Disk-star interaction: stellar magnetosphere and accretion

(and angular momentum evolution, disk lifetimes, and planet formation)

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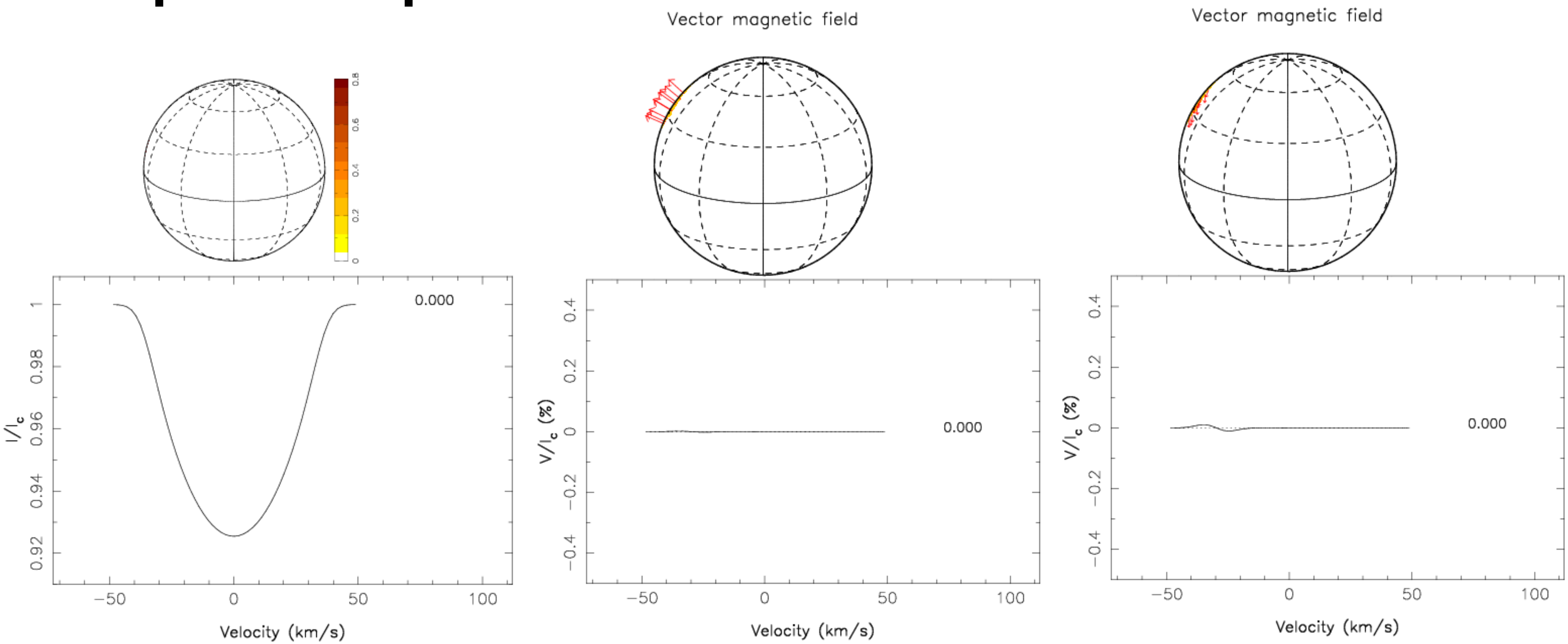
Outline

- Magnetic fields in young stars
- Magnetospheric star-disk interaction
- Angular momentum evolution, disc lifetimes and planet formation

Magnetic fields in young stars

Zeeman-Doppler imaging from spectropolarimetric measurements



Radial B field

Azimuthal B field

Unpolarized line profile :
brightness map
(Doppler imaging)

Circularly polarized line profile :
magnetic map : intensity + topology
(Zeeman-Doppler imaging)

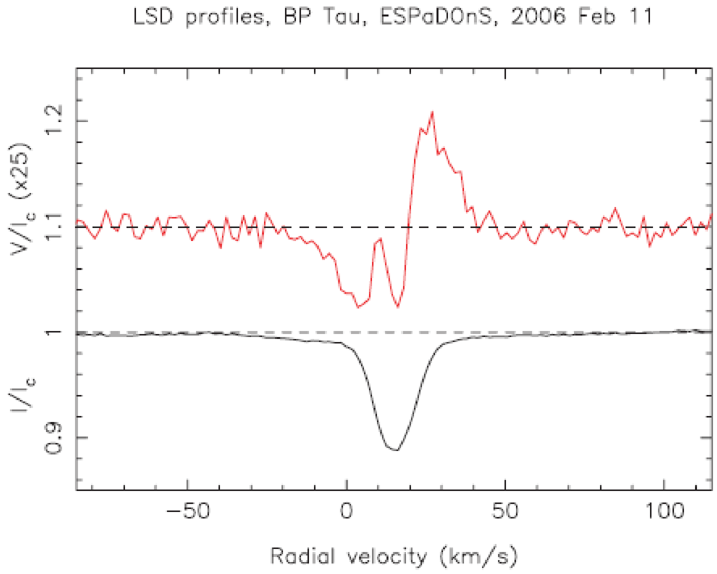
Donati et al. 1997

ZDI : BP Tau and V2129 Oph

- ZDI analysis of 2 accreting T Tauri stars

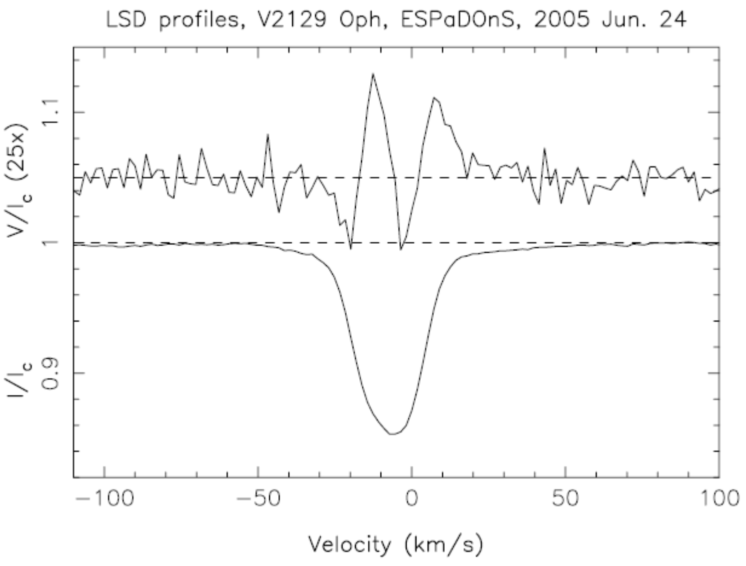
BP Tau (1.5 Myr)

$M=0.7M_o$; M_{acc}~$3.10^{-8}M_o/yr$



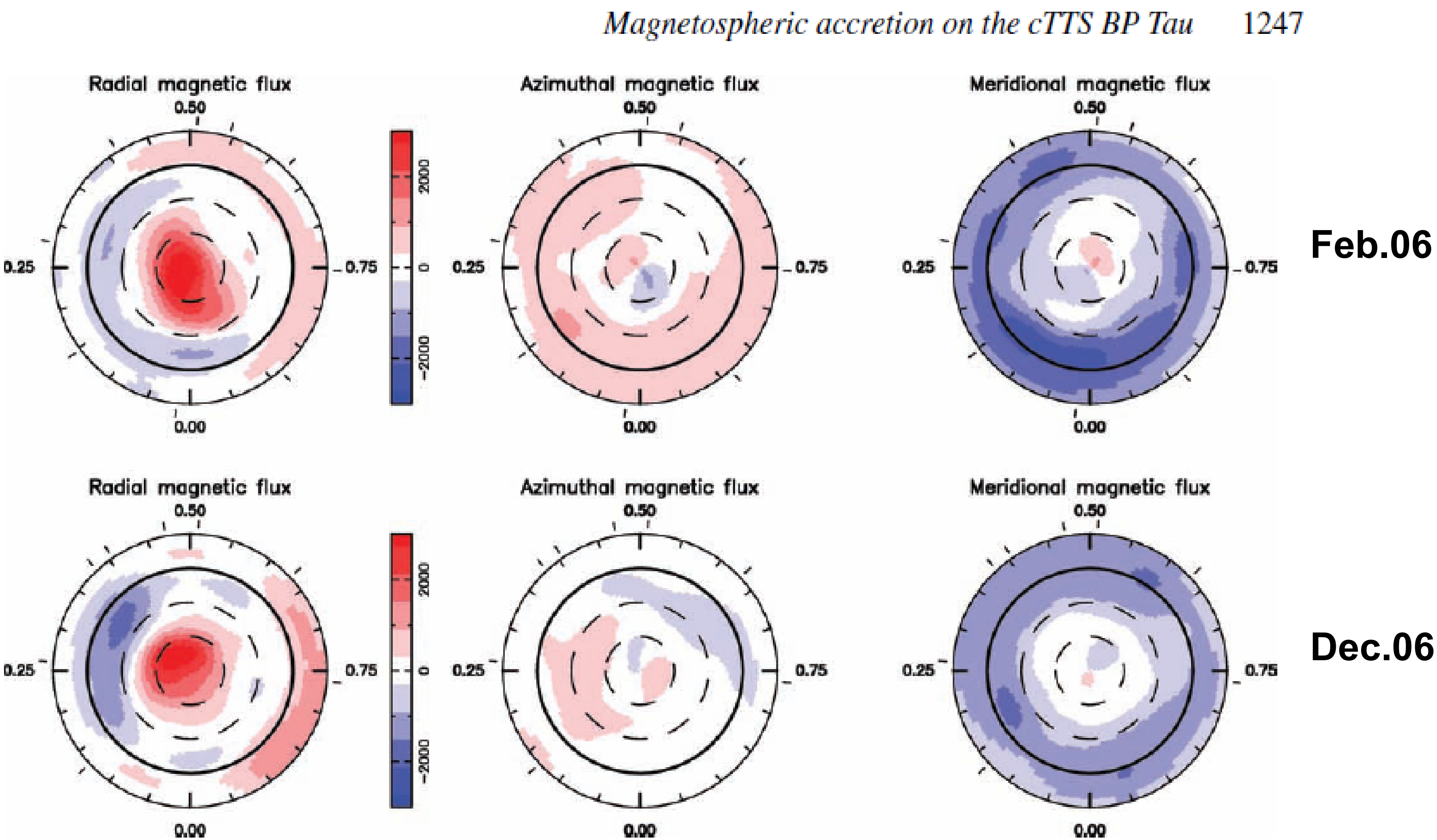
V2129 Oph (2 Myr)

