The Chandra Orion Ultradeep Project

G. Micela on behalf of the COUP team

Coup: Chandra Orion Ultradeep Project

9.7 day nearly-continuous exposure of the Orion Nebula, Jan 2003

Principal Investigator: Eric Feigelson (Penn State)

Group leaders:

Data reduction and catalog	K. Getman (Penn State)
X-ray spectra & variability	G. Micela (INAF-OA Palermo)
Optical Variability	K. Stassun (Vanderbilt)
Origin of T Taury X-rays	T. Preibisch(MpIfR)
Embedded Stars	N. Grosso (Grenoble)
Brown Dwarfs	M. McCaughrean (AIP)
Massive Stars	T. Montmerle (Grennoble)
Effects of X-rays	F. Palla (INAF-Arcetri)

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13 papers published in the ApJS special issue of October 1st

and

others in preparation

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THE *CHANDRA* ORION ULTRADEEP PROJECT

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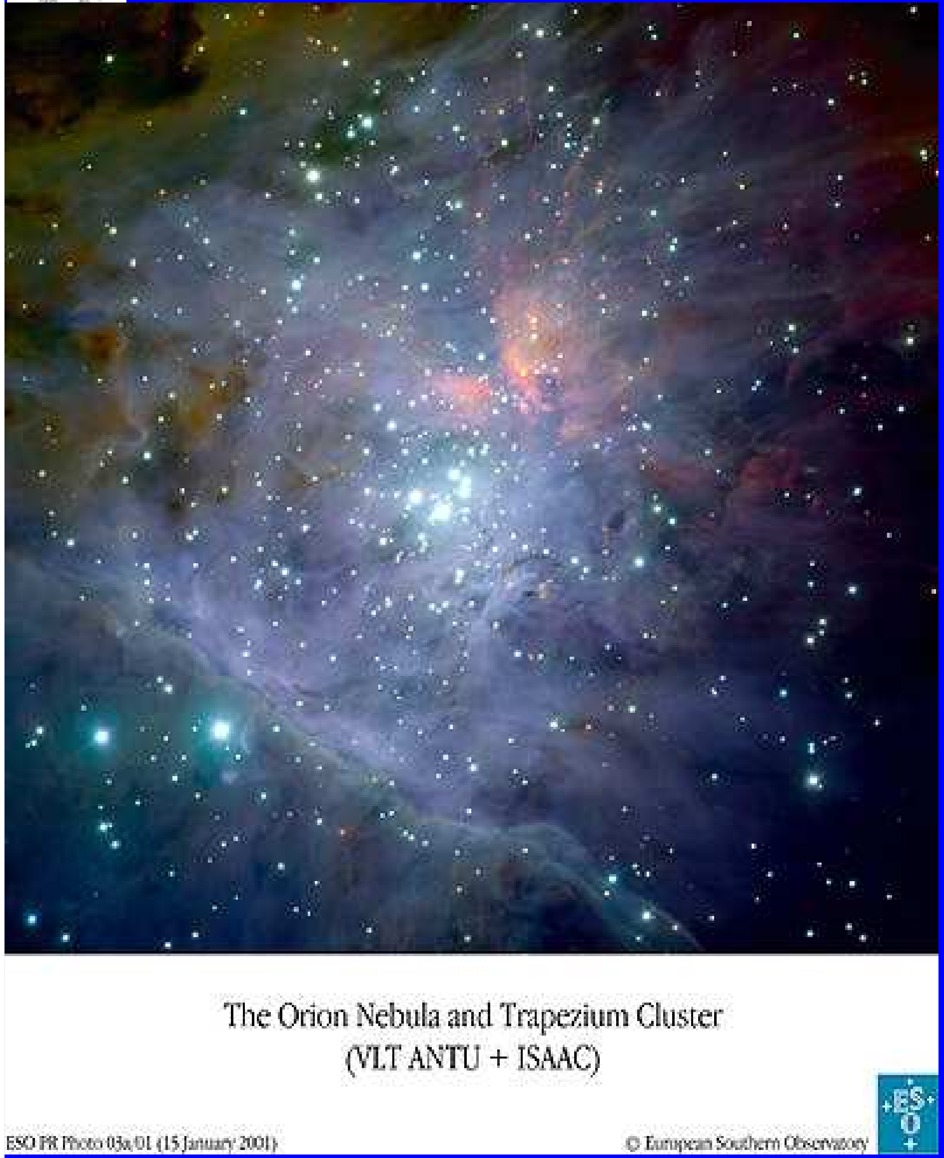


Orion Nebula Cluster
(0.5 kpc)
about 2000 members
just formed

A laboratory to study the role of high energy radiation during the stellar formation

Why to study X-rays in star formation regions?

- Physics of young stellar coronae (-> the early Sun)
- Stellar populations (-> embedded objects -> starburst galaxies)
- Irradiation in the circumstellar environment (-> disk evolution and formation of proto-planetary system)

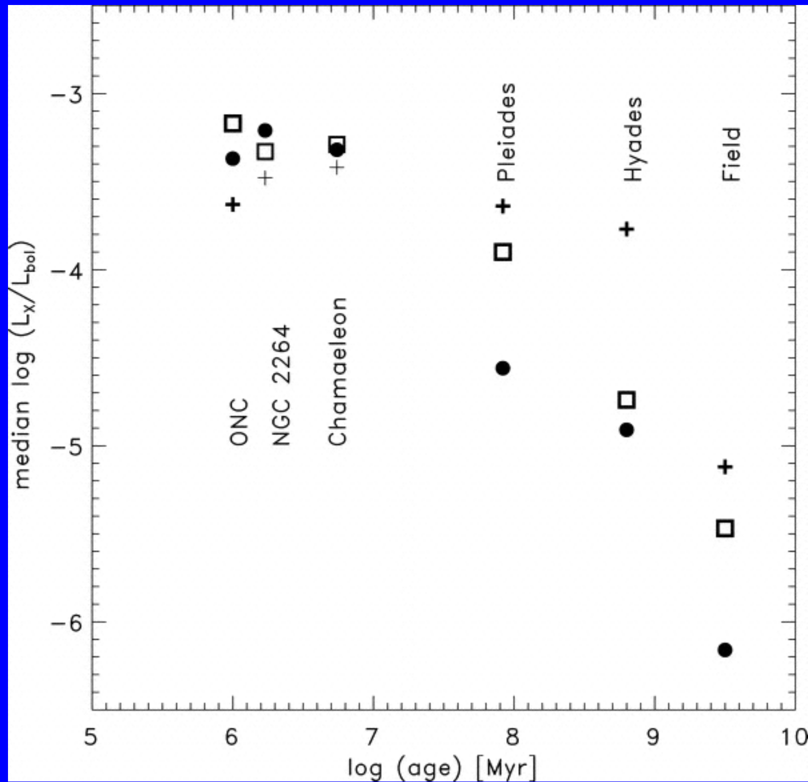
The observation

- January 10-22, 2003
- 850 ks of continuous ACIS-I time
  - 150 ks GTO from the HRC and ACIS teams
  - 700 ks GO. (PI E. Feigelson)
- Continuous except for 5 data gaps caused by Earth passage.
- Locked roll angle
- Very low background (great luck!)
- More than 1600 sources – 10/100000 photons per source

SPECTRA AND VARIABILITY

Physics of young stellar coronae

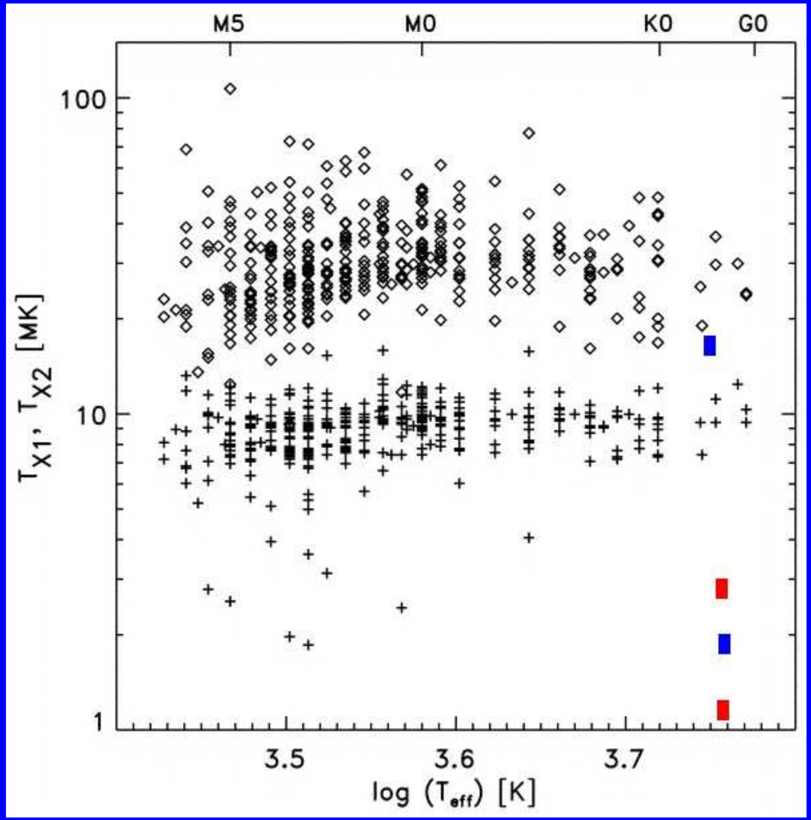
- X-ray luminosity decays by 1000-10000 from the PMS to the solar age
- Explanation related to the complex rotation history



Preibisch & Feigelson 2005, ApJS

Physics of stellar coronae: spectra

- Young stellar coronae are much hotter than solar corona, even of the flaring Sun (blue symbols)
- Continuos flaring emission?

