Accretion, winds and outflows in young stars

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CfA

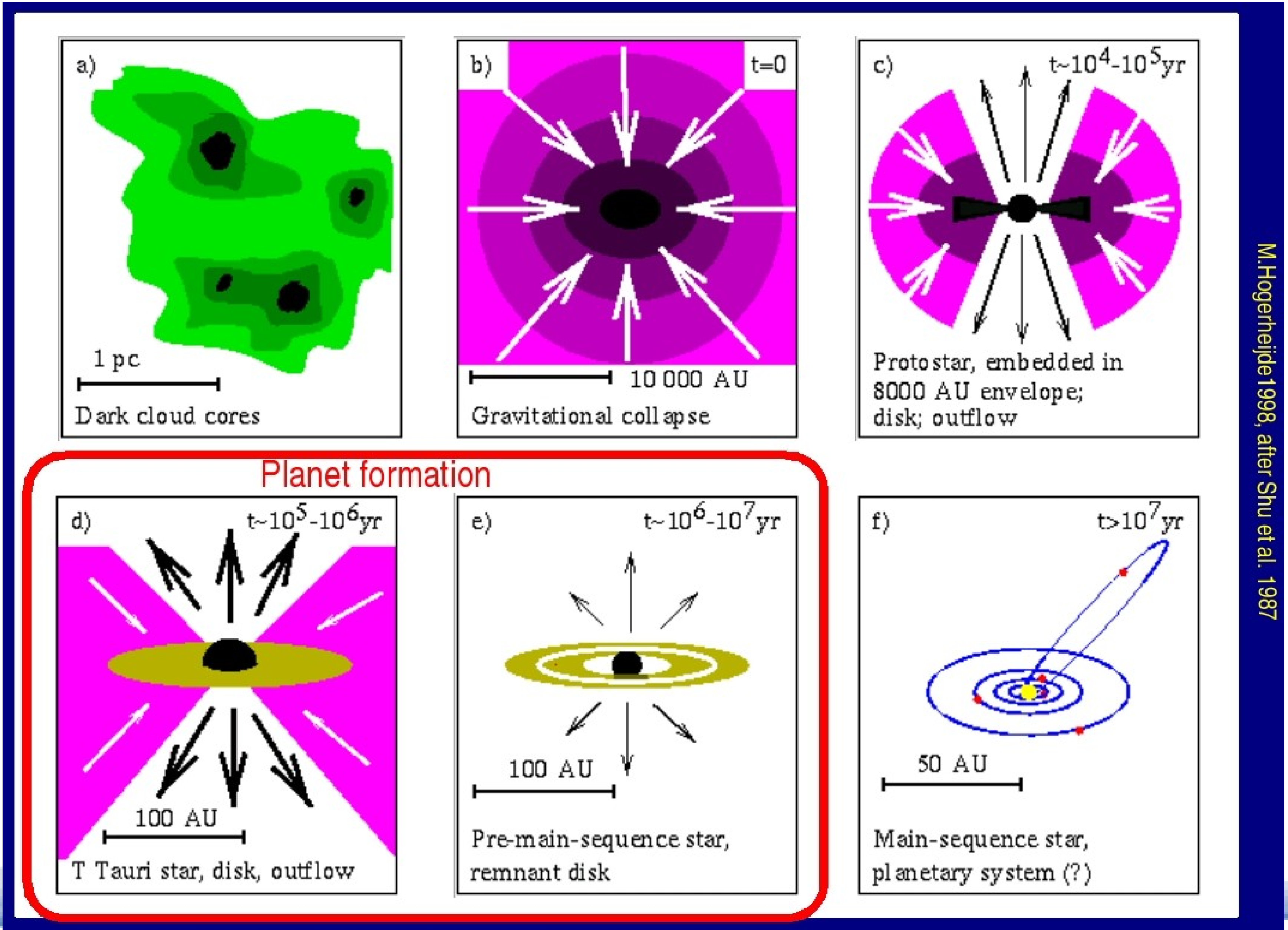
Outline

- Introduction
- Accretion
- Winds
- Jets
- Open questions

What I do not cover:

- Variability
- Sample statistics

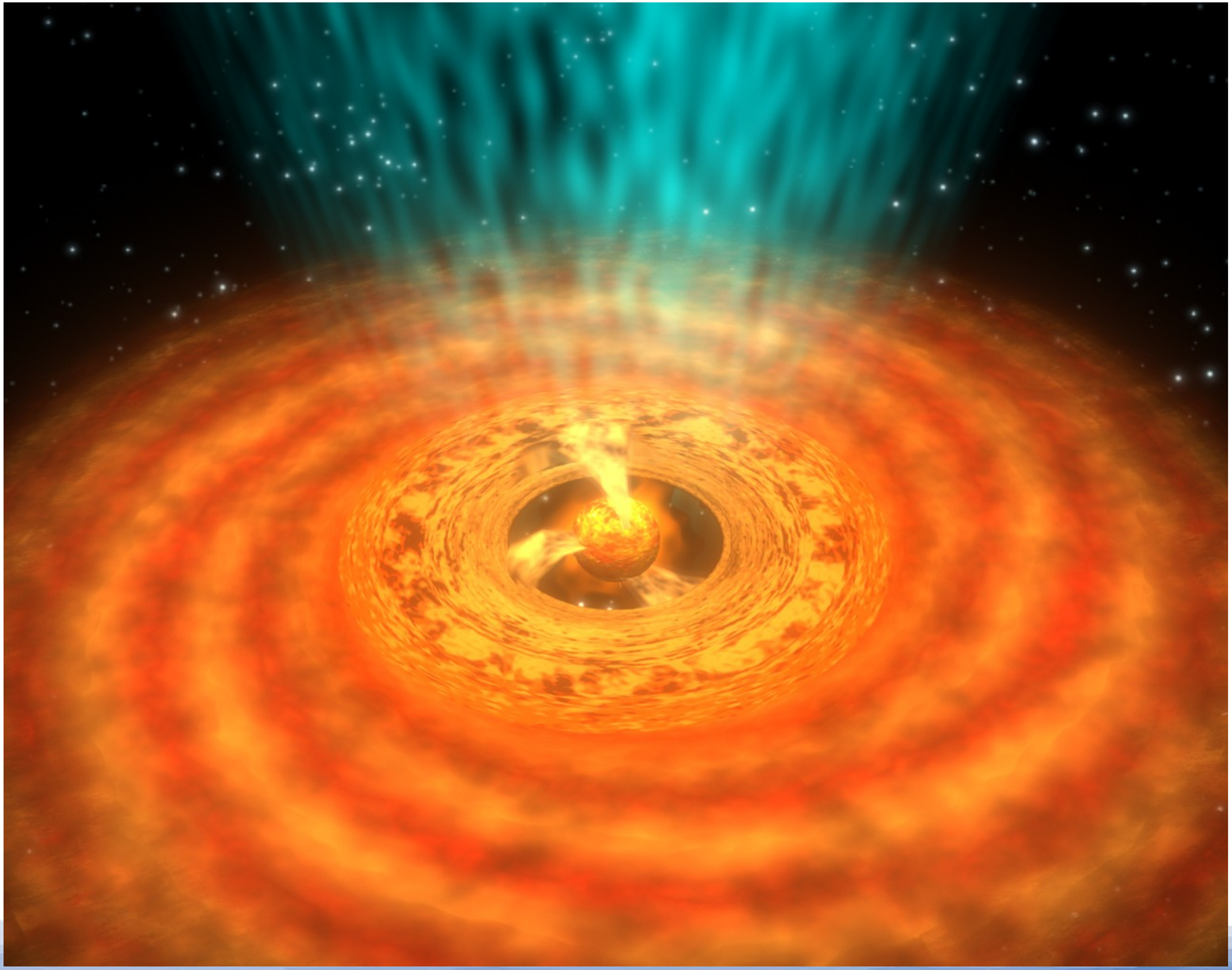
Time line of star formation



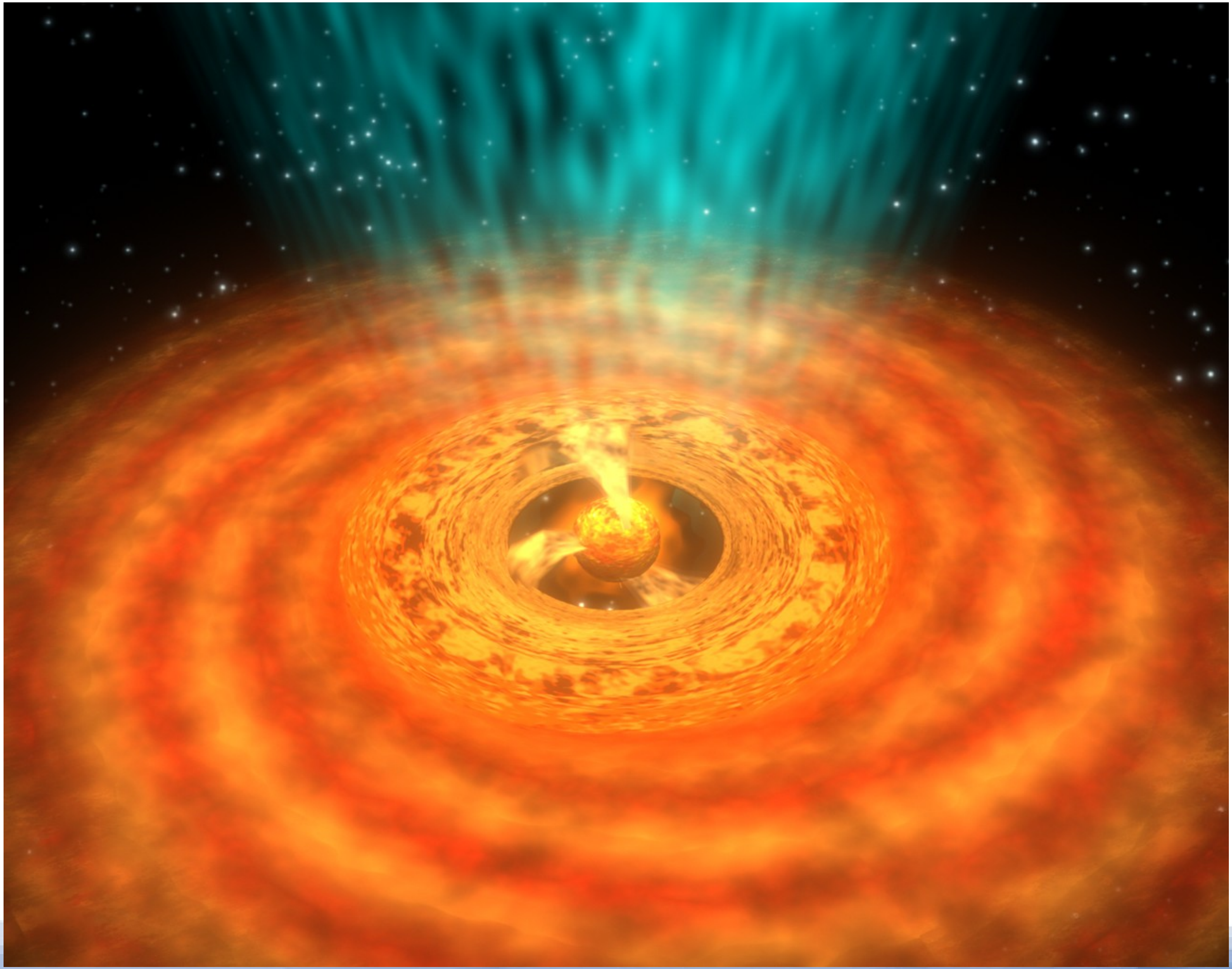
Classical T Tauri stars

- Cool Stars: spectral type M-F
- Definition: Hα in Emission > 10 Å
- Pre-Main sequence stars
- IR: class II source: Disk, but no envelope
- Radii larger than on main sequence

Emission from Classical T Tauri stars

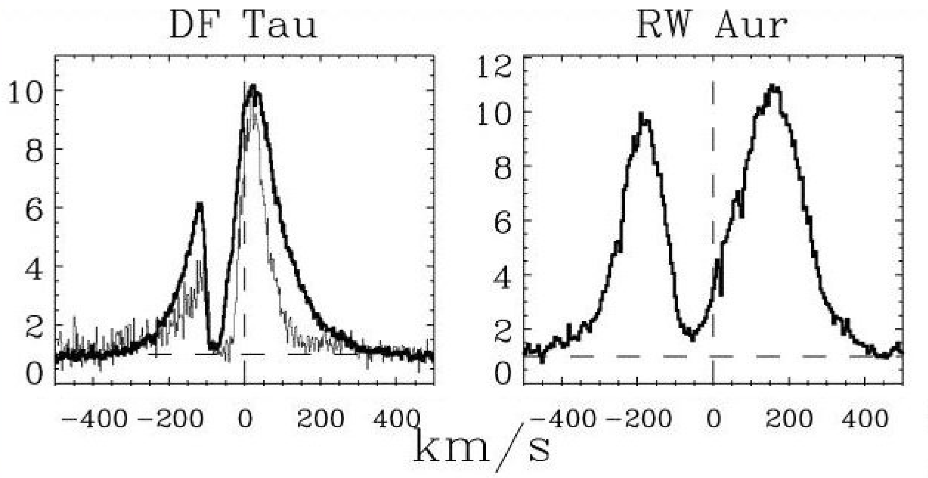


Accretion



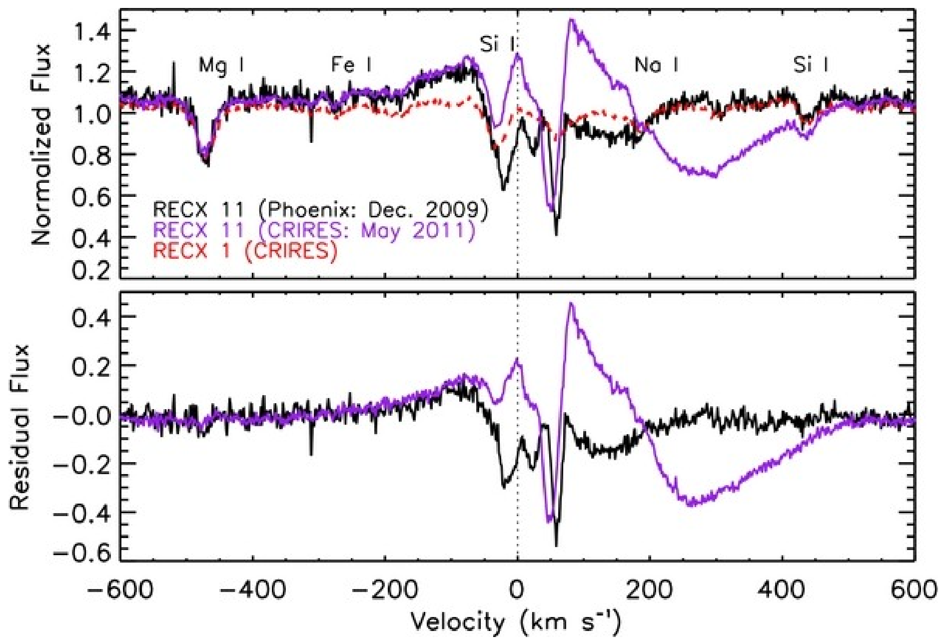
Tracers of accretion: Line profiles

- Optical lines (e.g. Hα)



