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A Pellicle Autoguider for the DSS-7 Spectrograph

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Abstract

A pellicle beamsplitter has been developed to guide long exposures for a SBIG DSS-7 spectrograph on a C-14 telescope. The motivation for this work was to get good quality classification spectra for variable stars in the 12+ magnitude range. The poster will discuss design tradeoffs, physical implementation, and include sample results.

1. Introduction

The SBIG DSS-7™ Spectrograph provides a combination of useful resolution (R~400) and unusually high efficiency nearing 40% (Holmes 2005).

This combination significantly extends the magnitude limit of spectroscopic observations that can be made with 20-40cm class telescopes. The resolution is more than sufficient for high quality stellar classification work and is particularly well suited for red variable stars.

2. Background

Stellar classification was the major focus of observational astronomy in the period from 1870 to 1920, culminating with the remarkable work of Annie Jump Cannon in the Henry Draper survey.

These spectra stop at about 9th magnitude, and have limited red coverage due the limitations of the instrumentation and photographic plates.

Despite the passage of newly 100 years, a quick check of the SIMBAD system showed only some 560K objects with spectral classifications.

In particular, many red objects that are routinely monitored by AAVSO observers do not have published classifications.

Until the introduction of the DSS7 there were limited opportunities to explore the spectra of objects below 8th magnitude.

On one side was the SBIG SGS instrument, which provided excellent resolution, but is limited to about 9th magnitude at 1-hour exposure.

On the other side was the use of a grism, objective prism, or simple diffraction grating. These have limited resolution (typically R~80).

The DSS-7, in contrast, can reach 9th magnitude in about 30 seconds at R~400 and allows much better background subtraction than a simple grating. And it is matched with a highly red sensitive camera.

3. Instrumentation

The DSS-7 presents a slit onto which the star image must be maintained during the exposure. On a C-14 telescope, this slit subtends approximately 2.2 arc seconds at F13.

The instrument provides a imaging mode for initial positioning, but has no provision for guiding during the exposure.

While I have no doubt that some amateurs have systems that are drift free for long periods of time, I don't. Hence the challenge was to find a way to exploit the efficiency inherent in the device by enabling long guided exposures.

Note that while the DSS-7 guiding problem is very similar to that found in normal imaging, it is not exactly the same. The difference is that the star position is absolutely fixed, you cannot slide the image back and forth to get a guide star on the guide chip.

The second point is a corollary of the first, there will always be a guide star at a fixed position i.e., the star on the slit.

There are several standard ways of guiding long duration images: Independent guide scope, off-axis guide camera, a coplanar guider and on-axis guiders.

In my case I found that differential flexure limited exposures to 5 minutes using my co-mounted C-8/ST7 as independent auto-guider.

The use of a coplanar guide chip (the SBIG self guiding design) does apply because the entire image space is illuminated by the dispersed spectrum.

In a meeting with Dr. Russ Genet, Tom Smith, Dr. Dale Mais, Dr. Eric Crane, John Pye, Dr. Alan Holmes of SBIG and myself held at Orion Observatory in August of 2006, we considered a number of alternatives for guiding the DSS-7.

These concepts included off-axis, near-axis and on-axis alternatives. The near-axis idea, proposed by Tom Smith, was to use a hole in the middle of a flip mirror. The on-axis concept, which I pursued after the meeting, was to make use of a simple optical element called a "pellicle". In retrospect, I am not sure who introduced this idea, but Alan Holmes made some comment about it, so I will give him credit.

Pellicles are thin films of Nitrocellulose, which can be used as optical windows and as beamsplitters.

According to the information provided by the Edmund Optics catalog, they have a flat spectral transmission over the 400-800nm range of the spectrograph.

Using a pellicle as a beamsplitter, one can guide on the same star that illuminates the spectrograph slit. Essentially this becomes an on-axis guider.

4. Design considerations

Using a beamsplitter reduces the amount of light reaching the spectrograph. Since my objective was to image dim stars, I wanted the least light loss consistent with guiding requirements.

The practical limit for using the DSS-7 is reached when the star image obtained using the imaging mode is too dim to allow convenient positioning onto the slit using short exposures (1-5 seconds).

The imaging mode of the DSS uses a zero order reflection from the grating as its mirror. This grating reflects about 15% in zero order. Hence the DSS image is about two magnitudes fainter than an equivalent direct image.

As a practical matter, I have found that 14^{th} Magnitude is about the limit for star positioning. In this case, a 14^{th} magnitude star has the apparent brightness of a 16^{th} magnitude star in the DSS imaging mode. This is about the limit of a 5 second integration.

My goal was to provide the auto-guider with an image of similar brightness. Using the rule of thumb that 10^{th} magnitude = 0.1 seconds for guiding, an effective 16^{th} magnitude requires a guide time of about 25 seconds.

