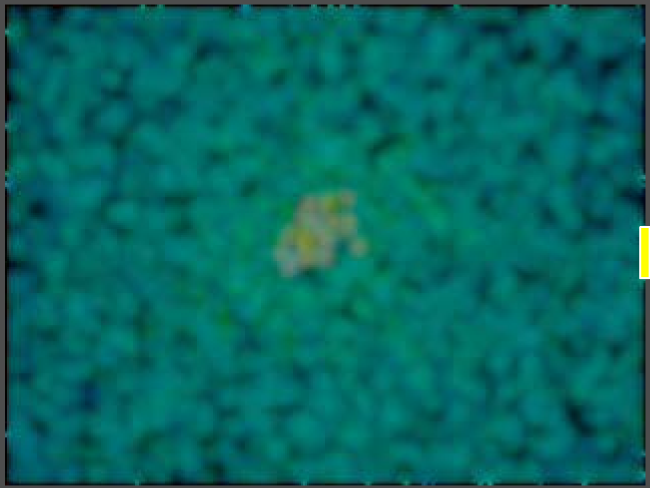
The formation of planetary systems: a UV view

Prof. Ana I Gómez de Castro
Universidad Complutense
in colaboration with Eva Verdugo and Brigitta von Rekoswki

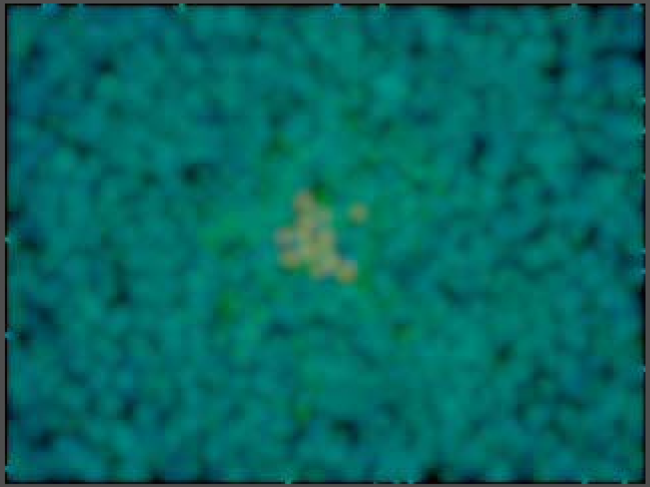
Universidad Complutense de Madrid

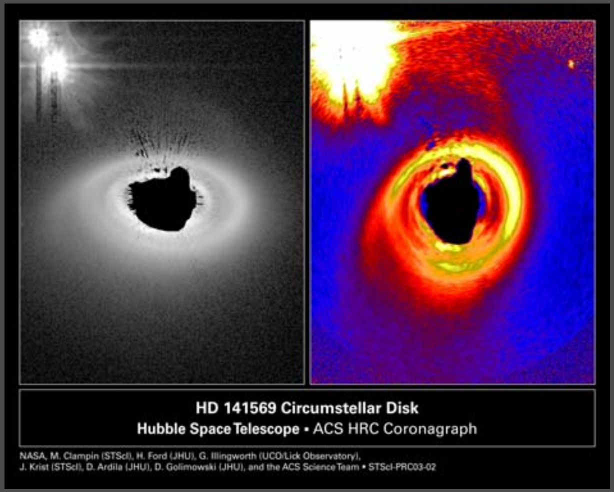
Menu

- From clouds to disks and young planets
- From the Solar System to disks and young planets
- The current paradigma
- Information from ultraviolet radiation
- Impact of the ultraviolet radiation field on the evolution
- Some concluding remarks

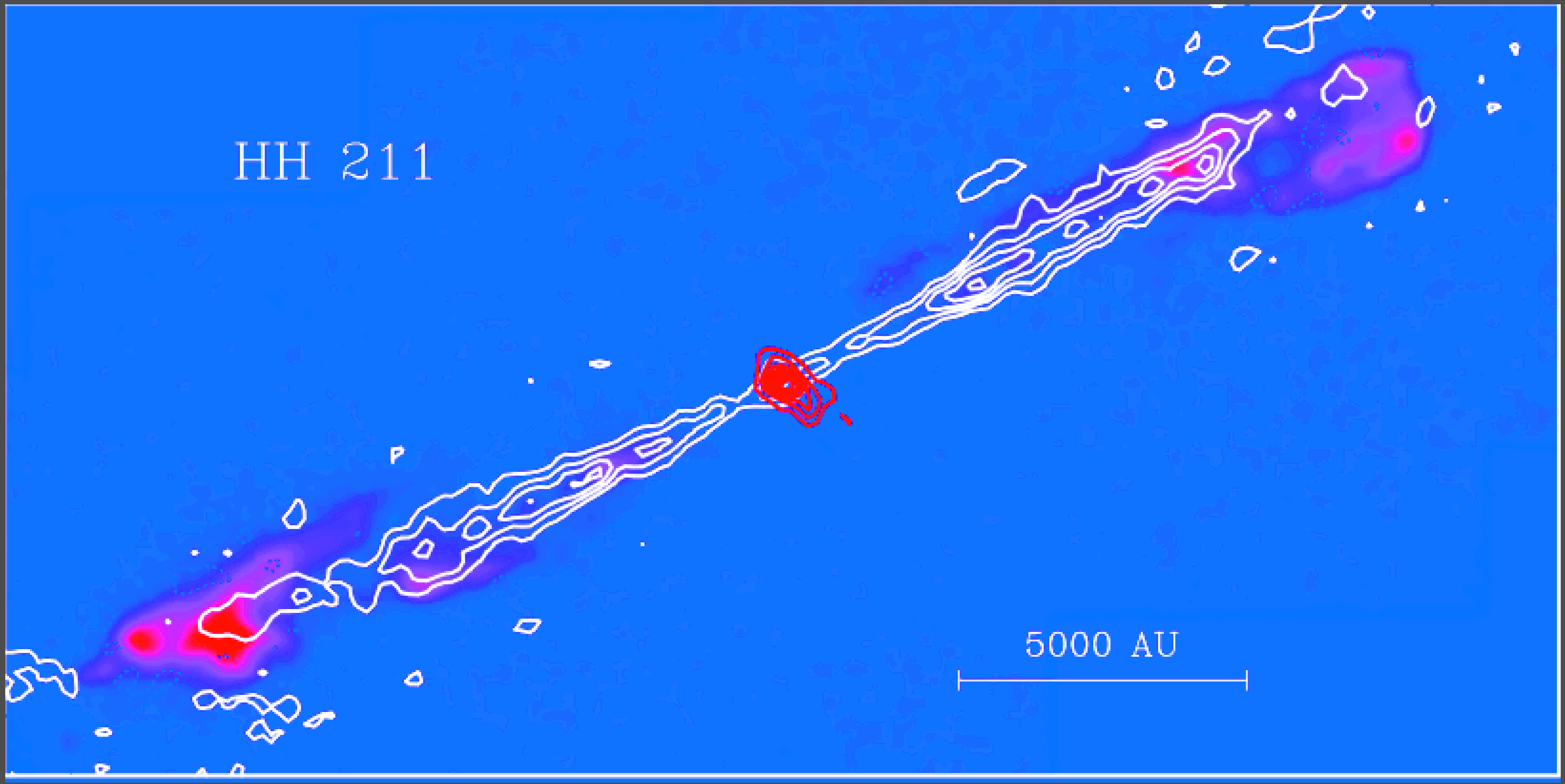


Edge-On Protoplanetary Disk
Orion Nebula
HST · WFPC2
PRC95-45c · ST ScI OPO · November 20, 1995
M. J. McCaughrean (MPIA), C. R. O'Dell (Rice University), NASA





HD 141569 Circumstellar Disk
Hubble Space Telescope • ACS HRC Coronagraph
NASA, M. Clampin (STScI), H. Ford (JHU), G. Illingworth (UCO/Lick Observatory),
J. Krist (STScI), D. Ardila (JHU), D. Golimowski (JHU), and the ACS Science Team • STScI-PRC03-02



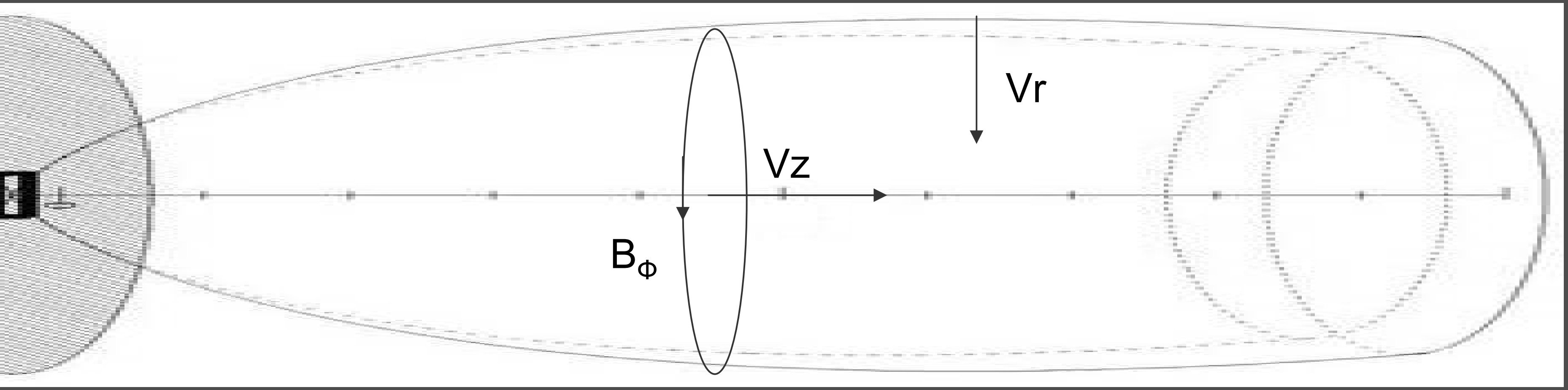
IRAM map

The source of the outflow

- Mechanical luminosity of molecular outflows larger than radiative luminosity from the stars.

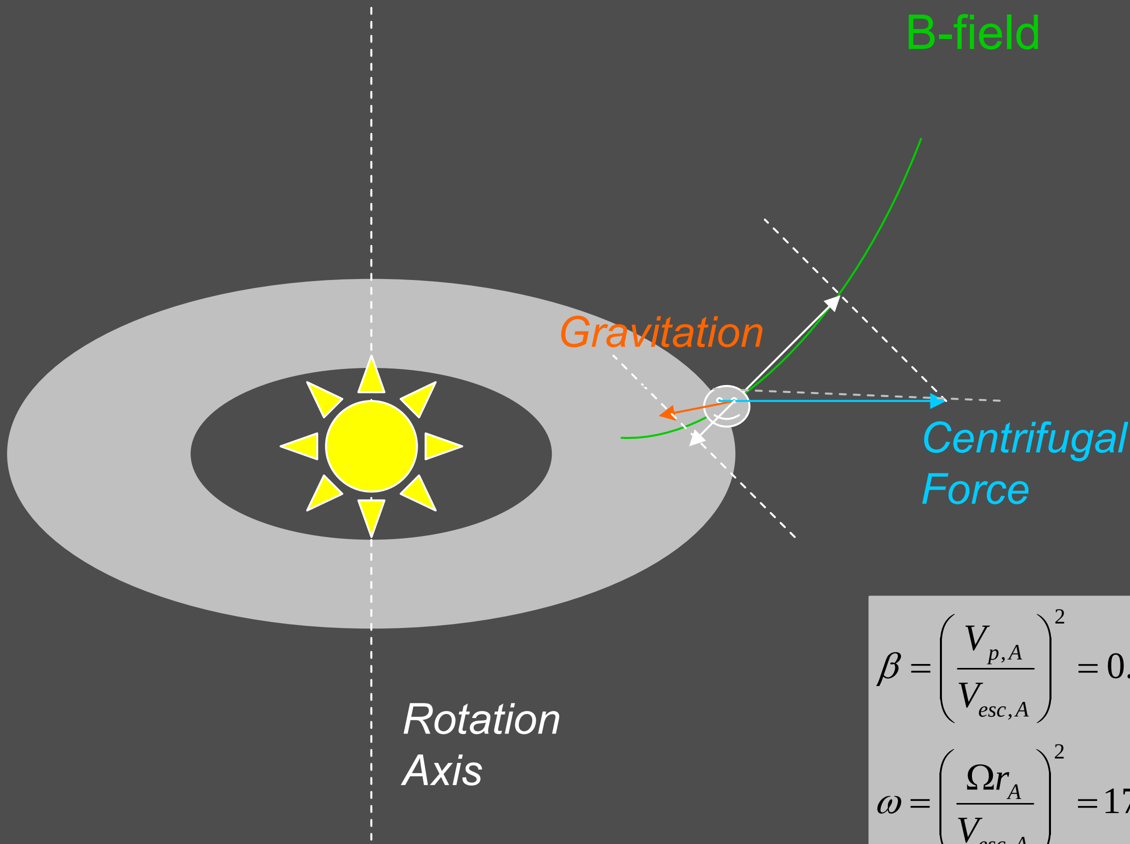
- Another source of thrust required: centrifugal gear from the disk

$\boldsymbol{J \times B} = -V_z B_\Phi \boldsymbol{u_r} = \boldsymbol{V_r}$



Blandford and Payne, 1982

An analogue of the solar wind for disks: disk winds (Pudritz,1986)

