PARSEC evolutionary tracks of massive stars up to 350$M_\odot$ at metallicities $0.0001 \le Z \le 0.04$

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1. Introduction

- Massive stars are among the most important agents of galaxy evolution. They are the most prominent stellar sources of ionizing and dissociation photons and among the main drivers of metal and dust enrichment, through their winds and their final explosions;
- We present the new comprehensive library of PARSEC evolutionary tracks of massive stars [1].

2. What's new in this study?

- We focus on the most recent mass loss recipes, indicating that mass loss is strongly enhanced when stars approach the Eddington luminosity [2], even at low metallicity [3];
- We compute new WM-basic SEDs for O,B stars encompassing a wide range in mass loss rates;
- We introduce new high-resolution PoWR Wolf-Rayet SEDs [4];
- We calculate the net yields from the stellar winds.

More details can be found in [1]. The models do not include rotation.

3. PARSEC evolutionary tracks with new mass loss rate recipes

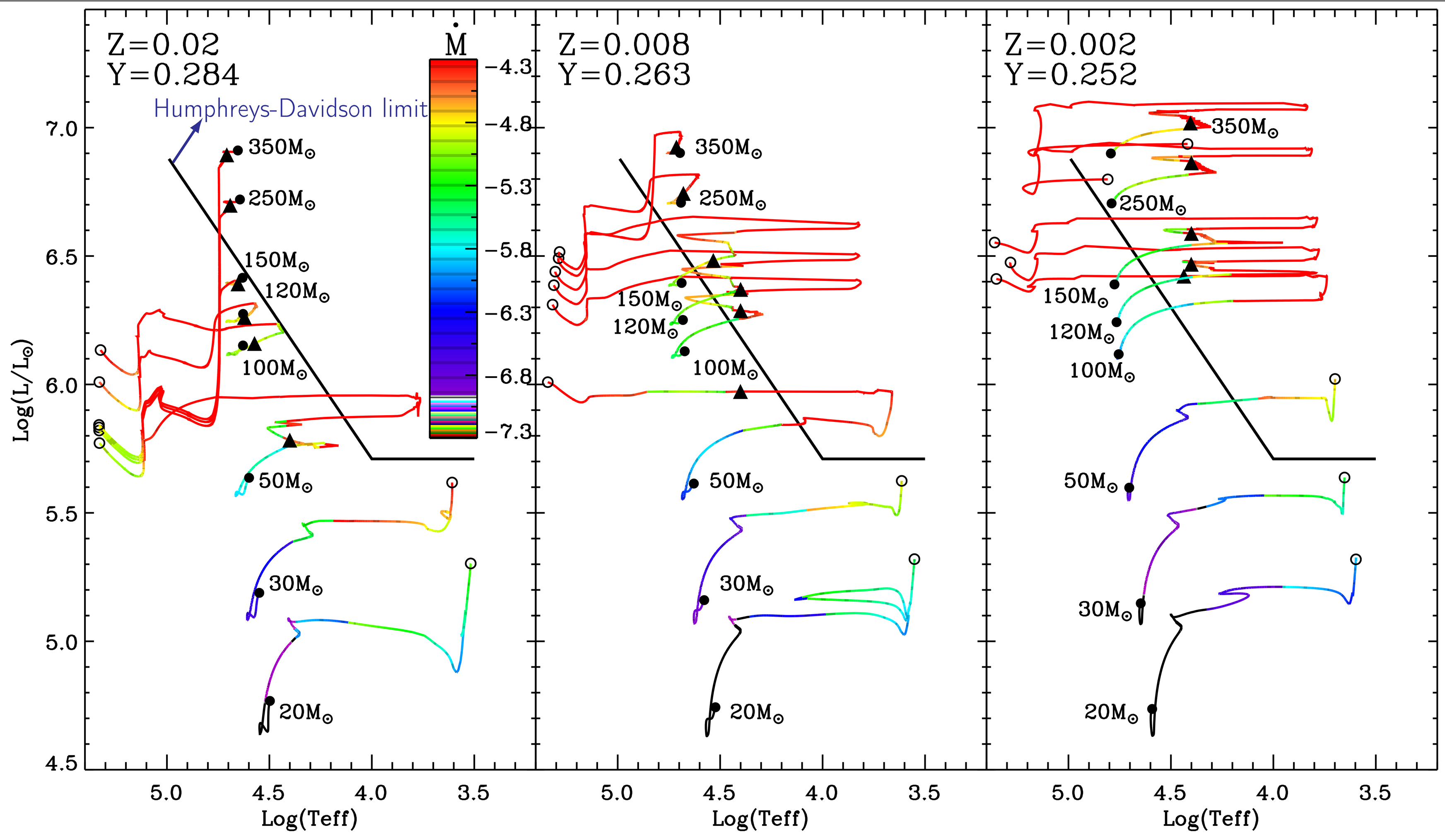

Figure 1: Selected evolutionary tracks for massive stars with Z=0.02 (left), Z=0.008 (middle) and Z=0.002 (right). The mass-loss rates are indicated with the colour bar. The Humphreys-Davidson limit [5] delimits the forbidden region above which only very few stars are observed in the Hertzsprung-Russell (HR) diagram of the Galactic massive stars. The big solid and empty circles indicate the ZAMS and the end points of the tracks respectively. The triangles mark the beginning of WR phase.

Usually adopted mass loss recipes:
BSG: Vink et al. (2000,2001); RSG: de Jager et al. (1988); WR: Nugis & Lamers (2000).
New: mass loss enhancement [2] and Z dependence [3] when $\Gamma_e \to 1$ ($\Gamma_e = \frac{L\kappa_{es}}{4\pi cGM}$):

$$\dot{M} \propto (Z/0.02)^{\alpha} \qquad (1)$$

with $\alpha = min(0.85, 2.45 - 2.4 * \Gamma_e)$ for $\Gamma_e < 1$ (i.e. $0. < \alpha \le 0.85$)

