X-ray Spectroscopy of HD 93129A (O2 If*)

Embedded Wind Shocks and a Mass-Loss Rate

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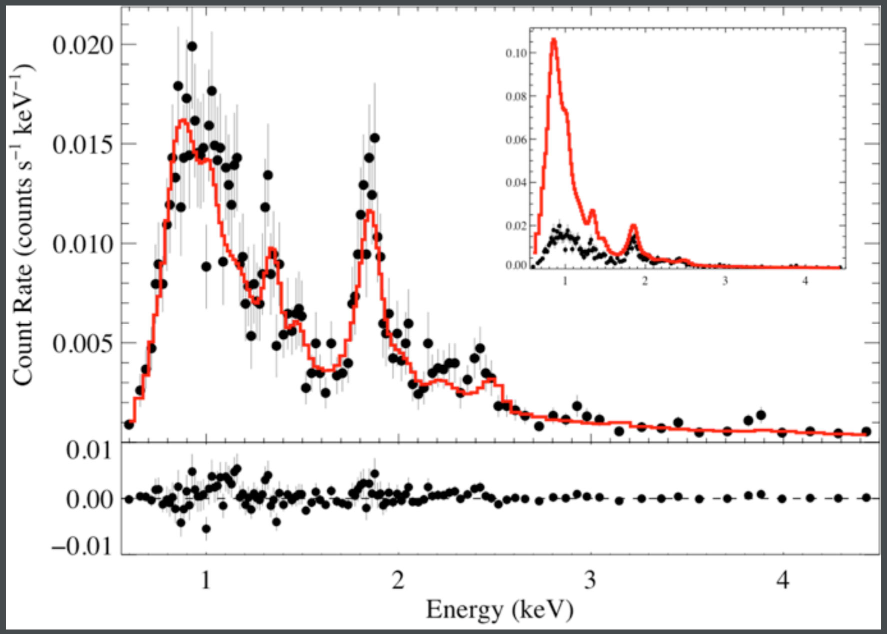
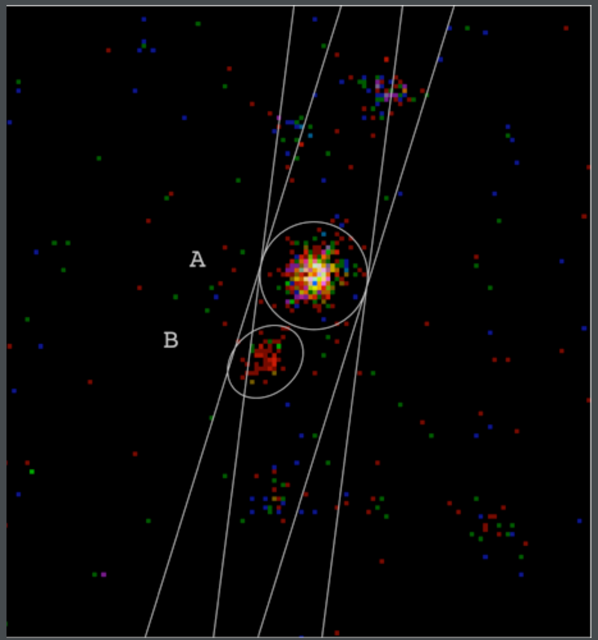
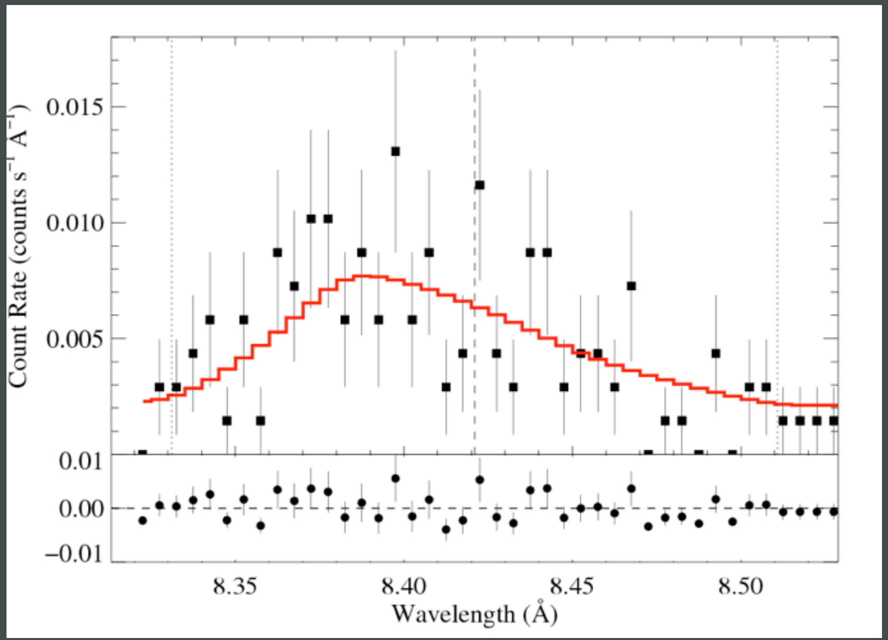
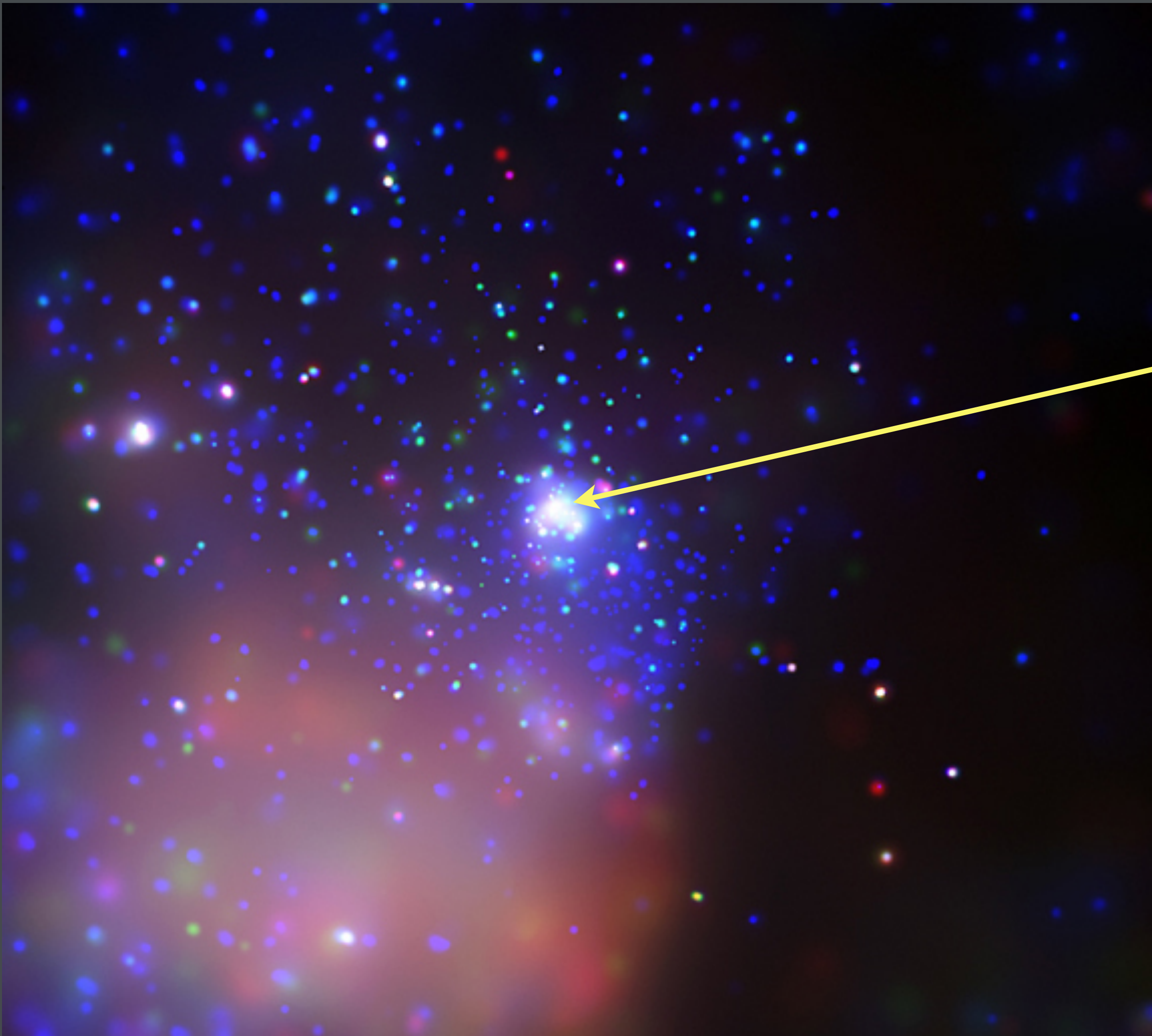




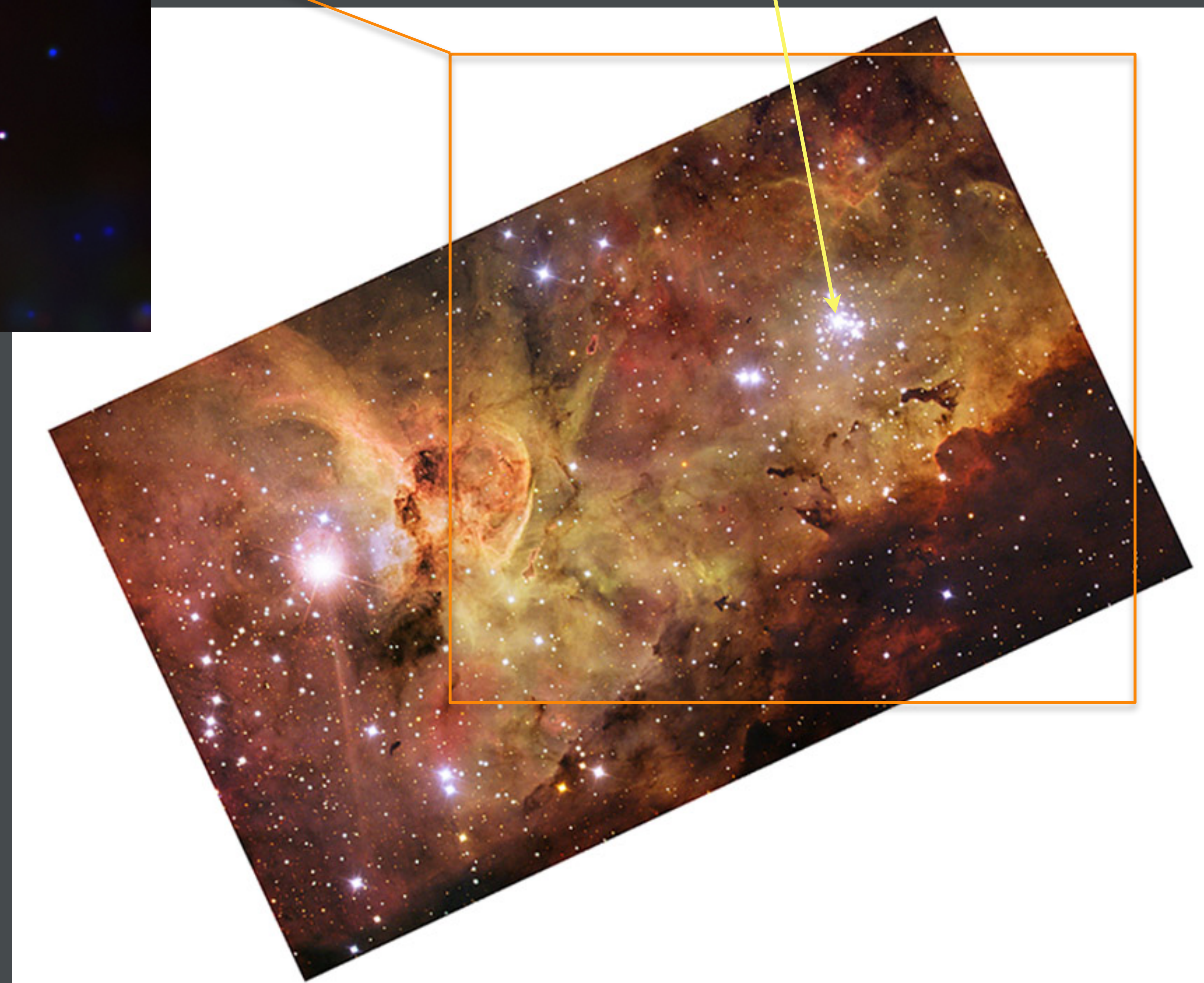


Outline: HD 93129A (O2 If*)

- 120 M_{sun} ZAMS, O star with the strongest wind?
- The X-ray spectrum is hard because of wind absorption
- The broadband X-ray spectrum confirms low temperature plasma and wind absorption
- X-ray line profiles from embedded wind shocks
- profiles, broadband: two mass-loss rate measurements



Tr 14: *Chandra*



Carina: ESO

HD 93129A

Tr 14: *Chandra*

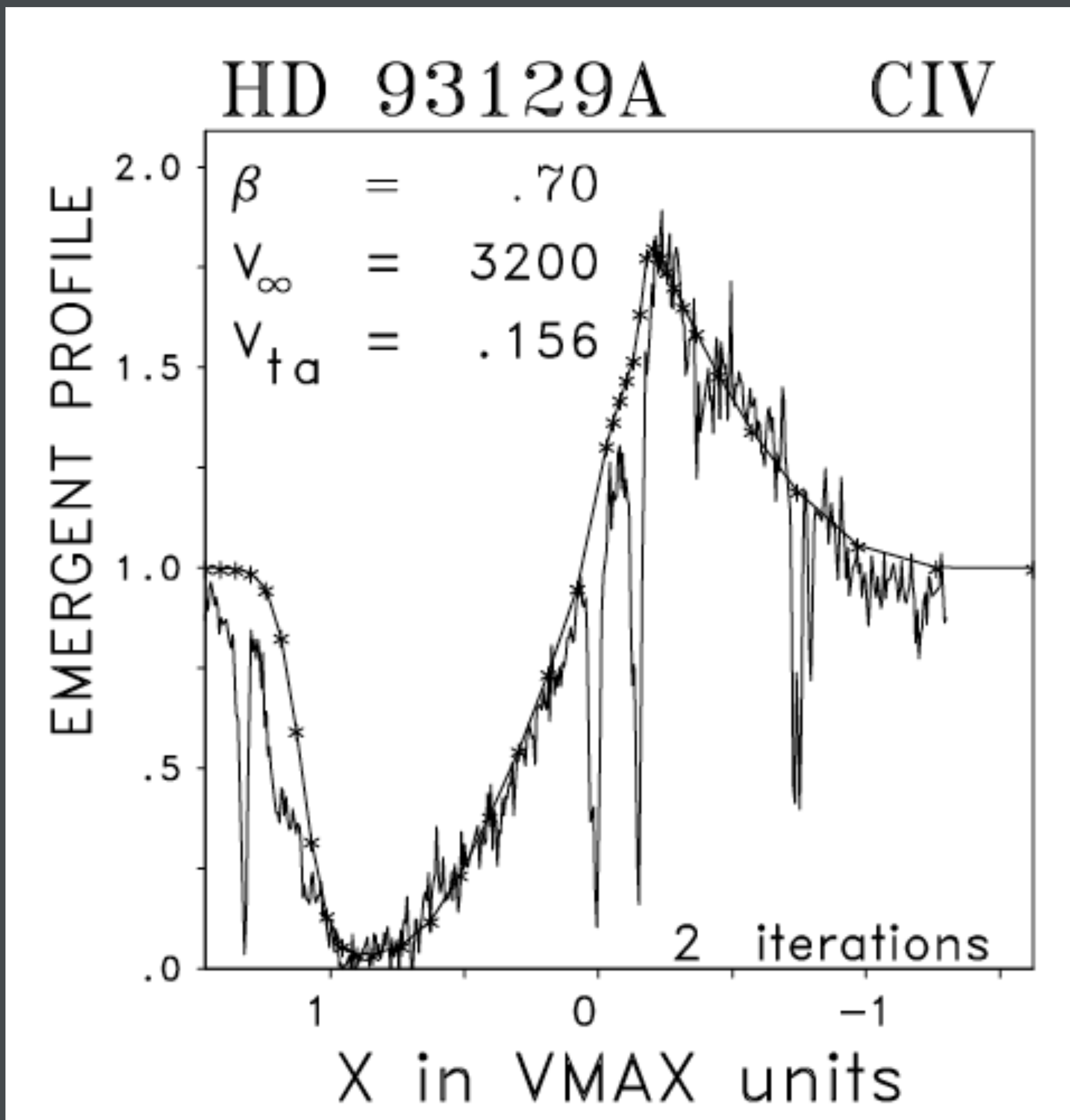
$L_X \sim 7 \times 10^{32}$

$\langle h\nu \rangle \sim 1$ keV

$\sim 10^7$ K

$L_{bol} \sim 2 \times 10^6\ L_{sun}$ so $L_X/L_{bol} \sim 10^{-7}$

Strongest wind measured in an O star



Taresch et al. (1997)

$\dot{M} = 2 \times 10^{-5}\ M_{sun}/yr$

$v_\infty = 3200$ km/s

Hα

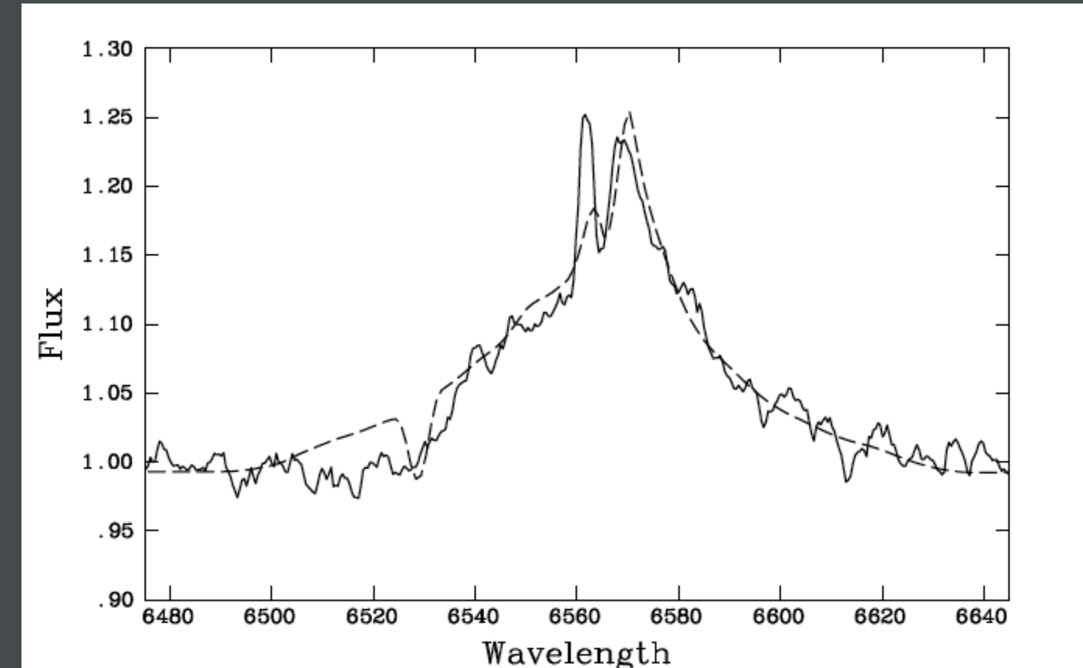


Fig. 13. Observed Hα profile (**solid**) compared with the calculation assuming a mass loss of $18\times10^{-6}\ M_\odot$/yr (dashed). Note that the blue narrow emission peak originates from the H II-region emission.

