The connection between magnetic field topology and accretion: an observational perspective

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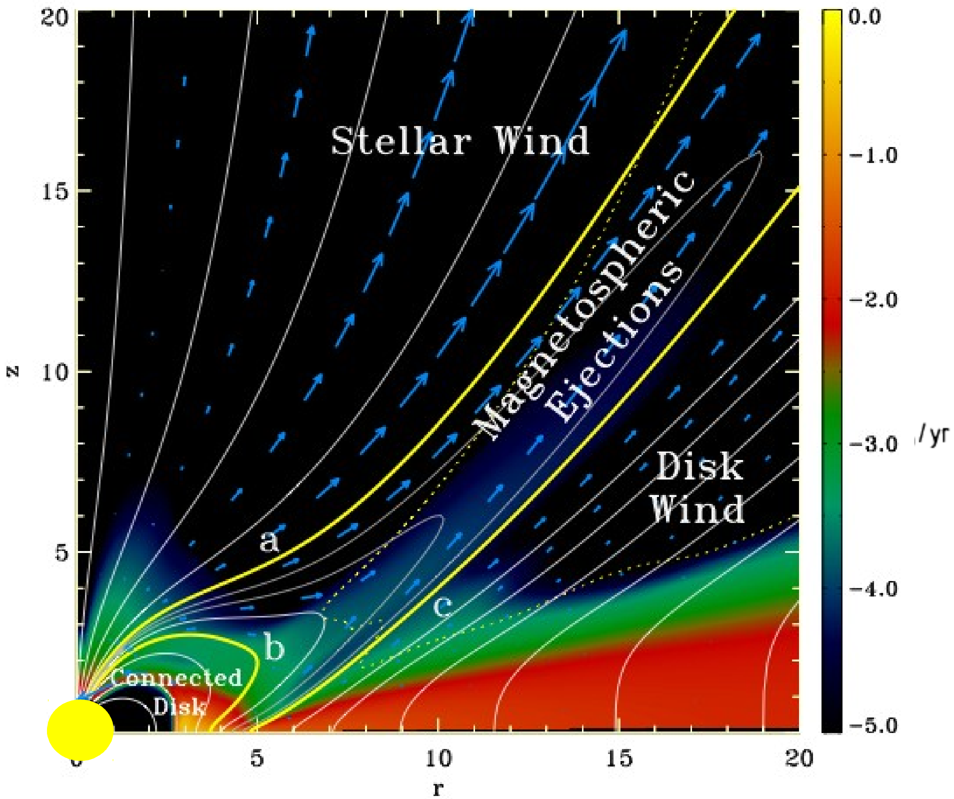
The importance of magnetic fields

- Activity
- Accretion
- Star-disk interaction
- Inner disk structure
- Outflows (stellar winds, disk winds, j
- Angular momentum transport



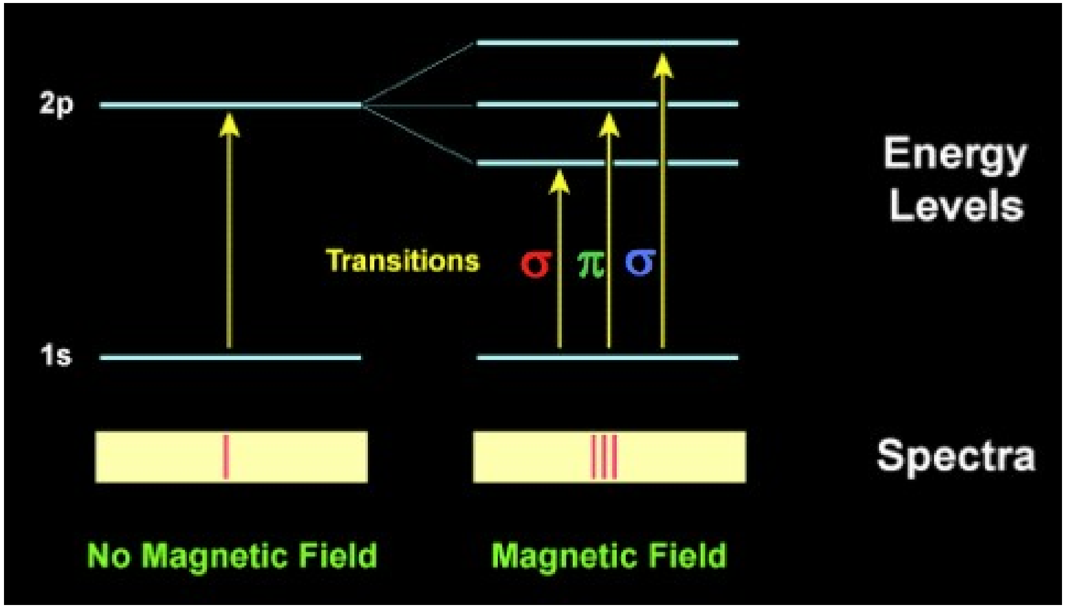
Zanni & Ferreira (2013)

Camer
Kurosa

(19

Magnetic field measurements: Zeeman effect

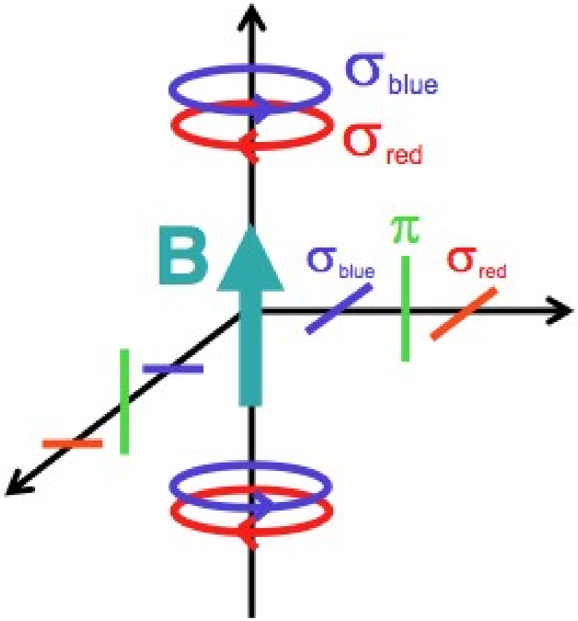
Line-splitting in the presence of a magnetic field



$$\Delta\lambda = \frac{e}{4\pi m_e c^2}\lambda^2 g B$$

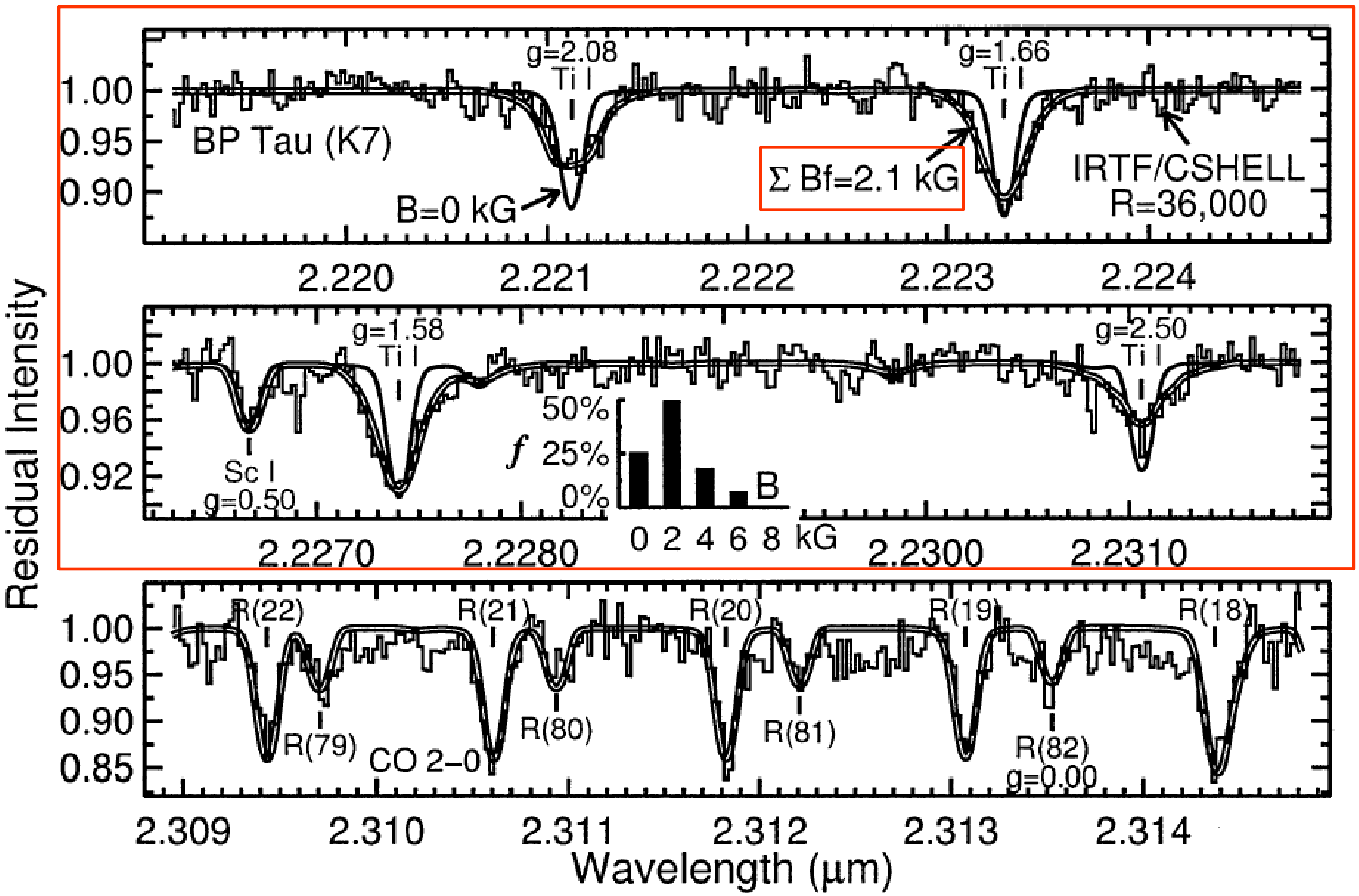
Reiners (2013)

The polarization of the components depends on the viewing angle



Magnetic field intensity: Zeeman broadening

$$\Delta\lambda = \frac{e}{4\pi m_e c^2}\lambda^2 g B$$ Magnetic flux (Bf)

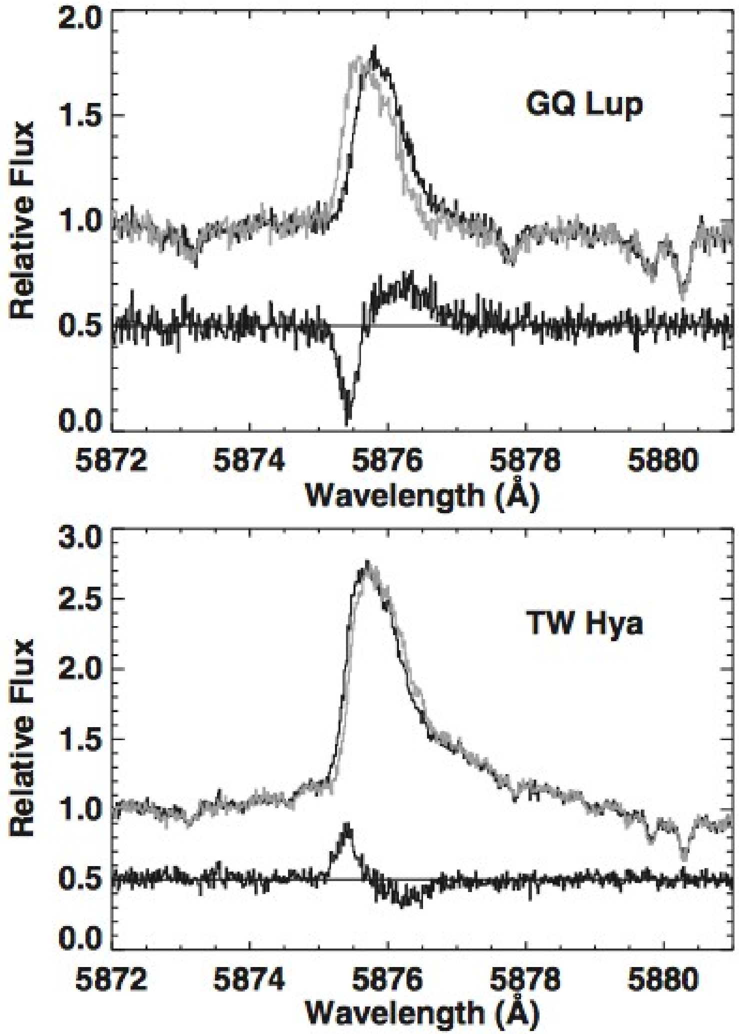


Valenti & Johns-Krull (2004)

