

GALEX Observations of Comet 9P/Tempel 1 During Deep Impact

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Abstract

GALEX observations of comet 9P/Tempel 1 using the near ultraviolet (NUV) objective grism were made before, during and after the Deep Impact event that occurred on 4 July 2005 at 05:52 UT when a 370 kg NASA spacecraft was maneuvered into the path of the comet. The NUV channel provides usable spectral information in a bandpass covering 2000 – 3400 Å with a point source spectral resolution of $R \approx 100$. The primary spectral features in this range include a solar continuum scattered from cometary dust and emissions from OH and CS molecular bands near 3090 and 2575 Å. In particular, the CS emission is unique to this bandpass. The observations allow the evolution of these spectral features to be tracked over the encounter. We will discuss our procedure for extending the GALEX absolute calibration to the wavelength region longward of 3000 Å where the modest “red leak” in the Cs₂Te photo-cathode is nevertheless high enough to provide good detection efficiency for OH emission. In general, the NUV emissions observed from Tempel 1 throughout the encounter are much lower than those observed by GALEX from comet C/2004 Q2 Machholtz (Morganthaler et al. DPS 2005). Production rates for the dust and molecules detected by GALEX in Tempel 1 will be derived and compared to other observations.

Introduction – GALEX not just for galaxies

GALEX (Galaxy Evolution Explorer) is a NASA Small Explorer whose primary mission is to map the history of star formation using two modes: two-band photometry (FUV, 1350 – 1750 Å; NUV, 1750 – 3100 Å) and integrated field grism spectroscopy with 10–20 Å spectral resolution. GALEX is also well suited to cometary coma studies as demonstrated by the 2005 March observations of C/2004 Q2 Machholz, (see Morganthaler 025.15). It has a wide field (1.2°) with a limiting spatial resolution of in the NUV channel of $\approx 5''$ sampled with 1.5 pixels. For deep impact only NUV data was obtained as the FUV side was not operating at time of the event. Both imaging and spectroscopy were obtained and a log of the observations is given in Table 1 however, here we concentrate on the results derived from the of low resolution slitless spectroscopy in the NUV channel 1 day before (7 spectra), immediately following (6 spectra) and 1 day after (2 spectra) the impact event.

Table 1 – 9P/Tempel1 Grism Observation Log

FILE	EXPTIME	DATE-OBS	TIME-OBS
G11_024001_DEEP_IMPACT_PRE_0001-ng-int.fits	820.000	2005-07-02	06:22:17
G11_024001_DEEP_IMPACT_PRE_0002-ng-int.fits	940.000	2005-07-02	08:00:53
G11_024001_DEEP_IMPACT_PRE_0003-ng-int.fits	940.000	2005-07-02	09:39:29
G11_024001_DEEP_IMPACT_PRE_0004-ng-int.fits	960.000	2005-07-02	11:18:04
G11_024001_DEEP_IMPACT_PRE_0005-ng-int.fits	940.000	2005-07-02	12:56:41
G11_024001_DEEP_IMPACT_PRE_0006-ng-int.fits	940.000	2005-07-02	14:35:17
G11_024001_DEEP_IMPACT_PRE_0007-ng-int.fits	940.000	2005-07-02	16:13:53
G11_024002_DEEP_IMPACT_0001-ng-int.fits	759.000	2005-07-04	06:01:47
G11_024002_DEEP_IMPACT_0002-ng-int.fits	959.000	2005-07-04	07:40:23
G11_024002_DEEP_IMPACT_0003-ng-int.fits	939.000	2005-07-04	09:18:59
G11_024002_DEEP_IMPACT_0004-ng-int.fits	938.050	2005-07-04	10:57:36
G11_024002_DEEP_IMPACT_0005-ng-int.fits	940.000	2005-07-04	12:36:11
G11_024002_DEEP_IMPACT_0006-ng-int.fits	939.000	2005-07-04	14:14:48
G11_024003_DEEP_IMPACT_POST_0001-ng-int.fits	299.000	2005-07-05	05:05:56
G11_024003_DEEP_IMPACT_POST_0002-ng-int.fits	919.000	2005-07-05	06:40:52
G11_024003_DEEP_IMPACT_POST_0003-ng-int.fits	931.200	2005-07-05	08:19:29
G11_024003_DEEP_IMPACT_POST_0004-ng-int.fits	939.000	2005-07-05	09:58:05

