Evolution & interaction in stellar binaries & triples

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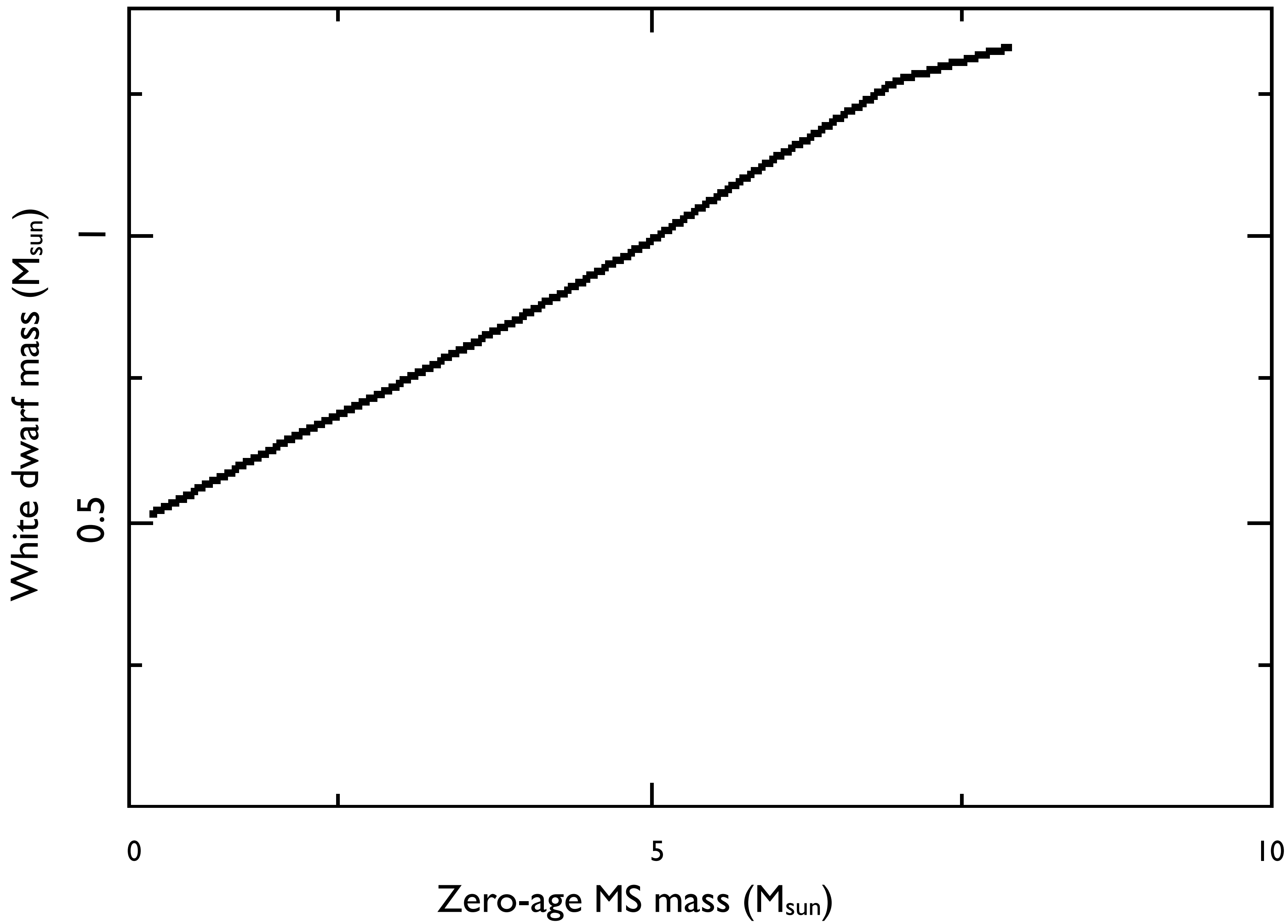
Single stars

Based on SeBa
(Portegies Zwart+ 96,
Toonen+12)

- Initial-Final mass relation for white dwarfs



- uncertainties e.g. convection, wind mass loss, rotation => See Monday

Single stars + binaries

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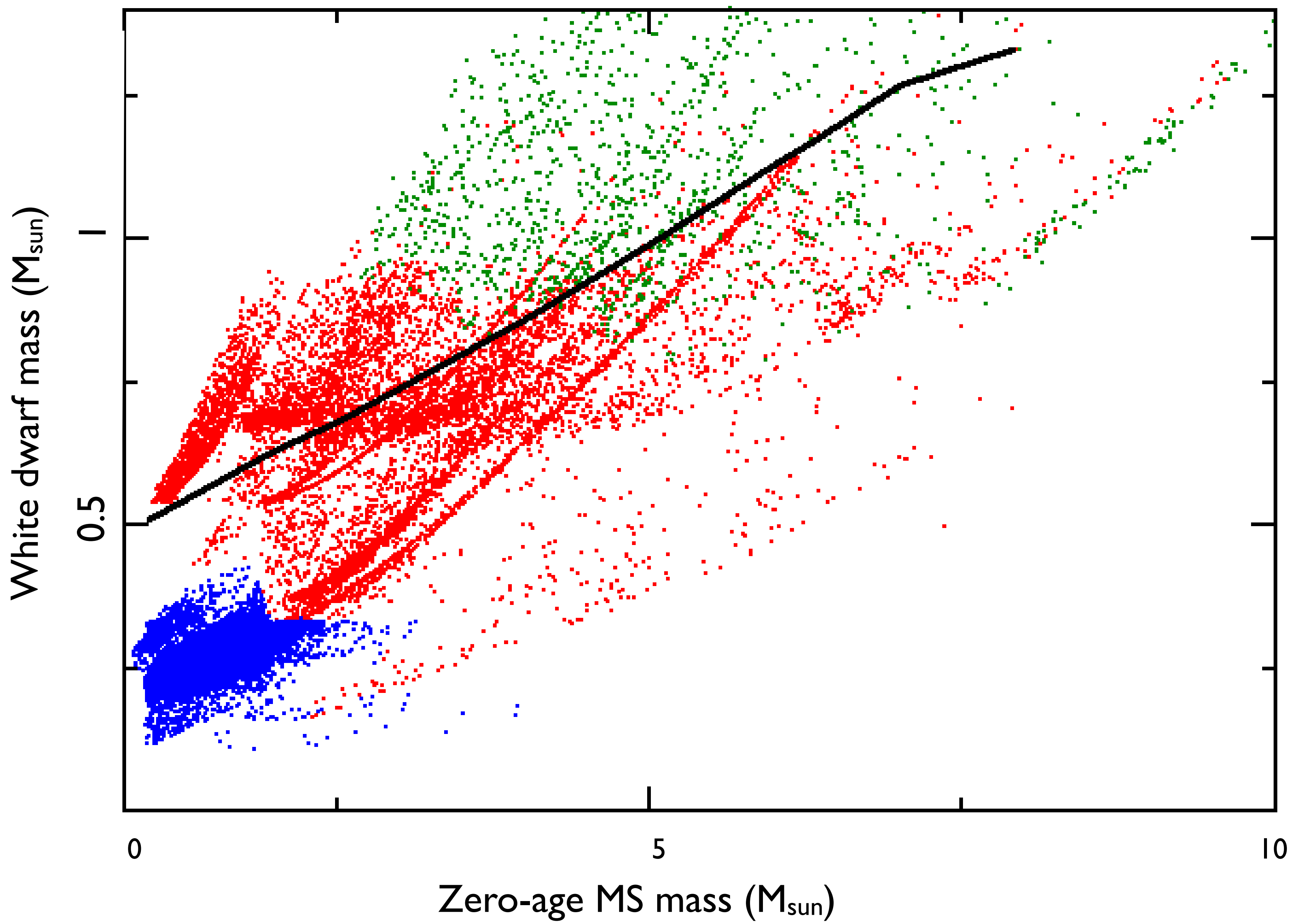

Composition of white dwarfs
Helium
Carbon-Oxygen
Oxygen-Neon

Binaries mess everything up!

