Proceedings of the 22nd IAPPP Western Wing Conference: Symposium on Telescope Science

Scott W. Teare and David A. Kenyon
Editors

© 2003, IAPPP Western Wing, Inc.
All rights reserved.

Published by IAPPP Western Wing, Inc.

First Published May 2003.

ISBN: 0-9714693-2-6

CONTENTS

PREFACE v
CONFERENCE SPONSORS vii

SCIENCE WITH YOUR TELESCOPE 1

CONFESSIONS OF A BEGINNER ASTEROID LIGHT CURVE PHOTOMETRIST
John Menke 3

AUTOMATION TECHNIQUES FOR SCIENTIFIC ASTRONOMY
Robert B. Denny 17

AN ECONOMICAL ASTRONOMICAL DATA ACQUISITION SYSTEM
Roy A. Tucker 29

WNCC OBSERVATORY
LeRoy F. Snyder 35

ALL SPHERICAL CATADOPTRIC GREGORIAN DESIGN FOR METER CLASS TELESCOPES
Peter Ceravolo 39

DISCOVERY OF VARIABLE STARS AS A BYPRODUCT OF ASTEROID LIGHTCURVE STUDIES
Robert Stephens & Robert Koff 45

MIRA VARIABLE STARS: SPECTROSCOPIC AND PHOTOMETRIC MONITORING OF THIS BROAD CLASS OF LONG TERM VARIABLE AND HIGHLY EVOLVED STARS
Dale E. Mais, Robert E. Stencel, & David Richards 55

THE PALMER DIVIDE OBSERVATORY
Brian Warner 65
POSTER PAPER (PAGE 1 OF 12 SHOWN)

PREFACE

This volume contains the Proceedings of the 22nd Conference of the IAPPP Western Wing, Inc., which was held May 21st & 22nd, 2003 at the Northwoods Resort in the City of Big Bear, California. Once again the theme of the meeting is the Symposium on Telescope Science. Much of the work presented here is aimed at using small telescopes to do scientific investigations, the passion of the majority of those attending the conference.

This conference series and its proceedings are the result of the efforts of many individuals. The organization of this conference is in the hands of:

Lee Snyder, Co-Chairperson
Robert Stephens, Co-Chairperson
Robert Gill
Colleen Gino
Dave Kenyon
Dale Mais
Scott Teare

We are particularly fortunate this year to have Dirk Terrell and Arne Henden back with us. Together they presented a workshop on photometry and photometric techniques.

This conference relies heavily on the financial support of several sponsoring organizations. These include: Sky Publishing Corporation (Sky & Telescope), Santa Barbara Instrument Group, Apogee Instruments, Inc and Software Bisque, and Highpoint Scientific.

Lastly we would like to thank the speakers and workshop presenters for their efforts in making this conference a success.

Scott W. Teare, New Mexico Tech, Socorro, NM.
David A. Kenyon, Sierra College, Rocklin, CA.
May, 2003.

CONFERENCE SPONSORS

The conference organizers would like to thank the following organizations for the 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

Highpoint Scientific,
provides more than 25 product lines for amateur telescope users.
http://www.highpointscientific.com/

SCIENCE WITH YOUR TELESCOPE

Confessions of a Beginner Asteroid Light Curve Photometrist

John Menke
John@Menkescientific.com
www.menkescientific.com

Abstract: With an eclipsing binary under my belt, I was now an expert and ready to tackle asteroid light curves--or so I thought. The darn things move! The reference stars are different every night. I have to learn about Landolts and extinction and air mass. But how do I use this new knowledge without taking filtered images, given that filters absorb so much light? Or spending all my time making arcane calculations? And no one ever told me how to mix different night data sets without fudge factors. And my nights are often cloudy, so how do I handle the data to get reliable results? And of course, there was the supernova I discovered (only to find it was an infrared star tricking my camera and me). Join me in a beginner's trials, tribulations, and solutions, as I discuss with examples how I have learned to do asteroid light curves even under lousy Maryland skies.
© 2003, IAPPP Western Wing, Inc.

1. Introduction

Many people seem to be able to learn how to do something by listening to or studying with those who already know—i.e., they are good students. This is certainly the most efficient way to master a new field, and surely leads to the best results. But there are others of us who need to make all the mistakes themselves. I'm one of those people who won't stop to ask directions. This may be inefficient, we tell ourselves, but in the end, having learned it on our own, we now "own" the knowledge. I suspect we are merely kidding ourselves, but anyhow, it IS the way many of us work.

In this report, I will describe the methods I developed for asteroid photometry and some of my results, both good and bad. I will describe some of the many wonderful and unique events (tongue in cheek) I have seen in my data: asteroid moons, super bursters, flare stars, near earth asteroids, and other misinterpretations of common image artifacts.

I emphasize that my purpose is *not* to tout my methods as the best, or even as good as others. It is clear that MPO software, for example, is easier for many people to use than "do it yourself methods" for it automatically provides corrections and analysis that I cannot do or can do only with difficulty.

On the other hand, my experience shows that you can "edge into" photometry with different ways of learning and doing things. If DIY is your thing, consider this kind of approach.

2. Setup

My usual setup for asteroid imaging is a C11 Optical Tube operating at f6.3 (x2 reducer) mounted on an AP1200. I use a color filter wheel with photometric filters and

an ST7E non-ABG camera. The equipment is in a ten foot Pro-Dome located about 400 feet from my house. A computer in the dome remotely operates the equipment, connected via a network cable to my home office.

For most work, I operate the observatory remotely, opening the dome, turning on equipment, starting and calibrating the scope and acquiring the object from my desk. I will monitor the operations as long as I am awake, but most nights allow the setup to run by itself all night. The next day, I transfer the images from dome computer to office computer for analysis.

Incidentally, one benefit of a remote operated system is the ability to take data while on trips. As an example, last fall my wife scheduled us for a play at The Shakespeare Theatre in Washington, 30 miles away. Naturally, the night was clear so I took along my laptop. A half hour before the play began, I stopped at a nearby Kinko's for a phone line to call my home computer. I linked into the dome, went through the whole startup process, began taking data and still arrived before the opening curtain. Pretty cool!

I use TheSky to link to the scope and move it to a known star for calibration (I have a wide angle video camera for rough calibration). I then use it to train the scope on the desired object(s). Of course, once the scope is on the object, TheSky is no longer needed as the scope will stay approximately on that RA/Dec (to within alignment error and refraction).

Because I have a long experience with MaximDL, I use it for all image taking and photometric image analysis (more on this below). My images are usually 60-240 seconds each, taken one after another, producing a sequence of 300 to 400 images. Efficient and fast image analysis is very desirable!

Maxim can do time series graphs directly within the program. While this is very convenient for use during the analysis process, there are major limitations in using this method for final data. Therefore, I export the photometric information from Maxim as a simple text file and import it into Excel for further analysis. I will be describing this process in some detail below.

Why do I use this software and analysis procedure instead of, for example, Brian Warner's MPO software? The answer is not that my package is better: it is not. MPO automatically does many things that my approach can only do manually, or not at all. What I'm seeking is more detailed control of my data and knowing what is happening with it. In addition, I find the planetarium interface of TheSky much easier to use for selecting objects (e.g., standard photometric stars) than standard catalogues, and I find the image manipulation powers of Maxim better suited for monitoring the data taking and the image reduction. I wish I could combine the two! In the long run, I suspect that I will, as they say, migrate to a different platform (i.e., MPO), but meanwhile, I can do productive work with my present software while I evolve the best system for me.

3. Data Taking

3.1 Choosing the Object

There are 20000 or so asteroids. How do you choose one to study? Brian and his collaborators have developed a wonderful website

(http://www.MinorPlanetObserver.com/astlc/default.htm) that periodically posts lists of interesting objects for which light curve data are needed, and that are in the reach of amateur equipment. You can use this site to:

- pick targets that interest you (usually, that means objects that are bright enough for your equipment and have interesting names!)
- download the orbital elements for your choices and bring them into TheSky for plotting (MPO has the elements built in to its catalogue)
- check whether others are working that particular asteroid and "reserve" it for your own work.

3.2 Planning your timetable

How long does it take to do a light curve? Well, it depends!

- If the object is bright enough,
- If it is winter so you have say 8-9 hours of darkness,
- If the object is well placed (high Dec) to be well above the horizon for a long time,
- If its variation amplitude is large enough to see easily (e.g., >0.3mag),
- And if its rotation period is fast (e.g., 6 hours)…

Then you can do it in one night! And then do 2-3 more nights to verify what you got and to improve the period measurement.

On the other hand, a slow, low amplitude period, particularly one that is close to a multiple or sub-multiple of 24 hours, may require many, many nights of data taking. A recent one I worked on (in collaboration with five other people) had a period of 72 hours. A month of data from folks scattered around the world still did not produce a complete curve, though enough for a good period measurement.

Of course, cloudy nights don't help. Nor does summertime, with its short observing nights. Then there are equipment problems, or social commitments and work-related travel that take you away from the observatory, etc. My advice is to assume a schedule that seems long enough, then add to accommodate the unexpected.

3.3 Tracking

Once you have selected the object, how do you track it for the many hours of data taking? I am lucky: the AP1200 mount has only about 3 a-sec peak-to-peak periodic error. My mount is aligned to within about 2-4 a-min (varies with season). With a field of view of about 7x10 a-min, I can usually run just about all night without active tracking.

A significant issue is that you would like to keep the same set of comparison stars, along with the moving asteroid, in the FOV for the whole night. The asteroid will likely move about 5 a-min during 8 hours. Thus, as you build experience with the system, and see how the field shifts in your scope during the night, you can plan to start with the asteroid and comparison stars in the best part of the FOV.

But what if your scope and alignment are not good enough for this kind of operation? One option is to re-center the asteroid/stars either manually or via a script during the run (both MPO and ASCOM scripting support the latter). However, this requires either that you be awake, or that you or the software make no error when re-

centering. Alternatively, you might consider active tracking (e.g., using the ST7 tracking chip).

With either re-centering approach, you want a method that will not lose the star if there are clouds present. I have many nights in Maryland when clouds pass through for hours at a time, but with clear periods in between. The purists will say that you have to have a "photometric night" for good data. Well, I decided not to want to wait for one of those in Maryland! Instead (and this is part of why I use Maxim and Excel), I build cloud checking into all my data analysis.

To give a feel for this, I have seen up to 2-3 magnitudes of extinction from clouds, but where I could detect no resulting error in the photometry (other than poorer statistics). I have seen 10-hour nights in which three major sets of clouds passed through, but the clear times produced good data. I wouldn't want to lose these because scripting failed!

Because the AP1200 is a German Equatorial mount, I may need to flip the scope during a night of imaging. Depending on the location of the object in the sky (especially its Dec), the mount may well be able to track several hours past the meridian without hitting the pier. In practice, my desire for sleep determines when I flip the scope. I may flip it early in the evening then let it go the rest of the night. Or I may get up at 2 a.m. to flip it remotely, a five minute job, including verifying the operation. Eventually, I will write a script for this task.

3.4 Shutting down the system

Without scripting, how do I turn things off in the morning? Running the scope into the pier will not really hurt anything except my pride and the calibration of the scope when the clutch slips. For quite a while, I would get up for a couple of minutes at dawn to park the scope using TheSky. The dome would already have closed, as I had set the timer in the dome control program (DCP). Recently, I began using another feature of the DCP that stops the scope tracking when the dome closes. Now I sleep through the dawn and later in the morning remotely restart the scope, park it and shut things down.

3.5 Image Calibration and Quality

How about binning? Because hard drive space is cheap and a 12-second once per minute download penalty is not too great, I choose to take all images unbinned. The benefit is that I have the maximum information available to judge or adjust image quality and to analyze asteroids when close to stars.

How about focus changes during the night? The C11 (in common with most S-Cs) has a big temperature coefficient. During a 20F degree temperature drop, I might see a star image go from 3-4 a-sec to 6-8 a-sec. The good news is that in photometric work, image size is not a big problem. Because I know the temperature changes that are likely, before I go to bed, I deliberately set the focus to what I think will be a good compromise. Why don't I use automatic temperature compensation (after all, we invented RoboFocus)? Well, I could, but I try to keep my system operation as simple as possible. Every opportunity for a mistake can cause another night of data to be lost!

How about darks? Relatively short exposures don't produce a lot of dark current. In practice, I usually take a single dark and use it all night in automatic subtraction mode.

And how about flats? My own system has less than 1% vignetting and dust effects. Because it is very difficult to guarantee that one's flat calibration will not introduce at least this much error, I usually do not do flats for my data. If your camera/scope combination has worse characteristics, you must do flats (failing to do so will introduce offsets and systematic errors in your data).

How about photometric filters and standard stars? Here is where photometry can get tricky. With amateur equipment, we normally can't afford to sacrifice light to filters.

However, let's consider what we are doing. We are using the camera wide open, and will compare the brightness of the asteroid to one or more comparison stars in the same FOV. As these objects rise, transit, and set, the atmosphere will introduce extinction (about 0.5 mag) which affect both the asteroid and the star, which is no problem. But it will also introduce a different extinction for different colors (0.1-0.2 mag). Thus, if the asteroid and any comparison stars are of different colors, you will have a built-in variance in your measurement that is very difficult to remove, especially if you are pushing your data-taking into the near horizon areas. Furthermore, there will be an additional offset because tonight's comparison stars will be different colors from tomorrow night's.

My method for handling this is to take an image of a standard known star every hour or so and use it to calibrate the comparison stars. To do this easily, I loaded the Landolt catalogue into TheSky so I can pick the best grouping of Landolt stars near to my asteroid. I swing the scope over, take my standard star images, then return to the asteroid. I can use the same Landolt stars for calibration for many nights (the asteroid is moving slowly). Thus I can use this data to cross-calibrate on successive nights of data, in essence, always referring the asteroid to the same reference star.

4. Image Analysis

Before we get into analyzing the images, let's take a moment to explore what it is we will be measuring. A night's work produces hundreds of images of the asteroid surrounded by stars. We cannot simply measure the asteroid brightness, because clouds or other factors can change the apparent brightness. Therefore, we measure the asteroid brightness *and* that of one or more comparison (reference) stars. We assume most factors change the apparent brightness of all the objects in our image to the same degree. Thus, we can just measure the *difference* in brightness between the asteroid and a reference star on the image (we usually use more than one to get better accuracy, and to detect a possible variable star).

By using this comparison measurement, we can plot changes in the asteroid brightness through the night relative to a constant star.

But what happens the next night, when the asteroid has moved and there is a different reference star(s), maybe even of different colors that register differently in our camera? The comparison measurement can change when the reference star changes. The asteroid brightness will now have an "offset" from one night to the next. A manual adjustment to accommodate this offset can introduce bias in the final calculations. Part

of the effort I have made has been to develop an easy way to reduce the need for this manual adjustment.

Now, on to the actual image processing.

4.1 Sorting the images into groups.

Every morning after a night of imaging, I have 350 or more new images. After moving the images to my office computer, I usually take a quick look by loading every 15th or so image. I "blink" through this set to see the general quality of the data, weather conditions through the night, determine the dawn cutoff (or when refraction started moving the images over the FOV too fast).

I decide which ranges of images are not usable (for example, the last 50 images of the night due to heavy clouds.)

I then load the first 100 images of those remaining (takes about 15 sec as these are unbinned) and blink through them to check for artifacts or problems. The reason for selecting 100 at a time is that Maxim analyzes by loading all the images into memory. If memory is too small, your first images will load fast into RAM, then the hard drive starts to handle them and speed slows down. I use 512MB of RAM to handle 100 unbinned images at a time.

Maxim photometry analysis requires designation of a reference star, and all measurements are made relative to that star. However, this means that you lose the absolute brightness data so information about clouds or other effects is lost, and you cannot play with different or combined reference stars. To meet this need, Maxim offers a free plugin that inserts a Gaussian Digital Reference Star (DRS) in the upper left of each image that can be used as the reference. I run this plug-in, which takes about half a minute. I can then invoke the photometry routine. When I have the photometry window, I designate the DRS as the reference, then select the asteroid and all my comparison stars.

After the routine has run, I check the photometry graph to verify that the process has not become mixed up and lost a star. Or perhaps some images are so bad that they should be rejected. Or the asteroid came too close to a star. Maxim allows you very quickly to select any point on the graph to review an image, thus allowing you to keep it or reject it.

This whole data vetting process usually takes only a few minutes. I can then export the brightness data of the asteroid and comparison stars into a text file for later analysis (each image has its Julian Date time of exposure, and the measured brightnesses in magnitudes relative to the DRS). Before closing the photometry window and going on to the next 100 images, I take a screen shot (Alt-PrintScrn then print with MSPaint) so that I have a record of which stars had which designations. This is essential for later data cross checks.

4.2 Data Analysis

My review of 300 images for the previous night produces three text files, each with 100 measurements for asteroid and star brightnesses. Using WordPad, I copy and paste these into an Excel spread sheet. I graph the brightness of all the relevant objects in the data set which shows the presence of clouds or other data problems. I may eliminate data points at this time (normally only if I have checked back on the images).

If the data look OK, the spreadsheet computes the hundred values of asteroid brightness minus brightness of the best comparison star (or combination of stars). This gives me the raw asteroid photometric curve, which I then plot. If the curve shows funny bumps and wiggles, I go back to the images to look for stars too close to the asteroid or other artifacts. I may even find the need to re-measure a set of images.

If I have taken images of standard (Landolt) stars, I now analyze those. I take four images: a clear and V-filter image of the asteroid field and the standard star field. Because there are only a few, I measure the star images manually using Maxim. I then enter these data in the spreadsheet, which computes the night's offset and computes the corrected asteroid curve. I have details of this procedure, and the spreadsheet formulae, on my web site.

I keep each night of data in a separate worksheet in the Excel workbook. After several nights of data, I copy the light curve from each night onto a master worksheet for that asteroid. I can plot the data sequentially, but for a period analysis I display it using manually set folding periods. To do this, I examine the data from a representative night. In most cases, I can quickly estimate a period that fits the data. It will, of course, be a very rough estimate, but it will be good enough for a starting point. I enter this estimate into the master spreadsheet. The spreadsheet then uses this value to compute the relative phase of the asteroid curve associated with the date/time for each of the hundreds of brightness measurements. The spreadsheet then plots the magnitudes vs. phase for all the data sets. If you have data covering a number of asteroid rotations, and if you have chosen the correct rotation period, then the peaks and valleys will superimpose. If you have the wrong period, the peaks and valleys will not line up. In that case, just enter a different period, and try again. You can quickly adjust the period for the best fit, and you can try small changes from that period to estimate how accurate your measurement is. You can also try grossly different periods such as ½ or twice the initial period to help guard against error. As your number of data sets increases, you can refine the period measurement.

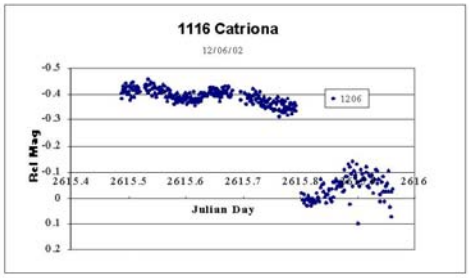
5. Results for my first four asteroids

I began doing asteroid curves in December 2002. The good news is that I got good and quick results. I began learning not only the practical problems, but also the details of what is going on. Over the next few months, I developed the whole technique I have described here. I made mistakes, sometimes (tentatively) misinterpreting what I saw (usually with substantial excitement). I learned about the terrific support and encouragement that folks like Brian provide. I have had a lot of fun. And I have been contributing to basic astronomy research!

Here are some of the results and some of the interesting things that happened along the way.

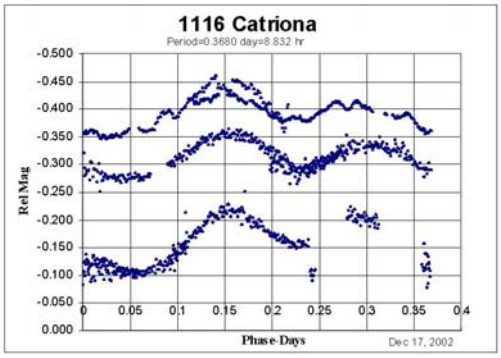
My First asteroid was 1116 Catriona. Around 13 magnitude, I judged it should be no problem, and with an unusually high Dec of +37deg, it would be high in the sky for a long time. I did a GOTO in TheSky, and took my first image. Yup, lots of stars: which one is the asteroid? The bright one in the middle of the field? After a series of images in about ten minutes, the movement was obvious — I was right on. Actually, in this step, asteroids are easier to identify for study than a variable star that does *not* move!

I set up Maxim to take a sequence. Within a few hours, it was obvious that the magnitude was changing relative to neighboring stars, so I let it run all night (midwinter, so with good weather, I can get 10-11 hours of data if the object is well placed). The next morning, low and behold, there was my curve! About 6.5 hours half period, but not much variation (only about 0.04 mag). However, it is a pretty bright asteroid so the statistics were good and the curve was clear. I did some thinking about why a double hump is the most common rotation period.



I noted a big offset in the data but knew the cause — I had flipped the scope, then used a different reference star for the rest of the night. Obviously, this is something to avoid! The scattered data toward the end of the run was also easy to understand. The asteroid was getting lower, there were some clouds present (I could see this by looking at the raw brightness data of asteroid and stars), and dawn was coming. Analysis showed that the average readings were not badly biased, so they were certainly usable.

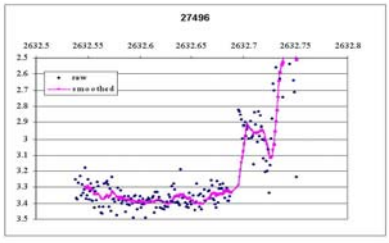
I also noticed a gentle downward then upward trend in the data—hmmm, I guess this is differential extinction from the color of the reference star. No problem, as I'm interested primarily in the period so I'll take more data over the next few nights to improve the precision.



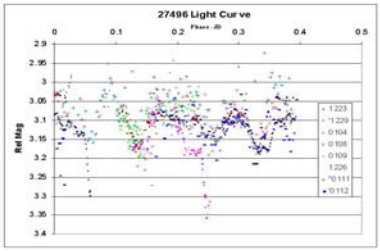
In fact, I took several nights of data. Overlapping the curves with a 0.3680day period produced the best fit. When I chose periods different from this, the curves would slide sideways, out of sync with one another.

Note the different vertical positions of the data. These offsets are the result of a variety of causes. The largest are various errors resulting from using different reference stars on each night, mostly because I had not yet learned how to use the same standard star for the whole series of data. I realized that I could manually make the curves overlap so they look better, but this degree of arbitrariness bothered the physicist in me.

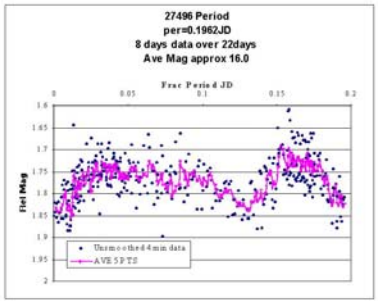
I was ready for my next asteroid. Now that I was "experienced and knew all the answers", I decided to pick a tougher one from the CALL list. Asteroid 27496 (no name) has a predicted mag.15. The first night of data showed obvious fairly fast variations, indicating a period in the range of a few hours, so this should be pretty easy thought I.



