Stellar Evolution Revealed with ASTRO-H

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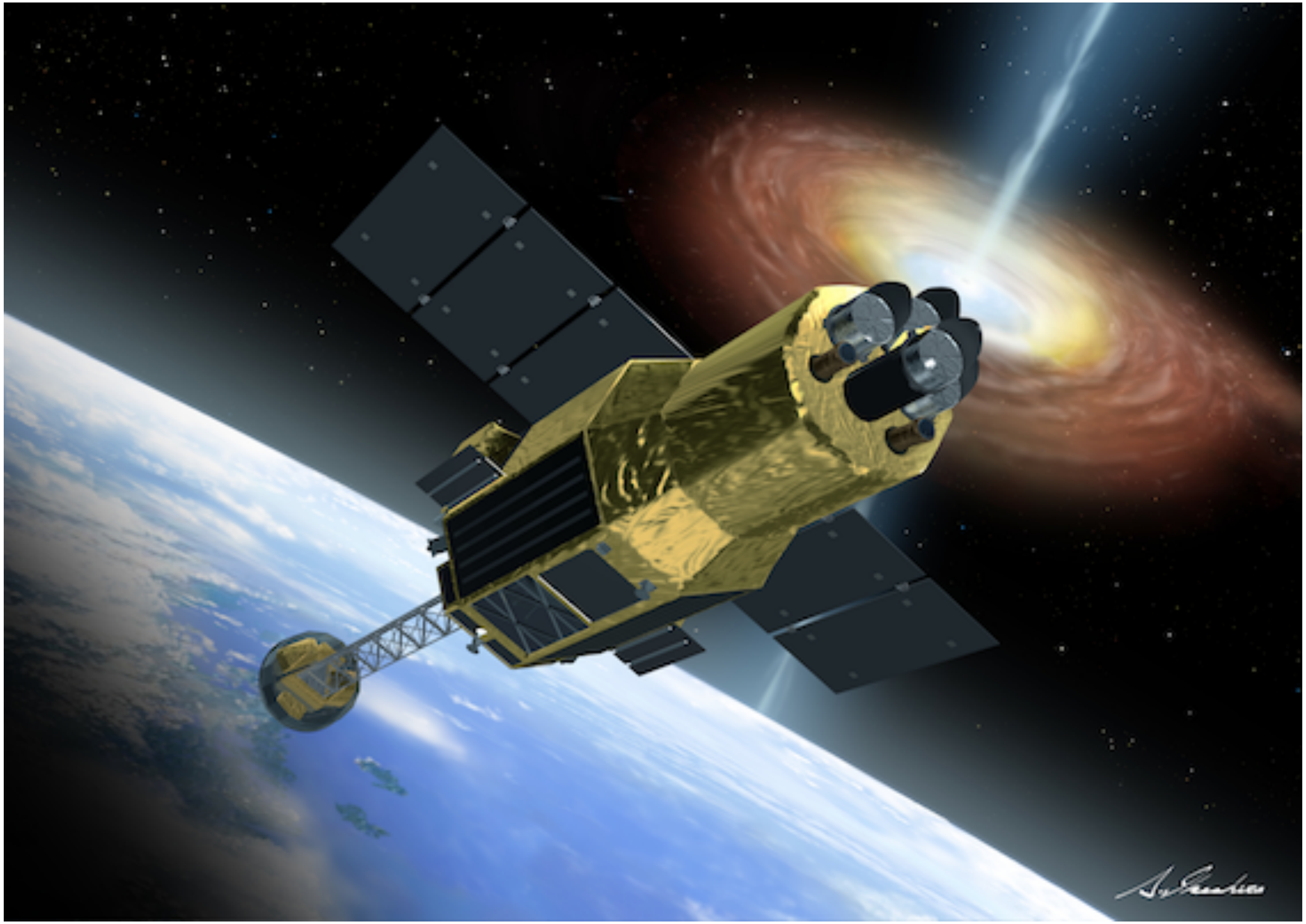
ASTRO-H to be launched in 2016



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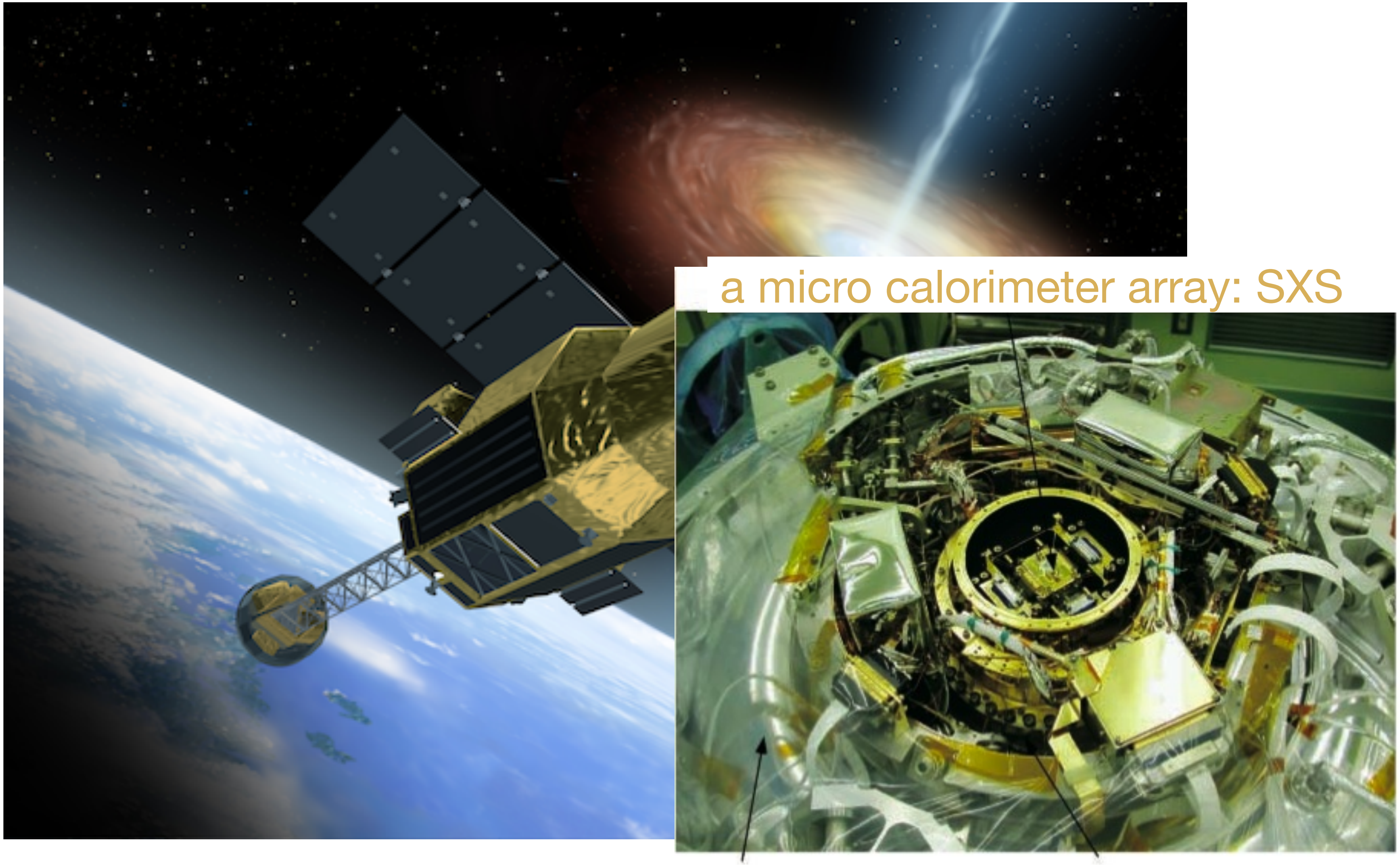
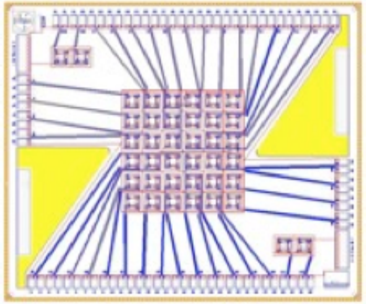
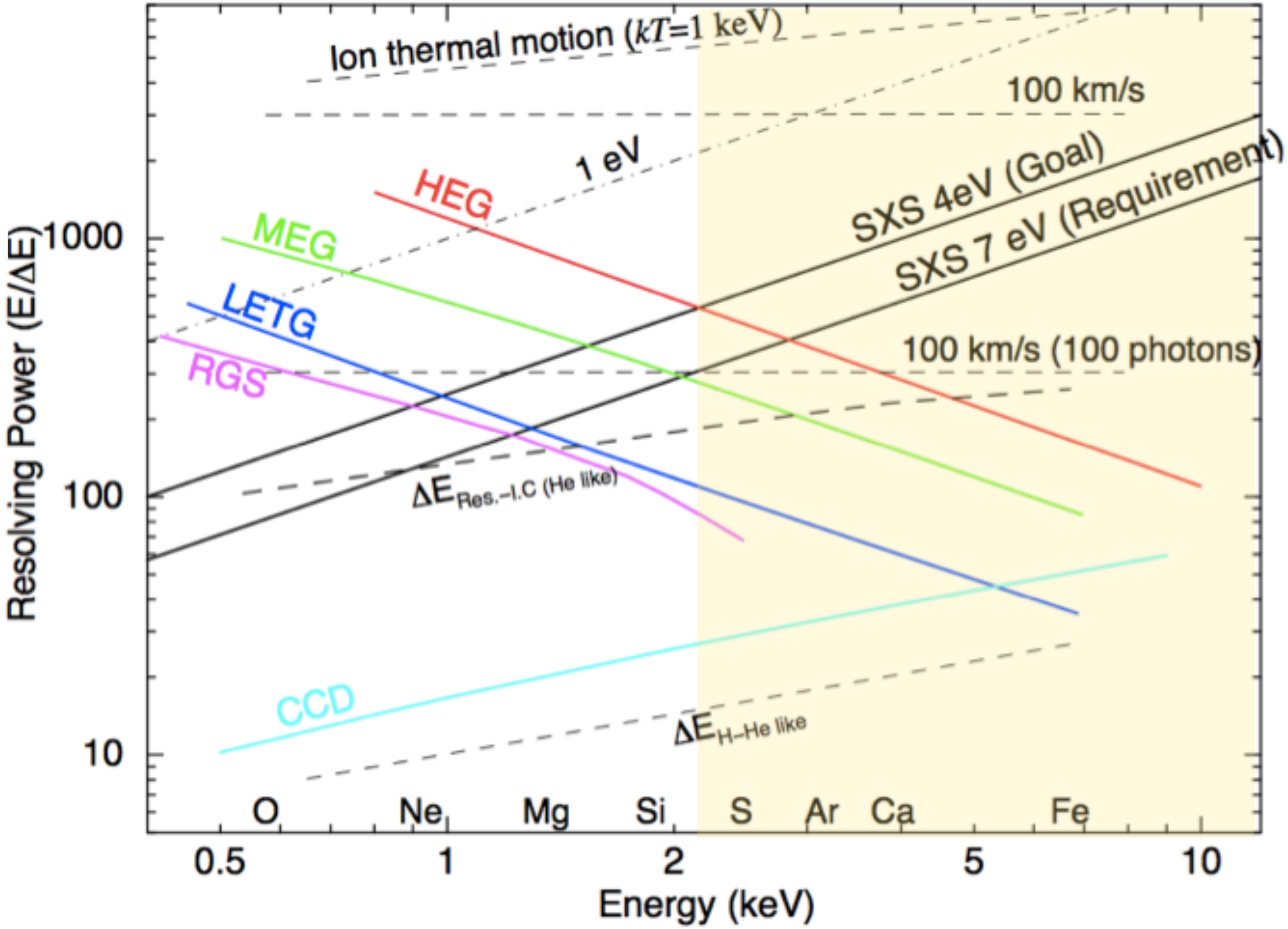


