pAggieSpec: A Low-Resolution, Commercial Lens, Optical Spectrograph

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Abstract

This summer, we were tasked with the design, construction and testing of a low-resolution, optical spectrograph. The preliminary Aggie Spectrograph (pAggieSpec), is a low-cost instrument that uses off-the-shelf Nikon™ lenses, a Mercury calibration lamp, and two CCD cameras. pAggieSpec is the first step in the creation of an instrument that will allow institutions to provide quality tools inexpensively. We found that pAggieSpec provides reliable spectra within the 4000-6000Å range. Further testing needs to be done to extend the coverage over the full visible spectral range (4000-7000Å).

Introduction

When designing an instrument, the first thing to consider is the science goal. For example, a possible goal might be to catalog the spectral types of various stars. To that end, one can perform spectroscopy over the visible wavelengths. A low-resolution spectrograph can accomplish this task. The resources necessary to build a spectrograph, however, are often exorbitant. Custom lenses can cost upwards of twenty thousand dollars and can take months to design and build. High quality CCD cameras can cost fifty thousand dollars. The expensive CCDs do offer superior quantum efficiency, and the custom lenses would provide extensive wavelength coverage. The coverage is wasted, however, outside of the visible range and that level of quantum efficiency simply is not necessary to accomplish all science goals. Commercial camera lenses and lower-quality CCDs can provide enough throughput over a large enough spectral range to perform the spectroscopy at a fraction of the cost, both in money and time.

