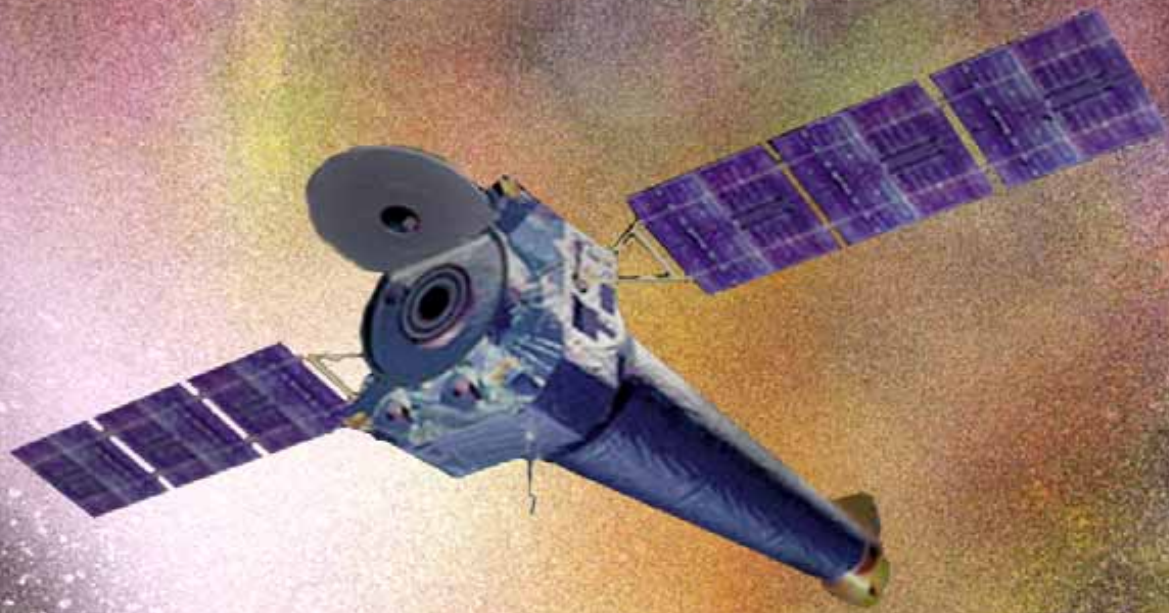
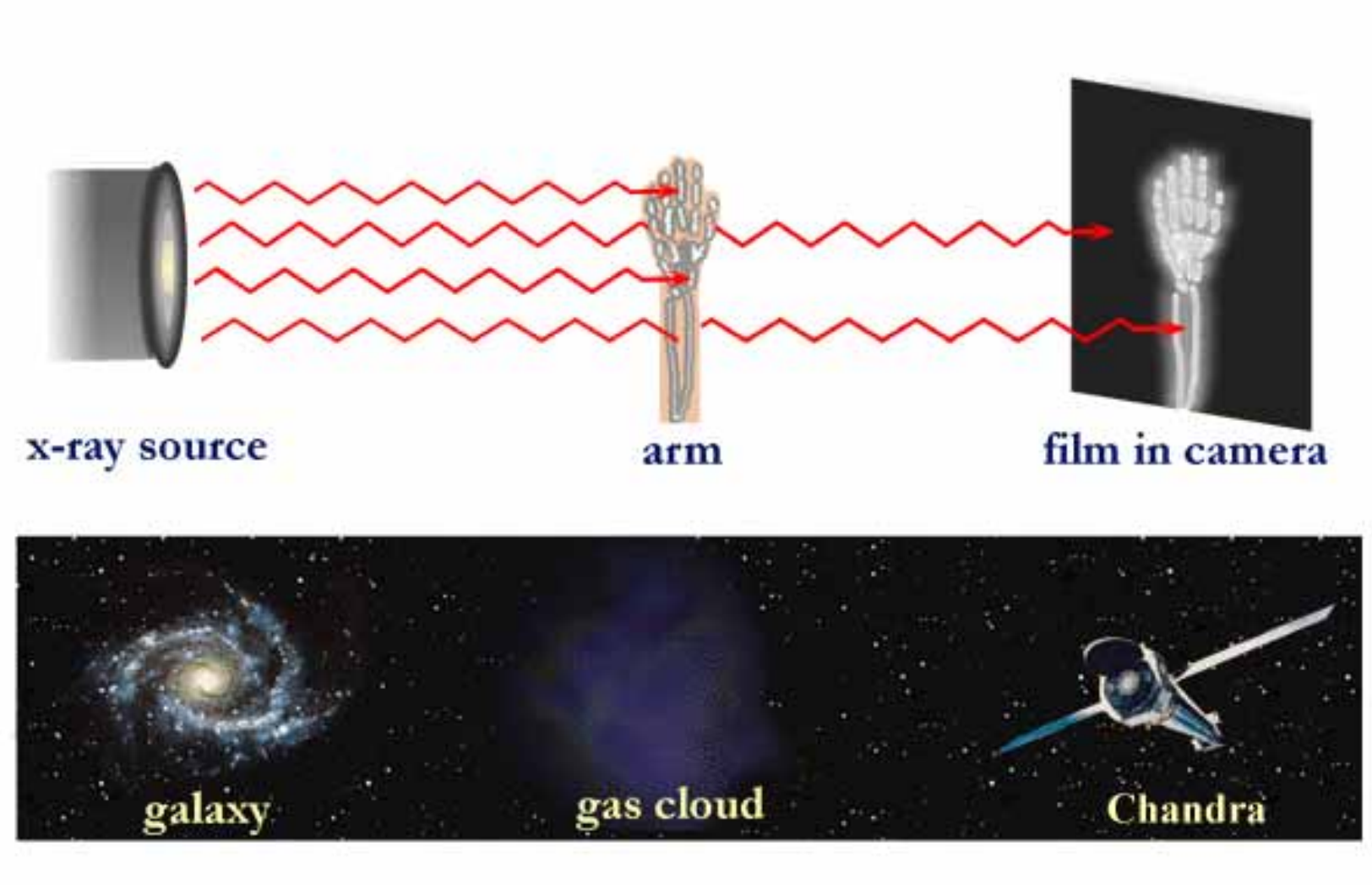
X線で探る星形成



坪井陽子
中央大学理工学部

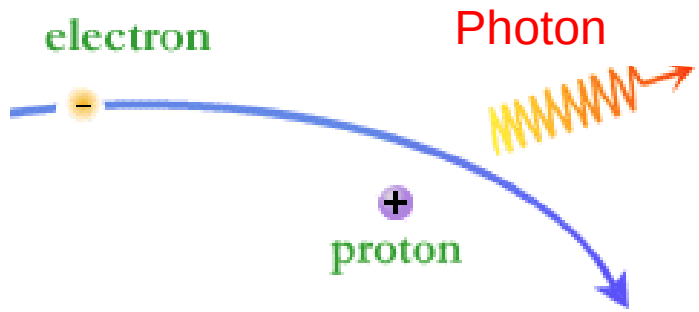
X線天文とは

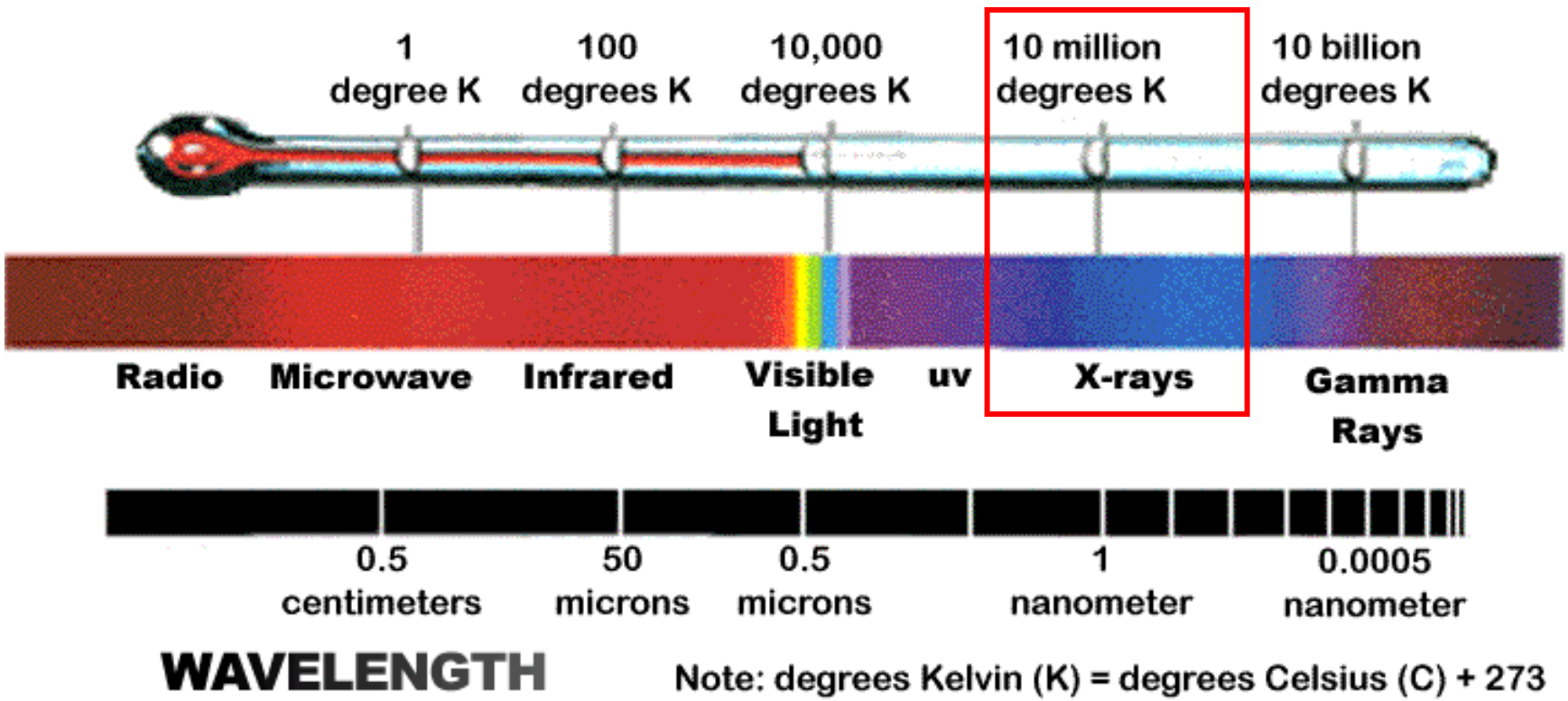
What can we learn using X-rays? (I)



X-Rays: Probing Deep Universe!!

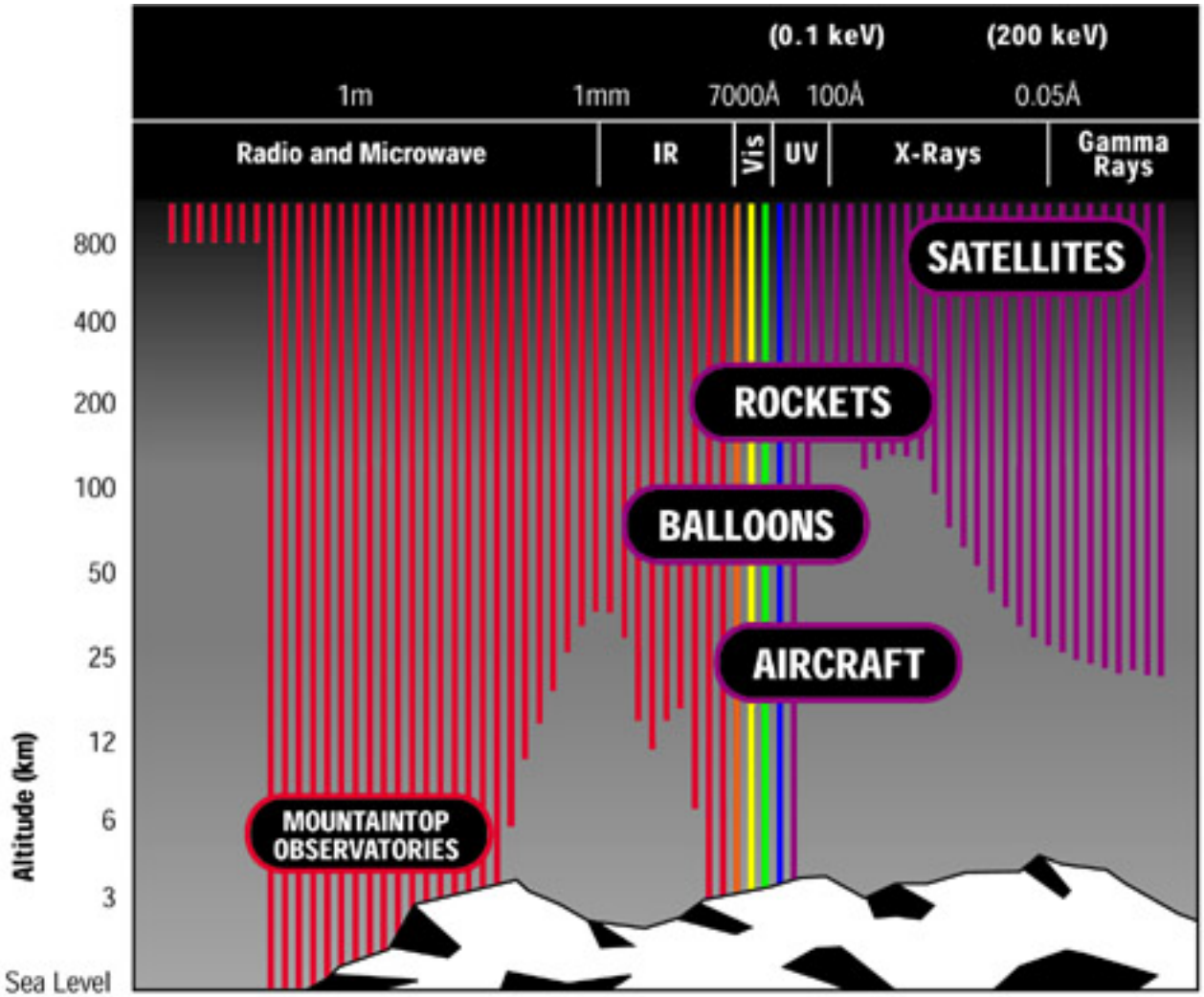
What can we learn using X-rays? (II)





X-Rays: Probing Hot Universe!!

How can we observe using X-rays?

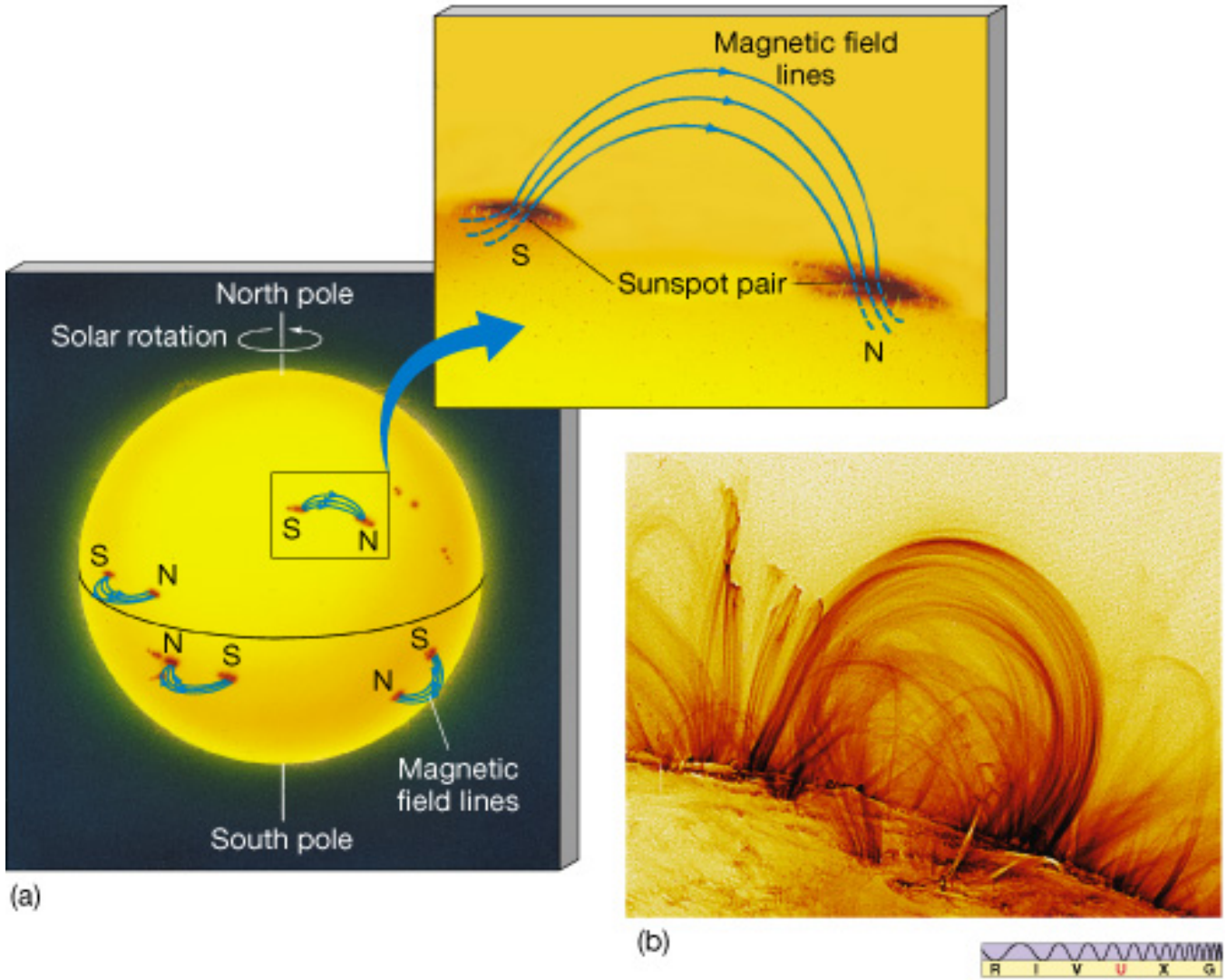


X-Rays: Fly into space

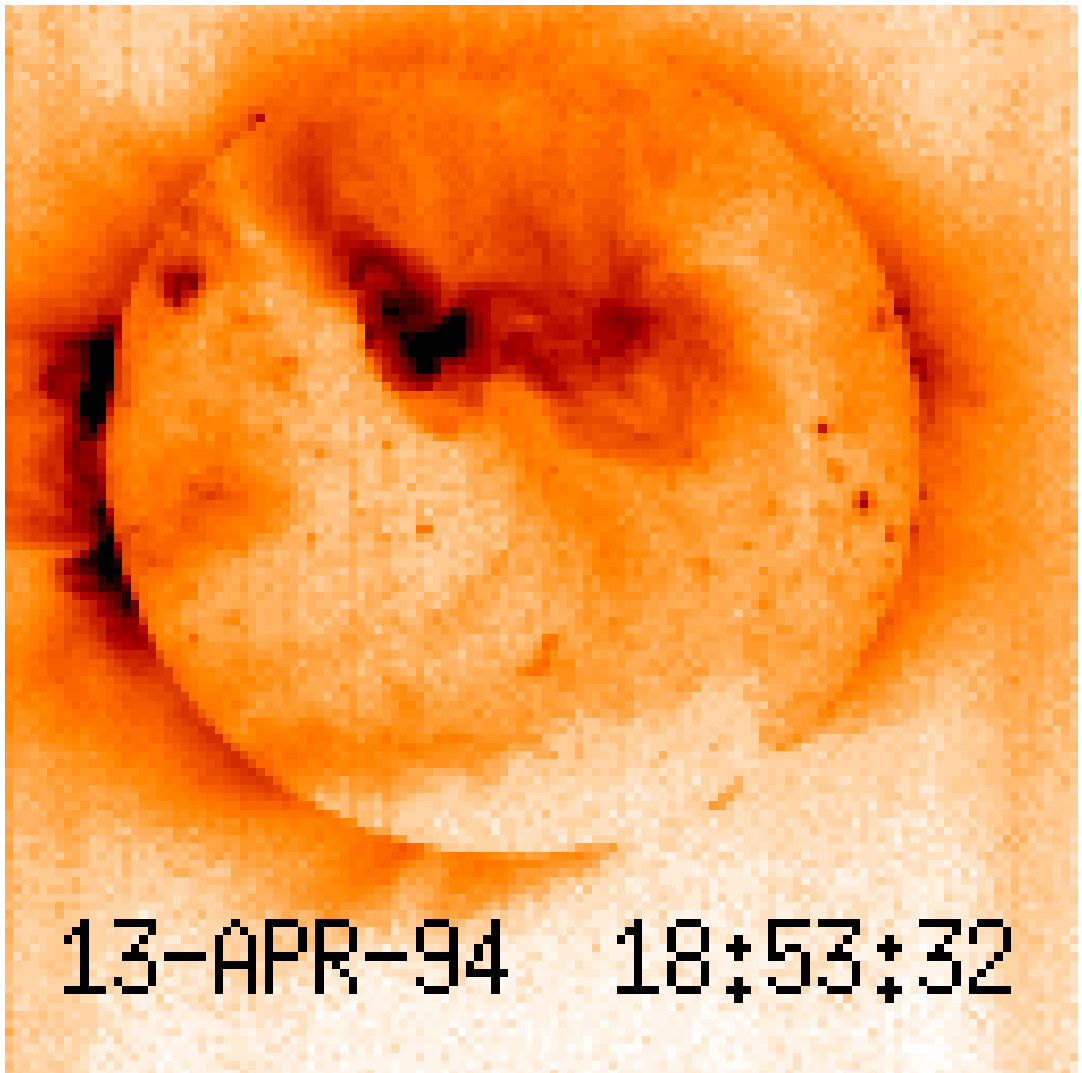
小質量主系列星からのX線

太陽観測衛星ＳＯＨＯがとらえた2003年10月28日の太陽フレア(X線写真)

