Tópicos

Close binary stars

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Lecture 2

14/08

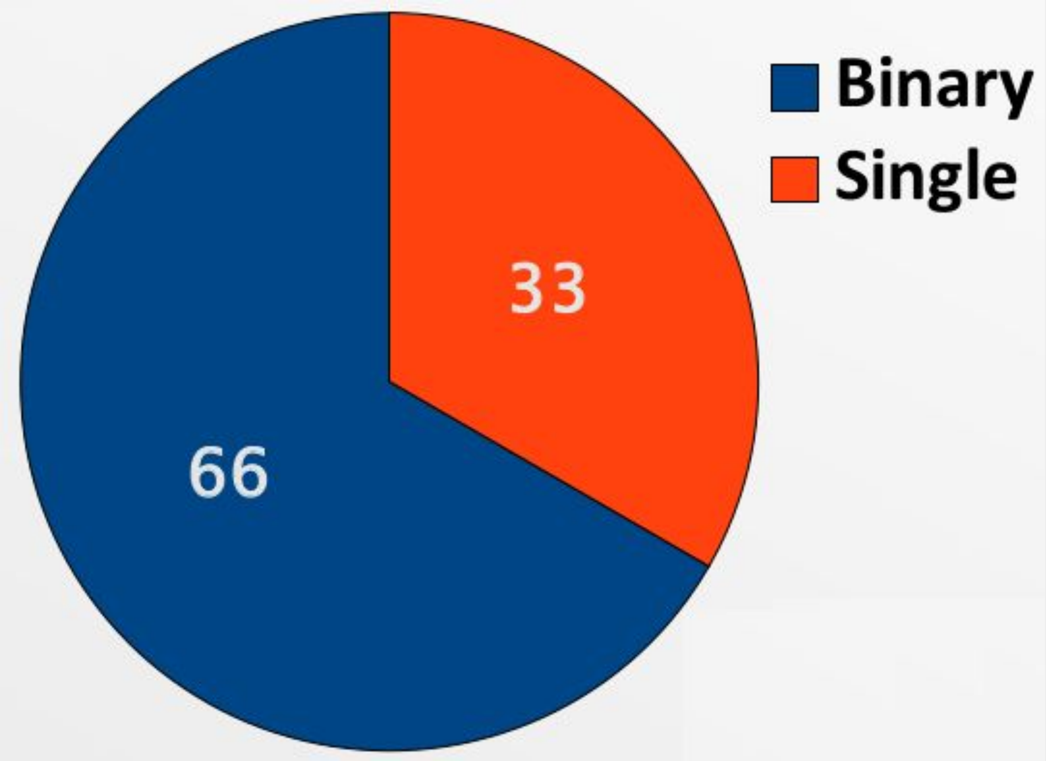
Statistics: Binary Fraction

First studies: Duquennoy & Mayor (1991)

1618 stars brighter than 5 th Magnitude:
- 825 Single-stars
- 793 Binary-star systems

- Binary System Fraction 49%
- Binary Star Fraction >66%

(2 stars in each Binary System)



Statistics: Binary Fraction

Duquennoy & Mayor (1991), studied the multiplicity of G stars and argued that two-thirds of all stars are not isolated.

Raghavan et al. (2010), updated the study and found that Sun-like stars have an overall multiple fraction of ~45%.

Are binary statistics for G stars representative of all stars?

Surveys suggest that the binary star frequency may be a function of spectral type, i.e. mass (e.g., Fischer & Marcy 1992)

The real fraction is not clear. Binarity fraction seems to depend on several parameters (mass, age, metallicity, stellar density of the medium...)

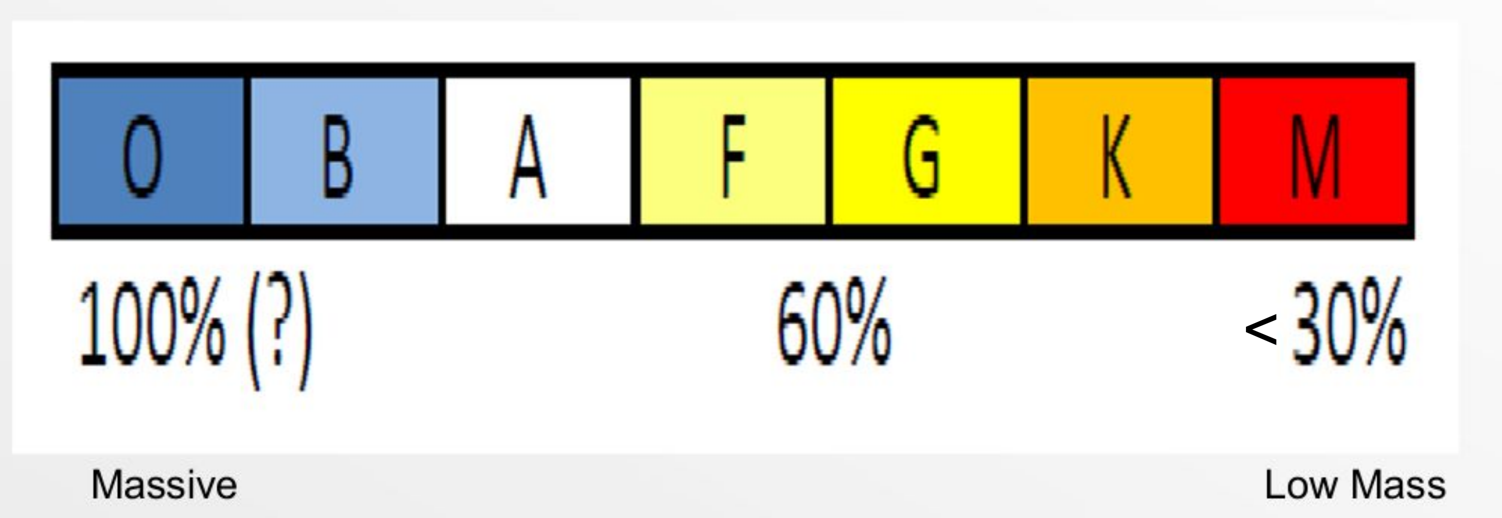
Binary Fraction
Mass dependence

Allen (2007) found that ultracool dwarfs (M6 and later) have a binary frequency of 20% ± 4%.

For more massive O stars, Sana & Evans (2010) report that ~75% are binaries.

Massive stars more likely to be binary

The overall binary frequency appears to be an increasing function of stellar mass, with more massive star more likely to have at least 1 companion. (e.g. Raghavan et al. 2010)



Are most stars born in binary or multiple systems?