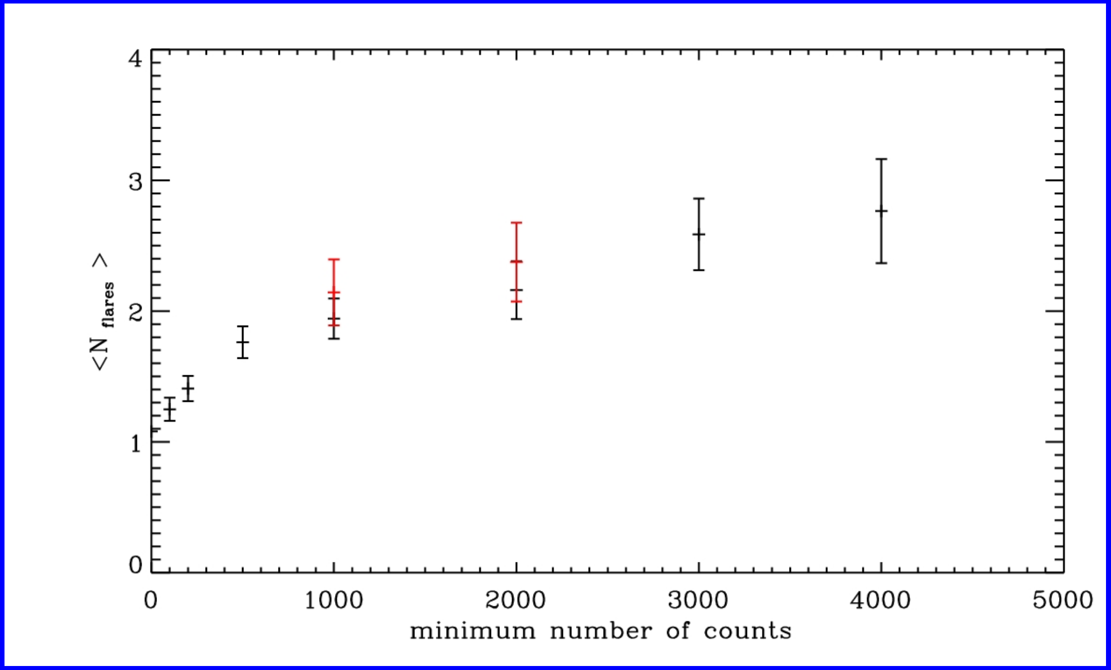


Preibisch et al. 2005, ApJS

Physics of young stellar coronae: variability

- Young stellar coronae are much more variable than solar corona

- Flare frequency is independent of stellar mass (solar mass, low-mass stars)



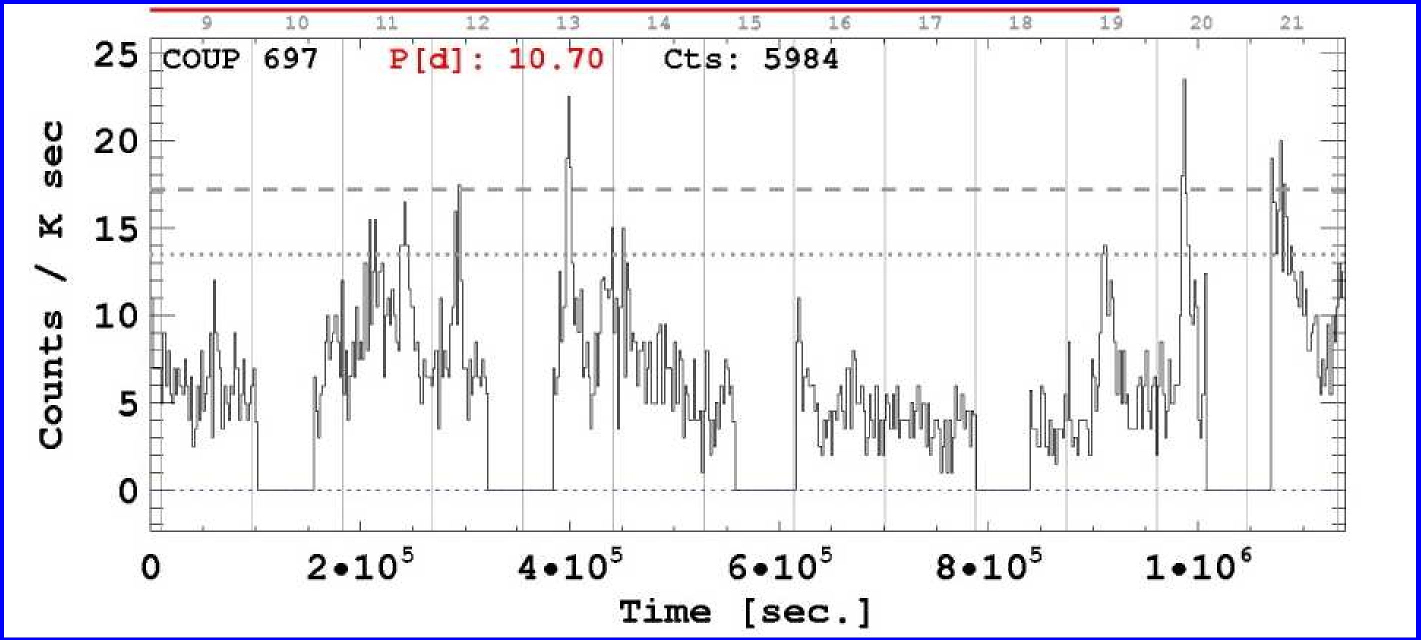
Wolk et al. 2005, ApJS
Caramazza et al. (poster)

Physics of young stellar coronae: variability

- Emission of young stars may be explained by continuous flaring *(Caramazza et al., see poster).*
- Variability properties evolution depends on stellar mass, likely following the mass-dependent evolution of stellar structure

Physics of young stellar coronae: structure

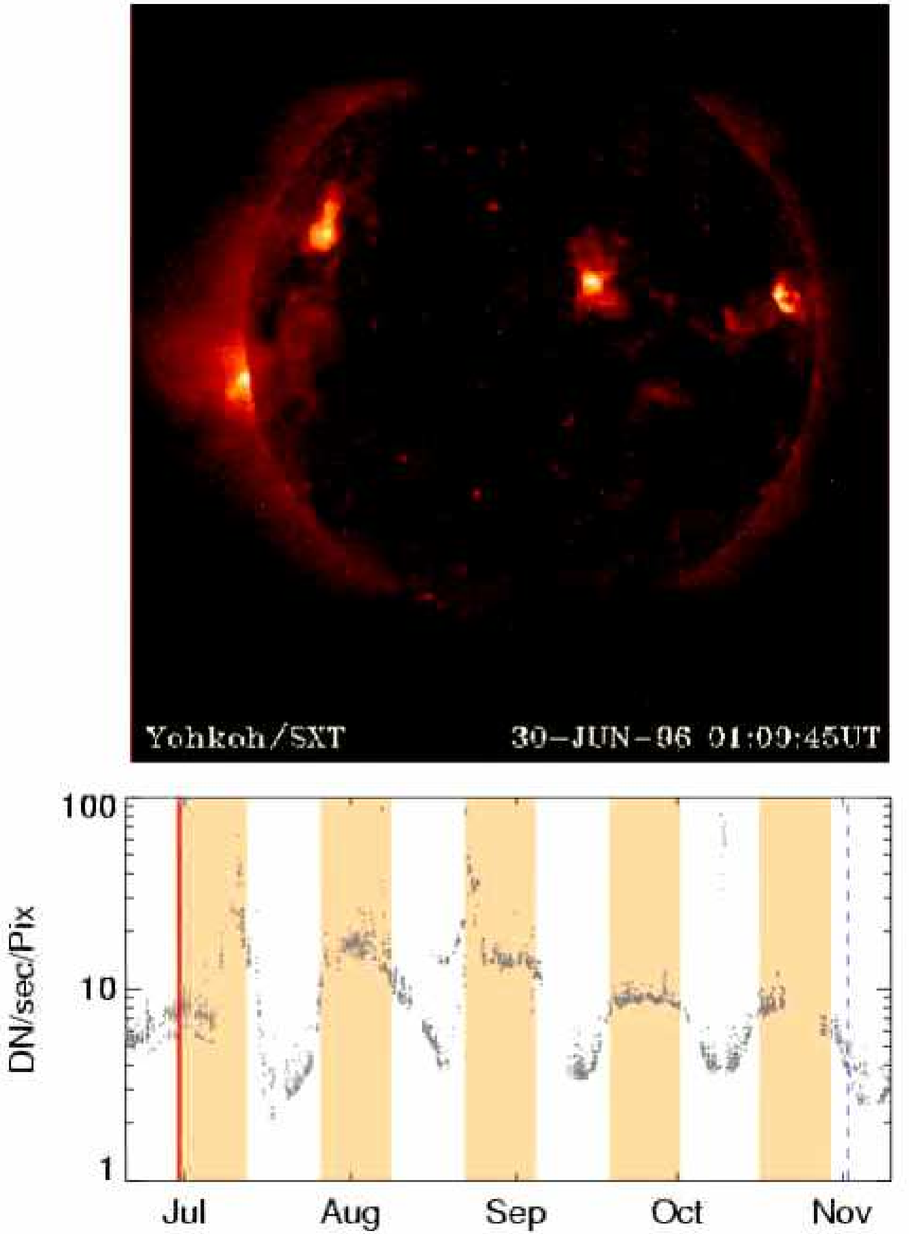
Emission may come from compact emission regions (rotational modulation)