1. *ASTRO-H* Uniqueness : High resolution spectroscopy at hard band

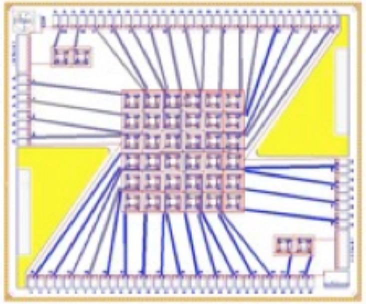
- a micro calorimeter array



814 μm
6x6 array
34 pixel readout
50 mK

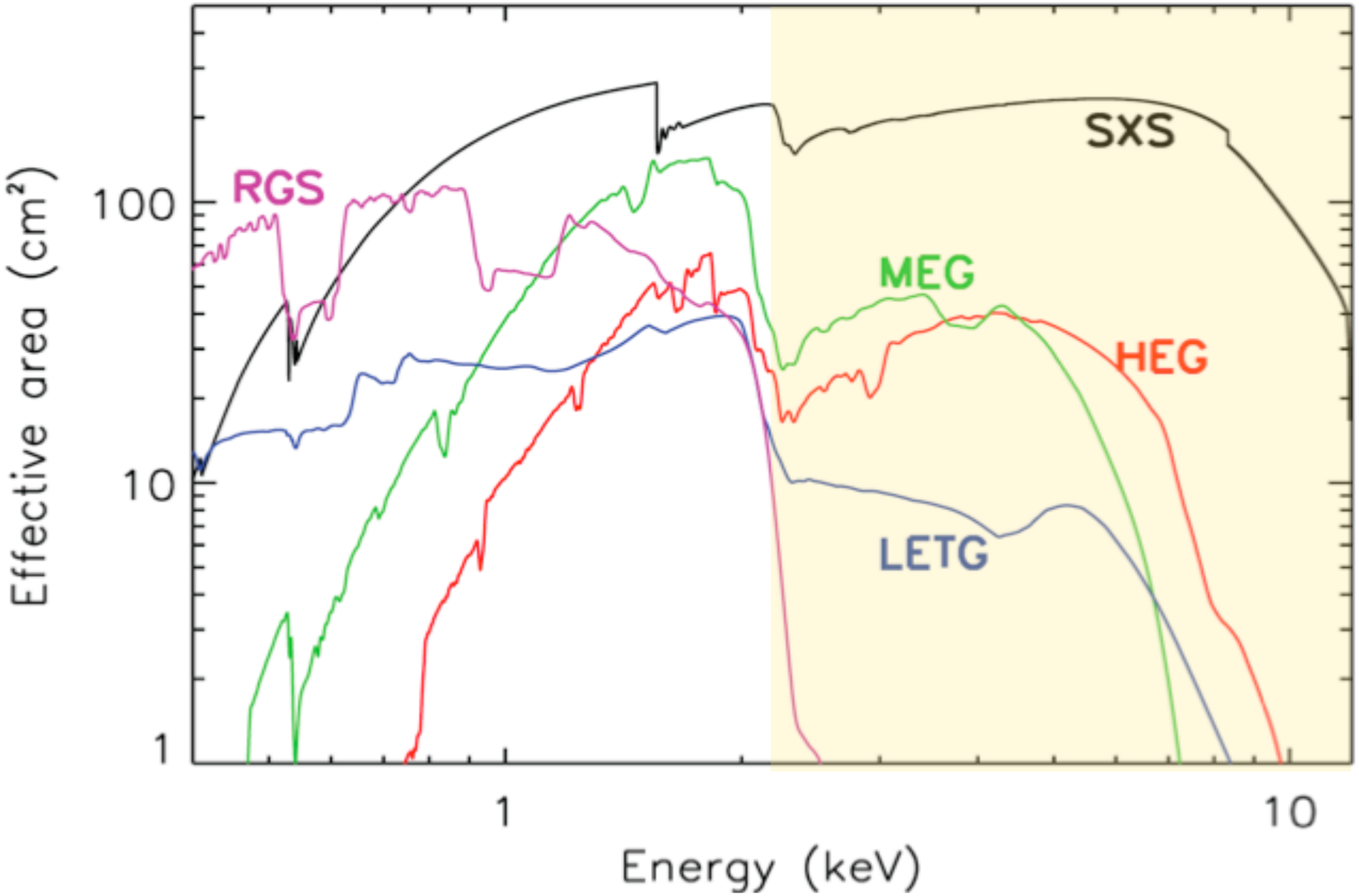


2. ASTRO-H Uniqueness : Large effective area at hard band



814 μm
6x6 array
34 pixel readout
50 mK

210cm^2@6keV



→ Powerful tool for embedded sources
with line emissions in hard band

Stellar Evolution Revealed with ASTRO-H

1. Dynamics and structures of protostars
2. Accretion process in T Tauri stars
3. High-mass evolved stars/binaries

The large effective area and the superior spectral resolution above 2 keV of ASTRO-H will help:

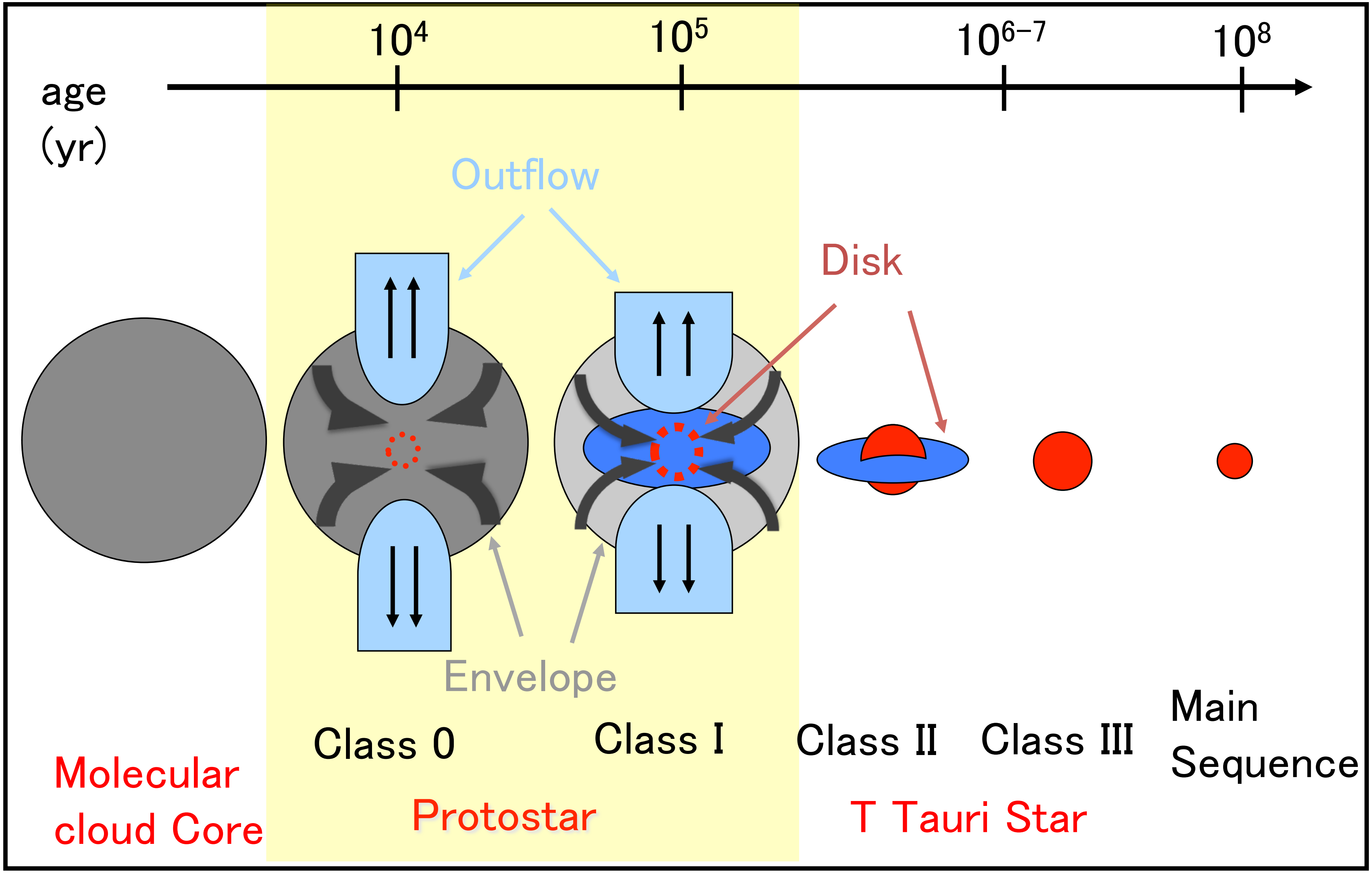
1) Detect Fe Kα emissions (6.7 keV, 6.4 keV) and constrain geometries and dynamics
2) Probe densities using Si III and Mg XI triplets

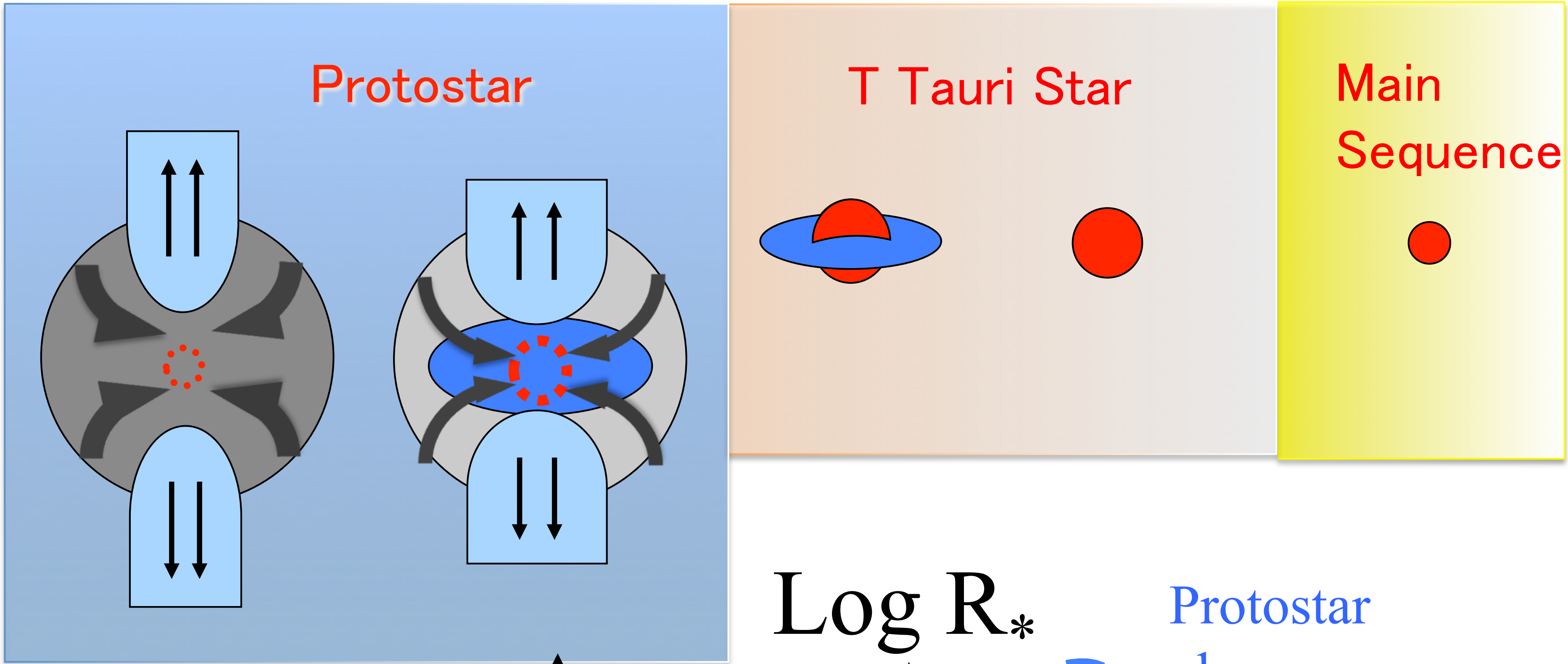
1. Dynamics and structures of protostars

