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Variability of the mass accretion rate in the very low-mass star Par-Lup3-4

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Accretion and outflows are key processes in early stellar evolution. The material accreted at the edge of the inner disc is channeled along magnetic funnel flows onto the star. Its kinetic energy is dissipated in standing accretion shocks. The accretion process is therefore sensitive to the spatial and temporal variations of the structure of the magnetic field and its mass load. Due to the change of view of the star-disc system throughout the rotation cycle, geometric effects are superimposed on such intrinsic variability and likely dominate the observed variability. An assessment of changes in the mass accretion rate is essential to understand the structure of the star-disc-magnetosphere system.

The young, very low-mass star Par-Lup3-4 displays a rich emission-line spectrum, hosts a disc with an almost edge-on inclination, and is in the critical mass range near the star/brown dwarf transition, where the knowledge of the accretion/outflow connection remains rather poor. These properties make this star a prime target for conducting a variability study of mass accretion. We make use of X-shooter's unique capabilities to monitor its broad-band spectrum in the range from ultraviolet to near-infrared. The sampling of our ten spectra covers timescales of hours, days, weeks, and years.

I) Extinction (A_v) and accretion luminosity (L_{acc})

- ✓ In this analysis we considered the following lines as accretion diagnostics: $H\alpha$, $H\beta$, $H\gamma$, and $H\delta$ lines, together with the Ca II triplet lines.
- ✓ The measured fluxes of these emission lines have been combined with the Gaia DR2 distance (Gaia Collaboration et al. 2018) of 151 ± 14 pc to derive the line luminosities (L_{line}).
- ✓ From each of them we evaluated the accretion luminosity ($L_{acc,line}$) by making use of the empirical $L_{acc,line} - L_{line}$ relations of Alcalá et al. (2017). In this way, we estimated the weighted mean accretion luminosity ($\langle L_{acc,line} \rangle$), as illustrated in Fig. 1.
- ✓ We have developed a new approach to estimate the extinction of our source, which corresponds to the A_v value minimizing the relative error of $\langle L_{acc,line} \rangle$ (Fig. 2). To this end, we corrected the observed spectra for extinction using the extinction law by Weingartner & Draine (2001) that covers the wavelength range of the X-shooter spectra.

