



Rocket Observations of IC 405

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Abstract

We present the preliminary results from a NASA/JHU sounding rocket mission (36.198 UG), launched on 09 February 2001 at 21:00 MST, to obtain a long slit ($200'' \times 12''$) spectrum of the reflection nebula IC 405 in the 900 – 1400 Å wavelength region. Several pointings within the nebula were obtained, including a high quality ($S/N \approx 10-15$ at $R = 300$) spectrum of the central star, HD 34078, which clearly shows absorption from molecular hydrogen (H_2). Observations of the nebula reveal a surface brightness to stellar flux ratio that rises by two orders of magnitude between 1400 and 900 Å. This is in contrast with the relatively flat nebular dust scattering observed during a prior sounding rocket observation of the reflection nebula NGC 2023. We will also present additional nebular pointings within IC 405, including a region observed by the Hopkins Ultraviolet Telescope showing evidence of H_2 fluorescent emission.

Sounding Rocket Observations

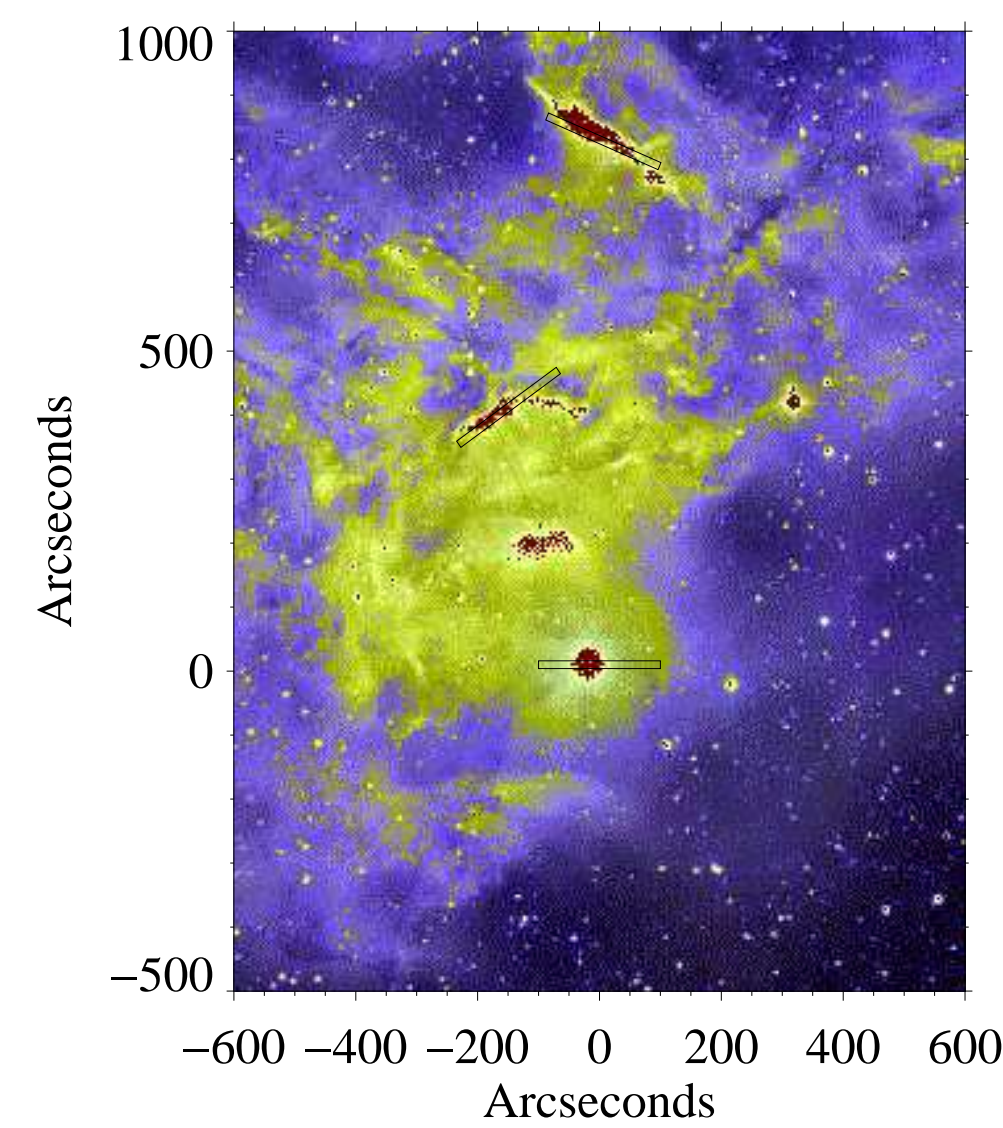


Figure 1. 0.9m KPNO image of IC 405, with slit positions overlaid and East in the negative x direction (courtesy of Travis Rector, NRAO).