Ardila et al. (2002)

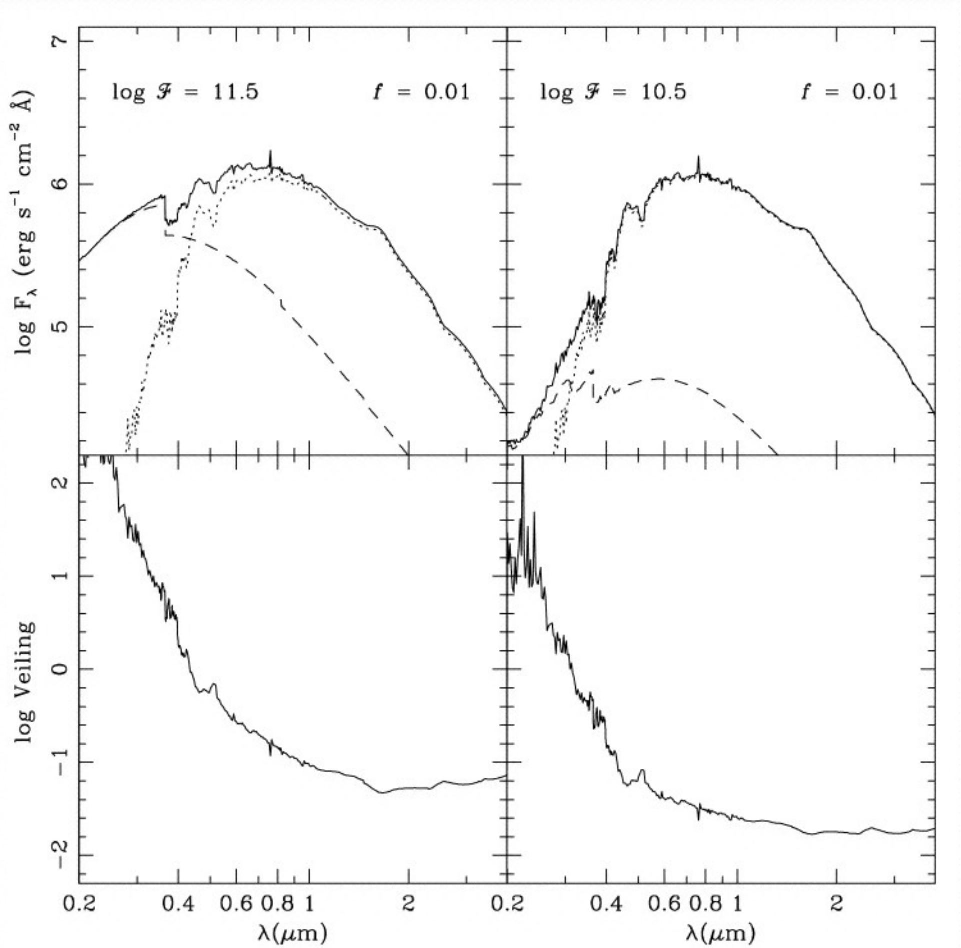
- He I 10830

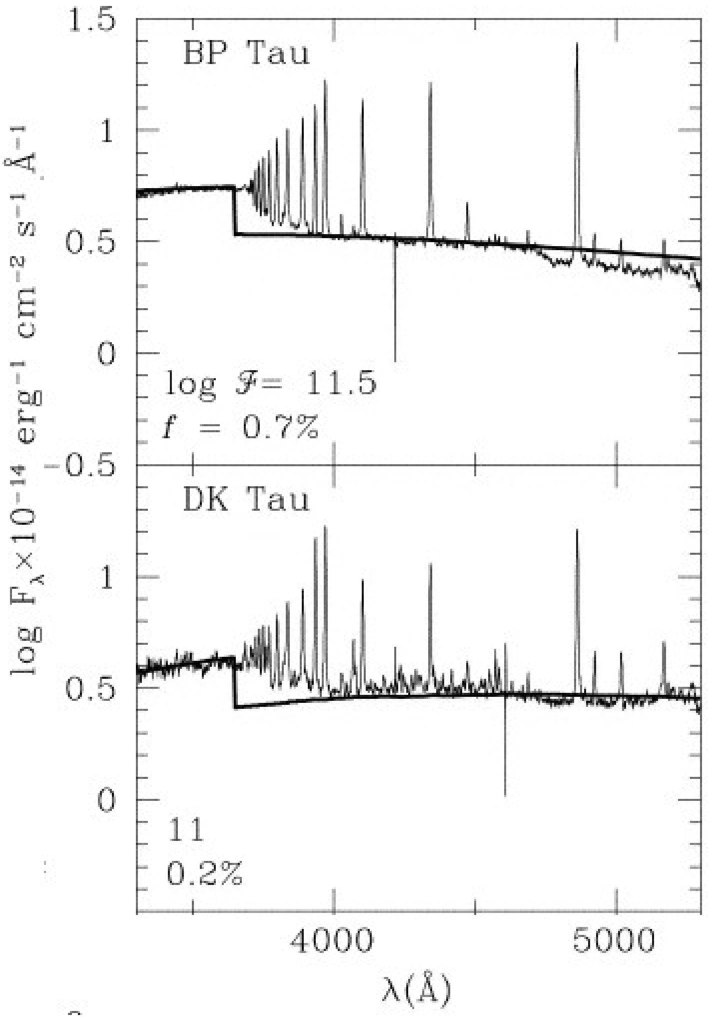


Ingleby et al. (2011)
See also work by
Edwards, Fischer, Kwan

Accretion funnels cause wide red wings up to 500 km/s (the free-fall velocity).

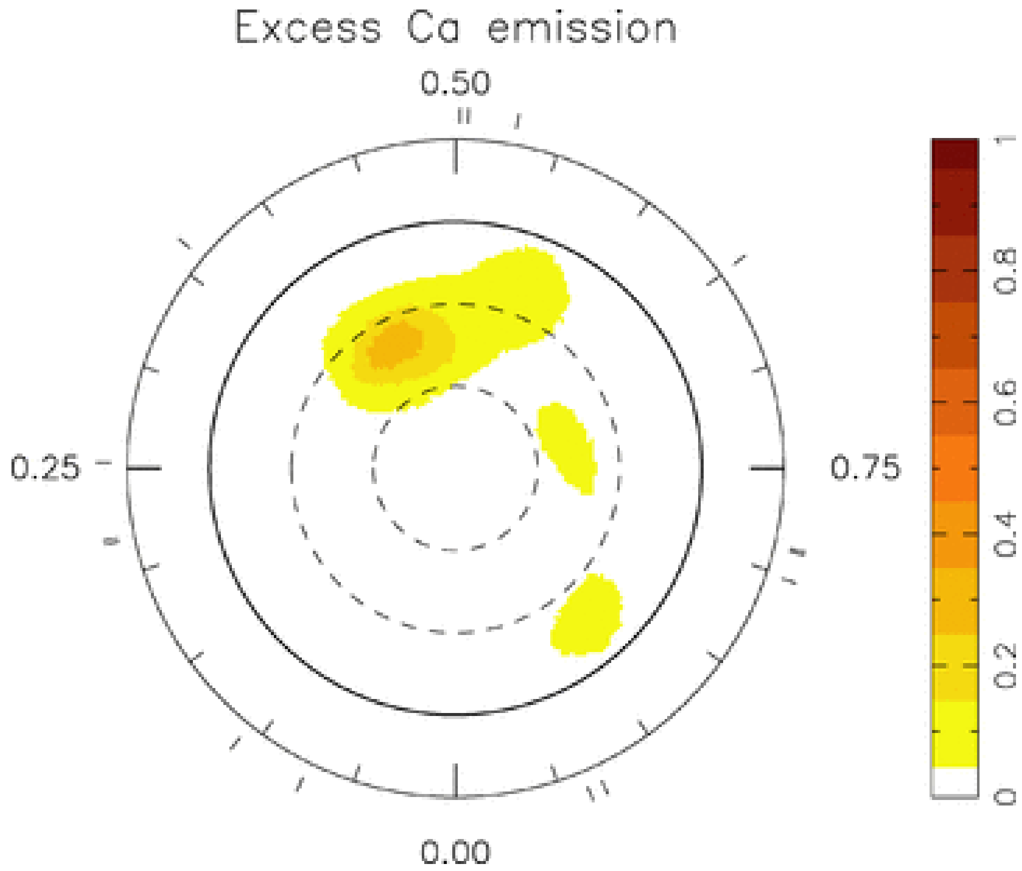
Tracers of accretion: Continuum





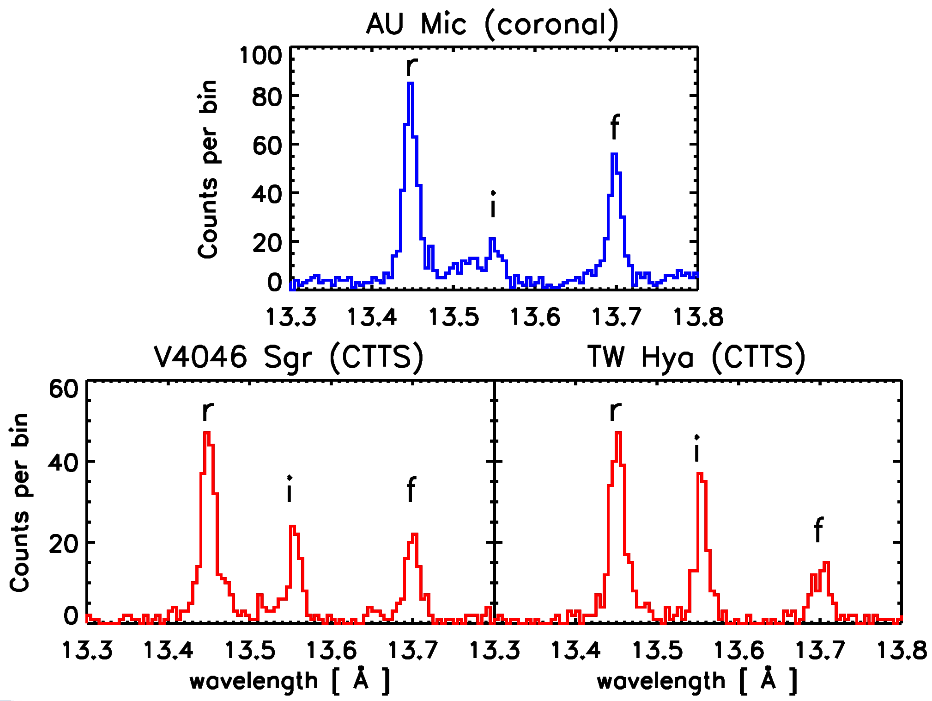
Calvet & Gullbring (1998)

Accretion spots:
(Zeeman-) Doppler imaging

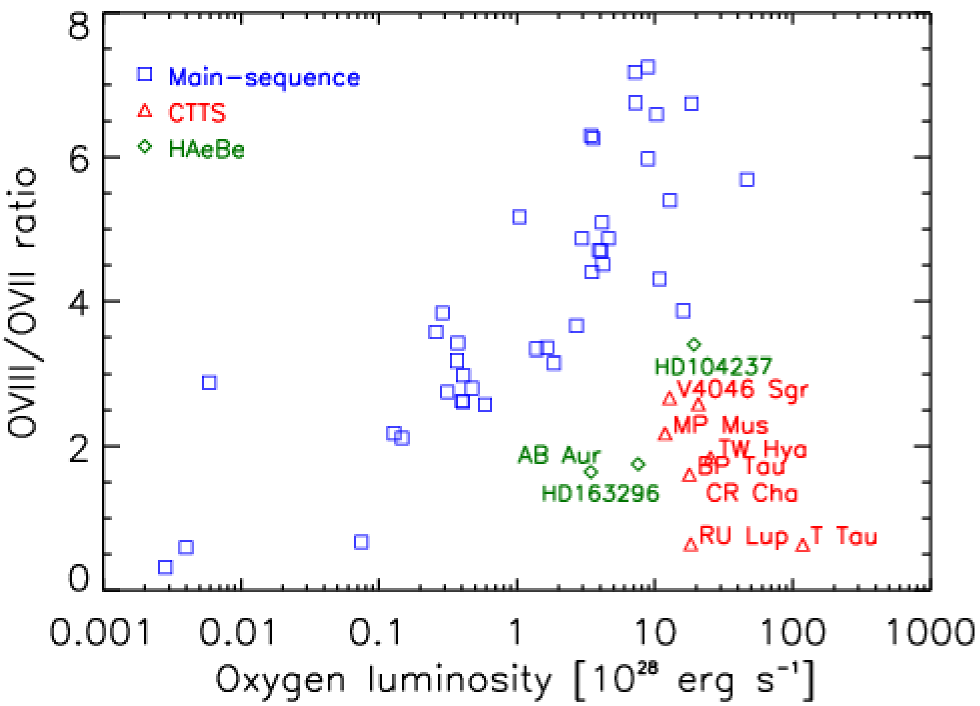


V2247 Oph: Ca II
Donati et al. (2009)

CTTS in X-rays:
He-like triplets and soft excess



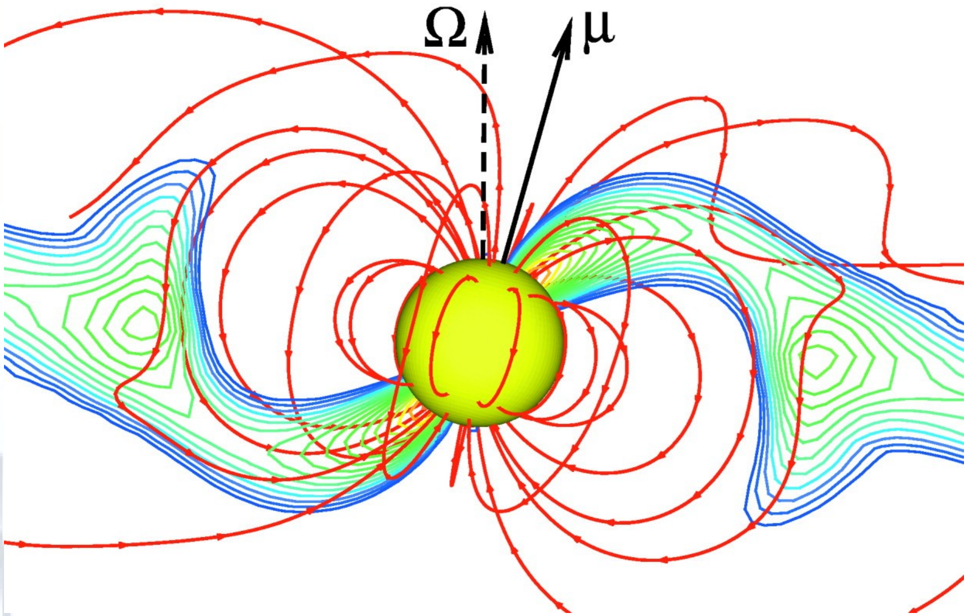
He-like triplets of Ne IX and O VII indicate densities > 10^{12} cm^{-3} in the X-ray emission region of CTTS.



