Evolution of massive binary stars

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mass $\uparrow$ \rightarrow our ignorance $\uparrow$

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

massive stars are so relevant
- ✓ SNe, GRBs, NSs, BHs
- ✓ determine state of ISM
- ✓ dominate chemical evolution

O stars
- ✓ high chance to be binary product
- ✓ self-evaporate
- ✓ at verge of instability ($\beta \rightarrow 0$)
- ✓ B fields sporadic

Sana
Alecian

ESO Garching, July 5, 2017 – p. 2
Rotational mixing: early BV stars

600 stars: distance- and reddening-independent

Mass loss rates

Bestenlehner, Gräfener, Vink et al., A&A 570, A38
Binary evolution

- tides
- mass transfer
- common envelope evolution
- merger
Tidal friction

Massive stars: radiative envelopes ⇒ radiative damping → dynamical tide

But: (shear-induced) turbulent viscosity may dominate

→ closer to tides in convective envelopes


Tidally dominated MS evolution

massive merging BHs!

Tidal spin-up of WR stars

Mass transfer: rejuvenation?


Image: Mass transfer: rejuvenation? with a graph showing the evolution of a binary system over time, with labels for semi, nuc. burn, conv, and therm.
Spin-up!

Spin-up!

Mass stripping $\rightarrow$ SNe Ibc


Goetheberg
Merger: > 20%: where are they?

Sana, de Mink, Koter, Langer, et al., 2012, Science, 337, 444
Ohlmann et al., in prep.
HD 148937 O6.5f?p: a smoking gun?

Langer, 2012, ARAA, 50, 107
Merger products

**MS merger: blue stragglers** Mathieu


**post-MS merger: blue supergiant**

B-field decay

B-field decay: mass dependent

Fossati+ 2016
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, arXiv 170508457

✓ massive stars: unclear core/envelope boundary
  envelope binding could be large, but also very small (LBV)
Common envelope evolution: observations

CEE occurs in massive binaries!

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


✓ ultra-stripped supernovae


✓ LMBHBs?


✓ However: no CEE in Galactic WR binaries!

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

![Graph showing the $M - L_{\text{Eddington}}$ relation with log L / L_☉ on the y-axis and log M / M☉ on the x-axis. The graph includes a line labeled "Eddington luminosity ($\kappa_e$)" and a curve labeled "ZAMS." ]
$M - L_{\text{Eddington}}$ relation

\[ \log \frac{L}{L_\odot} \text{ vs. } \log \frac{M}{M_\odot} \]

- Eddington luminosity ($\kappa_e$)
- Eddington luminosity ($\kappa_{Fe}$)
- ZAMS
$M - L_{\text{Eddington}}$ relation

![Graph showing the relationship between mass ($M$) and Eddington luminosity ($L_{\text{Eddington}}$). The graph includes lines for Eddington luminosity ($\kappa_e$) and Eddington luminosity ($\kappa_{\text{Fe}}$), with markers for TAMS and ZAMS.]
$M - L_{\text{Eddington}}$ relation

![Graph showing the relationship between $M$ and $L_{\text{Eddington}}$.](image)

- Eddington luminosity ($\kappa_e$)
- Eddington luminosity ($\kappa_{\text{Fe}}$)
- Eddington luminosity ($\kappa_H$)

**Axes:**
- Logarithmic scale for $L / L_\odot$ on the y-axis.
- Logarithmic scale for $M / M_\odot$ on the x-axis.

Key points:
- **TAMS** (Upper Main Sequence)
- **ZAMS** (Zero Age Main Sequence)
Very massive star models

Inflation

86.41 \(M_\odot\) eqb. model, \(\log T_{\text{eff}}=4.24\) K, \(\log (L/L_\odot)=6.27\)

\[\text{log density [gm/cc]}\]

\[\text{Radius [R}_\odot\text{]}\]

\(M_{\text{env}}=10^{-3} M_\odot\)

Inflated envelope

Density inversion

The Galactic sHRD

600 stars: distance- and reddening-independent

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