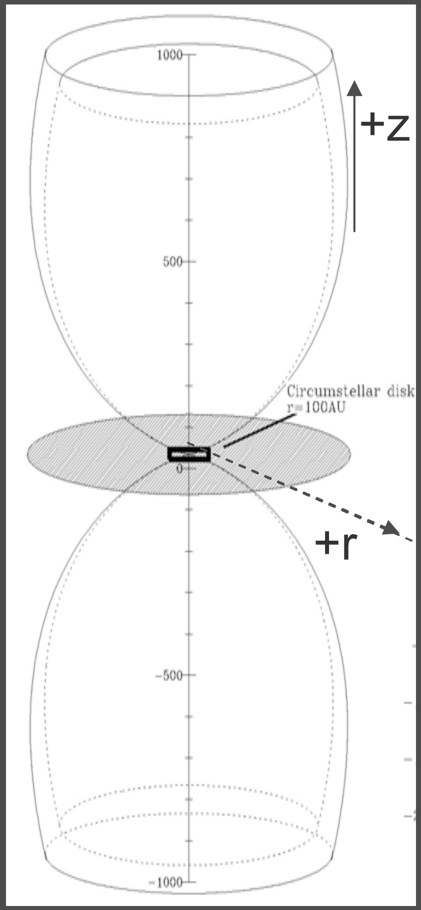


$$\beta = \left(\frac{V_{p,A}}{V_{esc,A}} \right)^2 = 0.125$$

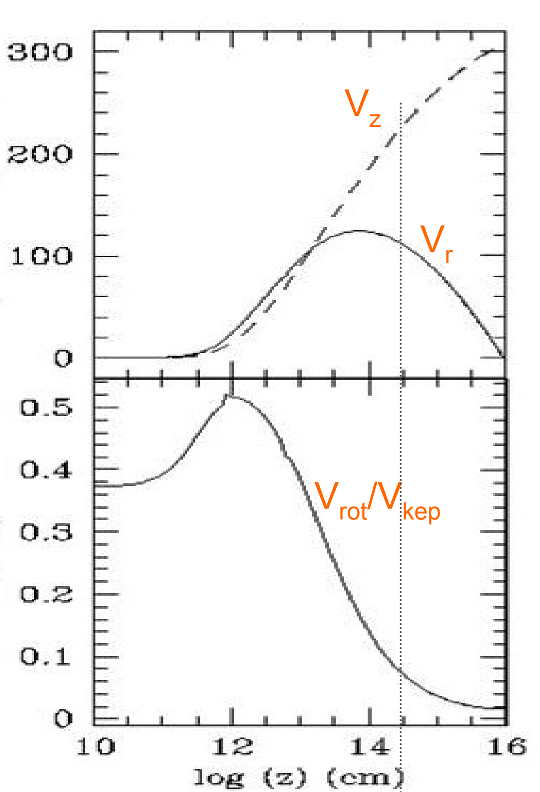
$$\omega = \left(\frac{\Omega r_A}{V_{esc,A}} \right)^2 = 17.1154$$

$$\theta = \left(\frac{C_{s,A}}{V_{esc,A}} \right)^2 = 0.196229$$

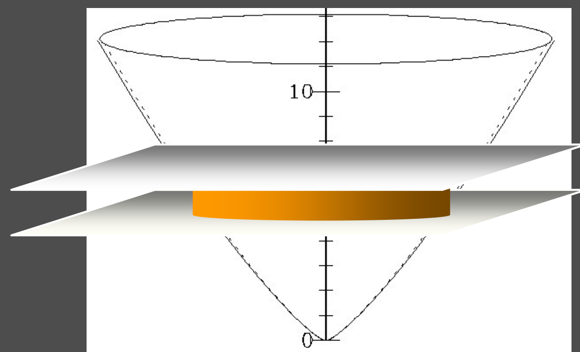
$$\gamma = 1.05$$



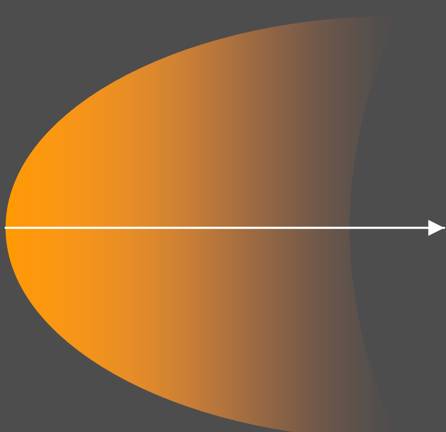
Gómez de Castro & Ferro-Fontán, 2005

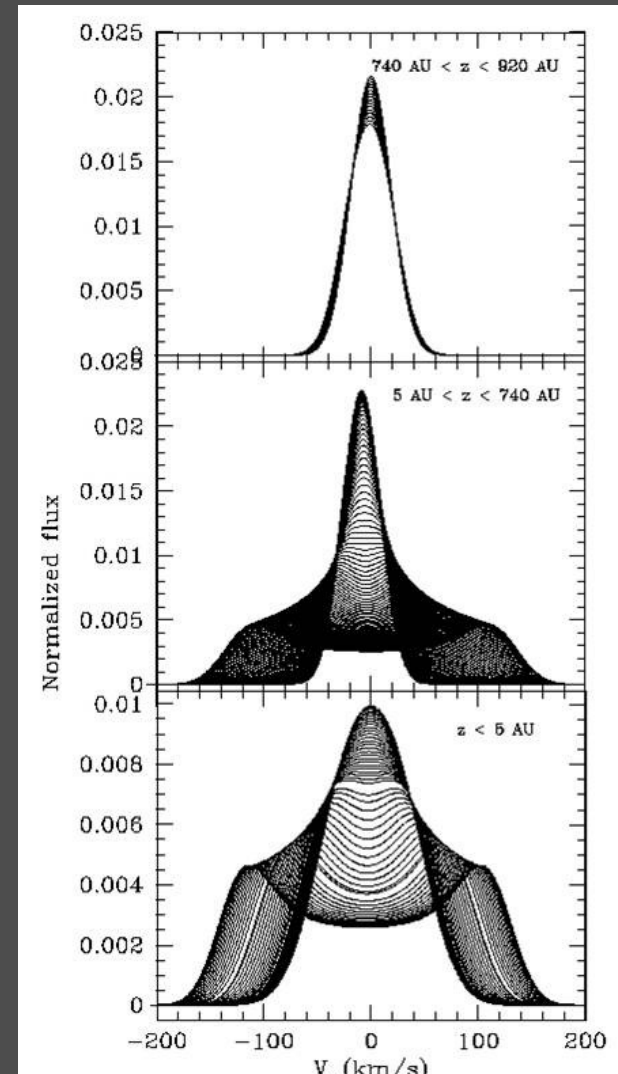


THE KINEMATICAL SIGNATURE OF EACH LAYER IS DIFFERENT



From z=0 to z=12 AU

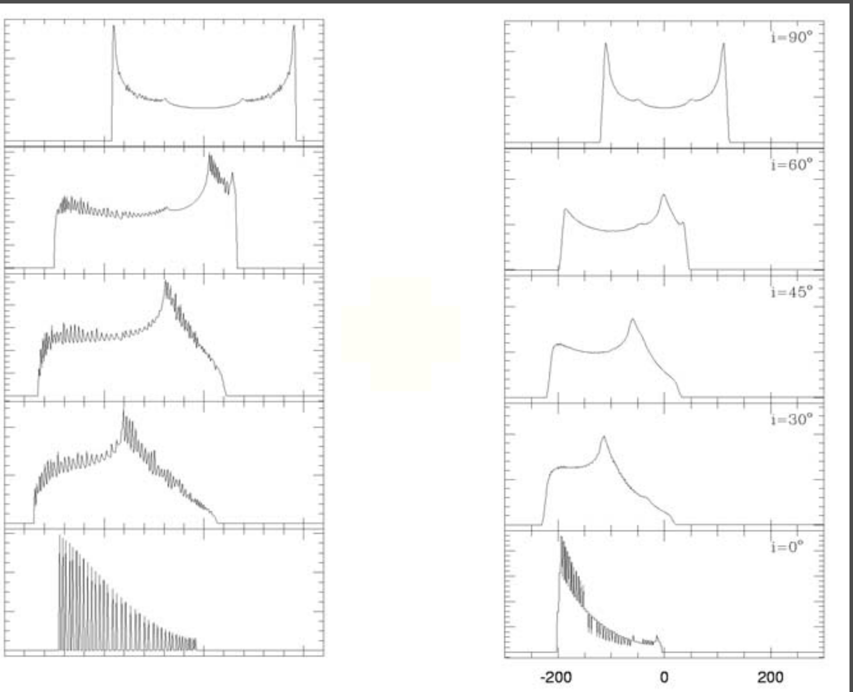




Building line profiles….

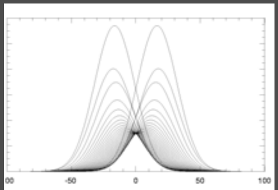
KINEMATICS

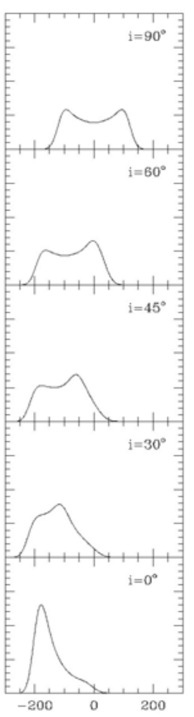
DENSITY
&
VOLUME



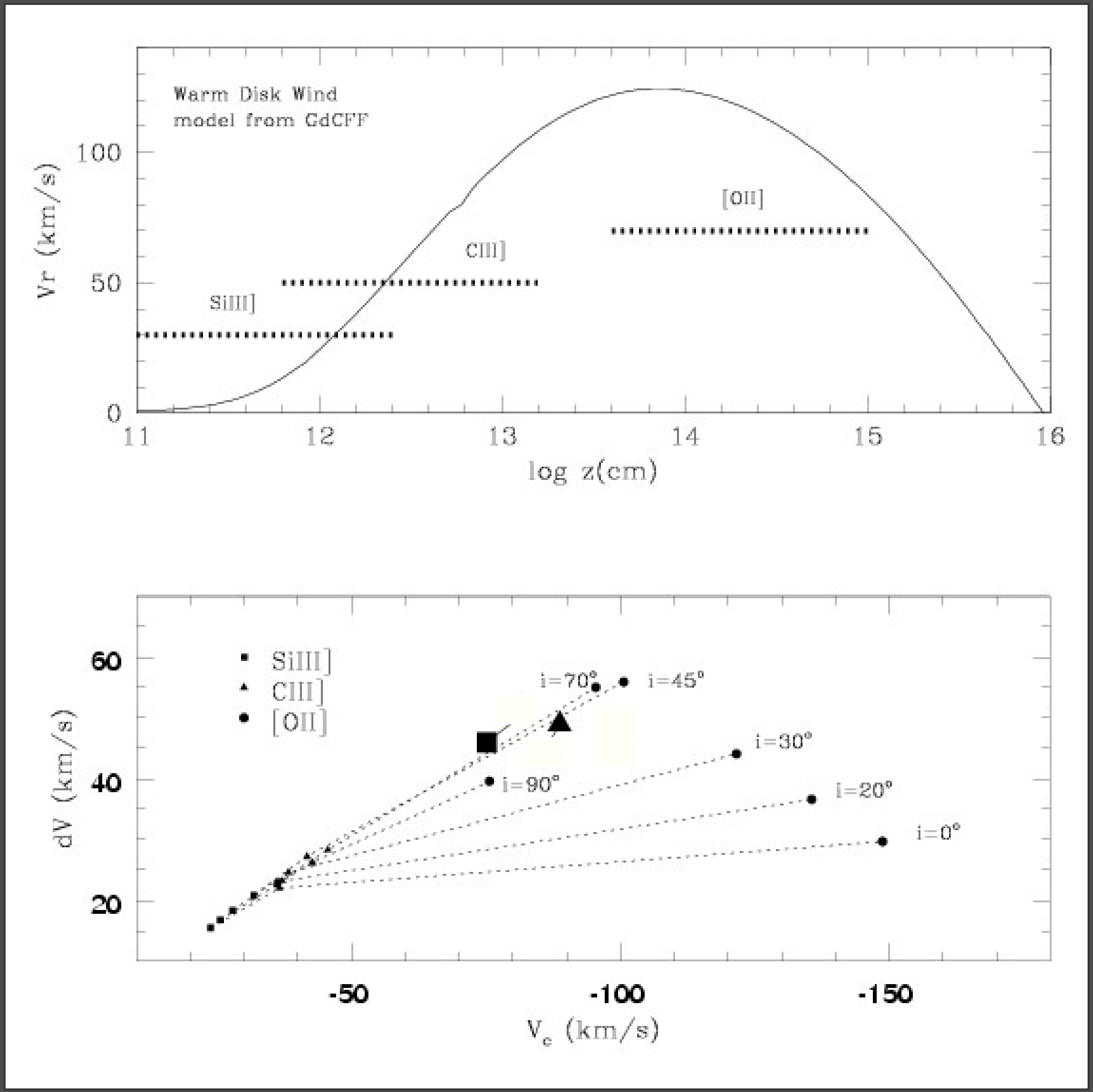
Gomez de Castro & Ferro-Fontan, 2004

THERMAL BROADENING





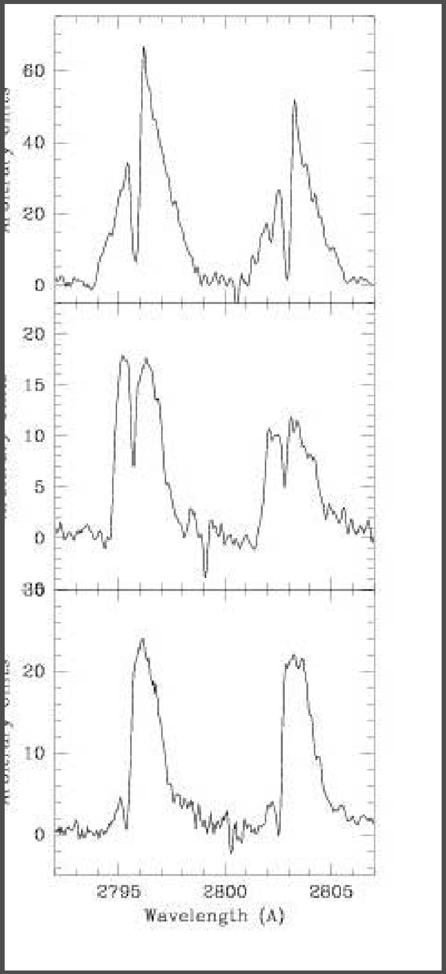
The thermal stratification could be used to study the properties of the flow

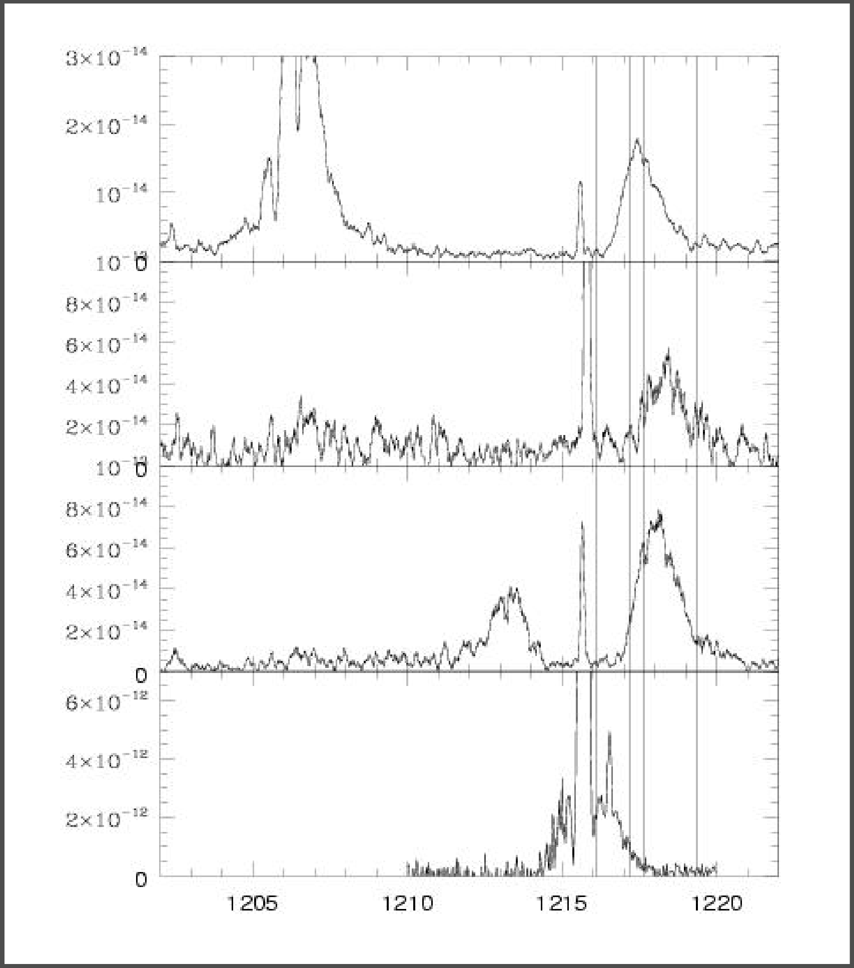


LATITUDE DEPENDENT OUTFLOWS

Mg II Profiles-types

Ly-alpha profiles

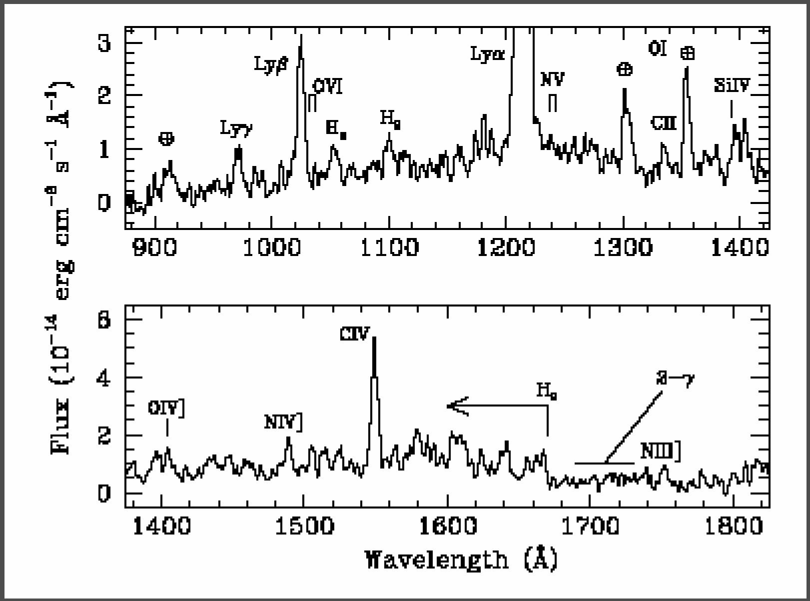




Gómez de Castro,97

Gómez de Castro,07

The large scale outflow



HH 2 with HUT: Raymond et al, 97

Two phase model:

- *warm component* (T=10^4K, n_e =10^3cm^{-3})
- *hot, dense component* (T=10^5K and n_e = 10^6cm^{-3}) and filling factor 0.1%-1%.

