What can X-rays tell us about accretion, mass loss, and magnetic fields in young stars ?

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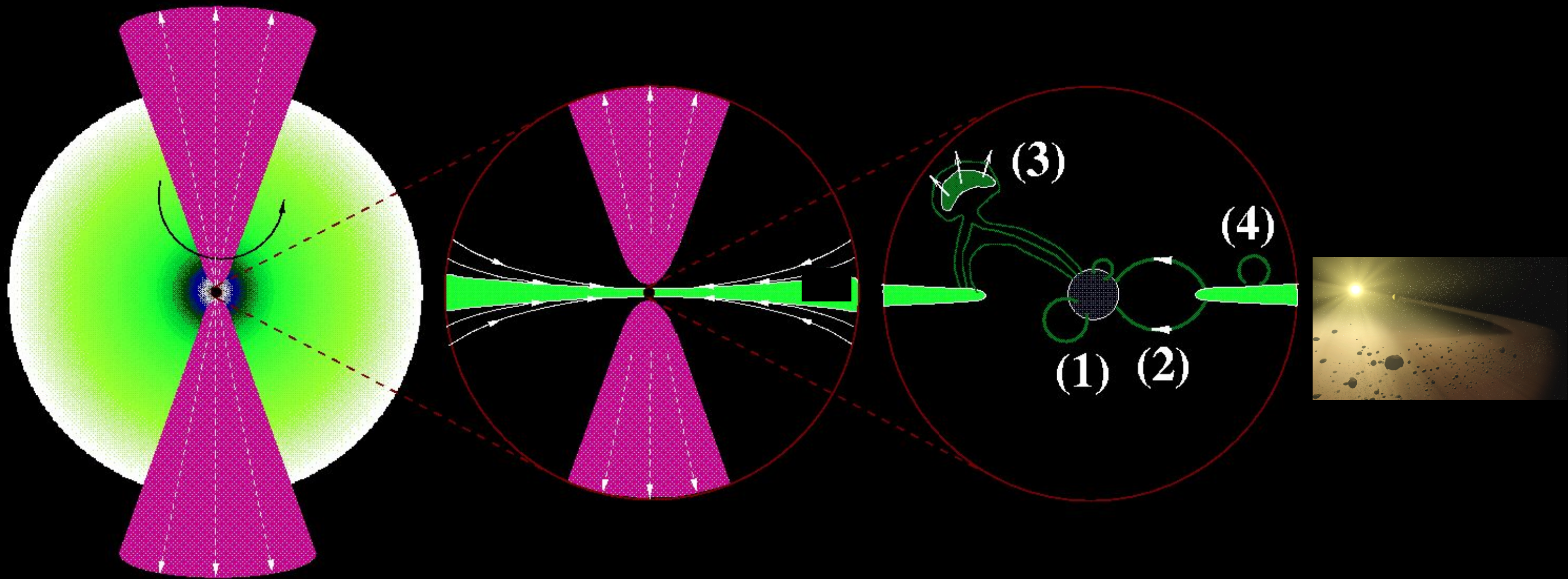
Outline

- 1. Accretion vs. Ejection: the central engine of YSOs
- 2. X-ray emission from young stars: processes and environments
- 3. Low/intermediate-mass young stars
- 4. The case of massive (OB) stars
- 5. Magnetospheric accretion
- 6. The mysterious Herbig stars
- 7. Evidence for other mechanisms ?
- 8. Conclusions

1. Role of magnetic fields in YSOs: the "central engine"

- "Accretion-ejection" paradigm (Shu, Pudritz, Ferreira...)
- Jets: "X-winds" vs. "disk winds"

A short history of early stellar evolution



10000 AU | **200 AU** | **0.5 AU**

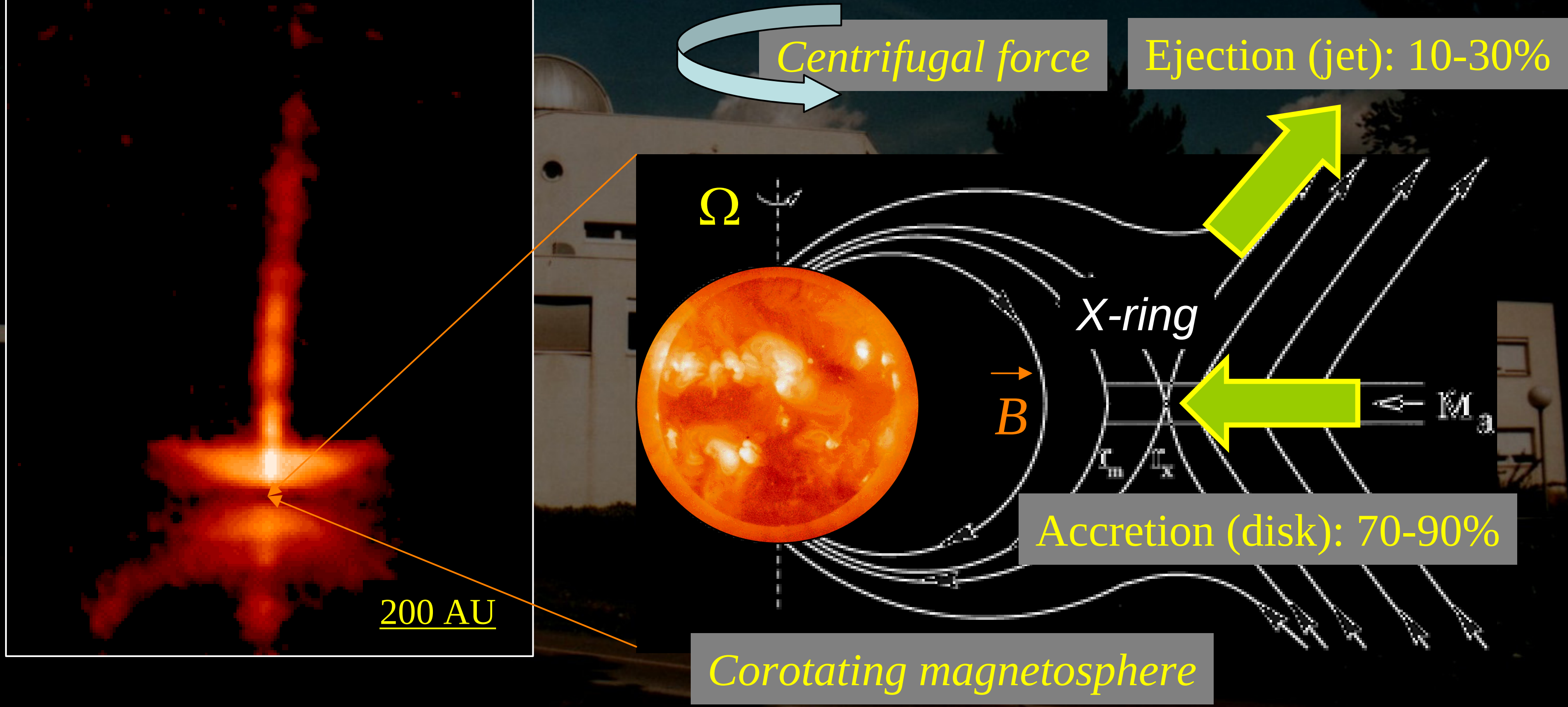
$10^{4\text{-}5}$ yrs | $10^{5\text{-}6}$ yrs | $10^{6\text{-}7}$ yrs

protostars | *T Tauri stars*

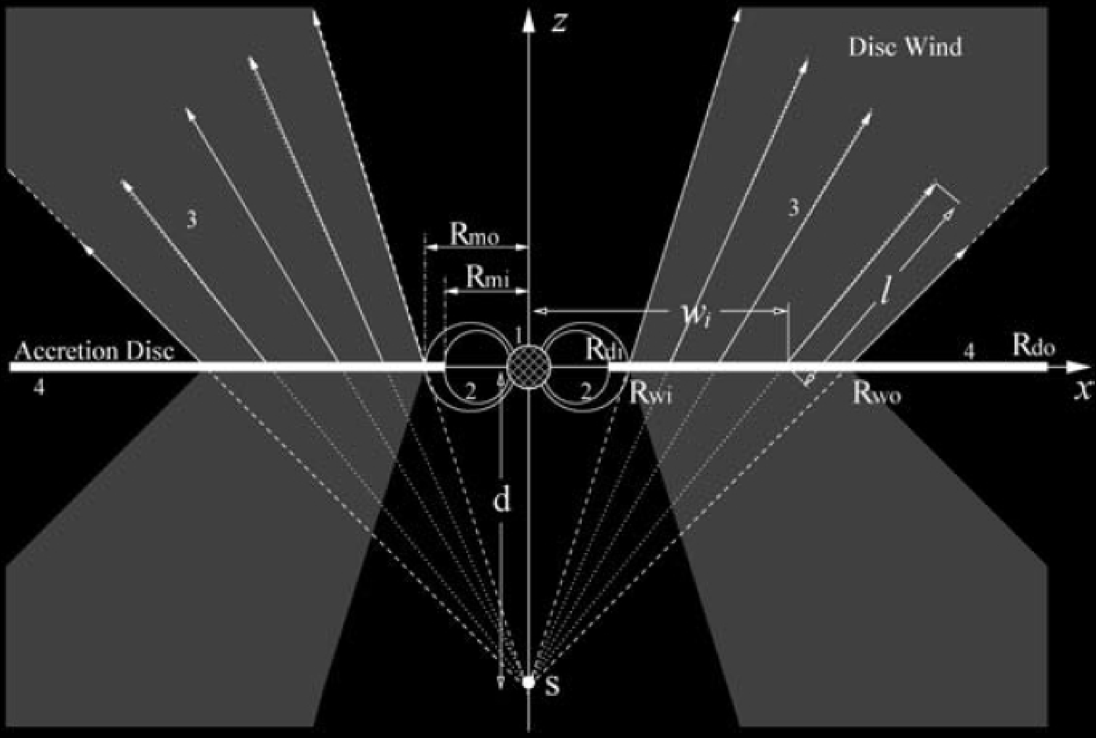
MHD model for star-disk magnetic coupling

(J. Ferreira et al., 2001 + this workshop)

(Shu et al., Pudritz et al., Heyvaerts et al.,...)