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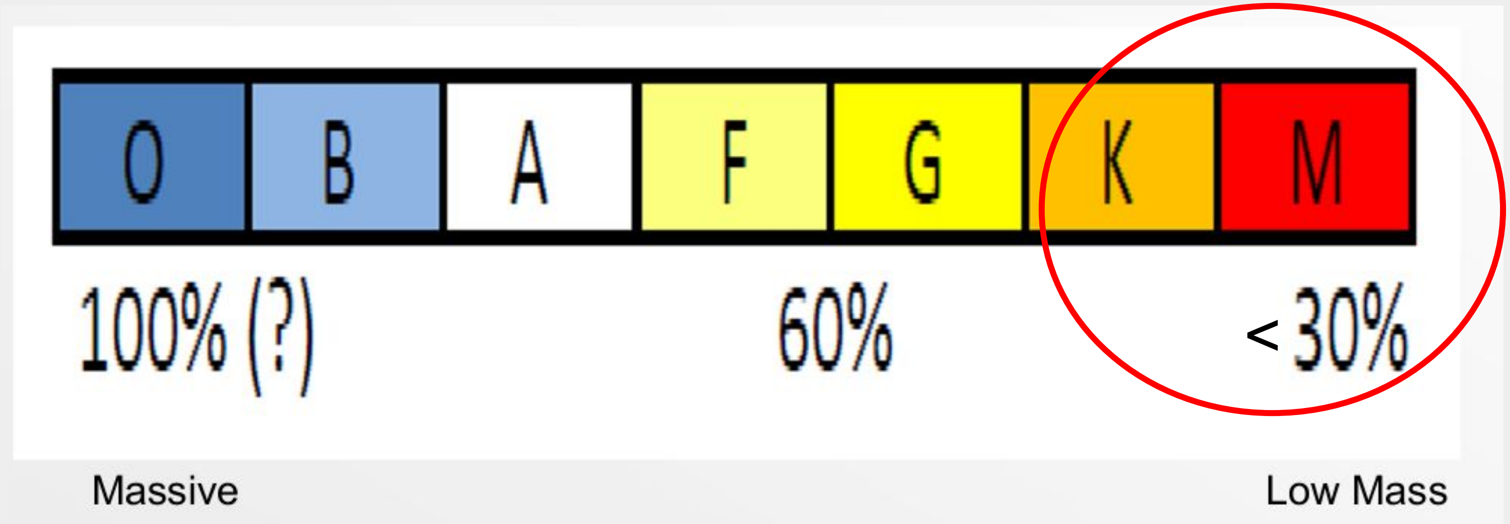
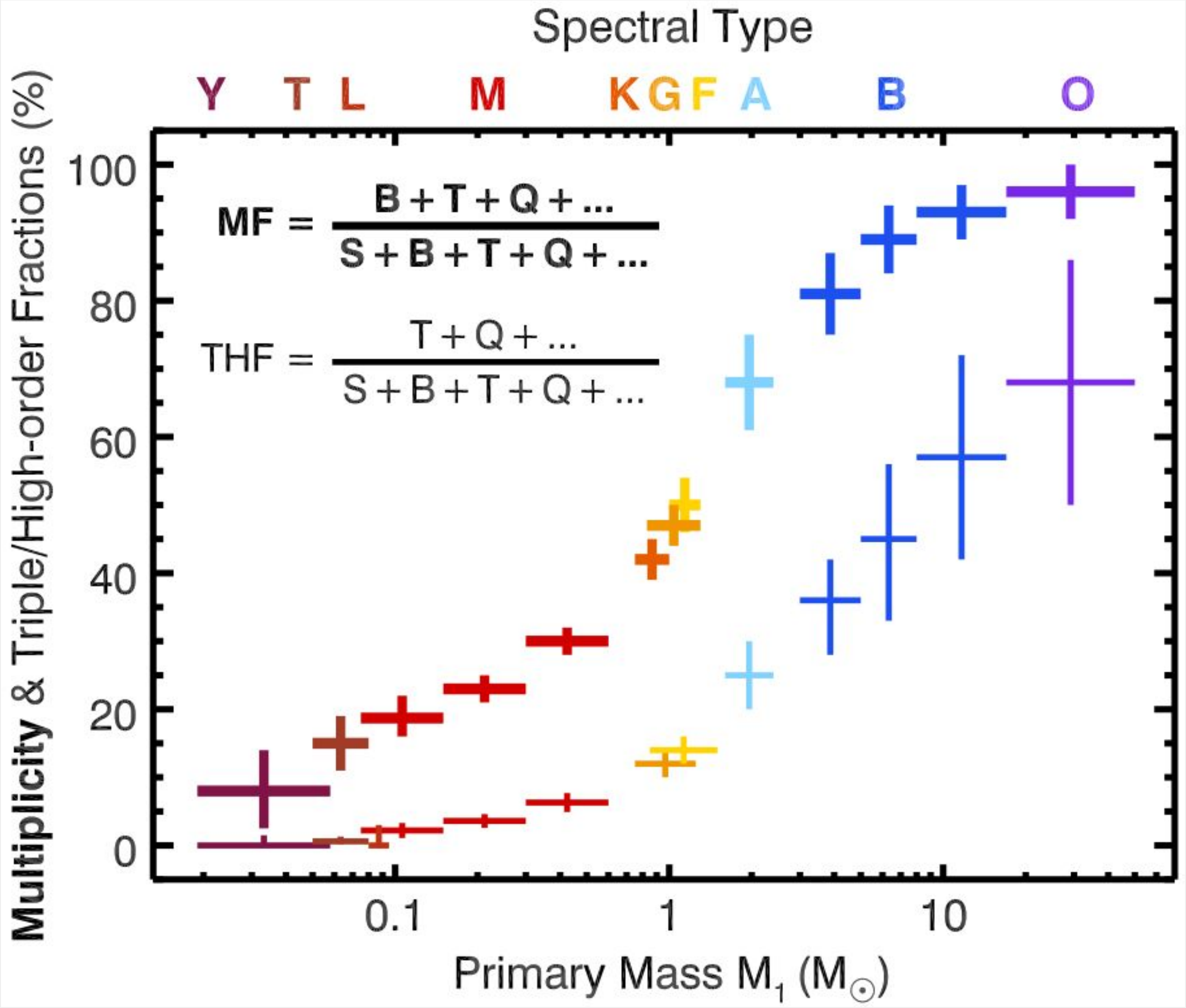


Lada (2006)
Given the IMF: are most stars single?

