Summary

The Impact of Binaries on Stellar Evolution

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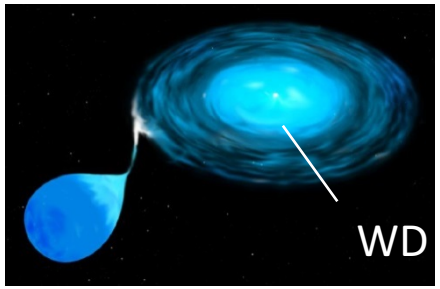
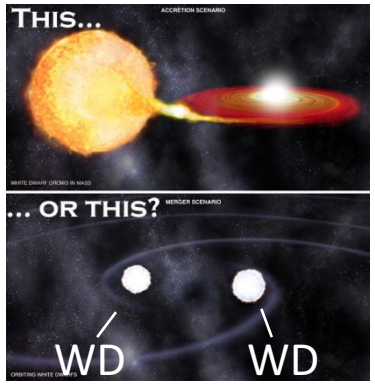
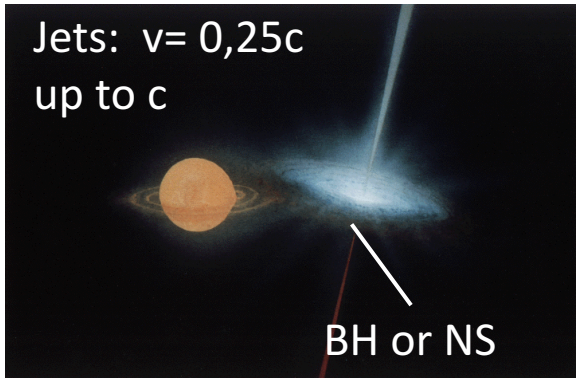






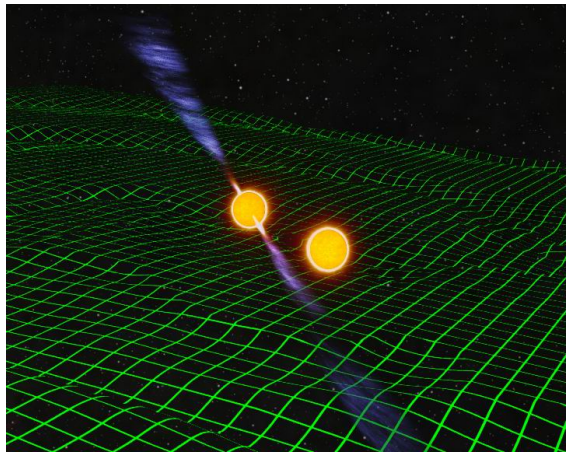
Nova: 10^4-10^6Lsun
(M.F.Walker,1954)

Type Ia SN: 10^{11} Lsun

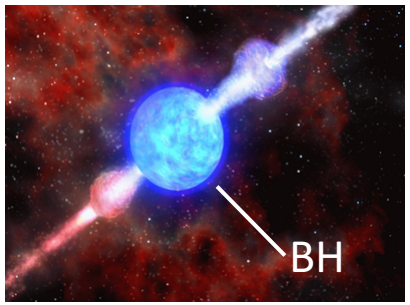
Nobel prize Physics 2011
(Patat)

Micro quasars: SS 433, Cyg X-3

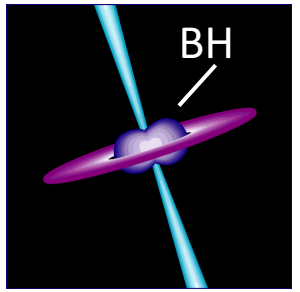
X-ray Binary
(Main sources of X-rays from normal galaxies)
Nobel prize 2002



Double NSs and BHs
Mergers are strongest sources of detectable Grav. Waves
Nobel Prize 1993 (and 2017?)



Long
(could be from Massive Binary
(Tanvir; Langer)



Short
(from merger two NSs(Tanvir)

Gamma Ray Burst
Long GRBs seen to z > 9

Almost any kind of important/interesting class of objects has been found to be related to binary evolution:

- Type Ib,c Supernovae [Schuyler van Dijk]
- Barium stars and other chemically polluted stars (Boffin and Jorissen):
- Ba dwarfs, extrinsic S stars, CH-giants and dwarfs, CEMP-s,
- Blue stragglers [Mathieu],
- Planetary nebula nuclei, “red novae”, Symbiotic stars [talks by Jones, Kaminski, Sokoloski, respectively], super-soft X-ray sources,

  etc., etc.