Disk-wind model: Hα emission



Kurosawa et al. 2006

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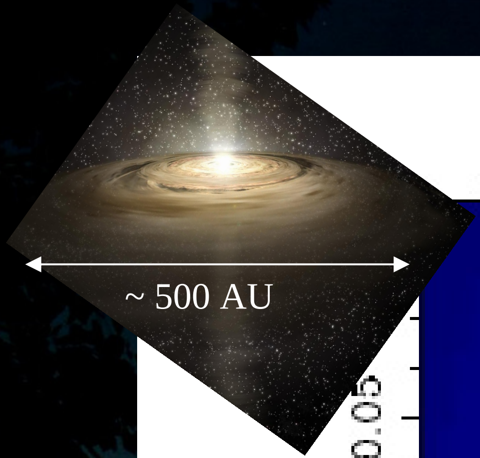
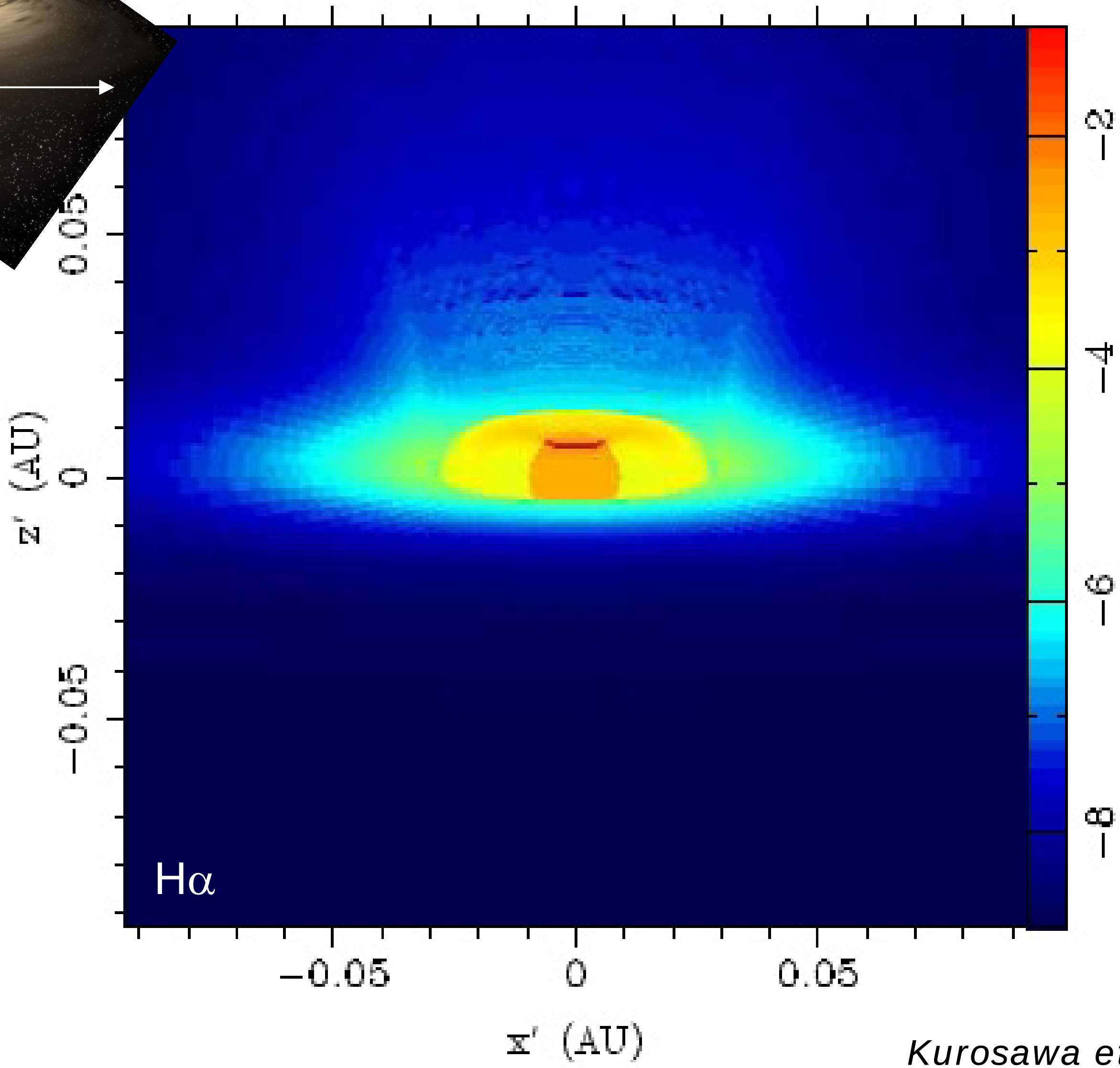
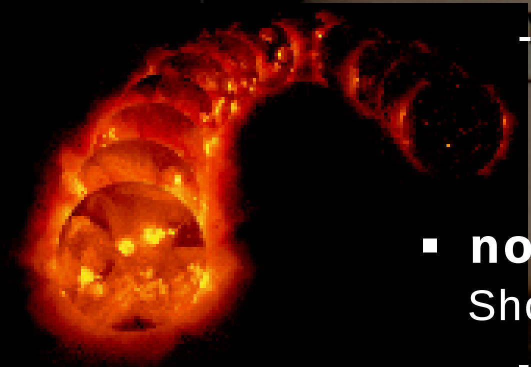




Kurosawa et al. 2006

2. X-ray emission from young stars: processes and environments (I)

- Links w/ internal structure:
  = intrinsic, independent of cs environment
  - **solar paradigm:**
    Convection/activity/reconnection/coronal winds (low-mass stars)
    - Signature: *temporal variability* (flares), *dominating hard spectra* (T_X ~ x 10 MK), but also soft component (T_X ~ few MK); n_e ~ 10^{10}-10^{11} cm^{-3}



Yohkoh

  - **non-solar:** Radiation/winds (massive stars)
    Shocks from radiative instabilities (Castor et al. 1975)
    - Signature: ~ *no temporal variability, dominating soft spectra* (relative v_s ~ x 100 km/s => T_X ~ few MK); n_e ~ 10ç-10^{11} cm^{-3}

X-ray emission from young stars: processes and environments (II)

- Links w/ external structure
  - = due to the presence of cs environment (e.g., disks, envelopes, ISM)
    - **Shocks:**
      - Magnetosphere: confined winds, accretion
        - signature: soft X-rays, *high densities* (n_e -> 10^{13} cm^{-3})
      - ISM: funnel walls, bow shocks
        - Signature: soft or high, depending on v_{shock}

HH46/47

3. Low/intermediate-mass young stars

- Class I (evolved protostar) + Class II (CTTS):
  - Multi-component: disk, wind, jets, envelopes, magnetosphere...
- HAeBe stars (details later)