Unfortunately, I began to learn one of the strongest lessons of asteroid light curves, that "pride goeth before a fall". Many nights of data later, I had no very clear result. The data were noisy (the result of low brightness) and the variation was small (only 0.1 mag or so). I could talk myself into a variety of periods. I swallowed my



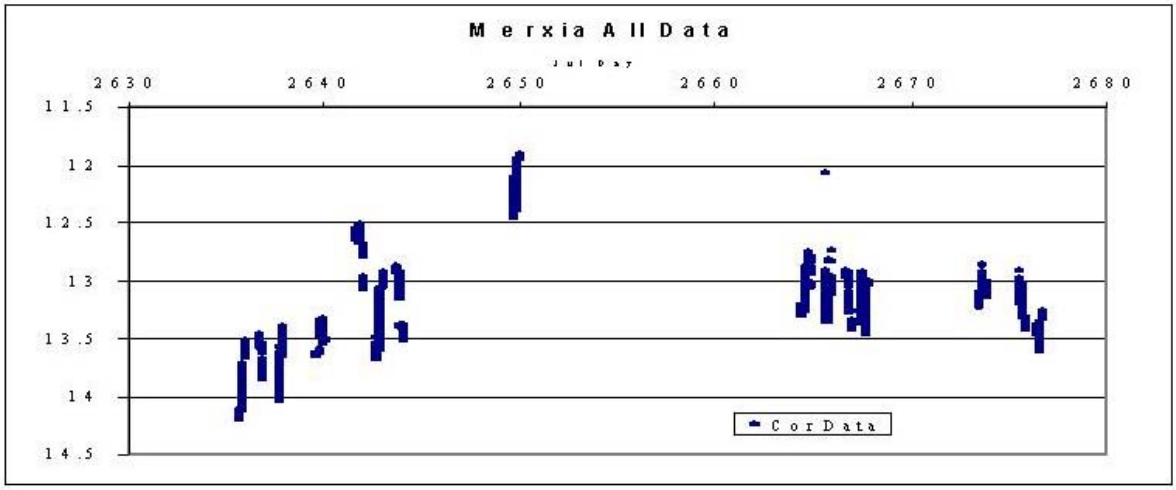
physicist's pride and applied adjustments in the data sets to make the data connect (the curves overlap).



After much more data taking, I had the second graph, and with much data smoothing, the third graph. The curve seems unreasonably asymmetric and the data are still very noisy. The result is a very doubtful assignment of period and amplitude (although the data clearly show that something is going on!).

Meanwhile, I had started on a third asteroid, 808 Merxia (cool name!) Ah, this was better. Merxia began showing an amplitude of about 0.6 mag. It had a longer period (which proved to be 1.276 day), but it changed enough during a night's run so that I had a good sense of what was going on. However, given my experience with 27496, I was beginning to be fussy about adjusting brightness values (i.e., countering the offsets from different reference stars) to make nightly curves line up.

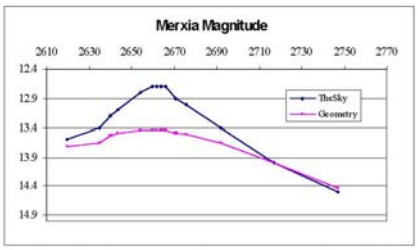
This is when I decided to use a standard star so that I could actually measure the offset each night (i.e., cross calibrate). I now had a more accurate justification to make the final curves line up without fudging. This worked well, and I was very proud, except that the darn curves for Merxia still would not line up. This graph shows a continuous plot of the Merxia data (includes data from Robert Koff, discussed below).



I did some more playing with the first few days of data, and discovered that if I added a harmonic of 3/2 the base period to the basic sinusoidal light curve, then all the night to night variations were explained! Cool — a new discovery! But the more I looked at it, and the more data I took, the weirder (and lower probability this got). So I began stopping at gas stations (i.e., I wrote to Brian Warner). Lo and behold, there are additional factors I had not considered, primarily relating to the changing geometry of the earth-sun-asteroid:

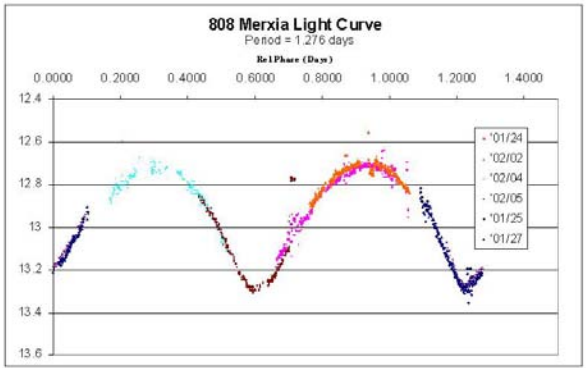
- Distance. Distance changes brightness during the measurement period (quick calculations showed these not to be a big factor)
- Phase. Phase change of the asteroid (again, only a very minor factor)

- Anomalous Brightening. Huh, Brian, what are you talking about? Back to Google and thinking. It turns out that most asteroids brighten more than simple geometry predicts when they are within a few degrees of opposition (similar to the excessively bright full moon). TheSky does include this in its magnitude calculations, so I plotted the predicted brightness vs. my measurements and voila' – the offsets were explained!

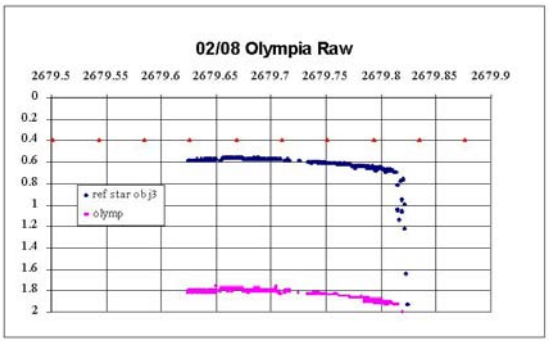


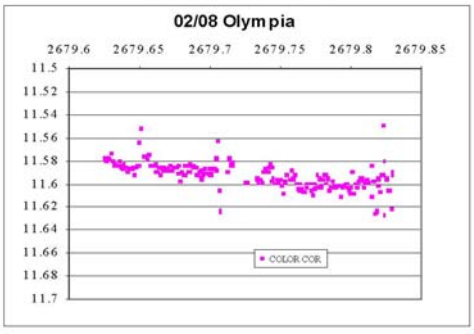
So now I could apply adjustments and make the Merxia curves overlay as shown and the result has high confidence. But my original goal not to use ad hoc adjustments to correct night to night is now getting farther away: To properly compute these factors requires that the program have all the orbital information, which is awkward in this Excel approach. But I still like the feel of the data I get this way, so onward I go.

During this period, I learned from Brian Warner that Robert Koff had previously "reserved" Merxia for study. As I had missed seeing this, I immediately contacted him. Via email, we negotiated that he would take the lead in publishing the results and that he would merge our data to improve the end result. He has submitted this work to MPB for publication. So now I have learned to be more courteous in my planning!



I am ready for #4. This time I picked 582 Olympia (no one had reserved this one!) Pretty bright, I should be able to nail this one using my new standard star approach. After all, I now *surely* know what I am doing. I began taking data. Hmm, not much variation, and what there was seemed to have a several day period. If the night-to-night offset adjustments are not done perfectly accurately, then how do you combine slowly changing data without introducing bias from your adjustments? The graph at the lower left shows the raw reference star and Olympia brightness through the night (see the extinction as they set?). The lower right shows the result of taking the difference, and then applying the color calibration process. Note the scale is rather small, and the curvature of the data is tiny. It's hard to guess the period at this point.



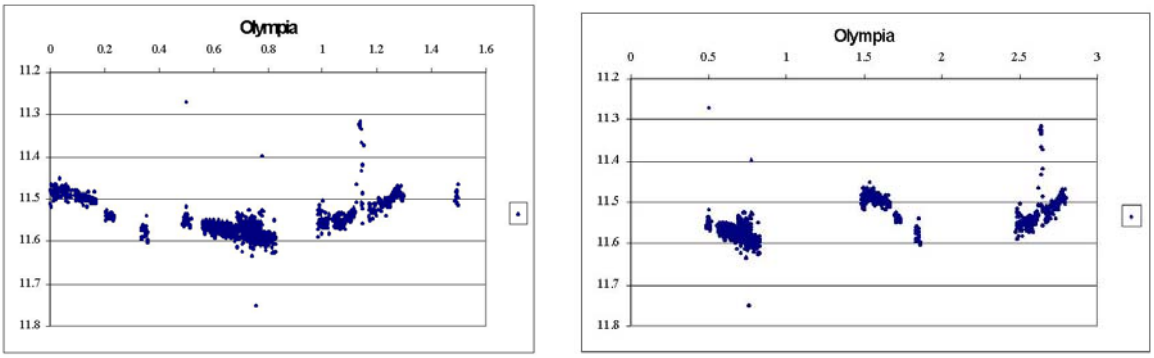


Well, after seven nights of data, I was fairly sure the period was in the 72 hour range. The left graph below presents all the data with a 1.5 day folding, showing a nice intensity curve but obviously only half of the two hump rotation curve. Below right shows the true coverage I made of the rotation curve, with a 3.0 day folding period. A little thinking shows that with a 72 hour period (a multiple of 24 hours)

(1) it is very easy to be misled into whether it is 48 or 72 or 96 since the change during a single run is relatively small.

(2) and more serious, a period that is synced to the earth's rotation means every night (after the first three), I am simply repeating data from the same part of the rotation curve—I can't fill it in!

If I wait for many weeks or longer for the period finally to come around, the asteroid is very differently placed in its orbit (and in the sky), so it is difficult to link up the data. Groan—is nothing easy?



In this case, Brian said he knew of a fellow in Australia who was also doing Olympia. Courtesy of the Internet, we soon had a network of what was finally five people contributing data. The data, of course, were of varying quality and extent, but we were able to fill in at least part of the curve. Thus, the report on this will be submitted by David Higgins. Again, I negotiated for him be the lead author (I'd rather measure and analyze than write papers!)

NOW that I *really finally* knew *ALL* the answers, I decided to go back to Anitra. It was a good set of data, and several months had passed. Maybe I should recheck this asteroid to see whether I would get the same answer. Huh—there's an idea!

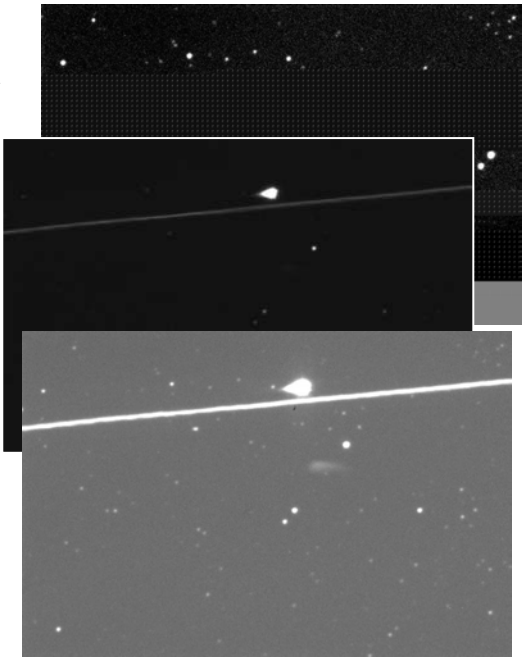
The asteroid is dimmer now, so the data are more scattered but not bad. Five days of data later, I had the result: the shape of the curve had changed and the period was different by about .0017 day (about 3 minutes)! I could understand the shape change (different aspect of the asteroid), but although the period change was just a bit bigger than my estimated error, it did seem to be a real difference. Wow, another new discovery! Collisions? Moons?

I rechecked all my data, even went back and re-measured all the original images. Same results: a changed period. What has caused this change in the period? I could find no error. Again, Brian brought me back to reality with a hint that referred to synodic period. Oh! Some geometry and calculation showed that he was right. Depending on the relative positions of the earth and asteroid in their orbits, and how fast they are moving and the time span of the data, from the earth we will measure a different period

as compared to several months later (earlier). My calculation showed this effect was about the right amount to explain the apparent change, and it would help determine the rotation directions of the asteroid. Again, the corrections for synodic period is a correction that is awkward to make in the spreadsheet (and one that is built-in to MPO).

6. Other Great "Discoveries"

Now we get to other cool stuff: you can't take thousands of images without seeing some unexpected results. For example, we would all love to discover a Near Earth Asteroid slicing through our images. Well, here are some of the more interesting images I've gotten in my 5000 images over the past few months.



6.1 My Burster.

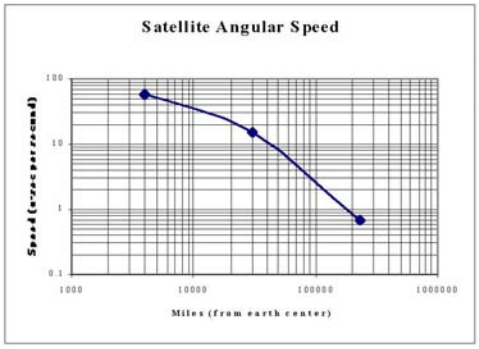
The biggest flash in the pan was this image, taken during the Anitra series. As you can see, a star in the first image flashed bright in the next one-minute exposure. Had I the good fortune to catch a gamma ray burster in the act? Cranking up the display gray scale showed the telltale trail of lights from an airplane whose strobe flashed at just the right time and place to match one of the stars. And the apparent comet is obviously just a reflection of the strobe. So much for my first minute of enthusiasm!

6.2 My Near Earth Asteroid

Actually, this is just one of several NEA "great discoveries". You can see this "thing" flashing (rotating?) as it moves across several image frames. I've seen slower, and I've seen faster. You usually won't see these in long exposures as they are usually buried in background which most of us rarely examine closely. Knowing the angular velocity (scale and exposure duration of the image), if you assume the object is an earth satellite, you can very roughly estimate the distance from the earth (see graph below).

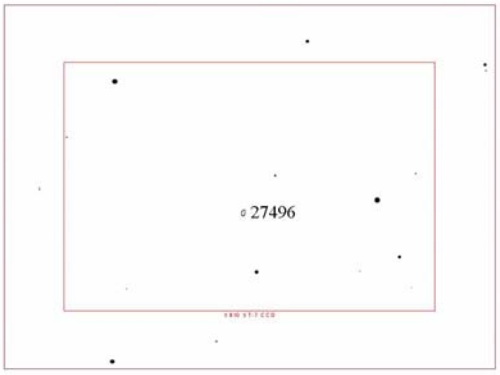
Luckily, I got both an end and a beginning of the track. With the known exposure interval of 17 sec, I could do some real measurements on it. The flash shows as about 10 mag, but the speed indicates that the flash duration is less than 0.2 sec. This implies a flash of about mag. 4 or brighter. This one was typical as it had an apparent altitude of 30,000 miles (it would have to be going at 1.5 miles/hour to be a balloon at 30,000 feet). It is not clear what this is, but it certainly is not a NEA nor a geosynchronous satellite (can you tell how I know this?)

Although it is conceivable that an amateur would discover an NEA, the space junk explanation is more likely. Most of these things are probably rocket parts: some astronomers (and NASA) get their kicks from tracking this stuff! More power to them! It's pretty tricky to track them, as they are moving fast. You need to check every image as it is made and be ready to reprogram your observing to make multiple short exposures from which to derive an orbit. But that's another story!



6.3 My SuperNova.

During one of the nights imaging 27496, I noticed that there was a change in the brightness of two check stars relative to my chosen reference star. I investigated what was going on (had I found a variable star or two?) and concluded that there was something strange with that reference star. After investigating the star using Pinpoint and other star catalogues, I realized (duh…) that the images were showing a bright star (about mag 10) where TheSky showed a faint 15mag. Wow, now I've discovered a supernova! And it was changing as I watched! Funny no one has announced it. Maybe I better check further...



Soon, rechecking my data against other information, I noticed a "little detail": the star was listed in one of the Simbad catalogues as an M8 spectral class object. Oops. Even I knew this meant a deep red star and, of course, an unfiltered CCD is very sensitive in the IR. In fact, the star is considered to be a relatively rare infrared star. The next clear night, I did a simple measurement of the same star field (now minus the asteroid) with my V filter and measured the brightness of the stars compared to a Landolt star.

Now the star in question measured mag. 15 (almost disappearing from the image!), with the remaining stars at about mag 10, as they should be.

In my original images, the very red star was dimming less as it came to the horizon than was the asteroid and comparison stars. So much for the supernova! Another lesson learned in checking the spectral classes of your reference stars and the importance of using some form of standard reference star calibration and of using multiple comparison stars!

7. Conclusion

I have enjoyed the challenge of learning and doing asteroid photometry. It is obvious that I have only begun really to learn this field. I look forward to the additional help from Brian and so many others in the field who are so generous with their time. It is rewarding to be contributing to the basic fund of astronomical knowledge, and it is fun to see the curves (and understanding) come up out of the noise. And since every asteroid is different, each one requires a somewhat different approach. Go to it!

Acknowledgements

Certainly Brian Warner and his coworkers deserve enormous credit for their continuing work in building the knowledge base that lets an amateur jump into this field and begin productive work almost immediately. Beyond this, their tireless and patient assistance for those of us trying to learn our way around a very tricky field makes all the difference.

Furthermore, IAPPP-West provides a superb place to come to learn. Contributors to the conference show us how to get over the threshold of ignorance, so thanks to all those who have made IAPPP such a great operation.

Finally, thanks to my wife, who with occasional good-natured eye rolling, shares the values of the drive to learn and has supported me in this and so many other activities.

Automation Techniques for Scientific Astronomy

Robert B. Denny
DC-3 Dreams SP, Mesa, Arizona
RDenny@DC-3.com http://DC-3.com/
IAU #663 Red Mountain Observatory

Abstract: This paper is an overview of automation technology available to educational and amateur astronomers who are conducting scientific research. The minimum pre-requisites for automation are (1) a computer controlled telescope, (2) a CCD detector, and (3) a computer for controlling both. This paper will provide you with a survey of tools and techniques with which you can get the most out of your observatory. In addition, a handful of case studies show what amateurs can do with an open mind and hard work.
© 2003, IAPPP Western Wing, Inc.

References:

1. International Amateur-Professional Photoelectric Photometry (IAPPP) web site: *http://www.iapppwest.org/*
2. Center for Backyard Astrophysics (CBA) web site: *http://cba.phys.columbia.edu/*
3. American Association of Variable Star Observers (AAVSO) web site: *http://www.aavso.org/*
4. The Minor Planet Mailing List website: *http://www.bitnik.com/mp/*
5. L. Weber and S. Brady, FocusMax Autofocus Software, web site at *http://www.focusmax.org/*
6. J. Smith, Sequencer (a sequencing program) – web site at http://www.hiddenloft.darkhorizons.org/sequencer/sequencer.htm
7. Software Bisque, Inc., Orchestrate Scripting Software, web site: *http://www.bisque.com/Products/Orchestrate/orchestrate.asp*
8. E. Beshore, TSCRIPT – A Scripting Application for Automating Time Series Data Collection, Proceedings of the IAPPP-Western Wing, May 2002
9. The ASCOM Initiative web site: *http://ASCOM-Standards.org/*
10. T. Puckett *et al.*, Puckett Observatory Supernova Search, web site: *http://www.cometwatch.com/search.html*
11. K. Y. Yeung, Desert Eagle Observatory, Benson, AZ. See *http://skyandtelescope.com/observing/objects/comets/article_657_1.asp*
12. M. Schwartz and P. Holvorcem, Tenagra Observatories, web site *http://www.tenagraobservatories.com/*
13. A. Rosner and J. Gross, The Rent-A-Scope System, Sonoran Skies Observatory, web site: *http://www.arnierosner.com/are/Rent-a-Scope/rent-a-scope.html*
14. D. Healy and J. Medkeff, Ultimate Control System for the Junk Bond Observatory, web site: *http://www.roboticobservatory.com/software/*
15. D. Harvey, PC-TCS Telescope Control System, web site:
16. P. Wallace, TPOINT Software, web site: *http://www.tpsoft.demon.co.uk/*
17. Software Bisque, Inc., TPOINT Telescope Pointing Analysis Software, via exclusive license for Windows from P. Wallace (*ibid.*) web site: *http://www.bisque.com/Products/TPoint/TPoint.asp*
18. Software Bisque, Inc., The Paramount ME and TheSky Astronomy Software (telescope control for the Paramount), web site *http://www.bisque.com/Products/Paramount/Paramount.asp* *http://www.bisque.com/Products/TheSky/TheSky.asp*
19. R. Denny, Astronomer's Control Program – web site at *http://acp3.dc3.com/*

1. Introduction

Over the last five years, the number of astronomers doing science has exploded. Many amateurs eventually tire of taking pretty pictures and want more meaning out of their work. Educators require their students to produce something more didactic than astro-art. Finally, the equipment and software has advanced tremendously in recent years. The International Amateur-Professional Photoelectric Photometry (IAPPP) Western Wing[1], the Center for Backyard Astrophysics[2], the American Association of Variable Star Observers[3], and the activities on the Minor Planet Mailing List[4], have all been big contributors to the growth of scientific astronomy.

In order for science to be productive, it's important not to be bogged down in the process of acquiring the data. Most science involves the *acquisition* and *processing* multiple images to obtain experimental data. For example, variable star and asteroid light curve work involves acquiring a time series of images and measuring the fluctuations in brightness of the body. Of course, one could simply move the telescope to a body and use the imager controls to automatically acquire images at intervals of time. In a sense, this is automation. However, it is crude and wasteful of telescope time. It would be better to plan a run where multiple stars are observed in an interleaved fashion, keeping the telescope busy. Ideally, no time would be wasted waiting for a sequence interval to expire.

Once the observatory is capable of producing significant amounts of data, the issue becomes one of processing/reducing the data to obtain the experimental result. Even the most modest amateur-class telescope can produce at least dozens, and perhaps hundreds, of limiting-magnitude images a night if automated. If traditional amateur-class analysis tools are used, the time to reduce this volume of data could be prohibitive. Amateurs and students alike have limited time. It's not practical for them to spend long hours blinking, taking flux measurements, clicking on images, etc., to get the numbers for their mission. Tools for automated processing of data are developing rapidly. We can expect to see these tools reach a critical mass in the near future. Automatic data reduction is a vast topic, and coverage will be left for a future paper. This paper covers automated data acquisition.

2. Classes of Automated Facilities

Once we cross the threshold where the telescope and imager are under the control of some sort of engine, the possibilities multiply and so do the dreams. At the low end, we have the back yard observatory using a simple sequencer that takes a list of objects and perhaps some image specifications (e.g., time, filter), and then commands the telescope and imager to move and acquire data. Toward the high end, we have the canonical "unattended observatory on a snow-capped peak" which possibly even takes requests from multiple observers and manages both the acquisition process and environmental controls autonomously. Finally, there is the global telescope network. 'Nuff said.

