High Resolution X-ray spectra of classical T Tauri stars

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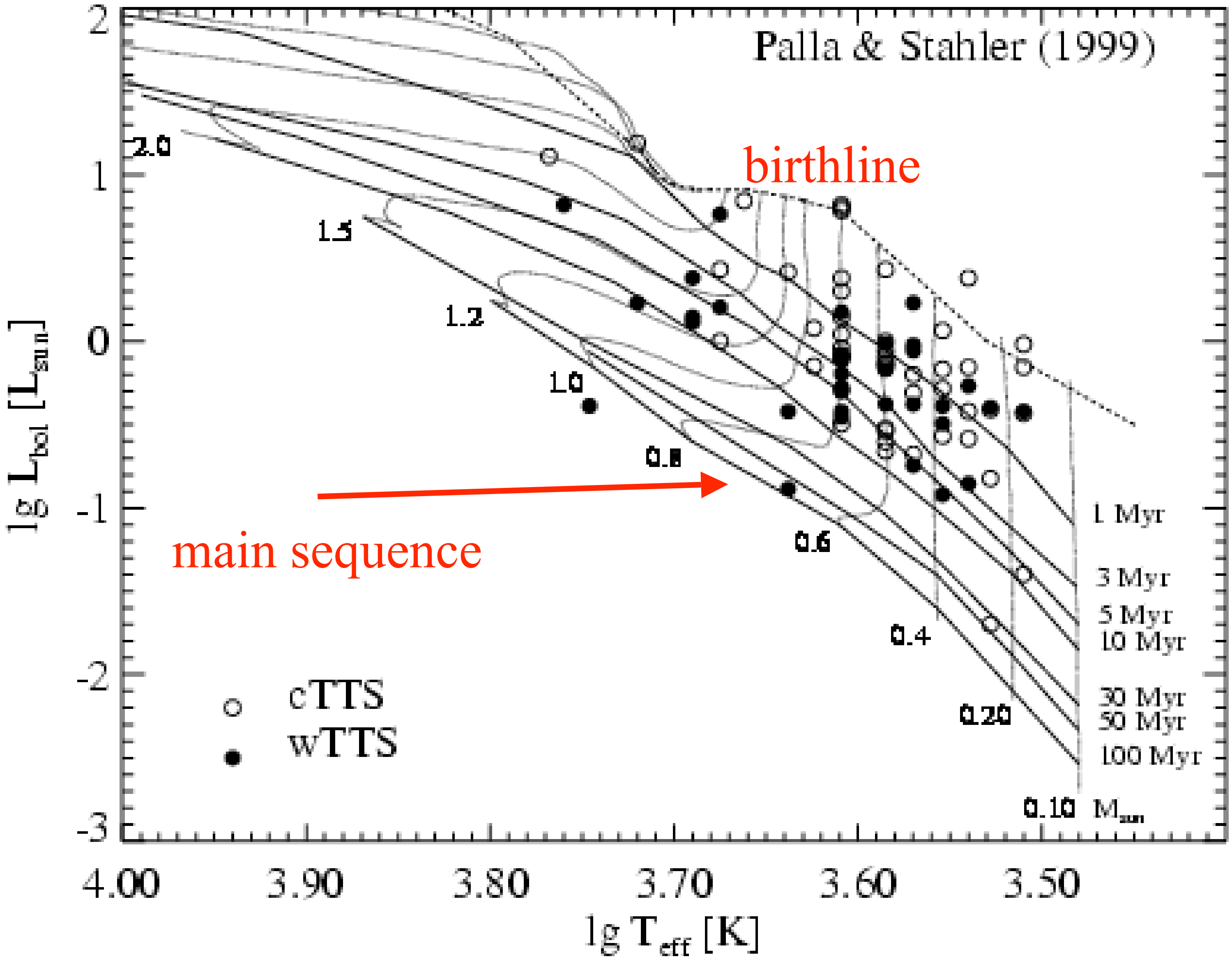
Outline:

- Why bother with TTs ?
- X-ray emission from cTTs and wTTs
- High-resolution X-ray spectra of cTTs

  Temperatures, densities, abundances,

  X-ray emission scenario

HR-diagram



Palla & Stahler (1999)
birthline
main sequence
2.0
1.5
1.2
1.0
0.8
0.6
0.4
0.20
0.10 M_{sun}
1 Myr
3 Myr
5 Myr
10 Myr
30 Myr
50 Myr
100 Myr
cTTS
wTTS
2
1
0
-1
-2
-3
4.00
3.90
3.80
3.70
3.60
3.50
lg L_{bol} [L_{sun}]
lg T_{eff} [K]

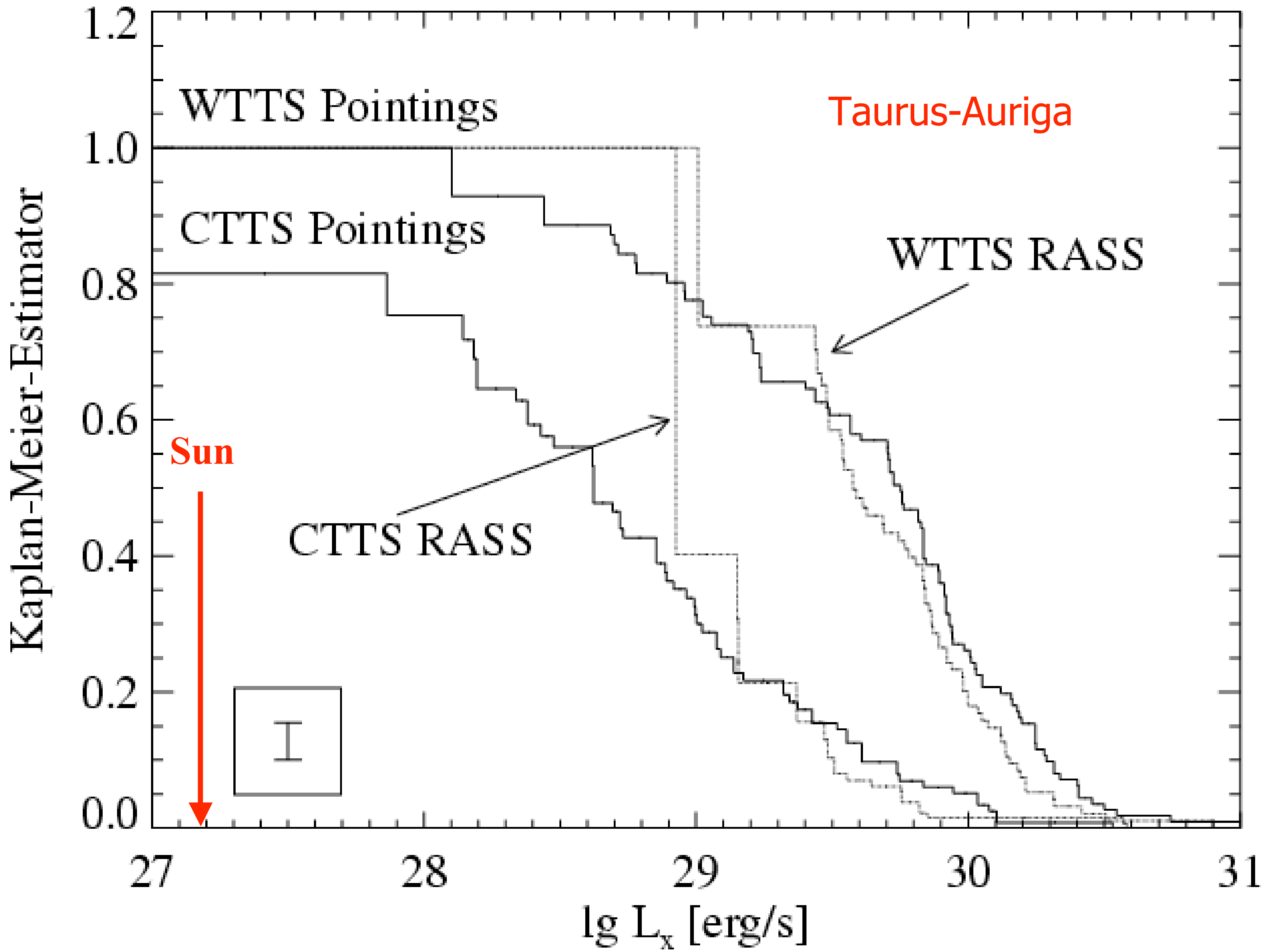
What are wTTs/cTTs ?

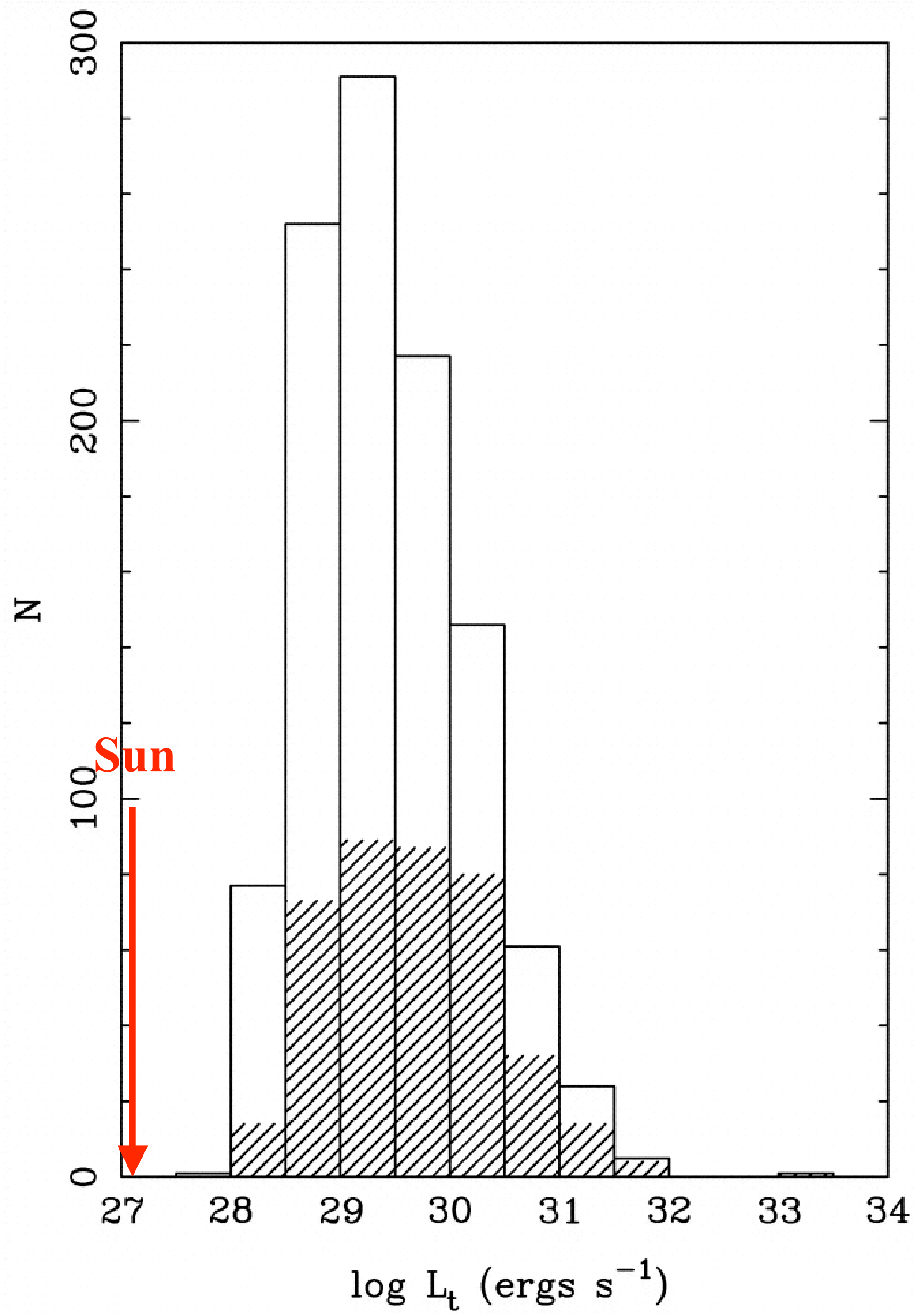
- pre –main sequence stars
- empirical: H_ equivalent width
- physical: disks cTTs

  no disks wTTs (_ planets)

What about X-ray emission from c/wTTs ?