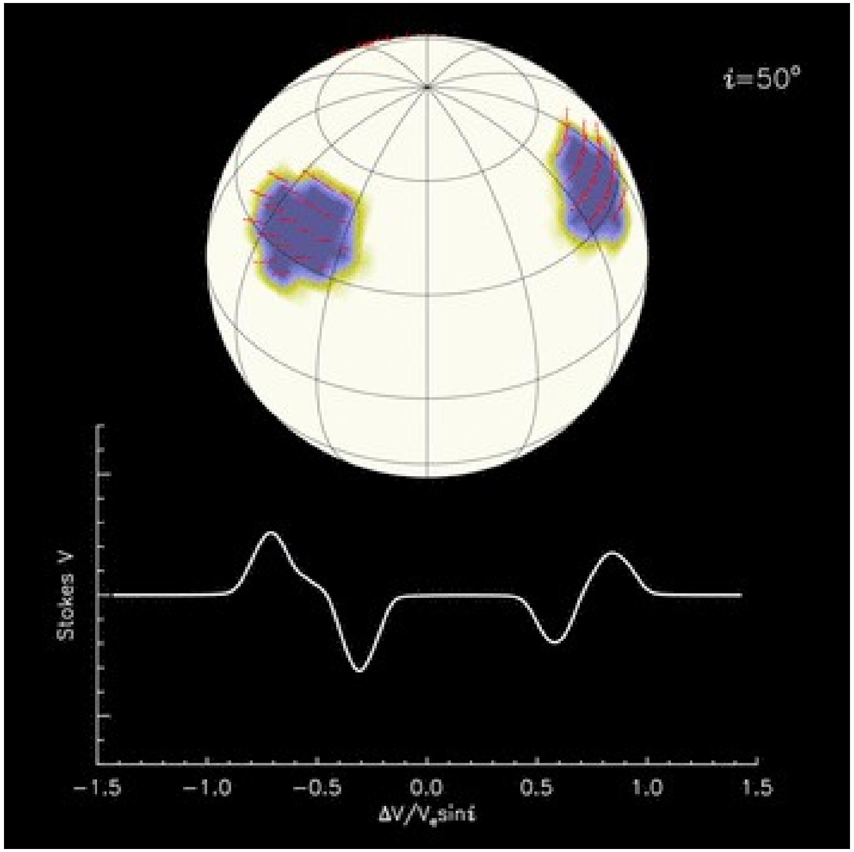
Star	<B> (kG)
AA Tau	2.57
BP Tau	2.17
DE Tau	1.35
DF Tau	2.98
DK Tau	2.58
DN Tau	2.14
GG Tau A	1.57
GI Tau	2.69
GK Tau	2.13
TW Hya	2.61
T Tau	2.39

Johns-Krull et al. (1999)
Johns-Krull et al. (2004)
Yang et al. (2005)

Magnetic field structure: Zeeman-Doppler imaging



Johns-Krull et al. (2013)



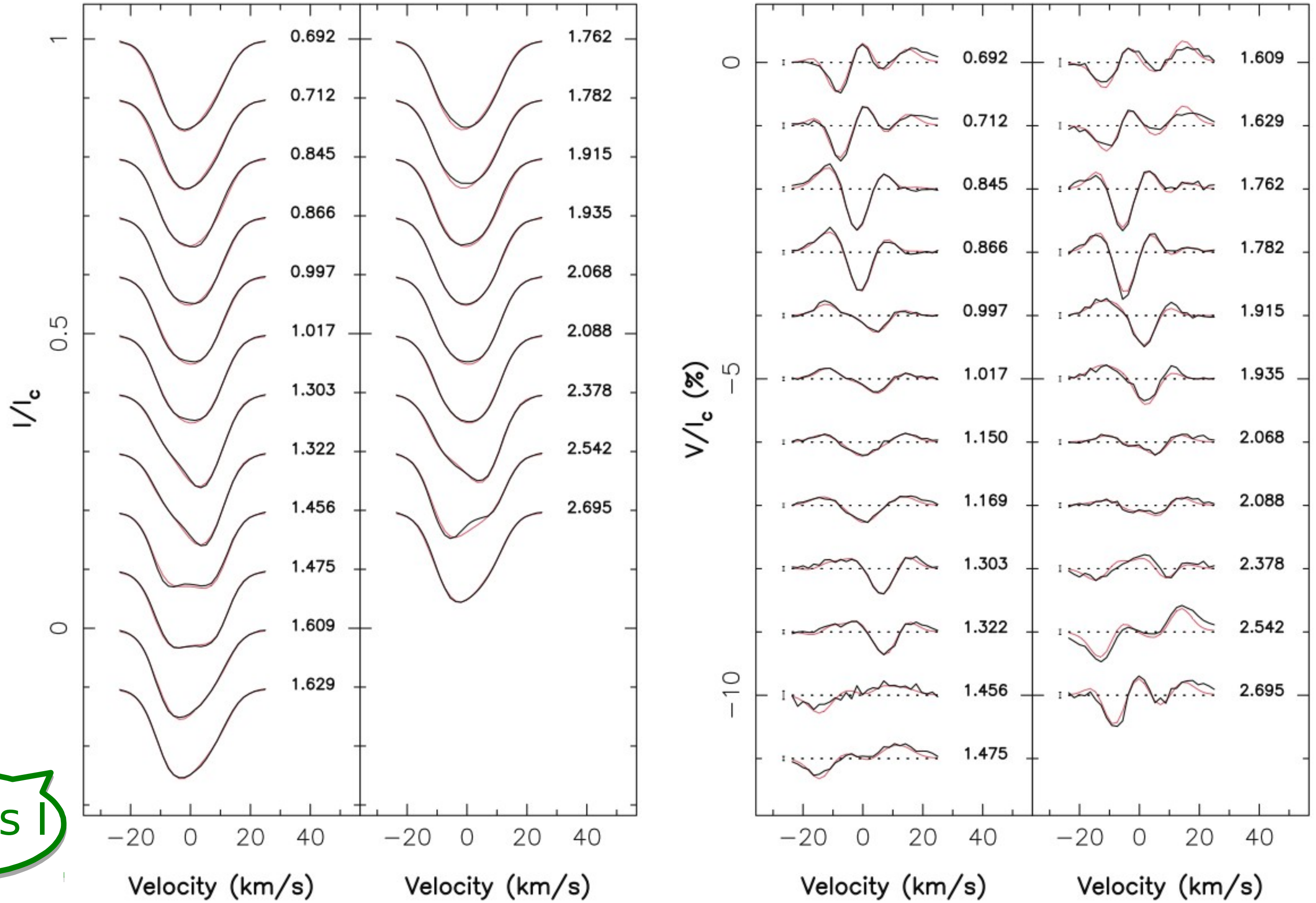
Circularly polarized line profile:
magnetic map: intensity+topology
(Zeeman-Doppler imaging)
Oleg Kochukov
http://www.astro.uu.se/~oleg
/

LSD profiles of V2129 Oph

Non-accreting regions

data

model



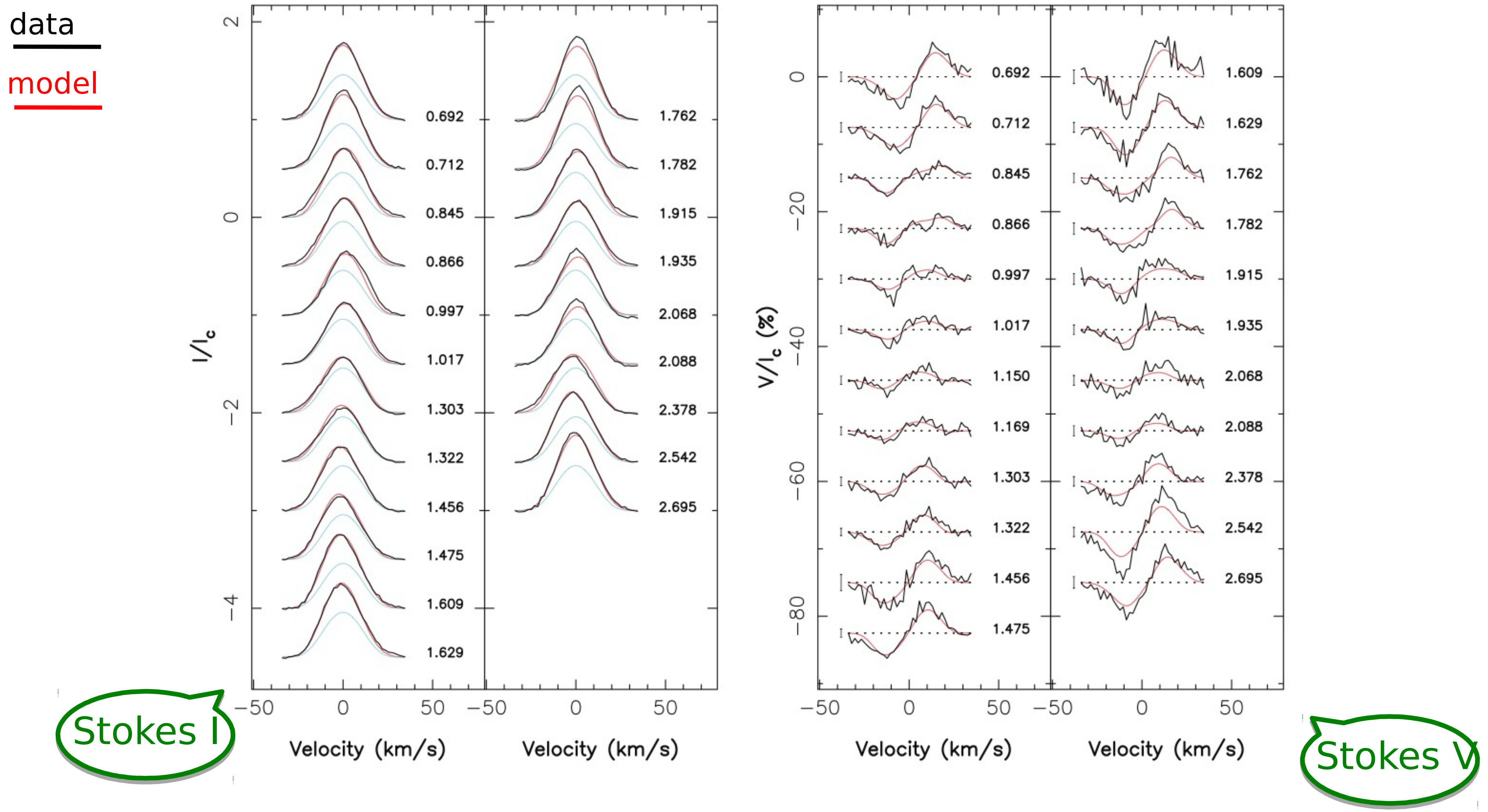
Stokes I

Stokes V

Donati et al. (2011)

