The power of Athena: X-ray spectroscopy of young accreting stars

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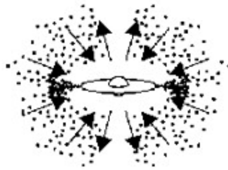
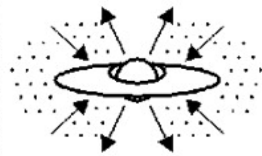
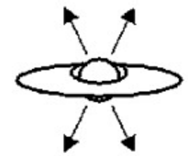
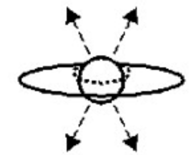
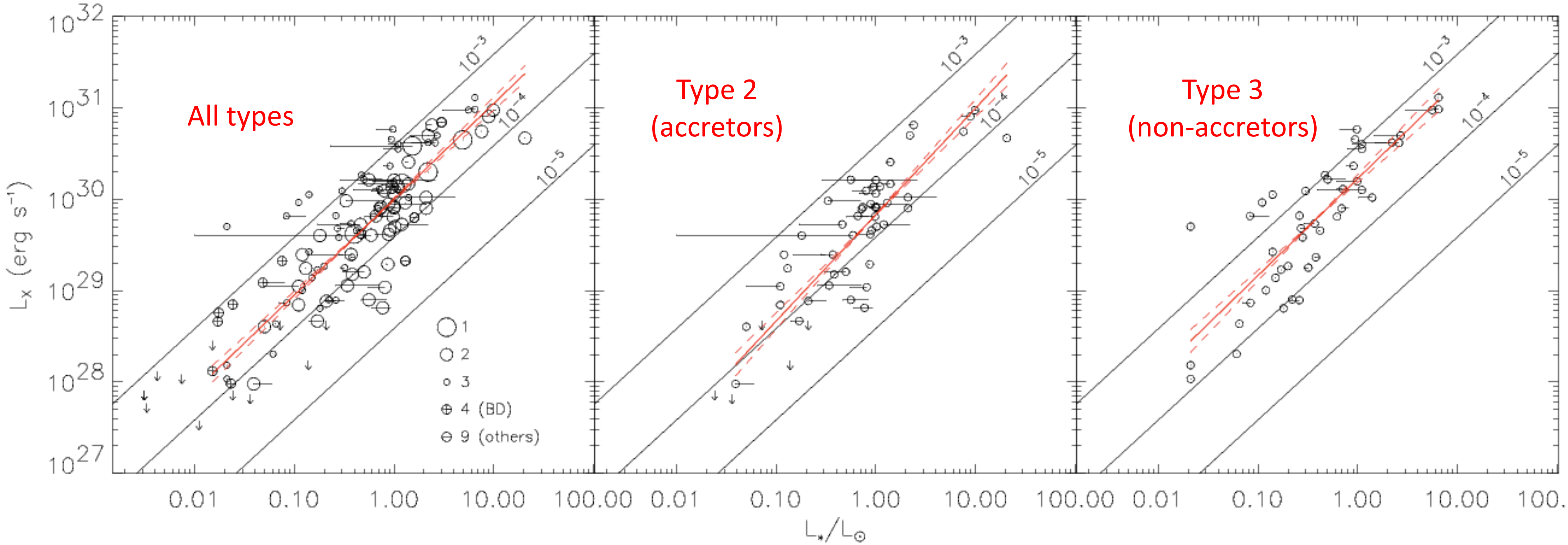
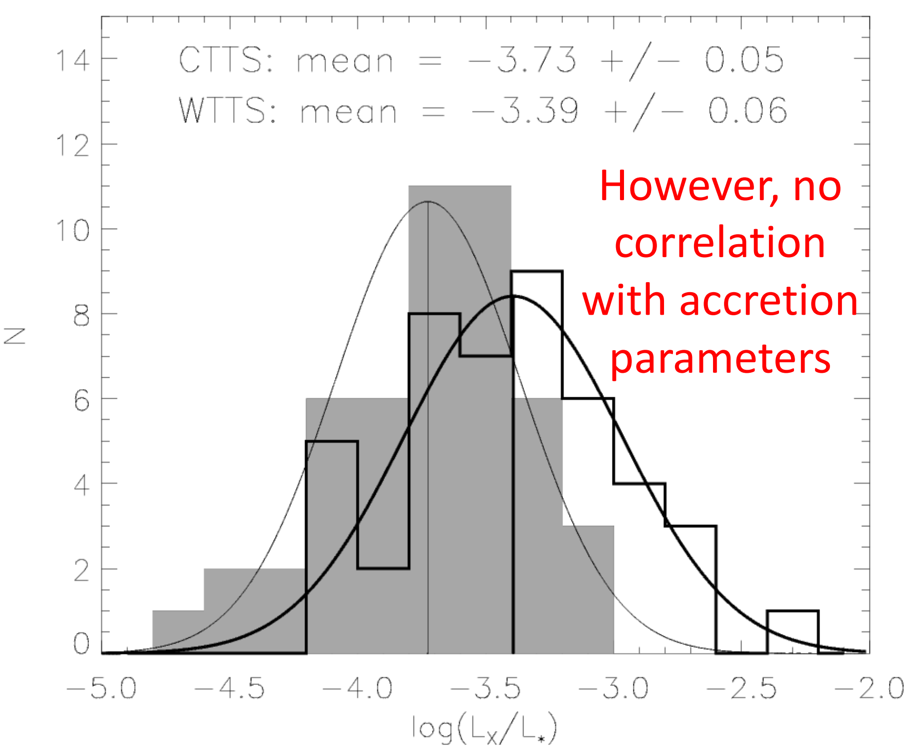
Properties	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
Sketch					
Age (years)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/Infrared Class	Class 0	Class I	Class II	Class III	(Class III)
Disk	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-ray	?	Yes	Strong	Strong	Weak
Thermal Radio	Yes	Yes	Yes	No	No
Non-Thermal Radio	No	Yes	No ?	Yes	Yes