$M=1.35M_o$; M_{acc}~$10^{-8}M_o/yr$



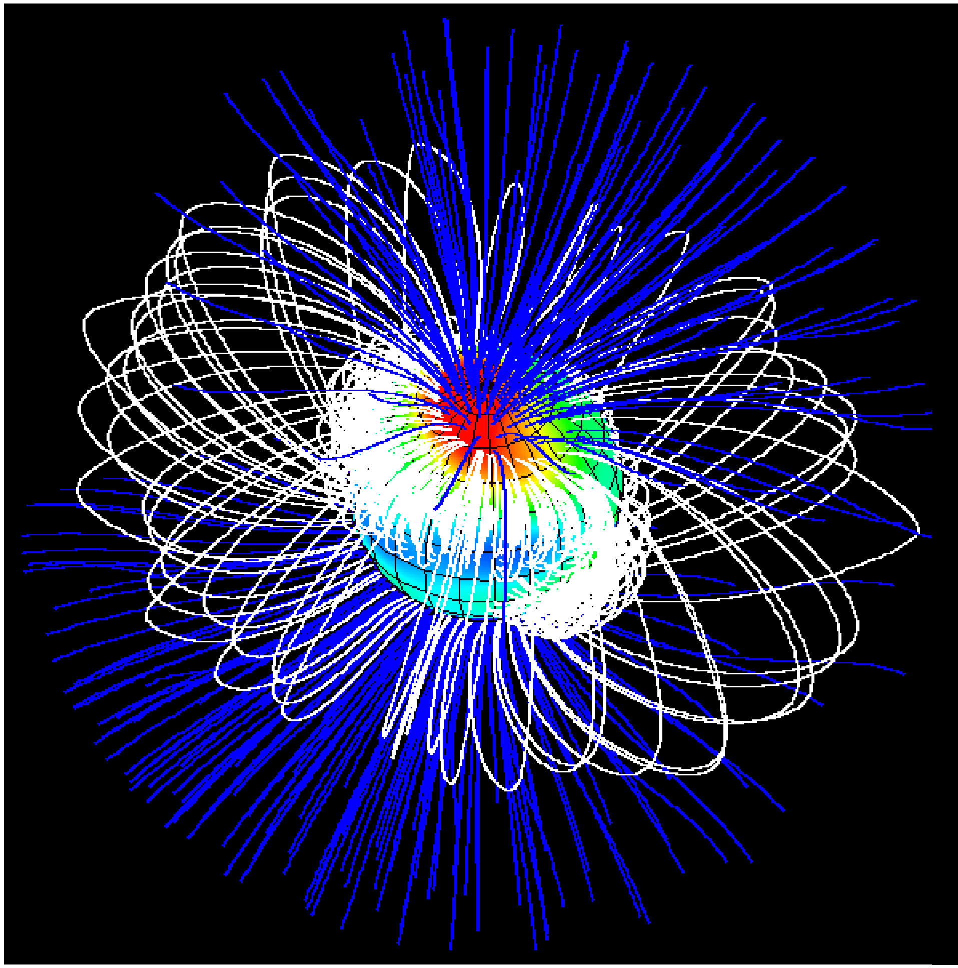
Donati et al. 2007, 2008

Surface magnetic map of BP Tau

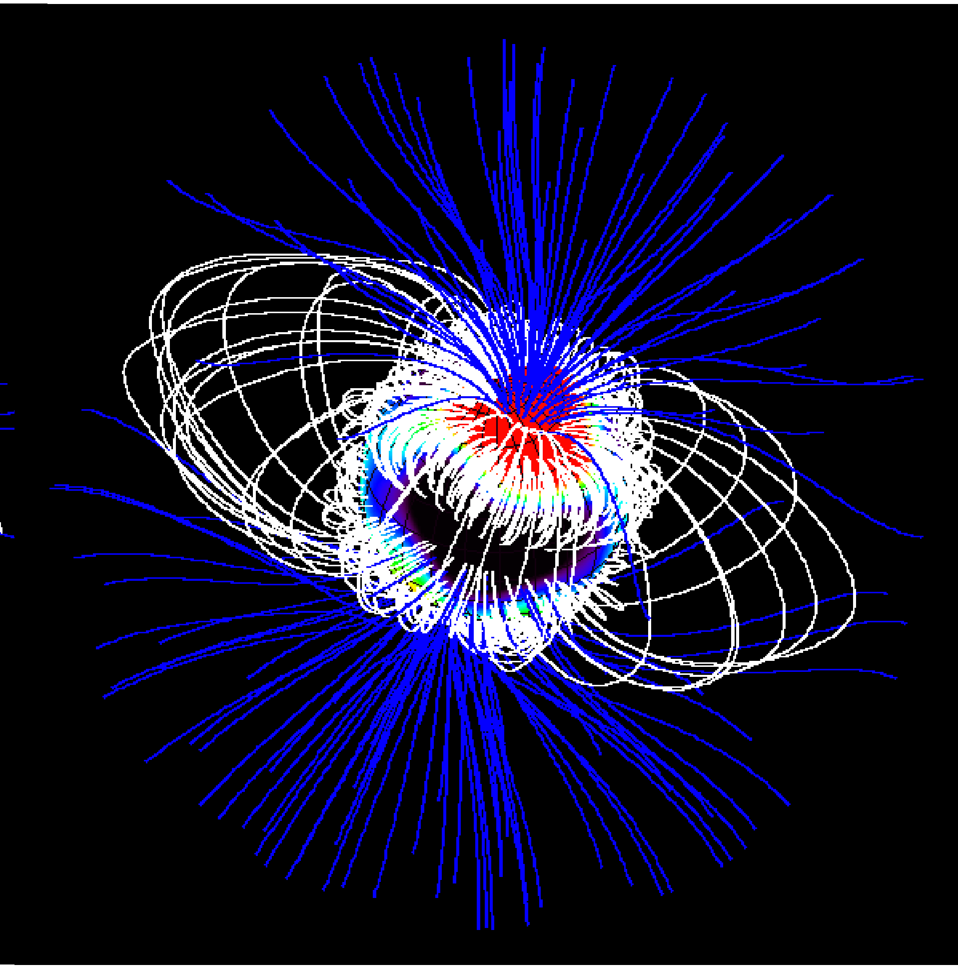


Donati et al. 2008

Magnetic structure of CTTS



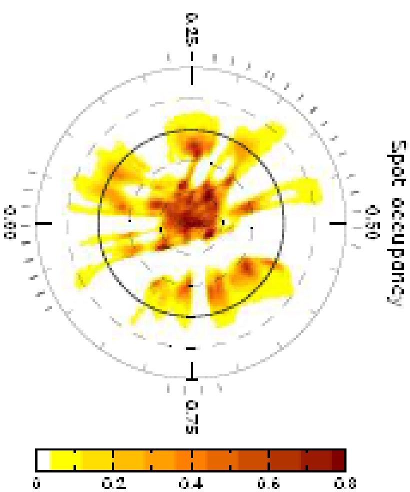
BP Tau (Donati et al. 2008; Gregory et al. 2008)



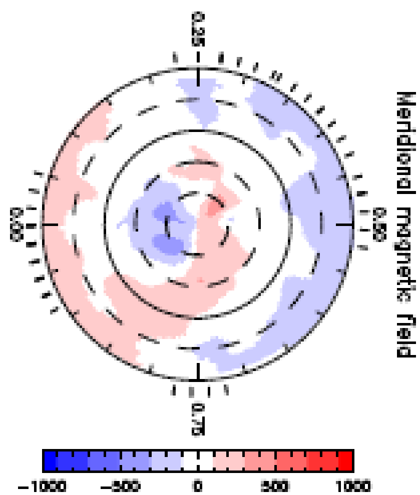
V2129 Oph (Donati et al. 2007; Jardine et al. 2008)

CTTS magnetic fields are strong, complex, and time variable !

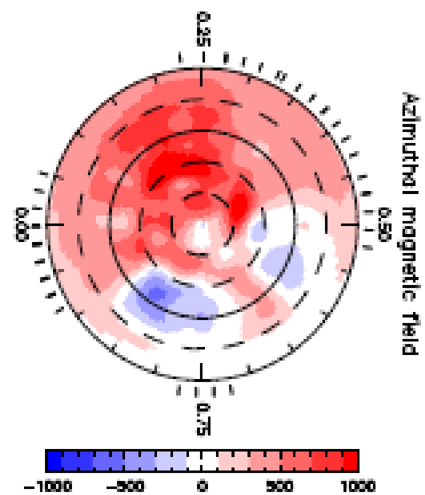
- **BP Tau:** 1.2 kG dipole + 1.6 kG octupole
- **V2129 Oph:** 0.35 kG dipole + 1.2 kG octupole
- **CV Cha, CR Cha:** ~ 400-600G **(Hussain et al. 2009)**
- **V410 Tau:** ~ 500G **(Skelly et al. 2009)**



