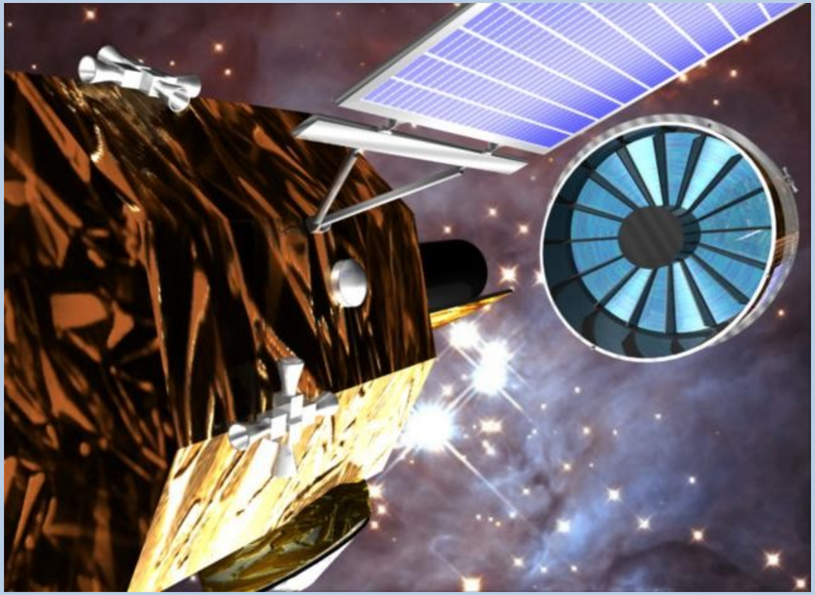
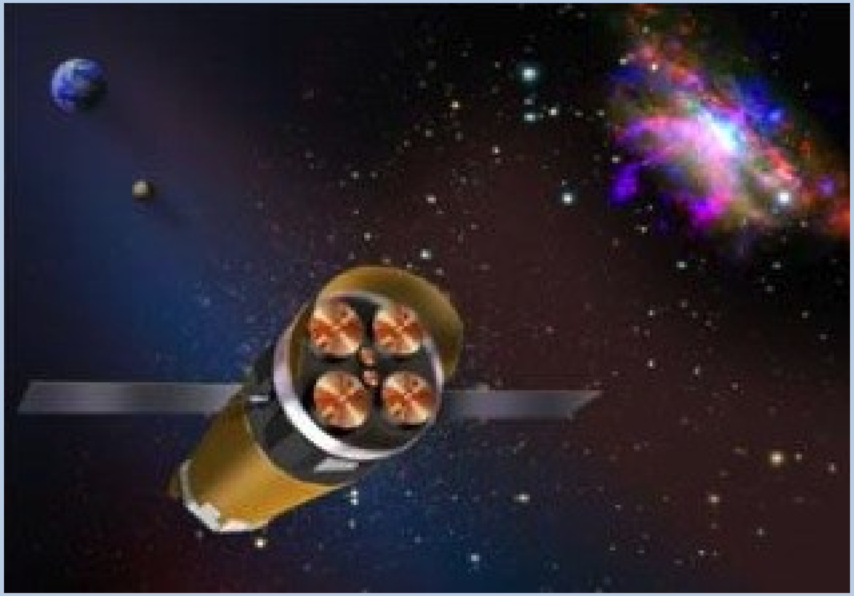
X-ray emission from normal stars and YSOs with IXO

Beate Stelzer (OA Palermo)
Contributions from A. Maggio, L. Scelsi, S. Sciortino





A quick tour of observables from pre-MS to MS ages

X-RAYS IN CLASS II
(1) TRACE ACCRETION (SHOCKS)
(2) IONIZATION AGENT OF DISK

X-RAYS IN CLASS III
IDENTIFY LATE Pre-MS STARS (CORON

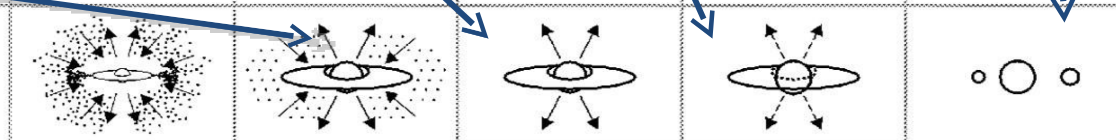
X-RAYS IN MS
CORONAL
STRUCTURE

-RAYS IN CLASS I
ETS
SHOCKS IN OUTFLOWS)

X-RAYS IN CLASS 0
VERY CONTROVERSIAL

- X-RAYS FROM
HOT STARS

- X-RAYS FROM
BROWN DWARFS

Properties	*Infalling Protostar*	*Evolved Protostar*	*Classical T Tauri Star*	*Weak-lined T Tauri Star*	*Main Sequence Star*
Sketch					
Age (years)	10^4	10^5	$10^6 - 10^7$	$10^6 - 10^7$	$> 10^7$
mm/Infrared Class	Class 0	Class I	Class II	Class III	(Class III)
Disk	Yes	Thick	Thick	Thin or Non-existent	Possible Planetary System
X-ray	?	Yes	Strong	Strong	Weak
Thermal Radio	Yes	Yes	Yes	No	No
Non-Thermal Radio	No	Yes	No ?	Yes	Yes

Adapted from Feigelson & Montmerle, ARA&A, 1999

Need

more sensitive
high spatial resolution
high spectral resolution

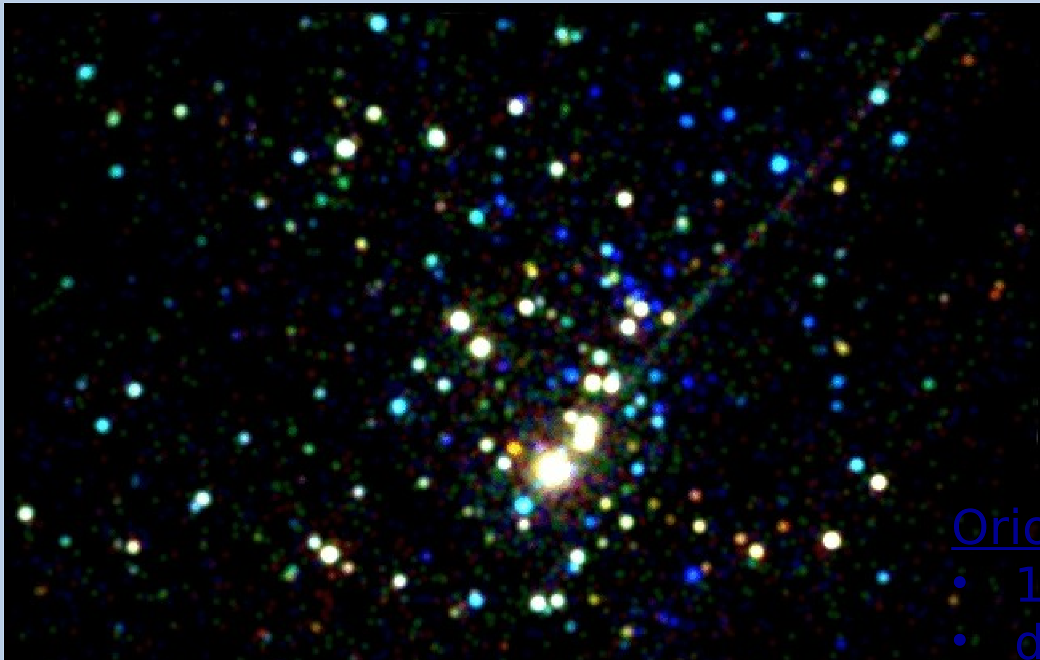
X-ray observations

Spatial resolution
for

4. crowded star forming regions

- complex YSOs with several components, e.g. jets + coronae

Chandra Orion Ultradeep Project (COUP)



850 ks Chandra
on Orion Nebula Cluster

PI Feigelson

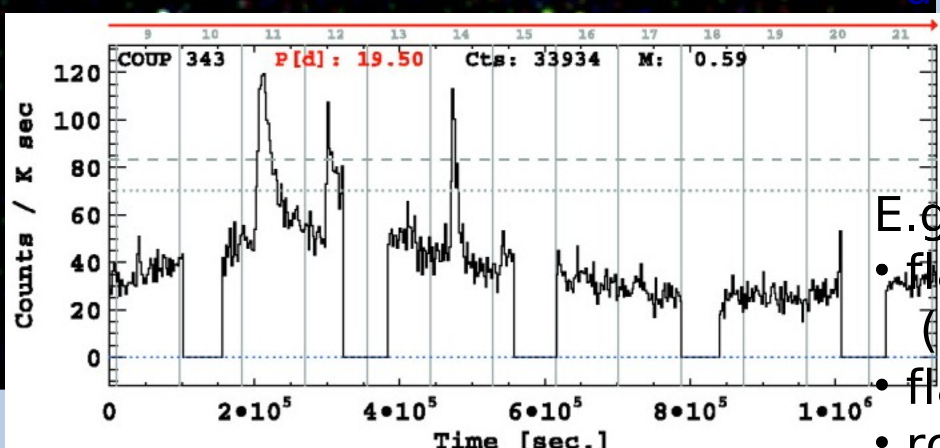
13 papers in ApJS Special Issue 160
and several others

Orion Nebula Cluster:

- 1 Myr PMS stars SpT from O to M
- d ~ 450 pc

mpact:

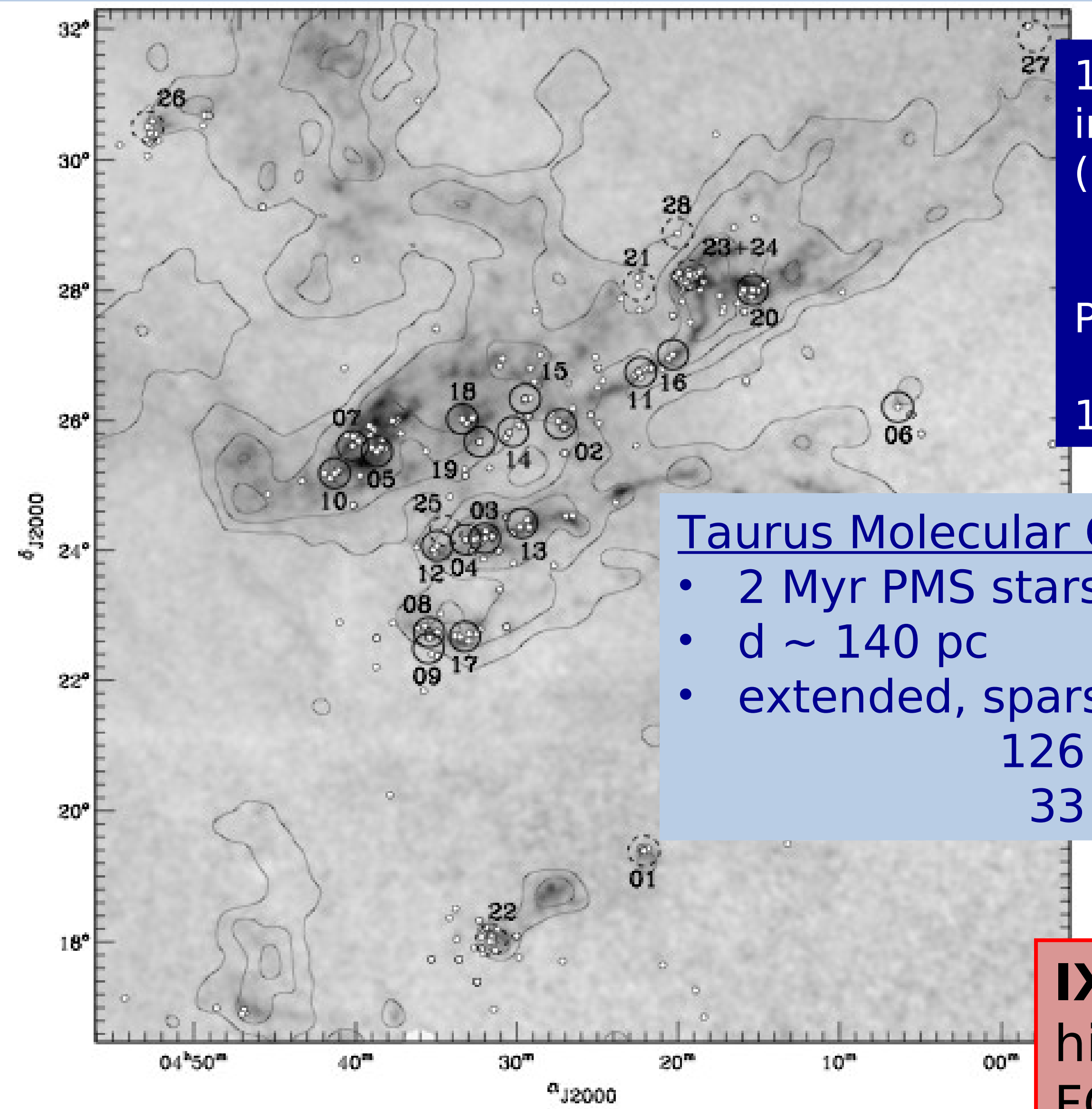
1616 X-ray sources
of which 1315 cloud mem



E.g.,

- flare frequency + energetics
  (nano-flare heating)
- flare evolution (loop lengths)
- rotational modulation (spot distribut

XMM-Newton Extended Survey in Taurus (XEST)



19 x 30 ks XMM-Newton
in Taurus Molecular cloud
(+ 9 XMM-Newton fields
in Taurus from archive)

PI Guedel

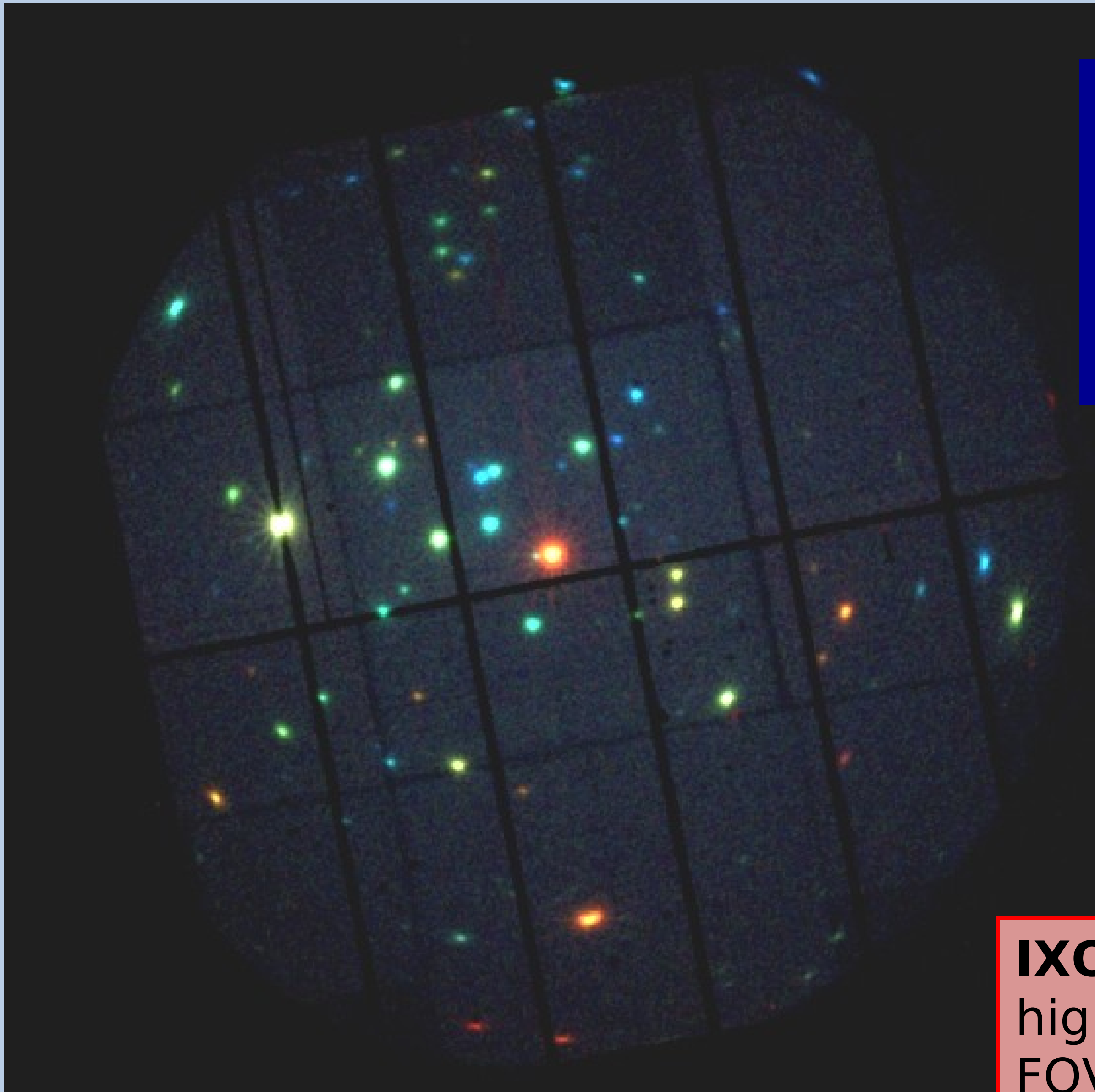
15 papers in A&A Special Issue 468

Taurus Molecular Cloud:

- 2 Myr PMS stars, no OB stars
- d ~ 140 pc
- extended, sparsely populated:
  126 cloud members detected
  33 cloud members undetected

IXO/WFI potential:
high sensitivity over large FOV
with good spatial

Deep Rho Ophiuchi XMM-Newton observation (DROXO)



500 ks XMM-Newton
in ρ Oph Core F

PI Sciortino

1 paper published, 2 submitted,
several in prep.

