EVIDENCE FOR EXCESSES IN CTTS - OUTFLOWS AND ACCRETION IN X-RAYS AND FUV.

Hans M. Günther, Jan Robrade, Jürgen H. M. M. Schmitt, *Hamburger Sternwarte, Gojenbergsweg 112, 21029 Hamburg, Germany*.

Classical T Tauri Stars (CTTS) show a wealth of in- and outflow phenomena, observed in different wavelength bands. Here we attempt to characterise their properties by a comparative study of CTTS observed with high spectral resolution in order to complement the recent low resolution COUP and XEST surveys.

1 Triplets in CTTS

With the exception of T Tau (Güdel et al. 2006) all CTTS observed so far with high resolution spectroscopy show traces of high density in their O VII tripletts and mostly also in Ne IX. To the already known stars TW Hya (Kastner et al. 2002; Stelzer & Schmitt 2004), BP Tau (Schmitt et al. 2005), V4046 Sgr (Günther et al. 2006) and MP Mus (Argiroffi et al. 2007). Here we show yet a further member: RU Lup (Robrade & Schmitt submitted to A&A). Its triplet is presented in Fig. 1. The f/i ratio of $f/i = 0.26 \pm 0.23$ for the PSF core clearly deviates from the low density limit of about 4. So it seems that TW Hya like densities are not the exception, but the rule in CTTS. Low f/i-ratios are naturally explained by a magnetically funnelled-accretion scenario, where a strong shock develops at the base of the funnel. We have simulated this shock in a 1-D static model taking into account non-equilibrium effects (Günther et al. 2007). Coronal components explain the high energy components and the flares observed on CTTS very similar to those on MS stars, the shock is responsible for the emission at lower energies. Other proposed mechanisms concentrate on the direct influence of the disk and accretion funnels on the coronal structure.

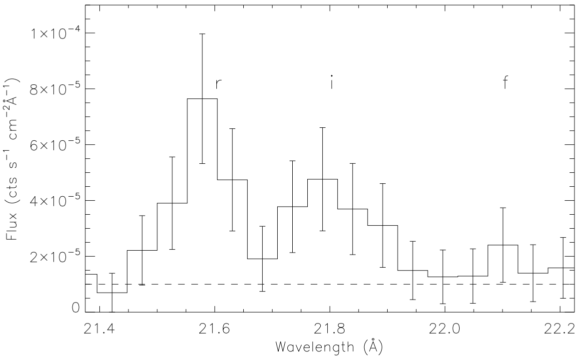

Figure 1: Fluxed O VII triplet for RU Lup from RGS data (PSF core, rebinned), the background level is indicated by a dashed line, labelled are the (r)esonance, (i)ntercombination and (f)orbidden line.

2 Soft X-ray excess

Observationally CTTS are surprisingly well distinguished from main-sequence stars by their comparatively low O VIII emission. In Fig. 2 the ratio of the O VIII(Ly$_\alpha$) flux to the O VII(r) line is plotted in relation to the sum of the fluxes for all CTTS with sufficient signal in their high-resolution X-ray spectra and a large sample of MS stars at various activity levels (Ness et al. 2004). The CTTS all cluster in the lower right corner of the plot, their O VII lines (peak formation temperature 2-3 MK) are stronger than in MS stars with the same total oxygen luminosity. By using only oxygen lines we eliminate the influence of the non-solar abundances observed in the X-ray spectra of CTTS. Very similar to the CTTS is the Herbig AeBe star AB Aur. The robust results indicate that in CTTS more plasma is found lower temperatures around 1-2 MK. Using a similar diagnostic Telleschi et al. (2007) could already show a clear seperation of CTTS on the one side and WTTS and zero-age MS stras on the other side. Again this soft excess can be explained naturally as originating from an accretion shock, where the temperatures are limited by the accretion with free-fall velocity to less than 2 MK with most emission measure concentrated at lower temperatures.

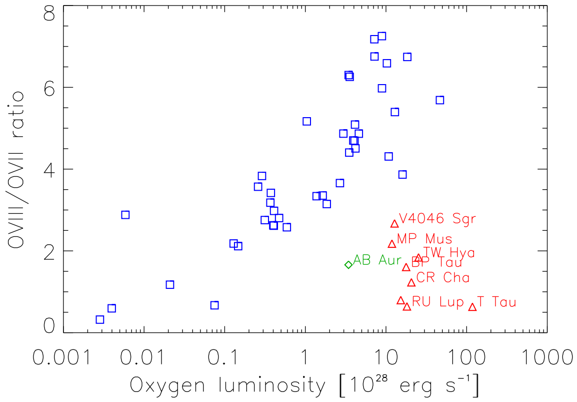

Figure 2: Ratio of the emitted O VIII(Ly$_\alpha$)/O VII(r) line flux vs. oxygen luminosity (O VII(r)+O VIII)(Ly$_\alpha$) for main-sequence stars (diamonds), CTTS (triangles) and the Herbig Ae star AB Aur (square).

3 Absorption excess

Although potentially difficult due to the optical veiling many CTTS have reliable reddening values from optical observations. Long X-ray exposures allow to fit the absorbing column density N_H. It turns out that the usual conversion law $N_H = A_V \cdot 2 \times 10^{22}$ cm^{-2} fails for a number of them, as shown in Fig. 3, where the line indicates compliance with the conversion formula. The optical reddening is caused by dust, whereas the main contributor to the X-ray absorption is gas. AA Tau, DF Tau, SU Aur, T Tau and to lesser extend RU Lup need to have an dust-depleted absorber in the line of sight. We speculate that this gas could be the disk in AA Tau (Schmitt & Robrade 2007), because this object is seen nearly edge-on, and possibly outflows in the other objects. RU Lup is known from studies of the surrounding H_2 to have outflows (Herczeg et al. 2005). We note that in these objects not only the ratio of X-ray to optical extinction is larger than usual, but they are also those with the largest absolute values for the absorbing column density, although their distance is comparable to the other studied CTTS e.g. in the Taurus molecular cloud. Some theoretical models predict a dense stellar wind (von Rekowski & Brandenburg 2006), which is too hot to form dust. Another emission region could be the termination shock of stellar jets.

