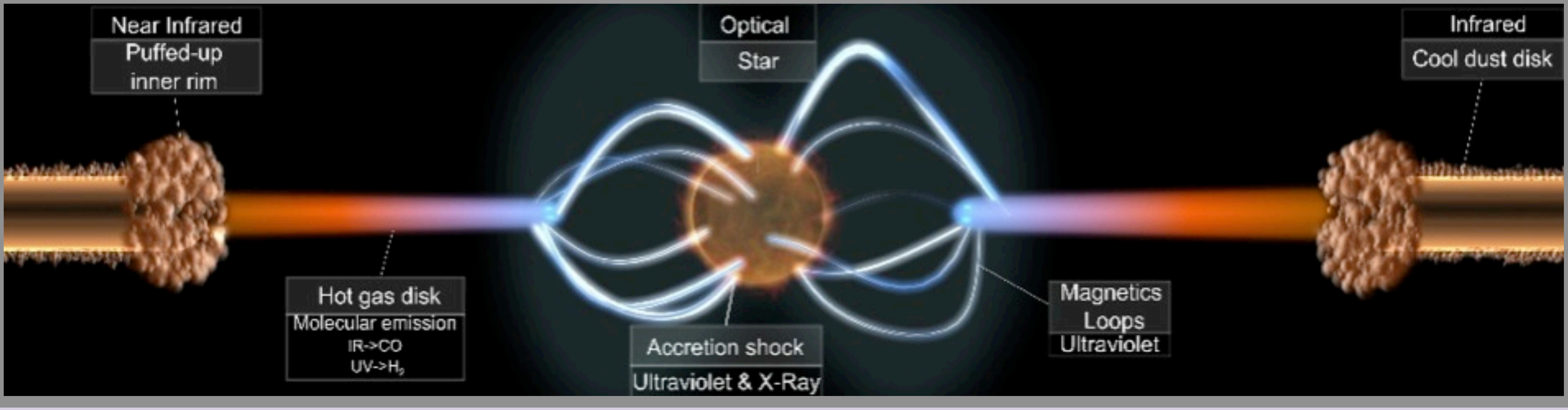

SHADOWING OF YOUNG PLANETARY DISKS

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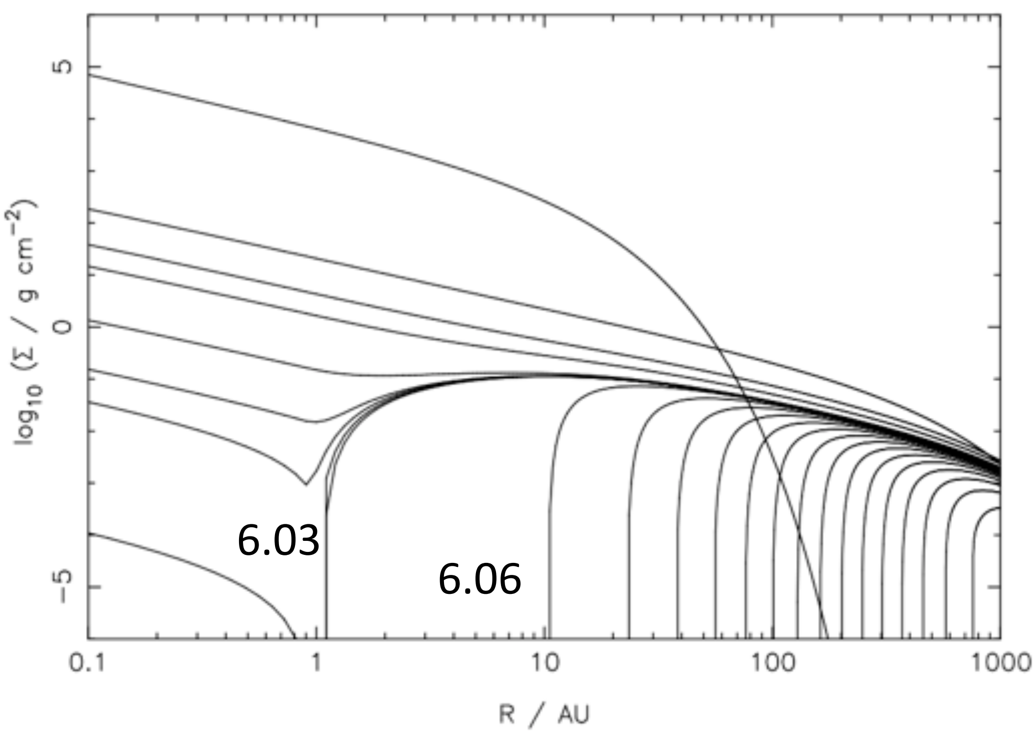
UNIVERSIDAD COMPLUTENSE DE MADRID

YOUNG PLANETARY DISKS EVOLUTION

COLD EVOLUTION: driven by the exhaust of remnant material in the molecular core to feed the disk with fresh gas (Young & Evans 2005, Dunham et al. 2010)

HOT EVOLUTION: gas from the disk photoevaporates after heating by absorption of stellar radiation (Alexander et al. 2006, Alexander et al. 2014, Gorti et al. 2015)



Alexander et al. 2006

RADIATION, HEATING THE DISK ATMOSPHERE

THE MAIN GASEOUS COMPONENT OF YOUNG PLANETARY DISKS IS H_2

X-RAY RADIATION (0-3-1 keV) absorbed by K-shell ionization of heavy elements (O,C,Fe) and the photoelectrons collisionally heat/ionize the H, H_2
(Ercolano et al. 2008, 2009;Gorti & Hollenbach, 2009; Owen et al. 2011, 2012)

EXTREME UV RADIATION AT THE LYMAN LIMIT (912 Å) directly ionizes the H. The heating rate depends on the number of photons ϕ_{UV}
(Hollenbach et al. 2004; Alexander et al. 2006; Clark 2011)

FAR UV RADIATION (1000-1700 Å). Photodissociates and heats H_2 producing a PDR also, heats the dust producing hot photoelectrons. The heating/cooling balance depends strongly on:

incident flux density/gas density

In TTSs about 80% of the FUV flux is radiated in Lyα, absorbed directly by the Werner bands of H_2 and radiated back in the FUV.
(Adams et al., 2004; Gorti & Hollenbach 2009; Clark 2011, Schindhelm et al. 2012).

