Extending a Spectroscopic Survey of Main Belt Asteroids With Micro Telescopes: A Proof of Concept Project

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Abstract

In 2002, Schelte J. Bus and Richard P. Binzel proposed a new taxonomy for main belt asteroids based on slope values over segments of the spectral curve; this new classification system has started to gain general acceptance.

Their analysis was based on spectrographic data gathered in the late 1980s and early 1990s at Kitt Peak Observatory on research instruments of 2.4 and 1.3 meters in aperture. Most of the original 1447 asteroids were each observed on a single night. A few, which were observed on multiple nights, exhibited unexplained variations. Spectrums and photometric color studies have been done of some asteroids since then, mostly as studies of dynamical families.

The authors have undertaken a "proof of concept" project to explore and resolve the technical challenges associated with reobserving some of these asteroids and extending the survey beyond the original targets using small telescopes. Employing a commercially-made 0.36 meter catadioptric telescope and camera/spectroscope combination, the authors have attempted to reproduce some of the curves from asteroids included in the Bus and Binzel papers. Their work has focused on demonstrating the fidelity and repeatability of a data capture and analysis process on targets of at least 13th magnitude.

The authors profile the hardware and software used to conduct the proof of concept project, techniques for data collection and analysis, and review the results of their work to date.

1. Introduction

For over a decade amateur astronomers have made important contributions to the understanding of main belt asteroids via photometric observations conducted on telescopes of less than 0.5 meters with CCD cameras. Data collected in this manner have served as the basis for numerous papers addressing the rotation rates, shapes and, in some cases, the binary nature of these solar system bodies.

Just as the photometric study of asteroids shifted from large, professional facilities to backyard observatories, advanced amateurs are now exploring the opportunity to use the quality and capabilities of commercial, off-the-shelf (COTS) astronomical equipment, as well as increasingly sophisticated image capture techniques, to make new contributions to the study of asteroids.

One promising arena for amateur observers is the classification of asteroids through spectra and photometric color studies, particularly as part of the study of dynamical families.

In 2002, Schelte J. Bus and Richard P. Binzel proposed a new taxonomy for main belt asteroids based on slope values over segments of the spectral curve (Bus & Binzel, 2002a, 2002b). Their data used color curves generated from spectrographic data gathered in the late 1980s and early 1990s at Kitt Peak Observatory as part of the Massachusetts Institute of Technology's Small Main-belt Asteroid Spectroscopic Survey (SMASS).

SMASS used research instruments of 2.4 and 1.3 meters in aperture and observed 1447 asteroids. For most, data was captured on only one night; a few, which were observed on multiple nights, exhibited unexplained variations. One asteroid, when observed with two different spectroscopes, exhibited slightly different color curves.

The authors have undertaken a "proof of concept" project to explore and define the technical challenges associated with reobserving some of these asteroids and extending the survey beyond the original targets using small telescopes and other COTS astronomical gear.

This paper was amended on 27 May 2009 with a change to the 1 Ceres data and differs from a version appearing elsewhere.

2. Telescope & Camera Configurations

Based at the Goat Mountain Astronomical Research Station (GMARS–G79), the authors operate a total of three observatories, all equipped with commercial 0.36 meter catadioptric telescopes. The two telescopes that were used to collect data as part of this project were a Meade LX200R operated on its standard fork mount, and a Celestron C-14 on a Paramount ME. The two observatories are further differentiated by their control systems, one of which is based on Apple Macintosh computers running TheSkyX Serious Astronomer (LX200R), and the other utilizing the Windows XP platform running TheSky6 Professional (C-14/Paramount).

In all cases the instrumentation package was an off-the-shelf SBIG DSS-7 spectrograph and ST-7XME CCD camera. The strengths of this equipment choice are its relatively high sensitivity, moderate weight and ease of use. Its shortcomings include a limited spectral range (0.350 to 0.750 μm) and an inability to guide on the target or any other object in the camera's field of view.

For spectroscope control and image capture the authors used two different software packages. When in the LX200R observatory, the instrumentation was run by Equinox Image (EI), a Macintosh application for SBIG camera control. The version of EI used by the authors was modified to support slit and grating operations, as well as provide a slit proxy in the focusing display for telescope aiming. When using the C-14, SBIG's CCDOPS was the capture and control software; CCDOPS was also used to crop the spectra prior to processing.

3. Operational Considerations

Technically, both observatories could fulfill the requirements of the data gathering process. Target asteroids could be identified and located by either version of TheSky, and GOTO slews on the instruments were generally accurate to within one arc minute with both systems aided by TPoint. Overall accuracy and productivity was higher for the Paramount observatory – a combination of its superior mechanical precision and the fact that it is a refined configuration for robotic photometric observations of asteroids.