IC 405 is a diffuse nebula in Auriga whose central star, AE Aur (HD 34078 – O9.5 Ve) is passing through the nebula with a high proper motion after having been ejected from the Orion Nebula roughly 2.5 million years ago. IC 405 provides a setting to study a star interacting with a nebula not associated with its birth. The cloud and star are approximately coplanar at a distance of 446 pc. HD 34078 is visually bright, $V = 6.0$ and mildly extinguished, $E(B - V) = 0.53$.

This experiment was launched aboard a Mark 70 Terrier-Black Brant IX sounding rocket (NASA flight number 36.198 UG) from White Sands Missile Range, New Mexico ($106^\circ 3' \text{ West}, 32^\circ 4' \text{ North}$), on 09 February 2001 at 21:00 MST. The target is obtained by referencing the startracker to two bright guide stars (Sirius and Capella), then reorienting to the target. The obtained field is within a few arcminutes of the nominal target, and this field is relayed to the ground in real-time through a Xyberon TV camera imaging the slit jaw ($20'$ field-of-view). Fine adjustments are performed with real-time ACS command uplinks to argon jets.

Data was obtained of IC 405 from our arrival at the target field to experiment turn-off ($T +150 - T +490$ seconds). The command uplinks were used to place HD 34078 into the slit. The star was in the spectrograph slit for 106 seconds, and Figure 3 shows the spectrum of HD 34078 measured by the experiment. During the flight, the pointing was adjusted to two previously defined offsets to sample other parts of the nebula. The flux at the second offset position was not appreciably different than the background.

