Massive Star Evolution in the Dwarf Galaxy I Zwicky 18

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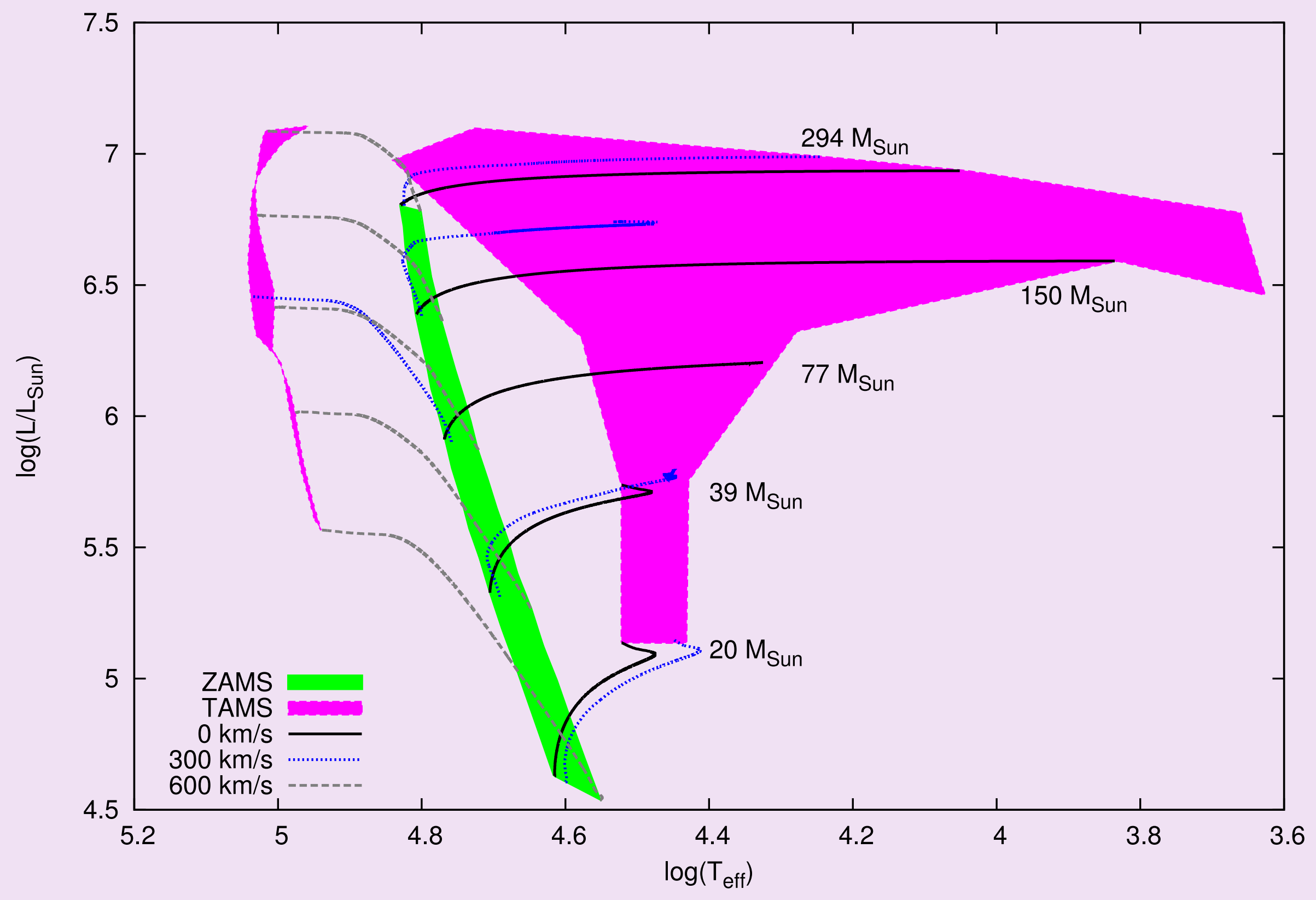
Abstract

From the study of luminous supernovae and long duration gamma ray bursts, as from observations of chemical anomalies in stars of galactic globular clusters, evidence has been accumulated that the evolution of massive stars proceeds very differently at low metallicity [7]. Nearby irregular dwarf galaxies provide excellent laboratories for star formation, massive star evolution and chemical enrichment processes. One of the key objects is I Zwicky 18, which has a high star formation rate and contains Wolf-Rayet stars [1]. We present a grid of evolutionary tracks of massive, rotating single stars with an initial composition corresponding to that of I Zwicky 18 ($\sim$1/50 $Z_\odot$, or $\sim$1/10 Z_{SMC}).

