The Evolution of Stellar Triples

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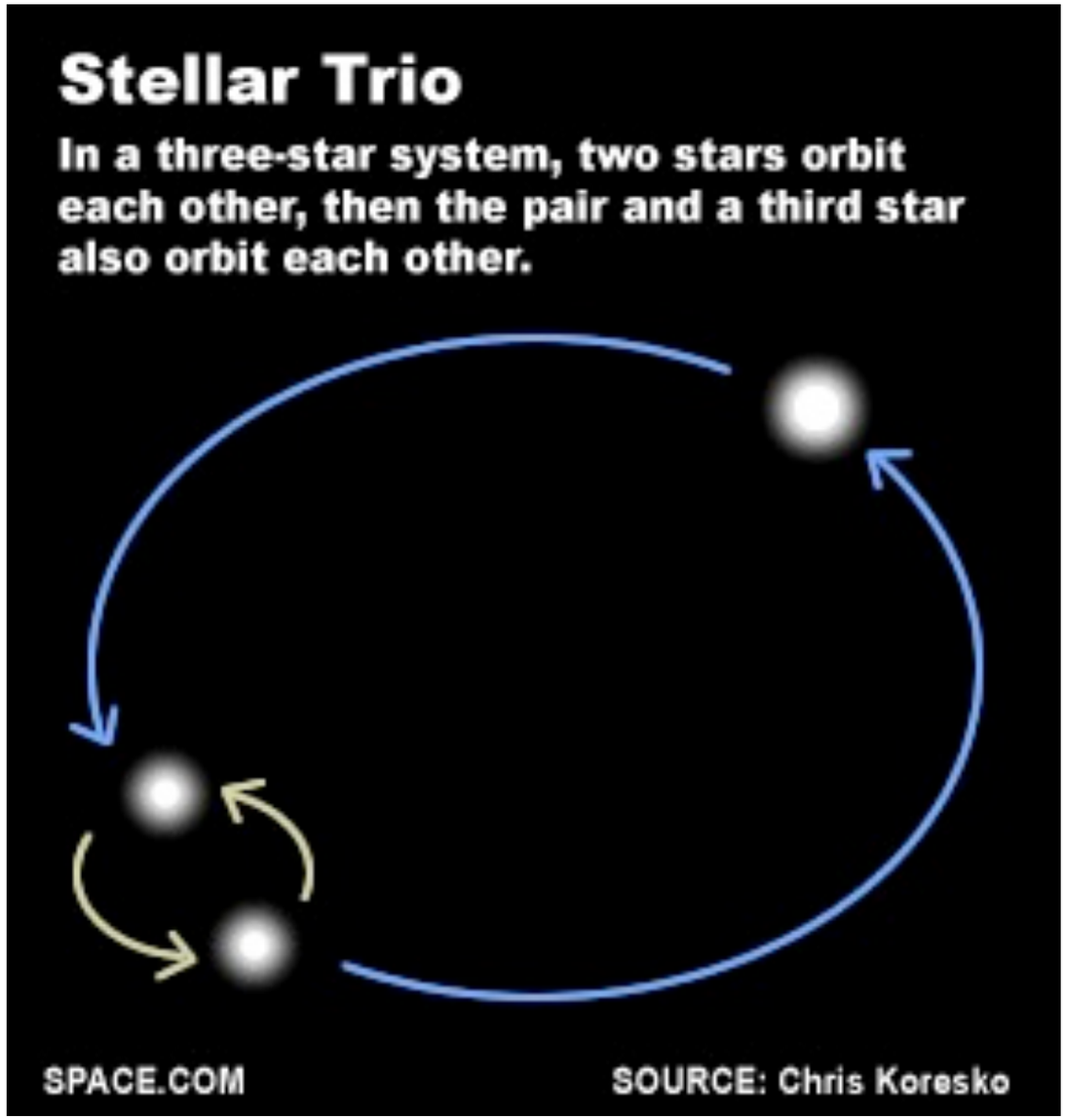
Adrian Hamers, Hagai Perets, Fabio Antonini

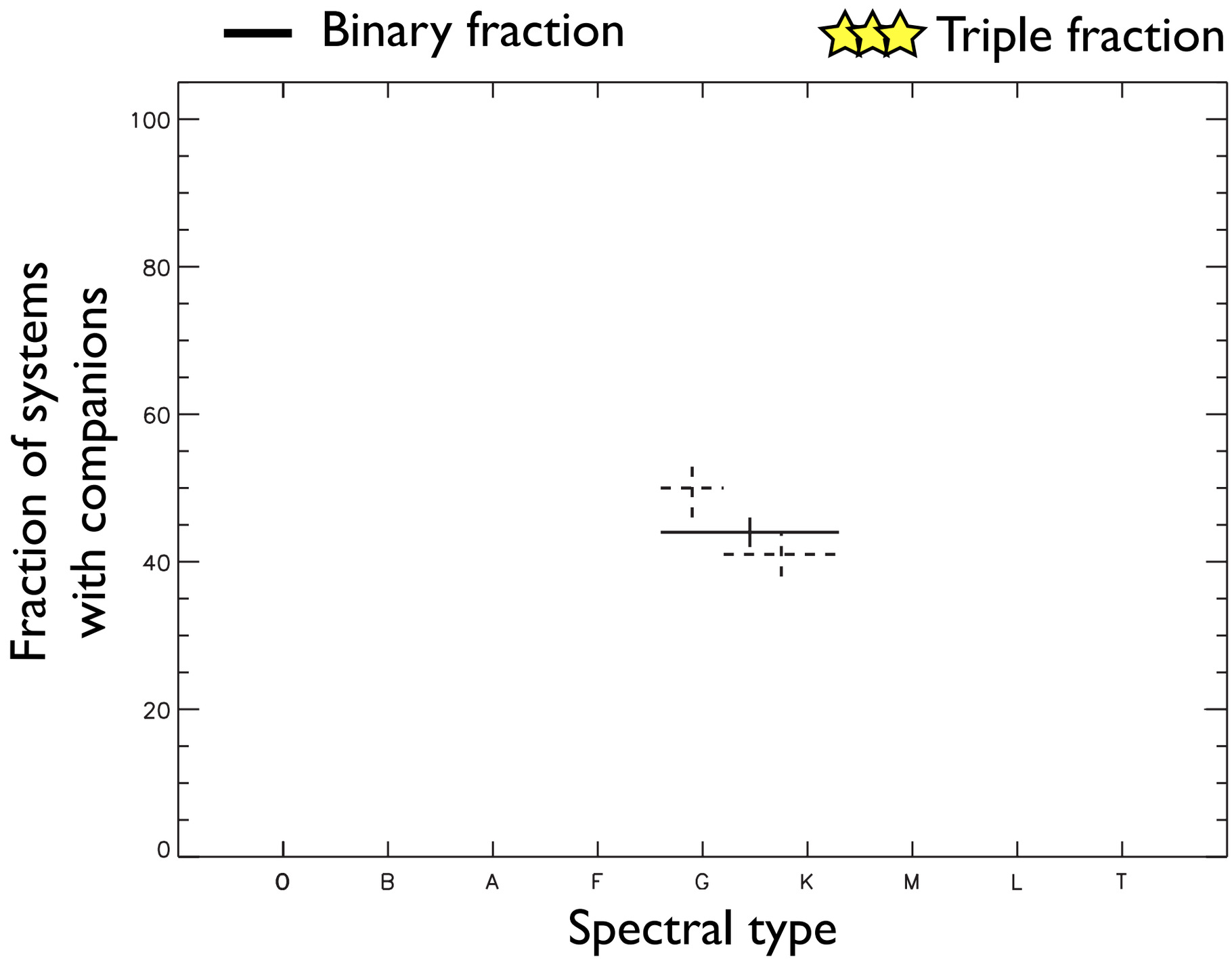
Triple evolution

Isolated Hierarchical Stellar triples:

- Long-lived
- Common



Triple stars are abundant



Initially distribution - young systems

Raghavan+ '10, Tokovinin '08, '14, Evans '05, Duchene & Kraus '13, Sana+ '14, Moe+ '17

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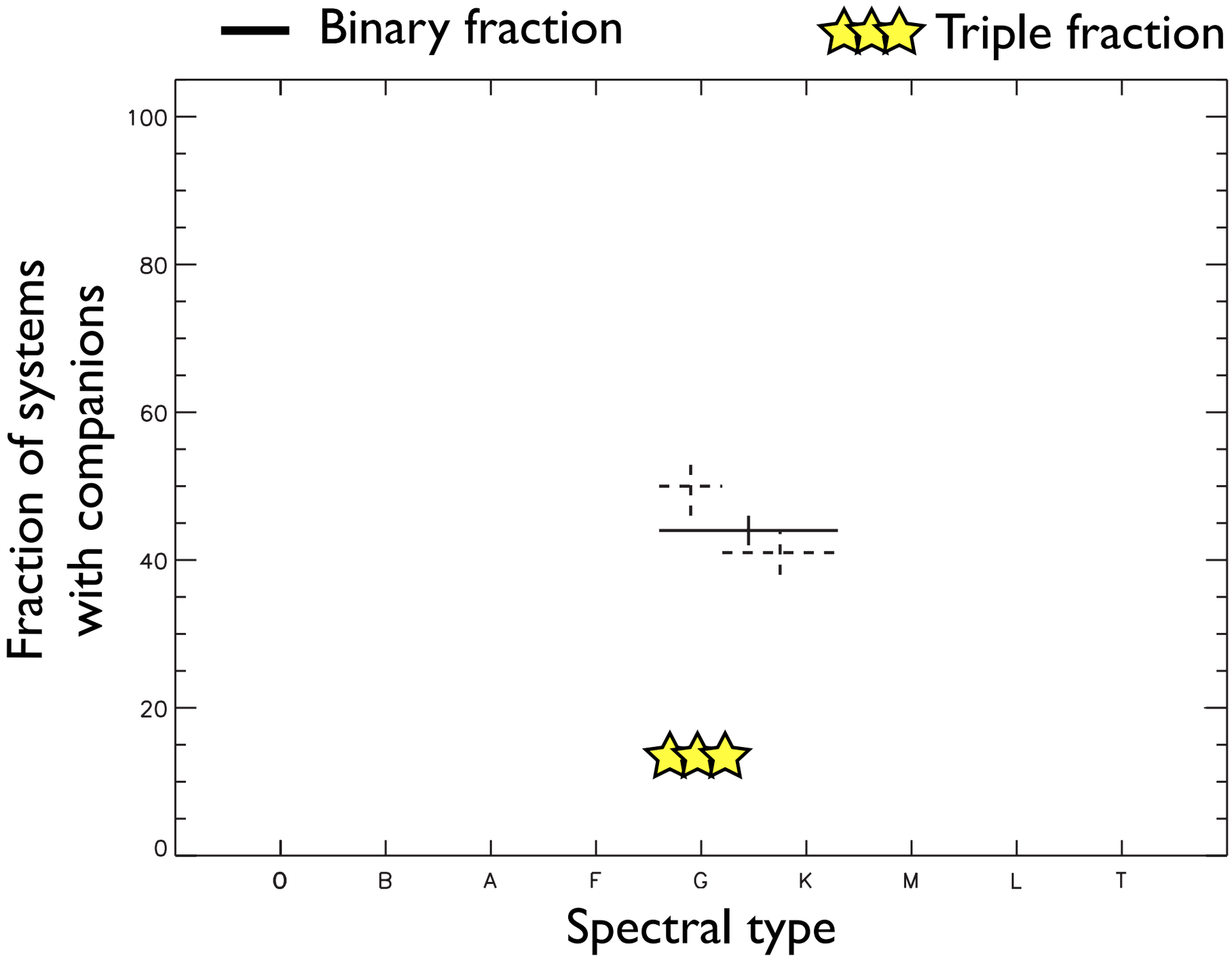