Understanding

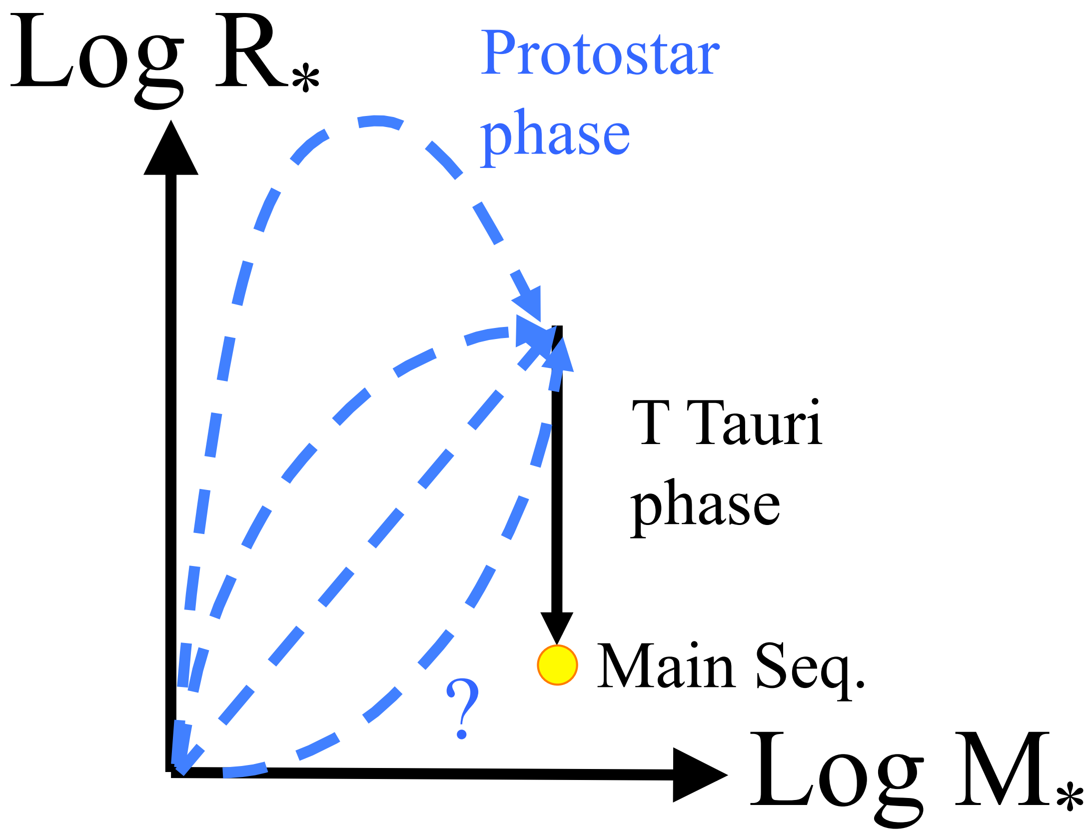
of star formation process

Early Evolution of a Star

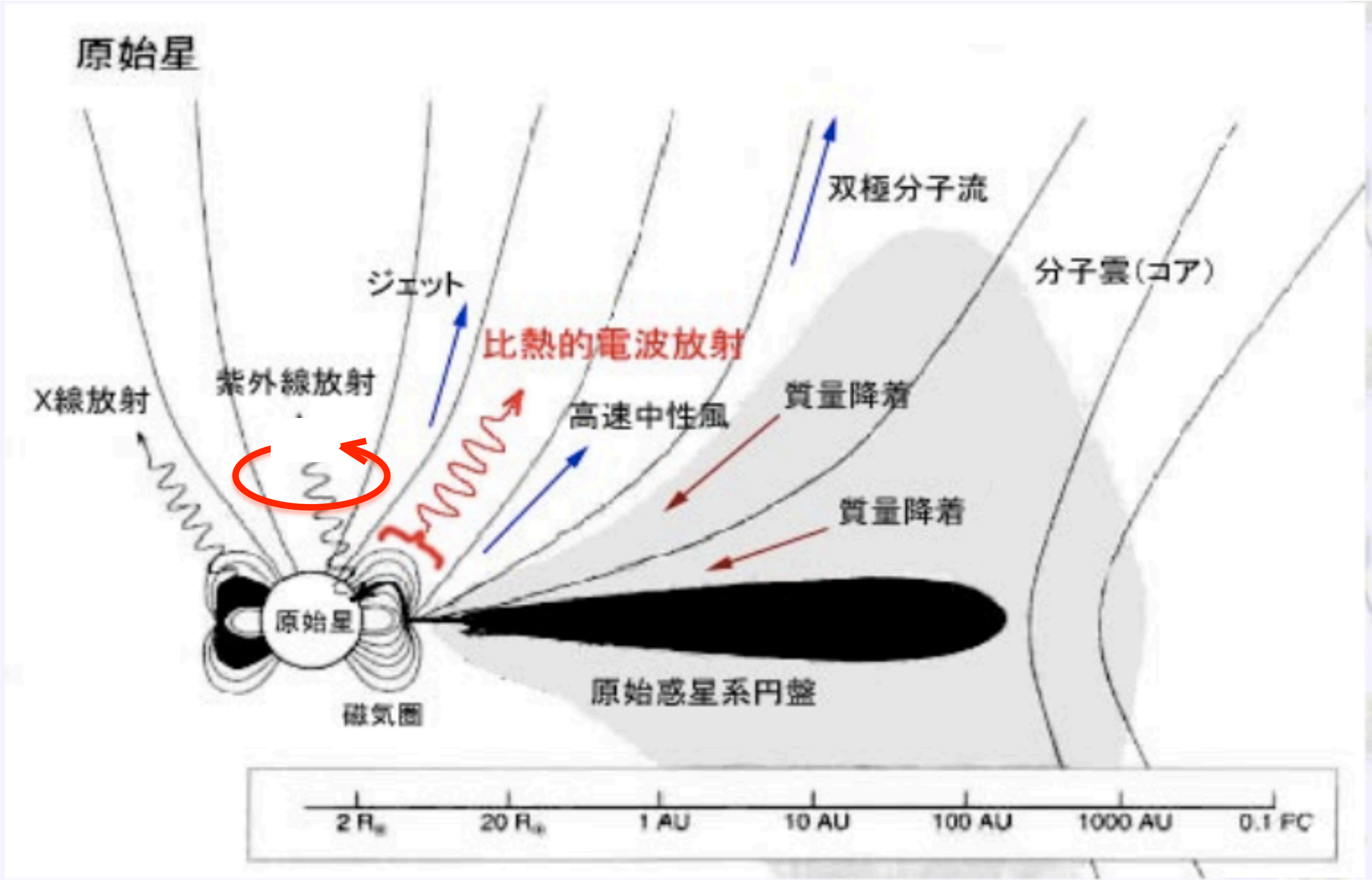




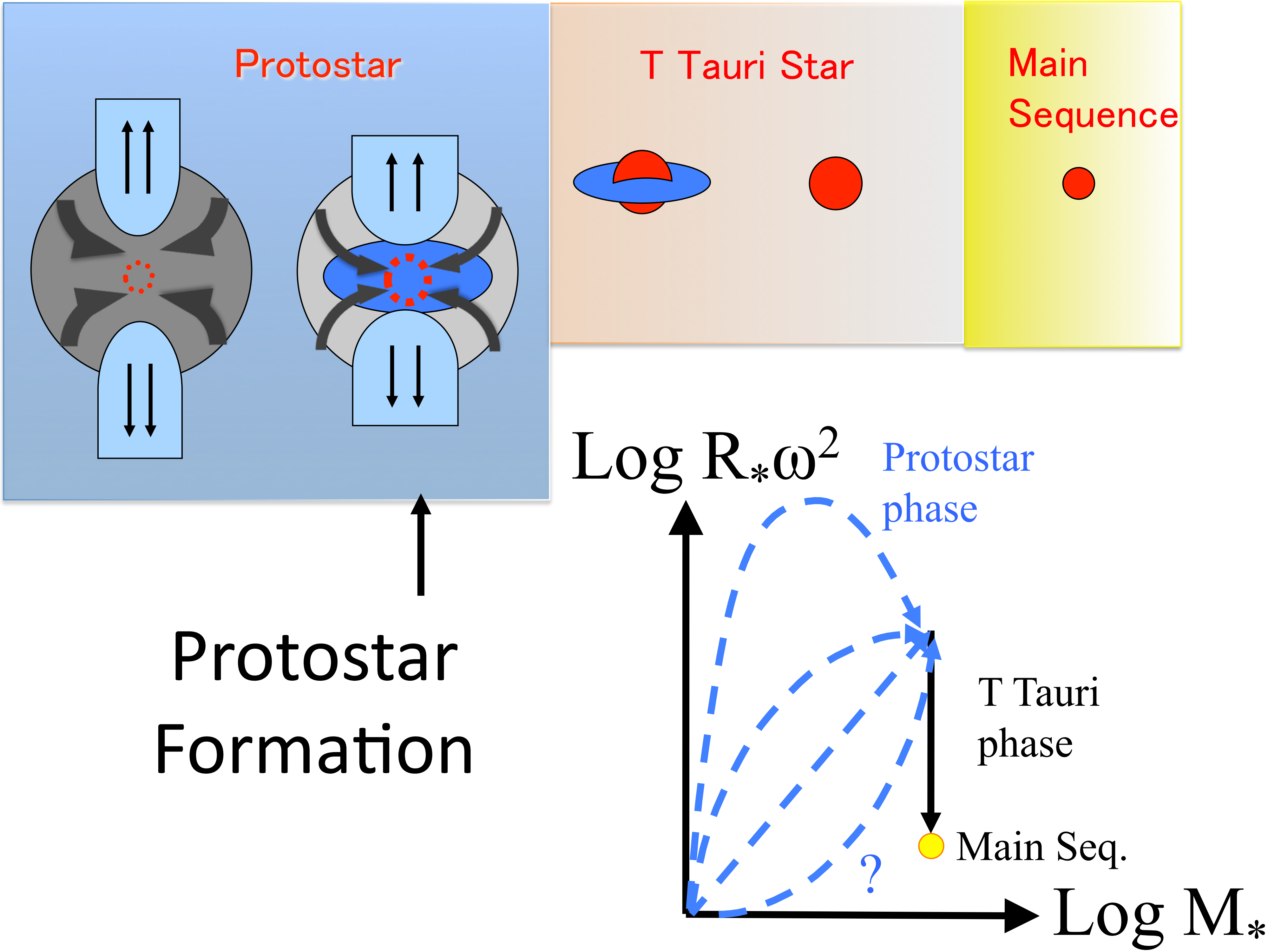
Protostar Formation



Angular Momentum Transfer in a Protostar

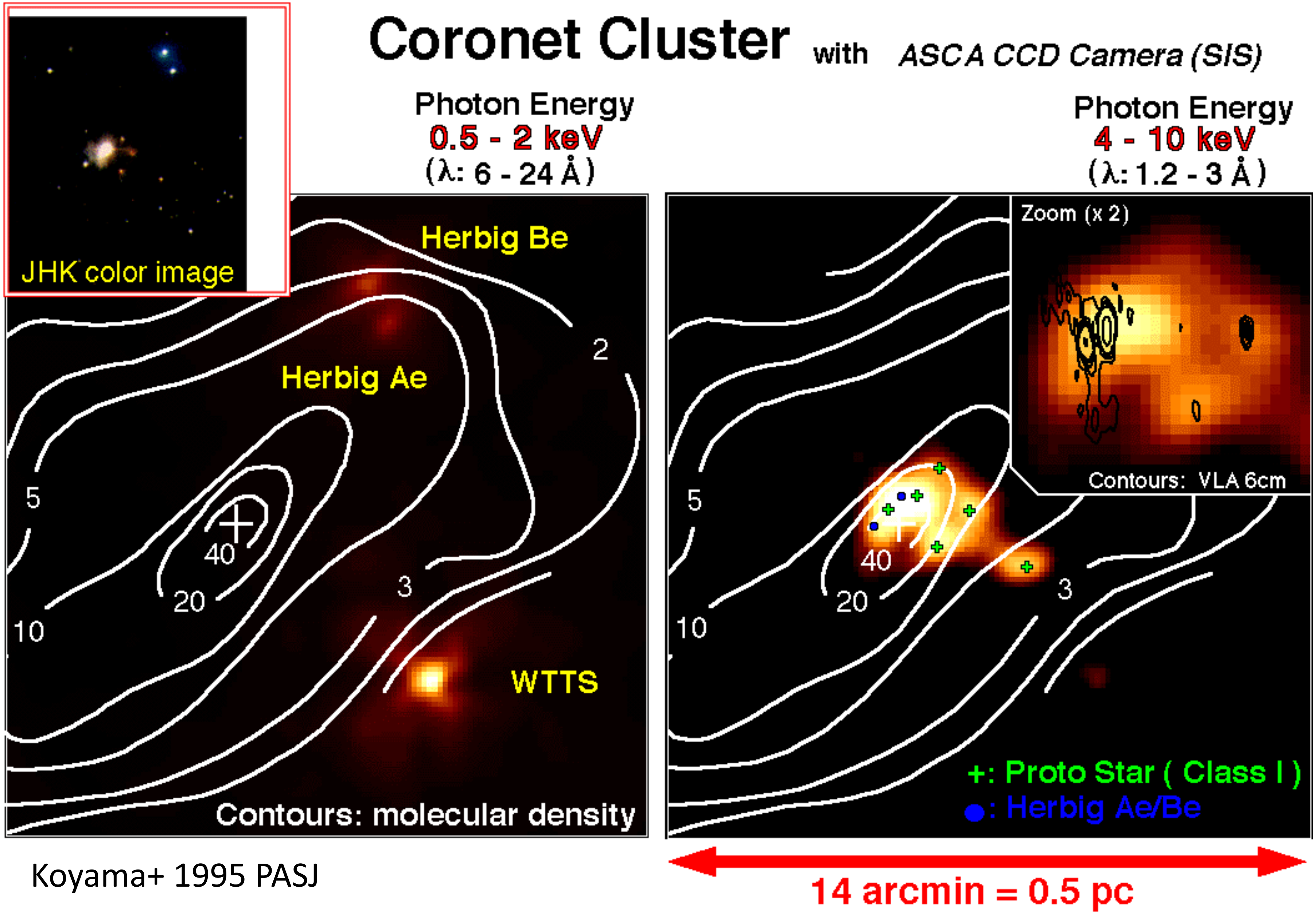


http://wwwj.vsop.isas.jaxa.jp/vsop2/science/star.html



Protostar
T Tauri Star
Main
Sequence
Protostar
Formation
Log $R_* \omega^2$
Protostar
phase
T Tauri
phase
Main Seq.
?
Log M_*

X-rays from Protostars



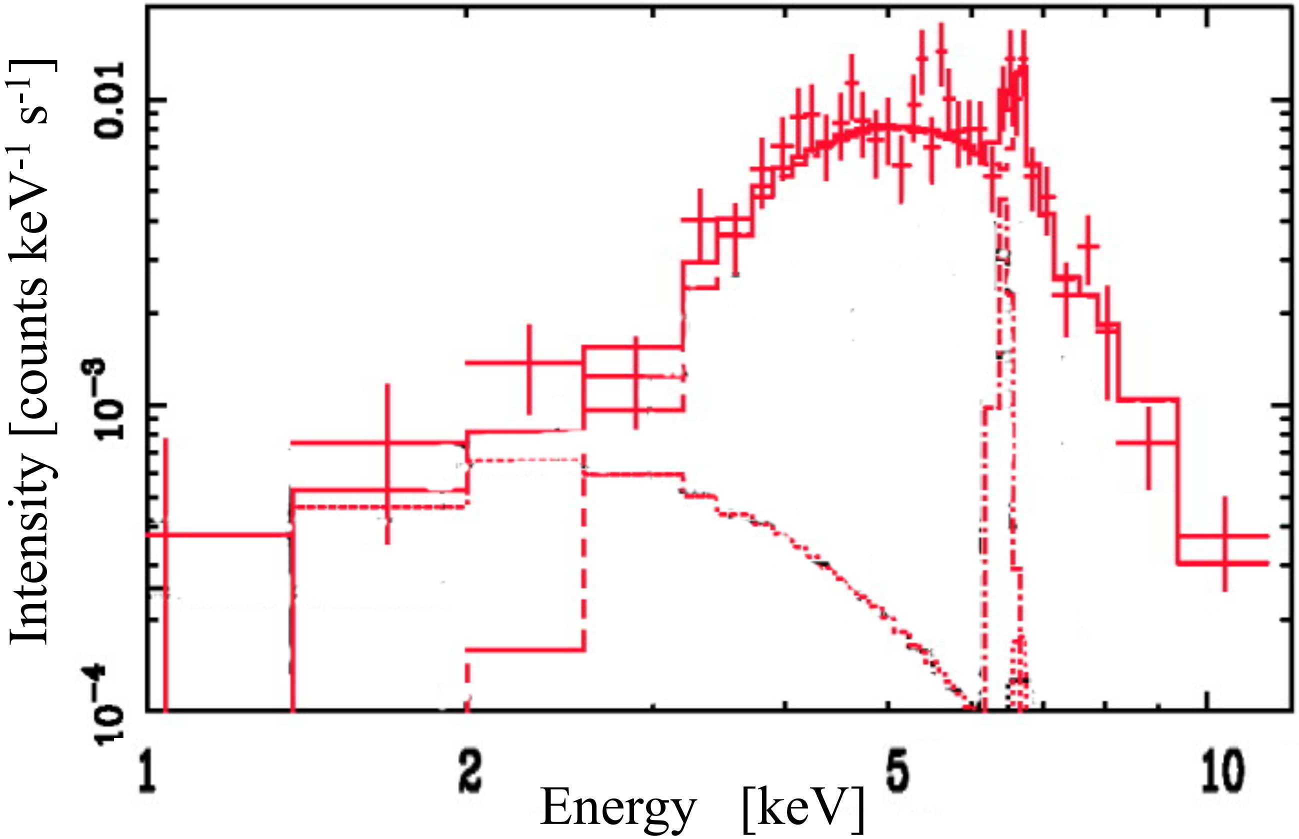
Koyama+ 1995 PASJ

Protostars are detectable, *if we use hard X-ray band*

X-ray Spectra of Protostars

Well described with highly absorbed thin thermal plasma

