Determining the Absorption towards Classical T Tauri Stars from Hydrogen Emission Lines

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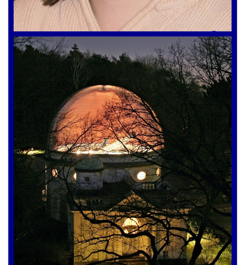
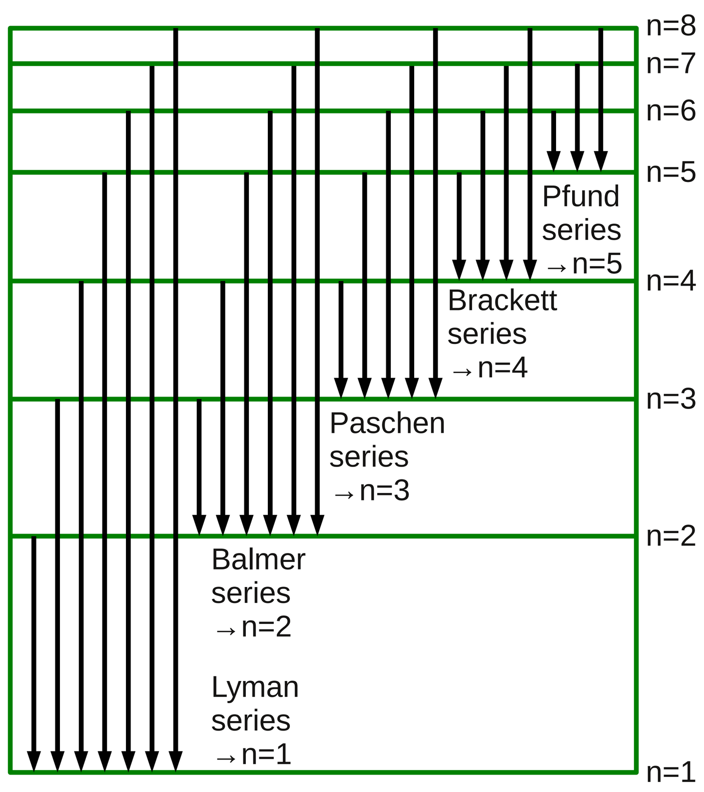


Abstract: **Classical T Tauri stars (CTTS) are low-mass pre-main sequence objects surrounded by an accretion disk and still partially embedded in the parent circumstellar cloud. We observed a sample of 20 CTTS covering different ages and evolutionary stages with VLT/X-Shooter. Its wide wavelength coverage allows to simultaneously observe H I lines in the Balmer, Paschen, and Brackett series, which supposedly originate mainly from the accretion funnel. We present the results of our study of reddening in CTTS using ratios of common upper level lines. We determine new extinction values A_V for several objects, but cannot find deviations from the standard parametrisation $A = A_V \cdot \lambda^{-1.84}$ (Martin & Whittet 1990) of the reddening at infrared wavelengths.**

1. Determining A_V from common upper level hydrogen lines



The photon rate $F_{u \to l}$ produced by a specific transition in an optically thin hydrogen gas is determined by