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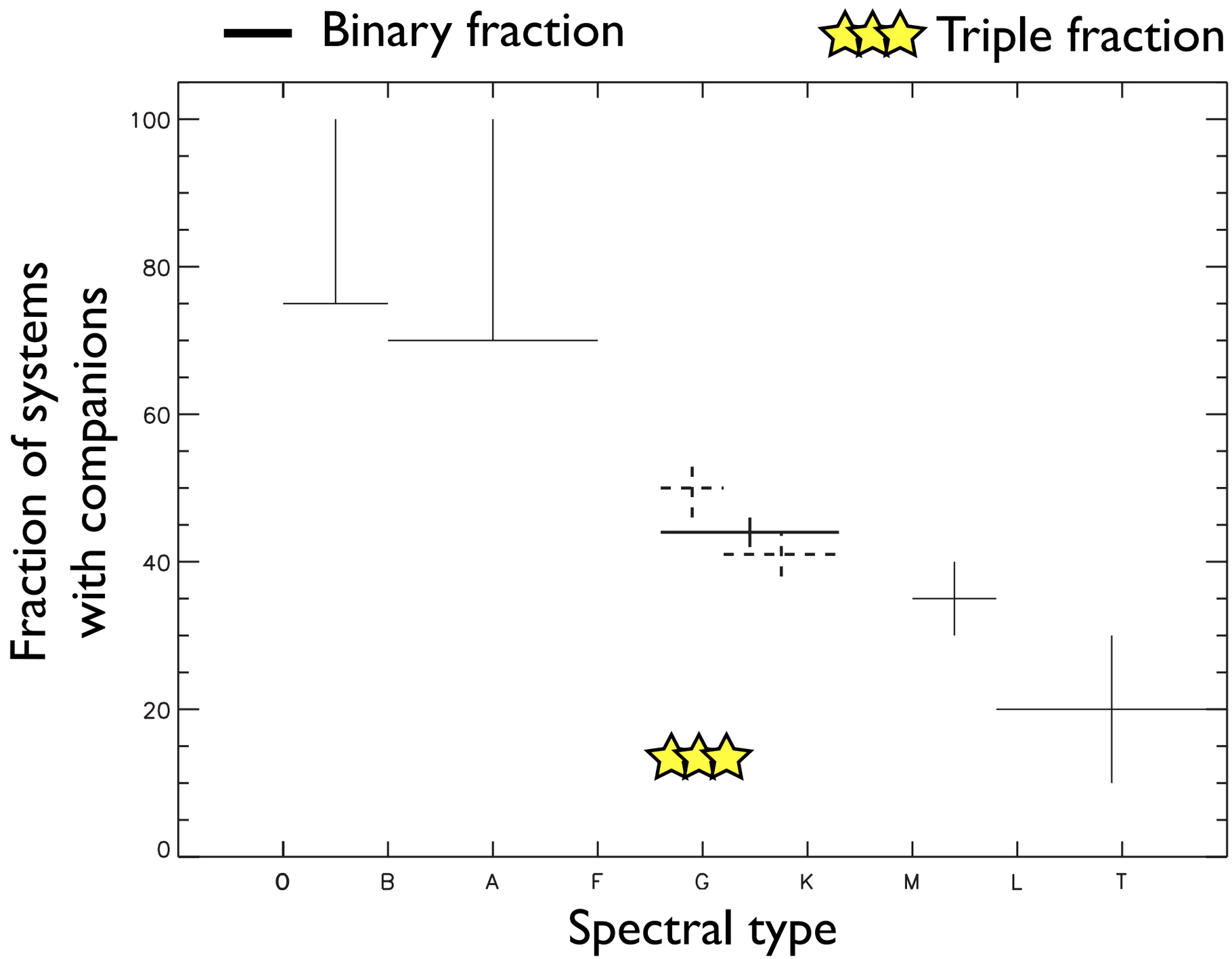

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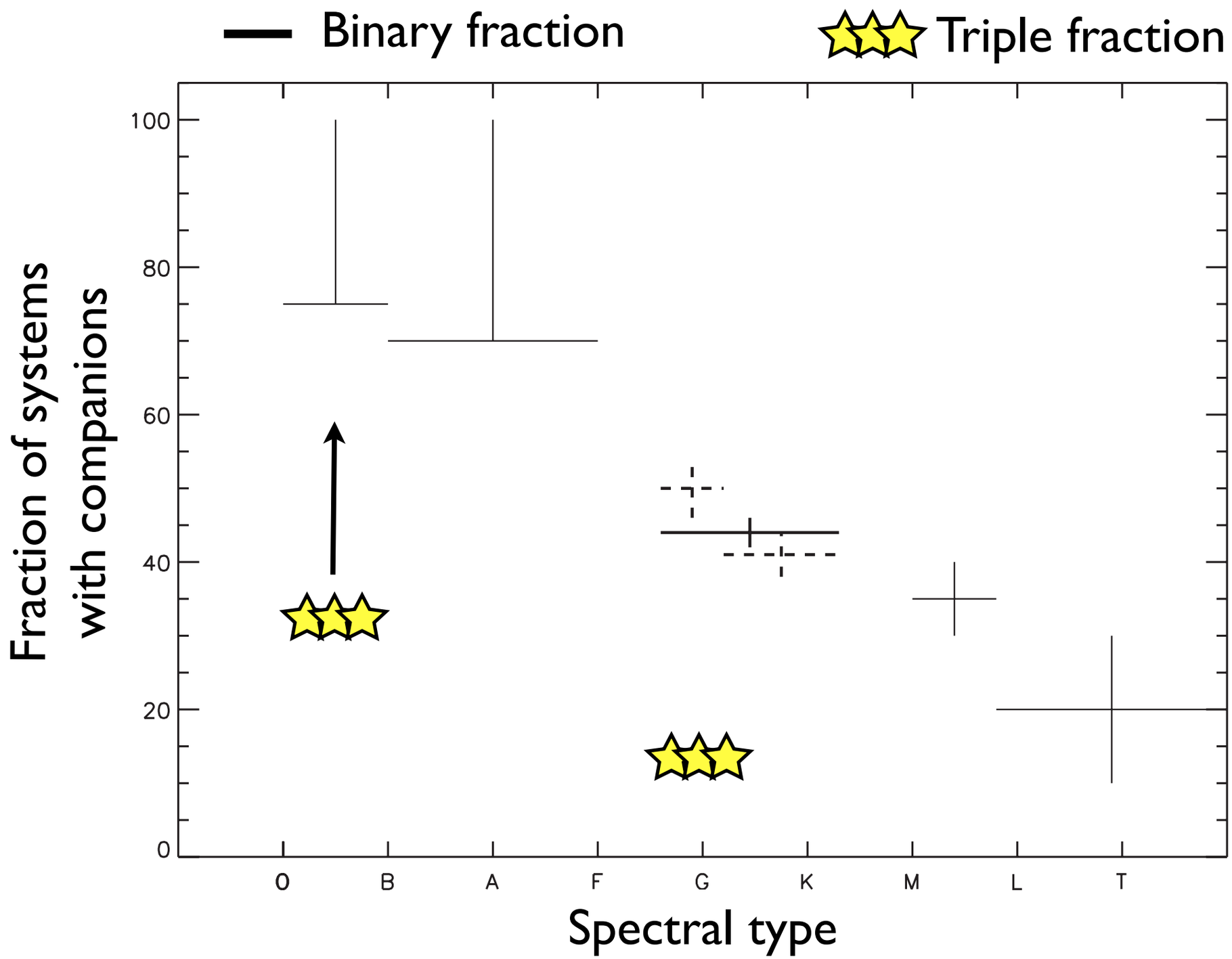

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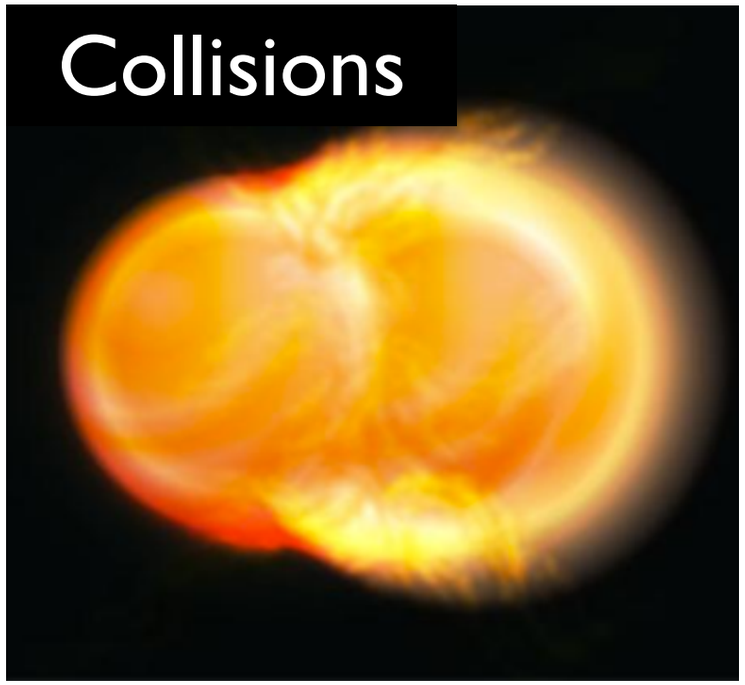