Biggest eye openers / paradigm shifts (for me):

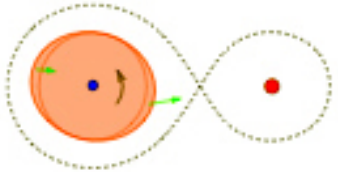
1. The existence of “wind driven mass transfer” or “wind-driven RLOF”, in wide, relatively low-mass binaries, explaining “polluted” stars
   Boffin and Jorissen (1988); Reviews of *Pols, van Winckel, Saladino, Escorza, Whitehouse.*

2. Evidence for binary nature of LBV stars, and demise of the single-star
   LBV model for origin of WR stars: O-star (H-rich) → LBV → WR-star (Smith). WR stars are due to binary stripping → Type Ib,c Supernovae.
   Further: models of Eta Car (*Smith, Kashi*)

3. Distributions of parameters of unevolved binaries are correlated:
   $f(M_1, P, q, e) \neq f(M_1).f(P).f(q).f(e)$ (*Moe and DiStefano, 2017*)

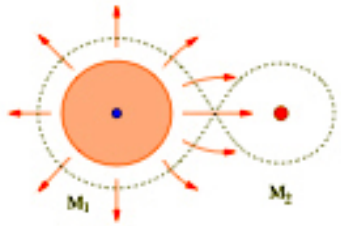
Related to 3: Massive star IMF top-heavy, probably due to binary mass transfer
(*Kroupa; Schneider, de Mink*)

stars in binaries can interact in various ways:

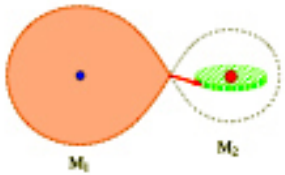


tidal interaction

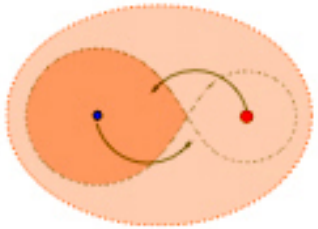
e–log *P* diag., mixing; [e.g.: talk by Langer: Homog. Evolution; poster Nr. 1]