IN SUMMARY

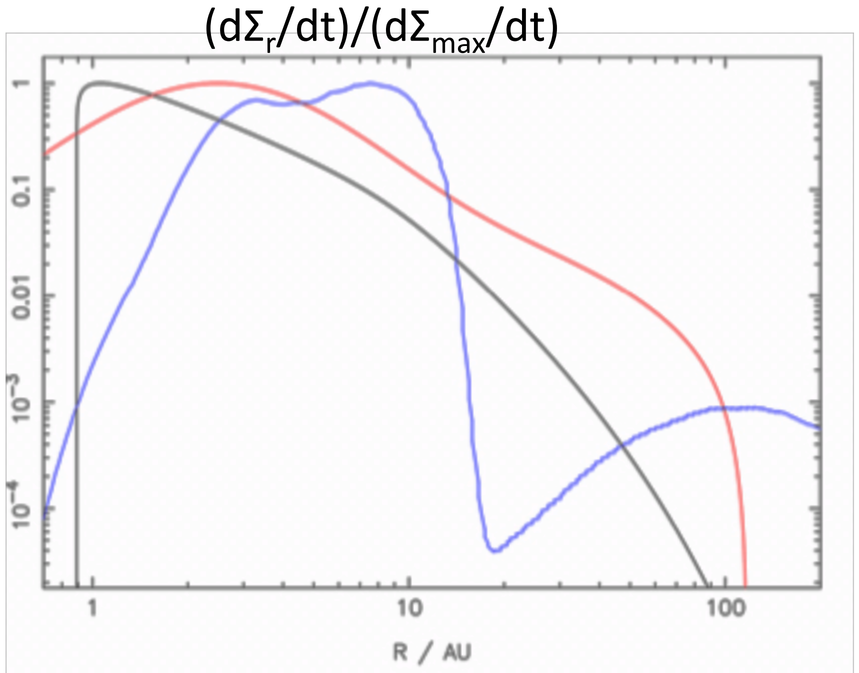
$$\frac{dM(X,EUV)}{dt} = A_{X,EUV}\Phi^{\alpha}_{X,EUV}\left(\frac{M_*}{M_\circ}\right)^{\beta}$$

	A (M_o/yr)	α	β
X-ray	6.3e-9	1.14 (ϕ_0=1e30 erg/s)	-0.068
EUV	1.6e-10	0.5 (ϕ_0=1e41 s^{-1})	0.5

X-ray
Absorbing column 10^{21}-10^{22}cm^{-2}
Temperature: 3000-5000 K

EUV
Launch velocity: 0.3-0.4cs
Temperature: 10,000 K

FUV
Absorbing column: $10^{21} – 10^{23}$cm^{-2}
Temperature: > 1000K (@ few AU) to < 100K (@ 100AU)

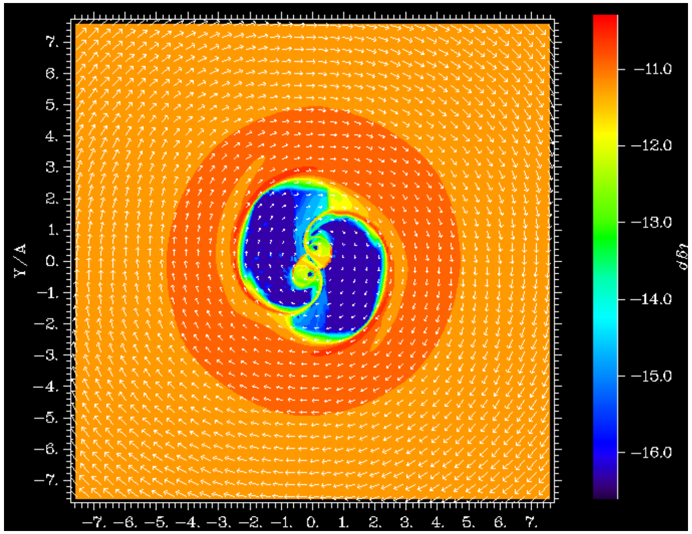


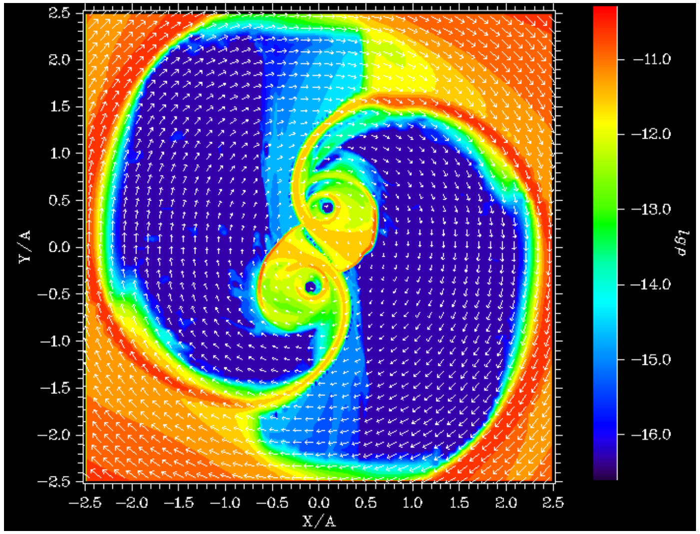
(from Alexander et al. 2014)

X-ray (0.3-1 keV)
EUV (900-1000 Å)
FUV (1000-1800 Å)

UNCERTAINTIES

1. EUV and FUV flux reaching the disk surface
   - ✓ Sources of radiation and location
   - ✓ Sources of opacity to EUV/FUV photons (winds and flows)
2. Gas to dust ratio in the disk atmosphere (see Gorti et al. 2015)
3. Impact of binarity, geometric distortions, departures of cylindrical symmetry (warps, etc…)

