X-ray Diagnostics and Their Relationship to Magnetic Fields

David Cohen
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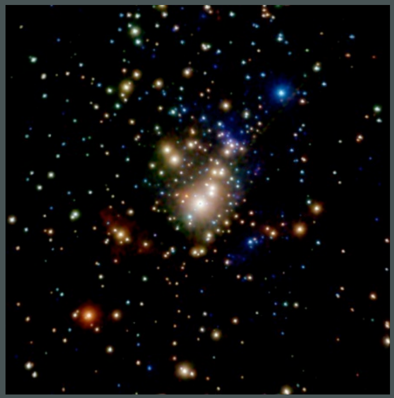
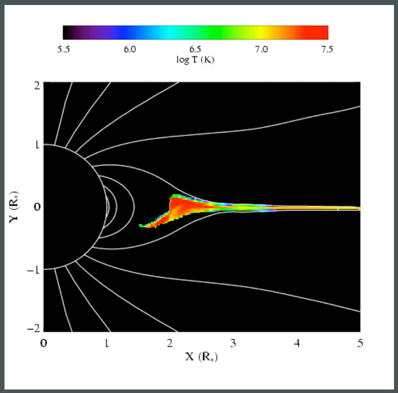
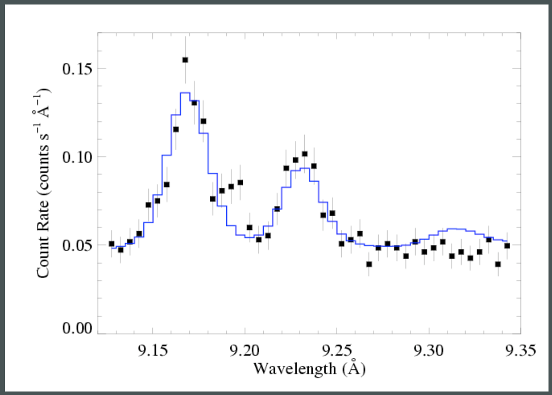
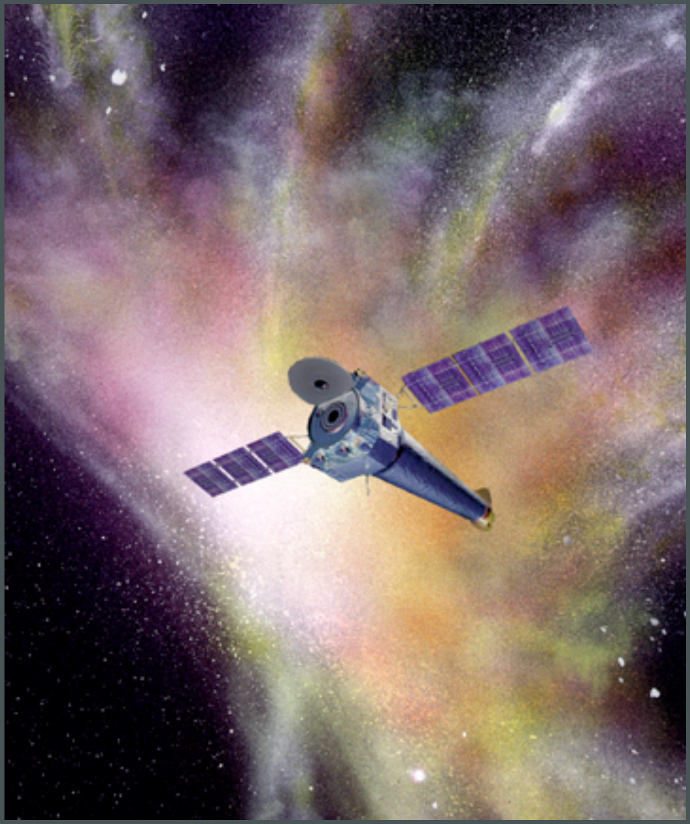






Launched 2000: superior
sensitivity,
spatial resolution, and
spectral resolution

Chandra

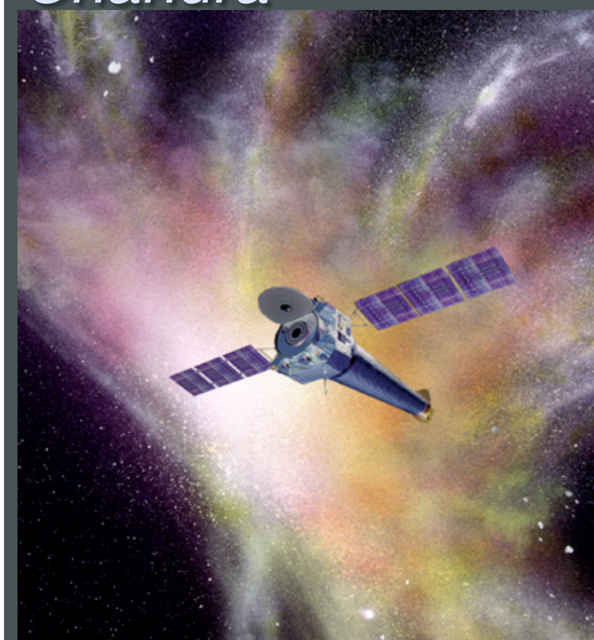


XMM-Newton

sub-arcsecond resolution

XMM-Newton

Chandra

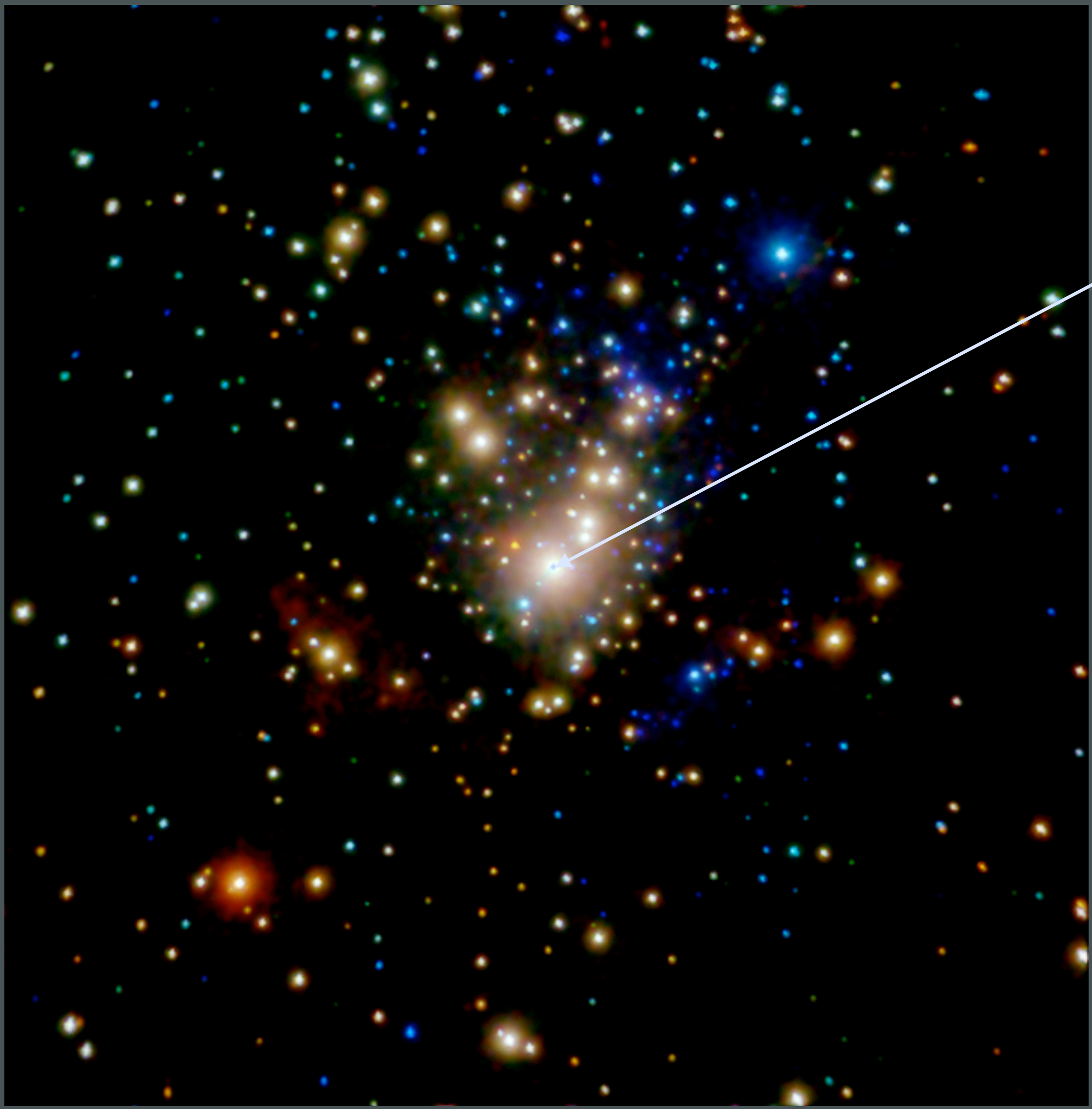


Both have CCD detectors for imaging spectroscopy:

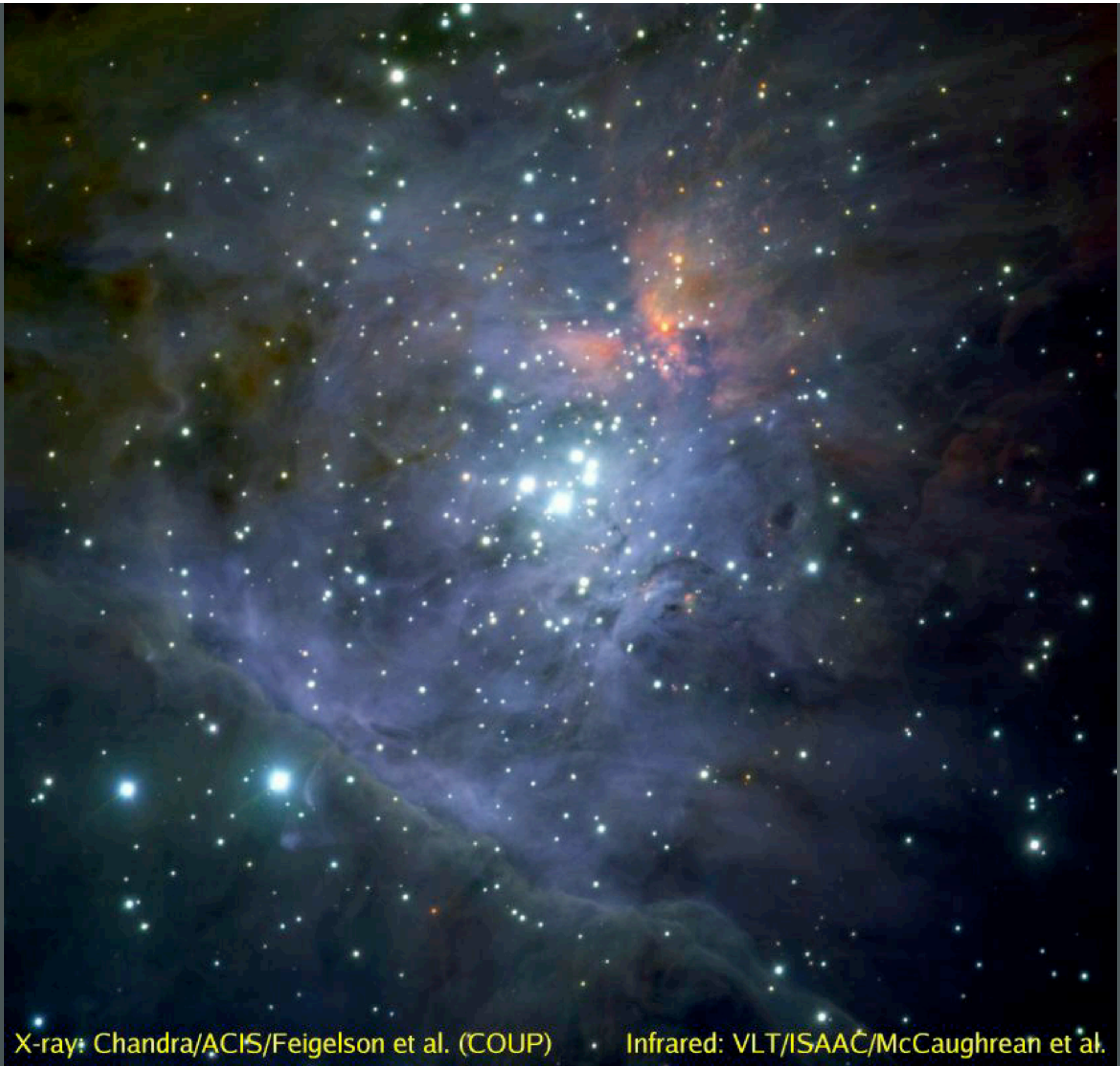
low spectral resolution: $R \sim 20$ to 50

