Diffuse X-rays from PNe with WR-type central stars

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H-deficient Central Stars of Planetary Nebulæ

WD 25% with helium-dominated atmospheres, i.e. BD

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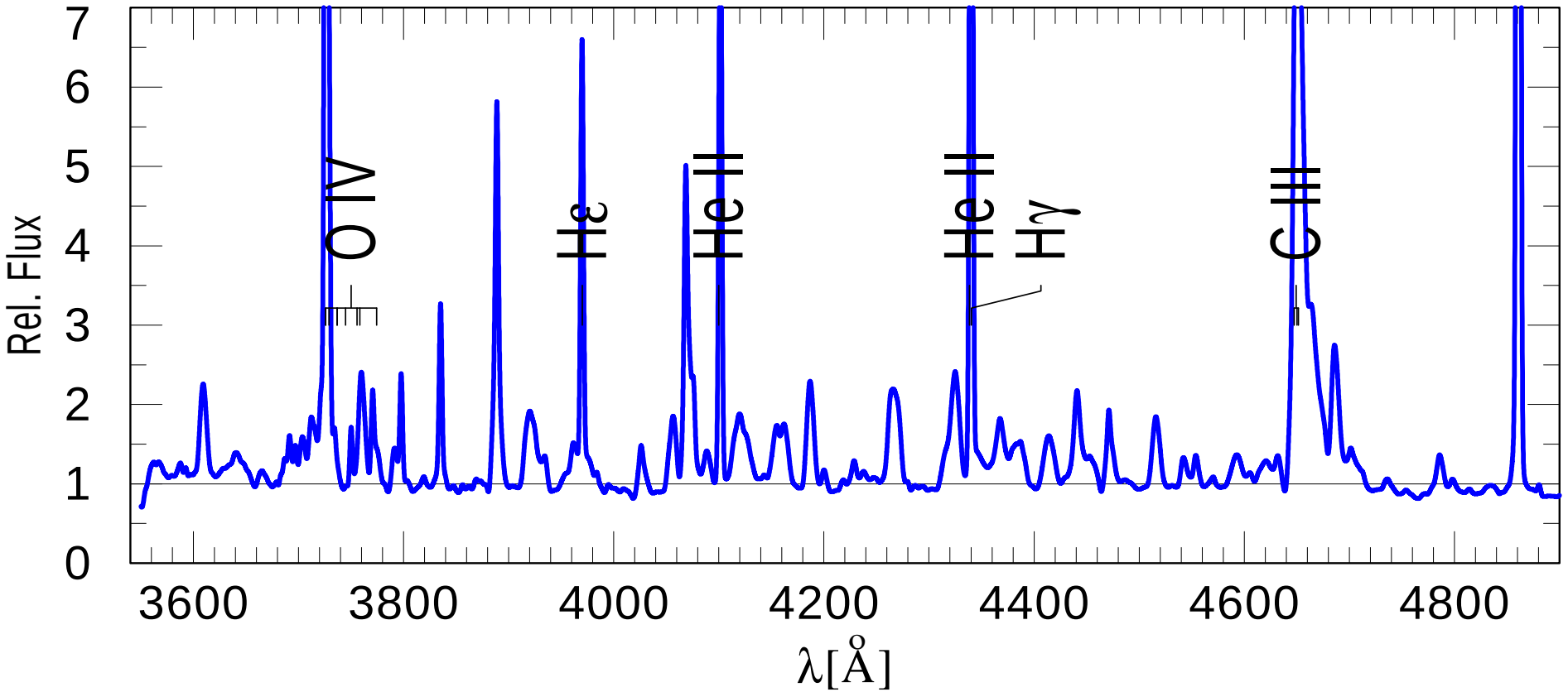
CSPNe 10%-30% with helium-dominated atmospheres, i.e. [WC]



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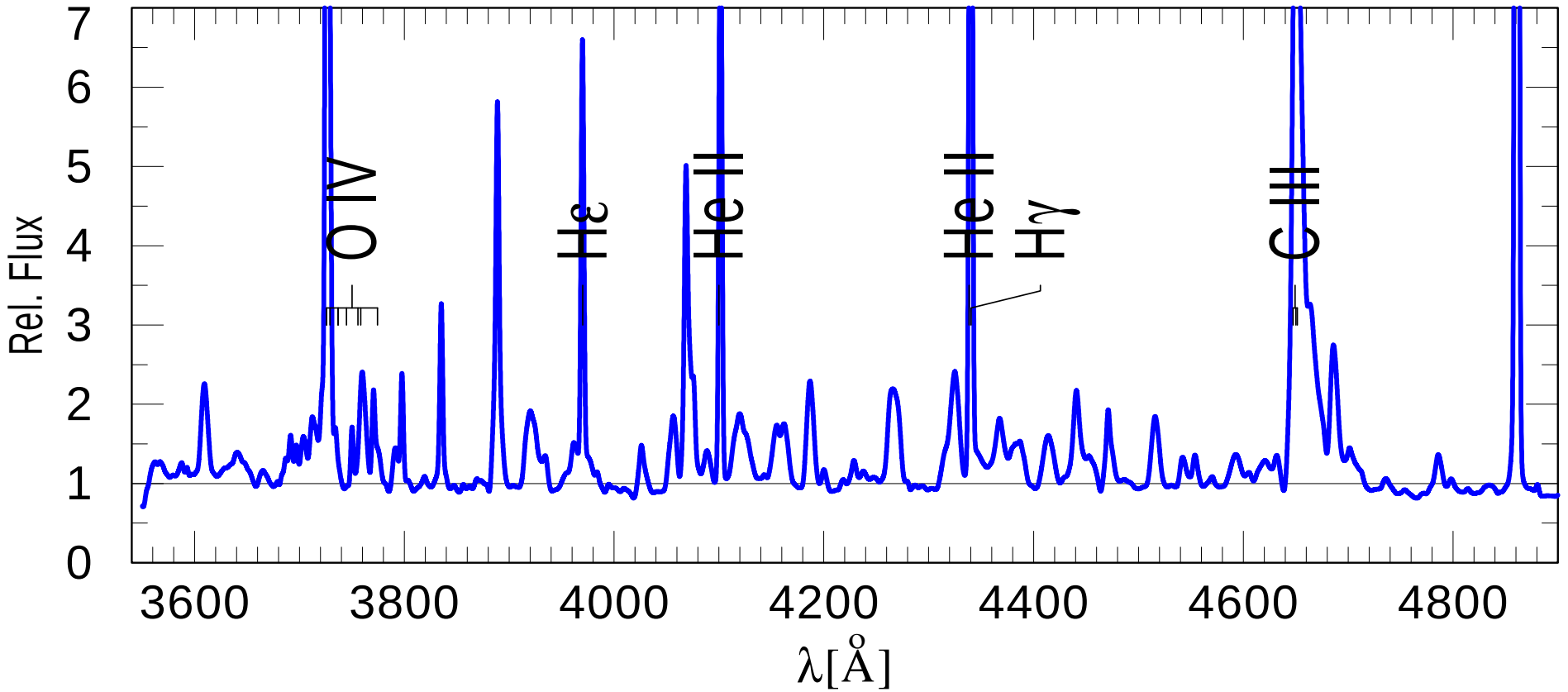
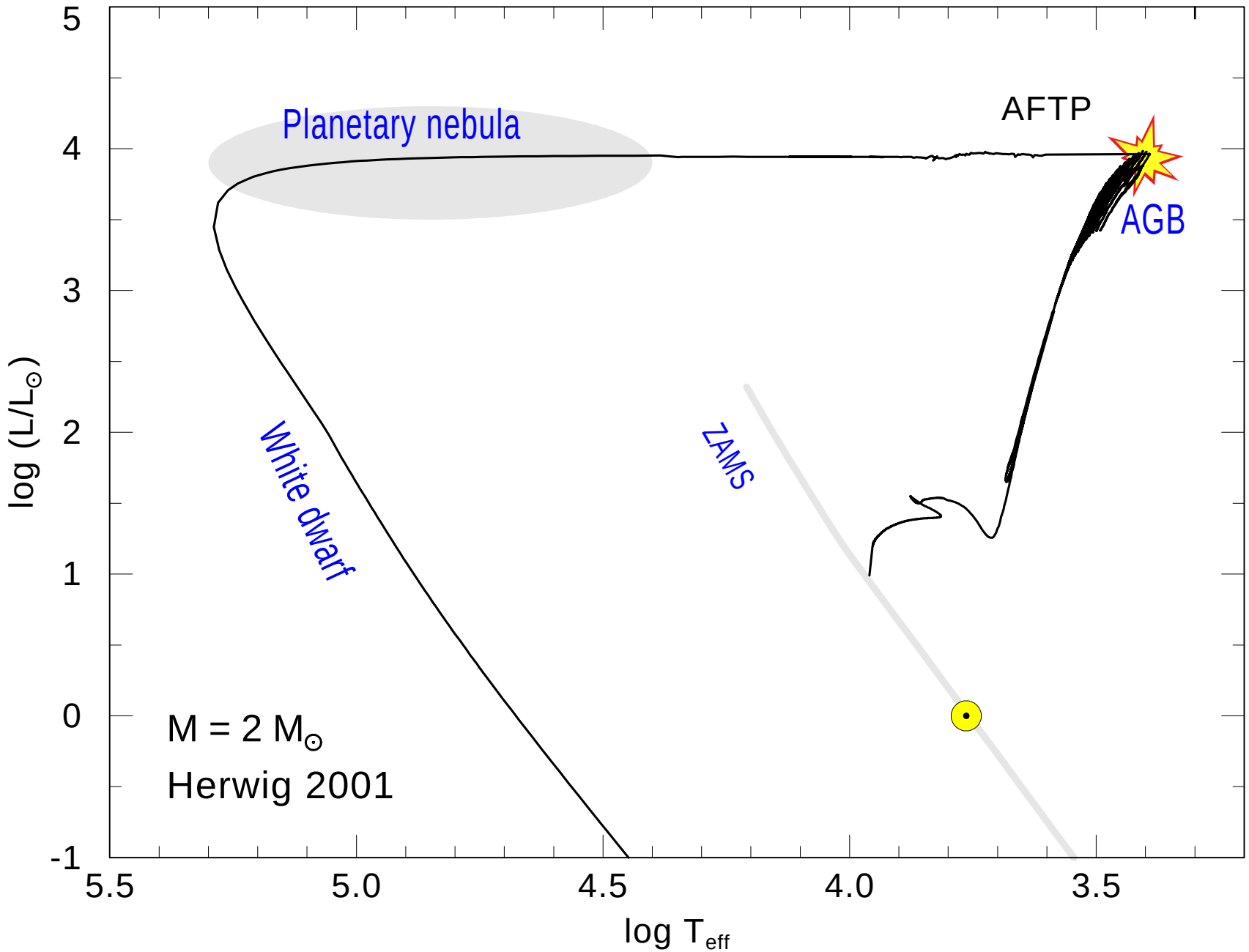


How do these stars form?