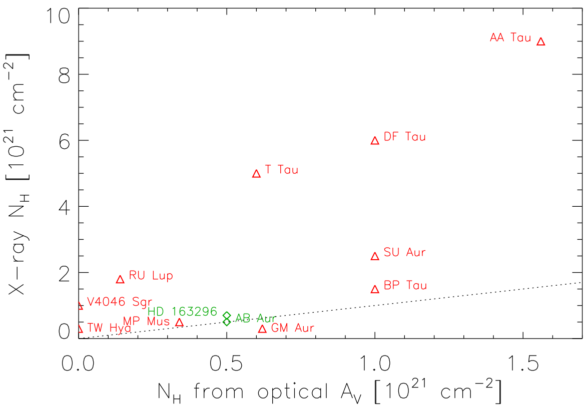

Figure 3: Absorbing column densities from X-ray and optical measurements in cm^{-2}.

4 Anomalous line forms

Some CTTS are observed in the FUV with *FUSE*. From the available CTTS spectra we extracted the C III lines at 977 Å and the O VI doublet 1032 Å and 1038 Å (Fig. 4). They range from blue-shifted by -200 km s^{-1} for RU Lup to redshifted by up to 100 km s^{-1} in TW Hya. All CTTS with excess absorption show here blue-shifted lines: RU Lup, T Tau and DF Tau. This supports the hypothesis that the emission is formed in outflows. We do not have a compelling explanation for the formation of the red-shifted lines. It is tempting to assume an origin in the accretion funnels, however, this requires temperatures up to 300 000 K for the formation of O VI, which are only reached in a very small regions close to the stellar surface, so this cannot explain the width of the lines. In the post-shock region the temperatures are high enough, but according to the Rankine-Hugoniot jump contition the velocities there do not exceed 125 km s^{-1}, much less then the observed line widths.

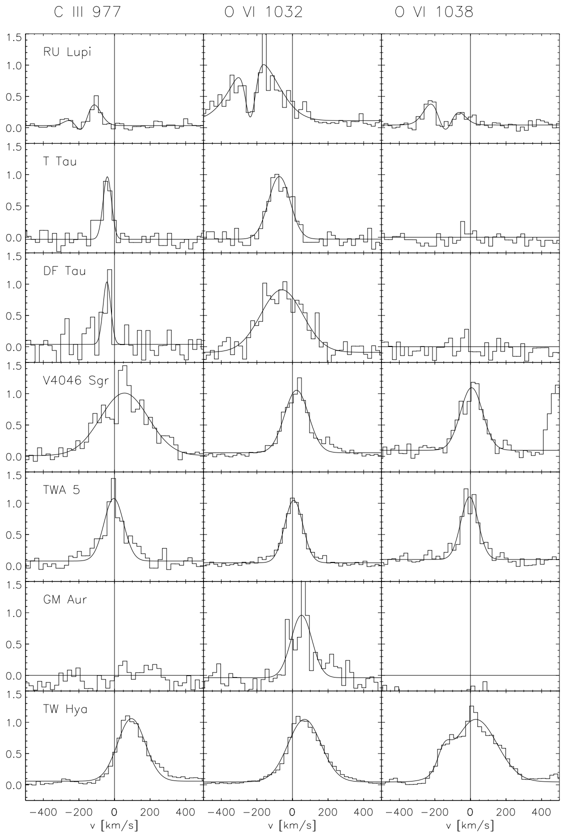

Figure 4: Hot ion lines observed with *FUSE* in CTTS and best fit Gauss profiles. For RU Lupi an additional absorption component is fitted. All line profiles are normalised rebinned to instrumental resolution.

References

Argiroffi, C., Maggio, A., & Peres, G. 2007, A&A, 465, L5

Güdel, M., Skinner, S. L., Mel'nikov, S. Y., et al. 2006, ArXiv Astrophysics e-prints

Günther, H. M., Liefke, C., Schmitt, J. H. M. M., Robrade, J., & Ness, J.-U. 2006, A&A, 459, L29

Günther, H. M., Schmitt, J. H. M. M., Robrade, J., & Liefke, C. 2007, A&A, 466, 1111

Herczeg, G. J., Walter, F. M., Linsky, J. L., et al. 2005, AJ, 129, 2777

Kastner, J. H., Huenemoerder, D. P., Schulz, N. S., Canizares, C. R., & Weintraub, D. A. 2002, ApJ, 567, 434

Ness, J.-U., Güdel, M., Schmitt, J. H. M. M., Audard, M., & Telleschi, A. 2004, A&A, 427, 667

Robrade, J. & Schmitt, J. H. M. M. submitted to A&A

Schmitt, J. H. M. M. & Robrade, J. 2007, A&A, 462, L41

Schmitt, J. H. M. M., Robrade, J., Ness, J.-U., Favata, F., & Stelzer, B. 2005, A&A, 432, L35

Stelzer, B. & Schmitt, J. H. M. M. 2004, A&A, 418, 687

Telleschi, A., Güdel, M., Briggs, K. R., Audard, M., & Scelsi, L. 2007, A&A, 468, 443

von Rekowski, B. & Brandenburg, A. 2006, Astronomische Nachrichten, 327, 53