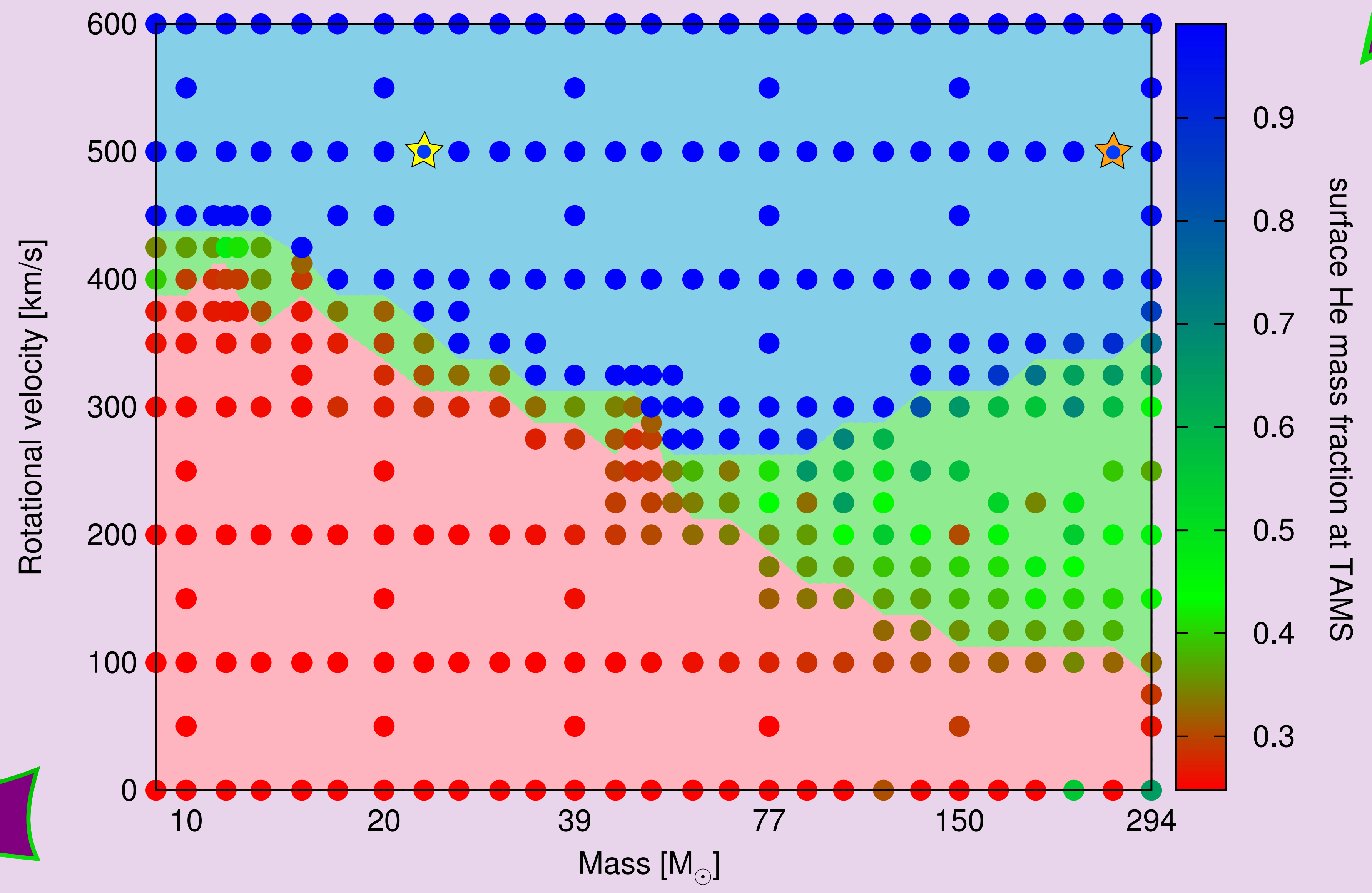
The grid contains $\sim$350 evolutionary sequences of single stars in the mass range of 9-300 $M_\odot$, with initial rotational velocity between 0-600 km/s. We find a significant fraction of them following a chemically homogeneous evolutionary path, evolving bluewards in the HR diagram and becoming WR stars. We also derive hydrogen and helium ionizing fluxes emitted from our stars. Furthermore, we estimate the fractions of pair instability supernovae and gamma-ray bursts from our models.