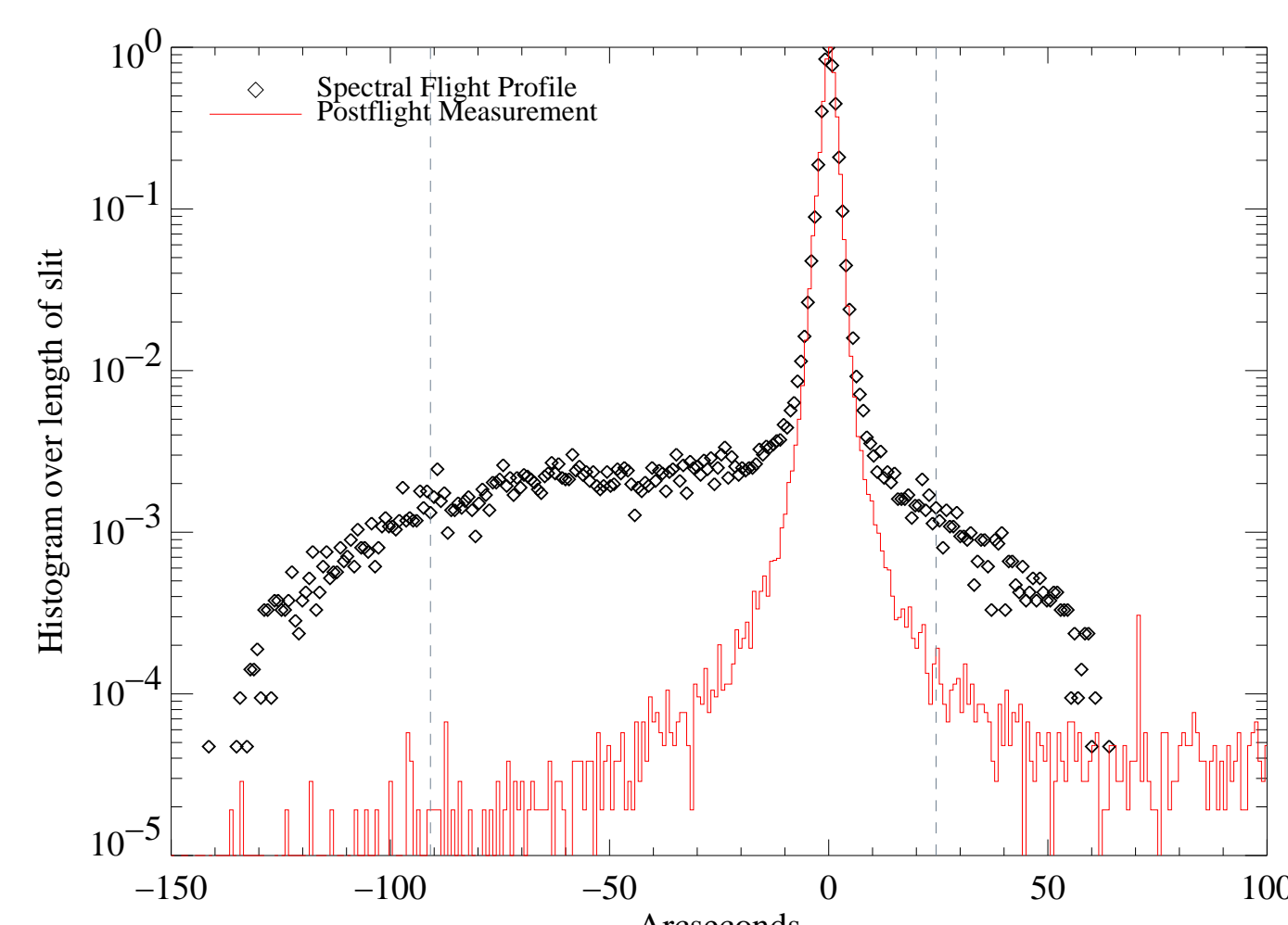


Figure 2. Spatial profile of the flight data in black (excluding Ly- α airglow). Postflight determination of the instrument line-spread-function (LSF) reproduces the flight profile. The dashed lines represent the portion of the spectrograph slit unaffected by instrumental vignetting. One notices the extension of the nebula beyond the stellar peak. LSF measurement discussed below.

Far-UV Stellar Spectrum

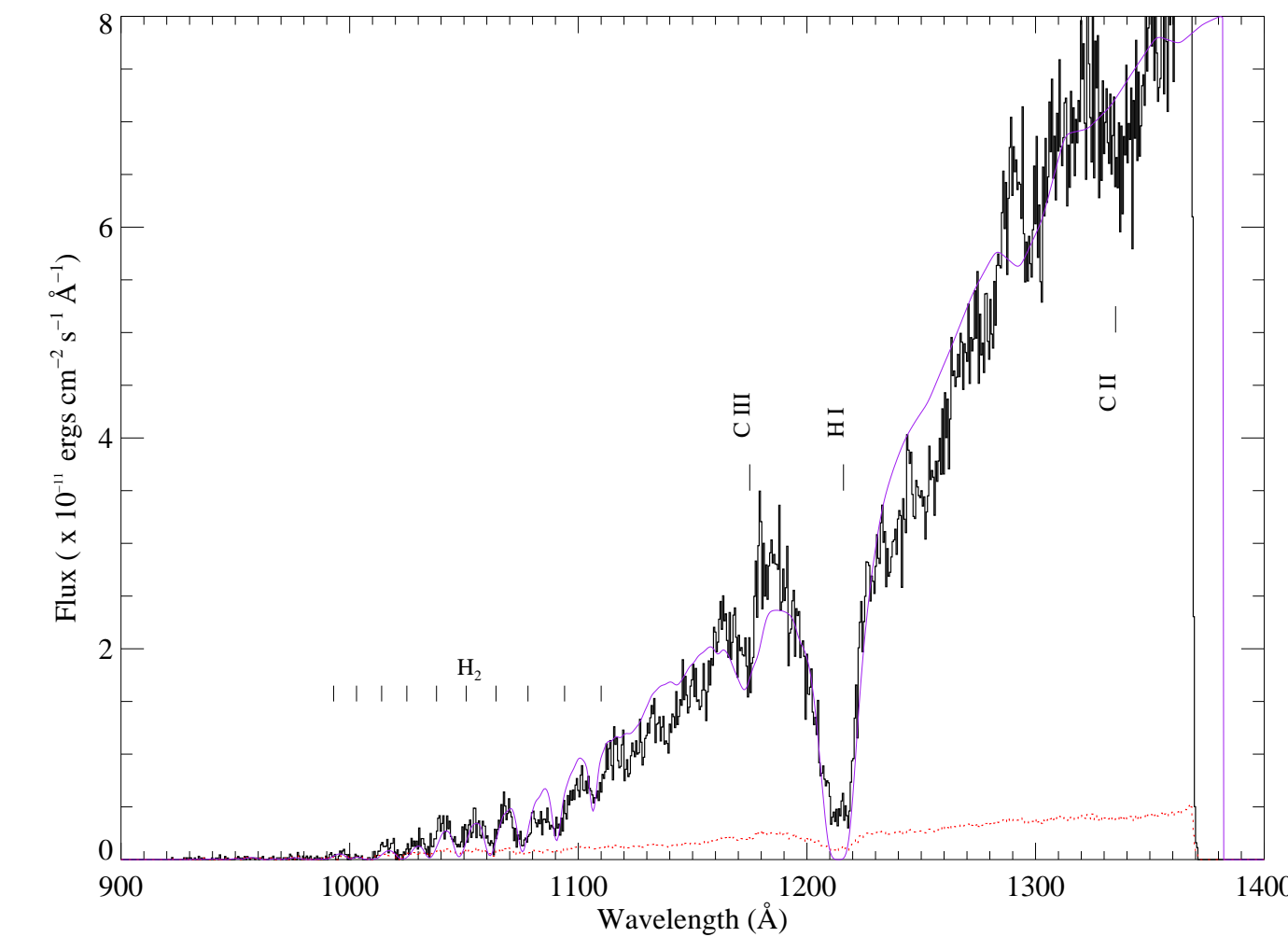


Figure 3. Flux calibrated spectrum of HD 34078, the central star in IC 405, overlaid with a Kurucz stellar model extinguished by a Fitzpatrick and Massa parameterization, and atomic and molecular hydrogen absorption (using a column density of 2.1×10^{21} , dominated by $T = 80$ K) along the line of sight – Error plotted as red broken line.