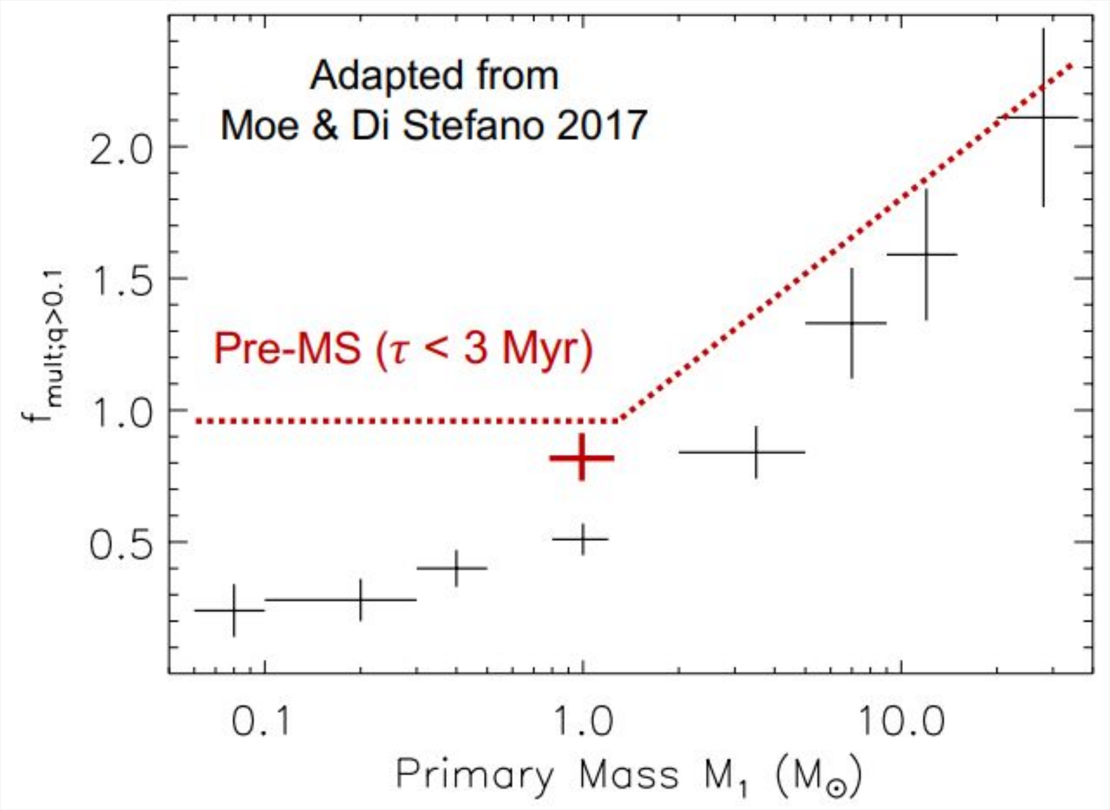
Did most single low mass stars born single?



Offner et al. (2023)

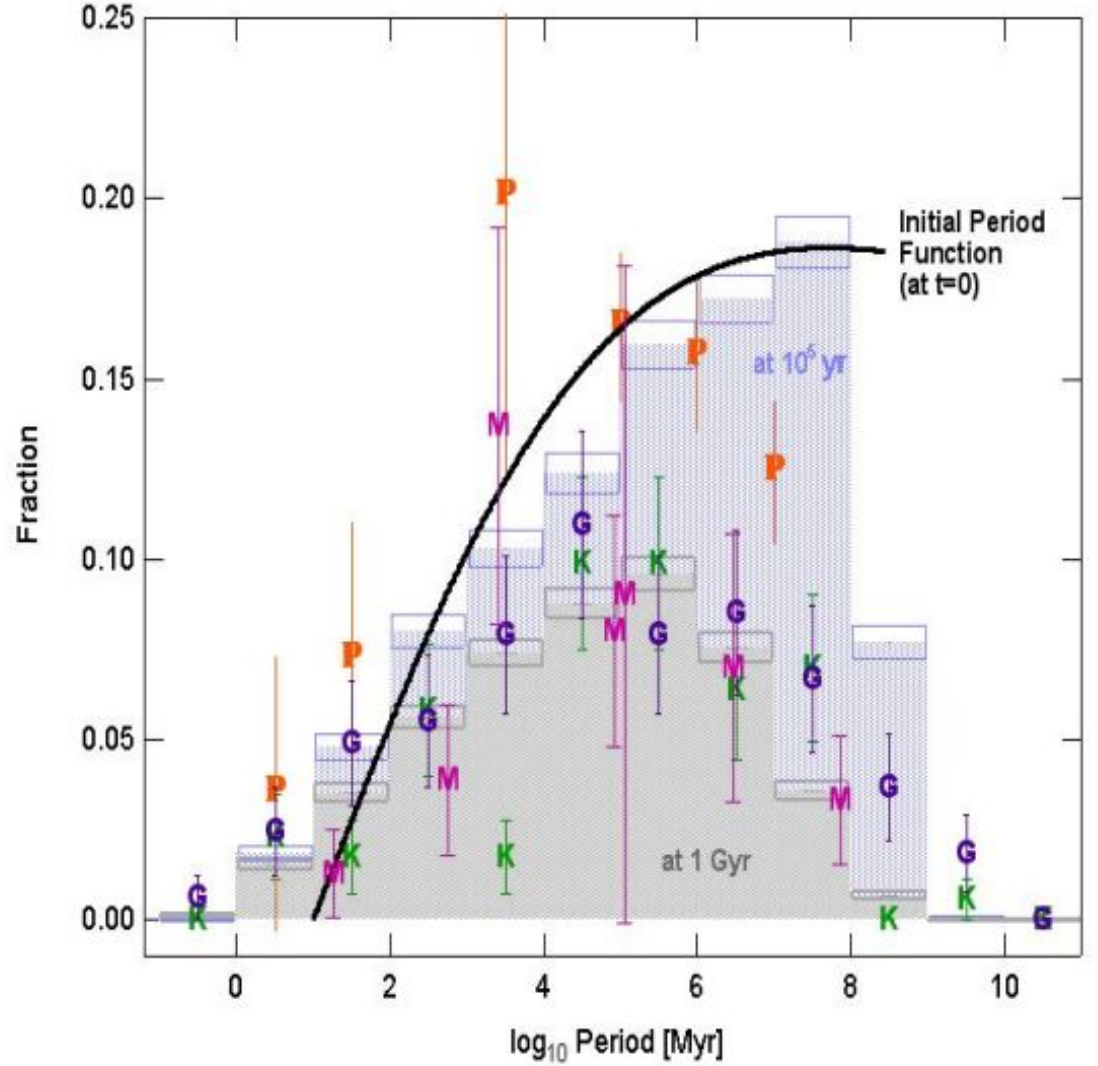
Did most single low mass stars born single?