Soft excess as a temperature tracer
Robrade & Schmitt (2007)
Güdel & Telleschi (2007)
Günther (2011)

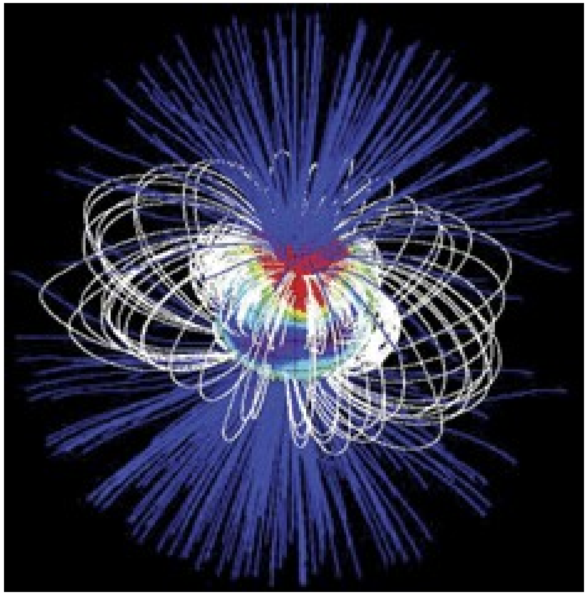
Accretion

- MHD models with multipolar fields



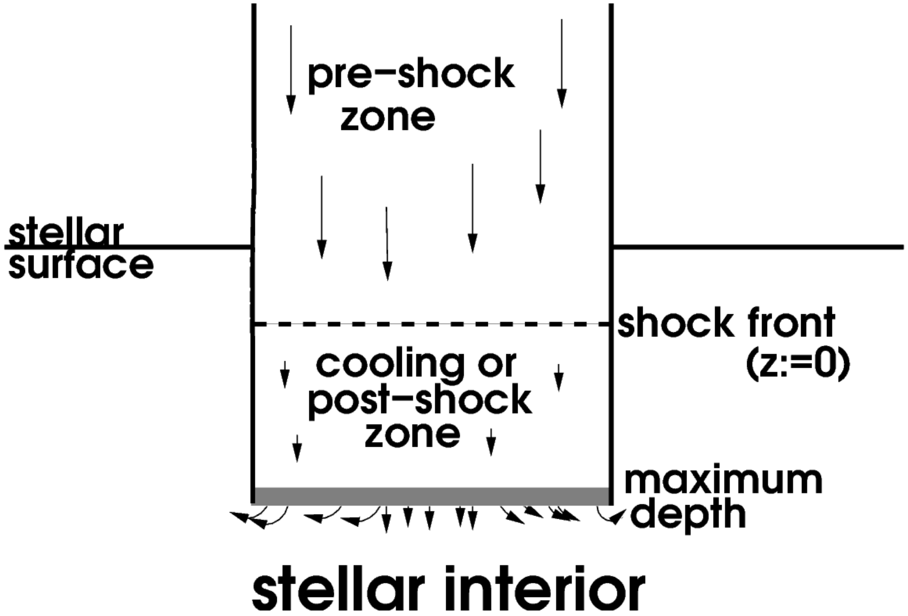
Romanova et al. (2004)

- Field reconstruction with Zeeman Doppler imaging



BP Tau: Complex small scale fields
Donati et al. (2008)

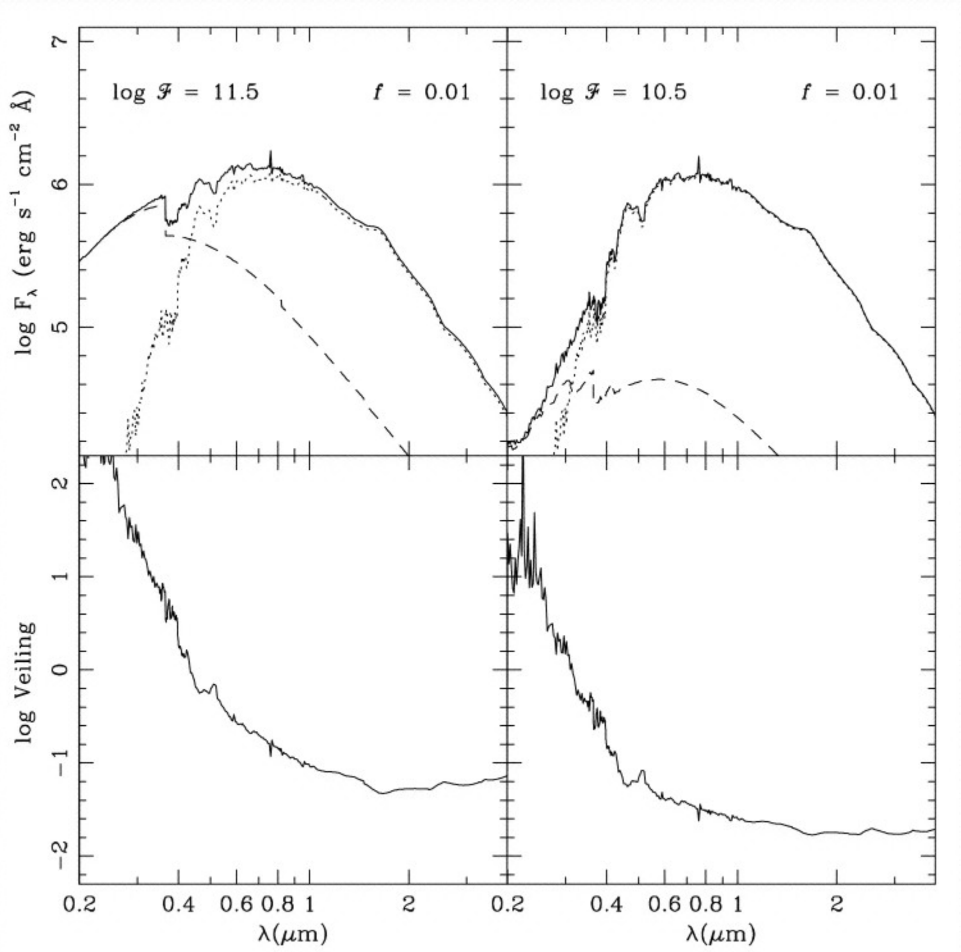
Accretion: Simulations: 1d spot

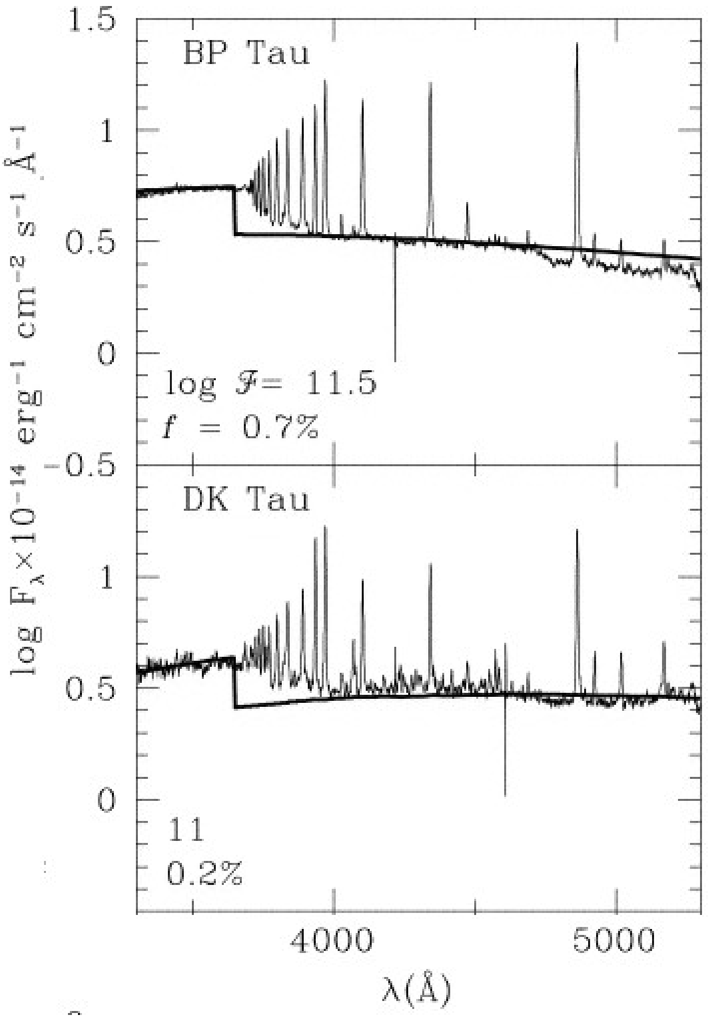


$$
\begin{aligned}
T &= 4\ \mathrm{MK} \left(\frac{v_{\mathrm{shock}}}{500\ \mathrm{km\ s^{-1}}} \right)^2 \\
n &= 4 n_0 \\
f_{\mathrm{spot}} &= \frac{A_{\mathrm{spot}}}{4\pi R_*^2} \\
\dot{M} &= A_{\mathrm{spot}}\ \rho\ v_0
\end{aligned}
$$

Several groups use essentially the same setup:
Calvet & Gullbring (1998), Lamzin (1998), Günther et al. (2007), Sacco et al. (2009), Brickhouse et al. (2010)

Tracers of accretion: Continuum

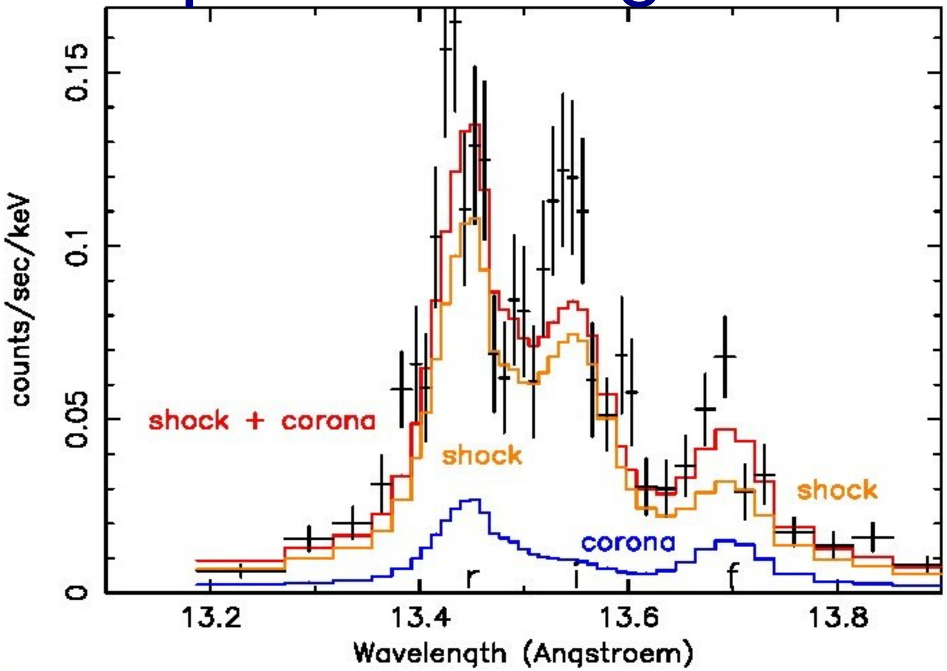




Calvet & Gullbring (1998)

Accretion simulations: The 1D spot

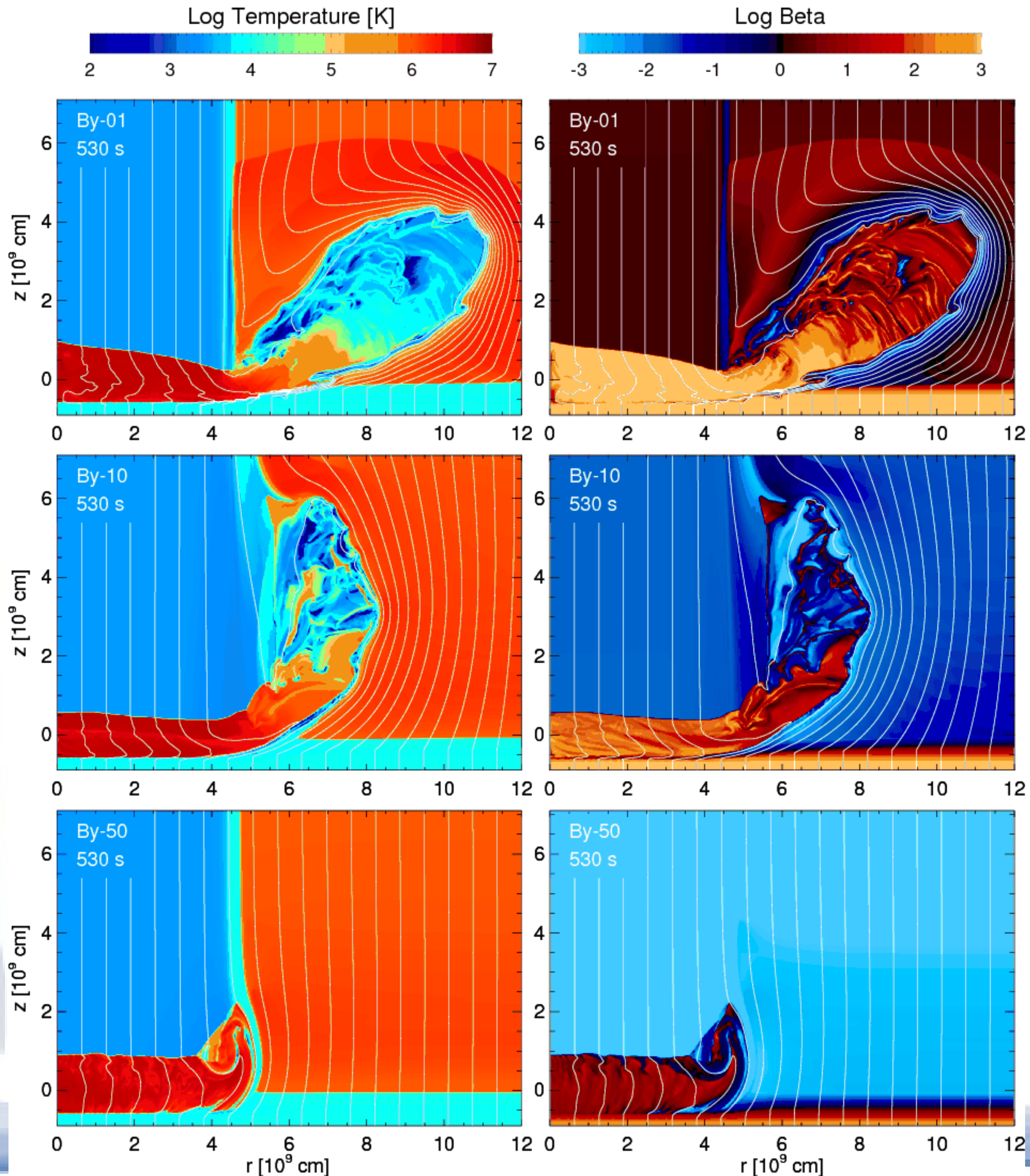
- Spectral fitting



XMM-Newton: TW Hya
Günther et al. (2007)

