# An X-ray Outburst from the Accreting Protostar that Illuminates McNeil's Nebula*


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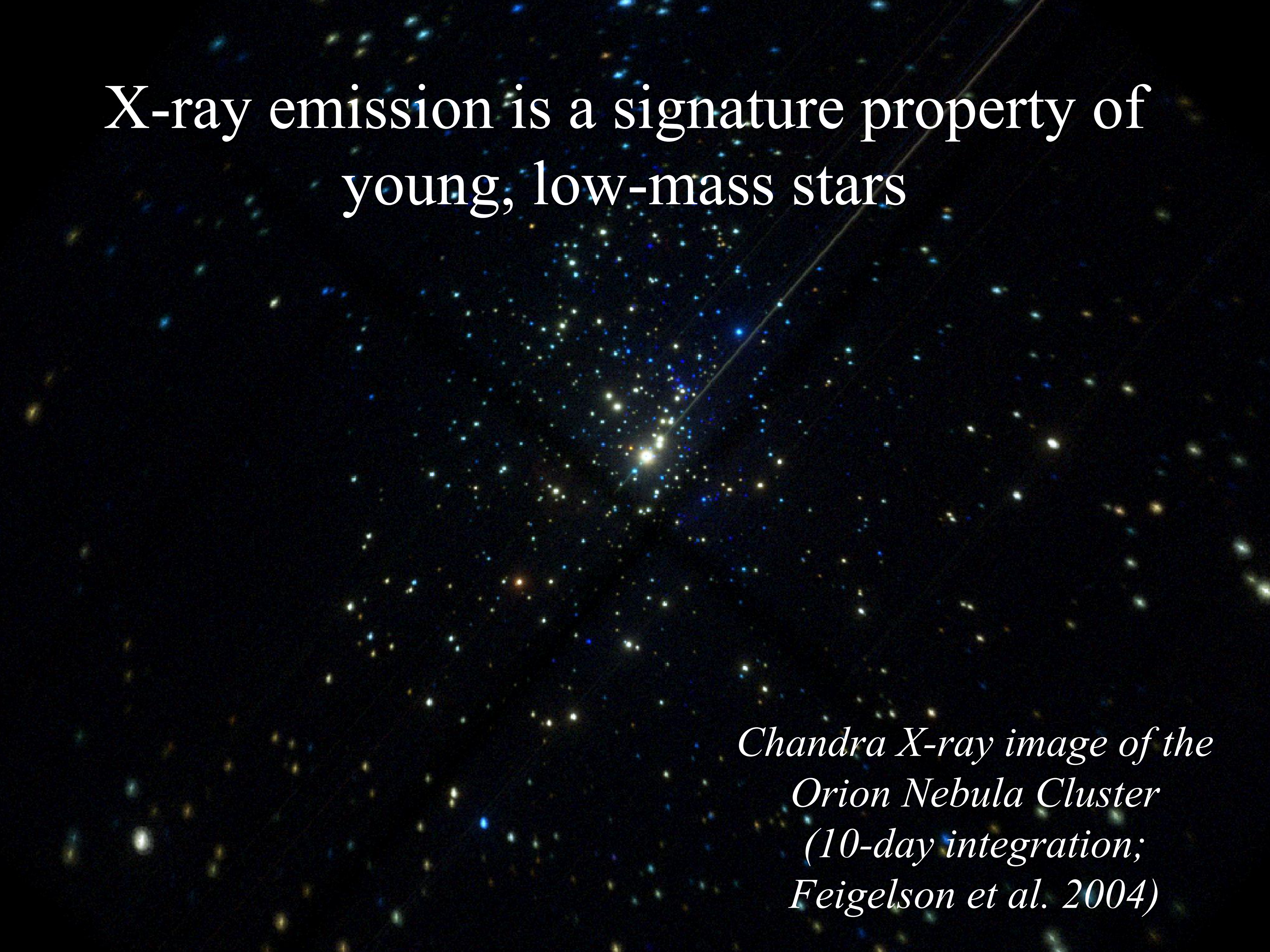
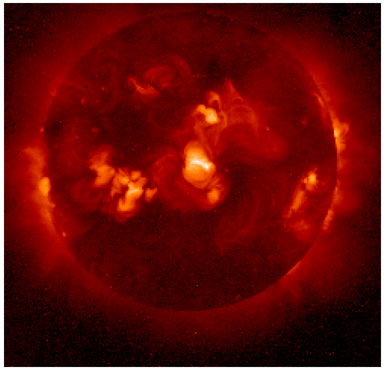
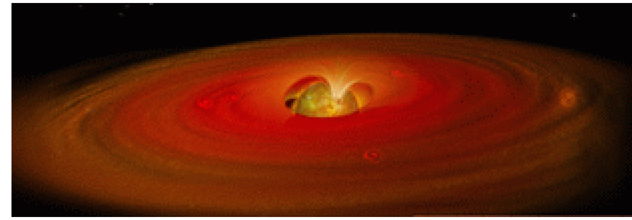



*Chandra X-ray image of the Orion Nebula Cluster (10-day integration; Feigelson et al. 2004)*





**BUT:**
**Is T Tauri X-ray emission diagnostic of coronae, star-disk interactions, or both?**

- Evidence for & against coronal origin for X-rays
  - *for:* flaring, trend of $\log(L_X/L_*)$ with age, $T_X$
  - *against:* lack of trend of $\log(L_X/L_*)$ with rot. period (but see Stassun et al. 2004, June AJ)
- What about star-disk interactions?
  - X-ray emission predicted theoretically, in magnetospheric accretion model; flaring likely
    - e.g., Shu et al. (1997)
    - strong X-ray flaring observed from very youngest protostars

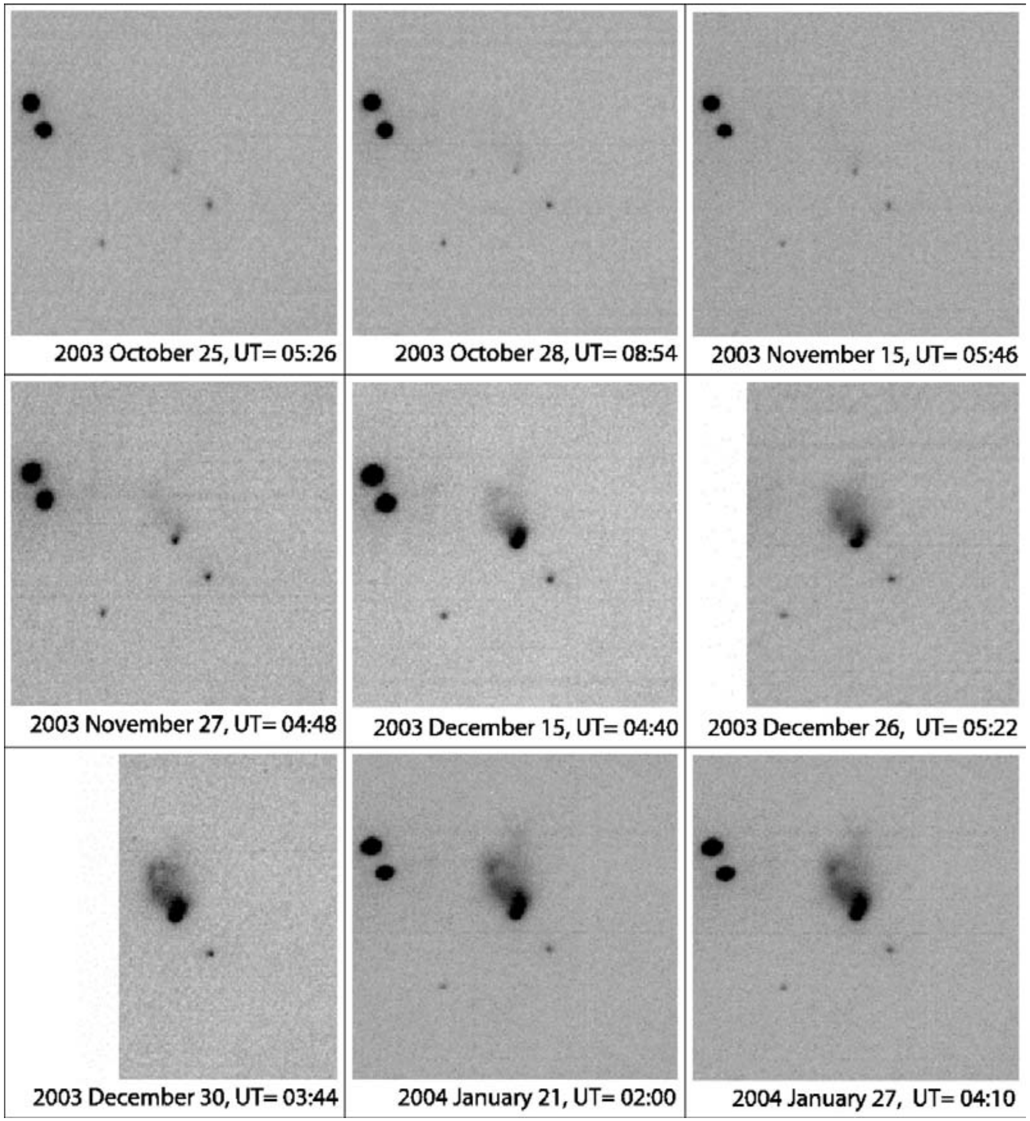
=> perhaps X-rays can probe evolution of disk-related processes (e.g., accretion)