太陽磁場と磁気リコネクション



太陽：激動するフレア

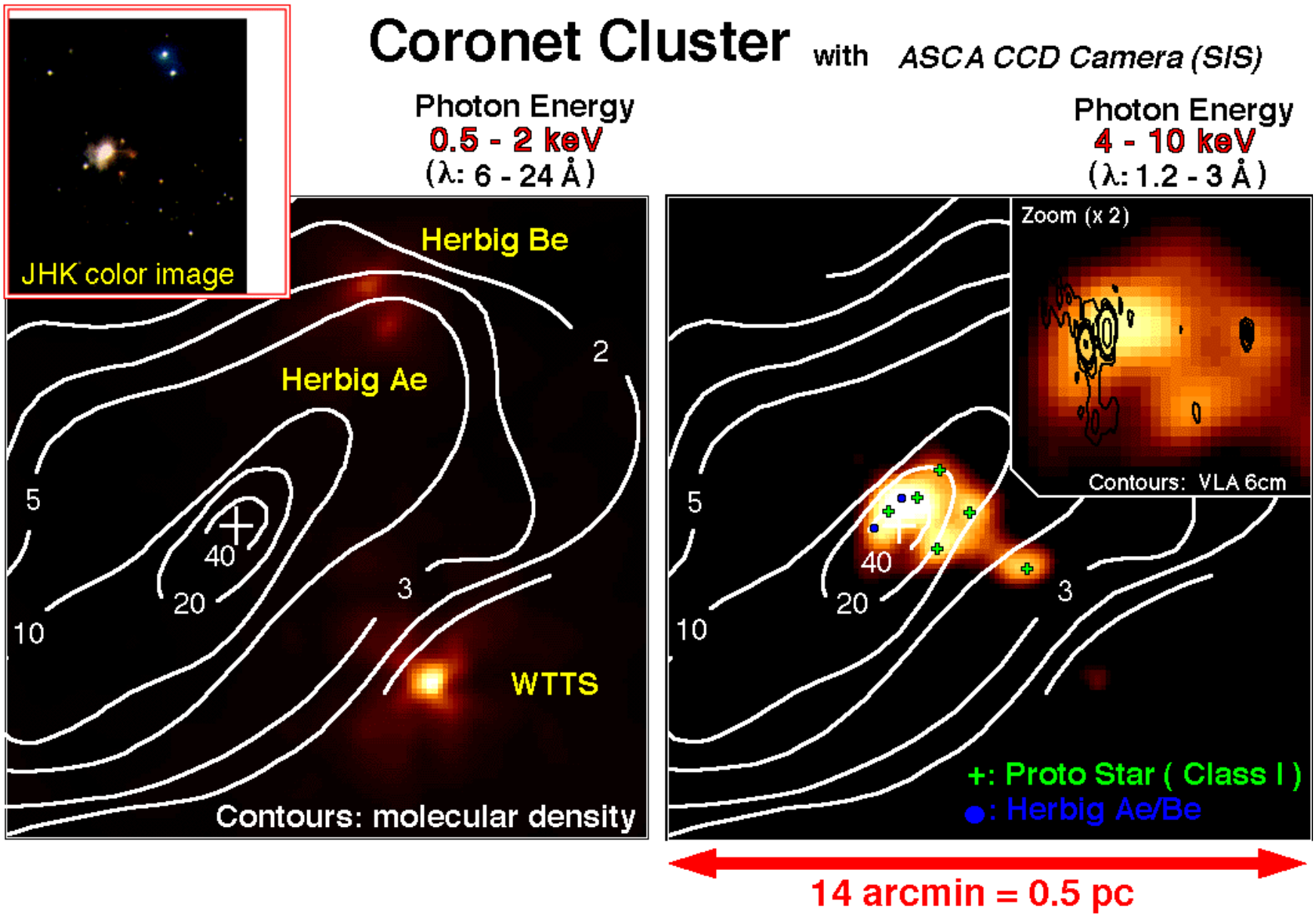


Big flare on V773Tau (TTS)

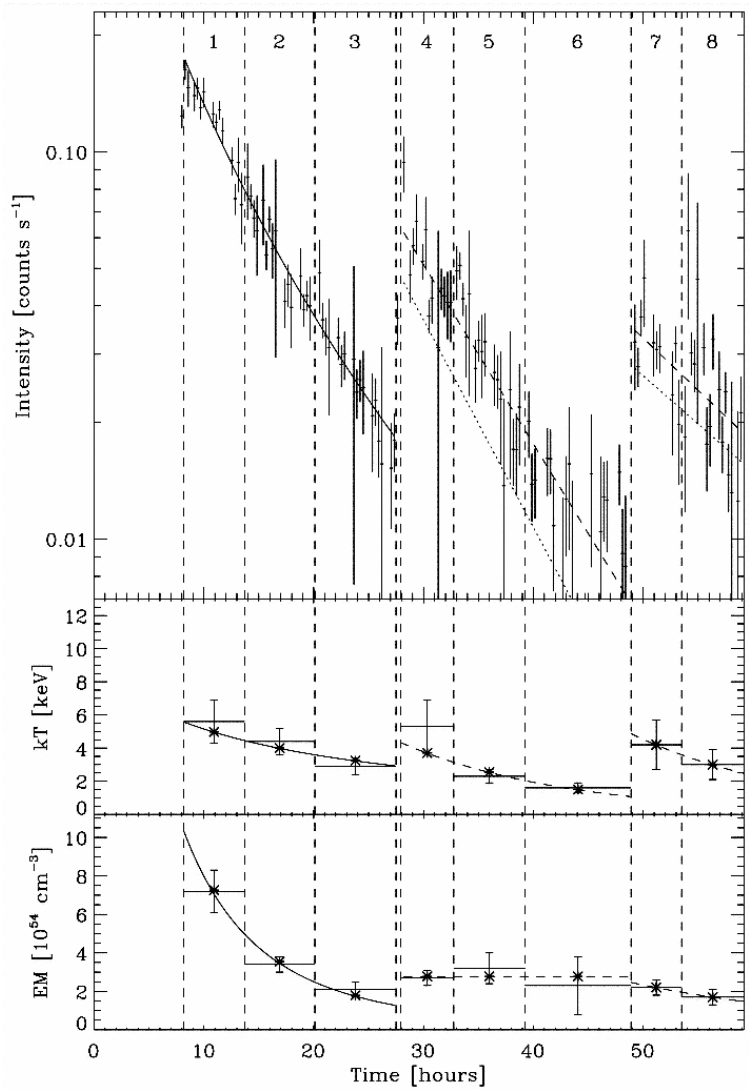
$\sim 10^{33}$ erg s^{-1}

フレア成分のパラメータ変化

原始星（YSO前期）


Coronet Cluster with ASCA CCD Camera (SIS)
Photon Energy
0.5 - 2 keV
(λ: 6 - 24 Å)
Photon Energy
4 - 10 keV
(λ: 1.2 - 3 Å)
JHK color image
Herbig Be
Herbig Ae
WTTS
2
3
5
10
20
40
Contours: molecular density
Zoom (x 2)
Contours: VLA 6cm
+: Proto Star (Class I)
●: Herbig Ae/Be
14 arcmin = 0.5 pc

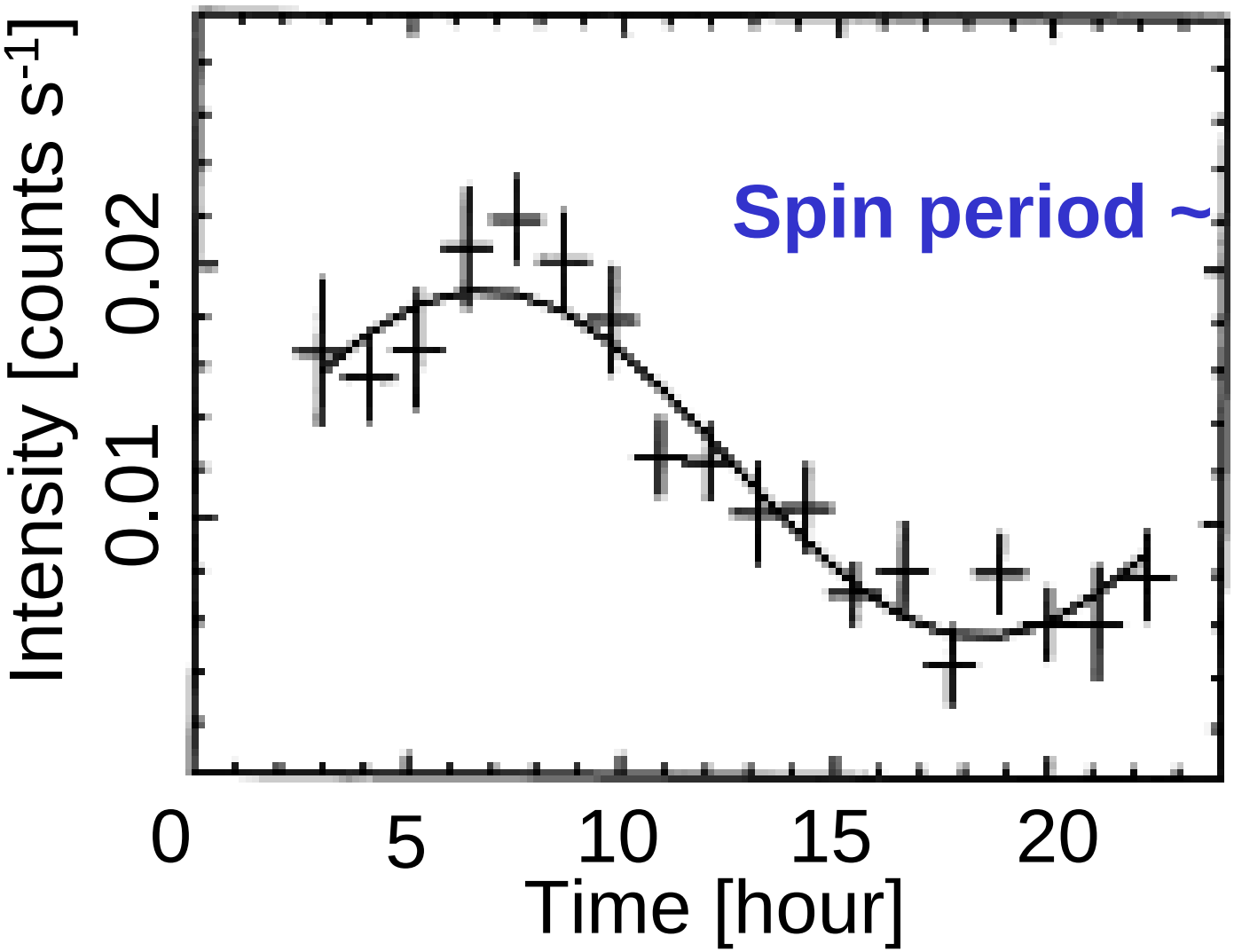
YLW15 (ClassI) in Rho Oph



QuickTimeý Ç² TIFFÅià èkÇ»ÇµÅj êLí£ÉvÉçÉOÉâÉÄ Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç ÅB

Spin period ~ 1 day!?

Sinusoidal light curve of WL6



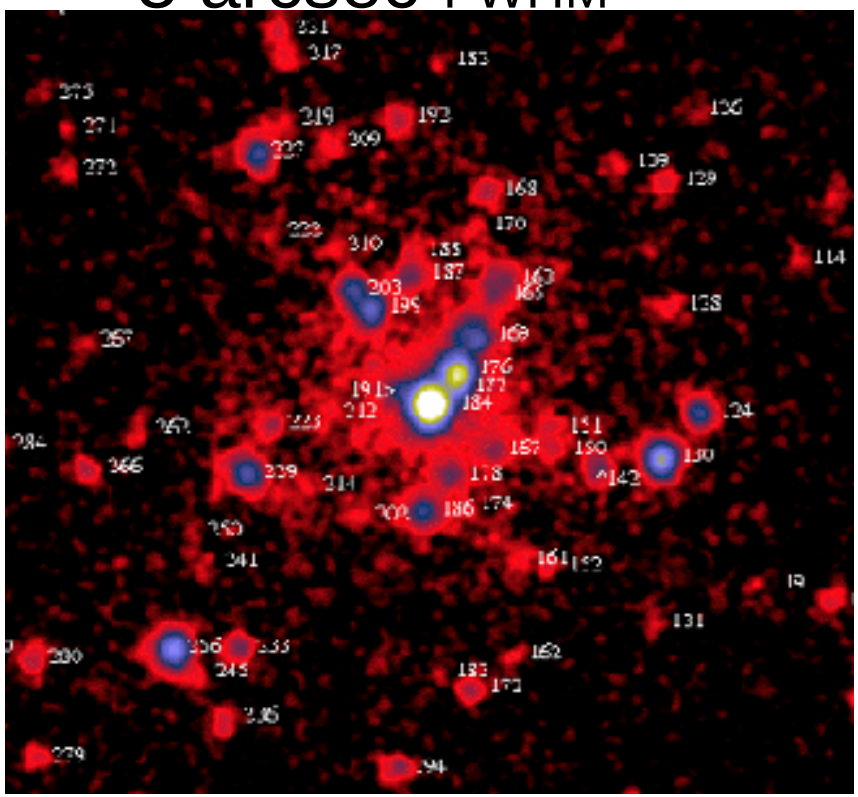
Spin period ~ 1 day!?

チャンドラ衛星

Unprecedented spatial resolution

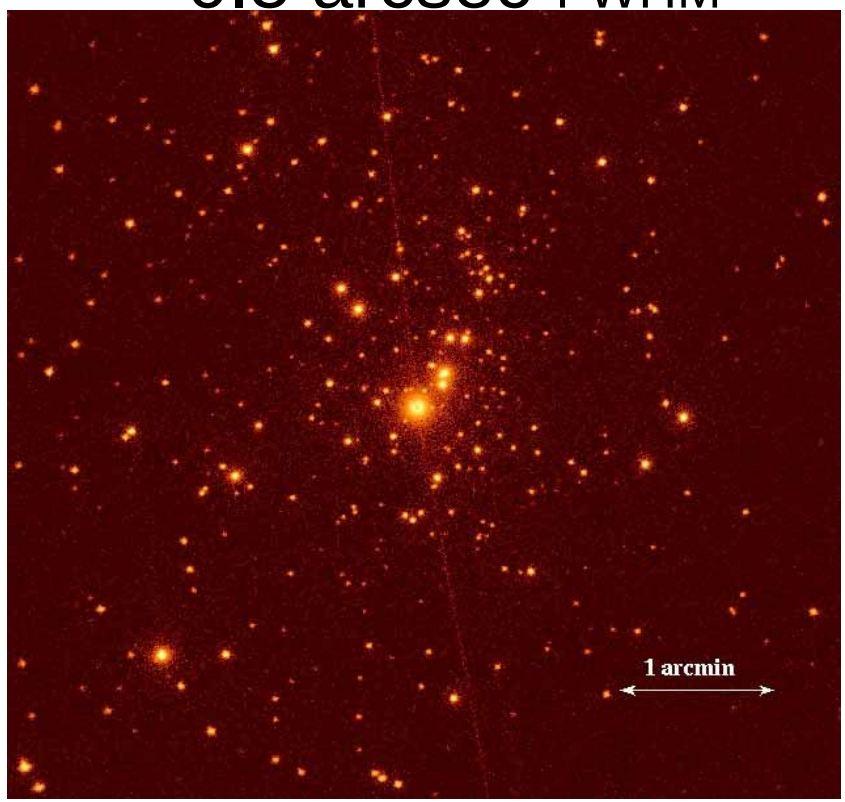
Orion nebula

5 arcsec FWHM



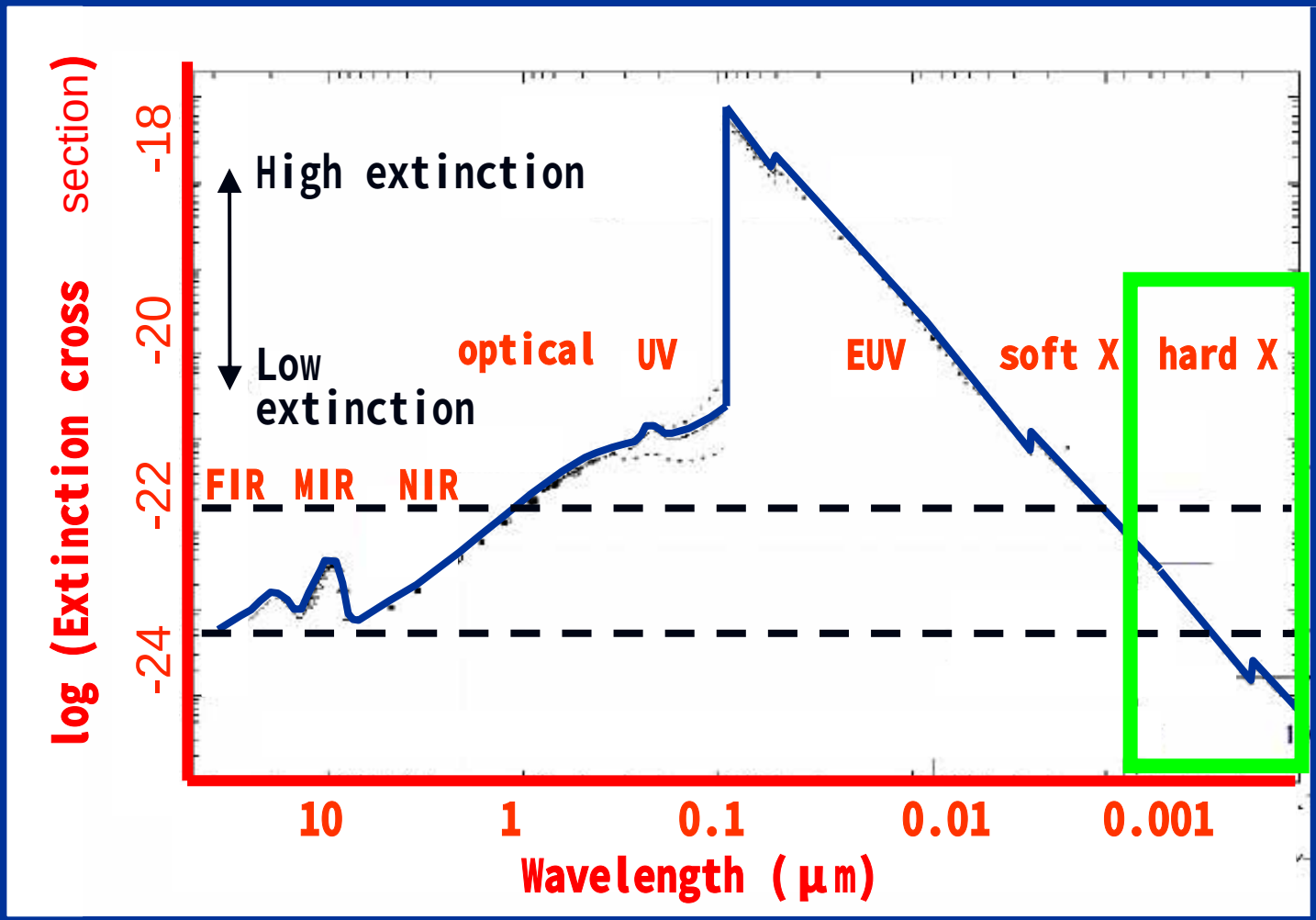
Rosat HRI Observation

0.5 arcsec FWHM



Chandra ACIS Observation

How can we detect the central star of a protostar?

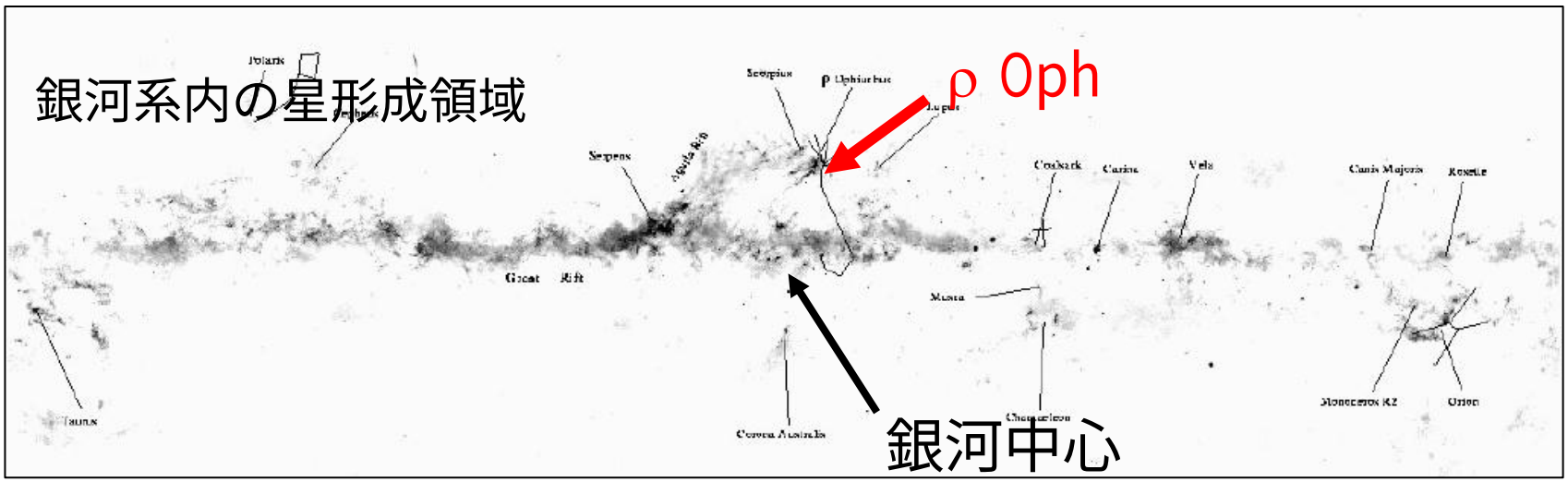


Ryter et al. 1996

(Hard) X-rays could be powerful to detect them

観測ターゲット：ρ Oph分子雲

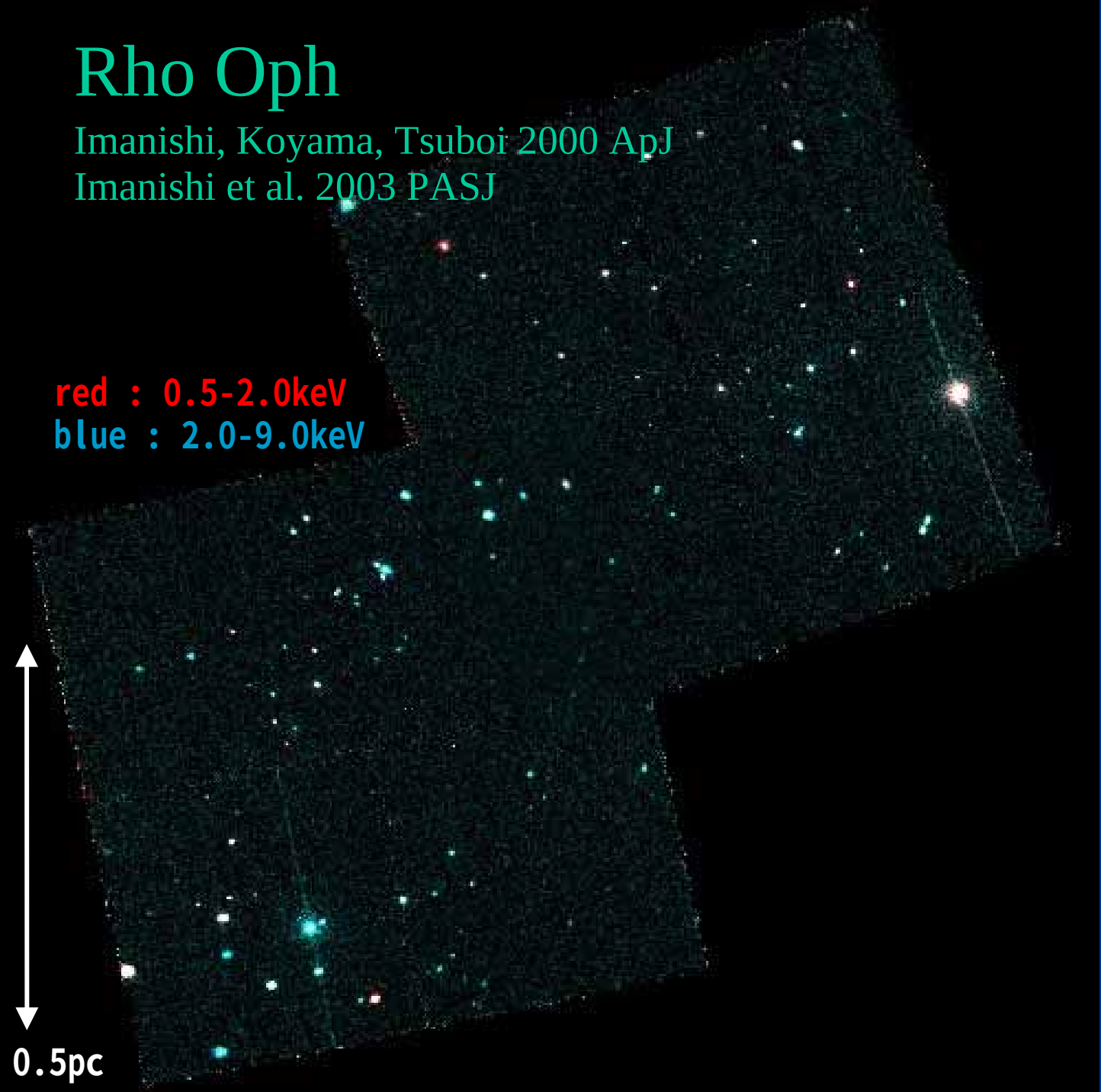
The nearest cloud ⟶ (d~165 pc)