ROSAT: Stelzer & Neuhäuser (2001)





Feigelson (2002)

(Orion)

X-ray emission from wTTs/cTTs:

- wTTs: scaled-up solar activity
- cTTs: solar activity

  accretion ←

  star-disk interaction

  jets ?

  ……………

X-ray emission from accretion onto cTTs ?

- magnetic accretion funnel (no boundary layer !)
- free-fall velocity $$v_{ff}^2 = \frac{2GM}{R}$$
- strong shock $$T = \frac{3}{16k} \mu m_H v_{ff}^2$$

⇨ **T ~ 2 – 4 MK**

What about evidence for accretion related signatures in X-ray spectra of cTTS ?

High resolution X-ray spectroscopy of cTTs

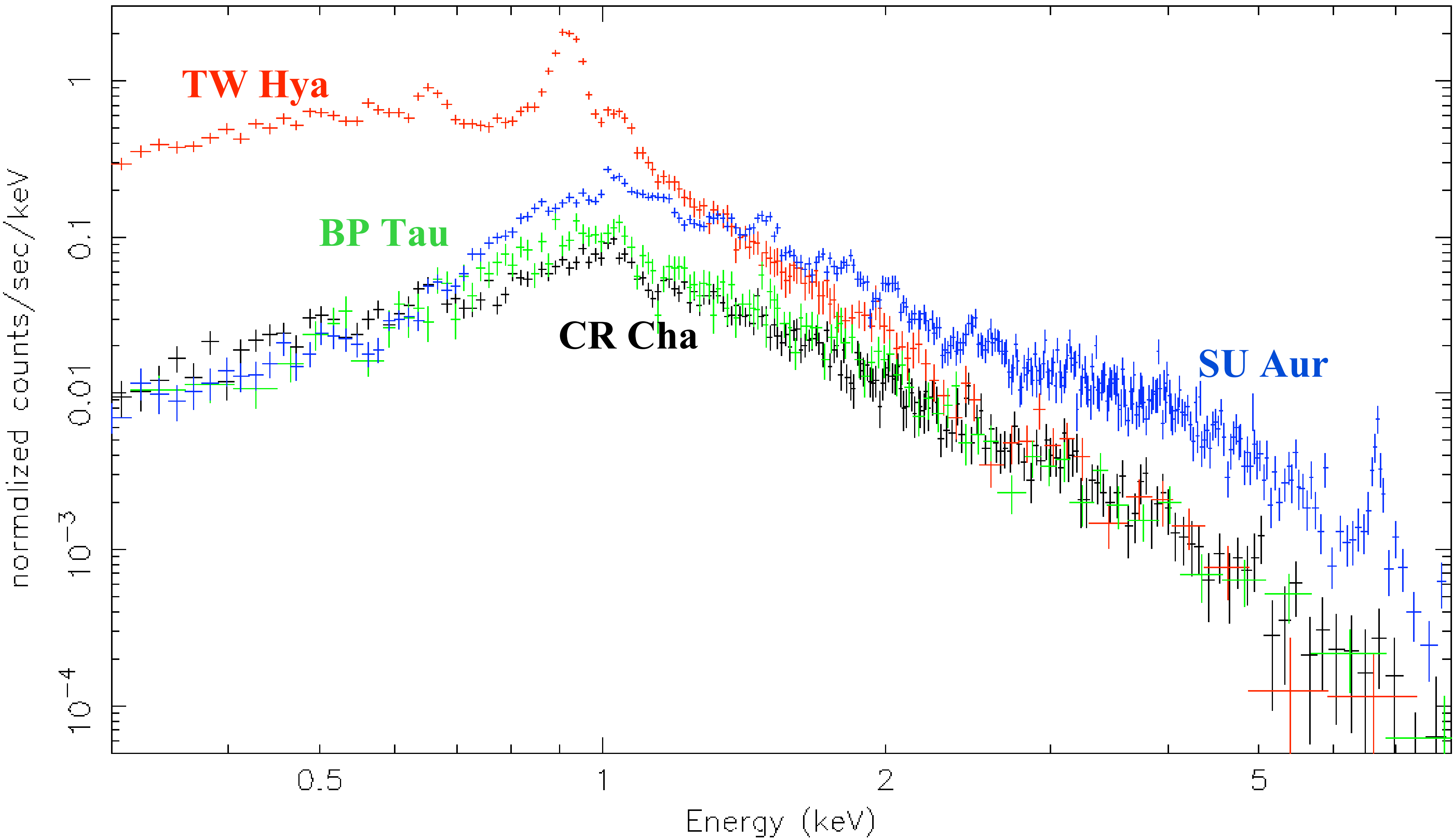
Comparative study:

- **TW Hya** (Chandra HETGS: Kastner et al. 2002; XMM-Newton RGS: Stelzer & Schmitt 2004)
- **BP Tau** (XMM-Newton RGS: Schmitt et al. 2005; Robrade et al. 2005)
- **CR Cha** (XMM-Newton RGS: Robrade et al. 2005)
- **SU Aur** (XMM-Newton RGS: Robrade et al. 2005; Pallavicini et al. 2005)

BP Tau	EPIC	RGS	
CR Cha	EPIC	RGS	
SU Aur	EPIC	RGS	HETGS
TW Hya	EPIC	RGS	HETGS

The broad band spectra in comparison

Robrade et al. (2005)



Line detections in cTTS

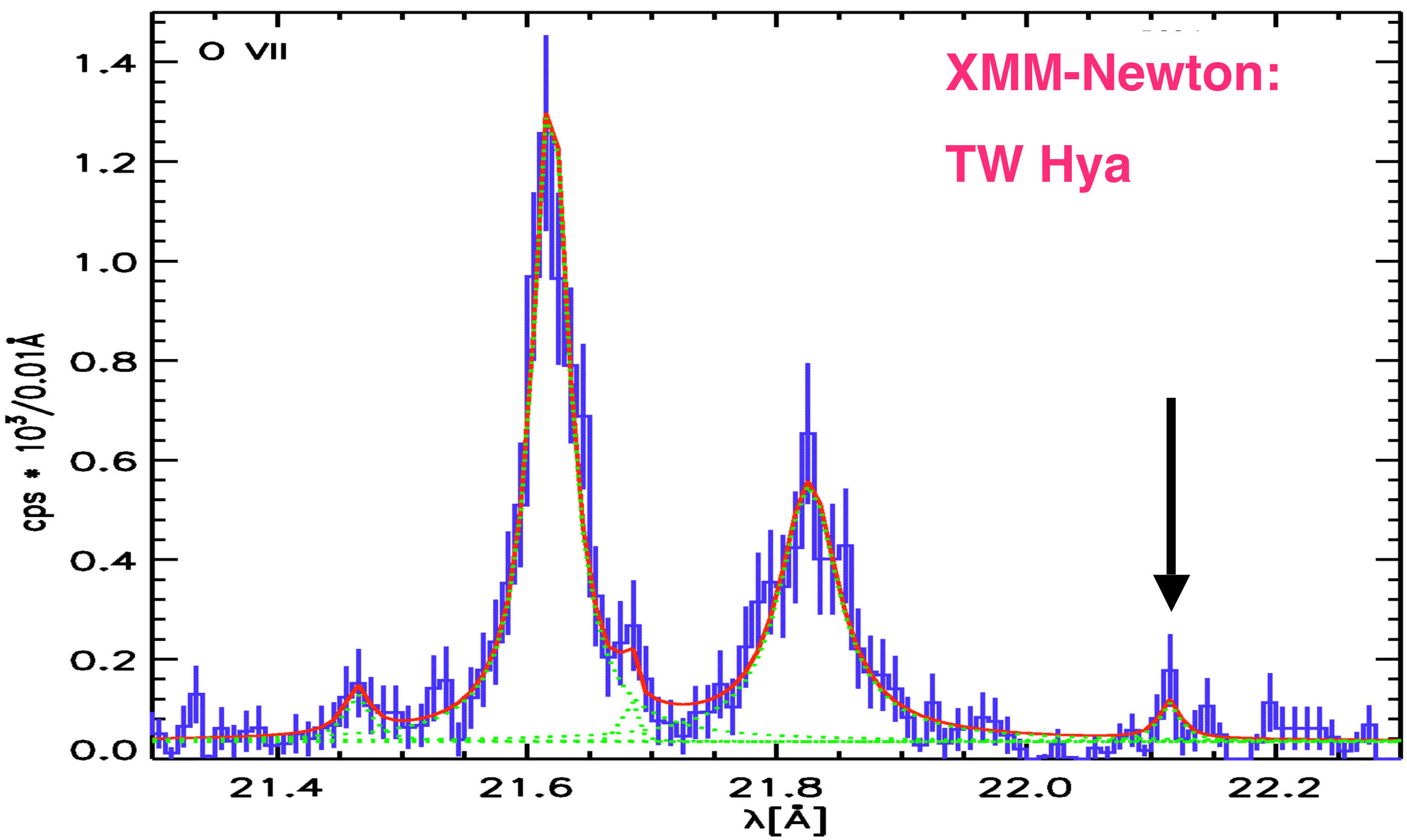
Star	OVII	OVIII	NeIX	NeX	FeXVII	FeXVIII	FeXX	FeXXI	FeXXII	FeXXIII
BP Tau	Y	Y	Y	Y	Y	Y				
CR CHa	Y	Y		Y	Y					
SU Aur		Y	Y	Y	Y	Y	?	Y	Y	Y
TW Hya	Y	Y	Y	Y	Y	Y	Y	W	W	

Y: detection

W: weak detection

?: questionable detection

X-ray spectrum of TW Hya (CTTS): OVII triplet



forbidden line almost absent !

