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de Grenoble

Young stellar objects
Kinematics study and imaging

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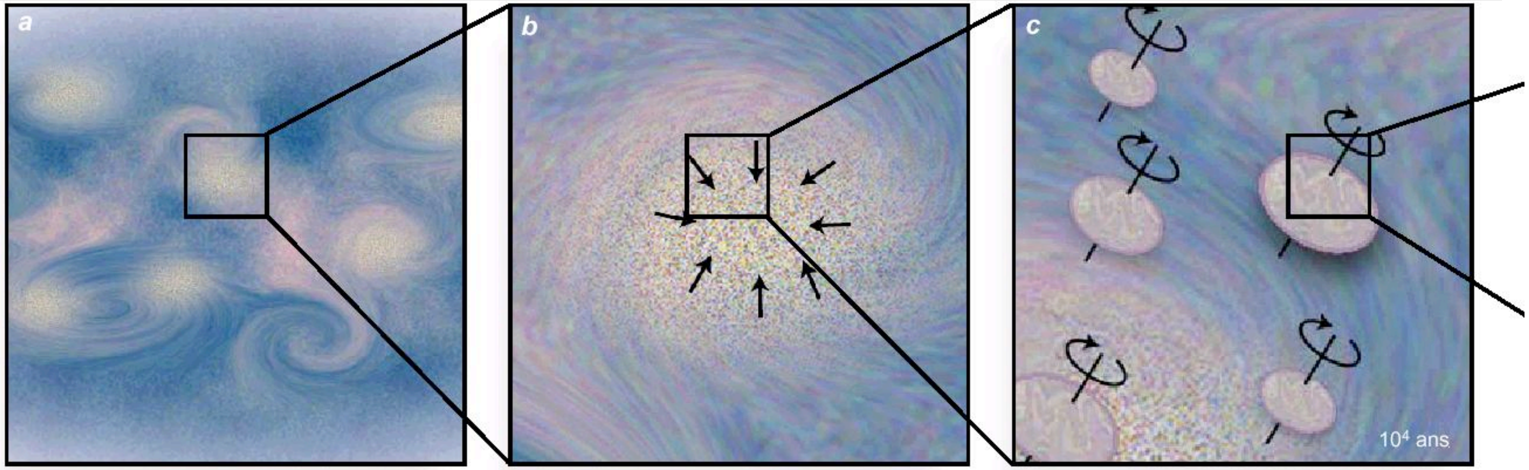
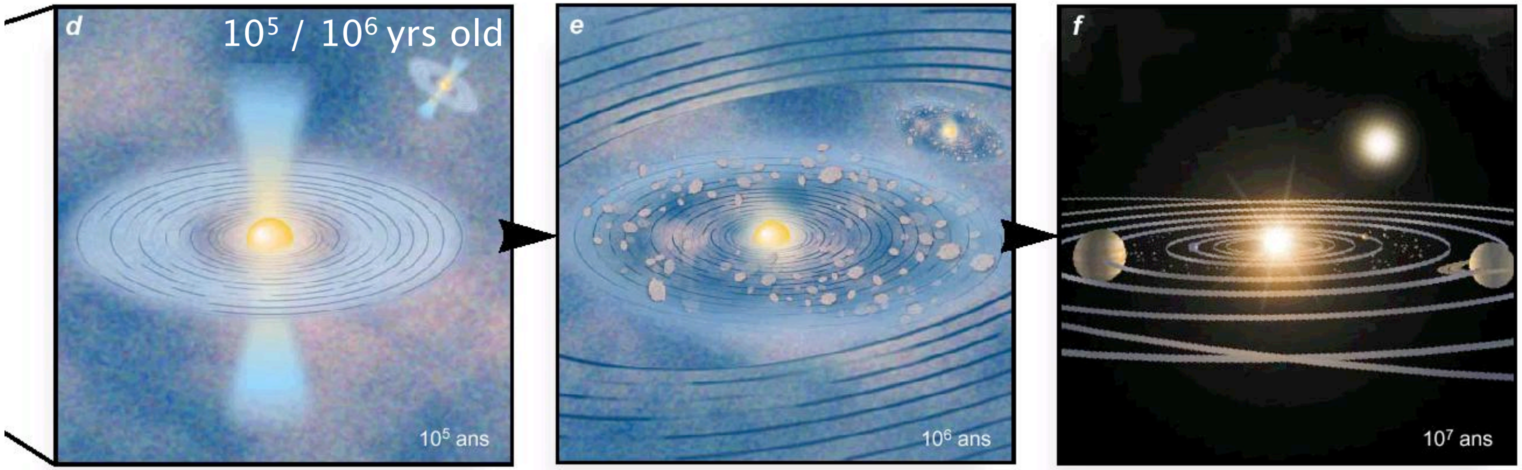
Scenario of stellar formation



10 pc – 4° **(Taurus)** **1 pc – 20'** **0.1 pc – 2'**

Accretion disk and bipolar ejection **Debris disk and protoplanets** **Planetary system**



1000 AU – 7" **300 AU – 2"** **30 AU – 0.2"**

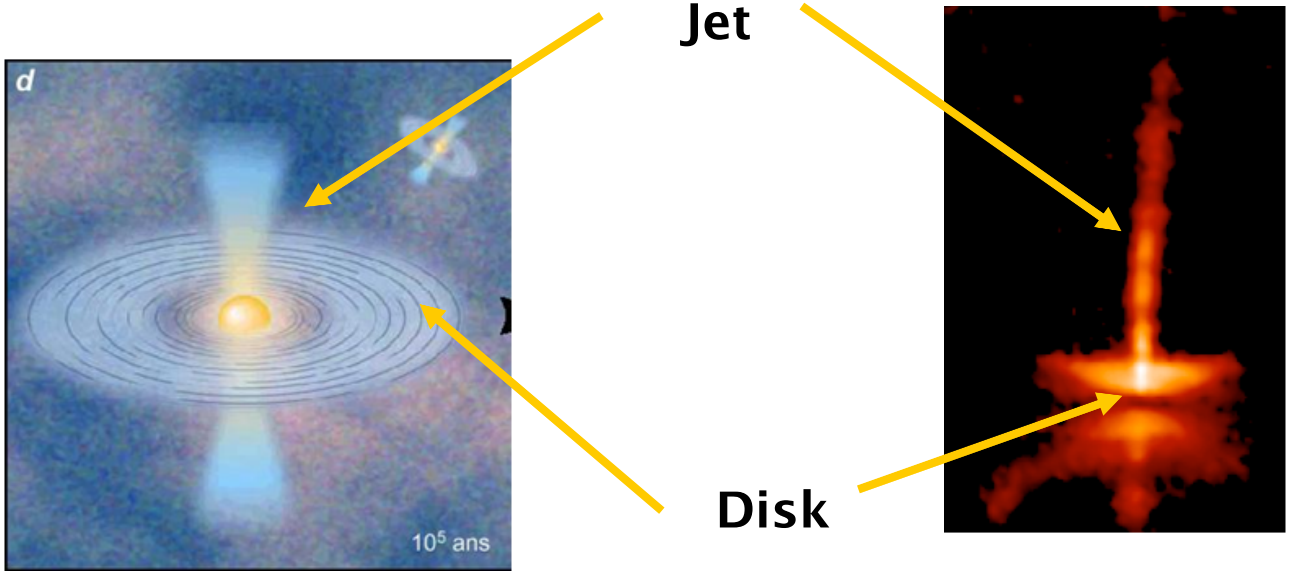
[Bouvier & Malbet 2001]