The Spectrograph

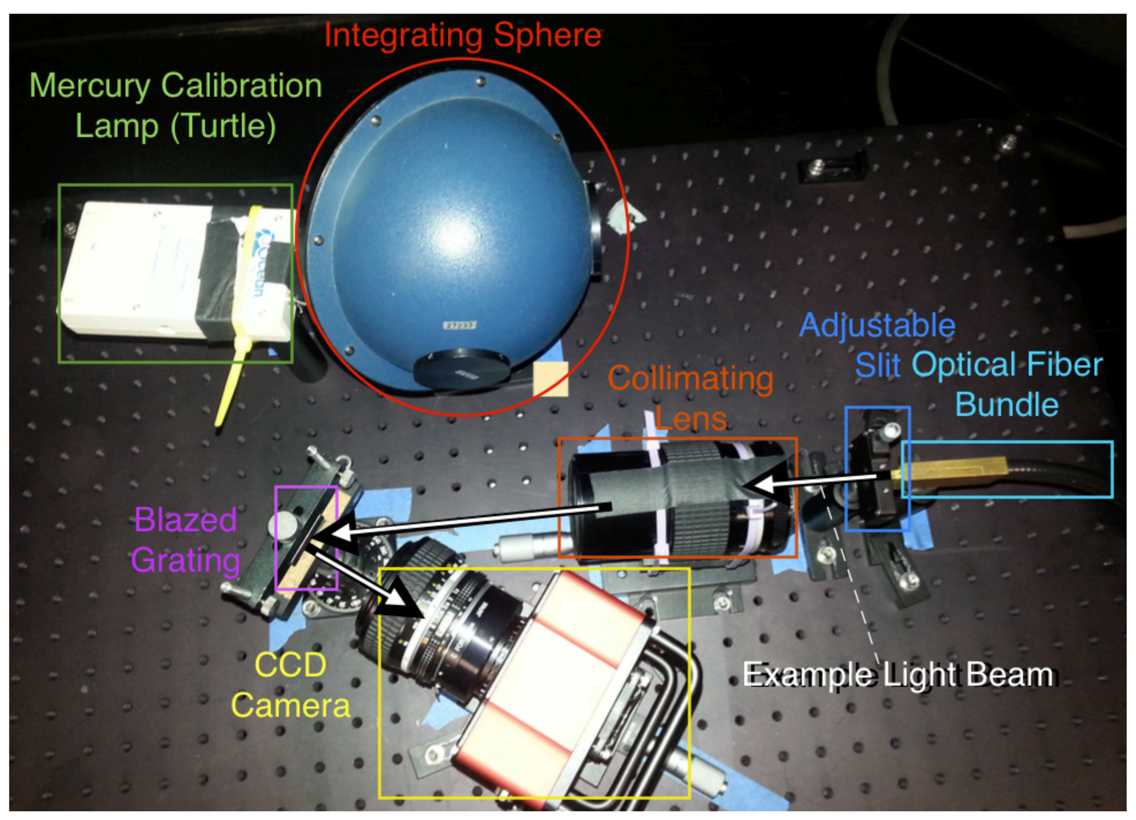

Figure 1 . pAggieSpec with each component marked. Light follows the path marked by the white arrows originating from the optical fiber bundle and ending at the CCD camera.

pAggieSpec consists of several components. The Mercury lamp serves as a calibration source, allowing the user to create a wavelength solution that can be applied to spectra, changing it from pixel space to wavelength space.. The integrating sphere serves two purposes. Firstly, it acts as a filter, decreasing the intensity from the Mercury lamp. Secondly, it transforms the light from the calibration source into spherical wavefronts, creating a cleaner image to use in calibration. The optical fiber bundle consists of ten individual optical fibers. Only nine of these fibers were used. They were used in both imaging and calibration. The adjustable slit, set at 40 microns for the early science, also serves a few purposes. It can be used as a selection mechanism by isolating the target on the sky, although in this case the fiber bundle also serves this purpose. Also, it defines the size of the image projected on the detector. The image size is also defined by the magnification of the optics, as well as optical aberrations.

Light leaves the slit in the shape of a cone. The collimating lens changes the shape of the beam into a cylinder with a defined radius. The grating serves to separate the incident light into its wavelength components and reflects them into the lens attached to the CCD. The angle at which the grating is blazed defines how the different wavelengths are reflected. This grating was blazed at 500nm, thus its throughput is very good in the green wavelengths and worse at both the red and blue wavelengths. The lens in front of the CCD serves to help focus the light onto the small CCD chip located inside the red case.

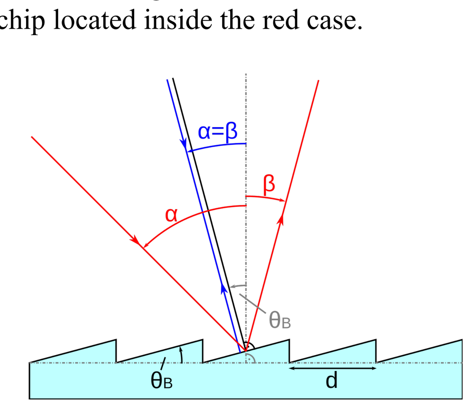

Figure 2. A diagram illustrating how a blazed grating works. Light strikes the grating along the path of the red line associated with the incident angle (α). It is diffracted along the other red line, the diffraction angle (β). θ_B represents the blazed angle. d is the distance between the grooves.
https://en.wikipedia.org/wiki/Blazed_grating

Acquisition and Guide Camera (AGC)

The Acquisition and Guide Camera (AGC) provides the user the ability to manually track a target star. It is housed inside of an aluminum case and is attached to the telescope's interface plate. Light enters the aperture in the attachment plate and strikes the dichroic. The dichroic reflects visible light while allowing infrared light to be transmitted to the guidance CCD. The infrared light and the camera operation software, CCDOps, create an image of the field of view that allows the user to guide and track. The reflected visible light is directed into a fiber optic bundle attached to pAggieSpec. The dark material on the inside of the case serves to lessen reflected and scattered light inside the apparatus.

