Binary Interaction

» affecting yields

Affecting our "view" on yields

Selma de Mink
Utrecht → Bonn → STScI

On behalf of

Onno Pols (Utrecht, The Netherlands)

- Carbon enhanced metal poor stars (Carlo Abate)
- SN Ia progenitors (Joke Claeys, Alex Chiotellis)

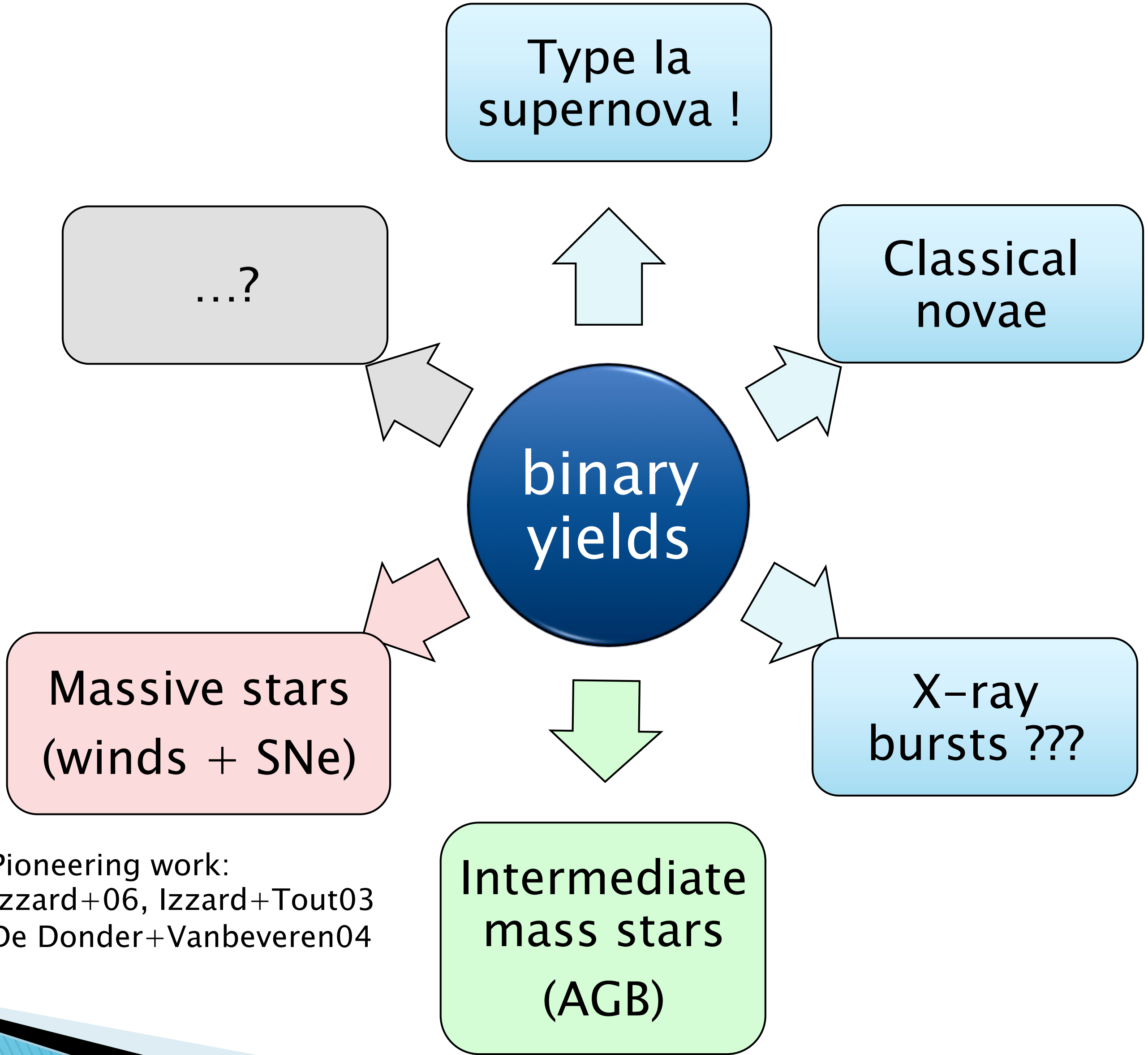
Nobert Langer (Bonn, Germany)

- Effects of rotation in massive (binary) stars
- Sung-Chul Yoon, Matteo Cantiello, Ines Brott…

Rob Izzard (Brussels, Belgium)

- Binary population synthesis,
- Pioneering work: GCE with binary yields

Outline



Pioneering work:
Izzard+06, Izzard+Tout03
De Donder+Vanbeveren04

Major challenges– individual systems

1. Single stellar physics

All single star uncertainties apply to binaries, twice.

- Mixing of the interior
- Mass loss
- Nuclear reaction rates
- Rotation

2. Binary physics

- Mass transfer, Angular momentum transfer
  - Accretion efficiency
  - Common envelope evolution
- Tides
- Contact systems, Mergers

Major challenges – populations

3. Distribution of initial parameters

– Selection effects
– Current distribution ≠ Initial distribution

Single stars	Binaries
• Mass	• Binary fraction • Mass primary • Mass ratio • Separation
• Rotation rate	• Eccentricity • Rotation rates (2x)

Warnings

Different definitions!

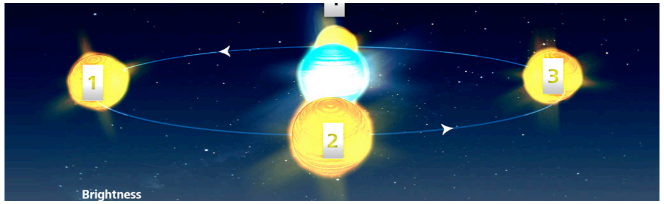
Not all binaries interacting
→ separation distribution

Binary fraction of 50%
→ 2 out of 3 stars in a binary

Depends on mass
→ OB stars often in close binaries

“Numeric” codes Full (binary) stellar evolution codes	“Semi-analytic” codes Synthetic codes
intended to compute	
individual binary systems	complete (binary) populations
Computing time per system	
hours	milliseconds
Utrecht examples	
BEC	Binary_C
Full stellar evolutionary code Solves equation for stellar structure …	Population synthesis code Uses analytic fits and tables
(developed by Wellstein, Braun, Langer, Heger, Yoon, …)	(developed Izzard, Hurley, Pols, Tout, …)

Major opportunities



Binaries are excellent test cases

Accurate determinations of stellar parameters

- masses, radii, temperature, …

Claret+, Andersen+91, Hilditch+07

- Surface abundances

– Single stellar physics

Pols+97, Schroeder+97 (Overshooting)

Pavlovski+09, De Mink+09 (Rotational mixing)

Izzard+09 (low Z AGB stars)

……

– Binary physics

Zahn+ (tides)

VanRensbergen+06,08,10, De Mink+07 (Efficiency of mass transfer)

……

Type Ia supernova

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Type Ia Supernova

What do we (think we) know?

- By far the most significant contribution of binaries to GCE
- Common ingredient in GCE models
- Major producer of iron peak elements

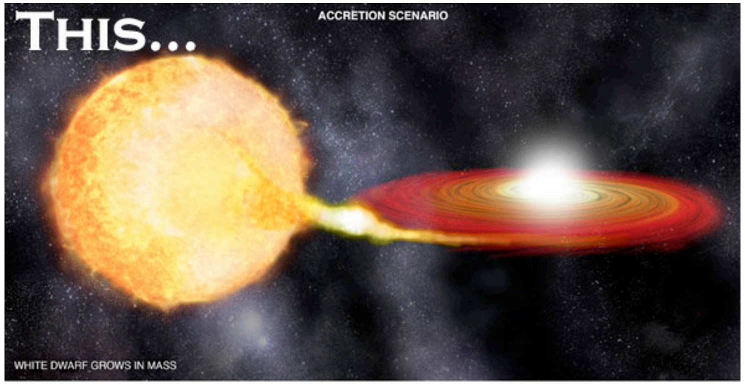
- Thermonuclear explosion of a White Dwarf
- Carbon ignition under degenerate conditions

- Resulting from stars M < 8 solar masses in binary systems
- Delayed (> 40 Myr) with respect to core collapse SN

e.g. Nomoto+84 (W7 model), Thieleman+86, Iwamoto+99,Timmes, Woosley, Weaver 1995, Podsiadlowki 2010

Evolution before the explosion is uncertain and controversial

Type Ia – What are the progenitors?



Single degenerate channel

One accreting white dwarf

- "Chandra exploders"

  Carbon deflagrates in center of a Chandrasekhar mass white dwarf

- "Sub-Chandra exploders"

  Detonation of He layer inducing off-center carbon detonation

Nomoto82, Woosley+Weaver94, Livne+Arnet95

Double degenerate channel

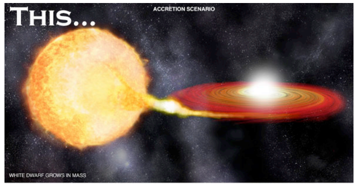
Two merging white dwarfs

Gravitational wave radiation leads to orbit shrinkage and merger

Iben+Tutukov84, Webbink84,

Review: Hillebrandt+Niemeyer00

Type Ia – Pro's and Con's.



