FUSE

Far Ultraviolet Spectroscopic Explorer

Molecular and Atomic Excitation Stratification in the Outflow of the Planetary Nebula M27 – Stephan R. McCandliss

Department of Physics and Astronomy, The Johns Hopkins University, 3400 N. Charles Street, Baltimore, MD 21218, stephan@pha.jhu.edu

Abstract

The velocity structure of outward moving atomic and molecular material in the planetary nebula M27 (the Dumbbell) as revealed by STIS and (*FUSE*) absorption line spectroscopy and Dwingeloo 21 cm observations is presented. Comparisons are made to the velocity profiles of Hα, [N II] λ 6584 and [O III] λ5007 emission observed by Meaburn et al. (2005, 1992) and CO (2-1) 230 GHz emission observed by Bachiller et al. (2002). Highly excited molecular hydrogen is found at velocities between -30 and -35 km s^{-1}, blueshifted from the central star ($RV \approx$ -42 km s^{-1}). The molecular hydrogen appears at a transition velocity demarcating a high ionization, low velocity flow (-10$\lesssim v_{hi} \lesssim$-30 km s^{-1}) from a low ionization zone, high velocity flow (-30$\lesssim v_{low} \lesssim$-50 km s^{-1}). H I absorption is found in the low ionization zone, consistent with four velocity components between -35 and -59 km s^{-1}. Molecular hydrogen rovibrational excitation shows statistically significant deviation from pure thermal excitation at a temperature of 2040 K. It is incompatable with the excitation expected from continuum fluorescence, but may be compatable with expectations for the recently discovered Lyα fluorescence pumping of hot thermal molecular discussed by Lupu (see 175.01).

In addition, the line of sight nebular material produces no reddening of the stellar continuum. This is at odds with the dust extinction ($E(B-V) \approx 0.1$) inferred from Hα/Hβ line ratios. We discuss dissociation channels for molecular hydrogen that might result in a preferential enhancement of Hα/Hβ, relative to that expected from radiative recombination, and thereby mimic the effect of extinction. The consequence of low dust content, atomic and molecular excitation and velocity stratification are discussed in the context of molecular clump formation models for planetary nebulae.

Figure Talking Points

(Start at column 2 and move down and left.)

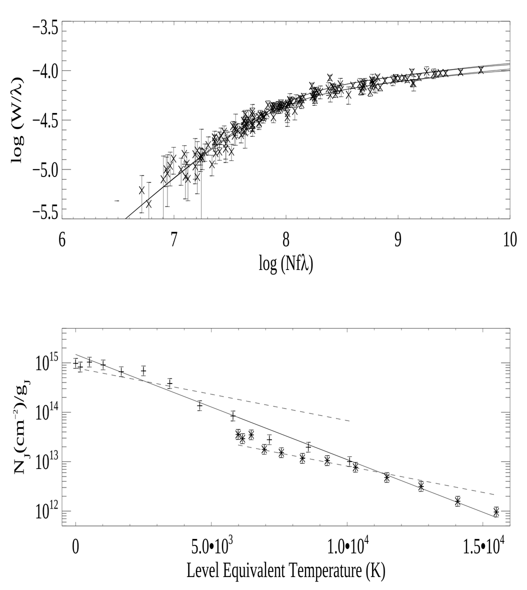
- The nebular molecular hydrogen is highly excited and blue shifted by -71 km s^{-1} heliocentric (-29 km s^{-1} wrt the central star).
- The population deviates from a pure thermal. The best fit thermal model is 2040 K. The total column density is 7.9×10^{16} cm^{-2}.
- The model of Continuum Absorption by Hydrogen is remarkably effective at revealing underlying stellar photospheric, nebular and non-nebular ISM features after subtracting it from the *FUSE* data.
- The STIS E140M absorption line spectra show most of the high ionization material is in the velocity range from -42 km s^{-1} to -71 km s^{-1}, while most of the low ionization material is in the velocity range from -71 km s^{-1} to -100 km s^{-1} heliocentric.
- Fe II seems to be absent from the nebula.
- Dwingeloo 21 cm data indicate that there are high velocity H I components at -99, -89 and -75 km s^{-1}. However, a large background subtraction was required to obtain this result. A high spatial resolution mapping of the nebula be useful. We find $N(HI)_{neb} = 3 \times 10^{19}$ cm^{-2}.
- The absorption lines and 21 cm emission show material at velocities higher than the peaks of the optical emission lines.
- Balmer line ratios indicate that there is a small amount of extinction in the nebula.
- However, the central star SED from the Lyman edge to 7000 Å is incompatible with even a small amount of reddening.
- We believe that the high excitation of molecular hydrogen in combination with the Lyc radiation from the star allows the following dissociation channel (discussed by Stecher and Williams 1967)

$$H_2^* + \gamma \lesssim 1000\text{Å} \rightarrow H_2^+ + e \rightarrow H(1s) + H(nl),$$

which cause the balmer line ratios to deviate from the expectations of pure radiative recombination.

