50 (38) years of Stellar X-ray astronomy

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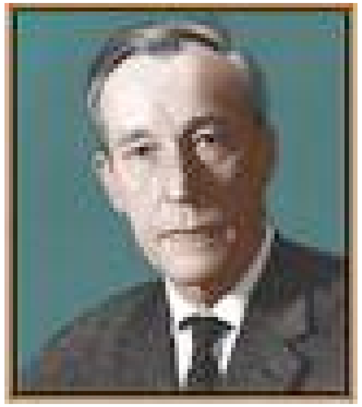
Outline:

- X-rays from the Sun
- Stellar X-ray astronomy:
  X-ray emission throughout the HR-diagram
- Stellar X-ray astronomy :
  Plasma diagnostics of hot plasmas
- (Some) Open problems

B. Edlen, MNRAS, 1945, 105, 323



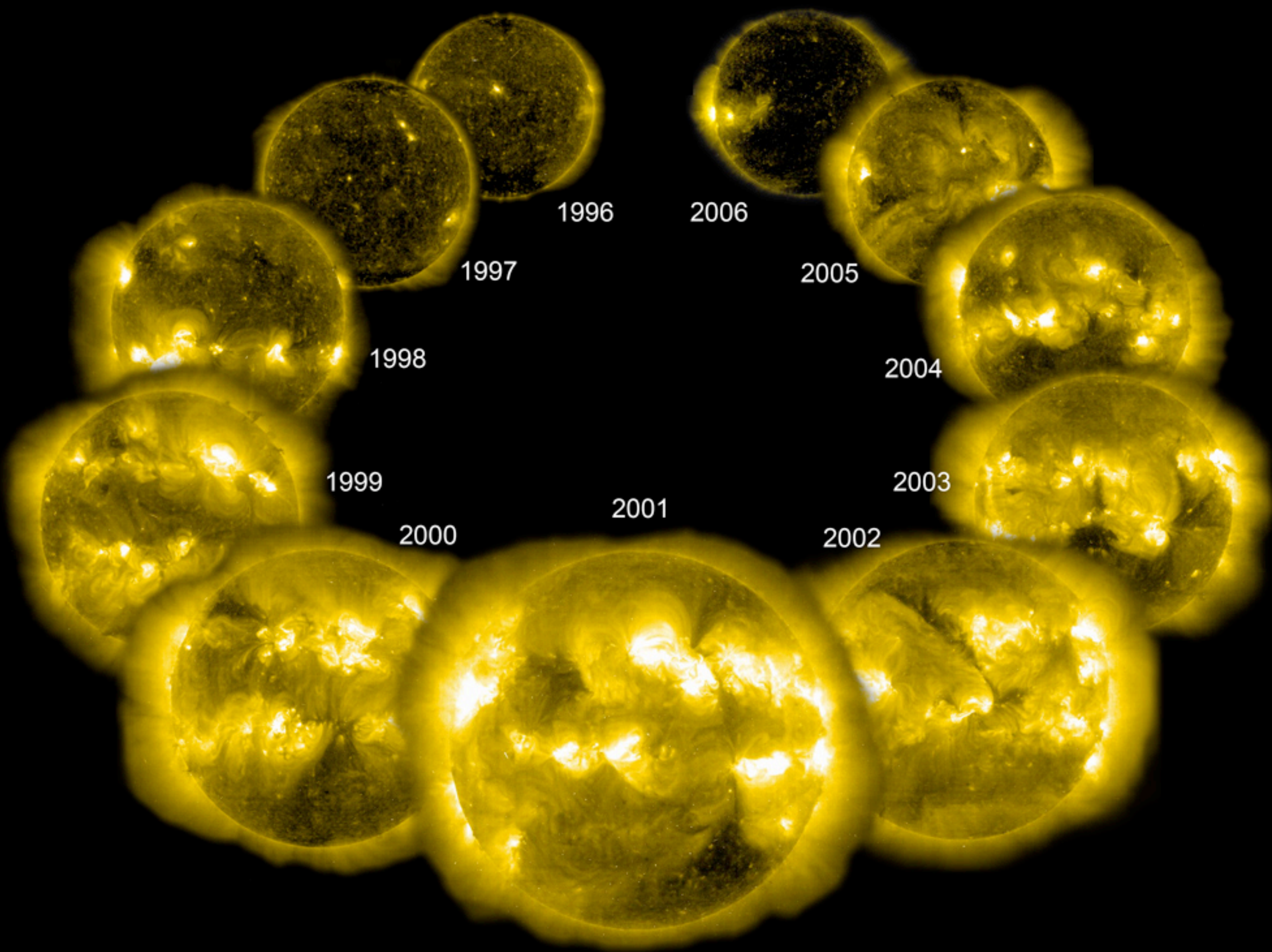
THE IDENTIFICATION OF THE CORONAL LINES

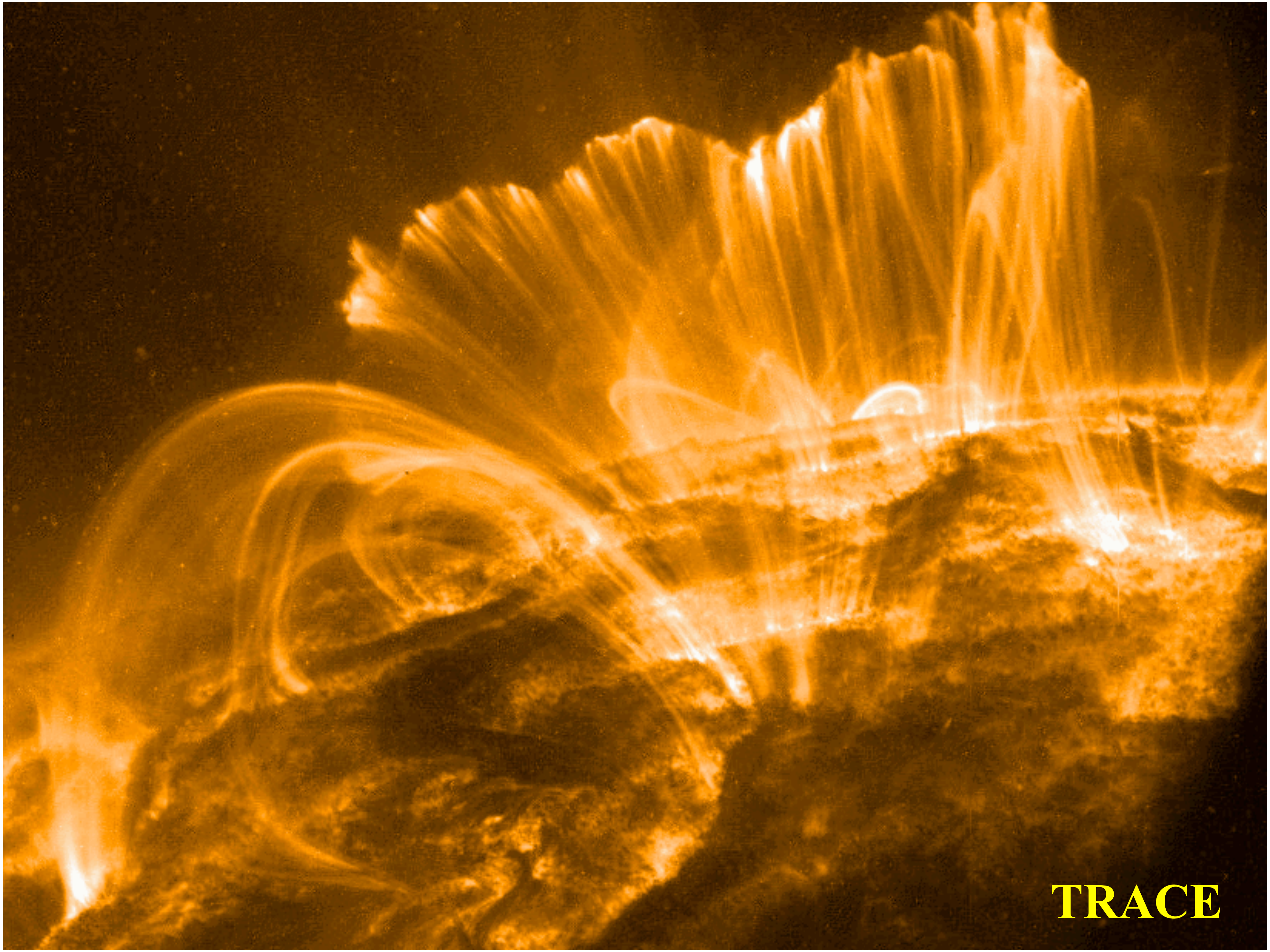
(*George Darwin Lecture, delivered by Professor Bengt Edlén on* 1945 *October* 12)

The coronal emission lines are superimposed on the continuous radiation of the inner parts of the solar corona, the region of their appearance extending from the top of the chromosphere to a height generally not exceeding 10 minutes of arc (half a million kilometers) from the Sun's limb. The lines are responsible for only a small fraction of the total intensity of the corona.

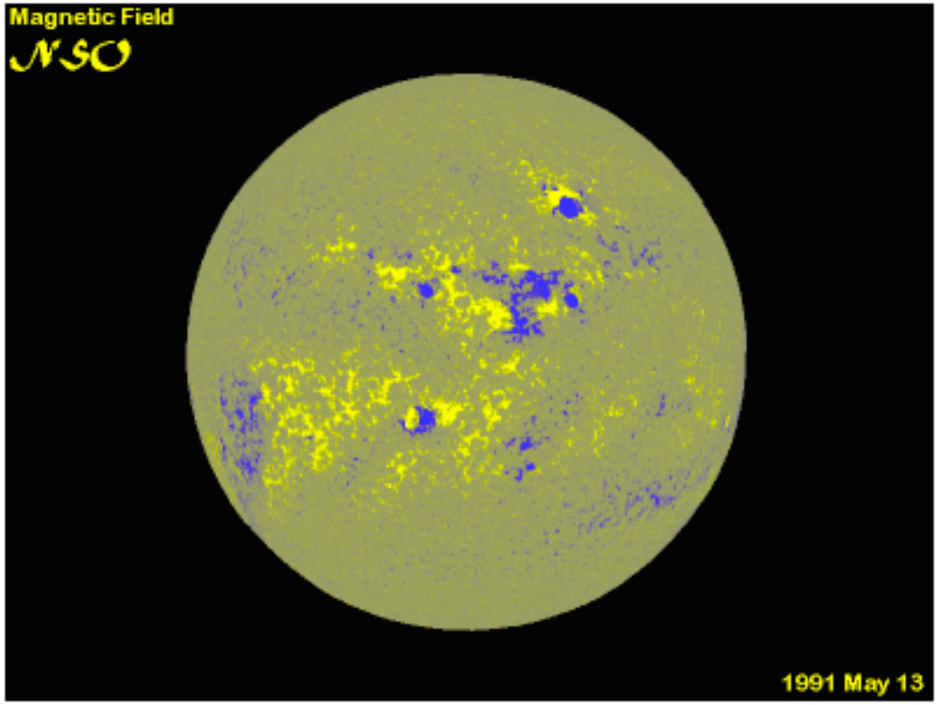
the infra-red part of the spectrum. At present, as a net result of all observations, the wave-lengths of some twenty coronal emission lines have been established. Six of these lines are much stronger than the rest. These conspicuous lines are: λ 3388, λ 5303, λ 6374, λ 7892, λ 10747 and λ 10798. None of the coronal lines has been observed in a laboratory light-source and there is no real coincid[illegible] lines nor with any line in the chromospheric spectrum. The coronal lines were in fact a unique feature of the solar corona until in 1932 a number of them showed up in the spectrum of the recurrent nova RS Ophiuchi. Recently the coronal lines have

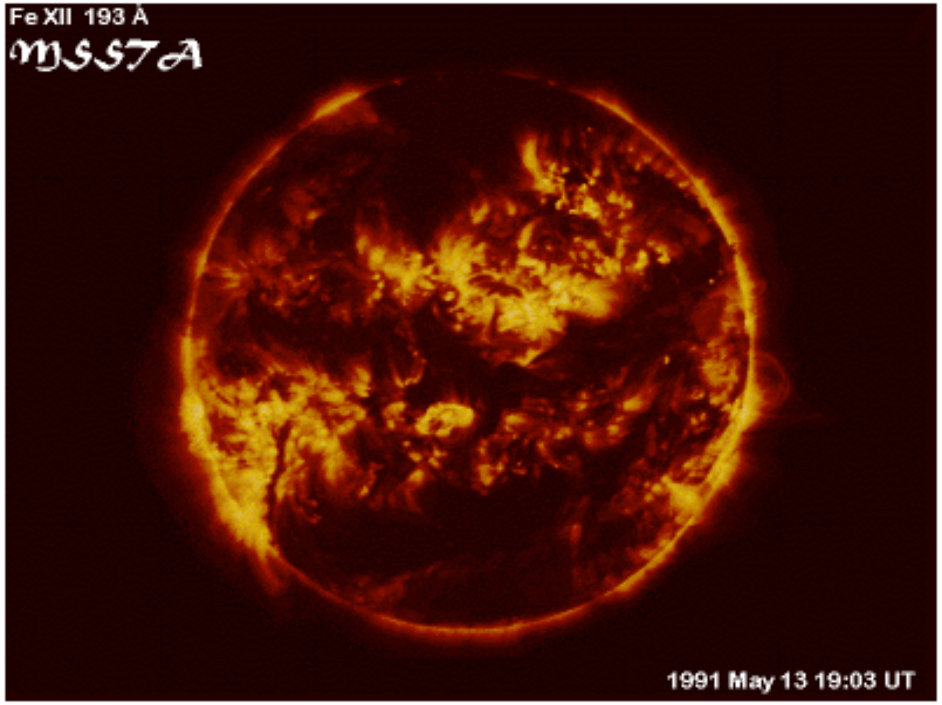
The SOHO Sun



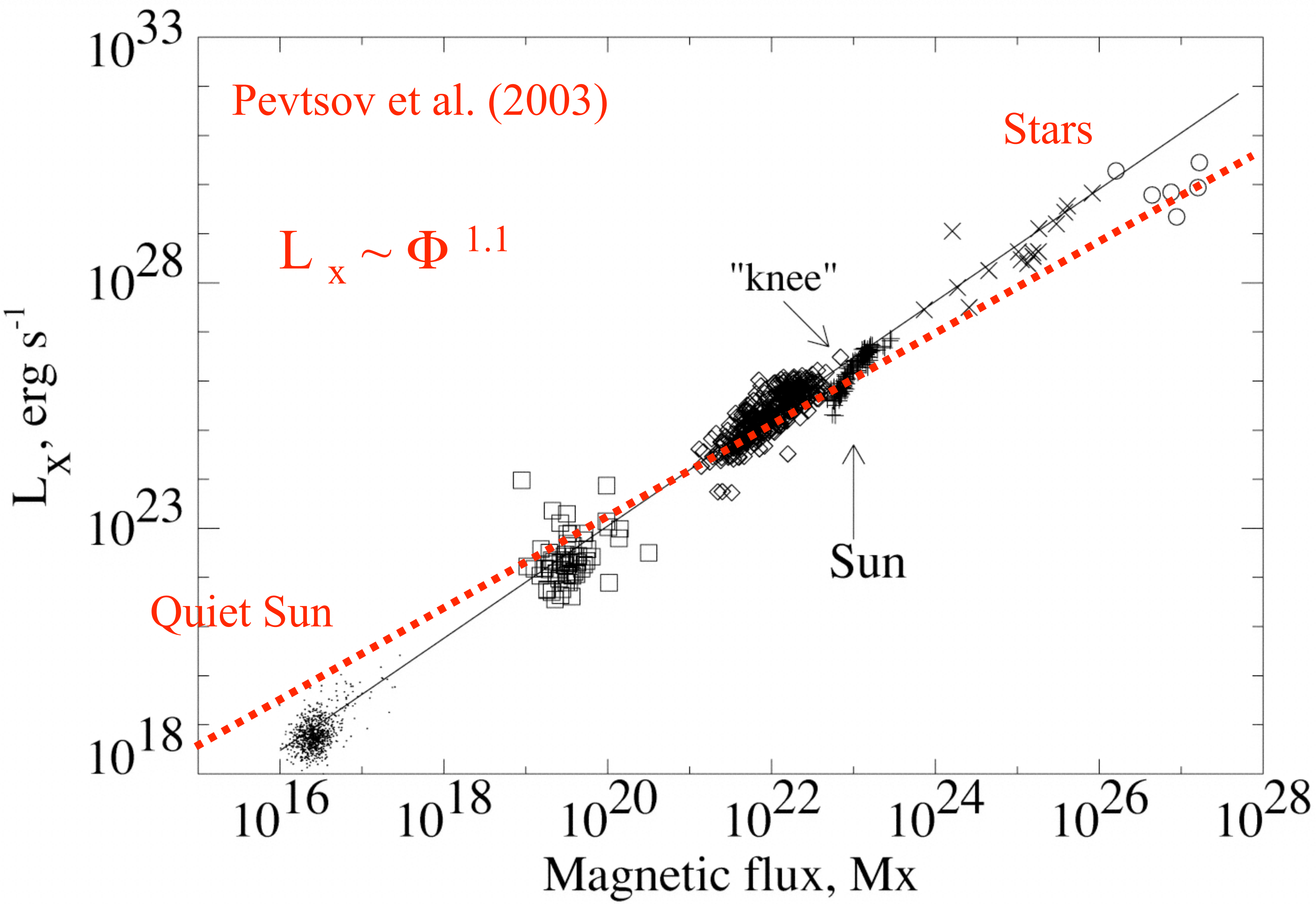

TRACE

Why study X-ray emission ?