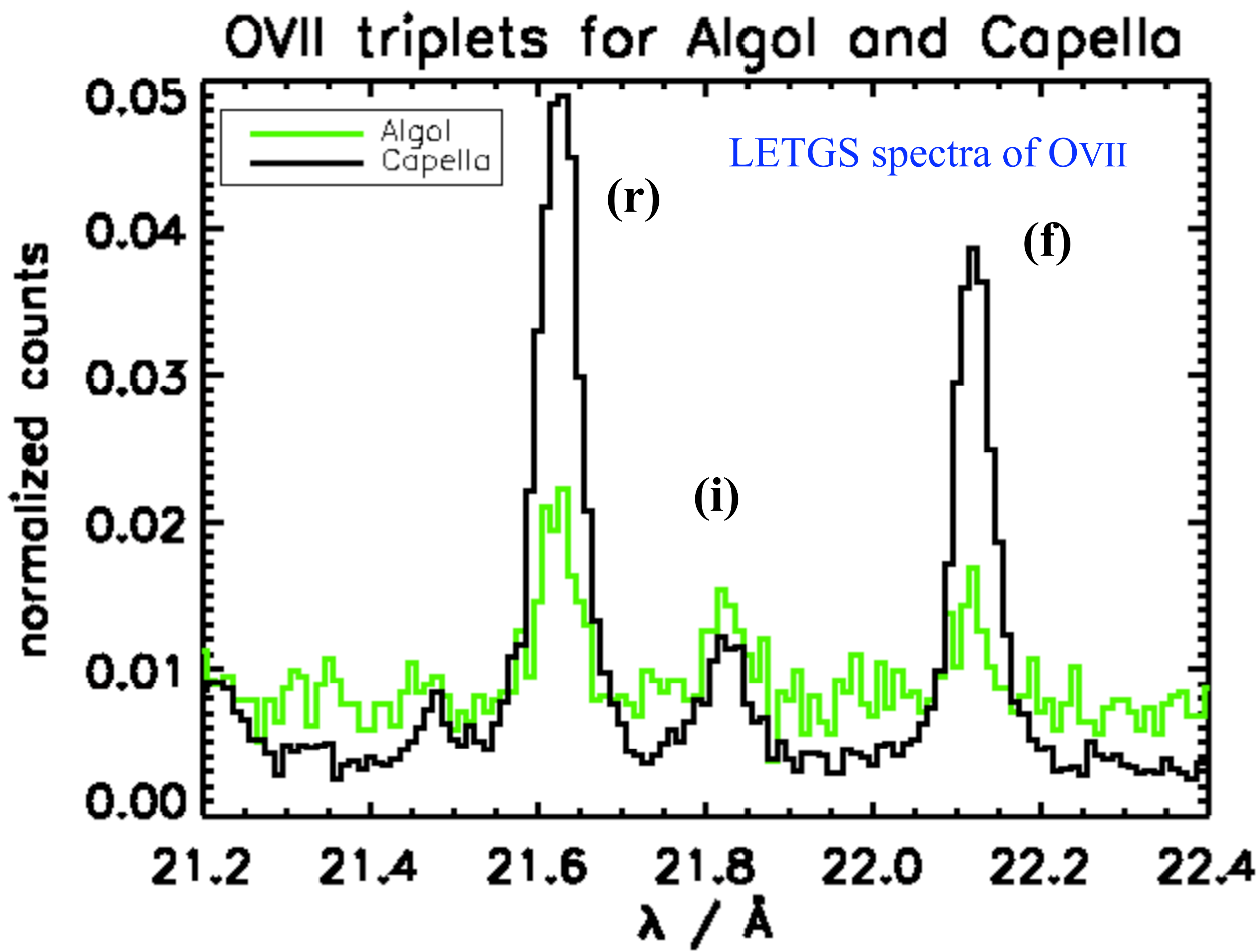
$n_e \geq 10^{13}\ cm^{-3}$

$T \approx 2.8\ \ 10^6\ K$

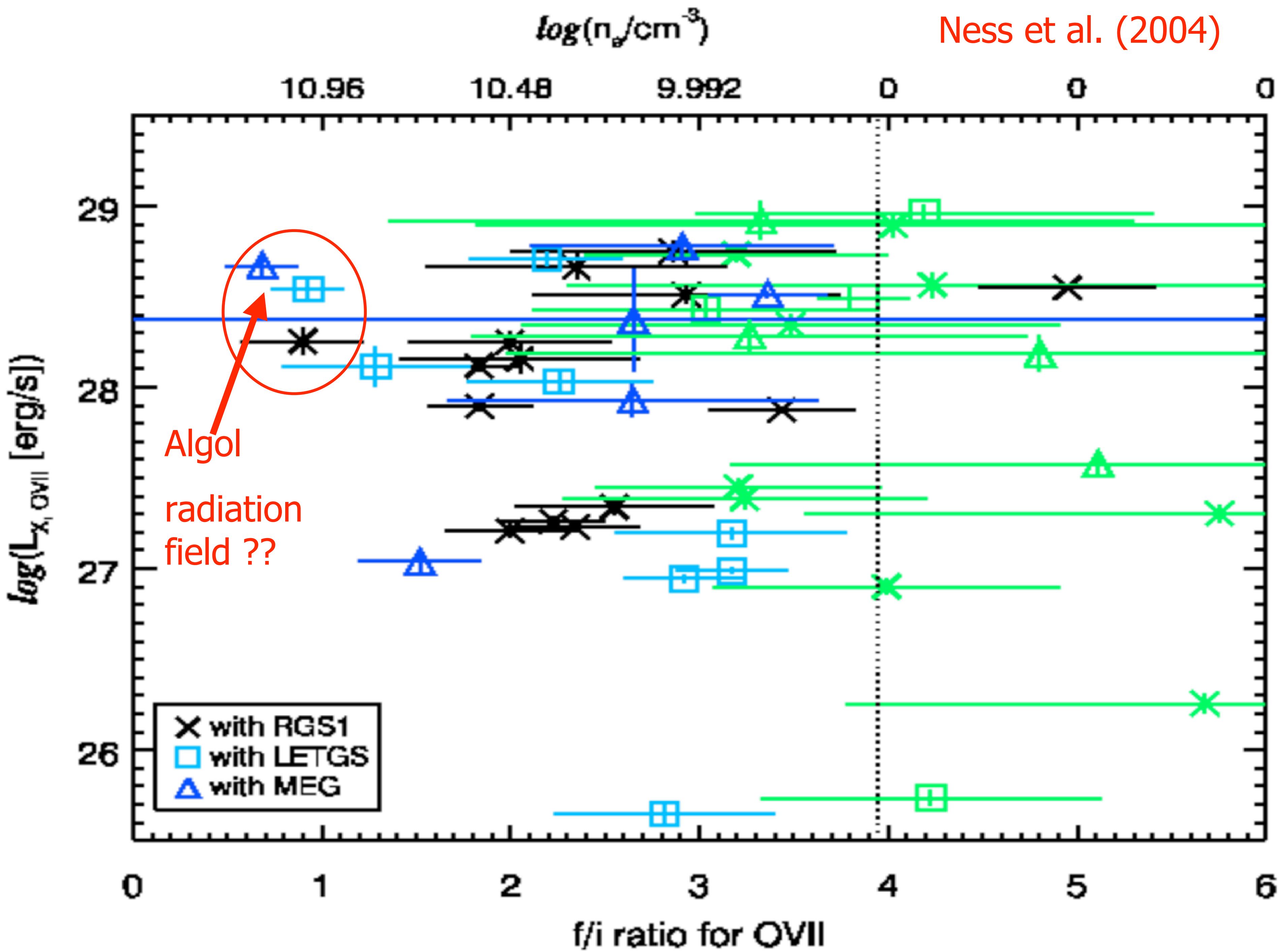
$L_X \approx 10^{30}\quad erg/\sec$

XMM-RGS: Stelzer & Schmitt (2004)

Chandra: Kastner et al. (2002)

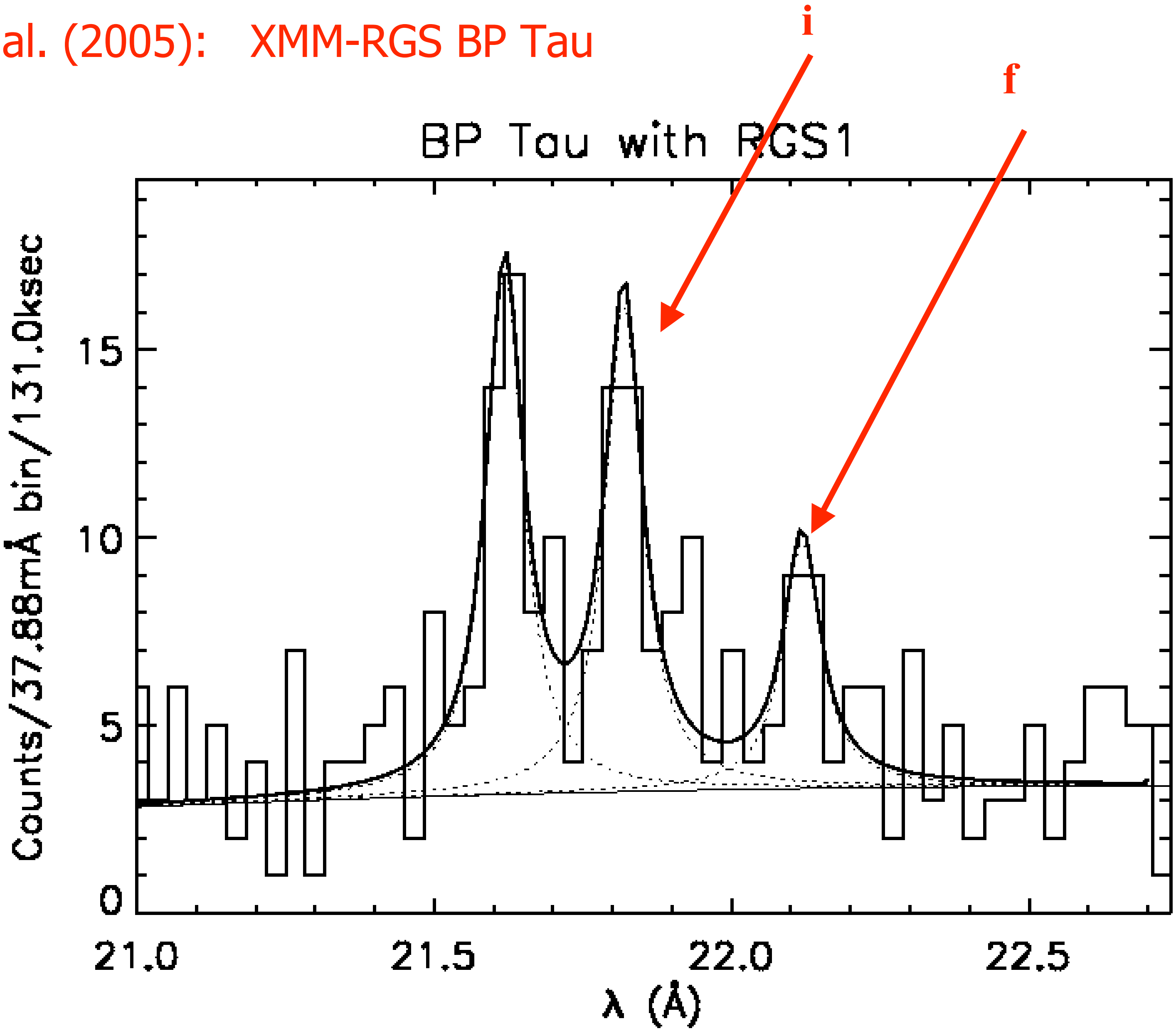


OVII triplets for Algol and Capella
Algol
Capella
LETGS spectra of OVII
(r)
(i)
(f)
normalized counts
0.00
0.01
0.02
0.03
0.04
0.05
21.2
21.4
21.6
21.8
22.0
22.2
22.4
λ / Å

