Konkoly Infrared Space Astronomy Group

Konkoly Observatory, Budapest, Hungary

Search for structural changes in T Tauri disks via optical-infrared variability

Péter Ábrahám[1], Ágnes Kóspál[2], Michel Curé[3], Carol Grady[4], Thomas Henning[5], Mária Kun[1], Michael R. Meyer[6], Attila Moór[1], T. Prusti[2]

[1] Konkoly Observatory, Hungary, [2] European Space Agency, The Netherlands, [3] Universidad de Valparaiso, Chile, [4] NASA Goddard Space Flight Center, USA, [5] Max-Planck-Institut für Astronomie, Germany, [6] ETH Zürich, Switzerland

ABSTRACT

Exploration of the time domain as the fourth dimension of circumstellar disks may have a high impact on many aspects of our knowledge on the formation of stars and planets. Here we present an optical-to-mid-infrared coordinated ground-based and Spitzer photometric monitoring study of seven low-mass young stars in Chamaeleon I. Our on-going analysis revealed differences in the inner disks' response on their changing optical irradiation, potentially related to differences in the circumstellar structure and its time behavior.

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 early stellar evolution.

- **Reasons of variability**

  The observed infrared flux changes may partly be linked to the central star (e.g. hot or cold starspots). However, to a larger part, they are related to the circumstellar matter, either to its varying extinction along the line-of-sight, or to its changing thermal emission.

- **The 4th 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.

METHODOLOGY

- Only very few dedicated analyses on infrared disk variability have been completed so far, thus, **methodology is yet to be developed** and consolidated. One can attempt to deduce structural information directly, or constrain it by disk models.

- **Disk tomography**

  When the reason of flux change is the variation of the central source's luminosity (monitored at optical wavelengths), then at different epochs different disk areas will be illuminated. Since one measures the integrated flux of the illuminated region, a tomographic technique is used to reveal the disk structure.

- **Time-dependent disk models**

  Fit the optical-infrared spectral energy distribution at a reference epoch, and fine-tune model parameters (stellar luminosity; height of the puffed-up rim,...) to fit the SEDs at other epochs. **NOTE:** using a sequence of steady-state equilibrium disk models may not be sufficient to reproduce fast flux changes. Numerical codes that can handle the delayed response of an optically thick medium are highly needed.

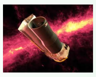
OBSERVATIONS

KONKOLYVAR: A Spitzer warm-phase GO-6 science program

In 2009-10 we conducted a multi-epoch survey of a carefully-selected sample of 38 YSOs with Spitzer/IRAC. We followed our targets for 2 weeks with daily cadence. Here we present preliminary results on part of the sample, seven T Tauri stars in the Chamaeleon I star forming region.

Supporting ground-based observations

In order to extend our wavelength range, we obtained simultaneous ground-based optical and near-infrared monitoring observations of the Chamaeleon stars using the Rapid Eye Mount Telescope in La Silla Observatory.



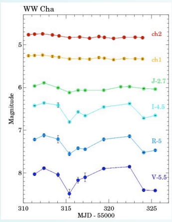
(Spitzer PR)

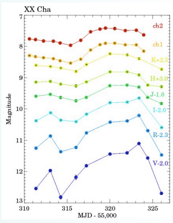
(ESO)

LIGHT CURVES

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

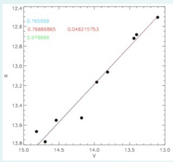
- All stars were detected at 3.6 and 4.5 micrometer.
- MIR excess over the photosphere
- MIR flux varies on weekly timescale
- All MIR changes correlate with optical variations, but…
- …not all optical changes correlate with MIR variations!

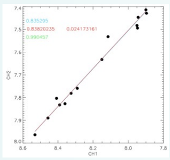


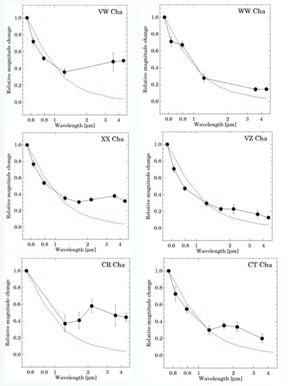


CORRELATION DIAGRAMS

- Scatter plots were used 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 and to I is significantly faster than would be expected from the interstellar extinction curve (red curve).
- In some cases (CT Cha, VZ Cha, WW Cha) the variability amplitude decreases towards longer wavelengths.
- In other systems (CR Cha, VW Cha, XX Cha) the amplitude has a minimum in the J or H bands, and increases again in the Spitzer bands

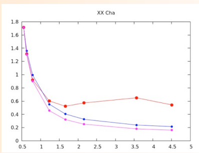






HOT STELLAR SPOTS

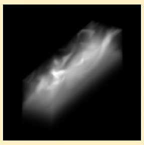
- The wavelength dependence of the relative variability amplitudes in the optical regime (red curve) was fitted with stellar cold/hot spots (blue and purple lines).
- Simple spot modeling (polar spots, limb darkening). Fitted parameters: blackbody temperature, spot area.
- In all cases, hot spots were needed to fit the data
- The contribution of the spots was extrapolated to mid-infrared wavelengths, and subtracted from the observed variability amplitudes



Source	T_{eff} [K]	T_{spot} [K]
CR Cha	4590	6000
CT Cha	4060	6000
VW Cha	3950	6000
VZ Cha	4050	8000
WX Cha	3690	4000
WW Cha	4350	7000
XX Cha	3600	7000

CONCLUSIONS

- In part of the sample (CT Cha, VZ Cha, WW Cha), the relative variability amplitude becomes low in the mid-infrared. In the other group (CR Cha, VW Cha, XX Cha), large mid-infrared flux changes were detected.
- One possibility to explain the different behavior is that in the first group the observed optical variability is only a line-of-sight effect due to rotating spot, but the luminosity of the star (and thus the irradiation of the disk) remains constant.
- Our other hypothesis is that 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 vertical structure may be long-lived (e.g. an orbiting warp, left figure), or short-lived (turbulence-driven dust clumps in the disk atmosphere, right figure).



Left panel: artists' impression (Spitzer PR) of the orbiting warp proposed for the low-mass star LRLL 31 (Muzerolle et al. 2009).

Right panel: magneto-hydrodinamical models predict lift up of temporary dust clouds into the disk atmosphere (Turner et al. 2010)

FOLLOW-UP

A monitoring program of the same Chamaeleon stars has been completed in 2013 January. We obtained simultaneous optical and near-infrared (CTIO, 1.3 m telescope), L- and M-band (VLT/ISAAC) and far-infrared (Herschel Space Observatory) photometry. We look for far-infrared flux changes and their correlation with the optical-near-infrared light curves.

Contact

Péter Ábrahám
Konkoly Observatory
Budapest, Hungary
abraham@konkoly.hu