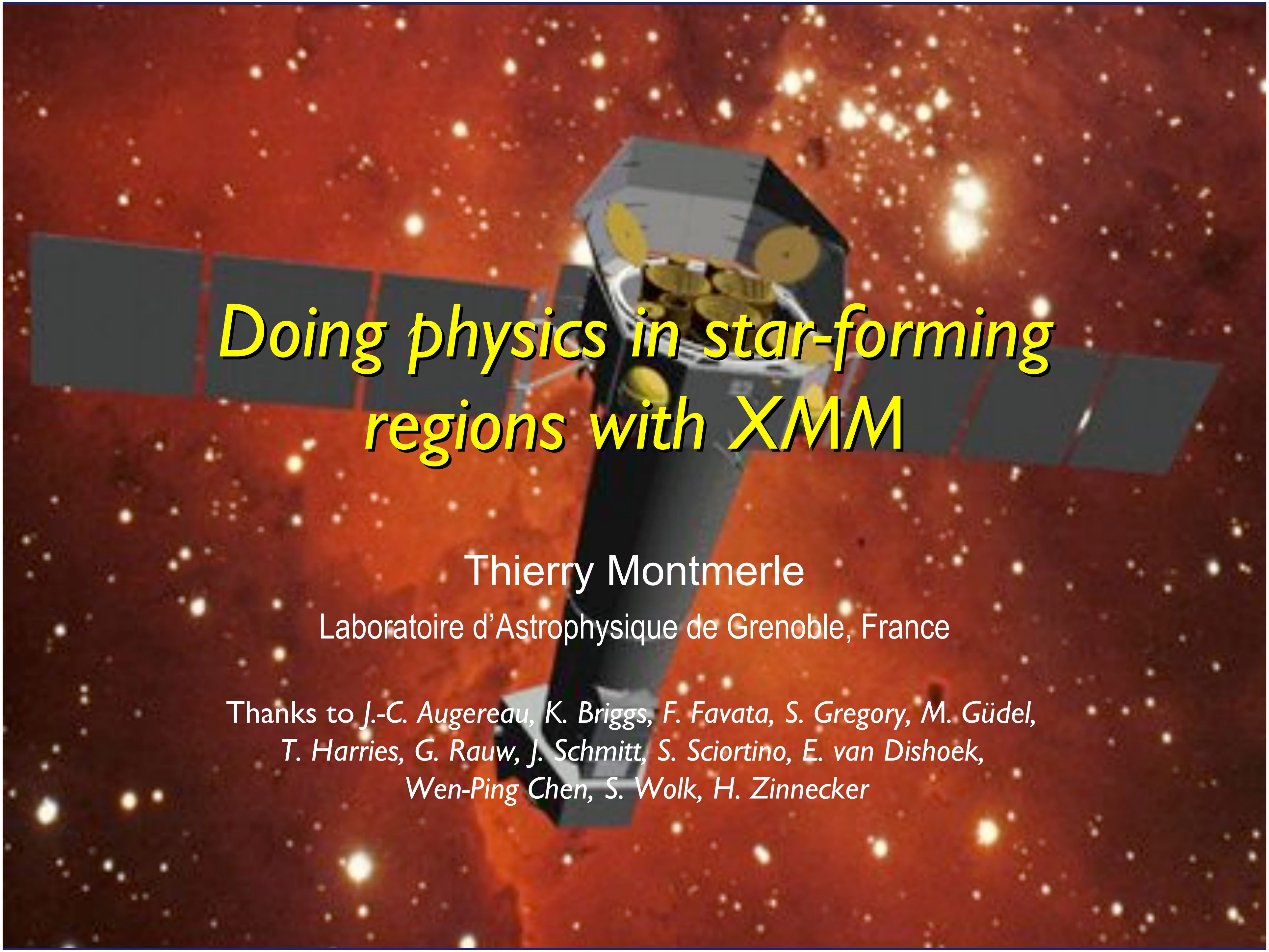

Doing physics in star-forming regions with XMM

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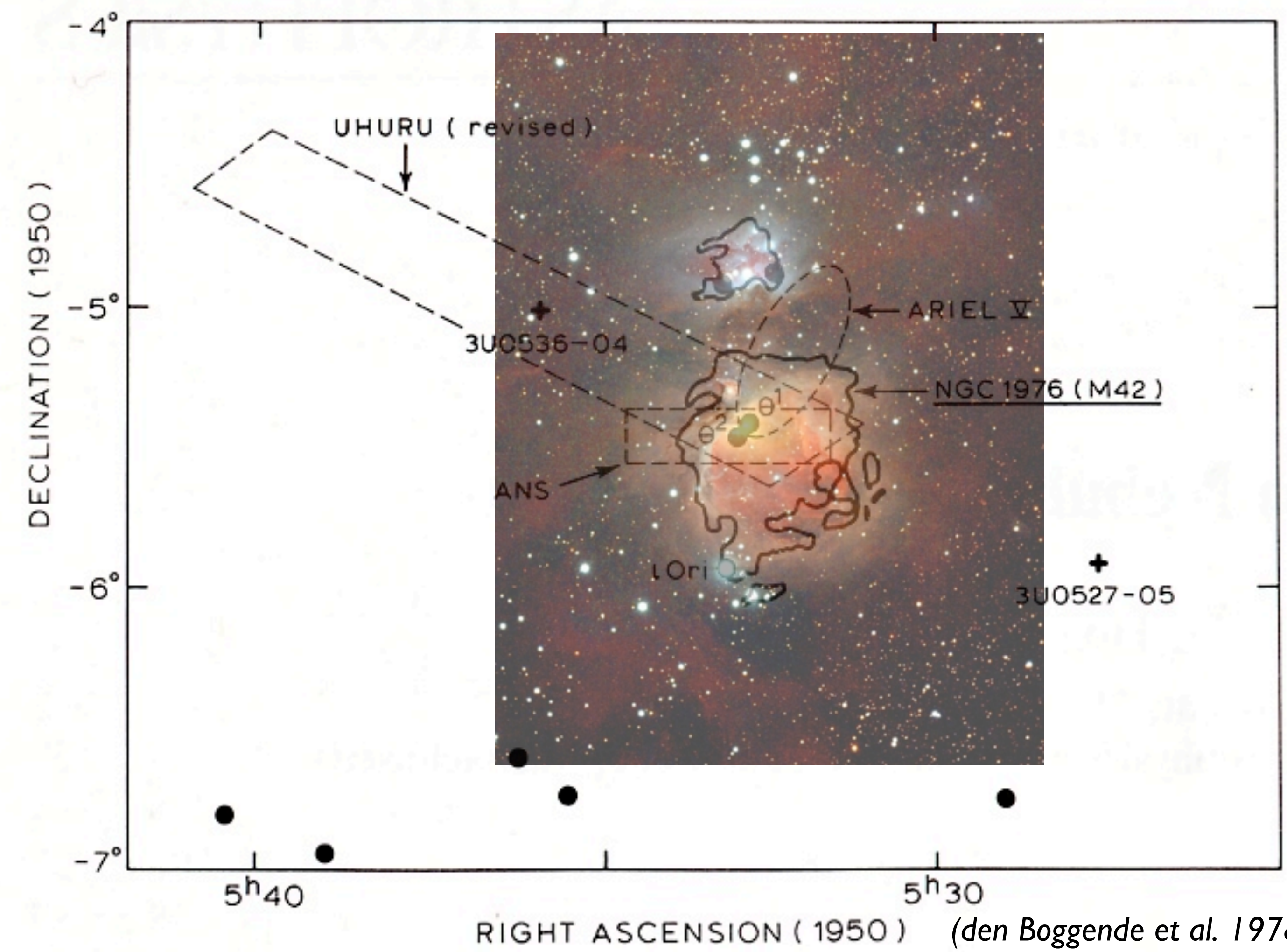
Thanks to *J.-C. Augereau, K. Briggs, F. Favata, S. Gregory, M. Güdel, T. Harries, G. Rauw, J. Schmitt, S. Sciortino, E. van Dishoek, Wen-Ping Chen, S. Wolk, H. Zinnecker*

