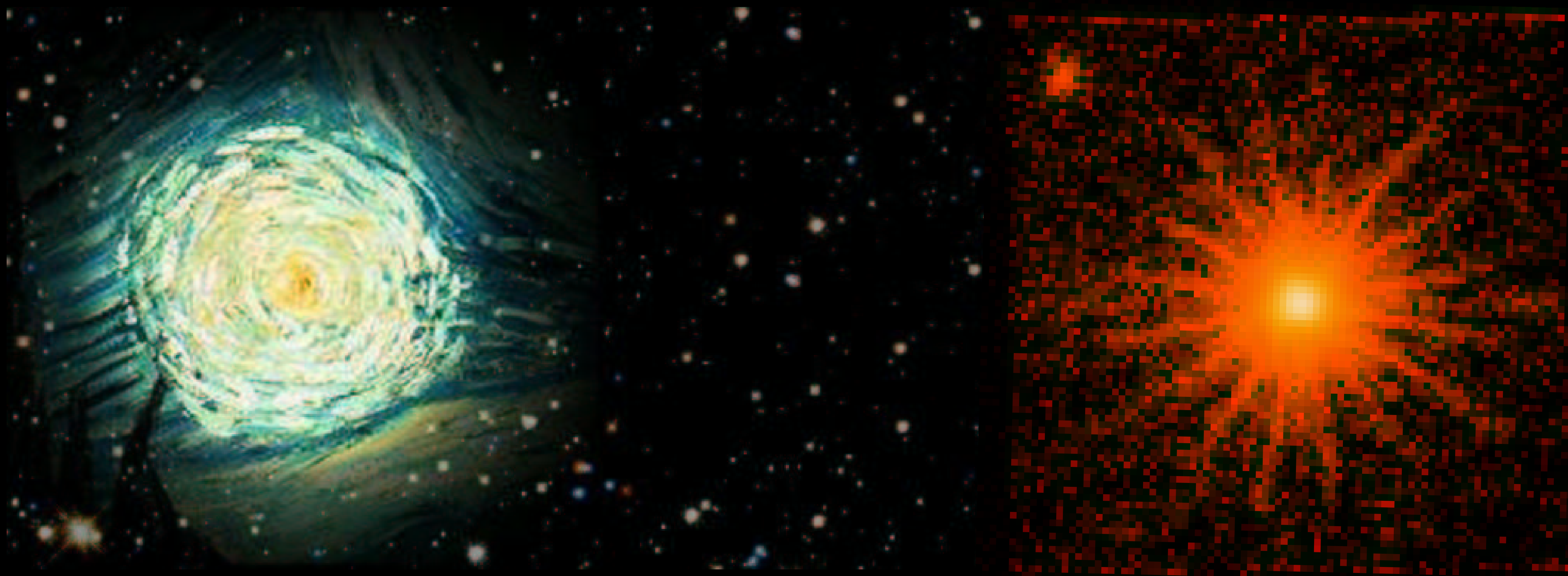
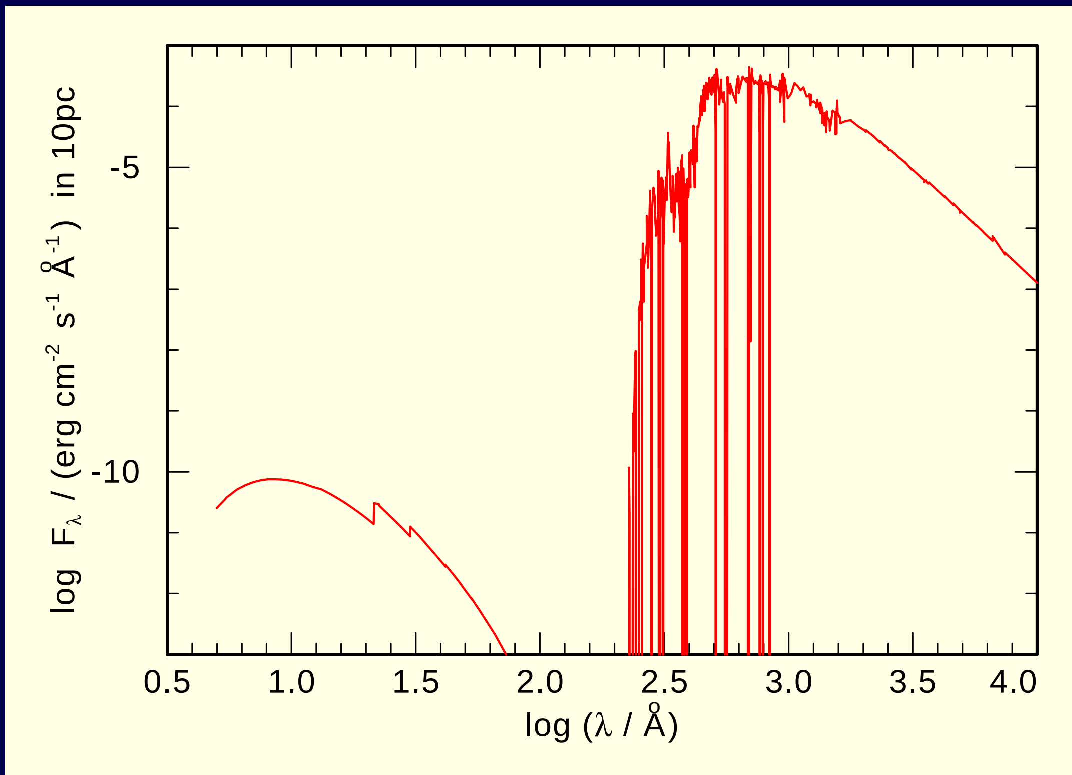


X-ray Universe 2008

Lidia Oskinova
W. Waldron, J. Cassinelli, A. Feldmeier, W.-R. Hamann

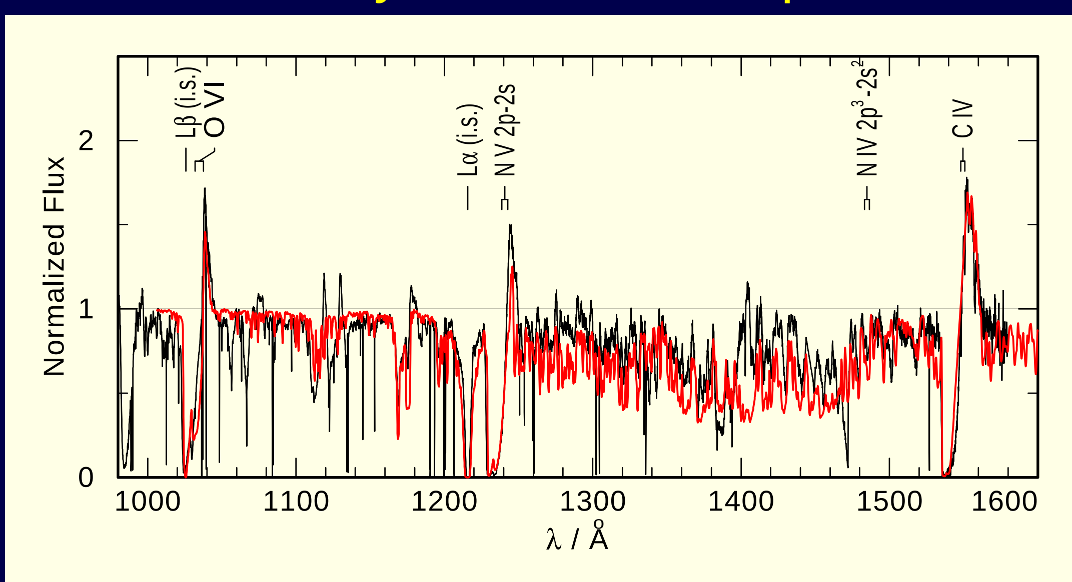
X-ray spectroscopy of single O stars

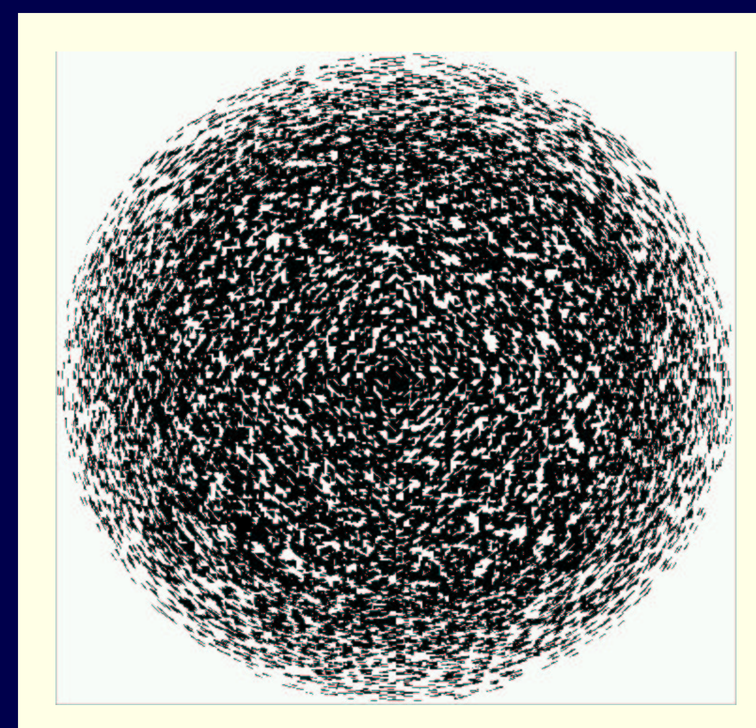
All O stars emit X-rays



- 0.01MK<T_{eff}<0.06MK, L_{bol}=$10^{4..6}$ L_{sun}
- Clumped wind $\dot{M} = 10^{-6..-8}$ M_{sun}/yr, v_{wind}>10^3 km/s
- Superionization (e.g. OVI) = X-rays (Cassinelli etal. ’79,’83)
- Einstein, Rosat: $L_X \sim 10^{-7} L_{bol}$ (Seward etal. ’79, Berghoever etal. ’97)

