Results and Perspectives of Young Stellar Object long look programs

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Long look YSO observations

- 2 with *Chandra*
  - *COUP: 850 ks ACIS-I observation of Orion*

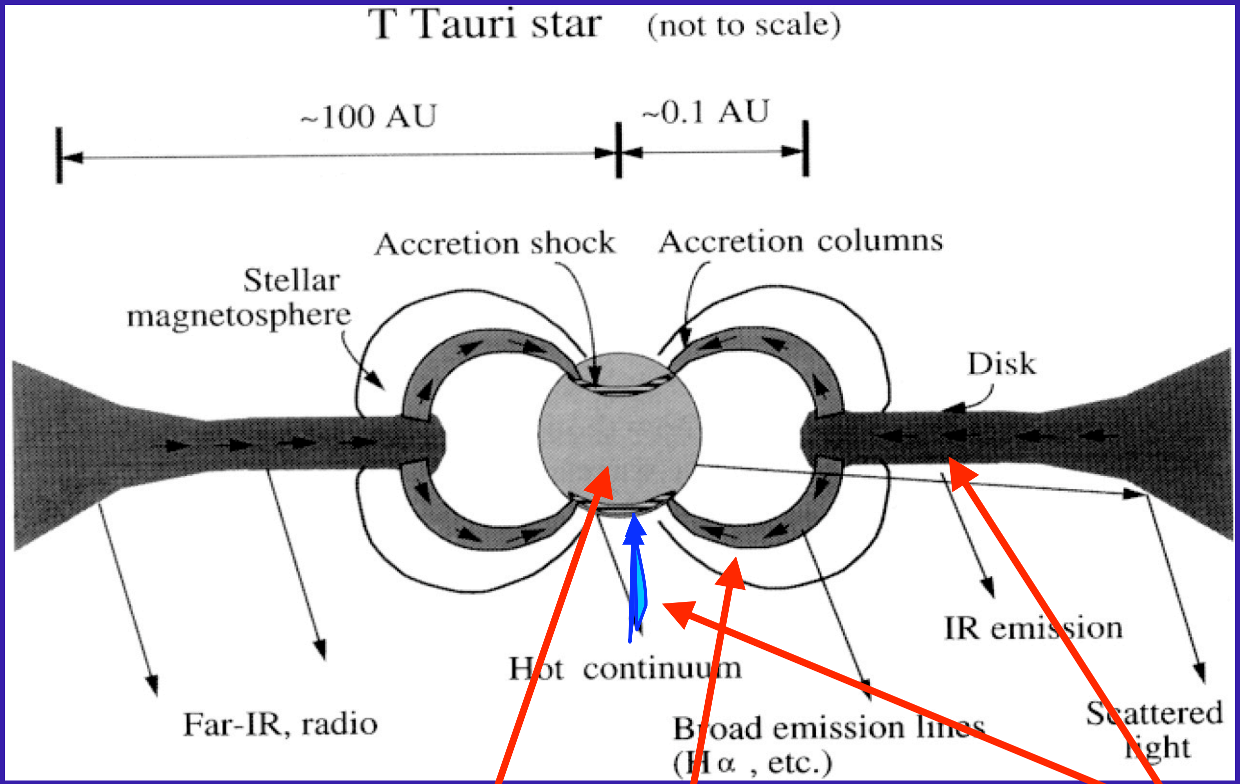
    -->> YSO Properties, Embedded Population
  - N1893 400 ks Chandra+Spitzer Observations

    -->> IMF in the external region of Galaxy
- ***1 with XMM-Newton***
  - ***DROXO: 500 ks EPIC observation of rho Oph, centered on core F***

    -->> YSO Properties thanks to time resolved spectra

Hartmann (1998) scenario of class I-II YSO

Magnetically funneled accretion streams emit broadened emission lines



X-rays could come from: Star, Funnel and/or Funnel/Star, Disk and Jets

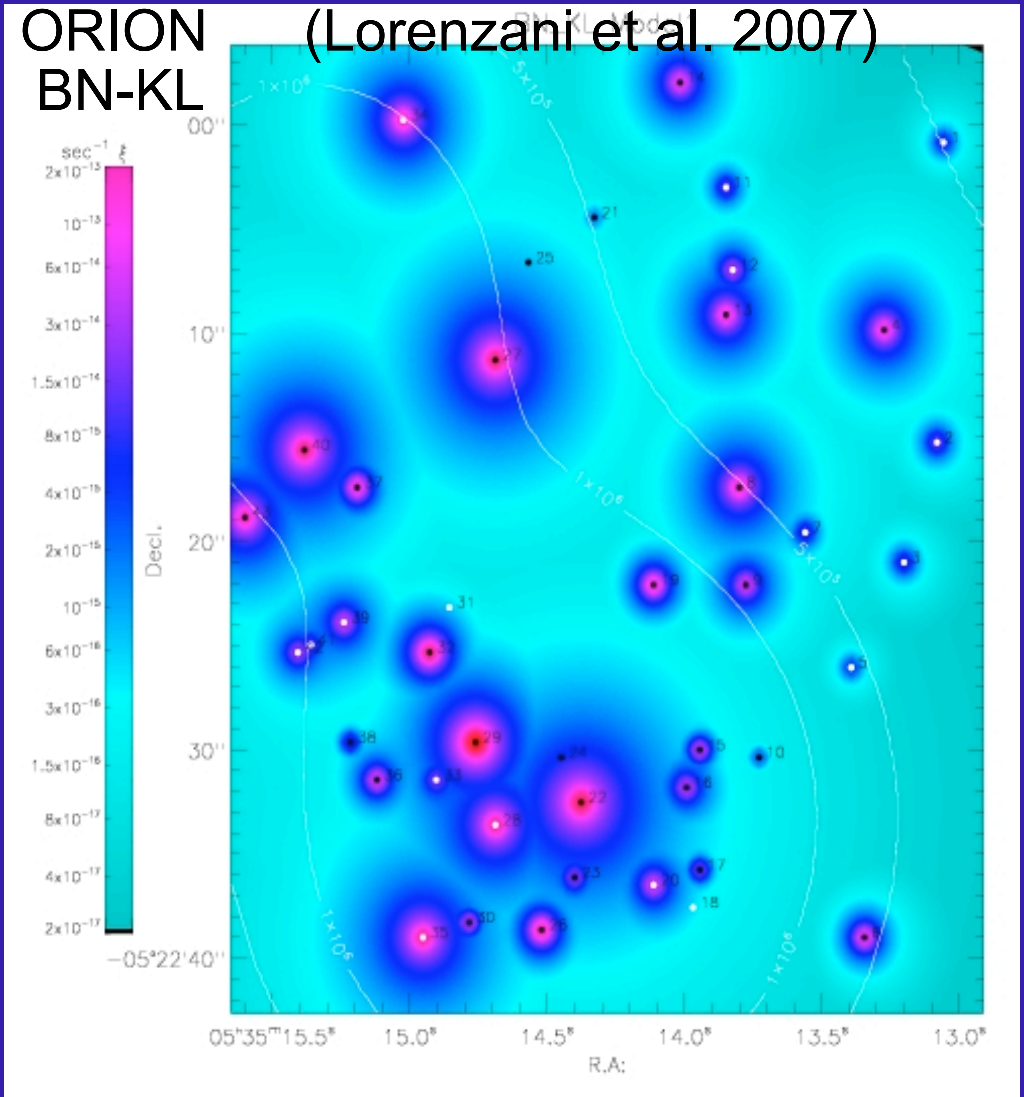
CAN WE RECOVER/DISTINGUSH THE DIFFERENT CONTRIBUTIONS ?

Open Issues

- X-ray fluorescence from YSO disks
  ... alias X-rays and Chemistry of Proto-Planetary Disk
- Flares and sizes of magnetic structures in YSOs
  .... alias Star-Disk Interplay Issue
- X-ray Emission from Class 0 YSOs,, i.e. very young (~10^4 year old) protostars
  ... alias Effects of High Radiation on SF
- Shock-driven X-ray emission in YSOs

- Modelling of COUP data predicts X-ray from YSOs as a major ionization sources

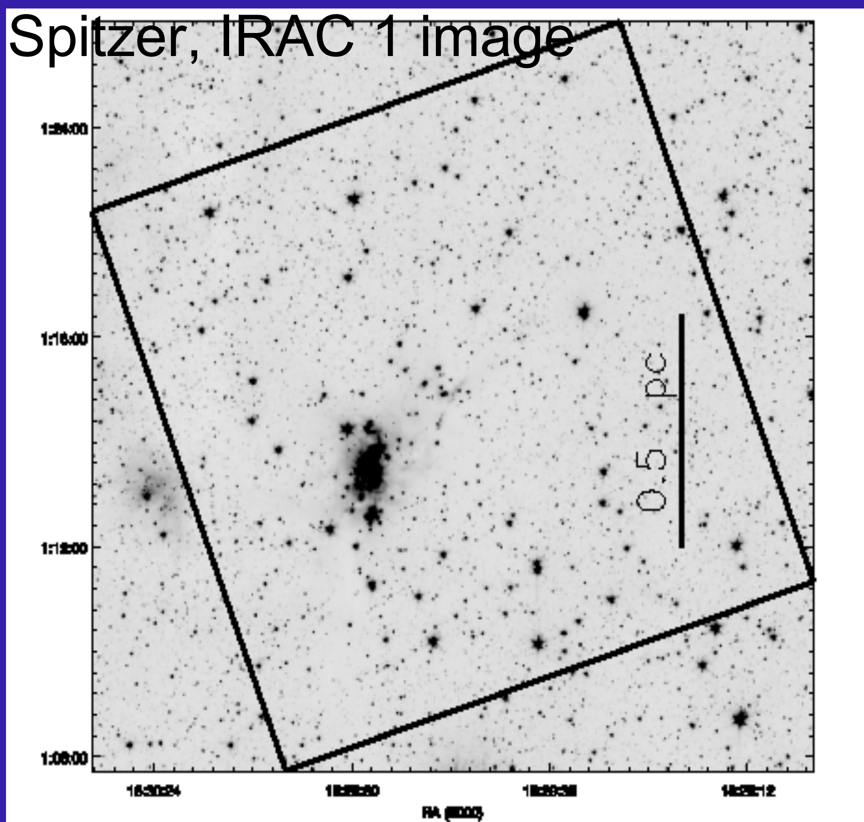
- *If X-rays suppress ambipolar diffusion, they may terminate growth of stellar clusters and inhibit (or delay) future SF in their vicinity*
- Moreover X-rays may have a role on the early evolution of circumstellar disk (& subsequent planetary system formation)