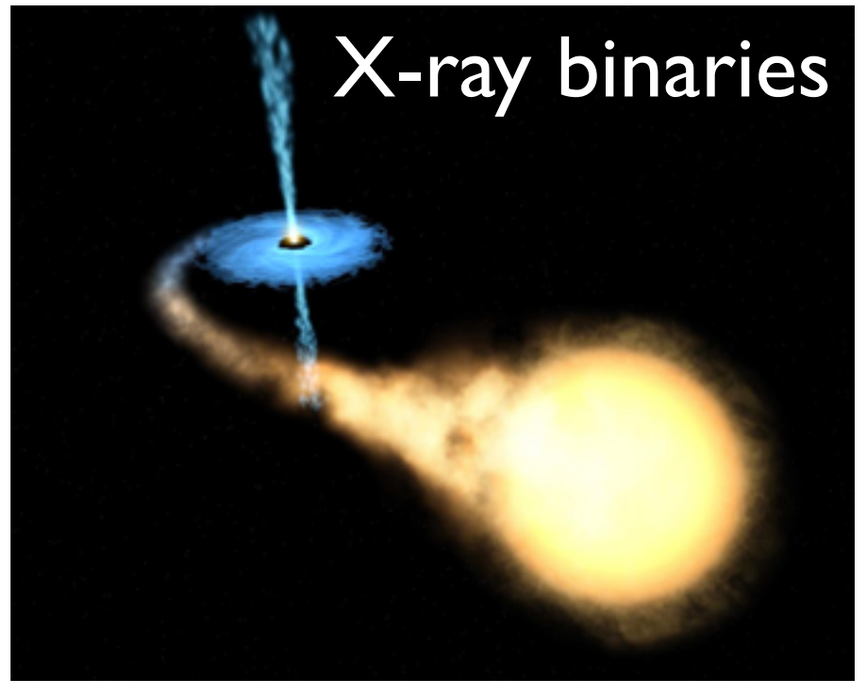

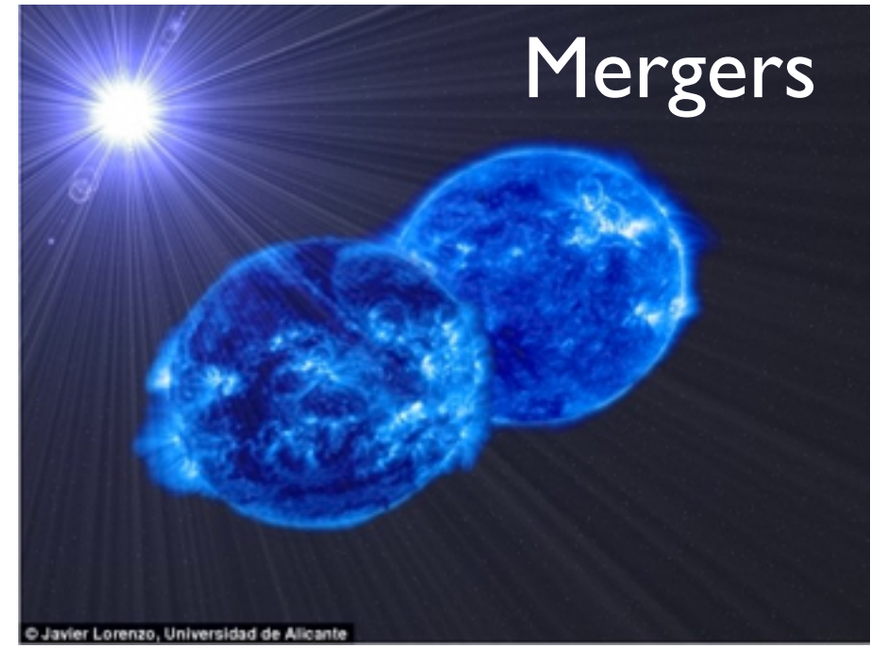

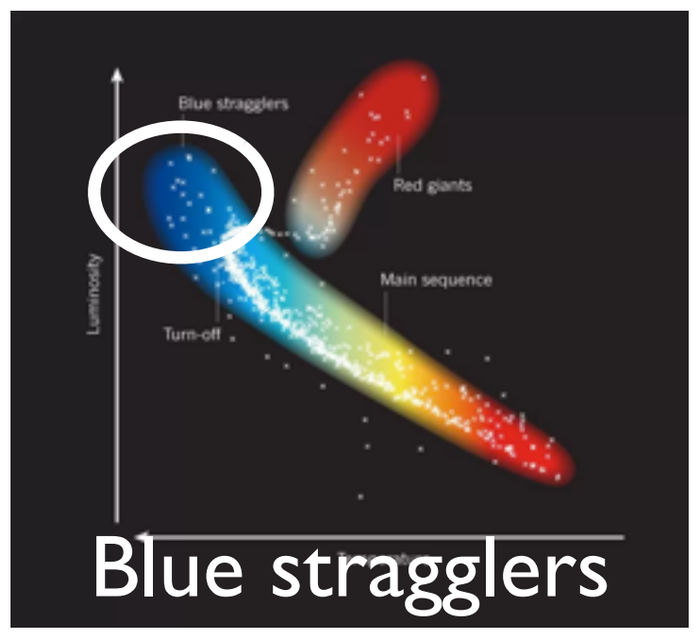

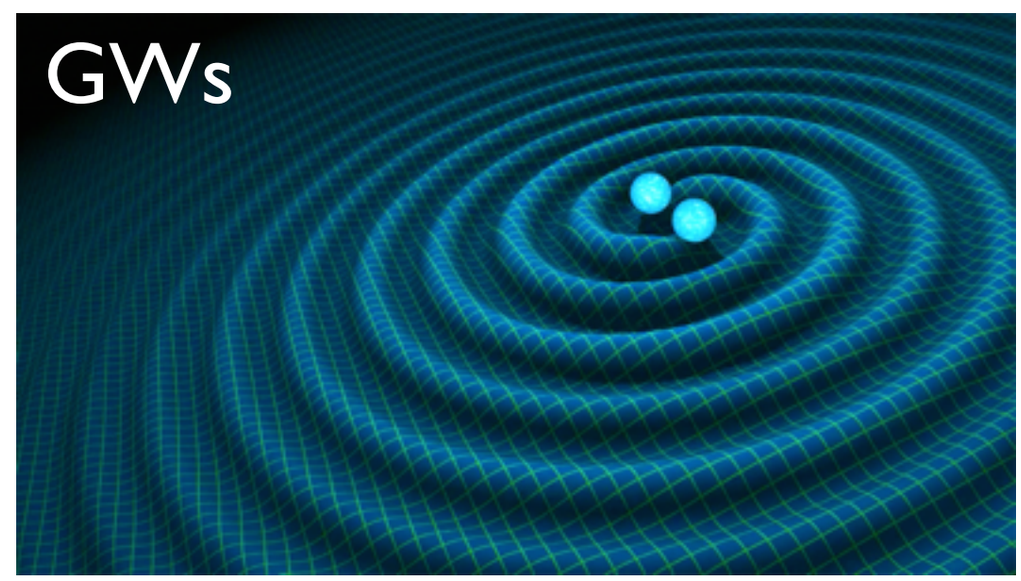

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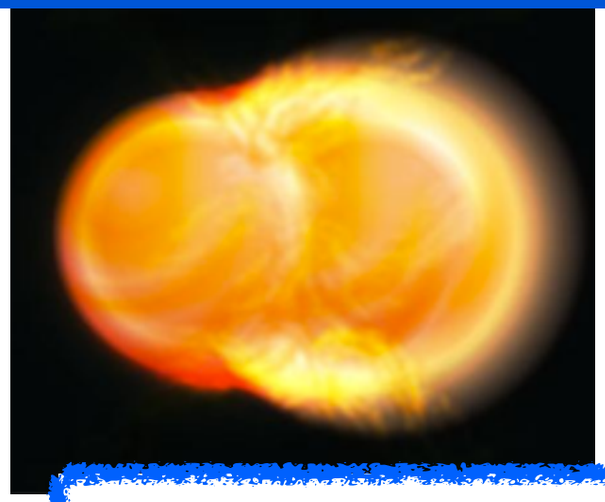
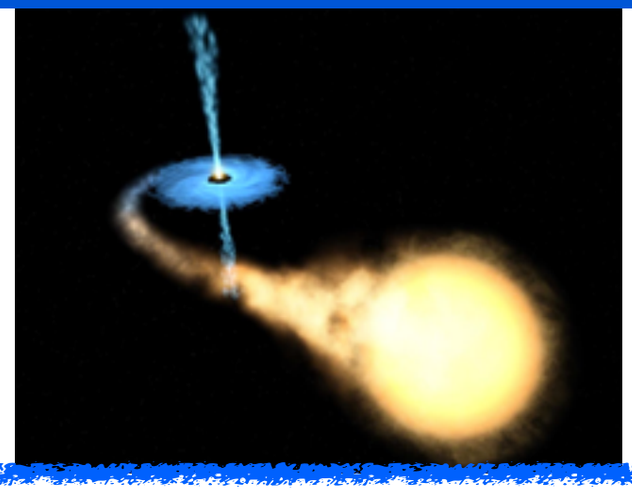
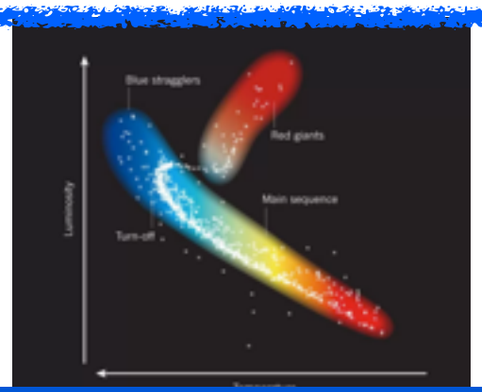
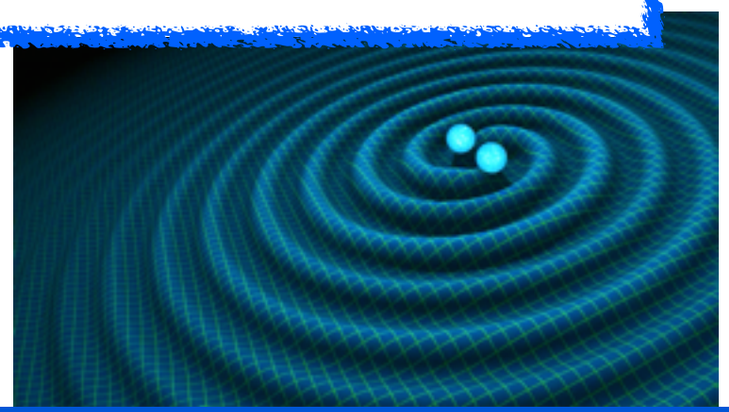