wind accretion



Roche-lobe overflow

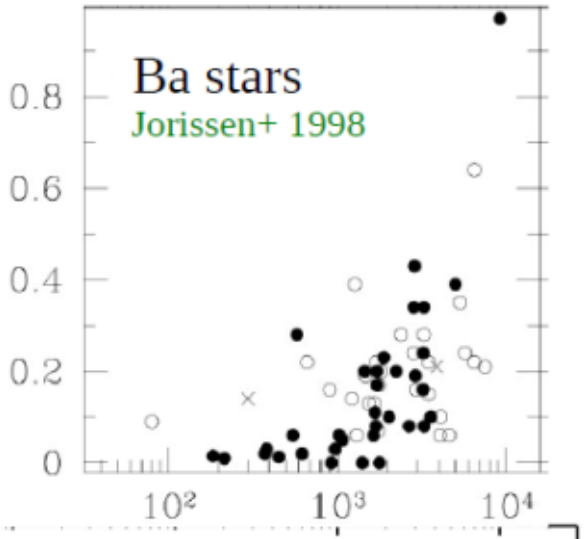


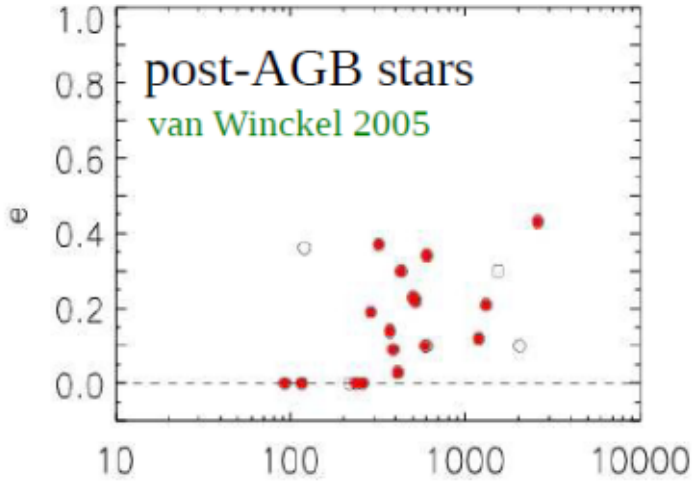
common envelope evolution

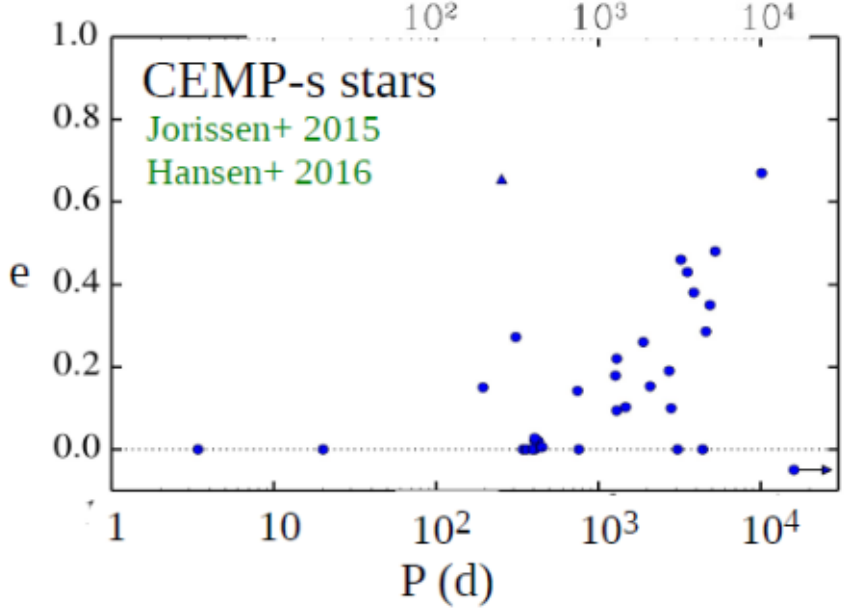
orbits of AGB descendants

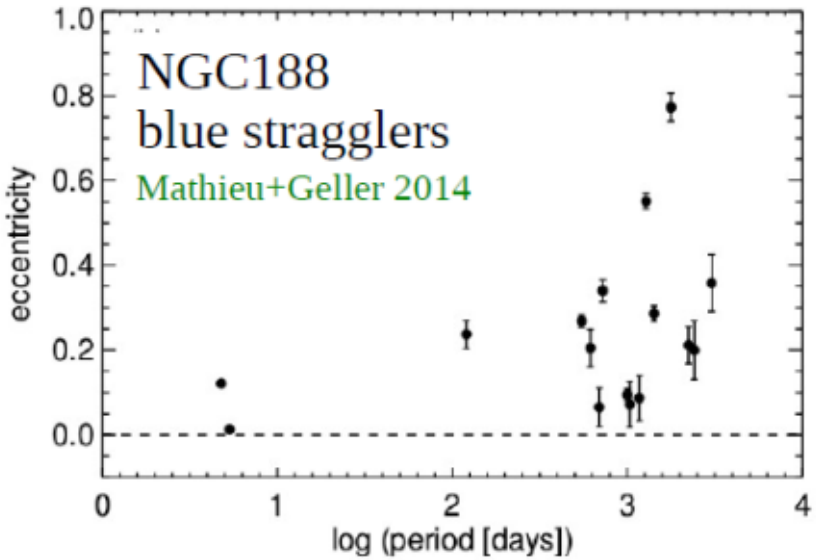
eccentricity versus orbital period

filled circles = strong Ba stars: complete sample