Far-UV Nebular Spectra

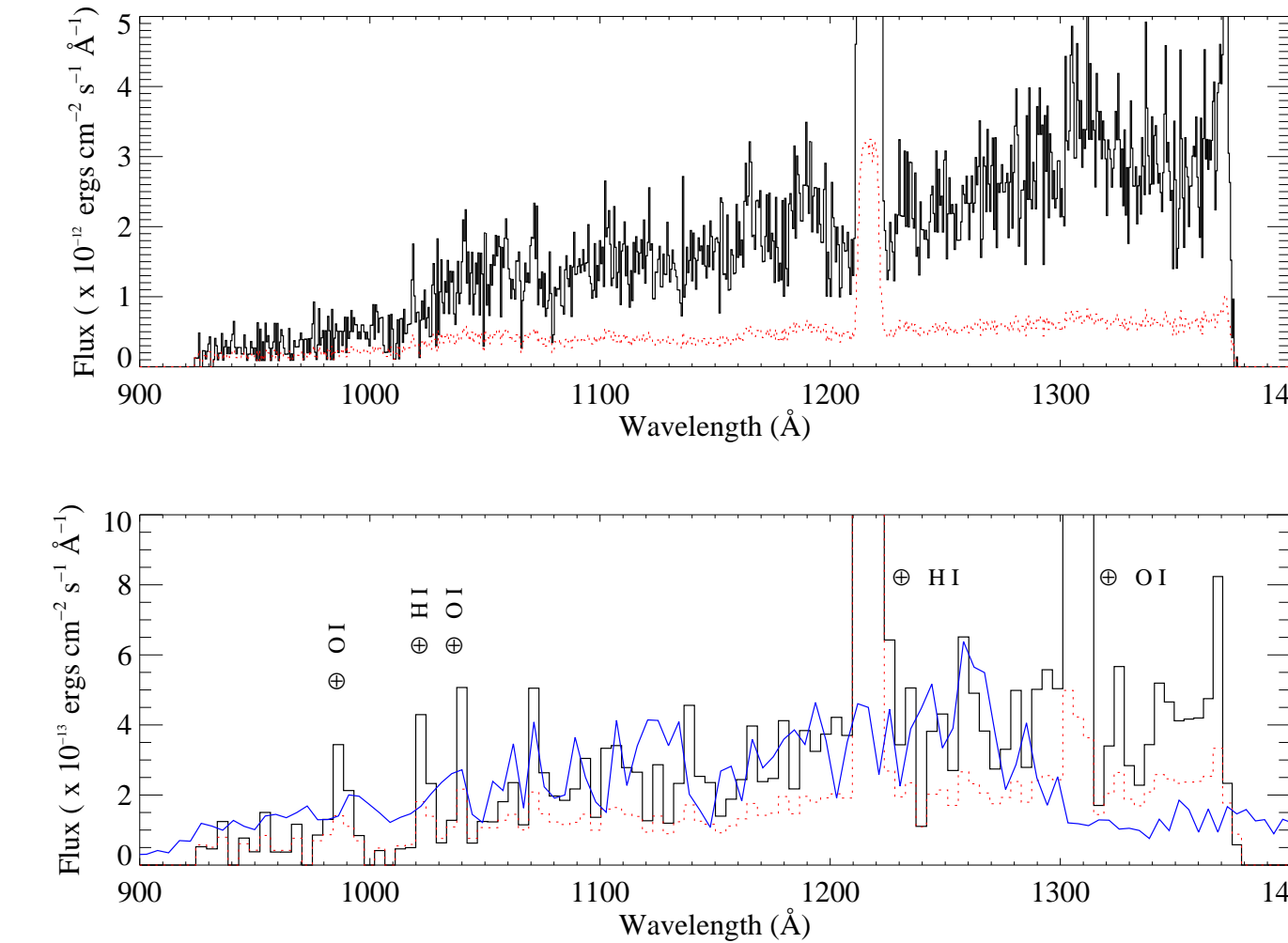


Figure 6. Spectra were also obtained for regions away from the central star. The top spectrum was obtained near HD 34078 during target acquisition and maneuvering. Below is the spectrum measured at a pointing offset, a position previously observed by the Hopkins Ultraviolet Telescope, overlaid with a modified Wolsen model for fluorescent emission of H_2 . Errors are plotted in red.