It is suggested that disruption of wide binaries with smaller binding energies (smaller M1) reduces f_{mult} on the main sequence



Corrected frequency of companions with q > 0.1 and log P (days) < 8 (a < 10,000 AU) per primary near ZAMS (normalized to the multiplicity of solar mass stars at ZAMS)

Binary Fraction by Period
Age dependence



Binary fraction by period at 100 kyr and 1 Gyr (Goodwin et al., 2006).

Binary fraction decreases after cluster formation.

Very wide binaries are separated.

Field **G**, **K** and **M** stars
P = pre-main sequence
Blue histogram = initial binary population (simulations of Kroupa 1995)
Gray histogram = Evolved through dynamical interactions in a cluster into a field-like distribution.

Initial multiplicity fraction may be as high as 100%.
Much higher than in field stars for wide binaries. (Goodwin et al., 2006)

Binary Fraction
Metallicity (age?) dependence

Reference	Spectral Type	Minimum $\log(Z/Z_\odot)$	As Z↓, ΔF/F
Carney+ 2005	G	−2.4	<|30%|
Gao+ 2014	G	−1.5	+50%
Hettinger+ 2015	F	−1.7	−25%
Moe+ 2013	B	−0.7	<|20%|
Dunstall+ 2015	B	−0.4	<|30%|

Variations with respect to Z are small and possibly due to sensitivity and selection biases, e.g., lower-metallicity stars are systematically older and more likely to contain WD companions (harder to detect)

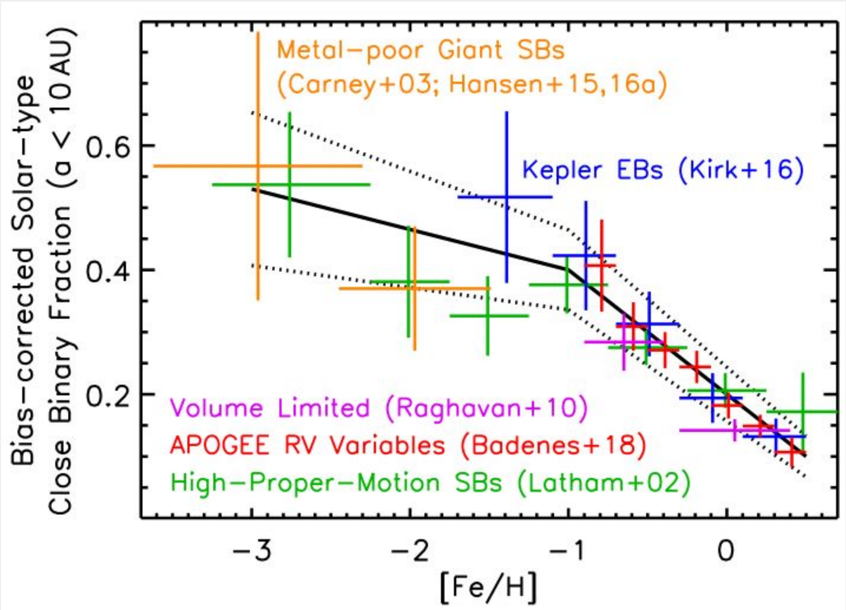
Binary Fraction
Metallicity (age?) dependence

For close binary companions, metal poor stars seem to have a binarity fraction 2-3 times larger than metal rich stars.

(e.g. Badenes et al. 2018, Moe et al. 2019).

→ Metal poor = old.

Close binaries get closer?

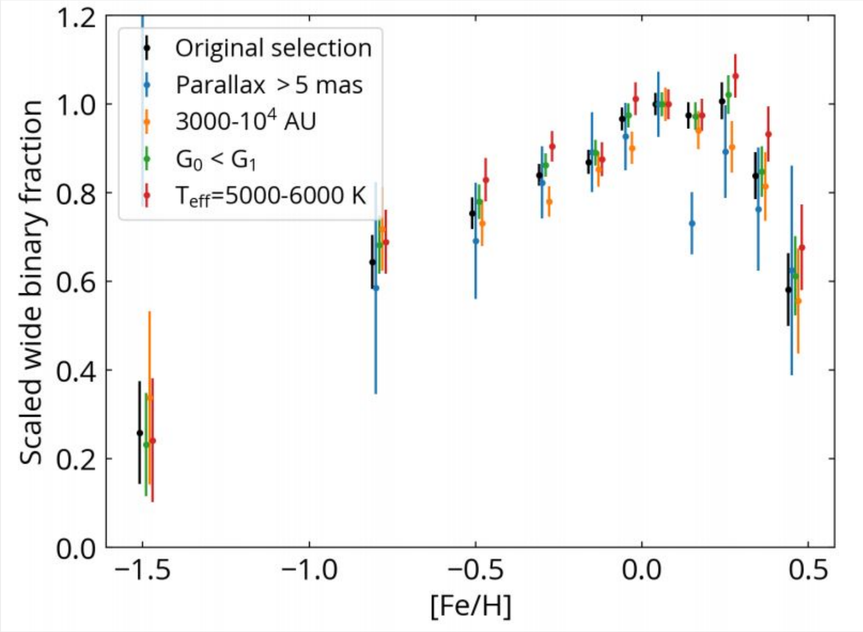


For wide binaries, it seems to be the other way, with metal poor stars being less likely to have wide companions.

(e.g. Hwang et al 2021).

→ metal poor = old.

Wide binaries get unbound?



