Evolution of massive binary stars

Norbert Langer (Bonn University)

mass $\uparrow \longrightarrow$ our ignorance $\Uparrow$

G stars

- $\surd$ low chance to be binary product Moe
- $\surd$ $\dot{M} \simeq 0$
- $\surd$ high internal stability $(\beta = 1)$
- $\surd$ B fields ubiquitous

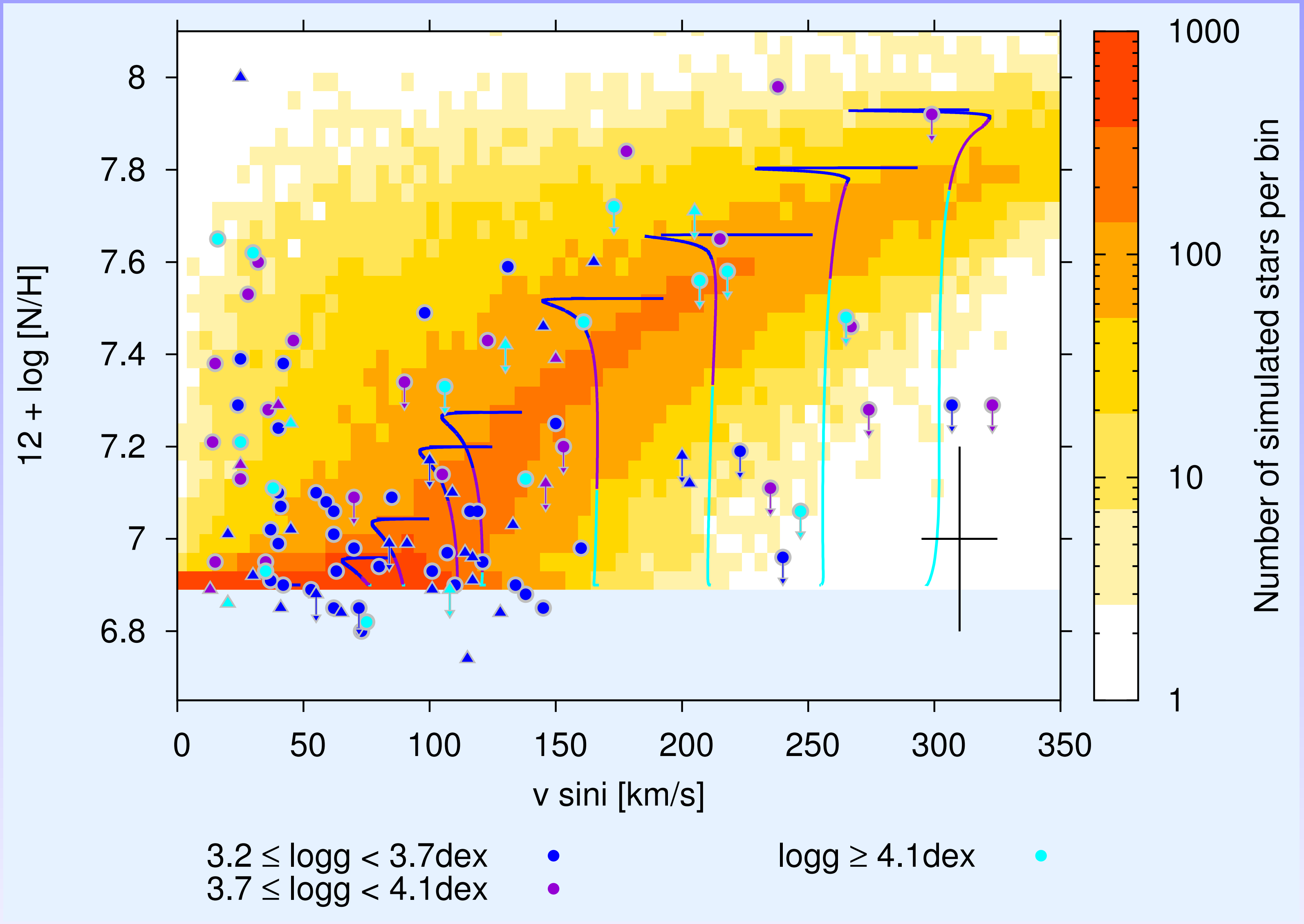
O stars

- $\surd$ high chance to be binary product Sana
- $\surd$ self-evaporate
- $\surd$ at verge of instability $(\beta \rightarrow 0)$
- $\surd$ B fields sporadic Alecian

massive stars are so relevant

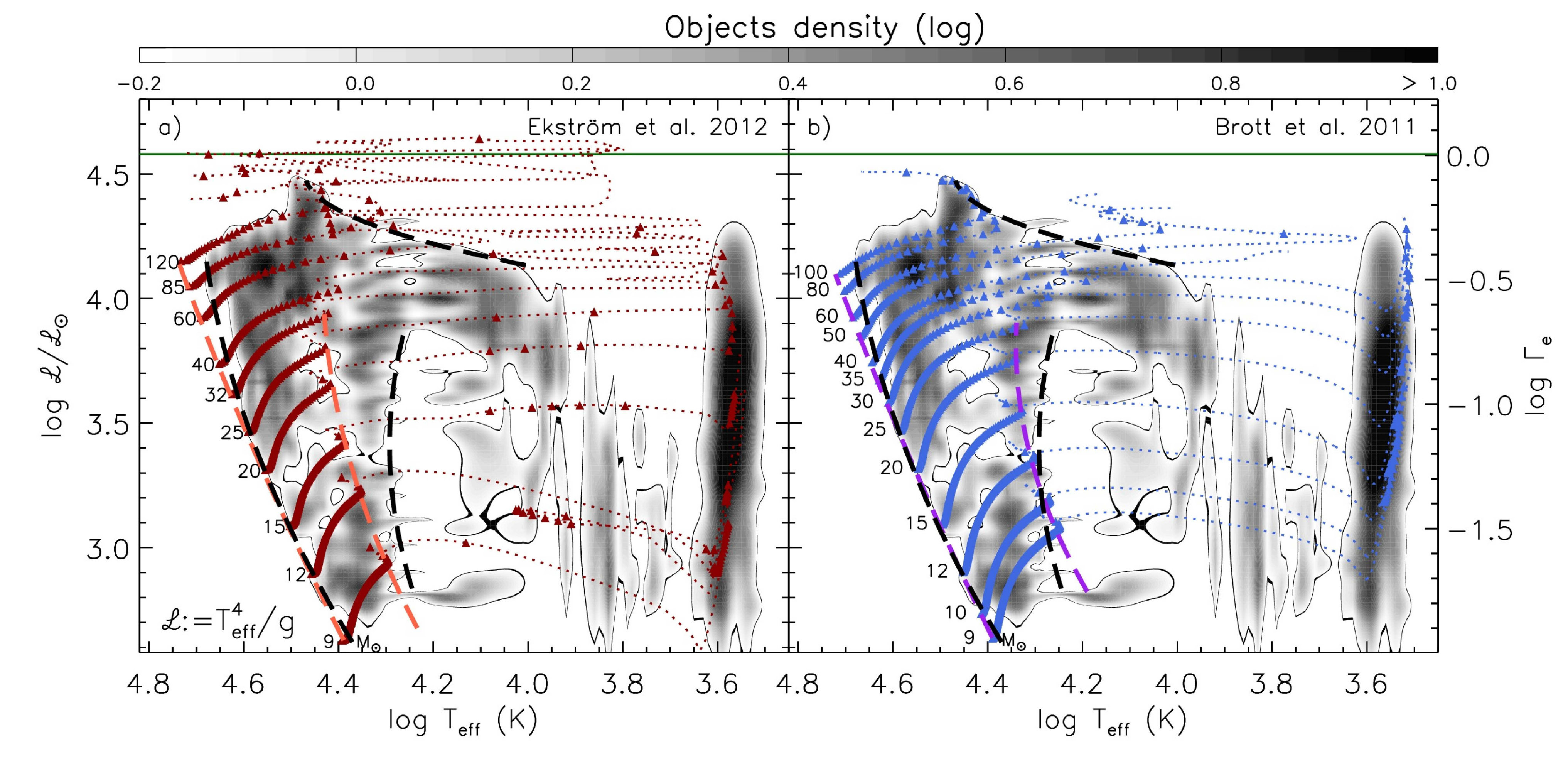
- $\surd$ SNe, GRBs, NSs, BHs
- $\surd$ determine state of ISM
- $\surd$ dominate chemical evolution