360°

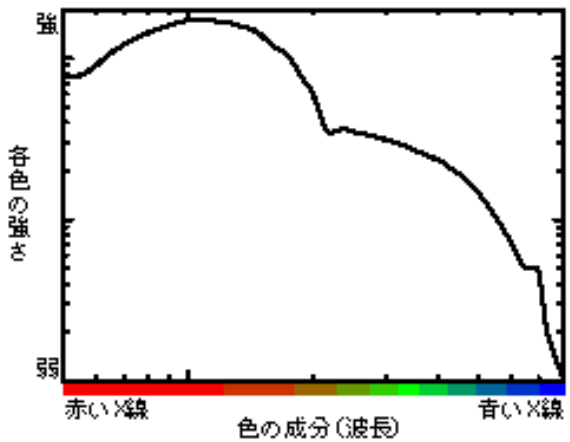
Rho Oph

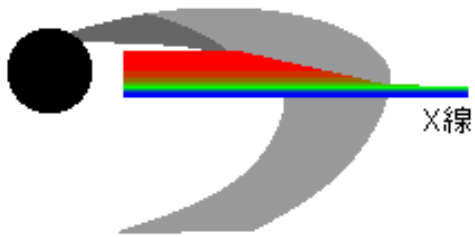
Imanishi, Koyama, Tsuboi 2000 ApJ
Imanishi et al. 2003 PASJ



False Color in X-ray

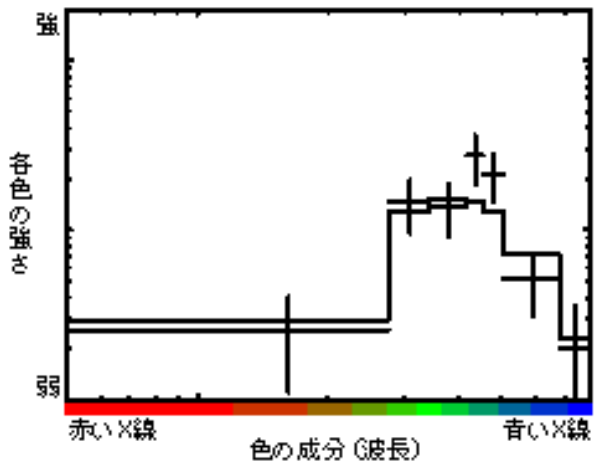
元々のスペクトル





濃い塵

観測されるスペクトル



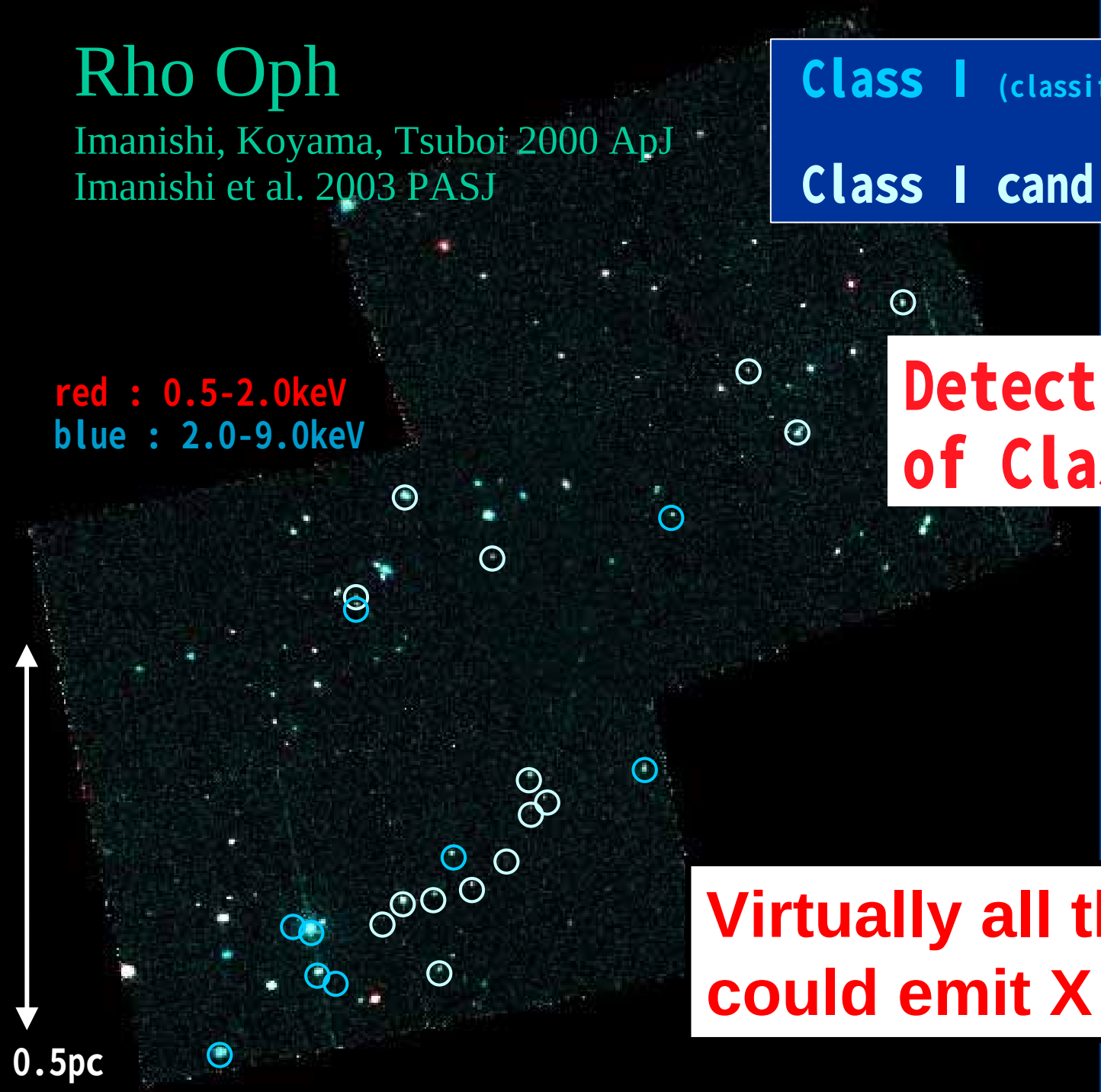
星の環境

Rho Oph

Imanishi, Koyama, Tsuboi 2000 ApJ
Imanishi et al. 2003 PASJ

Class I (classified in all references) **9/15**

Class I candidates 15/19

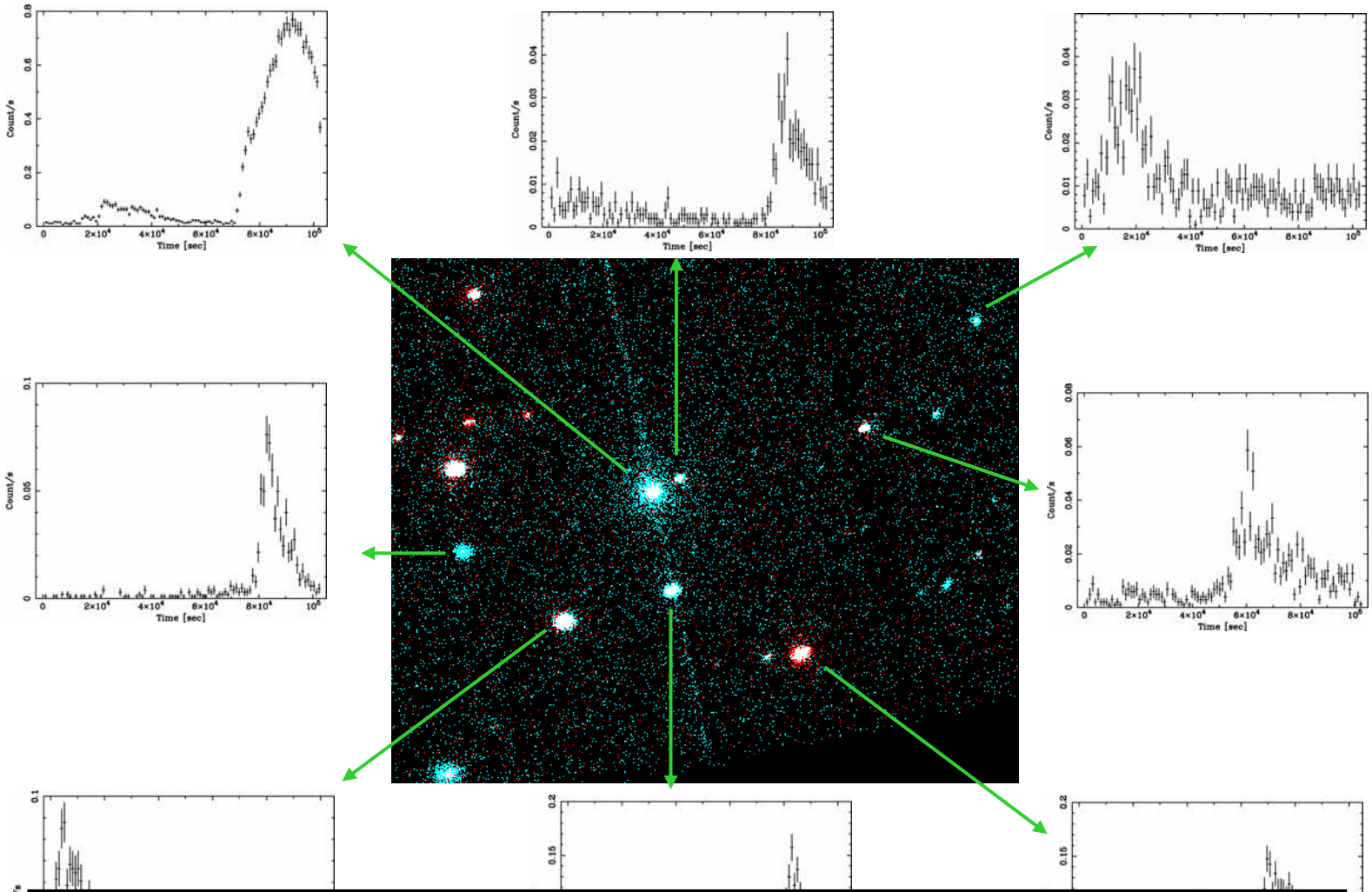


Detection rate of Class I ～70%

Virtually all the Class I could emit X rays.

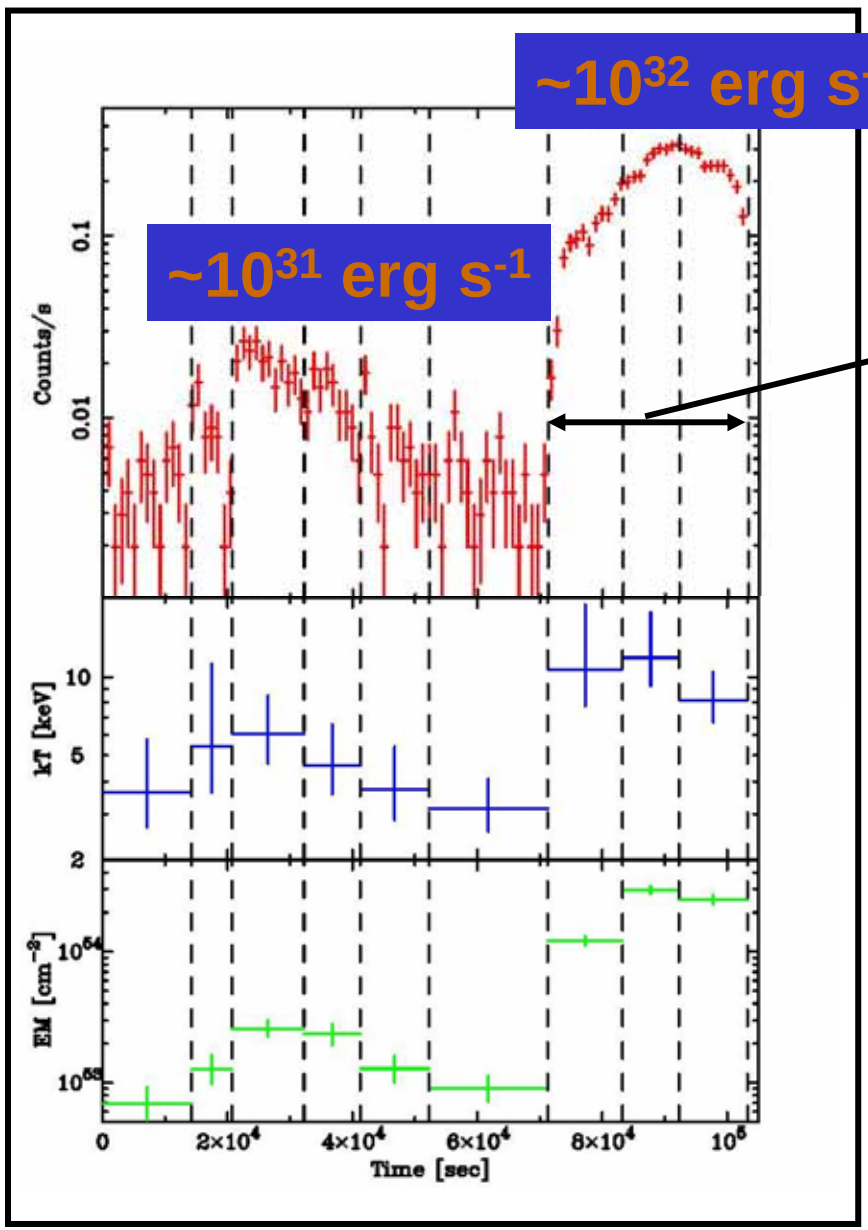

Movie

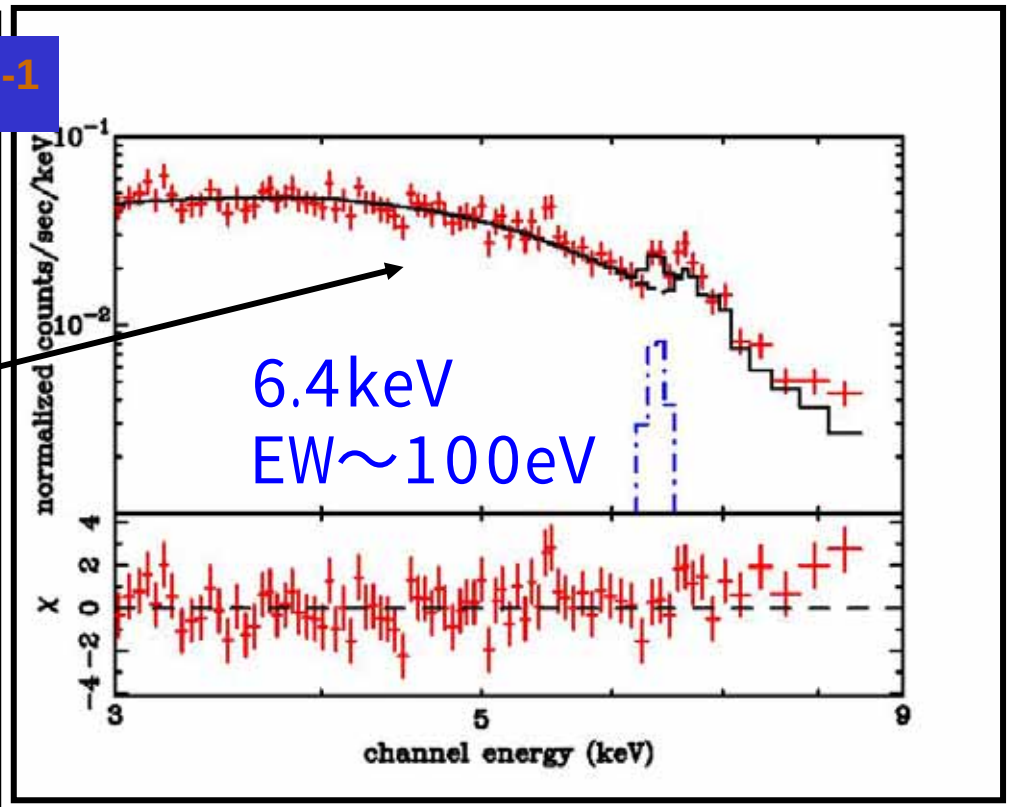

Movie



>60% of the Class I showed flares with 10,000-100,000 times larger luminosities than solar flares.

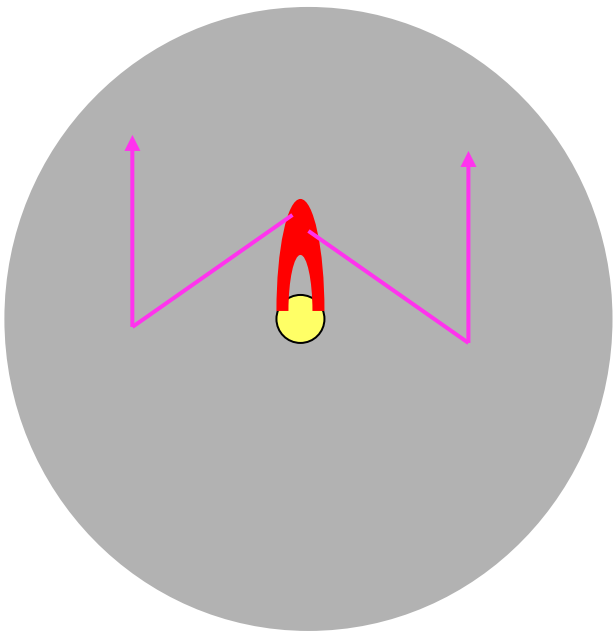
6.4 keV line at flare from YLW16A (protostar)





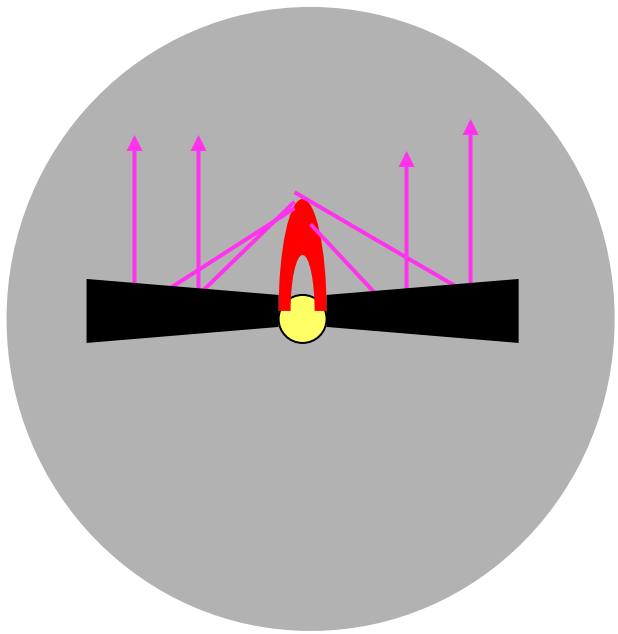
2nd Flare: neutral Fe line
⇒reflection by a cool matter