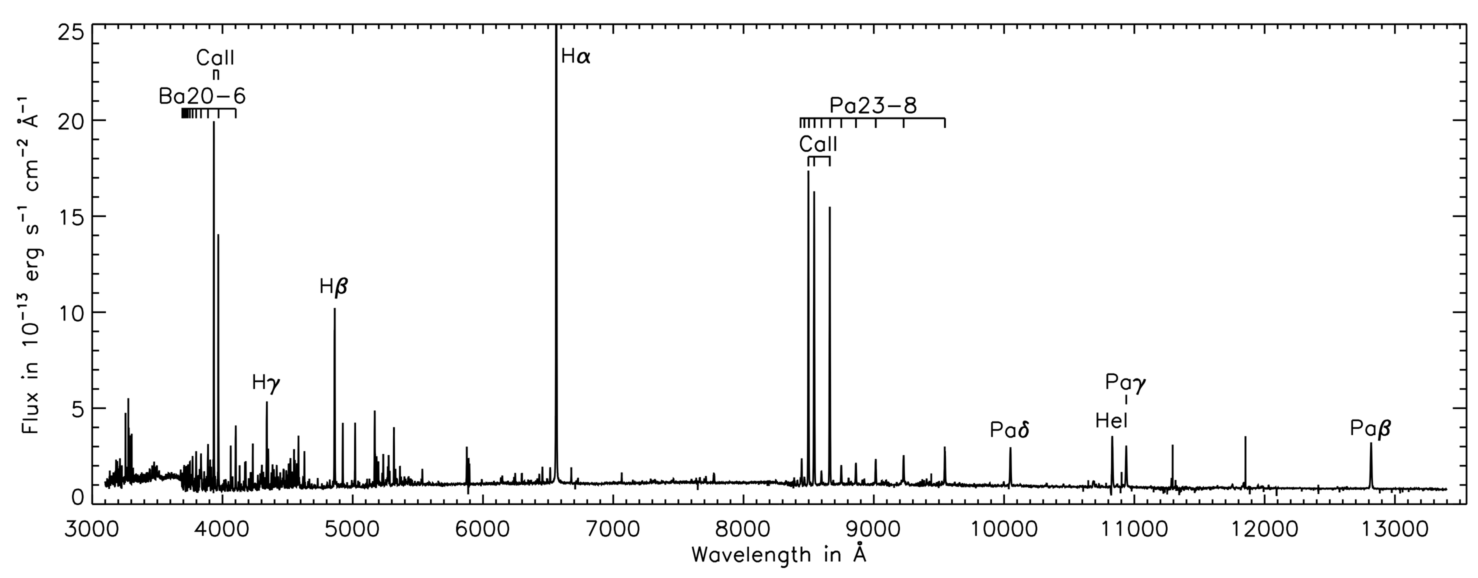
$$F_{u \to l} = N_u \cdot A_{ul},$$

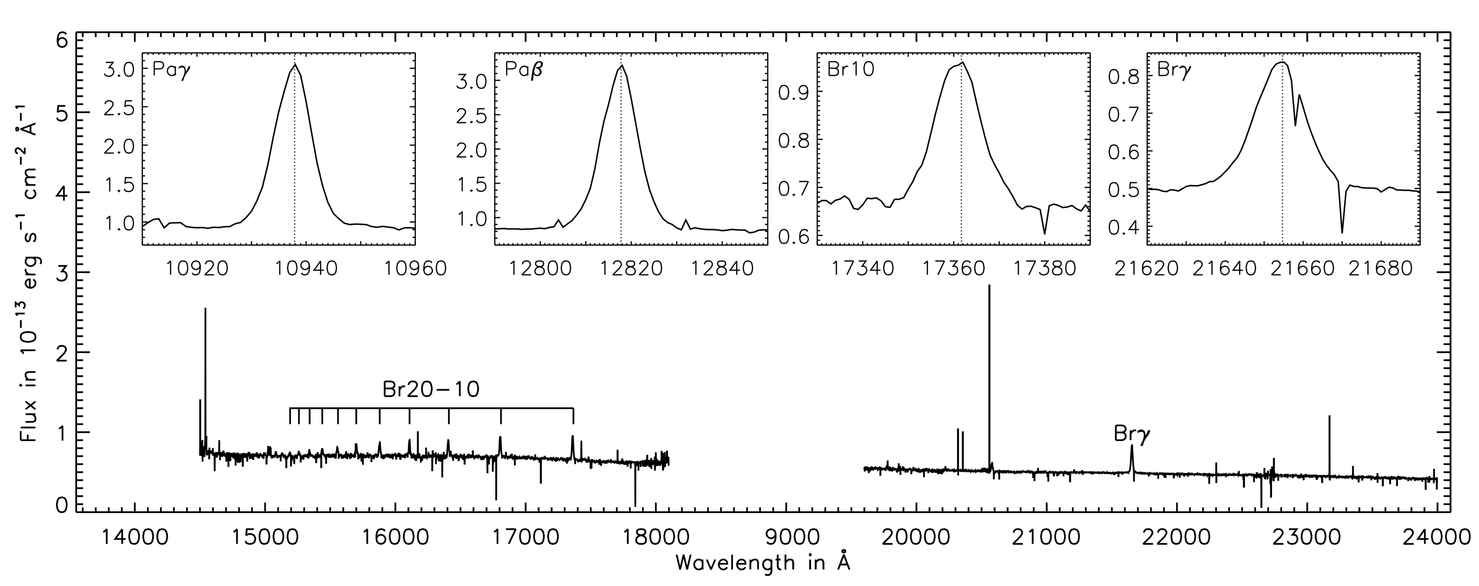
where N_u is the population density of the upper level and A_{ul} the Einstein coefficient of spontaneous emission. Stimulated emission is not relevant here. In ratios of lines from a common upper level the population density cancels and the ratio is given by the Einstein coefficients only:

