

A CCD Spectrometer for One Dollar

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Abstract. We describe preliminary tests on a very low-cost system for obtaining stellar spectra for instructional use in an introductory astronomy laboratory. CCD imaging with small telescopes is now commonplace and relatively inexpensive. Giving students direct experience taking stellar spectra, however, is much more difficult, and the equipment can easily be out of reach for smaller institutions, especially if one wants to give the experience to large numbers of students. We have performed preliminary tests on an extremely low-cost (about \$1.00) objective grating that can be coupled with an existing CCD camera or commercial digital single-lens reflex (DSLR) camera and a small telescope typical of introductory astronomy labs. With this equipment we believe it is possible for introductory astronomy students to take stellar spectra that are of high enough quality to distinguish between many MK spectral classes, or to determine standard *B* and *V* magnitudes. We present observational tests of this objective grating used on an 8" Schmidt-Cassegrain with a low-end, consumer DSLR camera. Some low-cost strategies for reducing the raw data are compared, with an eye toward projects ranging from individual undergraduate research projects to use by many students in a non-majors introductory astronomy lab. Toward this end we compare various trade offs between complexity of the observing and data reduction processes and the usefulness of the final results. We also describe some undergraduate astronomy education projects that this system could potentially be used for. Some of these projects could involve data-sharing collaborations between students at different institutions.

1. Introduction

The basic concept we are investigating is to make, by printing a pattern of bars onto acetate with a laser printer, a low-dispersion diffraction grating suitable for the *objective* of a small telescope. The objective grating spectra which result are then imaged with a CCD camera placed at the prime focus of the telescope, and the data reduced and calibrated.

We have performed our test observations with an ordinary Celestron 8" Schmidt Cassegrain with a simple clock drive but no separate guide telescope (all of our observations are tracked but unguided, and thus limited to short exposures). The CCD detector used was a low-end commercial digital single-lens reflex (DSLR) camera, purchased new for about \$500. We made this choice even though we have available a more sophisticated, thermoelectrically-cooled camera designed for astronomical use, because a goal of this study is to see whether it is practical for an entire astronomy lab to be inexpensively outfitted for this capability. And so we have tried to keep the cost as low as possible.

2. The Grating

A Hewlett Packard HP4000N 600 dpi laser printer was used to print gratings of 100, 150, 200 and 300 lines/inch. These gratings were examined with a microscope and tested with a HeNe laser. Even at half the resolution of the laser printer, a usable grating resulted, although the throughput was greatly diminished over a lower-resolution grating. For the test observations described below, a 200 line/inch grating was used.

3. The Telescope, Detector, and Calibration Equipment

For the observations presented here an 8-inch aperture, 2.03 m focal length Schmidt-Cassegrain telescope was used. Neither the corrector plate nor the mirror were equipped with interference coatings. The telescope was driven, but not guided. The detector was a Nikon D40 DSLR camera, which uses a Sony 3008×2000 pixel CCD array, of size 23.7 mm \times 15.6 mm at the focal plane.

We used simple, inexpensive equipment to obtain calibration data. To obtain “dome flats,” we used a defocused Kodak slide projector (which uses a 300 W quartz lamp) to illuminate a white screen placed a few feet from the objective of the telescope. We set up quartz and emission line sources 20 m away from the telescope, covered by all but a small pinhole with a sheet of black mat board, in order to produce an “artificial star.” For the quartz lamp source we used a krypton-bulb flashlight and we used a dark-room safe-light, low-pressure sodium lamp as the emission-line source for wavelength calibration.

4. Observations and Data Reduction

On the night June 7–8, 2010, we observed the stars α Lyr and γ UMa (both A0 V) and γ Dra (K5 III). α Lyr was chosen as the standard star, and the other two stars were chosen to cover a wide range of spectral type. The entire observing program for this set of data, including all calibration frames, required less than two hours of observing time. The setup and take down time combined added roughly one hour of additional time. All observations were made from Appleton, Wisconsin, under moderately light-polluted conditions.

We used IRAF to reduce and calibrate the data presented. The Nikon RAW format data files were converted to FITS format (necessary for IRAF) by the freeware program ImageTOOLSca (see below). With a few exceptions arising from the slitless nature of these spectra, the reduction procedures we used are typical for CCD spectrographic data.

5. Low-Cost Software for Data Reduction

IRAF has many advantages for the reduction and analysis of the data, even for beginning students. It is free and can now be installed fairly easily on nearly any platform. The experience that students gain using it is directly applicable if they are to ever do research in astronomy. The disadvantage, of course, is its notoriously steep learning curve. But the complexity of IRAF is the very aspect that allows the instructor to

pre-package much of the work by writing scripts for students to use, thus picking and choosing how much of this mountain they expect the students to climb.

ImageTOOLSca is a low-cost software package that can be used to do basic CCD reduction, such as bias and dark subtraction and flat fielding. Probably its most useful feature, however, is that it can efficiently batch-convert most digital camera raw data formats to FITS format, and it correctly reads and writes FITS headers.