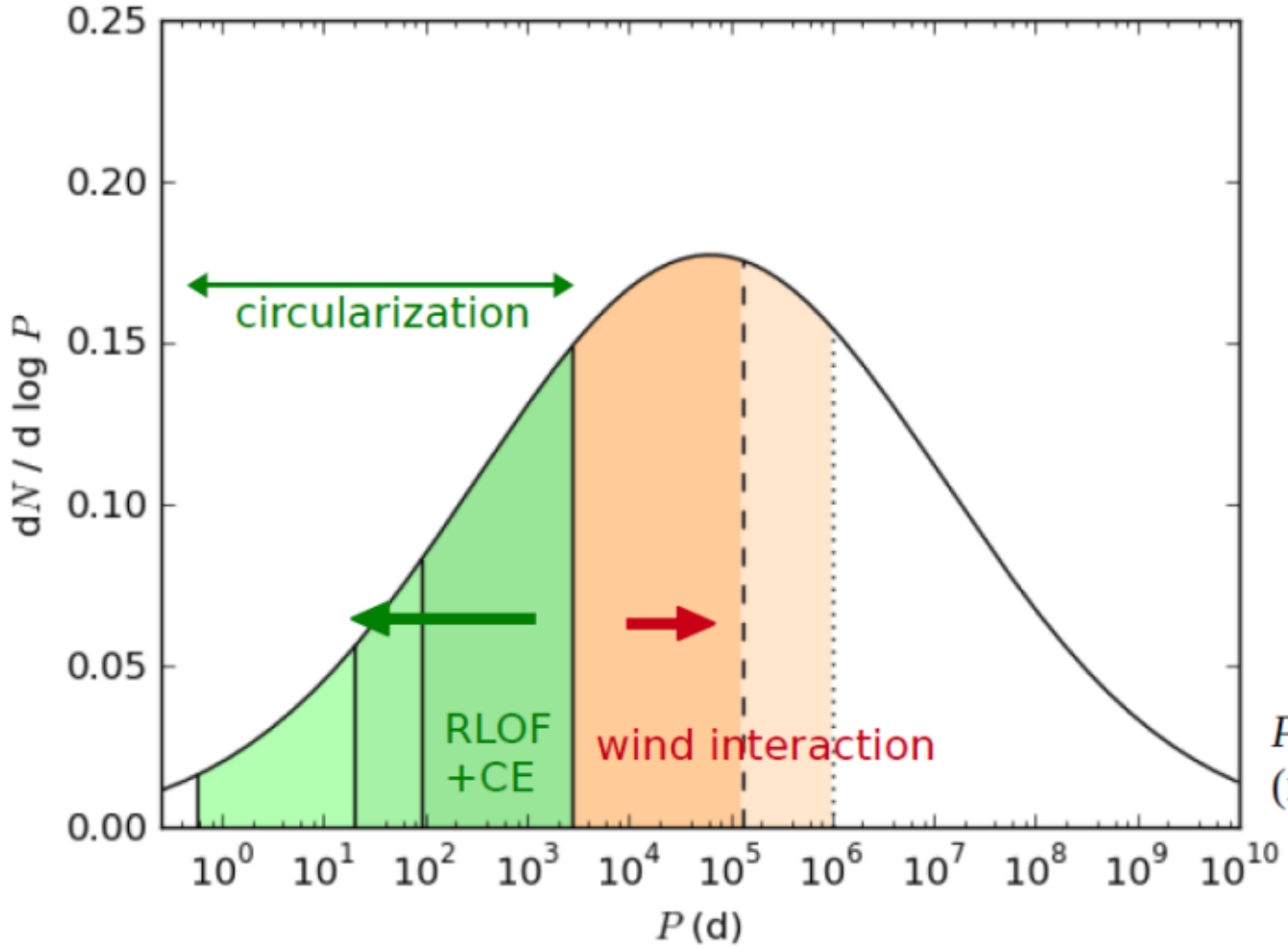






descendants of AGB binaries

- expectations from canonical binary evolution:
  close binaries should tighten and circularize, wide binaries should widen



Expected: - Gap at ~ 600-2000 days
- many systems > 10 000 d

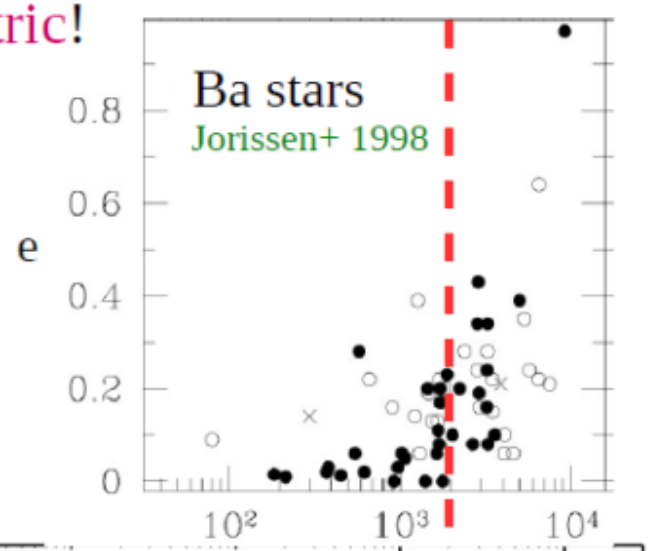
Observed: - No Gap, most systems:
P = ~ 600- 5000 days
- no systems > 10 000 d