Flaccomio et al. 2005, ApJS

X-ray Rotational Modulation observed in the Sun – Yohko data

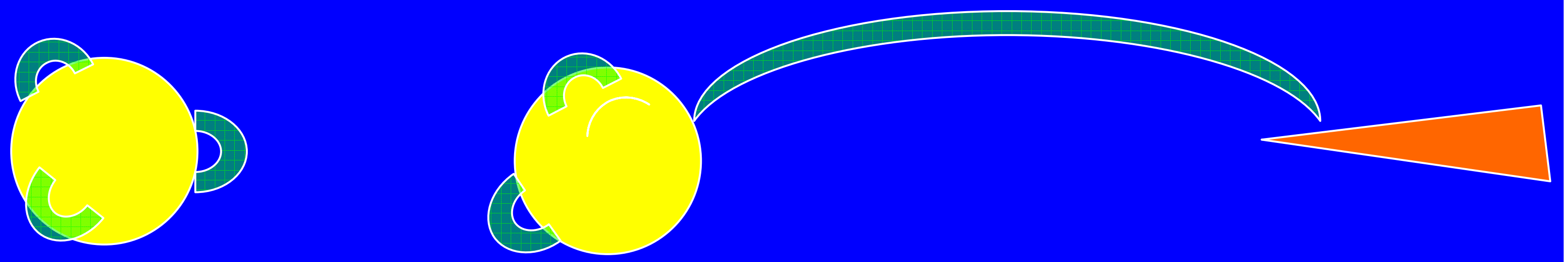
(courtesy of S.Orlando)



Physics of young stellar coronae: structure

but also from very long structure, possibly connecting star with circumstellar disk

(Favata et al. 2005 ApJS)



Normal Stars

Pre main sequence stars with disks

Very long structures from long flares

COUP 1343: tau~40 ks

very hot plasma (100 MK)

almost free decay

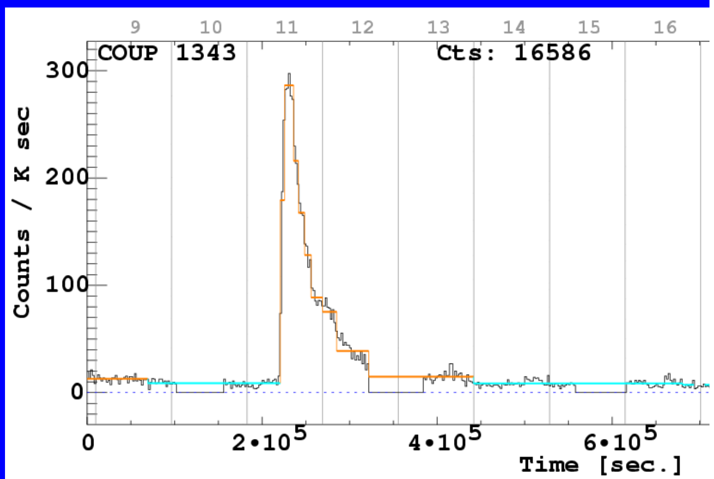
fast temperature decay

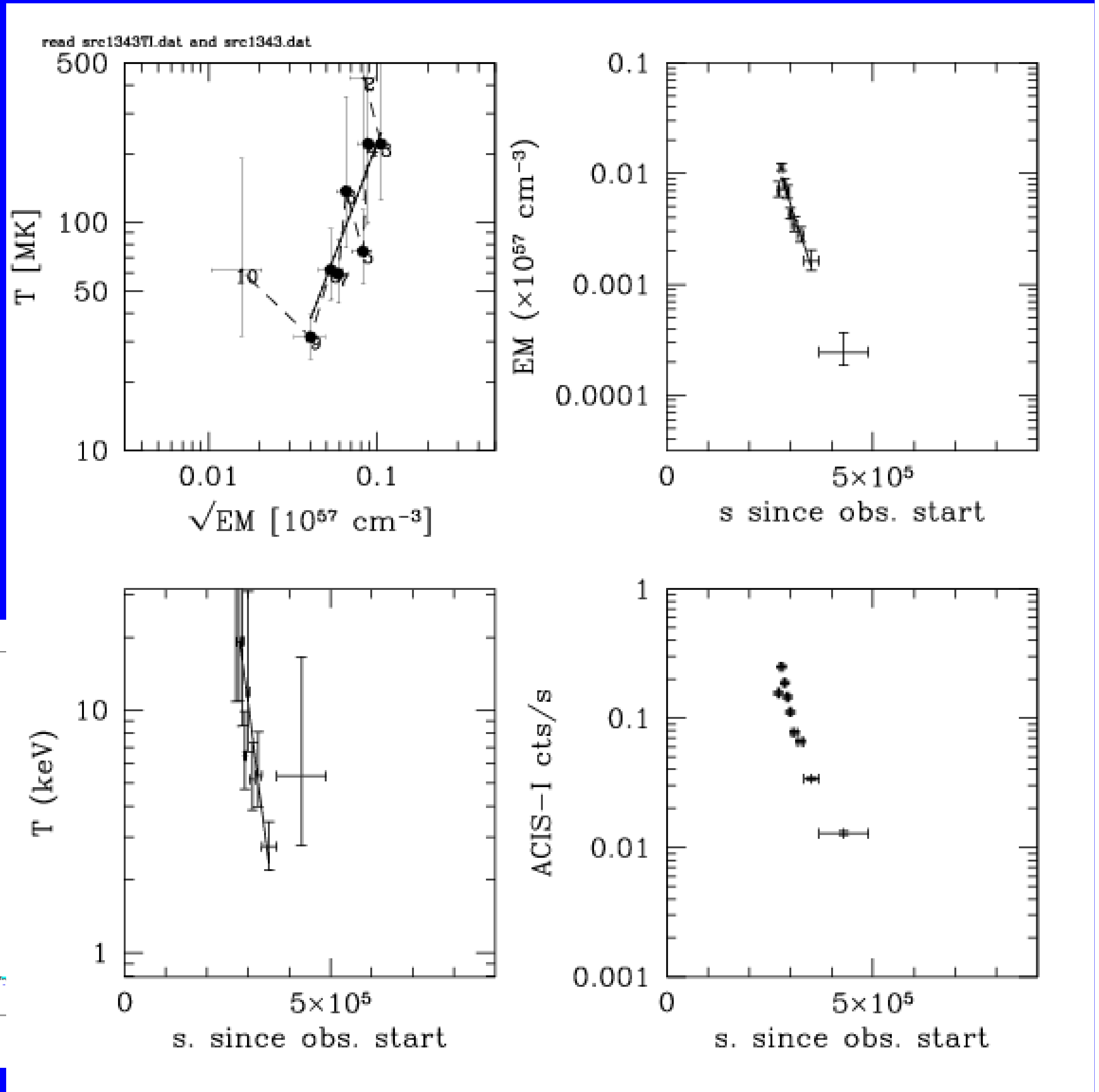
<u>Long loop</u>

2×10^{12} cm (~0.1 AU!)

Confining *B* field 150 G

(Favata et al ApJs)