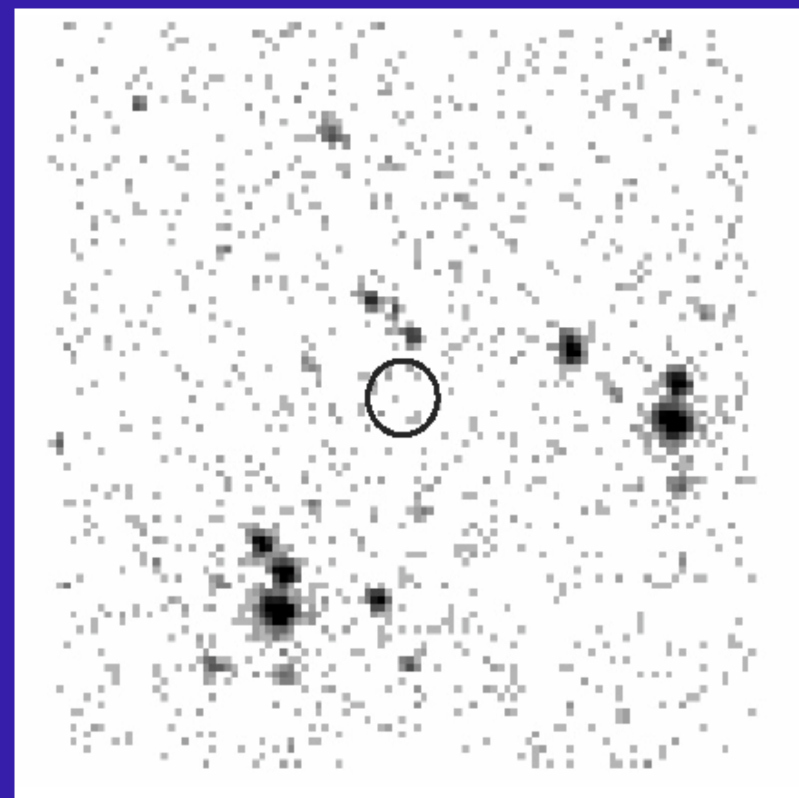


No X-rays from Class-0 in Serpens

Giardino et al. (2007)

Just a 100 ks Chandra exposure, but Co-adding at 6 Class-0 positions
-->> a ~ 600 ks equivalent exposure ... i.e. a long look observation





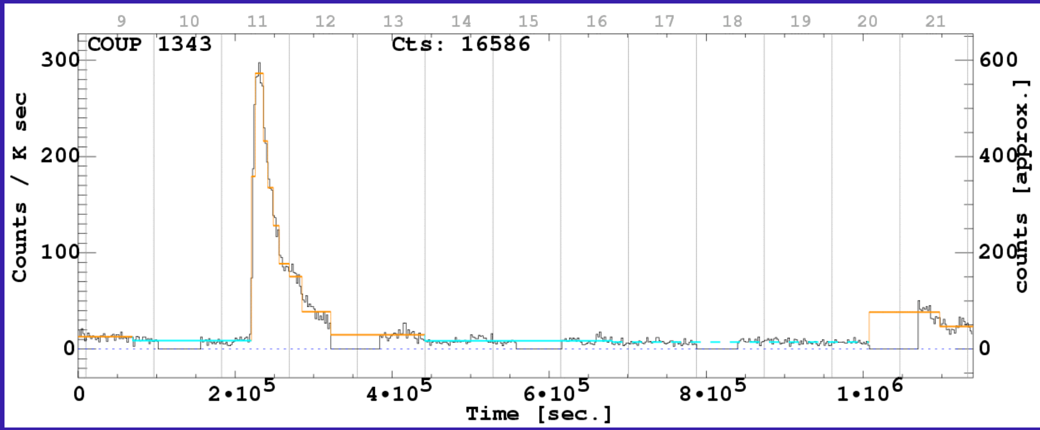
N_h = 4 × 10^23 cm^{-2}, kT = 2.3 keV -->> $L_X < 4 \times 10^{29}$ erg/s
Still a dex higher than active Sun !

X-ray flares and size of magnetic structures

- X-ray flares are classic tool to derive physical parameters of emitting region
- Use of dynamical information (decay time, etc.) allows derivation of physical characteristics of flaring region
- Flaring plasma ***must*** be magnetically confined, thus this allows to measure the size of individual magnetic structures
- Observed YSO flares typically scaled-up version of solar ones, ***BUT FEW CASES*** ....

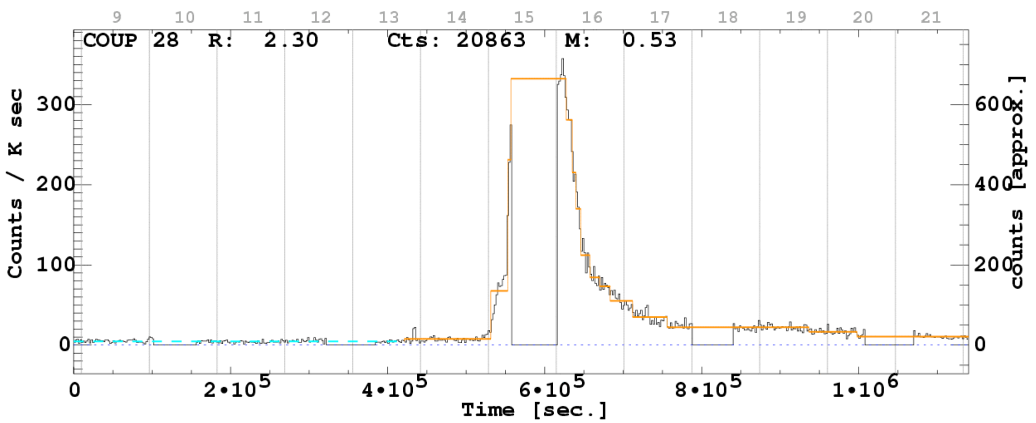
Analysis of COUP Flares

COUP 1343



long lasting ($\tau \approx$40 ks)
very hot plasma (100s MK)
almost free decay
  fast temperature decay
Long loop
  2×10^{12} cm ($\approx$ 0.1 AU!)
Confining *B* field 150 G

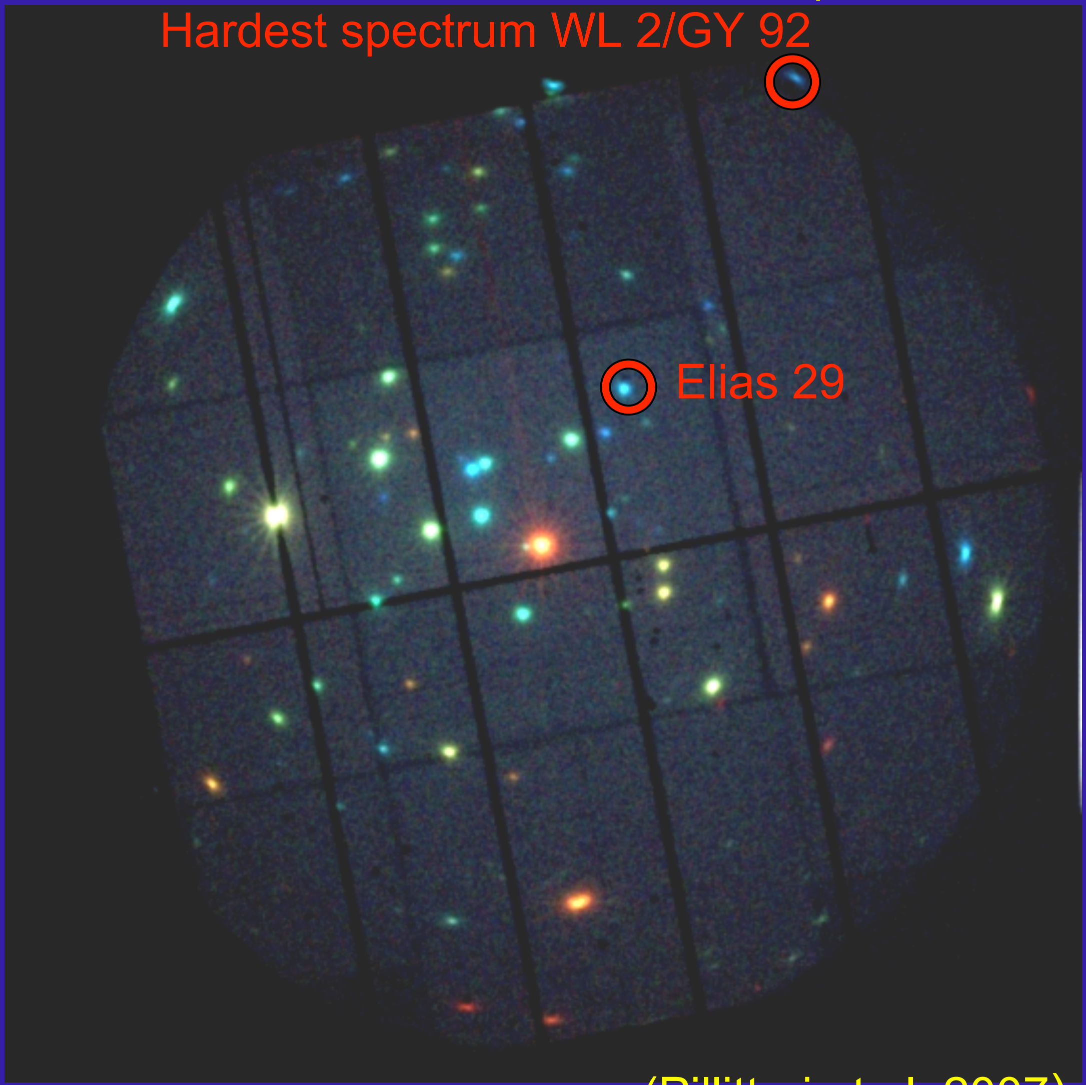
COUP 28



very long lasting ($\tau \approx$80 ks)
moderate *T* plasma ($\leq$100 MK)
sustained heating
  slow temperature decay
Longish loop
  1×10^{12} cm ($L/2 \approx 2.5\ R_*$)
Confining *B* field 180 G