Rotational mixing: early BV stars



Brott, Evans, Hunter et al. 2011, A&A, 530, A116

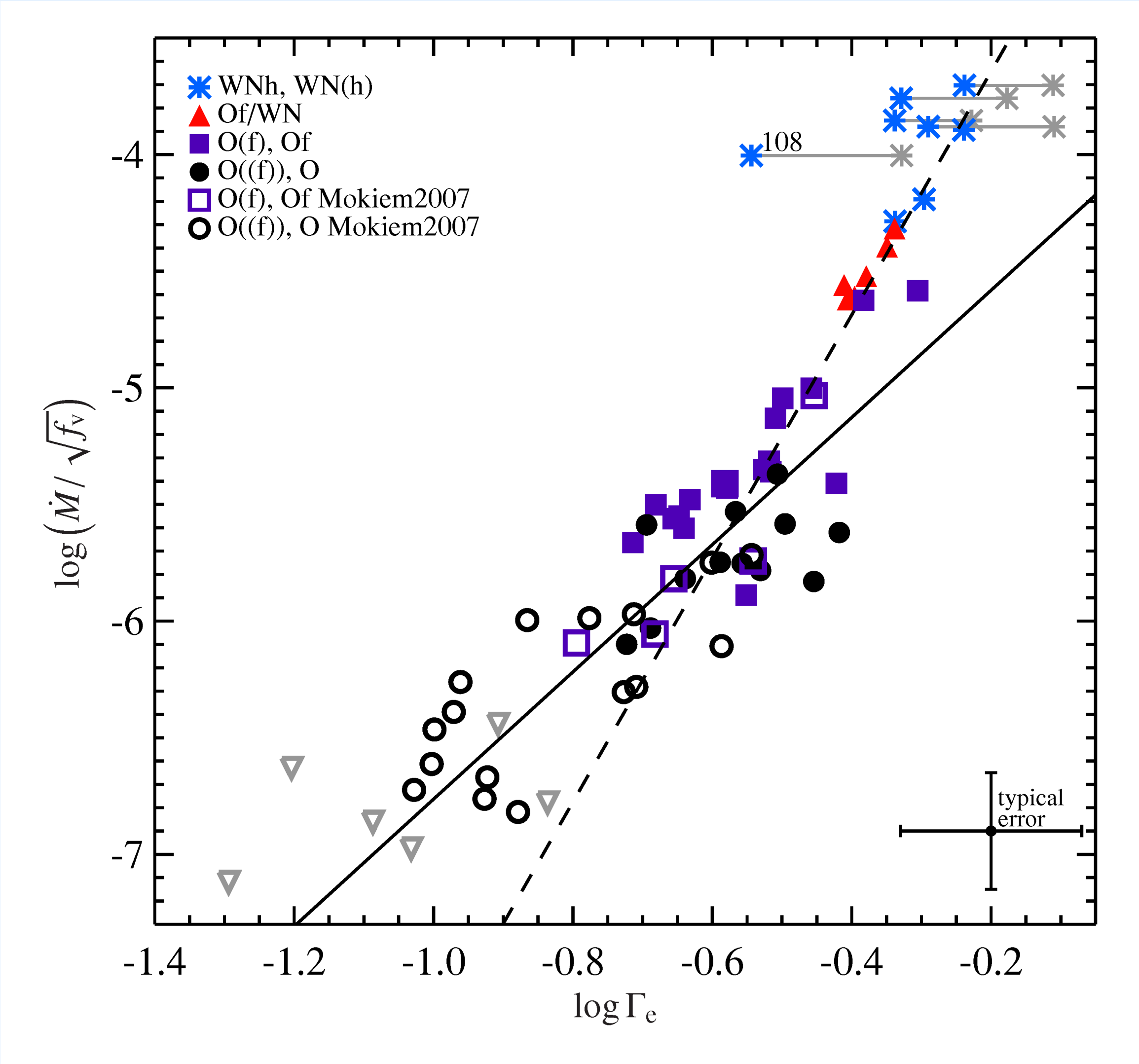
Overshooting: Galactic sHRD



600 stars: distance- and reddening-independent

Castro, Fossati, Langer, Simon-Diaz, Schneider, Izzard, 2014, A&A, 570, L13

Mass loss rates



Gräfener, Vink, de Koter, Langer, 2011, A&A, 535, A56
Bestenlehner, Gräfener, Vink et al., A&A 570, A38

Binary evolution

- tides
- mass transfer
- common envelope evolution
- merger

Tidal friction

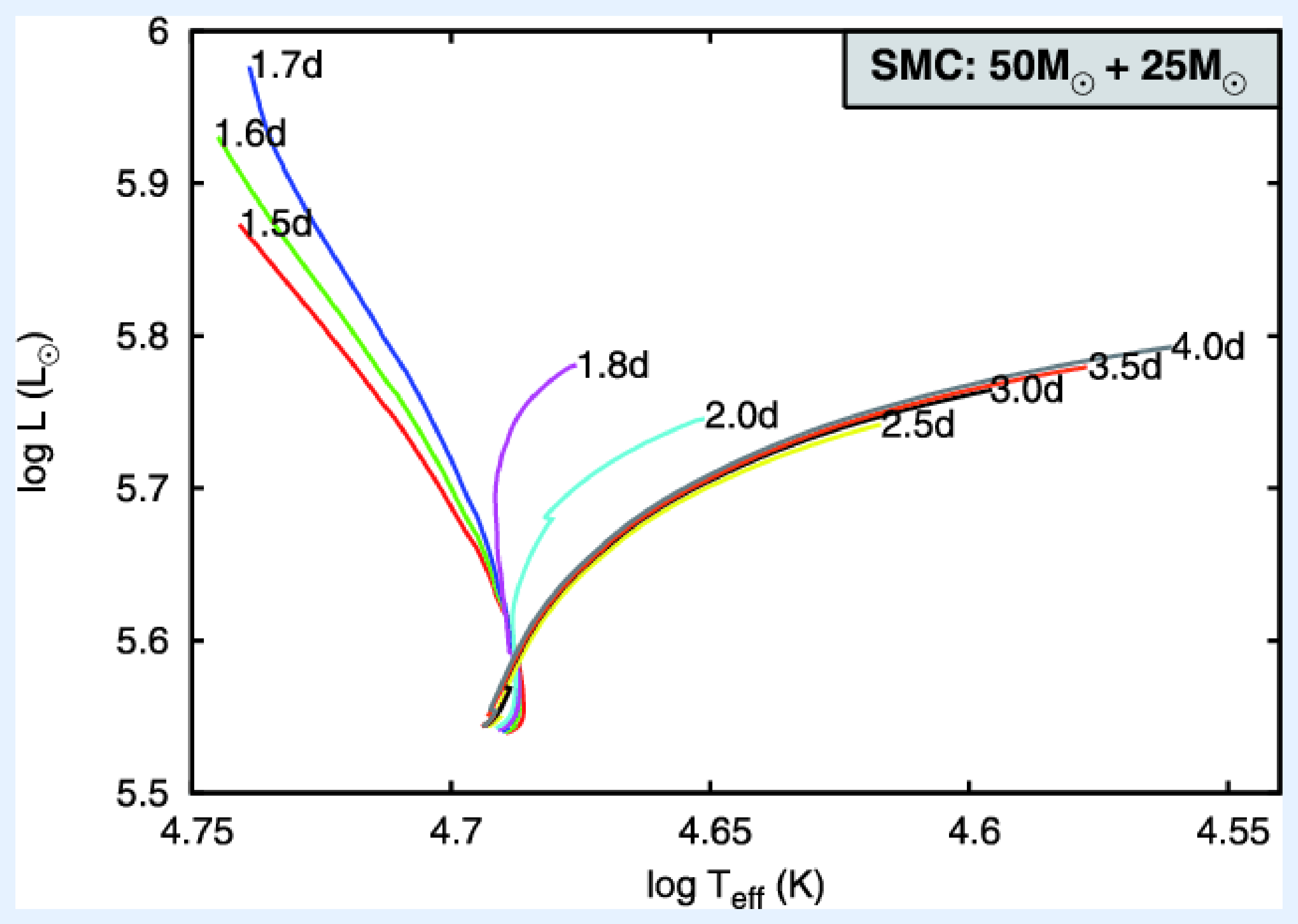
Massive stars: radiative envelopes
$\Rightarrow$ radiative damping $\rightarrow$ dynamical tide Zahn 1975, A&A, 41, 329

But: (shear-induced) turbulent viscosity may dominate

Moreno, Koenigsberger, Toledano, 2005, A&A, 437, 641
Toledano, Moreno, Koenigsberger, Detmers, Langer 2007, A&A, 461, 1057

$\rightarrow$ closer to tides in convective envelopes Zahn 1977, A&A, 57, 383

Tidally dominated MS evolution

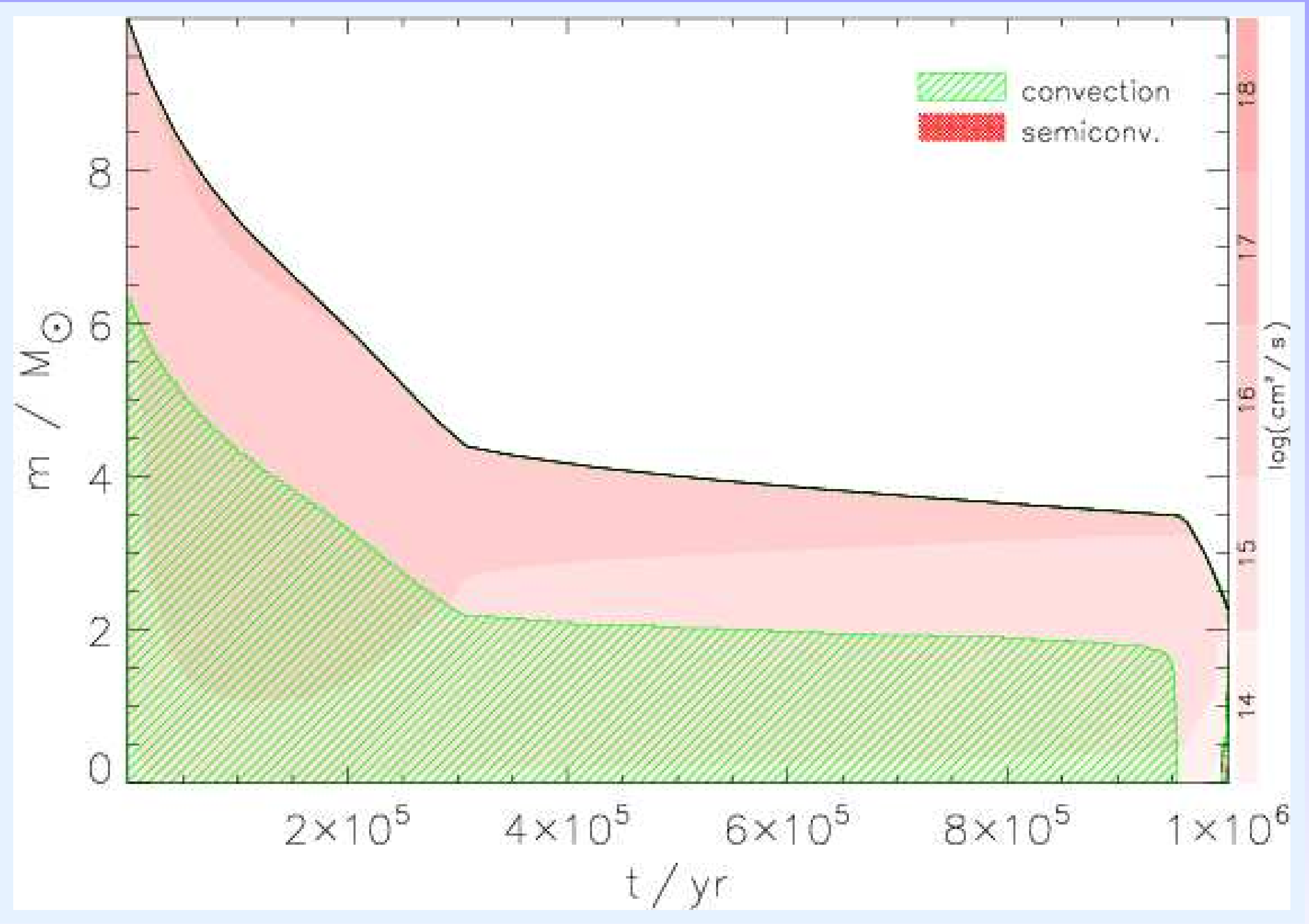


de Mink, Cantiello, Langer, Pols, Brott, Yoon, 2009, A&A, 497, 243

massive merging BHs!