Strongest wind measured in an O star

Hα

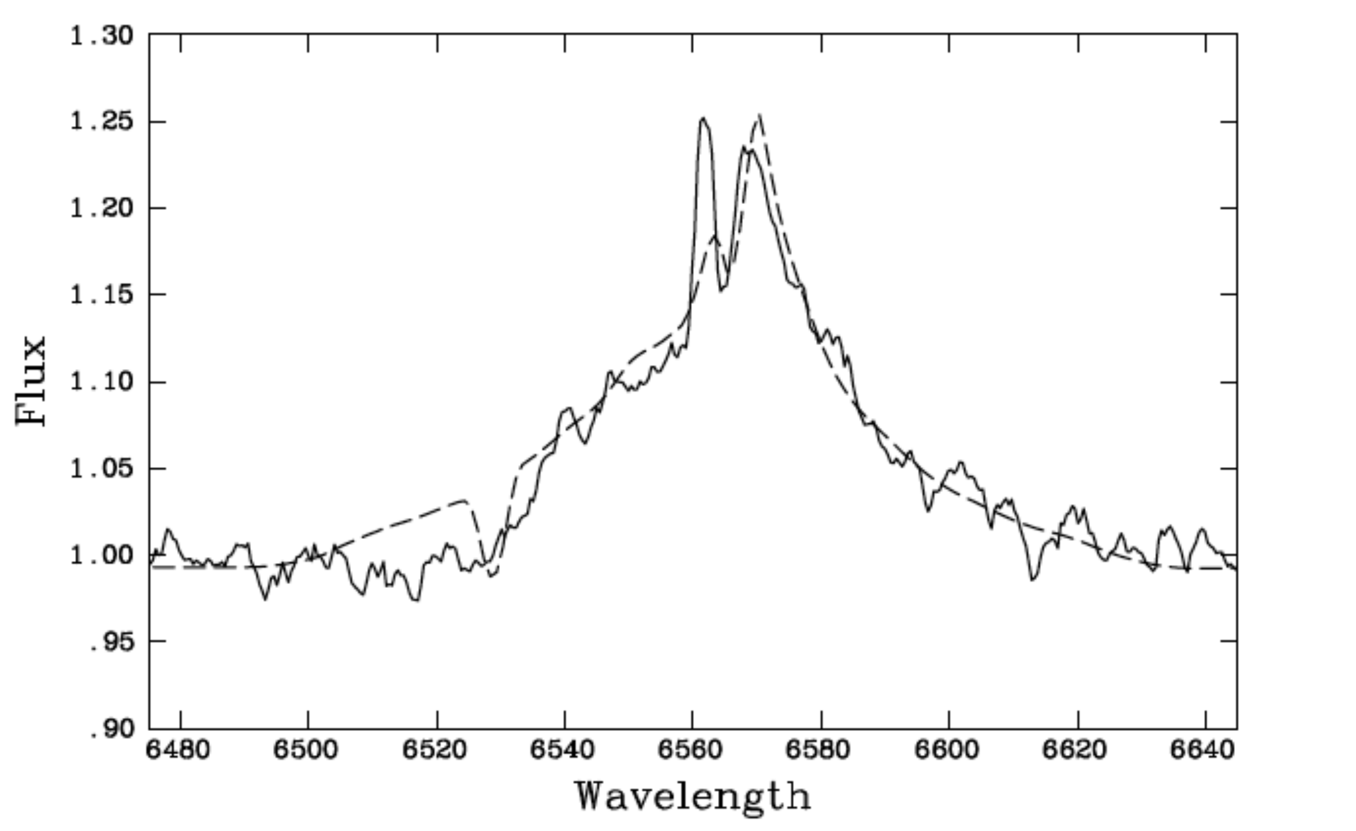


Fig. 13. Observed Hα profile (**solid**) compared with the calculation assuming a mass loss of $18 \times 10^{-6}\ M_{\odot}$/yr (dashed). Note that the blue narrow emission peak originates from the H II-region emission.

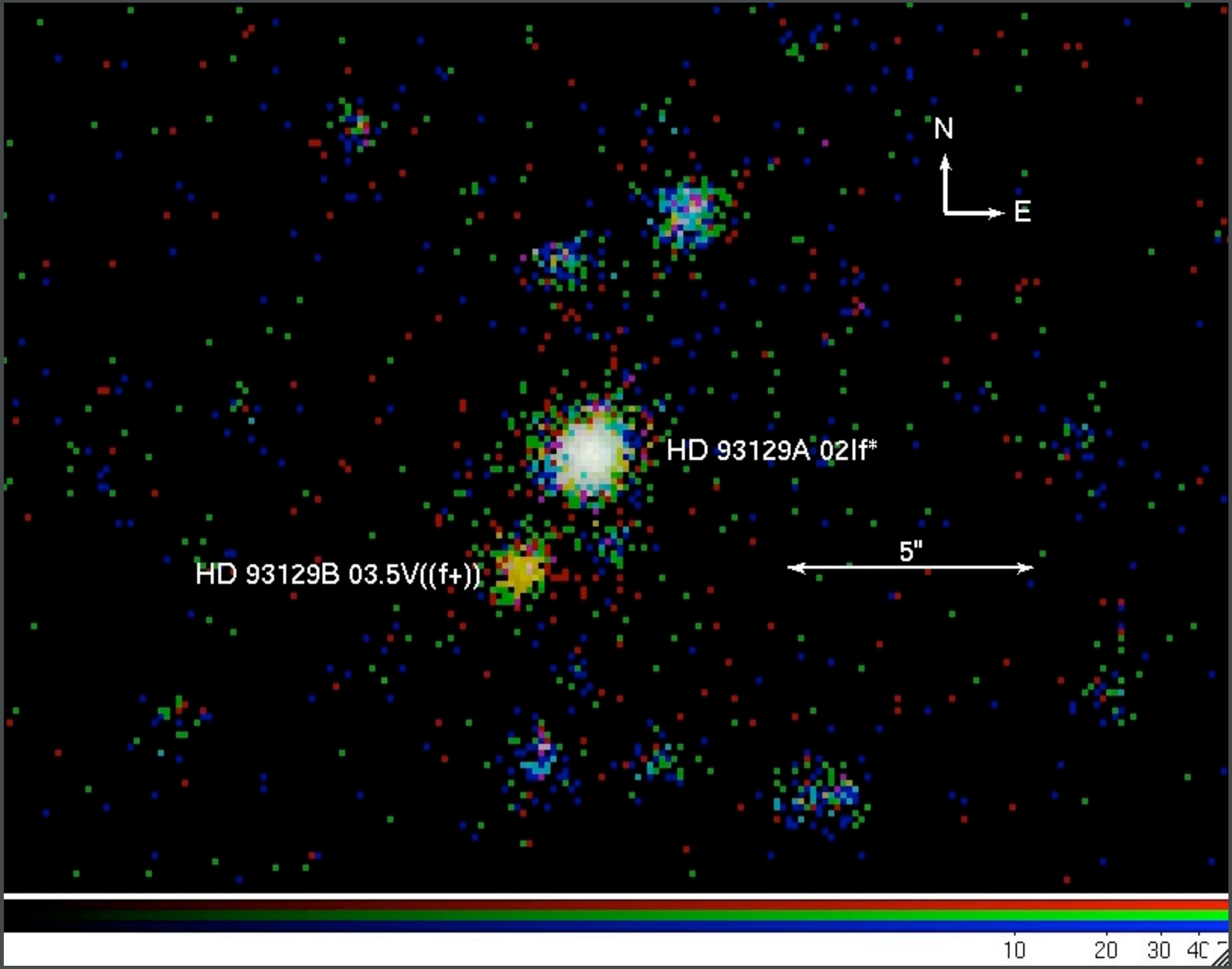
Taresch et al. (1997)

$\dot{M} = 2 \times 10^{-5}\ M_{sun}$/yr

assuming a *smooth* wind

i.e. no clumping

Chandra ACIS image, redder = softer X-rays

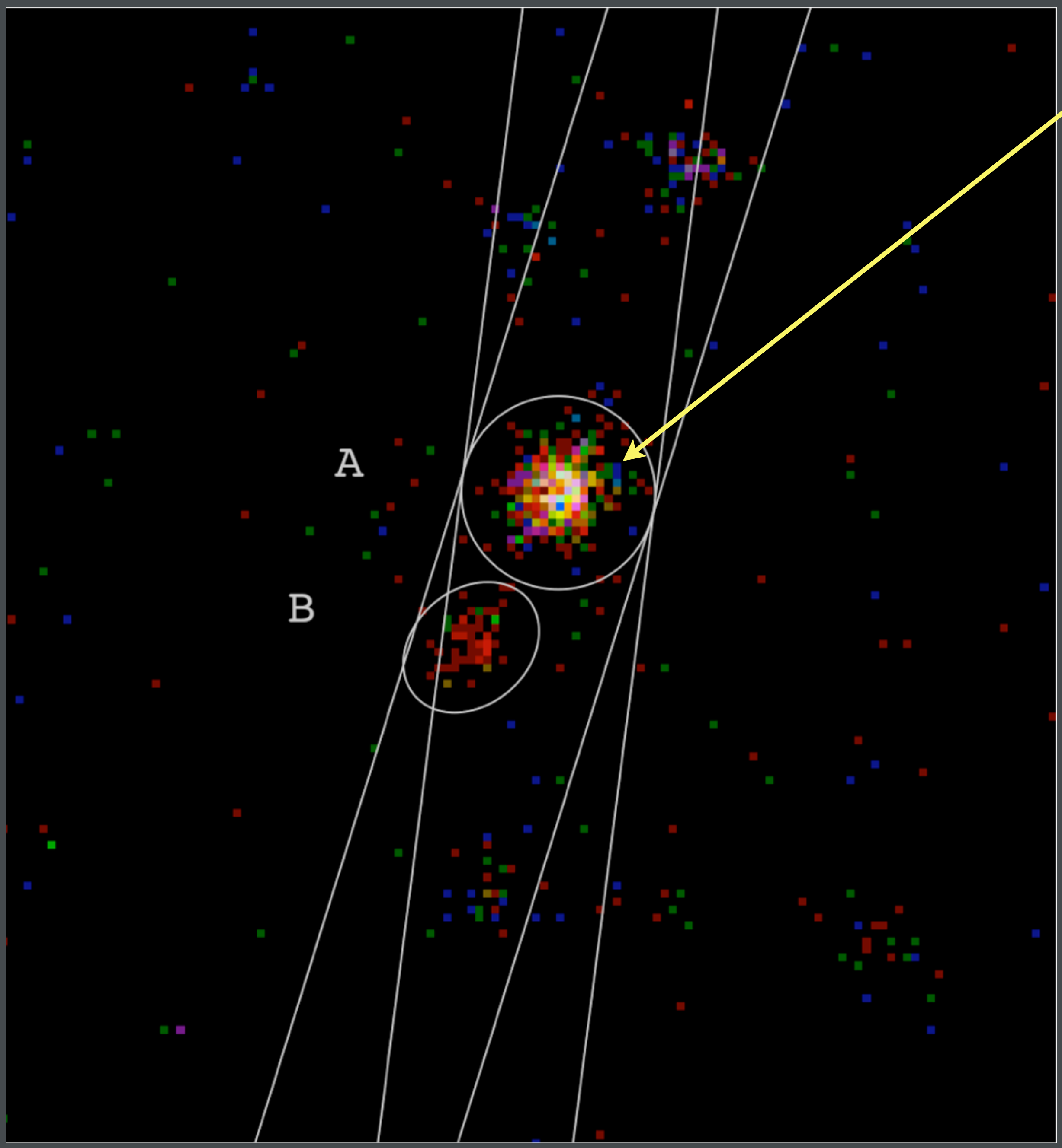


components A & B separated by 2.7″

component A is actually a binary itself:

sep. 0.05″

$\Delta m = 0^m.9$



Nelan et al. , 2004, AJ, 128, 323

a ~ 100 AU (~ 1000 R_*)

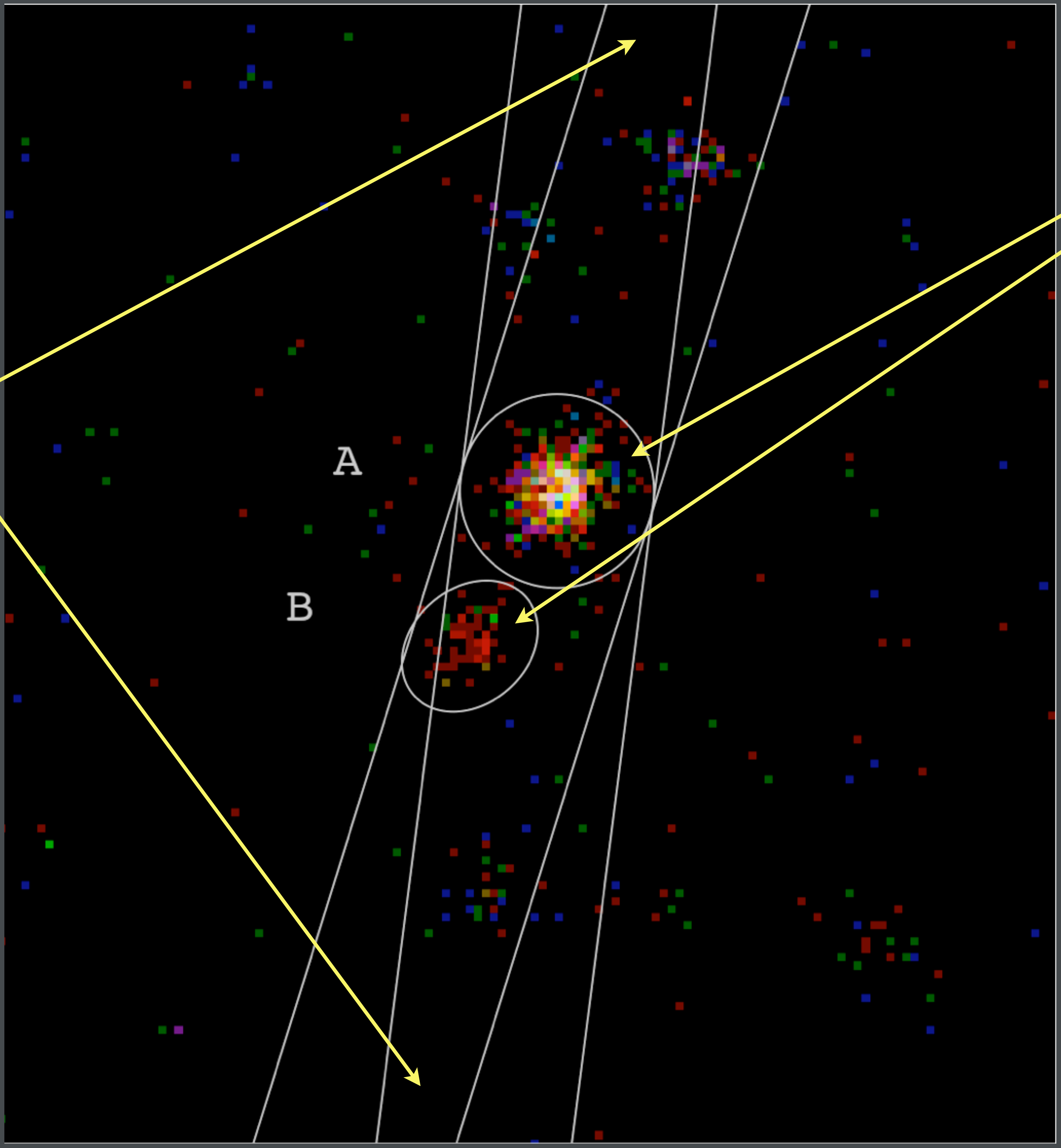
O2If* + ~O3.5V

Questions

- What is the role of **binarity** in the X-ray emission?
- What is the role of **wind attenuation** of the X-rays?
- What is the actual **mass-loss rate** of HD93129A?
- How does the **embedded wind shock** (EWS) mechanism operate in such a powerful wind?

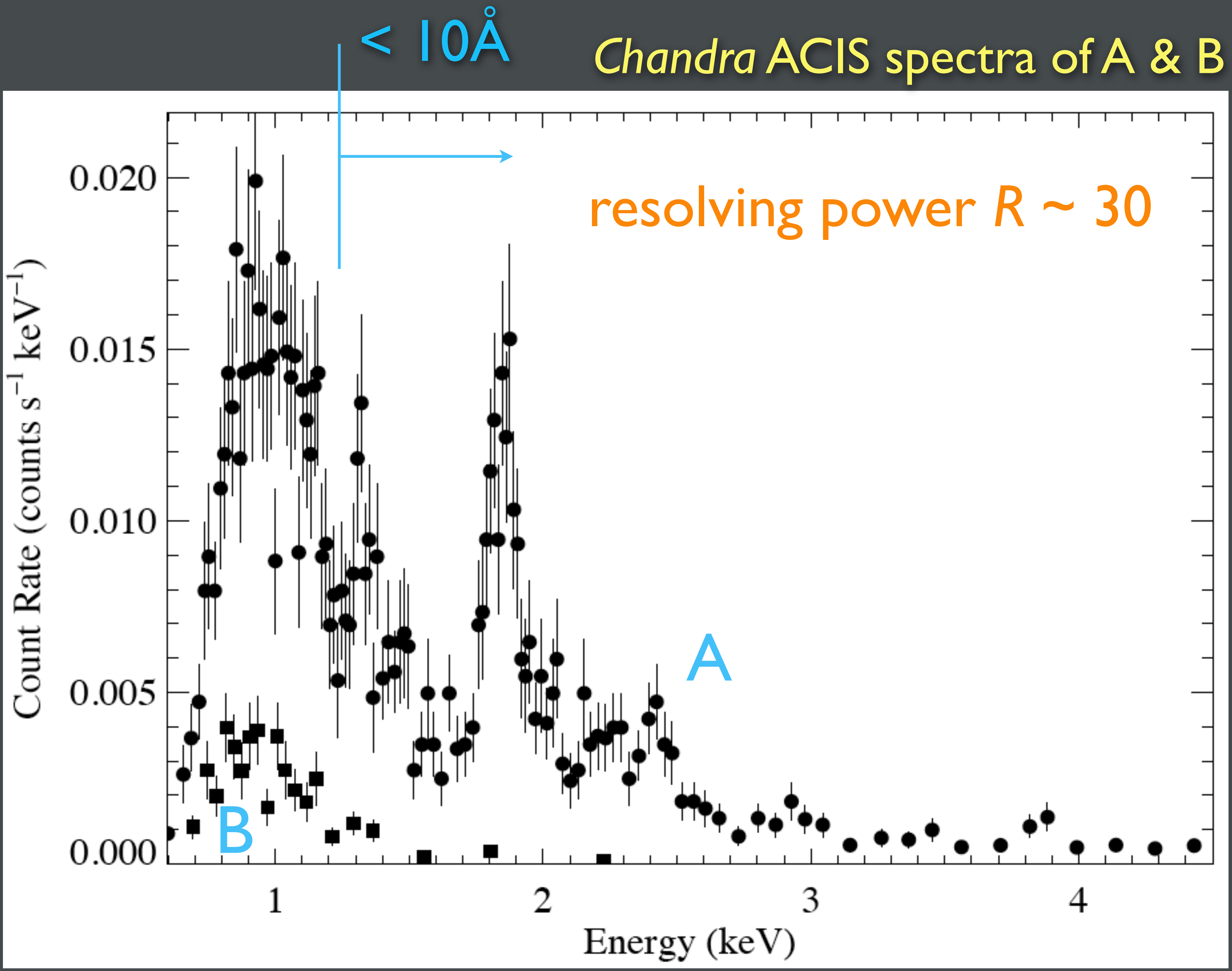
Chandra High Energy Transmission Grating Spectrometer