Single degenerate

+ homogeneity SNe Ia
+ Possible progenitors: supersoft X-ray sources

van den Heuvel92; Rappaport+94; Di Stefano+97, Voss+Nelemans08

– Fine tuning accretion rate needed
  - Too low → nova eruptions prevent mass gain
  - Too high → formation of extended envelope

Nomoto79,82, Hachisu+96,99

– Rates predicted by population synthesis models are low (model dependent!)

Cappellaro+Turatto 1997, Han+Podsiadlowski04; Fedorova+04

+ some Ia's show evidence for circumstellar material

Patat+07

Iben & Tutukov (1984)

Double degenerate

+ Explains absence of hydrogen naturally
+ Population synthesis models predict high rates

Livio00, Yungelson+94;Han+95; Iben+97; Han+98, Nelemans+01

+ Progenitor system observed

e.g. Napiwotzki+04 Koen+98

– Explosion or an accretion induced collapse → NS

Saio+Nomoto98

– What about the homogeneity of Ia SNe?

Accretion onto compact object

- White dwarfs: Classical novae

thermonuclear explosion
Photo Credit: David A. Hardy & PPARC

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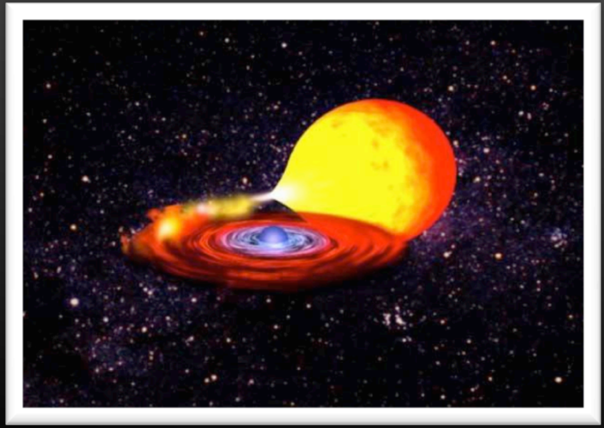
Classical novae

- Explosive H-burning on surface of accreting WD
  - Failed SN Ia progenitors
- Not significant for overall metallicity
  - Ejected amount very small: < 1 $^{0}/_{00}$ galaxy disk gas
- Interesting for specific isotopes
  - Production of isotopes: ^{7}Li, ^{13}C, ^{15}N, ^{17}O
  - Radioactive nuclei: ^{22}Na, ^{26}Al,
  - Heavier species: ^{31}P, ^{32,33}S, ^{35}Cl

Livio+94, e.g. yields and review from Jose & Hernanz 1998

Accretion onto a compact object

- Neutron star: X-ray bursts



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X-ray bursts: ejection of burst ashes?

- Can it be ejected?
  - Nuclear energy ~ few percent of gravitational binding energy!
  - At most a few percent can be ejected
- What is ejected?
  - ashes or unprocessed top layers?
  - Mixing?
  - No plausible ejection mechanism
- Neutron deficient p-isotopes?
  - Explanation for unusually high abundances of ^{92,94}Mo, ^{96,98}Ru ?

e.g. review by Schatz & Rehm 2006, Nucl. Phys. A, Strohmayer+Bildsten06 (book), Heger+07

Massive stars in binaries

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Massive stars (> 8 solar masses)

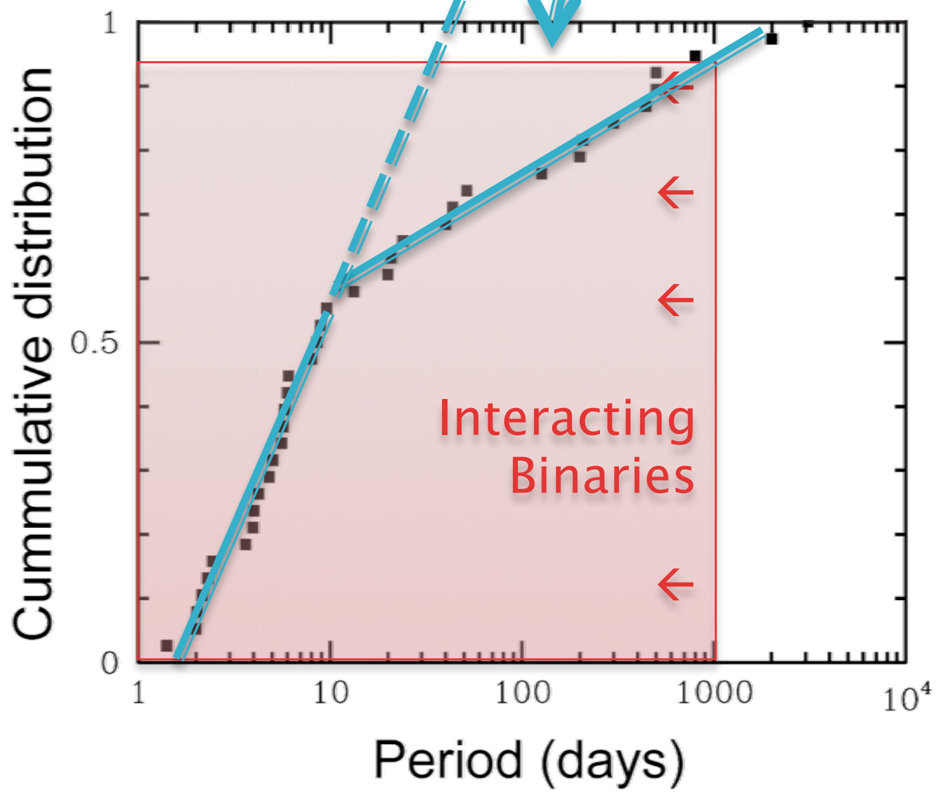
- Binary fraction is very high

e.g. Mason+09, Kobulnicky+Fryer07

- Massive stars have a preference for
  - massive companions → "Twin binaries"
  - close systems → interaction

Selection effect? … not only …

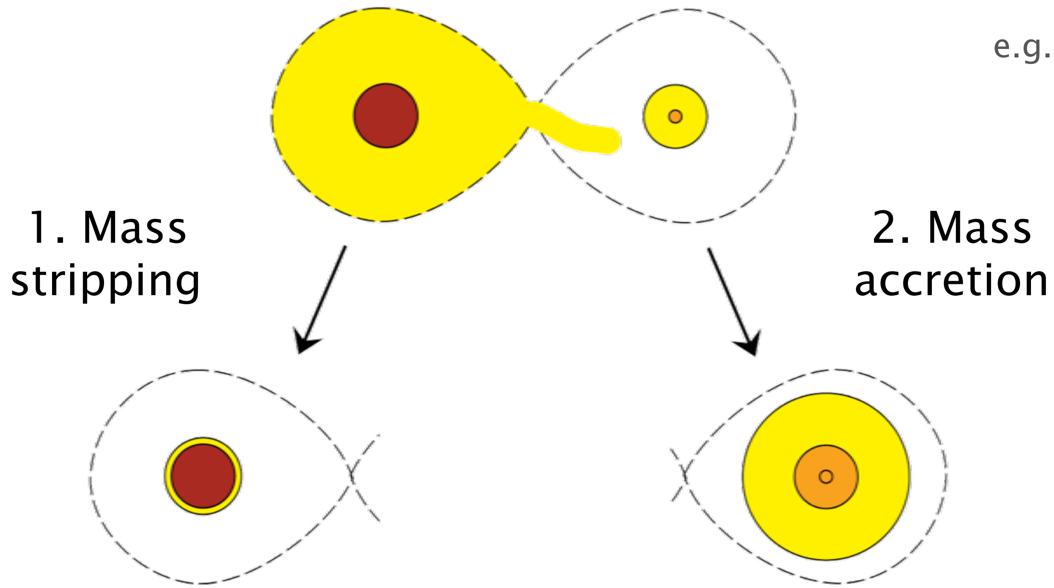
50 % of massive stars in nearby open clusters are spectroscopic binaries
Mason+09



