Proceedings of
the 21st IAPPP-Western Wing Conference

Symposium on Telescope Science

Edited by:
Scott W. Teare and David A. Kenyon

Proceedings of the 21st IAPPP Western Wing Conference: Symposium on Telescope Science

Scott W. Teare and David A. Kenyon
Editors

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CONTENTS

PREFACE v
CONFERENCE SPONSORS vii

SCIENCE WITH YOUR TELESCOPE 1

Science with your telescope 3
David A. Kenyon
The Discovery of Extrasolar Planets by Backyard Astronomers 9
T. Castellano & G. Laughlin
The Whys and Hows of Asteroid Lightcurves 19
Brian D. Warner
Wratten Filter Photometry 29
J. E. Hoot

INSTRUMENTATION AND SOFTWARE 37

Software Interoperation and Compatibility: ASCOM Update 39
Robert B. Denny
Synthesizing Large Telescope Apertures: Adaptive Optics and Interferometry 45
Scott W. Teare
High Resolution and Wide Field Optical Systems for CCD Imaging 53
Peter Ceravolo
CCD Mosaics 57
Douglas George
Automatic Photometric Telescopes: Past and Present 61
Russel M. Genet
Amateur Spectroscopy: From Qualitative to Quantitative Analysis 67
Dale E. Mais

ASTRONOMY I 77

Probing A Comet's Nucleus 79
John E. Hoot
Astronomy's Embarrassment of Distance Determination – Small Telescope Science Will Calibrate an Accurate Determination Method 87
LeRoy F. Snyder
A Neophyte's Determination of EY Ceph Curves and Orbital Constants 97
John L. Menke
On-line Masters Degree in Astronomy 107
M. Colleen Gino
Undergraduate Astronomical Research: Adventures in Photometry 113
Cheryl L. Genet

ASTRONOMY II 117

New Telescope at an Old Observatory 119
Sean Hoss
Stellar Classification with the SBIG Spectrograph 125
Daniel A. Klinglesmith III
TSCRIPT - A Scripting Application for Automating Time-Series Data Collection 133
Edward Beshore
GSC 1839-78, a New W Ursae Majoris Variable 143
Robert D. Stephens
A Robotic Observatory for Education and Science 151
David A. Kenyon

POSTERS 157

Interferometry with a Meade ETX-125 Telescope 159
Denis W. Oesch & Dale J. Neimeier

PREFACE

This volume contains the proceedings of the 21st Conference of the IAPPP-Western Wing, Inc., which was held May 22 and 23, 2002 at the Northwoods Resort in the city of Big Bear Lake, California. The title chosen to set the theme of this year's meeting was the Symposium on Telescope Science and much of the material presented at the meeting was on using your telescope to do scientific investigations.

The purpose behind the IAPPP-Western Wing Conference Series is two fold. First we want to provide a forum for astronomical researchers, of all levels, who are interested in providing and/or using astronomical measurements from electronic instruments to plan, discuss and share their work within the astronomical community. In the development of this program our other goal is education. In tackling these two aims this year we adopted a new approach to the conference. To help the works of the researchers reach the widest audience we have prepared this proceedings of the conference, as well this book provides a resource to those wanting to learn more about specific topics. In this way a record of this work is available to the many interested members of the astronomy community as well as those who regularly attend this conference series.

The conference series and this proceedings are the result of work by many individuals. The Conference Committee is made up of:

Lee Snyder, Co-Chairperson
Robert Stephens, Co-Chairperson
Robert Gill
Dave Kenyon
Scott Teare

The editors would like to thank Lee Snyder, Robert Stephens and Robert Gill for their efforts and support in bringing this work to completion.

Conferences of any size take considerable effort and many dedicated volunteers to keep things running smoothly. We are grateful to the many volunteers who assisted at the conference and made this year's conference a success. We would also like to express our appreciation to the staff and management of the Northwoods Resort in Big Bear Lake, CA for their efforts at accommodating our group and supporting our activities.

Considerable financial support is need for a meeting of this type and we are very grateful for the generous support of the following organizations and their representatives for their financial contributions to this meeting: Sky Publishing Corporation (Sky & Telescope), Santa Barbara Instruments Group, Apogee Instruments, Inc. and Software Bisque.

The IAPPP-Western Wing is associated with the parent organization, IAPPP, the International Amateur Professional Photometry association in Tennessee founded by Douglas S. Hall and Russell M. Genet. We would like to express our appreciation for the

support of the IAPPP and the personal interest that Professor Hall has shown in the success of the IAPPP-Western Wing.

In the proceedings, the papers are organized in the following categories which follows their presentation order:

- Science with Your Telescope
- Instrumentation and Software
- Astronomy I
- Astronomy II

Lastly, we would like to thank the invited speakers and poster session contributors for their interesting presentations and the valuable information they brought to the conference. It is without a doubt the dedicated efforts of these individuals that makes our meetings successful.

Scott W. Teare, New Mexico Tech, Socorro, NM
David A. Kenyon, Sierra College, Rocklin, CA
May 2002

CONFERENCE SPONSORS

We wish to thank the following organizations for their contributions and support for this conference.

Apogee Instruments, Inc.,
manufacturers of astronomical and scientific imaging cameras.
http://www.ccd.com/

Santa Barbara Instruments Group,
makers of astronomical instrumentation.
http://www.sbig.com/

Sky Publishing Corporation,
publishers of Sky & Telescope magazine.
http://skyandtelescope.com/

Software Bisque,
developers of TheSky Astronomy Software and the Paramount telescope mount.
http://www.bisque.com/

SCIENCE WITH YOUR TELESCOPE

Science with your Telescope

David A. Kenyon
Professor of Astronomy
Sierra College
Rocklin, CA
dkenyon@sierracollege.edu

Abstract

Conducting science with your telescope can span many areas of astronomy. This paper will cover the equipment needed from very simple to advanced setups. There are a few fundamental methodologies necessary to obtain scientific quality data which will be discussed. Included will be a bibliography of organizations which are in essence clearing houses for the data collected.
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Introduction

Modern astronomy probably began in 1609 when Galileo Galilei pointed his spyglass at the cosmos. Since then, astronomers have been conducting science with telescopes.

The simplest equipment set to conduct science with is as Galileo did with a telescope, time keeping device and a pencil. Events are noted and sketched for reference and analyzed at a later time. The difficulty here is that the data is heavily dependent on the objectivity and skill of the observer. This minimum set was the “standard” until 1840 when the photographic process was adapted for astronomical use by J.W Draper who successfully obtained an image of the moon.

With photography and the telescope, astronomical science made an enormous leap forward. Events and data could be permanently recorded and independently analyzed by many astronomers. While astrophotography is inherently a self documenting method, it is not completely analytical as emulsion response varied and thus data sets needed to be calibrated for each new emulsion.

With the development of the charged coupled device (CCD) in 1969 at Bell labs, astronomical sciences received another significant advancement. CCD's have all of the advantages of photography and eliminate many of the problems. They are more efficient than film, easier to transport and store due to their digital nature, as well as provide a qualitative and quantitative improvement of data collected.

A closely related recent development is the emergence of inexpensive low light level video cameras based on CCD technology. These "astrovideo" cameras are ideal for recording telescopic events which need precise timing.

Equipment Requirements

It goes with out saying that to be successful, use the right tool for the task at hand. In the pursuit of science with your telescope, all elements must be well understood and in perfect functioning order.

The telescope is the collection instrument and must be well maintained. If a "goto" mount is being used, a small computer with controlling software will improve data collection productivity. The data needs to be collected with a sensor of some type. This can be a video camera and video recorder, or a CCD camera and computer. In any case, knowing how to operate your system tools and using a good calibration process for processing images collected is essential.

At this point, the data collection for science can begin on many different areas of astronomy. In general, the following projects are listed in order of complexity. Each type of project has different data reduction requirements, and each type of project data will vary. These organizations will provide a submission format. The key point here is for *reduced data* to be submitted.

Projects

Occultations

With occultations, the objective is to precisely capture in time when the moon, planet or asteroid pass in front of a star. The key requirement for recording the data is an accurate timing device. This can be done visually with some accuracy, but for improved precision an audible timing device (such as a WWV radio receiver) and a tape recorder is superior. This requires the observer to "call out" events as they occur.

A more elegant solution is to use an astrovideo camera and record the event with a VCR. In this setup, the audible timing device is recorded with the VCR's audio channel. Results from this method yield accuracies better than 0.1 seconds

NGC/IC Project

The NGC/IC project is correcting the location, position and other data associated with objects listed in these catalogues. This is a project for astronomers who enjoy the digital imaging of galaxies. This is basically an astrometric project to identify the true coordinates of objects as well as other data on these objects.

Supernova Hunting

This is another opportunity for astronomers who enjoy digital imaging of galaxies. In this case, it is necessary to image the same galaxy periodically and compare the most recent image to the previous image. The objective is to find a star which has had a significant brightening. There is some software tool support available to automate this process. This process is ideally suited for the modern goto telescopes to increase productivity.

Astrometrics

Position identification of asteroids and comets is an imaging based project which requires software tool support. There are a number of tools available to aid in the precise coordinate identification of the imaged objects. Data submission formats vary by organization.

Photometry

Stellar, asteroid and comet photometry is a very broad area of science supported by many organizations. A digital camera and reduction software is necessary as a basic equipment set. Many projects require special purpose filters as well.

Spectroscopy

This is an emerging armature-professional collaborative area of opportunity. Spectroscopy requires a digital imaging camera and a diffraction grating or a spectrometer head. There are a few tool to support the analysis of the collected spectra currently available.

Submitting Data

There are many organizations which accept reduced astronomical data. The following is a list of a number of these which have major areas of focus for the above listed projects.

American Association of Variable Star Observers (AAVSO)

The AAVSO is a non-profit world wide scientific and educational organization of armature and professional astronomers who have an interest in stars that change in brightness.
http://www.aavso.org/

Association of Lunar & Planetary Observers (ALPO)

Our Association is an international group of students that study the Sun, Moon, planets, asteroids, meteors, and comets. Our goals are to stimulate, coordinate, and generally promote the study of these bodies using methods and instruments that are available within the communities of both amateur and professional astronomers. We hold a conference each summer, usually in conjunction with other astronomical groups.
http://www.lpl.arizona.edu/alpo/

Center for Asteroid Physical Studies (CAPS)

The purpose of CAPS is to help coordinate amateur asteroid research by establishing collaborations among observers in various programs. These programs can be at the request of a professional astronomer needing data for research or for the general advancement of knowledge about the minor planets.
http://www.minorplanetobserver.com/CAPS/default.htm

Center for Backyard Astrophysics (CBA)

This is an organization dedicated to the study of cataclysmic variable stars (CV's) in an amateur-professional collaboration.
http://cba.phys.columbia.edu/

Collaborative Asteroid Lightcurve Link (CALL)

The purpose of these pages is to allow those engaged in determining asteroid lightcurve parameters to coordinate their efforts so that the best use of observing time can be made.
http://www.minorplanetobserver.com/astlc/default.htm

Forum for Amateur Spectroscopy

This website is dedicated to amateur astronomers interested in the science of spectroscopy – for those who wish to go beyond the visual imagery of observation and photography. FAAS is designed to be an educational tool, and an internet forum for

observers wishing to learn about the make-up and physical characteristics of stars, nebulae and galaxies first-hand. FAAS is for the inquisitive amateur who wishes to take that one crucial step beyond 19th century viewing and leap into the 21st century to perform their own spectral data collection and analysis.
http://users.erols.com/njastro/faas/

International Amateur-Professional Photoelectric Photometry (IAPPP)

International Amateur-Professional Photoelectric Photometry (IAPPP) was formed in June of 1980. The role of the IAPPP is to facilitate collaborative astronomical research between amateur, student, and professional astronomers, by providing a medium for the exchange of practical information not normally discussed at symposia or published in other journals.
http://www.iappp.vanderbilt.edu/

International Occultation Timing Association (IOTA)

IOTA was established to encourage and facilitate the observation of occultations and eclipses. It provides predictions for grazing occultations of stars by the Moon and predictions for occultations of stars by asteroids and planets, information on observing equipment and techniques, and reports to the members of observations made.
http://www.lunar-occultations.com

JPL Comet Observation Home Page

This site provides a repository for comet images and astrometric information. Comet Ephemerides and other information is available from this site.
http://encke.jpl.nasa.gov/

NGC/IC Project

The NGC/IC Project is an attempt to correctly identify all of the original NGC and IC objects, starting with the original discoverer's notes and working forward in time to encompass the work of contemporary astronomers, both professional and amateur, such that the identity of each of the NGC and IC objects is known with as much certainty as we can reasonably bring to it from the existing historical record. In so doing, we shall collect images for each object and assemble basic data for the objects -- positions, classifications, photometric parameters (magnitudes, diameters, position angles, colors, etc), and distances -- insofar as the data are accessible.
http://www.ngcic.com/

Smithsonian Astrophysical Observatory (SAO)

The Minor Planet Center (MPC) operates at the Smithsonian Astrophysical Observatory, under the auspices of Commission 20 of the International Astronomical Union (IAU) and is a nonprofit organization, with principal funding coming from subscriptions to the various services offered by the Center. The MPC is responsible for the efficient collection, (computation,) checking and dissemination of astrometric observations and orbits for minor planets and comets, via the Minor Planet Circulars (issued monthly) and the Minor Planet Electronic Circulars (issued as necessary).
http://cfa-www.harvard.edu/cfa/ps/mpc.html

The archival of photometric observations may be sent to:
Dr. Edward G. Schmidt
Dept of Physics and Astronomy
Univ. of Nebraska
Lincoln, NB 68588-0111
eschmidt@unlinfo.unl.edu

The Discovery of Extrasolar Planets by Backyard Astronomers

Tim Castellano
NASA Ames Research Center

Greg Laughlin
University of California at Santa Cruz

Abstract: The discovery since 1995 of more than 80 planets around nearby solar-like stars and the photometric measurement of a transit of the jovian mass planet orbiting the solar-like star HD 209458 (producing a more than 1% drop in brightness that lasts 3 hours) has heralded a new era in astronomy. It has now been demonstrated that small telescopes equipped with sensitive and stable electronic detectors can produce fundamental scientific discoveries regarding the frequency and nature of planets outside the solar system. The modest equipment requirements for the *discovery* of extrasolar planetary transits of jovian mass planets in short period orbits around solar-like stars are fulfilled by commercial small aperture telescopes and CCD (charge coupled device) imagers common among amateur astronomers. With equipment already in hand and armed with target lists, observing techniques and software procedures developed by scientists at NASA's Ames Research Center and the University of California at Santa Cruz, non-professional astronomers can contribute significantly to the discovery and study of planets around others stars. In this way, we may resume (after a two century interruption!) the tradition of planet discoveries by amateur astronomers begun with William Herschel's 1787 discovery of the "solar" planet Uranus.
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1. Introduction and Background

Extrasolar giant planets that "transit" their host stars are rare and valuable. Recent observations of the atmosphere of the one known transiting extrasolar planet HD 209458-b via Hubble Space Telescope spectroscopy [1] demonstrates that detailed study of the physical nature of transiting planets is greatly enhanced compared to non-transiting planets. During a transit, a small fraction of the parent star's light passes through the planet's atmosphere and imprints characteristic absorption lines upon the stellar spectrum. This information taken together with the planet's size and density (obtained by careful analysis of the transit light curve shape) allows detailed study of the planet's physical makeup beyond the minimum mass, orbital eccentricity and period obtained from radial velocity measurements alone.

More than eighty extrasolar planets have been discovered around nearby stars by measuring the velocity wobbles of their parent stars [2]. Twenty percent of these planets reside in short period orbits where the probability of viewing a transit is about 10% [3]. In late 1999, two radial velocity teams discovered a planet orbiting the star HD 209458 [4,5,6]. Photometric observations detected a 1.7 % dimming of this star's light consistent with a planetary transit. The repeated transit signal allowed determination of the planet's mass (by knowing the inclination) and radius (from the depth of the transit), giving a mass of 0.63 Jupiter masses and a radius of 1.4 Jupiter radii [6]. The inflated physical size of the planet is consistent with models for hot extrasolar planets [7,8]. This photometric measurement of the transit of the planet orbiting HD 209458 and the subsequent detection of atmospheric sodium [1] by the Hubble Space Telescope (HST) has heralded a new era in astronomy where the fundamental properties of transiting planets around other stars can be studied. Obviously, in order to study these planets in detail, they must first be discovered. For the first time it is now possible for small telescopes equipped with sensitive and stable electronic detectors to make these discoveries. In fact, an amateur group in Finland observed the transit of HD 209458-b during September 2000 (Sky and Telescope, January 2001) and amateur Ron Bissinger observed the transit on the night of October 12, 2001 in Pleasanton, California using equipment similar to what we consider a typical system. The modest equipment requirements for the measurement of extrasolar planetary transits of hot Jupiters are achieved by commercial small aperture telescopes and CCD (charge coupled device) imagers common among amateur astronomers and educational institutions.

2. Approach

Although extrasolar planets are lost in the glare of their parent star and are not resolved by even the largest telescopes, the planet's presence can nevertheless be revealed by the periodic dimming of the star if the planet crosses the stellar disk as viewed from Earth. For the near-jovian mass planet found around the solar-like star HD 209458 (the only known transiting extrasolar planet), the planet produces a dimming of the star of 1.7 % that lasts for about 3 hours. Although this effect is far too small for the unaided eye to discern, a typical off-the-shelf amateur CCD detector has sufficient sensitivity and stability to measure relative changes in brightness much smaller than this given proper observing procedure and data reduction techniques [9]. Equipped with CCDs, small telescopes (Figure 1) CAN detect planets around other stars (as illustrated in Figure 2)! NASA Ames and UCSC scientists have identified several hundred stars more likely than average to possess short period planets. These planet candidates come from three search projects being conducted by our team as described in the following section "Target Stars".

Figure 1. Our prototype Santa Barbara Instruments Group (SBIG) ST-7E CCD and Meade LX-200 8 inch aperture telescope system

3. Target Stars

Hipparcos Satellite Photometry Identified Candidates A search of the 12,690 main sequence stars of spectral types F, G, K and M in the *Hipparcos* Satellite photometry catalog conducted by one of us revealed several dozen with photometric features consistent with a planetary transit [10,11,12]. Although some of these are likely due to previously unknown stellar companions, stellar variability or noise, a few may be newly discovered extrasolar planets that transit. See Table 1 for a representative sample labeled "Hipparcos Selected".

Metal Rich Stars Statistical analyses of the population of parent stars of the known extrasolar planets indicate that approximately one in ten metal-rich stars should harbor a short-period planet. Given the ten percent chance that a given short-period planet displays transits, we therefore expect that approximately 1% of the most metal rich stars will have a planetary companion detectable by this project. A catalog of 206 highly metal rich stars has been compiled [13]. See Table 1 for a representative sample labeled "Metallicity Selected".

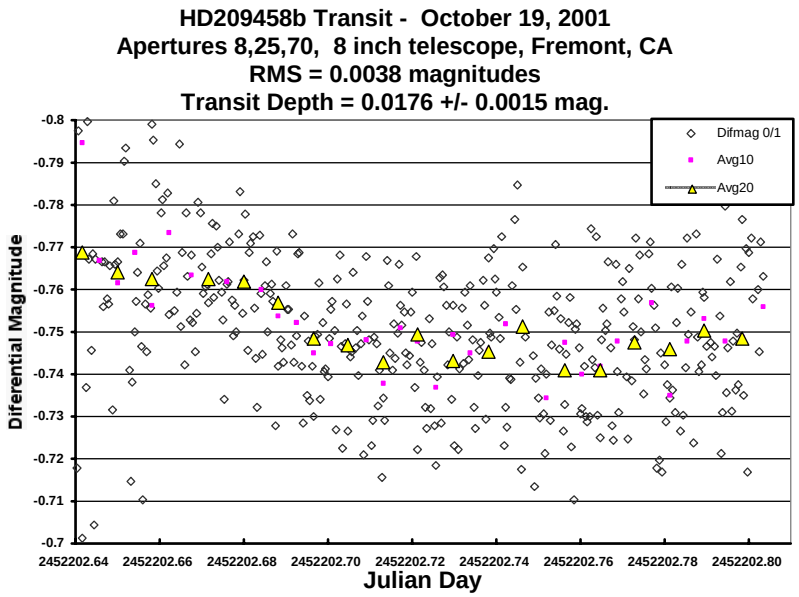

Figure 2. The transit of HD 209458-b observed in a typical backyard with the prototype telescope/CCD system. Images were reduced and the results plotted using commercially available software. The light colored dots are individual measurements and the dark triangles are the average of 20 measurements. The precision of the average of 20 measurements is about 0.4 % with a time sampling of about 10 minutes. The transit begins at JD 2452202.67. The end of the transit was not observed this night.

51 Pegasi Planets Stars found by radial velocity techniques to harbor massive planets in short period orbits will be potential candidates for transit measurements because on average 10% of these "hot Jupiters" are expected to transit based on random orbital inclinations. Several of these "hot Jupiters" are discovered by radial velocity techniques each year (**http://exoplanets.org/**).

4. The Amateur's Role

We have acquired a telescope/CCD/software system representative of what a dedicated amateur might own late in the "transit season " for HD 209458 (illustrated in Figure 1) and have begun experiments whose goal is to achieve the required photometric precision. A first attempt at observing the transit of HD 209458 was shown in Figure 2. These procedures will be further refined and communicated to the amateur community along with candidate lists, finding charts and sample images. Of the thousands of amateurs who own the necessary telescope/CCD systems, it is hoped that a few percent will take up the challenge and make the necessary observations consistently. A night's worth of data from each amateur will consist of several dozens images of the specified field of stars. To reduce the data each observer will download the images to a personal computer and use commercially available software to calibrate the images and extract the photometric brightness of each star in each frame via aperture photometry. These tables of individual brightness measurements along with their time tags and estimated errors can then be imported into a spreadsheet program resulting in differential photometry and a graph of the results (more about how to do this in Section 6). It is these tables of differential stellar brightness and times of observation that will be transmitted to the *transitsearch.org* data center in electronic form, where they will be further analyzed, their quality checked, and then placed in an online database

along with the contributor's identity. Candidate stars that show transit-like events that persist for several orbital periods, are seen by more than one observer and pass a test for stellar companions, will be added to radial velocity target lists for swift and unambiguous confirmation.

Preliminary Target List February 2002

HIP Catalog Number	HD Number	R.A. (hr.)	Dec. (deg.)	Spectral type	V (mag)	Fe/H (dex)	Distance (parsecs)
Hipparcos Selected							
17972	GJ3251	3	63	M1.5	11.5	NA	34.66
56299	…….	11	57	K2V	9.3	NA	38.52
62523	111395	12	24	G7V	6.3	NA	17.17
108859	209458	22	18	G0V	7.9	NA	47.08
111942	GJ 870	22	43	K8V	10	NA	42.94
Metallicity Selected							
94615	230999	19	19	G5	9.76	0.410	99.30
46639	233641	9	52	G0	9.28	0.335	96.62
66621	118914	13	31	G0	8.90	0.304	73.75
58318	103829	12	53	F8	9.29	0.274	89.21
49060	86680	10	28	G0V	8.05	0.262	99.70
New *Hipparcos* Variables?	HD Number	R.A. (hr.)	Dec. (deg.)	Spectral type	V (mag)	χ^2	Period (days)/delta
13313	17791	2	2	K5V	7.0	16.859	4.73954 / 0.1
111278	213617 (39 Peg)	22	20	F1V	6.5	5.071	1.79625 / 0.06
60074	107146	12	16	G2V	7.2	4.811	7.13116 / 0.06
77408	141272	16	1	G8V	7.6	3.712	4.15717 / 0.06
4956	SAO11548	1	61	K5V	9.0	2.853	3.01776 / 0.1
100346	193706	20	21	F9Vw	8.0	2.436	20.7231 / 0.08
18719	SAO 76384	4	20	G4V	8.8	2.406	5.88196 / 0.08
Well Known Eclipsing Binaries	Variable Name	R.A. (hr.)	Dec. (deg.)	Spectral type	V (mag)	Epoch	Period (days)/delta Prim, Sec
8115 (x2?)	V773Cas (Algol)	01	57	A3V	6.2	2448500.931000	2.93660 / 0.07, 0.03?
24836 (x2?)	DV Cam (Algol)	5	58	B5V	6.1	2448501.086000	1.529500 / 0.12, 0.12?
47279	VVU Ma (Algol)	9	56	A2V	10.3	2448500.2300	0.687377 / 0.8, 0.1
97263	HZ Dra (Algol)	19	69	A0	8.1	2448500.7650	0.772943 / 0.08, 0.02
114484	RT And (DW)	23	53	F8V	9.0	2448500.3671	0.628939 / 0.7, 0.2

Table 1. –Representative target stars selected based on *Hipparcos* photometry or high metallicity as well as possible new variable stars and some well known short period eclipsing binaries.

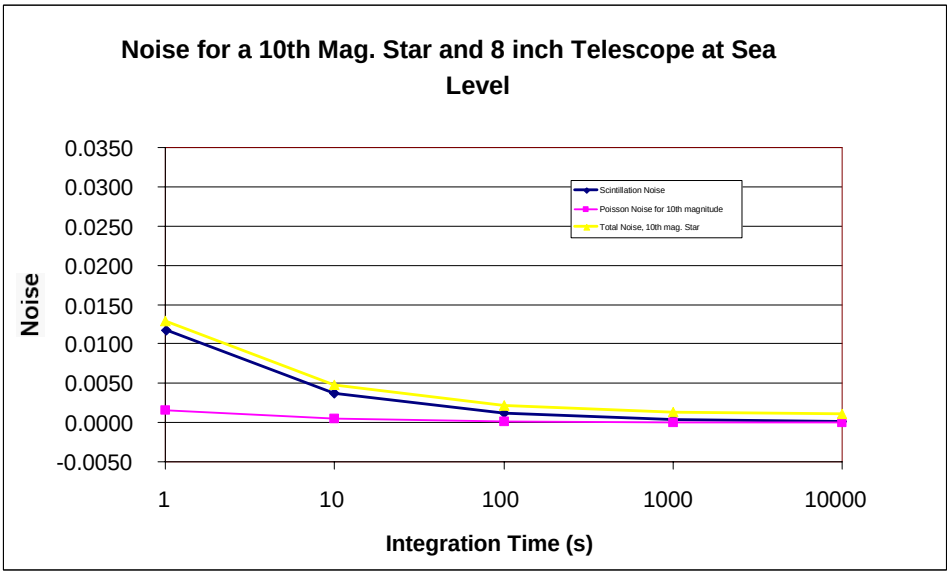

Figure 3. The calculated noise in magnitudes expected from atmospheric scintillation (twinkling) and shot noise for our prototype system (an 8 inch Schmidt-Cassegrain located at seal level).

5. The Technical Challenge

Achieving photometric precision of better than 1% for the bright stars found to have short period planets does not require a gigantic telescope or a remote mountain-top observatory, but it does require careful attention to some avoidable and some unavoidable sources of noise. These are primarily atmospheric scintillation (twinkling), random noise [14]. and CCD noise sources such as dark current and read noise. For a counting process, such as the detection of photons, the random noise is proportional to the square root of the number of photons received. Typically, scintillation rather than shot noise sets the precision limit for the bright stars found to have planets. Instrumental (CCD) noise sources such as read noise (15 electrons RMS typical for our ST-7E CCD) and dark current (less than 1 electron per second) can't be ignored. Figure 3 shows that for integration times approaching 100 seconds, scintillation and random noise added together results in total noise less than 0.5%.

6. How to Achieve Precise Photometry with an Off-the-Shelf CCD

The objective of our observing program is to measure the relative change in brightness of a star that (potentially) has a transiting planet as compared to another star in the same relatively small CCD field of view. By measuring the brightness of two stars simultaneously in the same CCD images, changes in the transparency of the atmosphere (clouds) or the response of the CCD with time become less important. By measuring the relative brightness of two (or more) stars, corrections due to first order extinction (extinction makes stars appear dimmer the further they are from the zenith) and color dependent extinction (bluer stars suffer from greater extinction) become very small or zero. In this way the difference in brightness of two stars can be compared over the entire night even though sometimes the stars are near the zenith and at other times the stars may be near the horizon. Experience with this technique (called differential photometry), reveals that changes as

small as 0.2 % in brightness can be measured in less than perfect observing conditions if great care is taken [9].

Transits of Jupiter sized planets in 3 or 4 day period orbits (the so-called 51 Pegasi-b type planets or "hot jupiters") in front of solar-sized stars last about 3 hours and produce a 1 to 2 percent dimming of the star's light. To detect these transits we need to be able to:

a) Image the star with the suspected planet and a suitable (equally bright and the same color ideally) comparison star and keep both well located on our CCD for at least a transit duration (3 hours) and hopefully all night long. Typically in order to have reasonable chance of finding a suitable comparison star, a field of view that is about 1/2 degree on a side is necessary. For an ST-7E and an 8 inch F/10 telescope a focal reducer is required (Figure 4).

b) Take multiple (many!) CCD images of our field of interest at intervals much less than a transit duration (every few minutes is very good) with the precision of each measurement being less than 1/3 the transit depth expected. Since each image can be close to 1 megabyte, plenty of hard disk space is required and a way to permanently archive raw, calibrated and calibration images (CD-ROM) is recommended.

   Precision – we will define it as the standard deviation of the measurements of a constant brightness star (think of precision as the repeatability of a measurement). Note we are not very concerned with *accuracy* (that is, being able to compare the magnitude of a target star to that obtained by someone else or in a catalog).

c) We need to minimize systematic effects produced by poor tracking, focus changes or telescope light throughput changes (dew on the corrector plate for example). Good autoguiding to keep the stars on the same places on the CCD chip seems to be especially important.

d) Allow long enough exposures so that the brightness variations due to the atmosphere (scintillation) is not the dominant source of error in each measurement. For HD 209458 and an 8 inch telescope, a focal reducer and no filter it is easy to saturate the CCD in just a second or two. For the data from the night of October 19, 2001 we were forced to take many short exposures and average them. This is not the best approach because a) each time the CCD is read out noise is introduced b) it takes 13 seconds or more to read the CCD. During this time the shutter is closed, no light is being collected and autoguiding is interrupted (for our 2–chip SBIG ST-7E CCD camera). Taking 100 images per hour makes the data reduction tedious and computer memory intensive. If exposure times could be as long as (for example) 6 minutes the scintillation noise will have very small values (more on this in paragraph h).

e) We need to be able to repeat results for the same star field on many nights in a row. To date we have not determined how best to do this.

f) Take very high precision calibration frames that do not introduce errors into our results. This requires taking many bias, dark and flat-field frames and averaging them to produce master bias, master dark and master flat-fields that are then used to reduce your science frames. Flat-field frames need to have at least 100,000 counts per pixel (for example 5000 counts per pixel

for each flat and 20 flats averaged together to make a master flat) to not introduce significant errors.

g) CCD limitations need to be understood and worked around. It would be great if we had the same CCDs that professional observatories have (very low noise, very uniform and very stable because of liquid nitrogen cooling) but we don't. Effects such as non-linearity must be considered. The CCD can saturate (the silicon wells cannot hold any more charge) or the analog to digital converter (A/D) can saturate first. Know what happens to your CCD as more light falls on it! The counts (analog to digital units or ADUs) displayed by your software reflects what the A/D measures, but the silicon collects a factor of the gain more electrons. So for example, our anti-blooming CCD becomes non-linear above about half-well capacity (20,000 electrons) so we have to limit the ADUs to about 8000 or so per pixel.

h) Carefully account for and minimize noise sources. We desire to have as many photons as possible to minimize the random noise inherent in any counting process. To get precision better than 0.3%, 100,000 electrons must be collected (see Table 2)! Note that in Table 2 below, 44,000 and 440,000 ADUs exceed the maximum A/D counts specified for the SBIG ST-7E [15] pixel's full well capacity. Do not be disturbed by this! The light we collect will be spread over many pixels, what we must pay attention to is the peak ADUs in any single pixel. For example, for the data we took on the night of October 19, 2001 we achieved about 4000 ADU maximum in one pixel for HD209458 which for a full width half maximum (FWHM) of about 5 pixels resulted in 50,000 total electrons (summed over an aperture of 8 pixels radius) and a best theoretical precision possible of about 0.5% per image. In practice, each measurement was limited by atmospheric scintillation to about 1.5% precision (theoretical for a 2 second exposure and about 1.5% actually measured). If the exposure could have been about 20 seconds long, we could have had two 0.5% precision measurements per minute rather than one 0.5 % precision measurement every 13 minutes! Fewer higher precision measurements are better than more lower precision measurements averaged together, because the former method keeps the CCD shutter open more of the time and results in fewer images to reduce.

ADUs (for a gain of 2.3)	**Electrons**	**Random Noise**	**Signal/Noise**	**Precision**
44	**100**	**10**	**10**	**10%**
440	**1000**	**31.6**	**31.6**	**3.2%**
4400	**10000**	**100**	**100**	**1%**
44000	**100000**	**316**	**316**	**0.3%**
440000	**1,000,000**	**1000**	**1000**	**0.1%**

Table 2. This is the best precision we could ever expect with zero atmospheric noise, zero detector noise and no systematic errors.

i) The data must be reduced (calibrated with flat fields, bias and darks) and the photometry performed without introducing additional errors. The selection of aperture sizes seems to be particularly important. This may require some trial and error for your observing setup and local conditions, so a facility for quickly evaluating the precision of your results for different aperture sizes is very helpful. For us MIRA AP 6.0 and a spreadsheet program worked well. Expect to spend at least a few hours reducing the data from each night. We found that star apertures on the small side worked best provided that tracking and image quality did not vary too much during the night.

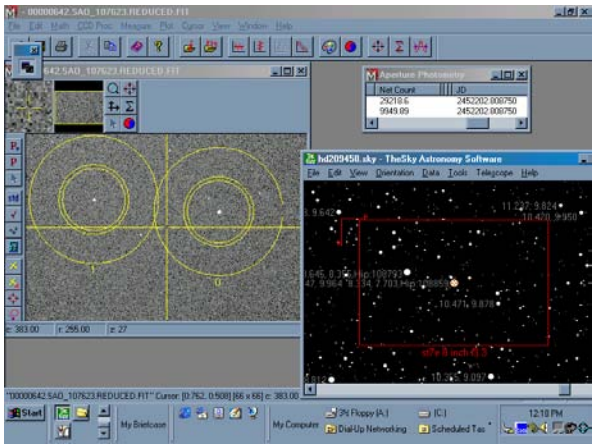

Figure 4. A sample computer screen showing HD 209458 (HIP 108859) and the comparison star HIP 108793 (left window) from MIRA AP 6.0. To achieve a field of view this large, a focal reducer was required. The large photometry apertures shown here would not be advised because it allows the read noise from too many pixels to contribute to the noise budget. The upper right window shows a portion for the photometry report generated by MIRA AP 6.0 for the image shown, The net count is the total number of electrons gathered within the apertures after the background is subtracted. Note that for this image, the dimmer of the two stars (the comparison star) has a net count of about 20,000 which we know is good for no better than 0.6% photometry by Table 2. Since this was in fact a 2 second exposure we were limited to 1.5 % precision by scintillation. TheSky Level IV 5.0's representation of the field of view of our LX-200 telescope and ST-7E CCD is shown in the right window, this allows the observer to confirm that the correct star field is being imaged.

6. Conclusion

Only one transiting Jupiter mass short period extrasolar planet has been found to date. Precision differential photometry (< 1 %) can be obtained with small telescopes and amateur grade CCDs with careful observing and data reduction. The large number of such systems owned by amateur astronomers makes it possible for additional transiting extrasolar giant planets to be discovered by a network of dedicated, careful, and patient observers. The potential scientific reward from such a discovery easily justifies the effort required. We hope you will join us!

The Whys and Hows of Asteroid Lightcurves

Brian D. Warner
Palmer Divide Observatory
17995 Bakers Farm Rd.
Colorado Springs, CO, USA 80908
brian@MinorPlanetObserver.com

Abstract: A thorough understanding of the formation and evolution of the minor planets depends on a substantial body of data on these lesser members of the solar system. One way in which amateur astronomers can make a significant contribution to that body of data is by determining the lightcurve parameters for as many asteroids as possible. In the paper below, the author reviews some of the physical traits of asteroids that can be determined from lightcurve and why those traits are important. Also covered are some of the specific considerations required to obtain useful data, both at the telescope and during data reduction and by establishing collaborations among other amateurs and professional astronomers.
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1. Why Do Asteroid Lightcurve Work?

In an e-mail message to the Minor Planet Mailing list [1], Dr. Alan Harris of JPL presented a list of reasons that lightcurve research is important. Here is a brief summary:

1. Establishing a correlation between taxonomic class and rotation period. The C, S and M classes are fairly well characterized but other classes are in need of more data.
2. Establishing the rotation rate vs. size. Of particular need are those of smaller size.

3. There is appears to be a "barrier" to rotation rates faster than ~2.25 hours, even among very small asteroids. This is exactly the rate below which centrifugal force would cause a loose conglomerate of rocks to "fly apart" against its own self-gravity. This lends further support to the "rubble pile" structure of even very small asteroids.
4. On the other hand, about two dozen asteroids have been found with periods well less than 2.25 hours and more on the order of a few minutes. These MUST be monolithic rocks, not "rubble piles".
5. There is a class of extremely slowly rotating asteroids, with periods of several days up to 2 months.
6. To determine the shapes and pole orientations of selected objects.

In addition to those points outlined in the original message, one can add:

7. Being able to separate lightcurve variations from measurements over large phase angles when trying to determine the H and G values for an asteroid.
8. Correlating lightcurve variations with occultation observations to infer 3-dimensional shapes.
9. To provide additional observational constraints in the analysis of radar observations.
10. To remove the observational bias towards brighter, main belt asteroids.

While it is apparent that there are many reasons to do asteroids lightcurves, the question often asked by amateurs is, “Will my observations really make much difference?” The reality of the situation is that, for the most part, obtaining the lightcurve parameters of any one given asteroid is of little value. Naturally, there are exceptions such as the new NEO, suspected dual asteroids or those having a satellite, etc. Those are covered in the other points of the list. The problem is that some of those points require a considerable amount of data taken over a significant period of time, not just weeks but many times months and years. Too, there are few studies being done in such depth on specific asteroids. That may change, should a new group or type be discovered, but that is not extremely likely.

2. Focusing on the Most Useful Task

Where the most benefit can be derived, and where amateurs can best concentrate their efforts, is by addressing the last point in the list above, i.e., to expand the pool of known lightcurve parameters. So far, especially among amateurs, there is a decided observational bias towards brighter objects, mostly main belt objects. The occasional NEO gets lots of attention but, for the most part, many other objects are neglected or at least under represented. This includes members of higher inclination families, Mars-crossers, and Martian and Jupiter Trojans. Of course, there are even more remote objects such as the Centaurs and TNOs. However, save for the very rare amateur, those objects are in the realm of the professional.

The above may discourage some, if not many, amateurs from taking up the challenge of asteroid lightcurves. After all, there seems to be a considerable amount of work involved and there is none of the rights and privileges associated with discovery. Yet consider what might and might not be if such an argument was used throughout science. A specific example relates to the extremely fast rotators among the asteroids. Until the late 1990's, no such objects had been found. Now there is a small hand-full. The "statistic of one" has expanded to where reasonable first theories about the composition of such objects can be made. The discovery of asteroids with rotation periods on the order of minutes instead of hours prompted the additional interest that lead to additional discoveries.

An oft-quoted statistic says that there are more people working in a single fast food restaurant than there are those working world-wide in dedicated programs searching for asteroids that might hit the earth in the "near" future. The number of people doing consistent asteroid lightcurve work is about the same. A look through the last four issues of the *Minor Planet Bulletin* [2] shows less than two dozen different observers contributed articles, either individually or as part of a collaboration. Expanding the search to prominent sites on the Internet may double that number. If each observer obtained 5 new curves a year (a bit more than the current rate), it would take between five and ten years to double the current number of known lightcurve parameter sets. If no new asteroids were discovered or numbered for that same period (not likely!) that would bring the sample of known parameter sets to about 8% of the *numbered* asteroids and only 2% of the asteroids in the MPC's database as of late March 2002. That's barely enough on which to build a solid foundation for theories using rotation periods.

Keep in mind, too, that with today's automation software and hardware it is entirely possible to work two asteroids for lightcurve data and "throw in" a variable star and/or several astrometric targets all in a single night. Such has been done by the author on many occasions, especially when working asteroid targets the first time. In those cases, the initial data was used to determine the best plan for follow up on subsequent nights. For example, to concentrate on a given asteroid to assure getting sufficient coverage because its rotation period is relatively short or observe the asteroid less frequently since it appears to have a long rotation period.

3. The Getting Started

So, once convinced that devoting some observing time to asteroid lightcurves is worthwhile, how does one go about it? What equipment, observing, and reduction techniques are required to make the data useful? These are all good questions and the subject of the majority of the remainder of this paper.

First, what equipment is required? Simply put, a CCD camera, a telescope, and the software to measure the images. Naturally, the higher quality (higher efficiency) CCD cameras as well as larger optics can greatly extend the number of potential targets. However, even with a scope as small as 20-25cm and an "average" CCD camera, there are hundreds of numbered asteroids within relatively easy reach for which there are no or poorly known lightcurve parameters. If you can push the limits a bit with careful work,

reaching down to 14.5m to 15m, you can extend the number considerably. Too, there is no small number of *unnumbered* targets within reach.

Notice that filters are not included in the initial list. That's because they are not absolutely required in most cases when the only goal is to determine the rotation period of the asteroid. This is particularly true if you are using data that only you obtained, i.e., you're not trying to merge your data with that from other observer's. Even then, with software that can adjust the "zero-point" of a given set of data, you can merge data from several nights and/or several observers. An excellent example is the work done by Robert Koff of Thorton Observatory, Thornton, CO, on (5587) 1990 SB [3]. Using MPO Canopus software written by the author [4], Koff was able to merge data from more than 50 sessions obtained by nine observers over a period of nearly six months during 2001. If all the data in that study had been reduced to standard magnitudes, it would have made analysis easier, no doubt, but the lack of filtered data did not preclude obtaining excellent results.

