The inner disk structure of classical T Tauri stars

Sílvia Helena Paixão Alencar

Physics Department – UFMG
Belo Horizonte - Brasil

Objective within COROT

To obtain heavily sampled light curves of young stars viewed at high inclinations in order to probe their inner disk regions and their circumstellar environment.

Motivation

Since magnetically dominated accretion occurs on a scale of a few stellar radii (≤ 0.1 AU) which, at the distance of the nearest star forming region cannot be resolved yet by current telescopes, one of the most fruitful approaches to probe the structure and evolution of this compact region is to monitor the variations of the system over several rotation timescales.

Classical T Tauri stars

- pre-main sequence

- low mass ($M < 2\ M_{\odot}$)

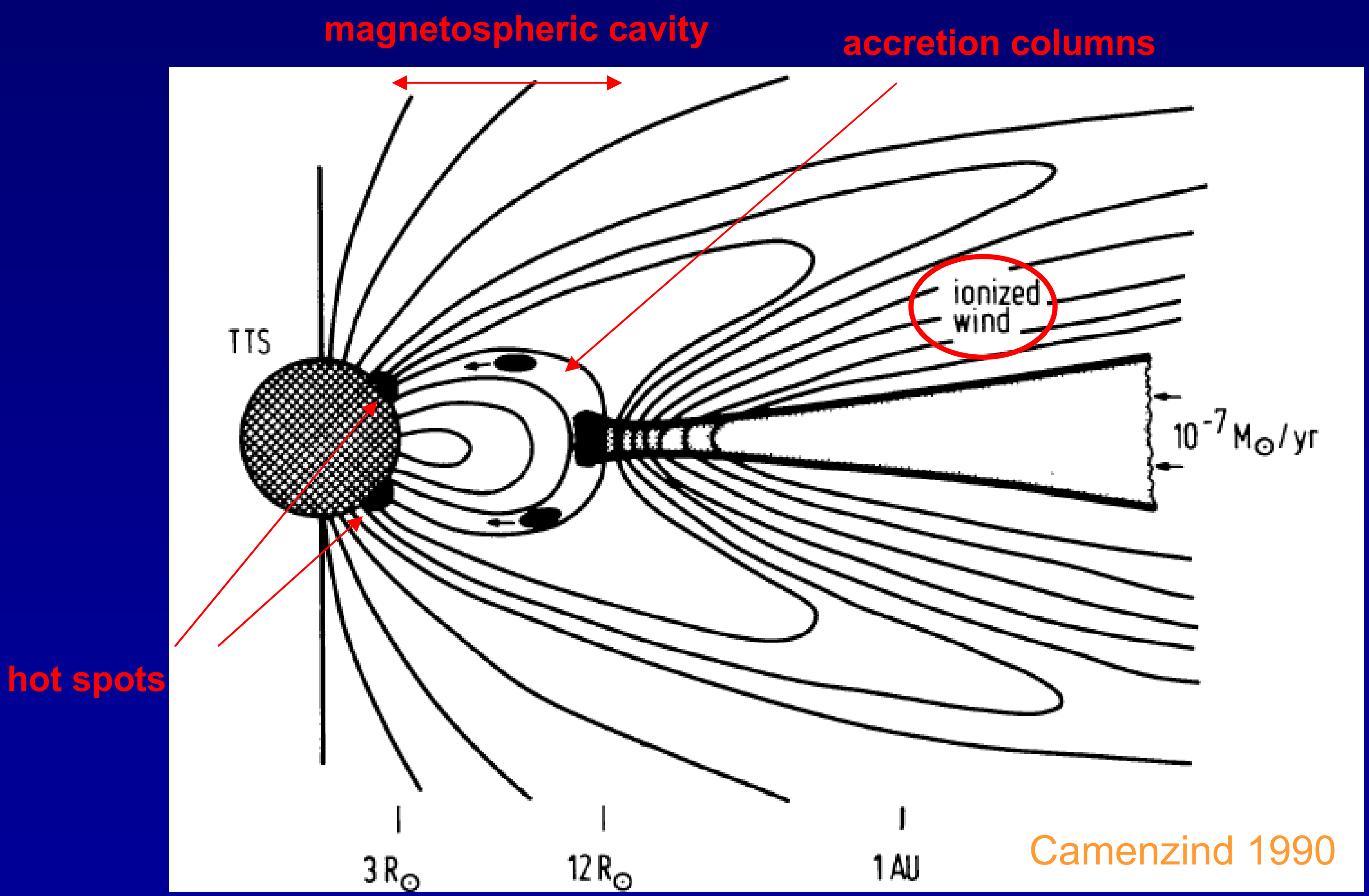
- accretion disk

- optically visible

Main observable characteristics:

- Li I (6708A) in absorption
- strong emission lines
- spectroscopic and photometric variability
- UV and IR excesses

Accretion in CTTSs: the basic concept



The PMS spectroscopic binary AK Sco

Sílvia Alencar[1], Cláudio Melo[2], Kees Dullemond[3], Johannes Andersen[4], Celso Batalha[5], Luiz Paulo Vaz[1], Robert Mathieu[6]

[1] UFMG, Belo Horizonte, Brasil

[2] ESO, Santiago, Chile

[3] MPIfA, Garching, Alemanha

[4] NBIfAPG, Copenhagen, Dinamarca

[5] ON-MCT, Rio de Janeiro, Brasil

[6] Univ. of Wisconsin, Madison, EUA

Introduction

- Single CTTSs
  circumstellar disks and strong emission lines
  magnetospheric accretion models

- Young binary systems (close and wide)
  circumstellar and/or circumbinary disks
  accretion at the same level as single CTTSs

Artymowicz and Lubow (1996)