The choice of beamsplitter ratios, however, is rather limited. You can get an uncoated pellicle that reflects 8% or a coated one that reflects 33%, 40% or 50%.

What I wanted was 15% to match the grating. I choose the 8% pellicle figuring I would rather have more transmission and a longer guide cycle.

5. Construction

A TECHSPEC™ Pellicle Beamsplitter (NT39-478) was obtained from Edmund Industrial Optics. The pellicle is mounted on an aluminum ring 35-mm in diameter and 4.7 mm thick.

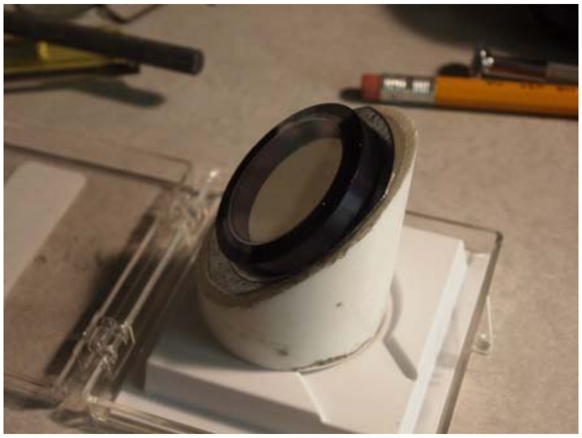

Figure 1. The 8% pellicle on its mounting assembly.

An older Celestron® off-axis guider body was recycled to hold the assembly. The pickoff mirror and field stop were easily removed leaving a 1.5 inch main body with a 1.25 inch side tube.

To mount the pellicle, I used a section of 1.25 PVC plumbing pipe. The outside diameter of this provided a close fit to the inside of the guider body.

A 45-degree cut was made using a miter box. The pellicle ring was attached to a metal plate and then to the finished face with superglue. The glue provides an adequate bond between the aluminum ring and PVC plastic, but it can be broken when needed.

Figure 2. Looking through the pellicle.

Note that while the clear aperture of the pellicle is 25mm, it is reduced to an ellipse of about 17 by 25 mm when mounted at 45 degrees. The mounting ring itself is about 4 mm high, which also slightly vignettes the beam.

In my system, the pellicle sees an f/13 beam. The 17 millimeter light cone allows a maximum back distance of about 220mm to fully illuminate an on-axis star.

Collimating this simple assembly with the spectrograph proved more difficult than I had envisioned. A series of thumbscrews were threaded into the housing to push the inner tube for collimation.

Final alignment was done on a C-5 telescope. A crosshair eyepiece was mounted in the pellicle tube and another mounted in a collimated diagonal mounted behind the assembly. Tweaking the thumbscrews brought the alignment to within 5 arc minutes, within the field of the guide camera.

6. Telescope Installation

First Light was achieved on October 26, 2007 using the assembly shown in Figure 3 mounted on the C-14. A piggybacked C-8 provides photometry.

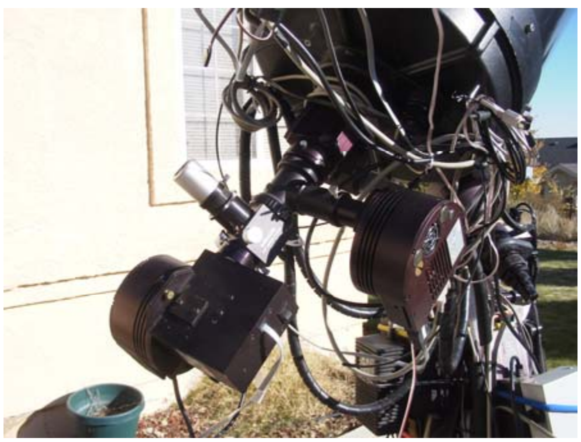

Figure 3. The pellicle is at the top with a ST-7E camera mounted on the long arm to the right. It is followed by a flip mirror and the DSS-7 assembly with its ST7-ME.

The initial test used the ST-7E guide camera at prime focus, but this was later changed to about f6 with the inclusion of a focal reducer. This also allowed the guide camera to move closer to the axis.

7. Observations

The image quality at the guide camera was not quite as good as I expected. I attribute some of this to unwanted reflections in my mounting hardware, but some loss in quality may be due to the pellicle. Significant distortions and reflections can be seen in Figure 4.

The pellicle surface is rated at 1 wave per inch. My FWHM at the spectrograph is about 5 arc seconds, and about 8 at the guider.

There was no visible degradation in the transmitted image, either though the spectrograph or in the eyepiece at high magnification.