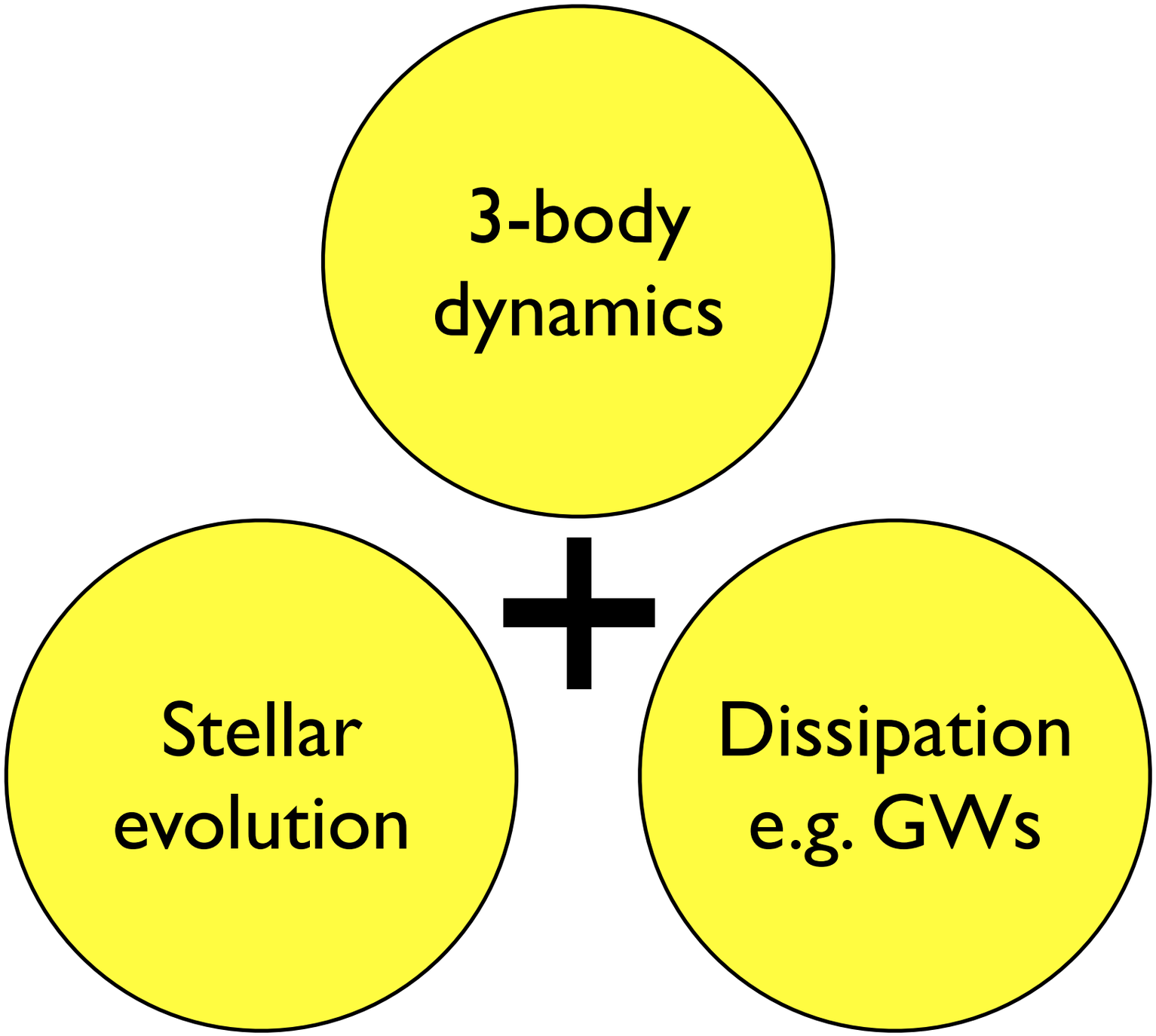

How important are triples?

How do triples evolve differently from binaries?



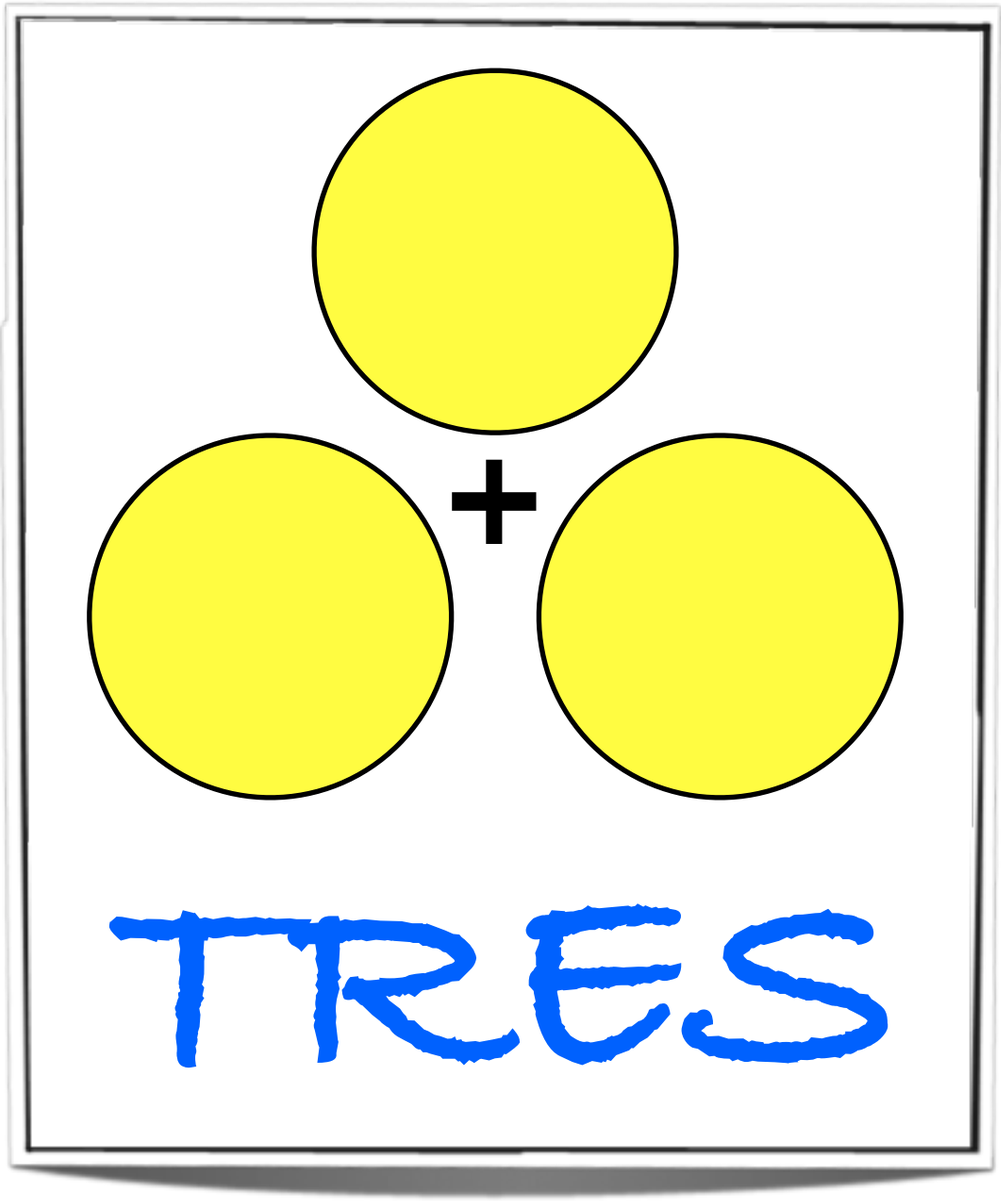
Unique evolution



Combination:
Shappee+ '13,
Hamers+ '13,
Michaely+ '14,
Toonen+ '16
Antonini+ '17
Toonen+ '18

New code

Portegies Zwart+ '09, '13



Toonen+ '16

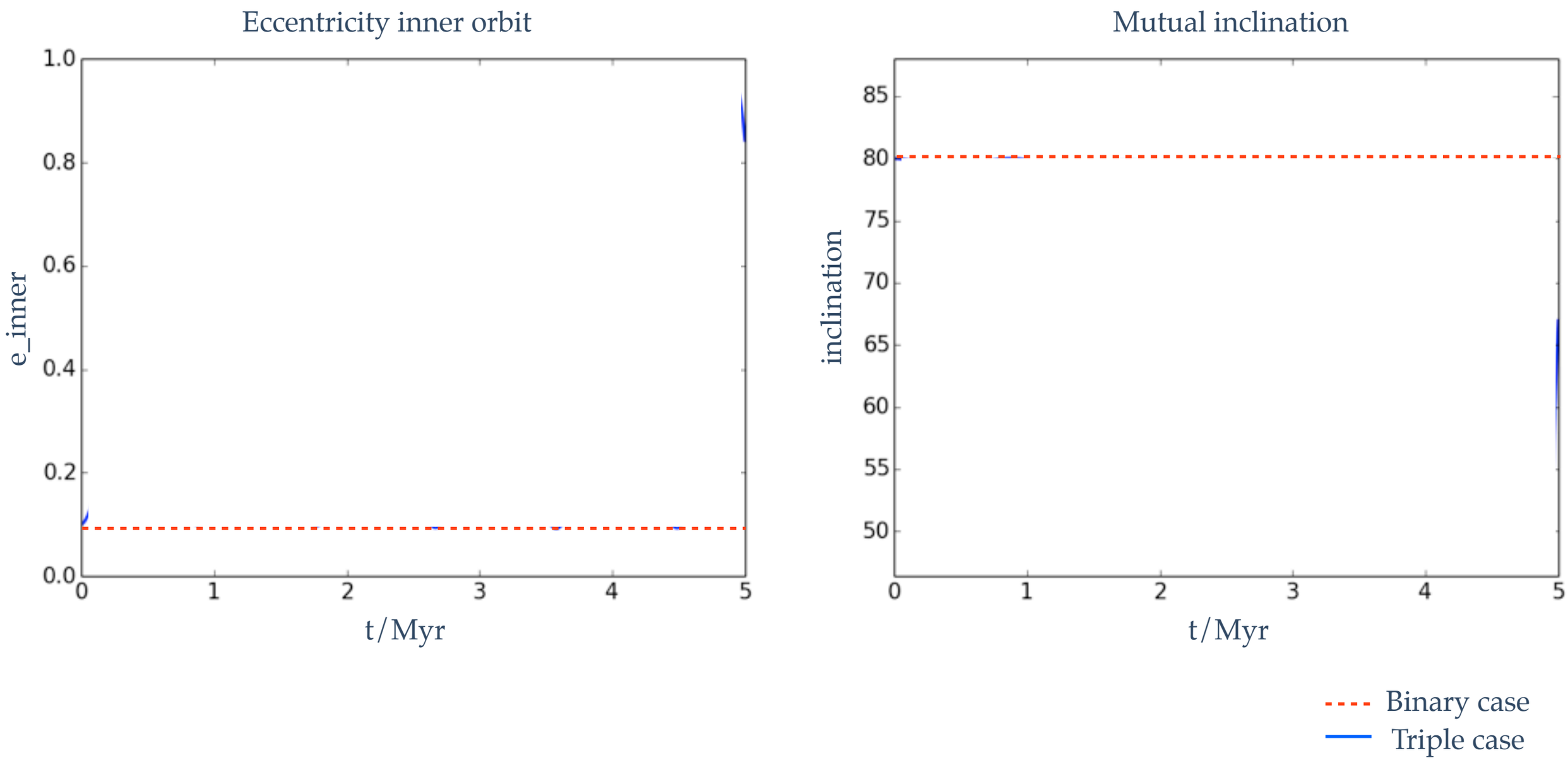
AMUSE

First results

- BH-BH mergers (Antonini, Toonen+ '17)
- Supernova type Ia (Toonen+ '18)
- Common evolution (Toonen+ in prep.)
- Fly-bys (Michaely, Perets & Toonen in prep.)