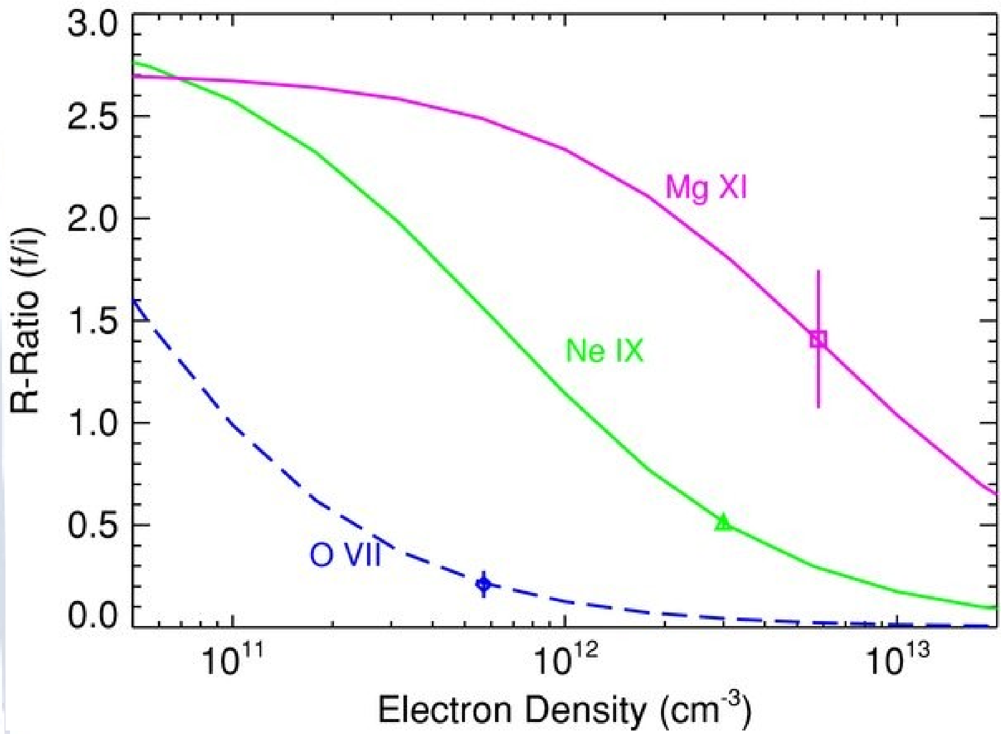
- Time variability
  - Predicted (Koldoba et al. 2008; Orlando et al. 2010)
  - But not found (Drake et al. 2009; Günther et al. 2010)

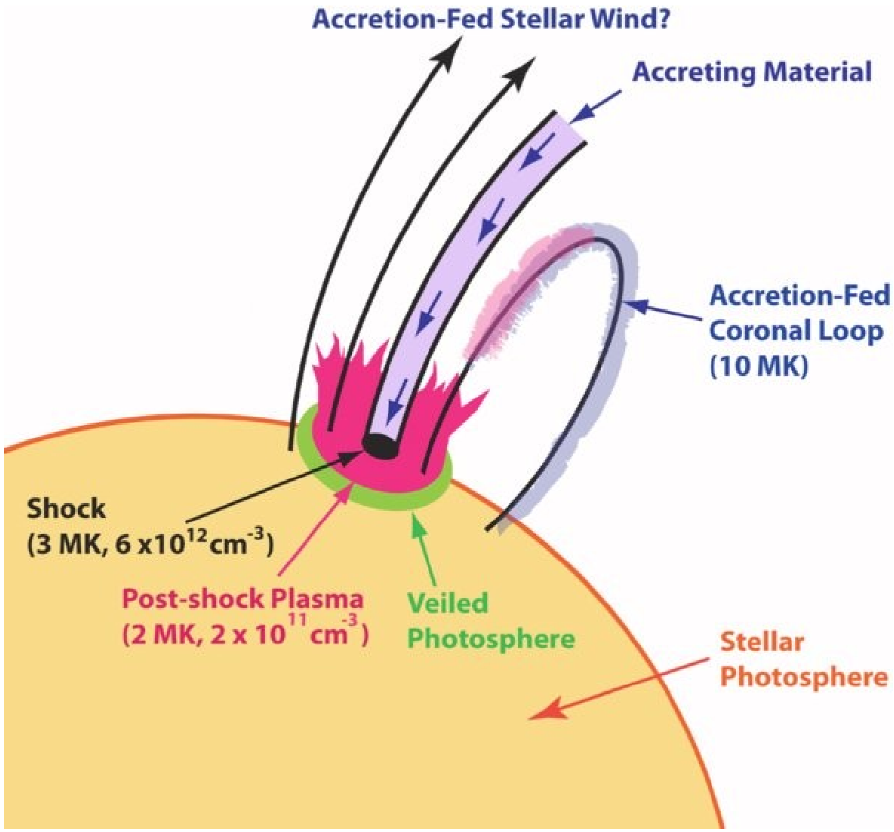
Accretion: simulations: The spot



Orlando et al. (2010)

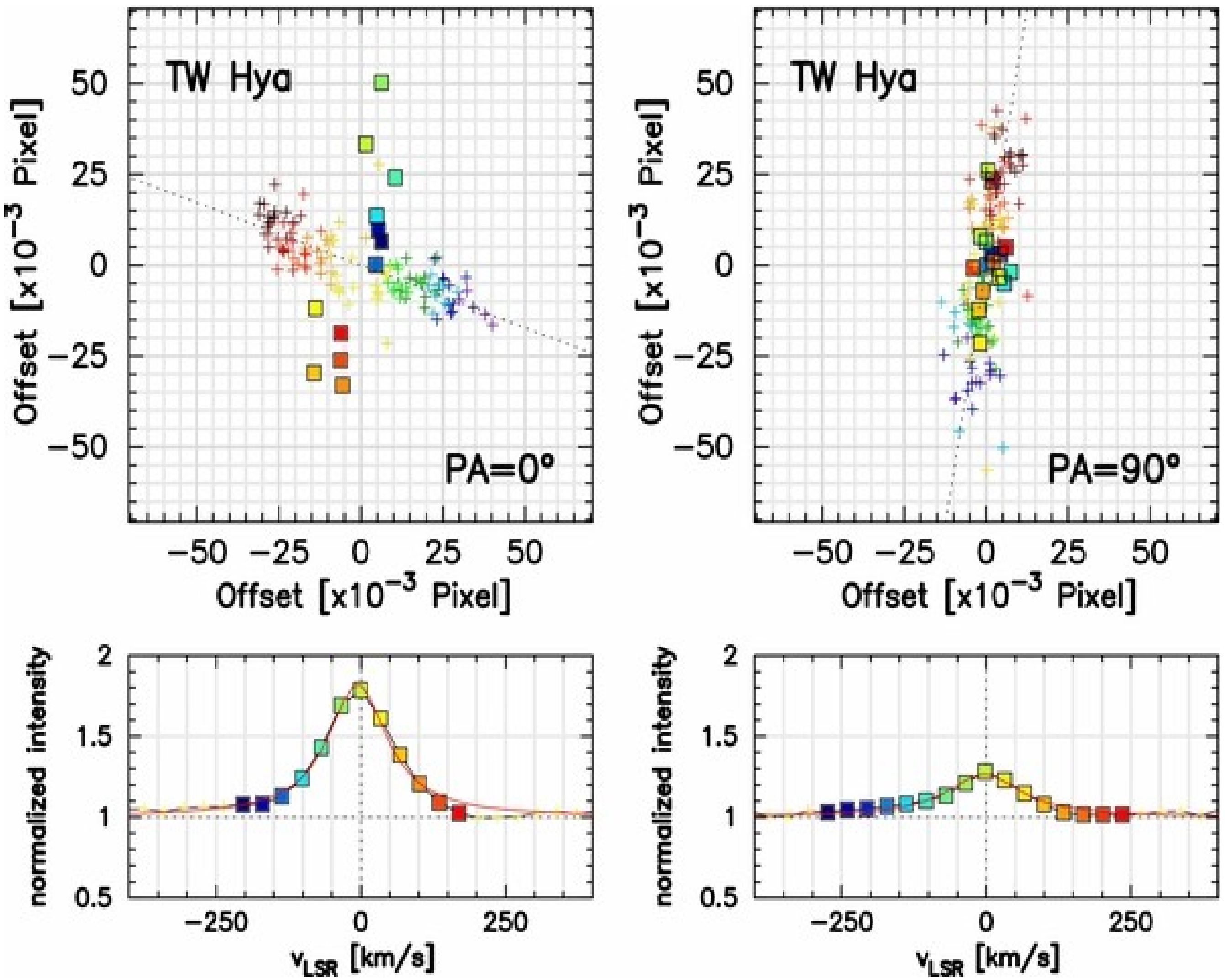
Accretion tracers: X-rays?





TW Hya: Brickhouse et al. (2010)

Where do the H lines originate?



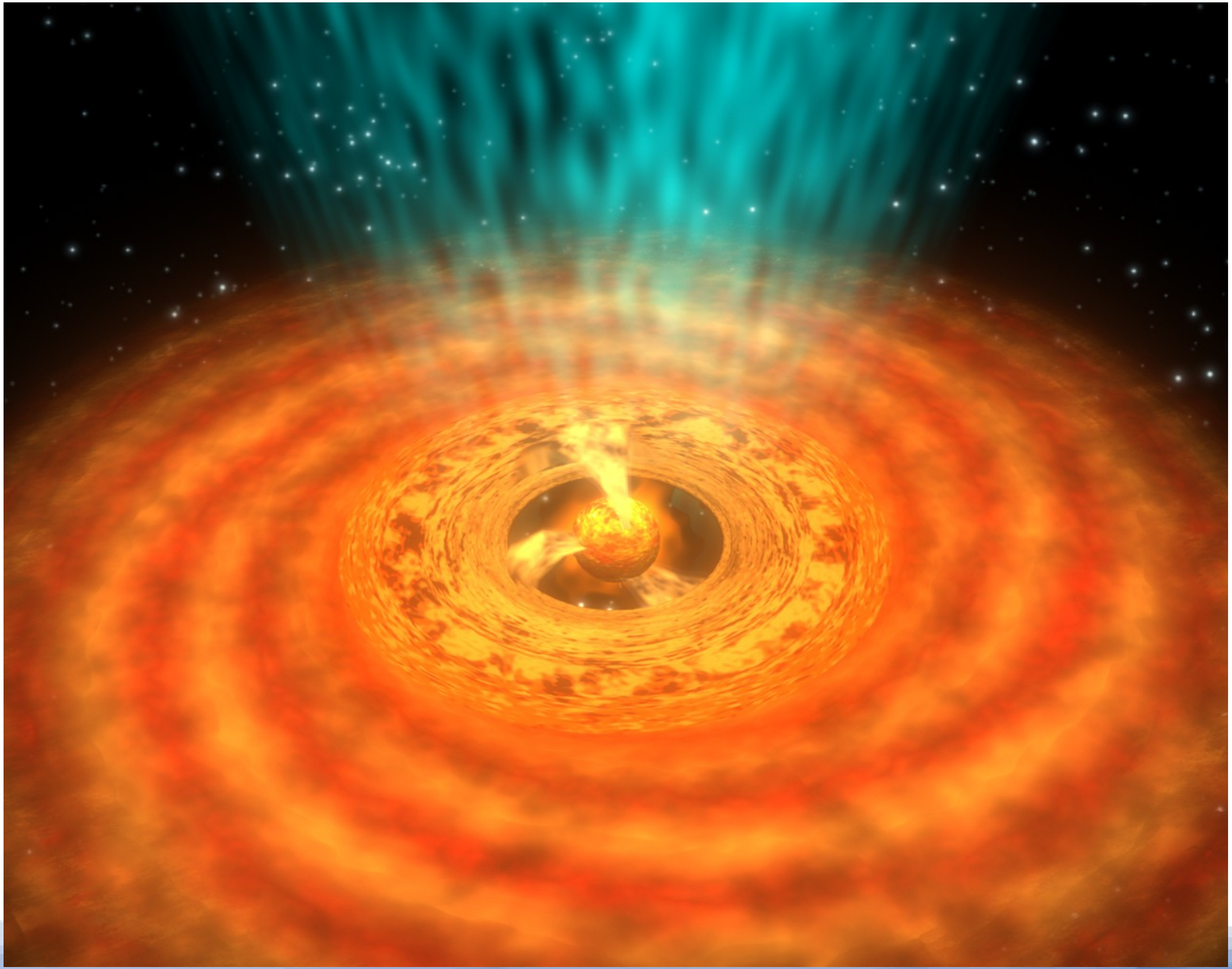
Br γ spectroastrometry: TW Hya

Goto et al. (2012)

Accretion: Summary

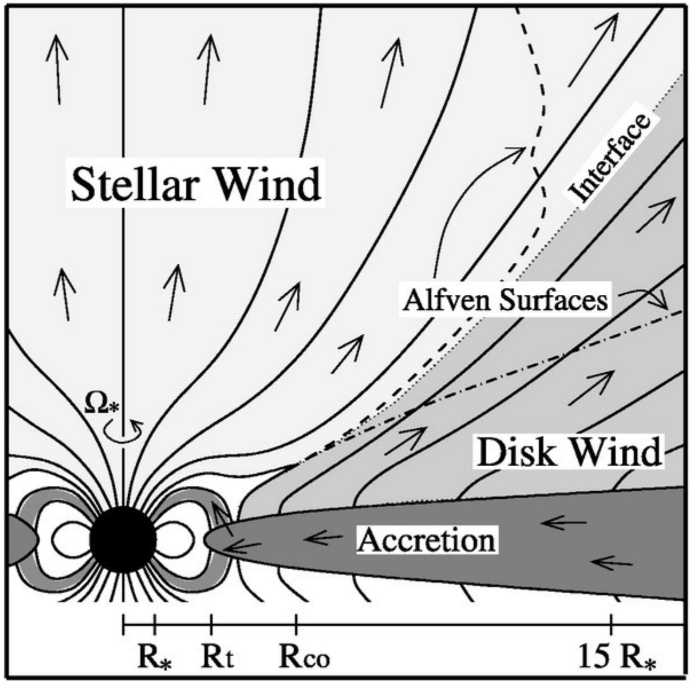
- Veiling / UV excess
- Emission lines (Hα, Ca II IRT, He I 10830)
- Soft X-rays
- Magnetically funneled from inner disk rim
- Mass accretion rates 10^{-6}-10^{-10} M_{sun}/yr

Wind



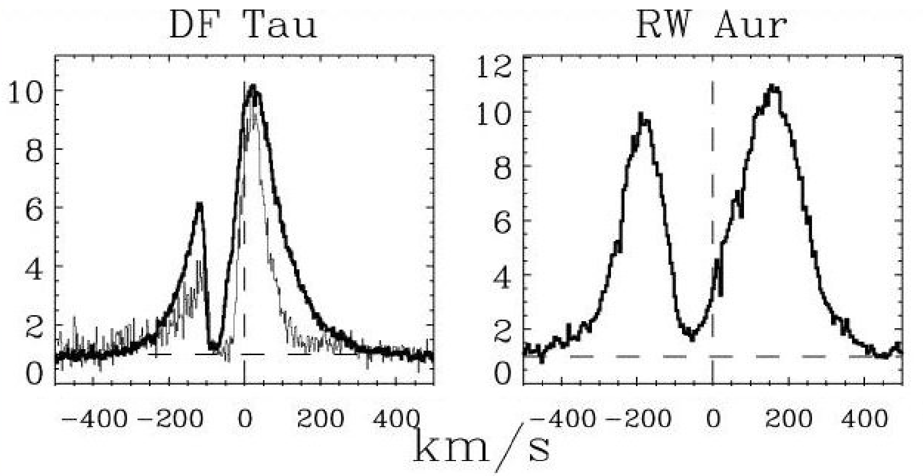
Wind: Where does it come from?