HRD



Evolutionary tracks for various masses and rotation rates on the main sequence are shown in the HertzsprungRussell diagram. Stars which rotate faster than a certain threshold are so efficiently mixed that they evolve almost chemically homogeneously [2]. The broadening of the Zero Age Main Sequence (green shaded) is an effect of rotation. The Terminal Age Main Sequence of the chemically homogeneous stars (purple shaded, left) is narrow, and that of the normally evolving stars (purple shaded, right) is more broad, especially for the highest masses. In that region, stars have enhanced He mass fraction at the surface, exposed by mass loss episodes, making the faster rotators cooler.

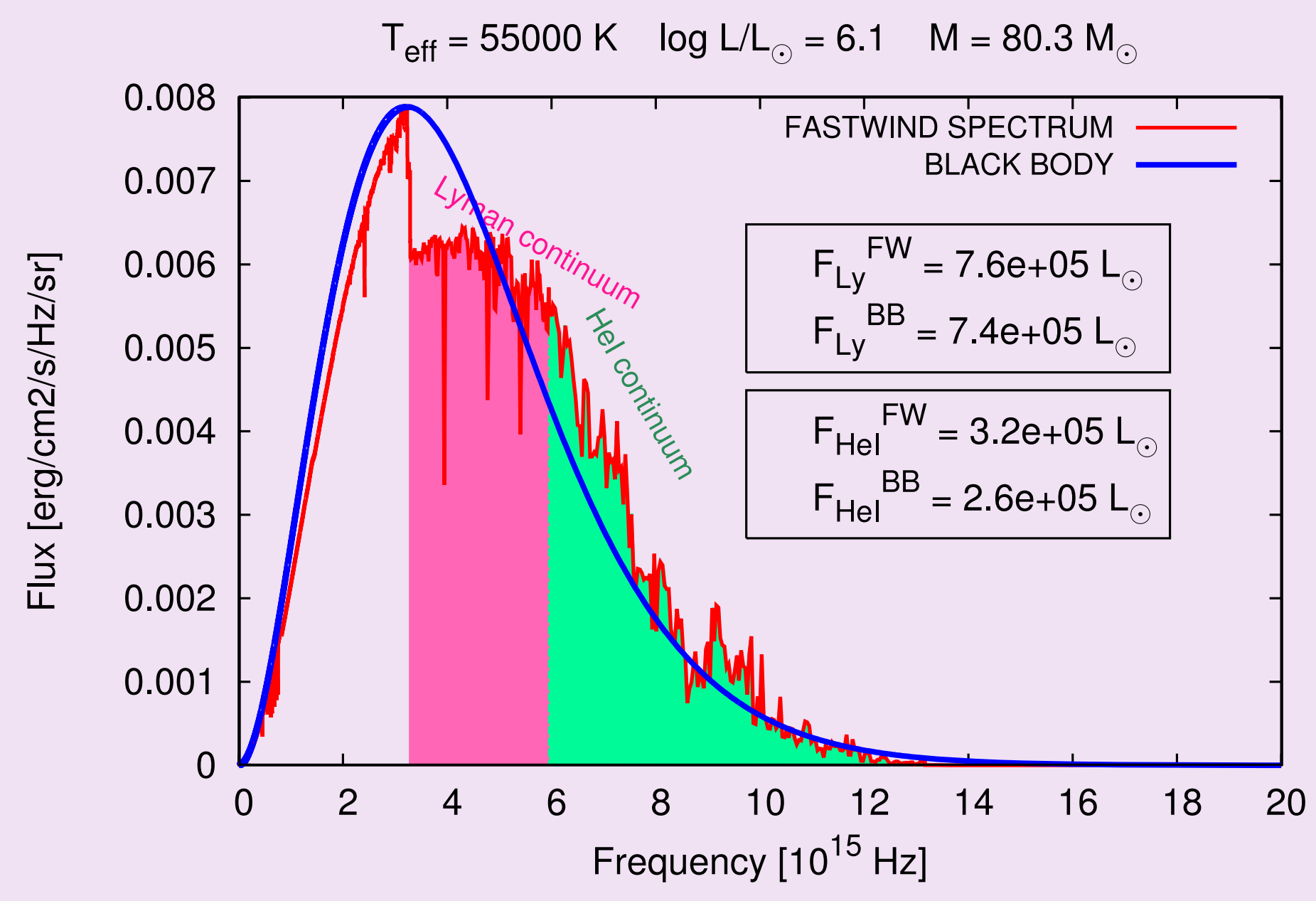
The Grid



Sequences marked with red follow normal evolution initially and become red supergiants. Sequences marked with green start their life chemically homogeneous and then they switch to normal evolution; we call this behaviour transitional evolution. The blue points represent chemically homogeneously evolving models [8]. The definition of the different types of evolution is based on the surface helium mass fraction at the end of the Main Sequence (color coded) [6].

Lower mass chemically homogeneous models (9-30 $M_\odot$) are long GRB candidates. Higher mass chemically homogeneous (30-300 $M_\odot$) and higher mass normally/transitional evolving models ($\sim$100-300 $M_\odot$) are probable to produce pair instability supernovae (PISNe, see also the corresponding panels). Normally evolving models of $\sim$10-25 $M_\odot$ can end as a SNIIp leaving a neutron star remnant, until normal/transitional models of $\sim$25-100 $M_\odot$ may collapse to a black hole directly.