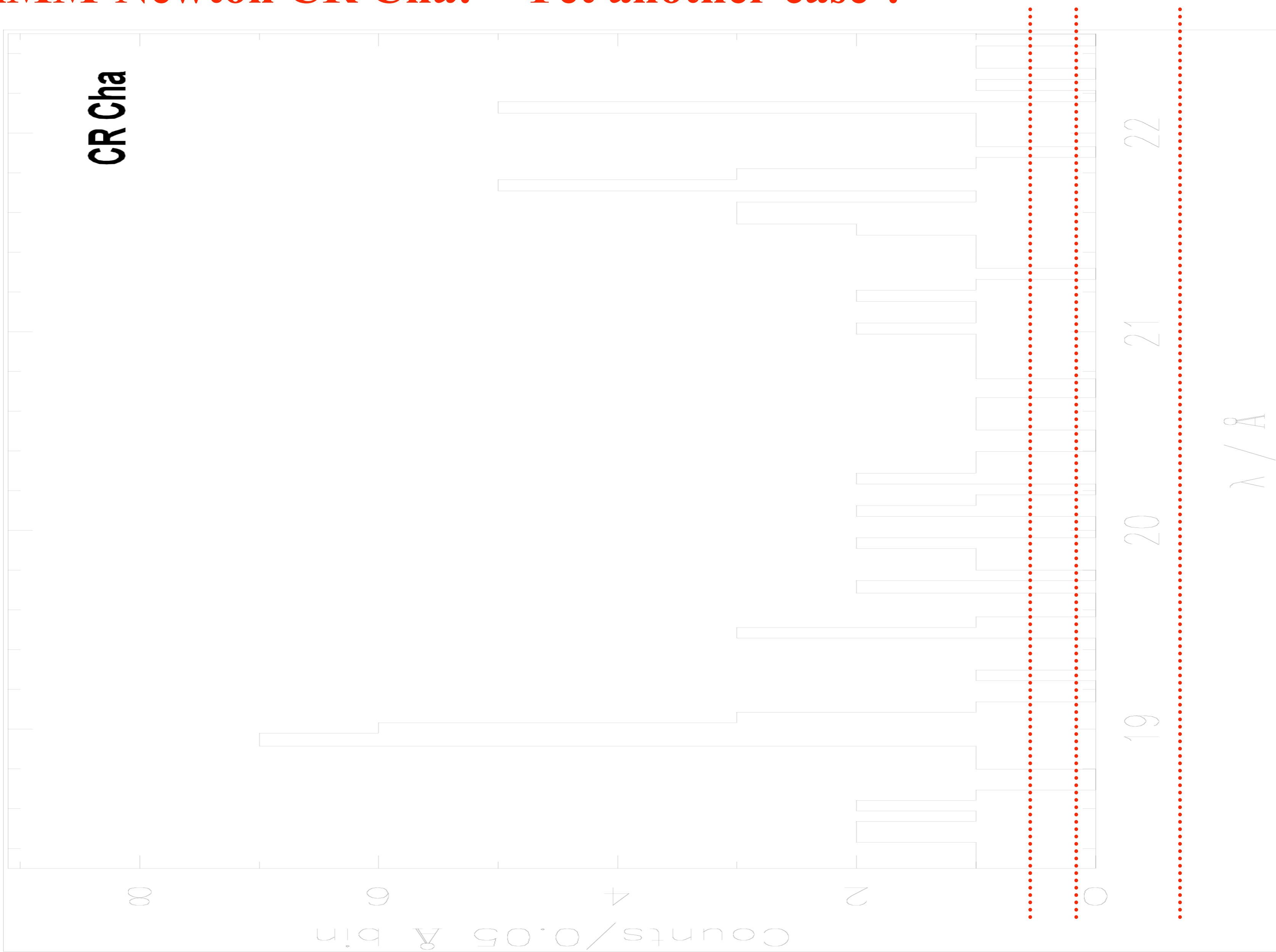


Ness et al. (2004)
log(n_e/cm^-3)
10.96
10.48
9.992
0
0
0
29
28
27
26
log(L_X, OVII [erg/s])
Algol
radiation
field ??
with RGS1
with LETGS
with MEG
0
1
2
3
4
5
6
f/i ratio for OVII

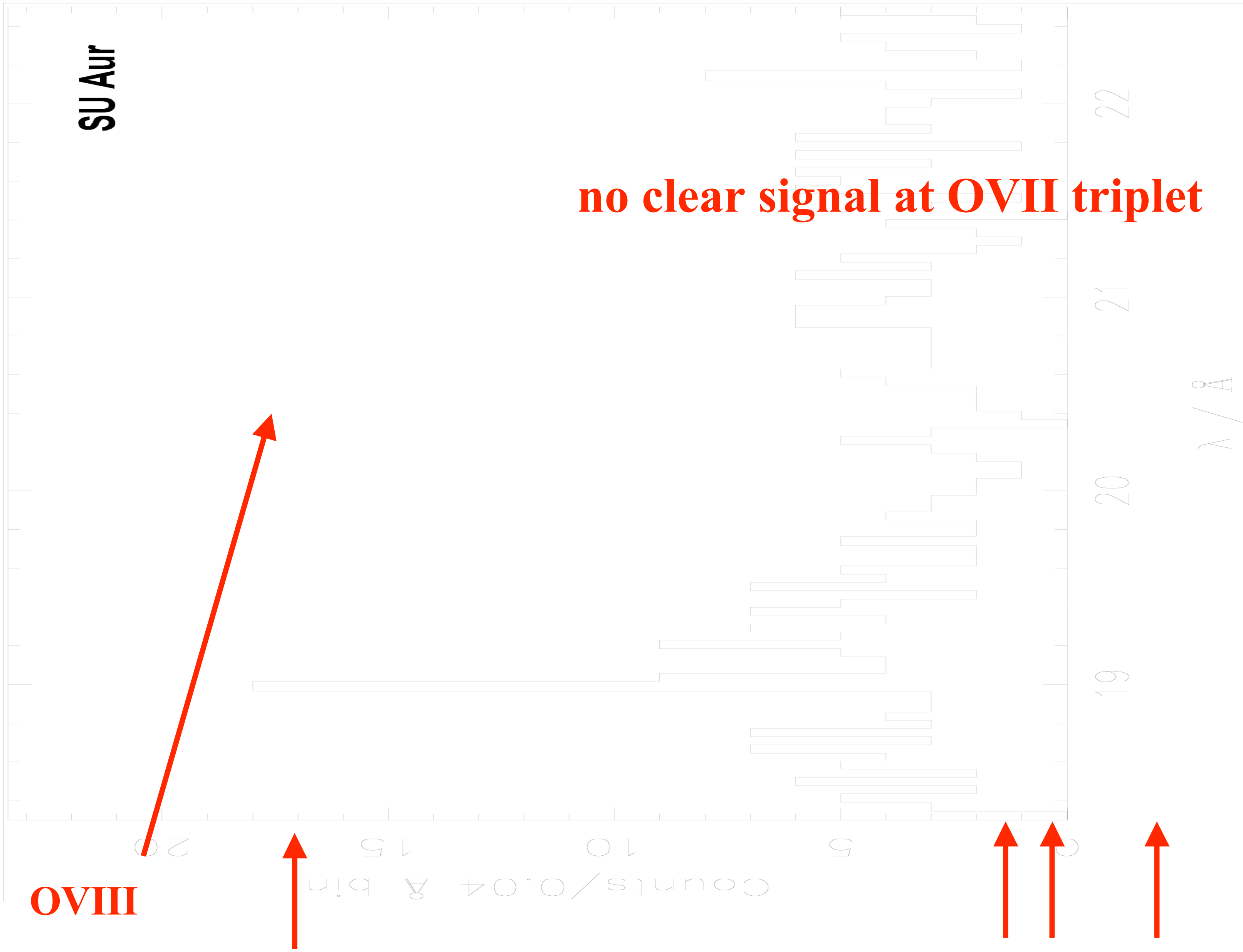
Schmitt et al. (2005): XMM-RGS BP Tau



XMM-Newton CR Cha: Yet another case ?