dispersed spectrum: high-resolution



"zeroth order spectrum": low-resolution

Chandra ACIS spectra of A & B



H-like vs. He-like

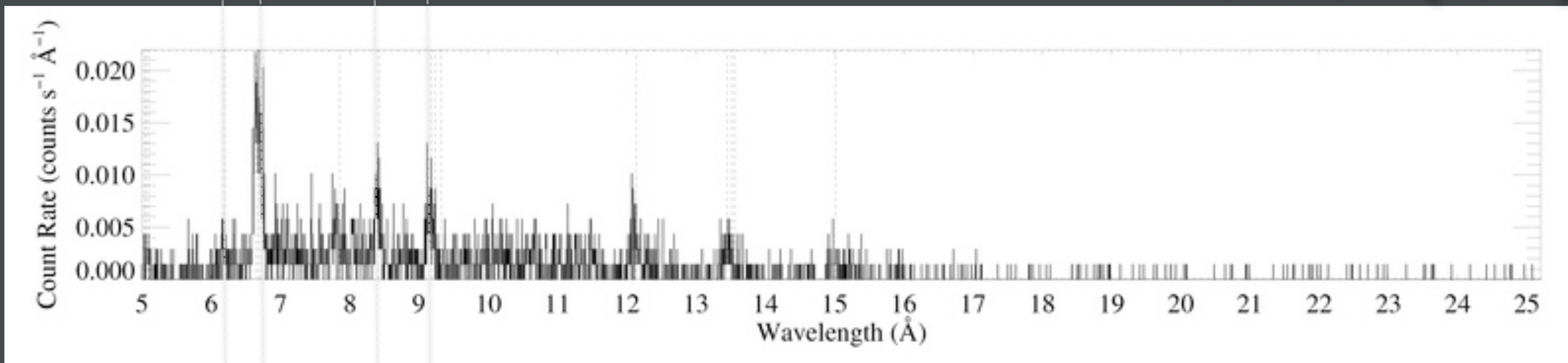
Chandra ACIS spectra of A & B

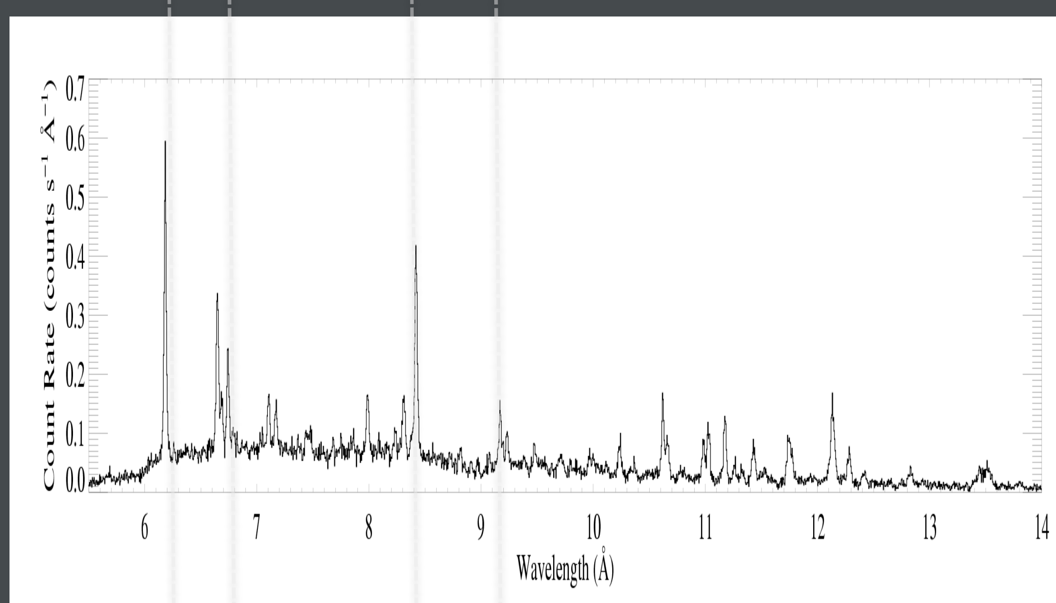
resolving power $R \sim 500$

Si XIII Mg XI

Si XIV Mg XII

HD 93129A (O2 If*)

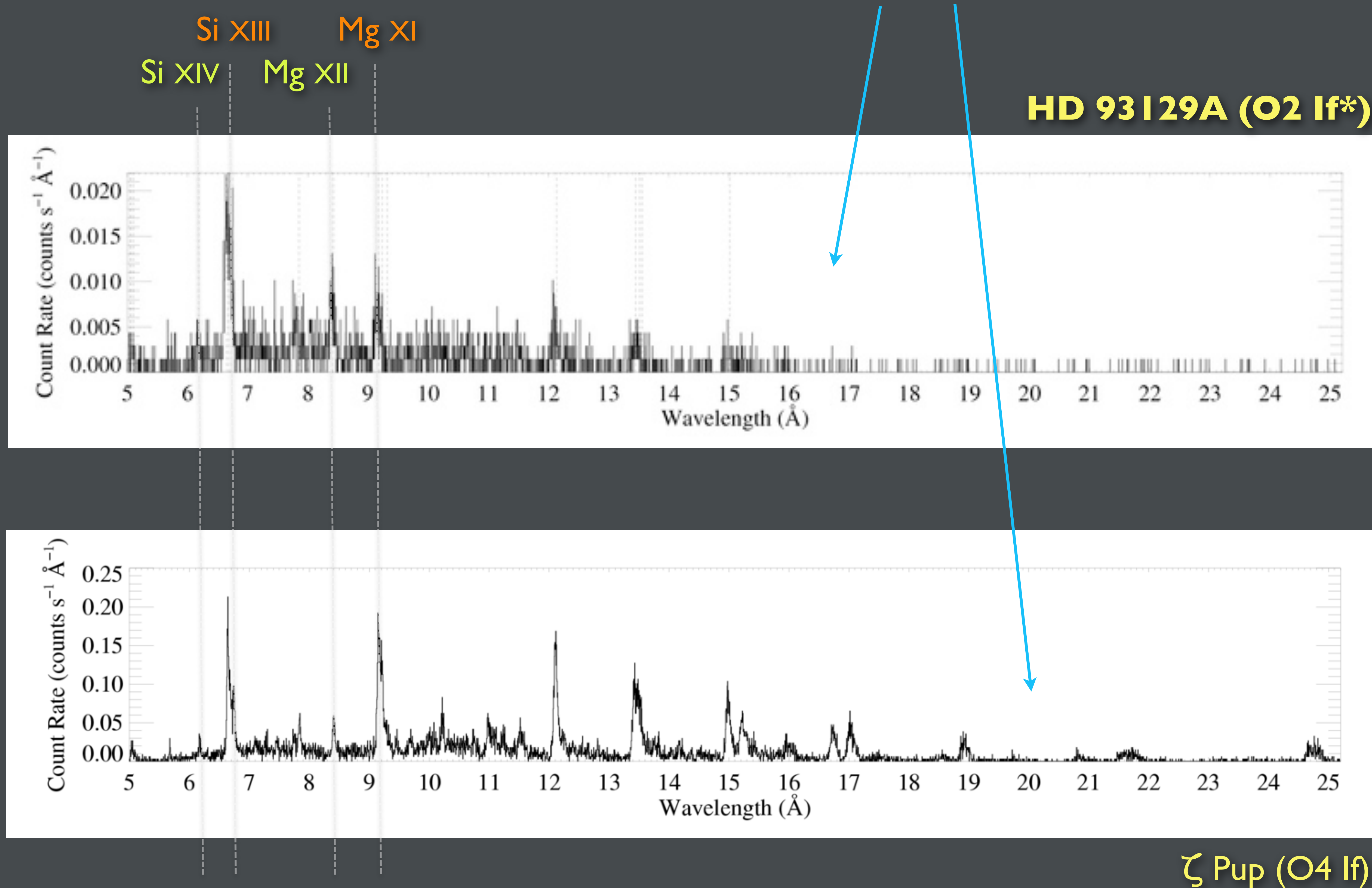




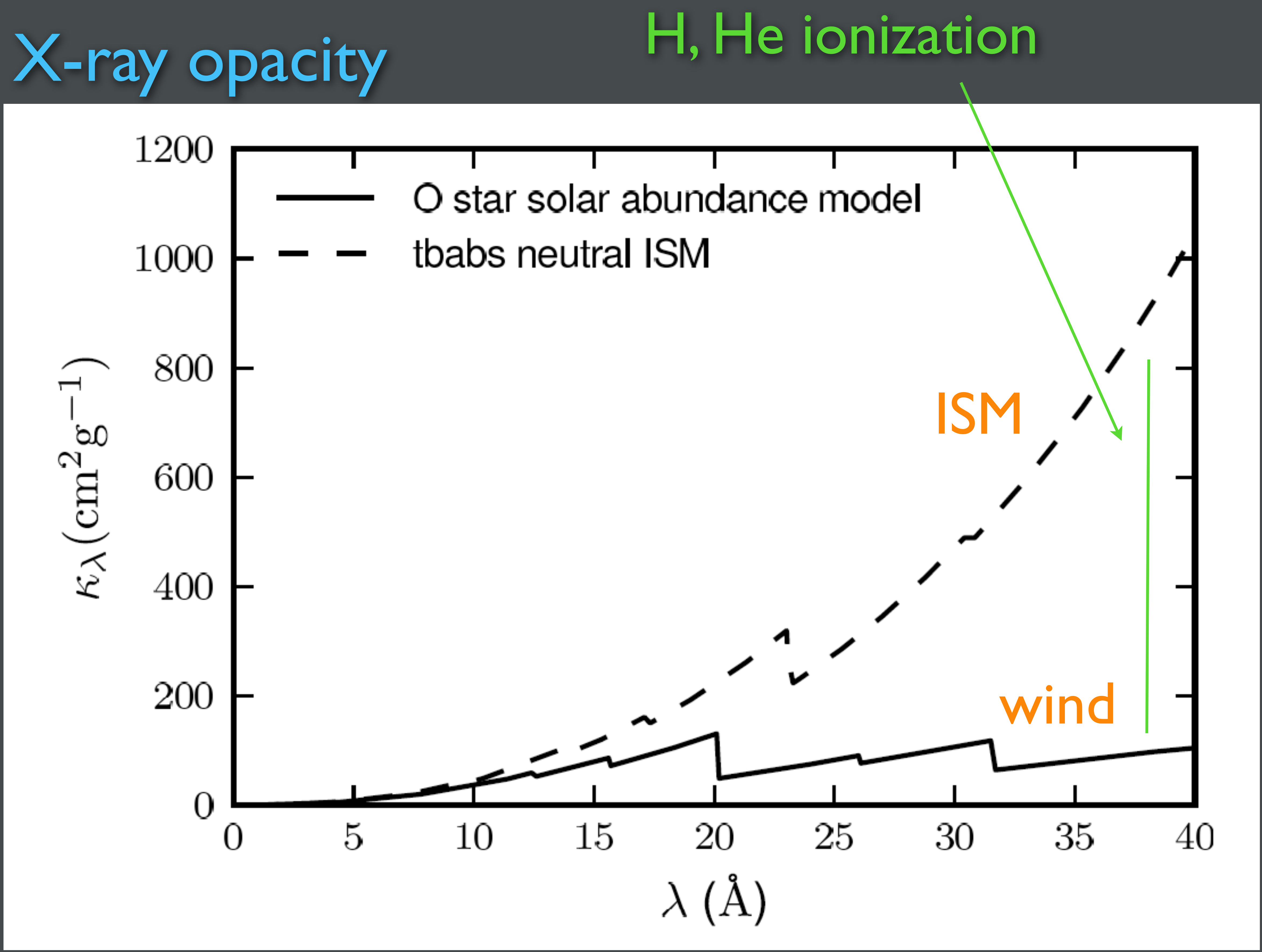
θ[1] Ori C (O7 V)

magnetically channeled wind: strong shocks, high temperatures, hard X-rays

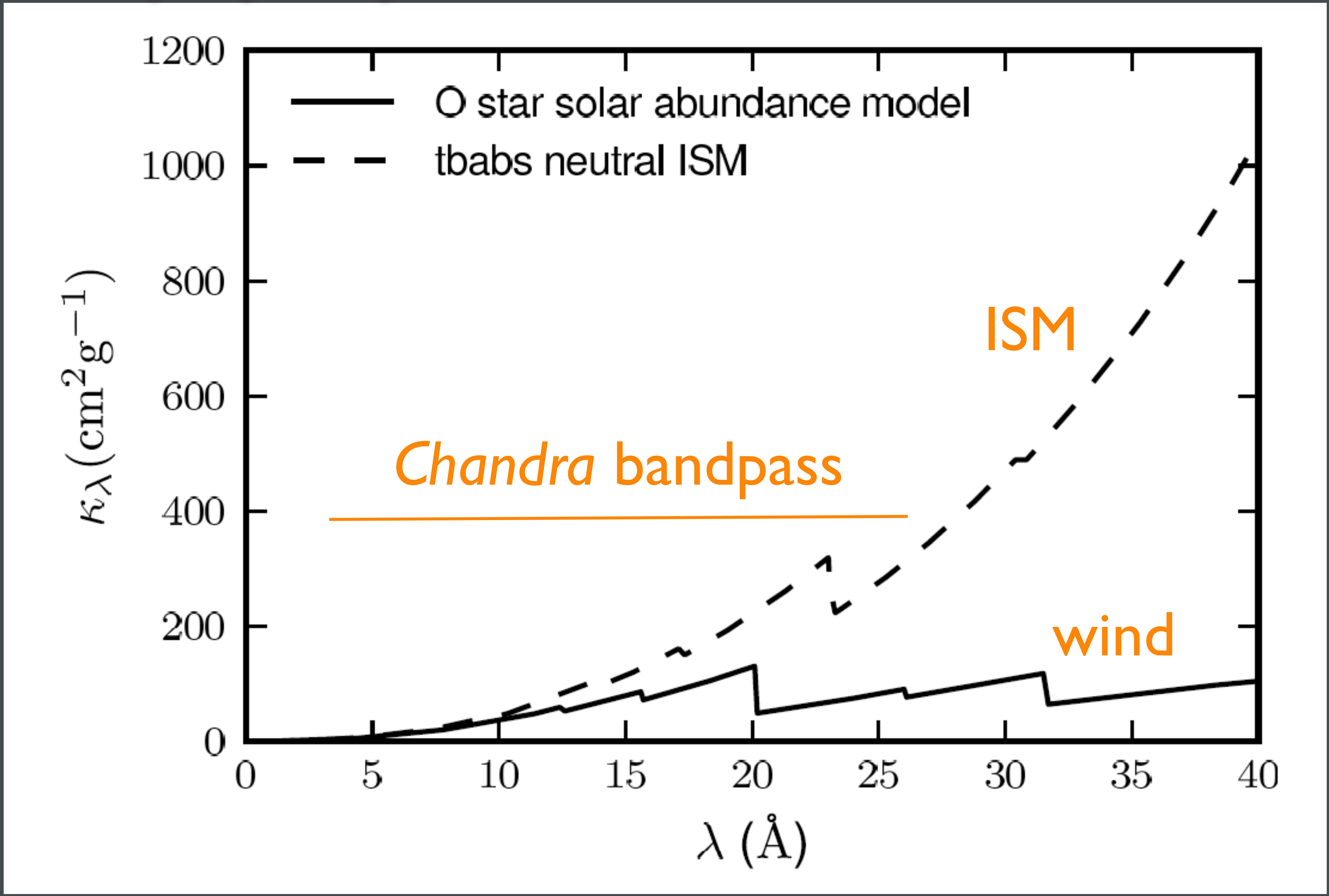
H-like vs. He-like soft emission absent: wind attenuation