4. Comparison with previous Padova and the FRANEC tracks

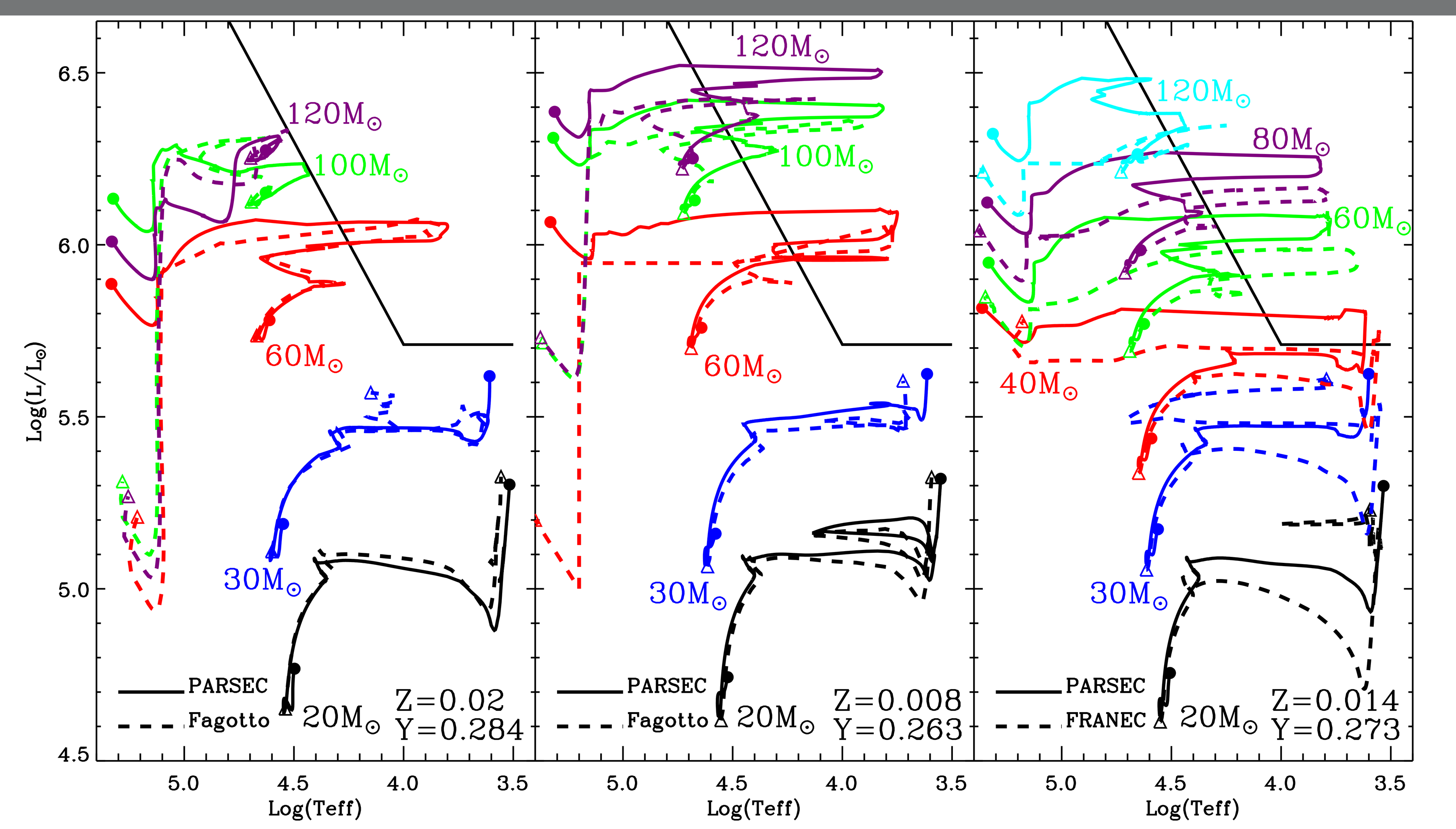

Figure 2: Left and middle: comparison with previous releases of Padova evolutionary tracks [6, 7] with $Z = 0.02$ (left) and $Z = 0.008$ (middle). Note that Helium abundances are $Y = 0.28$ for $Z = 0.02$ and $Y = 0.25$ for $Z = 0.008$ in [6, 7]. Right: comparison with the FRANEC solar abundance ($Z = 0.01345$) models without rotation [8]. The meaning of big circles is the same as in figure 1, while the big triangles are used for the alternative models. The Humphreys-Davidson limit is also drawn as in figure 1.