32 (1%) flares studied, $L/R_* > 3$ in 6 + 4 (less certain) cases

Enter DROXO, **A D**eep **R**ho **O**ph **X**MM-Newton **O**bservation (500 ks, Pi: S. Sciortino)



(Pillitteri et al. 2007)

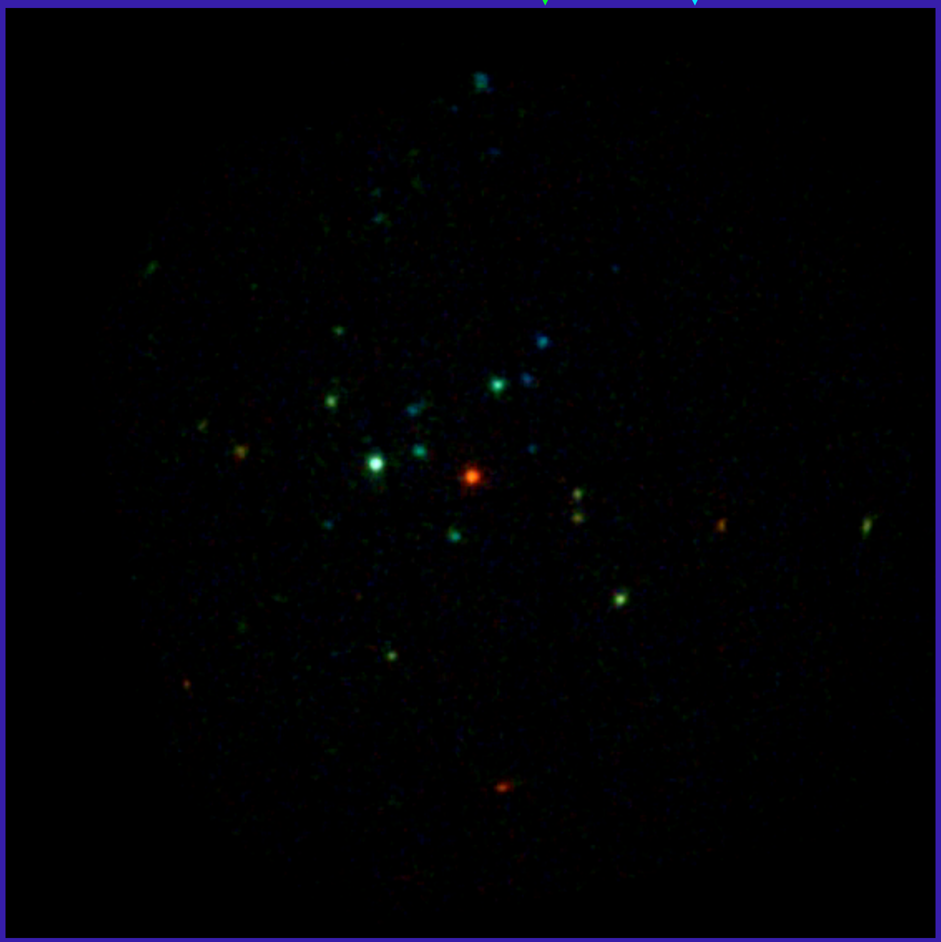
MOS1 + MOS2 + PN

Red : 0.25 – 1.8 keV
Green: 1.8 – 3.7 keV
Blue : 3.7 – 7.5 keV

- 110 Sources found in the combined data
- 17 new, 34 only X-rays, 59 IR (ISO/2Mass)

- Unfortunately background is high for about 40% of the observation time
- Sources found in optimally screened data

DROXO MOVIE



MOS1+MOS2+PN

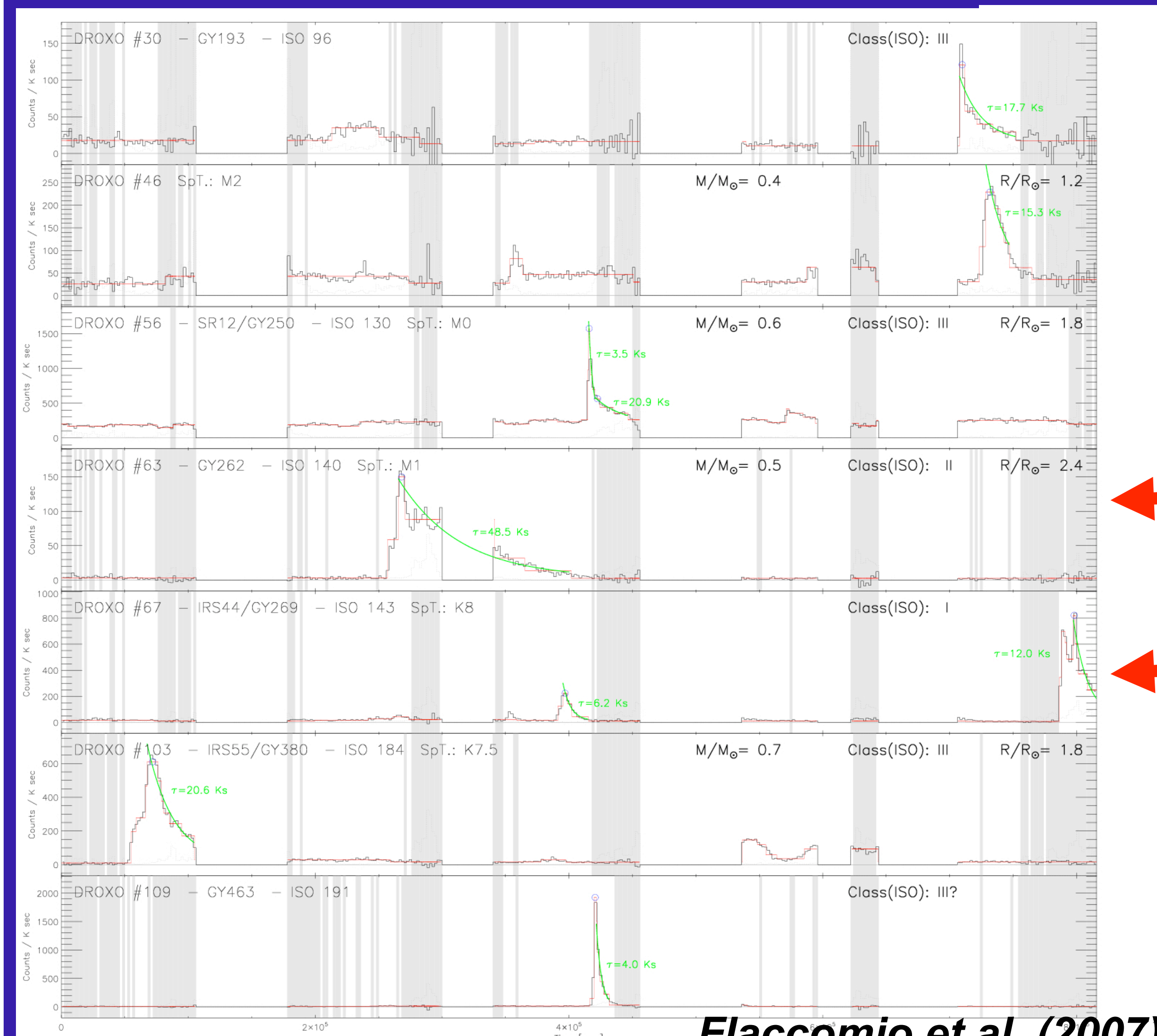
~ 250 ks over a time range of ~ 6 days

Red : 0.25 – 1.8 keV

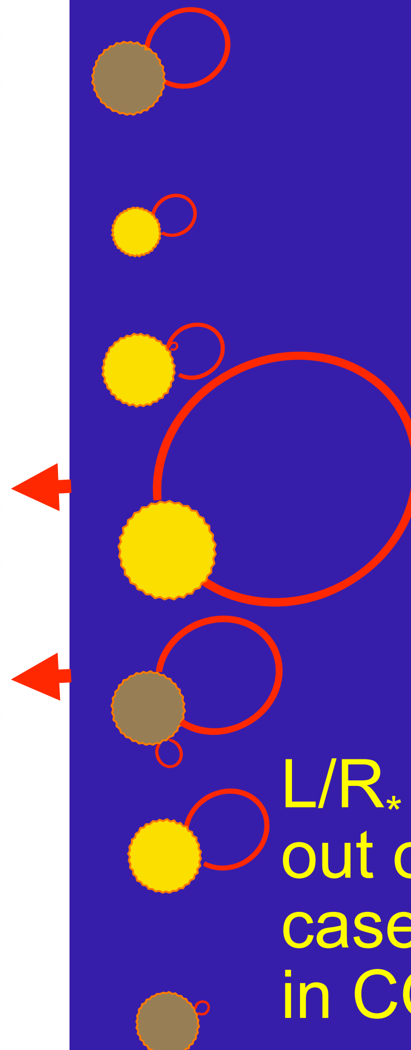
Green: 1.8 – 3.7 keV

Blue : 3.7 – 7.5 keV

DROXO 7 Bright Flares



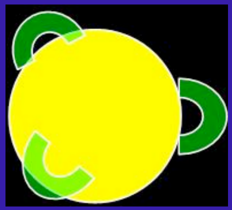
Flaccomio et al. (2007)



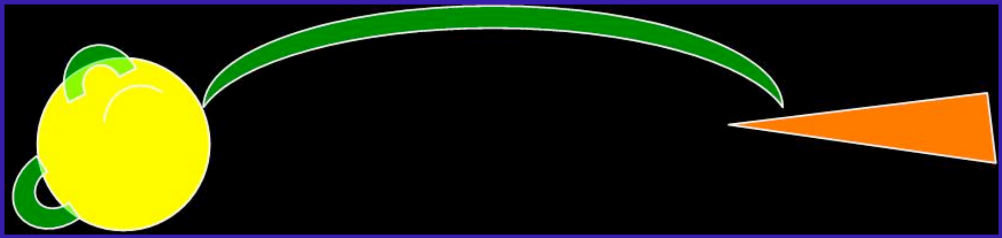
L/R* > 3 in 2 out of 7 cases, % as in COUP

How can these long loops be structured?