Thanks go to Patrick J. Huggins who provided encouragement to complete this work. Based on observations made with the NASA-CNES-CSA Far Ultraviolet Spectroscopic Explorer. FUSE is operated for NASA by the Johns Hopkins University under NASA contract NAS5-32985.

Hot Molecular Hydrogen Curve-of-Growth and Continuum Absorption by Hydrogen

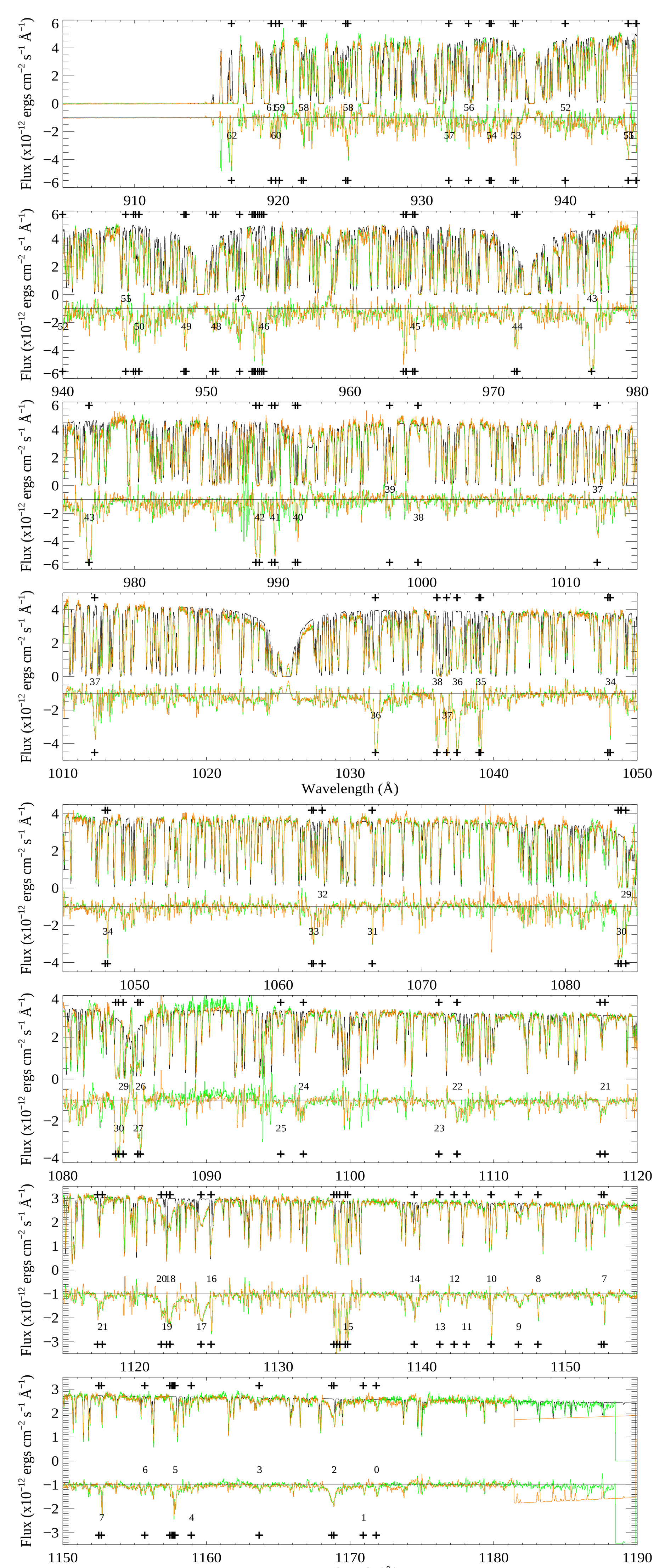


H_2 $X\,^1\Sigma^+$ Column Densities*

J″	log N(v″ = 0) log(cm^{-2})	n_{cog} lines	log N(v″ = 1) log(cm^{-2})	n_{cog} lines
0	15.0	2	13.6	3
1	15.9	11	14.4	5
2	15.7	8	14.2	3
3	16.3	4	14.6	9
4	15.8	4	14.1	10
5	16.4	8	14.6	12
6	15.7	8	14.1	5
7	15.8	5	14.5	11
8	15.2	7	13.9	2
9	15.2	11	14.3	4
10	14.6	13	13.5	2
11	14.8	5	13.8	2

