Dust in the near environment of classical T Tauri stars

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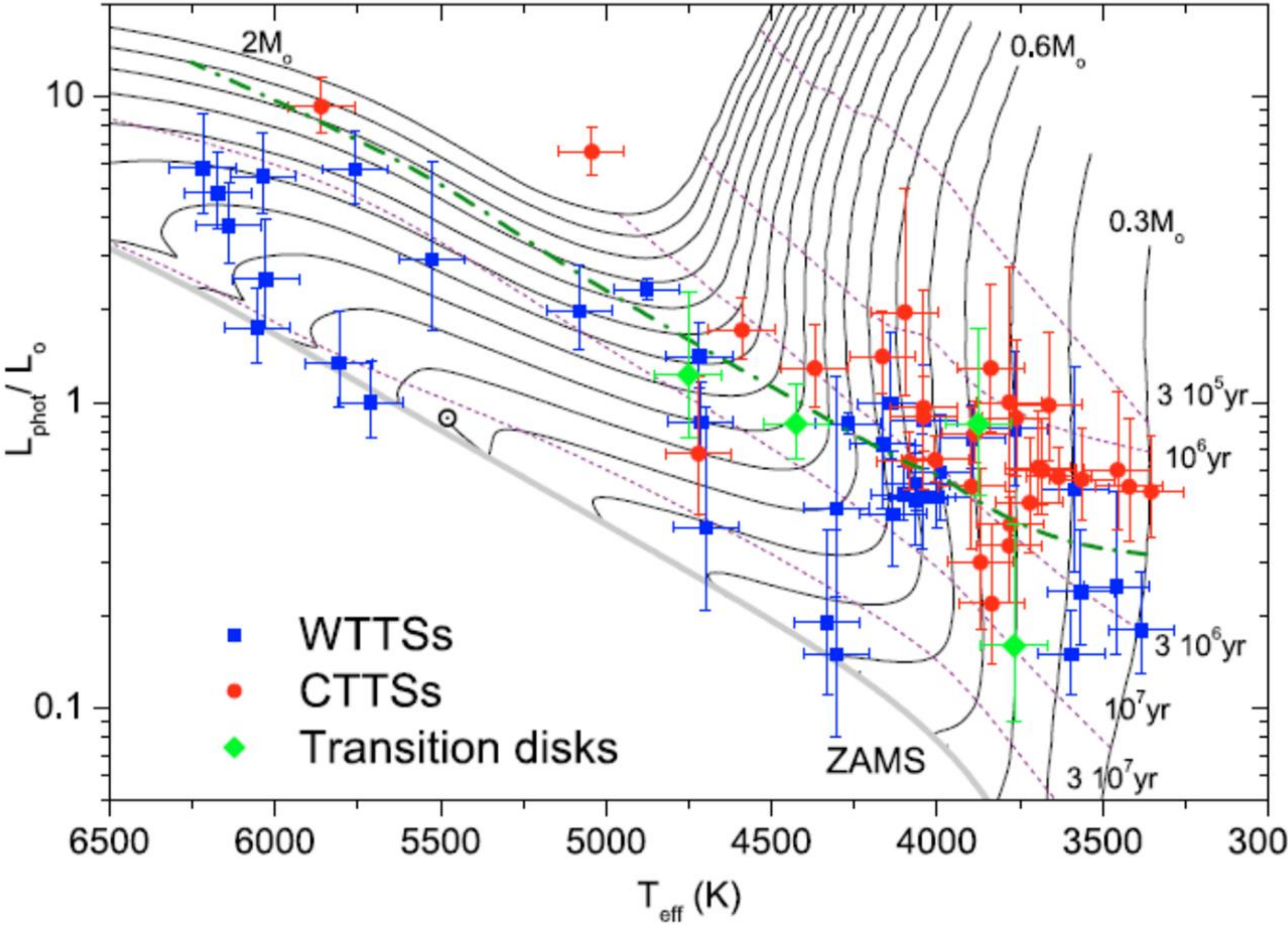
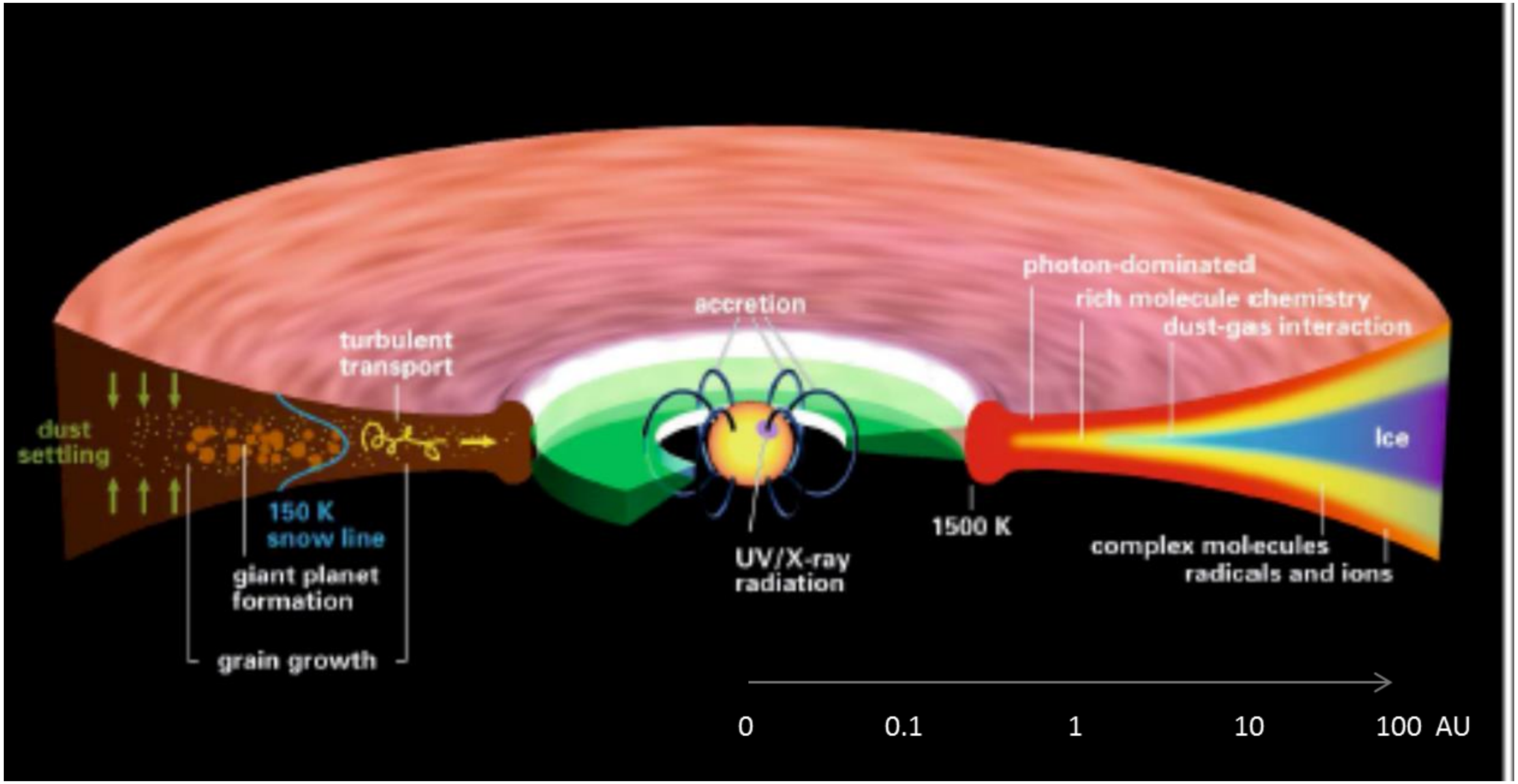