ImageJ is freeware that can be used to do much of the data reductions, in conjunction with a spreadsheet. It can read and write a variety of image formats (including FITS), and can do 32-bit floating-point pixel math. Also, one can use it to do a crude version of aperture extraction, the data from which can be saved as a tab-delimited ASCII file. Thus one can do the basic reductions of bias and dark subtracting and flatfielding, and then extract 1-d spectra, which can then be manipulated with a spreadsheet.

6. Results

The final calibrated spectra of γ UMa and γ Dra (α Lyr, having been used as the flux standard) can be seen in Figure 1. By using α Lyr (airmass=1.49) as the photometric standard, we found B and V magnitudes, extracted directly from the spectra with the IRAF task SBAND (using B and V sensitivity profiles from Ažusienis & Straižys 1969), in good agreement with accepted values. The results can be found in Table 1.

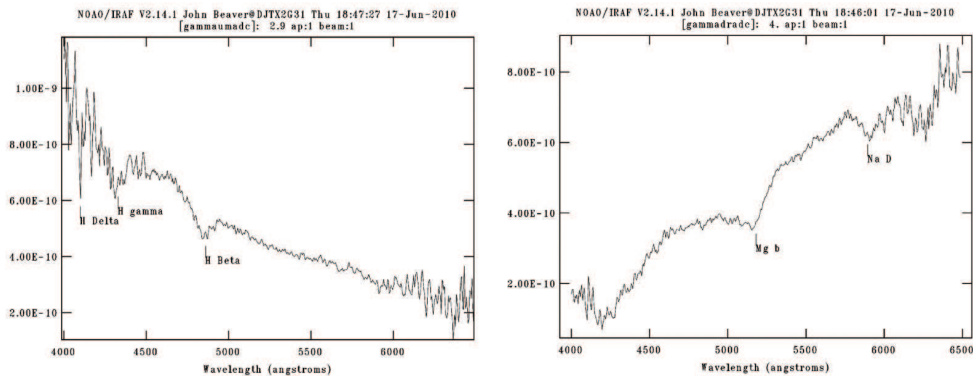


Figure 1. Calibrated spectrum of γ UMa (left) and γ Dra (right)

Table 1. Extracted B and V Magnitudes (primed values are from SIMBAD)

Star	Airmass	V	V'	$B - V$	$B' - V'$
γ UMa	1.095	2.42	2.43	-0.01	+0.04
γ Dra	1.22	2.07	2.23	1.46	1.52

7. Uses in the Classroom and for Undergraduate Research

One of the advantages of this observing technique that we see for beginning students is that the apparatus is transparent in its functioning. Students can make their own grating from scratch; there is no “black box” spectrograph. Students can crudely categorize the spectra of bright stars by simple visual inspection, with no data reductions performed, either visually through the telescope or by quickly taking images with a DSLR camera. This is similar to how stellar spectra were first categorized by visual inspection of objective prism photographic plates.

With greater effort, students could take quick spectra of bright stars with a consumer DSLR camera, and then extract the 1-d spectra graphically with ImageJ, and compare different spectral types in graphical form. And with even more effort, students could obtain the necessary calibration frames and perform the basic CCD reductions and calibrations, either with something like IRAF or, in simpler fashion, with programs such as ImageJ and Microsoft Excel. Groups of students could make the observations on one lab night, then reduce and calibrate the data as a project spanning several weeks. Or alternatively, students in an independent-study or observational astronomy course could collect the data and perform full calibration and analysis of a couple of night’s data with IRAF, as a semester-long project.

One could envision a multi-semester project in which individual students and groups of students contribute to the building of a “standard atlas” of spectral classes. Although this would, of course, be a very low-resolution atlas that would add nothing to the basic science, it would have the local advantage of having its own story when it is presented for introductory astronomy courses at the local institution.

Although we believe this observing technique will be useful toward a variety of instructional goals, from these preliminary results it is not clear whether this technique has any practical advantages over other techniques for any real science application. But the very low equipment cost makes this technique attractive for coordinated projects involving many student observers. In particular, this technique may be of practical use for obtaining standard B and V magnitudes of stars that need detailed time coverage, as this may be one of the least expensive methods for getting transformable standard magnitudes of at least the brighter stars. The American Association of Variable Star Observers (AAVSO), for example, lists many projects that are in need of standard magnitudes (AAVSO). It is our plan to further test the viability and limitations of this technique for obtaining accurate standard magnitudes of stars and to then consider what projects, if any, may be practical.

8. Conclusions

We have shown that it is possible to obtain low-resolution stellar spectra with nothing more than a small telescope, a commercial DSLR camera, and a diffraction grating made by printing with a laser printer onto a sheet of acetate. These spectra can be flux and wavelength calibrated, and standard B and V magnitudes can be extracted. Because of its very low cost and simple principle, this process is adaptable to a wide range of undergraduate instructional projects.

References

AAVSO, 2010, <http://www.aavso.org/news/campaigns.shtml>

Ažusienis, A. & Straižys, V., 1969, "Improved Determination of the Response Curves and Parameters of the UBV System. Summary of Results," *Soviet Astronomy*, 13, 316