(from HH29 optical and UV observations by Liseau et al. 1996)

BASIC PROBLEMS

There must be something else than disk winds because:

- Cool disk winds are unable to reproduce the hot plasma observed
- Hot disk winds do not reproduce the wide observed profiles
- Winds vary in scales of from 1000 seconds to 100 years
- All tracers (specially en HH flows) suggest clumpy winds with two clear components

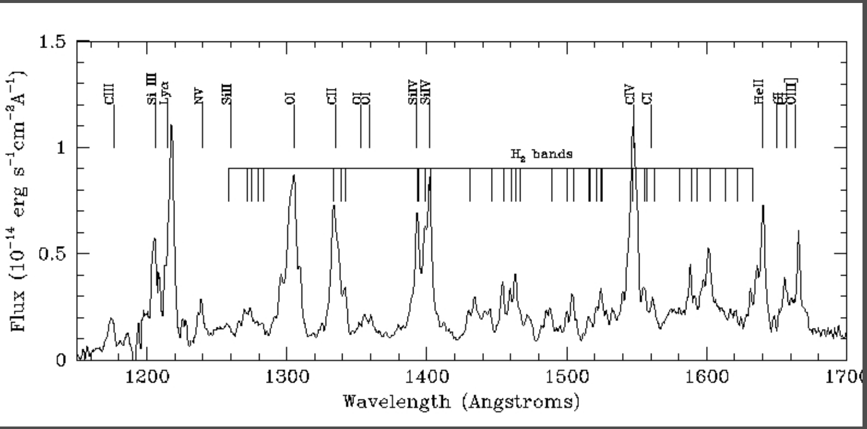
...

The paradigm of enhanced solar activity

The UV spectrum of the T Tauri Stars (TTSs) has:

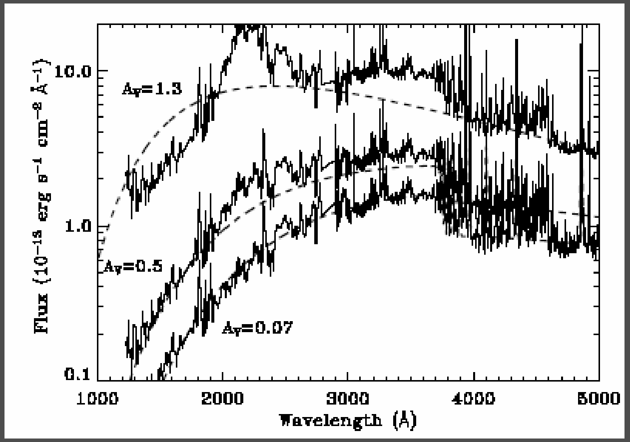
- weak continuum
- many strong emission lines (CII->HeII)

(about 2-3 orders of magnitude stronger than observed in main sequence stars).

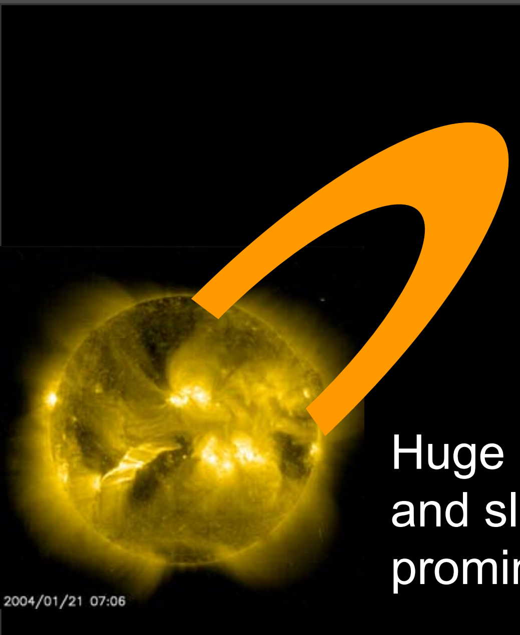


Simple models of hydrogen f-f and f-b emission added either to black bodies or to the spectra of standard stars reproduce the UV continuum reasonably well (Calvet et al. 1984; Bertout et al. 1988; Simon et al. 1990). The fits yield chromospheric-like electron temperatures (1-5 10^4K).

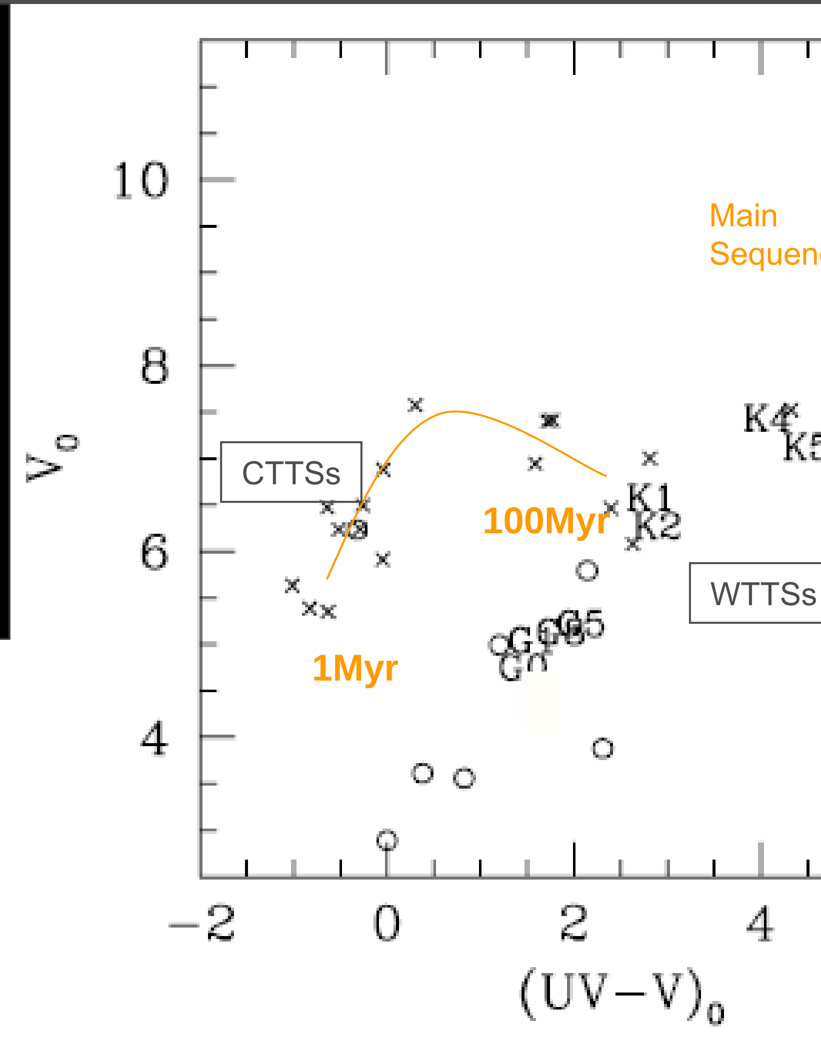
Extinction is not high for most of them, they are weak because unless TW Hya (…) they are at 140 pc.

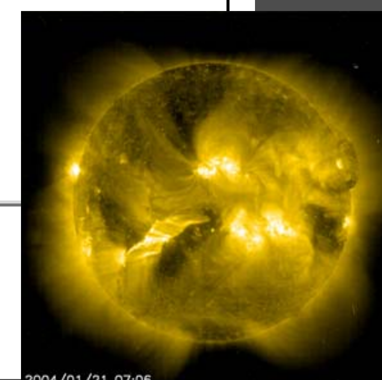


RU Lup: Herczeg et al 2005



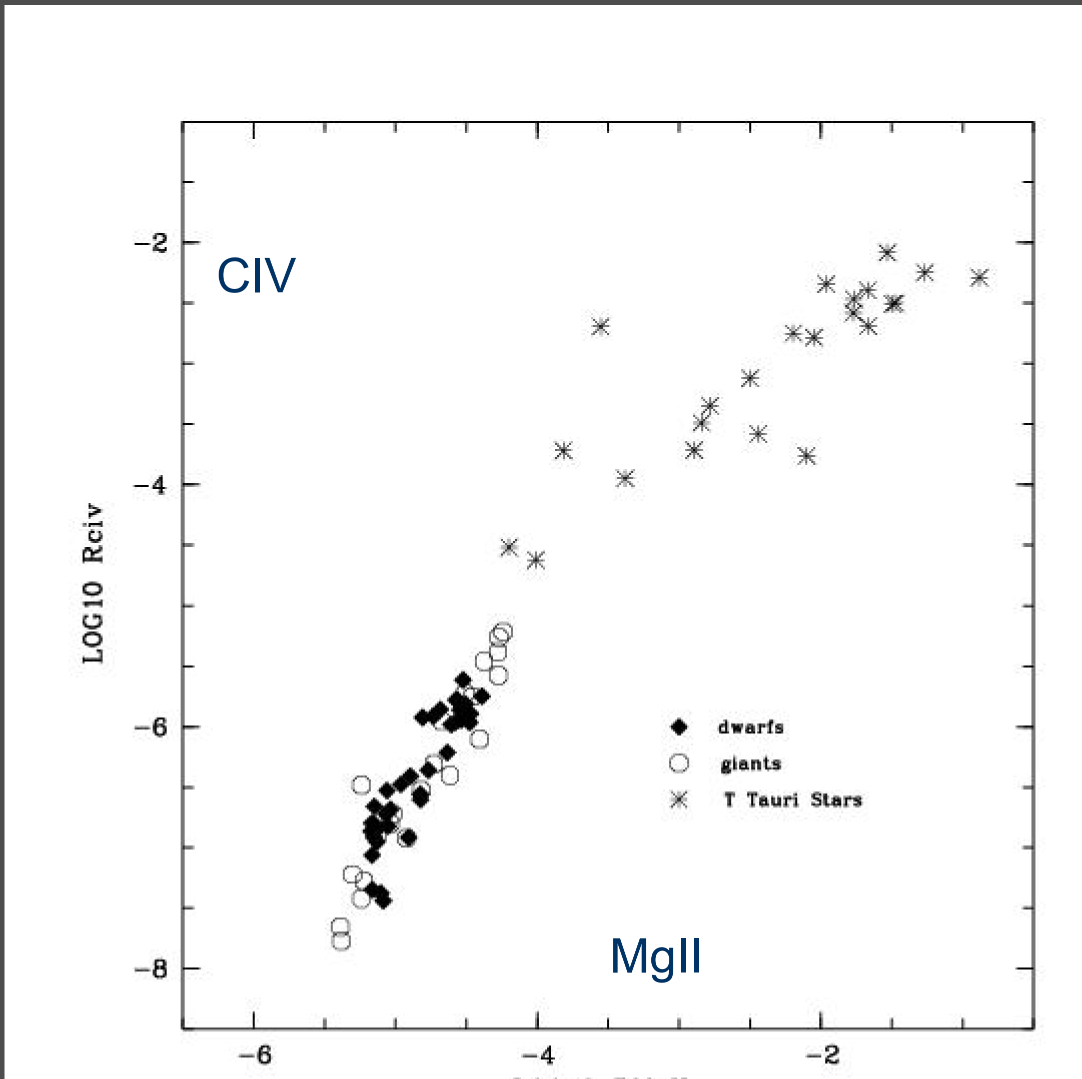
Huge loops and sling shot prominences

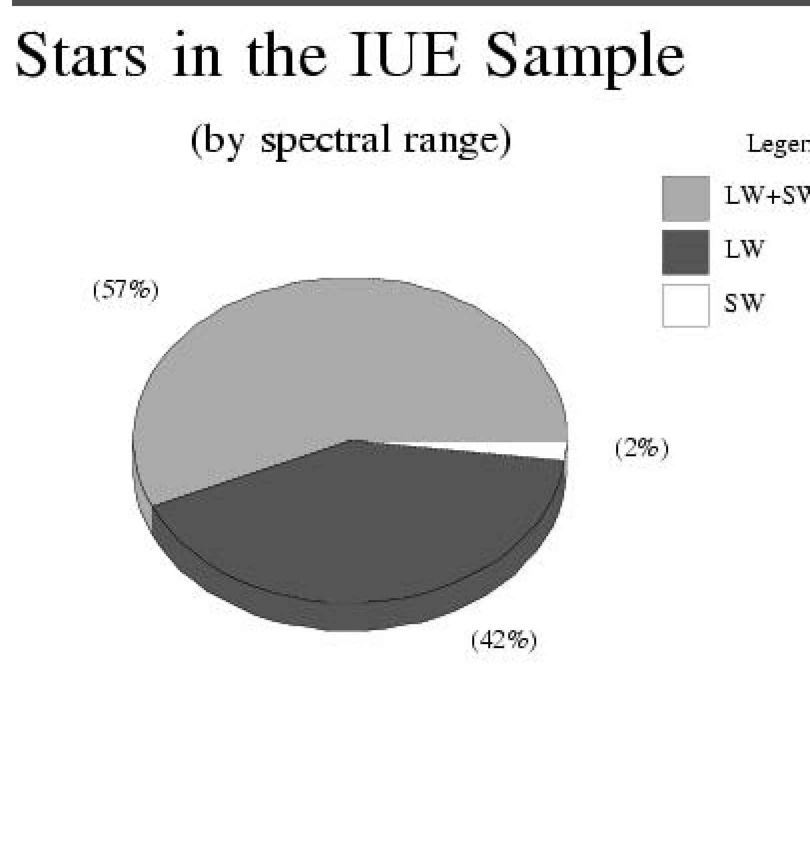




A factor of 50 enhancement on UV fluxes was converted into a factor $(20)^{1/2}$ in radius of the atmosphere