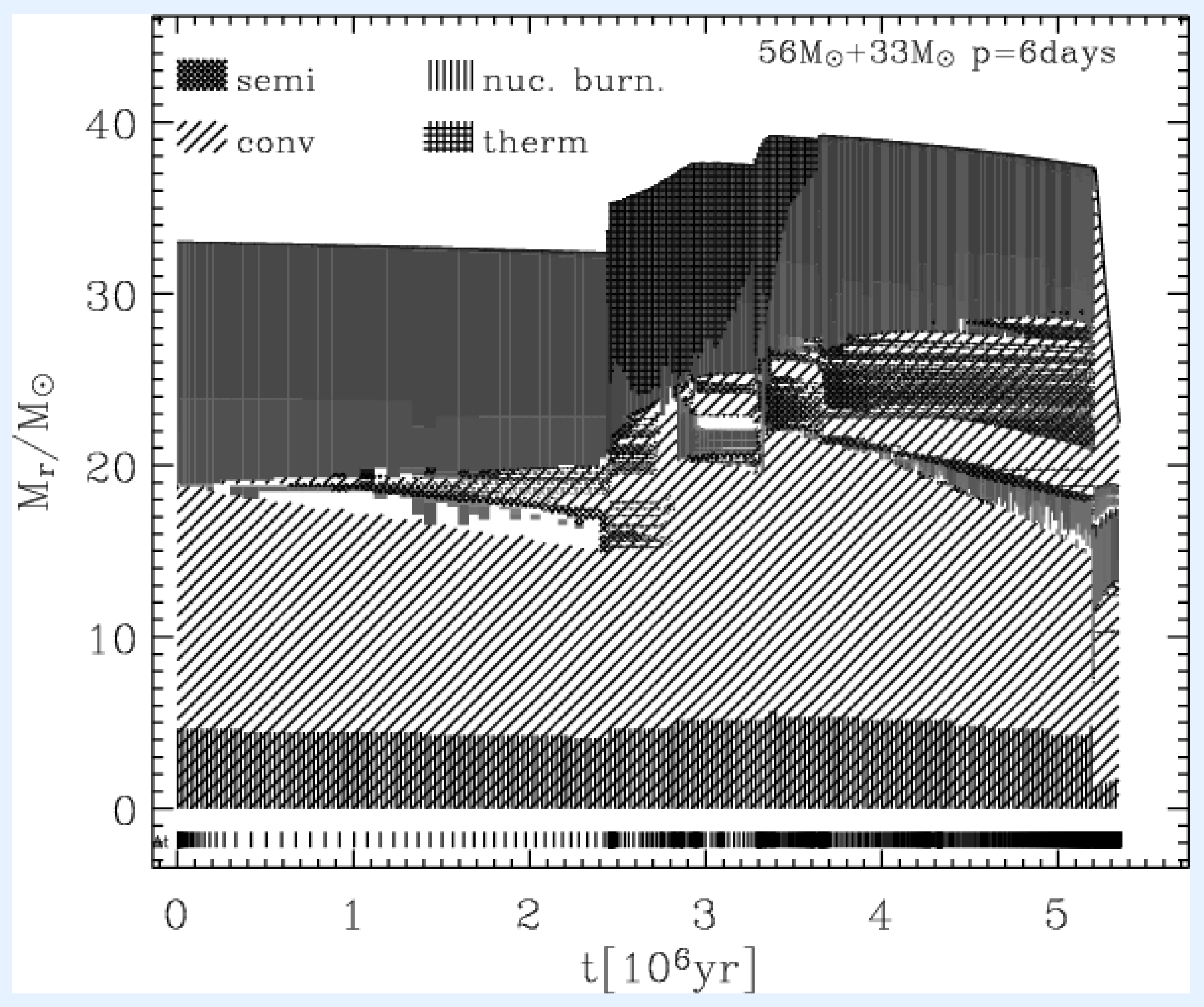
Marchant, Langer, Podsiadlowski, Tauris, Moriya, 2016, A&A, 588, A50
de Mink, Mandel, 2016, MNRAS, 460, 3545

Tidal spin-up of WR stars



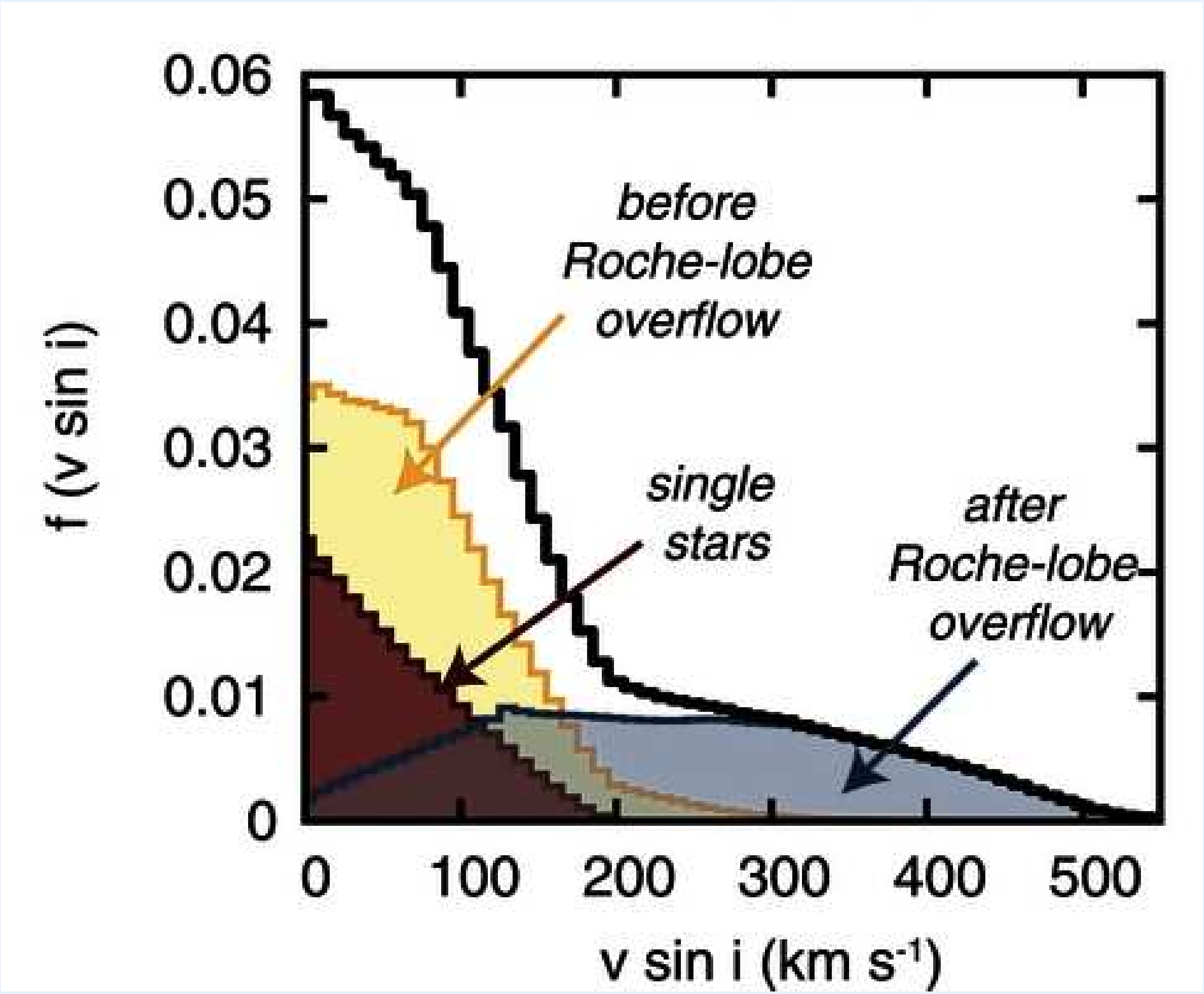
Detmers, Langer, Podsiadlowski, Izzard 2008, A&A, 484, 831

Mass transfer: rejuvenation?



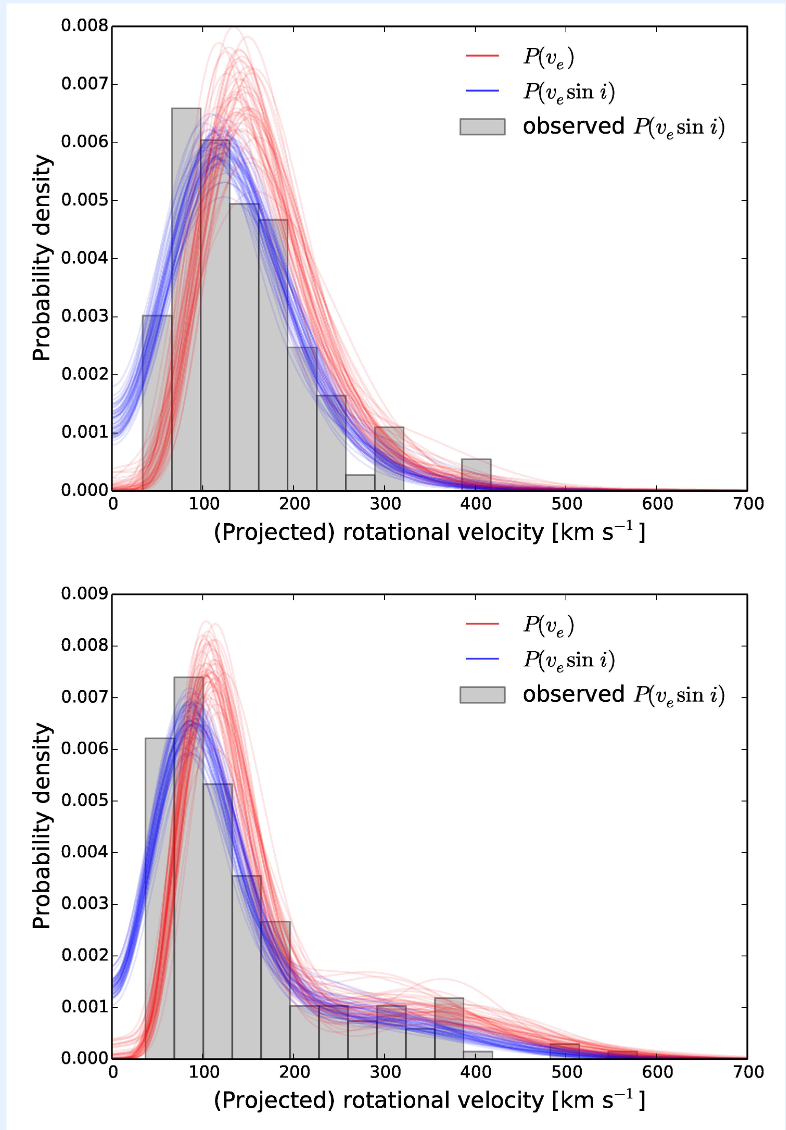
Petrovic, Langer, van der Hucht, 2005, A&A, 435, 1013

Spin-up!