Outline

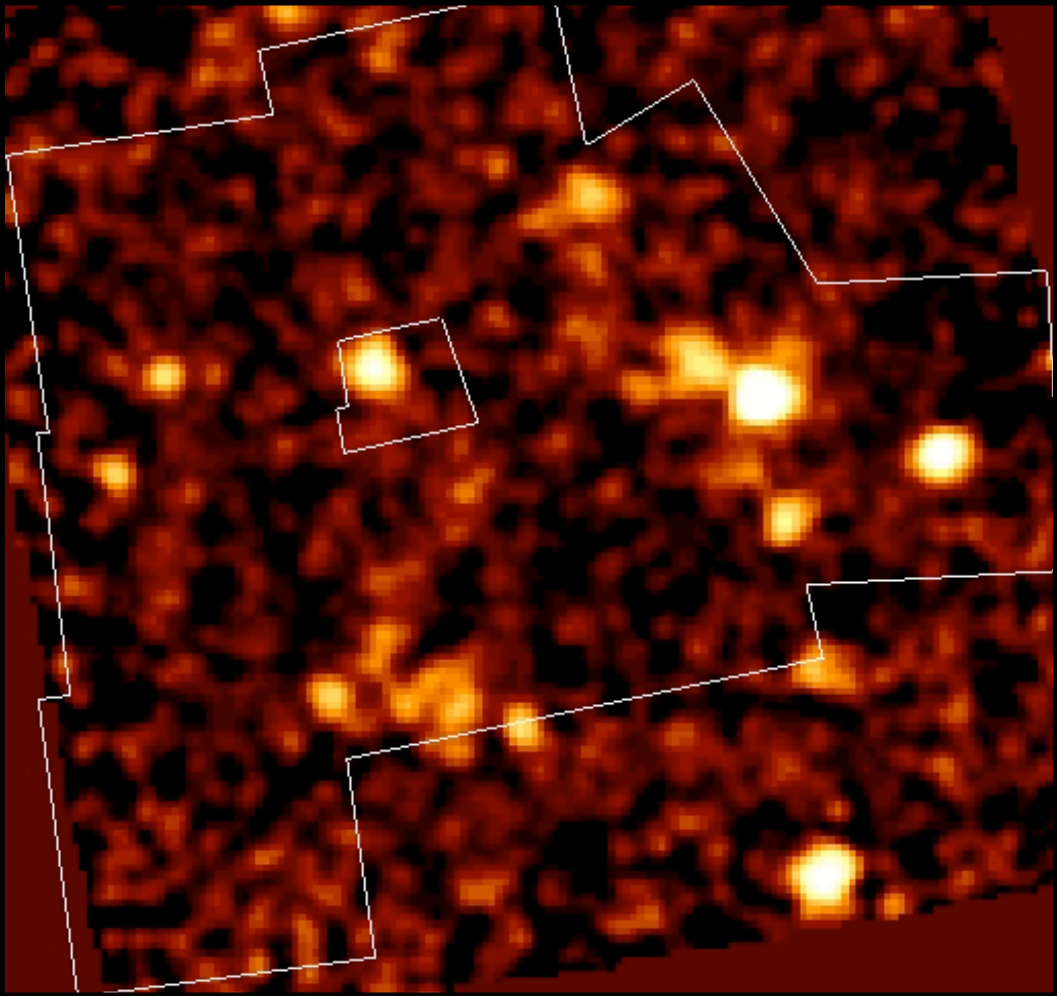
- Overview: Historical notes and the X-ray/IR connection
- Doing physics in young stars with X-ray satellites
- Setting the stage: Basics of early stellar evolution and X-ray emission
- Themes for the future: from today to tomorrow
- Concluding remarks

An old friend of the roaring X-ray seventies: the Orion nebula

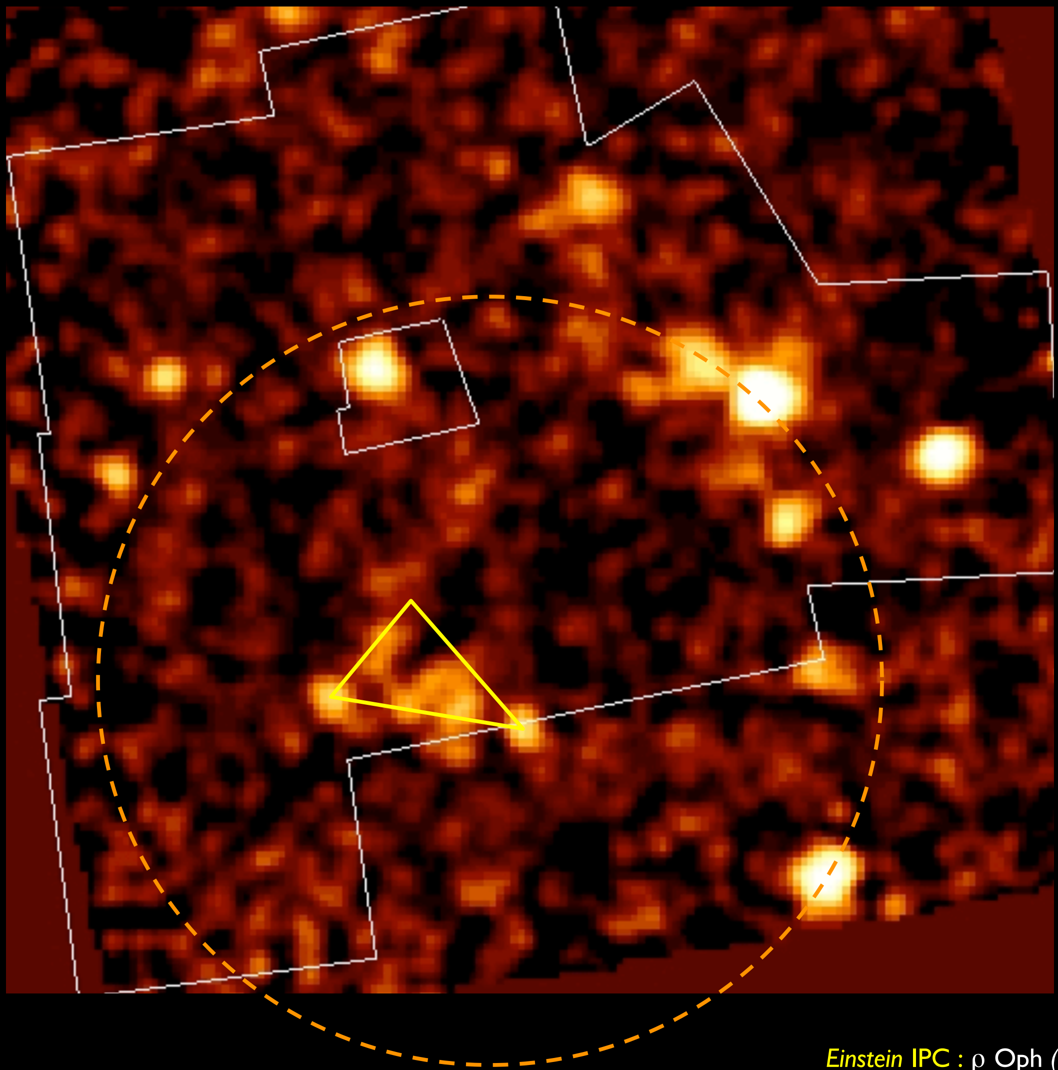


(den Boggende et al. 1978)

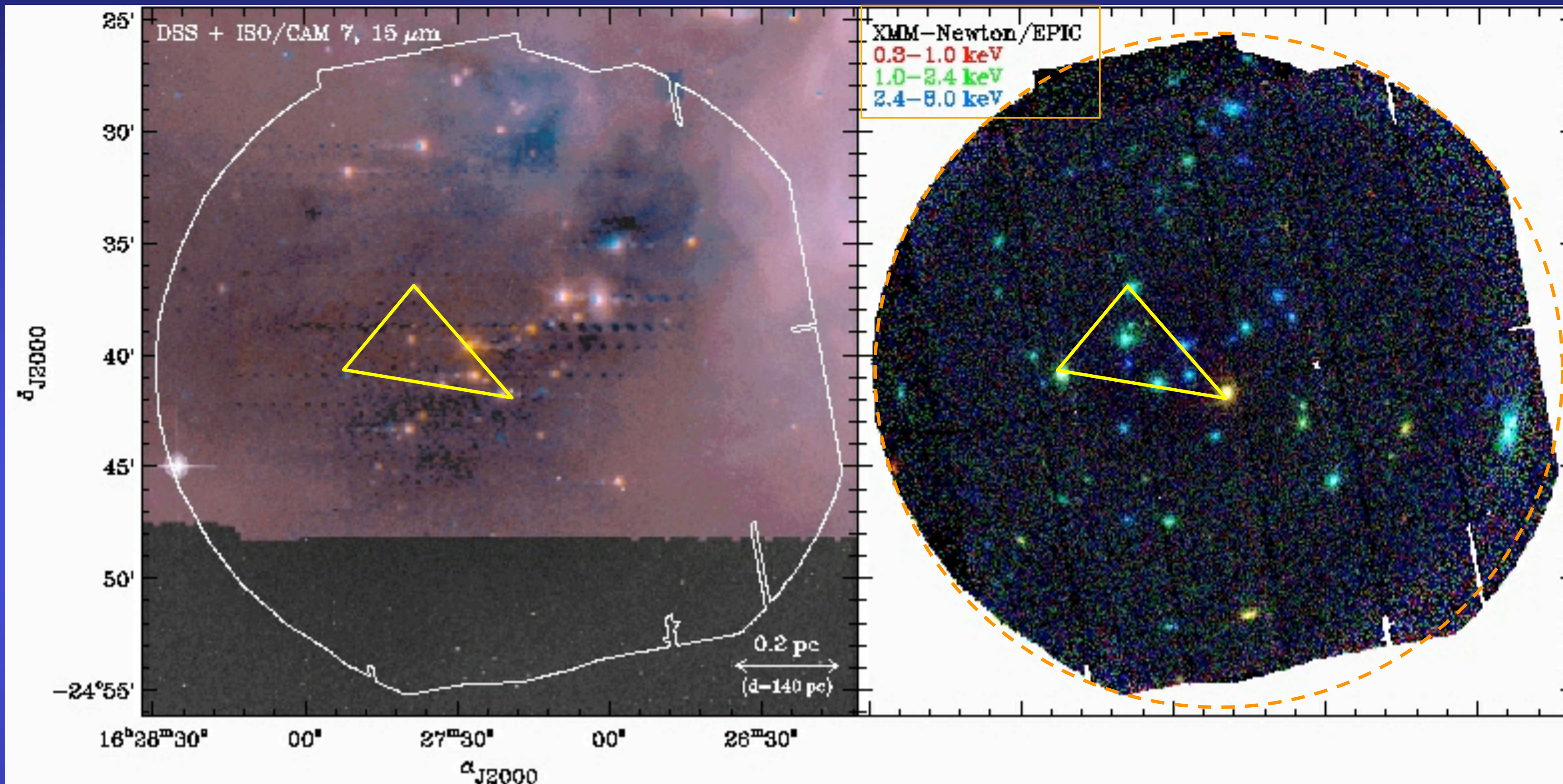
A nearby (160 pc) molecular core seen in (hard) X-rays: the ρ Oph cloud