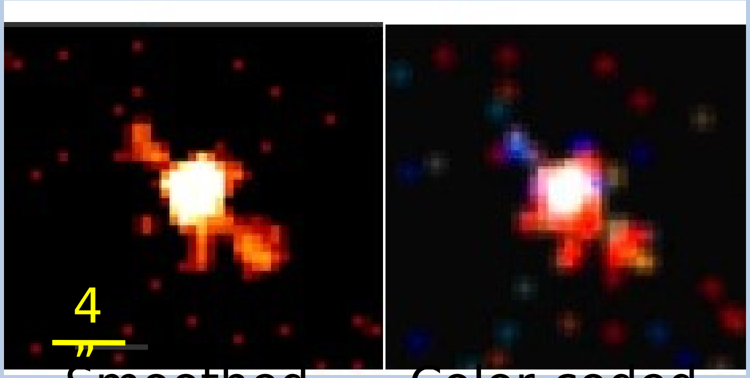
<u>ρ Oph:</u>

- 0.5 Myr PMS stars
- d ~ 120 pc
- 110 X-ray sources,
  poorly known membership
- Class I sources
  with Fe Kα emission

IXO/WFI potential:
high sensitivity over large FOV
with good spatial

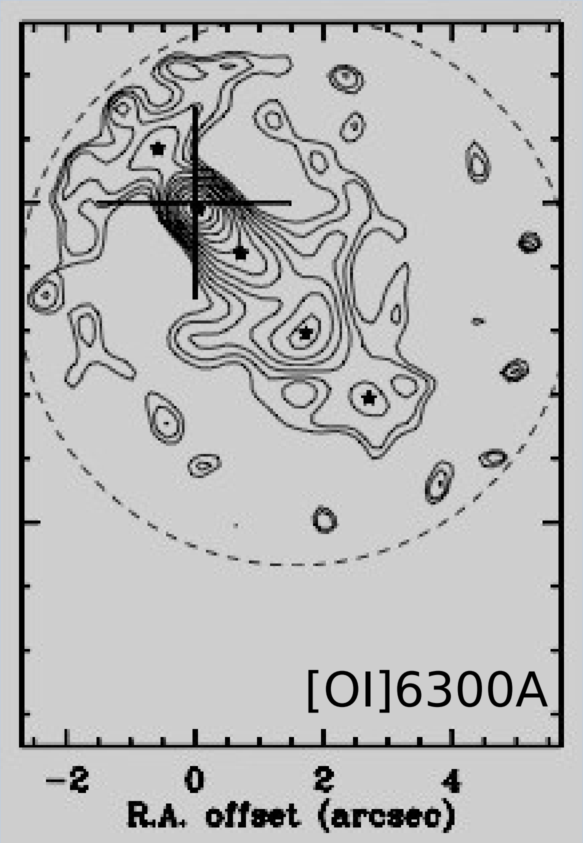
Spatial resolution
for protostars + YSO jets

0.6-1.7 keV ACIS-S: DG Tau + jets



Smoothed Color-coded

Guedel et al. (2008)



LaValley et al. (1997)

Spatial resolution
for protostars + YSO jets

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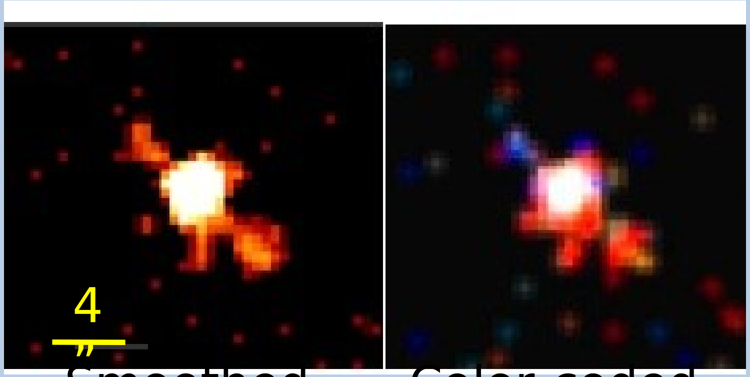

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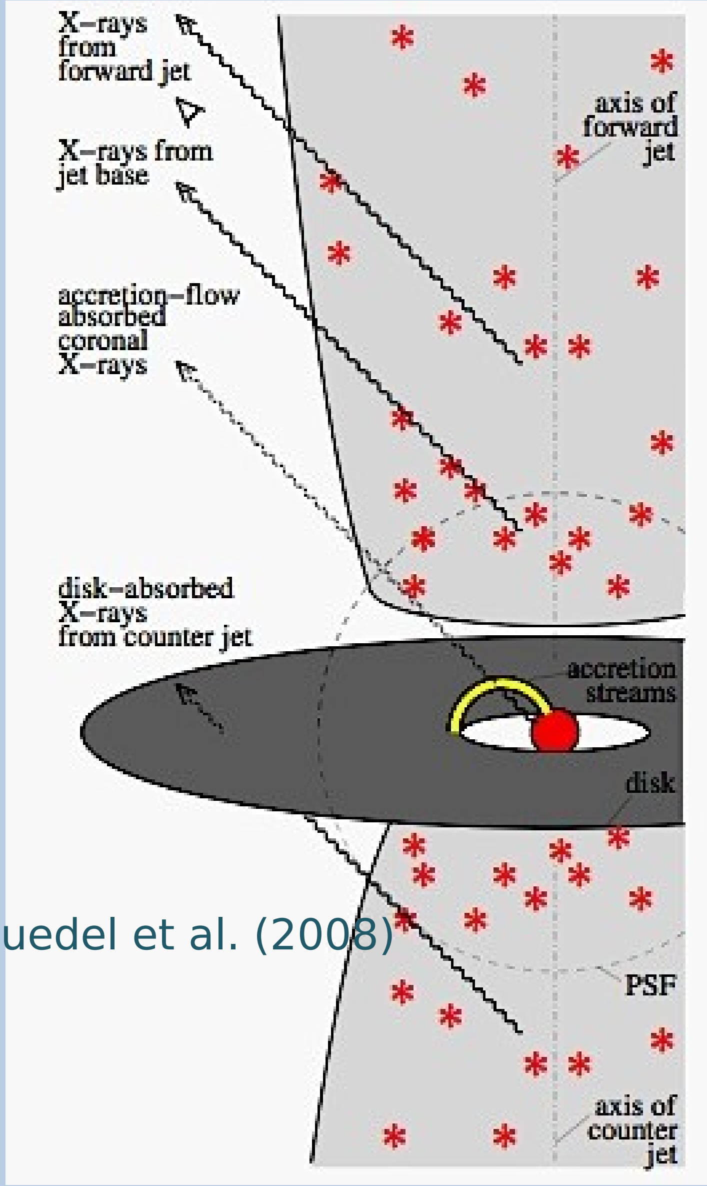


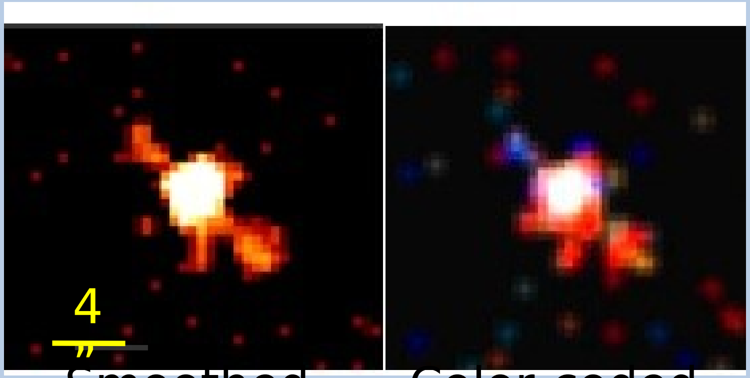
Guedel et al. (2008)

<u>4 X-ray emitters in DG Tau system:</u>

- soft, weakly absorbed jet
- soft, stronger absorbed counterjet
- soft, weakly absorbed base of forward jet
- hard stellar corona

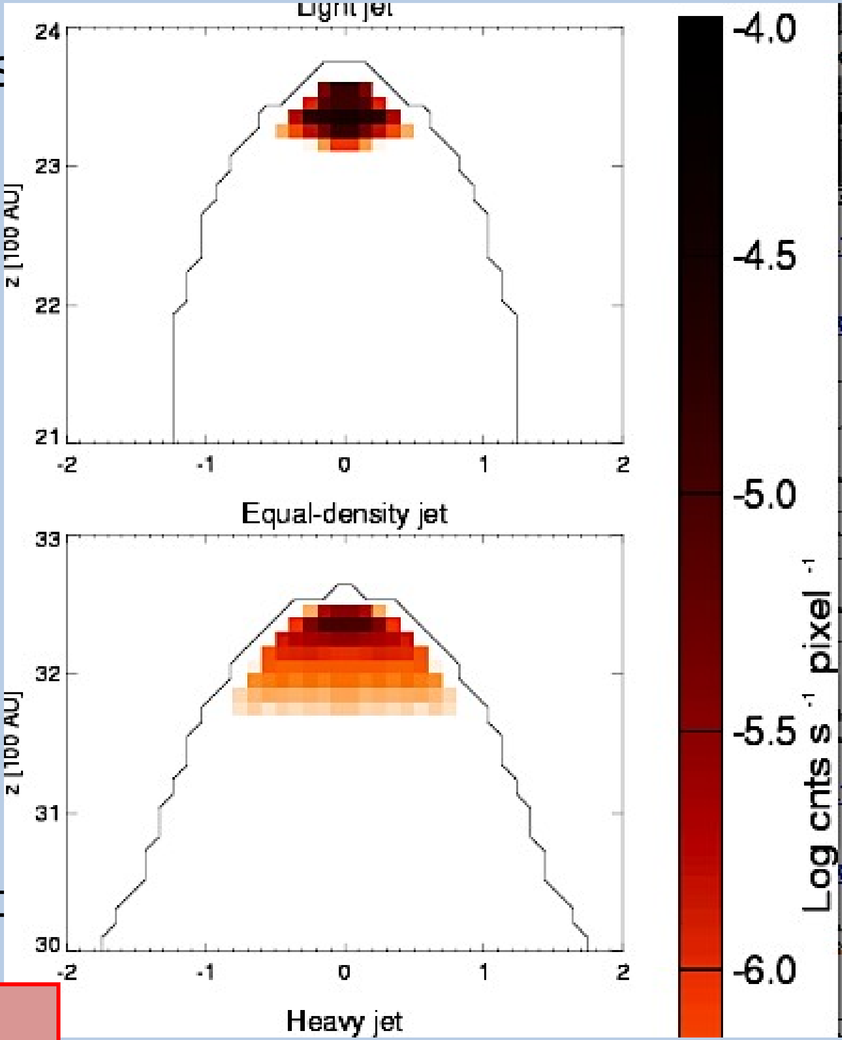
Spatial resolution
for protostars + YSO jets

0.6-1.7 keV ACIS-S: DG Tau + jets



Smoothed Color-coded

Guedel et al. (2008)



Bonito et al. (2007)

4 X-ray emitters in DG Tau system:

- soft, weakly absorbed jet
- soft, stronger absorbed counterjet
- soft, weakly absorbed base of forward jet
- hard stellar corona

IXO/WFI potential:
spatial resolution limited, but
sensitivity high

High sensitivity
for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved

medium-resolution spectroscopy

e.g. Fe Kα emission,

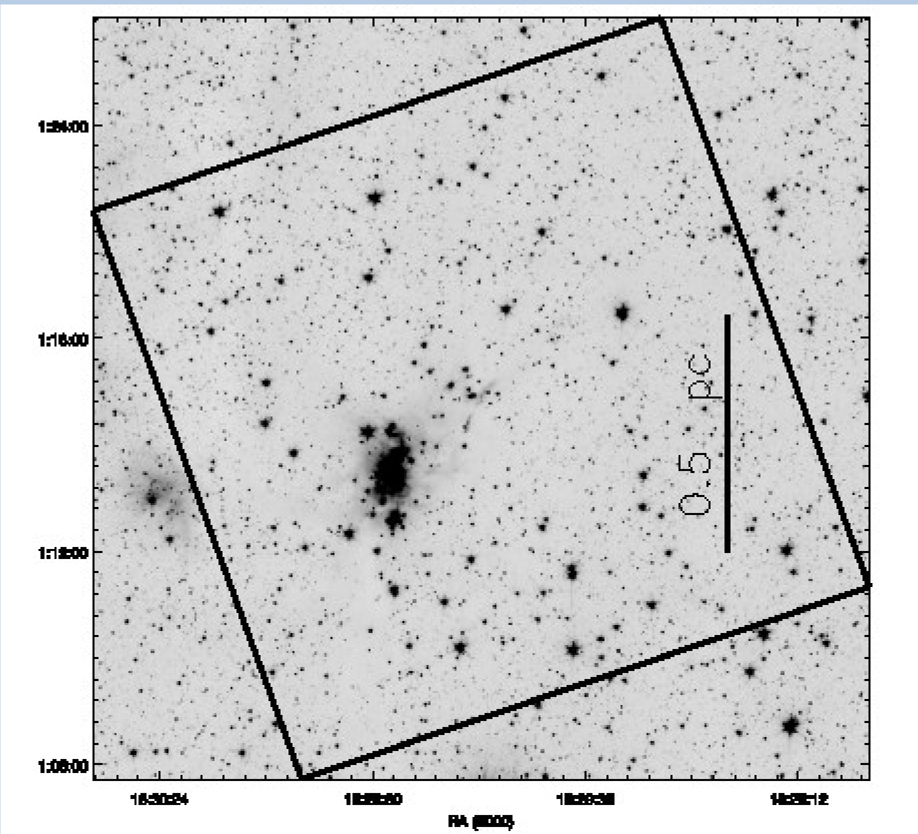
disk response to X-ray illumination,

flare evolution,

circumstellar absorption in

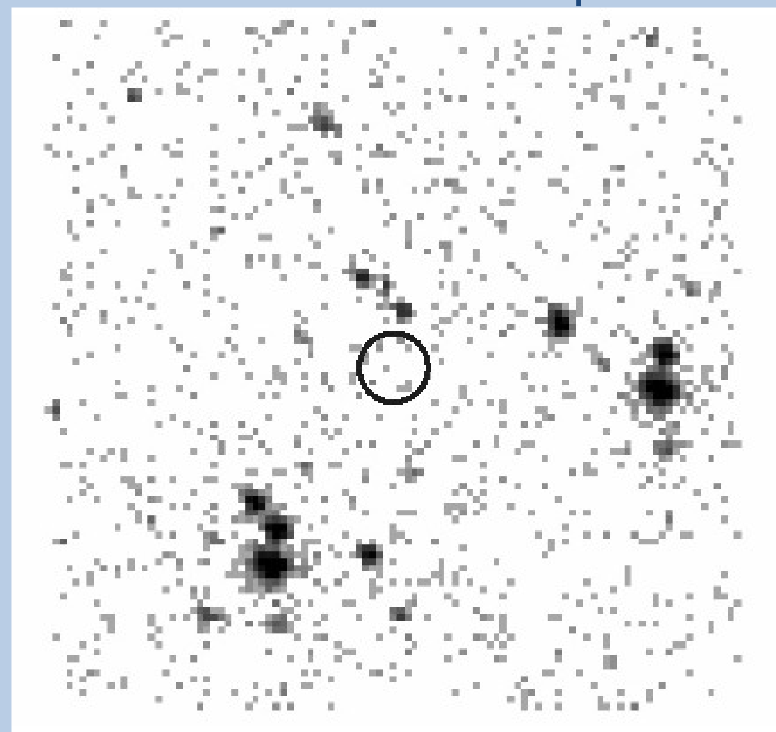
CLASS 0 protostars:
X-rays in earliest proto-stellar phase ?

rpens star forming region:
itzer/IRAC1 image with Chandra/ACIS field



Giardino et al. (2007)

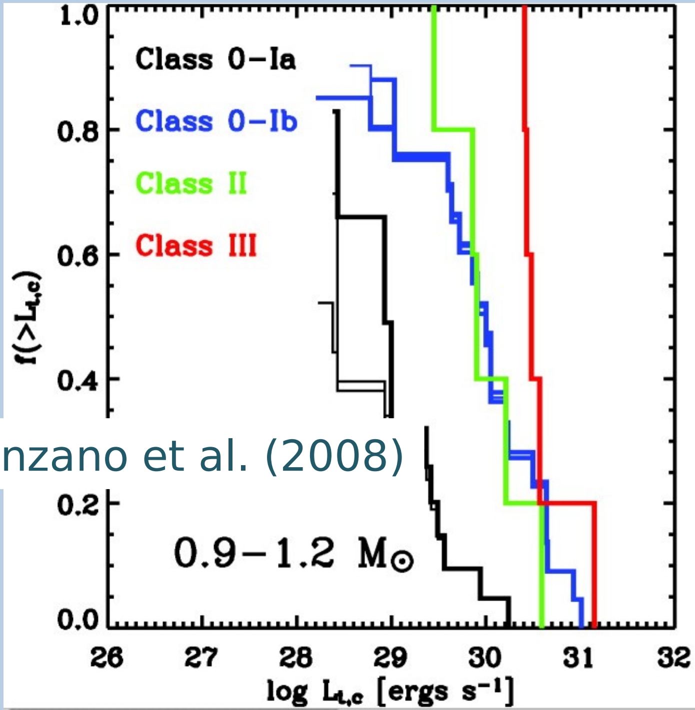
Co-added ACIS image from 6 Class
in effective 540 ks exposure:



Assume: N_H = 4 10^{23} cm^{-2}, kT = 2.4 keV
L_x < 4 10^{29} erg/s

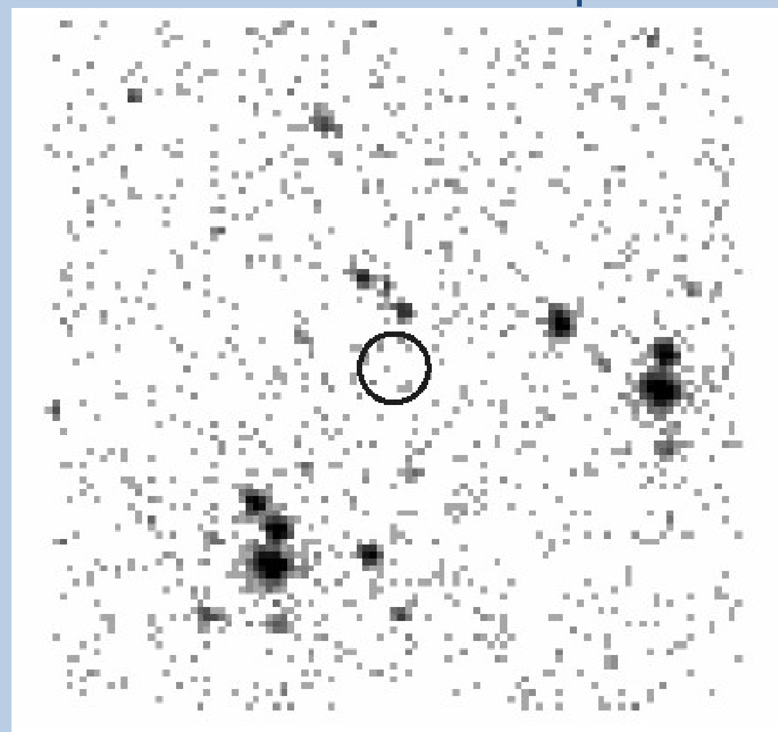
Class 0 fainter X-rays than Class I, II, III
or extreme extinction

CLASS 0 protostars:
X-rays in earliest proto-stellar phase ?



risinzano et al. (2008)

Co-added ACIS image from 6 Class
into effective 540 ks exposure:



ssume
aint, strongly absorbed, hard CLASS 0:

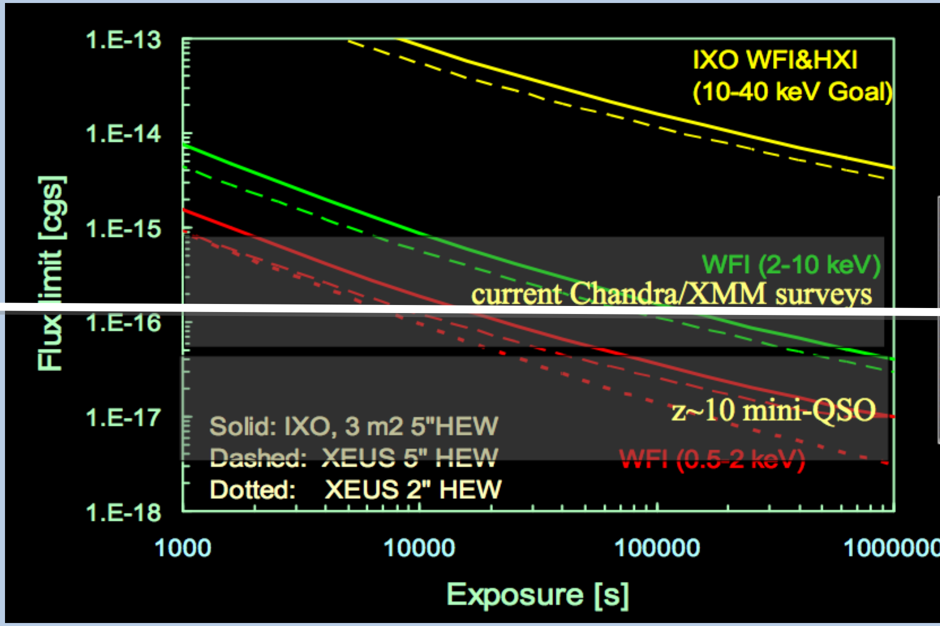
= 10^{29} erg/s @ 260pc

$_x$)$_{abs}$ = 1.5 10^{-16} erg/cm^2/s
@ 2-10 keV
for N_H = 10^{24} cm^{-2} (A_V ~ 500 mag)
kT = 2.4 keV

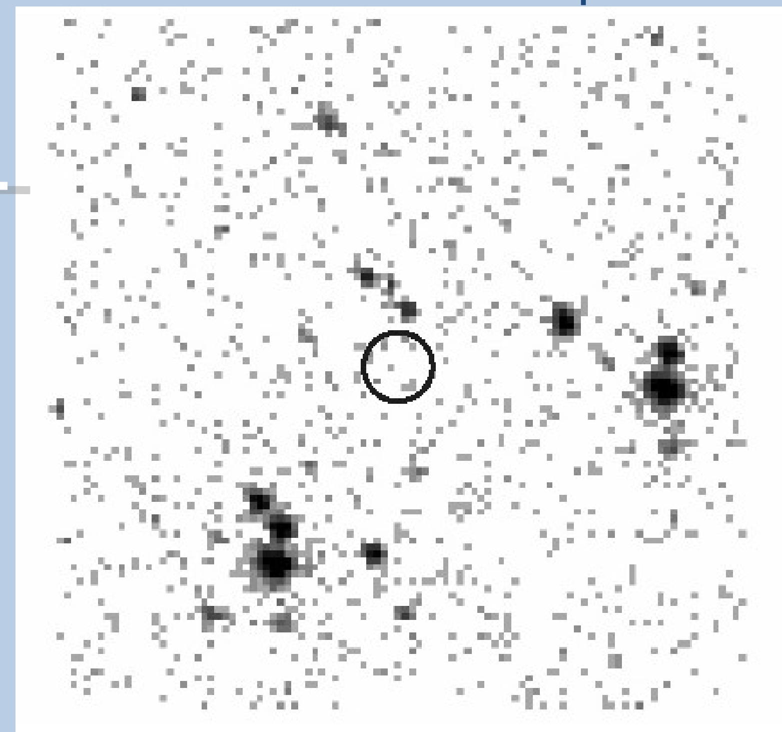
Assume: N_H = 4 10^{23} cm^{-2}, kT = 2.4 keV
L_x < 4 10^{29} erg/s

Class 0 fainter X-rays than Class I, II, III
or extreme extinction

Detecting Class 0 protostars with IXO/ WFI



Co-added ACIS image from 6 Class
into effective 540 ks exposure:



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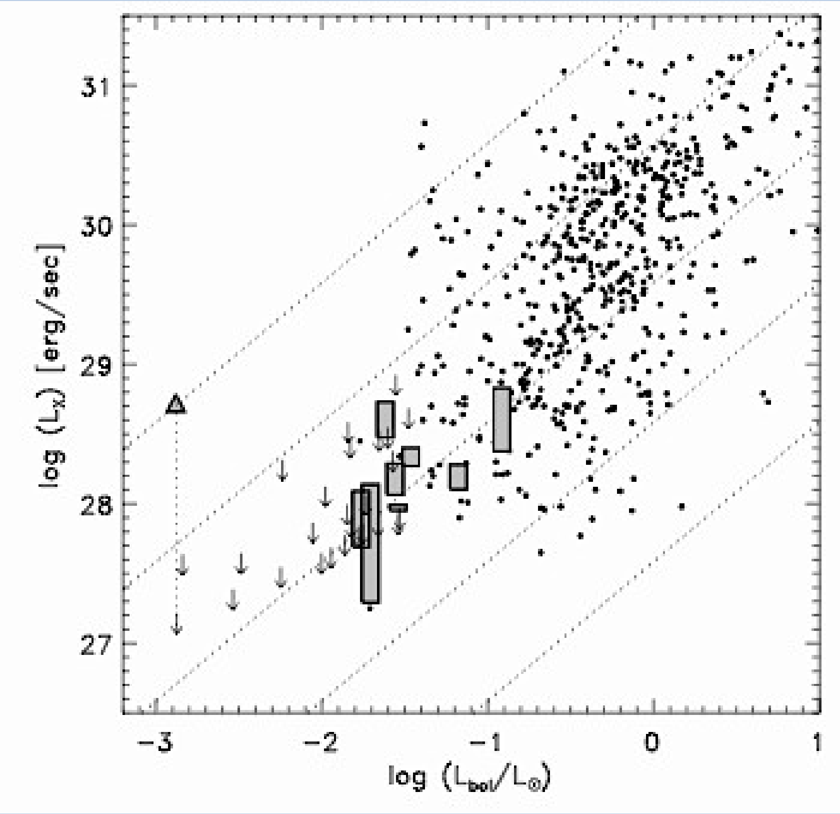
kT = 2.4 keV

Assume: N_H = 4 10^{23} cm^{-2}, kT = 2.4 keV
L_x < 4 10^{29} erg/s

IXO/WFI: L_{lim} ~ 10^{29} erg/s for N_H = 10^{24} cm^{-2}

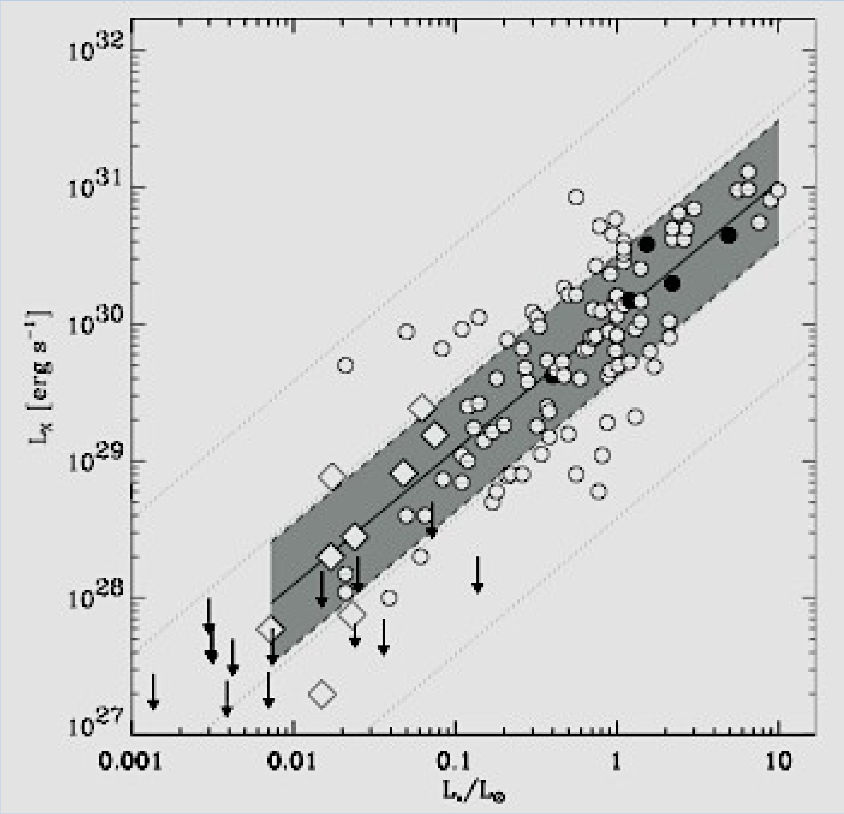
Brown dwarfs:
Dynamo in the substellar regime ?

COUP (ONC)



Preibisch et al. (2005)

XEST (TMC)



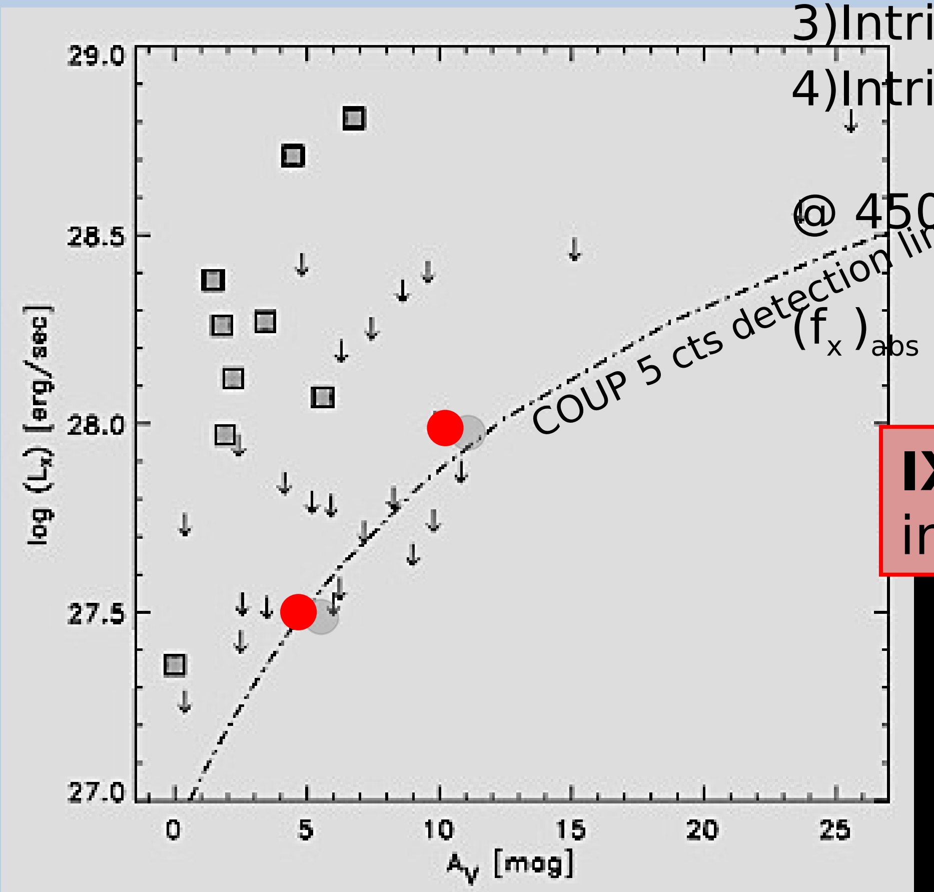
Grosso et al. (2007)

s L_x / L_{bol} of BDs in star forming regions comparable to higher-mass stars or lowe

Currently too few BDs are detected in X-rays.

Detecting brown dwarfs with IXO/WFI

COUP: 850ks Chandra in Orion
Only weakly absorbed BDs detected



Preibisch et al. (2005)

Assume a strongly absorbed BD in ONC:

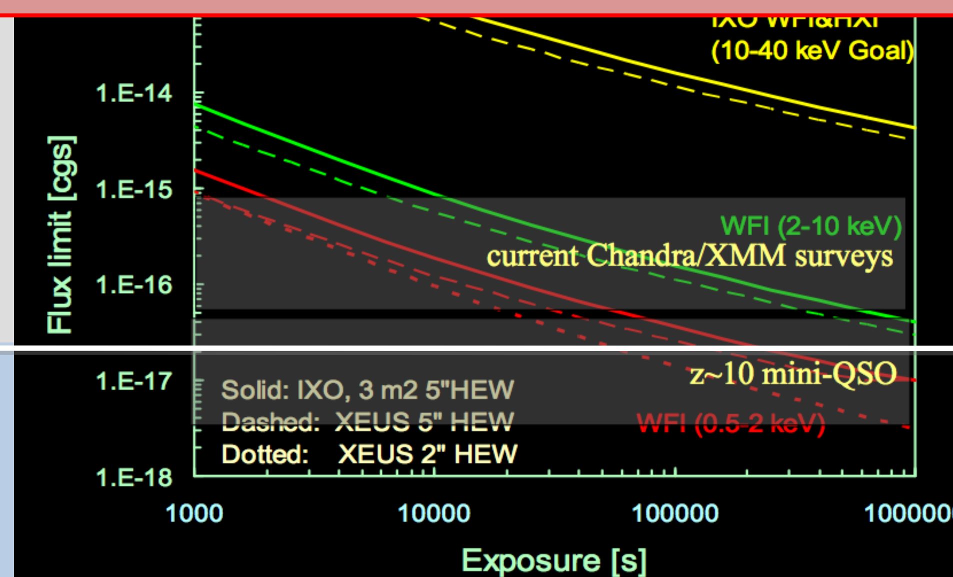
3) Intrinsic $L_x = 10^{28.0}$ erg/s with $A_V = 10$ mag

4) Intrinsic $L_x = 10^{27.5}$ erg/s with $A_V = 5$ mag

@ 450 pc

$(f_x)_{abs}$ ~ 2 10^{-17} erg/cm²/s
@ 0.5-2 keV for kT = 1 keV

IXO/WFI: detects these objects in ~200 ks



Brown dwarfs:
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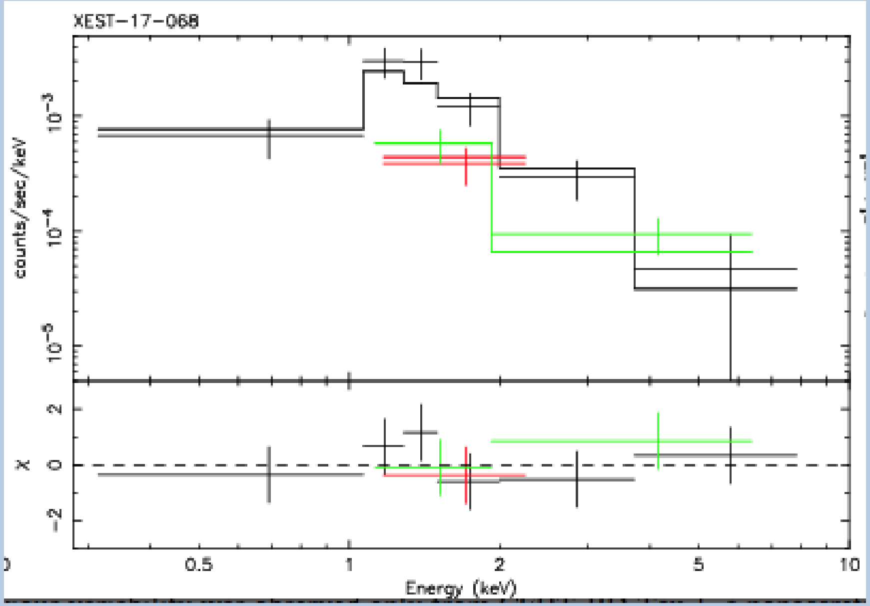
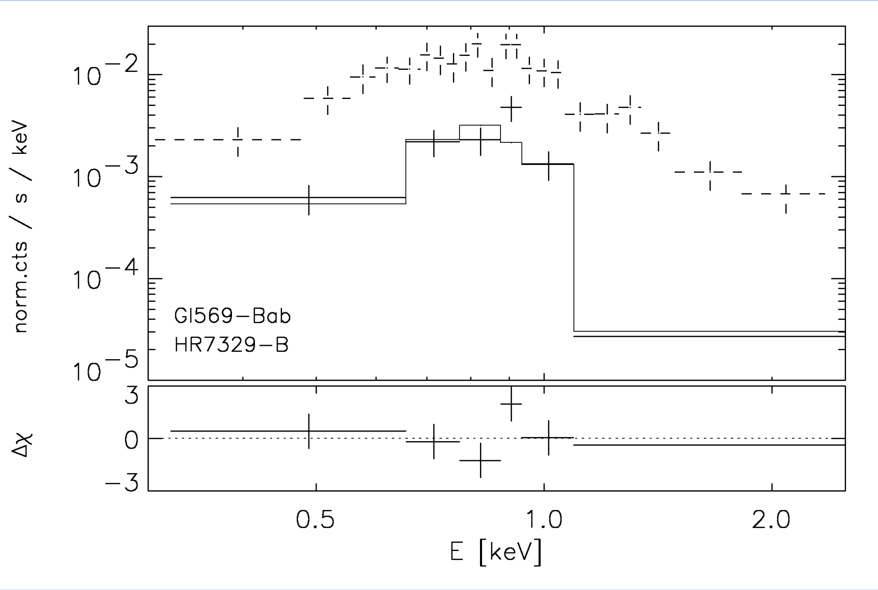


Grosso et al. (2007)

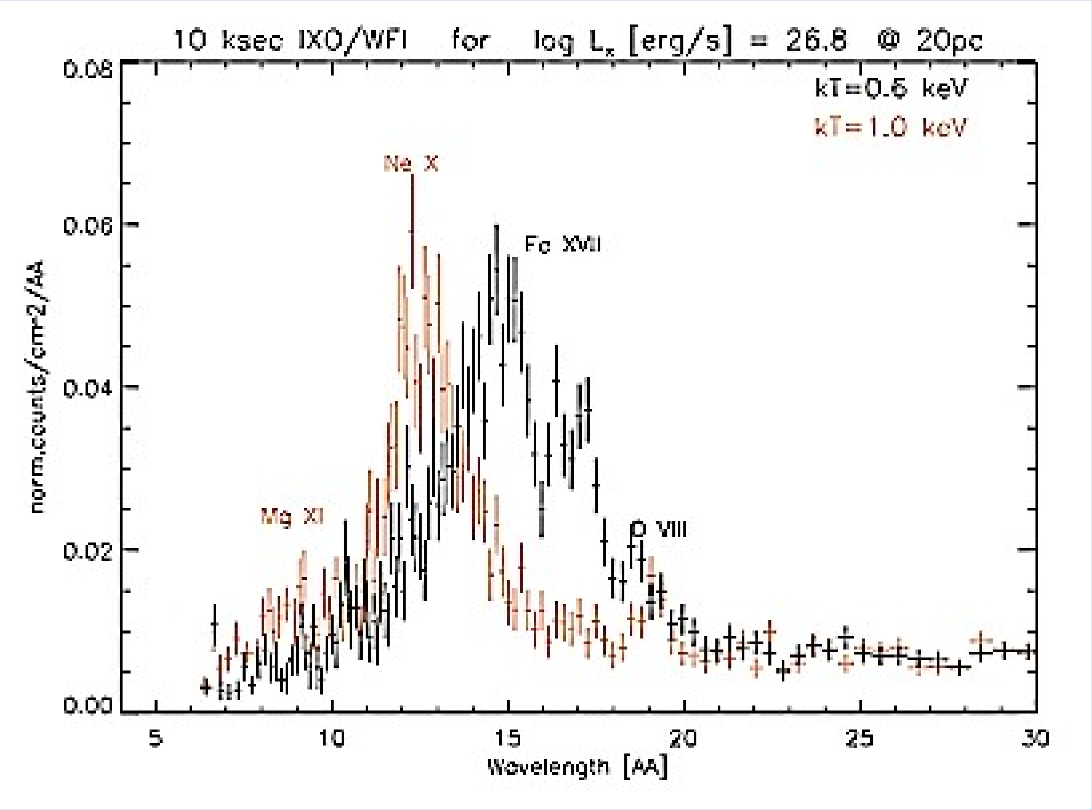


Stelzer et al. (2006a)

	2 Myr	10 Myr	100 Myr
	XEST-17-068	HR7329B	Gl569B
T [MK]	20	6	7 (in flare)

There are no good X-ray spectra of brown dwarfs as yet !