Evolutionary Scenarios



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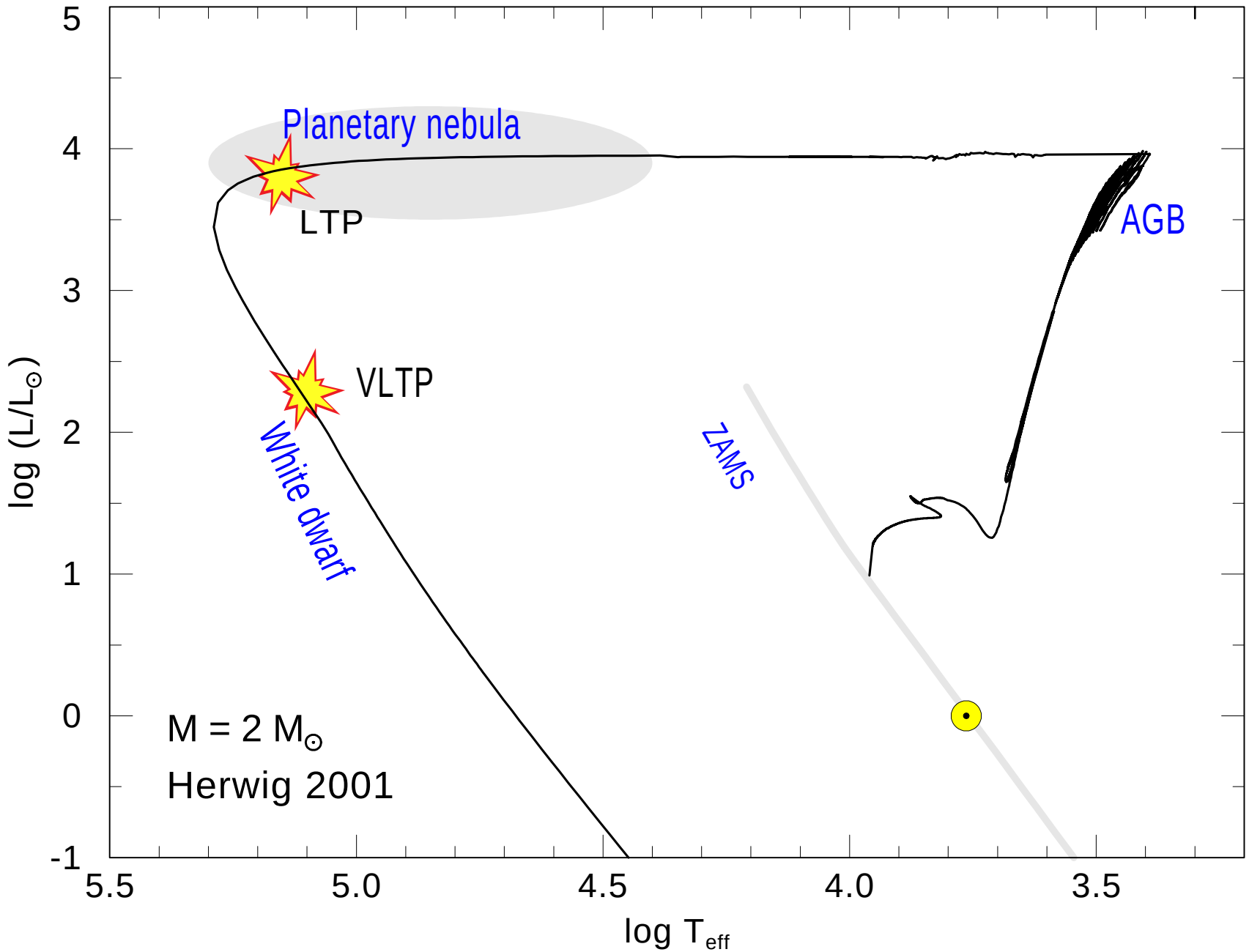

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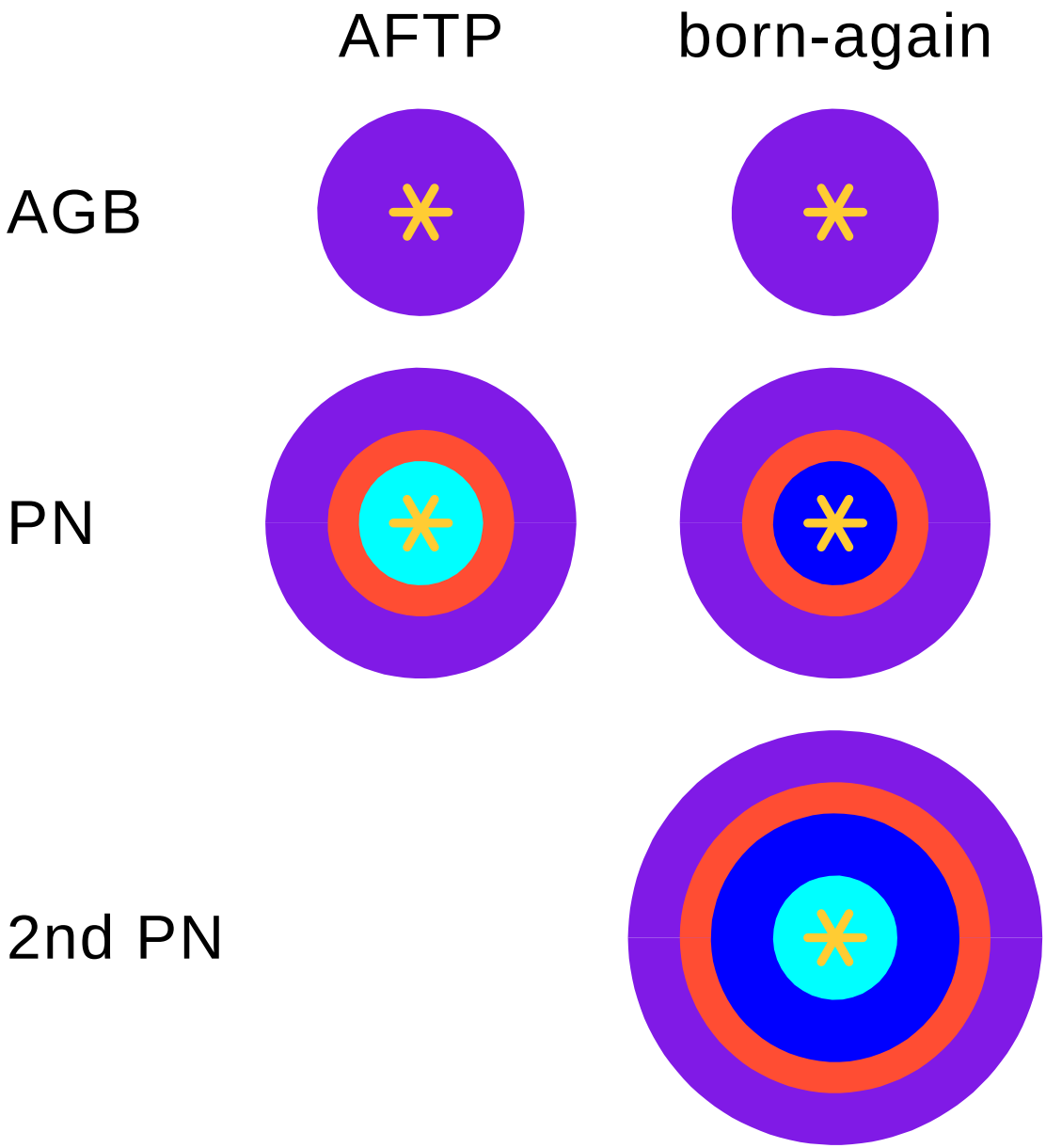


AGB wind ~10 km s^{-1}

optical shell

CS wind (H-poor)

~1000 km s^{-1}

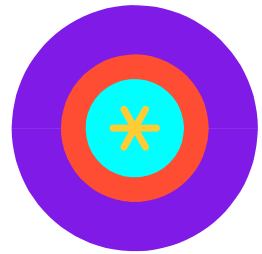
CS wind (H-rich)

~1000 km s^{-1}

Evolutionary Scenarios

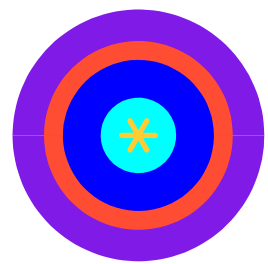
AFTP

- X-ray bubble fills the optical nebula

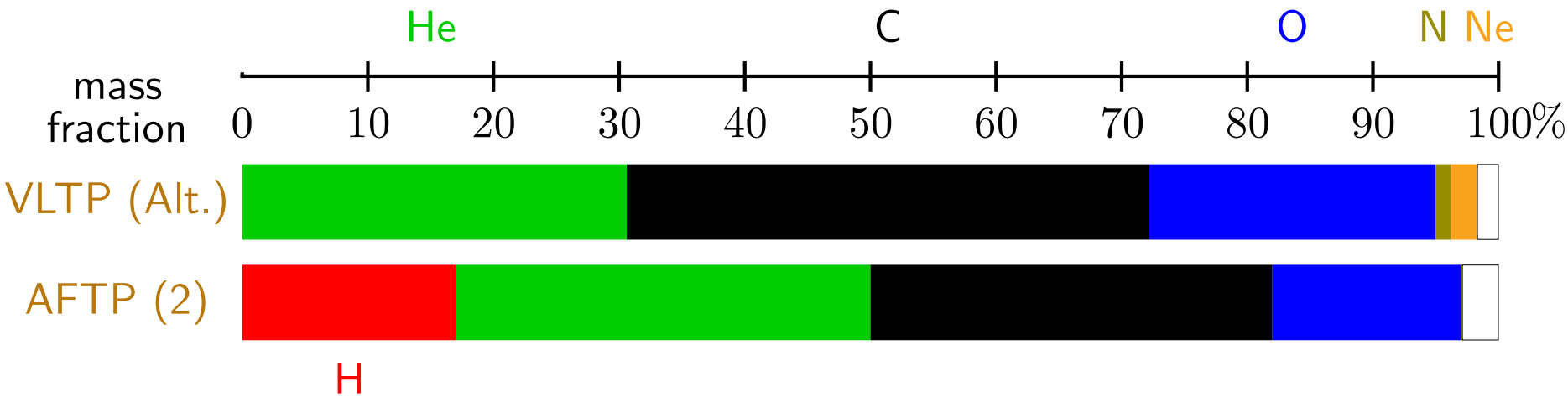


born-again

- X-ray bubble close to the central star



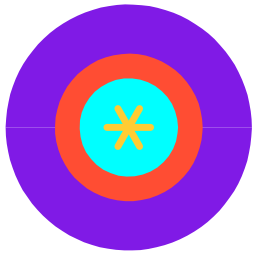
Predicted surface chemistry



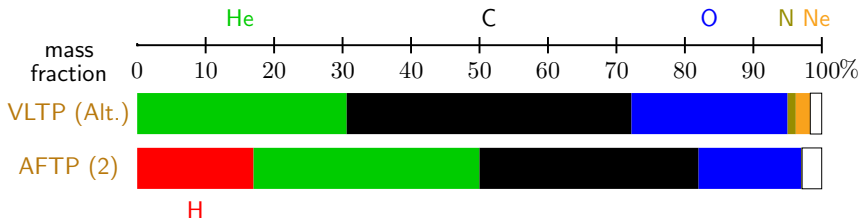
Surface abundances from stellar evolutionary models
by Herwig (2001), Althaus (2005)