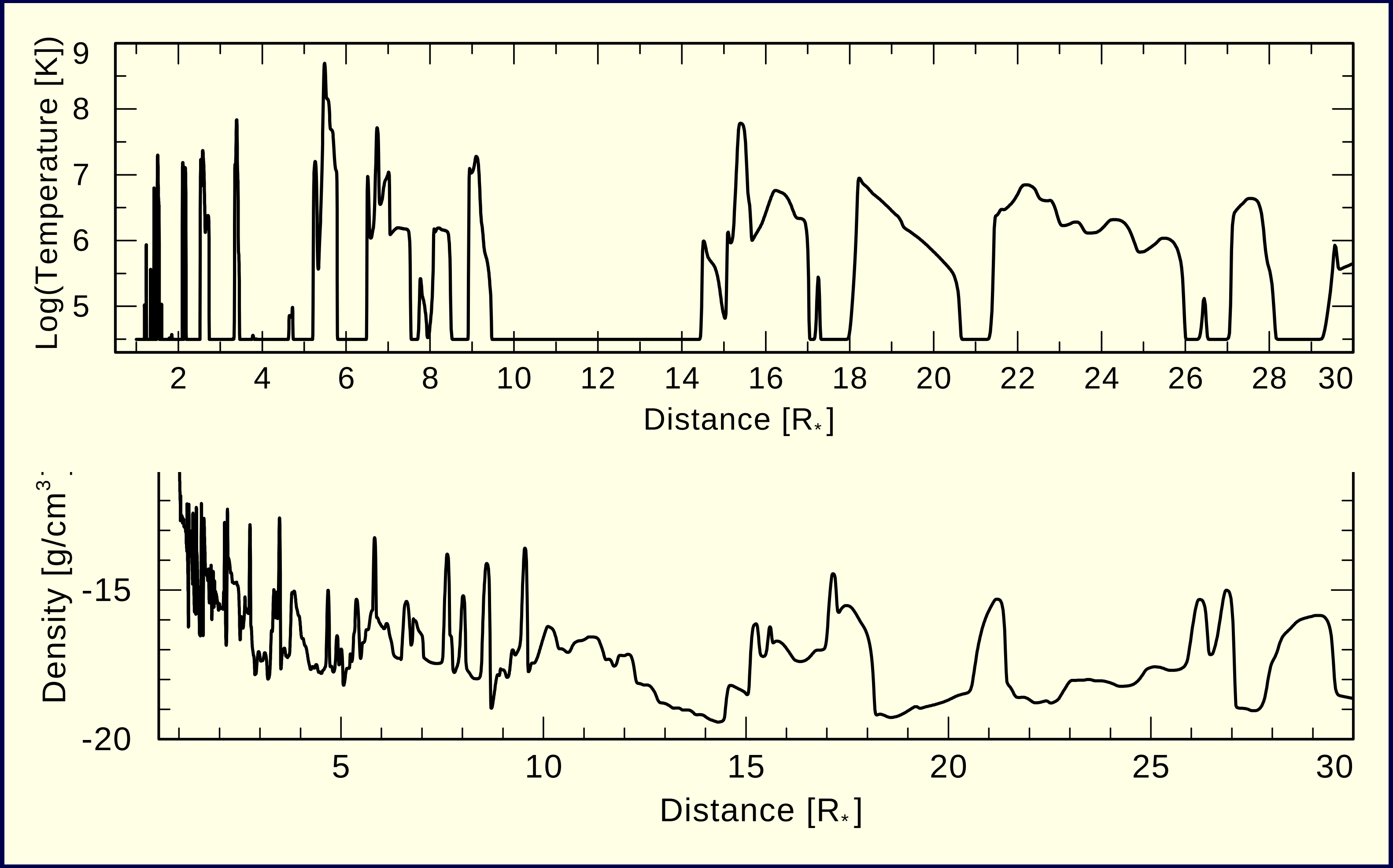
model+X- rays ⇒ O VI superionisation





How X-rays are generated in O stars? Leading theories.

- Bow shocks around blobs (Lucy & White ’80, Cassinelli etal. ’08)
- Magnetically confined loops at the stellar base (Cassinelli & Swank ’83)
- Wind shocks from the instabilities of radiation driving (Owocki etal. ’83)
- Collisions of dense shells in deep wind regions (Feldmeier etal. ’97)



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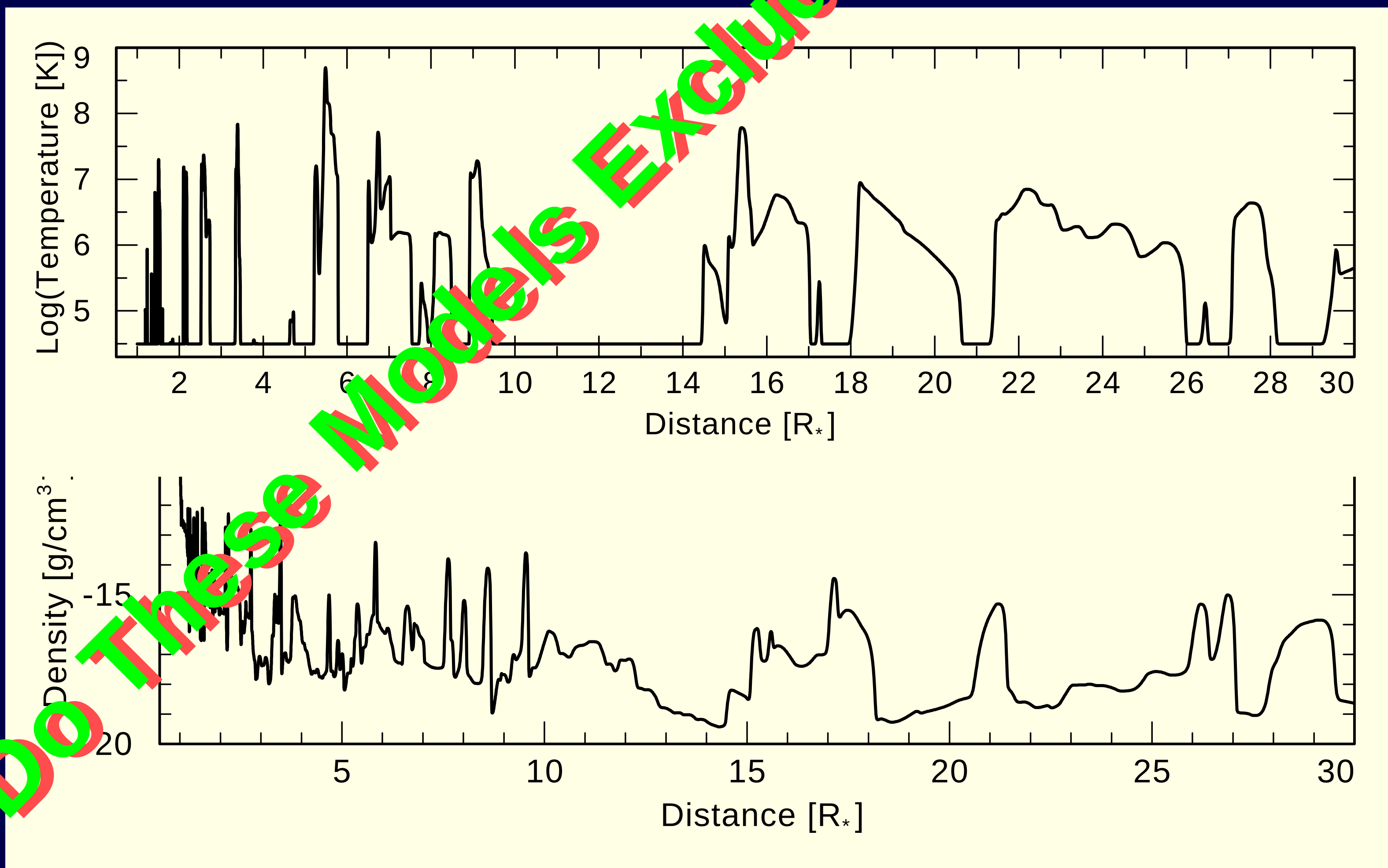
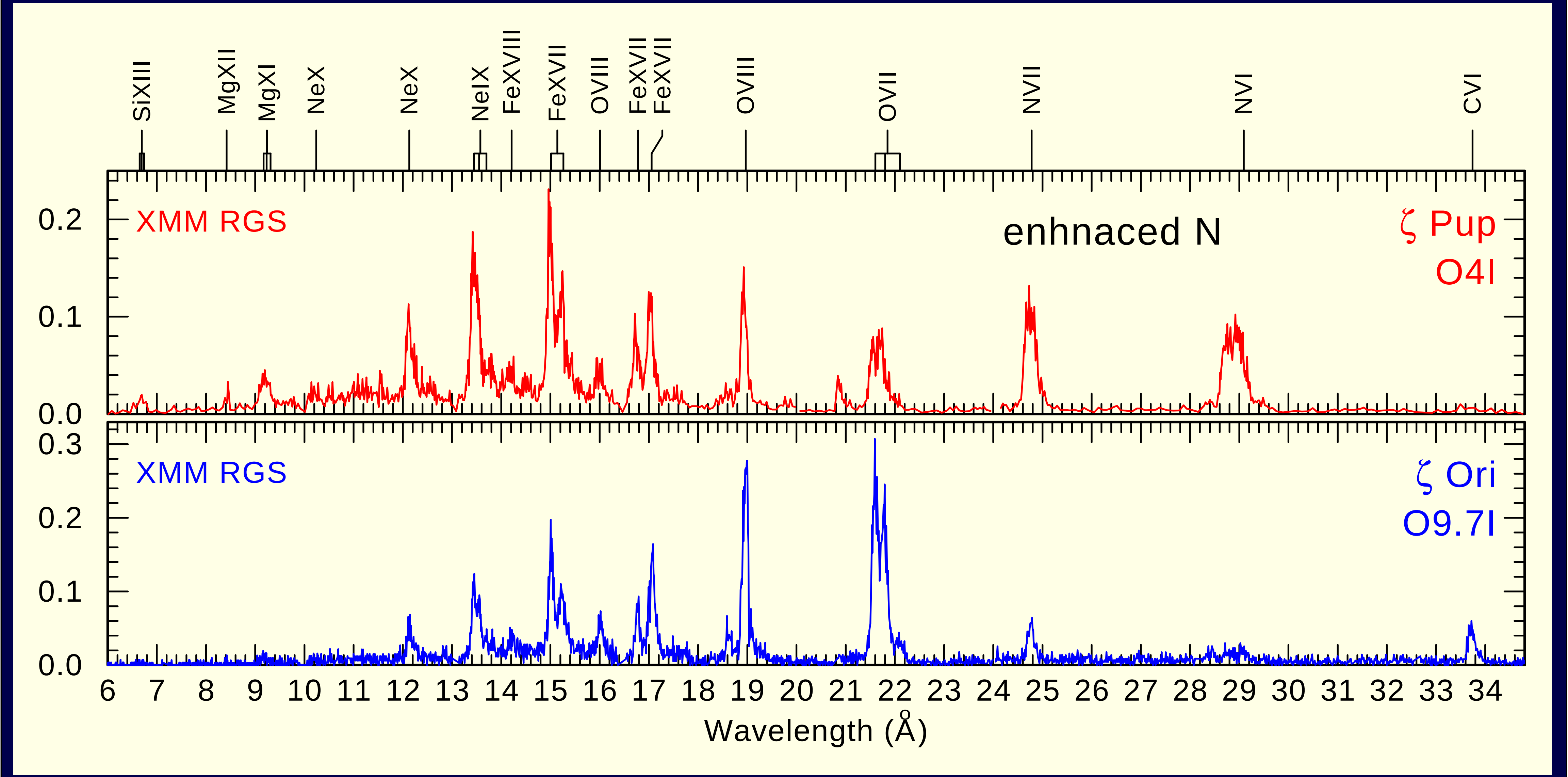
Do These Models Exclude Each Other?!