time-dependent gas streams inside the circumbinary gap

M_A/M_B~1 and e ~0.5
accretion enhanced near periastron

observational example: DQ Tau

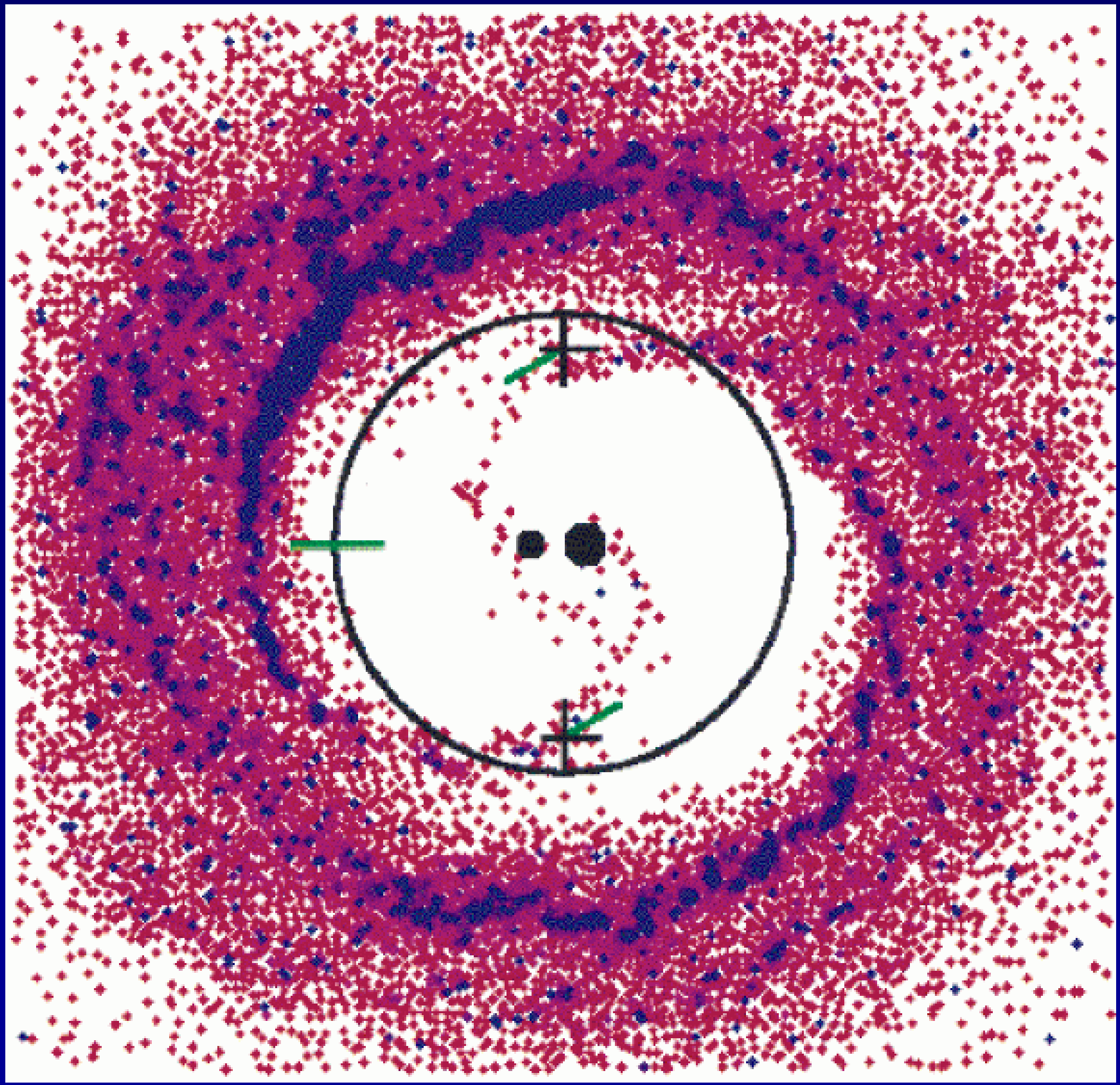


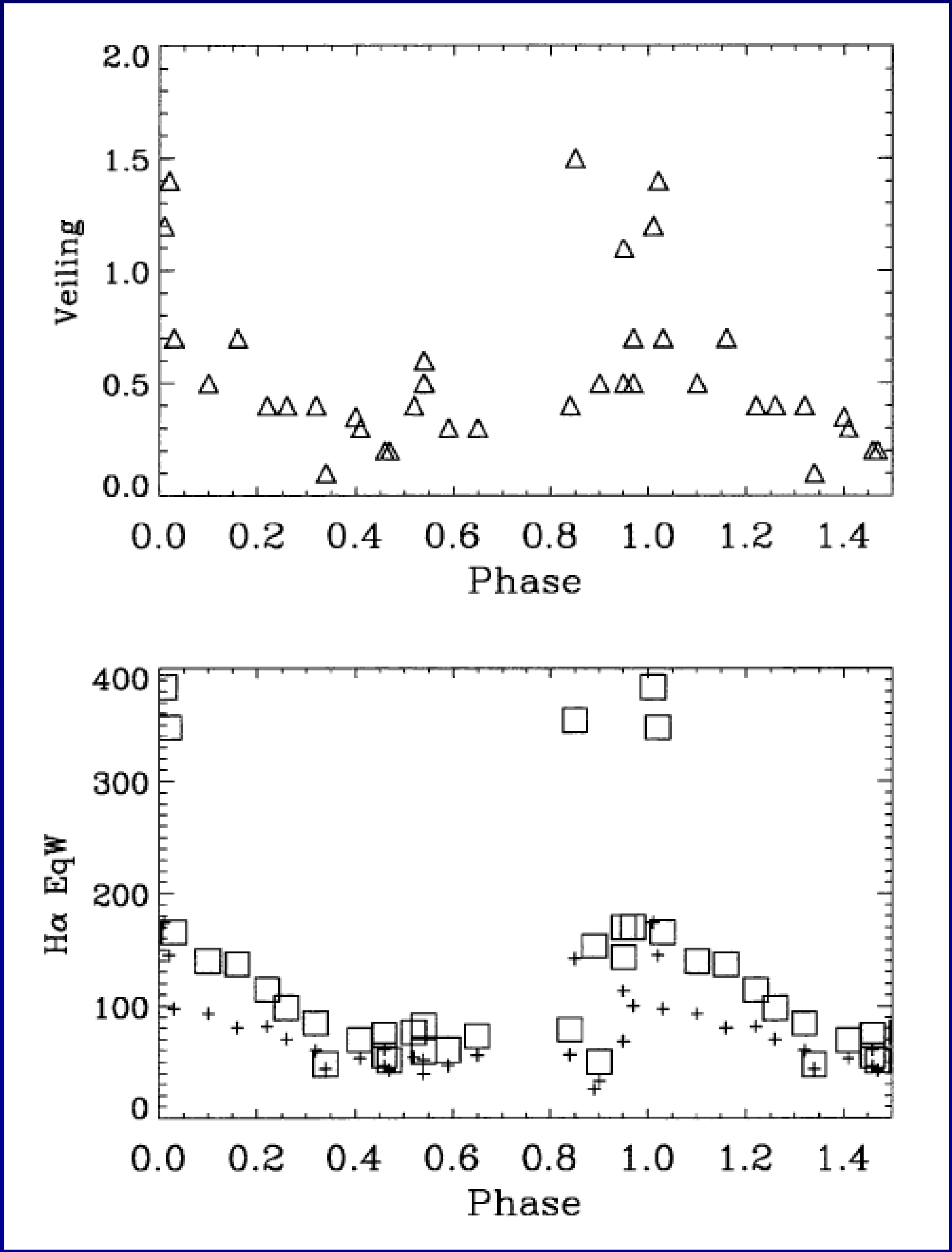
FIG. 1.—SPH simulation of two binary systems accreting mass through the circumbinary gap, in a frame of reference rotating at one-half the mean motion of the binary. The circumbinary disk has Reynolds number $Re \sim 4 \times 10^3$, with vertical pressure scale height equal to 10% of the radius. Particles in low-density regions are colored red, and those in high-density regions are colored blue. In this frame, the disk and the binary rotate in opposite directions. Black crosses denote saddle points of the effective potential associated with the combined $(m, l) = (0, 0)$ and (2, 1) harmonics. The black circles show the locations of the (2, 1) outer Lindblad resonances. The green mark on the circle follows the Keplerian circular motion of the matter at that radius in an unperturbed disk. In (*a*)–(*d*) the binary mass ratio is 3:7 and the eccentricity $e = 0.1$. Orbital phases (in binary periods since last pericenter) are 0.25 (*a*), 0.5 (apocenter; *b*), 0.75 (*c*), and 1.0 (pericenter; *d*). Notice the predominant feeding of the lower mass component at orbital phases about 0.75 via a stream. In (*e*) and (*f*) the mass ratio is 1:1.27 and $e = 0.5$; (*e*) is at apocenter, and (*f*) is at pericenter. Equal gas streams are always present in the disk gap. Analytical theory of the stream predicts that streams pass through the regions denoted by heavy crosses in the direction given by the green line segments (see text for further explanations).

ARTYMOWICZ & LUBOW (see 467, L77)

DQ Tau

Basri et al. (1997)

Pulsed accretion near periastron passage



Veiling is related to
mass accretion rate

AK Sco

- PMS system (two F5 IV stars) Herbig and Rao (1972)
- double-lined spectroscopic binary of short period (13.6 days) and high eccentricity (e=0.47) Andersen et al. (1989)
- no evidence for eclipses in the photometry
- belongs to the Upper Sco SFR Hipparcos
- spectral characteristics of a CTTS
- photometric characteristics of a Herbig Ae/Be star

Although we do not see eclipses in the photometry, implying that the inclination cannot be too close to edge-on, we can still obtain information about the material in the inner disk regions

Observations

Photometry

8 series of *uvby* and Geneva photometry obtained in 1987, 1989, 1990, 1992, 1994 and 1997