Summary

Current believes:

- Most stars are born in binary/multiple systems

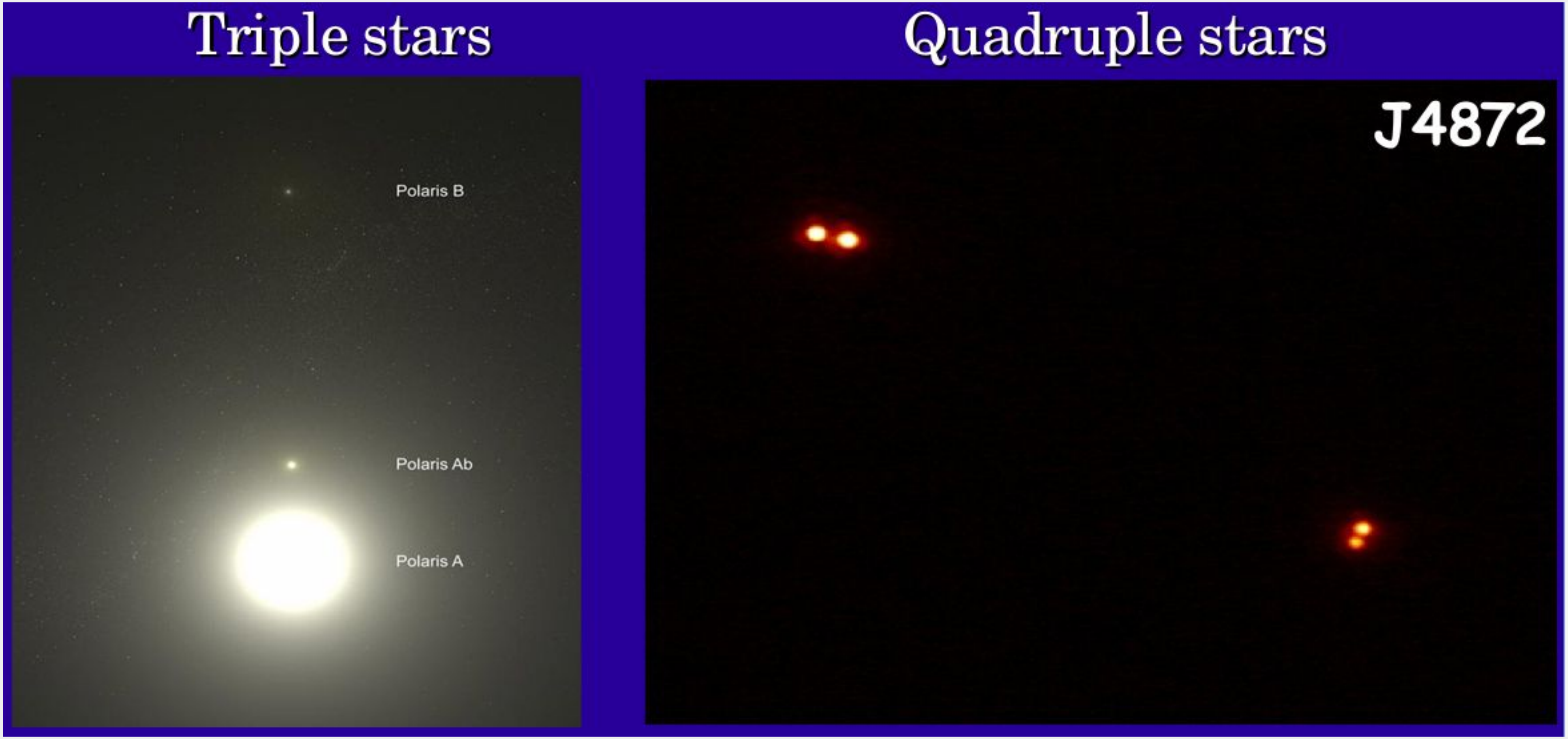
- Wide binaries are initially more common, but get disrupted if M1 is small → Smaller fraction of wide binaries at low z (older systems)

- Closest binaries are the result of interaction in multiple systems or binary evolution → (very) close binaries more common for low z (older)

What about triples, quadruples...

Higher order multiples

Stellar systems consisting of more than 2 stars orbiting around a common center of mass also exist



Higher order multiples

Previous picture neglects triples, quadruples etc…
BUT… they represent ≈ 25% of all solar-type multiple systems.
(Eggleton & Tokovinin 2008)

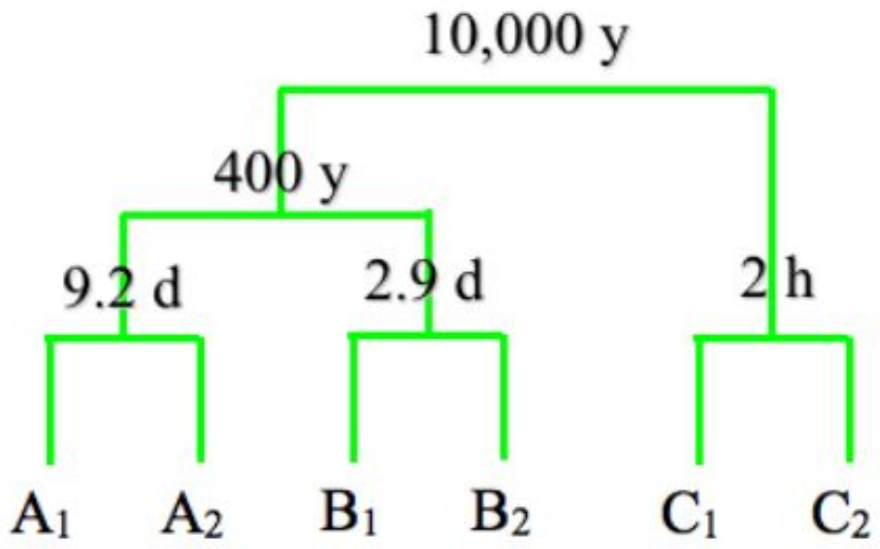
A large fraction of all binaries with P_{orb} ≤ 100 days are members of high-order multiple systems.