$$\frac{F_{u \to l_1}}{F_{u \to l_2}} = \frac{A_{ul_1}}{A_{ul_2}}.$$

Thus, the ratio is independent of the temperature and density of the emitting gas. Any deviation from this ratio has to be caused by reddening. At infrared wavelengths the reddening is parametrised by a wavelength dependent power law $A = A_V \cdot \lambda^{-\alpha}$ with the extinction value A_V and the exponent α, e.g. $\alpha = 1.84$ between 0.9 μm and 5 μm (Martin & Whittet, 1990, ApJ, 357, 113). From the difference between the expected and the observed ratios we can gather information on the reddening.

2. Example spectrum

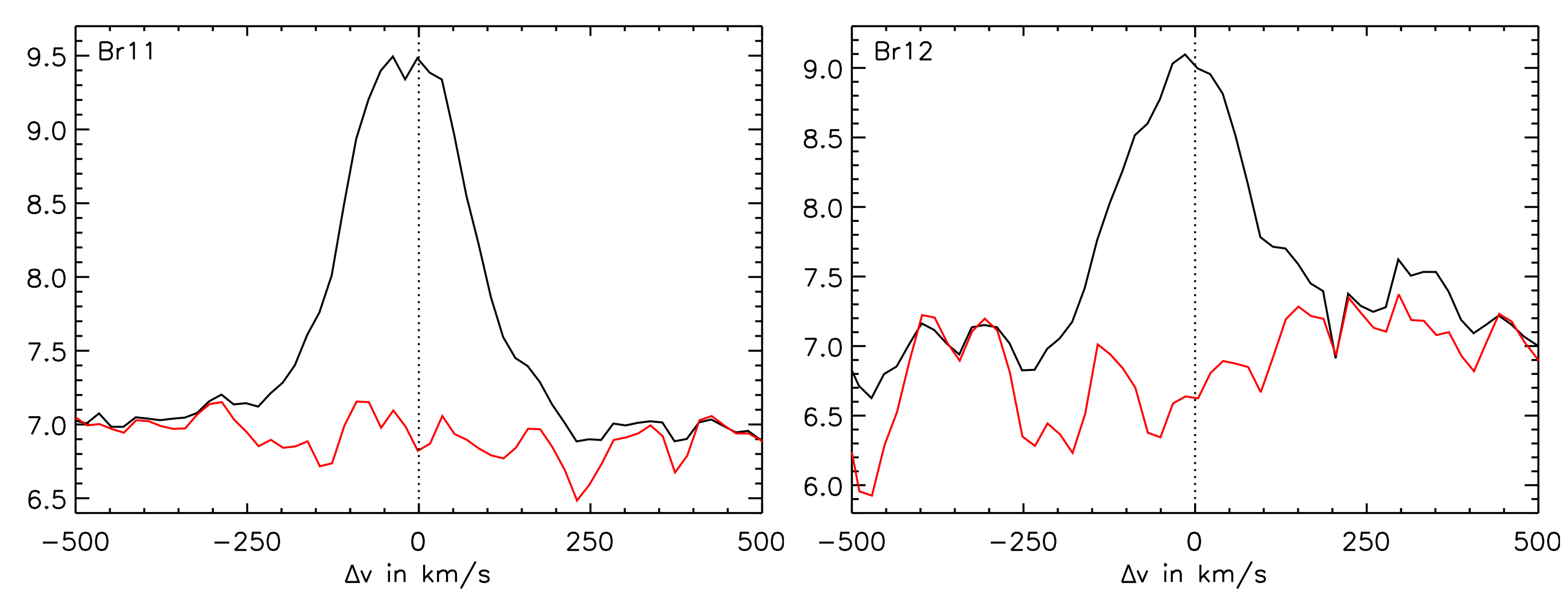




The plots show the flux calibrated VLT/XShooter spectrum of RU Lup annotated with important emission lines (Hα is cut off). In the lower plot the profiles of the hydrogen lines Paβ, Paγ, Brγ, and Br10 are shown in insets. The spectrum was corrected for telluric absorption using simulated atmospheric transmission spectra computed by the code LBLRTM (Line-By-Line Radiative Transfer Model, Clough et al. 2005, JQSRT, 91, 233). The omitted parts of the spectrum are too heavily contaminated by telluric lines to obtain a reliable correction.

