Effects of low metallicity on the evolution and spectra of massive stars

Image credit: A/J. Hester & A. Loll, Arizona State U. (Crab Nebula)

Jose Groh (Geneva Observatory, Switzerland)

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Take Away: effects of low metallicity

Reduced stellar wind mass and angular momentum losses

Stars are more compact, hotter, and more mixed

Spectral lines are weaker and less numerous; more ionizing flux

Outline

- Background on massive stars and stellar evolution
- Effects of low metallicity on stellar evolution
- Effects of low metallicity on stellar spectra
- Scary things

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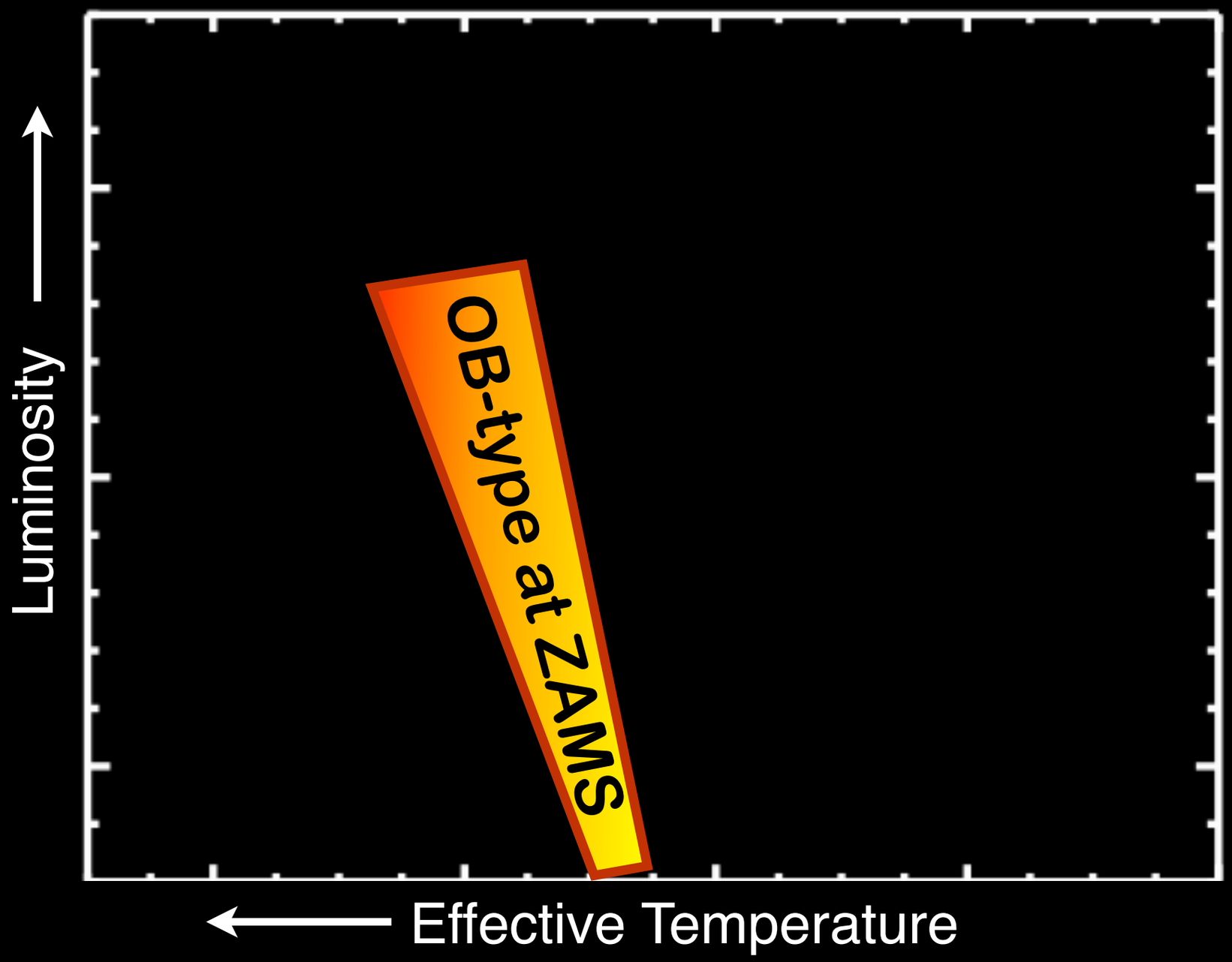
Massive stars bridge many fields of (astro)Physics

- Star formation
- Photoionized regions, chemical evolution
- Supernova, GRBs, Black Holes, Neutron Stars
- Distant Universe (starbursts, first stars, cosmology)
- Intergalactic, interstellar, circumstellar media
- High-energy physics, particle physics, ...
- Stellar evolution

Massive star evolution is challenging



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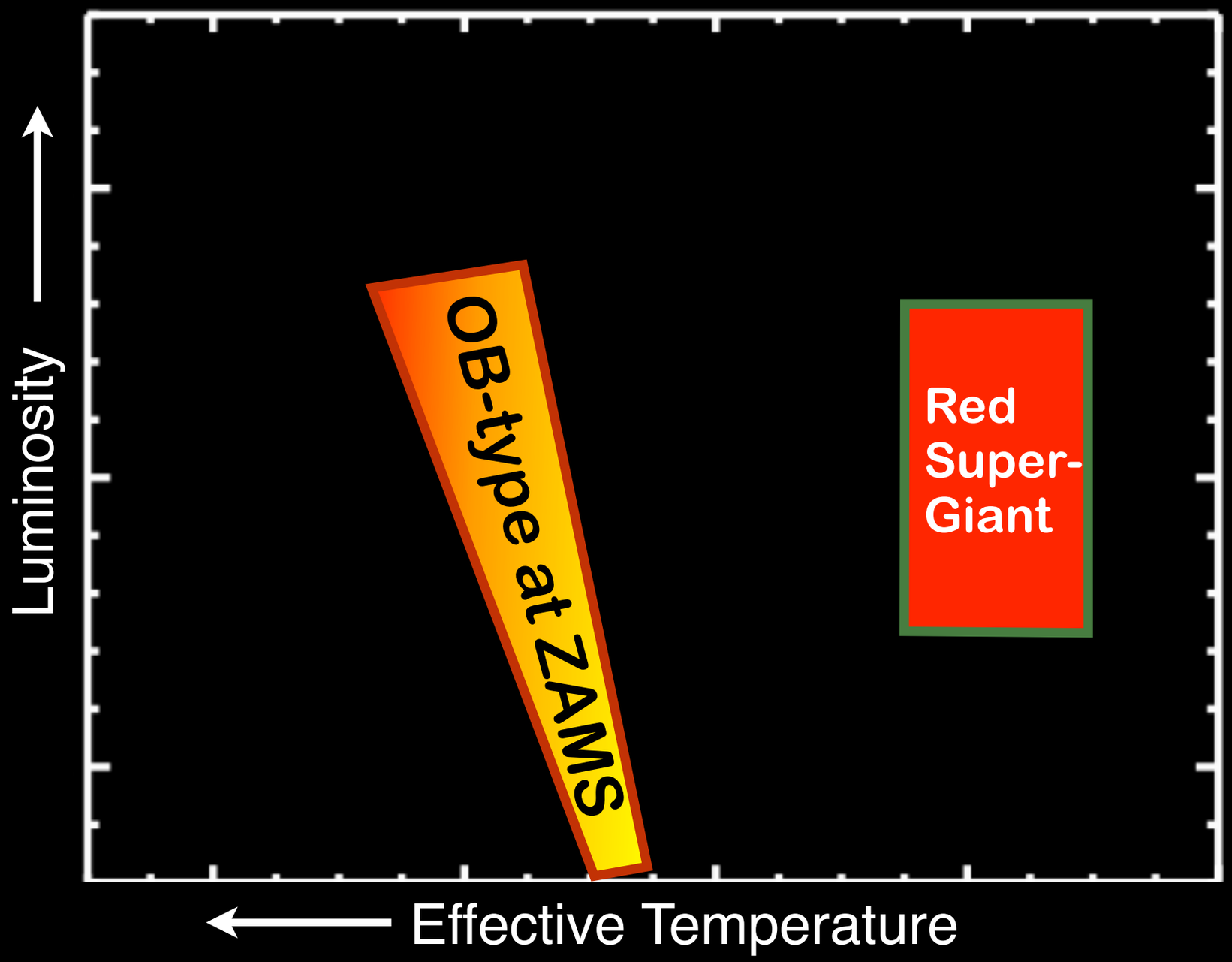

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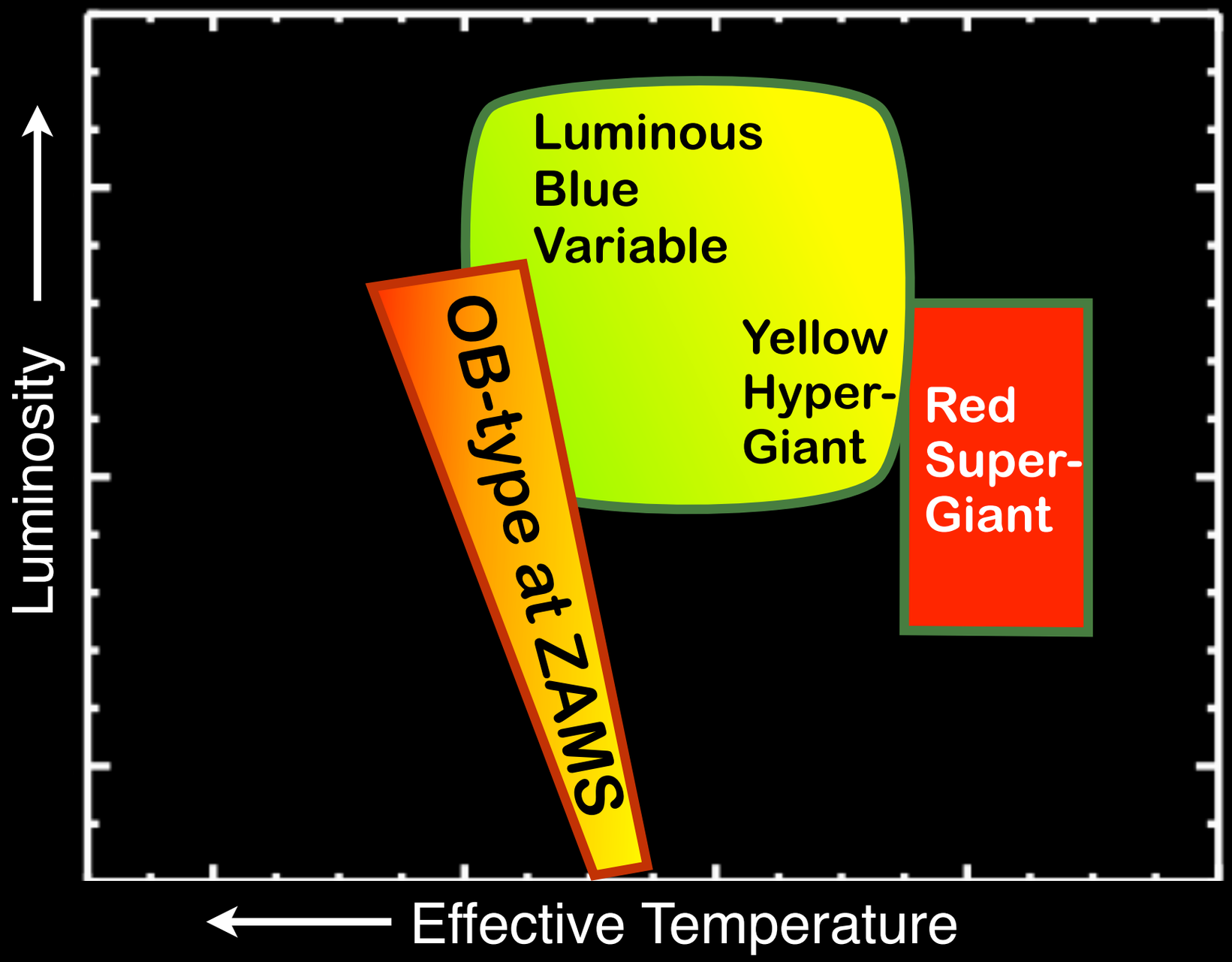

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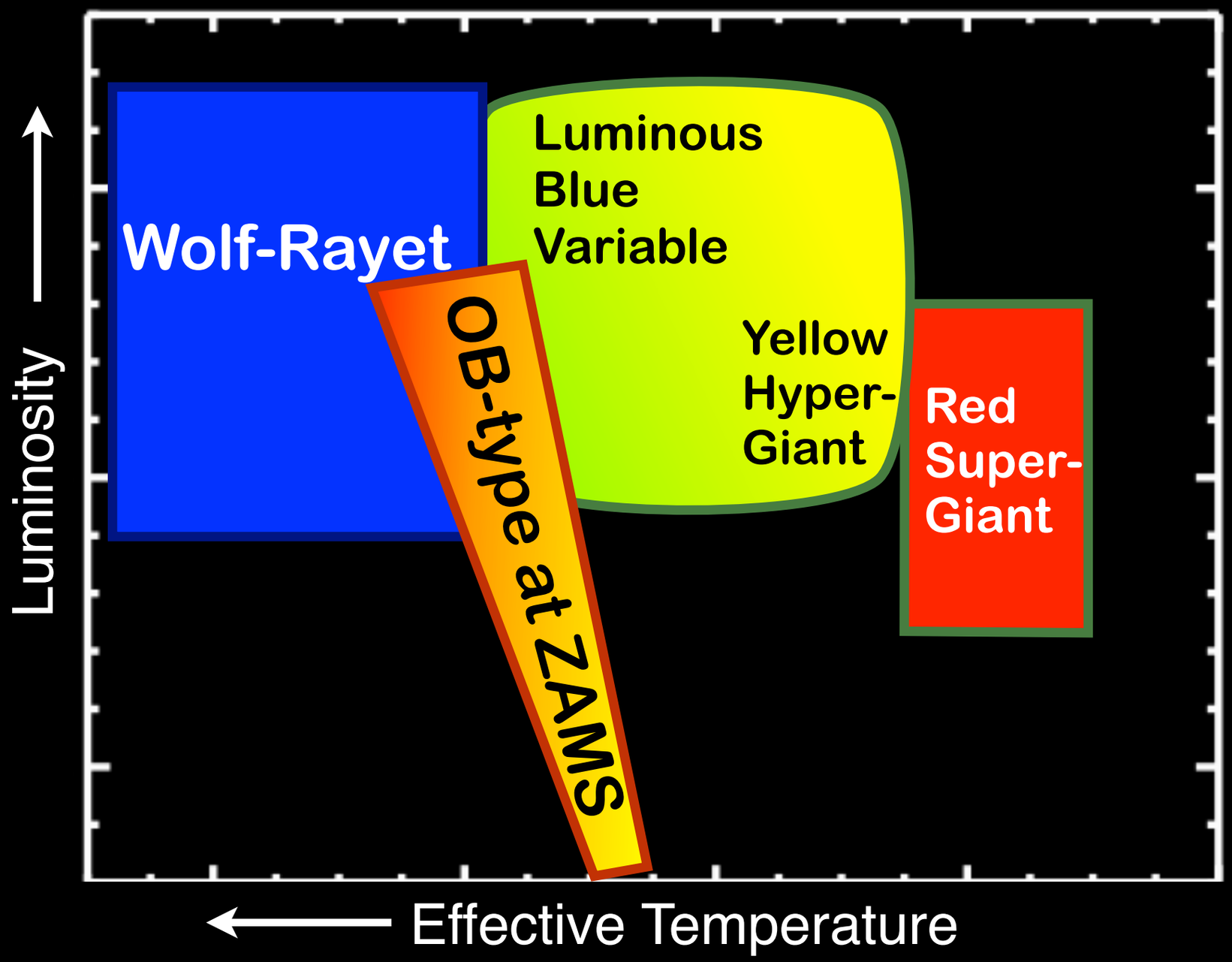

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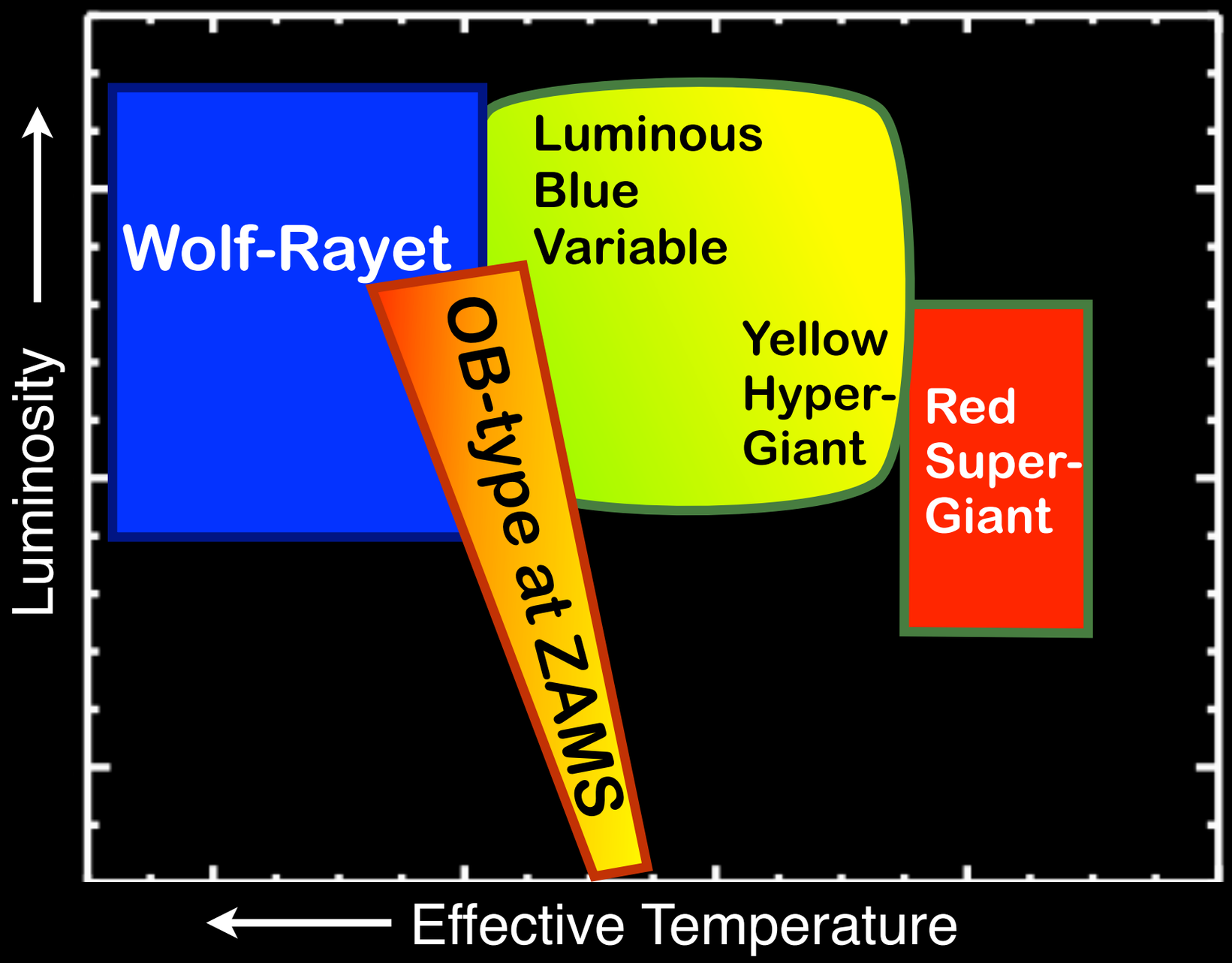

Science we want to do

- Evolutionary channels
- Initial mass ranges
- SN type + progenitor
- Single x binary evol.
- Metallicity effects, ...

