

A Spectroscopic Search for Jupiter's Chromophores

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Introduction and Background

Despite many decades of ground-based, space-based, and in situ observations of Jupiter's atmosphere, the chemical agent(s) responsible for the various colors seen in visible images of Jupiter remain unidentified. Identifying the chromophores present in each Jovian feature is not only valuable in its own right but will further our understanding of Jovian atmosphere structure and dynamics through subsequent studies of chromophore production, transport, and chemical evolution. Interest in chromophores has been heightened by the recent reddening of Oval BA, which is the first long-lived vortex observed to drastically change in color.

Its similarity to the Great Red Spot (GRS) begs the question: does Oval BA have the same coloring mechanism as the GRS? A detailed study of Oval BA's dynamical evolution during the reddening is desirable for this purpose (see Sussman et al. poster 11.01 at this meeting) and may constrain chromophore production scenarios, but direct observation of the chromophores is necessary to constrain their chemical composition. Positive chromophore identifications have been elusive due to a limited understanding of chemistry at Jovian temperatures and pressures and observational limitations.



Figure 1 : HST ACS/HRC image of Oval BA taken on 08 April 2006. (The edge of the GRS is visible to the far right.) Notice the turbulent mixing of light and dark clouds, which requires very high spatial resolution to fully resolve.

Jupiter harbors extreme conditions in its complex atmosphere. Its composition, temperature and pressure allow for the creation of a unique chemical environment. Few laboratories explore chemistry under similar conditions, which greatly limits our knowledge of possible chemical species in the Jovian atmosphere and the behavior of those known to exist. This information is crucial for correct identification of a chromophore, for the color of a given chemical species can depend on pressure and temperature.

Observational limitations have prevented the determination of any detailed chromophore spectra. Due to small scale spatial variations of cloud color, the spectral signature of a trace amount of colored gas or ice is easily washed out by the more reflective white clouds nearby. The spatial scale of variation is small enough that high spatial resolution is required to sample it adequately (see Figure 1). Although spatial resolution and coverage are gained with imaging, it only allows spectral sampling at select wavelengths.

A review of many chromophore studies can be found in West et al. (1986). Recent studies have mostly focused on high spatial resolution images taken in several narrow-band filters (Dyudina et al., 2001; Simon-Miller et al., 2001). These studies have set constraints on the number of chromophores through principle component analysis. The study presented here has taken a complementary approach and traded spatial resolution and coverage for high spectral resolution.

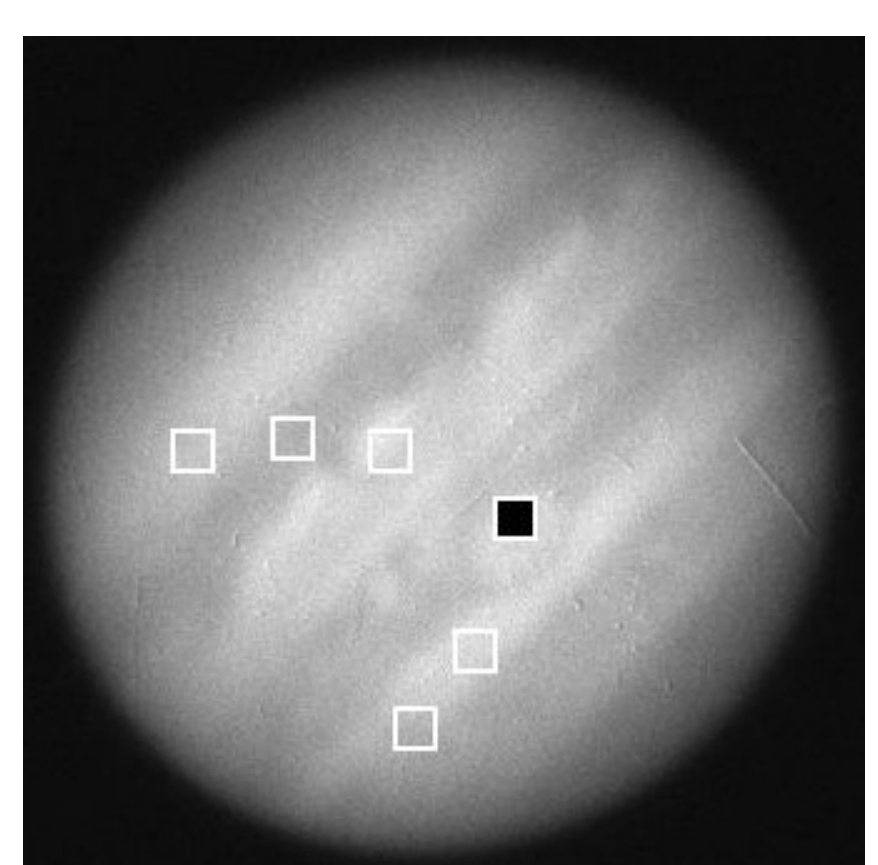


Figure 2 : Echelle guider camera image (0.134" per pixel) with boxes showing the positions of the 1.6" x 1.6" slit. Starting at the far left and moving clockwise, the targets are the NTrZ, NEB, EZ, GRS, STRZ, and Oval BA.