However, such will not always be the case and filtered observations are encouraged whenever possible, especially when working with professionals in a collaboration or when the observations are going to span long periods of time. Especially in the latter case, when the asteroid goes through a large span of phase angle, it may become critical to have standardized data in order to analyze the data correctly. Of course, filtered observations reduce the limiting magnitude of the system, sometimes by as much as a full magnitude. The author has explored the possibilities of using mostly unfiltered observations but calibrated to a standard system by the addition of occasional two color observations into the reduction process. So far, the results are promising and, if they prove sufficiently accurate, details of the necessary procedures and reduction process will be included in a future paper. The main point about filters is don't let the lack of them lead to a lack of observations.

Needless to say, obtaining good CCD images is important. Mostly this means getting and using master darks and flats. Remember that if using filters, you must get flats for each filter and not use a common flat for all images. Further enhancements are possible by using bias frames. How to create and use these correcting images is beyond the scope of this paper. Do not, however, assume that you can get by without at least a good dark and flat. At best, you might be able to get 0.05m precision without a good flat. The amplitude of some asteroid lightcurves is less than that!

By far and away, the most popular technique for observing asteroids is differential photometry. This is where at least one, preferably four or more, comparisons stars that are in the same frame as the target are measured along with the target. The average of the comparison star magnitudes is used as a common value for computing the differential magnitude. Those magnitudes are then plotted and/or put into a period analysis program to determine the period of the lightcurve as well as the amplitude. By using differential photometry, especially when using several stars, small variations due to changing sky conditions and random errors are smoothed out and so more reliable results are obtained.

When choosing comparisons, especially if doing unfiltered observations, it is extremely helpful to select stars both fainter and brighter than the target and, more important, of similar color. The latter helps eliminate color terms in photometric reductions and avoid systematic errors due to differential extinction. This is possible even

in a single CCD frame, especially if the field is large and observing at large zenith distances. This is one reason that you should try to observe the target only when it's at least 30° above the horizon.

For some time, using just a single comparison and a check star (to confirm the comparison is not variable) was standard. This was born out of the old days of photometry where getting observations of the target and comparison and check stars was time consuming. With the advent of CCD photometry, restricting the number of comparisons to only two is no longer required and is a waste of good data (how many stars are in the average field?). Since the comparisons should be similar in color to asteroids (solar color), the odds of selecting stars that are variable increase significantly. On many occasions, the author has found that two of the four to five stars selected for comparison stars were variable.

4. Shooting a Moving Target

Asteroids have a particularly nasty trait that makes obtaining lightcurve data more difficult than it might be otherwise: they move! Unlike working a variable star where the field is the same from night to night, working an asteroid usually means a different field from one night to the next. With a fast moving NEO, it could mean having dozens of fields per night. In order to analyze data in differential photometry from several sessions, the differential value must be based against a common value. Here, a session means observations made using the same set of comparison stars. This can be accomplished several ways but they are variations on two basic ideas. First by arbitrarily adjusting the average comparison star data so that the data from one session merges into the others or, second, by reducing the observations to standard magnitudes so that the data can be directly computed. The author's MPO Canopus program allows adjusting the offset for each session so that the differential values appear to be based on a common comparison star value. In addition, a program under development, PhotoRed, will determine the nightly extinction and zero points as well as color transforms, and then apply those to the instrumental magnitudes stored by Canopus to reduce the data to standard magnitudes.

There are two other problems resulting from the motion of the asteroid. First is that the time for each observation must account for light-time, i.e., the time of the observation must be for the time the light left the asteroid, not the time it arrived at earth. For example, if in session one the distance from the asteroid was 1AU and in session two the distance was 2AU, there would be about an eight-minute difference in the light time. Not accounting for this difference would result in finding the wrong period for the curve. The second problem is that the asteroid is naturally fading or brightening as a result of the changing sun and earth distances. On top of that is that the change in magnitude does not strictly follow the inverse square law. The well known "opposition effect" results in the magnitude of an object departing from the linear magnitude plot as the target approaches opposition. The differential magnitude against the common zero point must be adjusted to counteract these two effects, otherwise data analysis becomes more difficult if not impossible.

5. Analyzing the Data

After all this, the challenge is far from over. The most confounding issue is what's called "aliasing." This means that you have two successive runs of data spaced by a period of time that could be an integral (or half integral) of the actual period.

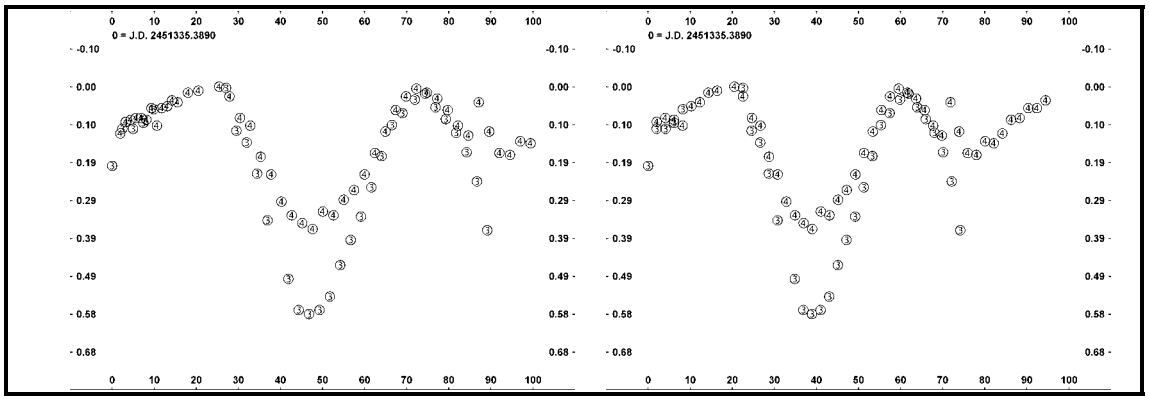

Figure 1. The two lightcurves based on the same but have different periods. Which is correct?

Figure 1 shows phase plots of combined data for 1022 Olympiada obtained by the author. The left-hand figure period is 3.83h while the right-hand figure period is 4.6h. There is good agreement in the phase angle for the extrema and the overlap of data seems reasonable for both. For the moment, ignore the difference in amplitude at about 40%. We'll come back to that. Which period is correct? Whenever such solutions present themselves, take a look at the periods versus the time between the data sets. For example, note:

4.60h * 5 rotations = 23.00h
3.83h * 6 rotations = 22.98h

When you consider that the *starting times of the two sessions were separated by 23 hours* it becomes difficult to say if the two sessions were separated by 5 or 6 revolutions.

Resolving this problem is definitively one of the bigger challenges in determining lightcurve parameters. That's because the tendency is to have sessions separated by the same amount of time (usually 24 hours or a multiple of that). This means that if the period has an integral or half-integral period near the separation period, one is catching the same part of the curve at the start of each session.

What's more, the shape of the curve is not always the same from one month to the next and quite often, one opposition to the next. In one case, the axis of revolution might be close to the line of sight, i.e., you're observing the asteroid pole-on. The next opposition may have the polar axis at right angles to the line of sight. There are many pitfalls to analyzing asteroid lightcurves. Don't be fooled into thinking that getting a good run on one or two nights means you've found "the truth" and don't assume that if you catch a single maximum in two successive sessions that you are catching the same maximum. For a bimodal curve (two maximums and two minimums per revolution), you

might be seeing the alternate maximum. For a trimodal or complex curve, it's anybody's guess as to which one you've caught - until you get more data.

Going back a bit, what about the difference in amplitude near 40% phase in the two curves in Figure 1? The quality of the data for each night was significantly greater (about 0.01-0.02m) than the 0.2m difference, so poor data is most likely not the answer. A check of the images shows no field stars on either night that might have changed the data by such an amount. The answer simply is, "I don't know." It might have been a satellite, though the size of the attenuation seems very large in comparison to curves of known dual asteroids. It's possible the curve is not really bimodal and may show three sets of extrema or the asteroid may be a tumbler and the curve is far more complex. These are questions that can be resolved only with more data.

A final note (though not the last word) about analyzing data: report the precision of your data and then only to the degree justified by the data. Just from general experience, Alan Harris has found that lightcurves can be "overlapped" to around +/- a few percent of the period (depending strongly on the amplitude and on the quality of the data) [5]. So to get a 1% solution, one needs data overlap spaced by several cycles. To get 0.1%, one need several tens of cycles data span, and so forth. In most cases, the worry is more about the risk of missing the right number of cycles, so cycle ambiguity is the biggest concern rather than the formal uncertainty of a particular solution. See Table 1 below for some specific guidelines.

Period (hours)	3 rotations (hours) 1%	Precision (hours) 1%	30 rotations (hours) 0.1%	Precision (hours) 0.1%
2	6	0.02	60 (2.50d)	0.002
5	15	0.05	150 (6.25d)	0.005
10	30	0.10	300 (12.50d)	0.010
24	72	0.24	720 (30.00d)	0.024

Table 1. The table shows the degree of precision one can use when reporting a period, based on the period and the number of rotations for which there is overlapping data.

6. Working Together

The problems of aliasing, possible double asteroids, and long-term observations to determine pole alignment are best handled through collaborations. Variable star observers have long done this but within the amateur asteroid lightcurve community, collaborations are still in early adolescence, if not infancy. By keeping track of the asteroid for extended periods of time in a given day, aliased periods can be more readily eliminated. Too, continuous observations for suspected dual asteroids can record an event (eclipse or transit) that might be otherwise missed.

In late 1999, a series of e-mails on the Minor Planet Mailing List and privately among the author, Dr. Alan Harris of JPL, and Dr. Petr Pravec of the Astronomical Institute, Ondrejov, Czech Republic resulted in the Collaborative Asteroid Lightcuve Link (CALL) web site [6]. This is an open site where observers can submit requests for collaboration,

notify others that a given asteroid is being worked, query if an asteroid is being worked, and submit summaries of their results.

The CALL site helps observers establish collaborations to work asteroids that present aliasing problems or require long-term observations because of a long period (days to months) or to help determine the pole orientation. As of the first of 2002 April, more than 150 lightcurve parameters had been posted and several important collaborations had resulted from queries on the CALL site.

7. Publishing Results and Data Availability

Asteroid astrometrists submit their observations to the Minor Planet Center [7]. Where do photometrists submit their results? The first choice, especially for amateurs, is the *Minor Planet Bulletin* [2]. This quarterly publication of the Association of Lunar and Planetary Observers is found in professional libraries around the world. There is no publication charge. The number of submissions has been growing steadily the past couple of years. Space is limited, so the time from submission to publication may be delayed by at least one issue.

Publication in the *Minor Planet Bulletin* does not usually include the raw data of the observations, just a plot of the data and the derived parameters. This leaves a gap for future researchers who would benefit from having access to the data. In some cases, researches have been forced to scan plots into the computer to get "observational data." This is not the best way to handle things. In addition to the features of the CALL site mentioned above, the author has created a web page [8] where observers can upload their observations in text files, thus making the data available to others for additional research. There is no fixed format for the data. In addition to the date and magnitude pairs, the text file should include as many details as possible about how the data was gathered and reduced so that the researcher can give proper weight to the data in comparison to other data.

8. Work at the Palmer Divide Observatory

Lightcurve observations have been made by the author at the Palmer Divide Observatory near Monument, Colorado since 1999 April. From that time through 2002 March, lightcurve parameters for approximately 40 asteroid have been determined and most of those published in *The Minor Planet Bulletin* (see Table 2 below) as well as posted on the PDO web site [9].

The lightcurves were obtained using either a 0.25m f/4-f/6 SCT and SBIG ST-8 or 0.5m f/8.1 Ritchey-Chretien and Finger Lakes IMG-1001. The telescopes were remotely controlled from approximately 30m away from the backyard observatory using MPO Connections [4], which allowed unattended scripted image acquisition.

The author's MPO Canopus is used to measure the magnitudes of comparisons and asteroid as well as determine the period of the lightcurve by using a modification of a

program written by Alan Harris [10] that uses Fourier Analysis to determine the synodic period of rotation.

Asteroid	Period	Amp.
321 Florentina	2.872	0.34
506 Marion	10.583	0.35
573 Recha	6.53	0.25
575 Renate	3.678	0.20
585 Bilkis	6.442	0.38
586 Thekla	10.630	0.33
605 Juvisia	15.855	0.25
620 Drakonia	5.485	0.52
687 Tinette	7.395	0.33
699 Hela	3.402	0.20
706 Hirundo	22.072	0.98
740 Cantabia	> 24	?
771 Libera	5.892	0.57
787 Moskva	5.371	0.55
860 Ursina	9.386	0.22
868 Lova	> 24	>0.11
898 Hildegard	> 24	?
957 Camelia	5.391	0.32
999 Zachia	22.77	0.32
1022 Olympiada	4.589	0.27
1069 Planckia	10.583	0.18
1146 Biarmia	11.51	0.30
1243 Pamela	26.017	0.44
1266 Tone	10.916	0.20
1282 Utopia	13.600	0.30
1325 Inanda	> 24	>0.1
1329 Eliane	8.0	0.08
1333 Cevenola	4.875	1.02
1506 Xosa	5.90	0.28
1582 Martir	15.757	0.40
1600 Vyssotsky	3.20	0.13
1659 Punkaharju	5.01	0.28
1719 Jens	5.867	0.54
1987 Kaplan	9.494	0.46
2105 Gudy	15.800	0.56
2460 Mitlincoln	2.77	0.04
2961 Katsurahama	2.935	0.21
3285 Ruth Wolfe	7.90	0.23
3447 Burckhalter	22.8	>0.24
7816 Hanoi	5.18	0.72
8041 Masumoto	14.10	0.30
11424 1999 LZ24	2.928	0.11
2000 DP107	2.775	0.21

Table 2. Results from work performed at the Palmer Divide Observatory or in collaboration with other observers.

9. Summary

The number of known asteroid lightcurve parameters represents a significant undersampling of the numbered asteroids and even more so for the entire asteroid population. While amateurs are somewhat limited by the size of instrumentation, they can make a considerable contribution towards increasing the sample size and so help the professional community in the effort to understand the system of minor planets. As with all photometry work, care is required during data acquisition and analysis but the virtue of patience is paramount, as many asteroid lightcurves are difficult to analyze because of the physical nature of the body producing the curve. Collaborations during data acquisition and analysis can make the difference between success and failure and should be sought out and encouraged by both the professional and amateur communities.

Wratten Filter Photometry

John E. Hoot
SSC Observatory, IAU#676

Abstract: The cost of a BVRI filter set puts many amateur astronomers off of performing filtered photometry and prevents their observations from being integrated into the body of observational records for objects of interest to the astronomical community. Results from the observations of Landolt standard stars made with inexpensive Wratten gelatin based photographic filters are present along with transformations of these results onto the Johnson-Cousins system. The suitability of the technique and its limitations are discussed.
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References:
1. M.S. Bessel, Pub. A.S.P **102,** 1181 (1990) **.**
2. A. A. Henden and R. H. Kaitchuck, *Astronomical Photometry.* (Willmann-Bell, Richmond, VA 1990).
3. H.L. Johnson and W.W. Morgan, Apj. **117**, 313 (1953).
4. Kodak, *Kodak Photographic Filter Handbook, (*Kodak, Rhochester, NY 1996).
5. A.U. Landolt, UBVRI Photometric Standard Stars Around The Celestial Equator, AJ **88,** 439 (1983).
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7. P. Stetson, Pub. A.S. P. **99,** 191 (1986).

Introduction:

Equipping an astronomical CCD camera with a good set of standard photometric filters is expensive. Commercially available sets start at over $500 USD. This expense is prohibitive to many amateurs. It is a pity that many photometric measurements made by amateurs are unfiltered. Unfiltered measurements cannot be easily correlated with the other observations. Additionally, without chromatic standards, collaborative efforts are difficult. The potential for Amateur/Professional collaboration is seriously diminished by many amateur's inability to provide filtered observations. In order to reduce these barriers to collaboration, a test was devised to determine if Wratten[4] photographic filters could be used in lieu of Johnson-Cousin[3,6] filters.

On a photometric night, Landolt[5] standard fields were observed at varying air masses using Wratten filters #23 (red) #58(green) and #47 (dark blue). These observations were then reduced and transformed onto the standard system. The results were then examined to see how well these substitute filters performed.

Filter Selection:

The filters were selected based on ready availability and by visually inspecting the filters next to a set of Johnson-Cousins filters formulated to the Bessel[1] specification. Filters were selected that displayed the closest apparent match to the Bessel filters under daylight illumination.

Observations:

CCD images of Landolt fields across the celestial equator and a different air masses were made on a single evening at SSC's observatory. An exposure was made through each filter. Each exposure was 30 seconds in duration. Observations were made using a 0.3 meter telescope operating at f5.0 using a Meade 1616XTE CCD Camera. The camera images were binned 2x2 to improve signal to noise performance. All images were dark subtracted and flat fielded prior to analysis. Sky transparency remained good throughout all observations and images demonstrated a mean FWHM PSF of about 2.5 pixels. This corresponds to about 5 arc seconds at this plate scale, relatively poor seeing conditions.

Once the basic image calibrations had been performed, instrumental magnitudes were measured for the Landolt stars in the images using the DaoPhot[7] package on an Linux based IRAF system. Table 1 below summarize the Landolt Magnitudes and Instrumental magnitude measured from the images.

Data Analysis and Transformation

The instrumental magnitudes were transformed onto the standard system using a least square error regression fit assuming a first order atmospheric extinction model as described by Henden and Kaitchuck[2]:

$$Mag_{Landolt} = Mag_{Inst} + X * K_{Filter} + ZP_{Filter}$$

The results of the first order fit are displayed in Table 2. The transform coefficients of the first order fits were:

$K_R = 0.00625$	$ZP_R = 0.148$
$K_v = 0.00130$	$ZP_v = -1.016$
$K_B = -0.0023$	$ZP_B = -0.088$

Scatter plots of Wratten values vs. Landolt values were generated along with statistics to assess the quality of the transformations.

Wratten Filter Observations

STAR ID	RA (1950)	Dec (1050)	V[L]	R[L]	B[L]	V[I]	X[VI]	R[I]	X[RI]	B[I]	X[BI]
SA101-333	9:55:53.00	-0:23:22.00	7.84	7.04	9.32	8.67	1.17	7.19	1.17	7.83	1.18
HD76082	8:53:13.00	-0:33:20.00	8.41	7.82	9.53	9.29	1.12	7.74	1.12	8.75	1.12
SA099-296	7:54:01.00	-0:27:12.00	8.45	7.85	9.64	9.36	1.11	7.85	1.11	9.05	1.11
SA103-483	11:54:15.00	-0:28:21.00	8.35	8.11	8.78	9.39	1.56	7.98	1.54	10.91	1.57
SA102-472	10:54:04.00	-0:50:15.00	8.75	8.23	9.77	9.69	1.29	7.99	1.13	9.15	1.28
SA100-162	8:52:29.00	-0:40:03.00	9.15	8.50	10.42	10.04	1.12	8.21	1.12	9.36	1.12
SA102-625	10:54:39.00	-0:43:57.00	8.89	8.58	9.44	9.90	1.29	8.42	1.13	9.65	1.28
SA102-466	10:53:52.00	-0:50:40.00	9.25	8.68	10.30	10.22	1.29	8.42	1.13	9.63	1.28
SA101-324	9:55:11.00	-0:18:56.00	9.74	9.15	10.90	10.63	1.17	8.85	1.17	10.09	1.18
SA099-358	7:53:12.00	-0:19:45.00	9.61	9.17	10.38	10.55	1.11	8.91	1.11	10.15	1.11
SA102-620	10:54:20.00	-0:43:31.00	10.07	9.43	11.15	11.03	1.29	9.19	1.13	10.36	1.28
SA104-461	12:42:21.00	-0:27:26.00	9.71	9.42	10.18	10.87	1.96	9.34	2.00	10.61	1.94
SA099-418	7:54:41.00	-0:15:07.00	9.47	9.48	9.43	10.44	1.11	9.35	1.11	10.59	1.11
SA099-447	7:55:21.00	-0:18:18.00	9.42	9.45	9.34	10.42	1.11	9.35	1.11	10.61	1.11
SA099-438	7:55:08.00	-0:14:26.00	9.40	9.46	9.24	10.40	1.11	9.37	1.11	10.57	1.11
SA099-418	7:54:41.00	-0:15:07.00	9.47	9.48	9.43	10.48	1.11	9.38	1.11	10.63	1.11
SA099-408	7:54:27.00	-0:23:08.00	9.81	9.55	10.21	10.78	1.11	9.38	1.11	10.65	1.11
SA101-282	9:56:19.00	-0:25:42.00	10.00	9.74	10.43	10.99	1.17	9.57	1.17	10.85	1.18
SA103-462	11:53:13.00	-0:26:48.00	10.11	9.79	10.68	11.17	1.56	9.63	1.54	9.26	1.57
SA100-241	8:51:49.00	-0:36:23.00	10.14	10.06	10.30	11.15	1.12	9.93	1.12	11.24	1.12
SA099-367	7:53:26.00	-0:23:13.00	11.15	10.62	12.15	12.16	1.11	10.36	1.11	11.60	1.11
SA104-337	12:41:42.00	-0:29:21.00	11.21	10.77	11.98	12.41	1.96	10.66	2.00	11.90	1.94
SA101-281	9:56:19.00	-0:27:20.00	11.58	11.12	12.39	12.66	1.17	10.91	1.17	12.23	1.18
SA100-280	8:52:50.00	-0:33:15.00	11.80	11.51	12.30	12.92	1.12	11.29	1.12	12.65	1.12

Table 1: Landolt Reference and Raw Instrumental Values

R[L] Landolt Red, Mag. B[L] Landolt Blue Mag., V[I] Landolt V Mag.
X[VI] Airmass of V Observation, X[RI] Airmass of R Observation, X[BI] Airmass of B Observation
R[I] Red Instrumetal Magnitude, B[I] B Instrumental Magnitude, V[I] V Instrumental Magnitude.

Wratten Transformed Values

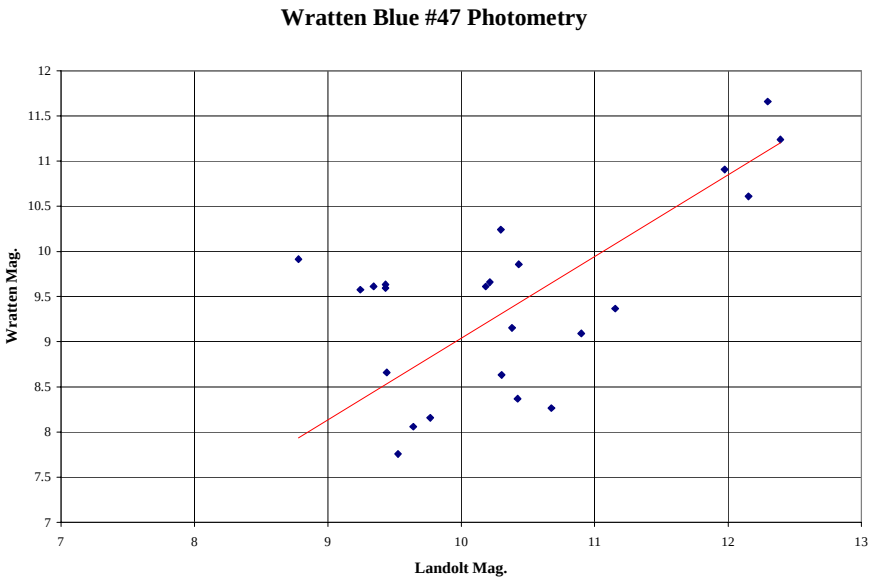
STAR ID	RA (1950)	Dec (1050)	V[L]	V[W]	V[Err]	R[L]	R[W]	R[Err]	B[L]	B[W]	B[Err]	Bw'*	Berr*
SA101-333	9:55:53.00	-0:23:22.00	7.835	7.671	-0.164	7.040	7.348	0.308	9.320	6.838	-2.482	8.088	1.232
HD76082	8:53:13.00	-0:33:20.00	8.409	8.283	-0.126	7.824	7.895	0.071	9.527	7.759	-1.768	9.085	0.442
SA099-296	7:54:01.00	-0:27:12.00	8.454	8.353	-0.101	7.854	8.007	0.153	9.641	8.060	-1.581	9.202	0.439
SA103-483	11:54:15.00	-0:28:21.00	8.353	8.390	0.037	8.108	8.142	0.034	8.780	9.914	1.134	10.408	-1.628
SA102-472	10:54:04.00	-0:50:15.00	8.754	8.691	-0.063	8.226	8.144	-0.082	9.768	8.158	-1.610	9.748	0.020
SA100-162	8:52:29.00	-0:40:03.00	9.148	9.035	-0.113	8.500	8.362	-0.138	10.422	8.369	-2.053	10.442	-0.020
SA102-625	10:54:39.00	-0:43:57.00	8.890	8.895	0.005	8.578	8.574	-0.004	9.442	8.660	-0.782	9.442	0.000
SA102-466	10:53:52.00	-0:50:40.00	9.246	9.218	-0.028	8.683	8.577	-0.106	10.302	8.631	-1.671	10.383	-0.081
SA101-324	9:55:11.00	-0:18:56.00	9.743	9.630	-0.113	9.152	9.003	-0.149	10.900	9.093	-1.807	11.038	-0.138
SA099-358	7:53:12.00	-0:19:45.00	9.605	9.549	-0.056	9.173	9.067	-0.106	10.381	9.153	-1.228	10.545	-0.164
SA102-620	10:54:20.00	-0:43:31.00	10.067	10.023	-0.044	9.425	9.342	-0.083	11.154	9.367	-1.787	11.272	-0.118
SA104-461	12:42:21.00	-0:27:26.00	9.706	9.876	0.170	9.416	9.498	0.082	10.184	9.612	-0.572	10.099	0.085
SA099-418	7:54:41.00	-0:15:07.00	9.474	9.435	-0.039	9.477	9.500	0.023	9.433	9.596	0.163	9.439	-0.006
SA099-447	7:55:21.00	-0:18:18.00	9.415	9.420	0.005	9.446	9.502	0.056	9.344	9.613	0.269	9.288	0.056
SA099-438	7:55:08.00	-0:14:26.00	9.399	9.396	-0.003	9.459	9.524	0.065	9.244	9.576	0.332	9.147	0.097
SA099-418	7:54:41.00	-0:15:07.00	9.474	9.482	0.008	9.477	9.534	0.057	9.433	9.635	0.202	9.385	0.048
SA099-408	7:54:27.00	-0:23:08.00	9.807	9.782	-0.025	9.554	9.538	-0.016	10.214	9.661	-0.553	10.314	-0.100
SA101-282	9:56:19.00	-0:25:42.00	10.002	9.989	-0.013	9.742	9.722	-0.020	10.431	9.857	-0.574	10.539	-0.108
SA103-462	11:53:13.00	-0:26:48.00	10.111	10.177	0.066	9.787	9.788	0.001	10.675	8.265	-2.410	9.067	1.608
SA100-241	8:51:49.00	-0:36:23.00	10.140	10.152	0.012	10.063	10.089	0.026	10.296	10.242	-0.054	10.296	0.000
SA099-367	7:53:26.00	-0:23:13.00	11.149	11.158	0.009	10.618	10.514	-0.104	12.154	10.611	-1.543	12.269	-0.115
SA104-337	12:41:42.00	-0:29:21.00	11.207	11.420	0.213	10.773	10.820	0.047	11.975	10.907	-1.068	11.885	0.090
SA101-281	9:56:19.00	-0:27:20.00	11.579	11.661	0.082	11.124	11.069	-0.055	12.393	11.239	-1.154	12.553	-0.160
SA100-280	8:52:50.00	-0:33:15.00	11.802	11.913	0.111	11.507	11.448	-0.059	12.298	11.660	-0.638	12.546	-0.248

Table 2: Landolt References and Transformed Wratten Magnitudes

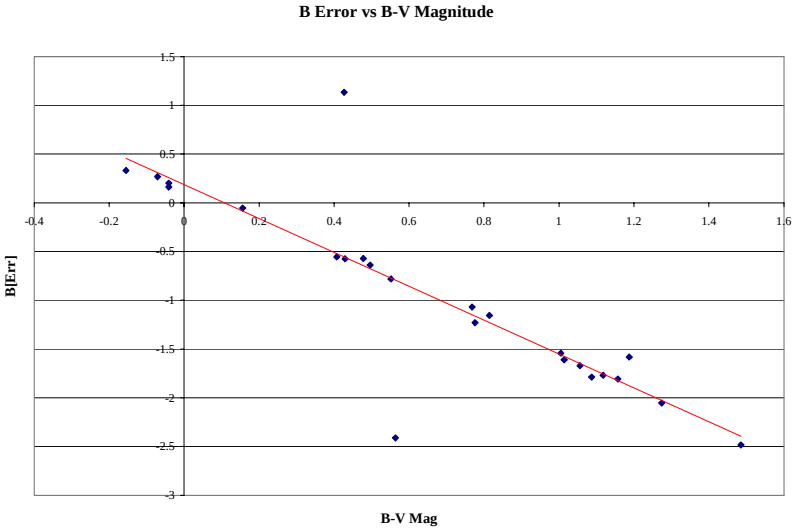
V[L] Landolt V Mag.. V[W] Transformed Wratten Mag., V[Err] Wratten Magnitude Error
R[L] Landolt R Mag.. R[W] Transformed Wratten Mag., R[Err] Wratten Magnitude Error
B[L] Landolt B Mag.. B[W] 1st Order Transformed Wratten Mag., B[Err] Wratten Magnitude Error
Bw* 2nd Order Transformed Wratten Mag., Berr* 2nd Order Wratten Magnitude Error

For the Wratten Red filter the scatter plot indicates a reasonably good fit was obtained. RMS error for this fit is 0.10083 indicating an accuracy in all sky photometry of about 0.1 magnitude. In this fit, the brightest star was omitted, as it had badly oversaturated the detector.

For the Wratten Green filter the scatter plot also indicated a reasonably good fit was obtained. RMS error for this fit is 0.089 indicating and accuracy in all sky photometry of better than 0.1 magnitude.



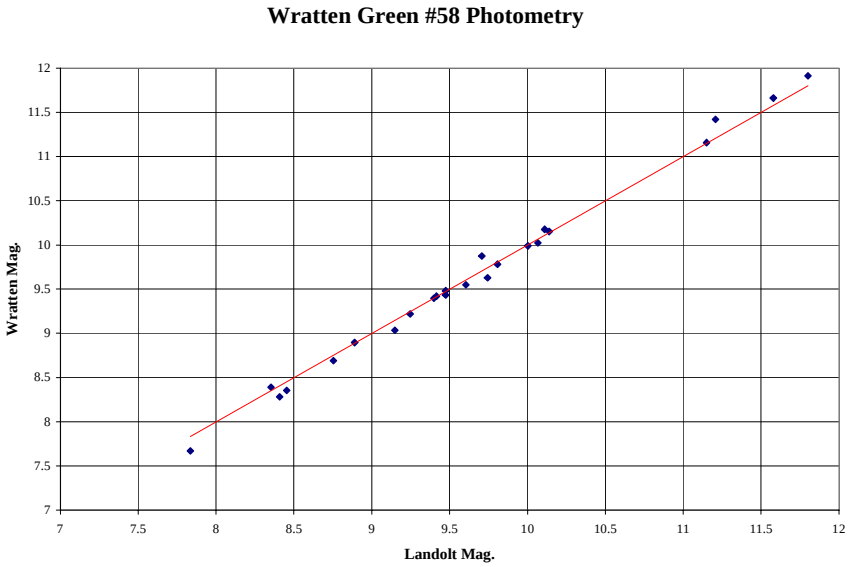
For the Wratten Blue the results were much less pleasing. The scatter appeared so bad as to almost be random. To see how this problem was related to the color index of the star, a second scatter was produced correlating color index with error.



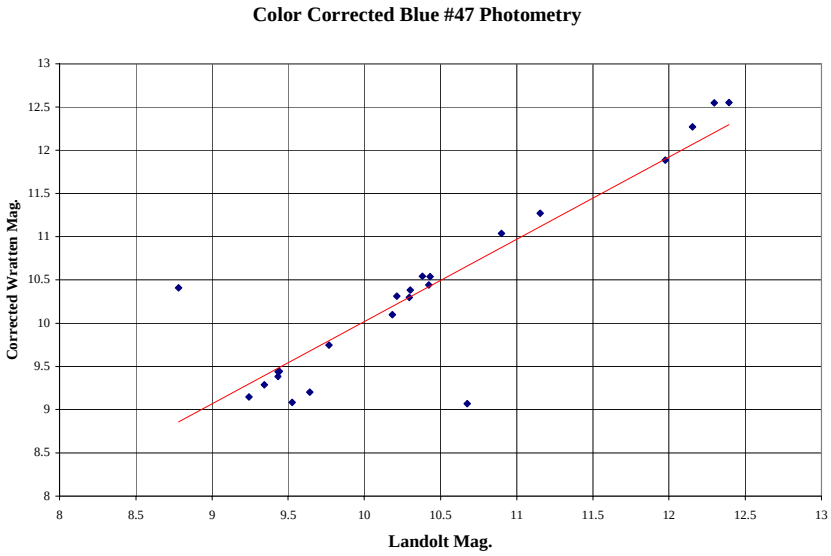
The second scatter plot clearly shows a systematic problem relating to the color index of the target star. To attempt to compensate for this chromatic problem a second order model was fitted to the data assuming:

$$B_{Landolt} = B_{Inst} + X_B * K_B + (V_w - R_w)*C_B + ZP_B$$

Where the new V_w is the Wratten derived V Magnitude and R_w is the Wratten derived R magnitude and C_B is the new term to color correct the transform. After the second color correction term was added and the model refitted, the resulting scatter plot show a much lower error in the transformation with the RMS error of the fit reduced from 1.34 Magnitudes to 0.55 Magnitudes. Still there are several data points

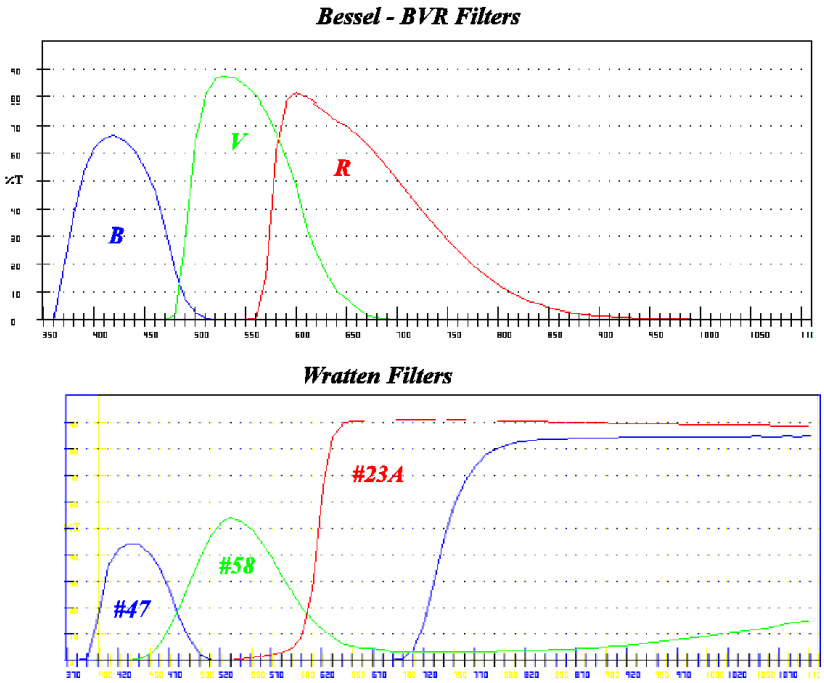


with error that are disturbingly large.



Discussion:

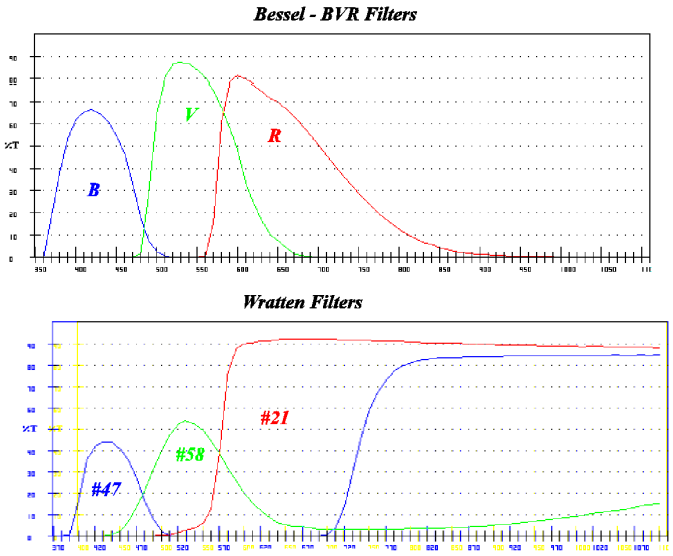
The sample size in this study is small and is subject to the quirks of small sample populations. In total only 24 data points are included and they represent only one night's observations. To validate the concept of using Wratten filters, more data points need to be measured. Additionally, the 30 second exposure time for this sample set turned out to be too long for the relatively bright Landolt standards. Some of the brighter stars in the data set had flux values that were moving into the non-linear region of the KAF1600 detector. Still, the resulting in the V and R bands are promising. The B band is problematic. The charts below indicate the problem presented by using these filters.



For the Blue #47 filter, the lack of any IR blocking filter caused a mixed R + I response to be added to the instrumental flux. This is what causes the severe chromatic contamination problem evidenced in the data set. For main sequence stars, using a V-R correction factor works almost acceptably, but for stars with excess reddening, dust, or white dwarf stars, the correction term will not make good corrections. There are a couple of potential methods to correct this problem. One is to use an IR blocking filter with the Wratten filters. These can be obtained for about $50 dollars and would reshape these filters to much more closely resemble the Bessel formulations. The other alternative would be to add a Wratten IR filter #87 or #89 to the set. A wieghted IR measurement could be subtraced from the #47 flux value as part of its transformation.

The Green #58 filter is a good overall match. Its roll off for the shorter wavelength is a little slower then a standard V filter, but for more precise work it may be corrected using a second order chromatic fit like similar to the one performed on in the B band.

The Red #23 filter was not the best choice. After reviewing the Wratten filter specifications, a better choice would have been the Wratten #21 red filter. This has a shorter wavelength cuttof than the #23 and would more closely model the Bessel R filter. The chart below compares the revised set of #21, #58 and #47.



In addition, both the #21 and #23 filters are essentially low pass filters. The do not have any natural cuttoff in the IR. Their roll off is determined by the IR roll off of the detector used. The addition of -IR filter to the set will improve the fidelity of R photometry with this set.

Conclusions:

Based on these preliminary results, future studies will be conducted with four filters Blue #47, Green #58, Red #21, IR #89B and a -IR blocking filter. I believe that these preliminary studies indicate that using a Wratten Blue-IR, Green-IR, Red-IR and IR observers be able to be transformed onto the standard BVRI system with an accuracy of better than 0.1 Magnitude for all sky work. I would expect even better fidelity may be achieved in differential photometry because extinction will present less of a problem.

For most amateurs, such a filter set is probably almost at hand. Certainly, results indicate that V/R two color photometry that transforms well onto the standard system is within reach of any amateur for about $25.

INSTRUMENTATION & SOFTWARE

Software Interoperation and Compatibility: ASCOM Update

Robert B. Denny
DC-3 Dreams, SP, Mesa, AZ

Abstract: During the preceding year, the ASCOM Initiative has reached some major milestones towards its goal of providing scriptable software tools with standardized interfaces. This talk will include a brief introduction to ASCOM, the Astronomy Common Object Model, and to the ASCOM Initiative, a group of astronomy providers with a common set of goals. Much of the talk will cover the accomplishments of the ASCOM Initiative since the last IAPPP West meeting. Standard scriptability is a powerful tool for the advancement of science in astronomy, and the ASCOM Initiative is focused on making science reachable and flexible while promoting open source exchange of standardized scripts as tools. Thus, this talk focuses on an important technology for Telescope Science, the theme of this year's conference.
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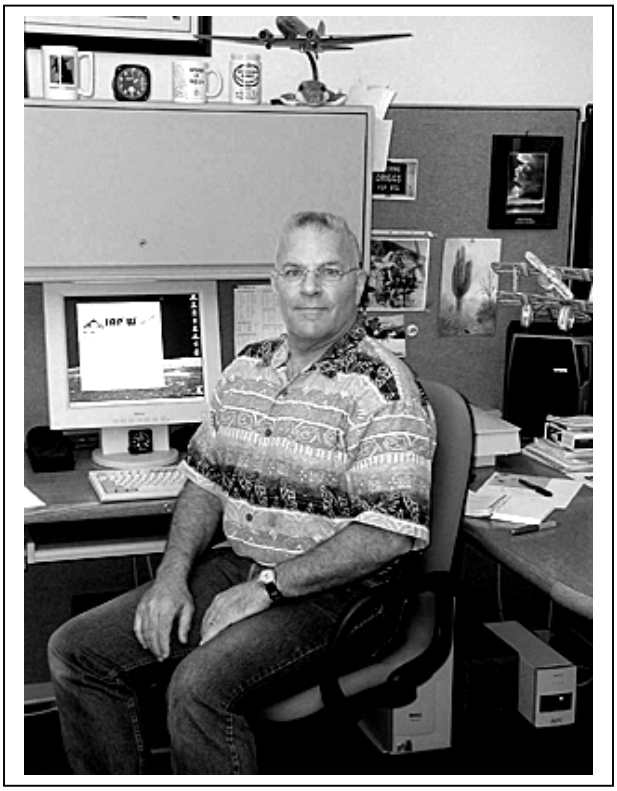
References:

1. ASCOM Initiative web site `http://ASCOM-Standards.org/`
2. FocusMax web site `http://www.idsi.net/~larryweber/`
3. Microsoft ActiveX web site `http://www.microsoft.com/com/tech/activex.asp`
4. Microsoft Scripting web site `http://msdn.microsoft.com/scripting/`
5. DC-3 Dreams web site `http://dc3.com/`
6. Diffraction Limited web site `http://www.cyanogen.com/`



Biographical Notes:

Bob Denny has a wide variety of experience including work in the aerospace industry as an engineer on navigation and communication systems, founding and operating for 14 years a medium sized software business, developing the first web server on Windows, making Visual Basic a web programming language, writing the first Java based web server back-end, and most recently developing and marketing astronomy software. He is quick to say that he is not an astronomer but an engineer and software designer.

Software has been his real love for most of his life. He has been programming for almost 40 years, having written his first program on an IBM 1401 in 1963. Since then most of his work has been in systems programming on machines like the PDP-11 and VAX, as well as 6 years with the Mac. He didn't touch PCs until 1995.