Ratio of Nebular Surface Brightness to Stellar Flux

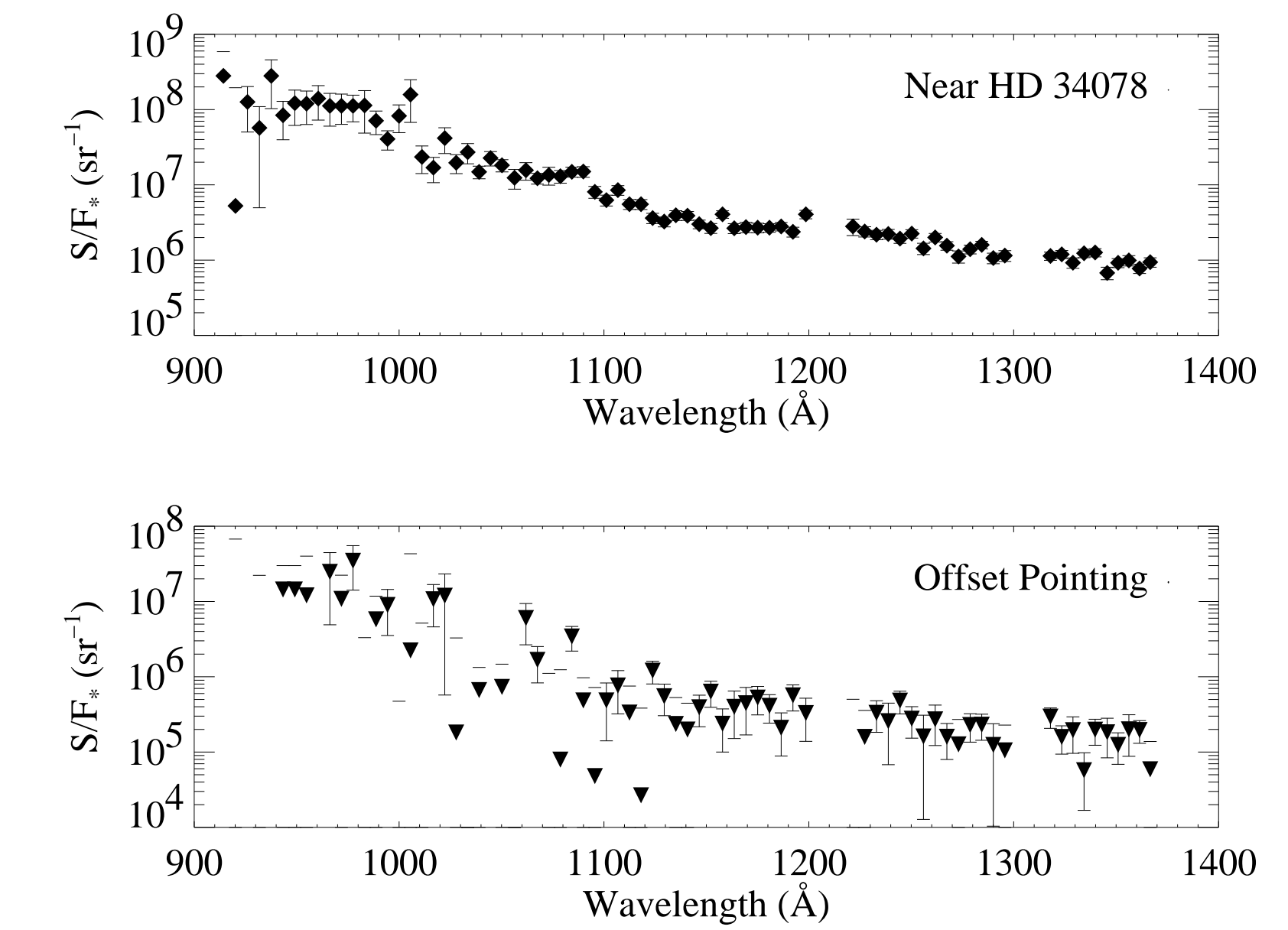
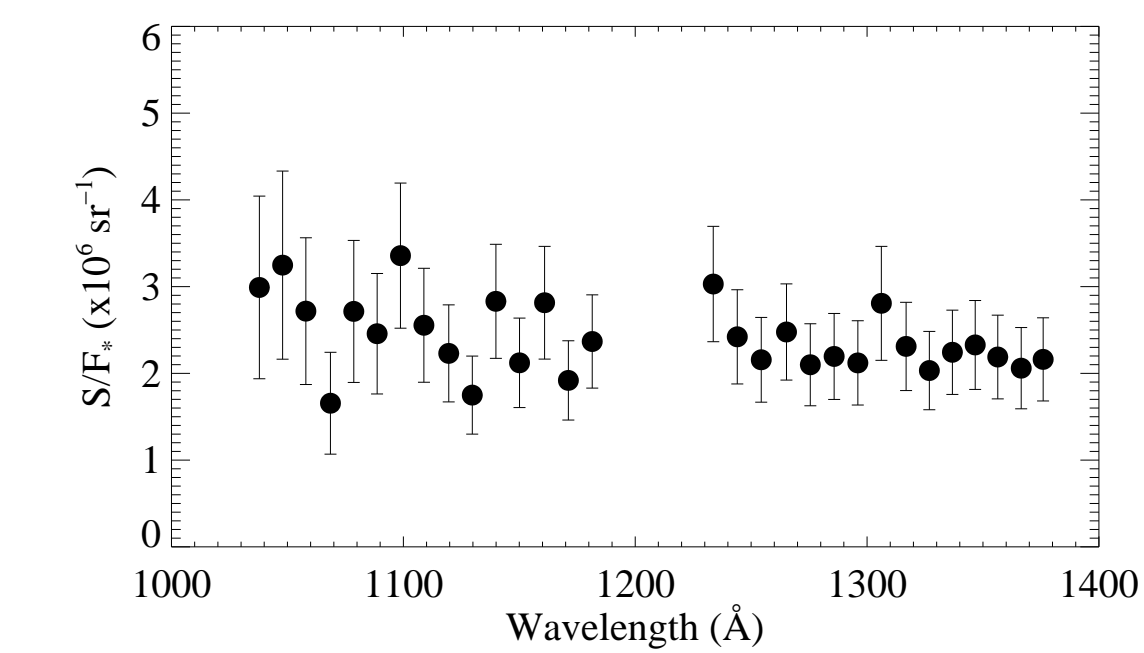