Observations

We present the analysis of observations of Jupiter acquired on 13 April and 02 July 2006 with the Apache Point Observatory (APO) echelle spectrograph ($R = 37500$), which has a spectral coverage of 3500 - 10000 Angstroms. Our April observations occurred between two HST ACS images of Oval BA: one using the high resolution channel on 08 April (Figure 1), and another using the wide field channel on 16 April.

We used a 1.6×1.6 arcsecond slit to target regions that differ in color: the North Tropical Zone (NTrZ), North Equatorial Belt (NEB), Equatorial Zone (EZ), Great Red Spot (GRS), South Tropical Zone (STRZ) and Oval BA. Figure 2 shows the slit positions on an image from the echelle guider camera. On 13 April the seeing varied between 1.5 and 2.0 arcseconds, and on 02 July the seeing was from 2.0 to 2.7 arcseconds. Note that Oval BA could not be resolved by the guider camera due to the poor seeing on both nights. For 13 April the slit was positioned based on Oval BA's position in the Hubble image taken on 08 April, and recent amateur images were used for 02 July.

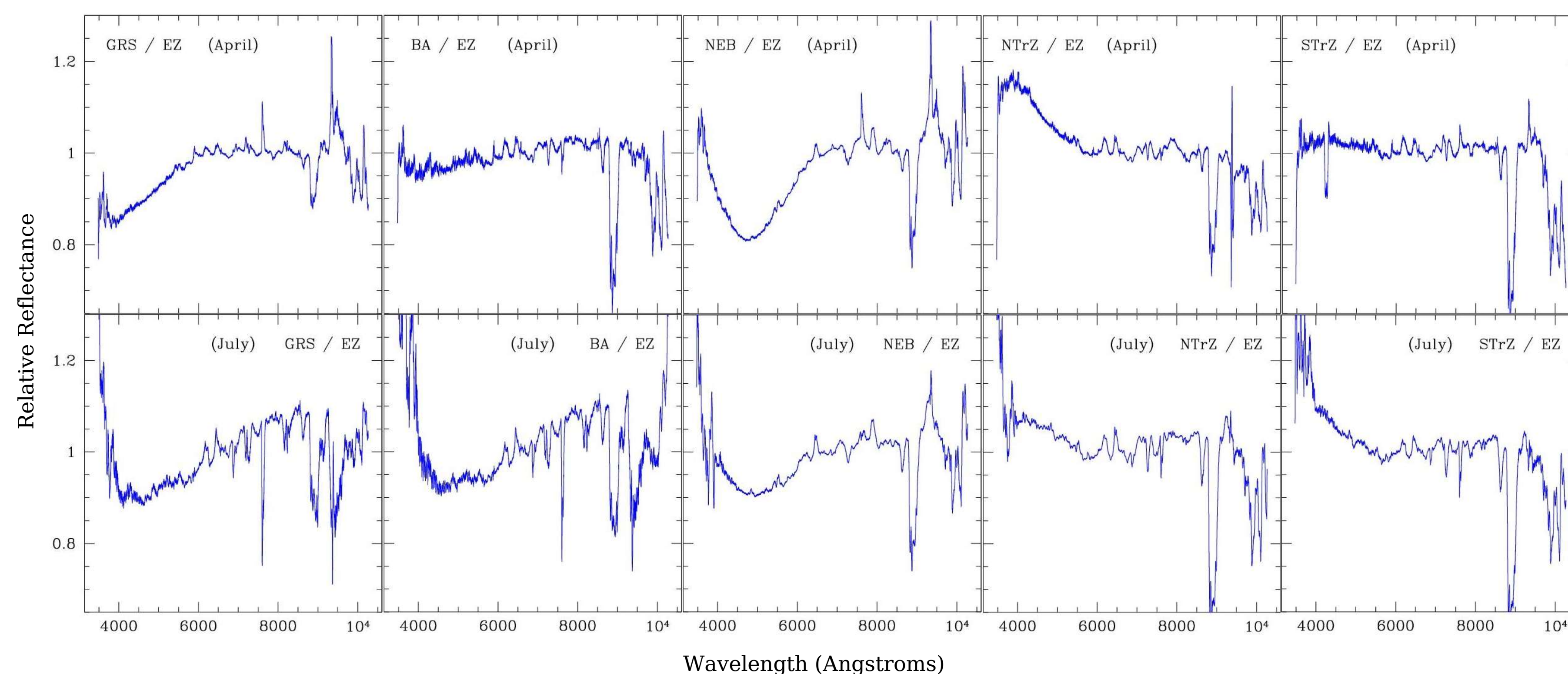


Figure 3 : Scaled spectra of GRS, BA, NEB, NTrZ, and STRZ after normalization by a G2V star and the EZ.