Einstein IPC : ρ Oph *(Montmerle et al. 1983)*



Einstein IPC : ρ Oph *(Montmerle et al. 1983)*

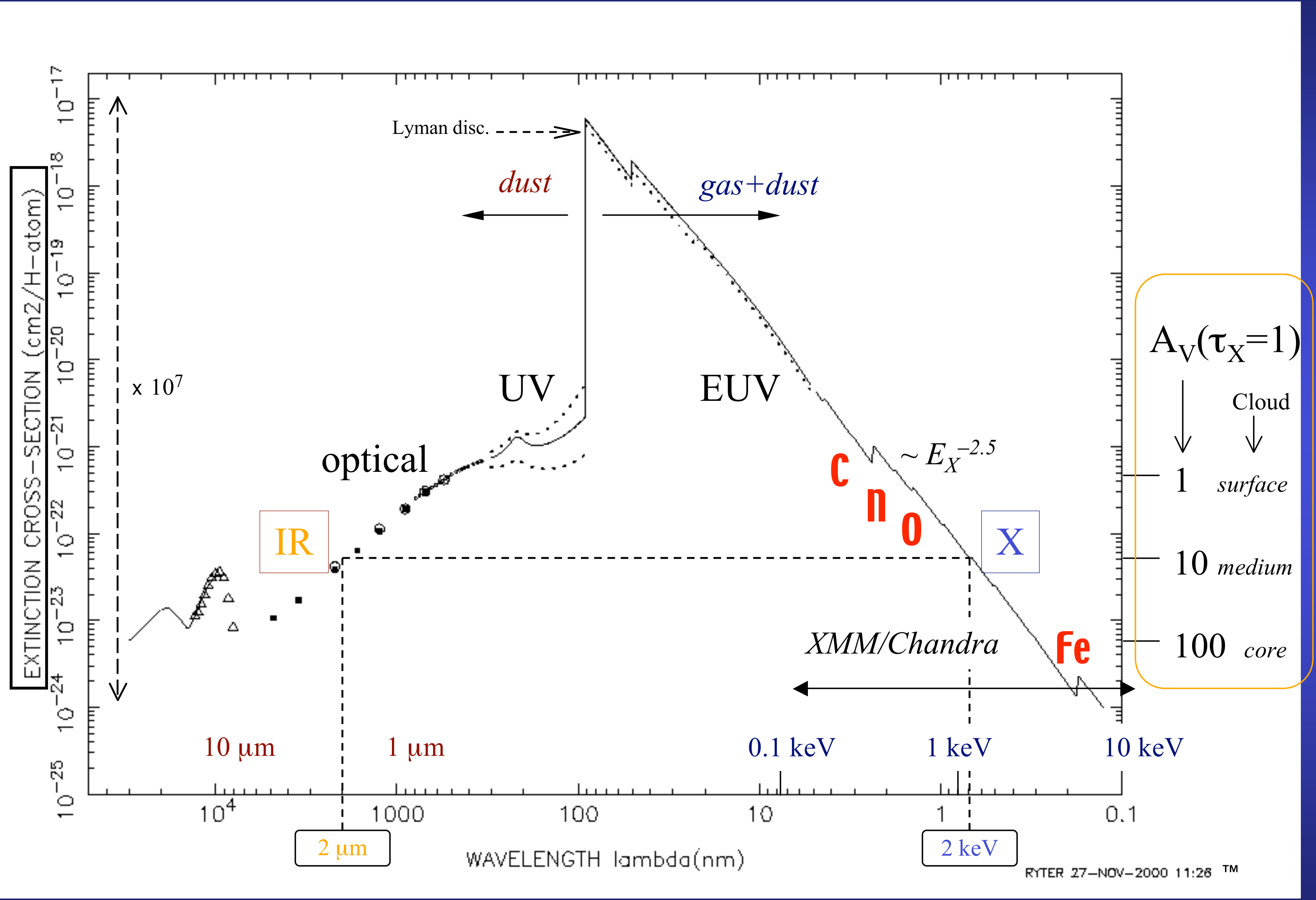


20 years after: The ISO/*XMM* view of the ρ Oph cloud core

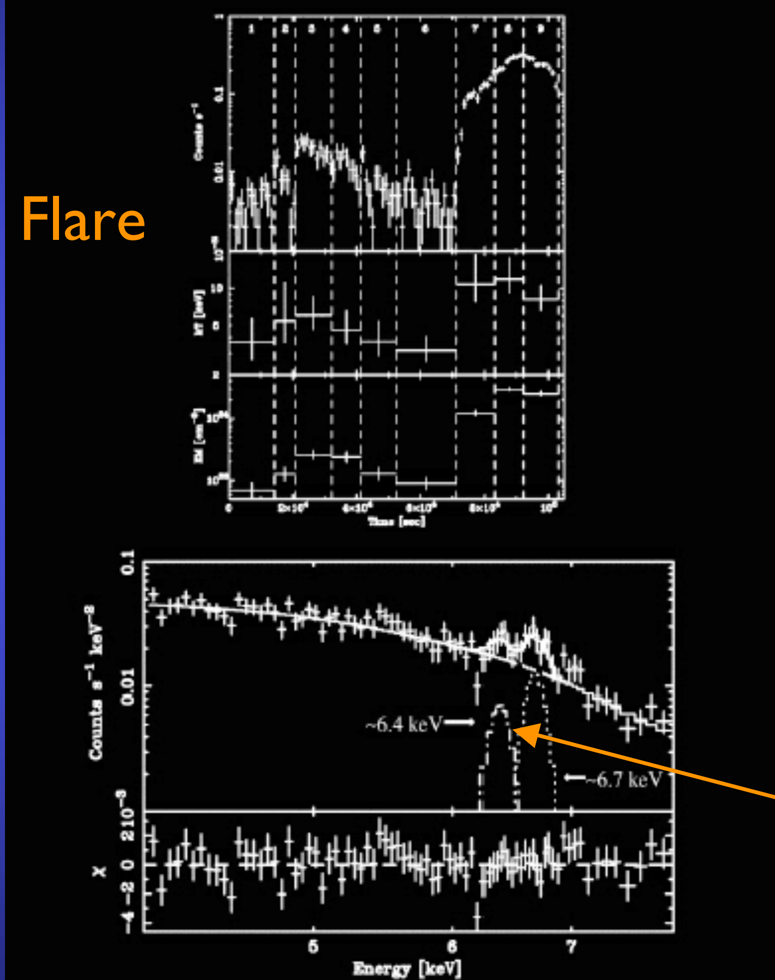
=> *Einstein* sources are a deeply embedded cluster of protostars !

(Grosso, Ozawa, Montmerle et al. 2003)

The X-ray/IR connection



The power of (hard) X-ray timing and spectroscopy



Flare light curve and spectrum from Class I protostar YLW 16A, observed with Chandra ACIS (Imanishi et al. 2001)

Discovery of a flare-induced Fe I Kα fluorescent line @ 6.4 keV in a low-mass protostar
(Chandra: *Imanishi et al. 2001)*

2. Doing SFR physics with X-ray satellites (~30 SFRs)

	ROSAT	XMM	Chandra
FOV	*** (center)	***	**
Spatial Resolution	* (HRI **)	**	***
Spectral range	*	**	**
Collecting area	*	***	**
Soft X-rays (< 1 keV)	*	**	—
Hard X-rays (> 1 keV)	*	**	**
Line spectroscopy	—	**	**
Optical monitor	—	***	—
Bckgrnd << 1 orbit	*	*	***
Bckgrnd > 1 orbit	*	—	***
Diff. Emission (excl. SNR)	—	* (soft)	** (hard)

LAOG

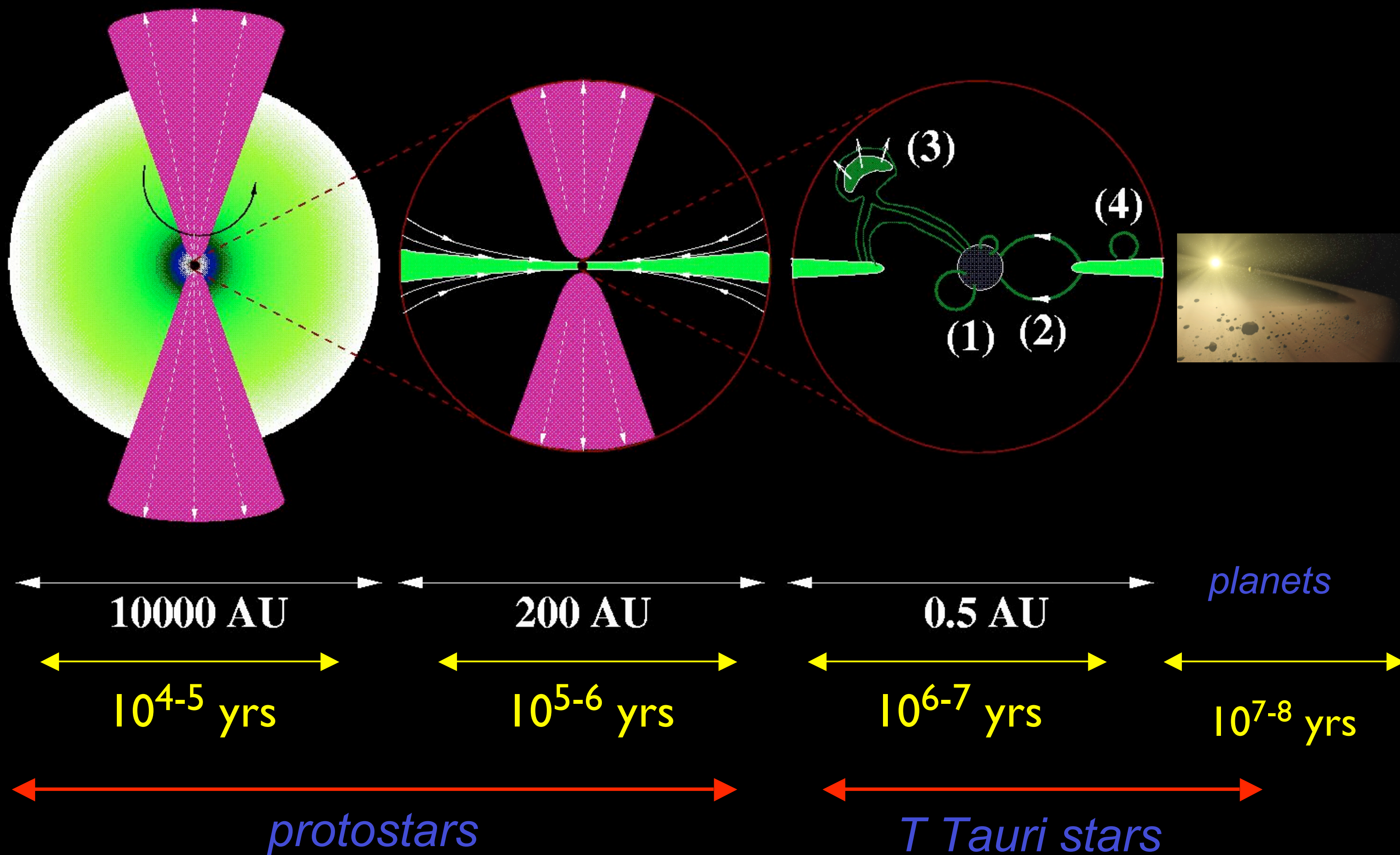
3. Setting the stage: Basics of early stellar evolution and X-ray emission