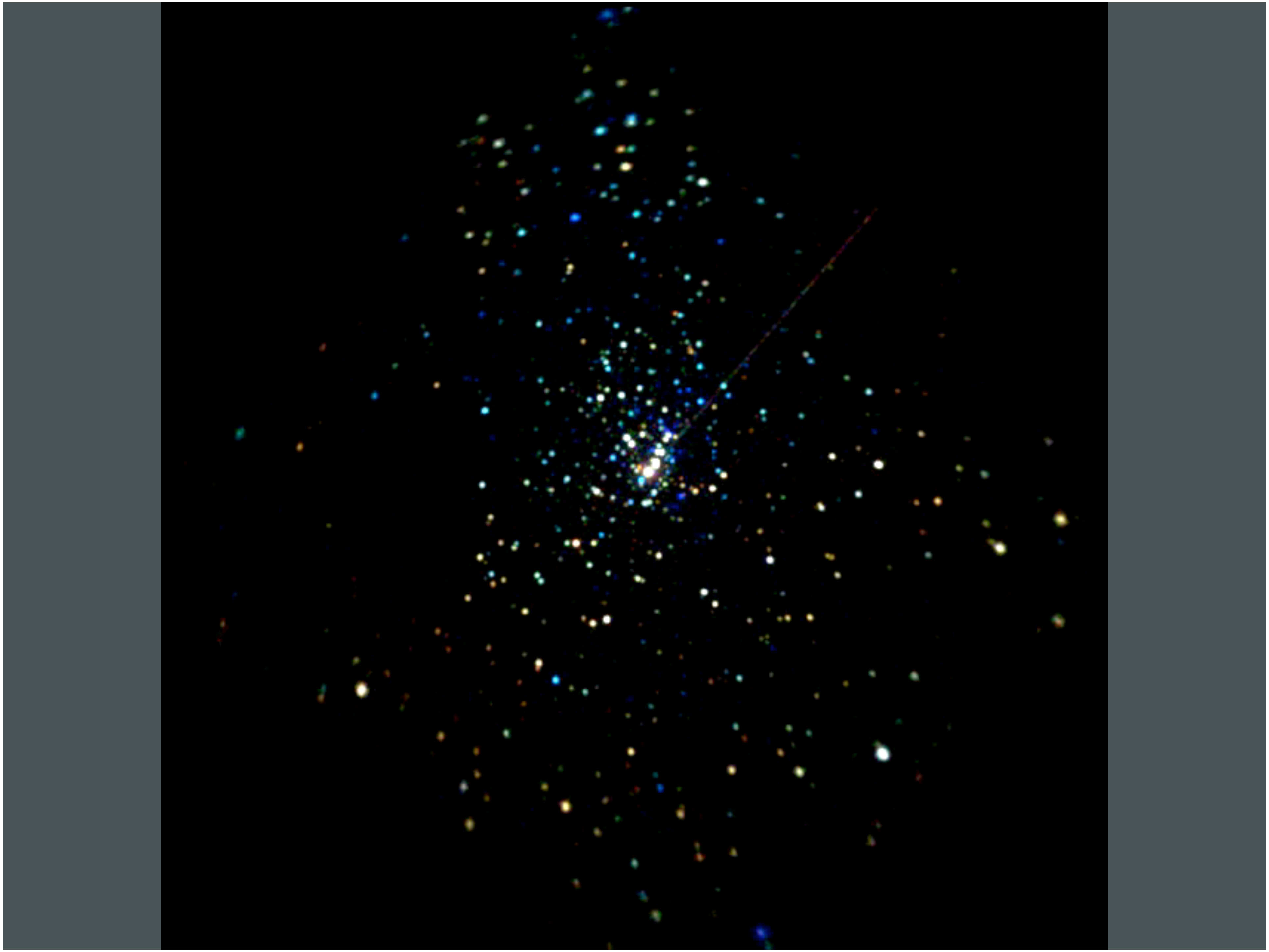
And both have grating spectrometers: $R \sim$ few 100 to 1000

Chandra ACIS
Orion Nebula Cluster (COUP)

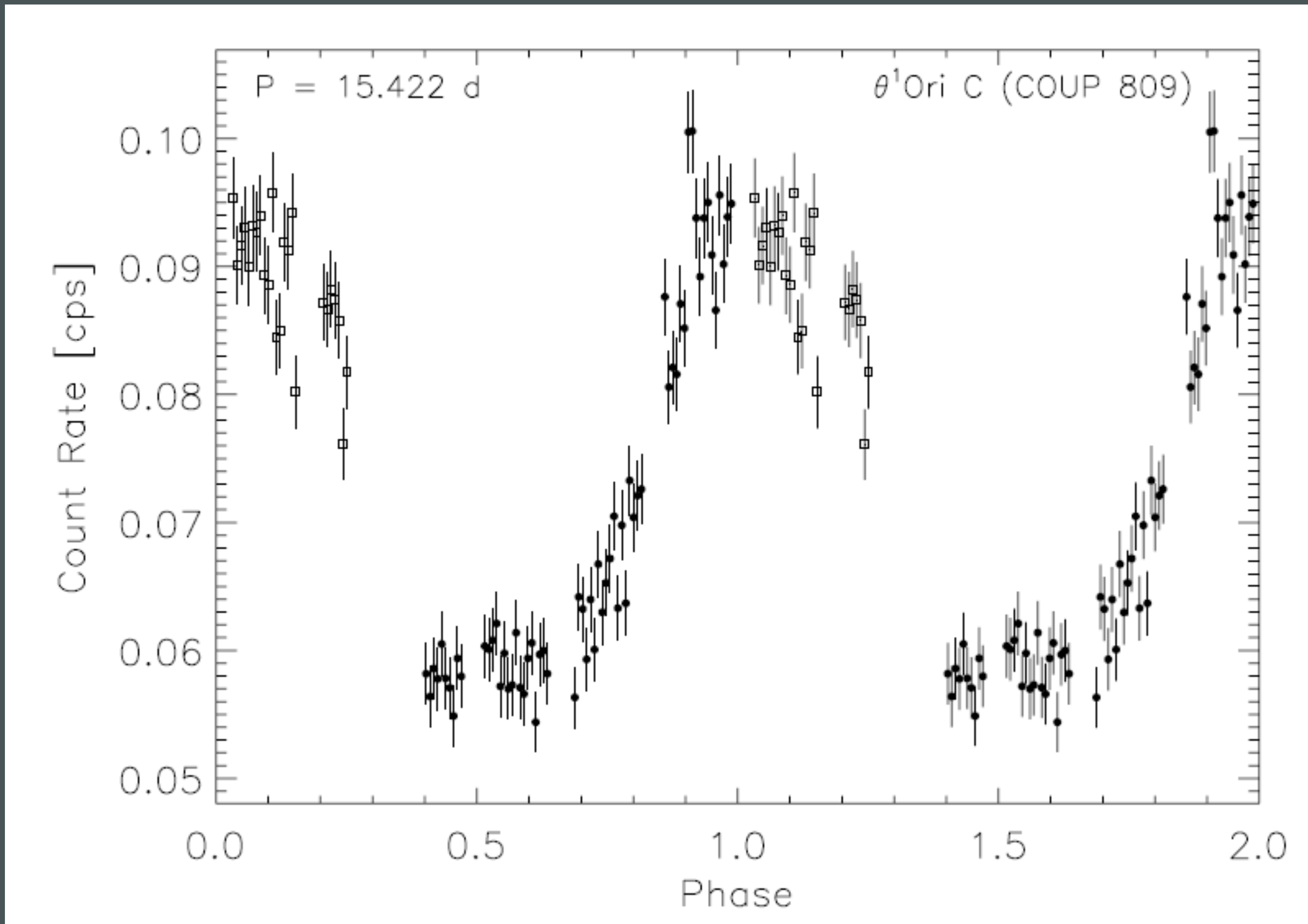


Color coded according to photon energy (red: <1keV; green 1 to 2 keV; blue > 2 keV)


X-ray: Chandra/ACIS/Feigelson et al. (COUP)
Infrared: VLT/ISAAC/McCaughrean et al.