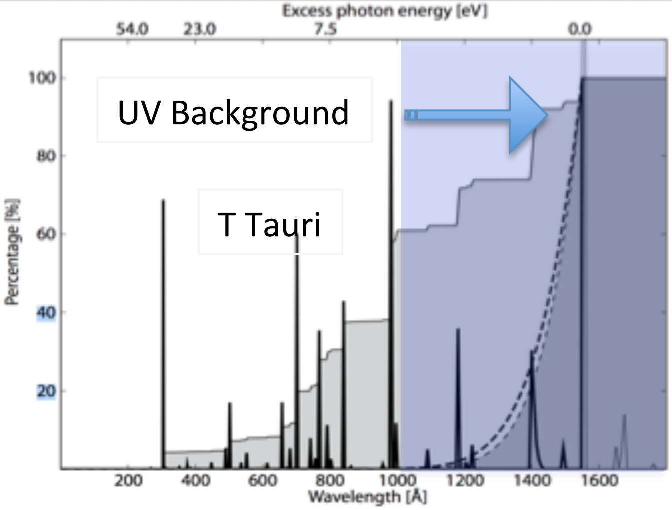


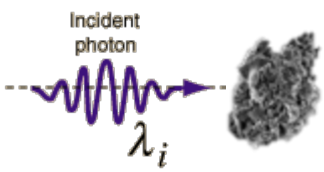


Gómez de Castro et al. 2013

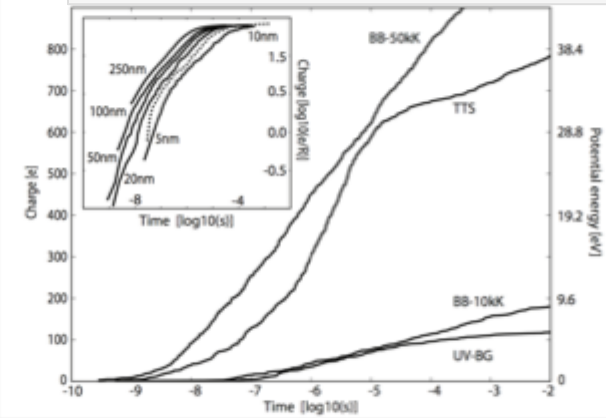
UNCERTAINTIES: EUV/FUV flux and DUST

Standard UV Background – Habing 1968

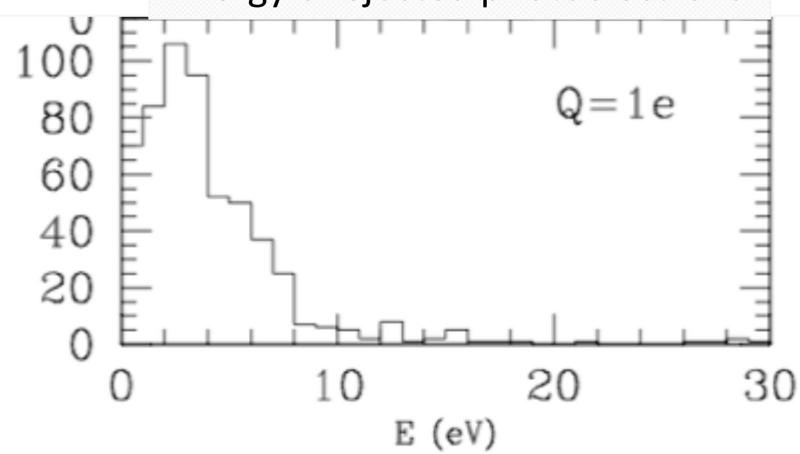




Silicate grains charging profile



Energy of ejected photoelectrons



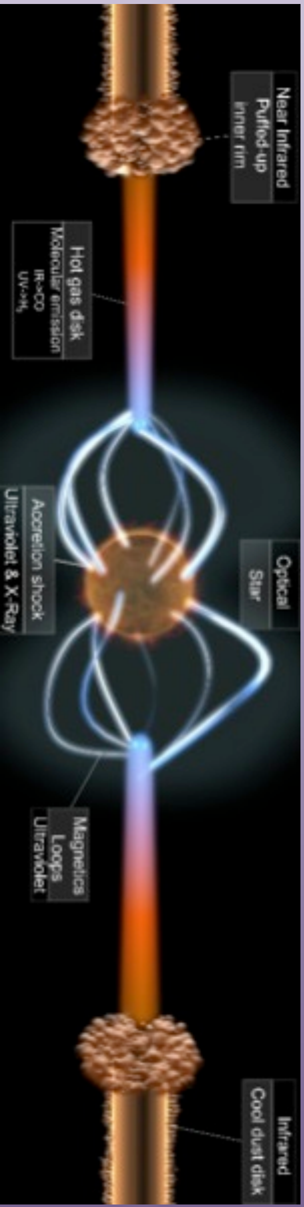
Photoelectrons energy distribution is not homogeneous:

- Peak at 2.5 eV is produced by the Lyα continuum
- Shoulder at 5.8 eV is caused by EUV (700–850 Å)