THE IUE SAMPLE

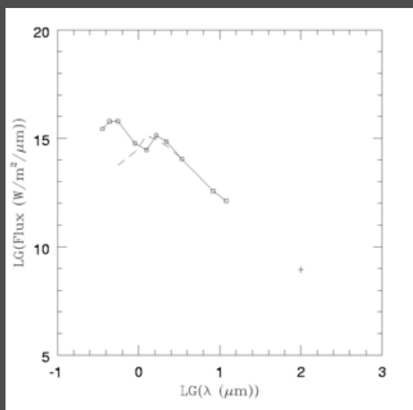




BUT INFRARED EXCESSES REQUIRED THE PRESENCE OF DISKS

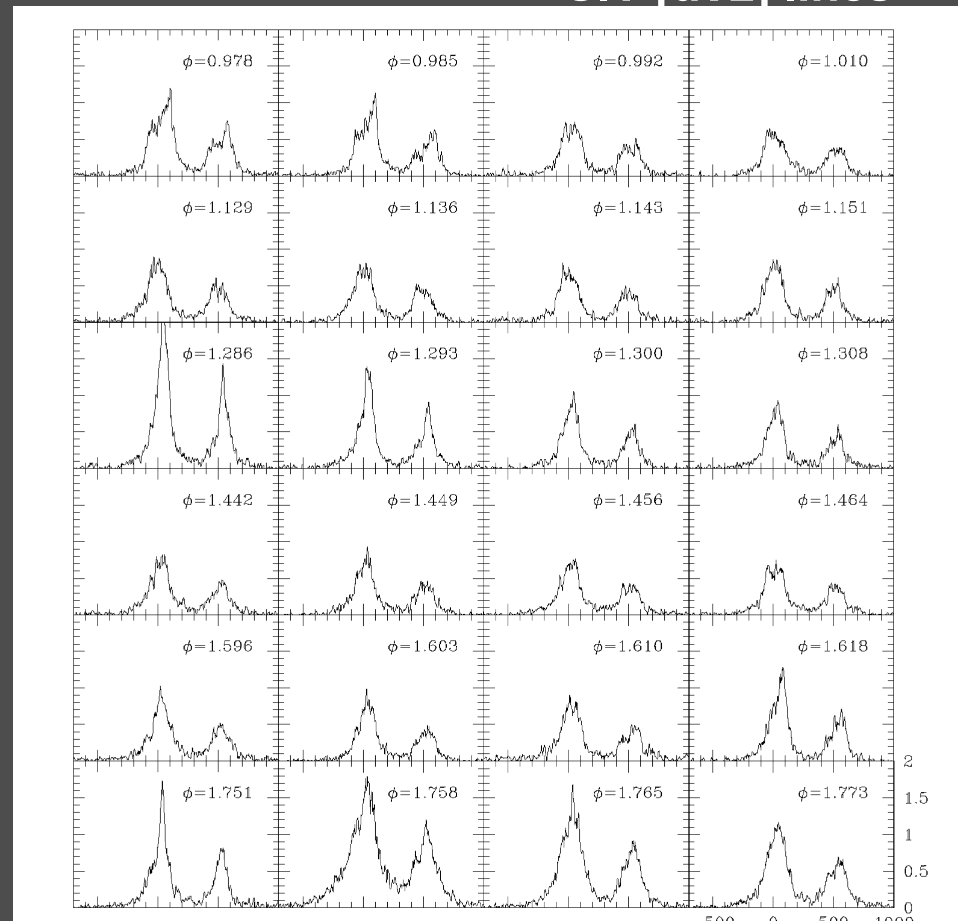
… AND THERE WERE SOME VERY PECULIAR FLARES!

AB DOR "FLARES":



Gómez de Castro 2002

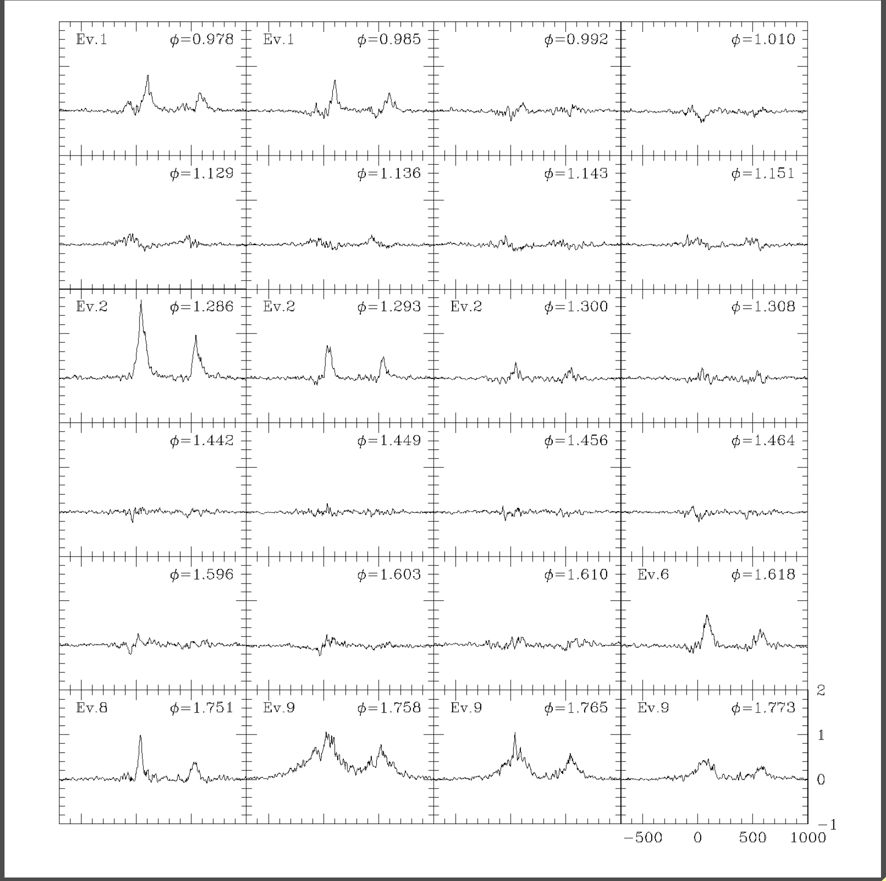
CIV [uv1] lines



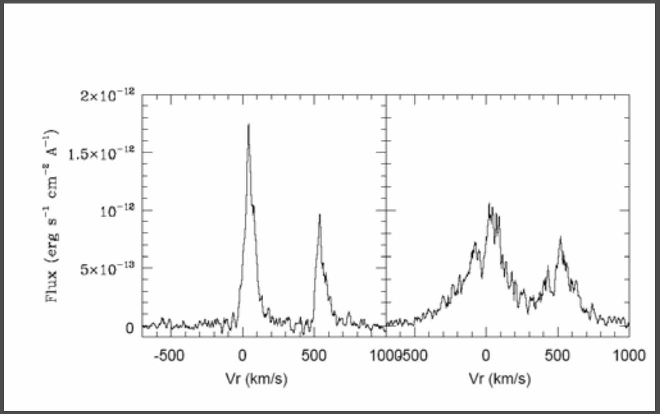
Gómez de Castro 2002

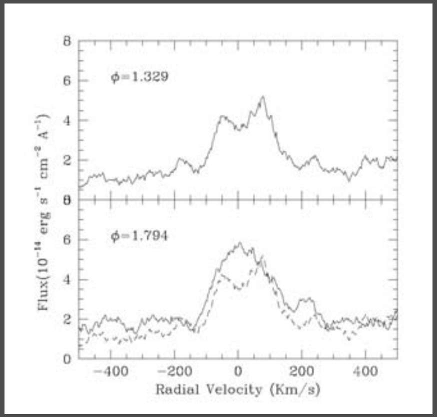
AB Dor Properties:

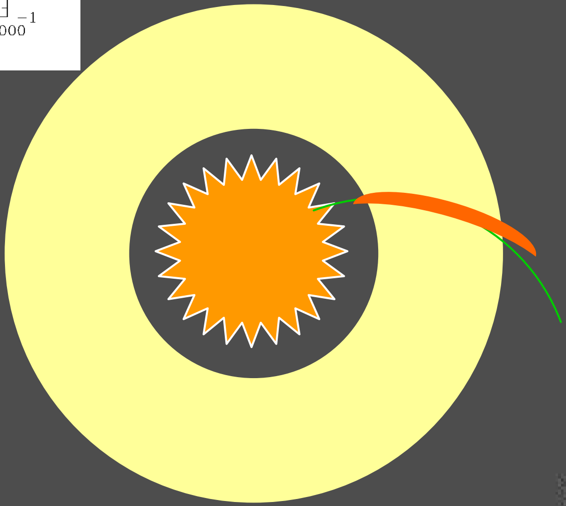
Age 20-30 Myrs
Rotation Period: 0.51479 d
Surface field: >500 G



The *very broad wings* are most probably related with the interaction of plasma flows along curved field lines with remnant gas in the disk...







A.I. Gómez de Castro

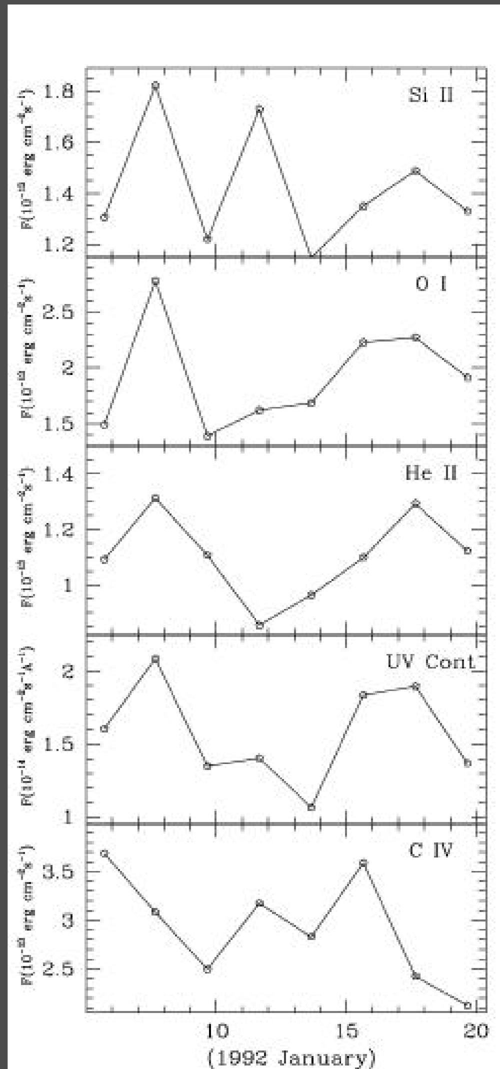
El Escorial-2007

Universidad Complutense de Madrid

- In 1988, Bertout, Bouvier and Basri applied for the first time an α-disk model to reproduce the continuum UV excess of T Tauri stars

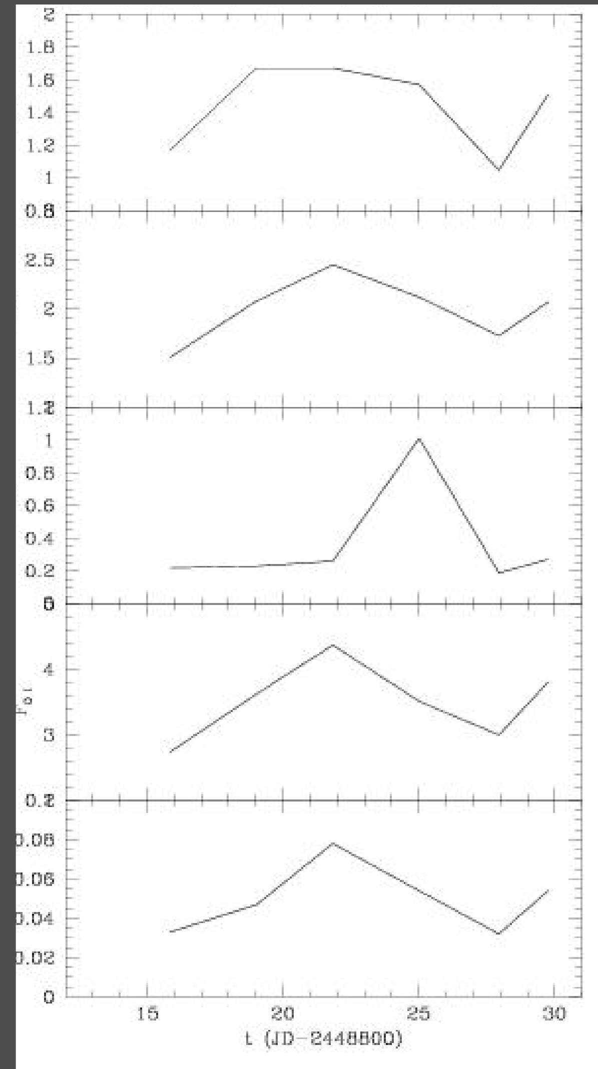
- In 1990, Simon, Vrba and Herbst showed that BP Tau´s UV excess was rotationally modulated → Accretion shocks

BP TAU'92



Gómez de Castro, Franqueira,97

DI CEP'95



Gómez de Castro, Fermández,96

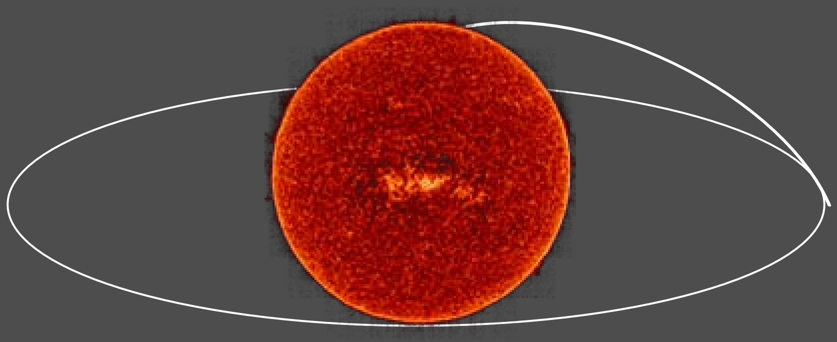
At a very basic level:

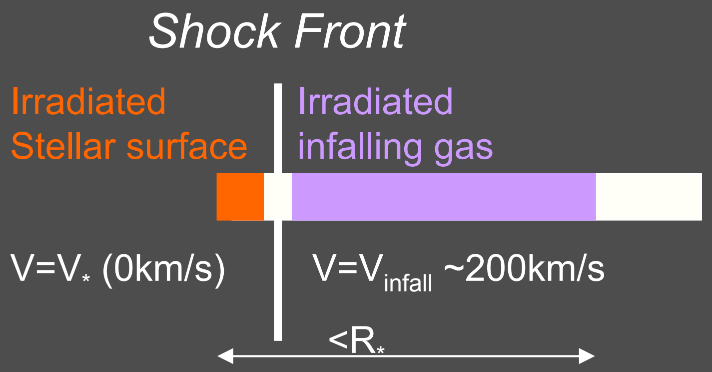
- The UV radiation caused by accretion has to be released close to the surface – Scales:<R_*

  Contribution: 0-~200 km/s Emission/Absorption

  (due to occultation effects)

- The outflow corresponds to a velocity motion along the jet axis in the asymptotic regime, at the base there must be a mixture of motions.

