Shocking Truth about Massive Stars

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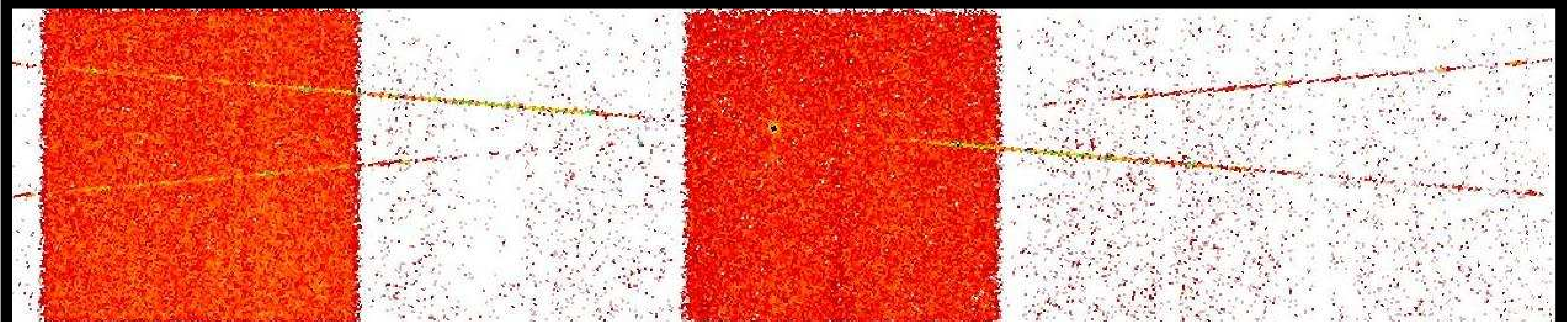


ACIS Raw Detector Image of O-type supergiant ζ Puppis, CXO archive

Chandra's First Decade of Discovery

22 - 25 September 2009, Boston, Massachusetts, USA

Massive Stars and Stellar Winds

Initial mass $M_* > 15 M_\odot$

Main Sequence: OB-type

Fast evolution (~Myr) → trace star formation

Hot. $T_{\rm eff} > 10\,000$ K $\longrightarrow$ high surface brightness

Photon momentum $\longrightarrow$ acceleration of matter

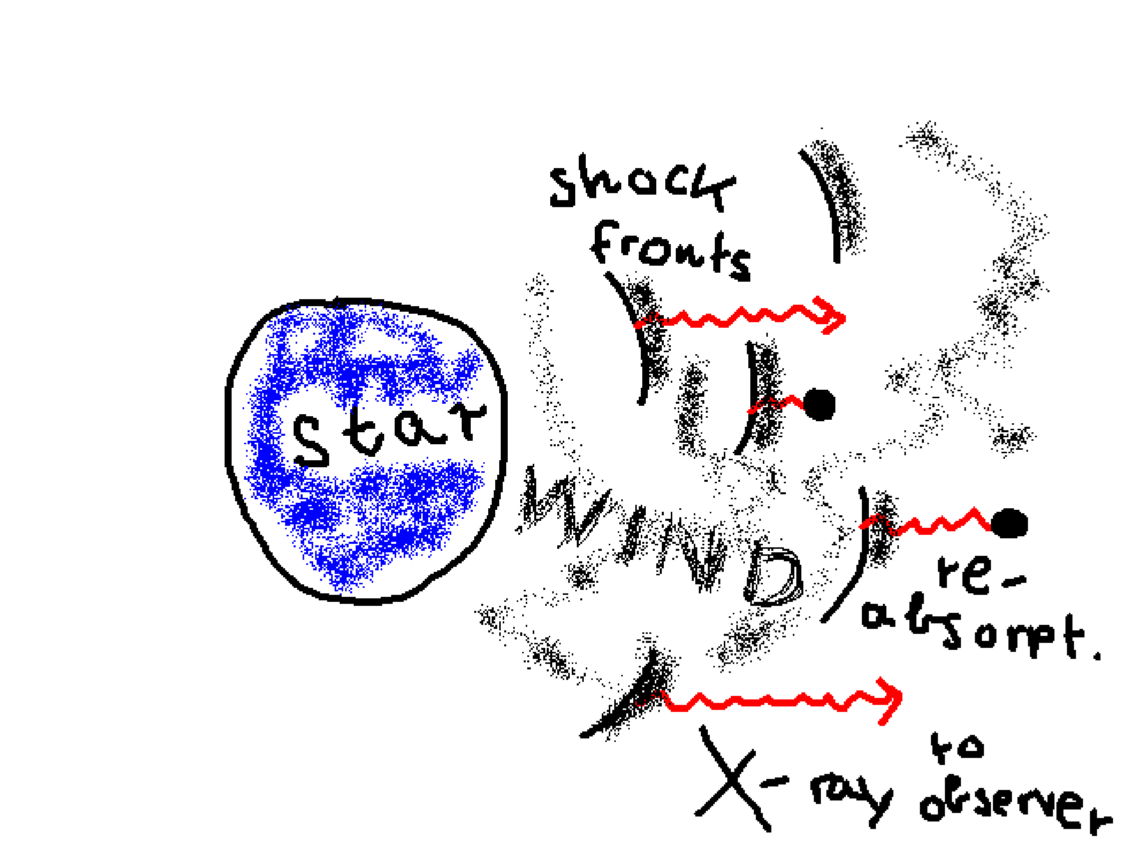
Radiative acceleration larger than gravitation $\longrightarrow$ supersonic **STELLAR WIND**

nasaimages.org

OB stars are X-ray active (Einstein observatory 1978)

Hot stars: radiatively driven stellar winds

Supersonic stellar winds are intrinsically unstable



Shocks

Heating

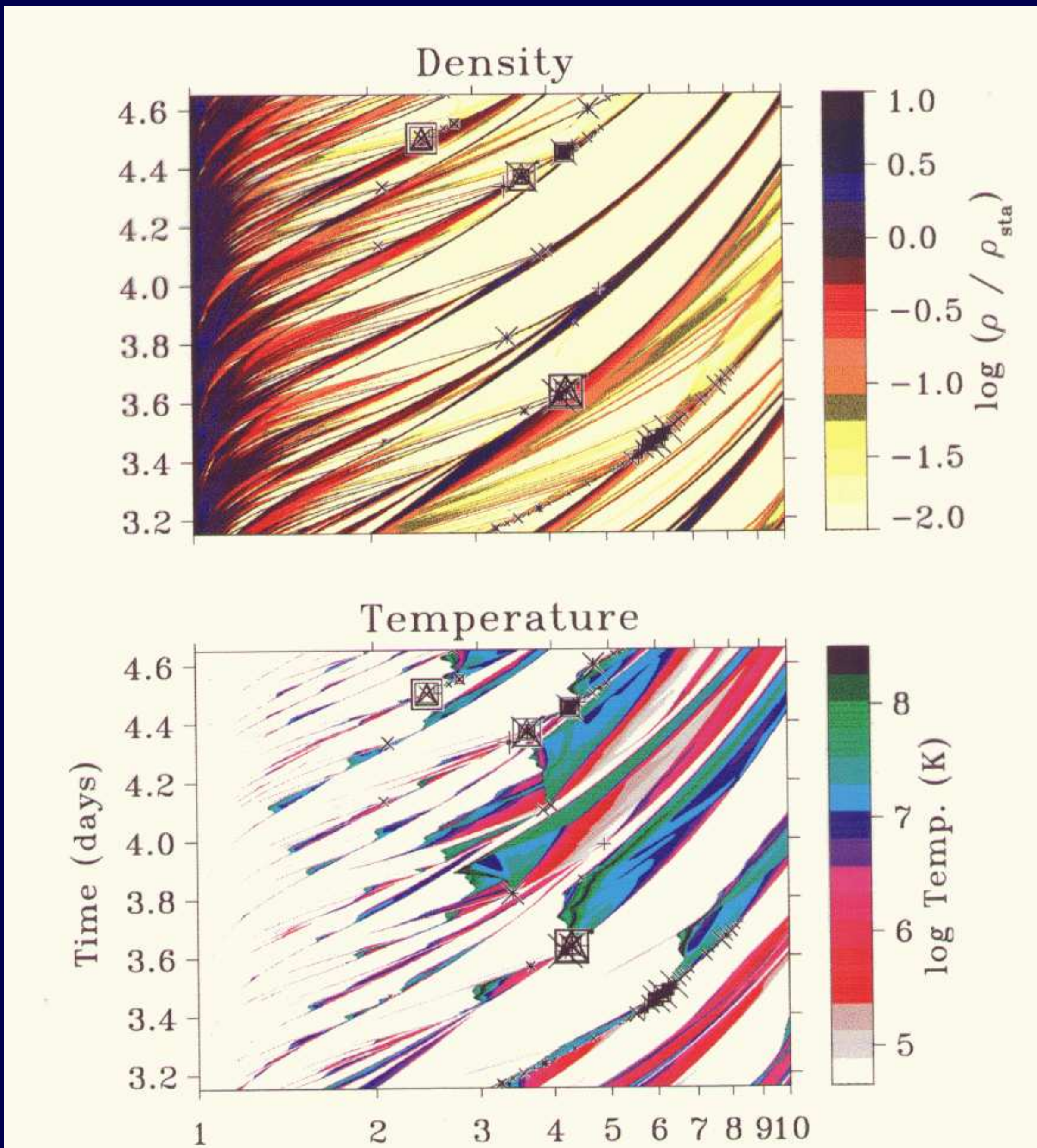
X-Rays

Shocks also result from:

- Collision of streams in magnetically confined wind
- Collision of winds in binaries

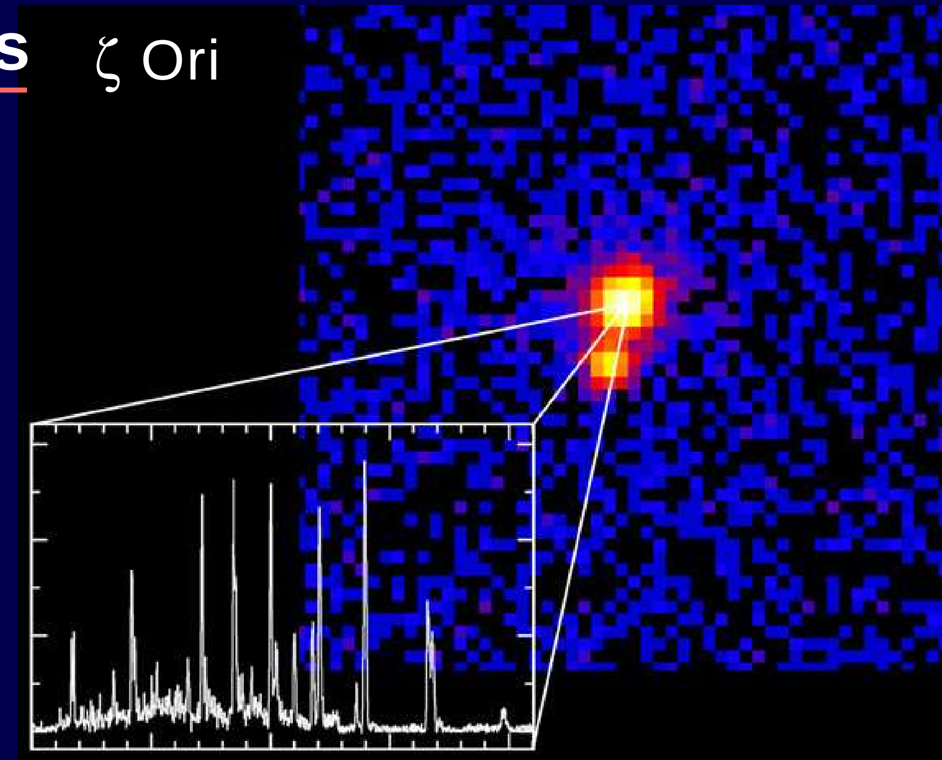
X-Ray Spectroscopy of Massive Stars

Prediction of hydrodynamic models



Distance [R_*]

Feldmeier et al. 1997



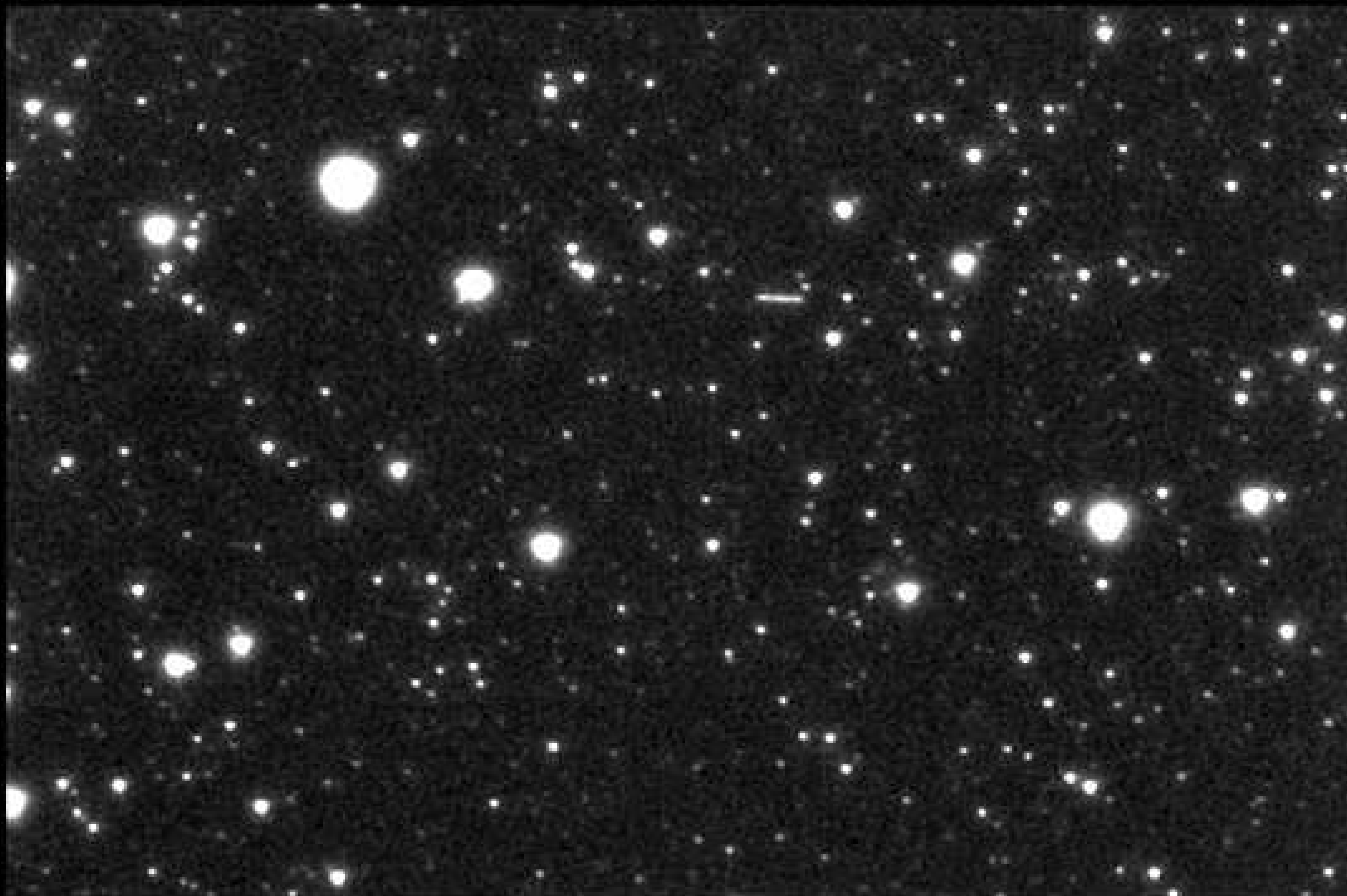
NASA/EIT/W.Waldron, J.Cassinelli

Models predict:

- X-ray emitting plasma (T_X = 1...10 MK) permeated with warm (T = 10 kK) absorbing wind
- X-rays originate at few R_* from the core

X-ray spectroscopy is needed!