Over the last few years, I've talked to a number of people who have started projects to build the latter type of system, only to run out of steam, money, and enthusiasm. Apart from the mega-buck professional realm, I know of only three global telescope network projects that are alive at present. All have been going for years, and none have more than a single attended observatory. One of the objectives of this paper is to help people set

realistic expectations and understand how valuable their existing observatories can be. In order to bring some clarity to the possibilities, let's first try to split the spectrum into some classes of automated facilities:

Table 1. Classes of Automated Facilities

Local	Observatory in backyard or on-campus – observers in direct control using computers physically located in the observatory (warm room) or somewhere on the property (in the den or shop a hundred feet away)
Remote Attended	Observatory on separate property with technicians available on short notice – observers in direct control but apart from facility, technicians responsible for on-site instruments and environmental controls
Remote Unattended	Observatory on separate property with no on-site technicians – observers in direct control but apart from facility, no one on site to manage instruments and environmental controls.
Remote Autonomous	Observatory on separate property with no on-site technicians – observers must submit requests to an automated scheduler that controls the instruments, no one on site to manage instruments and environmental controls.
Observatory Network	Multiple observatories on separated properties, under separate management, and with or without on-site technicians - observers must submit requests to a central automated dispatcher/scheduler that in turn submits requests to individual observatories based on constraints contained in observing requests. Individual observatories may or may not be autonomous, but must publish their capabilities and status. Central dispatcher also collects data from observatories and disseminates to observers.

With a bit of reflection, it's easy to see that both the complexity and cost grow exponentially from one end of this spectrum to the other. Sadly, many promising projects that could produce useful quantities of data run aground prematurely due to under-estimation of complexity and cost, not to mention the personal time required to create and manage the more complex of these facilities. Environmental control, autonomous scheduling, and network dispatching are complex topics, and will be left for future papers. This paper covers local and remote-attended facilities.

> At this point, it's important to mention that virtually all professional observatories rely on cut-to-fit and custom programming, usually done by grad students and post-docs. There are only a few tools in widespread use, and even they are used with custom-written scripts, user interfaces, etc. For automation to succeed in the non-pro world, it's necessary to have an open architecture with standard interfaces so that tools can inter-operate. Only in this sort of environment can commercial companies make business sense out of producing professional-grade software, and hobbyists can get the satisfaction out of seeing their creations used widely. A classic example of this is the FocusMax software. The authors freely acknowledge that they would not have been able to (or wanted to) write such a tool without the open architecture that is available now.

3. Basic Automation: Sequencers

As defined in section 1 above, true automation includes at least the capability of controlling both the telescope and imager (as well as optional supporting components such as the focuser and filter wheel) to acquire a series of images at multiple coordinates in a single run. A *sequencer* is a program that does just that. Input to the sequencer can be

via an on-screen fill-out form and/or via an *observing plan document* that is prepared by the observer beforehand.

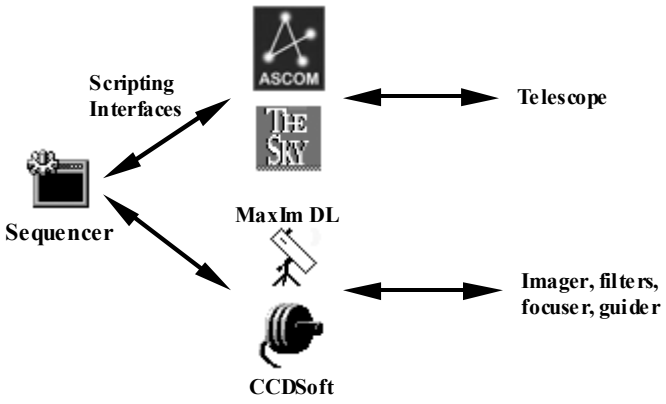


Figure 1. Block Diagram of *Sequencer* System

Sequencer[6] is a form-based sequencer. It has a series of forms into which you enter observation specifications (including calibration frames) in a tabbed window. Once you have completed your data entry, it executes the sequence and logs the results. Sequencer deals at a high level with *what* is to be done; the program figures out *how* to do the work on its own. Sequencer is compatible with a wide variety of telescopes and imager control programs.

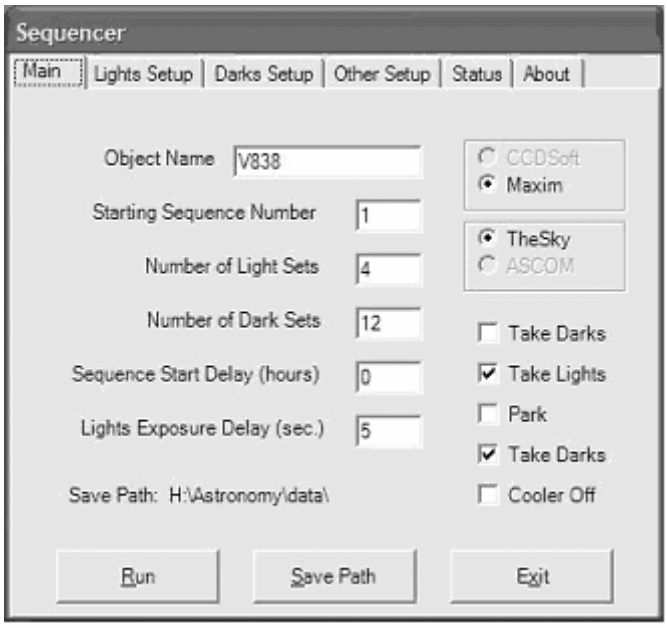


Figure 2. Main Form for *Sequencer*

The **Orchestrate Scripting Software**[7] is an example of a *hybrid* sequencer: it has both a form-based interface as well as the ability to accept pre-written observing plans. It displays a spreadsheet-like window into which you can enter commands, target names, coordinates, and other command parameters. Once completed an Orchestrate plan can be

saved to disk for later use. In addition, TheSky (another Software Bisque program) can export Orchestrate-format plans and save them to disk as well. These exported plans can be loaded into Orchestrate and executed. Orchestrate plans consist of lines of a *meta-language* that specifies commands and parameters to be executed in strict sequence. There is no decision logic or error trapping/handling.

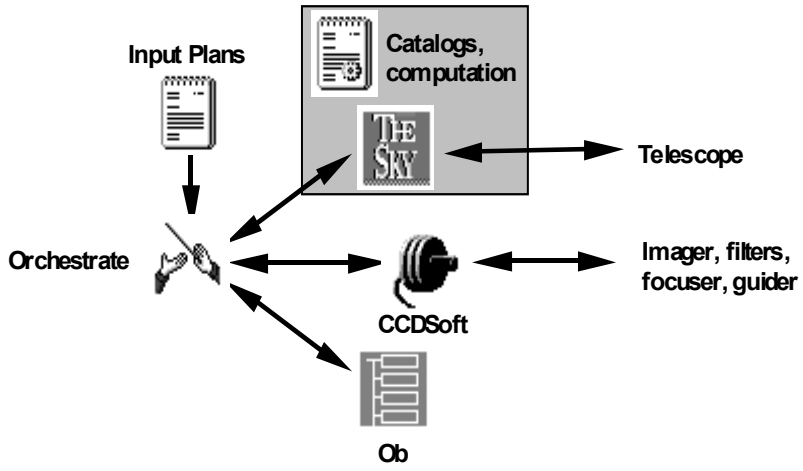


Figure 3. Block Diagram of Orchestrate-based Sequencing

TSCRIPT[8] is a plan-driven sequencer. Mr. Beshore has developed a specialized *meta-language* for plans that consists of a number of high-level commands. The command dictionary is specialized for data acquisition of time-series data for objects such as cataclysmic variables. Besides the basic commands to slew the telescope, etc., TSCRIPT includes a number of *supervisory* commands that provide enhanced capabilities. It also has a run logging facility that keeps a permanent record of the progress of the run, including any error conditions that develop. Finally, TSCRIPT has basic decision logic in the form of while-looping. There is no error trapping/handling.

4. Advanced Automation – Scripting

Sequencers are adequate for many tasks, but they are limited by the vision and resources of their developers. You can see this in the command sets of the available sequencers. TSCRIPT, for example, focuses on the task of acquiring time-series data. It would not be well suited, for example, to asteroid surveying or spectrometry.

The ultimate in flexibility comes from using a general purpose *scripting language* to control the observatory. Four years ago, the ASCOM Initiative[9] was founded to promote inclusion of scripted automation capabilities in astronomy software. Since then, particularly in the last year, scripted automation has become an accepted and valued feature of astronomy software.

The primary platform for amateur astronomy is Microsoft Windows. It is also widespread in the educational community. Windows' built-in scripting languages have made scripting automation practical for astronomy software. A spin-off from the Internet push of the latter 90s, languages such as VBScript and Jscript are powerful, flexible, able to control anything that can be wrapped in a *component model*, and best of all they are native to Windows. No compilers or specialized editors are needed. Notepad will suffice.

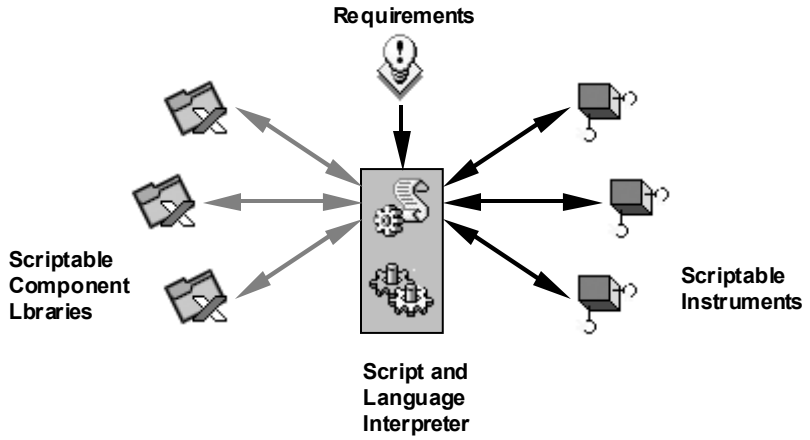


Figure 4. Scripted Automation

The flip side of this is that writing scripts is time intensive, requires a specialized skill, and requires an up-front investment to learn the library of functions available for various script-capable programs, component objects, and instrument drivers.

5. Intermediate Automation – Scripted Sequencers

The arrival of scripting automation on the scene has created two camps of automation users: those who employ canned sequencers and those who rely on scripting to achieve their automated runs. There is, however, a middle ground: *script-based sequencers*. As things have evolved, this has turned out to be the "sweet spot".

As pointed out above, "black-box" sequencers reflect the vision and resources of their developers. In addition, the user interface design itself necessarily limits the flexibility of a sequencer, and the fact that any changes must be made by the program's developer further limits its lightness on its feet. On the other hand, no one wants to write a script just to perform one night's run.

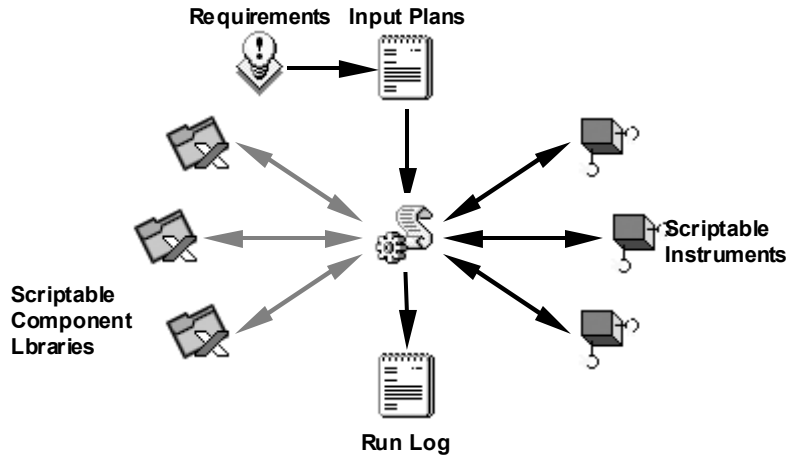


Figure 5. Scripted Sequencer

The key to using scripting effectively is to write scripts that handle a particular *type* of activity, and then feed a plan to the script for each run of that type. A knowledgeable

astronomer/programmer can write a script that implements a specialized sequencer, and then other astronomers with similar interests can use the script to run plans of their own (assuming the end user's system has compatible instruments, see the section **Increasing Leverage - Standardization** below). Changes are easily made either by the original script author or by others who know scripting, as the sequencer engine is just a script instead of a compiled program with a user interface, etc.

6. Case Studies – Scripted Sequencers in Practice

Figure 6. Puckett Observatory 24 inch Richey Chrétien

The Puckett Observatory Supernova Search in Ellijay, Georgia holds the non-professional record for discovered supernovae; as of April 20 they have 68 discoveries, a feat unmatched by all but one professional team. Puckett operates three telescopes, two of which he built himself – a 24 inch Ritchey Chrétien and a 20 inch of a special optical design and a mount that points under 30 arc seconds all-sky with no software correction! The third telescope is a Celestron 14 inch on a Software Bisque Paramount GT-1100S. The 24 inch and 20-inch run Astronomer's Control Program (ACP)[19] (see below) and the C-14/Paramount runs under Orchestrate, and TheSky.

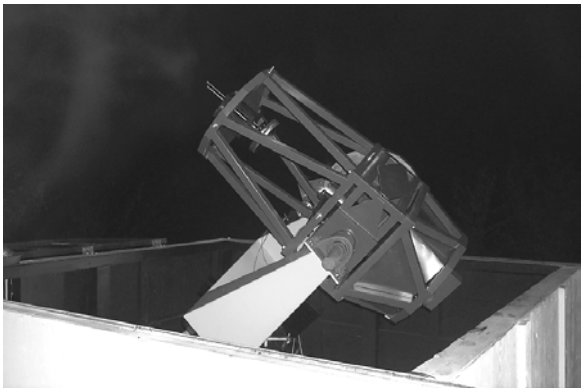


Figure 7. Puckett Observatory 20-inch

The cornerstone of Mr. Puckett's operation is a custom-written master-scheduling program that keeps a database of the fields that have been covered including the times that they were covered. This information is used as input to a tactical analysis program that determines the optimal fields to shoot and the times at which they will be in the best position. The scheduler is run daily. It produces ACP format observing plans for the 24-inch and 20-inch, and an Orchestrate format plan for the C-14. In addition, the scheduler produces scripts for an FTP client that pro-actively distributes the acquired image sets to the investigation team for analysis and detection.

Figure 8. Desert Eagle Observatory – Mr. William Kwong Yu Yeung

The Desert Eagle Observatory[11] in Benson, Arizona is privately funded and operated by William Kwong Yu Yeung, a Canadian astronomer who has a great passion for minor planet research. He operates four 18" f/2.8 Centurion telescopes, each with Apogee AP-9E imagers and guide-scopes with SBIG ST-237 imager/guiders. Mr. Yeung is a recipient of the 2002 Edgar Wilson Award for comet discovery, and holds the amateur record for verified asteroid discoveries in one dark run, over 450 in a three-week period. His observatory is treated as a "survey" by the IAU Minor Planet Center. Yeung uses the ACP standard scripted sequencer on each telescope to acquire at least a thousand images, sometimes several thousand, per night according to his needs.

Figure 9. Tenagra SciTech 0.81-m (32") F7 Ritchey-Chrétien

Tenagra Observatories[12] in Patagonia, Arizona has several telescopes. The top of their line is the SciTech 0.81-m (32") F7 Ritchey-Chrétien (see Figure 9 Above). Tenagra investigator Paulo Holvorcem has developed a scripted sequencer and observatory control program that runs 24/7, as well as a sophisticated scheduler that optimizes telescope time on multiple instruments given observing requests and constraints. The scheduler was developed in FORTRAN and runs independently of the instruments. It has knowledge of the time it takes for each telescope to complete various operations, and generates observing plans for each telescope that optimize telescope usage given this knowledge along with observing requests' constraints. The plans are submitted to the 24/7 sequencer scripts running each telescope, and which are executed under ACP. Tenagra's clients are exclusively university astronomers and the Lick Observatory Supernova Search program, to which Tenagra submits regular packages of data.

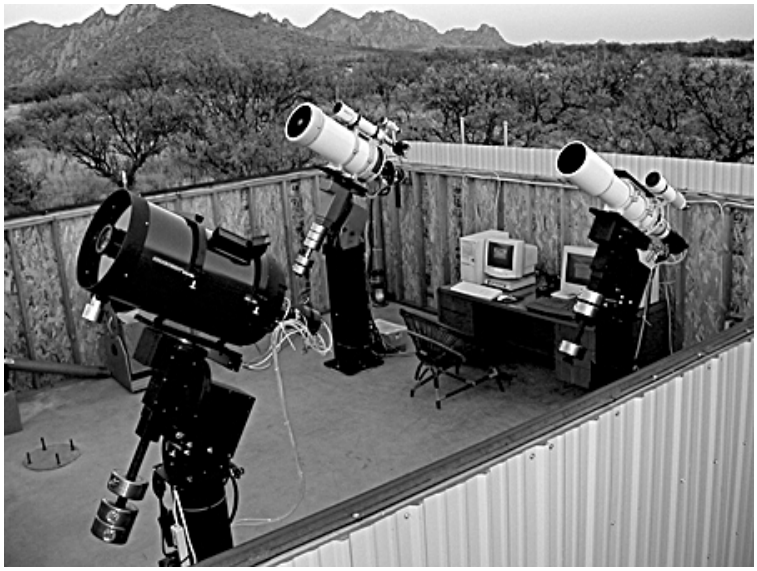


Figure 10. Sonoran Skies Observatory

The Rent-A-Scope system at the Sonoran Skies observatory in the Dragoon Mountains of Southern Arizona (see Figure 10 above) uses a scripted sequencer that accepts observing plans generated by web pages. Each telescope is mounted on a Software Bisque Paramount, which uses TheSky and TPOINT[16] as its telescope control system. The overall operation is handled by ACP, which serves the web pages and provides a set of fill-out forms that generate plans. The web pages submit the plans to ACP's special script host/engine, where they are executed on behalf of remote users. The facility is remotely located and uses a satellite internet connection, so the data is transferred overnight to a hosted FTP server where the observers retrieve their data the next day. Rosner and Gross have gained quite a following, with regular observers who pay by the hour for telescope time.

Figure 11. Junk Bond Observatory (with former 16" LX200)

Junk Bond Observatory in Hereford, Arizona has developed the Ultimate Control System[14], a scripted sequencer that controls their 24-inch OGS telescope and imager using ACP as the control hub and scripting host. Ultimate has some unique capabilities. For example, it has the ability to fill unscheduled time with dynamically selected targets such as asteroid survey fields, low-elongation moving object survey fields, supernova search fields, and other targets-of-opportunity. It manages the auto-guider and closed-loop pointing control as needed. The OGS is controlled by the PC-TCS telescope control system, which supports TPOINT[16, A]. TPOINT (via PC-TCS) assists in both pointing and during tracking. A specialized scripted sequencer is also used to gather data for input to TPOINT.

Some of the foregoing telescopes run ACP, a package that is designed specifically to host scripted sequencers. It has a built-in pointing corrector, specialized script "host", an observatory control user interface, an embedded web server with pre-written dynamic pages, and an embedded FTP server. It comes with several pre-written scripted sequencers and a toolbox library of support routines and objects designed to make constructing specialized sequencers easier and less time-consuming.

7. Increasing Leverage - Standardization

The ASCOM Initiative was mentioned in passing in section 4. Another primary goal of ASCOM is to develop and support *interface standards* for most astronomical instruments. With these capabilities, scripts become *portable*, able to run with a variety of telescopes, imagers, filter wheels, domes, etc. Since script development takes much more skill and time than writing observing plans, it's important to get the most of development time by making scripts universally usable by people other than the developer. With

[A] TPOINT is also available from Software Bisque, Inc[17]. When Software Bisque's TheSky Astronomy Software is used as a telescope control system, TPOINT can provide pointing corrections to the controlled telescope, and their ProTrack can provide corrections during tracking like PC-TCS does. The package also contains a user-friendly Windows interface to the TPOINT telescope analysis program.

standardized scripting interfaces, for example, all telescopes look the same to scripts. A script written for one telescope will run on another system with a different type of telescope *and different control software*. All details of each telescope's operation and control protocol are encapsulated in the driver for that particular telescope. The client scripts and programs are independent of the details.

Standardization also reduces the already difficult task of learning all of the methods and properties of the various instruments, library components, and programs that the script brings together. This represents a potentially large up-front investment for the programmer.

> Imagine how difficult it would be for a developer to have to learn the varied command sets and quirks of the hundreds of different printers available. Multiply that by the *types* of programs that need to print *and* the number of programs of each type and you can see the problem. There would be no consistency in user experience, only a few printers would survive in the market, and the consumers would be the losers. Windows establishes a standard programming interface for all printers. This is what ASCOM standards do for astronomical instruments (and more in the future).

The ASCOM Initiative has been very successful to date; twenty-one companies and individual authors have released programs that support scripted automation and/or use standard interfaces and drivers to control instruments. A free package, the ASCOM Platform, contains standardized scriptable drivers for a wide range of telescopes and focusers is currently available. It also contains templates, simulators, a helper library for new driver writers, and extensive scripting documentation. Most drivers are open-source and the list of developers working on drivers has grown to over a dozen. The Standards for imagers, filter wheels, FITS images, domes, and weather reporting stations are currently under development. As more standards are established, scripted automation will become far more practical than otherwise possible with proprietary scripting interfaces.

Acknowledgements: Over the last four years, I have met and worked with many astronomers, both amateur and professional, so my "long list" of debts of gratitude would be huge. There are a few standouts: I would like to thank SPACE.COM for sharing my vision of openness, scripting, and standardization very early – and for providing the substantial grant that got ASCOM started in early 1999. Starry Night Pro 3, and now Starry Night Pro 4, use ASCOM standard pluggable drivers for their telescope control, and their customers are beginners who have no tolerance for quirks or flakiness. I would also like to thank Jim Scotti of the Steward Observatory Spacewatch Program for a 1998 visit to Kitt Peak that provided the inspiration to me that got me started in this endeavor. Seeing the automated near-earth asteroid survey system at Kitt Peak gave me an "I can do that!" moment for which I will always be grateful. Finally, I must thank the early adopters of scripting, particularly Jeff Medkeff. Although not previously a programmer, he got the "ah ha!" experience before everyone else, and endured the harsh technical and political atmosphere with unflagging enthusiasm and understanding. He never lost his belief in what has now become *de rigueur* for advanced astronomy.

Robert B. Denny
April 11, 2003

An Economical Astronomical Data Acquisition System

Roy A. Tucker
Goodricke-Pigott Observatory

Abstract: The MOTESS (Moving Object and Transient Event Search System) instrument has been in operation since April of 2001. This system consists of three temperature-compensated, 14-inch aperture, f/5 Newtonian telescopes. Each telescope is equipped with a thinned, back-illuminated 1024x1024 CCD camera at the focus. Images are acquired using the scan-mode method of operation. Approximately 12 square degrees per hour are recorded by each telescope revealing stars as faint as about magnitude 20.5. During the past two years of operation, this facility has demonstrated its capability for asteroid observations by being the world's ninth most productive asteroid astrometry station. Efforts are now being made to photometrically analyze the accumulated imagery data to search for variable stars, extragalactic supernovae, and extrasolar planets. This instrument may be an excellent example of how abundant astronomical data may be reliably acquired at a modest cost.
© 2003, IAPPP Western Wing, Inc.