- Stellar wind (e.g. Matt & Pudritz 2005)
- X-Wind (e.g. Shu et al. 1994)
- Disk wind (e.g. Anderson et al. 2005)



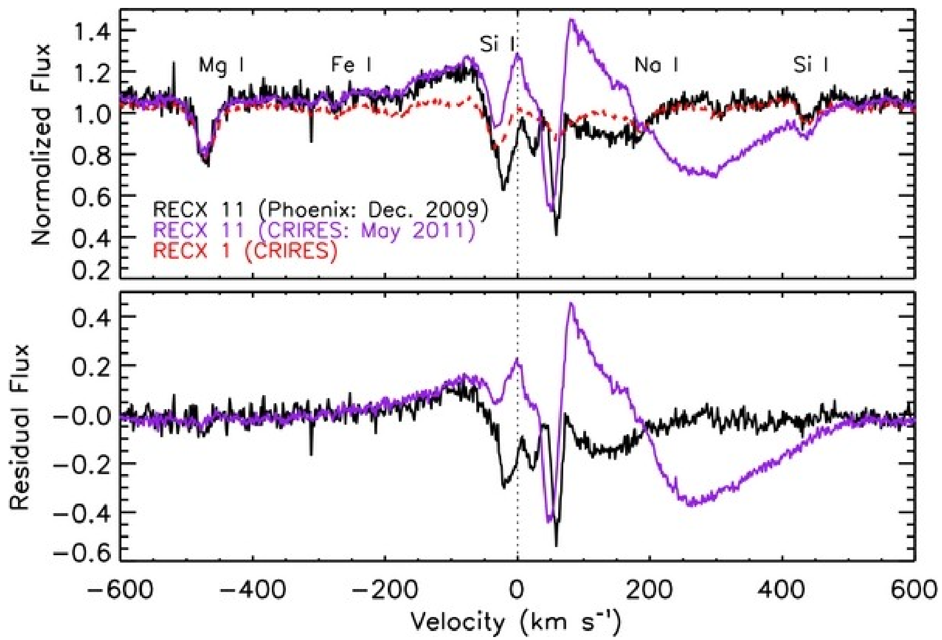
Cool wind: Line profiles

- Optical lines (e.g. Hα)



Ardila et al. (2002)

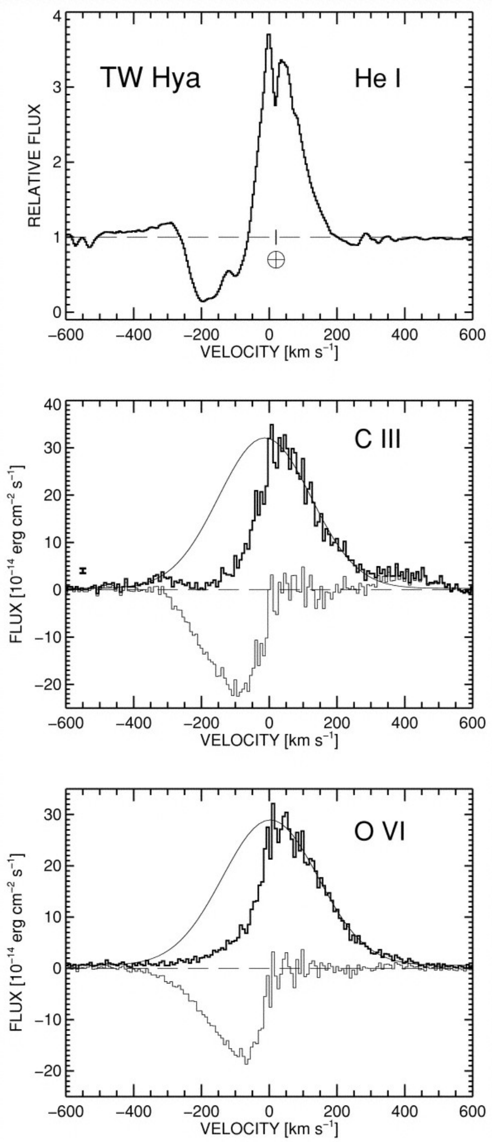
- He I 10830



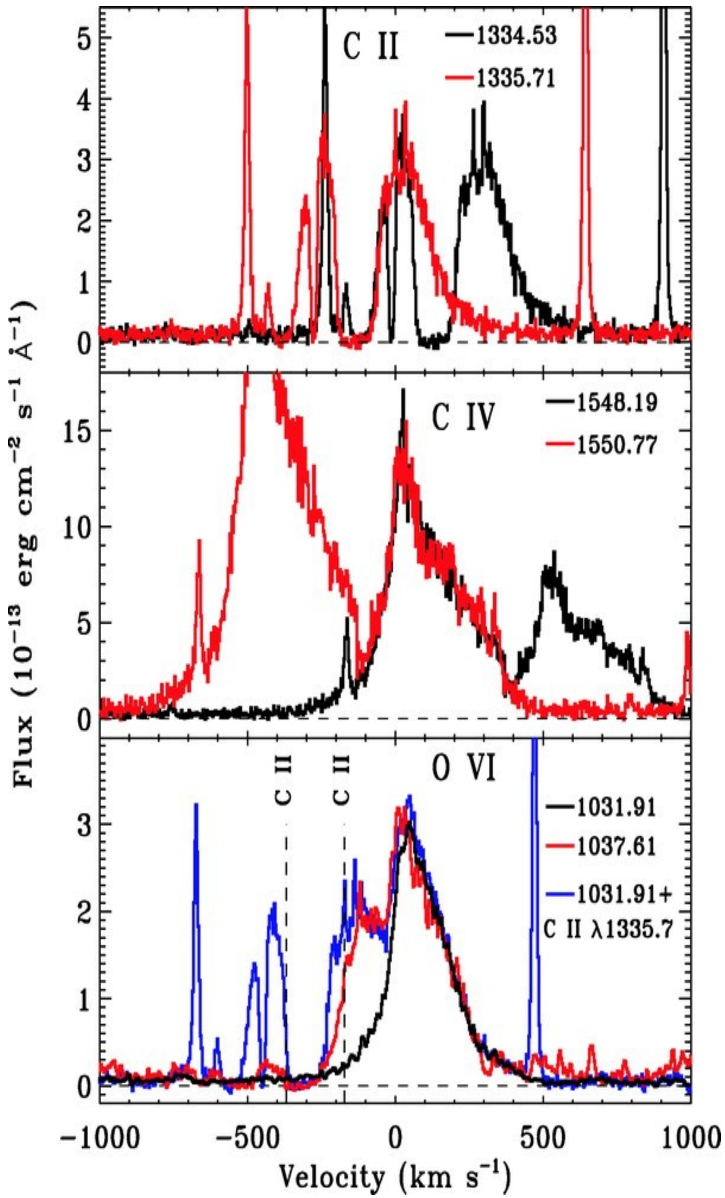
Ingleby et al. (2011)
See also work by Edwards, Fischer, Kwan

Wide-angle winds cause absorption in the blue wings at typically 50-200 km/s. This makes these lines asymmetric.

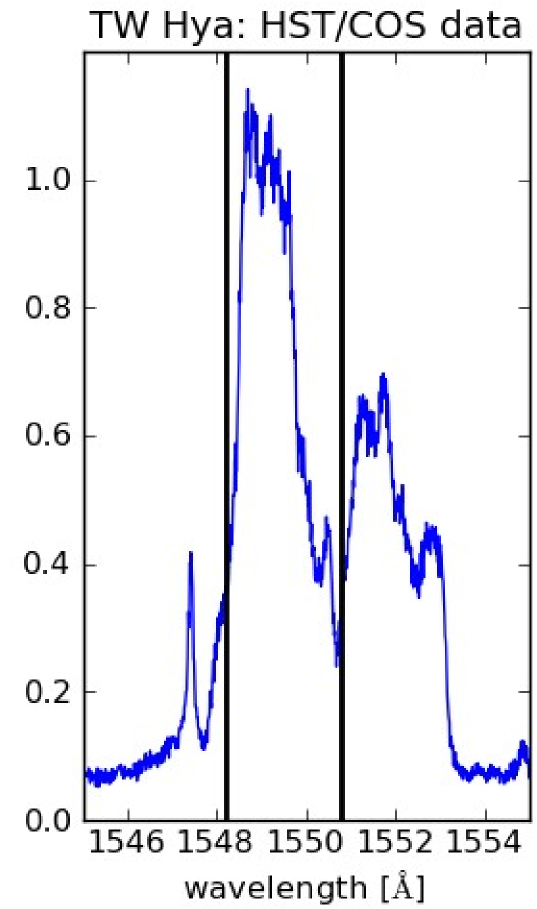
Wind: There is no hot wind.



Dupree at al. (2005)



Johns-Krull & Herczeg (2007)

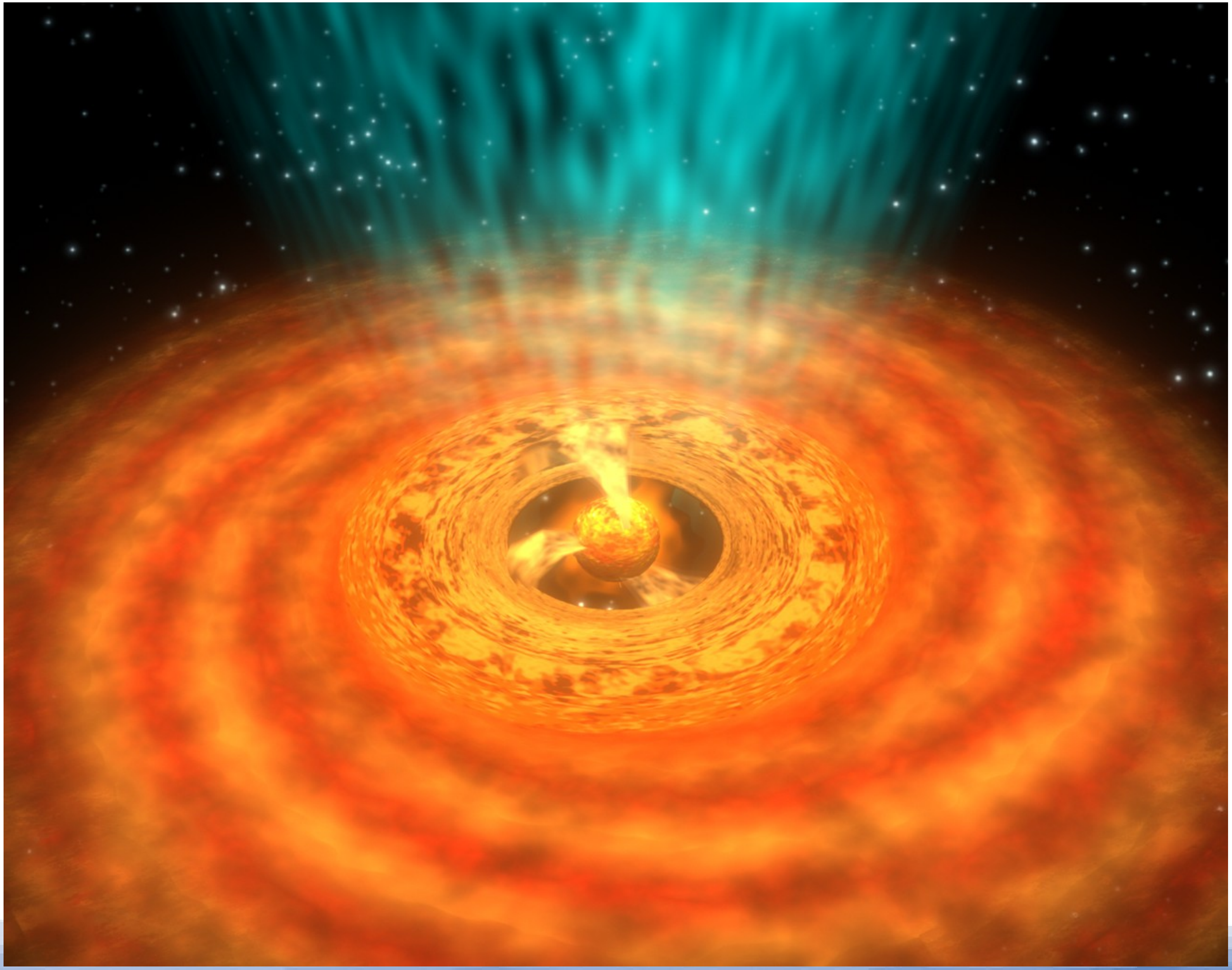


Günther et al. (in prep)

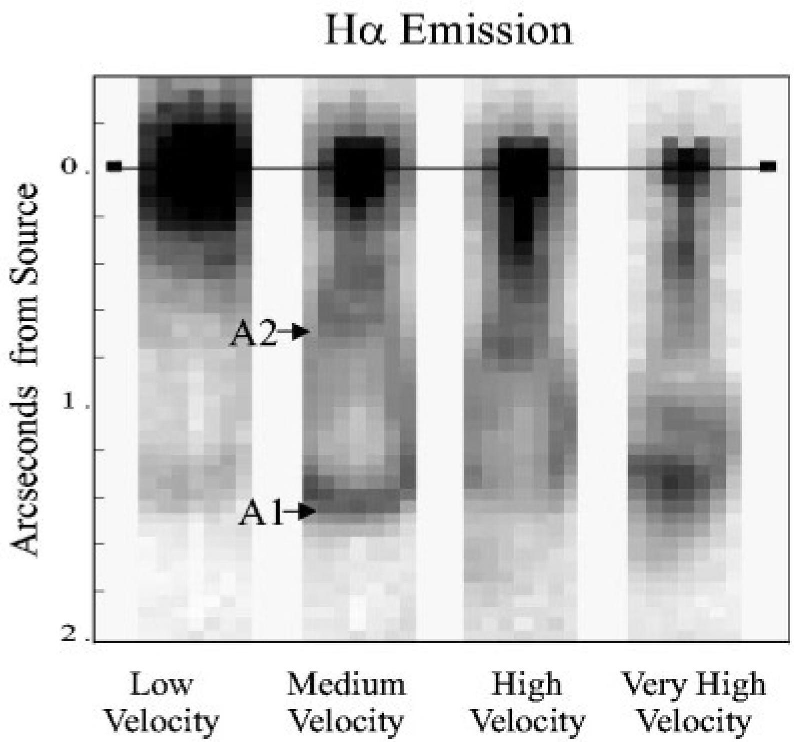
Winds: Summary

- 3 scenarios: Stellar wind (thermal), X-wind (magnetic), disk wind (magneto-centrifugal)
- Cool component in Hα, Mg II,...
- Hot component → see next talk
- Time variable