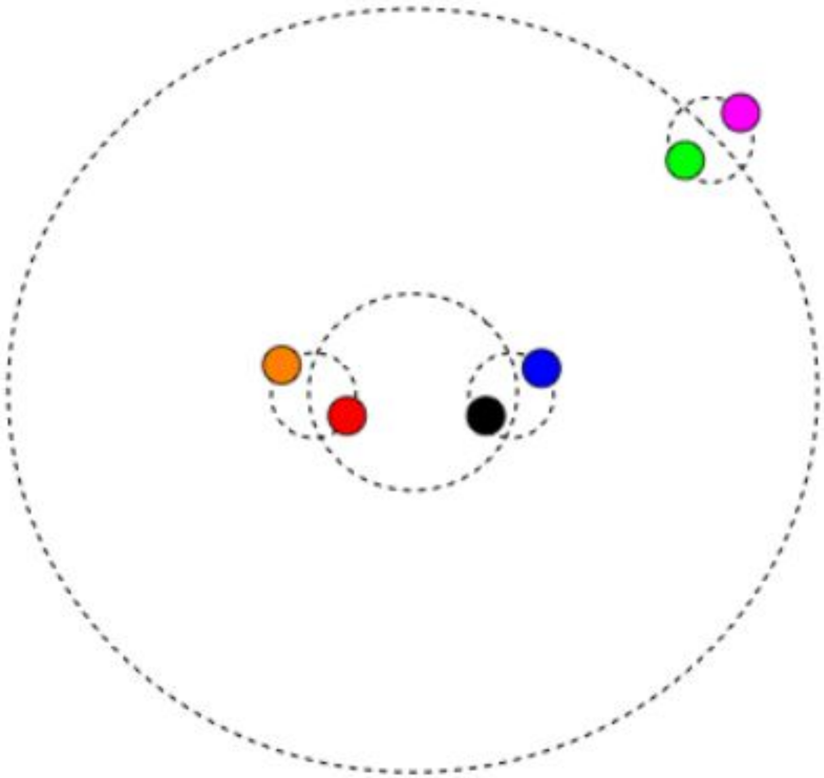
For binaries with initial period P_{orb} ≤ 3d, almost 100% have at least a third object.
(Allen et al. 2012, Tokovinin et al. 2006).
→ Suggests that the presence of an outer companion plays an important role in the formation of tight pairs, presumably through energy and angular momentum exchanges (e.g. Kozai-Lidov oscillation).

The frequency of triple systems among wide systems (separation ≥1000 AU) is also high.
(Makarov, Zacharias & Hennessy 2008).

Higher order multiples

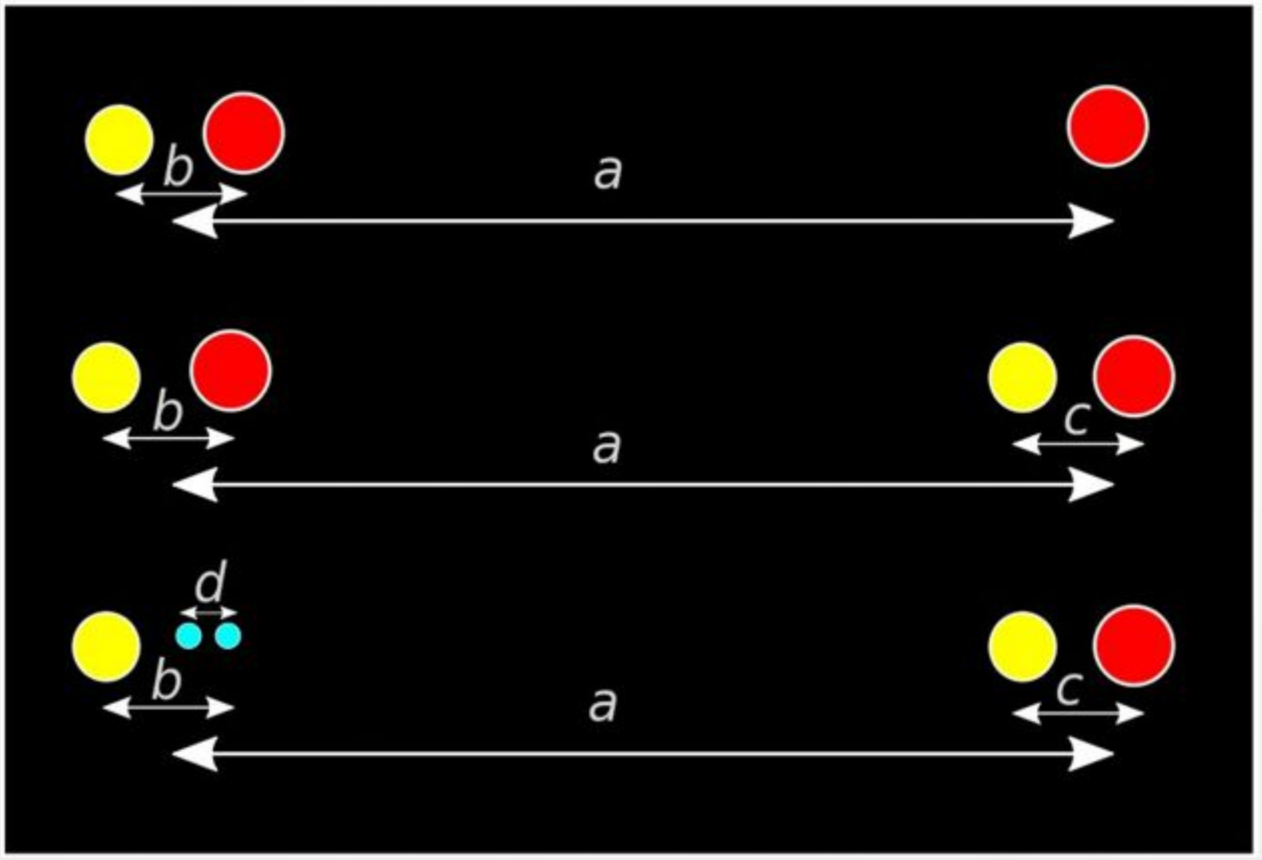
Multiple systems are always hierarchical with $P_{long}/P_{short} \gtrsim 5$ (e.g., Tokovinin 1997)