Evolutionary Scenarios

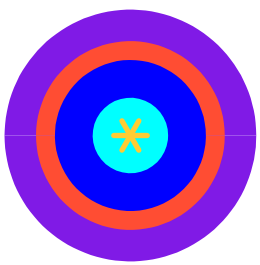
AFTP



- X-ray bubble fills the optical nebula
- AFTP abundances



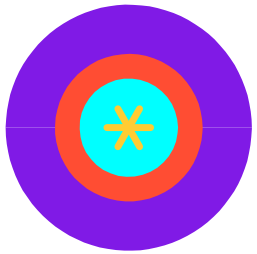
born-again



- X-ray bubble close to the central star
- LTP/VLTP abundances

Evolutionary Scenarios

AFTP



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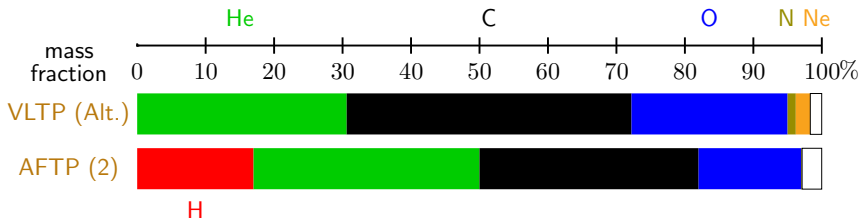

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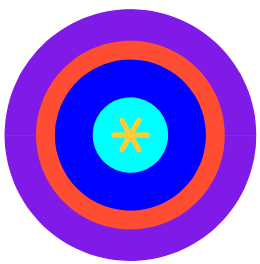
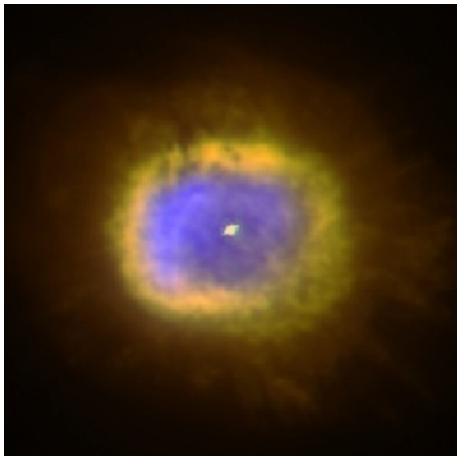


- X-ray bubble close to the central star
- LTP/VLTP abundances

More discriminating criteria from detailed modeling?

X-ray emission of PNe

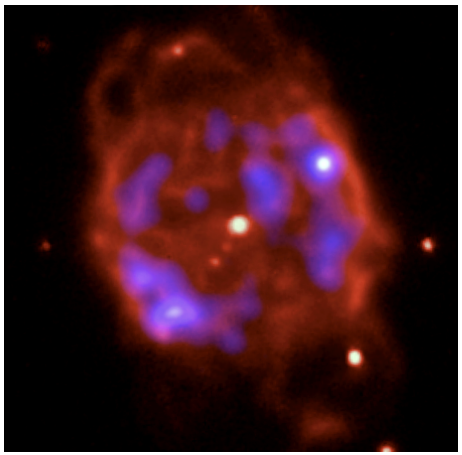
[WC 9]



BD+30° 3639

by Guerrero

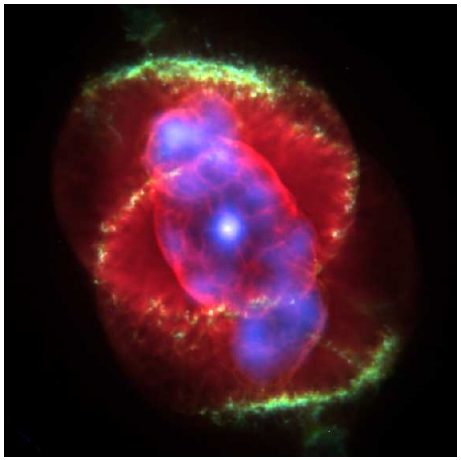
[WC 8]



NGC 40

by Kastner

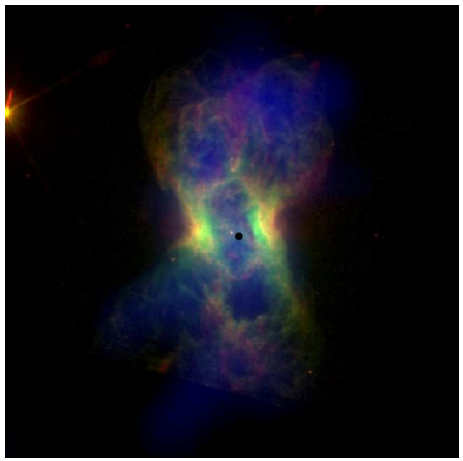
wels



NGC 6543

by Chu

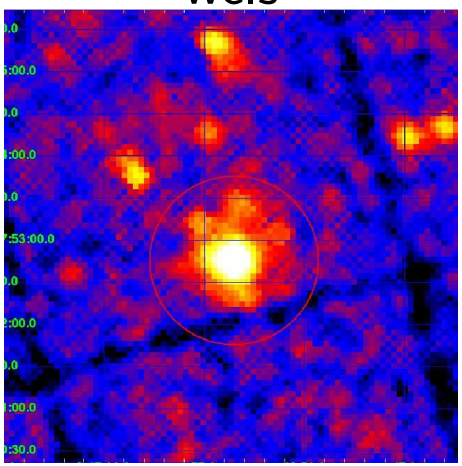
[WO 3]



NGC 7026

by Guerrero

wels



PN-Abel 30

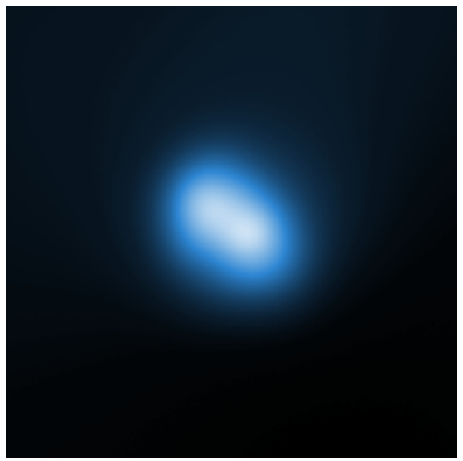
by Hamann

upper panel: X-Ray + opt.

lower panel: X-Ray

$$T_{\mathrm{X-ray}} = 0.5 - 2.5 \cdot 10^6\,\mathrm{K}$$

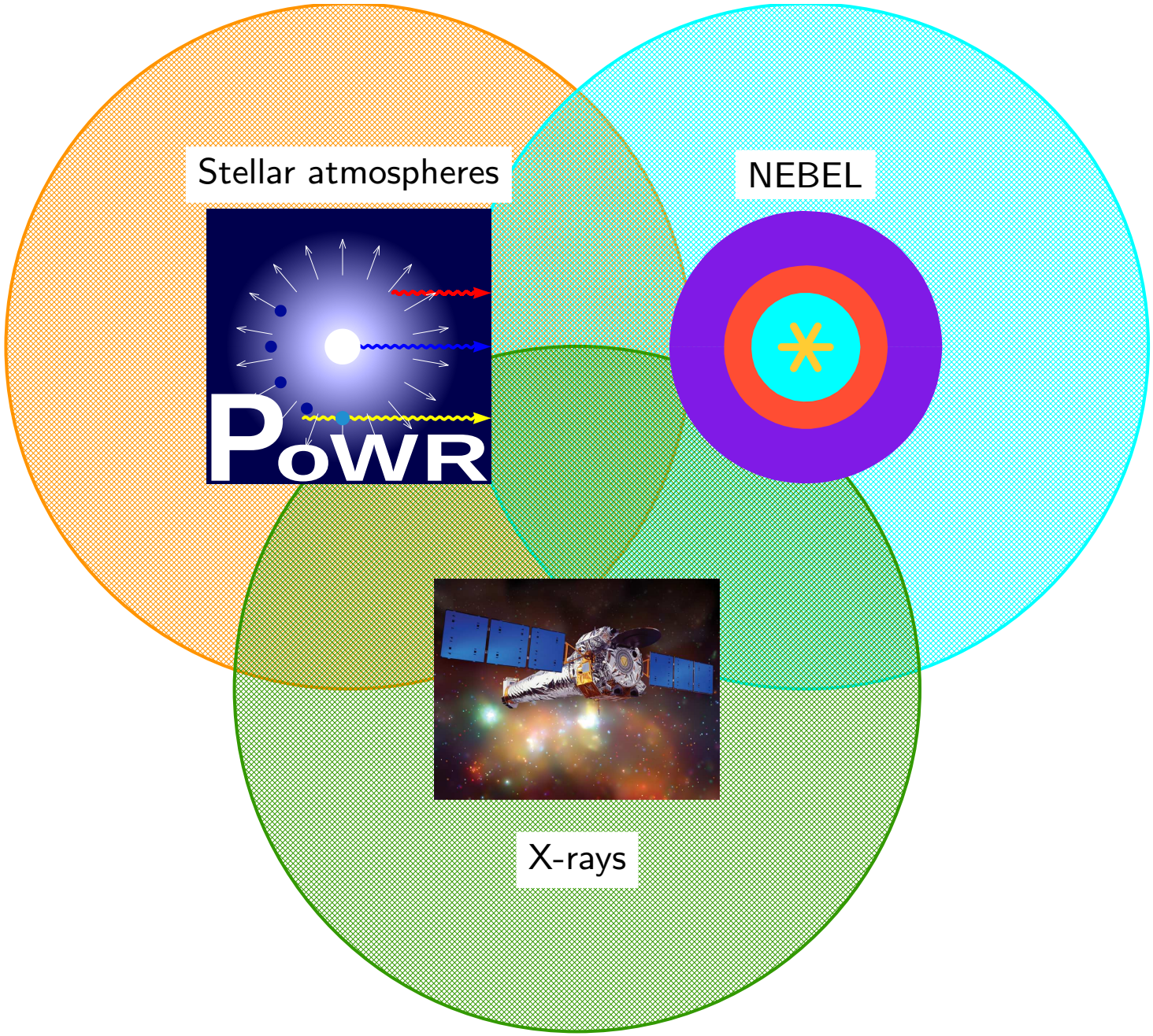
[WO 4]