X-ray opacity

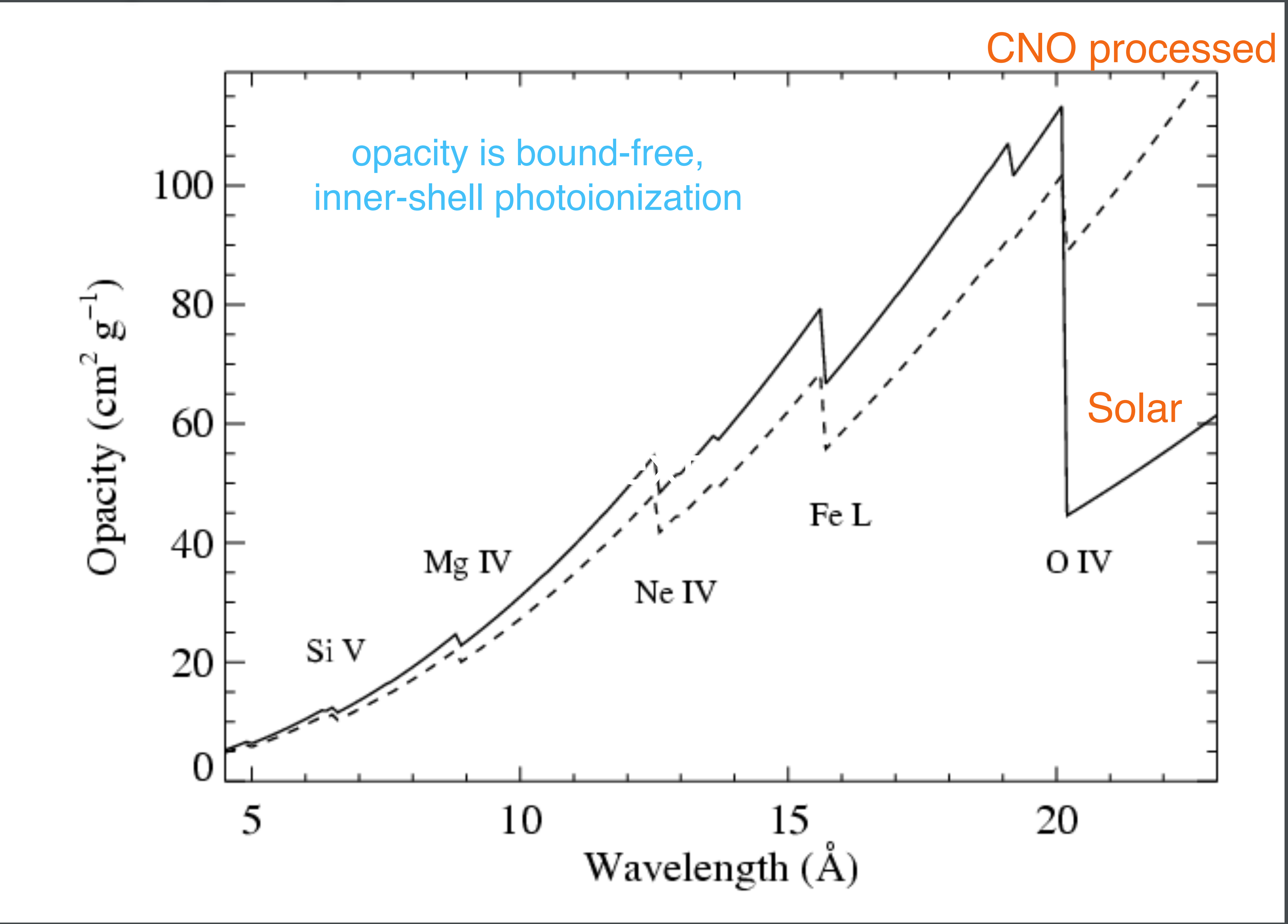


X-ray opacity



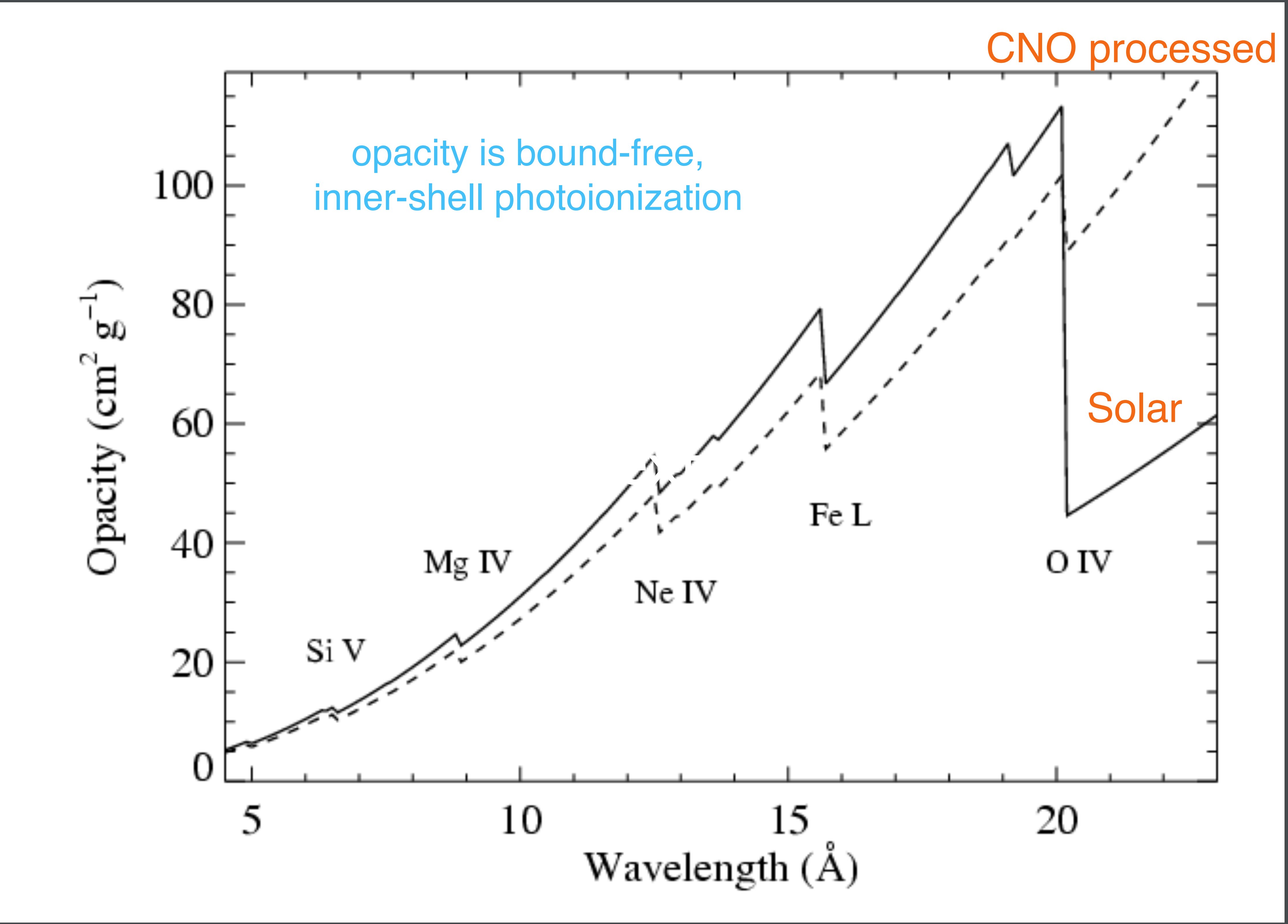
X-ray opacity: zoom in

abundance effects

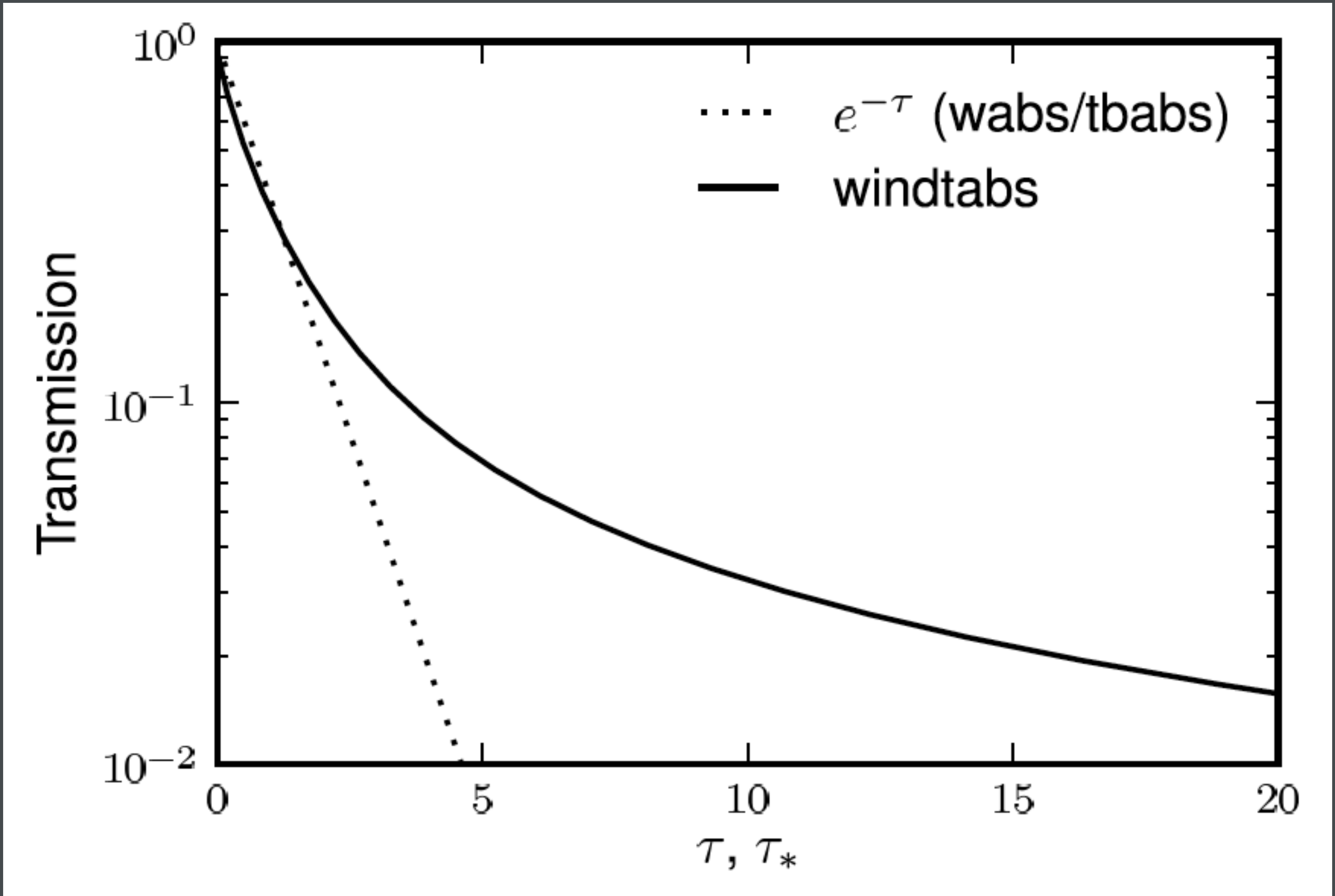


abundance effects

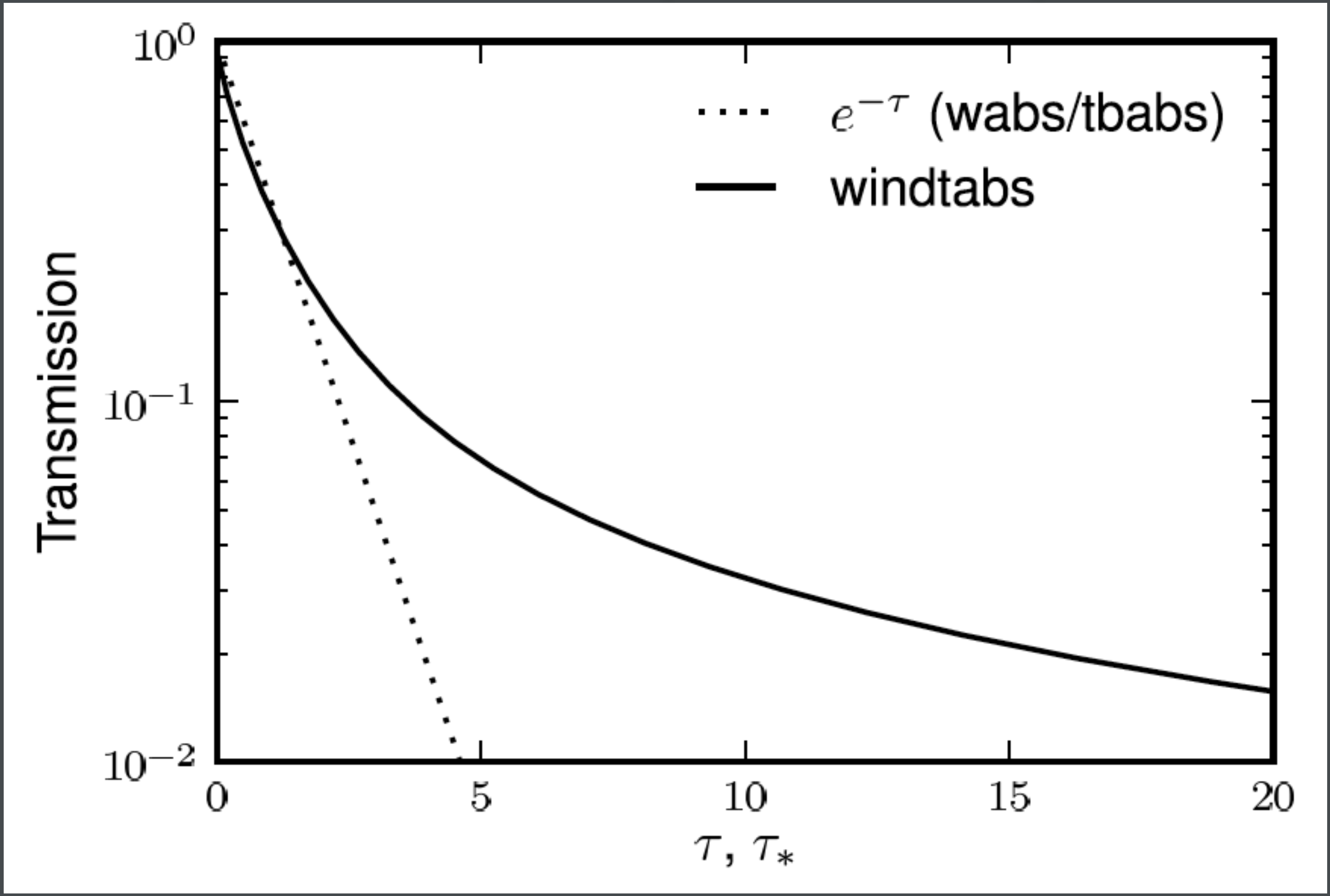
do *not* matter much in the *Chandra* bandpass



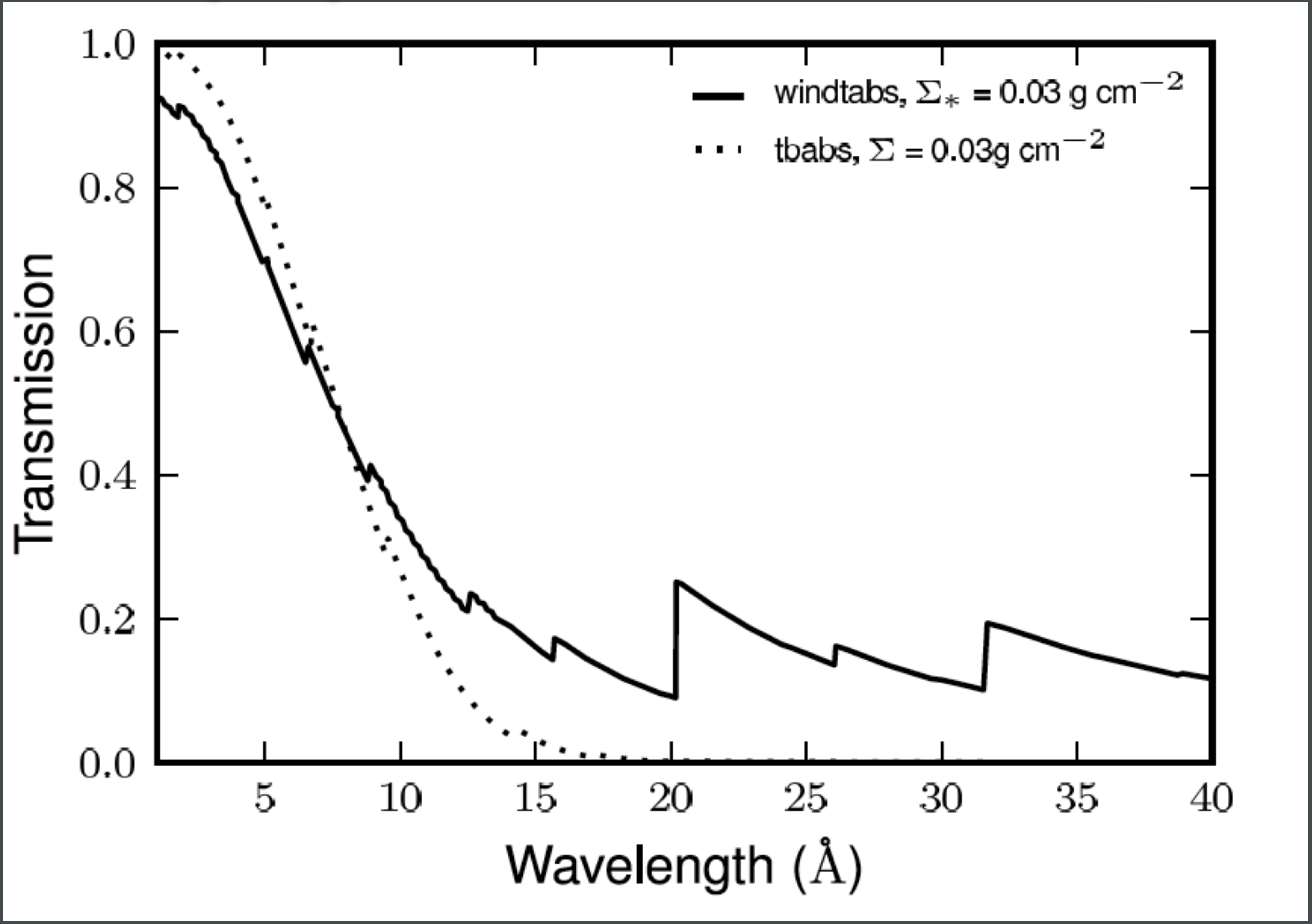
Radiation transport through the wind



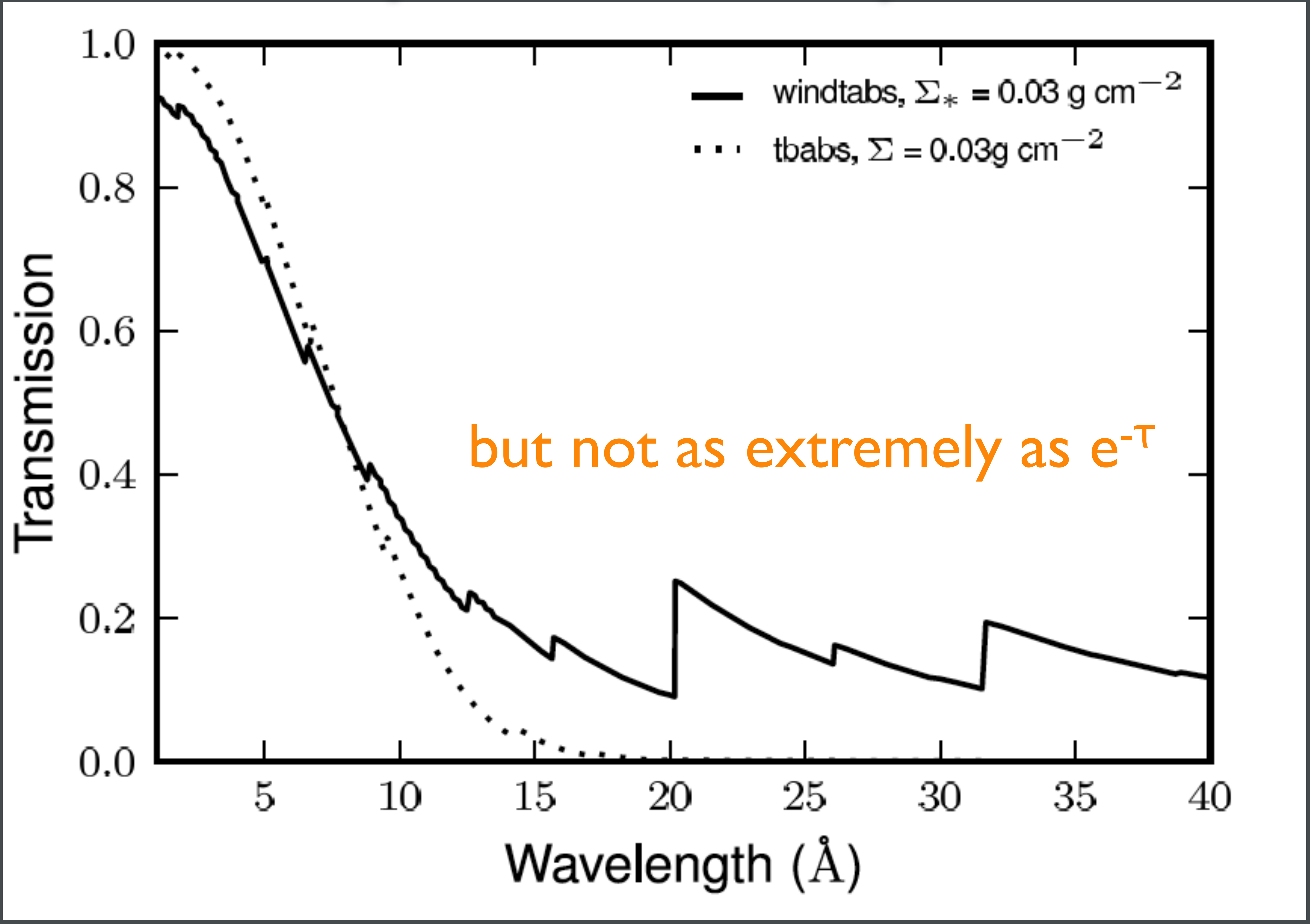
distributed emission escapes more easily