As for tracking, the Paramount provided more consistent results for exposures exceeding two minutes than the LX200R. However, even with object tracking enabled through TheSky6, keeping an asteroid on the spectrograph's narrow slit was a challenge for exposures that sometimes reached five minutes. Indeed, the inability to guide on the target asteroid – or for that matter, on any object in the field of view – proved to be a significant limitation the authors were unable to overcome during this phase of their project.

The other equipment shortcoming that compromised the project's ability to duplicate the SMASS results was the spectral range of the DSS-7. While easily capable of capturing the blue end of the spectrum as short as 0.350 μm, the usable range in the red effectively ended at 0.750 μm – considerably short of the 0.925 μm captured at Kitt Peak.

4. Spectra Capture

Spectra from 23 asteroids were captured February to April 2009 at the authors' observatories at GMARS, several on multiple occasions. Only eight are presented here. Those with insufficient signal-to-noise were excluded. Table 1 details the observing circumstances of the spectra included in this paper. Imaging was usually limited to clear, moonless nights when the relative humidity at the site was 35% or less, and transparency (as forecast by the Clear Sky Chart) was 80% or better. All targets were imaged when above 35° altitude and usually near their meridian crossings. With one exception, the asteroids were observed at air masses of 1.5 or less.

Asteroid	Date (2009)	Phase Angle	Magnitude	Air Mass
1 Ceres	18-Apr	19.6	7.78	1.05
10 Hygiea	15-Feb	16.3	11.5	1.47
27 Euterpe	19-Apr	26.9	10.96	1.35
115 Thyra	19-Apr	16.6	11.87	1.49
118 Peitho	19-Apr	16.5	13.02	1.18
230 Athamantis	19-Apr	23.9	11.94	1.43
246 Asporina	19-Apr	13.4	12.6	1.13
511 Davida	18-Apr	19.3	11.4	1.72

A typical imaging session included captures of a solar analog star and a flux reference star. The solar analog star was used to calibrate the asteroid spectra for its relative reflectance spectrum and the flux reference star the intensity (see Section 5). Each evening session also included a spectrum of a planetary nebula for use in checking the calibration of the spectrograph though the use of the prominent OIII and H*a* lines.

Ambient temperatures during the winter allowed the ST-7 camera to be operated at -20° C, thus limiting its electronic noise. Darks were captured at the same operational temperatures, averaged and subtracted from all exposures.

The DSS-7 has a multiple slit widths; in all cases we used the 100 micron slit as a compromise between resolution and light gathering. Exposures varied by reported target brightness. Asteroids ranging from magnitude 10 to 12.5 were typically recorded in 120 second exposures; targets in the magnitude range from 12.5 to 14 had 180 second exposures. In some cases multiple exposures were integrated to improve the signal-to-noise ratio. Several attempts to take 300 second exposures were disappointing as the target generally moved off the slit during the capture, limiting the effective exposure time.

5. Spectra Processing

The spectra were processed largely following the methodology in the Bus-Binzel papers. Data reduction was performed using Visual Spec, a spectroscopy analysis program developed and maintained by Valerie Desnoux (2008).

Asteroids reflect light from our sun. Observations were taken every night of solar-analog stars to calibrate relative reflectance of each asteroid. Two well established solar analogs were used; Hyades 64 (HD28099, M_v = 8.1, G8V) and HR4486 (HD101177, M_v = 6.4, G0V). HR4486 was checked against Hyades 64 on a single night and produced very similar results.

Each spectrum was divided by the solar analog and normalized to unity at 0.550 μm. Although the spectrograph/CCD combination produces wavelength coverage from approximately 0.340 to 0.780 μm, we trimmed the spectra to 0.435 to 0.750 μm to match the spectrums in the Bus-Binzel paper and because of the rapid quantum efficiency falloff from our system past 0.750 μm.

The plotted wavelength spectrum represents the flux ratio of sunlight reflected from the asteroid's surface relative in the incident sunlight. Some of the spectra contained broad absorption features that might indicate some minerals present on the asteroids. Some laboratory studies have made progress in identifying some of these minerals. However, the purpose of this survey is not to identify absorption bands but to measure the changing slope of the asteroid spectrum. This process has been more difficult to identify. It is thought that one of the primary causes of an increase in spectral slope (reddening) is space weathering (Chapman 1996).

In the Bus-Binzel paper they applied a parametrization process to each asteroid spectra. They used principal component analysis to modify each slope and ultimately decided to calculate and remove the average slope from each spectrum in the SMASS data set. Following their methodology, after having normalized the asteroid and solar analog spectra and having divided the asteroid spectra by the solar analog spectra, we then took the resulting spectral plot and applied a smoothing algorithm to assist in determining the slope. Then, we divided the asteroid's spectra by its average slope so that our spectra were prepared in the same manner with the residual spectrum whose value at 0.550 μm is still 1.00 and whose mean value over all channels is approximately 1.