- Within the first 10 Myr, a young, low-mass star radically changes its structure & environment (envelopes, jets, disks)
- X-ray emission is ubiquitous (x1000's "YSOs" known !), but X-rays alone cannot characterize them:
  - At all stages, dominant contribution from (10^3-10^4 enhanced, *hard*) "solar-like" *magnetic activity* (coronal emission, flares); seen in all cool stars

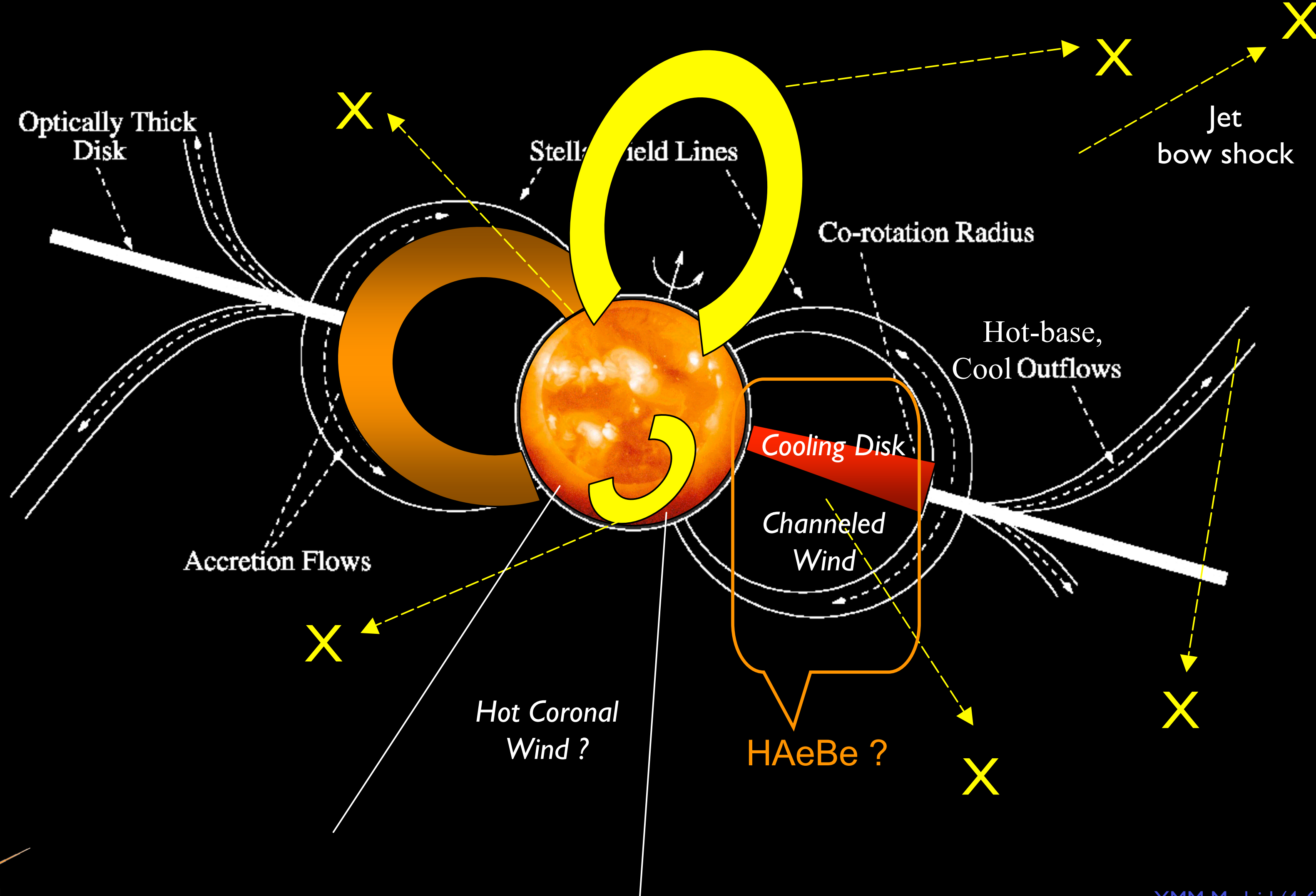
    [cf. talk by J. Schmitt]
  - Correlations with global *stellar* properties: L_{bol}, M_*, T_{eff}, but not with P_{rot}, age…
  - Hard-to-find correlations with environmental properties: weaker, *soft* X-rays from *shocks* caused by magnetically channeled accretion and bipolar jets (200-400 km/s) [cf. talk by M. Güdel]; infrequent very large flares [cf. talk by S. Sciortino]; *challenging physics & modeling !*
    - Only a handful of stars !
- Timing studies and line spectroscopy key to understanding "accretion-ejection" physics (see AGNs !)

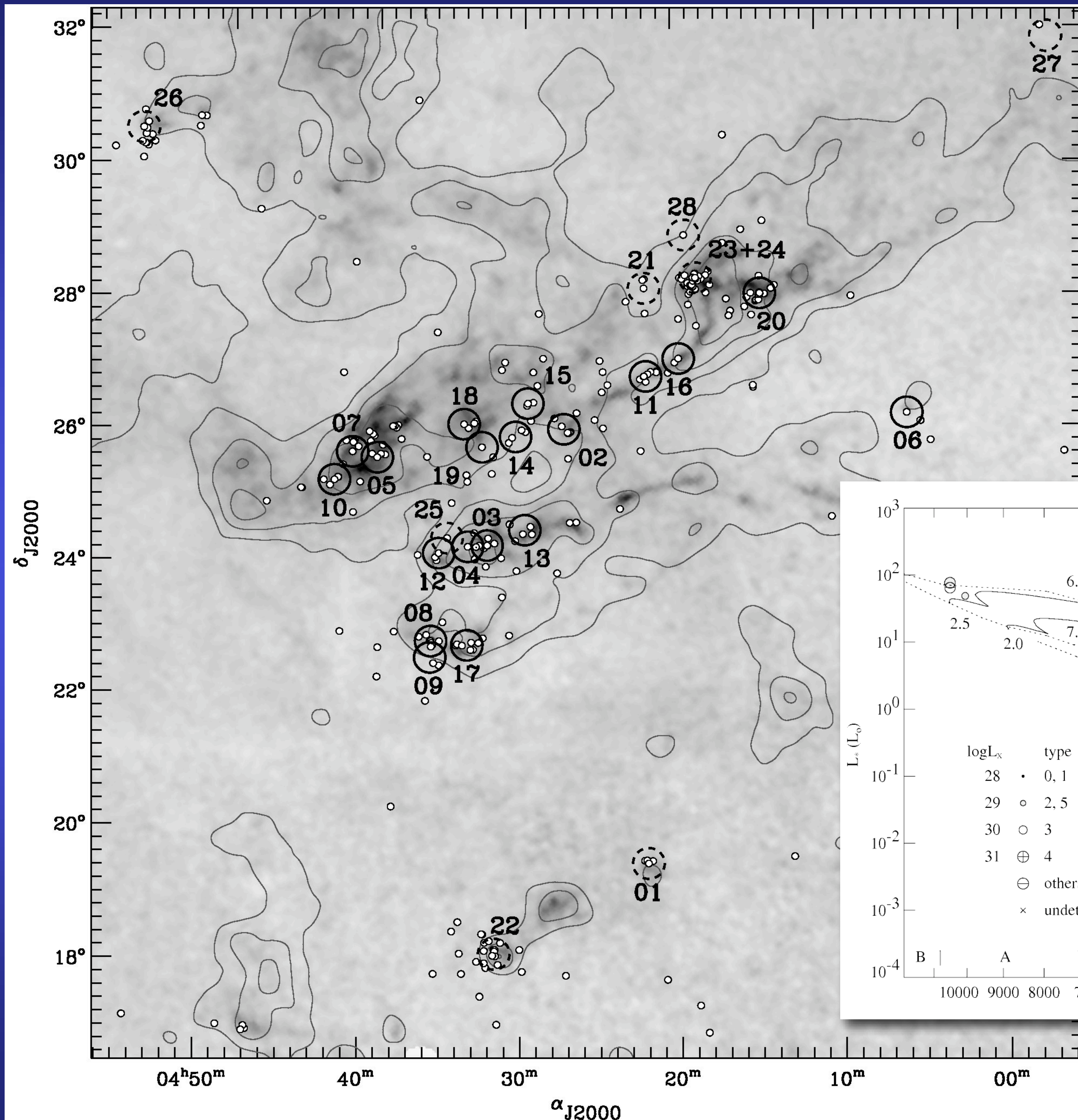
LAOG

A brief history of early stellar evolution



The star-disk interaction region (few R_*):
A complex, X-ray emitting accretion-ejection configuration...