He holds a BSEE from the University of Arizona, an FAA pilot's license with multi-engine and instrument ratings, and numerous certifications related to his volunteer work (averaging 100 hours a month) with the Maricopa County Sheriff's Office, where he

works armed and in uniform with the Lake Patrol Division, and also in the communications center where he answers 911 and dispatches on the radio. Bob is enthusiastic about almost everything!

1. Introduction

The professional astronomy community has evolved to a state where software and automation are critical parts of virtually all science data gathering and analysis. Amateur astronomy has not. Professional astronomy software is mostly custom-written, "cut-to-fit" for the individual observatory and/or the individual program, and maintained by grad students and specialists. Producing this sort of software for amateur use is economically unfeasible due to the small market and large cost. Thus, amateurs are stuck with relatively few tools that serve only general-purpose needs.

The goal of the ASCOM Initiative [1] is to put professional class tools into the hands of amateurs and educators. The strategy is to turn astronomy software inside out. Instead of large feature-packed "suites" of software that often seem to lack the one feature you need, ASCOM promotes software tools, engines, and objects that can be fitted together in limitless ways. Certain key tools such as telescopes, focusers, CCD detectors, filter wheels, domes, etc., need to have standard programmable interfaces regardless of their mechanical and electrical details. Other tools need not be standardized, but they need open interfaces so that they can be controlled via things ranging from simple scripts and spreadsheets to full-up programs.

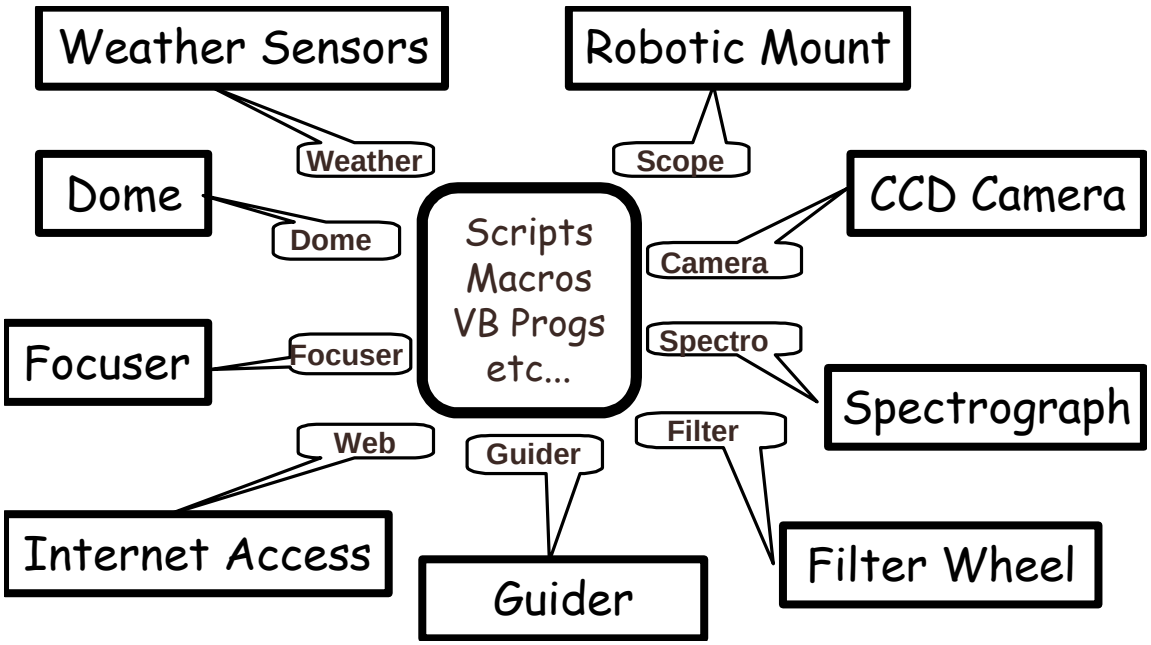


Fig. 1, Conceptual diagram of an ASCOM observatory

Once one adopts the building-block view of the world, the power becomes apparent. It is not necessary for everyone to know how to write scripts or special-purpose programs; a relative few can quickly and economically produce them for specific missions and share them with the amateur and educational community. *The standards effort multiplies the effectiveness of this by making it possible to use a script or program across a variety of different instrument setups*.

2. Technology

First, let me state my goal with ASCOM: *To revolutionize astronomy software by delivering an open, modular and standardized architecture for building specific solutions to science problems, and making it available to the widest number of people without requiring them to buy new computers or changing operating systems*. I knew that ASCOM would fail at birth if people had to buy new computers or ditch the software they have and switch operating systems. Thus, ASCOM *must* work on the Windows OS because 90% of the computers used by amateurs and non-professional educational astronomers run Windows.

At the outset, I had to make a fundamental decision: *cross-platform or not?* I have almost 40 years' computing experience, which gives me a certain degree of perspective. In my experience, cross-platform solutions are seductive but virtually never meet the expectations they generate. Java and Code Warrior are recent cross platform user interface tools. Neither delivers a satisfactory user experience when compared to native user interface designs on the Mac, Windows and Unix/X. No matter how hard they try, there are quirks and holes in the user interface that annoy the non-technical ("ordinary") user the most. For supporting an object/component oriented architecture like ASCOM, Java could fill the bill, but it has a huge learning curve and is inaccessible from native OS applications. It is cross platform, but it is an island unto itself. For example, a Windows VBS script or Excel spreadsheet can't use a component implemented in Java.

Should I risk ASCOM by trying to make it cross platform in order to gain the last 10% penetration? Nope. So ASCOM is built on the native Windows object oriented system, ActiveX [5], also known as Automation. These technologies are in turn built on a lower level technology, COM, which in its basic form is virtually useless for our missions. ActiveX, however, opens the door to simple scripts in an expanding variety of languages, Microsoft Office applications and macros, Visual Basic programs, in short, anything that uses the native Windows component object system and the strictly prescribed interface characteristics of Automation. The Windows Script [6] facility is supported by all versions of Windows beginning with Windows 95, as is ActiveX itself. These scripting languages are easy to learn, need no compilers or development environments, and plug right into the objects and controls that make up the basic fiber of Windows. What ASCOM does is add to this already huge library of components.

3. Examples

The TSCRIPT system, presented at this conference by Ed Beshore, is a perfect example of this. Beshore has written a special purpose sequencing system for his photometric data acquisition mission. ASCOM made it practical to produce this tool, owing to the availability of the simple programmable telescope, camera, etc., and some software tools (components or engines) to assist. If it were necessary to write all of the camera controls, telescope control, coordinate precession and reduction, and so forth, from scratch, into a large "do-all" program, this would not have been practical, nor could it be easily adapted to a variety of telescopes, cameras, focusers, etc.

FocusMax [4] is another perfect example. Here, Larry Weber and Steve Brady have implemented their breakthrough auto-focus algorithm in a very nice user interface that allows you to push a button and focus your scope. However, they didn't stop there! They

added an ASCOM scriptable interface to FocusMax so that someone doing automation with a script can use the services of FocusMax during their automated run. By adding scriptability, Weber and Brady made it possible for an automation system to do *automated adaptive refocusing*. It's not built into some monolithic package; it is out there for anyone who uses ASCOM.

But they didn't stop there. FocusMax talks to the actual focusers through the standard ASCOM focuser interface. Thus, any new focuser that appears will automatically be supported by FocusMax as long as the new focuser has an ASCOM standard Focuser driver for it. The case of the RCOS focuser is an example. Weber and Brady never tested with the RCOS, yet FocusMax works with it perfectly. The new JMI digital focuser purportedly also works with FocusMax. Imagine if they had to rewrite FocusMax every time a new focuser came along!

Moreover, they didn't stop there either! They implemented an ASCOM focuser interface on FocusMax itself, making FocusMax look like an ASCOM focuser. By doing this, they made it possible for other programs (such as MaxIm DL) that use the ASCOM Focuser interface to share the physical focuser. MaxIm talks to FocusMax, thinking FocusMax is its focuser. In reality, FocusMax passes MaxIm's Focuser calls through to the actual ASCOM Focuser driver which it has open to the physical focuser. Without this, it would be impossible for programs to share the focuser because only one program can own the serial port or whatever the physical focuser uses.

4. Presentation

The main part of the talk is presented using slides, which follow.

5. Summary

ASCOM has clearly reached its first goal, that of promoting awareness of open layered systems and protocols, and promoting the advantages of scriptable tools. The ASCOM initiative now has a large membership. Tools and products that use ASCOM are popping up all over. It has also demonstrated the feasibility of its second objective, developing and implementing standards. The success of the Telescope and Focuser standards and the imminent Dome standard prove this. ASCOM is so successful that we're starting to see the second-order effects, where people's imaginations and talents are being fired up by the existence of the ASCOM tools and standards. New capabilities are finding their way into the hands of amateurs and non-professional educators and thus astronomy is being advanced on a wide front.

Acknowledgments:
First and foremost, I would like to thank Tom Andersen and SPACE.com for their generous grant which made possible the ASCOM Platform package. Their support enabled the development of a variety of drivers for telescopes, the refinement of the Telescope standard, and in general helped kick-start ASCOM.

Just as important is the role that Doug George of Diffraction Limited played. He latched on to the ASCOM concept very quickly and added scriptable capabilities to MaxIm DL almost immediately. This made it possible to deliver automated systems for observing much earlier than I had imagined.

Thanks also to the rest of you out there who also embraced ASCOM, placed your early faith in it, and then jumped on the bandwagon as it was delivered. It is very gratifying to see that astronomers aren't as stodgy and resistant to change as I was warned of back in 1998.

Finally, my thanks go to my core team of associates: Doug George, Tim Puckett, Jeff Medkeff, Bill Yeung, Paulo Holvorcem, John Oliver, and others, who helped me to go beyond my self-imposed limits and reach new heights. They are true friends.

Synthesizing Large Telescope Apertures: Adaptive Optics and Interferometry

Scott W. Teare
Departments of Electrical Engineering and Physics,
New Mexico Tech, Socorro, NM 87801
Astronomy Department, San Diego State University, San Diego, CA 92182
Email: teare@ee.nmt.edu

Abstract: At sometime in every astronomer's life they are struck with "aperture fever", that is the desire for an ever-large telescope. Building filled aperture telescopes larger than a few 10s of meters in diameter is a costly and challenging endeavor, however, unfilled aperture telescopes can be constructed with very long baselines at considerably less cost. The adaptive optics technology available today allows novel interferometric telescopes to be constructed and such telescope could have applications for astronomers of diverse scientific interests.
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1. Introduction

Lord Rosse built the first of the large reflecting telescopes in 1826 at Birr Castle in Ireland. This telescope had a 36-inch aperture and used the metal speculum cast and polished into shape as the primary mirror. The success of this telescope inspired his second telescope, a 72-inch reflector of similar design that was completed in 1845[1]. In

the 200 years since then telescopes have been growing ever larger. Speculum mirrors were not ideal for telescopes and the next generation of telescope used glass substrates and in 1888 the Crossley 36-inch reflecting telescope, opened up a new race for the largest telescope. The largest refractor, the Yerkes 40-inch telescope, built in 1897, proved to be the last of the large refracting telescopes, but showed how far glass technology had come. In 1908 the 60-inch reflector at the Mount Wilson Observatory and the 100-inch Hooker telescope in 1919 were constructed pushing reflecting telescopes well beyond the size limits of refractors and set the new mark for large telescope. It was nearly 30 years later that the 200-inch telescope at Palomar Mountain saw its first light, and its success and new discoveries clearly showed the power of large telescopes for making astronomical discoveries. Today the 394-inch (10m) telescope on Mauna Kea in Hawaii is the largest aperture around and is regularly producing new wonders for astronomers.

The race for the largest telescope in the world has picked up again. There are plans for ground based 30 and 100-m telescopes each sporting catchy names such as the OWL (OverWhelmingly Large) Telescope, CELT (California Extremely Large Telescope) [2] and others. It is safe to say that aperture fever is alive and well in the astronomical community. There are of course drawbacks to these large telescopes, not the least of which is cost. From a use perspective these telescopes are planned for viewing from the earth's surface, their resolution then is limited by the earth's atmosphere. In addition the large size of the telescopes requires these telescopes to be built from segments so that they suffer from mechanical-optical alignment problems, which further degrades their performance. To overcome these problems, these telescopes must be equipped with both active and adaptive optics systems and most likely laser guided systems as well.

While these projects are coming into their own, there is another class of telescopes that is showing great promise in astronomy, interferometers. These telescopes are unique in that they have extremely high resolution, but have very little collecting area. Most interferometers are a collection of small telescope spread apart over distances greater than a 100 of meters. As such they can be thought of as a very large telescope but one, which has very few places in its diameter where the light can be collected. Several examples of such telescopes already exist, Very Large Array (VLA) and the Very Long Baseline Interferometer (VLBI) in New Mexico, the Navy Prototype Optical Interferometer (NPOI) in Arizona, the Center for High Angular Resolution Array (CHARA) in California and the VLT (Very Large Telescope) in Europe [2] and one on the drawing board, the Magdalena Ridge Observatory in New Mexico. These telescopes provide very large baselines and thus high resolutions with sparsely filled apertures and at considerably lower cost than their filled aperture counterparts would.

Interferometric telescopes that are to operate in the visible and near infrared wavelengths have the same issues with the atmosphere as regular imaging telescopes. Once the telescope diameter is larger than about 30-cm their resolution is limited by the atmosphere. Fortunately, the adaptive optics technology for meter class telescopes is fairly mature. In this paper we will discuss synthesizing large telescope apertures by considering how interference is created, the contributions of adaptive optics and sketches out a view of an interferometric telescope.

2.0 Interferometry

Interferometers use the beams from two or more light sources to produce interference fringes. These fringes are a measure of the angular variation between the two beams and if there is sufficient information available can be used to reconstruct images. The simplest demonstration of interference is the two-slit experiment developed by Young [3] and diagramed in figure 1. Here we show collimated laser light passing through two identical rectangular slits and being imaged on a screen. When the individual wavefronts from the two slits recombine rather than seeing just the shadow of the two slits as one may expect, the result is a fringe pattern of light and dark bands. The peaks of the intensity distribution are the bright bands and the valleys show the position of the dark bands. The fringes, the light and dark areas that appear in the pattern, are a measure of the separation of the properties of the Double Slit Screen, wavelength of light used and the separation of the Viewing Screen. The setup in figure 2 shows a modern version of the classic experiment.

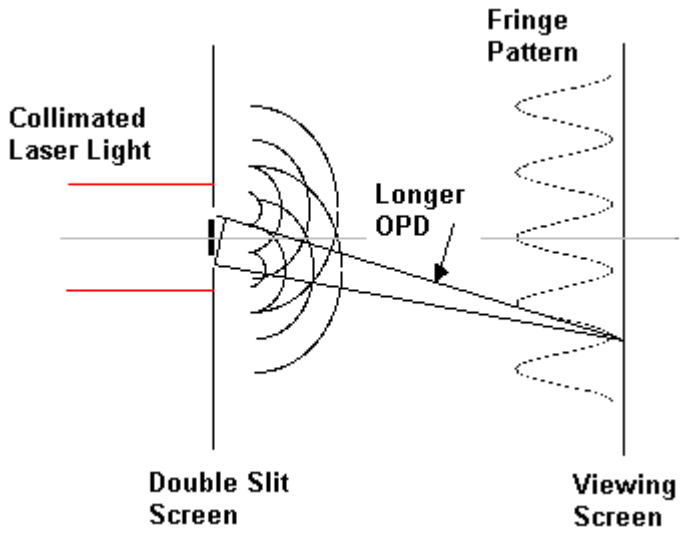

Fig. 1. A simple diagram of the two-slit experiment and the resulting fringe or interference pattern.

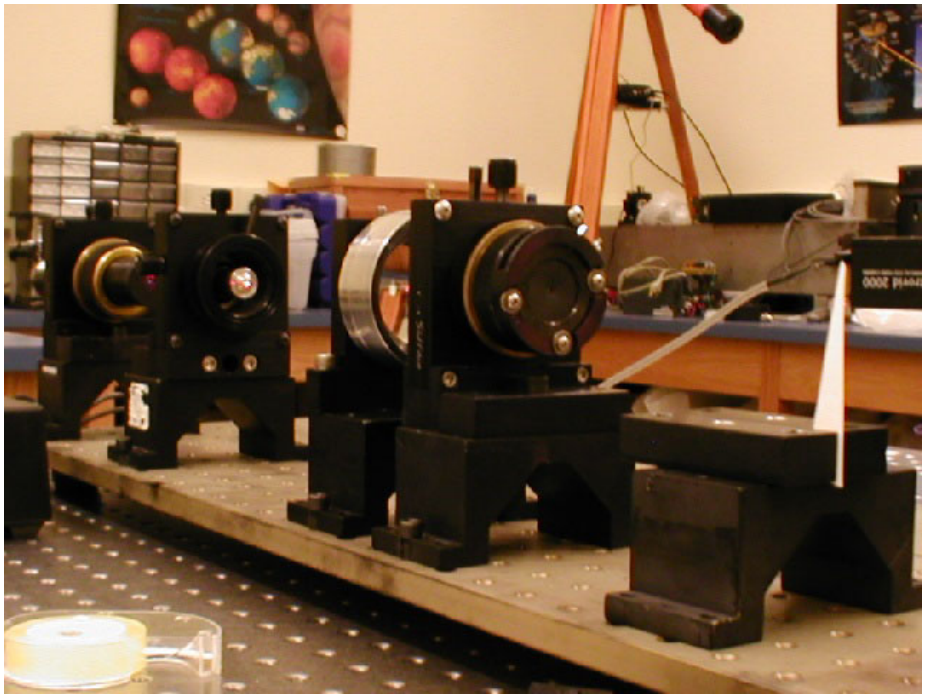

Figure 2. An image of a modern experimental setup used to obtain a double slit fringe pattern. In Young's classical 1801 experiment he used light from the sun as a source to obtain the first demonstrations of interfering two light beams. Here we use a laser as a source and a piece of a "recipe card" to split the beam from a circular aperture into two components, which recombine as fringes on a viewing screen that, is out-of-focus.

The simplest type of interferometer is the Newtonian Interferometer, basically a device used for viewing the flatness of an optic. It is commonly employed by placing an optical flat on a piece of glass (usually one in the process of being turned into a flat) and viewing the fringes produced when illuminated by a monochromatic light source. Using this interferometer it is possible to measure the differences between the two optical pieces to within a fraction of a wavelength of light (~500nm).

Interferometers are used in many aspects of optical testing and there are several types of interferometers [4]. The reason behind there being so many types of interferometers available can be understood by recognizing that they are each specific applications to specific problems. For example, testing curved optics can take advantage of a more advanced design than is needed for testing flat surfaces.

3.0 Interferometric Telescope

The first stellar interferometer used on a large telescope was that of Michelson and Pease, used on the Mount Wilson Observatory 100-inch telescope [4]. This intereferometer was constructed from a 20-foot beam with light collecting mirrors whose separation could be adjusted. This instrument was used to first obtain fringes on an object and then separation of the mirrors was increased until the fringes vanished. This meant that the separation of the mirrors matched the angular extent of the object being measured. This was successfully done for the star Betelgeuse which was measured as having an angular extent of 0.047 arcseconds [5].

The main problems to contend with in an interferometric telescope is that it requires the path length between the telescopes to be accurate within a few microns and to obtain good "fringe contrast", that is the ability to detect the bright and dark fringes, the wavefront errors delivered to in beam combiner must be better than about 1 rad rms or about $\lambda/6$ [6].

In Michelson's interferometer the individual apertures were square, about 12-inch across their diagonal and their light was collected in the same telescope aperture. A 12-inch telescope cannot collect much light and so Michelson's interferometer was limited to bright stars. The desire to look at fainter objects means that the aperture size has to increase. However, the disadvantage is that once a telescope becomes larger that 30cm the effects of atmospheric turbulence begin to degrade the wavefront that can be obtained from the telescope.

The simplest type of interferometric telescope is a variation on Michelson's made by placing a mask of non-redundantly positioned holes over the telescope. A representation of such a mask is shown in figure 3. This makes a sparsely filled aperture telescope, however, the path length from each opening to the image plane is the same. However, there is little advantage to such a system beyond a study or demonstration as much of the aperture is blocked off which reduces the overall performance of the telescope. In the next step to having individual telescopes connected together over long paths it is necessary to control the path length differences between all the telescopes to differences less than a few microns.

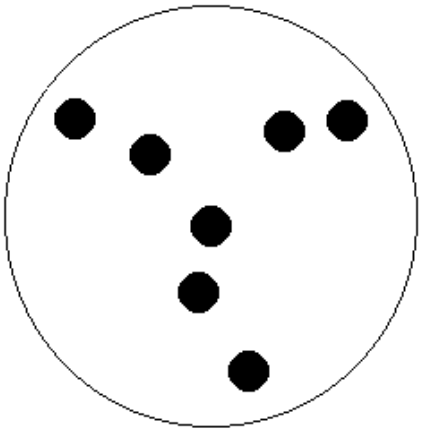

Fig. 3. Illustration of an aperture mask used for interferometric measurements on a single telescope. The advantage of this type of system is that the path length from each opening in the mask to the beam combiner is the same. Notice that there are several different spacings between the holes in the mask.

3.0 Adaptive Optic Wavefront Correctors

Adaptive optics systems are opto-electro-mechanical instruments that are used to minimize waverfront errors [6]. A simple model of an adaptive optics system is shown in figure 4. There are several different variations of adaptive optics, one of the most popular

combines a Shack-Hartmann wavefront sensor and a single facesheet style deformable mirror. The light from the telescope is sampled in the wavefront sensor and the deformable mirror is adjusted based on these measurements to minimize the wavefront error. As a result, a larger telescope can be used while retaining a good wavefront.

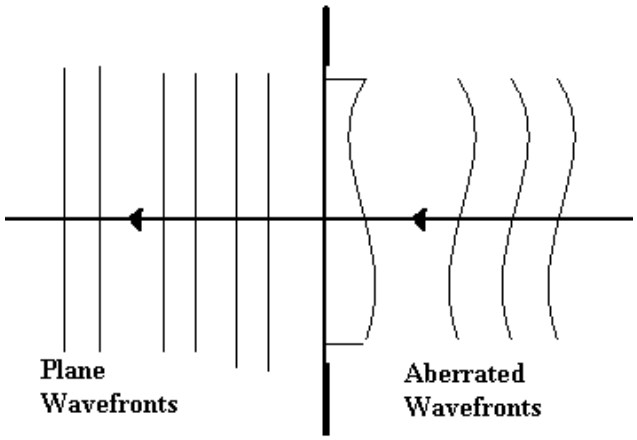

Figure 4. A simple diagram illustrating how an aberrated wavefront is corrected by an adaptive optical element.

It is important to remember that adaptive optics systems require a certain amount of light to operate and this light is removed from the light path and so cannot be used in the the imager. While adaptive optics improves the wavefront error, it does not improve the telescope resolution and will often reduce the amount of light that reaches the imaging camera.

Two common approaches to wavefront reconstructors are zonal and modal. Zonal reconstructors shape a deformable mirror to minimize the wavefront error while modal reconstructors are used to completely remove specific modes. If the waverfront errors do not have many high frequency components then a modal reconstructor can provide better corrections, however in most cases the “best fitting” approach of the zonal reconstructor provides better results [6,7].

4.0 Adaptive Optic Interferometers

In the same manner as with any large telescope, the adaptive optics system is used to produce a diffraction-limited beam from the telescope, that is the telescopes static aberations and the effects of the atmosphere are removed. When this is done for several telescopes and their diffraction-limited wavefronts are combined a high quality interferometric telescope can be created [8].

Interferometric telescopes can be used for imaging and synthetic images can be created from measuring the fringe spacing from the pairs or triples of the telescopes. The best example of an interferometric telescope is the radio telescope the VLA. Images of objects can be obtained from the sparsely filled aperture of the telescope using sophisticated software packages. Similar synthetic images can be made from optical systems as well. An example of such a telescope is shown in figure 4.

Figure 4. A photo of the VLA in central New Mexico. Image courtesy of M.C. Gino.

The maximum dimensions of the telescope set its resolution, however, the much of the telescope is unfilled. In an interferometer the telescope aperture is referred to as the u-v plane. One fortunate feature of a ground-based interferometer is that the earth's rotation can be used to improve the information coverage in the telescopes u-v plane. To make images, the greater the fill factor of the u-v the more information is available for constructing the image. Careful selection of the position of the telescopes aids in providing the additional information needed for imaging [8, 9].

5.0 Synthetic Apertures

Using many smaller telescopes to construct a high-resolution array provides an economical approach to achieving aperture sizes well beyond the size that could be constructed for a single filled aperture. Of course there are complications in creating these telescopes and the reduction of the data from the telescope is not as straight forward as in a single imaging telescope. The software that is used for radio interferometry is readily available for users of UNIX based operating systems allowing the images from an optical interferometer to be converted into images. This is a major plus as reconstructing the images from fringe data is not a simple process.

The basic components of the interformeter are the telescopes, light paths, path length compensation and beam combiner, the latter being the optical equipment that is used to interfere the beams. Introducing adaptive optics systems to correct the wavefronts prior to interfering the beams and stabilizing enhances the quality of the system. A fringe tracker is also commonly used to lock onto the fringe pattern of interest. Interferometers can get complex exceptionally fast, and such systems with many telescopes, usually more than 6, are capable of imaging and as 15 telescopes are approached snapshot imaging is possible, that is images can be build in a single set of observations of the object.

One draw back to Synthetic apertures is that the field of view of the interferometer is not particularly wide; most interferometers are referred to as zero field of view

instruments. That means that an image is built up by repositioning the telescopes with respect to the source, similar to performing a raster scan and this information is used to map an extended object. For many telescopes this is both a time consuming and challenging endeavor in itself.

In spite of the challenges, interferometry is still looking like the best approach for creating high-resolution images at affordable cost.

6.0 Summary

Synthetic aperture telescopes are becoming more popular in astronomy and the limits of large aperture sizes are being pushed forward thanks to the efforts of interferometrists. At the moment, interferometry is a specialization and there are not too many working systems, but this number is changing all the time. It will be most interesting to see how long it takes for synthetic aperture telescopes to be come popular outside the pure scientific field and have them showing up as working instruments among collaborations of astronomers.

High Resolution and Wide Field Optical Systems For CCD Imaging

Peter Ceravolo
Ceravolo Optical Systems

Abstract: An overview of the imaging performance of currently available telescopes are presented followed by examples of imaging systems at the low and high end of the resolution range that are new to amateur astronomers. The authors personal design quest for a high-resolution optical system for imaging faint objects will be outlined.
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1. Introduction

Most amateur CCD imaging is accomplished with readily available commercial telescopes and a typical image sampling rate of 1.5 to 2 arc seconds per pixel. In this paper, optical systems outside of this common resolution range will be considered, both at the coarser/wide field and high resolution, sub arc second/pixel resolution range, with special emphasis given to image quality issues.

2. Imaging performance criteria

Criteria for an excellent optical system, based on the author's personal biases, experiences and demanding expectations are as follows:

- image blur 2x2 pixels or less across the entire CCD detector
- little if any dispersion of light (color aberration) for luminance imaging with high efficiency CCDs (thinned and back illuminated) over a wide spectral band (360-900 nm)
- reduction or elimination of ghost images
- fully baffled, high contrast field of view
- compact OTA for reduction of mount and wind loading
- reduction of thermal effects via ventilation and fans

3. Conventional telescope performance

The following systems yield 1.4 - 2 arc seconds/pixel sampling with typical focal lengths and chip combinations. Performance criteria can be controversial since expectations vary widely. The following assessments are, again, based on the author's personal biases, experiences and expectations.

The Newtonian

- easily available and low cost optics
- poor optical system due to huge coma off axis in fast mirrors

The Apo Refractor

- suitable for wide field imaging with field flattener/corrector
- suitable for high resolution imaging with small pixel CCDs
- spectrally challenged with high efficiency chips and luminance imaging
- limited to small apertures

Maksutov-Newtonian

- best imaging solution in the Newtonian configuration
- suitable for wide field and high resolution images with small pixel CCDs
- near perfect achromatism for luminance imaging
- larger apertures subject to severe thermal effects

Schmidt-Cassegrain

- most compact OTA
- large coma off axis with field curvature
- significant spherochromatism (variation of spherical aberration vs. wavelength) at large apertures

Ritchey-Chretien Cassegrain

- among the best possible solutions for high resolution imaging
- difficult to align
- compact OTA

4. Wide field imaging optical systems

The proliferation of physically large multi mega pixel CCDs has made wide field imaging (>5 degree field and sampling of 3 arc sec/pixel or >) practical and appealing.

Telephoto Lens

- telephoto form suffers inferior color correction for broad band luminance imaging
- easily available and inexpensive
- off axis image definition varies widely with models and makes
- significant vignetting

Maksutov-Newtonian Astrograph

- moderate speed (f/2.5)
- excellent image correction over entire detector
- field corrector lens must be relatively close to detector (problematic with some cameras)

Compact Maksutov-Cassegrain Astrograph

- moderate speed (f/2.5)
- compact design – variant of Maksutov-Newtonian astrograph
- large obstruction reduces light throughput

Schmidt-Newtonian Astrograph

- moderate speed (f/3)
- excellent image correction over entire detector
- large field corrector lens to focal plane distance to accommodate camera/filter wheel

Conventional Schmidt camera

- very high speed- much faster than typically necessary for CCDs
- internal focus in small cameras unsuitable to CCDs cameras

5. High Resolution Deep Sky imaging systems

Image sampling rates of 1 arc sec/pixel and finer begin to extract detail in small deep sky objects hidden by coarser sampling rates. Faint object imaging requires sub arc second sampling to prevent sky background from reducing a faint objects signal to noise ratio. The increasing availability of ultra-small pixel CCD arrays allows the use of shorter focal length telescopes for high resolution imaging. Active optics (high speed guiding) allows high-resolution imaging with less massive mounts. Off axis aberrations become more problematic when larger, small pixel, arrays are coupled to a shorter focal length (faster and typically more aberrated) optical system. Dome seeing, mount tracking, optical collimation and OTA thermal effects must be minimized for successful high resolution imaging.

Field Corrected Newtonian

- 3 element Wynne correctors are best over very wide fields or fast systems (f/3)
- Ross 2 element corrector with hyperbolic primary suitable for (f/4.5) slower systems
- pupil ghosting must be reduced or eliminated in focal plane correctors

Maksutov-Newtonian

- best design form in smaller apertures
- excellent off axis image quality (4x better coma correction than straight Newtonian and flatter field)
- near perfect achromatism for luminance imaging
- relatively insensitive to collimation problems

Ritchey-Chretien Cassegrain

- most ideally suited to high resolution imaging
- best over all images achieved when detector is focused off axis (typically at the edge of the detector)
- very large arrays require field flattener
- collimation difficult due to the two strongly aspheric mirrors

Field Corrected Cassegrain (Ceravolo)

- Cassegrain configuration with elliptical primary, spherical secondary and sub-aperture corrective lenses
- less sensitive to collimation (i.e. centration of secondary—it's spherical)
- excellent field correction – better than RC over large arrays
- near zero color dispersion over broad band

6. Design Of A Faint Object Telescope

In order for any hobby to be truly fulfilling, one must have something substantive to do. Having produced a time-lapse movie of a comet, and having done considerable film astrophotography with custom astrographs, the author sought other challenges than imaging the Orion Nebula for nth time. The relatively recent discovery of Trans Neptunian Objects (TNOs) offers an opportunity start an observing program that can make a significant contribution to astronomy.

Due to the usual limitations of large telescope time, TNOs are being lost as fast as they are being discovered. The careful and dedicated observer can make a significant contribution by making follow up observations of these very faint objects. TNO, or any other faint object imaging, requires a carefully designed and fully optimized optical system to reach limiting magnitude of 22 or fainter. Tracking errors, thermal effects and optical aberrations that smear light will reduce a telescopes limiting magnitude.

The design approach

- choose the detector – Marconi with 13 micron pixels
- match focal length to pixel size to achieve 1 arc sec or finer pixel sampling – 2.5m
- 20" f/4.5 mirror available
- large Wynne corrector designed to yield a very large field to accommodate a future larger array and off axis guider
- prime focus configuration eliminates extra reflection from diagonal
- ideal baffling arrangement, stray light reduction easier than in Newtonian configuration
- requires liquid cooling of camera
- near perfect 1k Site array becomes available relatively inexpensively
- 5 m fl required for 1 arc second sampling with 24 micron pixel
- completely redesign the optical system!
- 20" conversion to Cassegrain system possible, but OTA long due to f/4.5 primary
- apochromatic Barlow and Newtonian configuration possible- due to very broad spectral band of array, images not as good as Cassegrain, baffling Newtonian problematic
- dump 20" primary and start over with a typical Cassegrain system?

CCD Mosaics

Doug George
Diffraction Limited
Email: dgeorge@cyanogen.com

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Introduction

First-generation CCD cameras were relatively small (32k pixels to 90k pixels). Photographic film, in comparison, has literally millions of individual grains. In a practical sense, however, the resolution of a typical film image is about six megapixel. Nevertheless, this is over 60X larger than a first-generation camera. So while the high sensitivity of a CCD camera made it very effective for high resolution imaging, it could not compare with photographic film for wide field imaging.

Commercially available CCD cameras now range up to 16 megapixel. Unfortunately, these large arrays come at an extremely high cost. Fortunately, 1-2 megapixel cameras are available in a price range within reach of many amateur astronomers. With this size of array, building 6-20 megapixel or larger mosaics is quite possible using suitable equipment.

Equipment

Optics

The actual optics used will depend on the nature of the intended mosaic. They might range from a long focal length telescope for high-resolution mosaics, to conventional photographic lenses for very wide area images. The essential requirements, in approximate order of importance, are:

1. High quality across the entire field of view
2. No vignetting or at least correctable vignetting
3. Fast F/ratio
4. Low distortion

The most important issue is image quality. No matter how good they are on-axis, all optical systems suffer various optical aberrations off-axis, including astigmatism, coma, and field curvature. Unfortunately CCD cameras are highly sensitive to aberration because of their sensitivity; on a relatively bright star, the faint outer tails of the point-spread function become visible. The larger the array, the more obvious these off-axis imaging problems become. Very few amateurs have optical systems capable of producing satisfactory image quality across the field with a multi-megapixel CCD camera.

Vignetting is a particularly troublesome aspect when you attempt to assemble the mosaic. A modest amount of vignetting might not be noticed in a single image because it occurs only near the edge. In a mosaic, however, it will be visible as a regular pattern throughout the combined image. Commercial camera lenses in particular have large amounts of vignetting, making it difficult to assemble a high quality mosaic. Flat fielding can help significantly, although taking the necessary calibration frames is time consuming and requires careful technique.

A fast f/ratio is important mainly for efficiency's sake. It is hard enough to acquire a single high-quality image; repeating this many times over is at the very least time consuming. If possible it is best to acquire all images for the mosaic in a single night, since sky conditions can vary significantly from night to night. Having a fast optical system naturally makes this easier.

Distortion is inevitable because we are projecting a spherical surface – the sky – onto a flat detector. In addition, many optical systems have more severe distortion characteristics that are related to their specific design. These distortions make it difficult to align adjacent images without having stars "double up" at the edges. Software can overcome this difficulty, but it is always best to minimize the amount of correction required.

Another optical component that may be overlooked is the filter wheel. Unlike film cameras, color imaging with CCD cameras requires alternating exposures with an RGB filter set. In fast systems it is very important to ensure that the filters are properly perpendicular to the optical axis; tilt can cause distortion at the edges of the field. This can be especially problematic if the individual filters are not coplanar.

Mount

The main purpose of the mount is to continuously point the camera at a particular location on the sky, without significant drift that would compromise the image quality. A variety of commercially available mounts are now available which meets this basic requirement, although at high resolutions expensive mounts and/or autoguider systems may be necessary.

With the advent of computer-controlled telescope mounts, the actual mechanics of taking mosaics is now much easier. The entire acquisition sequence can be automated; once the equipment is set up and configured, the whole process can amount to pressing a button. This minimizes human error – which is a significant issue at 4:00 am – and minimizes wasted time between exposures.

GOTO mounts also allow for more efficiency in other ways. Since the pointing accuracy is generally very high, the individual fields are positioned very accurately relative to each other. This reduces the need for overlap between adjacent frames, which means that more sky area can be covered per unit time.

Computer Control

This is an area of rapid advancement. There are two parts – generating the mosaic "script", and actually taking the images.

Some planetarium programs will output mosaic patterns automatically, allowing you to define the field centers quite easily. A more powerful approach is to use an Excel spreadsheet to generate the field center list. With a bit of tinkering, you can explore different scenarios including varying overlap, different camera orientation, etc. Frame spacing can be calculated automatically using simple trigonometry. At high declinations and wide fields it is important to make sure that the lower edge of the frames have adequate overlap.

For acquisition, off-the-shelf sequencing and scripting software is now widely available. For example, the combination of MaxIm DL/CCD and ACP2 provides a fully automatic method for sequencing exposures. In addition, the entire setup can be customized as needed by modifying the VBScript modules used by ACP2.

Practical Aspects

Producing a high quality mosaic requires the best possible sky conditions: clear dark skies, good transparency, low sky glow, and minimal sky gradient. In addition, the target area must be well above the horizon for an extended period of time. In many cases, this will require travel to a remote site. This imposes constraints on the equipment, which must be reasonably rugged and portable.

For portable use, a fast, accurate polar alignment is important. A good technique, developed by Paul Boltwood, is to take a 60 second exposure of the pole. Half way through the exposure, the mount is rotated smoothly as far as it will go. This produces an image with circular patterns centered on the location of the mount's axis. It is very easy to measure the distance from the refracted pole and make the required adjustment.

Simply completing a high-quality mosaic can be a problem. It is not too difficult to acquire a single set of images for one field. The difficulty comes in achieving the same high quality over a larger area of sky over a period of time. Often it is discovered that a particular field is missing or bad because of user error, an equipment glitch, trees encroaching, clouds wandering through the field, or other transient event. This can be particularly troublesome if the target area is relatively low in the sky, limiting the time available to shoot it. If observing opportunities are limited, you may have to wait a couple of seasons before the field is available again.

The simplest approach to this problem is to shoot the entire area several times. This shotgun approach tries to ensure that at least one good image set is available for every field. Even so, sometimes Murphy's Law sometimes interferes!

Software

Once the images are acquired, there are still challenges in producing a seamless high-quality mosaic, such as accurately aligning adjacent frames, leveling background variations and color balance, and ensuring a smooth transition from image to image.

Image alignment can be particularly troublesome when there is geometric distortion in the images. RegiStar from Auriga Imaging can overcome these problems by "morphing" overlapping images to match each other.

Background leveling is a more difficult problem to solve, especially if there are gradients in the image. In areas away from the Milky Way, it is usually possible to individually level each image prior to combining using a standard processing algorithm. In areas with substantial nebulosity this is difficult to do automatically; often, manual tweaking is required for the best results.

To ensure that the edges of the individual images do not show up in the final result, a technique known as "feathering" is used. In the areas that overlap, a gradual transition is made from one image to the other. Since the changeover is gradual, it is hard to see the edge of the individual pane even if the backgrounds are not perfectly matched.

Conclusions

Wide-field imaging is no longer the sole domain of photographic film. High quality, wide-field mosaics are quite practical with CCD cameras. The use of mosaics allows for a large, high-resolution image to be generated even with a modest sized CCD array.

Automatic Photometric Telescopes: Past and Future

Russell M. Genet
The Orion Institute

Abstract: A summary history of the development of automatic photoelectric telescopes (APTs) is given, with emphasis on how operational efficiency and high accuracy were achieved. The paper closes with a brief consideration of the future of such telescopes, especially NASA's Kepler, a space-based APT.
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1. Introduction

In the history of robotic telescopes, automatic telescopes devoted to stellar photometry—especially the photometry of brighter stars—hold a special place simply because they were first. There are, perhaps, three reasons for this. First, stellar photometry is, at its heart, a process of measuring the brightness of stars at discrete time intervals, essentially a string or small table of "zero-dimensional" numbers and thus, at least in principle, such stellar photometry is not nearly as data intensive as spectroscopy (one dimensional) or imaging (two dimensional). Second, bright stars are relatively easy to locate, easing the problems of automation. Finally, useful wide-band photometry can be accomplished with small-aperture telescopes. This is important because while one might let a robot run a small, low-cost telescope, one is less likely to trust a large, expensive telescope to the not always tender mercies of automation unless one were forced to do so due to the telescope's location in space.

2. The First Automatic Telescopes

Connecting a photometer and telescope to a computer so that observations can be made while one sleeps is a natural thought and was probably considered by a number of astronomers shortly after digital computers became available. Early computers, however, were large, expensive, environmentally sensitive, and not very reliable. These were the days when a computer occupied an entire, carefully air-conditioned room. Thus it is not surprising that some of the early attempts to automate astronomy left the computer down at "headquarters" with a radio or landline link to the remote, mountaintop telescope.

Early in its history, Kitt Peak National Observatory automated a 50-inch telescope, the controlling computer being many miles away in Tucson. The observatory was equipped with weather sensors, and the entire operation was fully automated [1]. Although a few observations were successfully made with this system, it was difficult to keep in operation and the telescope was soon converted to manual operation.

By the late 1950's it was clear to Arthur D. Code, at the University of Wisconsin, that there was an important future for astronomy in space, and he soon launched into the development of the first space telescopes which were, not surprisingly, automatic photometric telescopes. To gain experience with automated telescopes, Art wisely decided to get one going first on the ground, and to this end a ground-based version of the first space telescope (both 8-inch telescopes equipped with photoelectric photometers) was installed at Wisconsin's Pine Bluff Observatory [2].

The Wisconsin automatic photoelectric telescope (APT) ran entirely on its own. The small roll-off roof observatory, located on the lawn not far from the main observatory, was equipped with weather sensors and a power roof. Advances in computer technology had, by this time, led to mini computers. The first of these to receive widespread application was Digital Equipment Corporation's PDP-8. This relatively small desktop computer was well suited to real-time control tasks, and was used by Code and his associates. Their APT was controlled by a DEC PDE-8 located in the nearby basement of the main observatory, connected via wires. It is my understanding that this particular PDP-8 was the first such mini computer made by DEC, and DEC tried to buy it back, years later, for their museum. When I visited Pine Bluff many years ago, however, the PDP-8 was still there, although no longer operational.