# Enter McNeil’s Nebulous Object...

- Discovered Jan. ‘04 by amateur J. McNeil
  - in NGC 2068 (M78); L1630 dark cloud
- Outburst onset traced to Oct-Nov ‘03
  - increase of ~3 mags (K) to ~5 mags (I) in 1-2 months
  - has since remained in high state (though variable), w/ perhaps very slight decline
- MNO as FU Ori star…or is it an EX Lup type pre-MS star?
  - Either way it’s young, low-mass, & rapidly accreting

# Enter McNeil's Nebulous Object...

(Briceno et al. 2004)




Gemini image, post-outburst (Feb '04) (Aspin & Reipurth, unpublished)

# Aside: FU Ori and EX Lup stars

- FUors:
  - Characterized by sudden, spectacular (3-5 mag), prolonged (>10 yr) optical/IR outbursts
  - 3 “prototypes” and ~10 other FUor candidates
    - candidates show disk signatures, massive envelopes
- EXors (ugh...*):
  - More chaotic variability than FUors, w/ smaller, more frequent brightness excursions
  - half a dozen candidates(?)

*Don’t blame me, blame Herbig for “EXor” (but give Herbig a lot of credit, too!)

# FU Ori: light curve

Herbig (1977, ApJ 217, 693)

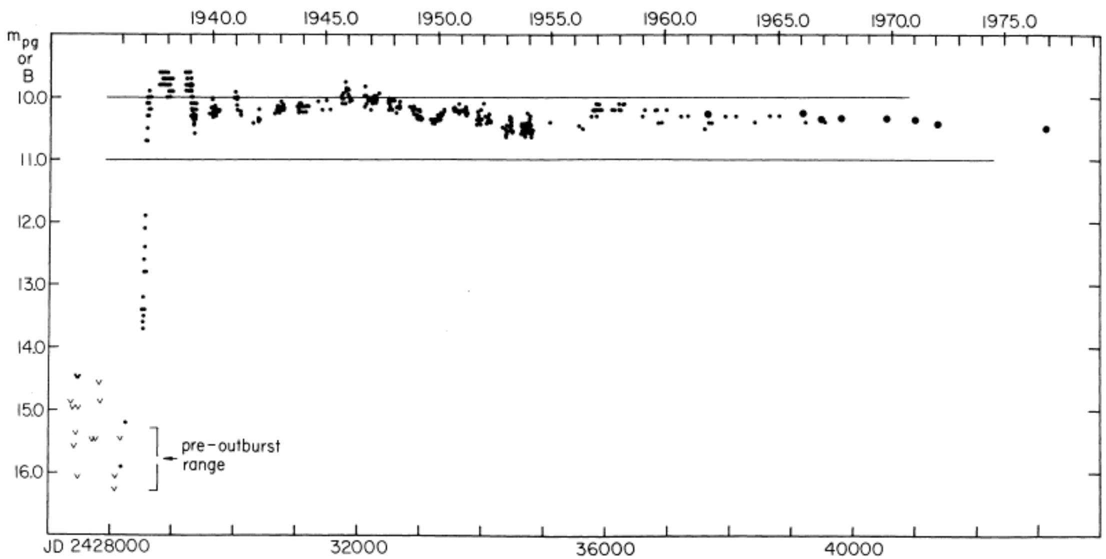
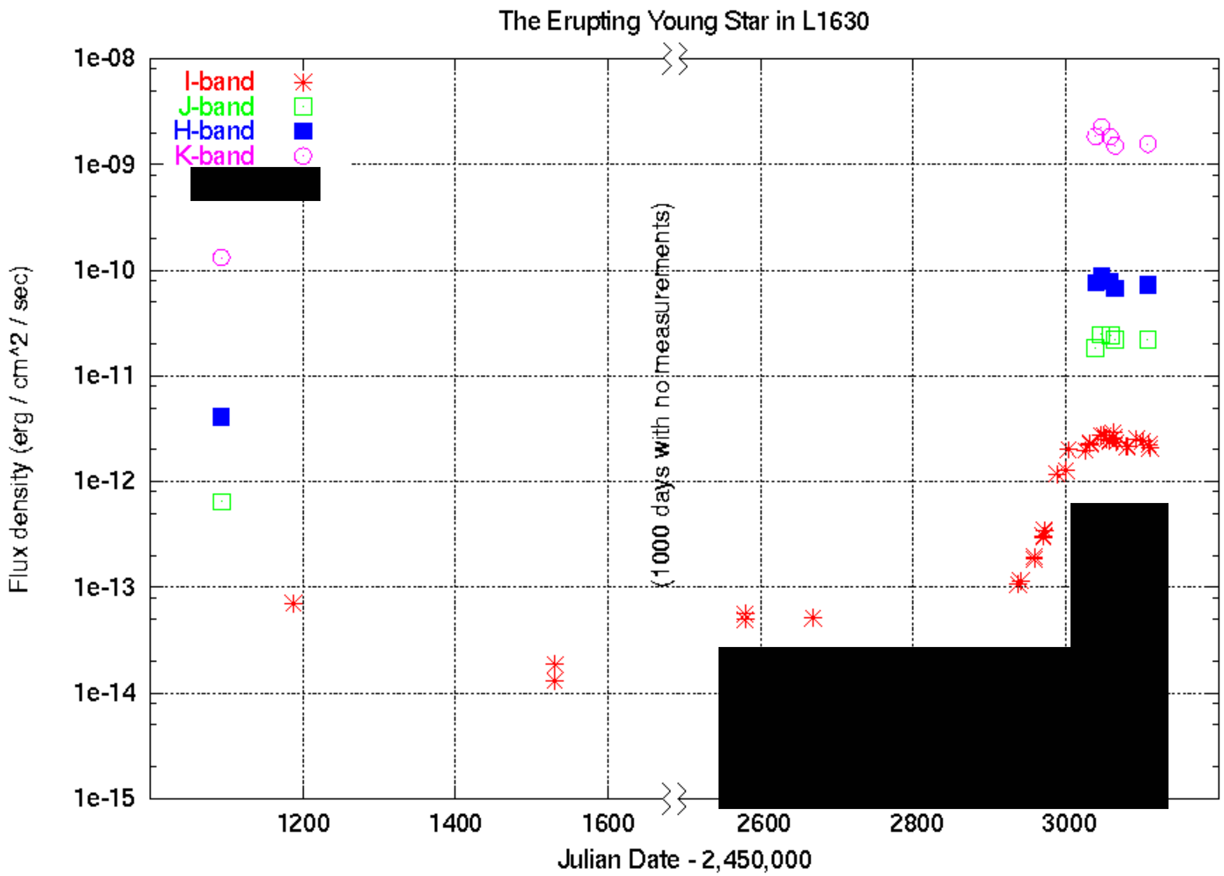