Photo: G. Emerson, E.E. Barnard Observatory

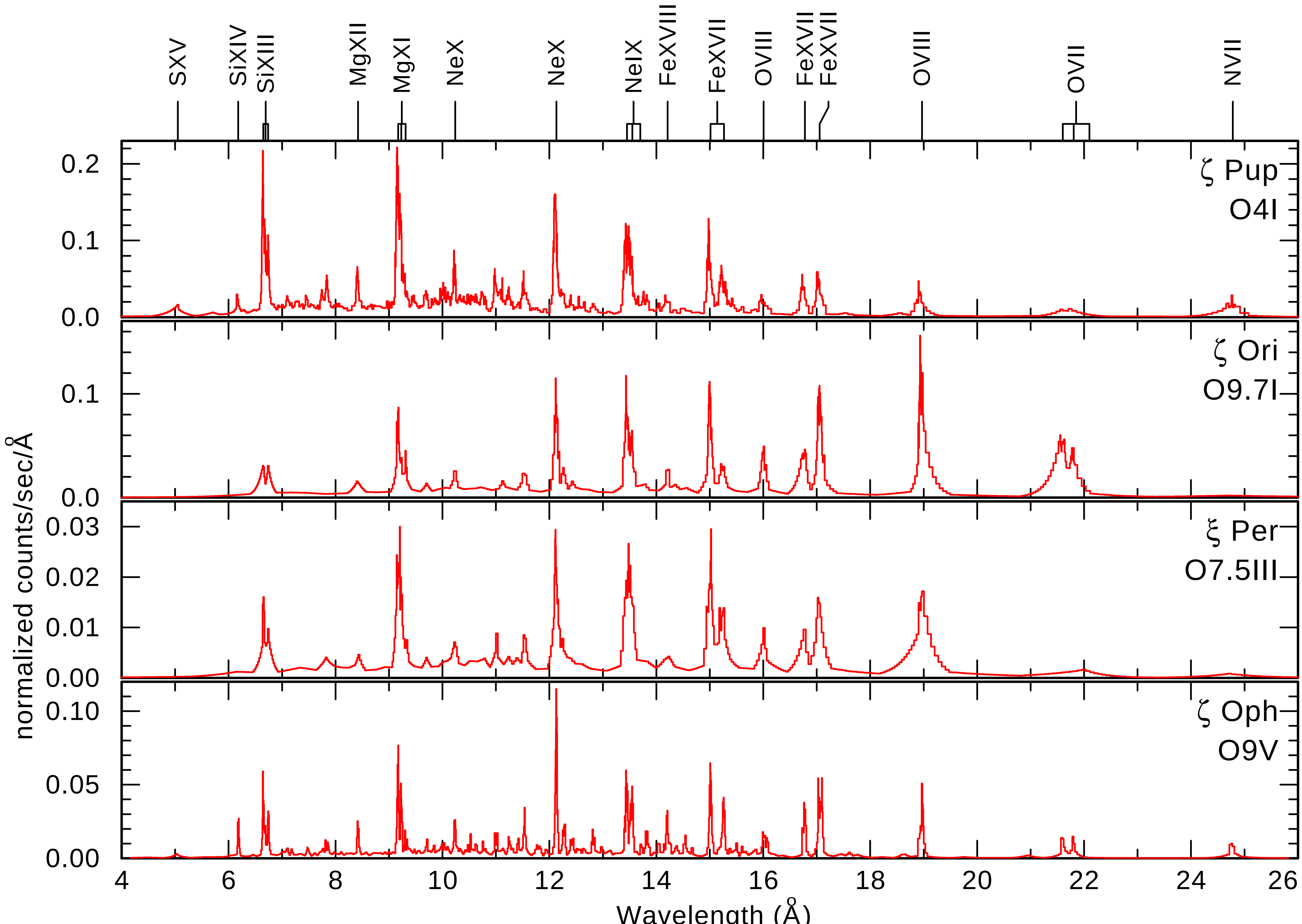


Chandra is in Orbit!!!

Cheering crowd →

prague-life.com

O-type stars



Oskinova etal. 2007

Analyses of the HETGS spectra

Temperature

- Range from 2 MK to 10 MK

Emission line profiles

- Broad; width scales with wind speed
- Line formation: deep in the wind
- Similar accross the spectrum
- Clumped wind treatment is needed

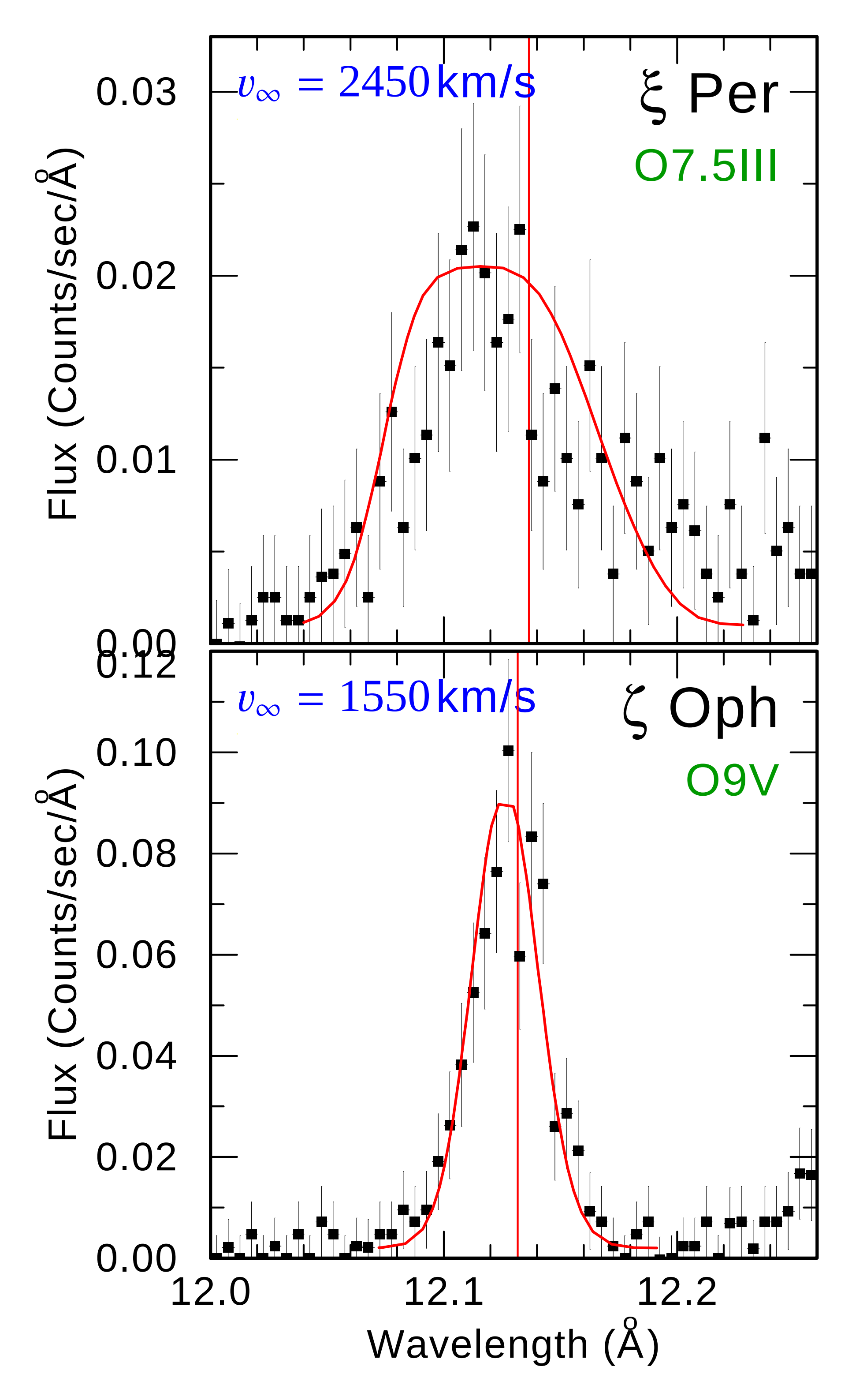
FIR line ratios

- Formed close to the photosphere
- Temperature decreases outward

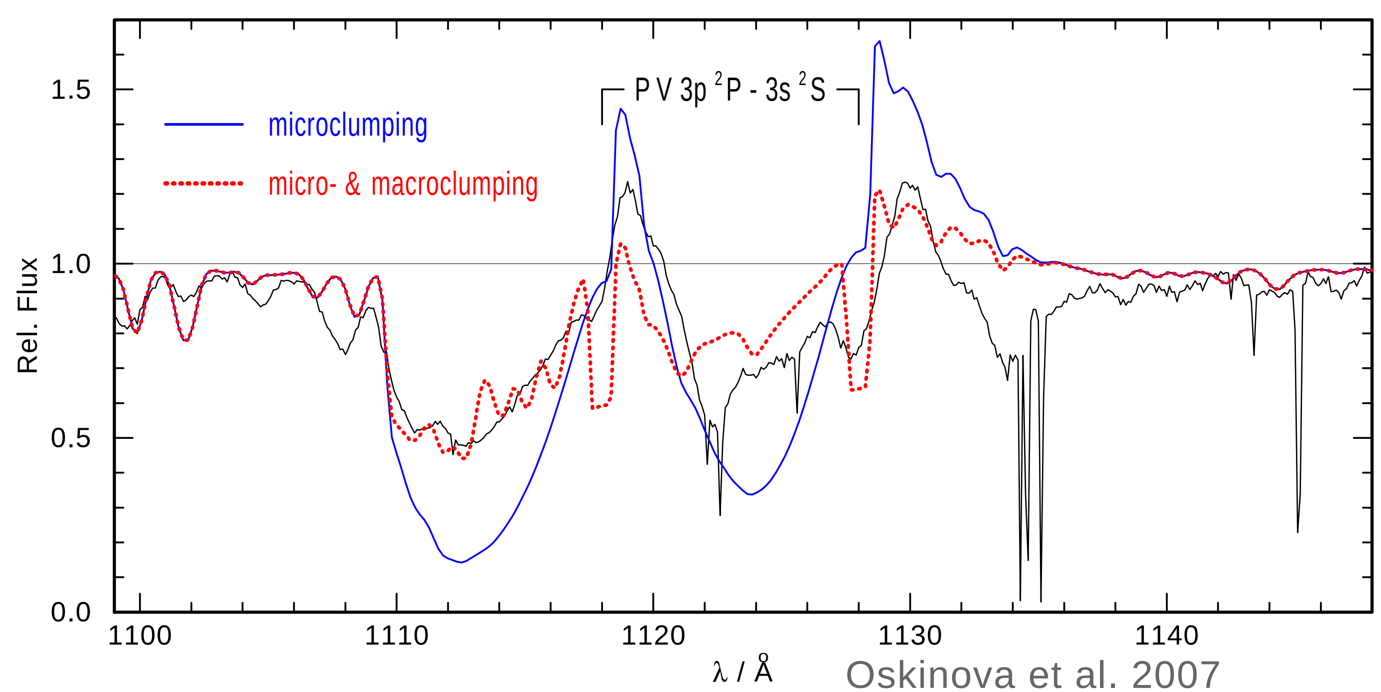
Abundances

- Agree with wind abundances

Wojdowski & Schulz (2005), Oskinova etal (2006), Waldron & Cassinelly (2007), Zhekov & Palla (2007), etc.