References:
1. Tucker, R. A. 1995, "A Public Domain CCD Camera Design", Bull. American Astron. Soc., 185, #63.04

1. Introduction

There is still much fundamental astronomical research to be done with modest-sized instruments. Often, a topic may be investigated that requires large volumes of data rather than a few precious photons from something at the edge of the observable universe. Described here is a simple, economical instrument design that has demonstrated reliable performance over a period of two years, producing an abundance of asteroid astrometry and a photometric record of 1.5 million stars.

2. Telescopes

The MOTESS instrument telescopes are conventional Newtonians with 35-centimeter aperture, f/5 primaries of low-expansion Astrositall material and 8-centimeter minor axis secondaries of fused quartz. A temperature-compensating optical support structure using the differential expansion of steel and aluminum rods eliminates the need for focus changes. Since the telescopes are intended to be directed towards a fixed azimuth and elevation for months or years at a time, there is no problem with structural flexure due to changing orientation and a relatively lightweight structure has been implemented.

At first glance, the optical support structure appears to be a simple steel box. However, the upper portion of the instrument is a box-within-a-box. The inner box, supporting the secondary diagonal mirror and CCD camera, is attached around the top and bottom edges by steel shim stock flexures that permit a few millimeters of longitudinal motion without

any transverse freedom. The position of this upper box is controlled by four temperature-compensated struts extending from the primary mirror cell. By this means, the focus of the instrument remains constant in spite of diurnal and seasonal temperature variations. Two of the telescopes have not required any adjustment of focus in two years of operation. The third instrument required readjustment once due to slow creeping of one of the primary mirror adjustment screws, apparently due to thermal cycling.

There is a fine nuance in the design of the thermal compensation that I must comment upon. Not only must I compensate for thermally-induced variations in the length of the optical support structure but also in its width, since the light is projected from the diagonal mirror to the camera rigidly attached to the side. This is accomplished by having the temperature-compensated struts extend past the diagonal mirror a distance equal to the distance from the center of the diagonal to the camera. As the temperature rises, the steel support for the diagonal mirror expands, extending the mirror towards the primary mirror. This motion projects the focal plane farther to the side, neatly compensating for the increase in width of the steel structure supporting the camera.

The temperature-compensated struts consist of two half-inch diameter steel rods and one half-inch diameter aluminum rod. The first steel rod is attached to the primary mirror cell and extends almost to the attachment point on the camera support box. At that end, it is connected to one end of the aluminum rod. The aluminum rod is parallel to the first steel rod and reaches back almost to the primary mirror cell where it is connected to the second steel rod. This second steel rod extends back to and attaches to the camera support box. This arrangement works because aluminum has almost precisely twice the coefficient of thermal expansion as steel. The length of a rod may be described as:

$$L' = L + Lc_{material}T$$

where L is the length of the rod at some specified temperature, $c_{material}$ is the coefficient of thermal expansion of the rod material, and T is the temperature difference from the specified temperature. The length of this parallel bundle of three rods of steel and aluminum is then:

$$L'' = L'_{steel} - L'_{aluminum} + L'_{steel}$$

or $$L'' = (L + Lc_{steel}T) - (L + Lc_{aluminum}T) + (L + Lc_{steel}T)$$

Since $$c_{aluminum} = 2 \times c_{steel}$$

then $$L'' = (L + Lc_{steel}T) - (L + 2Lc_{steel}T) + (L + Lc_{steel}T)$$

or $$L'' = L$$

It is entirely a fortunate accident that two commonly available materials, steel and aluminum, just happen to have an almost exact 1:2 ratio in their thermal expansion coefficients. Perusal of lists of thermal properties of materials reveals only a few other pairs of possible candidate materials such as cadmium and plutonium. I initially considered use of a material of low thermal expansion such as Invar but this is an

expensive alloy. To equip my instruments with Invar struts would have cost almost a thousand dollars. The aluminum and steel struts cost only about one hundred dollars and actually provide superior thermal correction. Commonly available Invar has a temperature coefficient of about 1.5 parts per million per degree Centigrade. The aluminum and steel struts display a measured expansivity of -0.48 parts per million per degree Centigrade. This temperature compensation scheme has worked well since the distance from the primary mirror to the CCD must be maintained constant to within .002". This method of temperature compensation using two materials is ancient technology, used for two centuries to control the lengths of clock pendulums.

Another unusual aspect of the telescope design is that focussing is accomplished by moving the primary mirror. This is a somewhat tedious process but fortunately, due to the temperature compensation mechanism, must be done only at long intervals. First, the primary mirror is adjusted so as to be perpendicular to the optical axis. Three dial gauges indicate the positions of the three adjustment screws on the primary mirror. During the focussing process, the differences in the readings are maintained so as not to change the collimation while identical increments of displacement are applied to the three screws. Approximately an hour is required to fully accomplish the iterative focussing process.

To facilitate directing the instrument at the desired point in the sky, each telescope is supported by a short yoke English mounting fabricated from commonly available structural steel and plumbing fittings. There is no clock drive mechanism or precision slow motions other than some threaded steel rods and nuts to rigidly hold the instrument in the declination and hour angle positions. At those rare times when the instrument pointing is changed, those steel nuts may be "tweaked" with a wrench to effect a certain amount of coarse adjustment. One full rotation of the declination adjustment nut effects a motion of approximately 5.85 arcminutes. Fine positioning is accomplished using dial gauges to measure motions of the telescope primary mirror cell relative to the observatory floor. 0.001" corresponds to six seconds of arc.

3. CCD Cameras

Three home-brew cameras based upon an existing design (1) have been constructed using thinned, back-illuminated 1024x1024 CCD imagers from Scientific Imaging Technologies (Beaverton, Oregon). These TK1024 devices have 24 micron pixels and, in combination with the telescope system, produce an image scale of 2.83 arcseconds per pixel. The resulting field of view is 2898 arcseconds or 48.3 arcminutes or 0.805 degrees.

These cameras are operated in continuous scan mode and the equivalent integration time at the celestial equator is approximately 193 seconds. The combination of integration time and aperture reveals stars as faint as 20.5 magnitude. Scanning at the celestial equator permits each of the instruments to record just over 12 square degrees per hour. In normal operation, the three telescopes are aimed at the same declination but spread in Right Ascension at intervals of 15 to 60 minutes to produce a data stream of image triplets separated in time that reveal moving and time-varying objects. At this time, the instruments are centered on +03 degrees, 18 minutes, and 20 seconds declination. The separation between the three instruments is about 20 minutes of Right Ascension.

The presence of unattenuated bright moonlight greatly reduces the dynamic range of the images, perhaps even producing saturation of the CCD. Before each camera is a filter slide mechanism that permits insertion of a clear filter of anti-reflection-coated BK7 glass or a color filter, usually of photometric "V" or "I". Consideration was initially given to the use of neutral density filters to attenuate the light levels during times of bright moon but it was quickly realized that color filters produce the desired attenuation and also provide useful color photometry. The filters are arranged so that image triplets ordered in time in "I", "V", and "I" are obtained, permitting interpolation of an "I" magnitude at the time that the "V" image is acquired.

Operation in scan mode requires readout of lines of pixels at a carefully metered rate that is determined by the declination, image scale, and pixel size. A precision quartz oscillator in a temperature-controlled oven is used to produce the precise time intervals for this clocking.

Stare mode imaging involves three sequential steps: (1) the telescope is pointed at a desired location in the sky, (2) the shutter is opened and the optical energy is collected, and (3) the accumulated image data is read out and stored. Since starlight is not being gathered when the shutter is closed, this process can waste a lot of time. Scan mode imaging permits all three of these processes to be continuous, increasing the observing efficiency. The cameras of this instrument are not even equipped with shutters. To search for asteroids with a single telescope, three scans must be acquired. The use of three instruments permits almost 100% efficiency.

4. Instrument Shelter

A slightly unusual roll-off roof shelter was built for these instruments that takes advantage of their characteristics. Since the telescopes don't move, they may be closely spaced and require only a small enclosure. The three instruments occupy a shelter eight by twelve feet in size. The walls are high to provide shielding from surrounding sources of light. The roof rolls off only about two-thirds of the way since the telescopes are aimed towards the south. A garage door opener is used to control the roof. The mechanism extends across the middle of the shelter but the telescopes are aimed to avoid the obstruction.

5. Observing Procedure

Operating this instrument is a bit like teaching your pet rock to do tricks; it just sits there. At evening twilight, the roof is opened and the cameras are powered up. When the sky is dark enough, the image data acquisition software is invoked and image collection begins. Except for occasional interruptions due to weather, the image acquisition process normally continues until morning twilight while the system operator gets a good night's sleep.

Depending upon the season, this instrument produces 1 to 1.5 gigabytes of image data per clear night (150 to 220 image triplets, each covering 0.64 square degrees). It is not possible to examine all of these images intensively by eye and so it is necessary to rely upon computer image processing to search for interesting objects. One computer, a Pentium-class PC-compatible, is dedicated to acquiring images from the three cameras.

Although operated in continuous scan mode, the image stream is sliced up into 1024 squared FITS images for convenience. The images are then passed over an ethernet connection to a second computer for analysis and archiving on CD-R disc.

Images are examined semi-automatically using a software package called PinPoint written by Robert Denny of Mesa, AZ (www.dc3.com). This package of scriptable routines can detect moving objects, perform precision astrometry using a variety of catalogs for its reference frame, and compose an e-mail astrometry report message in Minor Planet Center format. The user may also examine the display for objects that the automatic motion-detection routines may have missed for some reason. An entire night's collection of images may be processed by an operator in four to five hours.

The same region of sky is searched night after clear night, a strip of sky 48 arcminutes wide at a particular declination, currently +3.3 degrees, limited at the west and east ends by evening and morning twilight. Because of their relatively slow motion along a primarily east-west line, Main Belt asteroids are generally observable on multiple nights. This strip of sky is a window of observability through which smaller bodies of the solar system will drift over time and be noted. I call this the "Fly-paper" or "Field of Dreams" strategy.

There are benefits from imaging the same field of sky, night-after-night. The three images from one night may be co-added to permit detecting objects another half-magnitude fainter, about magnitude 21. Images from three consecutive nights may then be blinked to find very slowly-moving objects such as asteroids near the stationary points in their retrograde loops or Trans-Neptunian Objects. A similar process may be used to examine the same field with a time interval of one month or one year to look for nearby faint red dwarves displaying large proper motion and/or annual parallax.

6. Results

The asteroid observing characteristics of this system have been exercised since initial regular asteroid patrols began in August of 2001. During the final four months of 2001, over 12,000 astrometric observations of asteroids were provided to the Minor Planet Center. In spite of a suspension of asteroid observing during the spring of 2002, 16,457 asteroid astrometric observations were submitted in that year. The first three months of 2003 have already netted 5,333 observations.

The system has demonstrated a high level of reliability. Not a single night of data has been lost as a result of instrument difficulty whereas two nights were lost as a result of the operator’s failure to remove the telescope aperture covers.

In the course of the past two years, over a thousand CDROMs of imagery data have been acquired. Analysis of these images began last year to identify variable objects. So far, some 2000 candidate objects have been identified

Although initially intended as an asteroid and comet search instrument, appropriate software will make it suited for the search for extra-galactic supernovae, the optical components of gamma-ray bursters, and variable stars. By increasing the number of instruments from three to as many as a total of 48 in several geographical locations, this instrumentation may become a tool in the search for extra-solar planets using both the transit and gravitational lensing methods of detection.

You can see that this type of instrument has no expensive precision mounting. The telescopes are fixed in position and scan the same strip of sky each night. The cost of the instrument is primarily in the optics and the cameras, those components that are required for the detection process. A precisely pointing and tracking mount, while very expensive, does not detect a single photon.

This instrument has been built by a single person working in his spare time over the course of two years for an investment of about $12,000. It should be possible for other amateurs and modest professional institutions to duplicate this system if they are strongly motivated. I consider this system to be essentially an engineering prototype. Later versions of this design will incorporate changes based upon lessons learned from it.

Acknowledgements

I wish to express my appreciation to The Planetary Society for their award in 2002 of a Eugene Shoemaker Grant in support of my asteroid observing activities.

WNCC OBSERVATORY

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

Abstract: Western Nevada Community College (WNCC), located in Carson City, Nevada, is a small two year college with only 6,000 students. Associate degrees and Certificates of Achievement are awarded. The college was built and started classes in 1971 and about 12 years ago the chair of the physics department along with a few in administration had dreams of building a small observatory for education. Around that time a local foundation, Nevada Gaming Foundation for Education Excellence, was looking for a beneficiary in the education field to receive a grant. They decided an observatory at the college met their criteria. Grants to the foundation instigated by Senators, businesses, and Casinos and donations from the local public now total $1.3 million. This paper will explain the different facets of building the observatory, the planning, construction, telescopes and equipment decisions and how we think it will operate for the public, education and research. The organization of local volunteers to operate and maintain the observatory and the planned research will be explained.
© 2003, IAPPP Western Wing, Inc.

Introduction: The idea by a couple of faculty members of Western Nevada Community College (WNCC) was to acquire $25,000 somehow and build an observatory and that was it. Carson City is a small town and because it is the capitol of Nevada it has a unique political scene. When this idea of an observatory generated across a lunch table, a former Governor of Nevada identified to one of the imaginaries of the observatory idea the existence of a grant that was available for educational purposes, the Nevada Gaming Foundation for Education Excellency, $100,000 worth of grant. When word was out that an Observatory for Education met the criteria of the grant and it became a viable project, State and Federal Government officials, businesses, casinos and the public sized the opportunity and started donating to the foundation. The project is so special because it is a local vision, inspired by the faculty and built with community and statewide support.

Approximate total foundation numbers now stand at $1.3 million, consisting of approximately $627,400 for building construction, $300,000 for telescopes, cameras and accessories, computers, classroom furniture and miscellaneous equipment. The planned observatory equipment is described below. The complete project is of such diverse dimensions requiring a unified effort by several different qualified and experienced professions a committee composed of local volunteers with these qualifications was formed and are directing the different aspects of construction and the final functions of an institutional observatory. It is hard to comprehend a final opening date or time line for this endeavor and First Light has been scheduled and moved back twice. November 17th, 2002, March 7th and the final May 15th, 2003, which coincides with the lunar eclipse.

First Light on May 15th will have a presentation by Buzz Aldrin, Apollo XI Astronaut, the second astronaut to step on the moon, and it will be a black tie and black leather fund raiser. Harley-Davidson, the motorcycle company, has made a donation and is sponsoring a Harley Fashion Show. This is the reason black leather maybe worn also. The following days will see approximately 400 students from the Carson City School District given tours of the observatory and Saturday and Sunday is open to the public.

The 2,800-square-foot facility has a room with three piers for the three main telescopes with a clamshell sliding roof. See figure 1. A wall separates the telescope room from the only large room which is a classroom and accommodates 36 students. This classroom has several screens with projectors and will have six computers to control the three telescopes inside the observatory, a telescope inside a RoboDome, a radio dish antenna, and a weather station located outside the building. A small entry way, restrooms and a small storage room make up this 37 by 77 foot structure. There are eight wired piers outside which will accommodate almost any type of telescope.

Fig. 1

The equipment inside the telescope room on the three piers is as follows:

A Meade LX200 16" f/10, automatic focuser, color filter wheel and an ST-8 CCD camera. The filter wheel has two carousels, one for RGB images and one for BVRI photometry.

A Takahashi C-400 16" f/14, automatic focuser, ISIS eight position filter wheel, AO-7 adaptive optics and an Apogee AP-8 CCD camera. This system is operated on a Paramount ME and will be operated using alternate equipment such as a Spectrograph with an ST-7 CCD camera.

A Takahashi BRC 250 10" f/5, automatic focuser, five position filter wheel with two carousels, and an Apogee AP-16 CCD camera. This system is on a Paramount ME. Alternate equipment is a ST-10 CCD camera.

A RoboDome, located outside the observatory has a Takahashi FSQ-106 on a Paramount ME. The

FSQ-106 has an aperture of 4“ and a focal ratio of 5. It has an H Alpha and White Light filters Its primary purpose will be to track the sun having a video camera in the eyepiece so prominences and sun spots can be displayed on screens inside the classroom of the observatory along with the moon and deep sky objects. In addition, the computers and telescopes are connected to a large overhead TV screen and a plasma TV screen, so entire classes can view the stars, sun, planets and deep sky objects from their desks.

Besides research data coming thru the telescopes, spectrograph and CCD camera, a Campbell Scientific research-grade weather station outside next to the observatory will be gathering atmospheric information and be tied into the US weather system. The Desert Research Institute of the University of Nevada will be using the data for its regional weather database studies. This weather station will serve as a weather center for Carson City, the observatory and surrounding areas with up-to-date information available over the Internet. In addition to the weather station a16 foot dish will act as a radio telescope and will be located next to the weather station.

The observatory is located approximately 1000 feet above the WNCC campus and a Planetary Walkway connects the main campus with the observatory. The walkway was a fund-raiser for the observatory and it features massive four-to-six foot tall rocks placed along a pathway from the lower college campus to the observatory. Artistic inmates from the Nevada State Prison created the monuments from sandstone at the prison’s old quarry. The monuments have carved images of the planets and a dedication to the donors at $25,000 each planet. After donations for the nine planets were received, the head of the fundraising efforts for the project asked if there was a tenth planet. We thought about planet X but decided to stop with the nine known.

The Western Nevada Astronomical Society was created as a result of the observatory and besides directing star parties and astronomical functions for its members and the community it has become a source for volunteers who will help conduct tours for the local schools and the public and operate some equipment at various scheduled activities.

Research projects which will be conducted by students and individual researchers will not be limited by the type of telescopes and associated equipment. The different aspects of variable star research, astrometry and asteroids, including shape determination, and projects to determine distance to various stars are just a few of the many activities available to the students and the astronomical community. The system will have its own web site and browser franchised by Software Bisque and configured by Ron Wodaski. Any research or student project can be accomplished remotely from the classroom or from the home computer.

Summary: This will be the only public observatory in northern Nevada. The Jack C. Davis observatory, named after a former WNCC president will bolster students’ and public interest in science. With a browser allowing remote access to the telescope and research equipment from anywhere, it is anticipated a lot of educational and research time will have to be allocated and may be the answer to funding to maintain and operate the observatory.

All Spherical Catadoptric Gregorian Design For Meter Class Telescopes

Peter Ceravolo
Ceravolo Optical Systems

Abstract

An all-spherical catadioptric Gregorian telescope design suitable for meter class telescopes is described. A group of small lenses is placed at the intermediate focus of the Gregorian system to correct the aberrations of the f/1.5 spherical primary mirror and spherical secondary mirror. The corrective lenses are of simple form and conventional substrate. The system's performance is ideal for broadband CCD imaging and is diffraction limited in the visible portion of the spectrum.
© 2003, IAPPP Western Wing, Inc.

Introduction

Much effort has been expended in eliminating the need for aspherics in reflective telescope designs. Typically, the imperfect imaging properties of spherical mirrors are best corrected with lenses at or close to the pupil of the system, or in other words, full aperture correctors. The massive lenses become optically, mechanically and thermally impractical when the aperture of the system exceeds 0.4 m. Sub-aperture correctors, when applied to conventional Cassegrain and Newtonian systems with spherical mirrors, have not met with much success since the residual color aberrations typical of such systems are undesirable.

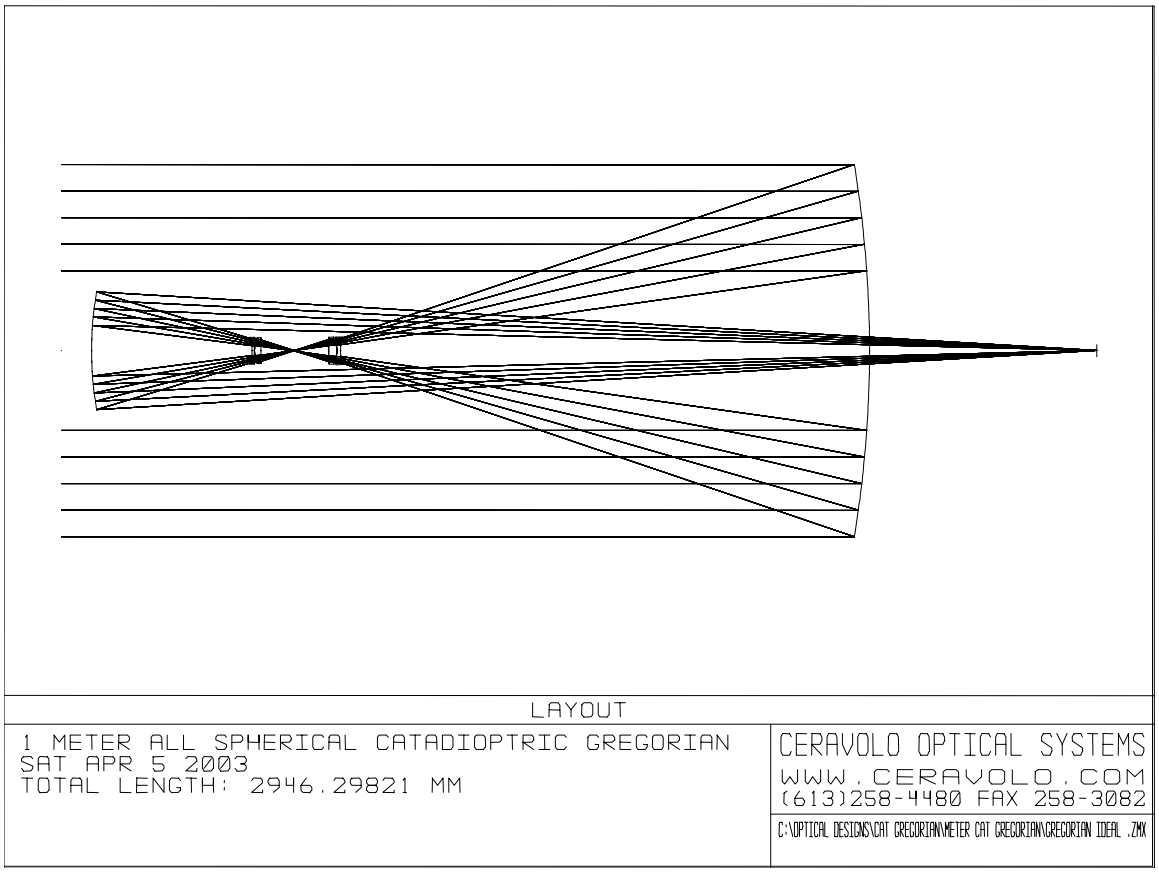
The advances in computer aided optical fabrication and active telescope technology have tamed the difficulties associated with the production and use of aspherics in very large observatory telescopes. However, exploring the elimination of aspherics in smaller, meter class telescopes is still worthwhile in order to bring costs down to a level affordable by smaller institutions and advanced amateur astronomers.