e.g. R CrA src X_E : Hamaguchi+ 05 XMM-Newton EPIC-pn

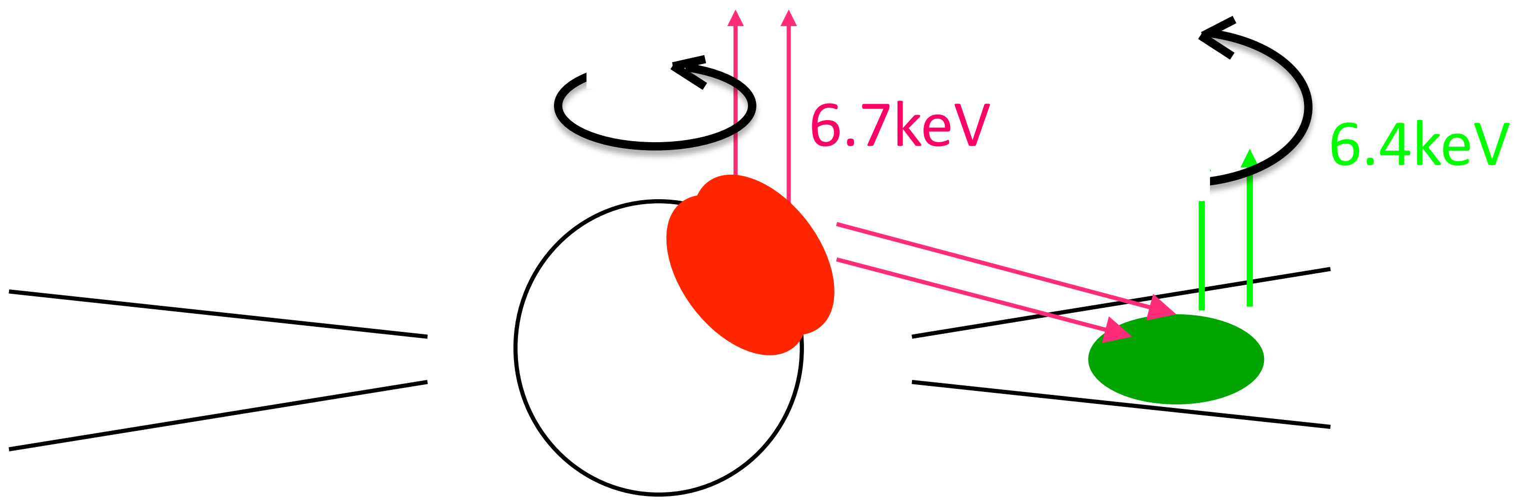


Fe-K line (6.4 keV):
EW = 300 eV

Protostar in general

kT = 1～10 keV
Abundance ～0.3 solar
$N_H = 10^{22} \sim 10^{23}$ cm^{-2}
Emission Measure
= $10^{50} \sim 10^{54}$ cm^{-3}
$L_X = 10^{28} \sim 10^{32}$ ergs s^{-1}

Some fraction of protostars have 6.4 keV fluorescent Fe line



From 6.7 keV line

P_{star}, v_{star} → R_{star}

From 6.4 keV line

P_{disk}, v_{disk} → M_{star} , r_{disk}

The two lines play independent role to obtain the parameters

AH will open a new discovery window for understanding the structure and the dynamics of the central protostar

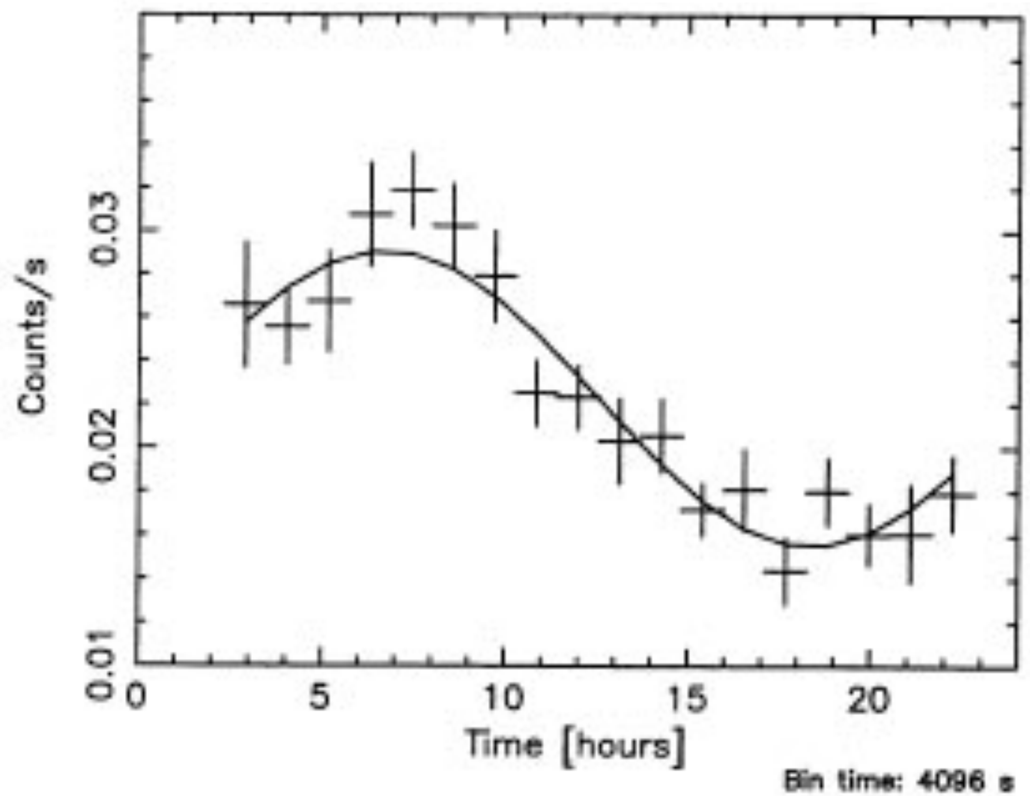
Break-up-speed rotation?