Spectroscopy

1986-1994 → 71 CORAVEL radial velocities

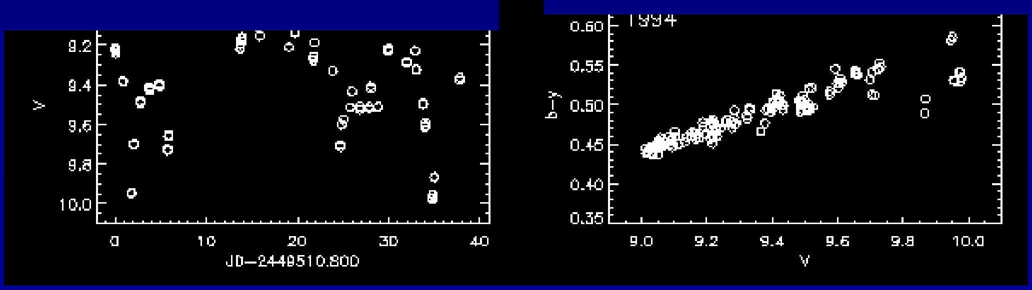
1998-2000 → 26 CORALIE échelle spectra

2000 → 6 FEROS échelle spectra

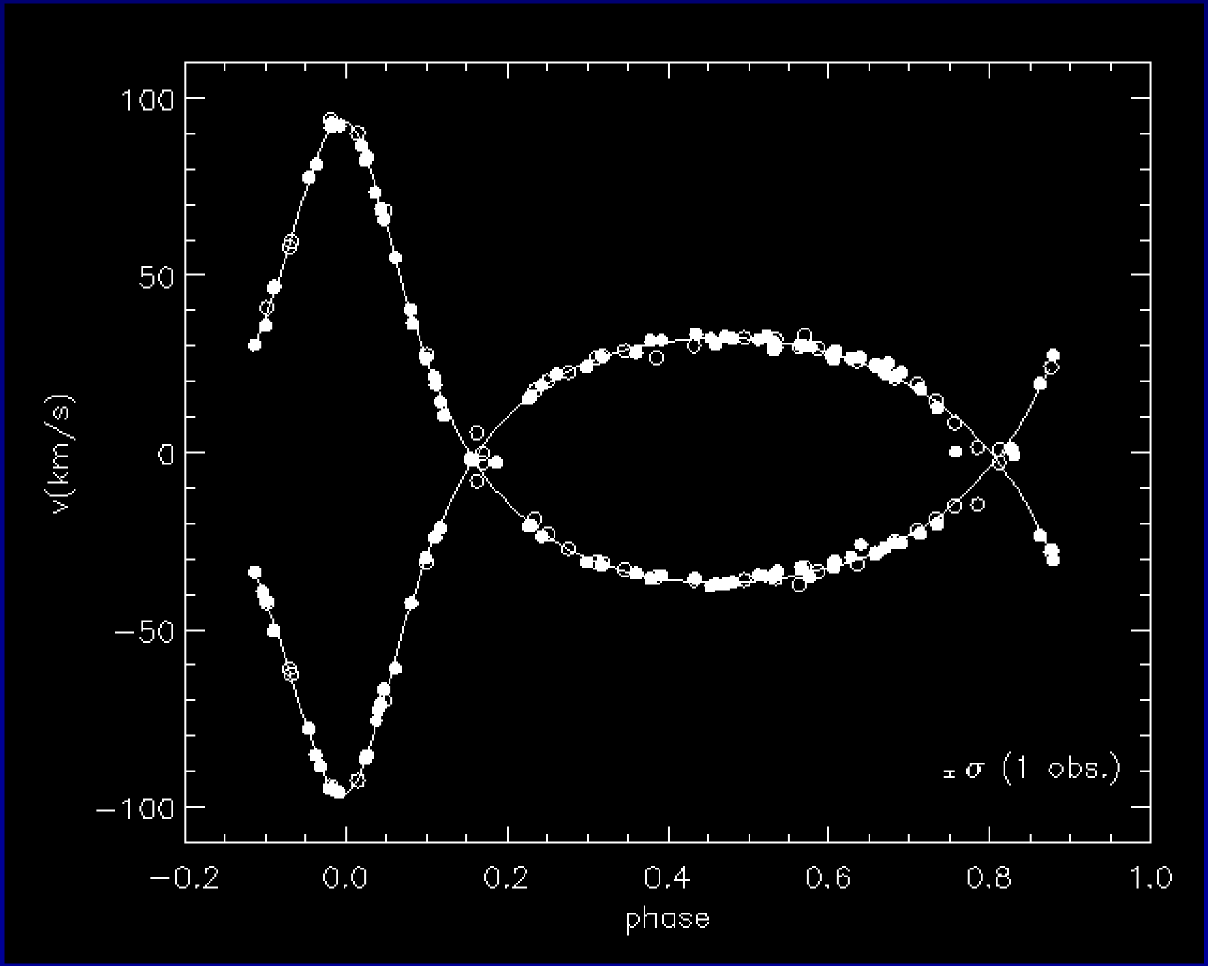
Photometry

- The star becomes redder when fainter as expected for dust obscuration
- Considerable scatter
- Anomalous, steep extinction law, characteristic of dust with large grains R(b-y) ~ 6-7 against 4.3 for normal interstellar dust

- Irregular light variations similar to HAeBes
- Brightness changes of up to 1 magnitude from night to night
- No sign of eclipses or any periodic variability



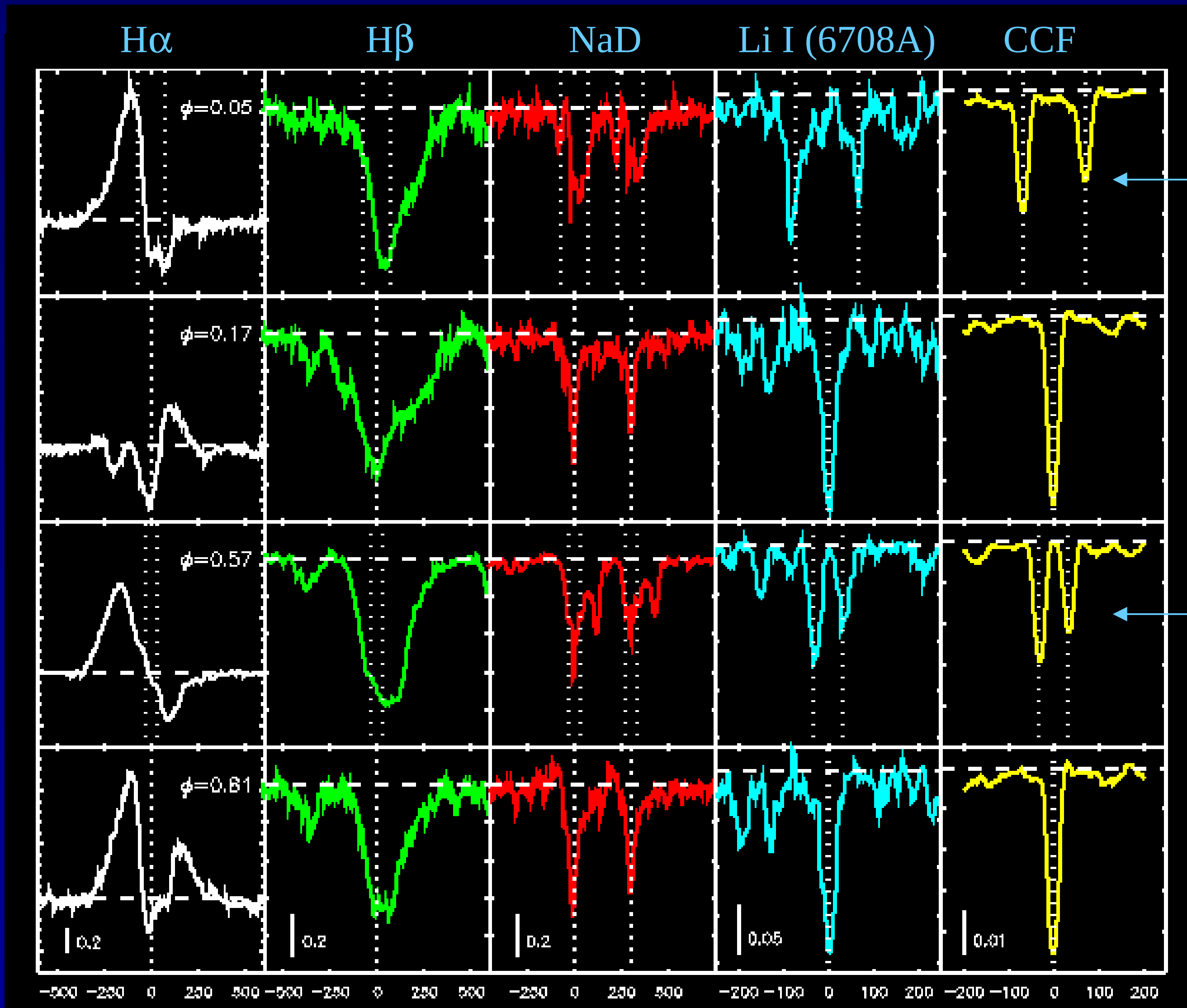
Spectroscopy: radial velocity curve



● CORAVEL

○ FEROS/CORALIE

Sample of observed lines



Normalized intensity

velocity (km/s)