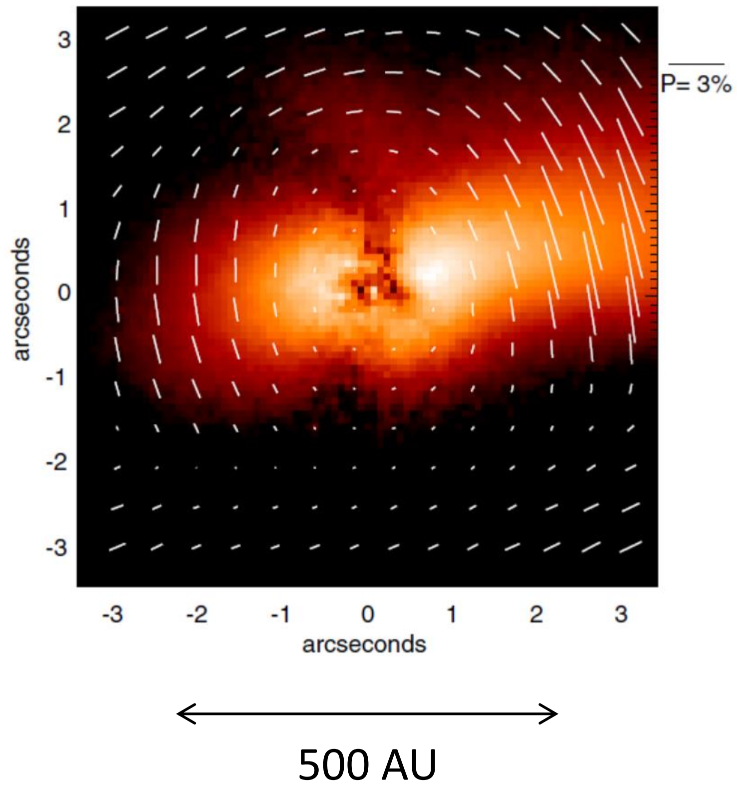
from *Bertout et al,* 207 AA 473 L21



from: Henning & Semenov (2013)

- Dippers (AA Tau - type stars)
- Dimming events in cTTS
- Dusty disk winds

Circumstellar environment of SU Aur in polarized light



Jeffers et al, 2014

- where is the obscuring dust?
- why does it appear on the line of sight?
- what is the gas-to-dust ratio in the obscuring matter?

NGC 2264 with *CoRoT* and *SPITZER*

Multiple origins of variability, by *Cody et al. 2014*

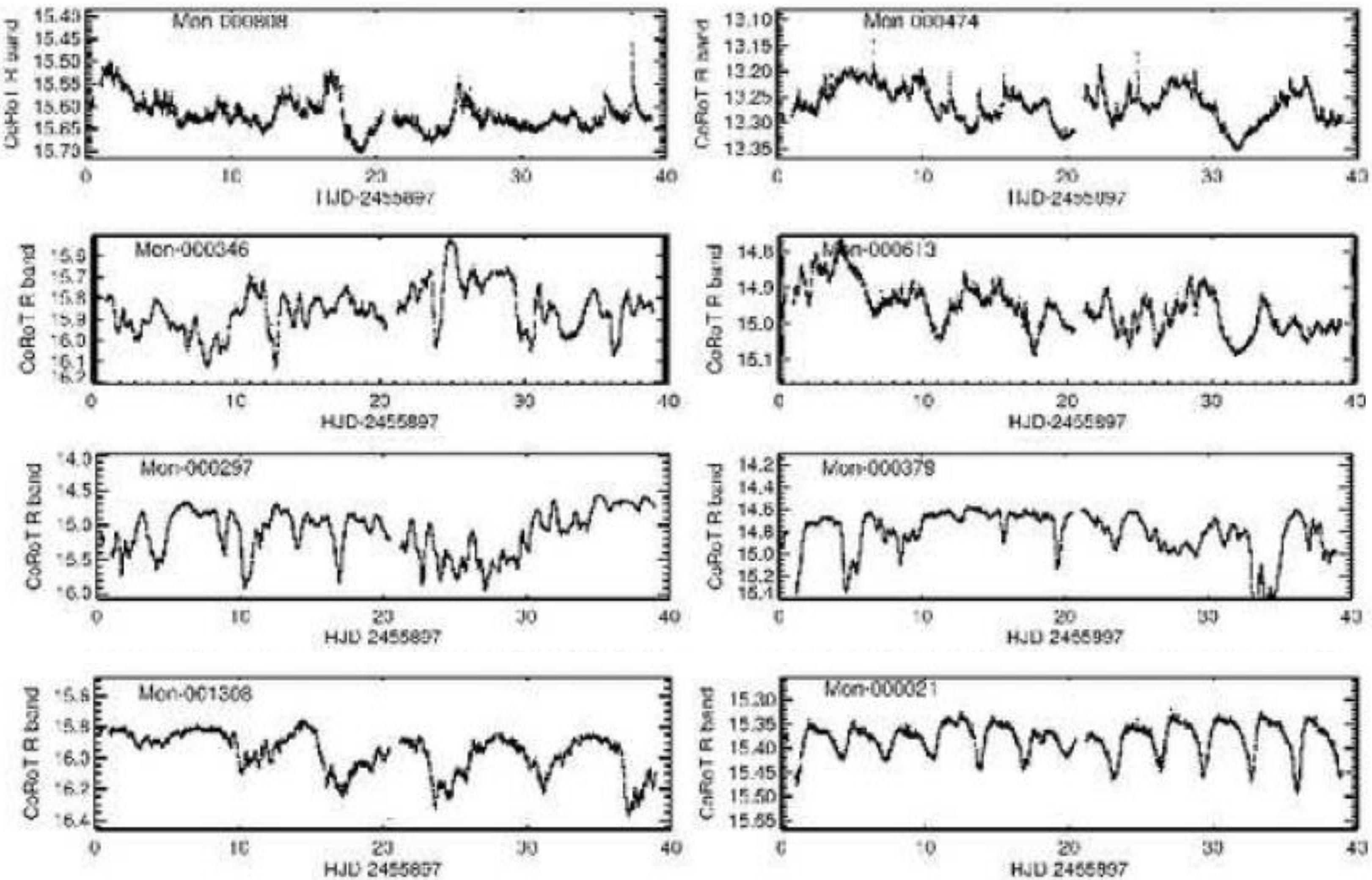
Continuous 30-days monitoring of **162 cTTSs**
in optical and NIR (Dec 2011)

Morphology of light curves:
- *Periodic* (cool spots)
- *Bursters* (short events of accretion)
- *Stochastic* (circumstellar dust)
- *Dippers* (discrete fading events lasting 1-5 days)

The largest category (>20 %) are optical dippers.