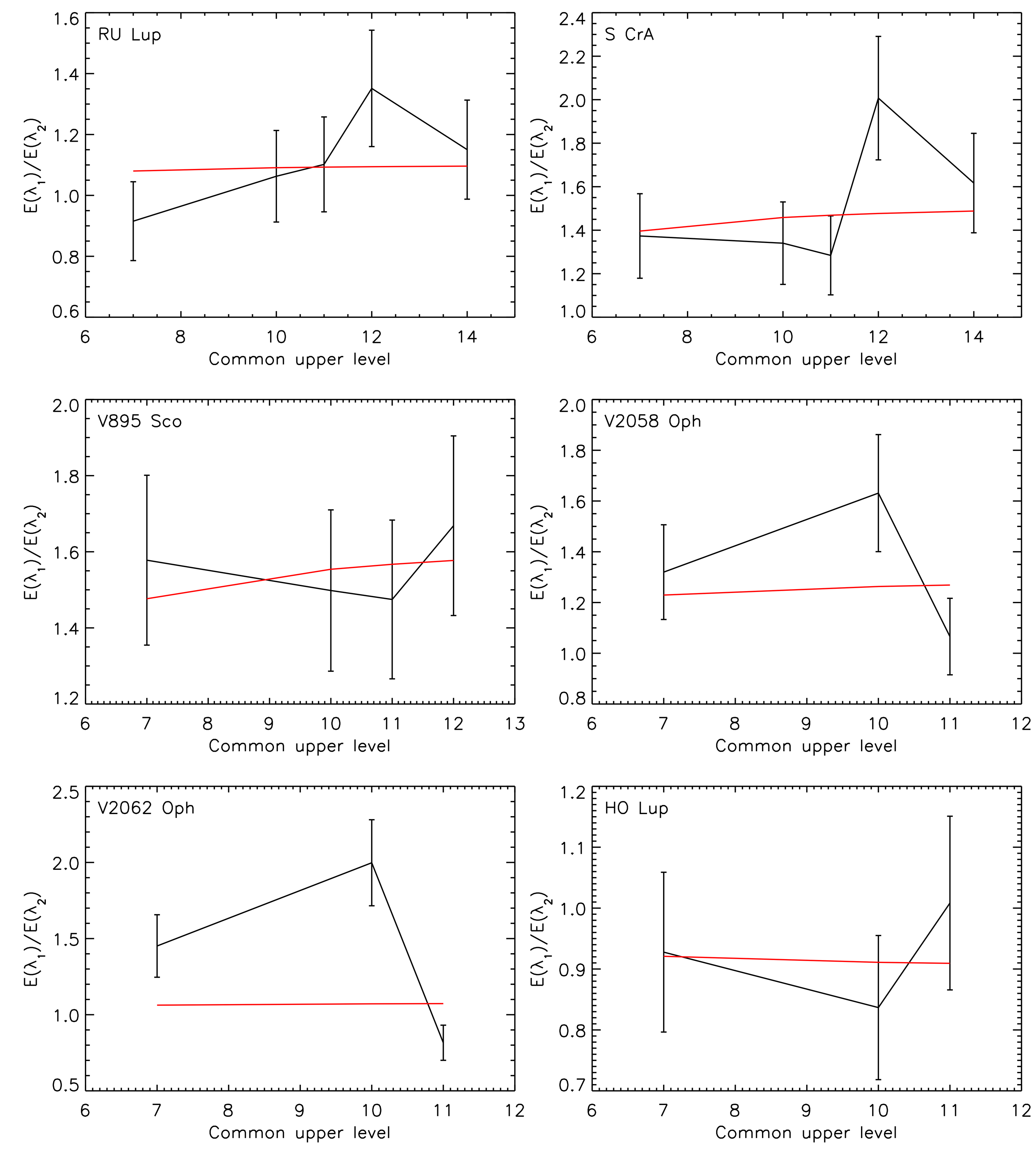
3. Measuring line fluxes

For the 6 objects in our sample that show more than one common upper level pair of the Paschen and Brackett lines in emission we measured the line fluxes by subtracting a template spectrum, i.e. the spectrum of a matching non-accreting star from the sample. In this way we take into account that the emission first has to fill up the photospheric absorption. The best template is chosen by looking at a number of emission-free regions. To calculate the ratios we only use the blue side of the line as the red side is often affected by absorption from the accretion funnels. The plots below show as example the lines Br11 (*left*) and Br12 (*right*) of RU Lup (*black*) together with the template IM Lup (*red*).



4. Results of fitting reddening law $A = A_V \cdot \lambda^{-\alpha}$ in our sample

We then determine the difference $E(\lambda_1)/E(\lambda_2)$ between observed and expected ratios, i.e. the extinction, which is shown for each object in *black* in the plots below, and fit the power law $A = A_V \cdot \lambda^{-1.84}$ to it (*red*).



The table below summarises the results for each object along with their spectral type and the range of A_V values we found in the literature. This new method provides A_V values within the literature range for most objects.