Feigelson & Montmerle (1999)



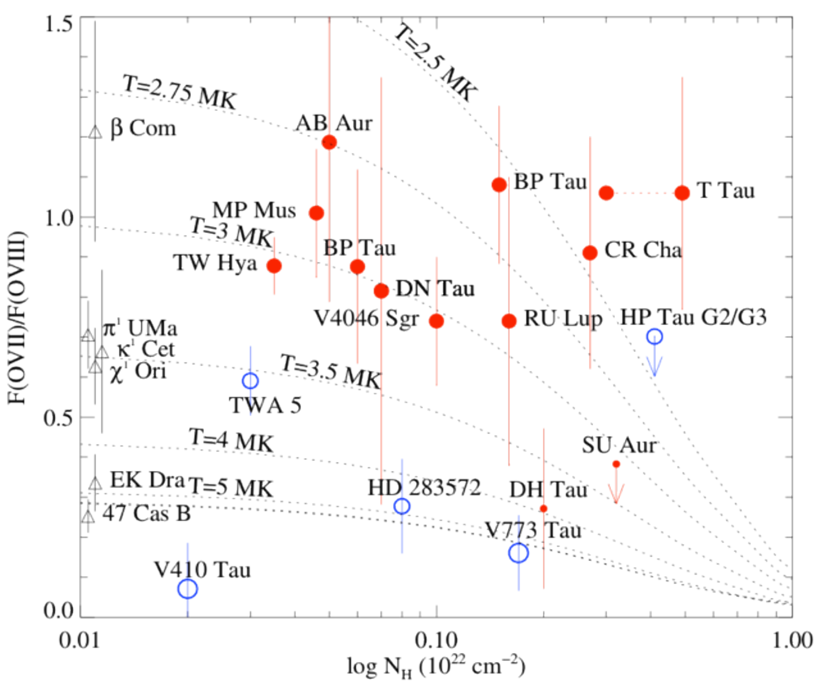


XEST; Telleschi et al. (2007a)

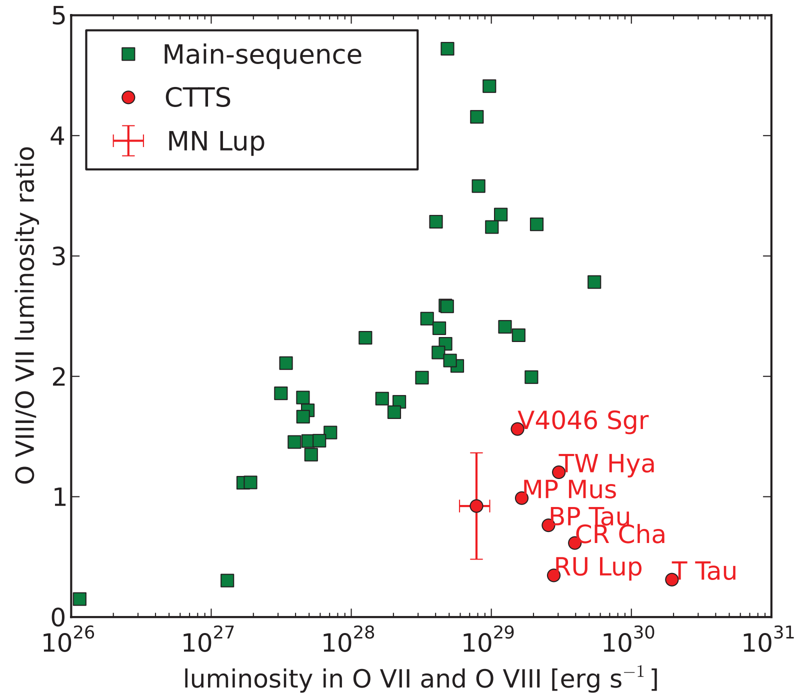
X-ray light curves of *accreting* young stars also do not generally show correlation with the UV light curves tracing accretion (e.g., Audard et al. 2007; Stassun et al. 2006)

Accreting stars more variable, with stronger signatures of rotational modulation in soft X-rays (Flaccomio et al. 2012)

- Accreting stars show a soft X-ray excess (T≈2.5-3 MK) in high-resolution X-ray spectra compared to non-accreting and ZAMS stars (Telleschi et al. 2007; Güdel & Telleschi 2007; Robrade & Schmitt 2007; Günther et al. 2007; Günther 2011)
- *Accretion* is the likely culprit, but in some cases could be due to magnetically confined *wind shocks* (e.g., AB Aur; Telleschi et al. 2007b), or even shocks in *jets* (e.g., RY Tau, DG Tau; Güdel et al. 2005, 2008; Skinner et al. 2011)