X-ray emission is a good proxy for magnetic flux !



Pevtsov et al. (2003)
Stars
L x ~ Φ 1.1
"knee"
Sun
Quiet Sun
10^33
10^28
10^23
10^18
L_X, erg s^-1
10^16
10^18
10^20
10^22
10^24
10^26
10^28
Magnetic flux, Mx

- X-ray emission diagnoses magnetic flux
- Magnetic flux is difficult to measure for stars
- What about X-rays from stars ?

The Sun as an X-ray source

$L_x = 2 \times 10^{27}$ erg/sec at solar max !

Placed at a distance of 10 pc:

$$f_x = 1.8 \times 10^{-13} \text{ erg/sec/cm}^2$$

Sensitivity limit of ROSAT all sky-survey:

$$f_{x,lim} \sim 2 \times 10^{-13} \text{ erg/sec/cm}^2$$

Only nearby sources detectable ?

Capella (Apr 5 1974)!

THE ASTROPHYSICAL JOURNAL, 196:L47–L49, 1975 March 1

EVIDENCE FOR X-RAY EMISSION FROM CAPELLA

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Received 1974 November 7; revised 1974 December 5

ABSTRACT

X-ray emission in the range from 0.2 to 1.6 keV has been detected from an area of the sky which contains the binary star system Capella. The X-ray source is at most a few arc minutes in extent and shows no spectral turnover at low energy, consistent with a nearby source. We suggest Capella as the source of this emission and that this object belongs to a new class of galactic X-ray sources with a luminosity of 10^{31}–10^{34} ergs s^{-1}. Emission from this class of objects is variable, predominantly below 2 keV, and originates from nearby stellar objects.

Subject headings: spectra, X-ray — stars, individual — X-ray sources

Pre-Einstein review by R. Mewe (1979)

STELLAR CORONAE—EVIDENCE FOR THEIR EXISTENCE FROM X- AND UV OBSERVATIONS

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(Received 5 February; in revised form 16 February, 1979)

Abstract. Stellar coronae were among the first predicted X-ray sources. Because of their relatively low X-ray luminosities, however, they have been discovered only during the last few years.

In the present paper the current state of stellar coronal X- and UV observations has been reviewed, including some preliminary observational results from the *HEAO-1* and *IUE* satellites, but still without any result from the recently launched X-ray satellite *HEAO–2*.

Late 1978 about two dozens of stellar soft X-ray sources have been detected, e.g., normal stars like the Sun (e.g., α Cen), very active stars (*RS CVn* systems), and possibly a corona around an intermediately hot white dwarf (*Sirius B*).

The observational results of various objects have been discussed and compared with X-ray luminosity predictions based on minimum-flux coronal models.

First revolution in stellar X-ray astronomy

Soft X-ray imaging !

Einstein Observatory

1978 - 1981

Launch: Nov 13 1978

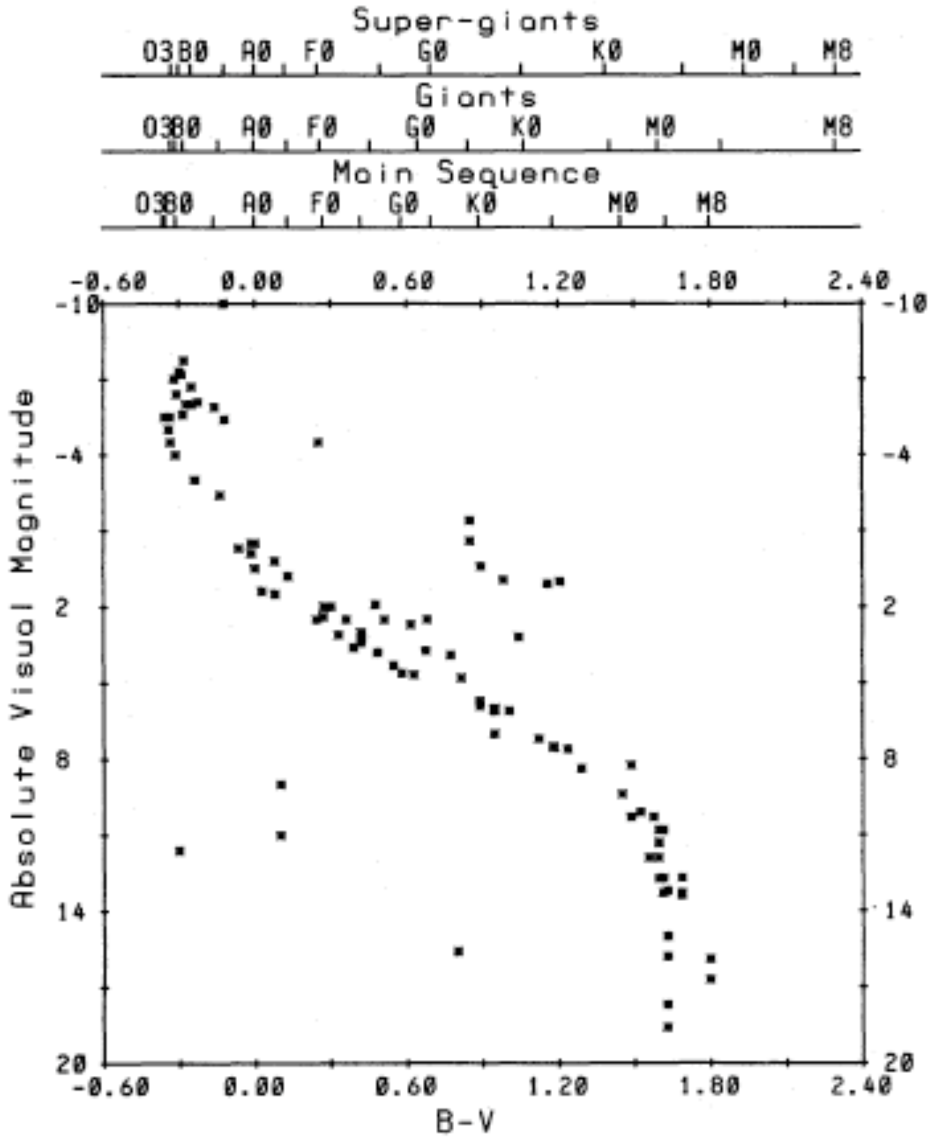


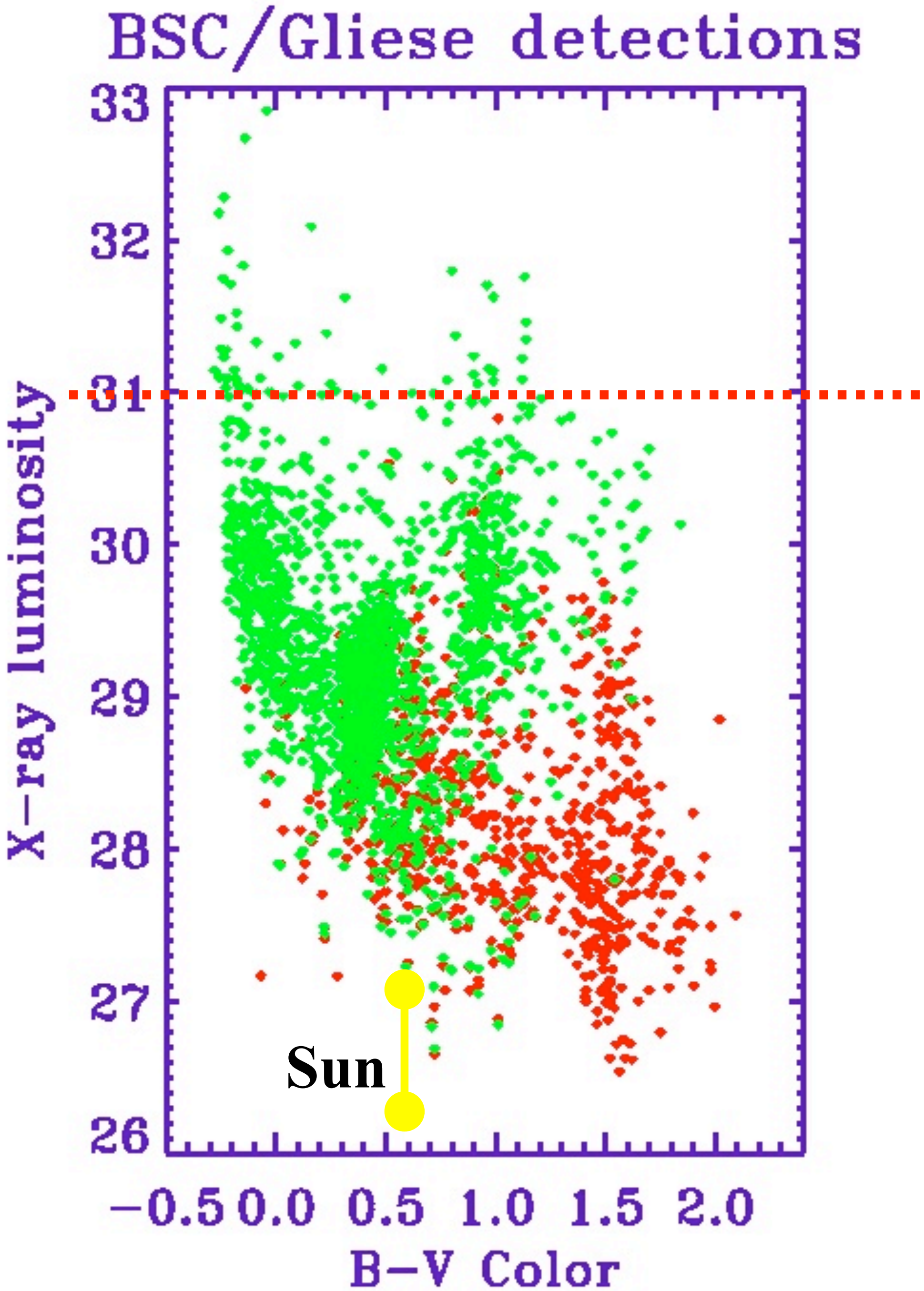
FIG. 1.—An H-R diagram for stars detected as soft X-ray sources by *Einstein*. The figure only includes that subset of Survey stars for which absolute visual magnitude could be determined either from the luminosity class or from parallax data; these stars are referred to as the "optically well-classified" sample.

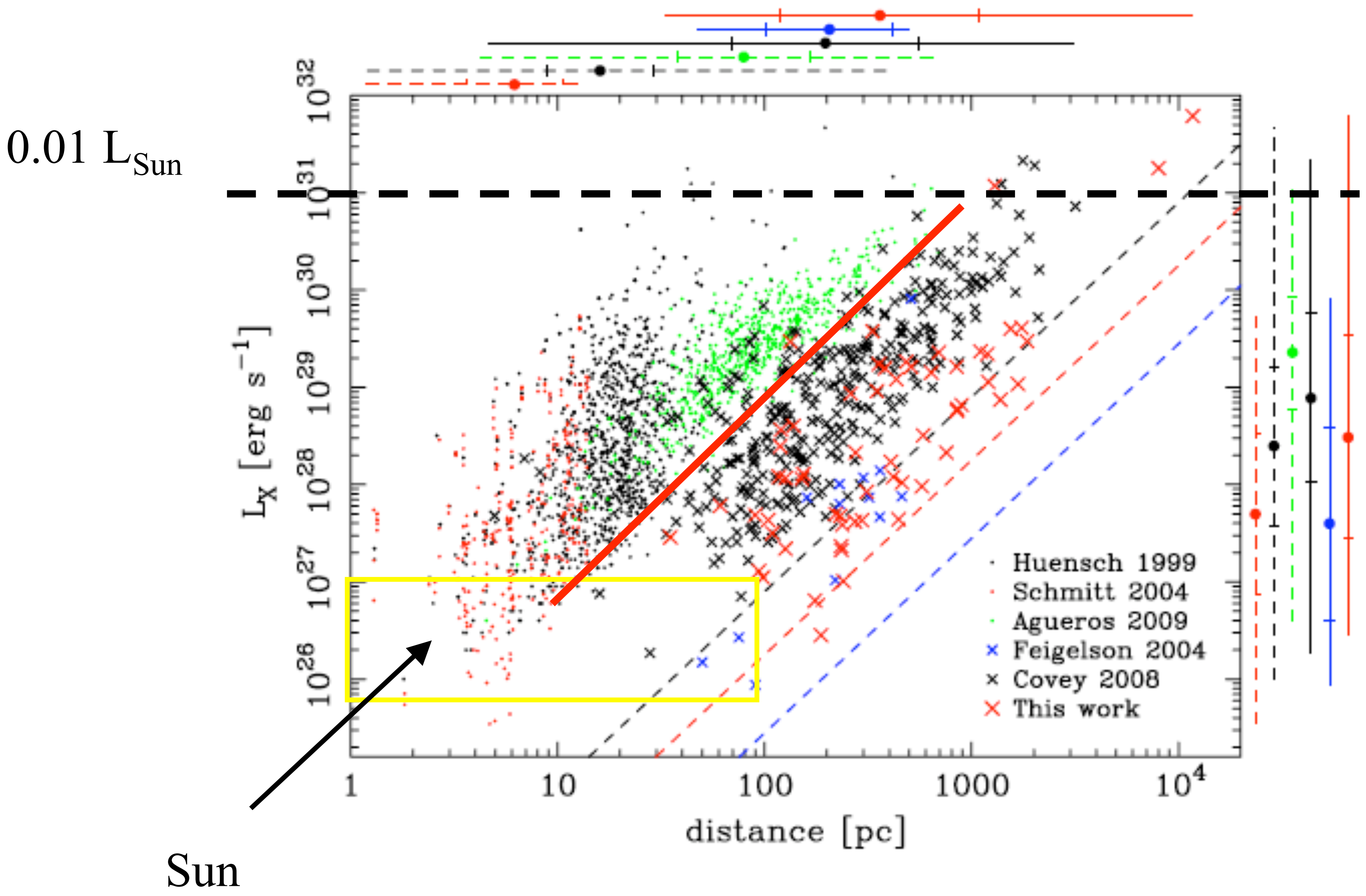
Vaiana et al. (1981)

First X-ray HR-diagram

with 143 stars !