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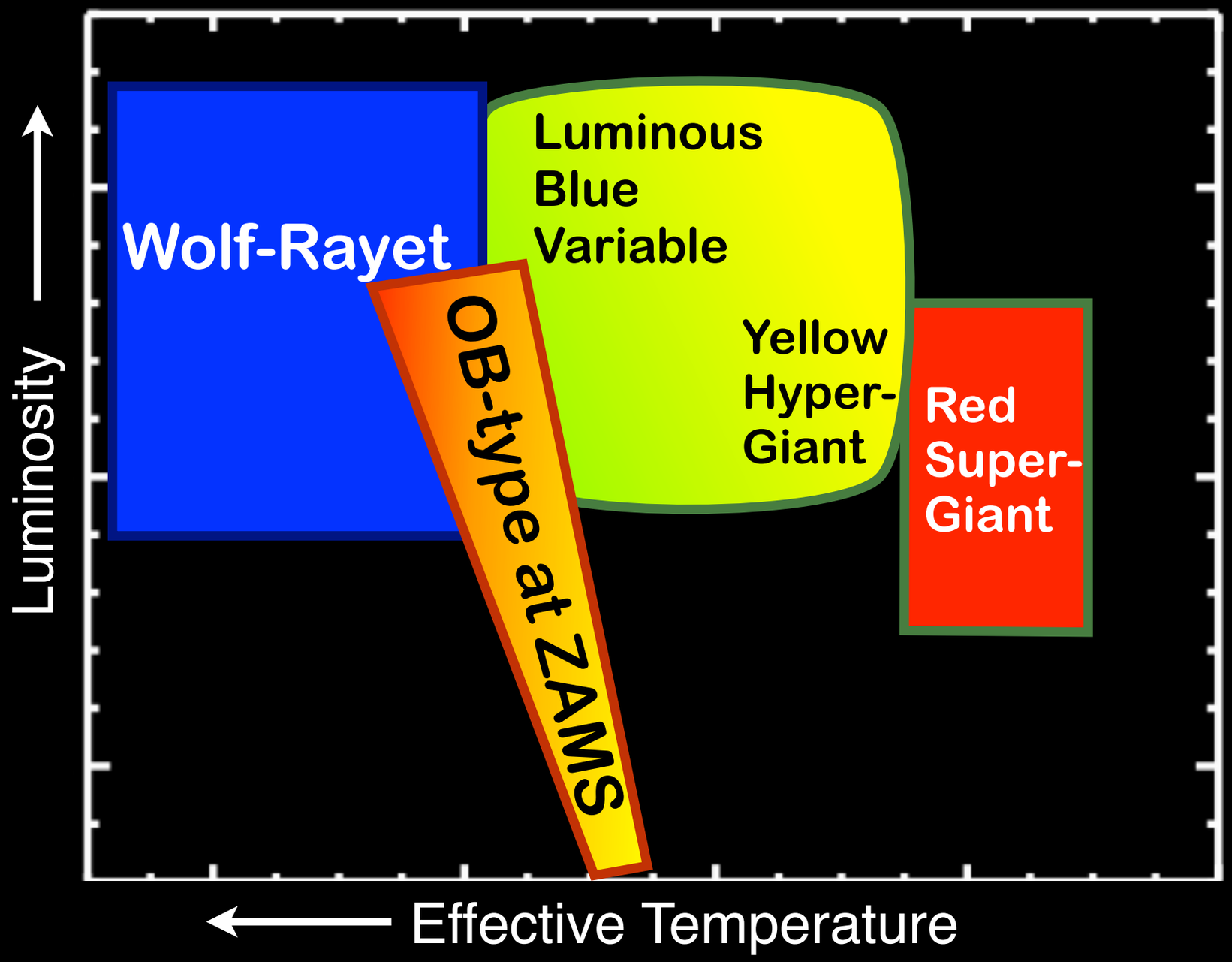

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However

- rarity of massive stars
- mass loss + rotation
- binarity
- models vs. observations

Single stellar evolution models

binaries: de Mink talk

Five flavors

Single stellar evolution models

binaries: de Mink talk

Five flavors

- non-rotating Eldridge talk

Single stellar evolution models

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- non-rotating Eldridge talk
- differential rotation (NO MAGNETIC FIELDS)

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Leitherer talk; Levesque talk

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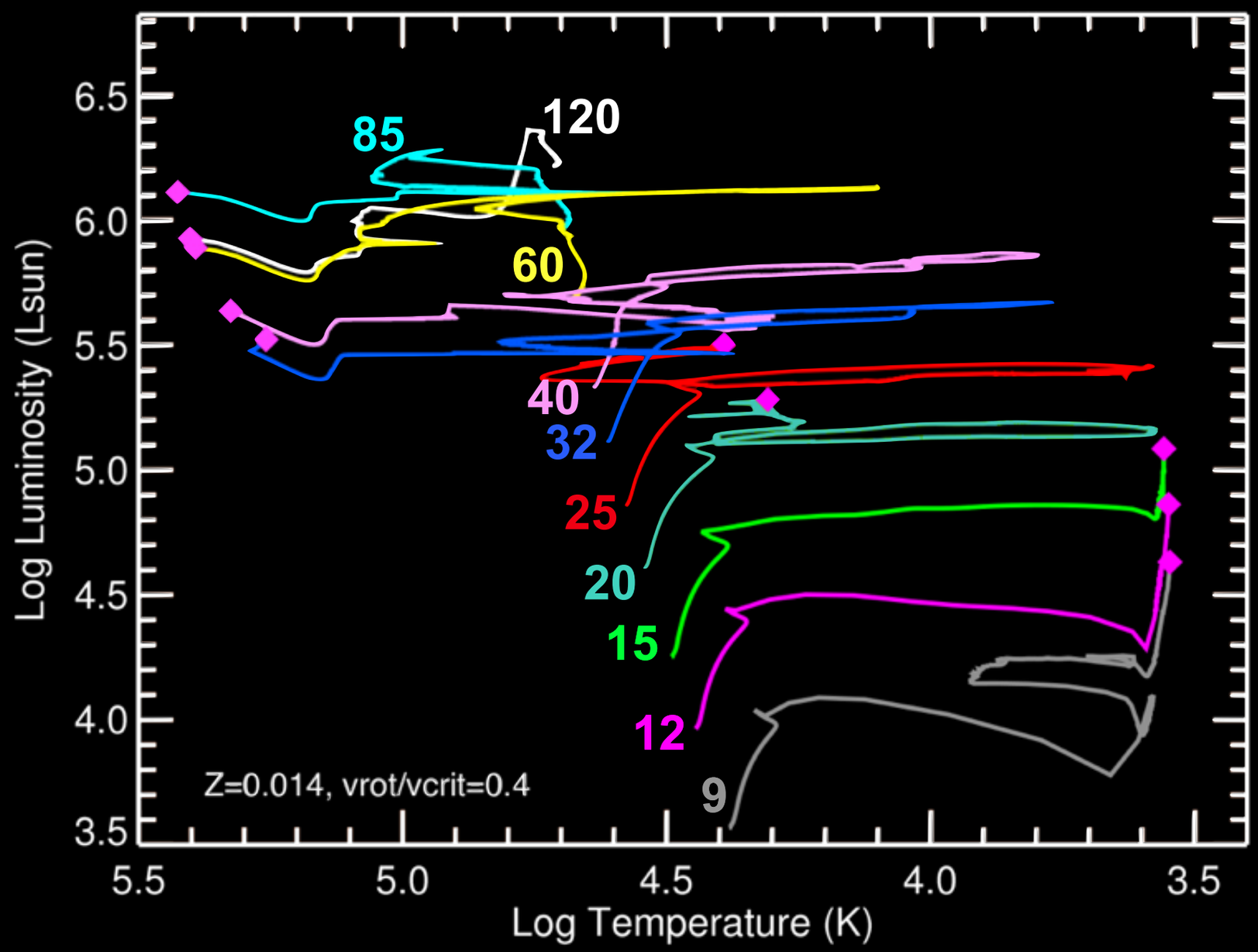
Observational constraints are key

- asteroseismology: differential x solid-body rotation
- spectroscopy+polarimetry: rotation and magnetic fields
- Metallicity dependence?

Rotating massive star evolution models at solar metallicity

Z=0.014



(Groh+ 13b after Ekstrom+12, Georgy+ 12)

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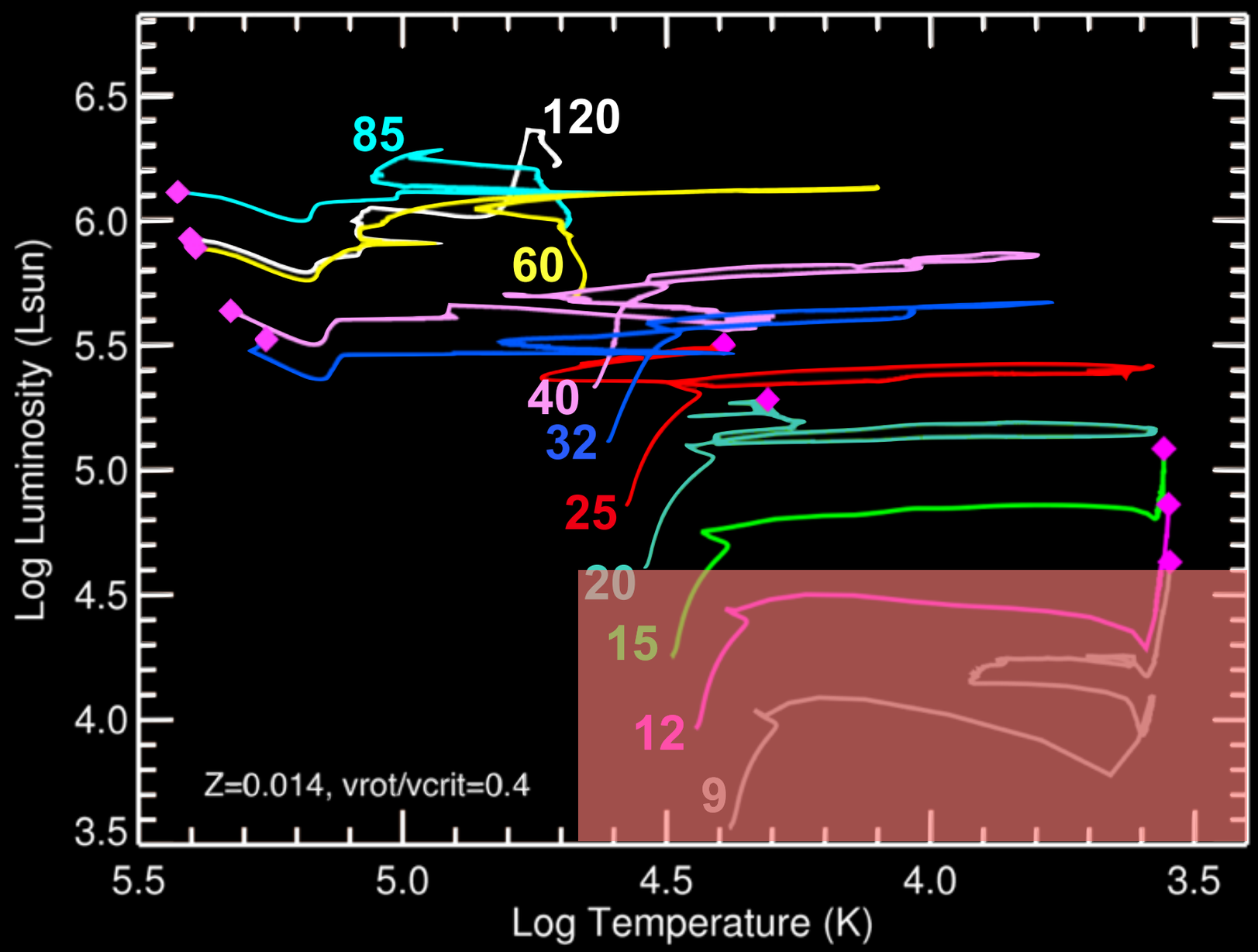

~8 to 17 $M_\odot$

(Groh+ 13b after Ekstrom+12, Georgy+ 12)

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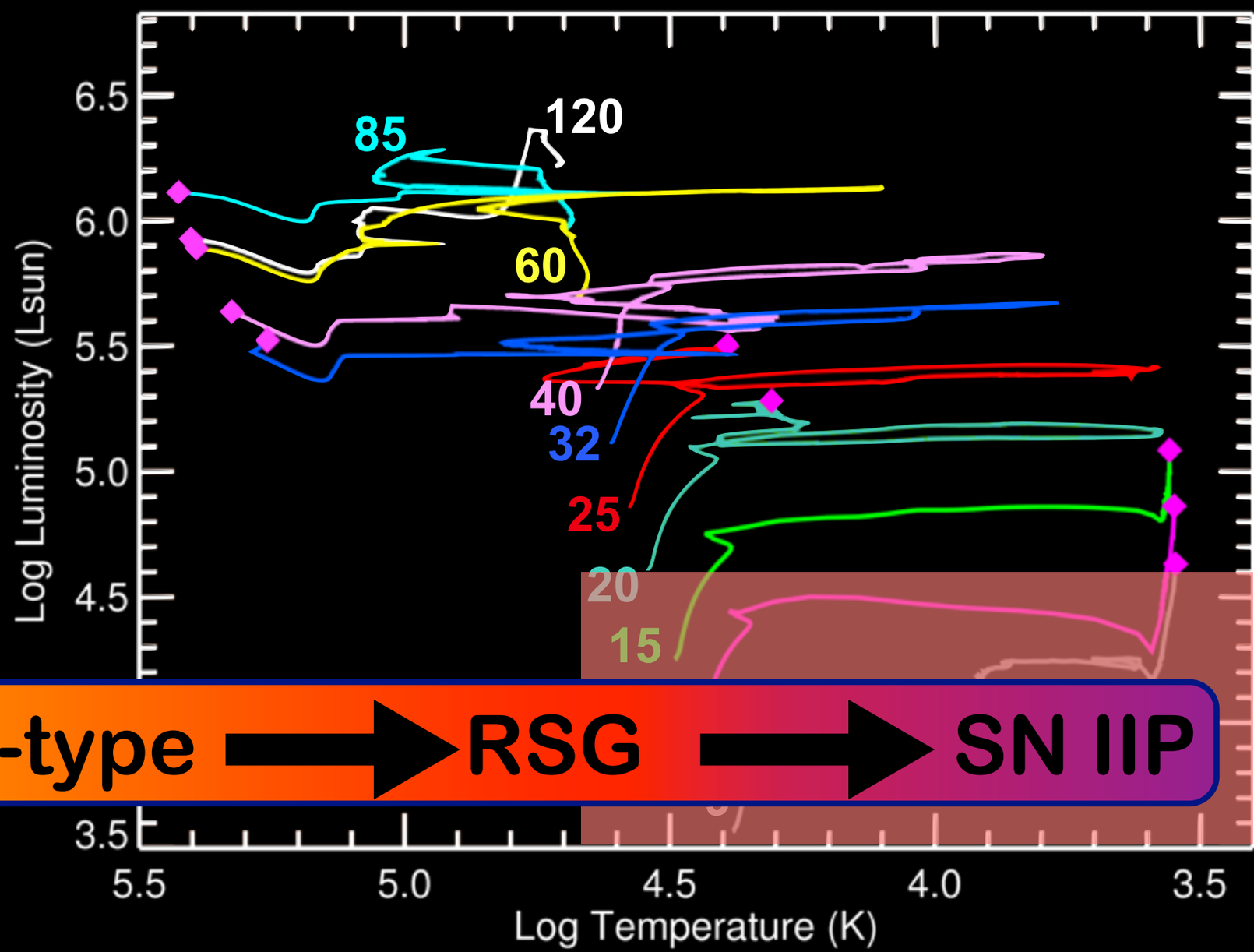

OB-type → RSG → SN IIP

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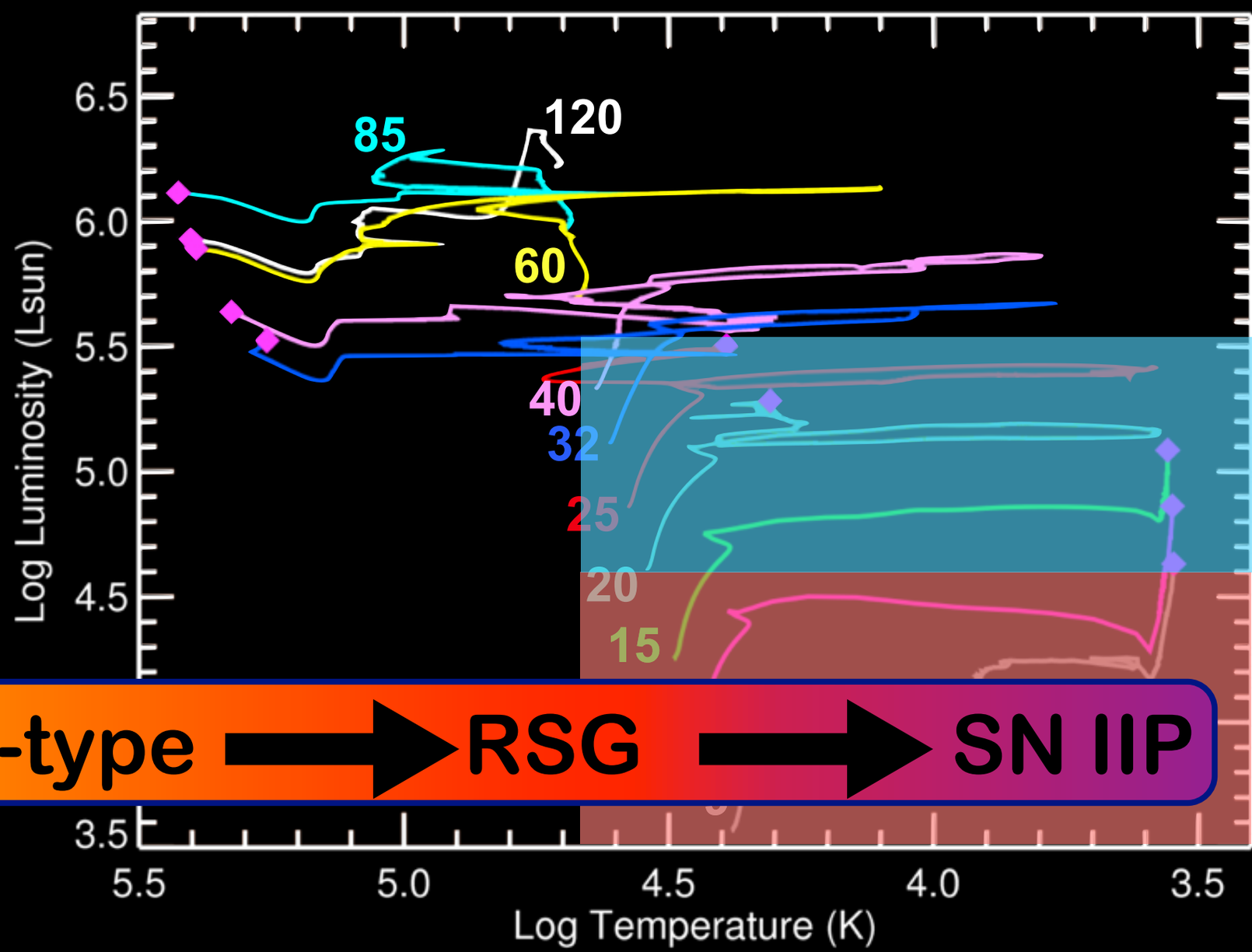

OB-type → RSG → SN IIP

~17 to 30 $M_\odot$

~8 to 17 $M_\odot$

(Groh+ 13b after Ekstrom+12, Georgy+ 12)

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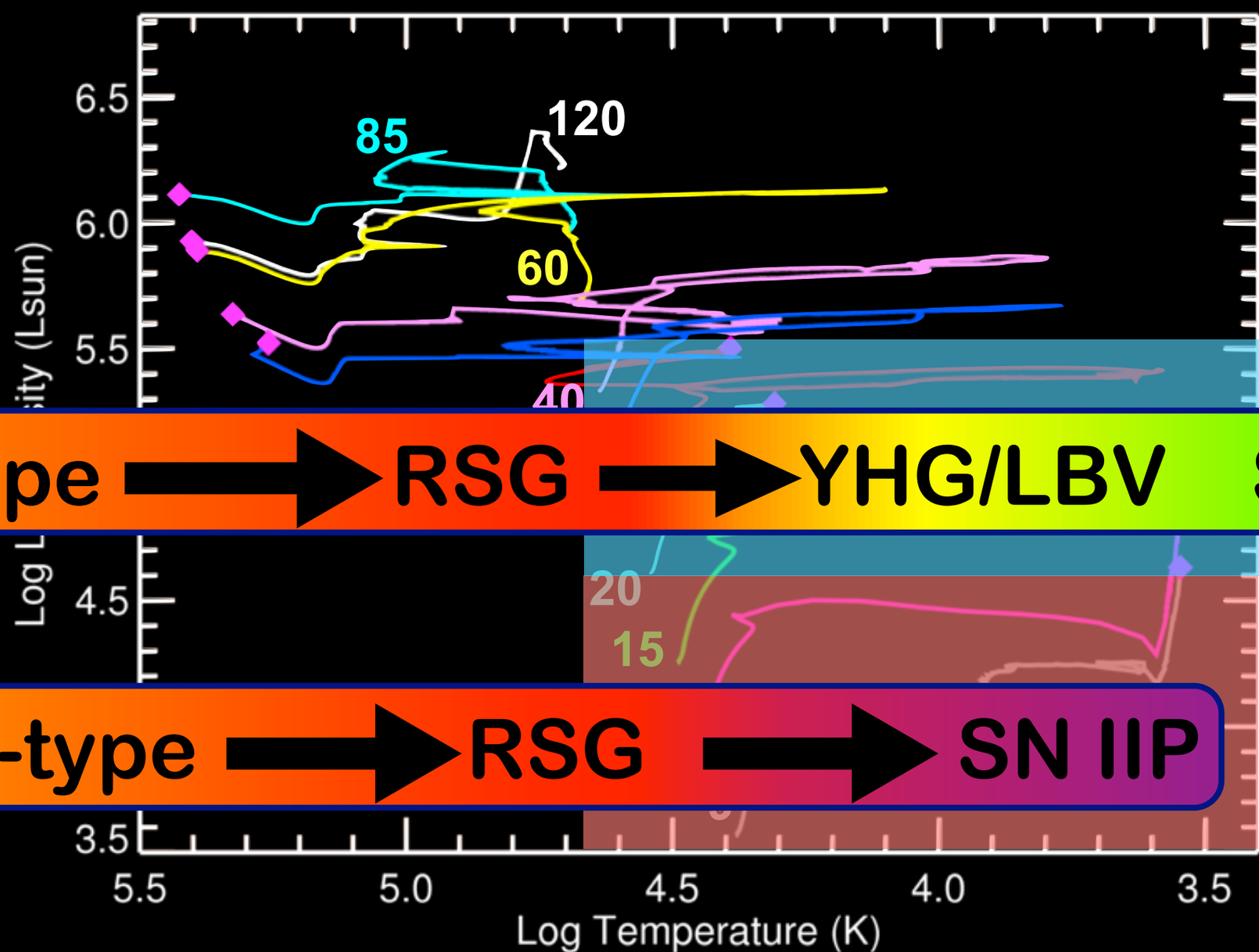

OB-type → RSG → YHG/LBV SN IIL/b

0 $M_\odot$

OB-type → RSG → SN IIP

~8 to 17 $M_\odot$

(Groh+ 13b after Ekstrom+12, Georgy+ 12)