Brown dwarf spectra with IXO/WFI



ay temperature can be constrained in short (few ksec) exposure time
bright, nearby brown dwarfs

/WFI can verify/refute dependence of X-ray spectrum on age in brown d

High sensitivity
for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved

medium-resolution spectroscopy

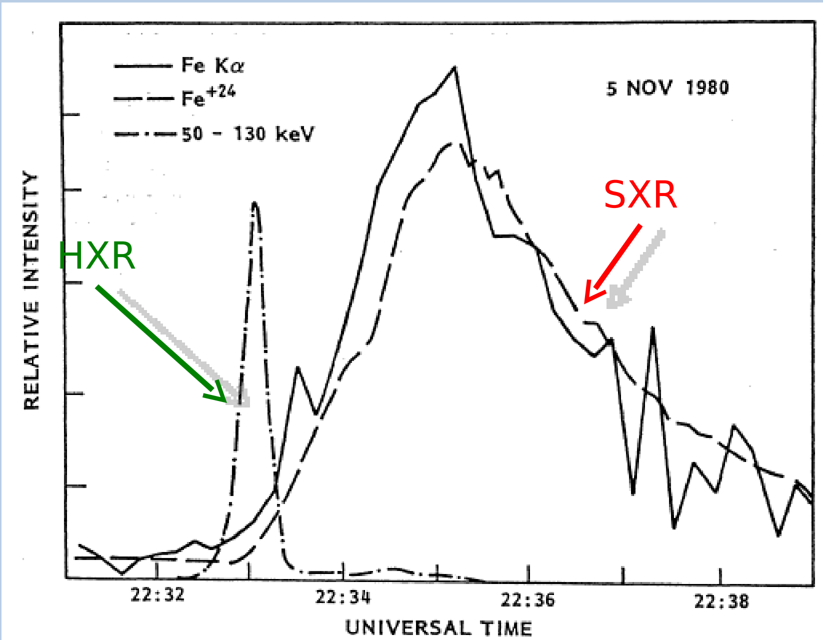
e.g. Fe Kα emission,

disk response to X-ray illumination,

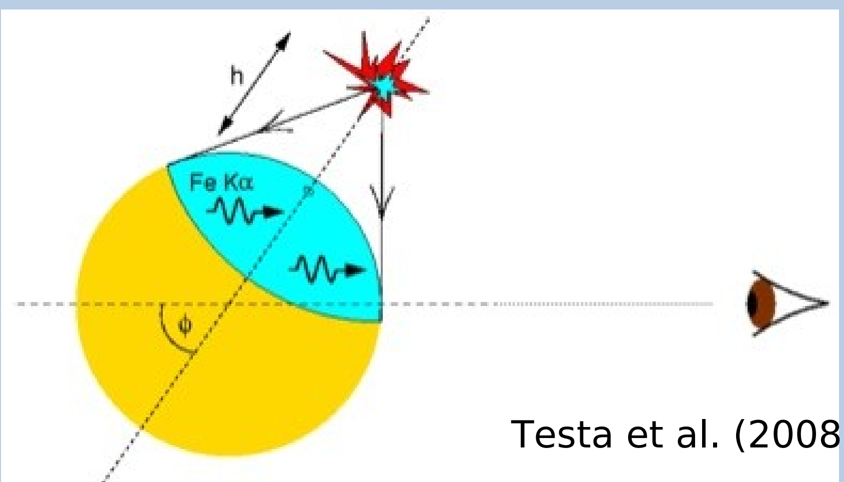
flare evolution,

circumstellar absorption in

Fe Kα emission from the Sun



Culhane et al. (1981)



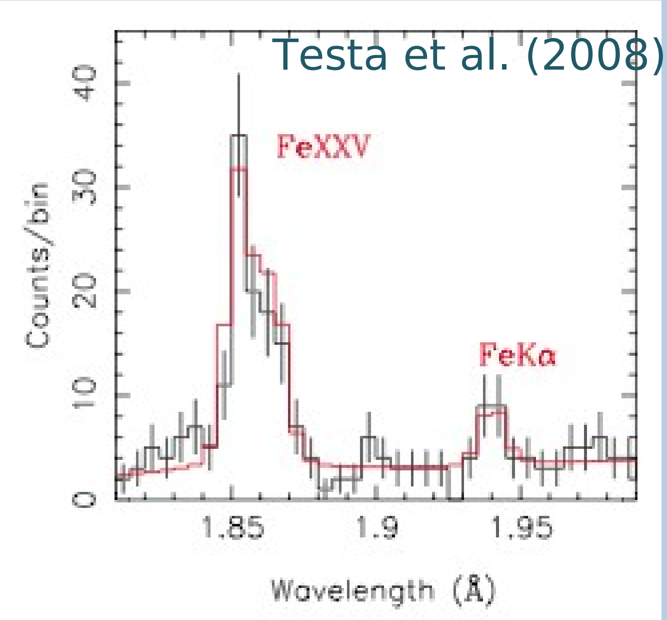
Testa et al. (2008)

Sun:

6.4 keV Kα line
during gradual phase of flare
(similar to soft thermal X-rays;
unlike hard non-thermal X-rays)

→ fluorescence of photosphere illuminated by X-rays

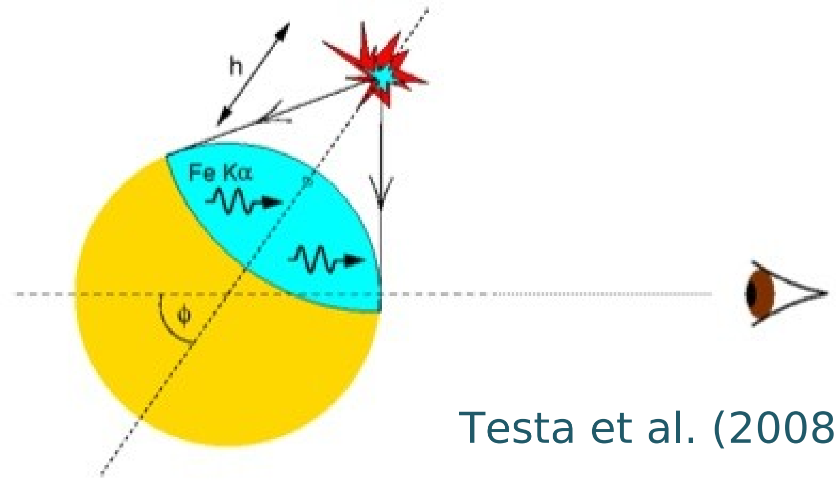
Fe Kα emission from normal stars:
Fluorescence → flare location



HR9024 (G giant)

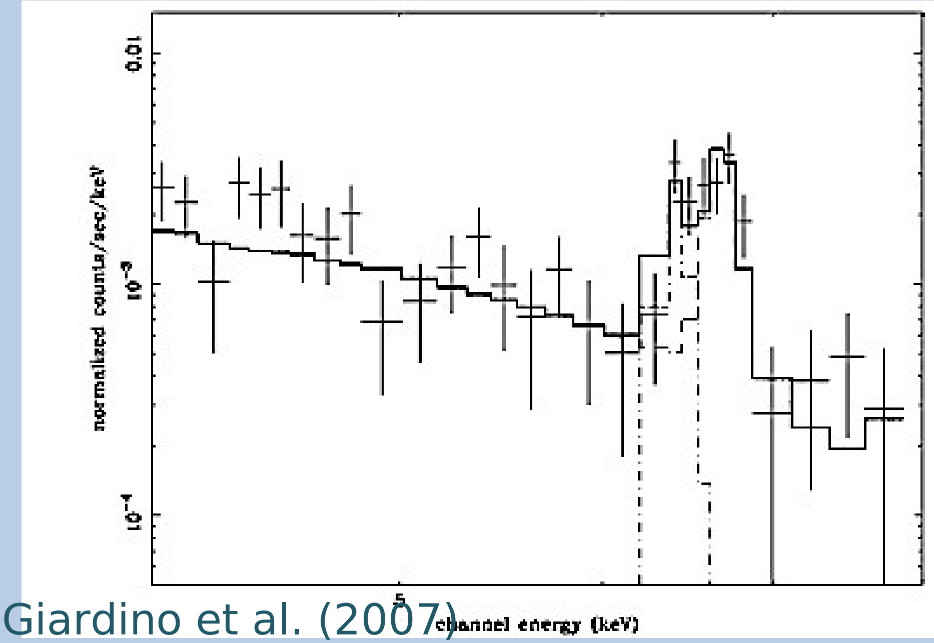
6.4 keV Kα line
during initial phase of flare

photospheric fluorescence model constrains flare height: ~ 0.1 R_*



In pre-MS stars
Fe Kα emission comes from disk
(e.g. Tsujimoto et al. 2005)

Fe Kα emission from pre-MS stars: fluorescence or e⁻ impact ionization ?

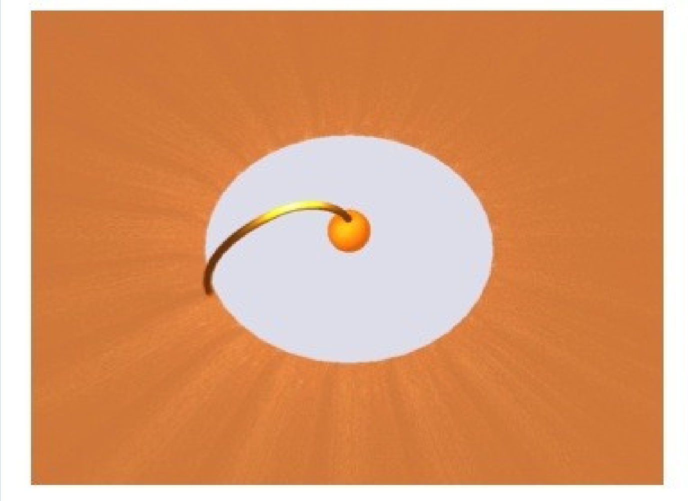


Giardino et al. (2007)

Elias 29 (Class I in DROXO):

6.4keV line
in quiescent phase after a flare

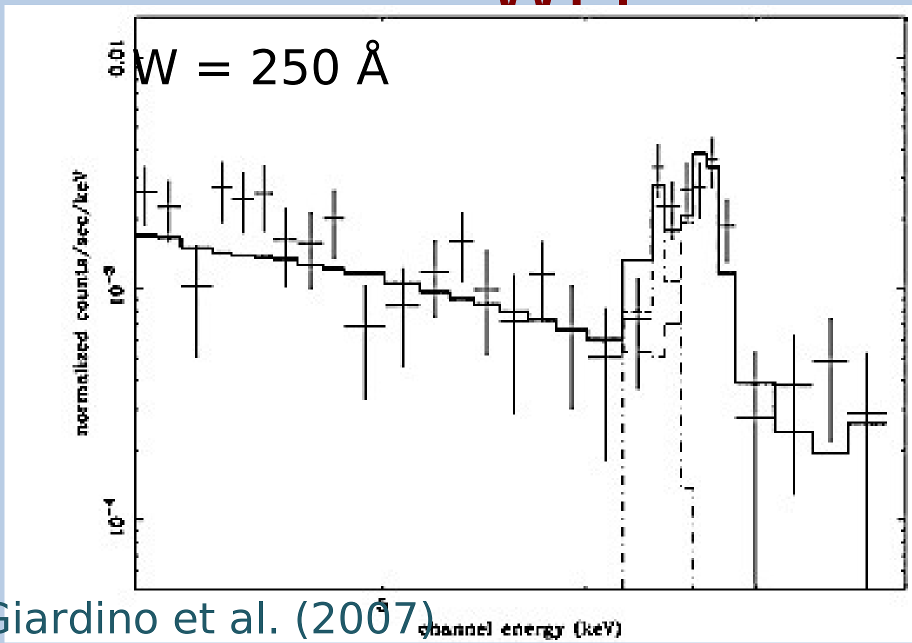
sustained ionization mechanism
independent of X-rays;
coll. ionization by non-thermal electrons in star-disk loops



Reverberation mapping
reveals geometry of system

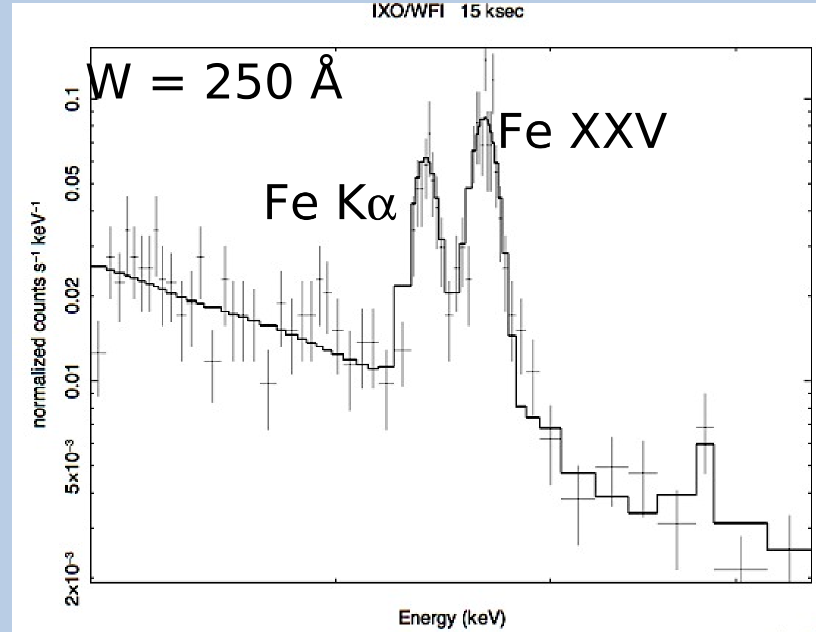
Fe K□ emission with IXO/WFI

85 ksec XMM/pn



Giardino et al. (2007)

15 ksec IXO/WFI

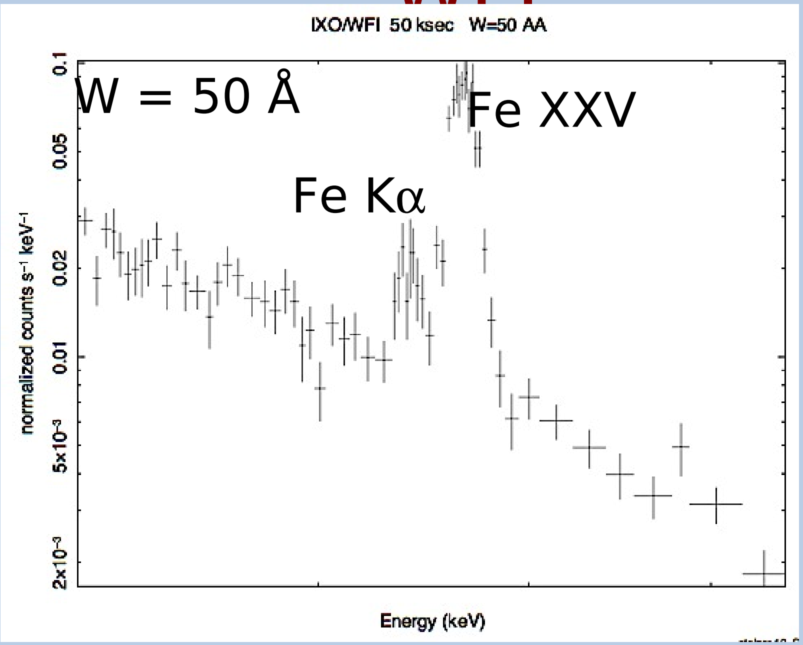


IXO/WFI:

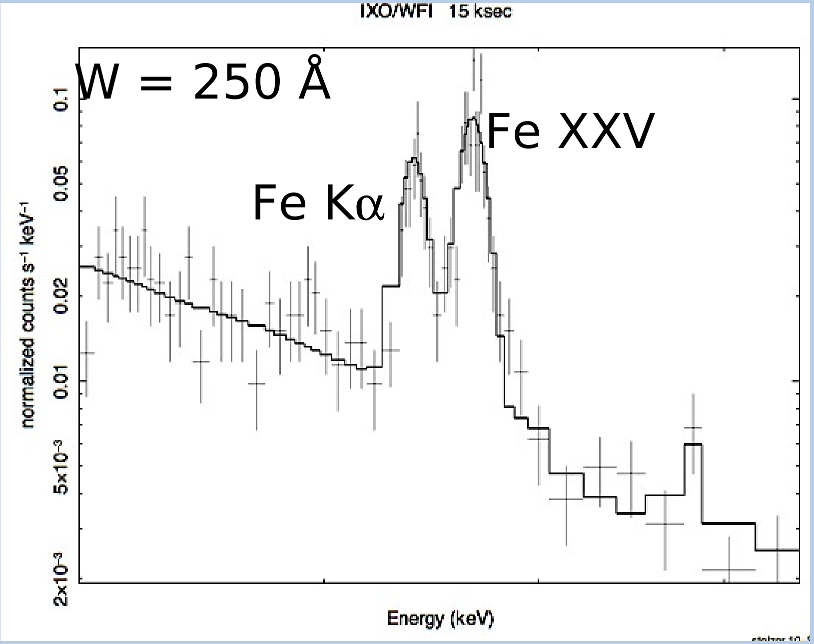
- detection of Fe Kα in large sample of stars in different evolutionary phases
  (large FOV → several stars in 1 field)
- time-resolved Fe Kα spectroscopy:
  detecting time-delay between flare and appearance of Fe Kα line from disk

Fe K▪ emission with IXO/WFI

50 ksec IXO/WFI



15 ksec IXO/WFI



IXO/WFI:

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  (large FOV → several stars in 1 field)
- time-resolved Fe Kα spectroscopy:
  detecting time-delay between flare and appearance of Fe Kα line from disk
- detect photospheric Fe Kα fluorescence ($W_{H\alpha}$ ~ 50 AA in 50