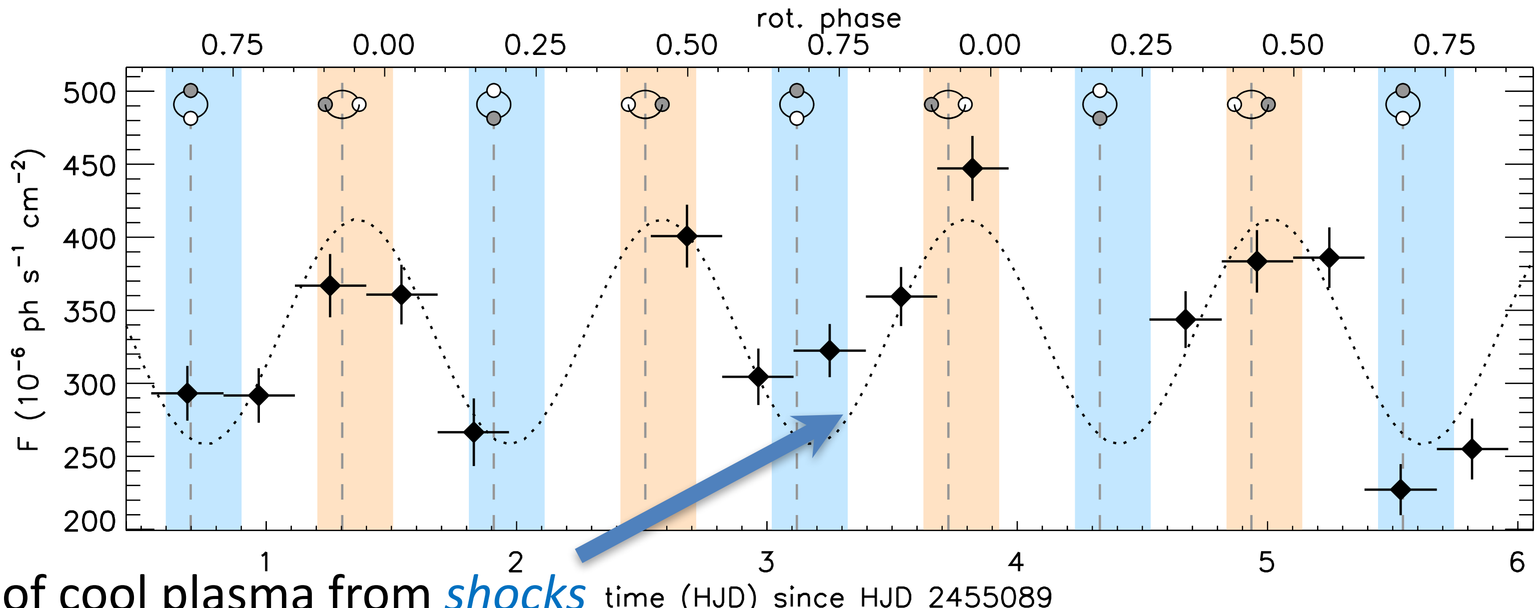


Güdel & Telleschi (2007)



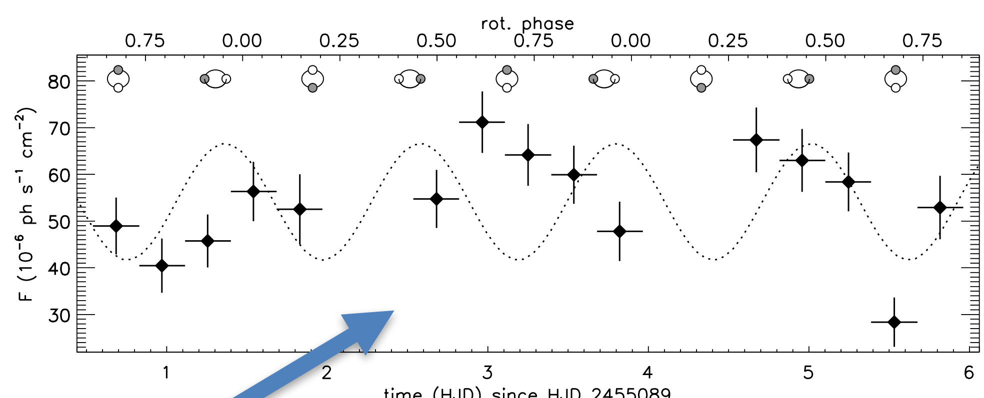
Günther et al. (2013); see also Robrade & Schmitt (2007)