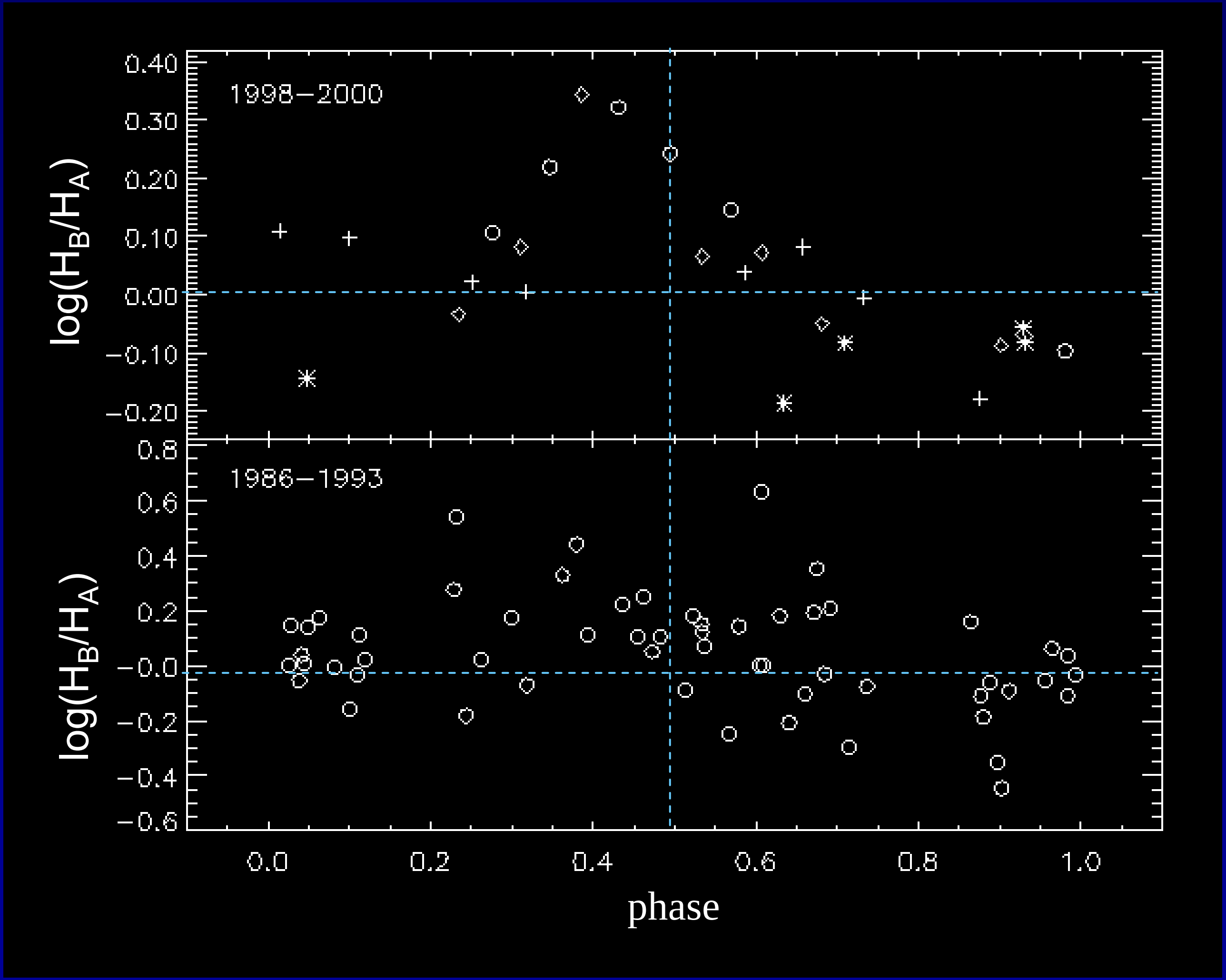
$H_B/H_A > 1$

$H_B/H_A < 1$

Ratio of the CCF dips intensity

1998-2000

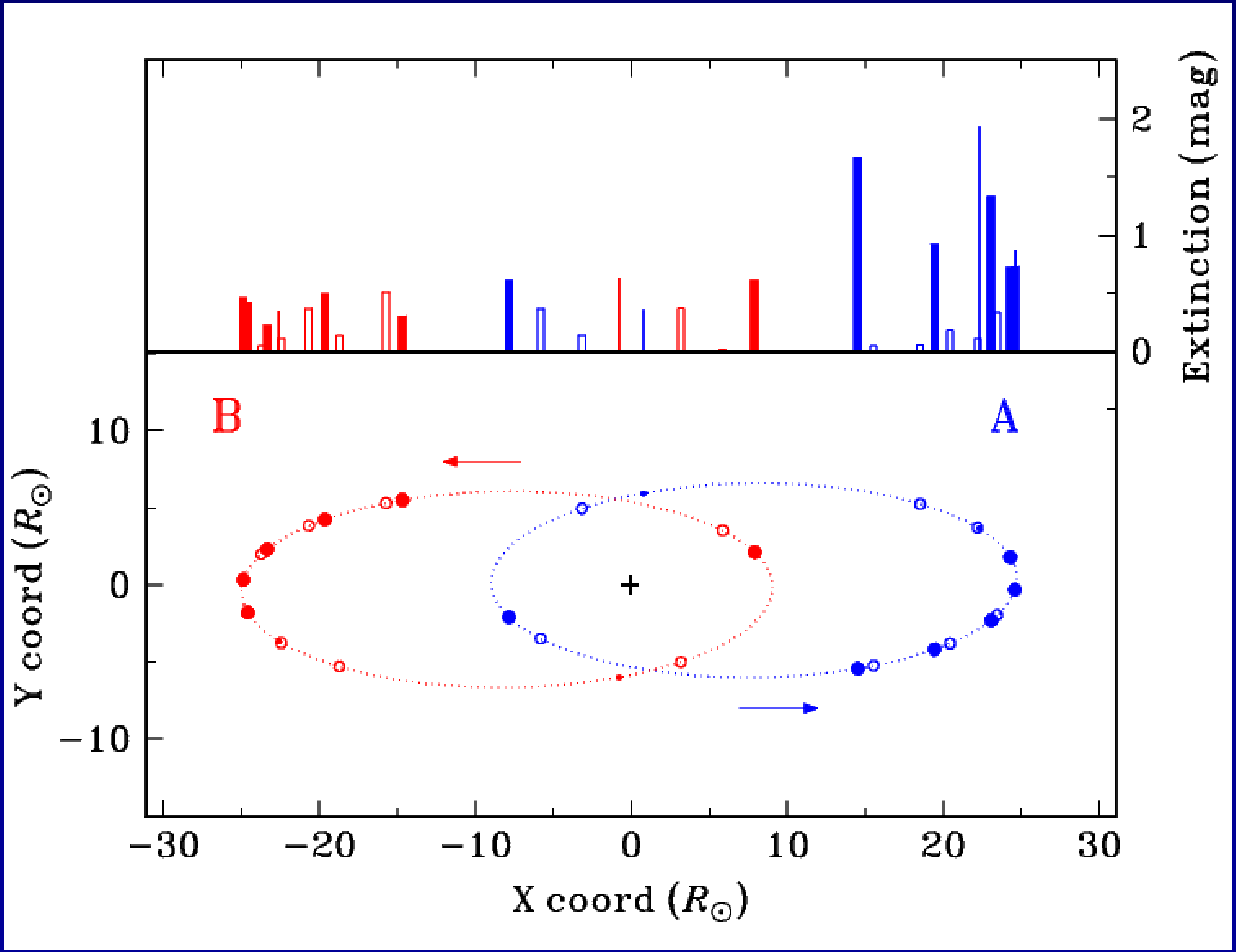
1986-1994



Phases 0 to 0.5 → star A in front → dust mainly located in the disk instead of the cavity corresponds to $H_B/H_A > 1$ (deeper lines from star B, then less extinction in B)