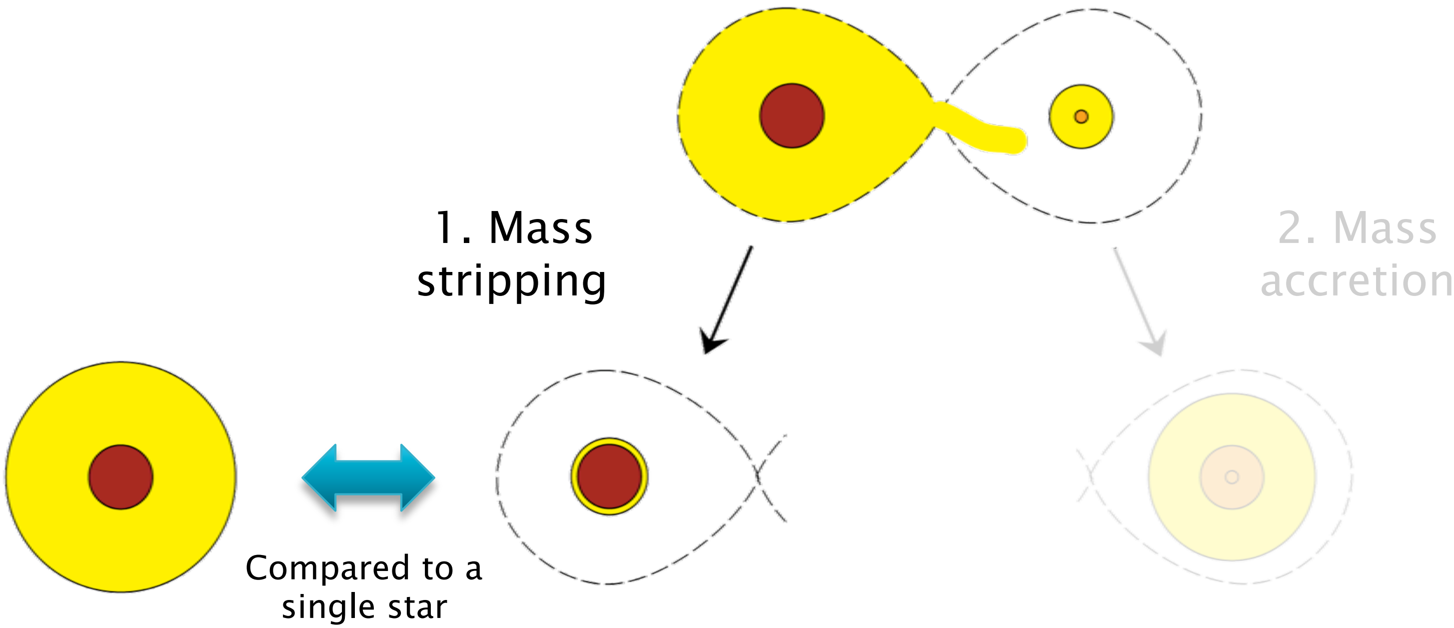
Properties OB binaries in 6 nearby open clusters Sana+Boquin09

Binary interaction

e.g. Podsiadlovski+93



1. Effects of mass stripping on yields



Stellar Wind:
Single stars need to be very massive to loose their envelope.

$M > M_{min} = 30\ldots60\ M_{sun}$ at $Z_{sun}\ldots Z_{LMC}$

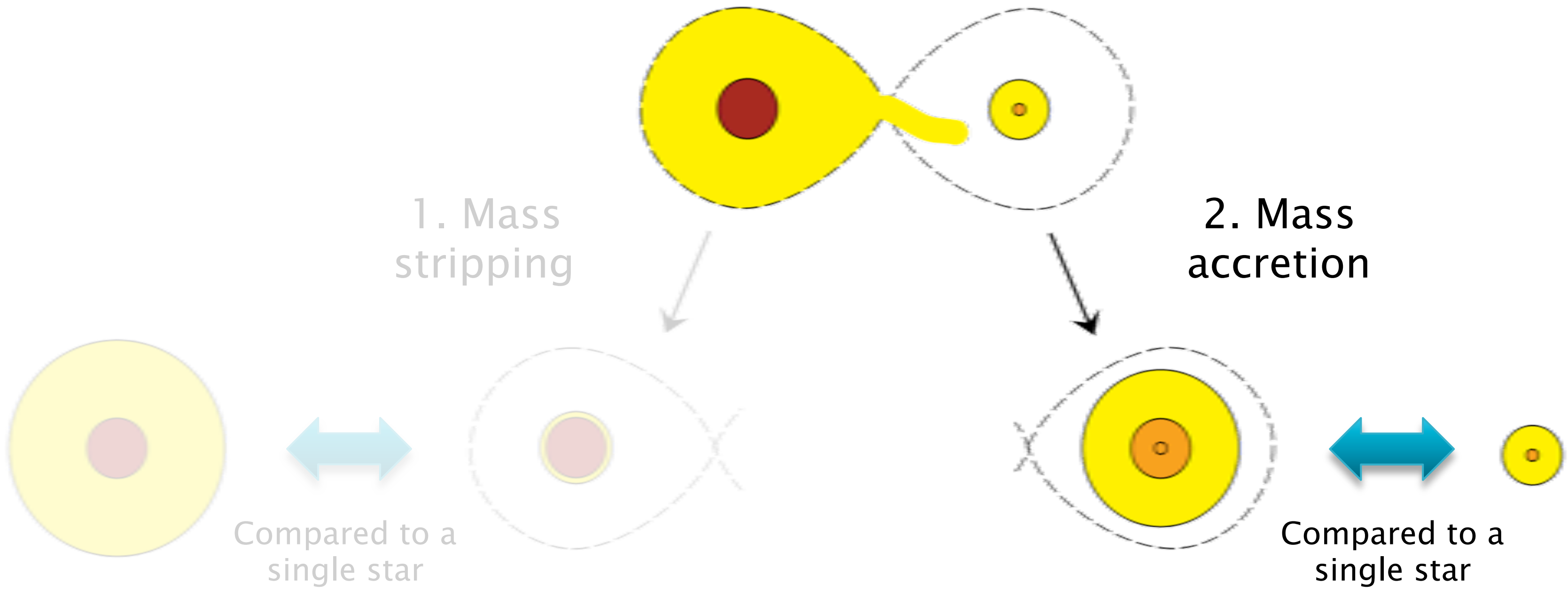
Woosley+Langer+Weaver95

Binaries will produce Wolf-Rayet stars independently of the mass
• ejecta: N, C, He, O-18 …
• mass loss rates still uncertain
• especially at low Z, where binary interaction is interesting

Supernova explosion:
• Type Ib/c instead of Type II → consequences for explosive yields?
• Core mass smaller at explosion

e.g. Woosley+Weaver95

2. Effects of mass accretion

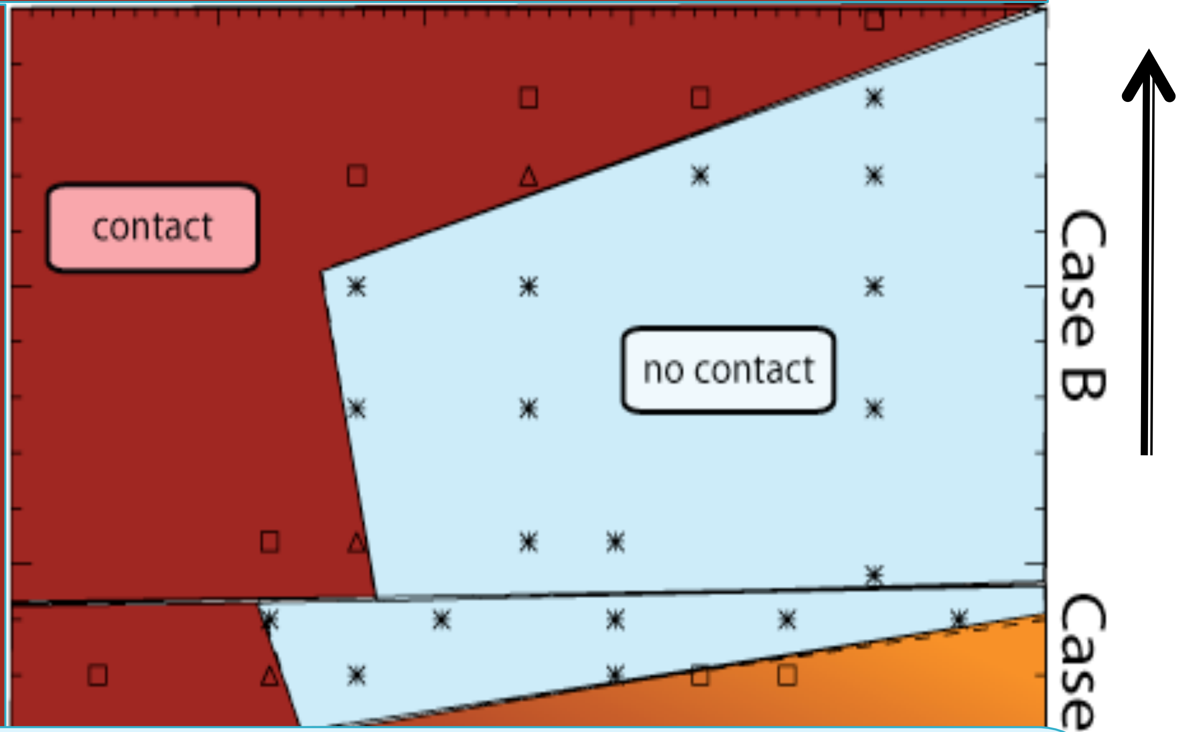


Evolution:
Star will adapt its internal structure
- fresh H mixed into core → star "rejuvenates"
- Similar to a more massive star

- May reach high rotation rates → mixing → C, primary N
- Interesting at low Z → surface enrichment may help to drive a wind

Supernova explosion:
- Stars with initial masses well below 8 Msun can explode as core collapse SN
- More massive core :
- "a more top-heavy IMF"

Mergers ?