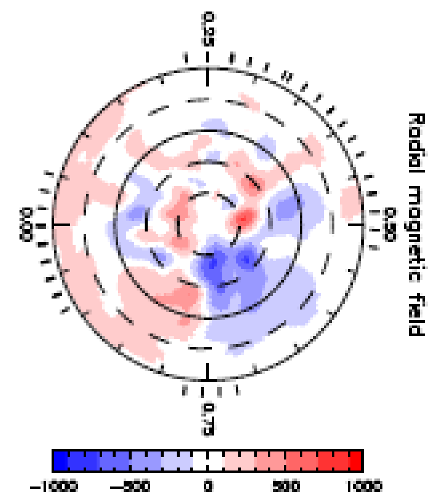
Surface spots



B_Meridional



B_Azimuthal



B_Radial

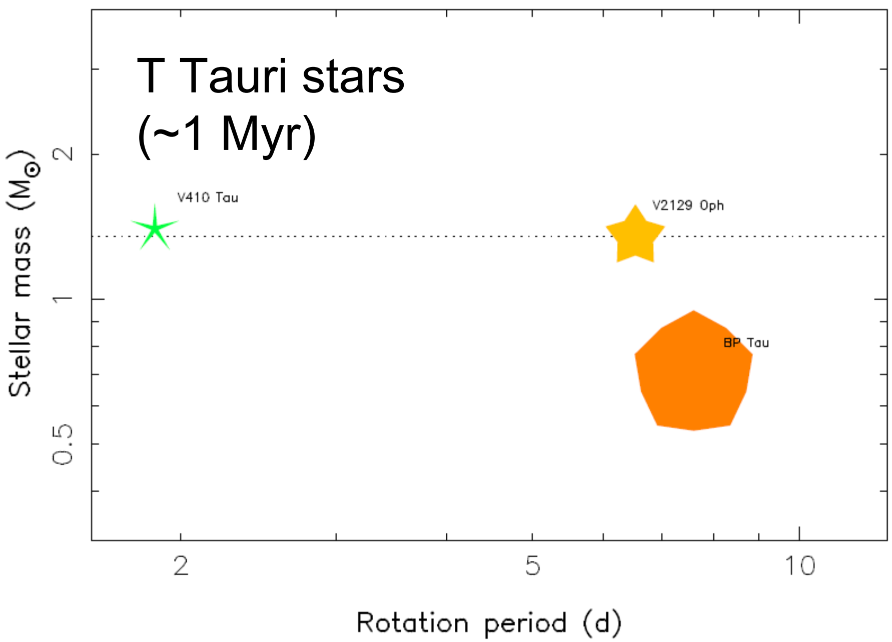
Magnetic field origin

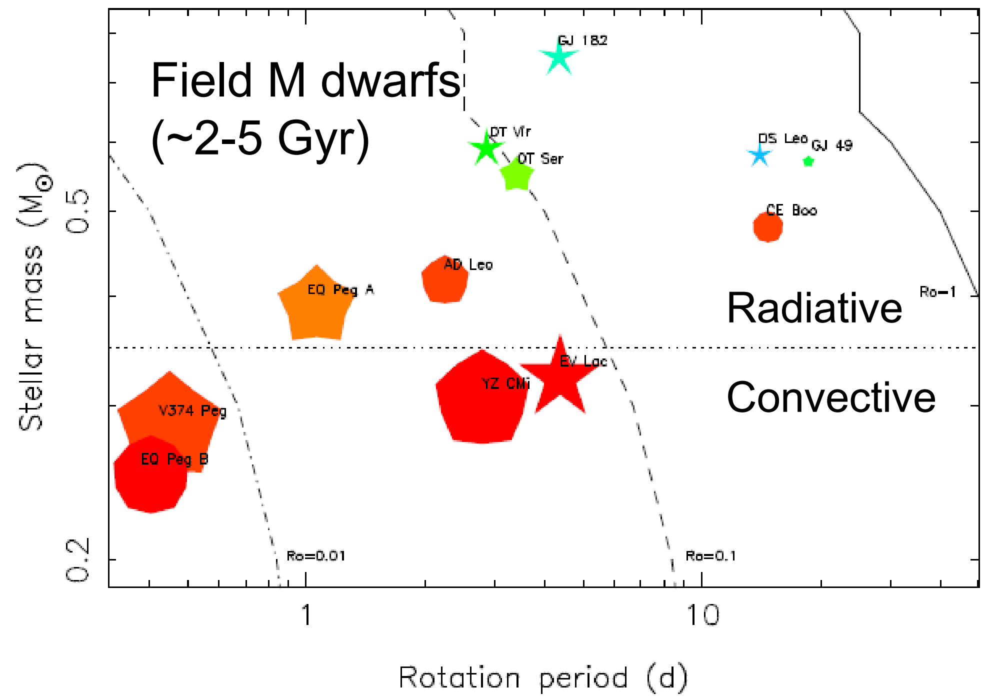
The topology of the magnetic field varies across the convective / radiative boundary, with more axisymmetric fields in completely convective stars.

The magnetic field is stronger in fully convective stars

Donati et al. 2008

Skelly et al. 2009





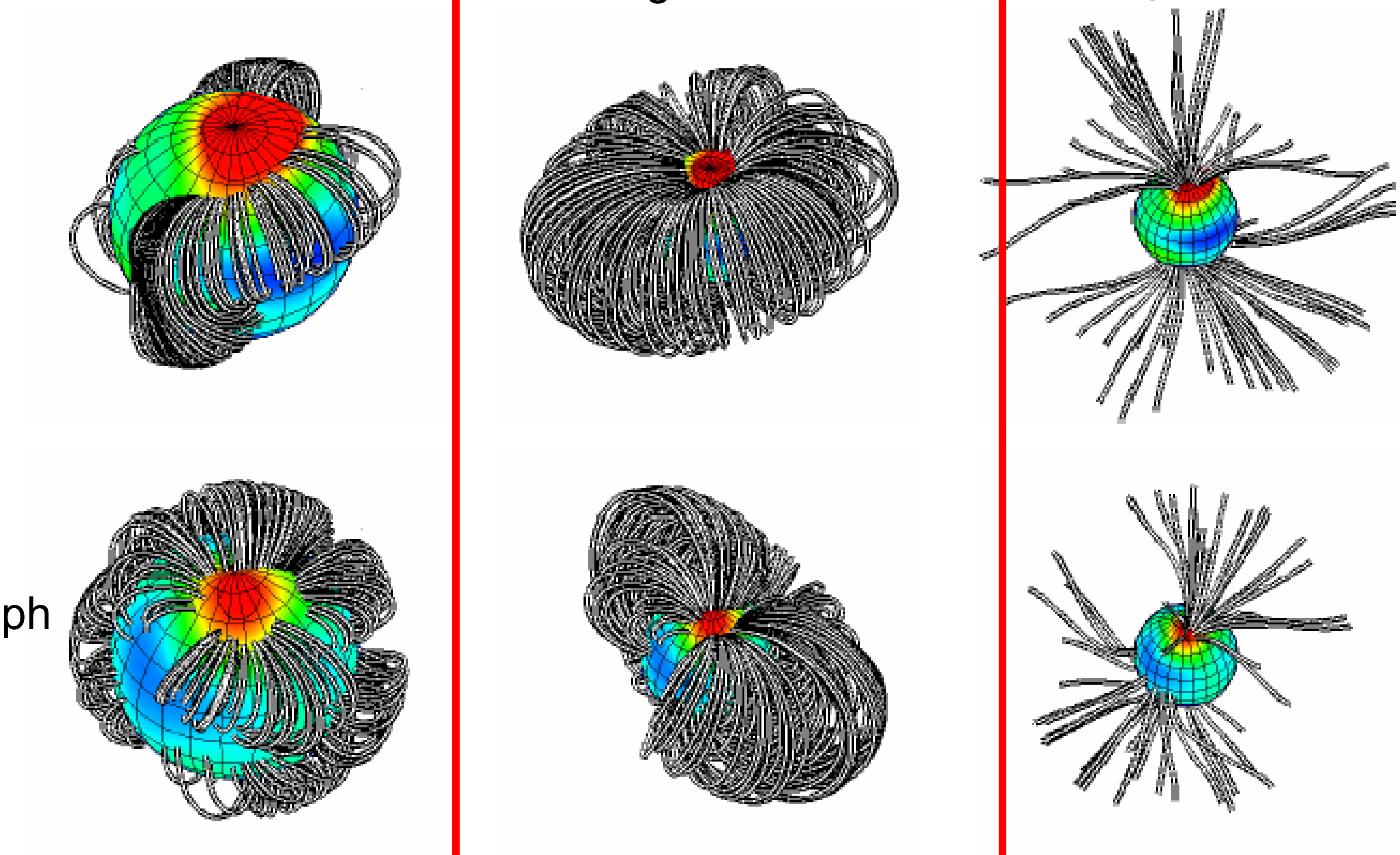
CTTS magnetic field structure

Gregory et al. 2008

Surface field | Large scale field | Open field

BP Tau

V2129 Oph



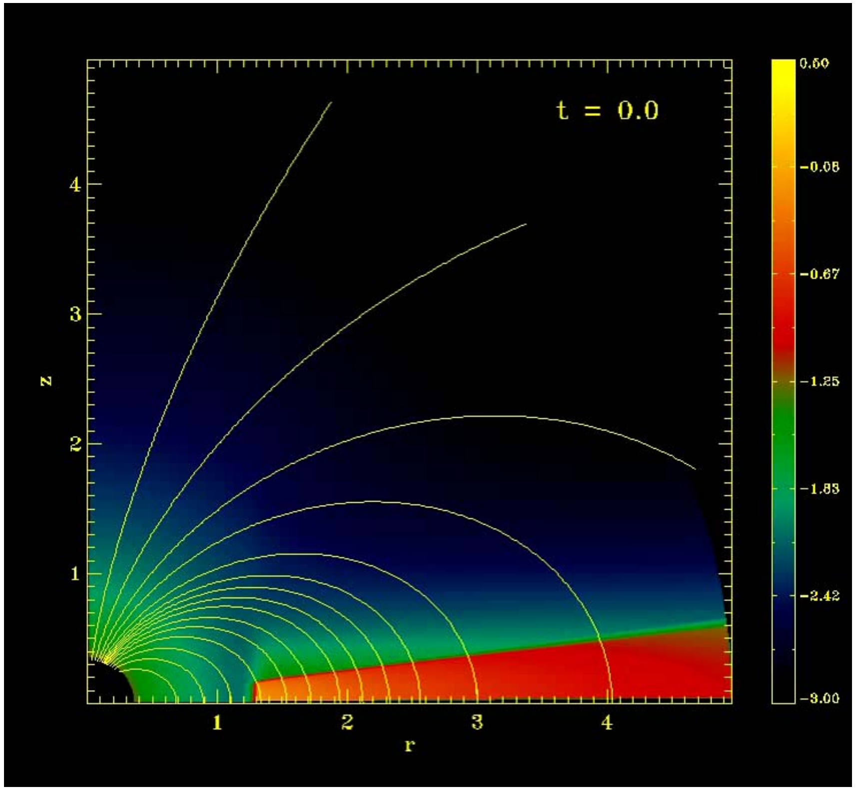
X-rays | **Disc interaction** | **Wind?**