- Never “seen” in more evolved normal stars



- Stability problem respect to centrifugal force
  - 1-2 Myr YSOs are fast rotators ($P \approx$ 3-6 d)
  - Co-rotation radius typically at 3-4 R_*
  - → *Long loops anchored on star only would be ripped open*
- *Solution: loops connecting star and disk (at corotation radius)*



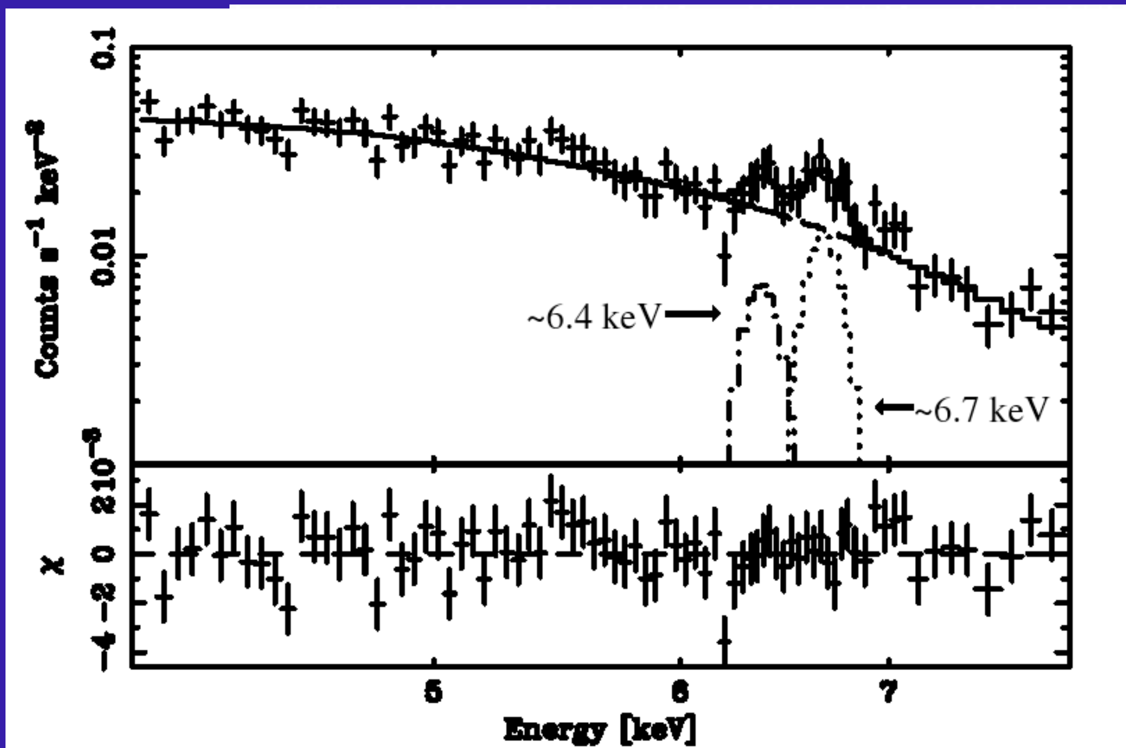
  - *Postulated by magnetospheric accretion scenario*

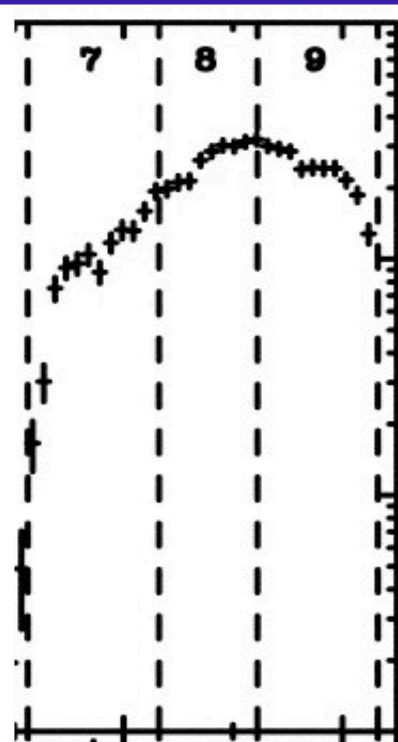
Fluorescence: observations and statistics

- 'Cold' Fe 6.4 keV line thus far detected in a number of YSOs, never in "normal" stars
- One detection in YLW16A in ρ Oph during an intense X-ray flare (Imanishi et al. 2001)
- 7 cases of fluorescence in ONC YSOs (Tsujimoto et al. 2005) during intense X-ray flaring
- One detection in Elias 29 in ρ Oph during quiescence *and* flaring (Favata et al. 2005), but the observation was short (34 ks long)
- $L_{bol,El29} = 26\ L_{bol,sun}$ $L_{acc,EL29} = 15\text{-}18\ L_{bol,sun}$ (very high)

The YLW 16A 6.4 keV fluorescence

Time (100 ks span)

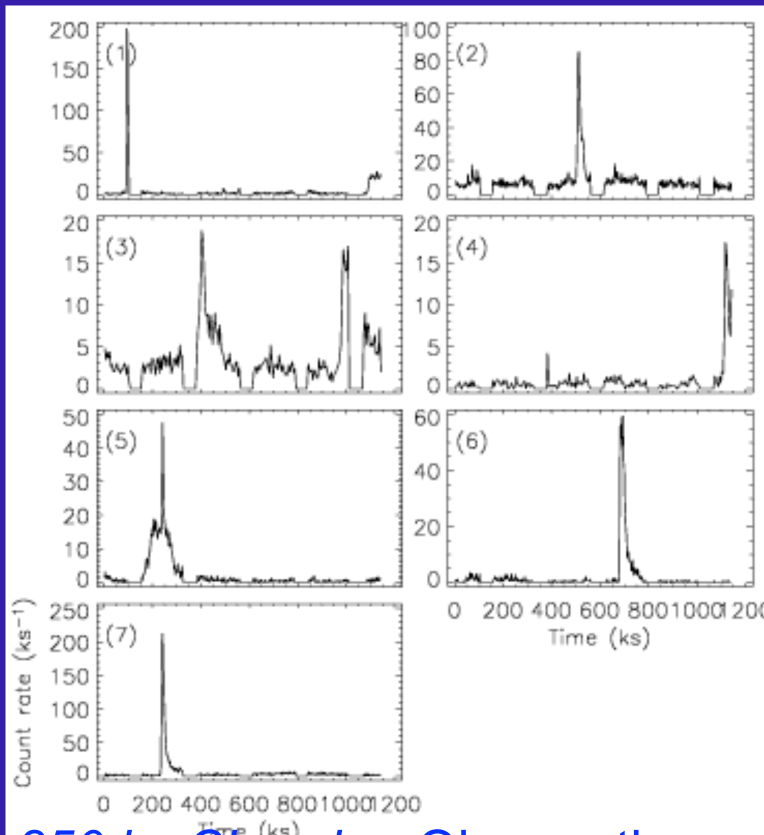




column density, respectively (Inoue 1985) observed column density of 4.7×10^{22} cm^{-3} interstellar gas, that of circumstellar gas shoul this value. Using the iron abundance of 0.3 sol the maximum equivalent width to be ≈15 significantly lower than the observed value Hence, we require nonspherical geometry; a la of gas should be present out of the line of sight. A possible