Formation scenario for T Tauri stars

T Tauri stars (TTS):

- Solar mass objects (~M⊙)
- Spectral types G-M

- Optically thick disks
- Obscuration the central star according to geometry
- Detailed vertical structure of the disk, physics of grain formation
- Jets and nebular structure (accretion, shocks)



HH30 seen almost edge-on by the HST (optical + NIR)

Formation scenario for HAeBe stars

- HAEBE = PMS stars of intermediate mass (1.5 – 10 $M_{\odot}$)
- Spectral types: B to F8

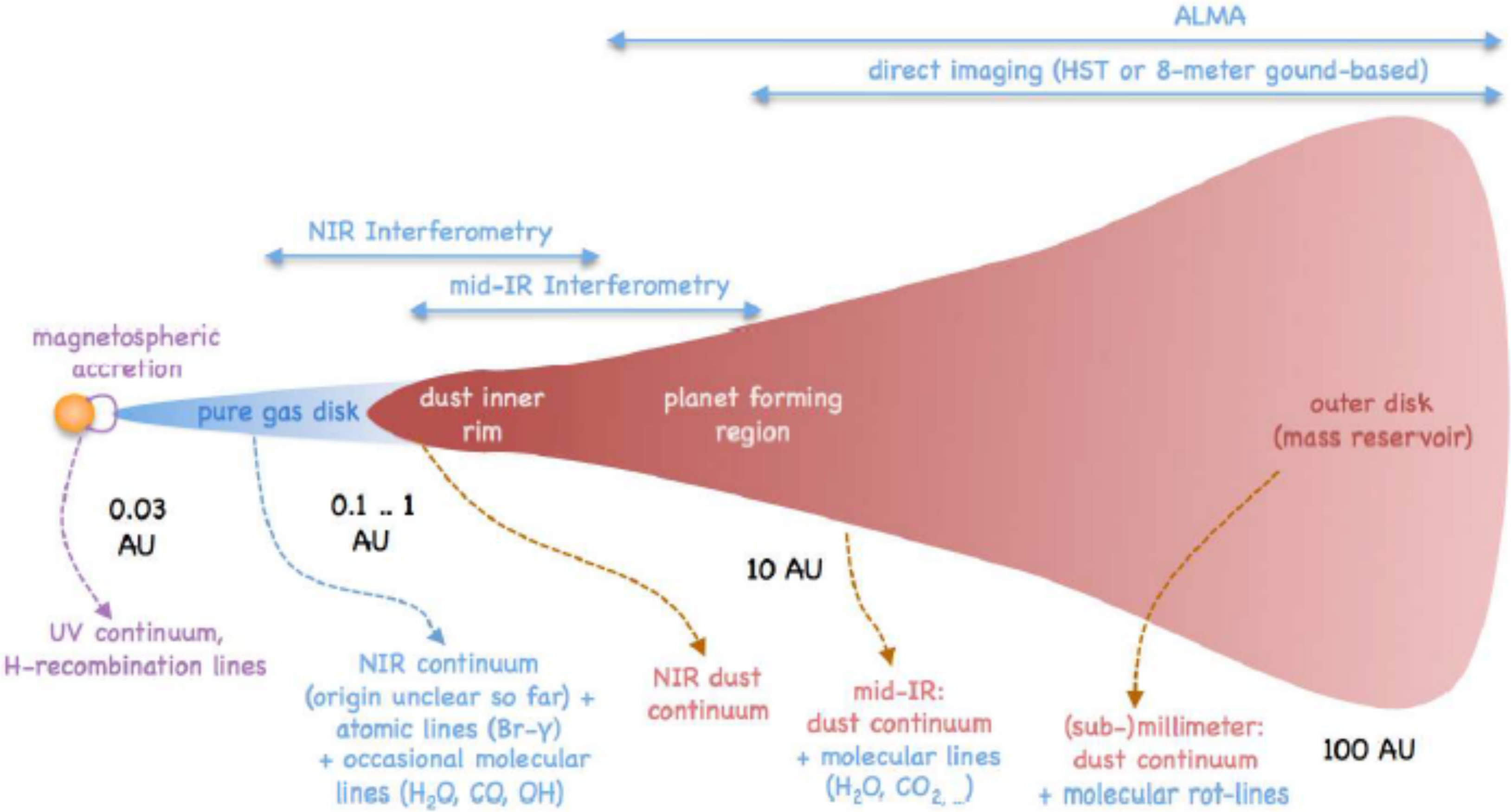
- Surrounded by a protoplanetary disk of gas and dust (complex environment)

- Like T Tauri stars, a large fraction of HAEBE lies in multiple systems (68 ± 11% – *Baines et al. 2006*).

- BUT contrary to the less massive T Tauri stars, formation scenario is very uncertain.