A few hints are obtained for protostellar rotation (P_* ~1 day) at near-break-up speed

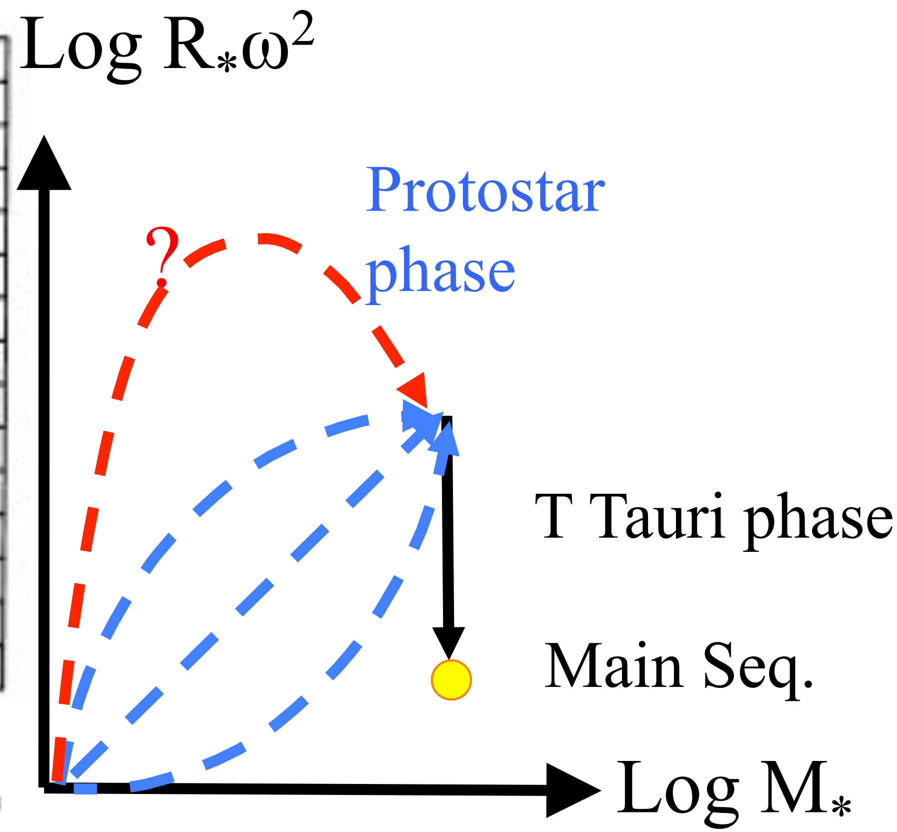
e.g. Tsuboi+2000, Montmerle+2000, Hamaguchi+2012

WL6 in Rho Oph

Kamata+ 1995 PASJ



Spin period ~ 1 day?

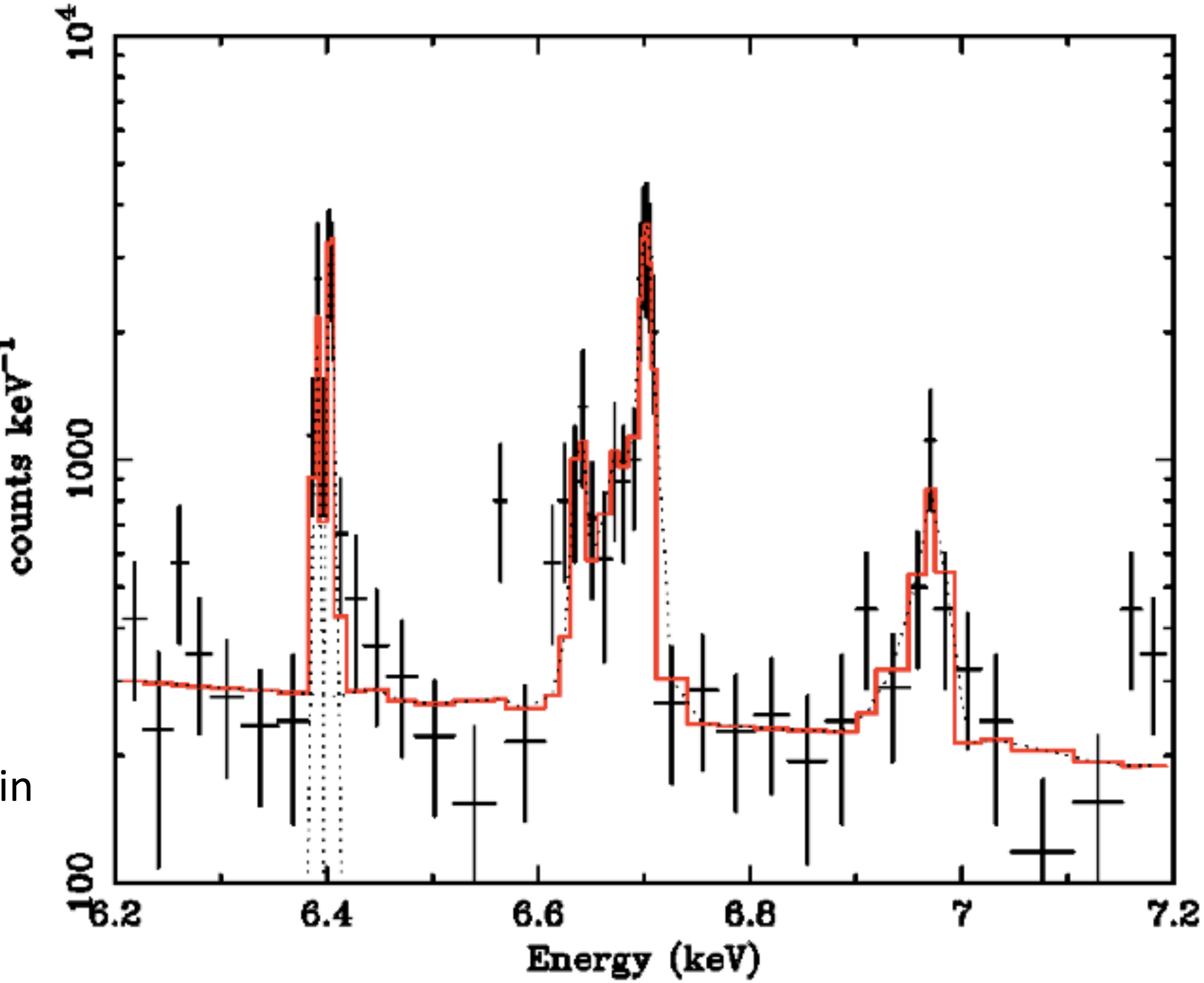


Faked spectrum

The used model is

$L_X = 10^{31.5}$ erg s^{-1}, kT = 6 keV,
NH = 4 ×10^{22} cm^{-2}, and
the abundance of 0.3 solar.
The exposure time is ¼ day.
The response with the energy resolution of 5 eV is used.
For the 6.4 keV line (Kα1 and Kα2, we used two gaussian functions which have natural width of 1.6 eV (FWHM).

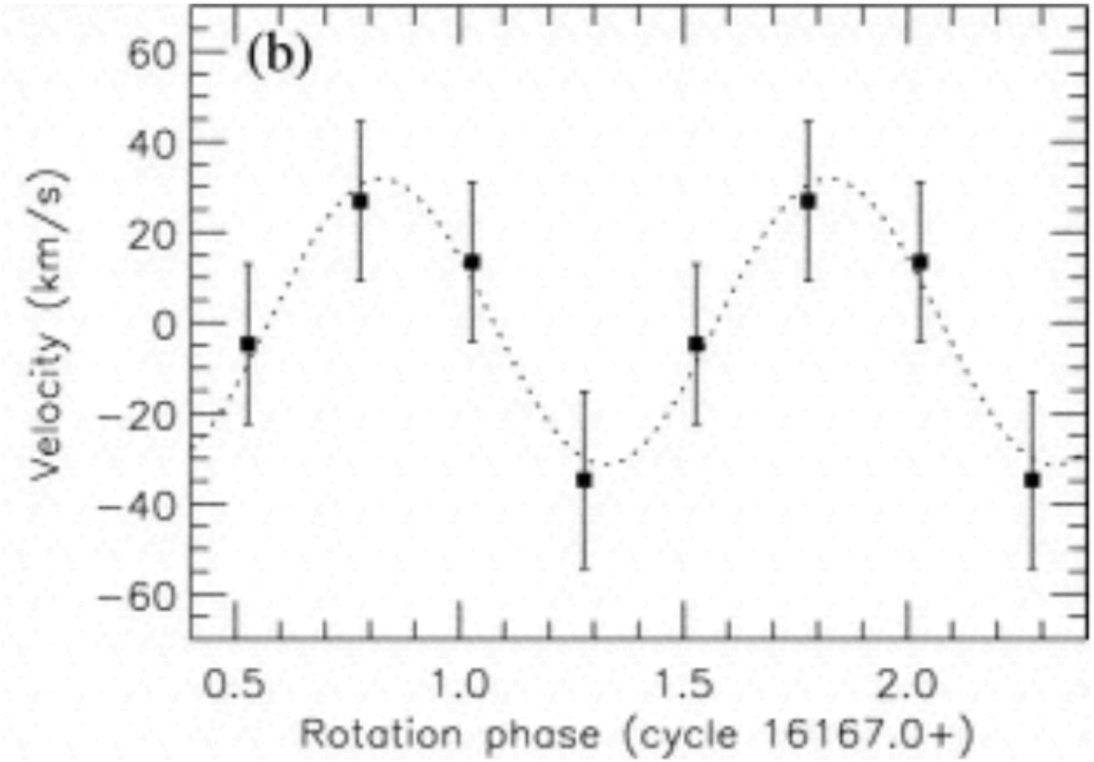
With this spectrum, we will obtain the error for the line center of 0.27 eV.



If P_*~1 day, R_*~5 R_{sun}, then V~250 km s^{-1} (ΔE~2.2 eV).
2ΔE(FW at tangential position)/σ_{Ecen} ~ 20.