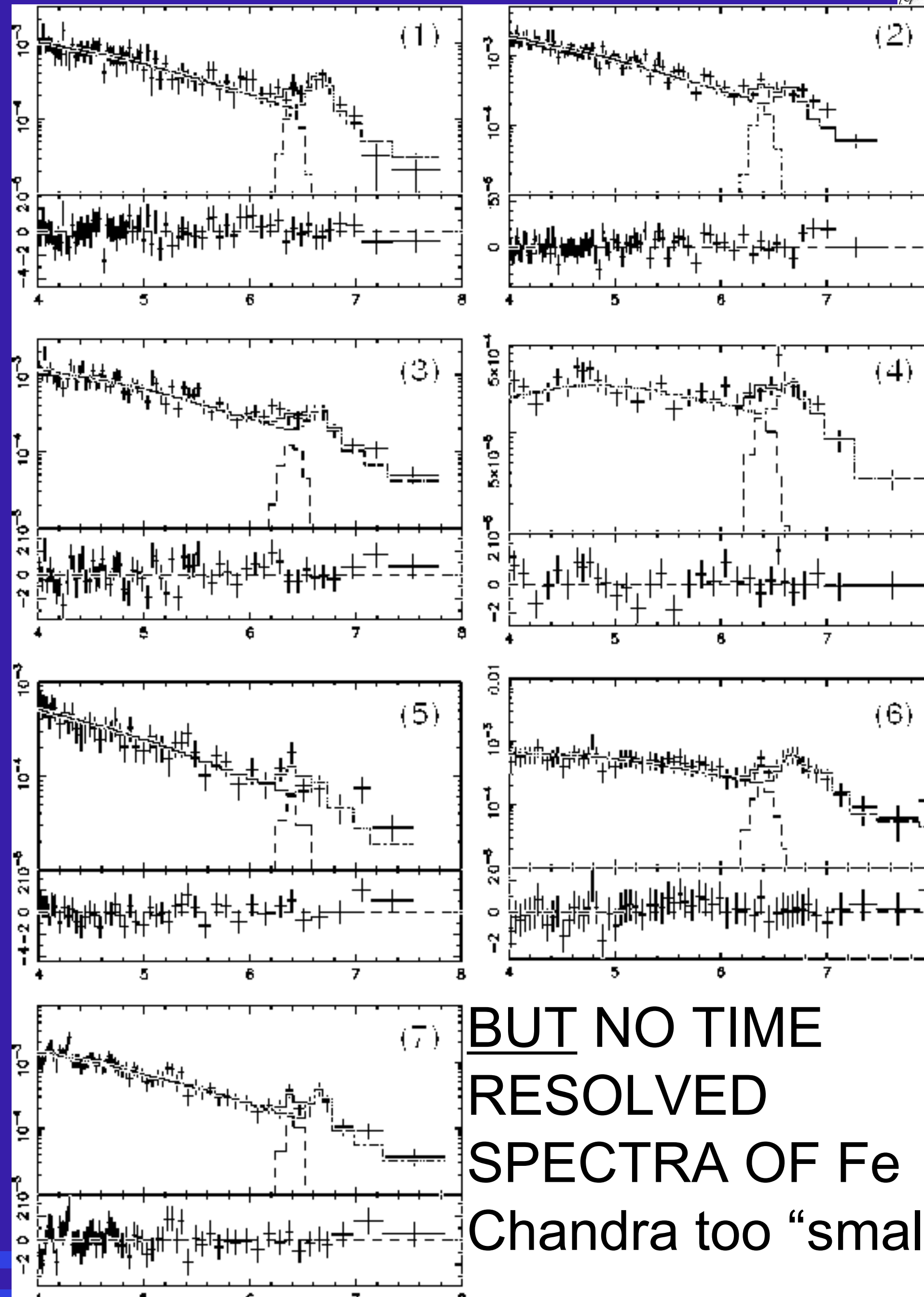
scenario is that YLW 16A has a disk with face-on geometry (Sekimoto et al. 1997), and this disk is responsible for the fluorescent 6.4 keV line. Since we see no time lag (reflection timescale) between the flare onset and the 6.4 keV iron line appearance within $\lesssim 10^4$ s, the separation between the star and the reflecting region should be $\lesssim 20$ AU, consistent with the disk origin.

Fluorescence in ONC YSOs



850 ks Chandra Observation

Tsujimoto et al. (2005), ApJS COUP Special Issue



BUT NO TIME RESOLVED SPECTRA OF Fe
Chandra too "small"

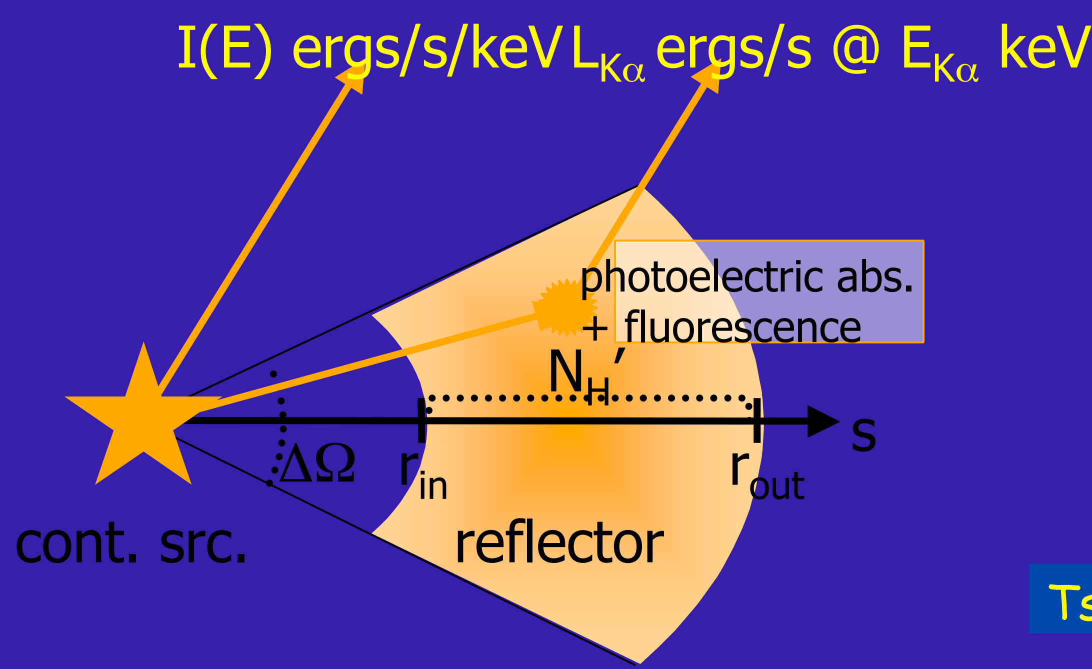
Schematic view of the reflection geometry

$$EW_{\mathrm{K}\alpha} = \frac{L_{\mathrm{K}\alpha}}{I(E_{\mathrm{K}\alpha})}$$

$$= \left(\frac{\Delta\Omega}{4\pi}\right) Y_{\mathrm{K}\alpha} \frac{E_{\mathrm{K}\alpha}}{I(E_{\mathrm{K}\alpha})} \int n_{\mathrm{Fe}}(s)ds \times \int_{\chi}^{\infty} \frac{I(E')}{E'} \sigma_{\mathrm{Fe}}(E')dE'.$$

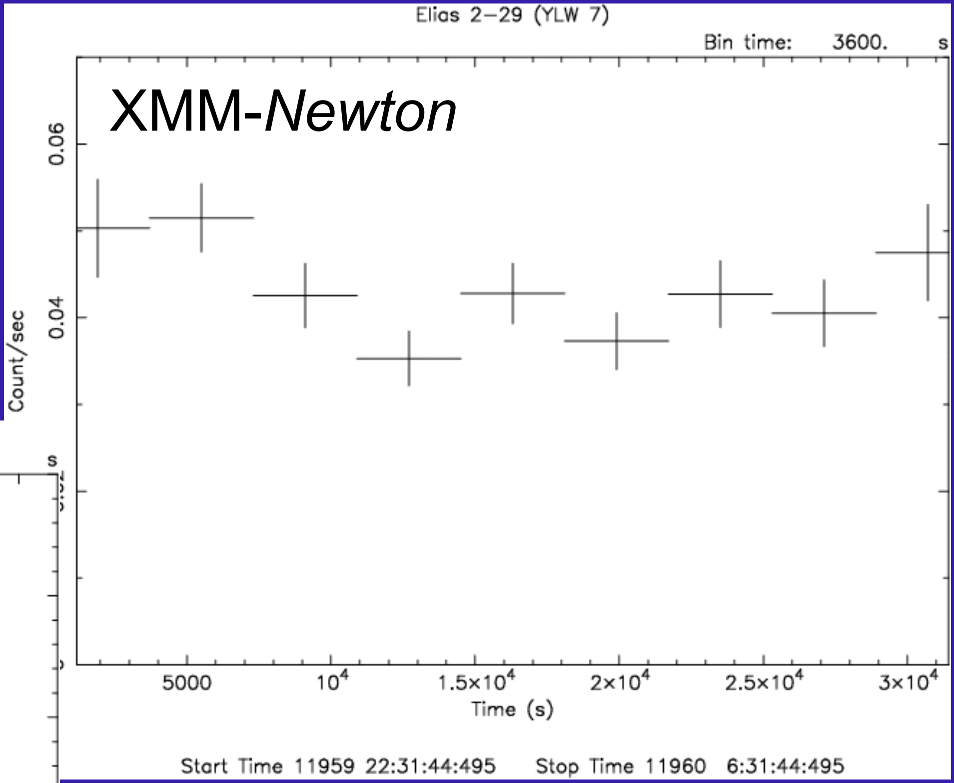
$$= 2.5 \times \left(\frac{\Delta\Omega}{4\pi}\right)\left(\frac{N'_{\mathrm{H}}}{10^{22}\ \mathrm{cm}^{-2}}\right) [\mathrm{eV}]$$