Small scale structure in the disk

Optical dust extinction at points along the binary orbit



o → 1989
• → 1993
} simultaneous photometry and spectroscopy

Photometry → total absorption
H_B/H_A → distribution between the stars

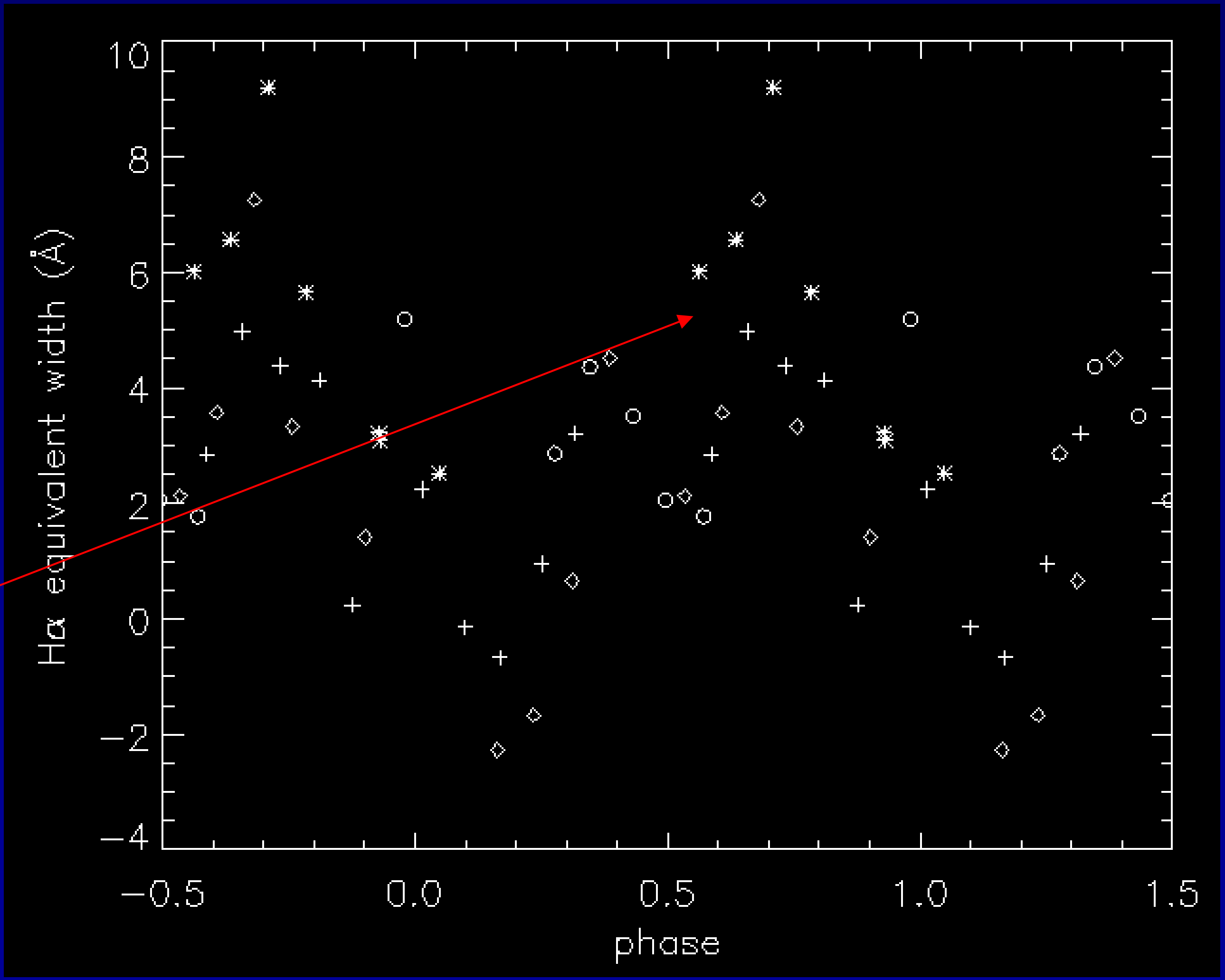
Variations from cycle to cycle

In general, the largest absorption is in front of the nearest of the two stars

Dust obscuration in front of an individual star may change significantly over a projected distance of just a single stellar diameter

Dust is not symmetrically distributed around the binary orbit

Hα and Hβ presented periodic variations at the orbital period, with some scatter



Peak at phases ~ 0.6-0.7

Some conclusions

- Our detailed extinction data indicate the presence of significant asymmetries of the order of 1 stellar diameter in the inner disk region
- Dust is mainly located in the disk instead of the cavity but there is evidence of dust in the cavity as well
- We see no sign of enhanced accretion near periastron as expected theoretically for binary systems with high eccentricity and almost equal masses

The non-stationary variability of AA Tau

Silvia Alencar[1], Jérôme Bouvier[2], Catherine Dougados[2]
and collaborators

[1] UFMG-Belo Horizonte
[2] LAOG-Grenoble

Magnetospheric accretion in CTTSs

The static view: steady-state models

- Statistical evidence (TTS group properties)
- Snapshot evidence (one spectrum, one light curve)
- Monitoring studies (short term spectro photometric variability)

The dynamical view : magnetospheric instabilities

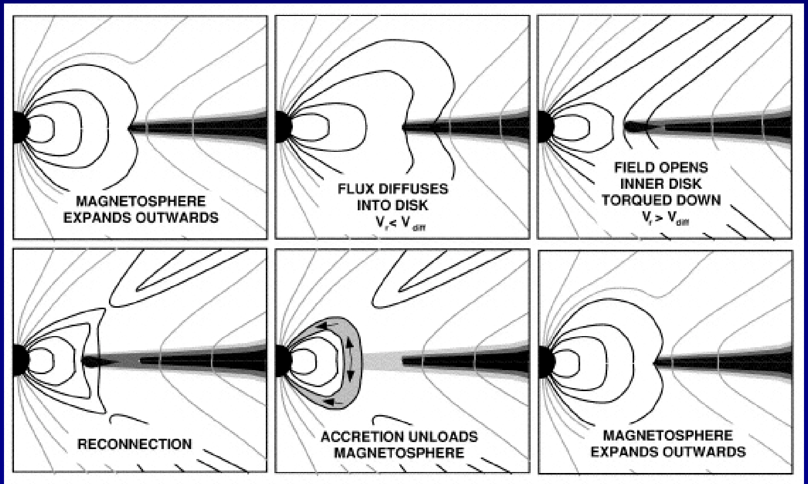
- Inflow-outflow variability
- Magnetospheric reconfiguration

A dynamical interaction between the disk and the stellar magnetosphere

Model predictions :
Differential rotation along the field lines leads to their expansion, opening and reconnection

Timescale of a few rotation periods

Goodson et al. 1997
Romanova et al. 2003



Need for nightly monitoring on daily/week timescales in order to investigate time variability of the magnetospheric configuration