CaII emission line of V2129 Oph

Accreting regions

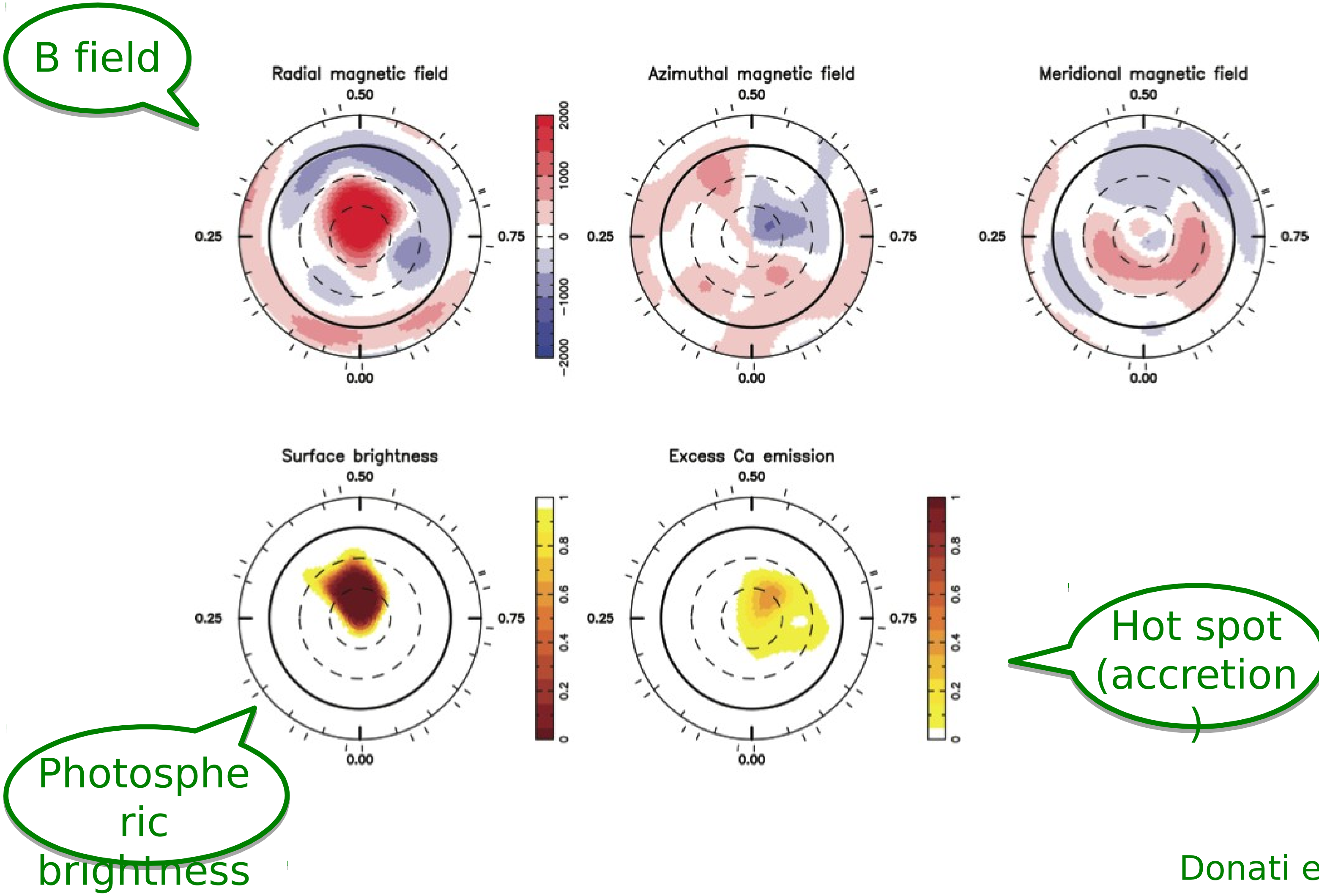


Donati et al. (2011)

V2129 Oph in 2009

Octupole: 2.1 kG, **Dipole**: 0.9 kG

Surface map reconstructed with tomography

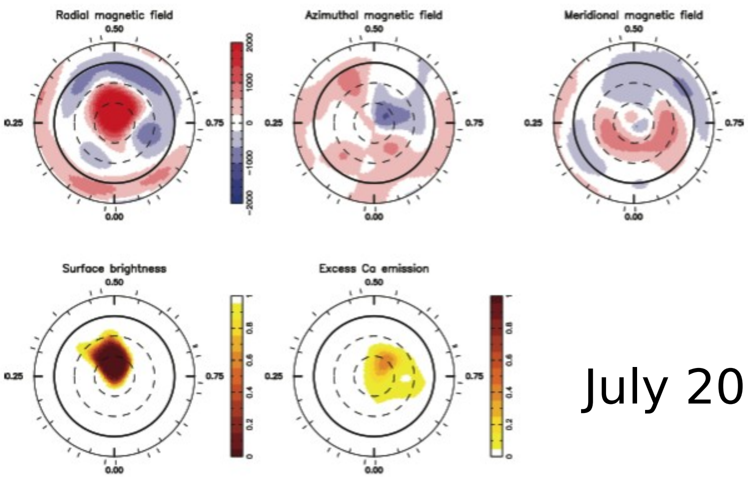


Donati et al. (2011)

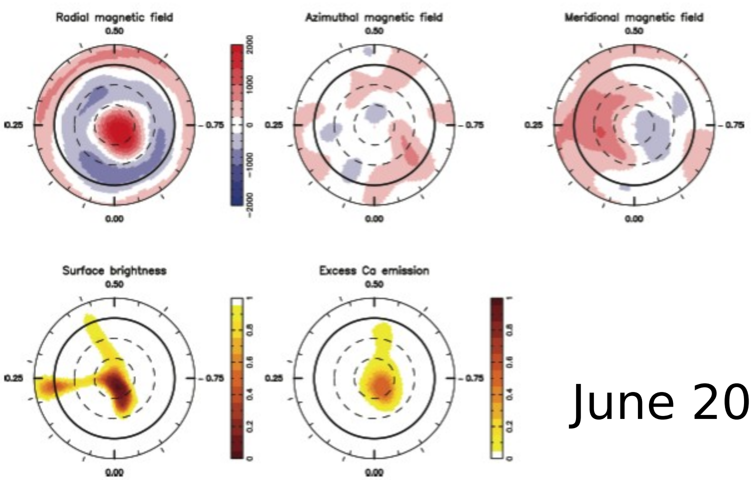
V2129 Oph (Donati et al. 2007, 2011, Jardine et al. 2008, Gregory & Donati 2011):

Axisymmetric, poloidal magnetic field, dominated by the octupole

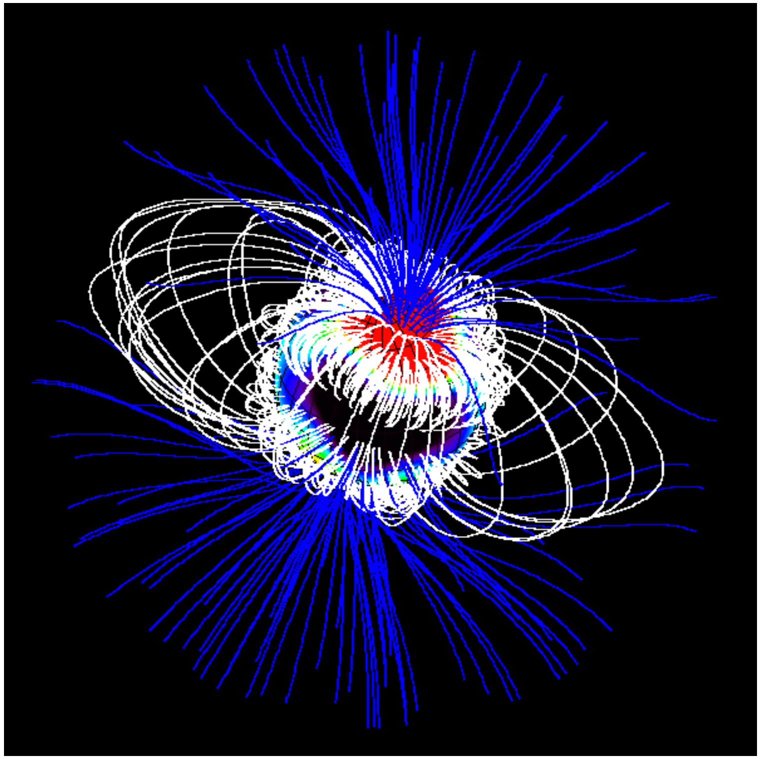
The dipole and octupole components varied between the two epochs



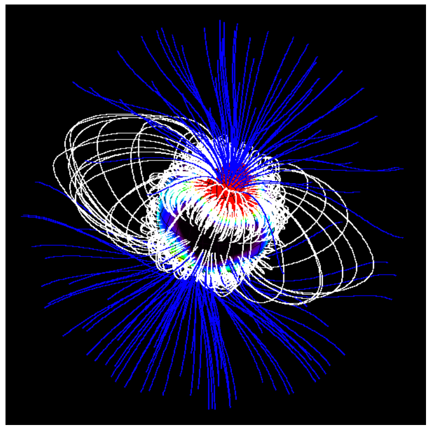
July 2009

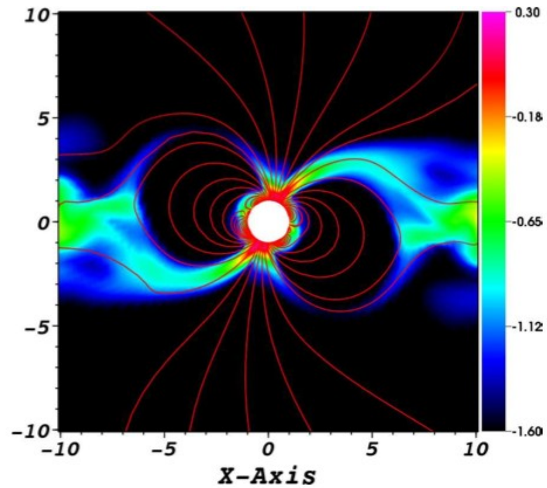


June 2005

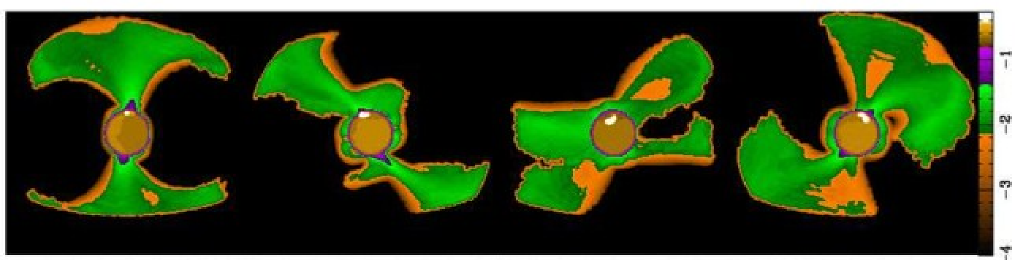


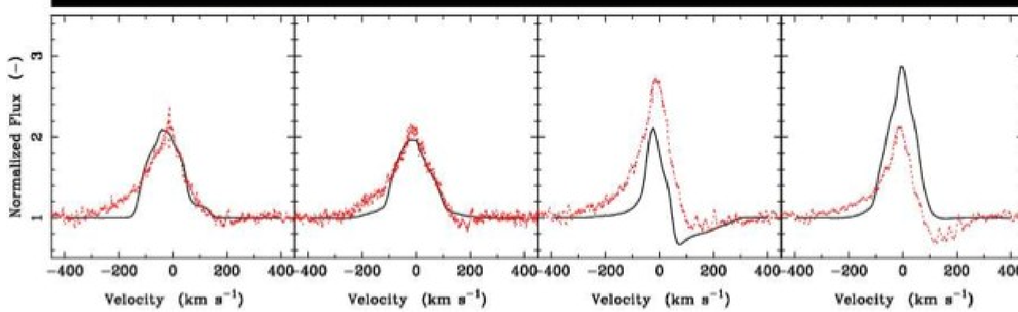
V2129 Oph
Simulations and data comparison





Hβ dipole+octupole





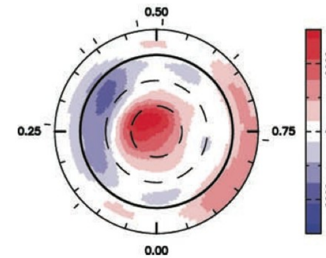
model

data

Alencar et al. (2012)