ROSAT all-sky survey





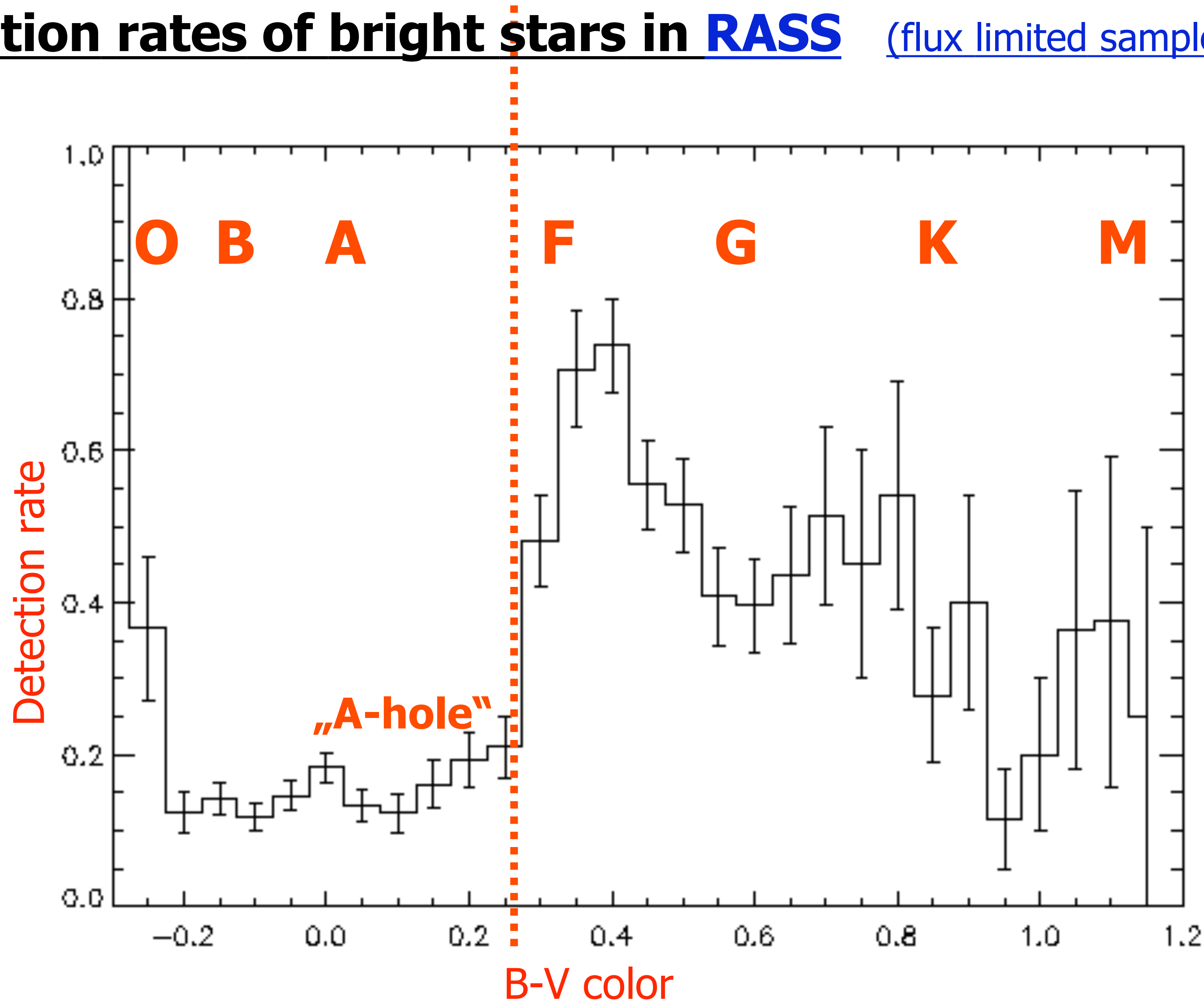
Wright et al. (2010)

Main results:

- X-ray emission from all stars with outer convection zones
- Minimal flux
- Rotation-activity relation
- Activity-age relation
- Solar phenomena on stars (cycles, flares)

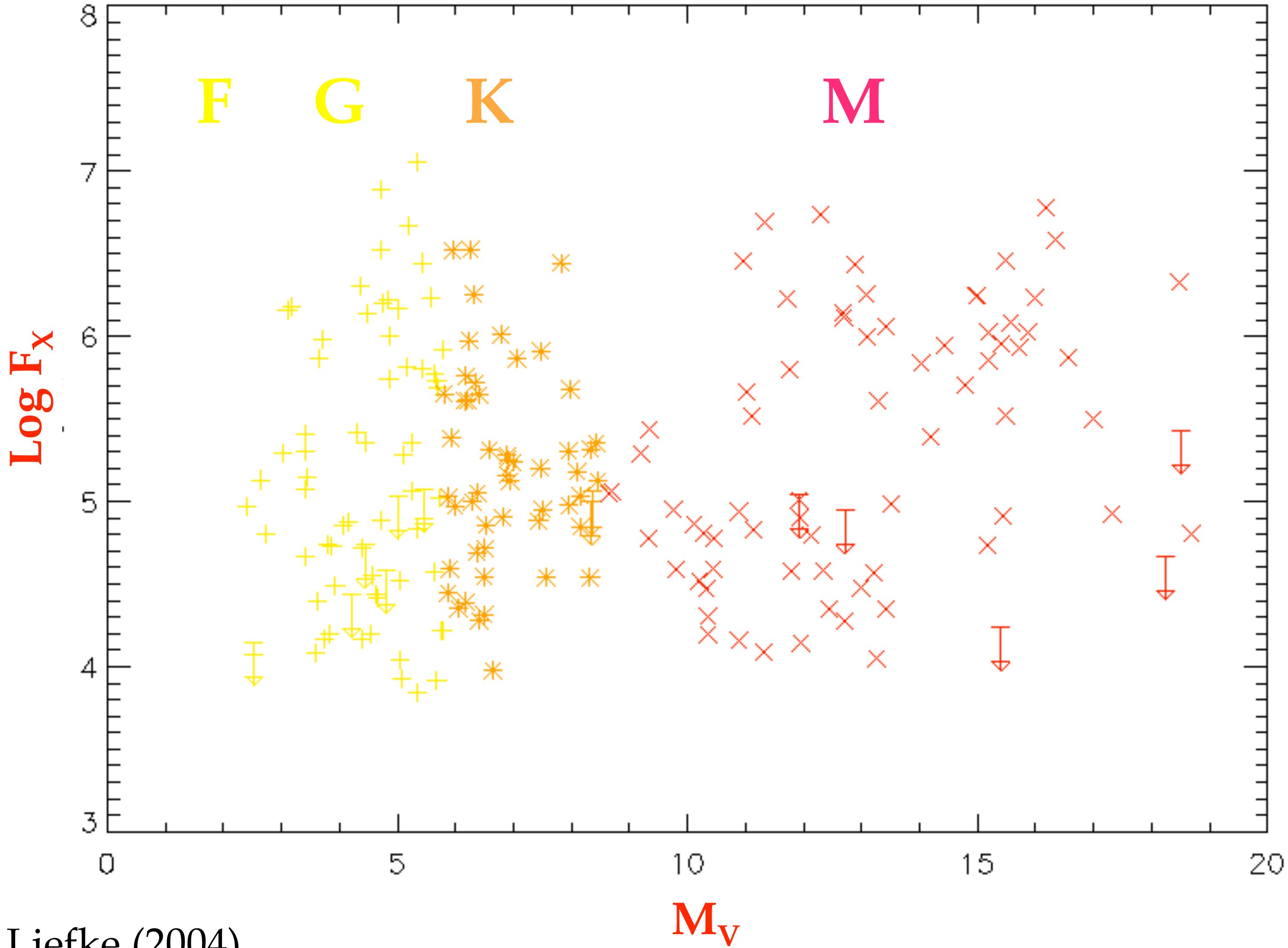
Which stars do we see as X-ray sources ?

Detection rates of bright stars in RASS (flux limited sample)



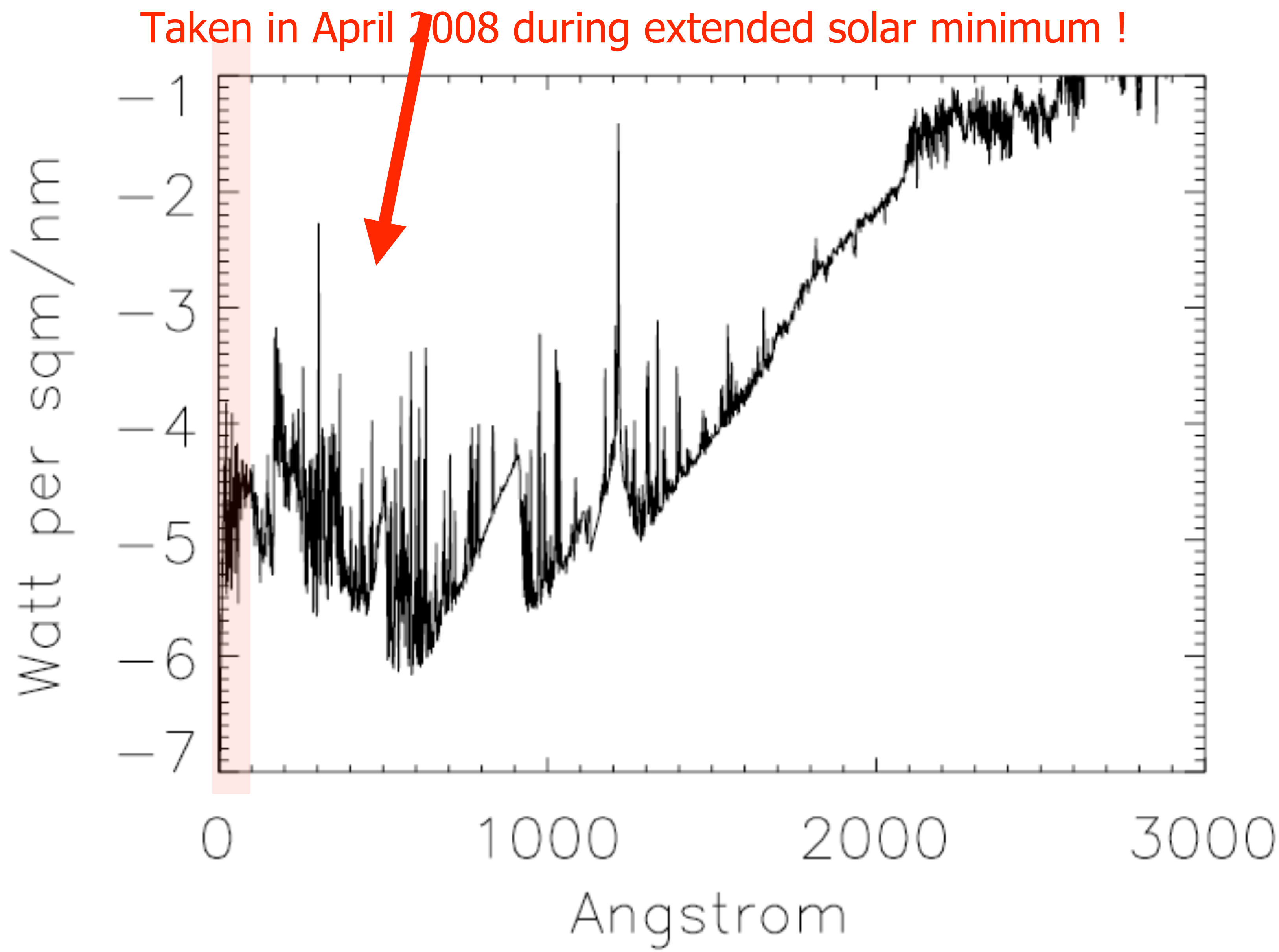
Onset of convection

Volume-limited sample of F,G,K,M dwarfs: F_X vs. M_V



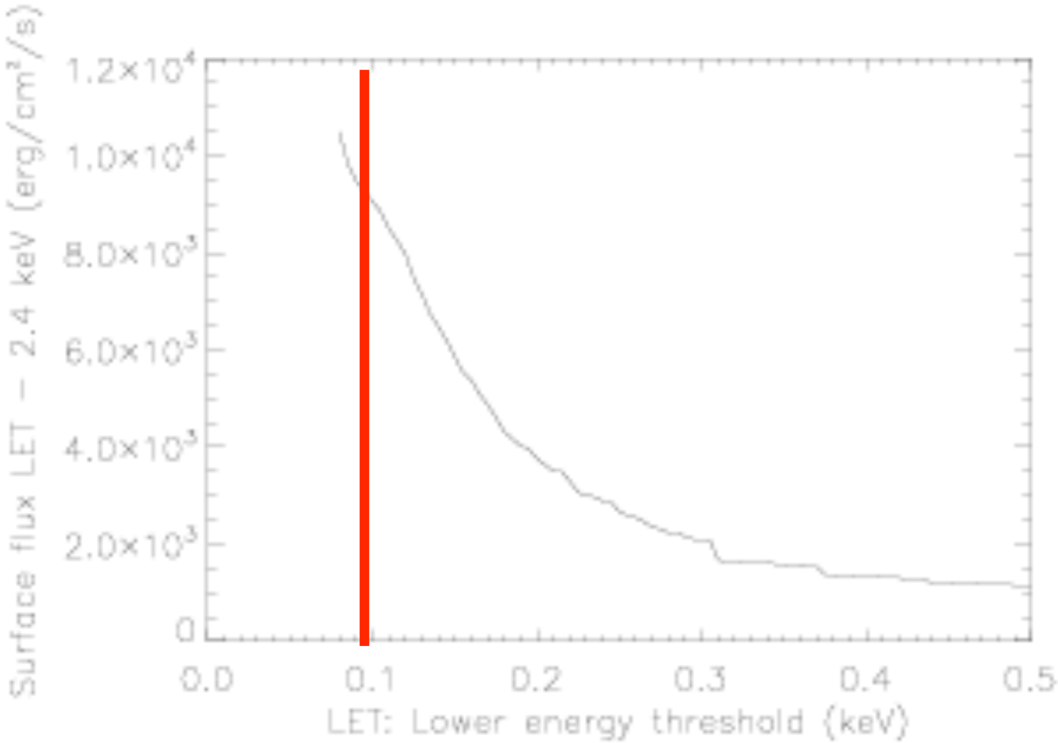
Schmitt & Liefke (2004)

What is the meaning of the minimal flux ?