H_2 collisional dissociation threshold 4.52 eV
MgI ionization potential 7.64 eV

Pedersen & Gómez de Castro 2011

SHADOWING BY OUTFLOWS



MASS REPOSITORY

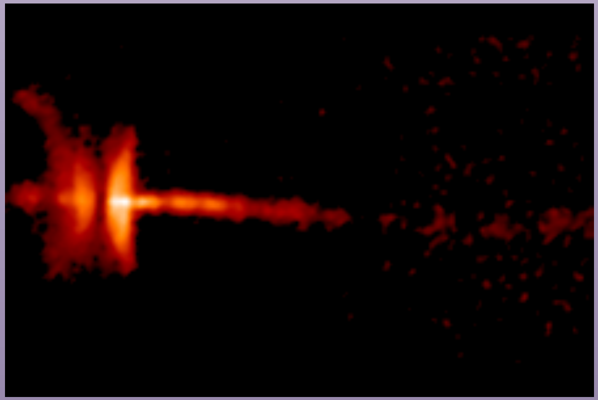
GAS DOMINATED REGION

MAGNETIC MEDIATOR

COMPACT SOURCE OF GRAVITY

MAGNETIC MEDIATOR

GAS DOMINATED REGION

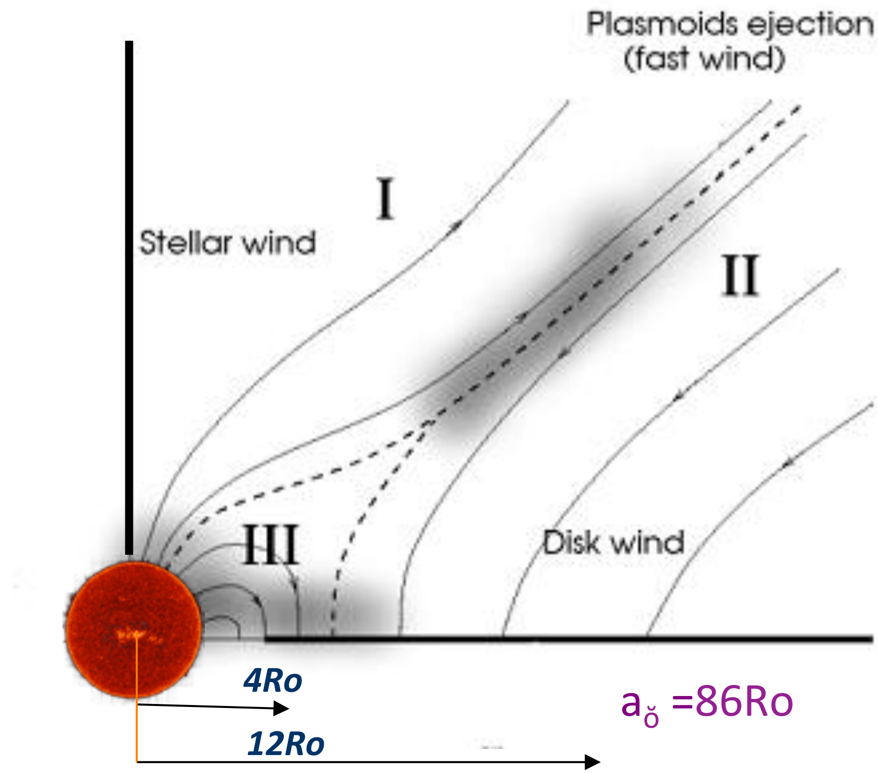


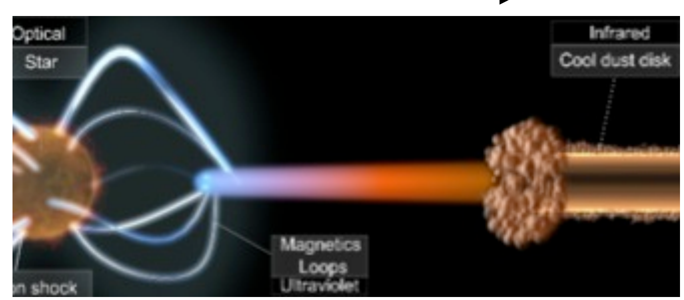
Transport process warranting a continuum fuel supply from the mass respossitory into the engine.

Goodson & Winglee 1997, Matt et al. 2002, Von Rekowsky & Brandenberg 2004, Uzdensky 2004, Romanova et al 2012

STAR-DISK INTERACTION

1. Matter falls onto the star though a fraction of the gravitational energy is carried through a mild disk-wind
2. A magnetic boundary layer is established between the stellar magnetic field and the disk
3. The magnetic boundary is not stationary – a current sheet forms that it is broken recurrently driving to plasmoid ejection

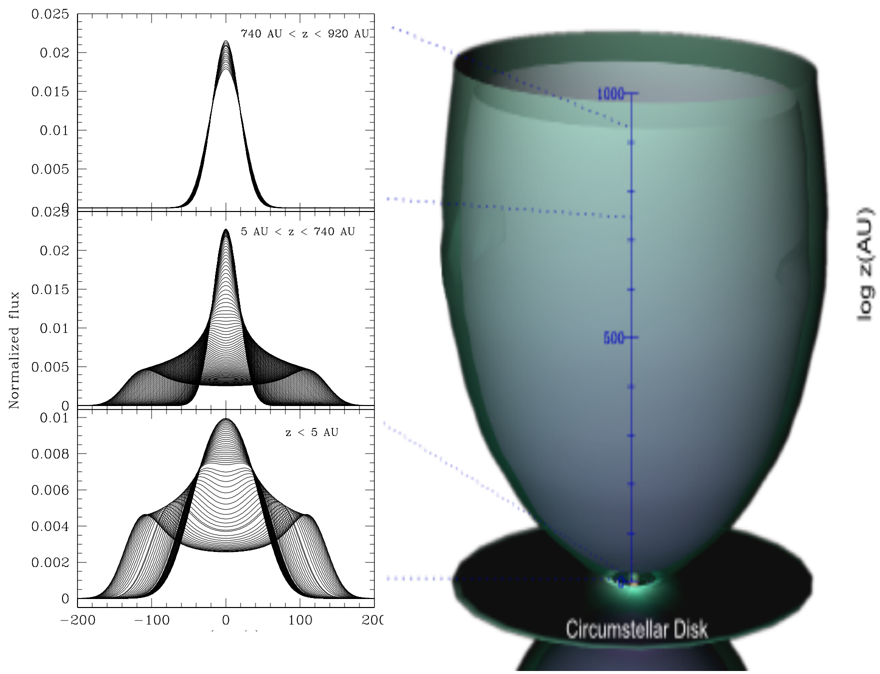


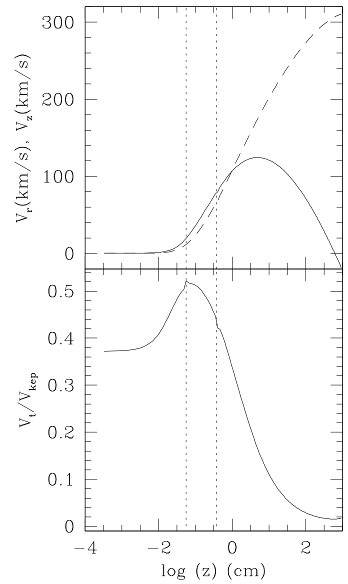


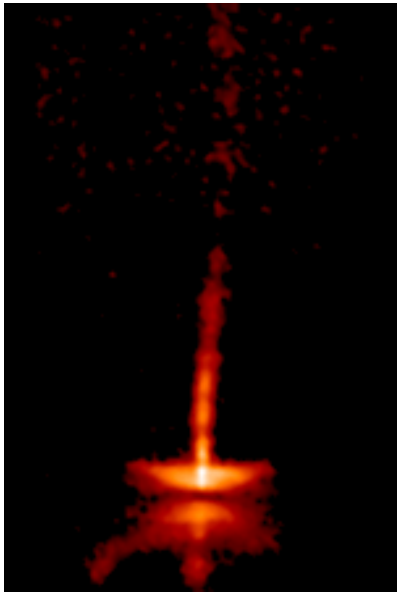
Star-disc interaction physics still poorly understood (from magnetospheres to reconnection micro physics).

The role of stellar radiation and magnetic field on the engine performance the evolution of the disc.

THE OUTFLOW: FROM SMALL TO LARGE SCALE



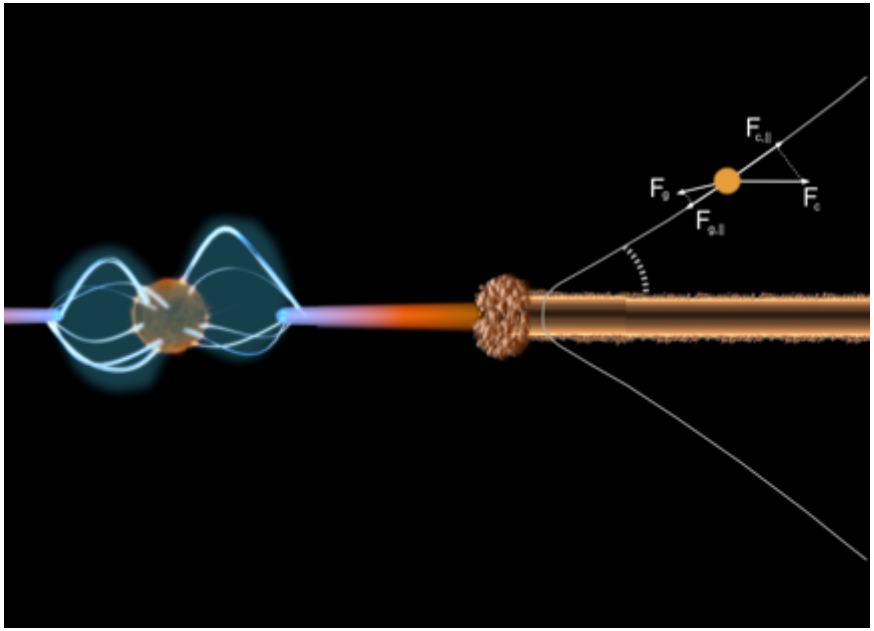




Gómez de Castro & Ferro-Fontán 2005

- At the *base, rotational broadening* dominates producing broad, Gaussian-like profiles
- In the *acceleration region, beam expansion* dominates producing double peaked profiles
- In the *free inertial regime, just collimated motion* along the axis is produced