References

- A'Hearn, M. F., et al 1984, AJ, 89, 579 – 591
 Keller et al. 2006 doi:10.1016/j.icarus.2006.09.023
 Milani, G. A., et al. 2006, arXiv:astro-ph/0608180 (accepted for Icarus DI Special Issue)
 Schleicher, D. G., Barnes, K. L., & Baugh, N. F. 2006, AJ, 131, 1130 – 1137
 Woods, T. N., et al. 1996, JGR, 101, 9541 – 9569

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Observations of Gas and Dust Distributions

At the time of impact comet 9P/Tempel 1 was at a distance of $r = 1.51$ AU from the sun and $\Delta = 0.89$ AU from the earth. The 1.5 pixels subtend 975 km at this distance. While both grism and direct imaging data were obtained before, during, and after impact, here we only discuss the spectroscopic data. OH, CS, and solar scattered UV continuum were detected prior to impact and just after impact the brightness and spatial extent of these emissions increased. The following day saw the return of these emissions to near the pre-impact levels.

The measurement of the discrete emissions from CS and OH is complicated by the blended continuous solar spectrum produced by the scattering of sunlight off of cometary dust grains in the coma. An additional complication arises from the different spatial distributions of the dust and gas components that result from the quiescent outflow and the subsequent time evolution of these distributions after the impact. Between 1700 – 3400 Å the solar spectrum rises steeply and at the long wavelength end can contribute to the extended OH(0-0) band near 3090 Å. The effective area A_{eff} supplied by the GALEX project did not extend beyond 3080 Å. We identified a field F8 V star and an IUE calibration standard to extend A_{eff} to the wavelength region between 3080 and 3400 Å. This allows us to account for the dust scattered solar contamination of the OH(0-0) band, as shown in Figures 1 and 2. We find that the dust signal mixed with the OH is small but not insignificant. It contributes strongly to the CS signal. The dust emission must be subtracted before the gas emission can be measured.