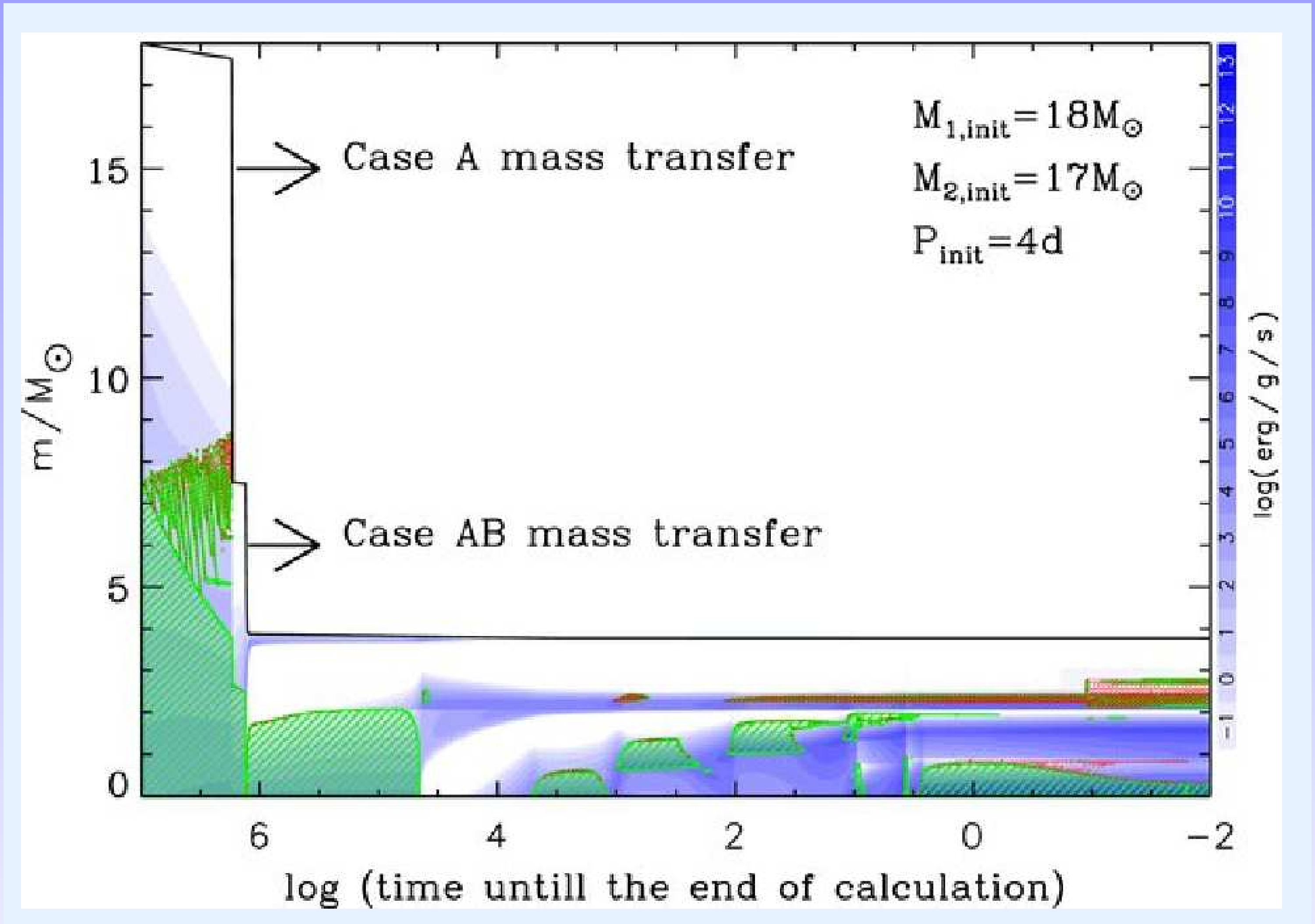
de Mink, Langer, Izzard, Sana, de Koter, 2013, ApJ, 764, 166

Spin-up!



Ramirez-Agudelo, Sana, de Mink, et al., 2015, A&A, 580, A92

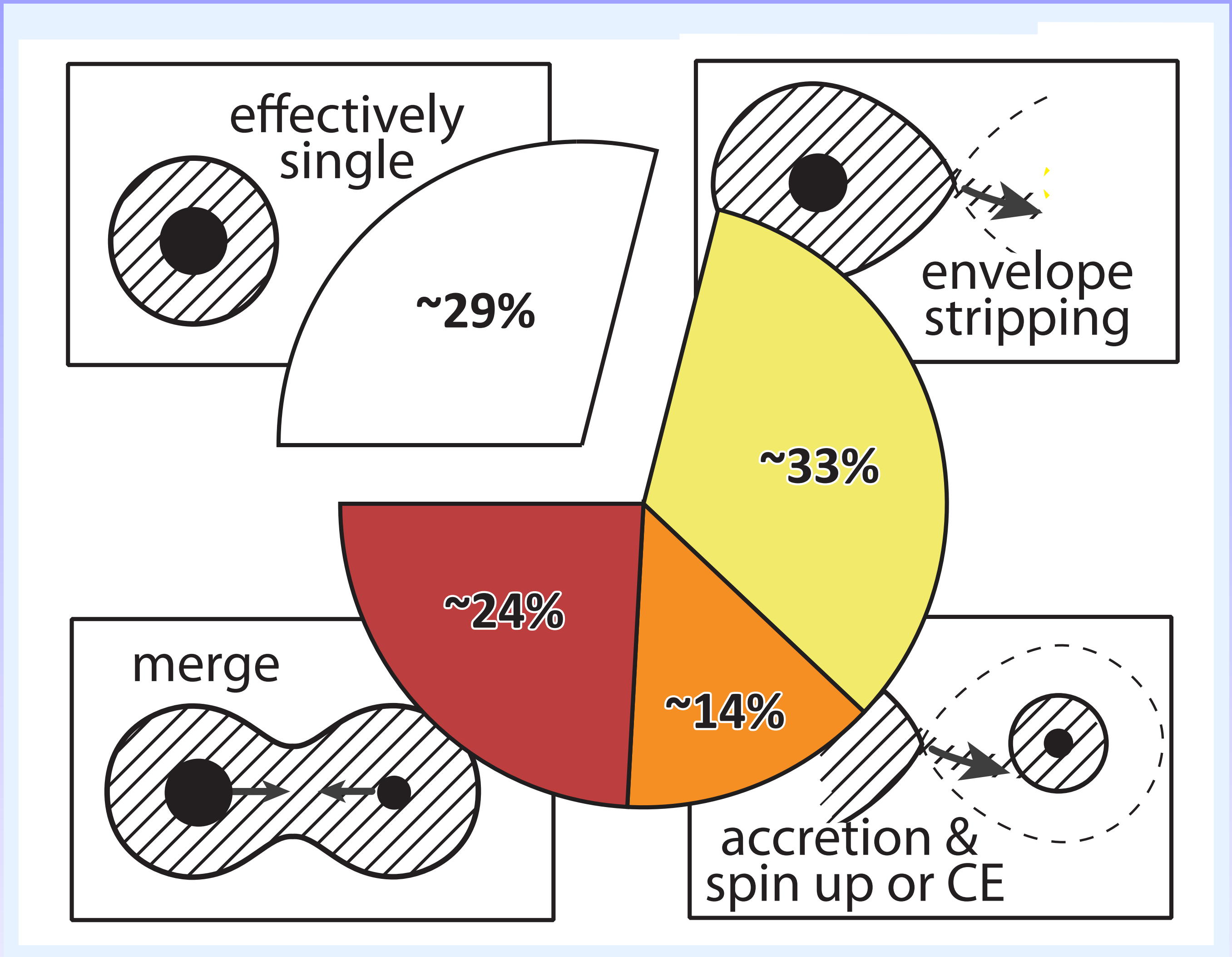
Mass stripping → SNe Ibc



Yoon, Woosley, Langer, 2010, ApJ, 725, 940

Goetberg

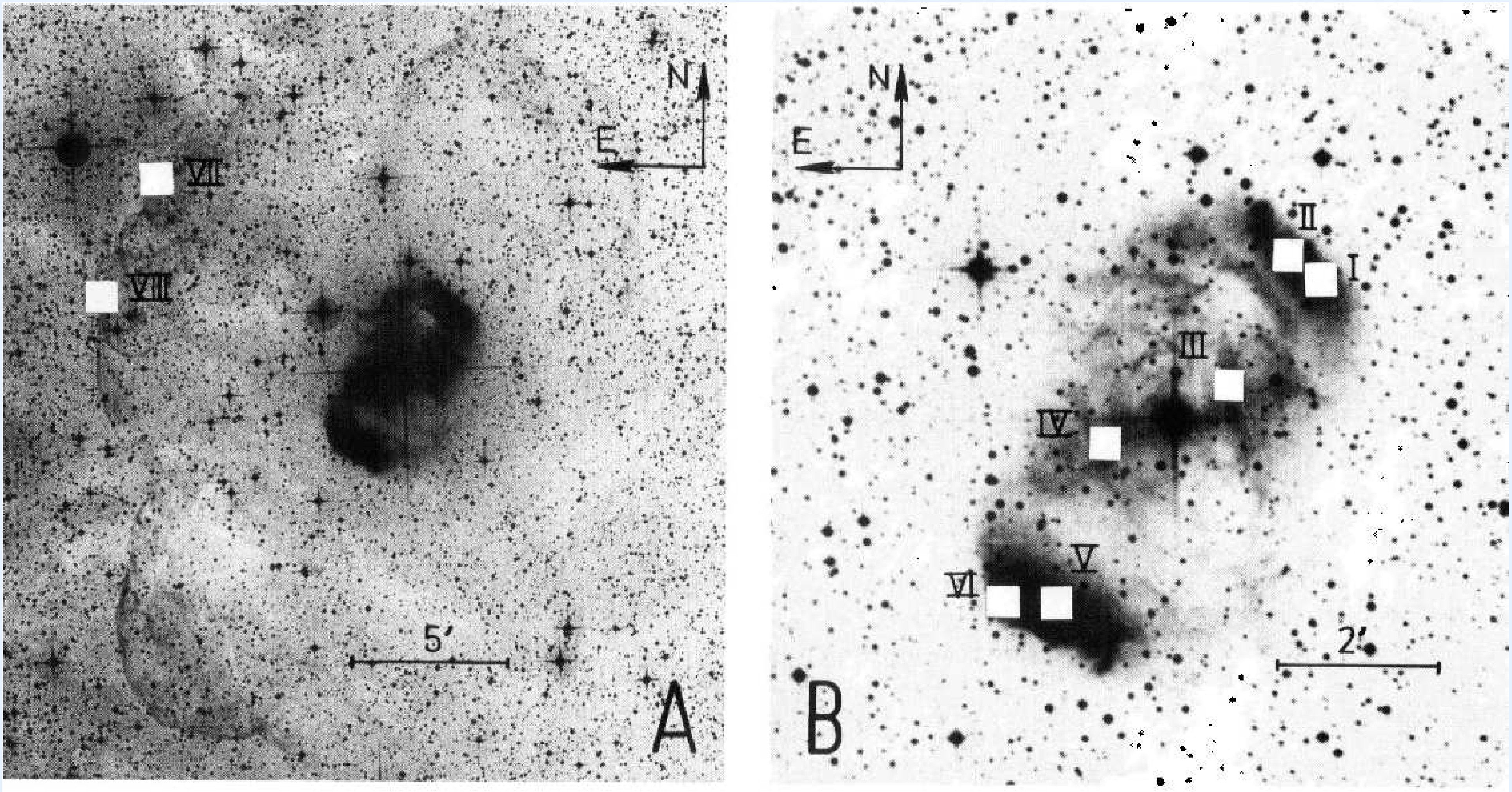
Merger: > 20%: where are they?