The Wisconsin APT was in nearly nightly operation for several years, primarily devoted to observing extinction stars to compliment the photometric observations of variable stars made on the observatory's larger, manual telescope. It was, however, also used for variable star research in its own right in an observing program of Robert Millis' while he was a graduate student at Wisconsin. Art informed me that one of the reasons the telescope was eventually shut down was that students, who often lounged on the observatory's grassy grounds in spring and summer evenings, discovered that by pouring beer in the rain sensor, the roof would snap shut in a manner bound to impress one's girlfriend.

3. Automatic Photoelectric Telescopes Come of Age

Mini computers remained expensive, but when microcomputers became available, the doors to automation were opened wide. Although not fully automated, David Skillman

developed a system based on the just available Apple computer. Skillman's system required "training" the system manually at the beginning of the evening on some variable and comparison star, but once trained, the system would continue making the same observations until the star set or David shut the system down due to inclement weather [3].

In 1979 I purchased a Radio Shack TRS-80 shortly after founding the Fairborn Observatory. I used this computer, initially, to reduce photometric data, and then to prompt my observations and log photometric data directly. Many of my observations were made for Douglas Hall at Vanderbilt University, and we eventually collaborated on a book on stellar photometry [4]. As I stood there, running the telescope night after night, I began to consider having my TRS-80 not only control my photometer, but also my telescope so I could sleep. I was encouraged in this line of thinking by my wife, by my boss at the lab where I worked who often caught me napping, and by Kenneth Kissell, my astronomer friend.

Fortunately, before I had proceeded very far on automating my telescope, I met Louis Boyd in Phoenix while visiting several amateur photometrists on my way to an observing run at Kitt Peak. Lou had already built his automated photometer and had started work on his automated telescope, the Phoenix-10. I was, to say the least, utterly fascinated, and followed Lou's work closely for the next several years via long telephone conversations, letters, and occasional visits. Finally, in October 1983 we watched his APT do its thing all by itself for a few hours and then went to bed. When we got up in the next morning, the telescope had repeatedly (some 600 times) found, centered, and made photometric measurements of a number of bright stars. Some six months later I had a somewhat similar system, the Fairborn-10, in operation in Ohio [5].

Ohio proved to be particularly ill-suited to automated photometry, however, so taking advantage of the location in Arizona of one of the branches of the Air Force laboratory I worked for, I moved to clearer skies, and Lou and I joined forces under the auspices of the Fairborn Observatory. I was able to interest the National Science Foundation (NSF) and the Harvard-Smithsonian Center for Astrophysics in our robotic telescopes. Doug Hall, Lou Boyd, and myself requested and received funding from NSF for the Vanderbilt-16 APT. Sallie Baliunas took an interest in our APTs, and after I briefed David Latham, the Center for Astrophysics approved the use of an unused satellite tracking facility on Mt. Hopkins for our telescopes.

When Dave phoned us with the news that the Smithsonian had approved our use of the Mt. Hopkins facility, Lou and I loaded up my Fairborn-10 telescope which I had brought with me from Ohio, and drove down to Mt. Hopkins. Less than 24 hours after Dave gave us the go-ahead, I called him back, informing him the first APT was bolted to the floor. Of course it was quite some time before the Fairborn-10 was operational as a telescope again, and even longer before the observatory itself was fully automated, but finally, one clear day, Lou and I drove away, leaving microcomputers in charge of the entire operation.

5. Achieving Operational Efficiency

As the number of APTs in operation at the Fairborn Observatory on Mt. Hopkins multiplied, the problem of handling all the observational requests and resulting flood of

photometric data became critical. Lou and I both had regular daytime jobs, and the time we could devote to the Fairborn Observatory was limited. We devised two primary solutions to this difficulty.

The first solution was the appointment of "principle astronomers" (PA's) to be the interface between the APTs and the using astronomers. Each telescope was assigned a PA, and it was the PA's job to check and consolidate observational requests and, on receipt of observational results, to appropriately reduce and distribute them back to the original requesters. Michael Seeds at Franklin and Marshall College was the first PA, managing the Phoenix-10 telescope for us. All these years later, Mike is still the PA for the P-10 telescope, an amazing record of service.

The second solution overcame the difficulties of loading stars onto the telescopes and matching the resulting observations to the initial requests. Lou and I quickly realized that we needed some sort of high-level scripting language to facilitate the use of the APTs. On an airline flight to visit Sallie Baliunas at Mt. Wilson, we sketched the outlines of the Automatic Telescope Instruction Set (ATIS). Astronomer Donald Hayes helped us refine and document ATIS, as did Donald Epand. The key to ATIS was "echoing" all the input commands to the output such that one could reconstruct all that had transpired, including the initial observational request, from the output file alone [6]. Other high-level scripting languages have now been developed, and I'm looking forward to hearing about Edward Beshore's TSCRIPT at this meeting.

7. Achieving High Accuracy

Once an efficient operation was achieved, our next goal was to improve the accuracy of our automated observations. Accuracy, at the time, was about 0.01 magnitudes, typical of most photometric observations, but not as good as those made by the best photometrists, such as G. Wesley Lockwood at Lowell Observatory.

To this end I organized two workshops on precision photometry, both held at my house in Mesa, Arizona. Attending at one or both were Sallie Baliunas, William Borucki, Robert Donahue, Donald Epand, Douglas Hall, Gregory Henry, G. Wesley Lockwood, Diane Pyper Smith, Andrew Young, and myself. We considered all the possible causes of imprecision and inaccuracy, both short and long term, and possible ways of overcoming them, both via refinements to hardware and improvements in operations—especially quality control procedures. Andy Young was quite conversant with sources of photometric error, Wes Lockwood consistently made accurate manual observations and knew how he achieved them, Greg Henry had many suggestions for improving quality control operations, and Lou Boyd was ever vigilant for ways to avoid problems via equipment design.

The workshops were documented in a paper that saw much outside review and many revisions before it was finally published [7]. Lou Boyd (equipment) and Greg Henry (operations) went on to implement the recommendations in this paper, turning ultra-precision automated photometry into a reality, achieving millimagnitude accuracies on a fairly routine basis [8]. Bill Borucki continued ever onward in his search for ultimate photometric accuracy, holding two workshops at NASA Ames on the topic.

8. Future APTs

Computer-controlled telescopes have become readily available and affordable, as have computer-controlled CCD cameras (and aperture photometers). Thus the stage is now set for an increasing number of APTs of various sorts, and they are appearing with increasing frequency. Hopefully one will soon be able to afford entirely off-the-shelf hardware and software for a complete home APT system. This would be a boon to both professional and amateur scientists—particularly variable star observers—who desire to accumulate lots of data without having to stay up late on many nights. It appears we are close to achieving this goal with respect to telescopes, CCD cameras, and photometers. However, automating observatories replete with weather sensors in an integrated fashion to form an entire off-the-shelf system remains for the future.

Looking out into the future, 2007 to be specific, the ultimate APT should begin operation, as the Kepler mission begins its search for transits of earth-like planets. Although Bill Borucki and I briefly considered the use of ground-based APTs to detect extrasolar transits [9], and an APT at the Fairborn Observatory was the first to detect such an extrasolar transit [10], the detection of Earth-sized planets really required a space-based telescope, a task to which Bill Borucki has admirably devoted himself for over a decade. Once in a near-Earth orbit around the sun, Kepler will simultaneously and continuously observe some 100,000 stars photometrically, watching for the slight dips in stellar light caused by planetary transits. It is expected that the transits of about 100 Earth-like planets will be observed by Kepler.

9. Conclusions

APTs of any sort have been in operation for just over three decades now, and in continuous, routine operation for less than two decades. At first APTs were limited by the computers used to run them, but with the advent of microcomputers this restraint was effectively removed. Operational difficulties were overcome by assigning principle astronomers as a human interface between the robots and their users, and by developing a high-level scripting language for instructing the robots and recording their observations. High levels of automated accuracy were achieved by very careful attention to hardware design and, especially, through extensive, rigorously-enforced quality control operational procedures. As computer-controlled telescopes and CCD cameras become more numerous and affordable, an increasing number of APTs should become operational. Finally, with the launch of Kepler in 2007, APTs may contribute to humanity's quest to find life elsewhere in the universe.

Acknowledgments

Although I moved on to other endeavors a decade ago—science writing, teaching, and additional schooling—it is a pleasure to acknowledge those I worked with for a decade on APTs and also to acknowledge their many accomplishments in the years since then. Lou Boyd has very ably directed the Fairborn Observatory for the past decade, expanding the number of APTs from seven to a dozen. In this he has been greatly assisted by Don Epand. Doug Hall continues his research at Vanderbilt University. Greg Henry is now

the principle astronomer for five APTs, serving astronomers world wide while he searches for additional planetary transits. Don Hayes teaches physics and astronomy at Pima Community College in Tucson. Michael Seeds, about to retire from Franklin and Marshall College, vows to continue on as the PA for the P-10 APT. Bill Borucki is now the Principle Investigator on NASA's Kepler mission. Kenneth Kissell still encourages me in things astronomical. Sallie Baliunas and Dave Latham are still at the Center for Astrophysics, while Wes Lockwood is still making precise photometric observations at Lowell Observatory.

Amateur Spectroscopy: From Qualitative to Quantitative Analysis

Dale E. Mais
Mais Observatory

Abstract: Spectroscopy is a new field of study for the amateur. This type of exploration by an amateur is the result of the availability of several types of off-the-shelf spectrometers, which can be coupled to a CCD camera. For the most part, amateurs pursuing this area have done so more from a qualitative standpoint: stellar classification and identification of the more prominent emission and absorption lines in stars and gas clouds. However, a spectrum contains much more valuable information about the physics of the region under survey. My talk will describe my initial efforts in the use of synthetic spectroscopy and how it can be used to determine a variety of stellar parameters such as temperature and abundances. The process involves the creation of stellar atmospheric models where a variety of variables can be altered and the resulting spectrum fitted to the actual spectrum obtained at the telescope to find the best fit.
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1. Introduction

The continuing advance of technology and instruments which are affordable to the amateur and small observatory community has now made it possible for amateurs to work in areas of astronomy, until now, previously the domain of the professional. This includes spectroscopy. The first break-through occurred with the introduction of low cost CCD detectors. This paved the way for a breathtaking increase in what the amateur could now accomplish in photometry and astrometry. Closely coupled to this has been the increase in low cost computing power and versatile and user-friendly software. Never before has the amateur had such an array of technology and tools available to conduct and contribute to scientific research.

Most recently, the availability of spectrometers has made it possible for the amateur to do spectroscopy using moderate resolution. Coupled to sensitive CCD detectors, these instruments, coupled to even modest sized telescopes, allows the amateur to do a wide variety of projects such as classification, identification of atoms, ions and molecules in nebulae, stars and interstellar regions. This only represents the beginning however. The analysis of a spectrum tells one a great deal about conditions and processes within astronomical objects. This kind of information is contained within the spectrum, as intensity of the line, the shape of the line and the presence, absence and ratios of intensities of lines. I will describe in this paper some of my initial attempts at using software, freely available, which calculates the spectrum of a star. Various inputs are possible and a comparison of the computed spectrum with the actual spectrum allows for the determination of various physical conditions in the atmospheres of stars.

2. Results and Discussions

My primary instrument for spectroscopy is a Celestron 14, which has had a Byers retrofitted drive system. The Santa Barbara Instrument Group (SBIG) Self Guiding Spectrometer (SGS) is linked to the telescope with a focal reducer giving a final f6 ratio. The CCD camera attached to the spectrometer is the SBIG ST-7E with 9-μm pixel size. The SGS instrument appeared on the market during the later half of 1999 and was aimed at a sub group of amateurs with special interest in the field of spectroscopy. The light from the telescope reaches the entrance slit, which can be 18 or 72-μm wide. The light passes through the slit and reaches the grating and ultimately the CCD cameras imaging chip. The remaining field of view is observed on the guiding CCD chip of the camera and allows the viewer to select a field star to guide upon once the object of interest is centered on the slit. In this paper only results obtained using the 18-μm slit will be presented. The SGS features a dual grating carousal, which, with the flip of a lever, allows dispersions both in the low-resolution mode (~ 4 Angstroms/pixel, ~ 400 Angstroms/mm) or higher resolution mode (~1 Angstrom/pixel, ~100 Angstroms/mm). In the low-resolution mode, about 3000 Angstrom coverage is obtained whereas in the high-resolution mode, about 750 Angstroms. Wavelength calibration was carried out using emission lines from Hydrogen and/or Mercury gas discharge tubes.

Initial attempts at quantitative analysis focused on planetary nebulae. These objects give rise to emission line spectra in which a number of well-defined species are observed and their relative intensities are easily measured. In the study of gaseous nebulae, there are a number of diagnostic lines whose ratios are sensitive to varying degrees with temperature and electron densities. Equations have been derived from theoretical starting points, which relate these ratios to temperatures and densities within the nebula. Two such equations are seen in equations 1 and 2. Equation 1 relates the line intensity ratios

1. $\mathbf{(I_{4959} + I_{5007})/I_{4363} = [7.15/(1 + 0.00028N_e/T^{1/2})]10^{14300/T}}$
2. $\mathbf{(I_{6548} + I_{6584})/I_{5755} = [8.50/(1 + 0.00290N_e/T^{1/2})]10^{10800/T}}$

for transition occurring at 4959, 5007 and 4363 Angstroms for O^{+2} while equation 2 relates the lines at 6548, 6584 and 5755 Angstroms for N^{+}. Figure 1 shows the results for NGC 7009, The Saturn Nebula.

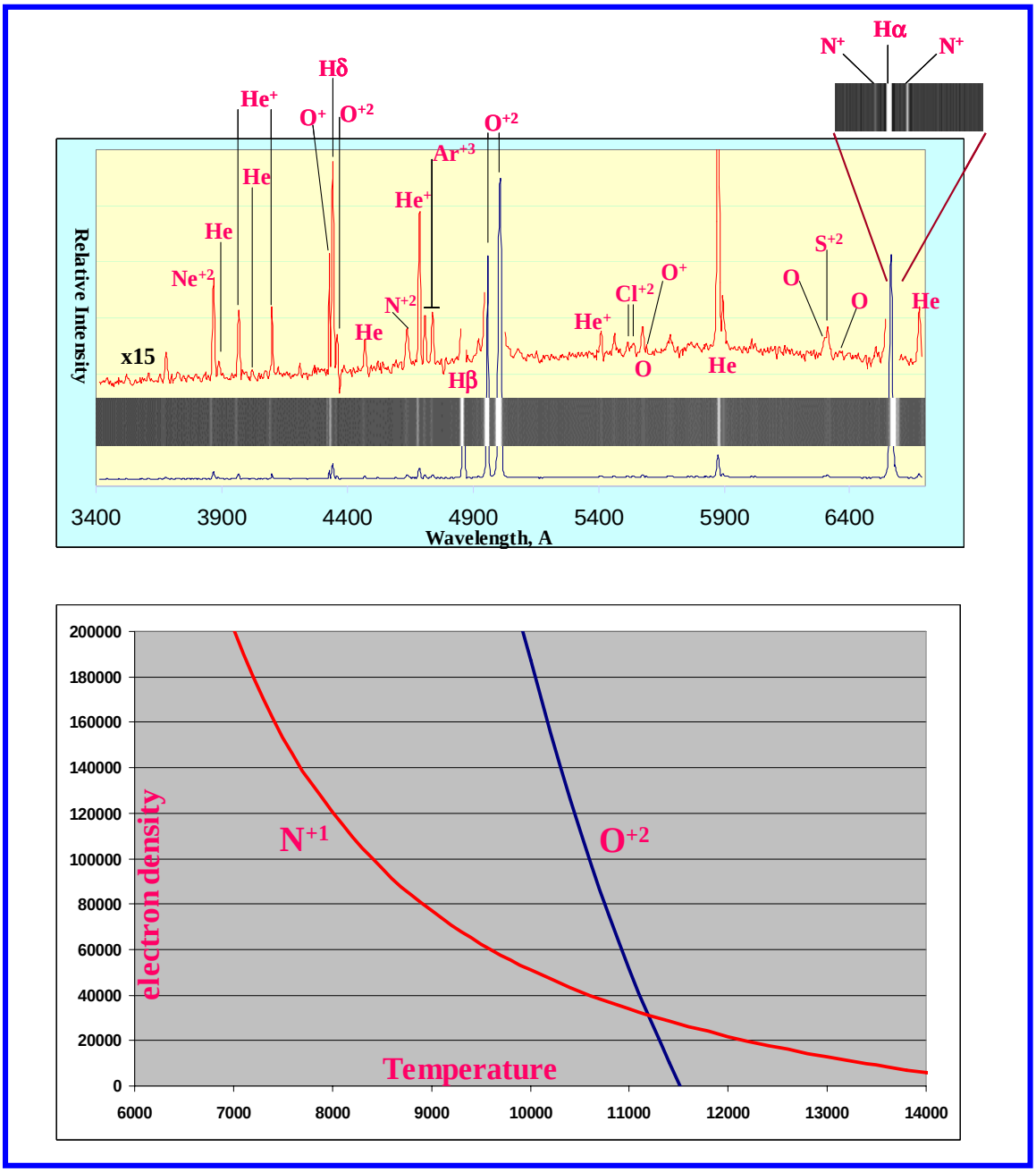

Figure1. The emission spectrum of NGC 7009 (above graph) in low-resolution mode. Several ionized species are indicated. In high-resolution mode, the Hα line is resolved to show the presence of flanking N^+ lines. The bottom part of the figure shows the curves generated once the appropriate line intensity ratios are inserted into equations 1 and 2. The intersection of the 2 curves represents the solution in Temperature and Electron density for the 2 equations. (Temperature = 11,200 K, literature = 13,000 K; Electron density = 30,000/cm^3, literature = 32,000/cm^3)

The analysis of stellar spectra involves examination of absorption lines, their positions as far as wavelength and their relative depth (intensity). Identification of lines and assignment to particular atomic, ionic or molecular species represents the first step in the analysis. Further analysis involves the particular shape of lines wherein is buried

details such as abundances, surface gravity, temperature and other physical attributes. Figure 2 shows the spectrum of 13-theta Cygnus demonstrating the variety of spectral

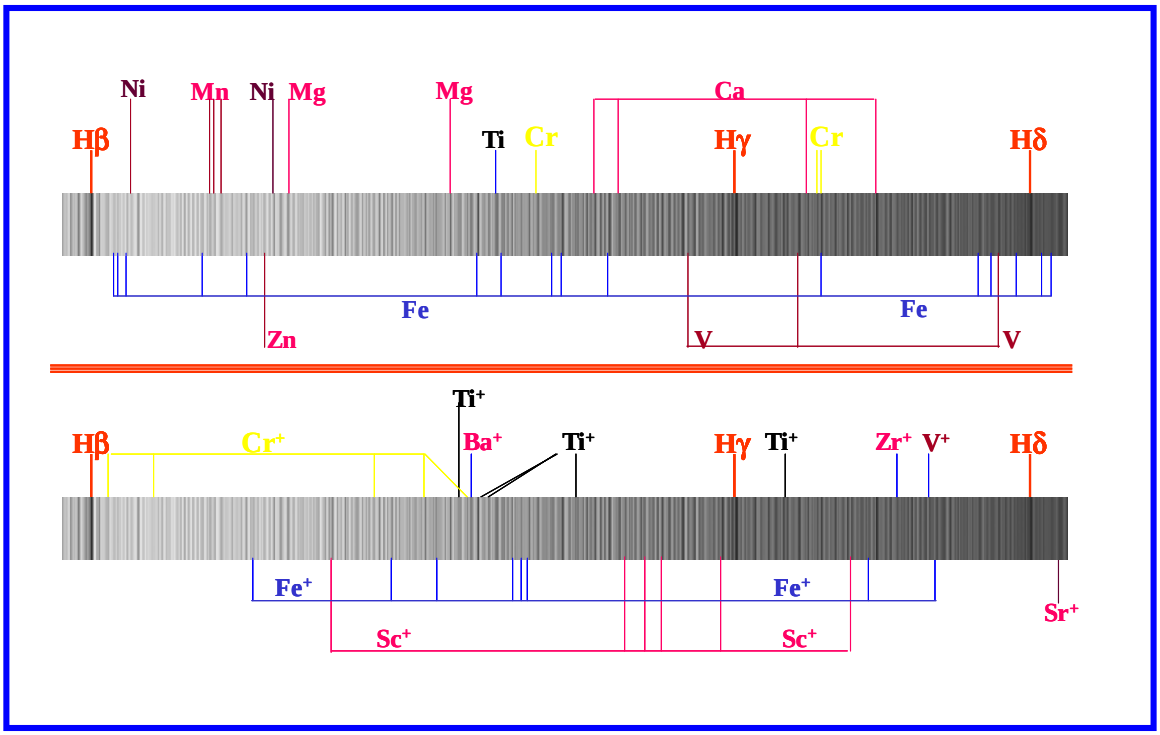

Figure 2. The high-resolution spectrum of 13-theta Cygnus in the region from Hβ to Hγ. The upper spectrum identifies a number of neutral atomic species. The bottom spectrum is identical except that different lines for ionized atoms are identified.

lines that can be identified in the atmosphere of this star and generally any star of interest.

The first 50-60 years of astronomical spectroscopy focused on cataloging stars as to type and spectral features. This included more qualitative analysis of the spectra such as line identification. Indeed, these efforts were responsible for the identification of helium, not yet discovered on earth. During the 1930's, techniques were established which allowed for the quantitation of species observed in spectra. This technique was called "curve of growth" analysis and its basic features are illustrated in Figure 3. This method was strongly dependent upon work carried out in the physics lab to provide reliable values for (f), the oscillatory strength of a line transition. This value is a measure of the likelihood a particular transition will occur producing a particular line feature. Even to this day, many of these values are not known reliably. This technique allowed for the first time, the quantitation of the elements in the atmospheres of stars and established beyond doubt that hydrogen and helium make up the bulk of material in the stars. Before this, the belief was that the relative proportions of the elements in the stars were similar to that found on the earth. In other words, very little hydrogen and helium. Use of this technique continued into the 1960's and 1970's. But as computing power has increased and become available to many astronomers, not just those with supercomputer access, a new technique began to take hold, spectral synthesis. Spectrum synthesis is a computing intensive procedure that calculates what the line spectrum should look like under a variety of conditions. Many different things can influence how a spectrum looks such as

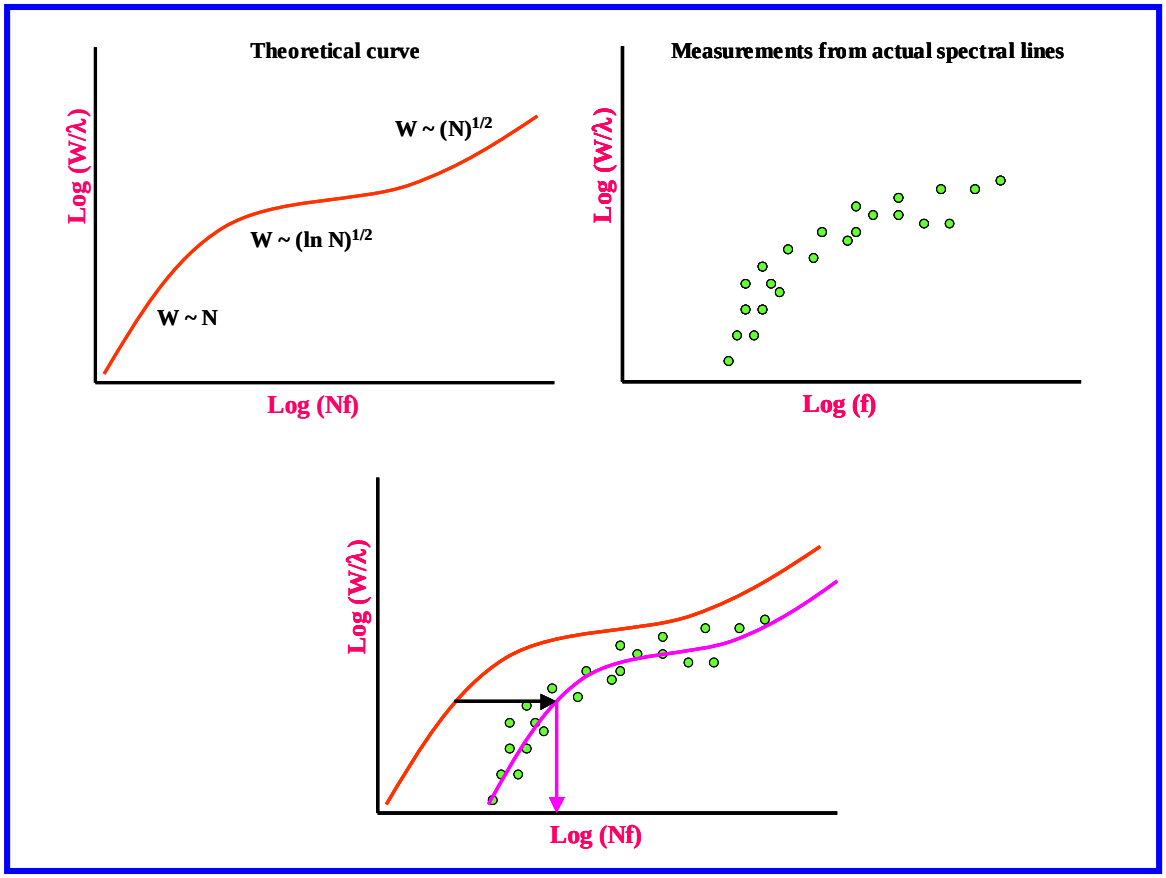

Figure 3. The use of curve of growth to determine element abundances. A theoretical curve for a particular atom, iron for example, is generated as shown in the upper left panel. It is known that the depth of an absorption line (W, equivalent width) and its dependence on various factors such as abundance depends to differing degrees with N, the element abundance. Also required are what's called oscillator strengths (f), the likelihood of particular transitions occurring. If one plots, for various iron lines whose f values are known, theoretical intensities (W) versus increasing abundance, N, one generates a "theoretical curve of growth for iron. Next you examine your real spectrum and measure the W for various iron lines and plot versus f. Finally, by superimposing both curves and sliding the theoretical over the measured, one can read N, the column density, as total oscillators (iron) per square cm. Repeating this procedure many times with other elements allows construction of relative abundances present in the atmosphere of a star.

abundances of species, temperature and pressure. What spectral synthesis does is to allow you to input differing conditions and then calculate what the spectrum for a particular wavelength interval should look like. The way this is done is as follows: one creates a stellar atmosphere model, which gives a run of temperature and pressure with depth. This model is used to compute ionization ratios of different atoms, populations of different energy levels in atoms and ions, electron density, Doppler broadening and other things as well. Tens of thousands of potential lines are computed along with their intensities for 40+ of the more common elements, their first and second ionized state and a number of simple molecular species commonly observed in stellar atmospheres. The factors you can input are temperature, surface gravity (log g), metallicity relative to the sun and micro-turbulent velocity (view this as velocity of granular cells rising or sinking on stellar surface). An example of a synthetic spectrum between 4200 and 4400 Angstroms is

shown in Figure 4. This segment required about 3 minutes of time on a 1 G Hz machine. Also shown is an expanded 40 Angstroms wide version centered at 4260 A. This spectrum was calculated for an F5V type star of solar metallicity and surface gravity and temperature consistent for this type star. It is at once apparent that the excruciating detail present in the spectrum is not at all observed with real spectrometers except those with

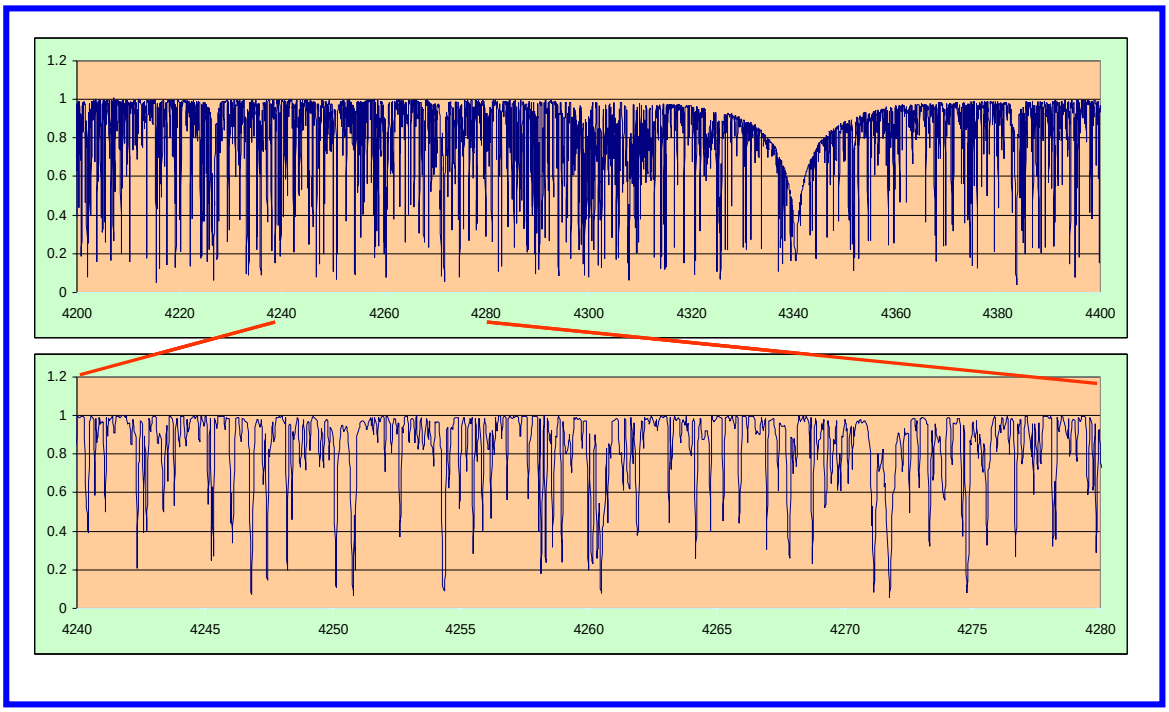

Figure 4. Synthetic spectrum of a F5V type star. Note the large number of lines present. Below is an expanded version covering a 40-Angstrom range. The large, deep line above at approximately 4340 A represents hydrogen gamma line.

the highest resolution attached to the largest telescopes. Fortunately, one of the options available allows for a Gaussian smoothing to provide a wavelength resolution consistent with your particular spectrometer-telescope combination. Shown in Figure 5 is the result of smoothing the synthetic spectrum to match that of the SGS. It is clear when comparing the synthetic spectrum in Figure 4 with the smoothed synthetic spectrum that a great deal of information is lost in the way of blending of various lines into single lines. This is a fact of spectroscopy.

Fortunately, one does not need to know all the intricate details as to how the spectrum is obtained through the various applications of physical laws. The atmosphere models are obtained from the inter-net and astronomers collect these just like one may collect coins or stamps. My collection runs to several thousand and covers stars with many permutations of temperature, metallicity, surface gravity and micro-turbulent velocities (MTV). The software package called SPECTRUM, which is a Unix based system, is then used to carry out calculations on a particular model over a particular wavelength range.
All of these efforts can be carried out with a home PC. What is needed is a Unix emulator. I use a software package called Cygwin, which allows your PC to act as a Unix

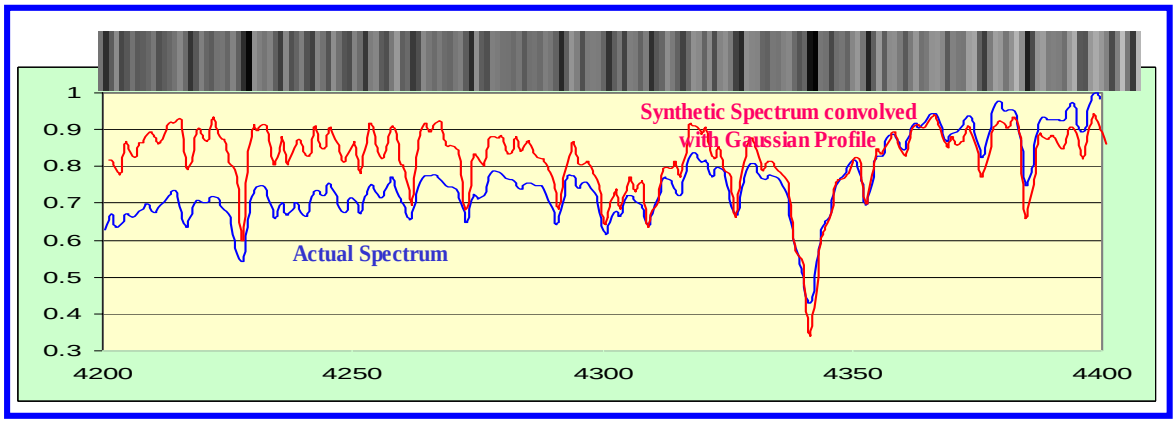

Figure 5. Smoothing of synthetic spectrum (red) to match the spectrum in resolution with SGS in high-resolution mode (blue). The line spectrum obtained with the SGS is shown above with the graph in blue labeled "actual spectrum".

machine. Once the spectrum is obtained, you can apply the gaussian filter in order to match your resolution, import it into Excel for graphic presentation. Varying some of these parameters while holding others constant is illustrated below in Figure 6 in which the spectrum at three different temperatures of an atmosphere are plotted while holding other conditions such as metal abundance's, surface gravity and MTV constant.

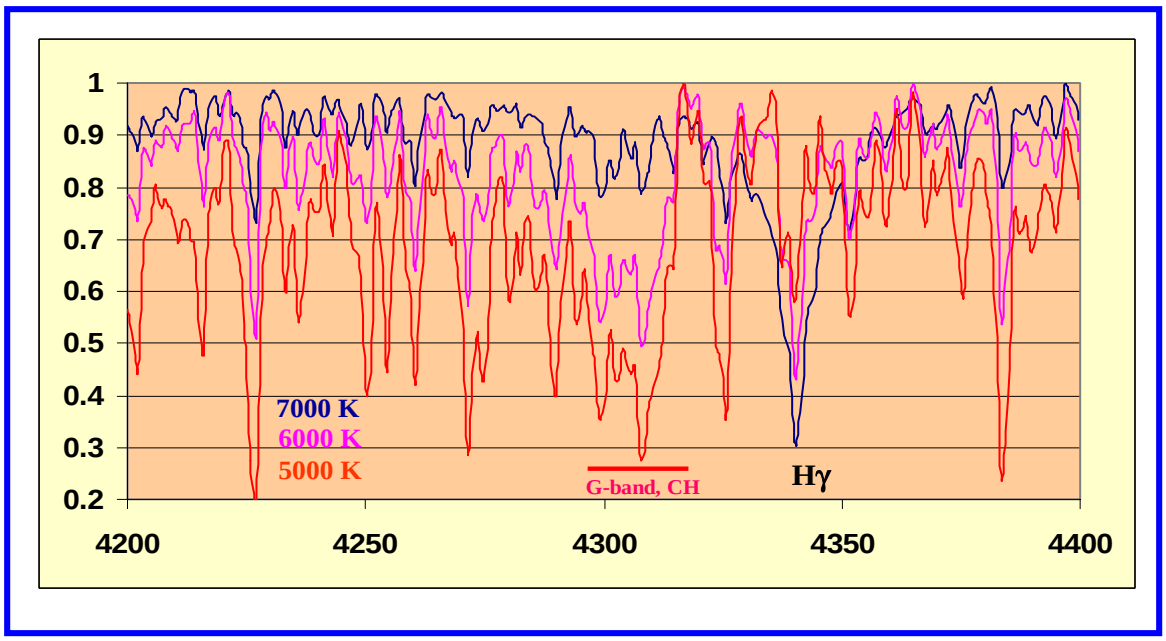

Figure 6. Effect of temperature on the spectrum of a K1.5V type star in the 4200-4400 Angstrom region. Surface gravity, MTV and metallicity were held constant. Note how, in general, the lines for various metals become more intense as the temperature is lowered. An exception is the Hγ line, which is more intense at the higher temperatures examined.

Figure 7 illustrates the same type star but with a constant temperature of 5000 K and constant MTV and surface gravity, but varying metallicity abundances relative to the sun. The metallicity of a star is expressed in a logarithmic manner such that $\mathbf{[M/H]_{star}}$ /

$[M/H]_{sun}$ =0 signifies that a star has the same metallicity as the sun. A value of –0.5 means that a star is depleted a half-log or 3.2 times in metal compared to the sun whereas a value of 0.5 means an enhancement of metals by 3.2 times compared to the sun. Note, as one would expect, the lines become more intense as one proceeds to greater metallicity.

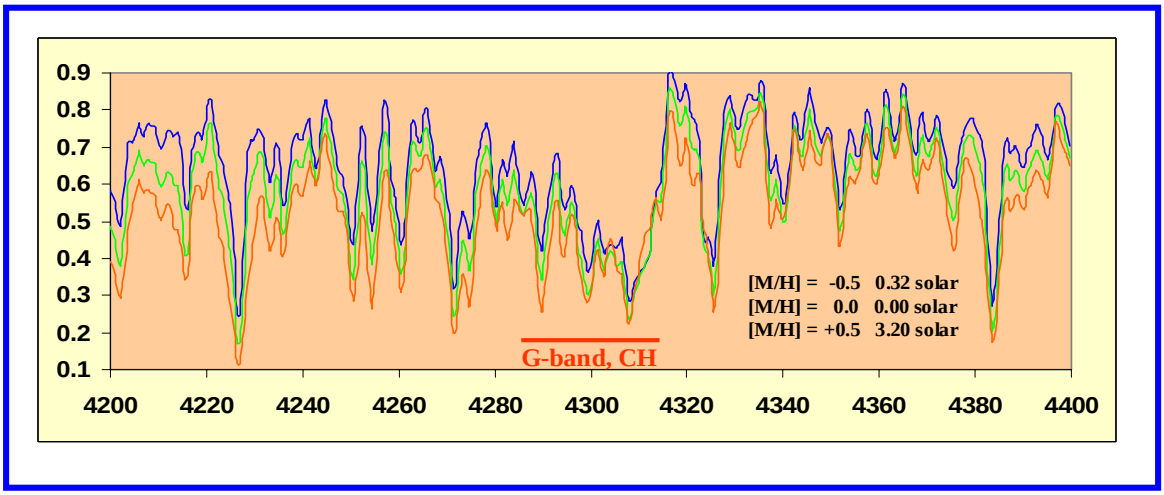

Figure 7. Three different metallicity values and the effect upon the absorption line spectrum of a K1.5V type star. All free parameters were held constant. As one would expect the lines become more intense as one proceeds from low metallicity ([M/H] = -0.5 to a higher metallicity of +0.5.

Similar types of graphs can be made which demonstrate the effect of MTV and surface gravity (Luminosity class). The idea of spectral synthesis is to take your spectrum and match as closely as possible the spectrum obtained by synthetic routes by varying the free parameters. When this is done correctly, temperature, luminosities, abundances and MTV values can be obtained, all from just a modest resolution instrument available for the amateur. This represents cutting edge efforts that the amateur can partake in, only generally available even to the Professionals not many years ago, mainly because of the availability of computing power of the desk top PC. Figure 8 shows a close match for a F5V type star.

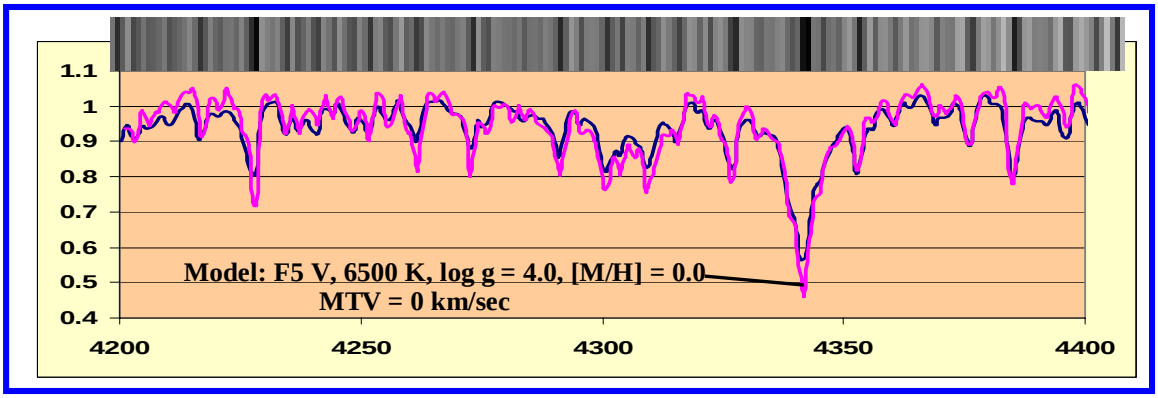

Figure 8. Matching your spectrum to the spectrum computed synthetically is the goal in spectrum synthesis. As one varies the free parameters, the spectrum begins to match up with actual spectrum. When as good of fit as is possible has been found, abundances, temperature, MTV and surface gravity (luminosity) are determined.