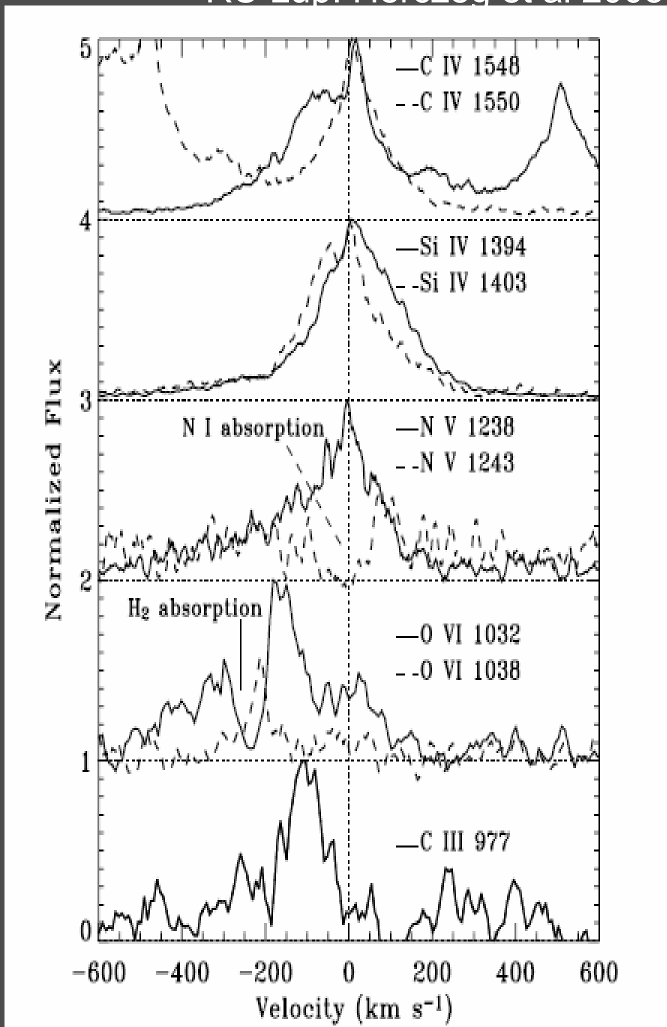


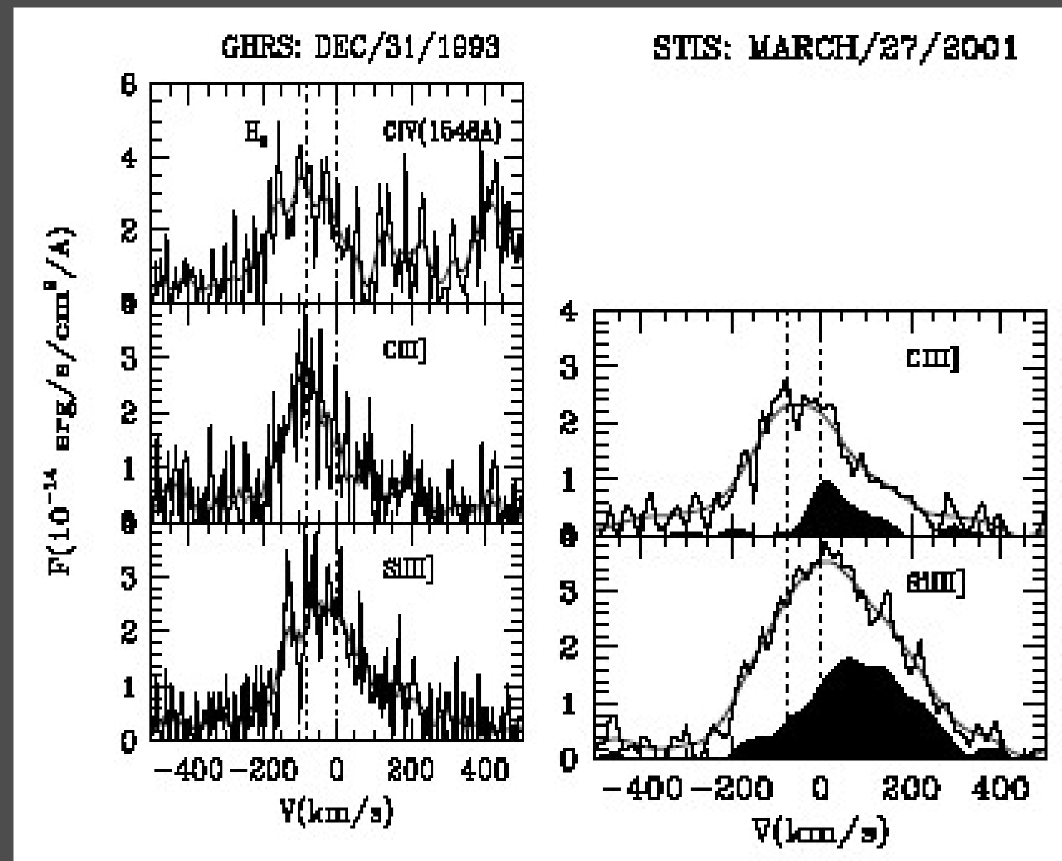


(Lamzin 1998)

High resolution spectroscopy & Time evolution

RU Lup: Herczeg et al 2005





RY Tau: Gómez de Castro & Verdugo, 2006

BASIC PROBLEMS

Accretion is neither stationary nor being chanelled ONLY to the magnetic poles:

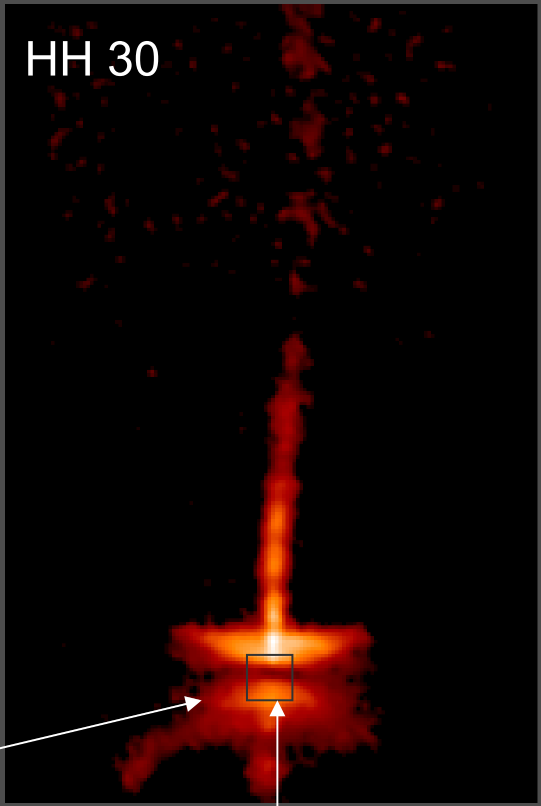
- Magnetospheric accretion models define atmospheric structures that extend to $3R_*$
- Stellar fields are not dipolar (Johns-Krull,Valenti and col. from 1999 till 2005)
- It is correlated with outflow (Bouvier et al 2003, Gómez de Castro & Verdugo, 2003)

. . .

Star Formation Physics:

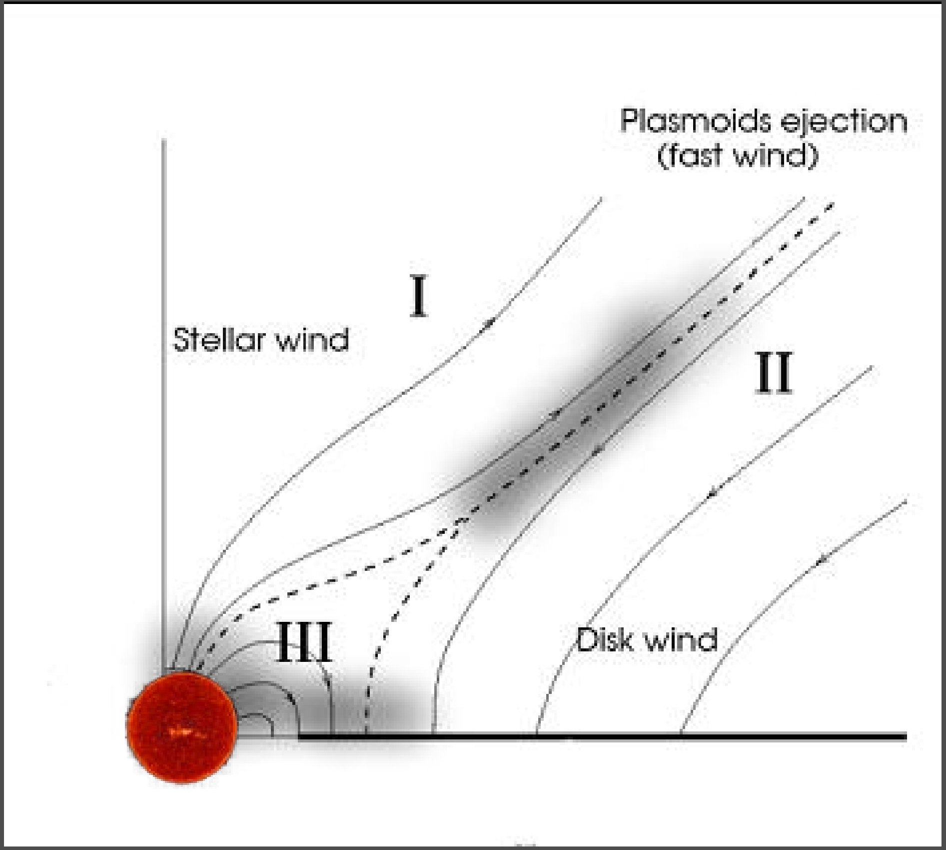
- Gravitation & Angular Momentum Transport
- Generation & Dissipation of Magnetic Fields

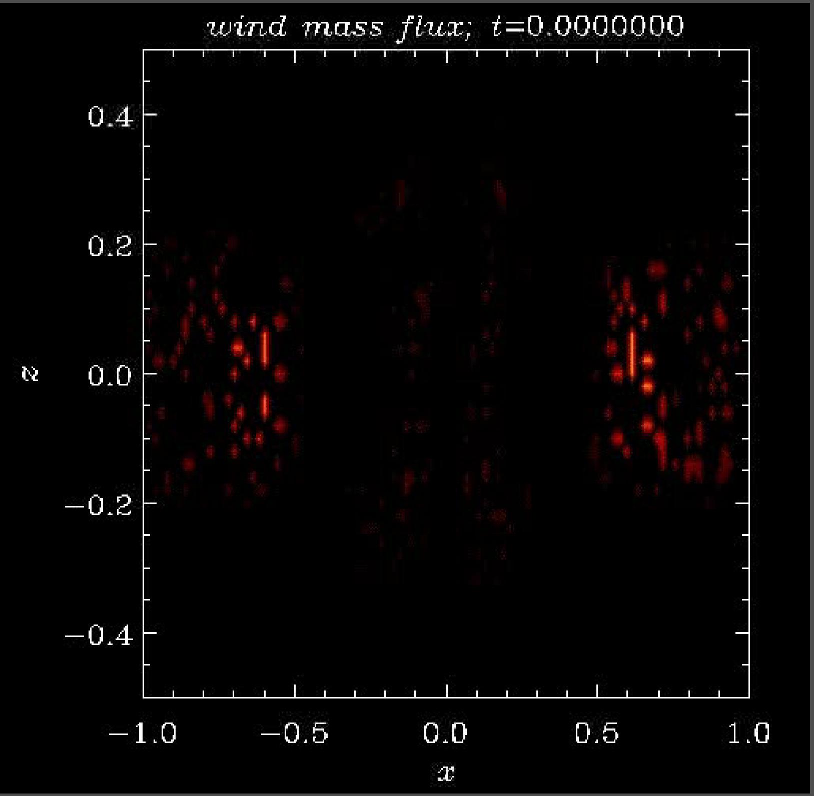
(Rich microphysics: particle-field interaction, molecules formation, dust grains)



Jet engine (*mas-μas* scales)

A NEW PARADIGMA



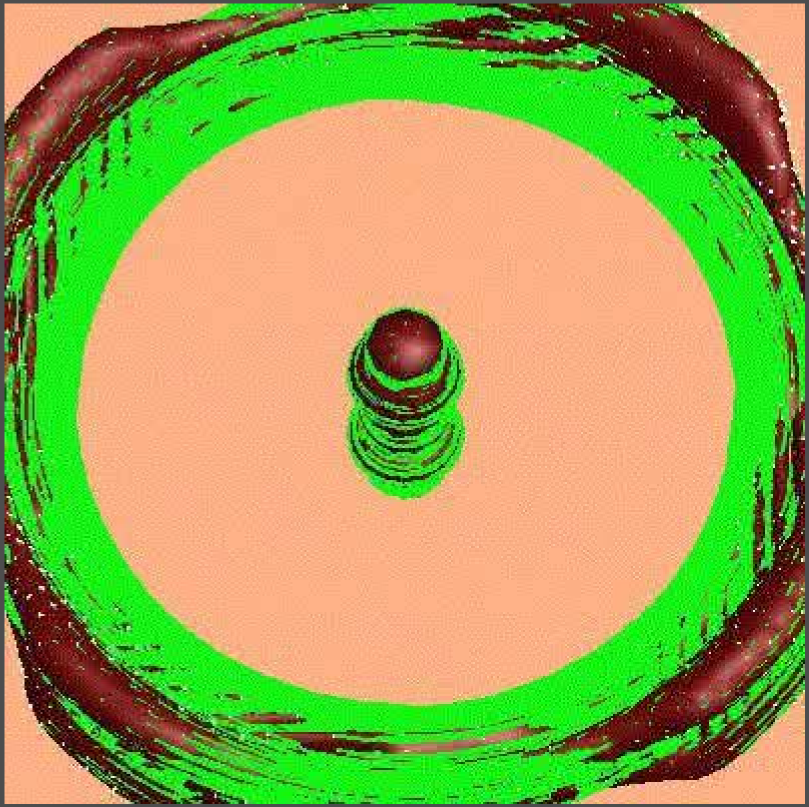


The engine is a small structure (< 0.1AU) with several different constituents:

- the accretion flow,
- stellar magnetosphere,
- winds,
- and inner part of the accretion disk

all radiating in the ultraviolet.