Single stars + binaries

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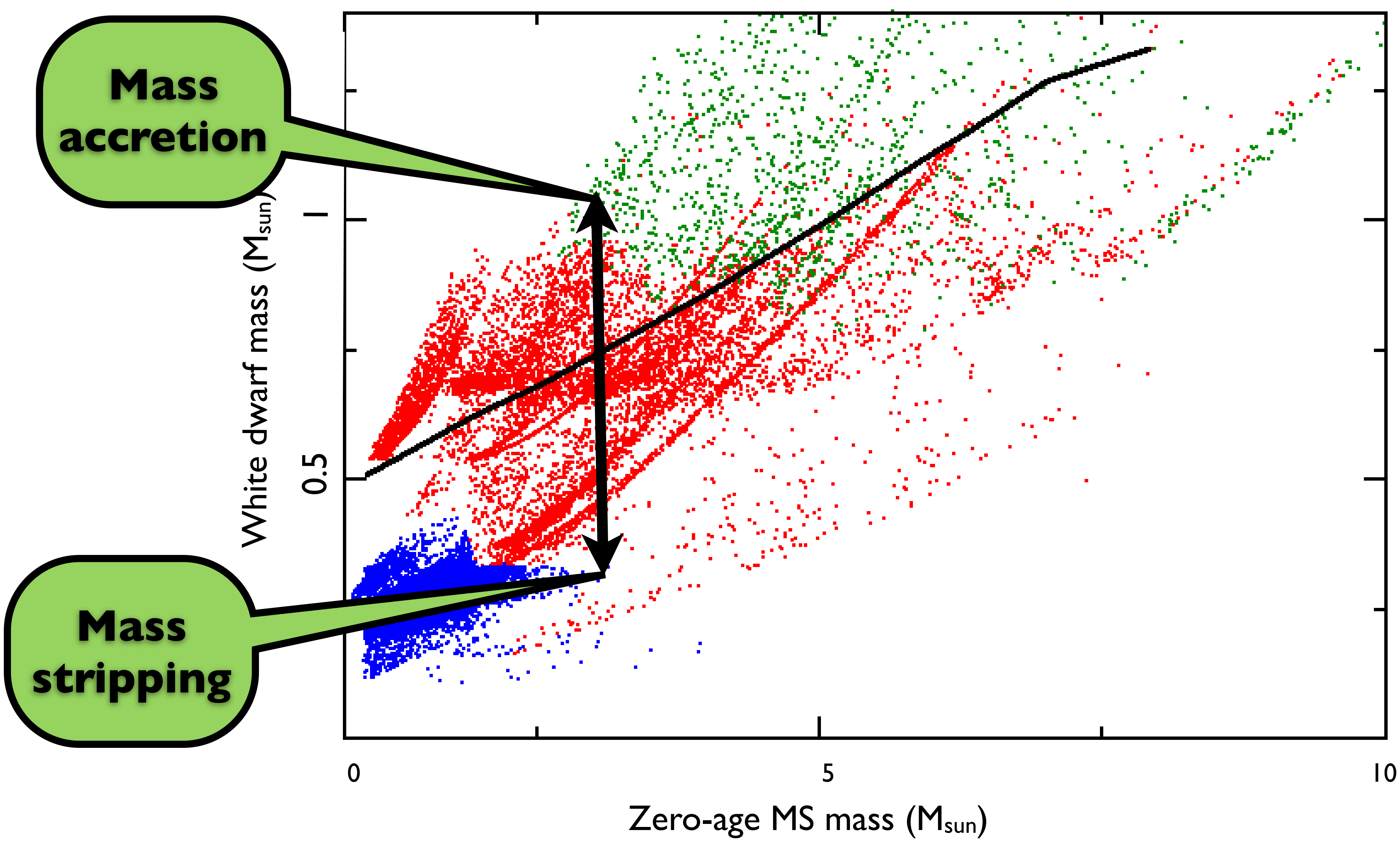

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Outline

- Binary statistics (see also Wednesday morning)
  - How do young binaries look like?
  - How often are stars affected by their companion?
- Evolution of binaries: Effects of mass transfer
- Evolution of triples

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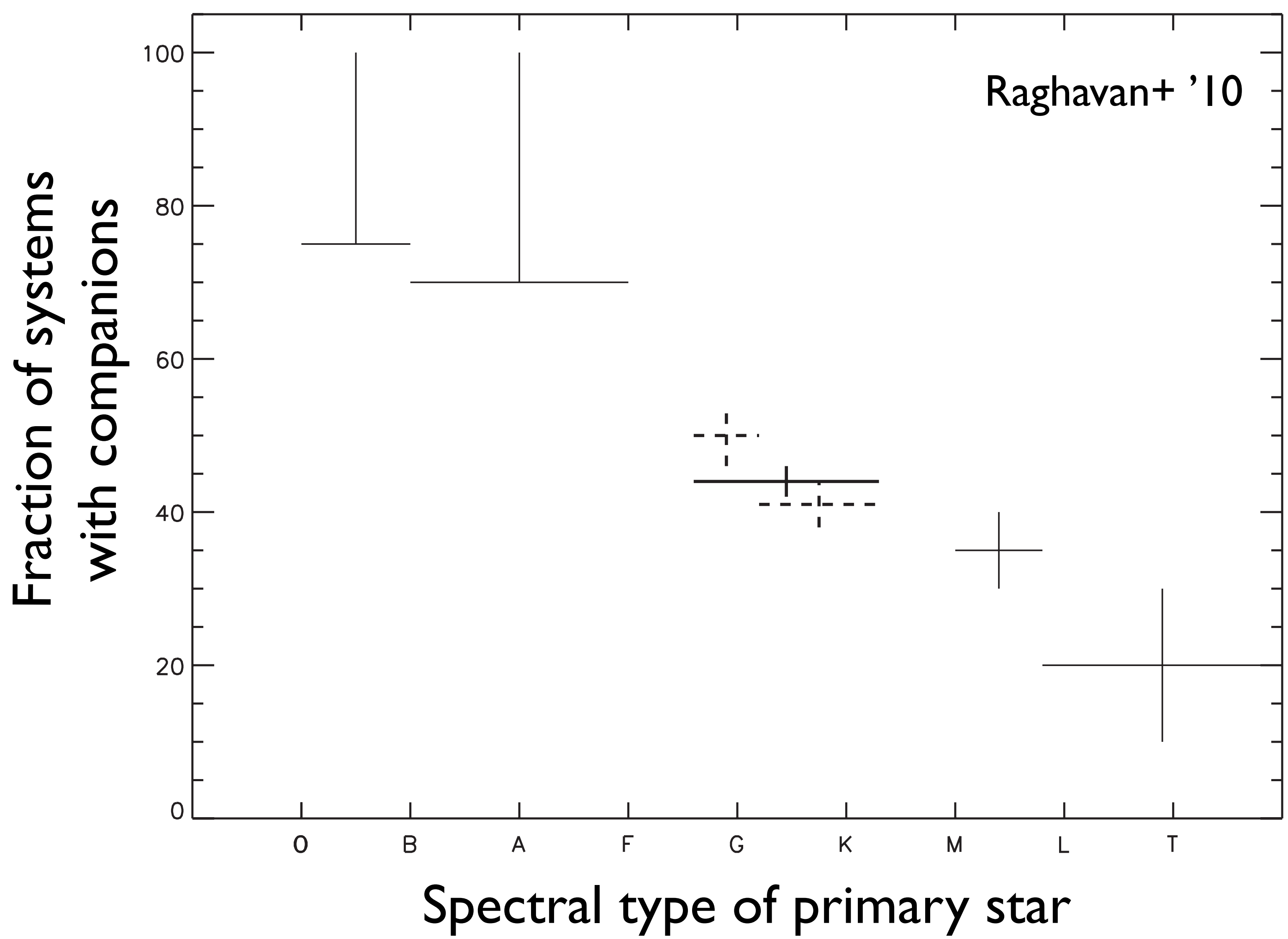
How often are stars affected by companion stars?