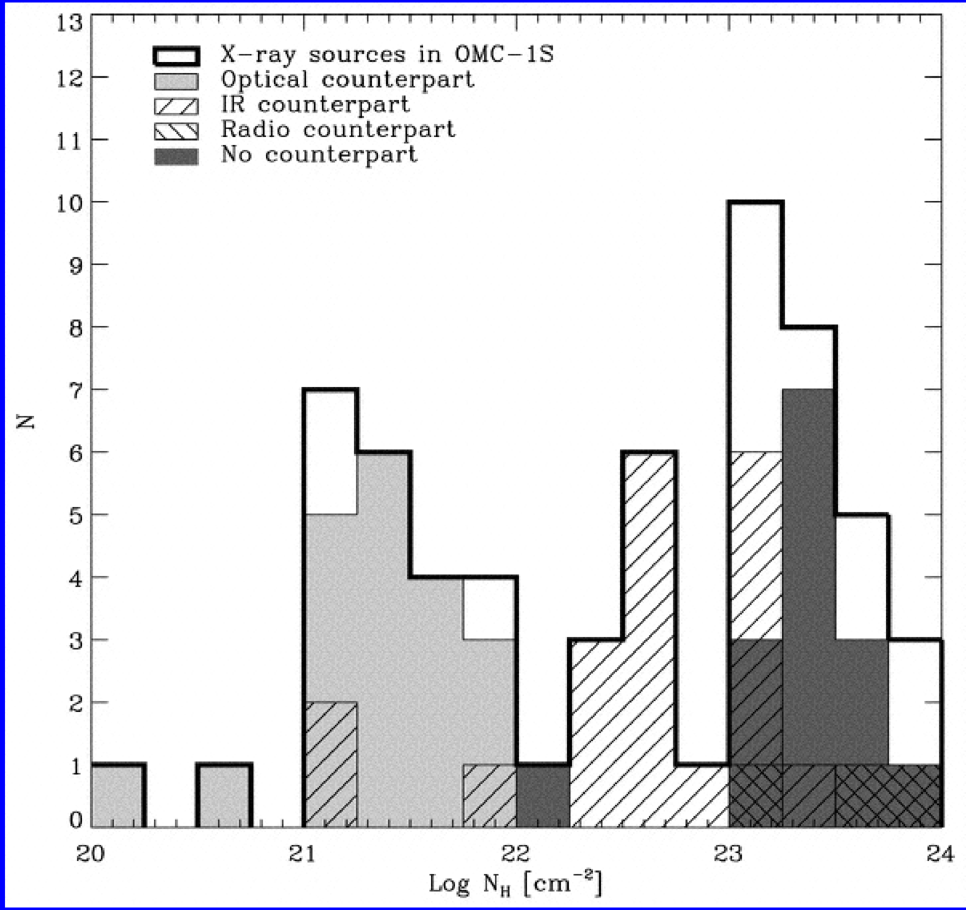




Stellar Populations

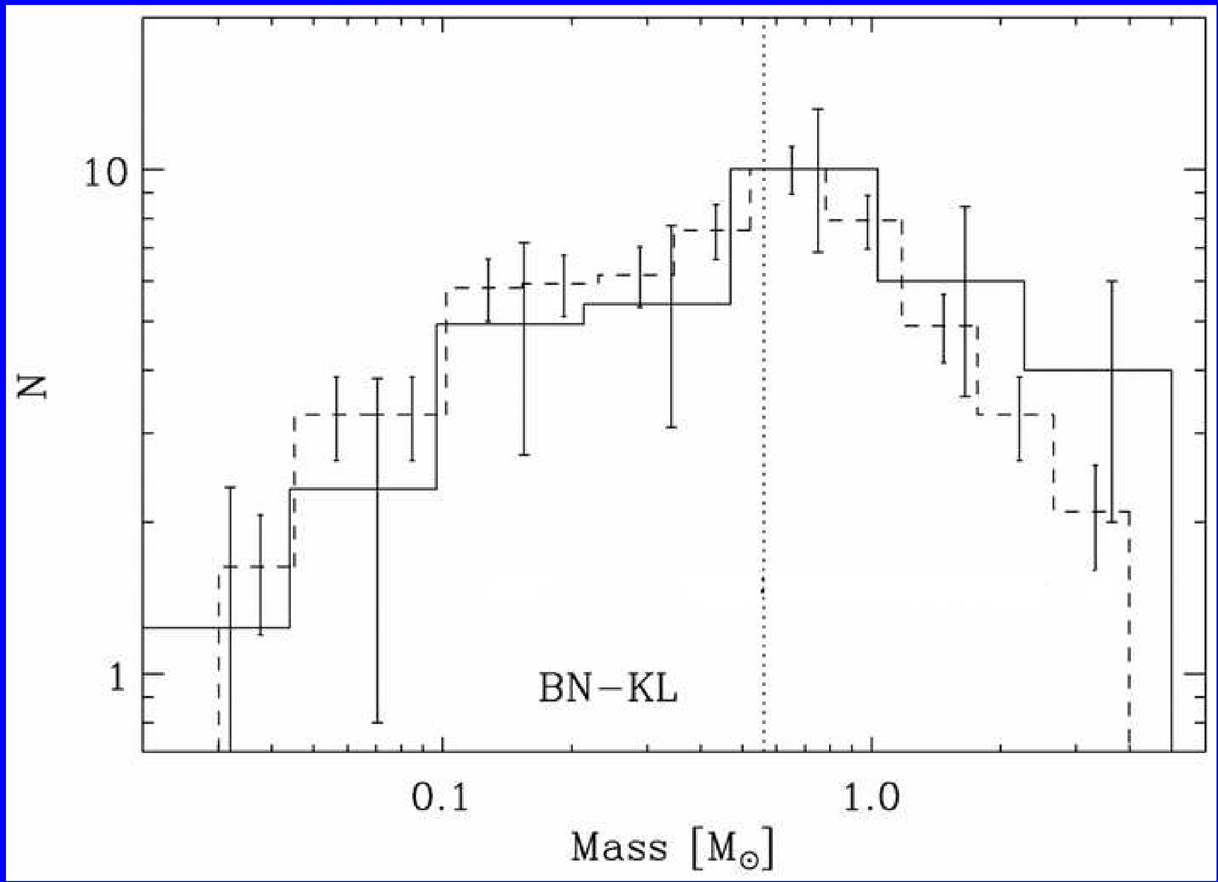
X-rays penetrate very deep in the interstellar medium and are very efficient in identifying embedded young stars

Stellar Populations



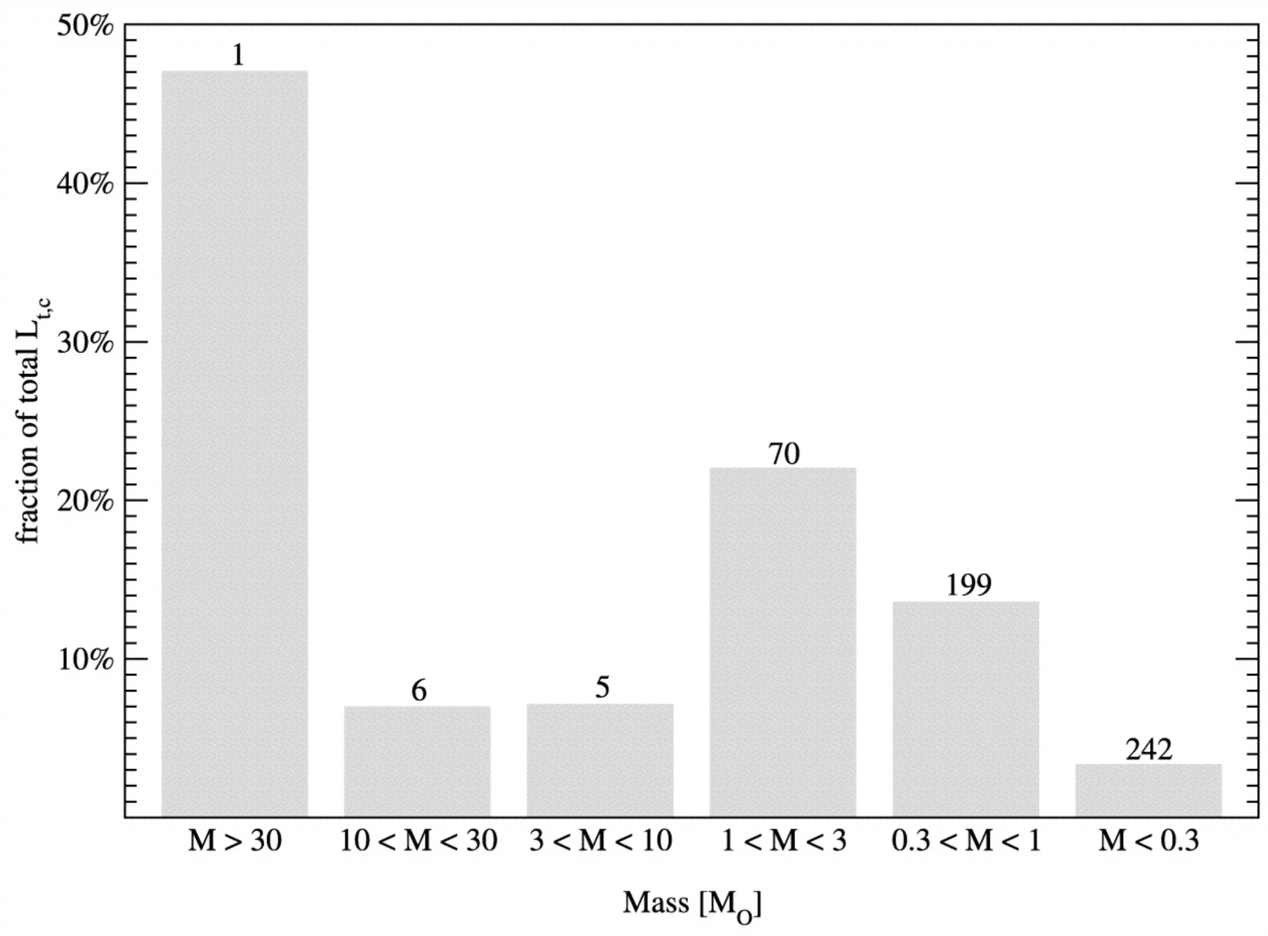
Very embedded sources are detected in high density regions (Grosso et al. ApJS)

Stellar Populations



The mass distribution of very embedded source and lightly absorbed populations are very similar (Grosso et al. ApJS)

Stellar Populations



Fraction of X-ray luminosity contributed by different mass intervals.
(Feigelson et al. ApJS)