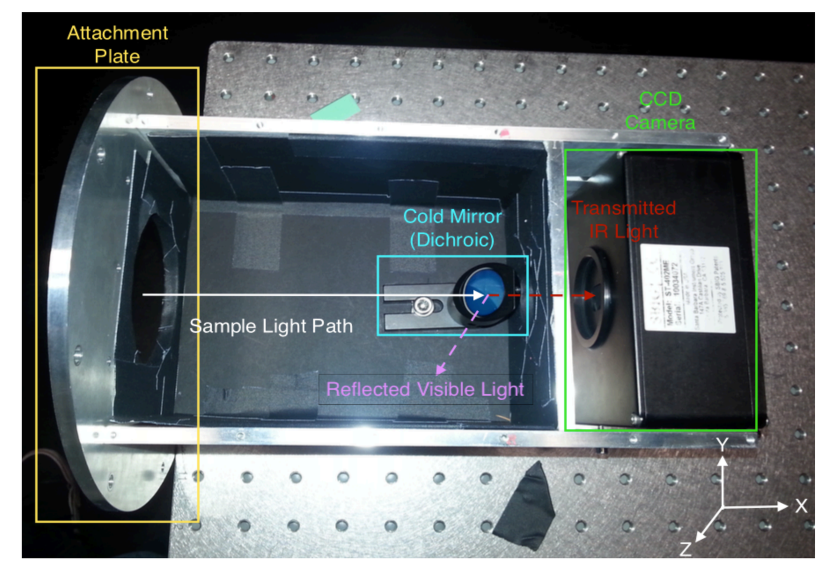

Figure 3. The Acquisition and Guide Camera

Spectrograph Testing

We used Python scripts to run tests to investigate various aspects of the spectrograph such as optimal focal lengths of the lenses, estimations of the throughput at different wavelengths, and optimal distances between components.

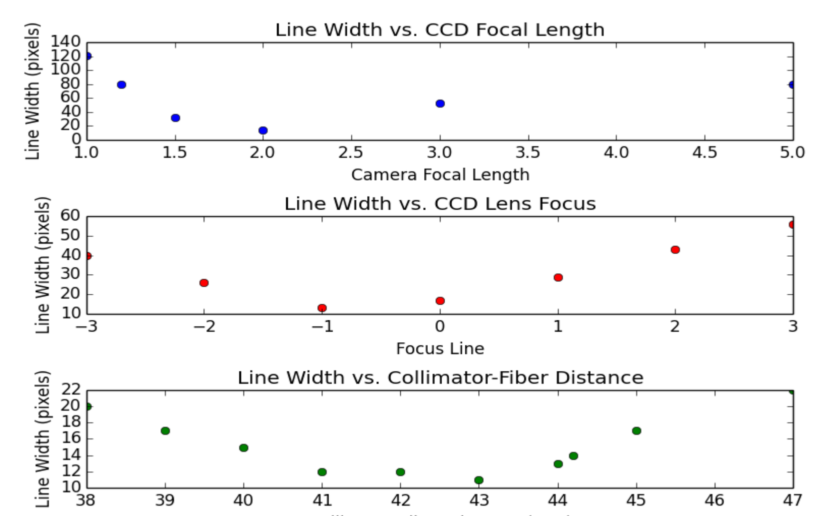

Figure 4. Results of various focusing tests. The best focuses are represented by the smallest line widths which occur at 2.0, 0, and 42 respectively.

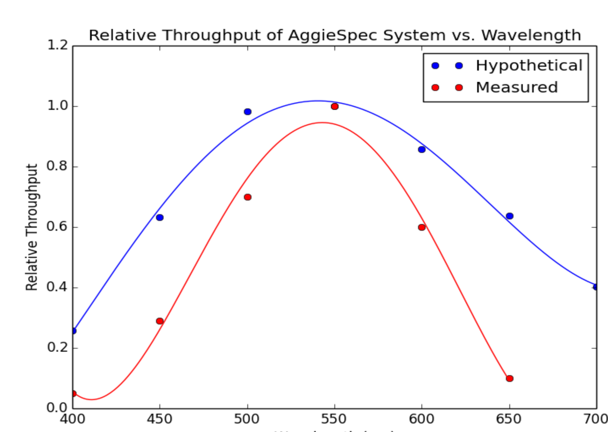

Figure 5. The throughput of the pAggieSpec system prior to inclusion of the dichroic. The measured throughput is less than the hypothetical in all cases. We find, however, that when used in the field we lost more red light and less blue light than expected. We believe this is due to the fact that the flashlight used to make this graph had little emission in the blue wavelengths.