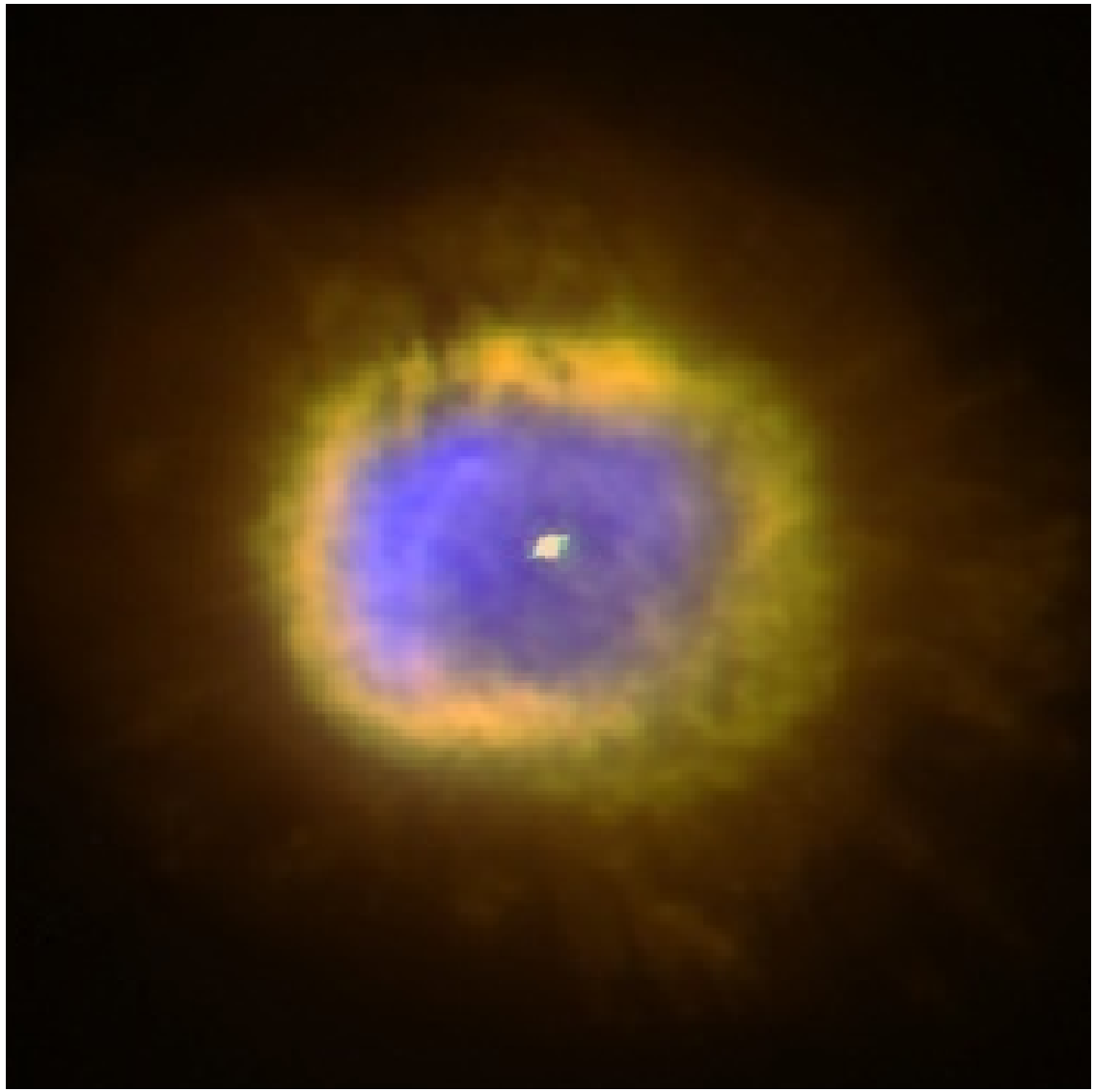
NGC 5315

by Kastner

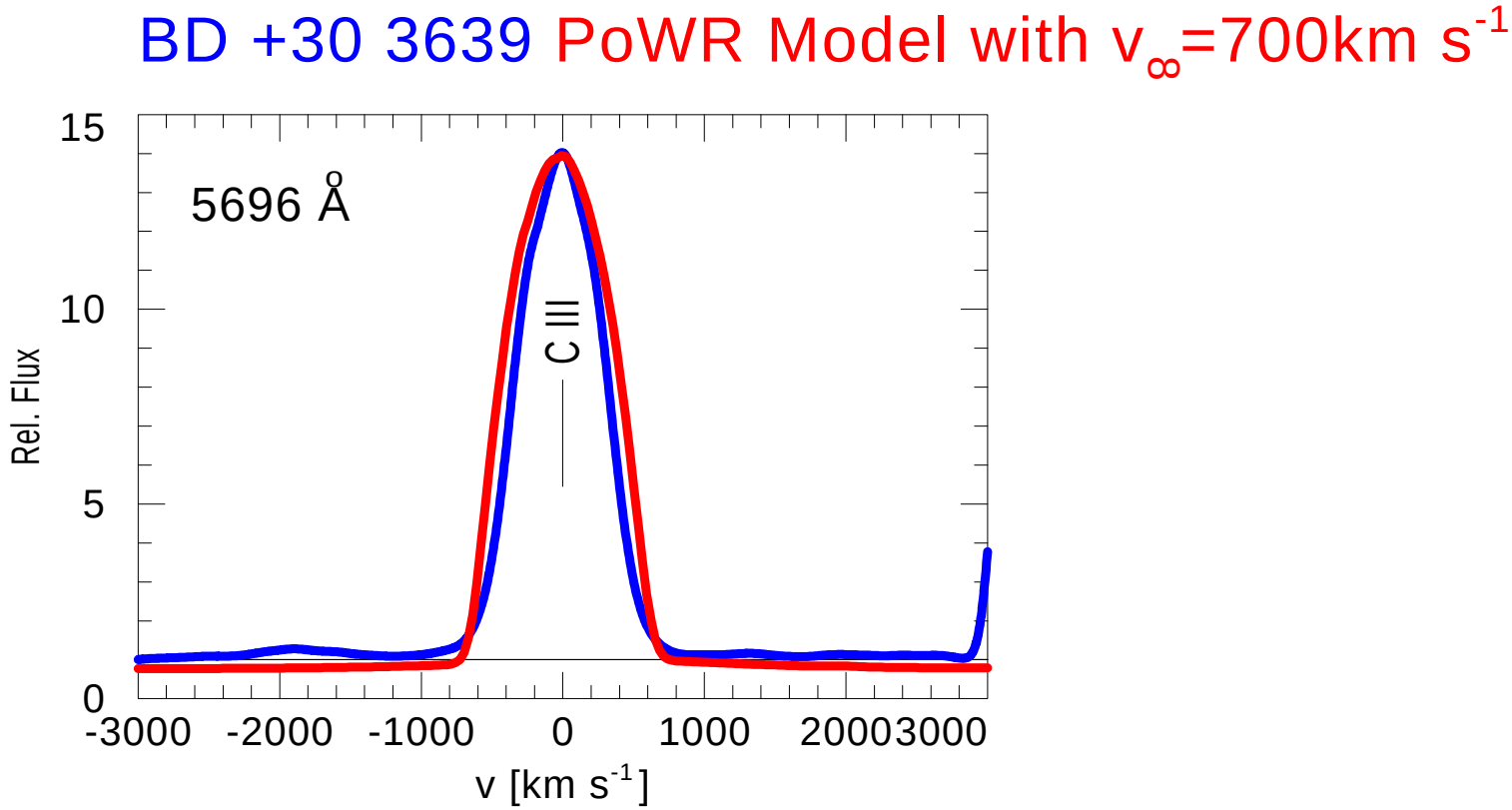
Collaboration



First case study: BD + 30° 3639



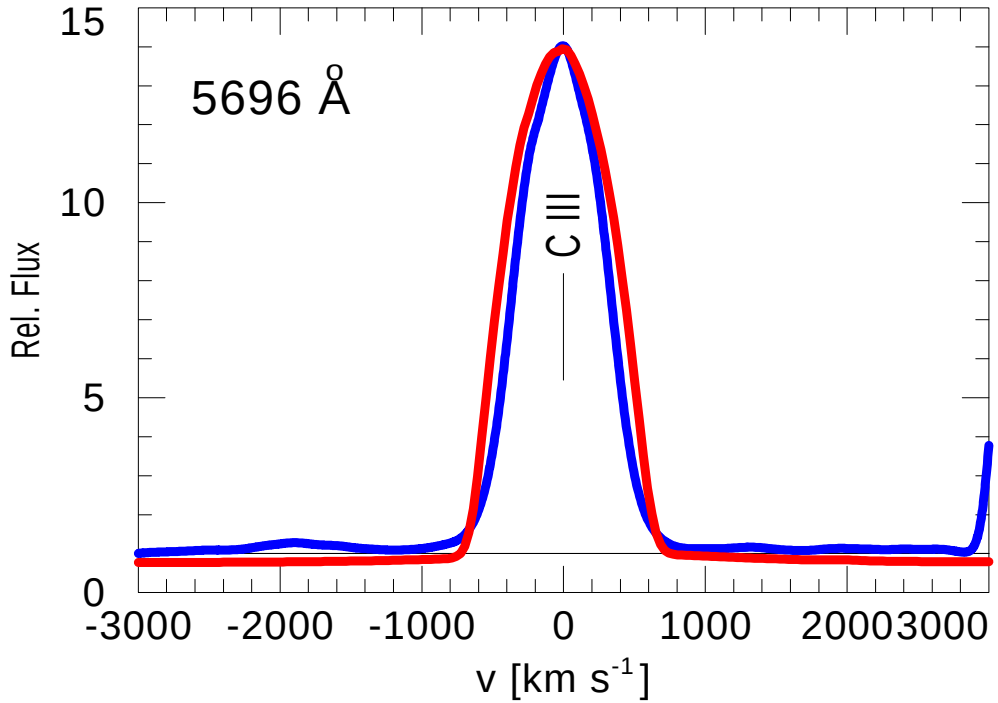
Exemplary parameter: terminal velocity v_∞



$v_\infty = 700\,\mathrm{km\,s^{-1}}$ (Marcolino et al. 2007)

Exemplary parameter: terminal velocity v_∞

BD +30 3639 PoWR Model with v_∞=700km s^{-1}



$v_\infty = 700\,\mathrm{km\,s^{-1}}$ (Marcolino et al. 2007)

Not enough to form a hot X-ray emitting bubble!