- Characteristics of young binaries (zero-age MS)
  - **Binary fraction** increases with primary mass



- See reviews of Duchene & Kraus '13, Moe & DiStefano '17

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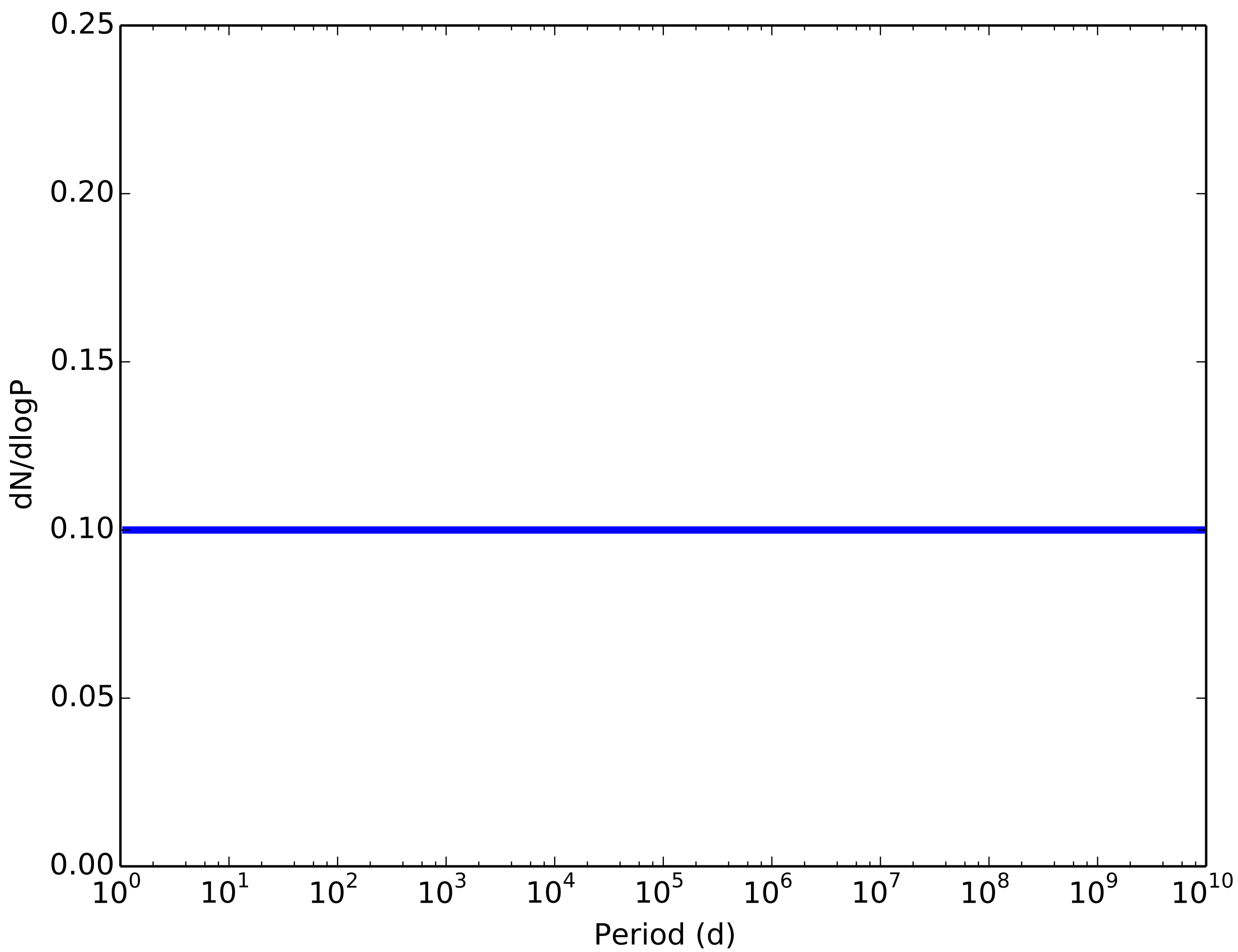