Wind-shock Theory has Predictive Power



Oskinova et al. 2007

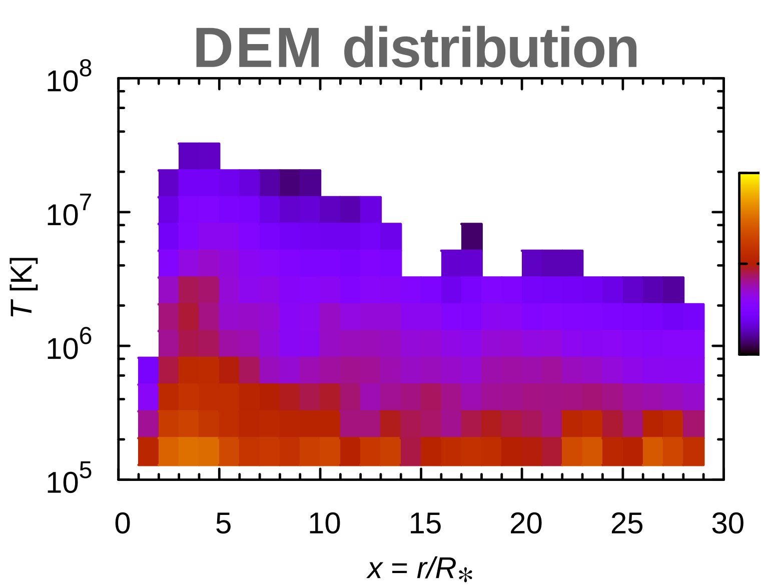
UV and X-ray spectra

PV resonance doublet →

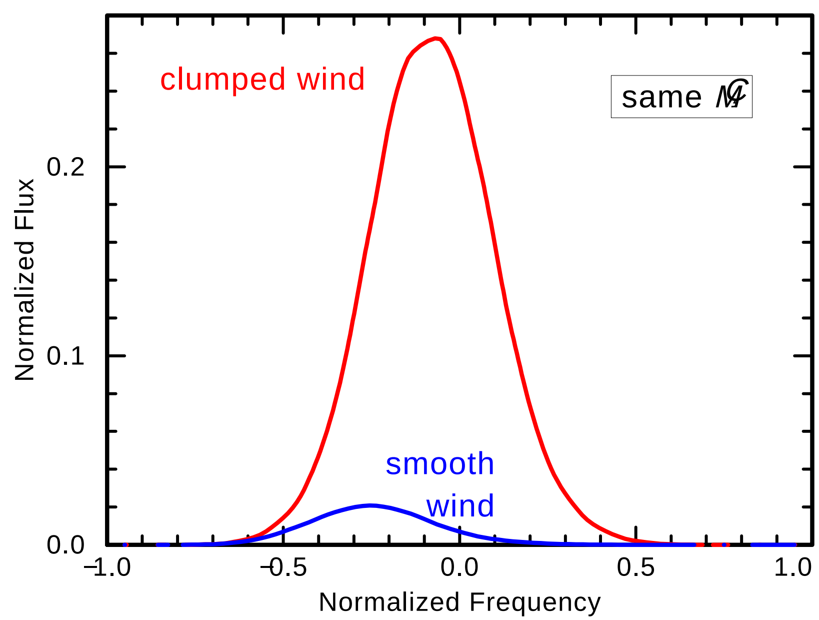
Mass-loss rates!