High sensitivity for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved medium-resolution spectroscopy

e.g. Fe Kα emission,

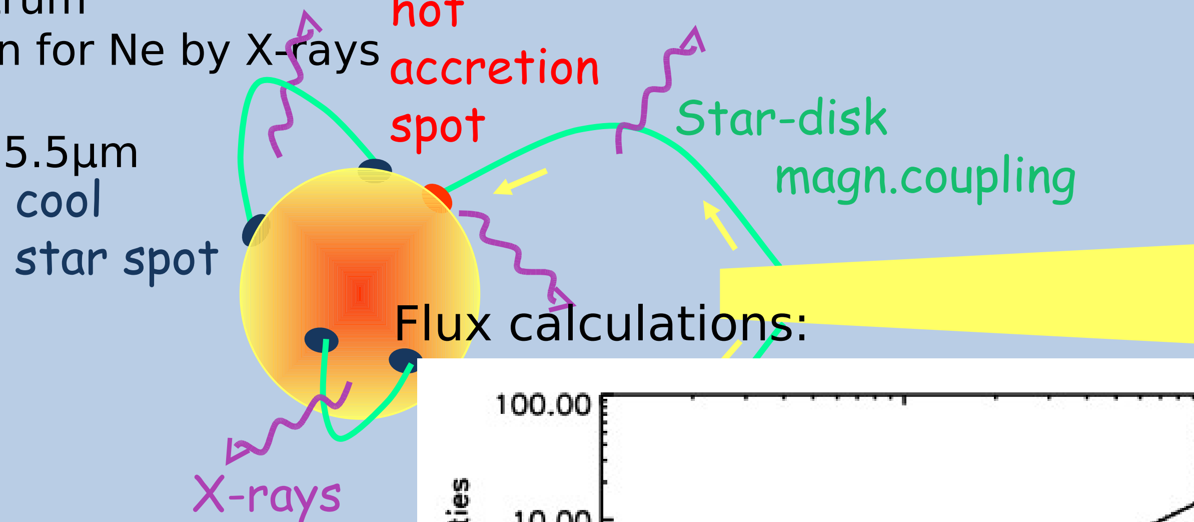
disk response to X-ray illumination,

flare evolution,

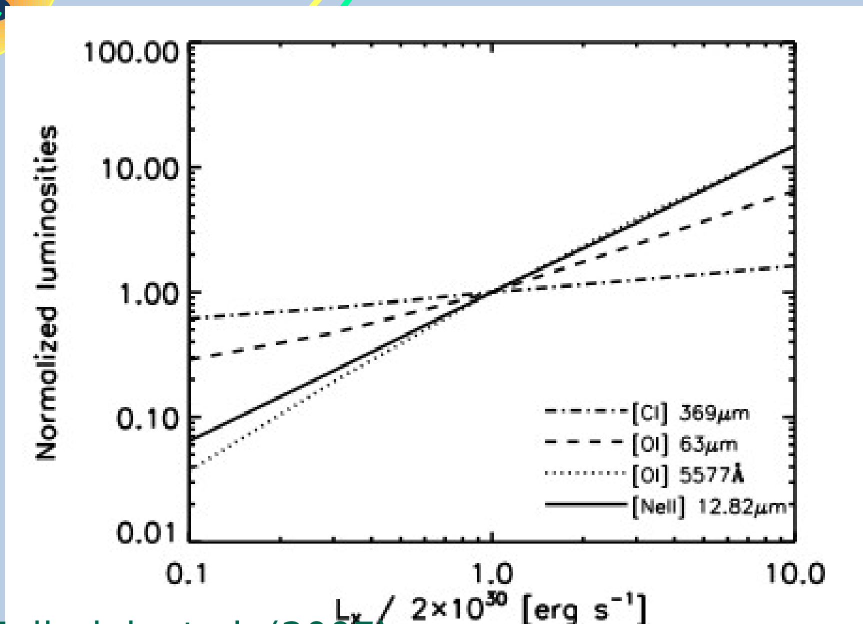
circumstellar absorption in

Disk response to X-ray illumination

K-shell ionization energy of Ne (0.9 keV)
~ peak of stellar X-ray spectrum
→ high photo-ion. cross-section for Ne by X-rays
fine-structure transitions
of [Ne II] 12.8μm and [Ne III] 15.5μm
by collisional excitation

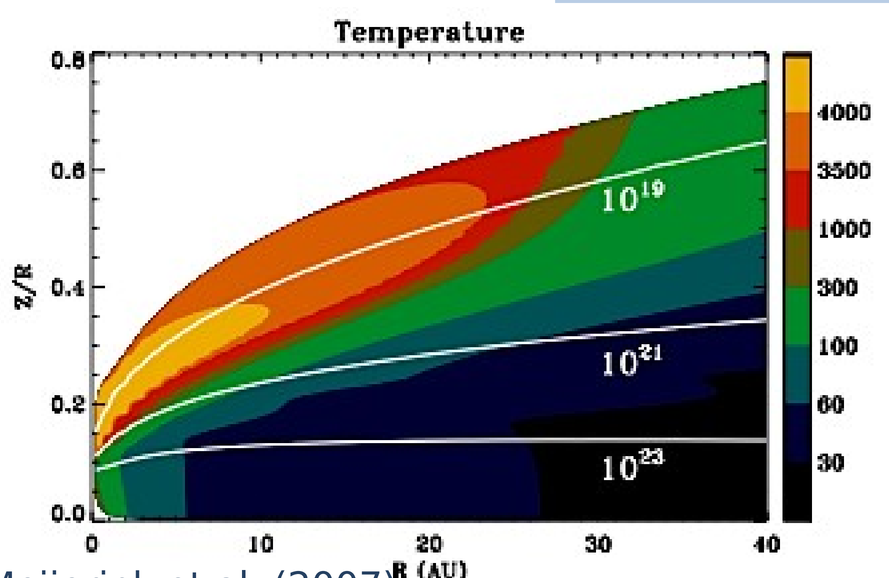


Flux calculations:



Meijerink et al. (2007)

X-ray irradiation produces
warm disk atmosphere:
~ 4000 K

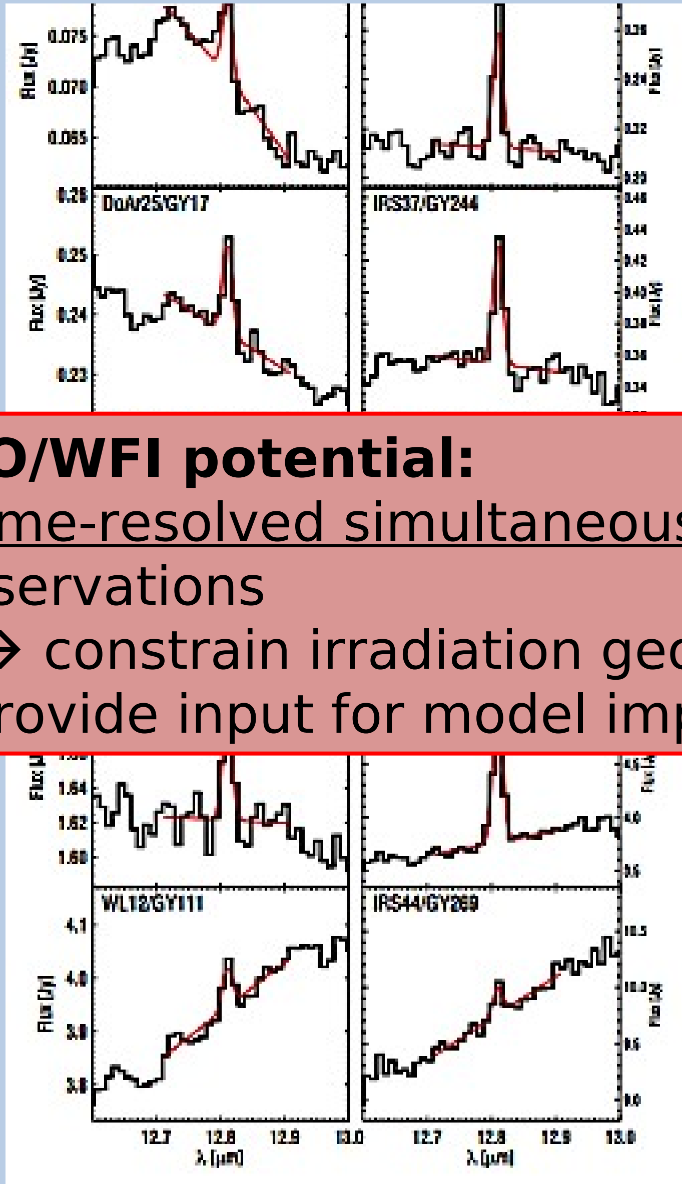


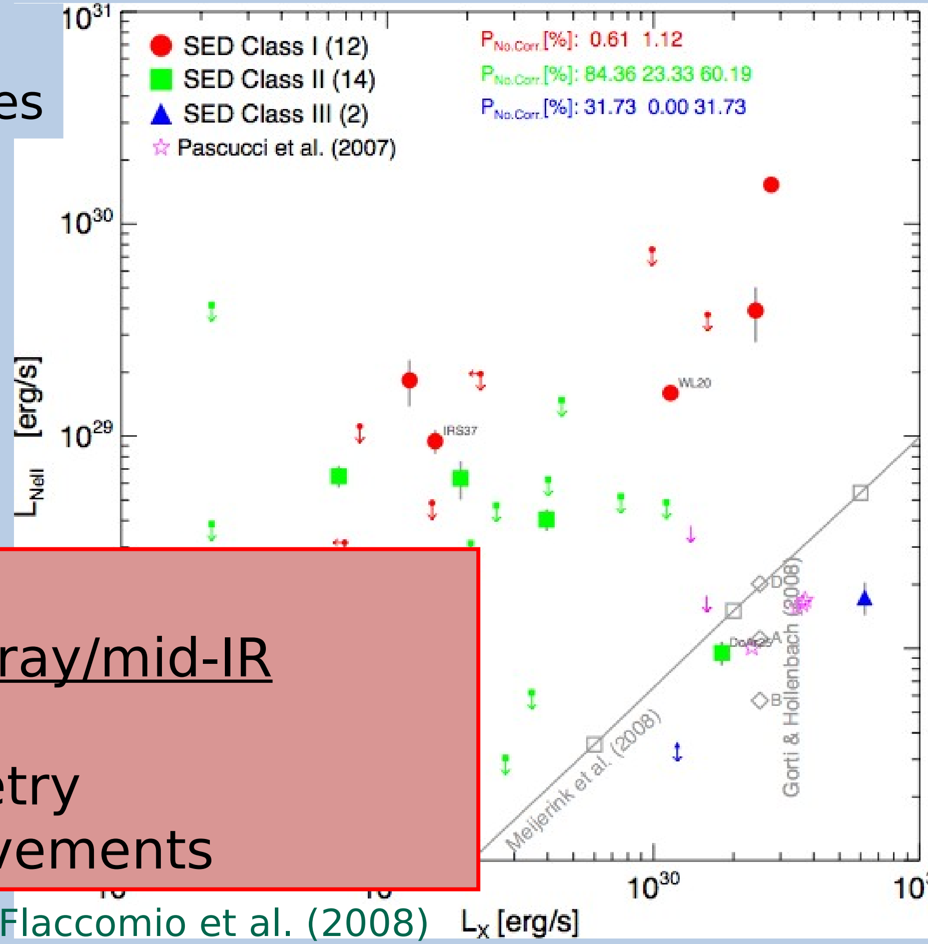
Meijerink et al. (2007)

Disk models predict
correlation between X-ray flux from star
and [Ne II] 12.8μm flux from disk

[NeII] emission of DROXO

10 [NeII] detections in DROXO field;
All [NeII] detections are X-ray sources





Flaccomio et al. (2008)

IXO/WFI potential:

- time-resolved simultaneous X-ray/mid-IR observations
  → constrain irradiation geometry
- provide input for model improvements

- No obvious correlation L_x – L_{Ne} observed !
  → possibly influence of
  disk, envelope and stellar parameters

2) No agreement with model predictions
→ models not adequate for observed st

High sensitivity
for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved

medium-resolution spectroscopy

e.g. Fe Kα emission,

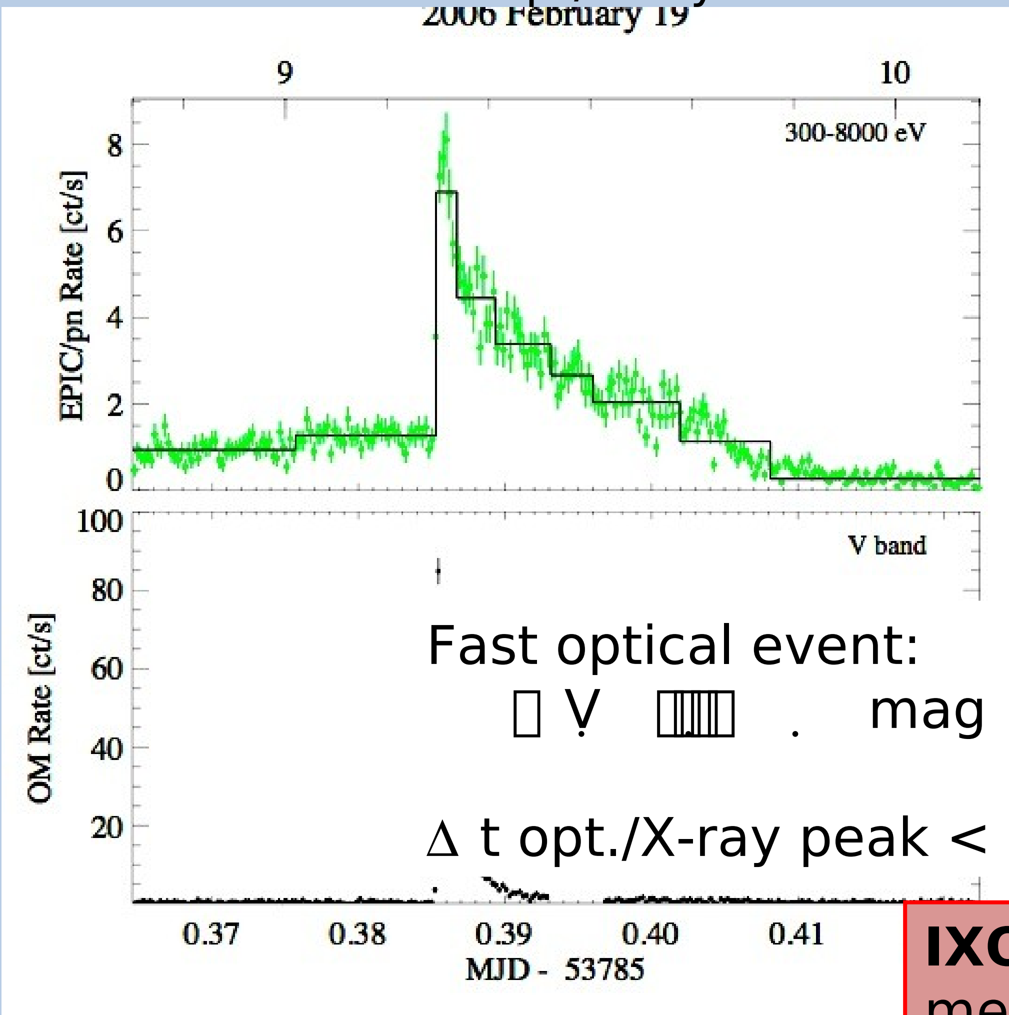
disk response to X-ray illumination,

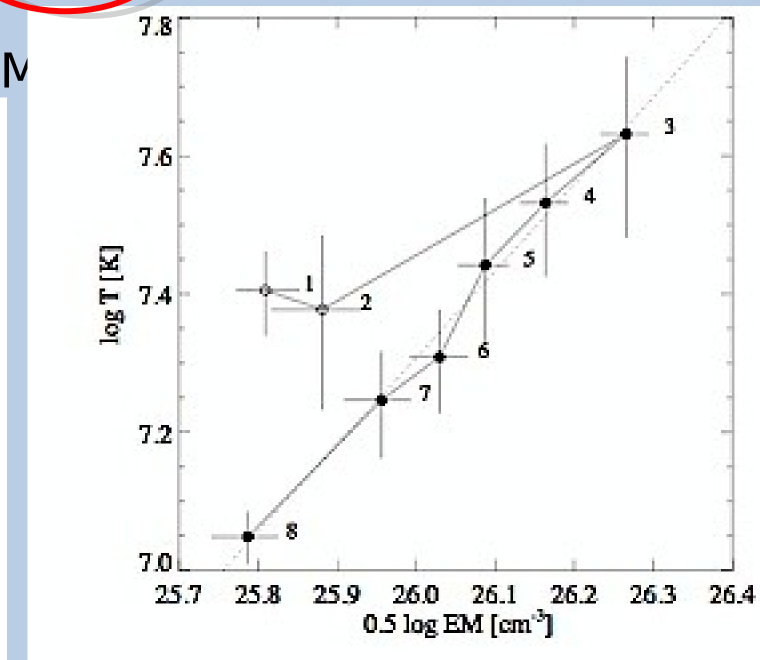
flare evolution,

circumstellar absorption in

Time-resolved flare spectroscopy: plasma evolution in decay phase

P412-31: simultaneous opt/X-ray flare with XM





Fast optical event:

ΔV . mag 40 sec

Δ t opt./X-ray peak < 20 sec

Time-resolved spectroscopy

HD model of flare decay

⟶ heating, loop length

FILL LONG LOOP IN SHORT TIM

I.E. HIGH VELOCITY

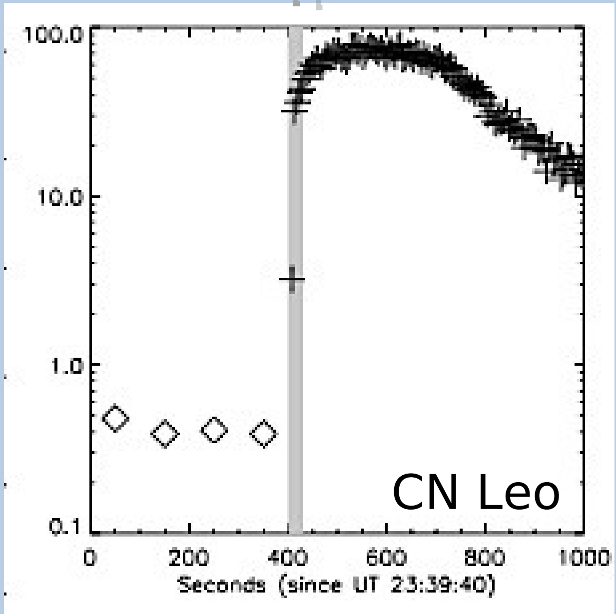
IXO/TES:
measure line shifts due to mass motions in stellar flares (Talk by

Stelzer et al. (2006)