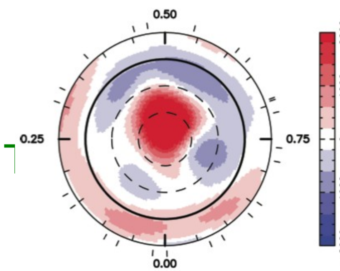
Magnetic field structure

ully convective star
mo: strong axisymmetric dipole - AA Tau, BP Tau, GQ Lup
rotation rates (p~8d)
 et al. (2008, 2010, 2012), Chen & Johns-Krull (2013)



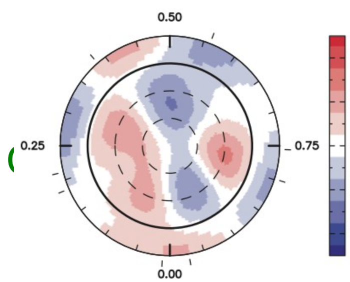
BP Tau

onvective shell with depths > 0.5 R*
mo: strong axisymmetric octupole – TW Hya, V2129 Oph, DN T
to spin-up (p~4d to 6d)
 et al. (2011, 2012 2013)



V2129 Oph

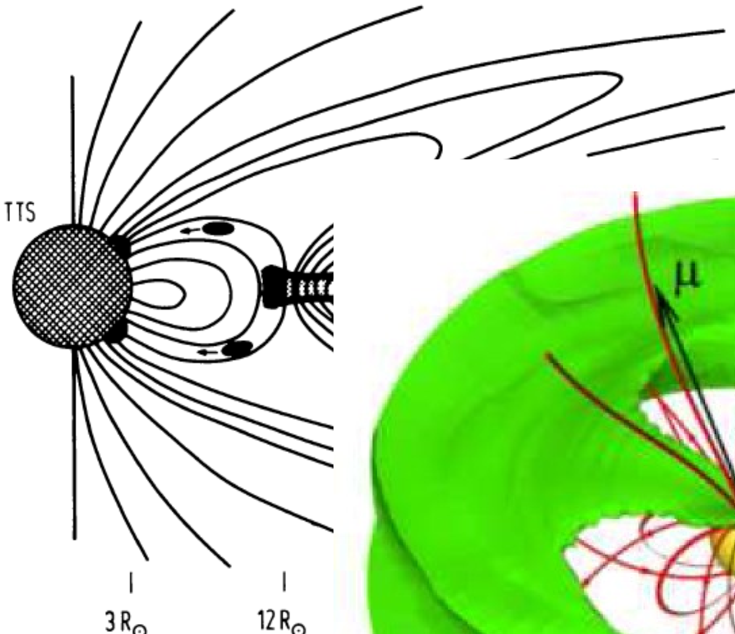
onvective shell with depths < 0.5 R*
mo: weak non-axisymmetric multipole - V4046 Sgr, CV Cha, C
rotation rates (p~2d)
n et al. (2009), Donati et al. (2011)



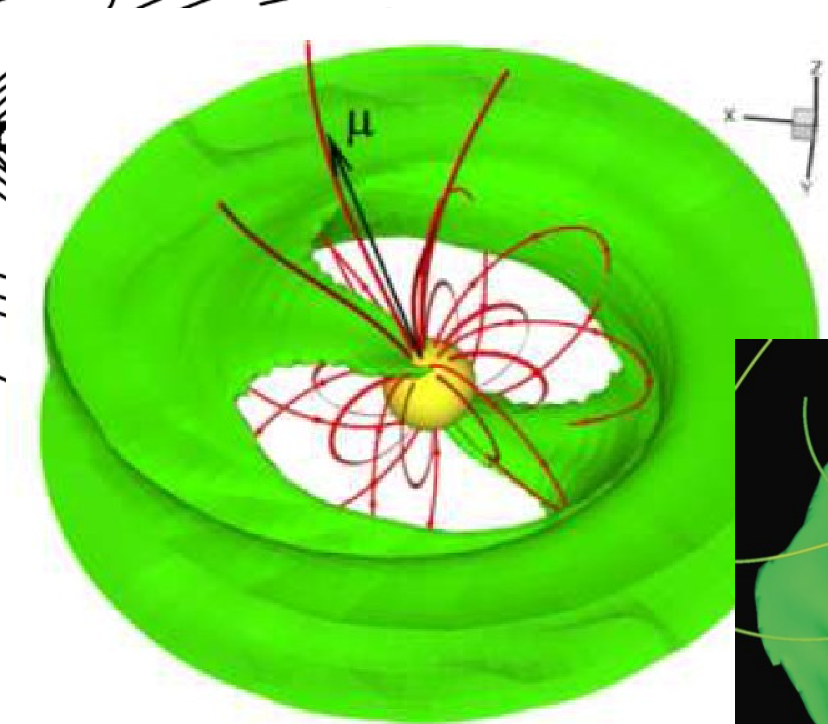
V4046 Sgr

ilar results obtained for Main-Sequence stars (Morin et al. 2010, 2011)

Magnetospheric accretion through complex fields

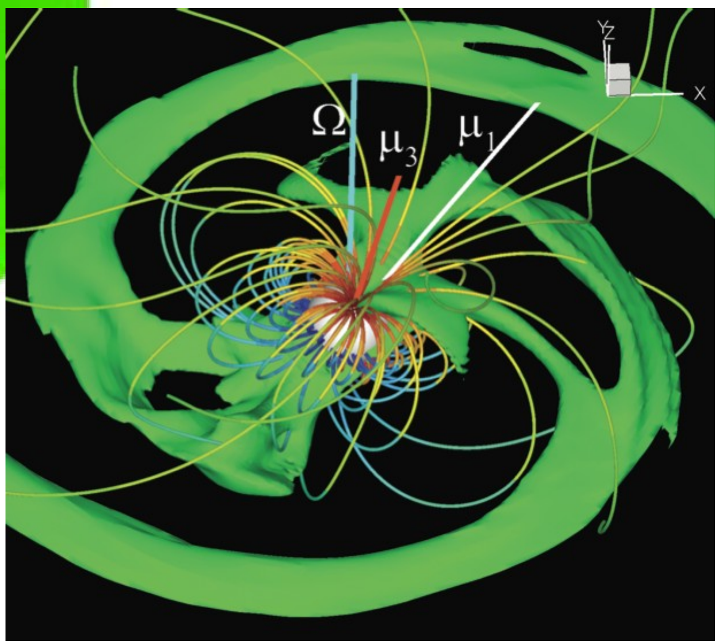


Camenzind (1990)



Romanova et al. (2003)

V2129 Oph



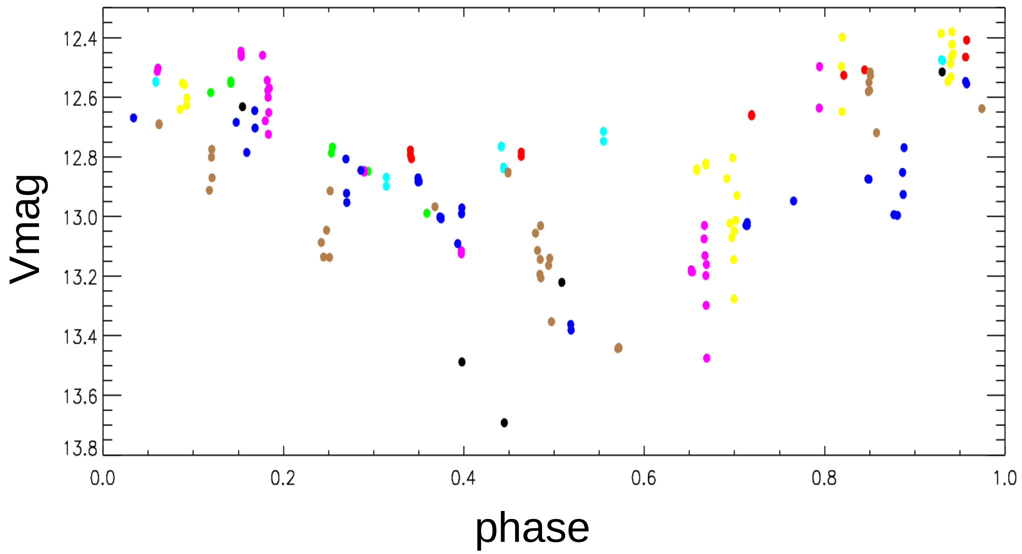
Romanova et al. (2011)

The importance of synoptic photometric and spectroscopic surveys

- Probe several timescales (hour/day/months)
- Inner disk structure
- Star-disk interaction
- Accretion process dynamics

AA Tau: a test case

Bouvier et al. (1999, 2003, 2007)

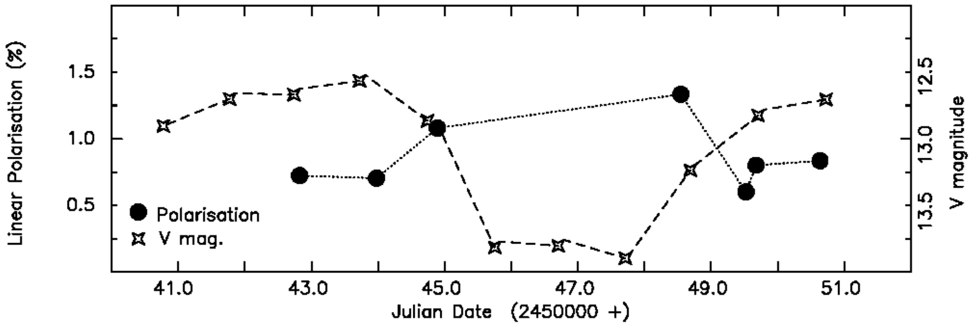


Bouvier et al. (2007)

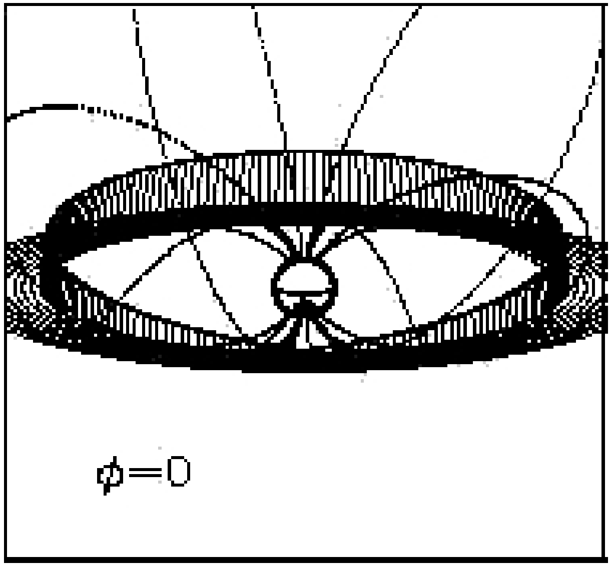
Light curves with periodical eclipses (~8.2d) of the photosphere that occur without much color change.

The linear polarization increases when the star is eclipsed.

Periodical occultation of the photosphere by an inner disk warp, created by the stellar magnetic field, inclined with respect to the stellar rotation axis.