The catadioptric Gregorian reflector design described here is believed to be a novel approach to an all-spherical optical system that is both simple and relatively inexpensive to produce optically. The design is diffraction limited over most of the visual spectrum and the image size over a very broad spectral band lies within a 1 arc second circle. The overall dimensions of the system's optical tube assembly are similar to those of a conventional Cassegrain telescope due to the high-speed, f/1.5 primary mirror. The Gregorian optical configuration also offers superior baffling of stray light to that of a typical Cassegrain layout.

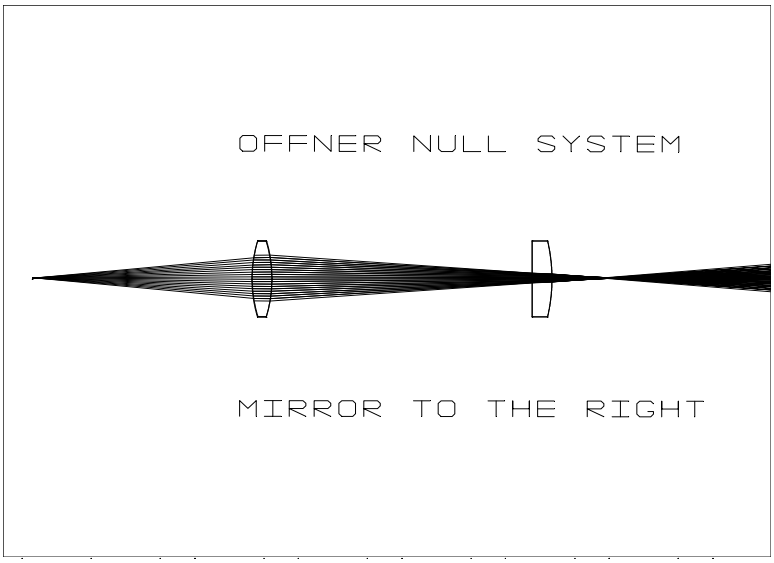
The Design

The all-spherical catadioptric Gregorian design was inspired by the desire to build a large telescope, and the availability of a 1 meter f/1.5 mirror blank. The use of an aspheric primary was ruled out due to the difficulty of figuring such a large and fast mirror with conventional fabrication techniques, not to mention the significant problems associated with collimating the finished telescope.

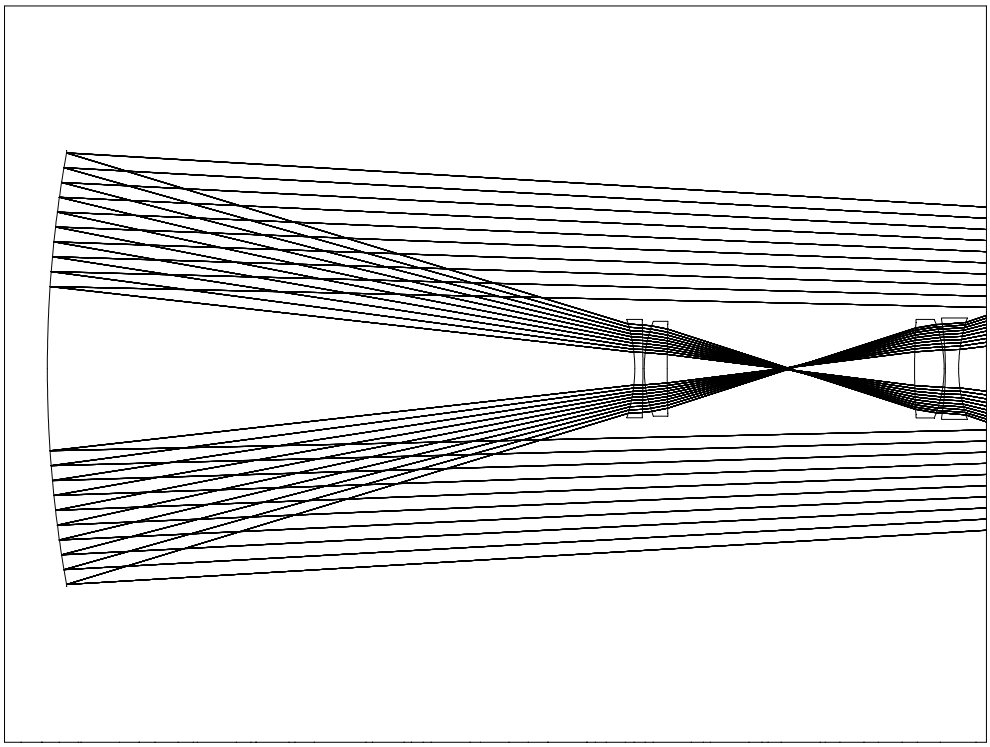
The challenge of eliminating the primary's considerable spherical aberration in a simple system seems daunting, but this feat is accomplished regularly in optical shops when null test techniques are applied to aspheric mirrors. The spherical aberration correction in the catadioptric Gregorian telescope design, illustrated below, was inspired by the Offner null test technique. While the Offner null corrects the spherical aberration of a mirror at the center of curvature, in this adaptation it corrects the aberrations of a spherical telescope mirror at its infinity focus and over an extended field.



Of a two-lens form, the Offner null's small positive relay lens corrects most of the primary spherical aberration, while the field lens close to the center of curvature contributes to the correction of higher order spherical aberration residuals.



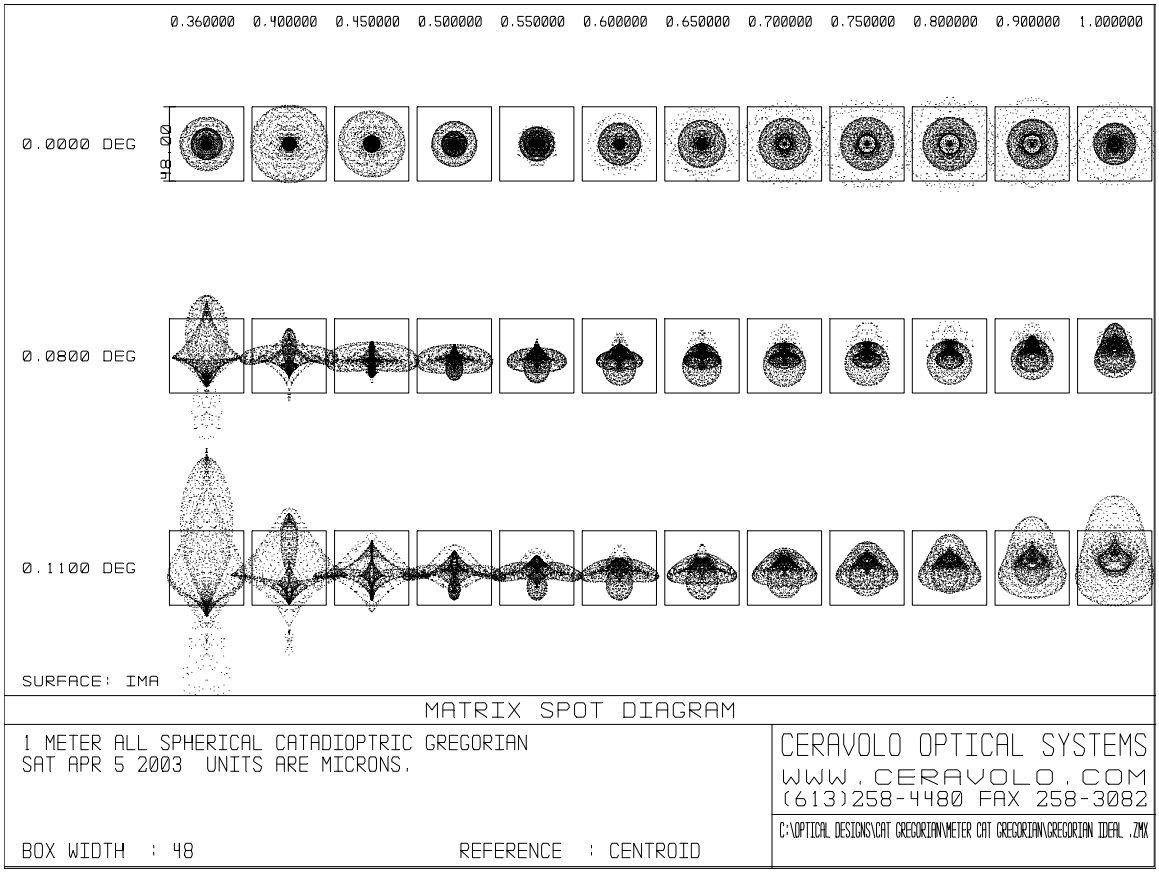
Since null tests are performed using monochromatic light, chromatic aberration is not an issue. Adapting the null lens concept to a white-light imaging telescope necessitates replacing the positive relay lens with a mirror, since color dispersion by this element would be overwhelming. The resultant optical system now resembles a Gregorian configuration with the field lens at the intermediate focus. The corrector lens diameters are constrained to fit within the centrally obscured region of the imaging rays.



The initial design of the system, once the basic idea was conceived, was surprisingly easy. A Gregorian mirror system was laid out and a few weak positive lenses were "tossed in" around the intermediate focus. The Zemax default merit function was used, and after several optimization runs the design quickly converged toward a system that provided reasonable images, although the lens forms were far from ideal. Further design effort revealed that excellent performance could be achieved with as little as four small corrective lenses of conventional glass types.

Performance

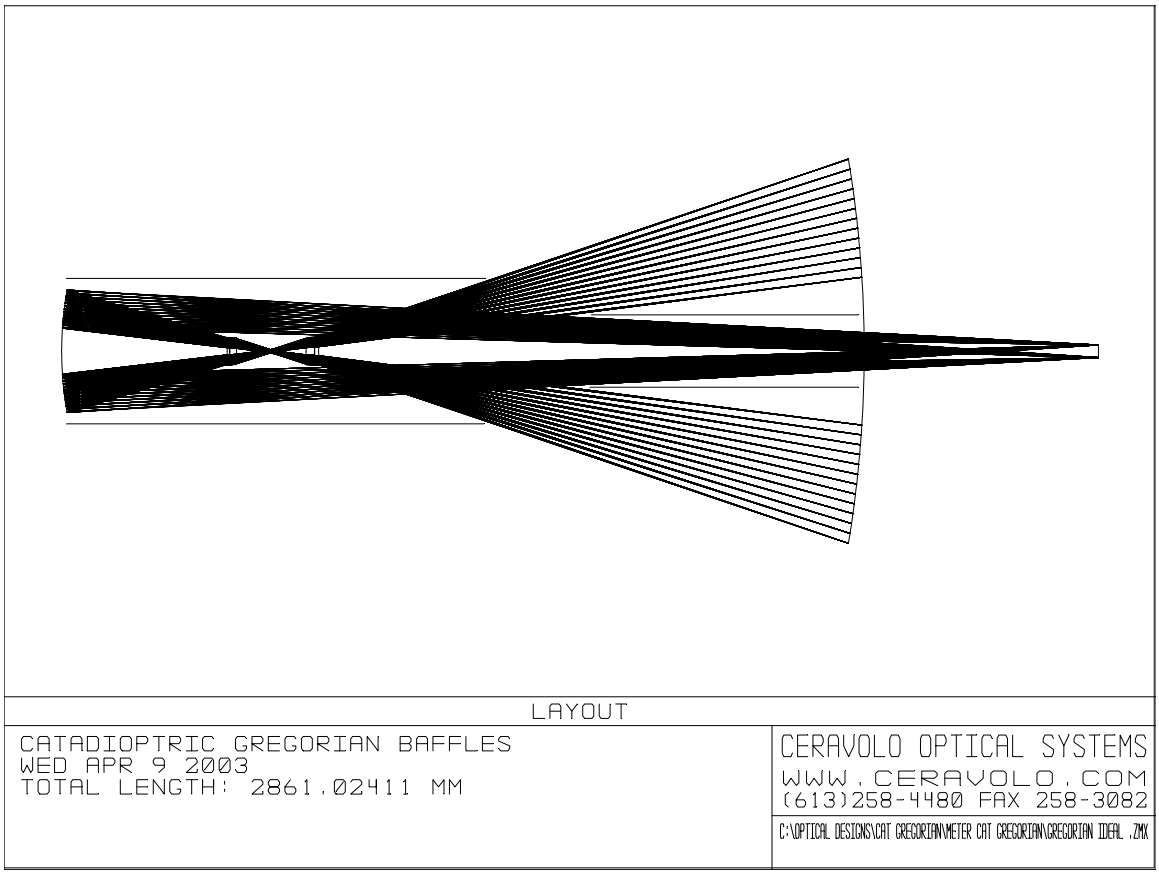
The f/8.5 design presented here is diffraction limited in the central visual part of the spectrum using only four corrective lenses of conventional glass types. The image size over the broad spectral range of 360 nm to 1 micron is no larger than 1 arcsecond (corresponding to a 2x2 array of 24 micron pixels) across much of the central area of the detector's field, with degradation occurring in off axis images only at the extreme ends of the spectrum. The spot diagrams illustrate the performance of the system over a 1k square CCD array of 24 micron (0.55 arc second) pixels. An all-silica, six element corrector lens design has also been formulated to access a broader range of the spectrum, from 340 nm to 1 micron, more efficiently. There is only a slight decrease in image quality that will not likely be noticed in practice.



Construction Issues

A thorough tolerance analysis has yet to be completed. However, a sensitivity analysis, and even a simple visual examination of the layout alone, suggests that construction of this system will pose some challenges. Light rays converge upon the corrector group and secondary mirror at steep angles, suggesting the alignment of the secondary with respect to the corrector lenses will be critical. The lenses themselves do a significant amount of "work" to compensate for the primary's aberrations, and therefore will be sensitive to manufacturing and mounting errors, hence requiring a carefully designed and fabricated cell. Aligning the spherical primary with the secondary-corrector lens assembly is straight forward, as it has no discrete optical axis, however the primary's radius of curvature must be very tightly controlled in fabrication since a small variation will result in a significant change in its spherical aberration contribution.

The telescope will require two sets of spider supports. The spider supporting the corrector lens cell can be mounted in a tube that also holds the secondary mirror. This tube would also serve as one of the baffles for the optical system, as illustrated below. The other spider support will suspend the secondary/corrector assembly in the main tube. In order to minimize the number of diffraction spikes, the spider vanes will have to carefully aligned.



Prescription Data

Title: 1 Meter All Spherical Catadioptric Gregorian

All dimensions in millimeters

Entrance Pupil Diameter	:	1060
Effective Focal Length	:	9000
Image Space F/#	:	8.490566
Total length	:	2946.298

SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter
OBJ	STANDARD	Infinity	Infinity		0
1	STANDARD	Infinity	2300		0
STO	STANDARD	-3256.573	-1505.802	MIRROR	1060.167
3	STANDARD	118.6191	-10.30369	BAK4	78.95786
4	STANDARD	-244.7791	-1.000114		76.64665
5	STANDARD	-98.83866	-22.97498	SK18A	76.67311
6	STANDARD	602.551	-192.429		72.03239
7	STANDARD	1276.971	-17.90319	SK16	69.32805
8	STANDARD	98.83866	-0.9999581		73.86686
9	STANDARD	-1443.362	-6.369977	SK4	75.42739
10	STANDARD	-121.0674	-456.9428		76.55445
11	STANDARD	951.5192	2861.024	MIRROR	339.0405
IMA	STANDARD	Infinity			34.74072

While initial exploratory optical design work has been done on the all-spherical catadioptric Gregorian telescope, a thorough tolerance and ghost image analysis has yet to be performed. Nor has a prototype been fabricated. Builders should be cautious, as there may be unforeseen problems with this design in practice. The design prescription is offered here to encourage others to explore this design form further.

Discovery of Variable Stars as a Byproduct of Asteroid Lightcurve Studies

Robert Stephens
Santana Observatory

Robert Koff
Antelope Hills Observatory

Abstract: To determine an asteroid lightcurve requires hundreds of CCD images taken over several nights. After measuring the brightness change in the target asteroid, and perhaps checking the field of view for other moving objects, these hundreds of CCD images are then stored away. New features added to "Canopus", a photometry and astrometry program published by BDW Publishing now allows for automatic detection of possible variable stars in a group of images. In January 2003, using this method, two new variable stars were discovered by the authors at Santana Observatory (MPC 646) and Antelope Hills Observatory (MPC H09). This paper will discuss the methods used to search for variable stars in a group of CCD images and the general approach to investigating the variable star.
© 2003, IAPPP Western Wing, Inc.

References:

1. "Minor Planet Observer". BDW Publishing.
Website: http://www.minorplanetobserver.com/

2. "Simbad Astronomical Database". CDS, Strasbourg, France.
Website: http://simbad.u-strasbg.fr/

3. "General Catalog of Variable Stars". Sternberg Astronomical Institute, Moscow.
Website: http://www.sai.msu.su/groups/cluster/gcvs/gcvs/intro.htm

4. "VSNET". Department of Astronomy, Kyoto University, Japan. Website: Website:
http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/index.html

5. "Binary Maker 2 Software", Dr. David H. Bradstreet, (Contact Software, 705 Standbridge St., Norristown, PA 19401, 1993)

6. "Wilson-Devinney Windows Interface". R. Nelson. Eclipsing Binary Observer's Homepage.
Website: http://binaries.boulder.swri.edu/binaries/

1. Introduction

The determination of asteroid lightcurves requires that the object be observed all night over a series of nights. In the process, many images are generated each night. Since the asteroid is constantly moving, each night the object will be imaged against a different star field. This is necessary to determine an asteroid's lightcurve, and it also creates the necessary images to look for the lightcurve signature of a variable star.

In the past, the authors have discovered variable stars serendipitously, when a comparison star being used for an asteroid lightcurve proved to be variable. It was clear that other variables lay undiscovered in the archives of images from past asteroid investigations.

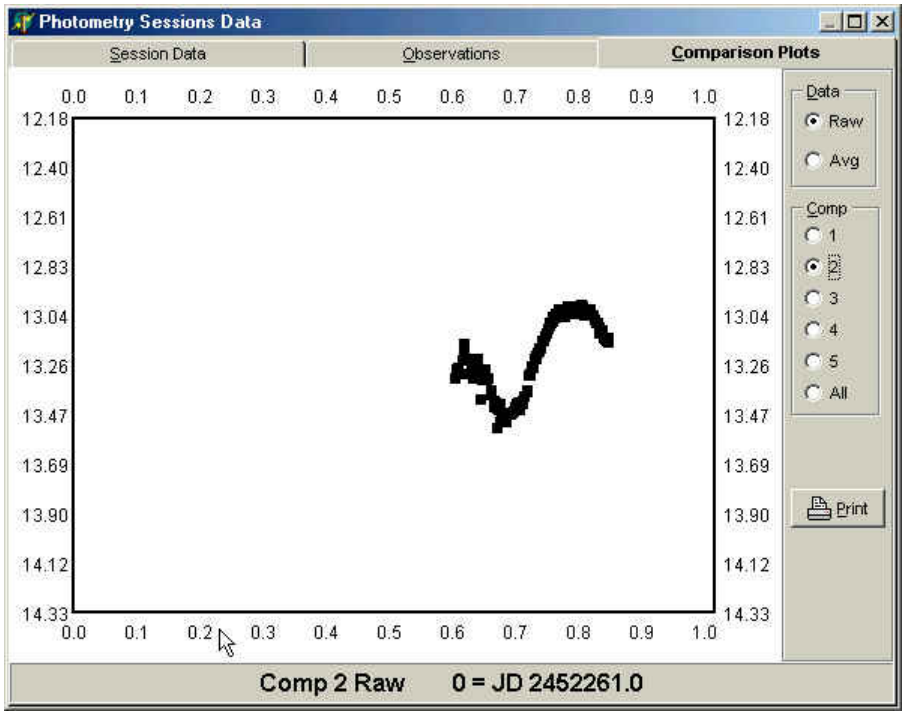


Fig 1. A Comparison Star Turns Out to be Variable

Both of the authors use the program "Canopus" written by Brian Warner of BDW Publishing [1]. Since the program was designed to produce and analyze lightcurves, it seemed a natural extension to try to apply it to variable star lightcurves. Koff had indeed pursued this aspect of the program while investigating eclipsing binary stars. Koff subsequently requested that Warner add certain features to the program to suit the specific requirements of variable star work. As those discussions progressed, Koff inquired as to the viability of some form of variable star search. Warner modified the program to provide specific variable star options, and created a variable star search routine, with the goal of testing every star in the image series for variabily.

The Variable Star Search utility evolved through various versions, finally arriving at the current version in the winter of 2003. This version was tested by both of the authors. On the first series of images tested by Koff, the program detected a previously unknown eclipsing binary. Stephens

followed with two discoveries and Koff with another. The viability of the program was immediately evident.

The procedure consists of first setting up the search parameters.

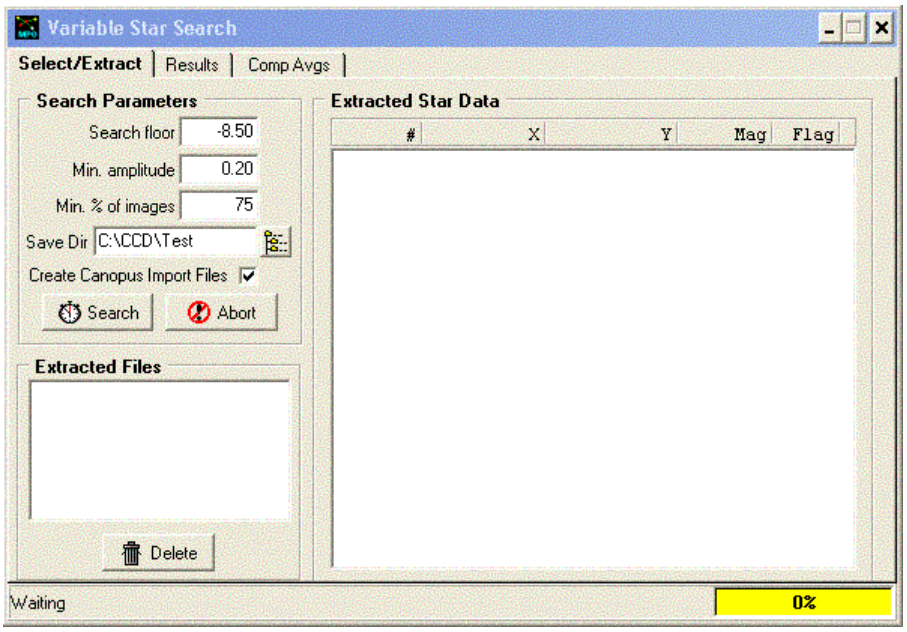


Fig 2. Setup Page for Search Parameters.

Then, one selects the images to use in the search. They should cover the same approximate star field, although the program allows for drift of the image centers during the night. It is not necessary to examine every image, which would require considerable computer time. One can select, for example, every tenth image. It is necessary to have at least six images, and more have proved helpful. Once the program has measured the images, it asks the user to select comparison stars.

