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AN ATLAS OF IUE FAR ULTRAVIOLET SPECTRA OF T TAURI AND HERBIG Ae/Be STARS

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ABSTRACT

We present an atlas of IUE low-dispersion short-wavelength spectra of pre-main sequence stars. These spectra are co-additions of all useful images that have been reprocessed with the NEWSIPS software. We have identified 128 objects observed by IUE, including 50 T Tauri stars and 78 Herbig Ae/Be stars. Our atlas consists of co-added spectra for each star based on the 663 usable spectra available from the IUE Final Archive.

Our objective is to obtain the highest quality spectra of these stars and to extract fluxes of the broad range of emission features produced in the atmospheres and disks of different kinds of PMS stars. These spectral features consist of emission lines formed at temperatures as high as 150,000 K (N V), molecular features (e.g., H_2), nonstellar continua in classical TTS, and absorption lines formed in the hotter stars.

Key words: T Tauri stars; Herbig Ae/Be stars; ultraviolet spectra; International Ultraviolet Explorer

1. WHAT WE HAVE DONE

The IUE Final Archive now contains essentially all of the short-wavelength low-dispersion SWP spectra obtained by IUE over its 18 year lifetime. These data have been reprocessed and the spectra extracted with new software developed by the IUE Project that rejects cosmic ray events and blemishes, minimizes fixed pattern noise, and extracts the spectra in an optimal way. Since the fixed pattern noise is now small, the S/N of these spectra increases at nearly the rate predicted for Poisson noise when many spectra are co-added.

Figure 1 demonstrates the increase in S/N and in our confidence in the reality of weak spectral features that results from using the new processing software. The figure shows a single spectrum of RU Lup processed with the old IUESIPS software, the same spectrum processed with the NEWSIPS software, and a co-addition of 22 NEWSIPS spectra of the same star. The confidence with which one can identify weak spectral features increases dramatically in this sequence.

Using the available lists of pre-main sequence stars (e.g., SIMBAD, Herbig and Bell catalog, Thé et al. catalog, Walter Sco-Cen catalog, and Jones and Walker catalog), we have identified 128 objects observed by IUE, including 50 T Tauri stars and 78 Herbig Ae/Be stars. A total of 663 usable spectra are available from the IUE Final Archive for these targets, and our atlas consists of co-added spectra for each star based on up to 94 individual spectra (AB Aur). The stars cover the spectral type range from B0 to M3. This atlas contains a complete sample of all PMS stars that were adequately observed by IUE in the far-UV (1175 – 2000 Å). This co-addition technique should result in the best available time-averaged spectra of a large sample of pre-main sequence stars, which will be useful both for analysis and for guidance of future observing programs.

Figure 2 shows typical examples of co-added spectra of T Tauri stars. Inspection of all of our data shows that the character of these spectra changes dramatically with spectral type: the cooler stars show primarily emission line spectra and the hotter stars show complex spectra containing many absorption lines.

2. RESULTS

We compare in Figure 2 (top panel) the co-added IUE spectrum of T Tau with a composite GHRS spectrum of the same star degraded from its original resolution ($\lambda/\Delta\lambda = 2000$) to the IUE SWP-LO resolution of 6Å. The GHRS spectrum is a montage of two GHRS low resolution (G140L) spectra (exposure times 1414 and 1768 sec) of T Tau itself obtained from the GHRS archive. The GHRS and IUE spectra are in good agreement, except in the 1400 – 1530 Å and 1560 – 1620 Å spectral regions where H_2 emission lines are present. Table 1 lists both the observed H_2 emission features and the emission lines that pump these H_2 lines (cf. Bartoe *et al.* 1979; Jordan *et al.* 1978; Sandlin *et al.* 1986). The most likely explanation for why the H_2 lines are more prominent in the IUE spectrum is that the entrance aperture of IUE is 200 sq. arcsec, whereas the GHRS large aperture is only about 3 sq. arcsec in size. The brighter H_2 emission observed in the IUE spectrum compared to the GHRS spectrum is consistent with both the H_2 emission being spatially extended and the fluorescent H_2 lines being pumped by Lyman-α and other bright emission lines.