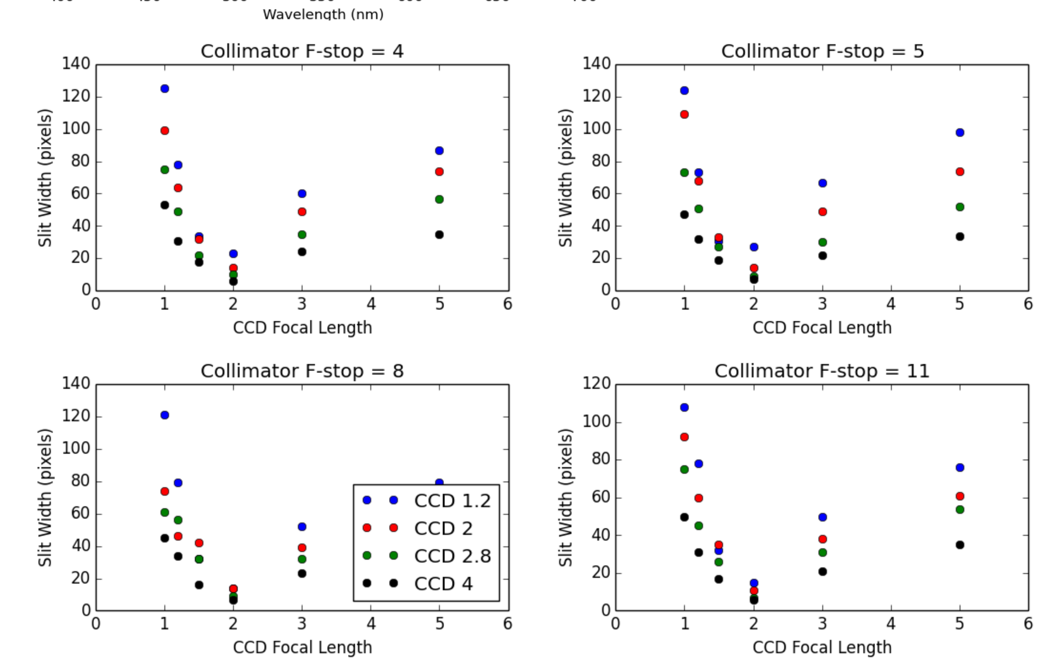

Figure 6. Results of various f-stop combinations on the Nikon™ lenses. The optimal combinations are represented by the smallest slit widths, which occurs at a CCD focal length of 2 in all cases.