2-5M_{sun}: Abt 83

~1M_{sun}: Duquennoy+ 91, Raghavan+ 10

>10M_{sun}: Sana+ 12

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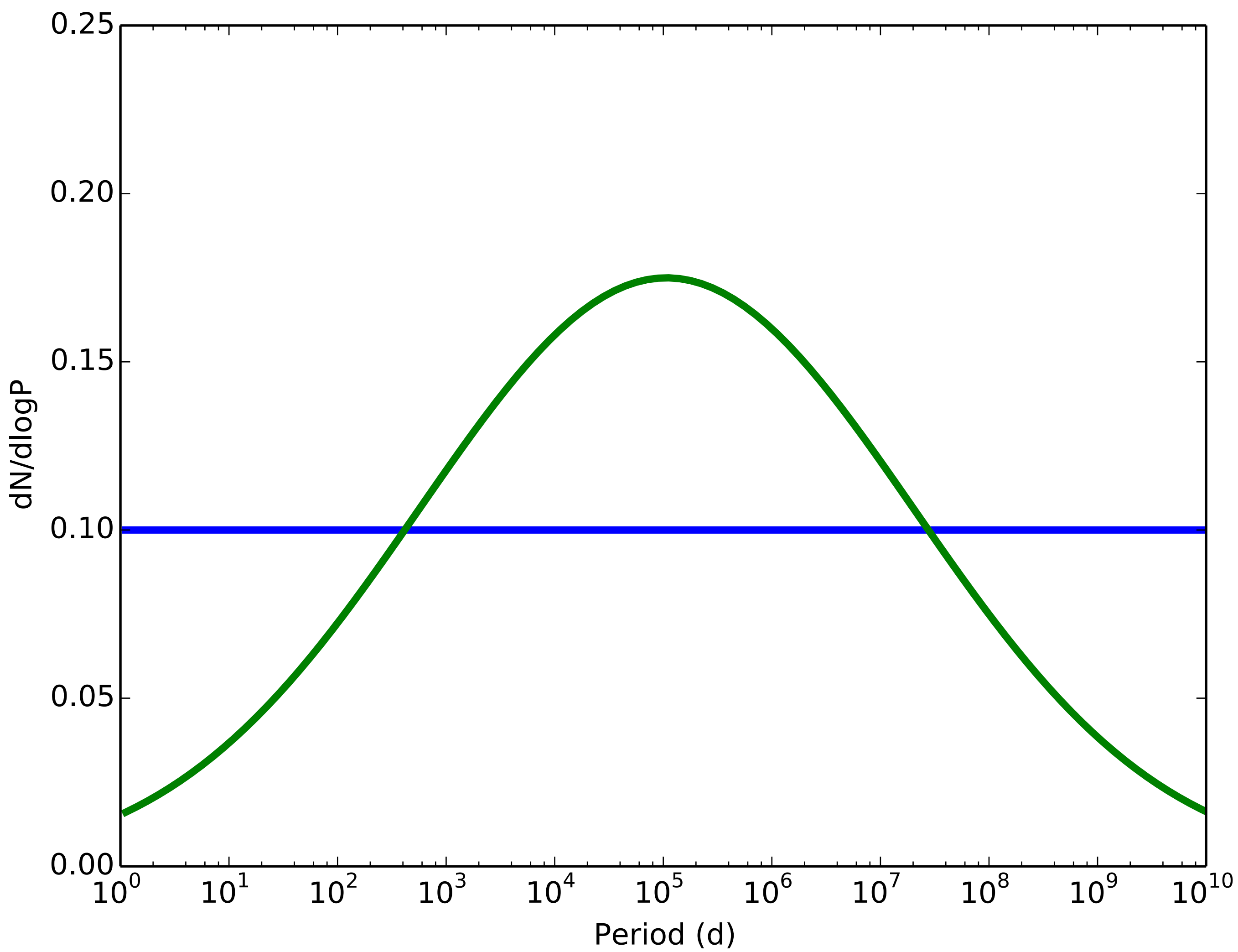

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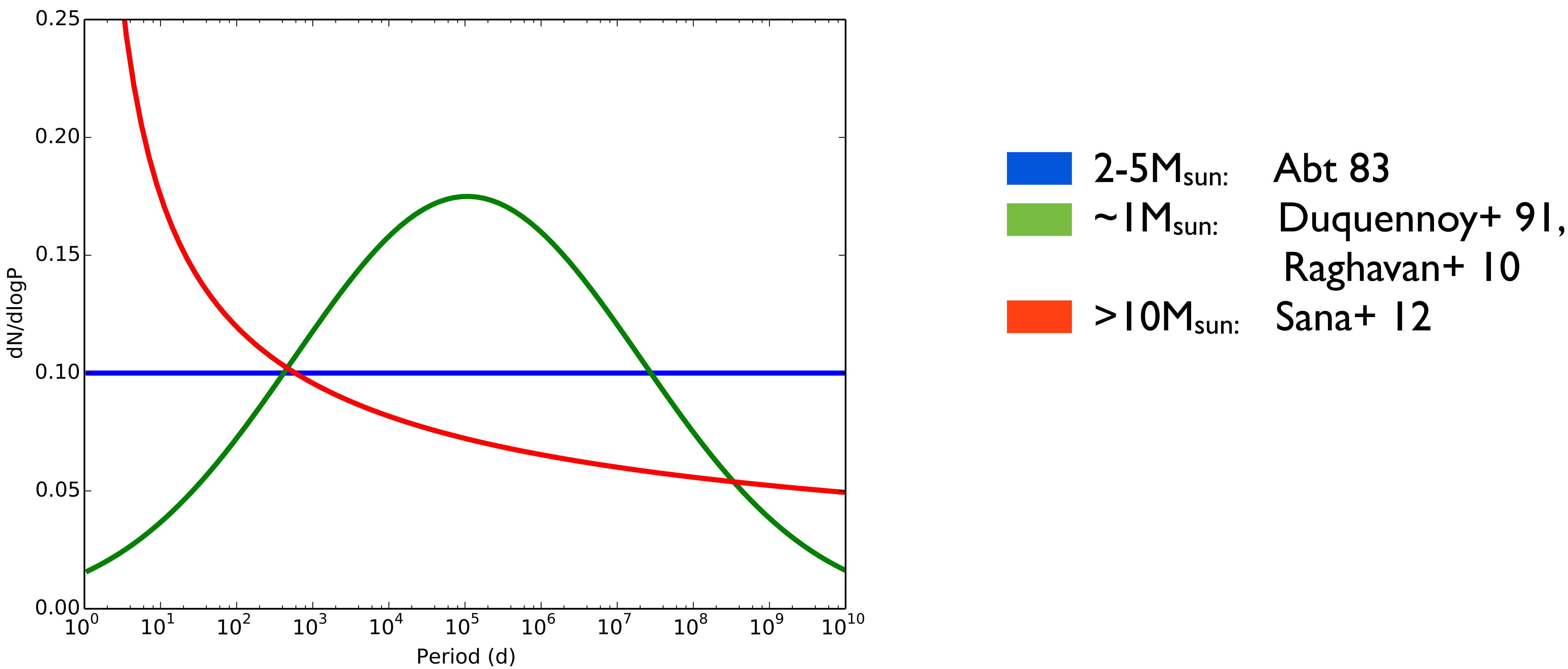