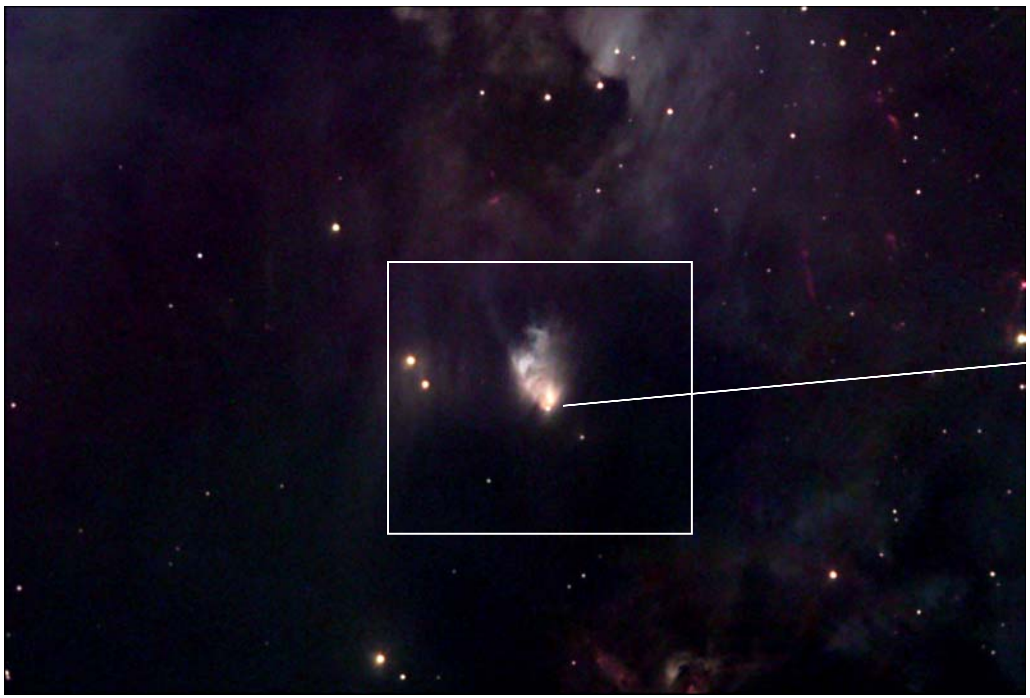

FIG. 1.—The photographic/*B* light curve of FU Ori through 1976. Small points represent photographic observations by Hoffleit (1939), Wachmann (1954), and Weber (1956, 1961, 1964, 1967). The larger points are photoelectric measures of *B* by Smak (Herbig 1966), Mendoza (1968), Dibai and Zaitseva (1968), Lee (1970), Lee and Low as quoted by Rieke *et al.* (1972), Landolt (1972), Schweitzer (1975, private communication), and Stone (unpublished).

- "Standard model" (see, e.g., Hartmann & Kenyon's 1996 ARAA paper): sudden accretion rate increase from $10^{-7}$ $M_{sun}$/yr to > $10^{-4}$ $M_{sun}$/yr --- star gains 0.01 $M_{sun}$ during FUor outburst!

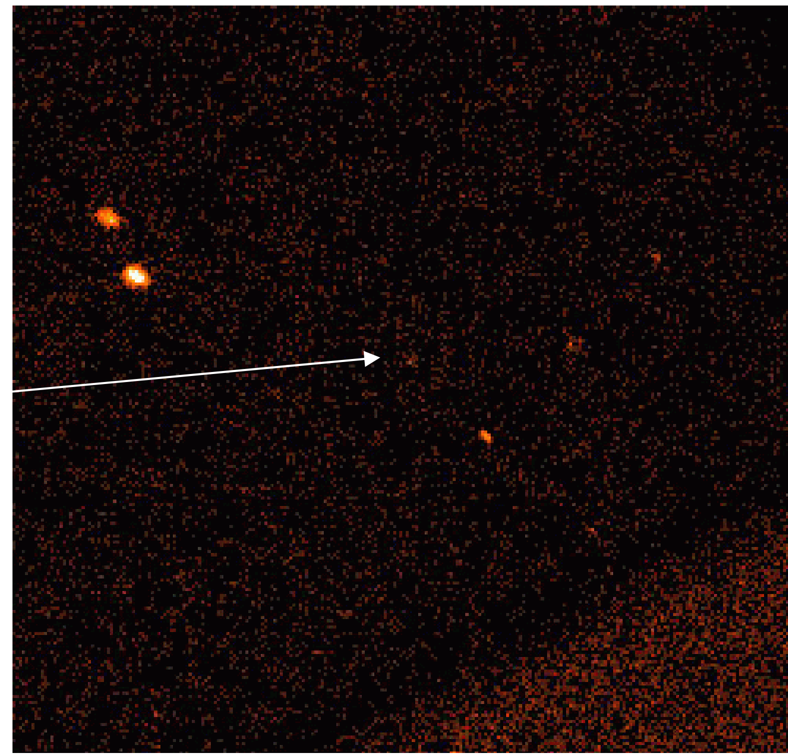
# The FUor-like outburst of MNO



# Serendipitous, *pre-outburst* detection* of X-rays from the optical/IR/submm source at the "heart" of MNO



Optical image

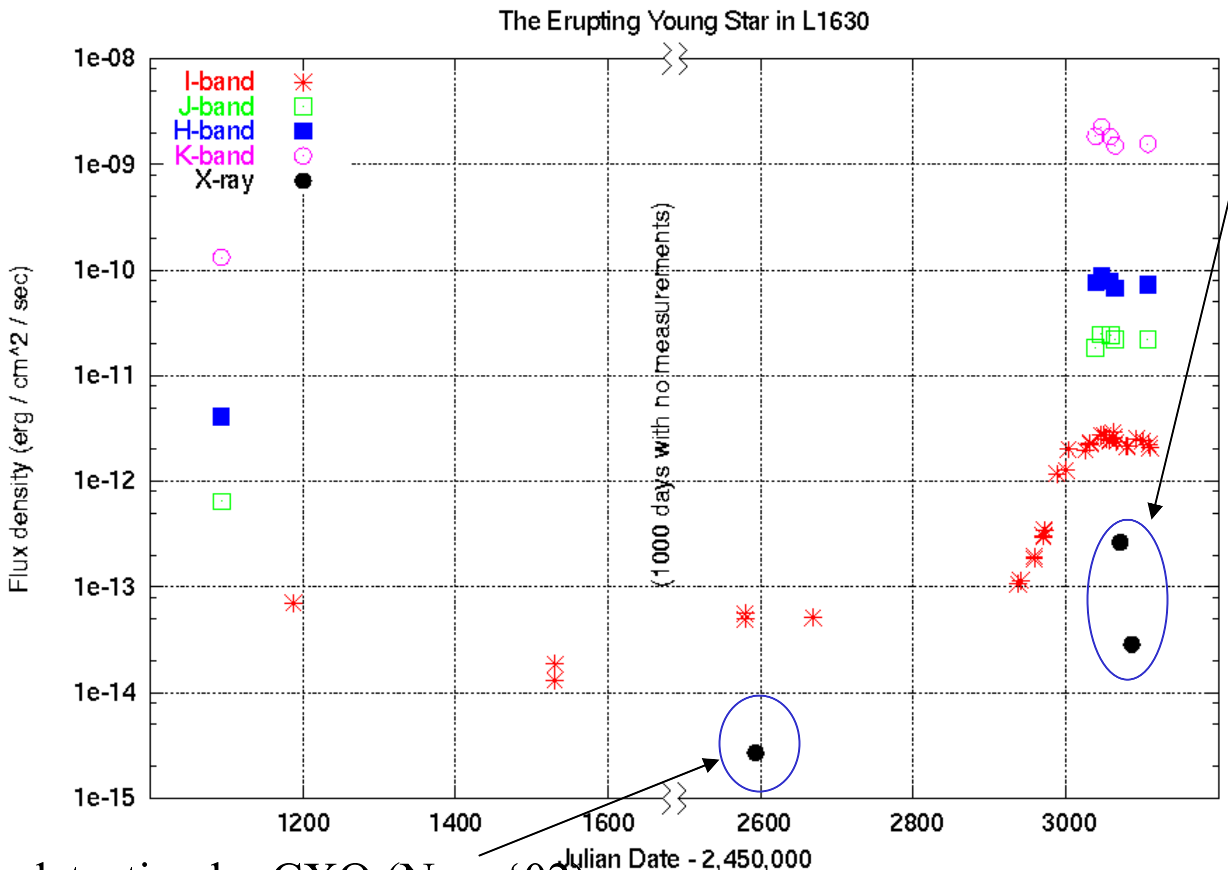


CXO X-ray image

*during Nov. '02 Chandra imaging of L1630 (Simon et al. 2003)