Kozai-Lidov cycles

M1=1.3, M2=0.5, M3=0.5MSun, a1=200, a2 =20000RSun, e1=0.1, e2 =0.5, i=80, g1=0.1, g2=0.5



review: Toonen+ '16

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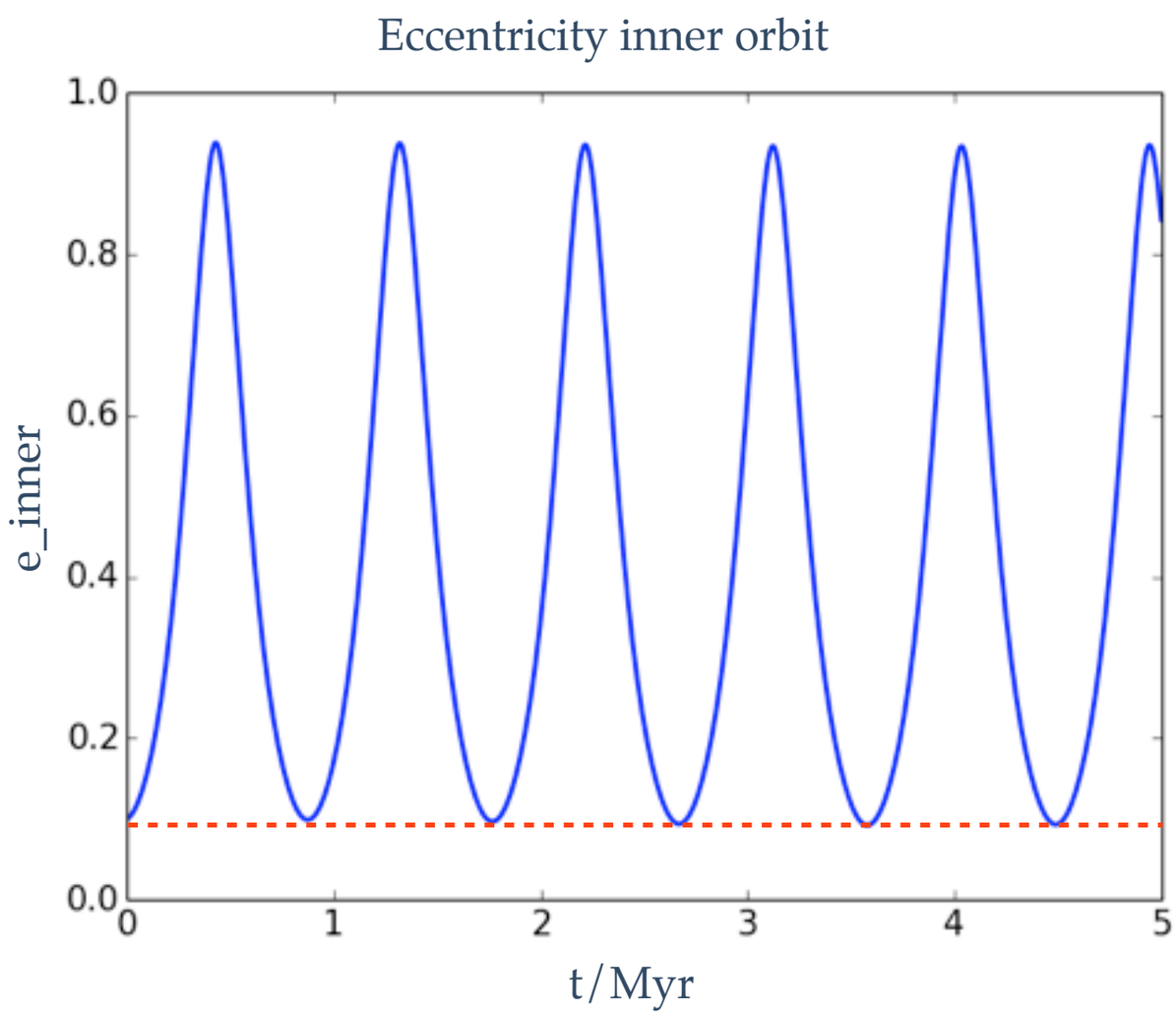

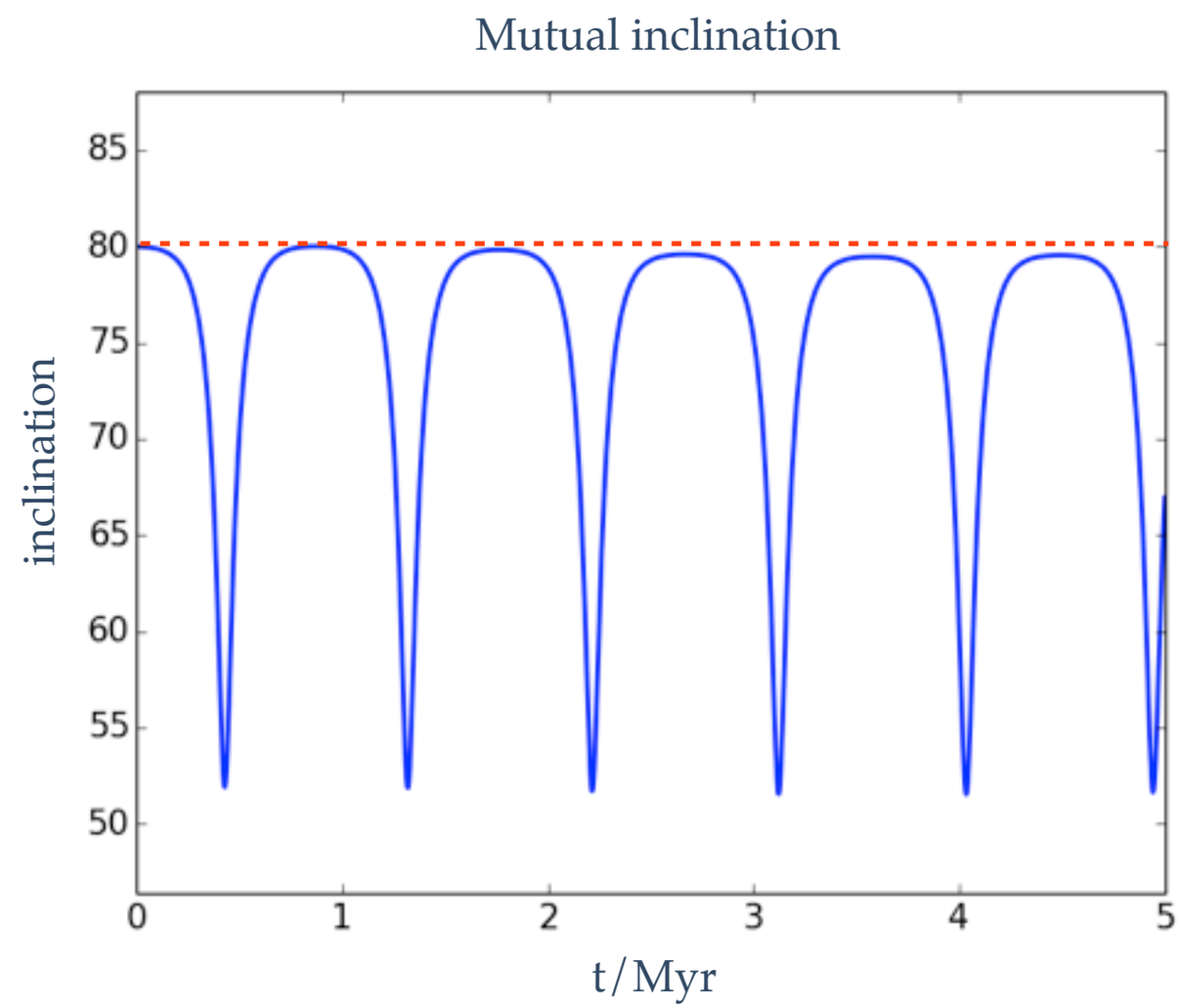

$$P_{\rm KL} \sim \frac{P_{\rm outer}^2}{P_{\rm inner}} \frac{m_1+m_2+m_3}{m_3} (1-e_{\rm outer}^2)^{3/2}$$

Binary case
Triple case

review: Toonen+ '16

Mass transfer

- Occurrence rate (low & intermediate mass primaries)
  - in binaries: ~40% of systems
  - in triples: ~60-75% of systems

➡ Enhanced occurrence rate of mass transfer (Toonen+ in prep.)