Fig 1 – F8 Star Defined $A_{eff}(\lambda \geq 3080 \text{ \AA})$

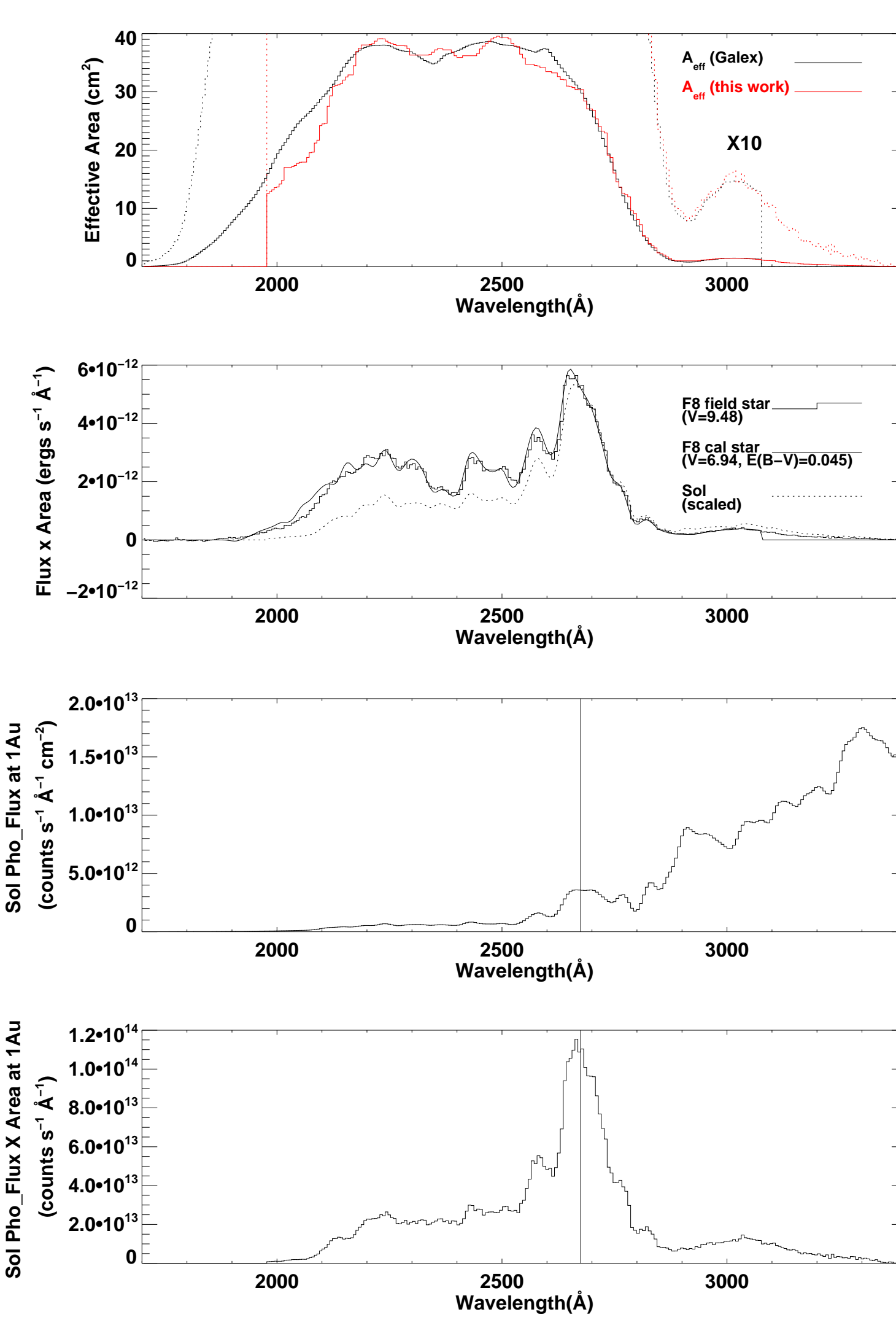
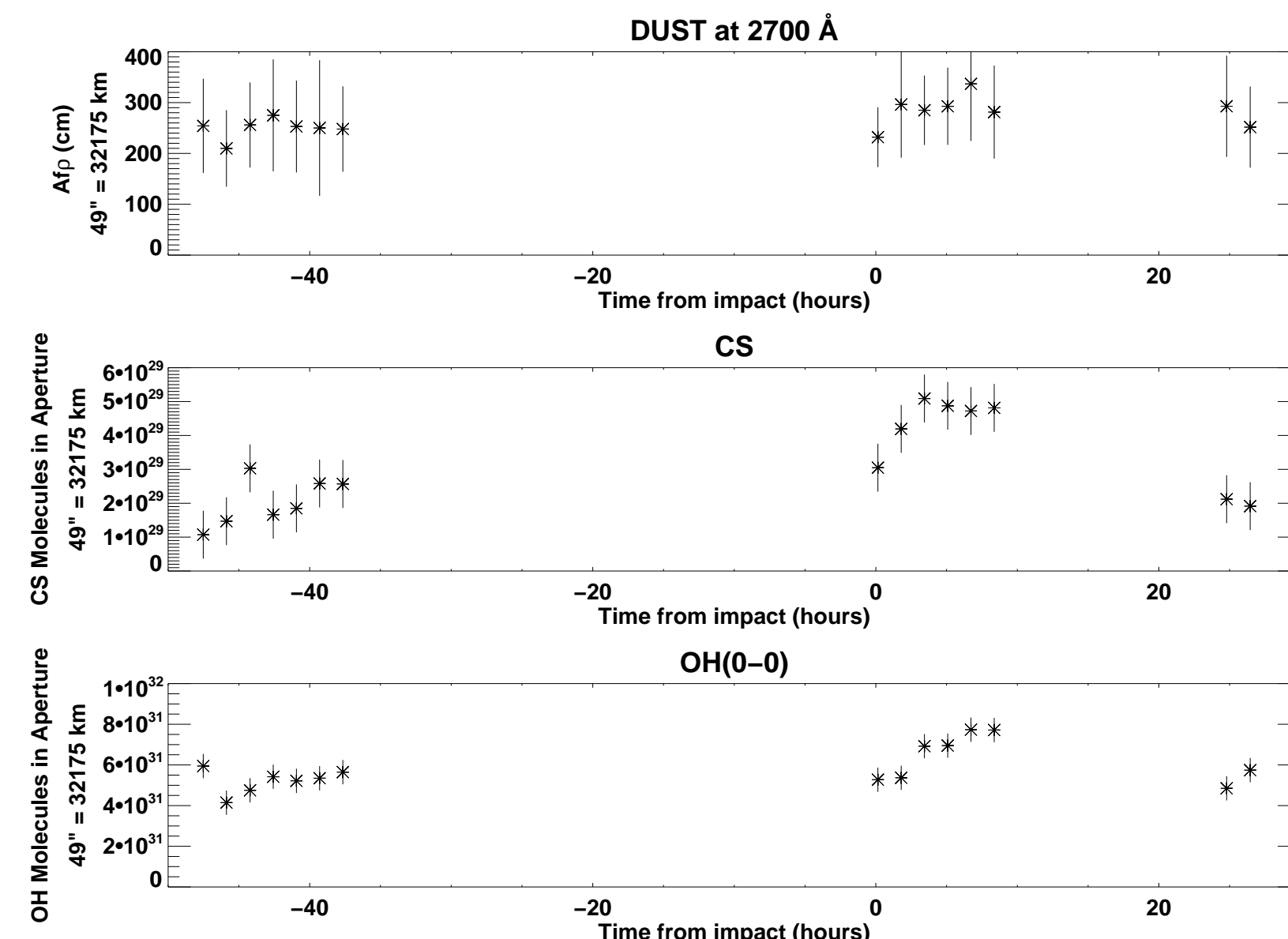