Early Science

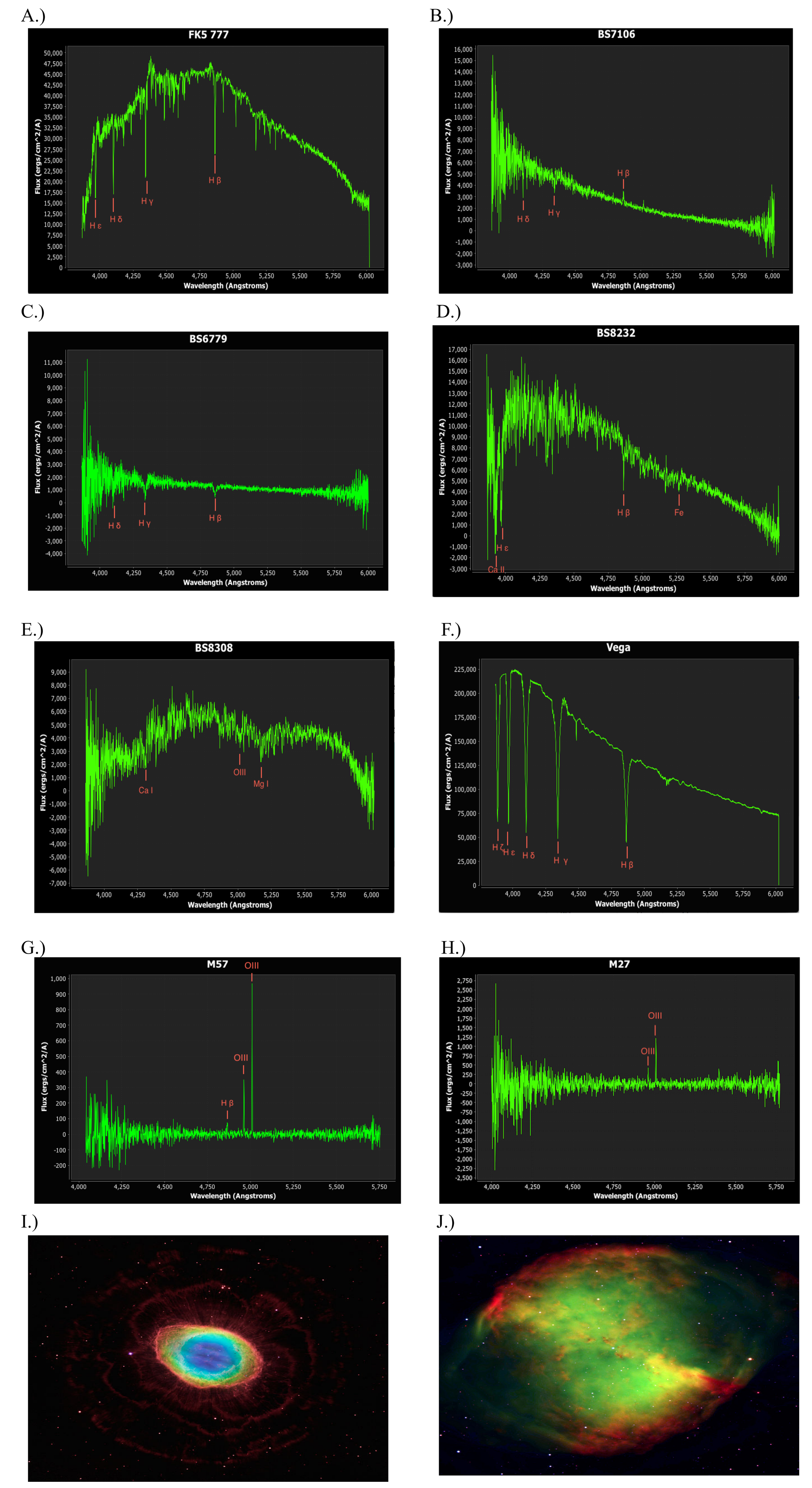

Figure 7. A.) FK5 777 (A2Ia Star) B.) BS7106 (B8II-IIIep Star) C.) BS6779 (B9.5V Star) D.) BS8232 (G0Ib star) E.) BS8308 (K2Ib-II star) F.) Vega (A0Va star) G.) M57 Spectrum H.) M27 Spectrum I.) M57 Ring Nebula (https://en.wikipedia.org/wiki/Ring_Nebula) J.) M27 Dumbbell Nebula (https://en.wikipedia.org/wiki/Dumbbell_Nebula)

Conclusions

pAggieSpec demonstrates the capacity of using commercial lenses to accomplish spectroscopy of bright stars while simultaneously reducing the cost of the spectrograph. As with most things, however, reducing the cost has side effects. This rendering of pAggieSpec experiences major loss of light in the red wavelengths for unknown reasons. Possible explanations are: the dichroic reduces the red light reflected into the fiber bundle, the Nikon™ lenses have lower throughput in the red wavelengths than expected, or the aperture of the camera lens may have blocked the light due to the camera's angle. Further investigation is required to either prove or refute these possibilities. Furthermore, some features can be updated to make the system more user friendly, such as putting the dichroic and CCD in the AGC on movable mounts. Despite these issues we consider pAggieSpec to be a success and look forward to future iterations.

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