Analysis

The spectra were cleaned, flat-fielded and wavelength calibrated using IRAF. The Jupiter spectra were each divided by a G2V standard star spectrum (taken on the same night) to remove the solar spectrum. In order to compare the differences in spectral shape and amplitude between regions, each spectrum was then multiplied by a constant to set the average reflectance between 6300 and 6900 Å (a window with no methane absorption) to unity before normalizing by the EZ. The final comparison spectra (Figure 3) were smoothed for better viewing and because of the low resolution of the candidate chromophore spectra (Figure 4). However, if high resolution lab spectra become available, the full resolution of our data will be utilized to confirm or set an upper limit on the presence of each chemical species.

Results

The most notable difference between the targeted regions is the broad blue absorption in the GRS, NEB, and Oval BA. In the April data, the GRS and Oval BA are similar in that they tend to absorb more than the EZ from approximately 3500 to 5900 Å, and their peak absorption occurs around 3900 Å. The NEB absorbs more than the EZ between 3700 and 6400 Å, with the peak around 4800 Å. Interestingly, the peak absorption shifts redward by about 100 Å for all three regions in the July data, but since the seeing was worse in July we used the April data.

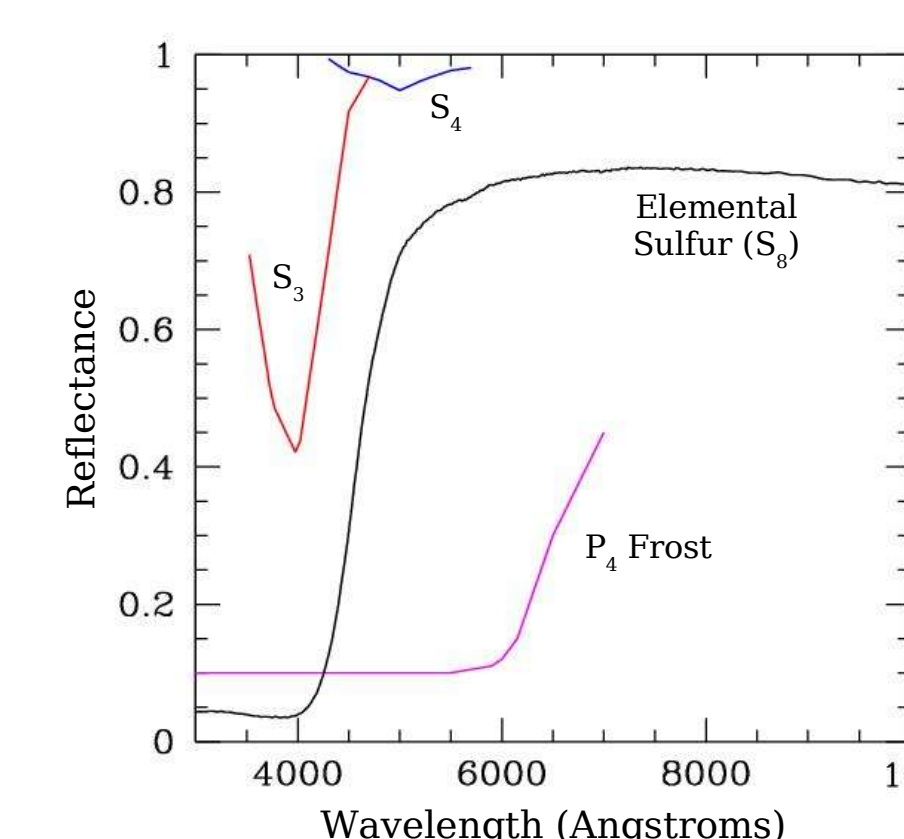


Figure 4 : Reflectivity relative to BaSO_4 of elemental sulfur (S_8) and phosphorus (P_4) frost from West et al. (1986), and reflectance (in arbitrary units) for S_3 and S_4 from Billmers and Smith (1991).