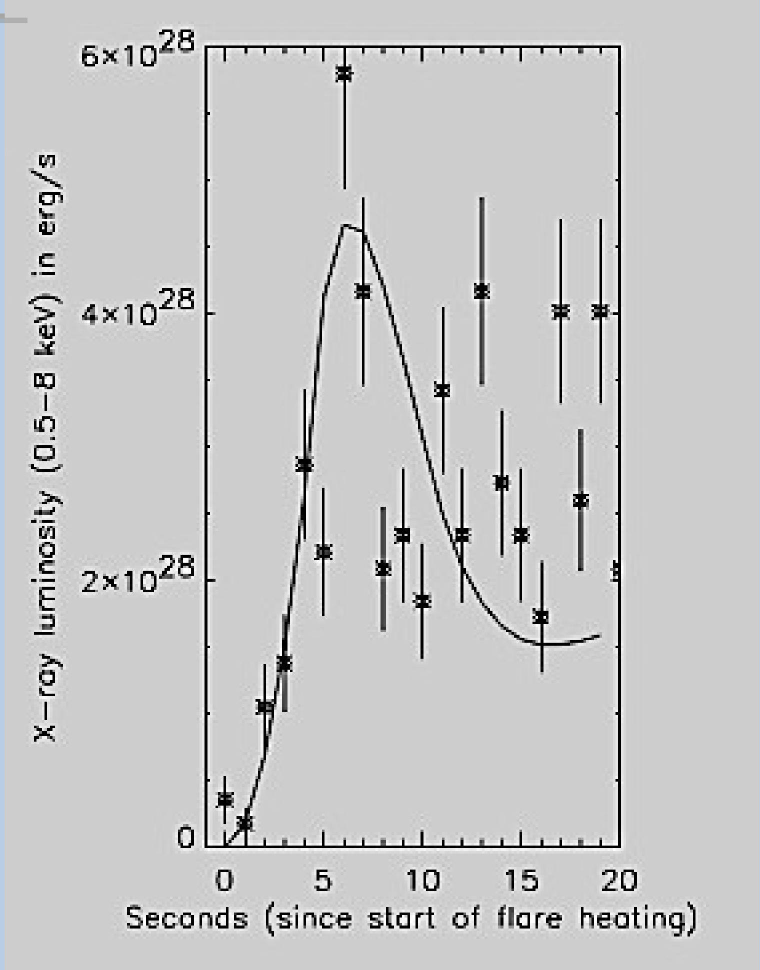
Time-resolved flare spectroscopy: plasma evolution in rise phase

Soft X-ray pulse

XMM/EPIC



Schmitt et al. (2008)

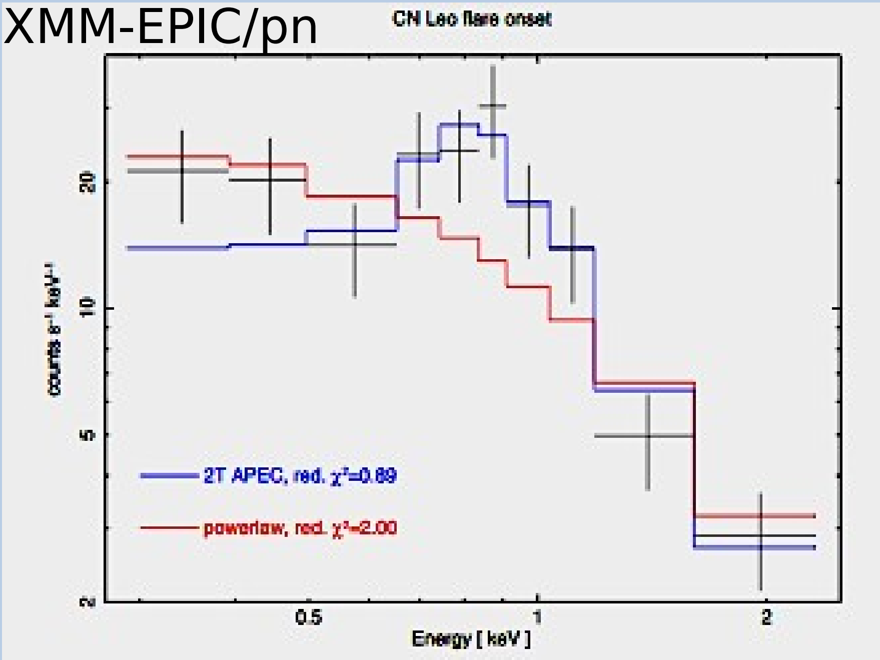


IXO/WFI:
high sensitivity allows to resolve
heating history in flare rise

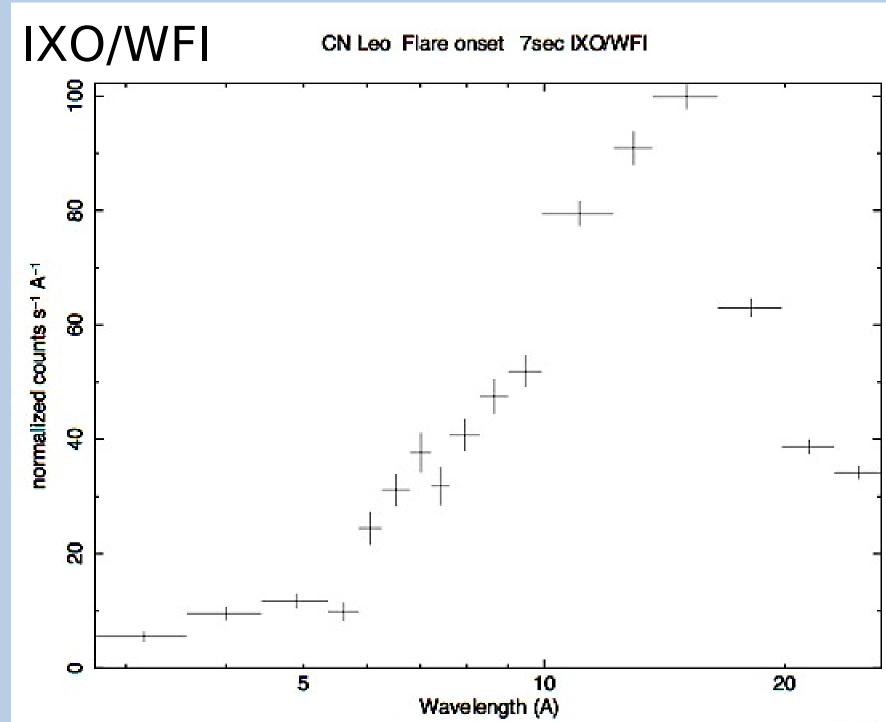
ID simulation of coronal loop
with transient heating

→ X-ray peak at end of heating phase

Time-resolved flare spectroscopy: flare evolution studies with IXO/WFI



Schmitt et al. (2008)



Non-thermal X-rays in flare rise ?

Need time-resolved spectroscopy of flare rise phase

Factor 50 higher eff.area @ 10-20 AA of IXO/WFI w.r.t. XMM/pn

→ <u>Few seconds</u> exposure with IXO/WFI determines spectral shape, i.e. physics in flare rise + decay

High sensitivity
for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved

medium-resolution spectroscopy

e.g. Fe Kα emission,

disk response to X-ray illumination,

flare evolution,

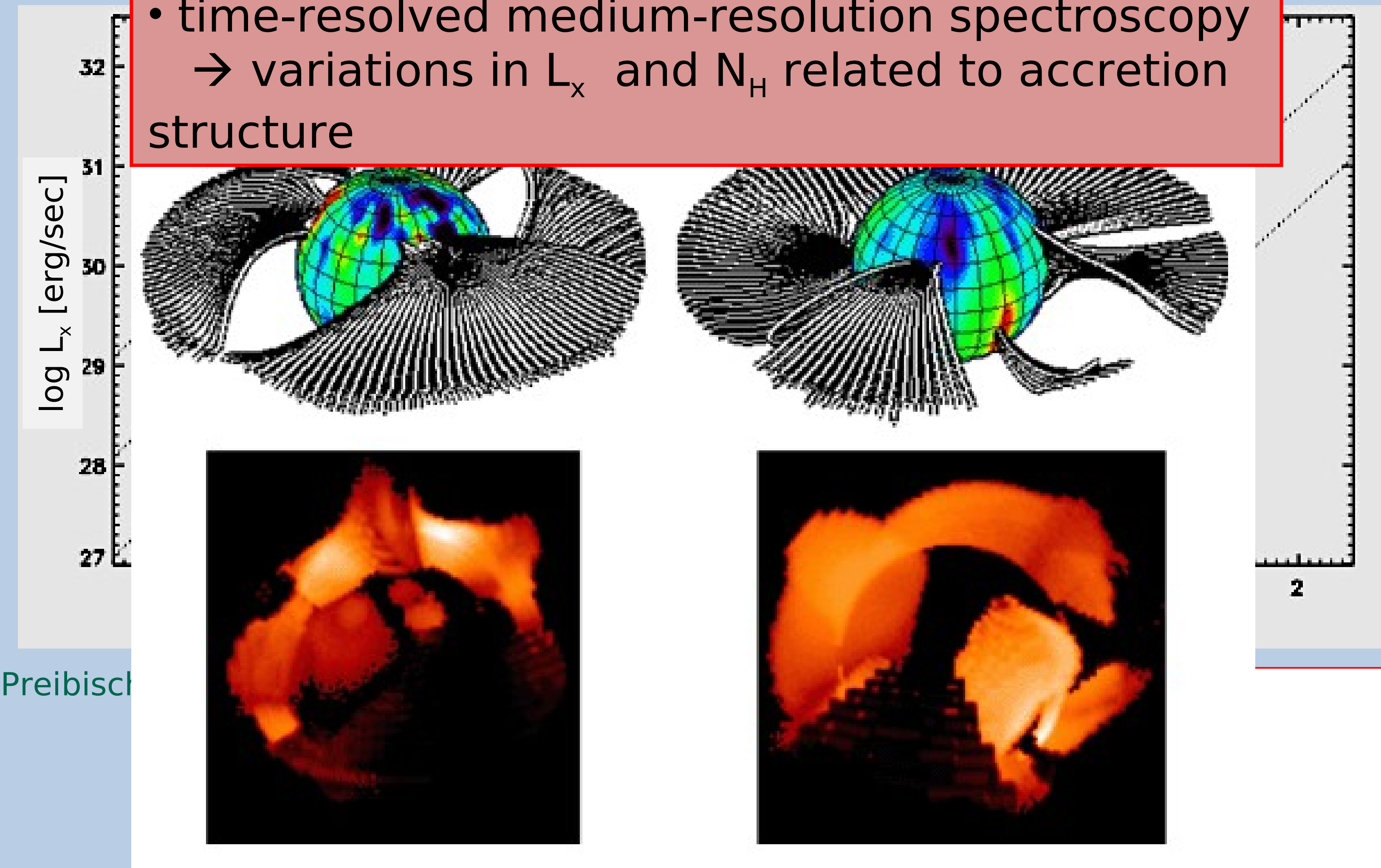
circumstellar absorption in

Time-resolved spectroscopy of pre-MS stars:

COUP (=

IXO/WFI potential:

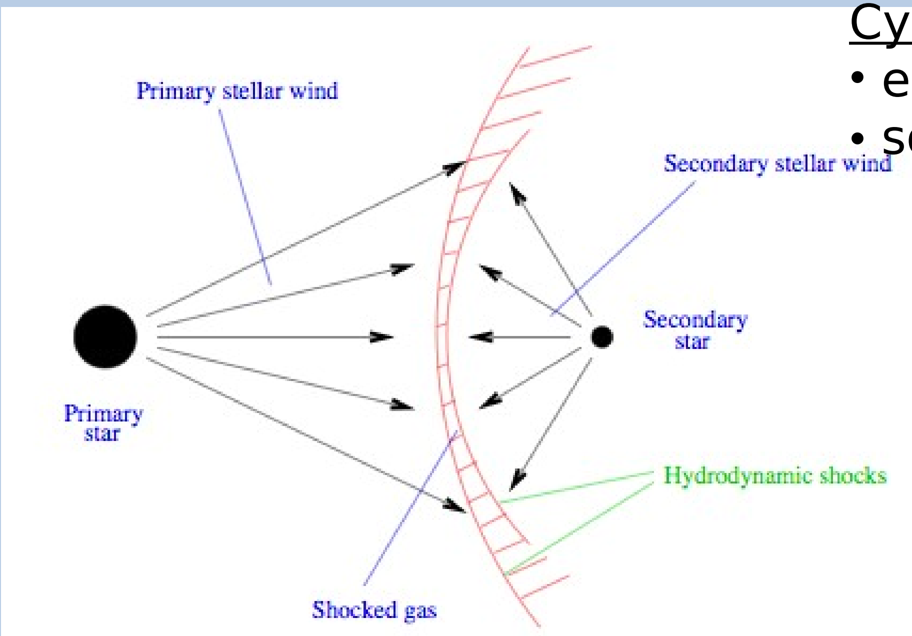
- time-resolved medium-resolution spectroscopy → variations in L_x and N_H related to accretion structure



Preibisch

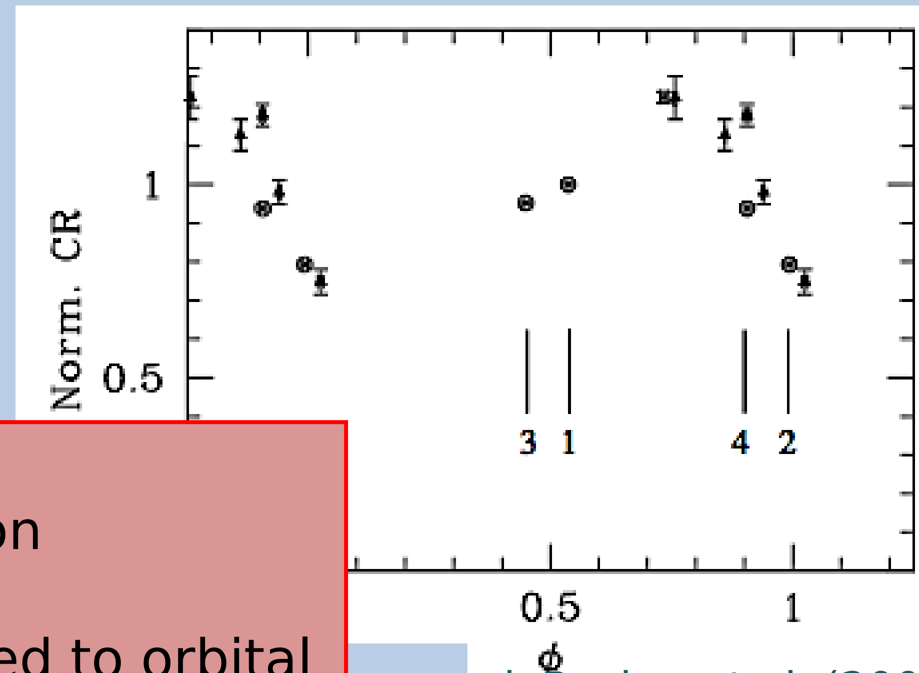
E)X-ray emission obscured by accretion streams (Gregory et al. 20

Time-resolved spectroscopy of hot stars:
Colliding wind binaries



<u>CygOB2 #8a:</u>

- eccentric binary of 2 O-stars (P~22d)
- soft X-rays from colliding winds: $L_x \sim 10^{34}$ e



deBecker et al. (2006

IXO/WFI potential:

- time-resolved medium-resolution spectroscopy
  → variations in L_x and N_H related to orbital motion

has

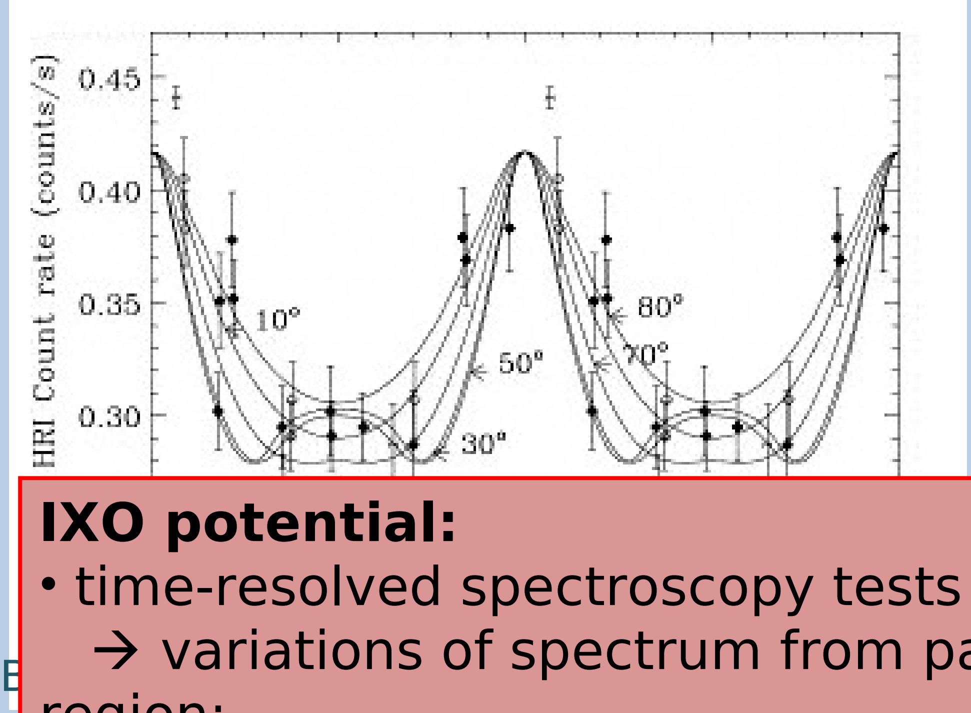
ons ons:

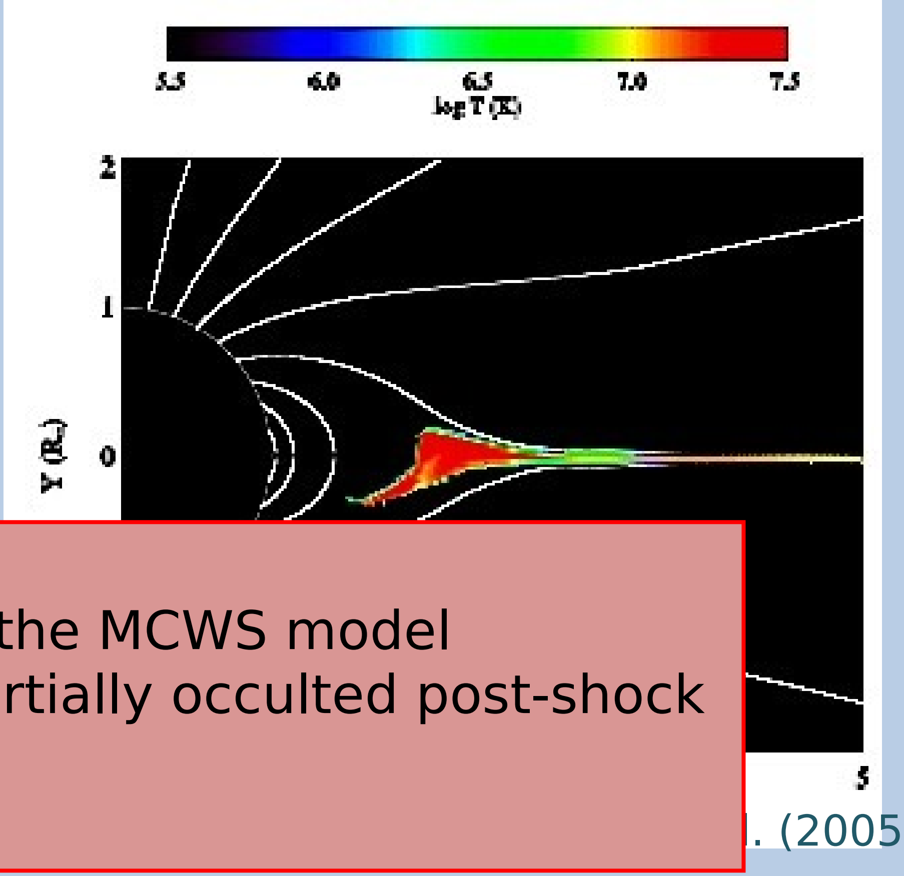
Orbital modulation due to changing N_H

Varying shock conditions due to changing separation

Time-resolved spectroscopy of hot stars:
Magnetically confined wind shocks

Θ[1] Ori C (O7V star):





IXO potential:

• time-resolved spectroscopy tests the MCWS model
→ variations of spectrum from partially occulted post-shock region:
e.g. $T_x = f(z)$

B

. (2005)

ri

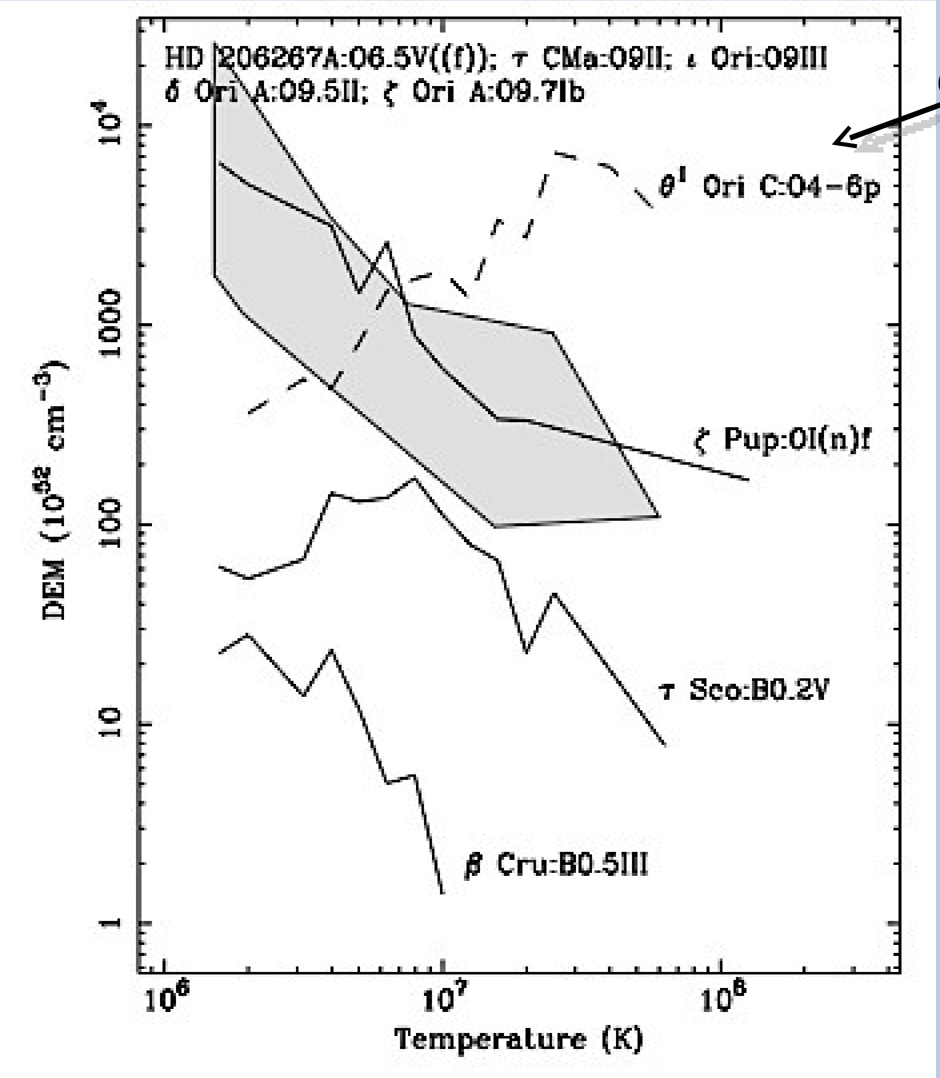
her T_x than in O-star shocks

magn.field channels wind to equator

shocks from collision of winds from 2 hemispheres

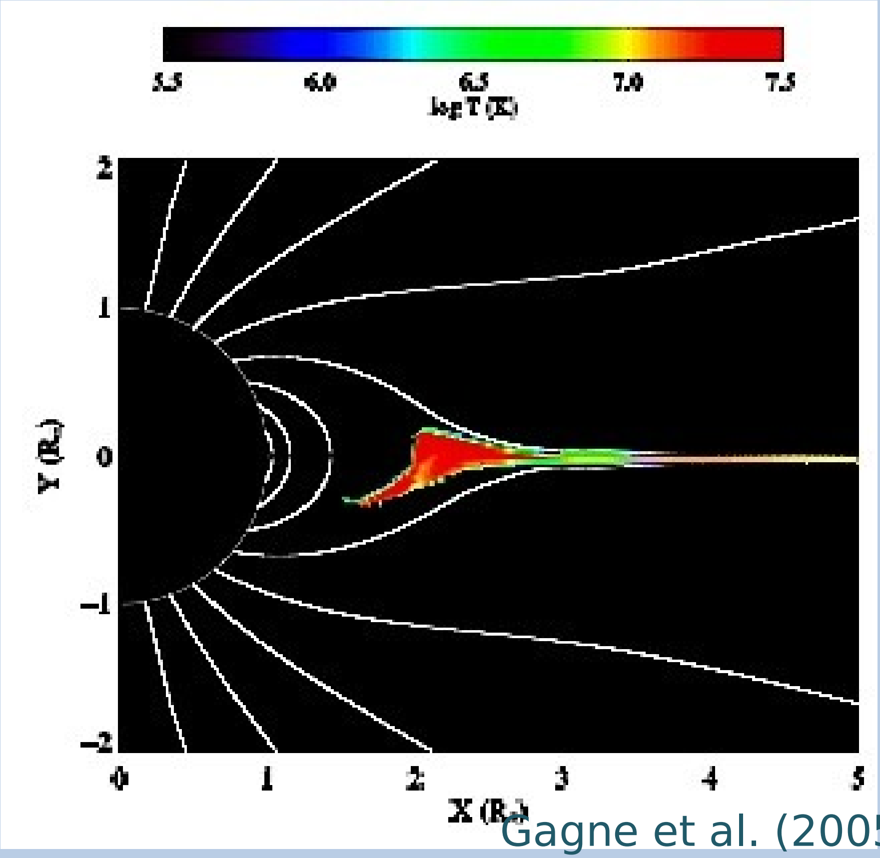
opaque cooling disk modulates X-rays thru rotation cycle

Time-resolved spectroscopy of hot stars: Magnetically confined wind shocks



Wojdowski & Schulz (2005)

ð ¹. Ori C only hot star with rising



Gagne et al. (2005

X-rays from magn. Confined win

High sensitivity
for

- Faint objects,

e.g. protostars + brown dwarfs

- Time-resolved

medium-resolution spectroscopy

e.g. Fe Kα emission,

disk response to X-ray illumination,

flare evolution,

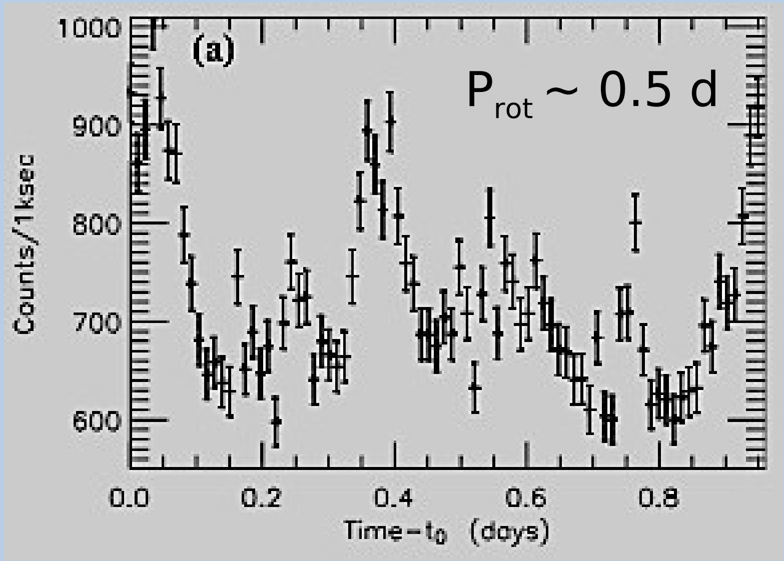
circumstellar absorption in

Time-resolved spectroscopy of normal stars:

Coronal mapping

Rotational modulation of X-ray emission on nearby flare star AB Dor

→ inhomogeneous distribution of X-ray emitting material ?



Hussain et al. (2005)

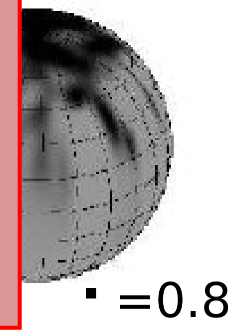
Time-resolved spectroscopy of normal stars:

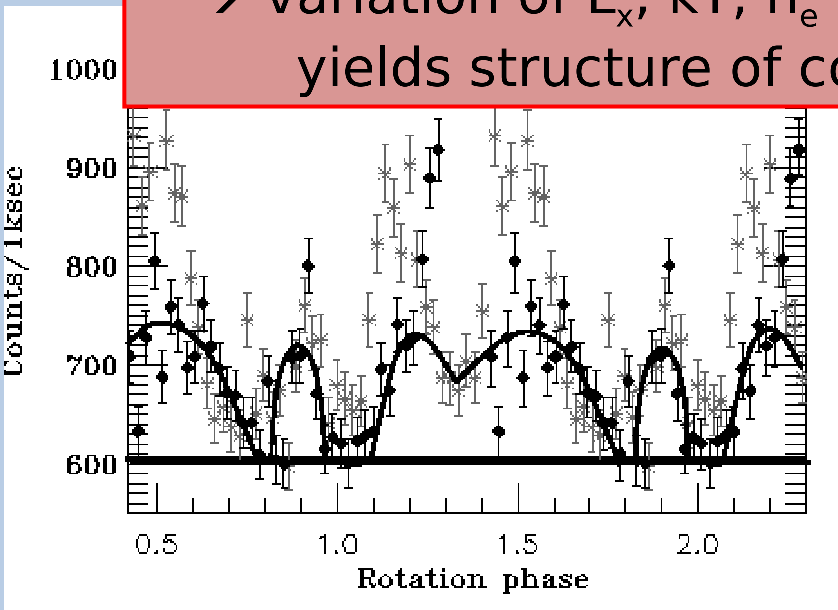
apolation

IXO/WFI+TES potential:

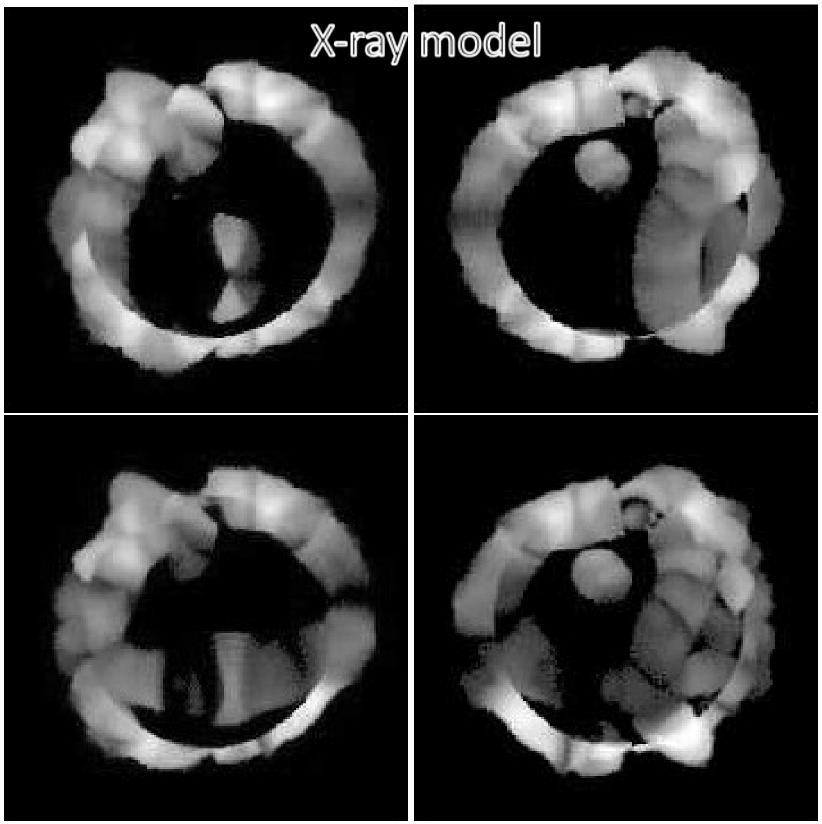
• time-resolved medium- and high-resolution spectroscopy

→ variation of L_x, kT, n_e across rotation yields structure of corona





Hussain et al. (2007)



RESULTS:
no polarity reversal between the two hemispheres for AB Dor

High spectral resolution
for
plasma diagnostics

e.g. accretion signatures in cTTS
wind signatures in hot stars

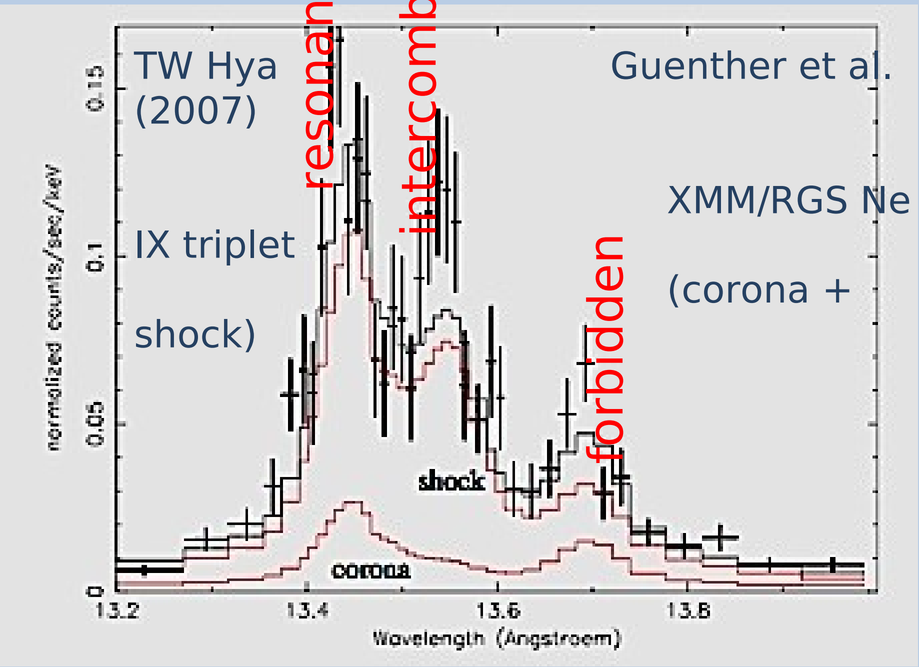
(also talk by M.Audard)

What have we learned from XMM + Chandra?

High-resolution X-ray spectroscopy: Densities from He-like triplets

- Diagnostic for accretion shock: high-density (~ 10^{12} cm^{-3})
  (vs. low-density corona ~ 10^{10} cm^{-3})

→ line diagnostics, He-like triplets: **low f/i flux ratio indicates high n_e**



Few cTTS bright enough for XMM/Chandra gratings:
TW Hya, BP Tau, V4046 Sgr, CR Cha, T Tau

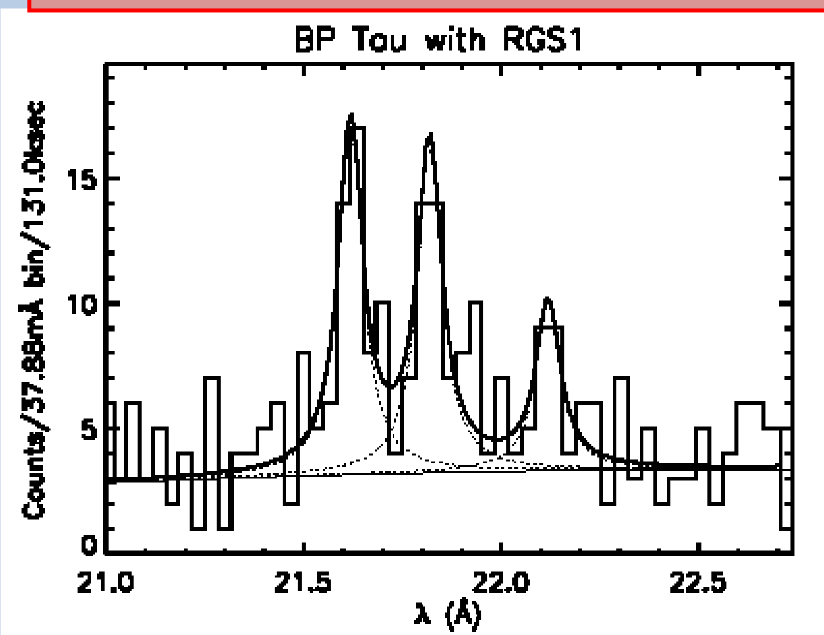
High-resolution spectroscopy of cTTS with

nly

IXO/TES potential:

- time-resolved high-resolution spectroscopy
  - → n_e in cTTS
  - → n_e variations in stellar flares (see talk by M.Audard)