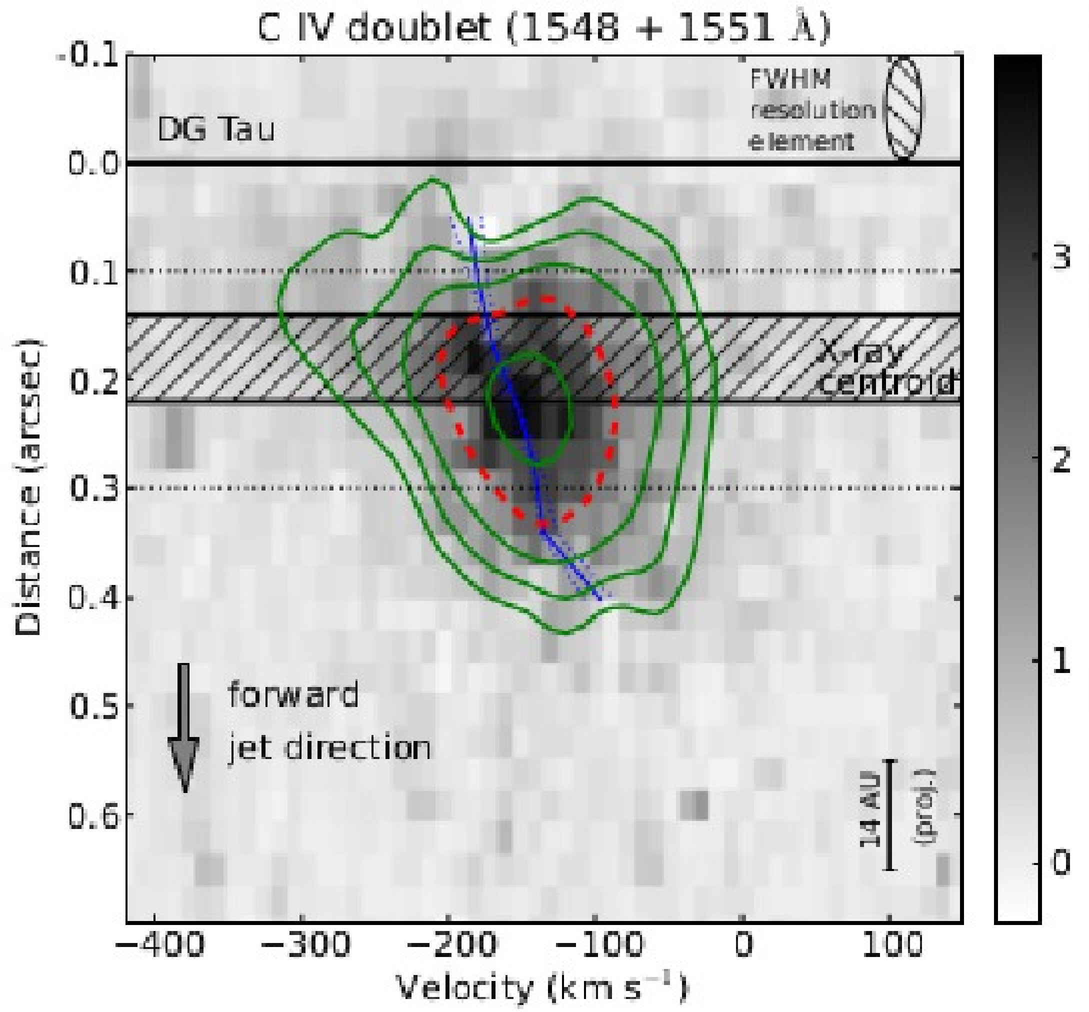
Jets



Jets: Velocity structure

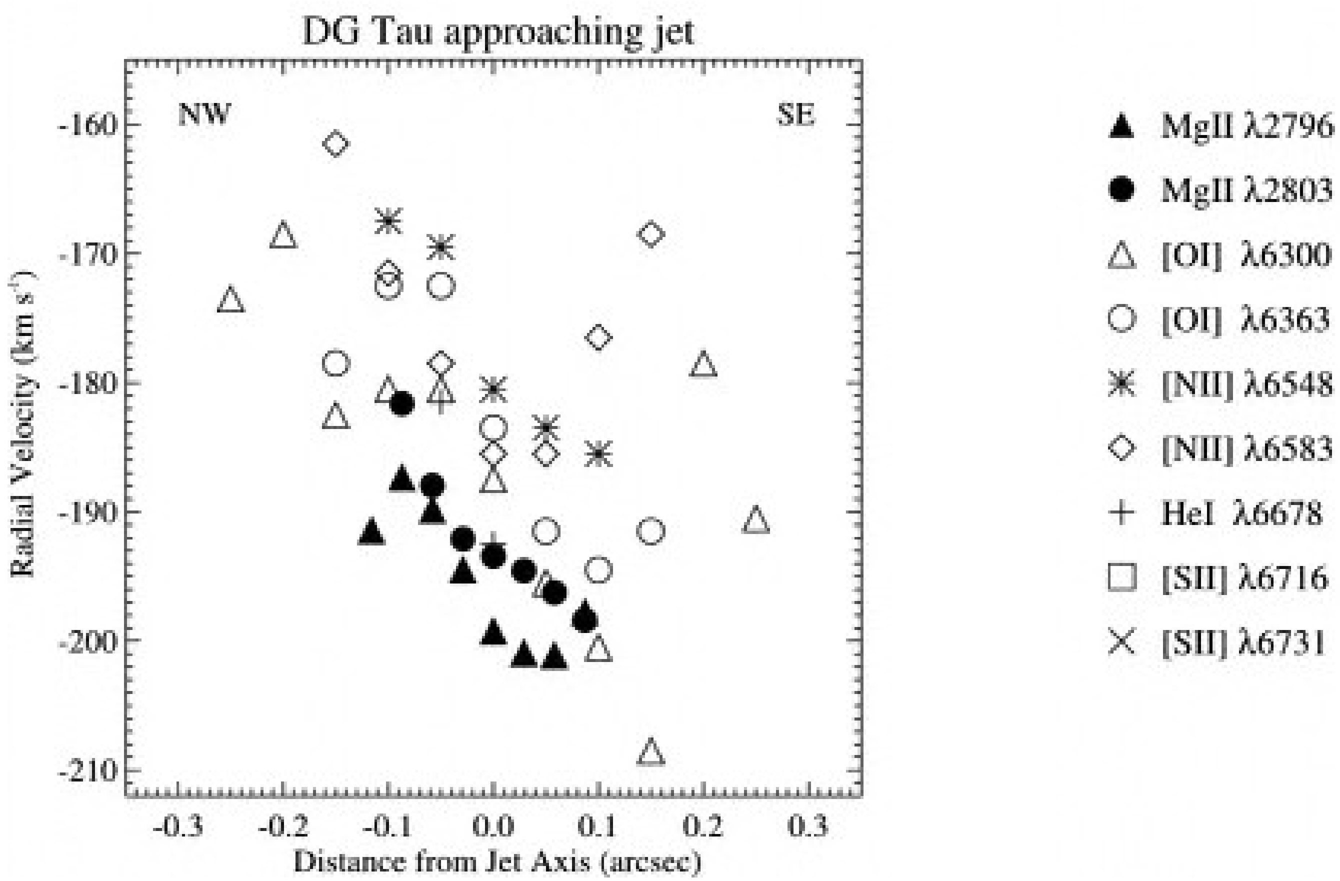


HST/STIS: DG Tau
Bacciotti et al. (2000)



HST/STIS: DG Tau
Schneider et al. (submitted)

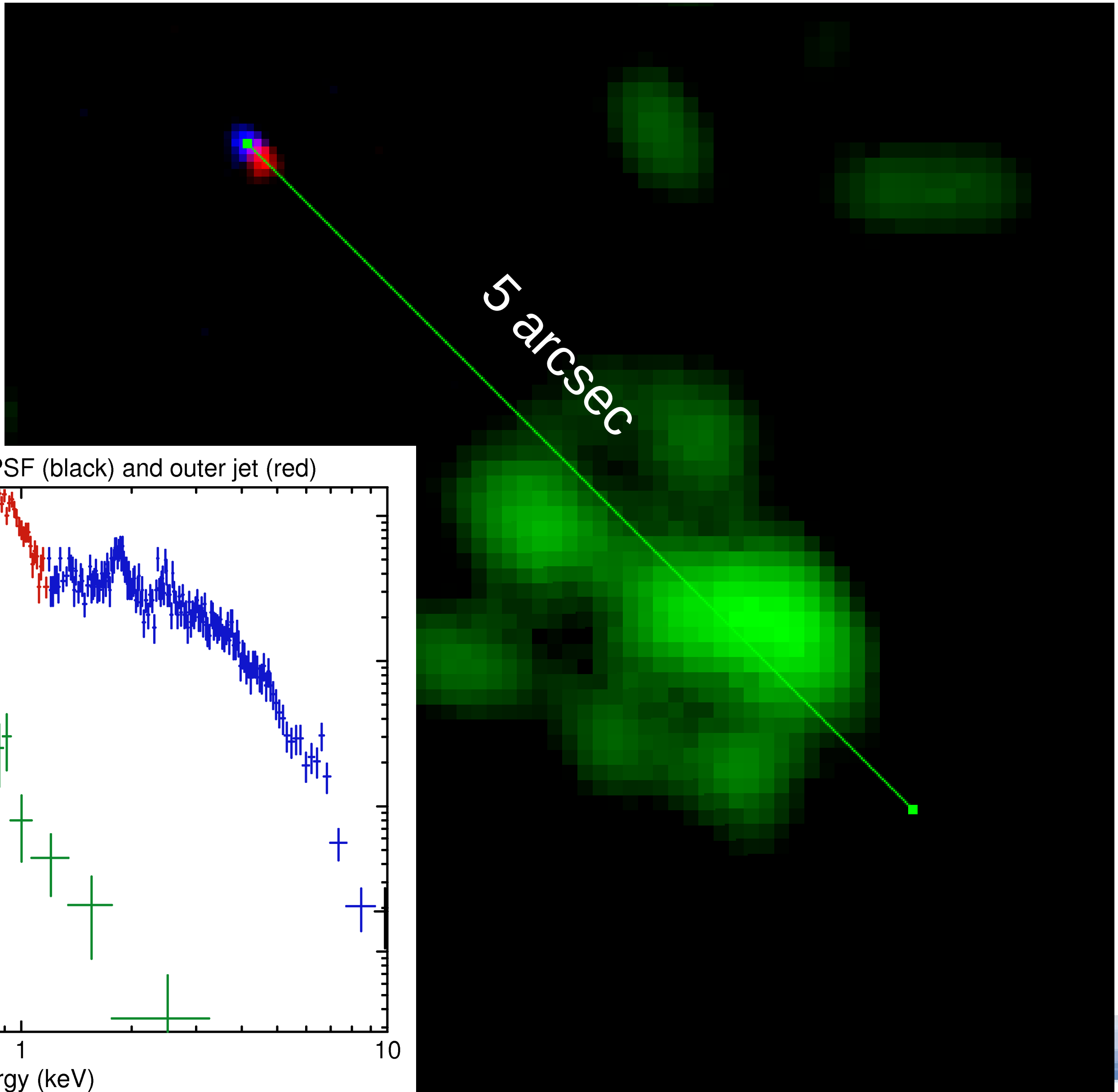
Jets: Rotation

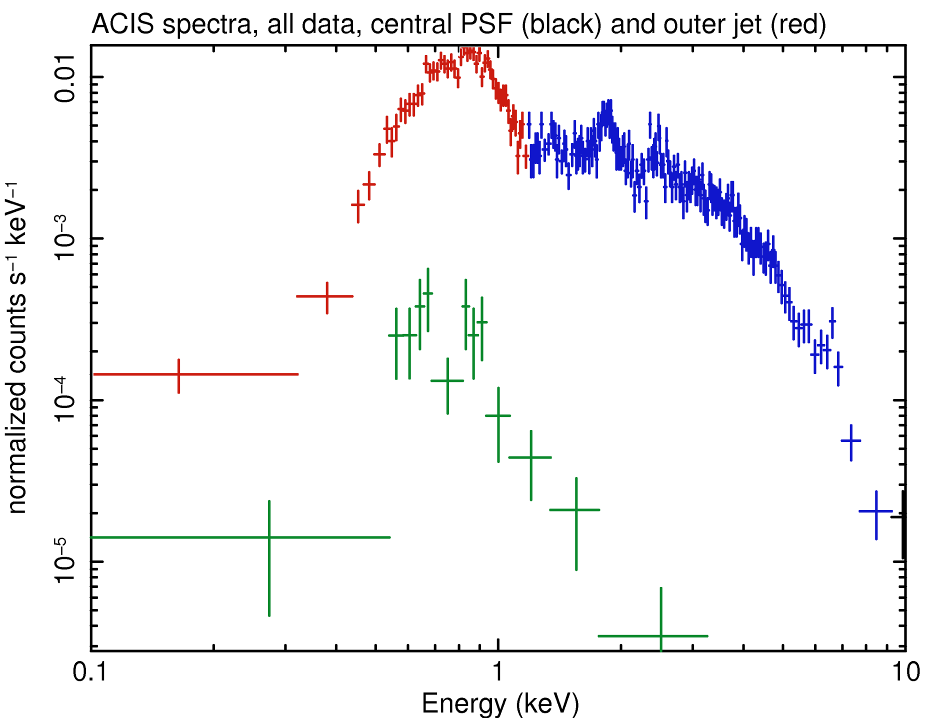


Coffey et al. (2007)

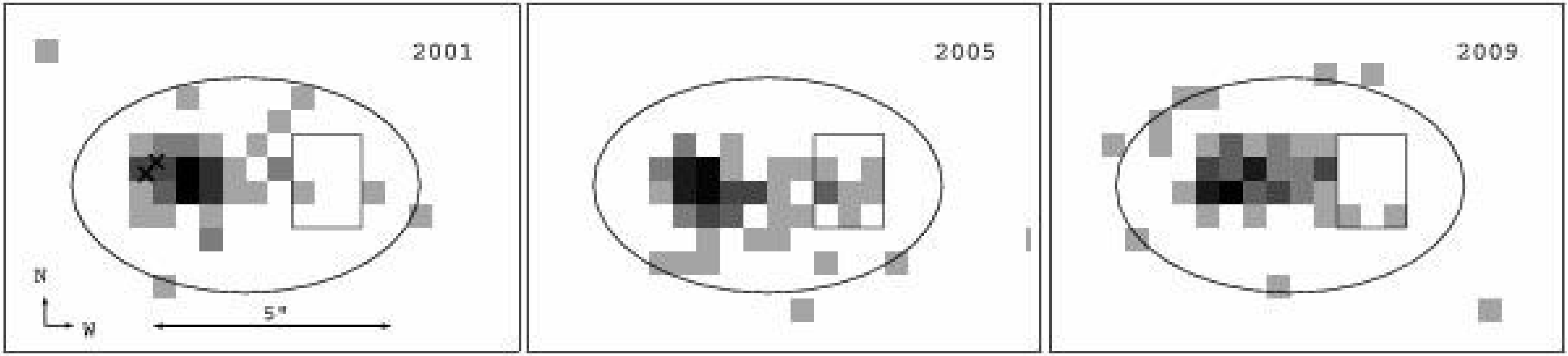
Jets: X-rays: DG Tau

Chandra
450 ks
Güdel et al.
(in prep)