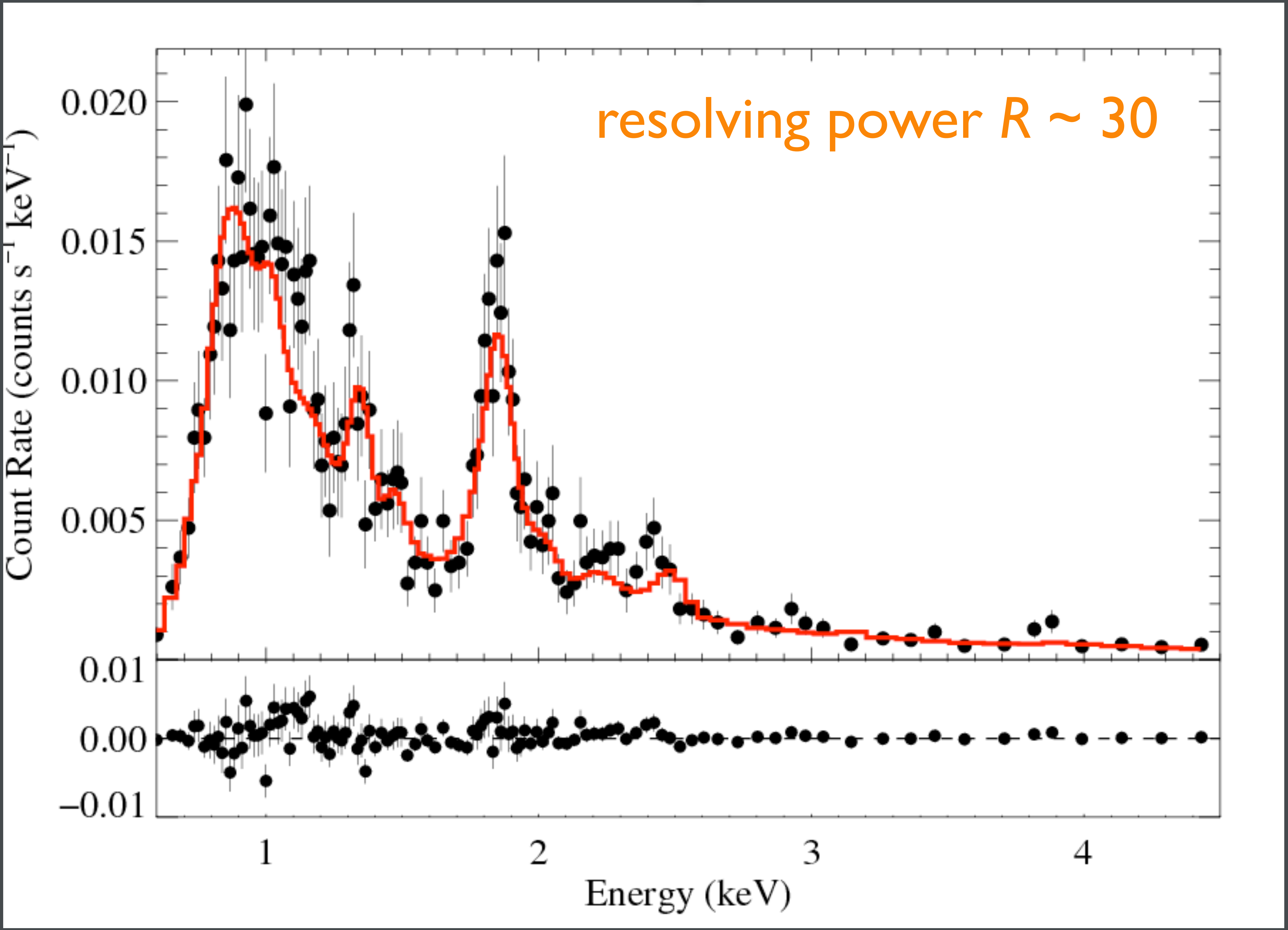
combine opacity and RT models: *windtabs* (Leutenegger et al. 2010)



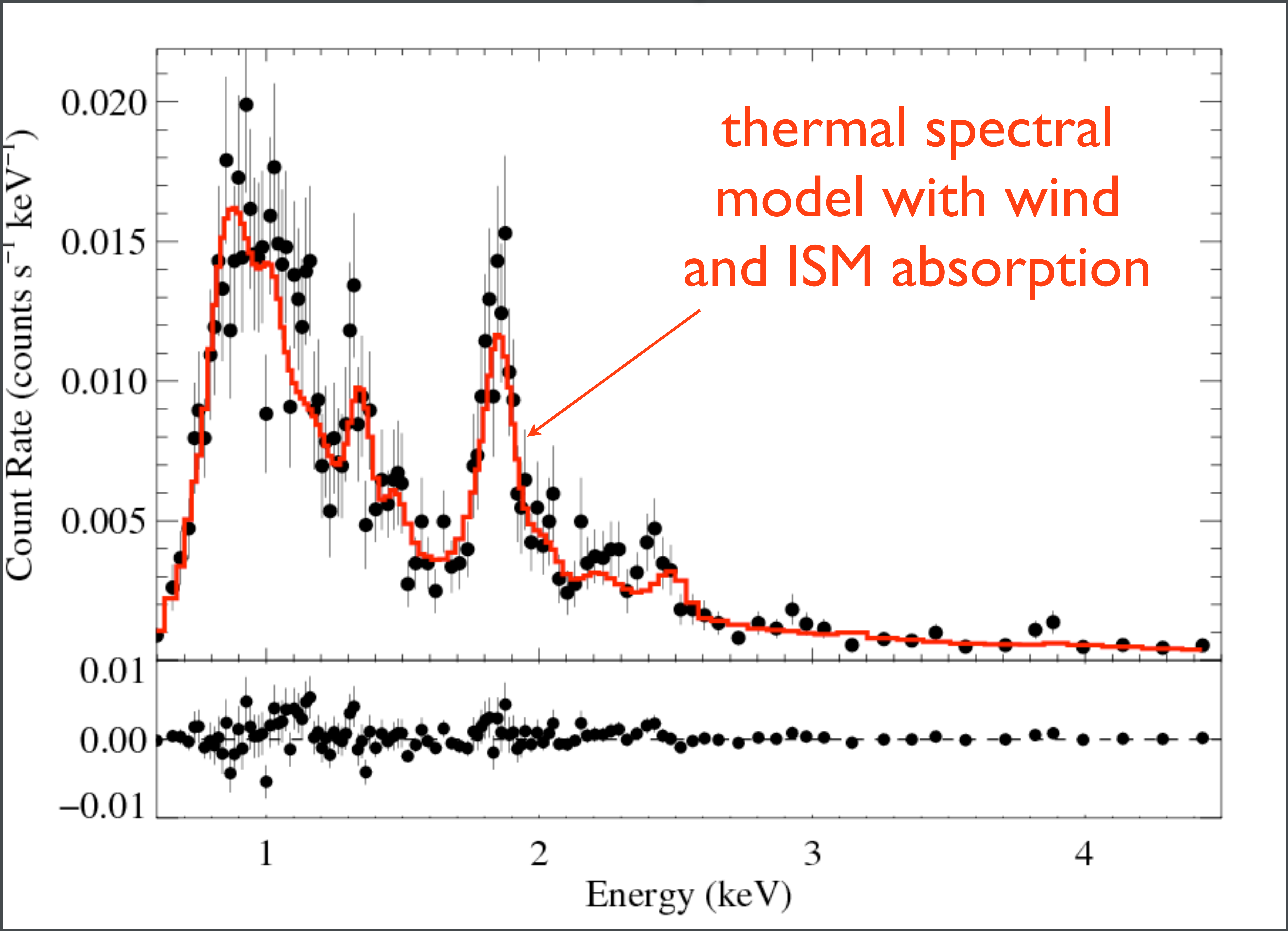
soft X-rays are attenuated by the wind



HD 93129A: *Chandra* ACIS spectrum



HD 93129A: *Chandra* ACIS spectrum



The Spectral Model

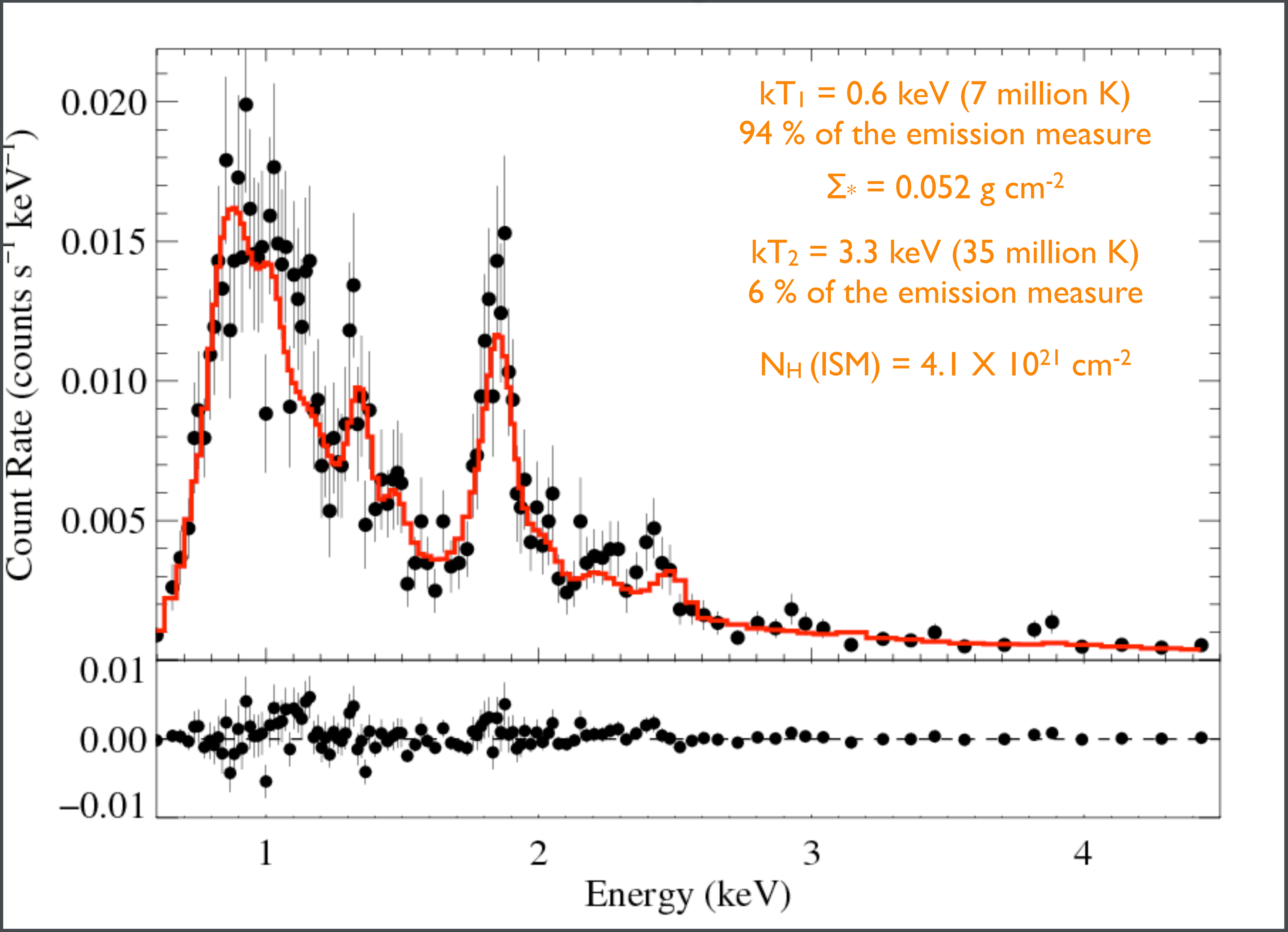
*(apec*windtabs + apec)*tbabs*

ISM attenuation

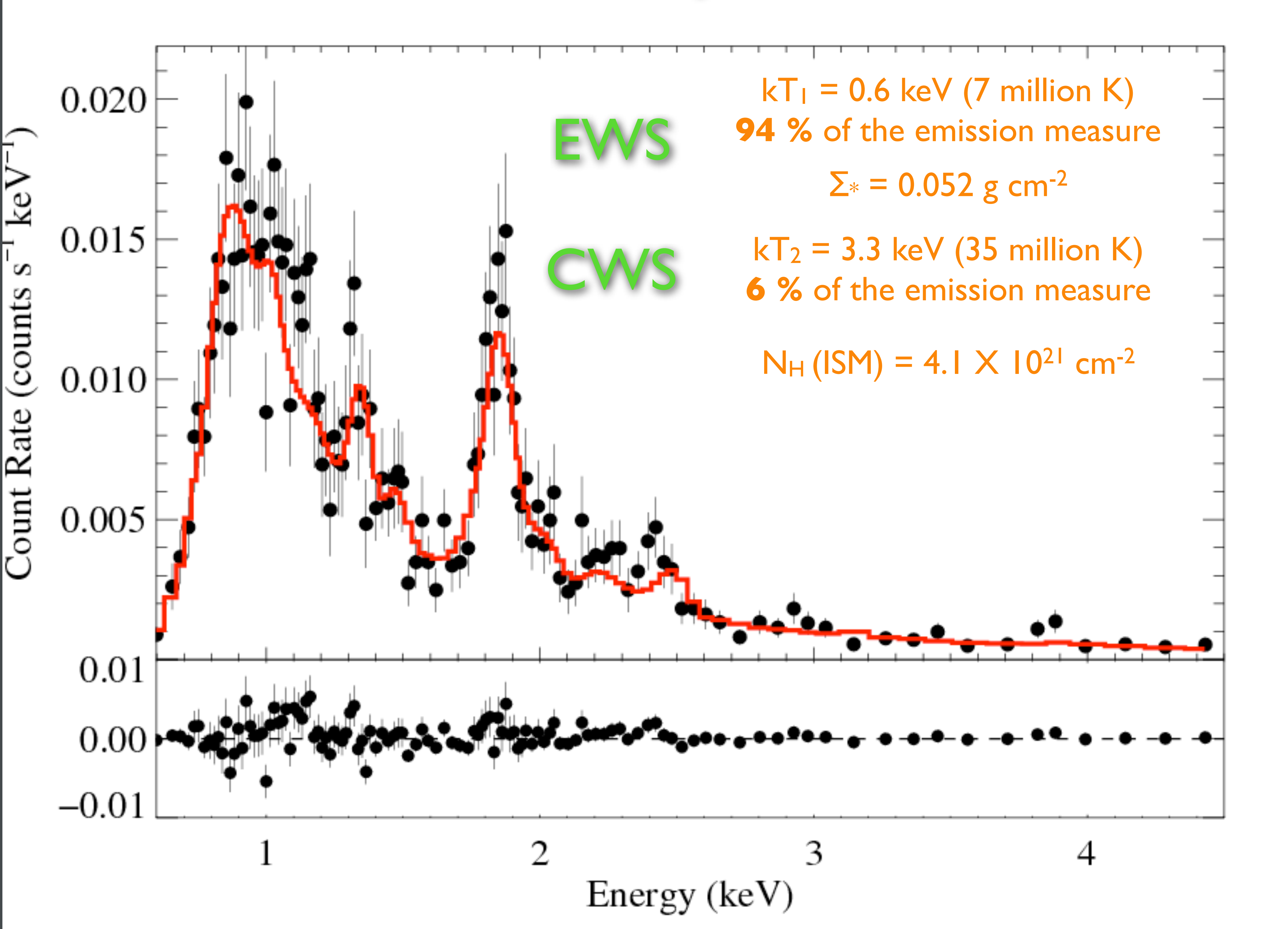
wind attenuation

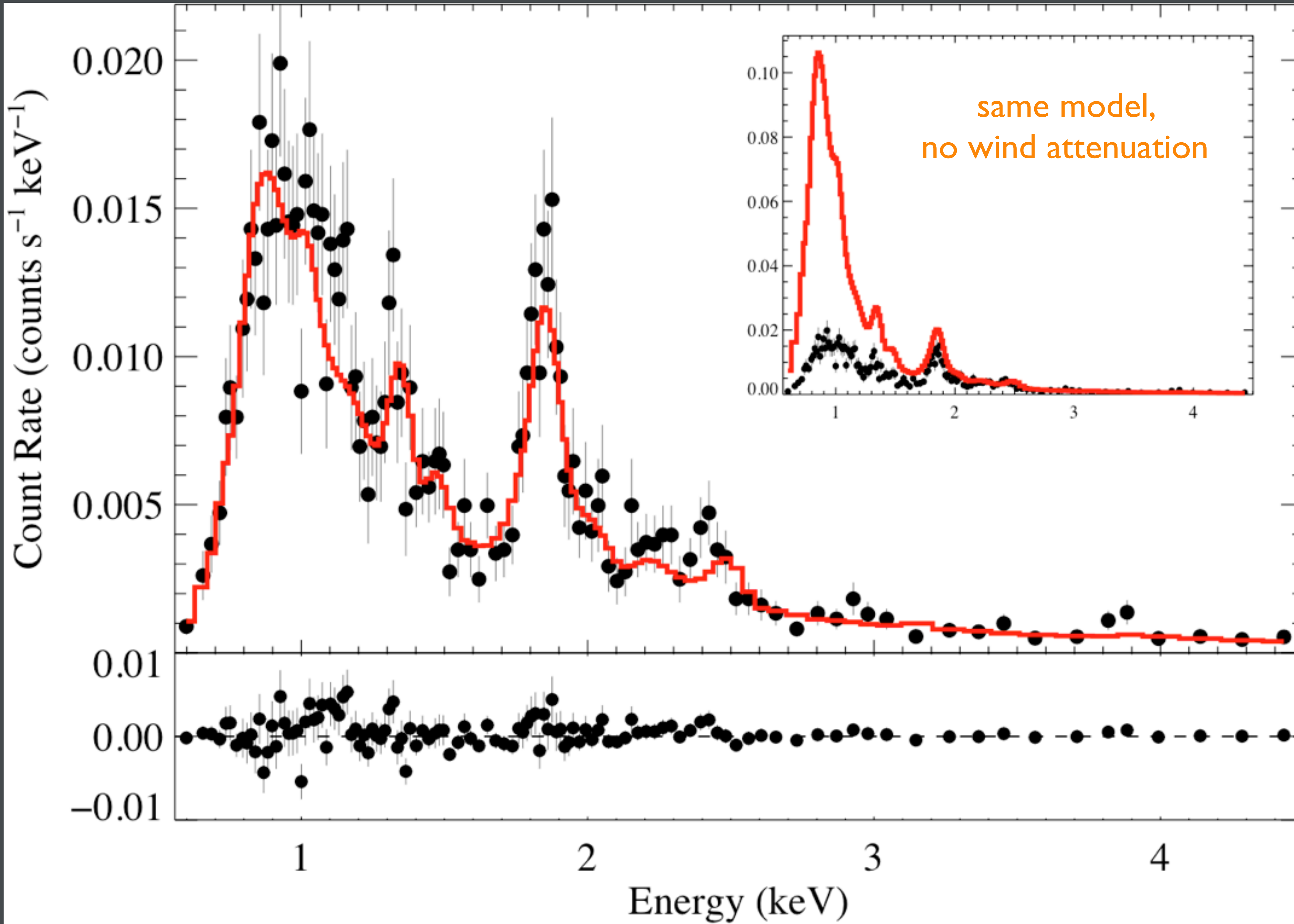
thermal emission (bremsstrahlung + emission lines)