5. Stellar spectral libraries

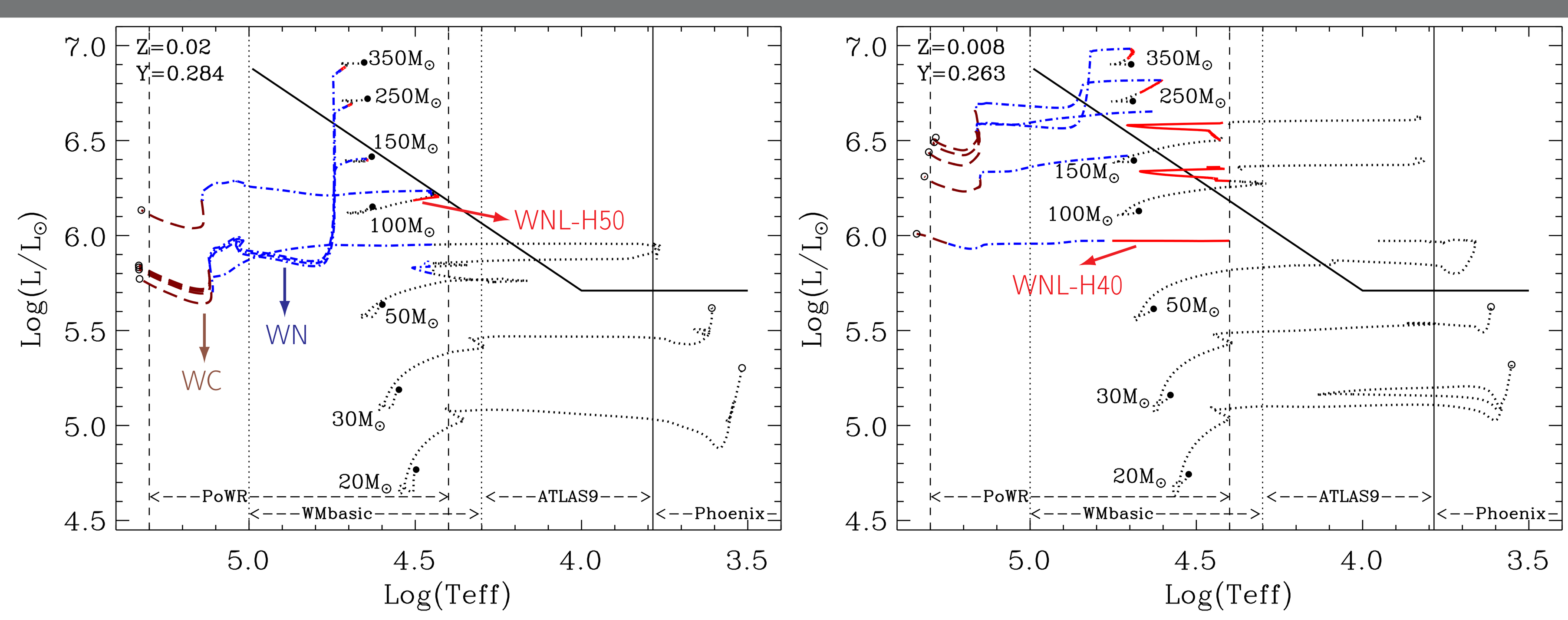

Figure 3: We use new stellar spectral libraries to transform the evolutionary tracks into observable colors or spectra, as indicated in the panels. WM-basic models are computed at three mass loss rates: 10^{-7}, 10^{-6} and 10^{-5} $M_\odot yr^{-1}$. Different colours are used for PoWR WC (brown), WN (blue) and WNL-H50(40) (red) models.

6. Color-magnitude diagrams and isochrones

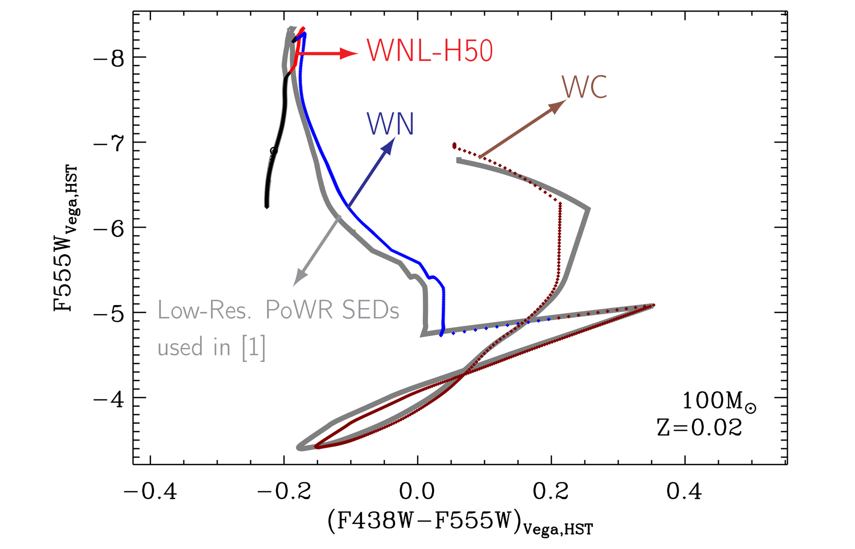

Figure 4: Colour-magnitude diagrams in HST/WFC3 broad bands for tracks of $M_{ini}=100M_\odot$ with Z=0.02. The meaning of colours and line styles is the same as in figure 3. For the gray track we use previous low resolution PoWR models.