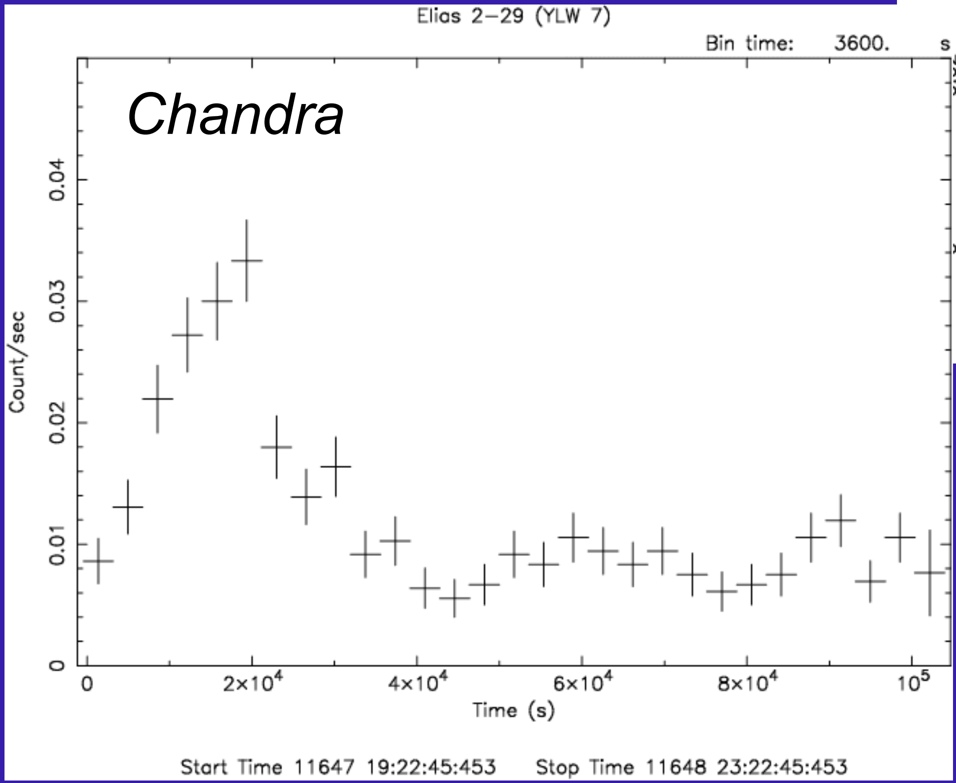
$EW_{K\alpha}$ larger than "available" N_H (X-ray measured)



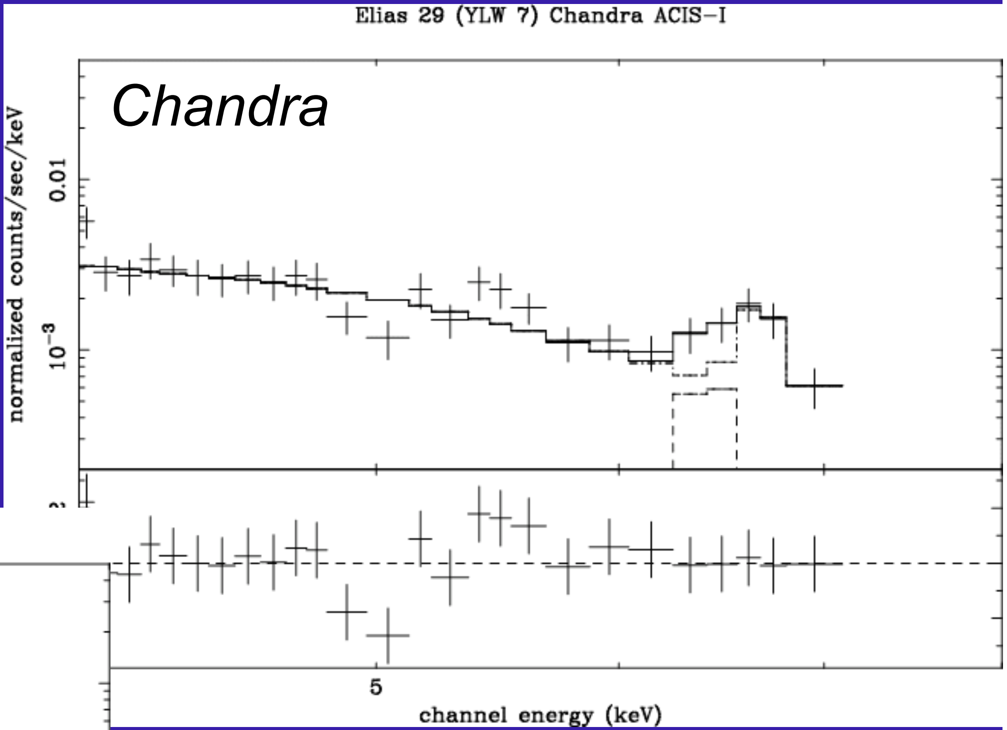
Tsujimoto et al. (2005)

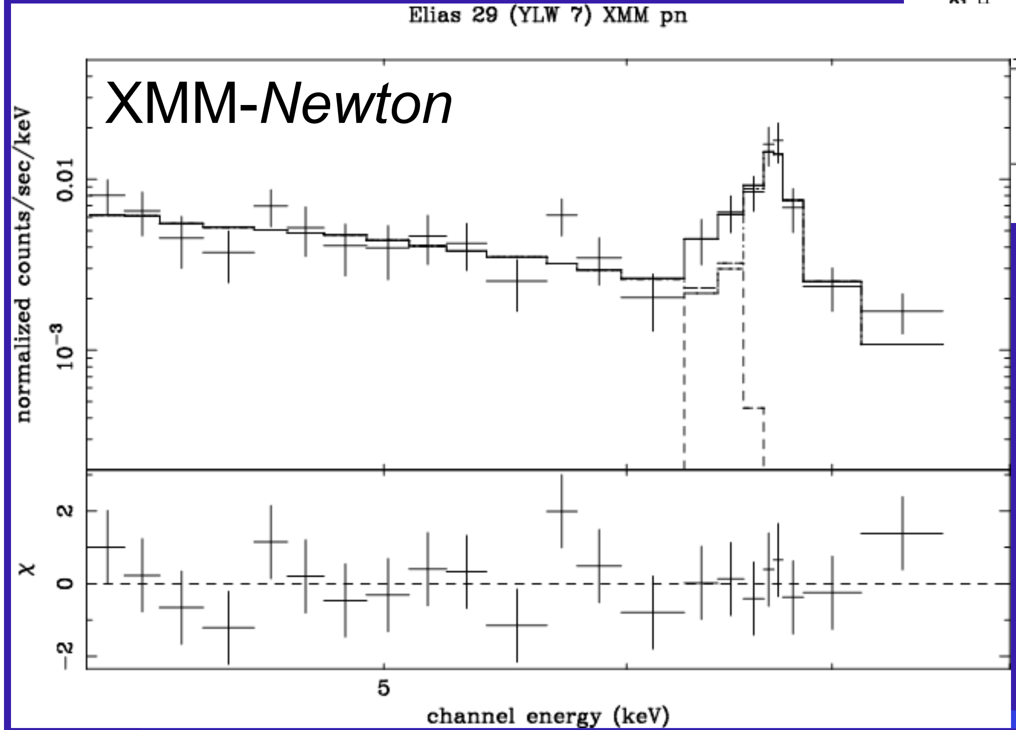
Elias 29, Chandra and XMM light curves





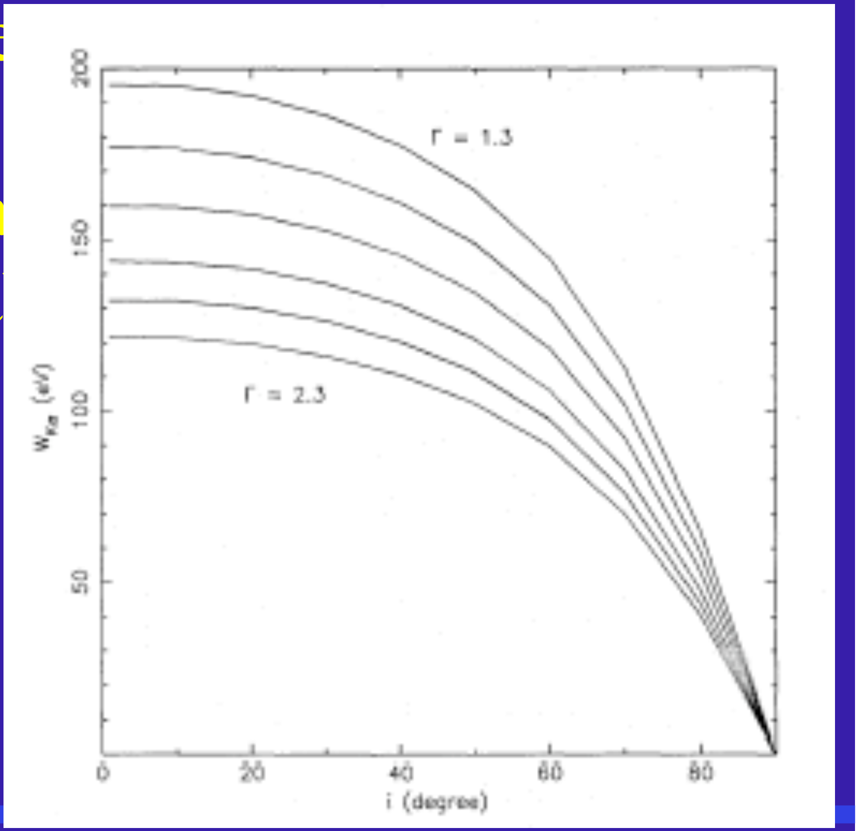
Elias 29, fluorescence





Elias 29, equivalent width

- Classic analysis by George and Fabian (1991) for a power law exciting spectrum ($I \sim A\, E_o^{-\Gamma}$ ph keV^{-1})
- Equivalent width function of incident spectrum (known) and cold material ge
viewing angle)
- Incident spectrum ($\Gamma \sim 2.6$) a
out reflection from a cold sla
  - $EW_{pred} < 100$ ev for $\Gamma > 2$