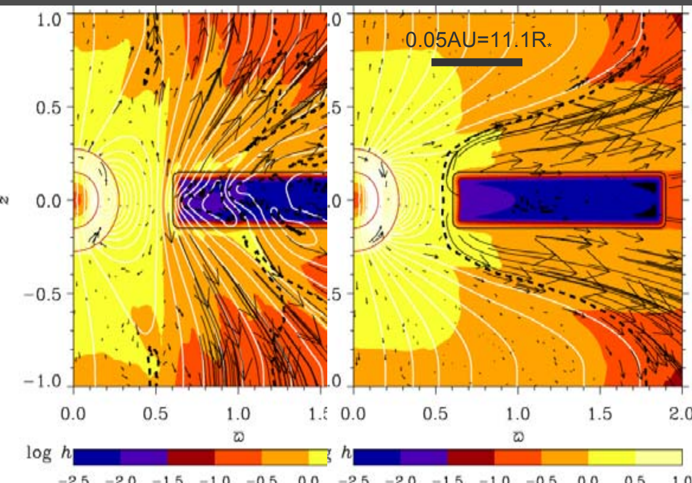
THE JET ENGINE



Von Rekowski & Brandenburg 2005

Star-disk Interaction

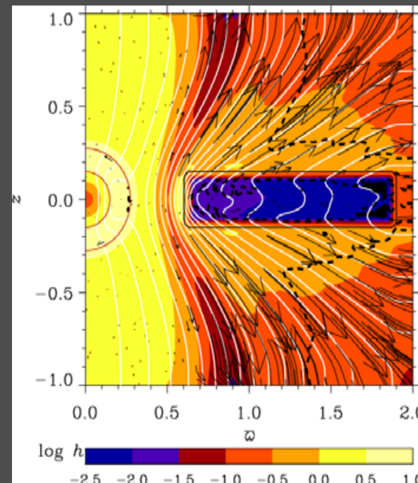
B*≈1 kG



with disk dynamo

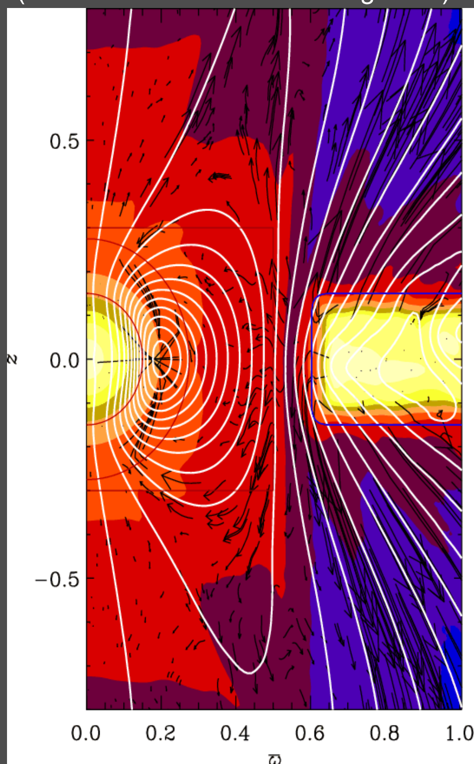
without disk dynamo

B*≈200 G



with disk dynamo

(von Rekowski & Brandenburg 2005)



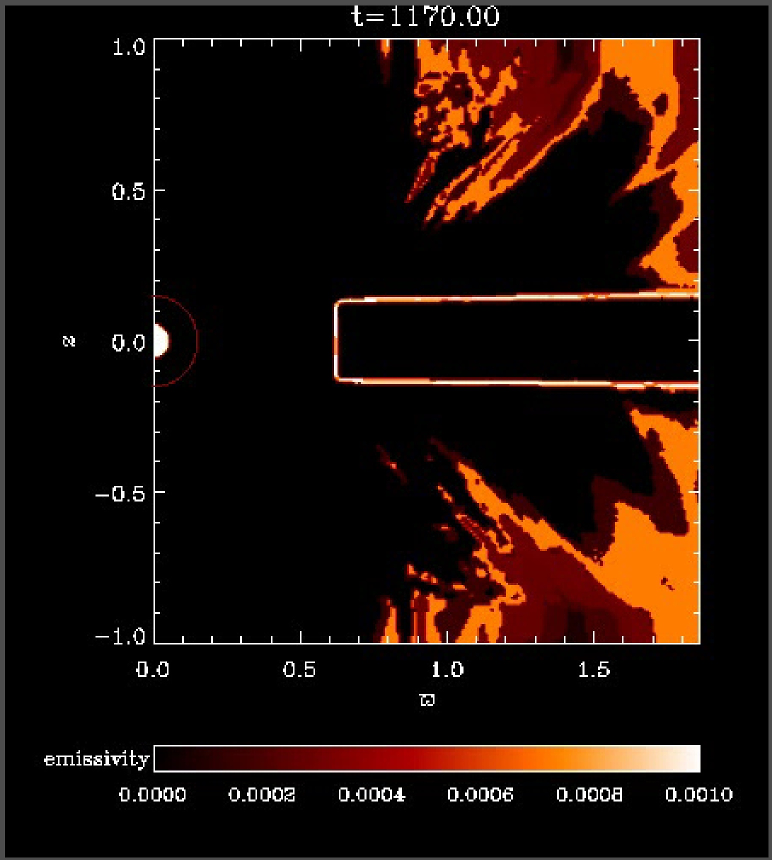
The black dashed lines shows the Alfven surface. In the left and right panels, the Alfven surface is outside the main acceleration region of the wind, i.e., the magneto-centrifugal launching is significant. In the central panel, the Alfven surface is inside the acceleration region, e.g., wind is pressure driven.

The accretion flow, at maximum, for (B*≈1 kG) with the disk dynamo.
Colors code increasing density and arrows mass-flux.

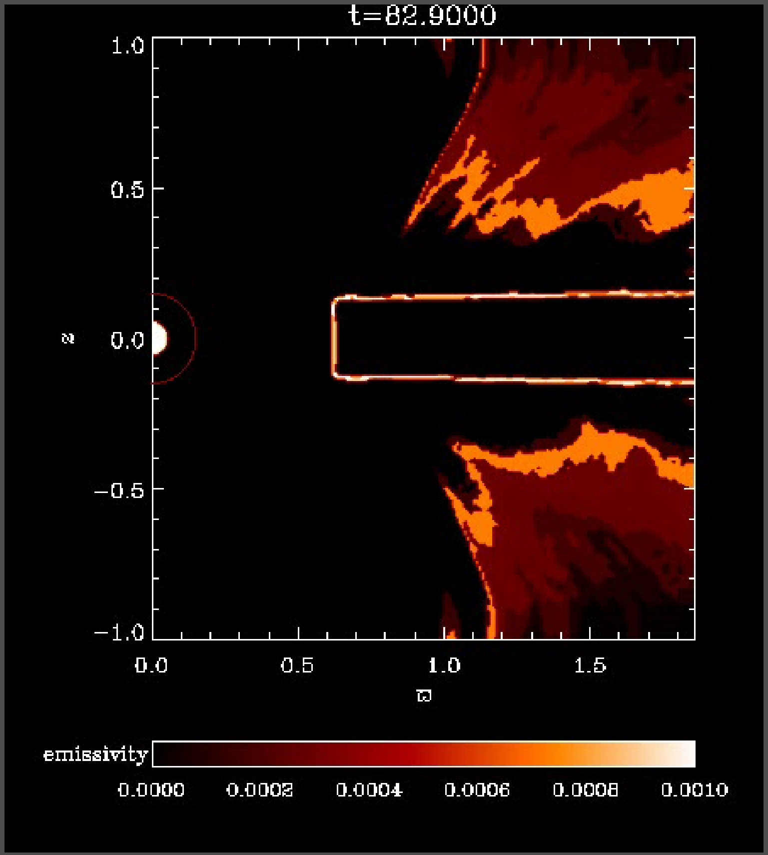
Simulations line (Si III]) emissivity

$B_* \approx 1$ kG

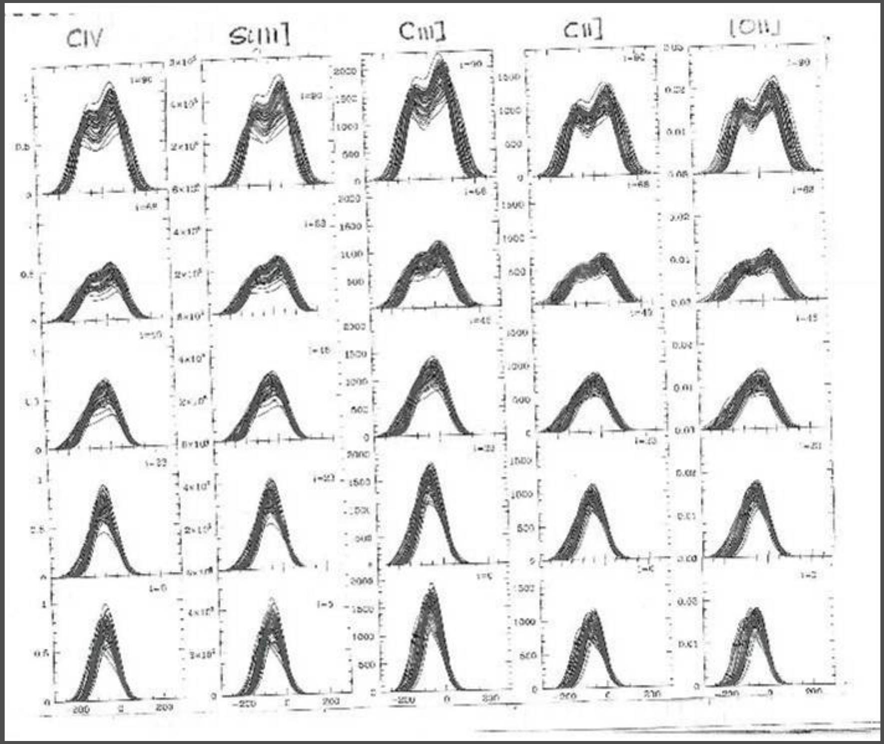
with disk dynamo



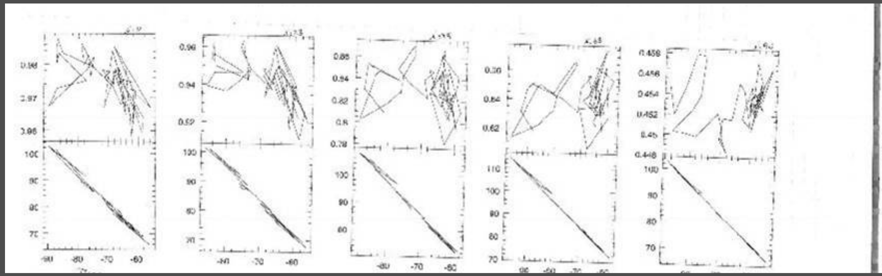
without disk dynamo



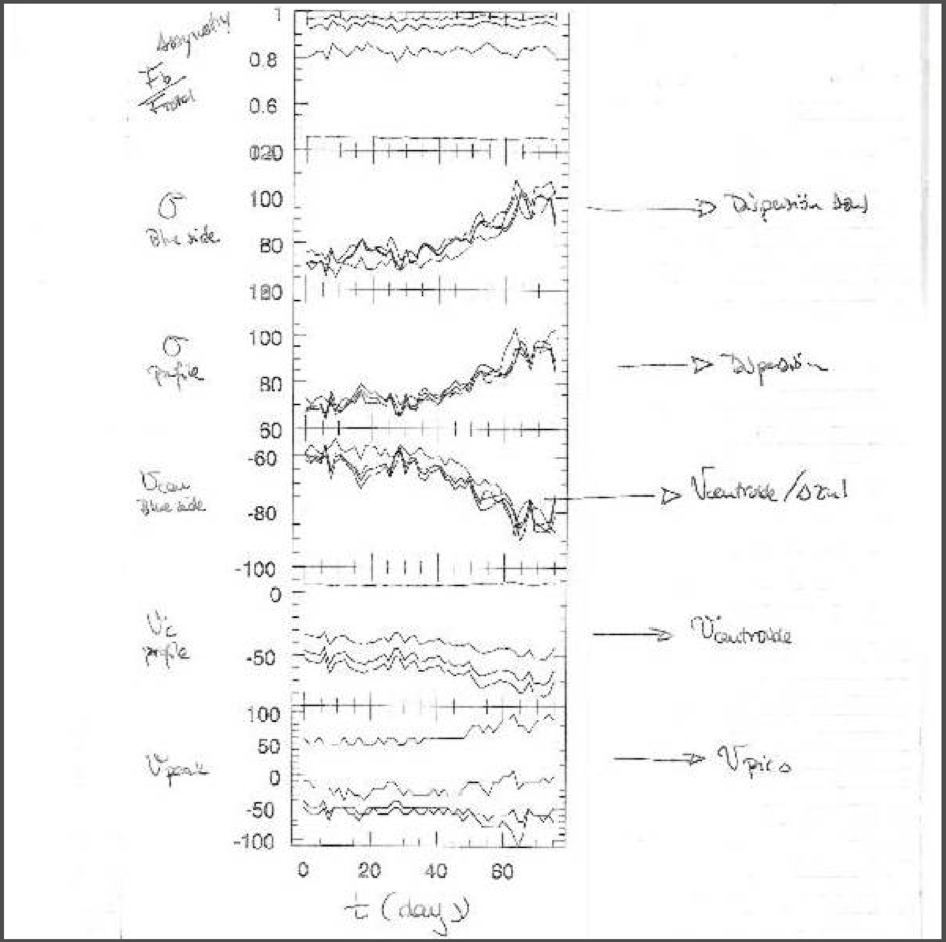
The variations can be tracked in the profiles



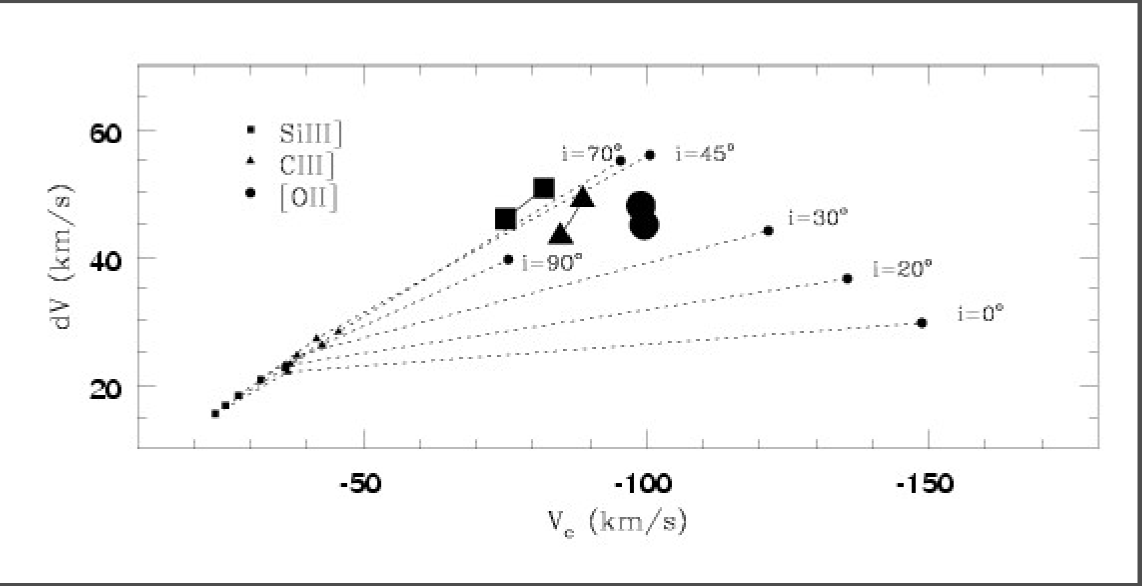
The variations and in Vc,σ plots



Vc



Asymmetry
Fb/Ftotal
σ Blue side
σ profile
Vcen Blue side
Vc profile
Vpeak
1
0.8
0.6
100
80
100
80
60
-60
-80
-100
0
-50
100
50
0
-50
-100
0 20 40 60
t (days)
Dispersión azul
Dispersión
Vcentroide/azul
Vcentroide
Vpico



And different sets-up produce different results that are able to reproduce the observed wide profiles.