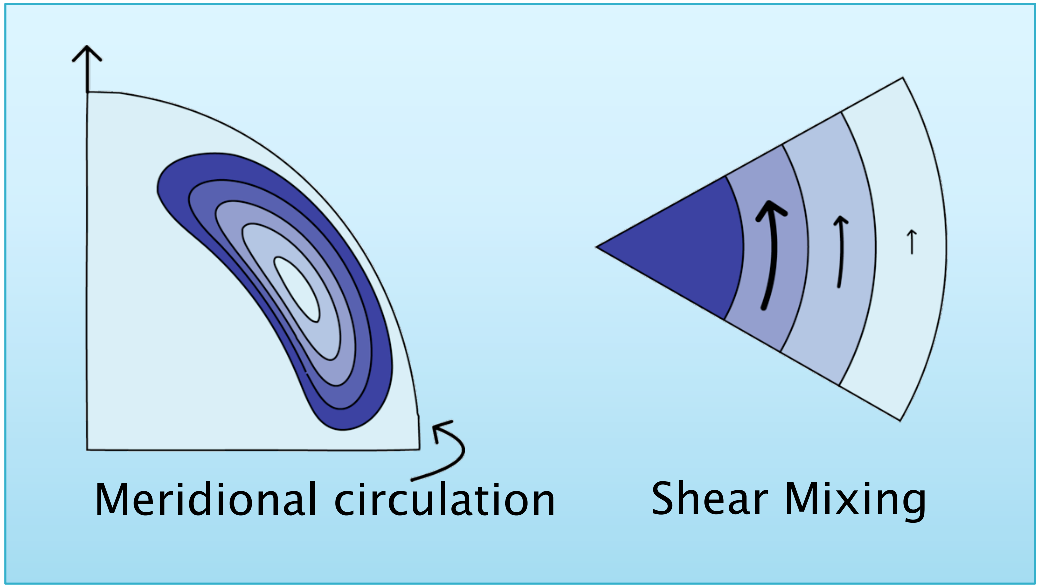
- More massive star
  - → "a more top-heavy IMF"
  - → delayed core collapse supernovae
- Fast rotating star
  - → mixing affects yields
- Type II SNe with small CO core (of the originally most massive star)

Current "state-of-the-art"

Rotation

- Standard ingredient in massive single star models
- Induces mixing processes

e.g. Heger+00 Maeder +Meynet00



Binaries

high rotation rates are achieved naturally

- Spin up

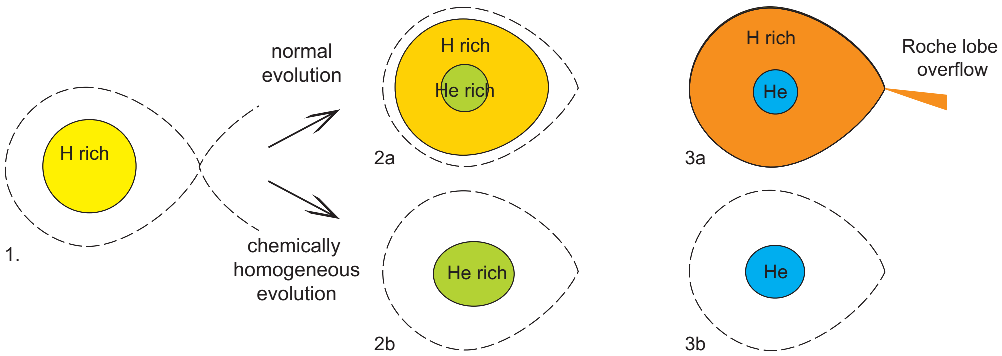
  Wellstein_thesis, Petrovich +07, Cantiello+08

- Tides

  Detmers+08, DeMink+09, Yoon+10

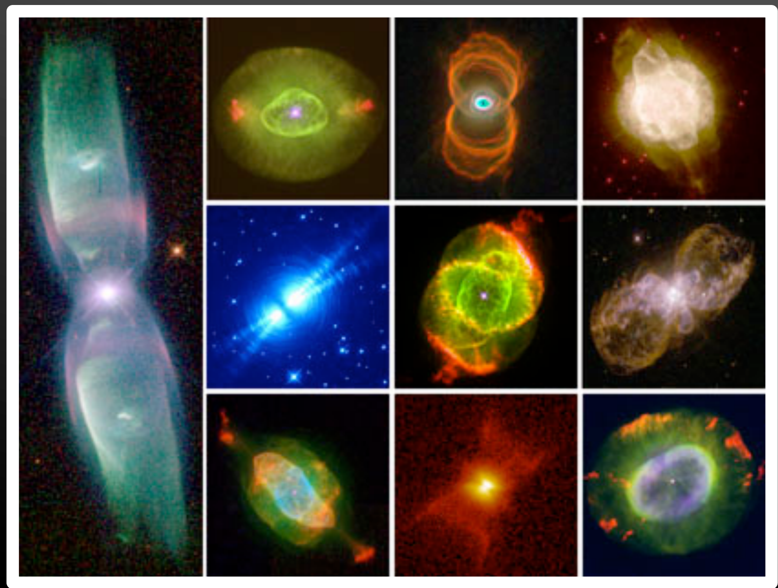
- Mergers

Very fast rotators may stay compact



Yoon+Langer05, De Mink+09

Intermediate mass stars



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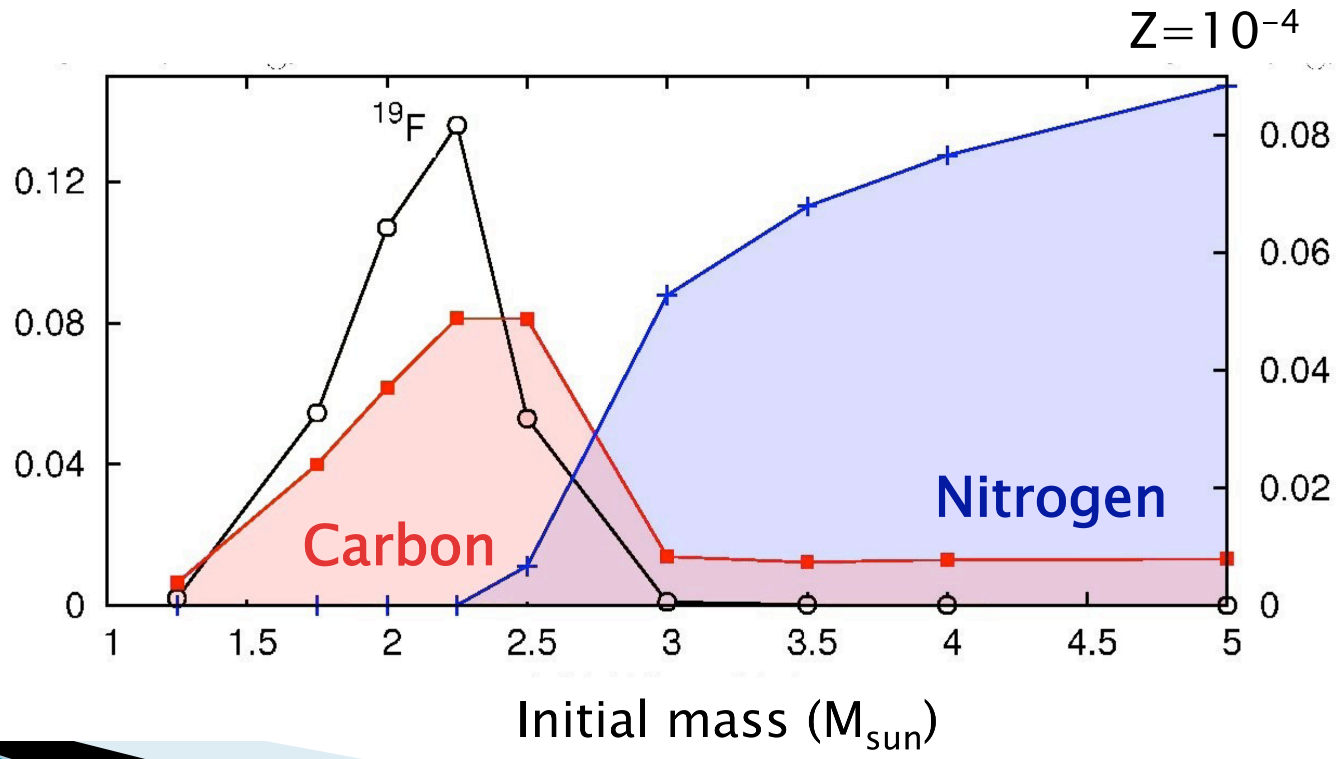
Intermediate mass stars

Contribution during final evolution phase

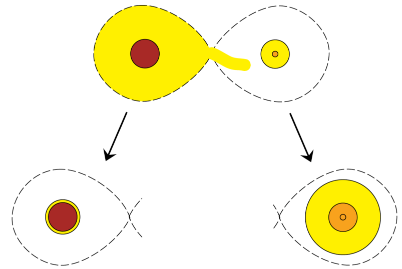
- Asymptotic Giant Branch (AGB) stars during thermal pulses
- H and He burning alternated in two shells around the CO core
- Intershell: unique location for nucleosynthesis
- S-process elements, carbon (-> nitrogen)
- "Dredge-up" can bring it to the surface, where it is ejected

From Lugaro, De Mink, Izzard et al. (2008), based on Karakas et al 2004



Main effects from binary interaction

- Primary star is stripped
  - Prevents thermally pulsating AGB phase
  - Reduction yields (less C, N)
- Companion may gain mass
  - More massive AGB star
  - May become massive enough for dredge up
  - Higher temperatures affect yields (e.g. N ↑ C ↓)
- Stars may merge
  - If the merger has too small core for its envelope …
  - … it will experience more thermal pulses …
  - … more time to process



Reduction:

^{12}C	14 %
^{13}C	37 %
^{14}N	31 %

Izzard & Tout (2003)

Izzard (PhD thesis), Izzard & Tout (2003) Izzard et al. (2006) De Donder & Vanbeveren (2004)

Carbon Enhanced Metal Poor stars

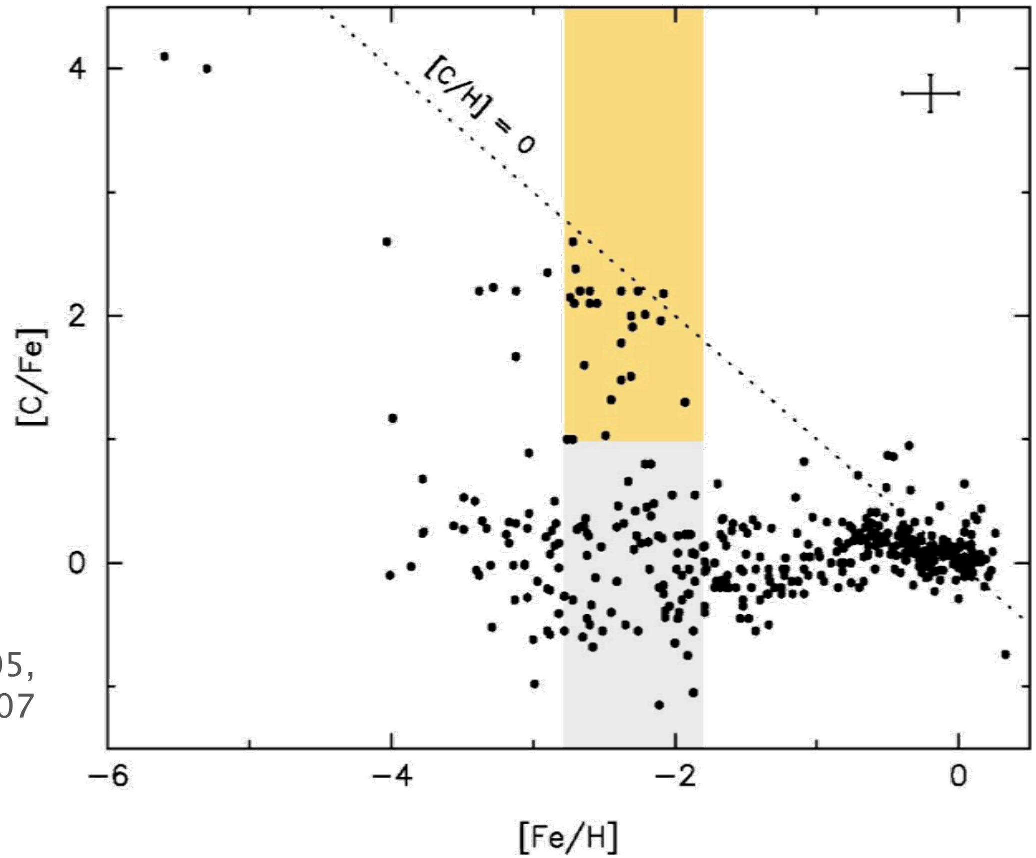
Why are roughly 20% of metal poor stars in the halo are surprisingly carbon rich?

- Primordial faint SNe?
- Massive "Spinstars"?
- Former AGB companion?

CEMP-s

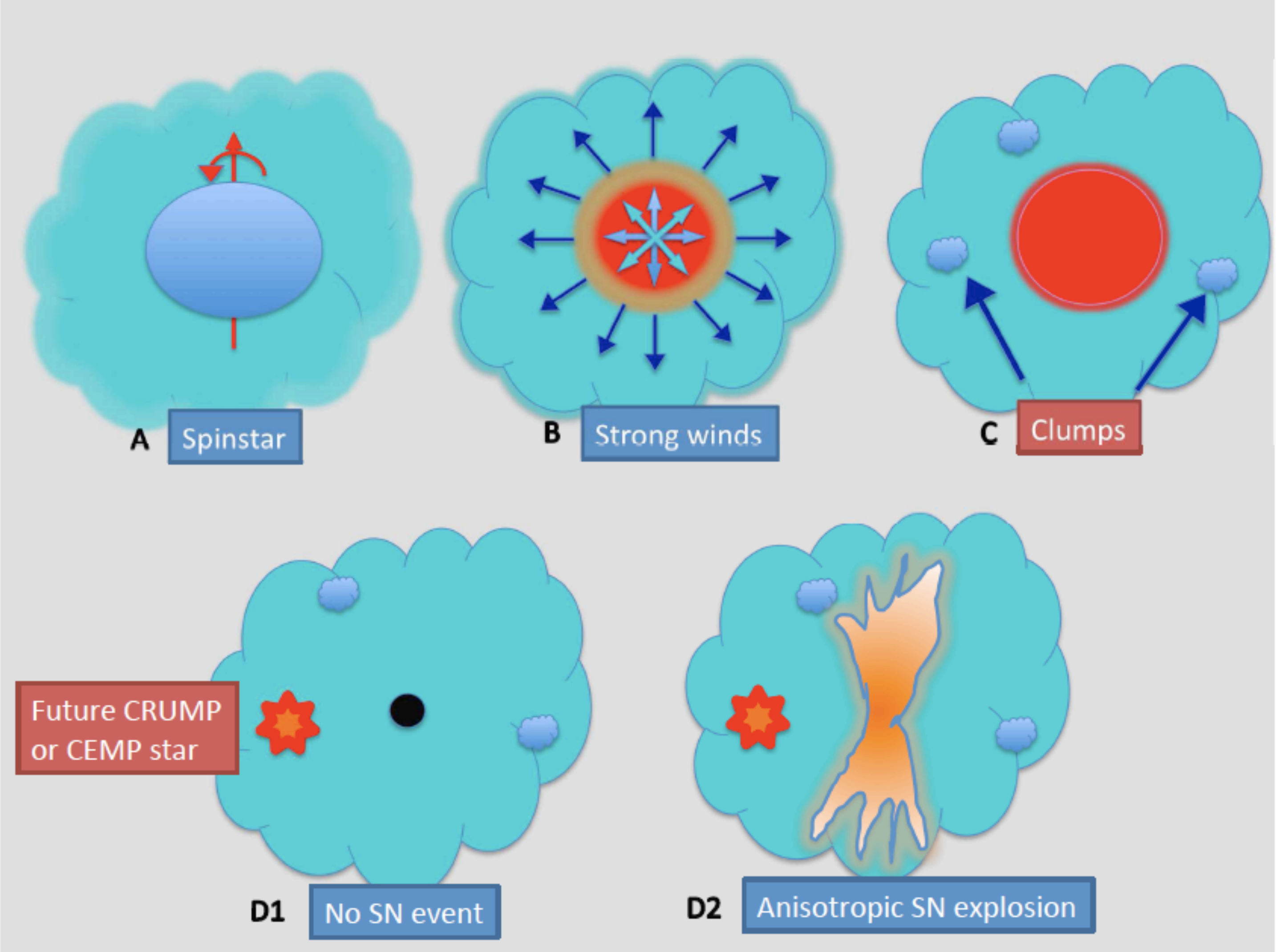
- 80% show s-process elements
- Evidence for binarity in a large fraction (consistent with all)
- Lithium?

Tsangarides+04, Lucatello+05, Johnsell+06, Tumlinson07



(Beers+92, Christlieb+01, Frebel et al 2006; Lucatello et al 2006; Suda 2008)