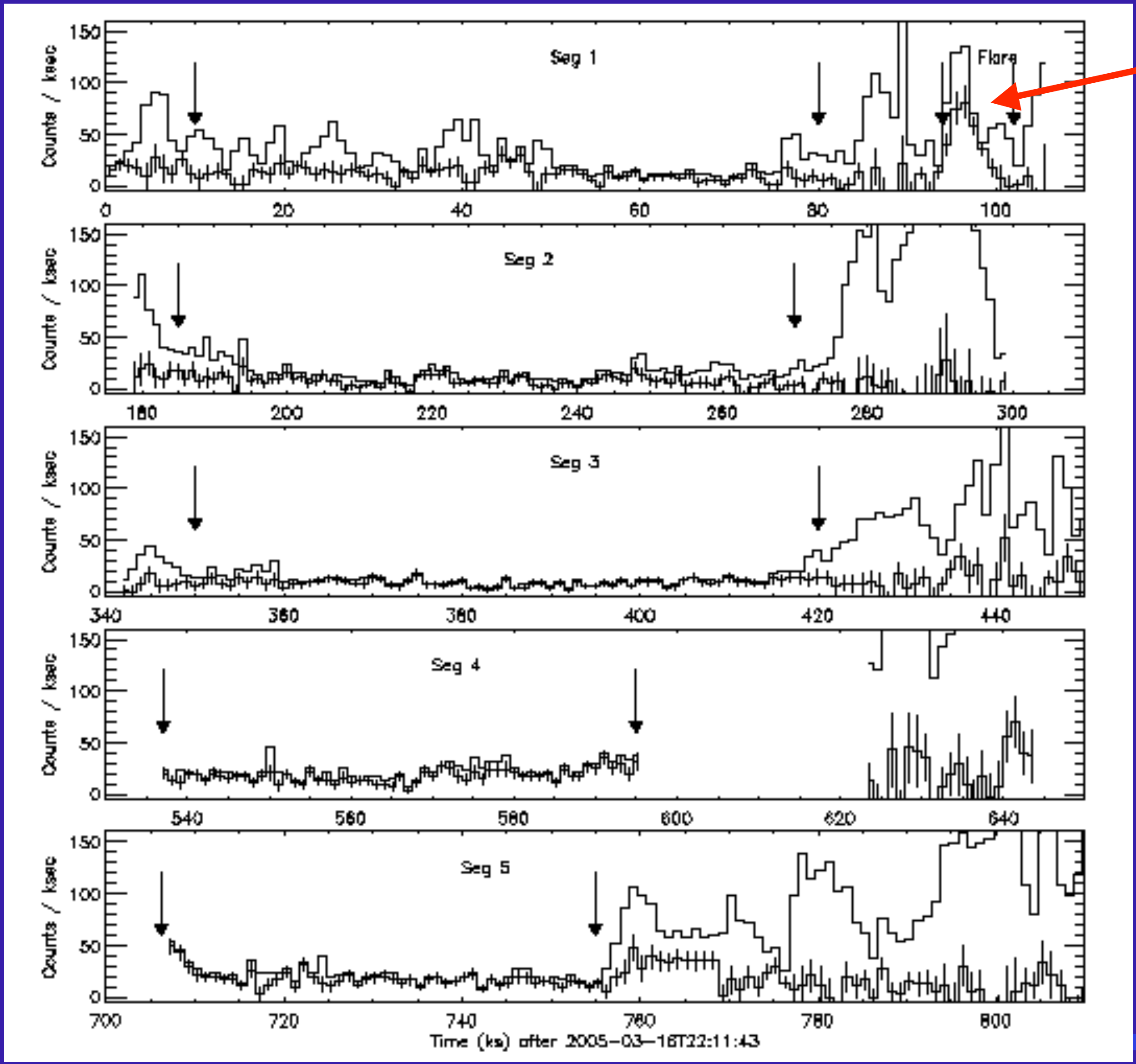


EW(6.4 keV) = 150 eV requires a centrally illuminated disk *and* a
a face-no viewing geometry

Fluorescence, as today understood

- Emission of X-ray radiation from photo-ionized cold material
  - Photo-ionizing photons come from star, cold material in circumstellar disk
- *If* Fe I Kα line at 6.4 keV is photo-ionized **then** photons energy need to be $E > 7.11$ keV
  - High-energy X-rays needed
- Fluorescence is a tracer of 'intimate relationships' between hard X-rays and cold material
- It can give clues to the geometry of the circumstellar material

DROXO Elias 29 Light Curve



Flare:
quite typical
Factor 8
in Intensity
Decay time
6 ksec

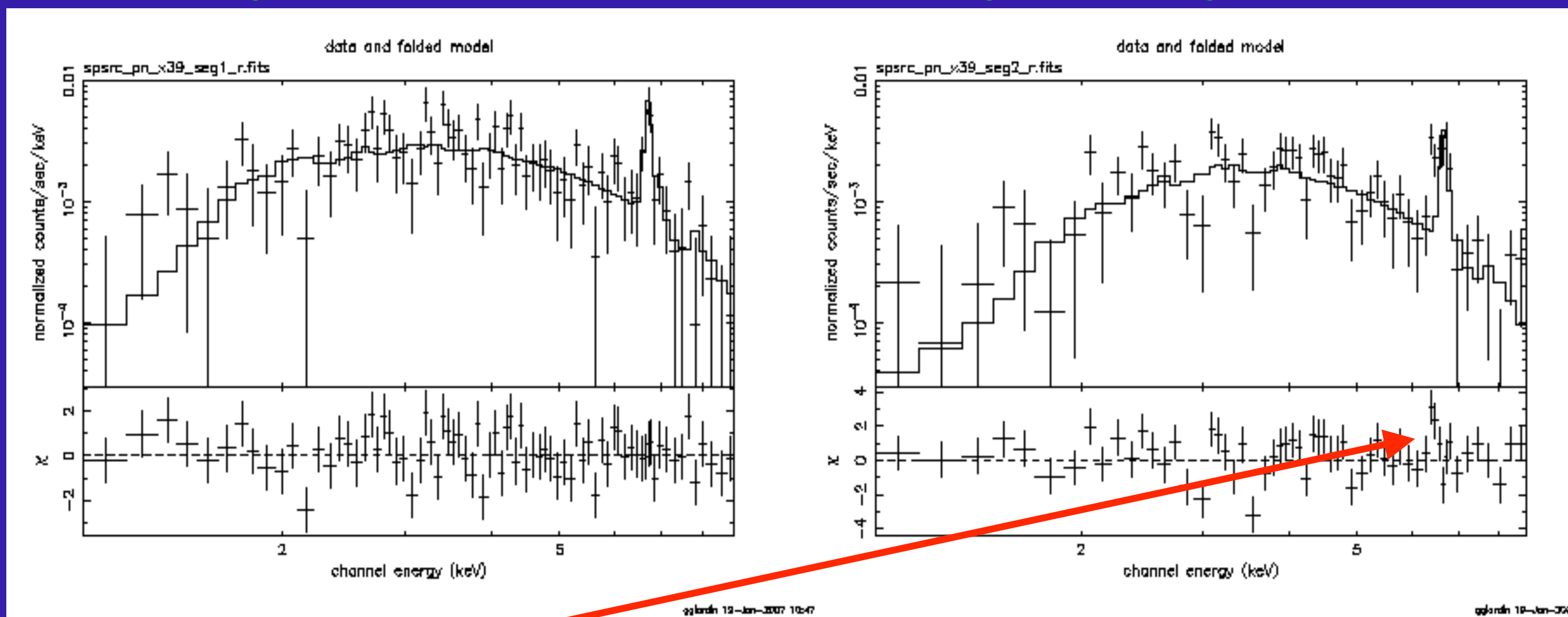
Elias 29
Class I YSO

DROXO
Light Curve

DROXO 500 ks look of Elias 29

Seg 1: before flare Seg 2: after the flare

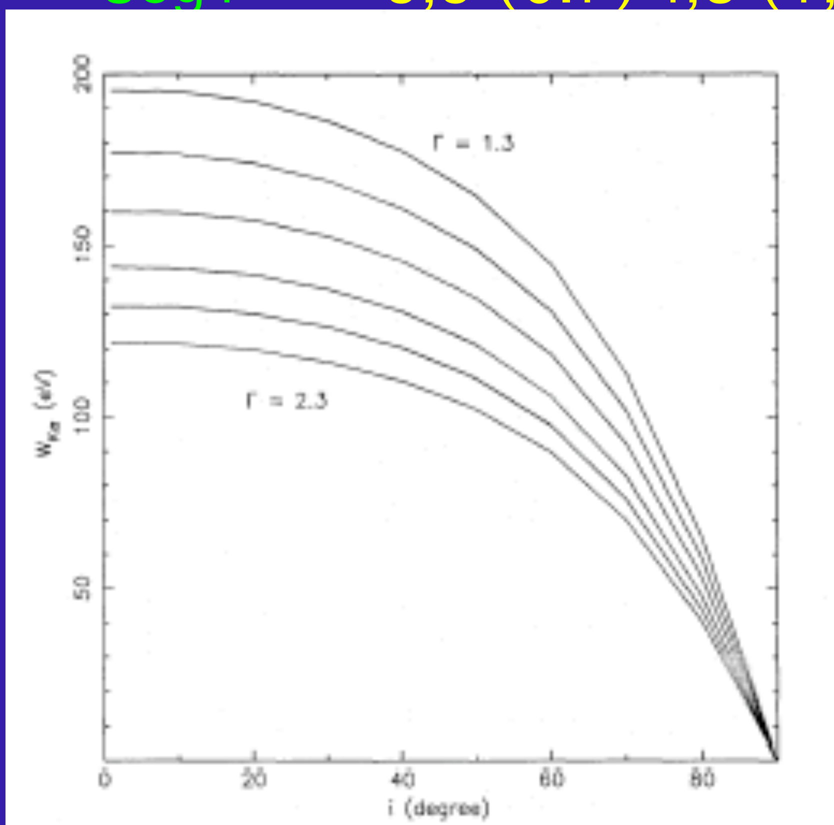
Flare quite typical: Factor 8 in intensity, Decay-time of 6 ksec



Fe 6.4 keV fluorescent line appears EW ~ 250 eV
It Stays Up for following ~ 300 ksec EW ~ 150 eV
Variability of Fe 6.4 keV line unrelated to variation of thermal spectrum, too large EW for hard photons in thermal spectrum
Sustained mechanism ionizing "cold" Fe must operate for days
(Giardino et al. 2007, submitted)

Fe 6.4 keV fluorescent line EW vs. Time

Interval	Nh[22]	kT[keV]	EW_Fe[eV]	Prob_line[%]
Seg1	5,5 (0.7)	4,8 (1,0)	13	45
		4)	60	23
		6)	249	0,1
		7)	108	4,2
		5)	68	3,5
		8)	162	0,2
		1)	147	0