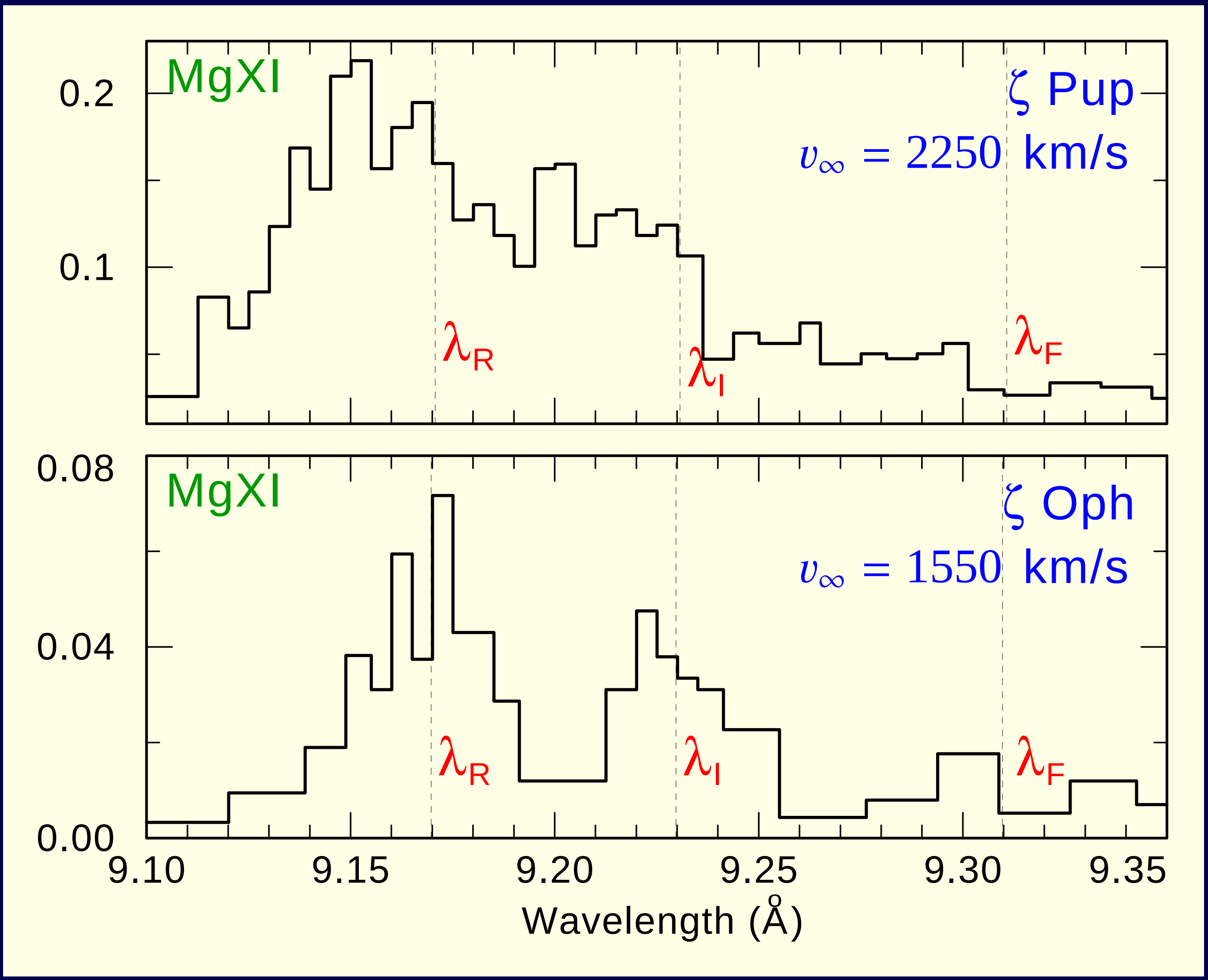
High-Resolution X-ray Spectra



* Overall spectral fitting → plasma model, abundunces
* Line ratios → $T_X(r)$, spatial distribution
* Line profiles → velocity field, wind opacity

Line Ratios of He-Like Ions: Location and Temperature

- Strong UV field $\Rightarrow$ radiative de-population of metastable level ^3S
- f/i is diagnostic of UV field. UV field dilutes with radius