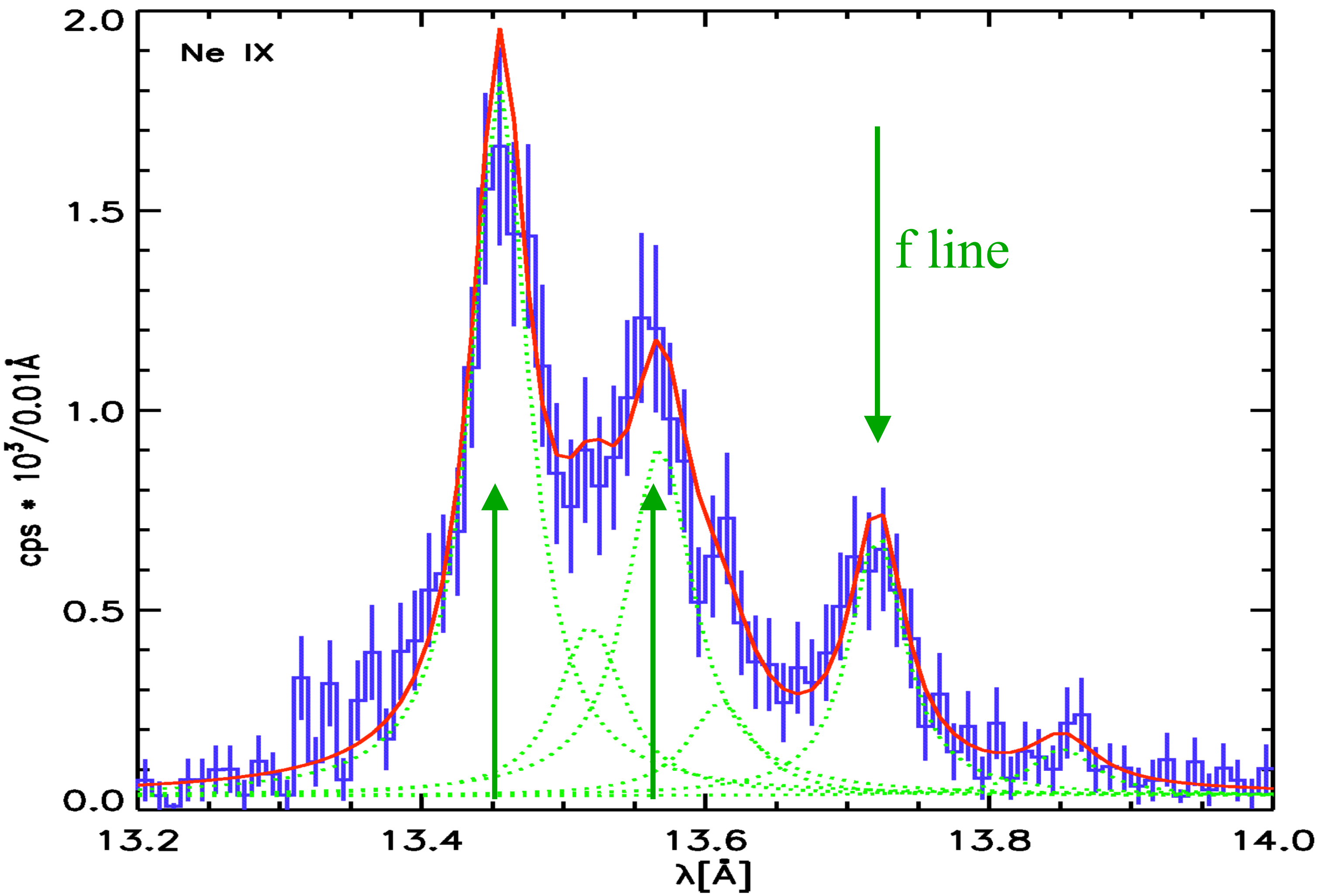
XMM-Newton RGS: SU Aur



Line count statistics for OVII and OVIII lines in BP Tau and CR Cha

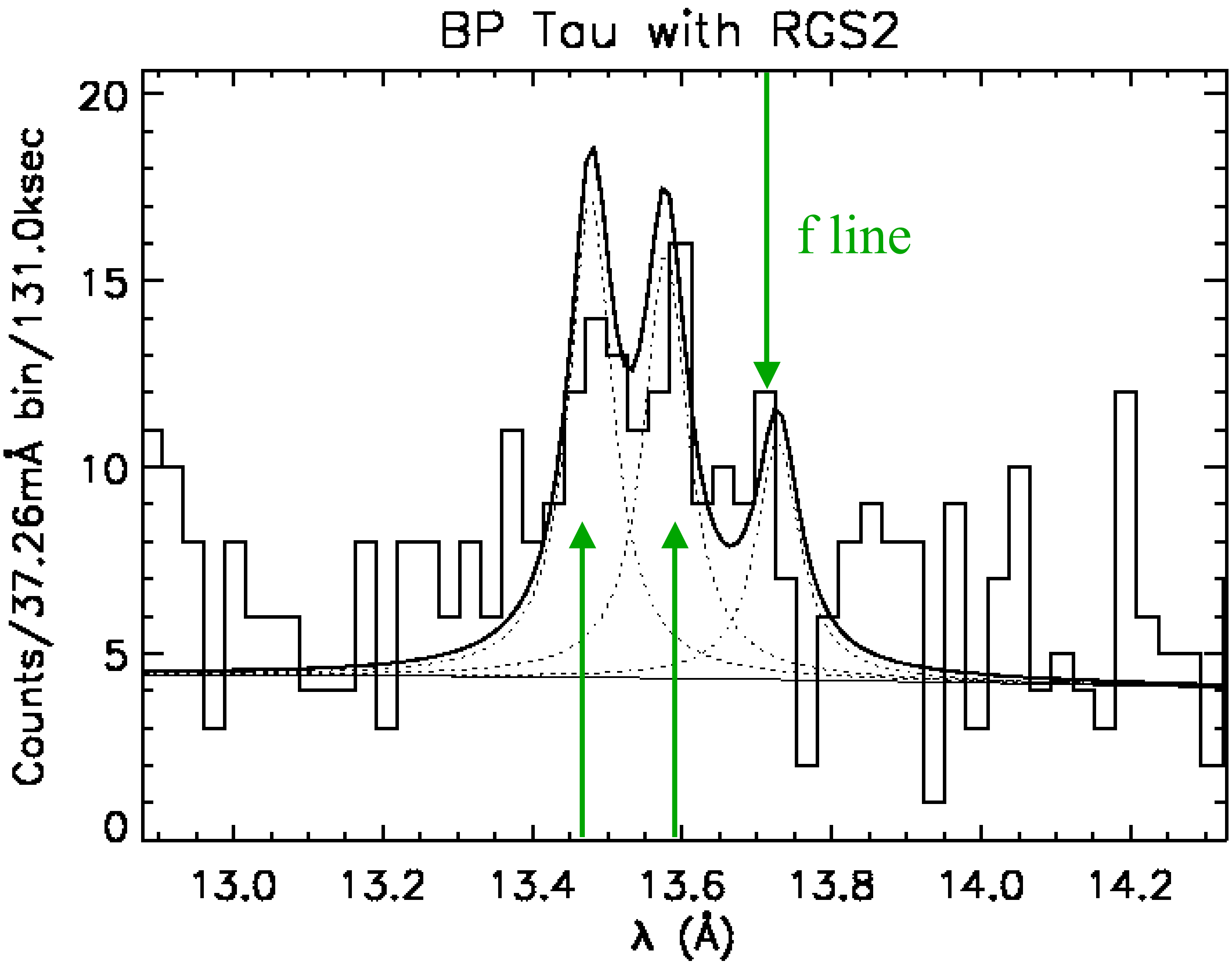
	BP Tau	CR Cha
OVII He r	47.7+/-8.6	5.5+/-3.5
OVII He i	36.6+/-7.8	7.6+/-3.7
OVII He f	13.7+/-5.5	4.6+/-2.9
(f+i)/r	1.05+/-0.28	2.22+/-1.65
f/i	0.37+/-0.17	0.61+/-0.49
OVIII Ly_	94.5+/-11.4	20.4+/-5.5
OVIII/OVII	1.98+/-0.43	3.7+/-2.6

Ne IX triplet in TW Hya (XMM-Newton RGS)

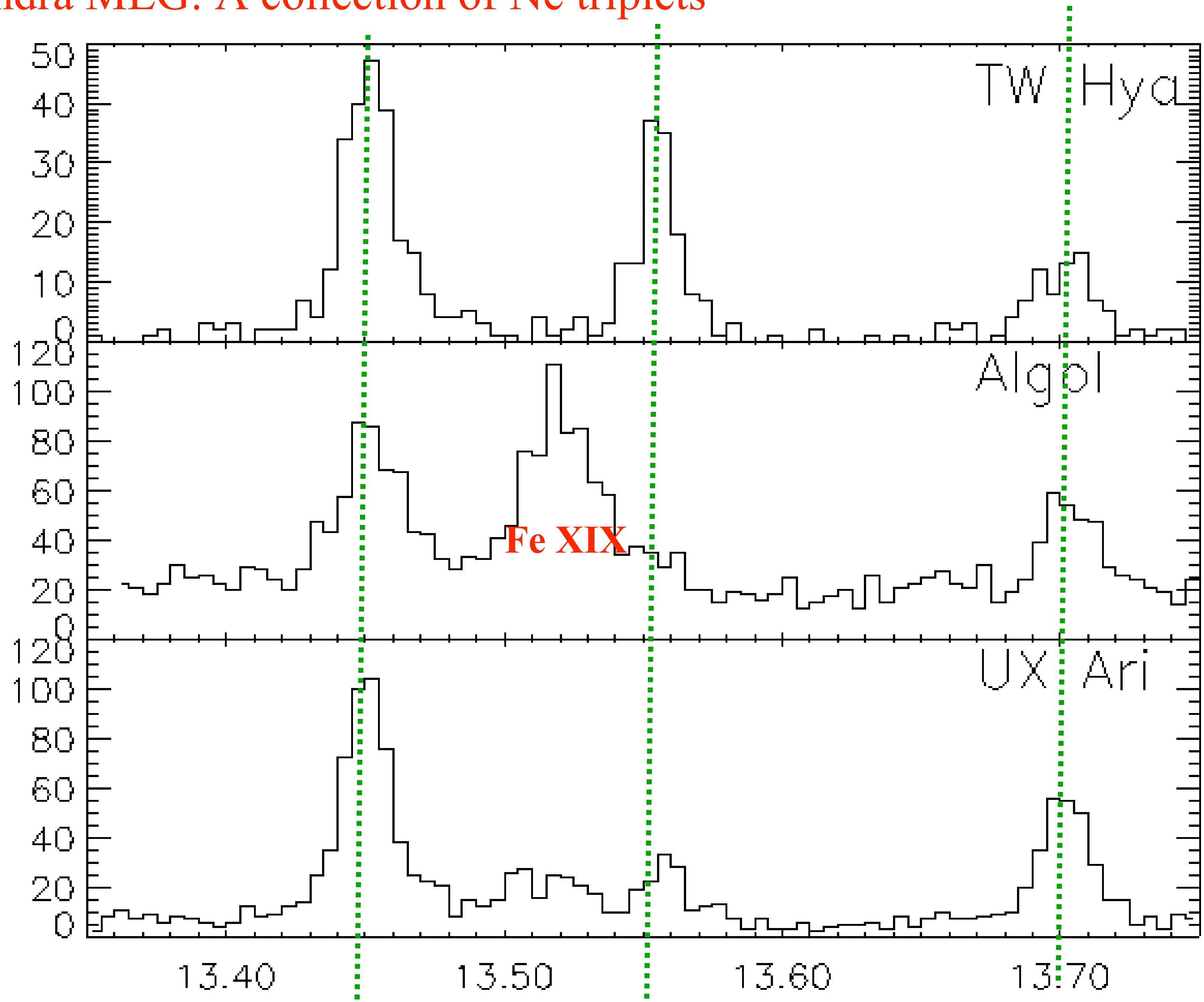


XMM-RGS: Stelzer & Schmitt (2004)