Solar Irradiance Reference Spectrum (Woods 2009)

SIRS Solar spectrum

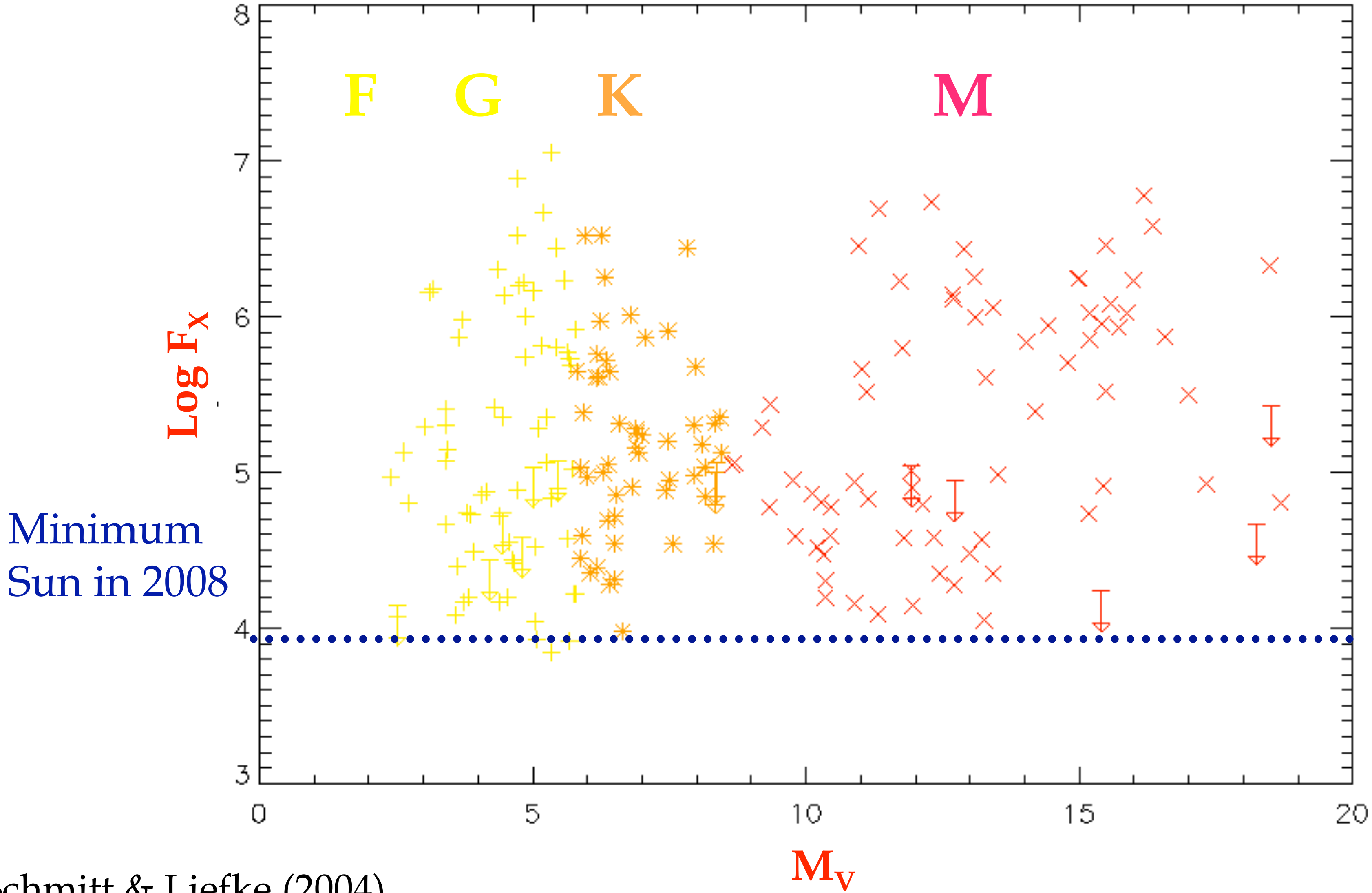


Schmitt (2011)

In PSPC-band pass: F_X = 9000 erg/cm^2/sec

$L_{X,tot,min}$ = 5.5 10^{26} erg/sec

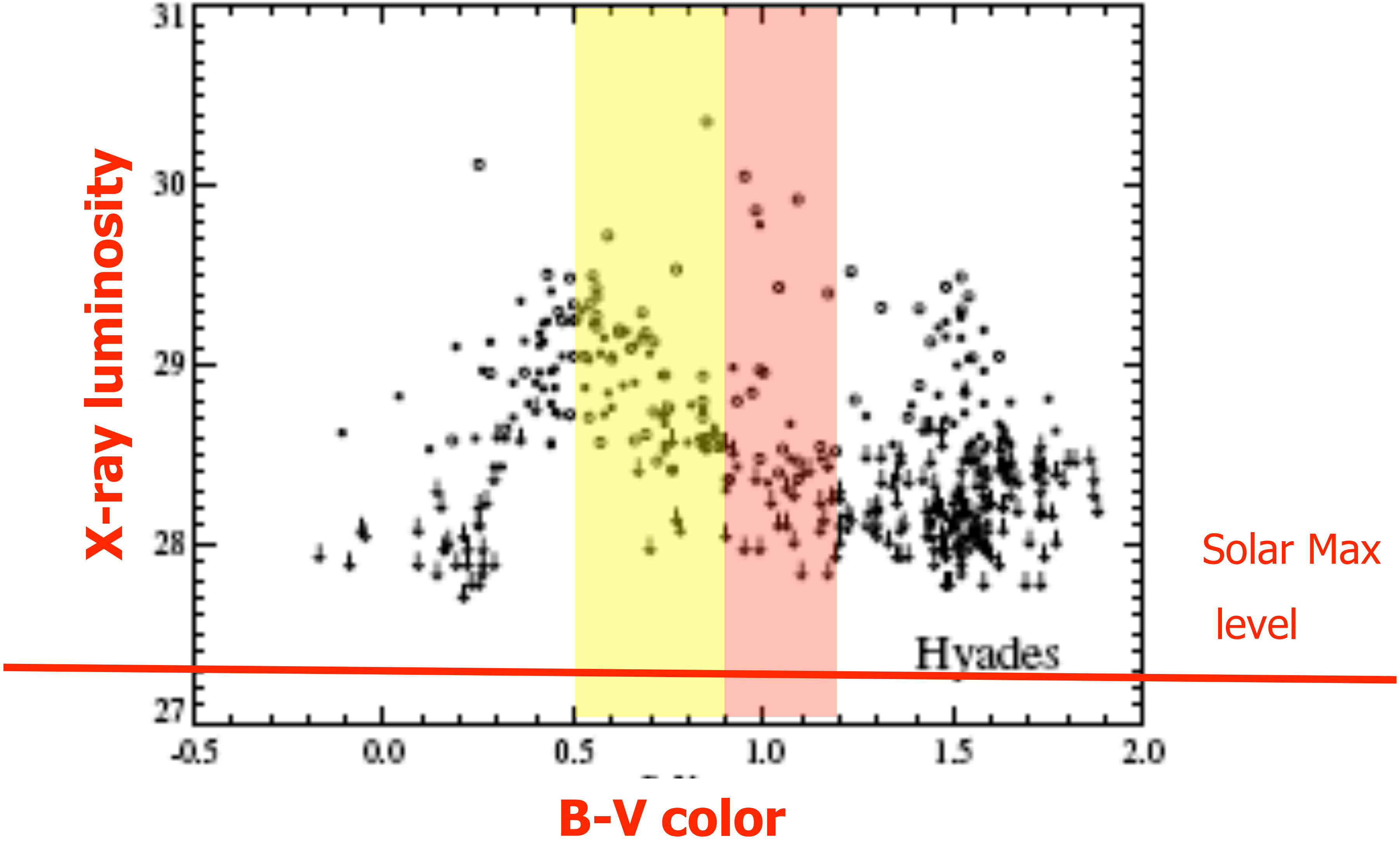
Volume-limited sample of F,G,K,M dwarfs: F_X vs. M_V



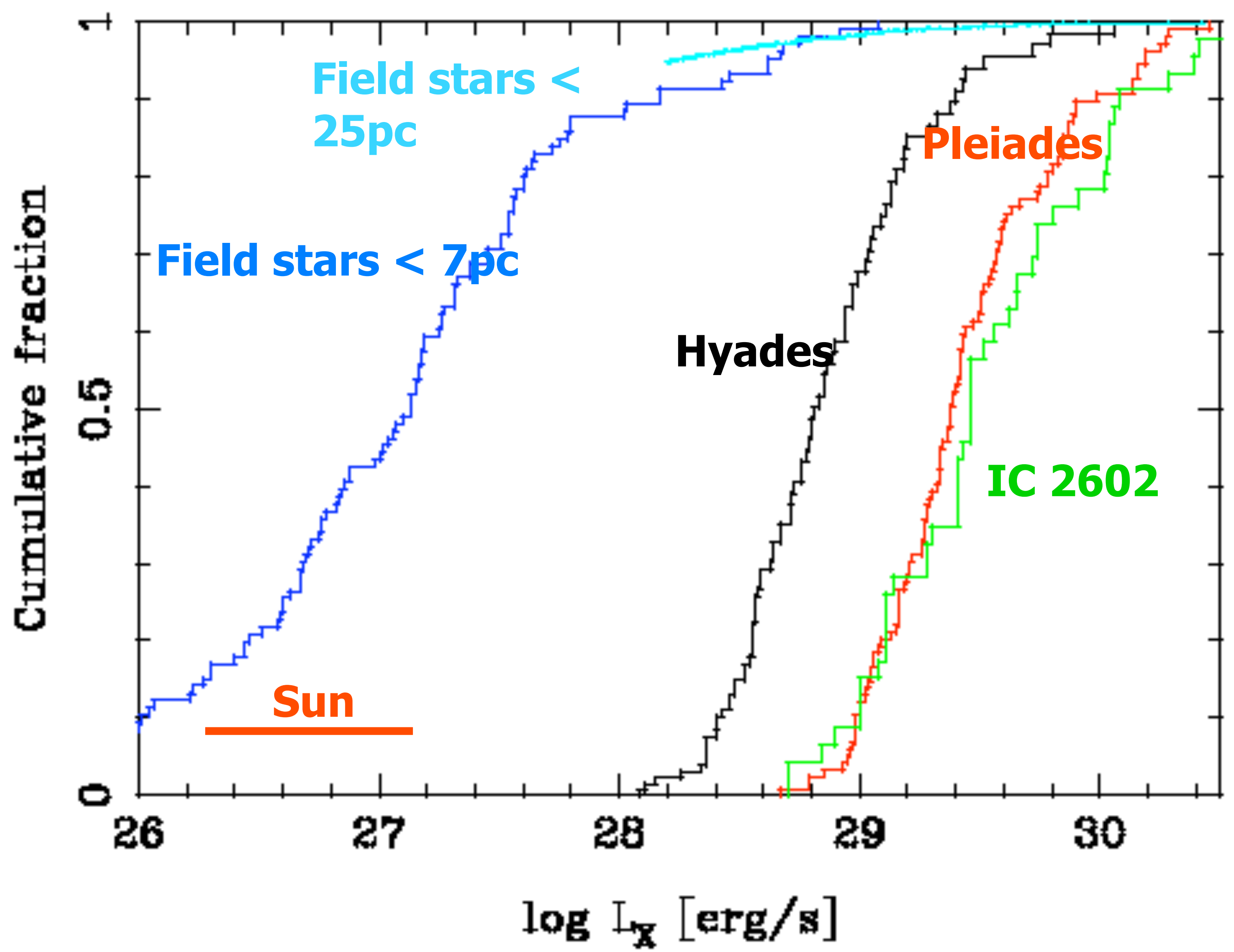
Schmitt & Liefke (2004)

Age-activity connection

Hyades cluster (Stern et al. 1994)



X-ray luminosities of solar-like stars



Rotation-activity connection

RELATIONS AMONG STELLAR X-RAY EMISSION OBSERVED FROM *EINSTEIN*, STELLAR ROTATION AND BOLOMETRIC LUMINOSITY

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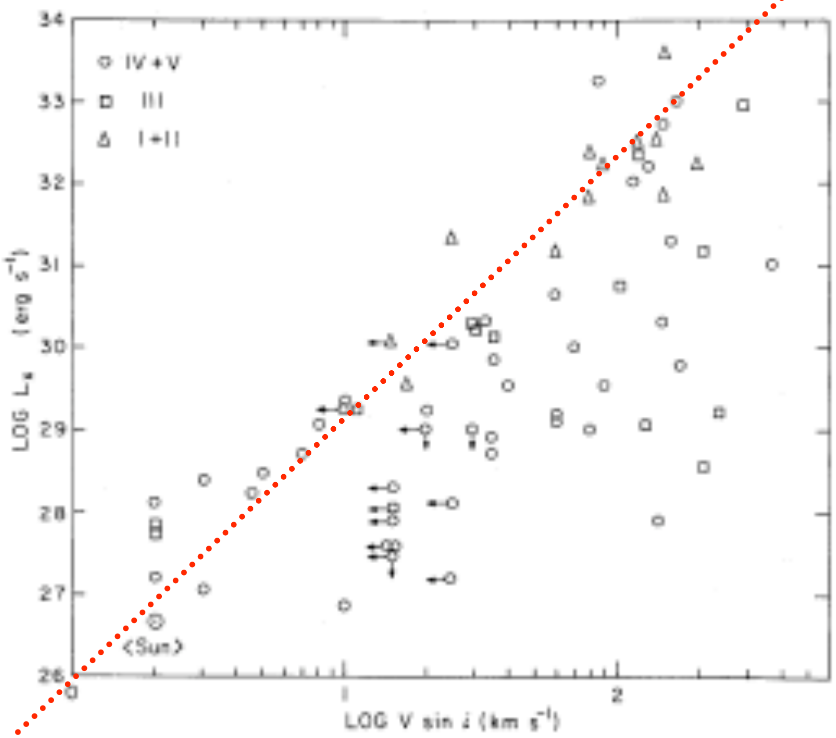
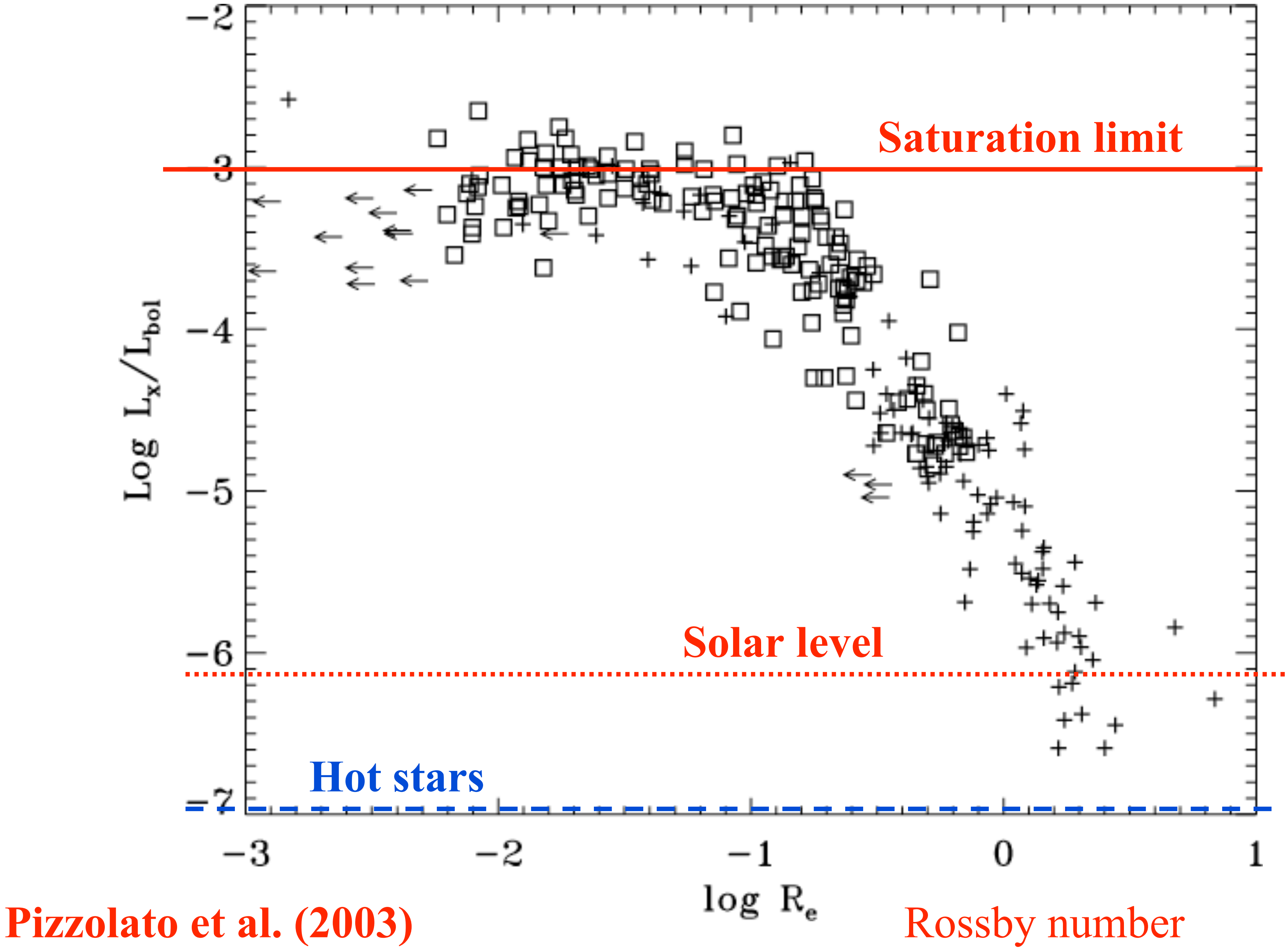
Received 1980 December 9; accepted 1981 February 12



First X-ray activity vs. rotation diagram by Pallavicini et al. (1981)!