Exemplary parameter: terminal velocity v_∞

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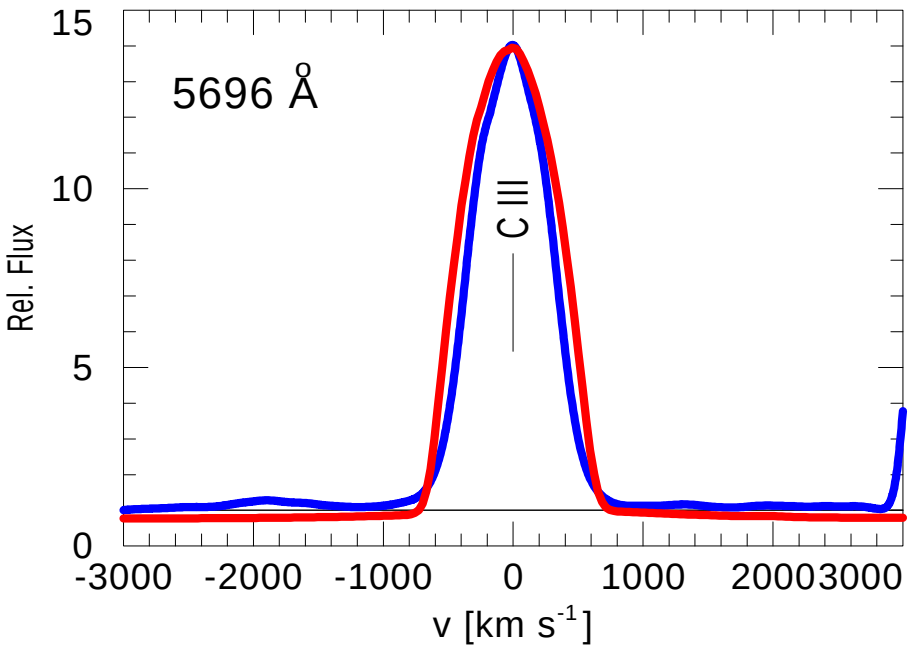

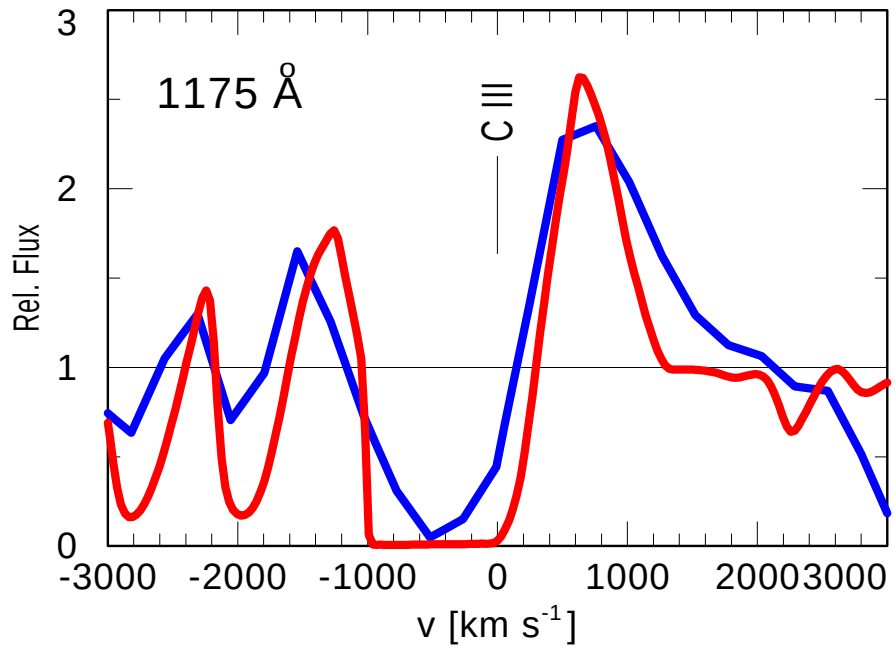

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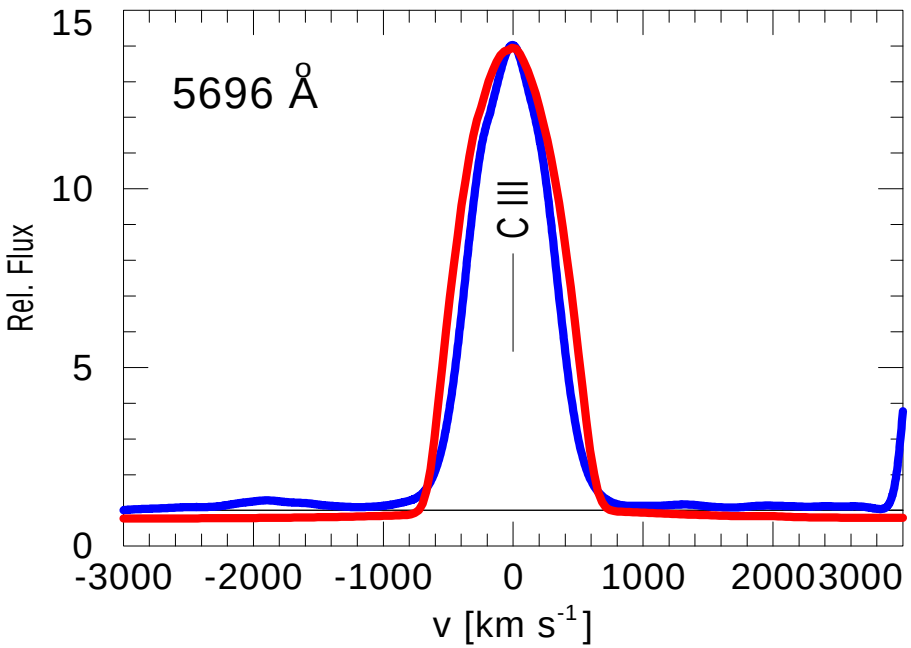
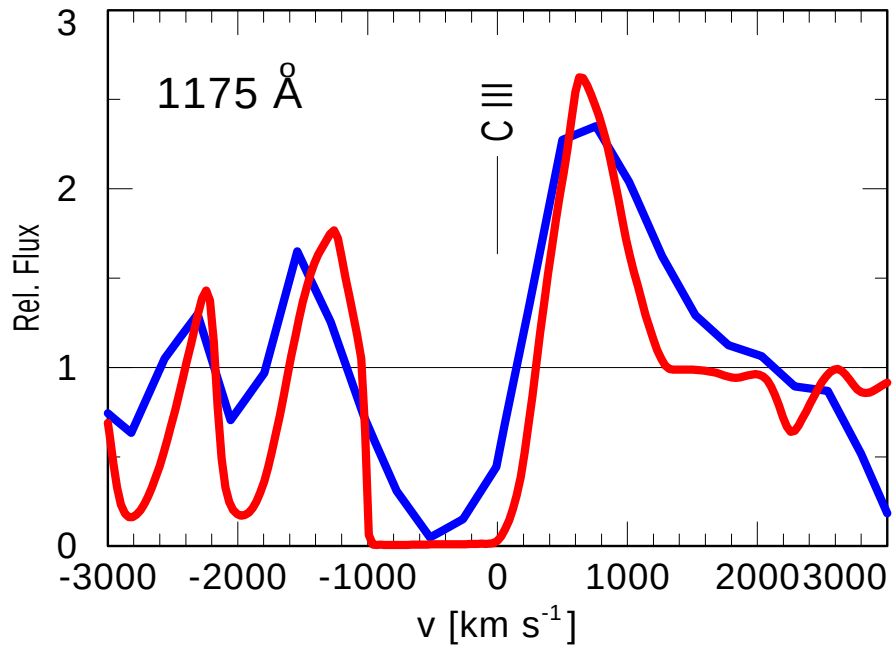
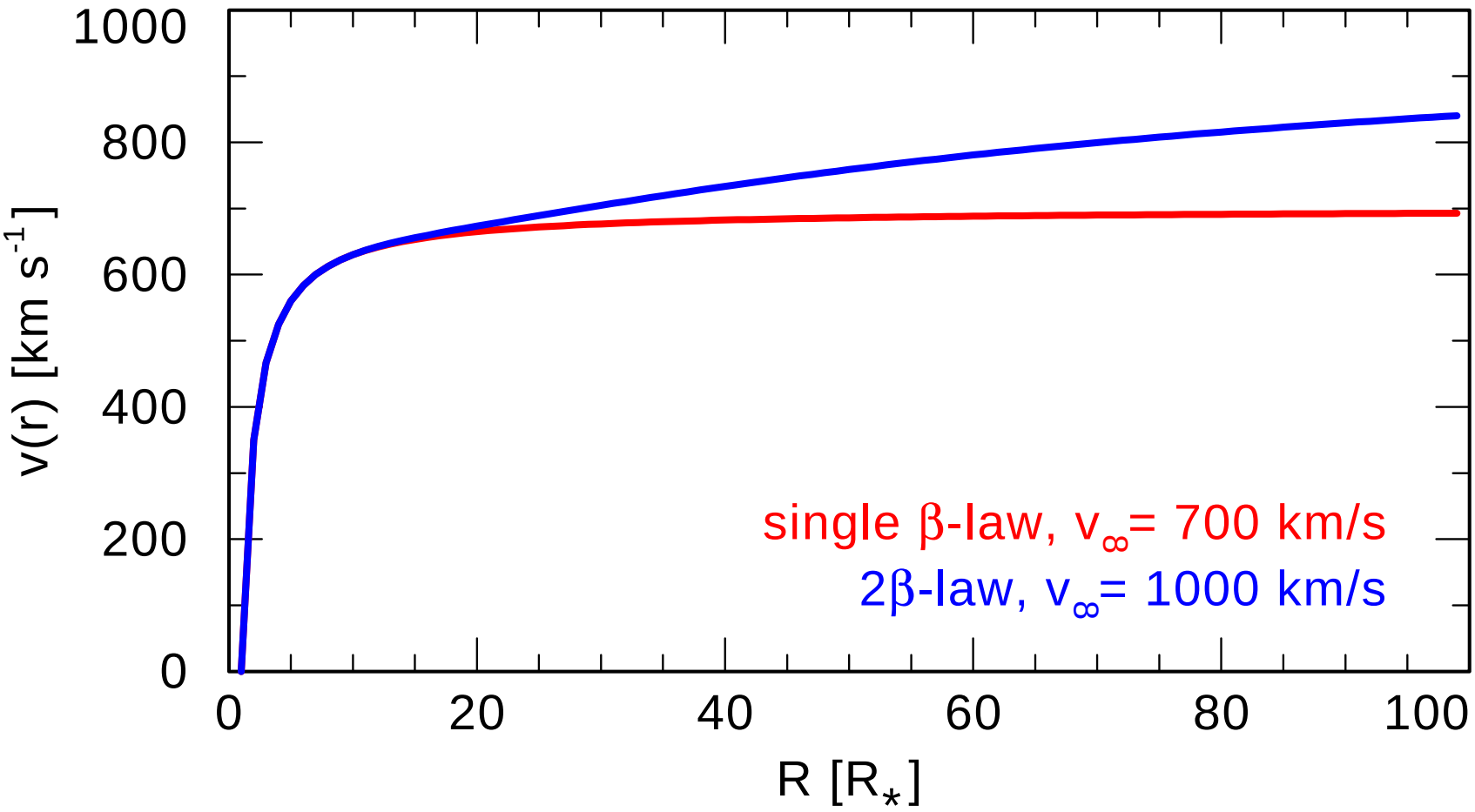