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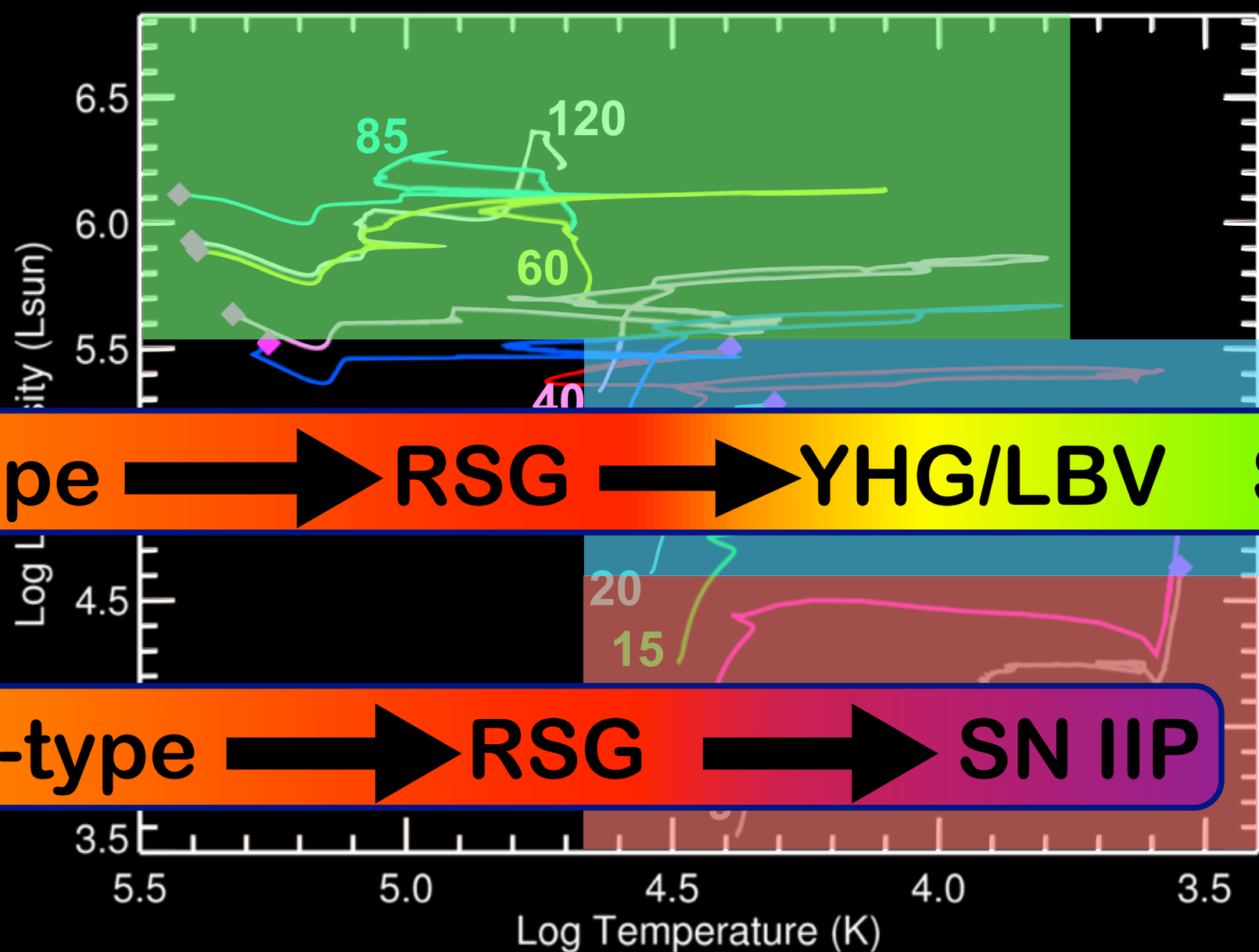

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> ~30 $M_\odot$

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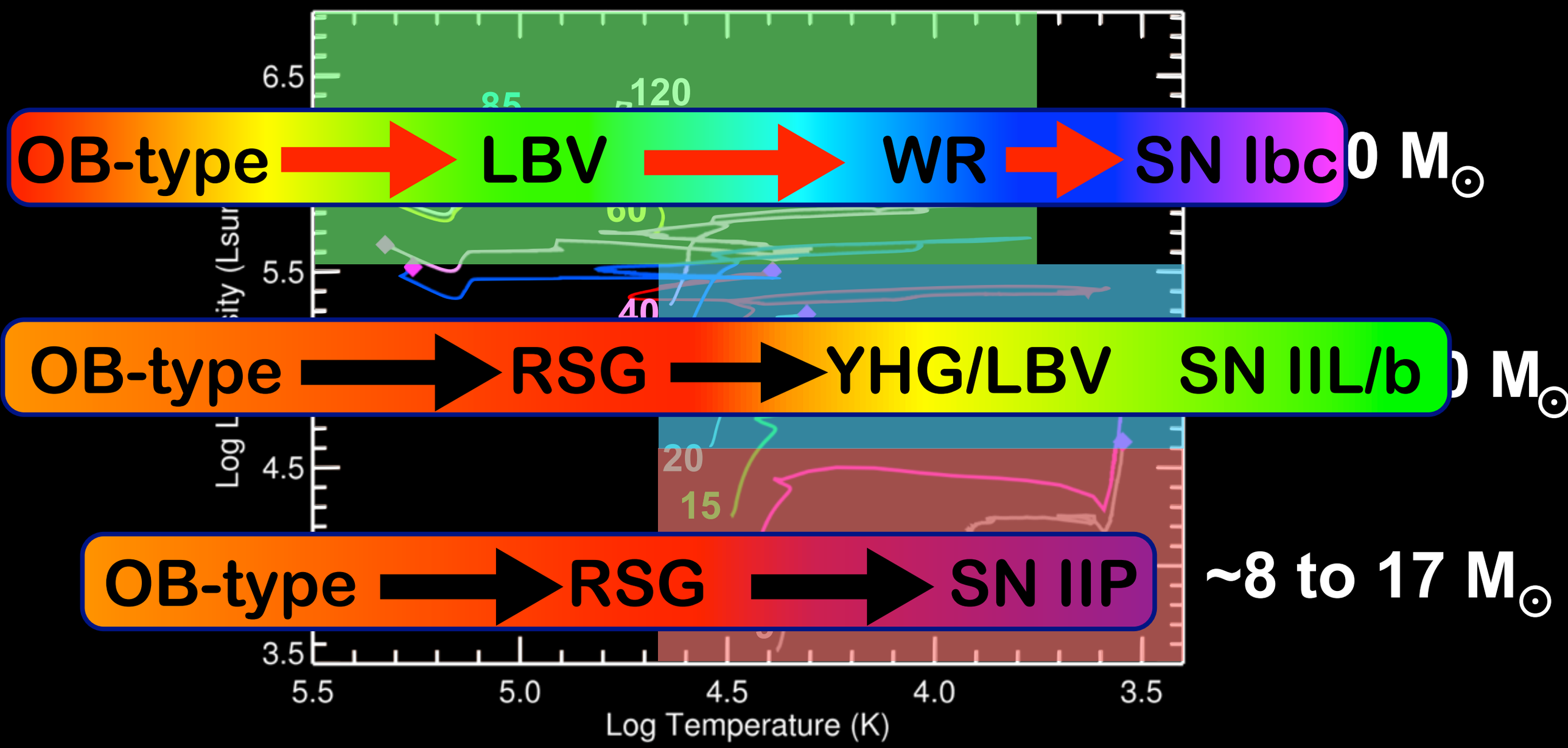

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A change of metallicity affects:

1. Opacities

2. Equation of state (via mean molecular weight)

3. Nuclear reaction rates

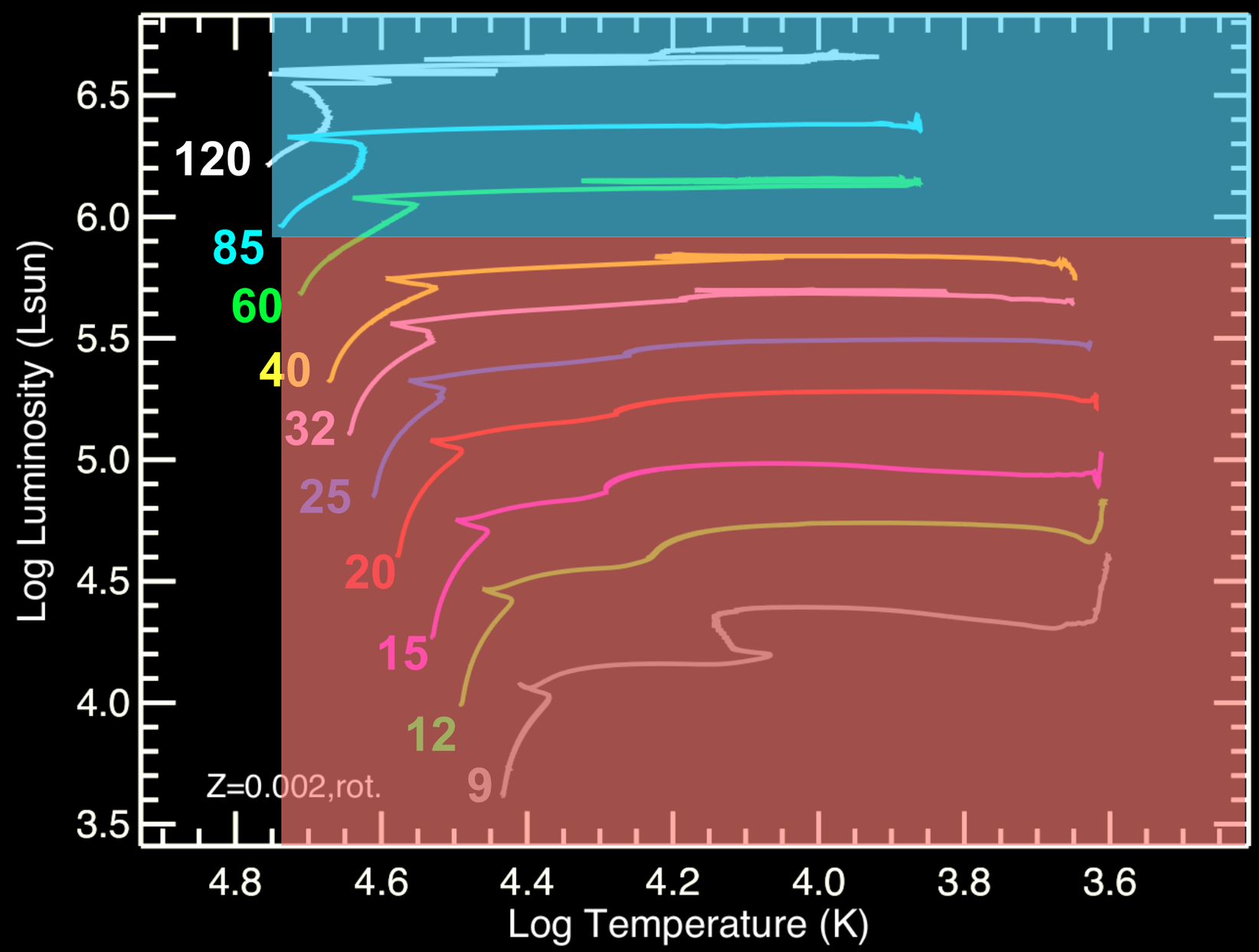
4. Fuel available during MS ($X = 1 - Y - Z$)

5. Mass and angular momentum losses from stellar winds

6. Rotational effects and angular momentum transport

Rotating massive star evolution models at SMC metallicity

Z=0.002 (i.e. 1/7 Zsun)



>50 $M_\odot$

8 to 50 $M_\odot$

(Groh+ 15 in prep after tracks from Georgy+ 13)

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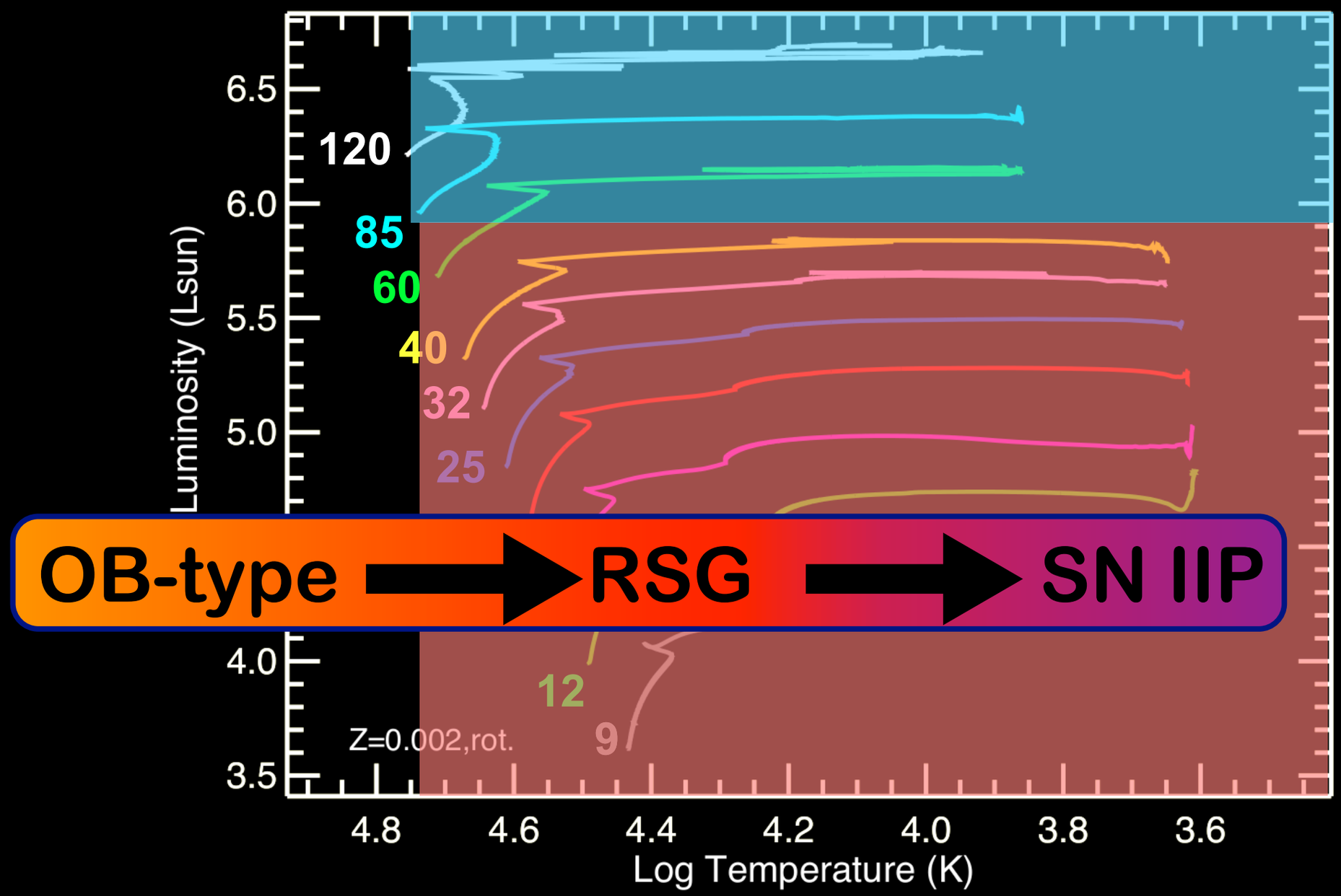

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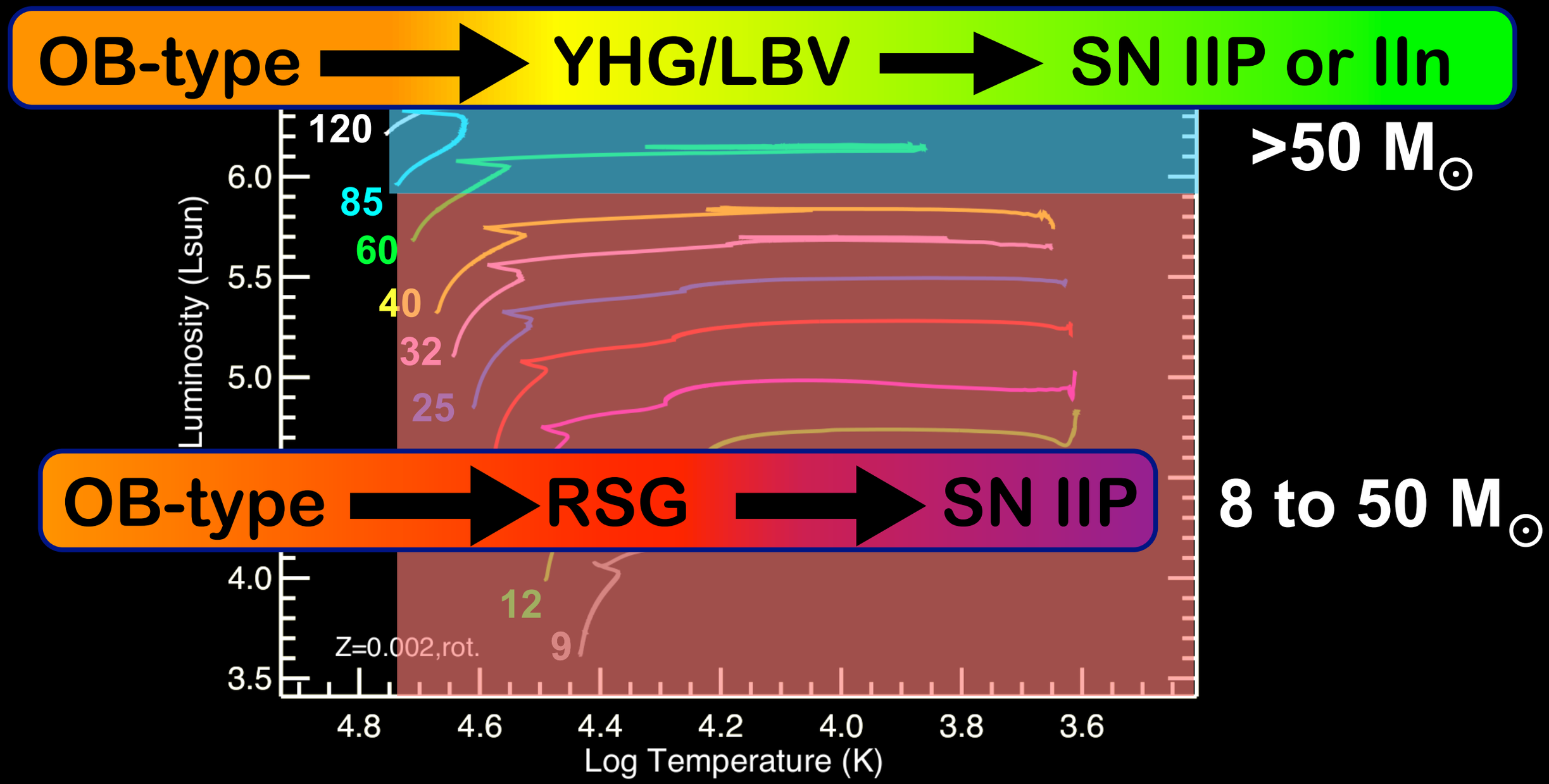

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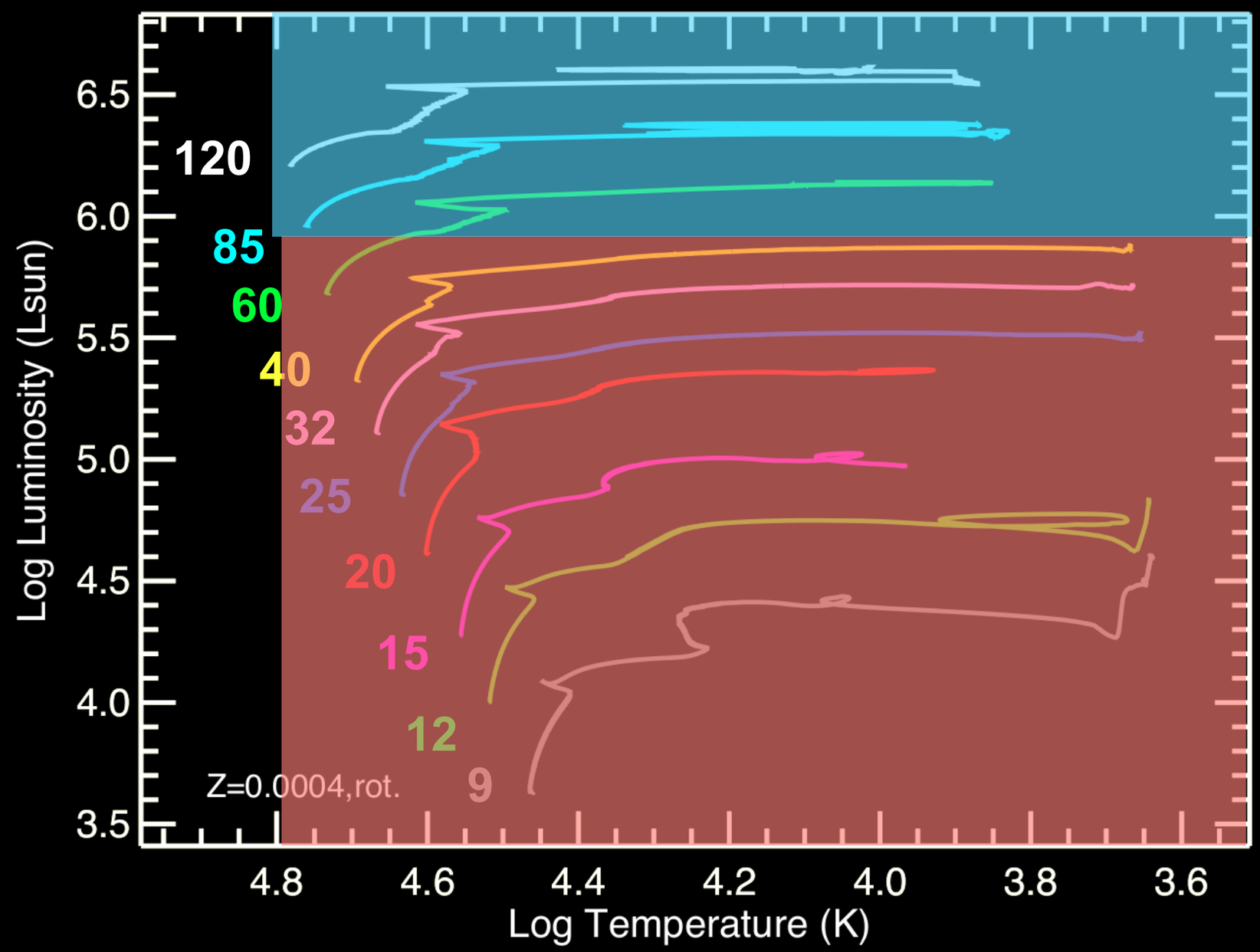
Rotating massive star evolution models at ~ IZw18 metallicity

Z=0.0004 (i.e. 1/50 Zsun)



