The evolution of massive stars: constraints from surface abundances

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Evolution of massive stars

Large uncertainties in predictions of stellar evolution
⇒ need for observational constraints
Evolution of massive stars depends on initial mass, rotation, metallicity, and mass loss. The diagrams illustrate how luminosity changes with effective temperature, showing different behaviors for varying initial masses and metallicity.
Surface abundances

- H burning through CNO cycle
- Timescale for nuclear burning longer than mixing timescale (e.g. in rotating stars)
- C (and O) converted to N

→ chemical patterns should be observed at surface of stars
→ surface abundances = good indicators of mixing processes
Determination of surface abundances

Observation

Model

C
N
O

Normalized flux
Data from the MiMeS survey (ESPaDoNS, NARVAL, HARPSpol optical spectra)

Wade et al. 16

3700-7000+ Å
R > 65000
Echelle spectra
S/N > 300

Martins et al. 15a
See also Bouret et al. 12, 13, Rivero Gonzalez et al. 12, Przybilla et al. 10, Maeder et al. 14
Surface abundances depend on 1) initial mass, 2) time, 3) metallicity, 4) rotation
More evolved stars have more chemically processed surfaces

Martins et al. 15a
See also Heap et al. 06
Surface abundances depend on 1) initial mass, 2) time, 3) metallicity, 4) rotation

Brott et al. 2011
(also: Maeder & Meynet 97, 00, Ekstroem et al. 2012, Georgy et al. 2013, Langer 12...)

Surface abundances and rotation
Trend: chemical enrichment depends on mass

Martins et al. 15a
Trend: chemical enrichment depends on mass

O stars from Martins et al. (2017)
B stars from Hunter et al. (2009) and Nieva & Przybilla (2012)

Trend: chemical enrichment depends on mass
Surface abundances depend on 1) initial mass, 2) time, 3) metallicity, 4) rotation.
Models of Ekstroem et al. (2012) at solar metallicity account for the distribution of stars in the abundance - vsini diagram.

See also Cazorla et al. 17a, 17b
Models of Brott et al. (2011) at LMC metallicity do not reproduce the distribution of stars.
Surface abundances: B stars - effects of rotation

An uncertain fraction of stars escapes predictions (10-40% depending on authors, samples...)

LMC
B-type stars
(M=8-20 Msun)

Hunter et al. 2008
Brott et al. 2011

M = 13 Msun
Surface abundances show increasing degree of CNO processing:

- ✔ with age
- ✔ with initial mass
- • with rotational velocity:
  - ✔ at solar metallicity, above 30 Msun
  - ✗ below 30 Msun and at sub-solar metallicity
- ? with metallicity

Results also depend on formalism used to include rotational mixing in evolutionary models
Effect of binarity

Fraction of binary systems among OB stars:

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<th>Observed</th>
<th>Bias corrected</th>
<th>References</th>
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- What is the fraction of massive stars in binary systems?
- Does it vary with environment?
- What are the effects on stellar evolution (compared to single star evolution)?
Impact on interpretation of star forming galaxies at z~2-3

→ Binary models favored over single star models
Surface chemical abundances significantly different from single stars only after mass transfer (in donor)

Martins et al. 17b
data from OHP/T193
Large uncertainties on mass loss rates for all phases of evolution of massive stars

Impact on prediction of stellar evolution, progenitors of SN/BRG + GW emitters

See also Bouret et al. 15
Conclusions / Perspectives

- Some predictions of stellar evolution with rotation are observed - surface chemical processing larger at later evolutionary phases and higher masses

Others remain to be fully tested - effect of metallicity (including Local Group / ELT) - trend with rotation

- Effects of binarity on surface properties and stellar evolution remain widely unconstrained
  → need for observational constraints + evolutionary models

- What are the real mass loss rates of (massive) stars at different phases of their evolution?
  → PNPS action on mass loss?
Conclusions / Perspectives

Massive stars in the Local Group resolved with the E-ELT

- stellar winds at $Z < Z_{SMC}$ (see Bouret et al. 15)
- long-soft GRBs favored at low $Z$
- massive stars evolution and properties at metallicity typical of redshift of peak of star formation ($z \sim 2-3$)

Wei et al. 14

Yuan et al. 12

Wang & Dai 14
Atelier aux journées de la SF2A 2018

"Etoiles massives: de la formation aux stades ultimes, un état des lieux des recherches en France"

jeudi 5 juillet après-midi

Contributions bienvenues via le site des journées.

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