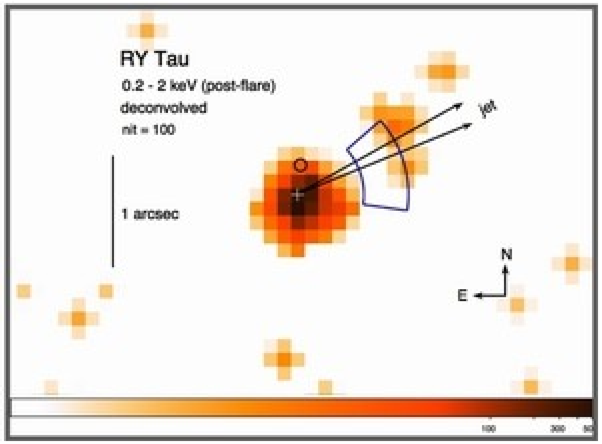




X-rays: Jets



HH 154: A stationary structure and a moving knot
3 epochs of Chandra: Schneider et al. (2011)



$$T = 4\ \mathrm{MK} \left(\frac{v_{\mathrm{shock}}}{500\ \mathrm{km\ s^{-1}}} \right)^2$$

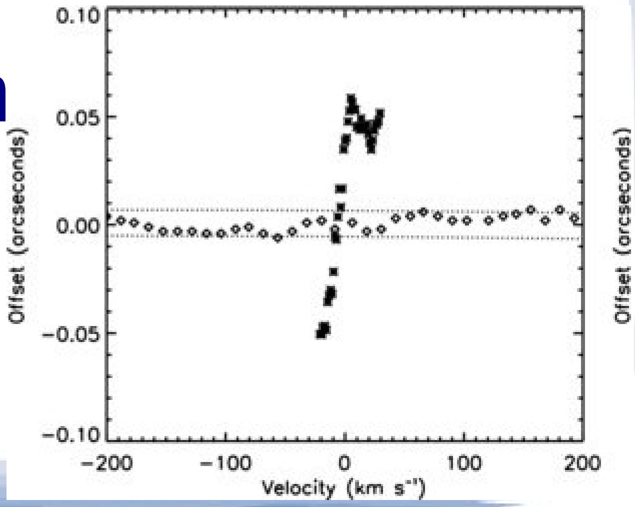
$$\dot{M} = A_{\mathrm{jet}}\, \rho\, v_0$$

$$d_{\mathrm{cool}} = 20.9\ \mathrm{AU} \left(\frac{10^5\ \mathrm{cm^{-3}}}{n_0} \right) \left(\frac{v_{\mathrm{shock}}}{500\ \mathrm{km\ s^{-1}}} \right)^{4.5}$$

RY Tau: Skinner et al. (2011)

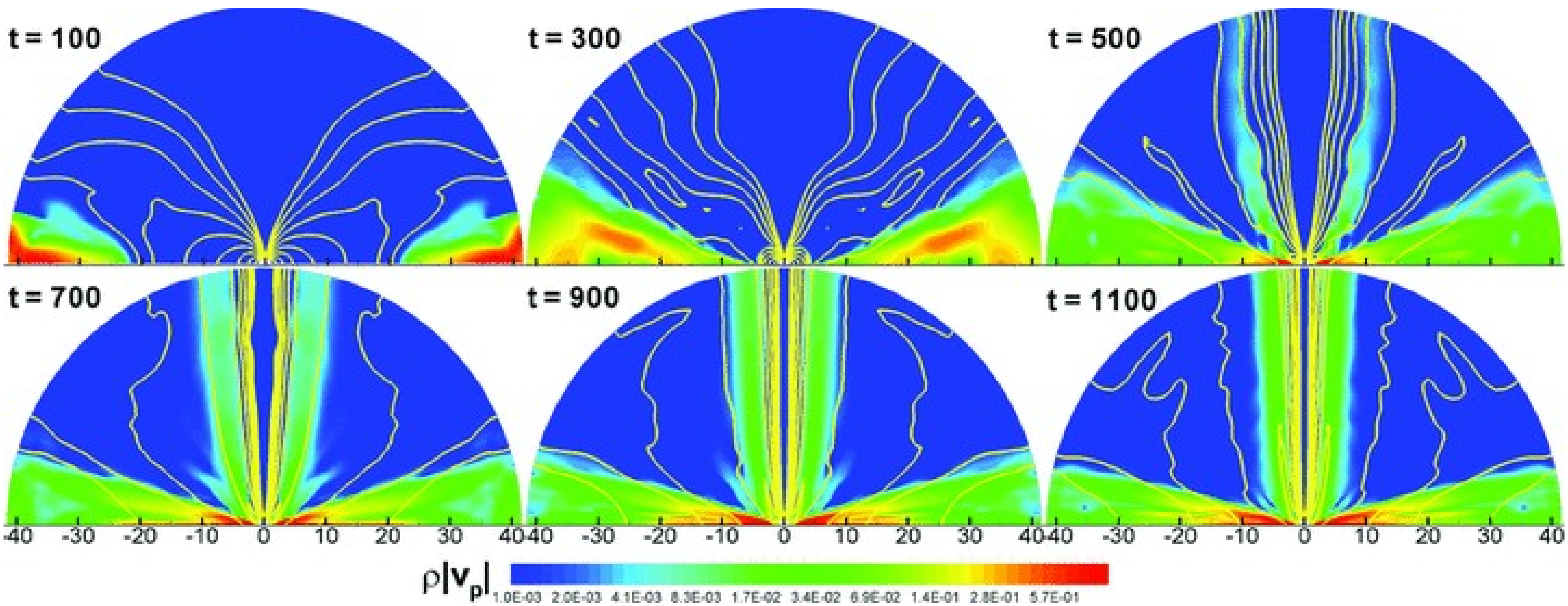
Jets: Brown Dwarfs

- Several BD jets found with spetroastrometry in Hα and forbidden optical emission lines ([O I], [S II])
  - Whelan et al. (2005, 2007, 2009a, 2009b)
- Jets appear similar to CTTS counterparts
- Mass loss rate comparable to accretion rate
- → See dedicated splinter session



ISO Cha I 217: [O I] 6300 Ang
Whelan et al. (2009)

Jet launching: Simulations



Jets are collimated by magnetic fields.
Lii et al. (2012)

Jet mass loss rate

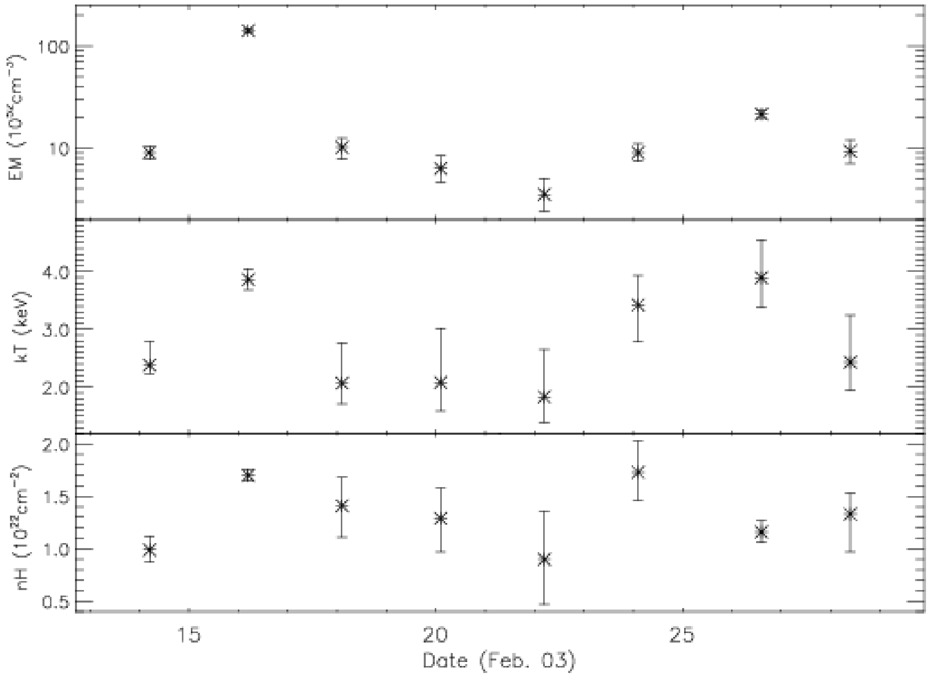
- Onion-like structure, faster on the jet axis
- Launching controlled by magnetic fields
- Mass loss rate is typically 5-20% of accretion rate (e.g. Sililia-Aguilar et al. 2006, 2010; Fang et al. 2010)
- <1 % of the mass is in the fastest (X-ray and UV) component (Günther et al., 2009)
- The angular momentum loss can slow down the star significantly (Matt et al., 2012)

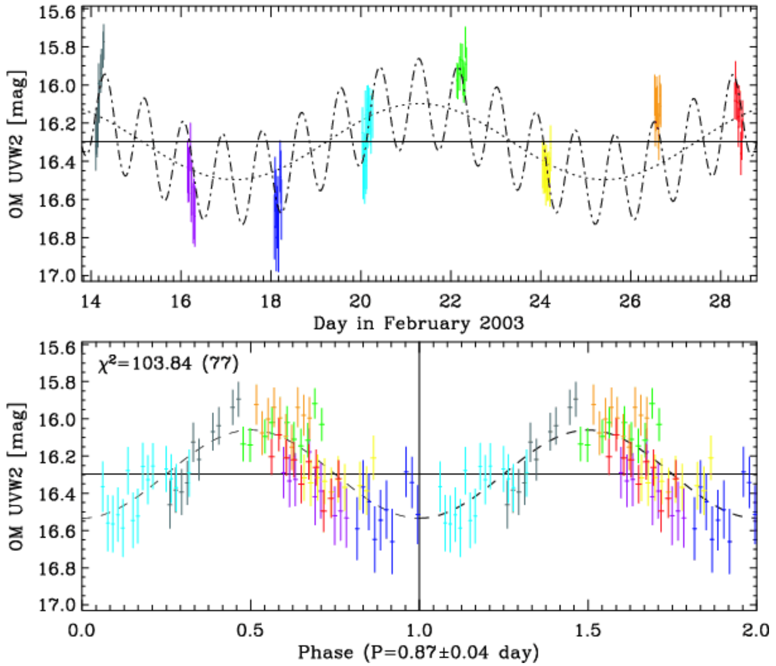
Big open questions

- How does the accretion shock interact with the photosphere and the corona?
- How is the jet launched?
- How are accretion and outflows related?
- What about binary accretion?

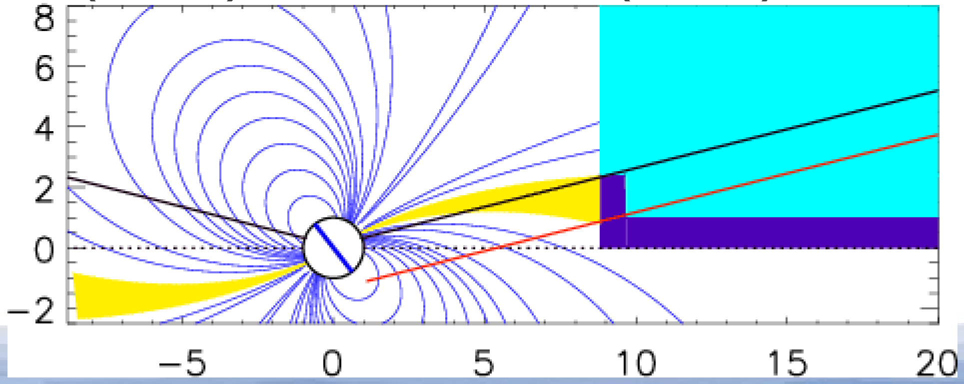
Thank you!

Example: AA Tau





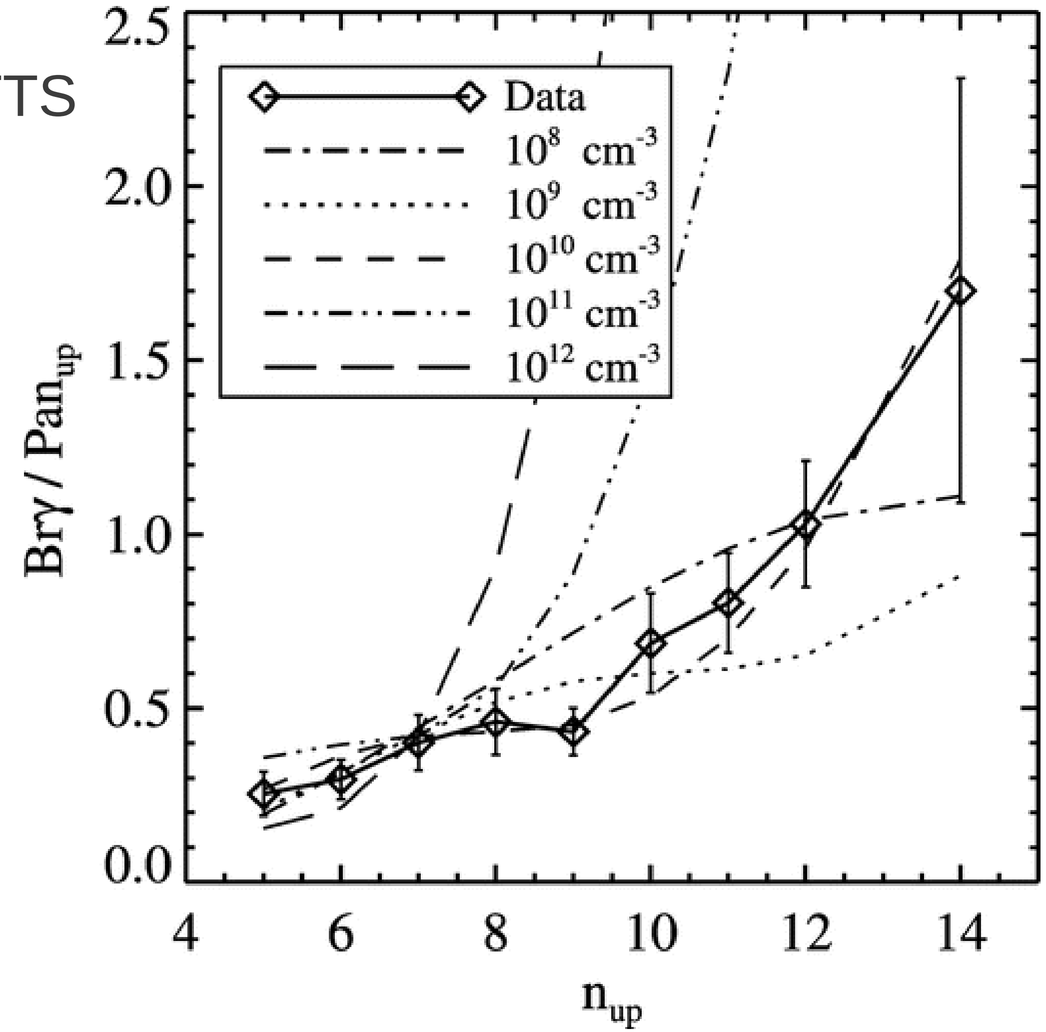
Optical, UV and X-ray emission are periodic:
An accretion spot and an absorbing column rotate in and out of view.
Robrade & Schmitt (2007), Grosso et al (2007)



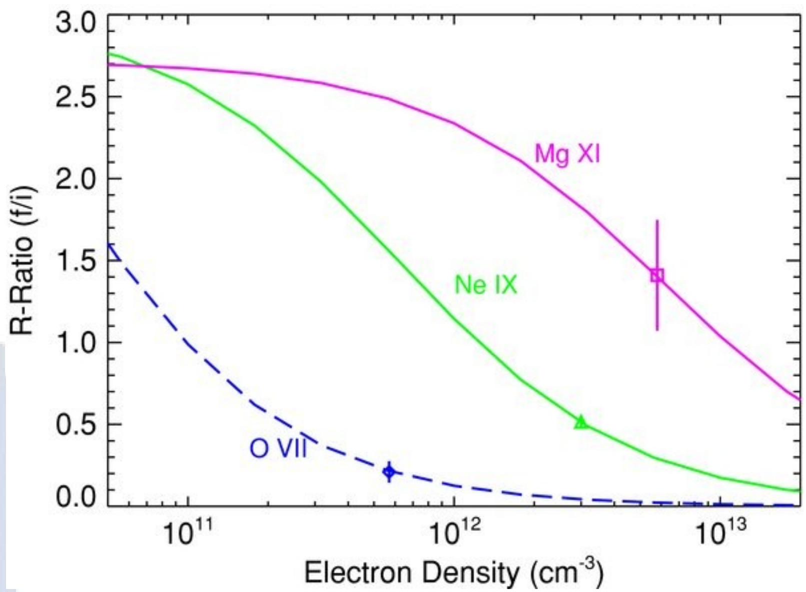
Where do the H lines originate?