Sana, de Mink, Koter, Langer, et al., 2012, Science, 337, 444

Glebbeek, Gaburov, Portegies Zwart, Pols, 2013, MNRAS, 434, 3497
Ohlmann et al., in prep.

HD 148937 O6.5f?p: a smoking gun?



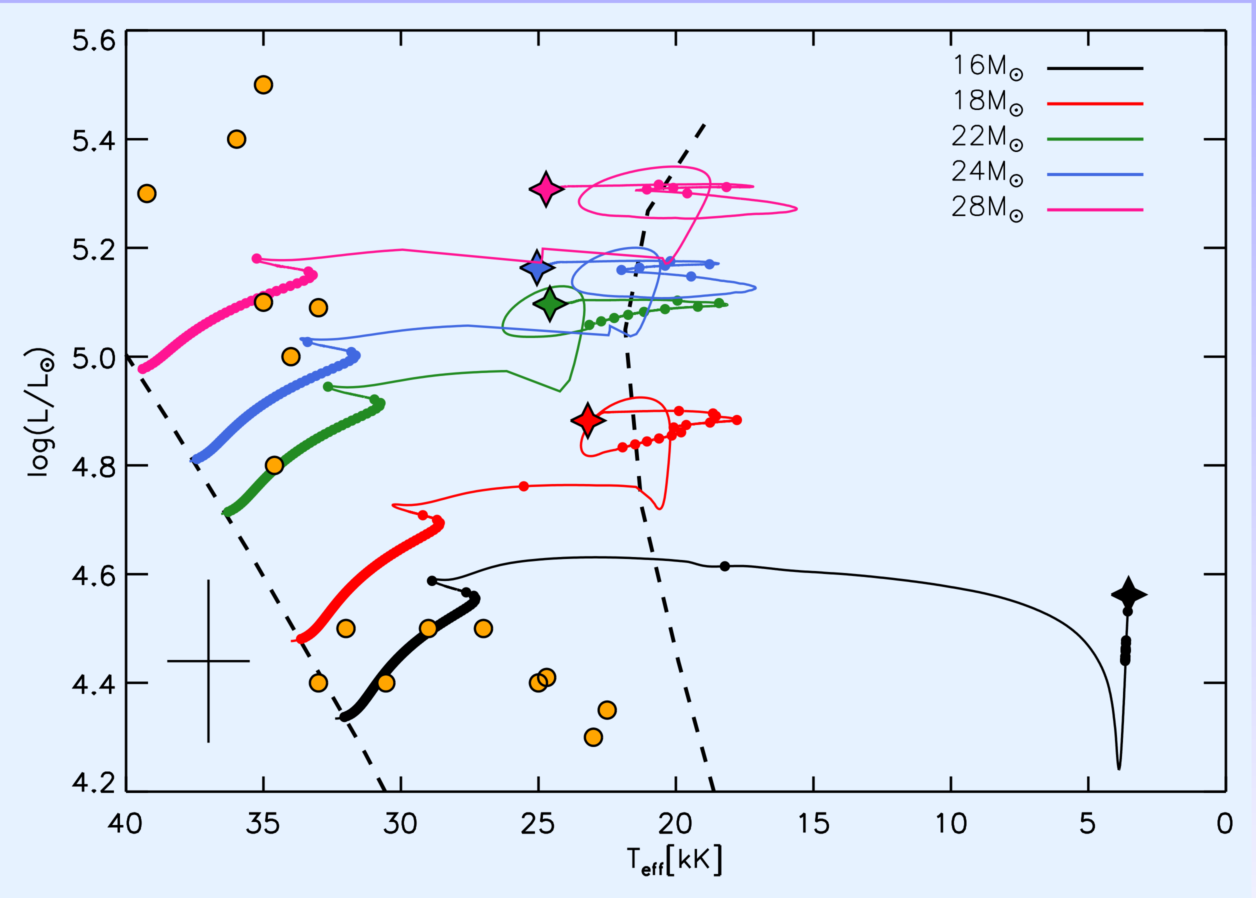
Leitherer, Chavarria-K., 1987, A&A, 175, 208
Langer, 2012, ARAA, 50, 107

Merger products

MS merger: blue stragglers Mathieu

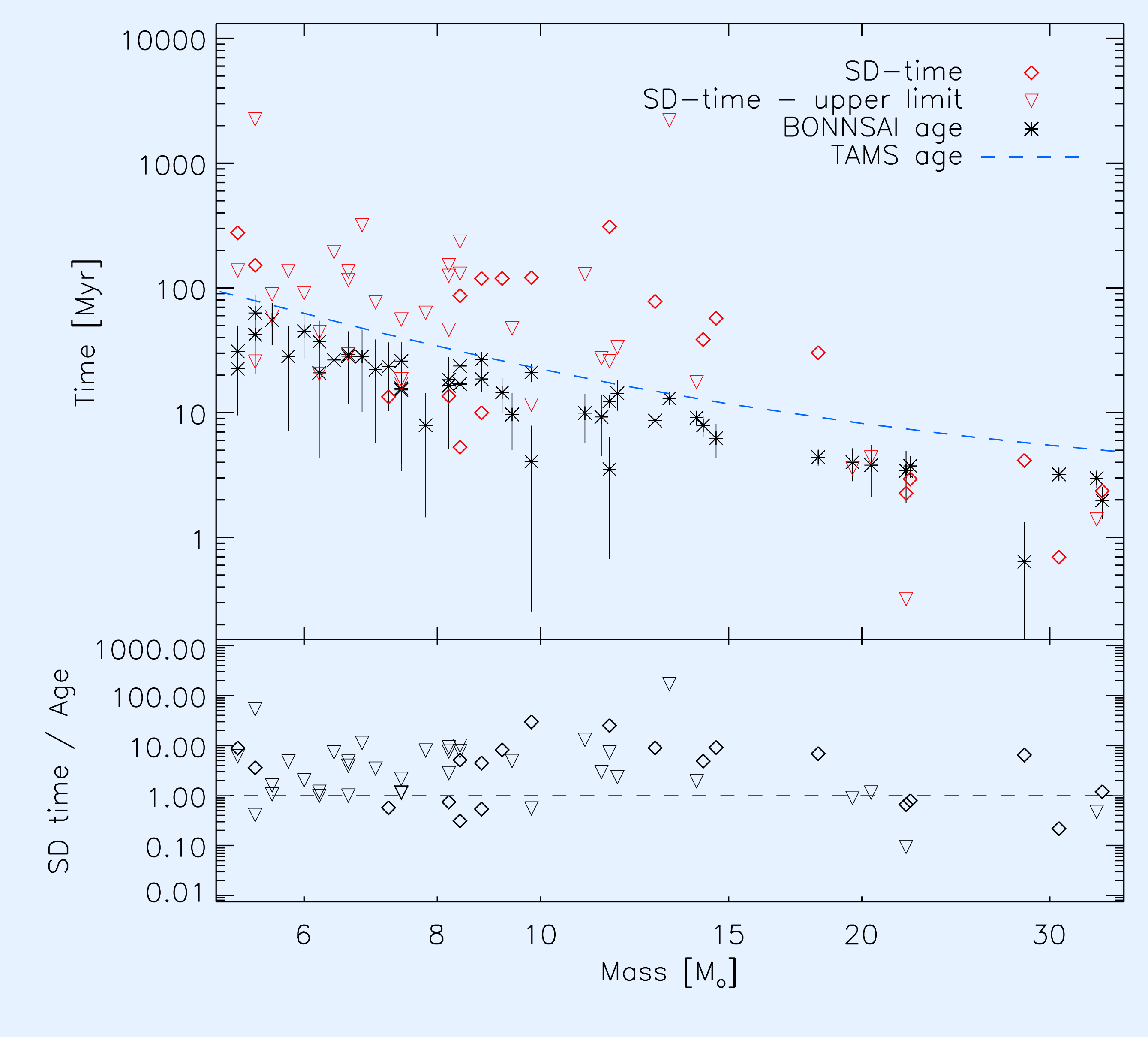
Schneider, Podsiadlowski, Langer, Castro, Fossati, MNRAS, 2016 457, 2355
Petermann, Langer, Castro, Fossati, 2015, A&A, 584, A54