⇒ HAEBE are at an interface between two regimes of star formation

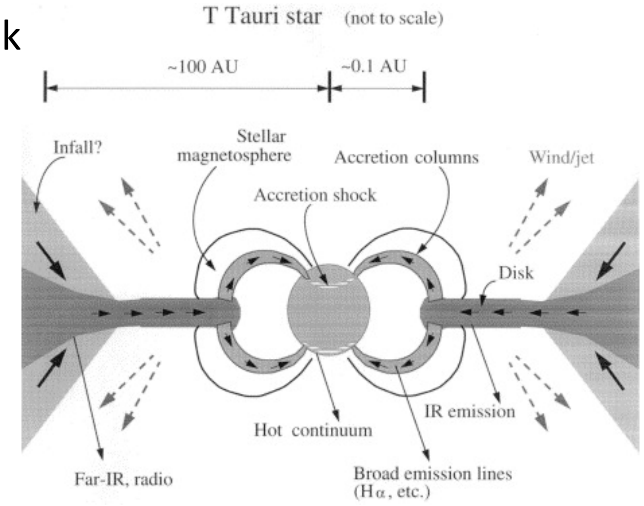
Structure of a protoplanetary disk



[Dullemond & Monnier 2010]

Accretion-ejection phenomena

- **Accretion** via the accretion columns (T Tau) or the inner disk
  - ⇒ Veiling, IR excess
    - Connections star/inner disk, inner disk/dust disk ?
    - Morphology of the inner rim of the dust disk ?
    - Processus of dissipation and evolution of the disk ?
    - Law of temperature, velocity, density in the disk
- **Ejection** via a wind (star, disk, …) and jets
    - Launching point and morphology of jets ?
    - Mechanisms that favor jet collimation ?
    - Mass-loss rate wrt mass-accretion rate ?
- **Formation of the Hydrogen** emission lines
  - ⇒ Connection between accretion and ejection
    - Line forming regions ?
    - Mechanisms that could explain the temporal variability ?

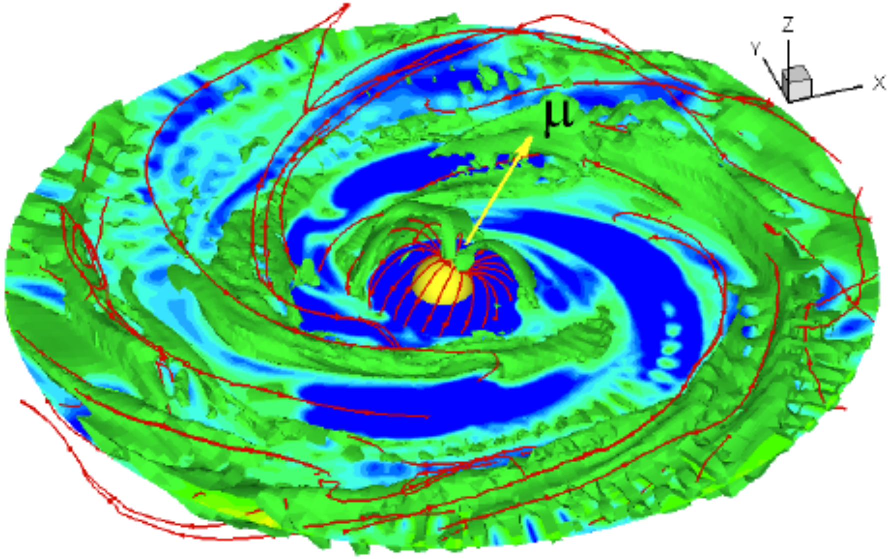


The complex innermost regions

- **Near-infrared (spectro-)interferometry** directly probes the emission within the innermost astronomical unit (AU), where key quantities for the star-disk-protoplanet(s) interactions are set. The regions probed by this technique are much more complex than expected.

- **3D MHD simulations** of accretion (driven by *magneto-rotational instability)* on to a rotating magnetized star with a tilted dipole magnetic field produce complex maps.

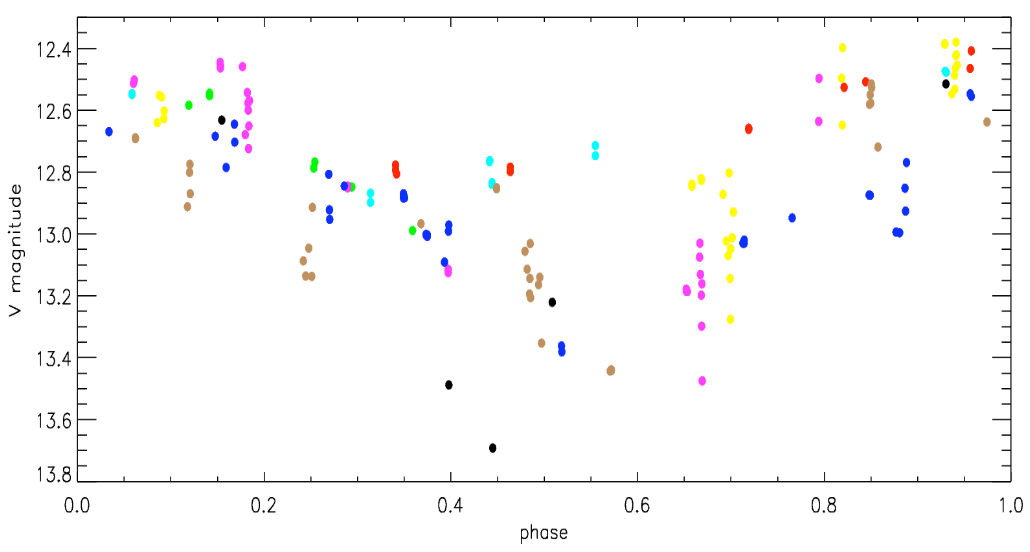
- All these complicated inner disk structures are strongly **time variable** on a timescale of weeks to years …

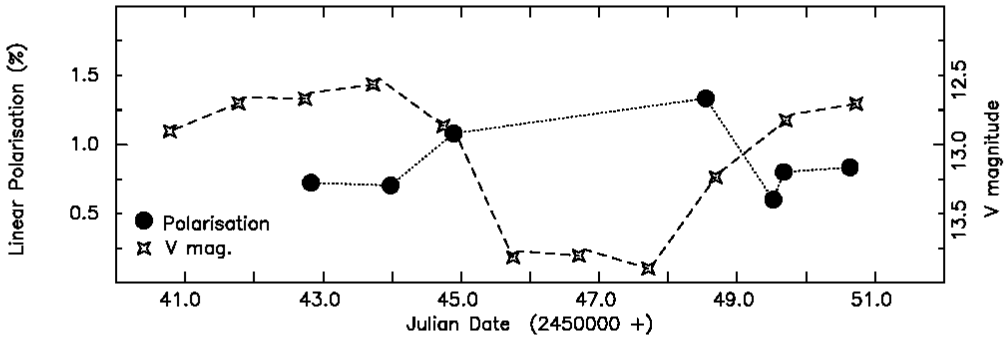


[Romanova et al. 2012]