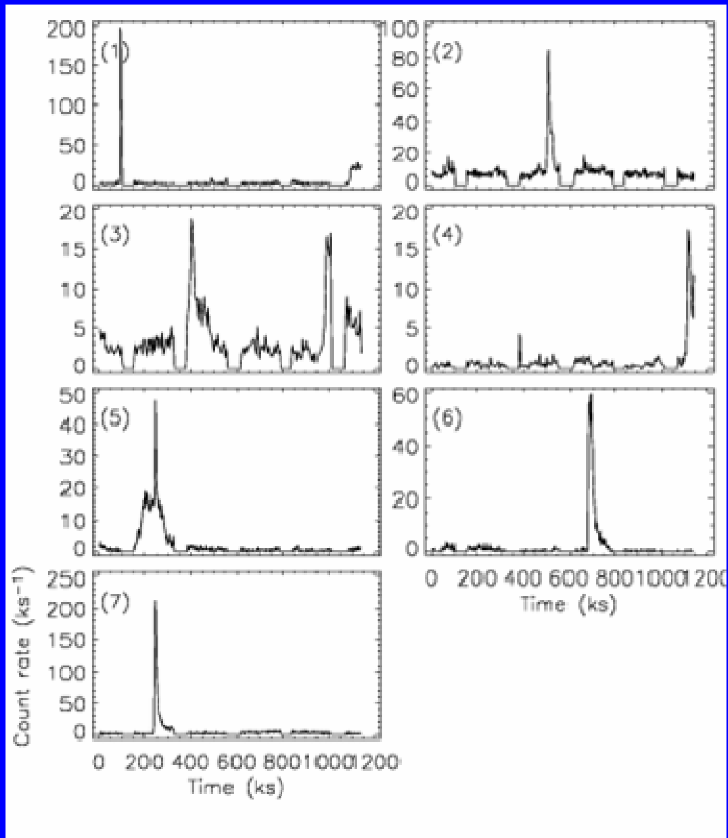
Effects of X-rays on the environment

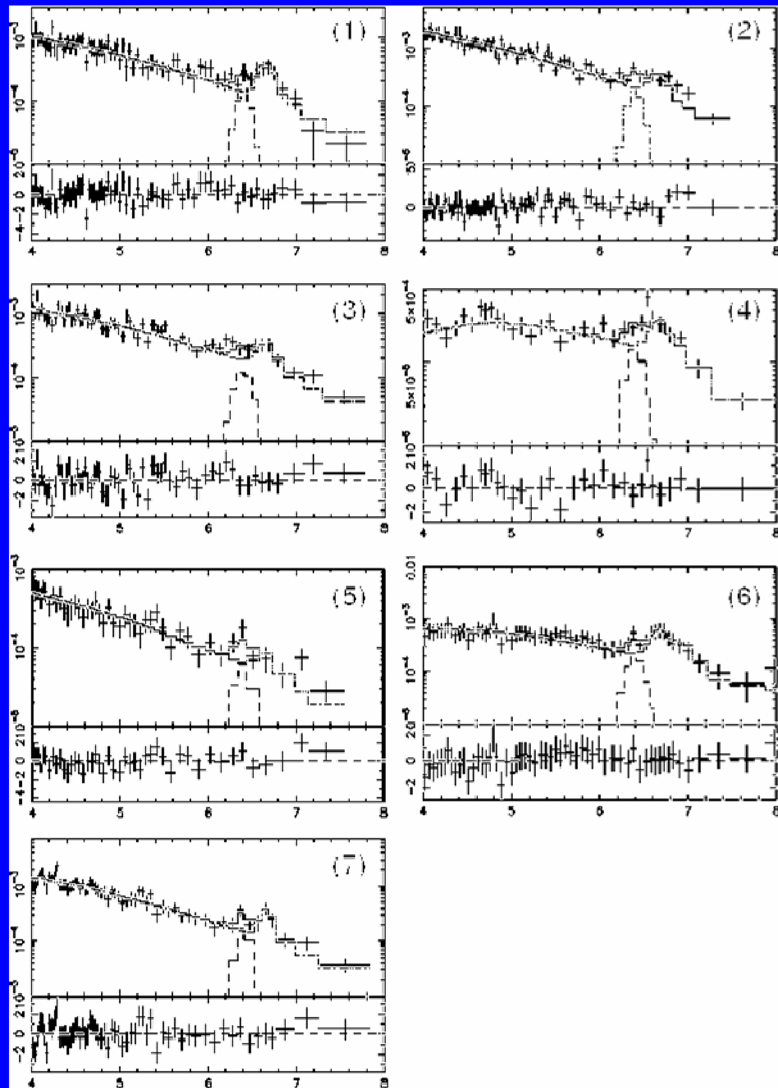
- On small (planetary) and large (mol. cloud) scale evolution?
- On accretion of YSOs ?
- On chemistry of protoplanetary disks
  - How do complex molecules form?
    - Catalyst processes?
  - Isotopic ratios?

Effects of X-rays on the environment

- X-ray-induced ionization crucial for disk-*B* field coupling
  - e.g. viscous friction, accretion rate
- Strong hints for chemistry in accretion disks being significantly affected by X-rays
  - Detection of calcite in YSOs disks by Ceccarelli et al. requires 'ice thawing'

