**Mass loss notes**

* A phenomenon observed in all stars. Triggering events can cause a sudden ejection of mass out of the stars:
  + Coronal mass ejection
  + Gravitational attraction in a binary system
  + The Ascension from the MS phase to a red giant or red supergiant
  + Solar winds

Solar winds [1]

* Caused by radiative pressure in the solar core
* The Sun loses around 3x10-14 solar masses per year

Binary system

[1]

* When a star is a member of a pair of close orbiting binary stars
* Gravitational attraction of the gases near the centre of mass is sufficient to pull gas from one star to its partner. [1]
* Especially prominent when the partner is a black-hole, neutron star or a white dwarf star

[4]

* Mass transfer occurs when star expands to fill the Roche-lobe
  + Roche-lobe is the region around a star in a binary system within which orbiting material is gravitationally bound to that star [2]

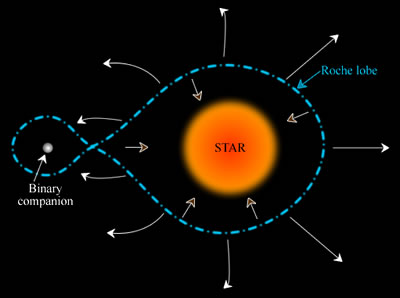


Figure : Roche lobe diagram explanation [3]

* If angular momentum is decreased, then the orbit of the partner can shrink and therefore the Roche-lobe can shrink allowing the transfer of material outside of this region
* The three cases of mass transfer in binary systems are:
  + Mass transfer when the donor is on the MS phase (pre-core H exhaustion)
  + Mass transfer when the donor is in or evolving into a red giant phase (Post-core H exhaustion)
  + Mass transfer when the donor is in a supergiant phase (Post-core He burning)

[5]

* Observations by Sana et al. (2012) reported an interacting binary fraction of 0.69 ± 0.09 for O-type stars in open clusters in the Galaxy.
* Sana et al. (2013) and Dunstall et al. (2015) studied the Tarantula region in the LMC, reporting interacting binary fractions of 0.51 ± 0.04 for O-type stars and 0.58 ± 0.11 for B-type stars, respectively.
* Because BSGs are typically the brightest stars in their galaxies in optical light, they are ideal candidates for determining extragalactic distances

[6]

* The FGLR uses a spectroscopic method that allows for accurate correction of interstellar reddening and extinction of individual BSGs, which avoids extinction and metallicity induced uncertainties.
* The dereddened apparent magnitude in conjunction with the absolute magnitude obtained from the FGLR can then be used to determine accurate distances. This method has been successful to galaxies up to distances of 7Mpc (2.16x1020km) ((Urbaneja et al. 2008)
* The observed FGLR can also be used to constrain the stellar evolution models, in this case using BPASS suite of binary models and the MESA stelar evolution code to study properties.
* BPASS models: initial masses of 9, 15, 20 and 30 solar masses, metallicity of 0.02 and mass ratio of q=0.9 from the v2.1BPASS suite of binary models
* MESA models: same properties as BPASS models
* [5]
* The secondary stars in the binary system begin their evolution on the MS phase, once mass transfer occurs from the primary star to the secondary star, due to the Roche-lobe overflow (RLOF), luminosity and temperature increase
* When the primary star dies, a new system composed of a neutron star and another secondary star is formed.
* we find that primary stars of mass 30 Mʘ in binary systems with initial periods P & 4,000 days (log(P/days) = 3.6) will not undergo mass transfer to the secondary
* At short distances, tidal interactions occur, and systems are more likely to come into contact during their evolution.
* To induce chemically homogeneous evolution (CHE) by tidal interaction, a short initial orbital period is needed, stellar winds tend to widen the orbit and prevent CHE, therefore preventing true BSGs from forming.
* In very short orbital period systems (orbital period of around 1 day), tides rapidly cause the period of rotation to match the orbital period (by process of synchronisation). Due to the orbital period being so small, stars may be rotating so quickly that they may follow a homogeneous evolution (such stars will not evolve into BSGs).
* “Rotation has an impact of the duration of the RSG phase and therefore impacts the probability that a system will undergo RLOF during that phase”.
* This may effect rotation of the star (increase of the mass of the core during the MS phase) which leads to the beginning of the RSG phase at an early stage of the core He-burning process.
* Convection also plays a crucial role in producing BSGs (using the Ledoux criterion instead of the Schwarzschild criterion), can affect the surface chemical composition and possibly the timing of the mass transfer episodes in binary systems.
* Based on the BPASS suite and a rad of models computed with MESA, we find that most BSGs in close binary systems follow the observed FGLR. There are some BSGs outside the FGLR observed scatter which are produced when primary stars in a binary system undergo a mass transfer episode during the RSG phase and then evolve back to blue with reduced mass and reduced flux-gravity, gF.
* These systems might also be produced by single star evolution with strong mass losses during the RSG phase.
* A high mass ratio will in general maximize the effects of the secondary on the primary spectrum, for a mass ratio of q=0.9, the contribution of a secondary star to the spectrum of a primary BSG has only a very small effect on the determination of Teff and log g.
* The effects on the determination of interstellar reddening and bolometric magnitude are also small.
* Most BSGs in close binary systems should be suitable for extragalactic distance determinations using the FGLR, although some possible outliers exist.
* After mass transfer and interaction with he companion star, massive stars may only be recognized as BSGs in binary systems with a certain range of orbital periods, which depends on the mass ratio of the two components

Mass ejection

* Solar flares and CMEs can cause stars with weak hold on upper layers (common in WR stars due to it having a weak hold on the upper layers of the star) using the flux-weighted gravity luminosity relationship (FGLR):
* The FGLR is an observational relationship for BSGs between the absolute bolometric magnitude, Mbol and the “flux-weighted gravity”, gF. For a star with a given temp, Teff­ and surface gravity, g: gF = g/T4eff

[1] Carroll, B.W. and Ostlie, D.A., 2017. *An introduction to modern astrophysics*. Cambridge University Press. [Accessed 1 April 2021]

[2] Paczynski, B., 1971. Evolutionary processes in close binary systems. *Annual Review of Astronomy and Astrophysics*, *9*(1), pp.183-208.

[3] Astronomy.swin.edu.au. 2021. *Roche-lobe | COSMOS*. [online] Available at: <https://astronomy.swin.edu.au/cosmos/r/roche-lobe> [Accessed 26 February 2021].

[4] Horne, k., n.d. *Mass transfer in binary systems*.

[5] Farrell, E.J., Groh, J.H., Meynet, G., Kudritzki, R., Eldridge, J.J., Georgy, C., Ekström, S. and Yoon, S.C., 2019. Impact of binary interaction on the evolution of blue supergiants-The flux-weighted gravity luminosity relationship and extragalactic distance determinations. *Astronomy & Astrophysics*, *621*, p.A22.

[6] Meynet, G., Kudritzki, R. and Georgy, C., 2015. The flux-weighted gravity-luminosity relationship of blue supergiant stars as a constraint for stellar evolution. *Astronomy & Astrophysics*, 581, p.A36.

BSG pairs with black-hole

<https://phys.org/news/2011-06-cygnus-x-blue-supergiant-pairs.html>