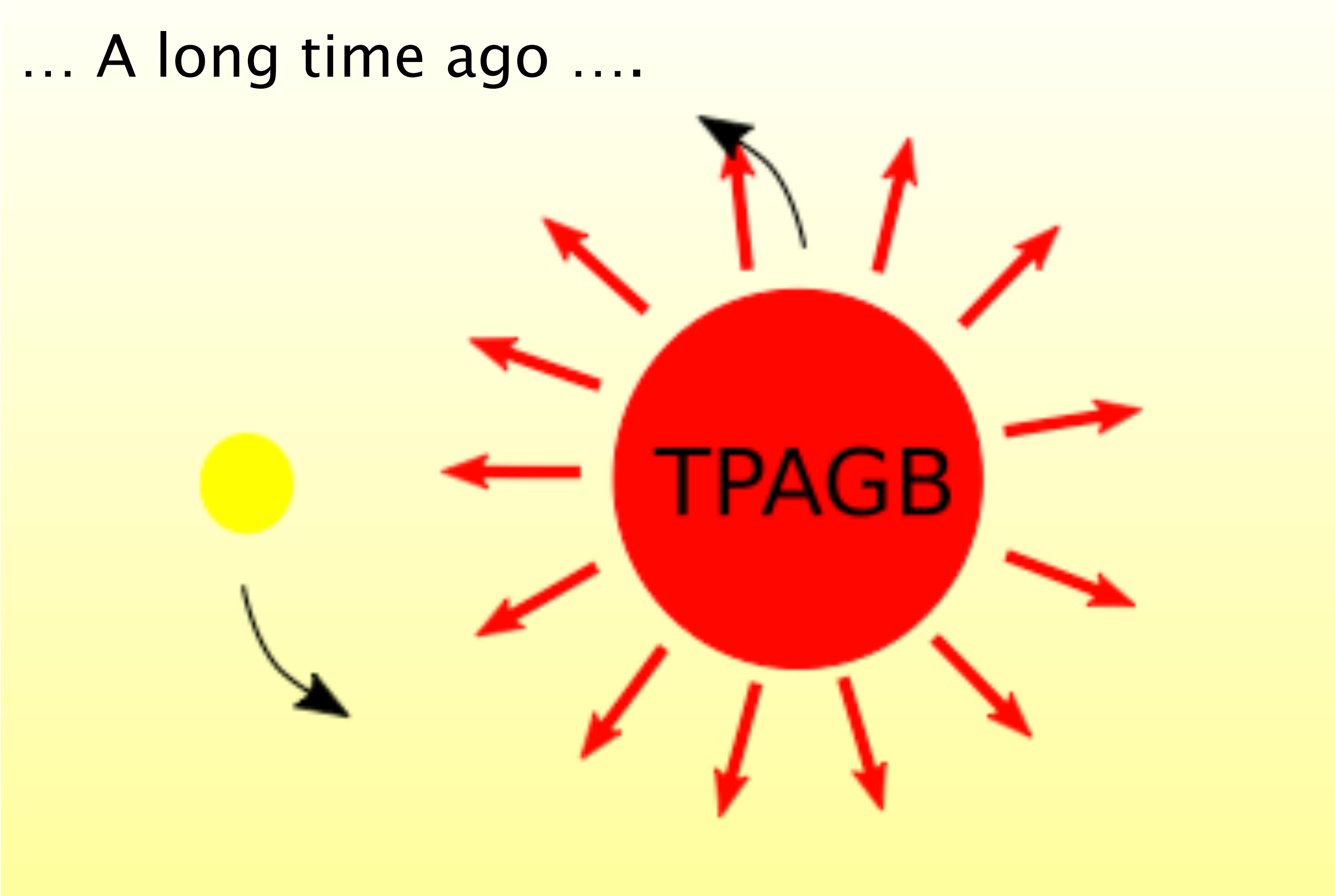
Intermezzo: "Spinstars" → CEMP-no



Meynet et al 2010
(this morning on astro-ph!)

How to make a Carbon Enhanced star?

Slides adapted from Rob Izzard



TPAGB =Thermally Pulsating Asymptotic Giant Branch

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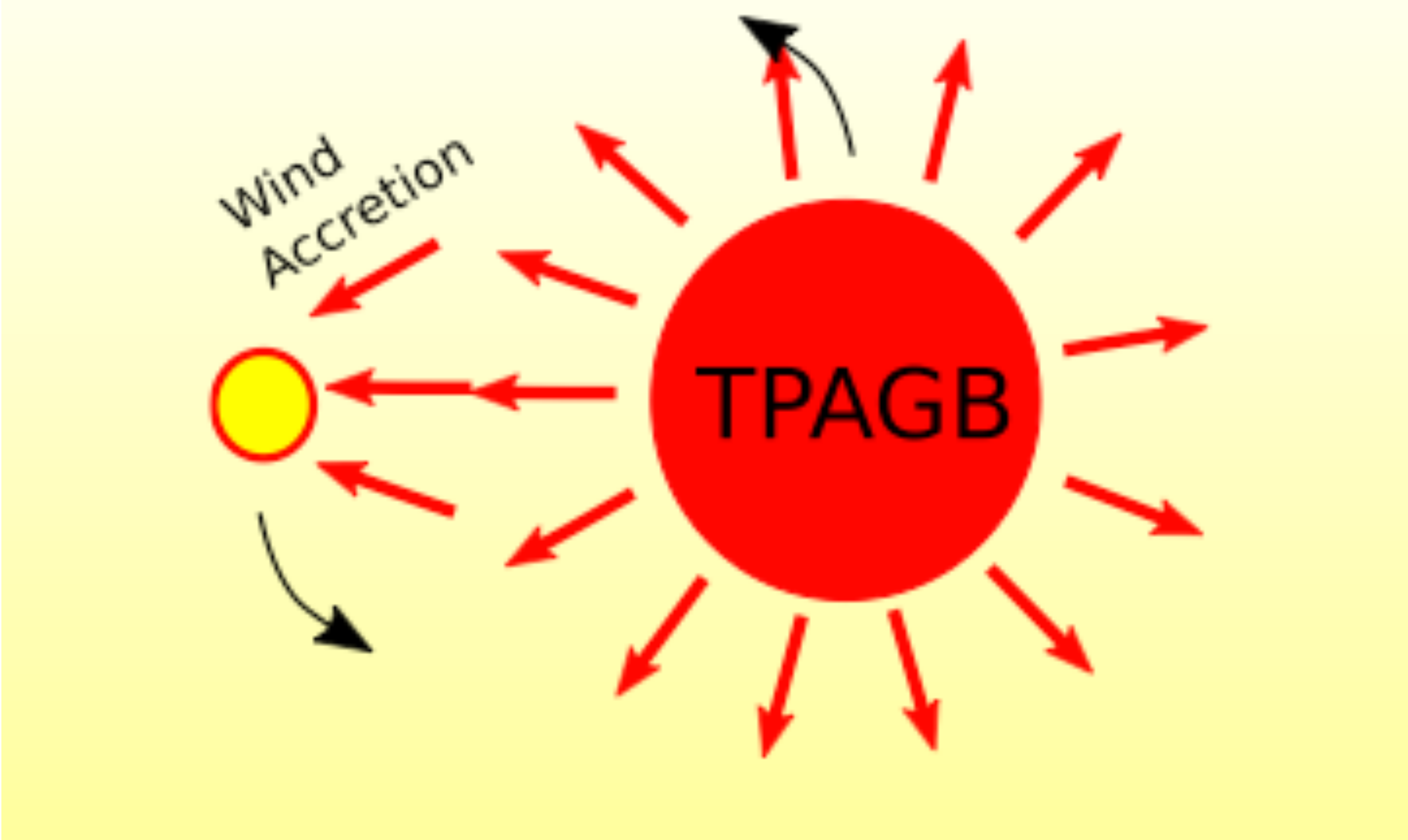
… A long time ago ….



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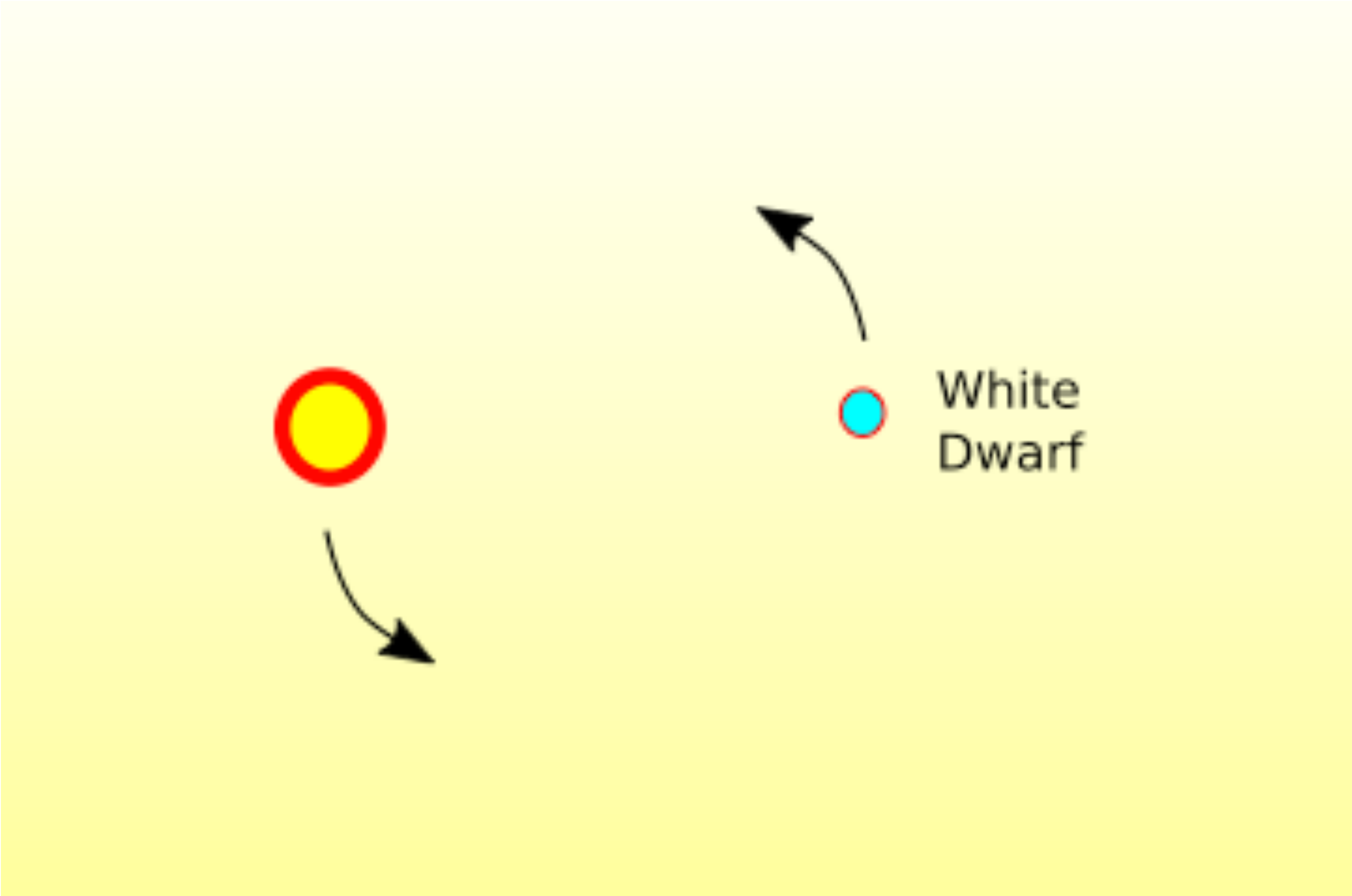