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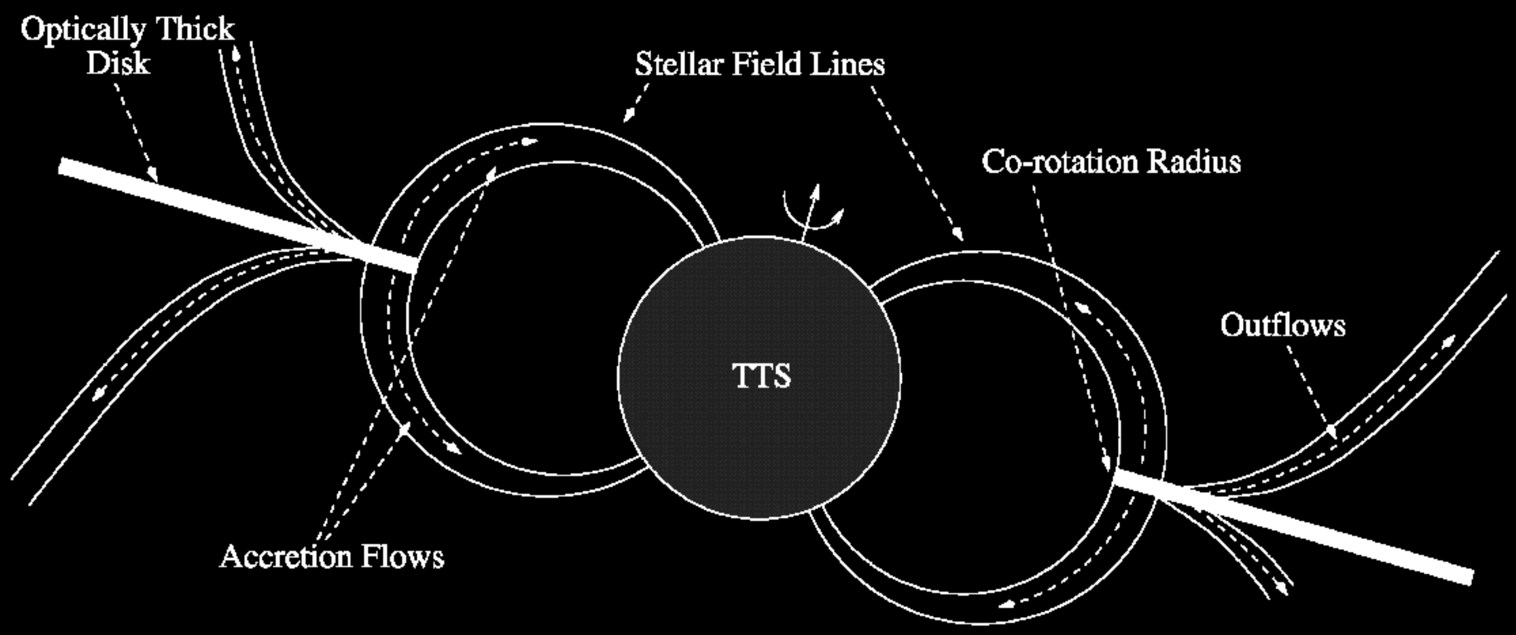
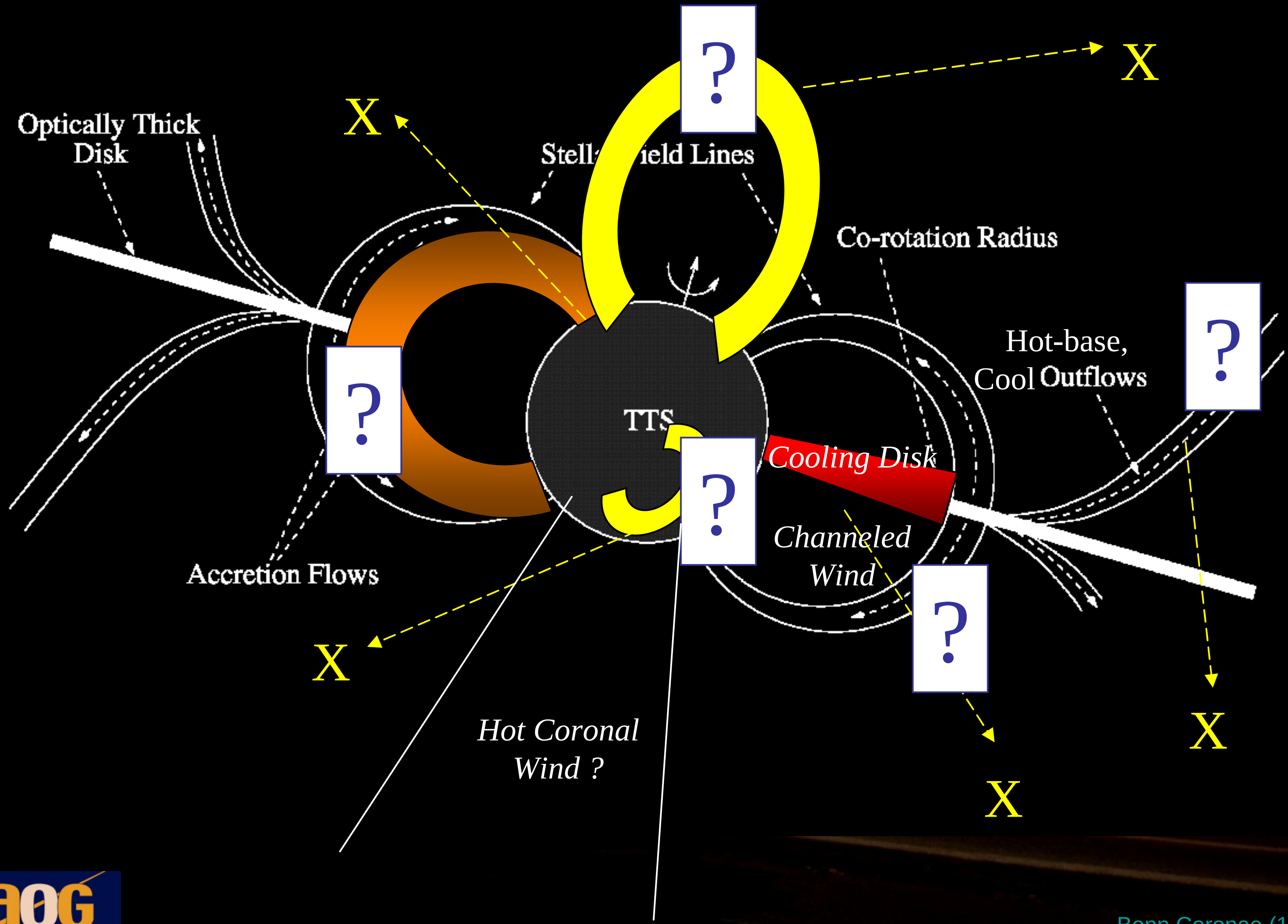
The magnetic structure of a "classical" (= accreting) T Tauri star



Stassun 2001

A complex accretion-ejection configuration...



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4. The case of massive (OB) stars

- Winds
  - Radiative winds, unstable
    - L_X/L_{bol} ~cst ~10^{-7}
    - Soft spectra
  - "Magnetically channeled wind shocks": examples, predictions (θ^1 Ori C, τ Sco…)
    – Initial model by Babel & Montmerle (1997) for the Ap star IQ Aur, X-ray overluminous
    – Predicted B_* for θ^1 Ori C found by Donati et al. (2001)
    – B_* ~ few 100 G - few kG
  - Generic model for a magnetized O star
    – Best clue: X-ray rotational modulation