Saturation limit
Solar level
Hot stars
Log L_x/L_{bol}
log R_e
Rossby number
Pizzolato et al. (2003)

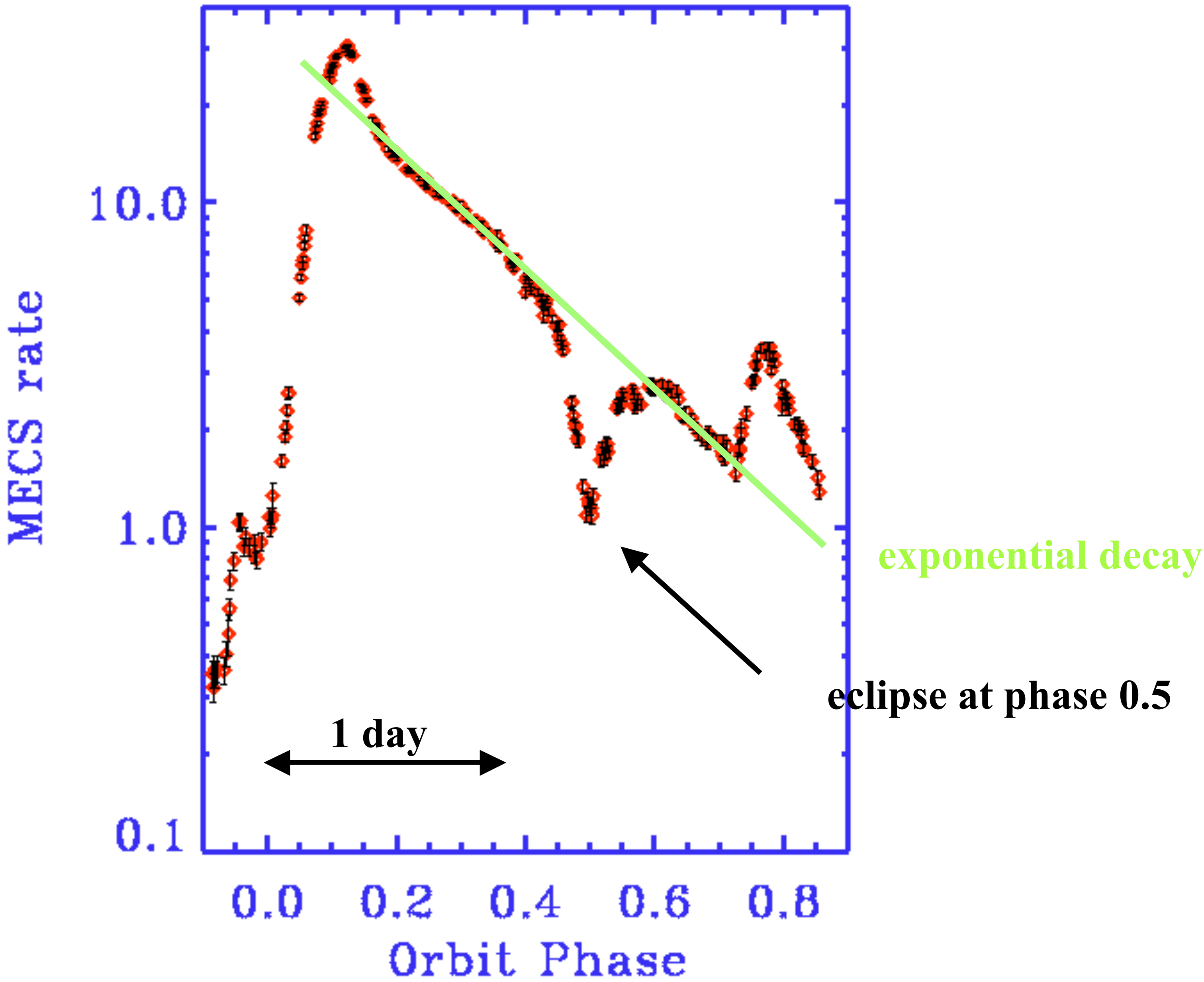
Solar phenomena on stars:

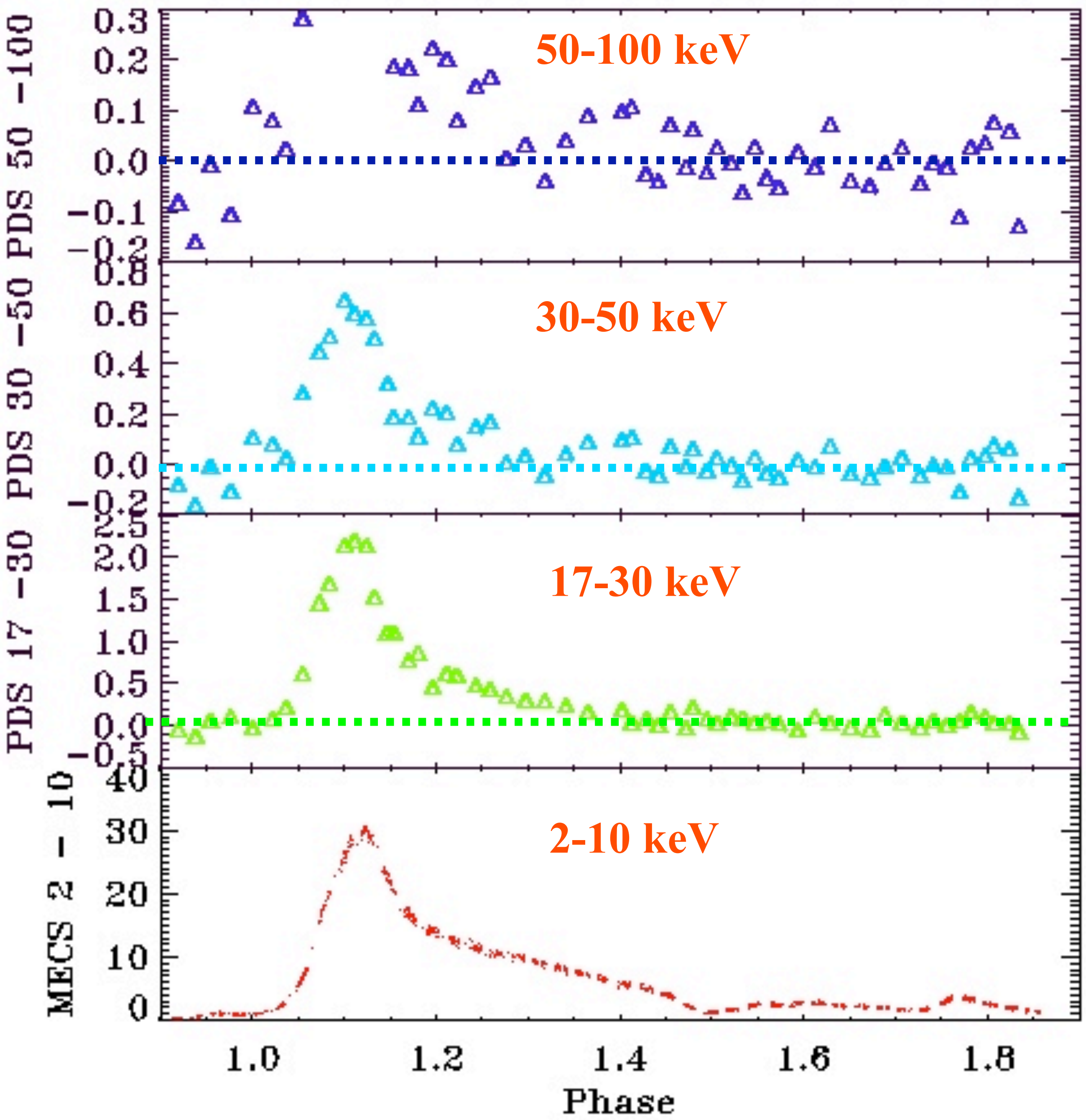
Flares

Cycles

Giant X-ray flare on Algol observed with BeppoSAX

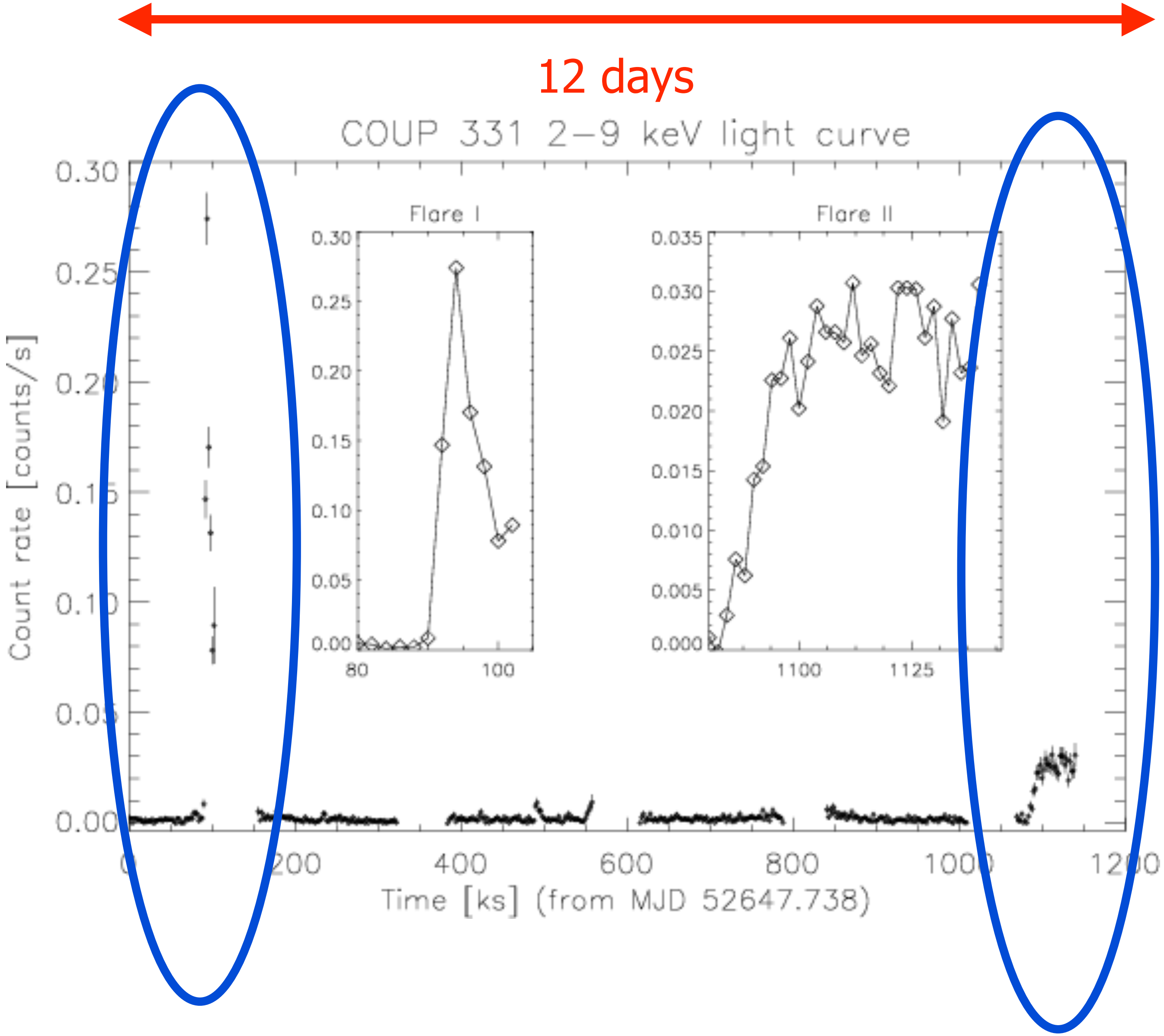
(Schmitt & Favata 1999)