Rotational modulation from accretion shocks



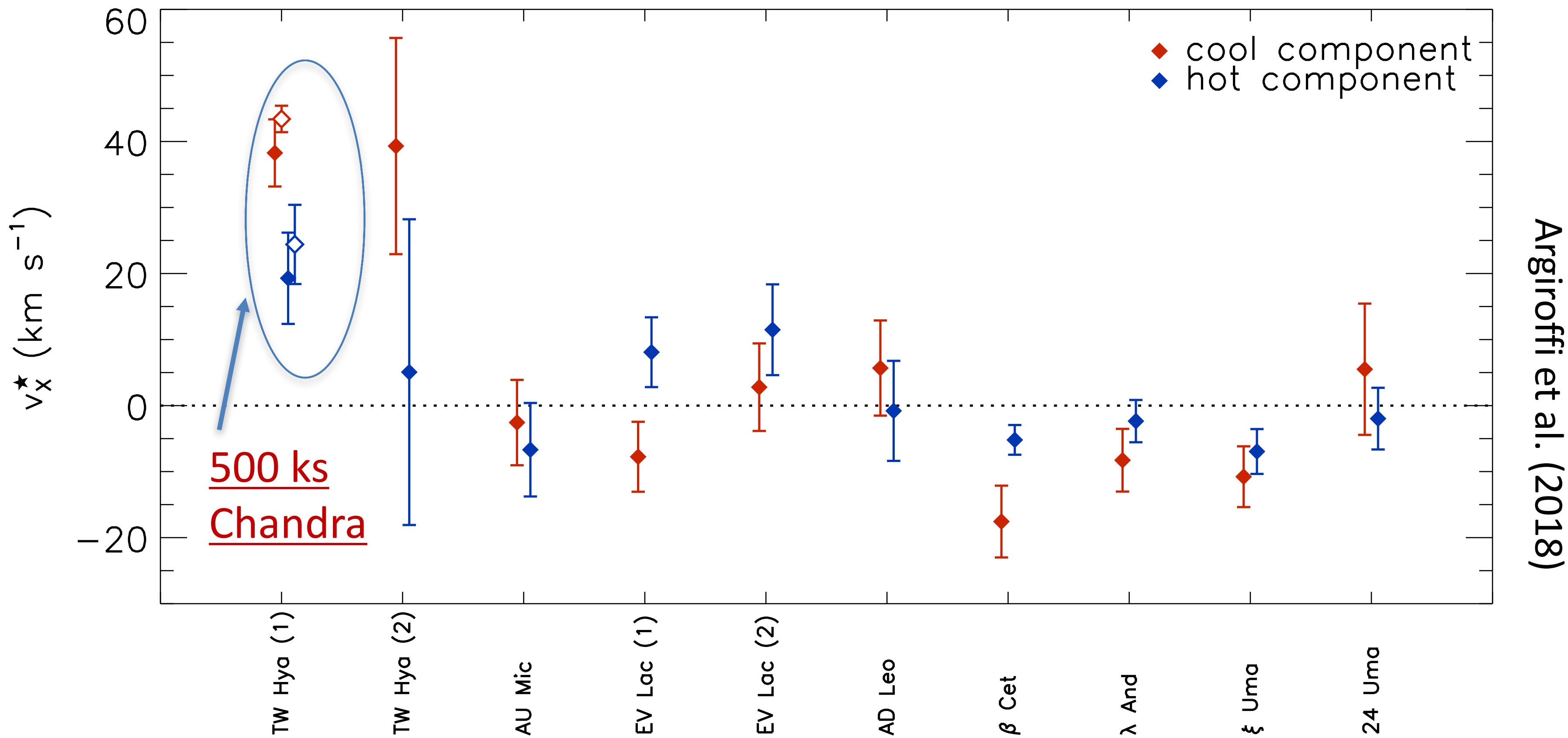
Lines of cool plasma from *shocks*

Athena will trace line shifts from the shock region



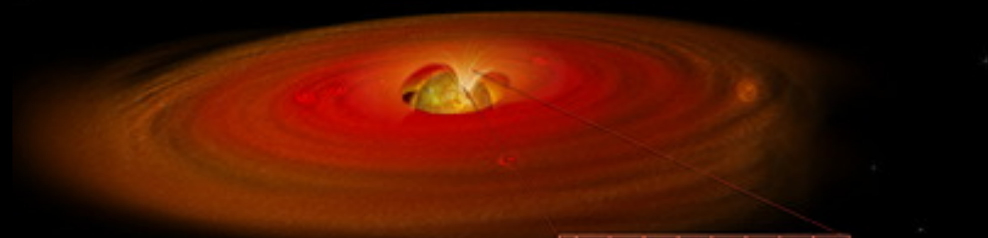
Lines of hot plasma from *corona*

Argiroffi et al. (2012)



Athena will detect easily line shifts

High densities

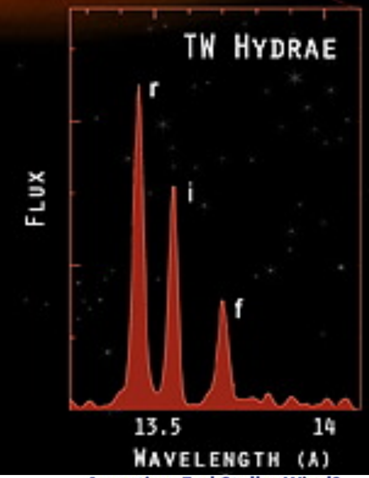


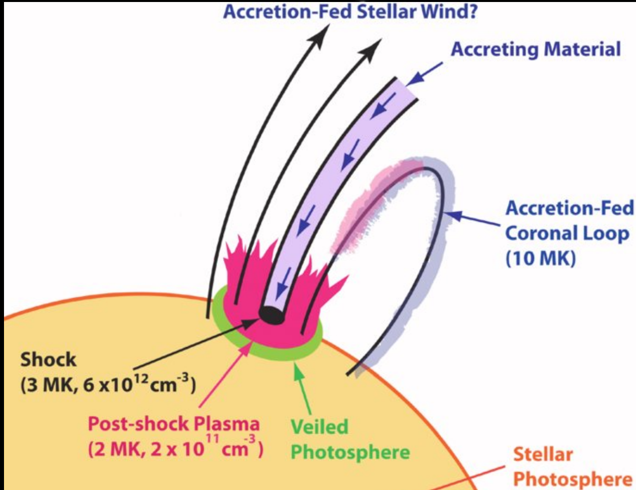
- **High i/f ratio in He-like triplets of TW Hya indicate n_e≈a few 10^{12} cm^{-3} (Kastner et al. 2002; Stelzer & Schmitt 2004; Raassen 2009; Brickhouse et al. 2010; 2012). Also Fe XVII (Ness & Schmitt 2005)**
- **Evidence of velocity offset of soft X-ray plasma coming from post-shock region (Argiroffi et al. 2018)**
- **Plasma T≈3 MK consistent with adiabatic shocks from gas in free fall (v_s≈150-300 km s^{-1})**