Geometry of the protostar



N_H~5×$10^{22}$$cm^{-2}$

EW~15eV

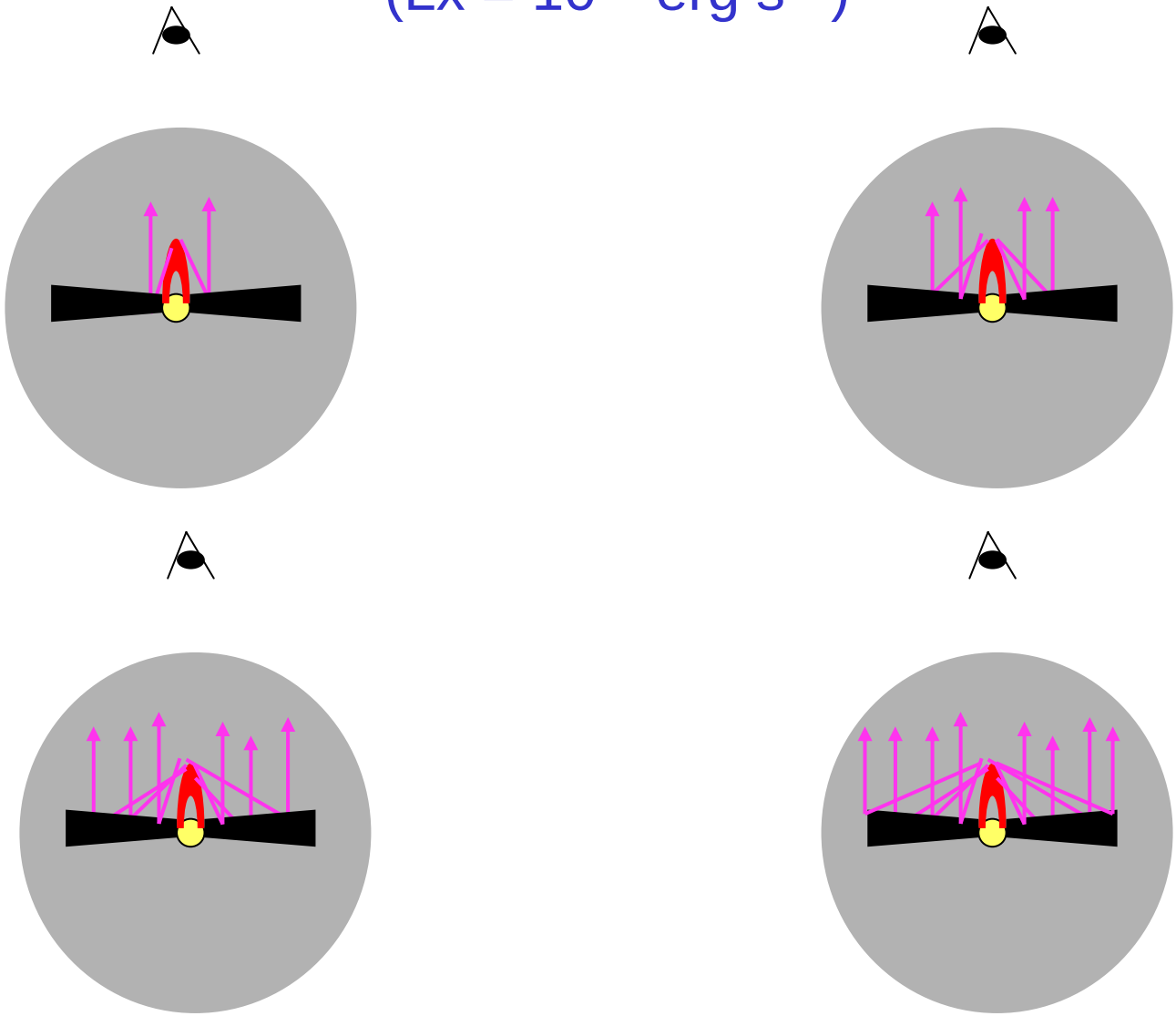


N_H~ 5×$10^{22}$$cm^{-2}$

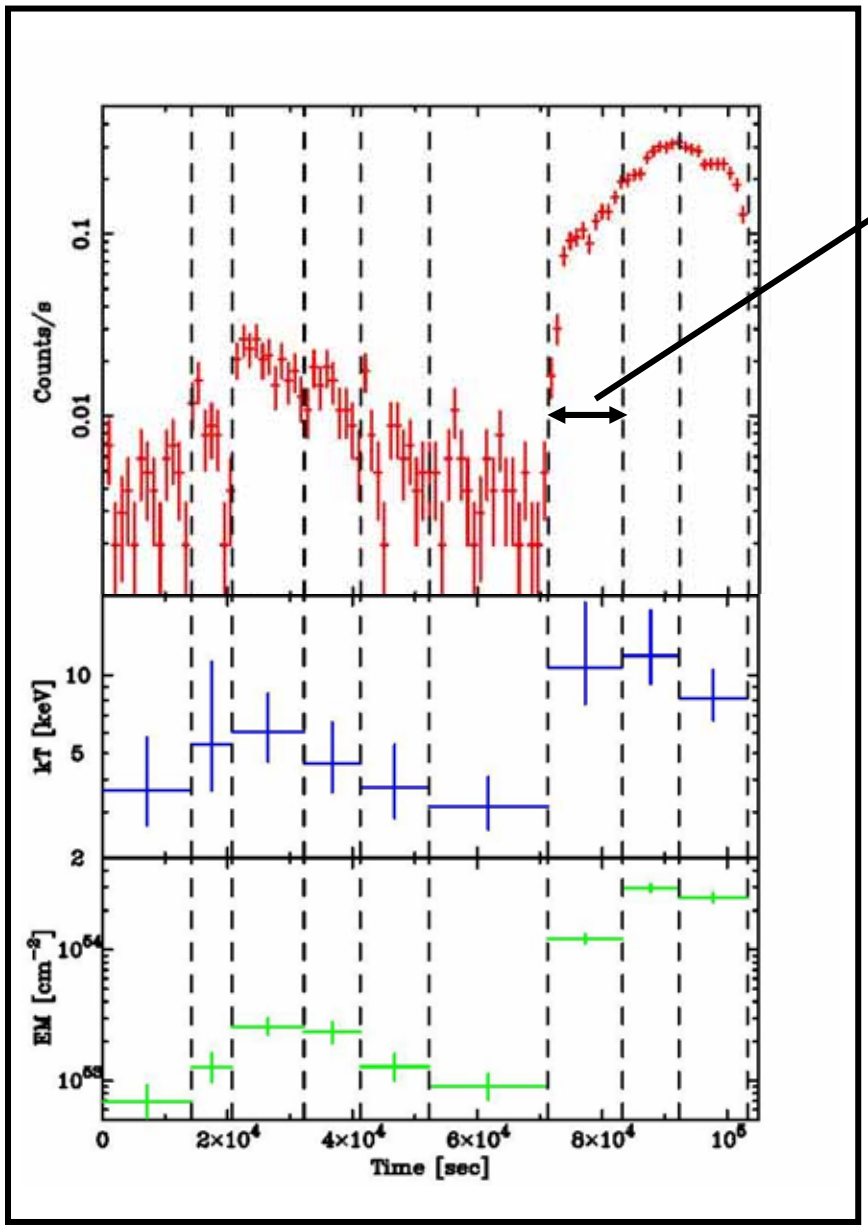
EW~100eV

6.4 keV line appearance (XRS)

(Lx = 10^{32} erg s^{-1})



6.4 keV line appearance (Chandra)



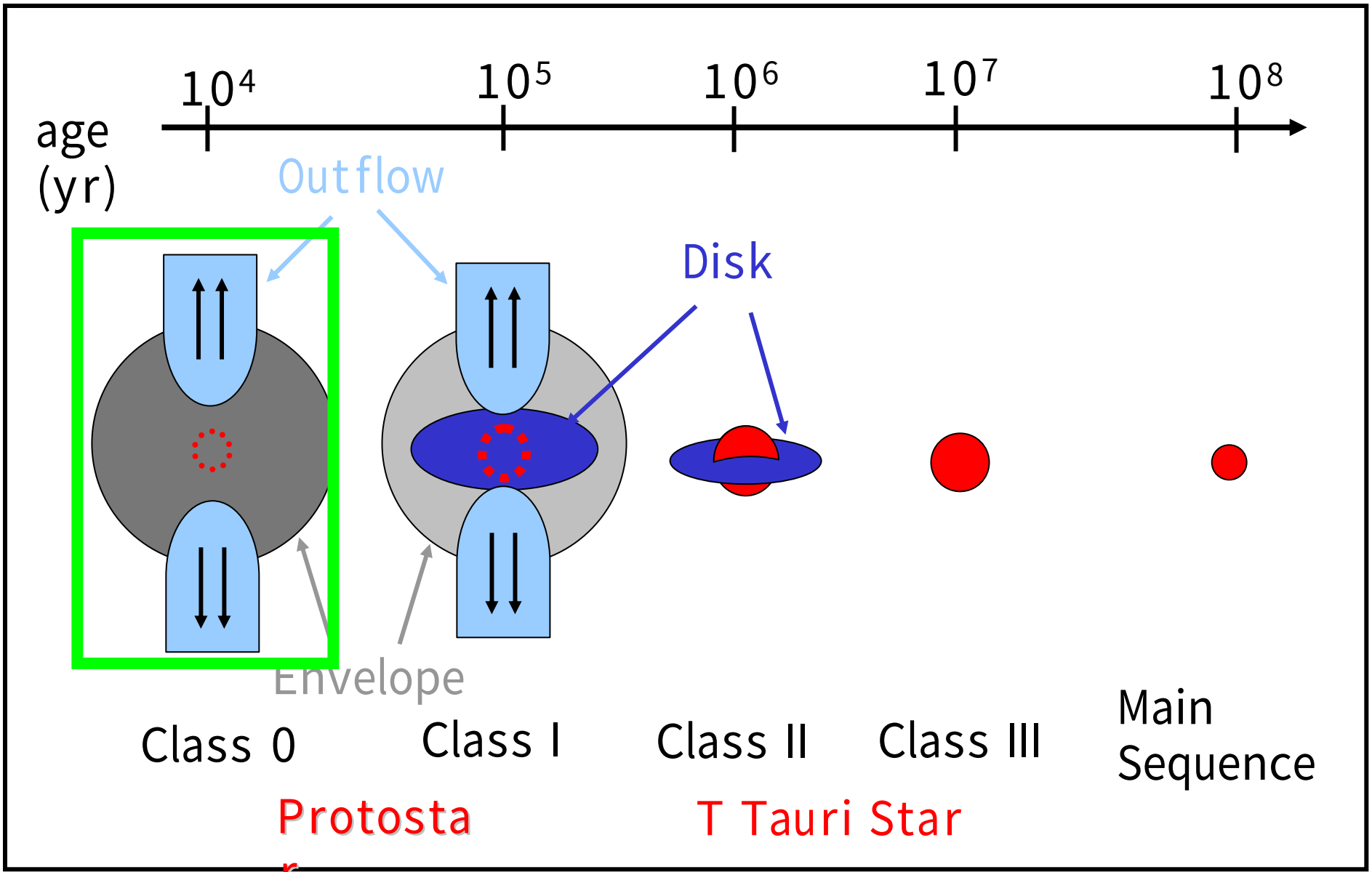
6.4keV line appeared

Δt ~160min

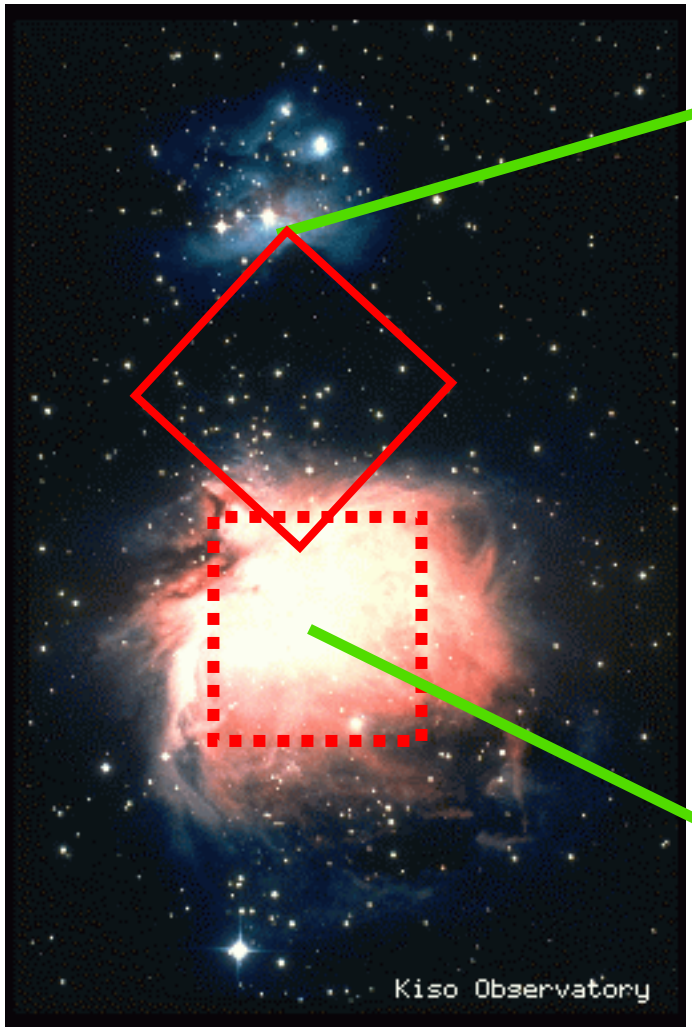
$\Rightarrow \Delta$r~20AU

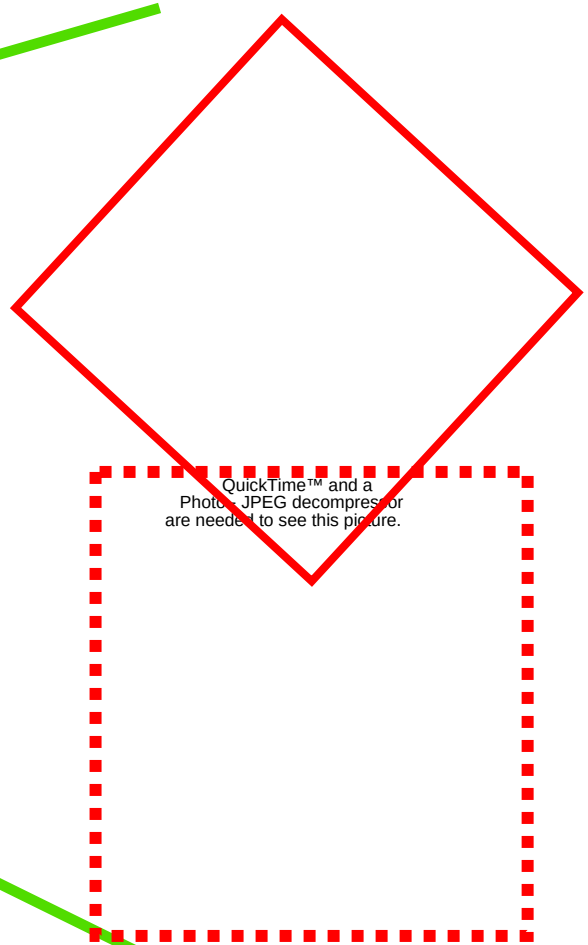
Reflecting material exists within 20 AU from the protostar.

Early Evolution of a Star



Orion Molecular Cloud

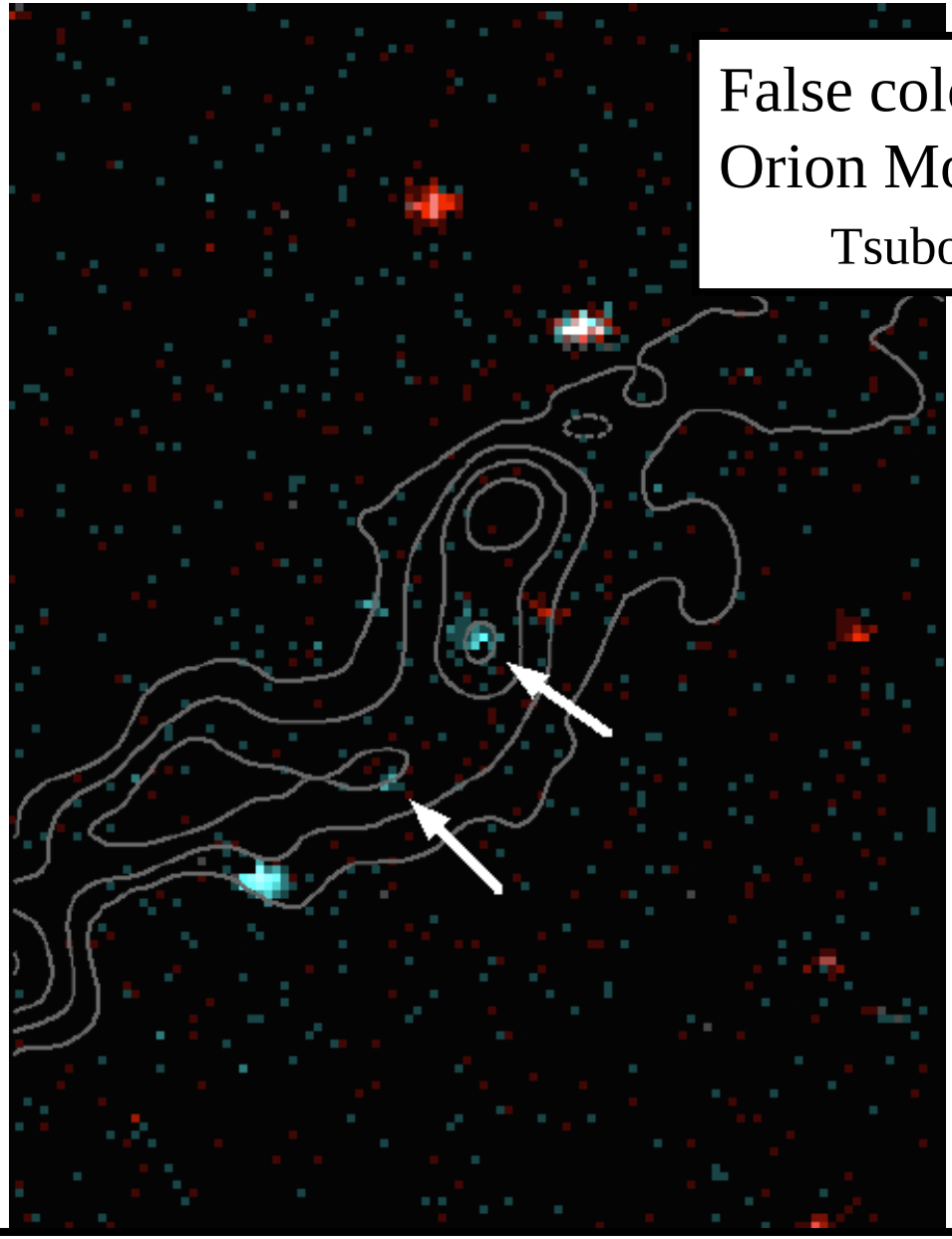




Colder

Younger

Lis et al. 98



False color image of
Orion Molecular Cloud 3 region

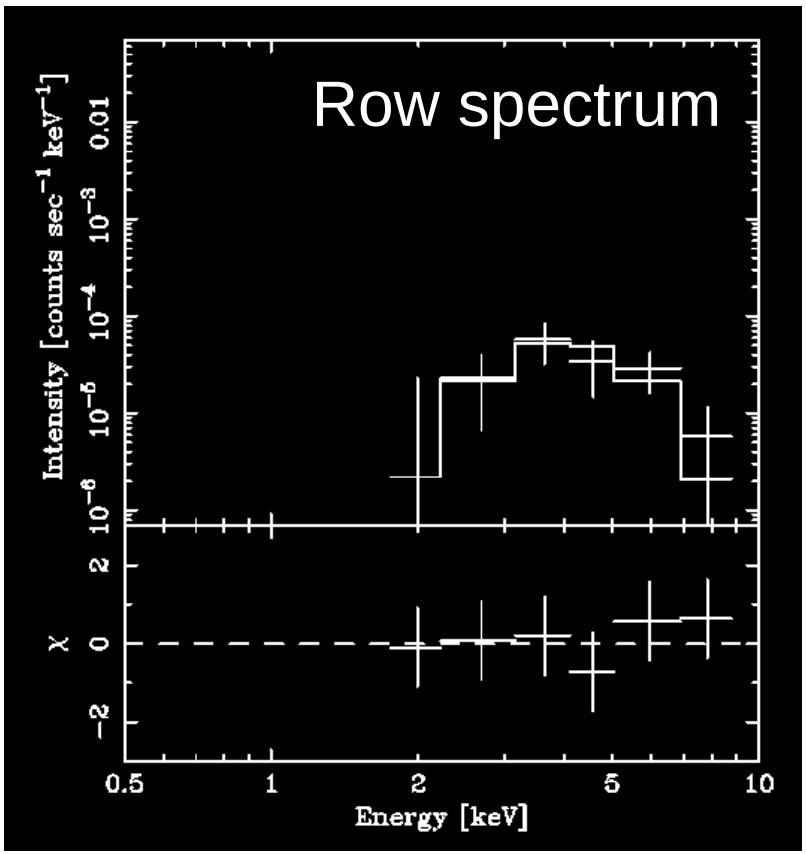
Tsuboi et al. 2000 ApJ

Red : 0.5-3.0keV
Blue : 3.0-8.0keV

Contour :
dust emission map
(Chini et al. 1997)

X rays from Class 0 candidates were discovered.