CoRoT = COnvection, ROtation and protoplanetary Transits
Orbital telescope (2 x 27 cm), 2007-2013.
SPITZER: photometry at 3.6 mkm

Morphology of optical light curves:



Bursters

Stochastic

Aperiodic dippers

Quasi-periodic dippers

Cody et al. 2014

NIR light curves are different!

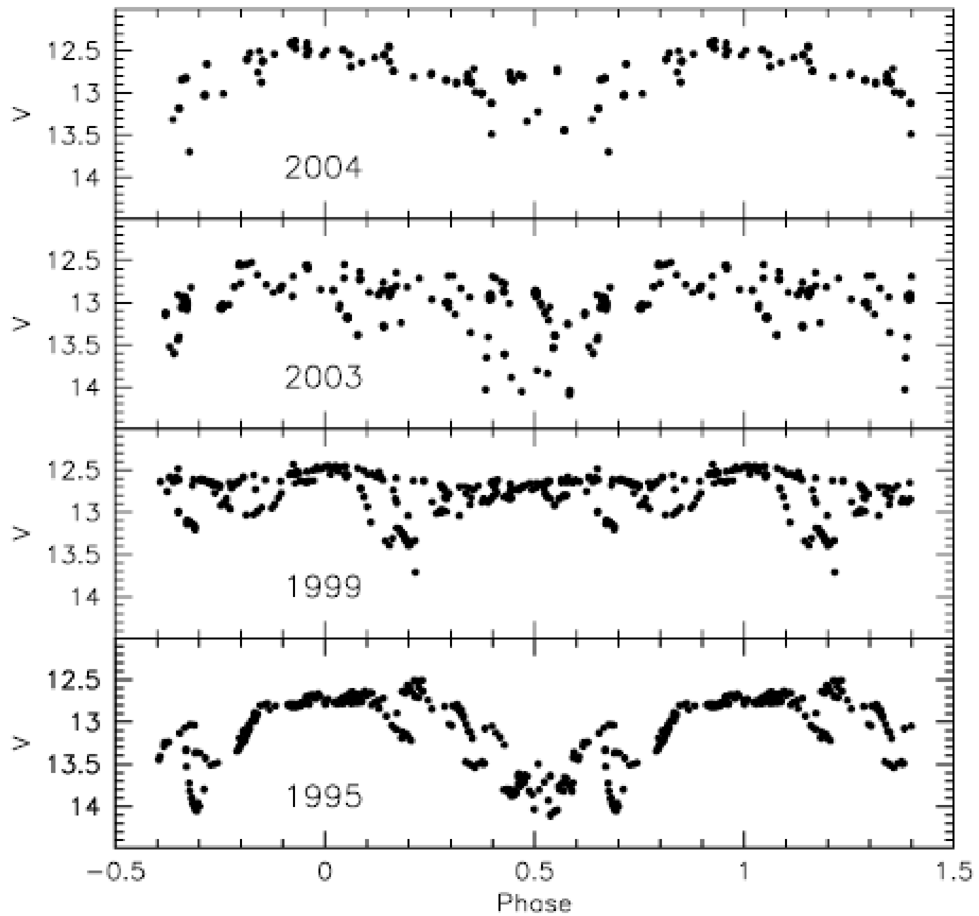


Fig. 15. *V*-band light curves of AA Tau at different epochs: 1995 (Paper I), 1999 (Paper II), 2003 (unpublished), 2004 (this paper). All light curves have been folded in phase with the same period of 8.22d but the origin of phase for each season is arbitrary. Note how the shape and depth of the eclipses vary on a timescale of several years.

Bouvier et al 2007

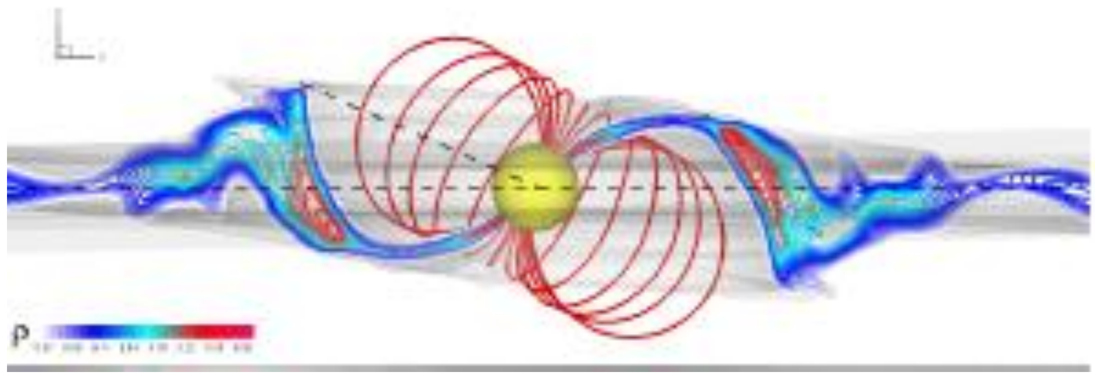
AA Tau

cTTS, K7
8.22 day period
of axial rotation.
High Inclination(edge-on)

The amplitude of the minima
is about 1 mag in V.

Polarization rises as the star fades
The circumstellar extinction
corresponds to the interstellar law,
that is the dust particles are small.

The mechanism of light-blocking by a warped inner disk has been proposed as an explanation for dips in the light curve of AA Tau (Bouvier et al. 1999) and some other cTTS (Bouvier et al. 2003, 2007, Alencar et al. 2010).



Romanova *et al*, 2013

The disk warp periodically eclipses the central star, causing a modulation of its optical light curve.