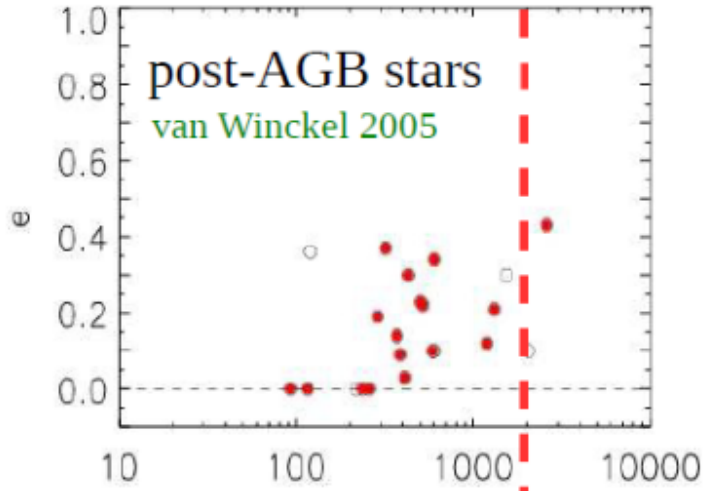
P distribution for G dwarfs
(may be flatter for IM stars)

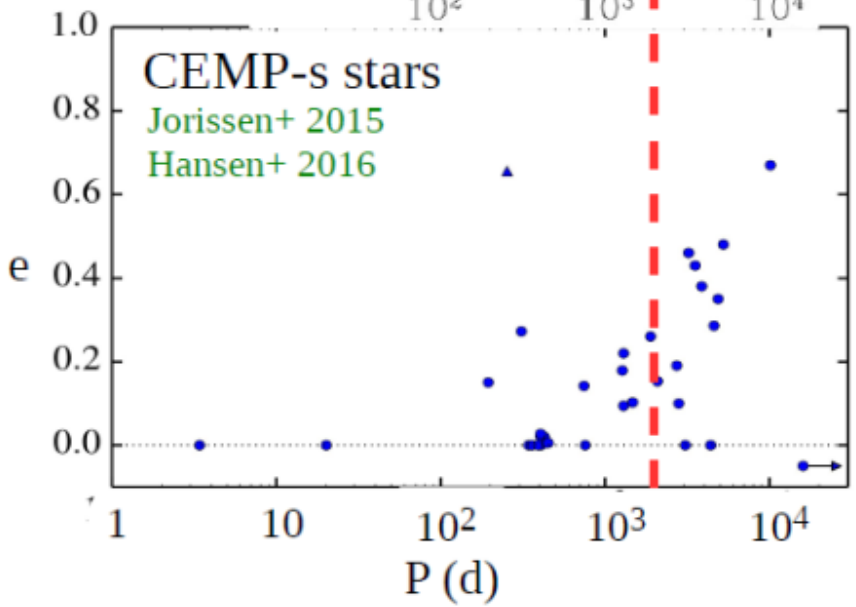
Duquennoy &Mayor 1991,
Moe & Di Stefano 2017