Higher order multiples

- Must be hierarchical to be stable: treat as binaries



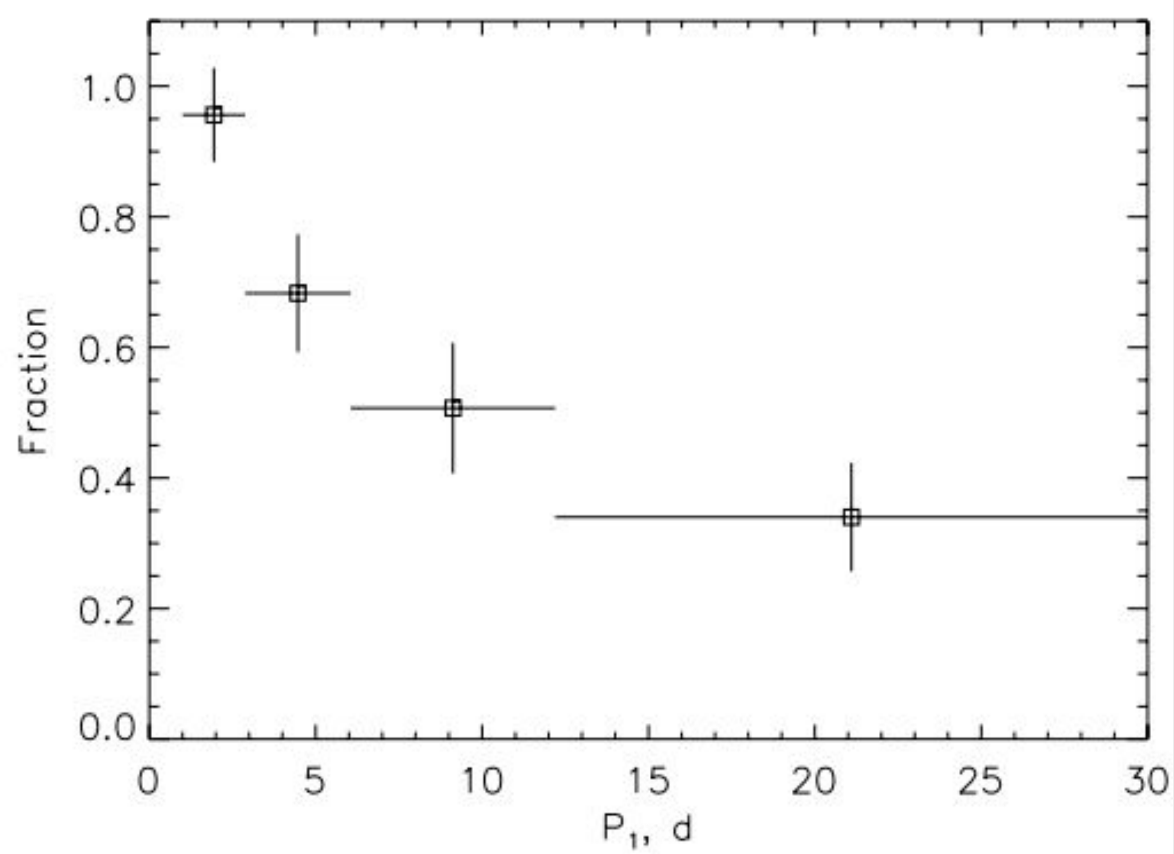
a >> b

a >> b, c

a >> b, c; b >> d

Triples leading to very close binaries

Very close binaries derive from dynamical interactions in triples.



~96% of solar-type binaries with P < 3d have a distant tertiary companion.

Fraction decreases with increasing period.

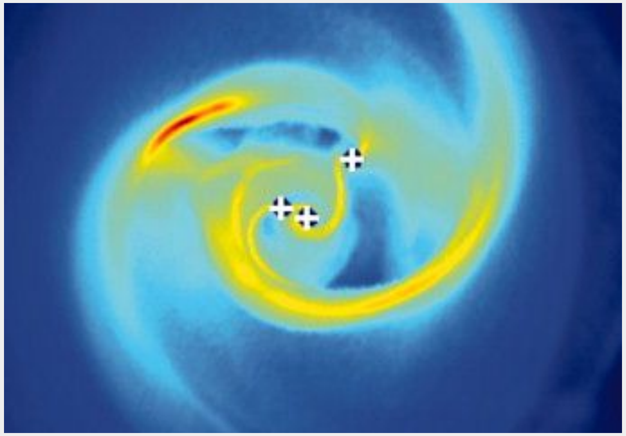
(Tokovinin et al. 2006)

Triples leading to very close binaries

Recommended lecture: (Moe & Kratter 2017)
https://arxiv.org/pdf/1706.09894.pdf

Two mechanisms

1) Dynamical unfolding of unstable triples + significant energy dissipation in disk (pre-MS).

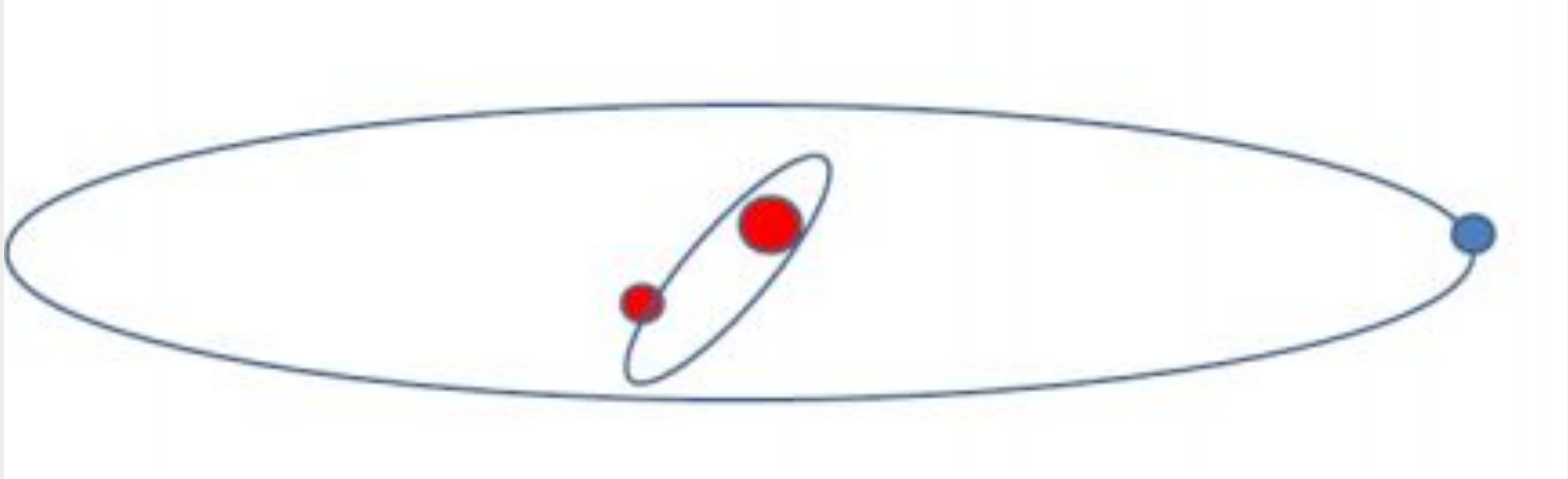


Triples initially born in non-hierarchical configurations (e.g. by disc fragmentation). One of the components is dynamically ejected, leaving behind a binary in an eccentric orbit with slightly reduced separation (at periastron tidal energy dissipation could be more effective).
Substantial extra energy dissipation due to interactions with primordial gas is needed to explain the closest binaries (P<10 days).