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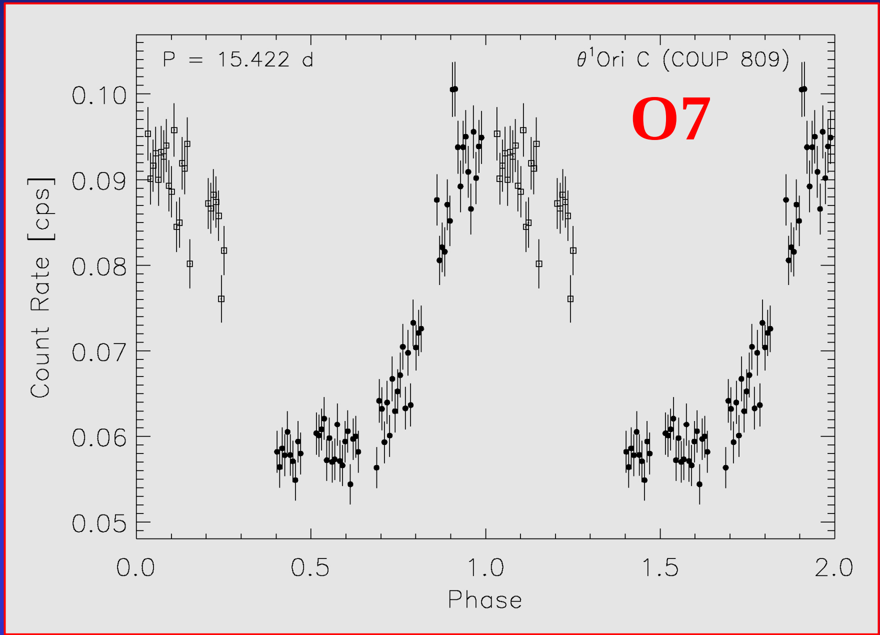
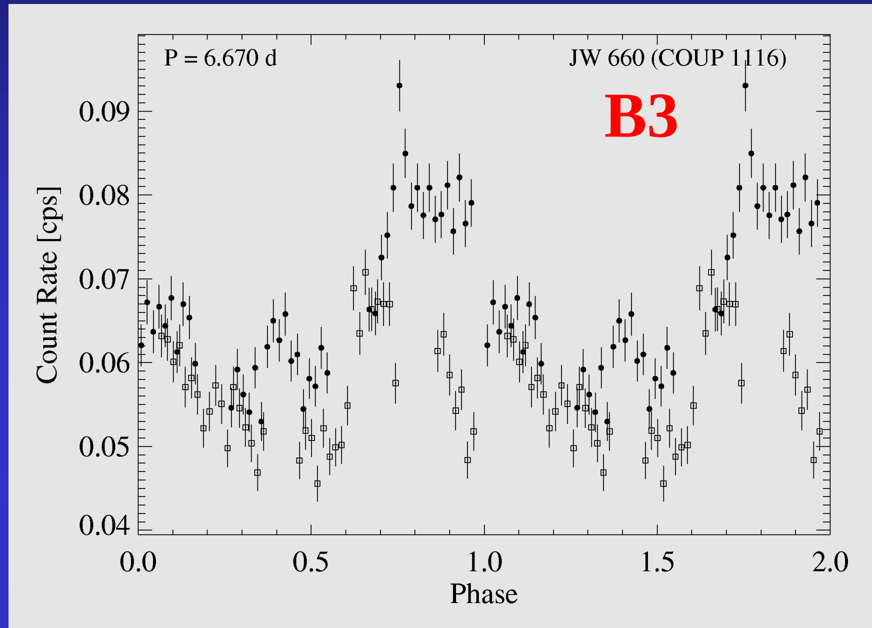
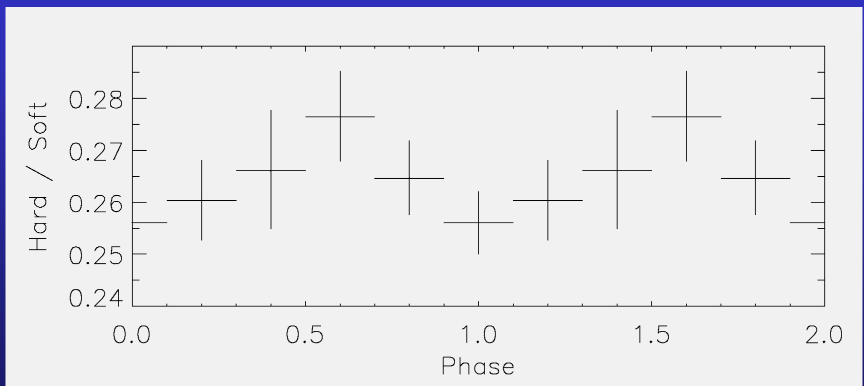
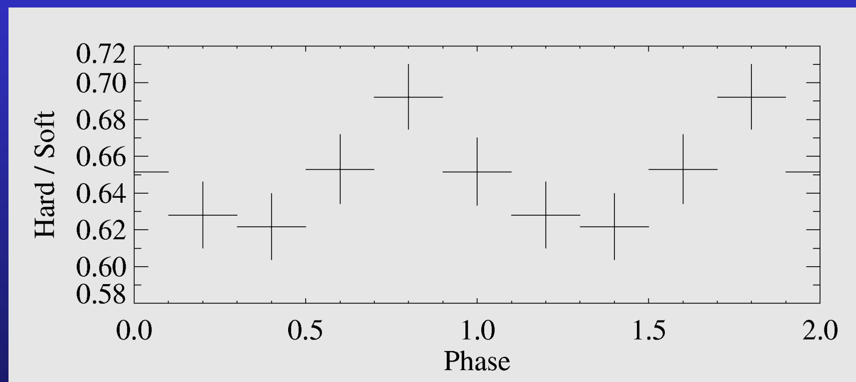
O-early B stars in Orion:
Week-long periodic X-ray rotational modulation



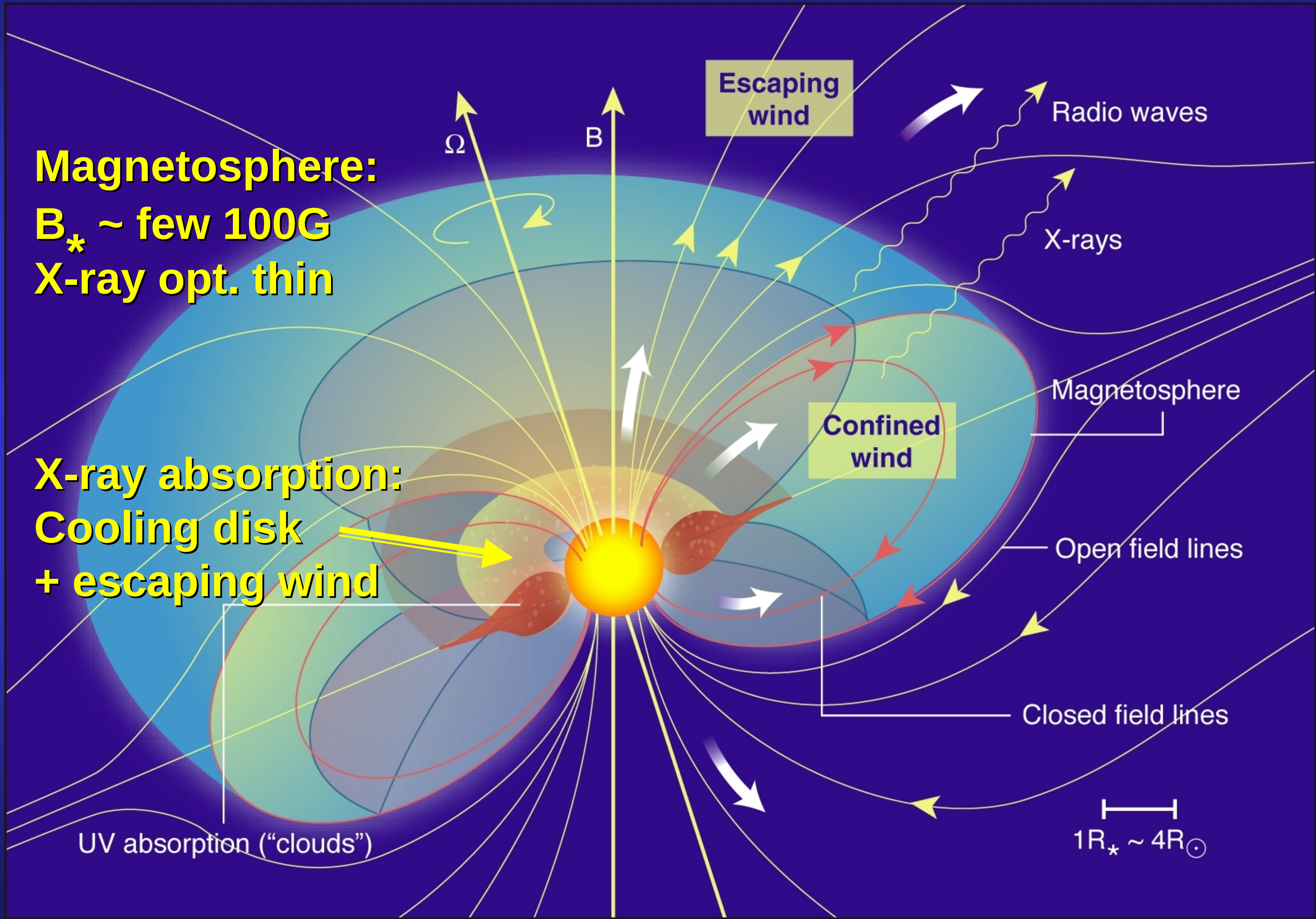






COUP: Stelzer, Flaccomio, Montmerle et al. 2005

*The **Magnetically Channeled Wind Shock** (MCWS) model*



Montmerle 1999, Science *(after Babel & Montmerle 1997)*

5. Magnetospheric accretion

- Paradigm:
  corotating magnetosphere + jet + disk
- Star-disk interactions
- Evidence (spectroscopic): optical (Hα, Hβ, NaD, CaII…) + UV, X-ray
  - Prototype: TW Hya (age ~ 9 Myr; Kastner et al. 2002)
- X-ray abundance anomalies/disk evolution
  - planets ?
- MHD models