$$T_s = \frac{3\mu m_{\rm H} v_s^2}{16k}$$

- ***High densities in accreting young stars* (Schmitt et al. 2005; Robrade & Schmitt 2007; Günther et al. 2006, 2013; Argiroffi et al. 2007, 2012; Günther & Schmitt 2009, Huenemorder et al. 2012; Robrade et al. 2014, etc), *but not all* (Audard et al. 2005; Telleschi et al. 2007; Güdel et al. 2007; see Güdel & Nazé 2010 and refs therein)**

- ***Very limited sample, with poor signal-to-noise ratio in grating spectra***

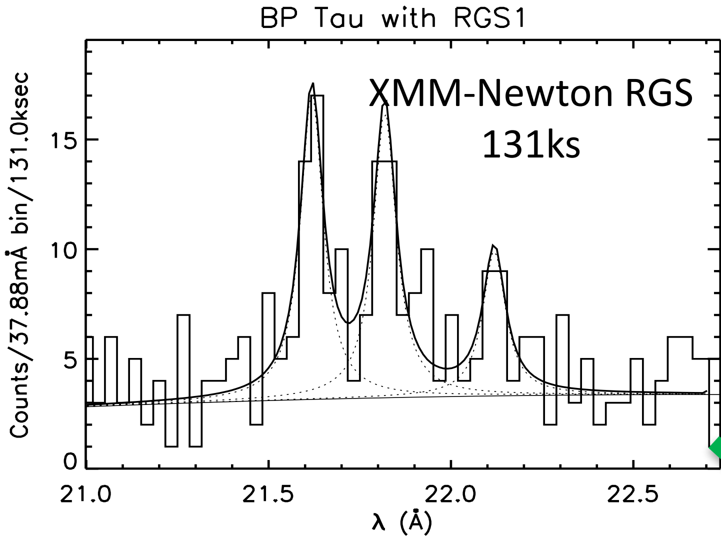


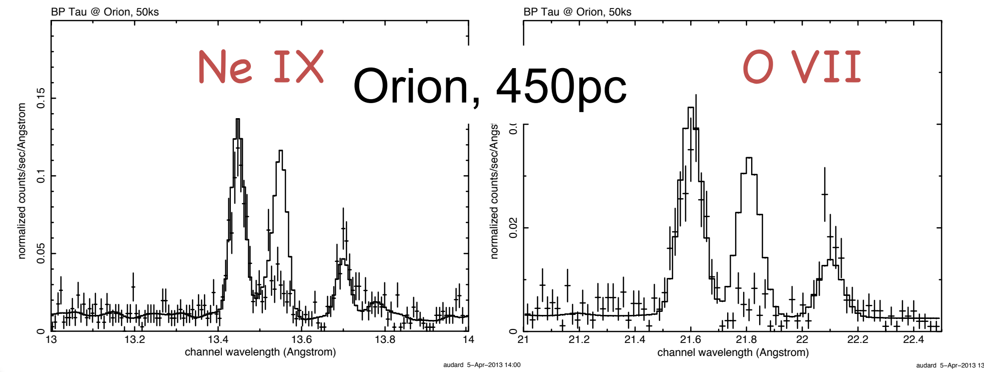


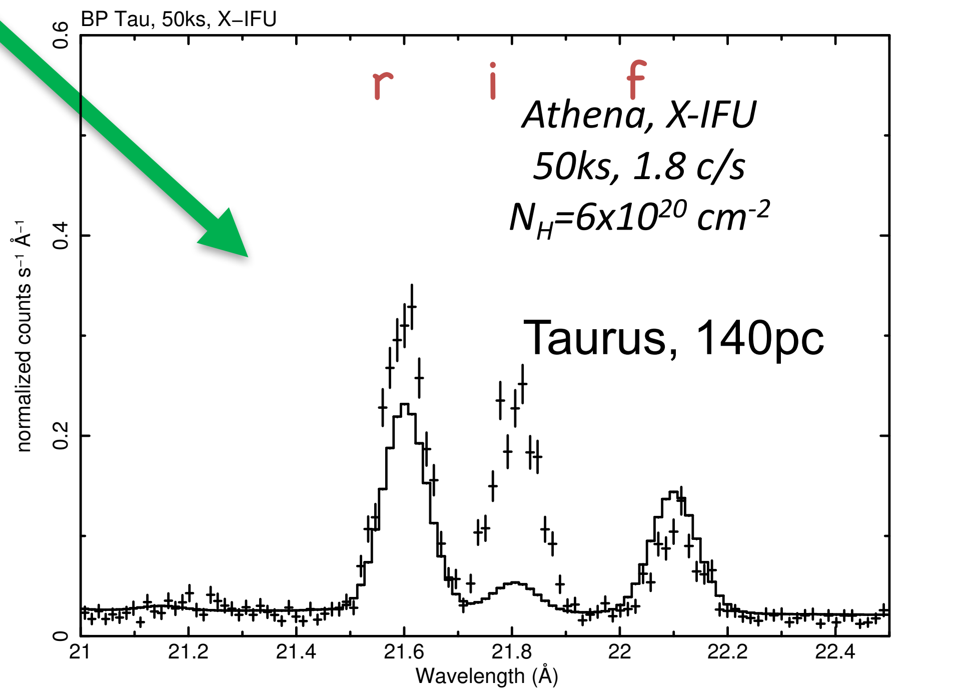
Brickhouse et al. (2010); see Argiroffi et al. (2018)