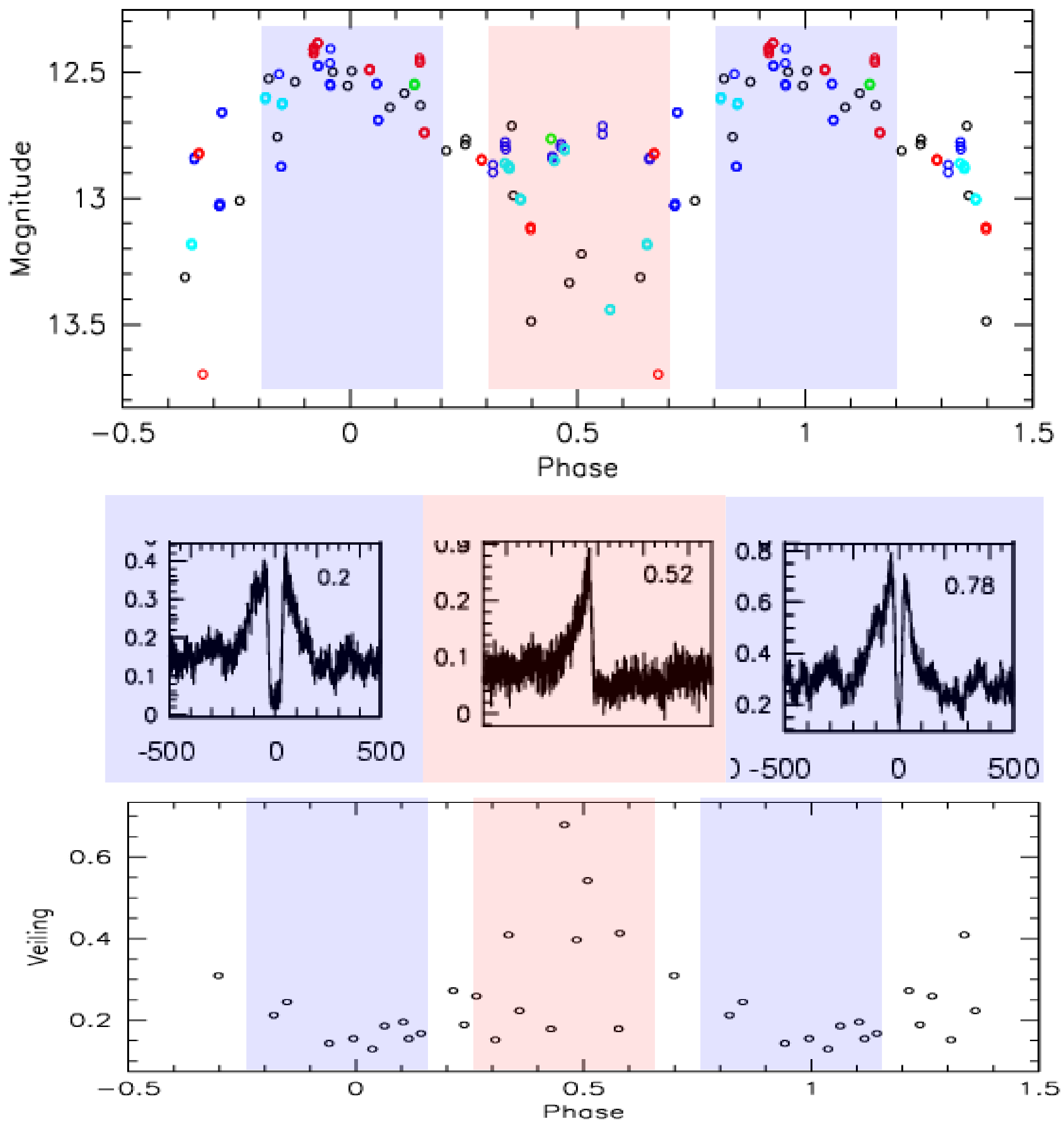


Ménard et al. (2003)



Inclined magnetosphere

Bouvier et al. (2007)



Periodical eclipses

inner disk warp

P=8.22d

Balmer lines

accretion funnel

Veiling

accretion shock

Is AA Tau peculiar ?

Is an inner disk warp a common characteristic of CTTSs ?

Is the star-disk interaction with a timescale of a few rotation periods the rule among CTTSs ?

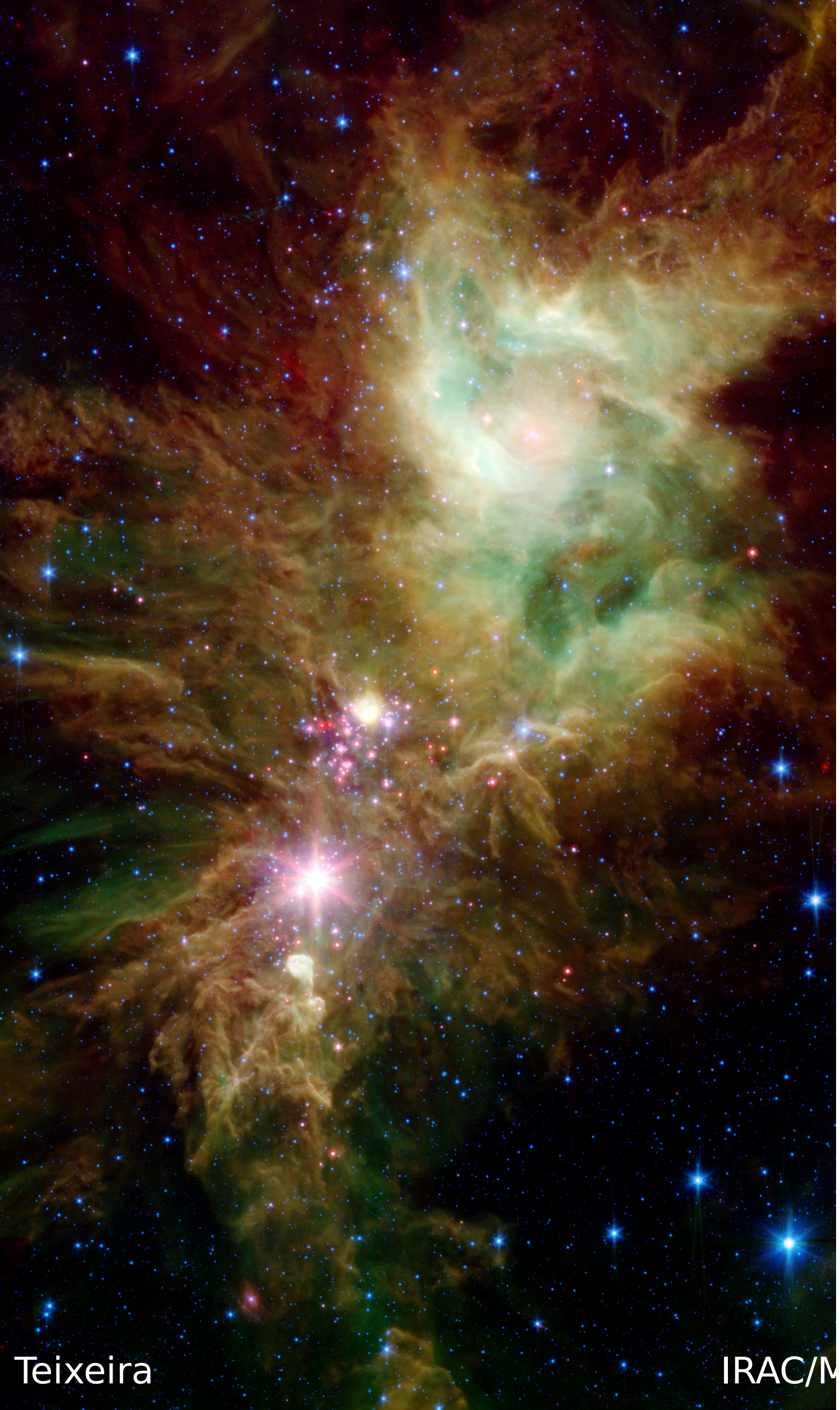
Is the association between an inclined magnetosphere, the inner disk warp, accretion columns and accretion shock observed in other CTTSs ?

Coordinated Synoptic Investigation of NGC 2264 CSI 2264

PIs: J. Stauffer, G. Micela

December 2011 - January 2012

- CoRoT: 40 days – optical
- MOST: 40 days – optical
- *Spitzer*: 30 days – 3.6μm, 4.5μm
- Chandra/ACIS: 3.5 days – X-rays
- VLT/Flames: ~20 epochs – Hα region
- Ground-based monitoring: ~3 months – U-I bands



NGC 2264

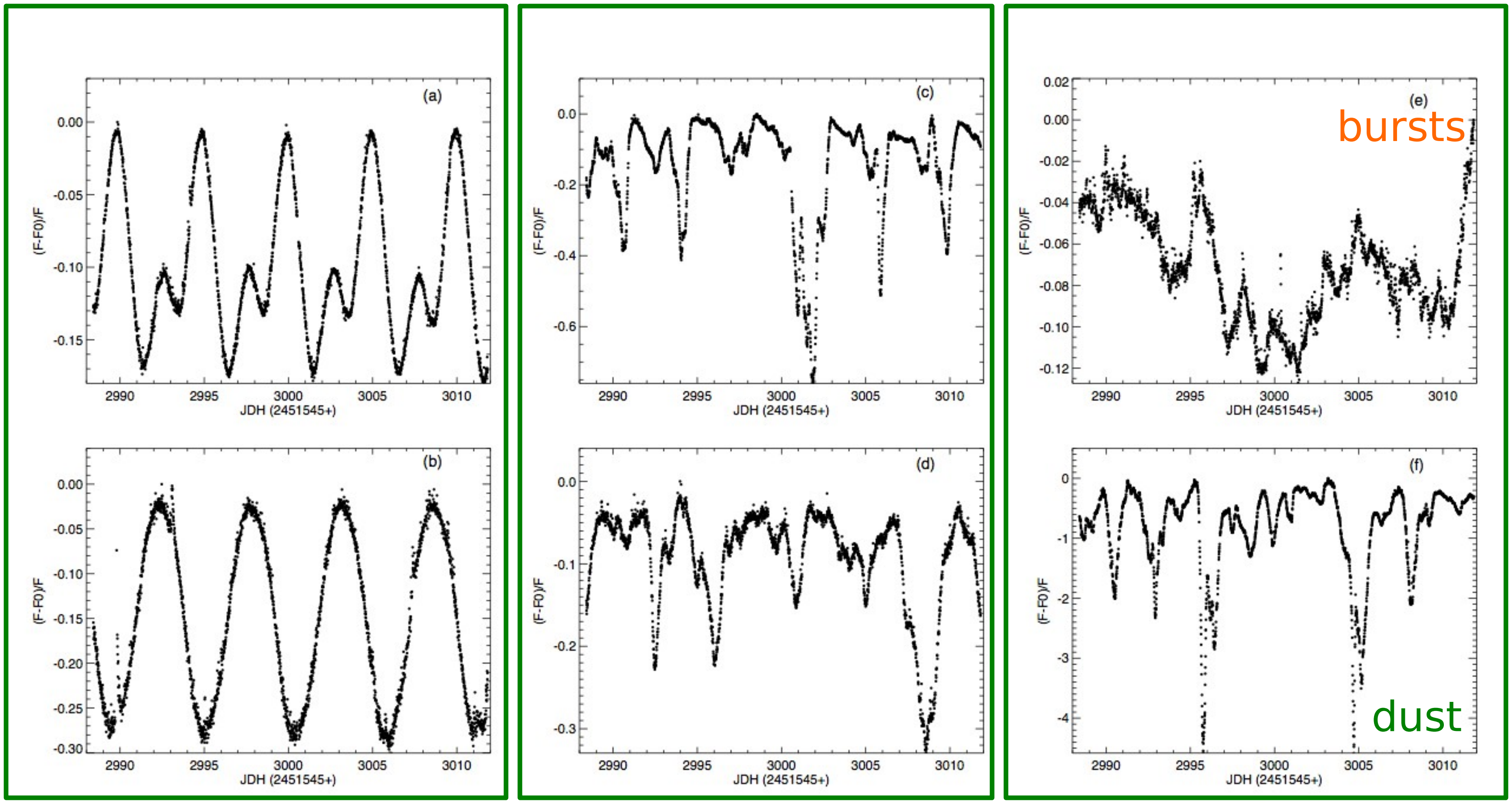
- distance ~ 760 pc
- age ~ 2-4 Myr
- known members: ~2000
- large photometric and spectroscopic database
- many CTTSs