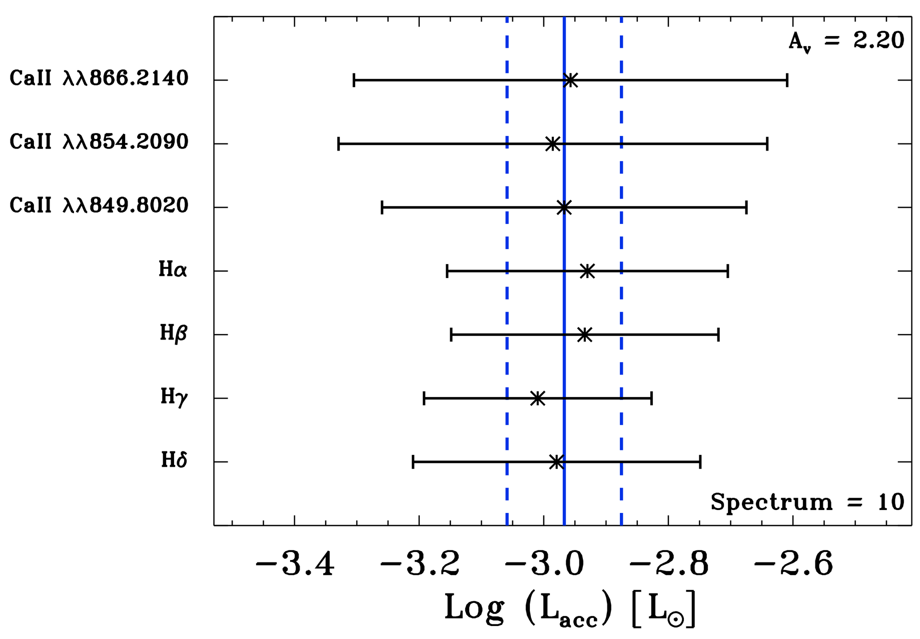
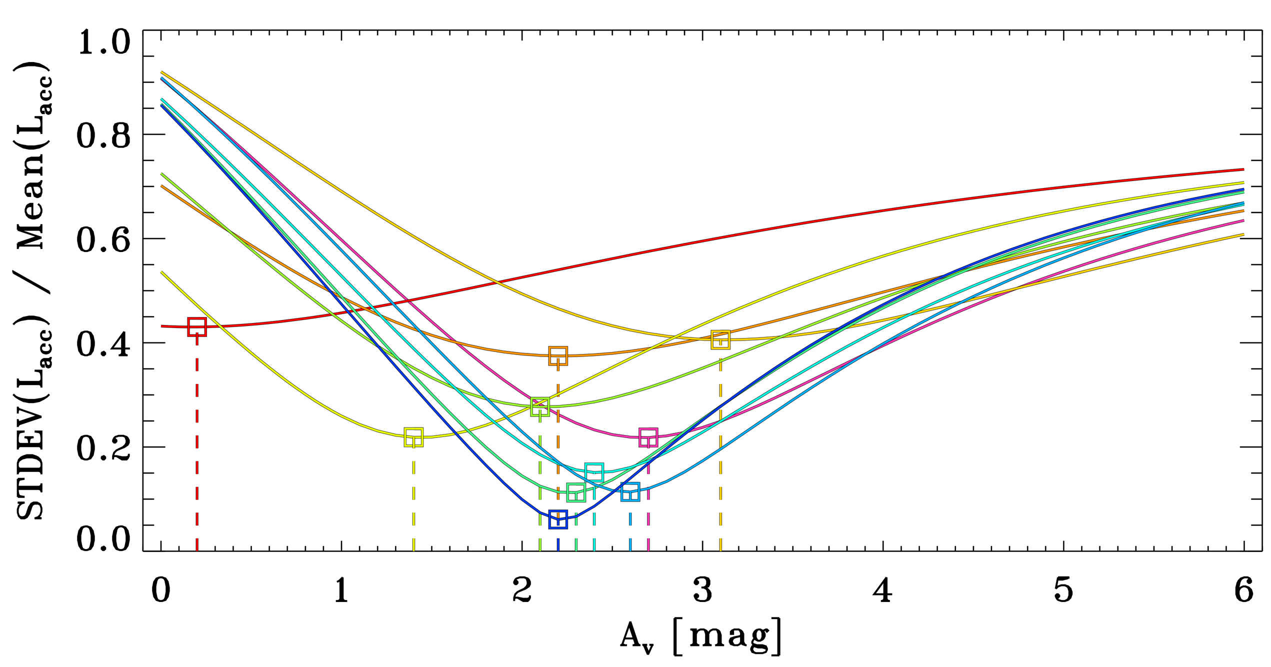


Fig. 1. Accretion luminosity as a function of line diagnostics in the case of spectrum 10. The adopted A_v value and the spectrum number of Par-Lup3-4 are marked in the upper and lower right corners, respectively. The solid vertical line corresponds to $\langle L_{acc,line} \rangle$ and the dashed lines delimit the area of $\pm 1\sigma$ around it.



Spec #	Observing start time
1	2010-04-07 04:07:31
2	2012-06-08 04:03:54
3	2013-05-09 02:57:32
4	2013-05-09 08:23:23
5	2013-05-10 05:18:28
6	2013-05-10 06:45:24
7	2013-05-11 03:10:25
8	2013-05-11 07:04:49
9	2013-05-20 01:16:30
10	2013-05-20 06:30:12

Fig. 2. Relative error of $\langle L_{acc,line} \rangle$ as a function of A_v. The vertical lines indicate the A_v values minimizing this parameter at any given epoch.

II) Results

- ✓ The A_v values are almost constant over time (Fig. 3), with the exception of the spectrum acquired in 2012 (i.e., epoch 2).
- ✓ Due to a bad seeing, the error on $L_{acc,line}$ is higher and, as a consequence, the determination of A_v is poorer in epochs 3−6.
- ✓ We evaluated the weighted average extinction $\langle A_v \rangle$ at:
  - 1.95 ± 0.25 mag with the method described by Manara et al. (2013).
  - 2.35 ± 0.25 mag with the approach presented in Sect. I.
- ✓ These values agree with each other within the errors and are consistent with those in the literature for Par-Lup3-4, which range from 2.4 to 5.6 mag (Comerón et al. 2003).
- ✓ We also obtained a good agreement between the L_{acc} values derived with these two methods (Fig. 4).
- ✓ After correcting for the extinction, a small variation of L_{acc} can be seen (Fig. 5). We obtained $log(L_{acc}/L_\odot) = -3.0 \pm 0.1$, which corresponds to a mass accretion rate of $log(\dot{M}_{acc}) = -10.4$ or $\dot{M}_{acc} = 4 \times 10^{-11}\ M_\odot\ yr^{-1}$.