The example of AA Tau

Simultaneous spectroscopy and photometry studies [Bouvier et al. 1999, 2003, 2007]



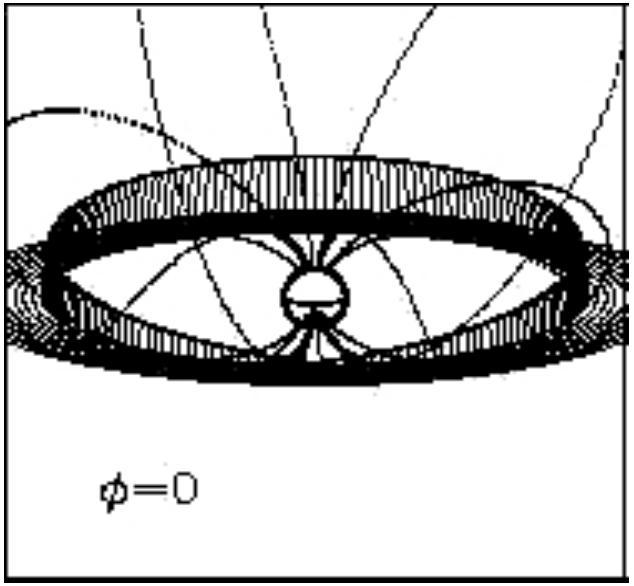


[Ménard et al. 2003]

Light curve shows periodical (~ 8.2 days) eclipses of the photosphere that occur without much color variation.

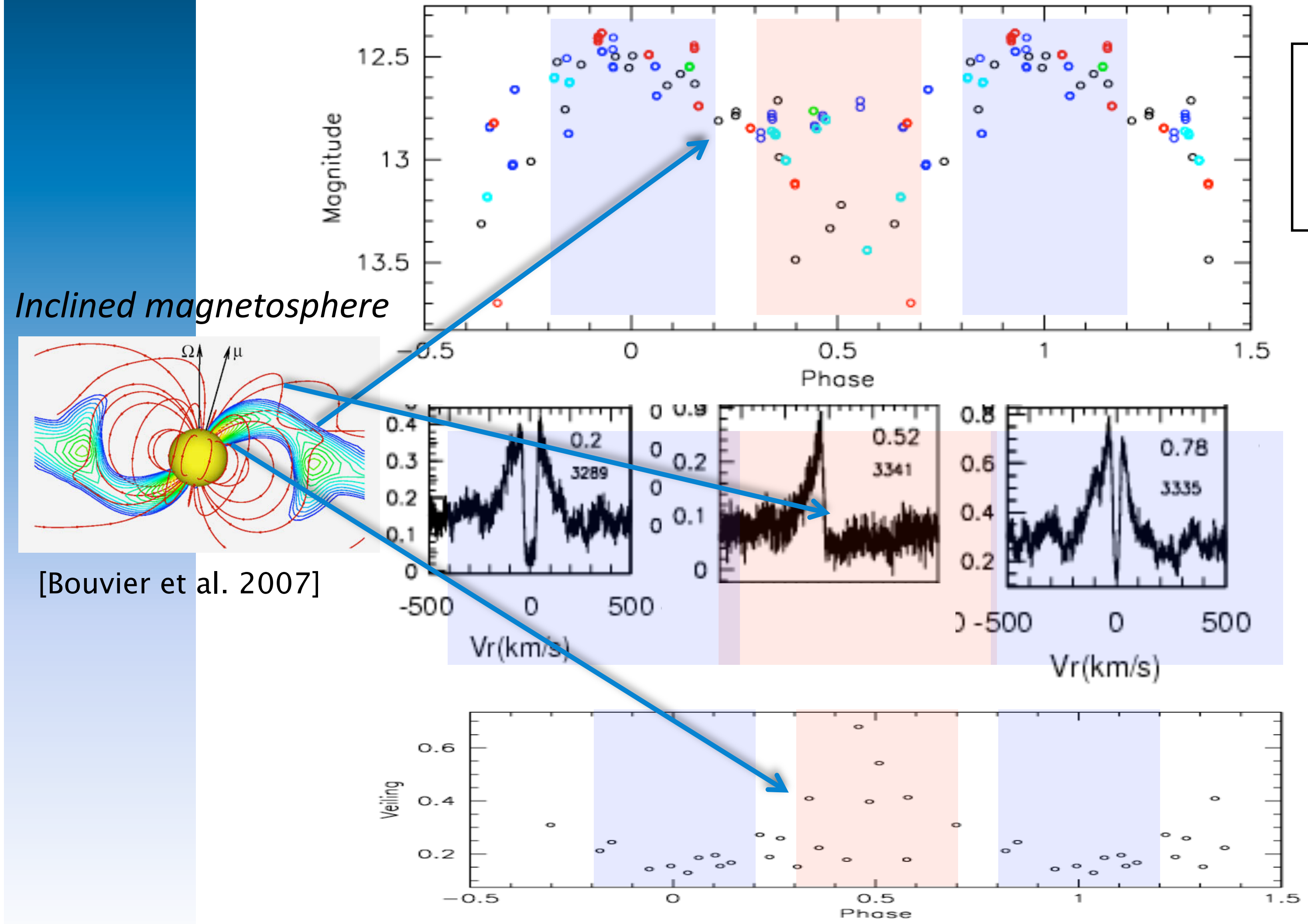
The linear polarization increases as the system fades.

Periodical occultation of the photosphere by an optically thick, magnetically-warped inner disk region



The example of AA Tau

Disk warp, accretion column, accretion shock : all spatially associated



Inclined magnetosphere

[Bouvier et al. 2007]

Periodical eclipses

(inner disk warp)

P=8.22d

Balmer lines

(accretion funnel)

Veiling

(accretion shock)