post-MS merger: blue supergiant



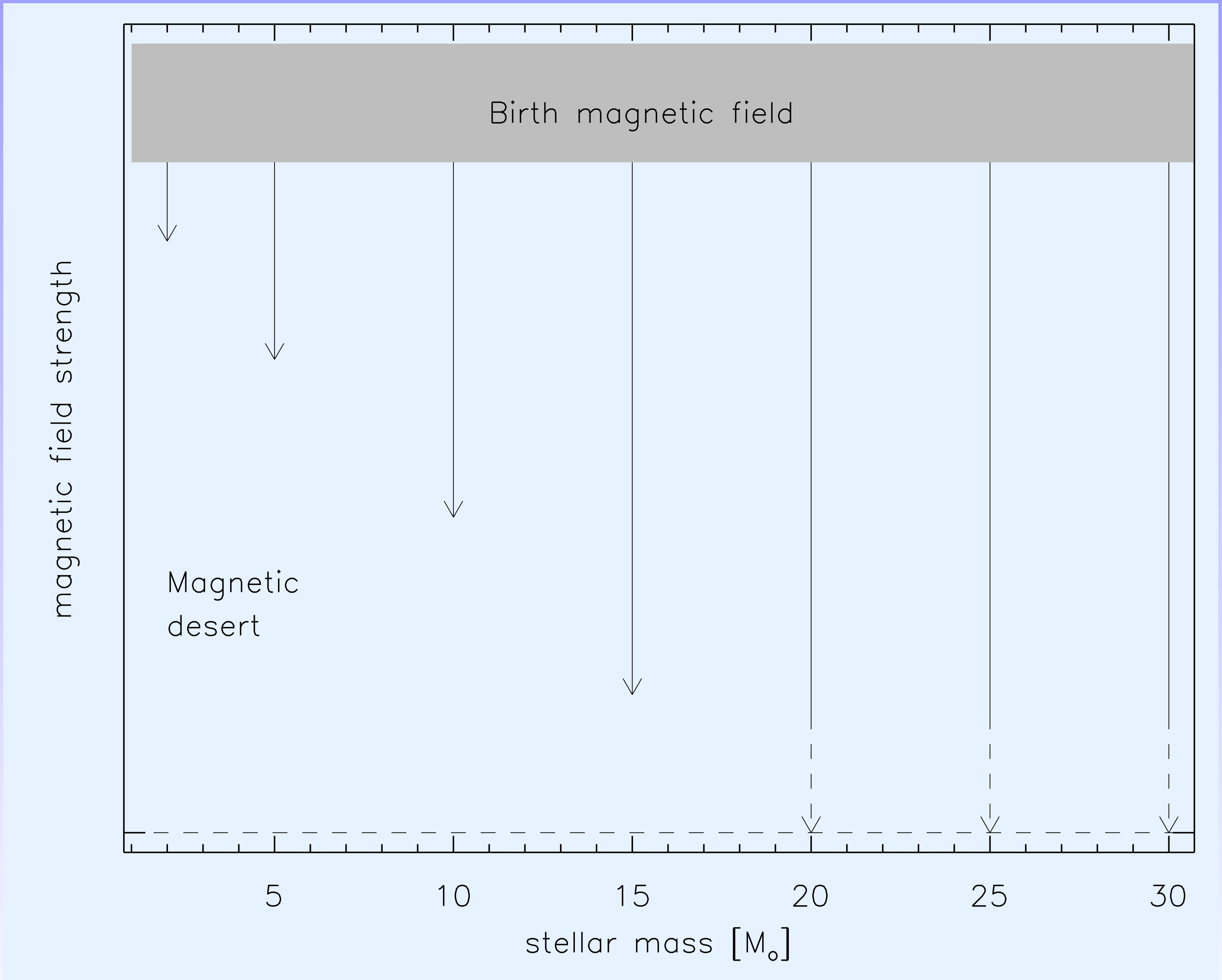
Braun, Langer, 1995, A&A, 297, 483
Justham, Podsiadlowski, Vink, 2014, ApJ, 796, 121

B-field decay



Fossati, Schneider, Castro, Langer, Simon-Diaz, Mueller, de Koter, Morel, Petit, Sana, Wade, 2016, A&A, 592, A84

B-field decay: mass dependent



Fossati+ 2016
Potter, Chitre, Tout, 2012, MNRAS, 424, 2358

Common envelope evolution: models

established for low-mass stars (CVs, ...)
not much known for massive stars ...

- ✓ theoretically, even low mass CE ejection difficult
  Clayton, Podsiadlowski, Ivanova, Justham, arXiv170508457
  Ohlmann, Röpke, Pakmor, Springel, 2016, ApJ, 816, L9
- ✓ massive stars: unclear core/envelope boundary
  envelope binding could be large, but also very small (LBV) Kruckow, Tauris, Langer, Szecsi, Marchant, Podsiadlowski, 2016, A&A, 596, A58

Common envelope evolution: observations

CEE occurs in massive binaries!

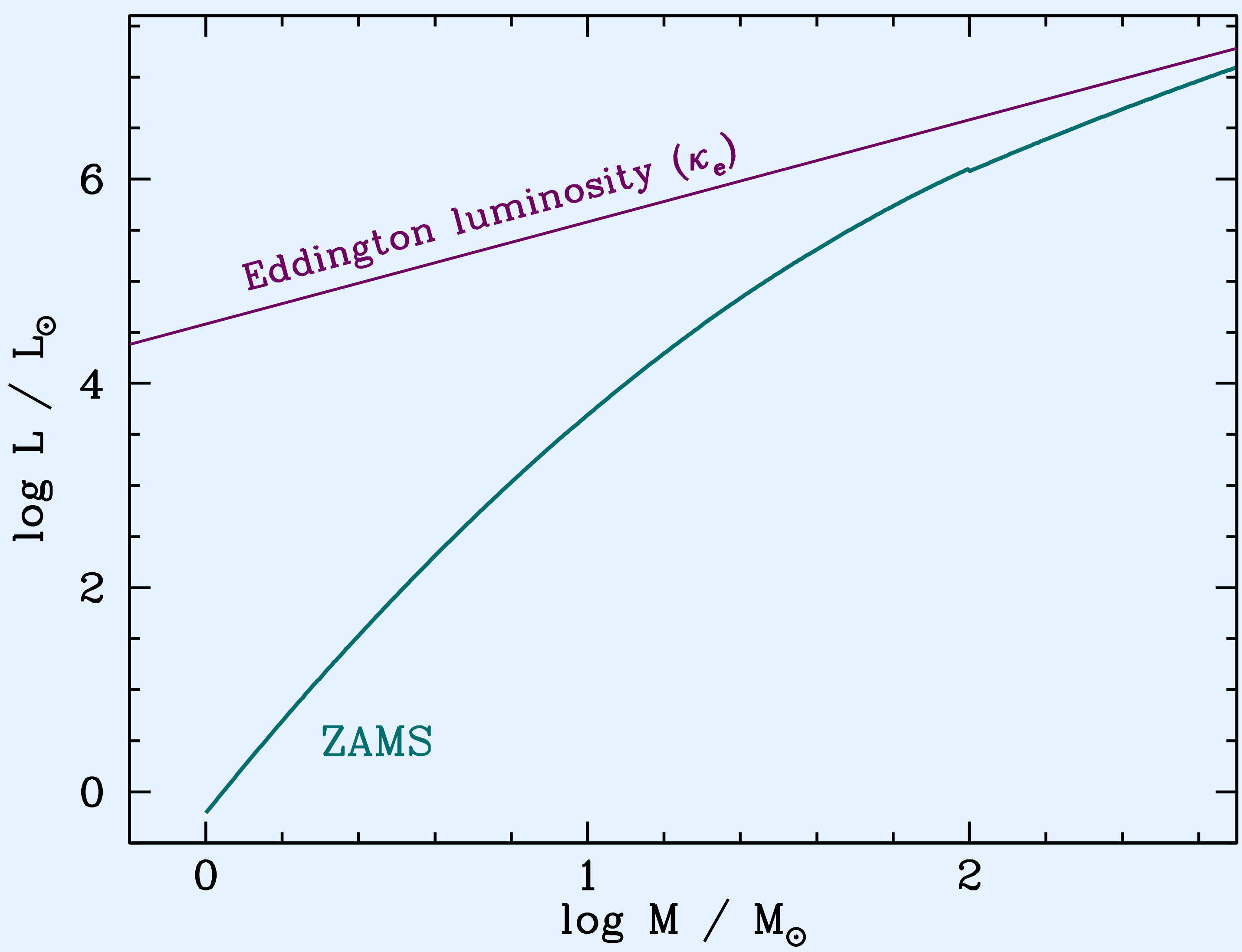
- ✓ 15 NS-NS binaries, 7 with $P_{\mathrm{orbit}} < 1.2\,\mathrm{d}$

  Tauris, Kramer, Freire, Wex, Janka, Langer, Podsiadlowski, Bozzo, Chaty, Kruckow, van den Heuvel, Antoniadis, Breton, Champion, ApJ, arXiv:1706.09438

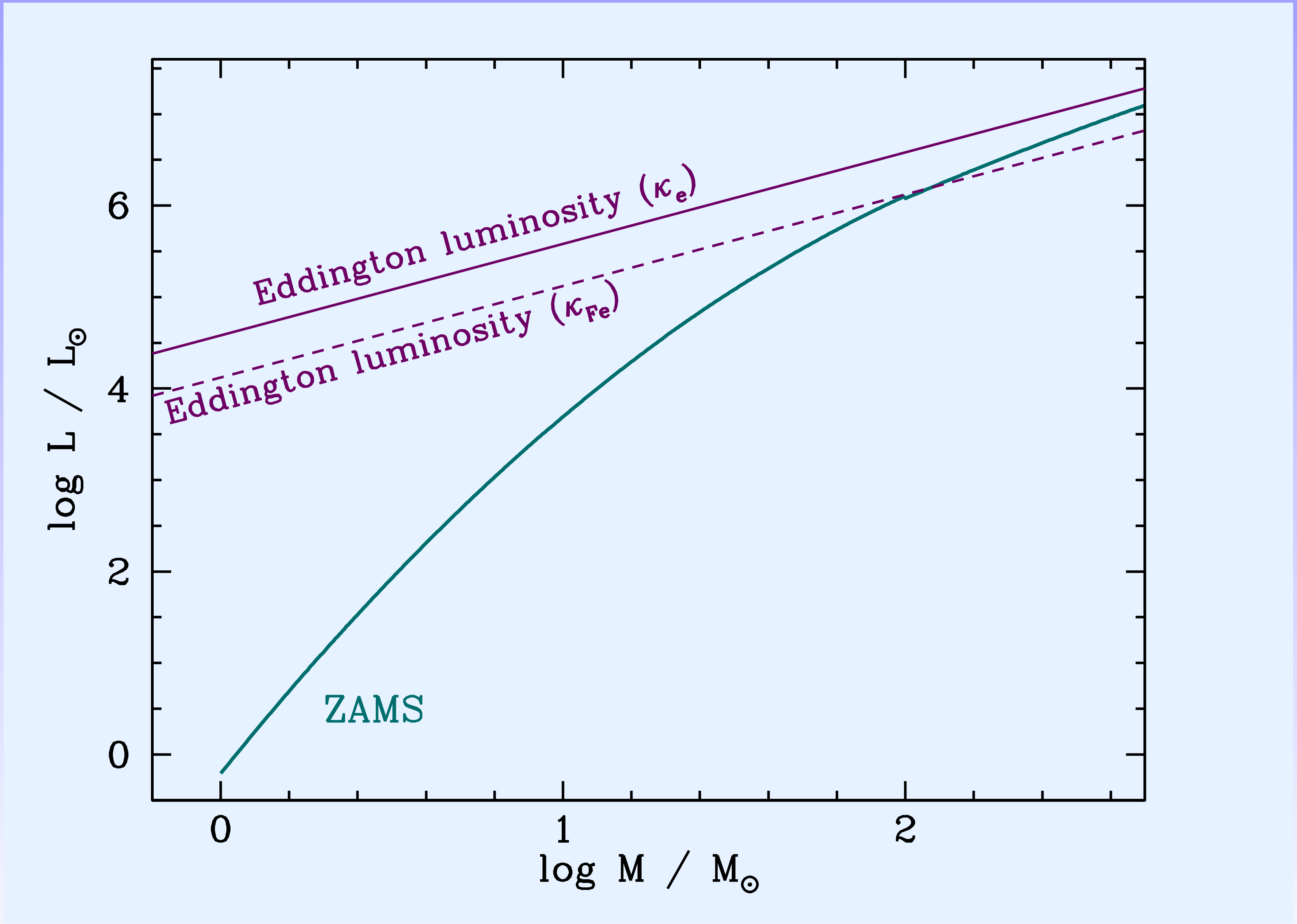
- ✓ ultra-stripped supernovae Tauris, Langer, Podsiadlowski, 2015, A&A, 451, 2123
- ✓ LMBHBs? Fragos, McClintock, 2015, ApJ, 800, 17
- ✓ However: no CEE in Galactic WR binaries!