# Post-outburst:
# catching a contemporaneous X-ray eruption via Chandra DDT "quick looks"

CXO DDT observations
(March '04)




Serendipitous detection by CXO (Nov. '02)

# MNO in outburst: a (relatively) hard X-ray source

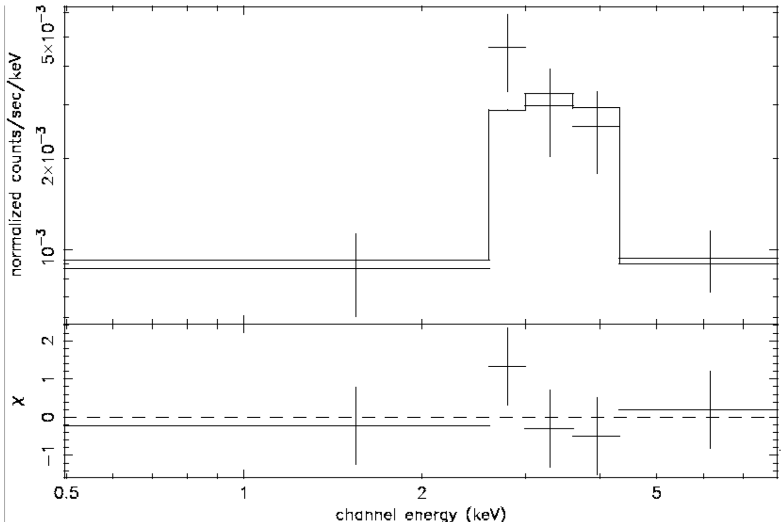
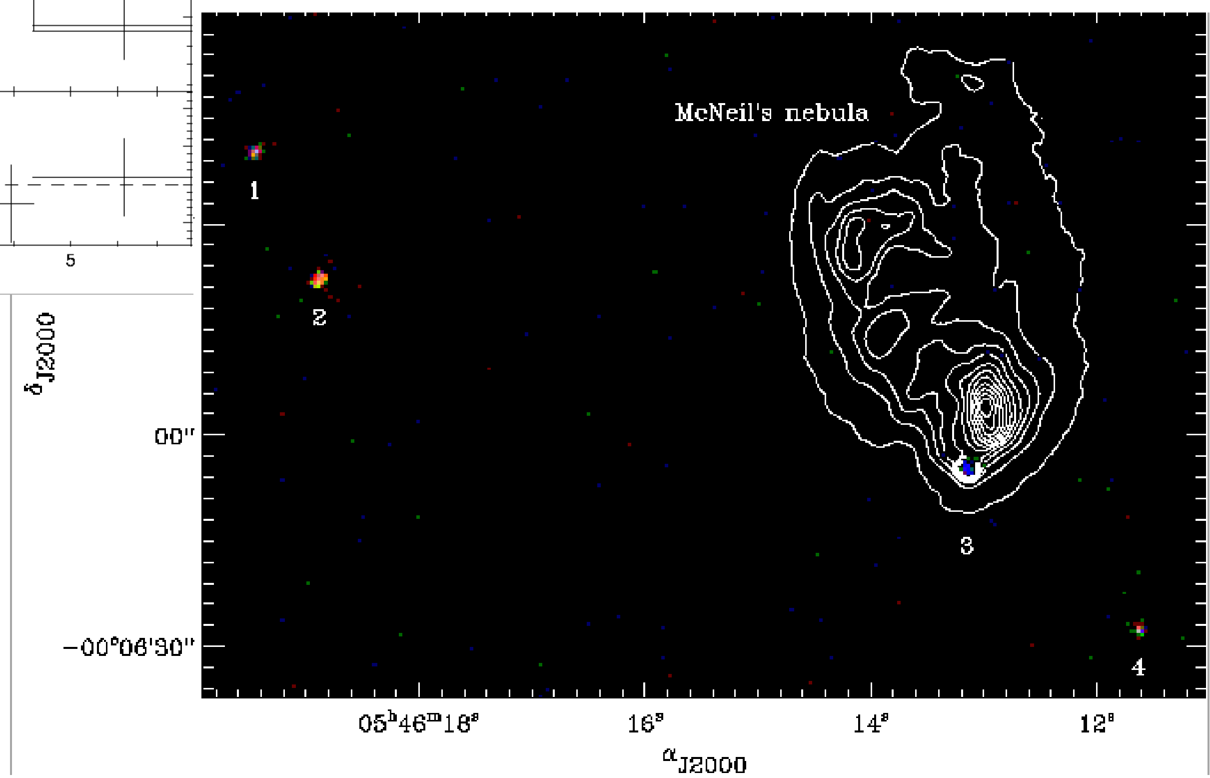



*Image and spectrum from March 7 CXO DDT data*




Model (watch out... only ~50 photons!):

- $N_H \sim 6\text{x}10^{22}$ cm$^{-2}$
- $T_X \sim 6\text{x}10^{7}$ K

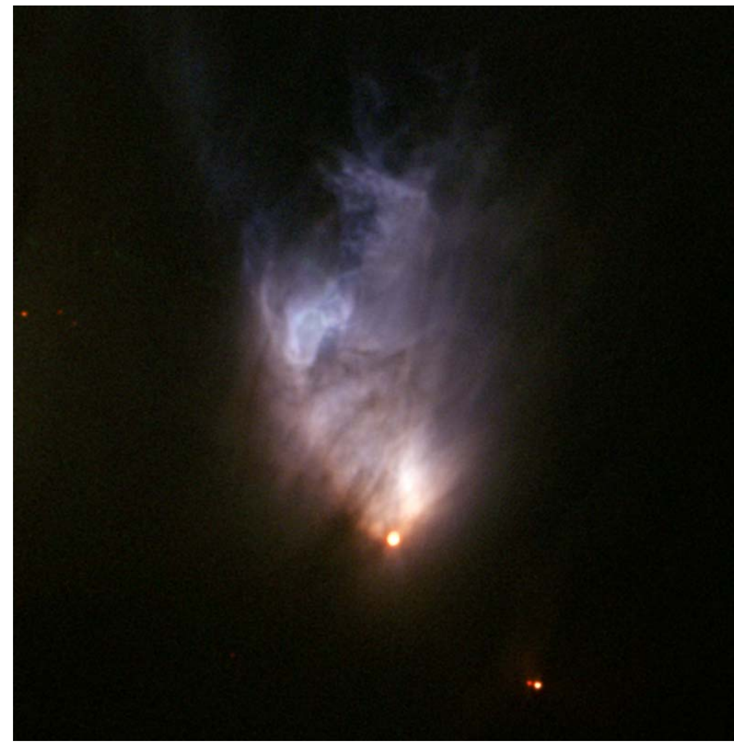
# What does MNO tell us about the nature of X-rays from pre-MS stars?