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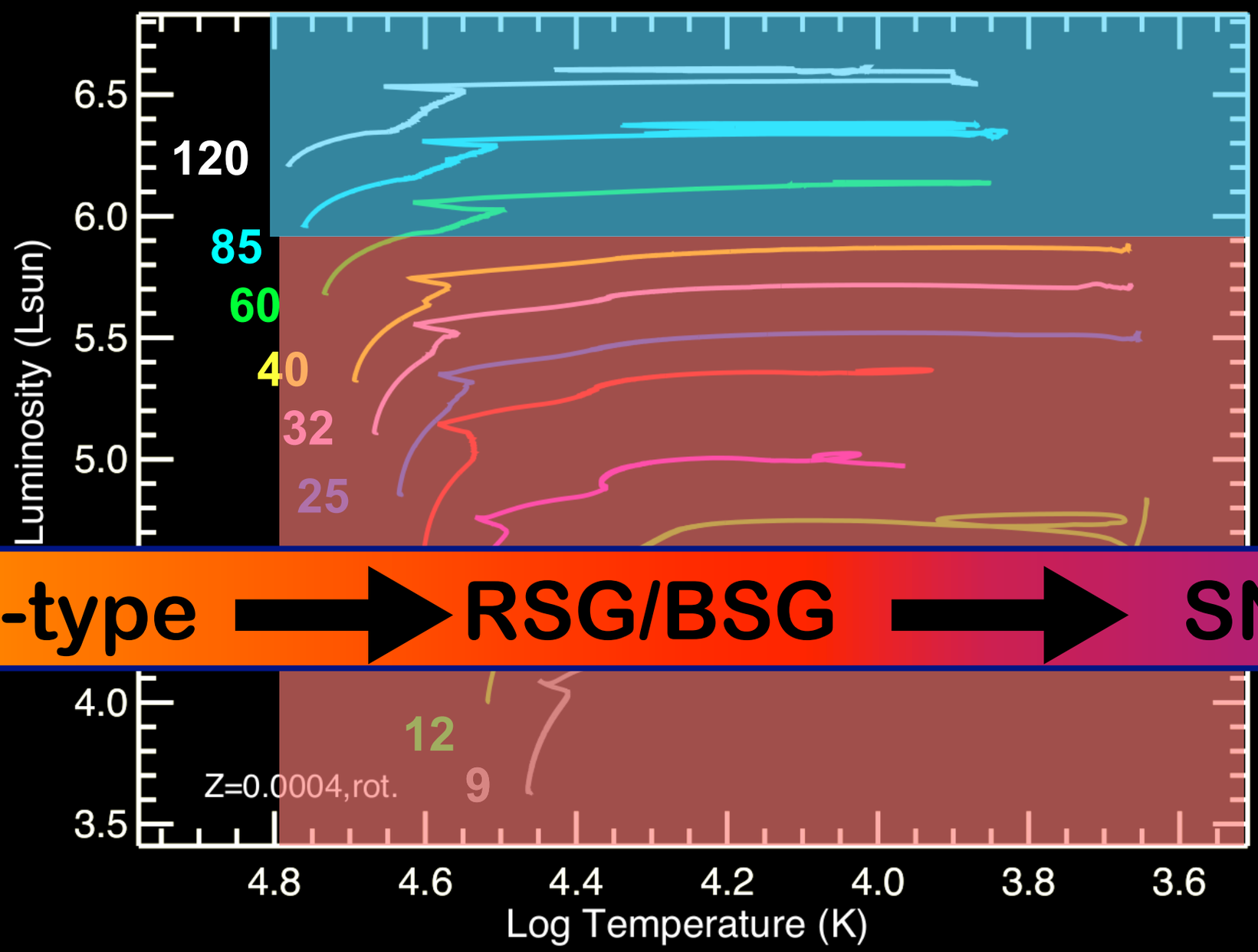

>50 $M_\odot$

OB-type → RSG/BSG → SN IIP

$M_\odot$

(Groh+ 2015 in prep)

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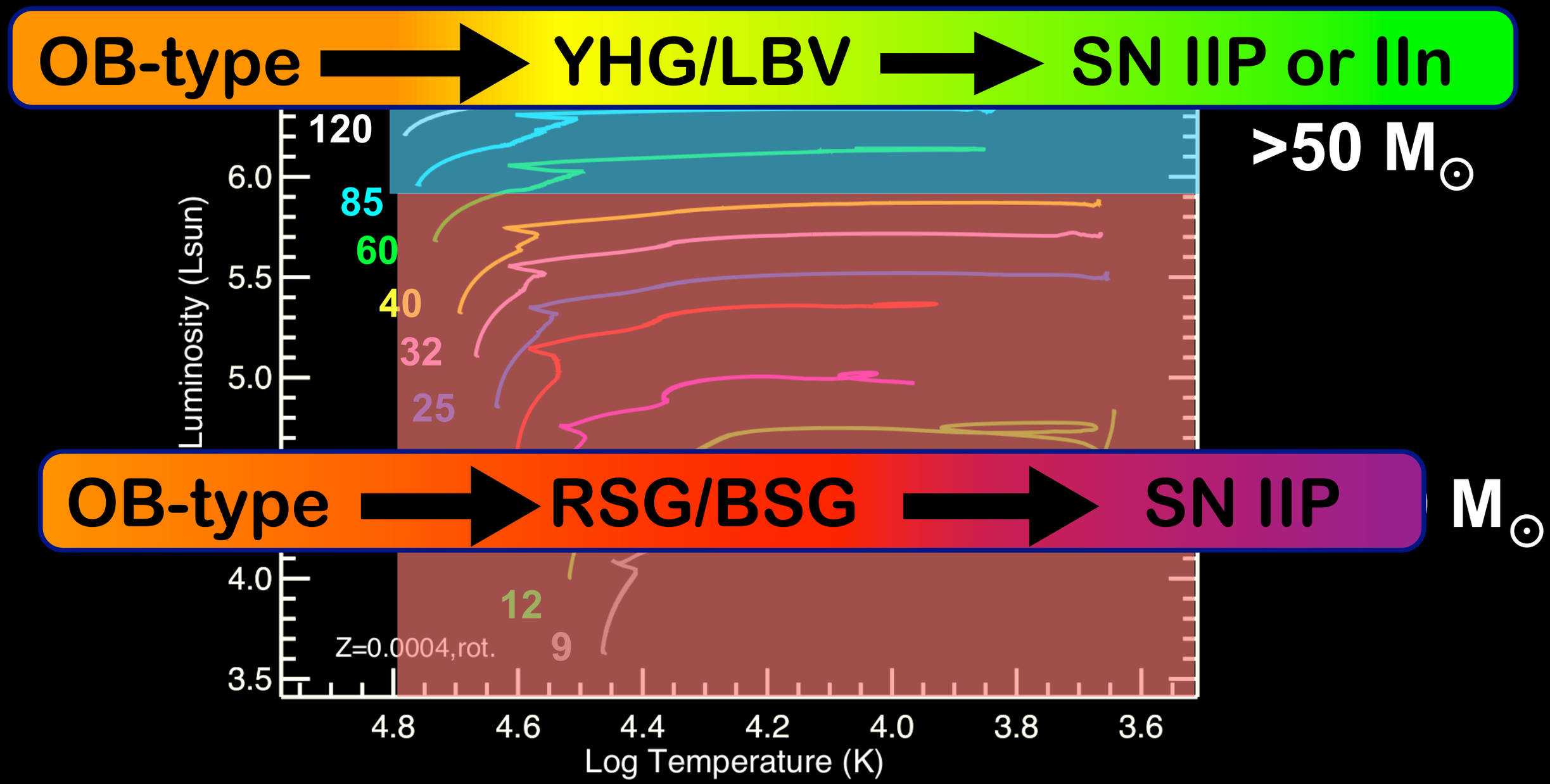

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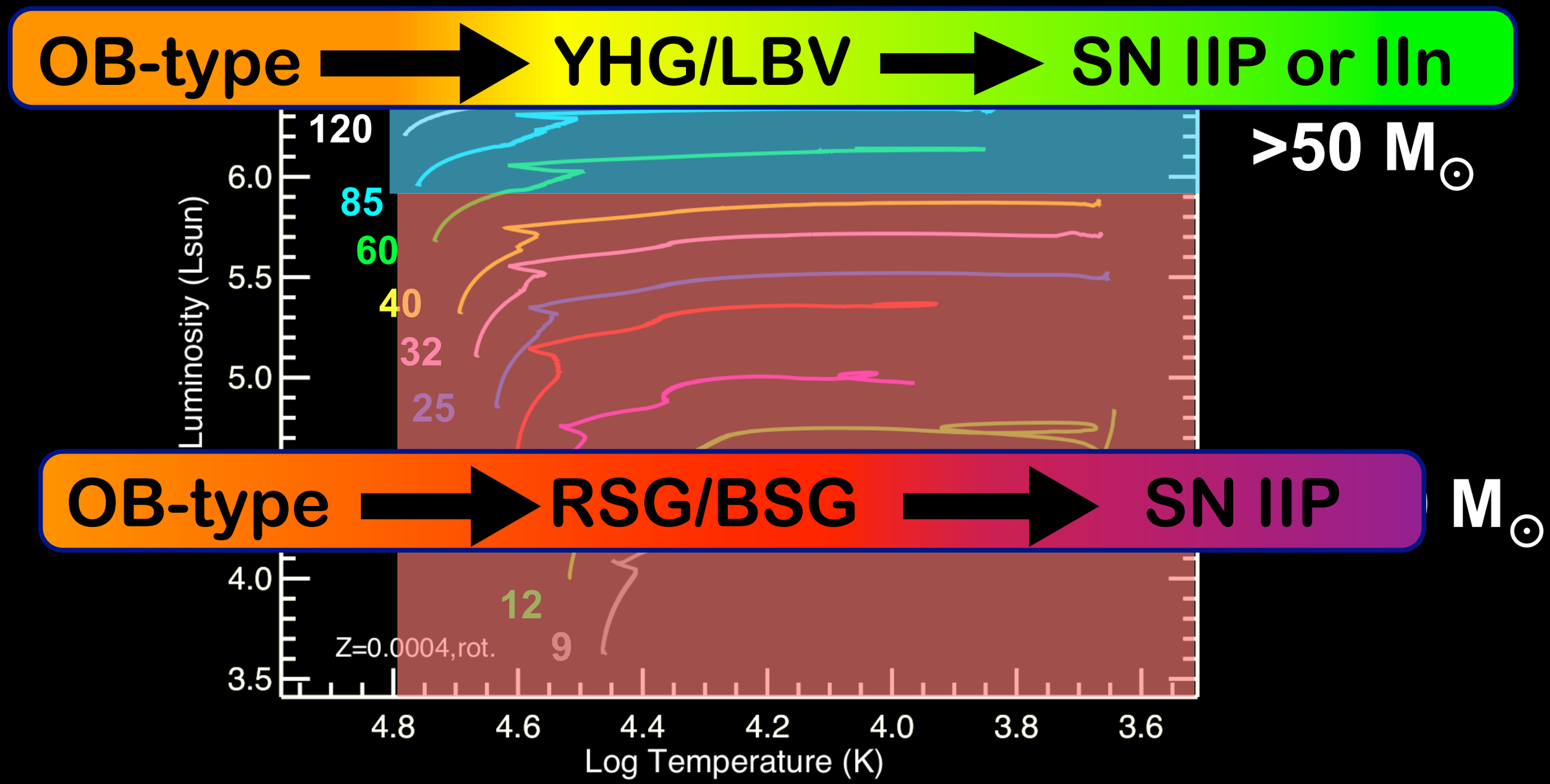
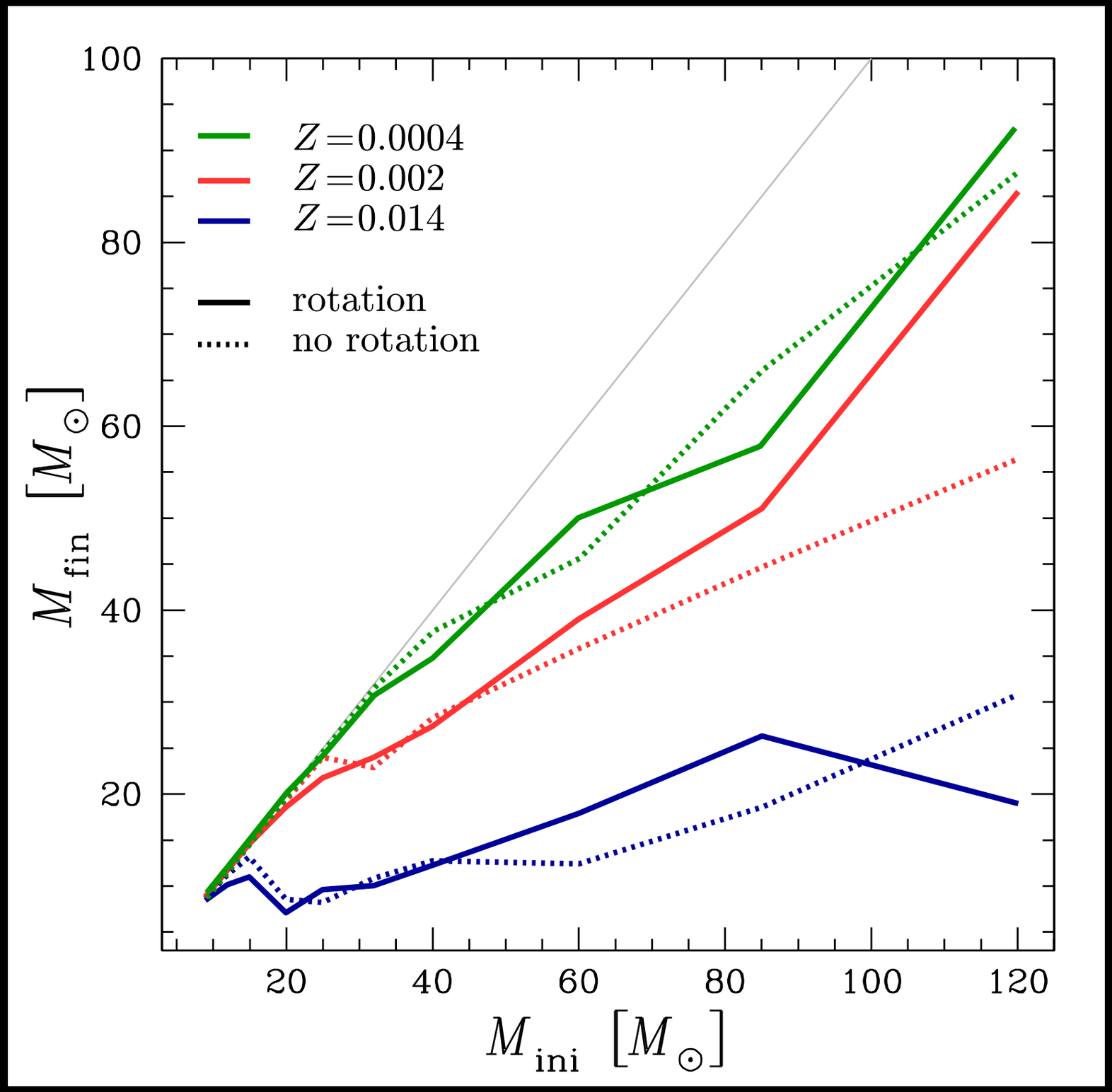


(Groh+ 2015 in prep)

Stars reach the RSG phase only at late times: less RSGs

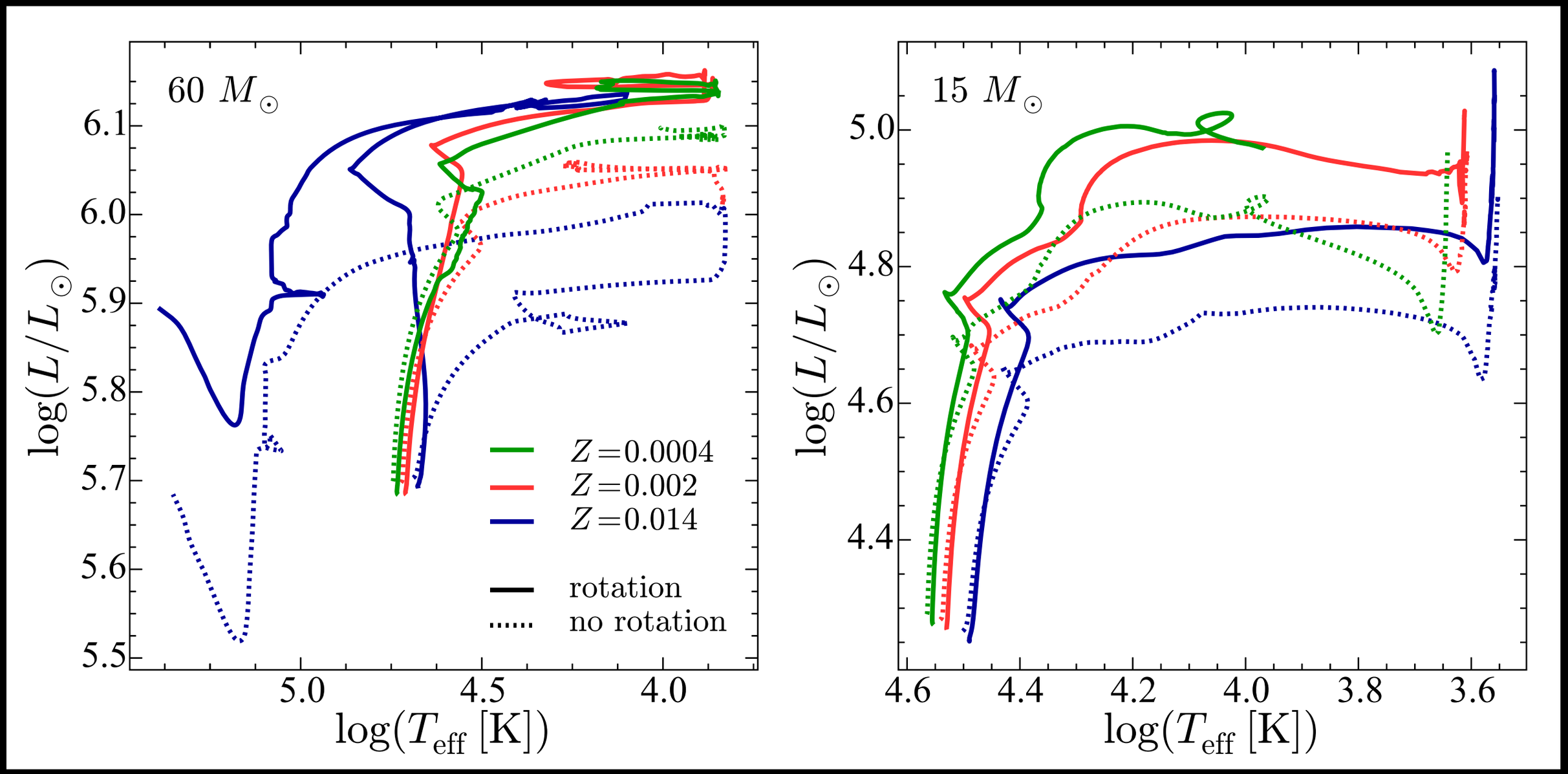
Metallicity trends in stellar evolution

Low metallicity: mass loss diminishes



Groh+ 2015, in prep

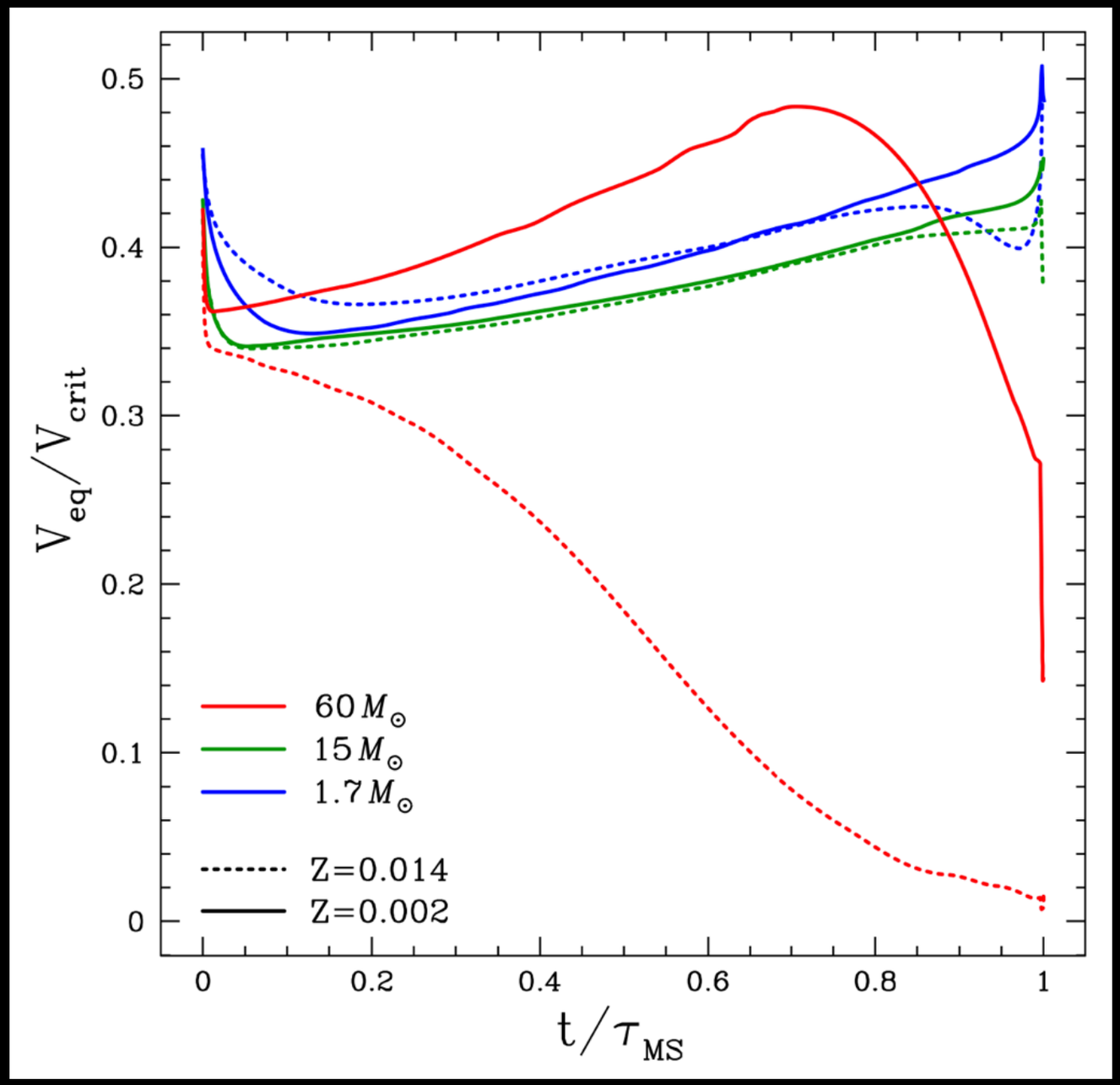
Low metallicity: stars are more compact and hotter



Groh+ 2015, in prep

Low metallicity: faster surface rotation

For high mass stars:
Reduced mass and angular momentum losses from stellar winds

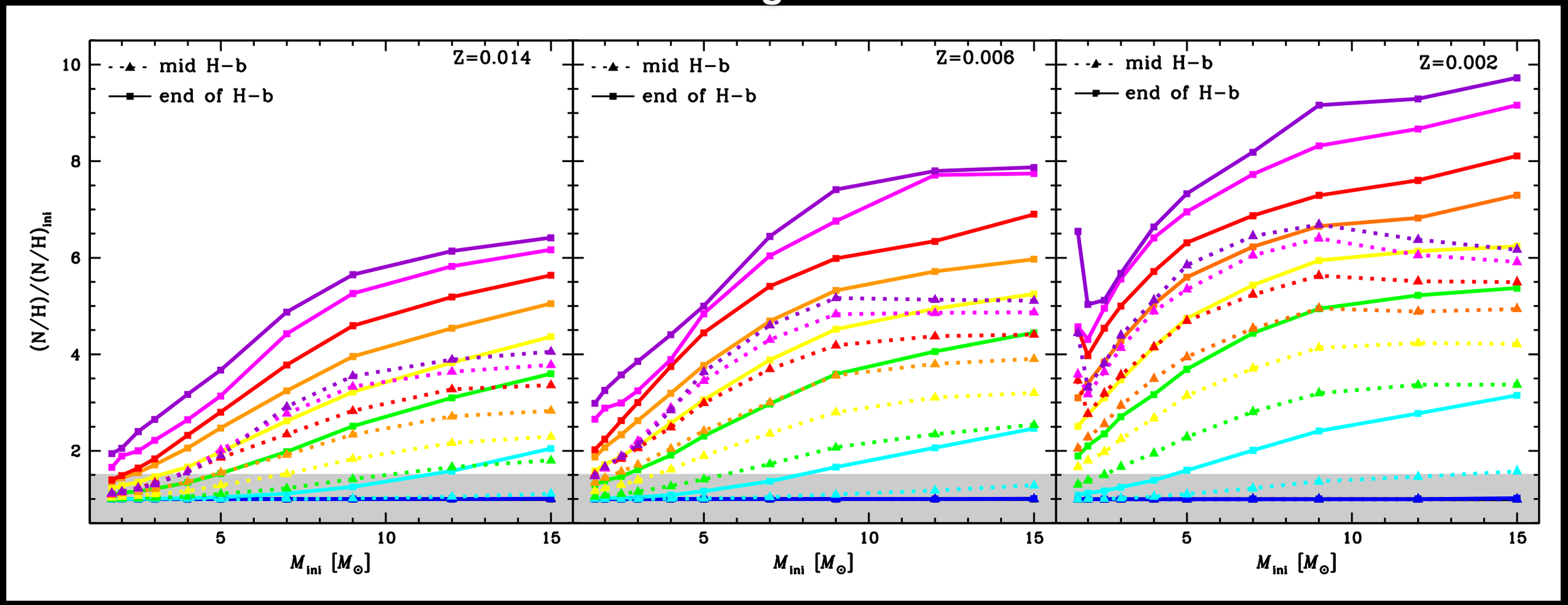


Georgy+ 2013

Low metallicity: chemical mixing is favored

At low Z: stars are more compact;
transport of angular momentum is less efficient.