The most striking revelation in using this software to synthesize spectra are the large number of lines that are actually present. Under the conditions with which most observatory and amateur spectrometers will function, the resolution will not distinguish all of these lines. The result is that a majority of lines are actually blends of two or more lines. Actual line identification most commonly represent the most prominent line within the blend. This explains the constant drive behind astronomers need for both higher resolution spectrometers and the necessary greater sized telescopes required as you spread the light of a spectrum out more and more. To this end, SBIG has developed a prototype new grating carousal for the SGS, which contains a 1200- and 1800-line/mm gratings. The 1800 line grating would represent a 3-fold improvement in resolution over the current 600-line high-resolution grating. What might we expect from such an improvement? Figure 9 shows a synthetic spectrum, which should match closely with

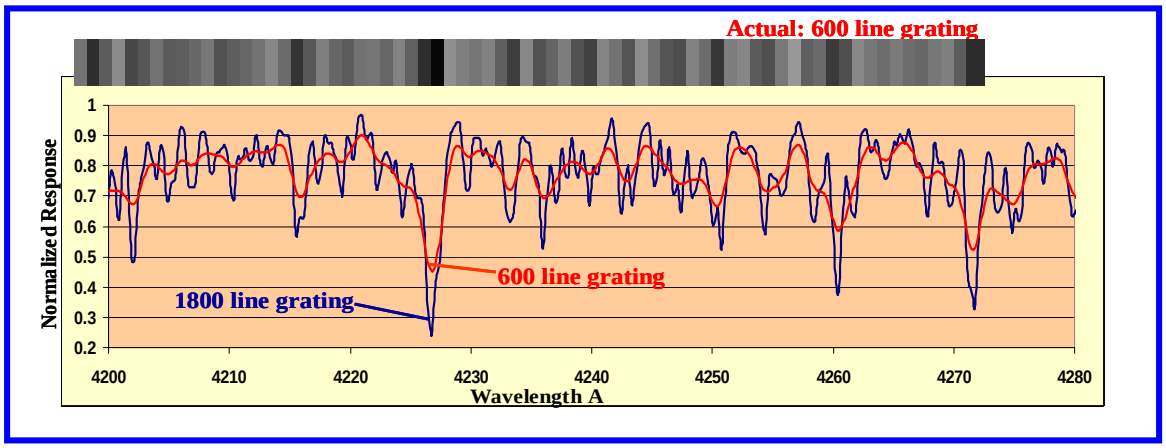

Figure 9. The red line (marked 600 line grating) represents an actual spectrum over an 80 Angstrom region centered at 4240 A. The blue line (marked 1800 line grating) shows the result of synthetically deriving a spectrum with the resolution expected for a 3-fold improvement over the 600 line grating. The actual line spectrum is also shown overlaid on the figure. Note the increased resolution, where previously blended lines are slit into multiple lines.

what would be observed realistically with an 1800 line grating. As can be seen, many of the blends and shallow dips are now further resolved into multiple lines. This kind of improvement in resolution will greatly aid in efforts to better match synthetic spectra with those actually obtained at the telescope. This kind of increased resolution will make matching synthetic spectra with the actual spectra more precise and thus a more accurate determination of the physical characteristics will be obtainable.

3. Summary

What an amateur can now carry out has certainly come a long ways in recent years. This has been a function of advances in detector technology, instrumentation and inexpensive desktop computing power. Amateurs now possess the capabilities of both obtaining spectra which can rival that obtained at many observatories but also to synthesize spectra with an input of various physical conditions. Followed by best-fit analysis, the amateur or

small observatory is at a point where cutting edge work can not only be accomplished but also published in astronomy's leading journals.

I have tried to demonstrate in this paper my initial attempts to do qualitative analysis of spectra obtained in my observatory using a modest (Celestron-14) telescope and the SBIG SGS instrument. Much more work and learning on my part remain. The software SPECTRUM has many other capabilities beyond the few I have shown here. For example, it is capable of carrying out a best-fit analysis of your spectral data to provide the most likely physical conditions in a stellar atmosphere. What I have shown here is more of a manual approach to this analysis. This approach was by choice since it was my wish to get a feel for what the output of the calculations are and what they are telling you as you systematically change the input parameters. Eventually, I will allow the software and computer to do what they do best. This will be a story for a different time.

Acknowledgments

The author wishes to acknowledge Mr. Kurt Snyder of Ligand Pharmaceuticals for his help in getting the UNIX emulator Cygwin up and running for me. Also, most importantly, Dr. Richard Gray of Appalachian State University for freely making available his spectral synthesis software SPECTRUM, providing the stellar atmosphere models and endless email discussions on getting the software to work and correctly interpreting the results.

ASTRONOMY I

Probing A Comet's Nucleus

John E. Hoot
SSC Observatory, IAU #676, JPL Solar System Ambassador

Abstract: While the coma and tails of comets are easily imaged, the dynamics of out gassing, plumes and jets that perturb the comet's trajectory and greatly influence the comets appearance are hidden inside its coma. Methods of imaging comets and subsequent processing techniques are presented that reveal the comet nuclei and jets.
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1. E. Anderson and R. Seaman, *An Introductory User's Guide to IRAF Scripts*, NOAO 1996
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1. Introduction

Recently, Deep Space 1 completed its three year mission to pioneer new spacecraft technology by providing our best ever views of Comet P19/Borrelly. Firgure 1 left shows the comet's nucleus. Visible on its surface are bright fissures. These are the likely location of the gas and dust geysers that feed the coma and tail of the comet. Figure 1 right is another DS1 image that has been highly contrast enhanced to show the plumes of dust and gas emanating from the comet as the spacecraft approached the comet.

Figure 1: Comet Borelly as imaged by the Deep Space 1 (credit: NASA 2002)

The comet's tail trails from upper right to lower left behind the comet's path. On the leading edge of the comet a curly geyser shoots out in front of the comet.

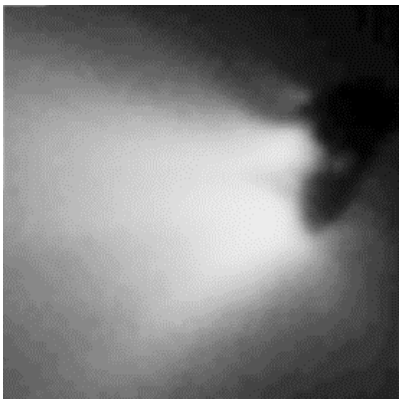

Figure 2: Giotto Image of Comet Halley (credit: ESA)

While these spacecraft images are revealing, they are hard to come by. Space probes have imaged only one other comet. The Giotto probe flew by Comet Halley in 1986. Giotto's imaging system and many other instruments did not survive the sandblasting it received during the flyby. To better understand the dynamics of these bodies, ground based techniques are needed that can effectively image the nucleus and jets of these bodies.

2. Observations

This winter featured a relatively bright comet, Linear 2000WM1. The comet just reached naked eye visibility in early December. The comet was discovered by the LINEAR (Lincoln Labs Near Earth Asteroid) search program. It was discovered in the first half of December 2000. Lately it seems that most comets are ending up named Linear, Loneos, or some other survey. The automated surveys are proving to be very effective discover engines. Initially, I started a campaign to perform astrometry on the comet to help determine its orbit.

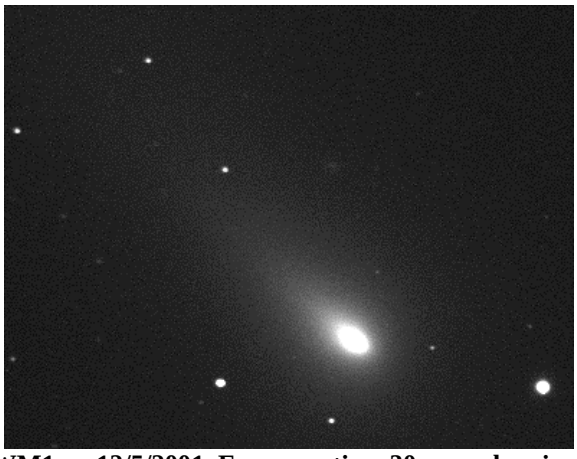

Figure 3: Comet 2000WM1 on 12/5/2001. Exposure time 30 seconds using a 0.3m telescope at f5. Field of view is approximately 30' x 20' with north up.

Cometary orbits are tough to predict. They are not simply ballistic rocks like asteroids. They are constantly being pushed around by their gas jets and are shedding

mass in the form of gas and dust at the same time. They may be periodic in large eccentric elliptical orbits, or they may be one-time visitors on parabolic or hyperbolic trajectories. To further complicate the matter, it is not always the case that the nucleus, whose position the astrometrist is trying to locate, is in the center of the coma. It was this concern that got me reading the literature trying to ascertain how to locate the nucleus of the comet.

During my search I came on an article in the 1984 Astrophysical Journal by S. Larson and Z. Sekinina[2]. In the article they describe a powerful technique they had developed for bringing out fine detail in the structure of comet nuclei and jets. Their technique involves subtracting images of the comet that are rotated and scaled radially from the original image to emphasize small variations in the coma brightness.

Figure 4: Comet Halley Jets 1910 (Credit: Larson & Sekinina)

Their technique, applied to Mt. Wilson plates of the 1910 apparition of Halley's comet, so impressed me, I resolved to try the technique on my many images of Comet Linear 2000WM1. Because of the rigor of the math required, I developed a Larson-Sekinina filter script under IRAF[1,3] (Astronomomical Image Reduction and Analysis Facility) distributed for Linux by NOAO at Kitt Peak. I first developed a script to calibrate and align all of my comet images. As a side benefit of this alignment, I generated a series of time lapse animations showing the comet moving in front of the background stars. Some of these animations can be viewed on my web site at: http://www.ssccorp.com/observatory/.

After the images were aligned, I median combined all the images. In this type of image merger, for each point in the final image, the script examines the values of all of the pictures at the same point. It excludes those points with intensities more than several standards of deviations away from the mean and then selects the median value of the remaining images as the value to be placed in the final image. This method of combining images drops out all of the background stars. Unlike a guided comet photograph, where the stars will appears as lines behind the comet, this method of combining many short exposures allows you to process out any of the background stars. The resulting image is shown in Figure 5.

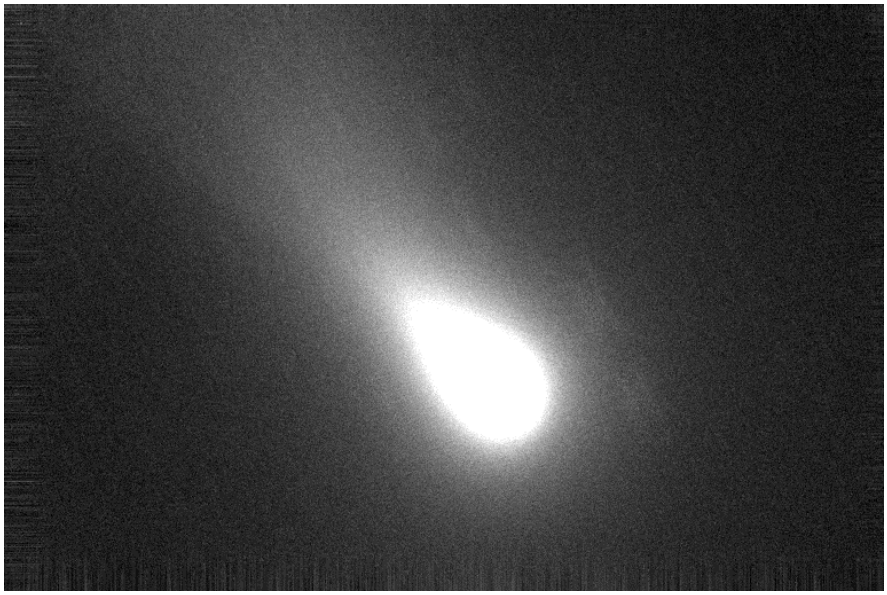

Figure 5: Comet Linear 2000WM1 12/5/2001 After Sigma Clipped Median Filtering

Finally, scripts subtract of the radially scaled and rotated images to produce the final result in Figure 6.

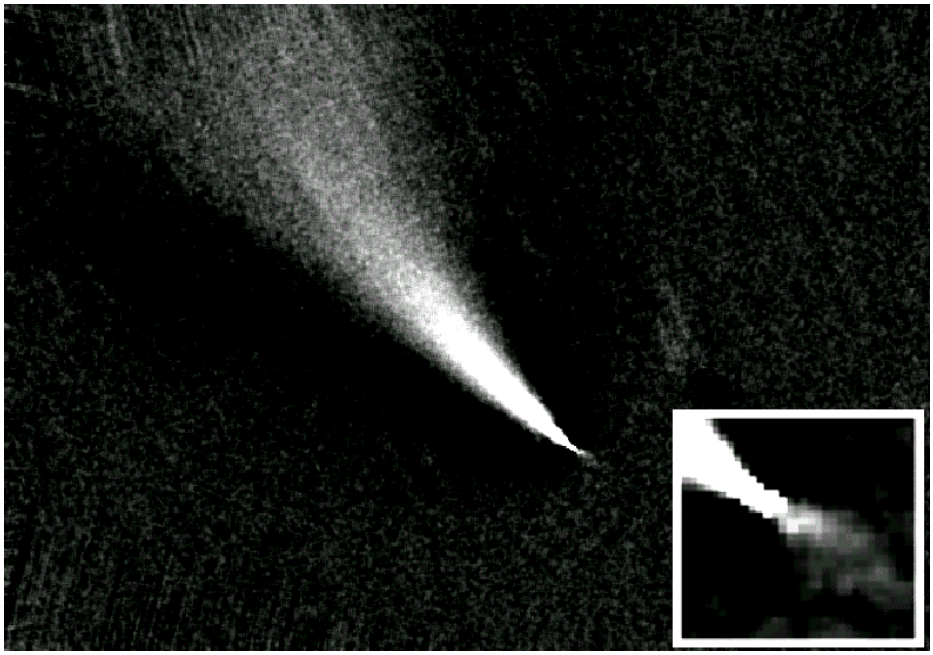

Figure 6: Comet Linear 2000WM1 12/5/2001 After Larson-Sekinina Enhancement

3. Discussion

The insert at the lower right of the Figure 6 is a blow up of the comet nucleus. It clearly shows the anti-jets spiraling out the front of the comet. Anti jets are commonly visible after this sort of processing. It is theorized that most material is actually jetted out the front of the comet on its inbound path. This is the face of the comet towards the Sun and should heat more quickly, Once jetted out, the material is then pushed back behind the comet by the solar wind.

As the original intent of this project was to perform astrometry, the comet's position for astrometric purposes was determined by mathematically centroiding the image in Figure 5. Subsequent to Larson-Sekinina processing, the comet nucleus is asserted to be at the point where the radial symmetry breaks down. This location is located graphically from the processed image. The asymetry's offset from the original centroided position is noted. This offset is then applied to the centroids of the individual exposures, such as the one shown in Figure 4, and astrometry is then reduced from the field stars visible in the image.

Since the geometry of the jets and coma structure varies over periods of only a few hours, the nucleus's offset from the coma centroid must be redetermined for observations that vary by only a few hours to insure the maximum accuracy.

When processing Comet 2000WM1, the image scale of the comet was small enough that radial scaling changes did not clearly reveal any new structure. For the purpose of astrometry, disabling the radial scaling by setting its parameter to 1.0, both speeds and simplifies the processing.

4. Conclusions

Larson-Sekinina processing has proved an interesting tool for investigating cometary jets. Like many powerful and specialized tools, care must be taken when interpreting the meaning of the resulting images. Any small irregularity in the image, or flat fielding errors are greatly magnified and can be mistaken for structure not actually present in the target image.

```
    ############################################################
    #         IRAF Median Combine and Align Image Script
    #
    # (c) 2001 SSC, John E. Hoot
    ############################################################
    procedure medcombine( srcimages, destimage )

       string srcimages
       string destimage
       struct *coords

       begin
       string src,dst
       real xavg, yavg,x,y
       int imgcnt,cnt
       bool done

       # read paramters
       src = srcimages
       dst = destimage

       delete( "coords.txt" )

       imexamine (src, 1, "INDEF", logfile="coords.txt", keeplog=yes,
                  defkey="a", autoredraw=yes, allframes=no, nframes=1, ncstat=4,
                  nlstat=6, graphcur="", imagecur="", wcs="logical", xformat="",
                  yformat="", graphics="stdgraph", display="display(image='$1',
frame=$2)",
                  use_display=yes)

       # compute mean center
       imgcnt = 0
       xavg = 0
       yavg = 0
       coords = "coords.txt"
       done = no
       while ( !done ) {
             cnt = fscan(coords,x,y)
             done = (cnt == EOF)
             if (cnt==2) {
                imgcnt += 1
                xavg += x
                yavg += y
                print( x,y,imgcnt )
                }
             }
       xavg /= imgcnt
       yavg /= imgcnt
       print("Mean Center = ",xavg,yavg

       lintran ("coords.txt", xfield=1, yfield=2, min_sigdigit=4, x1=xavg,
                y1=yavg, xscale=-1., yscale=-1., angle=0., x2=0., y2=0.,
            radians=no, > "shifts.txt")

       imshift (src, src, INDEF, INDEF, shifts_file="shifts.txt",
                interp_type="linear", boundary_typ="constant", constant=0.)

       imcombine (src, dst, rejmask="", plfile="", sigma="",
                  logfile="STDOUT", combine="median", reject="none", project=no,
                  outtype="real", offsets="none", masktype="none", maskvalue=0.,
                  blank=0., scale="none", zero="none", weight="none", statsec="",
                  expname="", lthreshold=INDEF, hthreshold=INDEF, nlow=1, nhigh=1,
                  nkeep=1, mclip=yes, lsigma=2., hsigma=2., rdnoise="8",
                  gain="1.2", snoise="0.", sigscale=0.1, pclip=-0.5, grow=0.)

       display( dst, 1)
       end
```

Figure X: IRAF Median Combine Script

```
    ################################################################
    #           IRAF Larson-Sekenina Processing Script
    #
    # (c) 2002 J. Hoot SSC
    ################################################################
    procedure lsfilter( src, dst, ctrx, ctry, deltax, deltap )
       string src          { prompt = "Source Image" }
       string dst          { prompt = "Destination Image" }
       real ctrx           { prompt = "X Center" }
       real ctry           { prompt = "Y Center" }
       int  deltax         { prompt = "Gradient Radius" }
       int  deltap         { prompt = "Rotation Angle" }

       begin
       string infile, outfile
       string rotfile, radfile
       real cx, cy
       int xmax, ymax, dx, dp, px,py, junk
       real pixval,mx,my
       string dimensions
       int i
       real pix,dist
       string pixloc

       # read paramters
       infile = src
       outfile = dst
       cx = ctrx
       cy = ctry
       dx = deltax
       dp = deltap

       # get dimensions
       imgets(infile,"naxis1")
       print(imgets.value) | scan( xmax)
       imgets(infile,"naxis2")
       print(imgets.value) | scan(ymax)
       dimensions = xmax//","//ymax
       print ("dims=",dimensions)

       # allocate temp files
       rotfile = mktemp("tmp$rot")
       radfile = mktemp("tmp$rad")

       # double init image
       imarith(infile,"+",infile,outfile)

       # rotate image clockwise, gradient and subtract
       rotate (infile,rotfile, dp, xin=cx., yin=cy., xout=cx, yout=cy,
            ncols=INDEF, nlines=INDEF,interpolant="linear", boundary="constant",
            constant=0., nxblock=512, nyblock=512, verbose=yes)

       export (rotfile,radfile, "raw", header="no", outtype="i4", outbands="",
interleave=0,
               bswap="no", verbose=no)
       imdelete(rotfile)

       # here we call gradient eventually
       print("!radgradient ",dx,cx,cy,xmax,ymax) | cl

       dimensions = xmax//","//ymax
       import (radfile,rotfile, format="none", dims=dimensions, pixtype="i4",
interleave=0,
               bswap="no", hskip=0, tskip=0, bskip=0, lskip=0, lpad=0, output="image",
               outtype="l", outbands="", imheader="", database="dataio$import/images.dat",
               verbose=no, buffer_size=64)

       display(rotfile,2)
       imarith( outfile, "-", rotfile, outfile )
       imdelete(rotfile)
       delete(radfile)
```

```
       # rotate image counter clockwise, gradient and subtract
       rotate (infile,rotfile, -dp, xin=cx., yin=cy., xout=cx, yout=cy,
            ncols=INDEF, nlines=INDEF,interpolant="linear", boundary="constant",
            constant=0., nxblock=512, nyblock=512, verbose=yes)

       export (rotfile,radfile, "raw", header="no", outtype="i4", outbands="",
interleave=0,
               bswap="no", verbose=no)

       # here we call gradient eventually
       print("!radgradient ",dx,cx,cy,xmax,ymax) | cl

       dimensions = xmax//","//ymax
       import (radfile,rotfile, format="none", dims=dimensions, pixtype="i4",
interleave=0,
               bswap="no", hskip=0, tskip=0, bskip=0, lskip=0, lpad=0, output="image",
               outtype="l", outbands="", imheader="", database="dataio$import/images.dat",
               verbose=no, buffer_size=64)

       display(rotfile,3)
       imarith( outfile, "-", rotfile, outfile )
       imdelete(rotfile)
       delete(radfile)

       display (outfile, 1, bpmask="BPM", bpdisplay="none", bpcolors="red",
                overlay="", ocolors="green", erase=yes, border_erase=no,
                select_frame=yes, repeat=no, fill=no, zscale=yes, contrast=0.02,
                zrange=no, zmask="", nsample=1000, xcenter=0.5, ycenter=0.5,
                xsize=1., ysize=1., xmag=1., ymag=1., order=0, z1=INDEF, z2=INDEF,
                ztrans="linear", lutfile="")

       end
```

Figure 5: Larson-Sekinena IRAF Script

Astronomy's Embarrassment Of Distance Determination - Small Telescope Science Will Calibrate an Accurate Determination Method

LeRoy F. Snyder
MacLean Observatory, Incline Village, NV
snyder@physics.unr.edu

Abstract: Discussion of ingenious indirect methods used to determine distances to stars and cosmic objects are covered to show the inaccuracy and large standard errors incurred when trying to determine distances beyond 300 light years (ly). Heliocentric and spectroscopic parallax and other methods are discussed and compared with parallaxes determined by the Hipparcos satellite. Hipparcos Catalogue parallaxes being ten times more accurate than previously achieved can be used to calibrate a visual surface brightness parameter (F_v) of EA-type eclipsing binaries. An EA-type binary with photometric and double-line spectroscopic orbits already determined along with the computed surface brightness parameter and a color index (V-R) can be used to calibrate the relation which can be used to determine the distance to the binary beyond the trigonometric stellar parallax capability. Observers using small telescopes and CCDs with proper filters can obtain the required color index (V-R). A list of 198 Hipparcos Catalogue stars without published absolute parameters are listed which needs the color index (V-R) determined. Eighteen detached and 8 semi-detached systems with known absolute parameters are also listed. Distances to 22 of these binary systems have been measured by Hipparcos Satellite and can be used to help calibrate the validity of the relationship once the (V-R) has been determined on these 22 systems.
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1. Introduction

When we acquire a photometric light curve of the orbit of an eclipsing binary (EB) we have the relative radii of both components, A and B, their separation and the inclination to our line of sight. We then acquire spectroscopic data and combining that with the orbital inclination from the photometric data we obtain the masses, radii and metric values of the system's dimensions. If we know the distance to the binary we then can compute the angular sizes of both components and this along with the apparent magnitudes of both, which comes from the photometric solution, we are able to compute the surface brightness for each component.

Surface brightness is a not used or understood by small telescope users because it is not a required value at our level of expertise. It can be used now in a method that can establish a calibrated single relation between the surface brightness of a star and whatever data can be acquired about the stellar temperature, (B-V), (U-B), (V-R) and (R-I). It will be shown later the color index (V-R) establishes the only working relation through out all the spectral types of stars. Once this relation has been calibrated and tested, than all that is required is the color index (V-R) of an EB which will give the value of surface brightness and along with the photometric and spectroscopic orbital data it will be possible to calculate the distance to the system.

Let us define surface brightness (F_v). It is the radiative flux emitted from a stellar surface per unit area measured in magnitudes per square arcsecond. It is the radiative flux per unit solid angle of the image so it has a value dependent upon the luminosity and area of the surface of the object. It is independent of its distance from us because the angular area subtended and the luminosity both decrease or increase with the inverse square when the distance changes. Surface brightness = Luminosity per unit area/magnitude per square arc second and is defined according to equation (1):

$$F_v = 4.2207 - 0.1\, V_o - 0.5 \log \phi' \qquad (1)$$

Here V_o is the unreddened apparent magnitude and ϕ' the stellar angular diameter in arc milliseconds. The sun was used as a calibration point to arrive at this expression.

This surface brightness *vs* color method of determining distance origins is not commonly known. Vogel first estimated surface brightness in 1890 [11] on Algol using the existing determination by trigonometric parallax of 70 milliarcseconds (mas). This is where the astronomical embarrassment comes in. The Hipparcos satellite launched in August 1989 determined a parallax value of 35 mas. That is a 50% error. Heliocentric parallax works accurately only for close stars. A parallax of a close star of 1 arcsecond is equivalent to looking at a quarter at a distance of over 5km (3 miles). The accuracy of measured parallaxes today is about 0.001 arcseconds or a distance of about 300 light years. Applying the period-luminosity relationship to Cepheids we can only measure distance to approximately 15 million light years with an accuracy estimated between 40% and 30% of the true distance. The moving-cluster parallax method doesn't have any more accuracy. The farther away a star or cluster the smaller its parallax and the more difficult it is to determine its distance. As the distance increases the error in measuring the parallax or the error in the method used becomes as large as the parallax acquired or as large as the distance determined.

The embarrassment goes on but the following method of "surface brightness to distance" will decrease the relative errors to less than 20%. A higher accuracy will be accomplished because the relationship of surface brightness to (V-R) validity will be calibrated using the parallaxes determined by Hipparcos on close eclipsing binaries with parallaxes larger than 5 mas or a parallax five times larger than its mean error. The estimated errors of the parallaxes determined by Hipparcos are less than 10%. When the relation between the surface brightness and color is used to determined the distance it can be compared with the Hipparcos determined distance and used as a constrain. This will improve our determination of distances beyond 300 ly to less than 10%.

There is one problem to surmount. When the calibration of the relation was started back in 1976 by Barnes and Evans [1] [2] they discovered the best relationship is found for the index (V-R) but unfortunately, (V-R) photometry was only available for only a few stars, 27 at that time. This paper list 198 eclipsing binaries from the Hipparcos catalog which are closer than 200 pc or with parallax 5 times larger than its mean error to insure accurate measured distances will be used for comparison. The 198 eclipsing binary stars do not have (V-R) color index determined photometry. It is desperately needed to add these binaries to the calibration to improve the validity of the relation.

To improve the calibration accuracy of the F_v parameter *vs* color index angular sizes have been determined by interferometry and lunar occultations. This helped determine the presence of limb darkening and the effect it had on surface brightness. Improved interferometric techniques have helped determine limb-darkened angular diameters of stars to help in the calibration. F_v is not strongly dependent upon luminosity class and therefore metallicity and is not particularly a problem nor is surface gravity, which is more accurately known.

In acquiring the (V-R) stellar color precise reddening does not have to be considered nor determined as the F_v vs the (V-R) color index plot is parallel to the reddening line, Figure 1. The effects of interstellar extinction can be ignored for the purpose of calibration at this time. As this relationship is applied to stars at great distances care will be necessary to remove these effects.

2. Relationship and correlation

Figure 1 shows the surface brightness parameter F_v as a function of (V-R). This was published in 1976 [1] [2]. A tight correlation exists over the entire distribution of stars used for the calibration from O4 thru M8 asserting the relationship is independent of surface gravity or luminosity class. The scatter in F_v about the mean curve is ± 0.033. The straight line segments of the (V-R) and F_v relation allows for usable computation of the relationship. The arrow shows the displacement, which would result from 1 magnitude of interstellar extinction.

Figure 2, 3 and 4 are shown here for completeness and to demonstrate only that the color indexes (V-R) and (R-I) have a usable correlated relation with F_v. There is no simple correlation using (U-B) as the relation drops off when (U-B) reaches 1.30, spectral type K5 to M0. When the index (B-V) goes above 1.35 the scatter precludes the possibility of a valued relation with F_v. There is enough scatter in the F_v – (R-I) relation in the late spectral types that it cannot be used alone to infer F_v. Barnes and Evans determined rms residuals in F_v of 0.040 for (V-R) and 0.082 for (R-I).

In three papers [1] [2] [3] it was shown that a value defined as the visual surface brightness (F_v) which is defined by $V_{o,}$ the unreddened apparent magnitude in UBV system and ϕ' as the limb-darkened angular diameter in multi-arcseconds (mas) as:

$$F_v = 4.2207 - 0.1\ V_o - 0.5 \log \phi' \qquad (1)$$

This is tightly correlated with the index $(V\text{-}R)_o$ in the following expressions:

$$F_v = 3.977 - 1.390\ (V\text{-}R)_{o\,,} \qquad (2)$$
$$-0.17 \le (V\text{-}R)_O \le 0.00$$

$$F_v = 3.977 - 0.429\ (V\text{-}R)_o, \qquad (3)$$
$$0.00 \le (V\text{-}R)_O \le 1.26$$

$$F_v = 3.837 - 0.320\ (V\text{-}R)_o, \qquad (4)$$
$$1.26 \le (V\text{-}R)_o \le 4.20$$

Because the relation is not uniform through the different spectral types A-G equations (2), (3) and (4) are used for the calibration of the different segments. Their later investigation [3] led to an improvement of the index values between 0.00 to 0.60 as shown in equation (5).

$$Fv = (3.966 \pm 0.005) - (0.390 \pm 0.019)\ (V\text{-}R)_O\ , \qquad (5)$$
$$0.00 < (V\text{-}R)_O < 0.60$$

3. Determining distance

Once F_v is determined and with the known (V_o), ϕ' the angular diameter can be determined from equation (1), and the stellar radius r is known from the spectroscopic radial velocity curve and photometric solutions. Using the following equations the distance d can be computed:

$$d = 2r / \phi' \text{ (radians)} \quad \text{or} \quad d\ (pc) = 1.337 \times 10^{-5}\ (r\ (km) / \phi'\ (mas) \qquad (6)$$

When the magnitude of the system is acquired in V and R it is the combined magnitude of the two stars V_{1+2} and R_{1+2} , and in a method shown by Lacy [7] [8] [9] the colors of the individual components can be calculated and therefore the surface brightness of each star which allows the computation of the distance to each. Those computations will not be addressed here. See the references [7] [8] [9].

5. Tables and Figures

HIP NO	HIP NO	HIP NO	HIP NO	HIP NO	HIP NO
270	18724	32900	59229	83491	101263
817	19062	33487	60812	83719	102037
1233	19571	34003	61006	84479	102041
1550	20657	34659	61882	84500	102545
3454	20806	35447	61910	84670	102827
3572	20896	35487	62801	84949	103505
4157	21213	36608	63592	85057	103542
4843	21334	38167	64120	86809	104263
5348	21604	41361	64293	87965	104604
5980	22000	41564	64607	88008	105515
7323	22229	41834	64661	88069	105584
7372	22498	42794	66683	89816	106024
8115	23453	42951	68064	90313	106981
9230	24552	44164	68258	92330	107083
9383	24663	44349	68384	92537	107960
10099	24710	45079	68692	92835	108606
10579	24740	45887	69211	93104	108644
10961	24836	46002	69781	93595	108646
12657	25760	46881	70287	93809	108797
12805	25776	48054	71487	94335	109354
13133	26760	50966	73473	95588	111162
14273	27309	51683	74127	95611	111454
14568	28360	52066	74866	96011	111809
14576	28537	52381	74950	96234	112317
15003	29455	52465	76196	96620	113442
15092	30270	53487	76267	96739	114206
15193	30651	53806	76658	97263	114305
15811	30806	53905	78523	97649	114484
16083	30878	54711	81519	97849	114639
17024	31017	54766	81530	98118	115200
17333	31173	54807	81589	98539	115990
17441	32015	56379	82080	98955	116167
17962	32374	58579	82977	100981	118223

Table 1: Hipparcos Eclipsing Binaries of the EA or EA: type with distance smaller than 200 pc or with parallax 5 times larger than its mean error [6]

HIP NO.	NAME	TYPE	SP TYPE A	SP TYPE B	P (DAYS)	E (2,400,000)	RA(2000	DEC	π(mas
25733	LY Aur	SD	F8III	--	4.0025210	48501.6933	05 29 42.	35 22 30	1.78
24201	SX Aur	SD	B3V	B5V	1.2100802	40162.3355	05 11 42.	42 09 55	3.16
68064	ZZ Boo	D	F2	F2V	4.9917618	40225.6780	13 56 09.	25 55 07	8.88
42432	RZ Cnc	SD	K2III K4	--	21.6430230	18702.5150	08 39 08.	31 58 21	3.25
64293	RS CVn	D	F4IV	K0IV	4.7978550	41825.5420	13 10 36.	35 56 06	9.25
35187	GZ Cma	D	A0	--	4.8008500	43581.5613	07 16 19.	-16 43 00	3.71
3572	YZ Cas	D	A2V	F2V	4.4672235	28733.4218	00 45 39.	74 59 17	11.24
106024	EI Cep	D	A0	F1	8.4393340	36820.4665	21 28 28.	76 24 12	5.03
42794	RS Cha	D	A5V	A7V	1.6698700	42850.7688	08 43 12.	79 04 12	10.23
108508	MR Cyg	D	B3V	B9	1.6770345	27014.8700	21 58 56.	47 59 00	1.32
---	CM Dra	D	M4V	--	1.26838965	42893.9324	16 34 20.	57 09 46	68.00
---	UZ Dra	D	F8	--	3.2613024	46227.4238	19 25 55.	68 56 07	---
14273	CW Eri	D	F2V	--	2.7283707	41267.6756	03 03 59.	-17 44 16	5.95
---	YY Gem	D	M1V	M1V	0.8142822	24989.1169	07 34 37.	31 52 09	---
50966	HS Hya	D	F3	F4	3.6650000	38471.5300	10 24 36.	-19 05 33	11.04
54255	X^2 Hya	D	B8III	B8V	2.267701	42848.6107	11 05 57.	-27 17 16	4.08
52066	UV Leo	D	G0V	G0V	0.6000848	32995.5560	10 38 20.	14 16 03	10.85
35600	AR Mon	SD	G8III	KOIII	21.2080000	27560.5110	07 20 48.	-05 09 54	3.62
---	DD Mon	SD	B5	G0	0.56801193	30321.4820	06 45 57.	-00 17 32	---
83719	WZ Oph	D	F8V	F8V	4.183511	35648.7750	17 06 39.	07 46 58	7.99
82339	V1010 O	SD	A5V	A3V	0.6614272	41090.7163	16 49 27.	-15 40 04	13.47
14576	β PER	SD	B8V	--	2.867315	42598.2080	03 08010	40 57 20	35.14
5980	UV Psc	D	G2	G5	0.86104771	44932.2985	01 16 55.	06 48 42	15.87
17962	V471 Tau	D	K0V	--	0.52118346	---	03 50 24.	17 14 47	21.37
65839	FO Vir	SD	A7V	--	0.7755674	45441.7130	13 29 47.	01 05 43	11.84
103833	ER Vul	D	G0V	G5V	0.6980941	35693.5112	21 02 25.	27 48 26	20.06

Table 2: Semi-detached and detached Eclipsing Binaries with known absolute parameters [4] [5]

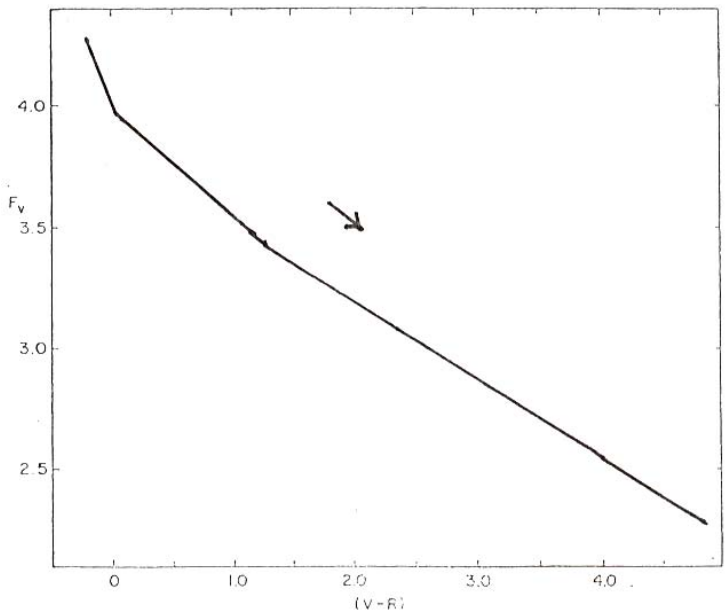

Fig. 1. The surface brightness F_v as a function of color index (V-R), the arrow shows the direction and effect of one magnitude of interstellar extinction/reddening. [2]

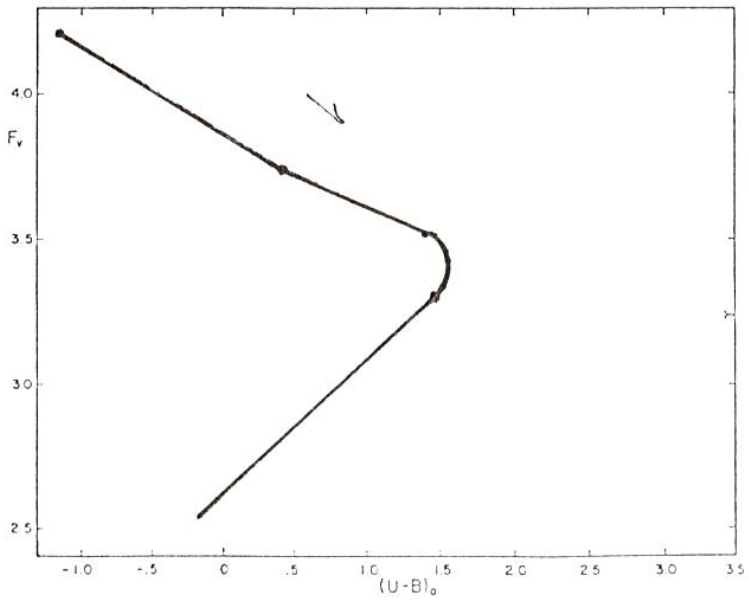

Fig. 2. The relation between visual surface brightness parameter F_v and color index (U-B). [3]

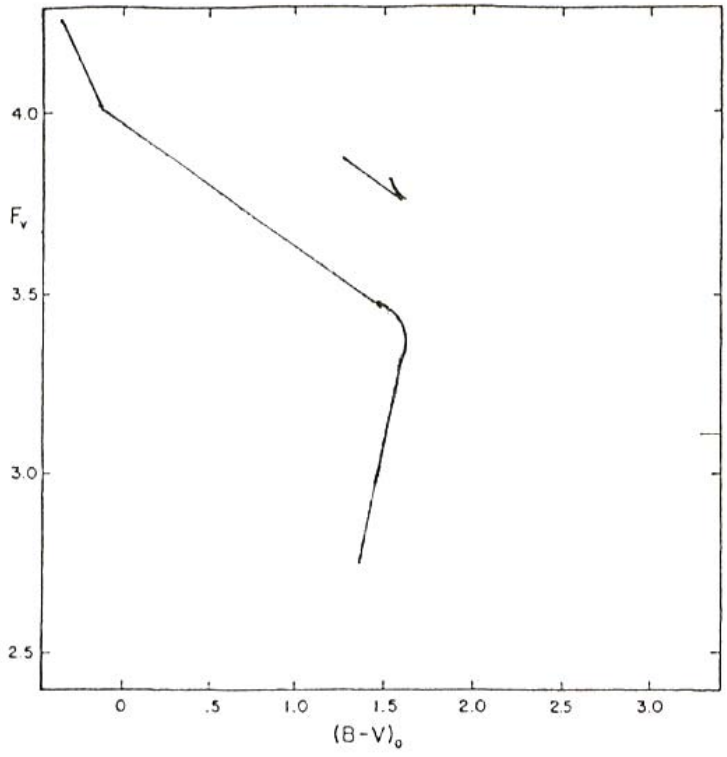

Fig. 3. Relation between visual surface brightness F_v and color index (B-V).

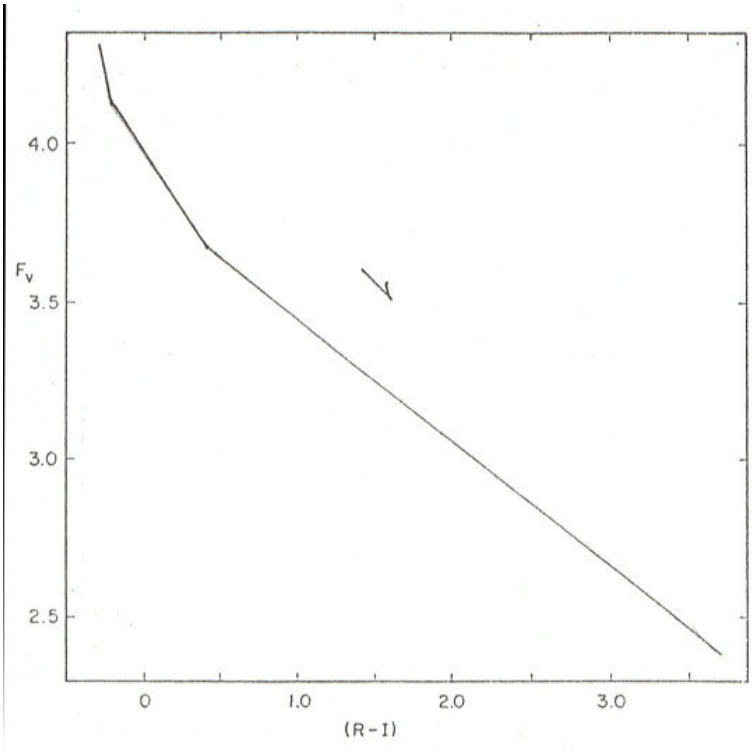

Fig. 4. Relation between visual surface brightness Fv and color index (R-I). [3]

4. Summary

This paper has made awareness of the need for filtered photometry in the V and R wavelengths on detached and semi-detached eclipsing binaries with measured parallax by the Hipparcos satellite to help establish and improve the relation between the surface brightness and (V-R) color index. Table 1 and 2 list a total of 224 EB systems that need your help. Both tables with the HIP Number, name, coordinates (2000), period and epoch and measured parallax are available on the IAPPP-West web site at:

http://www.iapppwest.org/Suggested_Projects/198_Hipparcos_Stars.pdf
http://www.iapppwest.org/Suggested Projects/26_Hipparcos_Stars.pdf

Also you can go to the Hipparcos catalog at:

http://astro.estec.esa.nl/Hipparcos/HIPcatalogueSearch.html

Enter the HIP number from the tables as the identifier to acquire the data.

Table 2 lists the information for 26 stars with absolute parameters determined. In the third column SD = Semi detached and D = detached systems. When the (V-R) index is determined on these stars, using the relation to the surface brightness, the distance to each star in the binary can be determined and compared to the parallax, π, determined by Hipparcos.

Any portion of the light curve with at least seven images over an hour period would suffice. Naturally, the best situation would be to acquire the complete light curve

for each system but this would sacrifice time getting the index of all 224 stars in the shortest time frame. Transformation and extinction coefficients at your site will have to be applied. I will be available to collaborate and lead the project through the IAPPP-West web site at http://www.iapppwest.org.