Figure 8. The ratio of nebular surface brightness to stellar flux rises by two orders of magnitude over the bandpass of the instrument, 900 – 1400 Å.

Figure 8 shows the ratio of nebular surface brightness to stellar flux near the central star and at the offset pointing (spectra of these regions shown in Figure 6). The most interesting aspect of the ratio is the rise of approximately two orders of magnitude at shorter wavelengths. The inner nebular region shows a clear rise, and the offset pointing exhibits the same trend, despite the decreased signal-to-noise. This result is in contrast with a previous sounding rocket observation of another reflection nebula, NGC 2023 (Burgh et al. 2002). Observations of NGC 2023 show a constant ratio of nebular brightness to stellar flux (see below). It should be noted that the flat surface brightness to stellar flux ratio is plotted on a linear scale while the more recent, 'blue', result is plotted on a log scale.



The result is also in contradiction with Murthy et al. (1993) observations of the reflection nebula NGC 7023. Using a combination of data from Voyager 2 and the Hopkins Ultraviolet Telescope (HUT), aboard Astro-1, Murthy et al. (1993) measure a roughly constant ratio of nebular brightness to stellar flux, explained as an increasing flux from fluorescing molecular hydrogen balanced by a decreasing dust albedo to shorter wavelengths.

Future Work

We will look to explain the two order of magnitude rise in the ratio of nebular surface brightness to stellar flux. This 'blue nebula' could be explained as a decrease in the dust absorption cross-section at shorter wavelengths or an increasing albedo. Another possible explanation could be H_2 fluorescence in the nebula. H_2 fluorescence could be produced by UV pumping, shock excitation, or formation pumping in the region as described by Sternberg (1989).

The possibility of fluorescent H_2 will be explored through further analysis of the flight data. HUT, on Astro-2, observed a pointing very near our nebular offset position. The spectrum obtained shows the double peak near 1600 Å characteristic of H_2 emission (unpublished). Our initial result, Figure 6, does not rule out fluorescent emission, and continued work will allow us to put an upper limit on what emission could be coming from the region. The flight data will be compared with other FUV and optical observations, for example, a recent FUSE observation of HD 34078 found variability in highly excited states of molecular hydrogen on the timescale of several months (Boisse et al. 2002). Measuring a limit on the UV H_2 emission will allow us to put a bound on the physical conditions within the nebula, namely the dust properties and excitation processes.