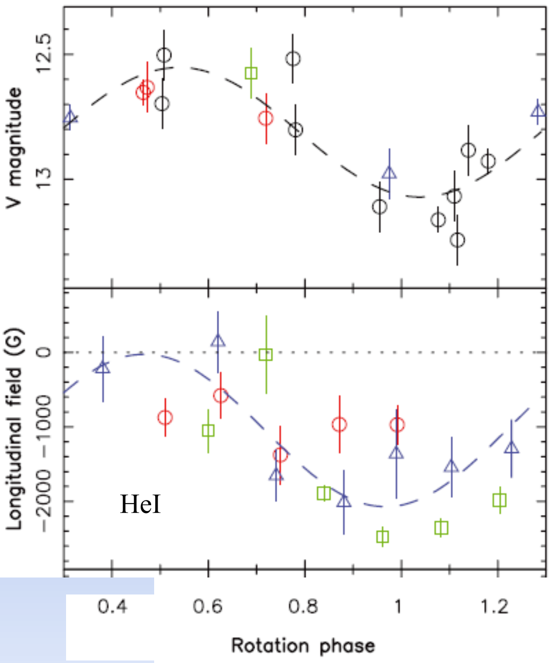
The example of AA Tau

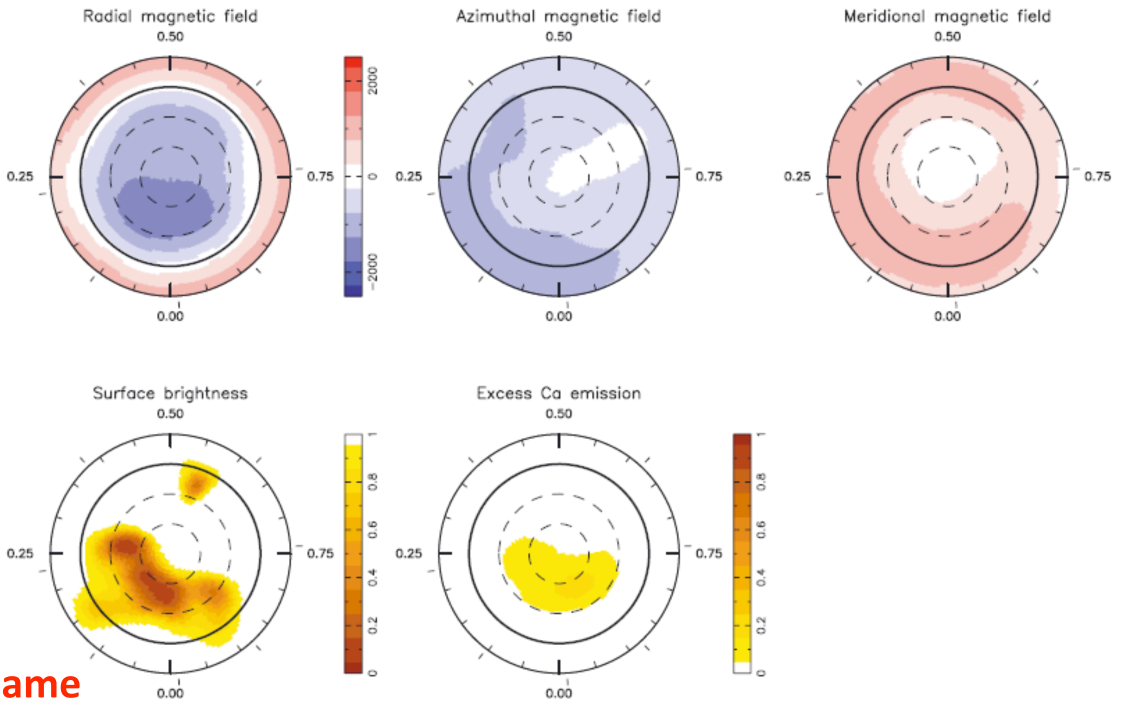
Spectro-polarimetric studies:

2-3 kG dipolar magnetic field, tilted at ~20 deg onto the rotation axis

[Donati et al. 2010]

Magnetospheric accretion and spin-down of AA Tau 1357





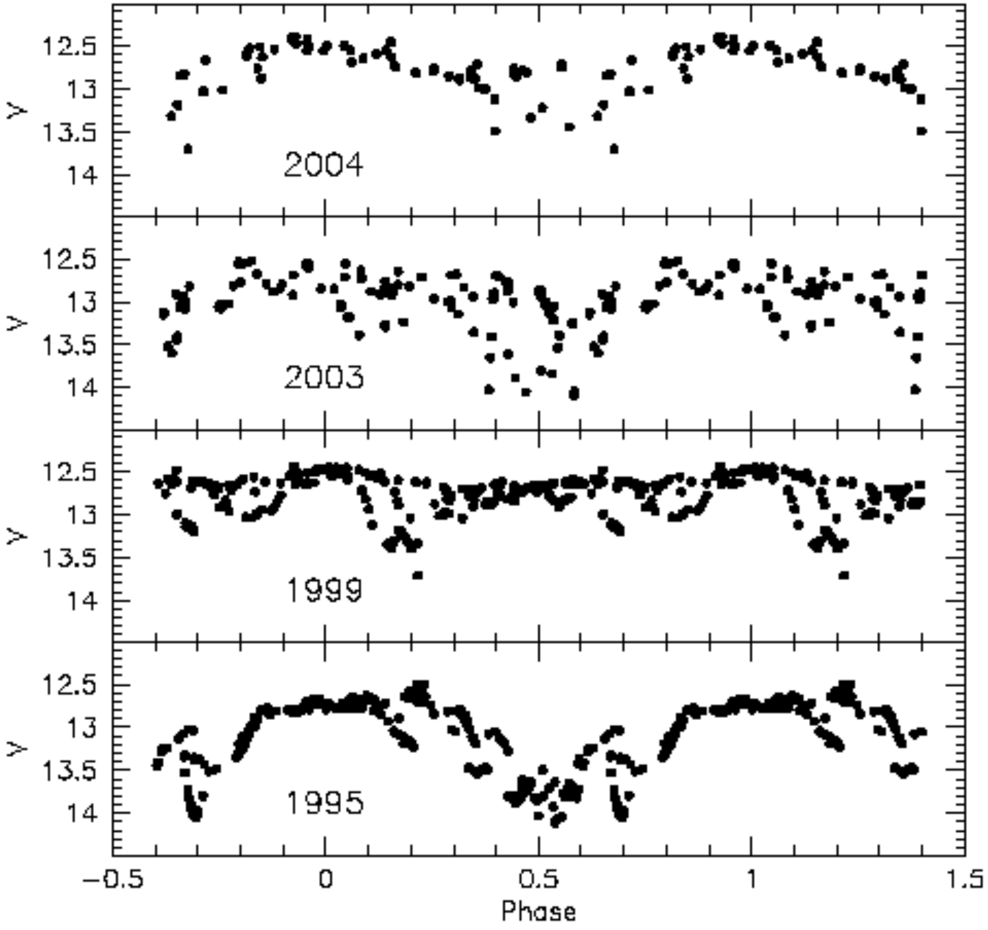
The magnetic pole is located at about the same azimuth as the disk warp that produces the eclipse