X-ray line profiles

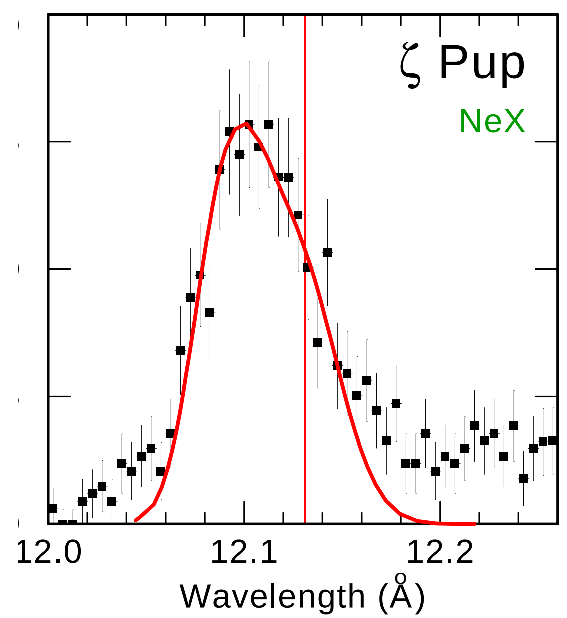
X-ray spectra

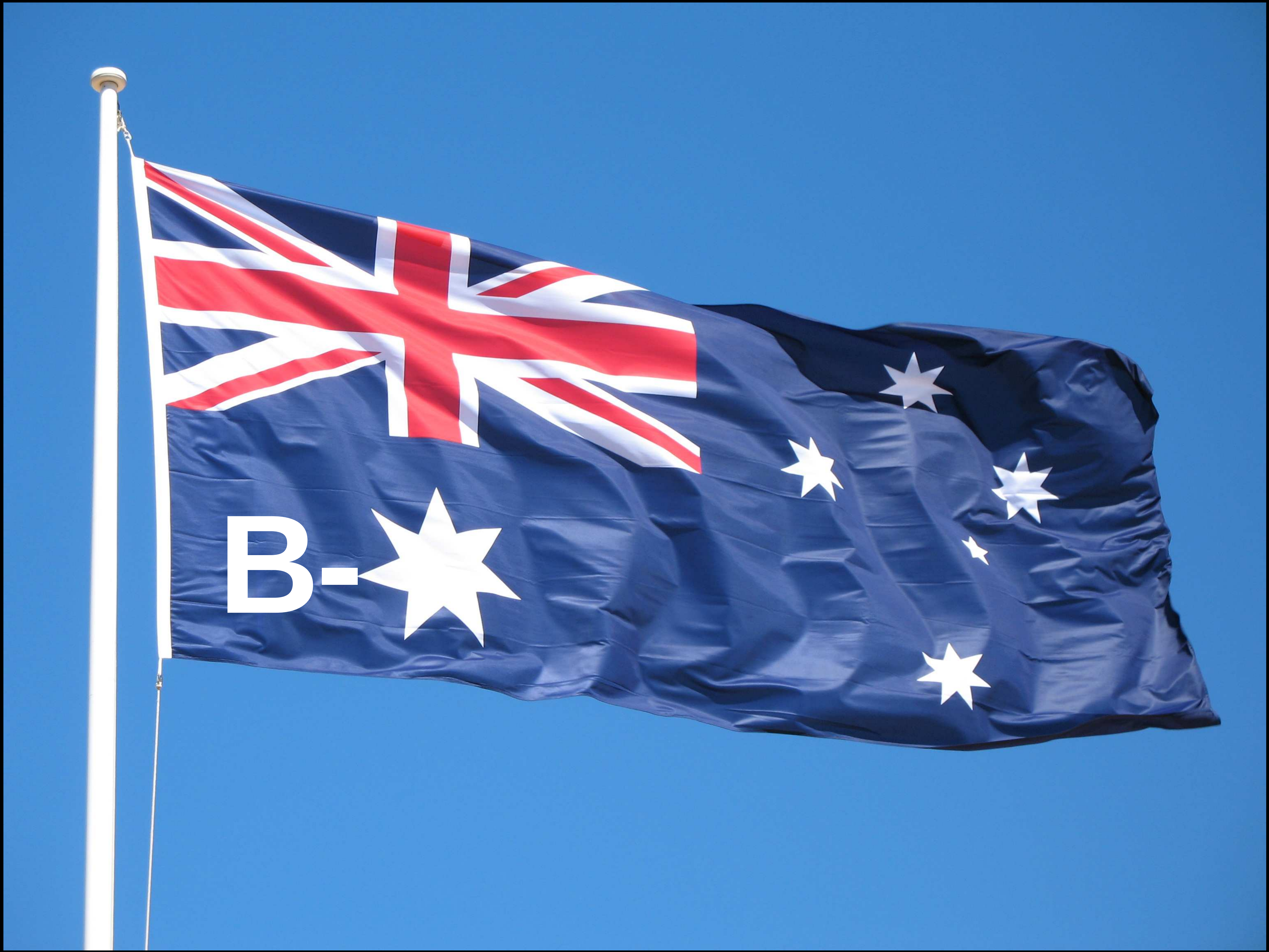


Krticka et al. 2009

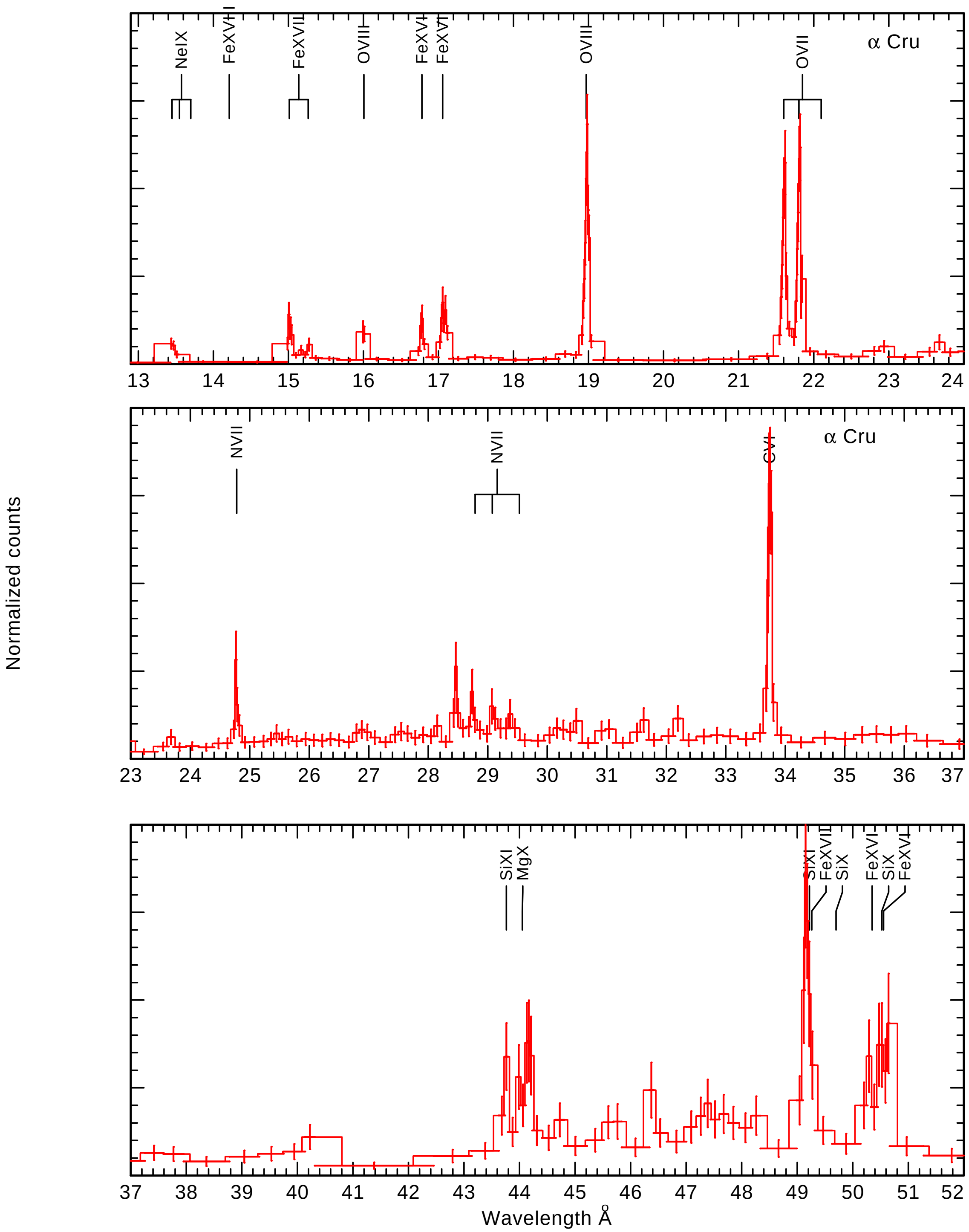


Oskinova et al.




B-

Chandra observations of α Cru

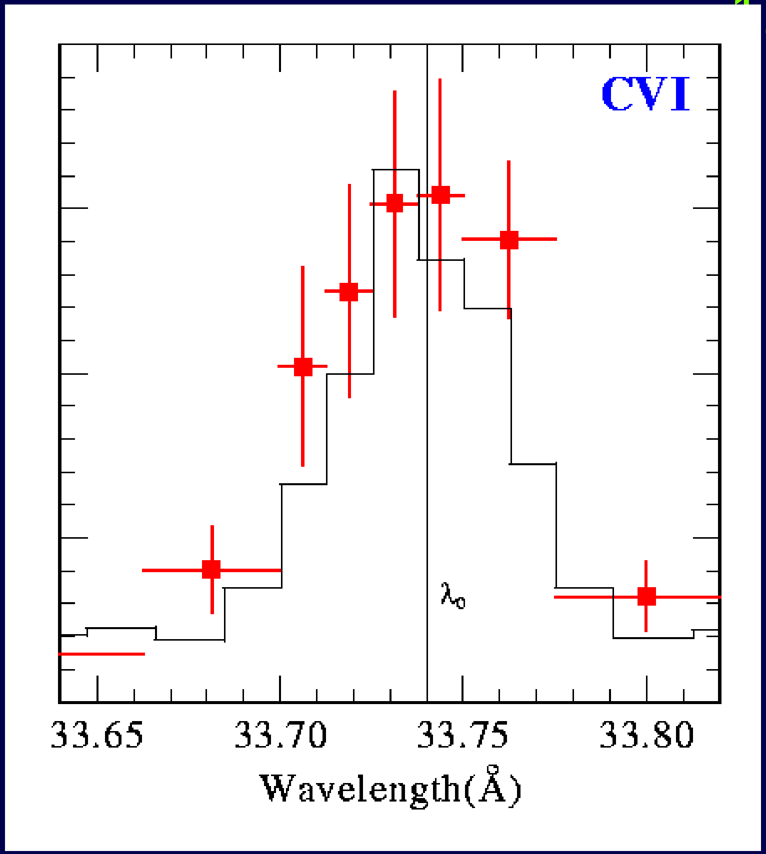


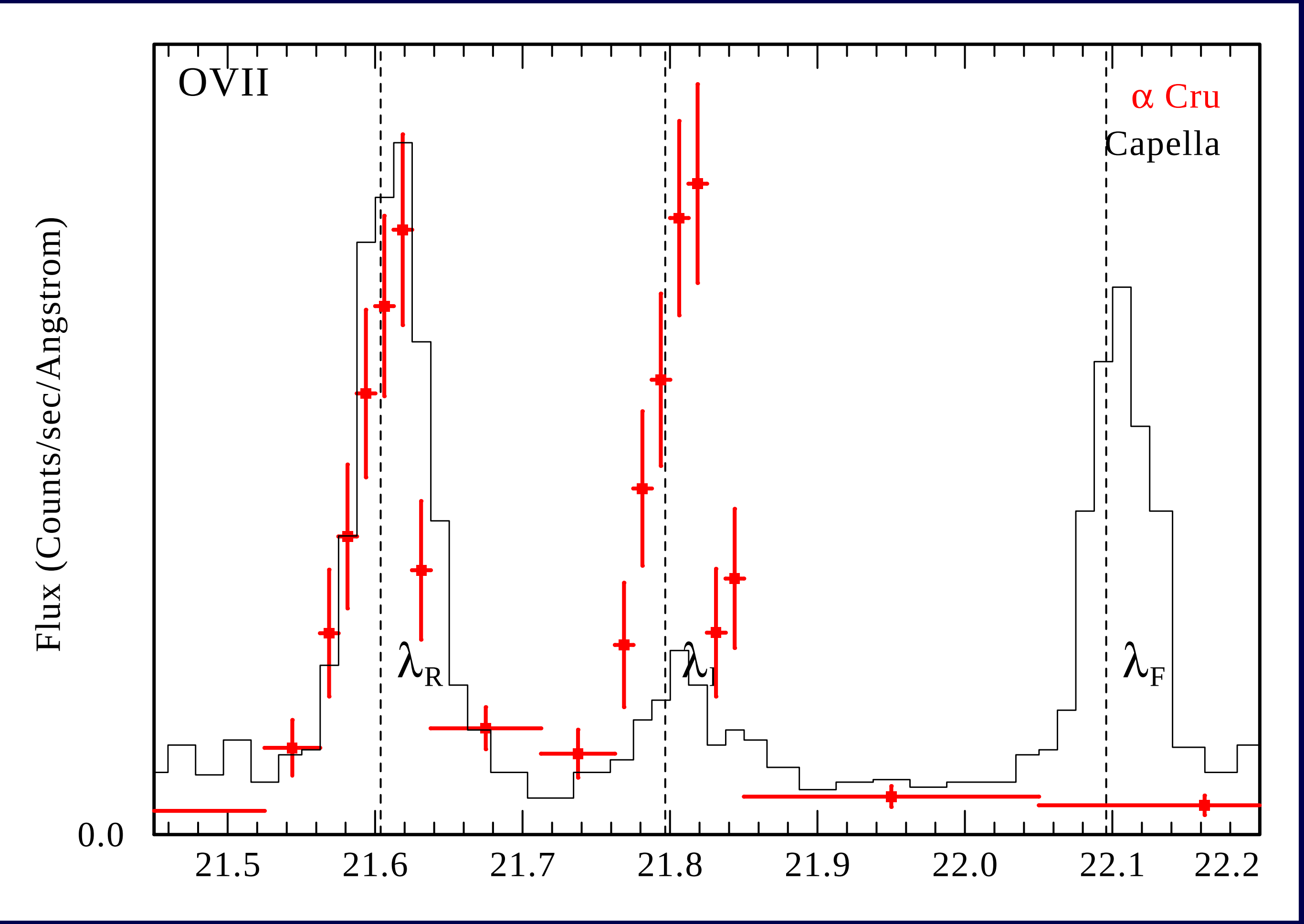
- **X-ray brightest massive star on sky**
- B0.5IV+BV at d=98 pc
- Companion B1V
- Soft spectrum T_X=1..3 MK

Oskinova et al. in prep.