- *In at least SOME cases, X-rays can be generated via pre-MS accretion processes*
  - But $T_x$ of MNO source too high to be explained by accretion shocks... => X-rays from magnetospheric reconnection events, probably intimately related to (responsible for?) “fresh” outflow activity
    - MNO source lies at end of HH 23 knot chain
- In that case, why aren’t all FUors bright X-ray sources*?
  - Perhaps FUor accretion “flood” eventually “quenches” magnetospheric reconnection processes

*only 2 known X-ray sources (e.g., L1551 IRS5); both are weak

# Next steps: continued X-ray monitoring of MNO (we hope…)

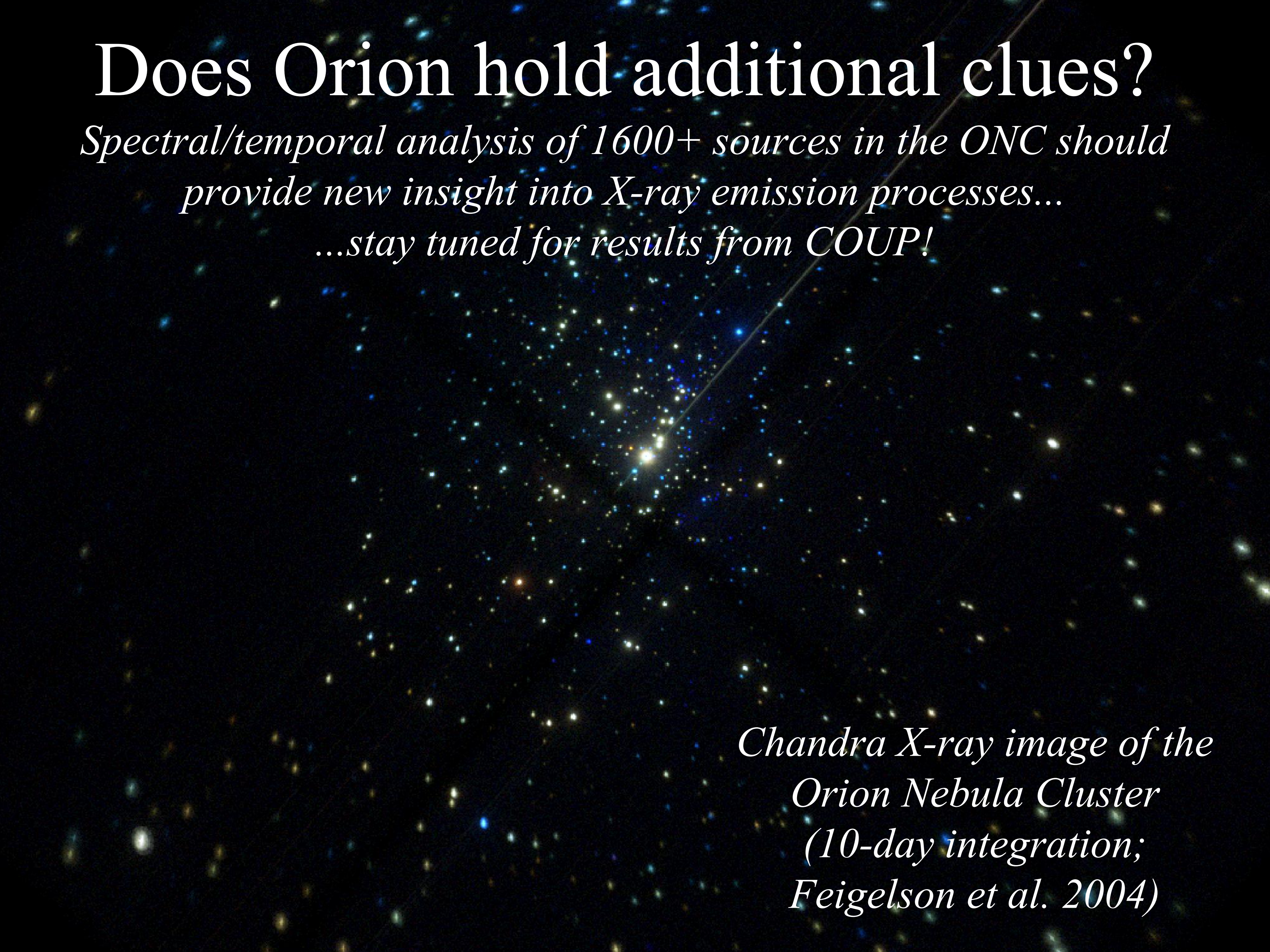
- XMM: 40 ks DDT observation obtained
  - April ‘04: source remains bright & highly variable
- CXO: another 3x20 ks campaign proposed for Cycle 6



# Does Orion hold additional clues?

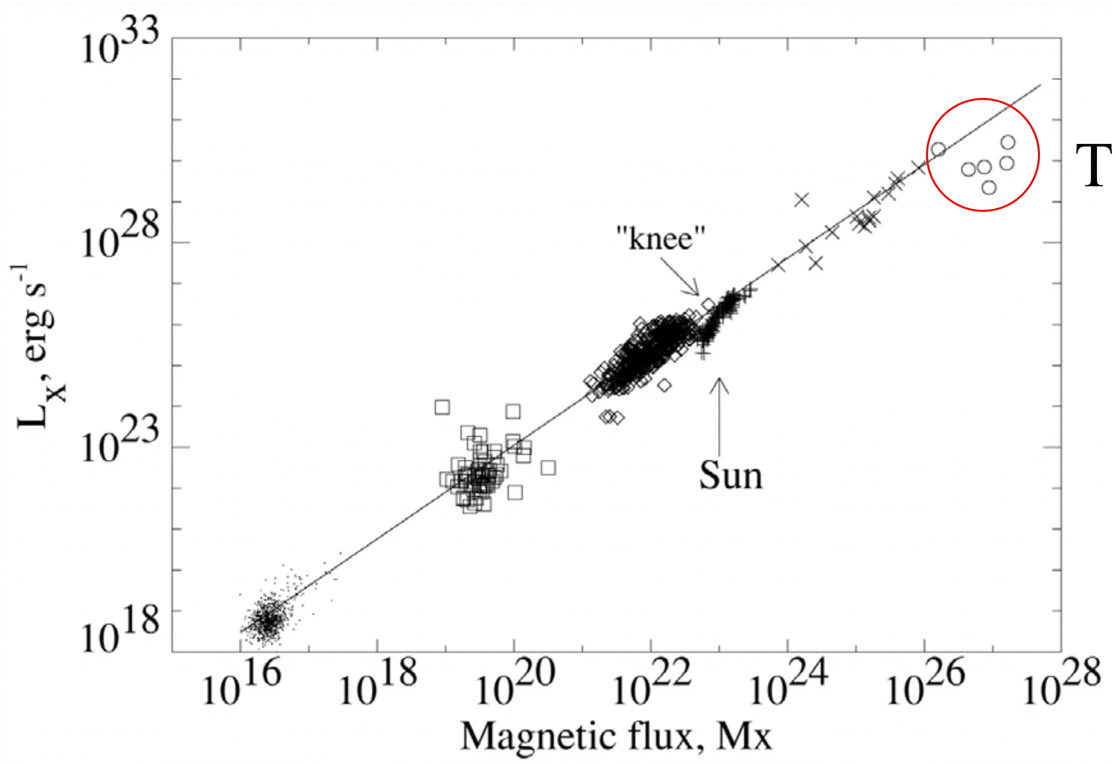
*Spectral/temporal analysis of 1600+ sources in the ONC should provide new insight into X-ray emission processes...*

*...stay tuned for results from COUP!*



*Chandra X-ray image of the Orion Nebula Cluster (10-day integration; Feigelson et al. 2004)*

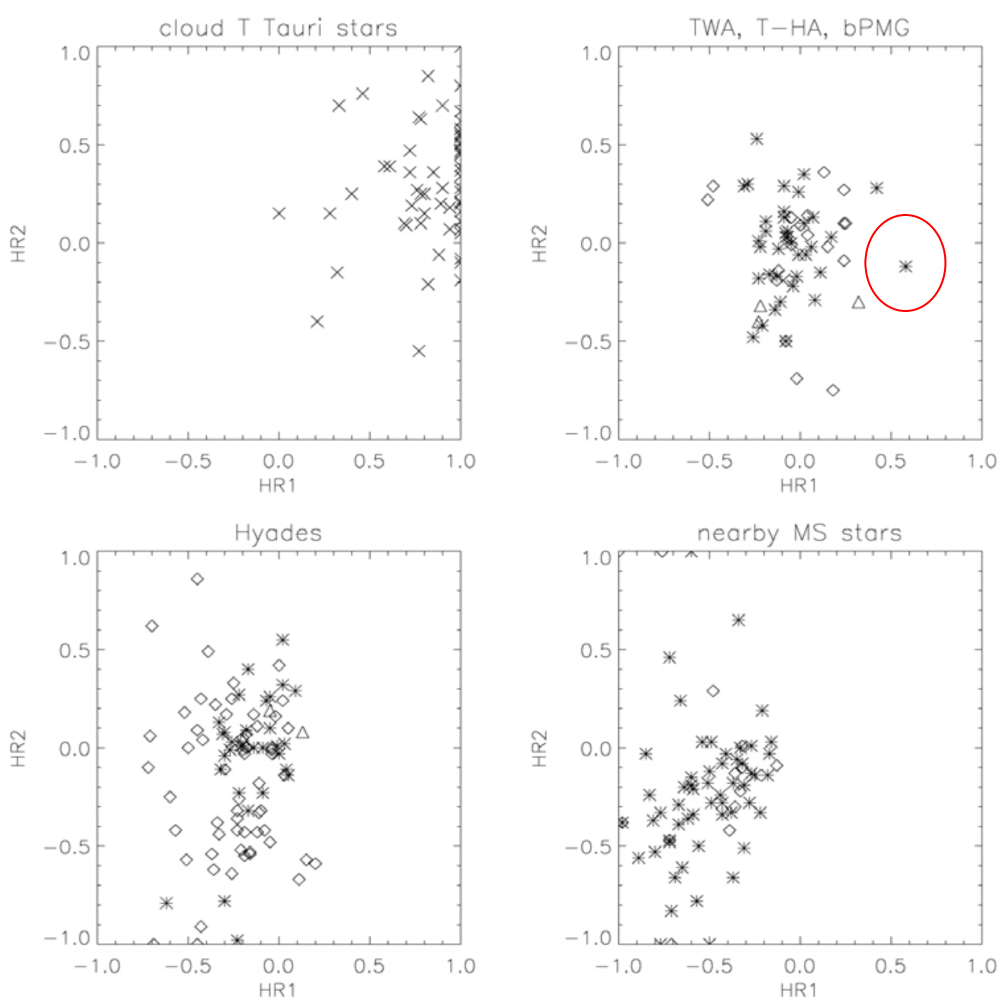
# Empirical solar/stellar B-$L_X$ relation