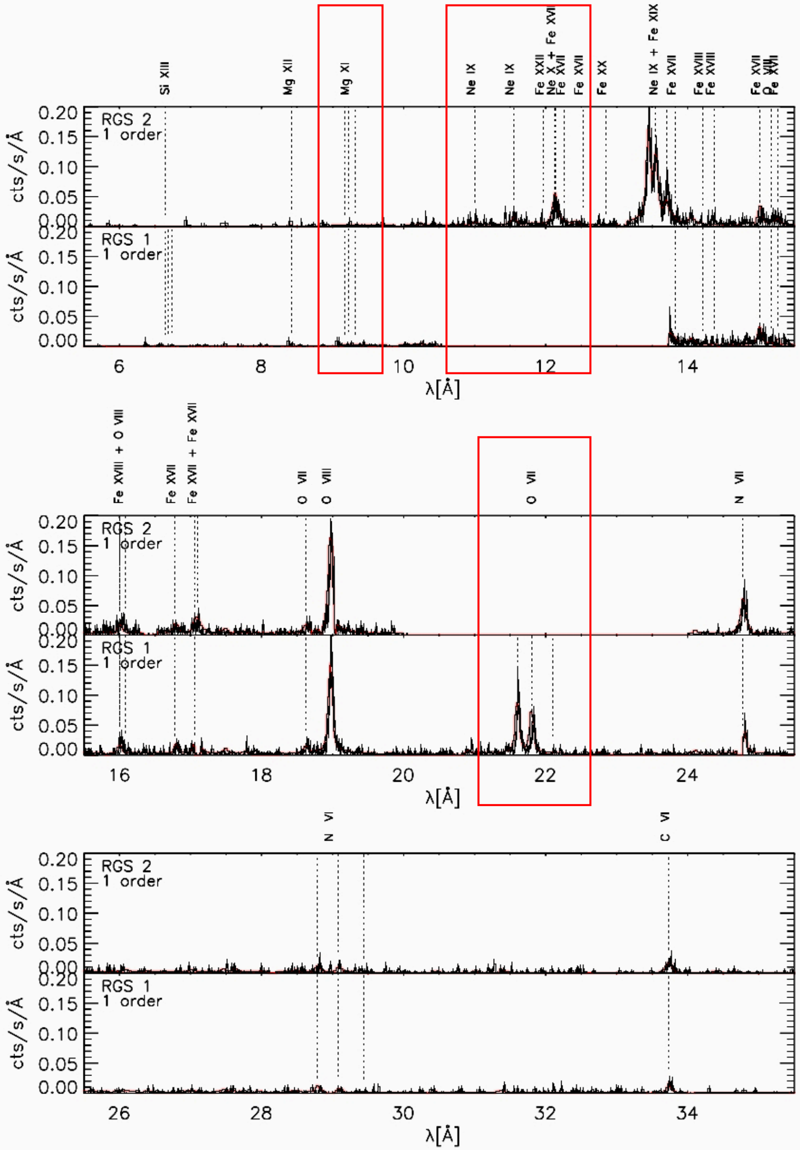


Fig. 2. First order background subtracted *XMM-Newton* RGS count rate spectrum of TW Hya. Overplotted is a 3-T VMEKAL model whose parameters were derived from a combination of emission line analysis and global fitting of the medium-resolution MOS spectrum. The MOS spectrum is shown together with the same model in Fig. 4, and the best fit parameters are summarized in Table 3. Exposure time is 29 ks for each RGS. Straight horizontal lines represent gaps due to CCD chain failure or individual chip separation. Emission lines typical for stellar coronae are indicated by labels and dashed lines.

Looking for He-like triplets (T_X ~ few MK; density indicators):
OVII, NeIX,MgXI

Stelzer & Schmitt 2004

The OVII triplet: signature of accretion ?

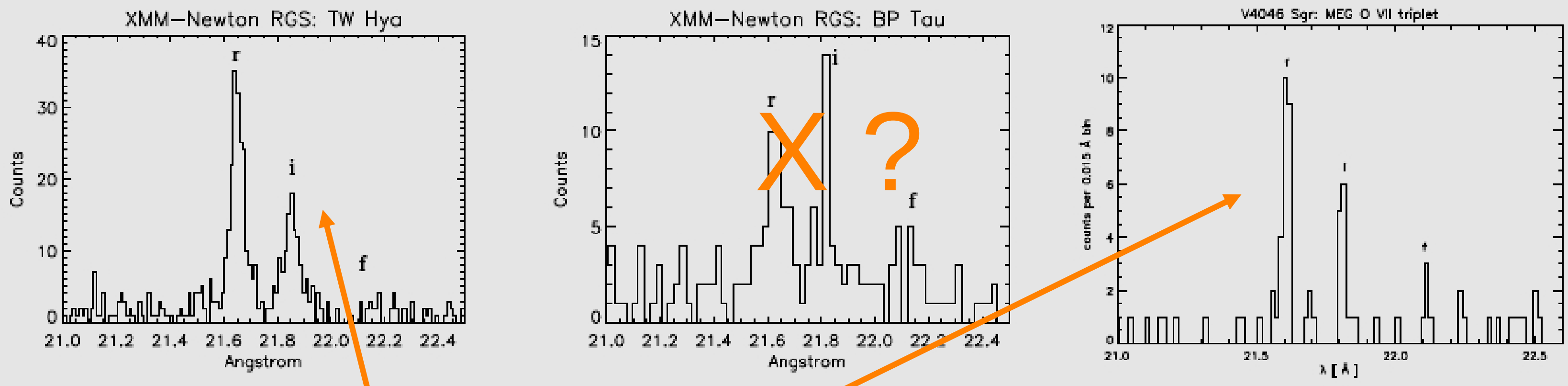


Figure 1: *Left panel*: O VII He-like triplet for TW Hya. *Middle panel*: O VII He-like triplet for BP Tau. *Right panel*: O VII He-like triplet for V4046 Sgr.

$n_e \sim 10^{12}$ cm^{-3}

Robrade et al. 2006

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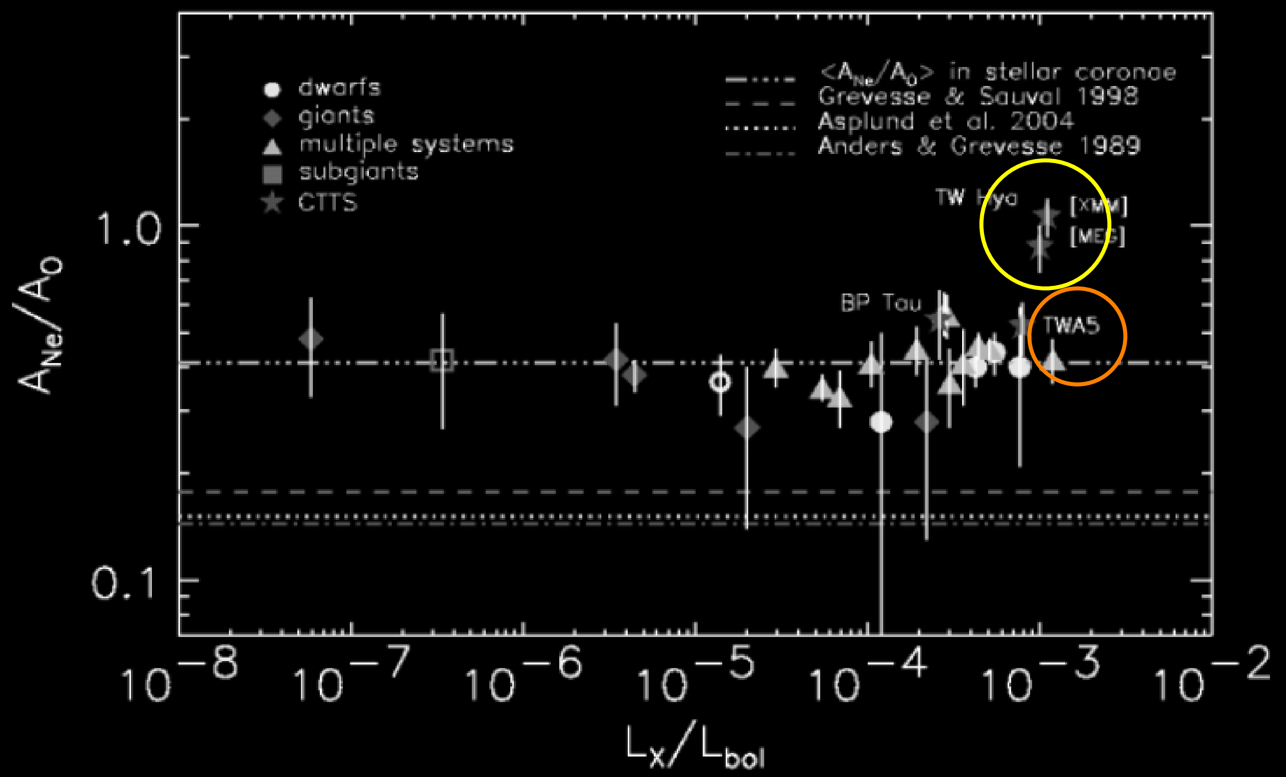
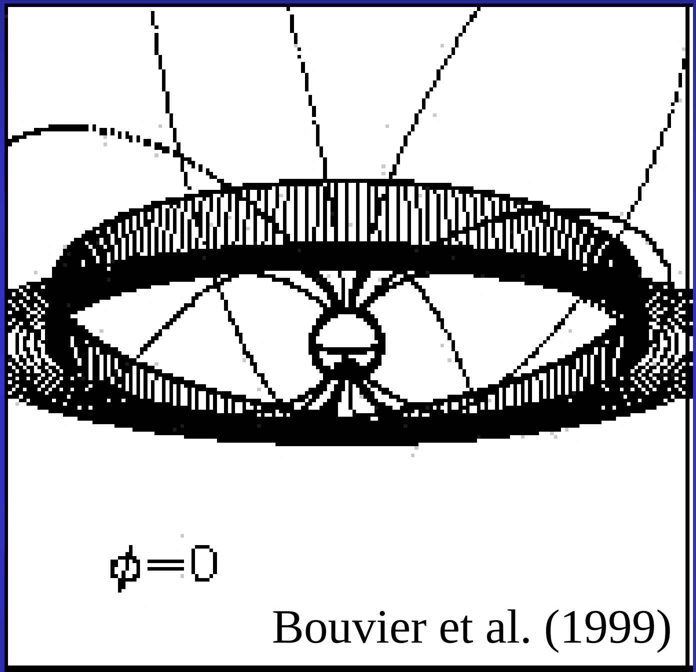
TW Hya: evidence for metal depletion in the accreted gas => locked in planets ?