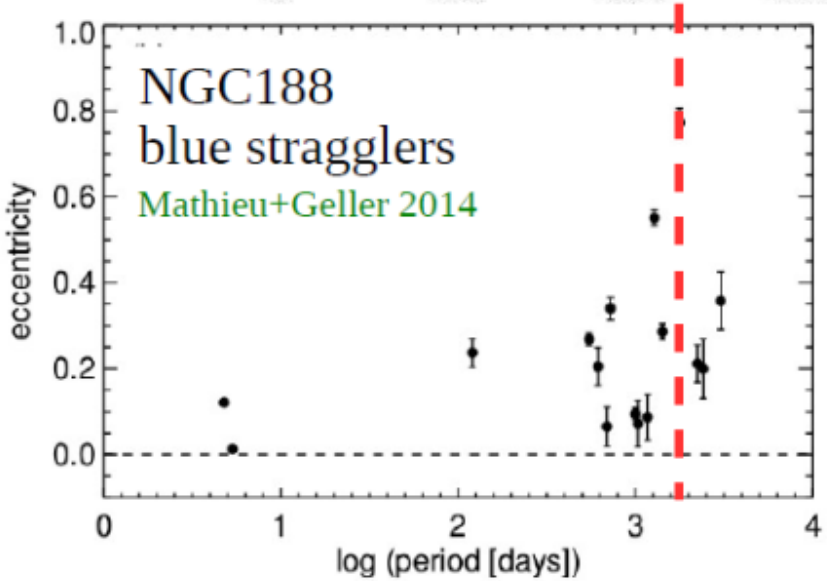
descendants of AGB binaries

- ... but known post-AGB binaires are right in the expected *P* gap, and often eccentric!