Magnetospheric star-disc interaction in young stars

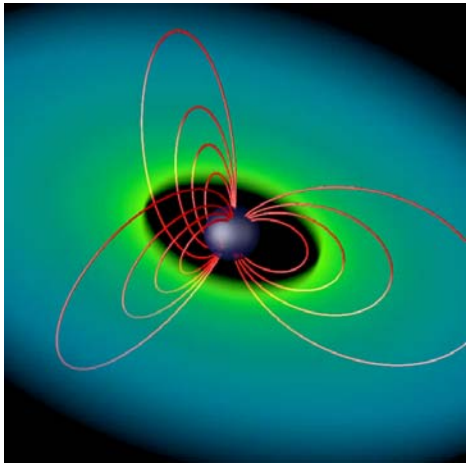
Star-disk magnetic coupling

2D MHD simulation of disk accretion onto an aligned dipole

Zanni et al. 2009



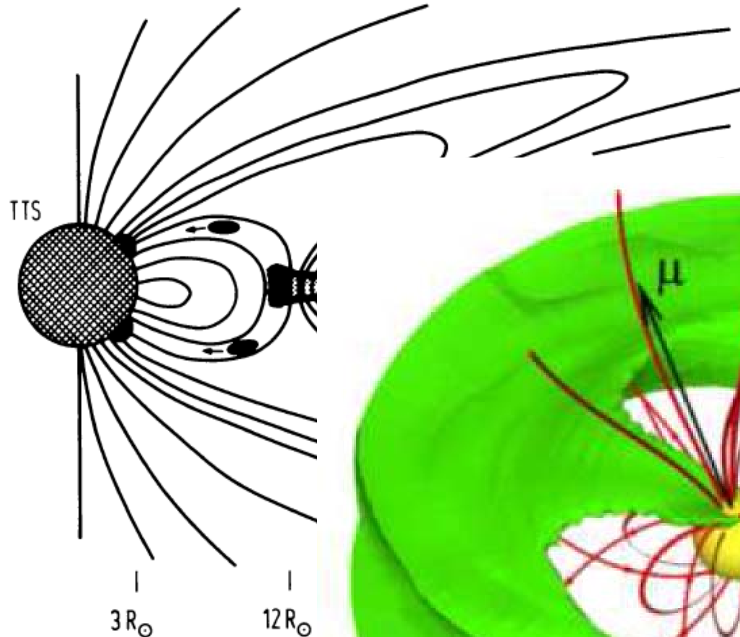
(.mpg)



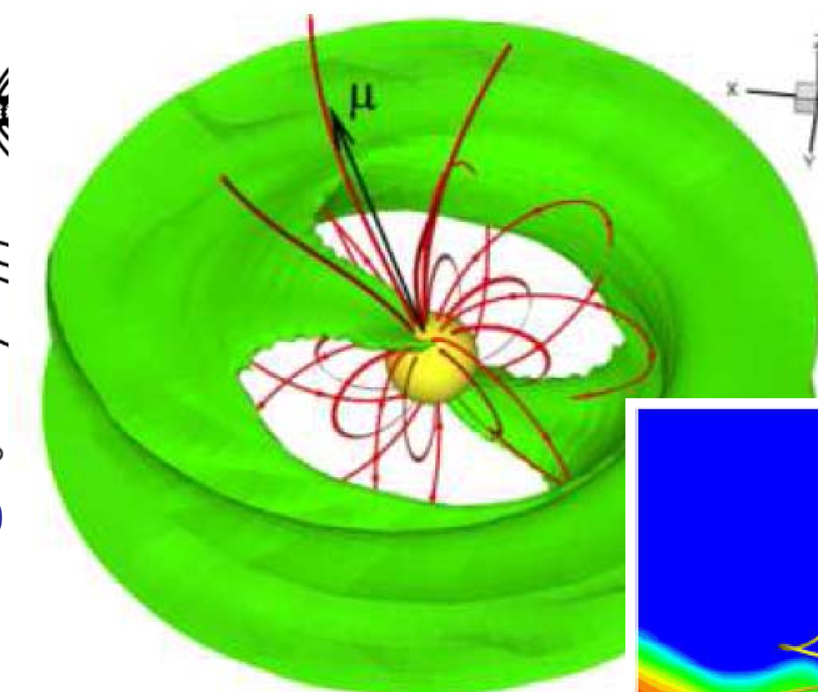
$M_{star} = 0.8M_o$; $R_{star}=2R_o$

$B_{dipole} = 800$ G; $dM_{acc}/dt = 10^{-8}\ M_o/yr$

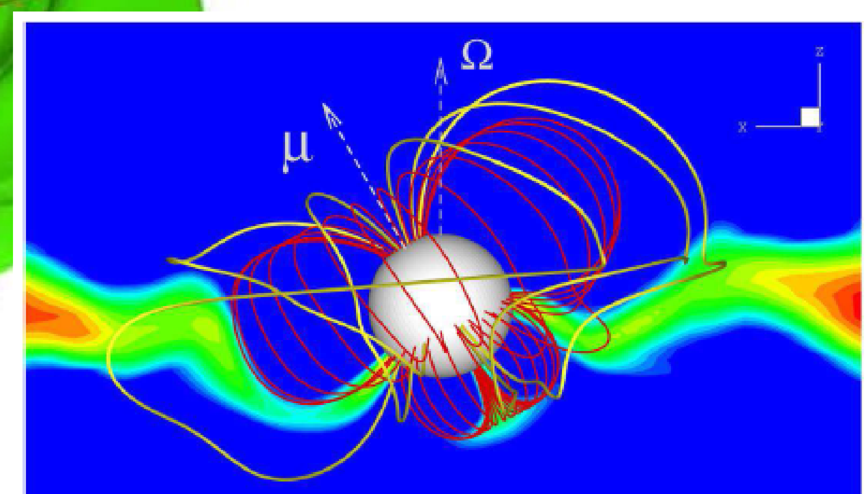
Magnetospheric accretion on complex magnetic fields



Camenzind 1990



Romanova et al. 2003

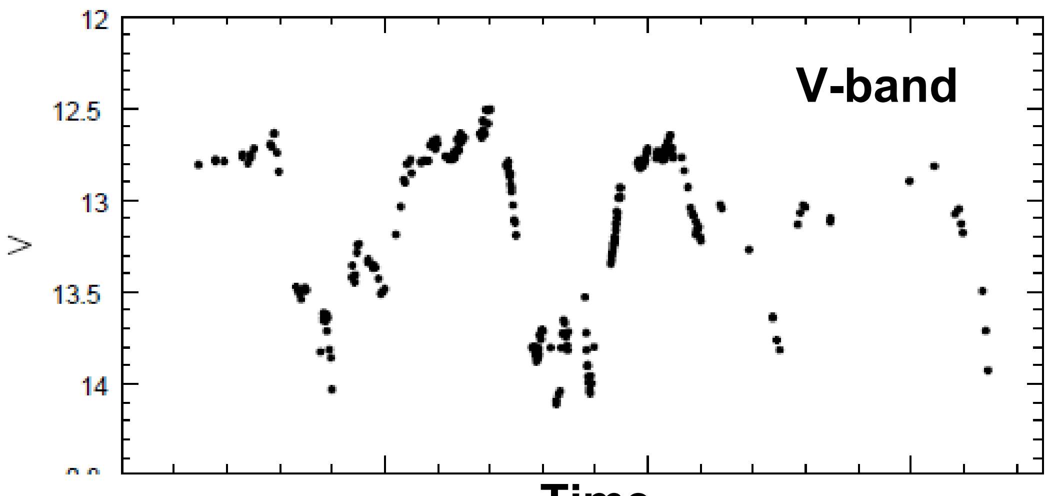


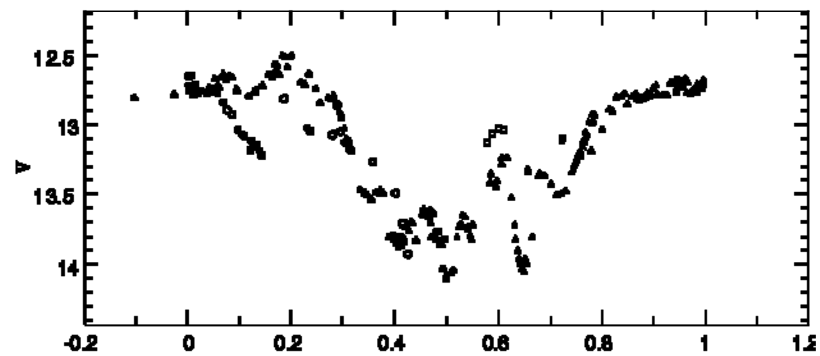
Long et al. 2007

Occultations by the inner disk warp
(AA Tau; P = 8.2 days)