From present challenges to future observations

Schmitt et al. (2005)







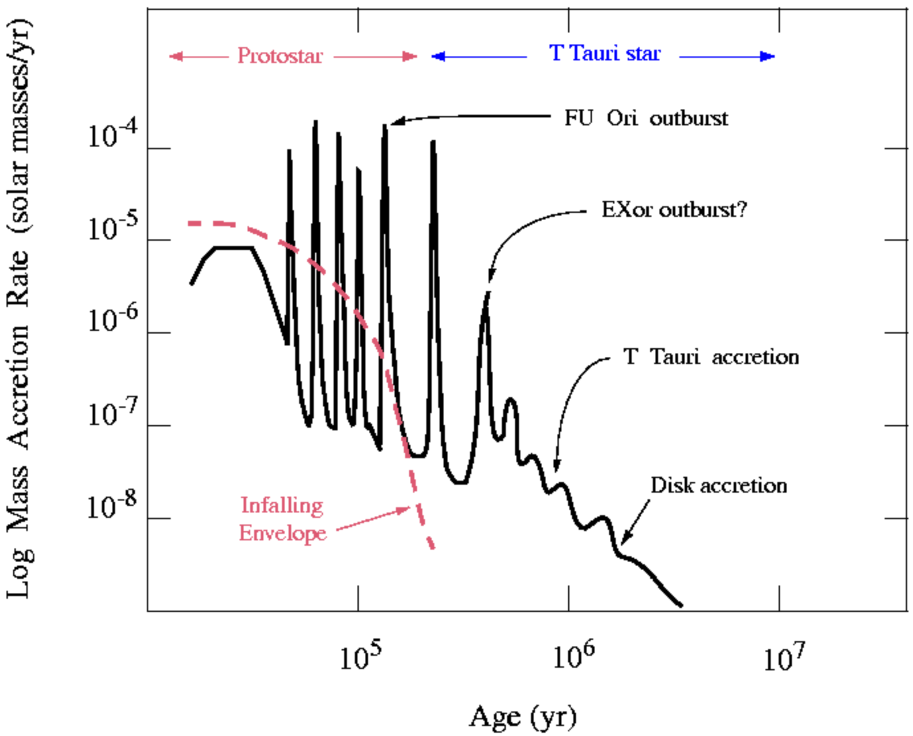
Athena IFU will routinely measure densities in accreting stars in nearby star forming regions (e.g., Taurus, Chamaeleon, Orion, etc)

Ne IX, Mg XI, and Si XIII triplets

→ range of critical densities

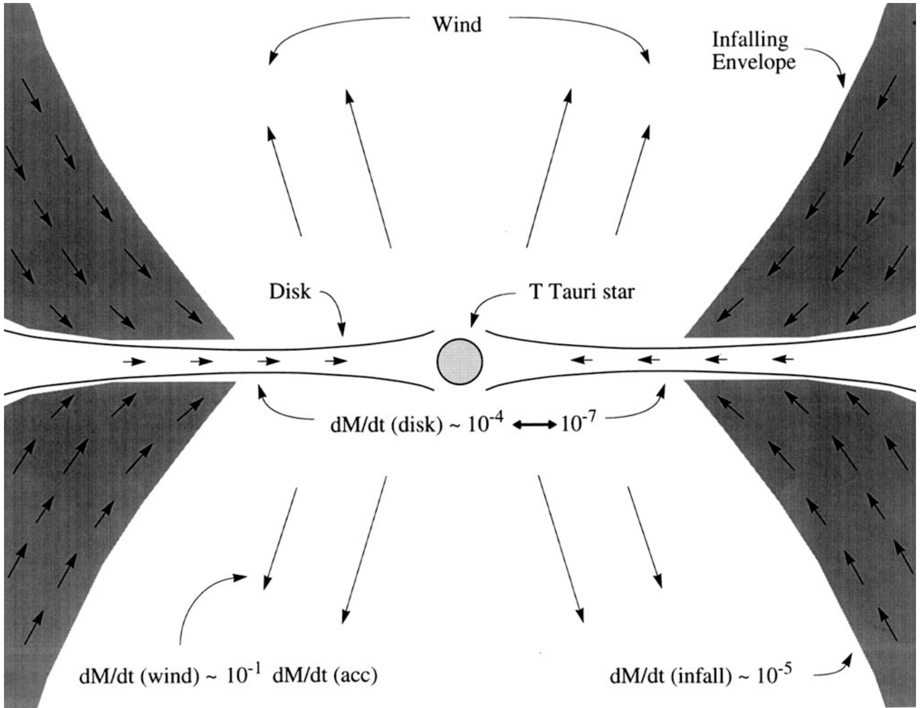
OVII will depend on column density (OK for $N_H<5\times10^{21}$ cm^{-2}, i.e., $A_V<3$ at 450pc).