2-10 M_o (Herbig Stars)

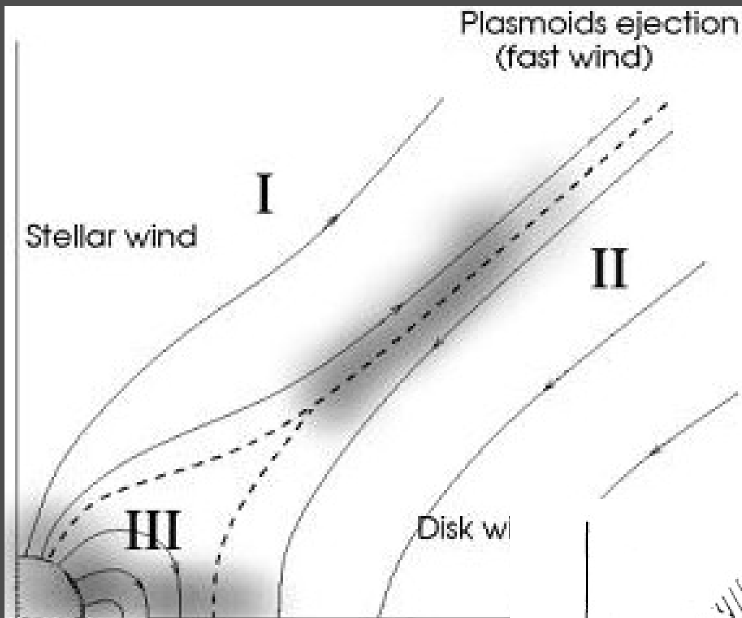
Azimuthal structures and the very hot clumps is often interpreted by means of a 2-component wind model:

• A ``slow'', dense outflow reaching terminal velocities of ~300 km/s, which produces the prominent P-Cygni profiles observed in the CaII and MgII[uv1] lines and the broad, blueshifted absorption observed in CIV[uv1].
 Mass-loss rates derived from semi-empirical models are a few 10^{-8} M_o/yr (Bouret & Catalá 1998; Catalá & Kunasz 1987).
•A ``high'' velocity component made by streamers of magnetically confined gas.

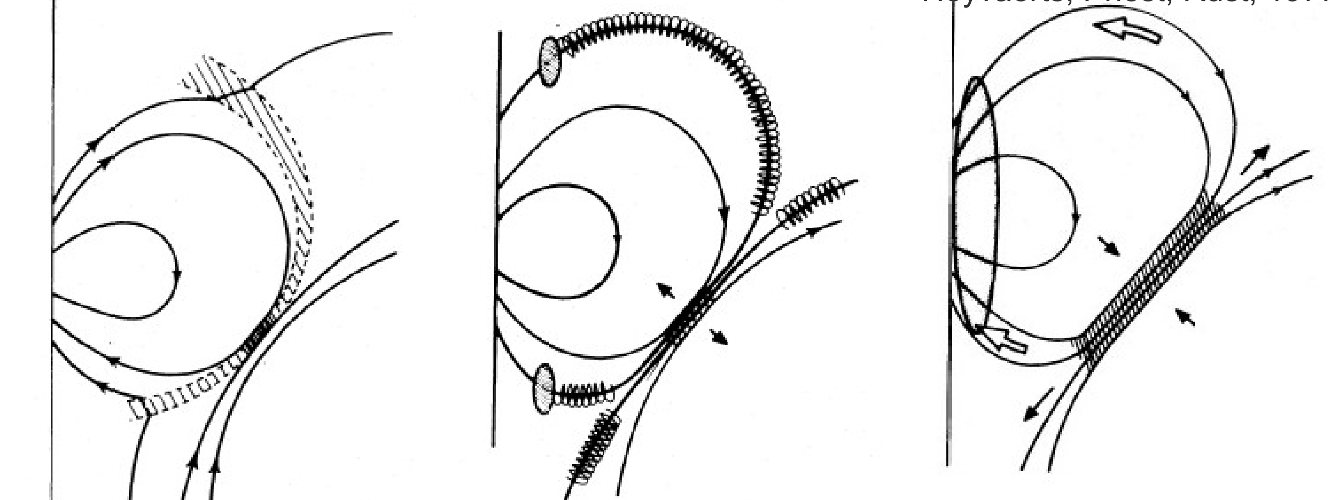
Since Herbig Ae/Be stars are fast rotators, gas in the streamers is forced to corotate up to the alfvén point and shocks are expected to occur between the ``slow'' and ``fast'' components. As a result, dense azimutal structures are formed in the corotating interaction regions (CIRs).

B-fields are active in 1Myrs old A-B stars!

Inner disk irradiation by the wind



Heyvaerts, Priest, Rust, 1977



Heating by radiation from shock waves

Turbulence Onset: Electric fields accelerate particles

Reconnection: particles are conducted by the field

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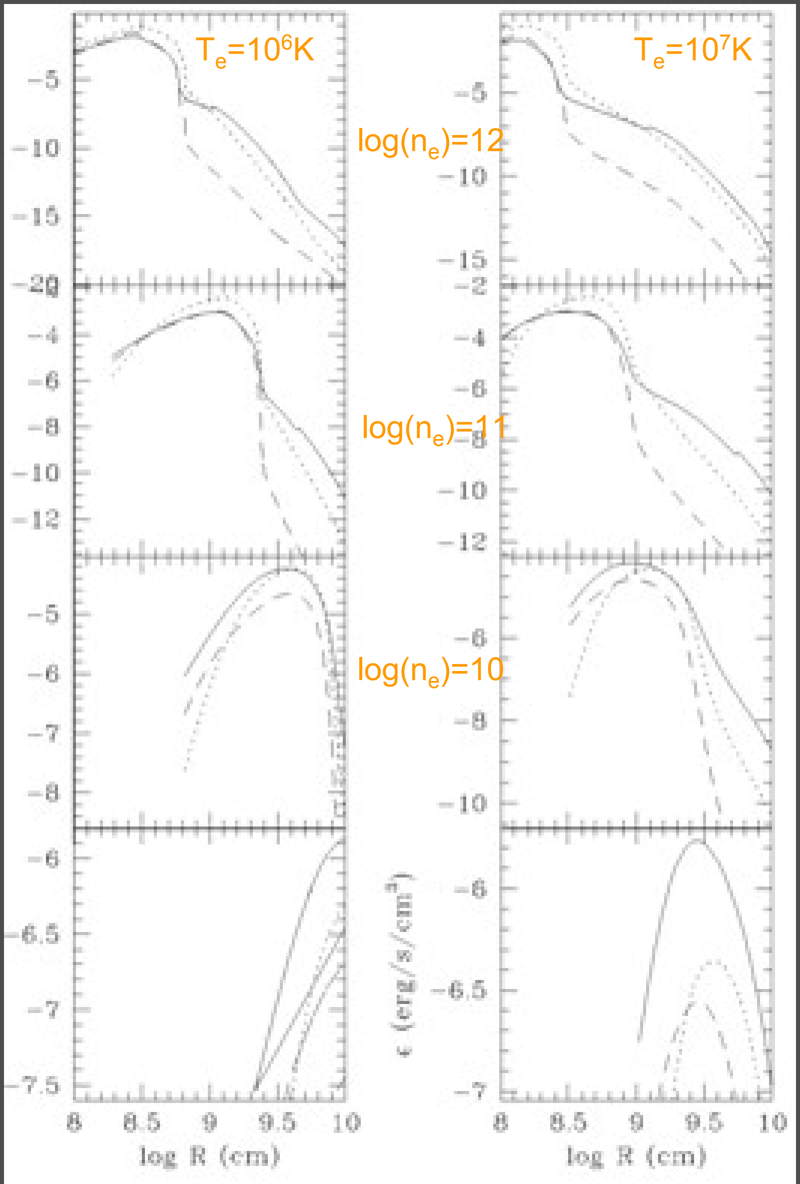
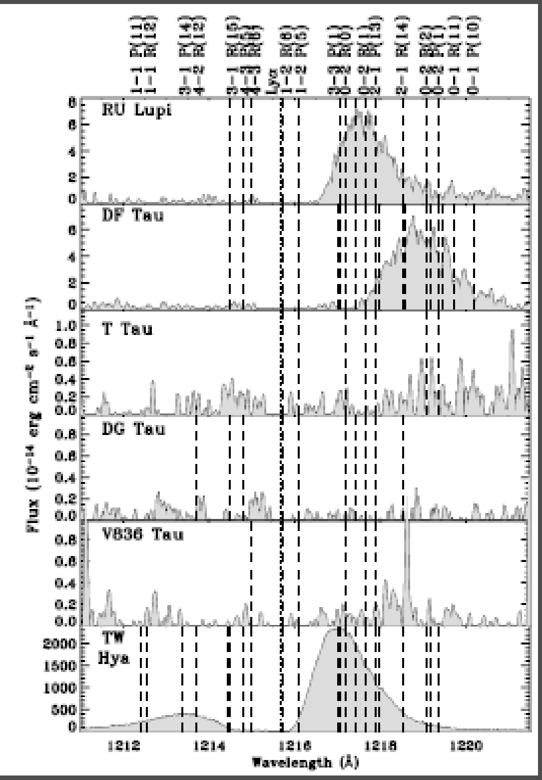


Disk irradiation – I X-ray

Photo Dissotiation Regions (PDRs) are geometrically thin and the disk adopts a layered structure in “r” and “z”

UV FORBIDDEN LINES EMISSIVITY AFTER X-RAY IRRADIATION OF DENSE MATTER

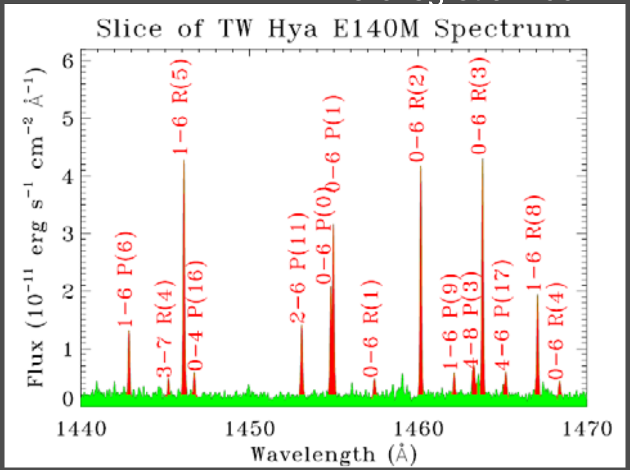
Disk irradiation – II
UV (and Lyα)



Herczeg et al 2006

H_2 pumping by Lyα

Herczeg et al 2002



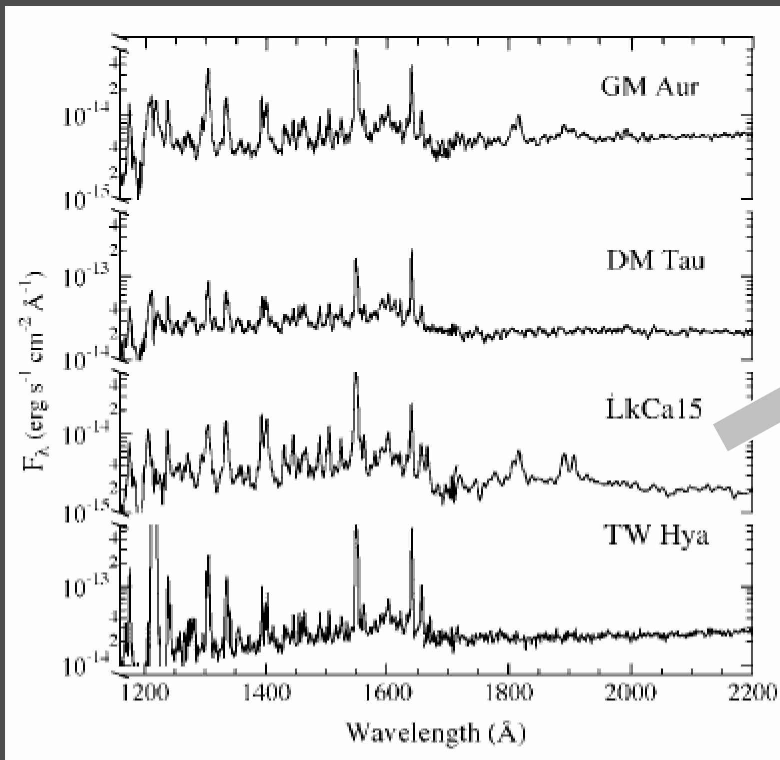
H_2 is observed in many TTSs:

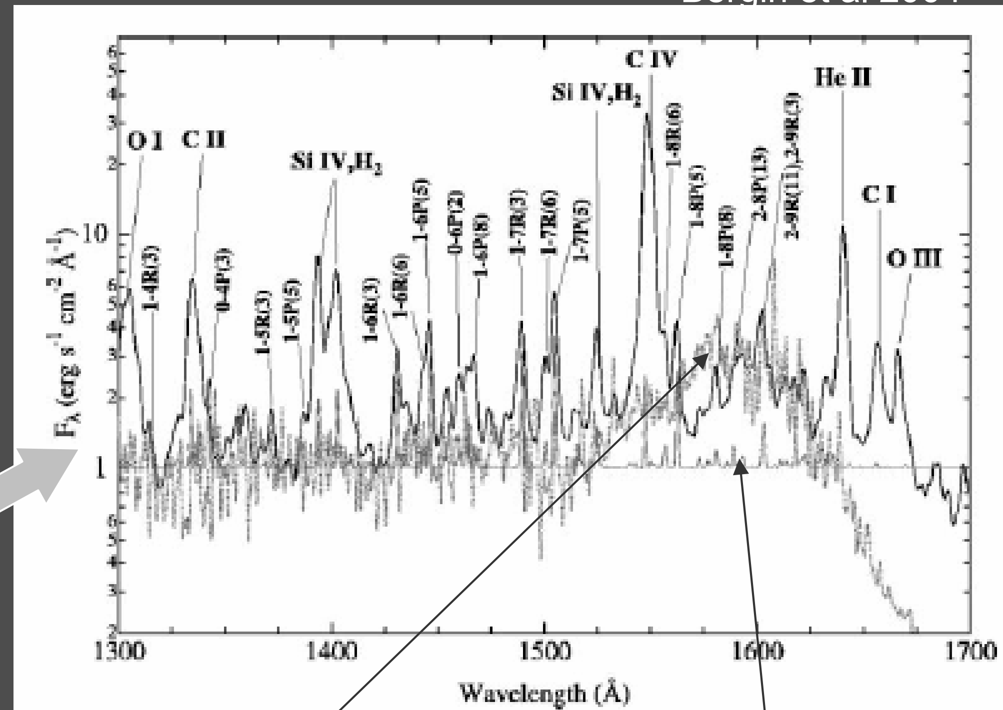
- RU Lup, T Tau and DG Tau associated with the wind
- TW Hya, DF Tau and V836 Tau ??? (disk?)