Interaction with disks: detection of the iron fluorescent line

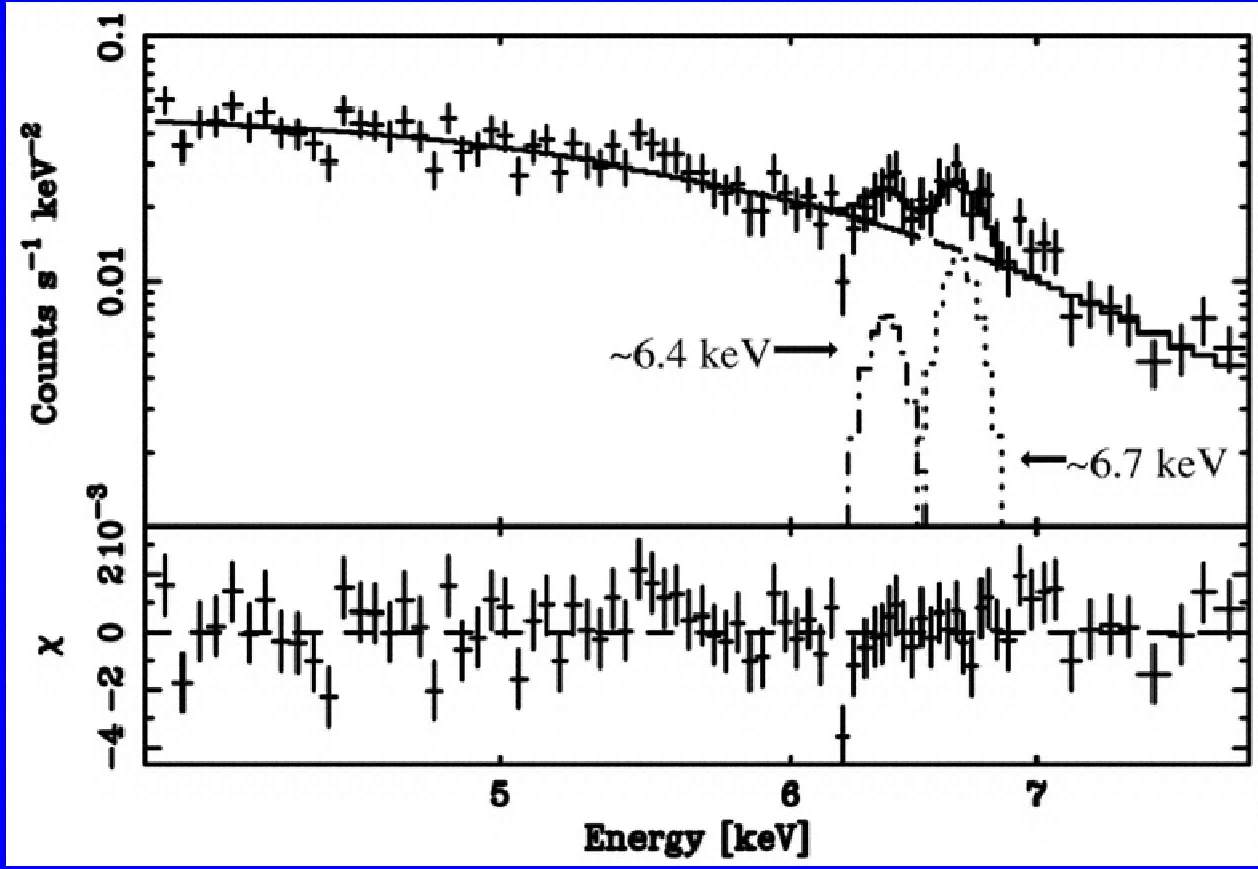




7 COUP sources presents the 6.4 keV fluorescence line.
(Tsujimoto et al. ApJS)

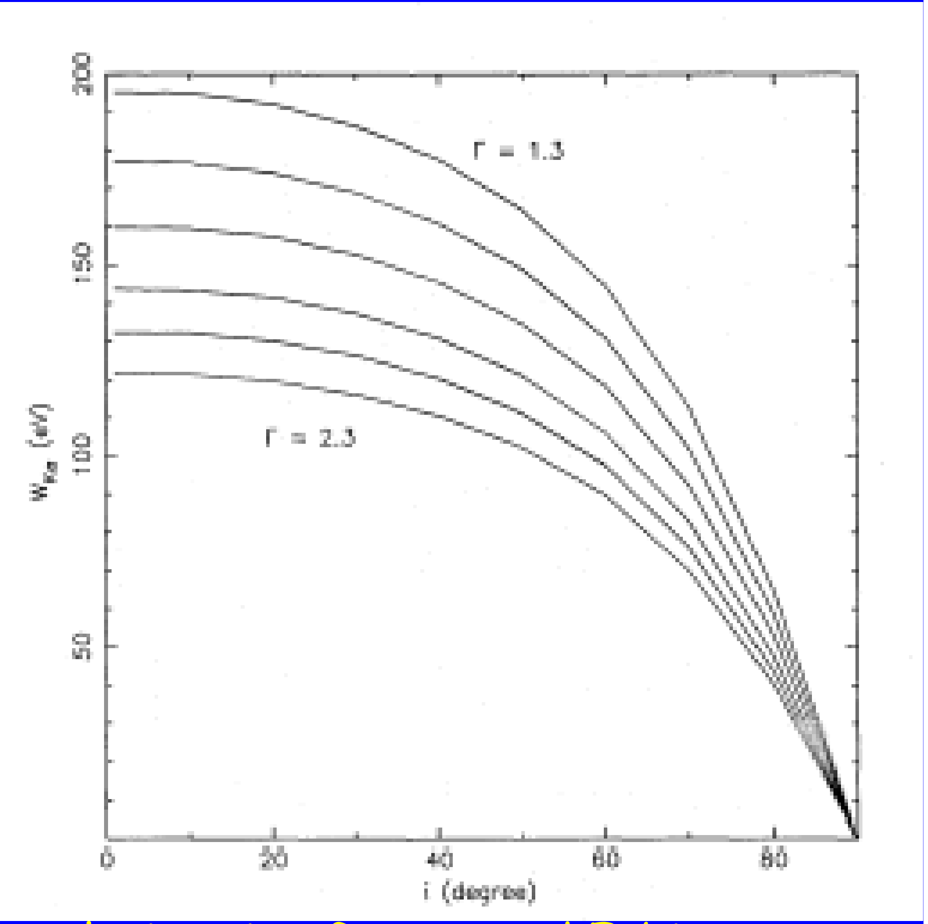
Interaction with disks: detection of the iron fluorescent line

YLW16a (rho Oph) the first fluorescent line observed in a PMS star, observed with Chandra during a flare.
(Himanishi et al. 2001)



Elias 29 in rho Oph

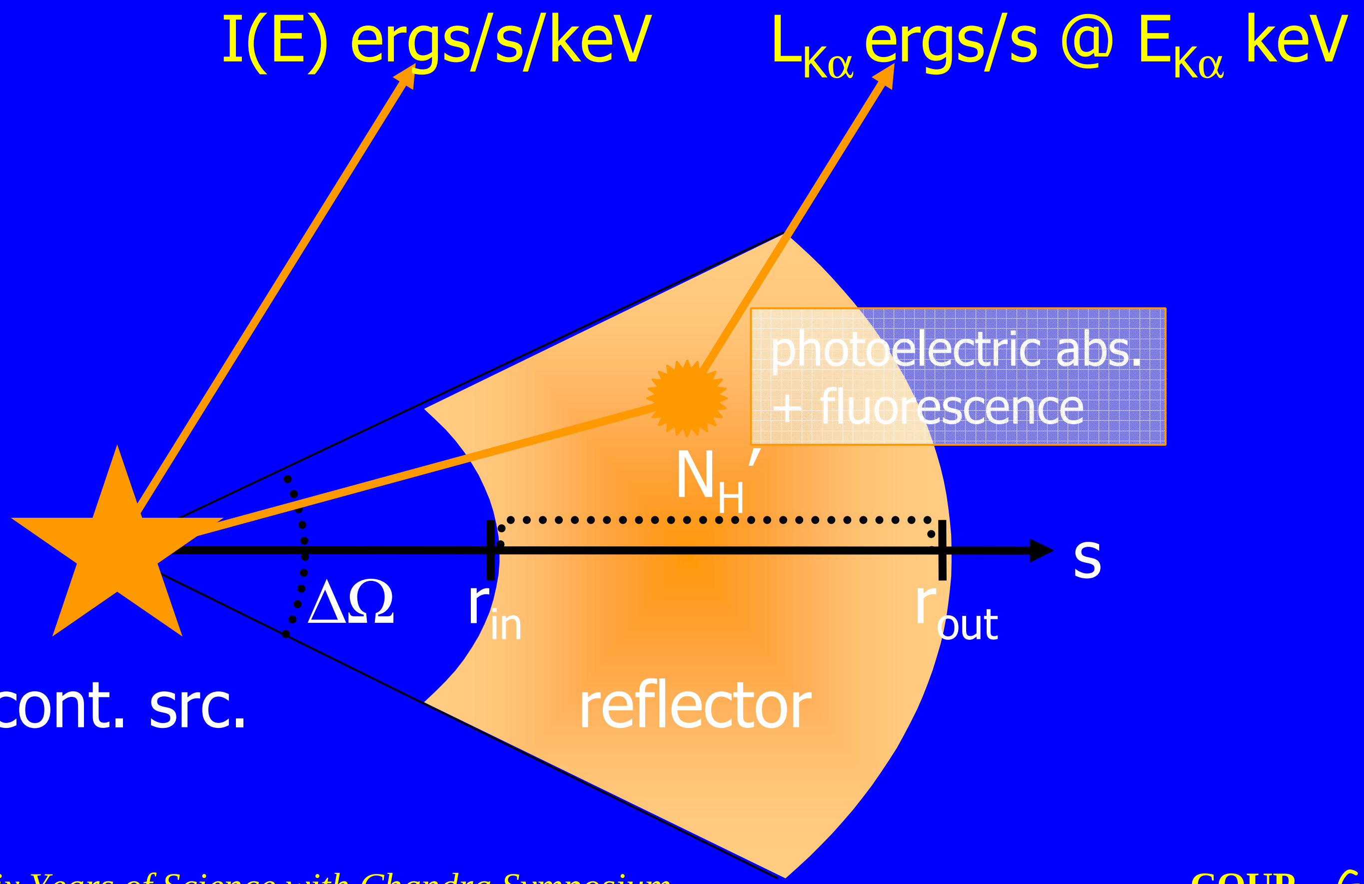
- EW(6.4 keV) = 150 eV requires a centrally illuminated disk *and* face-on viewing geometry *(Favata et al. 2005)*
- IR observations (Boogert et al. 2002) indicate face-on disk
- Chiavassa et al. (2005) observe calcite around Elias 29, => liquid water from X-ray heated ice on grain surface
- Ceccarelli et al. (2002) find superheated gas in disk, likely UV/X-ray induced



Analysis using George and Fabian (1991) for a PL exciting spectrum

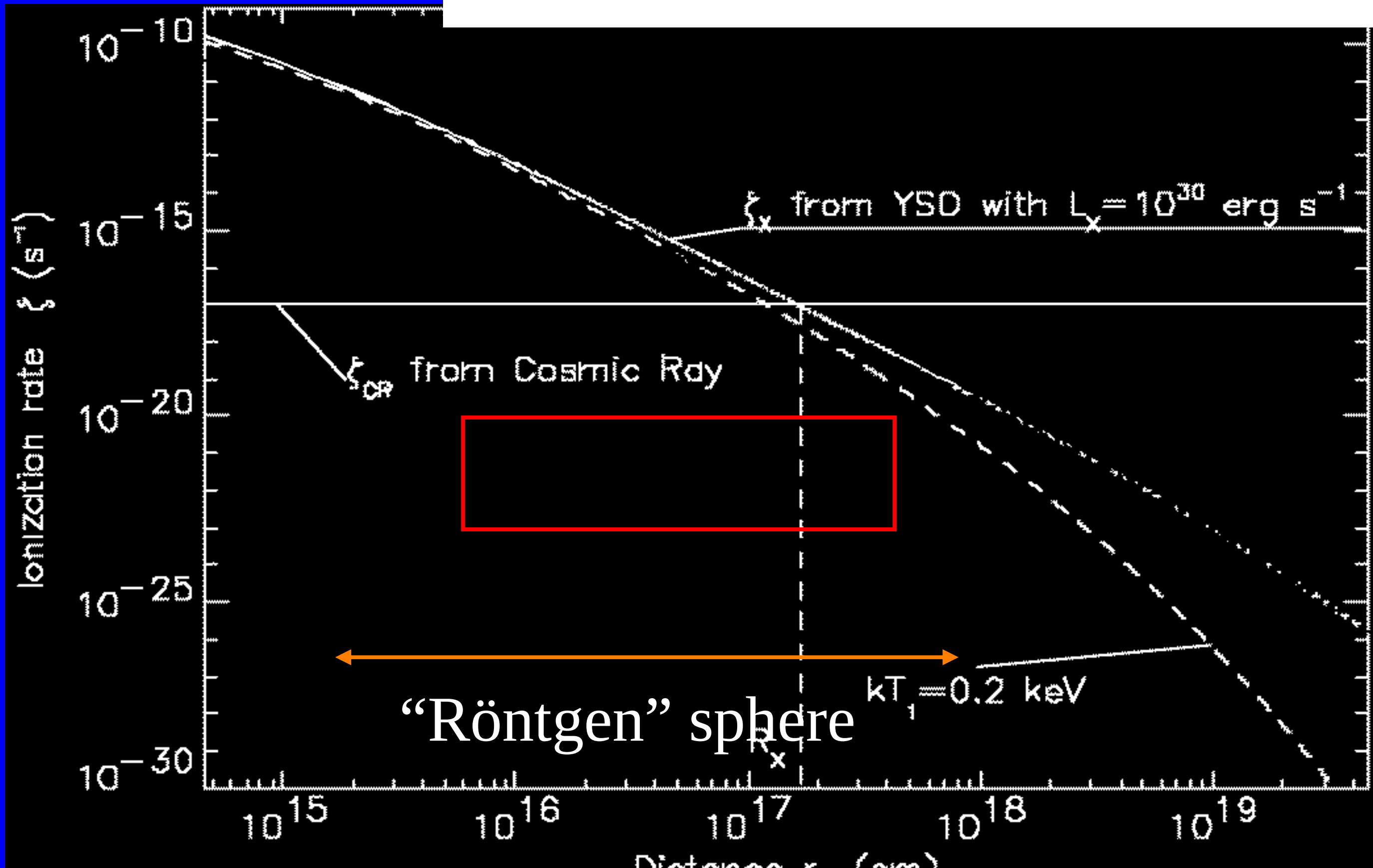
Schematic view of the reflection geometry