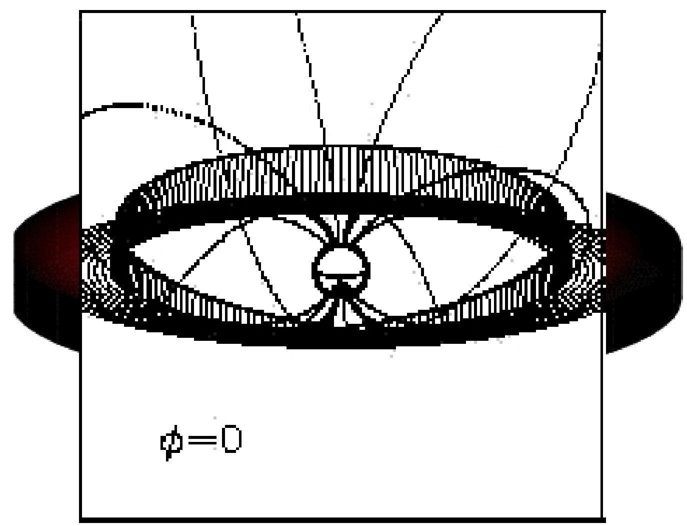
Bouvier et al. 2007

Recurrent luminosity dips





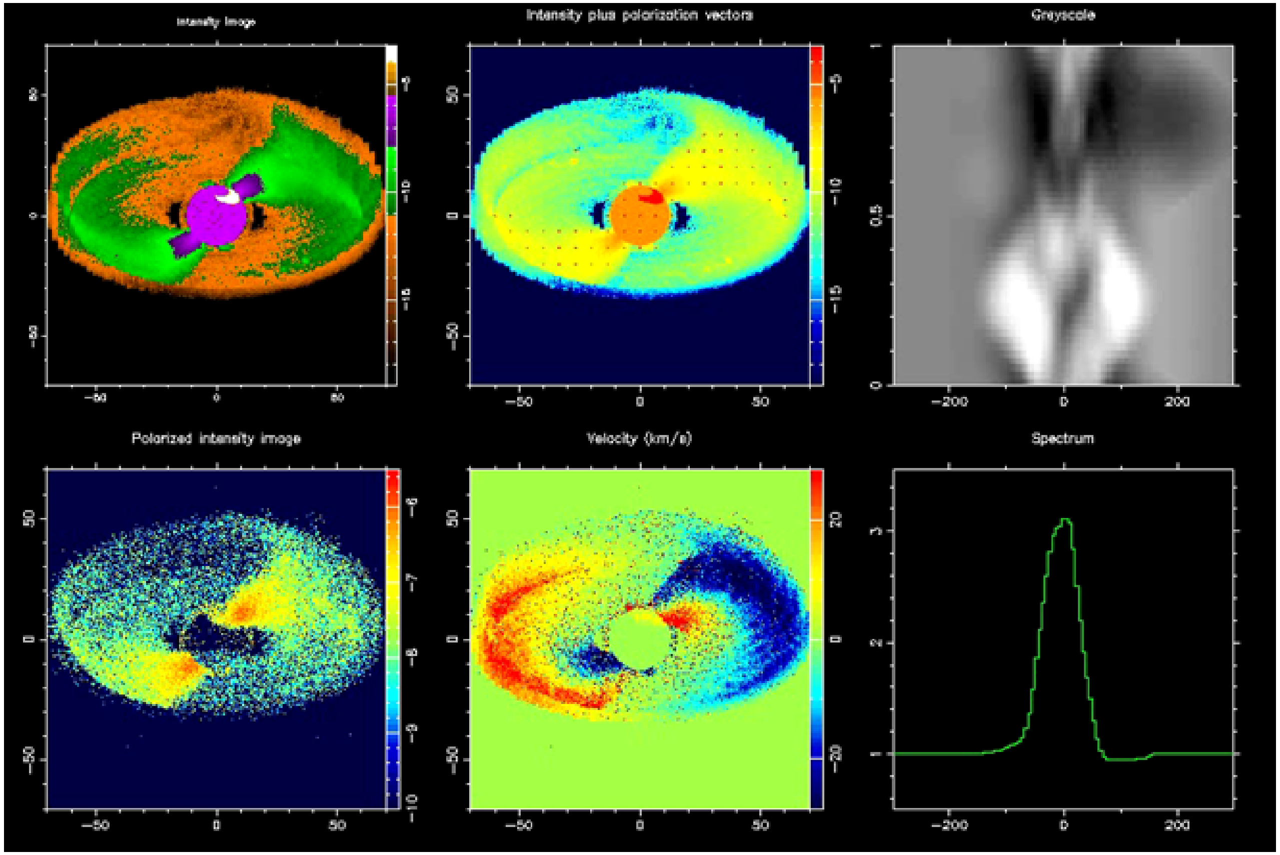
→ **Periodic occultations of the star by the rotating inner disk warp** **located at the co-rotation radius (8.8 R_{star})**

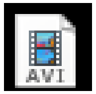


Line profile variability from inclined magnetospheres

Kurosawa, Romanova, Harries 2008

3D MHD simulations of accretion onto an inclined dipole
3D radiative transfer of rotationally-induced line variability (e.g. Paβ)

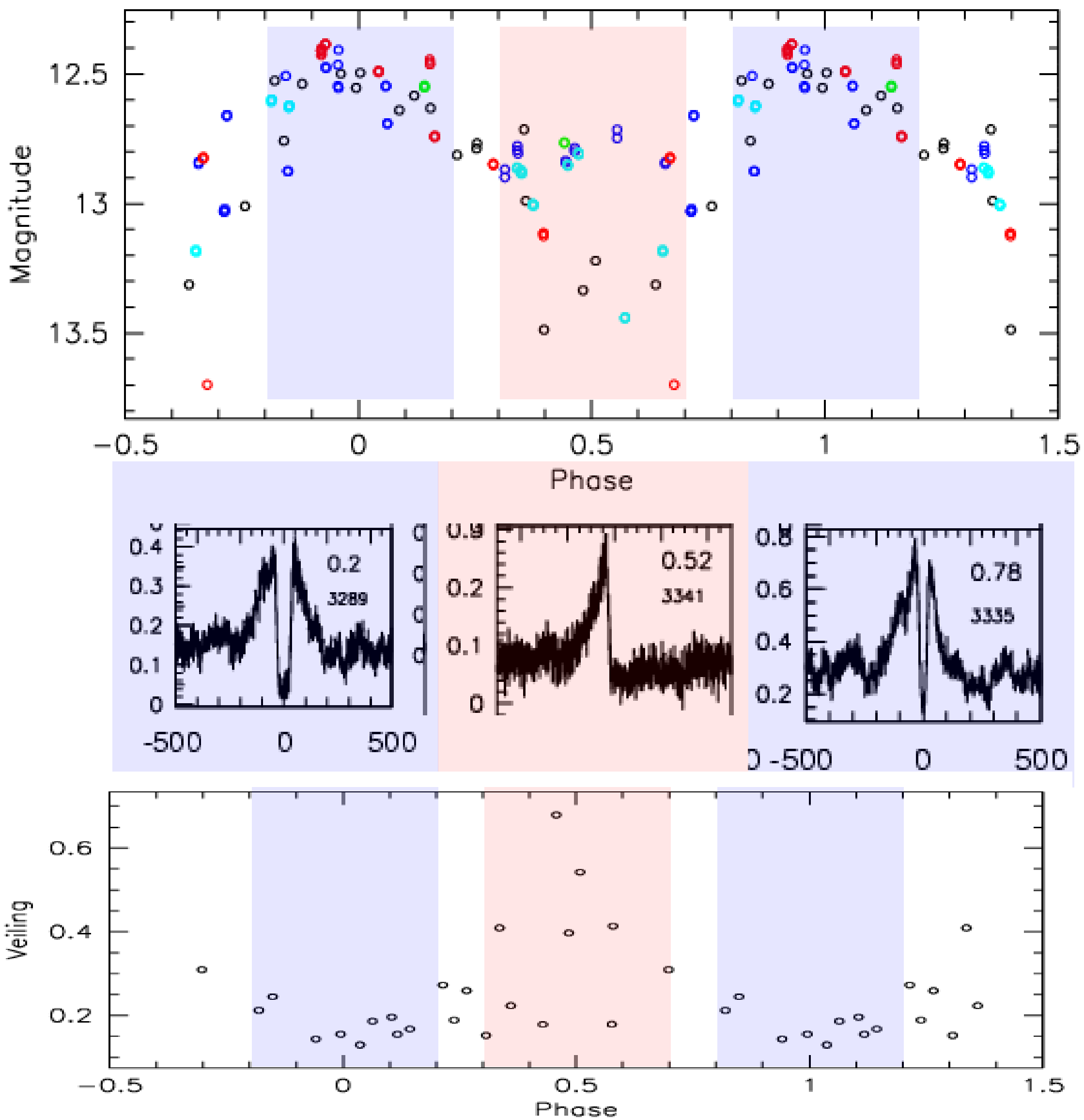




(.avi)

Inclined magnetospheres : AA Tau

Bouvier et al. 2007



Periodic eclipses

(disk warp)

(P=8.22d)

Balmer lines

(accretion funnel)

Veiling

(accretion shock)

