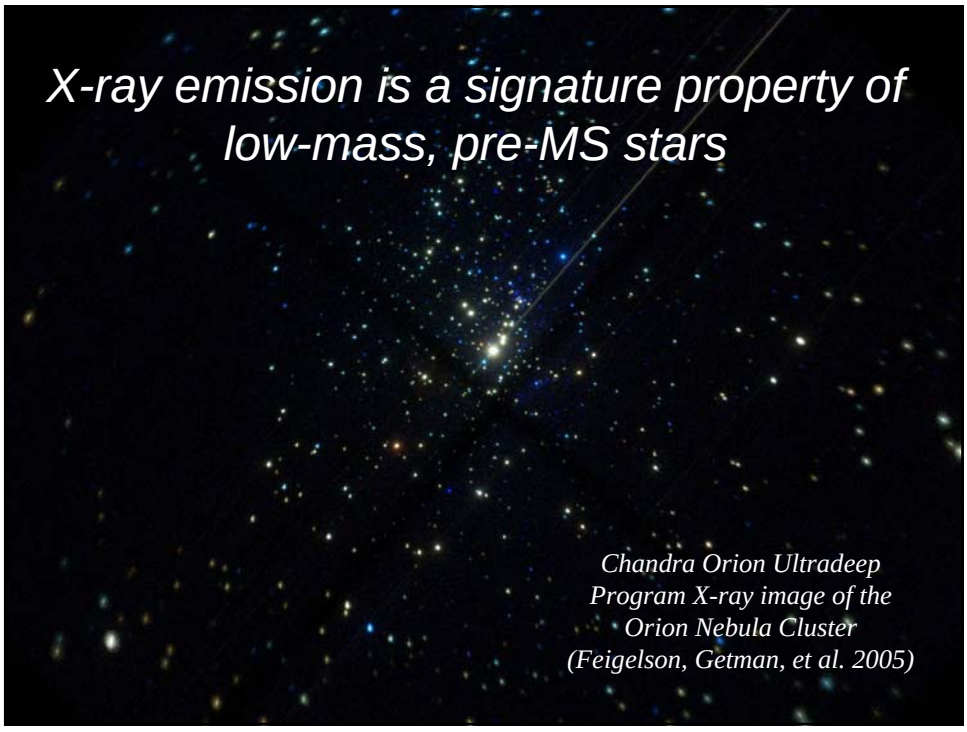
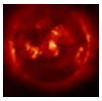
X-ray Diagnostics of Pre-main Sequence Accretion and Outflow Activity

Joel Kastner
Center for Imaging Science
Rochester Institute of Technology



Why do low-mass pre-MS stars generate X-rays?

- *Solar-like coronal activity*?



  - X-ray emission from many (most?) pre-MS stars consistent w/ convective dynamo model
    - Rotation is not the entire story though (Preibisch et al. 2005)
- *Accretion and/or outflow activity*?

  - Circumstellar accretion disks and bipolar outflows (& jets) are ubiquitous during pre-MS evolution
  - Accretion disks and jets are well-established X-ray sources in a wide variety of astrophysical contexts
    - AGN, CV's, symbiotic stars, planetary nebulae…
  - *Nevertheless, surprisingly difficult to establish whether <u>any</u> pre-MS X-ray emission can be directly (or indirectly) attributed to accretion or outflow activity!*

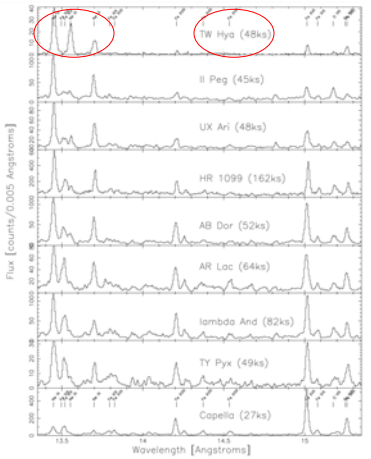
The evidence mounts…

Three recent & independent lines of evidence support a direct link between pre-MS accretion & outflow processes and pre-MS X-ray emission:

1. Measurement of anomalous line ratios of He-like ions in high-resolution X-ray spectra of certain actively accreting pre-MS (T Tauri) stars
2. Detection of an X-ray eruption coinciding with the optical/IR outburst from the pre-MS star V1647 Ori ("McNeil's Star")
3. Discovery of bimodal X-ray spectral energy distributions associated with pre-MS stars that drive well-collimated outflows (jets)