$EW_{K\alpha}$ requires optically thick process



Variation of the ionization rate as a function of distance from the central X-ray source:

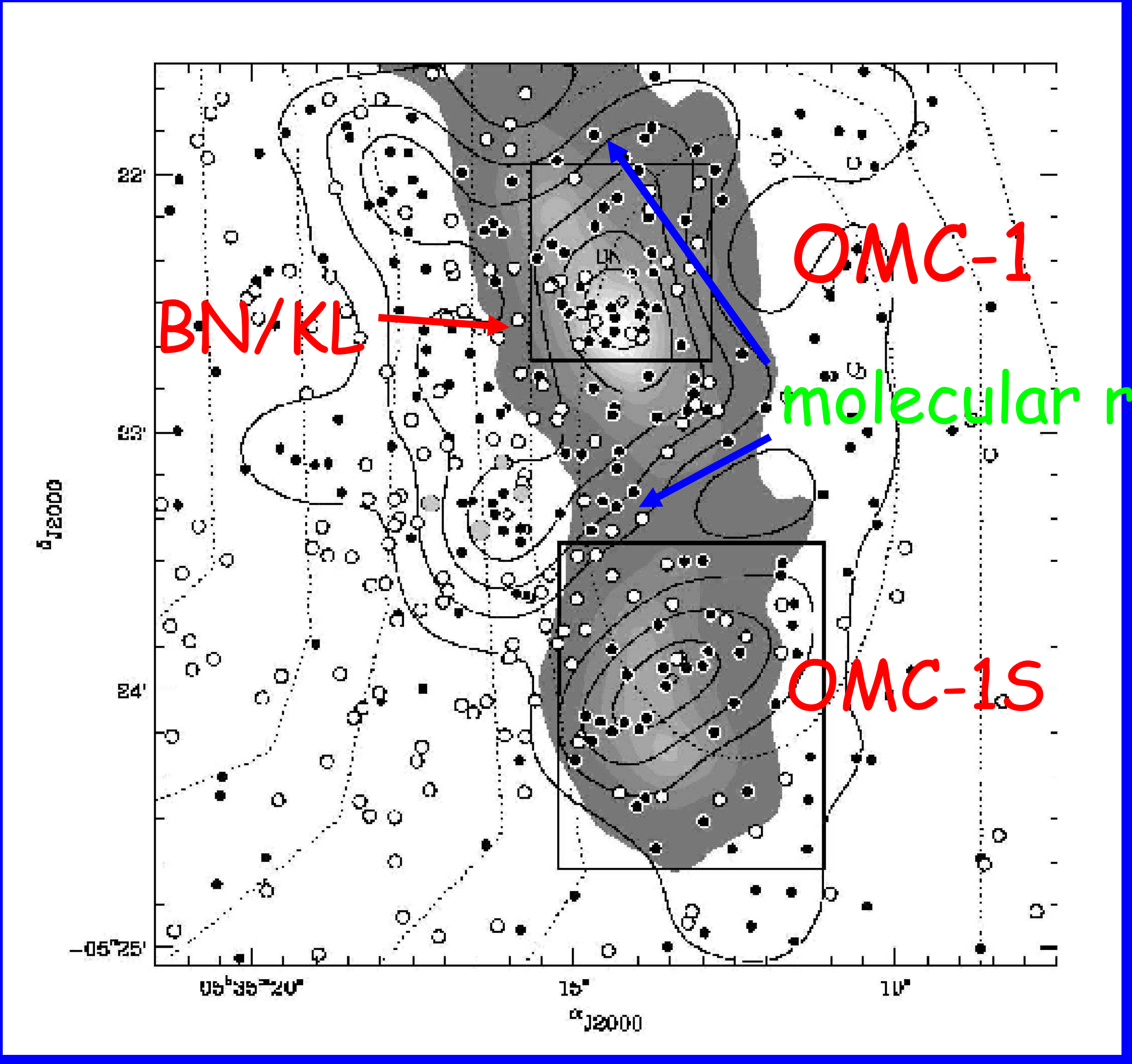
$$\zeta_X = 1.7 \frac{L_X \tilde{\sigma}}{4\pi r^2 \Delta\epsilon} \frac{\int_{\nu_0}^{\infty} J_\nu \left(\frac{\nu}{\nu_X}\right)^{-n} e^{-\tau_X \left(\frac{\nu}{\nu_X}\right)^{-n}} d\nu}{\int_{\nu_0}^{\infty} J_\nu \, d\nu} \ \mathrm{s}^{-1}$$



Typical range <~0.1 pc

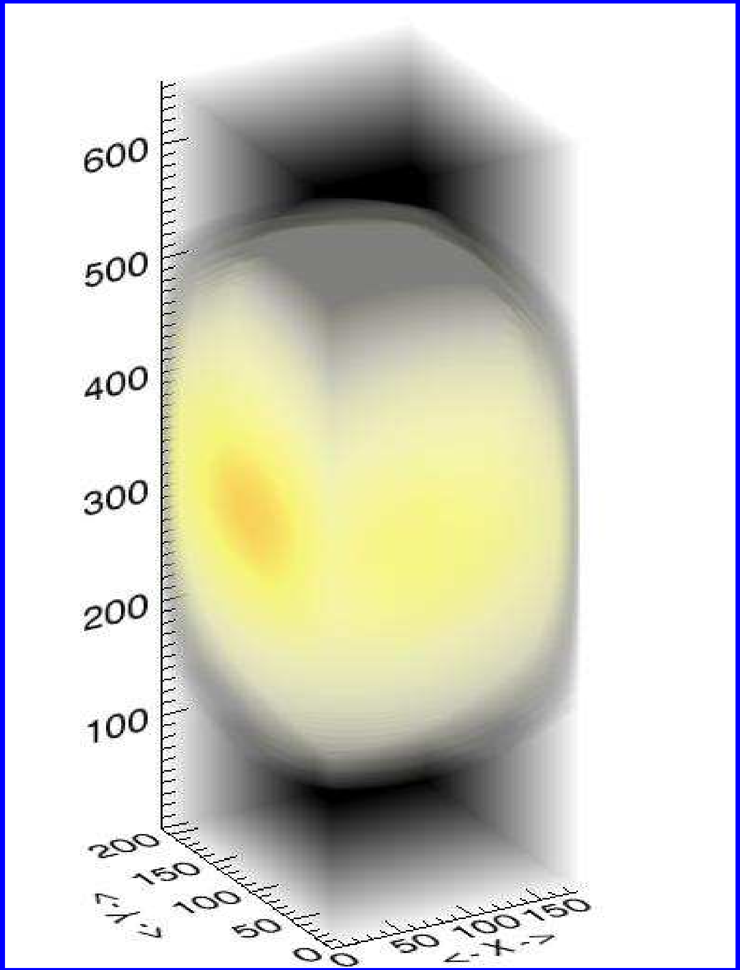
Lorenzani & Palla 2005, in prep.