  - ~1.5x more often compared to a binary population

Mass transfer

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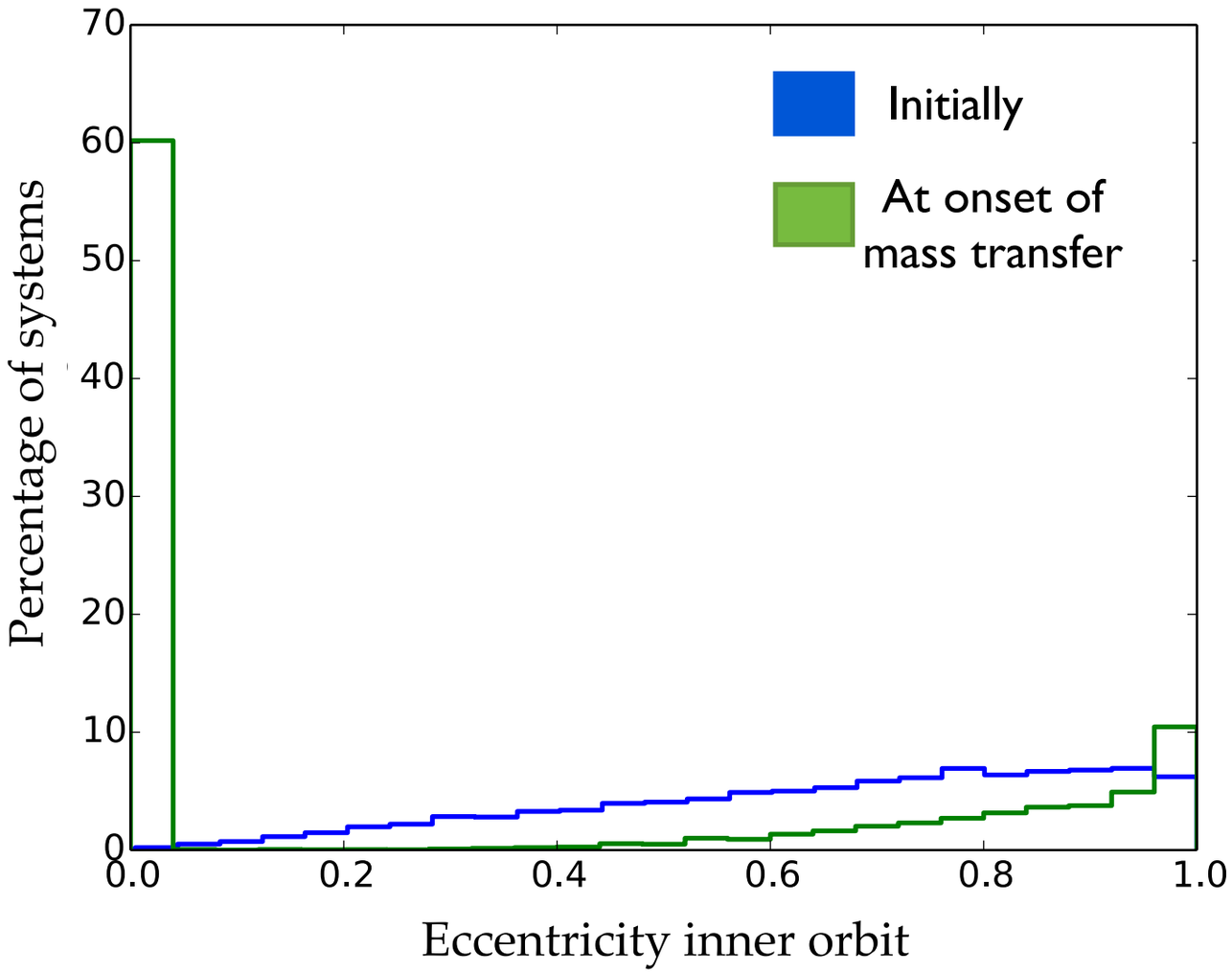
- ~40% of systems: onset of mass transfer in an **eccentric** orbit



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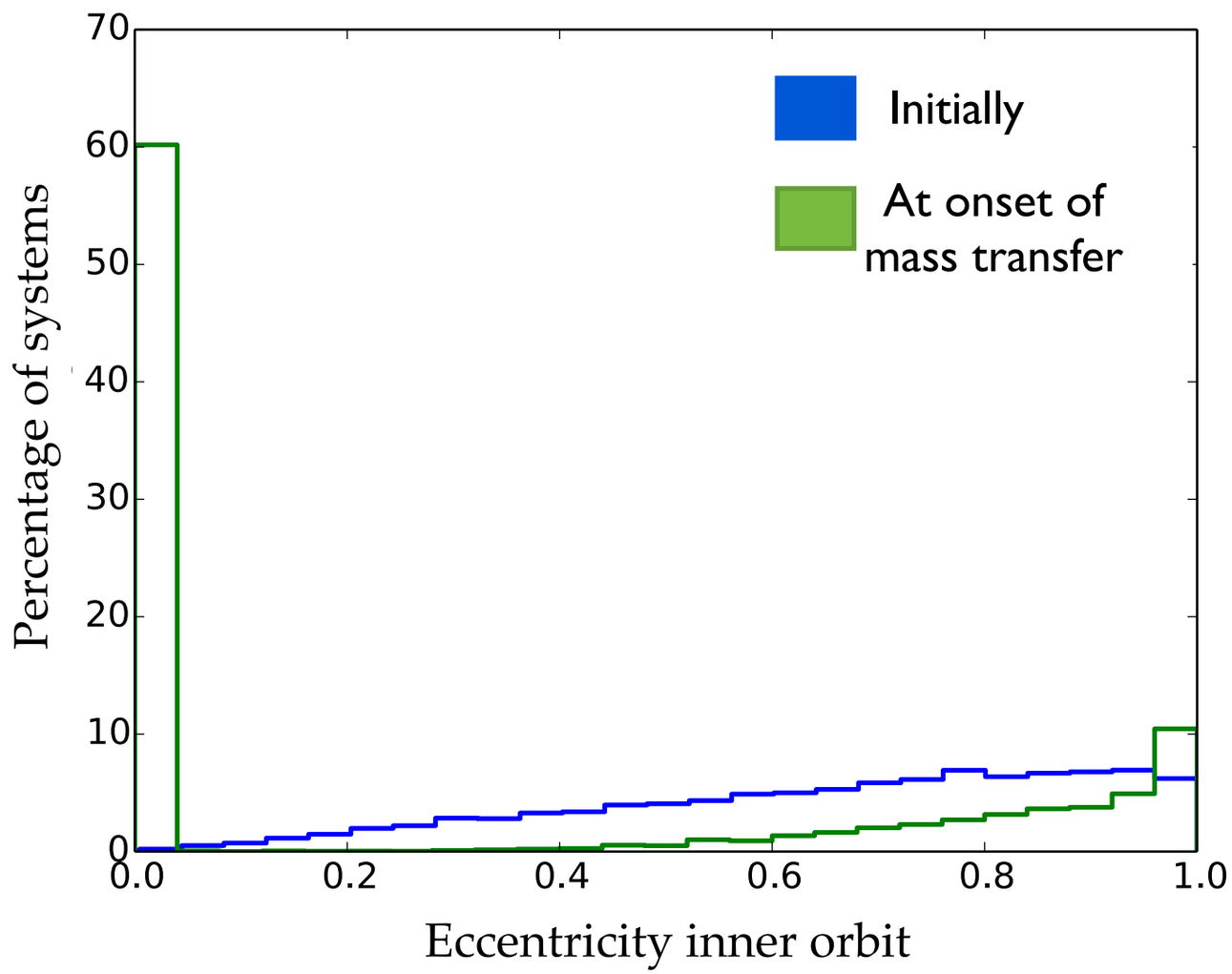

- Observed sources

  (e.g. Petrova & Orlov 1999, Nicholls & Wood 2012)

- Interesting for
  - Blue stragglers (Perets & Fabrycky '09)
  - Great eruption of Eta Carinae (Portegies Zwart & van den Heuvel '16)

ref: Toonen+ in prep.

Mergers & collisions

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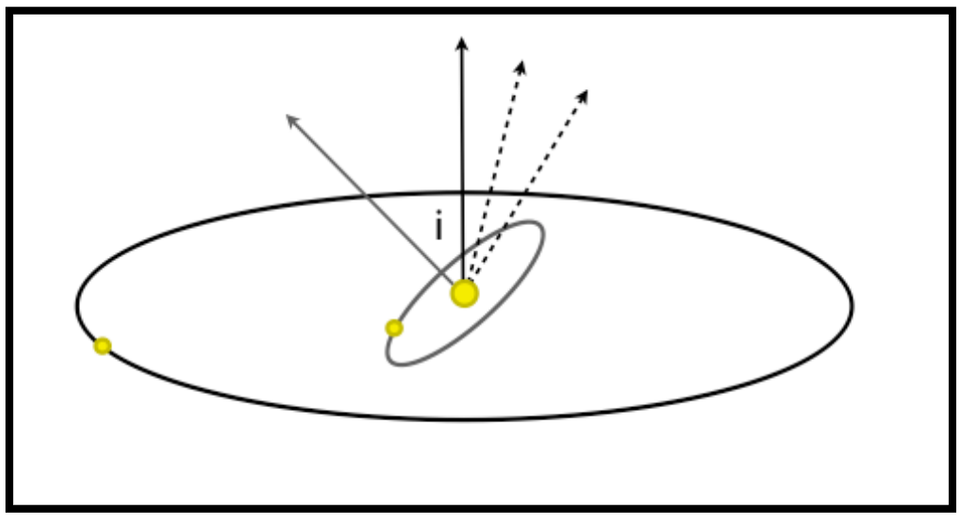
See e.g. Mardling & Aarseth '99, Antonini+14, Katz+ 14

from secular evolution → to dynamical or quasi-secular evolution



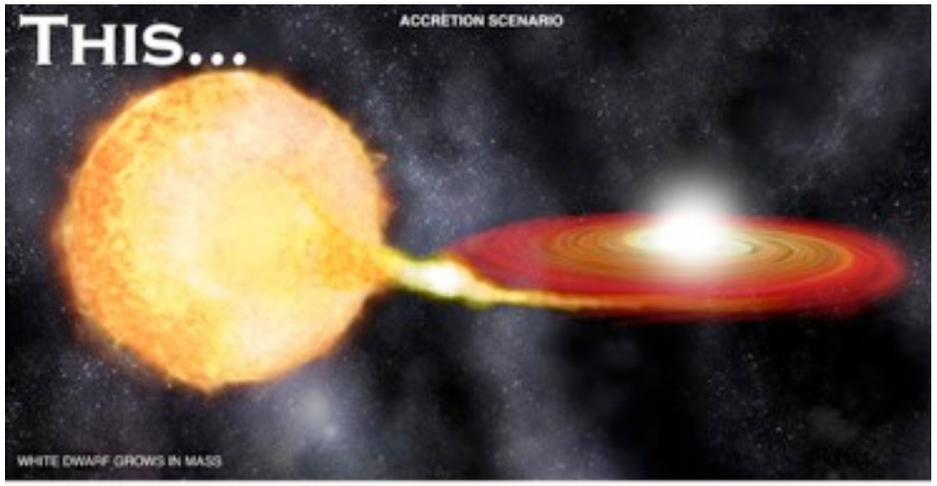
Courtesy of Carl Rodriguez

Type Ia supernovae

- One of the brightest cosmic explosions (~1e51 erg)
- Accelerating expansion of universe (Nobel Prize ’11)
- Chemical evolution of galaxies (e.g. iron)

Type Ia supernovae

- What are the progenitors? How does one detonate a white dwarf?