Members observed by CoRoT: ~500

CTTSs observed by CoRoT: ~150

CoRoT light curves of CTTSs in NGC 2264

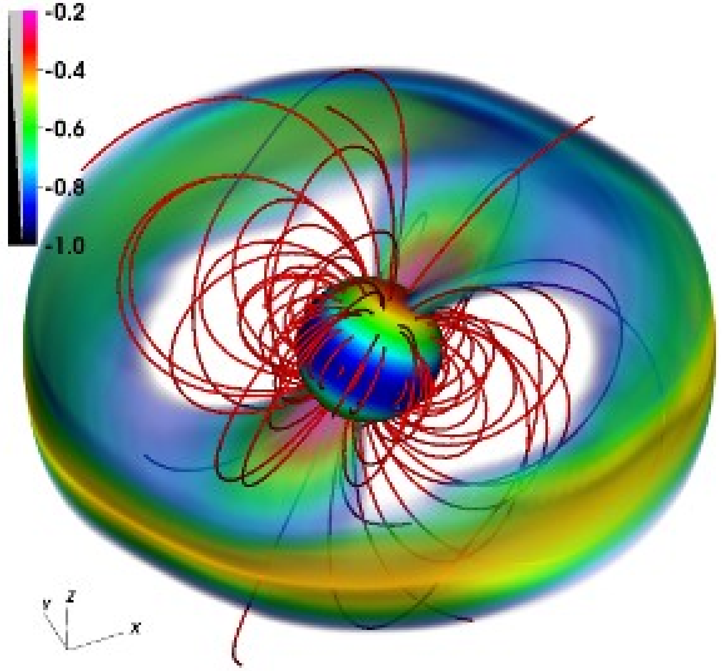
Spot Periodic | AA Tau Periodic | Aperiodic

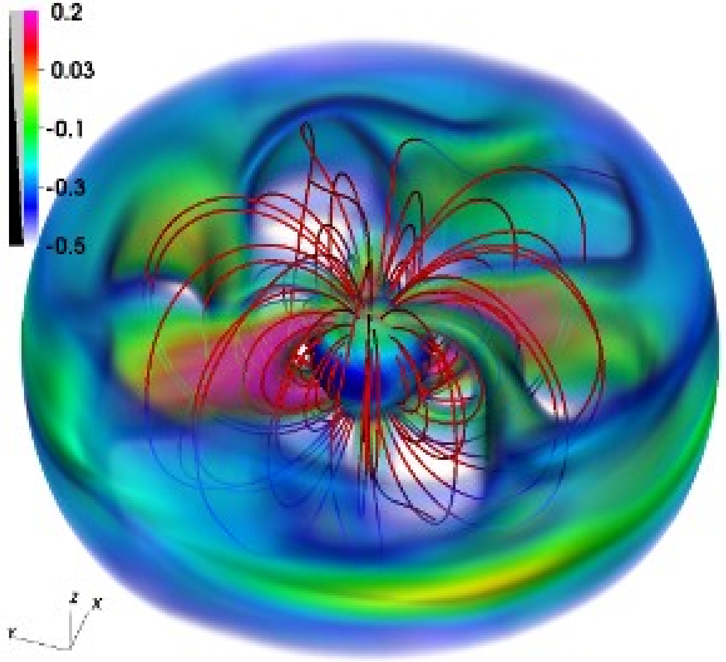


Alencar et al. (2010)

Stable and unstable accretion regimes

Kurosawa & Romanova (2013), Blinova et al. (2015)



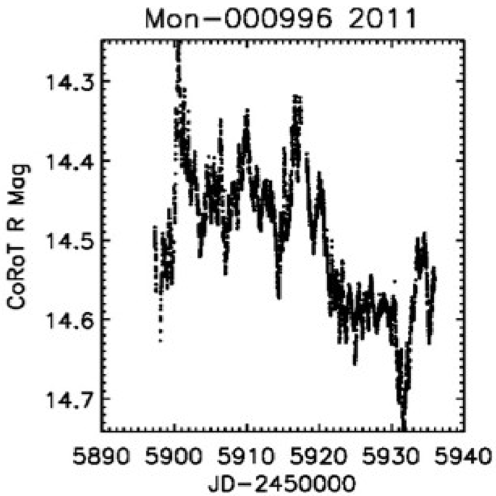


Raileigh-Taylor instability is favored at : small misalignement and Rm ≤ 0.7 Rco

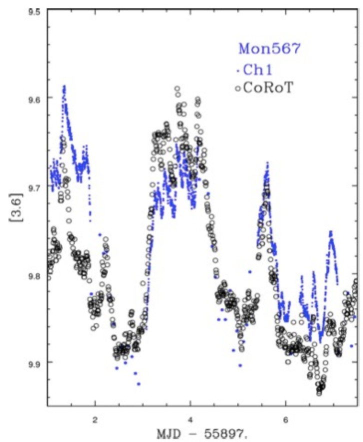
Accretion burst light curves (~12%)

Stauffer et al. (2014), Sousa et al. (2015)

CoRoT light curve

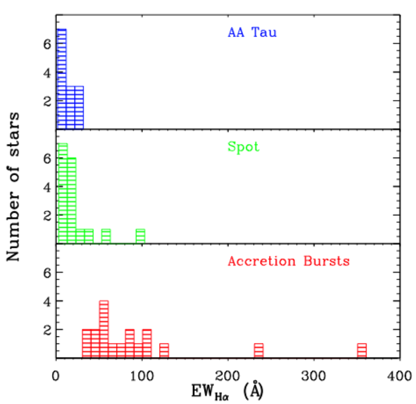


CoRoT + *Spitzer*

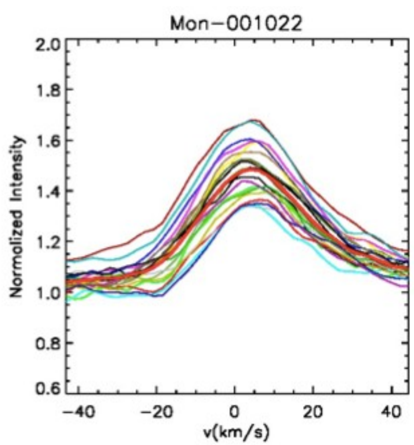


- Aperiodic light curves
- Non-steady accretion
- Burst duration 0.2d-0.5d, 10% amplitude
- Strongest accretors
- HeI 6678 Å in emission (only NC)
- Symmetric or P Cygni Hα profiles
- Strong outflow

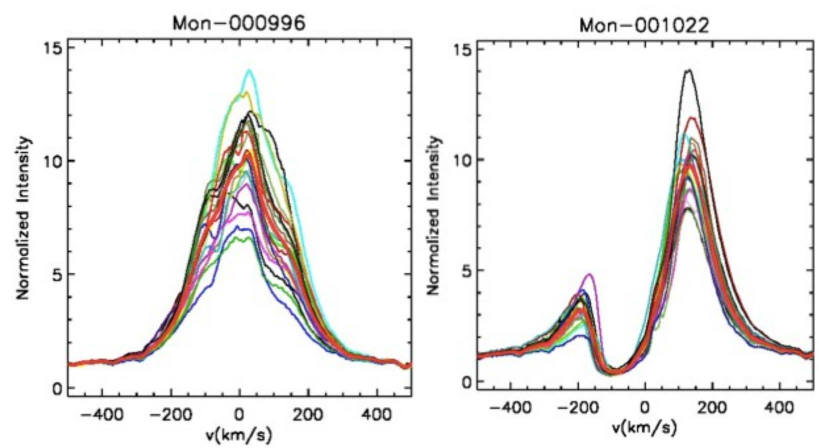
Hα EW



HeI 6678 Å



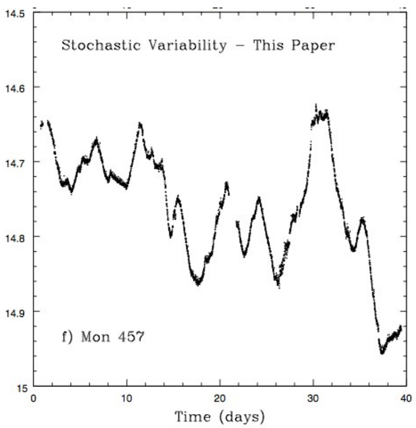
Hα profiles



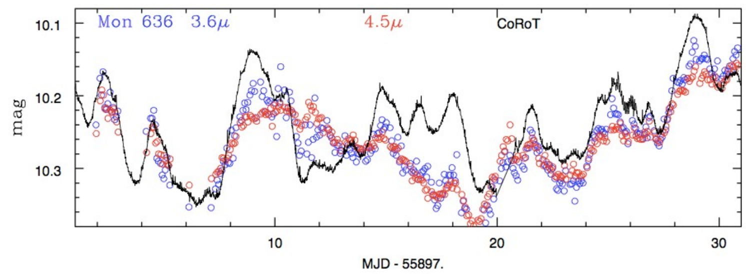
Stochastic light curves (~10%)

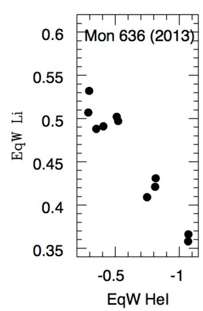
Stauffer et al. (2016)

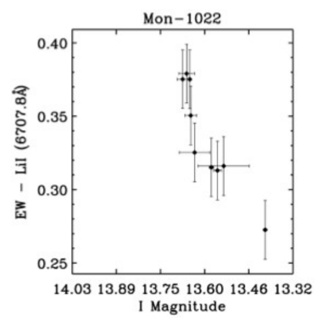
CoRoT light curve



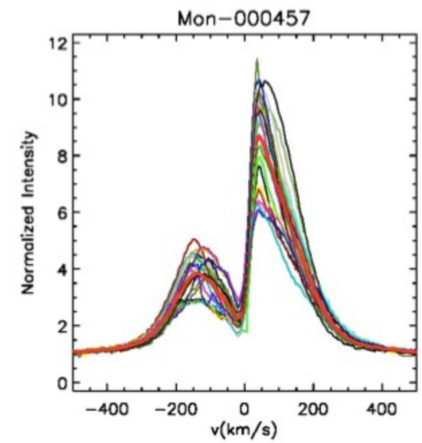
CoRoT and *Spitzer*

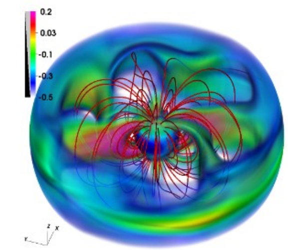


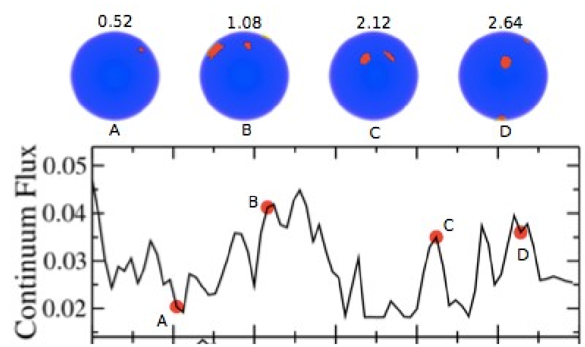




Hα profile







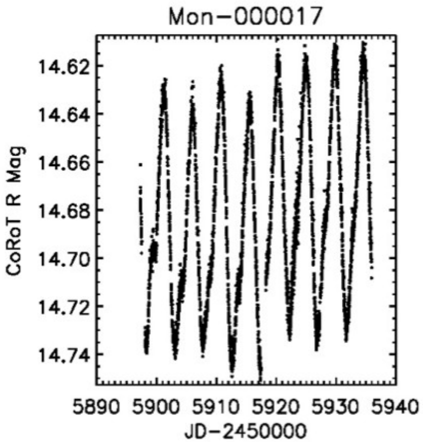
Kurosawa & Romanova (2013)

- Aperiodic light curves
- Light curve due to time variable accretion
- Small accretion bursts
- Moderate/strong accretors
- Hα profiles with blueshifted absorption

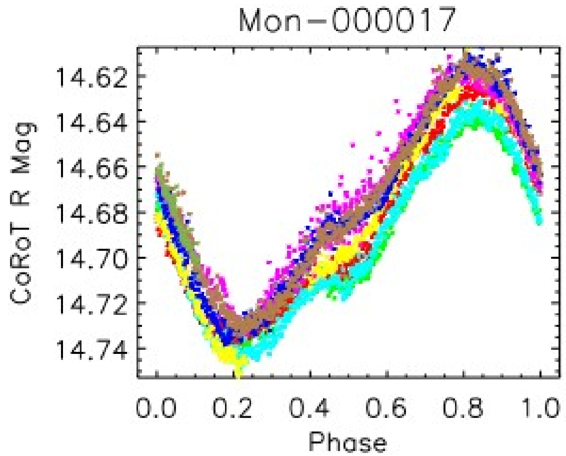
Spotted light curves (~15%)