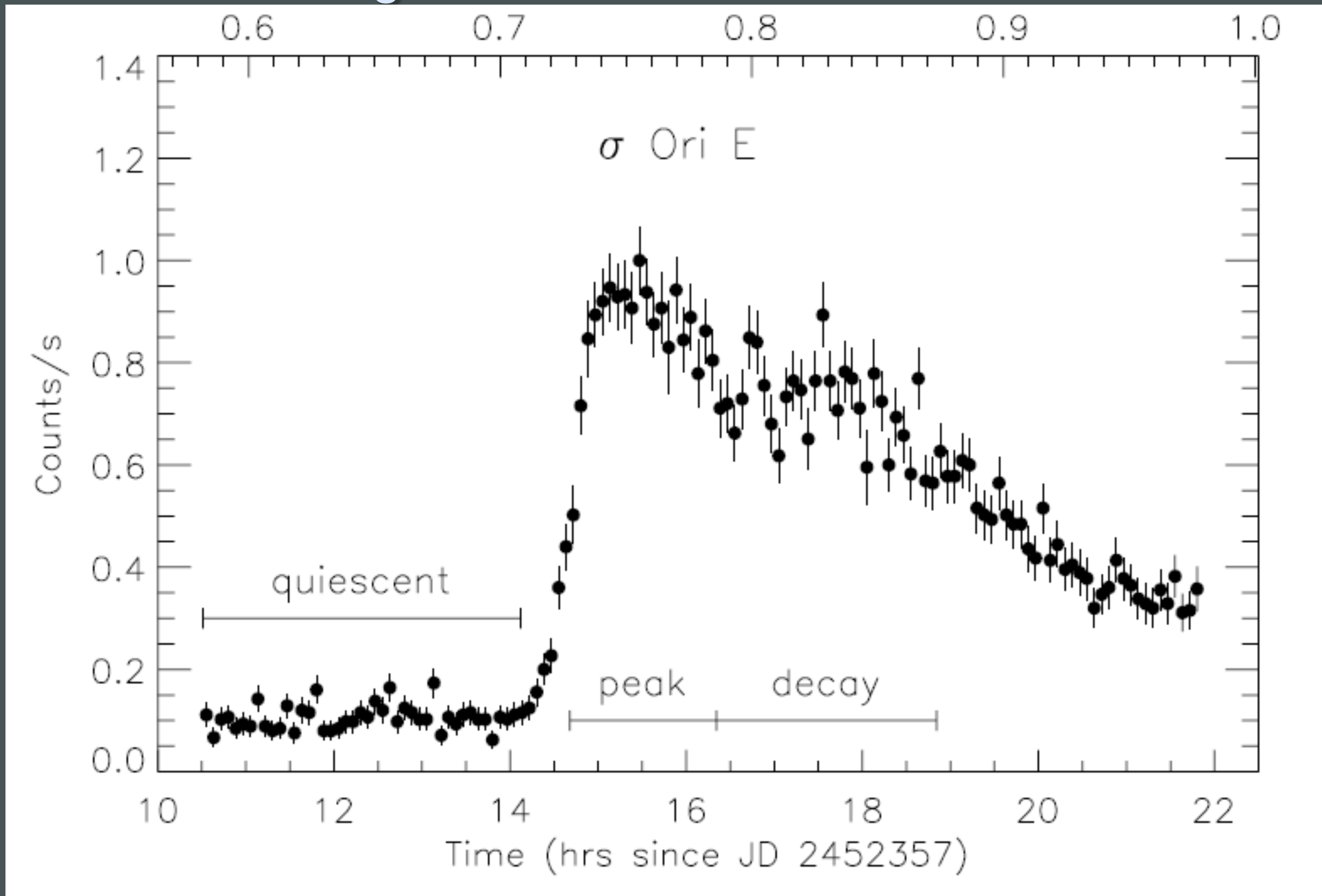


θ^1 Ori C: X-ray lightcurve



Stelzer et al. 2005

σ Ori E: *XMM* light curve



Sanz-Forcada et al. 2004

XMM EPIC spectrum of σ Ori E

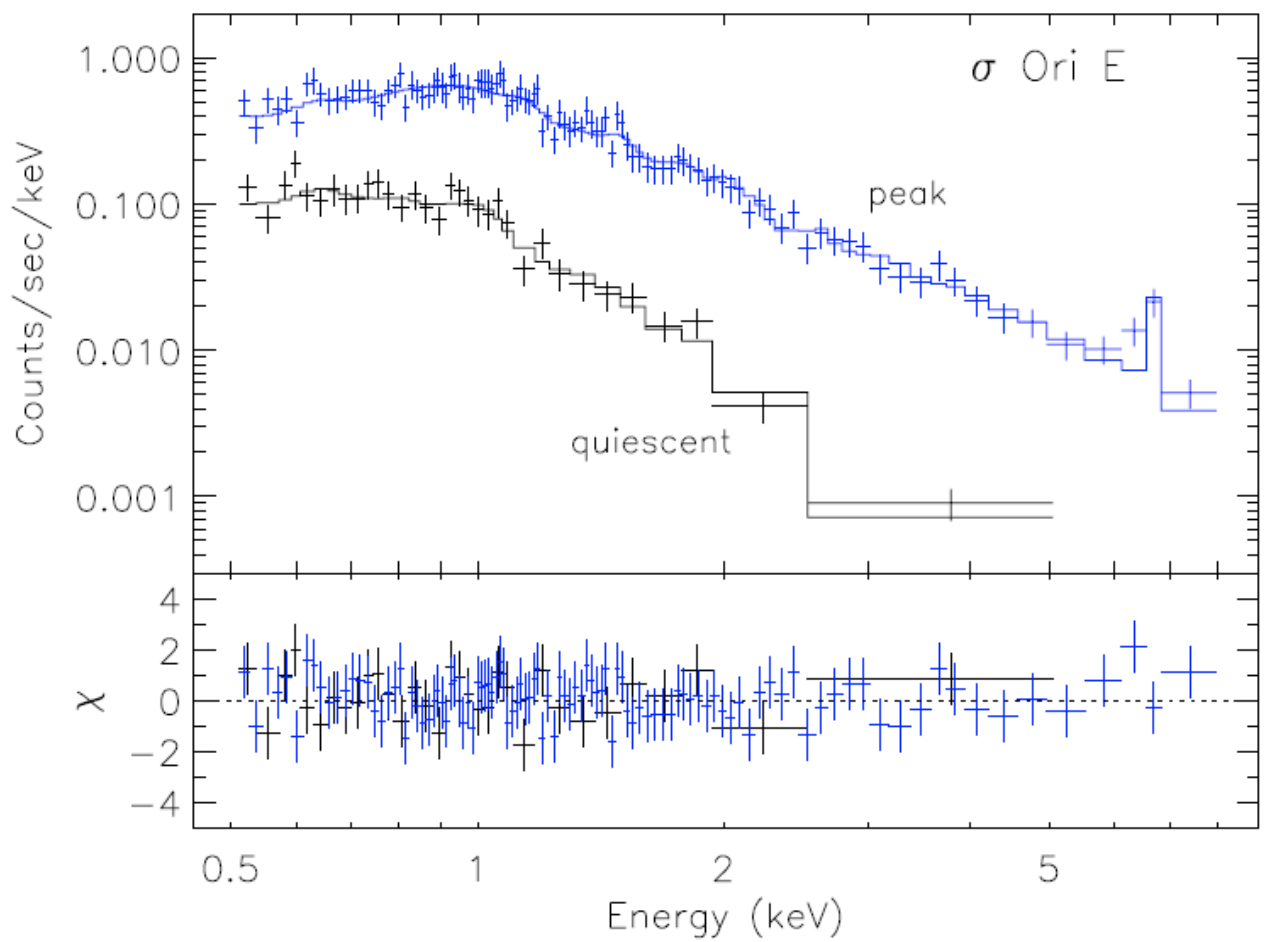
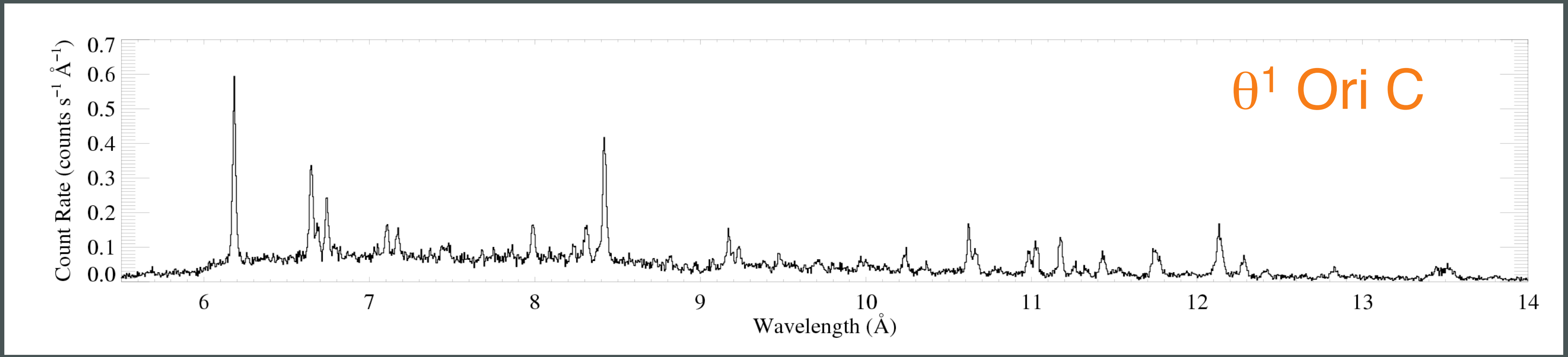
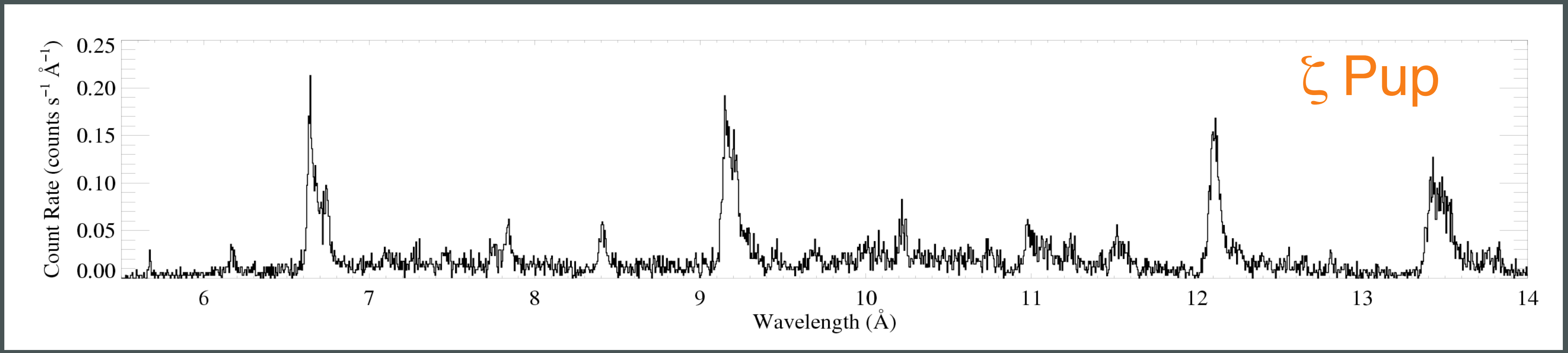


Fig. 9. PN spectra of σ Ori E during quiescence and at the peak of the flare. The best-fit model is also shown.

Sanz-Forcada et al. 2004

Chandra grating specra: θ¹ Ori C and a non-magnetic O star





Hot plasma emitting thermal x-rays

1 keV ~ 12×10^6 K ~ 12 Å

Shock heating: Δv = 300 km
gives T ~ 10^6 K (and T ~ v^2)

ROSAT 150 eV to 2 keV
Chandra, *XMM* 350 eV to 10 keV

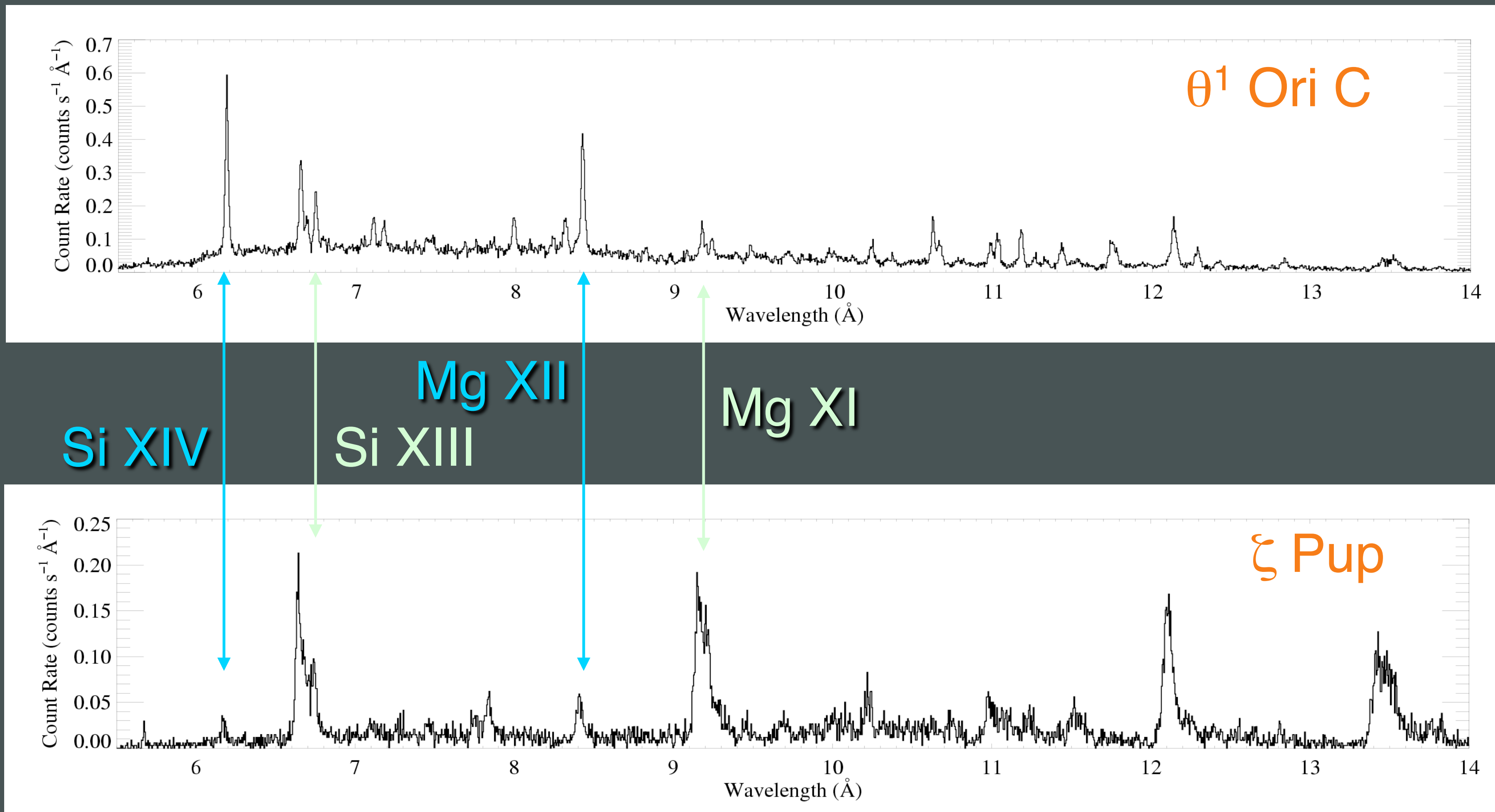
Hot plasma emitting thermal x-rays

1 keV ~ 12 × 10^6 K ~ 12 Å

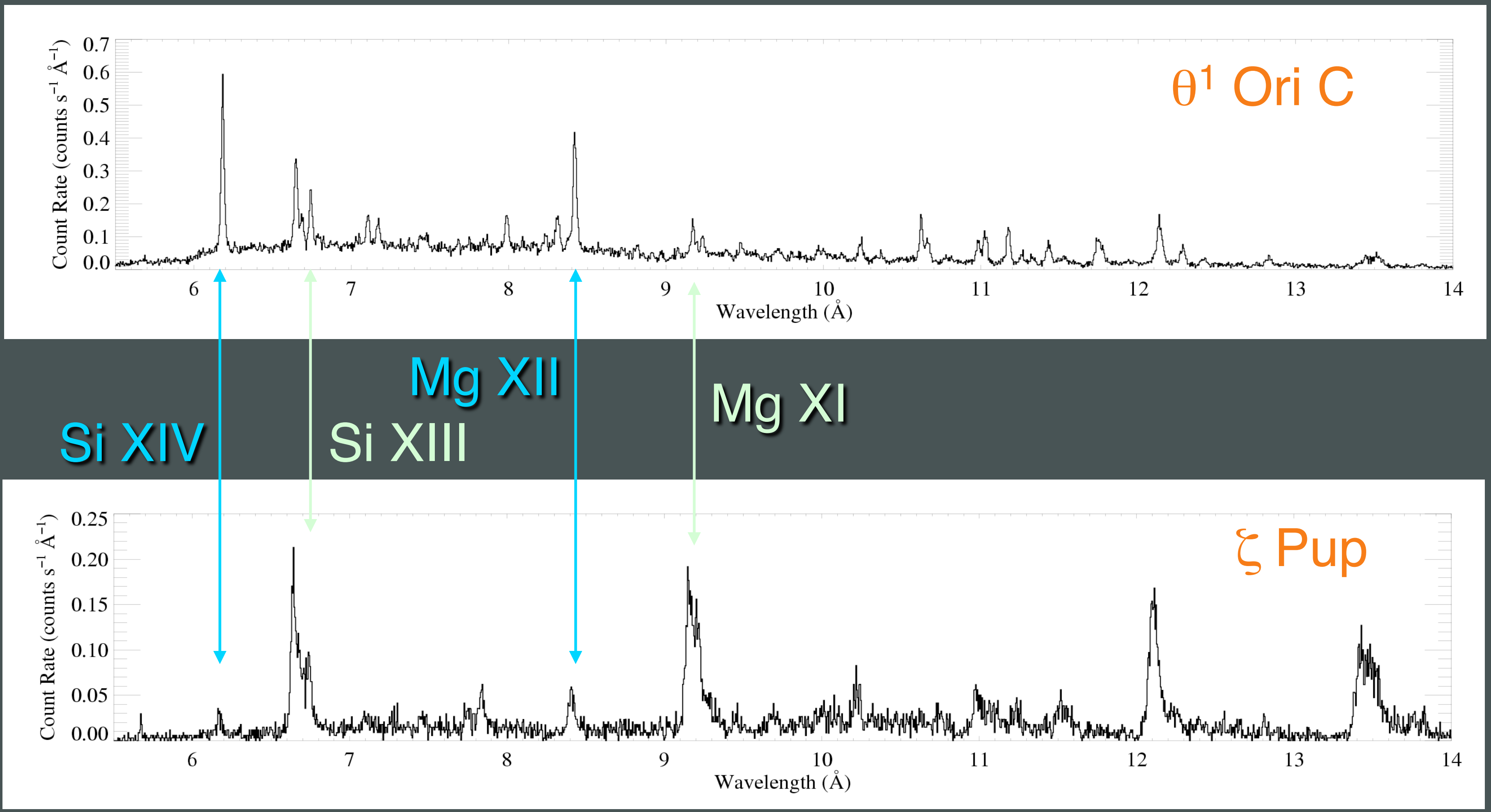
Shock heating: Δv = 1000 km
gives $T \sim 10^7$ K (and $T \sim v^2$)