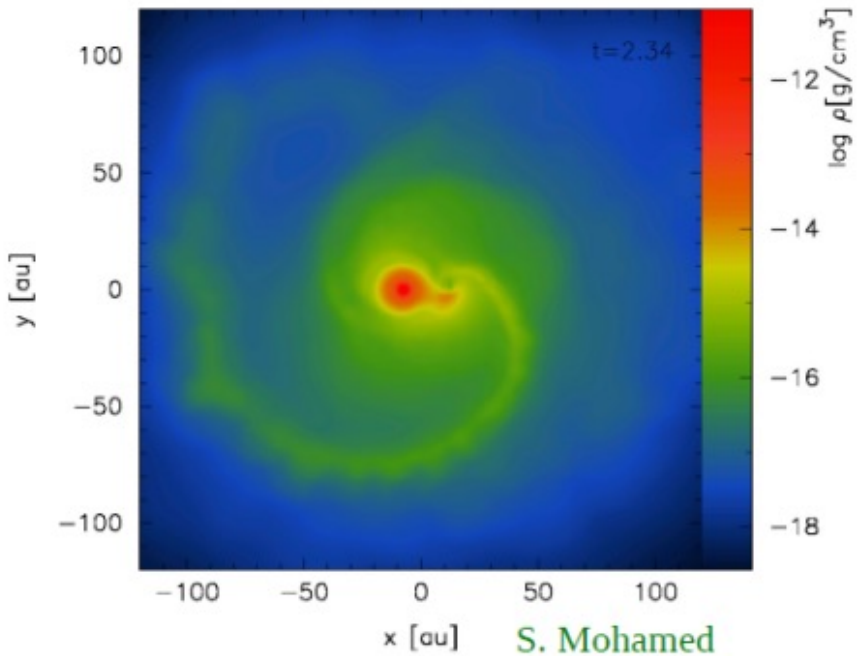




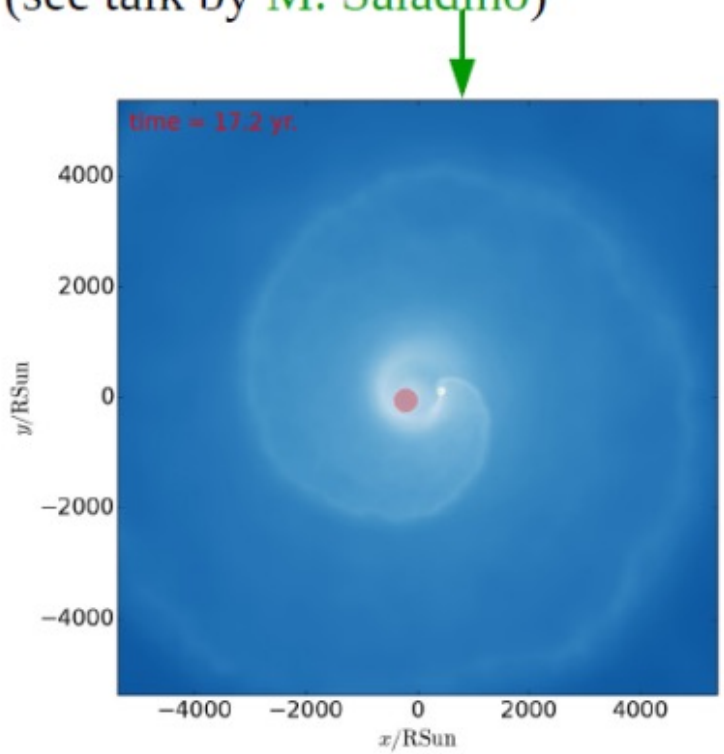
wind mass transfer simulations

- confirmed by hydro simulations of AGB wind mass transfer:
  - larger accretion efficiencies (compared to BHL) e.g. Mohamed 2010
  - formation of circumbinary discs e.g. Chen+ 2017
  - enhanced angular momentum loss (compared to isotropic wind)
    Jahanara+ 2005, Chen+ 2017, Saladino+ 2017

  ⇒ possibility of orbital shrinkage (see talk by M. Saladino)



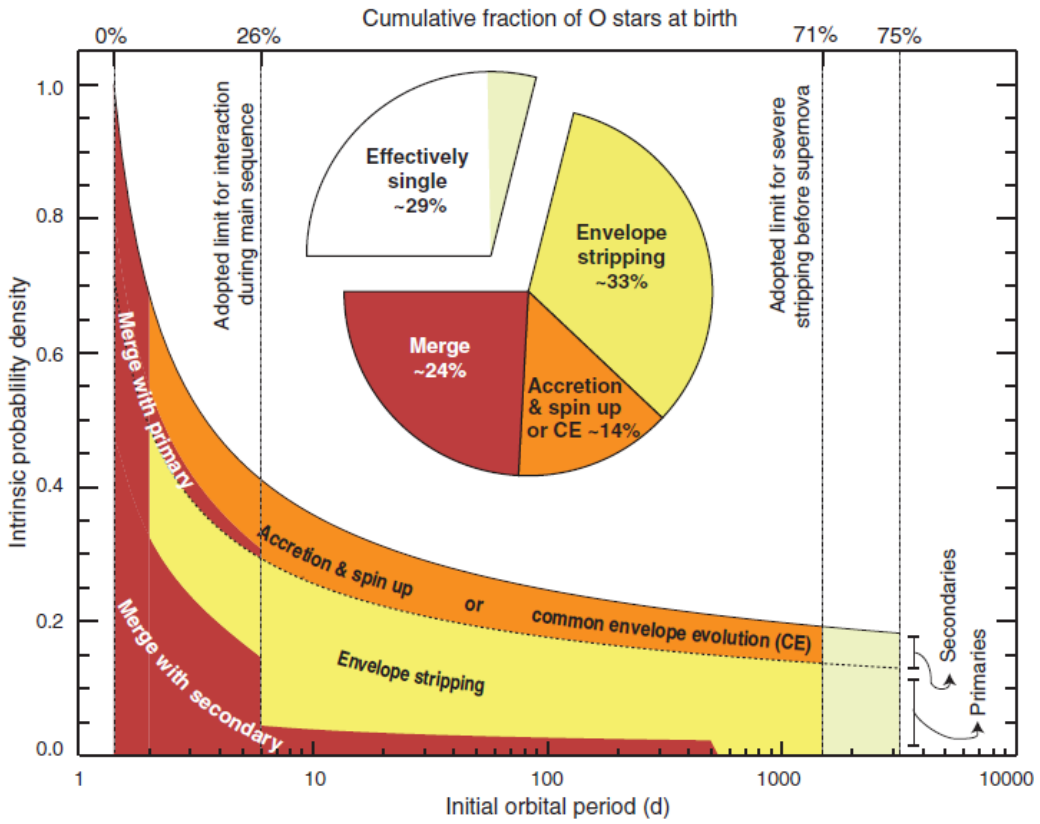
S. Mohamed



summary

- >50% of low- and intermediate-mass binaries undergo their main interaction during the AGB phase
  - provides interesting tests of both AGB nucleosynthesis and binary interaction processes
- combination of wind interaction, RLOF and common envelopes: far from being well understood
- evidence from Ba, CH and CEMP stars, as well as many other post-AGB binaries:
  - efficient wind accretion (wind-RLOF) with strong orbital shrinkage
  - stable RLOF or CE ejection *without* strong orbital shrinkage
  - pumping of eccentricity during interaction
  - continuity of properties across types of interaction

Older “eye opener”: Massive Star Evolution dominated by Binaries (Sana+ 2012; *Sana now*)



However: see M17: very young cluster has NO close binaries (*Ramirez-Tannus*)

Further eye openers:

- Planetary Nebula nuclei are > 80% binaries; if companion is MS star, it is much bloated, due to mass *transfer*, not expected in CE (*Jones, Sowicka*)
  (Jones: importance of having your own telescope)

- Fantastic progress concerning mergers: “Red Novae” (*Kaminski*)
  NB: CK Vul (1670), Hevelius, Cassini.