Fig 3 – Molecules in Extraction Aperture



Discussion and Conclusions

The dust is modeled using a variant on the $Af\rho$ method described by A'Hearn et al. (1984) for filter photometry where A is the albedo, f is the aperture filling fraction, and ρ is the radius of the circular photometry aperture at the distance of the comet. A square aperture with sides ρ_{eff} is more appropriate for objective grism observations, so $Af\rho_{eff} = (F_{\infty}/F_{\odot}(r = 1AU))4\pi(r\Delta)^2/\rho_{eff}$. We used the solar spectrum from UARS Day 582, described by Woods et al. (1996), scaled to the observed spectrum in a $\pm 35 \text{ \AA}$ region around 2700 Å where the solar spectrum multiplied by the GALEX A_{eff} has a clean shoulder.

We extracted spectra by summing together 33 rows ($49'' = 32175 \text{ km}$) in the direction perpendicular to the dispersion. In the top panel of Figure 2 we show the modeled solar dust signal overplotted on the spectra along with the summation intervals for the CS and OH bands. The bottom of Figure 2 shows the two-dimensional grism images around the comet moving through the stellar background. In the top panel of Figure 3 we show the variation in our modeled $Af\rho_{eff}$ values, which agree with those found in Milani et al. (2006). The next two panels show the total number of molecules found in the aperture, using fluorescent efficiencies at 1 AU of 5×10^{-4} and 2.3×10^{-4} photons s^{-1} molecule $^{-1}$ for CS and OH(0-0) respectively. We find the impact to have produced $\sim 2.5 \times 10^{29}$ molecules of CS and $\sim 2.5 \times 10^{31}$ molecules of OH. In the linear approximation and using a lifetime of 1 day (at 1 AU) we find $H_2O = 6.6 \times OH = 1.6 \times 10^{32}$ molecules. This is within the range of $1.5 - 3.0 \times 10^{32}$ found by Keller et al. (2006). The uncertainties are $\approx 20 \%$. The CS/H₂O ratio is 1.6×10^{-3} at typical IUE value. After 25 hours all gas and dust emissions within the summation aperture have returned to quiescent values.