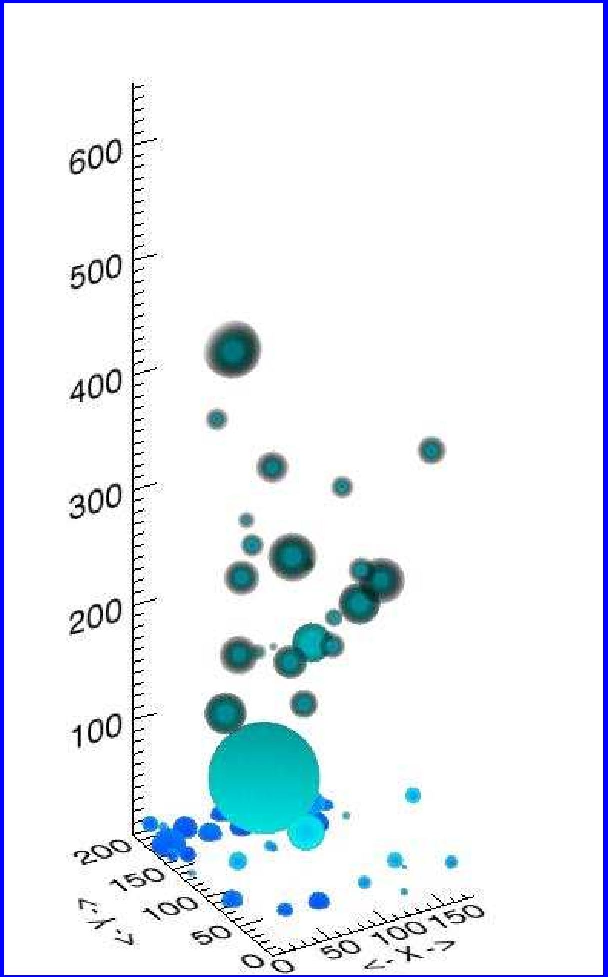
OMC-1 and OMC-1 South

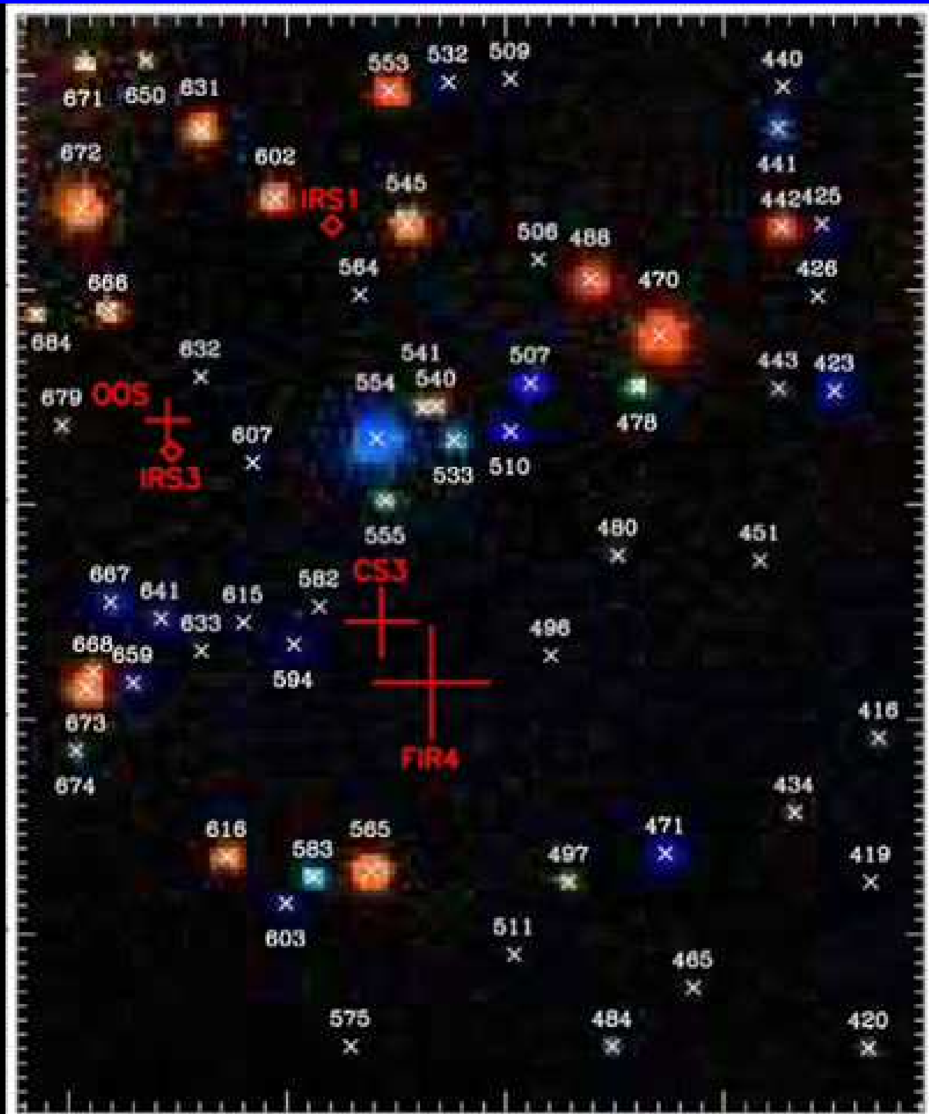


OMC -1S Model A *(Lorenzani & Palla in prep)*

Gaussian 1	Peak 1.3 $\cdot 10^6$ cm^{-3}	σ =30"
Gaussian 2	Peak 10^6 cm^{-3}	σ = 30"
Density	Base = 3 $\cdot 10^5$ cm^{-3}	Average =6 $\cdot$ 10^5 cm^{-3}



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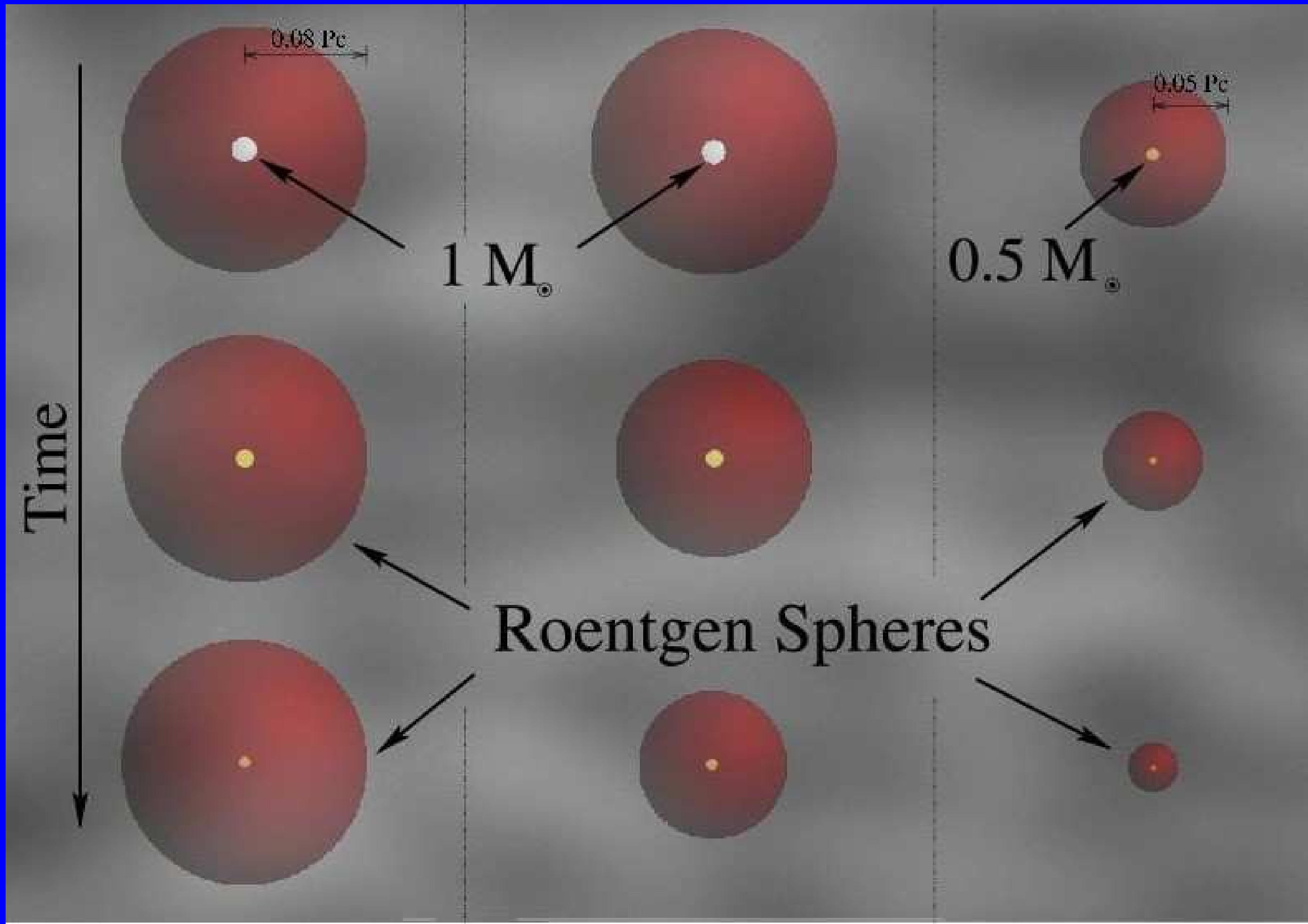
Possible variation of the size of the Roentgen spheres as a function of age



Summary (1)

X-rays observations of star forming regions allow us:

- To study the properties of the very young coronae (structuring, plasma temperature and variability)
- To unveil the presence of a significant embedded very young population, otherwise unknown
- To study the effects on circumstellar environment both on small and large scales

Summary (2)

In this context COUP is a milestone and will be a reference case for several years for the study of other star forming regions

It provides a wealth of data that has produced and will produce a lot of new science