Relative Nitrogen enhancement



blue= initial angular velocity Ω/Ωcrit = 0.10

purple= initial angular velocity Ω/Ωcrit = 0.95

Georgy+ 2013

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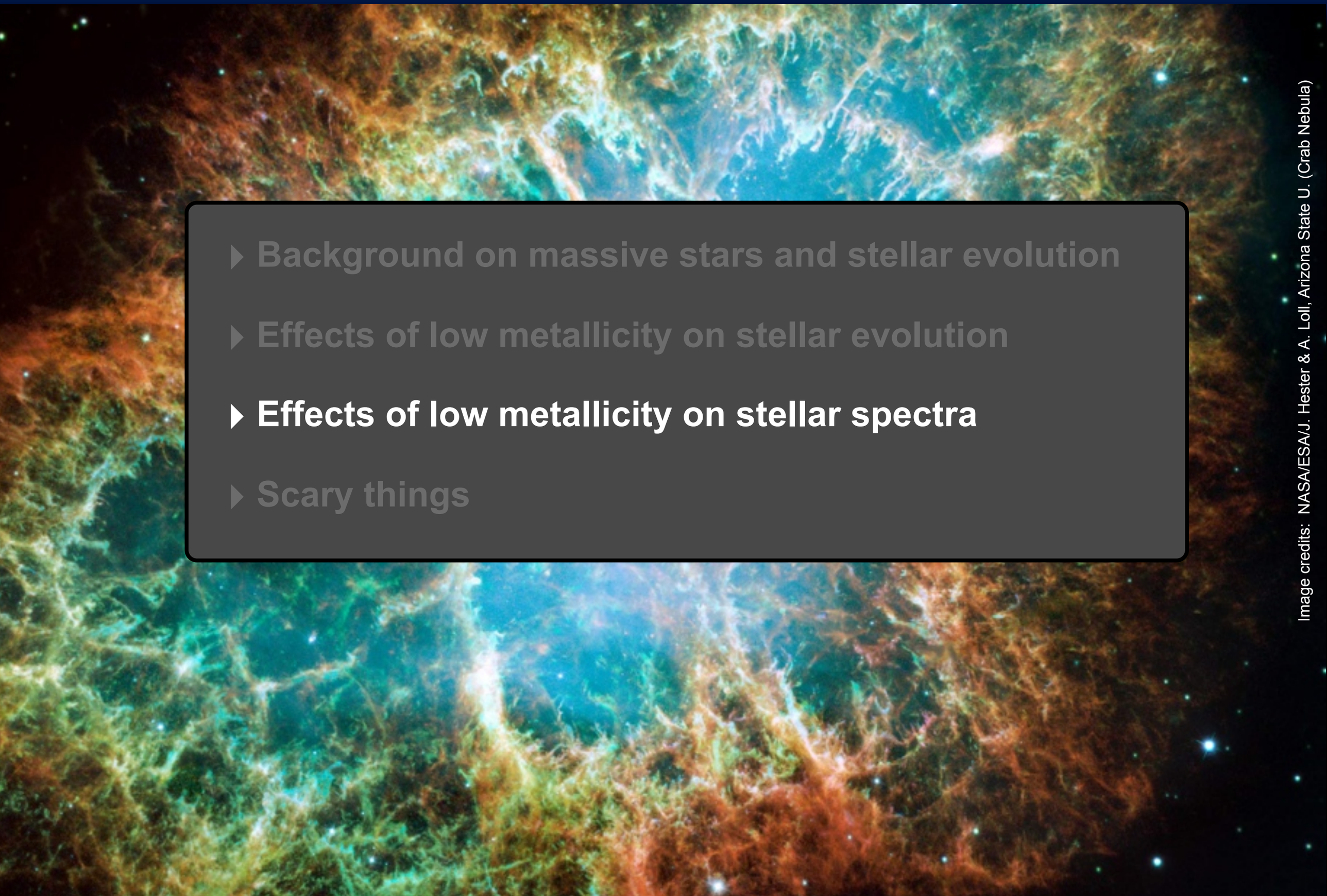

Image credits: NASA/ESA/J. Hester & A. Loll, Arizona State U. (Crab Nebula)

How to compare observations and stellar evolution models?

Issue: massive stars develop winds that become denser as the star evolves, hiding progressively more and more of the stellar surface.

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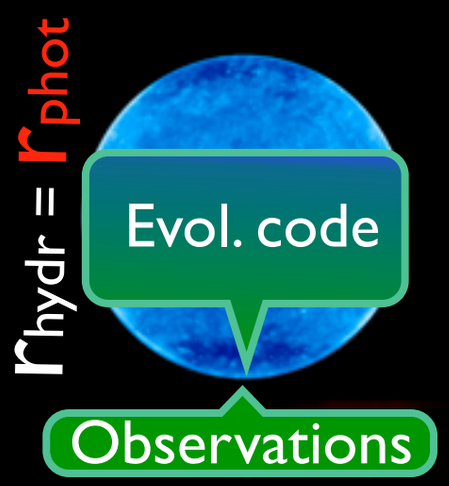
low-mass stars
(e.g Sun)



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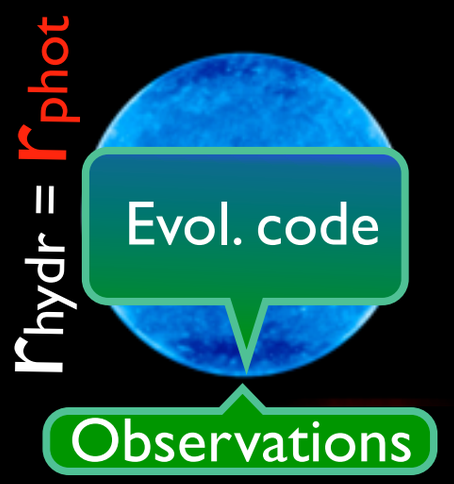
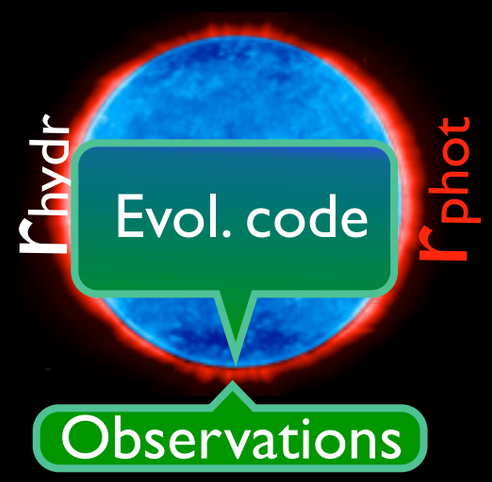


massive stars: low Mdot



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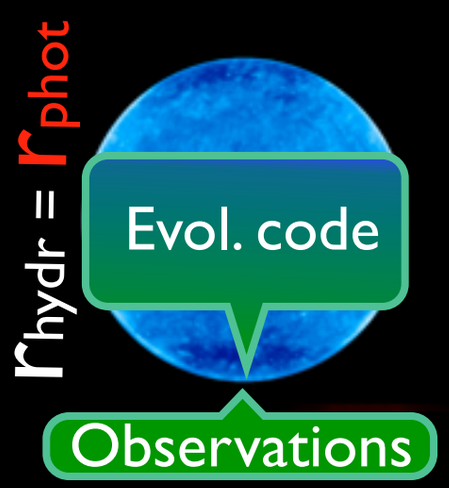

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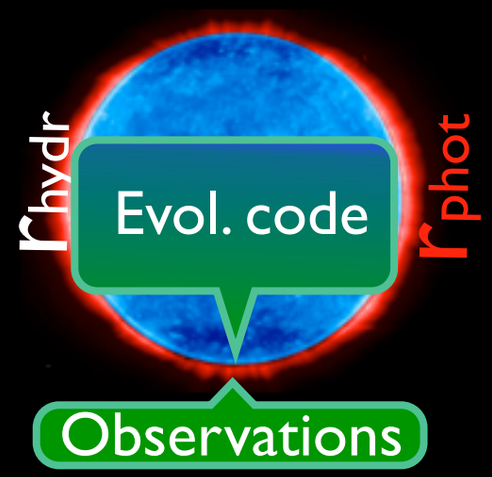
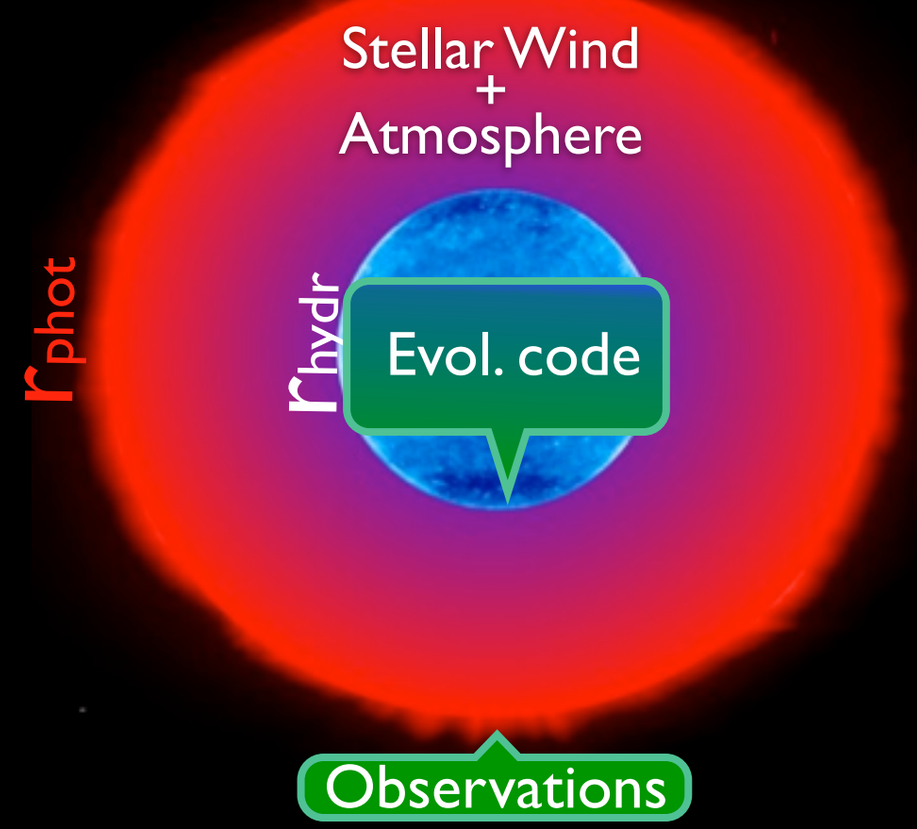


massive stars: high Mdot (evolved)



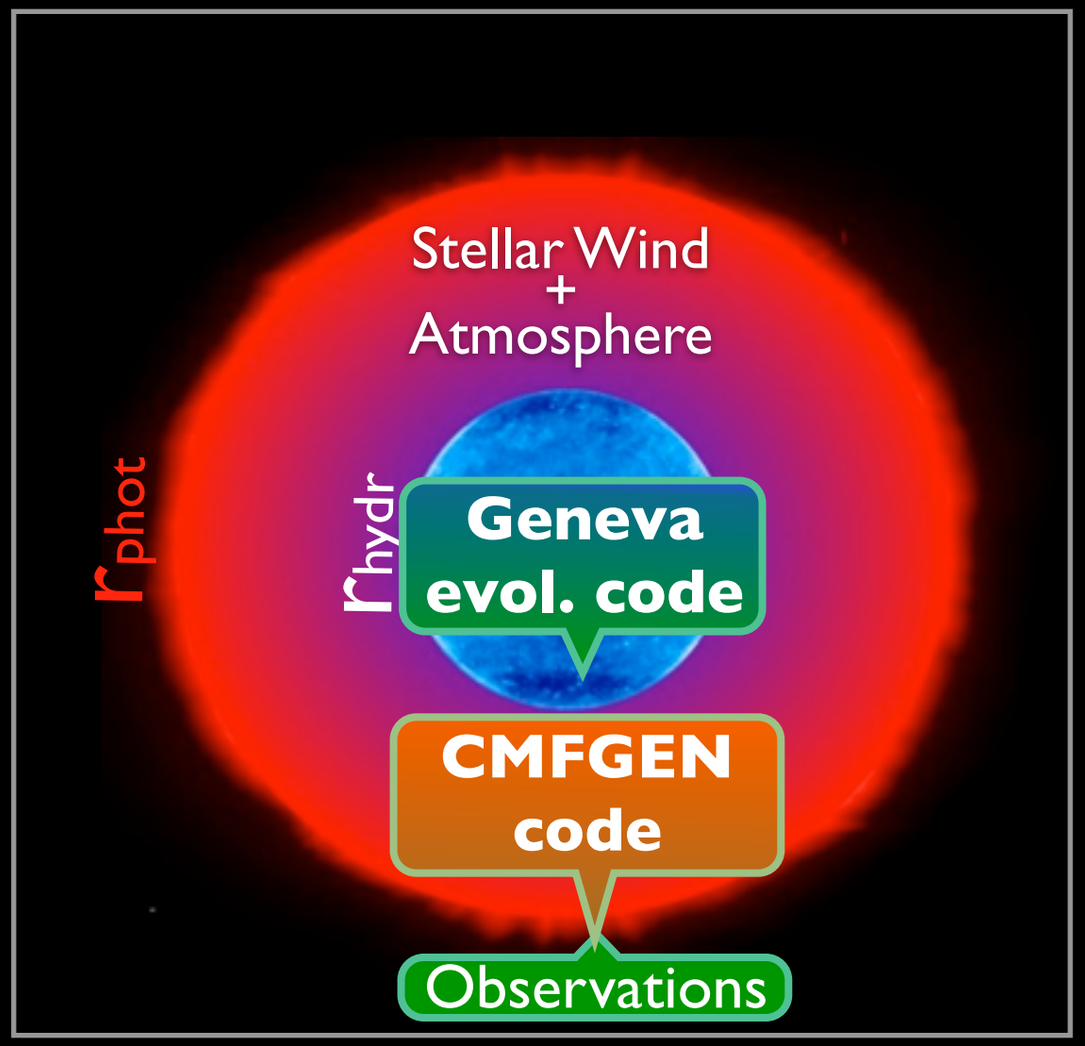
Consequence: challenging to compare interior models of massive stars and observations.

Solution: merge with an atmospheric code

Mass
Luminosity
Temperature
Surface abundances

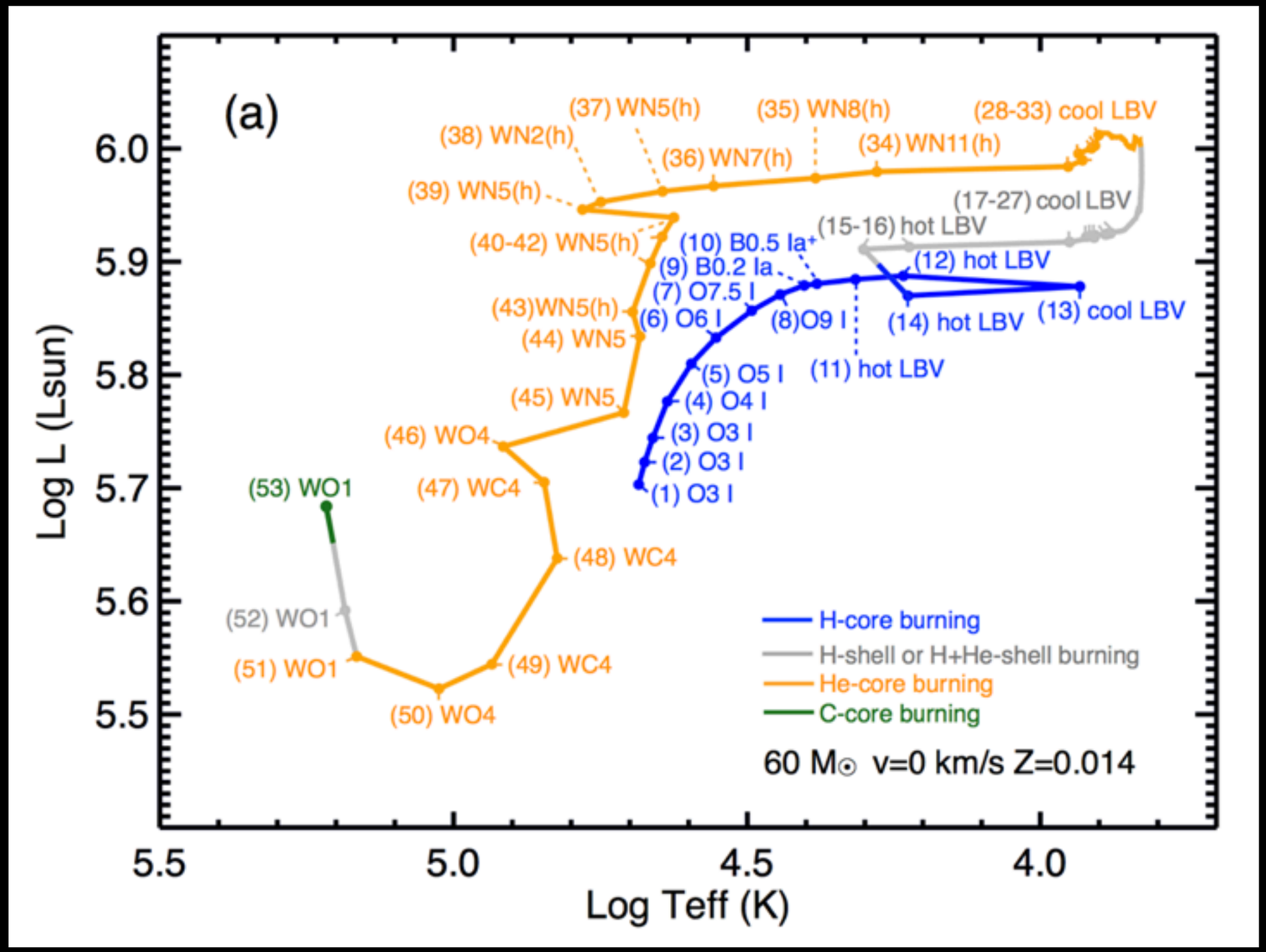
→

Magnitudes
Colors
SED
Spectrum



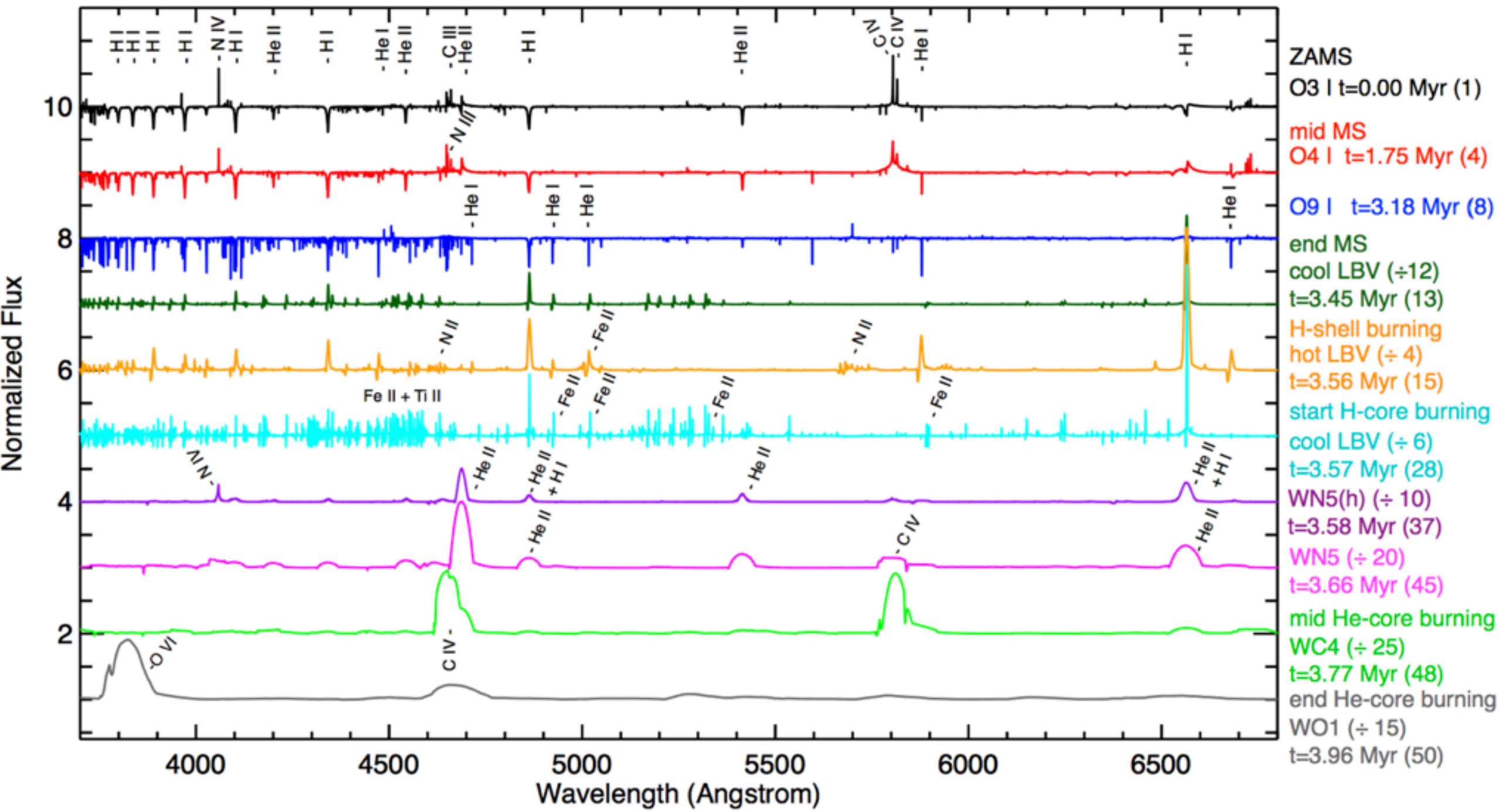
Unified stellar evolution and atmospheric modelling