This presentation will consider four proposed chromophores: elemental sulfur (S_8), S_3 , S_4 , and the red allotrope of elemental phosphorus (P_4). (For an exhaustive candidate list see West et al., 1986.) The laboratory reflection spectra for these candidates, shown in Figure 4, are not absolute reflectances. The values for S_8 and P_4 are relative to BaSO_4 . S_3 and S_4 were given in units of molar absorptivity and converted to reflectance with an arbitrary scale. However, the differing scales are not obstacles because we are interested in whether a combination of these species can cause absorption with a similar shape to that observed.

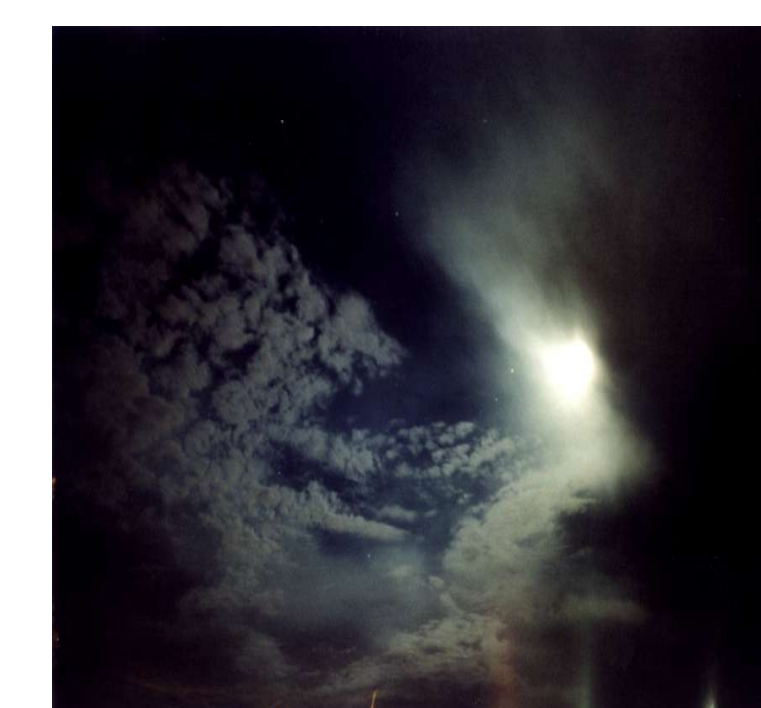
Model absorption spectra were created to match the shape of the blue absorption in the GRS (Figure 5) and NEB (Figure 6). A well-fitting model was found for the GRS by combining absorption from S_3 , S_4 and S_8 . The model for the NEB, containing only S_8 and S_4 , was only able to reproduce the peak of the absorption feature. The addition of P_4 to either model resulted in worse fits. This was expected because P_4 absorbs almost equally over the 3500 to 6000 Å range, with a sharp decrease in absorption from 6000 to 7000 Å.

Conclusions

In this preliminary study, the GRS and BA appear to have similar chromophore compositions, which are different from the NEB. The results are consistent with the possibility that S_3 , S_4 and S_8 color the GRS and Oval BA and that S_4 and S_8 may color the NEB. Although the presence of P_4 is not supported by this study, it is not ruled out, because its spectral shape may be different under Jovian conditions.

Future Work

We have been granted time at the Advanced Electro-Optical System (AEOS) on Maui to observe Jupiter with the NMSU Acousto-optical Imaging Camera (NAIC). NAIC has a tunable filter, with which we can acquire narrow band images with wavelength coverage from about 0.5 to 1 micron. We plan to acquire data cubes with spectral resolution of roughly 15 Å and sub-arcsecond spatial resolution. This data shall be used to search for chromophores via principle component analysis and direct comparison of spectra between Jovian features and with candidate chromophore lab spectra.