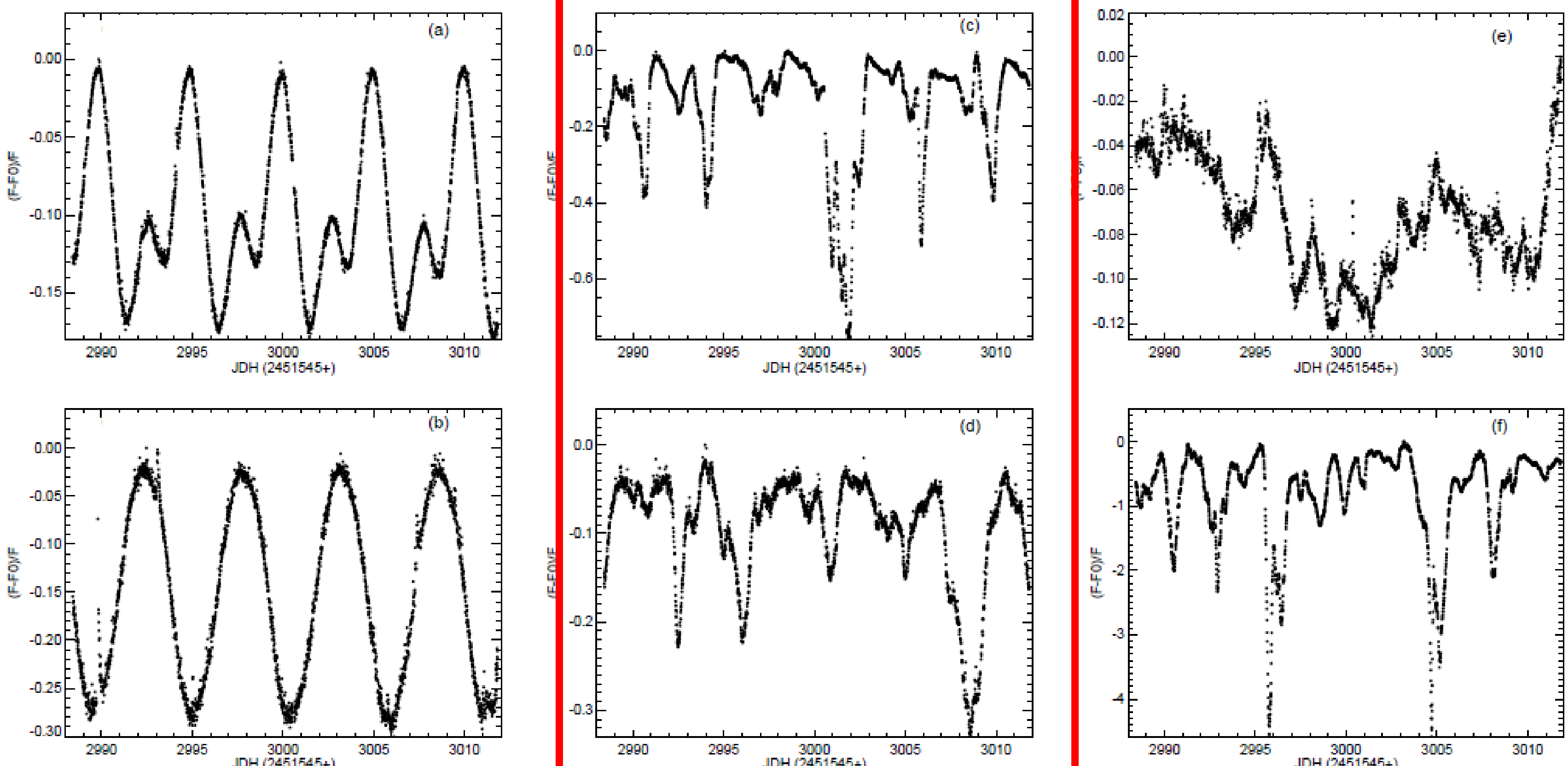
COROT light curves : NGC 2264

Alencar et al. 2009

Periodic; sinusoidal

Quasi-Periodic
AA Tau-like

Irregular



SPOTS

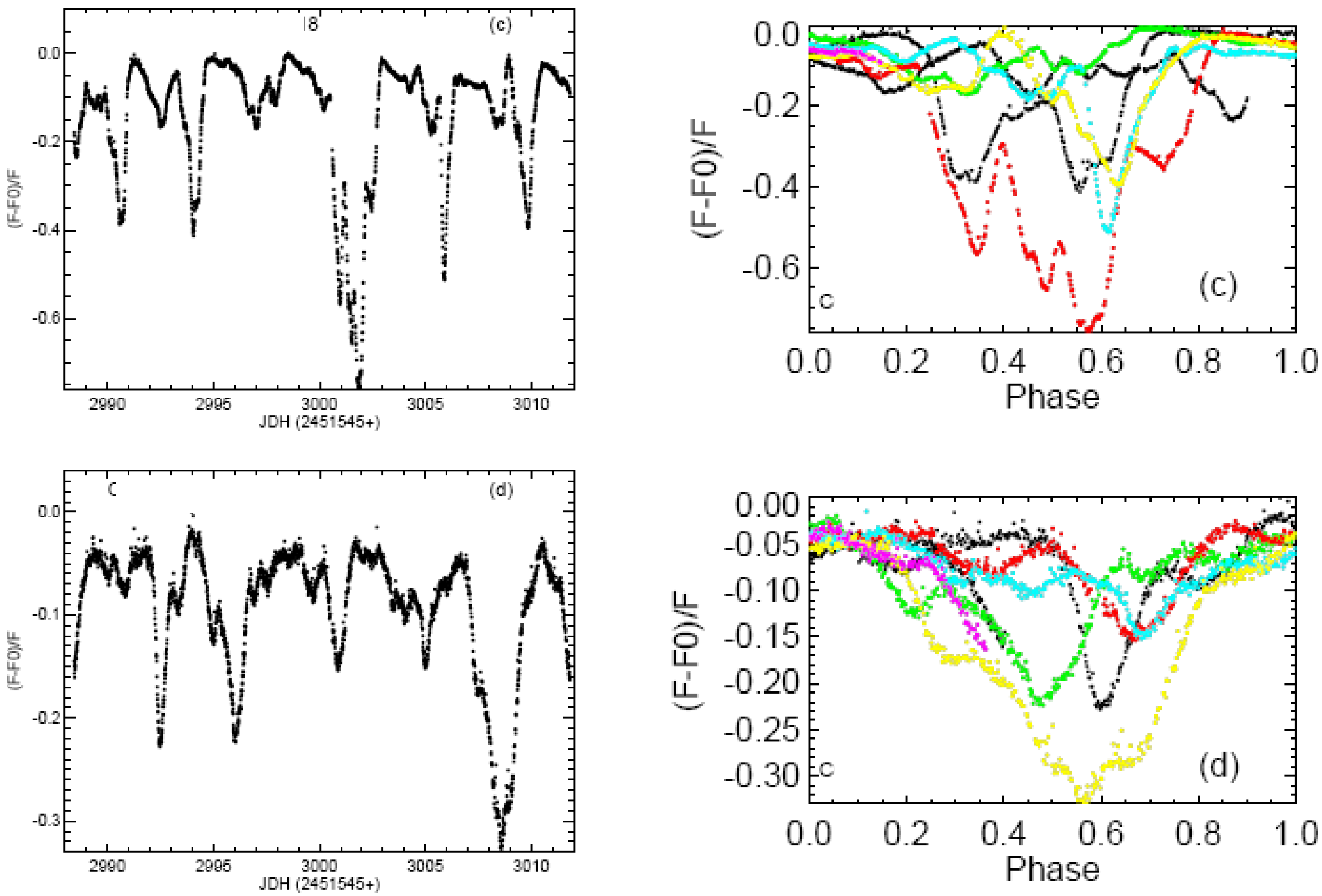
OBSCURATION

Accretion+obscuration?

AA Tau-like COROT light curves

Periods between 4 and 10 days

Alencar et al. 2009

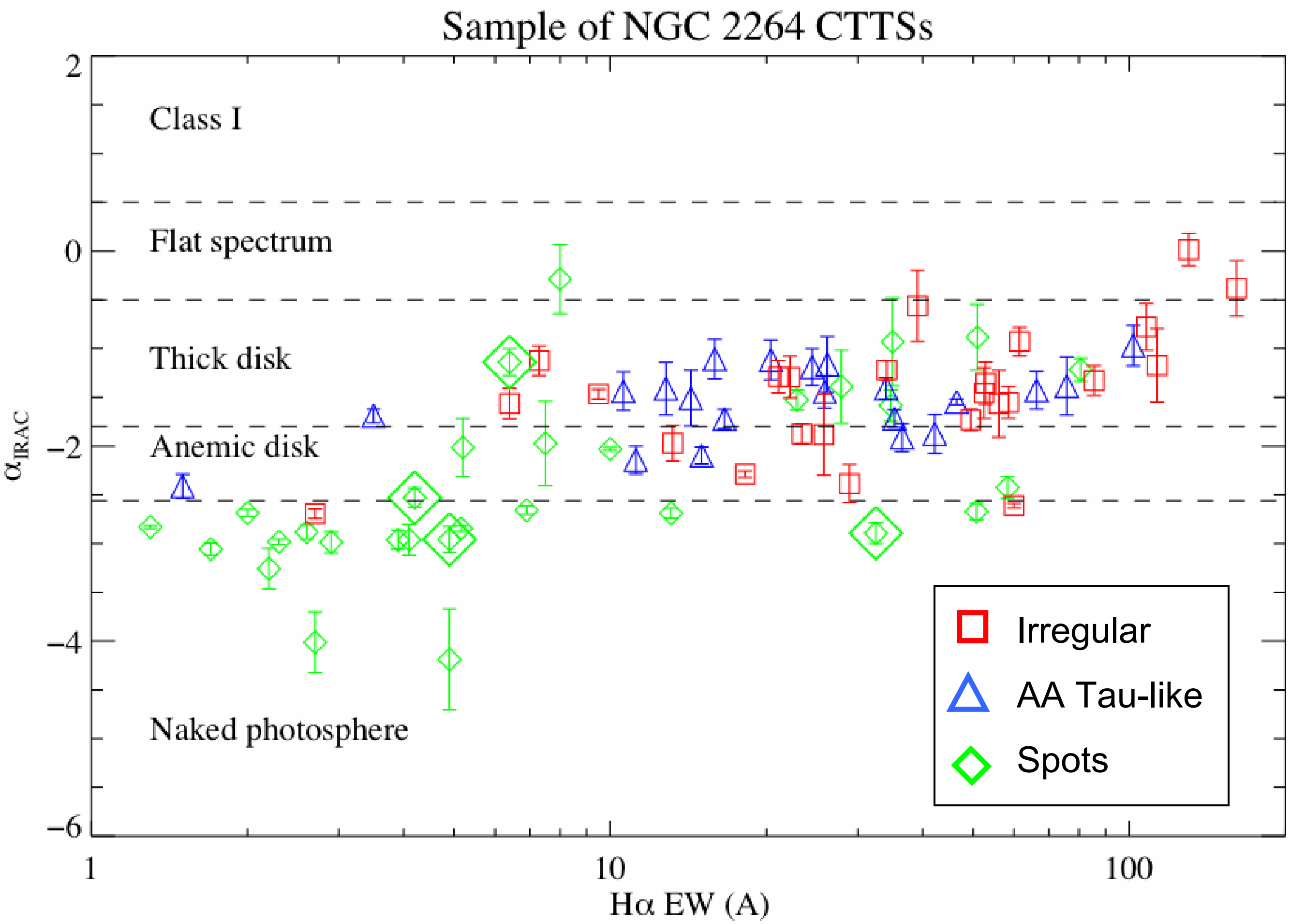


Rapid (~rotation cycle) and significant variations of the occulting material.

Corot light curves vs. disc evolution

Alencar et al. 2009

97 CTTS with IRAC [3.6-8]μm color



The Corot light curve morphology reflects the evolution of the disk

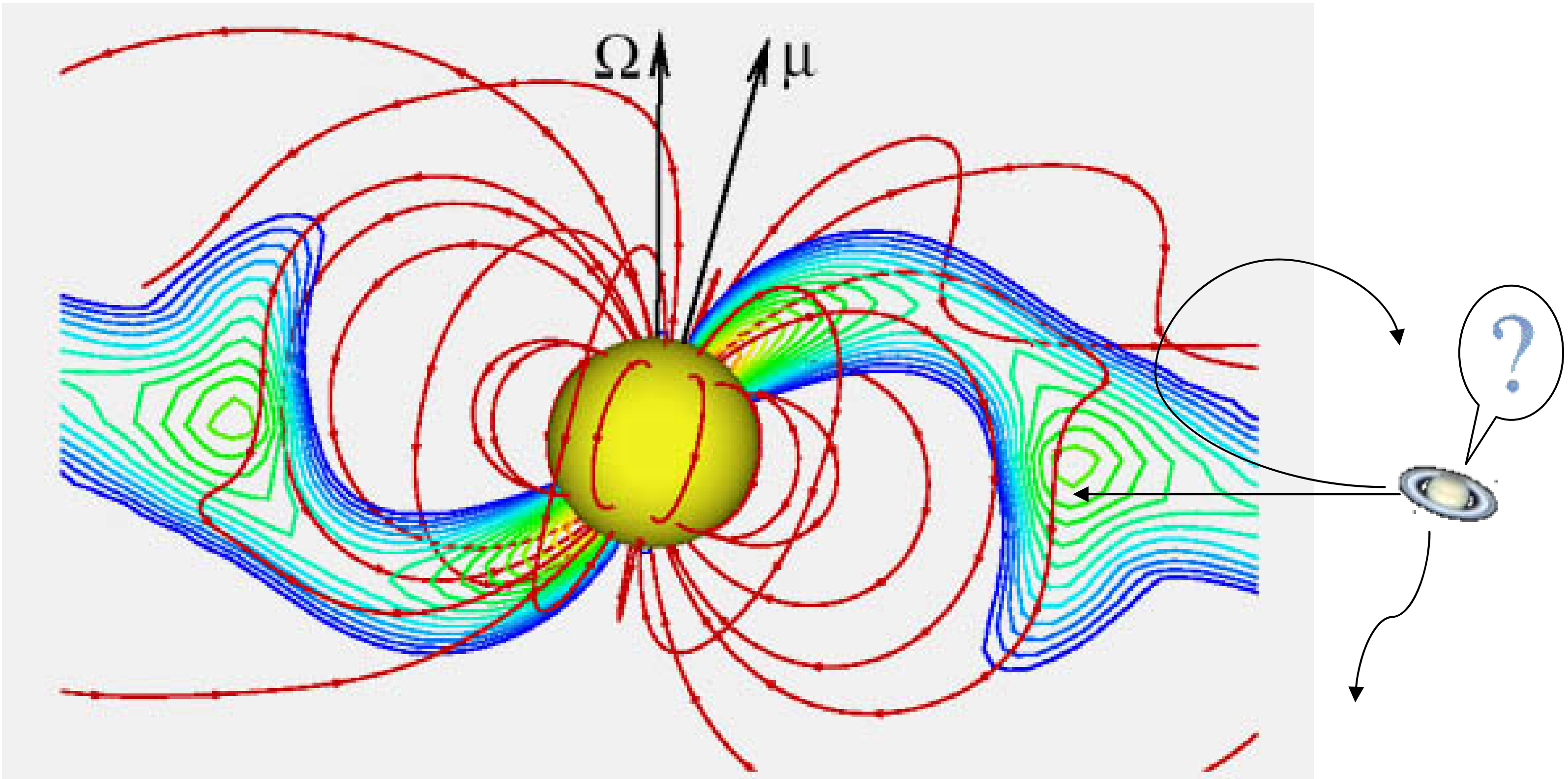
25% of CTTS exhibit AA Tau-like light-curves