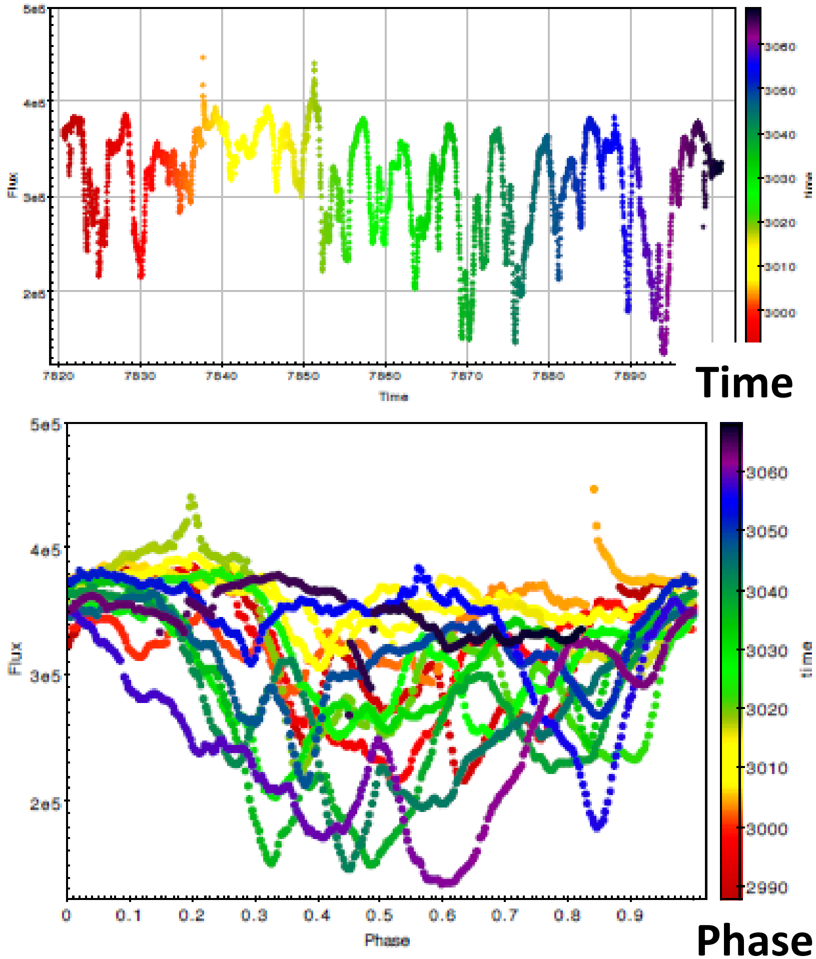


Fig. 3. Upper panel: Kepler K2 light curve obtained for LkCa 15 from March 7 to May 28, 2017. The light-curve morphology is clearly that of a dipper. Lower panel: K2 light curve folded in phase with a period of 5.78 days. The color code is the same in both panels and reflects the Julian Date of observations. Two flare-like events are visible in the light curve (t=7838 and 7851).

Alencar et al 2018

Lk Ca 15

cTTS, K5

P= 5.78 days

Kepler, K2
March 7 to May 28, 2017

The inner disk warp is changing due to temporal variations in the magnetosphere topology

V 354 Mon (AA Tau - like star in NGC 2264):
Differential absorption spectroscopy (three spectra) revealed a **low gas-to-dust ratio** in the inner disk, less than a tenth of the ISM value.

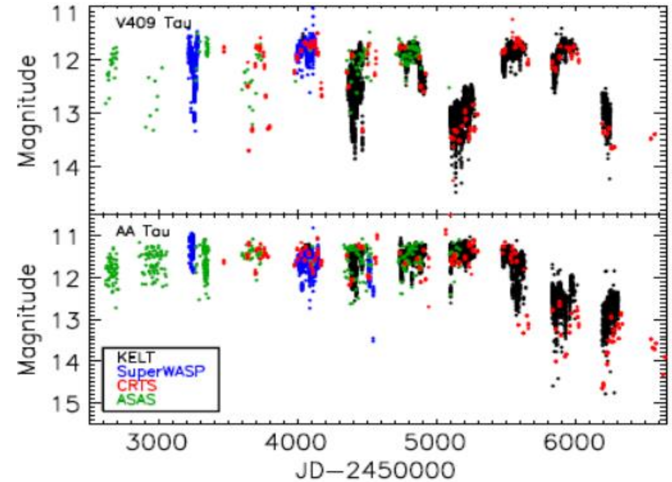
The **excess of dust** in the inner disk may be a result of the disk evolution toward dust-dominated disk or a fragmentation of larger bodies that drifted inward from larger radii in a still gas dominated disk.

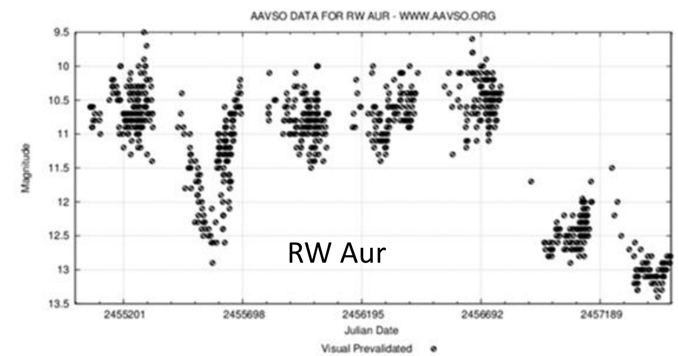
Schneider et al. 2018

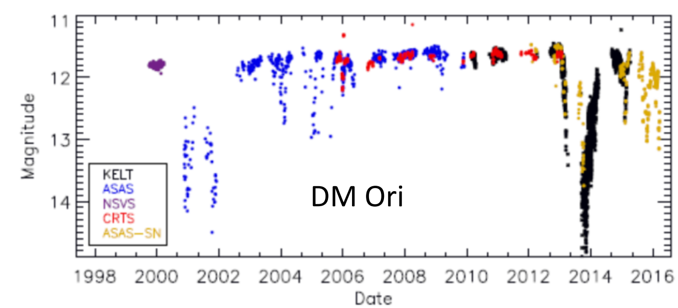
The dimming events in cTTS

A sudden increase of circumstellar dust extinction on the line of sight without concomitant change in the accretion rate (*Bouvier et al, 2013)*

AA Tau	Bouvier et ql 2013
RW Aur A	Dodin et al 2019, …
V582 Aur (FUor)	Abraham et al 2018
V1334 Tau (WTTS)	Rodrigues et al 2016
V409 Tau	Rodrigues et al 2015
DM Ori	Rodrigues et al 2016
…	