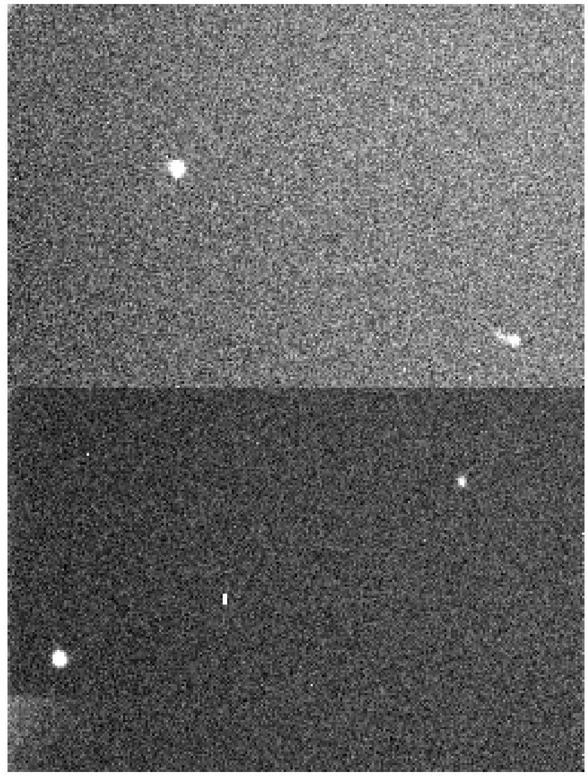

Figure 4. Peliicle guider image above and DSS image below. Vertical axis is flipped.

I have done guiding up to 1 hour and the star remains in the slit at the end of the exposure, proving that any remaining local flexure is negligible. Figures 5 and 6 illustrate this.

Figure 5. After 60 minutes of guiding, star UV Tau is still centered on the slit.

The image brightness was measured several times and was consistent with my expectations. The guider star images are about ½ as bright as the spectrograph stars images at equivalent focal lengths.

This combination of effects has meant that guiding on stars at the limit of the spectrograph has proved more difficult than I had anticipated. I have had to use exposures beyond 10 seconds with deep binning to track on the target star at Magnitude 13. On my G-11 mount this can lead to quite a bit of image wander.

For slightly brighter objects, the guider has worked very well, allowing convenient long duration spectrometry of stars at Magnitude 12 and guiding on galaxy cores such as M66. It also appears well suited for polarimetric and time series spectrometry where maintaining the exact pixel position is necessary. (Figure 7)

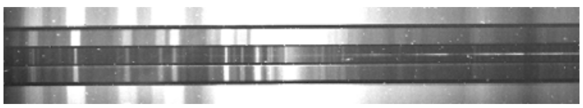

Figure 6. 2400-second pellicle guided DSS spectrum of UV TAU. Strong undulating TiO bands at middle right show ~M6 type. Skyglow accounts for all other lines. Simultaneous photometry showed the V magnitude was below 15, and I-band magnitude near 12.

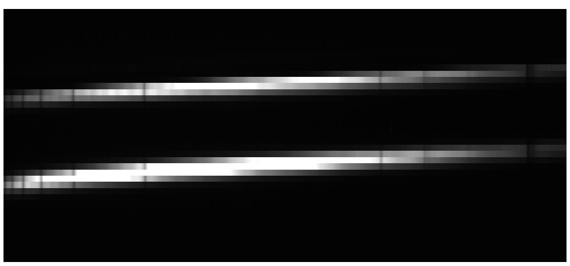

Figure 7. Direct addition of two spectra of Alpha And. A Savart calcite plate before the slit creates parallel spectra of opposite polarizations. Note that spectra are on precisely the same pixels in both exposures as indicated by the narrow central bands. This also illustrates potential for precision time series spectroscopy.

8. Future Plans

I am in the process of replacing the ST-7E as a guide camera with a much lighter weight SBIG remote guide head and shortening the entire assembly to about 6 inches. This in turn necessitates shortening the arm of the guider body to allow the camera to reach focus. With this I am intending to continue my work on classification of AAVSO variable stars and development of a spectro-polarimetric capability for the DSS7.

9. Conclusions

A pellicle beamsplitter works very well with the DSS7 spectrograph to allow long duration spectroscopy with an average quality mount.

Guiding on the target star makes this process no more difficult to set up than using separate guide scope.

The independent guider allows long duration time series spectroscopy below 10^{th} magnitude.

The choice of an 8% pellicle is probably not the optimal one. I intend to try a 33% one in the future to create a better balance between the guide star brightness and the spectrometer. The faster guiding may well make up for a 25% reduction in slit illumination.

Using one of the available 2-inch pellicles would provide an easy way to guide imaging without the usual problems of finding a guide star. This could be mounted in a modified Meade flip mirror assembly as done by Smith (2006).

10. Acknowledgements

I would like to acknowledge the help of Eric Crane, Russ Genet, Alan Holmes, Dale Mais, John Pye and Tom Smith for their design suggestions and encouragement in this project.

11. Acknowledgments

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