Sousa et al. (2015)

CoRoT light curve

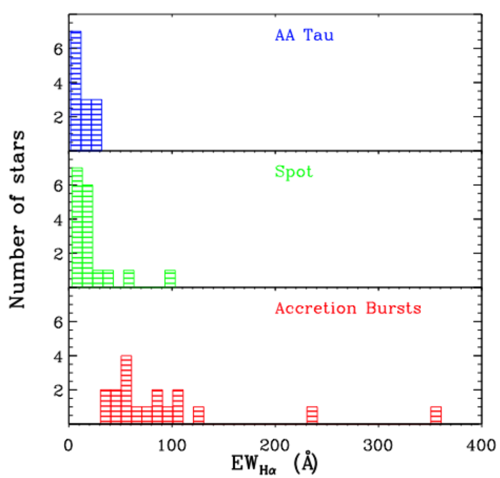


CoRoT light curve

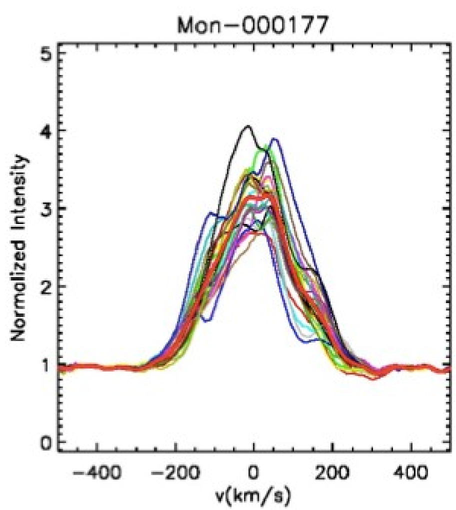


- Hot spots
- Stable light curves
- Typical periods of 3 to 10 days
- Moderate accretors
- Symmetric $H\alpha$ profiles
- Can change from periodic to aperiodic in 3 years

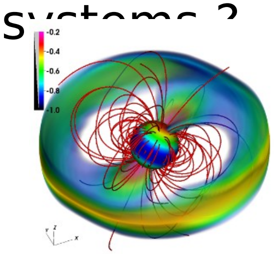
$H\alpha$ EW



$H\alpha$ profile



Stable funnel flows: low/moderate inclination counterparts of AA Tau systems ?

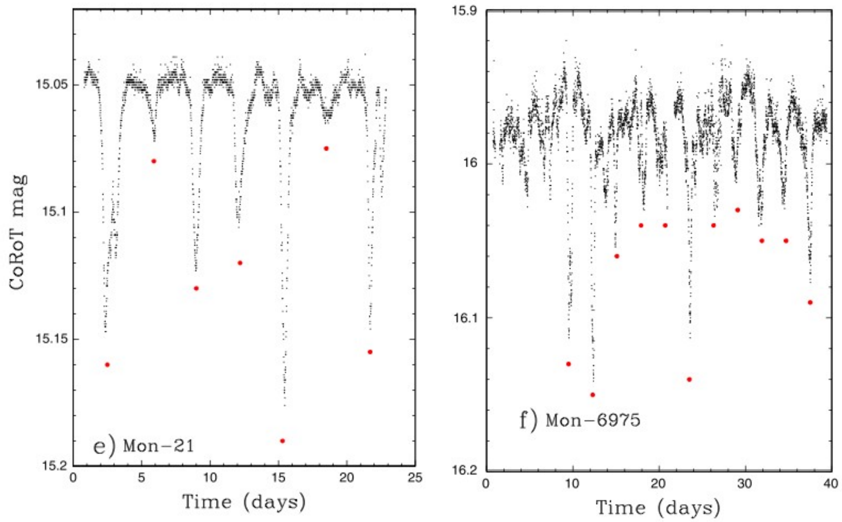


Kurosawa et al. (2013)

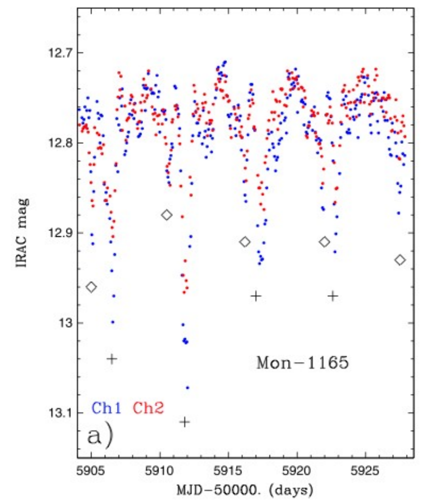
Short duration periodic dippers (~5%)

Stauffer et al. (2015)

CoRoT light curves

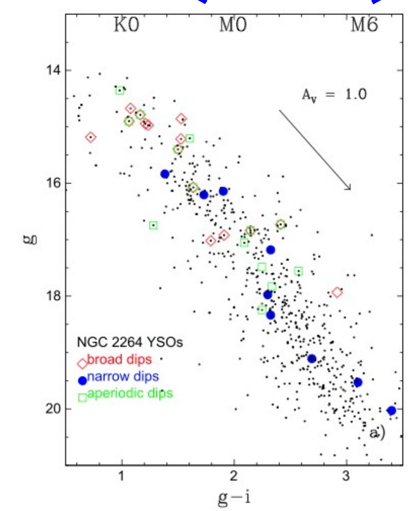


Spitzer



AA Tau's

Narrow dips

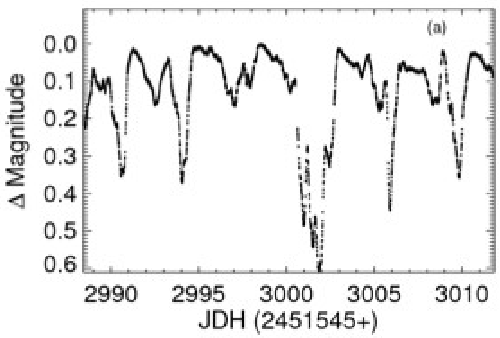


- Short duration (< 1 day) periodic dips (p=3 to 10 days)
- Low amplitude (< 15%)
- Clumps of dust close to co-rotation
- Moderate accretors
- Later SpT than AA Tau's on average

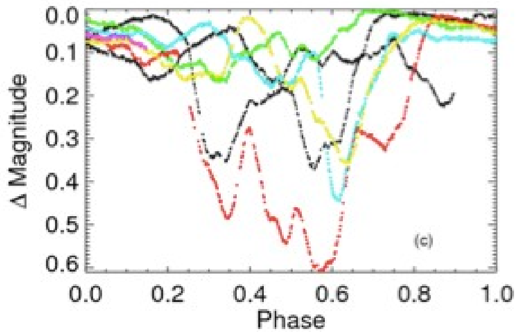
AA Tau light curves (~15%) + 10% aperiodic

McGinnis et al. (2015), Sousa et al. (2015)

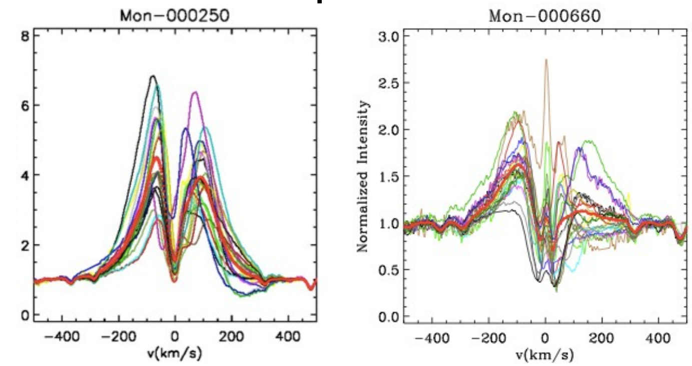
CoRoT light curve

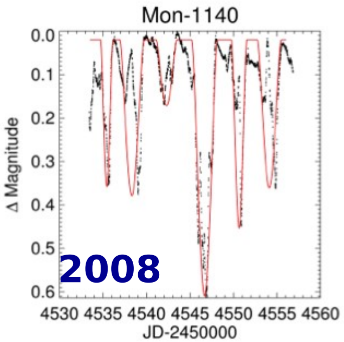


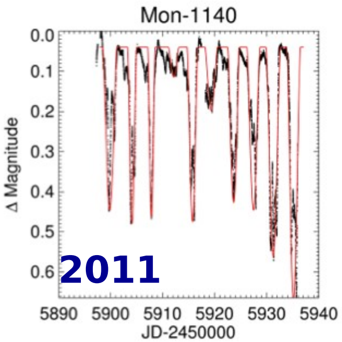
CoRoT light curve

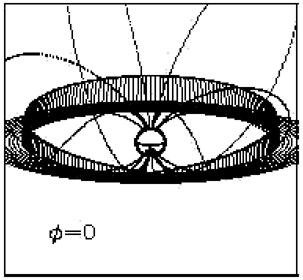


Hα profiles









Occultation models
i=75o ± 2o
2008: h/R= 0.16-0.24
2011: h/R= 0.14-0.24

- High inclination systems
- Periodic broad dips, with periods of 3 to 10 days
- Moderate accretors
- Hα profiles present redshifted and blueshifted absorptions
- Half of the AA Tau's changed from periodic to aperiodic in a timescale of 3 years

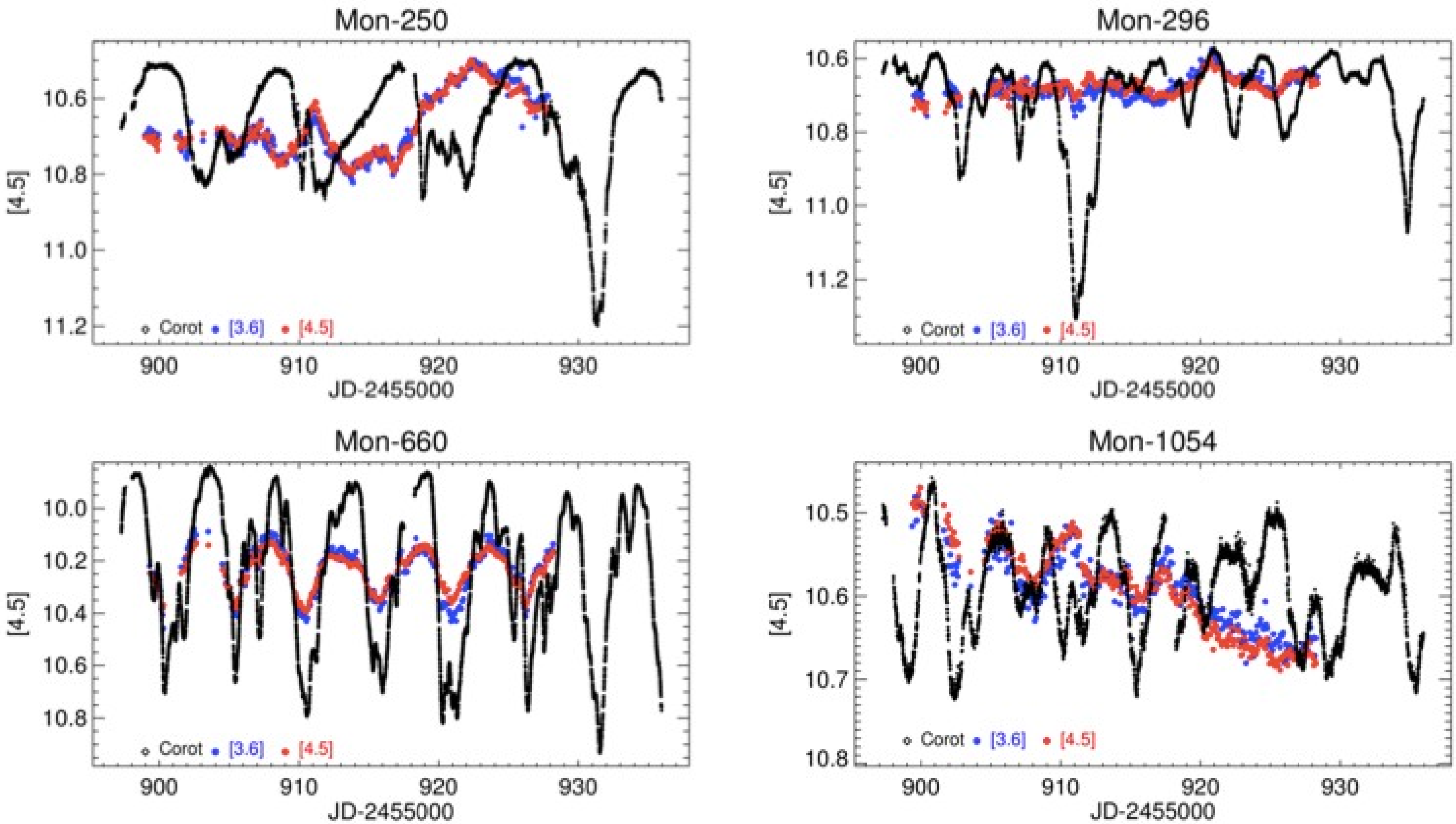
Optical and IR light curves of AA Tau's

McGinnis et al. (2015)