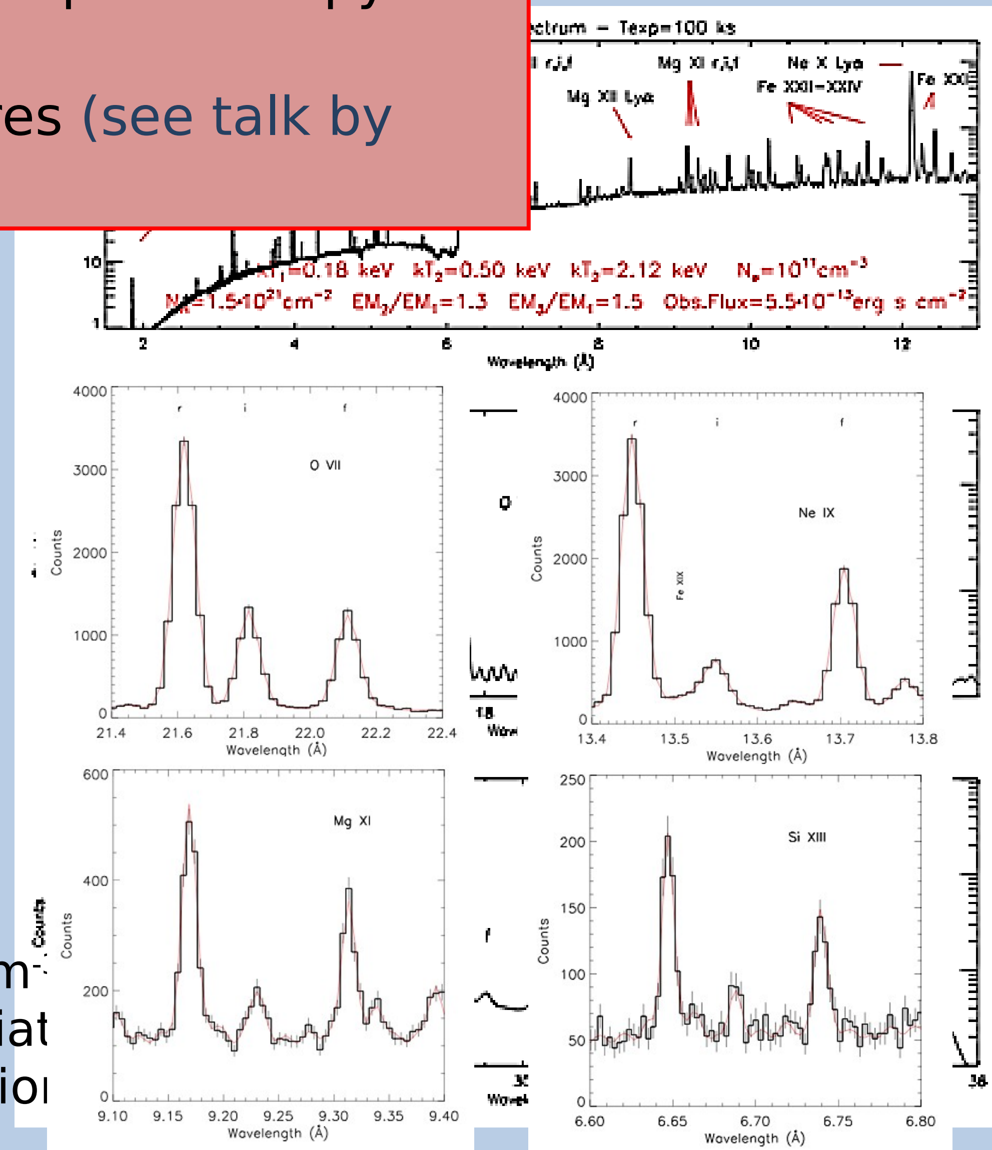
1

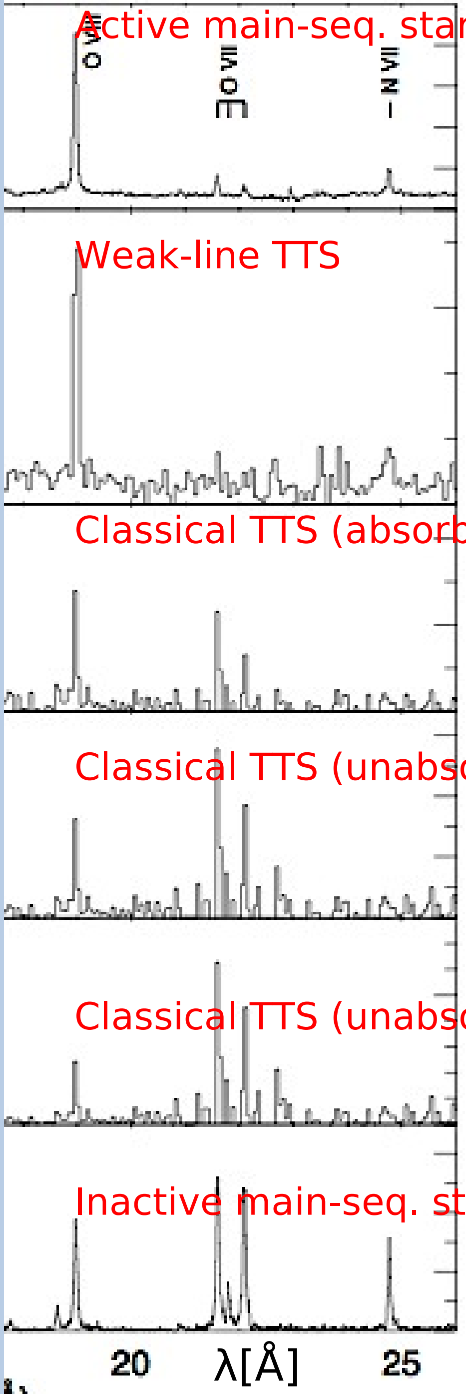


chmitt et al. (2005)

w f/i ratio → high density: $3\ 10^{11}$ cm⁻
(not considering UV radiat
and coronal contributio

IXO/TES





High-resolution X-ray spectroscopy

Soft excess from oxygen line ratios

VII triplet) / L (OVIII Lyα) is a measure for the temper

but depends also on I

In main-seq. stars:
O VII / O VIII ratio
higher for strongly active stars
due to hotter coronae

In weak-line TTS:
O VII / O VIII ratio very low;
continues trend of main-seq stars
at high-activity end

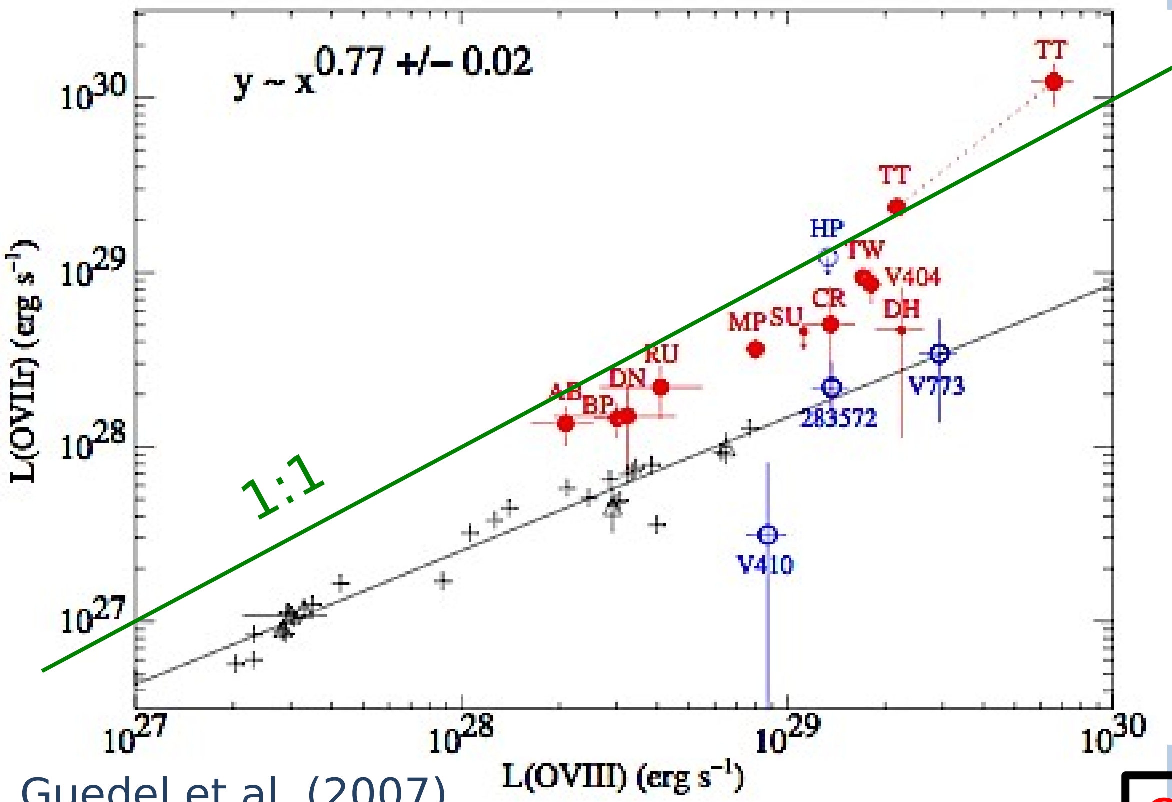
In classical TTS:
O VII / O VIII ratio
unusually large
considering their X-ray luminositie

Guedel et al. (2007)

High-resolution X-ray spectroscopy
Soft excess from oxygen line ratios

L (OVII triplet) / L (OVIII Lyα) is a measure for the temper
but depends also on l

Absorption corrected line luminosities:



Guedel et al. (2007)

<u>In main-seq. stars:</u>
O VII / O VIII ratio
lower for strongly active stars
due to hotter coronae

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O VII / O VIII ratio very low;
continues trend of main-seq stars
at high-activity end

<u>In classical TTS:</u>
O VII / O VIII ratio
unusually large
considering their X-ray luminositie

Cool X-ray emitting plasma in cTTS

X-ray emission mechanisms in pre-MS stars

mmary:

Examples:

weak-line TTS with hard X-rays + low densities

→ X-rays from corona

V410Tau, TWA-5

assical TTS with soft excess (low temperature) + high density

→ X-rays from accretion shock

TW Hya, BP Tau, V4046 Sgr

assical TTS with soft excess (low temperature) + low density

→ (A) X-rays from shocks in jets

T Tau

IXO: resolve spatially with high sensitivity

(B) X-rays from corona with reduced heating due to accretion

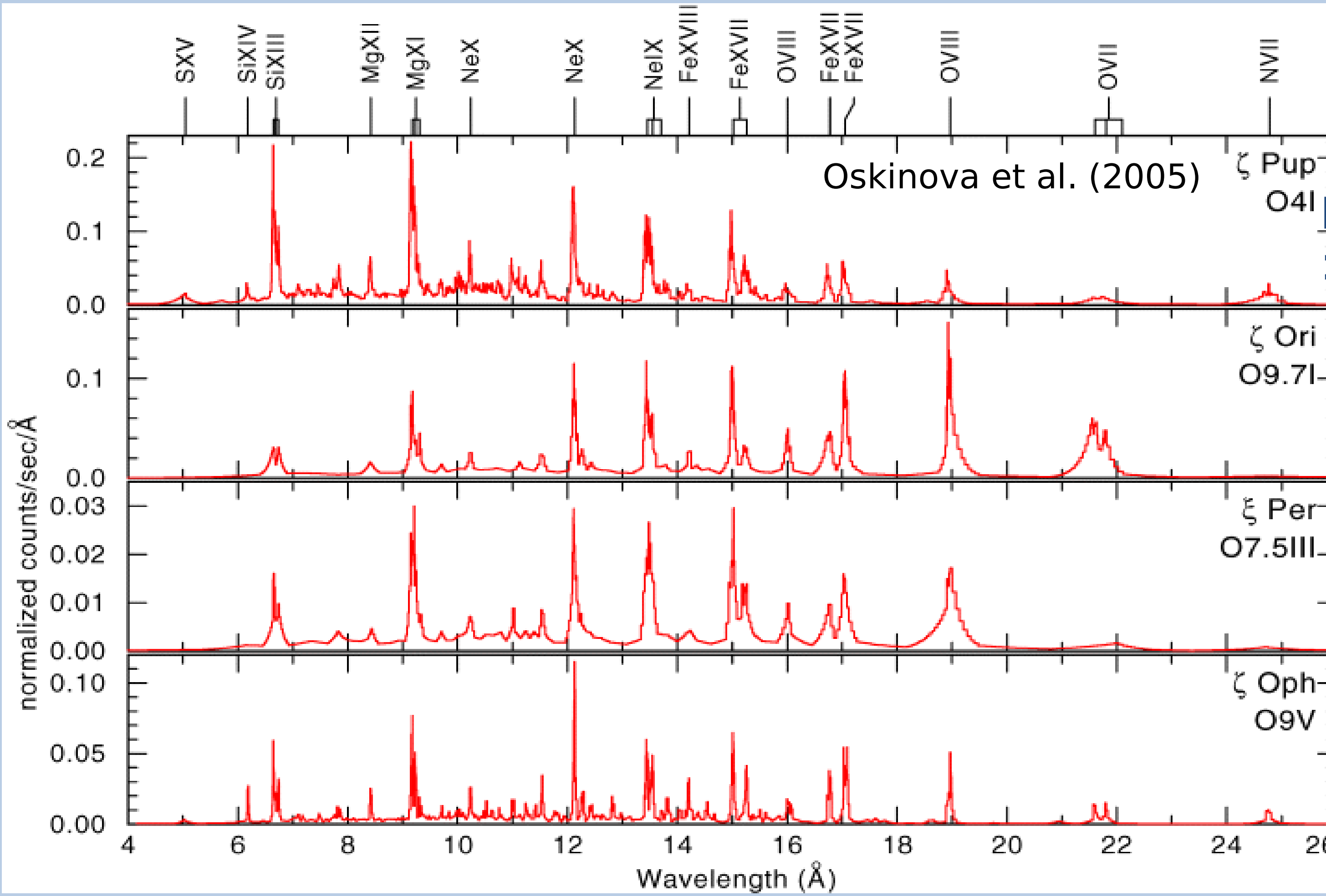
IXO: study time-resolved X-ray spectra for effect of accretion funnels

High-resolution spectroscopy of hot stars:

2.5 kev

line b 1 kev dening (winds)

0.48 kev



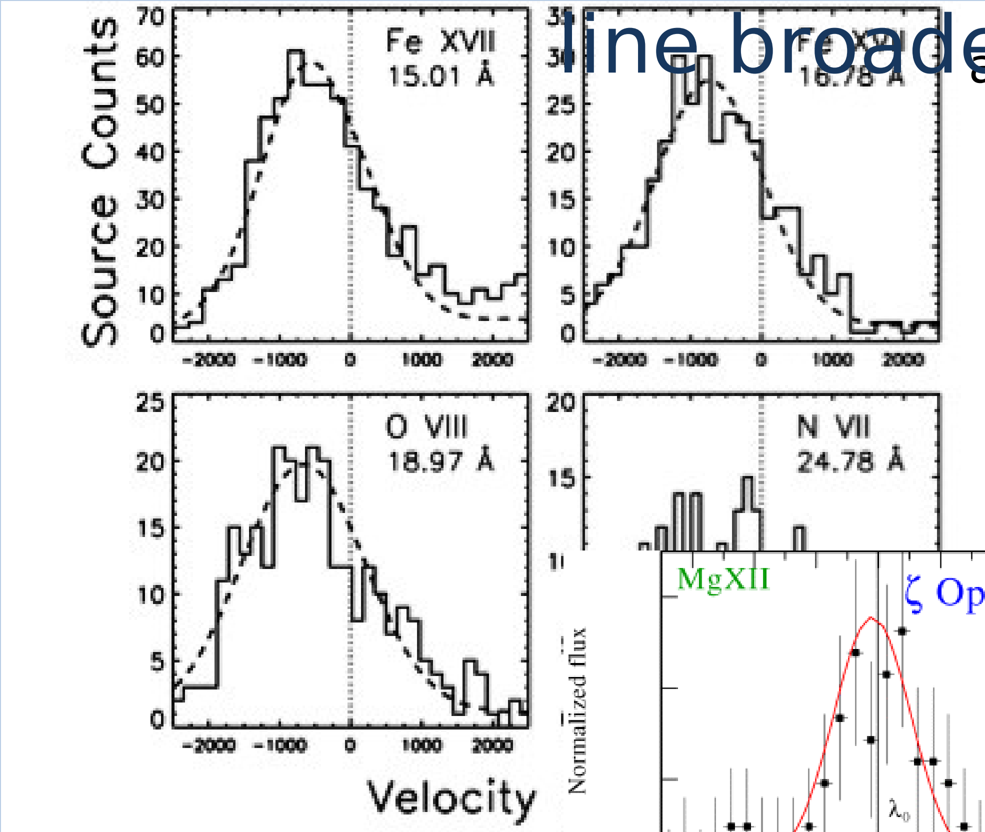
Broad

>1000km/s

Narrow

IXO/TES SIMILAR RES.(2eV) HIGHER

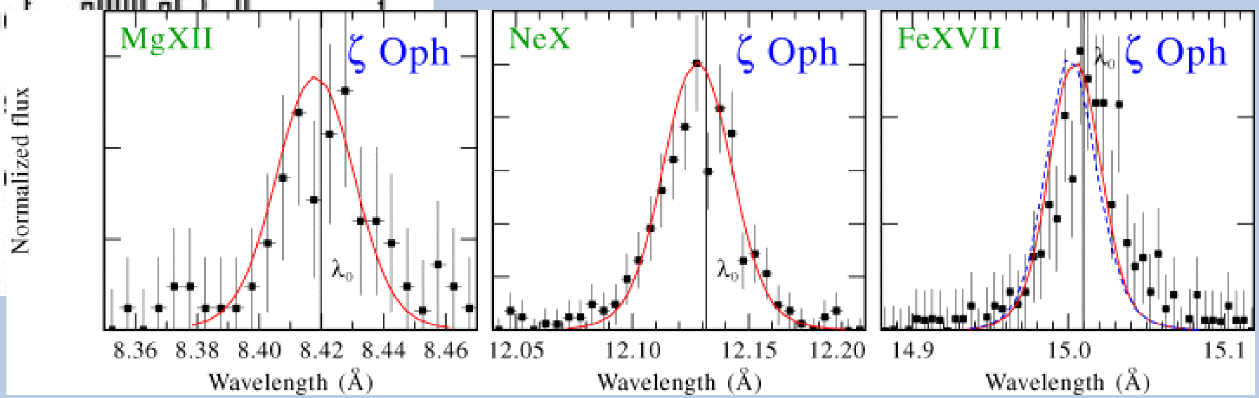
High-resolution spectroscopy of hot stars:
line broadening (winds)



...assinelli et al. (2001)

asymmetric, blue shifted lines
⟶ high optical depth in wind

symmetric, lines
⟶ (A) transparent wind due to clumping
(B) smaller than expected mass loss



Oskinova et al. (2005)

Triplet analysis yields distance X-ray source / star: ~ 1.5 R_{star}

Potential of IXO stellar studies

ive complete Pre-MS population (together with IR)
various environments → IMF, disk fraction, ...

ce + distinguish hot plasma from various physical processes
magnetic activity, accretion, jets and winds

ronal structure (field mapping, flare analysis)

e of X-rays for star formation
by ionizing circumstellar disks + facilitating accretion
and by evaporating planet atmospheres

ays from hot stars → wind clumping, mass loss rates, .

ays from brown dwarfs → dynamos in sub-stellar objec