ROSAT 150 eV to 2 keV
Chandra, *XMM* 350 eV to 10 keV

H-like/He-like ratio is temperature sensitive

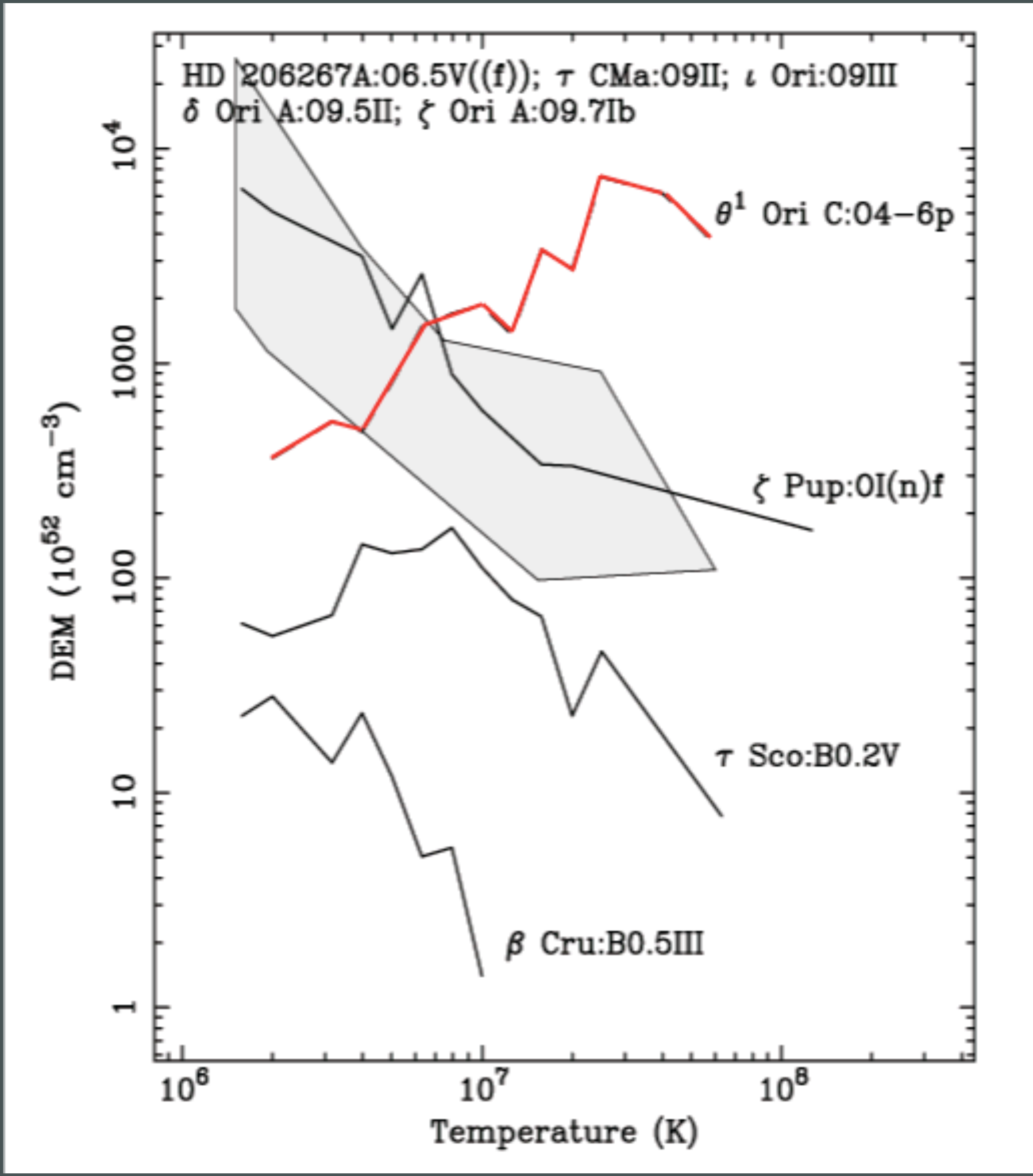


The magnetic O star – θ^1 Ori C – is hotter

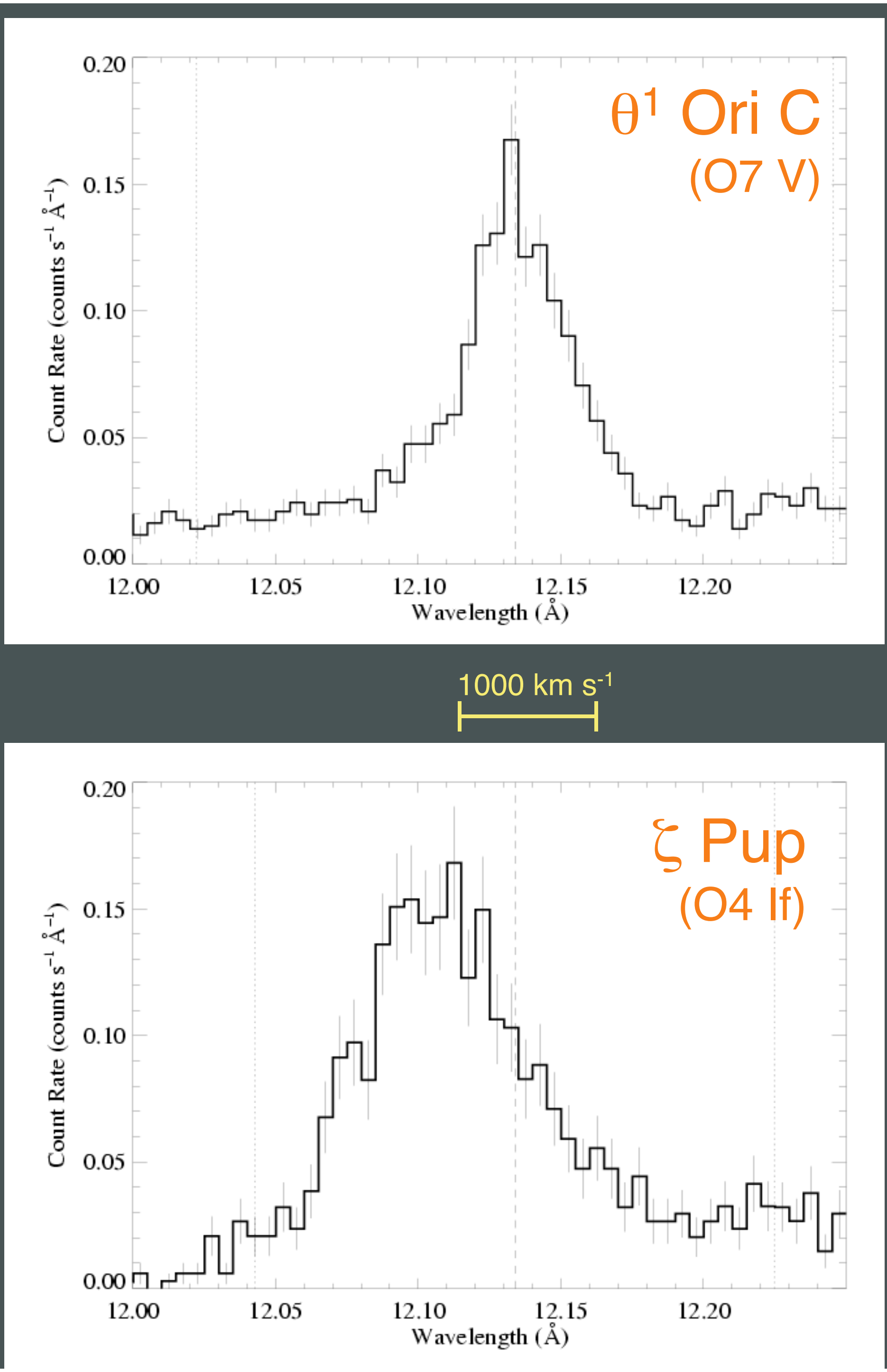


Differential Emission Measure
(temperature distribution)

θ^1 Ori C is much hotter

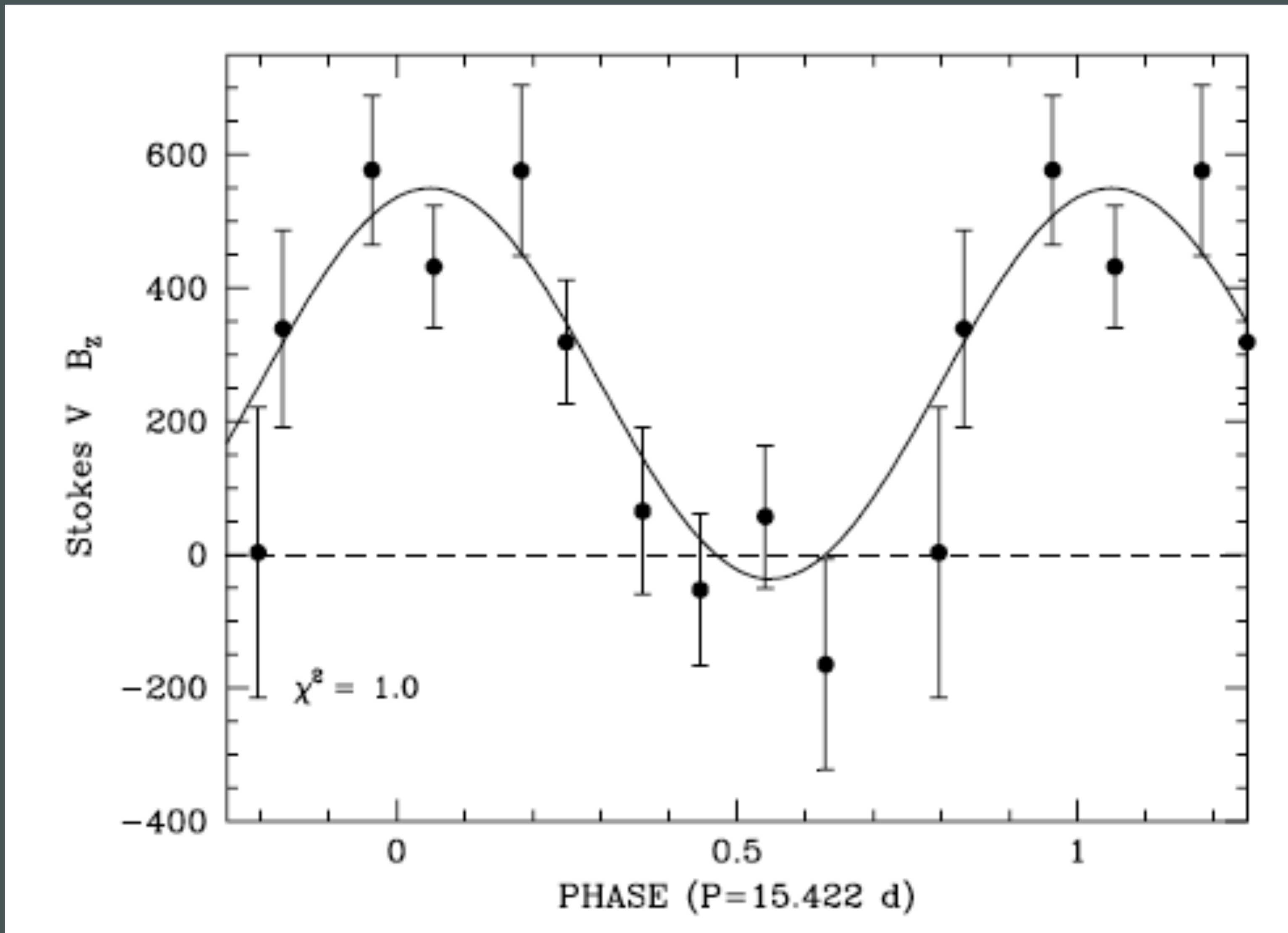


Wojdowski & Schulz (2005)