RW Aur dimming events in 2010-2019

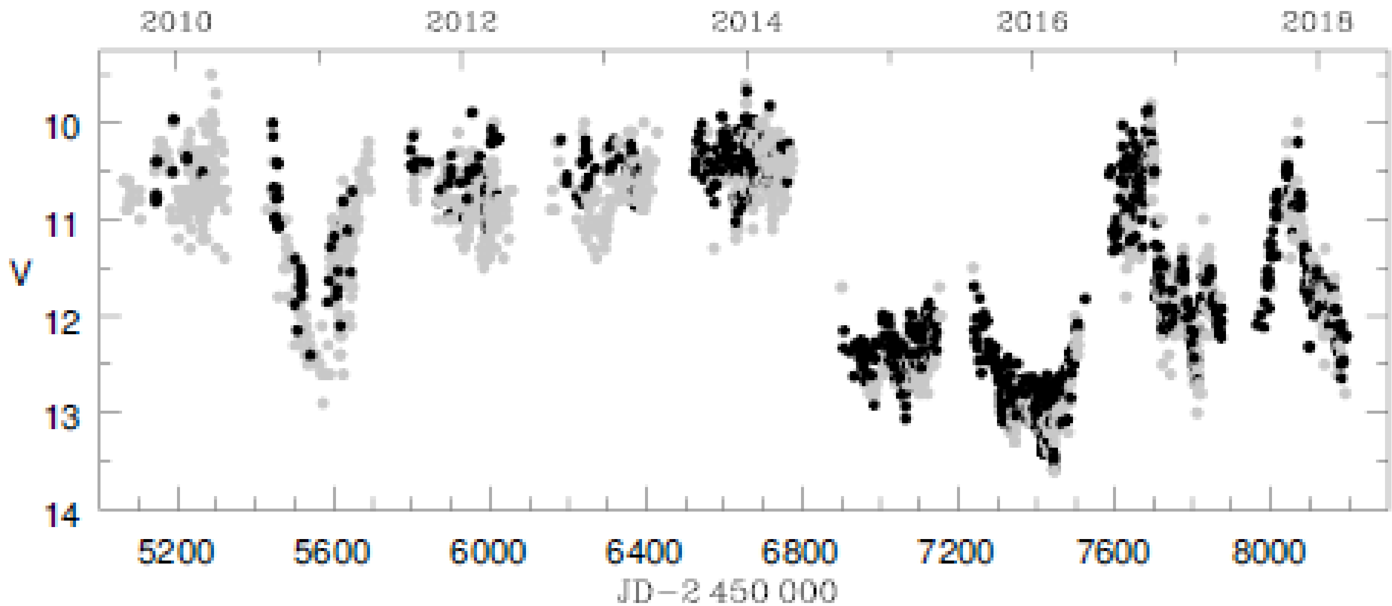
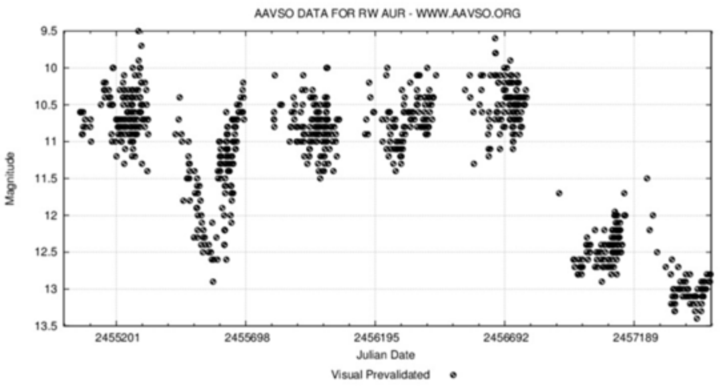


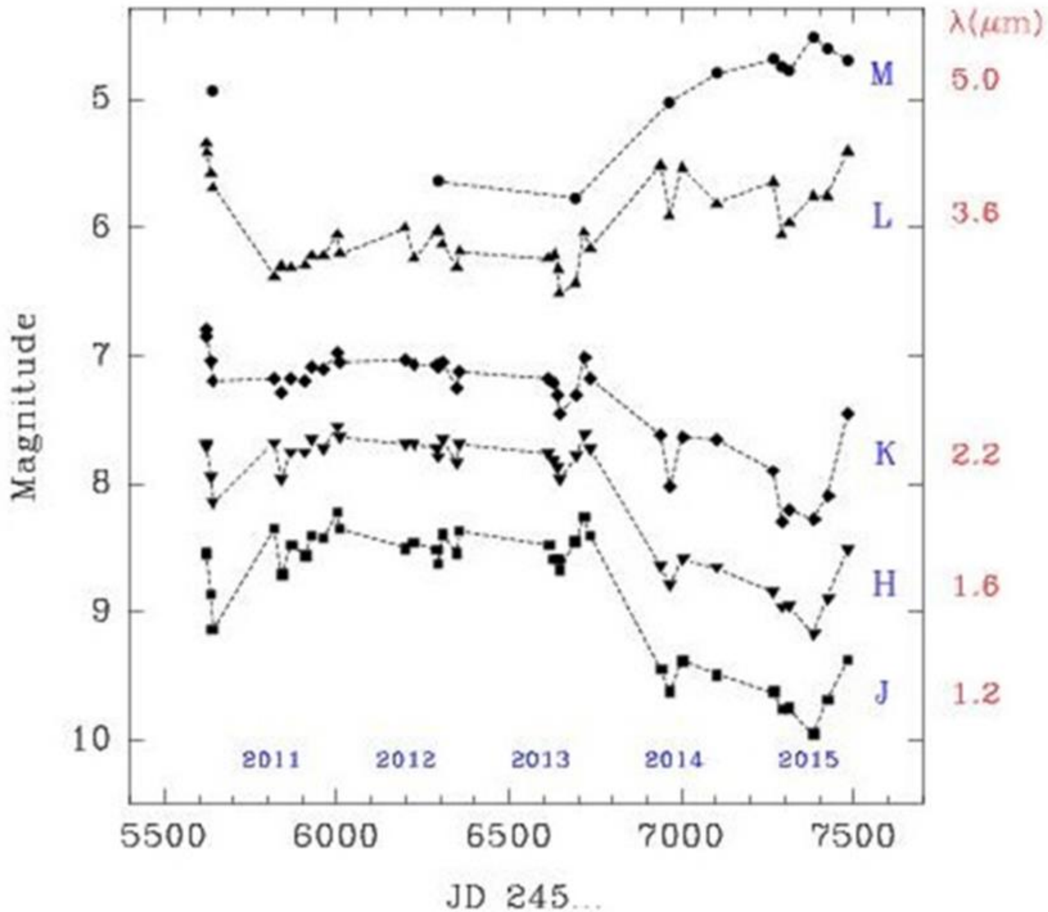
Figure 1. The light curve of RW Aur A+B in the V band after 2010 based on the visual (the grey dots) and photoelectric (the black dots) data from the AAVSO database and our observations. The upper axis is for calendar years, the ticks correspond to the beginning of each year.

from Dodin et al, 2019

RW Aur A:

appearance of hot dust during the optical minimum of 2014-2015

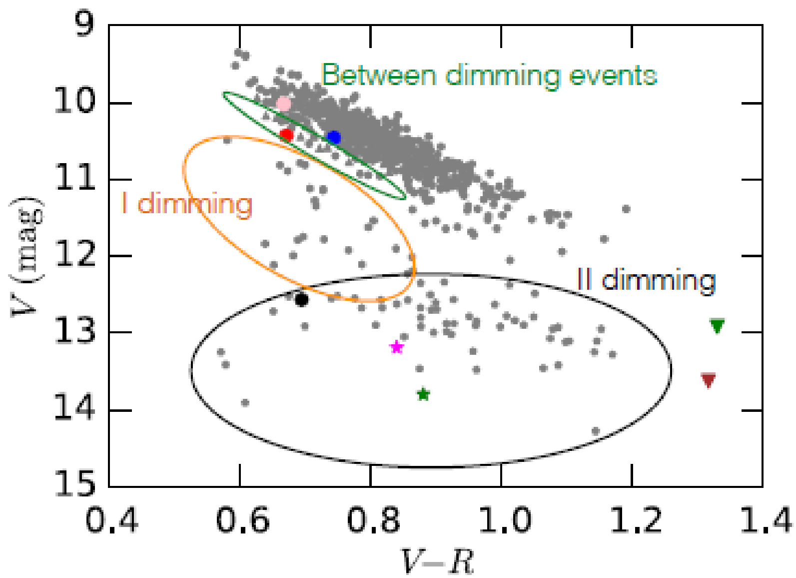




Hot dust in the disk wind ?
Inner disk perturbation ?
Destruction of a planetesimal ?