THE OUTFLOW: COOL VS. HOT WINDS



COOL WINDS [CW]: ONLY CENTRIFUGAL COMPONENT

HOT WINDS [HW]: GAS PRESSURE IS RELEVANT. WINDS DEPART FROM A "HOT" DISK CORONA

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

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

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

$$\gamma = 1.05$$

Some numbers for the fiducial HW model at r_A for r_0 = 0.1 AU

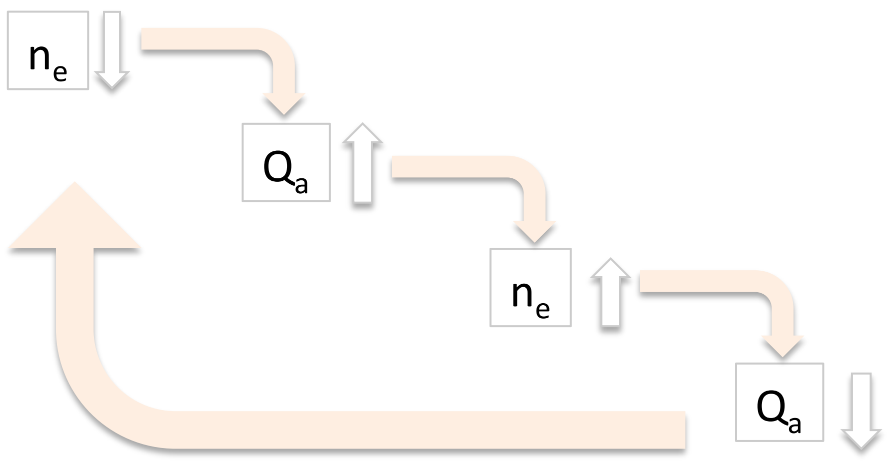
$C_{s,A}$ = 22 km/s (log T_A(K)=4.6)
r_A = 0.62 AU; z_A = 0.37 AU; R_A = 0.73 AU
Ω = 1/33.1 d
$V_{t,A}$ = 39.5 km/s ; $V_{p,A}$ = 17.5 km/s ; V_A = 43,2 km/s
V_{jet} = 310 km/s

RELEVANT CHARACTERISTICS FOR DISK EVOLUTION

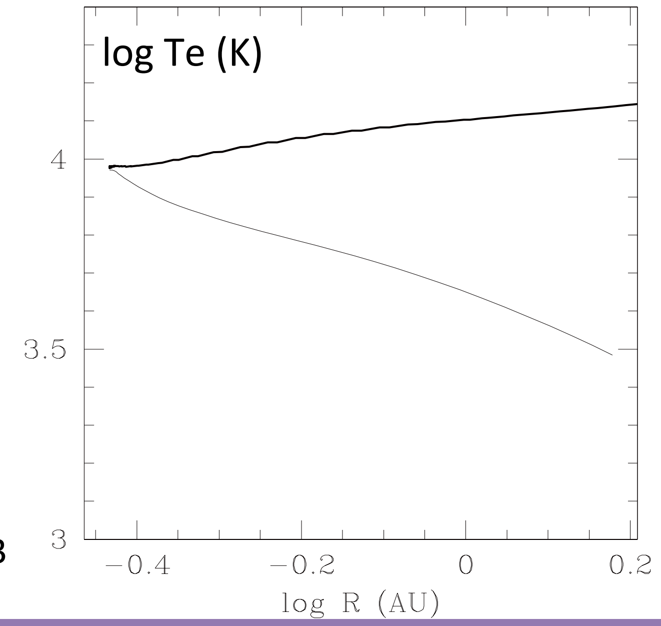
THE TEMPERATURE OF THE SURFACE OF THE DISK IS BELOW 50,000 K HENCE **HW** SOLUTIONS DO NOT APPLY (UNLESS MACRO-TURBULENCE AND SMALL FILLING FACTOR ~1% APPLIES).

MHD CENTRIFUGALLY DRIVEN WINDS OPERATE IN THE INNERMOST PART OF THE DISK (WHERE THE GRAVITATIONAL/CENTRIFUGAL PULL IS STRONGER).

CW WINDS IRRADIATED BY AN X-RAY SOURCE KEEP THE **CW** WIND AT A TEMPERATURE OF ~10,000K



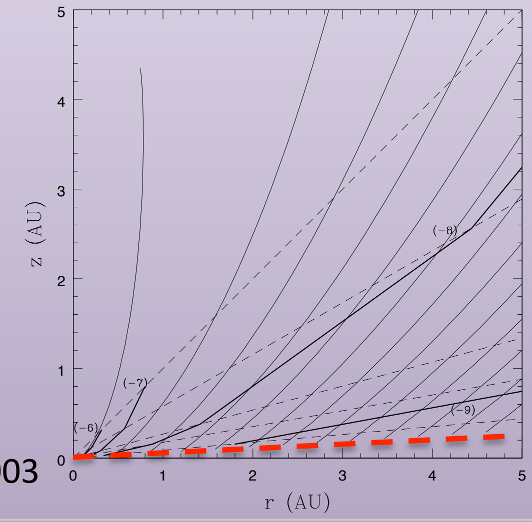
Ferro-Fontán & Gómez de Castro 2003



Colatitude: $\Theta = 85^o$ $R_{in} = 0.07AU$

$n(R) = 3.5x10^8 cm^{-3} (dM_{a,8}/dt)(M_*/M_o)^{-1/2} R_{au}^{-3/2}$

$N_H = 2.0x10^{22} cm^{-2} (dM_{a,8}/dt)(M_*/M_o)^{-1/2} R_{in}^{-1/2} (1-(R_{in}/R_{out})^{1/2})$