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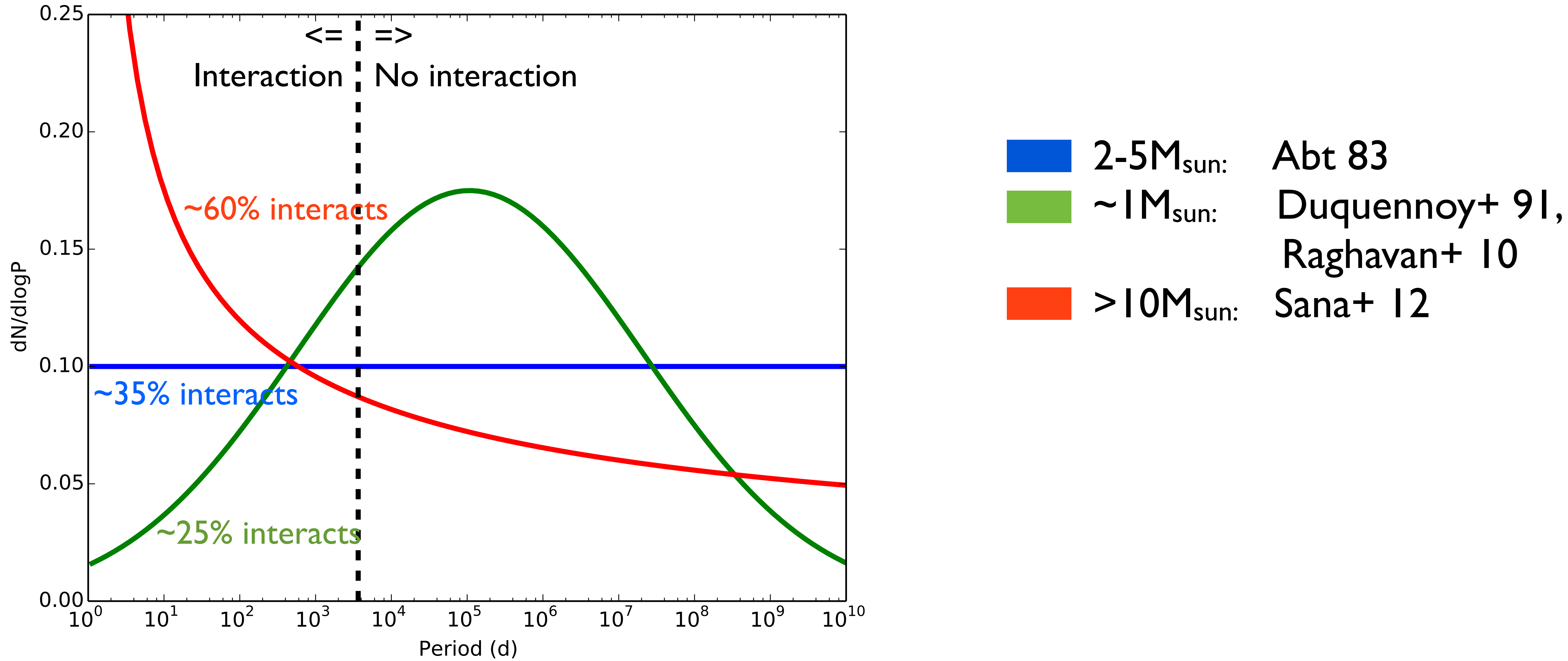

- **More binary interactions as primary mass increases**

Outline

- Binary statistics
- Evolution of binaries: Effects of mass transfer
- Evolution of triples

General expectations

- Population synthesis : Formation of WD-MS systems

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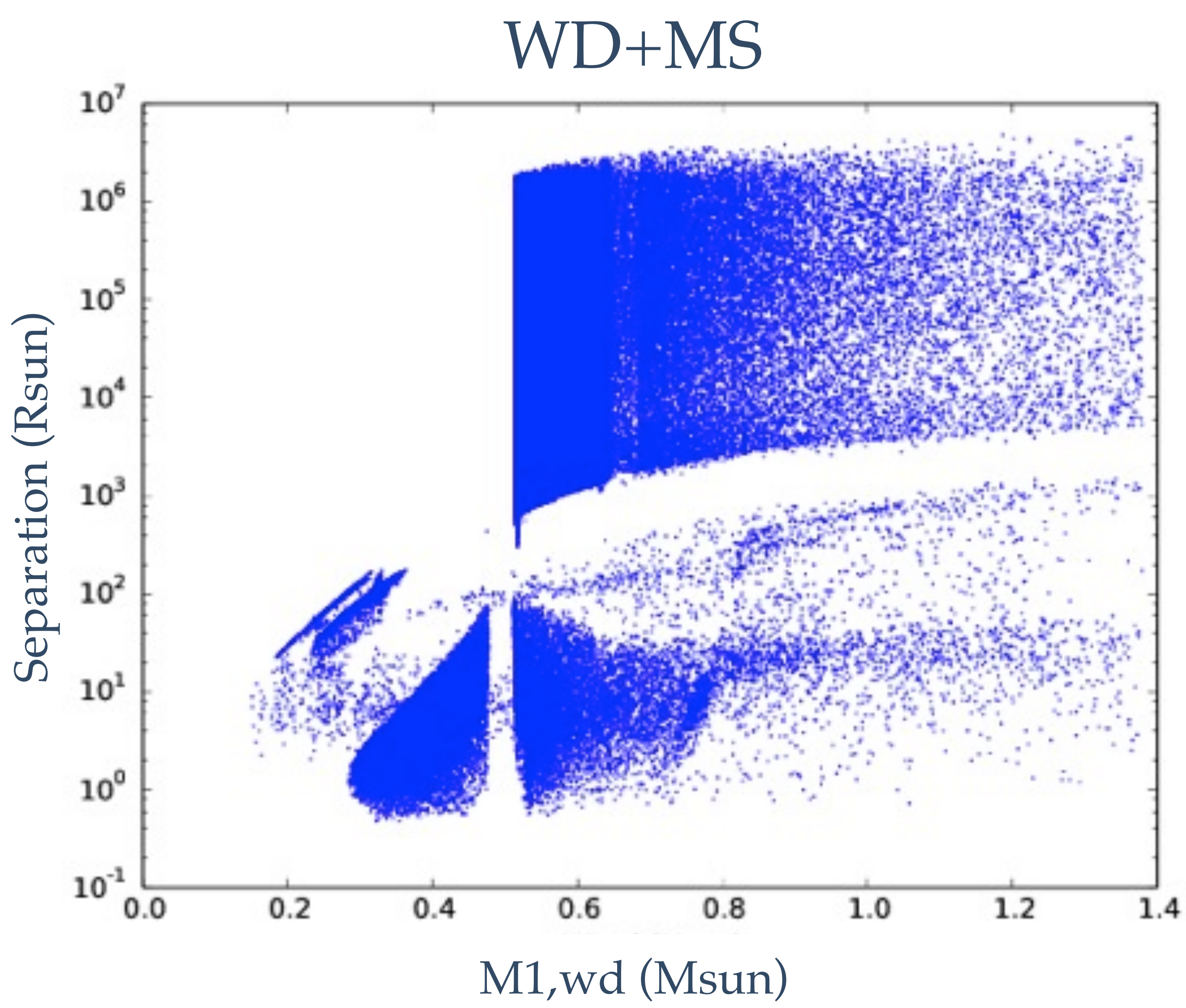