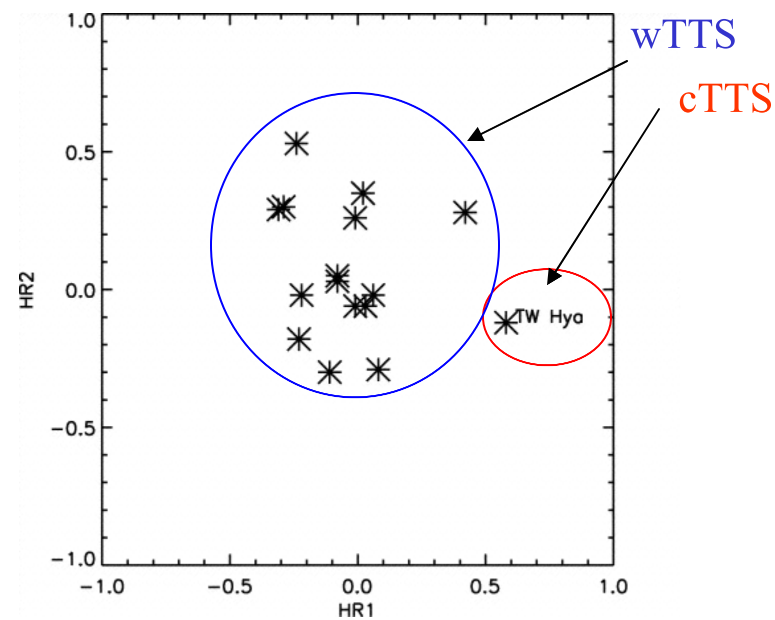



T Tauri stars

*Pevtsov et al. 2003, ApJ, 598, 1387*

# X-ray spectra soften from the T Tauri stage to the main sequence



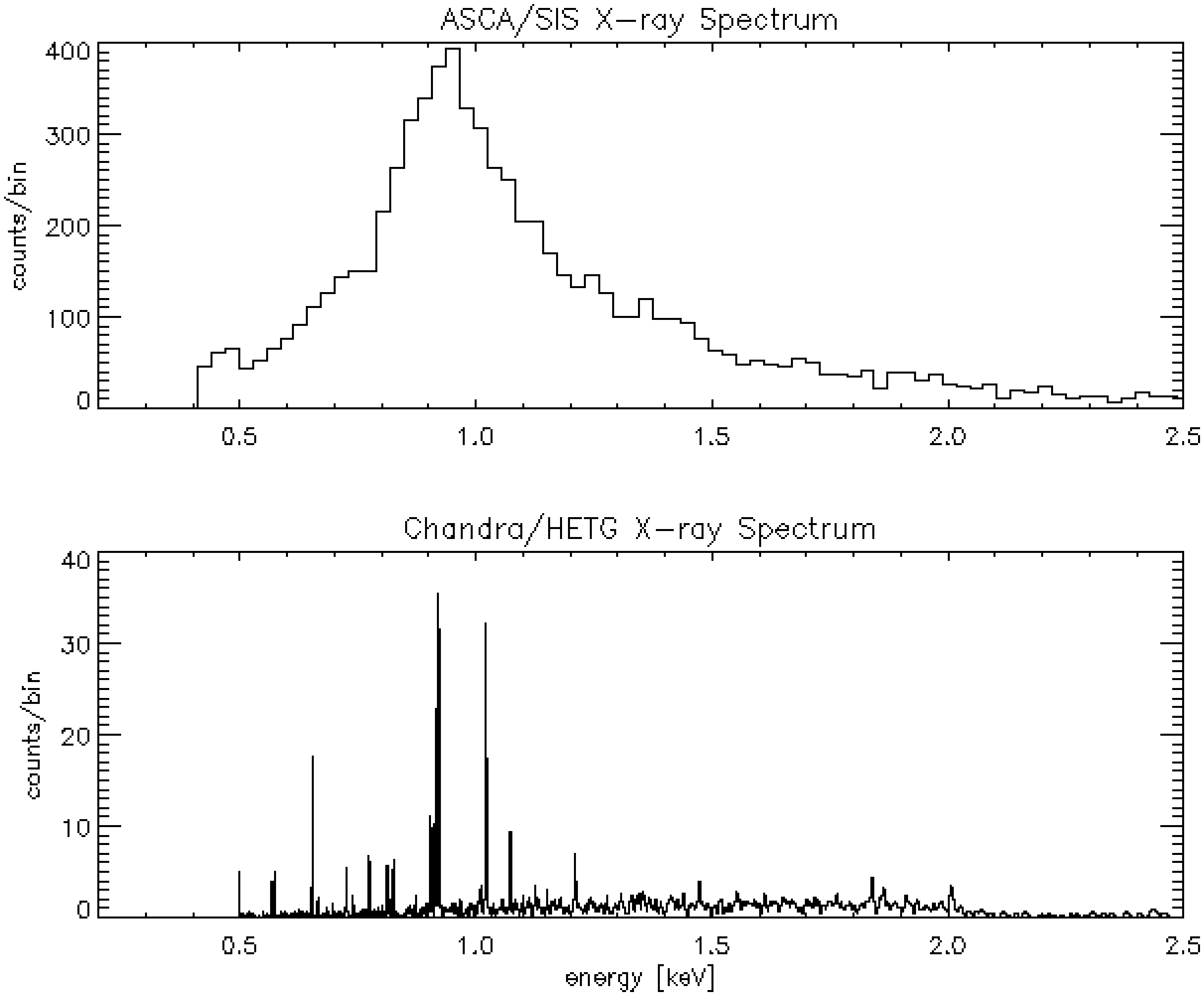




*Left: ROSAT HRs for Taurus TTS; nearby 10 Myr-old stars; the Hyades; and MS stars*

*Above: ROSAT hardness ratios for the TW Hya Association*

Kastner et al. (2003, ApJ, 585, 878)