AA Tau

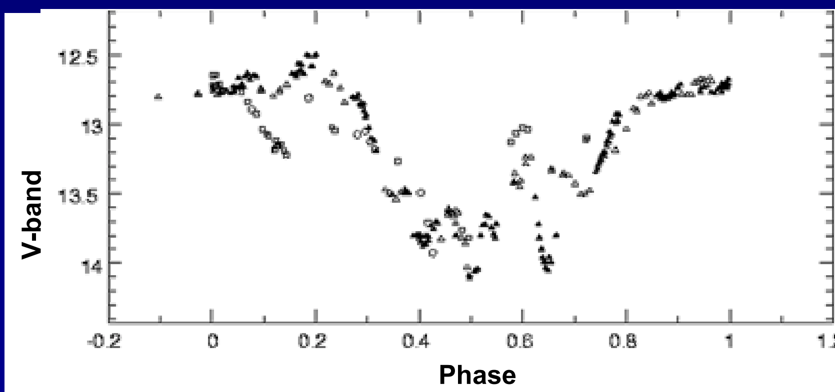
- Classical T Tauri star
- M0, V~ 12.4, ΔV ~ 0.5-1 mag
- Periodical photometric variability with small color variation

AA Tau proved to be ideally suited to probe the inner few 0.01 AU of the disk-magnetosphere interaction region. Due to its high inclination (i~75^{o}), the line of sight to the star intersects the region where the stellar magnetosphere threads the disk. The peculiar orientation of this otherwise typical CTTS maximizes the variability induced by the modulation of the magnetospheric structure and thus provides the strongest constraints on the inner disk and the magnetospheric cavity.

AA Tau : quasi periodic light curve (P = 8.2 days)

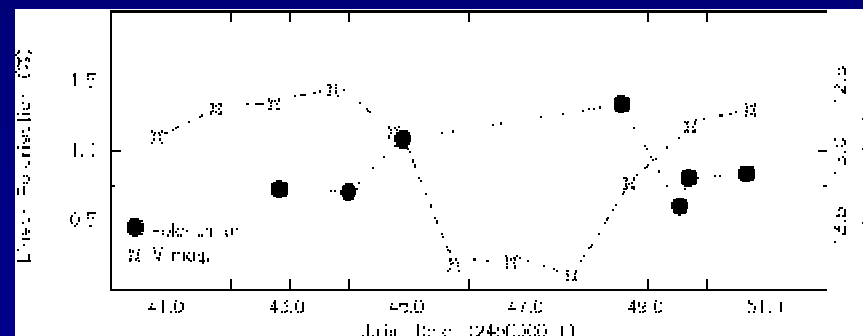
Recurrent luminosity dips

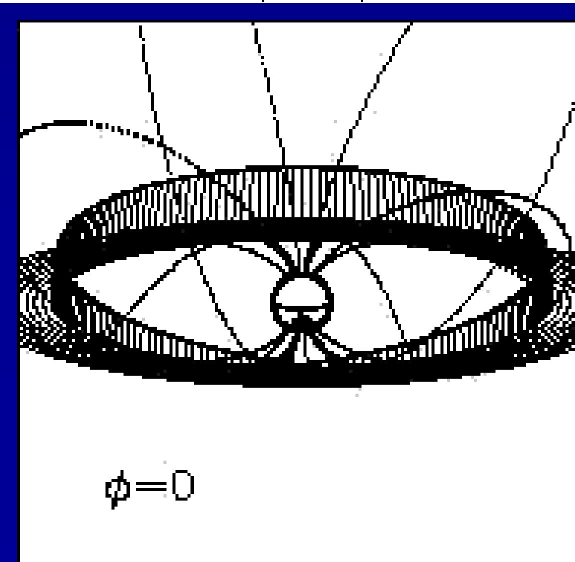
Bouvier et al. 1999



+ associated polarisation increase

Ménard et al. 2003





→ **periodic eclipses of the star by opaque circumstellar material**

Observations

November-December/1999

Photometry

UBVRI

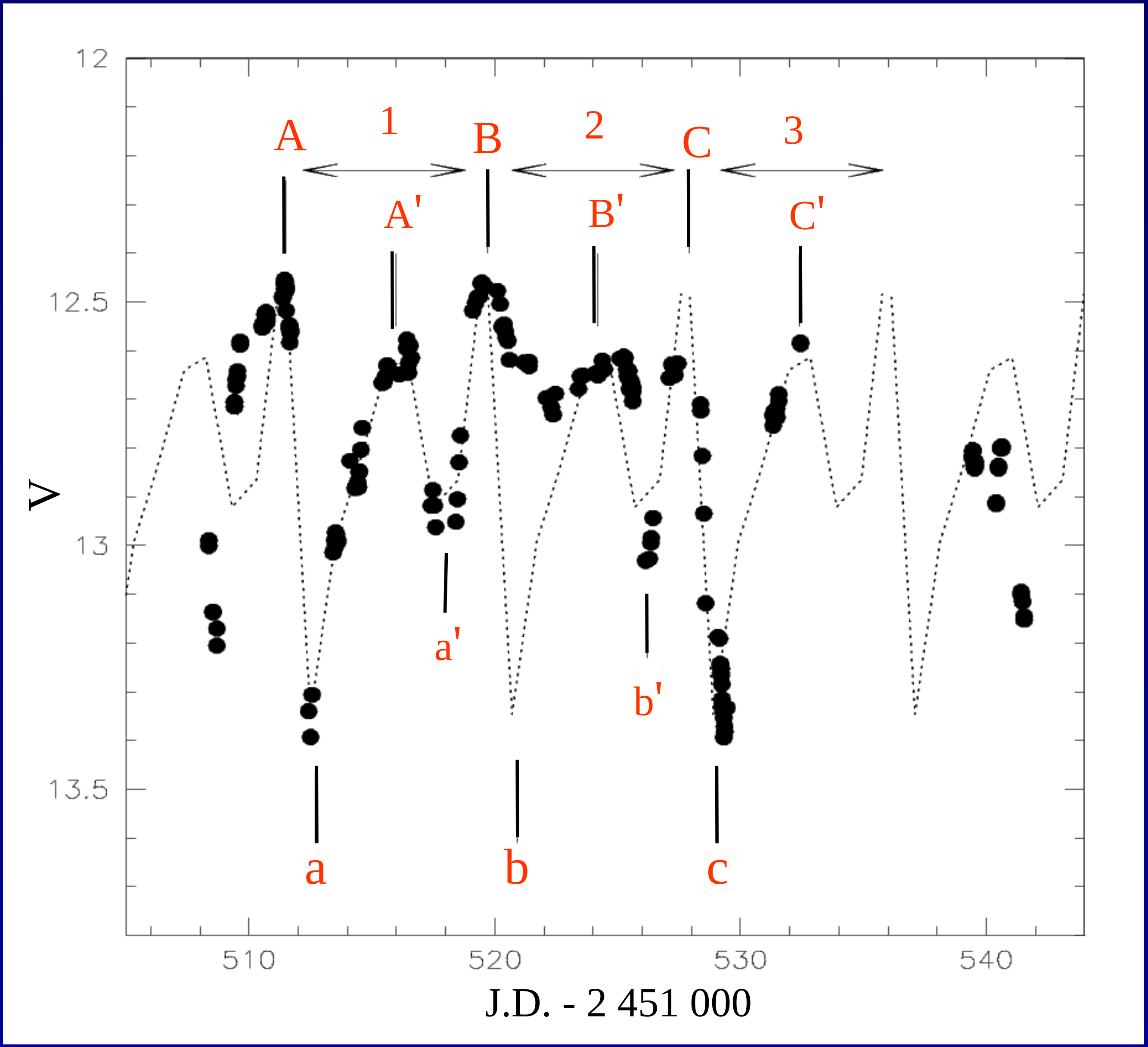
Mt. Maidanak, OHP, Byurakan, Calo Alto, Alma Ata, IAC

Spectroscopy

50 high resolution échelle spectra

observatory	telescope	spectrograph
ESO-La Silla	1.52m	Feros
Lick	0.6 and 3m	Hamilton
IAC-NOT	2.56m	Sofin
OHP	1.93m	Elodie