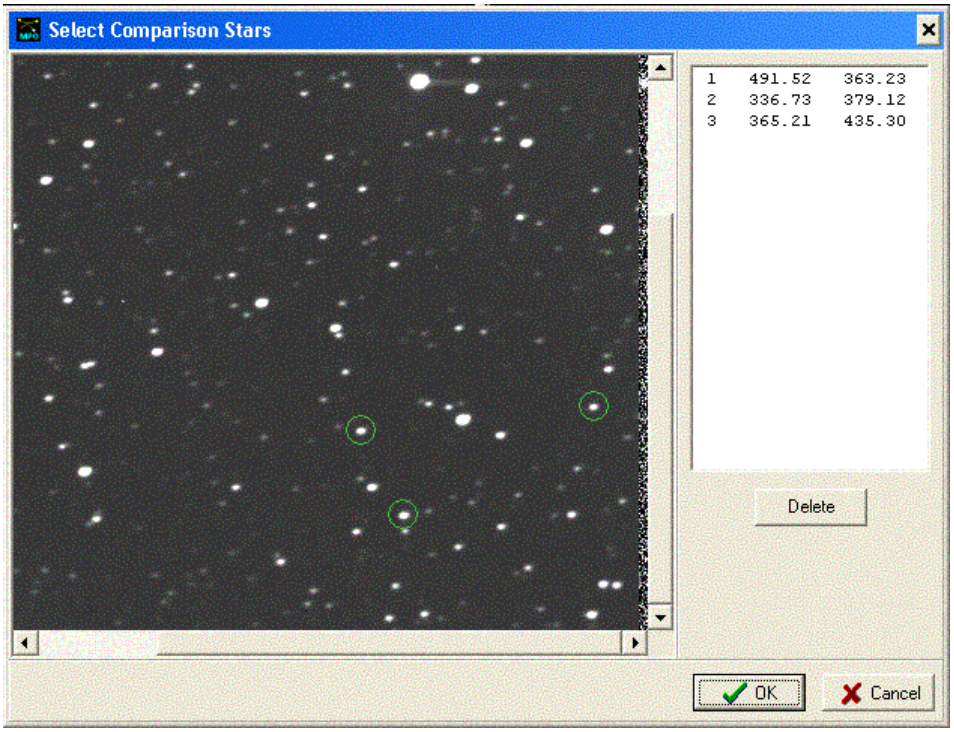


Fig 3. Selection of Comparison Stars.

The program then maps the images, computes light curves, and presents its report. One part of the report is a lightcurve of the average comparison star. Viewing this curve allow the user to determine the general quality of the run, and to see if any of the comparison stars are themselves variables. You expect to see a general brightening and then dimming of the average comparison star throughout the evening due to atmospheric extinction.

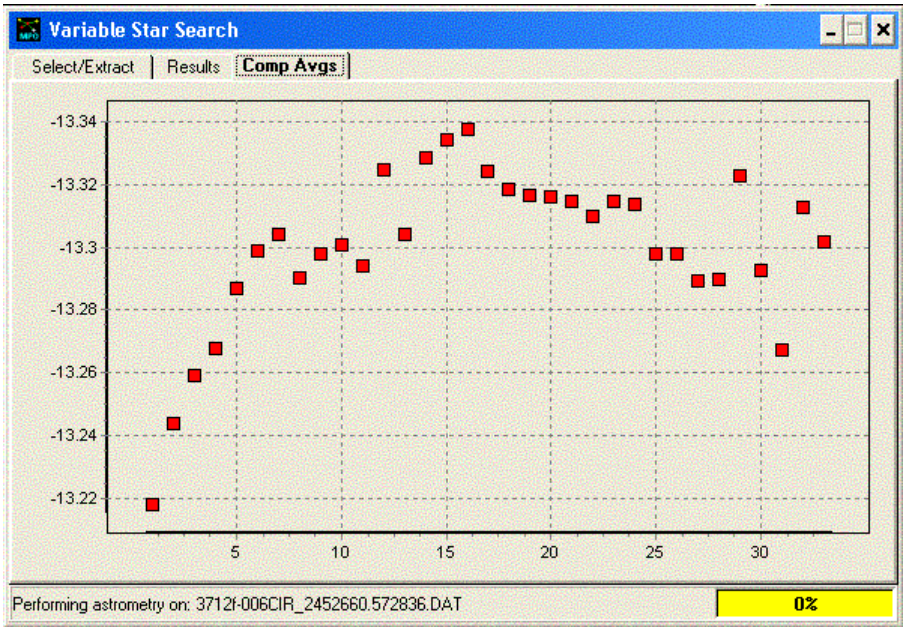


Fig 4. Lightcurve of Comparison Stars.

The user then goes to the results. First, a list of possible variable stars is presented. One can scroll through the list, viewing each lightcurve in turn. Depending on the sensitivity of the original search parameters, there may be a number of "false alarms" generated. These become evident as one scrolls the list, since they will often have the same characteristics, or will simply be scattered.

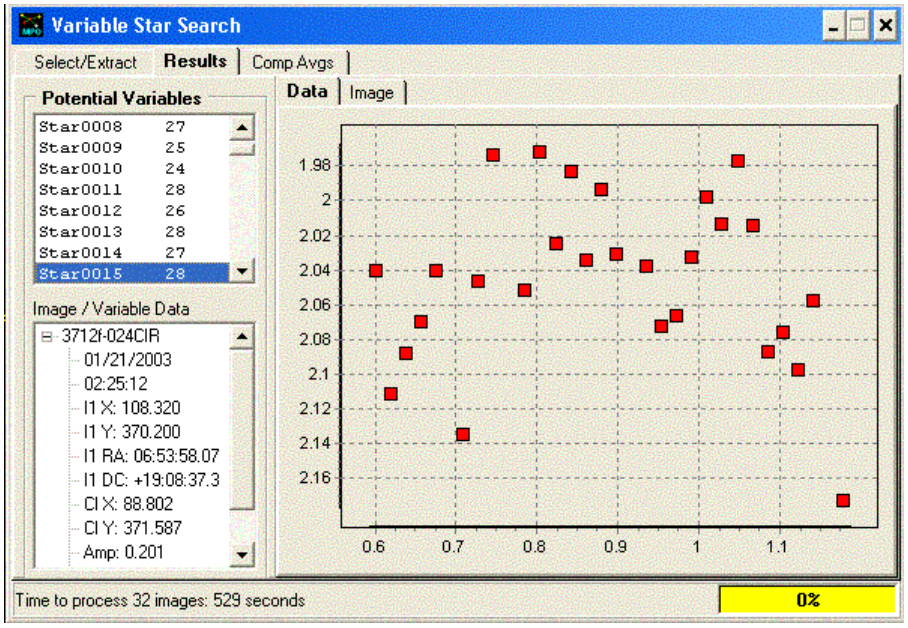


Fig 5. A Suspicious Detection.

We have found that a true variable star will often stand out. This is particularly true of short period eclipsing binary stars, or those eclipsing binaries where a deep eclipse is detected.

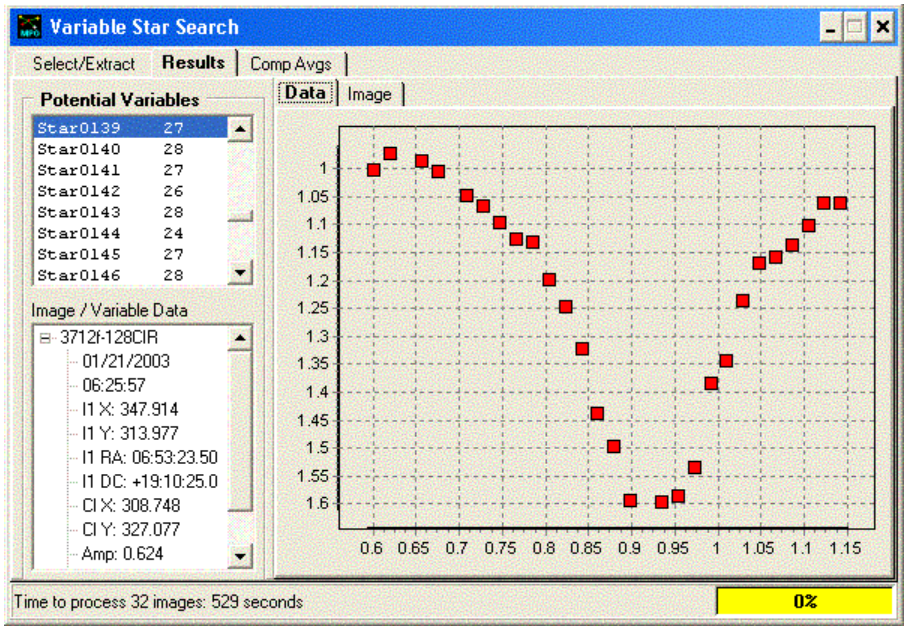


Fig 6. A Variable Star Detection.

Once a good candidate has been spotted, the program will pinpoint its location on the first image in the list.

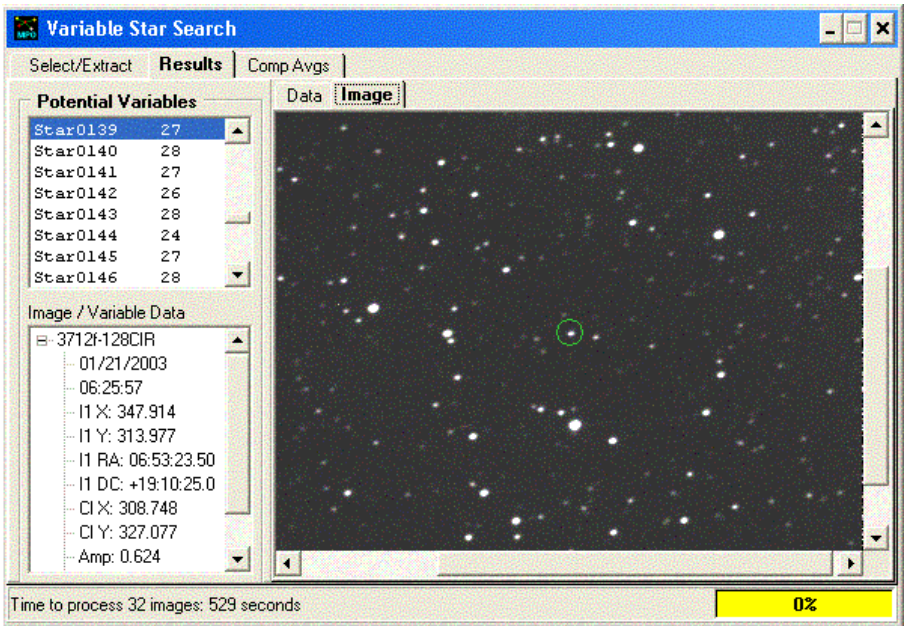


Fig 7. Pinpointing the Location of the Suspected Variable.

Generally, the next step will be to do a more detailed lightcurve of the object, using the full power of Canopus.

Once a variable has been discovered, the next step is to determine whether or not it is a new discovery. Several databases are commonly used for this step, most notably the Simbad [2] system. Also worth checking are the General Catalog of Variable Stars and New Suspected Variables Catalog [3], and the very extensive "newvar" list available from VSNET [4].

The new discovery then becomes a lightcurve project of its own. Multiple nights of observation are generally required. In order to maximize the scientific results of the project, observations through standard filters are recommended. It will be necessary as well to accurately determine the magnitudes and colors of the reference stars as well as the target. However, unlike asteroid work, you are now looking at a stationary target, so the same comparison stars can be used night after night, simplifying that aspect of the project. Also simplifying the analysis is the "Photored" program provided by Warner with "Canopus", which is designed to reduce observations to the standard system.

Obtaining a lightcurve may prove to be relatively simple in the case of, for example, a W Ursa Majoris with a period short enough to cover in a single night. Or, the lightcurve could prove difficult in the case of a long period Algol-type eclipsing binary. Some periods extend for years! Two of the variable stars so far discovered have such long periods that they have not yet been resolved.

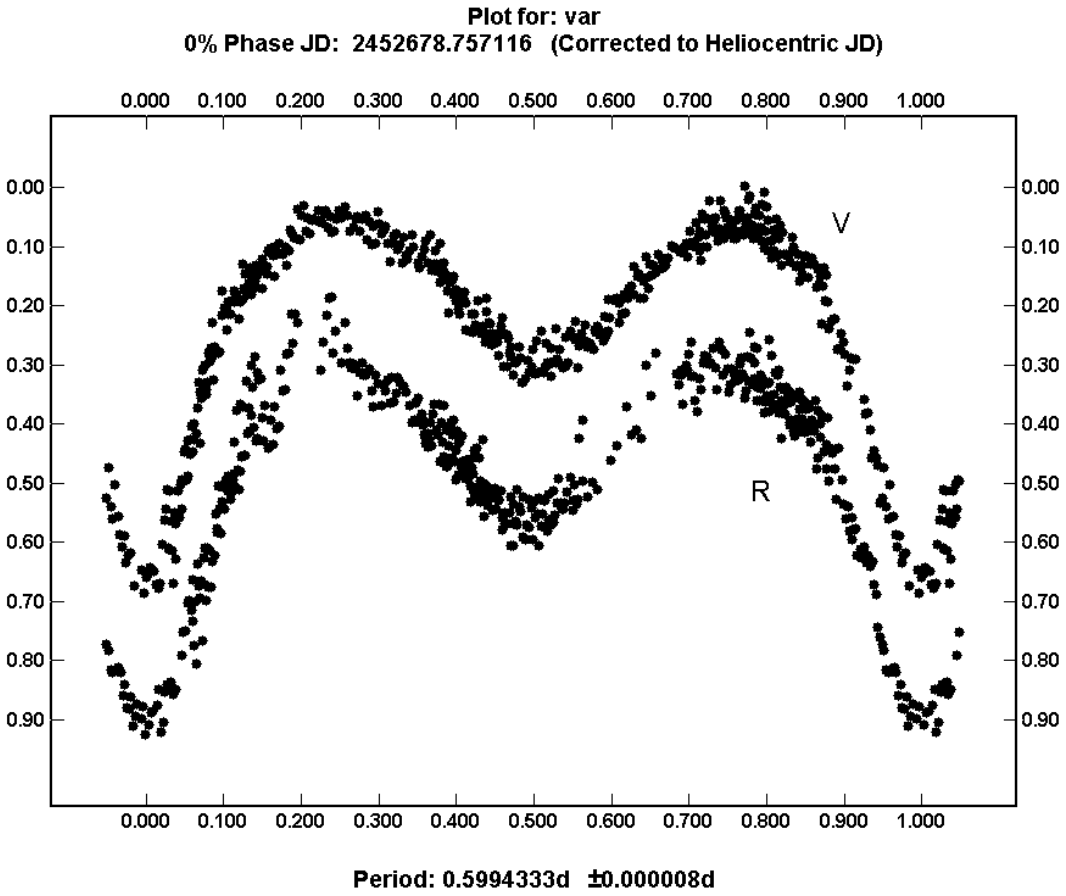


Fig 8. Completed Lightcurve, in V and R, of the Eclipsing Binary Detection of Fig. 6

Once you have your lightcurves, preferably in multiple colors, you are in position to analyze and model the results. Modeling adds greatly to the information that can be obtained from the lightcurve alone. Interacting binary stars can often reveal a great deal about the individual stars. Software that is available for this purpose includes David Bradstreet's Binary Maker [5] which will run under Windows.

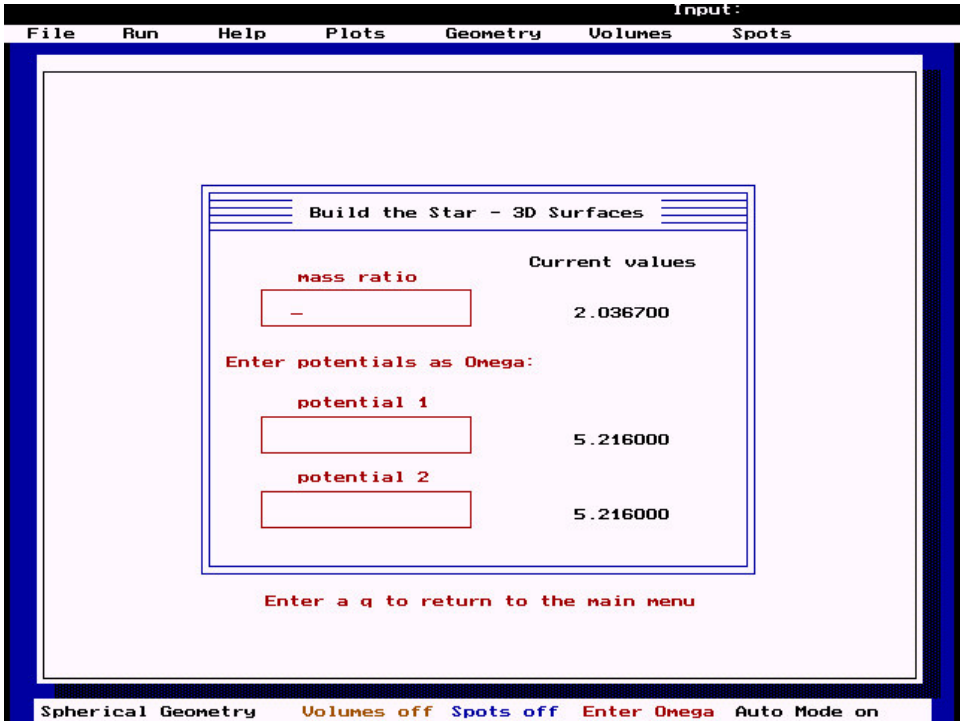


Fig 9. Binary Maker 2.0 Input Screen

Also available is the Wilson-Devinney program [6] which is currently available with a Windows interface.

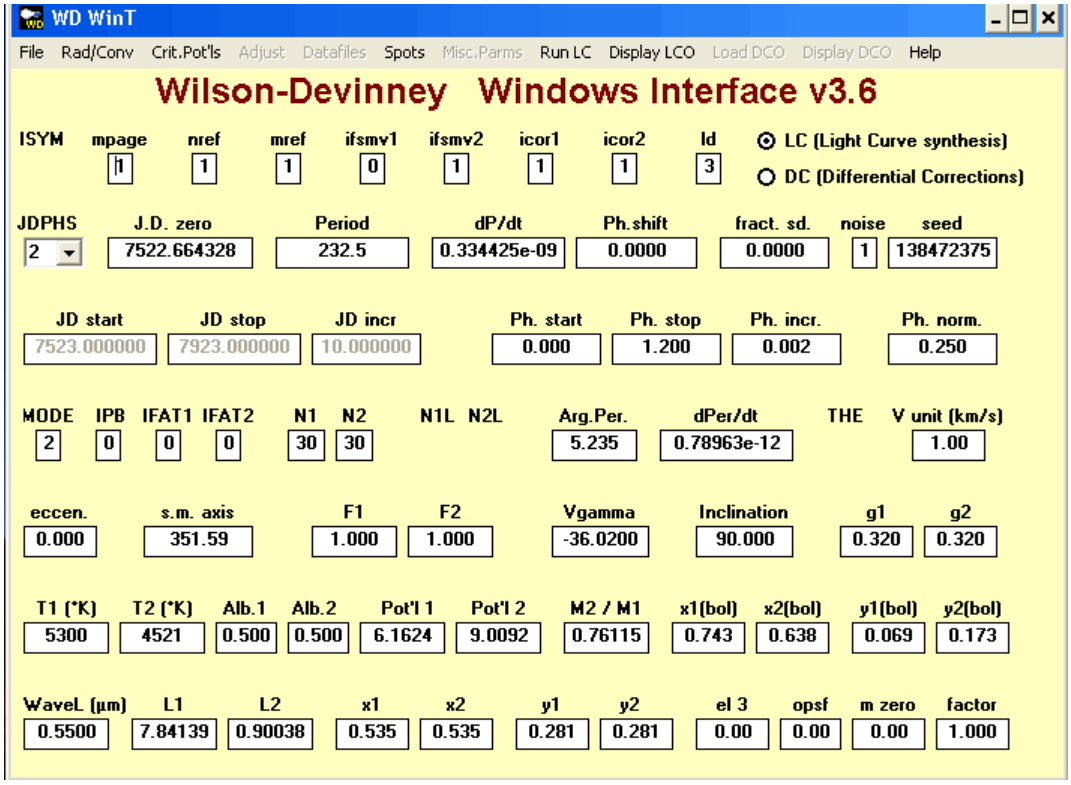


Fig 10. The Wilson-Devinney Windows Interface.

For many of the binaries that will be discovered and analyzed by amateurs, the modeling that we can do will be the final step in the analysis of the binary system. Ideally, it would be desirable to obtain spectra and radial velocity curves, which would allow the determination of absolute values for such physical properties as mass. Without these values, it may not be possible to eliminate competing solutions. However, large professional telescopes and large blocks of telescope time are required for these measurements, especially for the dimmer star systems that amateurs are now discovering. As worthwhile as binary star research may be, it is hard to compete for time on large telescopes.

Summary

The process of determining an asteroid lightcurve involves multiple imaging of different starfields on different nights. The large number of images involved lends itself to a search of those starfields for variable stars. The program "Canopus" from BDW Publishing has been expanded to allow for automated searches of multiple images and the detection of variable stars. The program has proven very effective. It is now possible to expand the usefulness of the images acquired for one purpose to serve as an expanded resource. The authors have only found one downside to the Canopus variable star search; with so many new discoveries, it is going to take more telescopes and more clear nights to keep up with them!

Acknowledgments

The authors express their gratitude to Brian Warner for all of his efforts at developing and expanding the "Canopus" program to encompass the needs of his users.

Table 1. Eclipsing Binary Discoveries by the Authors Using Canopus Variable Star Finder

Star Name	R.A./Dec. (J2000)	Observer	USNO Magnitude	Measured V Mag. Range	Period	Amp.
USNO B1.0 1250-0137945	06 42 39.24 +35 04 42.2	Stephens	B1 = 15.45 R1 = 14.62		Under Observation	0.55
USNO B1.0 1250-0137877	06 42 47.69 +35 06 47.0	Stephens	B1 = 15.08 R1 = 14.13		Under Observation	0.15
USNO A2.0 1050.04473675	06 53 23.5 +19 10 24.8	Koff		14.28 – 15.00	0.5998 Day	0.72
GSC 0804-0118	08 31 25.25 +11 48 13.1	Koff		13.63 – 14.18	0.32375 Day	0.55

Mira Variable Stars: Spectroscopic and Photometric Monitoring of this broad class of Long Term Variable and Highly Evolved Stars

Dale E. Mais,
Department of Astronomy, Palomar College, San Marcos, CA,
Robert E. Stencel,
Department of Physics and Astronomy, University of Denver, Denver, CO and
David Richards,
Wessex Astronomy Society, Dorset, UK

Abstract: Mira variable stars are a broad class of stars, which encompass spectroscopic classes of type M, S and C. These stars are closely related in terms of their long term variability, position on the Hertzsprung-Russell diagram their intermediate mass (from ~0.8 to ~8 solar mass) and the fact that class M evolves into the S and C type stars as certain stages of shell burning around the core proceeds. These shell burning episodes produce heavy elements beyond iron and also carbon which can appear at the surface of these stars during periods of convective instability resulting in greatly enhanced abundances of elements beyond the iron group and an increase in the carbon/oxygen ratio. In addition, it is suspected that these type stars, in particular, the M type Mira's can flare up over periods of hours to days by several tenths of a magnitude or more. The spectroscopic changes, which occur during these flare episodes, ultimately driven by core burning evolution, remain relatively unexplored. This project was initiated in order to monitor a group of program stars of these classes in the V and R photometric bands in the hopes of "catching" some of these stars during one of these flare ups and thus to be able to conduct spectral analysis of the flare-ups in real time and compare these spectra to the non-flare spectra. This talk will describe the background of these type stars, in particular, their evolutionary history and their spectroscopic differences. In addition, the strategies and initiation of this project will be described.
© 2003, IAPPP-Western Wing, Inc.