Acknowledgements

The SIMBAD database operated by the Strasbourg University and the Hipparcos Catalogue were used for all data searches.

A Neophyte's Determination of EY Ceph Curves and Orbital Constants

John L. Menke
Menke Scientific, Ltd.
john@menkescientific.com

Abstract: Using amateur level equipment, and with a beginner's knowledge of photometry, I have built the light curve for the eclipsing variable EY Cephei (subject suggested by Claud Lacy). This 10mag star has two 0.6mag eclipses per cycle, with a period of 7.97 days. The good observing news is that it is circumpolar (so easily visible), the bad news is that if the eclipses are not visible at night at your location (or if you miss them), you have to wait 6-8 months before they return. Combine this with only three days notice to start the campaign, no experience in precision photometry, and limited (but good) equipment, the amazing thing is that I achieved success in the first week (then the weather deteriorated...). I will present intensity curve results to date, discuss how I got to them, and provide the results of a preliminary calculation of the system parameters (orbits, sizes, etc).
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Introduction

EY Cephei is a 10mag eclipsing variable with a 7.97 day period (RA=03d40m15s Dec= 81d01m45s). In the late 1980's, Dr. Claud Lacy (Department of Physics, University of Arkansas) and others investigated the star period and radial velocities using spectroscopic techniques with the period determined by G. Torres (Harvard-Smithsonian Center for Astrophysics). The light curve data is necessary to compute many of the characteristics of the star system; however, because the period is almost an integer multiple of the day it will take approximately 8 months to develop the full light curve.

In late 2001, I had corresponded with Claud Lacey (one of our dome customers from our days as owners of Technical Innovations) concerning his use of the automated RoboDome for his long-term variable star studies. I expressed interest in photometry, and in early February he suggested I try EY as a project. He noted the 7.97144 day period, which conflicted with the period given in standard tables of 5.51672 days (such discrepancies are not uncommon). During the following week, I imaged the star field (C11/ST7 on AP1200), was able to identify which star was which, and saw BOTH eclipses (occurring within an hour of the predictions of ten years before)! I was hooked.

In this paper, I will describe the steps I took in learning how to do photometry with the equipment on hand. I am a physicist, and have many years' experience with advanced amateur equipment, which I have used primarily for a variety of imaging. However, I am almost a complete neophyte in the far more arcane art of photometry but decided that it looked interesting, and was both a way to learn a new field and to contribute to some real science.

Equipment

This observing campaign would involve very long runs over many months, with the goal of high accuracy measurements. I would need to use at least some photometric filters to improve the quality of the results, and to allow intercomparison with the work of others. I would also have to improve the quality of the tracking and other features of the observing setup.

I have used a 6" f12 refractor on an AP1200 with an ST7 ABG for many years. The equipment is housed in a remote controlled ten foot ProDome about 400 feet from our house operated over a local network. However, the need for better sensitivity caused me to upgrade to the ST7E NABG. I also installed a C11 OTA in place of the refractor (using a 6.3 reducer, the FOV is about 9x14 amin). Unfortunately, although optically acceptable, the C11 ultimately proved to have terrible mirror flop—so bad that I could not properly polar align the mount nor perform orthogonality correction. The pointing accuracy was about 15amin or worse. After months of frustration, I finally opened the C11 and found that the mirror was in effect supported by silicone caulk at the rear of the center hole, thus allowing the mirror to tilt as the tube changed direction. I installed a temporary fix to make the mirror rigid with the cell. Although the fix caused astigmatism (which does not hurt the photometry), it did solve the flop: the system now points accurately, and tracks within about 2-3 amin over 10-11 hours with no guide star. Thus I could start an observing run, go to sleep, and have an excellent chance of having good data the next morning. This is the way to go!

After the first week of gathering EY Cep data using the ST7E directly, I obtained a set of photometric filters and borrowed a filter wheel. Unfortunately, the filter wheel was old and its dimensions did not quite match the filters. No problem, just machine down the filters, and trim the threads with a file.

Software

I have used MaxIm DL for several years for both CCD control and image processing. I noted that the new V3 includes a set of photometry tools. These include the ability to measure dozens of stars on about 125 images at a time, and graph and save the results. The tools are extremely easy to use, and include many very nice features.

Unfortunately, the algorithm forces the user to choose a reference star; i.e., it will not measure the intensity of stars on an image except by comparison to one of the stars on the same image. This makes it impossible to move the data to a spreadsheet where the user can analyze and compare different combinations of stars among different images. After discussion, Ajai Sehgal, one of the original contributors to MaxIm, wrote a plug-in that installs a standard reference star in the upper left of each image. I can then choose this as the reference star, and measure the stars of each image relative to it and move the data to a spreadsheet. Using the spreadsheet, I can graph the brightness of all the star

measurements to look for clouds or other problems, and can compare any star with any other, on the same or on different images.

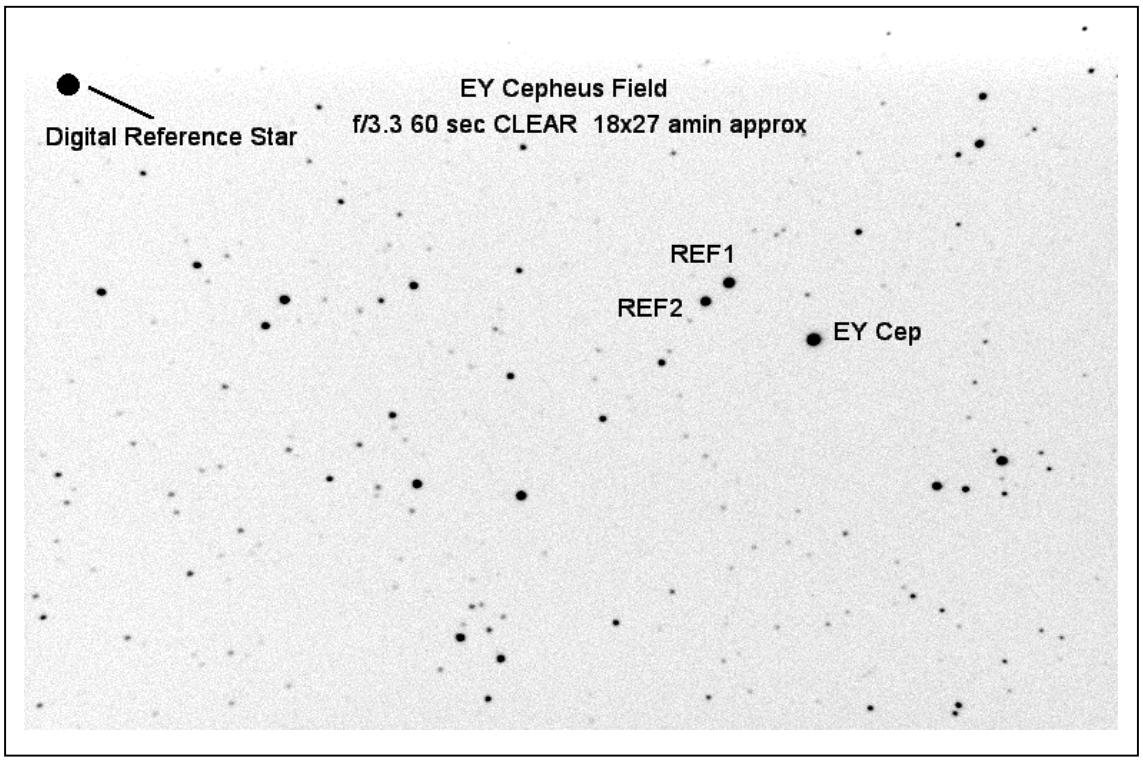
This system works very well. MaxIm reports the intensities as magnitudes (relative to the reference star) as X.XXX. The time of the measurement is recorded as Julian Day. Note that in the measurement of EY eclipse timings, the ultimate analysis will require the JD to be converted from geo-centric to helio-centric to correct for the light travel time differences as the earth moves around the sun relative to EY.

The observatory remote control uses Radmin, a very fast, yet inexpensive, remote control program. Because the dome computer has more RAM and is much faster than my desk computer, I perform the photometric analysis remotely, then download the magnitude data to my desk machine for Excel analysis.

Typical Run

A typical run starts at dusk with remote opening of the observatory. I turn on the scope and camera, move it to a bright star, and calibrate (synchronize) the mount. I usually do a quick look at supernova SN2002 (getting lower in the west), then move to a 5-6 mag star near EY where I focus the scope (usually "manually" or with FocusMax using RoboFocus on the C11 focus knob). I then move to EY, and begin imaging (usually using the autodark for these short exposures). This startup process takes about ten minutes (plus time spent at SN2002!). EY has two nearby stars (about 1.5-2 mag fainter) that I use as the prime reference stars, each about 2-3 amin distant. In addition, there are about 8 additional stars although another 2-3 mag fainter.

Over a ten hour run, the temperature may change by 10F or more at our location. The C11 at f6.3 will show a detectable change in the quality of focus for a 1-2F change, while 10-15F will grossly change the star image size (e.g., from FWHM=4 a-sec to 12 or so). For most runs when I expect the temperature to change more than a few degrees, I operate the RoboFocus using temperature compensation. Although some of the compensating moves take place during an exposure, the focus moves are normally in the same direction (the non-backlash direction to minimize mirror movement). Even when this movement occurred during an image (approximately 1 in 20 images), the elongated stars could still be used for photometry.



Observing runs normally go all night, terminated only by sunrise or gross weather changes. If clouds came through, I normally continue imaging as less than perfect data are still better than no data!

The next morning, I load the data blocks of 100-125 images into MaxIm. I first blink the images, looking for anything of interest and noting any large blocks of bad images (weather or other problems), taking about 3-4 minutes. I then operate the digital reference star plug-in, which takes about 3-4 minutes to insert the reference star into all the images. I then perform the photometric analysis (also about 3-4 minutes). After evaluating the graphs in Maxim, I save the block of intensity data to a text file for later Excel analysis.

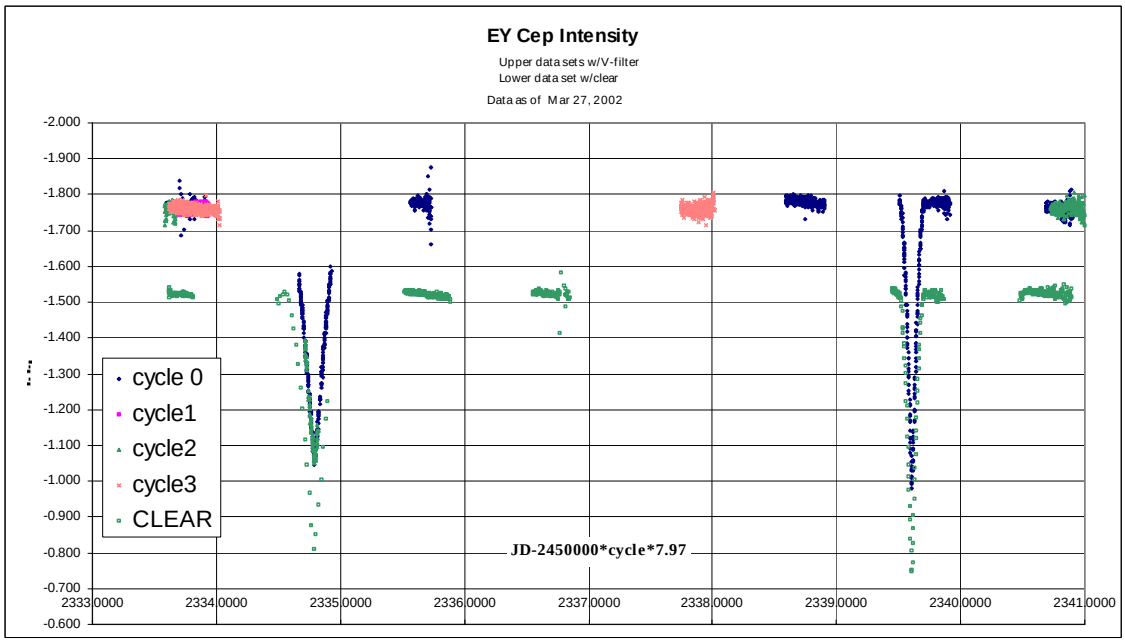
One of the issues in this kind of program is how to keep your data straight! Because these data will be taken over many months and under many conditions, one must be careful to establish standard nomenclature of the data sets. I also normally take a screen shot of the computer monitor as a record of which star was assigned which number.

Data Set Creation

After I analyze a set of images, I move the data into an Excel spreadsheet. I then do a plot of all the data vs. time, which shows the presence of clouds or other problems. I can mix and match data, compare different stars to one another, and generally get a feel for the data. I then plot the EY intensity minus the average of the two reference stars. Taking into account the weather and other data, I delete data points that are clearly

inaccurate or suspect. These amount to less than ten percent of the data. I then copy the resulting data onto a Master page in Excel.

On the Master page, I plot all the data sets together, both in a time linear fashion, and with time folding the data according to the 7.97-day period, as shown in the figure. Each group of data includes 100-300 data points (as listed in Table 1 below). The data on the lower curve ("CLEAR") are from the initial data set before I began using the V-filter. In the discussion below, I will refer to the Day Number during the cycle. The deepest eclipse takes place on Day7, and is known as the M1 eclipse (the other is M2).



Although there are many details of the light curve yet to measure (e.g., apparent structure on Day6 and small peaks preceding each eclipse as hinted in the CLEAR data), the overall shape of the curve is already clear including the timing, amplitude, and shapes of the eclipse events. These data, combined with the spectroscopic data previously obtained, are sufficient to allow calculation of the EY double star system characteristics. These data were sent to Claud Lacy who performed a preliminary EY star system evaluation (See Below).

System Evaluations

As this is my first photometry project using this equipment, I have committed a major effort to develop a detailed understanding of how well the system works. The result is a series of mini-studies (still ongoing) that evaluate different aspects of the system hardware and software, and on the data itself.

Hardware/software studies include

- Uniformity of CCD response across image and evaluation of how and whether to perform flats on the data
- Determination of whether the results depend on various settings in the MaxIm photometry tools

Data studies include
- Noise and consistency in the data
- Color changes during the eclipse (as one star blocks the other)
- Search for variability among reference stars

CCD Uniformity and Flats

Flat fielding is a method used to correct the images to achieve a uniform response across the chip. The flat field calibration of the raw image can reduce the effect of vignetting, dust, CCD pixel to pixel variability, and other sources of error that contribute to getting a different measurement depending on where the image is on the chip. I had previously used dome flats very successfully in imaging; however, I felt I had to investigate this practice more carefully. Indeed, I quickly discovered that the flats contained a 2-4% gradient across the field. Although the flats were smooth (and could thus correct pixel to pixel variations in sensitivity), such a gradient in a flat calibration could cause a photometric error if the star image moves across the field or if the images are reversed during a run (as a GEM flips).

I investigated a variety of flat production methods including:
- Dome flat with different lighting
- Tee shirt flat
- Sky flat using cloudy night data
- Sunset sky data

The flats usually showed very fine pixel to pixel variations under 1% variations and a few faint (1%) amplitude effects due to dust. More serious, however, I noted that most flats showed gradients as high as 3-4%. Such a gradient could be in the source, i.e. the flat field source is not truly uniform. It could be in the chip itself, i.e. the chip sensitivity varies across the chip. Alternatively, the gradient could be produced in the telescope/filter wheel/camera combination as a result of the light from the flat field source. A flat field floods the scope with light which can reflect within the system, reaching the chip where it can produce a gradient superimposed on the light directly reaching the chip.

I decided to investigate the gradient in two ways.

The first investigation began with imaging a convenient star field having several dozen reasonably bright stars in the field. I then rotated the camera on the scope, so that the star field would be rotated 180 deg. on the chip. I could then measure the same stars relative to one another on the normal and rotated images to determine whether there was any variation in response (after all, such a variation is what the flat is supposed to

correct). The result was that there was no measured sensitivity gradient across the chip in any direction that was greater than .014mag (1.4%). This result held for both straight through (no filter) and the V filter.

The second investigation was to take dome flats, which showed approximately a 2% gradient horizontally and vertically on the image (I evaluated the gradients using the MaxIm DL line analysis function). I then rotated the camera 180deg and repeated the images. If the image gradient rotated, then this would show that the gradient was in the source (dome flat or non-rotated telescope). The results showed that 1/3 of the apparent horizontal gradient and none of the vertical gradient was from the flat/scope. The remaining amount of the gradients evidently arose from asymmetric reflections within the scope, filter changer, or camera. The results were the same for the clear or V filter.

The flat data differs from the star measurement data, and shows that a flat source that floods the scope with wide angle rays will not produce a valid map of the sensitivity of this optical system suitable for use in a typical imaging situation. I have decided not to use flat calibration for this initial analysis, as it is likely to introduce more error than it cures in this particular system. The next step will be to conduct tests in which I rotate the scope as well as the camera. I will then reopen the scope and install improved light baffling (and fix the mirror mount), and continue this evaluation.

Evaluation of MaxIm settings

The user has several choices when performing photometry With MaxIm DL. One of the most obvious is the size of the aperture mask used in the software for making the intensity measurements. I investigated this using a typical data set with three choices (R=8,12,16) pixels by measuring the EY intensity vs. the two reference stars. Although changing the aperture radius changed the apparent intensity of any particular star by up to 0.1mag (relative to the digital reference star), the relative photometric readings changed less than .005mag. Aperture choice is clearly not a problem, at least for reference and object stars that are within two mag of one another as in this case.

Noise and consistency

Consistency and noise (image to image variations) can be gauged by comparing the average and standard deviation of a set of measurements that one expects to be uniform (as in portions of the light curve between eclipses). Contributors to reduced signal level such as clouds, filters, shorter exposure times, etc will all cause the apparent noise to increase. Variations in the color transmission of the sky (e.g., as EY descends toward the horizon) are reduced through the use of relative photometry and by using the V-filter.

Table 1 is a summary of the data to date. The columns are as follows
Col 1. Relative day during the eclipse cycle
Col 2. Note re data
Col 3. Calendar date in 2002 of start of data set (e.g., evening of 2/27/02)
Col 4. Julian Day (less 2452300)

Col 5. Cycle number after start of project (8 days per cycle)
Col 6,7. Average mag of EY rel to the digital reference star and Std. Dev.
Col 8,9 Difference in mag of two reference stars, and Std. Dev.
Col 10. Number data points in data subset

Table 1- Data Sets (to Mar.27, 2002)

Eclipse Day Phase	Note	MM/DD	JD	Cycle	EY	Std Dev	REF STARS DIF	Std Dev	# pts
1		02/27	33.9	0	-1.766	.011	-.860	.018	
		03/07	41.9	1	-1.760	.008	-.849	.014	
		03/15	49.6	2	-1.760	.016	-.847	.022	
		03/23	57.9	3	-1.761	.009	-.852	.016	
2	Eclipse	02/28	34.6	0	NA	NA	-.865	.016	
	Eclipse	03/16	50.6	2	NA	NA			
3		03/01	35.7	0	-1.776	.014	-.867	.022	
4	No Data								
5		03/27	61.9	3	-1.759	.015	-.848	.031	
6		03/04	38.7	0	-1.780	.008	-.865	.015	
7	Eclipse	03/05	39.6	0	NA	NA	-.864	.014	
8		03/06	40.9	0	-1.760	.013	-.846	.021	
		03/22	56.9	2	-1.762	.013	-.851	.025	
	AVE/SD				-1.765	.008	-.856	.008	

Color Changes During Eclipse

It is interesting to measure the relative colors of EY compared to the reference stars, and to measure whether there are color changes in EY during an eclipse (as one star blocks the other). As a first attempt, I measured the various stars using the Blue and Red photometric filters and evaluated the differences. The measurements showed that during the eclipse the color as measured by B-R changed less than .01mag. This is consistent with the spectroscopic data that show the two stars of EY as being of the same class.

Search for Variability among reference stars

EY has two convenient reference stars nearby that I have used for all the photometric measurements. However, it is still possible that these stars themselves may be variable. Although the main concern is to show that the reference stars are stable over the 8-day cycle of EY, because data will be taken over many months, one would also like to know the stability of the reference stars over that time as well. I have also measured additional stars on the images as additional checks (though not all stars are on all images).

The data in Table 1 show the variability as measured by the average and the standard deviation of the difference of the reference stars in each data set. The standard deviations are in the range of .014-.031 mag, and the standard deviation of the set of averages is about 0.008 mag. There is no indication in the data of variability in the reference stars over the time measured.

Preliminary Results

The purpose of the intensity data is to combine it with the spectroscopic data to permit computation of the EY Cep characteristics. Although I will not have the full intensity curve until next year, the present data allowed preliminary calculation of the system characteristics. Based on these data, the results reported back to me by Claud Lacy are as follows:

> From the light curve model you get the relative radii (relative to the semi-major axis), the orbital inclination, the relative surface brightness of the secondary (relative to the primary), and the eccentricity factors (e cos w) and (e sin w), hence the eccentricity and the longitude of periastron. From the RV curve model you get the mass factors (m sin^3 i), the projected semi-major axis (a sin i), and the eccentricity and longitude of periastron. The combination of the two sets of results produces the absolute dimensions and masses. The sharp bottoms of the eclipses are due to the facts that the orbital plane is almost exactly edge-on and both stars are essentially identical.
>
> The data you have already gathered is sufficient to fix the major geometric and radiative parameters of the model to an accuracy of about 1%! The eclipsing binary consists of a pair of essentially identical F2 stars with masses of 1.51 solar masses each, and radii of 1.43 solar radii, indicating they are very young main-sequence stars. The semi-major axis of the orbit is 24 solar radii and the orbital eccentricity is 0.45, quite eccentric and another indication of the youth of the system (they tend to circularize pretty quickly due to tidal forces). The orbital plane (as seen by us) is almost exactly edge-on. The standard error of the observations is about 0.013 mag, quite reasonable. Thanks for your research efforts so far. They bode well for the future of the project.

Conclusion

Even with little experience, with the proper equipment and software, and "a little help from your friends", one can do "real science". Of course, this particular project will require many more months of data taking for a complete data set, and many more internal and external data comparisons to assure that the data are as reliable as possible. Even this

work is just a “toe in the water”, as there is always the goal to do more accurate measurements, and to take on ever more challenging projects.

On-line Masters Degree in Astronomy

Colleen Gino
Schenectady Museum and Union College , Schenectady NY
Email: cgino@astrophys-assist.com

Abstract: Distance education has come along way in the past decade, such that now you can study astronomy at a university on one continent, with professors on a different continent while you work thousands of miles from either. Sounds intriguing? The experiences and challenges encountered by one student, a candidate for a master's degree in astronomy, are described.
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Introduction

Distance education has become an increasingly popular method for working adults to continue their education. Along with this popularity has come an increase in the number and subject matter of courses available, as well as an improvement in course delivery methods. Not too long ago, only individual courses were offered at a distance as a supplement to a traditional degree program, a program that required some level of on-campus attendance. Moreover, the small selection of available distance courses were primarily offered as correspondence courses, where one would be given a textbook and a certain number of written assignments to be completed within one year. Luckily, the situation has improved to the point that it is currently easy to find complete undergraduate and graduate degree programs offered wholly over the internet. One such degree program is Swinburne Astronomy Online (SAO).

SAO Degree Program

SAO was developed by the Swinburne Centre for Astrophysics and Supercomputing located in Melbourne, Australia. A variety of certificate and diploma programs are offered, as well as a Master of Science in Astronomy degree. The Master of Science in Astronomy degree program received full accreditation by the University in December of 1999, and has been offered both within Australia and internationally ever since that time.

While the Master of Science degree is indeed accredited, SAO does not advertise it as being a training program for professional research astronomers. The program requires only basic college mathematics and very little physics, so is therefore not an entry point into a Ph.D. program. Instead, SAO has targeted teachers, planetarium/museum educators, and those working in non-research positions at professional observatories or other astronomical facilities. A growing number of avid amateur astronomers, seeking to upgrade their “amateur” status to “professional” are enrolling in the program as well.

Entry into the Master of Science program typically requires the prior completion of an undergraduate degree. However, if an applicant can demonstrate equivalent prior knowledge and experience in astronomy, this requirement may be waived. An alternative

route is to enroll in one or two introductory courses on an individual-unit basis, and gain high enough grades to establish oneself as capable of entry into the degree program.

The master's degree program requires the completion of twelve five-contact-hour courses, designed to be taken over six semesters. Full-time enrollment is not currently supported because not all of the units are available every semester, with the more advanced units being offered only in odd or even semesters. However, if one plans their schedule carefully, the degree can be completed in four to five semesters.

Assessment for SAO courses does not include formal or proctored examinations. Instead, the coursework consists of a mixture of essays (20%), open-book tests (20%), newsgroup participation (30%), and final projects (30%). Final grades are awarded on the following scale:

High Distinction	100% - 85%
Distinction	84% - 75%
Credit	74% - 65%
Pass	64% - 50%
Not Pass	49% - 0%

To earn the master's degree, a minimum grade of 65% (credit) must be achieved in all twelve courses. In the first semester of 2000, the average mark for participants who completed the courses they enrolled in was between 70% - 75% for all courses, with a small number of students achieving a mark of High Distinction in each unit.

Introductory courses include Solar System studies, stars and the Milky Way and the exploration of galaxies. Observational courses include units on the tools of modern astronomy, astrophotography and CCD imaging. Advanced unit on radio astronomy, stellar astrophysics and studies in space exploration are offered. Among the major projects available are the history of astronomy and computational astrophysics. All combined, this selection of course work gives the student a solid grounding in the fundamental concepts and key issues of contemporary astronomy.

The obvious advantage of the SAO program is that one can participate regardless of their geographical location. SAO boasts of having had students from 34 countries around the world enrolled in their units to date. The instructors, mostly professional research astronomers, are nearly as varied in their origin, hailing from professional observatories or universities in Australia, South America, Europe and the United States. Rarely does one get the opportunity to be involved with such an wide variety of international students.

Is the SAO Degree Worth It?

If the willingness to bear the financial burden for the courses I have taken up to this point can be considered an indication of an employer's recognition of the value of the SAO master's degree, then my past employer, the National Radio Astronomy Observatory (NRAO), definitely recognized the value of the degree. Like many astronomical facilities that depend on government funding for their operation, NRAO offers its employees the

education benefit of tuition reimbursement for courses or degree programs that are work related. Final approval for such reimbursement must go through many administrative levels, from the employee's immediate supervisor to the director of NRAO. I was initially concerned that due to the non-traditional nature of the SAO coursework, I may not be eligible to receive the tuition reimbursement. Interestingly, it turned out that my professor for the first course I took with SAO, Introductory Radio Astronomy, was at the time (Fall 2000) the assistant director of the Charlottesville branch of NRAO. Needless to say, I had no difficulty getting approval for reimbursement!

With four years of optical, solar and radio telescope operation and half the coursework for the Master of Science in Astronomy degree under my belt, I decided that it was time to step out the role as telescope operator and into the role as educator, so I could put my education and experience to better use. Early this year I began my job search, and discovered many interesting positions which required a minimum of an undergraduate degree, with a preference for a master's degree, in astronomy. While I hold neither of these degrees at the present time, I applied for several such positions. My resume generated interest in a wide variety of facilities, from our national optical observatory to college observatories and planetariums. During the interview process I was asked many questions about the SAO degree program, but was never told that it was not a suitable considered to be a suitable degree program. Judging by my employment offers, the SAO program met my potential employers' standards and was considered to be an acceptable qualification, particularly for public education and outreach positions.

My job search proved to be highly successful, due in no small part to my status of master's candidate. I currently hold the dual position of Planetarium Manager at the Schenectady Museum and Observatory Manager at Union College in Schenectady, New York. The Schenectady Museum uses their planetarium to deliver educational programs tailored to complement the science curriculum of K12 school children. Public planetarium programs are offered as well, with the goal of educating the audience in an entertaining manner. My primary role at the museum is to serve as the astronomy content specialist, and to research and develop new planetarium presentations and educational programs.

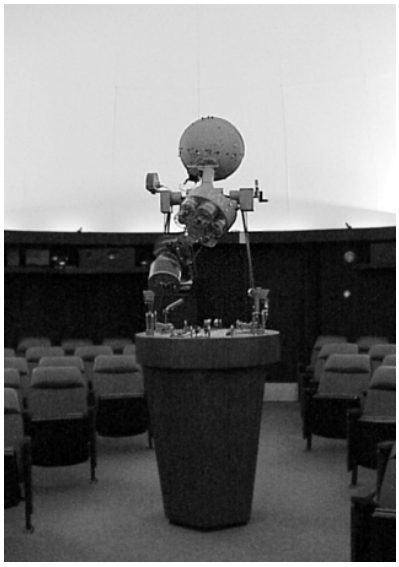

Fig. 1. The Schenectady Museum Planetarium uses a Spitz AP-3 Planetarium Projector to recreate the nighttime sky in its 65-seat planetarium theater.

Union College, founded in 1795, is an independent liberal arts college. The Physics Department maintains the campus observatory which houses a 20-inch f/8.1 Ritchey-Chretien telescope, which is used for both visual observing sessions and scientific data collection. When used by students enrolled in astronomy and physics courses, the telescope can be outfitted with either an AP-7, AP-8 or an Optomechanical model 10C spectrograph. A variety of data reduction software is available including IDL, Software Bisque's CCDSoft, IRAF, and MaximDL. For the monthly public visual observing sessions, the telescope is controlled by Software Bisque's TheSky. My primary role at the college is to manage the operation and maintenance of the telescope and assorted back-end equipment. In addition, I am responsible for training students on the use of the equipment and overseeing their observations, and conducting the monthly public viewing sessions. As if this wasn't enough, I have the added perk of being able to use the telescope for my own research projects as well.

Fig. 2. The Union College's 20-inch reflector telescope with an eyepiece installed at the Cassegrain focus, in preparation for an evening of visual observing for the public.

One of the most interesting and unexpected opportunities I have had since coming to New York, has been the opportunity to teach an undergraduate astronomy lab course at Union College. Once again, I firmly believe that my status as a master's candidate has enabled me to secure this position, regardless of the fact that the degree program I am enrolled in is a non-traditional one offered by a university in another hemisphere.

Fig. 3. A dome with a view. While it may be atypical to include a picture-window in a telescope dome, this west-facing window does supply us with a beautiful view of an example of the finest architecture on the campus with the sunset as a backdrop.

Conclusion

Degree programs offered at a distance may be the only viable means for many of today's busy, working adults to continue their education and attain an undergraduate or graduate degree. An online program such as Swinburne's Astronomy Master's Degree may not be suitable for everyone, but for the self-motivated individual who feels at ease with the process of studying, researching and completing projects primarily on their own, the Swinburne program offers an ideal alternative to a traditional on-campus degree program.

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Undergraduate Astronomical Research: Adventures in Photometry

Cheryl L. Genet
Orion Institute

Abstract: In the fall of 2001, I participated in a unique observational astronomy course designed to provide undergraduate students with the opportunity to experience scientific research through photoelectric photometric astronomy. Observational data was gathered from the Phoenix-10 automated telescope at the Fairborn Observatory and analyzed and reported by student teams in the class. Our papers will be published later this year.
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1. Introduction

I was just 6 years old when my older brother brought a new friend home from school. His friend's name was Russell Genet. Never did it occur to me for a moment that he would one day become my husband, but he immediately became my teacher. A young man with an insatiable curiosity about the universe, he, along with my brother, encouraged me to ask big questions as I grew older and increasingly entered into their explorations of the cosmos. Many a night was spent under the stars in the next few years, thinking about their meaning and the vastness of space—asking the same questions the stars have provoked of countless generations of humans. Of the three of us, only Russell actually became an astronomer in the end, but the fascination with the stars never left any of us.

There were other things as well that tied me to a love for searching the heavens. My grandfather ground the sixty-inch mirror at the Mt. Wilson Observatory in Pasadena, California. He was also a foreman on the project to move the mirror up the mountain and install it in the dome. My great uncle, Merritt Dowd, was the chief electrician for the observatory and wired the hundred-inch dome. His daughter Helen married Milton Humason, an assistant to Edward Hubble in his discoveries of the expanding universe. My mother spent many summers hiking the trails and visiting her uncle and aunt on Mt. Wilson, and my childhood was filled with beloved stories about the mountain.

Nevertheless, aside from pursuing my education over most of my lifetime and my independent study and reading, my career consisted mainly of raising my children—motherhood. So it was a special delight to have the opportunity to become involved in a most unusual course in observational astronomy, taught by my teacher and my husband, at Central Arizona College, Superstition Mountains Campus, in the fall of 2001. The

course was designed to allow students to participate in real scientific research and produce published papers by learning the process of obtaining and analyzing photometric data gathered by an automatic telescope at the Fairborn Observatory, and preparing the results for publication. At the time I was myself an instructor at the college and so assisted Russell in some of the course development, logistics, and mechanics. I also participated, however, as a student. Like the other nine students in the class, I was a bit wide-eyed, daunted, and excited by the prospect of doing real astronomy.

2. Science 298 – Observational Astronomy

From the first day, Russell challenged us to take off our student hats and think of ourselves as researchers. In fact, the course was designated as the research arm of the newly formed and student-directed Superstition Mountain Observatory. We were given the vision of producing published papers that would become a small, but very real part of the body of science. It was clear that accomplishing this feat in one semester was by no means guaranteed, and our success or failure would not be "canned" science education, but a real world experience. With Russell's guidance, and the kind assistance of several professionals in the field of photoelectric photometry, we plunged in, only vaguely able to imagine what lay ahead.

The first lesson we learned was that much "bread and butter" science is accomplished by teamwork, and to that end, we agreed to sink or swim together, all ten of us. Russell often exhorted us to "divide and conquer," share the work, don't duplicate efforts. Consequently, we decided at the outset that all our variable star work would center on Cepheids, and, although we divided into teams to work on separate stars, we all pulled together in the process of setting up observations, gathering information, contacting professionals, and analyzing data. One of the students kindly volunteered to pay for the observation time, while others applied their considerable computer skills. Some wrote letters, tracked professional help, and sent thank you notes, while others gathered past publications on the stars we chose.

The first and most pressing problem, after setting up our strategy and choosing to concentrate on Cepheids, was choosing the best stars to observe, and getting them loaded on an automated photoelectric telescope. We had hoped to use the Fairborn-10, which was the original automated telescope Russell built and put in operation in April of 1984, but due to its workload, it was necessary to shift to the Phoenix-10. The P-10, itself an automated veteran, was built by Lou Boyd, and put into operation in October of 1983. This put us into a working relation with Michael Seeds, the Principle Astronomer for the P-10, who became our able assistant throughout our research experience.

One of our first conference calls was to Ken Kissell, astronomer and long-time friend of Russell's, who helped us pick out 13 candidate stars. During a second conference call to Mike Seeds, we sought help in choosing which stars to observe and which to eliminate. This step brought us down to seven. Our next step was to choose comps, checks, and sky positions (the next step, that is, after we learned what these were and about the important role they play in assuring accurate observations!). A third conference call to Douglas Hall, another astronomer and long-time friend of Russell's, provided the assistance we needed in tracking down comps, checks, and sky positions. We were finally ready for our observations on the Phoenix 10 to begin.

While we were waiting for this remarkable telescope to gather observations for us, we set ourselves to looking up past publications on our seven carefully chosen Cepheids, FF Aqu, U Aql, S Sge, T Vul, DT Cyg, Delta Cep, and T Mon. For assistance in this area we turned to Janet Matte, Director of the American Association of Variable Star Observers, Tibor J. Herczeg, with the Department of Physics and Astronomy at the University of Oklahoma, and Katalin Olah at the Konkoly Observatory of the Hungarian Academy of Sciences, Editor of the International Bulletin of Variable Stars. It was Olah, however, who ultimately directed us to L. Szabados at Konkoly, who airmailed us the vital period updates of both northern and southern Cepheids in the knick of time. These updates contained magical keys—the epoch and the period of each star—that helped us unlock the pages of observational data we received from the P-10, and construct our light curves.

On November 11th, with only three weeks to go in the semester, we received from Mike Seeds our long awaited data—eighty-two observational groups. The observations were reduced using software written by Russell some 15 years ago and subsequently refined by Mike Seeds. Heliocentric corrections had been applied, magnitudes were given in millimagnitudes, and the comparison-check values were given to show the constancy of the comparison star. It pretty much all looked like Greek to us!

But each line of data had the name of a star at the end of it, stars that belonged to one or the other of our teams, and we knew that, Greek or no, those lines of data would tell us something about these stars. As Russell patiently guided us through the columns, we began to see that the numbers were Julian Dates, hours of observation, filter information, and other important statistical data. We rolled up our sleeves and rolled out our calculators, determined to translate "Greek" into light curves. Many calculations and late nights later, we still had just a bunch of numbers, but a picture was forming, ever so slightly, in our minds. Applying our magical keys of epoch and period, the data were beginning to transform. Nothing can compare, however, to the pleasure of plotting the first light curve, and seeing that vague picture brought into exquisite focus. The light curve tells a story about a special star, light years away, millions of years in the past, that we had chosen out of a vast expanse of stars to observe. It is a tiny bit of description, but a tangible one, about the universe I pondered as a child. It is, I suspect, the astronomers delight, which we were given the opportunity to taste.

3. Conclusion

In the last hour, with several late night sessions, we were able to achieve our goal—real scientific research, real science papers, and pending publications in a real science journal, the *IAPPP Communication*. Our papers should appear sometime later this year. One of the students in this class, Klay Lappa, was especially outstanding in his grasp of the process, and his diligent contributions. Of course, we all worked hard and learned much, but Russell and I remarked about Klay's competence on more than one occasion. He attended both of the field trips taken in conjunction with the Astronomy 101 class Russell was also teaching, and the activities of the Superstition Mountain Observatory, and we were surprised that his family accompanied him on these trips. This led us to discover that at the time of the class Klay was only 14 years old! An exceptionally bright and focused young man, he had been home schooled and deemed ready for college by the age

of 13. Klay will be presenting his paper this summer at the two-hundredth meeting of the American Astronomical Society in Albuquerque, New Mexico, probably the youngest person to ever do so.

In fact, two other students and myself will be doing the same. We are all looking forward to this unexpected opportunity rising out of this unique and innovative course. Klay in particular, is receiving attention from Central Arizona College administration, and from the local press. He will be receiving a special award for his accomplishments when he returns from the AAS meeting. Photometric astronomy provided us all with a remarkable, education-enriching experience and it is my hope that its unique capacity to do so will continue to be developed in the future.

4. Acknowledgements

I am deeply grateful to my husband and my mentor, Russell Genet, for his remarkable creativity, energy, and expertise that made Science 298, Observational Astronomy—real science for the undergraduate student—possible. I also wish to acknowledge the foresight and can-do attitude of Dean James Stuckey of Central Arizona College that made this course happen. Special thanks also go to the kind assistance and valuable expertise of Louis Boyd, Douglas Hall, Kenneth Kissell, Micheal Seeds, and L. Szabodos, professionals in their field and in the generous gift of their time.

ASTRONOMY II

New Telescope at an Old Observatory

Sean Hoss
Mount Wilson Observatory

Abstract: Mount Wilson Observatory has installed a 16" Schmidt-Cassegrain Telescope on an LX200 mount. This instrument is located in a clamshell dome on a concrete pier. The site offers a convenient location, excellent seeing, and despite the city lights the sky is well suited for intra galactic work, infrared observations, and is exceptionally dark when the marine layer rolls in. The telescope is available for eyepiece viewing, but instrument work has a higher priority. A trained operator will assist with observations and a computer and CCD camera are available, although guest instruments are welcome.
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1. Facility

There is a new telescope available for amateur-professional use at Mount Wilson Observatory. A recreational refractor has been replaced by a Meade Instruments 16" Schmidt-Cassegrain Telescope. The new instrument uses an LX200 fork mount and is supported by a permanent pier. The dome itself dates back to the beginning of the observatory and offers several benefits from that era. The concrete was poured when the construction crew was solving the problems of large telescope support. This smaller dome, built around 1910, followed shortly after the historic 60" Telescope was completed. The telescope pier is isolated from the building like its larger neighbor. The concrete has not settled appreciably. Also like the site's large telescopes, the dome diameter is large compared to the telescope aperture. Measuring 17 feet from wall to wall, there is ample floor space.

The prime reason to observe at Mount Wilson is the steady air. The prevailing wind direction is from the west, across the Pacific Ocean. The large expanse of water acts as a heat moderator and allows for a laminar flow. The observatory sits on the first mountain the air encounters and the as yet undisturbed air passes over it with little turbulence. George Hale evaluated the seeing at the site before he founded the observatory in 1904. Throughout its history, Mount Wilson Observatory has benefited from the superb atmospheric conditions. This reputation was upheld during a survey of several astronomical sites. It determined that Mount Wilson experiences some of the steadiest air in North America and ranks on a par with Haleakala in Hawaii. [1] This is attributed to its elevated position on a coastal mountain. At 1700 meters, it sits above a maritime inversion that forms 400-600 meters above sea level. This thermal inversion prevents air from rising, trapping the turbulent air in the valley below.

While Mount Wilson is affected by light pollution, the impact is not as damaging as the reputation. The observatory sits well above the city, insulating it from some of the light intensity. On moonless nights, the Milky Way and the stars of the Little Dipper are naked eye visible. The city glare has dimmed in recent years. George Eslinger, the former Director of the Bureau of Street Lighting for the City of Los Angeles (1984-1998), began the process of converting the city's lighting to full cut-off optics. Aside from our subjective impressions of improvement, nothing makes the point better than actual measurements. Data were taken in 1998 and 1999 which quantified the sky's limiting brightness. [2]

Band	Sky Brightness (magnitudes per square arcsecond)
B	19.9
V	18.8
R	18.5
I	18.8

Table 1. Sky Brightness values at Mount Wilson

2. Equipment

The historic telescope dome is complemented by modern electronics. The dome is connected to the observatory's fiber optic network and the internet. The telescope control computer is a 1 GHz P3 with 512 MB of RAM. It comes with a 19 GB hard drive, network interface card, a CD ROM burner, and a 17" monitor driven by a 2X AGP video card. There is also a networked server running IRAF (Image Reduction and Analysis Facility) for data processing. Visitors can bring their results home on a CD or post them to a local FTP (non-anonymous) server for later retrieval.