Stationary plasma in B-stars

- Wind speed is 1500 km/s
- But lines are narrow Comparable to instrumental profile!
- He-like ions: f/i line ratio probes distance to stellar photosphere





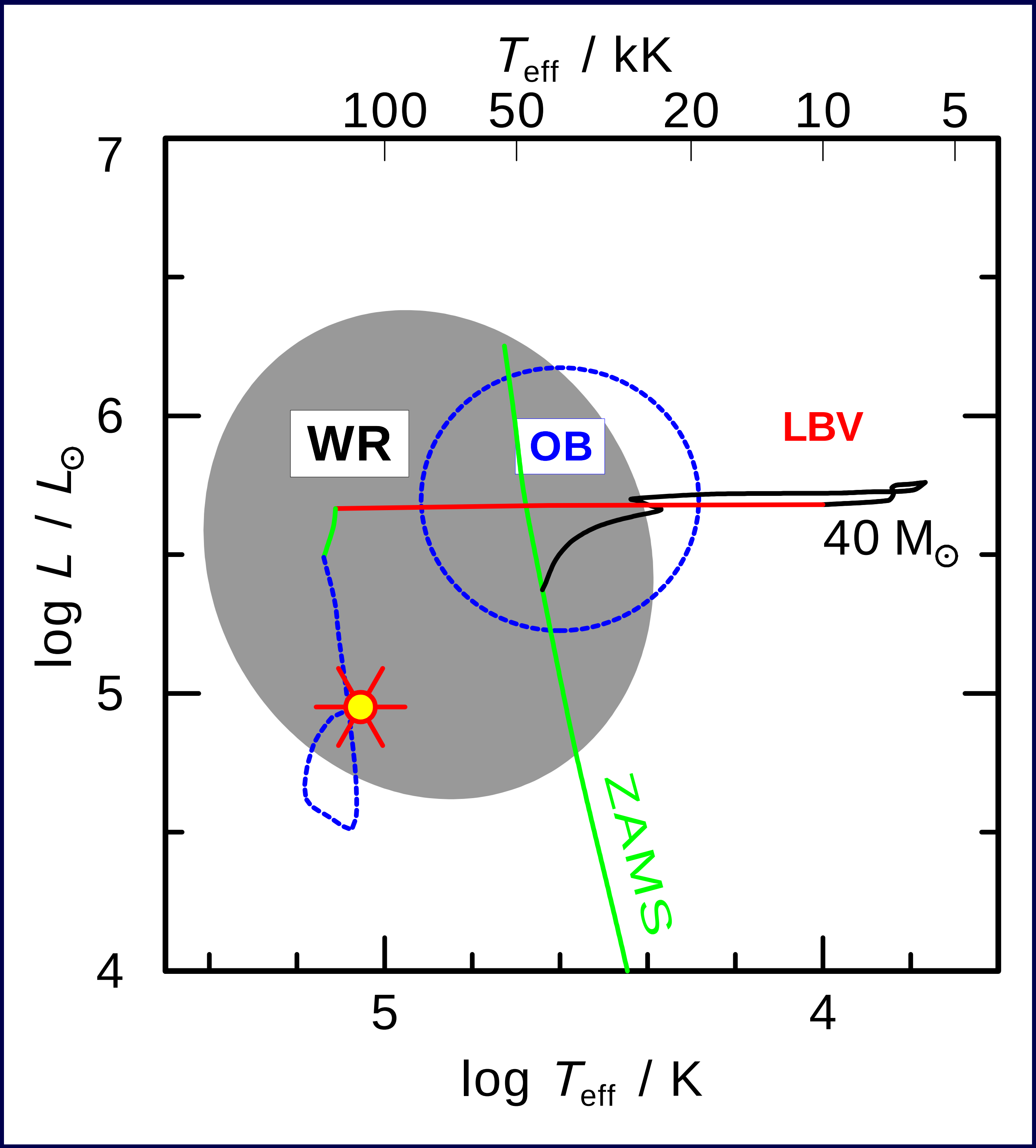
X-ray plasma in B-stars

- Close to the photosphere
- Stationary

Different from shocks in O-type winds

Pulsations? Coronae?

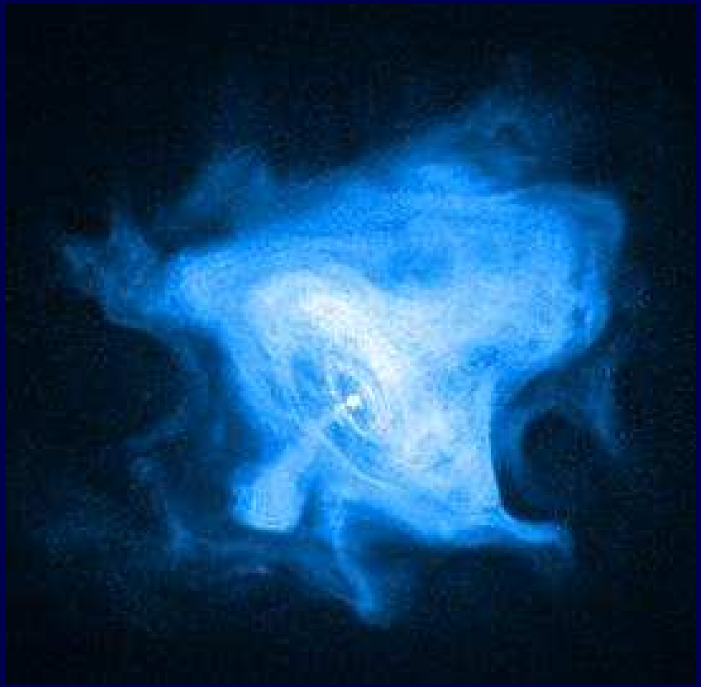
The evolution of (very) massive stars



Mass removal by wind drives the evolution

- OB → (short LBV) → WR
- Winds are getting dense and more enriched
- Wolf-Rayet (WR) stars