  Shara, Crawford, Vanbeveren, Moffat, Zurek, Crause, 2017, MNRAS, 464, 2066

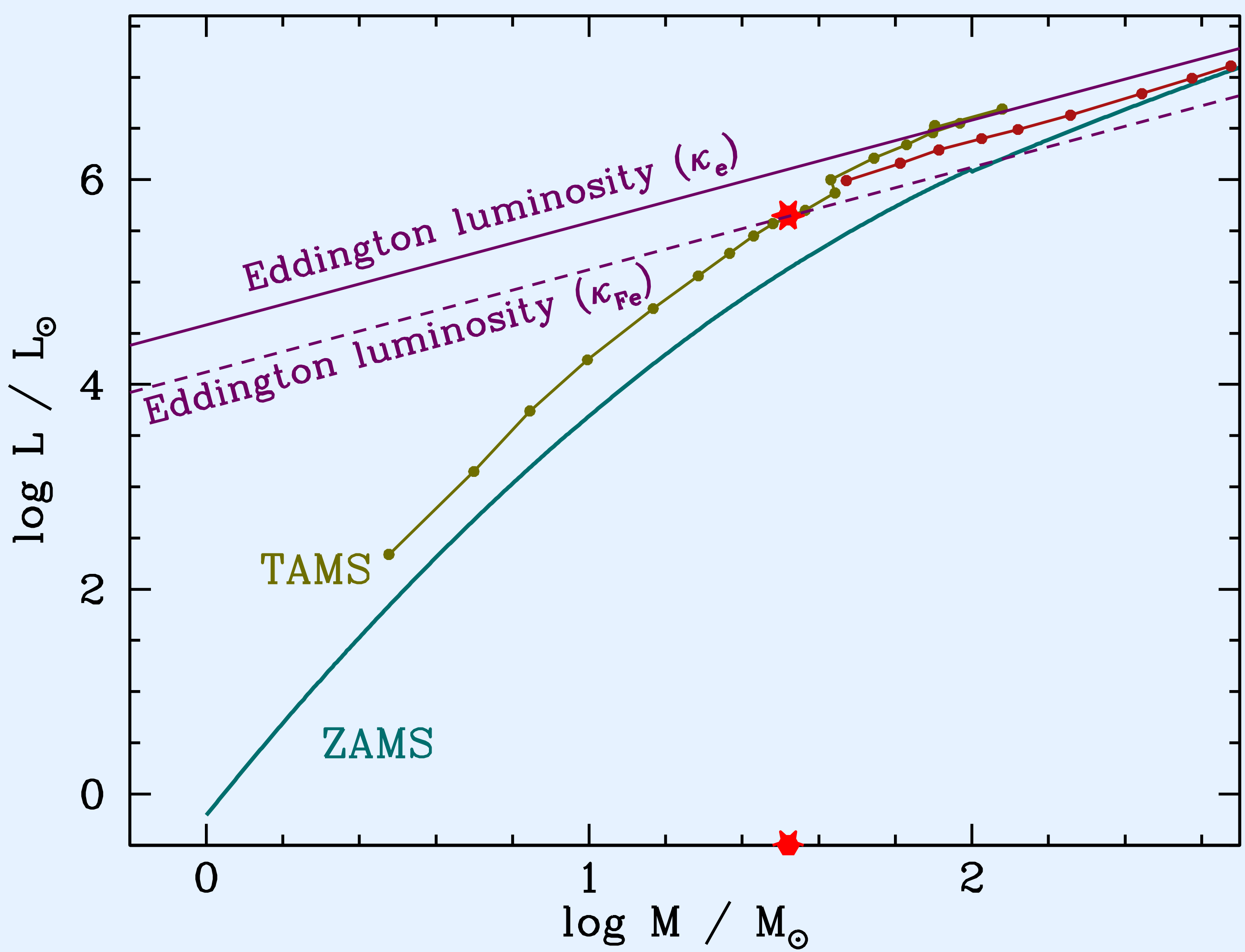
$M - L_{\mathrm{Eddington}}$ relation



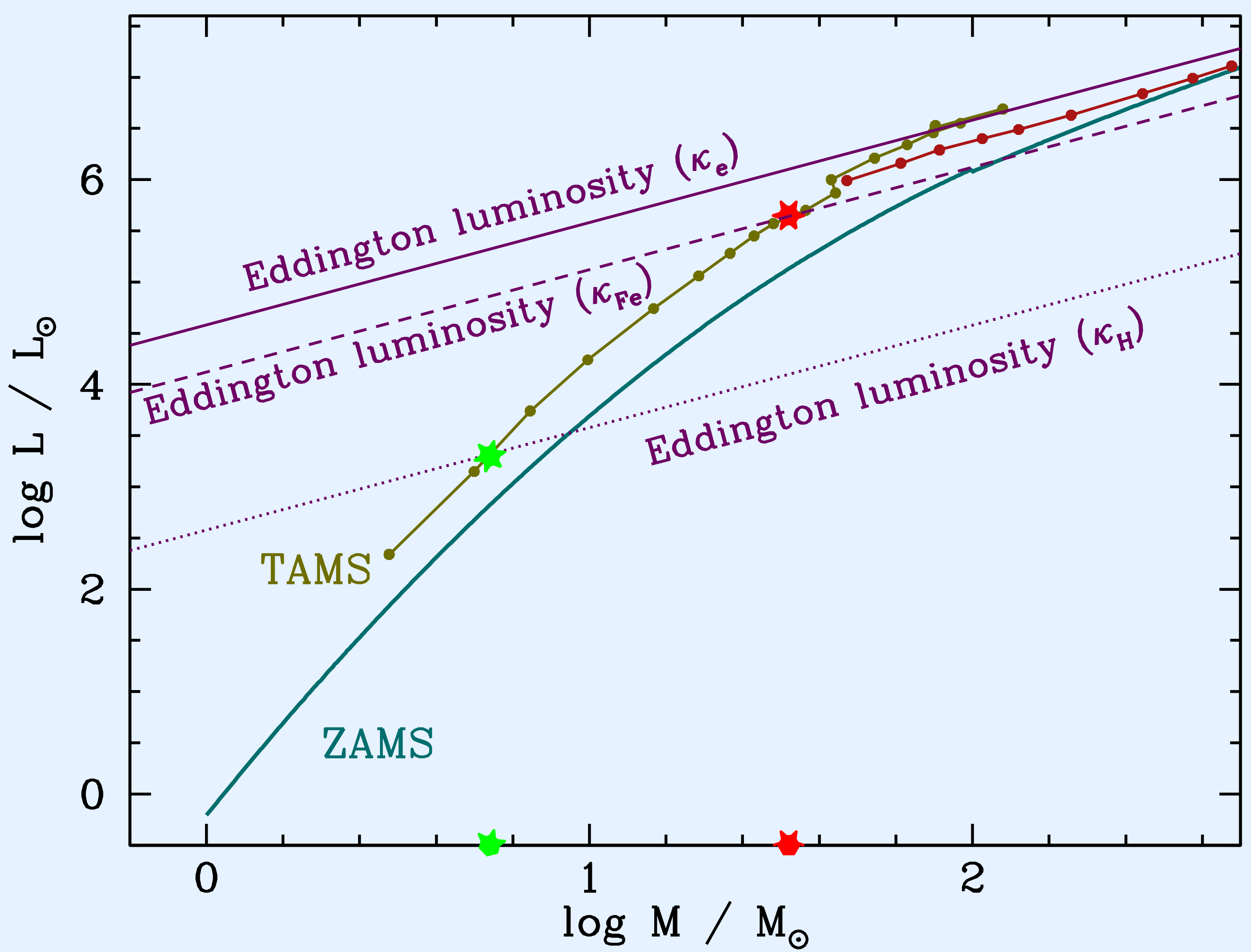
$M - L_{\mathrm{Eddington}}$ relation



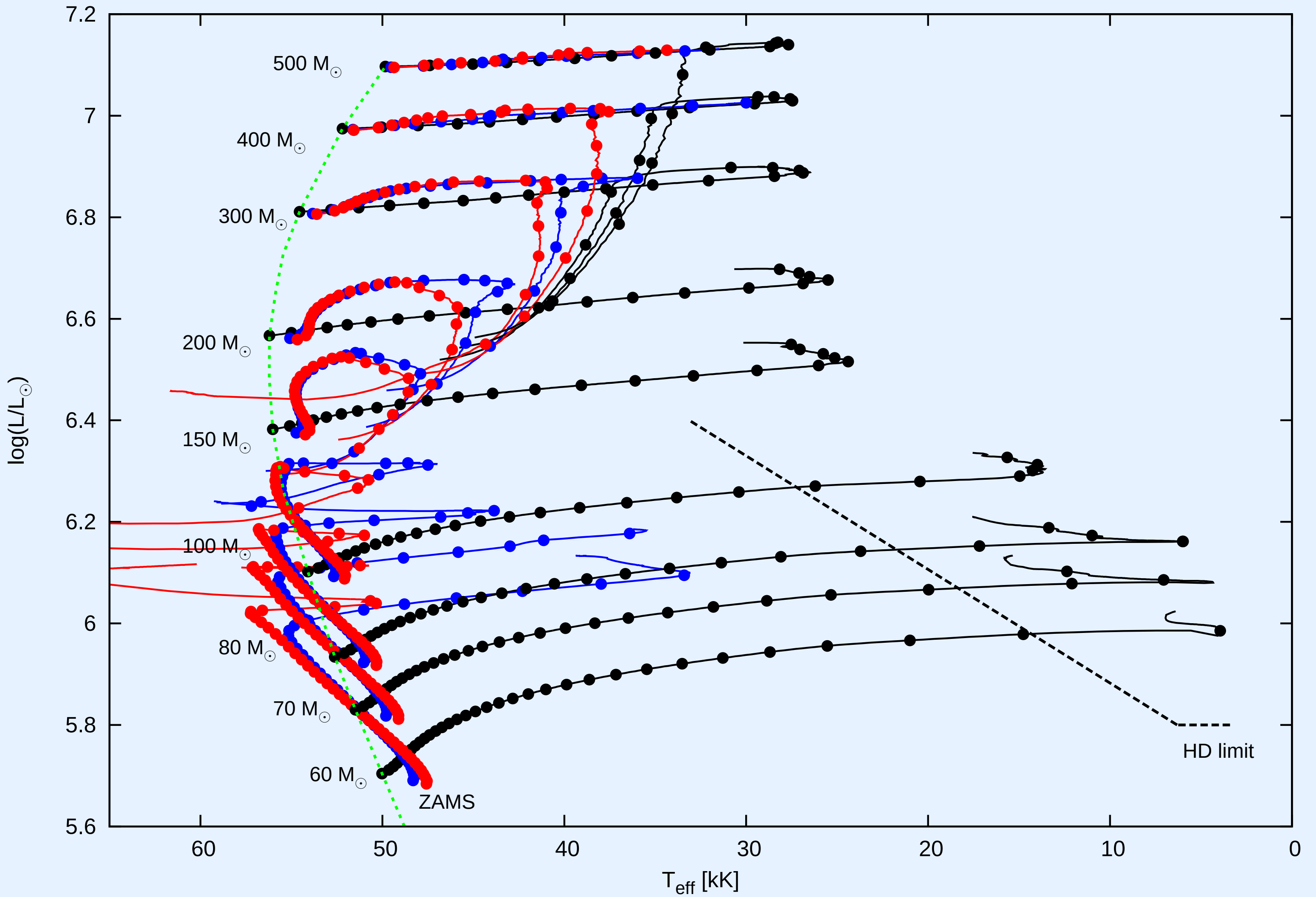
$M - L_{\mathrm{Eddington}}$ **relation**



$M - L_{\mathrm{Eddington}}$ relation

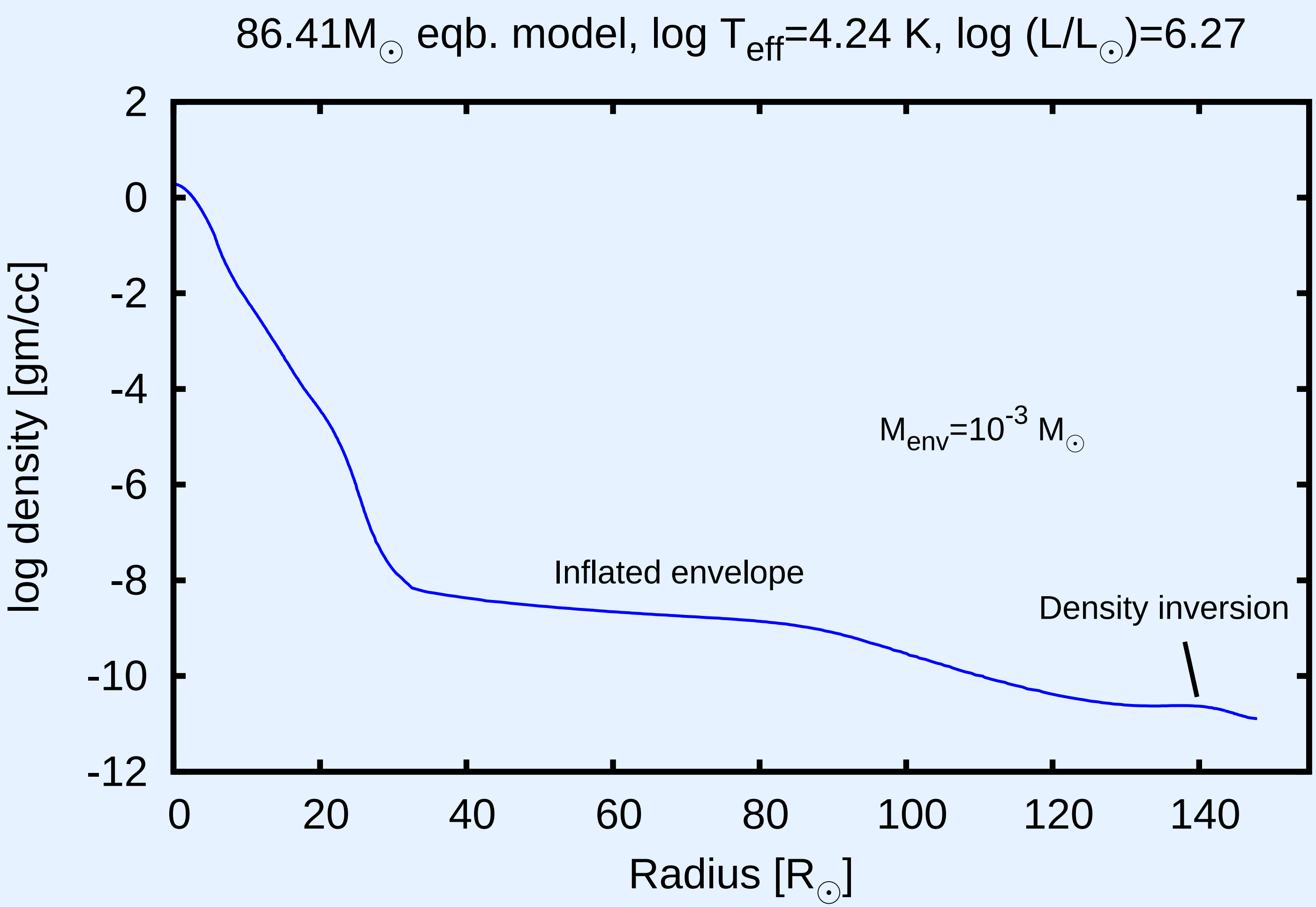


Very massive star models



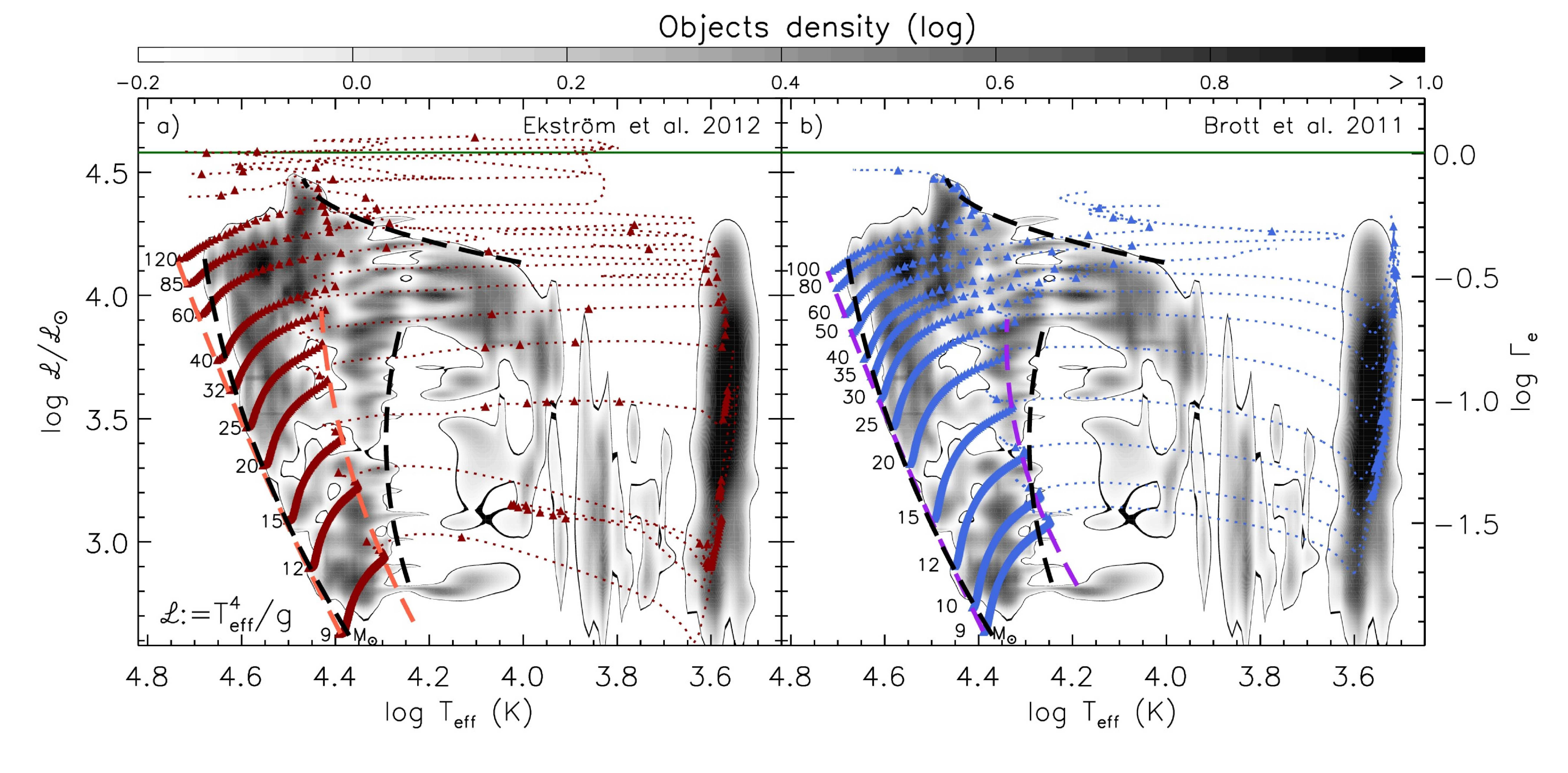
Köhler, Langer, de Koter, de Mink, et al. 2015, A&A, 573, A71

Inflation



Sanyal, Grassitelli, Langer, Bestenlehner, 2015, A&A, 580, A20

The Galactic sHRD



600 stars: distance- and reddening-independent

Castro, Fossati, Langer, Simon-Diaz, Schneider, Izzard, 2014, A&A, 570, L13

Summary

- √ stellar models: the higher the mass, the larger the uncertainty
- √ uncertainties in single star physics affects binary evolution model: mixing and mass loss
- √ rejuvenation of mass gainers?
- √ spin-up of mass gainers!
- √ merger: B-field?
- √ B-field decay in massive stars
- √ CE-evolution occurs massive stars
- √ CE-evolution occurs in VMS?
- √ VMS: inflation & LBV mass loss