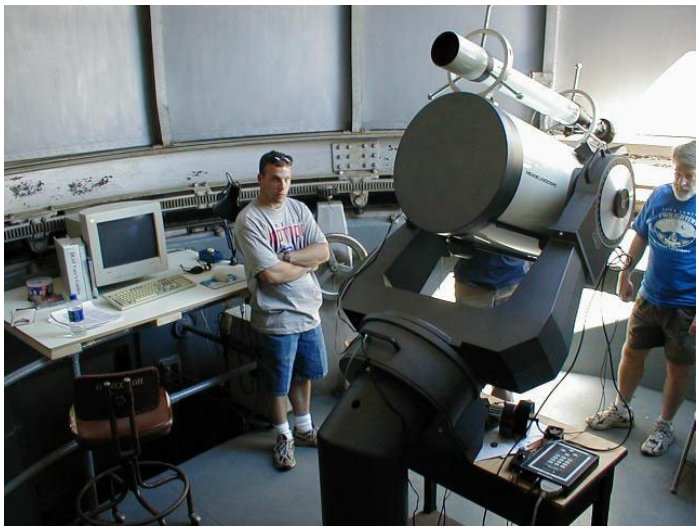

Figure 1: Main telescope and guider with computer

The telescope has been used routinely by students in the summer. A two week seminar focuses on astrophysics and observational astronomy. The program is called CUREA, or Consortium for Undergraduate Research and Education in Astronomy. In

August 2001, they captured an image of a 17th magnitude Type Ia supernova in the galaxy UGC11725.

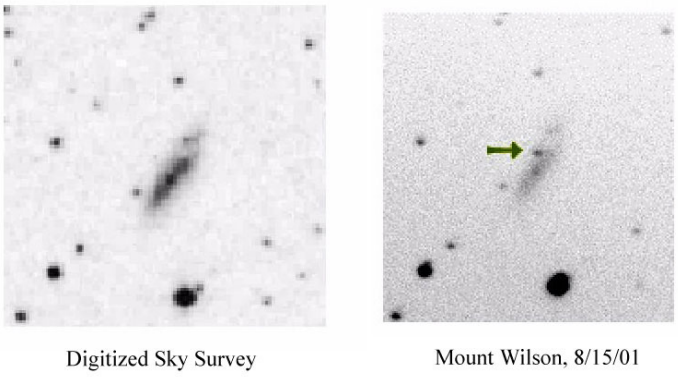

Figure 2: Type Ia Supernova in UGC 11725
Image is shown in negative.

In March of this year, David Held used the telescope to make a composite of the Crab Nebula. He took 2 exposures each in red, green, and blue and 5 exposures for luminance. The blue frames were 7 minutes long and the rest were 5 minutes each. The transparency was not good that night, with intervening high clouds. He used his own instrument and processed the data with MaxIm DL 2.0.

Figure 3: Crab Nebula

In addition to the main instrument, the support equipment available includes:
Meade 90mm f/11.1 refractor guidescope
Meade Pictor Model 416XTE CCD camera with integral model 616 color filter wheel
Pictor CCD imaging system on a SCSI bus for 416 XTE
JMI NGF-S motorized focuser with hand controller (installed on LX200)
Meade Pictor Model 216XT autoguider with relay box (mounted on guidescope)
Meade Model 644 Flip Mirror System (mounted on guidescope)

Meade Pictor Model 201XT autoguider with cables, nosepieces, HA-50 CCD filter and carrying case
Meade 2” off axis guider.

3. Limitations

This is the first year the program is available to amateur-professional astronomers. Until it becomes fully staffed, not all nights can be accommodated.

Due to the nature of the clamshell dome, the telescope can not be pointed at the zenith.

The dome floor is accessed by 9 narrow, short-tread stairs. There is no viable way to improve the entrance.

4. Arrangements

Reservations are required and need to be made at least two weeks in advance by calling the Hale Solar Lab in Pasadena. Their phone number is (626) 793-3100. There is a fee of $100 for half a night and $200 for a full night.

A telescope attendant will be on site to meet the visitor, show them the support facilities, and manage the telescope. They are familiar with its setup and operation and some of them can help with CCD camera exposures, flat fields, and dark frames. There is a common galley for observers to store and prepare food. It is presently self-service. Please bring your own food and beverages, alcohol is not permitted.

Overnight stays in the Monastery are available at $25 per night. Each room has a sink, desk, and full size bed and some rooms have bunk beds. The rustic dormitory has two common showers and toilets. The Monastery also supports scientific staff, so only one room is available for the 16” telescope users.

The observatory is 45 minutes from Pasadena or Burbank. Directions are available on the observatory web site at www.mtwilson.edu or you can get them from the Hale Solar Lab.

5. Summary

There is a 16" Schmidt-Cassegrain Telescope available for personal projects at Mount Wilson Observatory. Synoptic observing programs will be given serious consideration. Projects from astrophotography to variable star observations and anything in between are possible.

Acknowledgments

This program is possible due to the efforts of several key people.

Dave Jurasevich spear headed the training program. He stepped forward and began training others to operate the telescope. His enthusiasm and dedication are responsible for the program being available this year instead of next.

Scott Roberts started the ball rolling by offering to bring a new telescope to Mount Wilson. He followed through by delivering and installing the 16” SCT.

Paul Hobbs and Chris Morrison managed to polar align the telescope and test the optics even though they took a long break to observe an aurora borealis.

Scott Teare and John Hoot have encouraged us to promote public access. John has assisted significantly with computer configuration.

Don Nicholson and Mike Simmons of the Mount Wilson Observatory Association developed the concept for the program and have continued to guide its progress.

All of the equipment for the program has been donated. I apologize if I have neglected contributions by any individual or company.

Meade Instruments Corporation
Meade 16" Schmidt-Cassegrain Telescope
Meade UWA, SWA, and Super Plossl eyepieces
Meade Narrowband, Broadband, Interference, and color filters

John Hoot
Meade 90mm f/11.1 refractor guidescope, Meade 216 CCD autoguider, telescope accessories including filters, 2 computers, and a computer monitor

Allen Lund Company
1 GHz P3 w/ 512 MB RAM, 19 GB HD, NIC, CD-RW, 2X AGP, and a 17" monitor

Stellar Classification with the SBIG Spectrograph

Daniel A. Klinglesmith III
Etscorn Campus Observatory
Department of Physics
New Mexico Institute of Mining and Technology
Socorro, New Mexico

Abstract: In the Physics department of New Mexico TECH the astrophysics majors are exposed to the intricacies of the physics and math needed to understand the nature of stars and their evolution. But as in most other endeavors, a picture is worth 10,000 words. The pictures needed are the wide range of stellar spectra that can be obtained with a low-resolution spectrograph. This paper will show the results of two years worth of stellar spectra obtained by undergraduate students in an astronomy laboratory class as they attempted to make order out of the complexity. The equipment used was a Celestron C-14 telescope, SBIG ST-8e CCD, and the SBIG Spectrograph. Stars of all spectral types and magnitudes < 6^{th} were imaged and compared to the MK standards.
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1. W. W. Morgan , P. C. Keenan and B. Kellman, An Atlas of Stellar Spectra,(University of Chicago Press, 1942)
2. Morgan, W. W. and Keenan, P. C., Ann. Rev. Astron. Astrophys., 11(29), (1973)
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4. D. Hoffleit, Catalogue of Bright Stars, (Yale University Observatory, 3^{rd} revised, 1964)
5. Etscorn campus observatory**,** <<http://www.nmt.edu/~ecorobs/>>
6. New Mexico Tech astronomy club, <<http://www.nmt.edu/~astro>>
7. MK anchor points, << http://www.astro.utoronto.ca/~garrison/mkstds.html>>

1. Introduction

The New Mexico Institute of Mining and Technology Department of Physics has as an astrophysics option for its students. One of the required courses for the astrophysics option is a 2 semester "Astronomy Laboratory". This course is designed to give our students access to and experience with optical astronomical instrumentation, data collection, data reduction and analysis.

One of the student assignments was to search the Yale Bright Star Catalogue to find stars that could be observed in March and April with a reasonable exposure time and had as wide a range of spectral type/luminosity class as possible. Each student was given a range major spectral type category and required to obtain at least 5 spectra. They then combined their observations with the rest of the class to make their own MK atlas. The final project was to identify a set of unknown spectra using their atlas. They were generally able to get the spectral type correct to at least a ½ of a major spectral type. The luminosity class was a lot harder to get right.

2. MK Standard Spectral Types

In the natural progression of the course students learn about stellar spectra by obtaining their own set of MK standard spectra [1,2]. The current definition of the MK anchor points have been defined by Garrison [3]. As explained by Garrison [7] the MK anchor points are not necessarily the best examples of spectral and luminosity types but these 50 stars have been used for the last 50 years, so we will continue to use them. Table 1 gives the Yale Bright Star Catalogue [4] numbers for MK anchor points.

MK Anchor Points										
Spectral Type	Luminosity Class									
	Ia	Ib	Iab	II	III	IIIa	IIIb	IIIab	IV	V
O6										
O7										2456
O9										8622
B0										1855
B1	1903									
B2	2135	8279								
B3	2653									5191
B5	2827									
B7										
B8	1713									
A0	1040	3975								4554
A2	7924									
A3										8728
F0		1865			4031					
F2										4931
F3										
F5		1017								
F6										1543
F7										
F8	2693	7796								
G0		8232							5235	4785
G2										Sun
G5										996
G6		8313							6623	
G8		2473				2985		4932	7602	4496
K0					7949		2990			7462
K1									8974	
K2					6299			617		1084
K3				1577	5429					
K5					6705					8085
M0						337				
M1					45					
M2	8316		2061							

Notice that not all spectral type / Luminosity class bins are displayed and that not all bins have an anchor point. This is due mainly to historical reasons that these were the stars first observed and classified. Notice also that none of the peculiar type stars are mentioned as anchor points. Metalic line A stars, narrow line objects and emission line objects to mention a few are not in Table 1.

3. Observatory configuration

The telescope/spectrograph system used by the students is part of the Etscorn Campus Observatory [5,6] and consists of a Celestron C-14 telescope, a SBIG ST-8e CCD, a JMI computer controlled focusing device and an SBIG self-guiding spectrograph. Control of the telescope is done with Software Bisque's THESKY. We use SIBG's CCDOPS for CCD control when taking spectra. The pointing model for our telescope is good enough that we usually get the required star within the 3 ½ arc minute field of view of the slit jaw camera (the auto-guiding CCD in the ST-8e).

4. Data collection

The spectrograph was orientated so that the spectrum was approximately parallel to the long (horizontal) axis of the imaging CCD of the ST-8e. The slit on the other hand was aligned along the vertical axis of the imaging CCD. CCDOPS allows one to bin in the vertical direction to increase the signal to noise ratio. We used a 1x8 binning factor. The resultant image is 1530 samples long by 127 lines high. Spectral images were taken at 1, 10, 30, 60, 120 or 180 seconds depending on the visual magnitude of the star. Dark current images of the same exposure were also taken each night.

5. Data reduction

The data reduction steps were done using procedures written in the programming language, IDL and include subtraction of the correct dark current, rotation of the image so that the stellar spectrum is horizontal and extraction of a 1-D spectrum. The amount rotation was established by determining the slope of the original spectrum. The image was then rotated about the mid-point of the spectrum. The 1-D extracted spectrum was a sum of the counts in each column of the rotated image. The height of the slit was 7 pixels centered on the spectrum. A typical result is shown in figure 1. There are three parts to figure 1. The bottom part is the rotated stellar spectra. It shows the narrowness of the original spectrum. The top part is the extracted 1-D spectrum scaled to fit in the output image. The middle section is an artificially widen spectrum. It is generated by repeating the 1-D spectrum 50 times and displaying the result as an image. The Yale Bright Star Catalogue number and spectral type/luminosity class are added as a title. The widen spectrum is saved as a separate image and can then be combined with others widen spectra to create the student atlas.

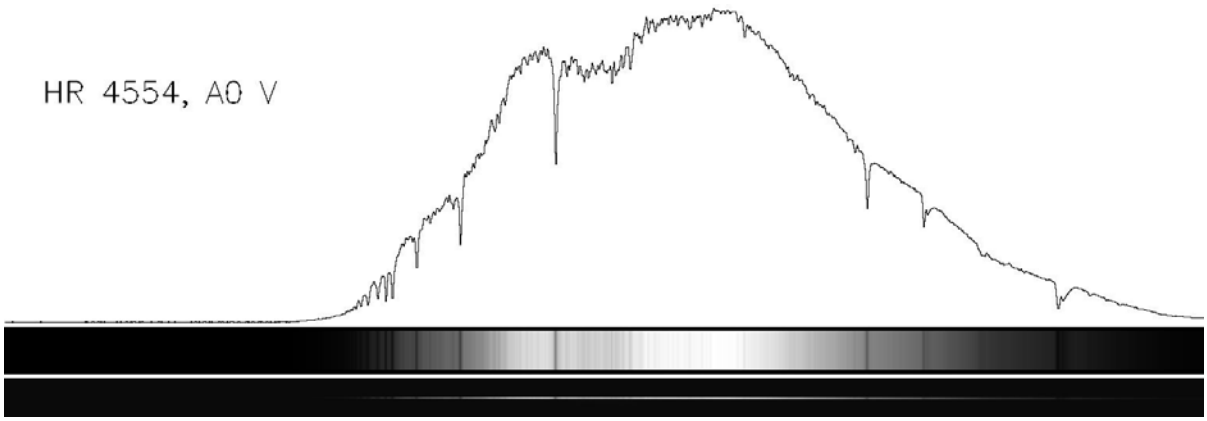

Fig 1. Extracted stellar spectrum

There are three major sources of distortion acting on our spectra: telescope, spectrograph and CCD. Our telescope is a Schmidt Cassegrain and has one glass corrector plate and two coated mirrors. The corrector plate does not transmit very well below about 3500 angstroms. The spectrograph has 4 mirrors and one grating. The mirror coatings do not really affect the spectrum but the grating most certainly does. The efficiency of the transmission of the grating falls off as one goes away from the central wavelength. Finally, the CCD sensitivity is wavelength dependent. In fact, the dip in the spectrum of HR 4554 at around 5000 angstroms shown in figure 1 is due to a decrease in the sensitivity of the Kodak KAF 1602E chip used in the SBIG ST-8E CCD system.

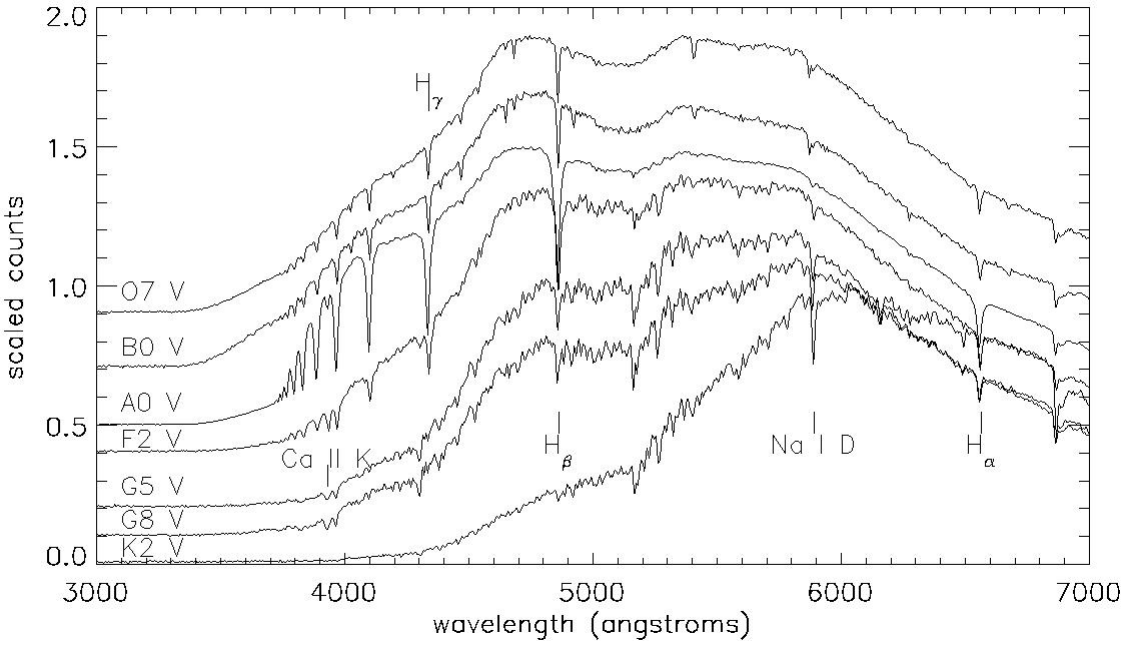

Fig 2. Progression of stellar spectra

Figure 2 shows a series of extracted 1-D spectra of Luminosity class V stars. These spectra have been processed in the manner mentioned above and then normalized to their

peek intensity. The wavelength range displayed is from 3000 to 7000 angstroms even though there is no real signal below about 3800 angstroms. In order to be able to see the effect of changing temperature the individual spectra have been shifted by 0.1 or 0.2 in the vertical scale. The Hydrogen lines Hα, Hβ and Hδ are marked as well as the Fraunhoufer K line of Calcium (Ca II) and the Sodium D line. One can clearly see the effect of surface temperature on the structure of the stellar features.

Figure 3 and 4 are the combined student atlas that we have obtained so far. Figure 3 shows the hotter stars and Figure 4 the cooler stars.

6. Conclusions

With modest equipment it is now possible to obtain detailed spectra of most bright stars. This provides New Mexico TECH's astrophysics students with look at the physics of stellar atmospheres. And it provides them with a hands on experience that will keep them coming back to the telescope to learn and enjoy the sky.

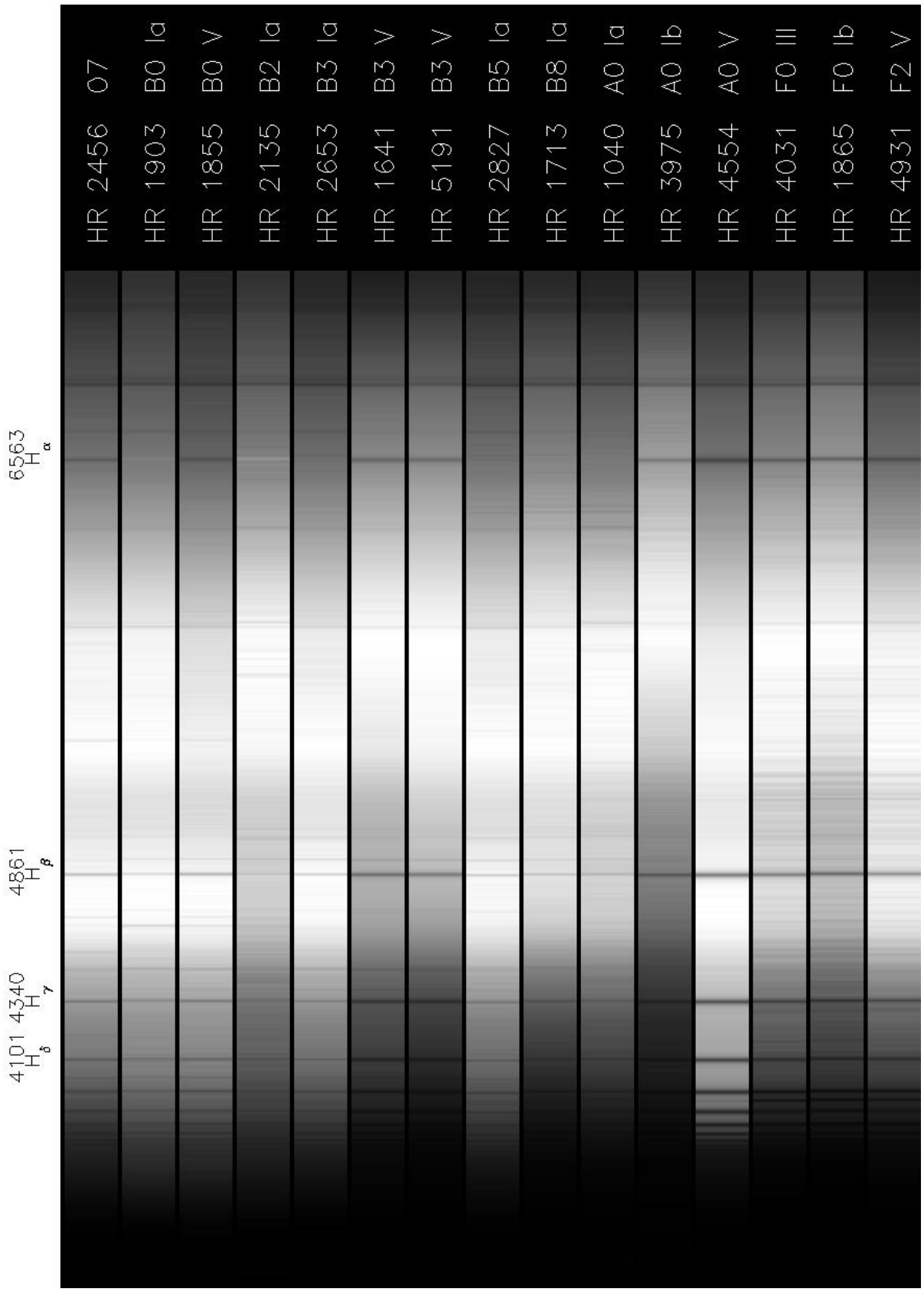

fig. 3 MK anchor points, hot stars

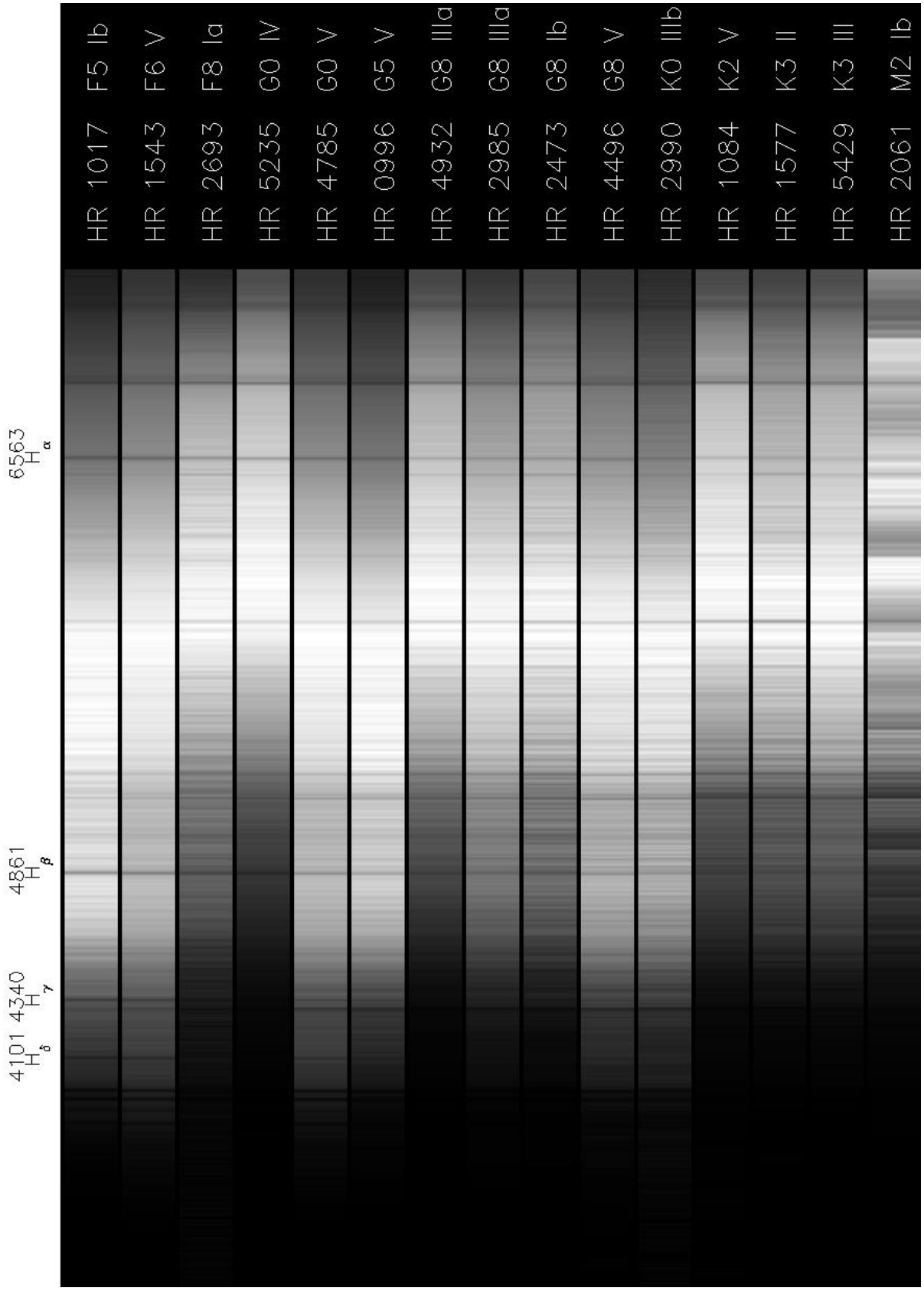

Fig 4. MK anchor points, cool stars

TSCRIPT - A Scripting Application for Automating Time-Series Data Collection

Edward Beshore
Pine Cone Observatory
ebeshore@pointsource.com

Abstract: There are some truly remarkable products to support the work of amateur astronomers interested contributing to professional research. Despite this, few, if any applications are available that directly support the observing methodologies used to obtain time-series data for objects such as cataclysmic variables. This situation forces observers to create additional software to automate key processes, or requires them to periodically intervene in telescope and camera operations throughout the night. TSCRIPT is an ASCOM-compliant scripting language that automates operations common to the collection of time-series data through a simple command vocabulary and easy-to-learn syntax. When used in conjunction with ASCOM-compatible products to control telescopes and CCD cameras, TSCRIPT can manage the cooldown and warmup of cameras; acquisition of calibration frames; the pointing of telescopes based on critera such as time of day or the airmass or altitude of target objects; periodic refocusing and pointing corrections; and the acquisition of filtered or unfiltered CCD frames. Additional features include the automatic flipping of German equatorial mounts after meridian crossing, and slew and horizon limits to restrict the pointing of the telescope.
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References:

1. Center for Backyard Astrophysics website: *http://cba.phys.columbia.edu/*
2. ASCOM Initiative Website: *http://ascom-standards.org/*
3. MaxIm DL/CCD V 3.0 Website: *http://www.cyanogen.com/products/maximdlccd/*
4. Microsoft ActiveX Website: *http://www.microsoft.com/com/tech/activex.asp*
5. DC3-Dreams Software Website*: http://pinpoint.dc3.com/*
6. Software Bisque's Website: *http://www.bisque.com*
7. NOVAS-COM Website: *http://ascom-standards.org/NovasDoc/novas-com.html*
8. GNU Public License Website: *http://www.gnu.org/copyleft/gpl.html.*

1. Collecting Time-Series Data

To those with some experience collecting CCD data, it comes as little surprise that a typical night's sequence of operations is dependent on the observing program. Those searching for supernova usually have a pre-defined list of objects that are visited once or twice a night to see if there is any unusual activity. Asteroid and comet hunters obtain mosaics in areas of the sky likely to produce a discovery. Long period variable observers may only visit stars infrequently to monitor progress. These different methodologies all influence what a night of observing is like.

Obtaining time-series data is no different. Organizations like the Center for Backyard Astrophysics [1] are interested in the light curves of cataclysmic variables on a minute-to-minute basis. Changes in brightness and the morphology of light curves reveal much

about orbital geometry, mass transfer from the secondary to the primary, accretion disk physics, and other important physical characteristics of these fascinating objects. The most effective observing programs take the form of *campaigns*, in which observers from around the world coordinate their efforts to obtain continuous coverage on a star. This helps to eliminate effects which confuse efforts to determine underlying periodicities in the data, and ensures that important changes do not go unobserved.

A night of observing generally consists of extended periods of time observing a single object through the acquisition of many hundreds of CCD frames. The series is often terminated by sunrise, a target's setting behind a natural or artificial object, or more often by high airmasses that compromise data quality. In this type of observing, periodic adjustments in pointing and focus are typically needed. For those with German equatorial mounts, the crossing of the meridian by an object will eventually require that the mount be flipped from one side to another, along with the requisite tuning of pointing and focus. A full night of observing often involves only one or two objects, and during a campaign, this pattern may be repeated every clear night for a month or more. Like other photometric programs, evenings typically begin and end with the acquisition of calibration frames — bias, darks, and flat fields.

Figure 1 shows an outline for a typical night of manual time-series data collection. Such a program can be constructed by spending a half an hour with a planetarium program to understand the relationship between sunrise, sunset, and the rising and setting of a set of targets. Once verified to be suitable, an outline like that shown in Figure 1 can easily work for several weeks before adjustments might need to be made.

```
1.   Wait until sunset
2.   Cool down the camera
3.   Wait until end of evening twilight
4.   Obtain ten bias frames
5.   Obtain ten two-minute dark frames
6.   Wait until GK Per is more than 20 degrees above the
     horizon, then slew
7.   Take 45 sec frames until RXS J1050 is 20 degrees above
     the horizon
8.   Slew to RXS J1050
9.   Take 120 sec frames until morning twilight begins
10.  Park the telescope
11.  Obtain ten two-minute dark frames
12.  Obtain ten bias frames
13.  Warm up the camera
```

Figure 1. A typical sequence of operations in a night of observing to collect time-series data for two stars.

2. Improving the Collection of Time-Series Data

After spending about 50 nights of observing in the late summer and fall of 2001, I became convinced of the need to automate the collection of the data I was obtaining for the CBA. Sitting up all night with the telescope, even in a warm room, was impractical — capturing time-series data was boring, and I had a day job to consider. Rising twice a night for days in a row to flip the mount, check pointing, or to slew to a new object gave me a new appreciation for the consequences of interrupted sleep cycles.

Clearly, the repetitive nature of time-series data collection is well suited to automation. Automation can also help provide better, more consistent results. Likewise a properly designed automation program improves the likelihood of collecting more data,

because the task of readying the telescope can be done anytime during the day, helping to reduce conflicts with other responsibilities and minimizing the total effort needed to prepare for a night's observing.

Upon investigating the status of scripted automation products from several sources, they all seemed to lack one or more important features that would not completely eliminate the need to manually intervene during an observing run. It was clear that some amount of custom programming would be required, and so I resolved to simply create exactly what I wanted rather than to compromise by modifying an existing product.

The situation was not without hope. At the 2000 IAPPP Western Wing conference, Robert Denny spoke of the emerging ASCOM specification [2] for controlling telescopes and cameras. Since then, many products, most notably Diffraction Limited's MaxIm DL/CCD V3.0 [3] has offered excellent access from other programs through its ASCOM-compliant interface that employs Microsoft's ActiveX [4] technology. Along with other software products that offered astrometric solution of images for pointing corrections, control of focusers, and common astronomical calculations, an automation tool optimized for obtaining time-series data was developed.

3. TSCRIPT – A Scripting Language for Obtaining Time-Series Data

TSCRIPT is a scripting engine that accepts command lines with a simple, consistent syntax that can be prepared using any word processor or editor. The core commands for TSCRIPT allow the pointing of a telescope to an object and the repeated acquisition of data until an important condition is met (morning twilight, excessive airmass, or the rising of a more interesting object.)

A mapping from the outline shown in Figure 1 to lines of a TSCRIPT script is shown in Figure 2. As the figure suggests, the meanings of the commands are intuitive and map well to the manual procedures.

One of the most important benefits of TSCRIPT is its independence from the use of absolute time values as factors in its decision making. In the example shown in the figure, camera cooling doesn't begin before sunset, calibration frames are not captured until twilight is over, and object coverage is initiated and terminated by elevation — no absolute time references are required. Avoiding the daily adjustments to scripts to compensate for changes caused by differences in the length of sidereal and solar days, sunrise, sunset, etc. allows scripts to be reused from night to night without maintenance. (For those circumstances where absolute time values are required, TSCRIPT does support them.)

1. Wait until sunset	1. WHILE, TIME < SUNSET LOOP
2. Cool down the camera	2. COOLDOWN, TEMP=-30.0, BACKOFF=1
3. Wait until end of evening twilight	3. WHILE, TIME < EVETWILIGHT LOOP
4. Obtain ten bias frames	4. BIAS, N=10
5. Obtain ten two-minute dark frames	5. DARK, N=10, EXP=120
6. Wait until GK PER is more than 20 degrees above the horizon, then slew to it	6. WHILE, OBJECT=”GK PER”, ALT<20 LOOP SLEWTO, OBJECT=”GK PER”
7. Take 45 sec frames until RXS J1050 is 20 degrees above the horizon	7. WHILE, OBJECT=”RXS J1050”, ALT<20 EXPOSE, EXP=45 LOOP
8. Slew to RXS J1050	8. SLEWTO, OBJECT=”RXS J1050”
9. Take 120 sec frames until morning twilight begins	9. WHILE, TIME < MORNTWILIGHT EXPOSE, EXP=120 LOOP
10. Park the telescope	10. PARK
11. Obtain ten two-minute dark frames	11. DARK, N=10, EXP=120
12. Obtain ten bias frames	12. BIAS, N=10
13. Warm up the camera	13. WARMUP

Figure 2. Sequence from Figure 1 mapped into TSCRIPT commands.

In addition to commands for pointing the telescope and exposing images, TSCRIPT provides a number of additional important functions. These include commands to specify the location of catalog and image files, commands to control file naming, camera cooldown and warmup, a command to initiate flipping of German equatorial mounts after meridian passage, commands to control periodic pointing and focus adjustments, as well as commands to define horizon limits, objects, filters, and FITS keywords. Table 3 lists all of the commands, although readers should refer to the user’s manual for TSCRIPT for a complete description of all commands and their arguments.

Meta Commands

#INCLUDE	Instructs TSCRIPT to insert the contents of a file into the script. Useful for frequently-used command sequences that define the horizon, object names, filter sets, and parameters for the PINPOINT Astrometric Engine [5].
; (COMMENT)	Precedes a comment. Comments may not occupy the same line as a command. Blank lines are ignored.

Figure 3. The TSCRIPT command repertoire.

File Control Commands	
DIRECTORY	Directs TSCRIPT to the disk location for image files, logfiles, star catalogs, etc.
PREFIX	Defines the alphabetic prefix for saved image files.
SEQUENCE	Defines the starting sequence number for image files.
FITSKEY	Defines FITS identifiers and values to be place in all image headers.
Camera Control Commands	
COOLDOWN	Controls cool down of the CCD camera. Allows temperature to backoff if target temperature cannot be reached.
WARMUP	Controls warm up of the CCD camera. Ramps temperature to avoid damage to CCD.
EXPOSE	Exposes a specified number of images for specified number of seconds using a specified filter.
BIAS	Exposes a specified number of bias frames.
DARK	Exposes a specified number of dark frames for a specified number of seconds.
Telescope Control Commands	
SLEWTO	Slew to an object specified by coordinates or object identifier. Pointing adjustment after slew can be optionally applied.
FLIPMOUNT	Controls flipping of German equatorial mounts after meridian crossing.
PARK	Parks the telescope.
Focus and Pointing Control Commands	
POINT	Controls periodic pointing adjustments.
FOCUS	Controls periodic focus adjustments.
PINPOINT	Allows user to set parameters to PINPOINT program.
Device Control Commands	
CONNECT	Establishes connection to telescope and camera.
SHUTDOWN	Terminates connection to all devices.
Miscellaneous Commands	
WHILE/LOOP	Allows commands between the while and the loop to be repeated. While tests can include time of day, sunset or sunrise, evening or morning twilight, object airmass or altitude, or absolute number of times through the loop. WHILE/LOOP command pairs can be nested.
WAIT	Wait for a specified number of seconds.

Figure 3. The TSCRIPT command repertoire (continued).

Miscellaneous Commands (cont.)	
OBJECT	Define the name and coordinates of an object.
FILTER	Define the name and position of a filter in a filter wheel.
SOLARCHECK/LUNARCHECK	Turn solar/lunar avoidance on or off.
PRINT	Print a message to the console
HORIZON	Define horizon azimuth/altitude pairs.

Figure 3. The TSCRIPT command repertoire (continued).

4. A Complete Scripting Example

Figure 4 illustrates a more complete example of a TSCRIPT program. Based on the simple program in Figure 2, this example expands the usage of keywords to include objects from a separate file, set up of periodic focusing and repointing, mount flipping, better programming style, etc.

```
; TSCRIPT program to observe GK Per and RXS J1050
; Last modified 4/3/02 ECB

print, Beginning TSCRIPT sequence....

; include pinpoint setup, object catalog, and horizon file

#include objects.tsf
#include pinpointsetup.tsf
#include pineconehorizon.tsf

; setup locations of files, FITS keywords, and filename prefixes

directory,                              save="d:/observations/test/",
point="d:/observations/test/point"
directory, log="d:/logfiles/", catalog="F:"
fitskey,observer="Ed      Beshore",      telescope="Meade      10",
instrument="Apogee KAF261E"
prefix, point="Point", Focus="Focus"

; start sequence number at 1

sequence, n=1

; flip the mount 30 minutes after meridian crossing
; and point and focus every 30 minutes

flipmount, true, minutes = 30
point, interval = 30
focus, interval = 30
```

Figure 4. A more complete TSCRIPT program.

```
; connect to devices

connect, camera
connect, telescope="ScopeSim.Telescope"

;   wait   until   sunset   and   then   cooldown   the   camera

while,                 time                <                sunset
  loop
cooldown, temp=-30.0, backoff=1

; after twilight is over take darks and biases

while,               time               <               evetwilight
  loop
bias, n=10
dark, n=10, exp=120

; start observing as soon the first object gets out of the muck
; and until RXS J1050 rises

while,             object=”GK             Per”,             alt<20
  loop

slewto, object=”GK Per”
prefix,                         save=”GK                         Per”

while,          object         =”RXS         J1050”,          alt<20
  expose,                                                     exp=45
  loop

; RXS is up and more interesting, let’s go to it
; and observe until twilight, but use B, V, and R filters

slewto, object =”RXS J1050”
prefix,                                              save=”RXSJ1050”

while,               time              <              morntwilight
  expose,          exp=240,          filter          =          “B”
  expose,          exp=120,          filter          =          “V”
  expose,        exp=90        ,        filter        =        “R”
  loop

; park the telescope and warm up the camera and then disconnect

park
warmup
disconnect
```

Figure 4. A more complete TSCRIPT program (continued).

5. User Interface

TSCRIPT provides a very simple user interface that allows the operator to monitor program status. A window provides the most recent commands along with the time they were executed. Operators can pause TSCRIPT operation after completion of the next command. Certain commands (slews and exposures) can also be aborted. Commands can also be skipped and repeated from the console (Figure 5.)

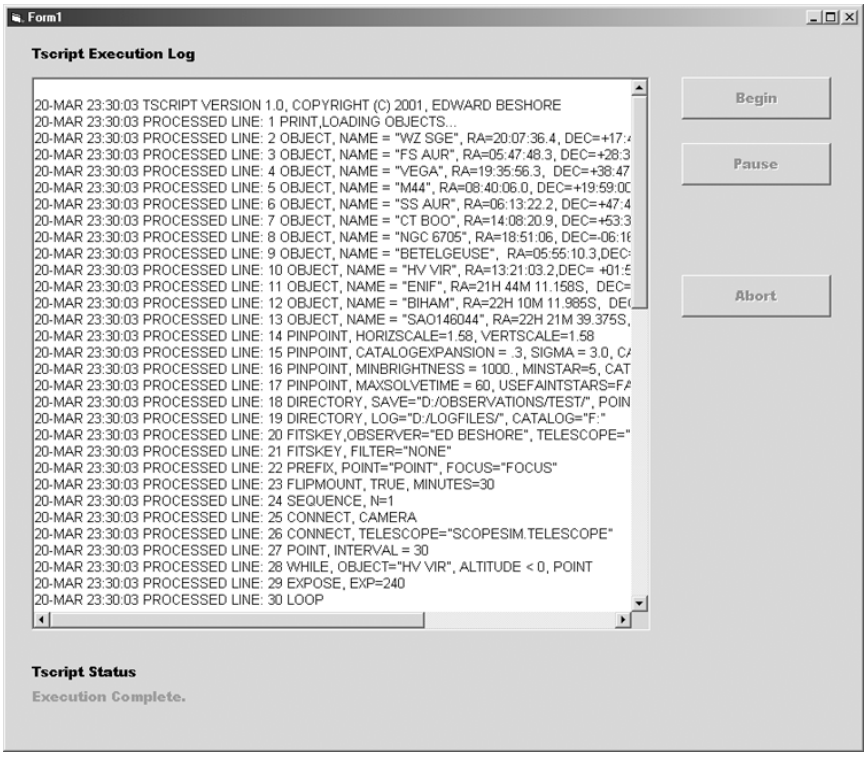

Figure 5. TSCRIPT provides a very simple user interface that allows the operator to monitor status.

6. Cautions

It is absolutely essential that TSCRIPT users understand that observing sequences must be carefully planned in order to avoid unintended results and possible damage to equipment. The most prudent approach is to observe telescope operation for a night to verify correct and safe operation. TSCRIPT is not failsafe, its error-handling capabilities are limited, and so appropriate safeguards should be taken.

Once verified, a script may be workable for several weeks, and then suddenly not properly account for changing conditions (night-to-night advancement of an object to the western horizon, changing sunrise and sunset times, etc.) TSCRIPT scripts require planning and maintenance and an understanding of how they are likely to behave as the calendar advances. A good planetarium program, like Software Bisque's The Sky [6], is an invaluable tool for planning and developing scripts. In addition, there are elements of programming style with TSCRIPT that can help eliminate potential problems. These will be discussed in more detail in the user's manual.

7. Construction Details

TSCRIPT consists of a few thousand lines of Microsoft Visual Basic. Visual Basic was chosen because of its richer interface options than the Windows scripting languages; its better performance should any image analysis algorithms be added in the future; its ability to establish linkages to routines written in "C" or Java; its better data typing and file I/O; more complete support for objects; and the superiority of its development environment. There were few considerations for portability, because TSCRIPT depends heavily on services obtained only through the ActiveX interface, which is unique to the

Windows platform. The code is heavily commented and a complete users manual will be available along with a programmers manual by mid-summer of 2002.