WN → WC → WO → SN



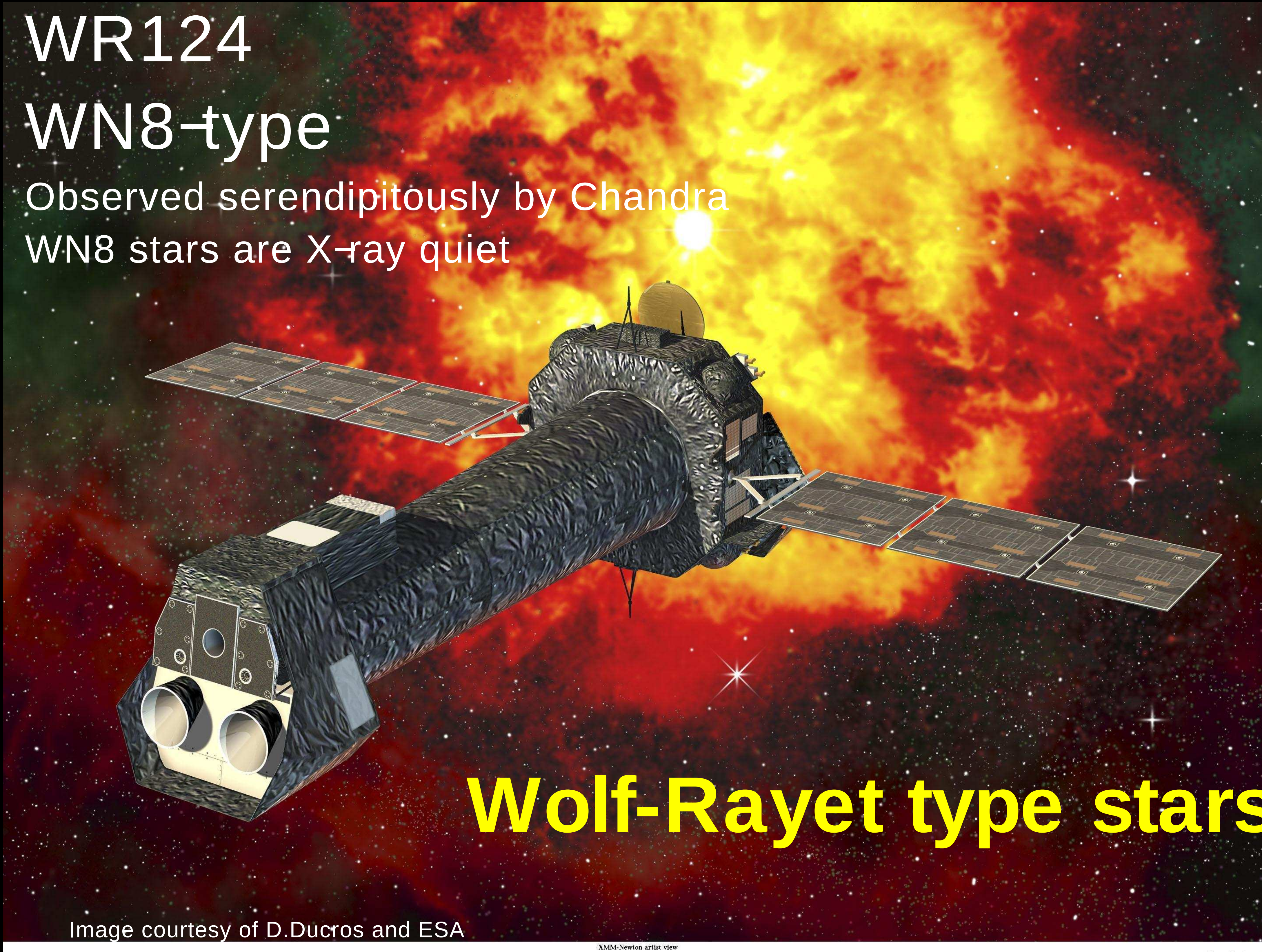
Credit: NASA/CXC/SAO/F.Seward et al

WR124

WN8–type

Observed serendipitously by Chandra

WN8 stars are X–ray quiet



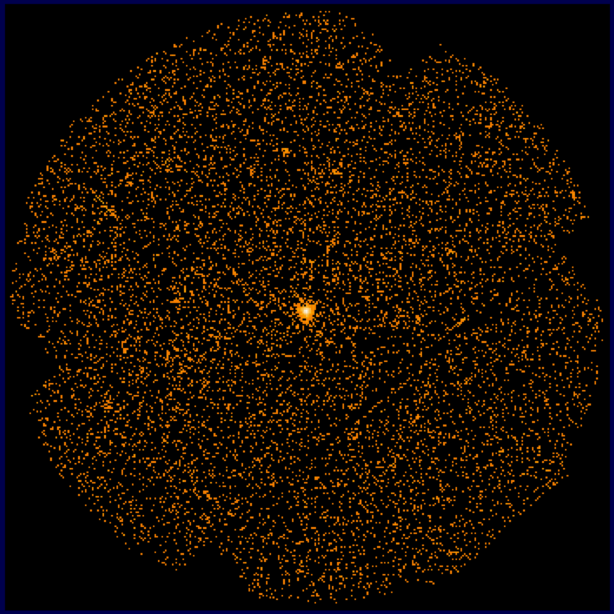
Wolf-Rayet type stars

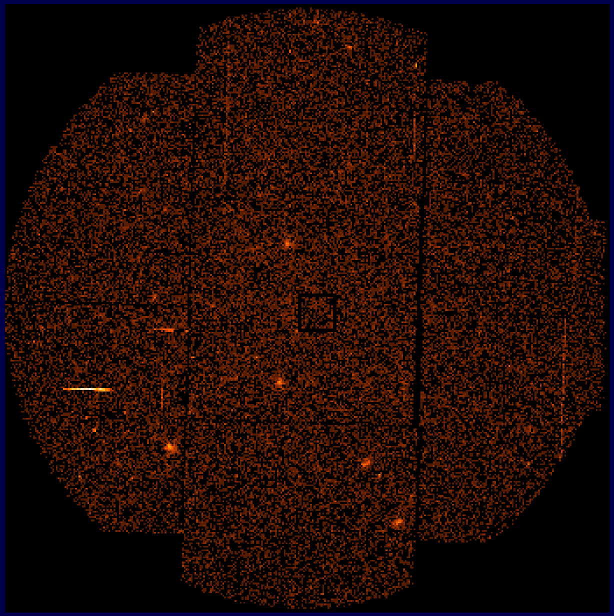
Image courtesy of D.Ducros and ESA

X-ray view on Wolf-Rayet Stars

- Not all WN-type stars emit X-rays. Lack of X-rays cannot be attributed **only** to the wind opacity (Oskinova et al. '06)
- X-ray spectra of single WN stars are harder than spectra of O-stars (Ignace et al. 2003)
- Single WC stars are X-ray quiet (Oskinova et al. 2003)
- X-ray bright WR stars are binaries (Oskinova & Hamann 2008)

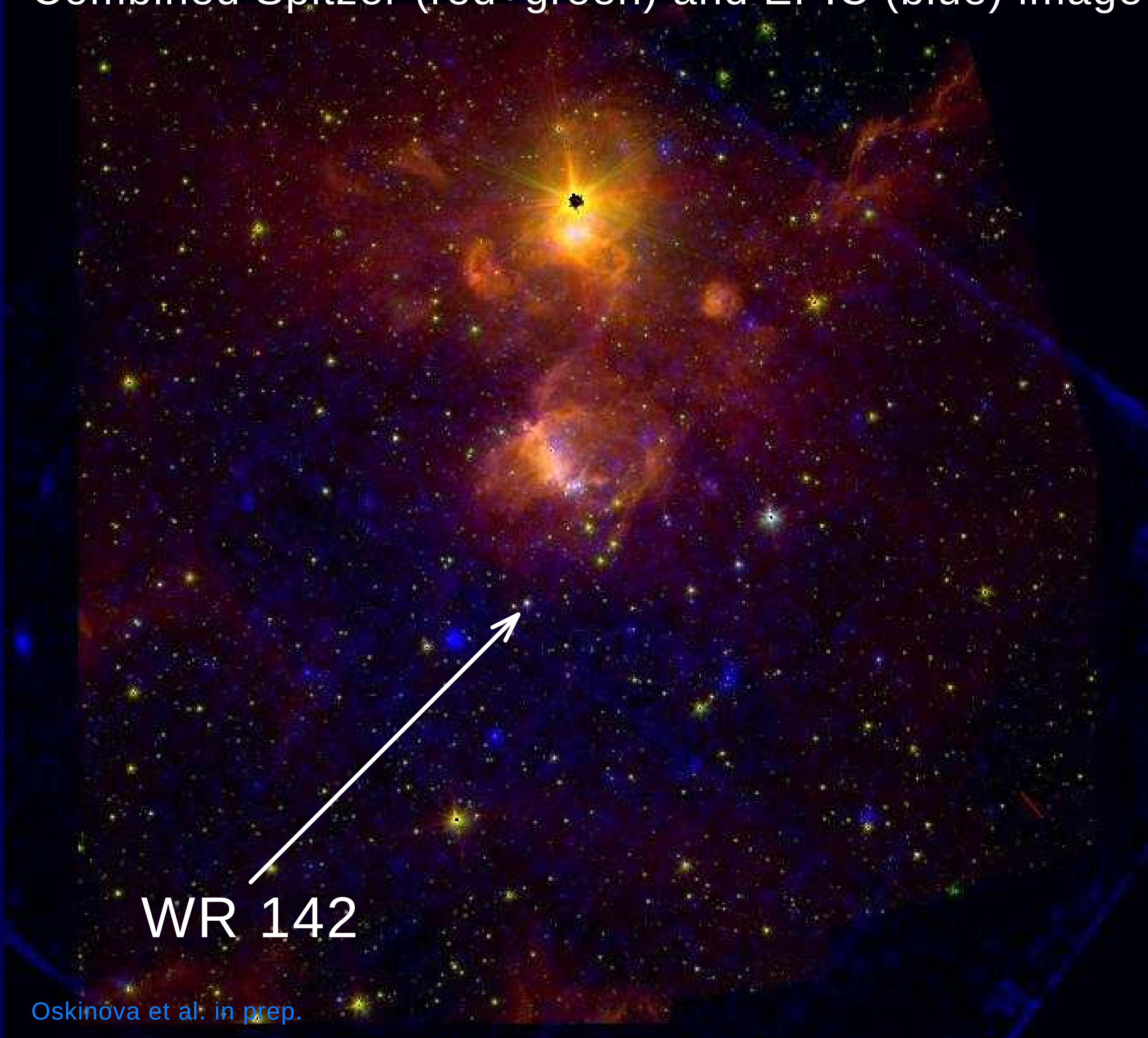

ζ Pup (O-type)


WR 1 (WN)


WR 114 (WC)

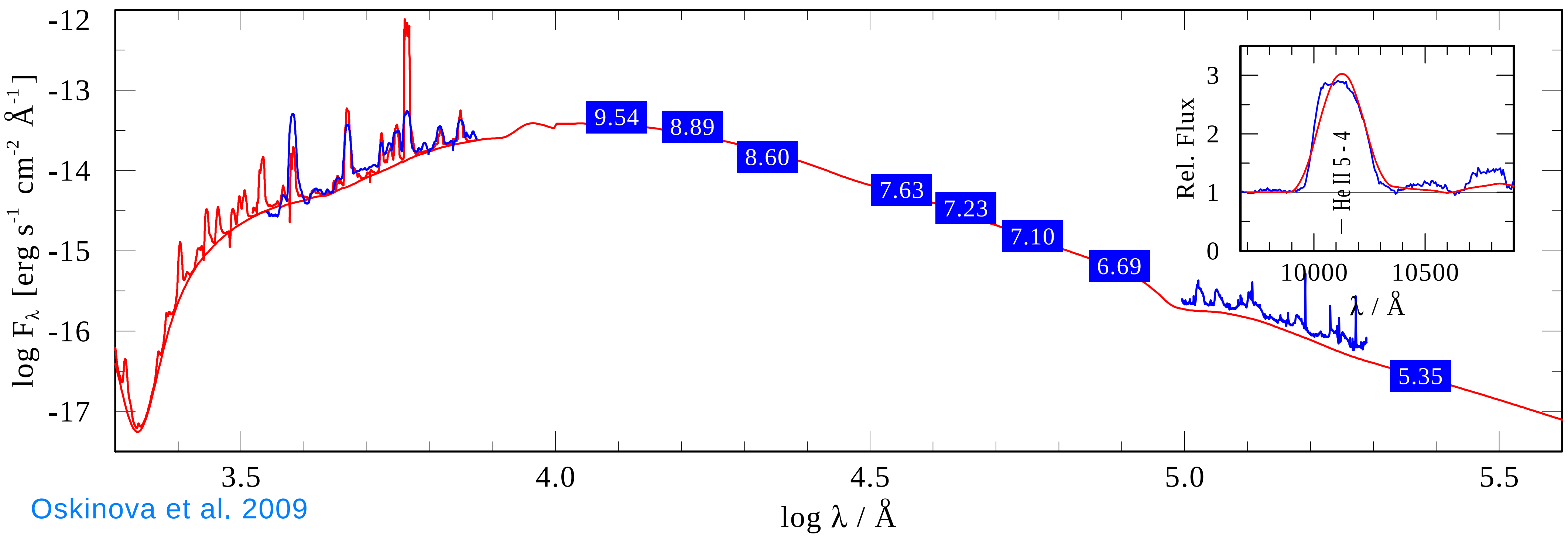
Closest WO-type Star WR142 in the Star Cluster Berkeley 87