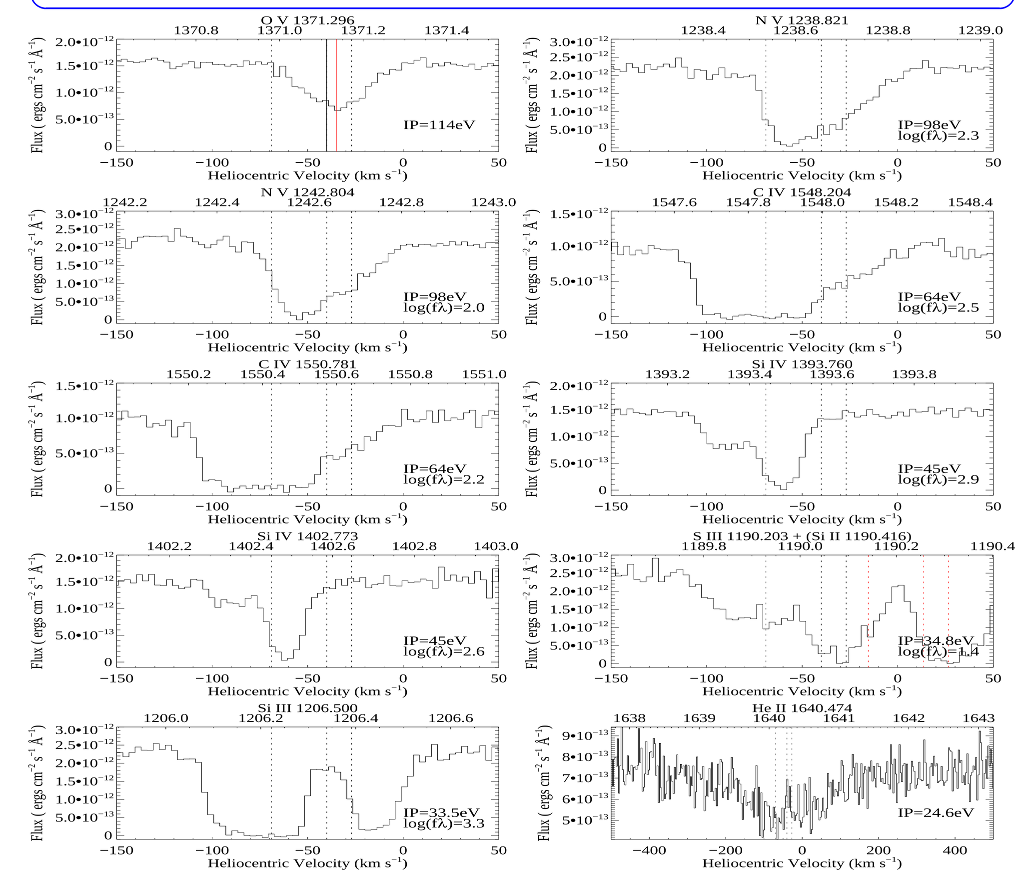
* Systematic dominated error = ± 0.1 dex.

The doppler parameter is 6.5 ± 0.5 km s^{-1}.