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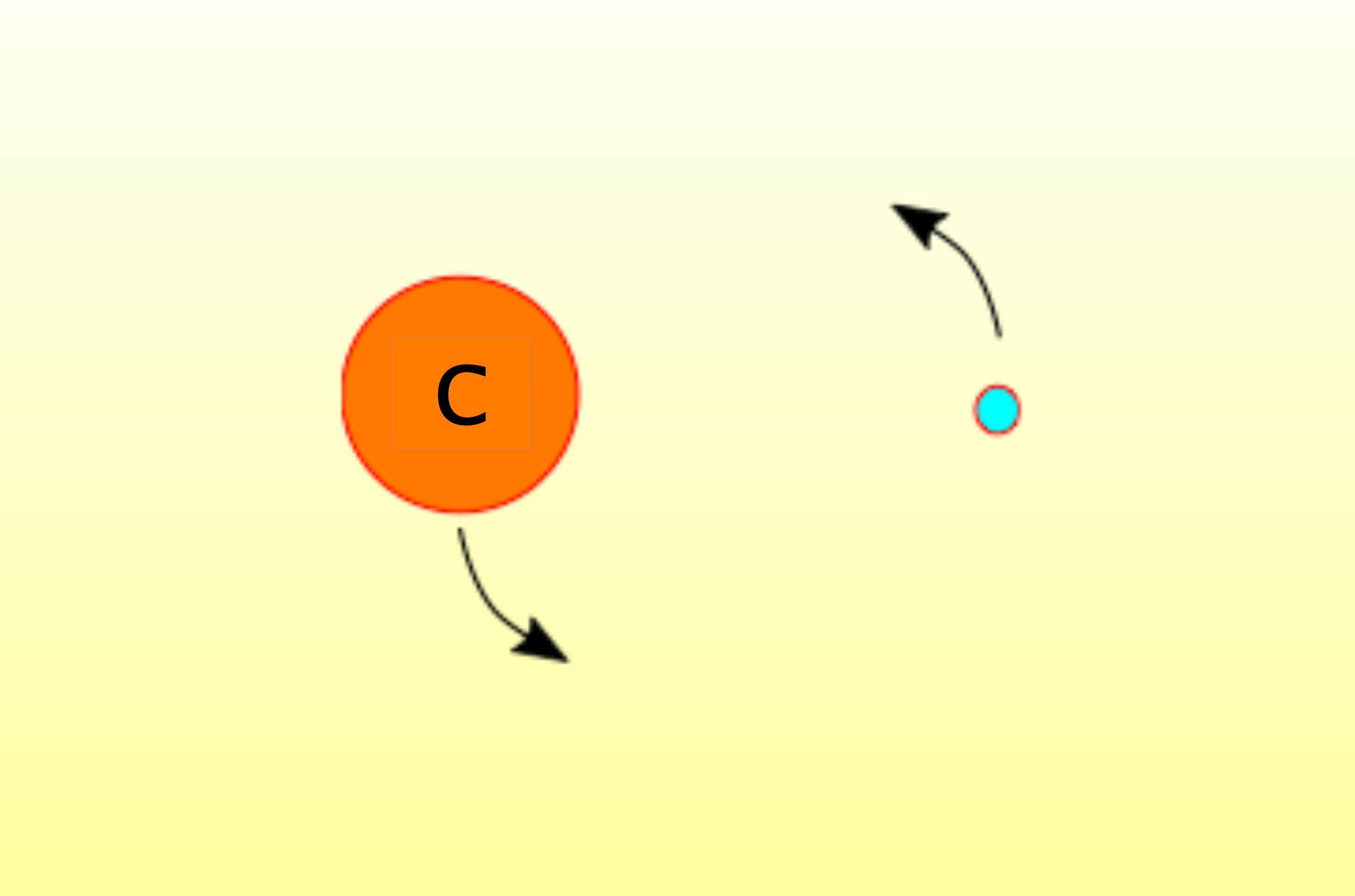
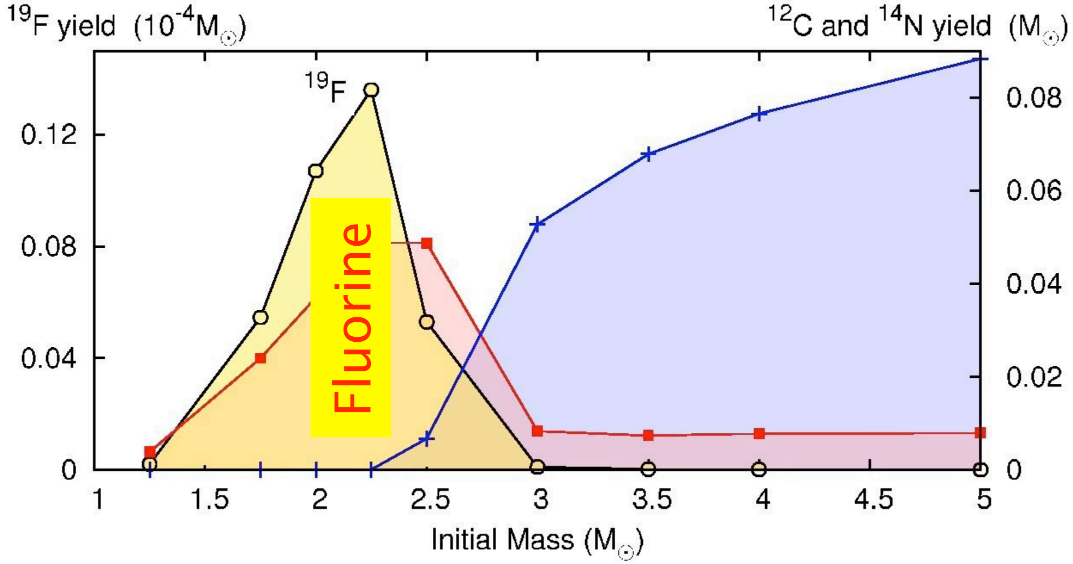


Carbon Enhanced Metal Poor stars

Testing the AGB binary scenario

- Additional predictions: fluorine

Lugaro, De Mink, Izzard et al. (2008)



- Population Synthesis

Izzard et al 2009

  – Hard to explain so many (20%) carbon-enhanced
    – Extra Dredge up in low mass TpAGB stars?
    – Different IMF at low metallicity?....→......

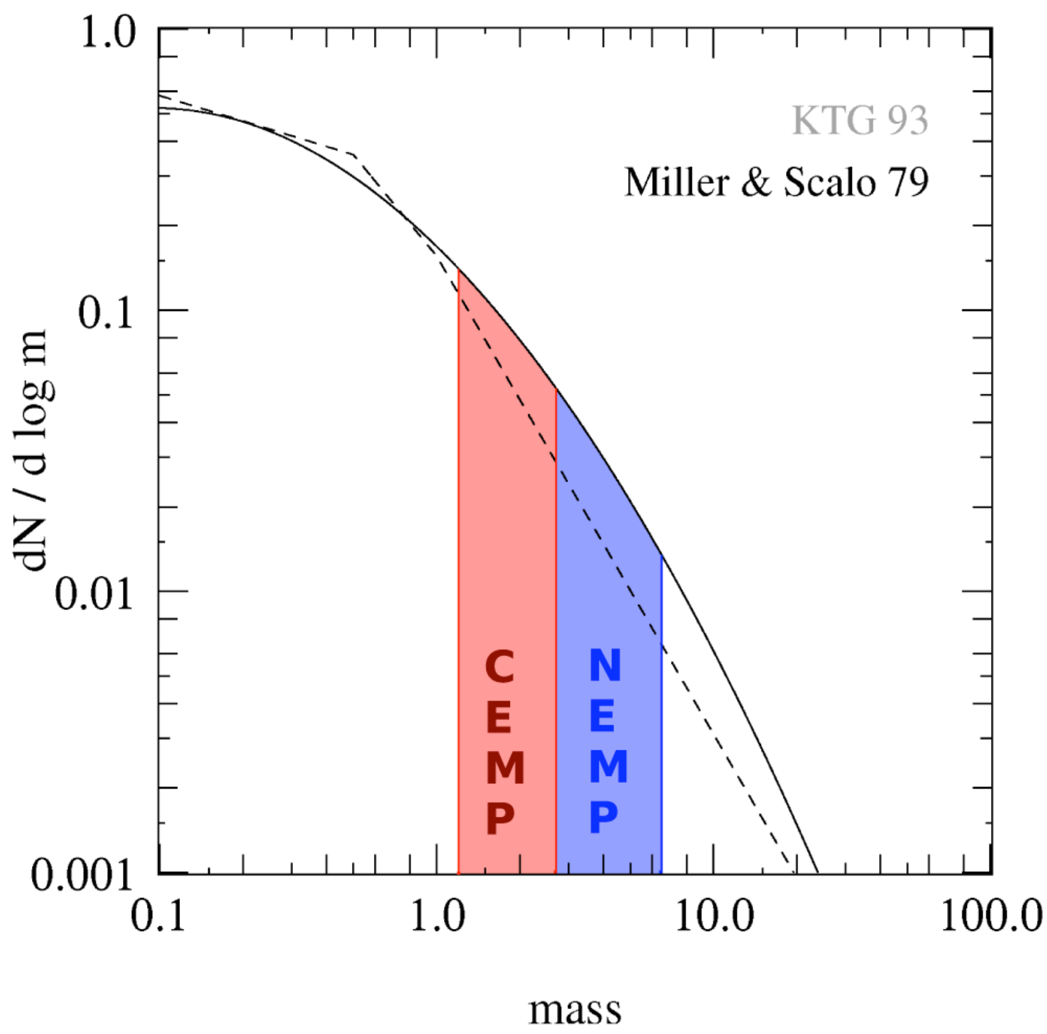
Testing the IMF at low metallicity

Nitrogen-Enhanced Metal-Poor stars → NEMP

[N/Fe] > 0.5 and
[C/N] < −0.5.