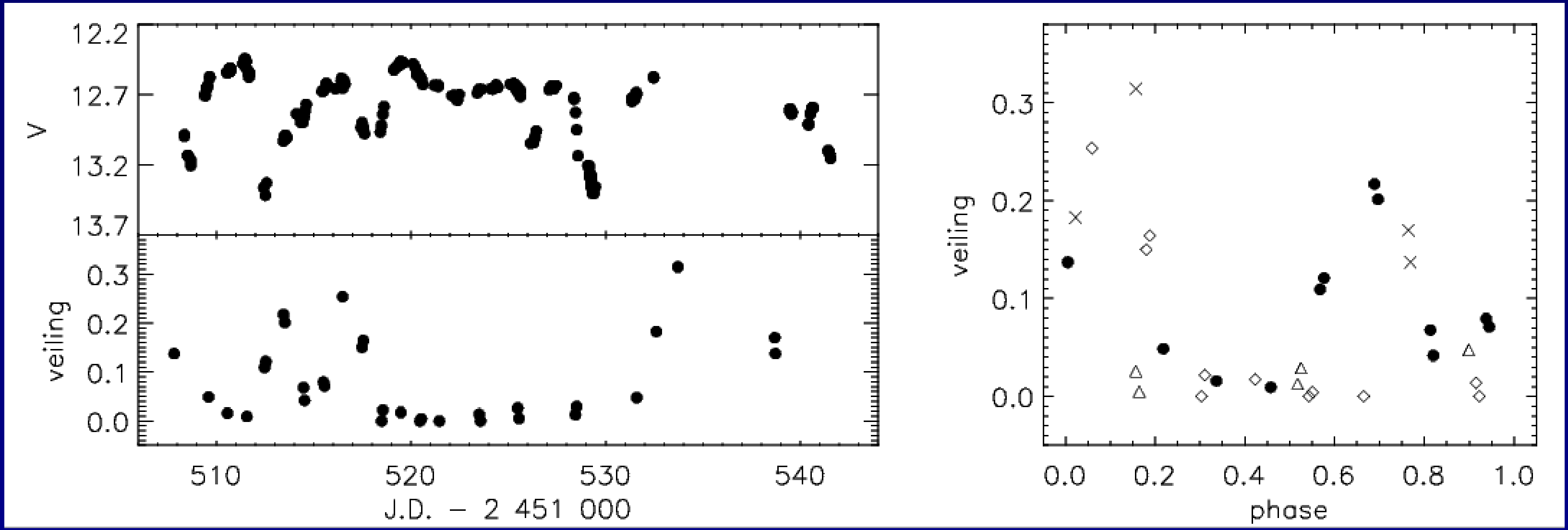
1999 photometry ⟶ no apparent periodicity



Veiling

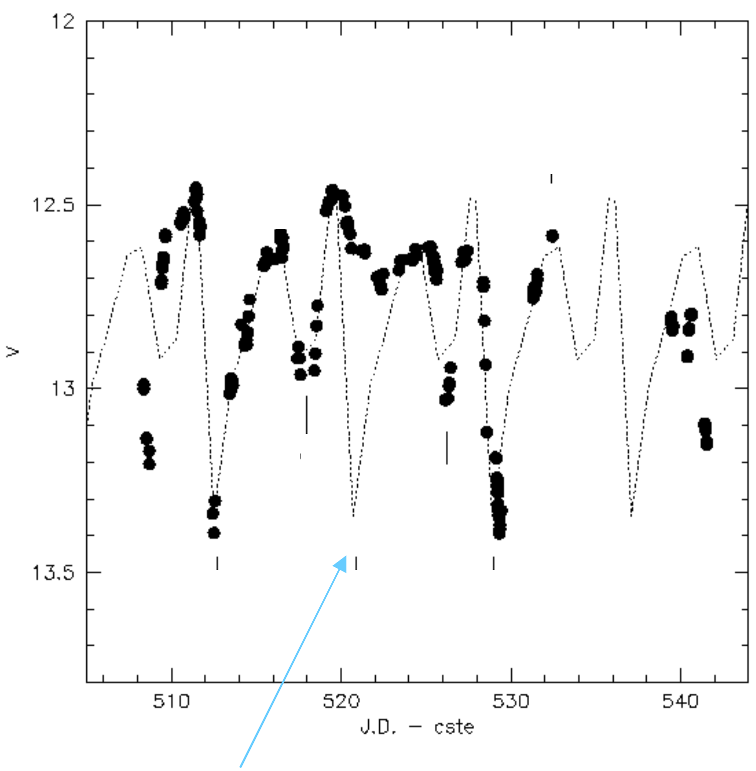
related to Macc

veiling = $F_{excess} / F_{photospheric}$



- Low veiling values (maximum ~0.3)
- During the photometric plateau the veiling is essentially zero
- Some cycles present periodical variations and other do not
- Variations overall consistent with the presence of 2 rotationally modulated hot spots in the magnetic poles

Puzzle 1…



missing eclipse !!!

- One eclipse is missing !!!
- The occulting screen has apparently vanished for a few days and was back a few days later
- During the same period the veiling and the line fluxes were strongly reduced

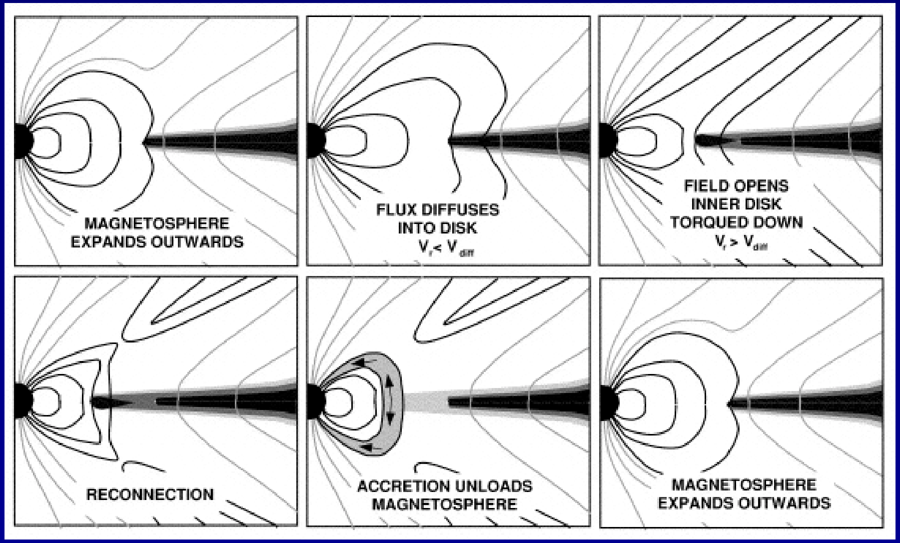
Magnetic topology ↔ disk warp ↔ eclipse

→ Temporary disruption of the magnetic configuration ?

Cyclical magnetospheric accretion

Goodson & Winglee 1999
Uzdensky et al. 2002
Romanova et al. 2002

- Differential rotation in the disk
- Shearing of the field lines
- Inflation, opening, reconnection
- Restoration of the initial magnetospheric configuration