non-rotating 60 $M_\odot$ at solar Z



Groh+ 2014, A&A 564, 30

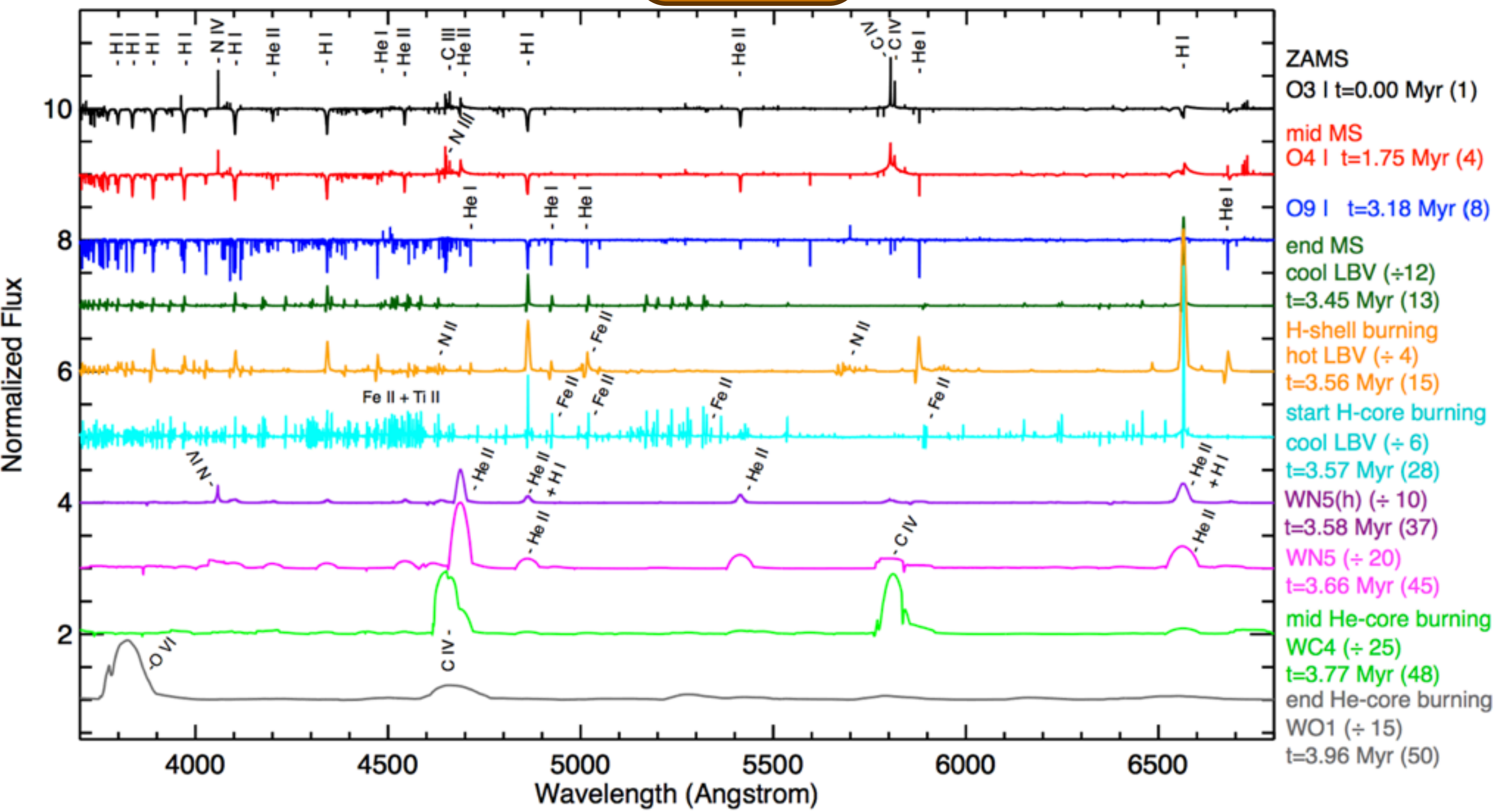
Spectral evolution of a non-rotating 60 Msun star



Groh+ 2014, A&A 564, 30

Spectral evolution of a non-rotating 60 Msun star

Optical



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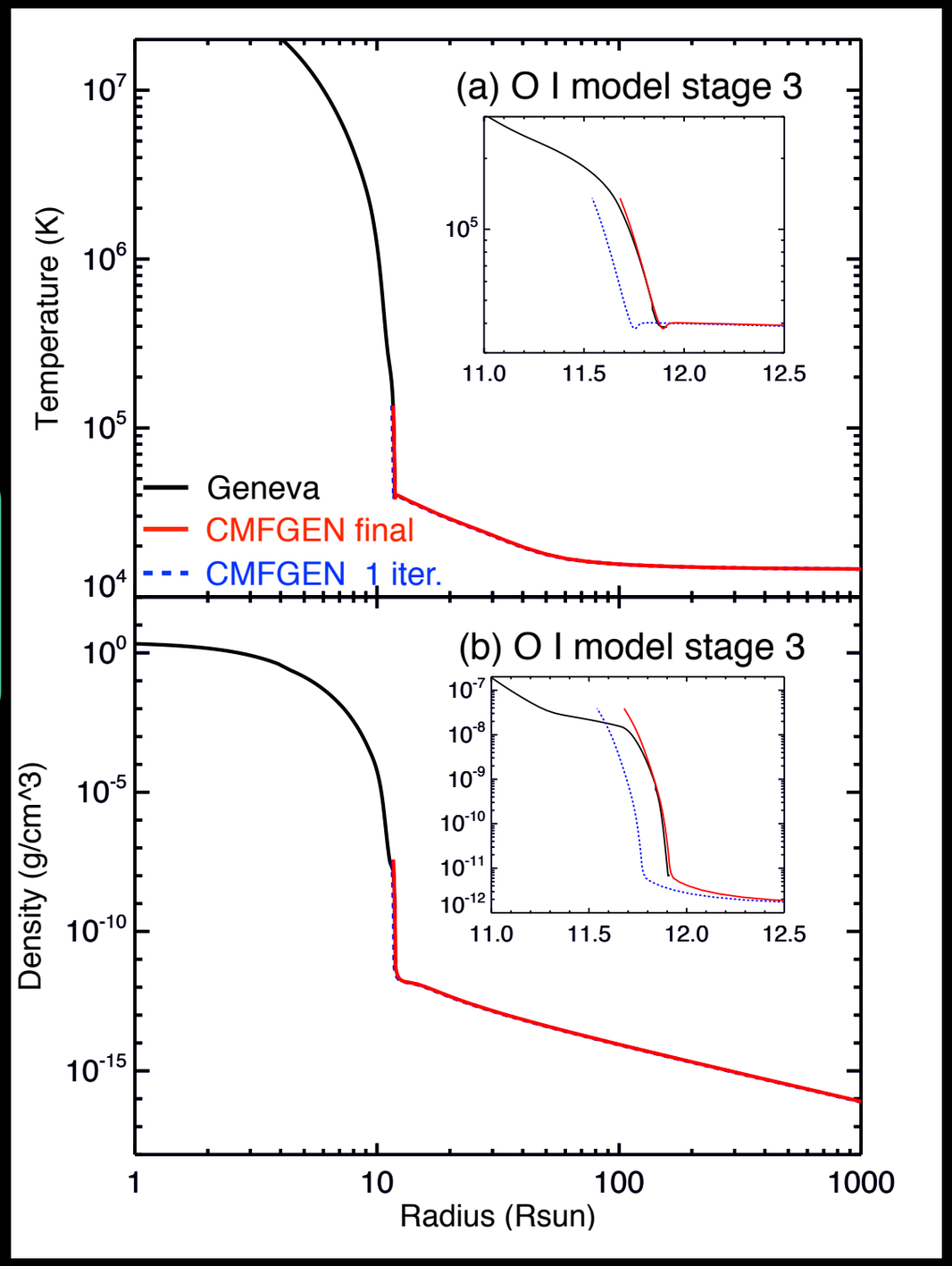
Unified stellar evolution and atmospheric modeling

See also Schaerer+96, Schaerer & de Koter 96

Groh+ 2014

merge T and density structures from stellar evolution and atmospheric codes

+ post-processing on a large grid of models
+ flexibility to study the effects of mass loss
+ effects of line blanketing, wind clumping



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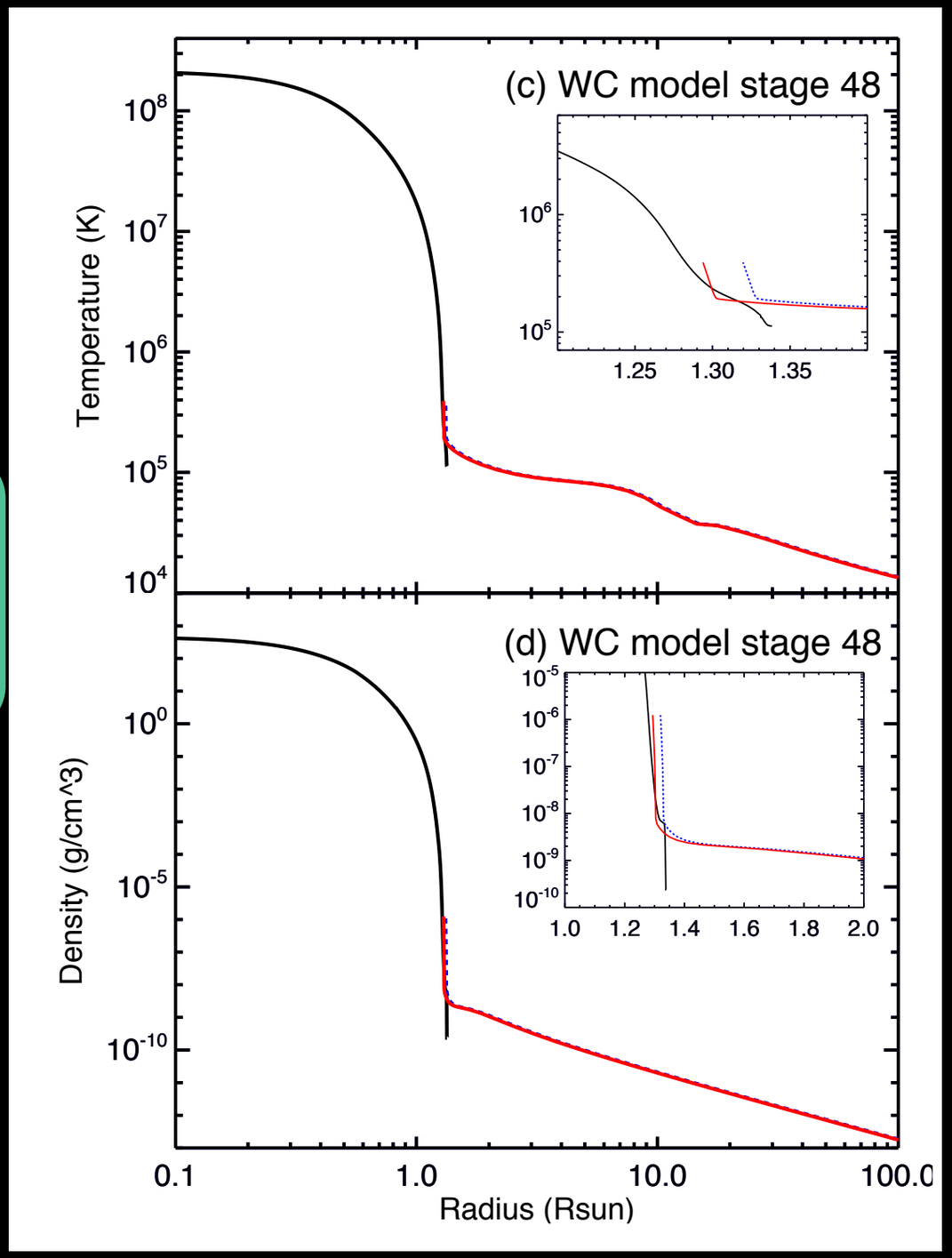

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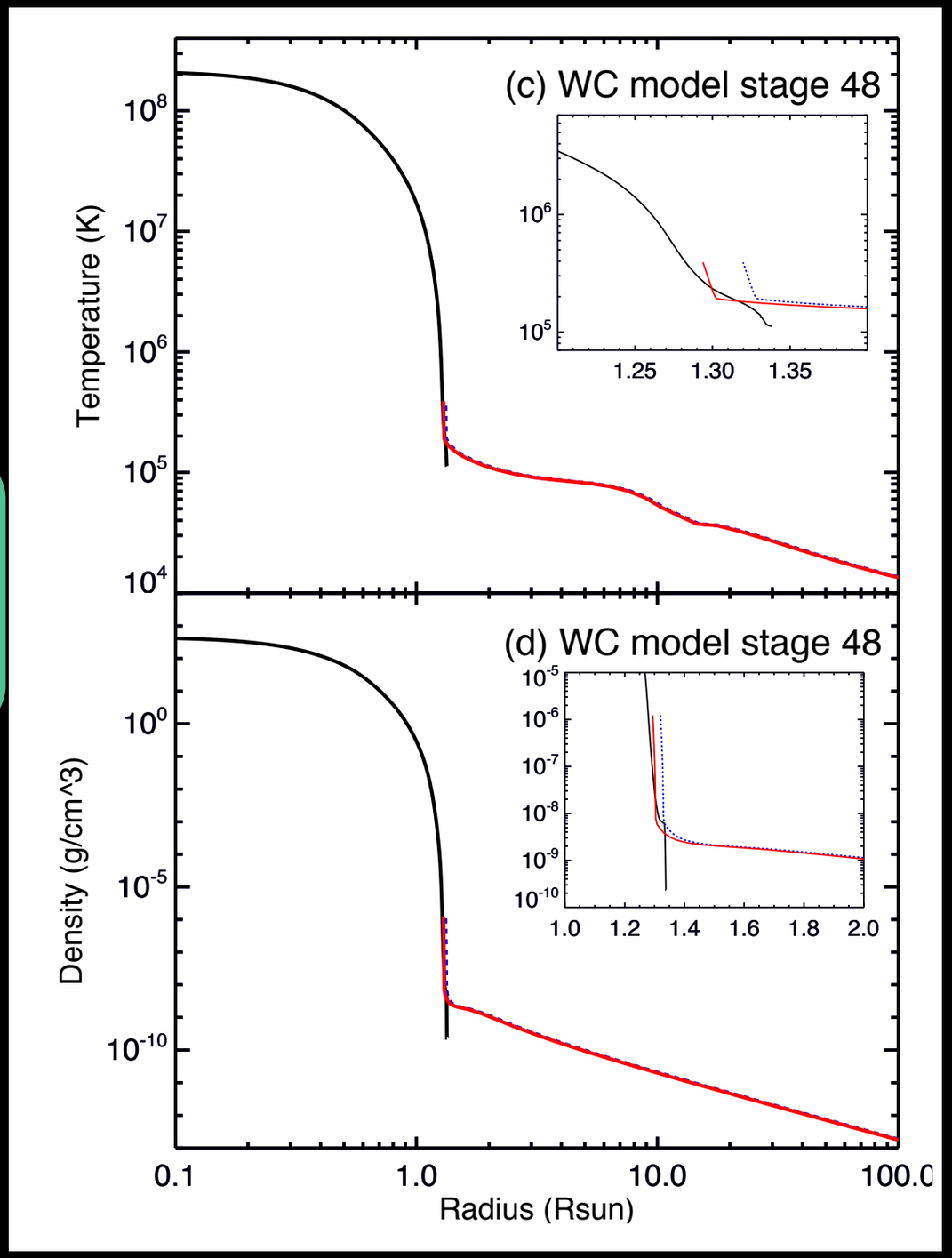

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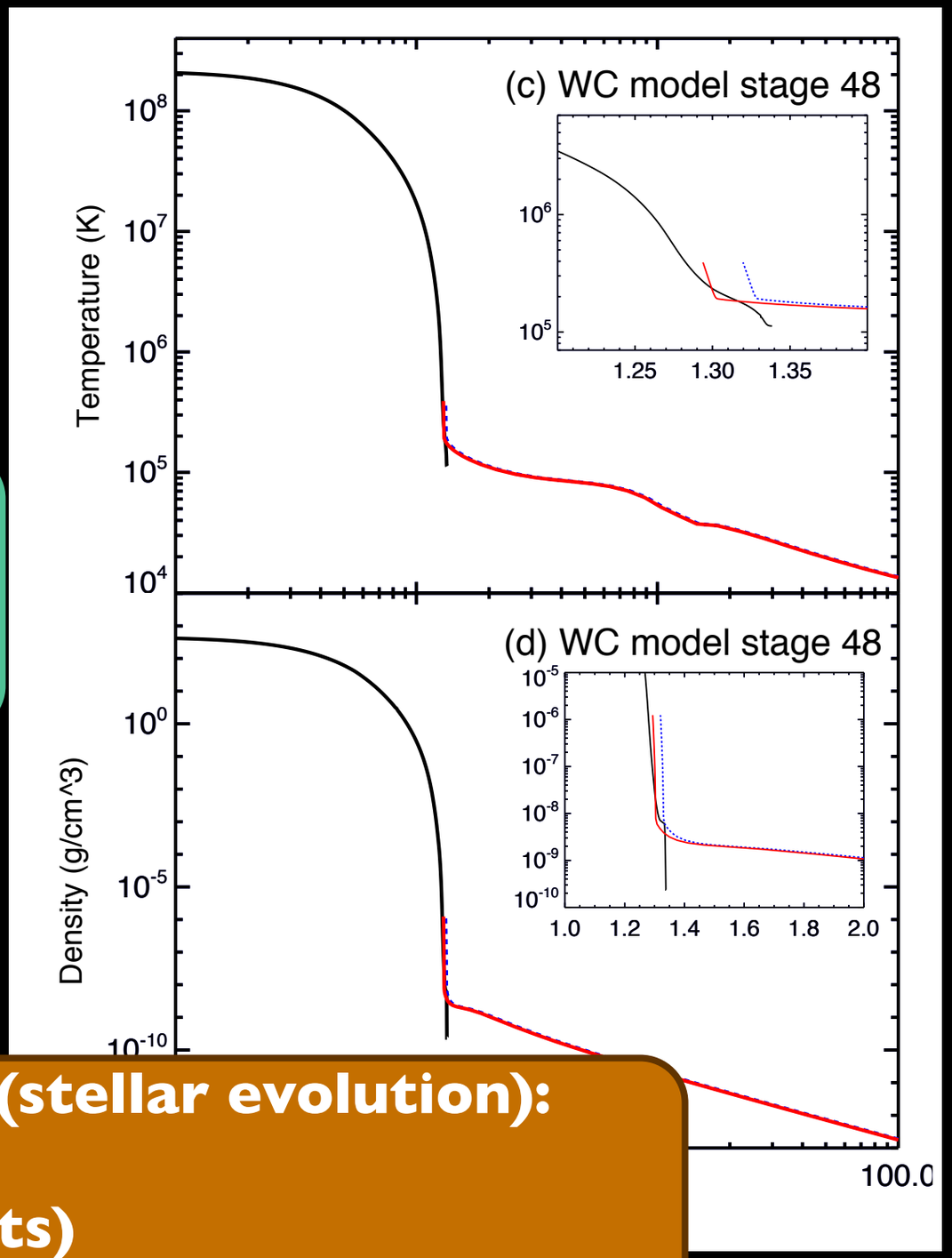
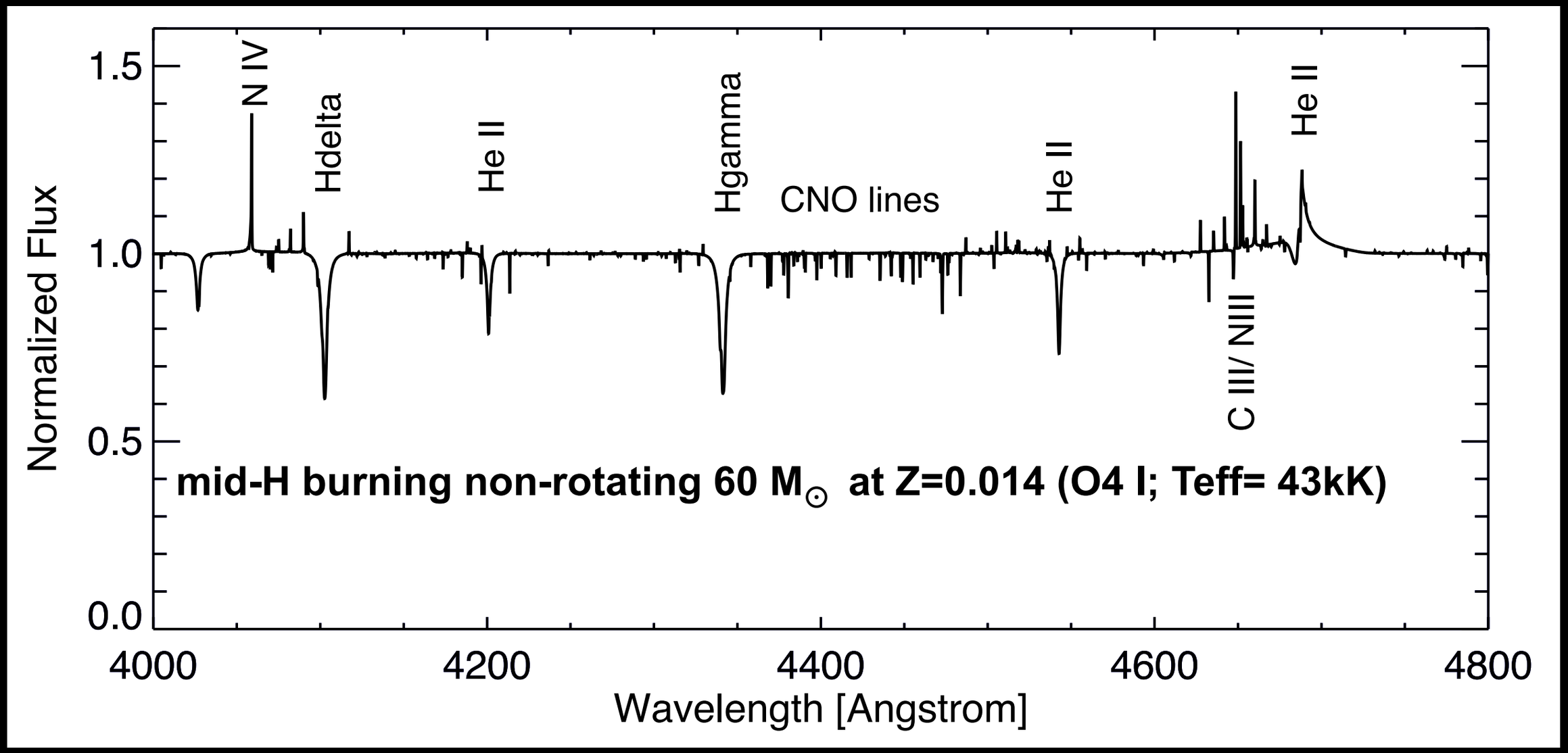