We also tried to fit both A_V and α, but the errors are too large to obtain reasonable results. Thus, we cannot examine the shape of the reddening law with our current data.

Object	SpT	$A_{V,\mathrm{lit}}$	Fit: A_V, $\alpha = 1.84$	Fit: χ^2_{red}
RU Lup	G5	0.07…1.28	0.29 ± 0.21	0.89
S CrA	G0 & K0	0.41…2.00	1.24 ± 0.21	1.31
V895 Sco	K5	0.83…1.67	1.45 ± 0.24	0.21
V2058 Oph	K5	1.43…4.50	0.77 ± 0.28	2.30
V2062 Oph	K3	1.16…4.40	0.23 ± 0.29	9.65
HO Lup	M1	1.25…1.60	-0.31 ± 0.28	0.44

5. Conclusions & Outlook

- Using common upper level lines allows to determine A_V without detailed knowledge about the object and independent of temperature and density of the emitting gas
- Test of phenomenological law of reddening at infrared wavelengths needs lower errors, e.g. by using model spectra plus a black body as templates in the flux measurements
- Compare to results from other studies of extinction and dust properties, e.g. Spitzer data:
  - A_V values from different wavelength regions
  - Look for connections, e.g. with the silicate features at 10 & 18 μm
  - Can NIR data add new information on dust properties?
  - What consequences follow for the environment of CTTS?

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