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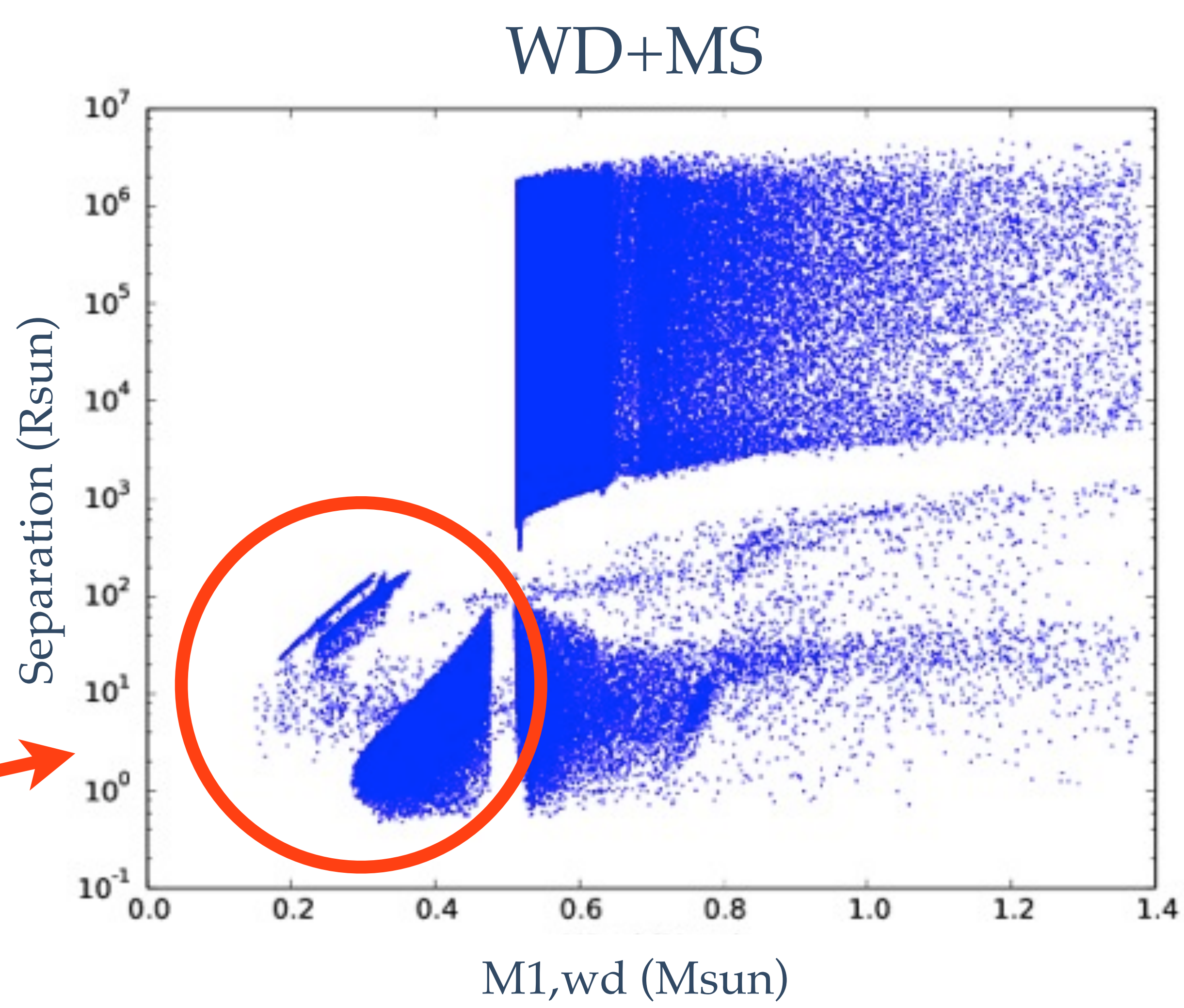
Mass stripping



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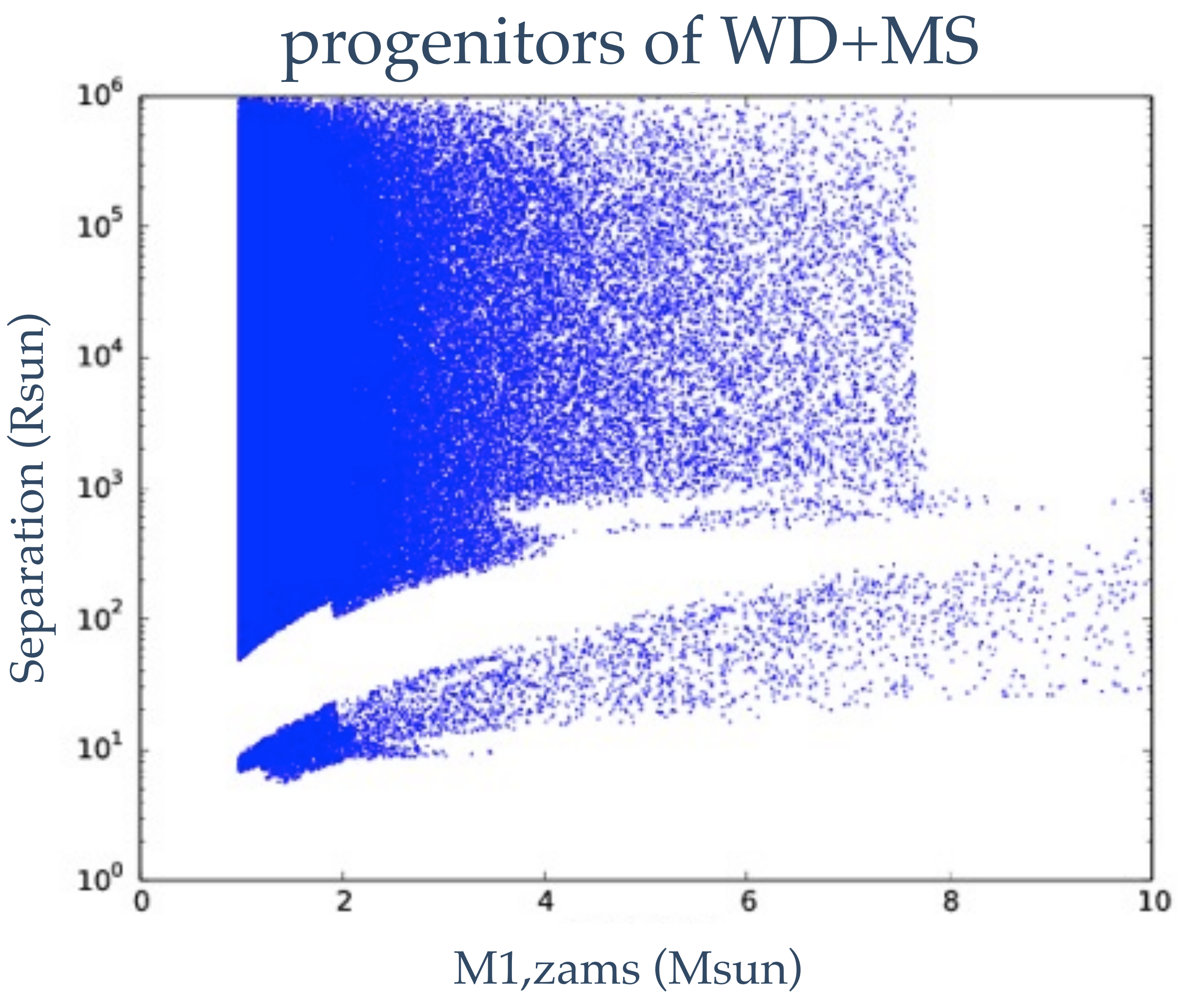