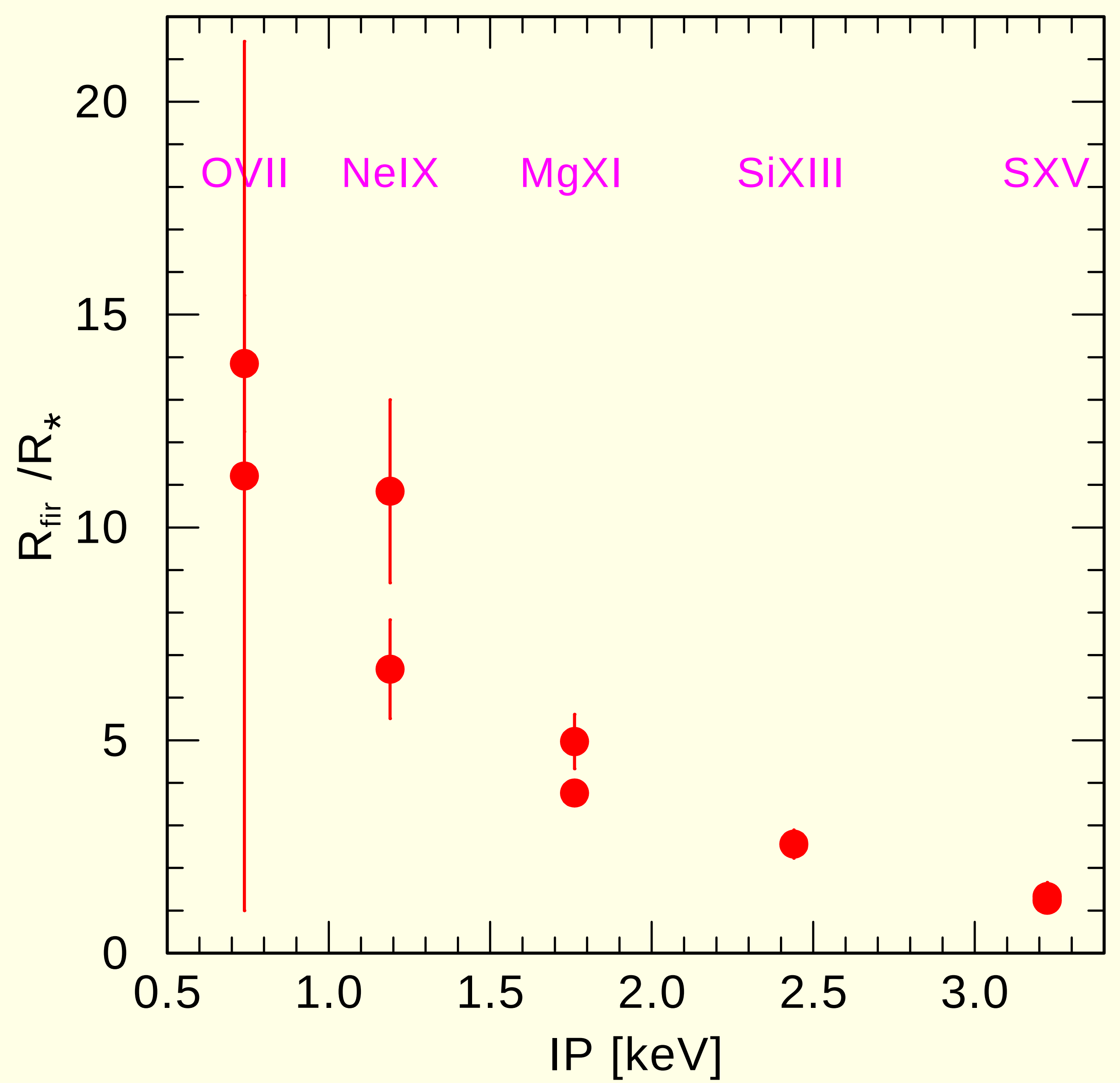


from Oskinova+'06

* Kahn + '01, Waldron & Cassinelli'01,'07, Wojdowski & Schulz'05, Oskinova '06, Leutenegger+'06, Raassen etal. '08
* Similar trends for different stars (Waldron & Cassinelli '07)
* Full UV RT needed: Mg XI $f \rightarrow i$ transition blended with O VI resonance line (cool wind) (Leutenegger etal. '06)

Near-Star High-Ion Problem (Waldron & Cassinelli '07)

O supergiants: strong photoabsorbing wind



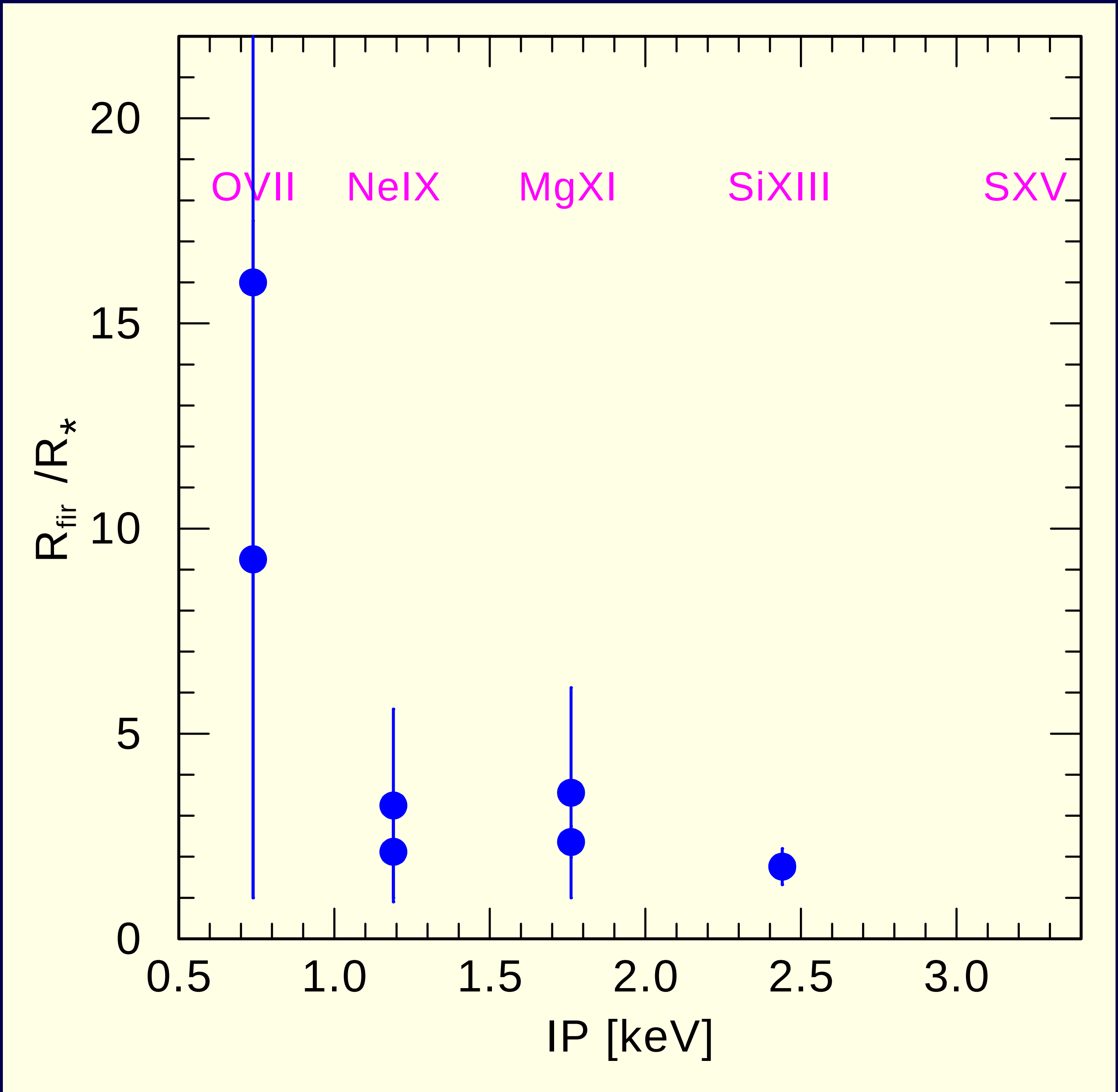
- Observed **f/i** → radii of formation
- Ions with **higher Z only close** to the base
- Waldron'05: $T_X(r)$ ↓

20MK @ 1.5R_* → 2.5MK @ 8R_*

- Contradiction to all shock models ??!
- **Magnetically confined loops @ surface ! (?)**

Near-Star High-Ion Problem (Waldron & Cassinelli '07)

O dwarfs: weak winds: low absorption of X-rays

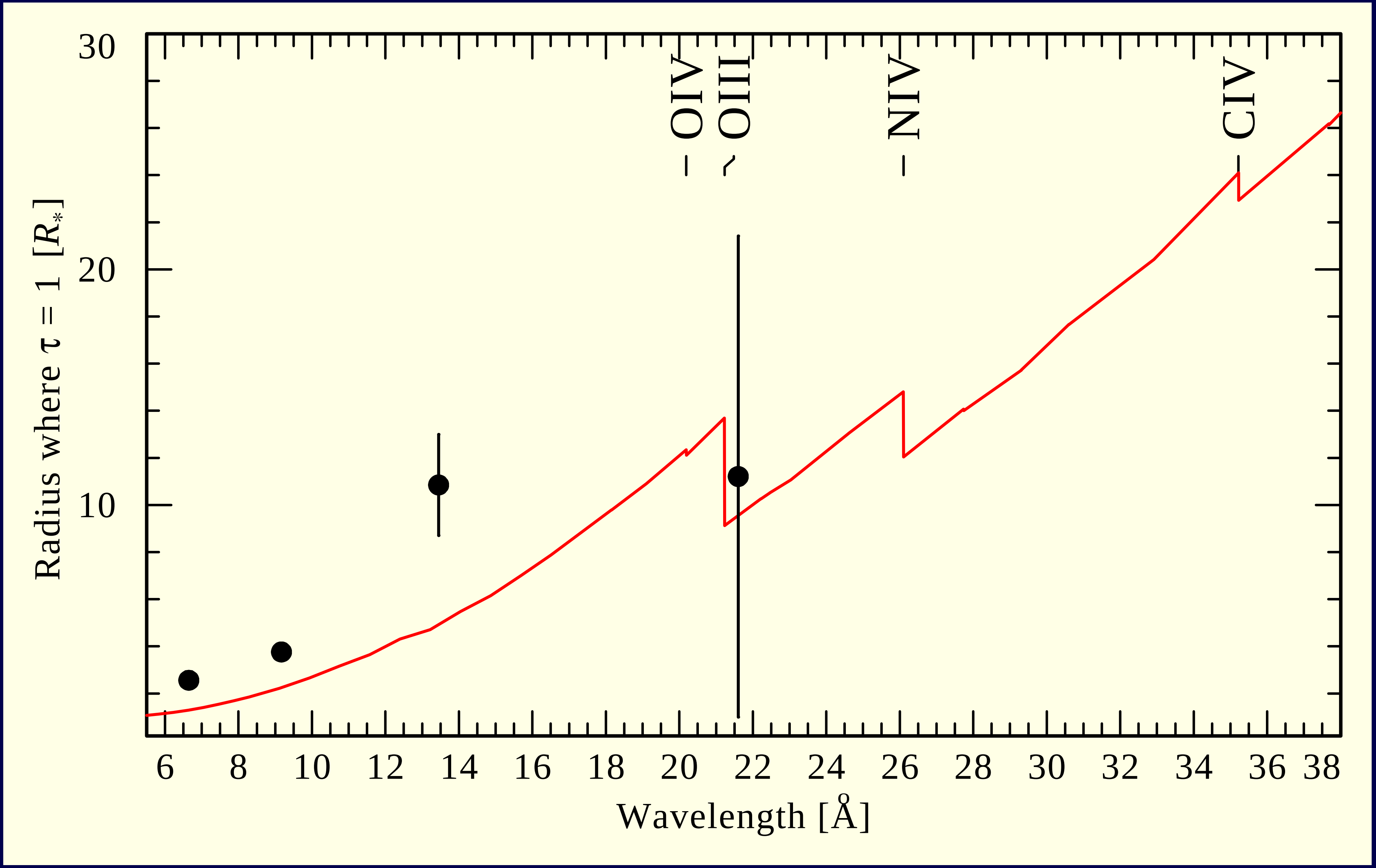


Ions with high and low Z are at the same distance, close to the core

Comparison with the O supergiants: correlation with wind τ_E is expected

Wind opacity for X-rays

Using modern atmosphere model ζ Pup $\dot{M} = 8.7 \times 10^{-6}\, M_{\odot}/\mathrm{yr}^{-1}$