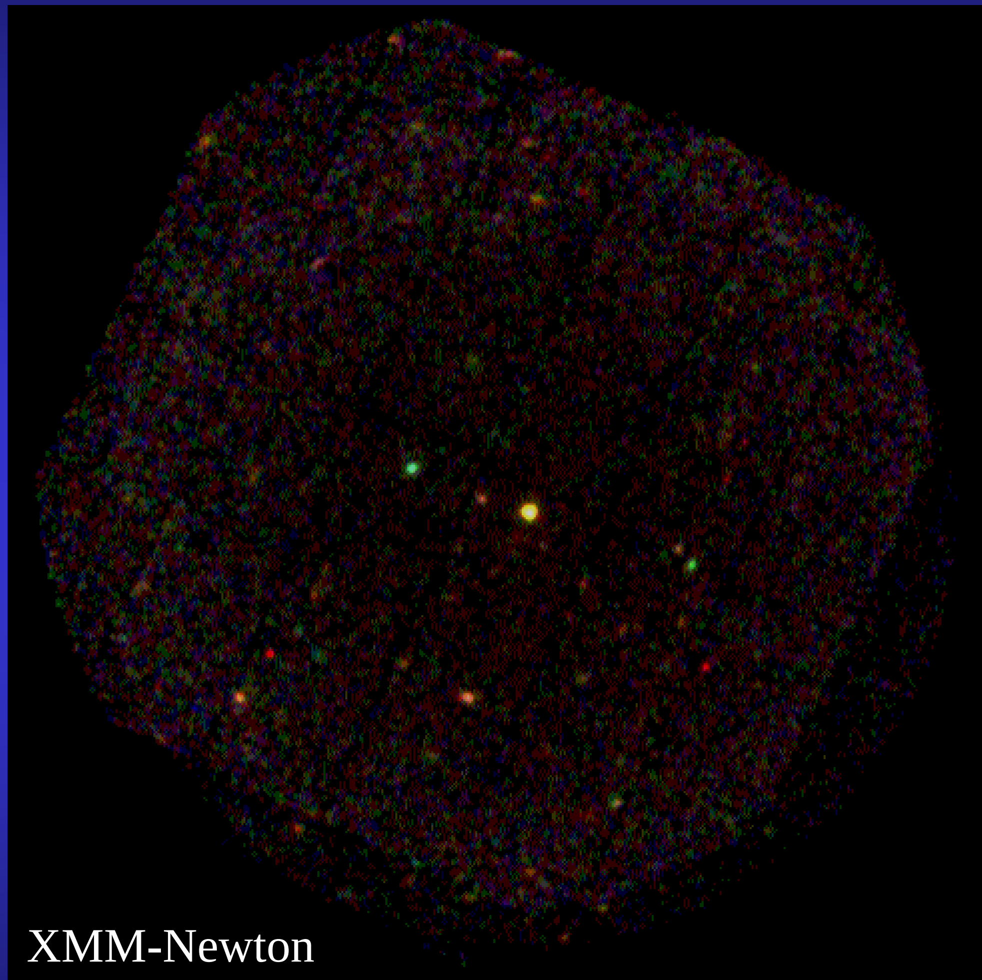
Drake et al. 2005

"Magnetospheric accretion": AA Tau, "Classical" T Tauri star



Magnetospheric accretion model

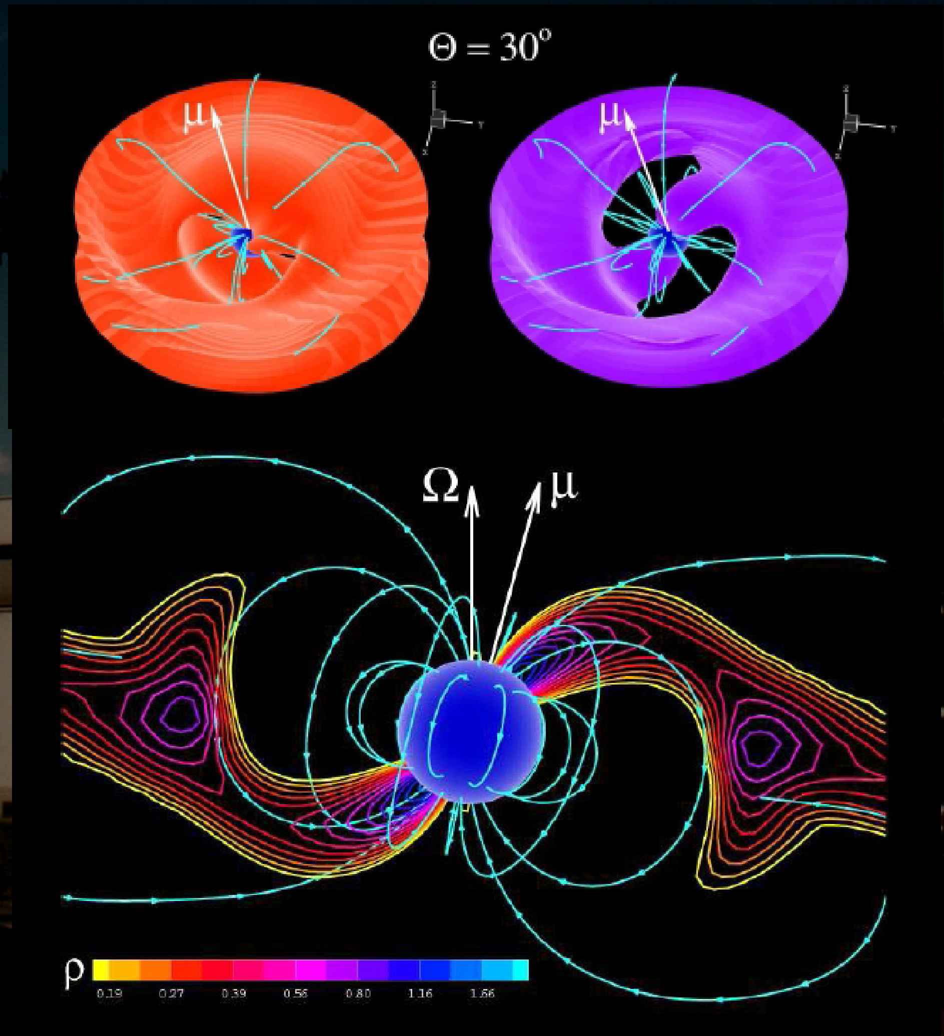
Rotation period ~1 week



0.5-1 keV **1-2.4 keV** **2.4-8 keV**

(Bouvier, Grosso, Montmerle et al., in prep.)

3D MHD corotating stationary models



Romanova et al 2004

6. The mysterious Herbig stars

- High detection rate of HAeBe stars (~70%, Stelzer et al. 2006)
  - In general, soft spectra
  - But free-fall too fast (600 km/s), winds too slow (300 km/s)
  - AB Aur: no evidence for high densities/accretion (Telleschi et al. 2006)
- Unless they all have unresolved companions, magnetic fields must be present, yet they are fully radiative
  - detected in 1 case
  - => *magnetically confined winds* ?
- Precursors to ApBp "magnetic" stars ? (< 10% of the AB population)
- Fossil fields ?