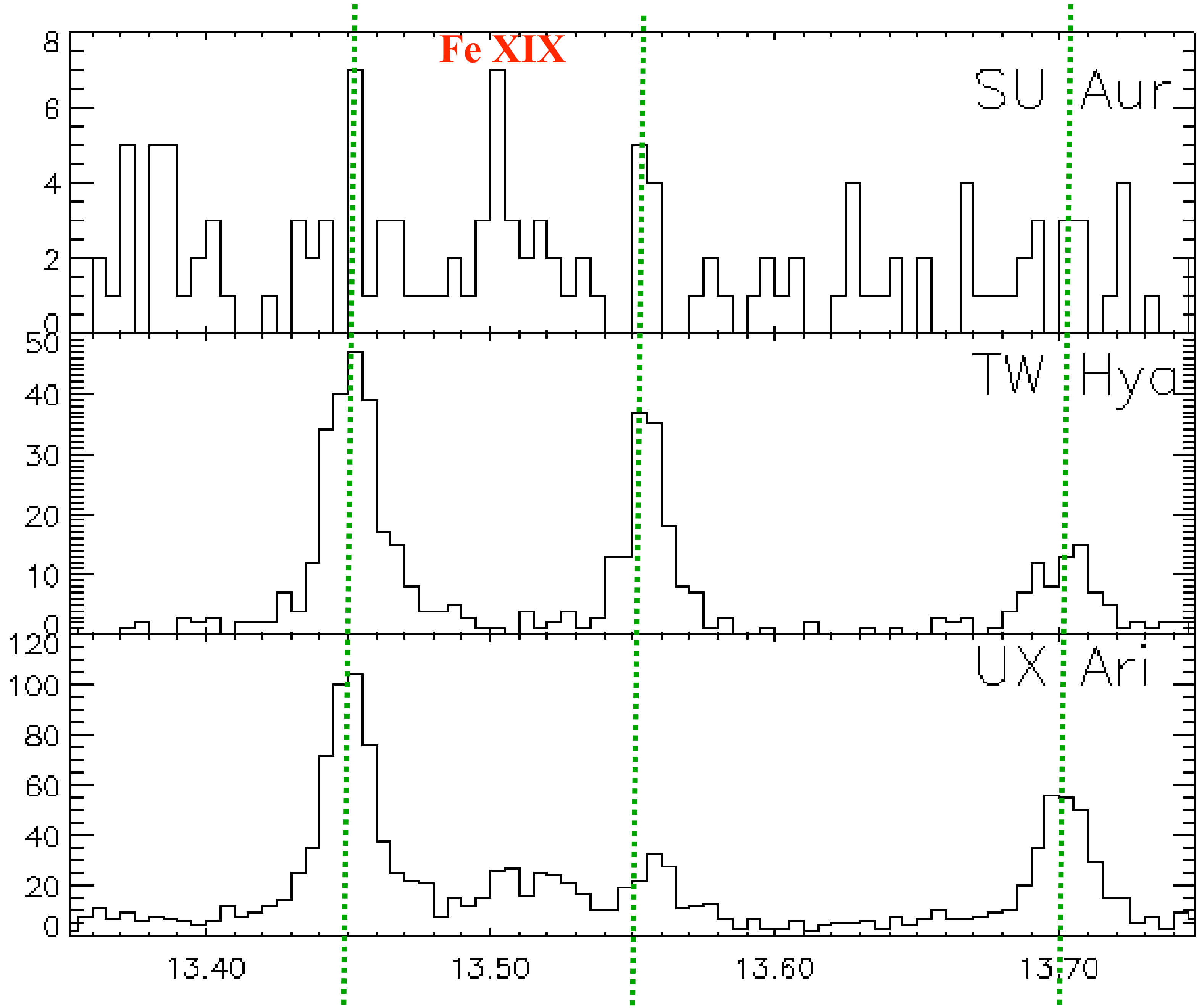
Schmitt et al. (2005): **Ne IX triplet in BP Tau (RGS)**



Chandra MEG: A collection of Ne triplets



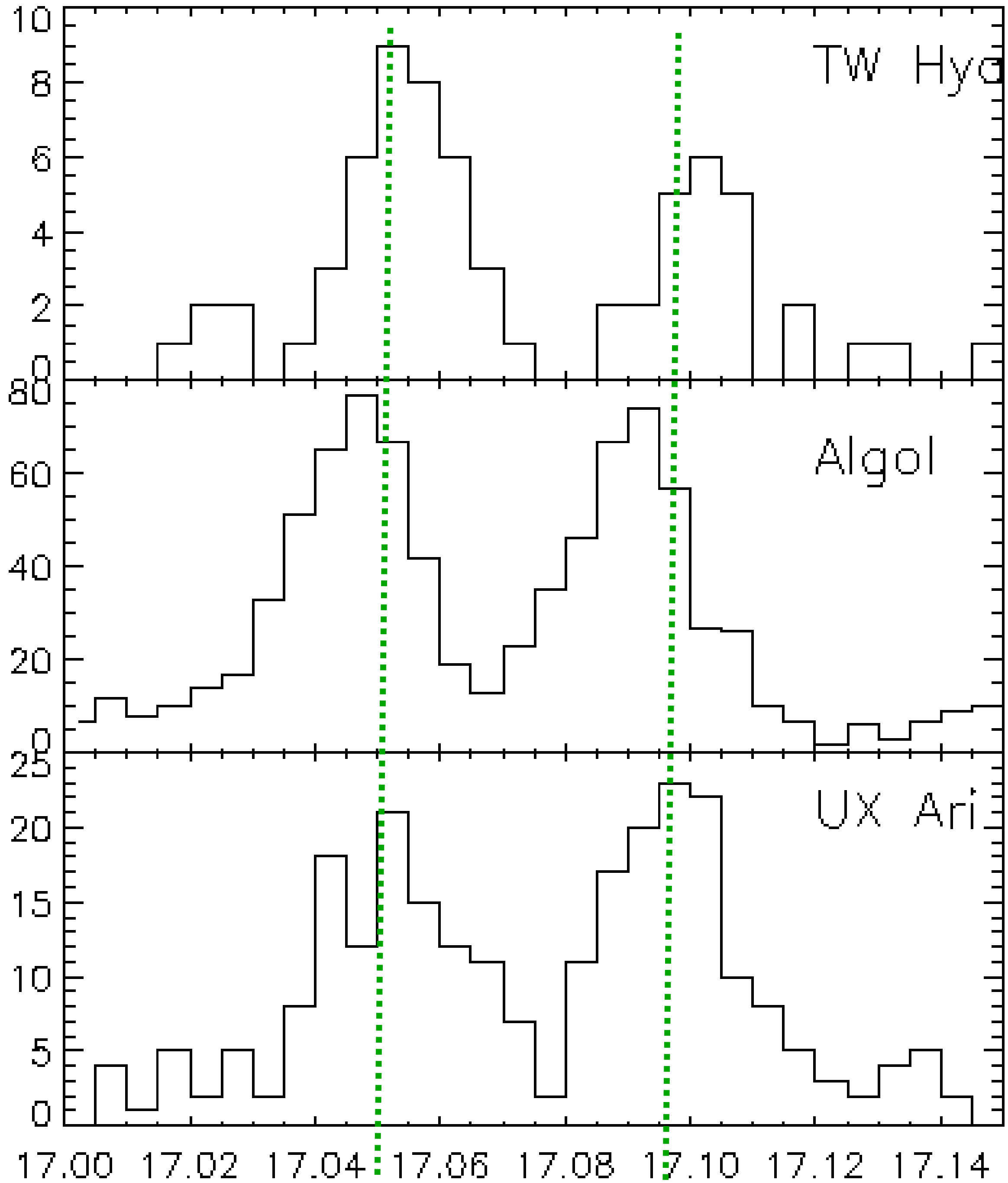
Chandra MEG: Ne IX emission in SU Aur ?