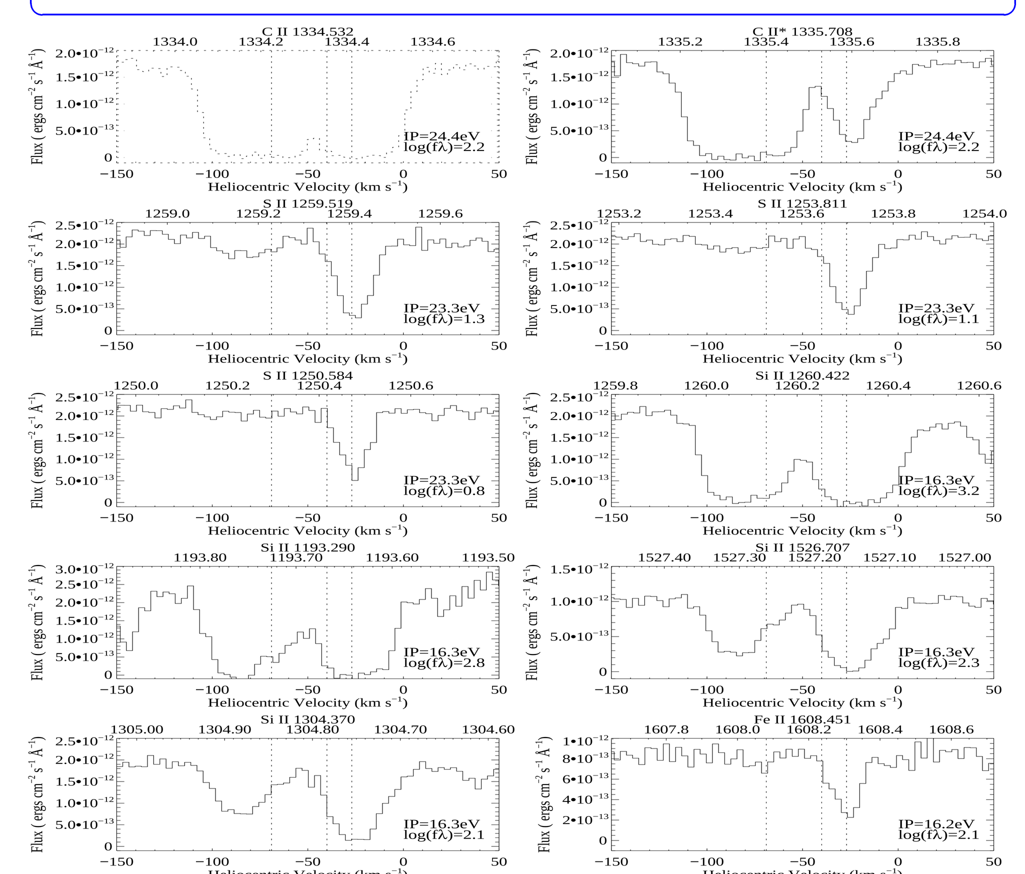


STIS E140M Line Profiles

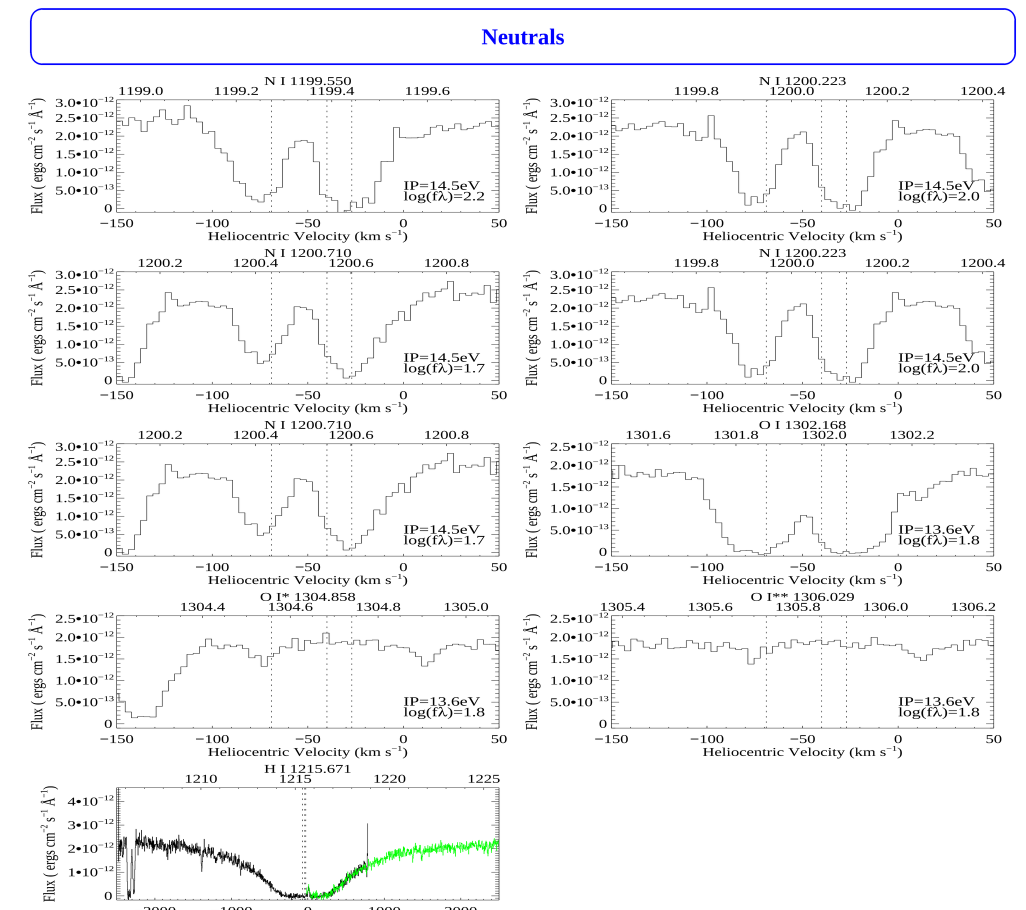
High Ionization



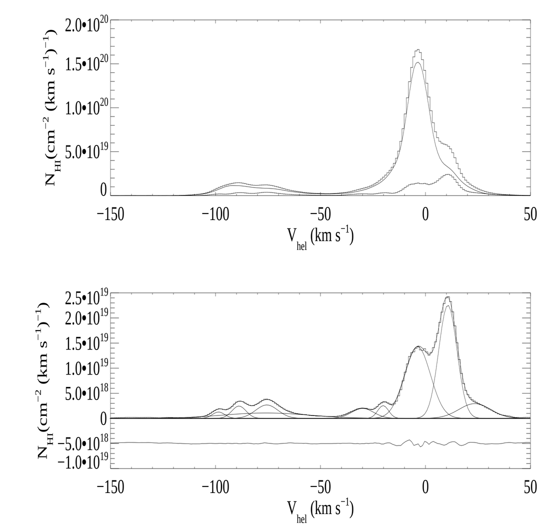
Low Ionization



Neutrals



Dwingeloo 21 cm H I Emission



H I 21 cm Velocity Component Column Densities*

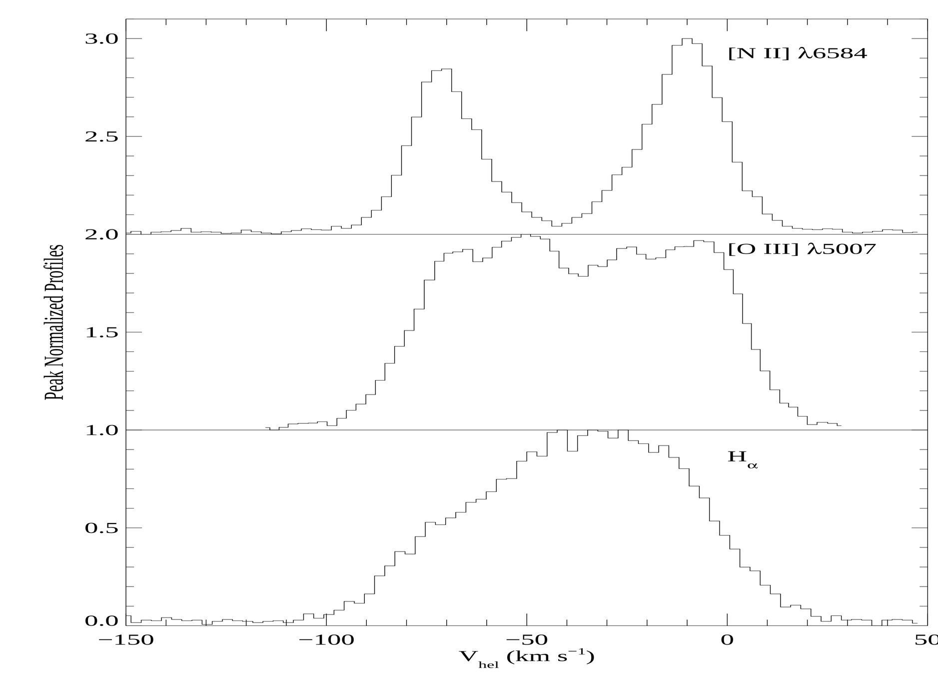
Component	log N_e† log(cm^{-2})	b (km s^{-1})	V_{hel} (km s^{-1})	log N_a‡ log(cm^{-2})
1	19.0	2.9	-98.5	18.9
2	19.3	3.4	-88.7	19.0
3	19.6	5.3	-75.3	19.0
4	19.7	20.4	-75.7	18.2
5	19.4	5.3	-29.9	19.4
6	19.2	2.6	-20.0	19.2
7	20.3	6.2	-3.5	19.3
8	20.4	4.3	10.7	18.0
9	19.7	7.5	23.6	omit

*–See figure to left. Error is ± 0.15 dex.