Assuming random inclinations, this fraction yields : h/R ~ 0.3 at the inner disk edge

(flared α-disks have h/R~0.1)

Inner disk warps

induced by the interaction with an inclined magnetosphere

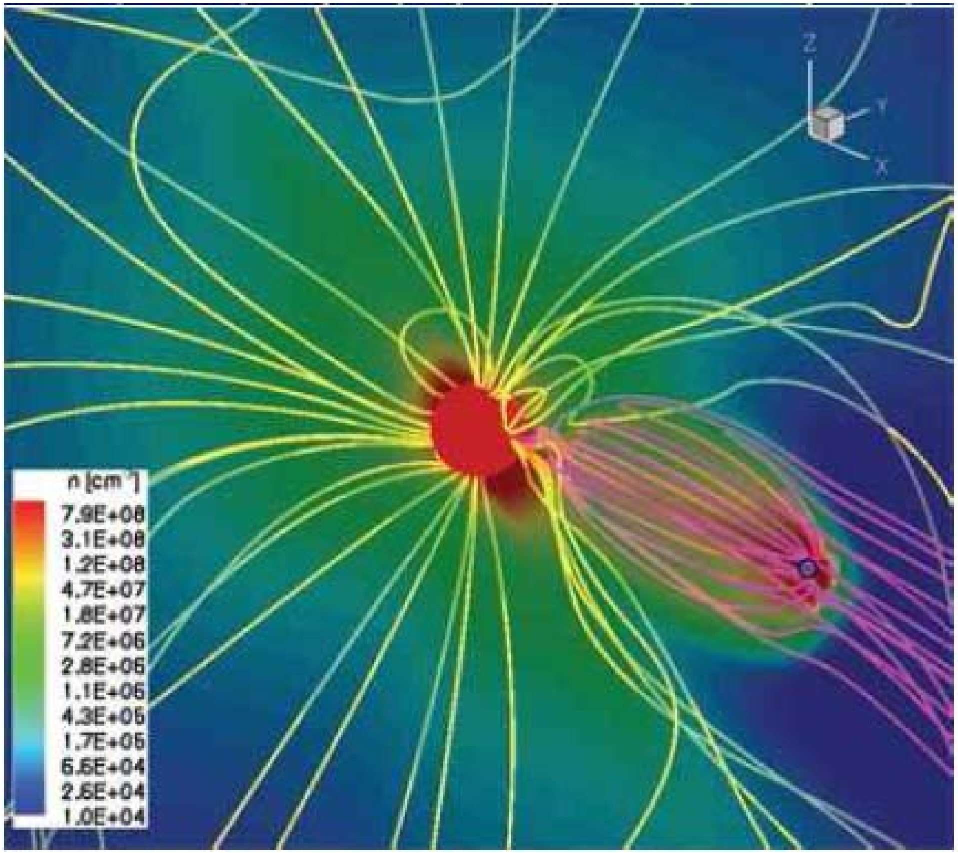


Halting the planet migration ?

"Hot Jupiters" (or Saturns…)?

Star-planet interacting magnetospheres

MHD simulations of the star-planet magnetospheres interaction



Cohen et al. 2009

Main sequence system:

B(star) = 5 G
B(planet) = 2 G

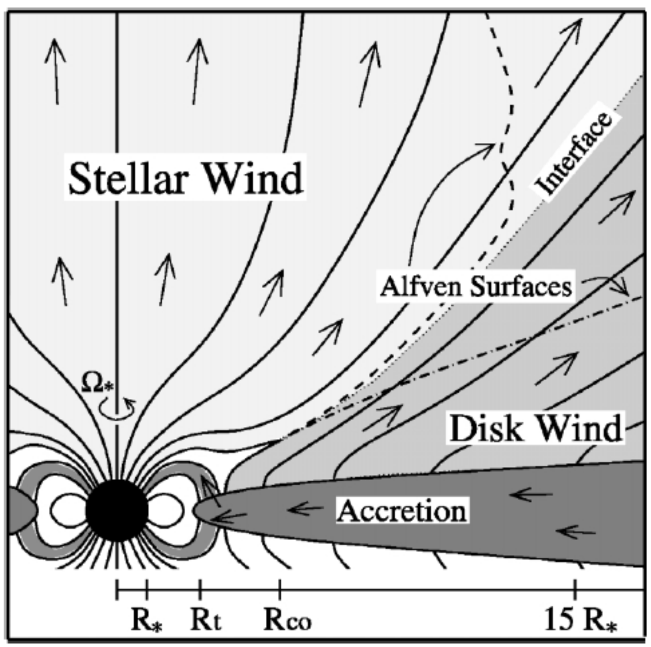
Much stronger fields to be expected at 1-10 Myr (~ 0.1-1.0 kG)

Angular momentum evolution, disc lifetimes and planet formation timescale

Angular momentum regulation

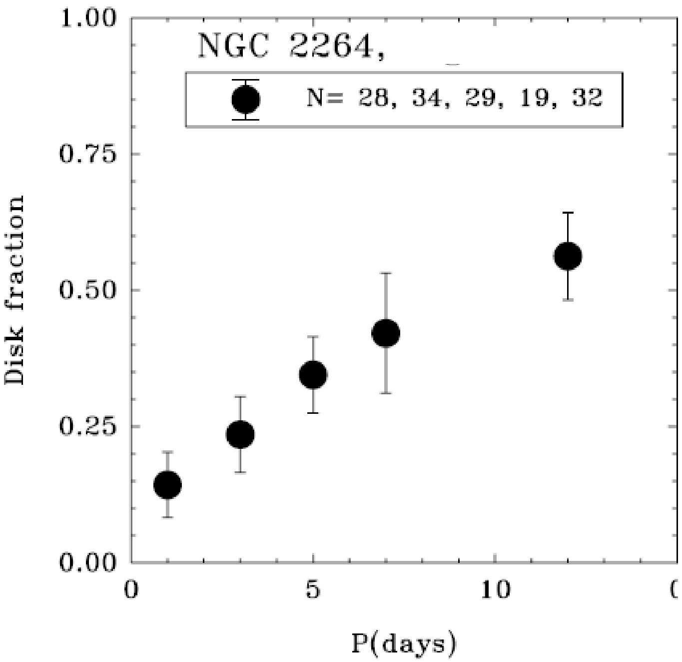
The magnetic star-disc interaction regulates the angular momentum of the star.

e.g., **accretion-powered magnetic winds** carry away angular momentum, thus braking the star



Matt & Pudritz 2005

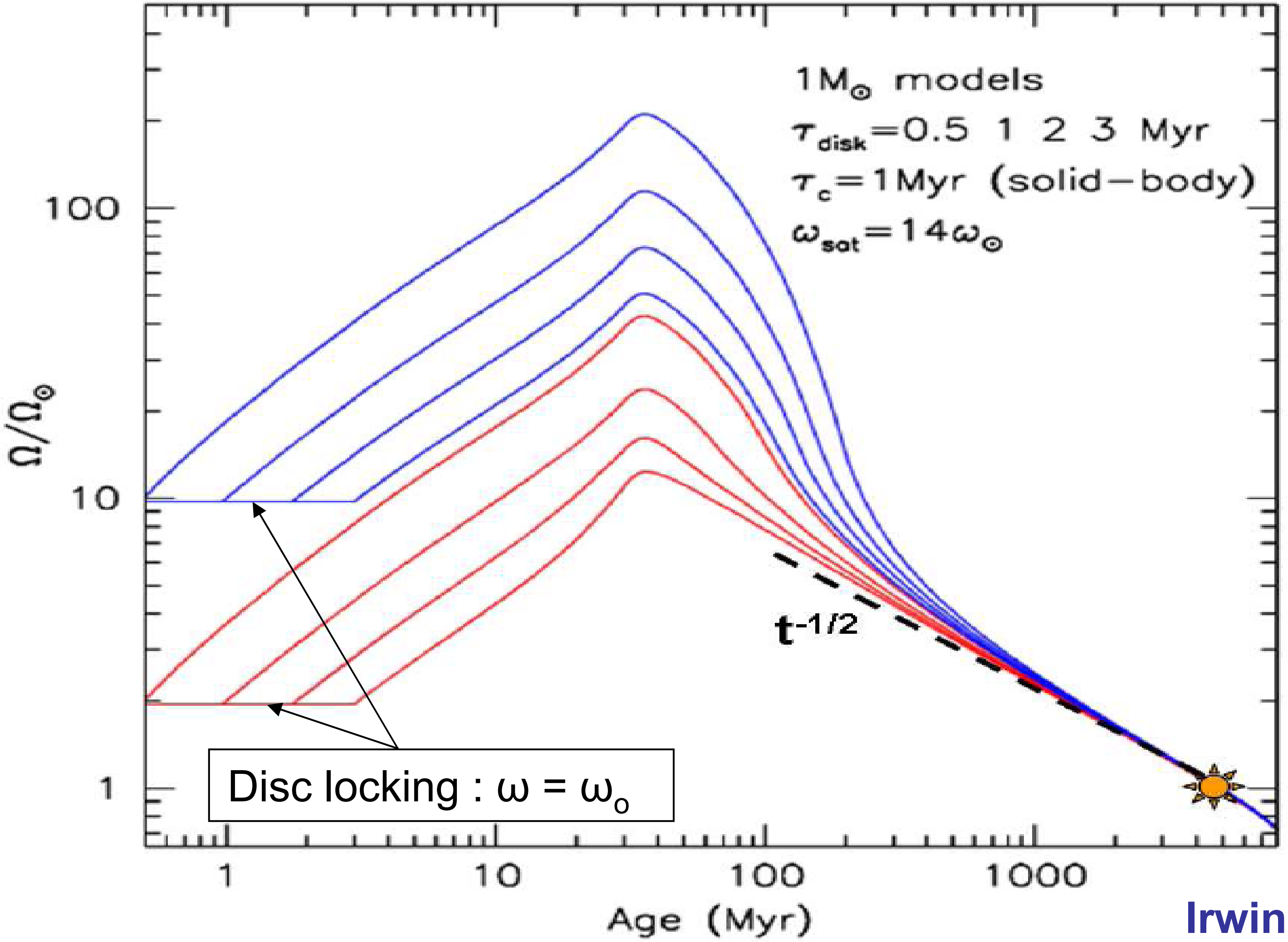
Cieza & Baliber 2007



Observational evidence for **« Disc locking » :** as long as the star accretes from its disc, it evolves at a constant angular velocity