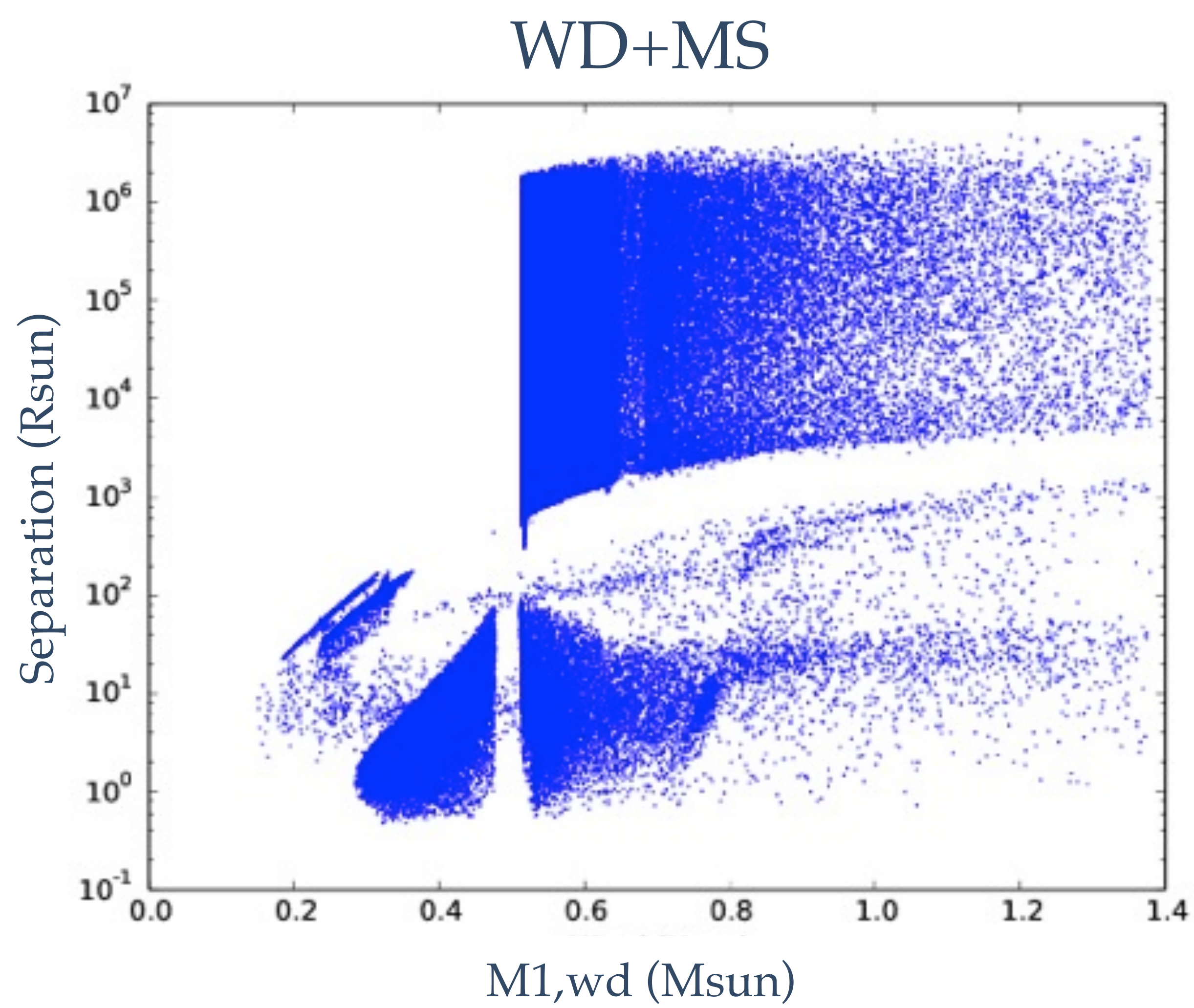

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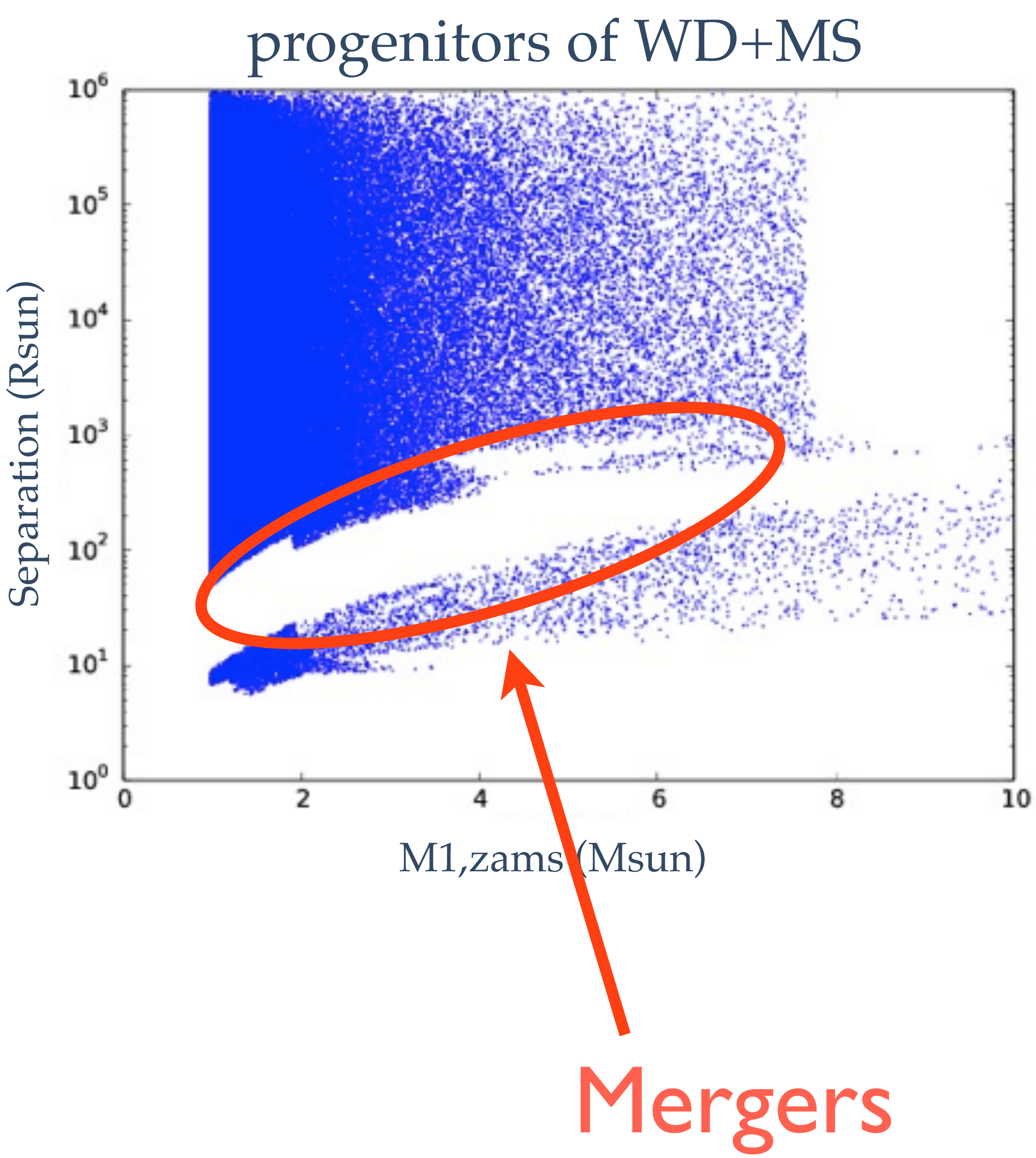