TSCRIPT relies on ActiveX linkages to commercial and publicly-licensed software products through ASCOM-compliant interfaces. TSCRIPT has been tested with Maxim DL/CCD to oversee camera control, and the publicly-available ASCOM driver for the Astrophysics GTO mounts (others are available at the ASCOM Website). No attempt has been made to verify correct operation with any other hardware configurations. TSCRIPT also relies on the NOVAS-COM Vector Astronomy Engine V2.0 [7] package for precessing and transforming coordinates, and the Pinpoint Astrometric Engine [5] to provide astrometric solutions to images for pointing corrections.

Those wishing to make modifications to TSCRIPT will find the code reasonably easy to understand and modify if they are comfortable with Visual Basic and the elementary concepts of working with objects. The relatively straightforward TSCRIPT command syntax is easily extended to support new commands or new arguments to commands. Objects were used to abstract certain elements of TSCRIPT (reading and parsing command lines, for instance) to support the easy extension or replacement of code in future enhancements.

8. Licensing

Amateur astronomy is a common collaborative enterprise of people who love the sky. Today amateurs are able to do things that would be considered amazing only a decade ago. Many of these capabilities are the result of advice and tools that have been unselfishly shared by others. In order to help promote this idea, and to help others achieve their goals a bit faster and a bit easier, TSCRIPT will be available free of charge for use under the terms of the GNU public license [8] which allows unrestricted use, but requires that the source code for all derivative works be made available under the same license. TSCRIPT is provided without any warranty whatsoever.

The intent in making TSCRIPT available under the GNU public license is to encourage enhancements to the program by others who have the ability and perseverance to do so. There will be very limited support beyond that supplied in the form of the comments and manuals included with the program, and those periodic enhancements that may be made to improve performance or eliminate errors.

9. Future Enhancements

TSCRIPT will not be a life-long project with regular releases and feature updates. Nevertheless, there are some enhancements that if time and continued use suggest they might be useful, may be made.

A few of them include:

- Cloud sensing integrated with an audible alarm. This might be most easily accomplished with periodic checks of image data to see if objects disappear.
- Declination limits for long-tube and fork-mounted telescopes.
- Tracking adjustments using one or two bright objects from image frames rather than pointing adjustments through astrometric solutions. This approach might be simpler, and independent of the ability to plate solve an image.
- Integration of guider functions for longer exposures
- An ActiveX interface that exposes selected TSCRIPT commands to other applications. This might be the best way to support 1) more complicated control structures for TSCRIPT rather than coding in direct support; 2) more comprehensive error management; 3) integration with other tools, catalogs, and databases; 4) image analysis and reduction, etc.
- More sophisticated error handling

10. Acknowledgements

I would like to thank Robert Denny for the hard work he has contributed to develop and promote the ASCOM initiative, and all of the vendors who have embraced ASCOM. Your efforts are making some really cool things possible.

Thanks also to all of the professional astronomers who, like Dr. Joe Patterson of the CBA, treat their amateur collaborators as equals. Their coaching and assistance allow us to share in the excitement of discovery. In addition, their recognition of our contributions through co-authorship on published papers is warmly appreciated.

GSC 1839-78, a New W Ursae Majoris Variable

Robert D. Stephens
Santana Observatory
11355 Mount Johnson Court
Rancho Cucamonga, CA 91737
Email: rstephens@foxandstephens.com

Abstract: While doing photometry of an asteroid, GSC 1839-78 was selected as a comparison star. It was checked to make sure it was not a variable, and it showed a large drop in magnitude during the night. Light curves were obtained unfiltered and with V and R filters and indicate that GSC 1839-78 in Taurus is a W Ursae Majoris eclipsing binary, having a .3975833 day period (9.542 hours). Physical parameters by modeling indicate an inclination of 72 degrees and a Mass Ratio of 2.20.
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5. http://simbad.u-strasbg.fr/sim-fid.pl
6. http://www.bisque.com/Products/TheSky/TheSky.asp
7. Binary Maker 2.0, David H. Bradstreet, Department of Physical Science, Eastern College, 10 Fairview Drive, St. Davids, PA 19087

1. Introduction

Santana Observatory [1] is a private observatory operated by the author. It is located in Rancho Cucamonga, California at an elevation of 1,500m. For several years, research has been done on asteroids under light-polluted suburban skies, concentrating on photometry of asteroids. I have participated in several international collaborative projects, been lead investigator on about two dozen photometry projects.

The observatory has a .28m (11-inch) Celestron Schmidt-Cassegrain working at F/8.91. An SBIG ST9 CCD Camera [2] is used. Observations for this paper were unguided for 90 and 120 seconds and were dark-subtracted and flat-fielded. The CCD camera was chilled to –15 degrees Celsius. All times are corrected to heliocentric times measured at the midpoint of the exposure.

Aperture photometry was done using the software program MPO Canopus [3] developed by Brian Warner and including the Fourier analysis routine developed by Alan Harris [4]. This program allows combining data from different observers and adjusting the zero points to compensate for different equipment and comparison stars. The program PhotoRed which transforms filtered observations to the standard system and adjusts for nightly zero points is a companion to MPO Canopus.

2. Observations

On December 18, 2001, I was doing photometry on the asteroid, 1189 Terentia. Determining the rotational period of an asteroid usually requires data from several nights or even weeks. Since an asteroid can move over several degrees it this time frame, comparison stars are selected from the asteroid's immediate field each night. Images of asteroids are often taken unfiltered since their color index falls within known parameters and to boost the signal-to-noise ratio on these 14^{th} to 15^{th} magnitude targets. Combining multiple nights of data requires adjusting the nightly zero points until there is a good fit on the lightcurves generated.

MPO Canopus lets you select up to five comparison stars and creates an average for comparison against the target object. As part of the process of reducing each night's data, the comparison stars are checked to see if they are variable. The current Beta version of MPO Canopus, has a new routine which checks all stars with a common set of CCD frames for changes in brightness. Alternately, a plot of the comparison stars can be generated and visually checked for changes in brightness as compared to the other comparison stars. GSC 1839-78 was one of the comparison stars selected and showed a dramatic change in brightness over the 5.75 hour run. When GSC 1839-78 was measured as the target, it showed about 60 percent of a classic W Ursae Majoris eclipsing binary lightcurve. A check of SIMBAD and VizieR databases [5], operated at CDS, Strasbourg, France did not reveal any previous variability determination.

GSC 1839-78's position is 04h 51m 34.1s, +26d 56m 18s (Epoch 2000). Figure 1 shows a finder chart generated with TheSky software by Software Bisque [6]. Comparison stars used were GSC 1839-434 and GSC 1839-897. Figure 2 shows a typical image taken December 23, 2001.

Despite the fact that my expertise is in working on asteroids, I thought it would be fun to attempt to resolve this variable star. Therefore, after the 1189 Terentia project was completed, another night of unfiltered observations was done of GSC 1839-78 on December 23 in an attempt to generate a complete lightcurve of unfiltered observations. This session did not fill in the missing part of the lightcurve and I decided that, rather that waste time, all future observations would be done with Johnson-Cousins V and R filters. Imaging through filters decreased the signal-to-noise ratio and introduced more scatter in the curve, but more information could be obtained to model the binary system.

In addition to the two nights of unfiltered observations, four more nights of data between January 2 and 21, 2002 was obtained through V and R filters. The entire phased lightcurve was eventually obtained even though some parts are more densely represented than others with data points. Figure 3 shows the phased light curve for both filtered and unfiltered observations.

The scatter in the filtered observations showed curious lumps in the lightcurve that was not present in the unfiltered observations. In particular, there is a flattening in the minimums that is likely caused by scatter due to the reduced signal-to-noise ratio caused when the variable is at its dimmest. The lightcurve from the unfiltered observations shows a smooth transition and is not flattened. The RMS fit on the unfiltered observations was 0.016 magnitude while the RMS fit on the filtered observations was 0.023 magnitude.

3. Analysis

The filtered observations were reduced with the program "PhotoRed" to transform them to the standard system using the All Sky Photometry method. The variation on the V-R measurements throughout the rotation of the system is smaller than the average scatter of the observations and is therefore reported as a constant (V-R) = 0.78. In the Visual band, the system brightens from 14.06 to 13.80 ± 0.02. In the Red band, it brightens from 13.29 to 13.02 ± 0.02.

MPO Canopus has a Fourier analysis routine that can determine the period. That is determined to be 0.3975833 days (9.542 ± 0.004 hours). MPO Canopus also has a feature that computes the time of minimum. The first minimum was determined to be Julian Date 2452276.7866410.

In order to attempt to model the binary system, the filtered data points were converted to a format readable by Binary Maker 2.0, a light curve synthesis program written by David H. Bradstreet [7]. Proper use of the modeling features of Binary Maker 2.0 is well beyond my meager abilities, so I leaned heavily upon the expertise of Leroy Snyder.

The V-R color index of 0.78 suggests a surface temperature of 4783k, which infers that the stars may be of the K2 or K3 type. Eventually, surface temperatures of 4,600 and 4,900 for Star 1 and Star 2 respectively were selected as being the best modeled fit to the observed data. Also, a Mass Ratio of 2.20 and an inclination of 72.0 degrees provide the best fit. Table 1 shows output data from Binary Maker 2.0.

Figures 4 and 5 respectively show the V and the R filtered observations plotted against the model. The modeled lightcurve shows the secondary eclipse is shallower than the primary. Star 1 is being eclipsed during the primary eclipse. Normally this is because Star 1 is hotter than Star 2. However, in this model, Star 1 is cooler, 4600k compared to Star 2's 4900k temperature. The reason the eclipse depth is greater even though Star 1 is cooler, its radius is 0.485841, or 37 percent larger than Star 2 which causes the luminosity to also be 37 percent greater. For this reason the primary is deeper even though Star 1 is 300 K cooler.

The modeled curve does not closely follow the data between phases 0.23 - 0.30. This is either caused by a systematic error in the equipment system or in the airmass effect. Star spots could also cause the deviation. This system is an overcontact eclipsing binary of the W Uma type (EW). The eclipse depths are similar and there is a continuous change between the two eclipses. Figure 6 shows the Binary Maker 2.0 model of the GSC 1839-78 binary system.

4. Tables and Images

Star 1	Star 2
Mass ratio input = 2.200000	Mass ratio < 1 = 0.454545
Omega 1 = 5.216000	Omega 2 = 5.216000
Omega outer = 4.929405	Omega inner = 5.532294
C 1 = 3.732656	C 2 = 3.732656
C inner = 3.930340	C outer = 3.553535
Fillout 2 = 0.524631	Fillout 1 = 0.524631
Lagrangian L1 = 0.580282	Lagrangian L2 = 1.566483
AS = r2(back) = 0.397820	AG = r1(back) = 0.524341
BG = r1(side) = 0.484535	BS = r2(side) = 0.339153
CS = r2(pole) = 0.320418	CG = r1(pole) = 0.448648
DG = r1(point) = 0.580282	DS = r2(point) = 0.419718
Surface area 1 = 2.971580	Surface area 2 = 1.569637
Volume 1 = 0.000000	Volume 2 = 0.000000
Mean density 1 = 0.000000	Mean density 2 = 0.000000
Mean radius 1 = 0.485841	Mean radius 2 = 0.352464
Mean radius 1 (vol) = 0.000000	Mean radius 2 (vol) = 0.000000
Inclination = 72.000	Wavelength = 6000.00
Temperature 1 = 4600.00	Temperature 2 = 4900.00
Luminosity 1 = 0.5785	Luminosity 2 = 0.4215

Table 1. Binary Maker 2.0 Data Output

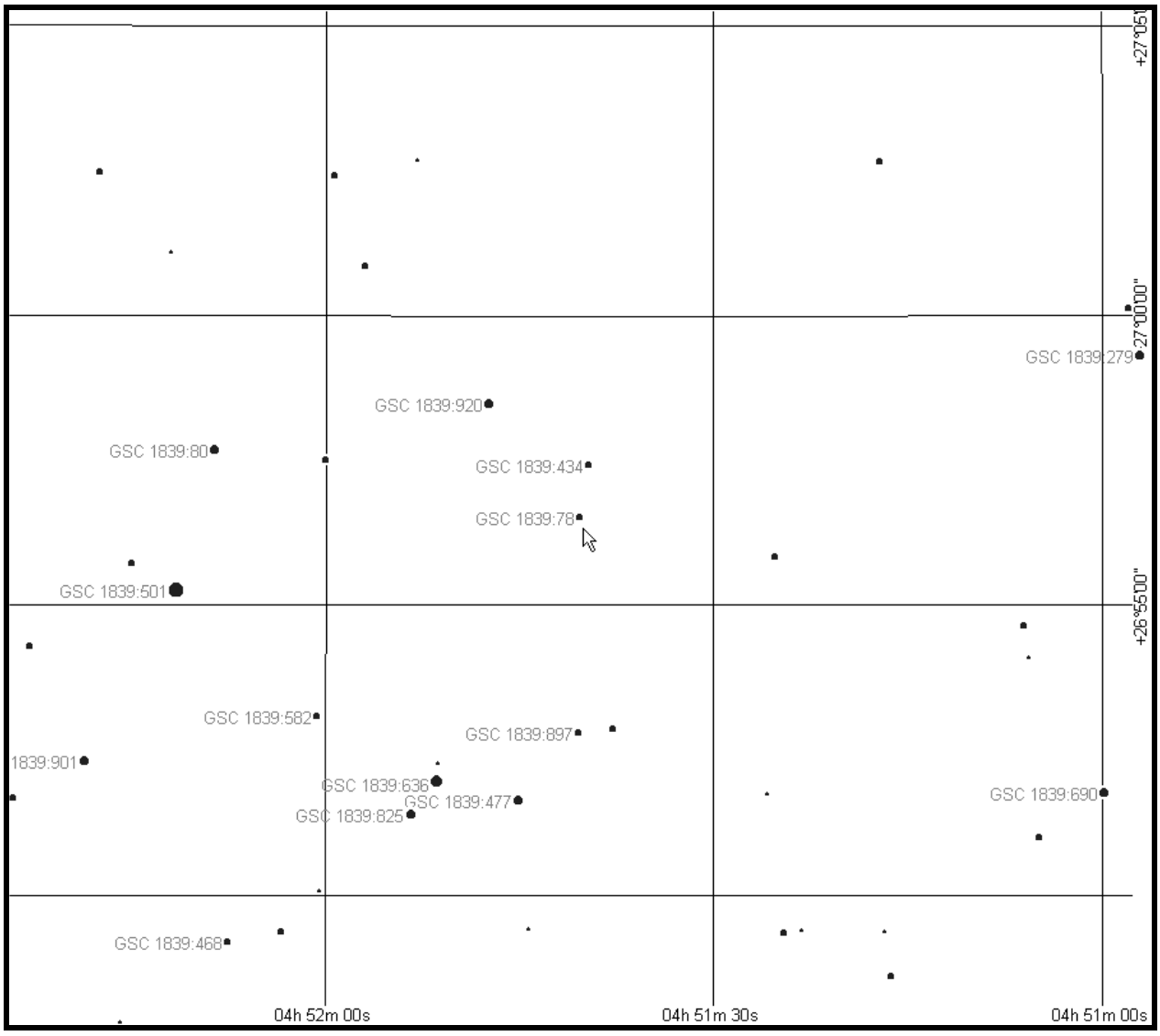


Fig. 1. Finder chart for GSC 1839-78 generated with TheSky Software

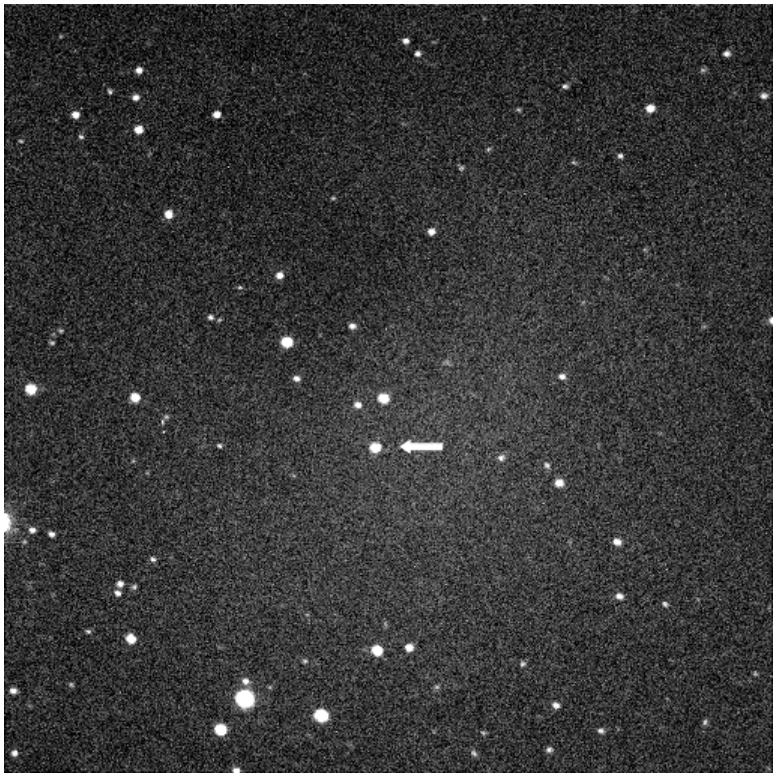


Fig. 2. Image of GSC 1839-78 taken on December 23, 2001

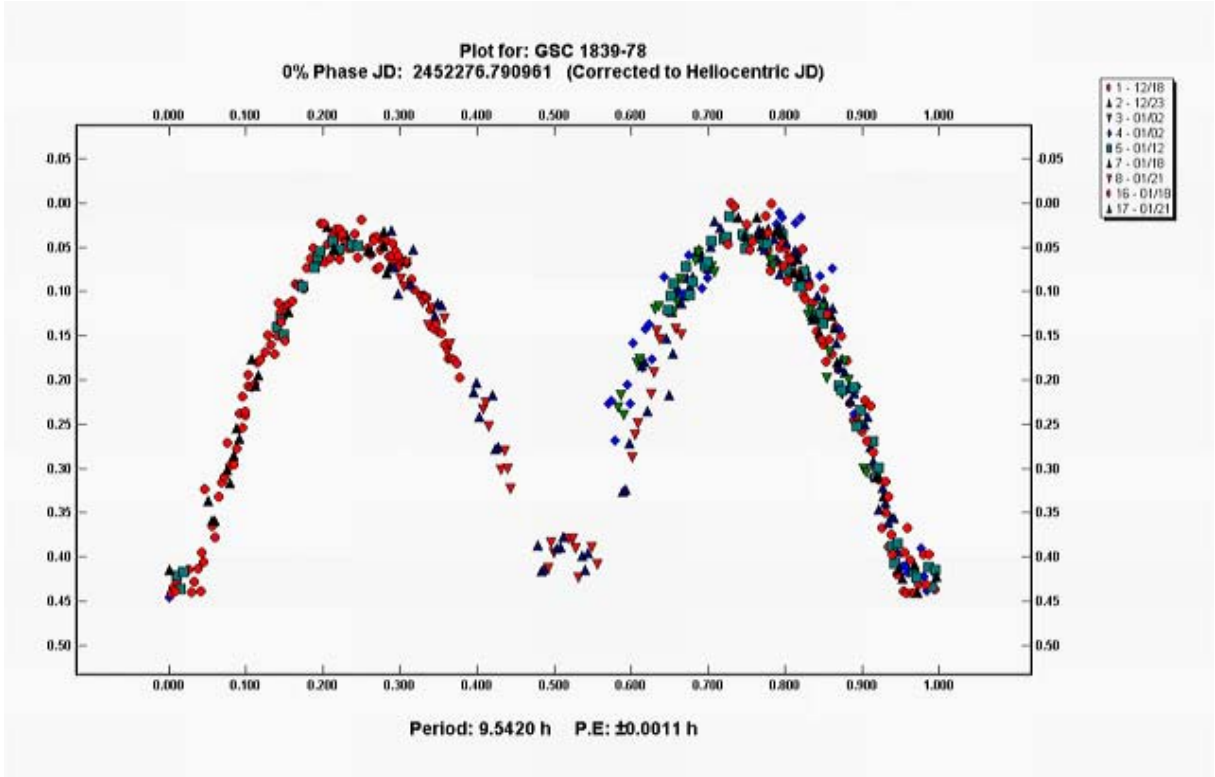


Fig. 3. Phased lightcurve generated by MPO Canopusshowing both filtered and unfiltered observations

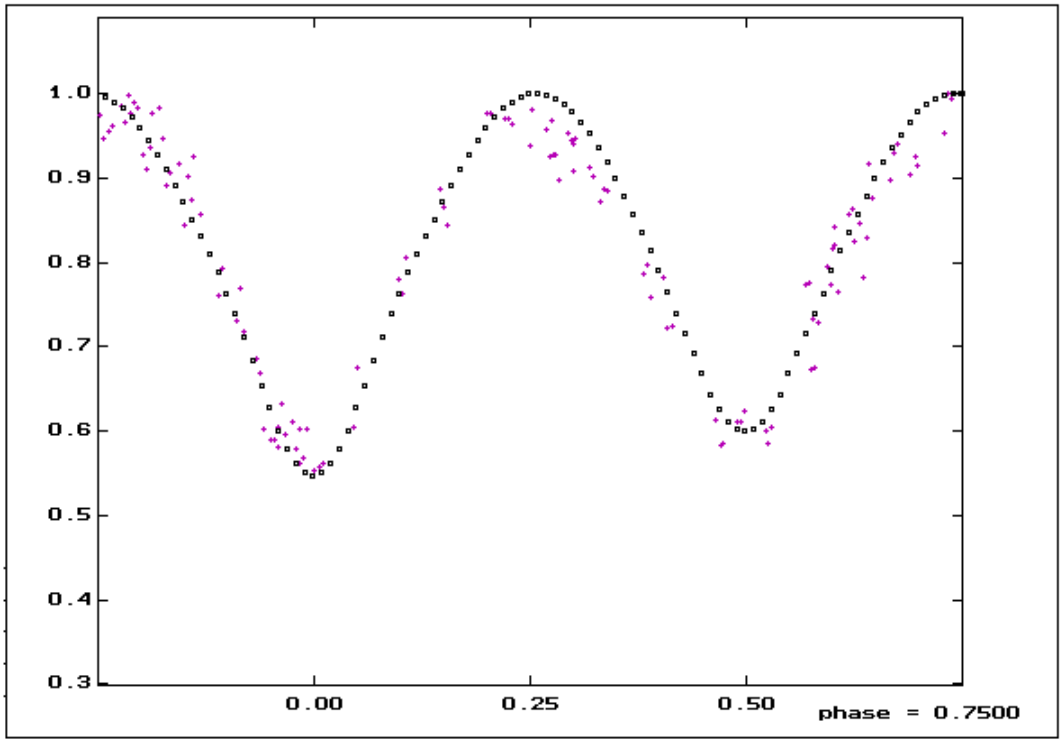


Fig. 4. Binary Maker 2.0 phased actual visual filter observations vs. theoretical model

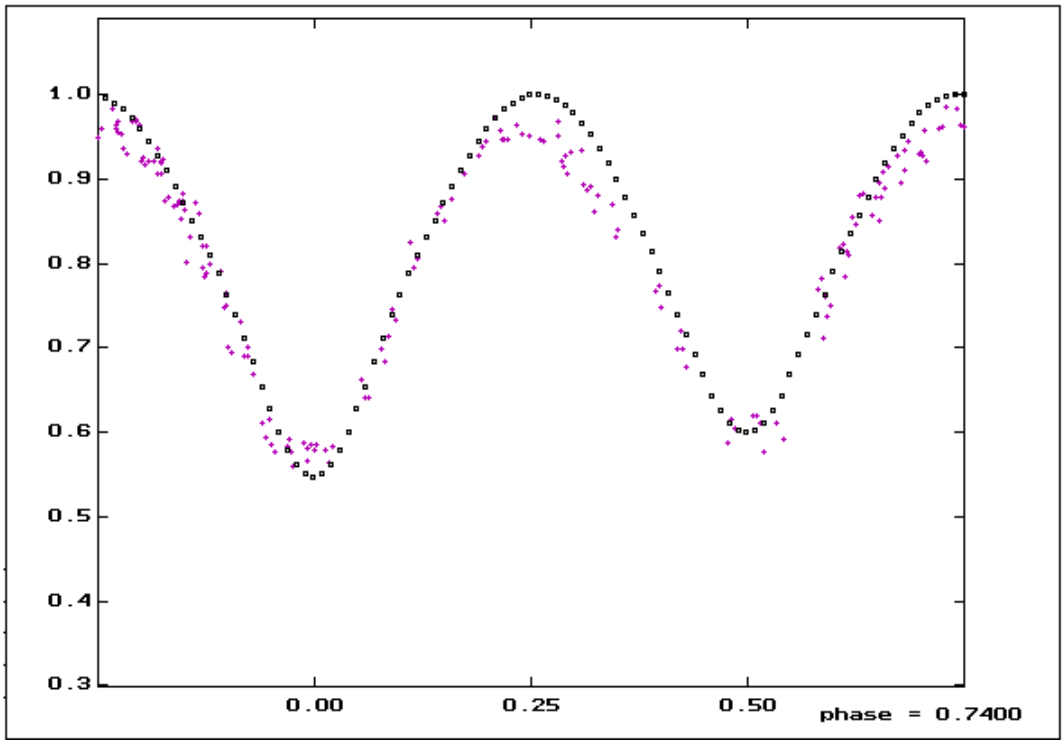


Fig. 5. Binary Maker 2.0 phased actual red filter observations vs. theoretical model

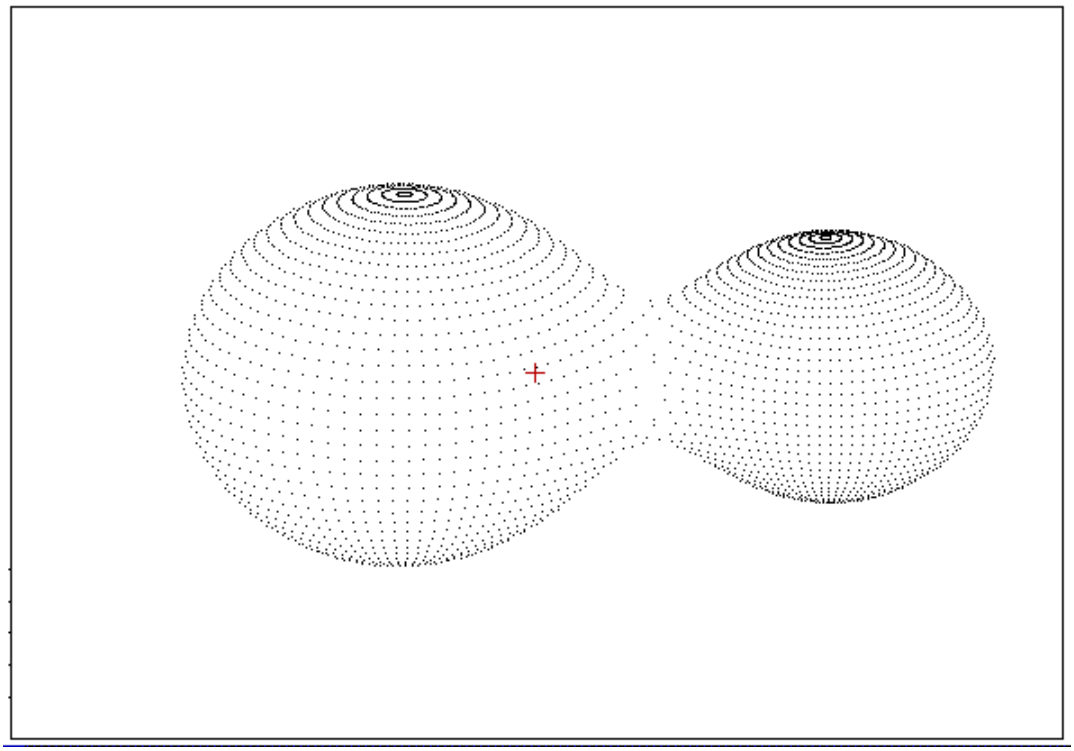


Fig. 6. Binary Maker 2.0 model of GSC 1839-78 binary system

5. Summary

While being used as a comparison star to measuring a passing asteroid, GSC 1839-78 was found to be an overcontact eclipsing binary of the W Uma type. It has a period of .3975833 days period (9.542 hours), an inclination of 72 degrees and a Mass Ratio of 2.20. The two stars are modeled to have a surface temperature of 4600K and 4900K respectively.

Acknowledgements

Some equipment in Santana Observatory was acquired with assistance from grants from the Weingart Foundation, the Riverside Telescope Makers Conference, and Celestron International.

Thanks to Leroy Snyder for his skill, expertise, and infinite patience in getting me started analyzing variable stars.

Much thanks to Brian Warner for his continued support and for providing products to amateur astronomers that assist them in doing science with their telescopes.

A Robotic Observatory for Education and Science

David A. Kenyon
Professor of Astronomy
Sierra College
Rocklin, CA
dkenyon@sierracollege.edu

Abstract

With the advent of advanced motorized telescope mounts coupled with off the shelf planetarium software a reliable robotic observatory can be assembled. The design, development of support components and construction will be covered. Details of equipment selection, software and access will be reviewed as well.

Introduction

One very important aspect of teaching Astronomy is student access to a telescope for observational studies. One of the complexities of an observational program is the time required for students to properly setup and disassemble the observing instruments. The solution is to have easy access to an observatory, and ideally via remote control of the telescope from the classroom.

The design of a robotic, remotely controlled dome style observatory requires a telescope and the following unique elements:

Remote open/close of the dome shutter
Remote azimuth rotation of the dome
Dome control software
A goto telescope mount
Planetarium software to point the mount
Video observation of the dome interior
A CCD camera for data collection
Camera control software
Remote focus control of the telescope
Remote flat field capability for the CCD camera

Observatory Elements

The Sierra College Astronomy Department robotic observatory consists of a ten foot diameter Ash Dome with a wide (48”) shutter (figure 1). The azimuth positioning and shutter are electrically operated.

Figure 1- Ash Dome in place.

To allow for remote operation, off the shelf relay control cards which are interfaced and controlled via a computer serial port were purchased (Electronic Energy Controls, Inc.) and assembled in an enclosure (figure 2). The dome and shutter motors are controlled by commands from a simple executable program developed by the author. This controller also controls illumination of the dome interior for video monitoring and CCD flat fielding.

Figure 2- Control computer and motor control enclosure.

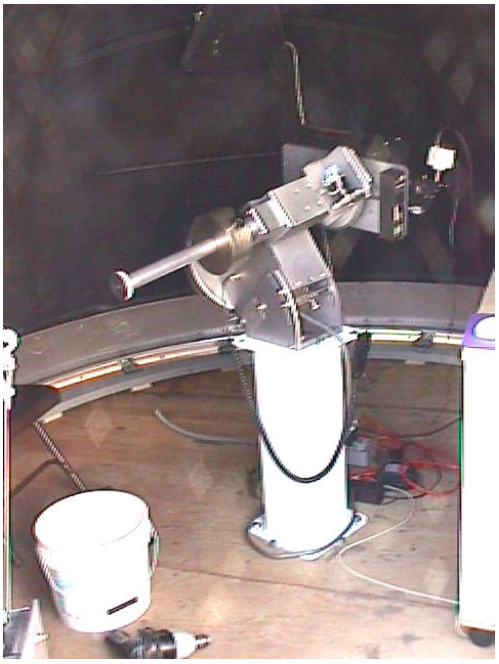


Figure 3- Telescope and mount

The mount selected is a Paramount from Software Bisque shown above which is controlled by TheSky planetarium software. Tpoint modeling software is also used to

improve the pointing accuracy of the mount.TheSky also allows for control of the remote focusing motor as well.

To allow the remote observer to view activity in the dome an astrovideo low light level camera is installed on the telescope to observe the dome position and doubles as a wide field finder scope. The video image is displayed on the computer screen via a video capture card from Pixelsmart.

The primary data collection sensor is a KX-13 CCD camera from Apogee Instruments. This camera has a large sensor array of 1.2K x 1K pixles. This yields a field size of 55 arcminutes in the larger direction with an 8inch f/6.3 optical tube assembly. Camera control is accomplished with MaxIm DL/CCD software from Diffraction Limited.

Flat fielding of the instrument is accomplished by parking the telescope and dome. A sheet of white (¼" x 2'x 2') foam core is mounted inside the dome and is positioned in front of the OTA when both are parked. The relay control card can turn on illumination for the flat field frame collection.

Computer Control

All of the control software (TheSky/Tpoint, Dome/Shutter control and video capture) resides on a computer placed in the control room located 10 feet north (behind) the dome. This computer is used to manage all aspects of the dome and mount pointing, as well as the video capture of the "finder scope". There are serial communications and coax (for video) run between the computer and the equipment in the dome.

The camera control software (MaxIm DL/CCD) runs on a separate computer due to the greater performance and mass storage requirements.

Network Control

Control of the observatory from any computer on the Sierra College campus is accomplished with Virtual Network Control software (VNC) which is available as freeware from ATT. This software allows any computer with a small installed viewer application to log on the dome and camera control computers. The dome and camera computers have VNC server software which allow password protected access. Currently, only the computers in the Astronomy Lab are available for access by faculty and students.

The observatory had "first light" in April, 2002 and is currently undergoing initial testing of the instrumentation. Initial programs include imaging and unfiltered photometry.

Future Plans

The first upgrade for the observatory is to move up to an 11” OTA. This should be accomplished in the early summer of 2002. Instrumentation up grades planned are an eight position filter wheel for tricolor imaging, photometric filter set and a diffraction grating for spectroscopy. Installation of the filter wheel should be completed by late summer 2002 in time for the fall semester. Last, a dedicated building with observing stations are planned for 2003 as invisioned below.

Figure 4- Sierra College NCC campus future observatory

POSTERS

Interferometry with a Meade ETX-125 Telescope

Denis W. Oesch and Dale J. Neimeier
New Mexico Institute of Mining and Technology

Abstract

Small aperture telescopes can be used for more than imaging. We have adapted a commercially available telescope to function in the laboratory as a Michelson Stellar Interferometer. This preliminary work can be extended to provide measurements of astronomical objects. This poster shows the results of the laboratory work and highlights some of the interesting features of interferometric measurements.

History[2]

In 1919 Michelson's dream of determining stellar diameters was realized using the 100-inch Hooker telescope at Mount Wilson Observatory. The telescope was chosen for its size and mechanical stability rather than for its optics. On the telescope was placed a 20 foot beam which held four flat mirrors, two mirrors which moved along the track and two mirrors that directed the light into the telescope.

The outer two mirrors would be positioned to allow for the light from the star to produce an interference pattern at the image plane of the telescope. The visibility is influenced by the spacing of the moveable mirrors. Once a good fringe pattern was established the mirrors were moved apart until the fringes vanished. The distance between the moveable mirrors at that point then translates to the angular size of the object. Using this method, Michelson determined the angular size of Betelgeuse and other stars.

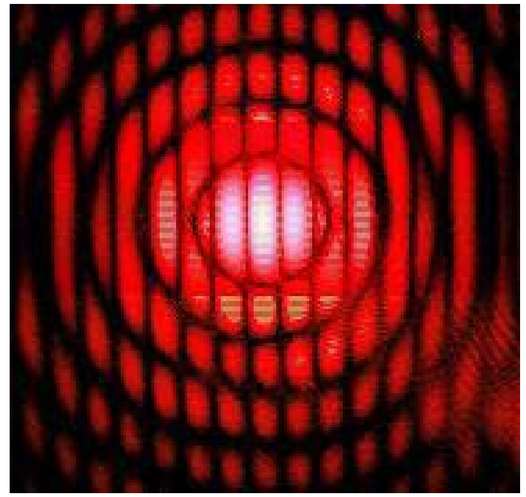


Image of the fringe pattern made from passing the laser through the dual-circular aperture mask

Angular Resolution

The interference pattern generated in this experiment arises from two sources: the Airy disk of each subaperture, and the path-length differences for light entering both subapertures. The path-length difference arises from a tilt in the incoming wavefronts through a slight misalignment of the telescope with the beam.

In measuring the angular extent of a single object, the light from the edges of the object will travel along a path from the origin to each subaperture, thus traversing different pathlengths. To measure the angular extent of the object, the distance between the subapertures must be changed until the visibility of the fringes reduces to zero. The figure below illustrates this idea.

Michelson found that the minimum resolution for the system is directly proportional to the ratio of the wavelength to the separation of the subapertures[2]. Furthermore, Anderson discovered that poor seeing conditions can broaden the fringes observed[3]. For the setup used in the lab experiment to produce fringes, we estimate that objects 30 arcseonds or more in angular extent/separation could be measured (at 632.8 nm).

By moving the subapertures to the extent of the Meade ETX-125 aperture, we could make measurements on the order of 3 arcseconds.

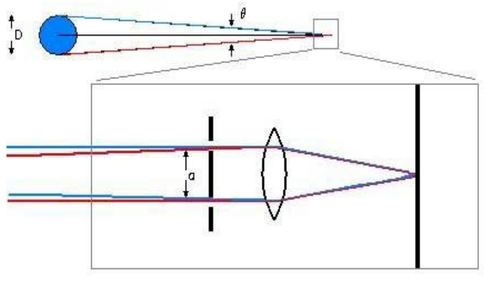
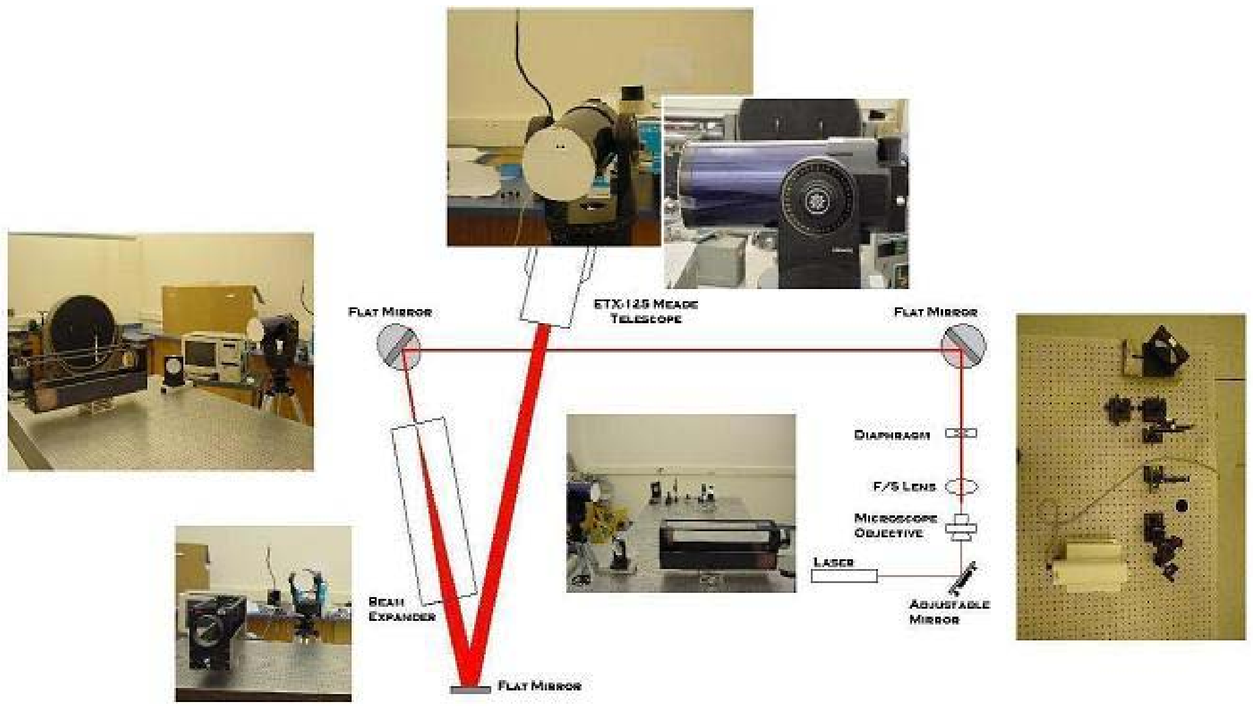


Figure showing the light path traversed from the source to the focal plane in the Michelson Stellar Interferometer[3]



This figure shows the components of the optical bench setup with the actual components shown in the adjacent images

Setup

The above diagram shows the experimental setup accompanied by photos of the actual equipment. Light from a HeNe laser (632.8 nm) is first passed through a 20x microscope objective as an initial beam expander. The light is then collimated using a moveable double-convex f/5 lens. The beam is then sent through an aperture stop to improve image quality. A pair of flat mirrors at 45° angels is used to direct the beam into a beam expander. The light is then passed to a Meade ETX-125 5" Maksutov telescope via a flat mirror. The telescope was fitted with a cardboard mask with two small off-axis subapertures. For this experiment, the subapertures are each .85 cm (cut with a hole-punch) and are 1.5 cm apart.

Using this telescope measure the angular extent or separation of astronomical objects requires a mask with moveavble subapertures. These subapertures should be no closer than 1 diameter apart and should be able to extend to the maximum diameter of the telescope.

Application

Using this Michelson Stellar interferometer for astronomy requires finding an acceptable tradeoff between subaperture diameter and image intensity.

Atmospheric seeing can cause distortion in the fringes as well[1]; however, the current mask has aperture diameters sufficiently small enough that the system will almost always be operating at the diffraction limit.

Finally, a mask with moveable subapertures is necessary to measure the separation between the sources.

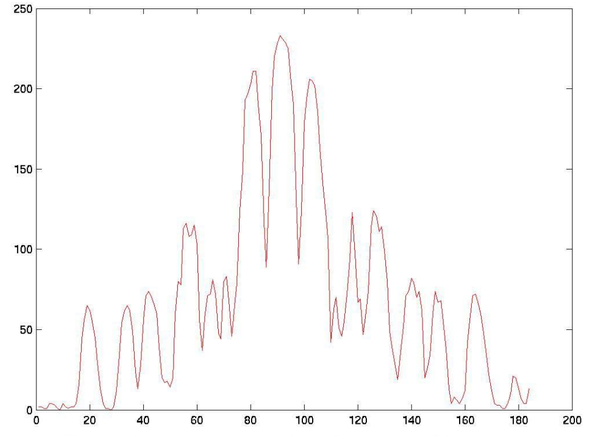


Figure showing cross section of the above fringe pattern.

Acknowledgements

We would like to extend our appreciation to Scott Roberts of Meade Instruments Corporation for providing the Meade ETX-125 telescope and thank Dr. Scott Teare, Dr. David Westpfahl, and Dr. Sergio Restaino for their contributions to this study.

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159