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HD 163296 (age ~4 Myr)

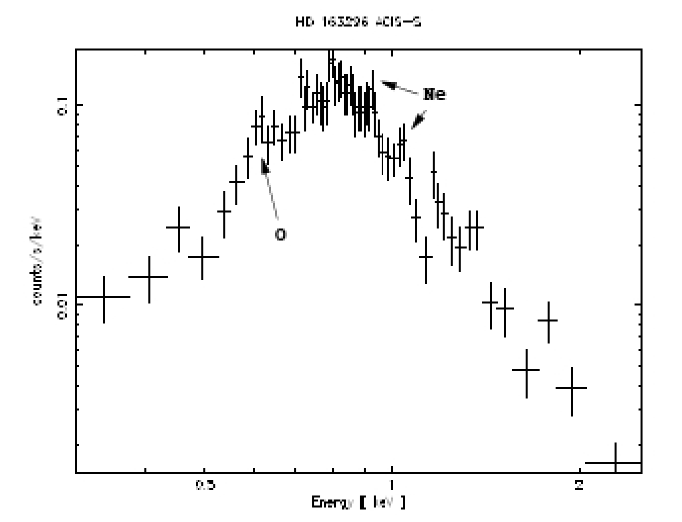
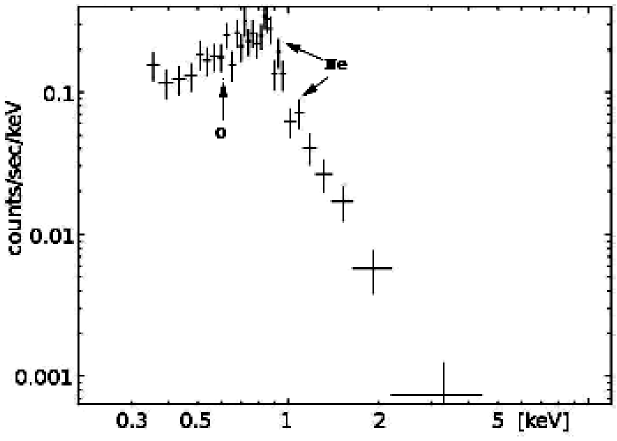
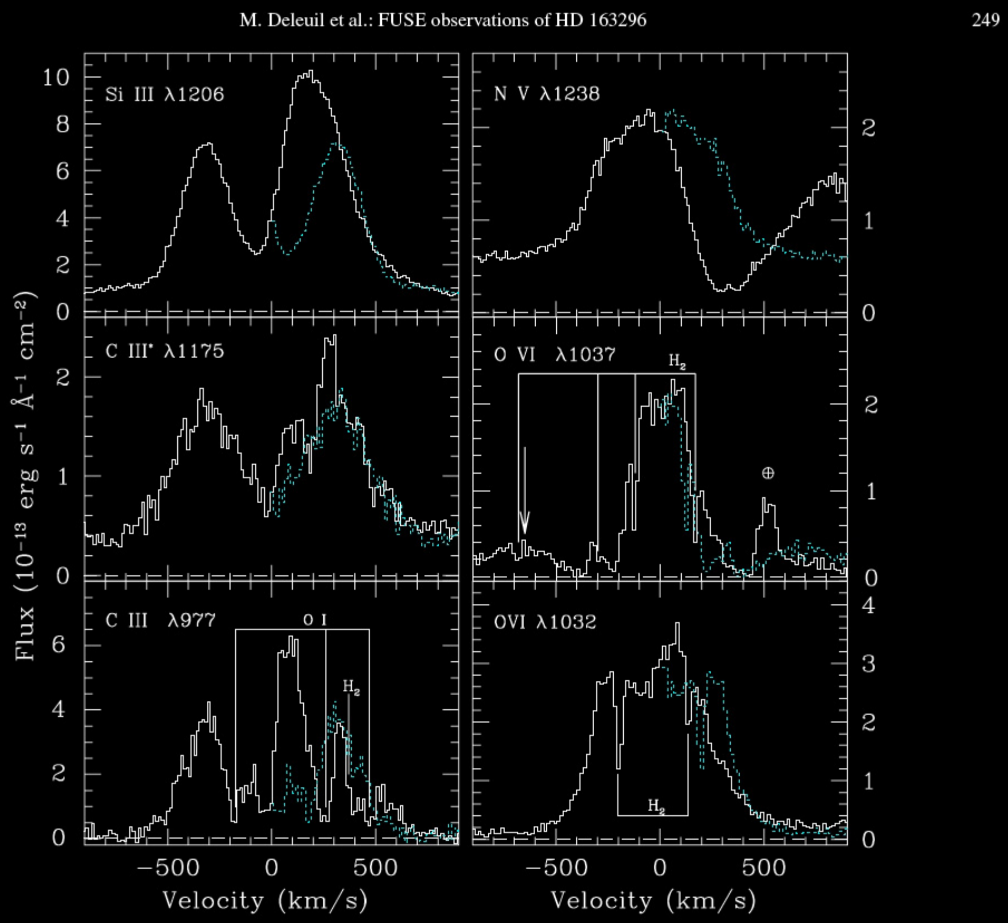


Figure 2: *Left panel*: *Chandra* CCD spectrum of HD 1632



(20 ks) *Right panel*: HD 163296 total PN count spectrum (7 ks).

Swarz et al 2005



magnetically confined winds ?

M_{dot} ~7 x 10^{-9} M_{sol}/yr, B_* ~ 700 G

Deleuil et al 2005

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S. Hubrig et al.: Magnetic fields in Herbig Ae stars (2004)

Table 1. Basic data of the studied Herbig Ae stars.

HD	Other	V	Sp. type	$T_{\rm eff}$	log G	$v \sin i$	Ref.	$(V-L)_{\rm obs}$	P	$\langle B_z \rangle$
139614	CD-27 10778	8.2	A7Ve	8250	4.5	13	(1)	$\sim 2^{\rm m}.0$	~0.1–0.5%	-450 ± 93 G
144432	CD-42 10650	8.2	A9Ve	7750	4.5	54	(1)	$\sim 2^{\rm m}.0$	~0.1–0.5%	-94 ± 60 G
144668	HR 5999	7.0	A7IVe	7800	3.5-4.0	180	(2)	$3^{\rm m}.0$–$3^{\rm m}.5$	~0.5–1.3%	-118 ± 48 G

(1) Meeus et al. (1998); (2) Grady et al. (1994).

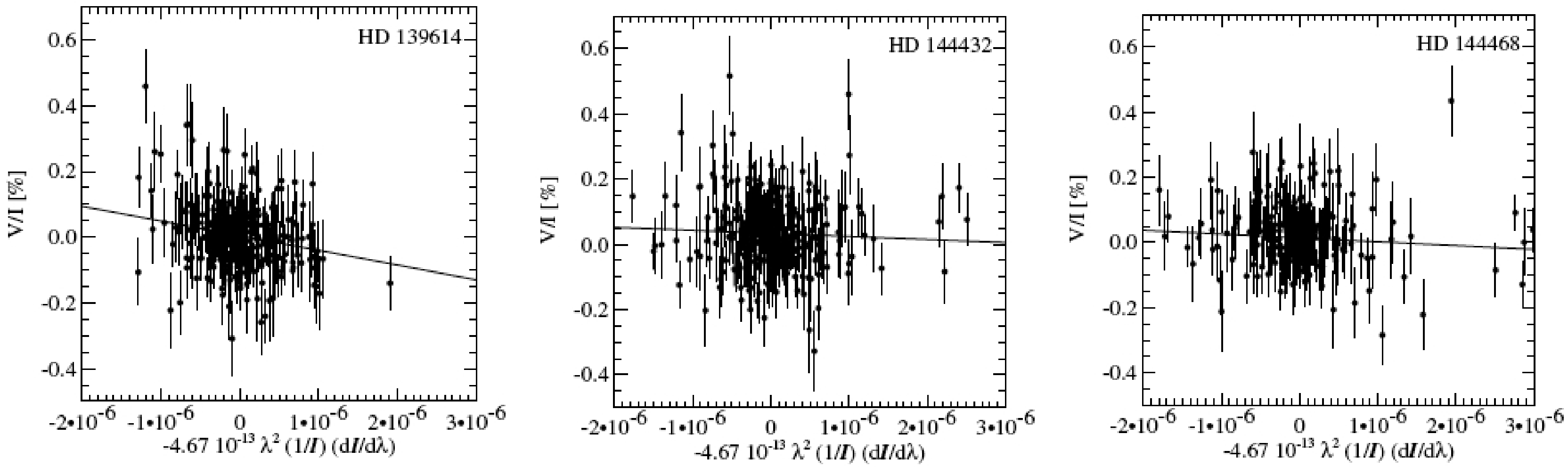


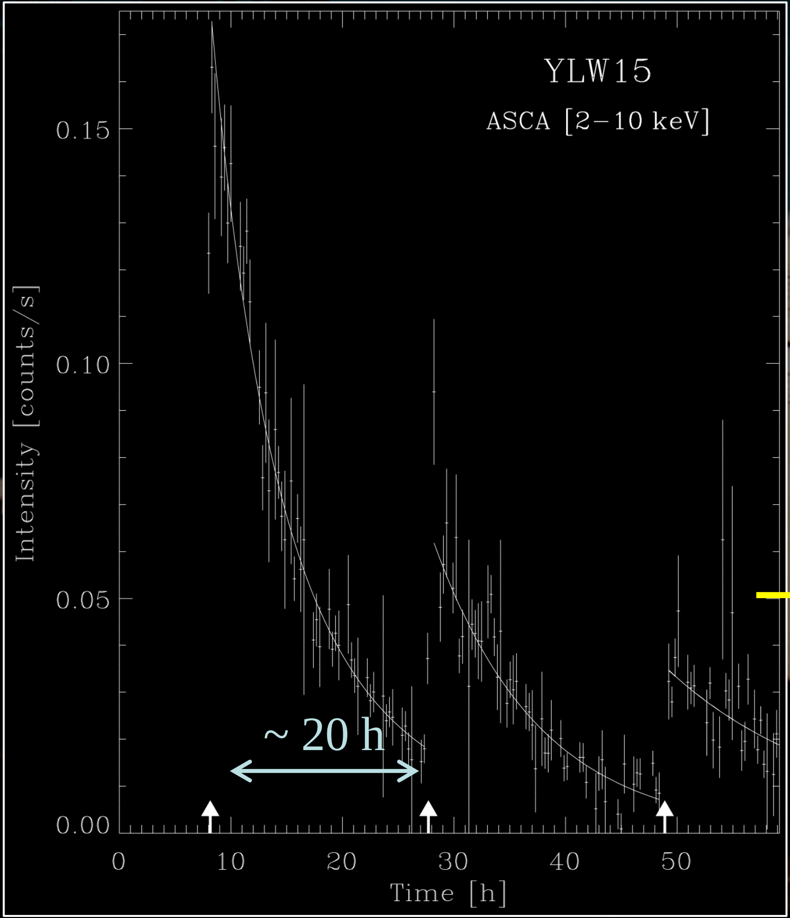
Fig. 1. Regression detection of a -450 ± 93 G magnetic field in HD 139614 and non-detections in HD 144432 and HD 144668.