Single degenerate
Whelan & Iben '73

Double degenerate
Iben & Tutukov
'84, Webbink '84

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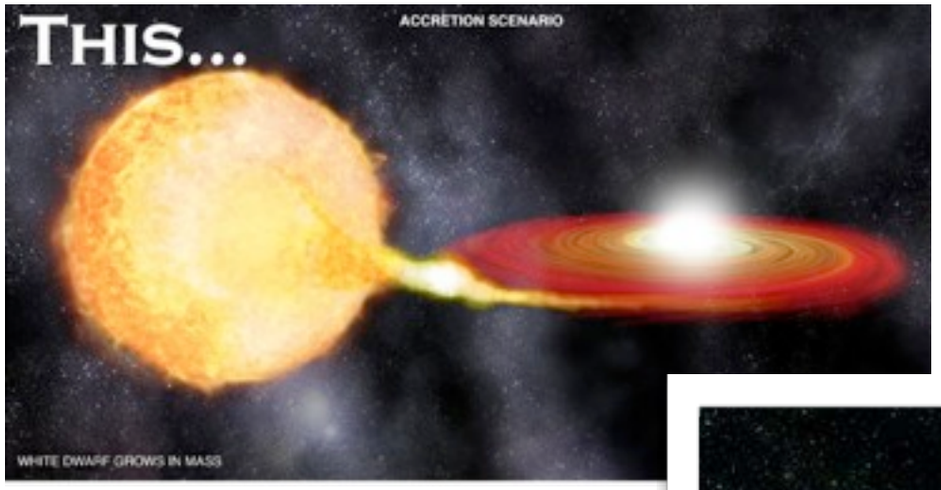

Single degenerate
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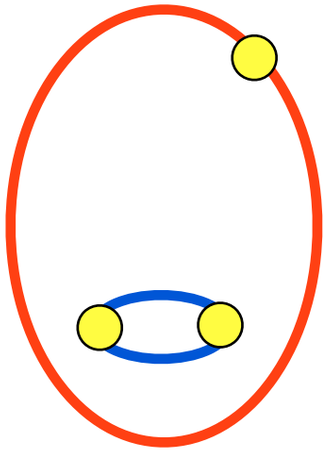
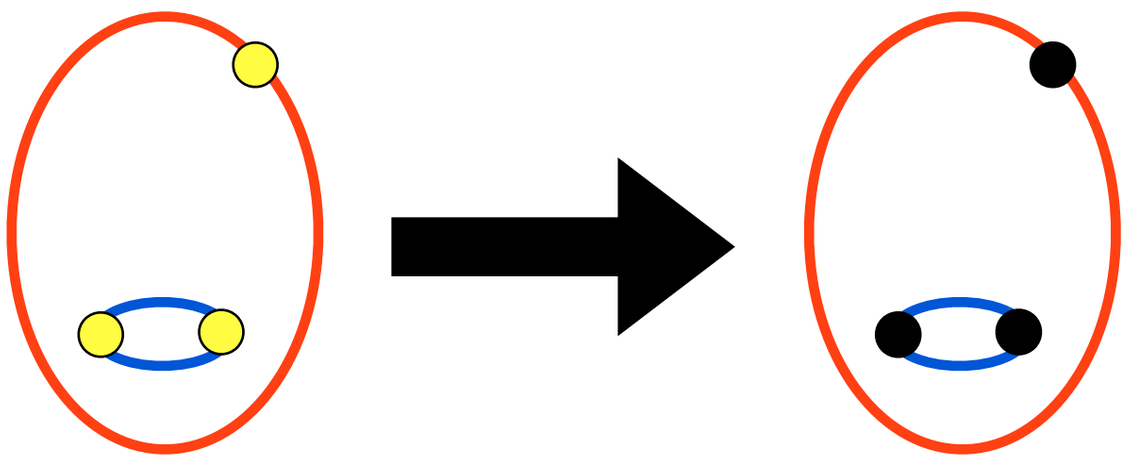
Collisions in
quasi-secular triples
(Benz+ 89, Katz & Dong '12, Kushnir+ 13)

Triple evolution



Triple with stars

Triple evolution

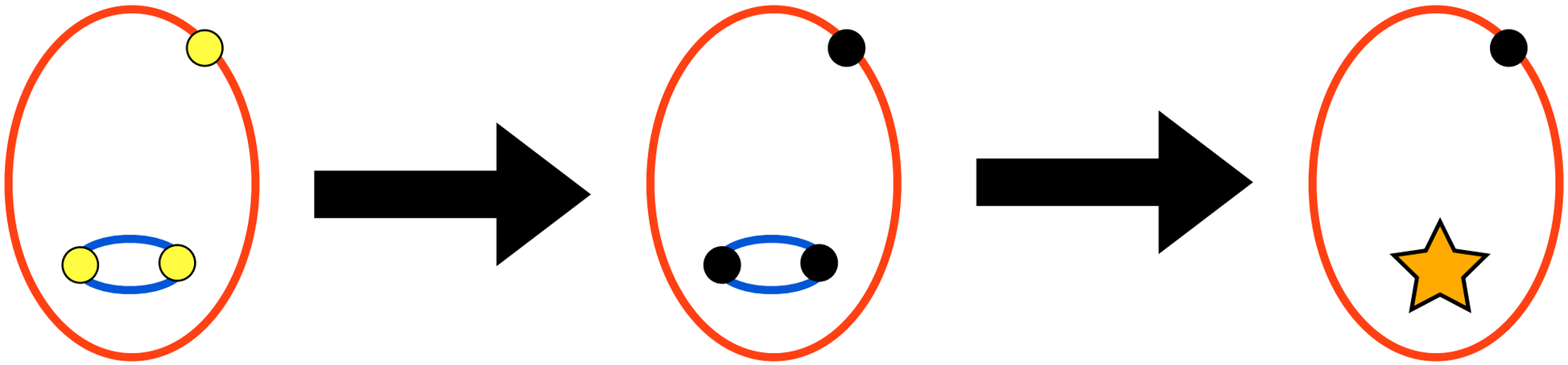


Triple with stars

Formation of white dwarfs

Triple evolution

Quasi-secular evolution

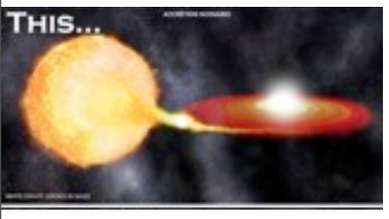


Triple with stars

Formation of white dwarfs

Collision of white dwarfs: Supernova

Type Ia supernovae



Time-integrated rate (1e-4 /Msun)		
Observed	e.g. Maoz & Graur 17	11.3 ± 2.4
Single degenerate	e.g. Bours, Toonen+ 13	0.6 - 0.8
Double degenerate	e.g. Toonen+ 12	2 - 5
Triple collisions	Toonen+ 17	

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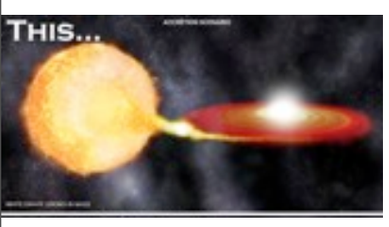

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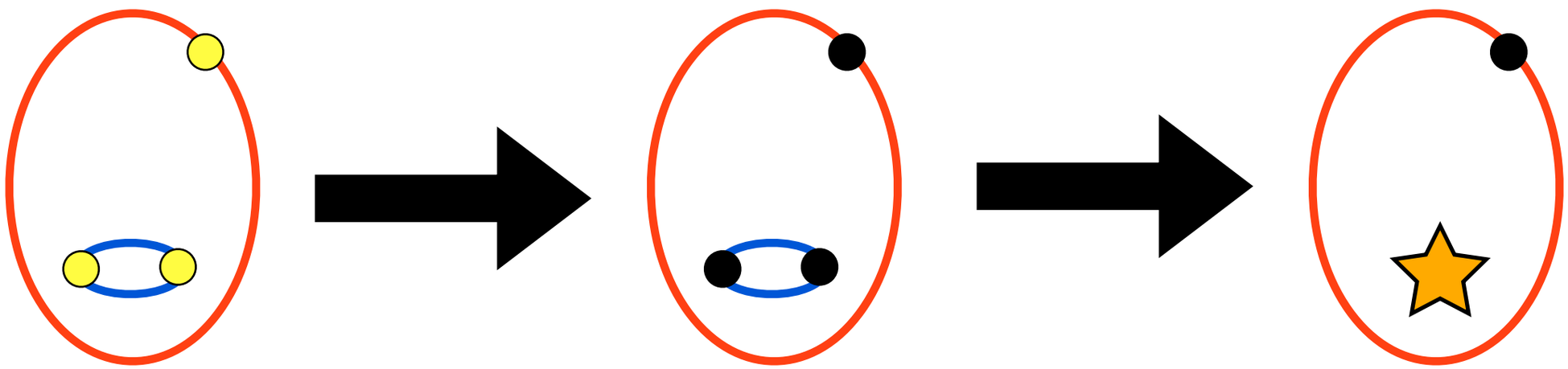
Triple collisions	Toonen+ 17	5e-4 - 2e-2

GW Sources

Change of
dynamical regime



Triple with
massive stars

Formation of
black holes:
supernova kicks

Hobbs / Arzoumanian, momentum-conserving kicks, direct collapse for M>40Msun,

Merger of
black holes:
Gravitational
waves

Merger rates

Black hole - black hole merger rate:

- Observed rate (Abbott+16, 17):
  12-213 per year per Gpc^3

Triples:

- With natal-kick: ~0.4 per year per Gpc^3
- Only Blaauw-kick: ~1.2 per year per Gpc^3
- Rate increases for lower metallicities (Rodriguez & Antonini, Arxiv)