References:

1. Schaefer, B., 1991, Astrophys. J. Let., **366**, L39
2. Maffei, P., and Tosti, G., 1995, Astron. J., **109**, 6.
3. Struck, C., Cohanim, B. and Willson, L.,2002, Ap. J., **572**, L83.
4. de Laverny, P., et. al., 1998, Astron. Astrophys., **330**, 169.
5. Stencel, R., and Ionson, J., 1979, PASP, **91**, 452.
6. Stencel, R., 2000, ASP Conference Series, **199**, 99.
7. Landolt, A., 1983, Astron. J., **88**, 439

1. Introduction

Among all the stars of the heavens, there exists a small sub-group, which has served as a key to our understanding of stellar evolution through spectroscopic examination. These stars are broadly called Mira variables and include the oxygen stars (M types), carbon stars (C type) and the S stars. They represent stars of the initial mass range from ~0.8 solar mass to ~8 solar masses which have evolved off the main sequence. These stars are peculiar in a variety of respects because of their high ratio of carbon to oxygen and the often-high abundance of heavy elements they contain, which are synthesized by the slow neutron capture process. They are also long

period variable stars, of the Mira class and the sequence from M to S to C types represent an evolutionary pathway during certain core burning events in their post-main sequence lives.

Recently, evidence has accumulated to suggest that Mira variables may go through flare up stages which result in brightening on the order of several tenths of a magnitude and can last hours to days in length (Schaefer, B., 1991, Maffei, P., and Tosti, G., 1995 and de Laverny, P., et. al., 1998). Very little is known about these events, especially spectroscopic changes that may occur during these events. This project was initiated with the view of monitoring a set of program stars in the V and R photometric bands and establishing baseline spectroscopic observations of moderate resolution in the red and near infra-red. In this manner, potential flare up episodes can be studied in this spectroscopic region.

2. Background, Results and Discussions

My primary instrument for spectroscopy is a Celestron 14 with a Paramount ME 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-8E with 9-µm pixel size. In this paper only results obtained using the 18-µm slit will be presented. The grating of 1200 or 1800 lines were utilized which represent a resolution of ~0.5 and 0.3 Angstroms per pixel, respectively. Wavelength calibration was carried out using the emission lines of a thorium-argon gas discharge tubes. Absorption and emission line identifications were carried out using tables from the Handbook of Chemistry and Physics.

Photometry was conducted with an Astrophysics 5.1-inch f6 refractor using an ST-10XME camera and 2x2 binned pixels and the Johnson V and R filters. Images were obtained in duplicate for each band and two reference stars used per variable star for analysis. Image reduction was carried out with CCDSOFT image reduction groups and specially written scripts for magnitude determinations, which allowed for rapid, nearly real time magnitudes to be found.

The currently believed interrelationships between the cooler M, S and C type stars are shown in Figure 1. As stars evolve into S and C stars, a number of changes are observed to occur in their outer atmosphere and these changes can be documented by examination of their spectra.

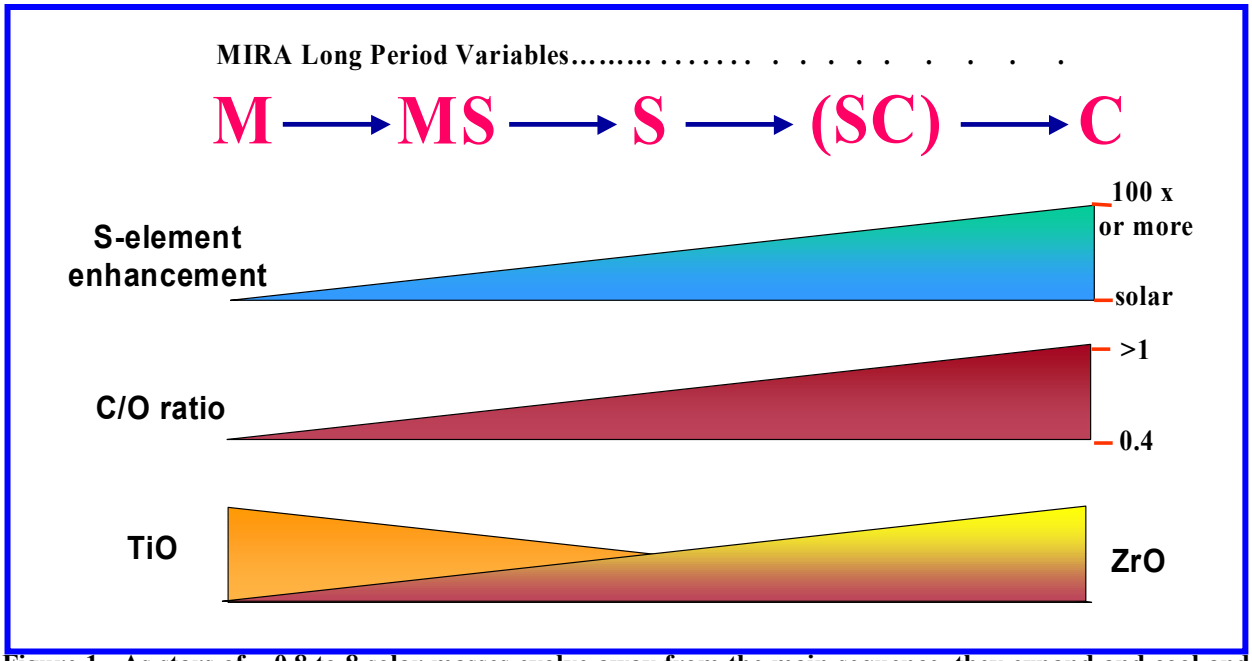


Figure 1. As stars of ~0.8 to 8 solar masses evolve away from the main sequence, they expand and cool and move into the red giant M type stars. From here they enter into Mira type long period variability and

gradually evolve into S and ultimately C type thermally pulsing phase where alternating burning of hydrogen to helium, helium burning to carbon and phases of slow neutron capture reactions. Intermittent convection sets in bringing many of these heavy elements to the surface including carbon and zirconium. As a result, enhanced s-elements are observed, increased carbon as expressed as a C/O ratio and the newly made zirconium has a higher affinity to react with free oxygen than titanium, resulting in the disappearance of TiO bands and the appearance of ZrO bands in their place. Either of these molecular species can be observed only in cooler stars such as M, S or C types. Whether the SC transitional class actually exists remains a bit controversial.

For example, one often observes an enhancement of s-elements in their atmospheres. These are elements synthesized by the slow neutron capture method in shell regions around the core of these stars. More will be said about this later. In addition, the carbon/oxygen ratio increases in these stars from a typical value of 0.4 up to values often greater than 1. Finally, the molecular bands of titanium oxide (TiO) observed in the spectra of cooler M type stars often disappears and are replaced by zirconium oxide (ZrO) bands and vanadium oxide (VO). (Zirconium is a slow neutron capture element).

Where do these stars lie on the Hertzsprung-Russell diagram? Figure 2 shows this diagram with the main sequence indicated. The main sequence represents where the vast majority of stars are found. These are "normal" stars in that they are burning hydrogen into helium in their cores. When stars have exhausted this hydrogen, they begin to evolve. How this evolution will proceed depends upon the mass of the star. Our discussion will focus on stars in the mass range of 0.8 to 8 solar masses. In this range, which includes the sun, stars migrate to the right of the diagram and upward. The green paths represent two such migrations for two different mass stars. These stars outer atmospheres expand and cool as helium ignition begins in the core and hydrogen burning in a shell around the core gets underway. As the stars cool they become M type stars and enter a region of the H-R diagram populated by long period and MIRA type variable stars. It is while stars are in this region of the H-R diagram that some very interesting things occur. Figure 3 is an enlargement of Figure 2 focusing on the variable star region of the diagram. It is while stars are in this region of the diagram that a series of nuclear reactions take place with profound evolutionary consequences.

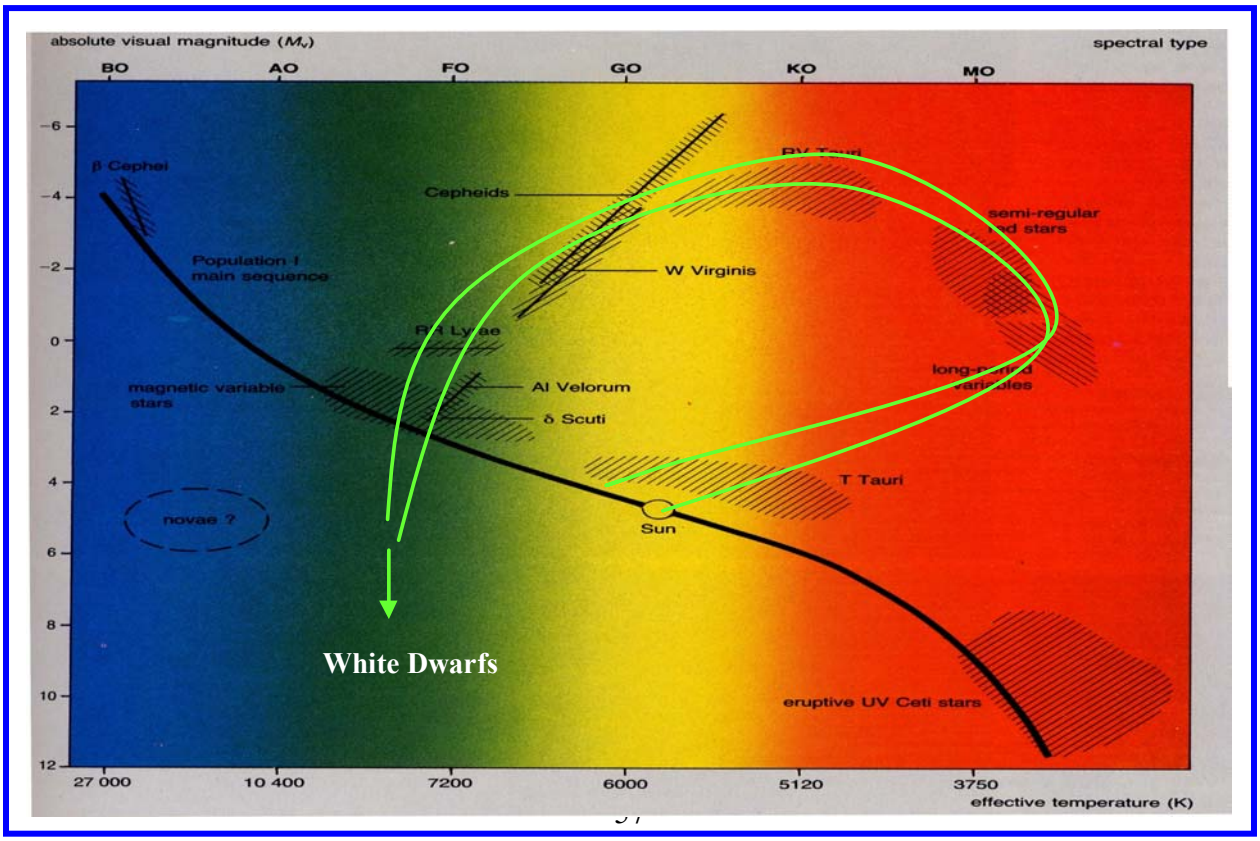


Figure 2. The Hertzsprung-Russell diagram showing the main sequence as a black line and various other areas where variable stars of different types are found. The green lines indicate the paths of evolution followed by typical stars in the solar mass range when they have exhausted their hydrogen supply in the core. They migrate into the region M type stars and long period variables of the Mira type (farthest right). After spending some time in this region, they ultimately shed their outer layers as planetary nebula and the stars enter into the white dwarf region.

Stellar evolution models show that while stars are residing in this area of the HR diagram they undergo a series of thermal pulses in which alternating burns of hydrogen to helium and helium to carbon can occur. At certain times during these alternating burns, there are regions where significant quantities of an isotope of carbon get made, ^{13}C, which contains one extra neutron in its nucleus over normal ^{12}C. At certain times during these alternating burn-rest periods, conditions can be appropriate such that the ^{13}C can fuse with helium yielding oxygen and, most importantly for our purposes, a free neutron. This appears to be the main source of neutrons for the slow neutron capture process and initiates at a temperature of ~1 x 10^8 K. Another process that is relatively minor, but requires higher temperatures, is the burning of ^{22}Ne to give ^{25}Mg. Now, free neutrons do not survive very long, having a half-life measured in minutes. But the important thing about neutrons is that they can enter into and fuse with the nuclei of other heavy atoms without the temperature requirements usually required for fusion of nuclei to heavy elements. At times in between these pulses, convection sets in and some of the

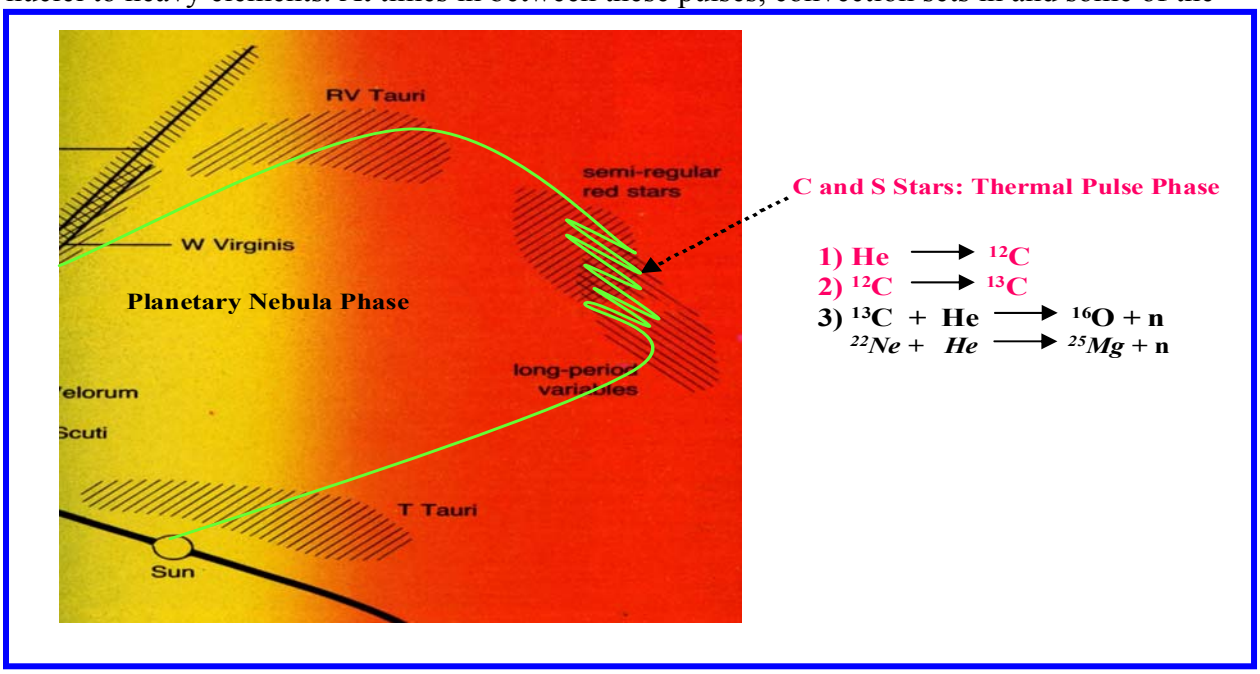


Figure 3. Close up of the region where stars enter the variable region of the H-R diagram and the thermal pulsing phase. In this phase, which can last a few million years, helium and hydrogen burning occur out of phase with each other and slow neutron capture reactions occur. The source of the neutrons appears to be ^{13}C with possible small contributions from ^{22}Ne. Dredge up periods between these episodes carries some of these products to the surface. Eventually, many of these slow neutron capture elements find their way back to interstellar space during the planetary nebula phase.

materials cooked up in these processes get dredged up and appears in the outer atmospheres of these stars. This represents the slow neutron capture process and can synthesize heavy elements beyond the most stable nuclei, iron. It is while stars are in this region of the HR diagram that they evolve into long period variables of the Mira type and this includes stars of type M and later, S and C types. Figure 4 shows a high resolution spectrum of omicron Ceti (Mira) in the blue region of the spectrum with some of the many lines identified. Note the prominent molecular TiO band around 4590 Angstroms. These type molecular bands (due to TiO) are the

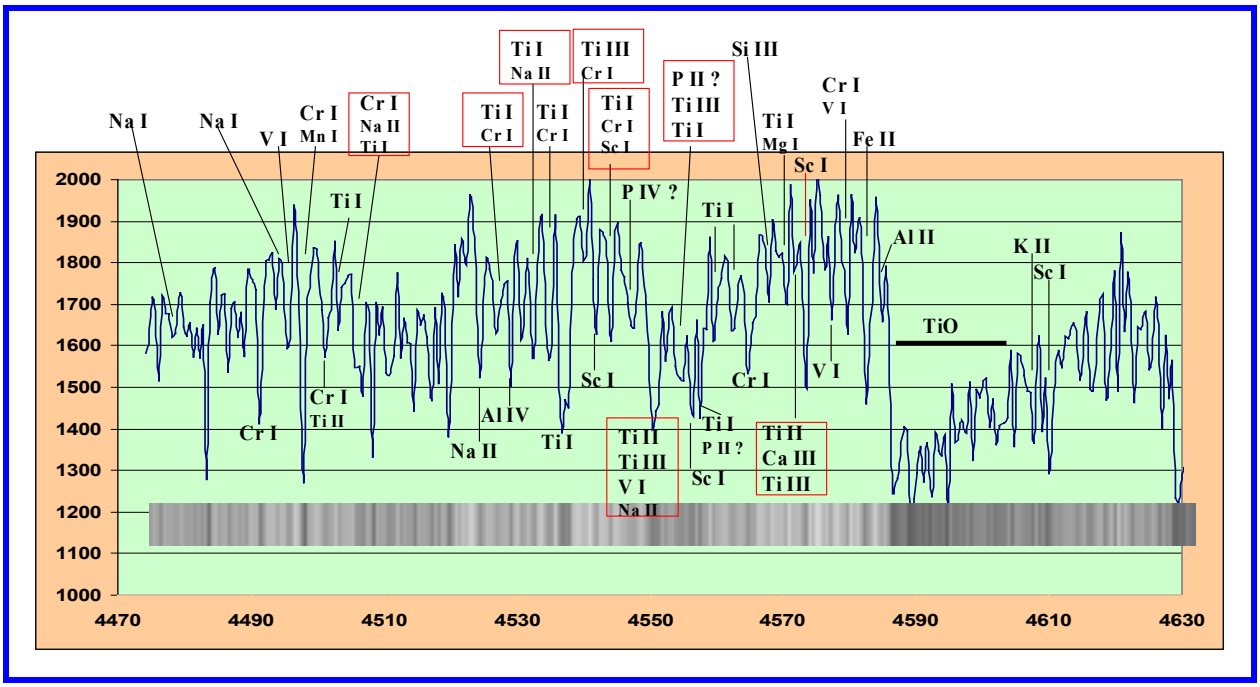


Figure 4. Spectrum of Omicron Ceti obtained near maximum light in the blue region of the spectrum using a moderate resolution grating (1200 line, ~0.5 A/pixel). The large number of lines, many blended, is typical of these type cooler stars as is the molecular TiO bands (one such seen at ~4590 A). These bands give way to ZrO bands in S stars and finally molecular C_2 bands in the C types as the evolution of these long period variables proceed.

first to go as stars evolve into S type (to be replaced by ZrO or ZrS bands). As the evolution proceeds into the C type Mira's, it is not uncommon to see essentially complete disappearance of the blue region of the spectrum due to the very heavy absorption of diatomic carbon (C_2). The ZrO bands remain but can be seen only more toward the red region of the spectrum.

There have been recent studies that suggest that these stars, especially the M type Mira's undergo flare up episodes with a brightening of several tenths to over 1 magnitude, lasting from hours to days. Schaefer (1991) reviewed what was known about these events from the literature and while suggestive, the evidence is not compelling; Maffei and Tosti (2000) performed a similar analysis. The strongest evidence came from a study of results obtained with Hipparcos observations by deLaverny et. al. (1998). Their analysis of thousands of individual observations on 251 Mira's over a 37 month period indicated what appeared to be 51 flare up events in 39 M type Mira's. No similar type flare-ups were observed with S and C type stars but the sample size was small for these type stars, which easily could account for the lack of observed events. De Laverny notes that these events occur in the later M type stars rather than earlier types and suggested that these events could be related to opacity changes that occur with the molecular bands of TiO and/or possibly VO.

Despite the challenges of verifying the existence and frequency of the "microflares" among selected Mira variable stars, it remains possible to speculate on causes. At least three scenarios present themselves: (1) shock induced; (2) magnetically induced, and (3) planet induced events.

(1) Many Mira variables exhibit radio maser emission arising from excited molecules of SiO in the outer atmosphere of such stars. The patchy nature of the bright SiO maser spots seen in VLBI maps varies in response to the Mira optical variation. If a consistent phase for microflares can be established, they could be related to shock propagation and interaction altitude.

(2) The same type of maser observations can be used to deduce magnetic field strengths via Zeeman line splitting. The analogy with solar magnetic phenomena [spots, flares, eruptive prominences, coronal holes and mass ejections] is compelling. However, in analogy to the R CrB phenomenon, brightness variation could also be a consequence of dust formation (fading) and dissipation (brightening) in front of a star's visible hemisphere. Additional observations will be required to discriminate which is occurring. True flare stars include Sun-like red dwarf stars with half the surface temperature and a fraction of the solar mass. These appear to have sizeable starspots and intermittent flaring behavior. In those cases, extensive spots and concentrated fields give rise to high energy output in UV and X-rays. The latter emissions are not seen in the case of Mira variables, suggesting a strong limit to the size and strength of spots. A more "dilute" and large-scale eruptive prominence analogy might suggest measurable changes in mass loss diagnostics, such as the cores of H-alpha or Ca II K, if these could be extensively monitored for microflares (Stencel, R., and Ionson, J., 1979, Stencel, R., 2000).
(3) An interesting speculation involves extending the discovery of extra-solar planets to their role around evolved stars like Mira variables. As the Mira red giant expands and engulfs its Jupiters, several kinds of accretion "fireworks" might accompany digestion (Struck et. al., 2002). However, the duration and frequency would be limited to either orbital periods or one-time events. Existing maser maps would appear to rule out large scale planetary wakes around some Mira variables, but additional observations are always merited.