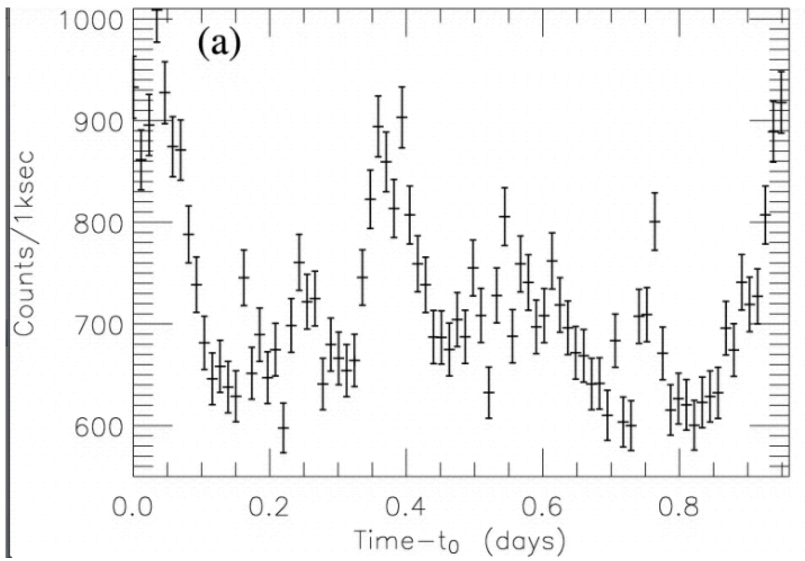
We can make a velocity curve.

V curve obtained with Chandra LETG HRC-S



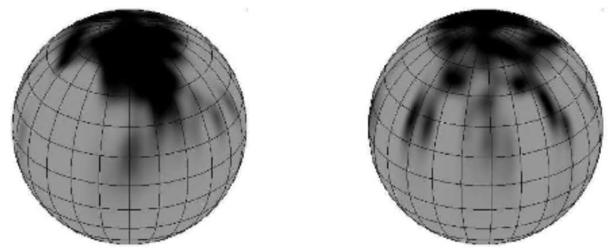
Phase-folded mean velocity shifts in the line centroids of the O CSCVIII/CSC 18.97 profile

AB Dor: Hussain+ 2005
ApJ 621, 999



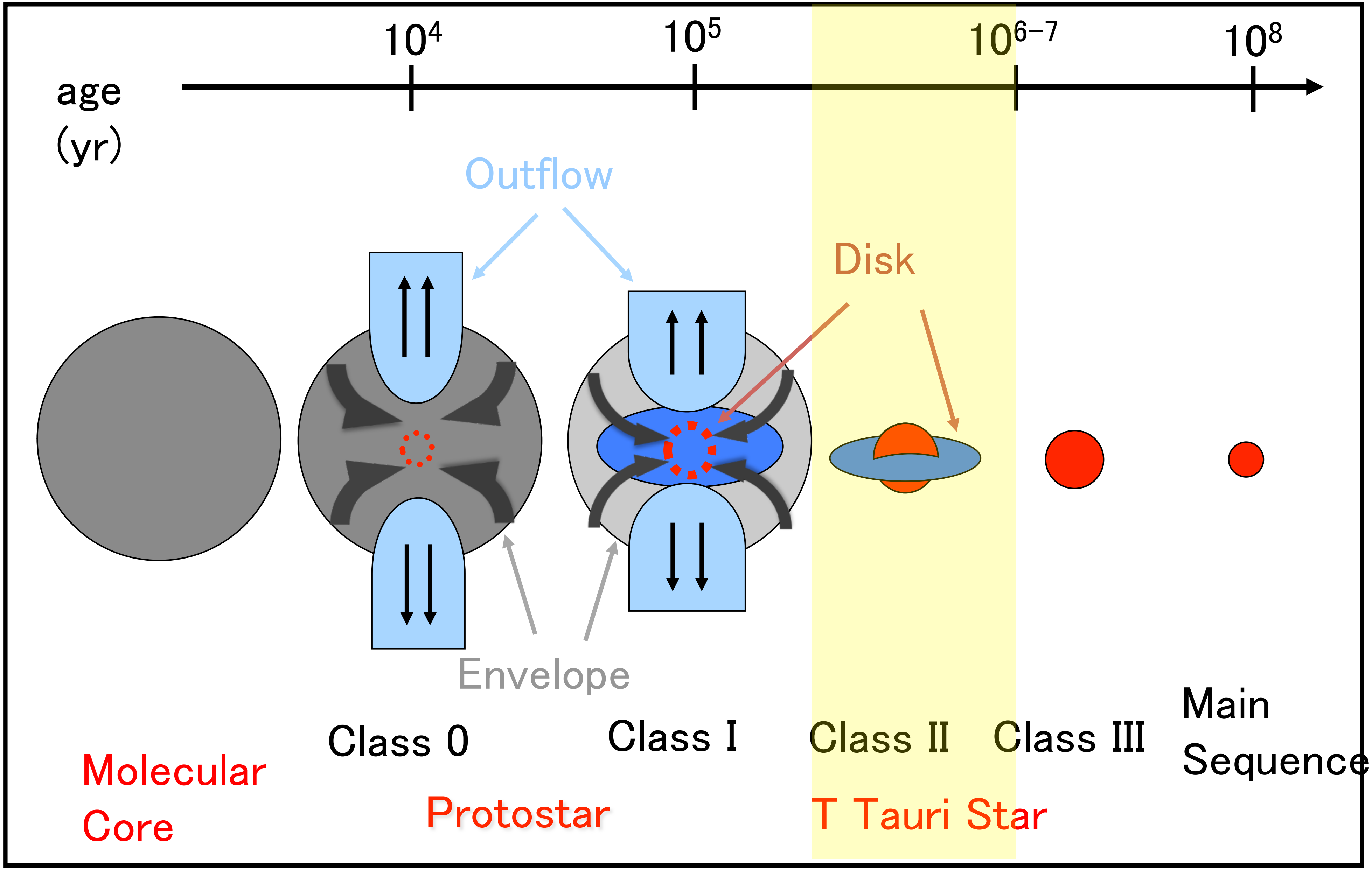
Light curve

AB Dor: Hussain+2007, MNRAS 377, 1488

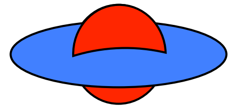


2. Accretion process in T Tauri stars

Early Evolution of a Star



ToO of an Erupting Young Star

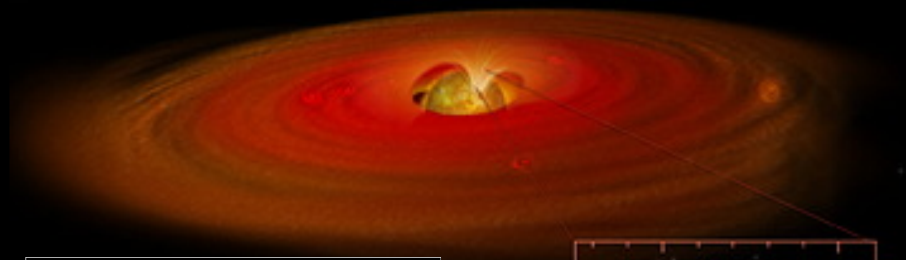


- A young star (CTTS) can experience strong outbursts due massive accretion events (not flares!)
  - Several stars in a decade in the sky. Recently,
  - V1647 Ori (2003~)
  - V1118 Ori (2001-2005), EX Lup (2008)
  - Such events last for a few *months* to >100 years.
- Significant mass can be dumped.
  - Several 1e-6 up to ~1e-4 Msolar yr^{-1}

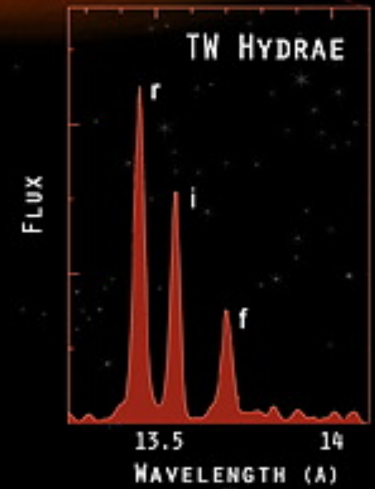
(accretion rate in protostar phase)

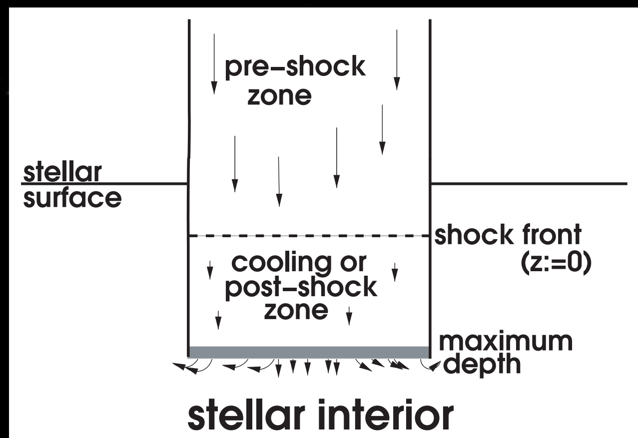
High densities in accreting stars

- High i/f ratio in He-like triplets of TW Hya indicate $n_e \approx 10^{13}$ cm^{-3} (Kastner et al. 2002; Stelzer & Schmitt 2004). Also Fe XVII (Ness & Schmitt 2005)
- Plasma T≈3 MK consistent with adiabatic shocks from gas in free fall (v≈150-300 km s^{-1})
- High densities in accreting young stars (Schmitt et al. 2005; Robrade & Schmitt 2006; Günther et al. 2006; Argiroffi et al. 2007), but not all (Telleschi et al. 2007; Güdel et al. 2007, Argiroffi et al. 2011; etc)