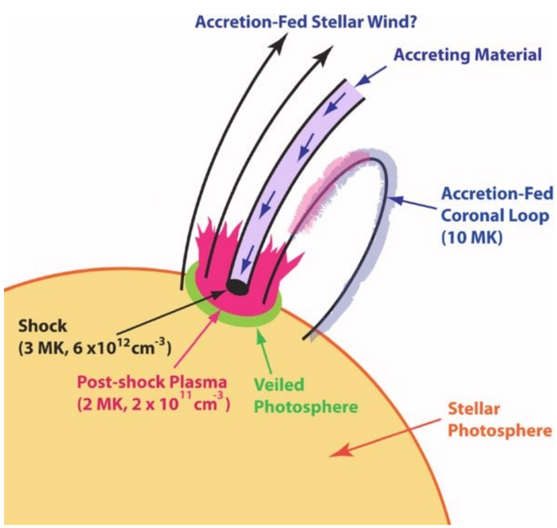
H-decrements in Ba and Pa series indicate T = 1000K and high densities in sample of CTTS → short cooling times

Bary et al. (2008)

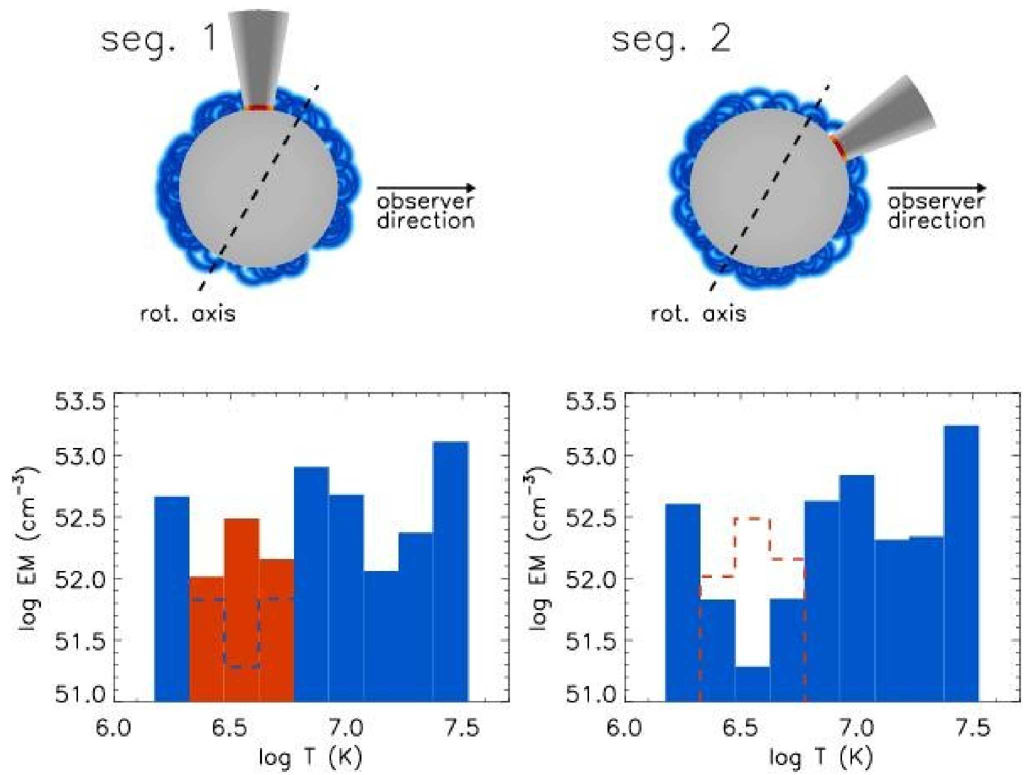


Accretion tracers: X-rays?





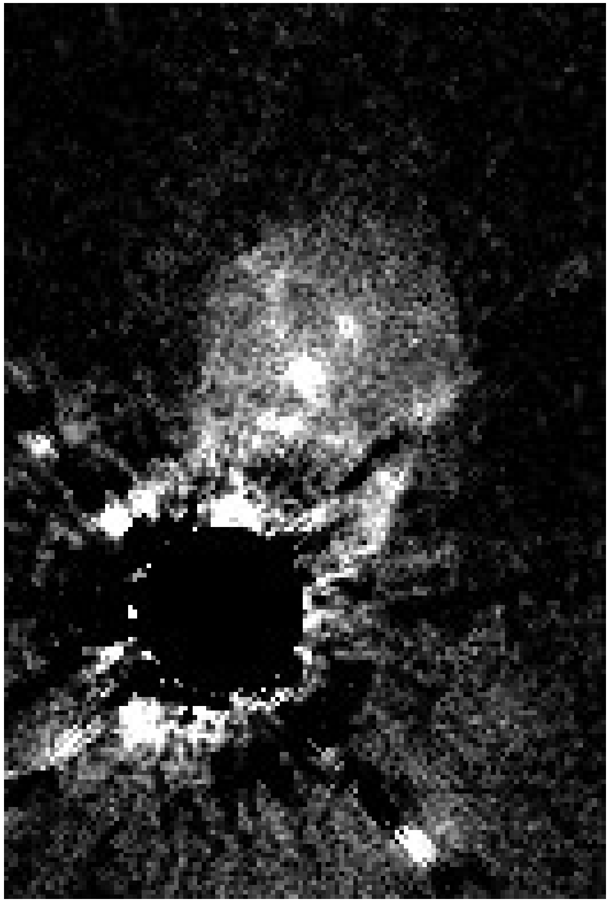
TW Hya: Brickhouse et al. (2010)



Temperature distribution reconstructed from X-rays: Soft plasma is only visible when looking perpendicular to the shock.

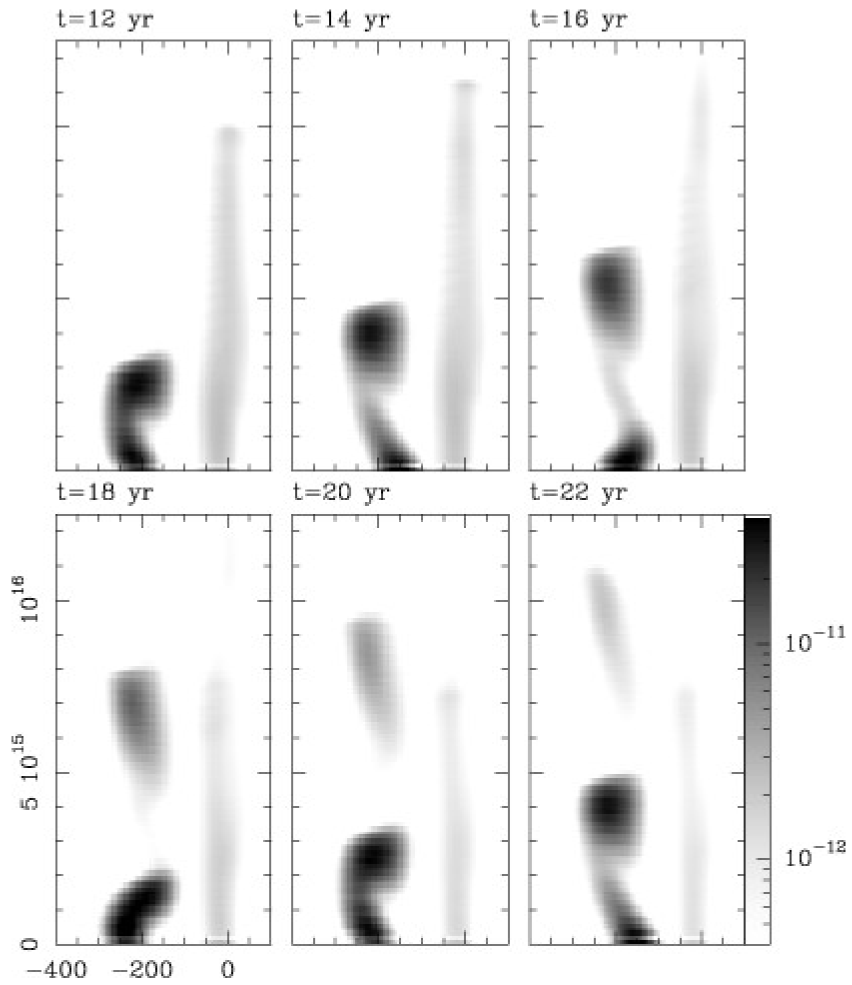
V2129 Oph: Argiroffi et al. (2011)

Example: XZ Tau

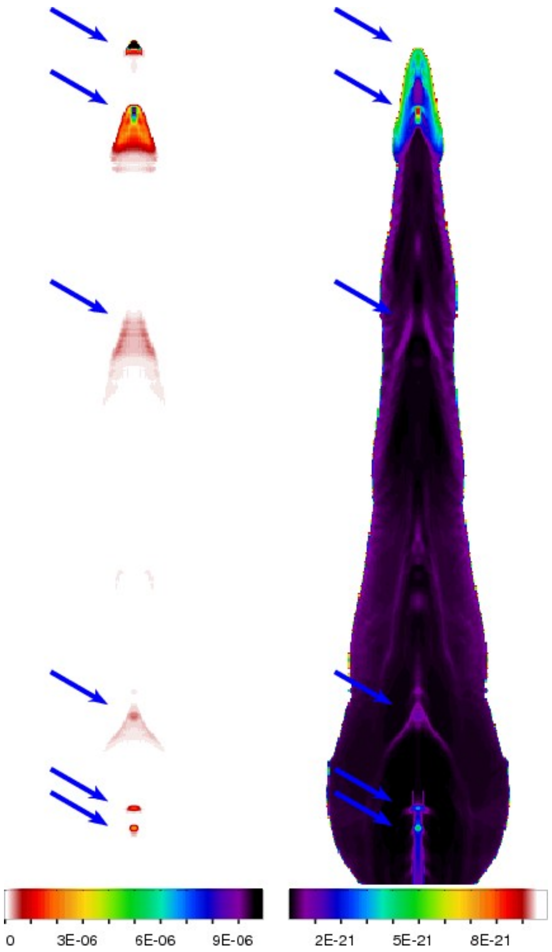


Krist & al. (2008)

Jet propagation: Simulations

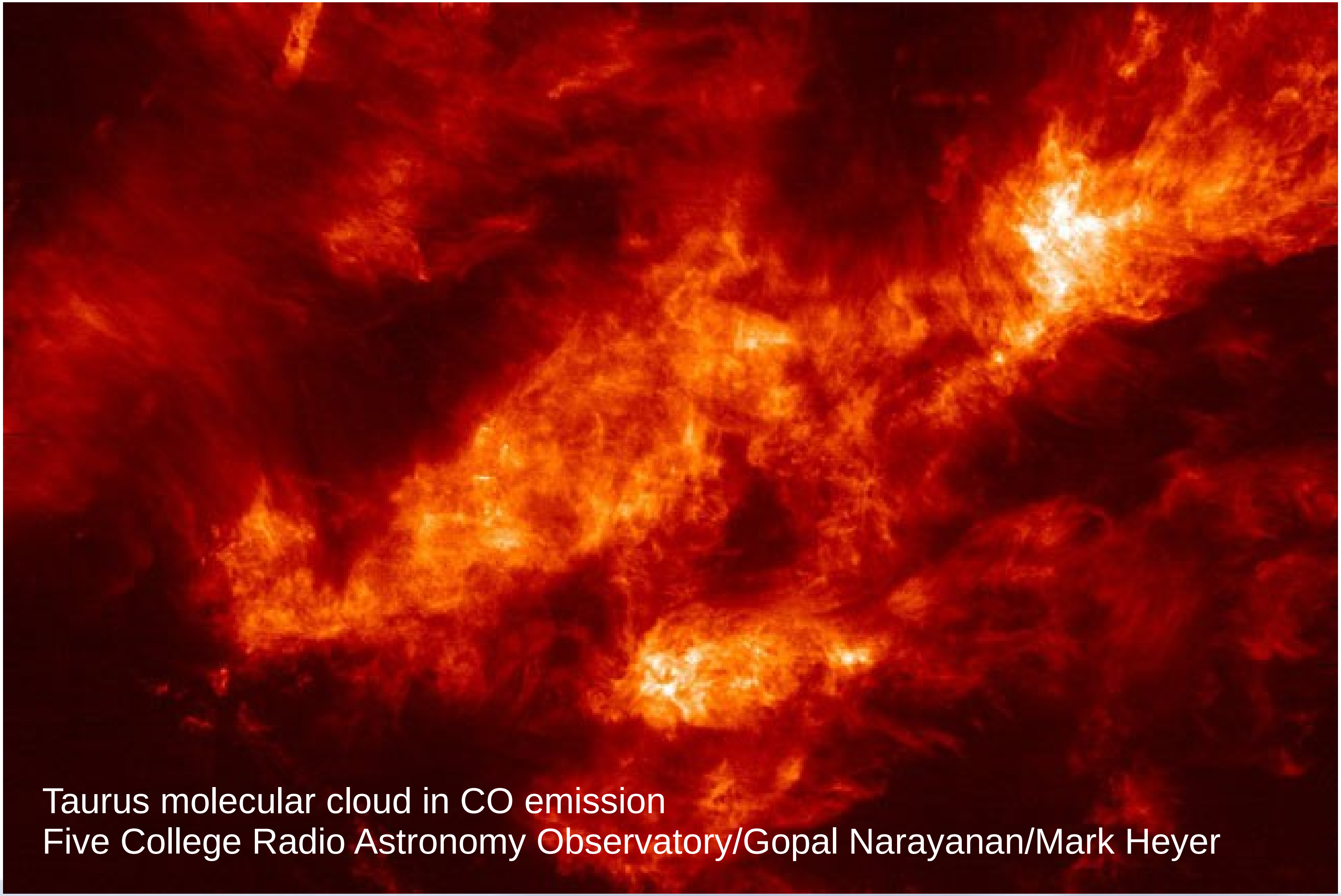


A precessing jet model for DG Tau
Raga et al. (2001)



X-ray emission (left) and density in a simulated jet
Bonito et al. (2010)

Star forming clouds



Different accretion tracers

Time variability