Ferro-Fontán & Gómez de Castro 2003

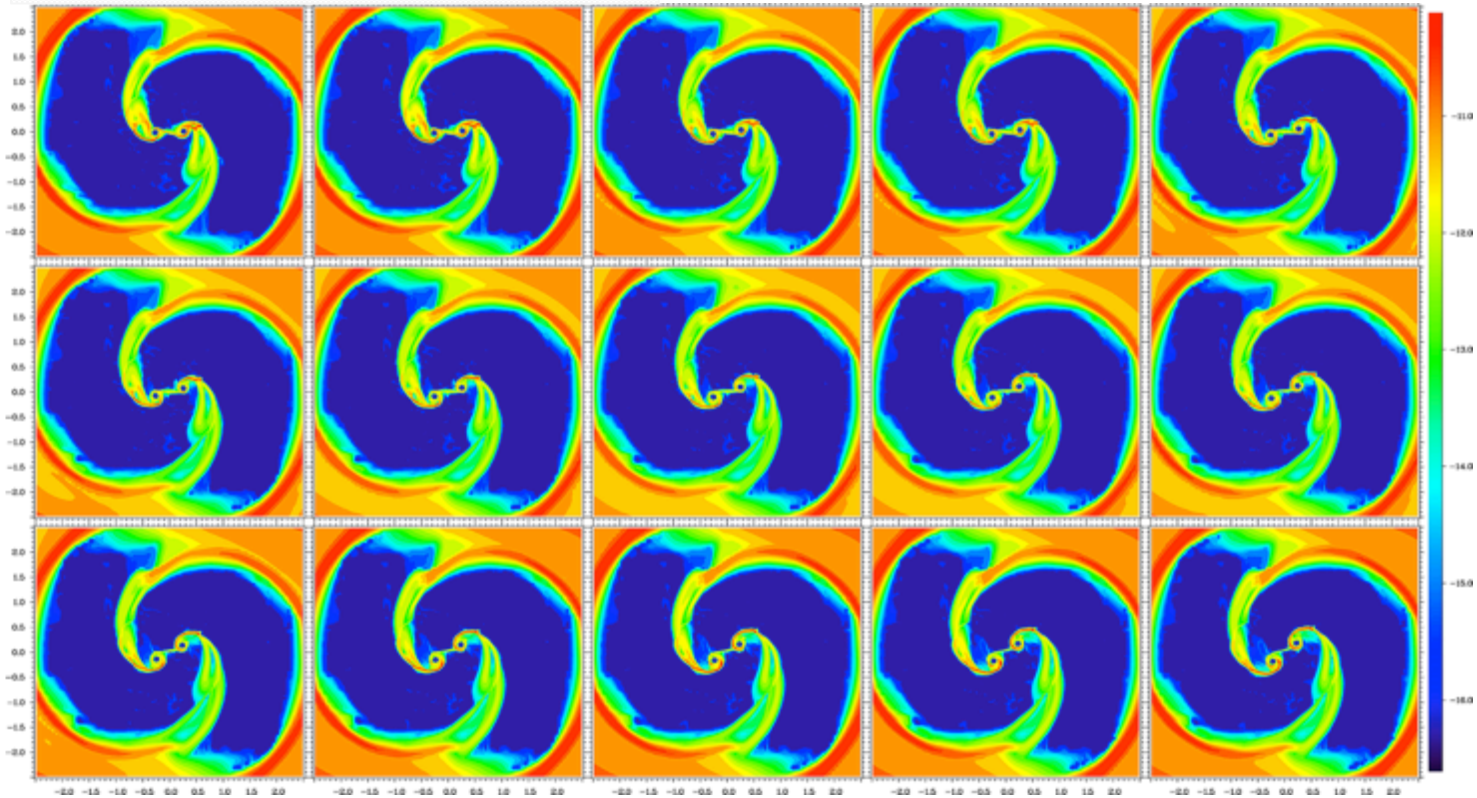
IN SUMMARY:

- ✧ DISK WINDS ACT LIKE A VEIL THAT PREVENTS STELLAR EUV, FUV PHOTONS TO REACH THE DISK SURFACE.
- ✧ DISK WINDS TRANSFORM THE X-RAY PHOTONS FROM THE STAR IN A DIFFUSE RADIATION FIELD (Te ~ 10,000 K) ILUMINATING THE DISK.
- ✧ PHOTOEVAPORATION BECOMES SIGNIFICANT WHEN THE ACCRETION RATE HAS DROPPED BELOW $\sim 10^{-9}$ M_{SUN}/YR

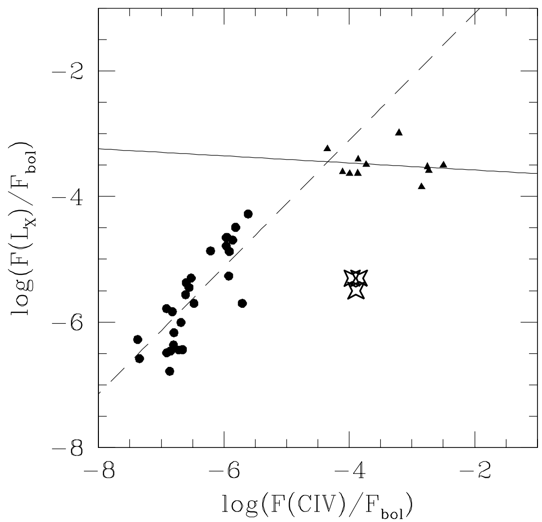
CAUTION: FILLING FACTOR OF THE OUTFLOW (10%?).

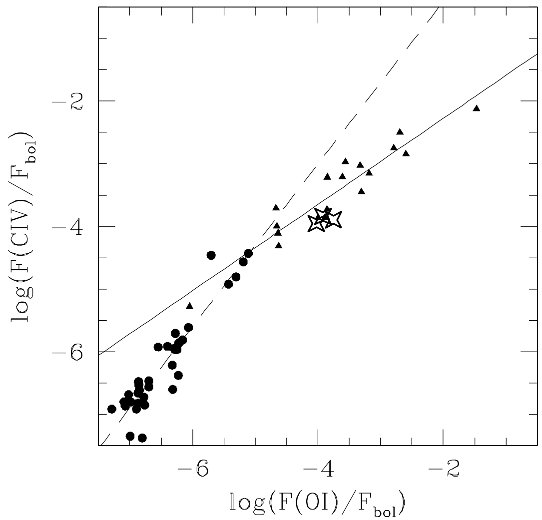
DISK SHADOWING BY THE ACCRETION FLOW: AK SCO

CLEAN CIRCUMSTELLAR ENVIRONMENT
NO DISK WINDS – NO JETS



LOW MAGNETIC ACTIVITY (F-TYPE)