Angular momentum evolution

Surface rotation is dictated by the initial velocity + disk lifetime + magnetic winds



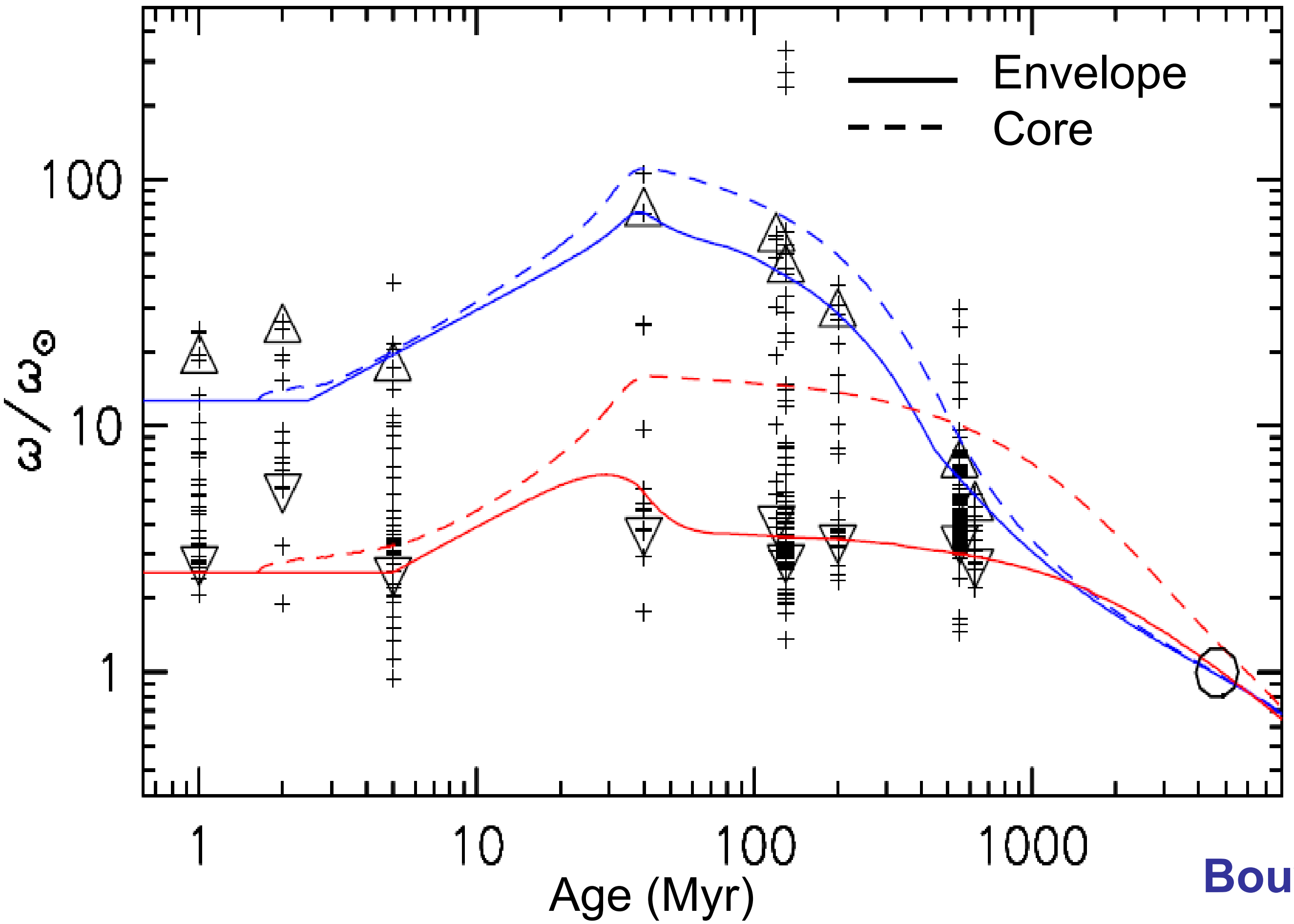
Short disk lifetimes
↓
PMS spin up
↓
Faster rotation

Long disk lifetimes
↓
Disc locking
↓
Slower rotation

Irwin & Bouvier 2009

Angular momentum evolution models vs. observations

Differential rotation → internal mixing → **enhanced Li depletion**



Slow rotation leads to lithium depletion

What about Li depletion in exoplanet hosts ?

Bouvier 2008

Lithium in exoplanet hosts :
a window to disc lifetimes

Solar-type stars with massive planets have lower Li abundances than solar-type stars without massive planets

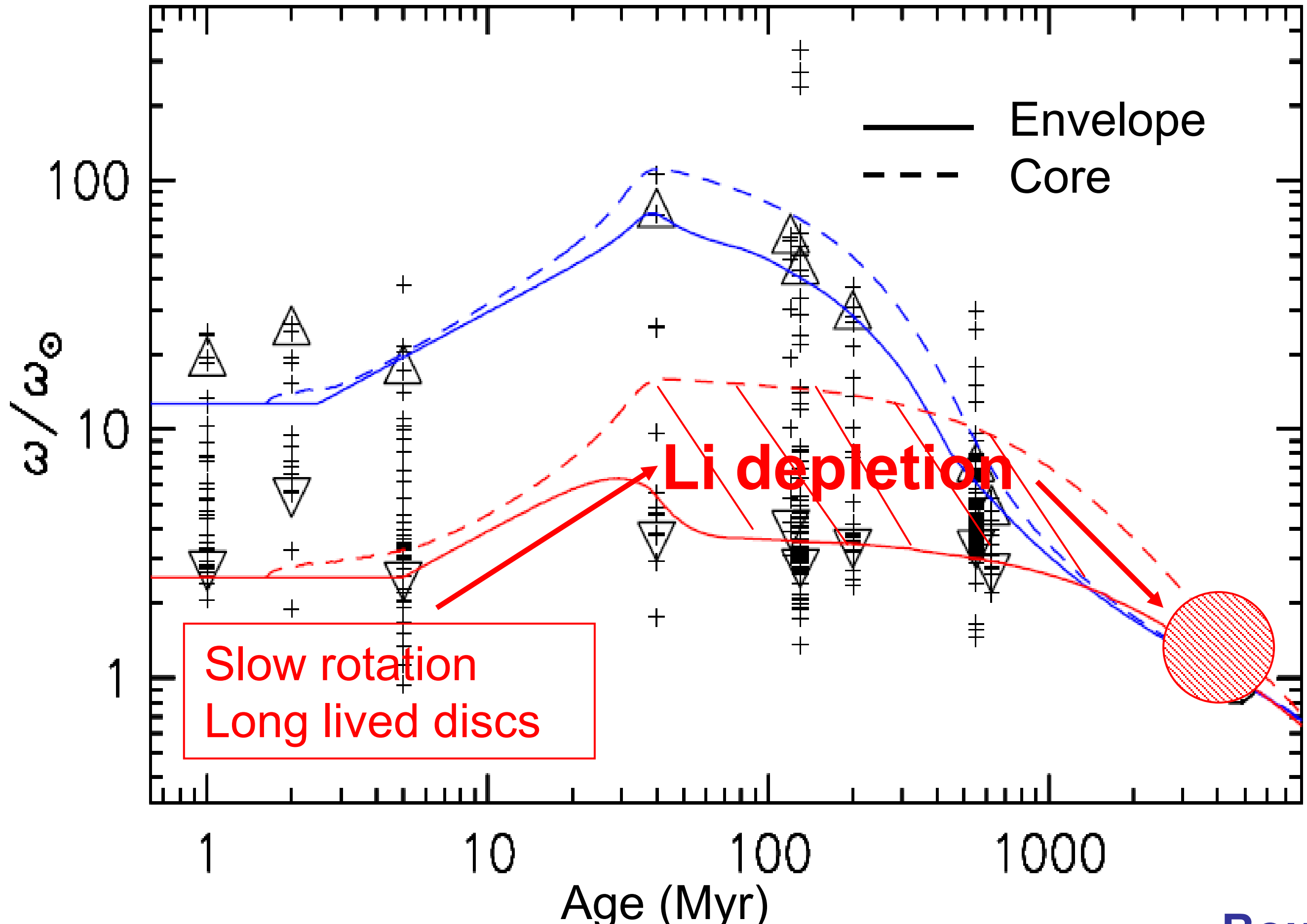
Israelian et al. 2009, Gonzalez 2008

Enhanced Li depletion in exoplanet hosts

→ links back to the initial rotational evolution of exoplanet hosts and their disc lifetimes

Angular momentum evolution and planet formation

Differential rotation → internal mixing → **enhanced Li depletion**



$\tau_{disc} \geq 5$ Myr required to form giant planets in circumstellar discs

Li-depleted exoplanet hosts

Bouvier 2008

Conclusions

- Magnetic star-disc interaction (magnetospheric accretion) is **a common occurrence** in young low-mass stars
- The accretion of the inner disc onto an inclined magnetosphere results in **a non-axisymmetric inner disc warp with (h_{max}/r) ~ 0.3**. The warped inner disc edge has to be taken into account when modelling SEDs, images, visibilities, variability, etc.
- The angular momentum evolution of young accreting stars and the lithium depletion history of exoplanet host stars together suggest that a **minimum disc lifetime of ~5 Myr is required to form giant planets in circumstellar discs**