Both a cold (magnetic) spot and a hot (accretion) spot are found close to the magnetic pole

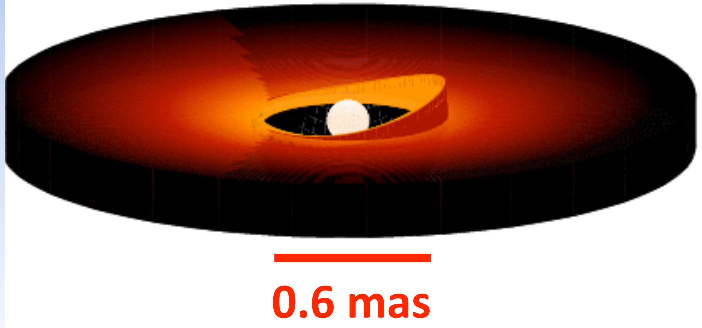
The example of AA Tau

Short term (weeks) **variability** supports the idea of **"magnetospheric accretion cycles"** on a timescale of a few rotation periods in accreting T Tauri stars.

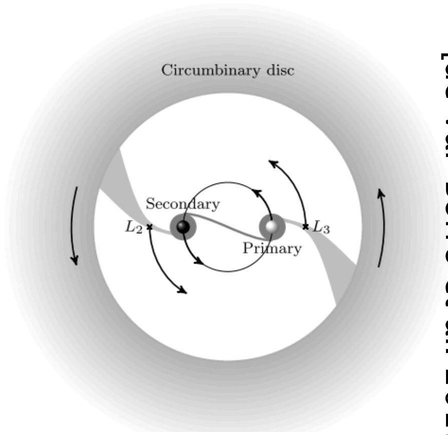
AA Tau's eclipses



Magnetic configurations of the star-disk interaction can also vary on a much longer timescale (~a few years).



Accretion in close binaries



[de Val–Borro et al. 2011]

- Stars orbit in a gap opened by tidal interactions inside a circumbinary disk.
- Young short period binaries (P < a few 10 days, sep~ a few 0.1 AU) cannot support large circumstellar disks.
  ⇒ They are surrounded by a **circumbinary disk**.
- Evidence of enhanced emission line activity close to periastron passages (DQ Tau (Basri et al.1997), UZ Tau E (Martyn et al. 2005)
  ⇒**non-axisymmetric accretion** perturbed by the orbital interaction with the inner disk

How does accretion proceed from the circumbinary disk onto the components of the system?

How do the components evolve if preferential accretion ?

Example of simulated accretion streamers

V4046 Sgr

[de Val-Borro et al. 2011]