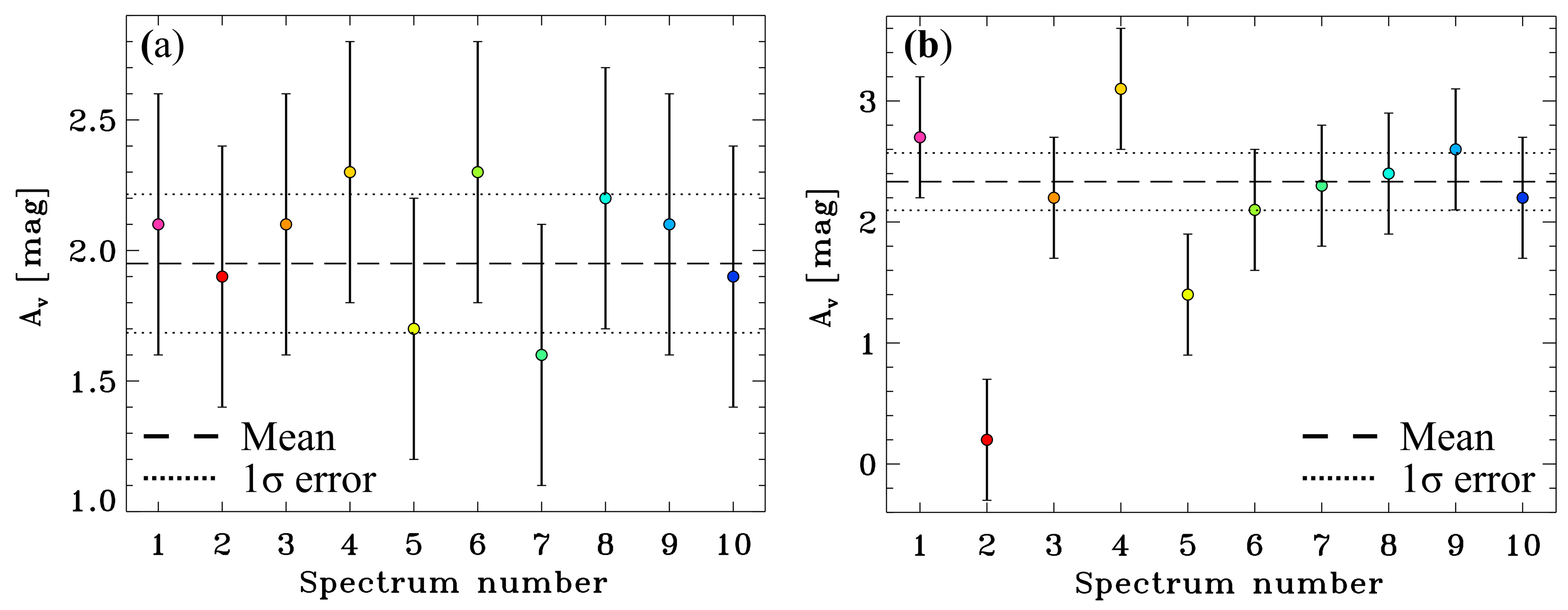


Fig. 3. Variation of the A_v value derived with *(a)* the best-fit procedure of the observed spectra with the slab models and *(b)* the minimization of the relative error of $L_{acc,line}$.