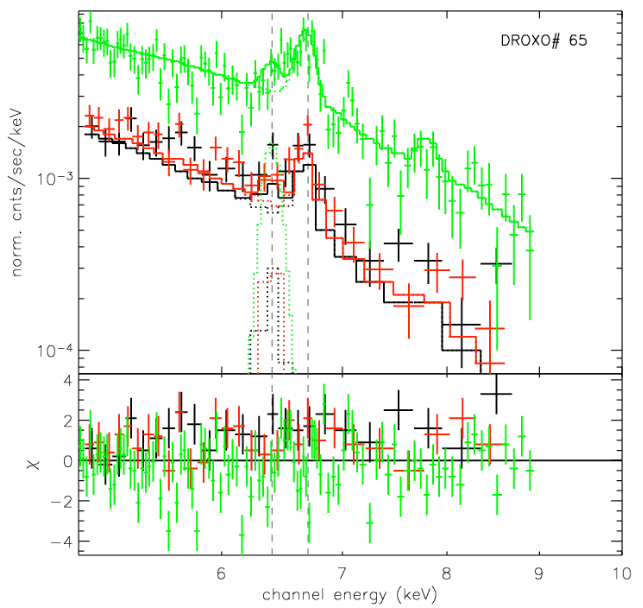


Not enough X-rays (E > 7.11 keV) for the observed Fe line EW

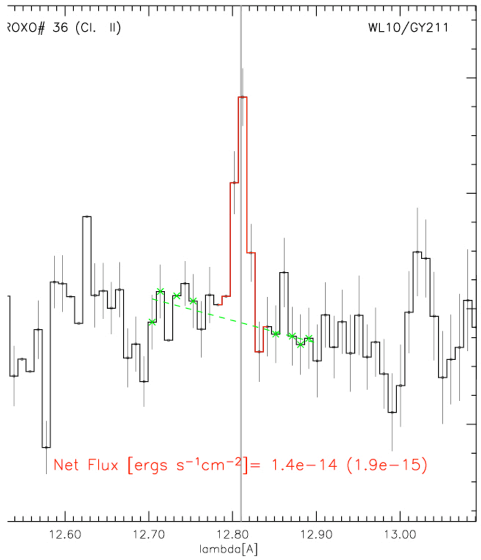
DROXO Elias 29 Fe 6.4 keV line

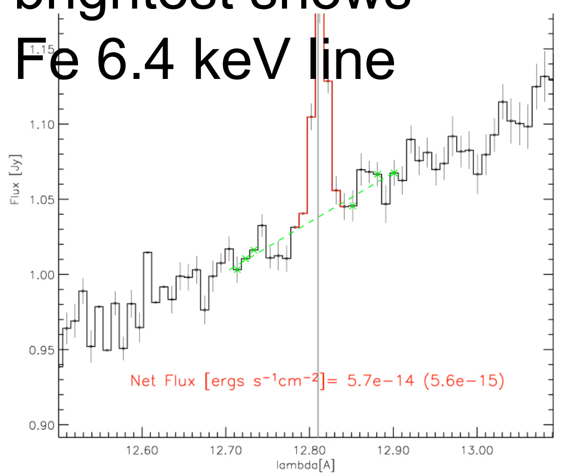
- Possible new scenario/explanation
  - Collisional ionization of K-shell electrons by a beam of non-thermal electrons (cf. Emslie et al. 1986)
- Scenario
  - In the magnetospheric accretion scenario, material is channeled in magnetic "tubes" from the disk to the star
  - Long-duration flares in YSOs provides evidence for flaring associated in these accretion streams.
  - The magnetic fields channeling the streams are stressed by differential rotation velocity between the star and the disk. This is a natural continuous "engine" for the reconnection events (and associated electron beams)

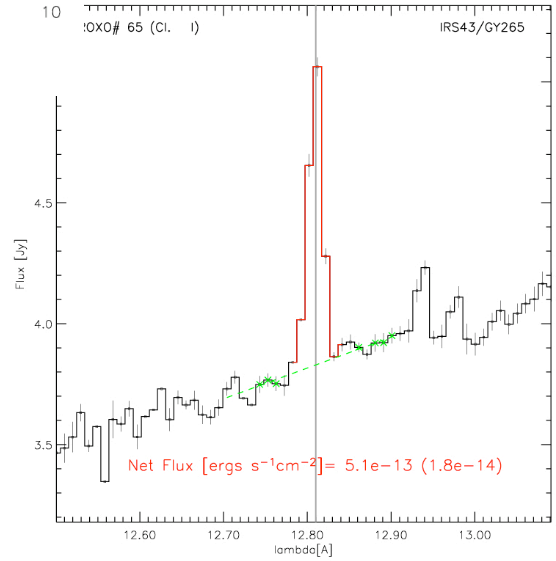
More on YSO Disk and X-rays



brightest shows Fe 6.4 keV line



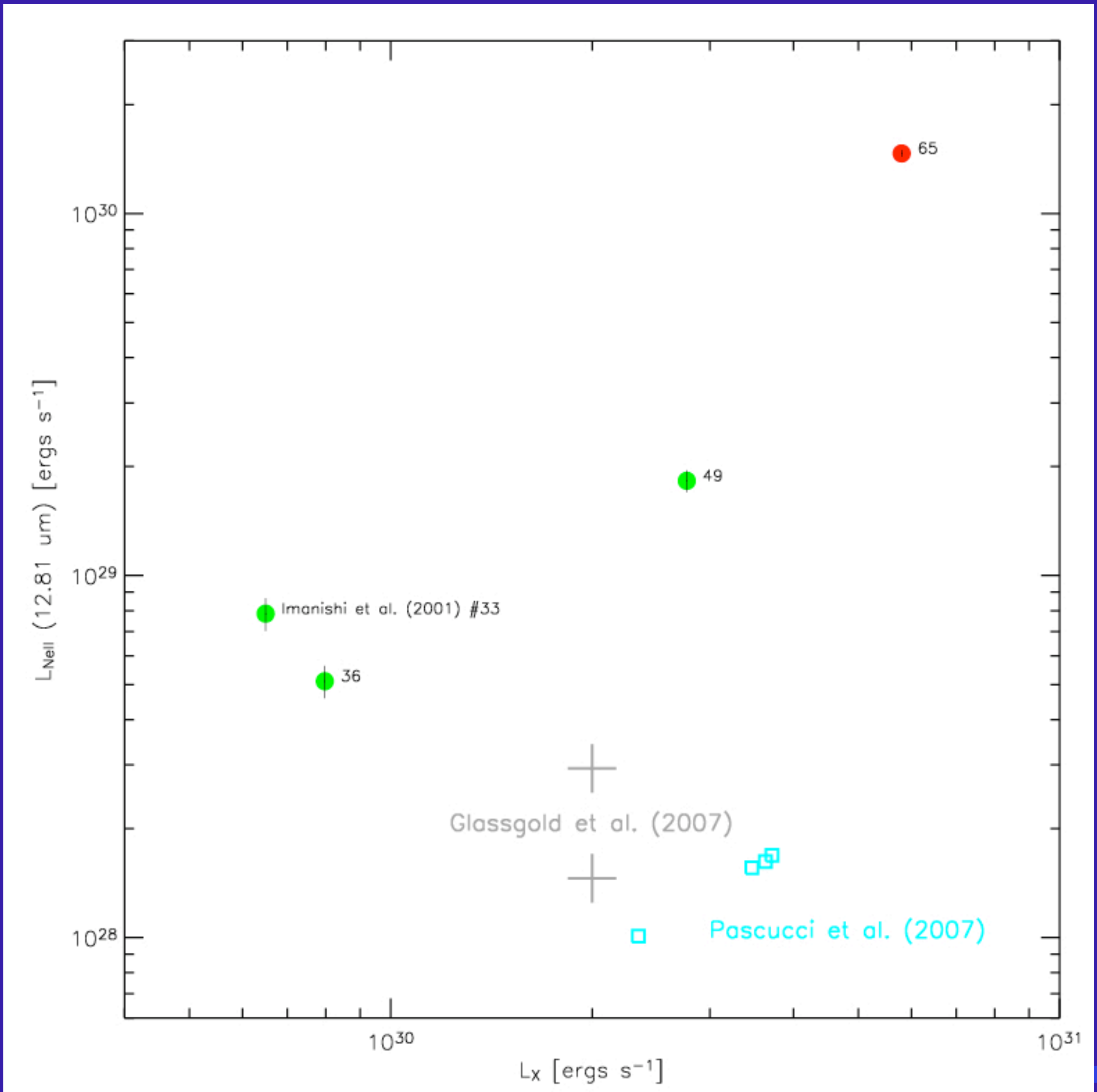




X-ray excited Ne Ir line predicted by Glassdold et al. (2007)
Line detected (Pascucci et al. 2007)

Line detected using Spitzer archive spectra in 4 rho Oph YSO seen in X-rays, 3 have DROXO EPIC spectra. (Flaccomio et al. 2007)

Ne IR line and X-ray luminosities



rho Oph L_{IR} higher than in “older” YSOs

Why ??

In perspective ...

- There is growing evidence of "interactions" between X-rays and YSO circumstellar disks: *big flare and the inferred long magnetic structures, Fe 6.4 keV fluorescent line, Ne Ir line X-ray excited*
- Our understanding of formation mechanism(s) of Fe 6.4 keV line is still limited
- DROXO time-resolved spectroscopy of Fe line challenges the "standard" Fe formation scenario
  ... but the Ne (IR) and Fe (X-ray) lines are there
- MORE LONG LOOK OBSERVATIONS AND TIME-RESOLVED SPECTROSCOPY NEEDED .....
  2-3 DEDICATED XMM PROGRAMS ON NEARBY SFRs OF, ***AT LEAST***, 0.5 MS EACH ARE NEEDED

THE END