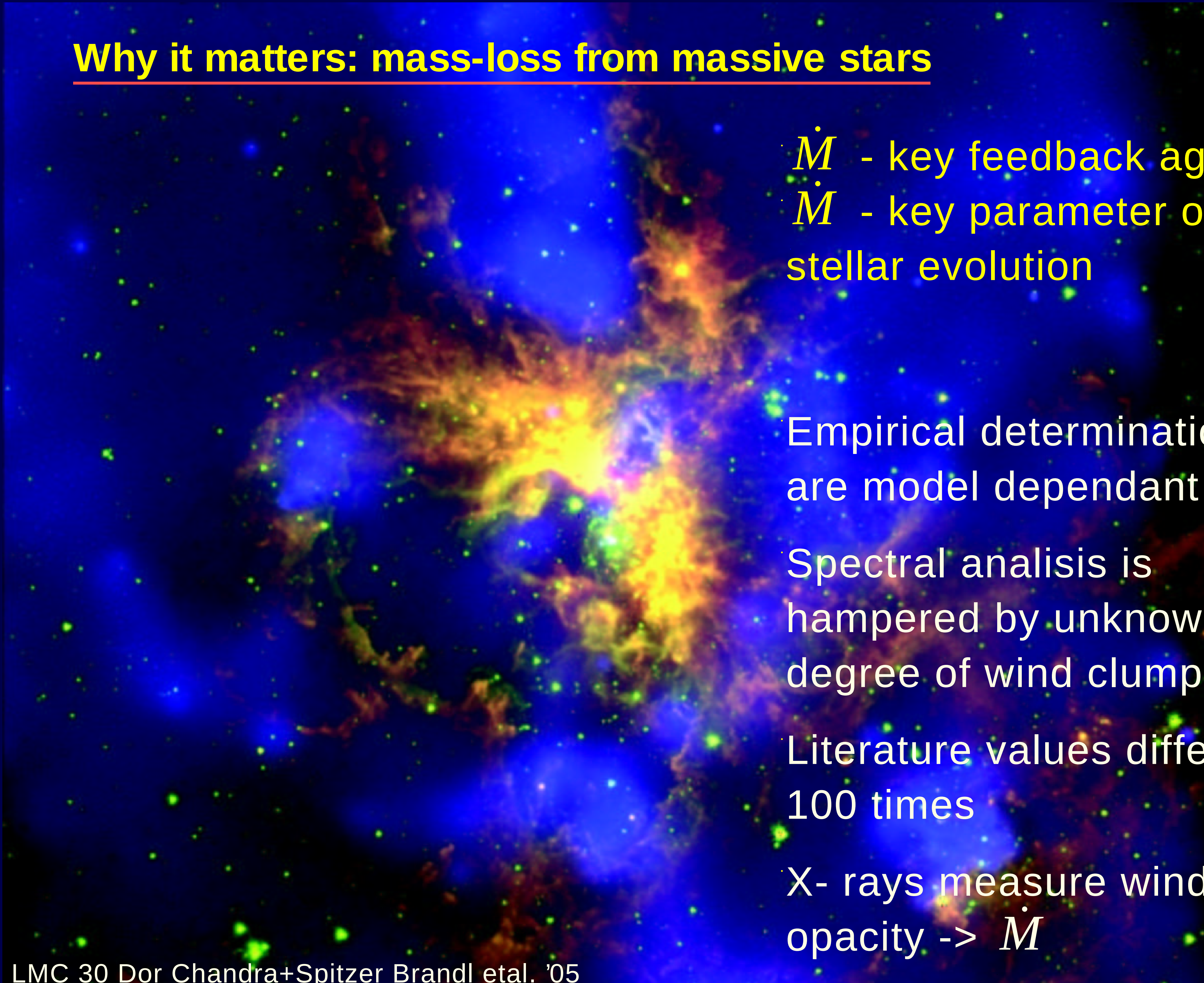


Agreement between wind τ_E and radii of line formation from fir analisis

Why it matters: mass-loss from massive stars

- $\dot{M}$ - key feedback agent
- $\dot{M}$ - key parameter of stellar evolution

- Empirical determinations are model dependant
- Spectral analisis is hampered by unknown degree of wind clumping
- Literature values differ by 100 times
- X- rays measure wind opacity -> $\dot{M}$



LMC 30 Dor Chandra+Spitzer Brandl etal. ’05

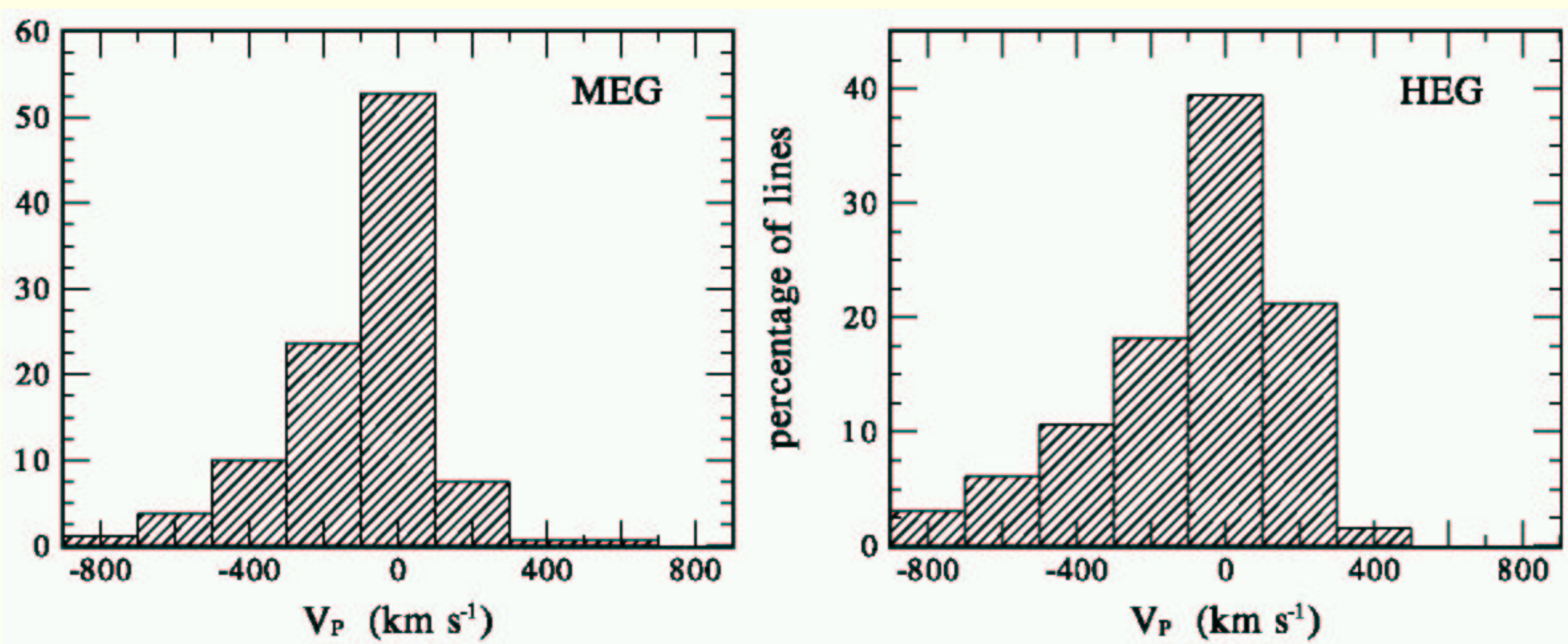
Observed X-ray emission line profiles

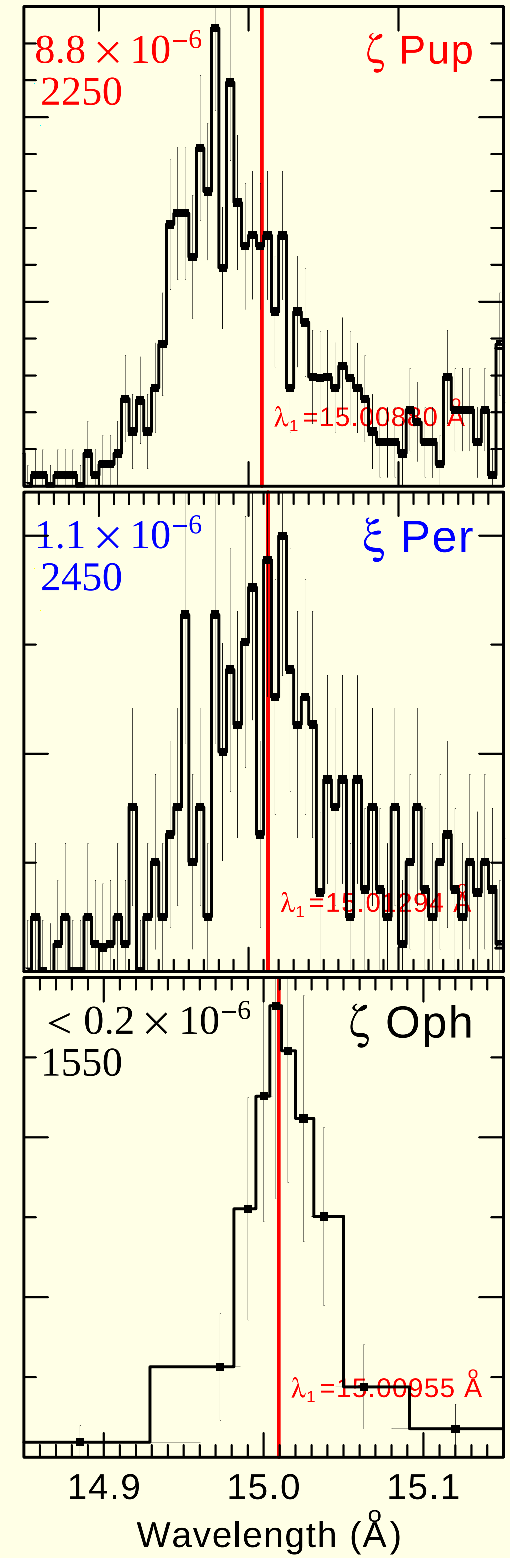
Waldron & Cassinelli'07 Analysis of spectra of 17 OB stars

