THE CRITICAL IMPORTANCE OF DATA REDUCTION CALIBRATIONS IN THE INTERPRETABILITY OF S-TYPE ASTEROID SPECTRA. Michael J. Gaffey, Department of Space Studies, University of North Dakota, Box 9008, Grand Forks, ND 58202. Email: gaffey@space.edu

Introduction: There is significant dispute concerning the interpretation and meteoritic affinities of S-type asteroids. Some of this arises from the use of inappropriate analysis methods and the derivation of conclusions which cannot be supported by those interpretive methodologies [1]. The most frequently applied inappropriate technique is curve matching. Whether matching spectra from a spectral library or mixing end-member spectra to match the asteroid spectrum, curve matching for S-type spectra suffers from a suite of weaknesses that are virtually impossible to overcome. Chief among these is the lack of a comprehensive comparison set. Lacking a complete library that includes both the mineralogical variations and the spectrally significant physical variations (e.g., particle size, petrographic relationships, etc.), curve matches are plagued with potential unresolved ambiguities. The other major weakness of virtually all curve matching efforts is that equal weight is given to matching all portions of the spectrum. In actuality, some portions of the spectrum (e.g., centers of absorption features) must be matched very accurately while other portions of the spectrum (e.g., continuum regions and overall slopes) do not require good matches since they are strongly effected by parameters unrelated to the mineralogy of the sample. Curve matching – when it is used at all – should only be a prelude to a more rigorous analysis such as those outlined below.

If one wishes to understand the origin, history and meteoritic affinities of S-type asteroids (or any type of asteroid), obtaining robust determinations of their mineralogy is the key. Extraction of the diagnostic parameters of absorption features from S-asteroid spectra and the use of laboratory derived interpretive calibrations relating those spectral parameters to mineralogy and mineral composition is the most reliable existing methodology to obtain such mineralogical determinations [1]. Although there is room for significant advancement in both the parameter extraction procedures and the laboratory-based interpretive calibrations [e.g., 2-7], these are the only procedures can provide the basis for viable discussions of asteroid genetic histories and possible meteorite affinities.

Implications of Data Reduction Procedures: However, even if an appropriate interpretive methodology is applied to an S-type spectrum, incomplete or inaccurate calibration and reduction of the raw spectral data can seriously compromise the final interpretation. Increasingly, moderate resolution (e.g., $\lambda/\Delta\lambda \sim 100$) near-infrared spectrographs (e.g., the SpeX instrument at the IRTF [8,9]; the NICS instrument at the Italian Telescopio Nazionale Galileo (TNG) on La Palma in the Canary Islands [10]) are being used to obtain near-IR (~0.7 – 2.5 µm) spectra of asteroids. These instruments represent a significantly improved capability over previous instruments employed in asteroid spectral observations. However, there are two major potential problems that can occur during the reduction of observational data from such instruments. One of these problems is unique to instruments of this spectral resolution operating in this spectral interval.

Corrections for atmospheric absorption features. The first is the issue of proper correction for the strong absorption features due to atmospheric water vapor near 1.4 and 1.9 µm, as well as weaker features at shorter wavelengths. Shorter wavelength CCD observations (e.g., ≤1.0 µm) have commonly been reduced by ratioing the raw asteroid spectrum to the raw spectrum of a nearby standard star at approximately the same airmass. This technique cannot be used to reduce the SpeX-type data, since the 1.4 and 1.9 µm atmospheric absorptions are much stronger than the shorter wavelength absorptions and even a small mismatch in the airmasses can lead to significant over- or under-corrections, significantly distorting the resulting spectrum. Observational protocols and data reduction methodologies to obtain much more reliable atmospheric corrections have been outlined which minimize the subjective nature of such corrections [1]. In particular, it is important to minimize the use of “dial-in” parameters in these corrections (i.e., adjusting the correction until the spectral curve “looks right”), since such an approach presupposes a knowledge of the final form of the spectrum, a situation that introduces a circular element into the process. Extinction corrections must employ strong objective criteria for determining which is the best correction. This is particularly critical for the 2 µm feature present in S-type spectra, since this feature is relatively weak and a small over- or under-correction of the 1.9 µm atmospheric absorption can significantly distort both its area and position.

Corrections for pixel offsets. The second critical issue is the correction for subpixel shifting of the raw spectra due to unavoidable instrument flexure. Fractional pixel offsets in spectral intervals with high frequency components (such as in the telluric water vapor features) produces "interference patterns" when spectra with different offsets are ratioed to each other [e.g., Figure 2 in reference 1]. The result is a repeatable pattern of large positive and negative excursions of data points away from the actual spectral curve. Spectra have been smoothed by use of running means or polynomial fits in order to ameliorate the effect of this "noise". For the weak features present in S-spectra, such smoothing will introduce a significant shift in the band center and will increase or decrease the band area, both of which are critical parameters in the mineralogical analysis. The apparent position of the 2 μm band center can be shifted by 0.1-0.2 μm for a S-type spectrum which is uncorrected for pixel offset and which has been smoothed to reduce the apparent noise resulting from the pixel offset. The band area ratio (BAR) can be altered by up to 1.0. These deviations would lead to serious errors in the mineralogical interpretations, and to invalid conclusions concerning the history and meteorite affinities of the asteroid being investigated.

The solution is to objectively determine the actual pixel offset of each observational data set (e.g., a set of contiguous observations of a single object) and then interpolate the raw data to the pixel offset selected as the reference set (e.g., one particular contiguous set of standard star observations) [e.g., 1,8]. The "interference pattern" provides an excellent objective criterion for determining the proper registration of pixel offsets.

Expectations for Asteroid Spectra: Asteroid observers should utilize data reduction codes (e.g., SpecPR) which are designed to optimize the quality of asteroid spectra in order to permit the most accurate determination of mineralogy and hence of asteroid history and meteorite affinities. When both the extinction correction and the pixel-offset correction are done properly one should routinely obtain excellent spectra with continuous coverage over the spectral range of the instrument. Figure 1 shows what should be expected without smoothing or removal of more than a few (e.g. 2-4) discordant points for the spectra of moderately faint (e.g., 16th magnitude) asteroids using these moderate resolution instruments on 3 meter or larger telescopes. Additional examples can be seen in abstracts at the present meeting [12-14].

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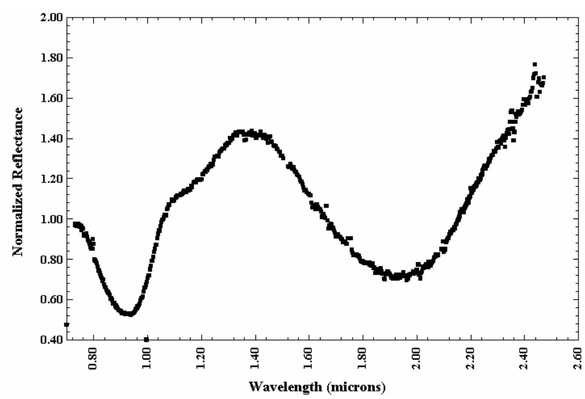

Figure 1: IRTF-SpeX spectrum of 1459 Magnya obtained at a V-magnitude of 15.74 [11].