EX Lup - episodic accretion under scrutiny

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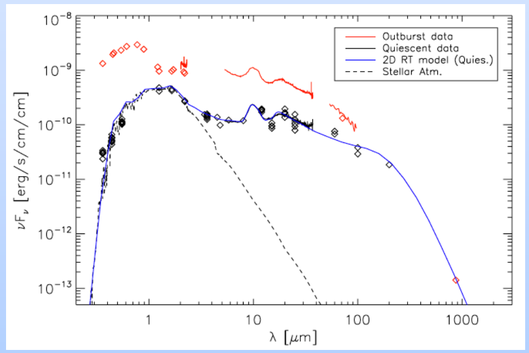
Abstract

EX Lup is the prototype of EXors, one of the two main classes of young eruptive stars. EXors are young low-mass T Tauri stars exhibiting repetitive outbursts due to a sudden increase of the accretion rate. In 2008, EX Lup exhibited its largest outburst ever observed. Here, we present results from our multi-wavelength and multi-epoch investigation of EX Lup, revealing interesting aspects of the disk structure and the accretion process.

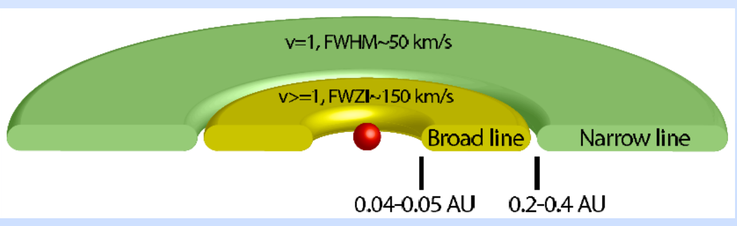
EX Lup in quiescence and in outburst

- EX Lup is a young (1-3 Myr) low-mass (<0.6 $M_\odot$) M0V-type star.
- The quiescent SED of EX Lup is similar to that of a typical T Tauri star, with one exception. The fitting of the spectral energy distribution requires a dust-free inner hole in the disk that extends beyond the dust-sublimation radius, to about 0.2 au.
- In 2008, the accretion rate from the disk to the star increased from 4×10^{-10} $M_\odot$/yr to 2×10^{-7} $M_\odot$/yr. This resulted in a 5 mag optical outburst, and caused brightening in the whole optical-infrared regime.



The inner disk in outburst

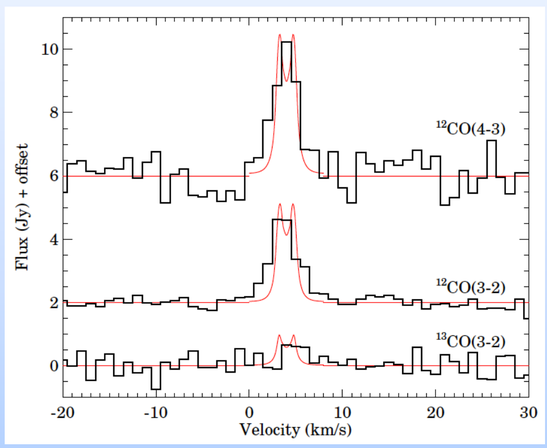
- During outburst, we spectroscopically monitored EX Lup in the optical, near-infrared and mid-infrared wavelength ranges, and found many strong permitted emission lines from hydrogen, metals, and carbon monoxide.
- The broad component of the optical lines suggest hot (6500 K), dense, non-axisymmetric, and non-uniform accretion columns that suffer daily velocity variations along the line-of-sight. The near-infrared hydrogen lines display strong spectro-astrometric signal, also suggesting a funnel flow or disk wind origin.
- The fundamental CO lines show narrow and broad components. The former is constant in time, and traces cool gas at about 0.4 au, the latter decays with time, and is emitted by hot gas orbiting the star at 0.04-0.4 au, clearly associated with the outburst event.



- The material accreted in the 2008 outburst should have been located within 0.1 au from the central star.
- The rapid recovery of the system after the outburst and the similarity of the pre-outburst and post-outburst state suggests that the geometry of the accretion channels did not change between quiescence and outburst, only the accretion rate increased.

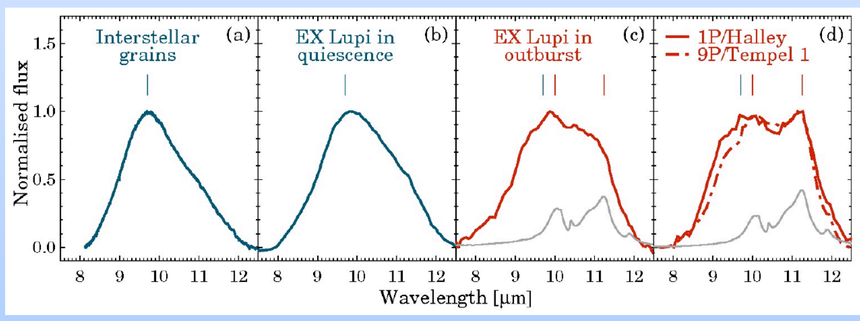
The cold outer disk

- We studied the cold, outer parts of the disk using millimeter CO rotational line observations. Our data indicates a gas temperature of 10 K and CO depletion factor of 100 (possibly due to freeze-out), a value which is not unusual among T Tauri stars.



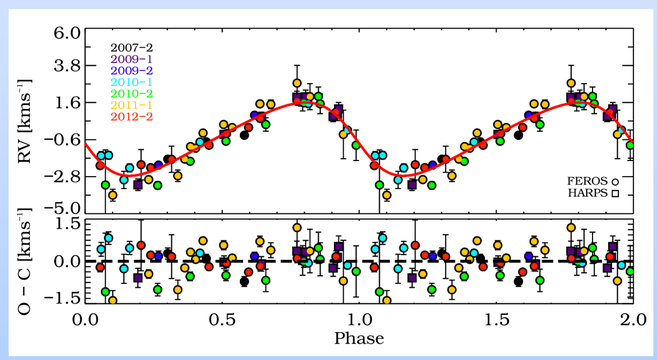
Episodic crystallization

- By comparing pre-outburst and outburst Spitzer spectra, we discovered that signatures of crystalline forsterite appeared in the previously amorphous 10 μm silicate feature. The crystals were produced through thermal annealing in the surface layer of the inner disk by heat from the outburst.
- Our spectral monitoring revealed that the crystalline features at 10 μm decreased but those around 15 – 35 μm increased as time progressed, indicating radial transport of material from the hot inner parts of the disk to the colder outer parts.



Brown dwarf companion?

- Our 5-year-long spectroscopic monitoring revealed that the absorption lines of EX Lup in quiescence show periodic (P = 7.417 days) radial velocity (RV) changes. A Keplerian fit suggests the possibility of a brown dwarf companion on an eccentric orbit around EX Lup, with $m \sin i$ = 14.7 M_{Jup} and e = 0.24.
- Interestingly, the emission lines also show periodic RV changes, suggesting very stable accretion columns, and rotational modulation of lines coming from close to the accretion shock above the stellar surface. This may possibly explain both the absorption and the emission lines without a companion.



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