Triples leading to very close binaries

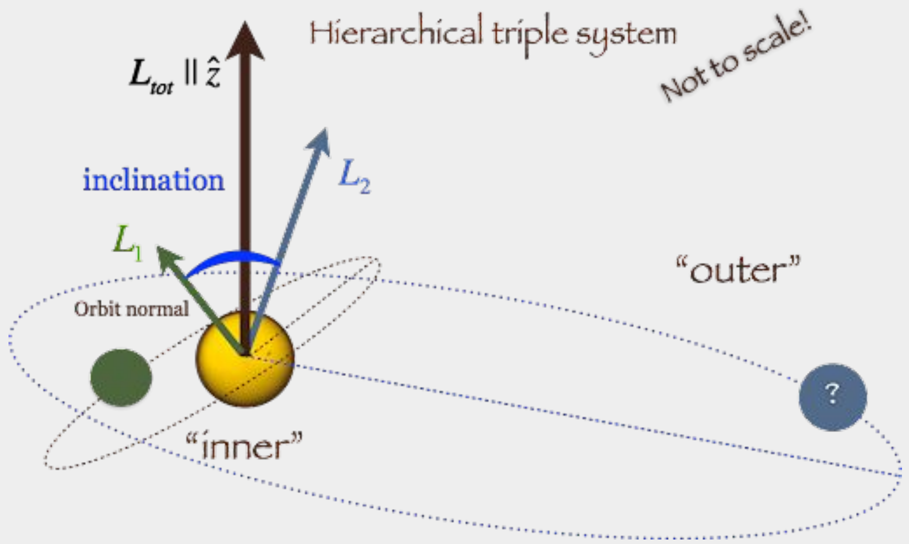
2) Kozai-Lidov oscillations in stable **not coplanar** triples + tidal friction

(e.g. Kiseleva et al 1998, Fabrycky &Tremaine 2007)



This mechanism works for hierarchical triples, if the orbits are inclined → oscillation of the inner eccentricity and inclination

Zeipel-Kozai-Lidov oscillations



If the orbit of the inner binary is inclined with respect to the orbit of the distant triple, the outer star can "pump up" the eccentricity of the inner orbit: **periodic exchange between its eccentricity and inclination**.

During high-eccentricity phases, tidal dissipation drains energy from the inner orbit → **circularization and reduction of the semi-major axis**.

The inner binary can merge, or become a very close binary (still with its triple distant companion, as observed)

For more details check Felipe Lagos's talk
https://drive.google.com/file/d/17IrPQeMMzoHS9iAbNyPOkKQFhW-fK7Qg/view?usp=sharing

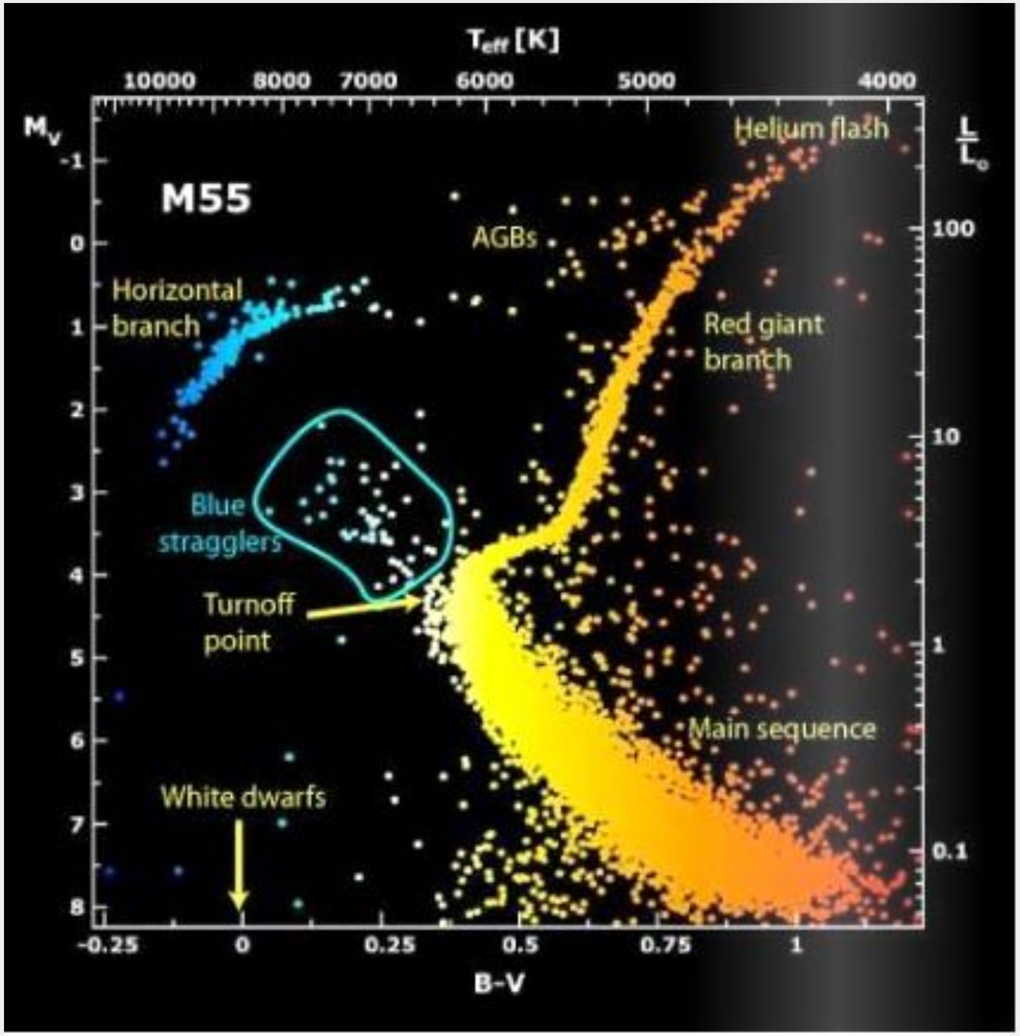
Merger result?

Merger result depends on the evolutionary phase when it happens.

If the inner binary merges while both stars are still on the MS, produces a **blue straggler**
(Perets & Fabrycky 2009).

If instead the inner binary first evolves into a pair of compact remnants (e.g. a close double white dwarf), the tertiary may accelerate the merger of the two compact objects and lead to the formation of a **Type Ia supernova** or **short gamma-ray burst**
(Thompson 2011).

Example: Blue stragglers



Blue stragglers are stars in globular clusters that appear to be anomalously young (given their mass they should have left the MS).

Possible origins:

- Stellar collision and merge (Kozai-Lidov oscillations in a triple might be a cause)
- Mass transfer in binary systems

Next: Parameter distribution