7. Evidence for other mechanisms ?

- Star-disk reconnection ?
- X-rays from jets ?

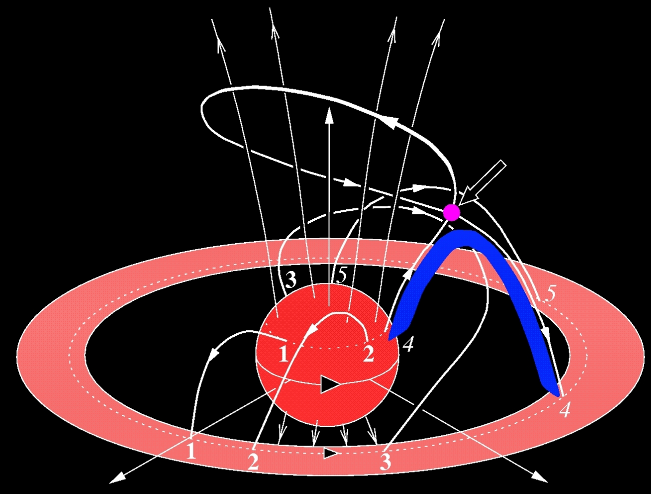
Star-disk reconnection ?

The case of the YLW15 protostar



Tsuboi et al 2000

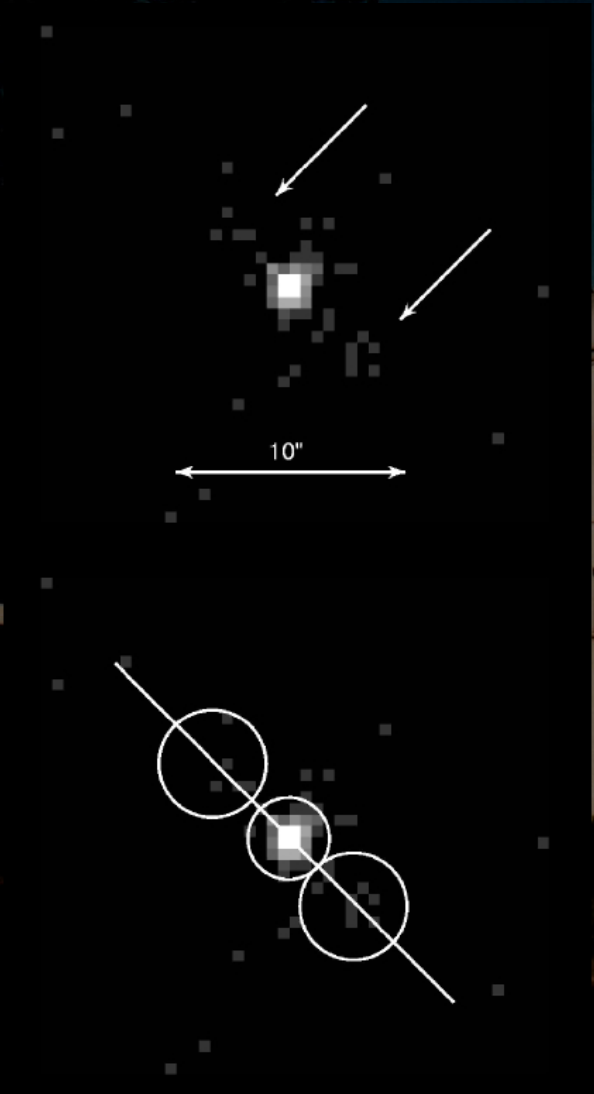
?

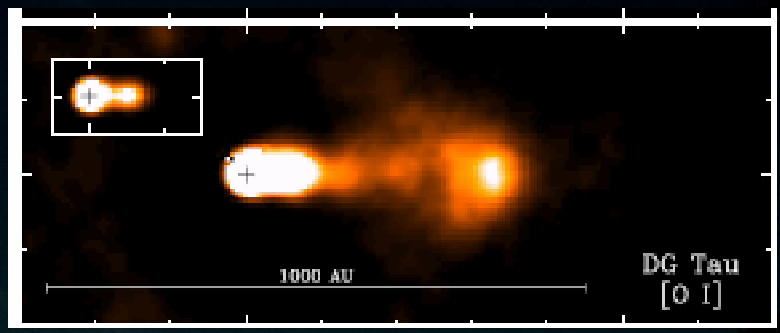


Differential star-disk rotation

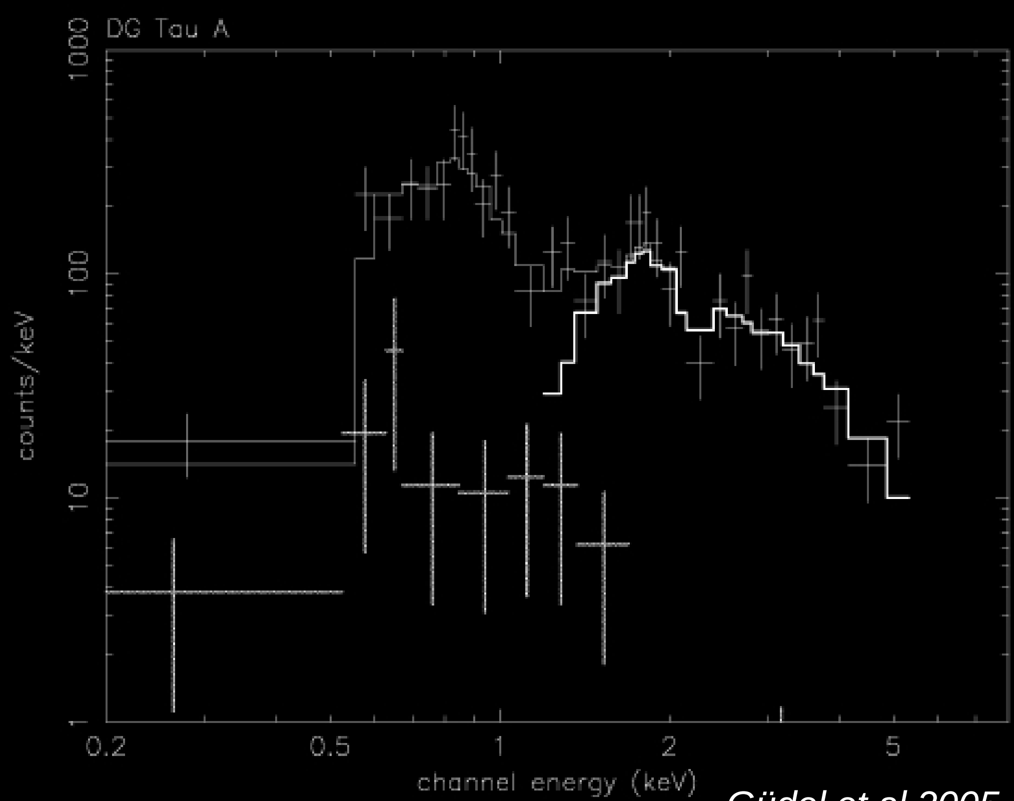
Montmerle et al 2000

DG Tau jet !





Dougados et al 2001



Güdel et al 2005

8. Conclusions

- Importance of high-resolution X-ray spectroscopy (RGS)
- UV/X-ray connection
- Only a few "non-solar" (= "non-coronal") cases of X-ray emission so far
  - Magnetospheric accretion
  - Magnetically channeled wind shocks
  - Jet shocks
- Hints of disk evolution (metal depletion) seen in X-rays; link w/ age unclear
- Significant fraction of intermediate/high mass stars may be magnetic: fossil fields ? buoyant magnetic fields from convective core ?
- *=> X-rays tell a lot, but it's not always easy to decipher the message...*
- Key role played by magnetic fields

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