Emission lines are significantly **narrower**, too

Dipole magnetic field



Wade et al. 2008

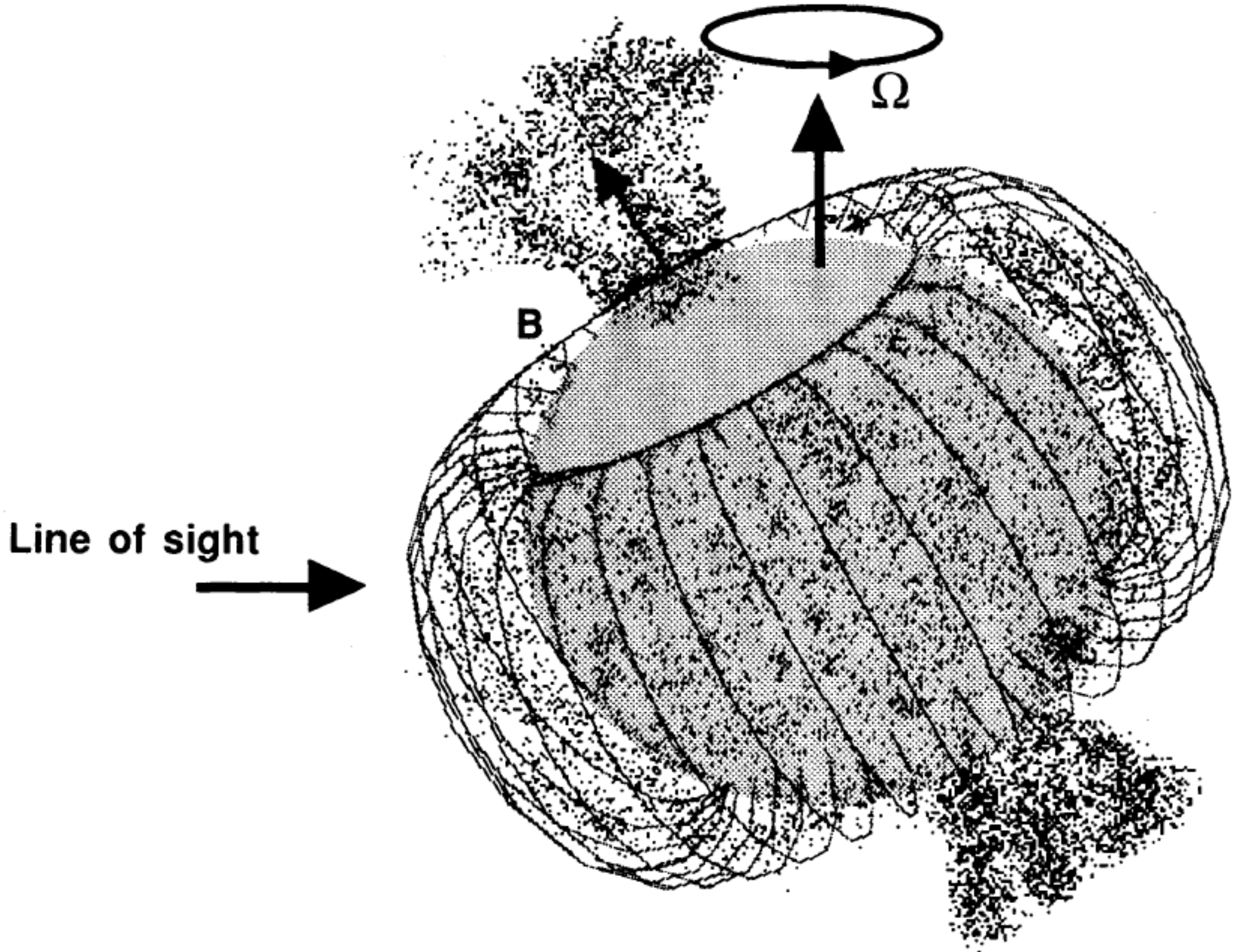
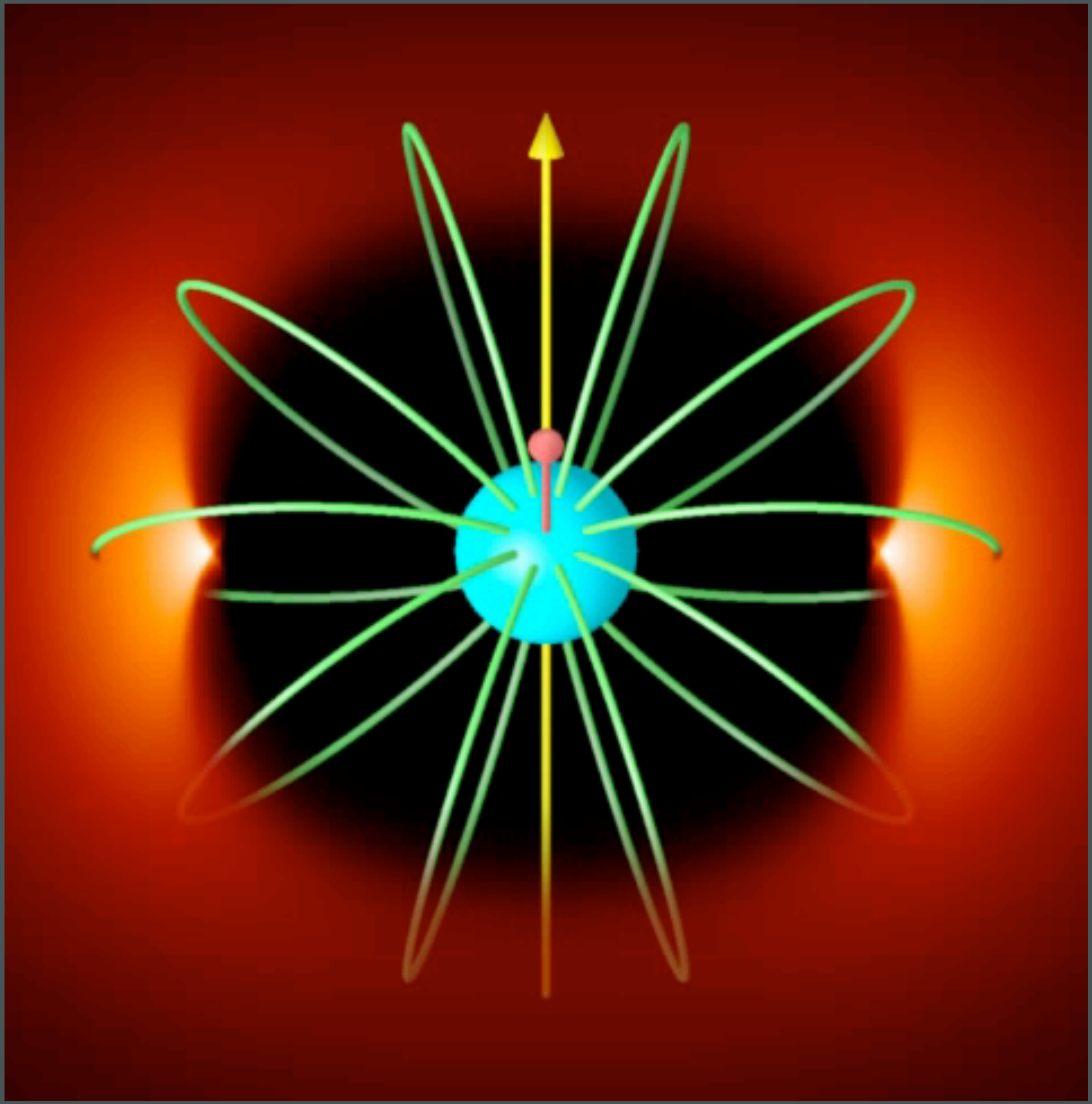


Fig. 11*b*

Shore & Brown, 1990

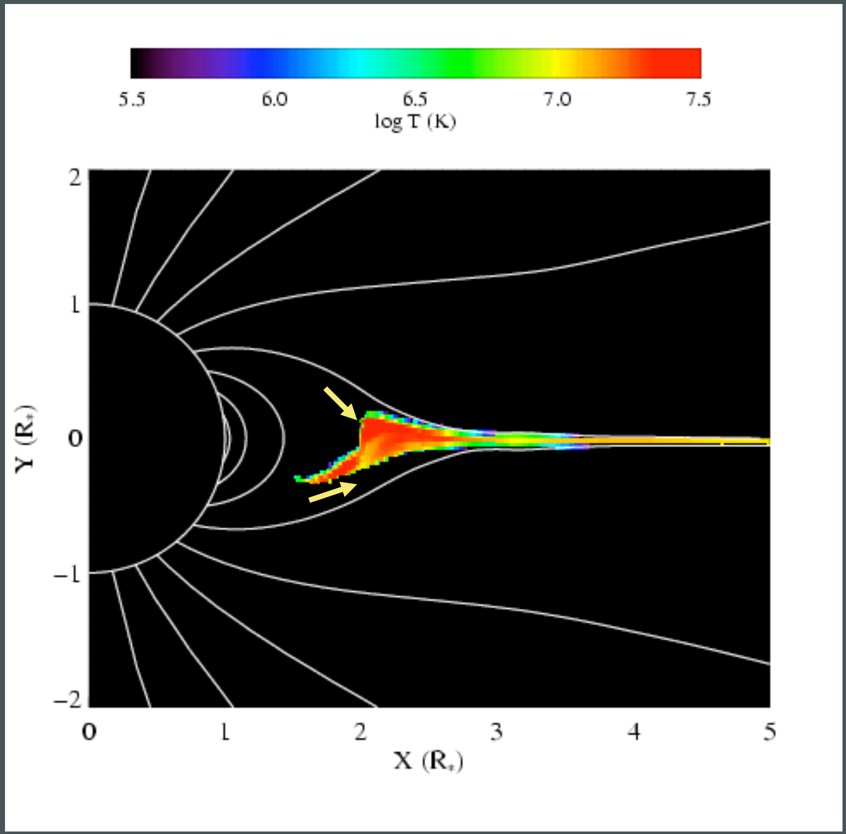
Rotating tilted dipole



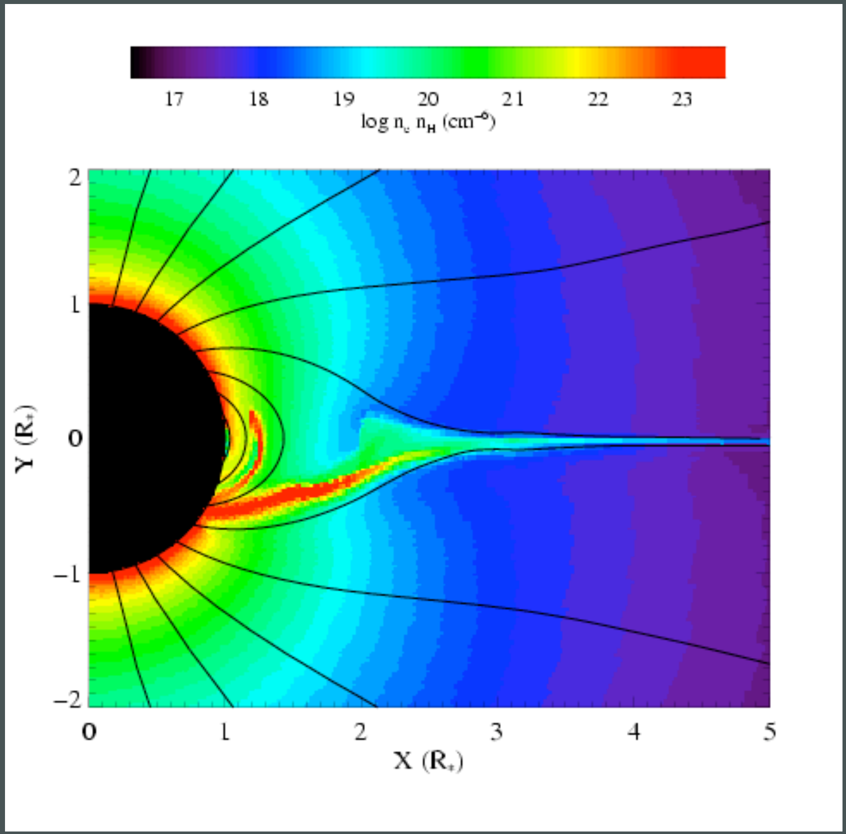
Simulation/visualization courtesy R. Townsend