(Ardila et al 2002, Herczeg et al 2006)

Bergin et al 2004

FUV continumm below 1700A



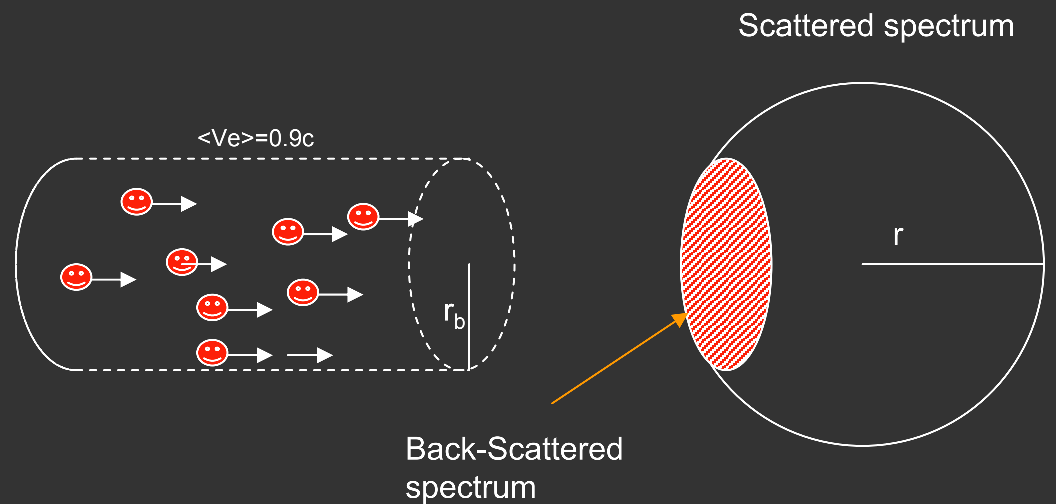


Lyα fluorescence
(lines dominated)

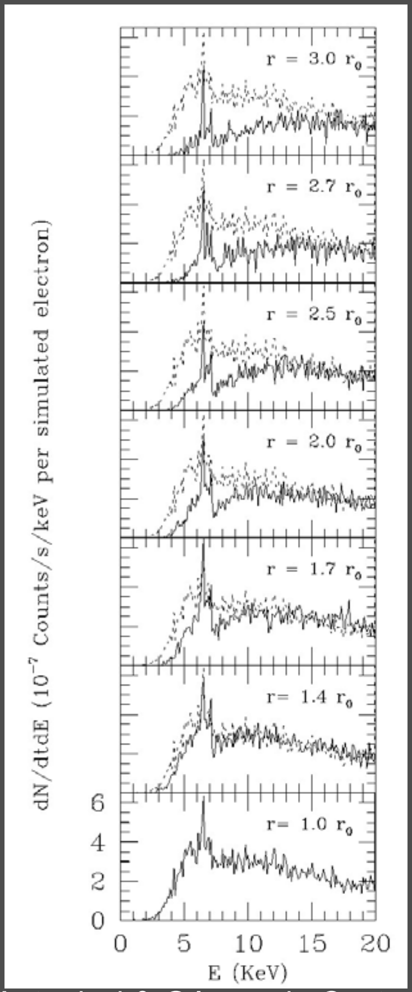
Electron impact excitation
(greater contribution from the H_2 dissociation continumm)
0.1 keV electrons

Numerical Simulations of the Propagation of Relativistic Electron Beams

H, He, O, C, Ne, N, Mg, Si, Fe, S



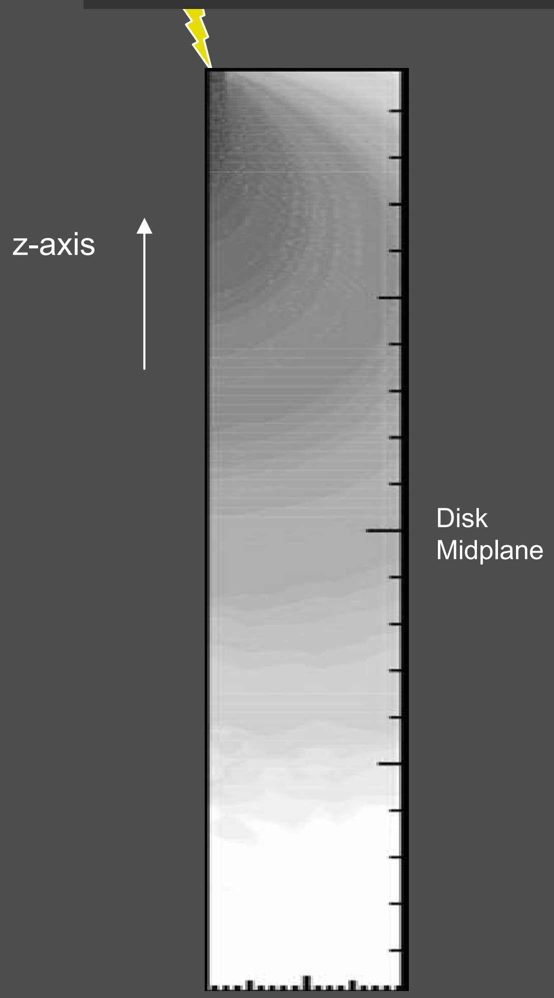
Transmitted X-ray



r_{12}	$N_{H,24}$
9	1.44
8	1.28
7	1.12
6	0.96
5	0.80
4	0.64
3	0.48

Antonicci & Gómez de Castro 2005

Propagation of 2MeV electrons in the inner border of the disk



- Most of the energy is releasead along the incidence direction within a beam of $2\ 10^7$ cm and a depth of $8\ 10^7$cm (disk height 10^9 cm)

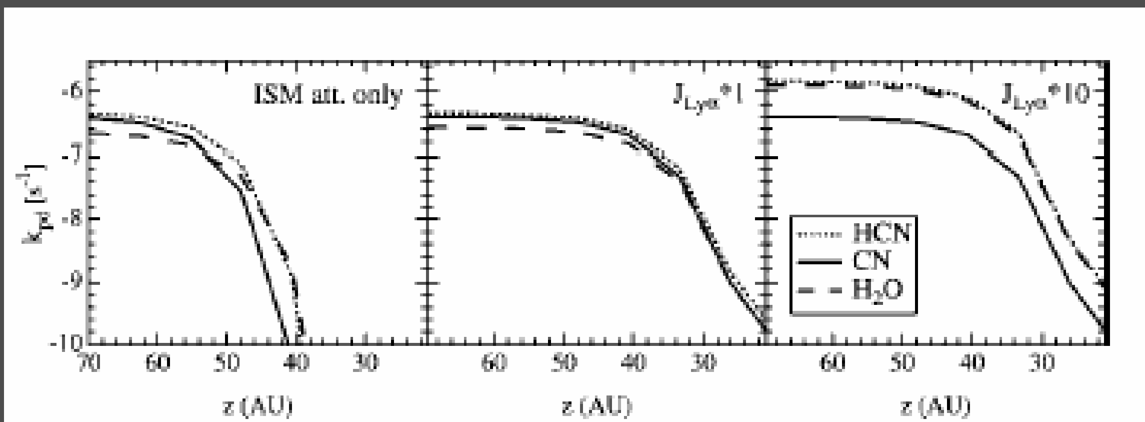
- Energy spreading has to be done through the Hard Bremsstrahlung radiation energy cascade. Selective absorption by disk molecules produces PDRs

- A non-negligible source of ionization further than the atmosphere.

- A source of high energy electrons to interact with molecules collisionally

Gómez de Castro & Antonicci, 2007

Summary -1 important connection with the chemistry

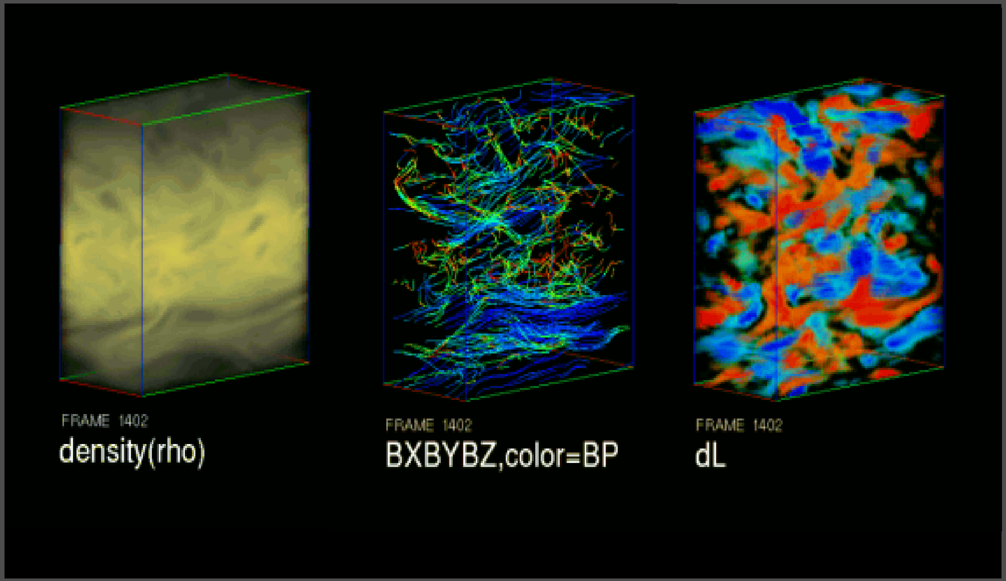


Bergin et al 2003

Photodissotiation rate r=100 AU with and without taking into account the contribution from stellar Lyα photons.

UV photons photodissociating organic molecules at λ > 1500A could play a key role in the chemistry of the inner regions of the disk, while those photodissociating H_2 and CO will control the chemistry of the external layers of the disk directly exposed to the radiation from the central engine (see e.g., Cernicharo 2004).

Important connection with the end of the magnetorotational inst.



Hawley et al 2002

- Vertical structure of the disk and switch-off of MRI
- The planets-disk decoupling time

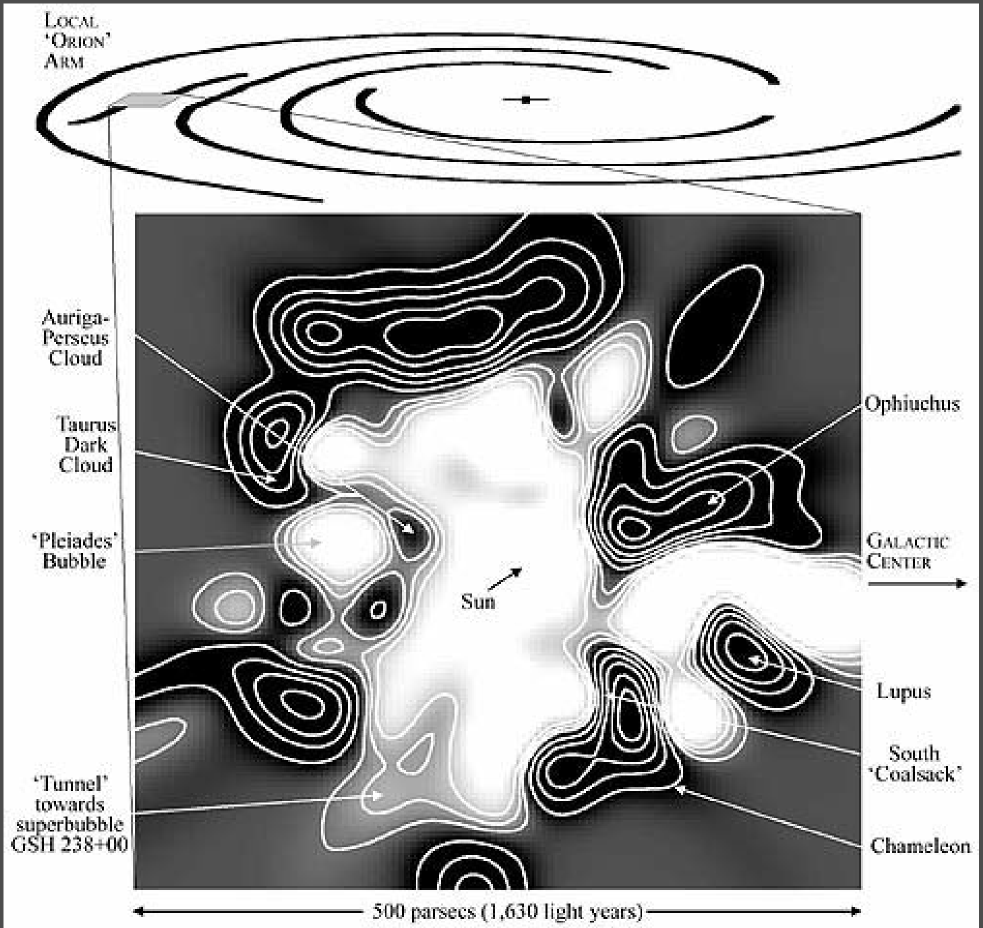
OPEN QUESTIONS

- How does the accretion flow proceed from the disk to the star? Is there a preferred accretion geometry?
- What roles do disk instabilities play in the whole accretion/outflow process?
- What are the dominant acceleration processes? What are the relevant time scales?
- How this high energy environment affect the chemical properties of the disk?
- How important is this mechanism when radiation pressure becomes significant as for Herbig Ae/Be stars?

There are several laboratories within 140 pc: Taurus, Lupus, Ophiuchus

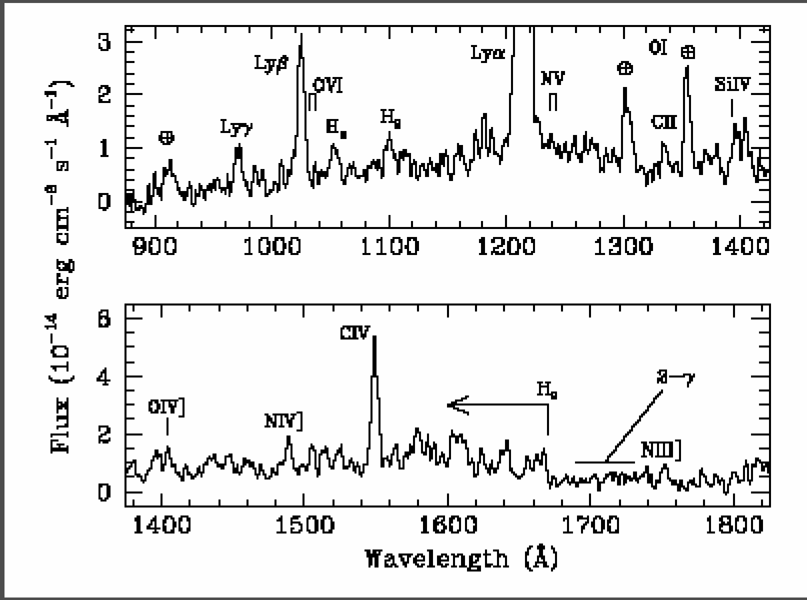
The nearest target is TW Hya, 10 Myrs old at 56 pc.

AB Dor (at 14 pc) is a young main sequence star 20-30Myr old.



We need more photons!

The large scale outflow



How the kinetic energy of the flow is damped into radiation?

Radiative cooling models cannot reproduce HH2 observations: strong CIV and H_2 emission with no OVI emission

(HUT: Raymond et al. 1997)

How H_2 emission is excited (in high excitation HH objects)?

Maybe collisional pumping of the H_2 levels by "hot" electrons

(Raymond et al. 1997)