Distinct characteristics

Taken from

Breivik+ '16

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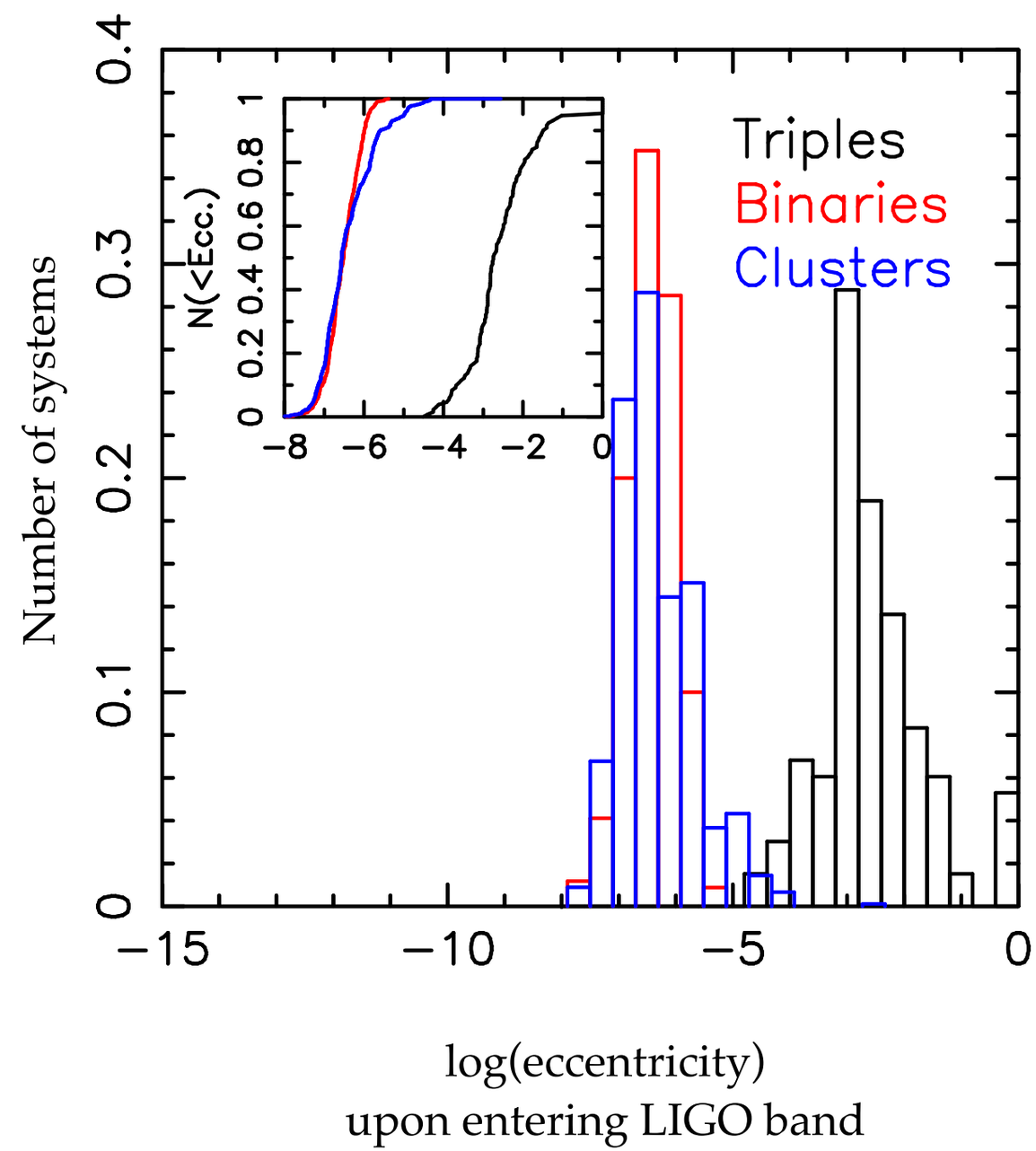
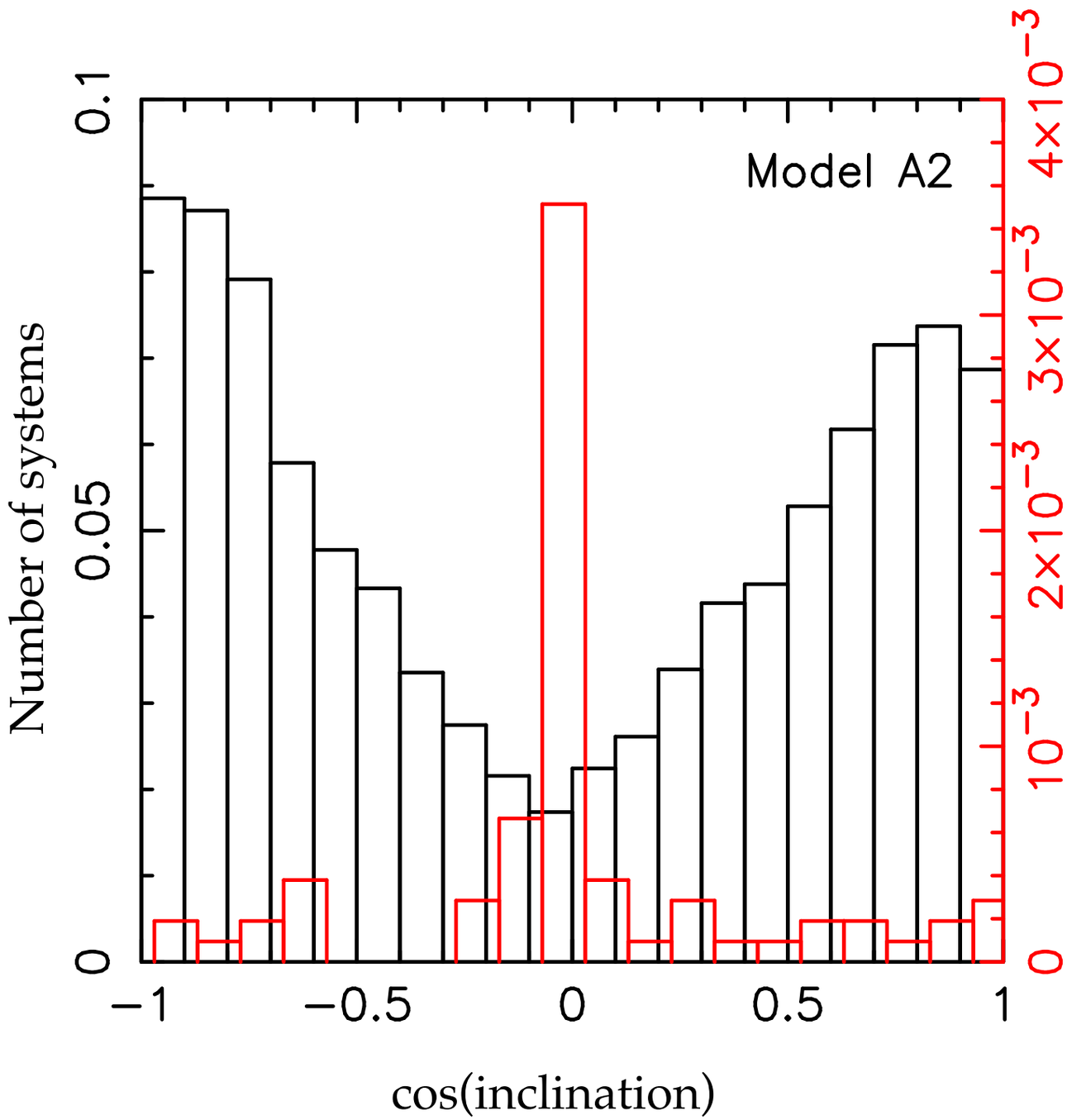


BH-BH mergers



- Triple BHs formed
- Merging BHs

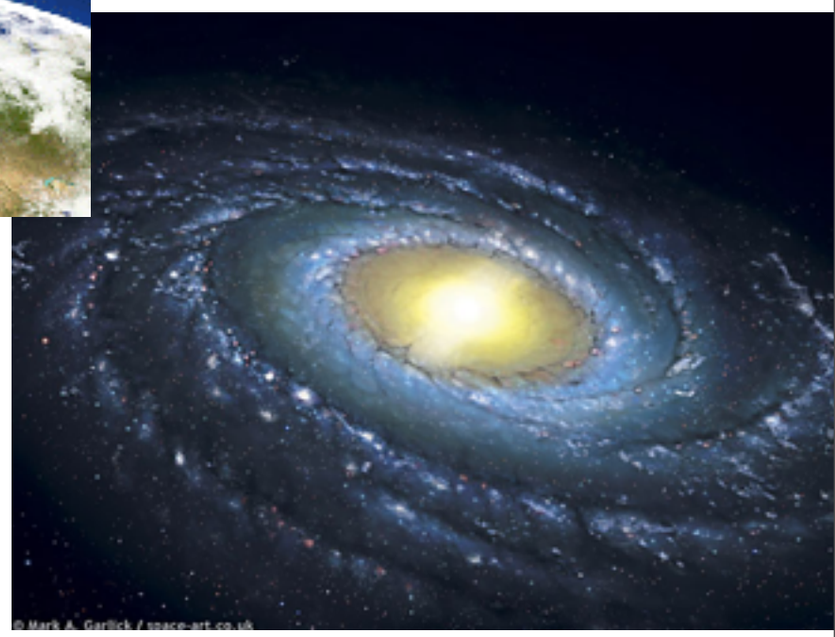
- Important to model formation of BH-BH in triples consistently

ref: Antonini, Toonen+ 17

Upcoming workshop:

Triple evolution and dynamics II

- When? September 10-14
- Where? Lorentz Centre, Leiden, The Netherlands



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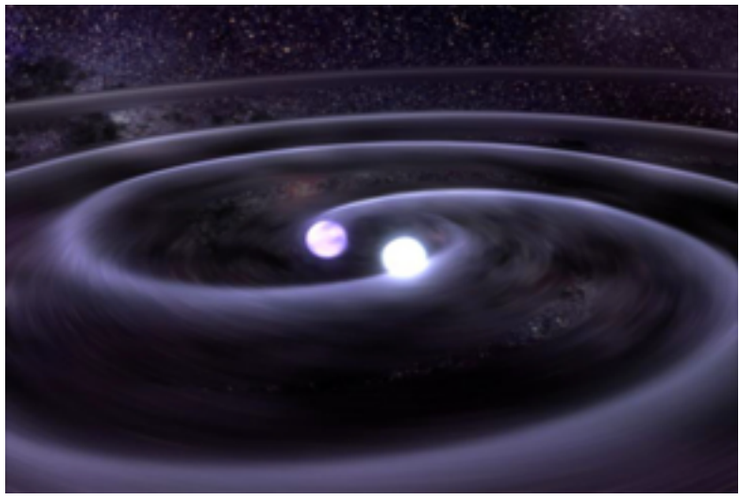
- From initially very wide orbits:



- WD-WD collisions
  - <0.1% of the observed supernova type Ia rate (Toonen+ '18)
- BH-BH mergers:
  - 0.3-1.2 per year per Gpc^3 (Antonini, Toonen & Hamers '17)

Questions

Thank you for your attention!