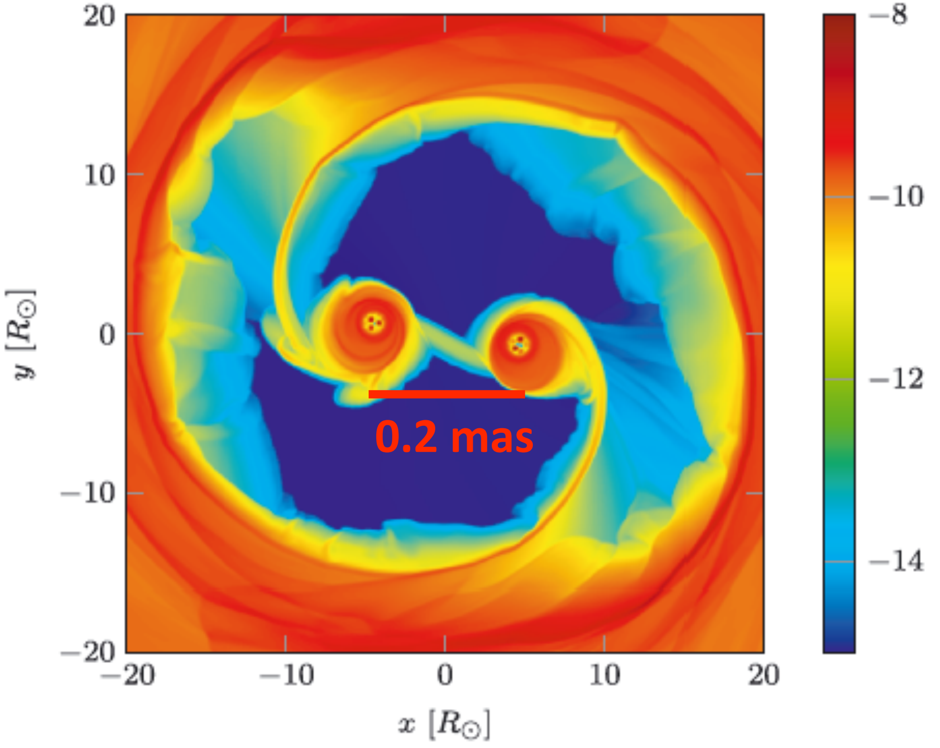


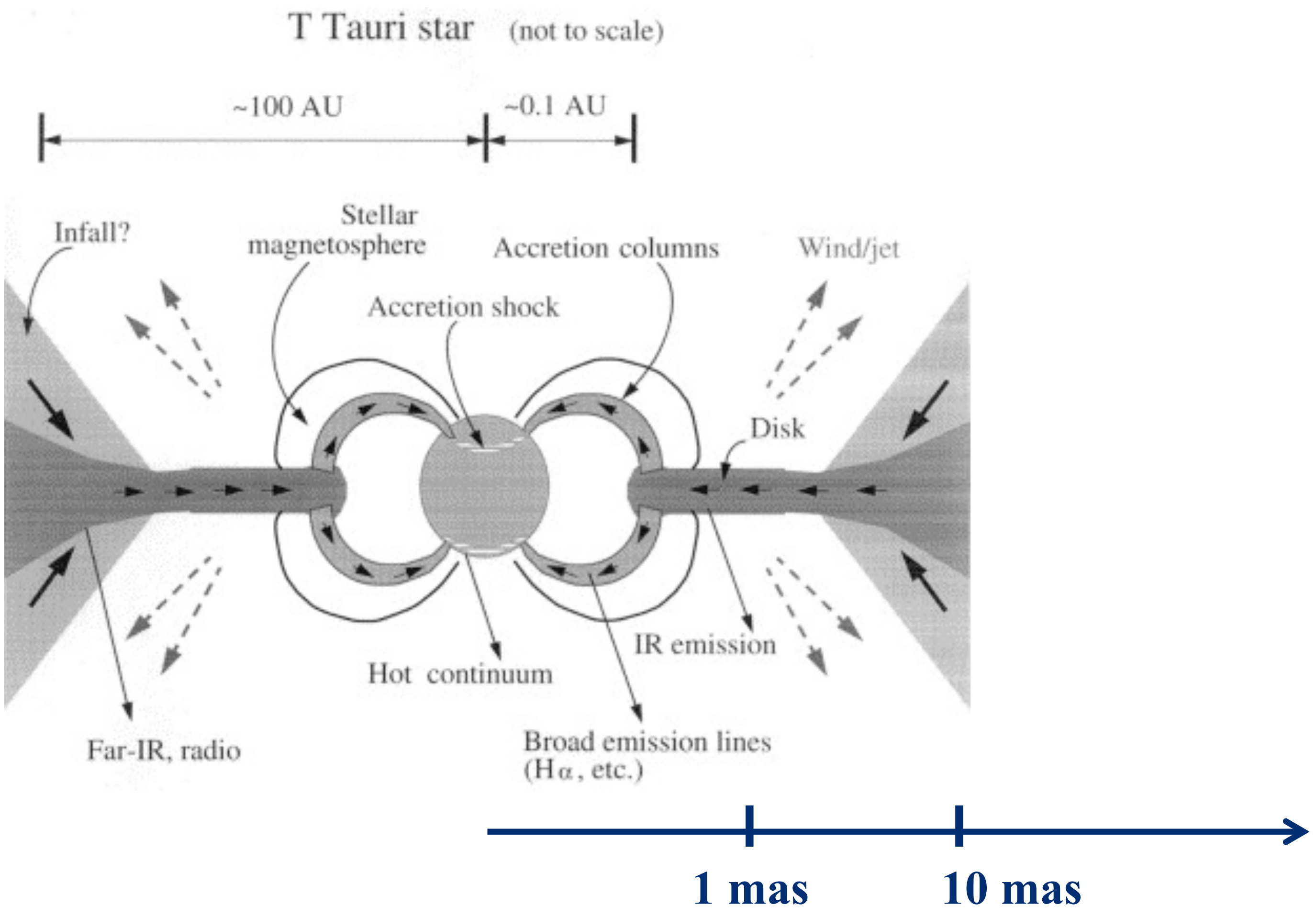
Figure 3. Surface density map in logarithmic scale for a simulation of the system V4046 Sgr after five orbits including accretion on to the stars. The initial surface density of the circumbinary disc is unity. The secondary is located at $(x, y) = (-4.72, 0)\,\mathrm{R}_\odot$, and the primary at $(x, y) = (4.52, 0)\,\mathrm{R}_\odot$. The system rotates in counterclockwise direction.

Parameter	Primary	Secondary
M	0.912 $\mathrm{M}_\odot$	0.873 $\mathrm{M}_\odot$
a_1, a_2	4.52 $\mathrm{R}_\odot$	4.72 $\mathrm{R}_\odot$
P	2.4213459 d	
i	35°	
e	$\lesssim$0.01	

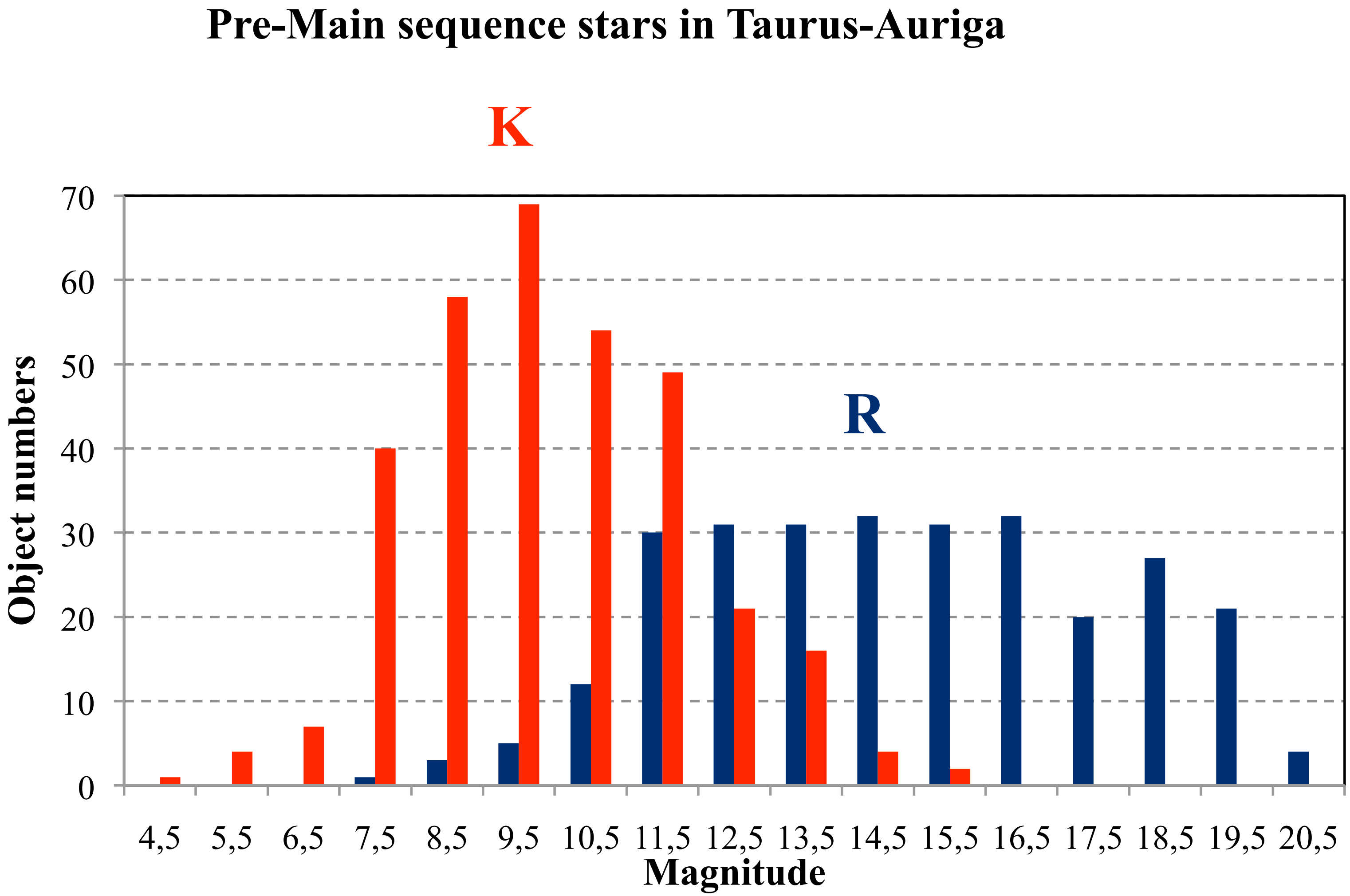
Magnitude en R = 9.5

Strong interest to access to **imaging capabilities** of these objects in the **visible** (+ IR) ranges