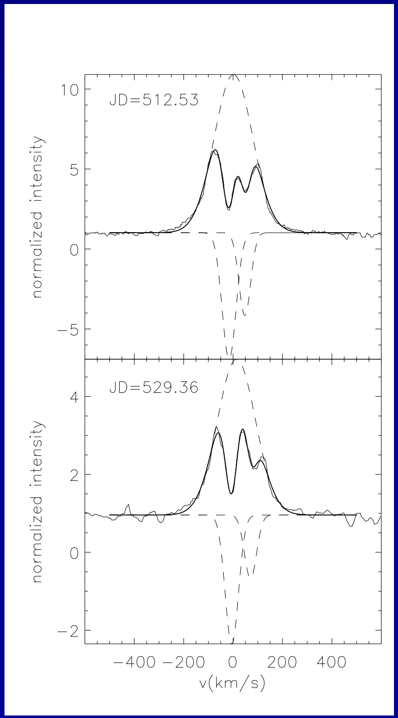


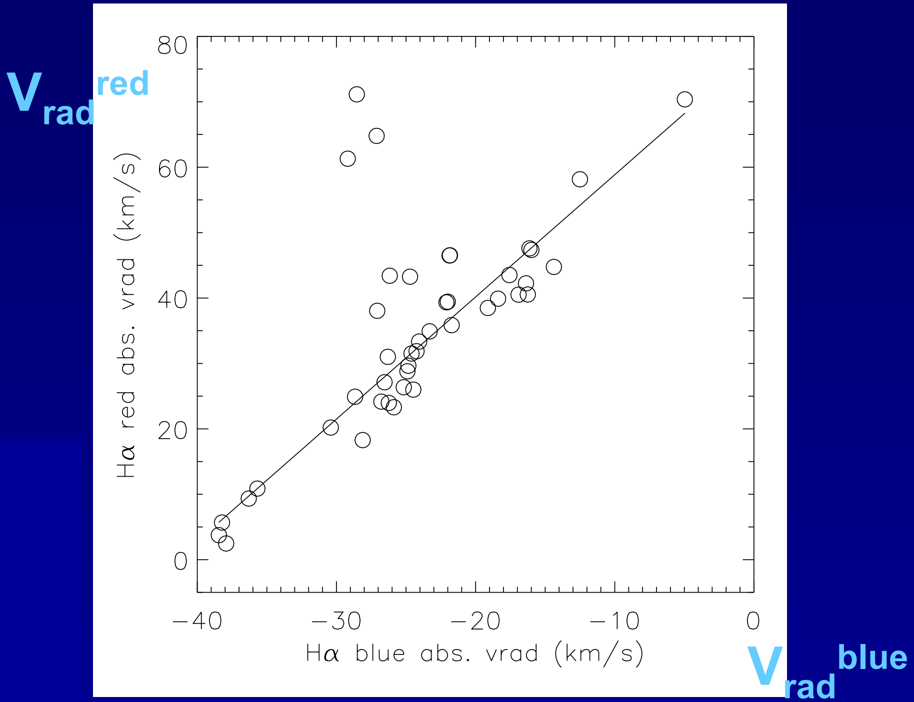
⟶ **The inner disk warp temporarily disappears as the magnetic configuration is disrupted**

Puzzle 2

Hα profile decomposition

- central emission component
- red absorption (accretion)
- blue absorption (wind)

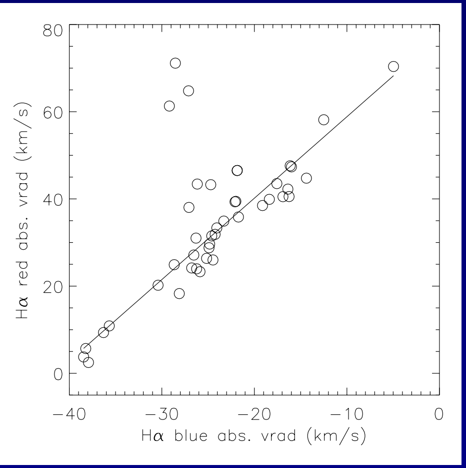




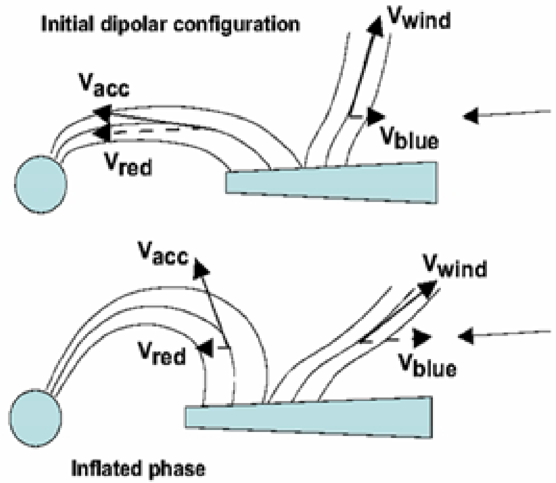
Tight correlation bewteen the blue and red Hα absorption components

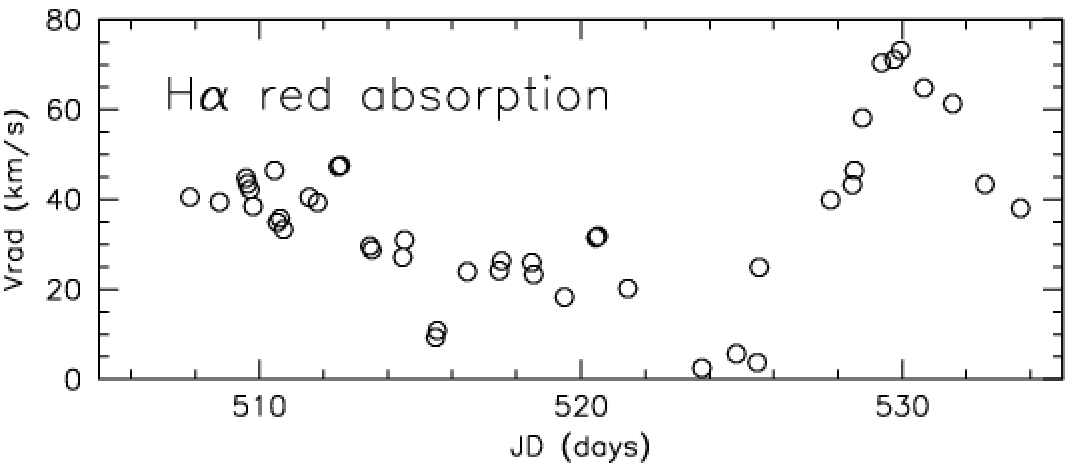
- accretion-ejection connection
- origin of the correlation ???

Magnetospheric inflation ?

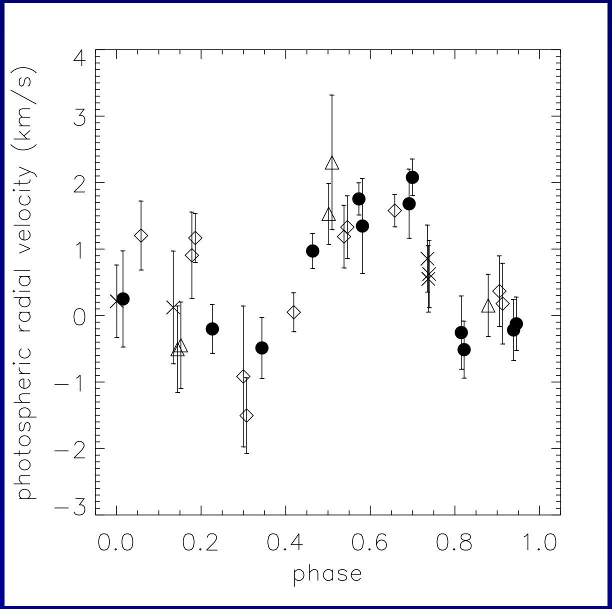


The radial velocity of the redshifted Hα absorption measures the field line inflation !!





Puzzle 3 …



Periodic variations of the photospheric radial velocity (P=8.2d)

A 10 Mjup planet at 8 R_* ? Maybe…

A large dark surface spot ? Not consistent with the photometry (small color variation)

Partial occultation of the photosphere ? Cannot be the primary cause of the variations, since Vrad also changes outside the eclipses.

A combination of dark spots and partial occultation of the photosphere ? Maybe…

To be solved…

Conclusions

A highly dynamical star-disk interaction mediated by the star's magnetic field

(timescales of hours to weeks (to years…?))

- Complex variability = spot modulation + *circumstellar extinction* + non steady accretion + episodic mass loss

- requires in-depth object-by-object studies combining *nightly photometric and spectroscopic (and polarimetric) monitoring*

- **Implications :**
  - **angular momentum evolution (?)**
  - **short term variability of inflows-outflows**
  - **origin of the observed variability of accreting young stars**
  - **near-IR variability, etc.**
  - **origin and *meaning* of the near-IR excess (eg as a Macc diagnostics)**

Except for the high inclination ($i>75^o$), AA Tau is otherwise a typical CTTS, implying that the type of variability observed here should be present in all CTTSs.