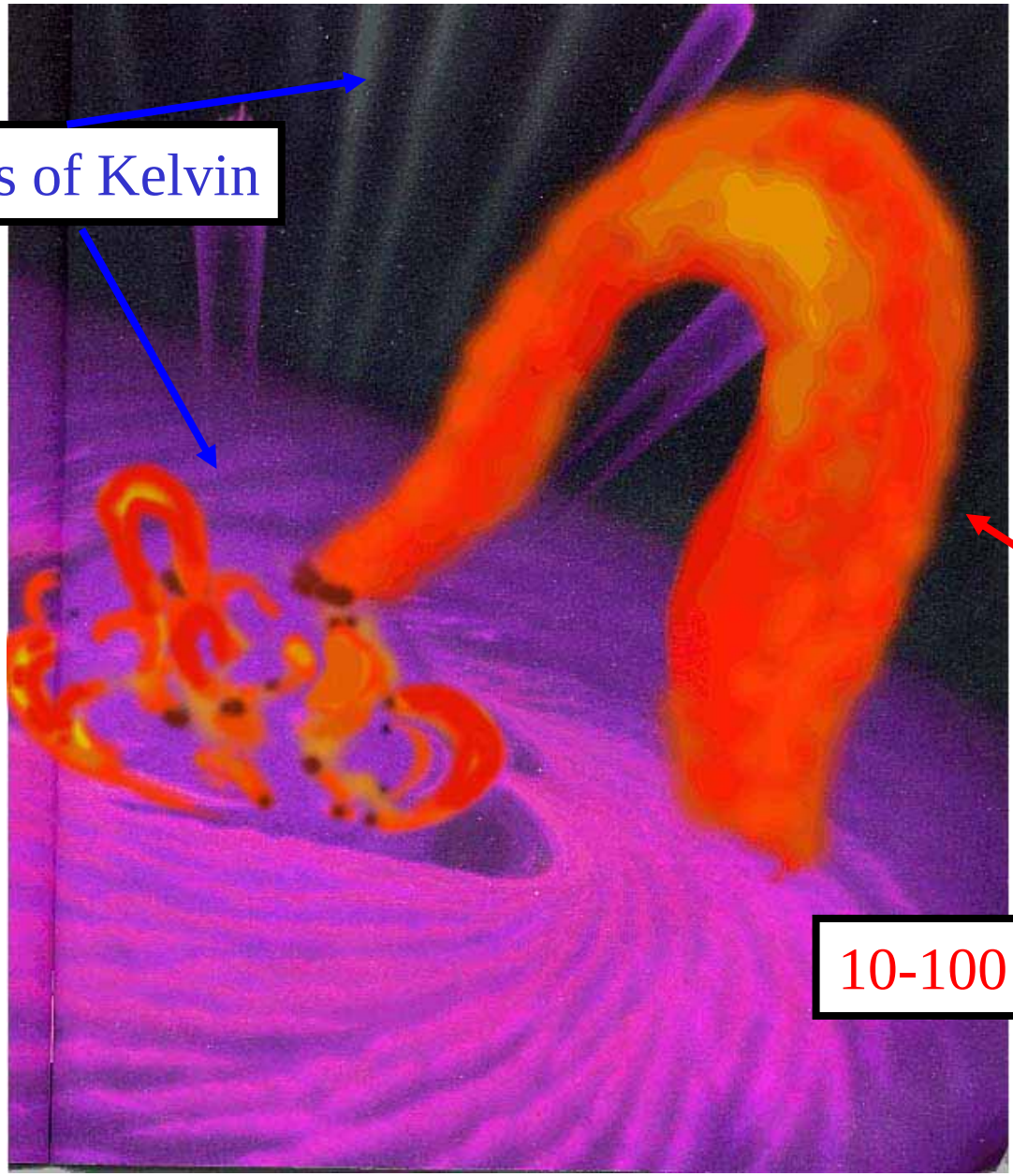
X-ray Spectrum of the Class 0 candidates

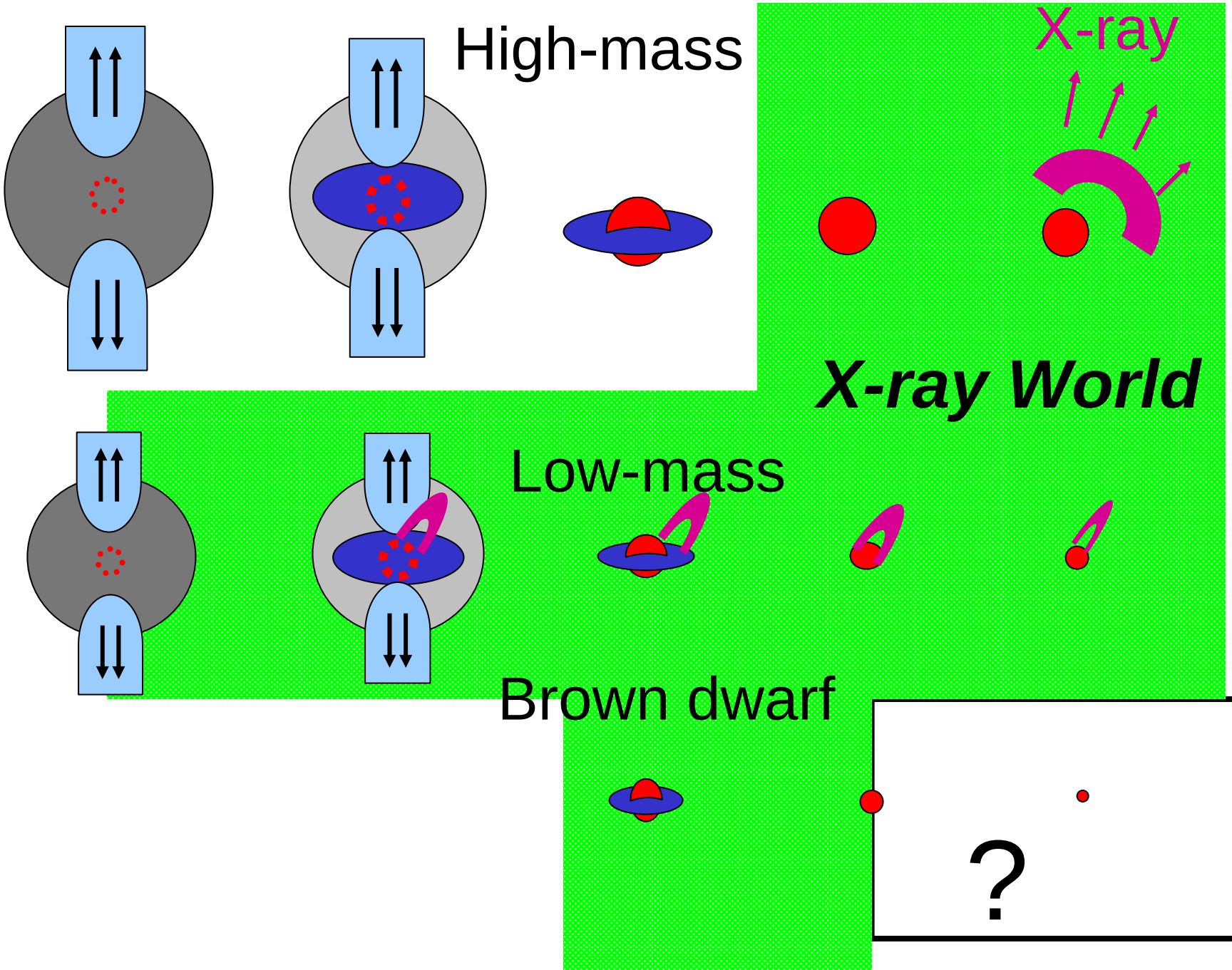


QuickTime™ and a
GIF decompressor
are needed to see this picture.

$N_H > 10^{23}$ H cm^{-2} !

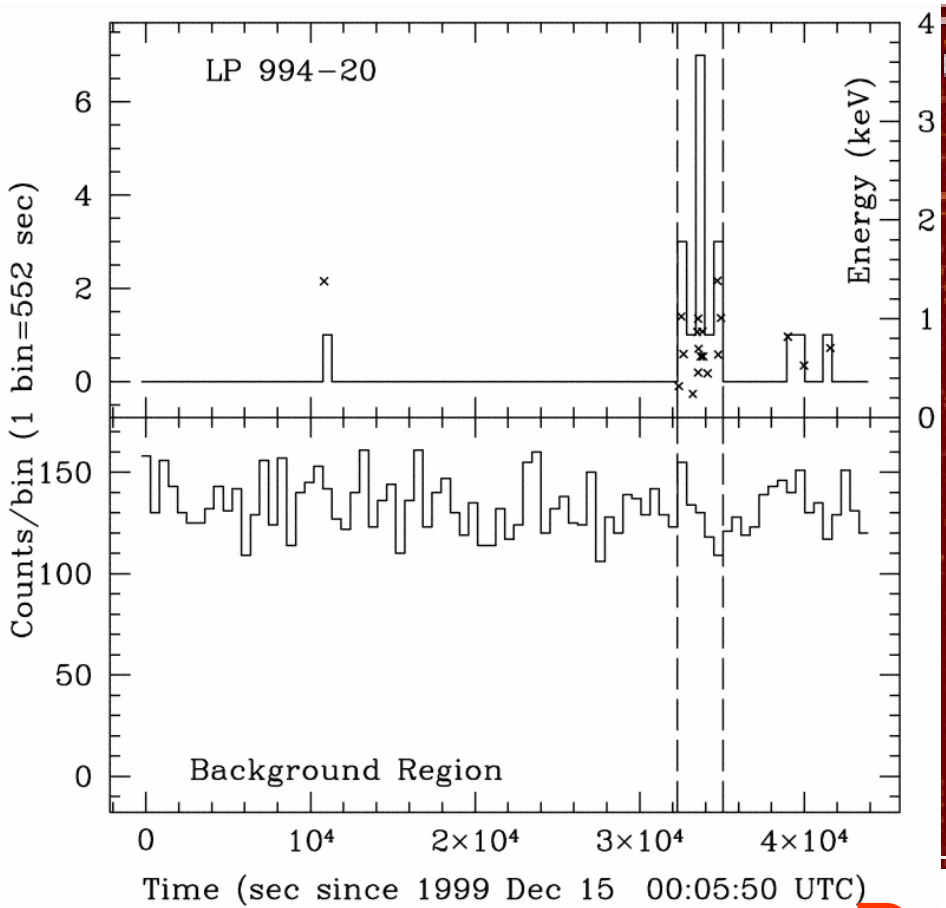
A Cartoon of a protostrar itself and the vicinity

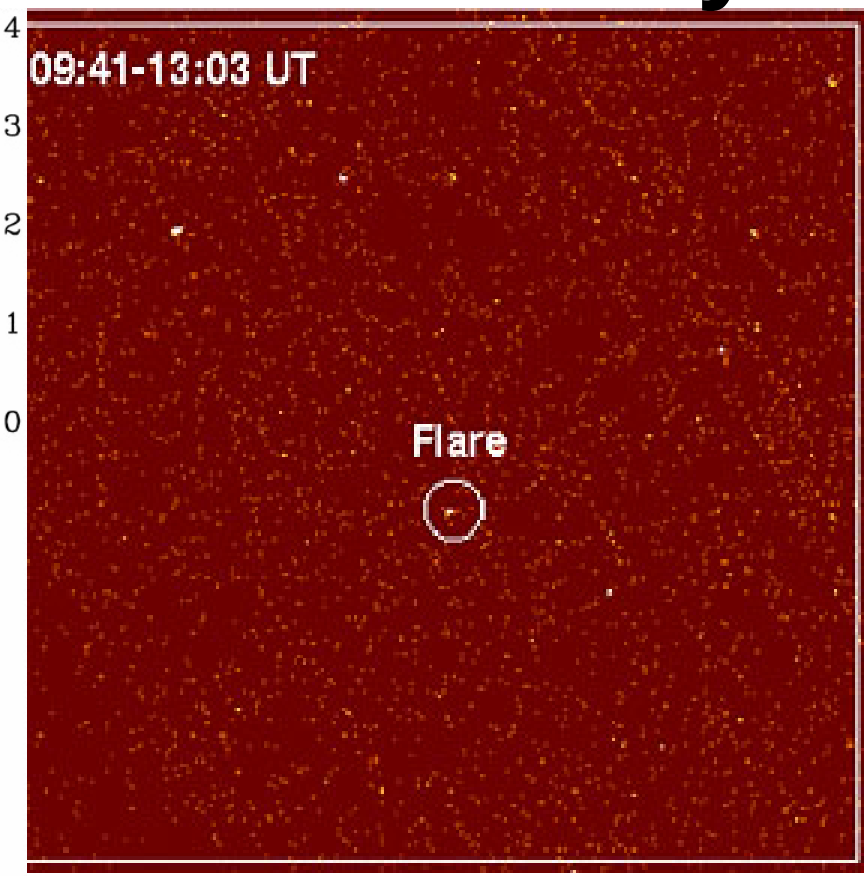



High-mass
X-ray
X-ray World
Low-mass
Brown dwarf
?

Flare from Old Brown Dwarf

LP944-20 (d ~ 5pc) $t \sim 10^9$ yrs





Rutledge et al. 2000, ApJ

Middle Aged Brown Dwarf

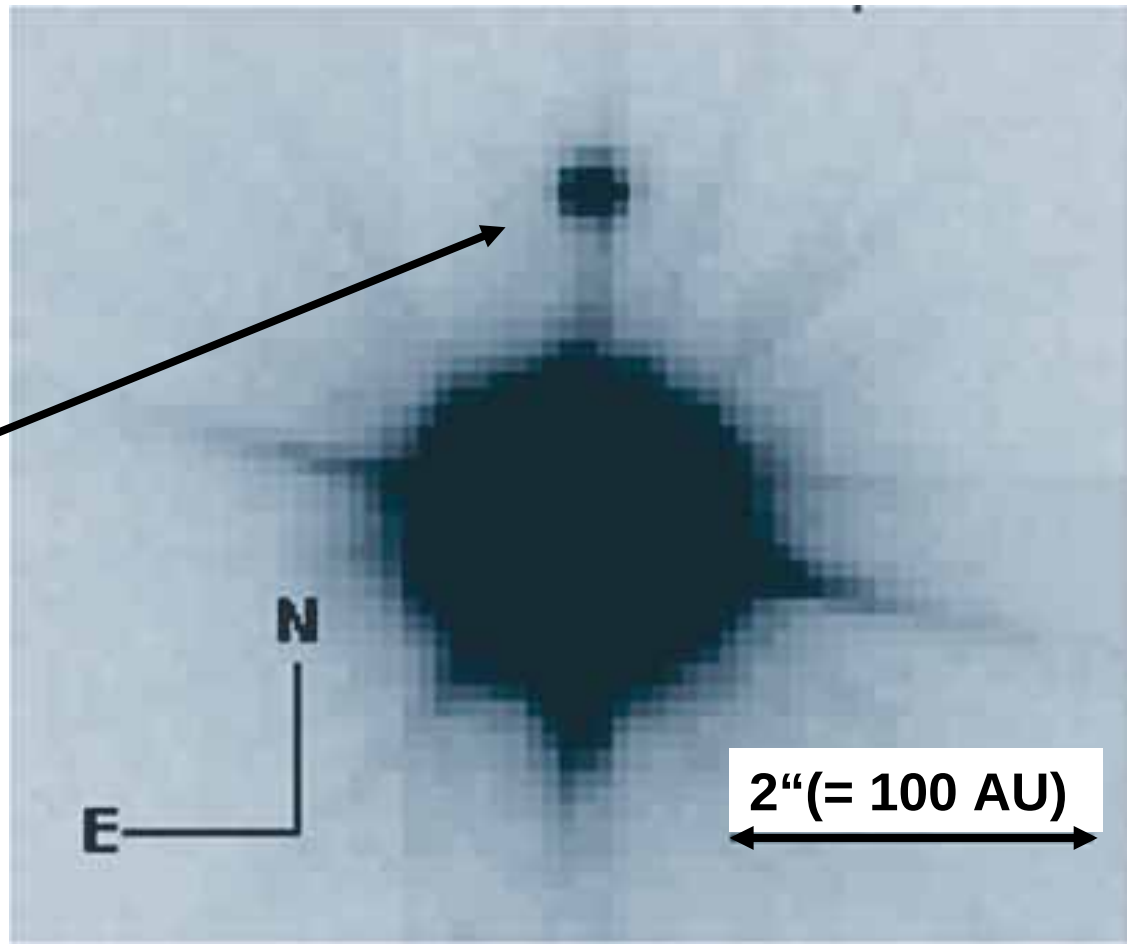
I-band image

TWA 5B

t ~ 10^7 yrs

$M_* \sim 20 M_J$

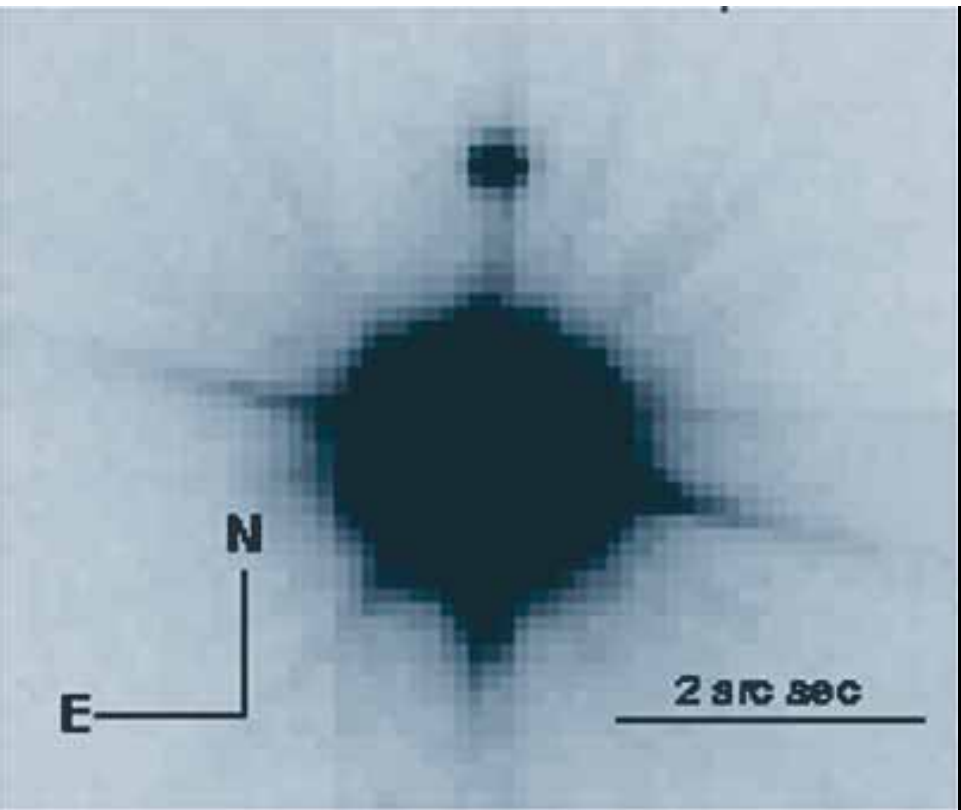
D ~ 55 pc

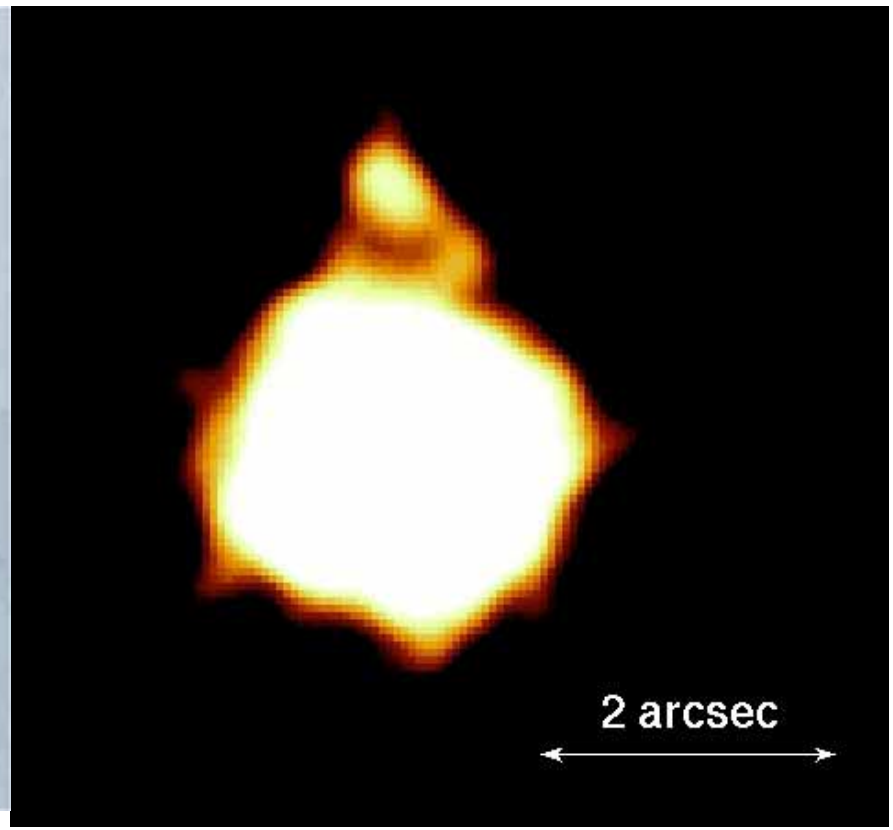


~Boundary between Planet and BD ($13 M_J$)