MHD simulations of magnetically channeled wind

temperature



emission measure

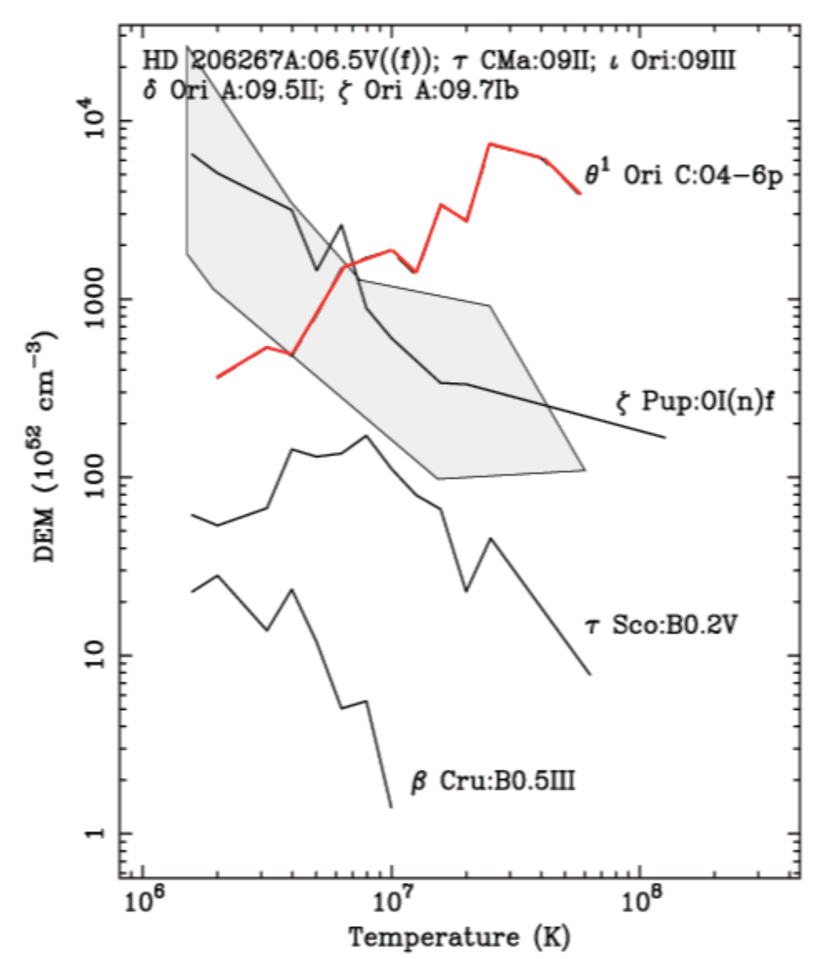


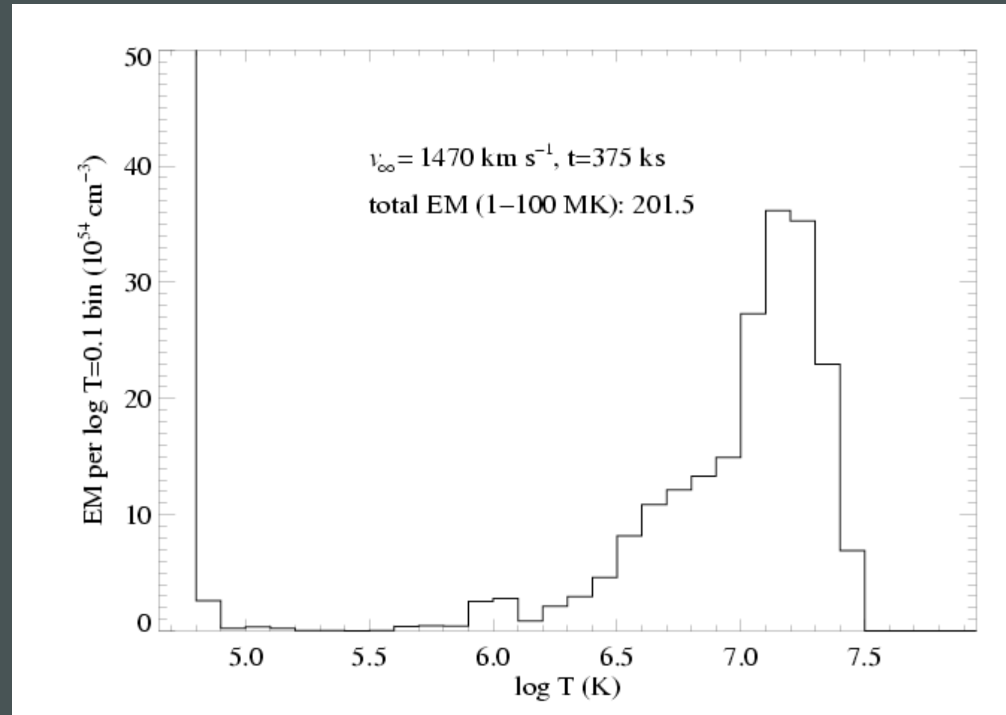
simulations by A. ud-Doula; Gagné et al. (2005)

Channeled collision is close to head-on:

$\Delta v > 1000$ km s^{-1} : $T > 10^7$ K

Differential emission measure
(temperature distribution)

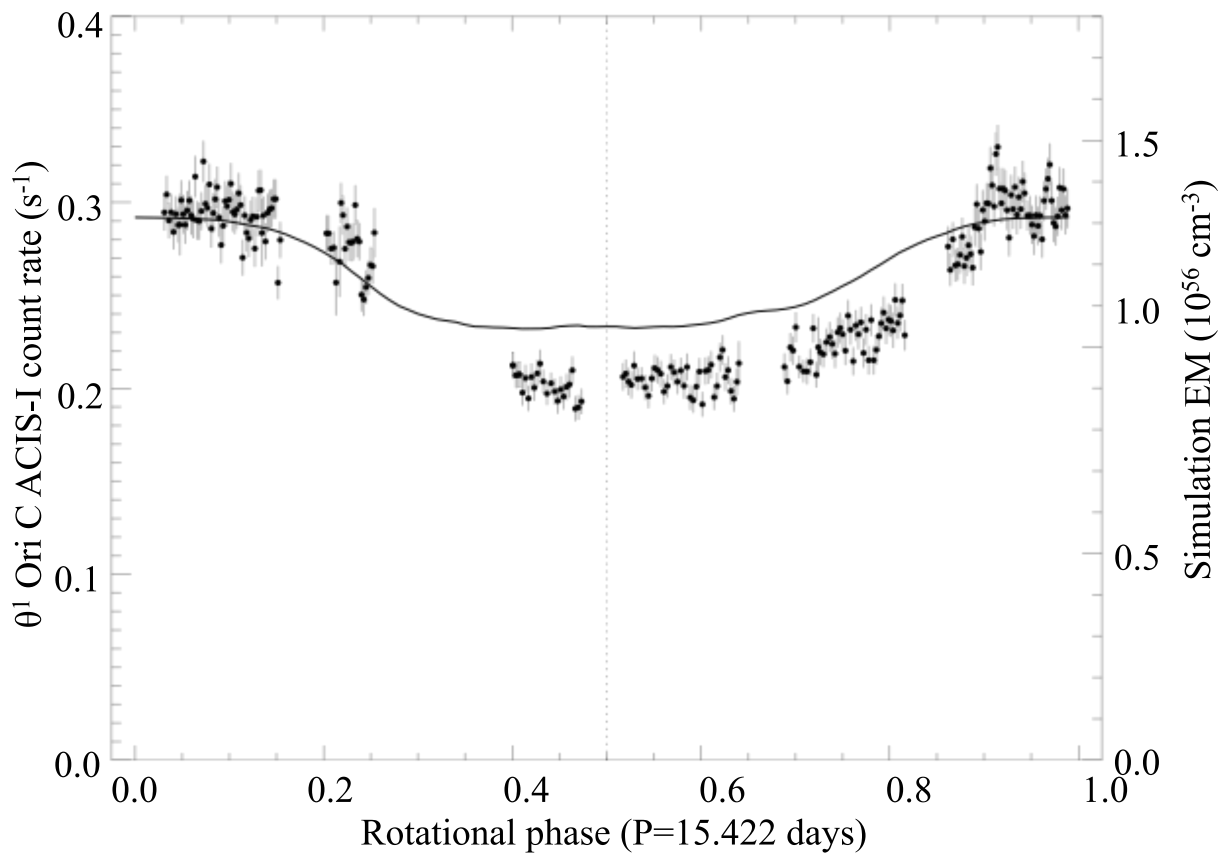




Wojdowski & Schulz (2005)

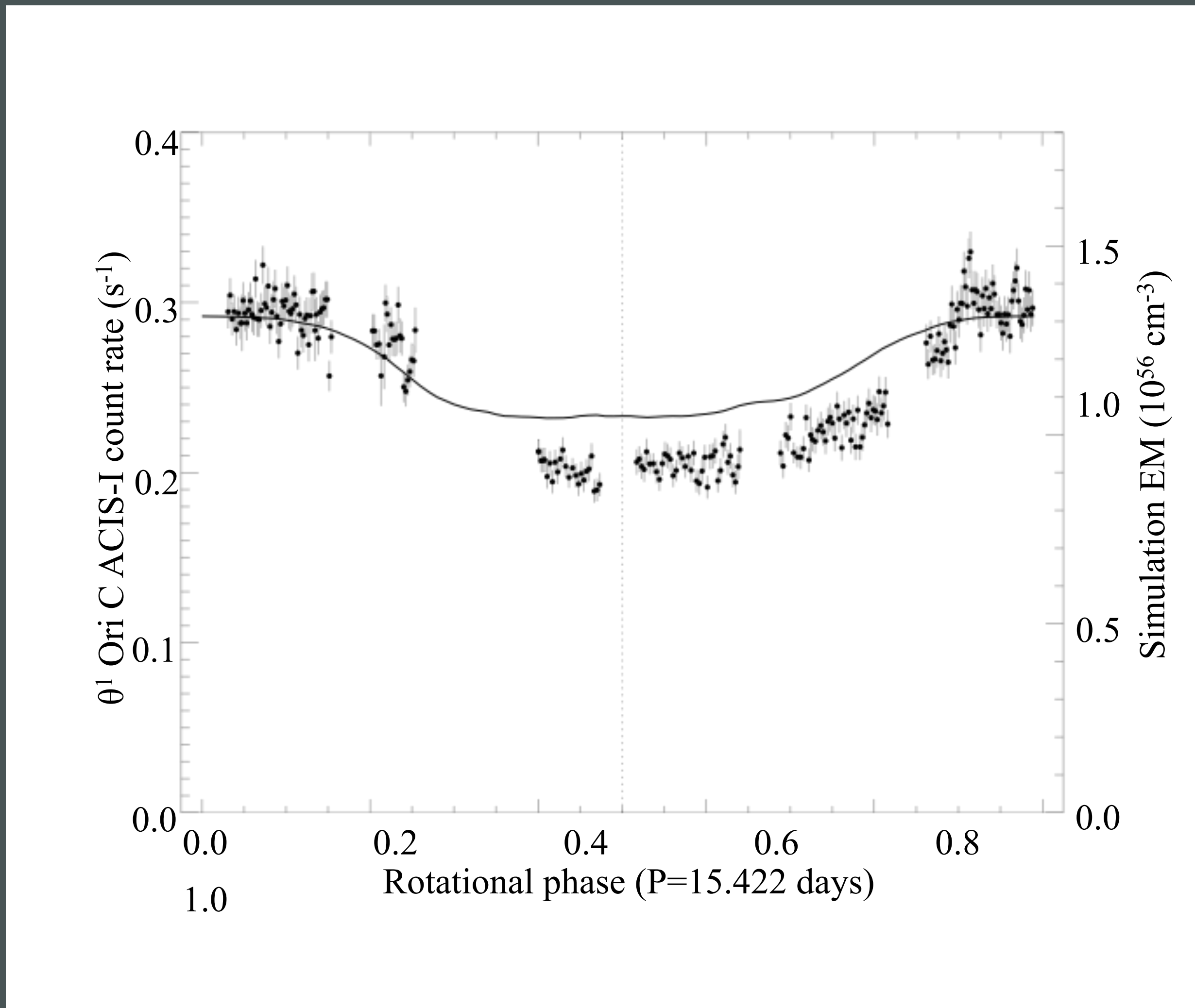
MHD simulation of θ^1 Ori C reproduces the observed differential emission measure