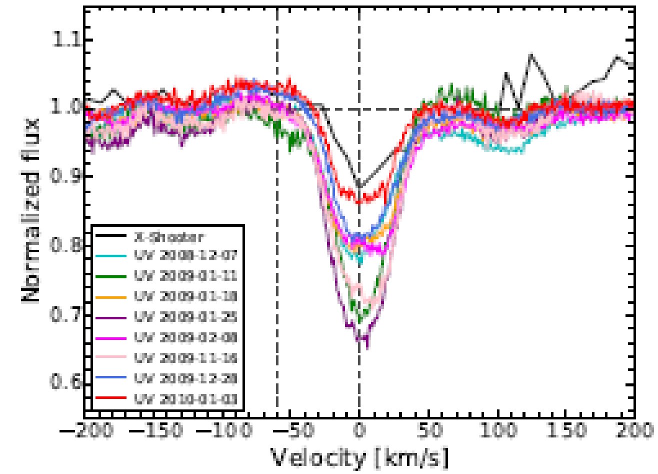
Shenavrin et al. 2015
Petrov et al. 2015

Resolved photometry of RW Aur A: dimming of 2010 and 2015



Photometry of RW Aur **A**

LiI 6707



Veiling of photospheric lines during the dimming

No major accretion variations were observed across the dimming events

Facchini et al 2016

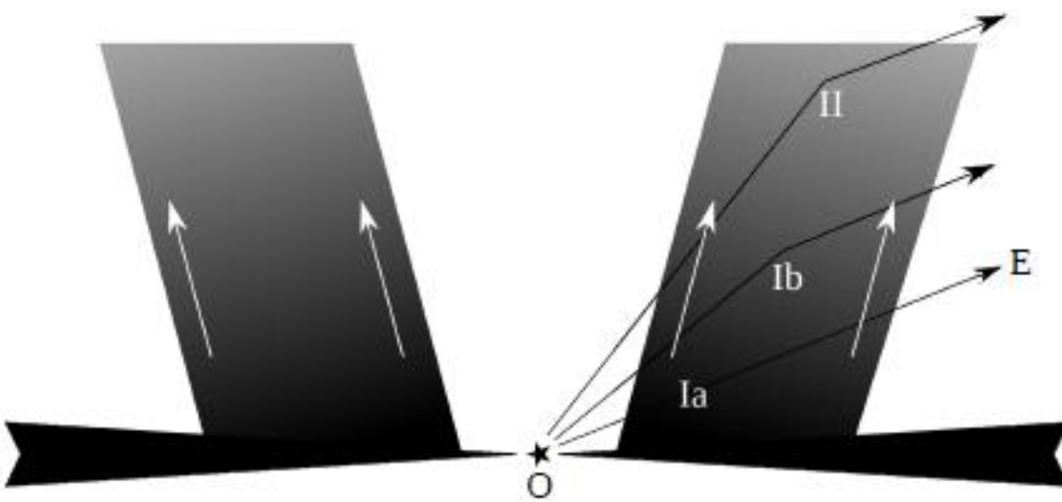
See also: Antipin et al. (2015); Petrov et al 2015
Takami et al 2016, Boshinova et al 2016
Dodin et al 2019

Veiling: at minimum light, the residual optical flux

RW Aur A

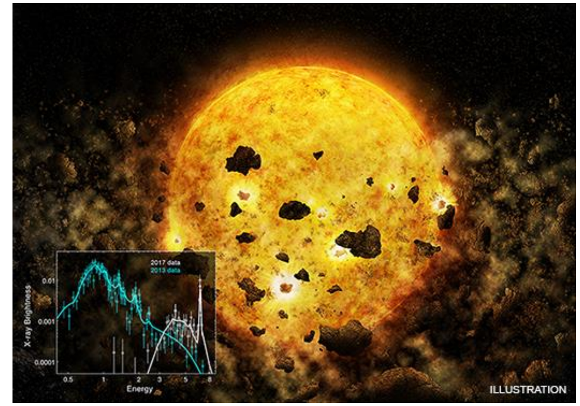
- During the minimum brightness, polarization degree reached **up to 30 %** in I band
- Polarization angle coincides with the jet axis

Conclusion: The polarization of RW A during the dimming was generated by scattering in a dusty wind which flows along the rotation axis



Dodin et al, 2019

A planet crash?



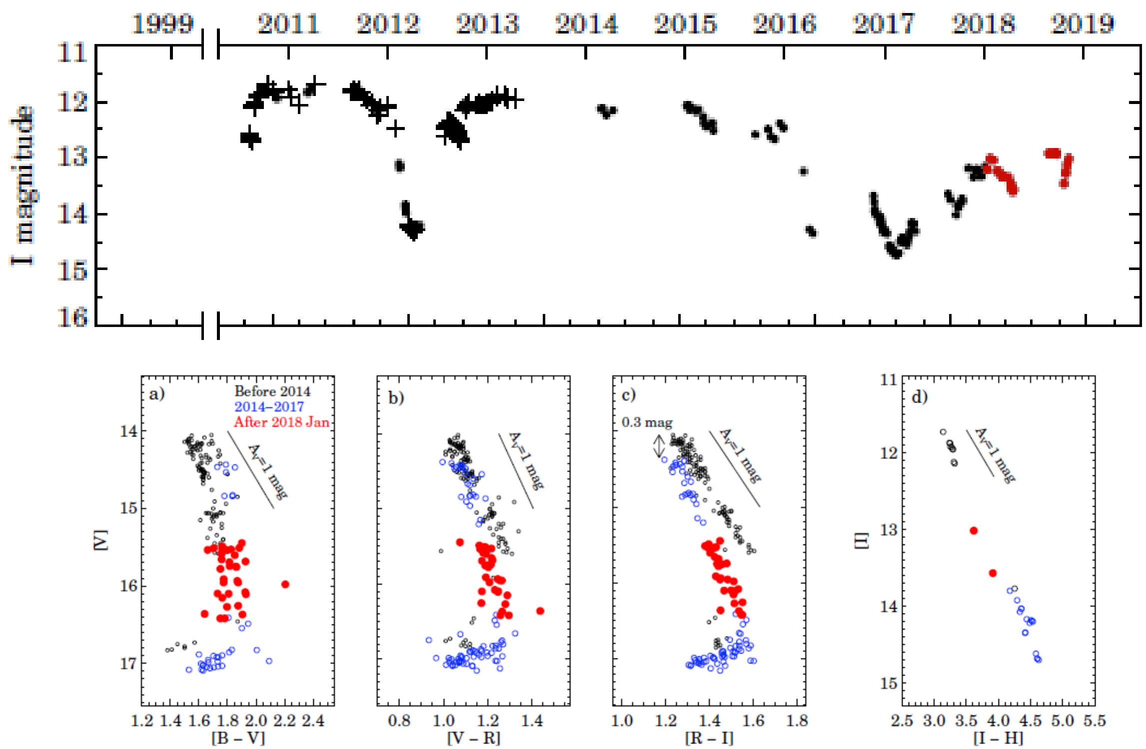
Chandra X-ray observations of RW Aur during the 2017 dimming event revealed that the **iron abundance in coronal gas** was an order of magnitude above Solar, in contrast with previous sub-Solar Fe abundance measurements.