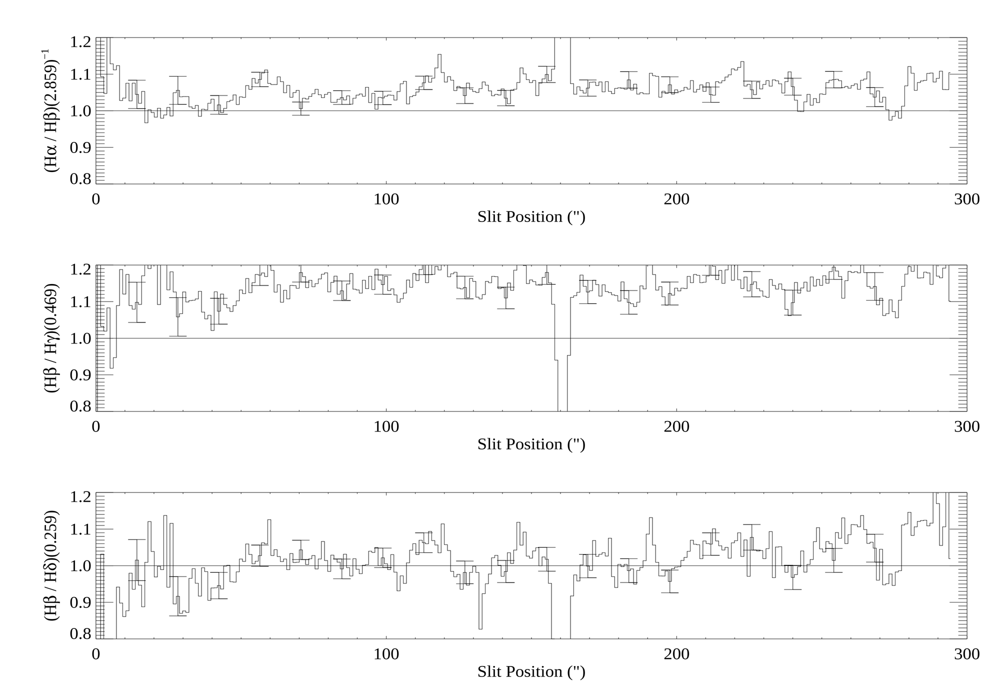
†–Emission column is upper limit.

‡–Column adopted for H I absorption model.

Hα, [O III] and [N II] Emission Profiles



APO DIS Long Slit Balmer Line Ratios – DUSTY?



Central Star SED – Where's the DUST?

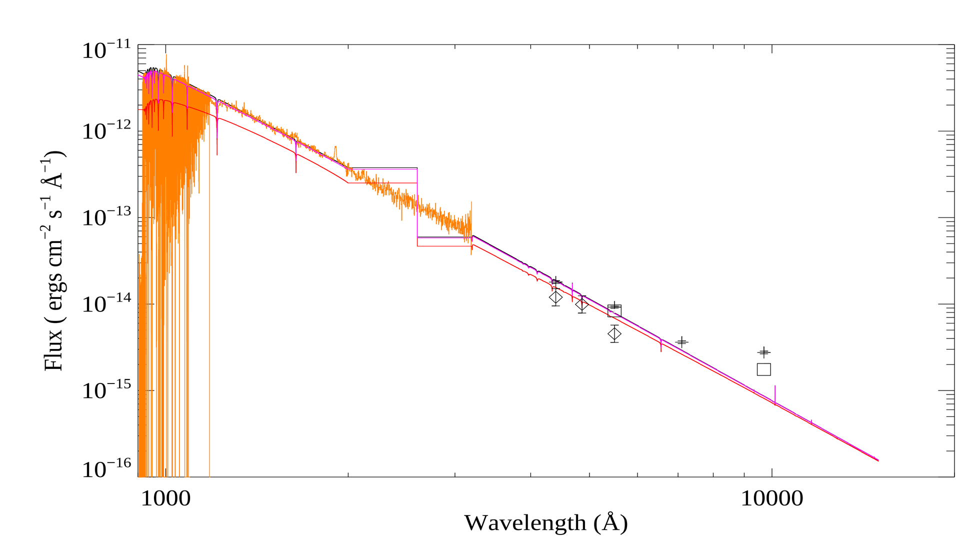


Fig. 1.—

Fig. 2.—

Fig. 3.—