# The (spectroscopic) power of Chandra



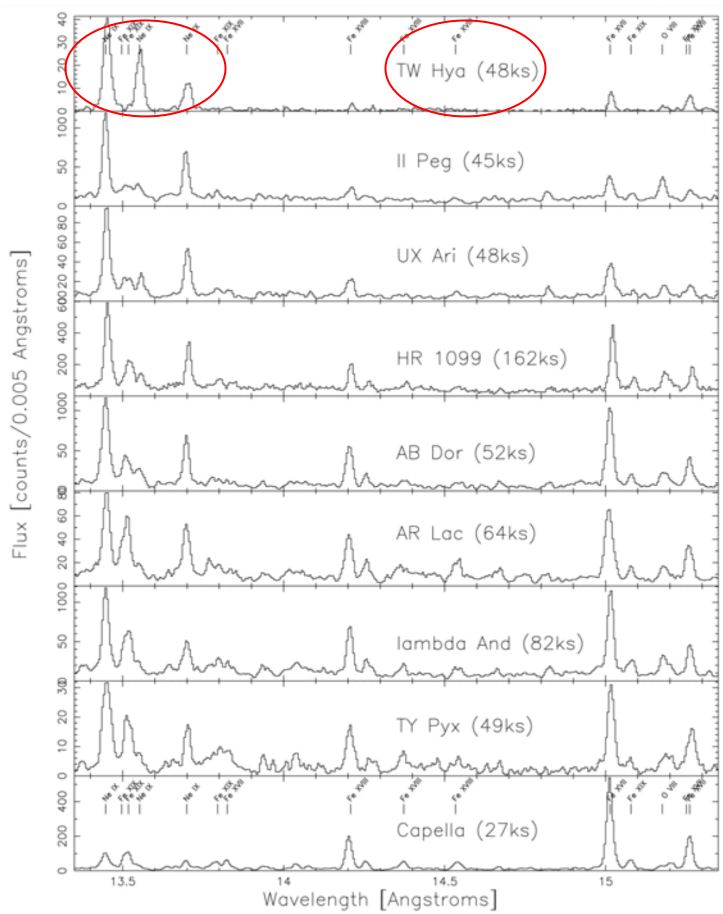

X-ray spectrum of TW Hydrae available B.C. (before Chandra) (*CCD data from ASCA; Kastner et al 1999)*

Chandra X-ray spectrum of TW Hydrae *(Kastner et al 2002)*

*Chandra/HETG spectrum demonstrates that the X-ray spectrum of TW Hydrae displays bright emission lines…of Ne!*

# Chandra spectroscopy of cTTS TW Hya: Evidence for accretion

Ne IX:
R I F

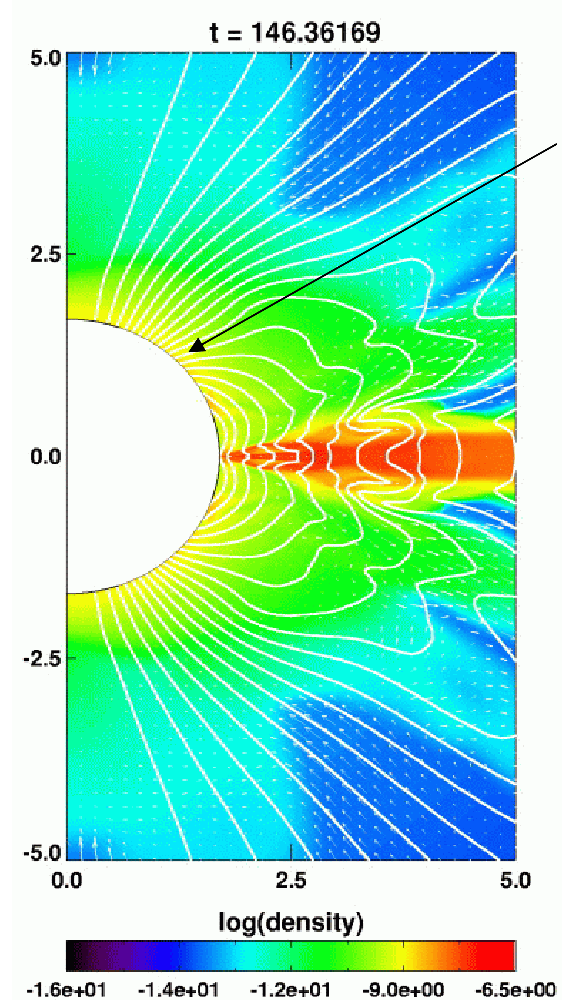



cTTS:
log n ~ 13

Coronal sources:
log n ~ 10-11

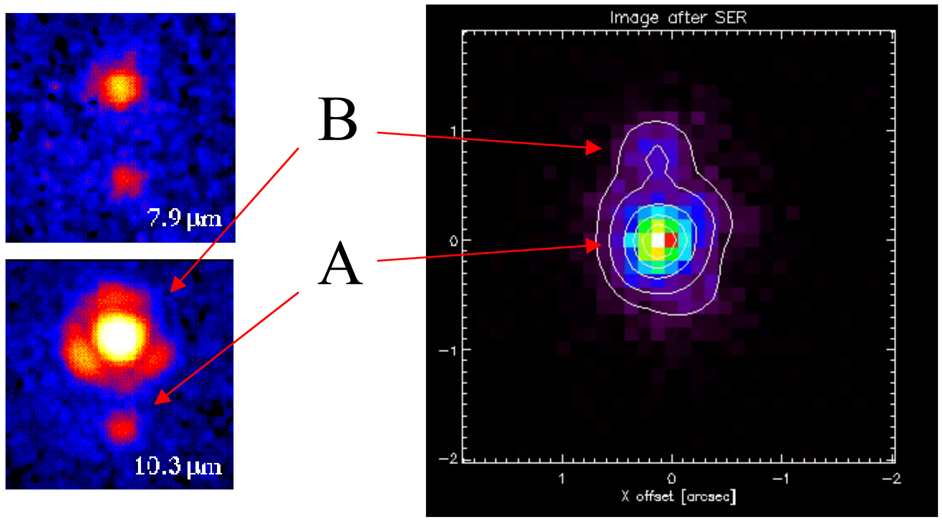
*CXO/HETG spectra*
(Kastner et al. 2002, ApJ, 567, 434)

log n ~ 14




*Magnetospheric accretion model*
(Kuker et al. 2003, ApJ, 589, 397)

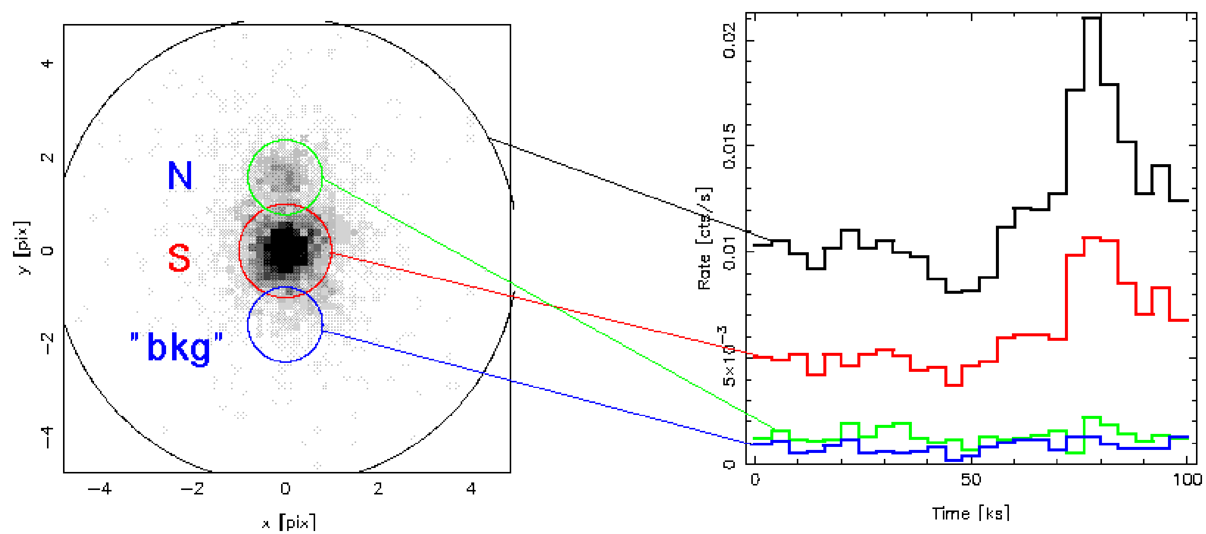
# Observing a "control": the quadruple *weak-lined* TTS system HD 98800