Far UV shows: additional wind acceleration far out in the wind

Exemplary parameter: terminal velocity v_∞



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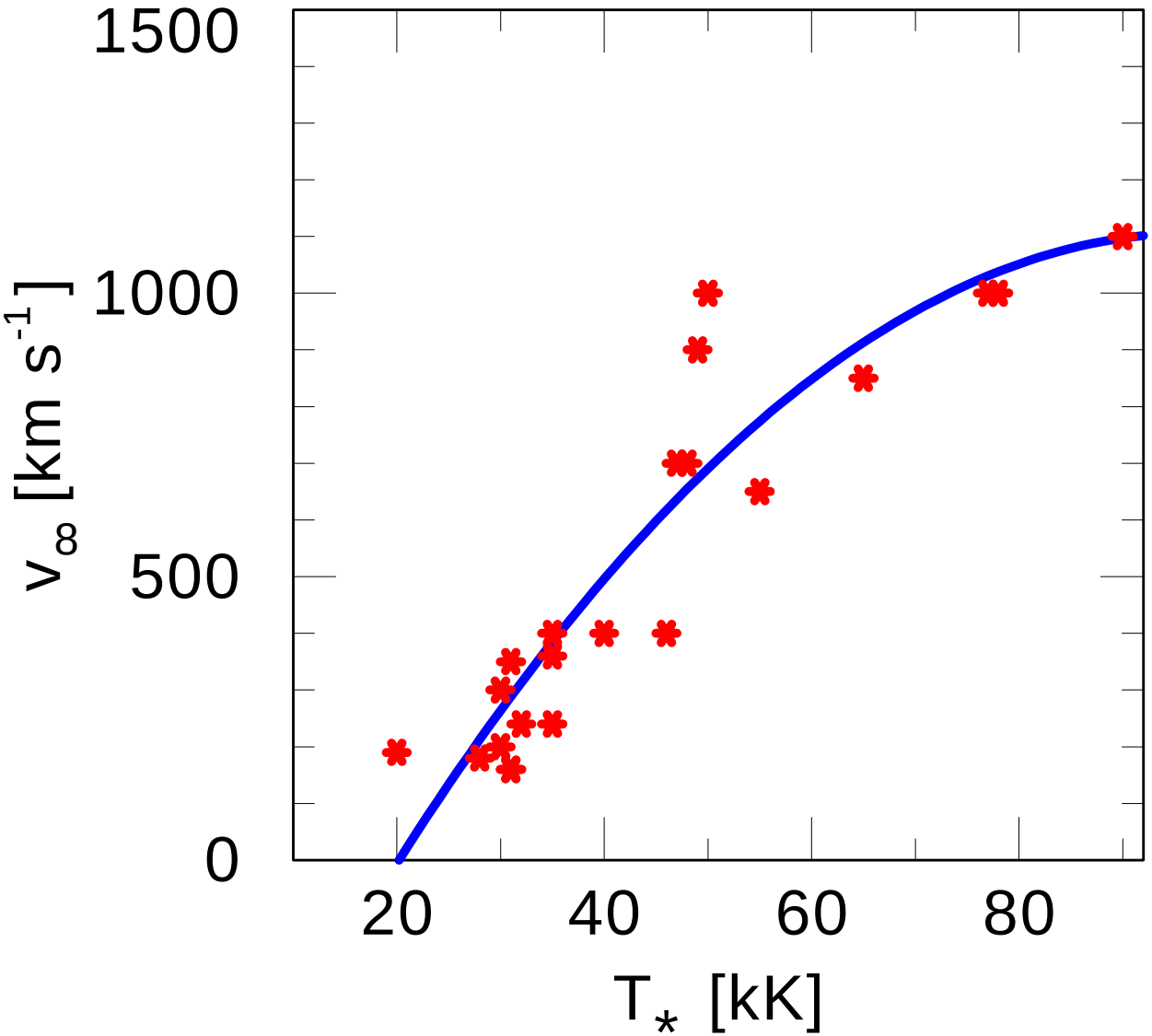


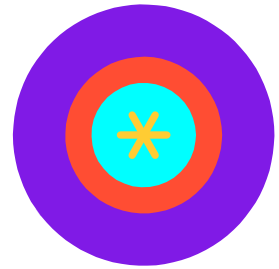
Evolution of v_∞

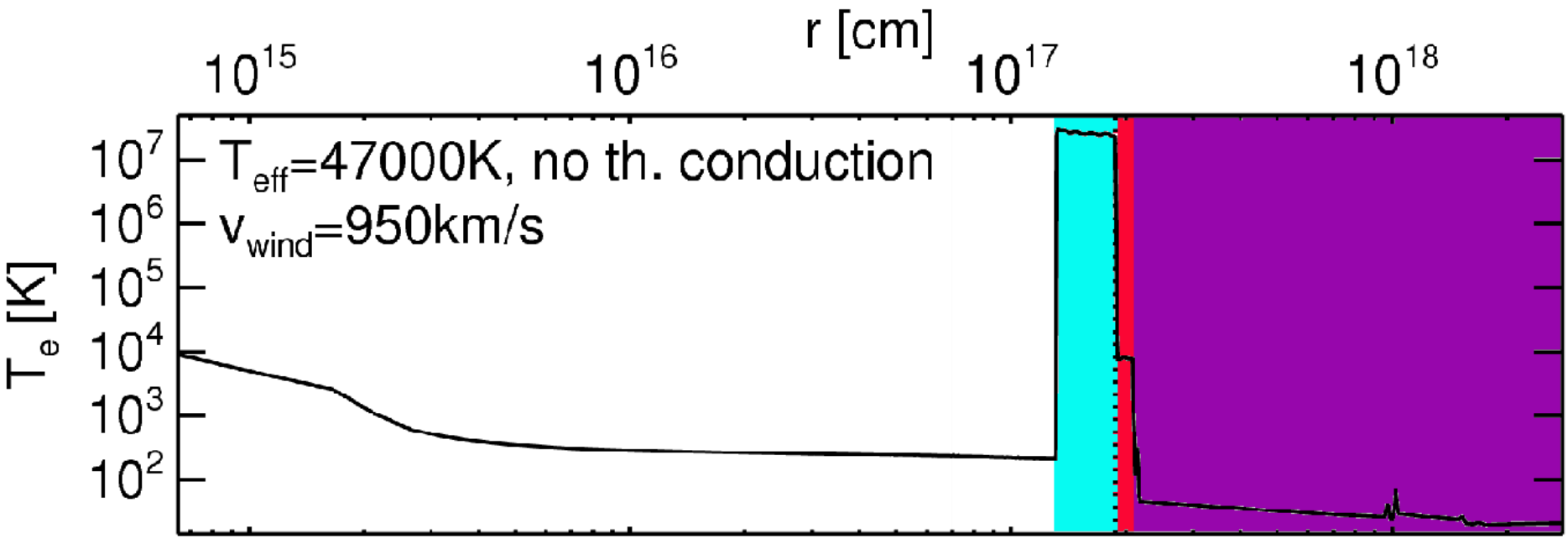
(Stellar parameters from literature)

NEBEL calculations

New physics:

thermal conduction in H-poor plasma
Fokker-Planck-based theory of Spitzer (1962)





Sandin et al., in prep.

NEBEL calculations

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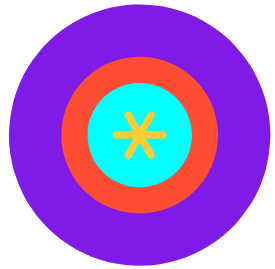
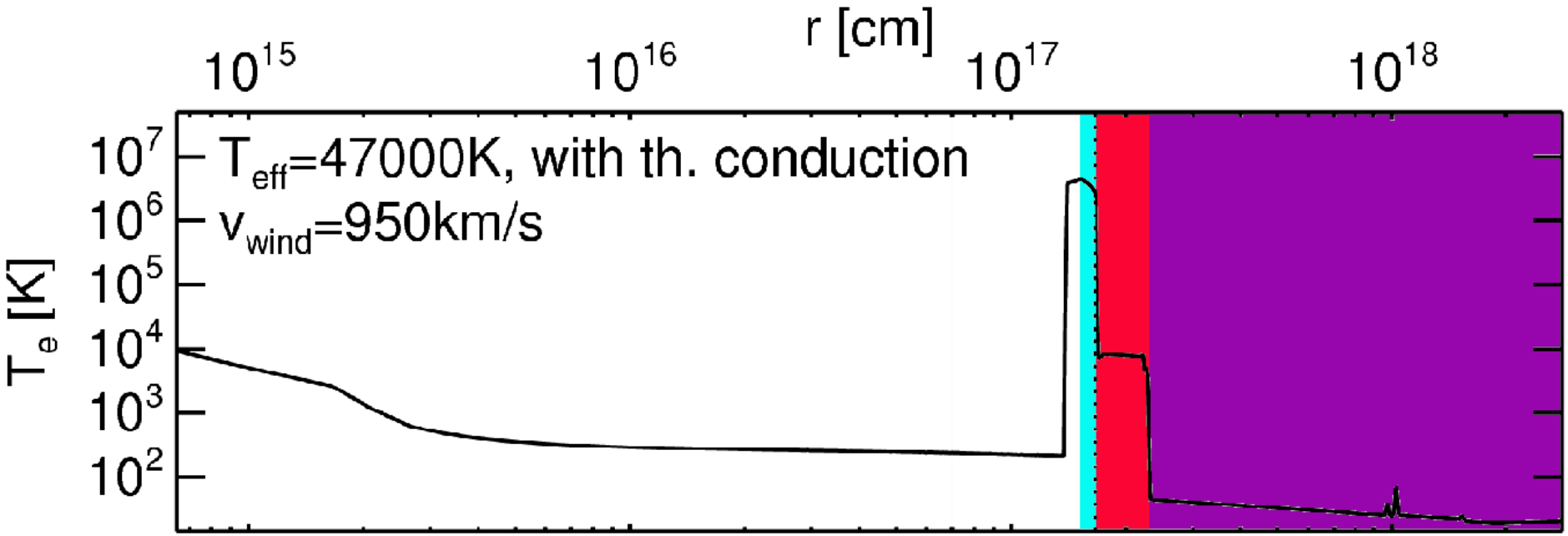


thermal conduction in H-poor plasma
Fokker-Planck-based theory of Spitzer (1962)