HD 93129A: *Chandra* ACIS spectrum

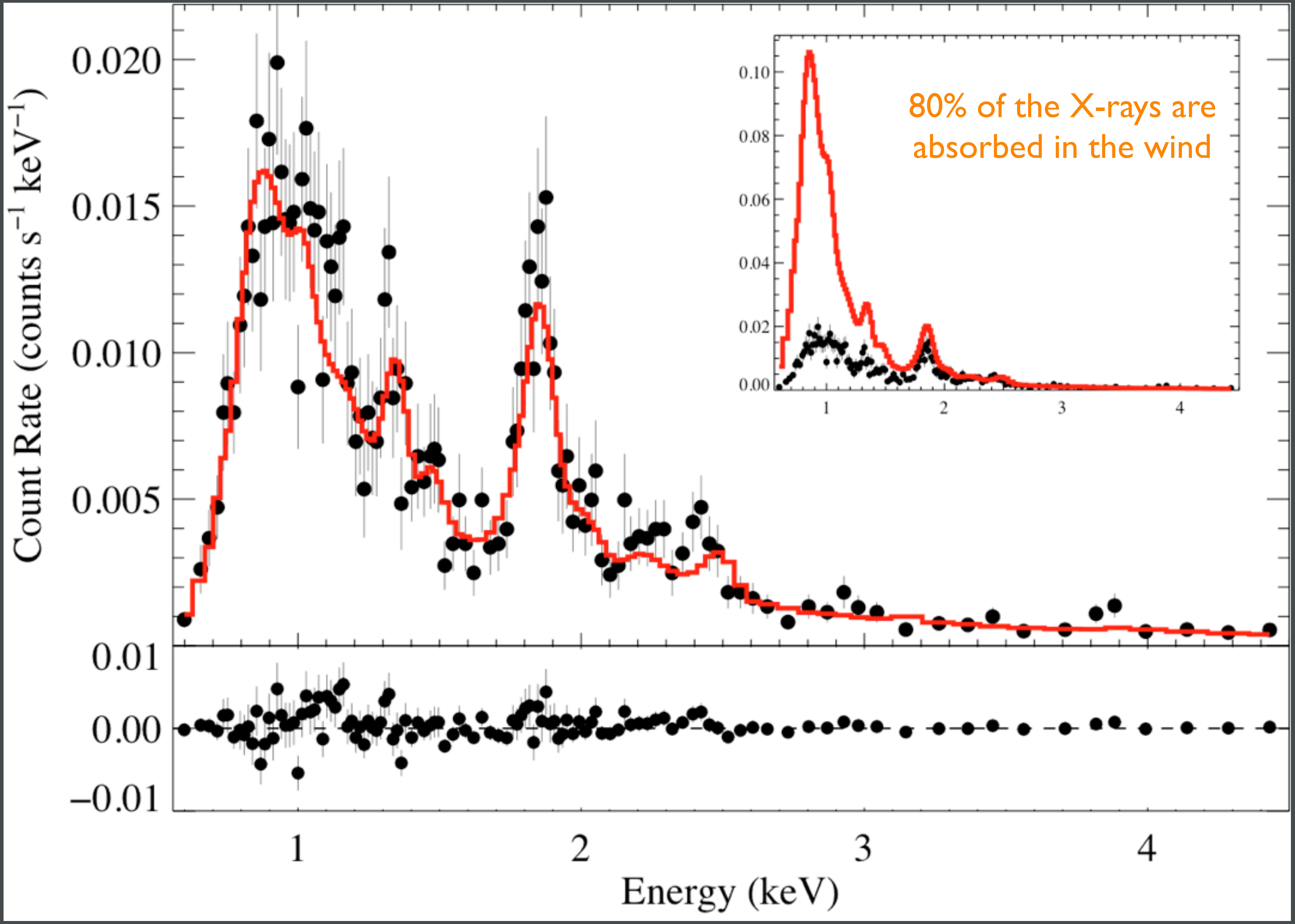


HD 93129A: *Chandra* ACIS spectrum





0.020
0.015
0.010
0.005
Count Rate (counts s⁻¹ keV⁻¹)
0.01
0.00
−0.01
1
2
3
4
Energy (keV)
0.10
0.08
0.06
0.04
0.02
0.00
same model,
no wind attenuation



80% of the X-rays are absorbed in the wind
0.10
0.08
0.06
0.04
0.02
0.00
1
2
3
4
0.020
0.015
0.010
0.005
Count Rate (counts s^{-1} keV^{-1})
0.01
0.00
−0.01
Energy (keV)

$\Sigma_* = 0.052 \text{ g cm}^{-2}$

where this mass column parameter

$\Sigma_* = \dot{M}/4\pi R_* v_\infty$

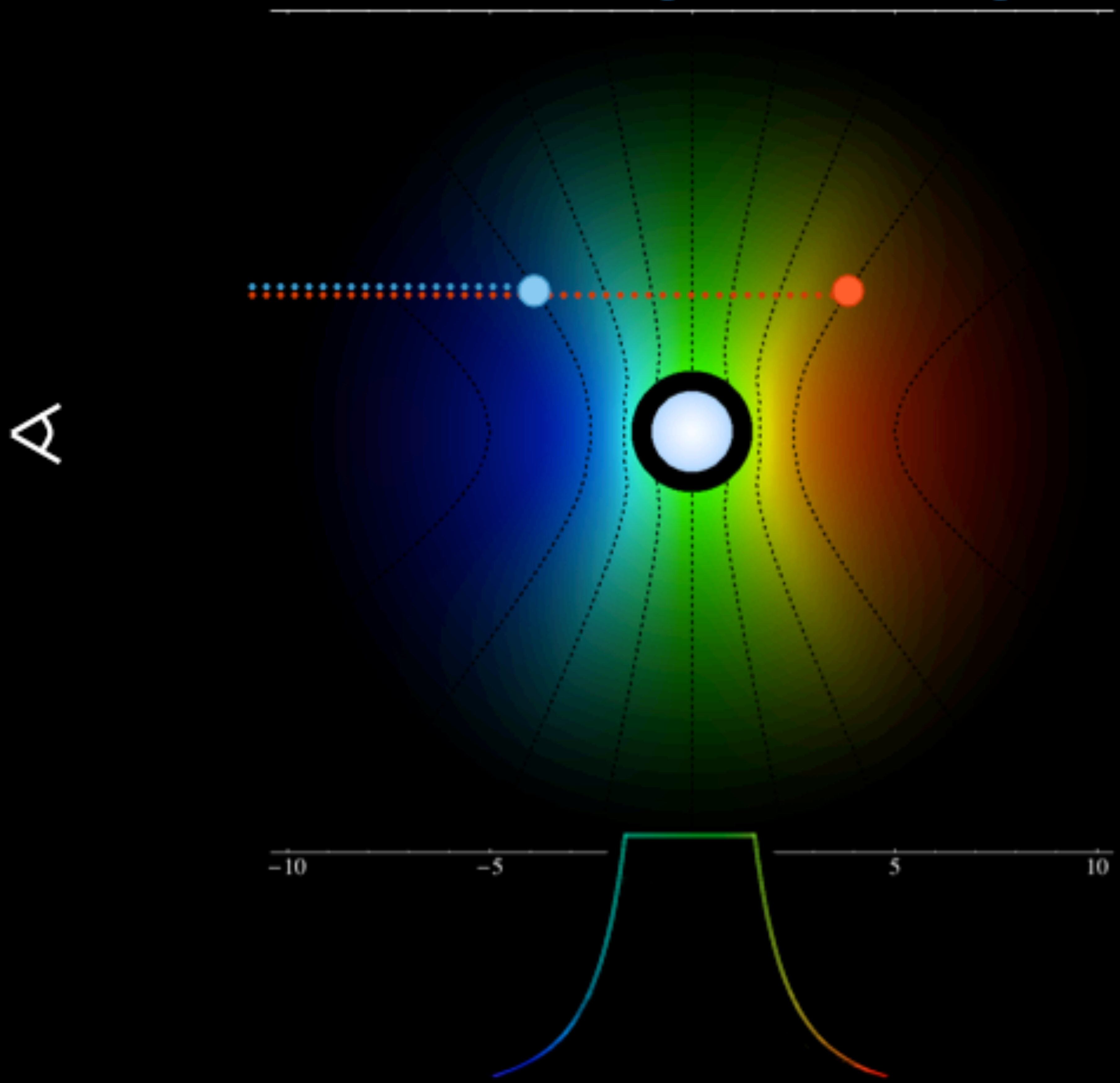
this fitted value corresponds to:

$\dot{M} = 5.2 \times 10^{-6} \, M_{sun}/yr$

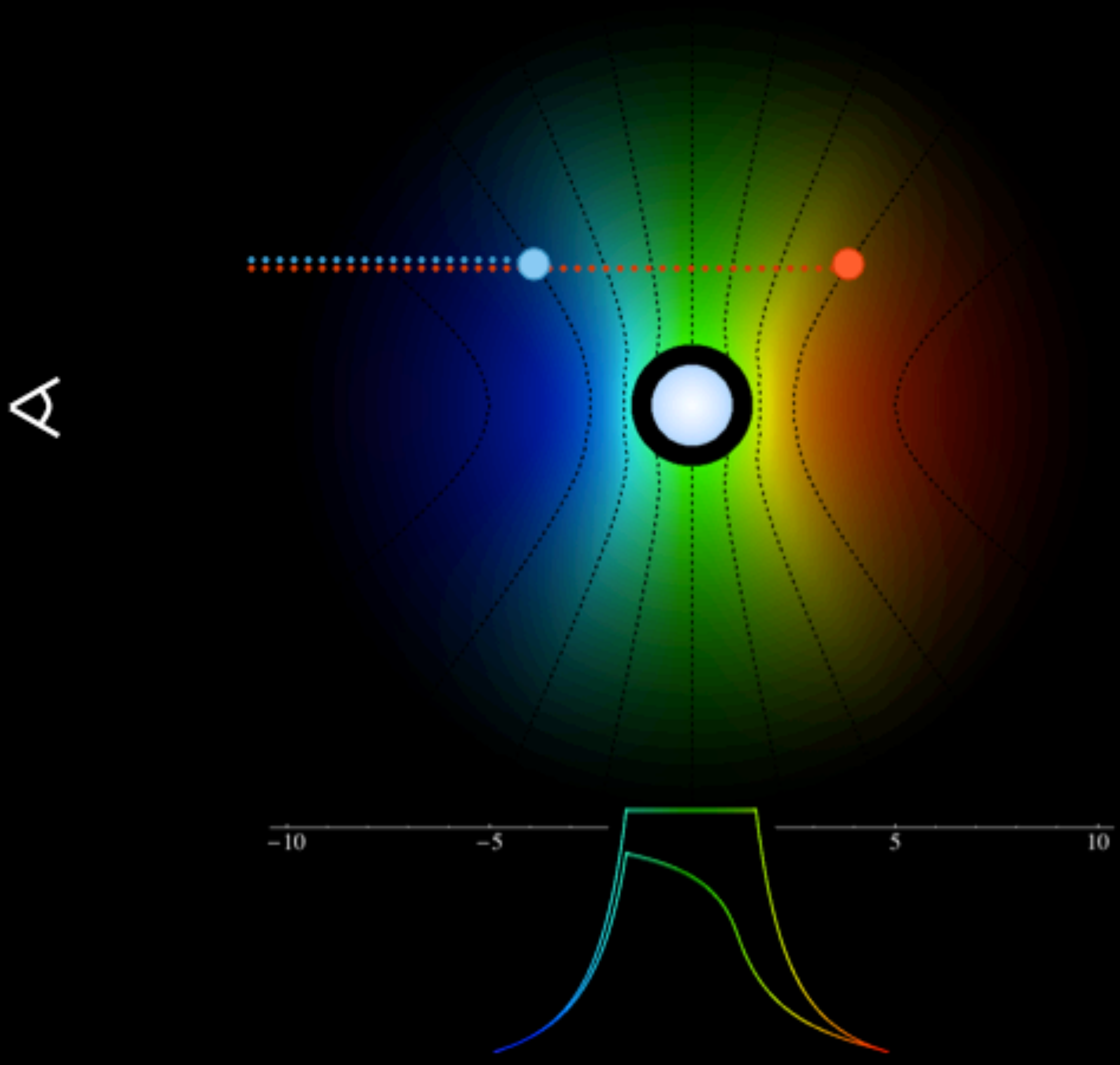
What do the individual X-ray emission *line profiles* tell us about the mass-loss rate?

...and about the wind-shock origin of the X-ray emission?