Error of computing spectra assuming Teff(stellar evolution):
200-500K (ZAMS)
1500-4000 K (O supergiants)
10000s K (WR stars and LBVs)

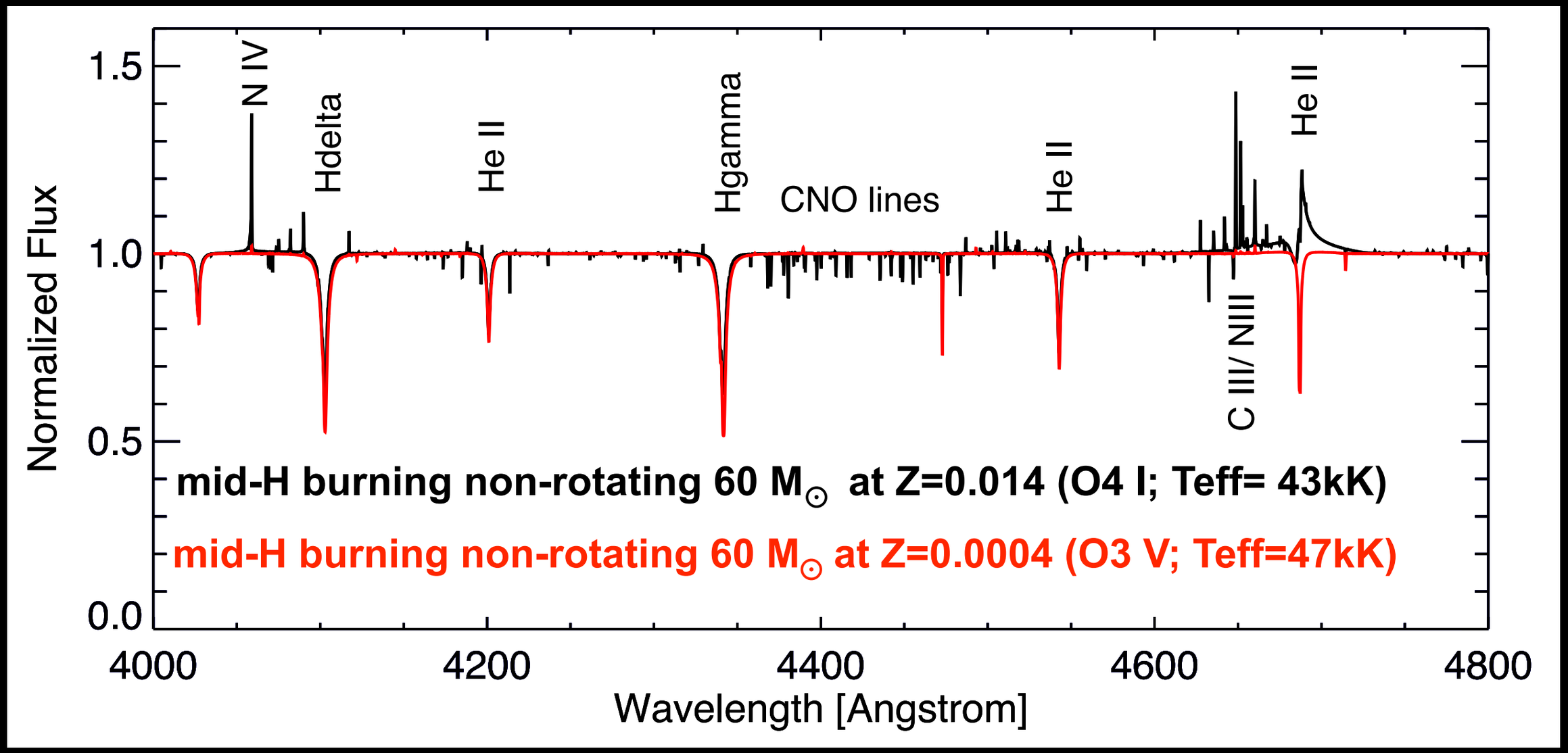
(Groh+ 14)

Metallicity effects on stellar spectra: unified models



(Groh+ 15 in prep)

Metallicity effects on stellar spectra: unified models

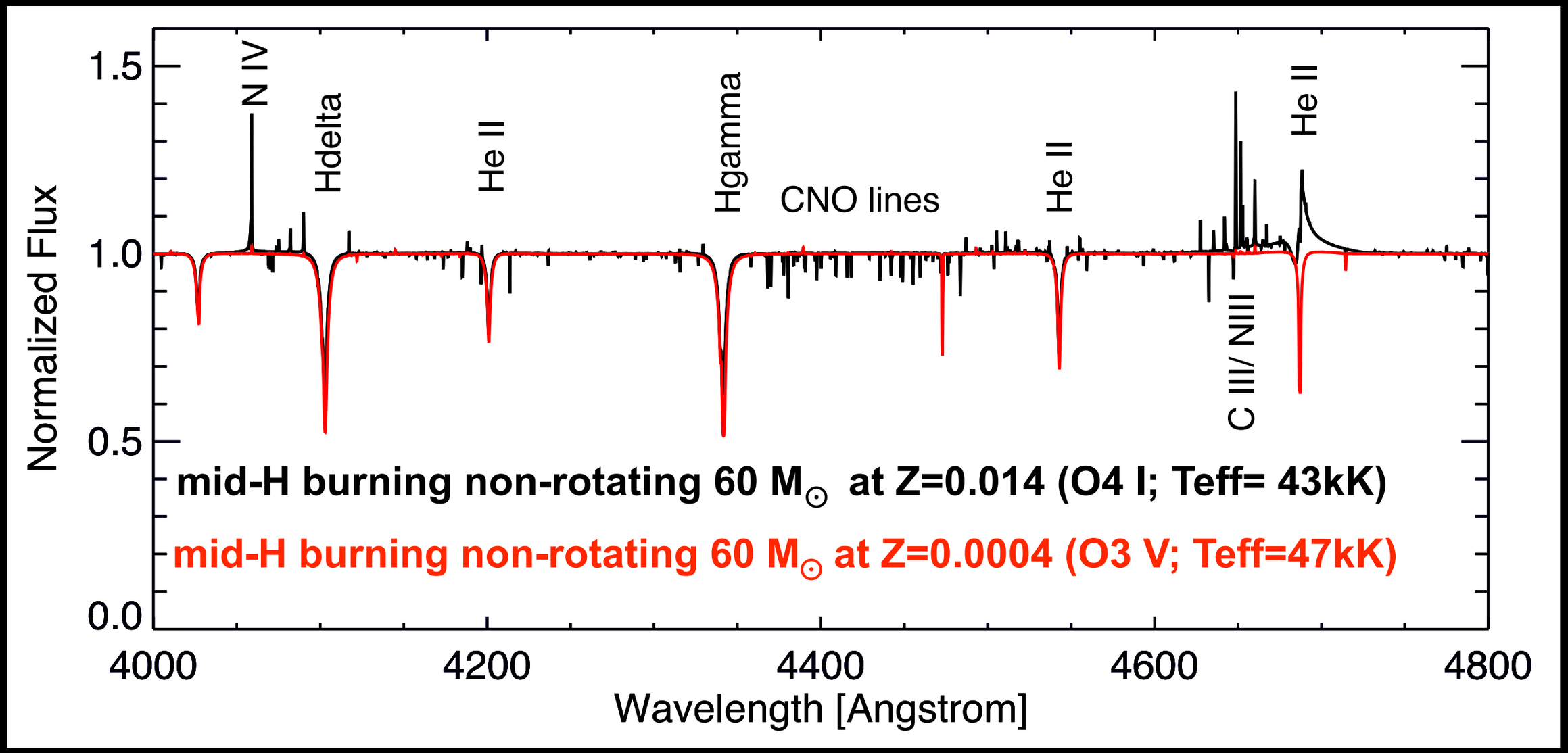


(Groh+ 15 in prep)

Metallicity effects on stellar spectra: unified models

He II 4686 line is weaker at low Z = Mdot effect (20x lower)

Spectral lines are less numerous (CNO) = abundance effect (50x lower)



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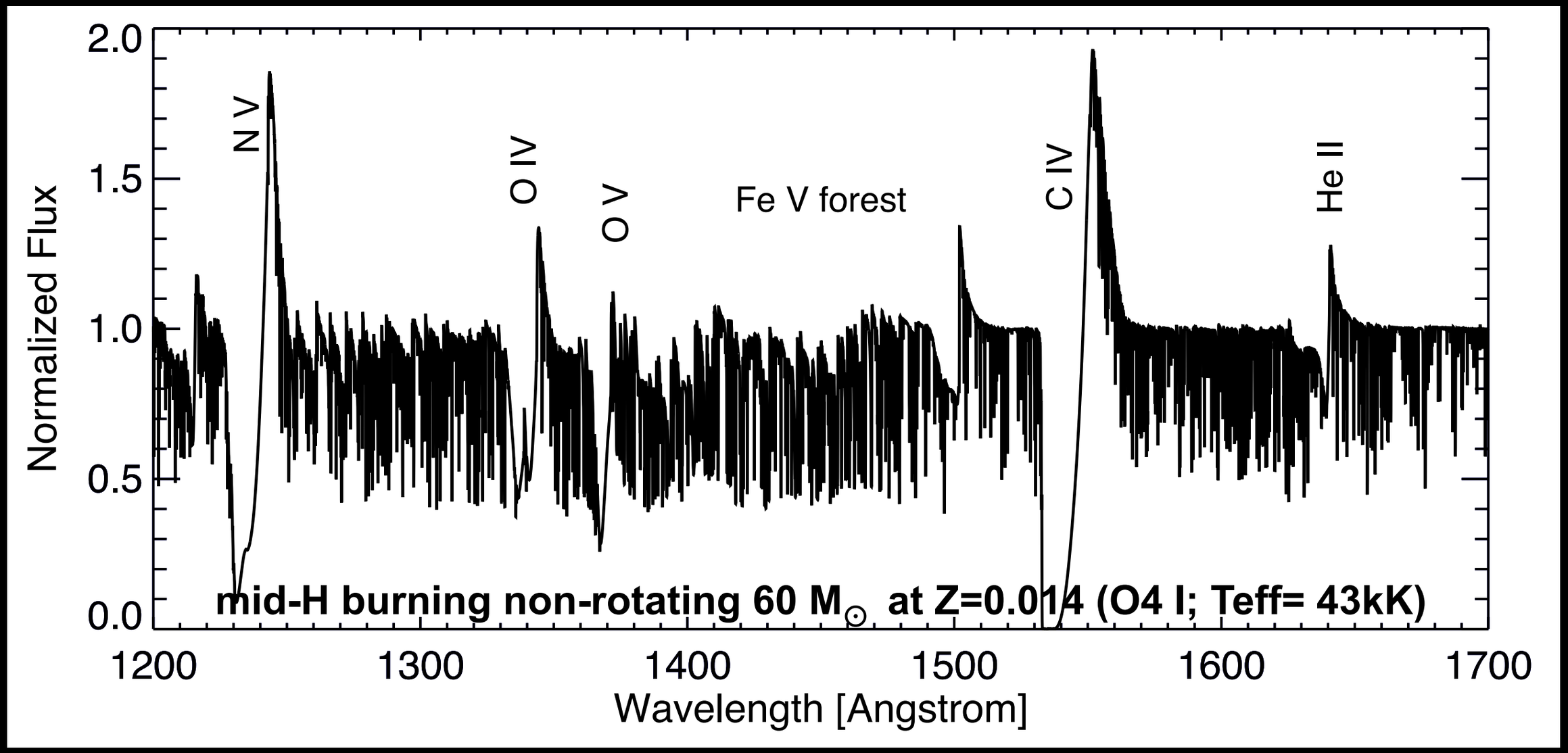
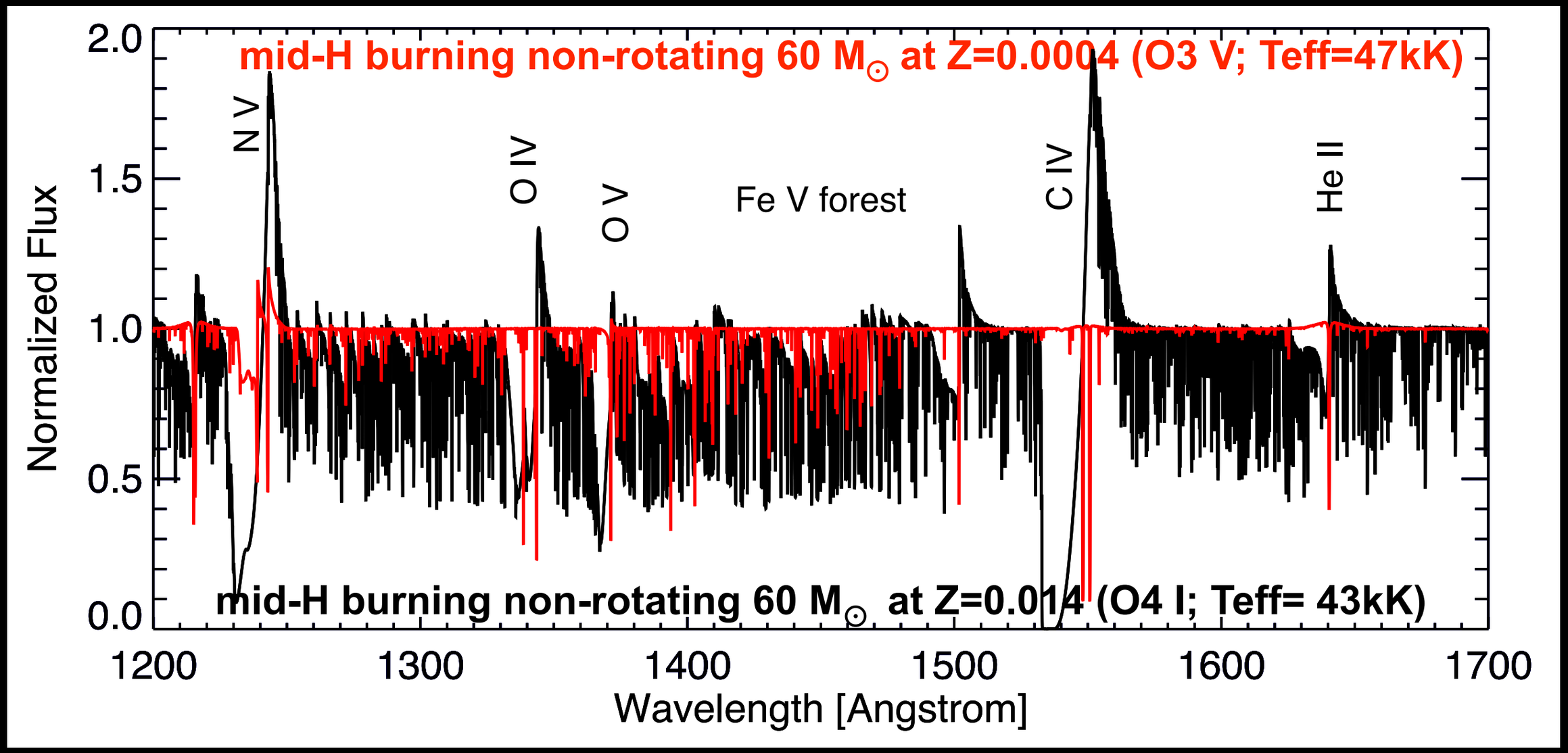


(Groh+ 15 in prep)

Metallicity effects on stellar spectra: unified models



(Groh+ 15 in prep)

Metallicity effects on stellar spectra: unified models

He II lines are weaker at low Z = Mdot effect (20x lower)

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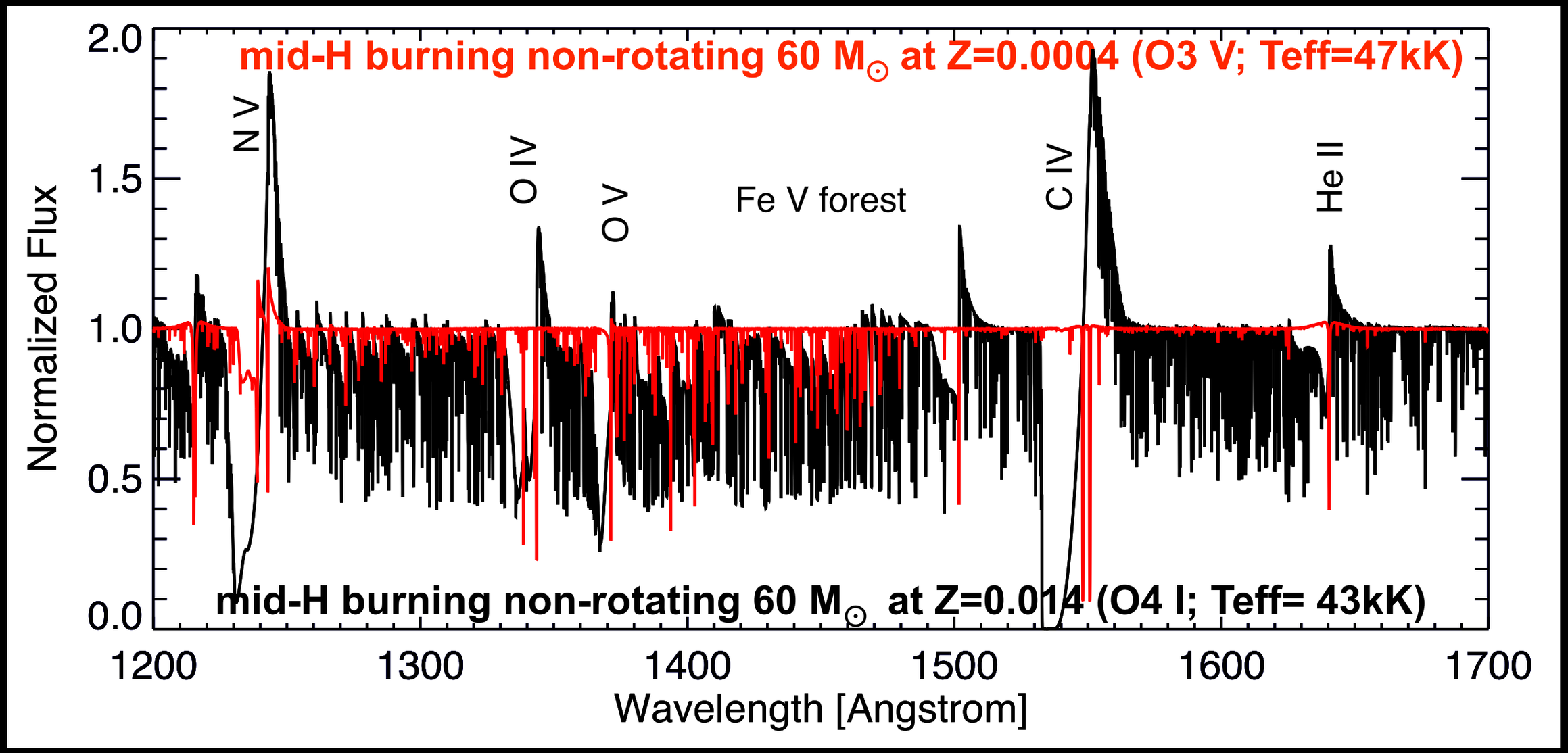
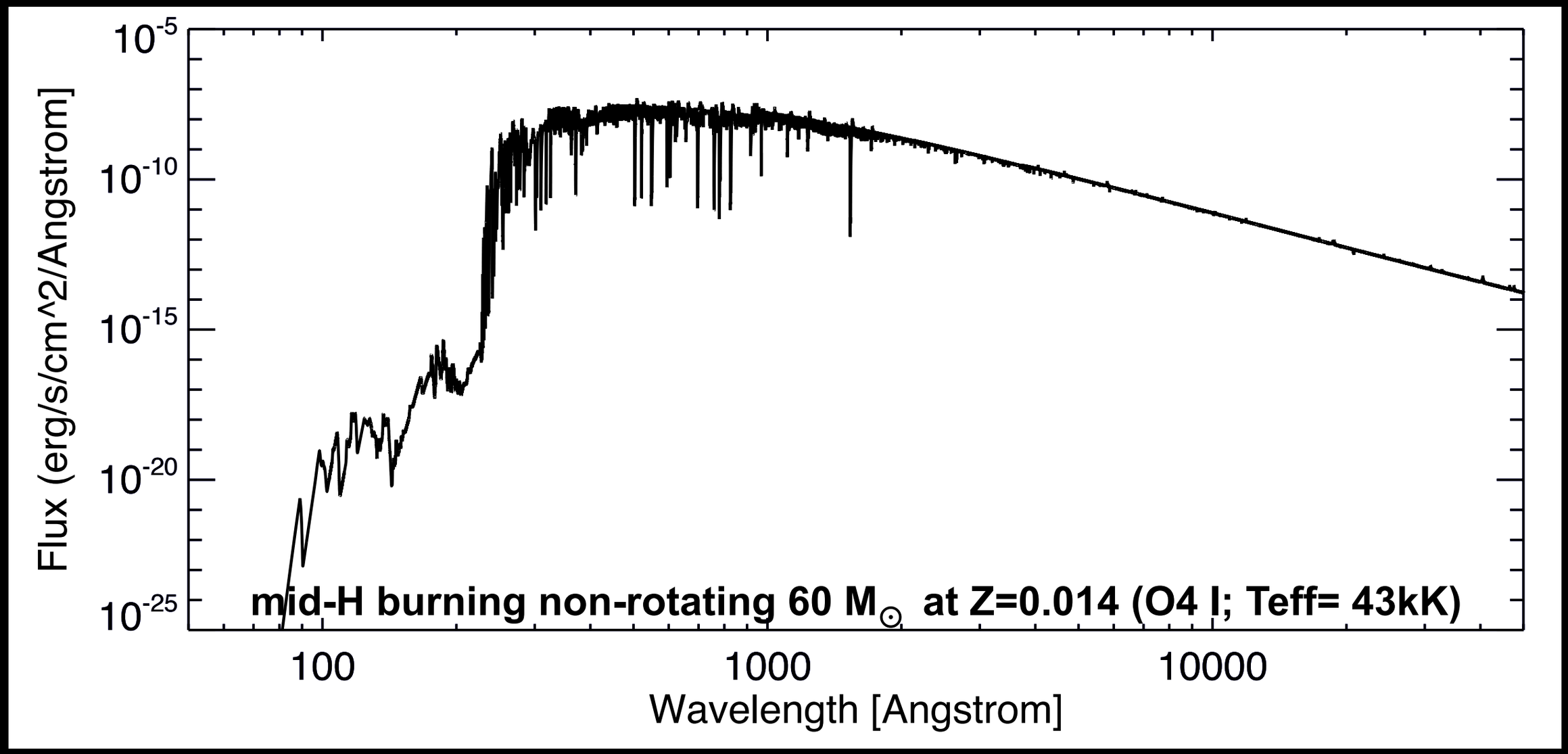