Table 1 shows that the Si IV 1393 and 1402 Å lines coincide with H_2 transitions that pump several of the fluorescent emission lines. As a result, the fluxes of the Si IV lines are weakened and the lines are shifted in wavelength. The C IV 1548 Å line is contaminated by H_2 emission, but the C IV 1550 Å line is clean and thus should provide a reliable estimate of the 10^5 K emission measure.

H_2 fluorescent emission, which was first identified in T Tauri stars by Brown *et al.* (1981), is strong in some stars (e.g., T Tau) and weak in other stars (e.g., DI Cep). We detect H_2 fluorescent emission in 12 of our 38 classical TTS. Since several of the remaining spectra have low S/N, the actual fraction of stars with detectable H_2 could be higher.

Figure 3 shows that the continuum flux at 1960 Å increases with the mass accretion rate (estimated by Hartigan *et al.* 1995); moreover the continuum flux also increases with the rotation period. Since there is excellent evidence that magnetic stellar activity increases with rotation rate (and thus decreases with rotation period), these correlations provide evidence that accretion, more than magnetic activity, powers the UV continuum emission in these stars.

Table 1. H_2 fluorescent lines in T Tauri.

Wavelength (Å)	H_2 Transition	Pumped by
1257.825	R(3) 1–3	H I 1215.67 Å
1265.689	R(5) 1–3	C III 1175.263 Å?
1271.93	P(5) 1–3	H I 1215.67 Å
1274.53	R(0) 0–3	Si IV 1393.755 Å
1283.113	P(3) 0–3	Si IV 1402.776 Å
1333.64	R(0) 0–4	Si IV 1393.755 Å
1333.64	R(1) 0–4	Si IV 1402.776 Å
1338.572	P(2) 0–4	Si IV 1393.755 Å
1342.254	P(3) 0–4	Si IV 1402.776 Å
1396.225	P(1) 0–5	
1398.95	P(2) 0–5	Si IV 1393.755 Å
1407.2	P(4) 0–5	
1431.01	R(3) 1–6	H I 1215.67 Å
1434.09	R(4) 1–6	
1446.11	P(5) 1–6	H I 1215.67 Å
1453.021	P(10)0–5	C II 1335.7077 Å?
1489.562	R(3) 1–7	H I 1215.67 Å
1500.3	R(6) 1–7	
1504.755	P(5) 1–7	H I 1215.67 Å
1525.155	P(3) 0–7	Si IV 1402.776 Å
1534.775	P(5) 0–7	H I 1215.67 Å
1547.35	R(3) 1–8	H I 1215.67 Å
1556.862	R(6) 1–8	
1562.393	P(5) 1–8	H I 1215.67 Å

3. FUTURE WORK

The first paper coming out of this project will be an atlas consisting of the co-added spectra of all 128 objects and the line identifications and fluxes for all of the stars. This paper will describe our analysis technique in detail.

The second paper will include correlations of UV line fluxes with other UV, optical, and infrared fluxes and correlations with stellar parameters, accretion rates, and mass loss rates. In particular, we will describe in detail our arguments in favor of accretion being the major energy source for the UV continuum and line emission. We will also search for correlations between the H_2 line flux and other parameters. Future work will address variability.

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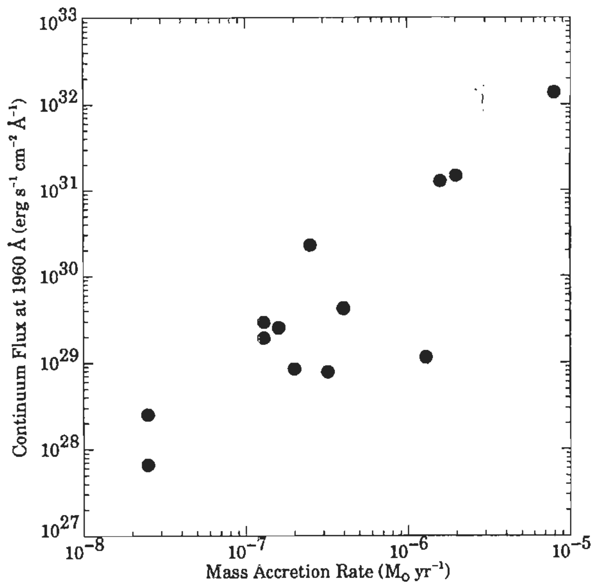

Figure 3. Dependence of the 1960 Å continuum flux on the mass accretion rate.