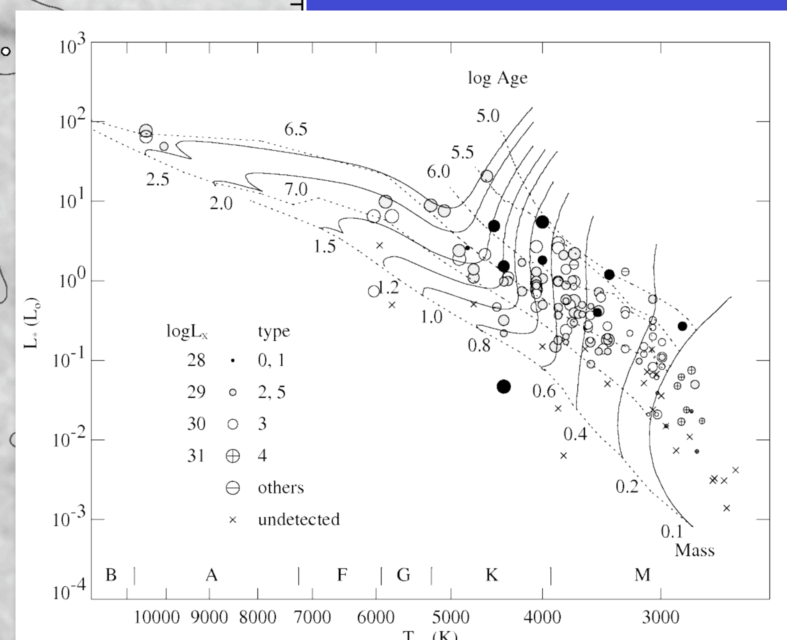
XEST:

XMM Extended Survey of Taurus

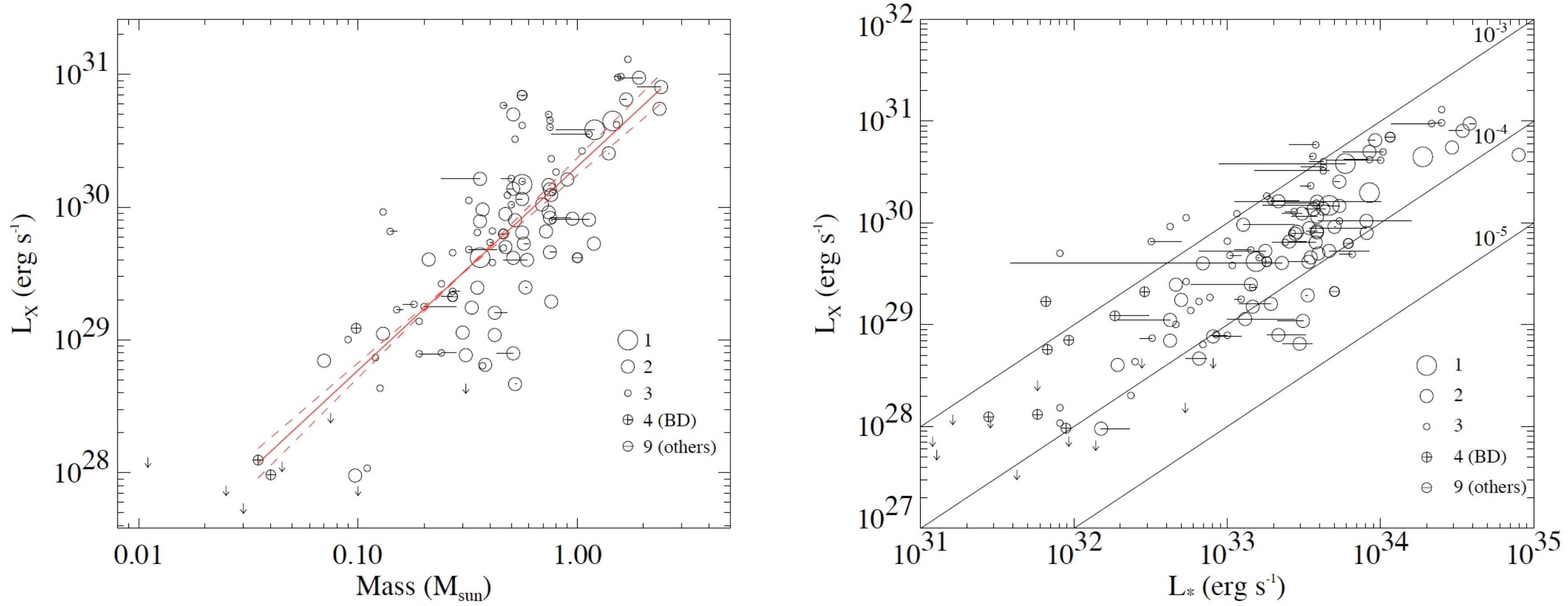
[talk by PI M. Güdel]

A&A 2007

25 x 60 ksec= 1.5 Msec

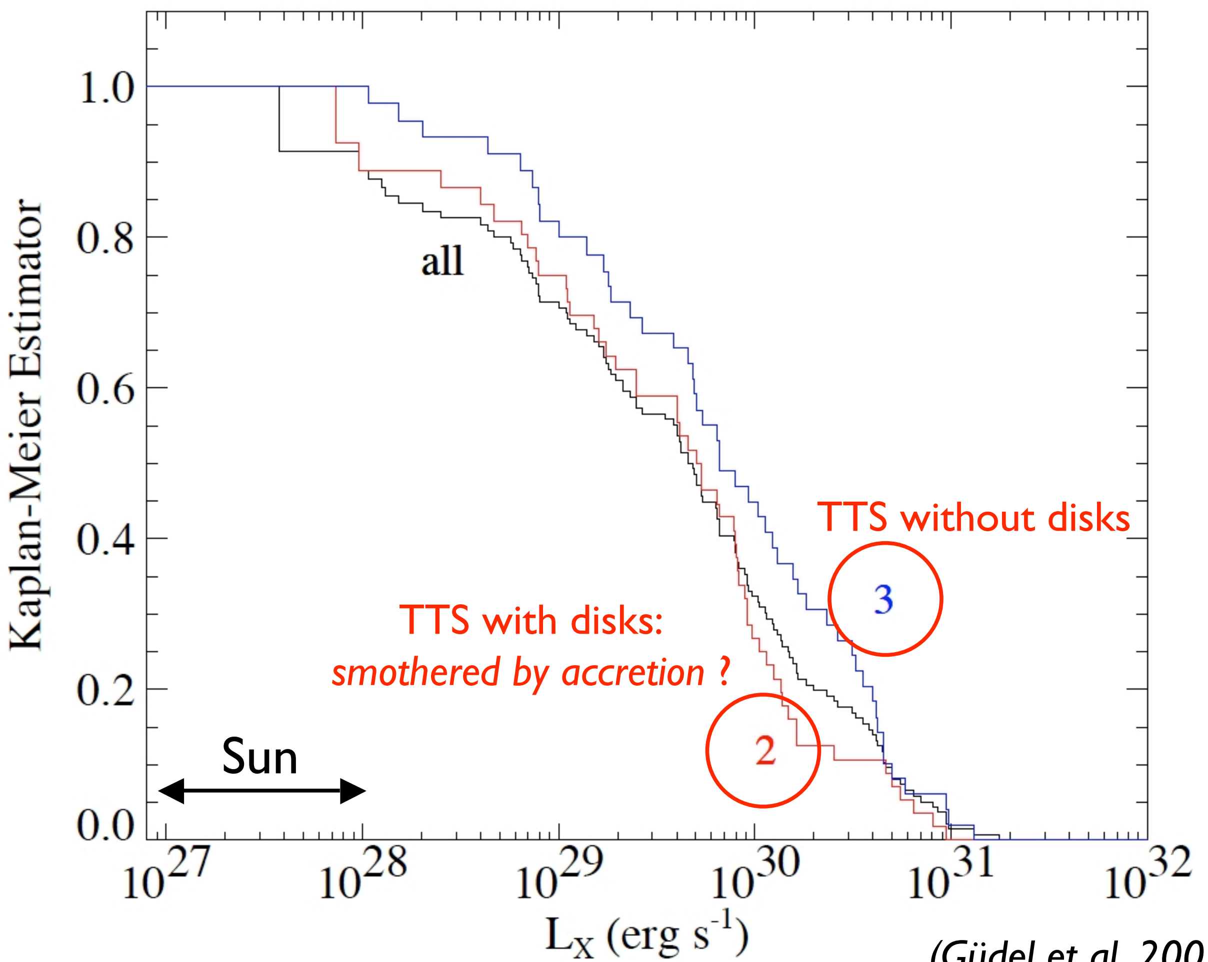


Global properties of XEST sources



(Güdel et al. 2007)