- New type of binary evolution: Dusty Post RG Branch Stars (envelope lost before ascending AGB (*Kamath*) .

- Blue stragglers in old open clusters (NGC 188, M67): all are products of binary evolution: wide binaries (e), RLOF, mergers, yellow giants, etc. (*Mathieu*)

- Distribution of blue stragglers in Globular Clusters as dynamical clocks (*Ferraro*)

Symbiotics (*Sokoloski*): Here the WDs are steadily burning H: L = 1000 L_{sun}

- Why is this shell burning so pervasive? What mode of mass transfer?
- What drives the winds? What are the WD masses?

Binaries with very low-mass companions:

- *Chen et al.* : Pop. Synthesis for binaries with very low-mass He WDs; EL CVns

- *Schaffenroth*: EREBOS: wonderful survey of Ogle-discovered HW Vir systems; gives important constraints on how low-mass Brown Dws may still drive off envelope in CE.

- This relates to CE computations by *Ohlmann*: How massive should companion be to lift off envelope in CE-evolution? Recombination energy makes it much easier.

- Lack of Period Bouncers (*Pala*): while 30-70 % predicted among CVs, only a few known.

GW sources and how to make Double black holes:

- Review of GW sources and detection techniques (*Nelemans*)
- Triple interactions by Kozai-Lidow can drive BHs together (*Toonen*)
- Maxwell's devil of Star clusters may lead to dynamical formation of double BHs and IMBHs (*Mapelli*), predicts 5 LIGO events /Gpc3/yr.
- Population synthesis with normal binary evolution with a CE event can produce the four observed double BH systems, provided Z= 0.001 (*Neijssel*).
- Homogeneous evolution of very close binaries can also do it (*Langer*: "Evolution of single solar mass stars well understood but not of their binaries; massive binary evolution well understood but not evolution of single stars"
- *Pakull*: NGC 5408 X-2 (ULX-like) looks like wide massive BH binary (a =1000Rsun) in CE, as needed for Belczynski et al. (2016), etc. Scenarios.

Helium stars in binaries and their descendants: HMXBs:

- *Goetberg*: low-L WR/O stars are medium mass He stars; can cause Gyr of reionization
- *Garofali*: M33 population of Be/XRBs; recent + 40 Myr old starburst.
- *Chaty*: galactic HMXB population and evolution: dusty B[e] system, P~ 80d, may be at beginning of spiral in. Many TZOs expected to be produced.

Type Ia Supernovae:

- Possible models (*Patat*)
- Delay time distribution tends to favor DD, but delay (:) t^-1.5 (*Pritchet*).
- Double WD-merger rate is 10x SNIa rate (*Hallakoun*); so only fraction of DD needed
- Peculiar faint SNIa may make galactic positron population (*Ruiter*)

Binaries and early Galactic evolution (*Starkenburg*), and binary fraction in EMP stars (*Lucatello*): binary fraction (~ 25%) remarkably independent of Z between -2.5 < [Fe/H] < 0. RV variations may give wrong impression of DM content of dwarf galaxies

High-mass star evolution (*Langer, Pavloski*): Main seq. is not boring

- Considerable puzzles about surface CNO abundances; much less mixing from interior to surface than expected.

Population Synthesis (*Izzard, Eldridge* + many other authors this workshop): Parameter space very large; Still: probably more robust than some skeptics (*Lars Bildsten*) think. Remains a very valuable tool. Also very important for simulating galaxy evolution.

APOGEE gives unique view of stellar multiplicity from MS to RG. Nice to connect observations and stellar evolution. Already constraints on Case B mass transfer & CE (*Badenes)*

Conclusions:

"The textbooks of stellar evolution have to be rewritten, as binary interactions dominate stellar evolution"

Henri Boffin

Congratulations to the SOC for putting together a very exciting and diverse scientific program!