Dark shadows in T Tauri disks: accretion-related changes indicated by infrared variability?

Á. Kóspál[1], P. Ábrahám[2], C. Weber[3], M. Curé[4], C. A. Grady[5,6], Th. Henning[7], A. Juhász[8], M. Kun[2], M. M. Meyer[9], A. Moór[2], E. Pantin[10], T. Prusti[1]

[1]ESA, Netherlands [2]Konkoly Observatory, Hungary [3]Vienna University, Austria [4]Universidad de Valparaíso, Chile [5]NASA Goddard Space Flight Center, USA [6]Eureka Scientific, USA [7]Max-Planck-Institut für Astronomie, Germany [8]Leiden Observatory, Netherlands [9]ETH Zürich, Switzerland [10]CEA Saclay

Abstract

Circumstellar disks around pre-main sequence stars, once thought to evolve only on million years timescale, turned out to be the sites of rapid structural and compositional changes. Several authors claimed that variability seen in their multi-epoch infrared data is related to geometrical changes in the disk. Our group has also found cases where variations in the mid-infrared spectra hinted at a changing obscuring structure in the inner disk that casts a variable shadow on the outer parts of the disk. With the aim of verifying this hypothesis, characterizing the obscuring disk component, and understanding its origin, we monitored eight T Tauri stars in the Chamaeleon I star-forming region. Here we present the first results of our coordinated multi-wavelength study, obtained between 0.5 and 4.7 μm with ground-based instrumentation, and between 70 and 160 μm with the Herschel Space Observatory.

Context

- **Variability in young stars**

  Optical variability is a long-known general characteristic of pre-main sequence stars. The growing number of ground-based observations and satellite missions at longer wavelengths make it increasingly evident that infrared variability is also widespread during the pre-main sequence evolution (see, e.g., the changing 10 μm silicate feature in EX Lup due to episodic crystallization, Ábrahám et al. 2009).

- **Reasons of variable disk emission**
  - Static disk but changing irradiation:
    - The variable luminosity of the central source causes changes in the disk's thermal emission (Kóspál et al. 2012)
  - Structural/geometrical changes in the disk:
    - Variable inner rim height (Juhász et al. 2007)
    - Disk instabilities at the dust sublimation zone (Sitko et al. 2008)
    - Variable scale height and/or warping of the inner disk (Flaherty et al. 2011)
    - The changing inner rim height casts a variable shadows on the outer part of the disk (Espaillat et al. 2011)

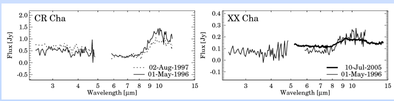
Motivation

- **Preparatory work**

  Using a large database of mid-infrared spectra taken by the ISO and Spitzer satellites, we compiled a spectral variability atlas of low- and intermediate mass young stellar objects (Kóspál et al. 2012). We found that most objects are variable in the mid-infrared and they display different wavelength-dependence of the variability.

- **Special case**

  We found cases where part of the spectrum increased while another part decreased, with a pivot point typically in the 5–9 μm wavelength range → hint for a changing obscuring structure in the inner disk that casts a variable shadow on the outer parts of the disk.



- **Our idea**

  Changes in the inner disk may affect the illumination pattern of the outer disk, which acts as a projection screen → need for simultaneous optical + near-infrared + far-infrared monitoring

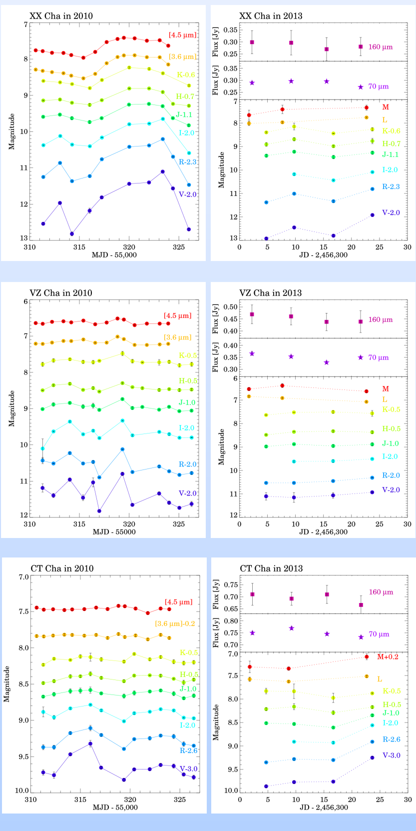
Observations

- Including both objects with wavelength-independent variability and those where the spectra showed a pivot point, we selected eight T Tauri stars in the Chamaeleon I star-forming region, and performed two photometric monitoring programs.