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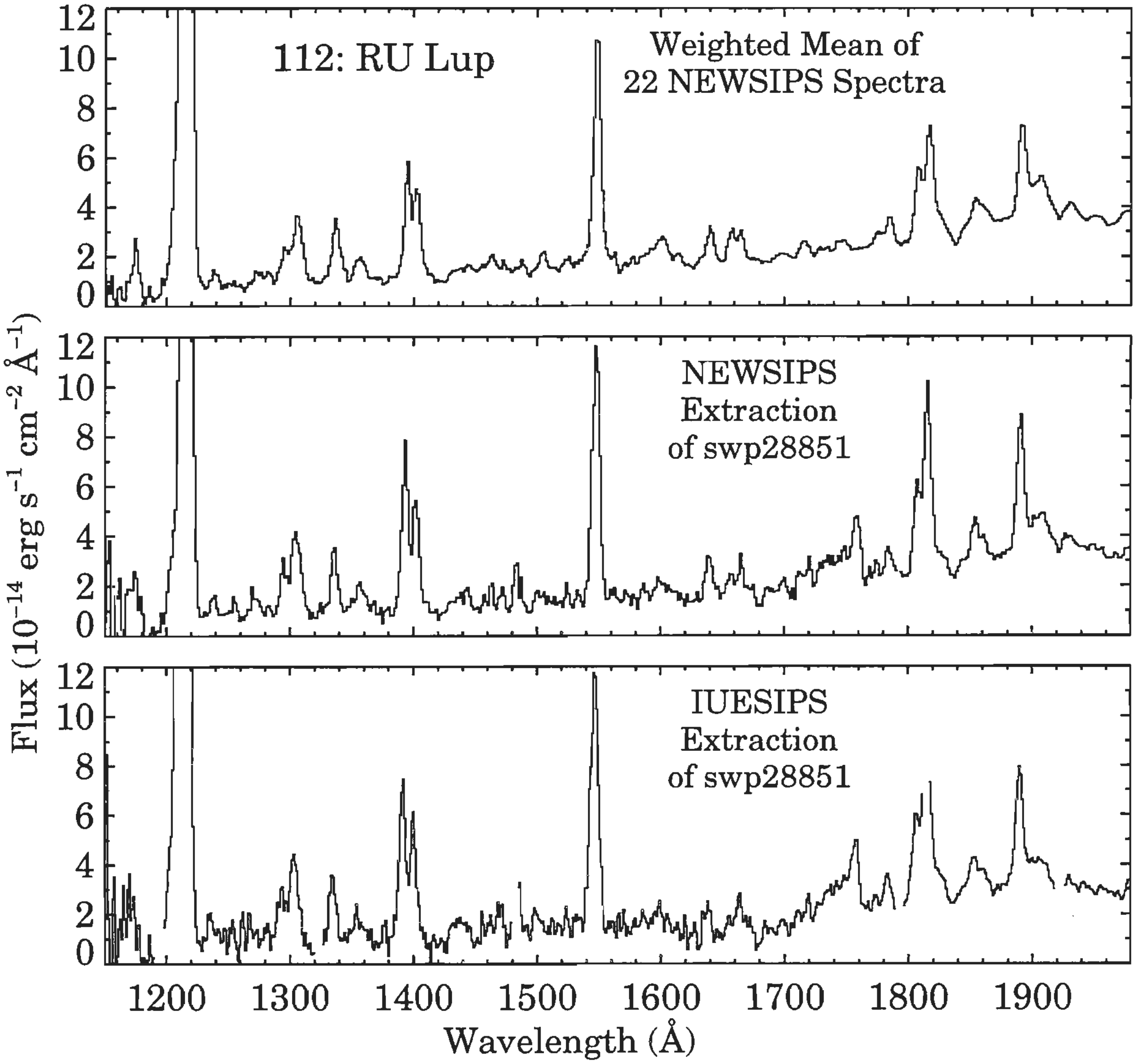

Figure 1. Bottom panel: a single spectrum of RU Lup processed with the old IUESIPS software; Middle panel: the same spectrum processed with the NEWSIPS software; Top panel: a co-addition of 22 NEWSIPS spectra of the same star.