Episodic accretion



Strong optical/infrared flux variations in young stars due to increases in mass accretion rates

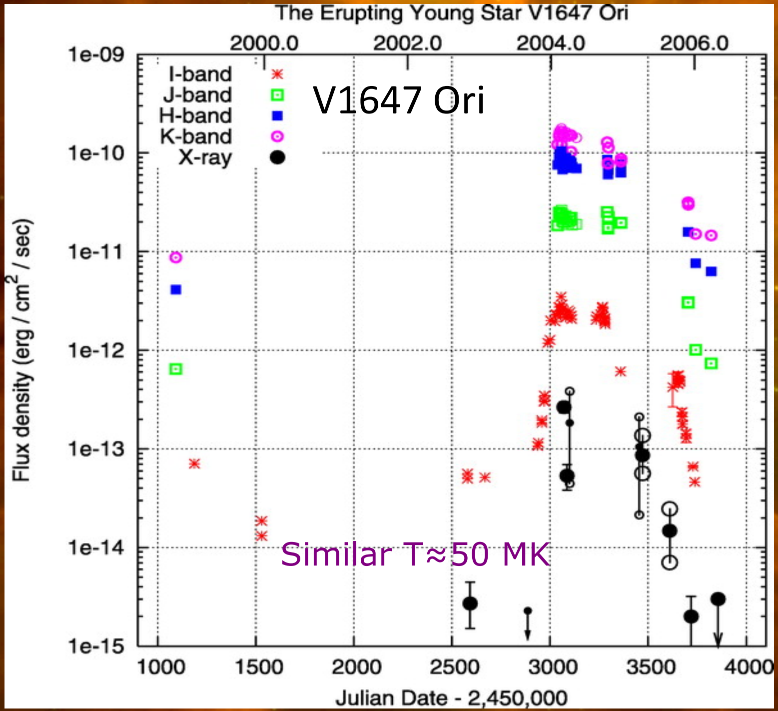
If accretion plays a role in producing X-rays, young stars undergoing episodic outbursts are ideal targets



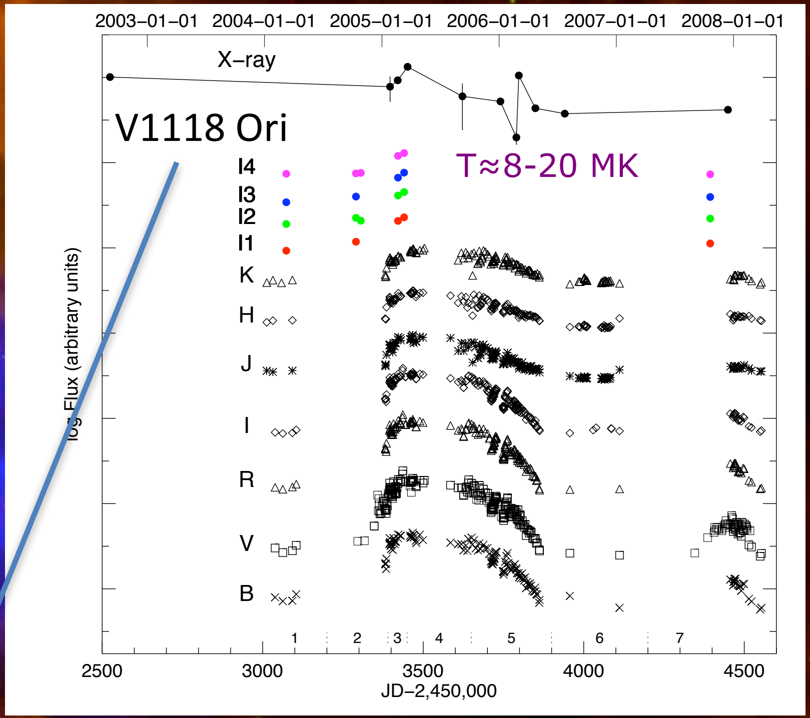
Mechanism for episodic accretion unclear (GI/MRI, interactions, etc)

See review Audard et al. (2014)

Impact on magnetosphere



Kastner et al. (2006)