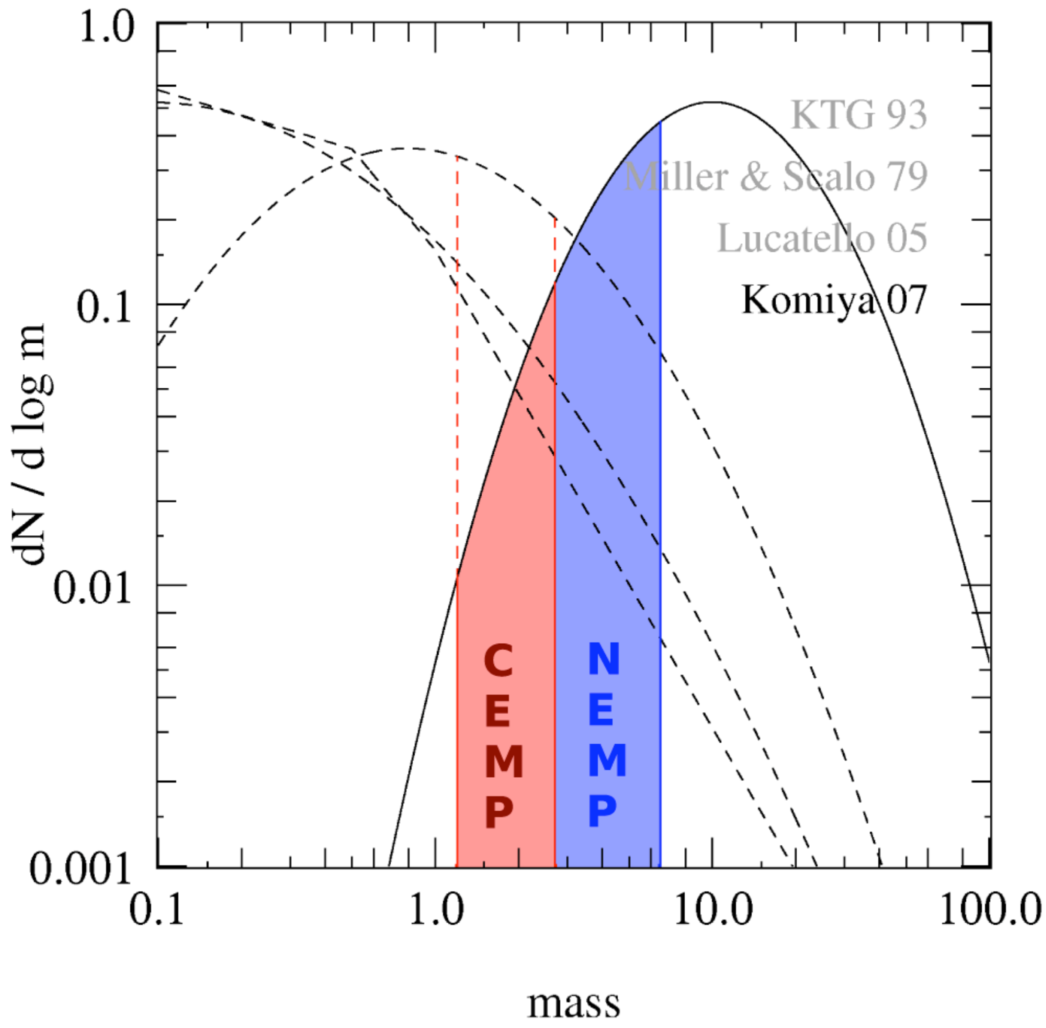
They appear to be very rare

Just a few examples are known, mostly at [Fe/H] < −2.9



Izzard et al. (2009), Pols et al (in prep.)

Testing the IMF at low metallicity



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Summary

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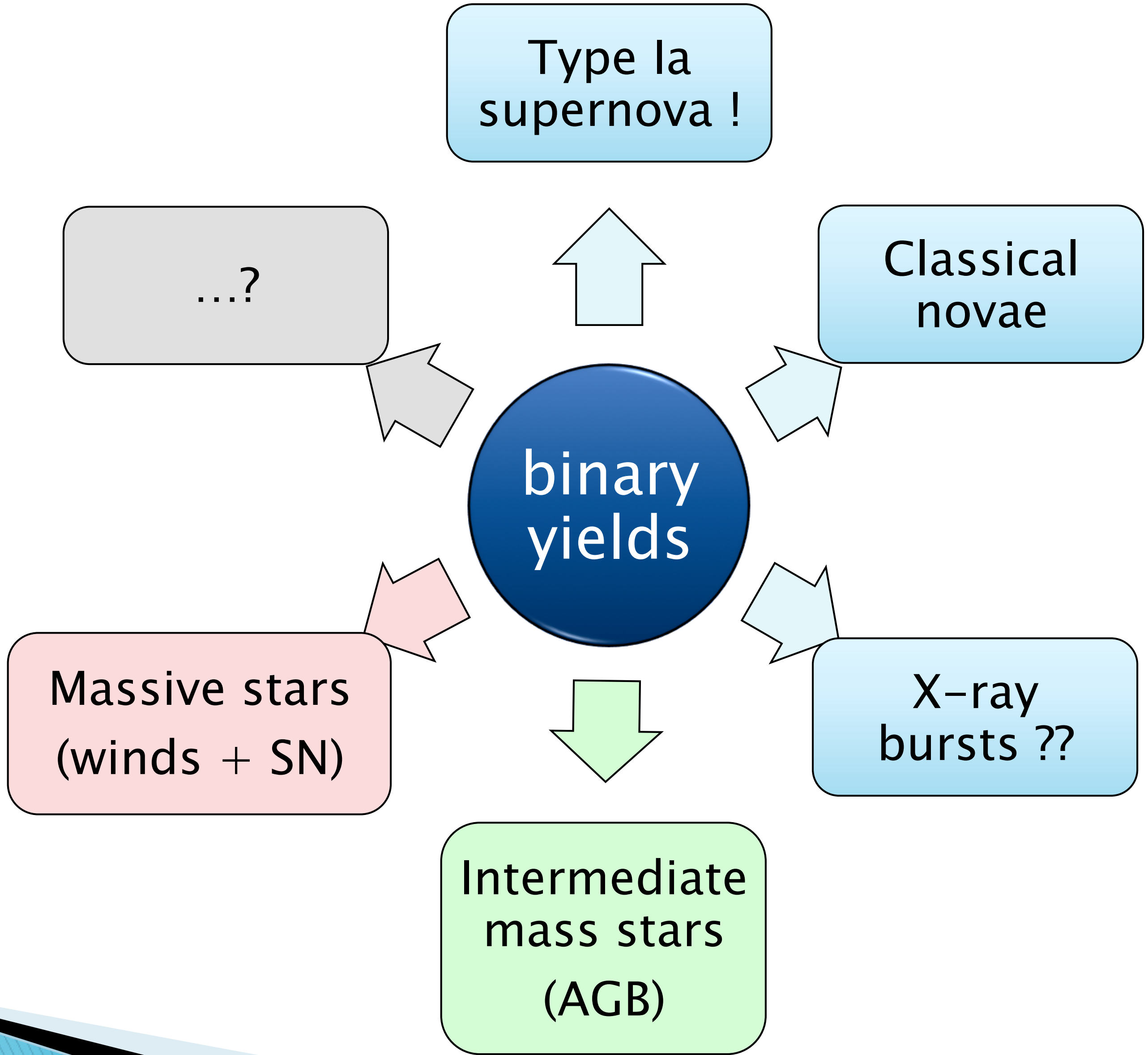
Type Ia
supernova !
...?
Classical
novae
binary
yields
Massive stars
(winds + SN)
X-ray
bursts ??
Intermediate
mass stars
(AGB)


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Properties of massive binaries

- Properties of 38 spectroscopic OB binaries in 6 well studied nearby open clusters, (IC 1805, IC 2944, NGC 2244, NGC 6231, NGC 6611 and Tr 16)

Fig from Sana+Boquin09 (proceedings paper), Mason+2009