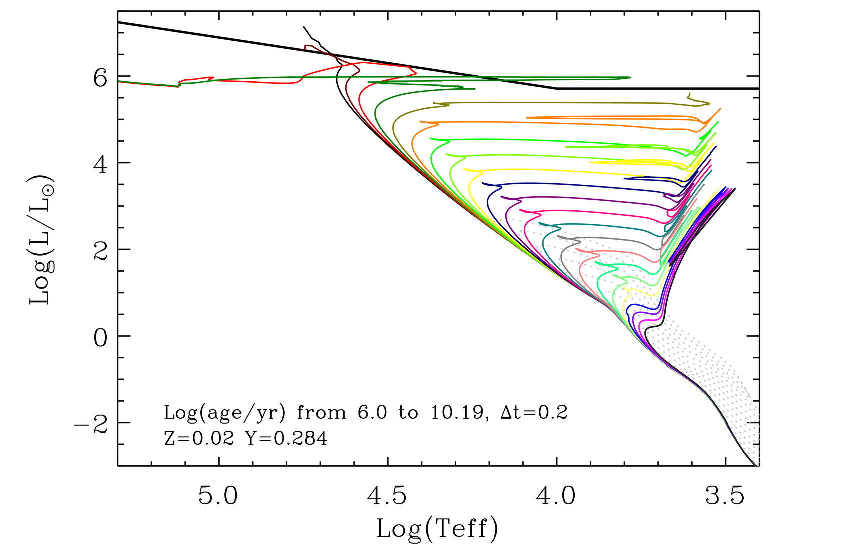

Figure 5: Theoretical isochrones of different ages, as indicated by the labels, are shown for Z=0.02. Grey dotted lines indicate the pre-main sequence phases at young ages.

7. Net yields from stellar winds

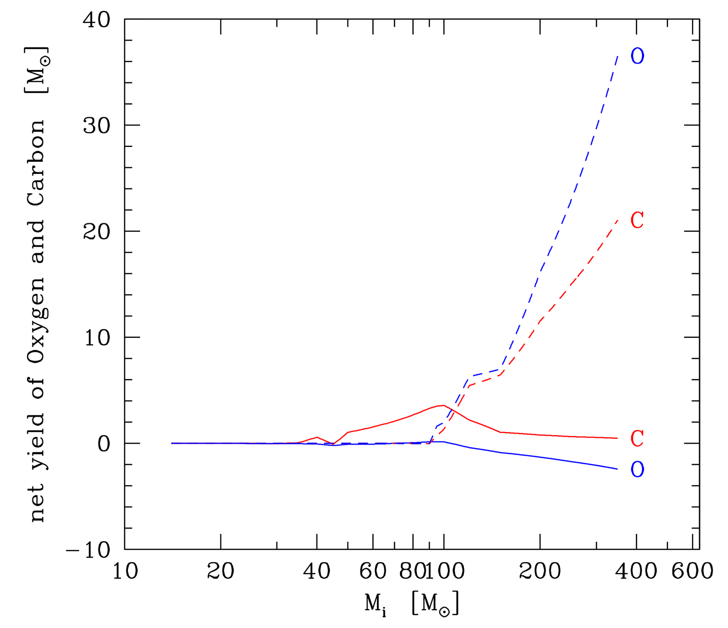

Figure 6: Net yields of carbon (red) and oxygen (blue) ejected by winds of stars with initial masses ranging from M=14 $M_\odot$ to 350 $M_\odot$ and for two metallicities, Z=0.02 (solid) and Z=0.002 (dashed).

- We compute net yields for stars with initial masses from M=14 $M_\odot$ to 350 $M_\odot$ (Slemer et al. 2015, in preparation). In Figure 6 we show yields of carbon and oxygen for two initial metallicities, Z=0.002 and Z=0.02. They include only the contributions of stellar winds from PARSEC tracks. Note the significant contribution from stellar winds in very massive stars at low Z.