Requirements: angular resolution



Requirements: limiting magnitudes

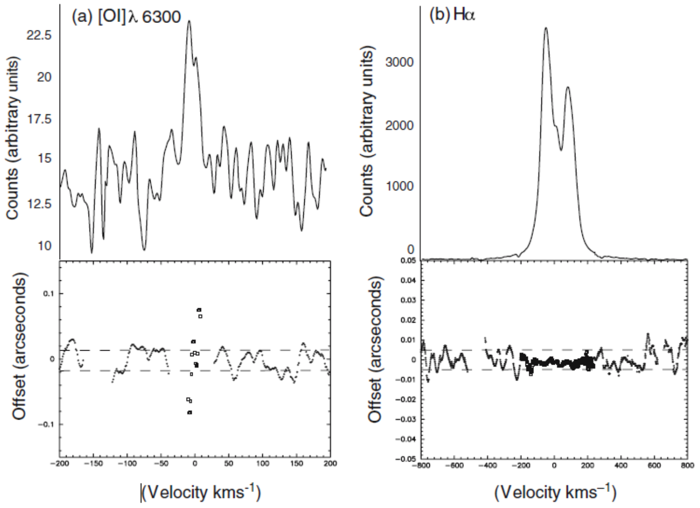


From Kenyon et al. 2008

Requirements: spectral resolution

Kinematics studies are of strong importance for:

- Wind and jets:
    - Several spectral channels in Hα



[Whelan & Garcia 2008]

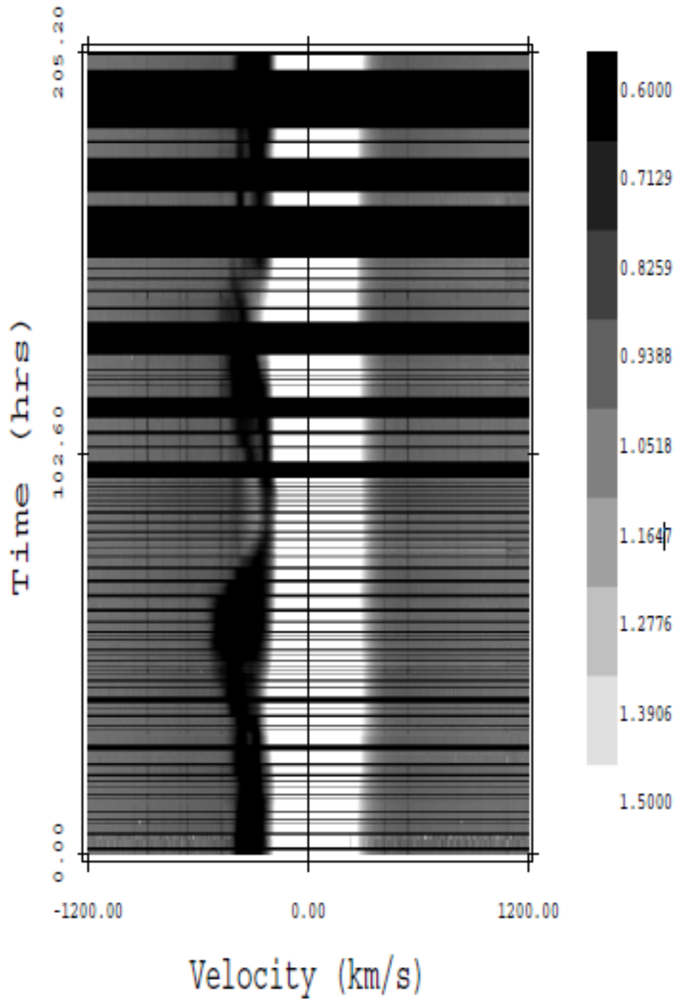
- Accretion flows:
    - Small radial velocity of the funnel flow close to the inner rim of the disk
    - Free fall velocity (~ 300 km/s) close to the star

➡ **Spectral resolution of several thousands and up to 20000**

Requirements: temporal sampling

All phenomena are timely variable
on timescales of days or even hours.

Snapshot imaging



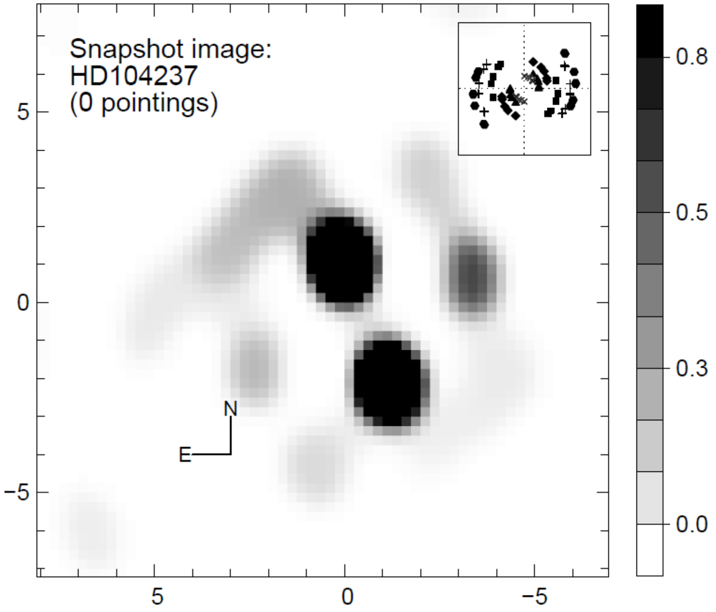
[Catala et al 1999]

Fig. 21. Dynamic spectrum of the Hα line. The height of each spectrum does not correspond to the actual duration of the corresponding exposure, but has been increased for display purposes.

How to go further?

- Interest to have a **limiting magnitude** high enough to allow to study a few numbers of typical objects.
    - TODO: identify these typical objects

- **Spectral Resolution**: structure and morphology can be studied with Hα considered as a whole
    - See Pionier YSO survey



- Interest of different spectral lines

(Hα but also OI for instance)