"We speculate that the break-up of a terrestrial planet or a large planetesimal might supply the gray extinction seen in the optical, …and also provide the iron in the accretion stream to enhance coronal abundances. "

Gunther et al, 2018

Alternative scenario: reactivation of a dead zone with following accretion of dust (*Garate et al, 2019)*

Dimming events in the **FUor** V582 Aur, 2014-2017 (the star has been in outburst since 1985)

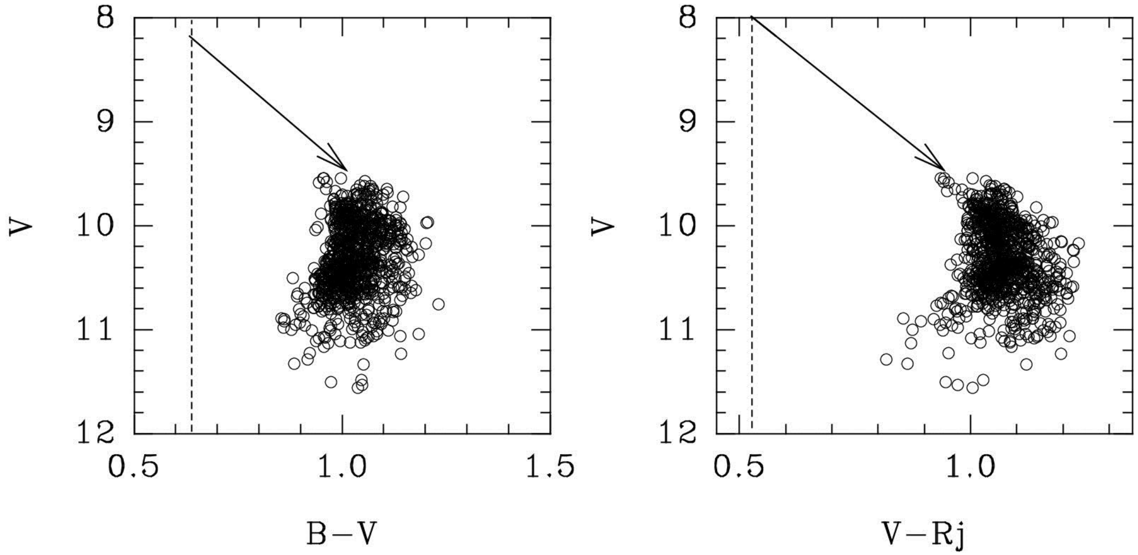


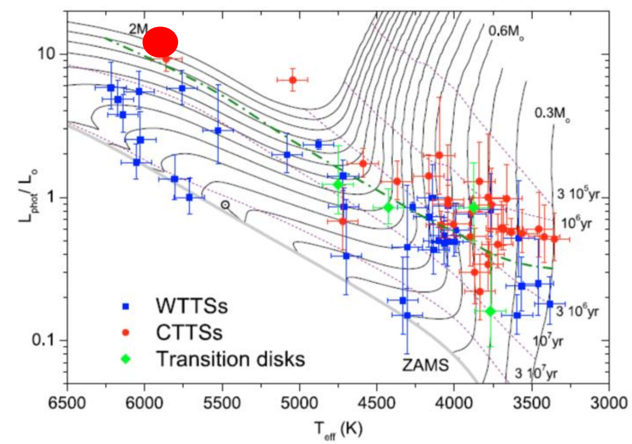
An extended dust cloud obscuring the inner disk ?

Zsidi et al, 2019, ApJ 873 130

Dust in disk wind

RY Tau: an UXor among cTTS





$L=13 \quad L_\odot$

$R=3.3 \; R_\odot$

$M=2.1 \; M_\odot$

$\mathrm{Maccr} = 10^{-8} \; M_\odot/\mathrm{yr}$

age = 4.7 Myr

G2 IV , T=5900 K, Vsin*i*=52 km/s

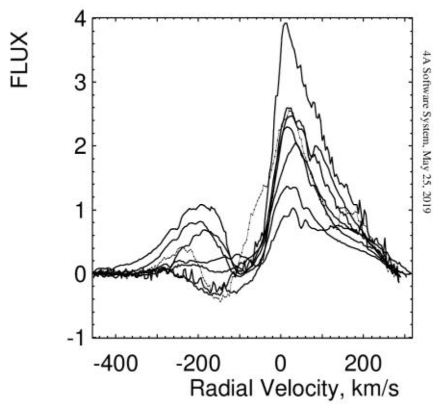
Inclination > 60 deg

The star is permanently obscured by circumstellar dust

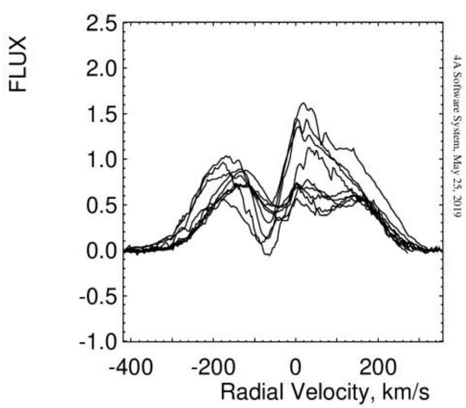
Petrov et al, 2019

RY Tau:

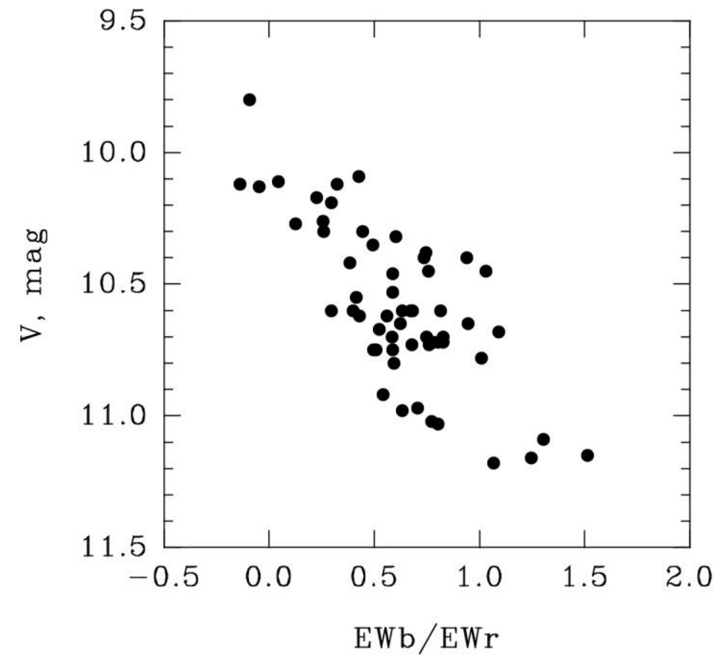
Hα line profile correlates with stellar brightness.
Impact of wind on circumstellar dust?