- Shift (skewness) correlates with τ_E
- Line shifts are small

- Lines are Doppler broadened

  less than terminal wind velocity





Directions to explain observed X-ray line profiles

- New paradigm of X-ray emission

  Colissionless shocks, Pollock ’07

- Optically thick X-ray emission lines

  Ignace & Gayley ’02

  Cannot be true for lines of ALL ions

- Reducing wind opacity via

  * $\dot{M}$ reduction

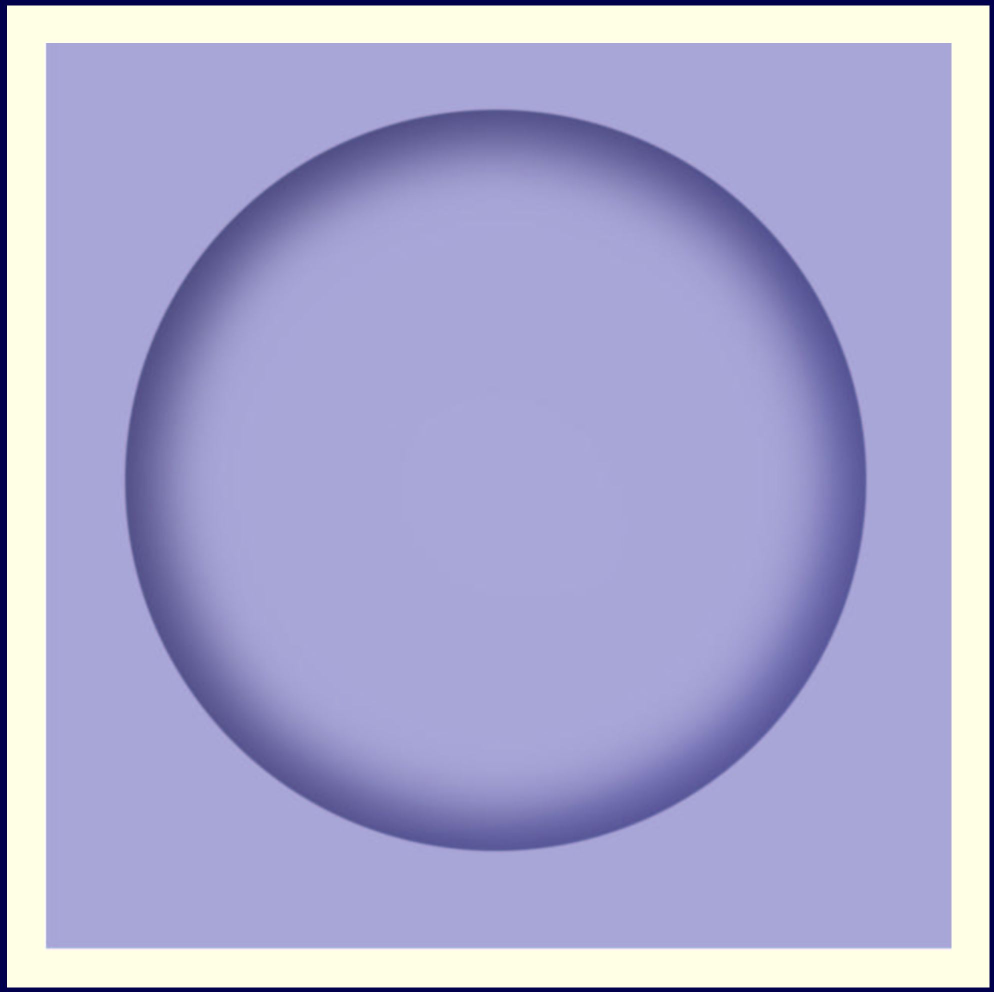
    Waldron & Cassinelli ’01, Kramer et al. ’03, Cohen et al. ’06, …

  * Wind clumping

    Waldron & Cassinelli ’01, Feldmeier etal. ’03, Oskinova etal.’06, …

Can X-ray line profiles be explained by reduction of $\dot{M}$? Hardly!

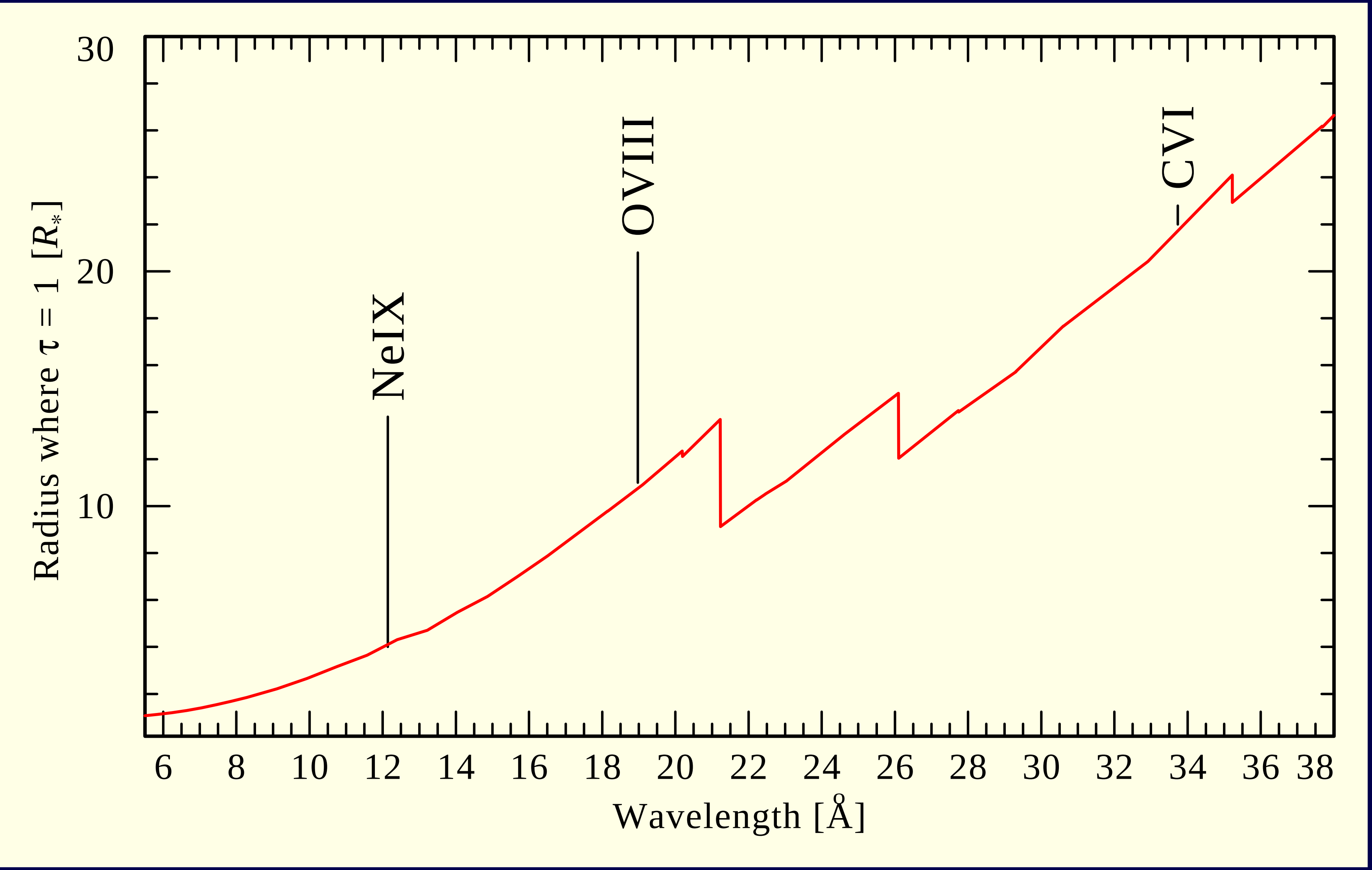
Spectral fits of UV and optical lines: $\dot{M}$ is reduced when wind is strongly clumped **ASSUMING** that clumps are optically thin



Sole justification: convinient to modify VERY complex stellar atmopshere codes

Line shift is a measure of wind opacity.