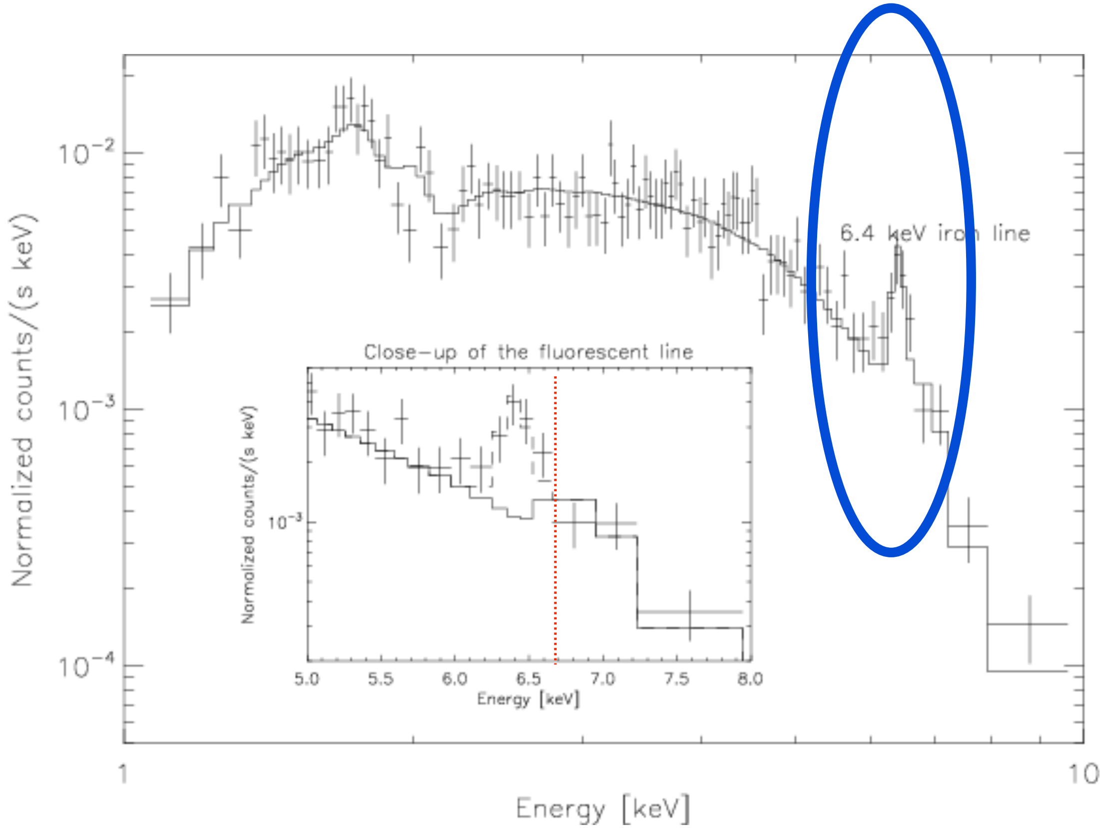


Consistent with thermal emission

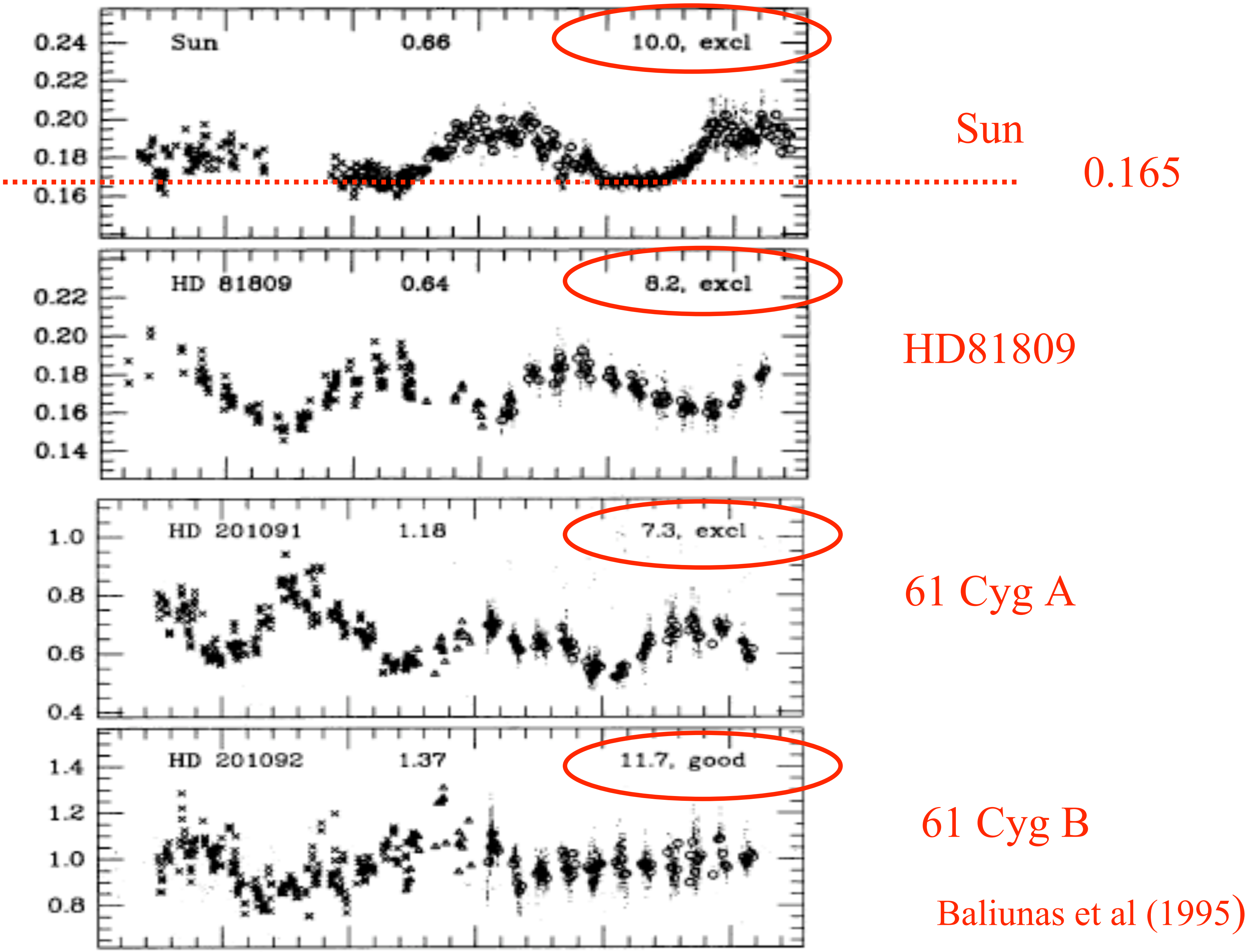
COUP 331 (Czesla et al. 2008)



COUP 331 (Czesla et al. 2008)

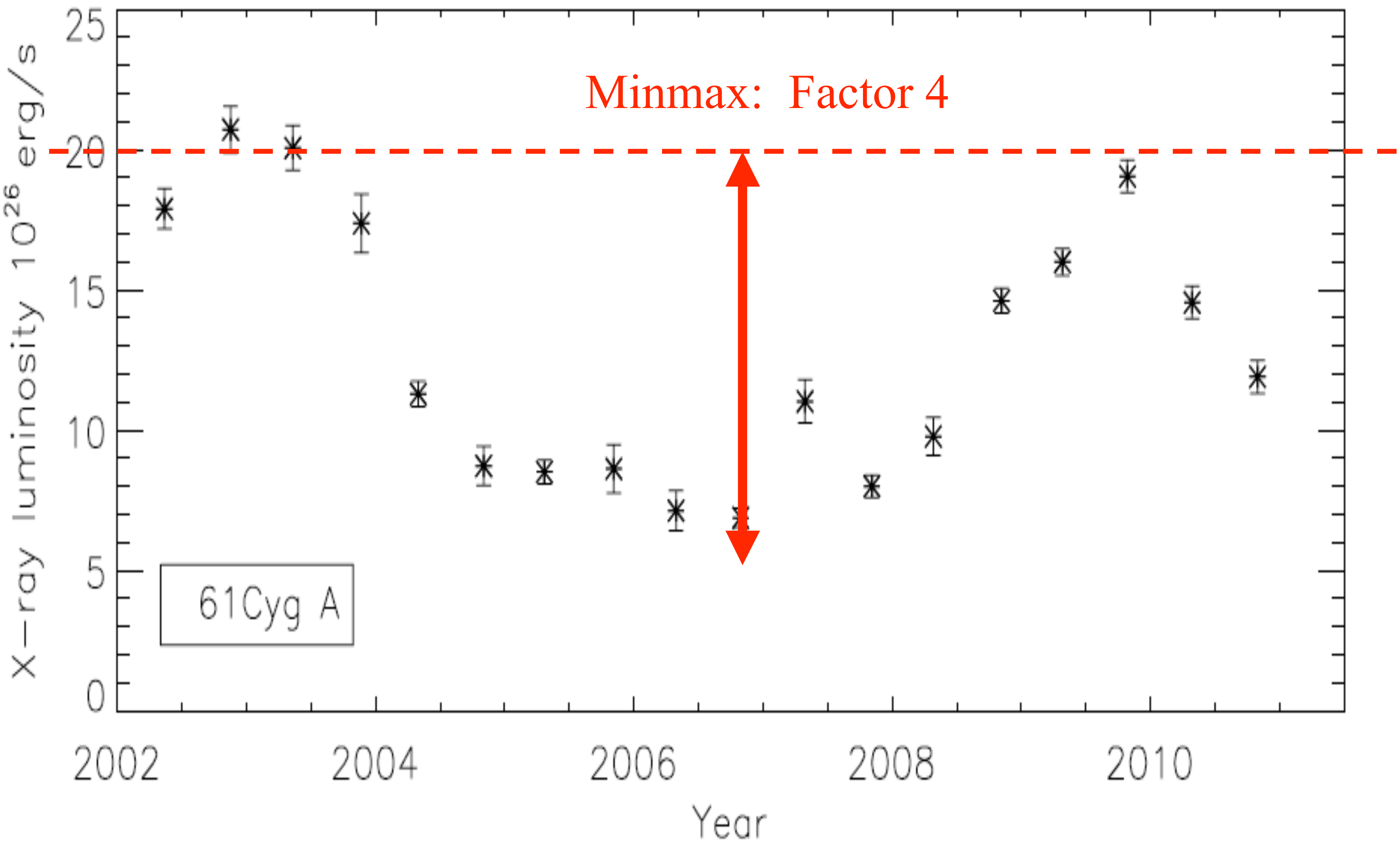


Fe 6.4 kev fluorescence line appears for the first 20 ksec of flare 2 !



Baliunas et al (1995)

61 Cyg A: A full X-ray cycle covered !

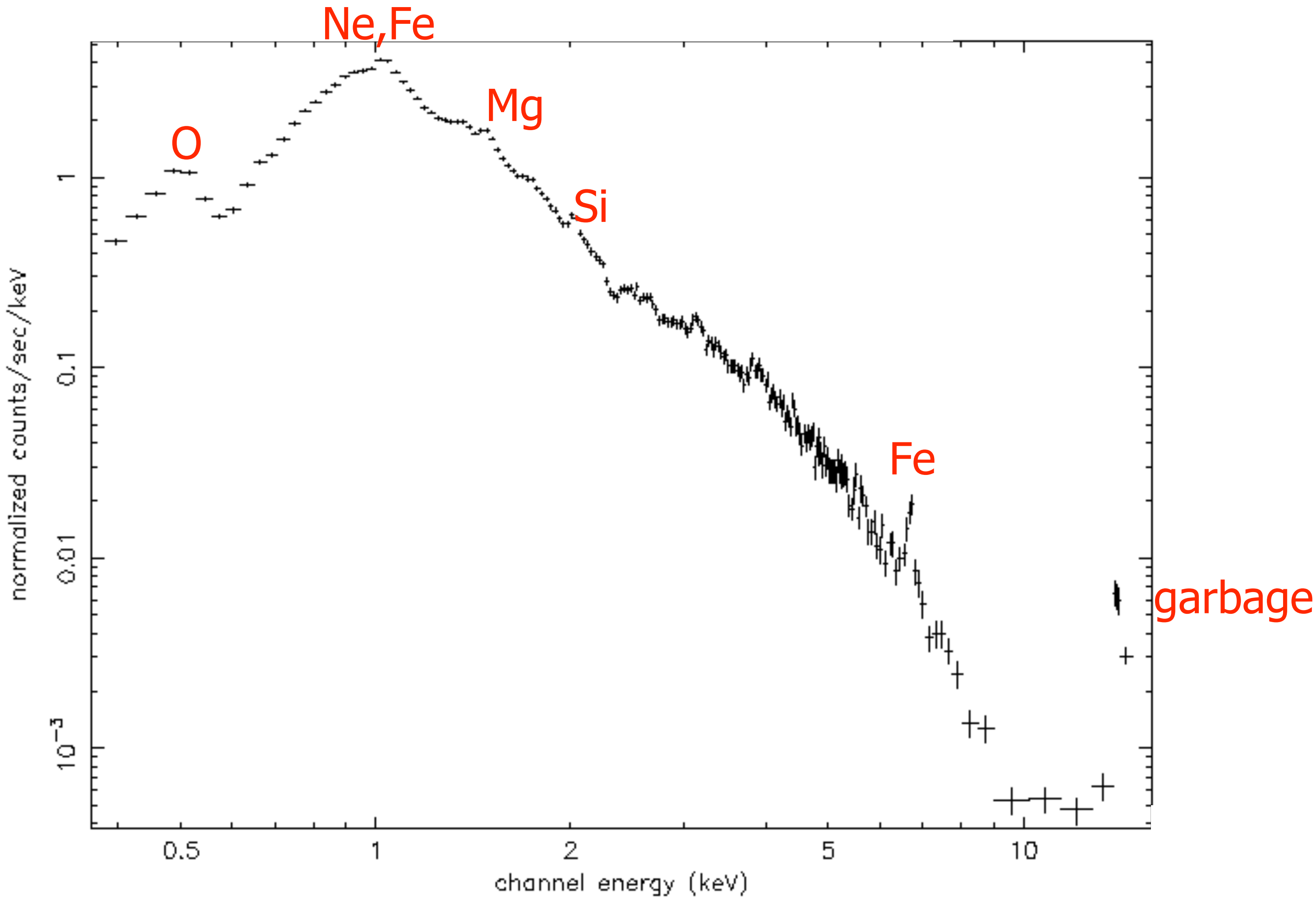


Robrade et al. (2011)

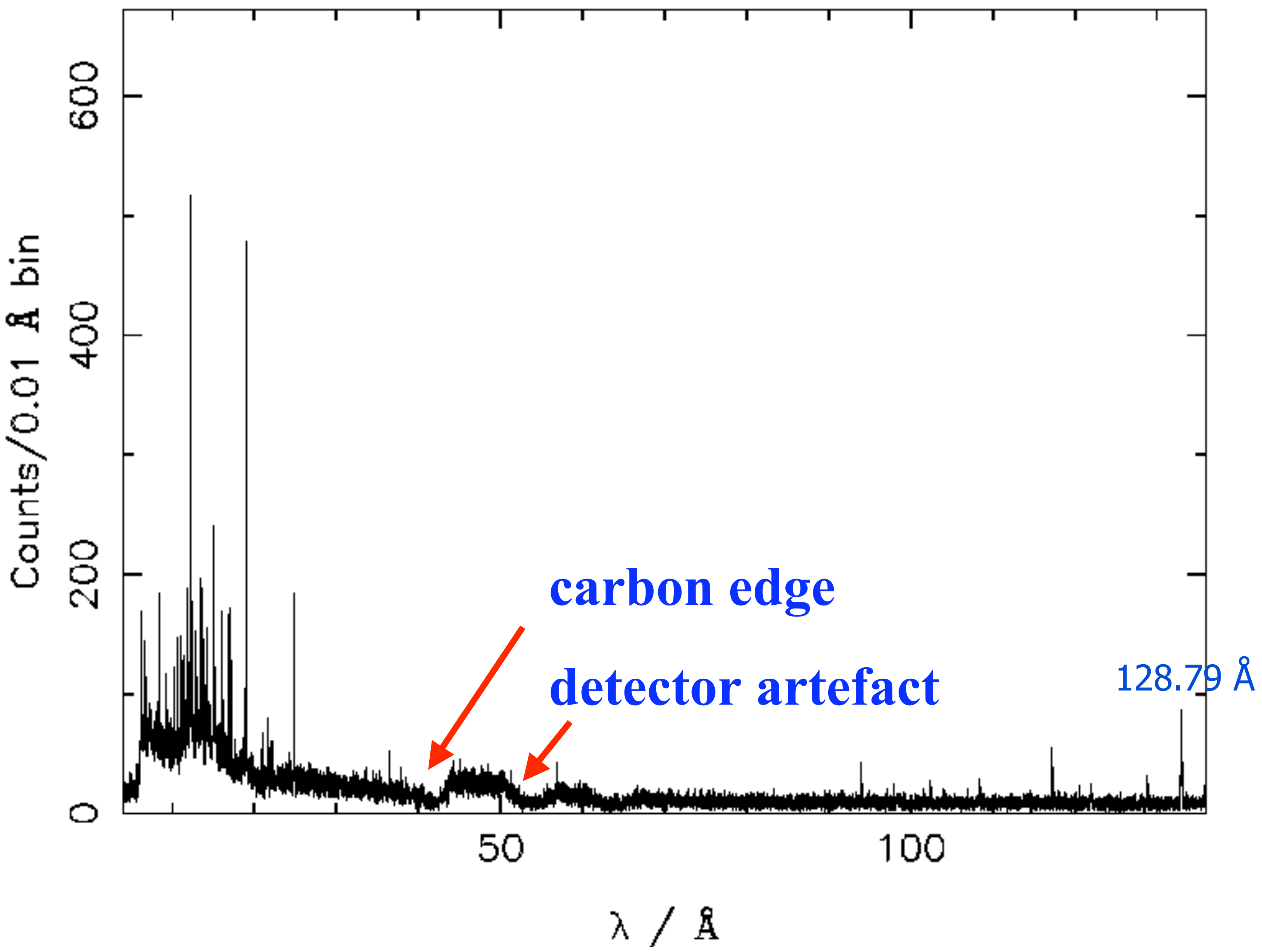
Second revolution in stellar X-ray astronomy