$$T_s = \frac{3\mu m_{\mathrm{H}} v_s^2}{16k}$$

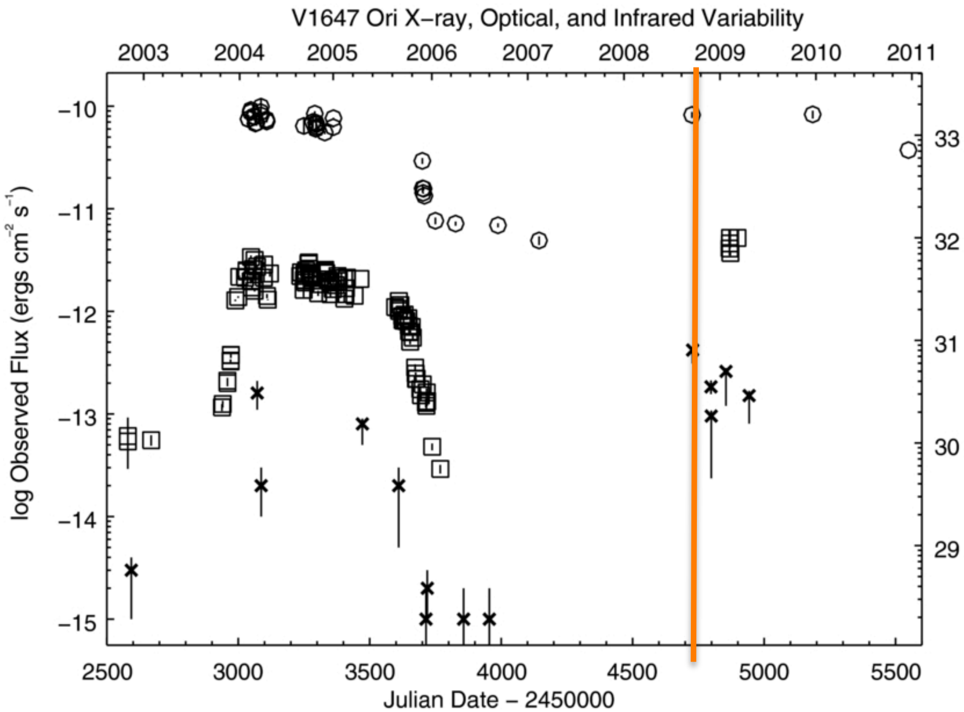




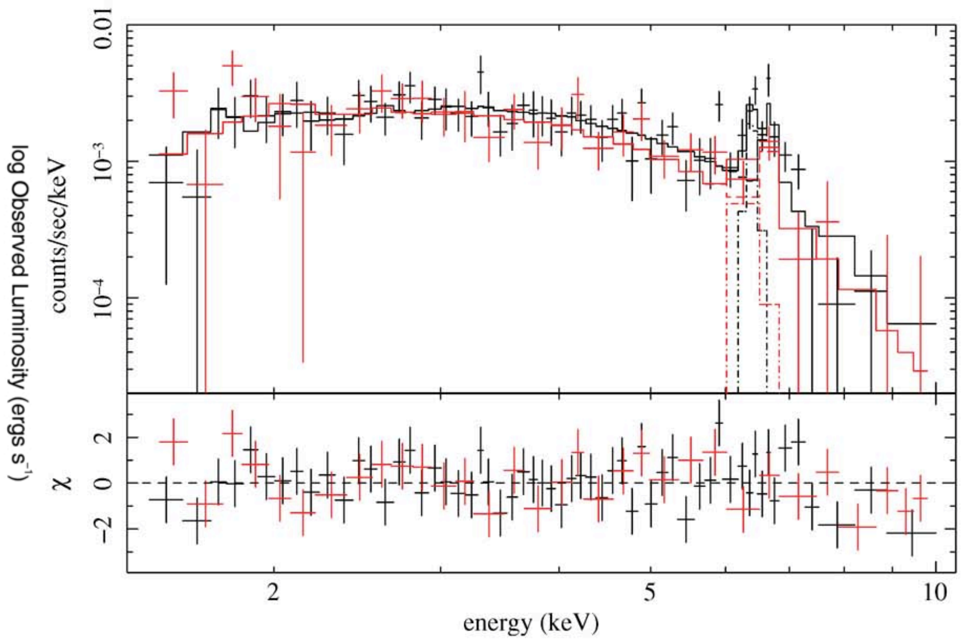
Slides and figures provided by M.Audard

L1647 outburst

Teets+12 ApJ



Hamaguchi+10 ApJ



Chandra: **x**
the IC-band: □
the H-band: ○

The event accompanies the flux increase in X-ray band also.

Suzaku Obs at 2008 October 8

kT ~ 5 keV

The temperature cannot be originated by accretion shocks, with only shallow gravitational potential.

← Opposed to the other accretion processes, i.e. those onto compact objects.

SXS observation

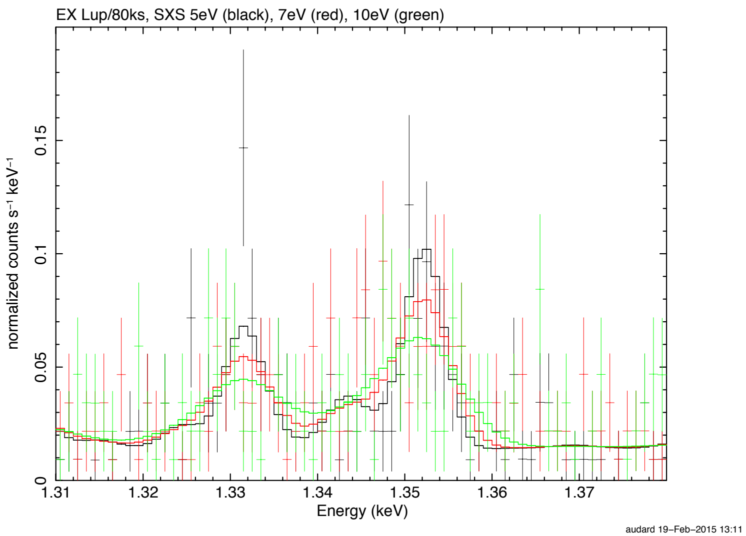
Goal: 1. measuring the Fe K profile/shift, to understand the accretion physics.

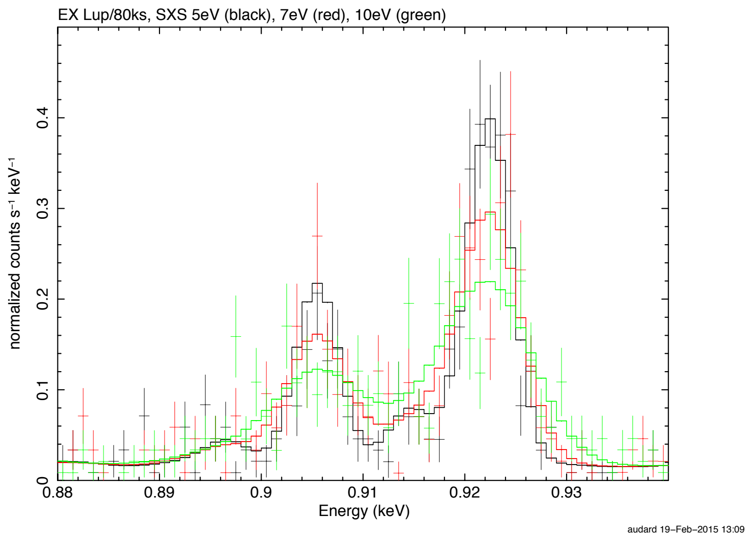
2. density diagnostics using Mg and Si triplets.

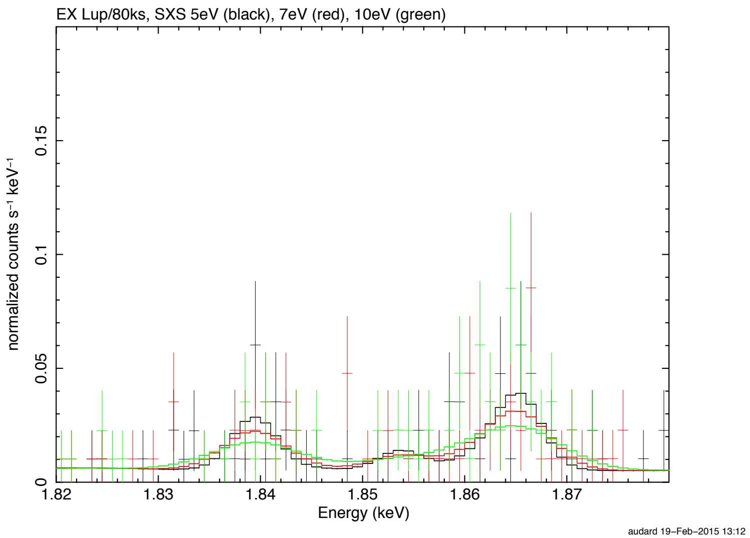
With the obtained density, we will obtain the volume of the region also.

These properties will be the clues to know the origin of the accretion process in star formation process, providing some implications to the accreting process in the other categories of objects.

SXS Spectra around Mg, Ne & Si







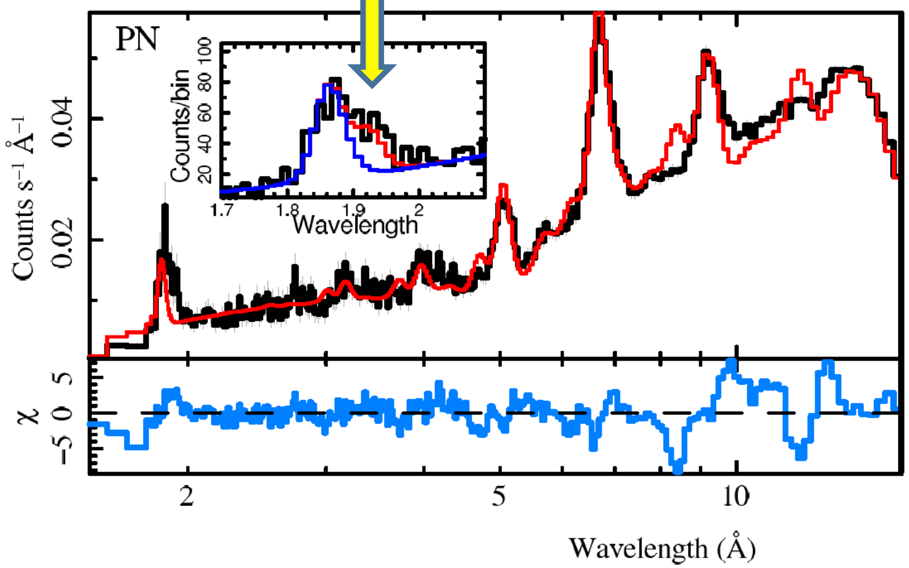
Expected densities > 1e12 cm^{-3}

→ Mg and Si triplets important

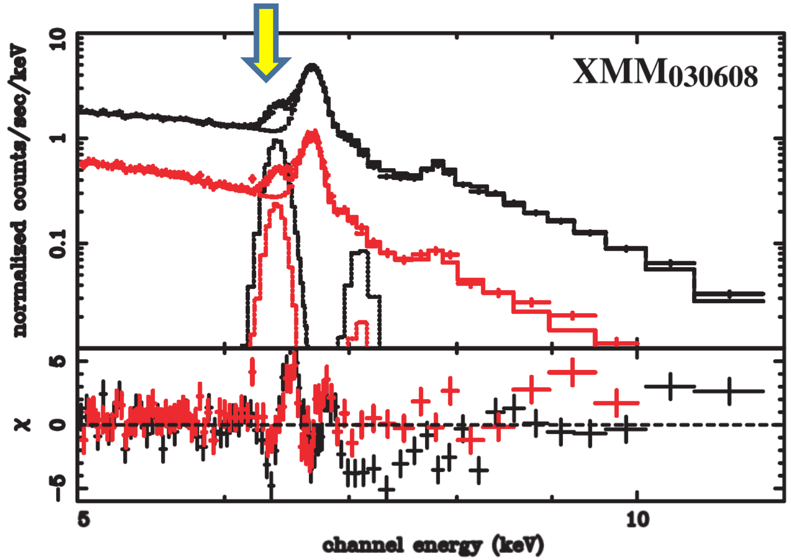
3. High-mass evolved stars/binaries

High-mass star - stellar wind measurement

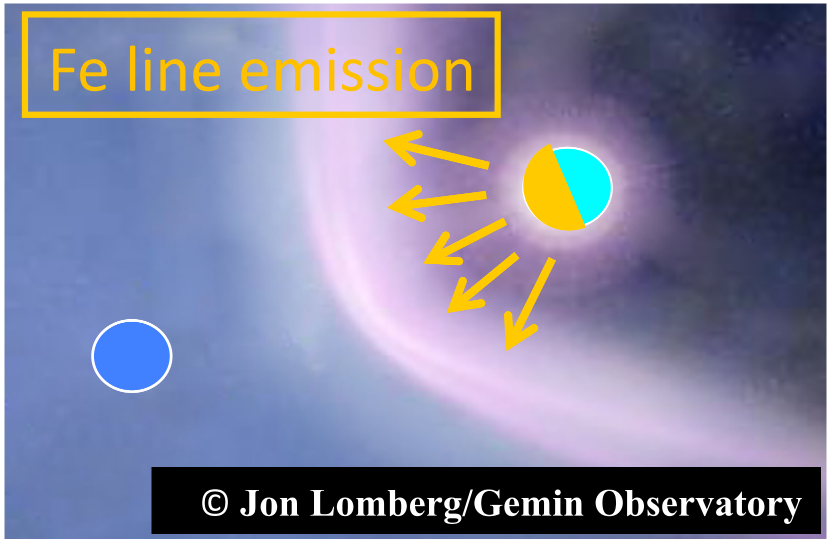
Fluorescent Fe line (6.4 keV) “Reflection”



WR6 (Oskinova et al. 2012)



Eta Car (Hamaguchi et al. 2007)