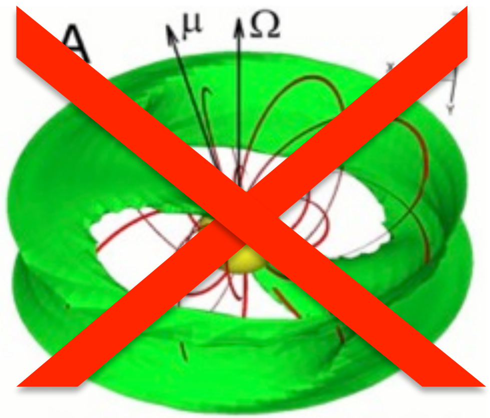


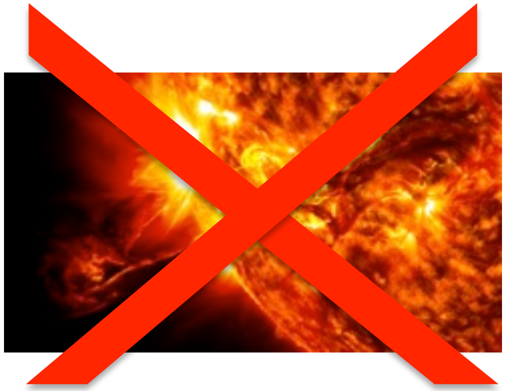


X-RAY SED (XMM-NEWTON/EPIC):

Optically thin plasma: $T_e \approx 7\ 10^6$ K ;
variable N_H column (0.08-1.1 10^{21} cm^{-2})

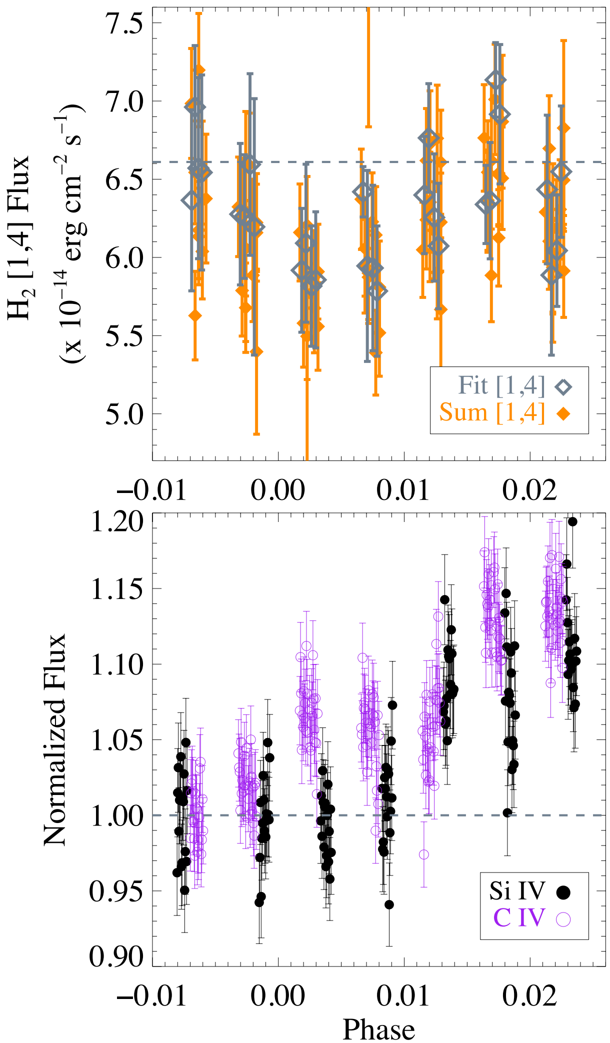
X-ray subluminous compared with other TTSs





Romanova et al 2008, 2012, 2013

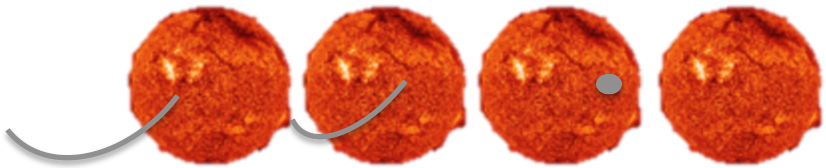
DISK SHADING BY THE INFALLING MATTER

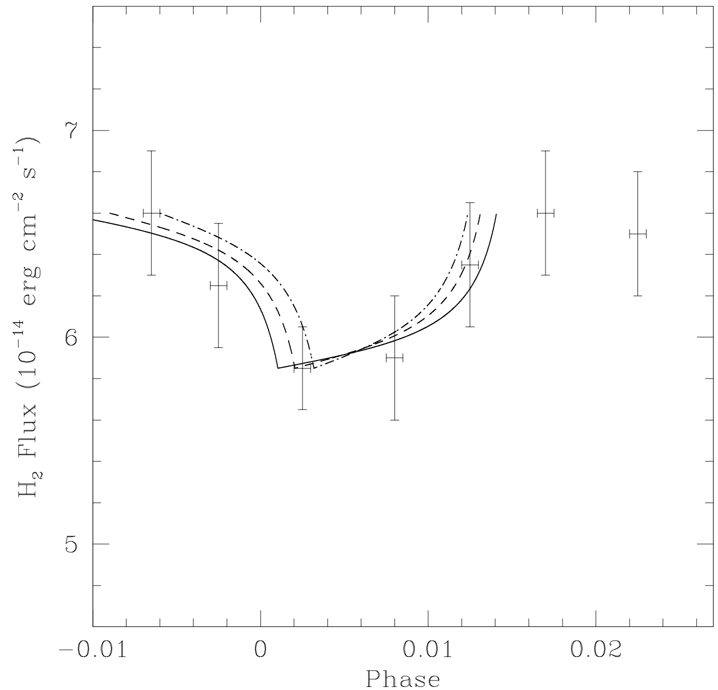


Gómez de Castro et al. 2016

$N_H > 5\ 10^{17}\ cm^{-2}$ blocks Lyα photons

R_i =2.3 R_*
Free fall 15,330 s; Δθ=1.7 rad





DOES THE LAMPOST MODEL APPLY TO TTSs ?

Gómez de Castro 2013

MHD SIMULATIONS OF PROTOSTELLAR JETS
formation and stability of shock diamonds

S. Ustamujic, S. Orlando, R. Bonito, M. Miceli, A. I. Gómez de Castro, J. López-Santiago

METHODS

- **2.5D MHD simulations** of the propagation of a **supersonic jet** into an an **initially isothermal and homogeneous magnetized** medium (includes thermal conduction and radiative losses).
- Exploration of the parameter space (ρ, v, B) to determine the **range of parameters leading to X-ray emission** from protostellar jets.
- We **synthesized the distribution of emission measure vs. temperature** and the luminosity from the simulations output data.