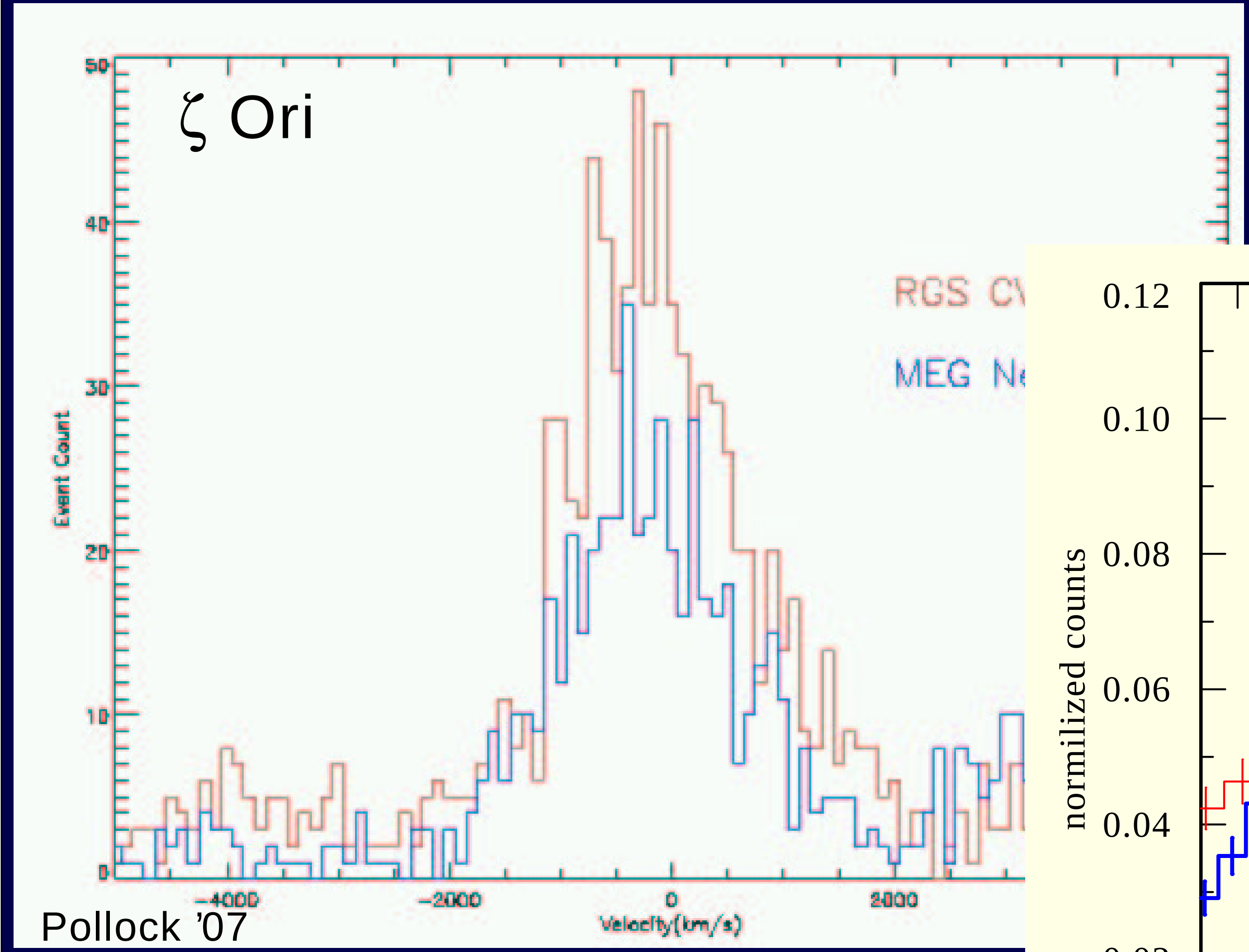
If clumps were optically thin X-ray lines would have different shape

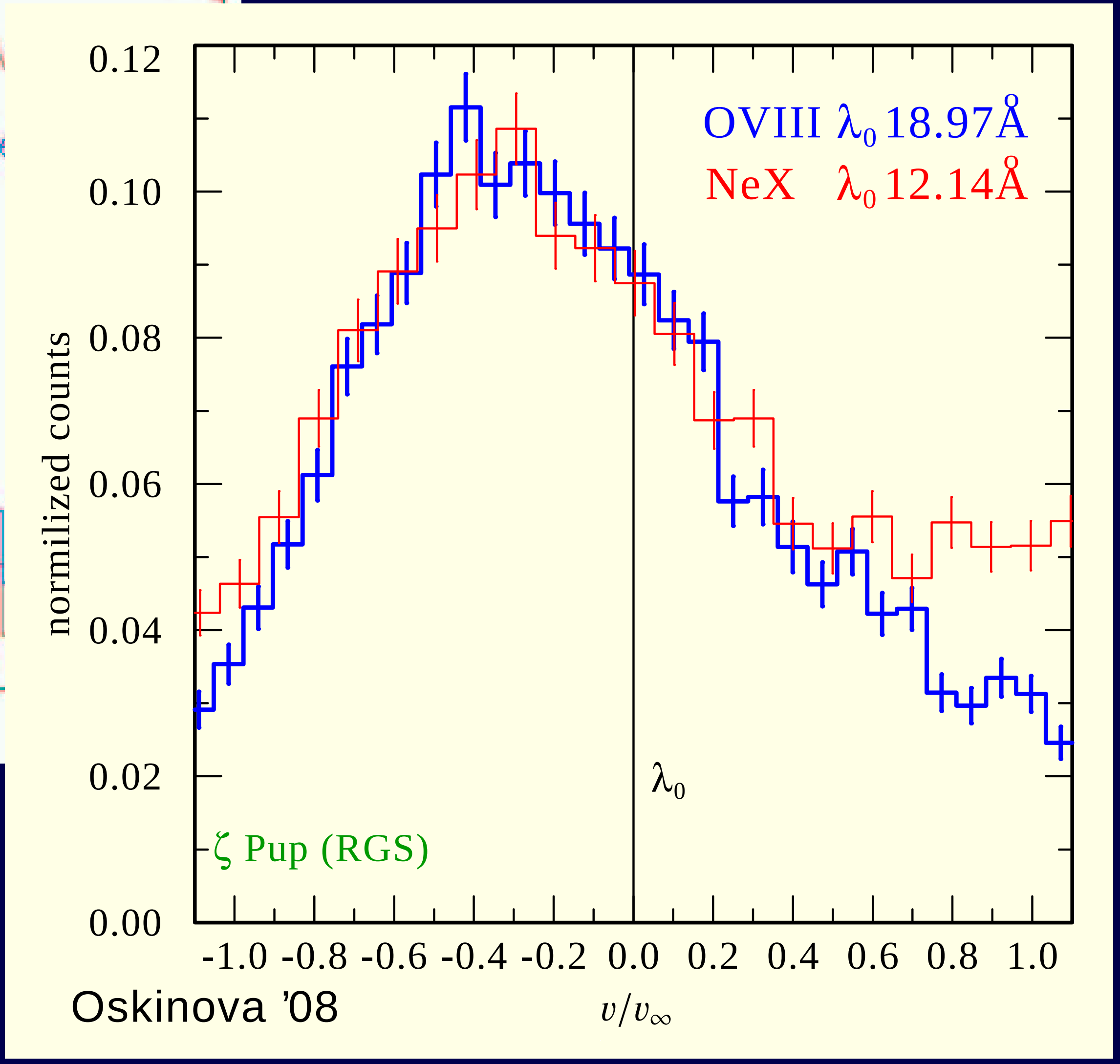


CVI should be more significantly more shifted/skewed than NeIX

Observed lines imply GREY opacity

Observed emission line profiles are similar, opacity **IS** grey

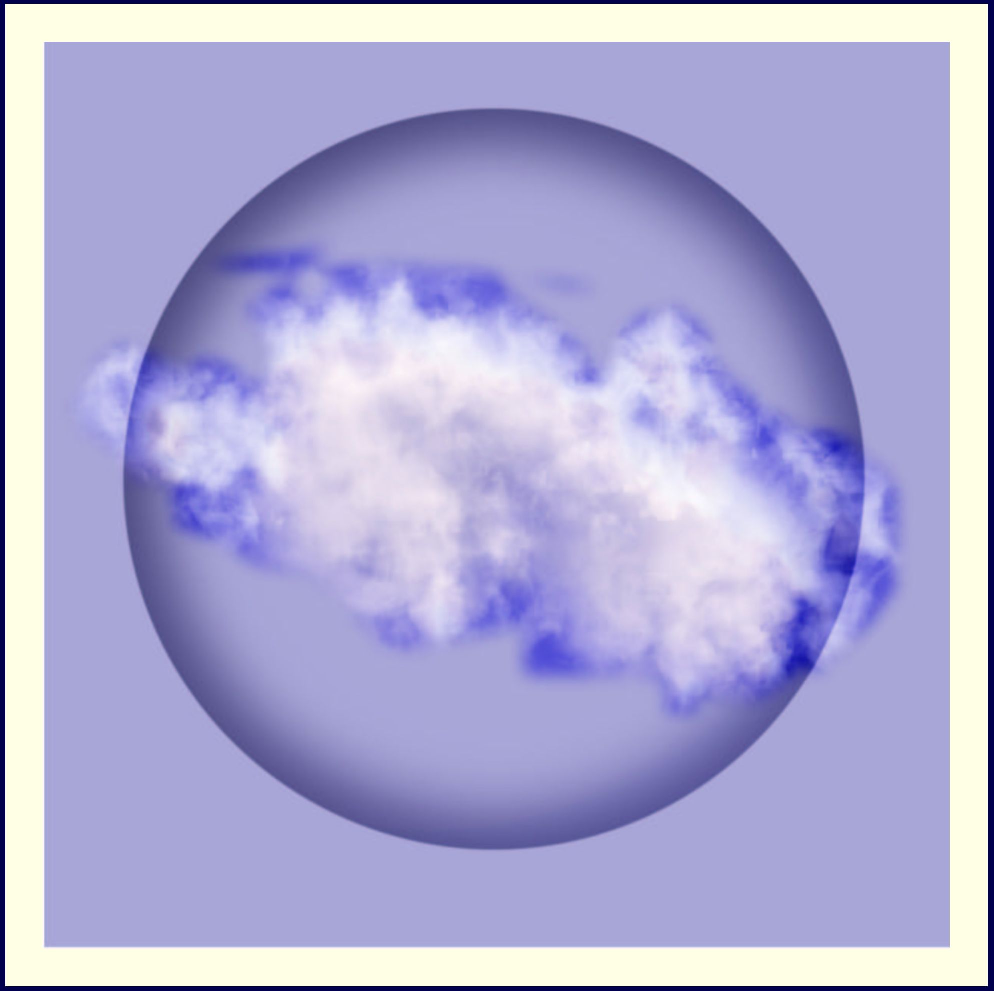




Assumption of optically thin clumps is not physically justified!