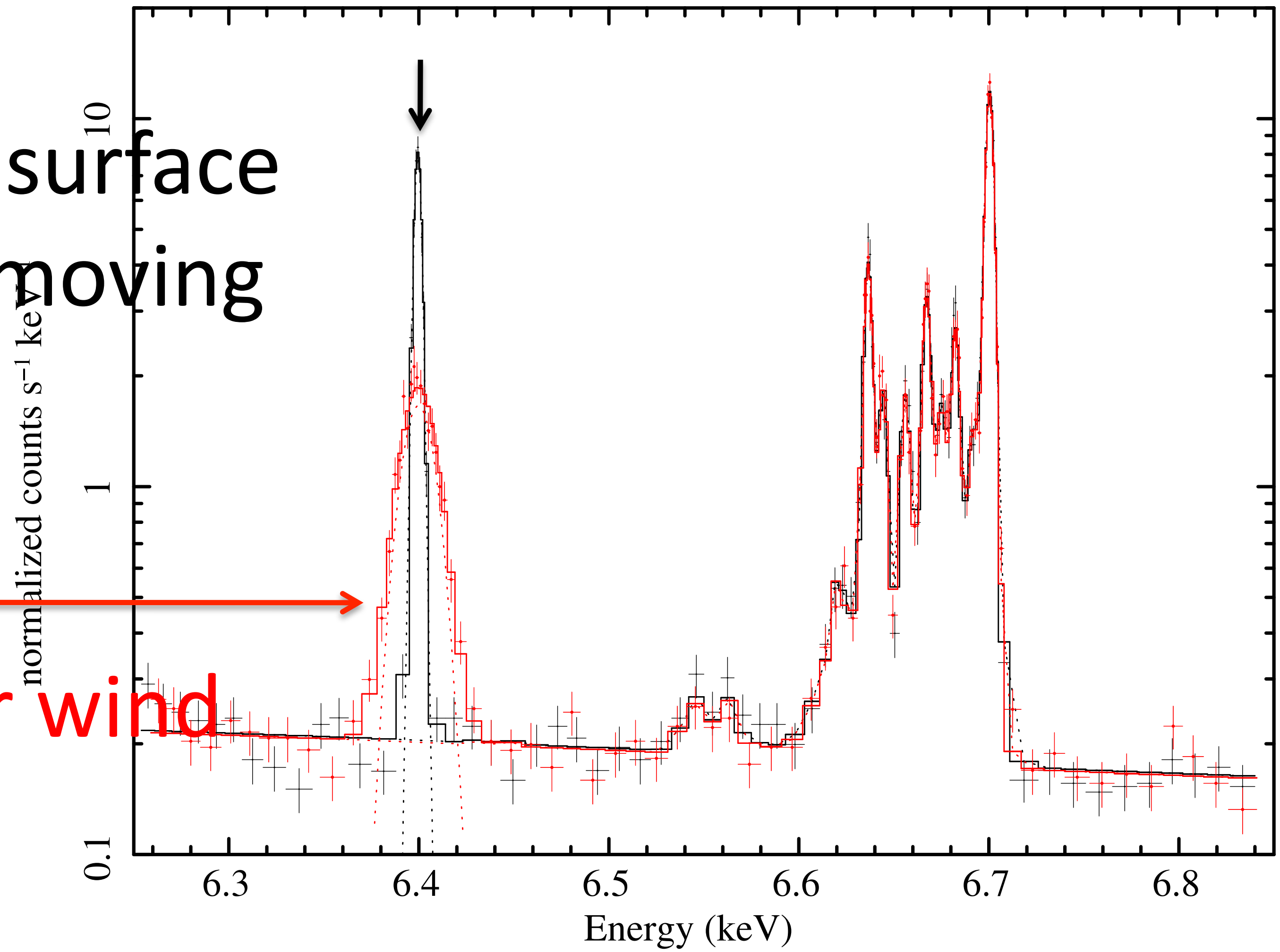


Wind-wind collision system is a strong Fe-K line emitter.

6.4 keV line

Eta Carina

Narrow
→ Stellar surface
Or slowly moving material

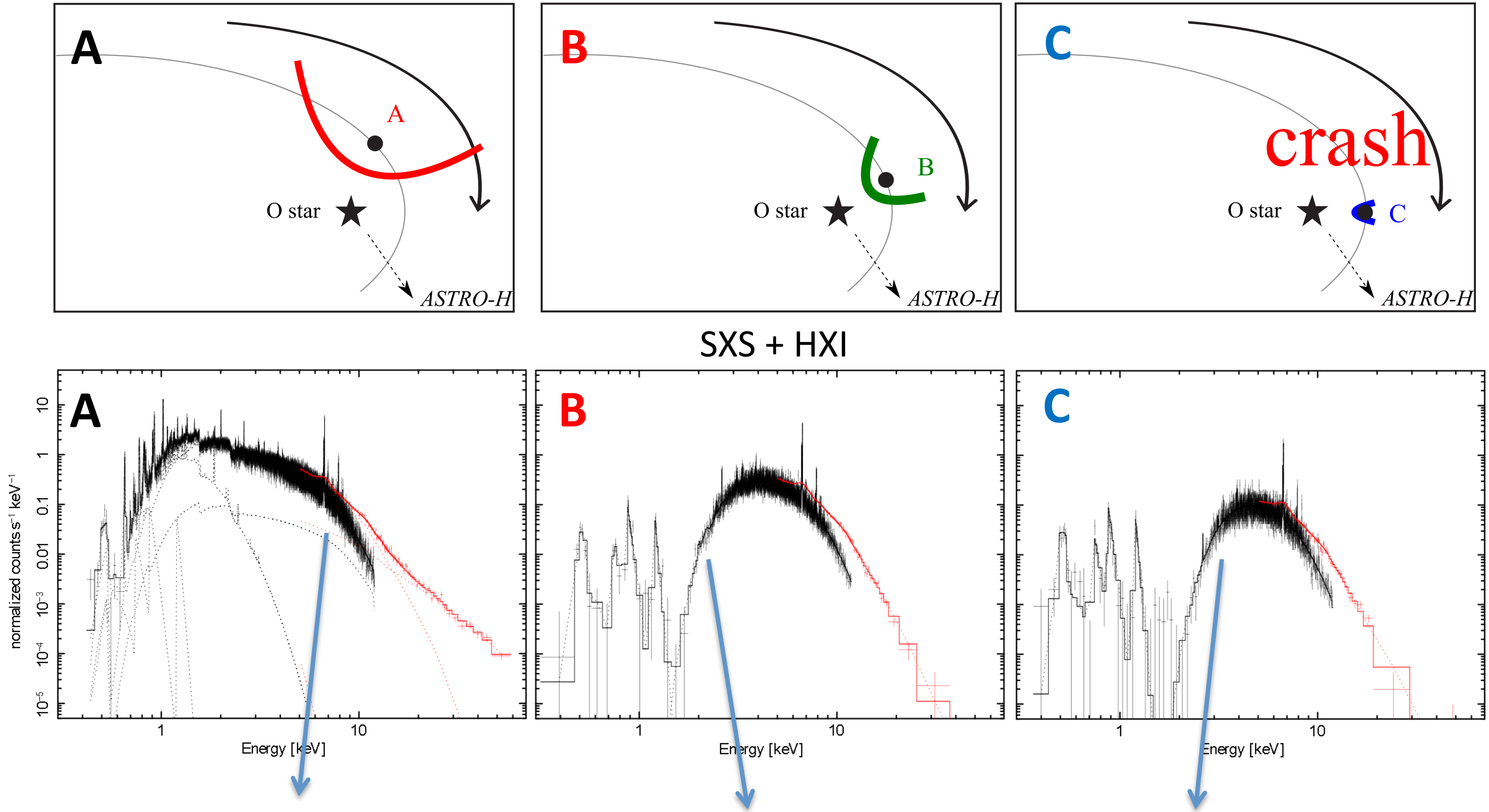


Broad
→ Stellar wind

Can measure the surrounding mass distribution (i.e., mass loss rate)

Stellar wind measurement of high-mass star: WR140

Big absorption. No grating data is useful.

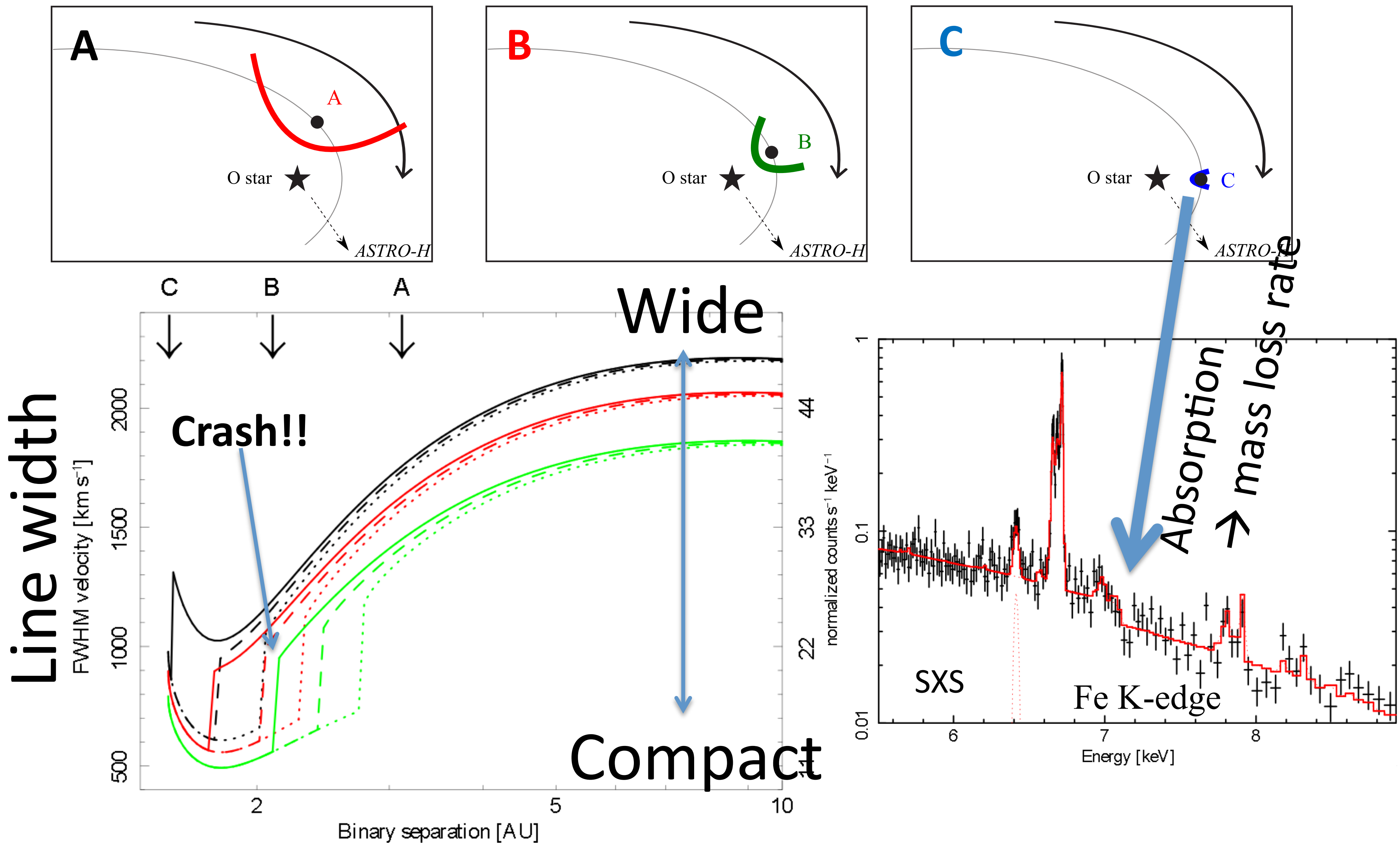


Fe-K flux maximum

Only Fe-K lines are bright enough.
→ No grating data is obtained.

Stellar wind measurement of high-mass star: WR140

Absorption column gives the mass loss.



Stellar Evolution Revealed with ASTRO-H

1. Dynamics and structures of protostars

   Only AH can do! Quite brand-new challenge.

2. Accretion process in T Tauri stars

   Density distribution will be obtained.

3. High-mass evolved stars/binaries

   Can be new tool to measure WR wind mass loss rate.