Neuhauser et al. 2000

TWA 5A/B

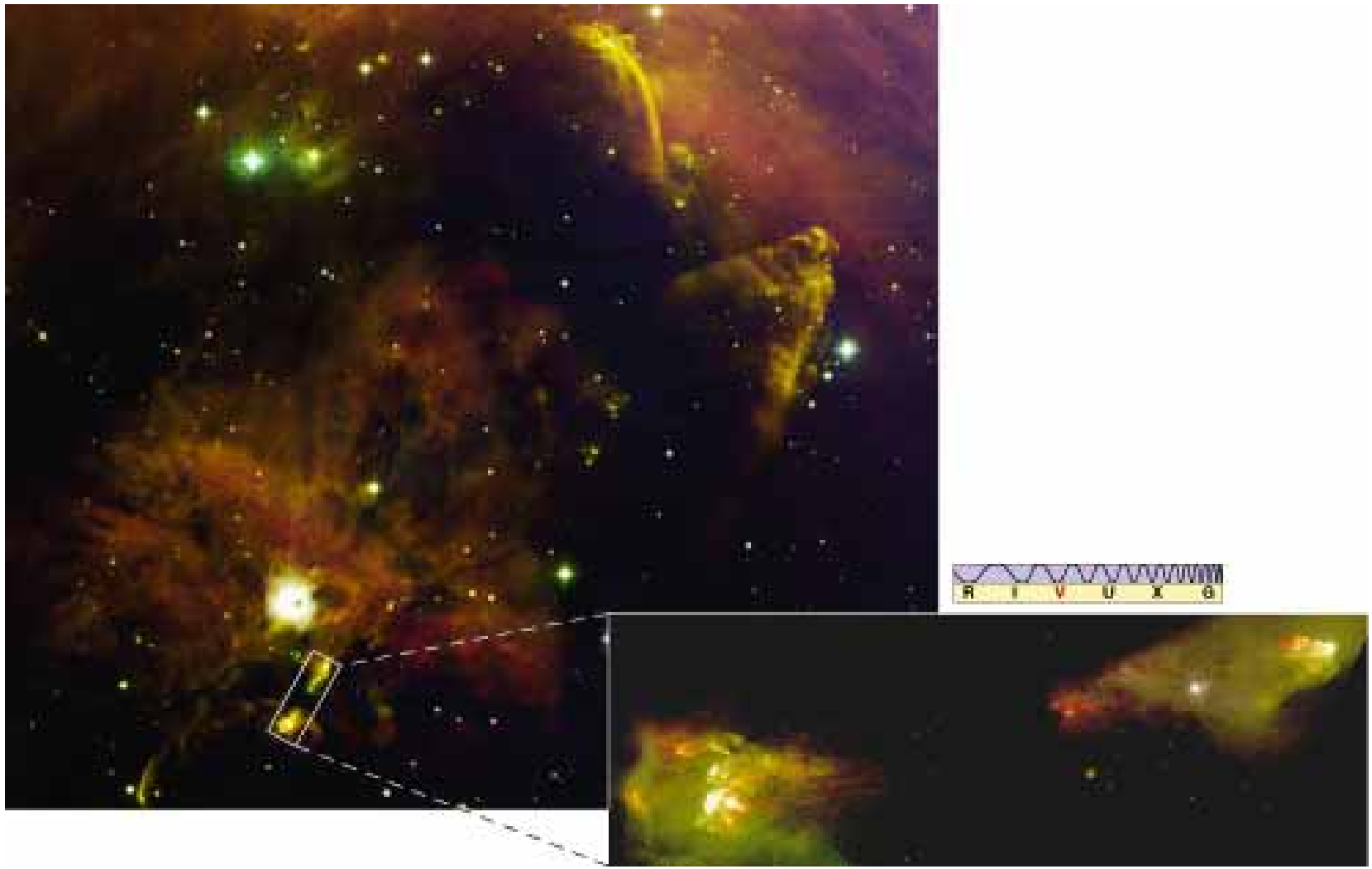




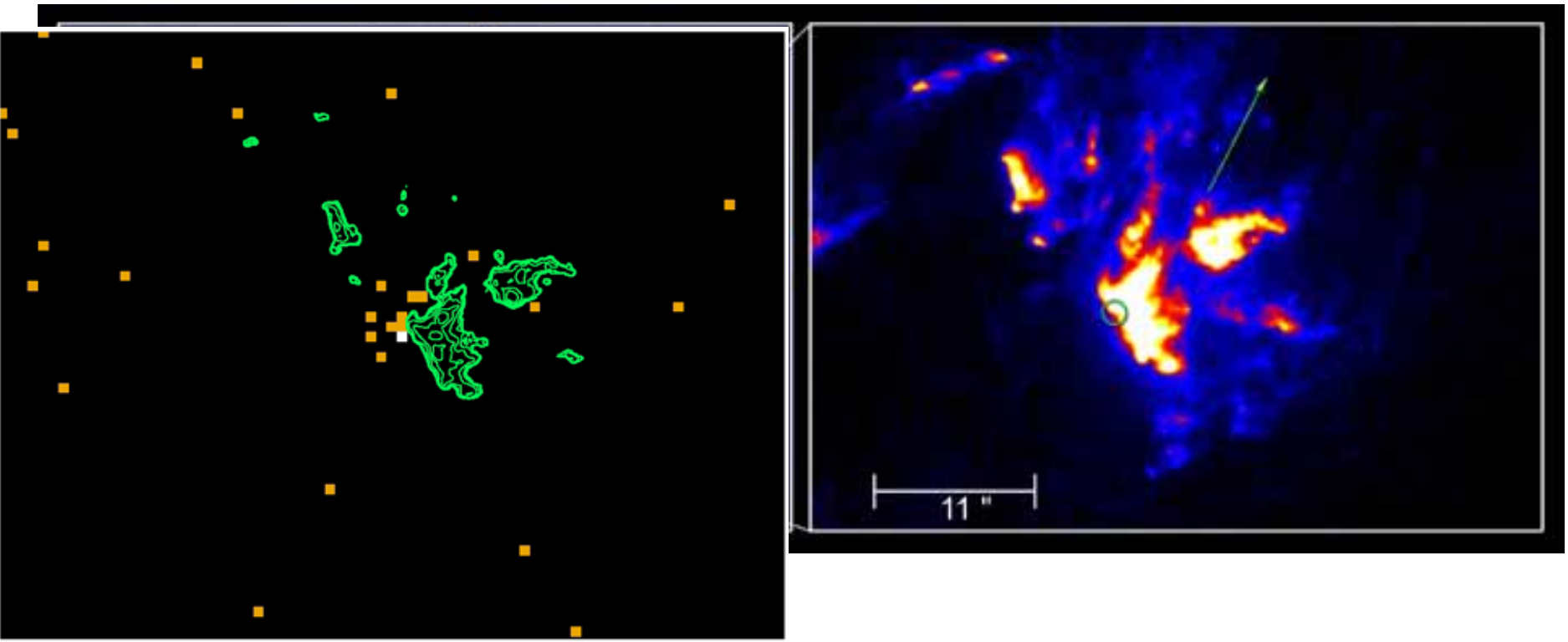
I band

X-Ray

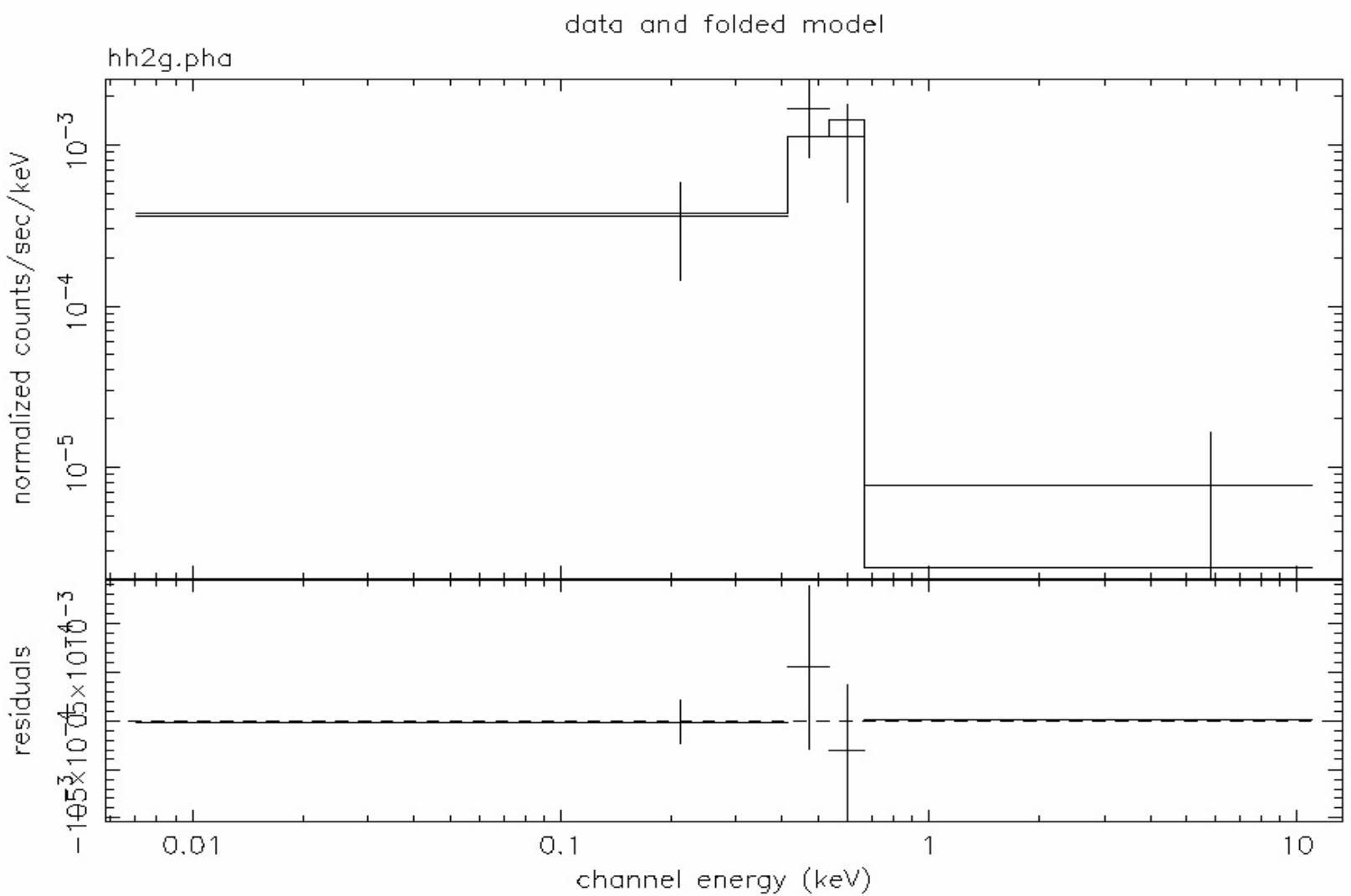
原始星 HH1/2 からのジェット



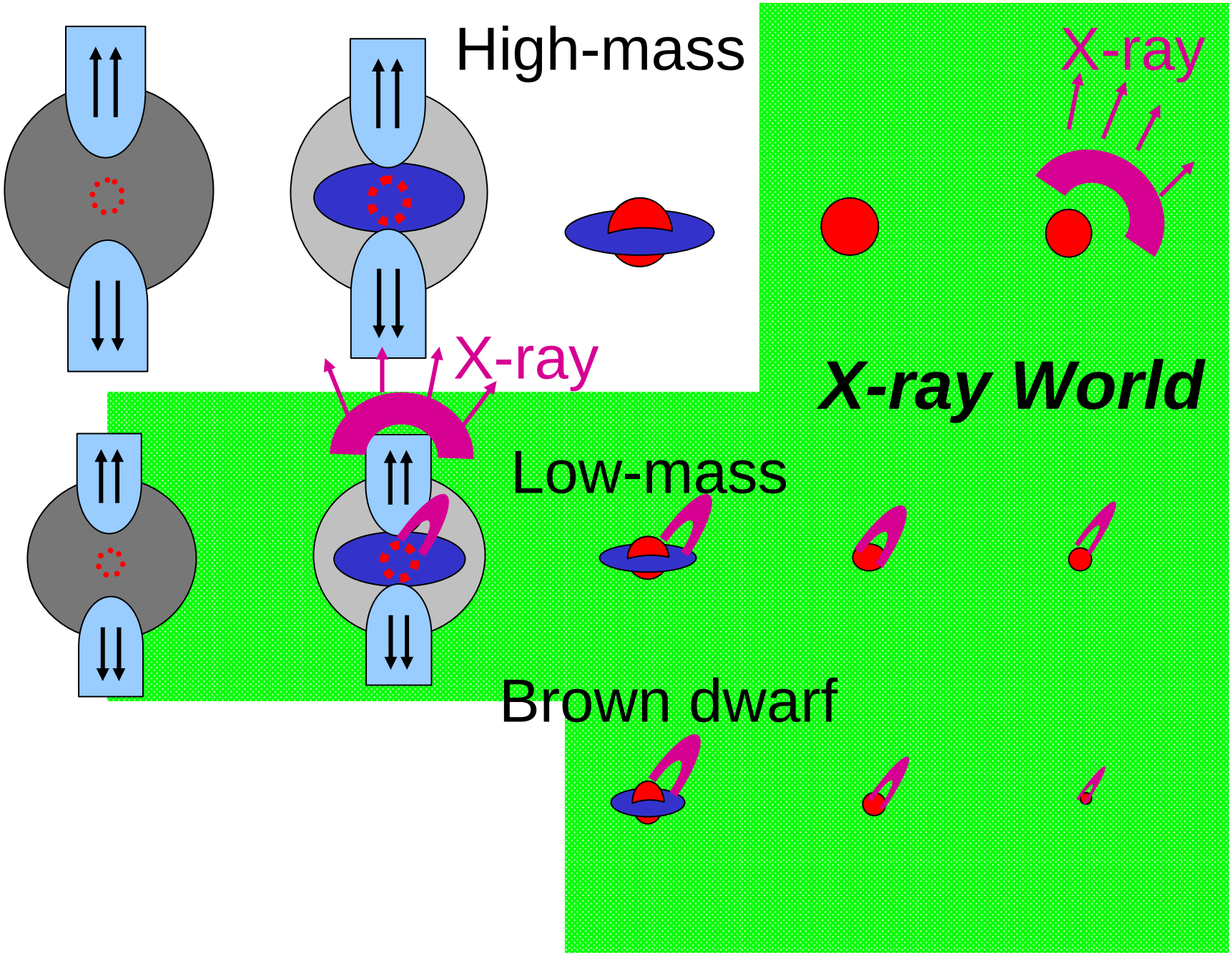
X-rays from HH 2 Pravdo et al. 2001 Nature



Spectrum of HH2

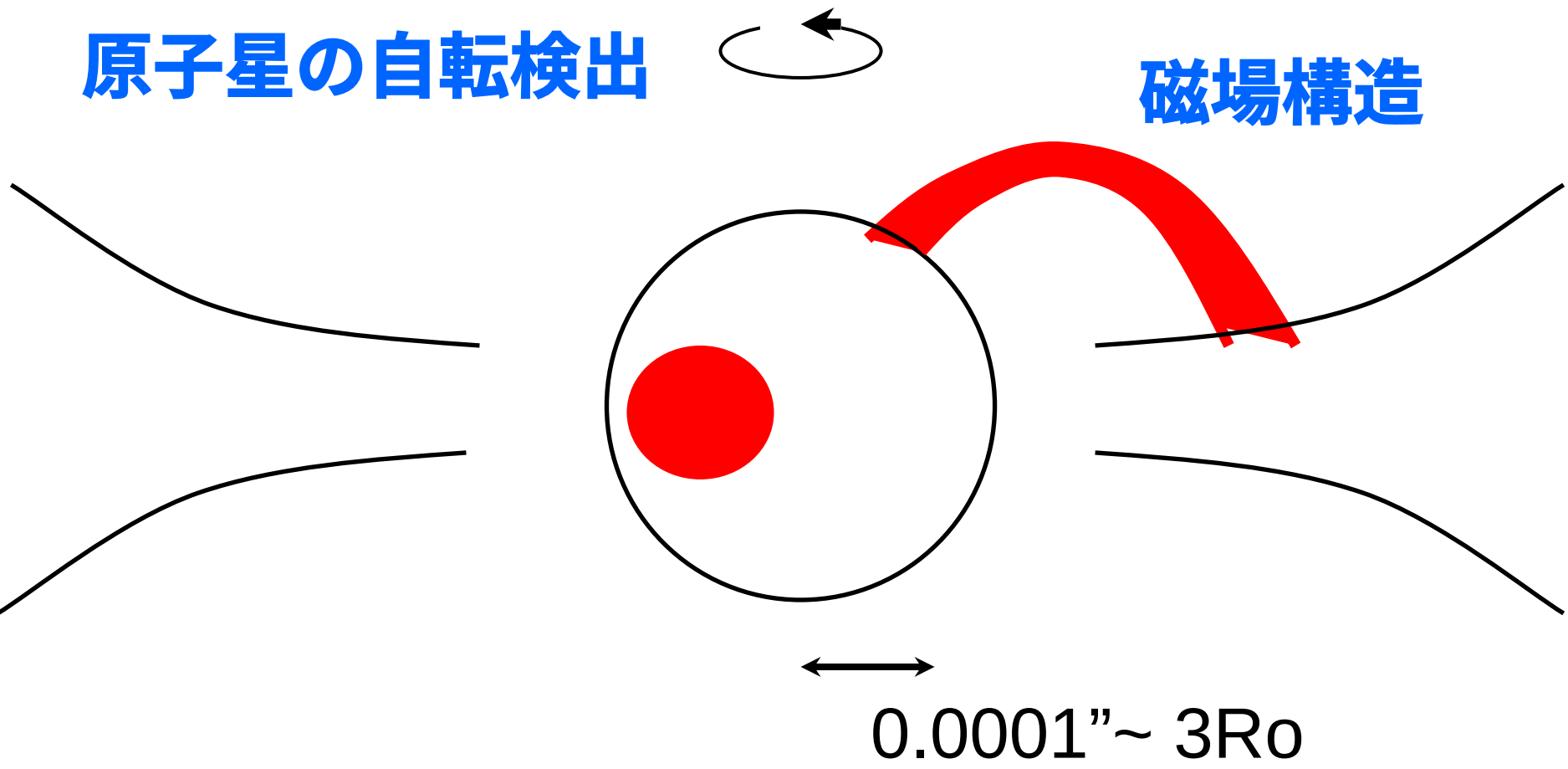


s-1


High-mass
X-ray
X-ray
X-ray World
Low-mass
Brown dwarf

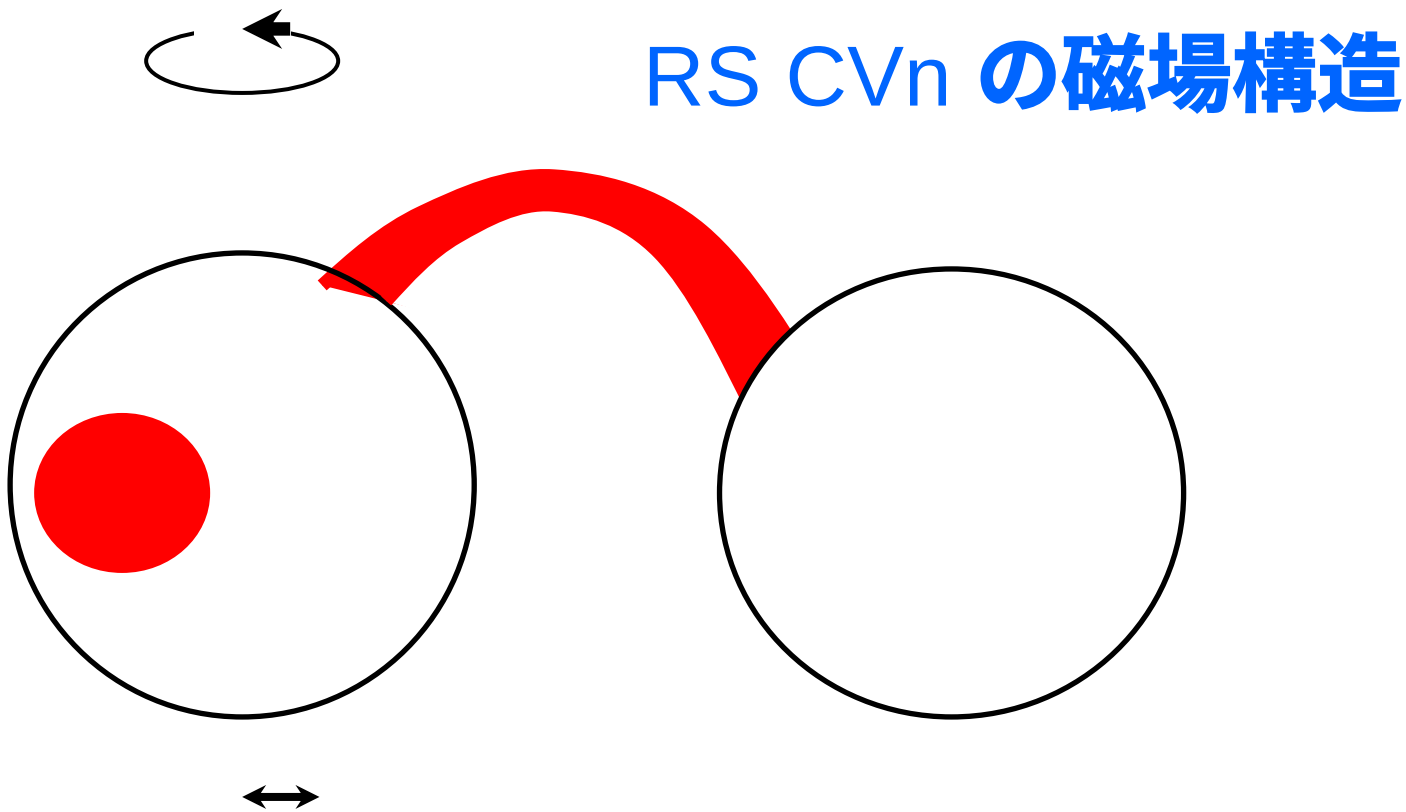
0.0001” で見える構造 (1)

- Rho Oph, Taurus, R CrA (d~150 pc)



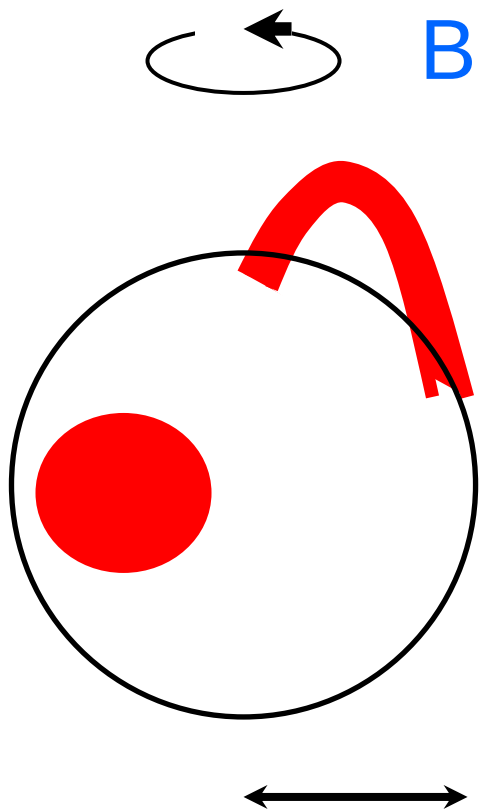
0.0001” で見える構造 (2)

- Nearby RS CVns (d~10 pc)

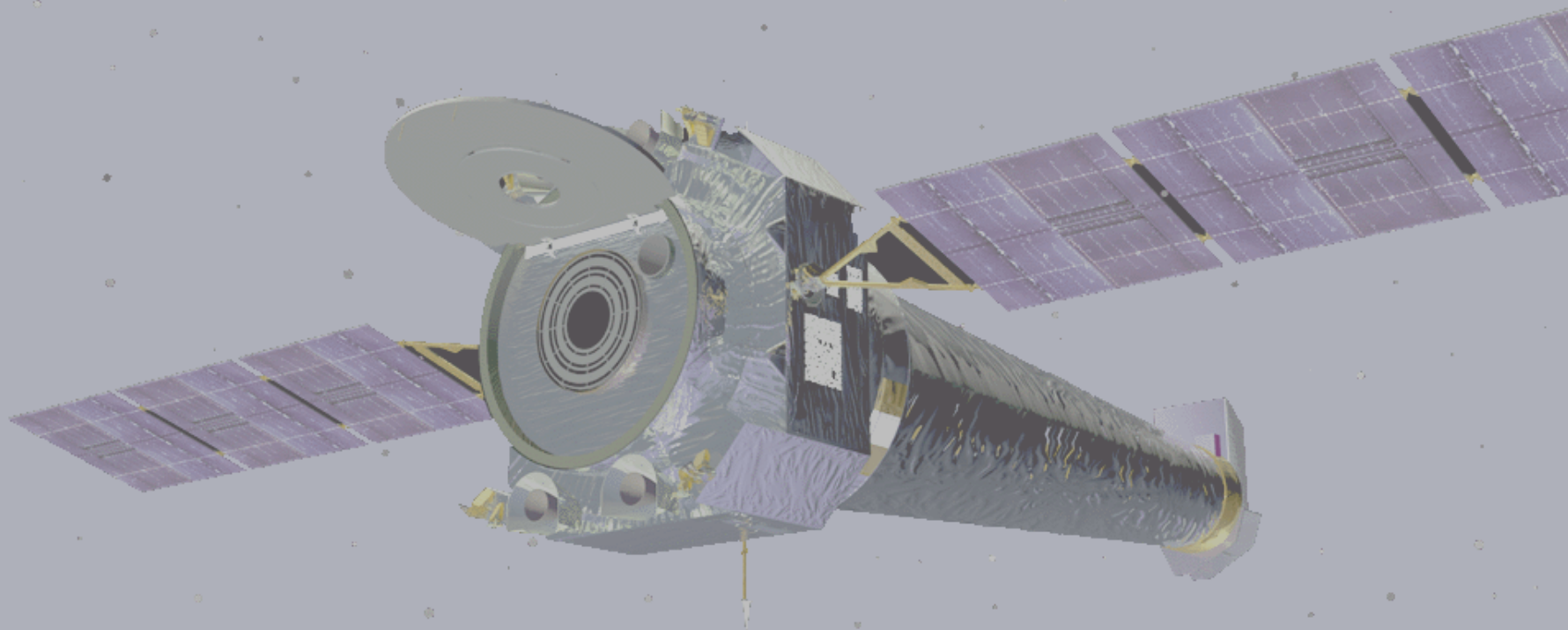


0.0001” で見える構造 (3)

- LP944-20 (d~5 pc)