X-ray luminosity functions of XEST T Tauri stars



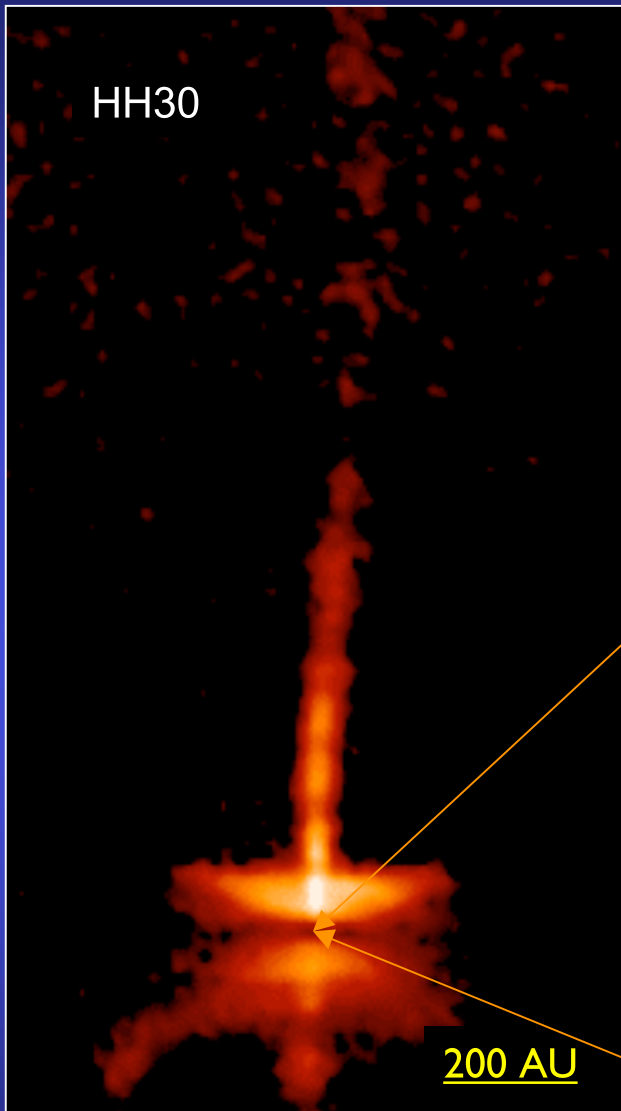
(Güdel et al. 2007)

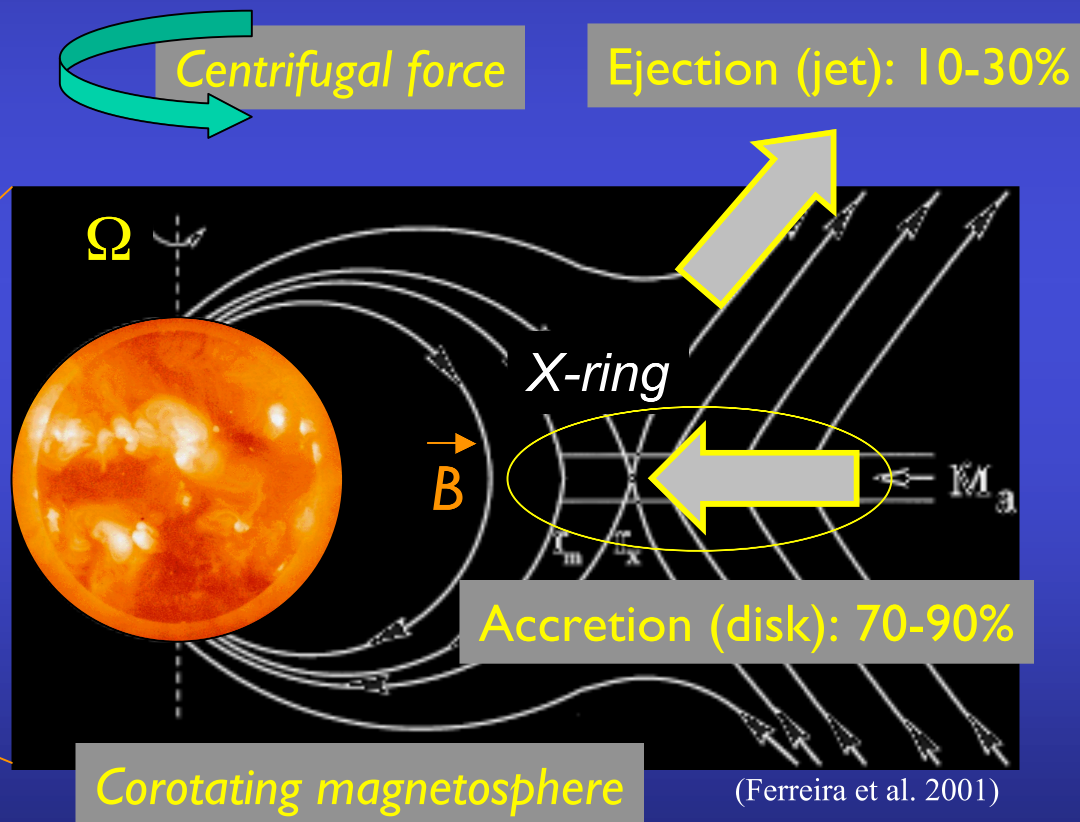
4. Themes for the future with XMM: from today to tomorrow

- Main theme: star-environment interactions
  - Growing interest in astronomy: multiwavelength observations, (use of large European instruments: VLT, ALMA…; *Herschel*), theory, heavy numerical simulations
  - *Strong drive from links with extrasolar planets and solar system formation*
- Star-disk interactions and the "central engine"
  - Key role played by magnetic fields: complex MHD geometry & flows
- X-ray (and particle) irradiation of circumstellar disks
  - Evidence for disk ionization => chemistry; dust processing and planet formation, etc…
  - Scaling the irradiation of meteorites in the young solar system
- Possible star-planet interactions
  - Atmosphere escape in "hot Jupiters" [cf. talk by A. Pollock]
  - Auroral emissions (if planet magnetized) ?

Zooming in: MHD model for star-disk magnetic coupling

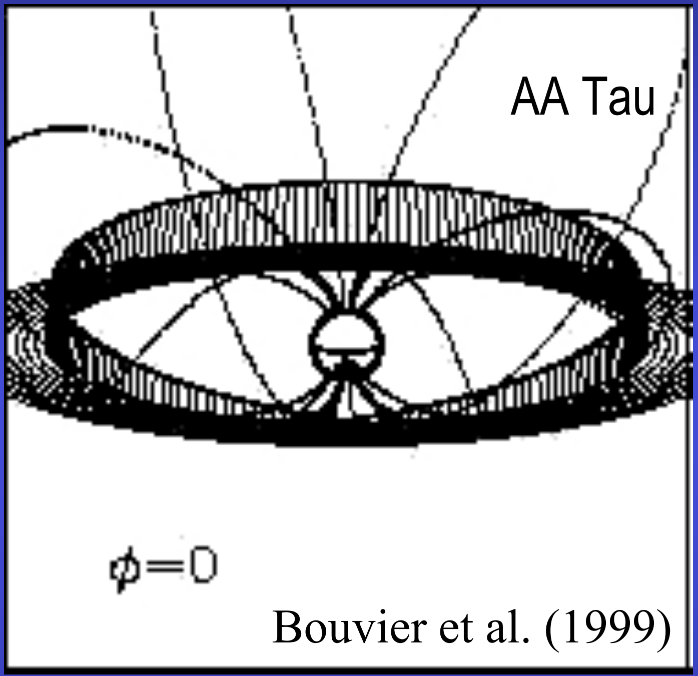
(Shu et al., Pudritz et al., Heyvaerts et al., Ferreira et al.…)



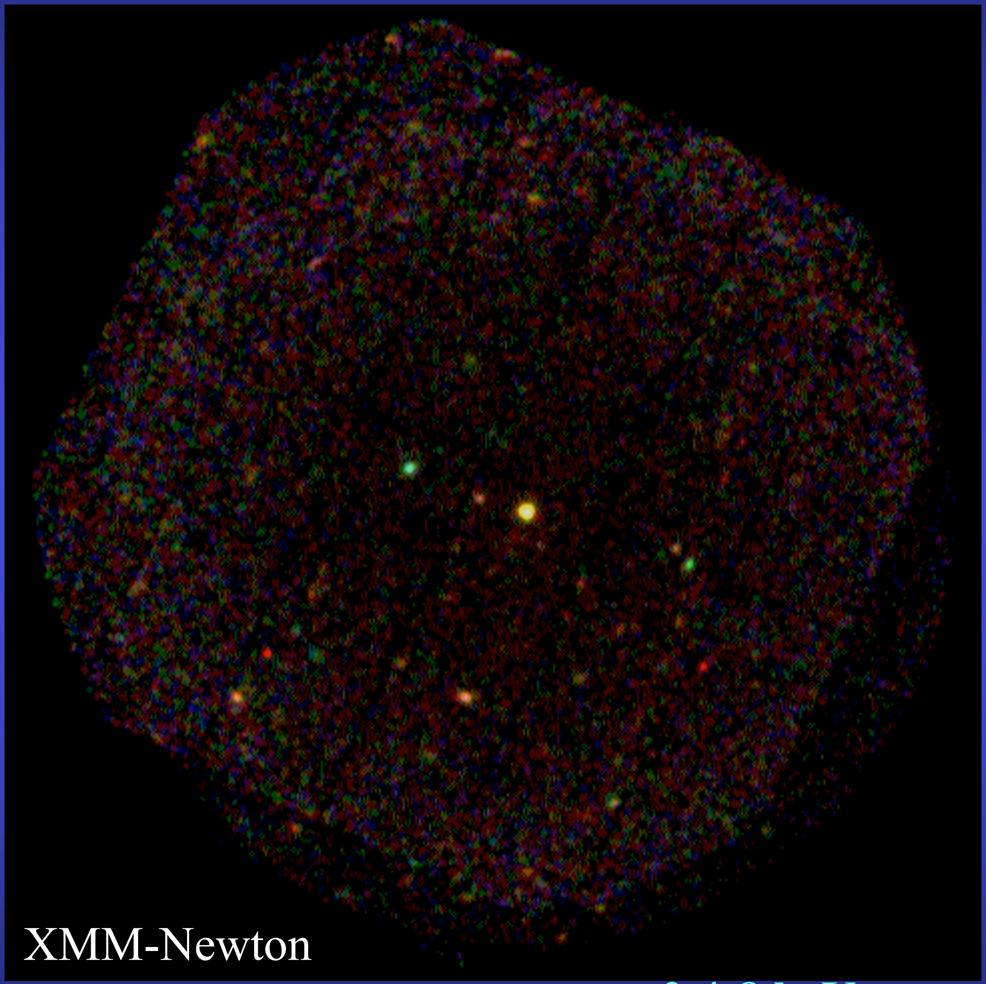


(Ferreira et al. 2001)