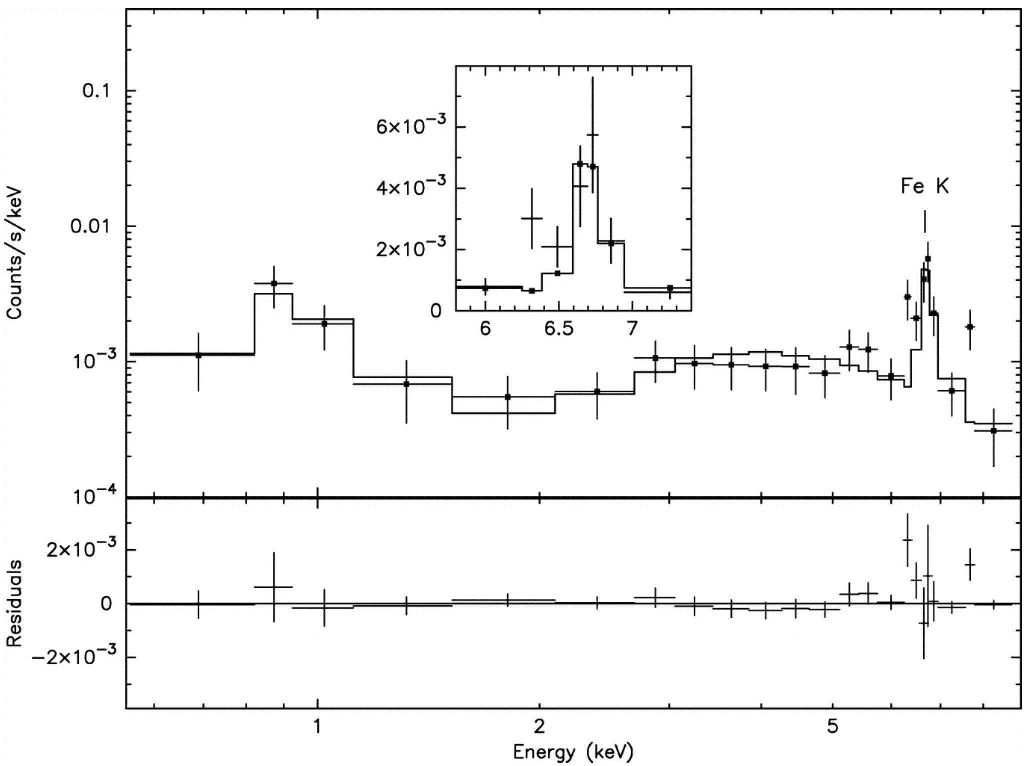


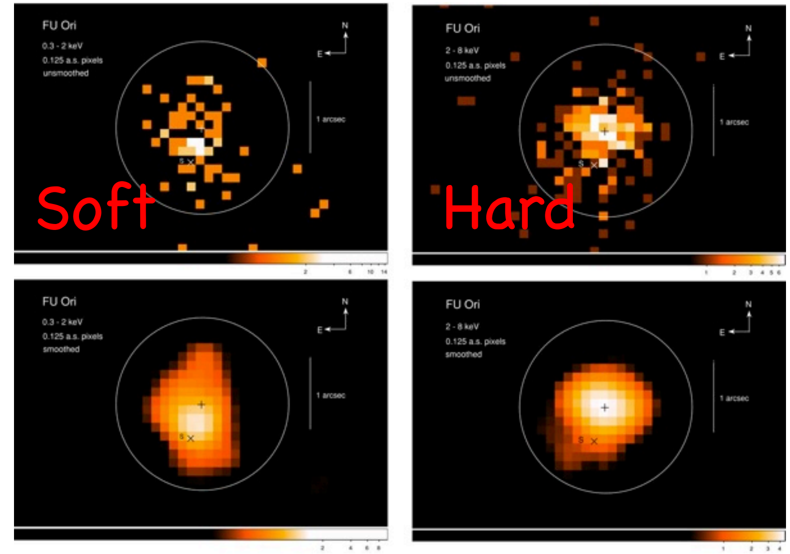
Audard et al. (2005, 2010)

Evidence of soft X-rays due to accretion, and a hot variable (smothered) coronal component; detection of cold (neutral) Fe K fluorescence → irradiation of disk → geometry **(Kastner et al. 2004; 2006; Grosso et al. 2005; 2010; Audard et al. 2005; 2010; Lorenzetti et al. 2006; Hamaguchi et al. 2010; 2012; Teets et al. 2012; Liebhart et al. 2014; etc)**

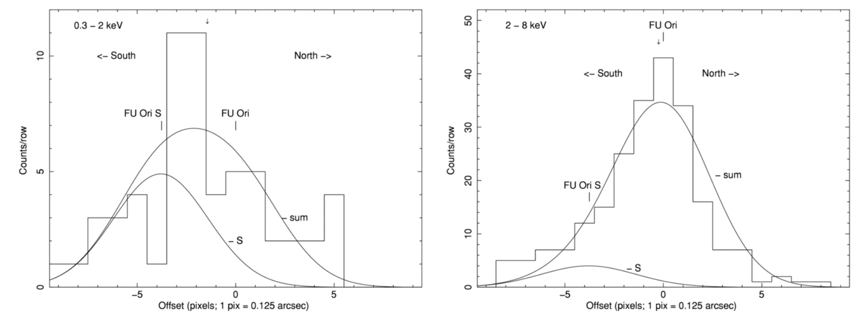
Episodic accretion modifies the magnetospheric configuration

Hot plasma in FU Ori objects





Skinner et al. (2010)



The prototype shows cool and hot (>5 keV) plasmas with *different* N_H: cool N_H consistent with A_V, 10x higher N_H ($\approx 10^{23}$ cm^{-2}) for hotter, variable, component, likely due to cold accreting gas or near-neutral wind. Strong Fe with possible Fe I at 6.4 keV.

Other FU Ori objects in Cygnus either undetected (V1057 Cyg/V1515 Cyg) or very bright, like FU Ori ($L_X \approx 10^{31}$ erg s^{-1}), again with a very high temperature component (Skinner et al. 2009)

Summary

- CCD and grating observations of accreting stars have revealed the *impact of accretion* on X-ray emission
- Accretion produces soft X-rays in which *high densities* were measured in line ratios, but sensitivity was poor or required long integration times
- X-ray monitoring during episodic accretion point toward interactions with magnetosphere → accretion-induced soft X-rays, with hot coronal component absorbed by cold accreting gas (or disk wind)
- *Time variability* will be at reach to study mass accretion rates during the outburst, providing an independent means from optical/IR
- Athena offers the required *sensitivity* and *spectral resolution* to boost the study of accretion in young stars and its effect in X-rays
- Not presented here: X-rays from jets, illumination of disk by X-rays → geometry!, rotation via Fe K line, young brown dwarfs in star forming regions with WFI, abundance depletion, etc…