Chandra broadband count rate vs. rotational phase



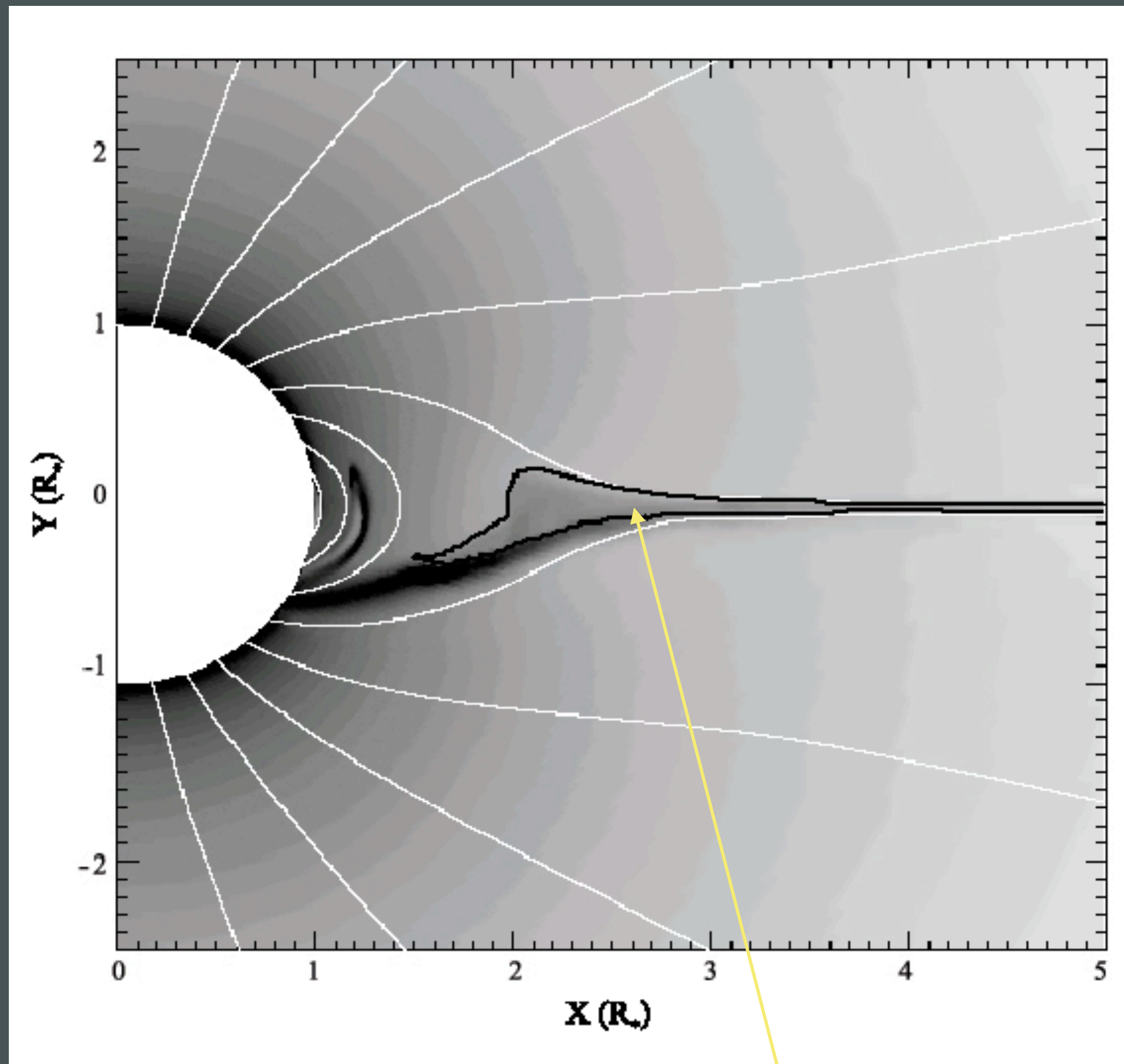
Model from MHD simulation

The star itself occults the hot plasma torus



The closer the hot plasma is to the star, the deeper the dip in the x-ray light curve

Emission measure

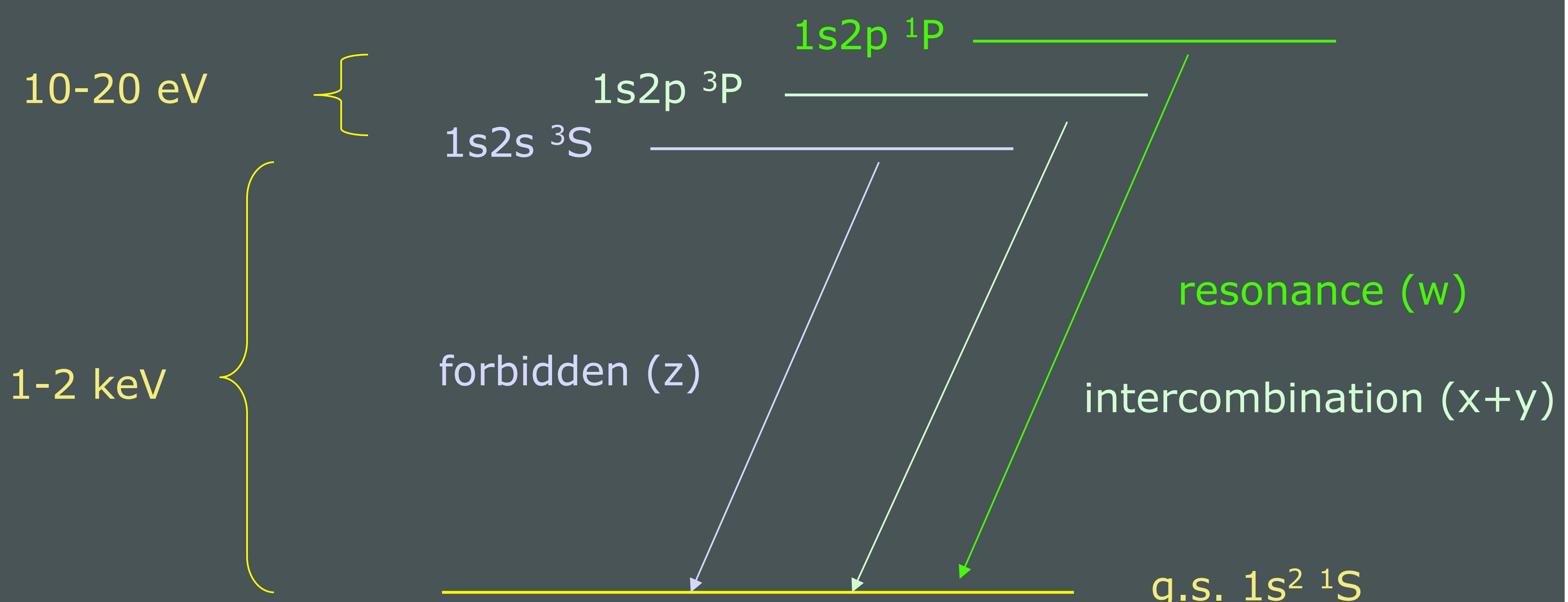


contour encloses $T > 10^6$ K

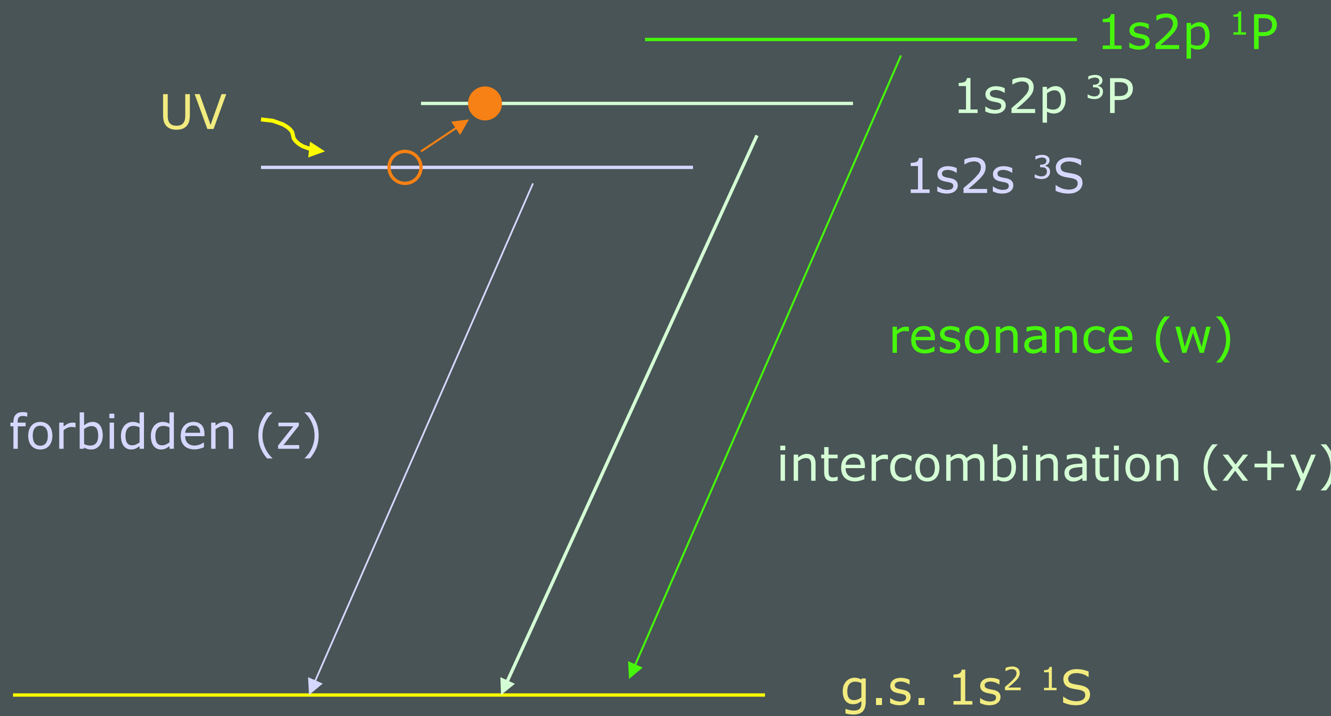
Helium-like species' forbidden-to-intercombination line ratios – *f/i* or z/*(x+y)* – provide information about the *location* of the hot plasma

…not the *density*, as is usually the case.

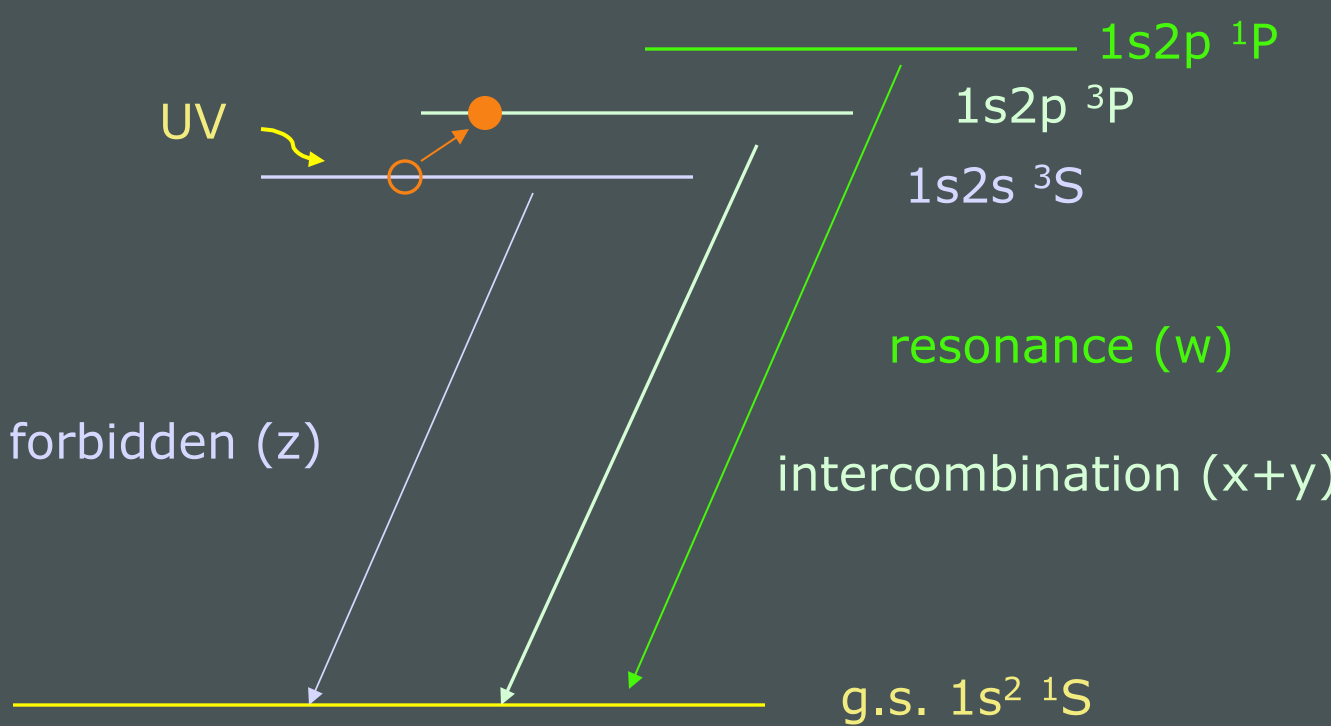
Helium-like ions (e.g. O^{+6}, Ne^{+8}, Mg^{+10}, Si^{+12}, S^{+14}) – schematic energy level diagram