6. Comparison to SMASSII Results

The authors expected from the start of the survey that spectra generated by our 0.36-m telescopes would be far nosier that those generated by the 1.3-m and 2.4-m telescopes at Kitt Peak. Midway into the project we also realized some of the limitations imposed by the inability of our spectrum to reach past 0.750 μm. Also, through happenstance, many of our targets were at a phase angle near 20 degrees or larger. Observing asteroids at a high solar phase angles can result in an artificial increase in the spectral slope called phase reddening.

Nonetheless, we were pleased to see that within these limitations, the resulting spectra generally compare favorably with those from SMASS. Spectral parameterization of the limited data set is probably not sufficient resolve each of the 26 classes defined by Bus-Binzel (2002a & 2002b). However, some broad categorizations such as the C or S taxonomic classes could be accomplished based upon slope parameters from 0.435 to 0.750 μm.

7. Conclusion

The authors believe that their proof-of-concept project has demonstrated that the telescopes and data capture techniques of backyard observers are capable of producing spectral analyses that are sufficient to support the classification of asteroids according to the taxonomy described by Bus-Binzel. The inability to characterize the spectral curves from 0.750 μm to 0.925 μm was a deficiency of the project, and limits the ability to address all 26 proposed categories. However, alternative instrumentation with a broader spectral range could remedy this shortcoming.

8. Future work

The authors are examining various options for COTS spectrographs that are capable of capturing spectra over the full range of 0.40 μm to 0.925 μm and incorporate cooled detectors for reduced noise on long exposures. Light weight, or the ability to cart-mount with a flexible low-loss fiber-optic connection to the telescope, are other key considerations.

Pending the identification of suitable hardware and software, the authors may seek a grant to pursue a systematic data collection project that would revisit work already done by the SMASS project, and then extend it to asteroids as faint as 15^{th} magnitude.

9. Acknowledgements

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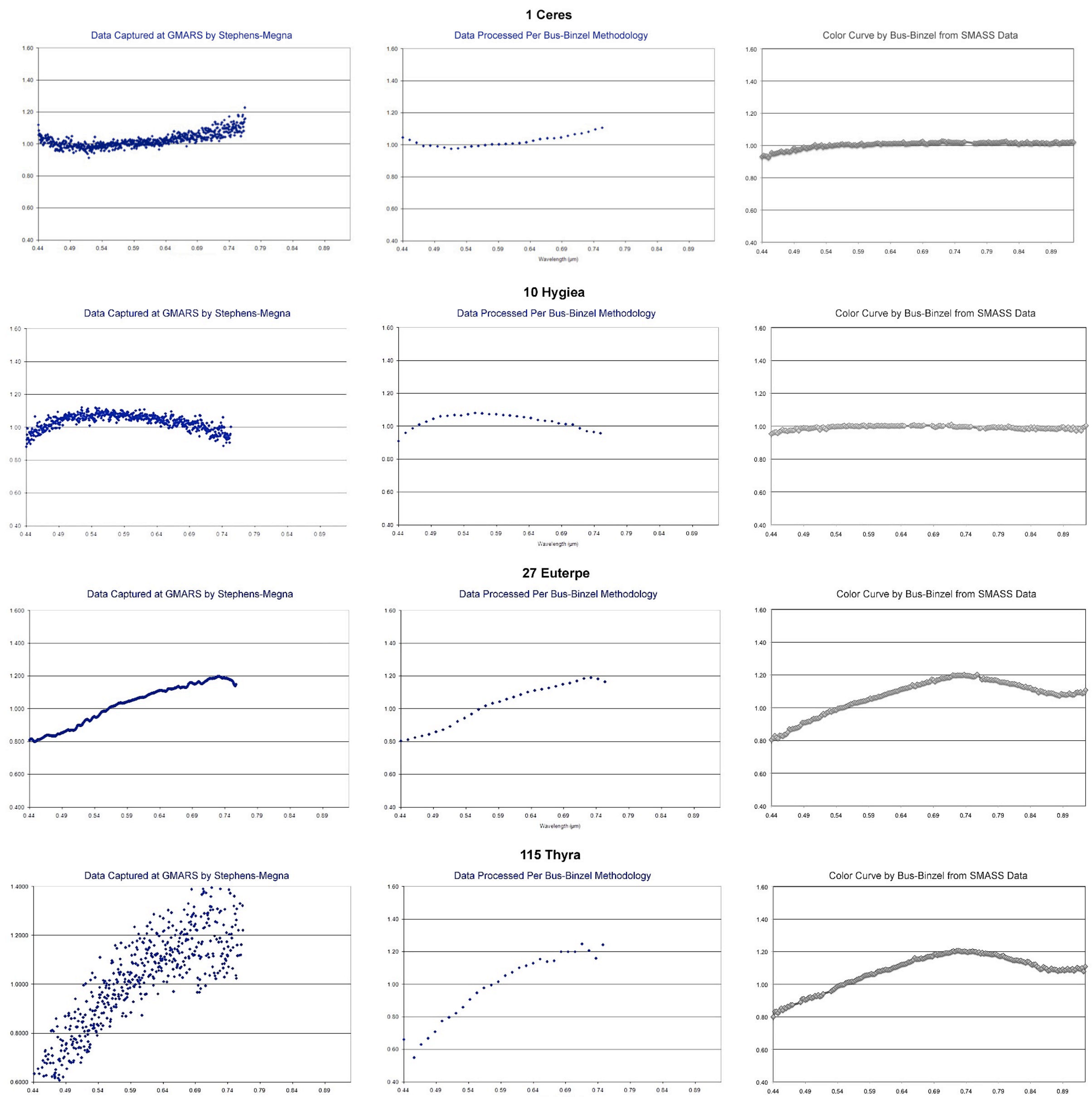