Fe XVII

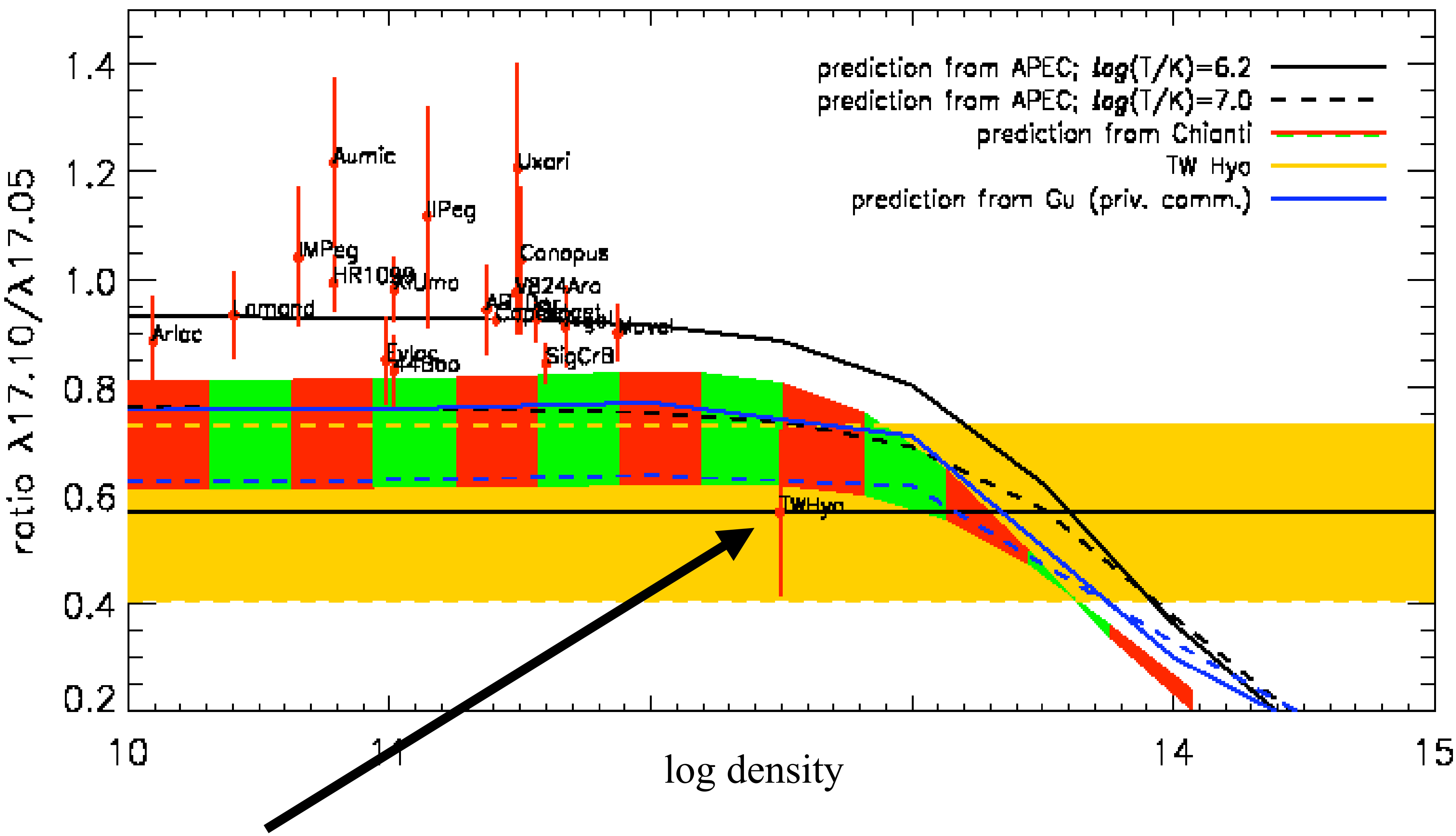
17.05 Å

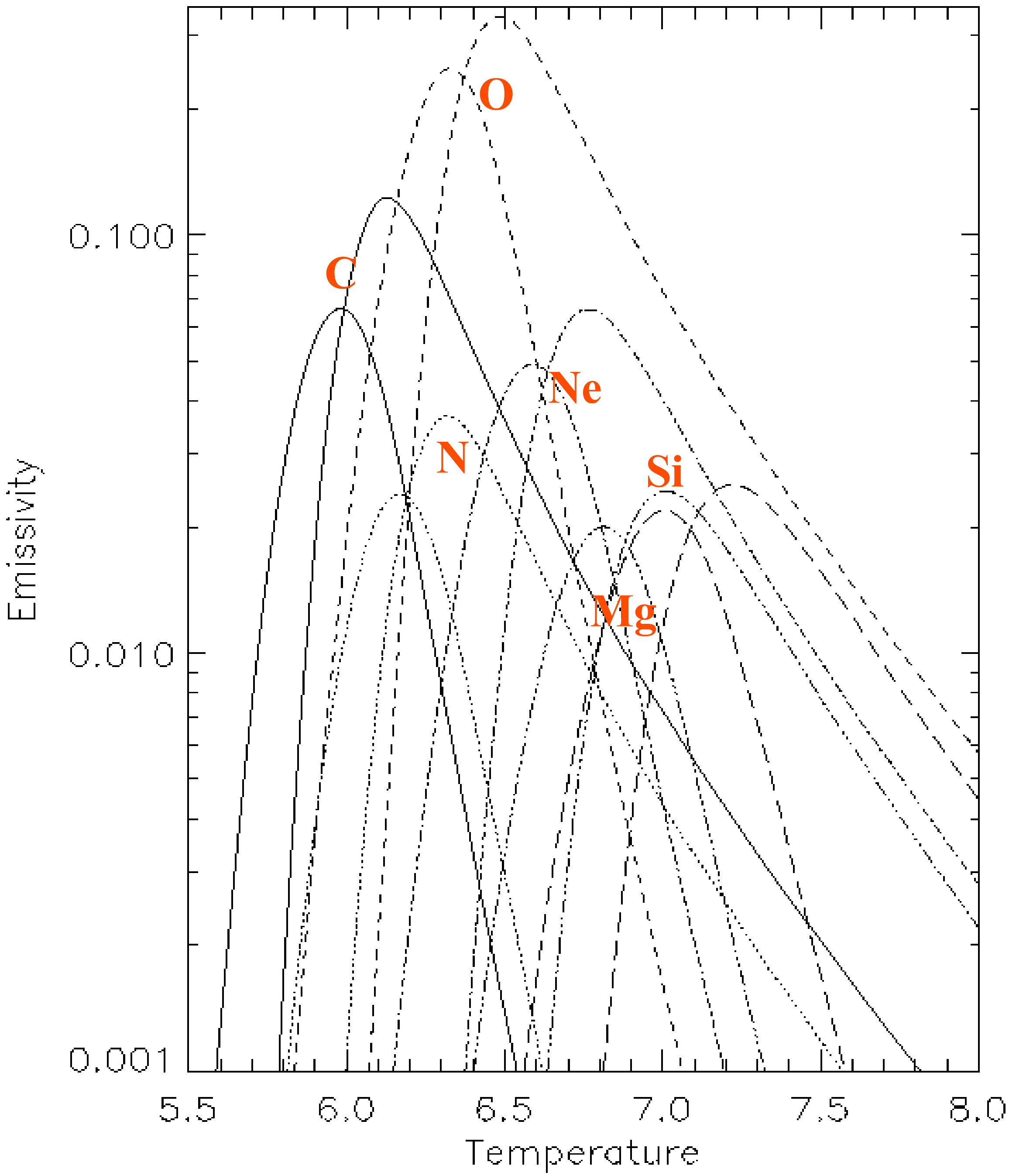
17.10 Å



Density or radiation field ?

Ness & Schmitt (2005)





Cooling functions of H-like and He-like ions of C,N,O,Ne,Mg,Si.

Line based abundance determination:

Set of line fluxes from element 1: $F_{Lyman\,\alpha,Mg}, F_{He-r,Mg}$

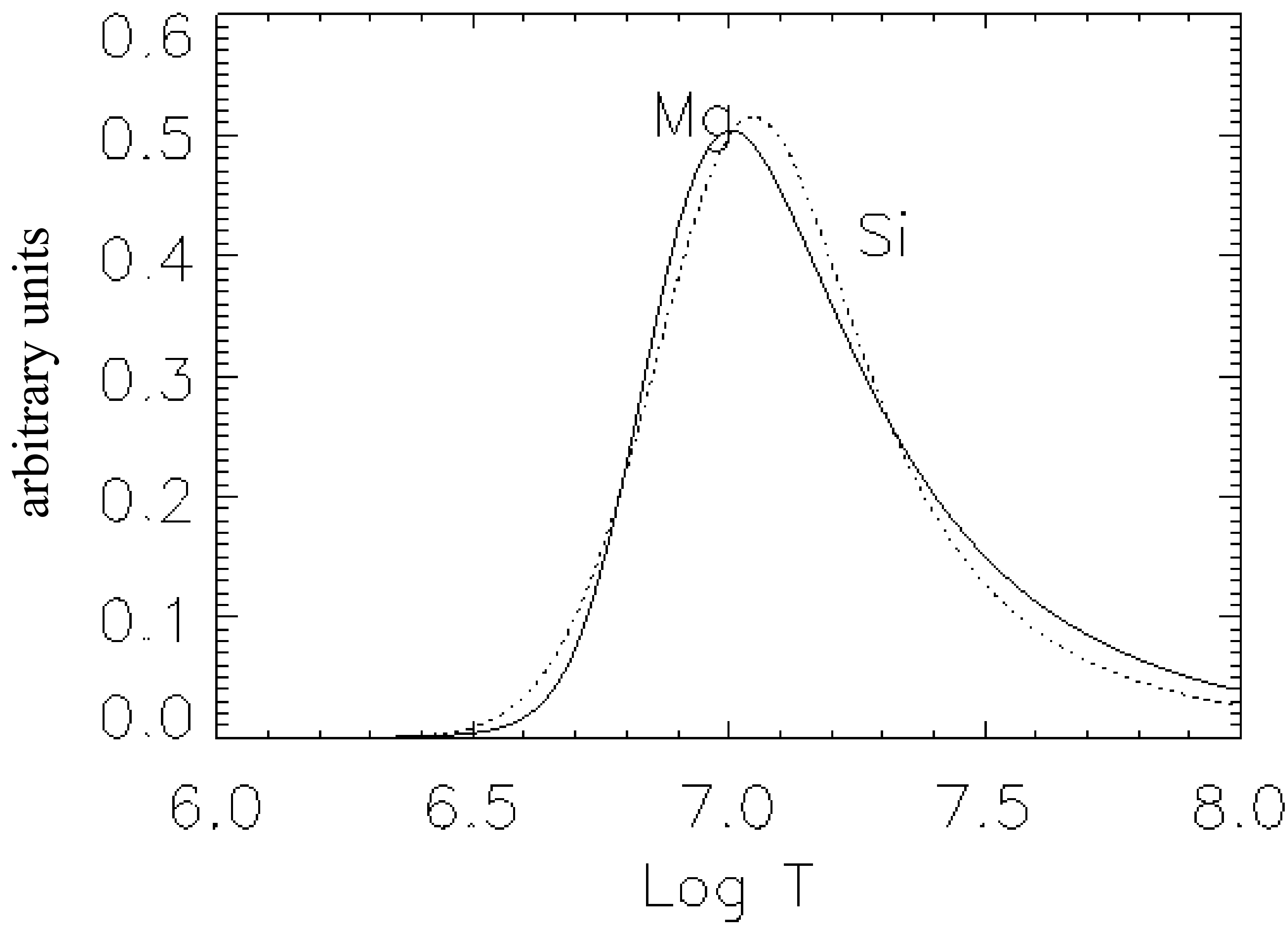
Set of line fluxes from element 2: $F_{Lyman\,\alpha,Si}, F_{He-r,Si}$

Seek coefficients $A_{1,Mg}$, $A_{2,Mg}$ and $A_{1,Si}$, $A_{2,Si}$ such that:

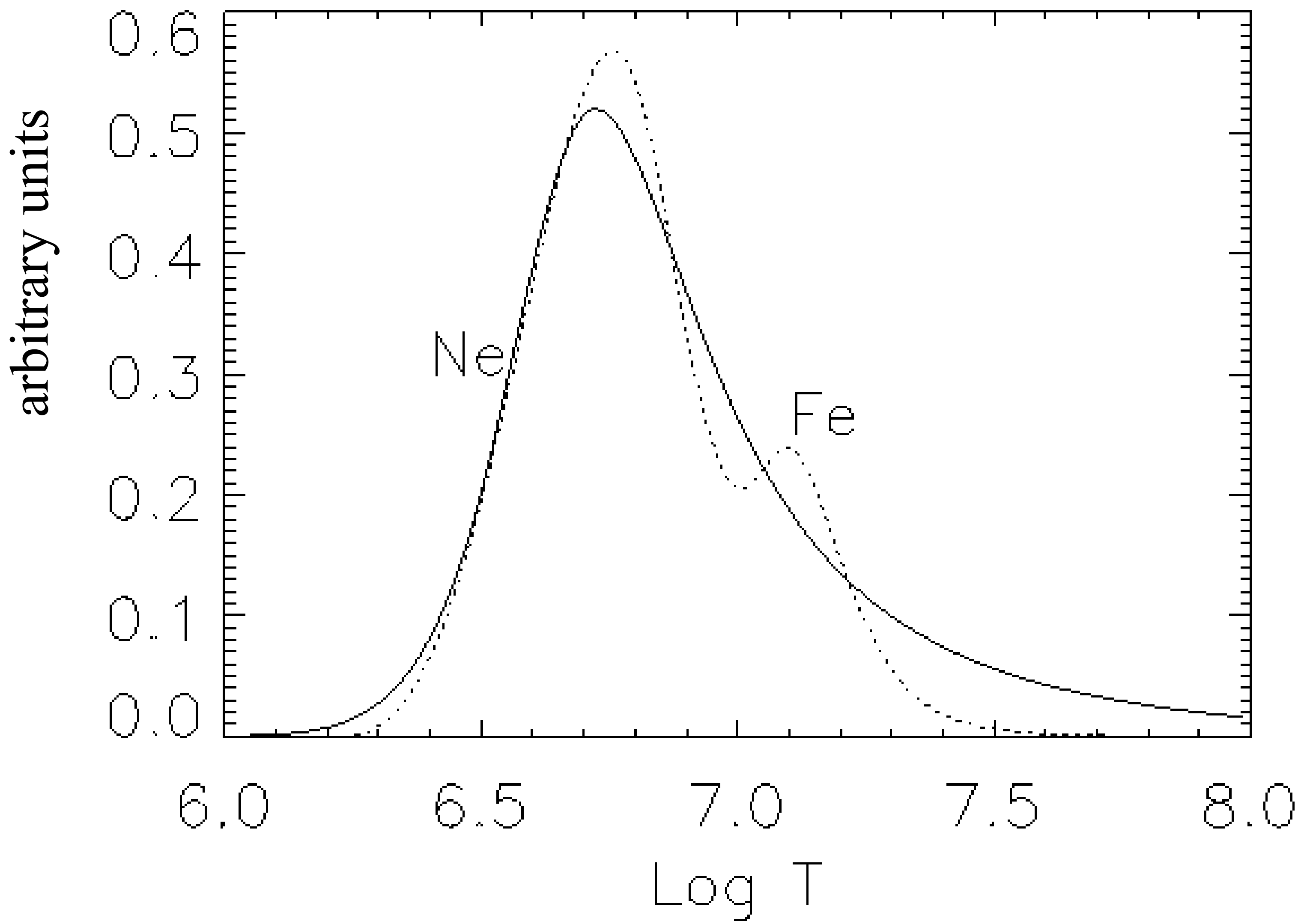
$$A_{1,Mg}F_{Lyman\,\alpha,Mg} + A_{2,Mg}F_{He-r,Mg} \text{ "=" } A_{1,Si}F_{Lyman\,\alpha,Si} + A_{2,Si}F_{He-r,Si}$$

best fit sense

Optimal linear combination of Mg and Si lines:



Ne IX, Ne X, Fe XVII, Fe XXI



Line based abundances for cTTs: (MEG/RGS)

Star	Ne/Fe	O/Ne	N/O	C/N
BP Tau	9.5 ± 1.2	0.28 ± 0.07	n.a.	n.a.
SU Aur	4.7 ± 0.65	0.73 ± 0.26	n.a.	n.a.
TW Hya	13.2 ± 2.0	0.17 ± 0.03	3.73 ± 0.77	0.18 ± 0.05

Global fit based abundances for cTTs: (EPIC)

Star	Ne/Fe	O/Ne	Si/Ne
BP Tau	5.25	0.42	0.10
SU Aur	1.29	0.37	0.59
TW Hya	7.0	0.13	0.07

Does an accretion scenario make sense (I) ?

Model (1D):

Infall with given velocity and density

Strong shock with ion heating

Energy transfer to electrons

Ionisation of ions

X-ray emission from shock cooling zone

Model fits predicted to observed line ratios

Obtain good fits for OVII, OVIII, NeIX, NeX and Fe XVII

Does an accretion scenario make sense (II) ?

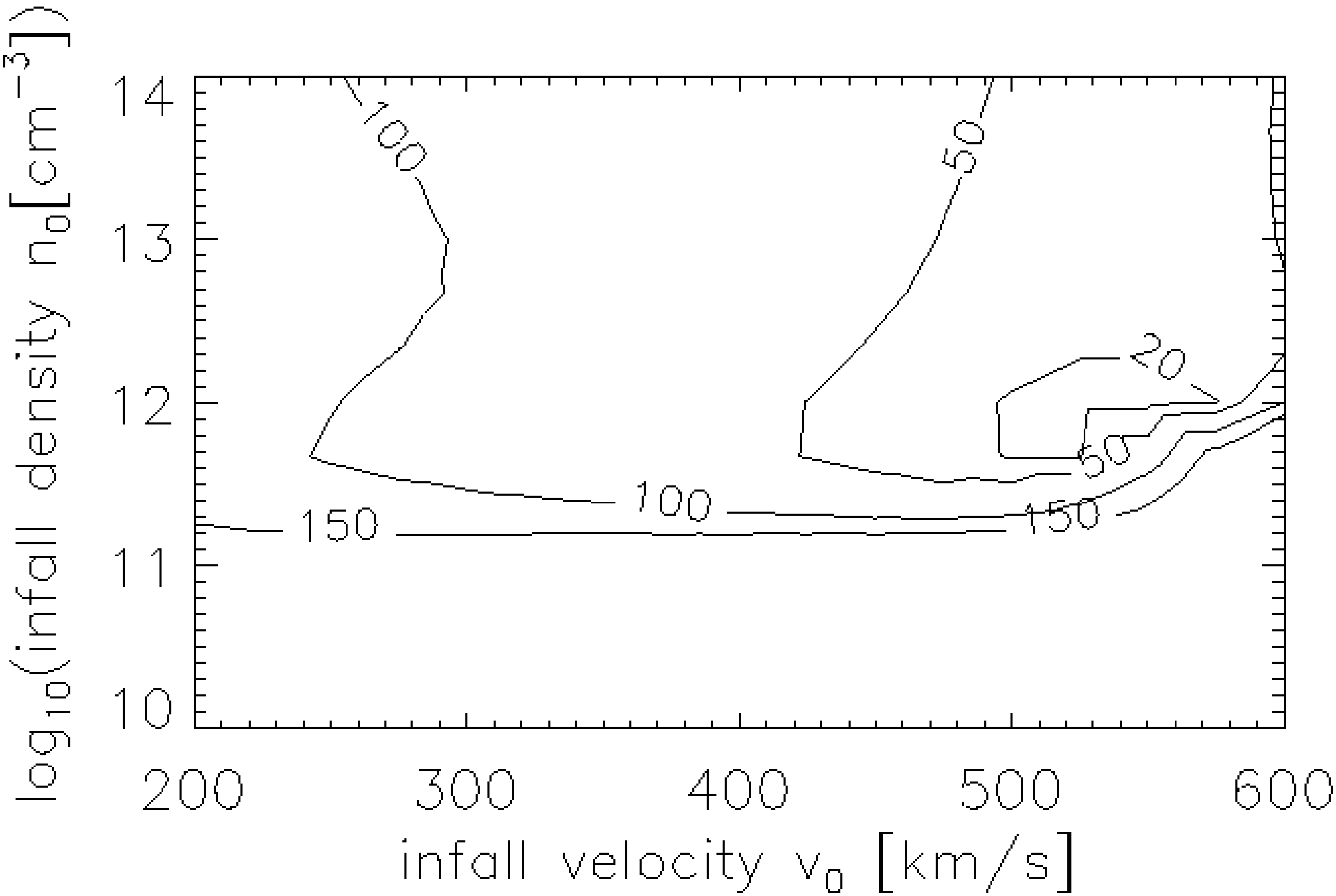
Best fit model parametersBest for TW Hya:

Preshock density: $n \approx 10^{12} \quad cm^{-3}$

Infall velocity: $525 \quad km/\sec$

filling factor: $f < 1\%$

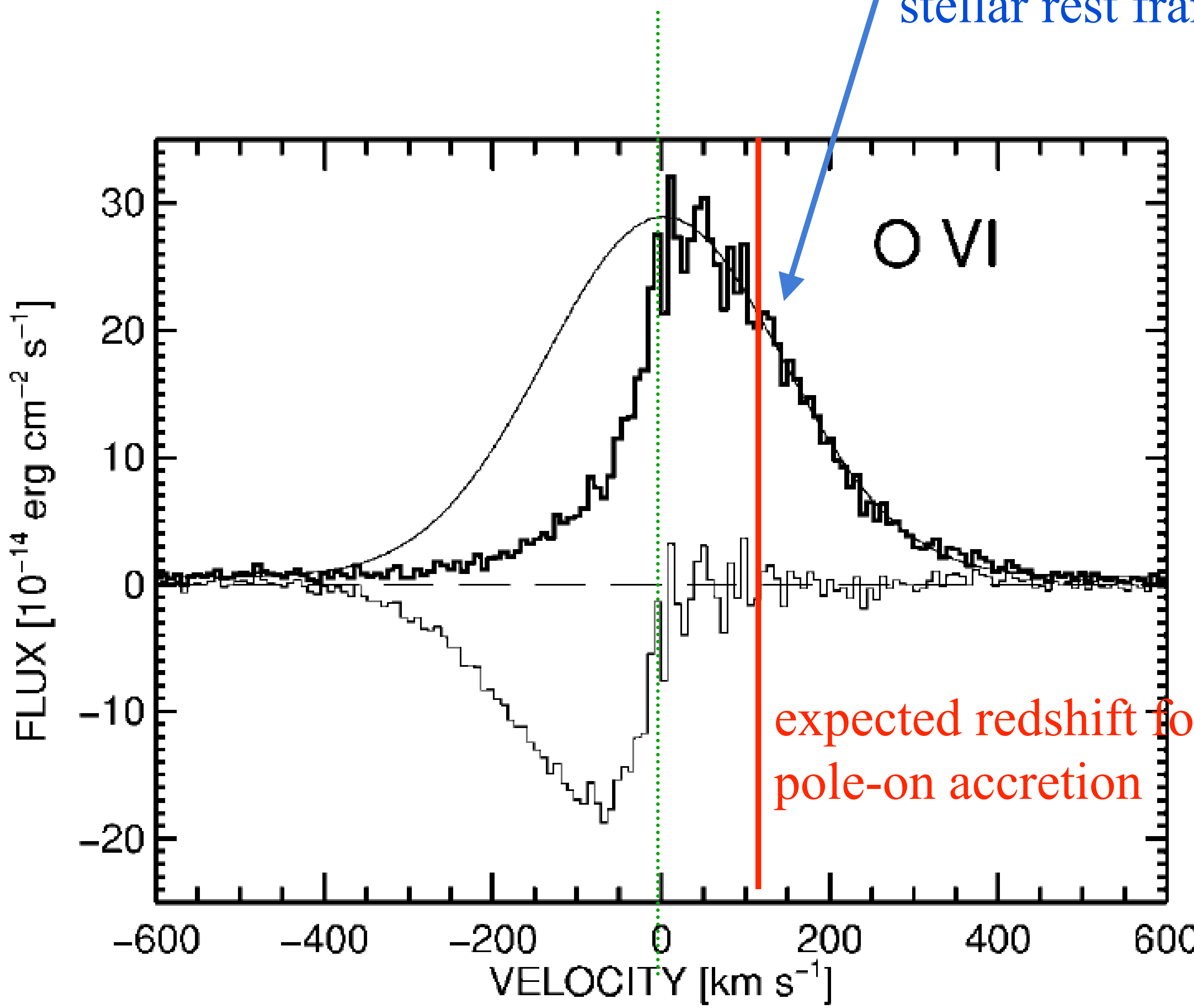
Mass accretion rate: $\dot{M}_{acc} \approx 10^{-10} \frac{M_{Sun}}{yr}$



log10(infall density n0[cm^-3])
14
13
12
11
10
200
300
400
500
600
infall velocity v0 [km/s]
100
50
20
50
100
150
150

Dupree et al. (2005): FUSE TW Hya

observed line profile in stellar rest frame



expected redshift for pole-on accretion

Conclusions:

- Strong evidence for accretion in TW Hya, BP Tau and quite possibly in CR Cha, SU Aur
- High densities very likely
- Overabundance of Ne (and N) and underabundance of Fe and C
- Hard spectral components (of various strengths) exist in all studied stars; they components cannot be attributed to accretion (easily)
- Is TW Hya peculiar ?