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JHU/NASA 36.198 UG - IC 405

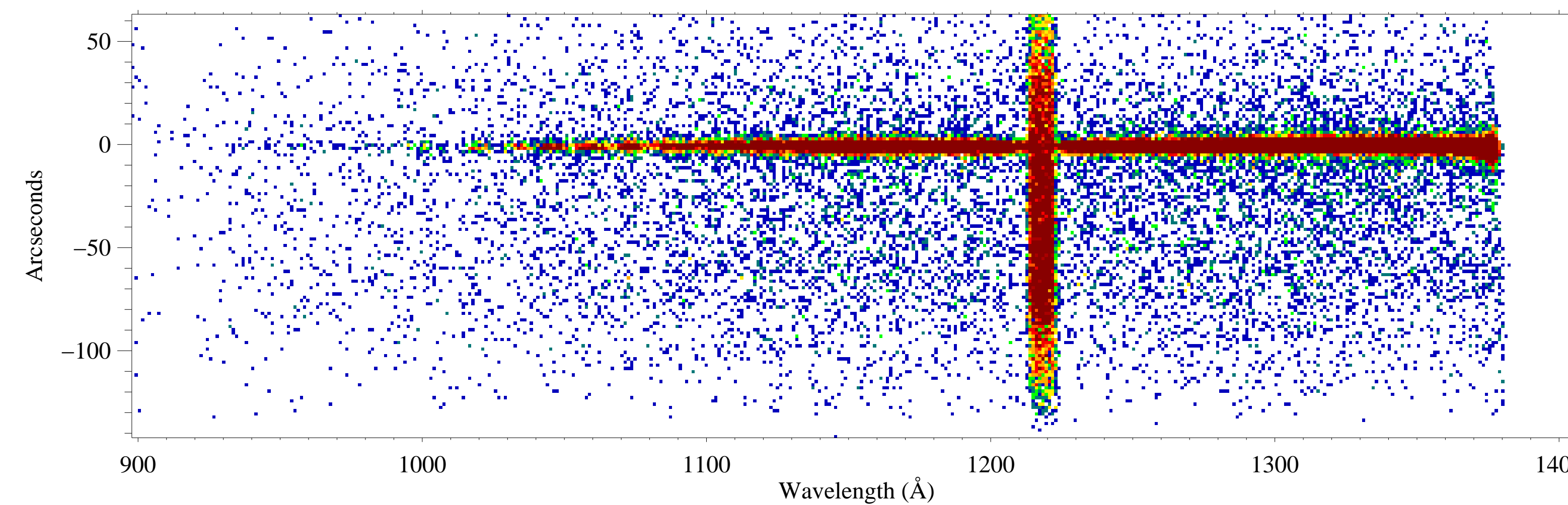


Figure 4. Raw flight data of HD 34078 and the surrounding nebula, after corrections for maneuvering, spectrograph alignment, and detector effects. In addition to the stellar and nebular flux, one notices the prominent hydrogen Ly- α airglow.