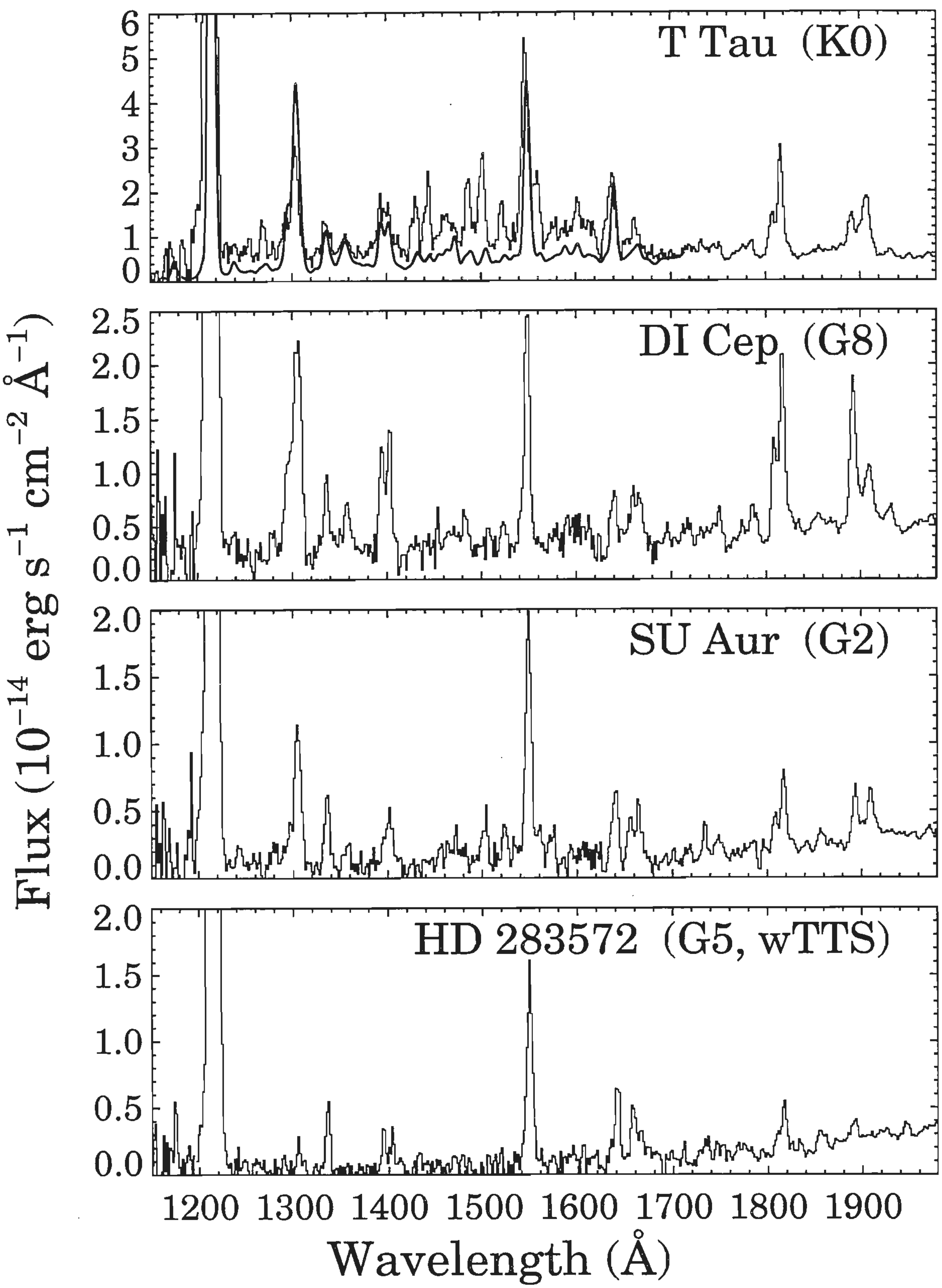

Figure 2. Examples of four T Tauri-type star spectra processed with NEWSIPS and co-added. The thick line in the top panel is a GHRS spectrum degraded to the IUE SWP-LO resolution.