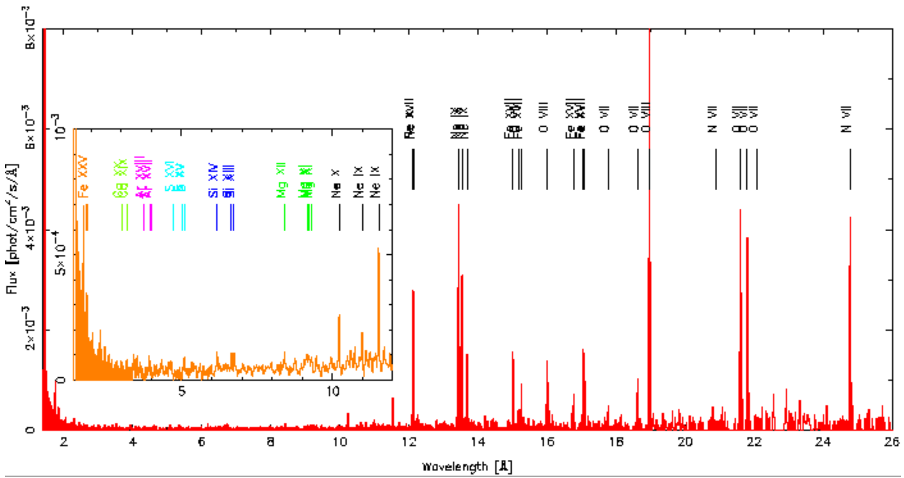

*Left: Keck mid-IR imaging (Prato et al. 2001)*

*Right: CXO/HETG 0th-order X-ray image (data obtained March, 2003)*

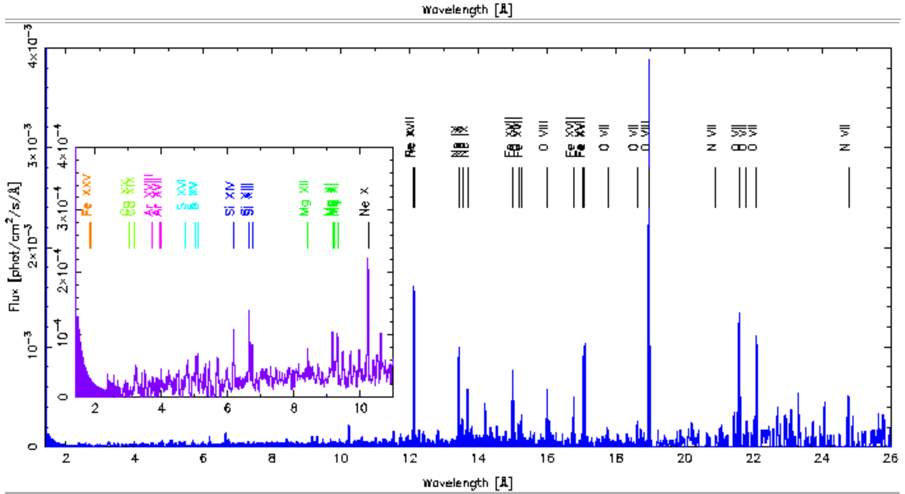
*Caught in the act: a flare on HD 98800 A*



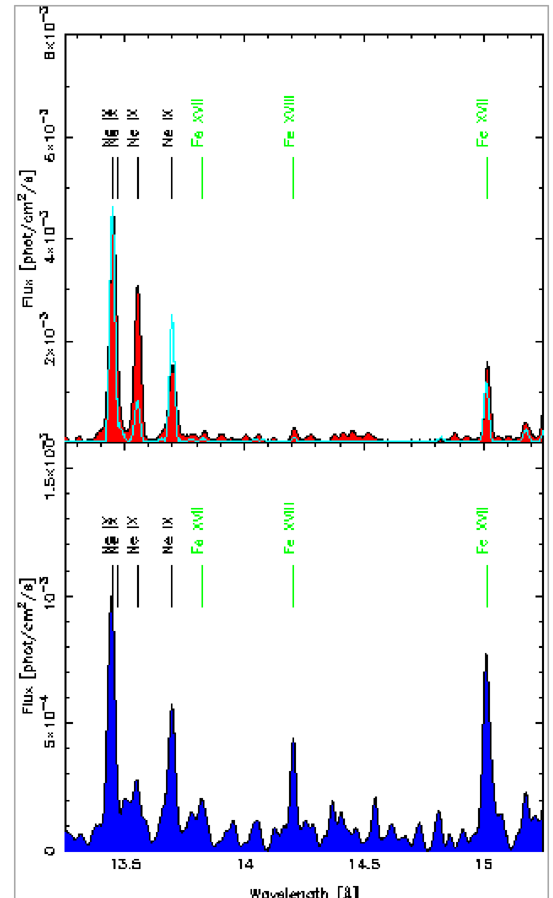
# TW Hya vs. HD 98800 in X-rays: Accretion vs. coronal activity?



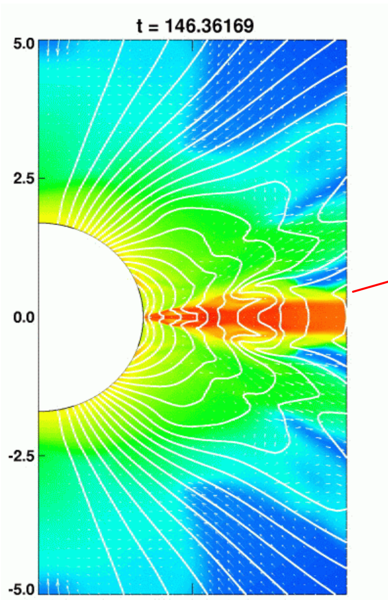

TW Hya:
high density,
low Fe/Ne,
"cool"

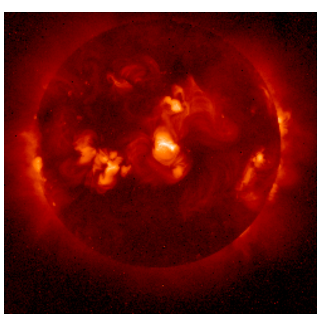


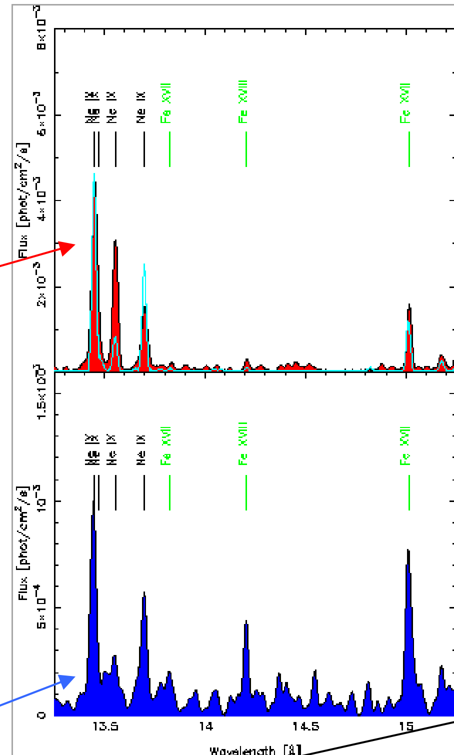

HD 98800:
low density,
larger Fe/Ne,
"hot"



# X-ray spectroscopy as diagnostic of accretion vs. coronal activity in TTS? Perhaps, but...more hi-res data needed!

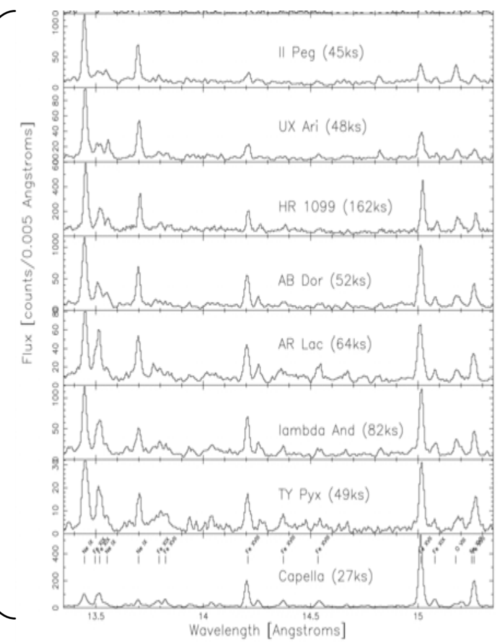





cTTS:
log n ~ 13*

wTTS and active MS stars:
log n ~ 10-11




*are TW Hya line ratios indicative of high density or strong UV?