(Groh+ 15 in prep)

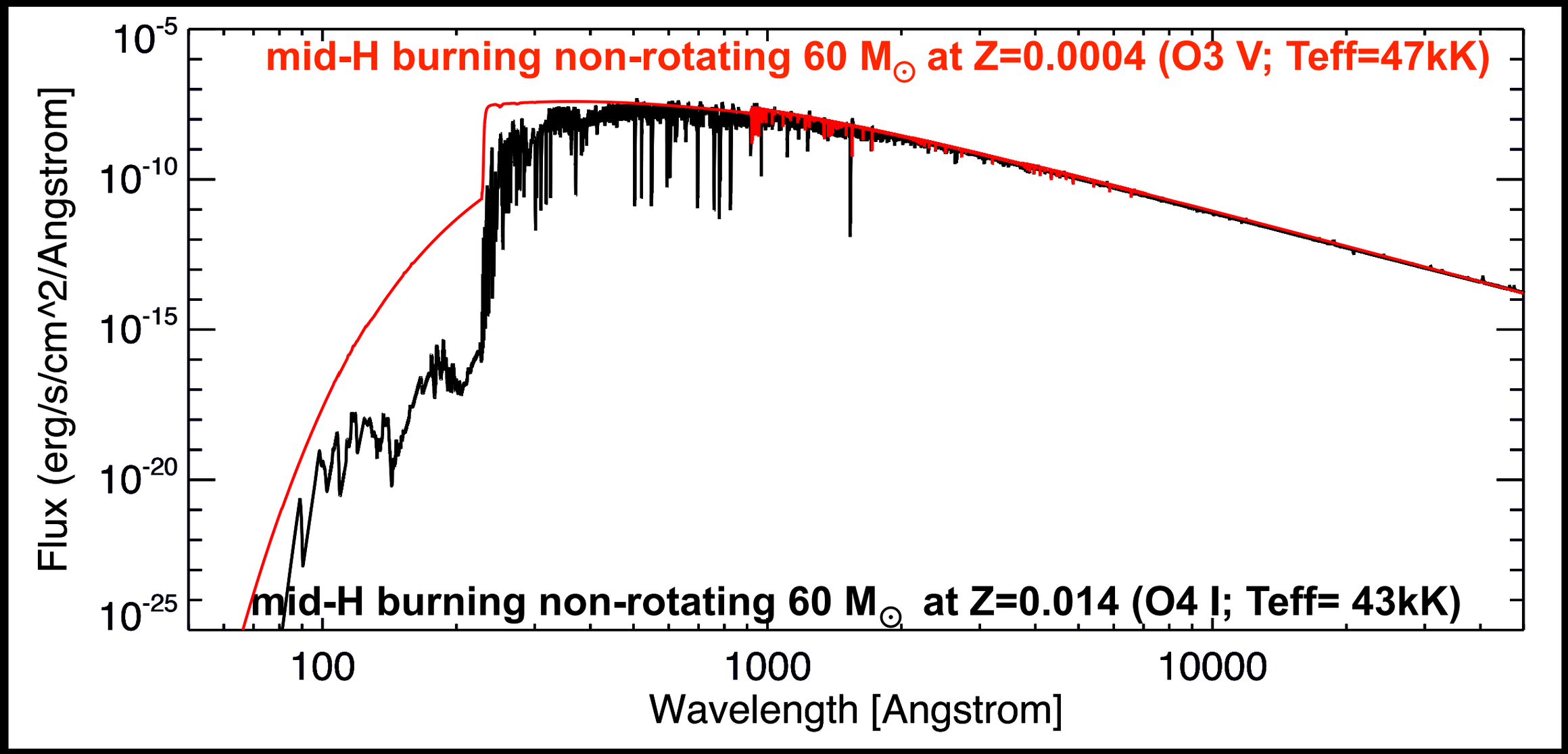
Metallicity effects on stellar spectra: ionizing fluxes



(Groh+ 15 in prep)

Metallicity effects on stellar spectra: ionizing fluxes

increase in ionizing fluxes (abundance/line blanketing effect)



(Groh+ 15 in prep)

Scary things: how do they change with metallicity?

- Mass loss and eruptions
- Wind structure (clumping)
- Blackbody vs model atmosp.
- Binarity
- Magnetic Fields
- Rotation
- Convection
- Eddington limit and inflation

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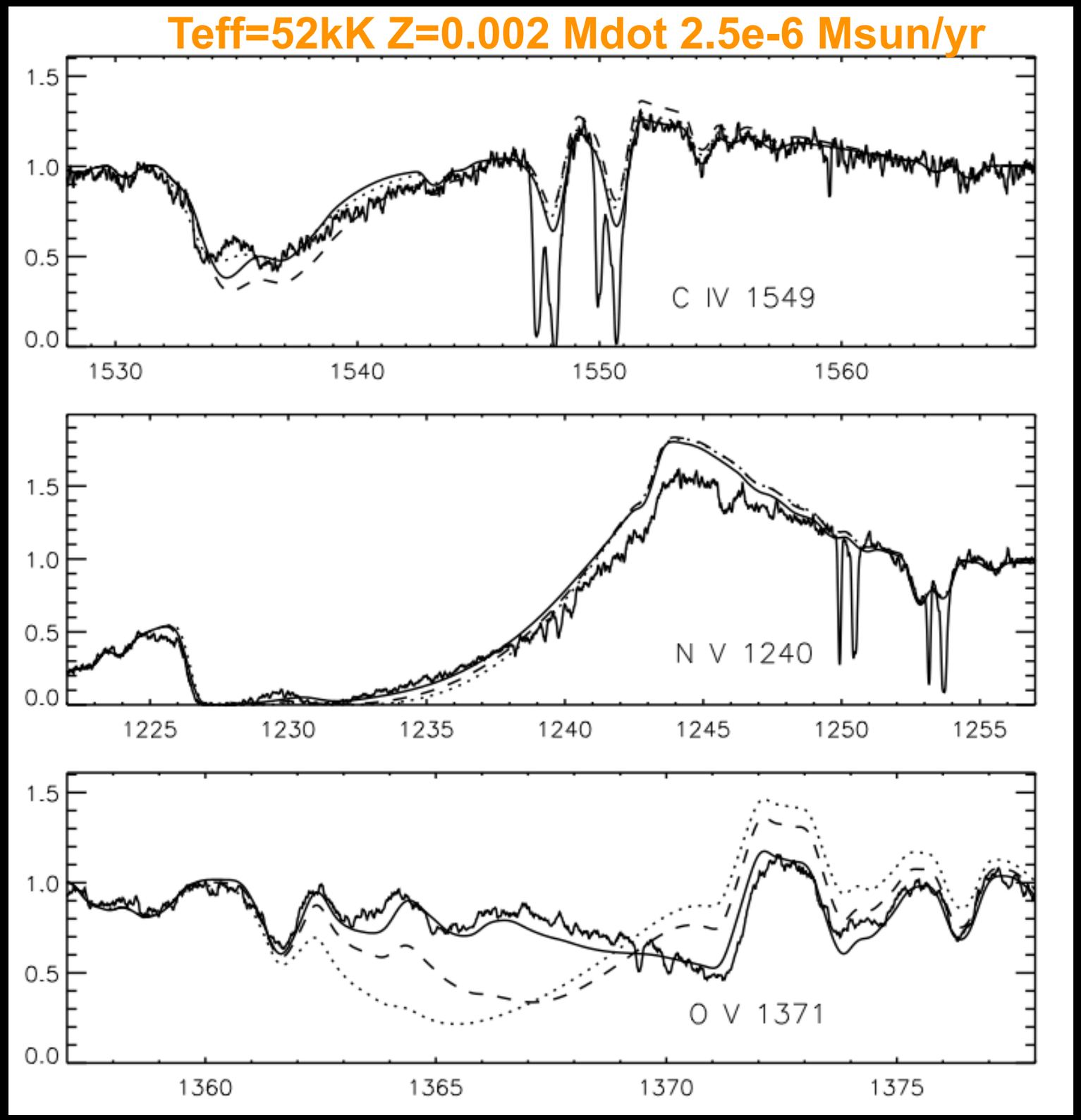
Wind clumping affects line profiles

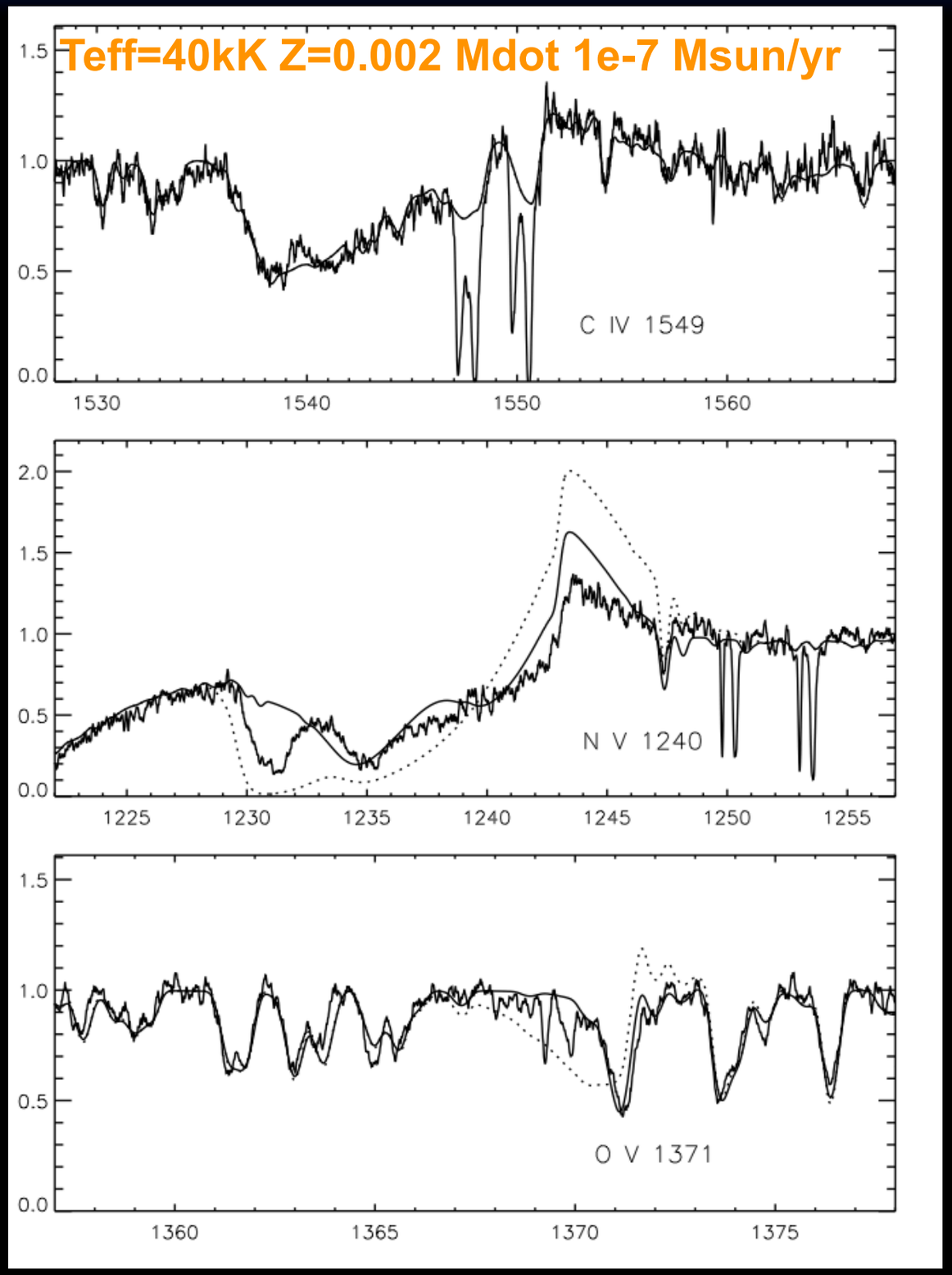
MPG 355 (O2 III)
in NGC 346



(Bouret et al. 2003)

Wind clumping affects line profiles

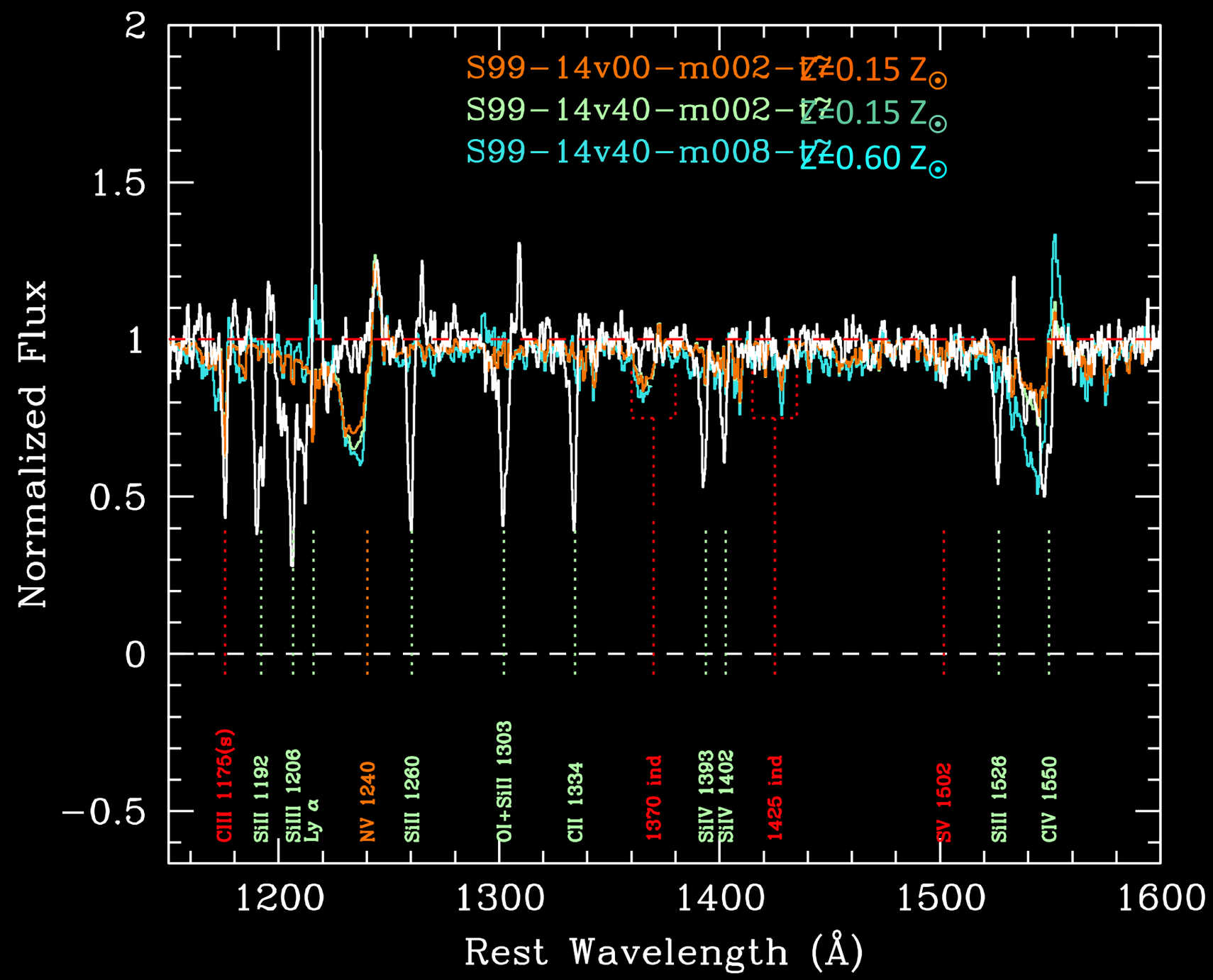
MPG 368 (O4-5 V)
in NGC 346



(Bouret et al. 2003)

atmospheric models with clumping not included in Stellar Pop. Synthesis

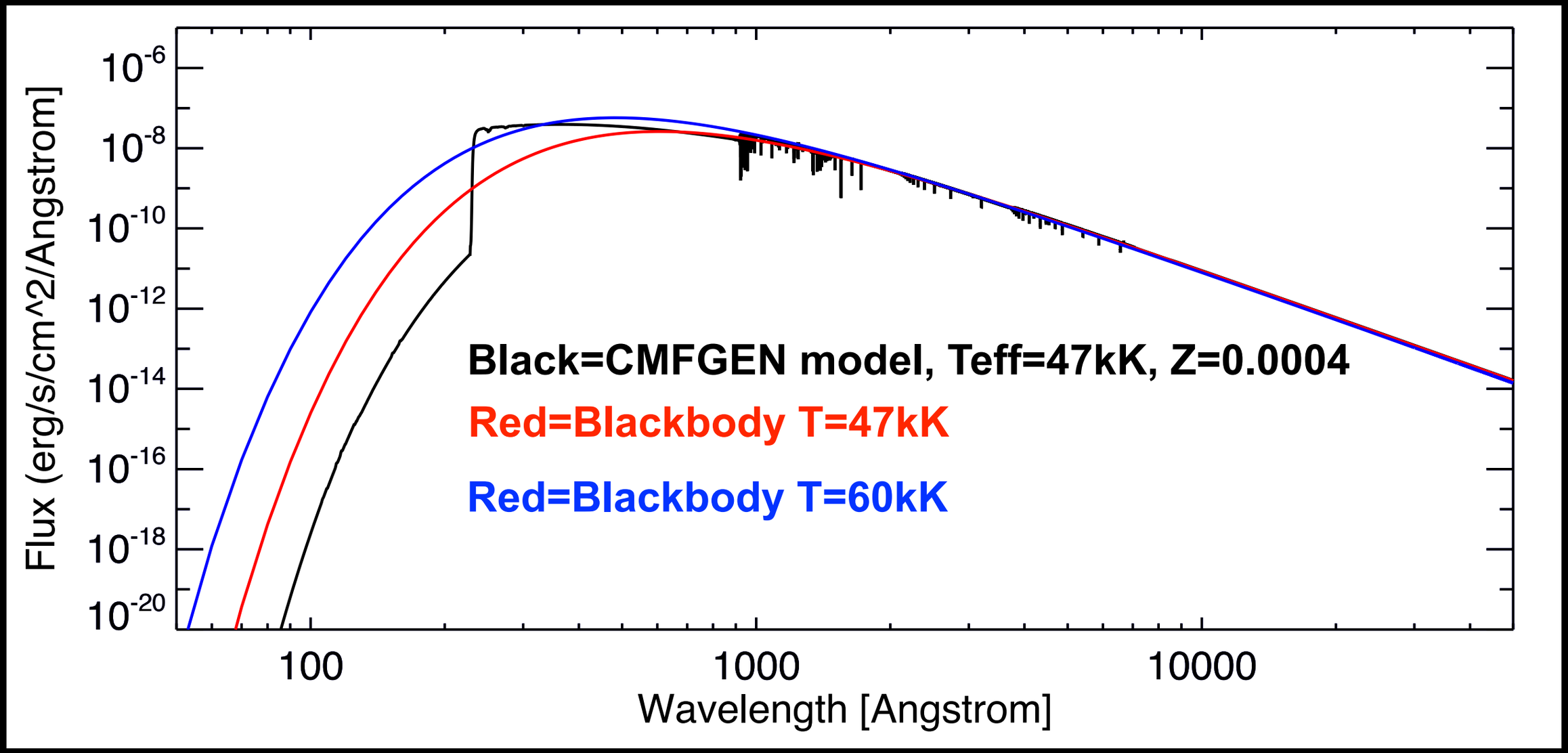
Clumping and Mdot effects?



(courtesy C. Steidel)

Blackbody vs. Model atmospheres

(or why I don't like blackbodies)



Take Away: effects of low metallicity

Reduced stellar wind mass and angular momentum losses

Stars are more compact, hotter, and more mixed

Spectral lines are weaker and less numerous; more ionizing flux