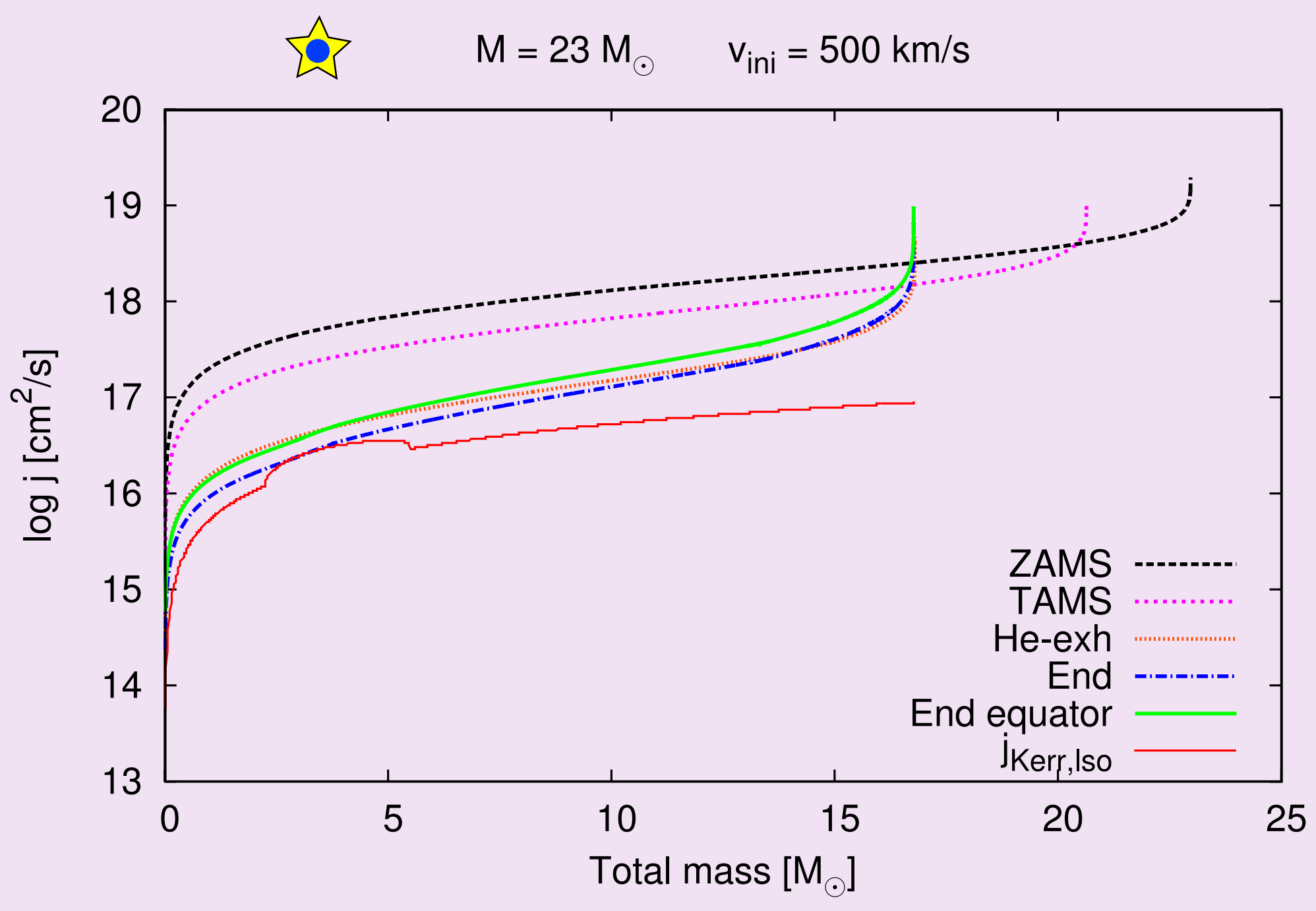
Spectra



In order to investigate the applicability of the black body approximation when deriving hydrogen and helium ionizing fluxes, we calculated synthetic spectra of a star with T_{eff} = 55000 K using FASTWIND [3]. The computed ionization fluxes in the Lyman and HeI continuum based on black body and FASTWIND spectra are close in this case. Further investigations are needed to define the applicability of the black body approximation of the synthetic spectra at lower and higher temperatures.

- [1] Aloisi, A. et al., ApJ 667, L151, 2007
- [2] Brott, I. et al., A&A 530, A115, 2011
- [3] Castro, N. et al., arXiv:1203.5115, 2012
- [4] Gal-Yam, A., Science 337, 927, 2012
- [5] Langer, N., de Koter, A. et al., AA 475, L19, 2007
- [6] Szécsi, D. et al., in preparation, 2013
- [7] Yoon, S.-C. et al., A&A 460, 199, 2006
- [8] Yoon, S.-C. et al., A&A 542, A113, 2012