High-resolution X-ray spectroscopy

ASCA (CCD) : Algol 1996



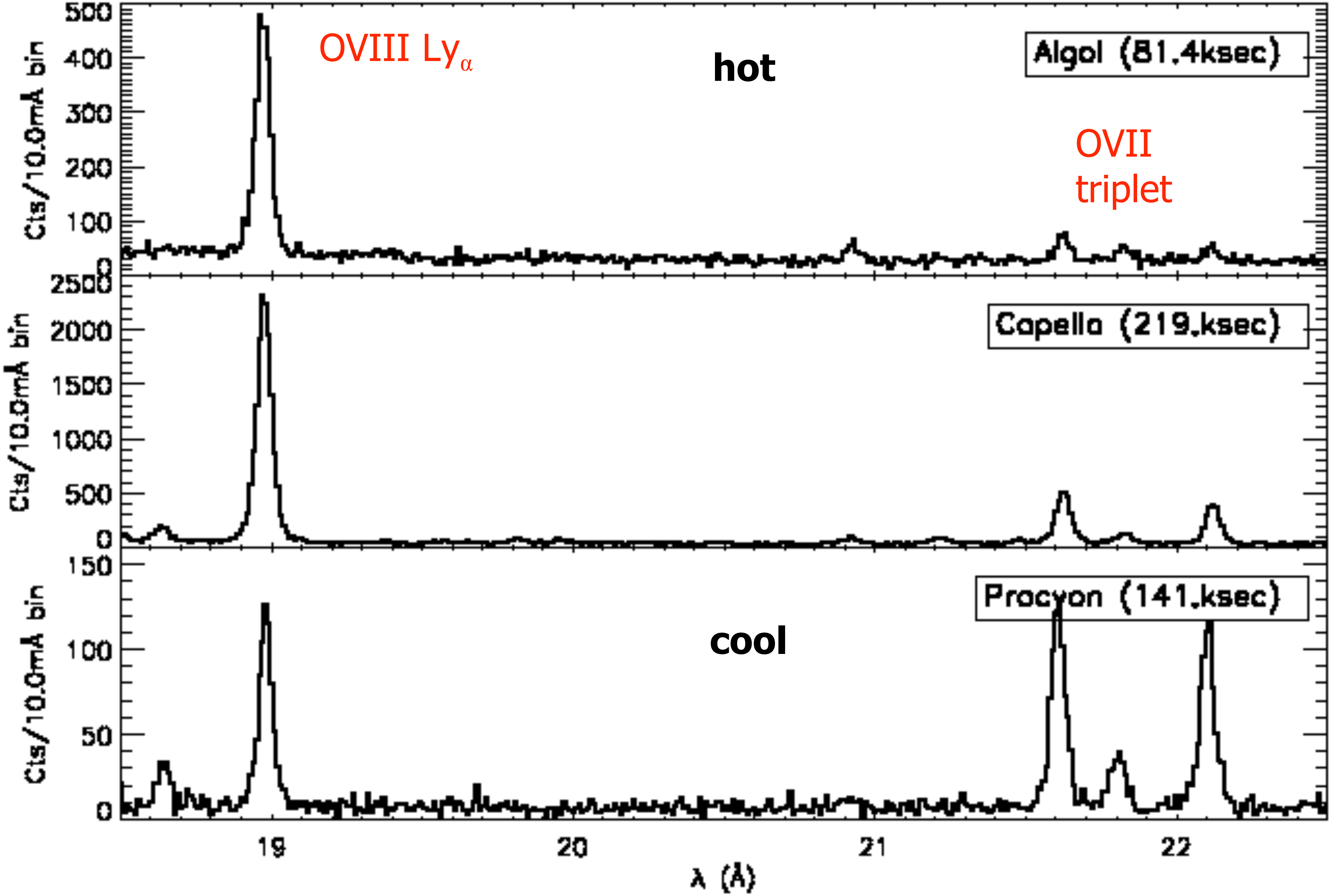
LETGS raw spectrum (of Algol 80 ksec) 2000

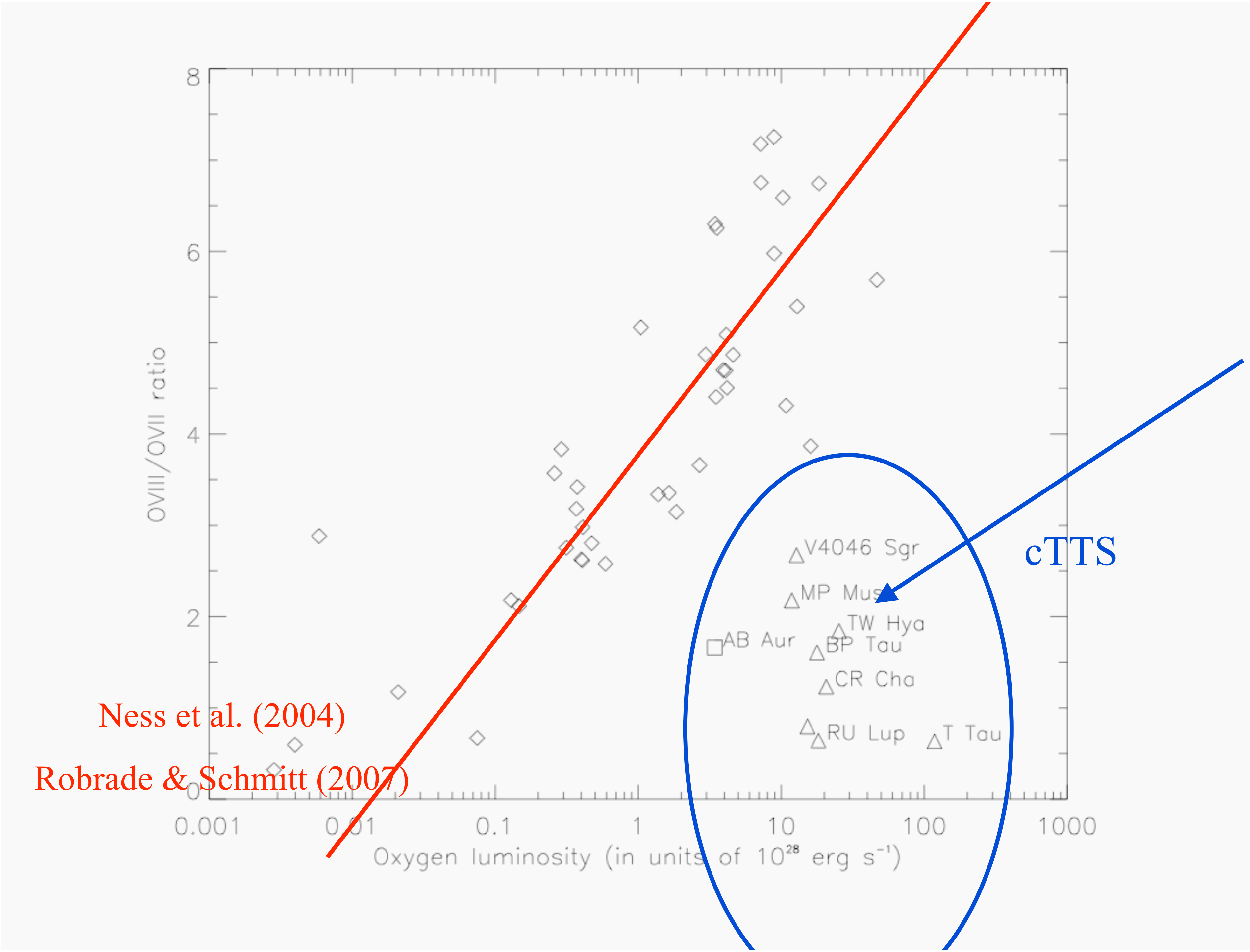


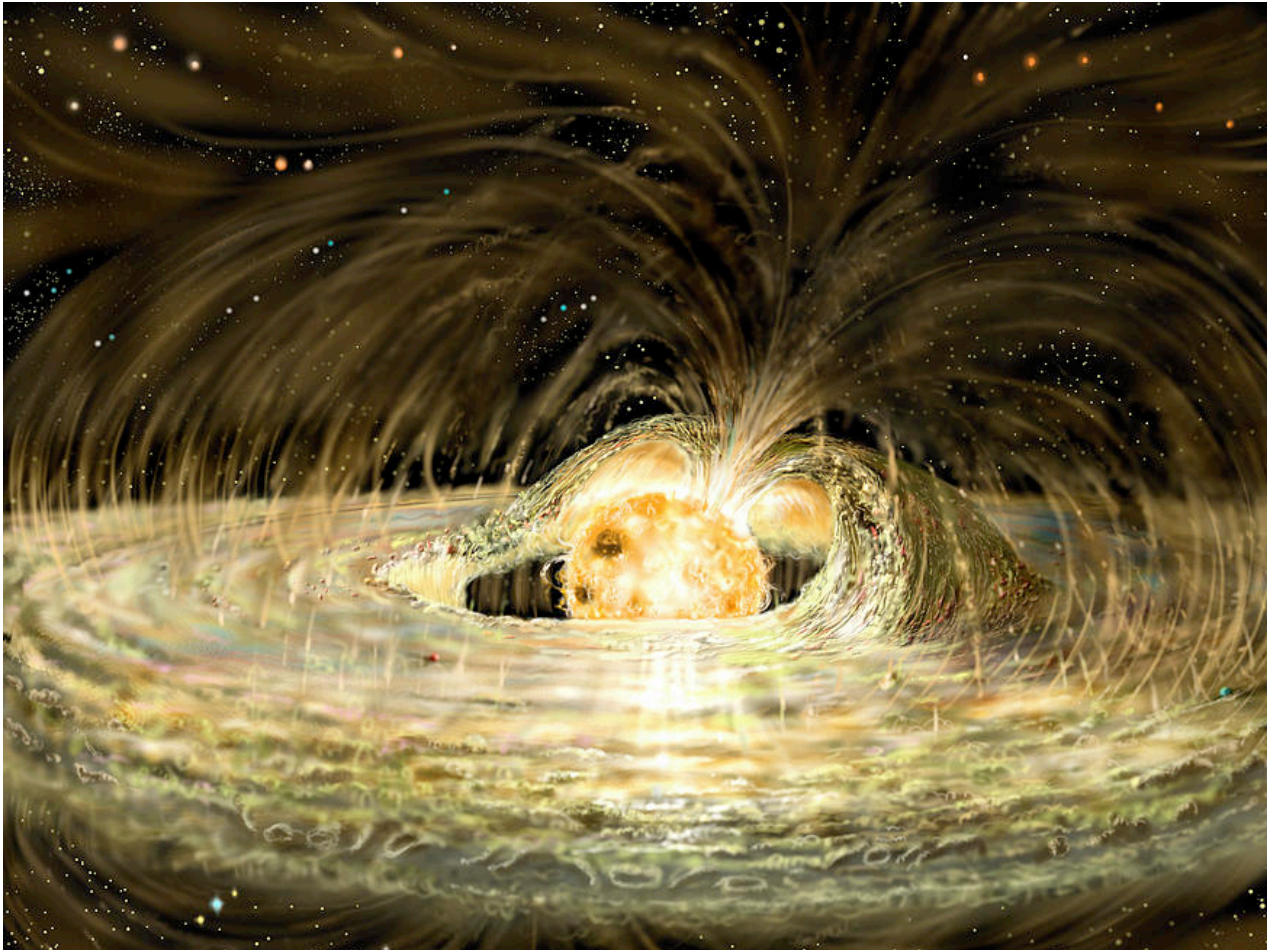
Diagnostic capabilities:

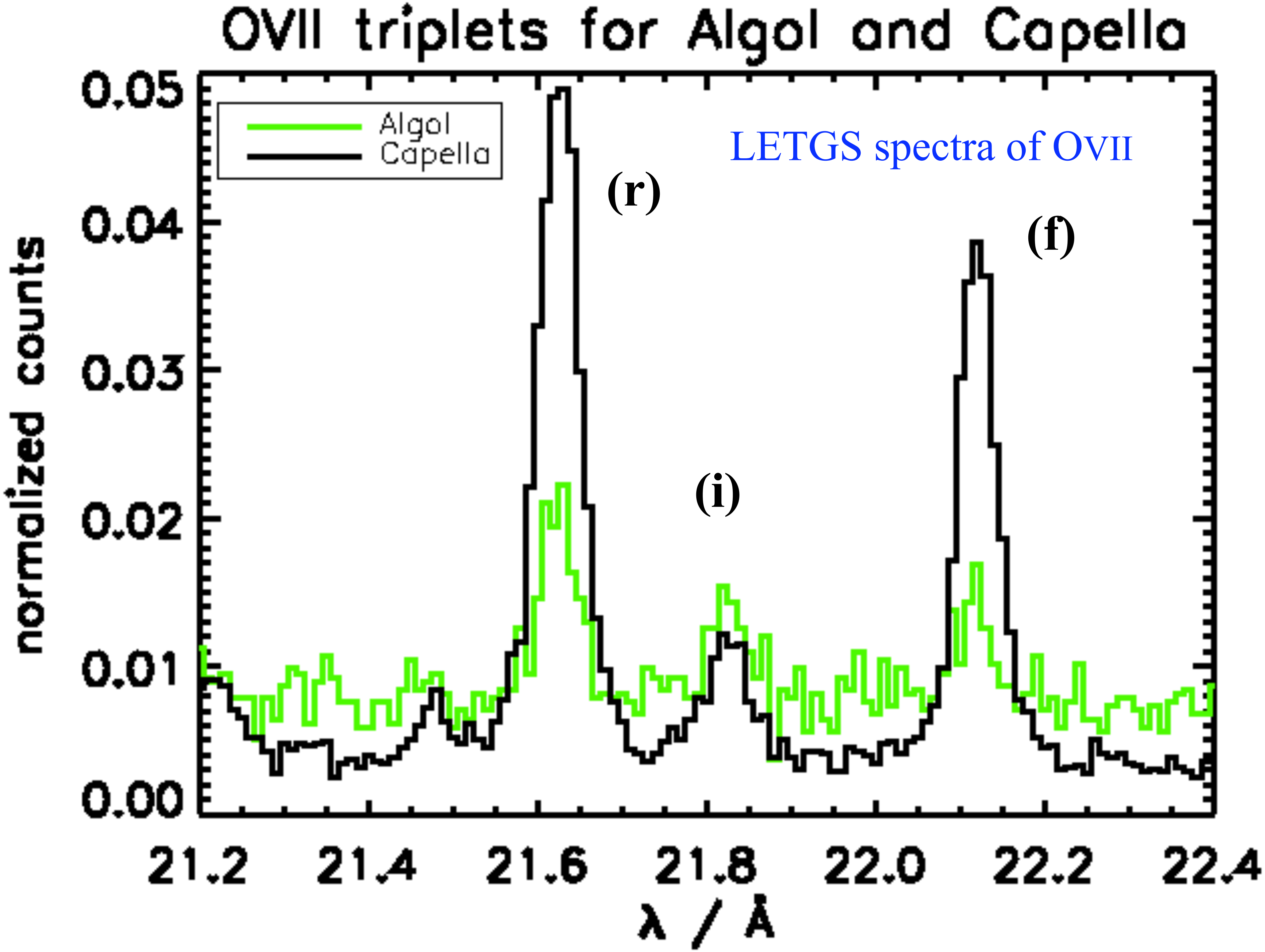
- Plasma temperature
- Plasma density
- Elemental composition
- Optical depth effects
- Doppler effects

Chandra LETGS:

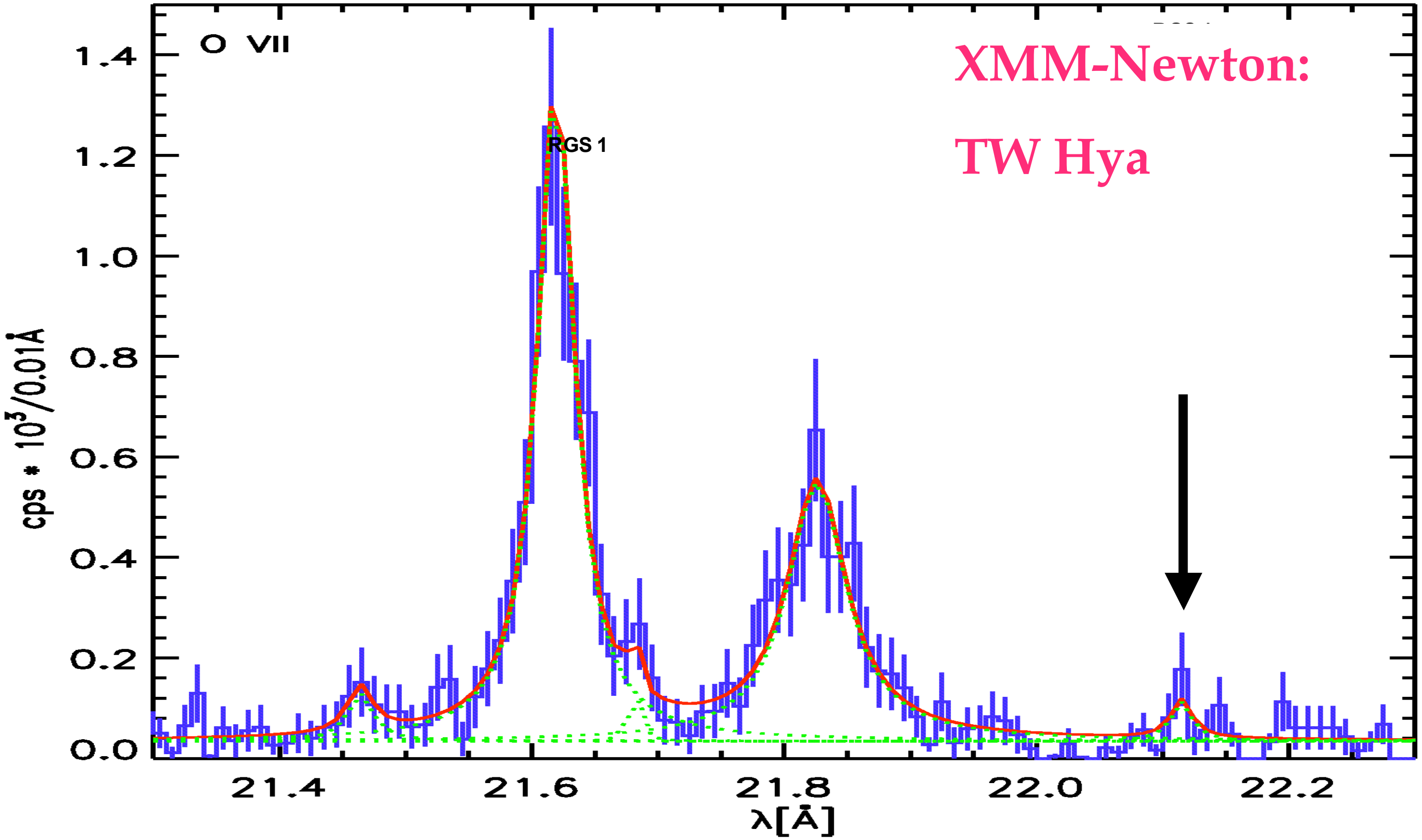



OVIII/OVII ratio
Oxygen luminosity (in units of 10^{28} erg s^{-1})
V4046 Sgr
MP Mus
TW Hya
AB Aur
BP Tau
CR Cha
RU Lup
T Tau
cTTS
Ness et al. (2004)
Robrade & Schmitt (2007)




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

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



forbidden line almost absent !

Stelzer & Schmitt (2004) TW Hya

Schmitt et al. (2005) BP Tau

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

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

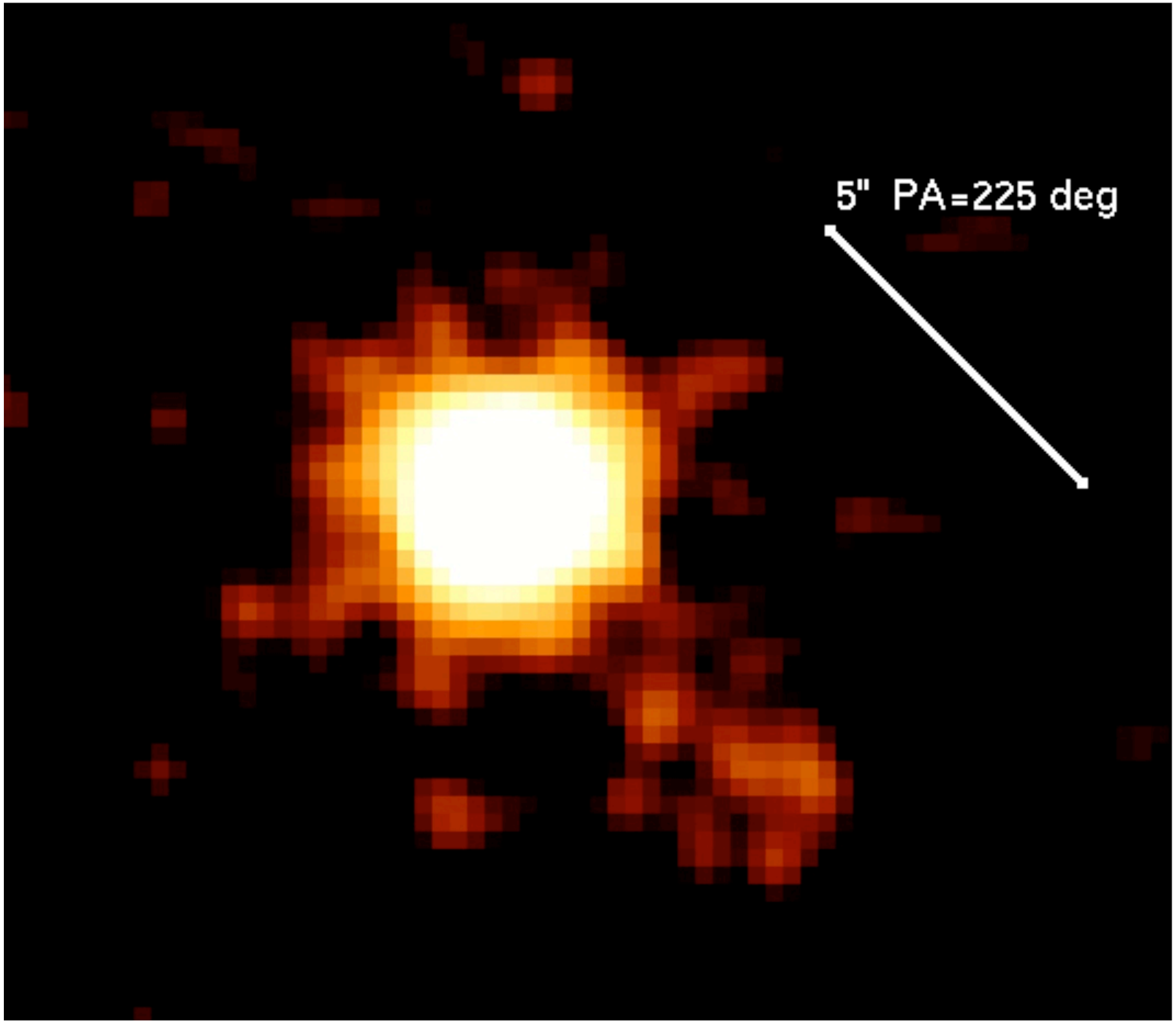
$L_X \approx 10^{30}\quad erg / \sec$

metal-depleted accretion shock !

New Topics:

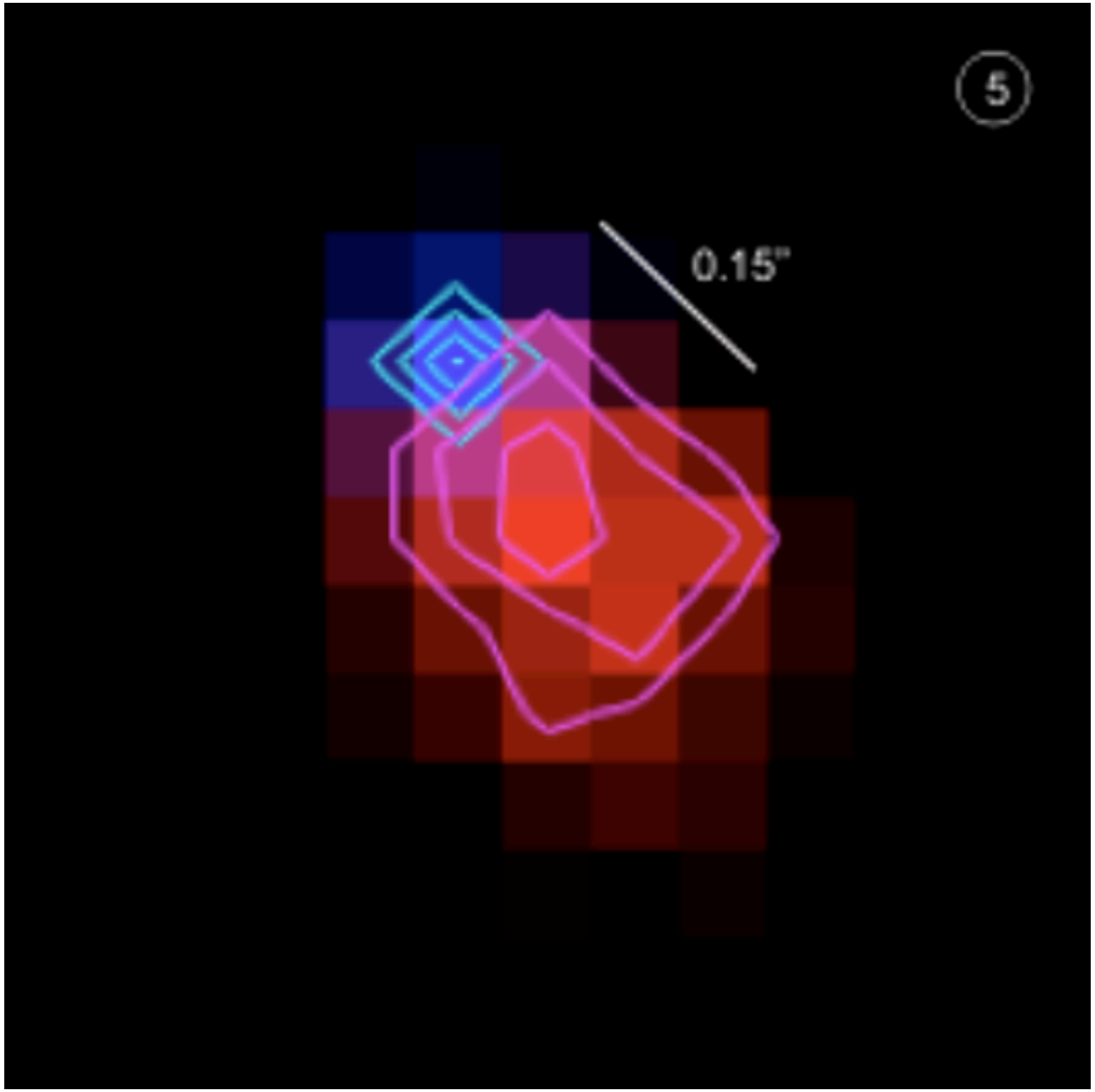
- Stellar X-ray jets
- Extrasolar planet host stars

The X-ray jet of the CTTS DG Tau

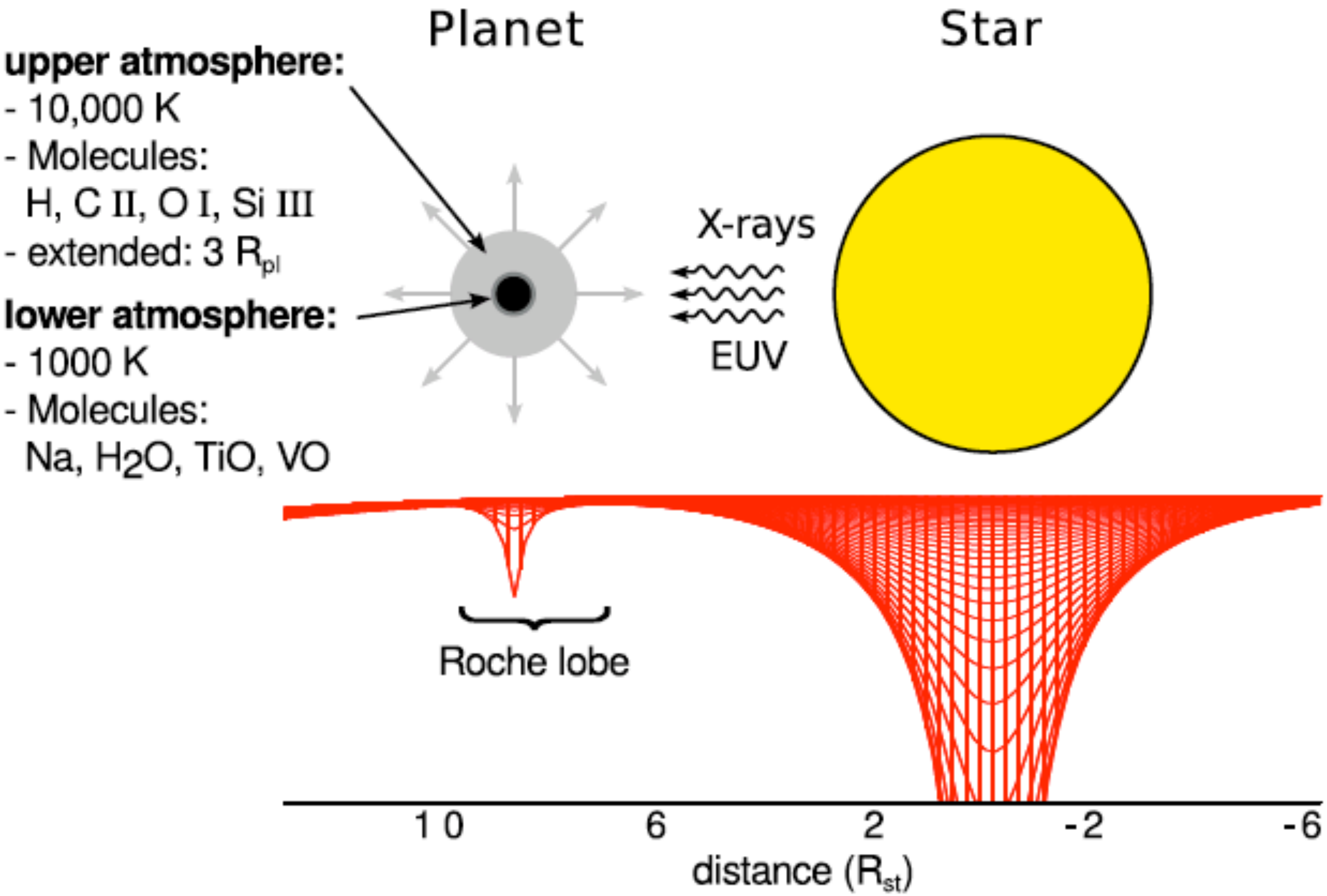


Guedel et al. (2008)

The inner X-ray jet of DG Tau



Schneider et al. (2008)



Extreme levels of X-ray irradiation on Hot Jupiters around active stars !

A little comparison ……

X-ray irradiation on solar system and extrasolar planets

	$L_{X,host}$ (cgs)	a (AU)	F_X (cgs)	T_{eff} (K)
Earth	10^{27}	1	0.35	300
Jupiter	10^{27}	5.2	0.013	120
51 Peg b	$5\ 10^{26}$	0.052	65.4	1250
CoRoT 2b	$4\ 10^{29}$	0.028	$1.8\ 10^{5}$	1800

CoRoT 2b is the planet with the largest known X-ray irradiation !

(Some) Open issues:

- Nonthermal X-ray emission ?
- Energetic particle production ?
- Dopplershifts ?
- Line profiles ?
- Jets and accretion spots ?
- ……………