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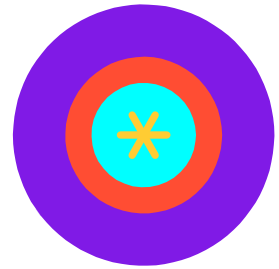
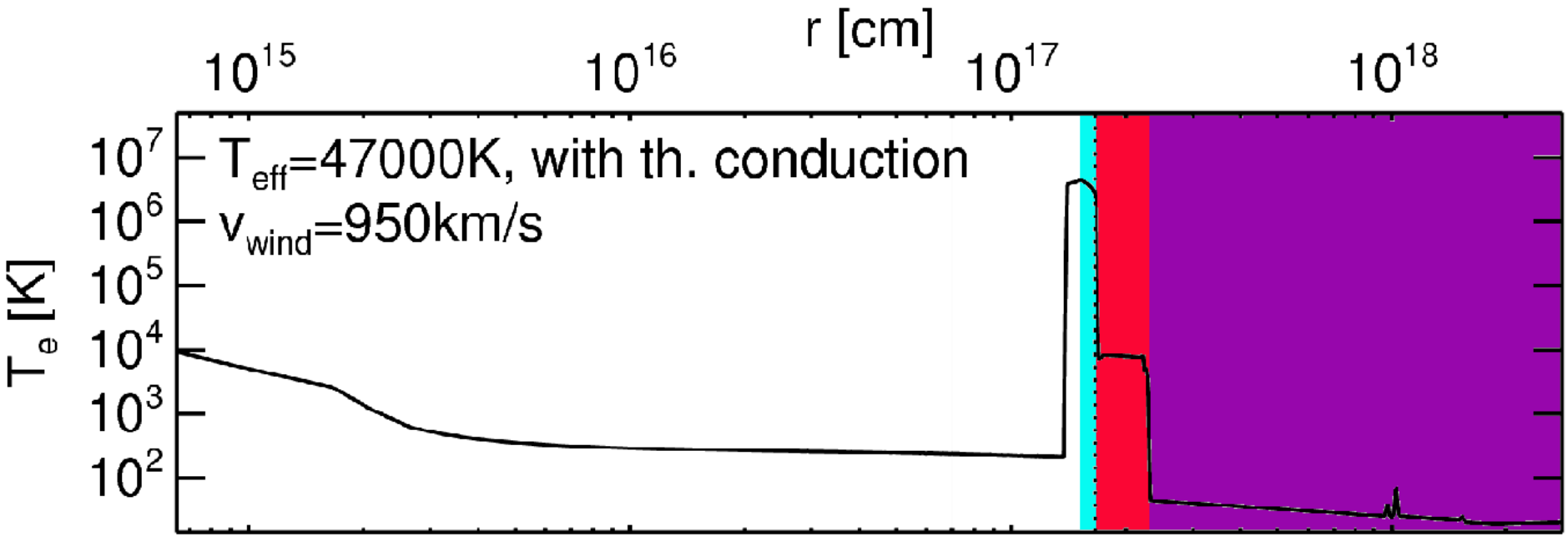


diffusion coefficient 2× lower compared to pure hydrogen plasma

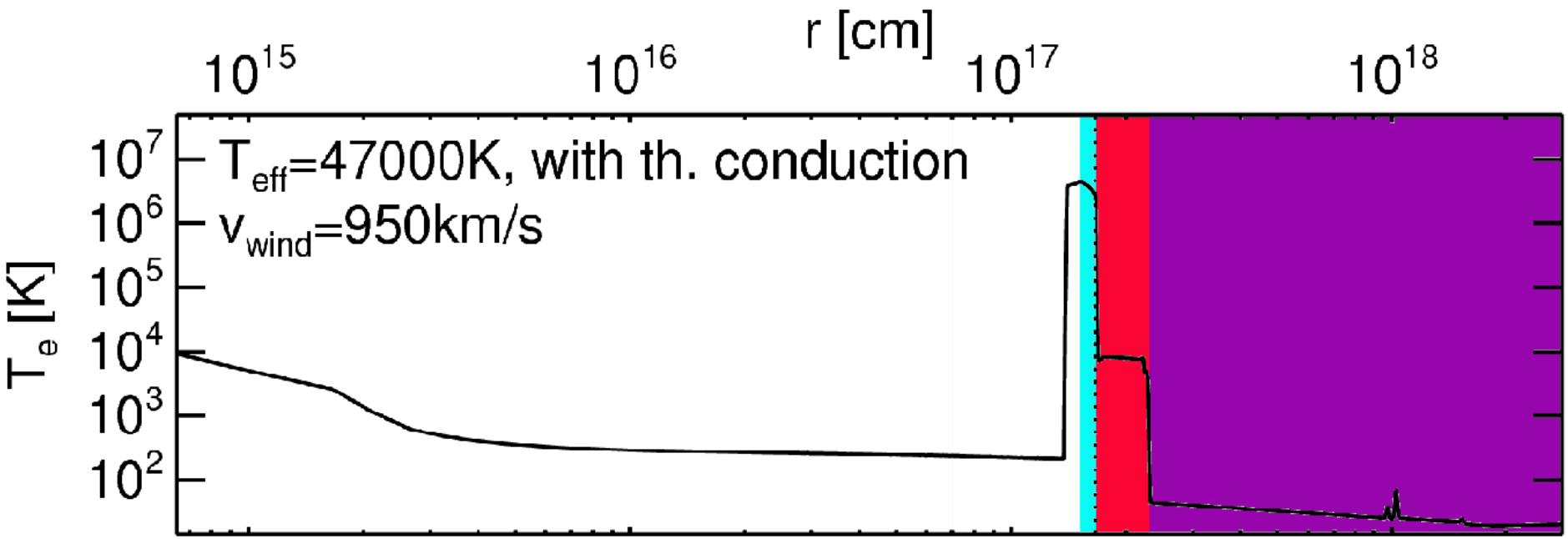


Sandin et al., in prep.

NEBEL calculations

Due to thermal conduction

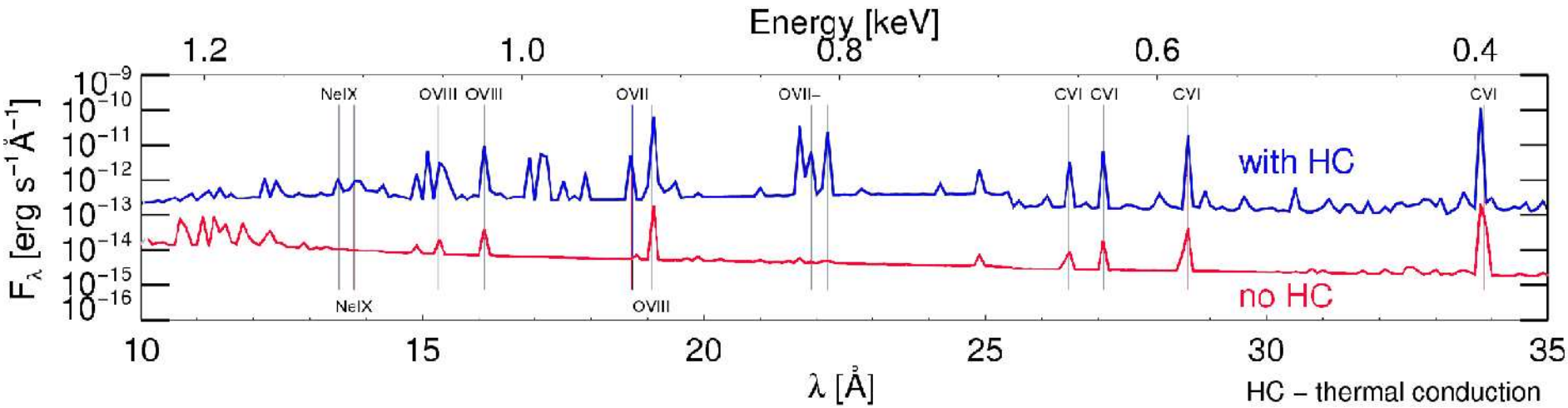
- the bubble forms later
- the bubble is located farther away from the star
- it has the observed temperature $\sim 3 \cdot 10^6\,\mathrm{K}$
- the electron density is higher ($n_{\mathrm{e,bubble}} \sim 50\,\mathrm{cm}^{-3}$)



Sandin et al., in prep.

Predicted X-ray spectrum

- AFTP model shows X-ray emission of $2 \cdot 10^6$ K



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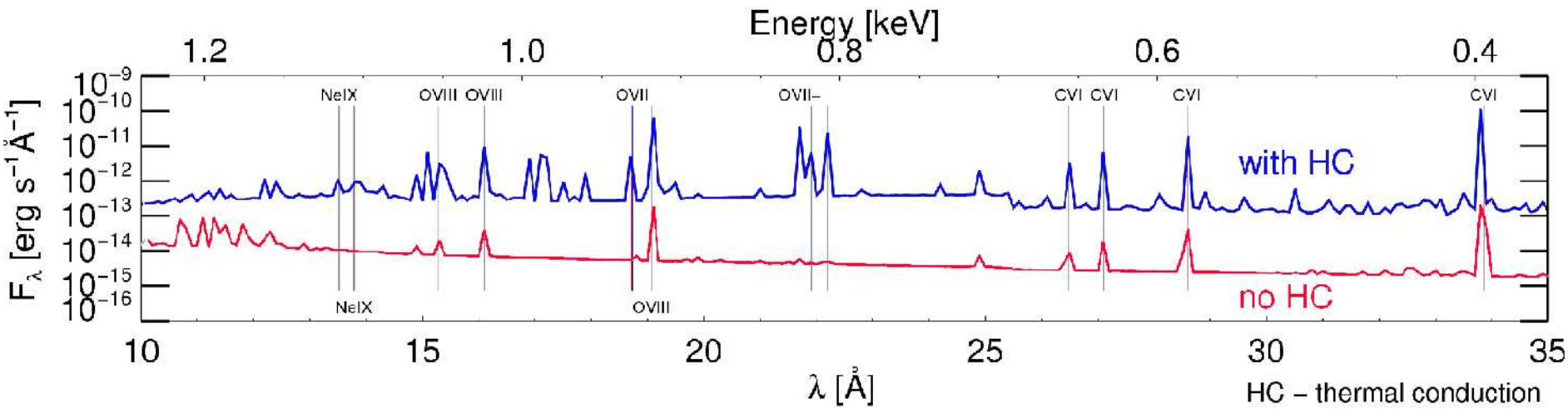
  are consistent with H-free wind abundances (Marcolino et al. 2009)