Fig 2 – Extracted Spectra

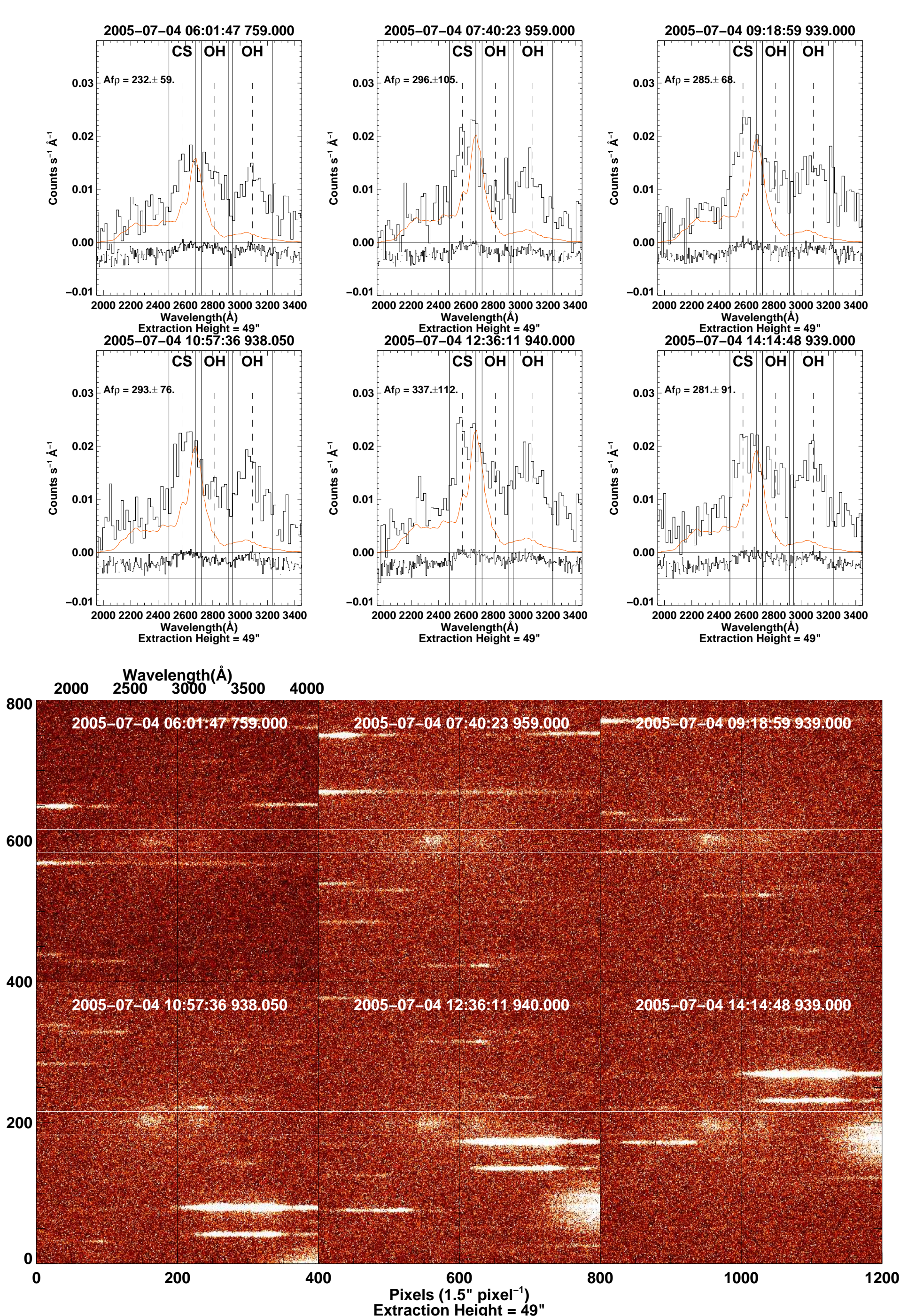


Table 1: Galex 9P/Temple1 Observation Log

Fig. 1.—

Fig. 2.—

Fig. 3.—