V = 9.8 -10.2 mag



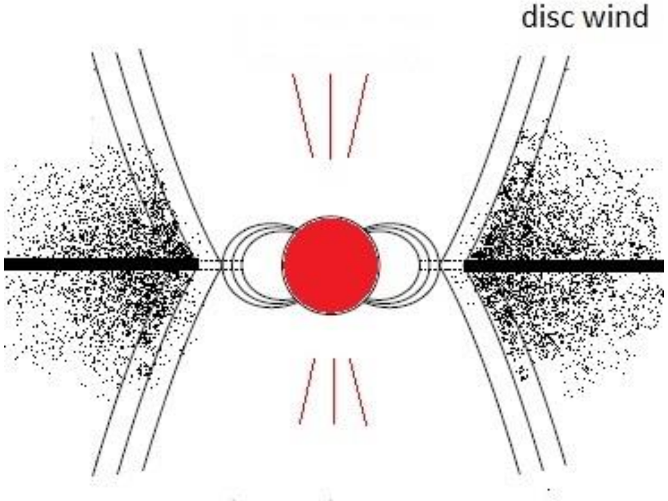
V = 10.8 -11.2 mag

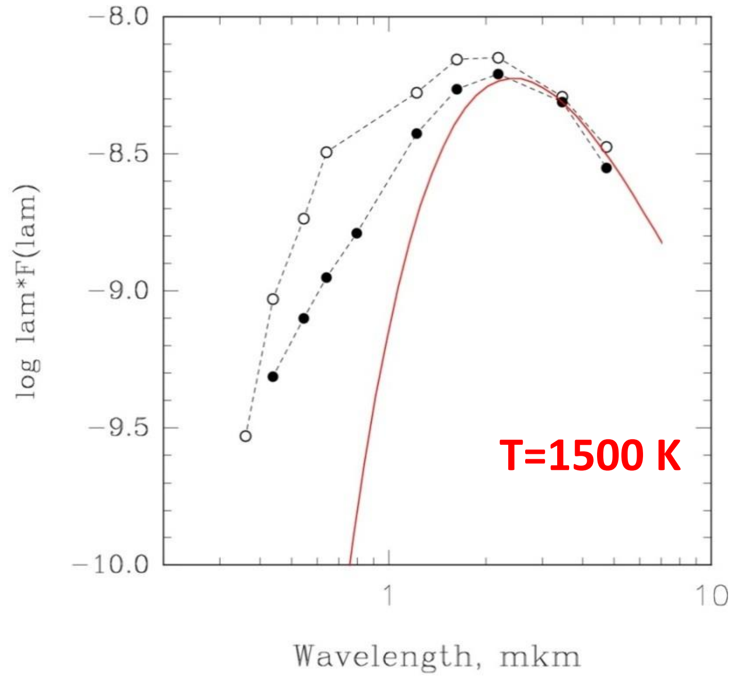


Babina et al, 2016

2 days x 100 km/s = 0.12 AU

RY Tau:
Dust-laden disk wind near the inner edge of accretion disk





2 days x 100 km/s = 0.12 AU

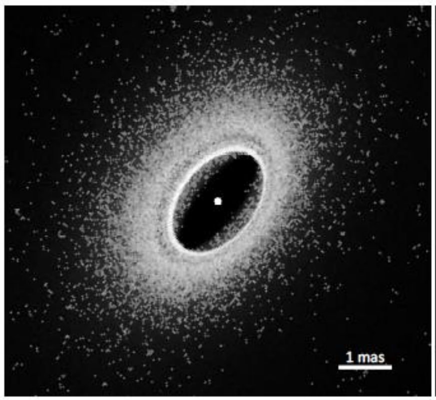
Ejection → disk mag. field ?

Petrov et al. 2019

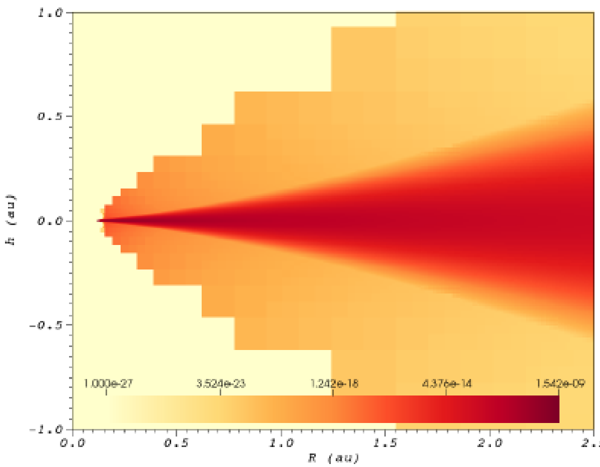
“Dust in the disk winds from young stars as a source of the circumstellar extinction” *Tambovtseva & Grinin,* 2008.

Dusty disk wind at the sublimation rim of **SU Aur**

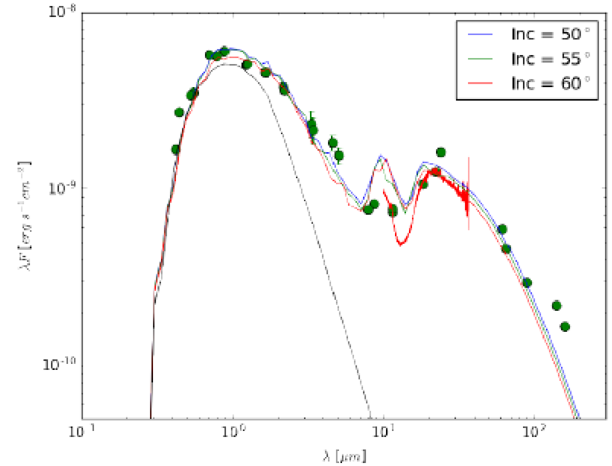
NIR Interferometry with CHARA array (Mt. Wilson, CA) and model of a dusty wind



Computed synthetic image in K-band



0 1 2 AU



Geometric model : inner rim at 0.17 AU with an inclination of 59 deg.
Radiative transfer model: flared disk with an inner radius at 0.18 AU, grain size of 0.4 mkm, silicates at Tsub=1600 K.
Only the dusty disk wind successfully accounts for the K-band excess by introducing dust above the mid-plane.

Labdon et al. [2019]

CONCLUSIONS

- the UXor effect is common for HAeBe and cTTS;
- a dusty disk wind is a source of the circumstellar extinction in cTTS;
- the outflow events in cTTS may affect the near dusty environment;
- a deep long-lasting dimming occur due to inner disk perturbations or collisions of planetesimals

Acknowledgements

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