CoRoT

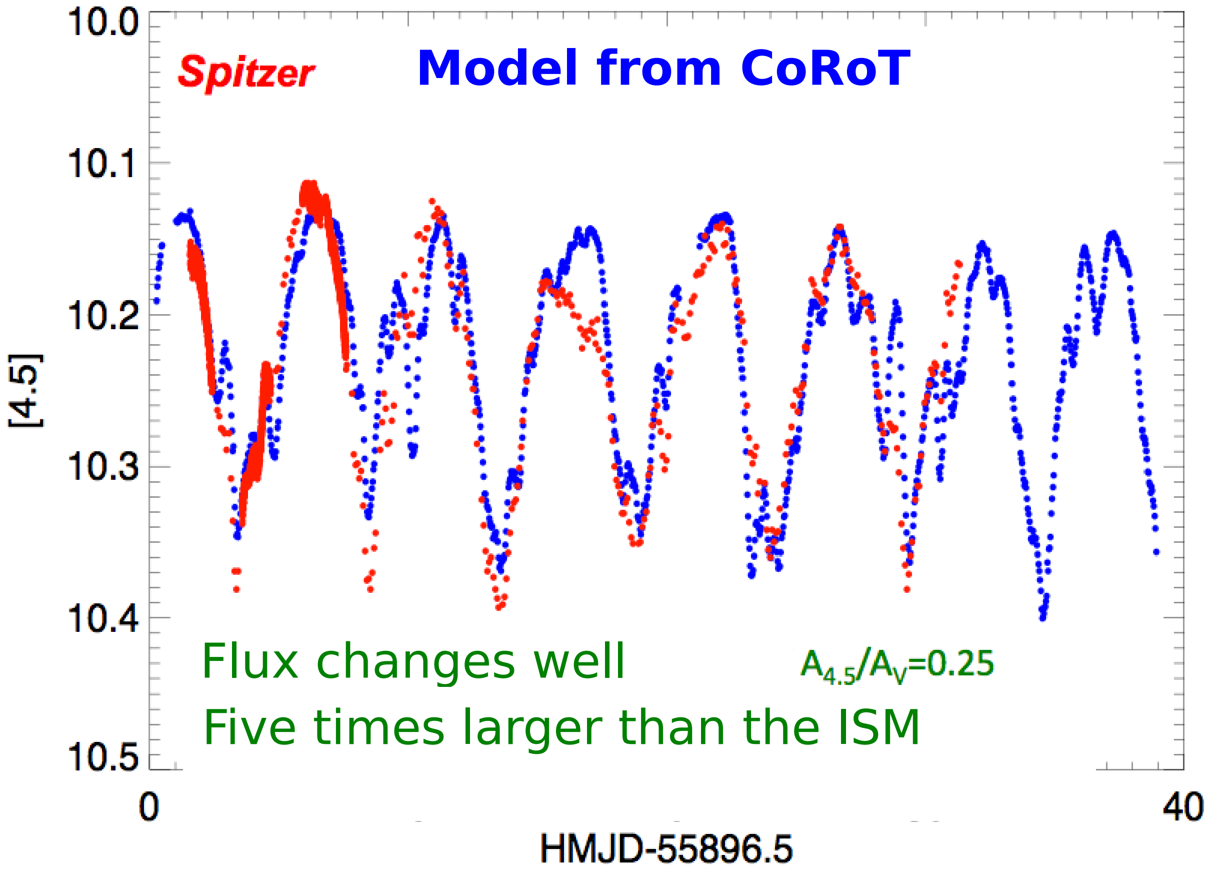
3.6 μm

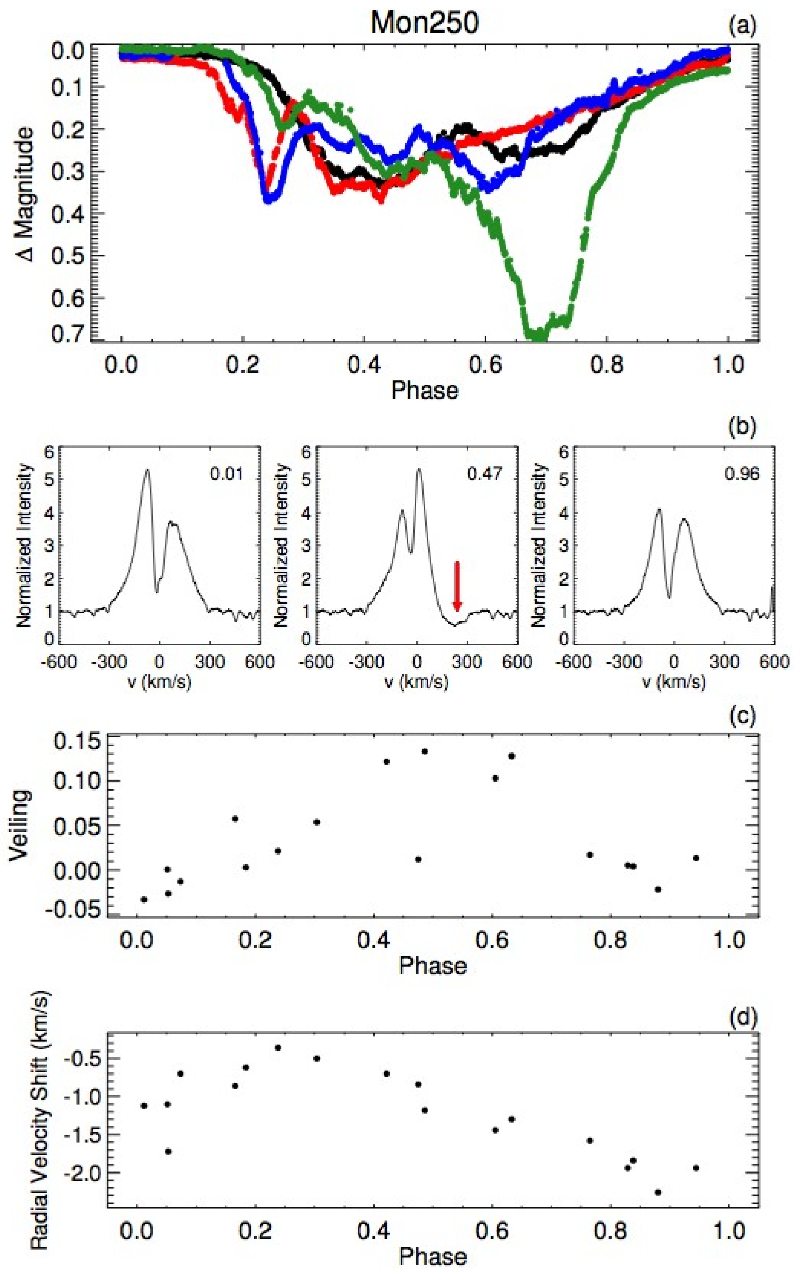
4.5 μm



Mon-660

Fonseca et al. (2014), McGinnis et al. (2015)





Mon 250

McGinnis et al. (2015)

Periodical eclipses
Inner disk warp
p=8.93 ± 0.50 days

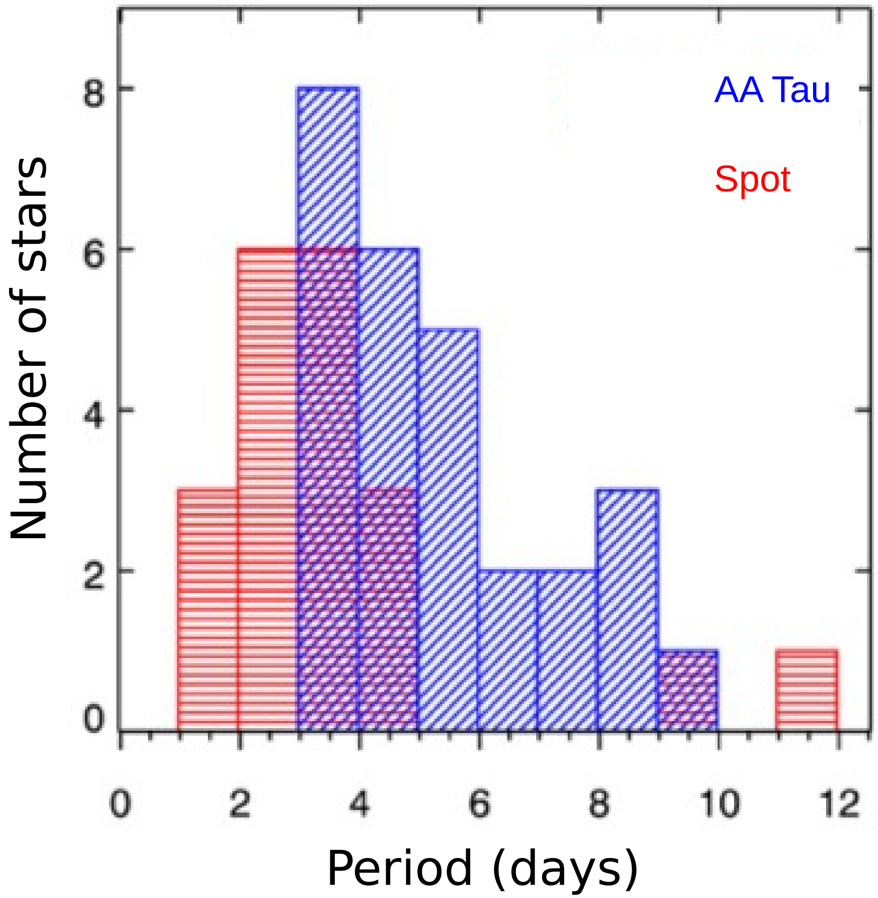
Balmer lines
Accretion column
p=8.9 ± 0.6 days

Veiling
Hot spot

Photospheric lines vrad
Cold spot
p=8.6 ± 0.5 days - stellar rotation per

Period distribution of CTTSs

McGinnis et al. (2015)



Similar periods between spot and AA Tau-like.

The occulting material must be close to the co-rotation radius.

Conclusions – magnetic fields of CTTSs

- Low mass stars have complex large scale magnetic fields that are strong enough to truncate the inner accretion disk.

- The magnetic fields of young low mass stars are not fossil. They are continously generated by a stellar dynamo.

- The large scale magnetic field topology seems to depend mostly on the internal structure of the star.

- Star-disk interaction is related to the dipolar component of the stellar magnetic field.

onclusions – synoptic studies of CTTSs

- Light curves may reveal the physics of the accretion process
- Suggest different accretion/ejection regimes in CTTSs
- Optical and IR variability are not always correlated

Accretion dominated (~70%): Burst, stochastic and hot spots light curves

Extinction dominated (~30%): AA Tau, dipper light curves

~30% periodic; ~70% aperiodic
Stable vs. unstable accretion onto the star?

Correlation between the type of variability with mass accretion rate
High accretion rates leads to unstable accretion ?

About 30% of the CTTSs moved from periodic/aperiodic in a timescale of 3 years
Magnetic field and/or mass accretion rate variability ?

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