X-rays from classical T Tauri stars
Accretion and wind signatures

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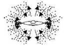
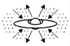
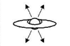
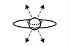
Overview

Evolution of young low-mass stars

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

(from Carkner et al. 1998)

CTTS vs. WTTS

- Hα EW ($> 10\,$Å)
  - Accretion/Activity

  $\rightarrow$ usually variable
- IR Class
  - Circumstellar material

$\Rightarrow$ CTTS are actively accreting matter from a circumstellar disk

$\rightarrow$ Influence on disk evolution and planet formation

Classical T Tauri stars in X-rays

X-ray production

- Magnetic activity (hot plasma, flares)
  $\Rightarrow$ coronae, star-disk interaction $\rightarrow$ fluorescence (Fe Kα)
- Accretion shocks (cool plasma, high density)
  $\Rightarrow$ magnetically funneled e.g. TW Hya (Kastner et al. 2002)
- Confined winds/jets e.g. DG Tau (Guedel et al. 2008)

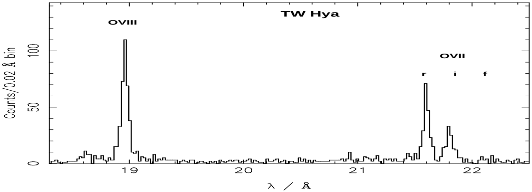
X-ray absorption

- Interstellar + circumstellar material

$\Rightarrow$ Requires high-resolution spectroscopy

Parameter space: viewing angle, mass, age, accretion/outflow rate, magnetic funneling, field geometry...

X-ray diagnostics with emission lines



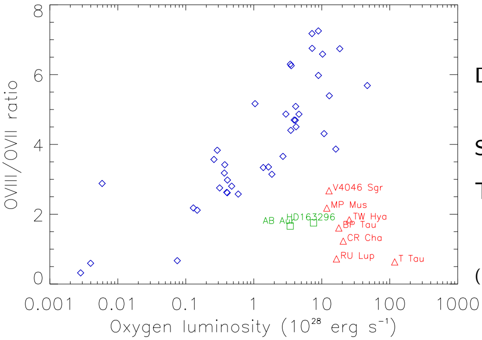
Example: He-like and H-like lines of oxygen

- strong lines, free of blends, but: absorption can be significant
- traces cool plasma regime (2 – 6 MK)
- OVII-triplet (21.6 – 22.1Å): $T_{max} = 2$ MK
  - f/i-ratio sensitive to density (and UV-field)
- OVIII Lyα (18.97Å): $T_{max} = 3.2$ MK

High resolution X-ray spectra of CTTS

CTTS	Mission	Reference
BP Tau	XMM	Schmitt et al. (2005)
CR Cha	XMM	Robrade & Schmitt (2006)
MP Mus	XMM	Argiroffi et al. (2007)
RU Lup	XMM	Robrade & Schmitt (2007)
T Tau	XMM	Guedel et al. (2007)
TW Hya	Chandra	Kastner et al. (2002)
"	XMM	Stelzer & Schmitt (2004)
V 4046 Sgr	Chandra	Guenther et al. (2006)

X-ray temperature diagnostics: OVIII/OVII-ratio



Diamonds: Main-sequence stars

(from Ness et al. 2004)

Squares: Herbig AeBe stars

Triangles: Classical T Tauri stars

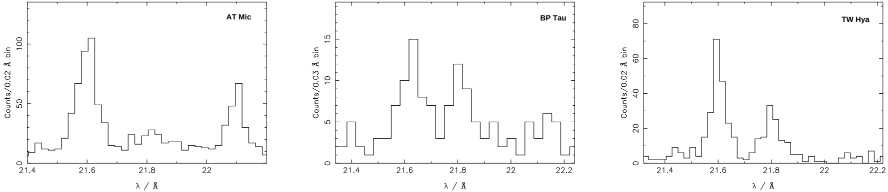
(Robrade & Schmitt 2007)

Low OVII ratio (comp. to coronal sources) in **all** accreting stars

OVII significantly enhanced/OVIII marginally enhanced or 'coronal'

⇒ Excess of cool X-ray emitting plasma

X-ray density diagnostics: OVII f/i-ratio

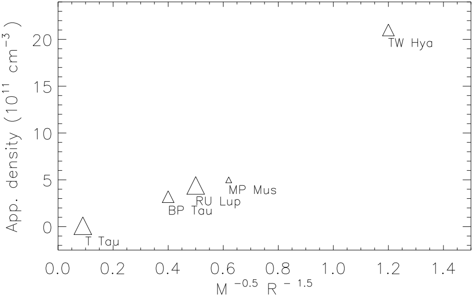


active coronal source	'typical' CTTS	'accretional' CTTS
f/i = 2.2	f/i = 0.34	f/i = 0.054

High plasma densities in **all** low mass (0.5 − 2.0 $M_{\odot}$) CTTS

X-ray emission from accretion shocks and corona
→ f/i-ratio changes during flares (e.g. BP Tau)

A common picture?



Size of symbols:

excess of cool X-ray plasma

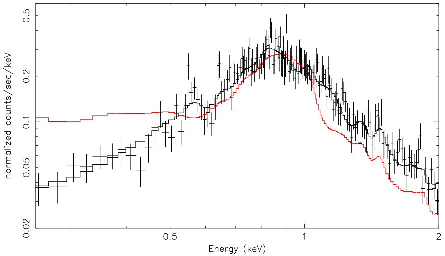
Density depends on stellar mass and radius

Adopting formulae from Calvet & Gulbring , 1998 and 'free-fall' accretion:

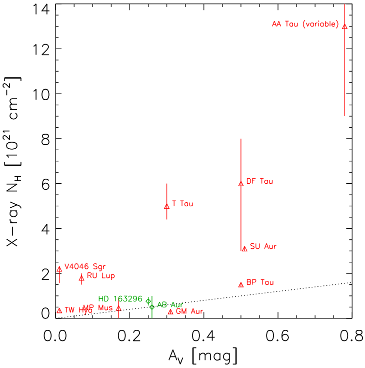
- Accr. density : $n \sim \dot{M} \times f^{-1} \times (M^{-1/2} R^{-3/2})$
- Accr. temp.: $T_{Shock} \sim V^2 \sim M/R$
- Accr. Lum.: $L_{Acc} \sim \dot{M} \times M/R$

Caution: Poor statistics

Exceptional X-ray absorption



The nearly pole-on CTTS RU Lup with absorption seen in the UV (red) vs. X-ray (black); TW Hya similar



(Guenther & Schmitt 2008)

'Extra' absorption in **several** CTTS: optically transparent medium

$\Rightarrow$ wind from star/disk and/or accretion flow

Summary

- CTTS exhibit a large variety of X-ray phenomena
- Magnetic activity dominantes hard X-ray emission
- Accretion contributes the the soft X-ray emission
- Excess of cool plasma in all CTTS
- High densities in **all** low mass ($\lesssim$ 2.0 $M_\odot$) CTTS
- Outflows affect X-ray emission