Combined Spitzer (red+green) and EPIC (blue) image of the SFR ON 2



- Only three WO stars are known in the MW
- WO is the latest possible evolutionary stage of massive star
- Core−collapse within 10 000 yr
- Strongly influence their environment

Glimpse at the pre core-collapse star

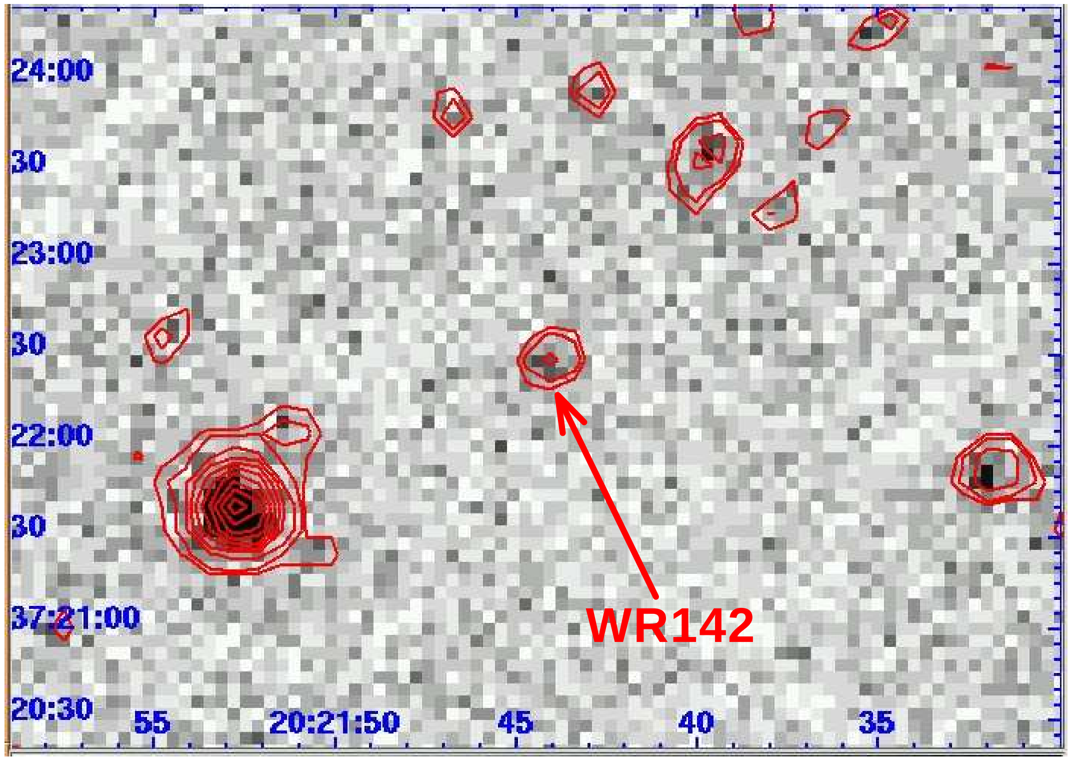


Oskinova et al. 2009

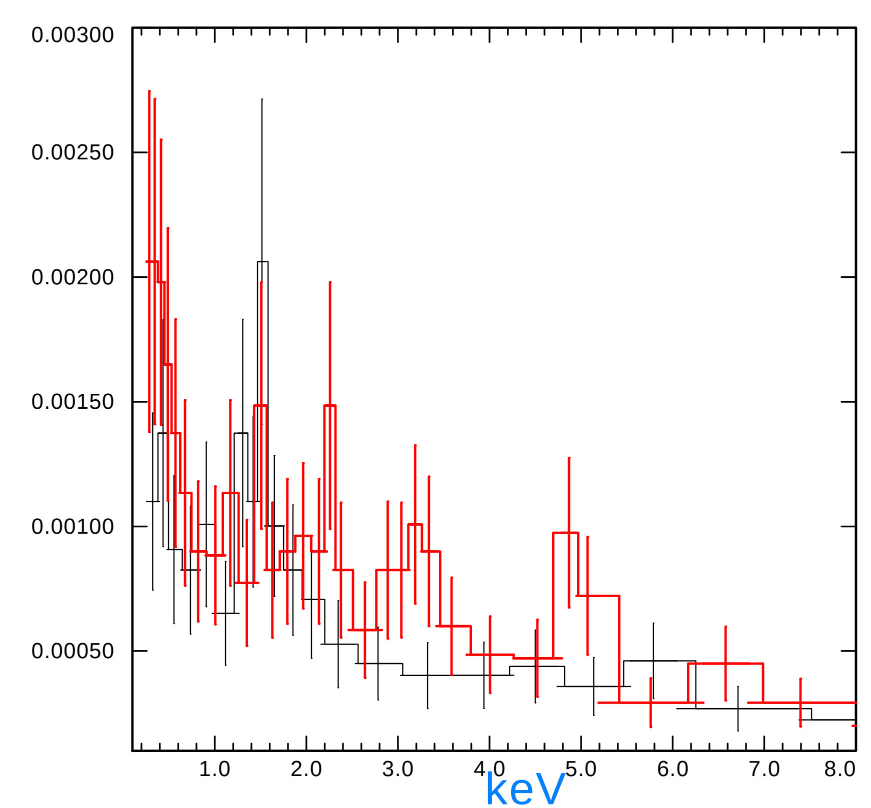
- Requires state-of-the art non-LTE models to fit observed optical and UV spectra. Such as PoWR code (Hamann et al. 2006)
- T_*=160 kK, **R_*=0.5$R_\odot$,** wind speed v=6000 km/s
- Our analysis indicates that star may be a **FAST ROTATOR** V_{rot} sin i =4000 km/s. **Current mass ~10 $M_\odot$**

Discovery of X-ray emission from a WO-type star

- Strong enhancement by CO → winds should be very opaque for the X-rays
- **X-rays are too hard to be explained by wind shocks**
- **Hint** on the presence of magnetic field B(r=2R_*) > 7 kG
- Chandra detects hard X-rays from another compact fast rotator WR2 (WN2)



Oskinova et al. (2009)



Mystery of X-rays from WR stars: Connection With Collapsars (?)

THE ASTROPHYSICAL JOURNAL, 494:L45–L48, 1998 February 10

ARE GAMMA-RAY BURSTS IN STAR-FORMING REGIONS?

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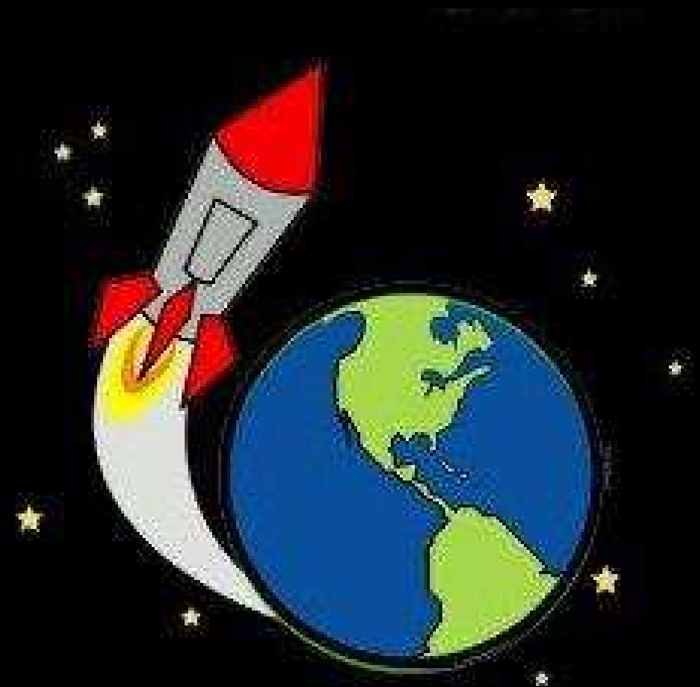
ABSTRACT

The optical afterglow of the gamma-ray burst GRB 970508 ($z = 0.835$) was a few hundred times n
than any supernova. Therefore, the name “hypernova” is proposed for the whole GRB/afterglow

”A very energetic explosion of a massive star is likely to create a … fireball…. the inner core of a massive, rapidly rotating star collapses into a ~10 $M_\odot$ Kerr black hole … A superstrong ~10^{15} G magnetic field is needed to make the object … a microquasar. Such events must be vary rare…to account for the … GRBs”

Do we indeed observe in our Galaxy massive, magnetic, rapidly rotating stars on latest stages of their evolution ?

Shocking truth?



- O–stars: X–rays are generated by wind shocks
- B–stars: not clear: magnetic fields, pulsation, winds.
- WR–stars: no hi–res spectrum exists! Magnetic field, rotation.

- X–rays are sensitive probe of stellar winds
- Generation of X–rays in stellar winds is important physical problem
- X–rays provide insights in stellar structure and evolution