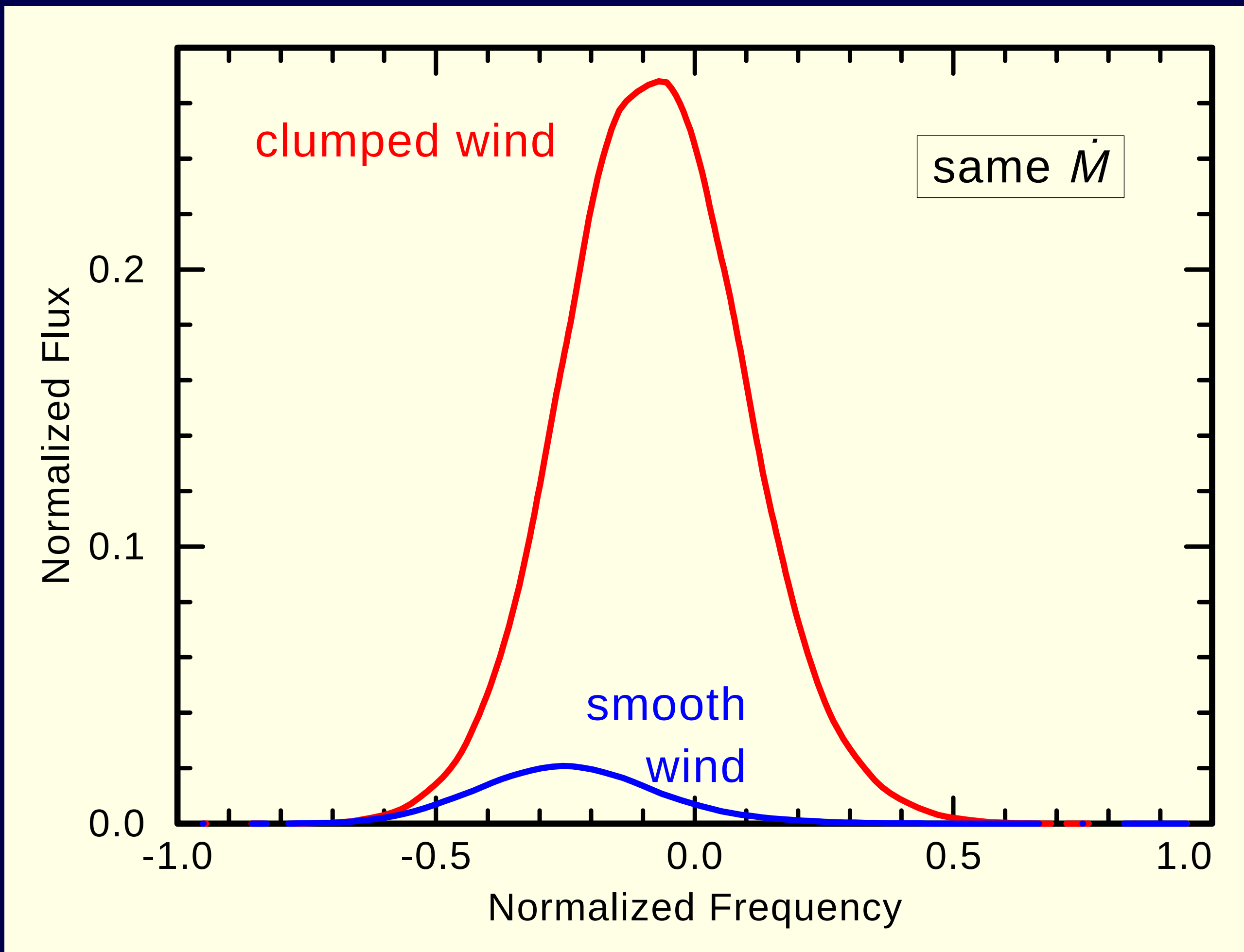
Macroclumping

Clump are allowed not to be optically thin.



Formalism: Feldmeier etal. ’03, Owocki etal. 04, Oskinova etal. 07

Clumping Reduces Effective Opacity



Wind opacity for X-ray drastically reduced by clumping if clumps are NOT optically thin

Opacity becomes "grey" if clumps are optically thick

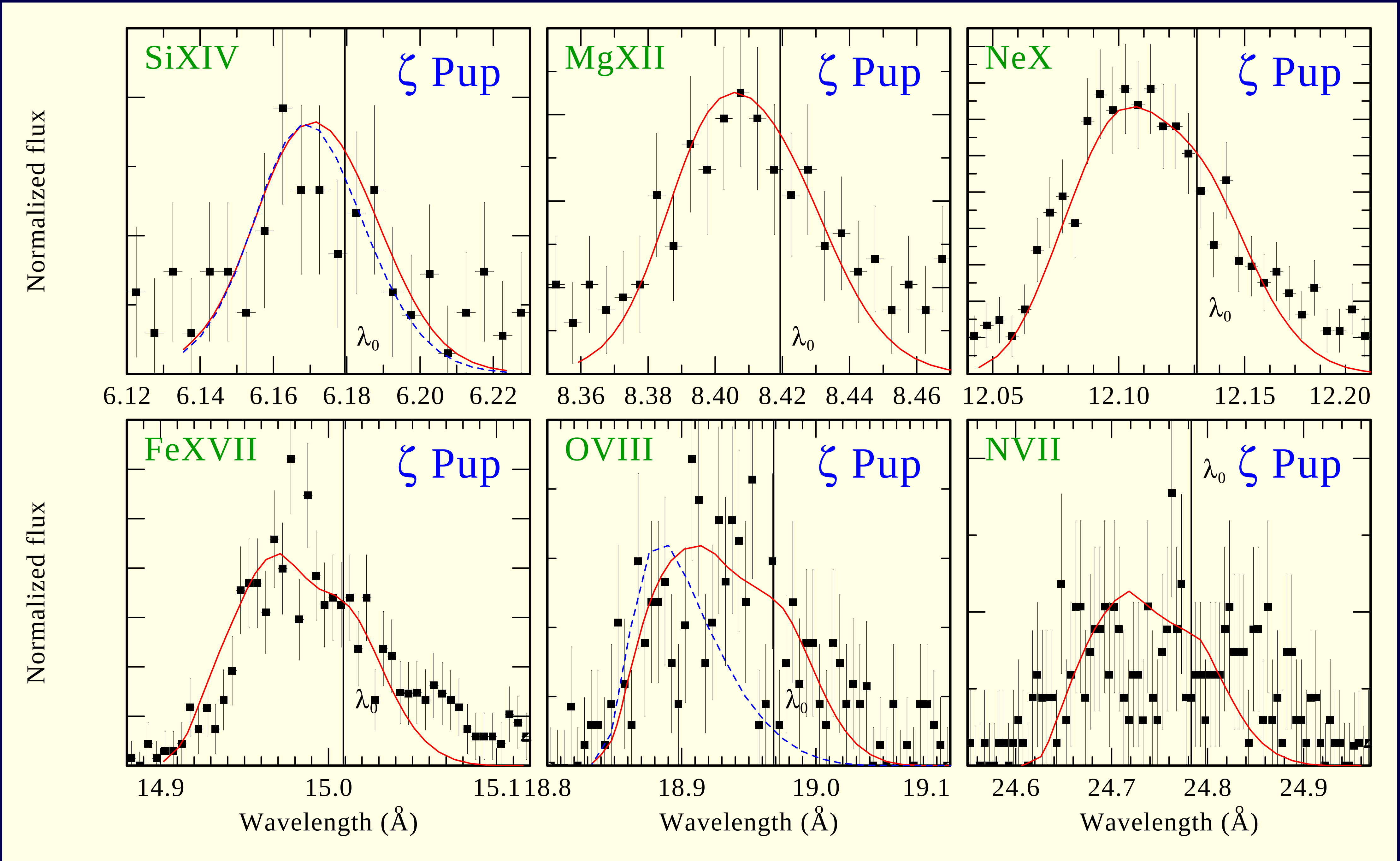
$\Downarrow$

Similar line profiles accross the spectrum

Symmetric lines due to anisotropic opacity

- Owocki & Cohen ’06: warnings

Observed and model lines of ζ Puppis (no fitting!)



Conclusions: Intrinsic wind emission from O stars

- X-rays originate close to the stellar core. Hot plasma fills some space between clumps.
- High-ion near-star problem. New implications for X-ray formation
- "Hybrid" model? Loop-like structures at the surface, shocks around blobs due to the wind instability?
- Stellar wind is clumped untill proven otherwise. Radiative transfer is affected by clumping
- Clumping explains shape of X-ray emission line profiles.
- Consitent $\dot{M}$ estimates based on analyses of spectra ranging from radio to X-ray