The approach we took toward this project was to select a group of program stars. Of the 39 M type Mira's described in the deLaverny paper, 20 of them are relatively bright and visible from the northern hemisphere. These along with a variety of brighter S and C type stars were also chosen. The Hipparcos data did not rule out a sample size effect of the S and C types as to why none were observed in these stars. Therefore it was felt to be prudent to include a good size group. The brighter stars were chosen since they represented stars with magnitudes, especially in the Hα region (6562 A) and higher, bright enough such that moderate resolution spectroscopy could be performed as part of the monitoring process. To accomplish this in a semi-automated

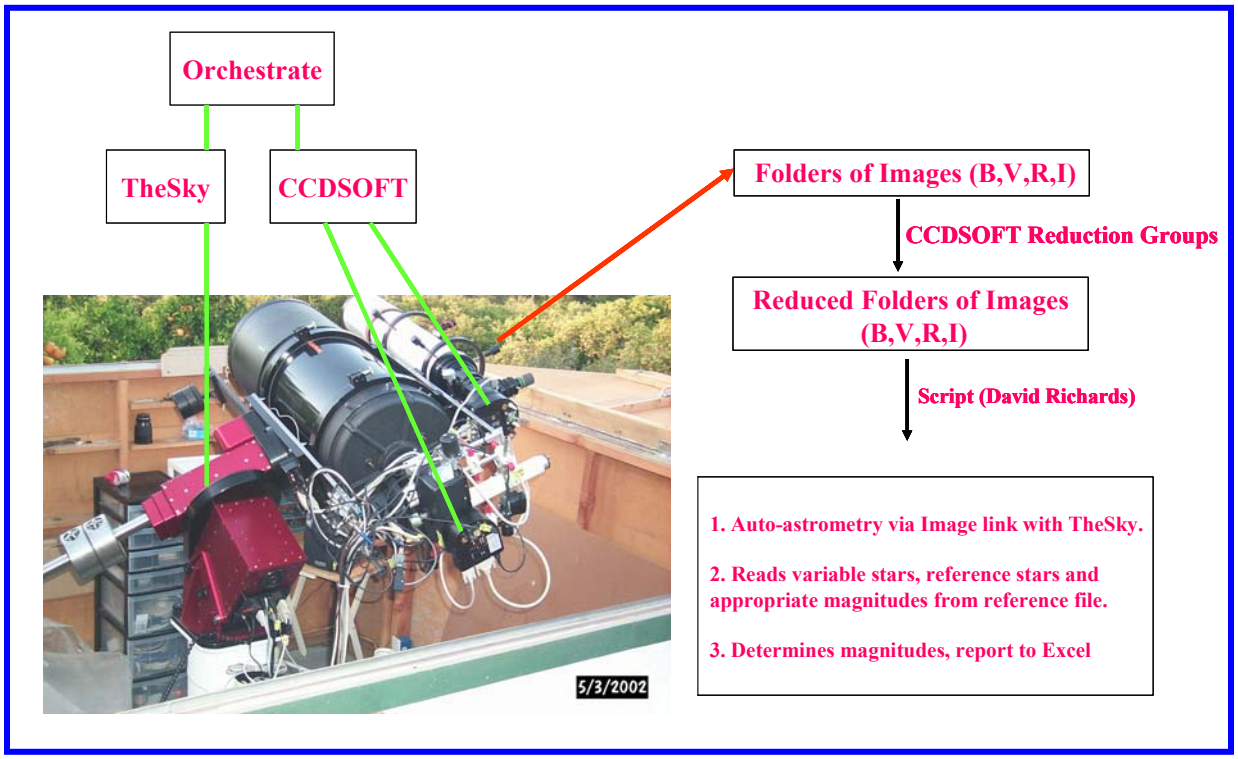


Figure 5. The flow of data acquisition and reduction for variable star monitoring. The imaging camera and filter wheel are controlled by CCDSOFT while the Paramount ME is controlled by TheSky. All of this is under the umbrella of Orchestrate which allows for non-intervention in acquiring images of varying length with different filters, dark subtraction and saving of images. The images are then reduced using CCDSOFT reduction groups routines and finally the use of a visual basic script written by one of the authors completes the data reduction with the magnitudes reported in an Excel format.

manner, the telescope, camera and filter wheel are controlled by a single computer with Orchestrate. Once the images are reduced, a script written by one of the authors (David Richards) runs through the images performing an image link with TheSky. The images obtained in this manner are stamped both with the name of the variable star, since this was how Orchestrate was instructed to find the object, and the position of the image in the sky. This allows TheSky to quickly perform the linkage with its database. Once the astrometric solution is accomplished, the program reads through a reference file with the pertinent data such as

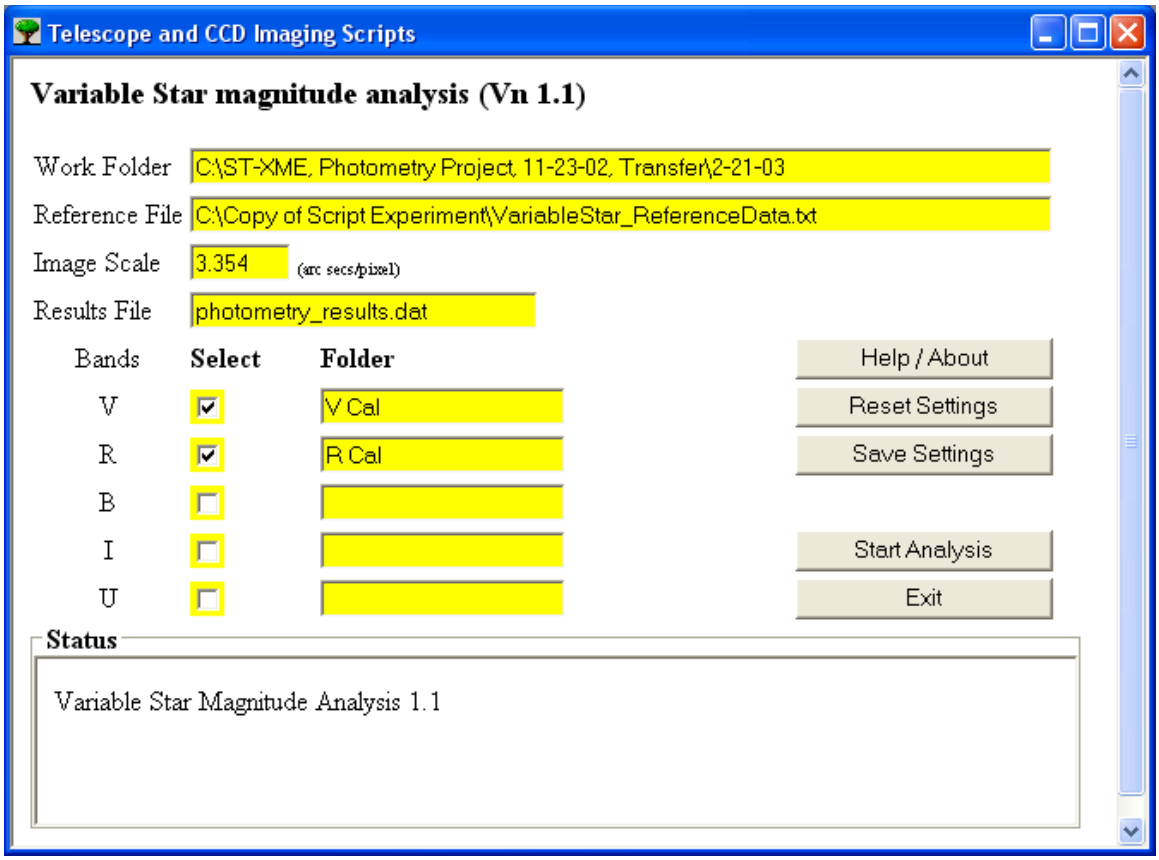


Figure 6. The window which appears when initiating the Variable Star Magnitude Analysis script. Several options are available such as which filters were used with the image sets to be analyzed. All that is required is that a reference file be created, just once, with the reference stars name and corresponding filter magnitudes along with the variable name. This list is flexible and other stars and/or filter set data can be added to be utilized by the script. Also required is the image scale in arc seconds per pixel. The more accurate this value, the faster the image link is performed and the astrometric solution determined.

reference star name and magnitudes along with variable star of interest. Figure 7 shows a portion of the reference file read by the script along with what the output file looks like. The input file is highly flexible, stars and filter magnitudes of reference stars can be added freely if your image sets so require it. This file only needs to be created once, especially convenient for a set of program stars which will have continuous coverage over time. There is no need for entering magnitude information of reference stars in a repeated manner. The results file is readily imported to excel where the various stars and their magnitudes can be plotted, almost in real

time. This is an important aspect of this project, the ability to see changes (flare-ups) quickly and as a result respond to these changes with spectroscopic observations.

A

SV_AND	GSC	2785:1315	V	GSC	2785:1549	7.899	GSC	2785:1090	8.399
SV_AND	GSC	2785:1315	R	GSC	2785:1549	7.59	GSC	2785:1090	8.32
R_CET	GSC	4691:926	V	GSC	4691:808	10.063	GSC	4691:808	10.06
R_CET	GSC	4691:926	R	GSC	4691:808	9.856	GSC	4691:808	9.856

B

Band	Variable	Time	Julian Da	MagV (Ca	MagV (Ra	MagC (Ra	MagK (Ra
V	GCVS W CAS	2:54:29	2452711	9.304	-2.604	-1.678	-1.618
V	GCVS W CAS	2:54:56	2452711	9.328	-2.589	-1.688	-1.595
V	GCVS V365 CAS	2:56:17	2452711	9.107	-1.254	-1.131	-0.64
V	GCVS V365 CAS	2:56:29	2452711	9.158	-1.248	-1.176	-0.65

Figure 7. Part A shows a portion of the reference input file which contains data to be read from the script such as the name of the variable star and the V and R magnitudes of 2 reference stars. Part B shows the output file which calculates the magnitude of the variable star along with all the raw magnitudes, Julian day, time, etc. The results file separates the filter sets being examined. For example in this case, the V magnitudes are shown first followed by a set of data for the R magnitude. U, B and I data could easily be added. You would only need to modify the reference star file to include the appropriate magnitudes at the appropriate filters and of course obtain the images with the desired filter(s).

The project has been underway now for only about 4 months and involves a total of 96 stars, 20 M type Mira's, 19 S types and the remainder C types. While there are certainly many more of these type stars, only those that had a significant part of their light curve under magnitude 8 were considered. This was because of magnitude limitations in the spectroscopy part of the project. Fortunately, these stars are much brighter in the R and I bands, often by 2-4 magnitudes when compared to their V magnitudes and many of the interesting molecular features are found in this region of the spectrum. Not all of the 96 stars have been observed yet since parts of the sky are not visible at this time of year. Gradually with time these program stars as they rotate into view, will be added to the list. Figure 8 displays 2 typical graphs obtained over the past several months for V Mon (M type) and R Gem (S type). The photometric analysis involves using 2 different reference stars. Their constant nature is readily discerned over the time period by the horizontal slope of their light curves, both in the V and R bands. After considerable effort, magnitudes are now determined at the 0.02 magnitude level. Thus any flare-ups in the range of 0.1 and above should be readily discerned.

Early on it was felt that semi-automating the process was the only way to go. The use of a mount such as the Paramount along with the Suite of software by Software Bisque got the project 80% of the way there. It turns out the real consumer of time in these efforts was the magnitude determinations. This took far longer than the actual acquiring and processing of the images. Fortunately, TheSky in conjunction with CCDSOFT lends itself to scripting and a script was put together that automated the magnitude determinations. It is now not even necessary to view any of the images. To give an example of how this has streamlined the effort, on a typical night using Orchestrate to control the telescope, camera and filter wheel, 40 stars, visible at the time, are imaged in duplicate in each of the V and R bands. This takes about 1 hour. Reduction of the images using image reduction groups in CCDSOFT takes another 5 minutes. The script that determines the magnitudes takes about 10 minutes to churn its way through all the images. Within another 20 minutes, the data, via Excel, has been added to each variable stars growing light curve. Thus in less than 2 hours all of the program stars have been observed and their

results tallied. Until more of your program stars rotate into view, one is free to pursue spectroscopic examination of the program stars, establishing baseline observations.

Another goal of this effort during the upcoming months will be to standardize the reference stars in each of the fields using the Landolt standards (Landolt, 1983). Once this is done all previous and subsequent observations of the variable stars will have their magnitudes expressed in absolute Johnson-Cousins magnitudes.

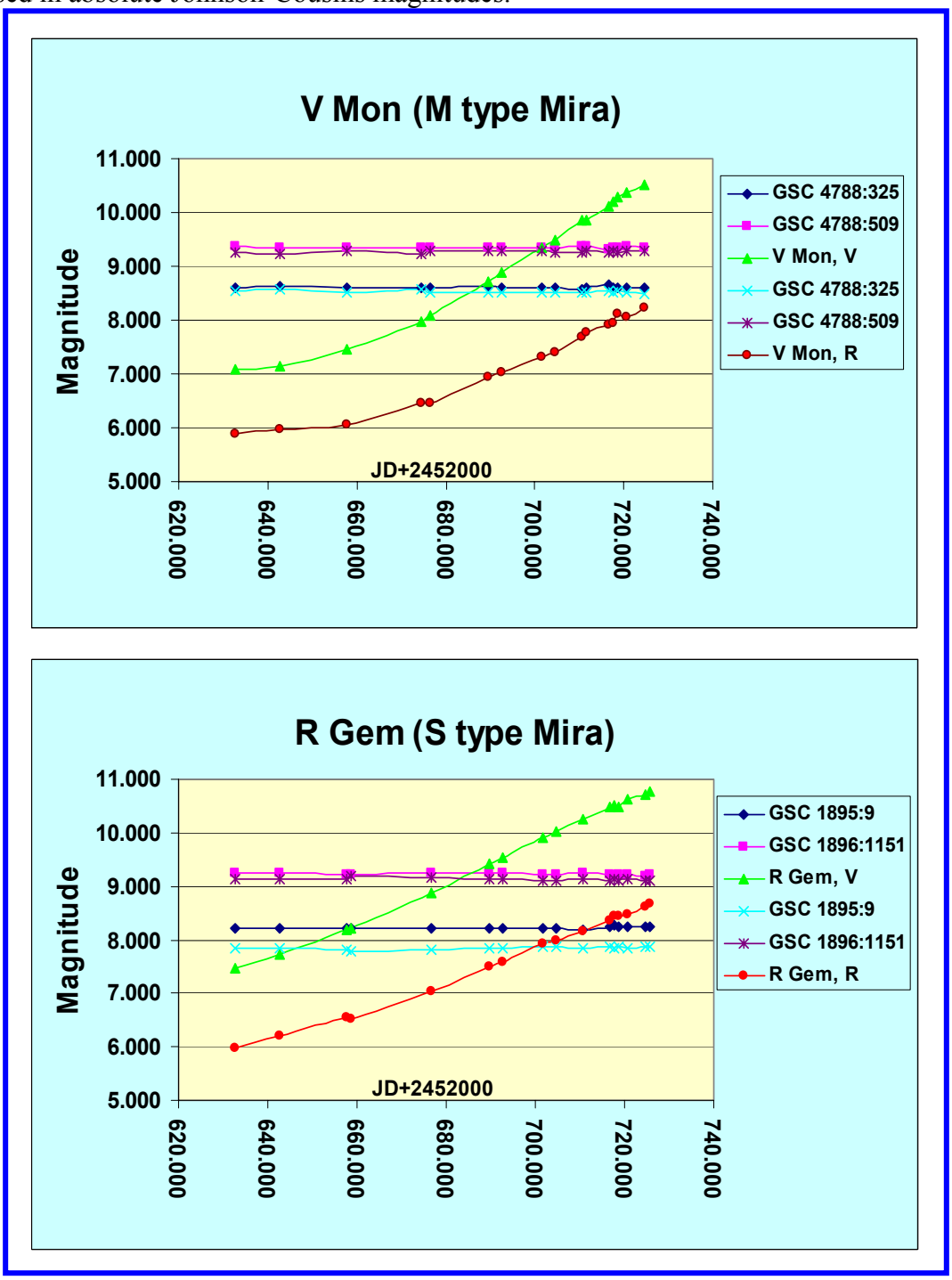


Figure 8. Typical light curves obtained for the first several months of the project. Shown above is a typical M type Mira, V Mon and below a typical S type, R Gem. Along the x-axis is plotted Julian day and magnitude is shown on the y-axis. The period of V Mon from the AAVSO database is 340 days. No data is available for R Gem.

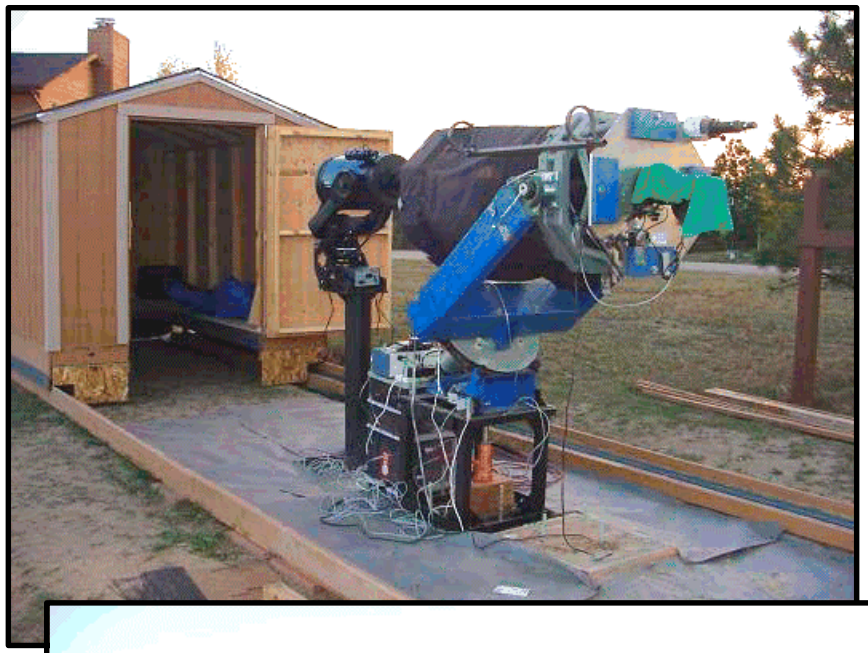
3. Summary

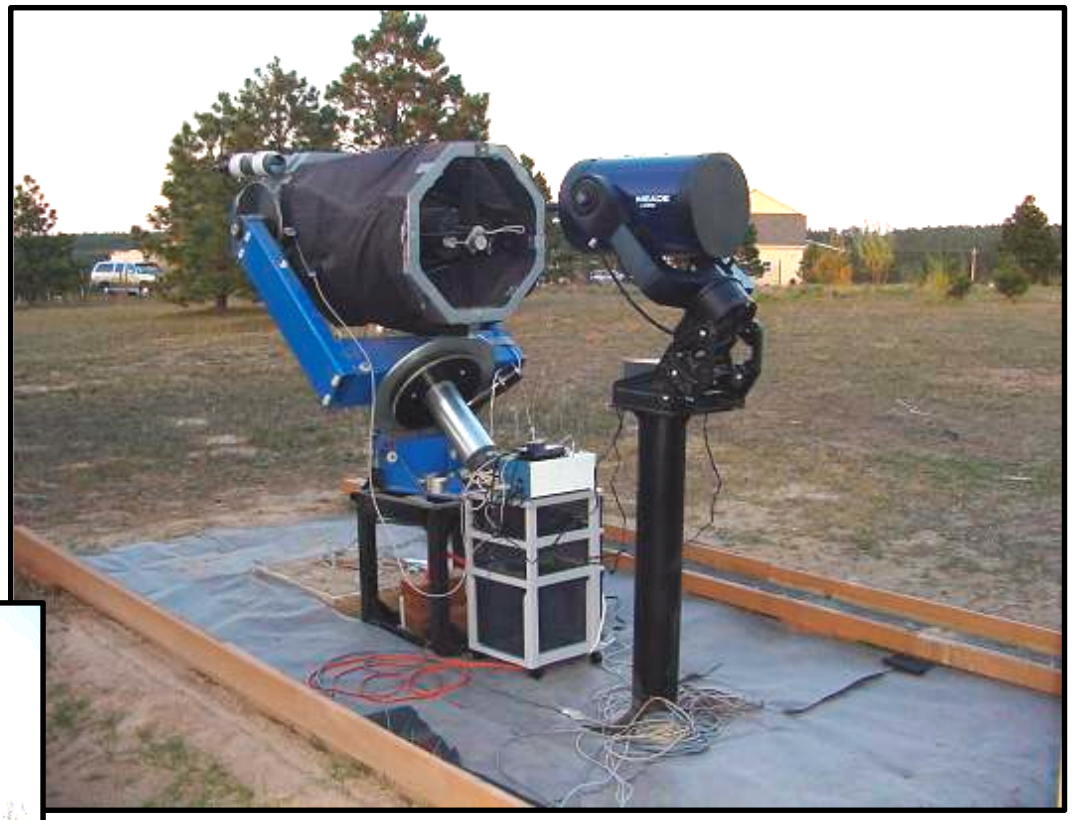
We have described the initiation of a program to follow Mira type long period variables to attempt confirmation of flare-up episodes. If these flare-ups are observed, to follow up with spectroscopic observations of moderate resolution. A group of 96 stars are part of the program and photometric observations are being conducted, currently, in the V and R bands. The photometric observations and data reduction have been automated to a large extend using software aimed at control of telescope-camera -filter wheel for image acquisition and image reduction. A script is described which proceeds to carry out the magnitude calculations. Hands-on analysis is kept to a minimum. This script could find wider use among those in the amateur community interested in variable star work as it removes the most time consuming part of the analysis.

Acknowledgments

The authors wish to acknowledge the assistance of Tom Bisque of Software Bisque for many useful discussions and help with the scripts.

The Palmer Divide Observatory





The Palmer Divide Observatory is located about 25 miles north of Colorado Springs, CO, at an elevation of 7500 feet. It sits at nearly the peak of a large ridge (The Palmer Divide) extending east from the Front Range of the Rocky Mountains.

The current instruments are a 0.5m f/8.1 Ritchey-Chretien paired with a Finger Lakes Instrumentation IMG-1001E camera and FLI filterwheel with BVRC(lear) filters. The other telescope is a Meade LX-200 12”, which is paired with an SBIG ST-9E and Optec MaxFilter (VRC). Both telescopes can be run simultaneously via computers located in my house about 100ft. away.

The building (modified Tuff-Shed) uses 4” steel casters and angle iron to roll to/from the observing position.