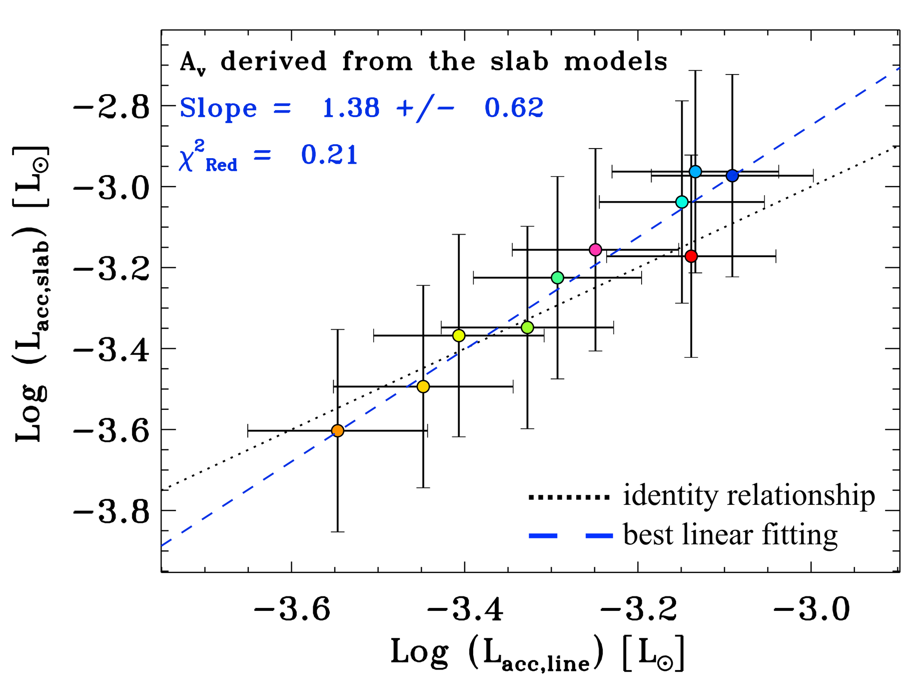


Fig. 4. Comparison of the L_{acc} values derived from the slab modeling and the line fluxes corrected for the extinction based on the A_v values shown in Fig. 3a. The color of the symbol codes the spectrum number.

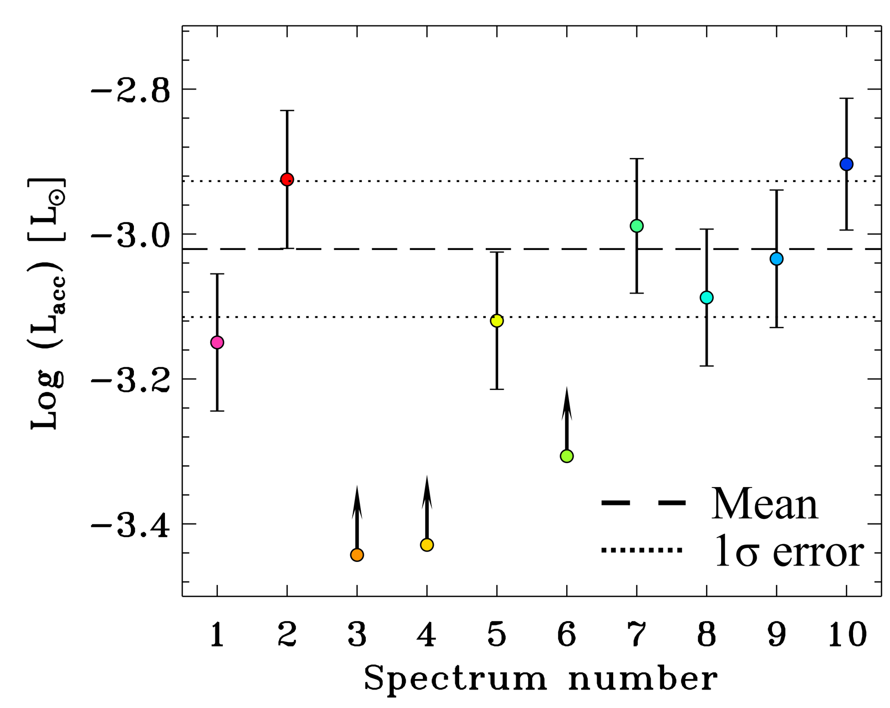


Fig. 5. Variation of accretion luminosity obtained from the extinction-corrected fluxes (A_v = 2.35 mag). The arrows are lower limits.

III) Conclusion

- ✓ The emission line profiles show significant variations, resulting in a small variation in accretion luminosity and no noticeable change in extinction.
- ✓ The spectrum acquired in 2012 remains quite puzzling. Despite optimal observation conditions, the emission lines used as accretion diagnostics did not allow us to accurately determine the extinction.

References • Alcalá, J. M., et al. 2017, A&A, 600, A20 ; Comerón, F., et al. 2003, A&A, 406, 1001 ; Gaia Collaboration, Brown, A. G. A., et al. 2018, A&A, 616, A1 ; Manara, C. F., et al. 2013, A&A, 558, A114 ; Weingartner, J. C. & Draine, B. T. 2001, ApJ, 548, 296.

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