Sounding Rocket Experiment

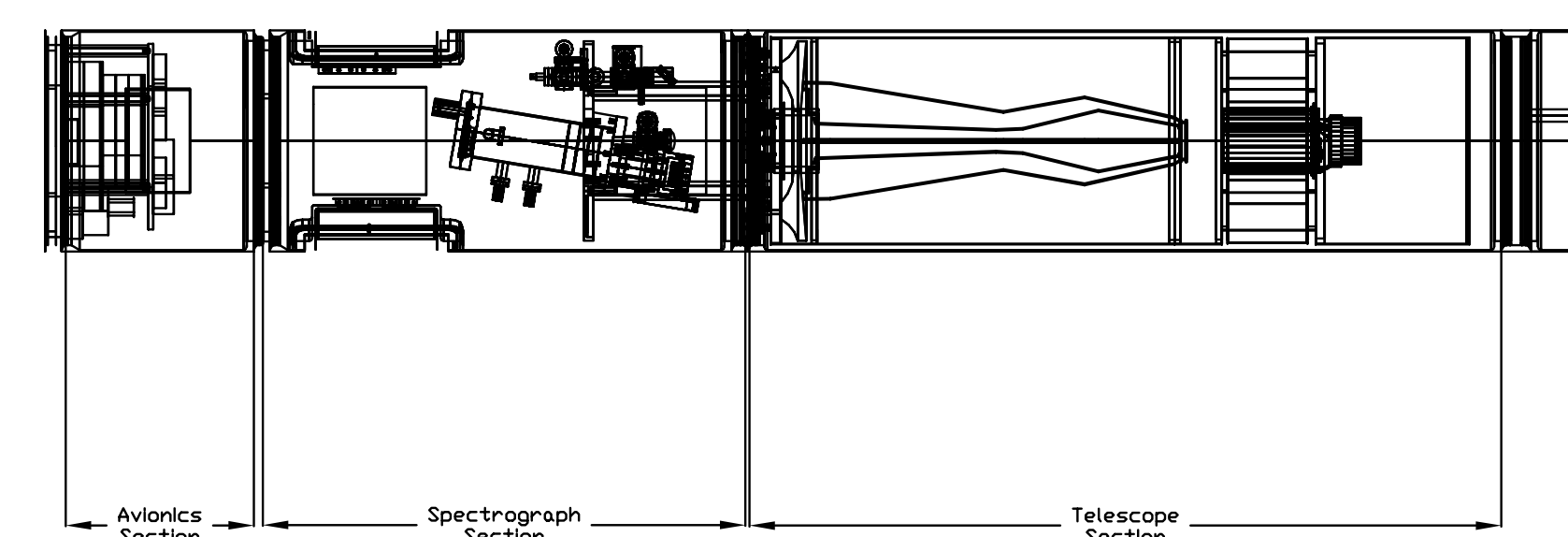


Figure 5. A schematic diagram of the JHU sounding rocket experiment.

Telescope Section consists of the Faint Object Telescope (FOT) and an Attitude Control System (ACS) startracker mounted aft of the telescope on a 'spider' that is fastened to an invar heat shield. The FOT is a 40 cm diameter Dall-Kirkham, with a focal ratio of ≈ 16 and SiC coated optics. The aft end of the telescope section is sealed by a vacuum door.

Spectrograph Section contains an evacuated Rowland Circle spectrograph, using a microchannel plate stack detector with a KBr photocathode, readout by a double delay-line anode. The spectrograph is kept at a vacuum of $\approx 10^{-8}$ torr, and isolated from the spectrograph section by a gatevalve that opens at the appropriate time in flight. The spectrograph and telescope sections share a common vacuum ($P < \text{few} \times 10^{-5}$ torr). A mirrored slitjaw lies at the telescope focus and a long slit ($12'' \times 200''$) projected on the sky) defines the entrance aperture to the spectrograph. The spectrograph achieves a pointing limited spectral resolution of $\approx 3 \text{ \AA}$.

Avionics Section is passively evacuated and houses all the experiment flight electronics. An onboard telemetry interface collects the raw detector pulses (three 16-bit words per event) and directs them to a parallel interface on the telemetry section.

Windowless Vacuum Ultraviolet Collimator

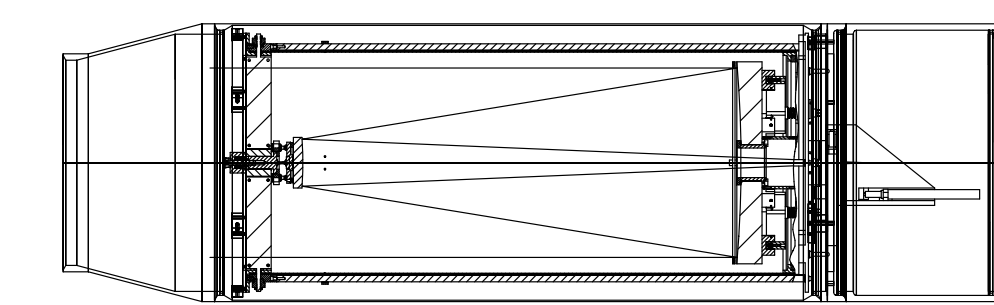


Figure 7. JHU Sounding Rocket Group Windowless Vacuum Ultraviolet Collimator.

FUV instrumentation requires testing and calibration in high vacuum environments to avoid contamination, operate microchannel plate detectors, and overcome the strong atmospheric attenuation of FUV light. Large vacuum calibration systems are expensive to build and maintain, and as a consequence, end-to-end testing of a vacuum ultraviolet optical system has traditionally been challenging. We have recently obtained a collimator used in calibrating the Far Ultraviolet Spectroscopic Explorer (FUSE), and fitted it with vacuum skins provided by Wallops Flight Facility (Burgh et al. 2001). The collimator is a Cassegrain telescope, with a 381 mm primary diameter, a focal ratio of ≈ 12 , and SiC coated optics for improved FUV reflectance.

The collimator vacuum skin tapers to 17.26 inches and couples to the aft end of the instrument section where it shares a vacuum with the Telescope and Spectrograph Sections. This allows for full end-to-end pre/postflight testing and calibration, including LSF and flat-field determination. A computer controlled motorized stage provides mounts for several light sources: a gas discharge pinhole lamp for point source simulation, an electron-impact lamp and a Bayard-Alpert ion gauge for filled aperture experiments. Precise knowledge of the LSF has enhanced the capabilities of the JHU sounding rocket experiment by allowing us to clearly distinguish between the profile of extended nebular flux and instrumental scattered light (Burgh et al. 2001). Flat fielding gives us a better understanding of detector non-uniformities and permits a more complete calibration.

Fig. 1.—

Fig. 2.—

Fig. 3.—

Fig. 4.—

Fig. 5.—

Fig. 6.—

Fig. 7.—

Fig. 8.—