The star-disk interaction: "Magnetospheric accretion"



Magnetospheric accretion model:
nearly edge-on warped disk

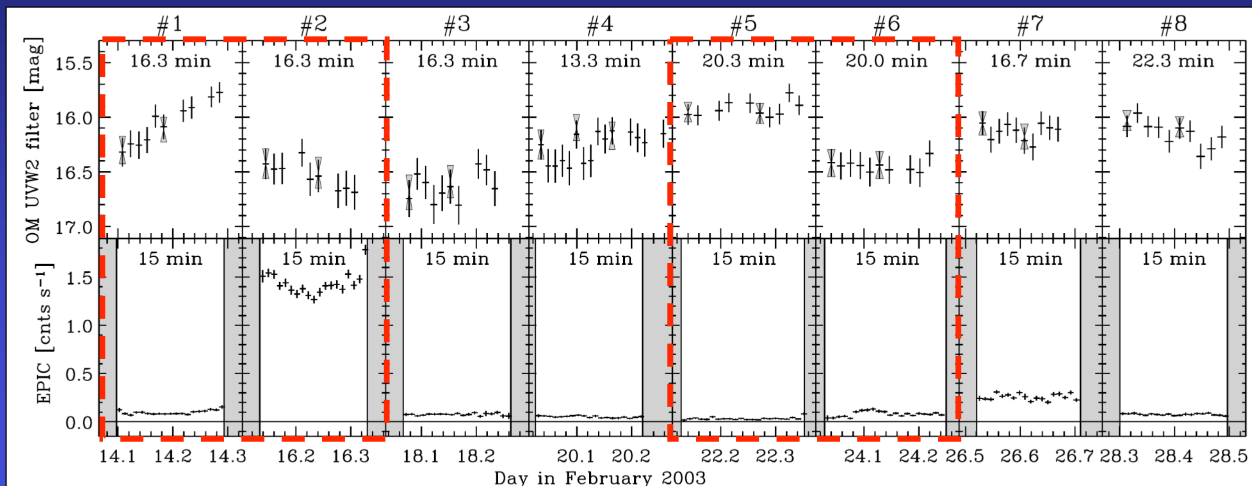


0.5-1 keV **1-2.4 keV** **2.4-8 keV**

Rotation period ~1 week

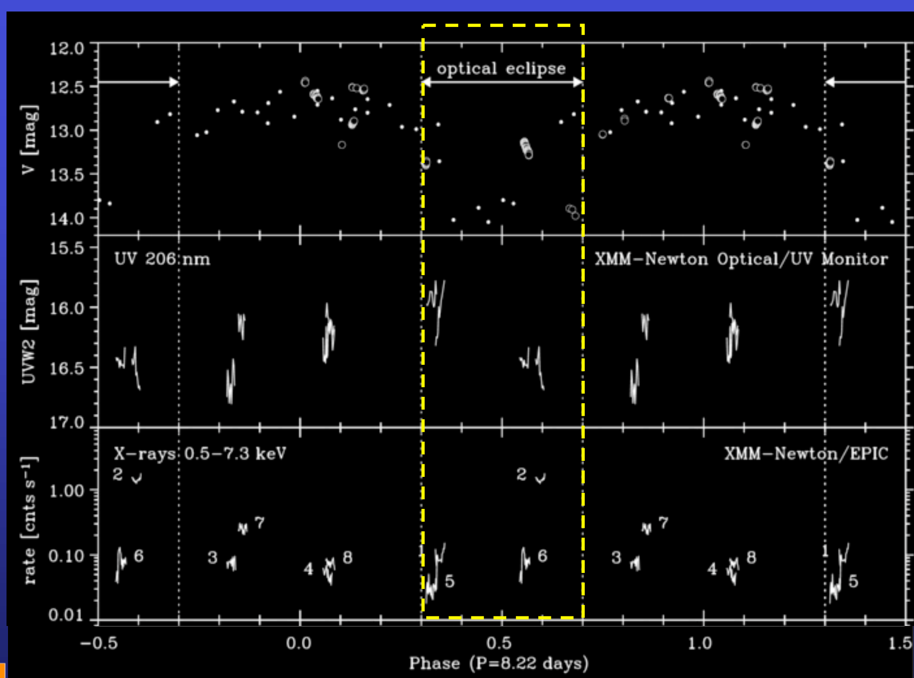
(Grosso, Bouvier, Montmerle et al., subm.)

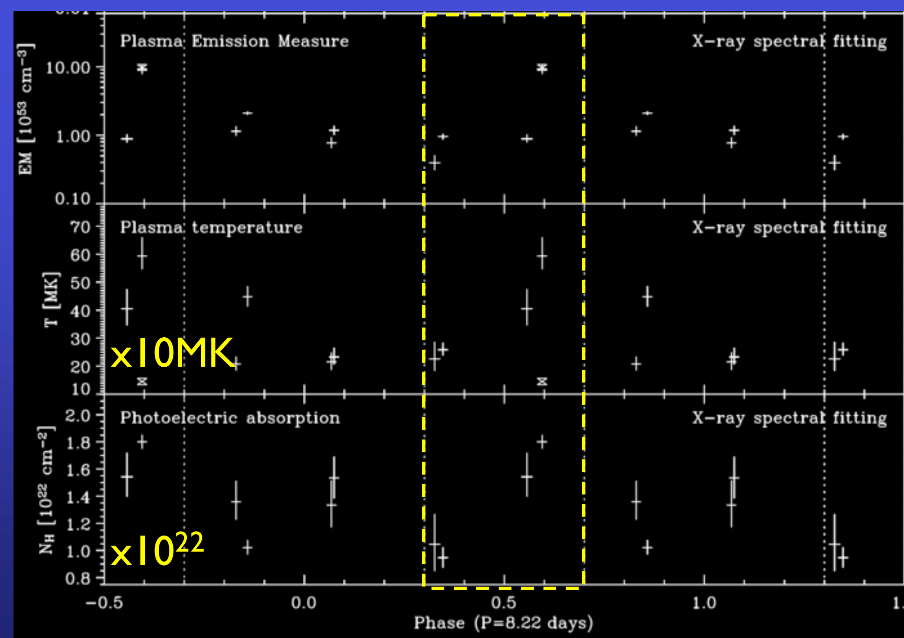
AA Tau: (disk) "eclipse mapping" of the coronal X-ray emission



2 periods:
8 x 15 ksec

(Grosso, Bouvier, Montmerle et al., subm.)





The OVII triplet in T Tauri stars with disks:
"in situ" signature of (magnetically channeled) accretion ?

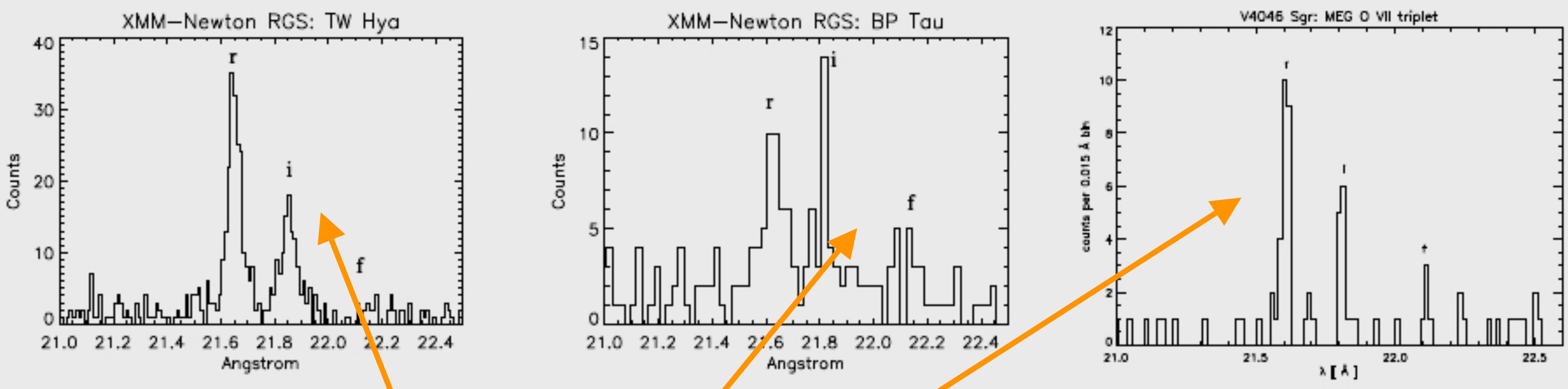


Figure 1: *Left panel*: O VII He-like triplet for TW Hya. *Middle panel*: O VII He-like triplet for BP Tau. *Right panel*: O VII He-like triplet for V4046 Sgr.