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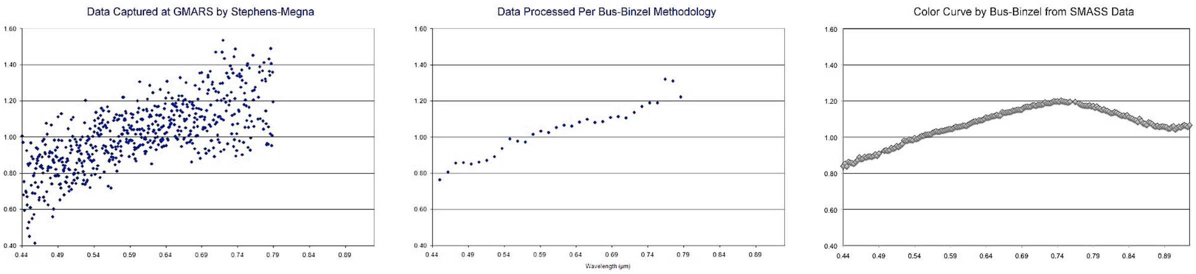

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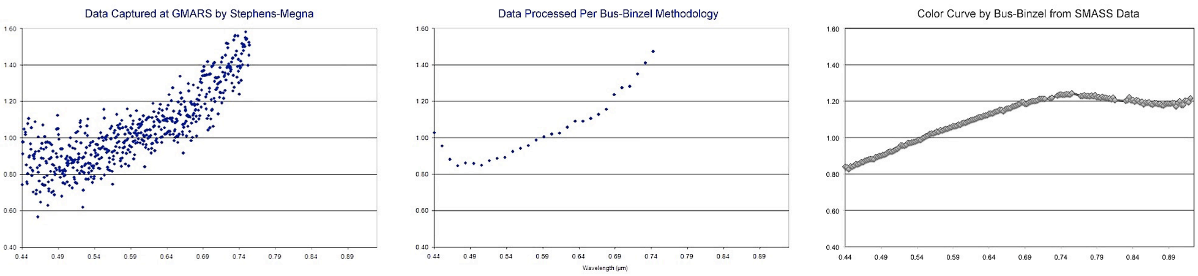

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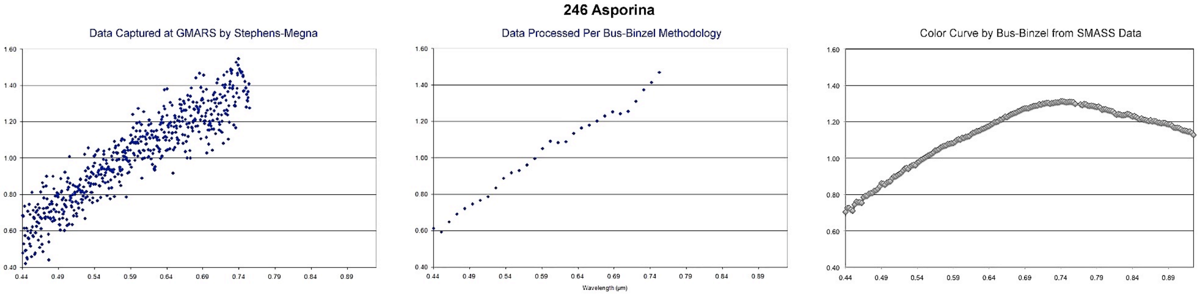

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