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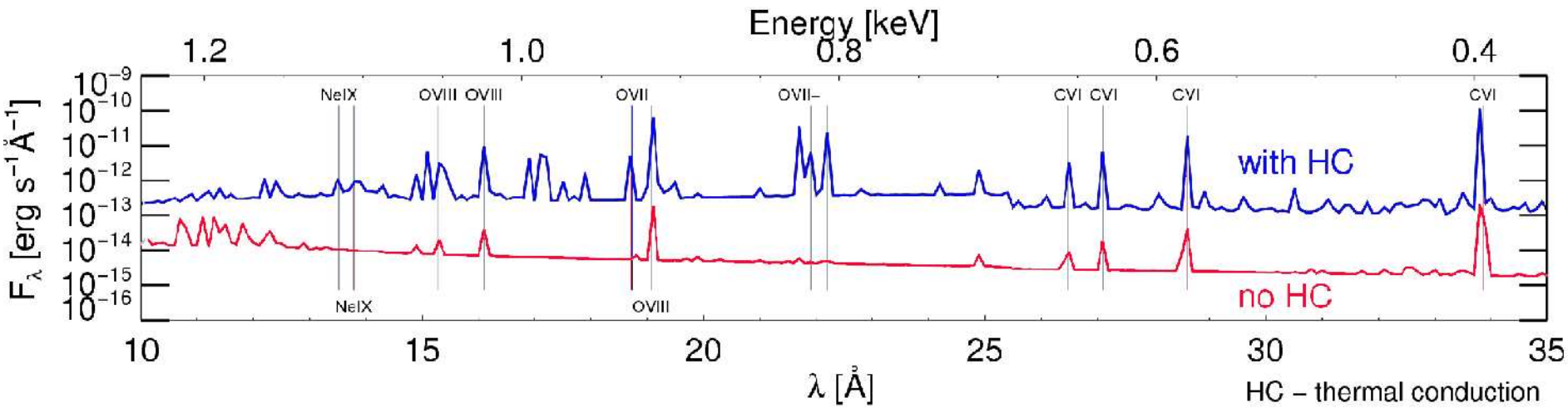
  compares well with the observed ratio of Yu et al. (2009)



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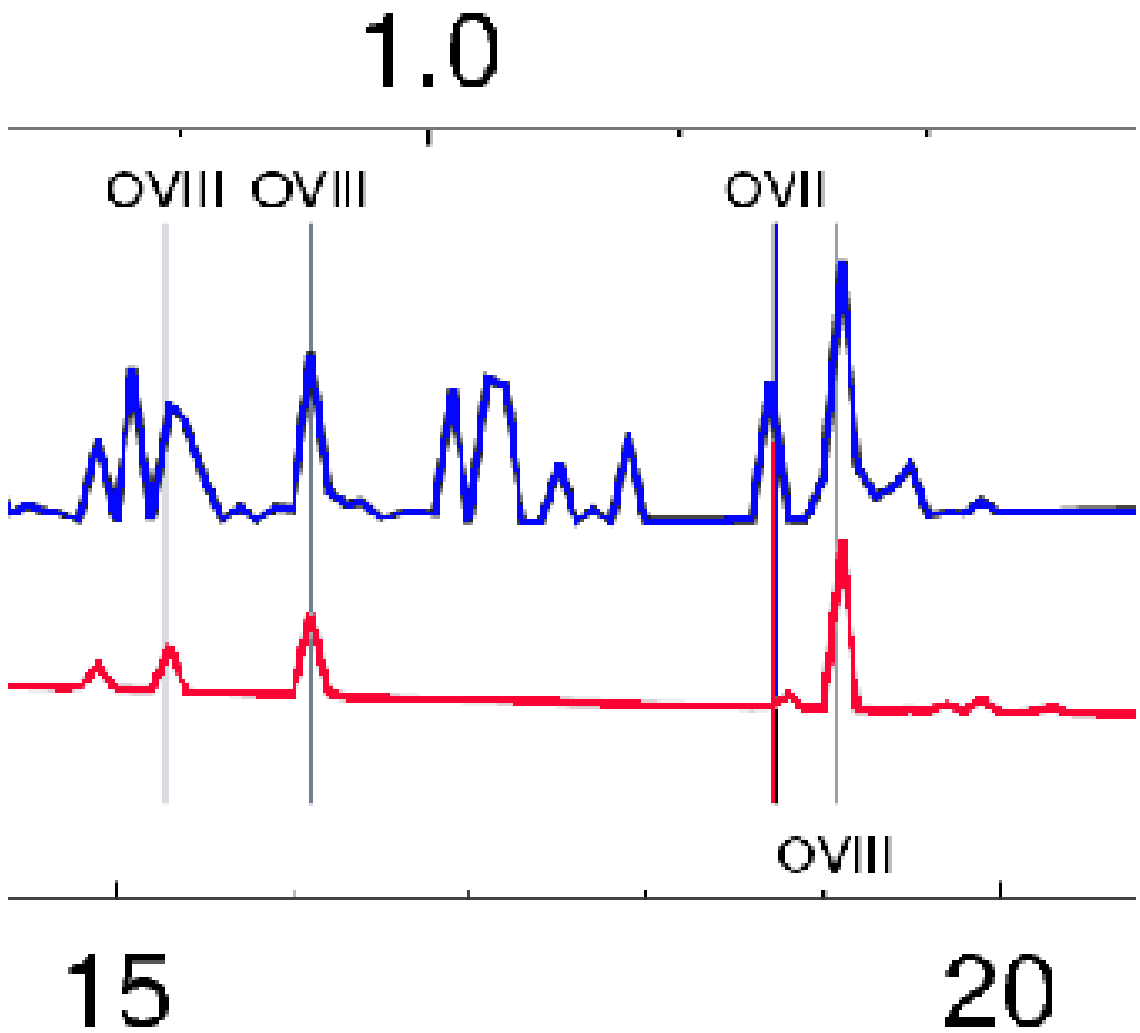
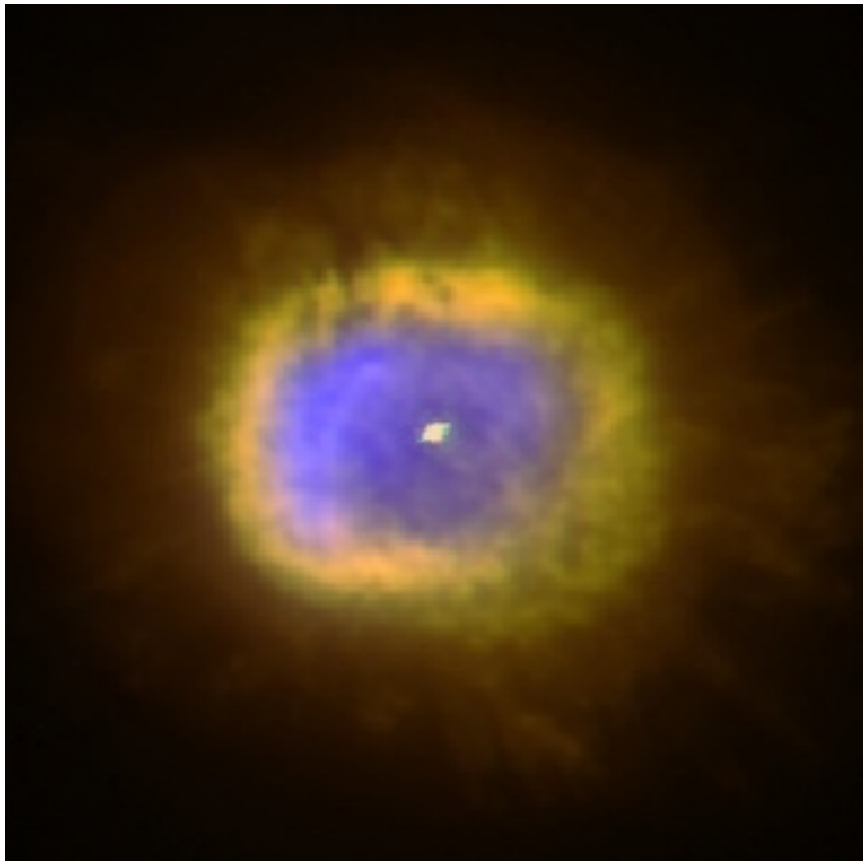


Preliminary results

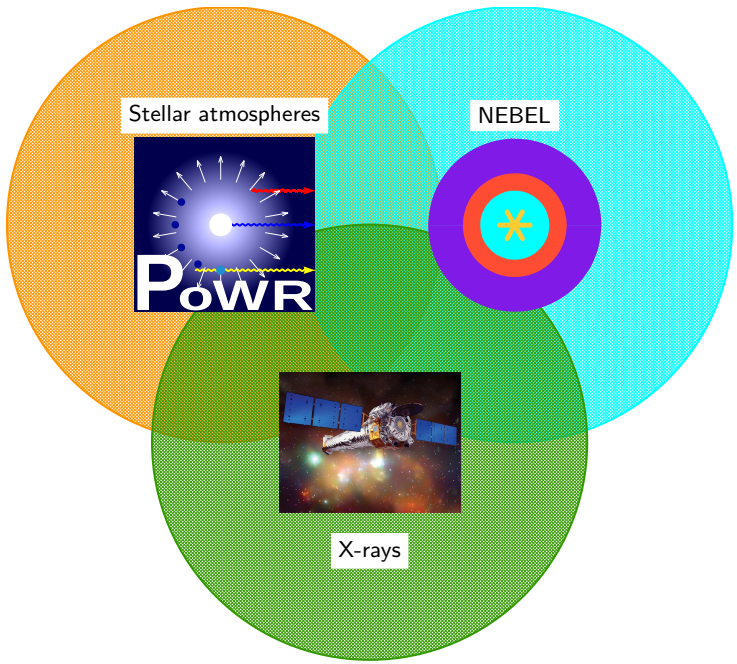
According to our current state of research, BD $+30^{\circ}$ 3639 is consistent with AFTP evolution predictions:

- X-ray emission fills the optical shell
- X-ray plasma shows present-day [WC] wind abundances
- X-ray emission seems to be reproducable with AFTP NEBEL models



On-going work

- Direct comparison of predicted and observed X-ray spectra
- Improved stellar parameters for cool late-type [WC] stars
- Analyses of more objects
- NEBEL models for born-again evolution




Thank you for your attention.