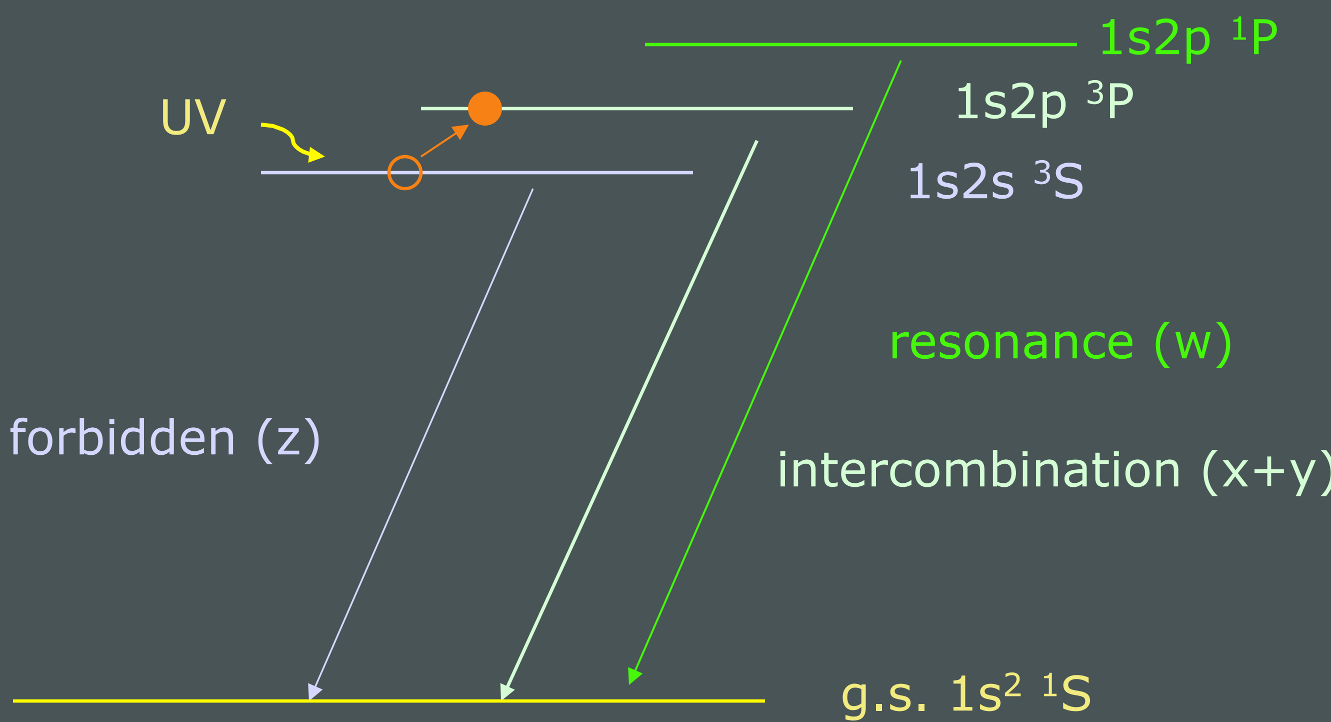
Ultraviolet light from the star's photosphere drives photoexcitation out of the ^3S level

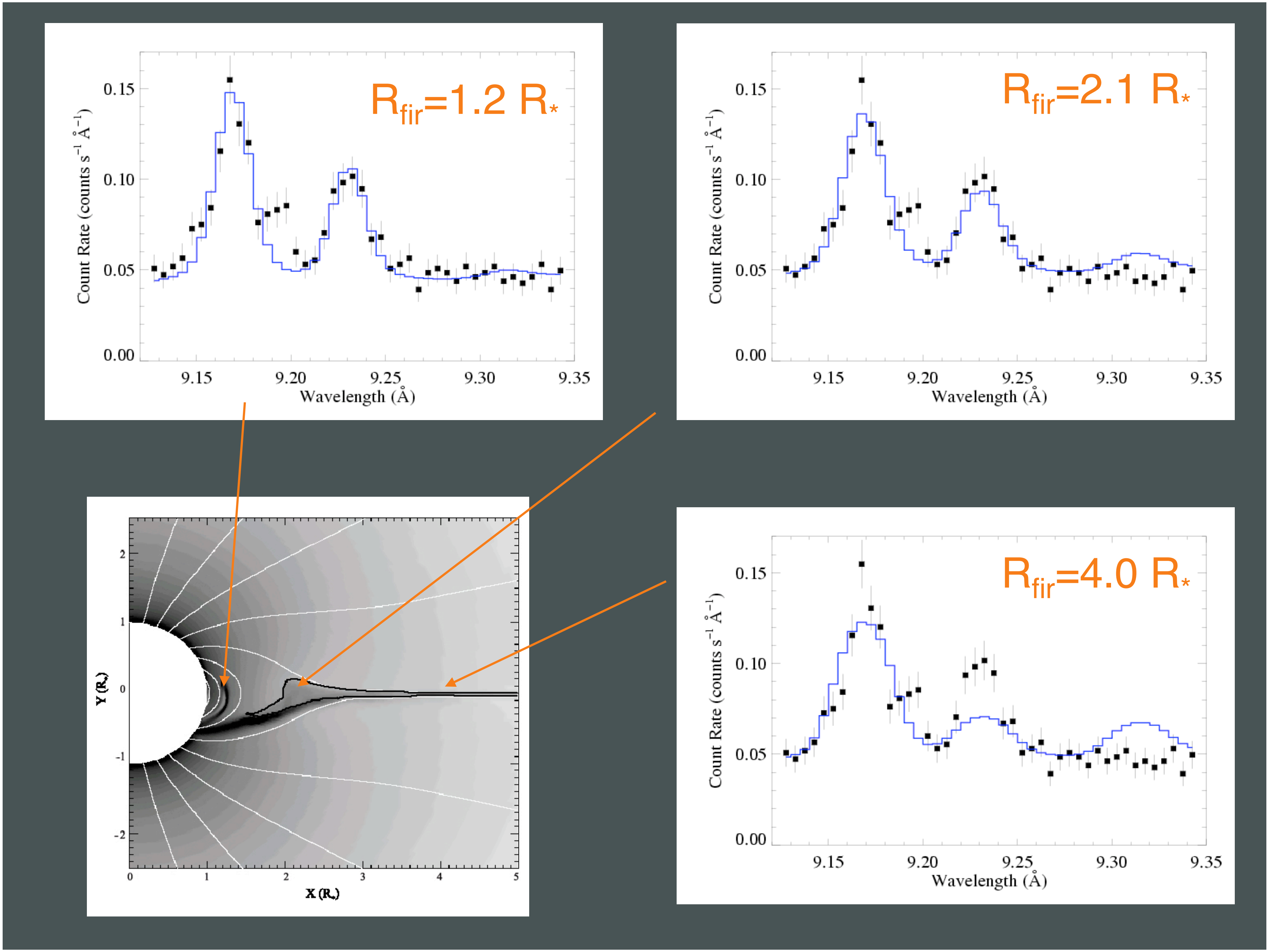


The f/i ratio is thus a diagnostic of the local UV mean intensity…



…and thus the distance of the x-ray emitting plasma from the photosphere



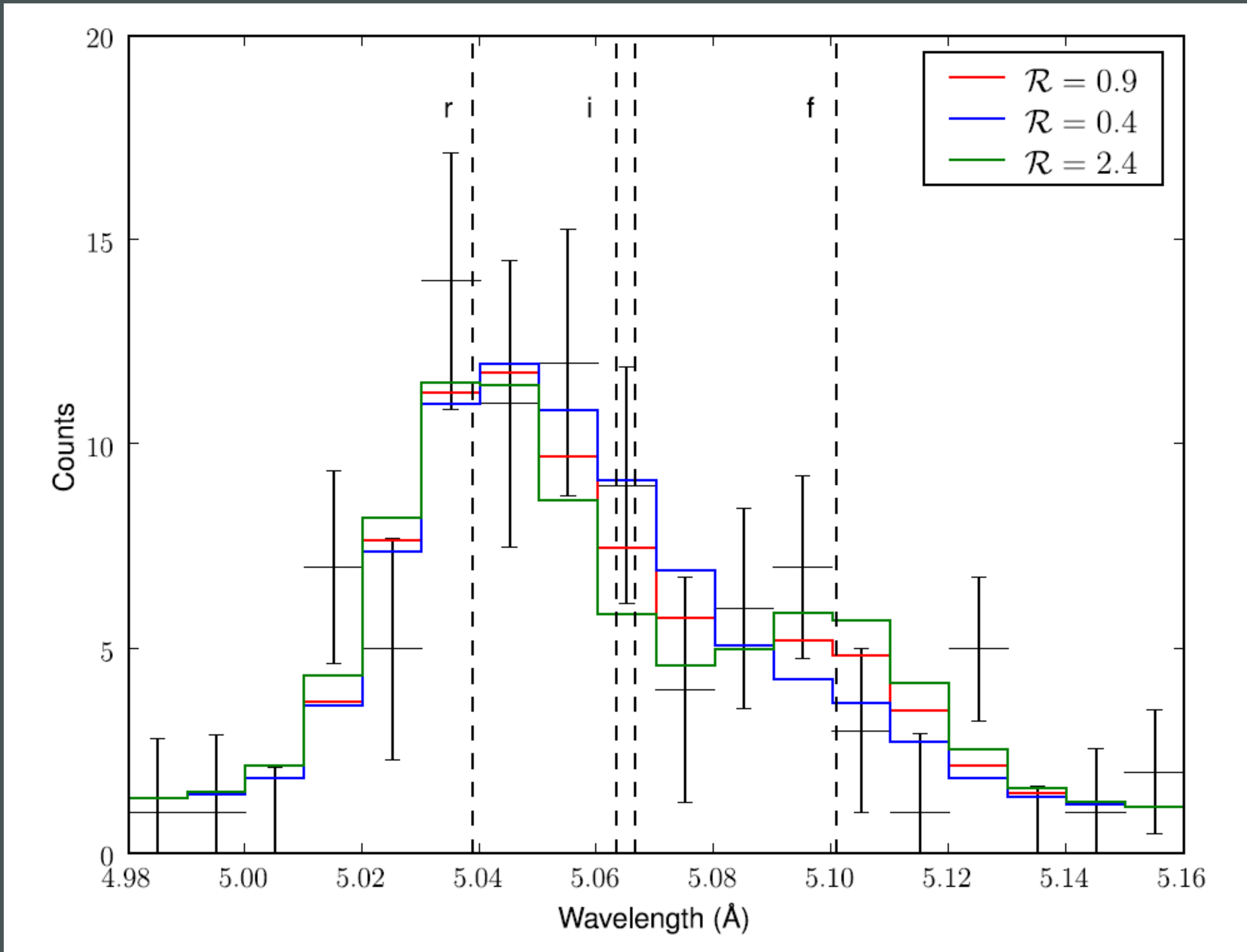


R_fir=1.2 R*
R_fir=2.1 R*
R_fir=4.0 R*
Count Rate (counts s⁻¹ Å⁻¹)
Wavelength (Å)
0.00
0.05
0.10
0.15
9.15
9.20
9.25
9.30
9.35
Y (R*)
X (R*)

He-like f/i ratios and the x-ray light curve both indicate that the hot plasma is somewhat closer to the photosphere of θ^1 Ori C than the MHD models predict.

Some slides showing f/i ratios in zeta Ori, tau Sco…
main point: there is NO evidence for a “near star high ion problem”

ζ Pup S XV *Chandra* MEG



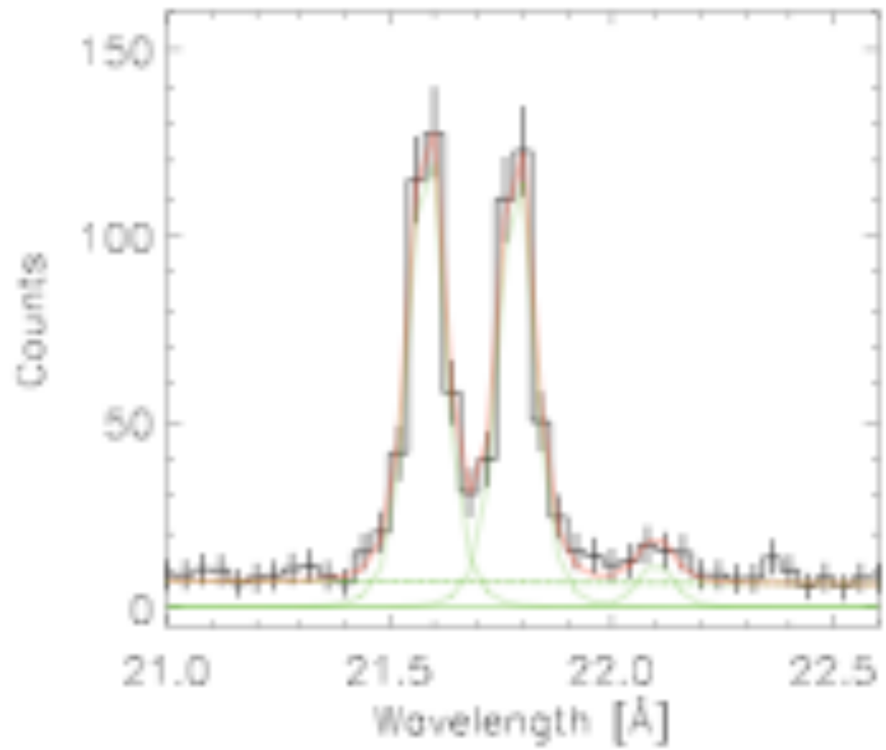


Fig. 8. The 4 coadded RGS1+RGS2 spectra in the region of the O VII triplet, with the fit to the 3 lines plus a constant.

More possible topics:

Zeta Ori, HD191612 – magnetic but X-rays look "normal"

Tau Sco – narrow lines but f/i ratios imply plasma far from the photosphere

Sigma Ori E – X-ray DEM well reproduced by Rich's RFHD modeling; flaring too (centrifugal breakout)

Early B stars are mysterious – large x-ray luminosities, soft spectra, narrow lines but no evidence for magnetic fields (theta Car, beta Cru)

Conclusions

Some conclusions…