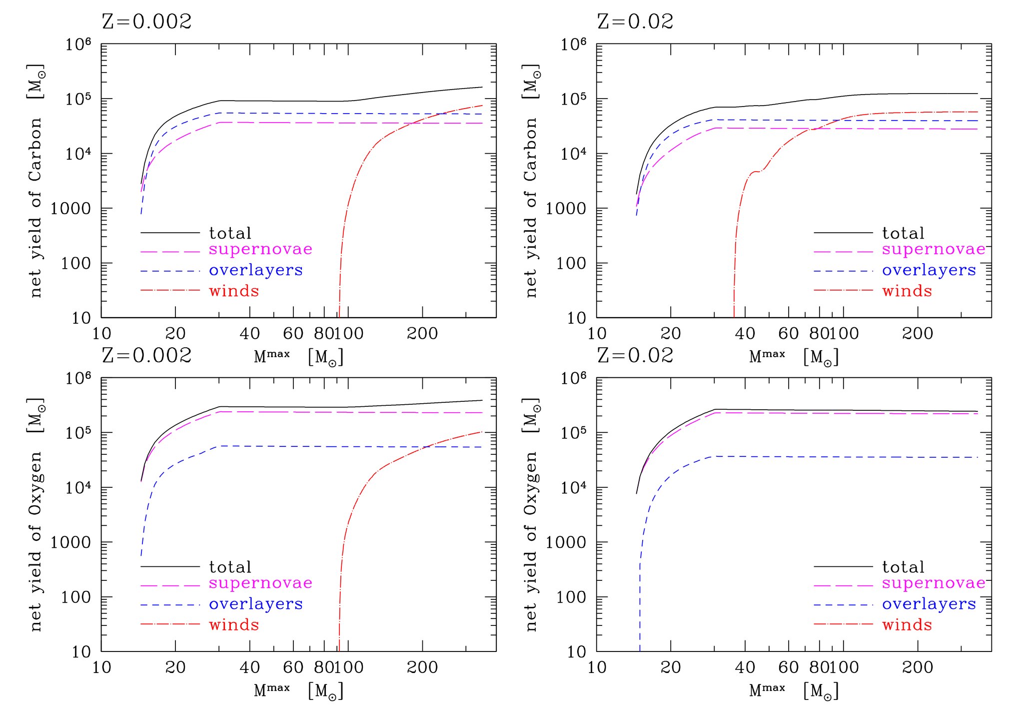

Figure 7: Integrated net yields of carbon and oxygen (in solar masses) for simple stellar populations of total mass $M=10^8$ $M_\odot$ and Z=0.002 and Z=0.02.

- Net yields that include SN explosions (from Limongi & Chieffi 2006) and stellar winds shown in Figure 6, are integrated over a Salpeter IMF from 0.1 $M_\odot$ to a variable upper mass limit (M^{max}), which is progressively increased from 14 $M_\odot$ to 350 $M_\odot$ (Figure 7). SN enrichment is set to zero for M>30 $M_\odot$, following the bi-parametric criterion for explosion by Ertl et. 2015 (see also poster FM7p.04).

Very massive stars of low metallicity, $0.002 \le Z \le 0.004$ enrich the ISM with significant amounts of new metals already in the early evolutionary stages (< a few Myr)

8. Conclusions

- We compute new evolutionary tracks of massive stars up to 350 $M_\odot$ for $0.0001 \le Z \le 0.04$ and from the pre-main sequence to carbon ignition. When stars approach the Eddington luminosity, mass loss is strongly enhanced [2] even at low metallicity [3]. The models reproduce the Humphreys-Davidson limit observed in the Galactic and LMC without ad hoc assumptions for the mass-loss rates;
- We provide newly computed stellar spectral library for O, B stars with WM-basic. The models are calculated at three mass loss rates: 10^{-7}, 10^{-6} and 10^{-5} $M_\odot yr^{-1}$; We use new high resolution Wolf-Rayet stellar spectral library provided at PoWR database;
- We generate isochrones of any age useful for studying star-forming galaxies;
- We compute integrated yields. Preliminary computations indicate that very massive stars at low metallicity may eject significant amounts of metals through their winds;
- Tracks and isochrones can be downloaded from http://people.sissa.it/~sbressan/parsec.html and http://stev.oapd.inaf.it/cgi-bin/cmd.

9. References

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PARSEC data base — Evolutionary tracks for massive stars — Our paper on massive stars — This poster