References and Acknowledgments

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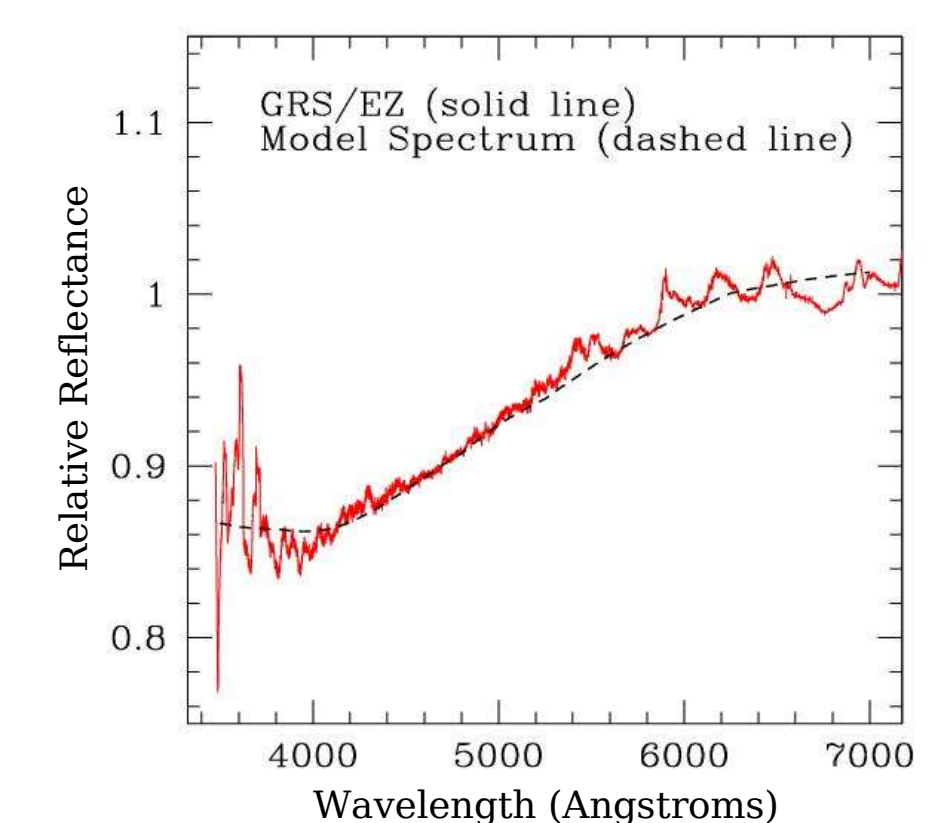


Figure 5 : GRS spectrum normalized by the EZ (solid line) and a model spectrum (dashed line) composed of a combination of absorption from elemental sulfur, S_3 and S_4 .

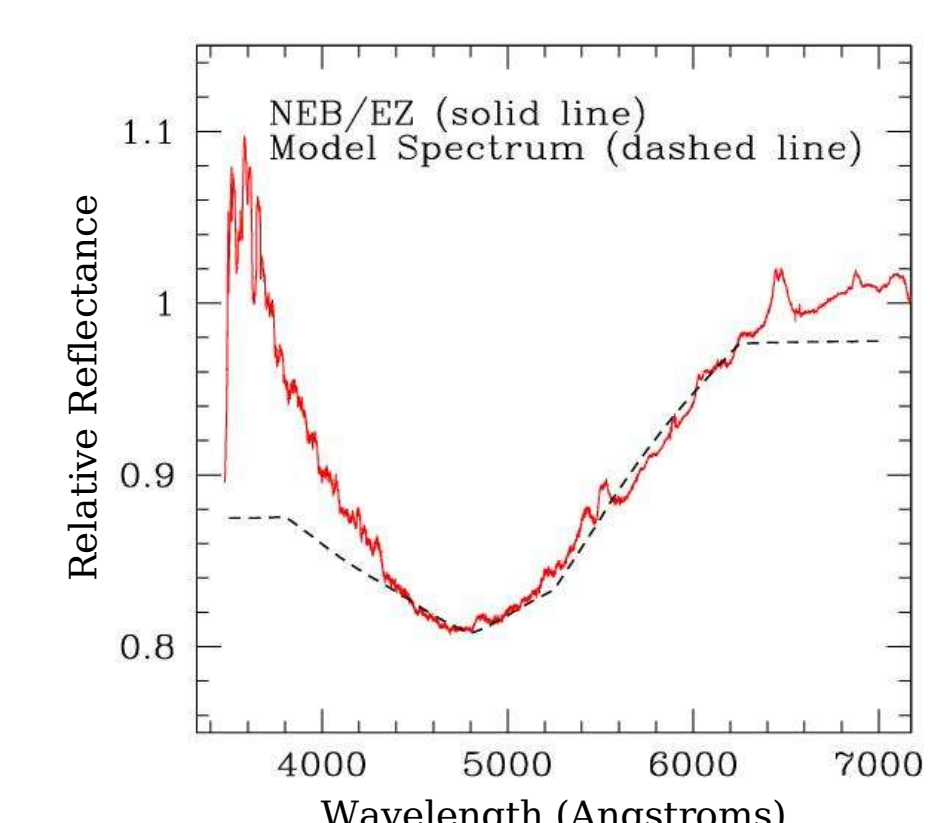


Figure 6 : NEB spectrum normalized by the EZ (solid line) and a model spectrum (dashed line) composed of a combination of absorption from elemental sulfur and S_4 .