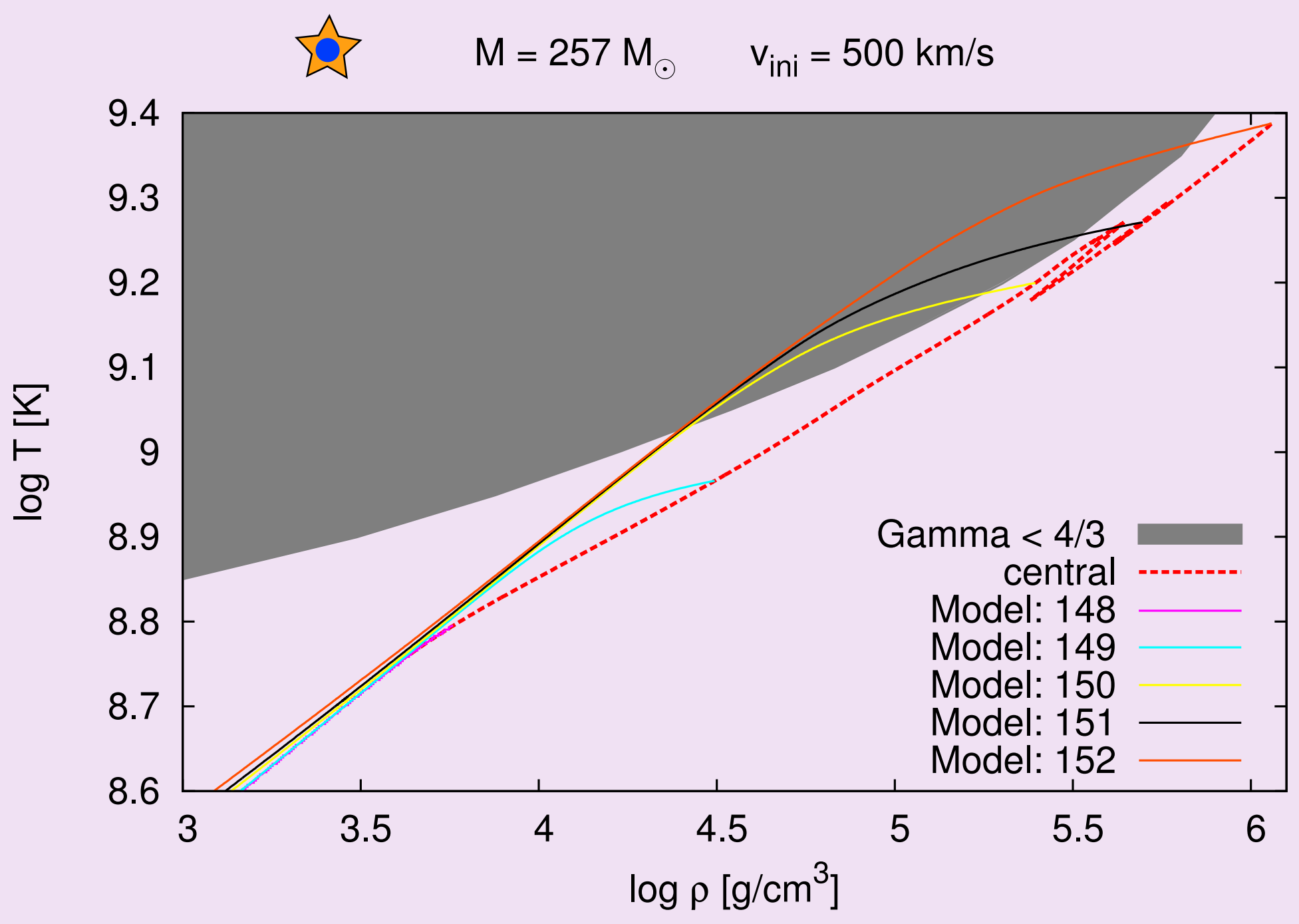
Long GRBs



In the collapsar model, a long gamma-ray burst can be created when a compact, fast rotating star retains enough angular momentum in the CO core to form an accretion disc around the central black hole [7].

The specific angular momentum (mean values over the shells) as a function of the mass coordinate is plotted for a lower mass chemically homogeneous model at different epochs. For the last calculated model, also the angular momentum of the equator is shown. Since the angular momentum is higher throughout all the evolution of the star than that of the stable orbit around a Kerr black hole, this model is a possible long GRB progenitor.

PISNe



At a certain density and temperature (grey shaded region, where the adiabatic exponent, $\Gamma < 4/3$), electron-positron pairs are produced by gamma-photons in the stellar plasma. This process reduces the pressure and lead to instability, collapse and explosive oxygen burning. The result can be the total disruption of the star producing a superluminous supernova [5].

Here we show the post helium burning evolution of a chemically homogeneous model. The very center of the star, shown with red dashed line, never enters the $\Gamma < 4/3$ region. However, some part of the stellar core goes through pair instability, as models 150-152 indicate.