Line Asymmetry

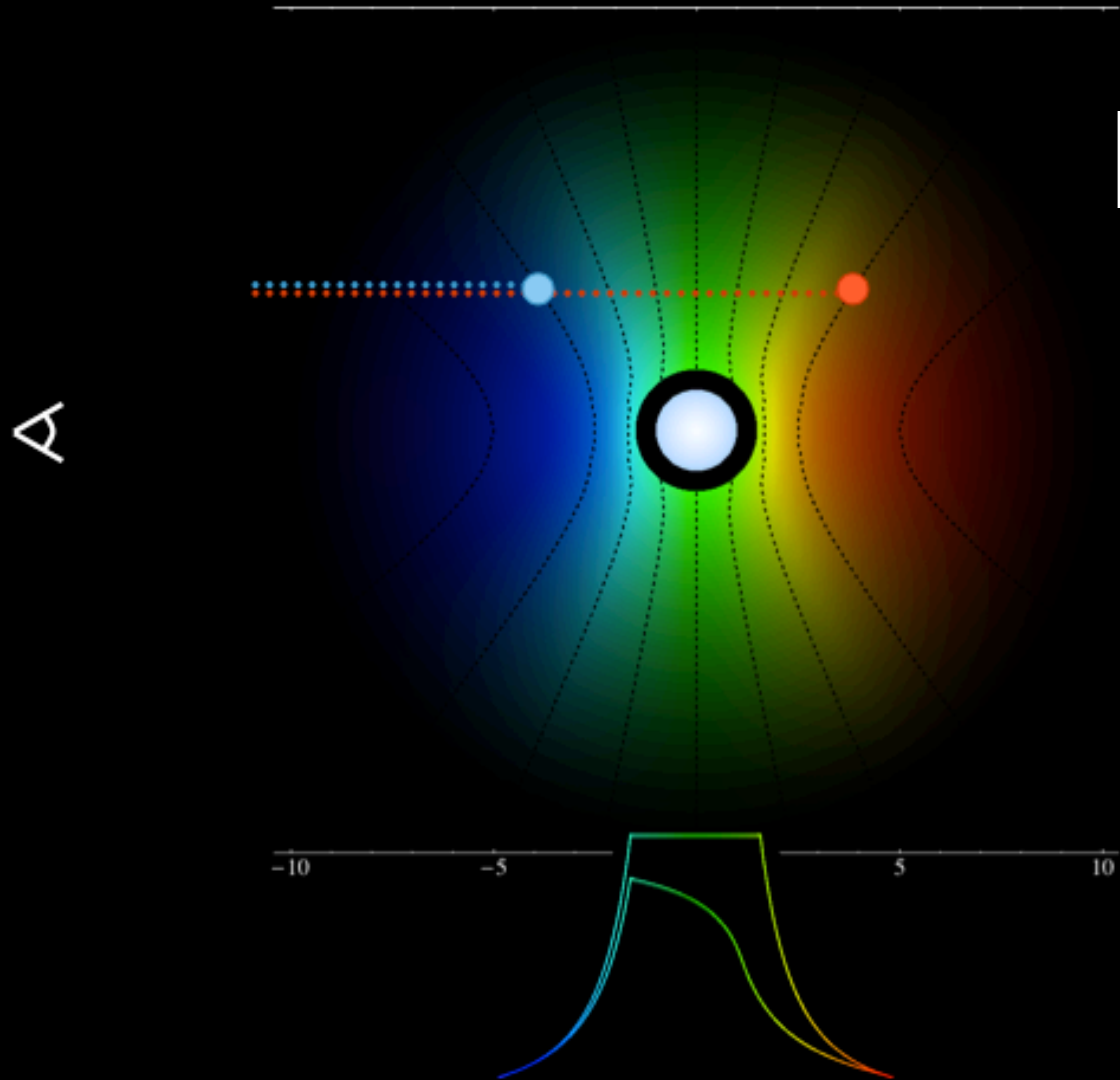


Line Asymmetry



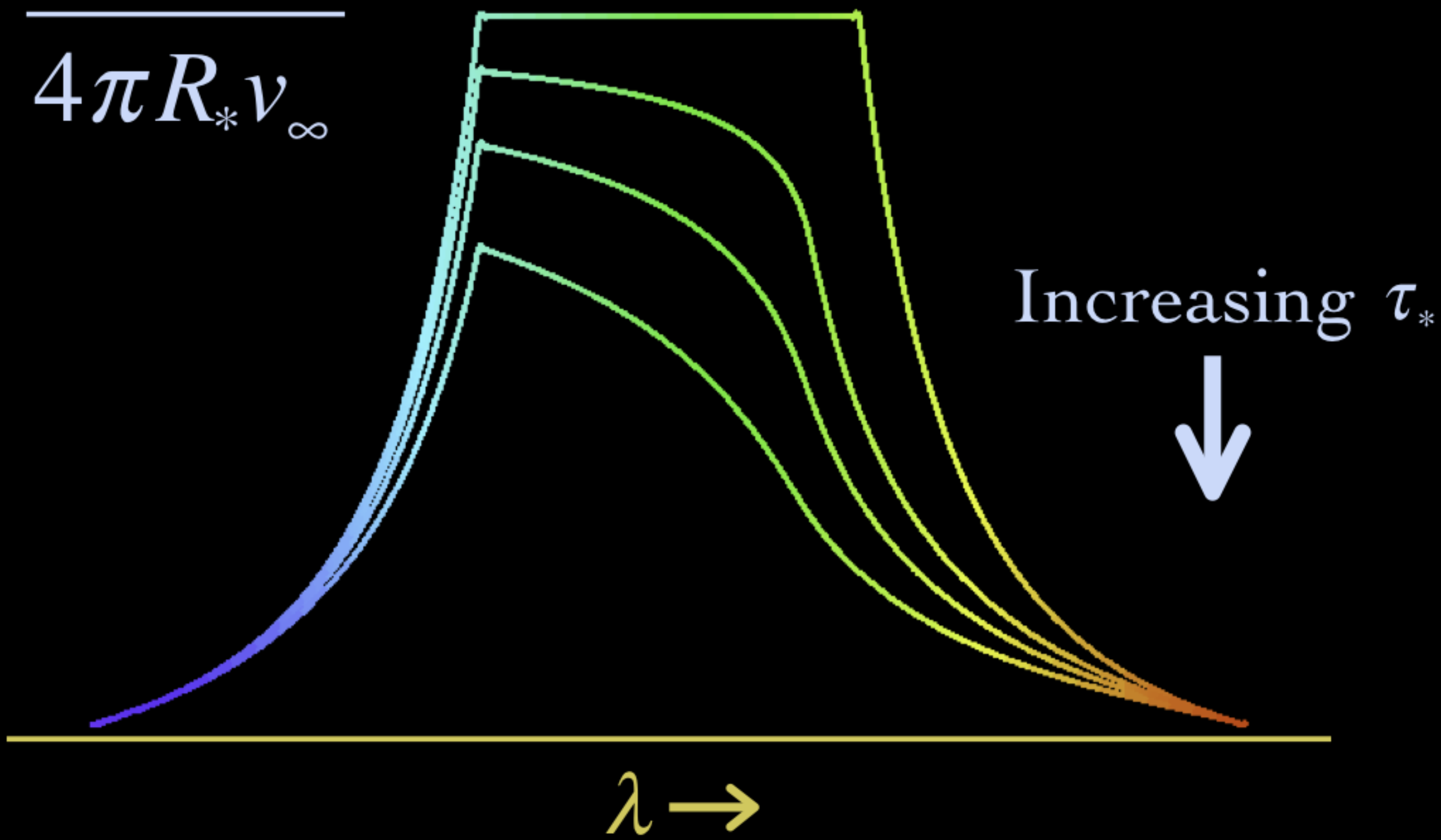
Line Asymmetry

$$\tau = \tau_* \int_z^\infty \frac{R_* dz'}{r'^2 (1 - R_*/r')^\beta}$$



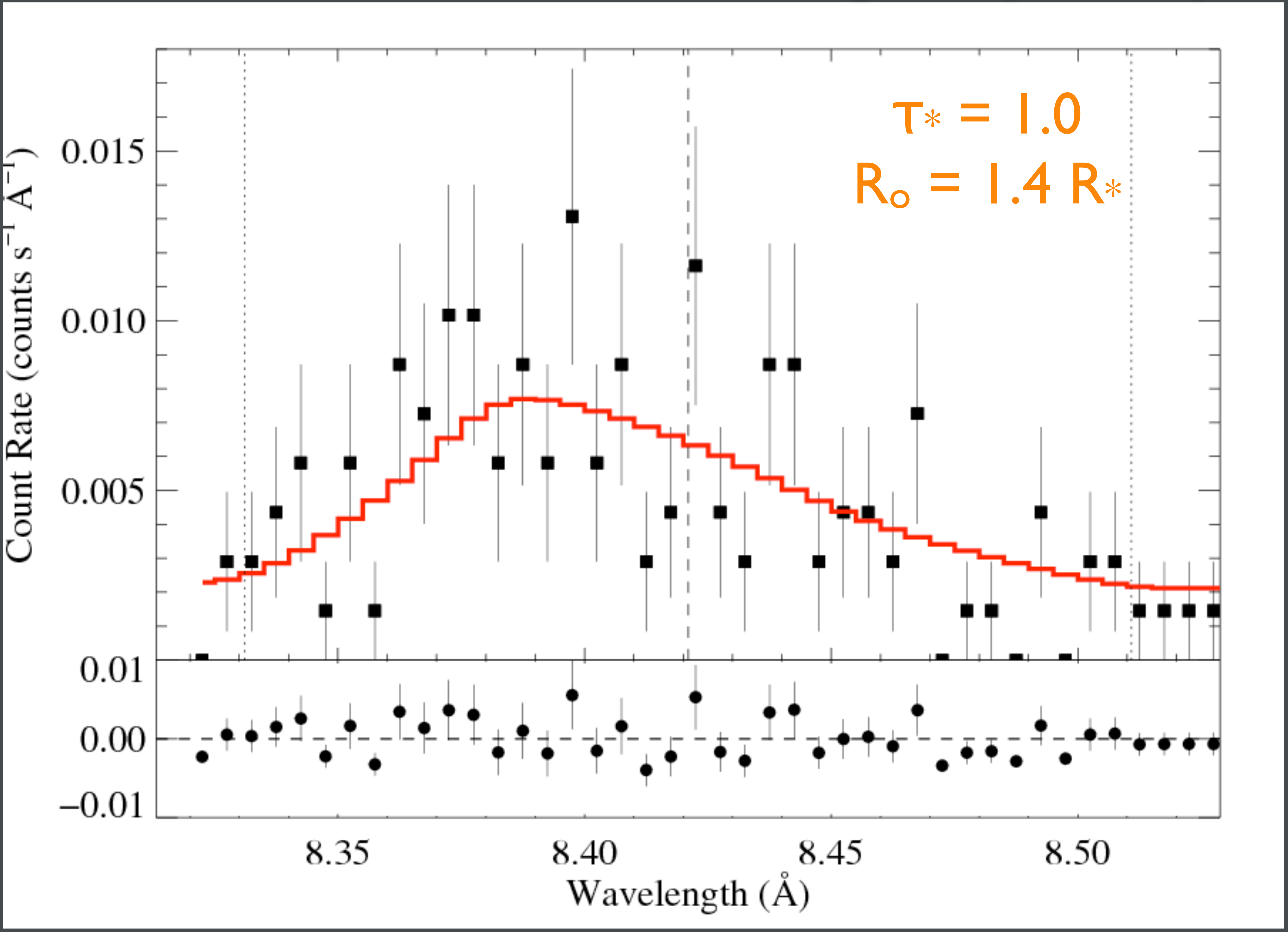
Wind Profile Model

$$\tau_* = \frac{\kappa \dot{M}}{4\pi R_* v_\infty}$$

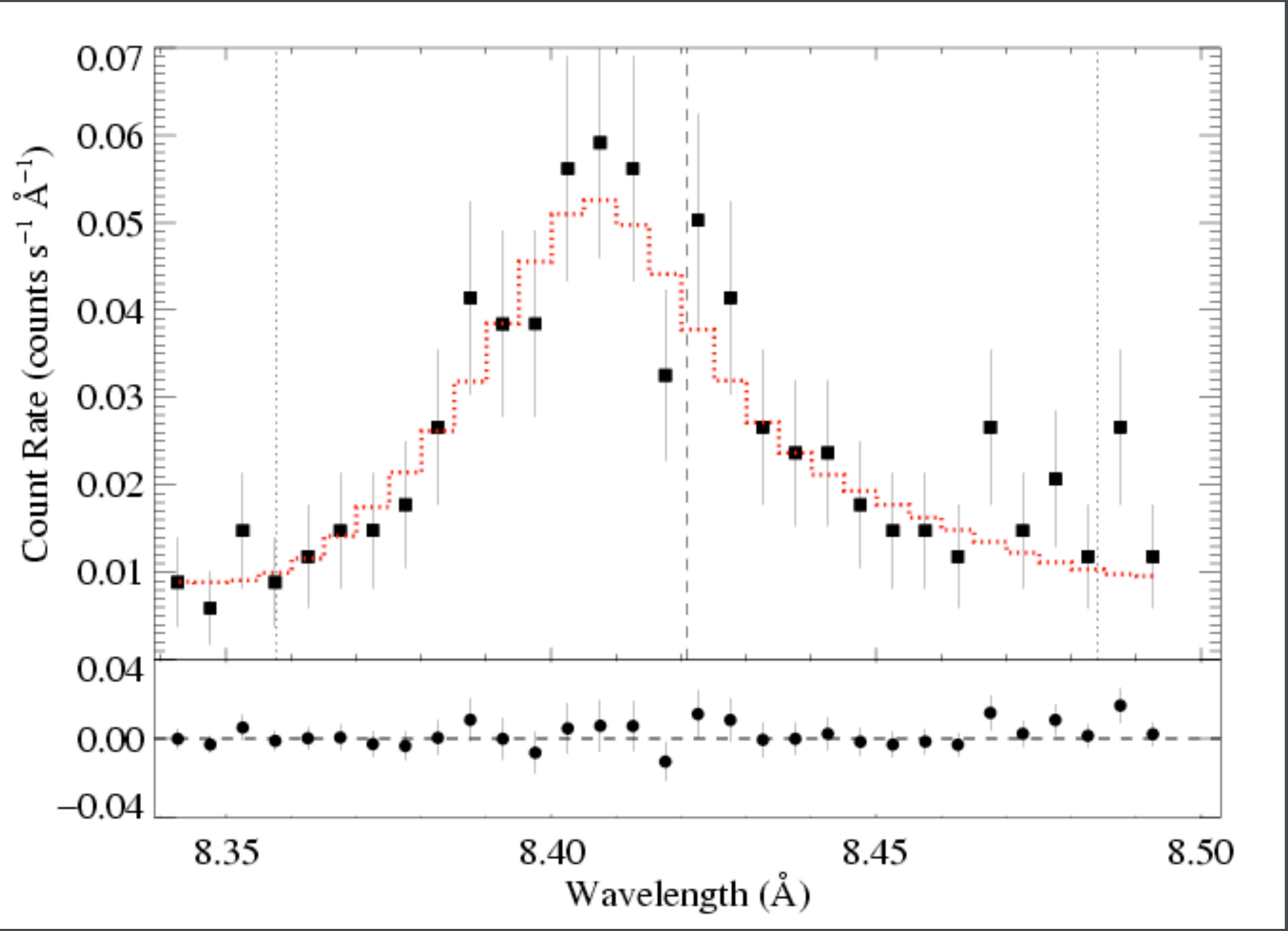


HD 93129A

Mg XII Lyman-alpha

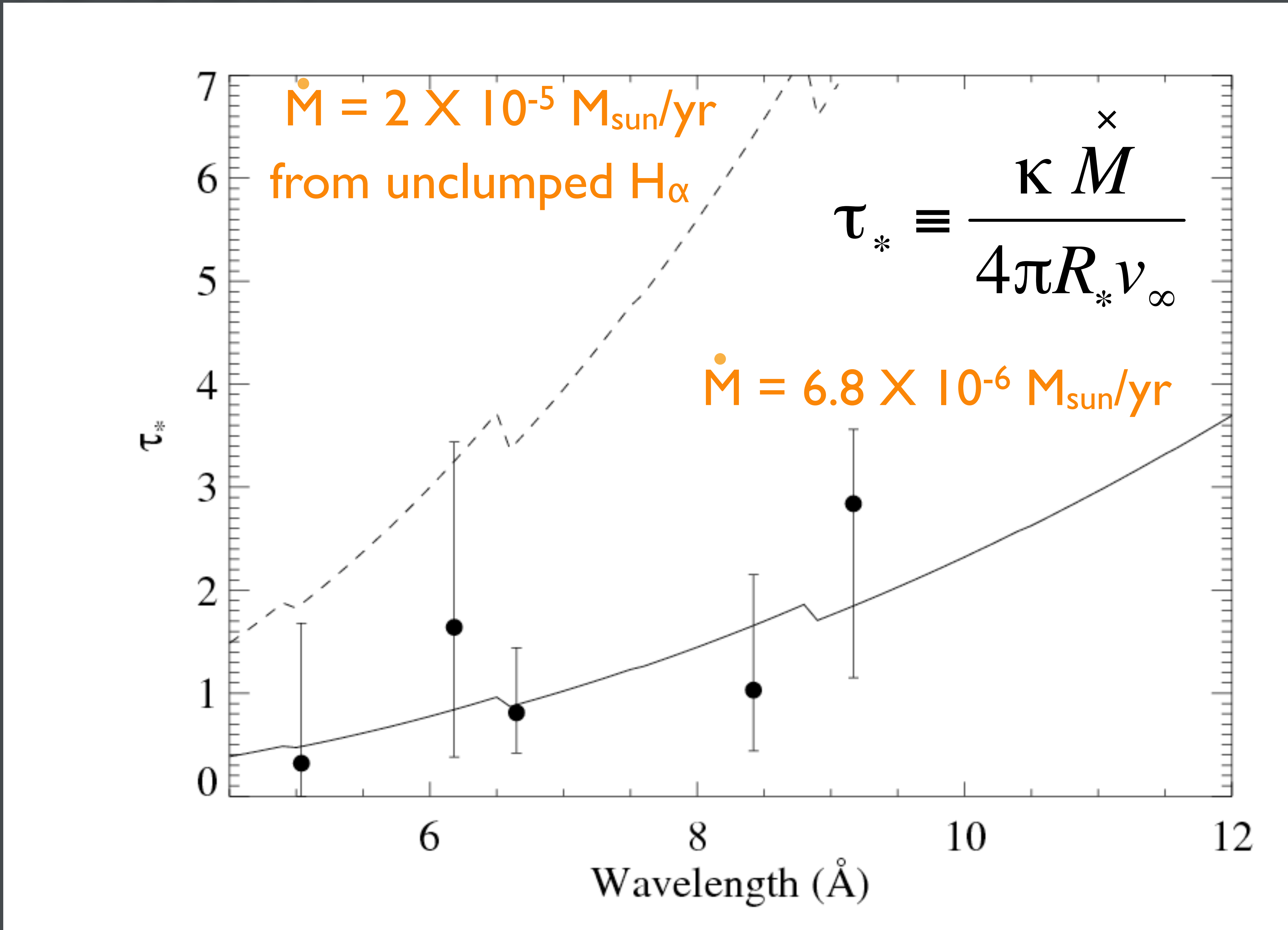


ζ Pup for comparison



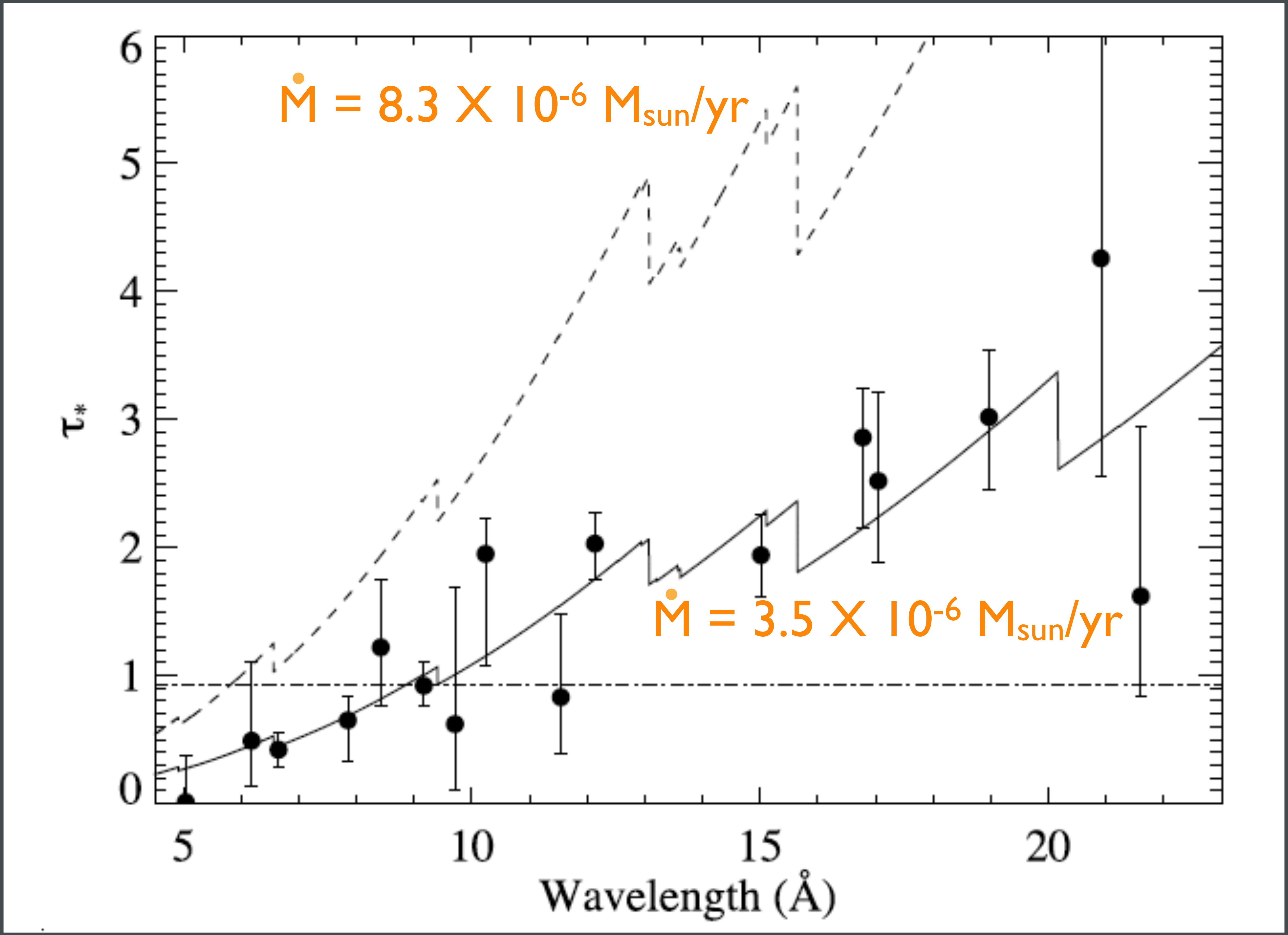
HD 93129A

τ* from five emission lines



$\tau_* = \kappa(\lambda)\dot{M}/4\pi R_* v_\infty$

ζ Pup for comparison



HD 93129A: First major conclusion

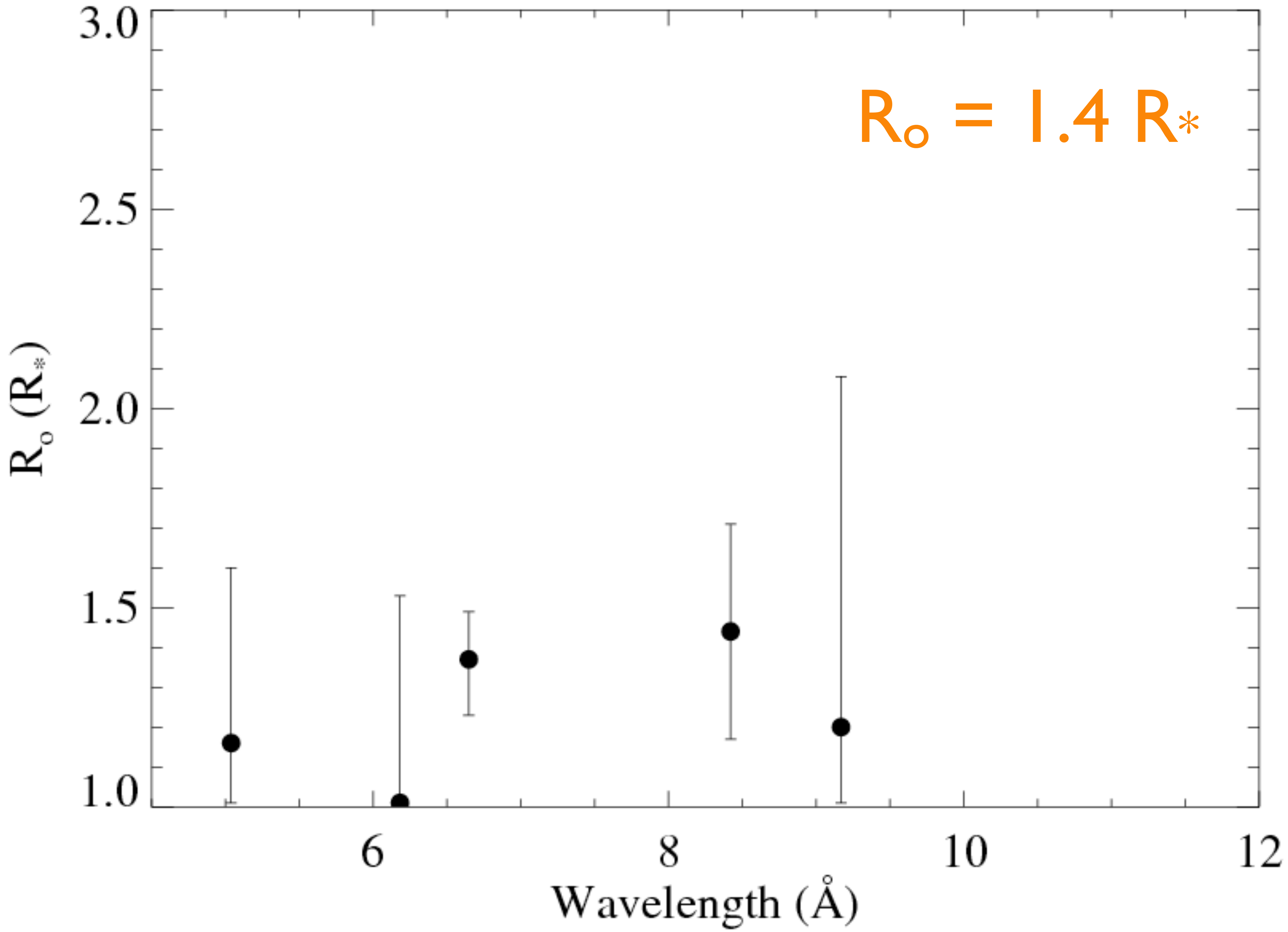
Two independent X-ray absorption mass-loss rate diagnostics give consistent results:

$\dot{M} = 6.8 \times 10^{-6}\ M_{sun}/yr$:line profiles

$\dot{M} = 5.2 \times 10^{-6}\ M_{sun}/yr$:broadband

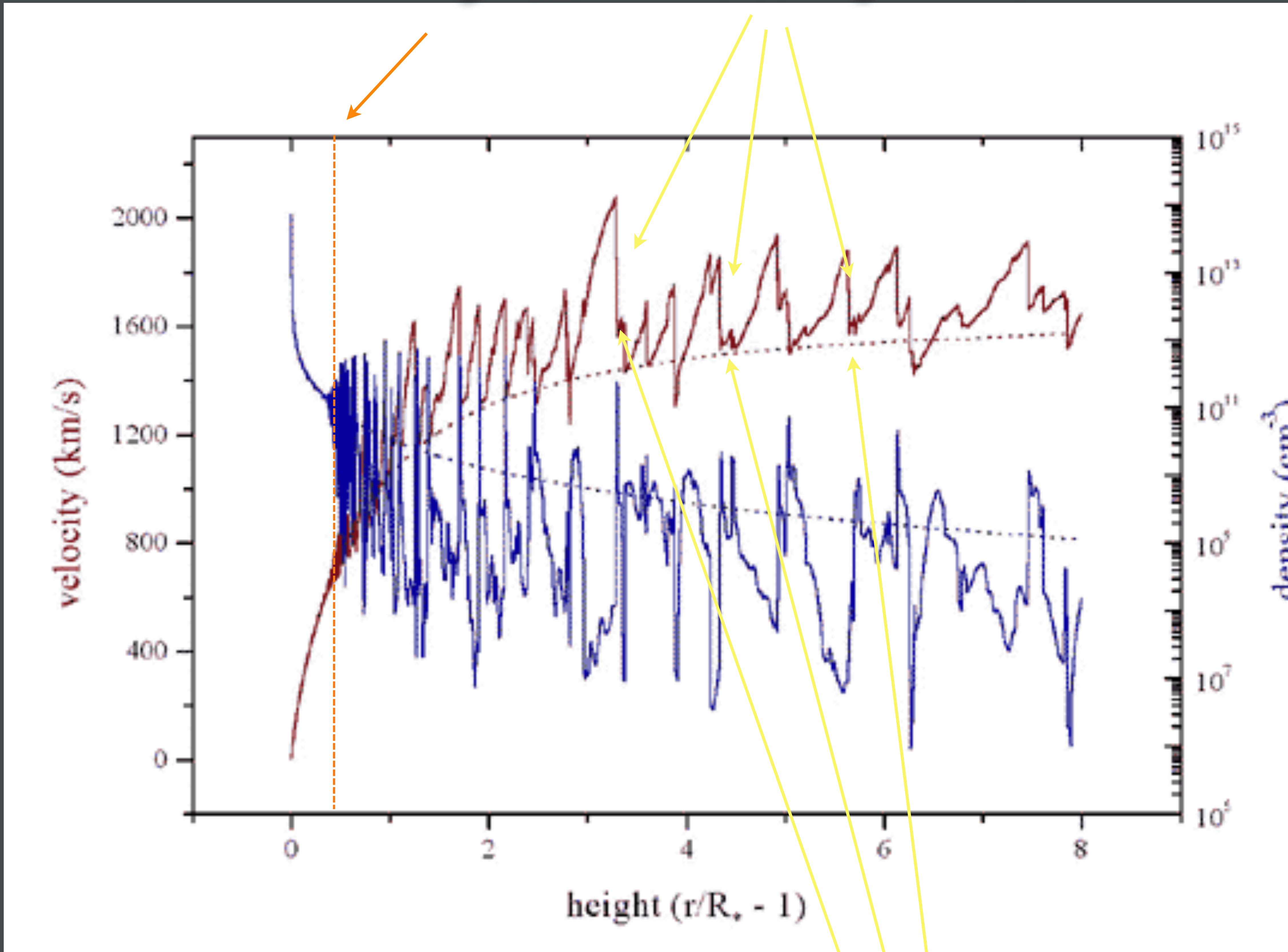
Factor of 3 or 4 reduction with respect to traditional (unclumped) Hα diagnostics

R_o = onset radius of X-ray emission



shock onset at $r \sim 1.5\ R_{star}$

$V_{shock} \sim 300$ km/s : $T \sim 10^6$ K



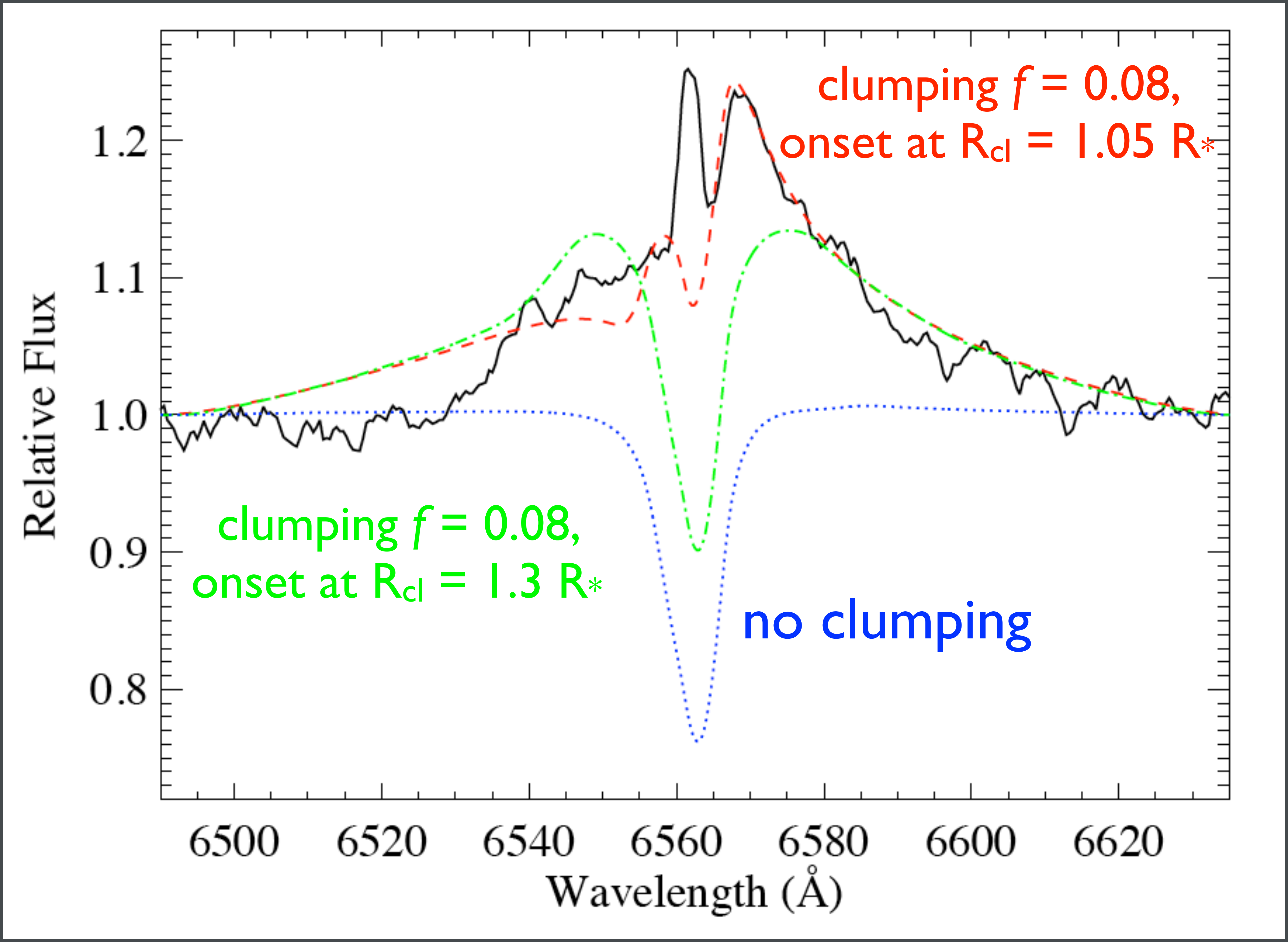
Shocked wind plasma is decelerated back down to the local CAK wind velocity

Lower mass-loss rate: consistent with Hα?

Lower mass-loss rate: consistent with Hα?

Yes! With clump volume filling factor of $f = 0.08$

$\dot{M} = 7 \times 10^{-6}\ M_{sun}/yr$



Questions

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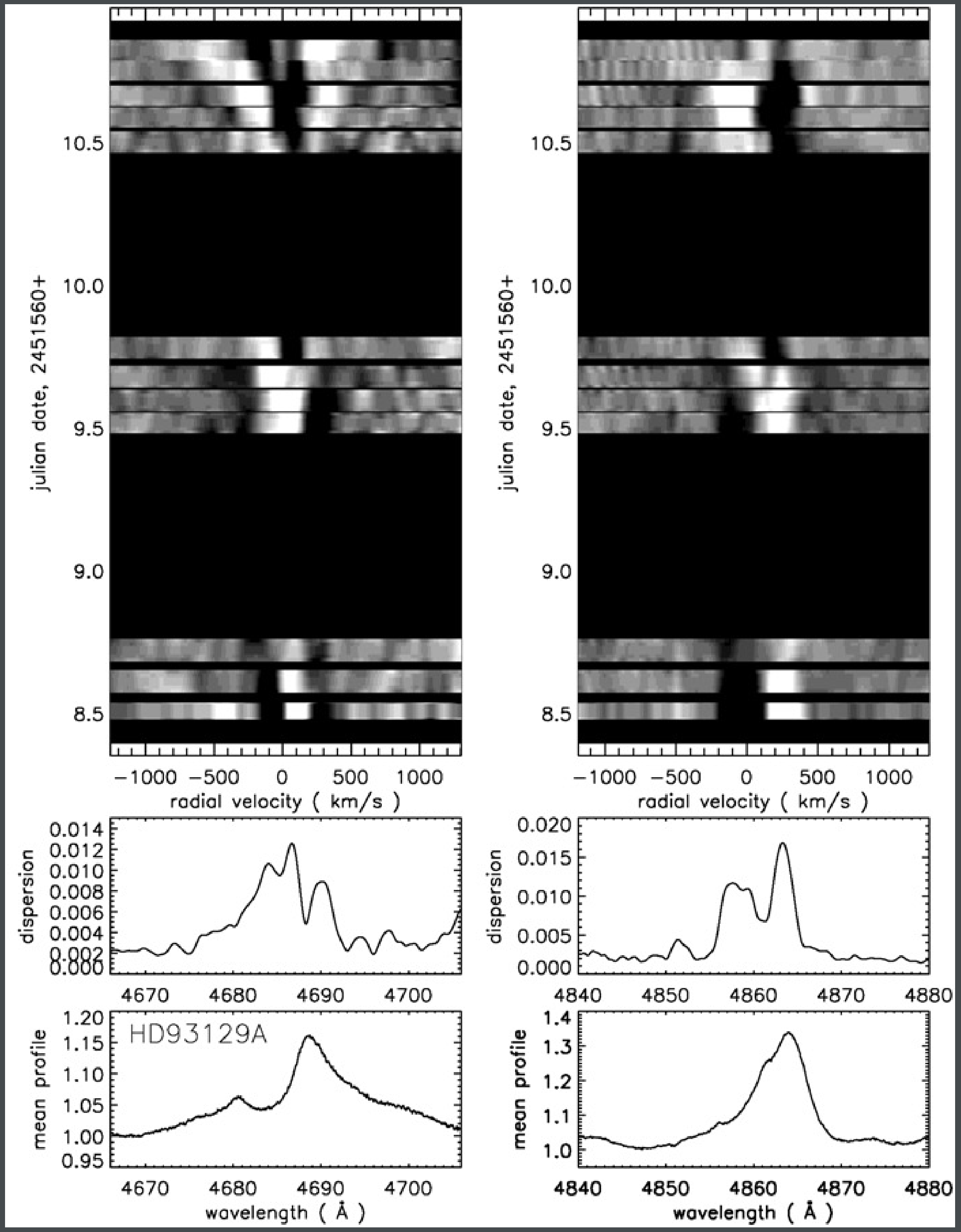
- What is the role of **wind attenuation** of the X-rays?
- What is the actual **mass-loss rate** of HD93129A?
- How does the **embedded wind shock** (EWS) mechanism operate in such a powerful wind?

HD 93129A: Conclusions

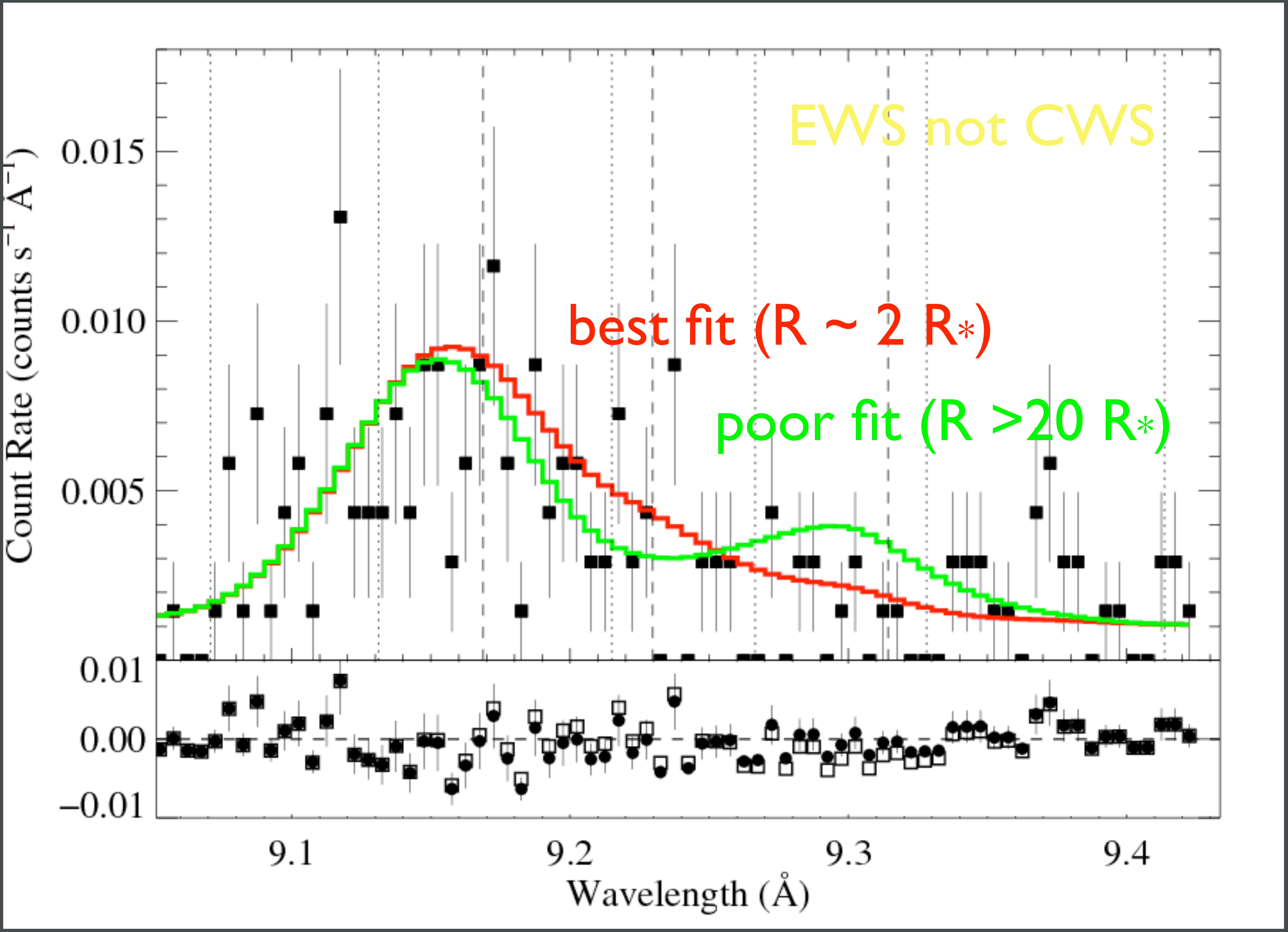
- Embedded Wind Shocks (EWS) dominate X-ray emission
- Wind attenuation is very important
- Mass-loss rate is reduced by factor of 3 to 4
- Shock onset radius is consistent with LDI simulations...but clumping onset is closer to the photosphere

Extra Slides

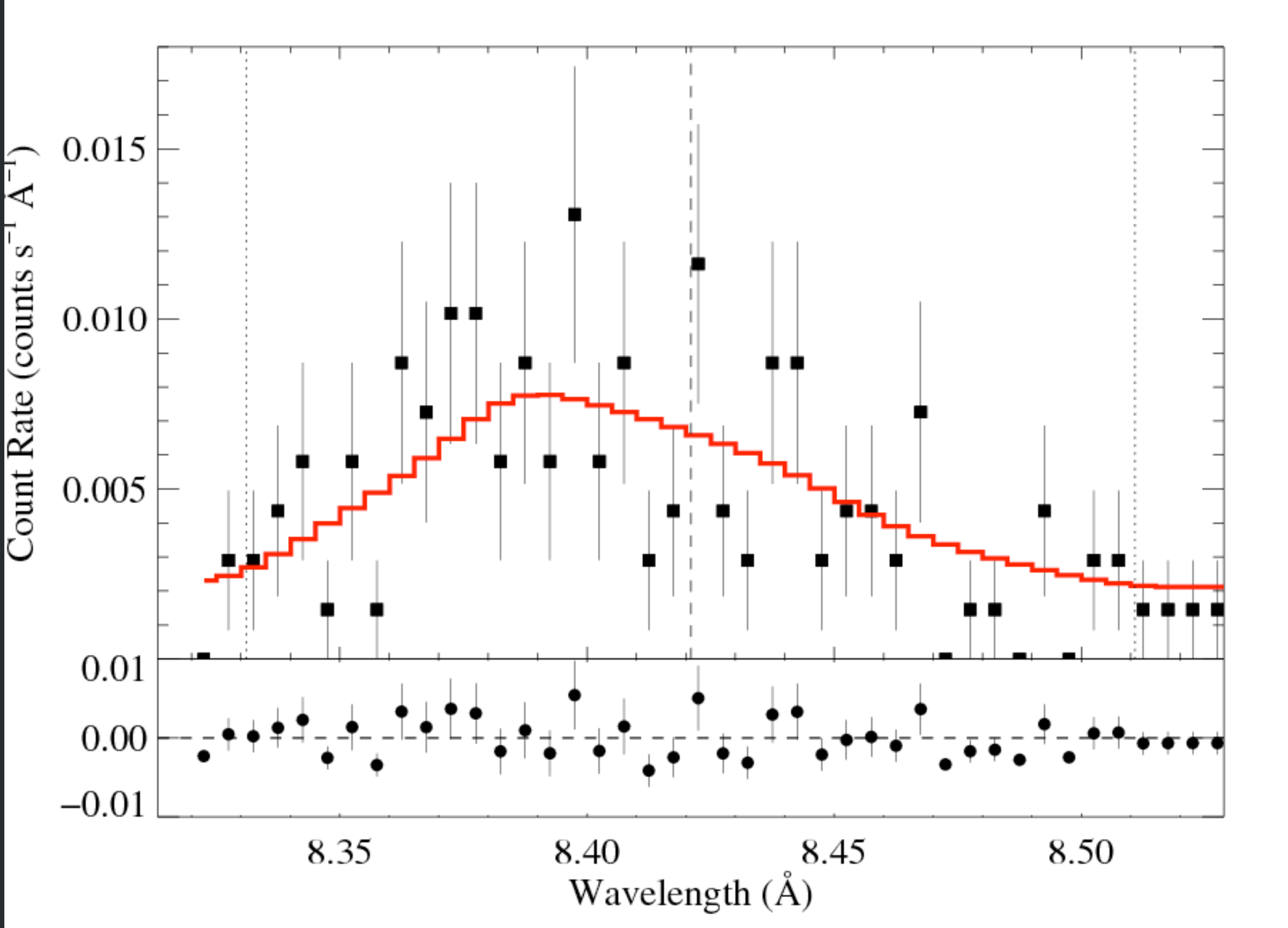
HD 93129A: optical wind clumping variability from Lepine & Moffat (2008)



Helium-like f/i line ratio: diagnostic of distance from photosphere



Incidentally, you **can** fit the *Chandra* line profiles with a porous model



But, the fit requires a porosity length of 5 R_*!