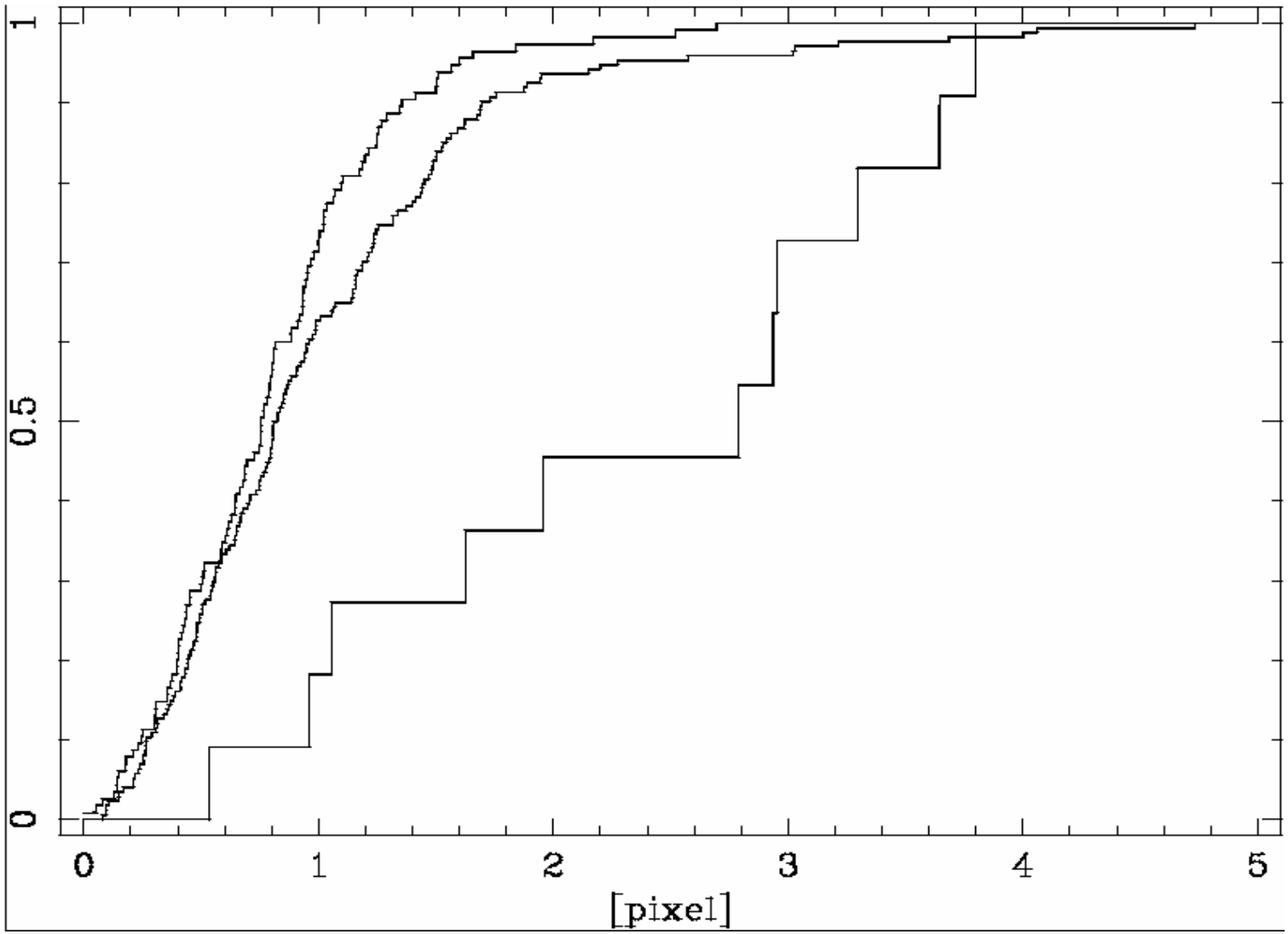
Chandra Observation of HH 1/2

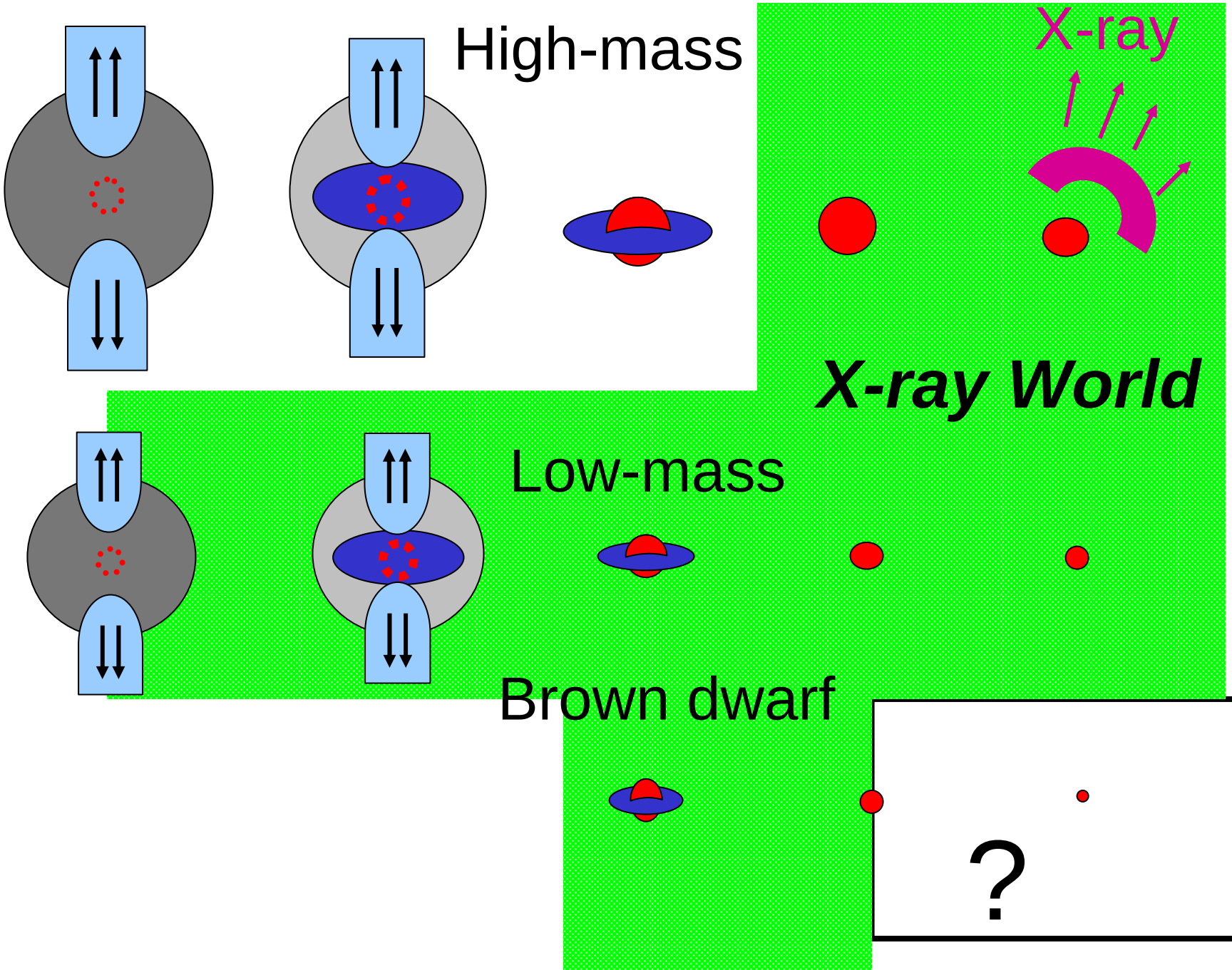


GTO Observation

8 Oct 2000, Exp. Time: 21.4 ksec, ACIS-S

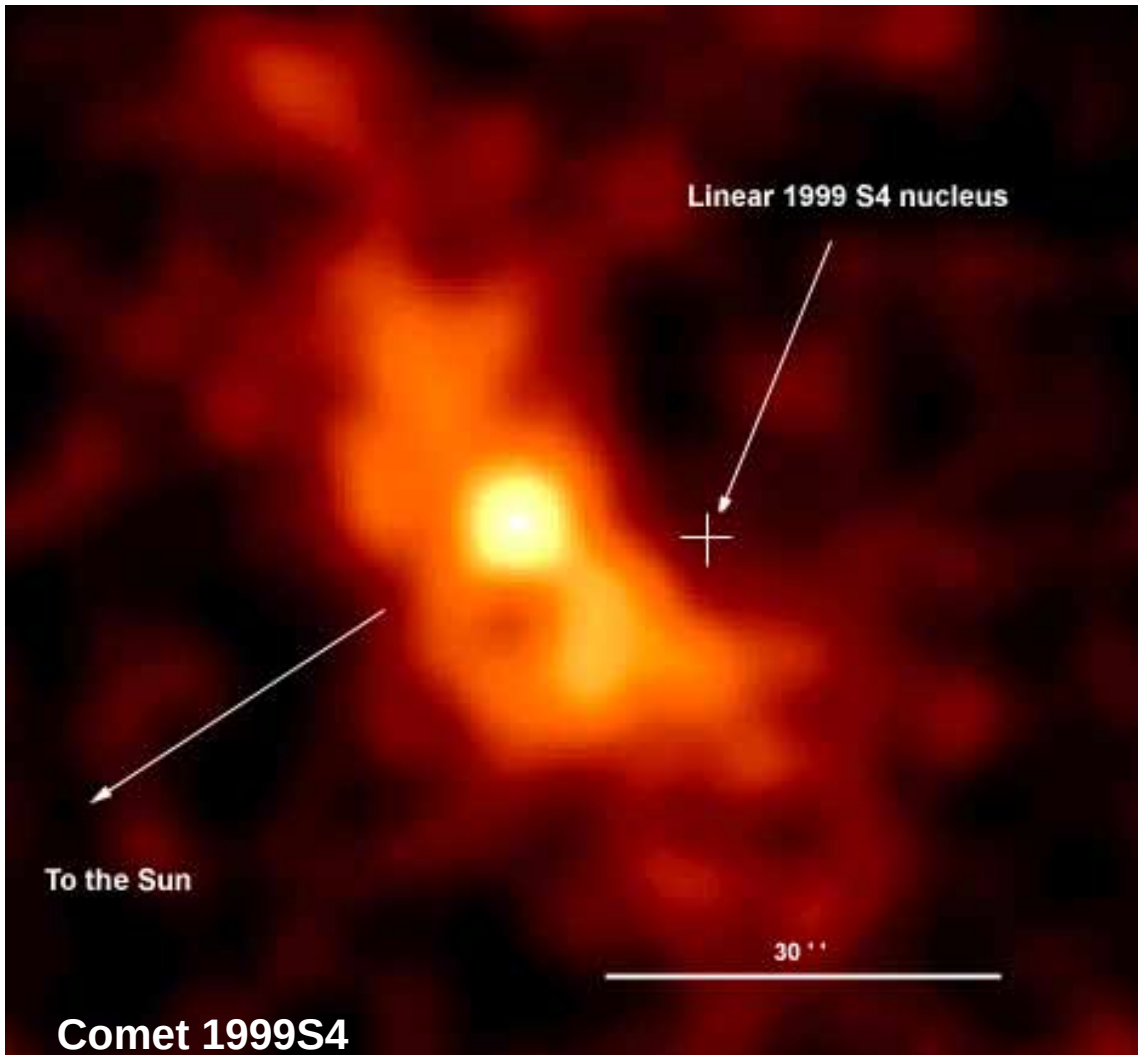
X線の広がり




High-mass
X-ray
X-ray World
Low-mass
Brown dwarf
?

Cometary X-rays

- Lines from Nitrogen and Oxygen ion
- Collisional excitation by solar wind



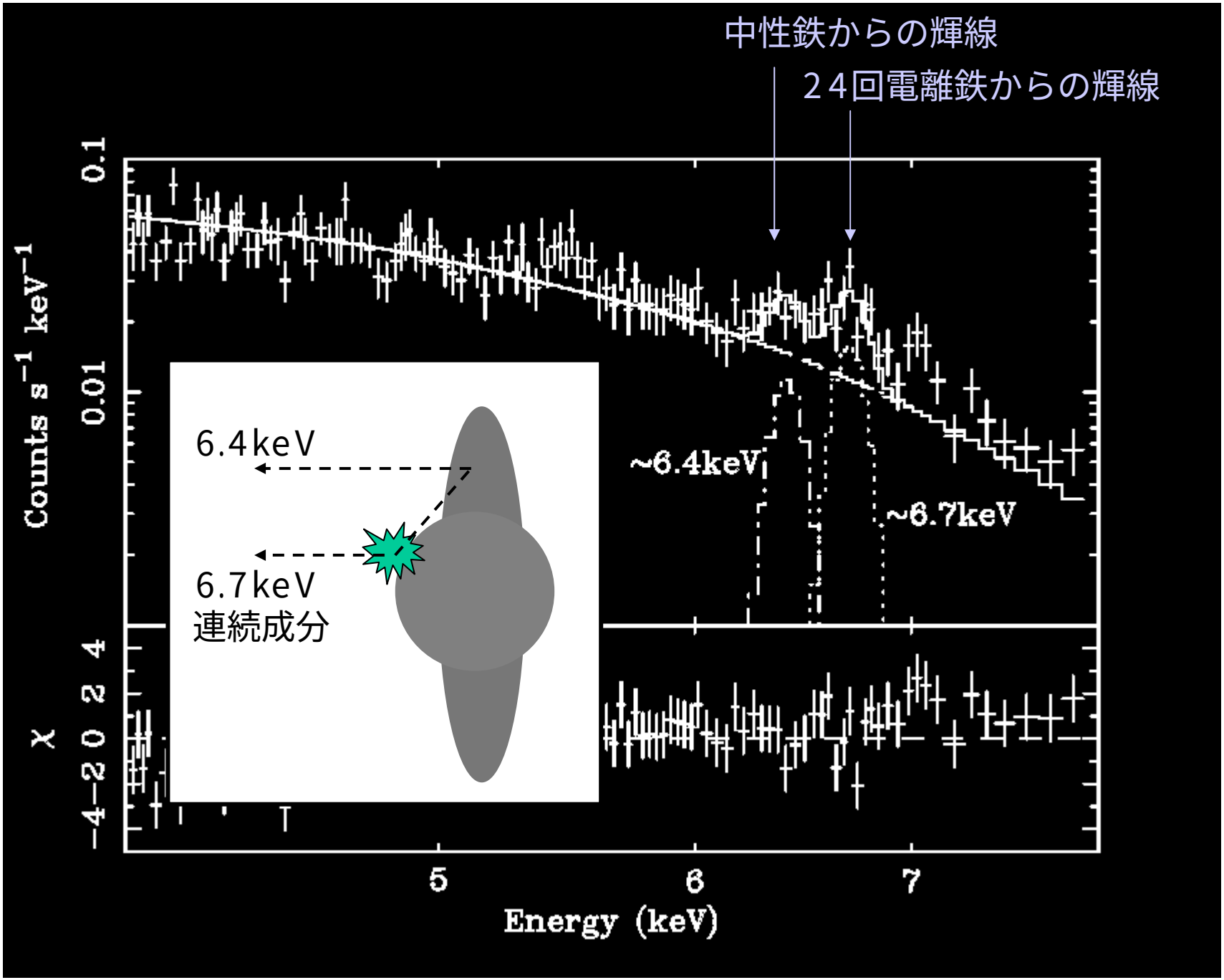
Summary

- Detection of X-rays from Class 0 candidates.
- Access to the nature of Class I, BD, PN, comets,Jets….

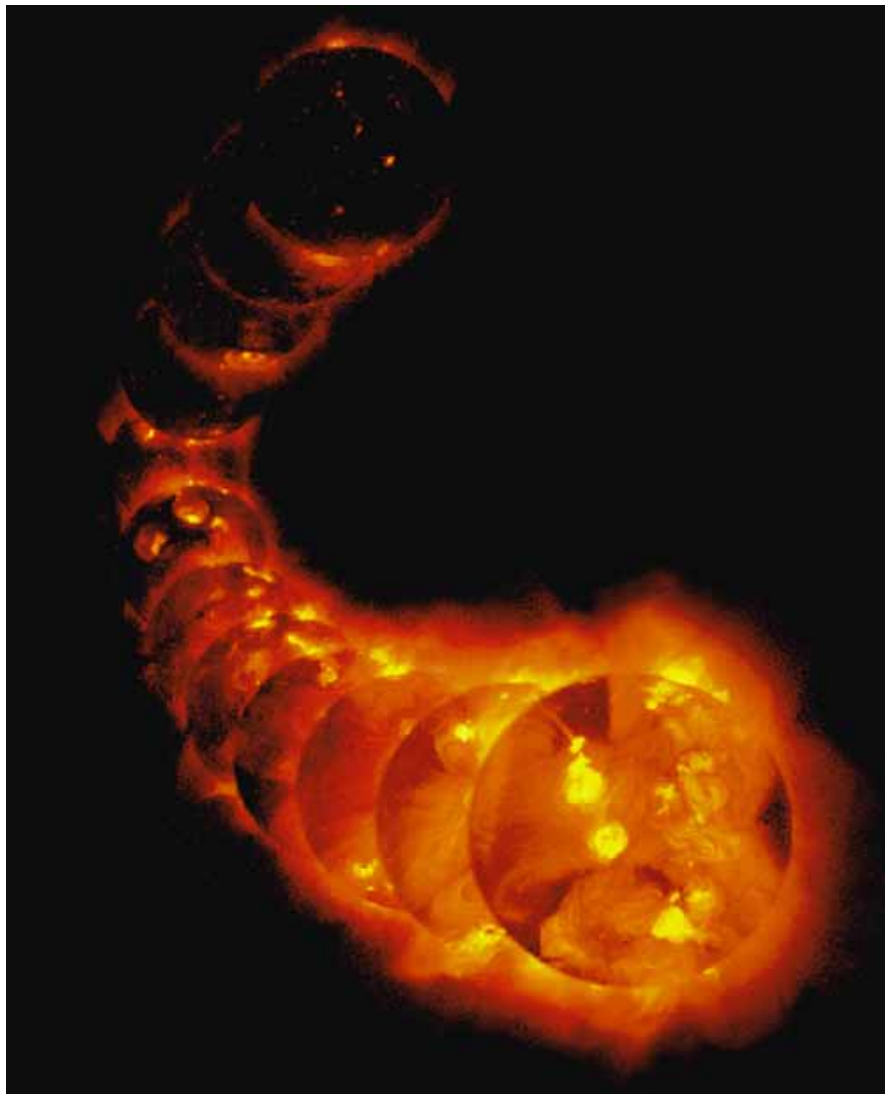
Whole life of a star ?

Future Challenge

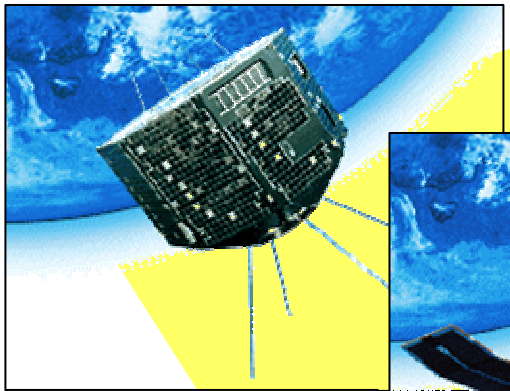
- Extra solar planets ??
- Class 0 protostars


中性鉄からの輝線
２４回電離鉄からの輝線
0.1
0.01
Counts s^{-1} keV^{-1}
~6.4keV
~6.7keV
6.4keV
6.7keV
連続成分
χ
−4 −2 0 2 4
5
6
7
Energy (keV)

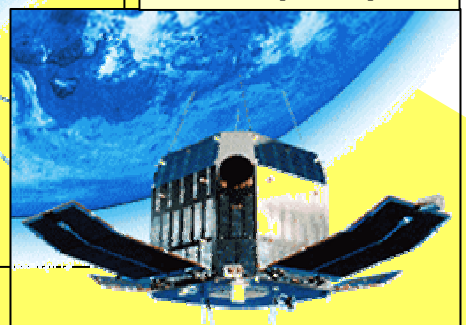
X線で見た太陽



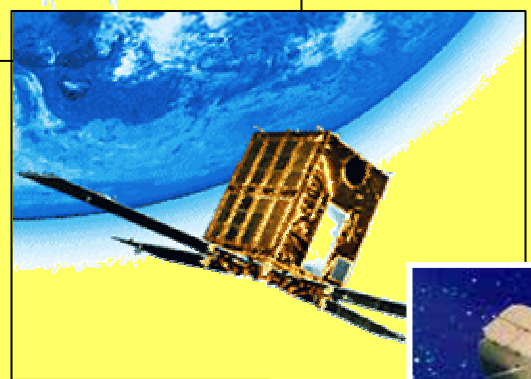
X線天文学



はくちょう (1979)

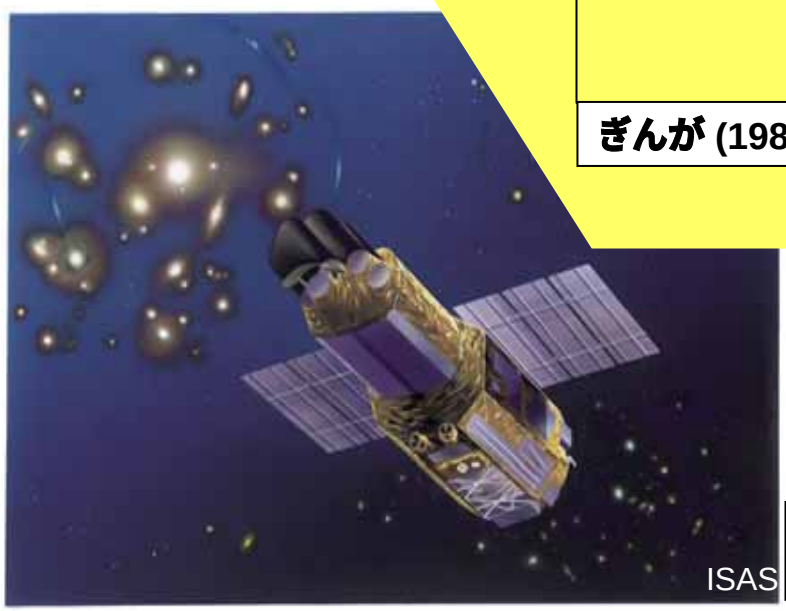


てんま (1983)



ぎんが (1987)

あすか (1993)