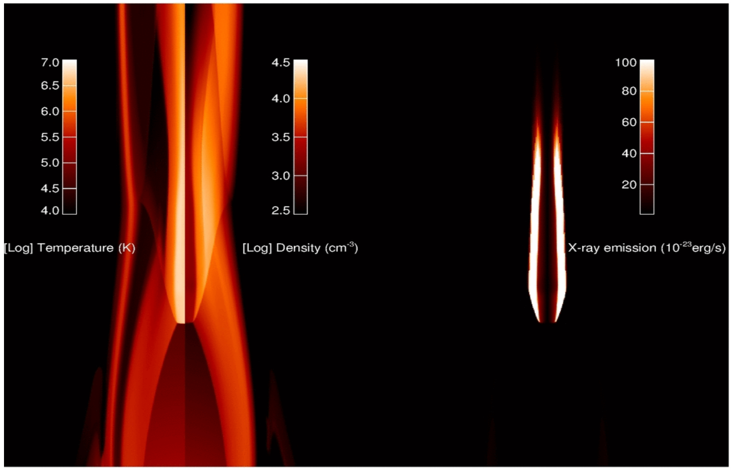


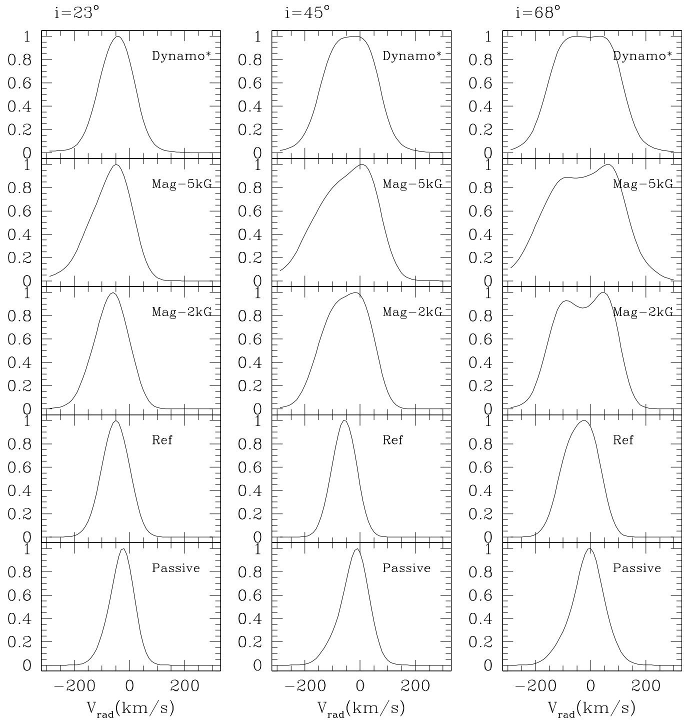
Fig.1: Density, temperature and synthesized X-ray emission in the plane r-z for the best case. A strong stationary shock is observed heating the plasma up to temperatures of a few million degrees. The total X-ray luminosity derived for the shocked region is 9×10^{28} erg s^{-1}, consistent with those detected in several HH objects.

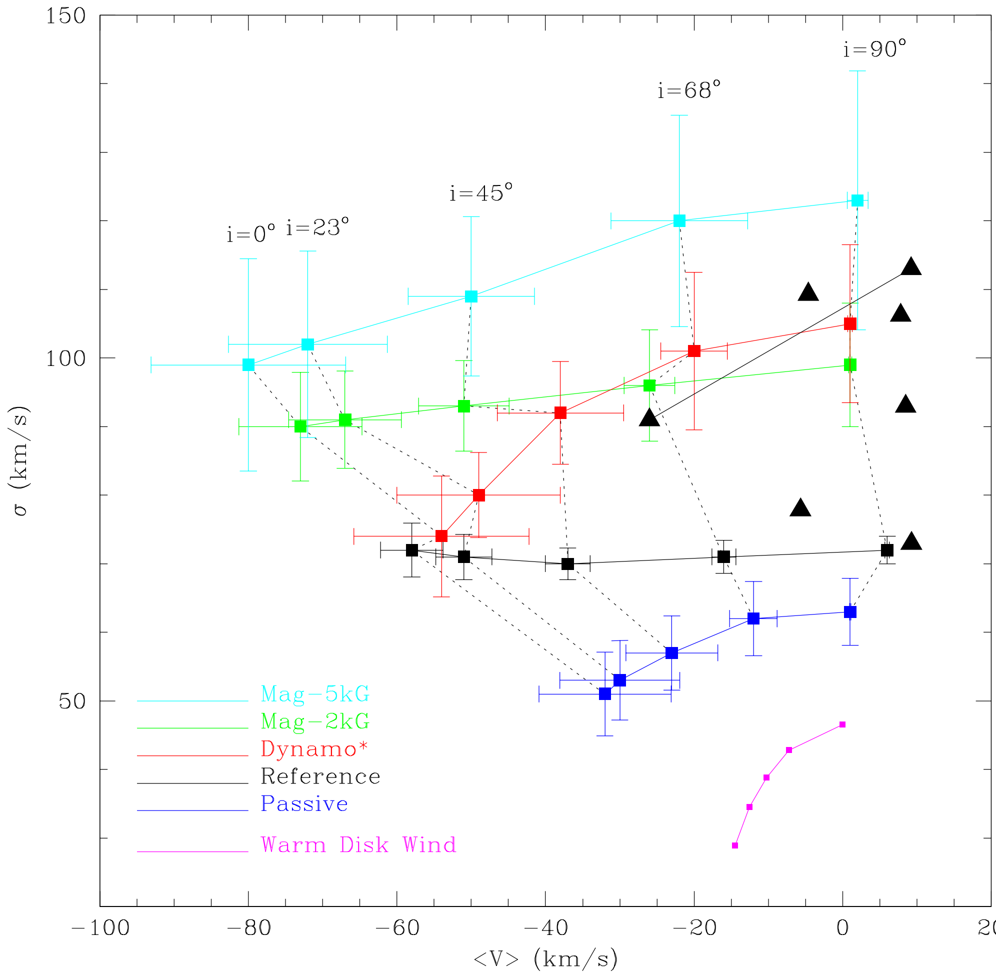
Fig.2: Three-dimensional density and magnetic field reconstruction.

In this case we consider an helicoidal geometry for the magnetic field, thus studying the lines twisting and providing insight on its influence on the stationary shock.

THANK YOU

THE OUTFLOW: MIXING WITH MAGNETOSPHERIC RADIATION





Gómez de Castro & von Rekowski 2011