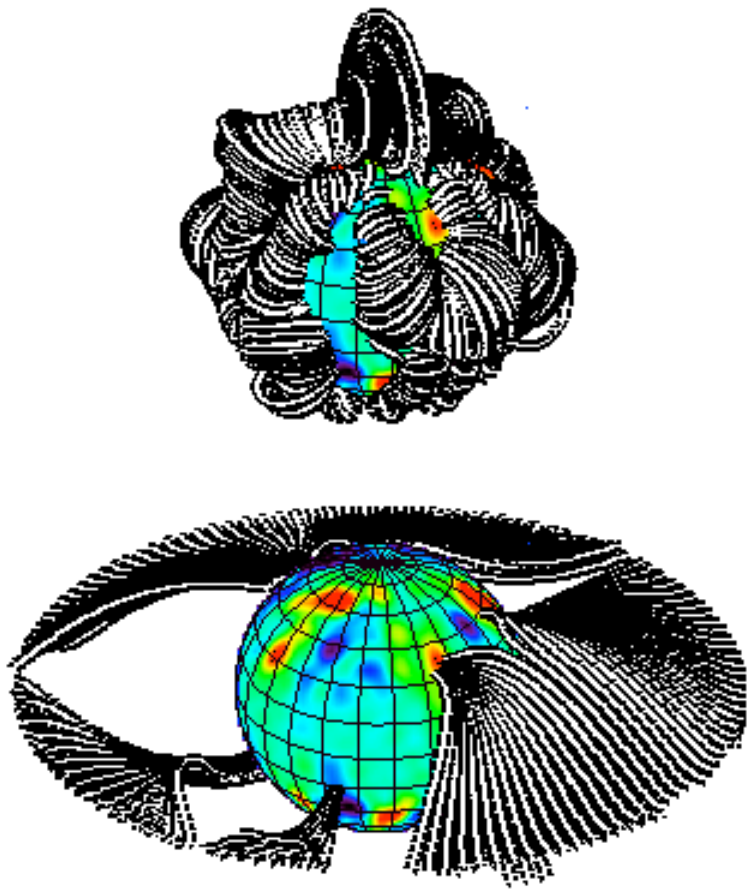
Robrade et al. 2006

kT regime (from broad-band spectrum): ~ 0.1-0.2 keV

f(forbidden)/*i*(intercombination) line ratio ~0.05

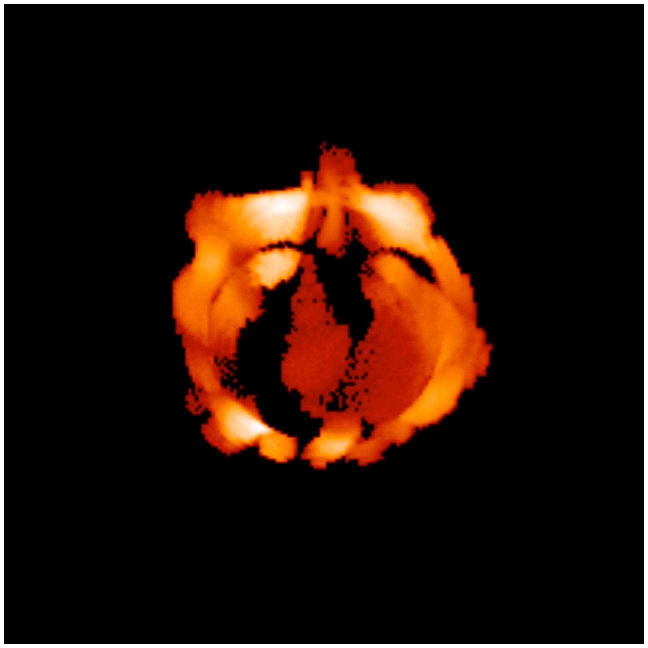
=> $n_e \sim 10^{12}$ cm^{-3} (>> coronal densities: funnel density)

Field Modeling: Extrapolations

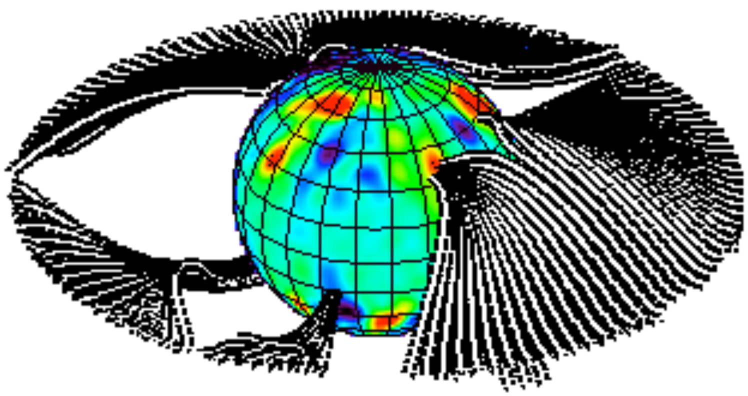


- Complex magnetic fields extrapolated from surface maps of main-sequence stars.
- Isothermal corona in hydrostatic equilibrium.
- Satisfies observational constraints.

(Gregory, Wood & Jardine 2007: Exeter + St Andrews)



Coronal X-rays



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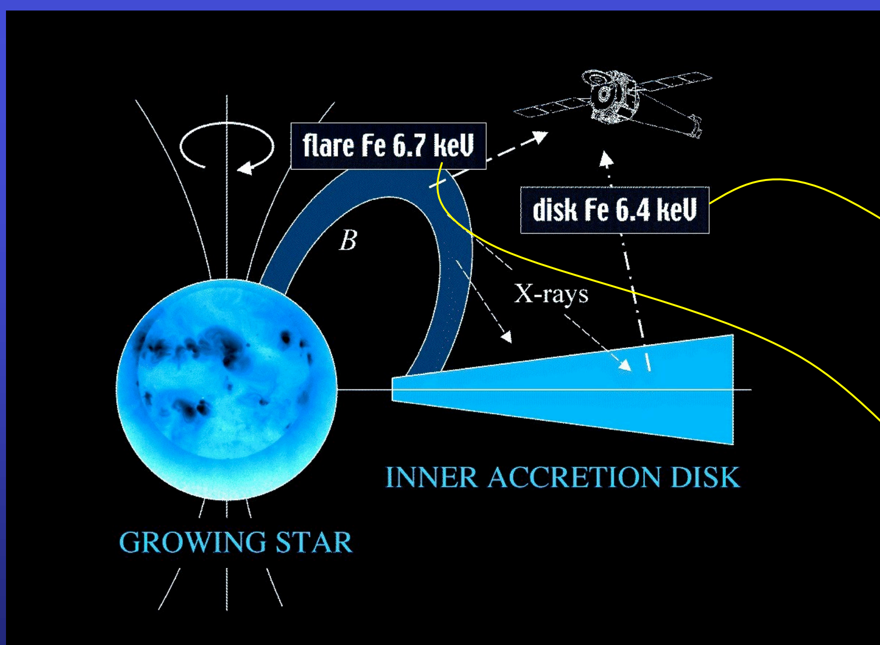
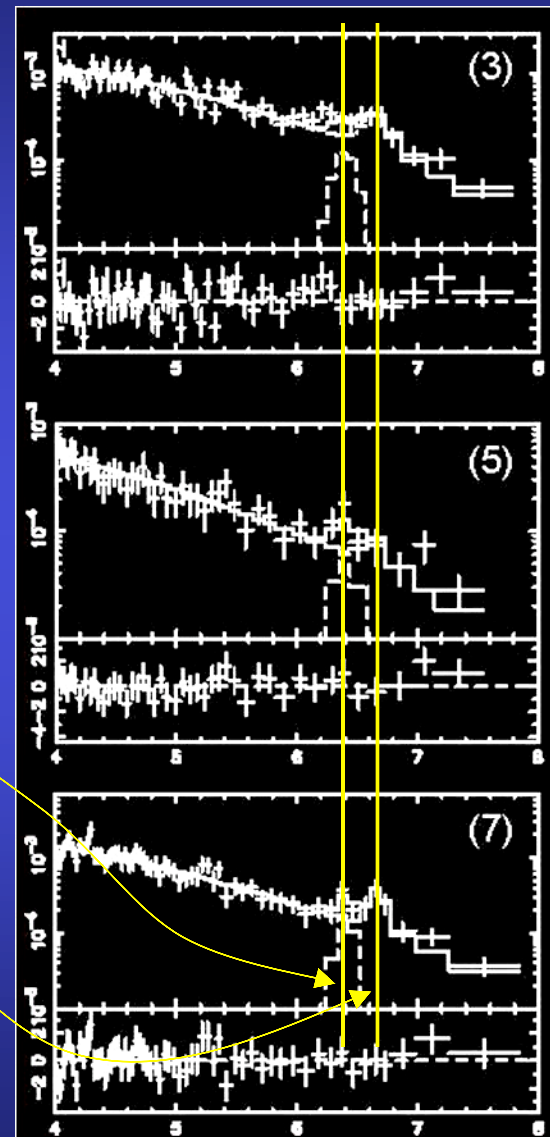
(Gregory, Wood & Jardine 2007: Exeter + St Andrews)

Fluorescing T Tauri stars in Orion…

Fe line @ 6.4 keV => *Direct* evidence for disk irradiation; but special orientation required !
Other evidence for X-ray irradiation: Ne II 12 μm line (Glassgold et al. 2007; *Spitzer*) [cf. talk by S. Sciortino]





(Chandra: *Tsujimoto et al. 2005*)

5. Concluding remarks (1/2)

- *Using the* XMM *tool for star-forming regions:*
  need for large programs: use of RGS and/or FOV
  - RGS spectroscopy (e.g., T Tauri stars, Herbig AeBe stars)
    - Exposure driven by sensitivity: ~ 200 ksec/source
  - Extended spatial surveys (e.g., *Spitzer* SFRs)
    - Only 2-3 key regions (NGC1333…)
    - Exposure driven by spatial extent (mosaicing): ~ 0.5-1 Msec/region
  - Long coverage of time-dependent phenomena (e.g., eclipses: AA Tau; rare very large star-disk flares, etc.)
    - Exposure driven by duration or duty cycle (days-weeks): 1 Msec/source
  - Combined: time-resolved spectroscopy (e.g., Fe fluorescent line)
    - Exposure driven by sensitivity/duration: ~ 1 Msec/field

5. Concluding remarks (2/2)

- *Problems that neither* Chandra *nor* XMM *can solve: the next generation (*Simbol-X, XEUS…*)*
  - Hard X-rays (100 keV): non-thermal phenomena (flare tails…)
  - X-rays from the youngest protostars ? (A_V ~ 500 - 1000 !) (Looking for the "birth cry of stars"…)
  - Very high spectral resolution ($E/\Delta E$ >1000…): mass motions (e.g., reverberation mapping of circumstellar disks, etc.)

- *In the mean time, no problem to use an additional 1 Msec/yr for 10 yrs !*