ISAS

Astro-E-II

USA 1960 ESA

Rocket

'70

UHURU

SAS-3

HEAO-A

Einstein

'80

EXOSAT

'90

ROSAT

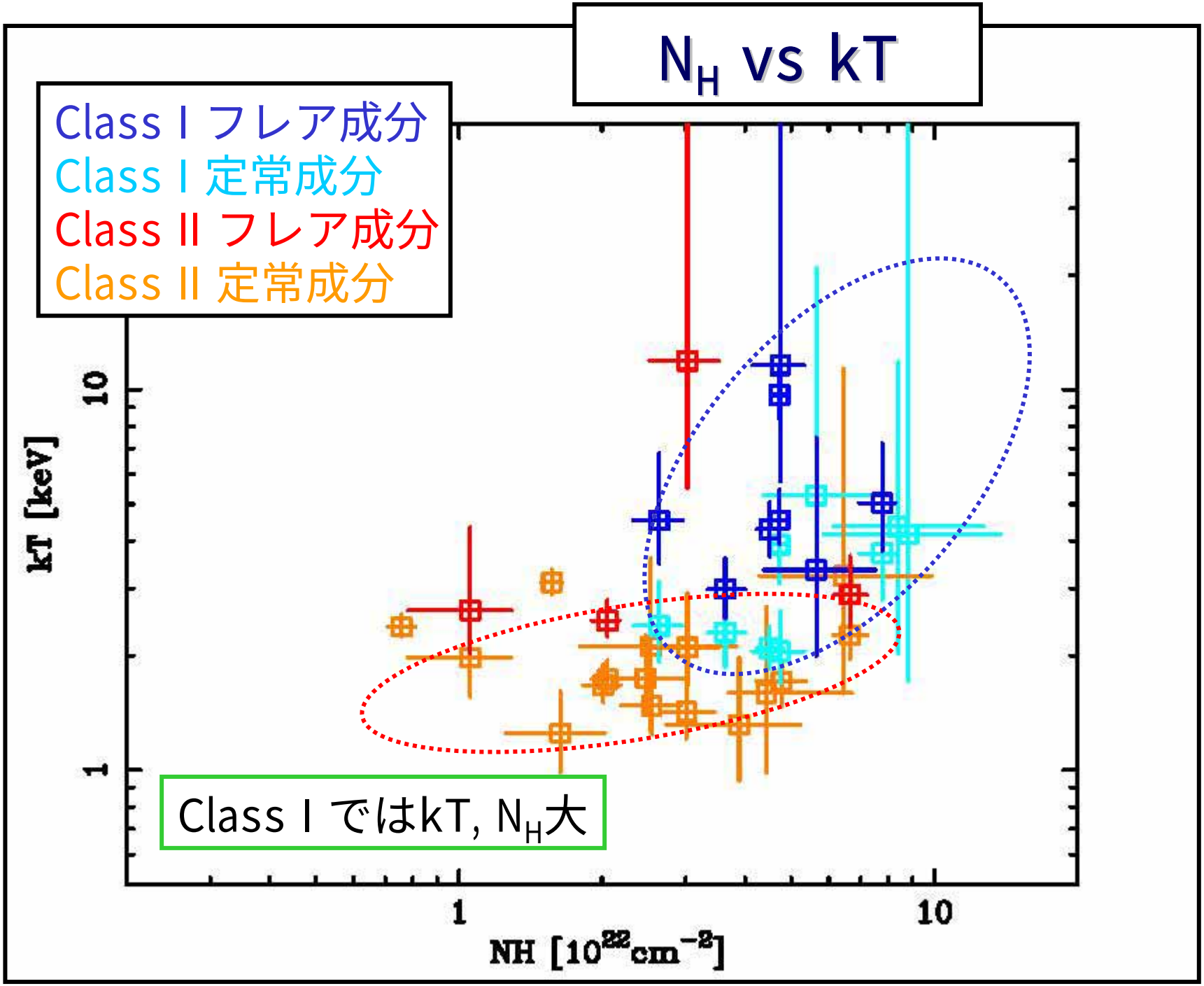
RXTE

Chandra

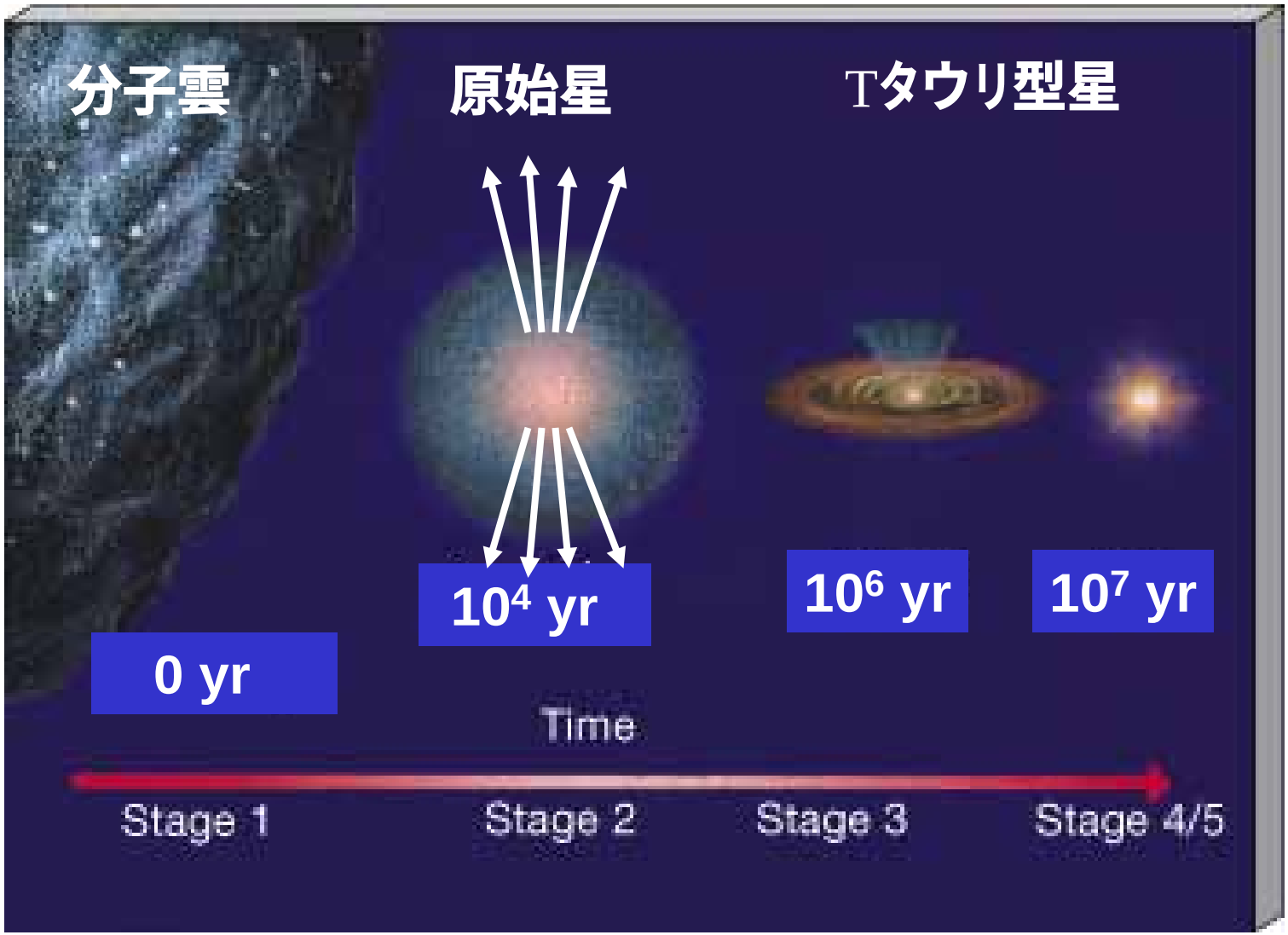
Newton

2000

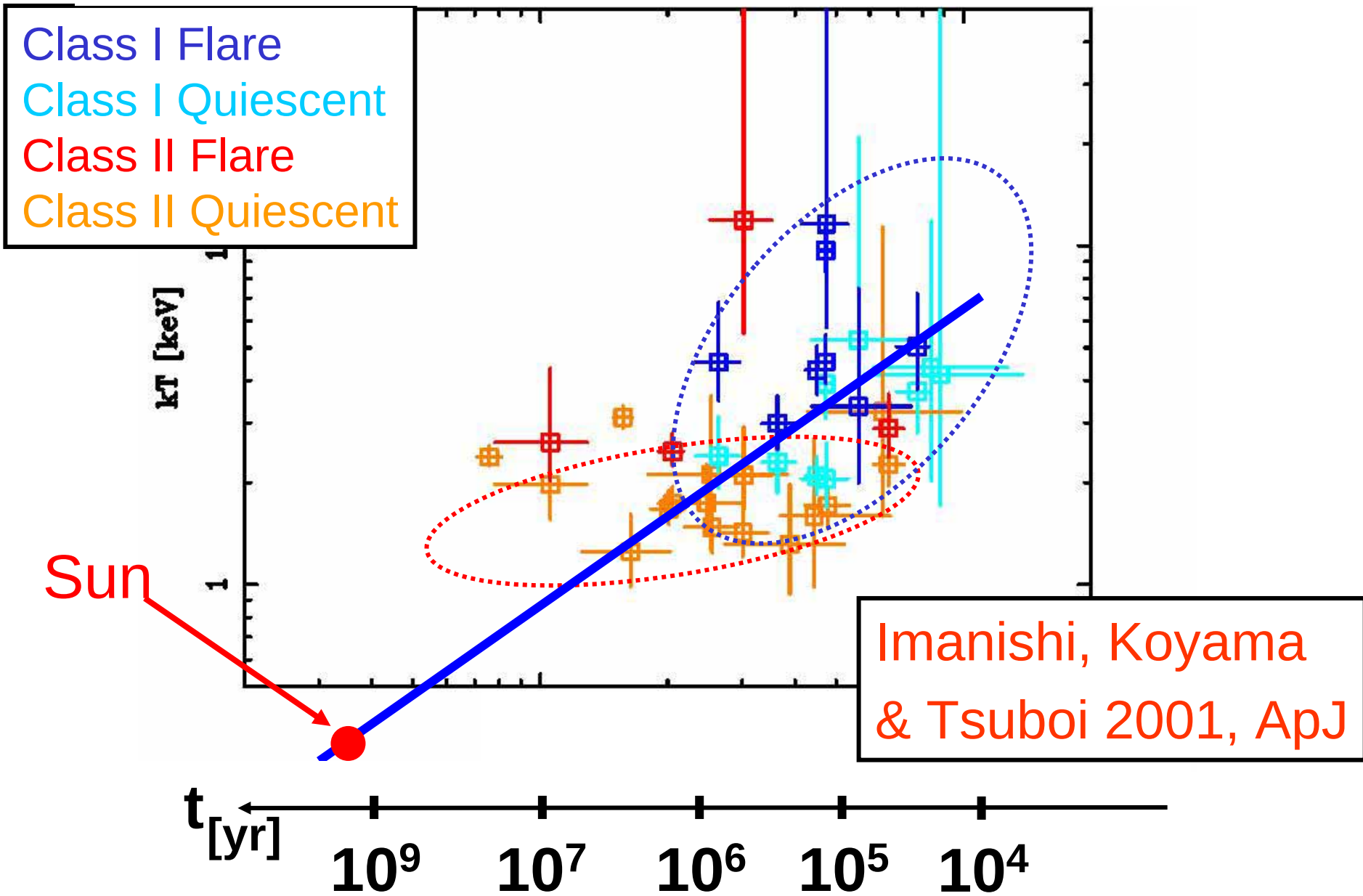
N_H vs kT


Class I フレア成分
Class I 定常成分
Class II フレア成分
Class II 定常成分
kT [keV]
10
1
1
10
NH [10^22cm^-2]
Class I ではkT, N_H大

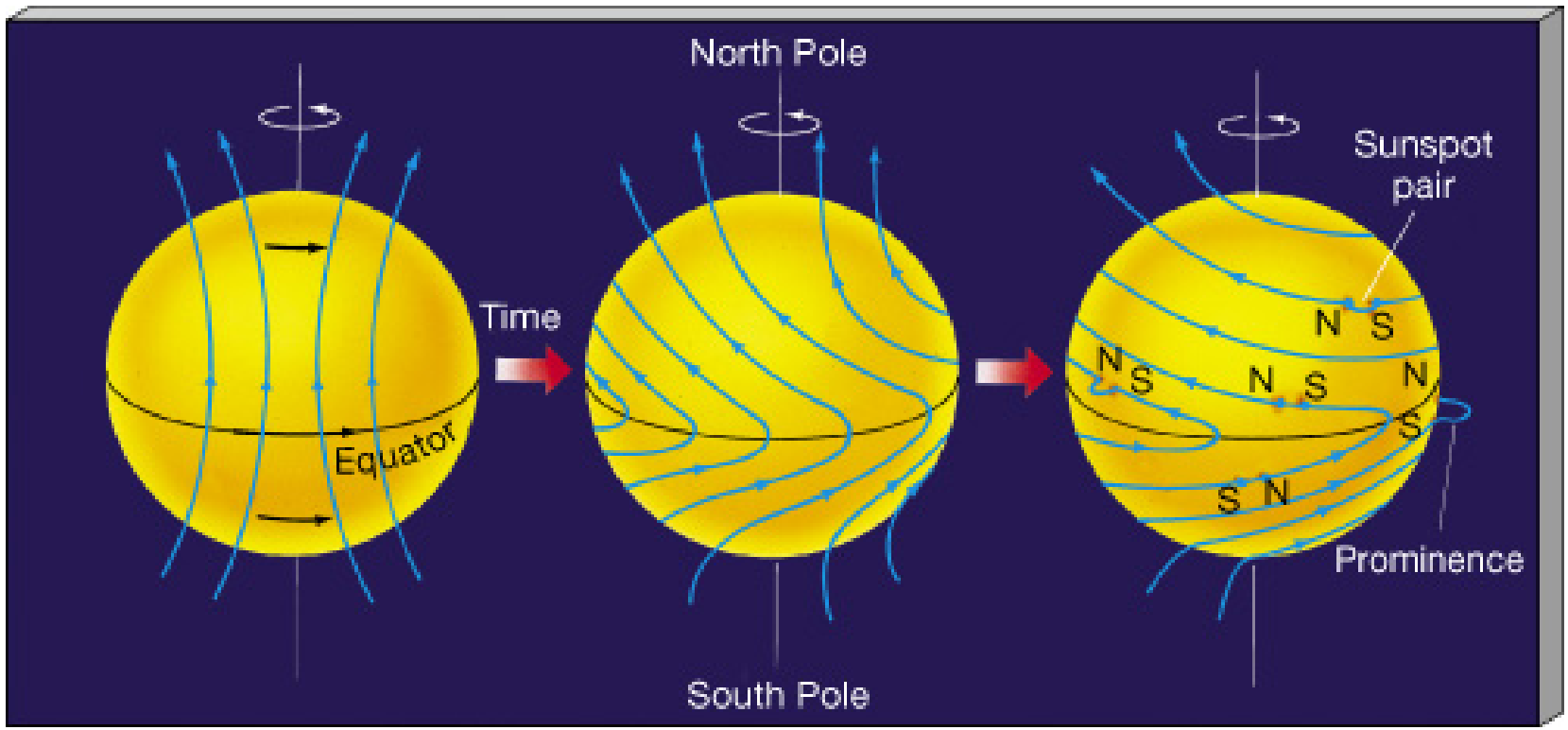
星の誕生


分子雲
原始星
Tタウリ型星
10^4 yr
10^6 yr
10^7 yr
0 yr
Time
Stage 1
Stage 2
Stage 3
Stage 4/5

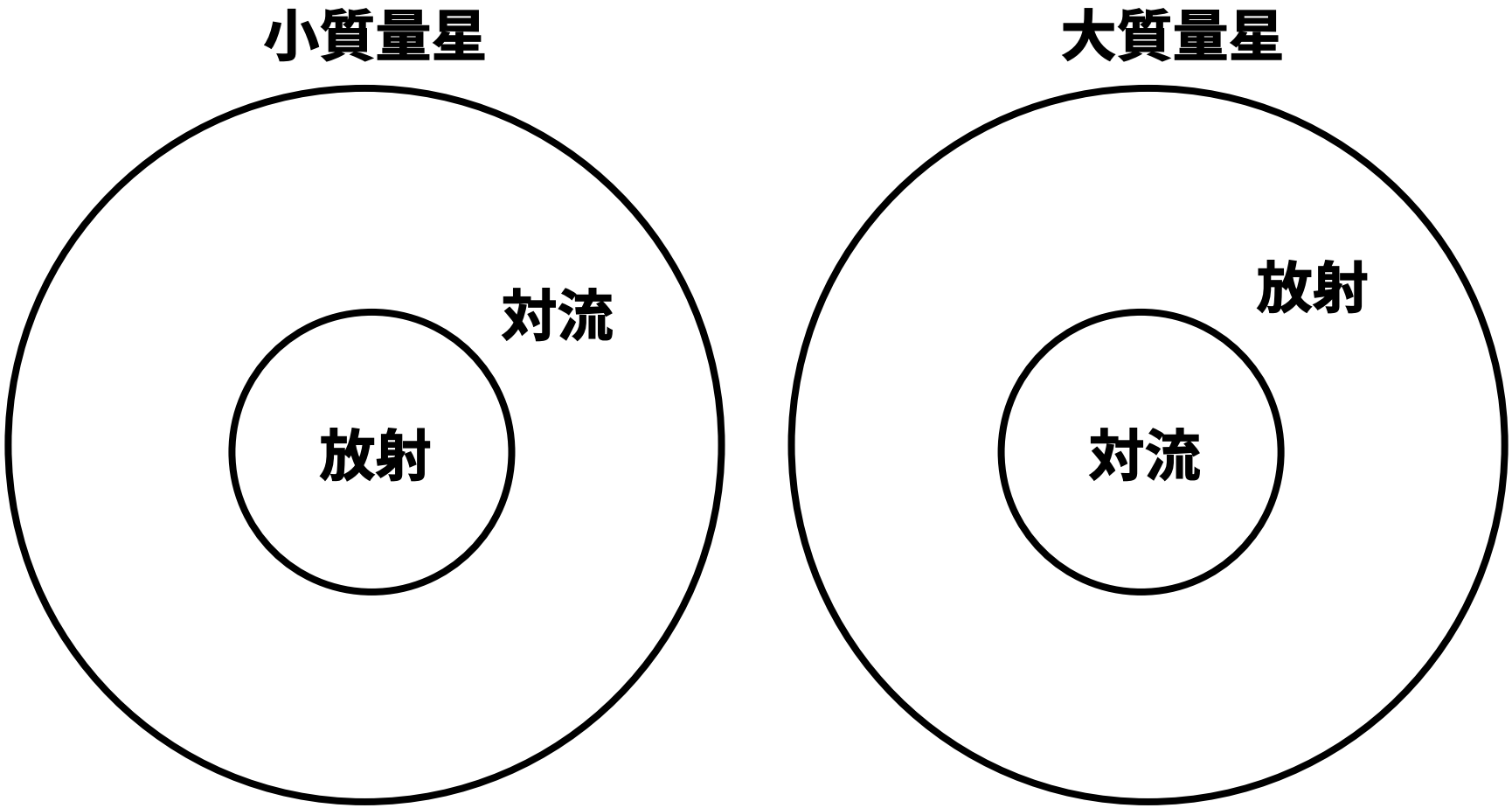
kT vs age of solar-mass YSOs



磁気リコネクションの起きかた



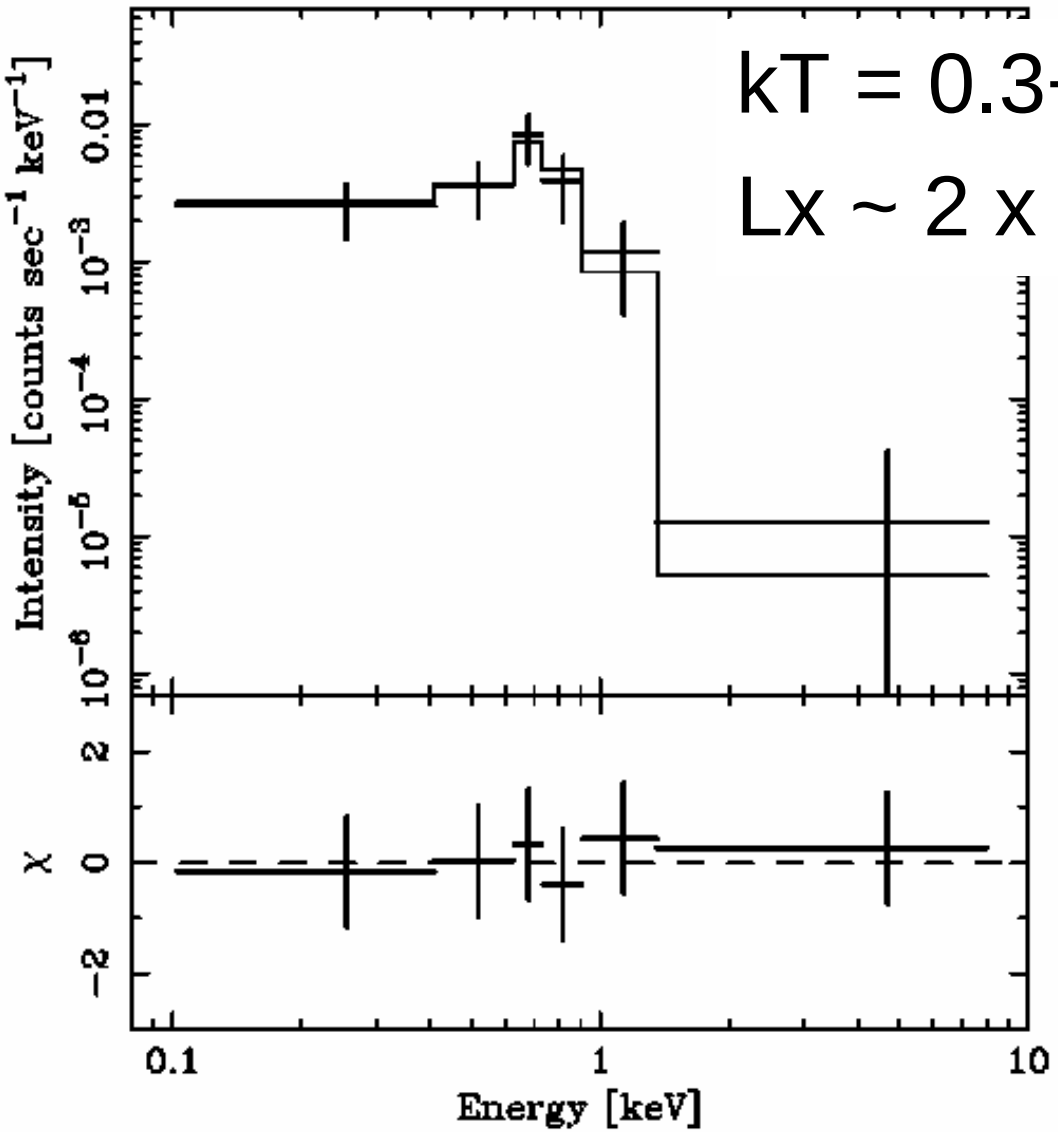
星の質量と構造の違い



Summary

- 70% Class I protostars (and candidates) are detected in Rho Oph with flare-like time variabilities. Virtually, all Class Is could emit X-rays possibly with magnetic activity.
- X-rays from two Class 0 candidates are discovered. We need more sensitivity and samples!

ACIS-S Spectrum of TWA 5B



kT = 0.3+/- 0.1 keV

Lx ~ 2 x 10^{27} ergs s^{-1}