1) High-res X-ray spectroscopy of T Tauri stars: Evidence for accretion

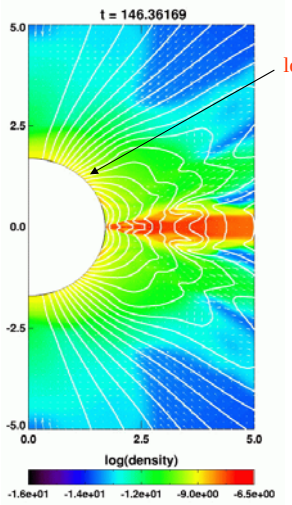
Ne IX:
R I F



cTTS:
log n ~ 13

Coronal sources:
log n
~ 10-11

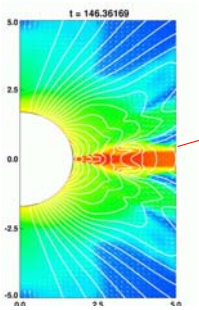
CXO/HETG spectra
(Kastner et al. 2002, ApJ, 567, 434)

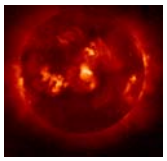


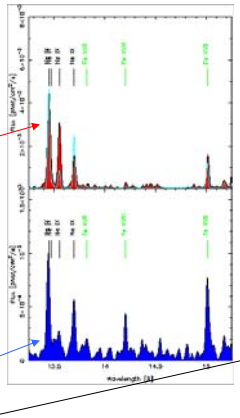
log n ~ 14

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

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

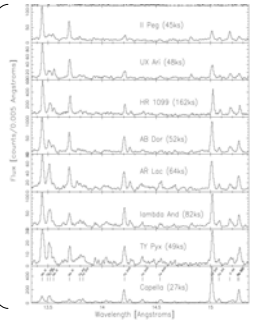






cTTS TW Hya:
log n ~ 13*

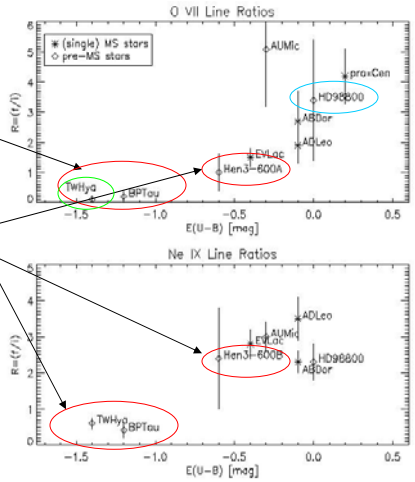
wTTS HD 98800 and active MS stars:
log n ~ 10-11



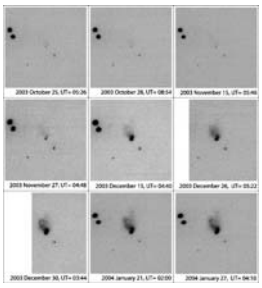
*are TW Hya line ratios indicative of high density or strong UV?

Recent progress

- BP Tau is found to display TW Hya-like line ratios in O VII and Ne IX (*Schmitt et al. 2005, A&A, 432, L35*)
- Line ratios of Hen 3-600 are consistent with its status as a "transition object" between TW Hya and HD 98800 (*Kastner et al. 2005, in prep.*)
- TW Hya's anomalous (X-ray) abundances likely are indicative of grain growth in its highly evolved, dusty disk (*Drake et al. 2005, ApJL, in press…subject of next talk*)



2) *McNeil's Star* (V1647 Ori): A low-mass, pre-MS star erupts

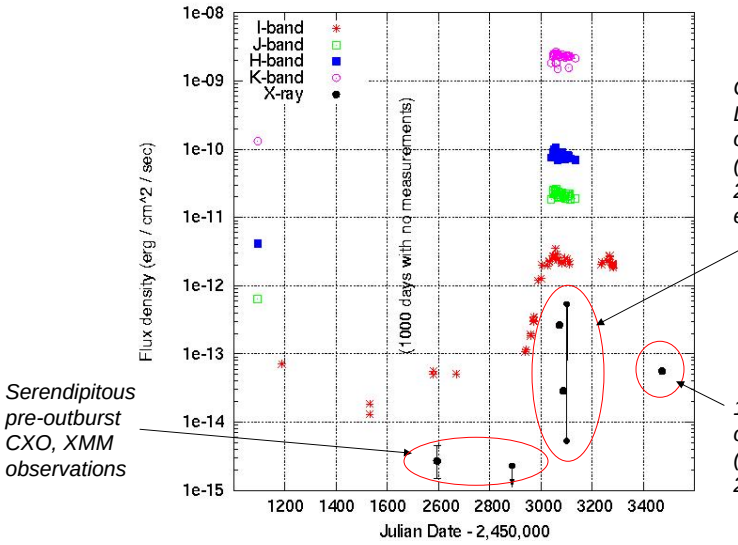


Left: caught in the act (from Briceno et al. 2004)

Right: Gemini image, post-outburst (Aspin & Reipurth)

- Optical/IR outburst occurred Oct-Nov '03
  - V1647 Ori now illuminates a cometary reflection nebula
- V1647 Ori has since remained in high state
  - Behavior generally characteristic of FU Ori or perhaps "EXor" outburst
  - Accretion "burst" likely responsible for optical/IR eruption

The X-ray eruption of V1647 Ori



CXO, XMM DDT observations (Kastner et al. 2004, Grosso et al. 2005)

Serendipitous pre-outburst CXO, XMM observations

1st CXO Cycle 6 observation (Kastner et al. 2005, in prep.)