Source list	
CR Cha	VW Cha
CT Cha	VZ Cha
Glass I	WW Cha
VW Cha	XX Cha

- **2010 observing season**
  - 2-week-long daily monitoring
  - Optical and near-infrared data (0.5 – 2.2 μm): REM Telescope
  - Mid-infrared data (3.6 – 4.5 μm): Spitzer Space Telescope
- **2013 observing season**
  - 1-month-long monitoring, weekly cadence
  - Optical and near-infrared data (0.5 – 2.2 μm): CTIO SMARTS 1.3m Telescope
  - Mid-infrared data (3.8 – 4.7 μm): VLT/ISAAC
  - **Far-infrared data (70 – 160 μm): Herschel Space Observatory**

Light curves



Results

- All objects are detected at all wavelengths
- All objects show mid-infrared and far-infrared excess over the photosphere
- The mid-infrared flux varies on weekly timescale
- All mid-infrared changes correlate with optical variations, but not all optical changes correlate with mid-infrared variations
- The far-infrared flux shows slight variability, which either correlates or anti-correlates with changes at shorter wavelengths

References

- Telescope image credits: http://ross.iasfbo.inaf.it http://www. spitzer.caltech.edu http://www.sr.bham.ac.uk http://www.eso.org http://spaceinimages.esa.int
- Ábrahám et al.: *Episodic formation of cometary material in the outburst of a young Sun-like star* (2009), **Nature 459**, 224
- Espaillat et al.: *A Spitzer/IRS study of infrared variability in transitional and pre-transitional disks around T Tauri stars* (2011), **ApJ 728**, 49
- Flaherty et al. : *The highly dynamic behavior of the innermost dust and gas in the transition disk variable LRLL 31* (2011), **ApJ 732**, 83
- Juhász et al.: *Long-term infrared variability of the UX Ori-type star SV Cep* (2007), **MNRAS 374**, 1242
- Kóspál et al.: *Mid-infrared spectral variability atlas of young stellar objects* (2012), **ApJS 201**, 11
- Sitko et al.: *Variability of disk emission in pre-main sequence and related star. I. HD 31648 and HD 163296* (2008), **ApJ 678**, 1070

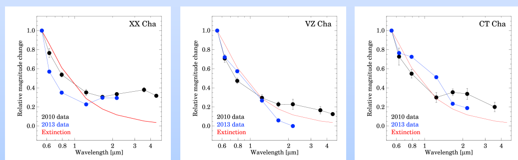
Contact

Ágnes Kóspál

ESA/ESTEC
Phone: +31 71 565 4508
E-mail: akospal@rssd.esa.int
Web: http:/rssd.esa.int/Faculty/Staff/kospal

Correlation diagrams

- We used scatter plots to determine the amplitude of flux changes at different wavelengths relative to the V-band.
- At optical wavelengths, the drop of variability amplitude from V to R to I is significantly faster than what would be expected from interstellar extinction (red curve).
- In some cases (CT Cha, VZ Cha, WW Cha), the variability amplitude decreases monotonically toward longer wavelengths.
- In other systems (CR Cha, VW Cha, XX Cha), the amplitude has a minimum in the J or H band, and increases again toward longer wavelengths.



Discussion

- In part of the sample, the relative variability amplitude becomes low in the mid-infrared. In the other group, large mid-infrared flux changes were detected.
- Our hypothesis: the geometry of the inner disk, and thus the illumination pattern on the disk surface, is different in the two subsamples:
  - The first group has a flatter inner disk, that can absorb only a limited amount of starlight, thus its MIR emission is low.
  - The second group might possess a vertically extended structure in the inner disk, that is directly and well illuminated by the star, and adapts its emission to the changing optical illumination. The variations of the vertical structure may be related to the changing accretion, also observed are optical wavelengths
- Weekly timescale FIR variability is observed, and suggests that the outer disk works as a projection screen and reacts to changes in the inner disk.
- There is no clear correlation with the far-infrared variability pattern predicted for the two different groups.

The fourth dimension of circumstellar disks

Variability, in particular its wavelength-dependence, carries new type of information about the physical mechanism causing the flux changes. It measures the response of a perturbed physical system, and provides otherwise unavailable knowledge on dynamical processes and their timescales.