What does V1647 Ori tell us about the nature of X-rays from pre-MS stars?

- *X-rays can be generated via pre-MS accretion processes*
  - But T_x of V1647 Ori too high to be explained by accretion shocks…
  - X-rays most likely due to magnetospheric reconnection events, probably intimately related to (responsible for?) "fresh" outflow activity
    - V1647 Ori source lines up with 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
  - Continued X-ray monitoring of V1647 Ori (and X-ray observations of other FUors and EXors) essential

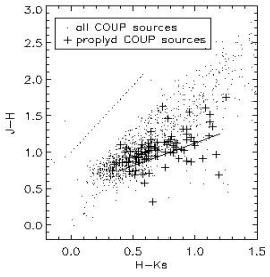
**only 2 known X-ray sources among FUors; both are weak*

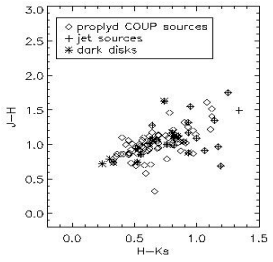
Ongoing X-ray monitoring of V1647 Ori

- XMM-Newton: deep exposures in 4/04, 4/05
  - April '04: source remained bright & highly variable (*Grosso et al. 2005, A&A, in press*)
- Chandra monitoring in 2005...and beyond?
  - three 20 ks observations scheduled during Cycle 6
    - Source still in "high" state as of first observation (April '05)
  - Additional observations in Cycle 7…?

3)X-rays from PMS jet sources: the disk/jet/X-ray connection

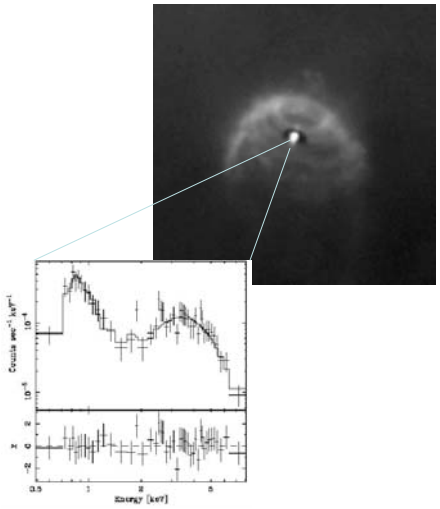
- COUP detected X-rays from ~2/3 of ONC stars that display (micro)jets in HST images
  - Part of COUP study of ~140 "proplyds" and related objects in ONC (*Kastner et al. 2005, ApJS COUP Special Issue*)
  - Jet sources have largest IR excesses, among X-ray-selected proplyd sample
    - Strengthens link between PMS accretion and jet activity





The X-ray buzz from the star-disk-jet system in the Beehive Proplyd

- Some ONC optical jet sources display two-component X-ray spectra
  - "Beehive Proplyd" (d181-825) is most notable example
  - DG Tau A is similar case (Gudel et al. 2005)
- Soft component: shocks at the base of the jet
  - Lightly absorbed, constant L_x
- Hard component: originates from the star-disk interaction region?
  - Heavily absorbed & variable



Summary

Thanks to Chandra & XMM, evidence is now accumulating for a direct link between pre-MS accretion & outflow processes and pre-MS X-ray emission.

1. Anomalous line ratios of He-like ions in high-resolution X-ray spectra of certain actively accreting pre-MS (T Tauri) stars
2. The X-ray eruption of the rapidly accreting pre-MS star V1647 Ori ("McNeil's Star")
3. Double-peaked X-ray SEDs of pre-MS stars that drive well-collimated outflows (jets)

Future Prospects

1. Additional high-resolution spectra of cTTS and wTTS needed to better establish whether and how line ratios of He-like ions (as well as abundance anomalies) serve as diagnostics of PMS accretion
   - Continue surveys of TW Hya Association & other nearby young groups
2. Expansion of FUor/EXor X-ray monitoring campaign would help determine luminosity, variability, and timescale of enhanced hard X-ray emission from accretion zones during outbursts
   - Unique probe of PMS star-disk interactions
   - Subject of modeling efforts by U. Rochester theory group
3. Comprehensive/exhaustive analysis of 1000's of X-ray SEDs obtained in CXO & XMM observations of young clusters would establish frequency of "bimodal" SEDs among PMS stars
   - Primary science driver for NASA AISRP-funded study of X-ray spectral classification schemes (Hojnacki, Mu, Kastner, Micela, et al.)