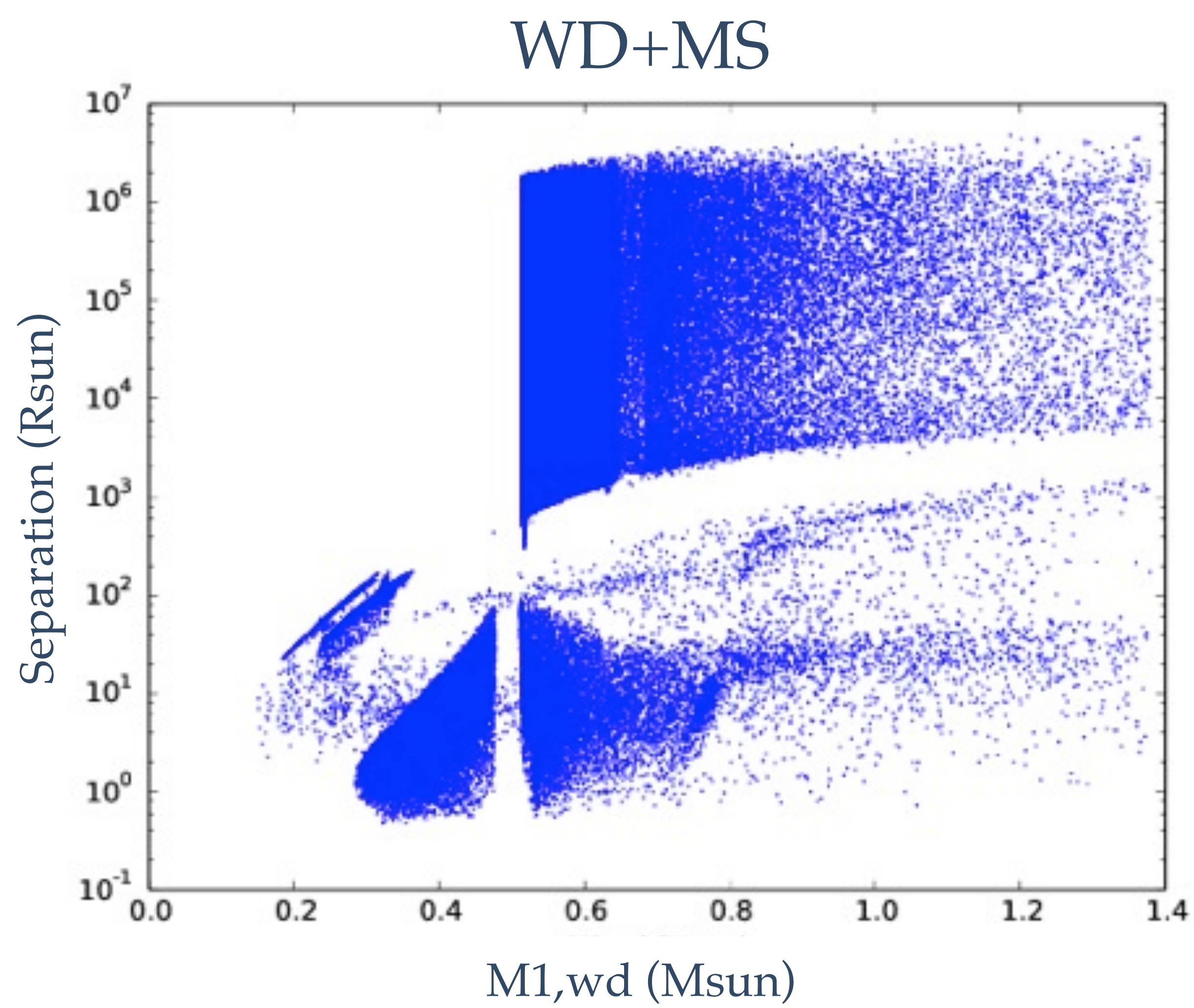

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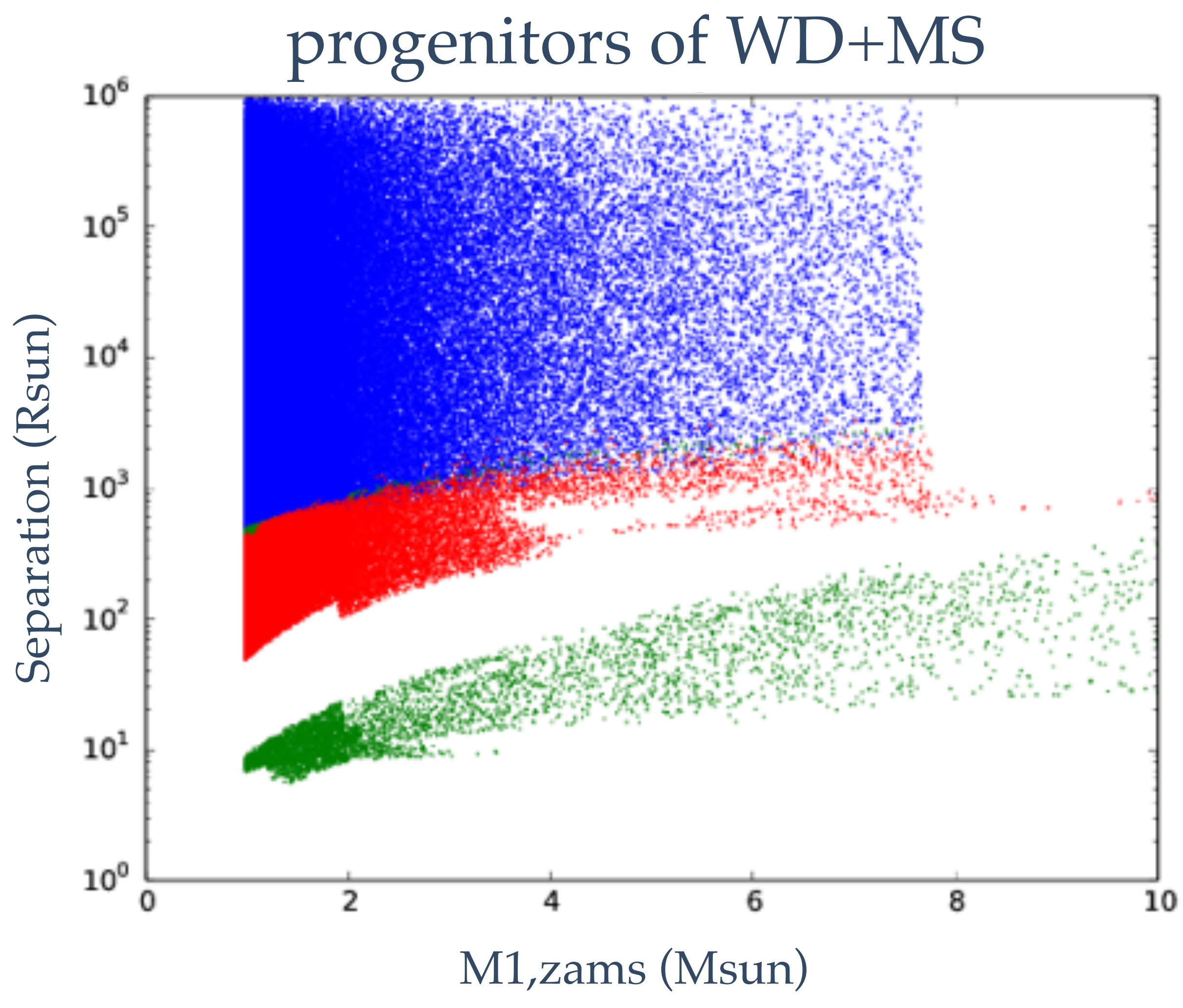
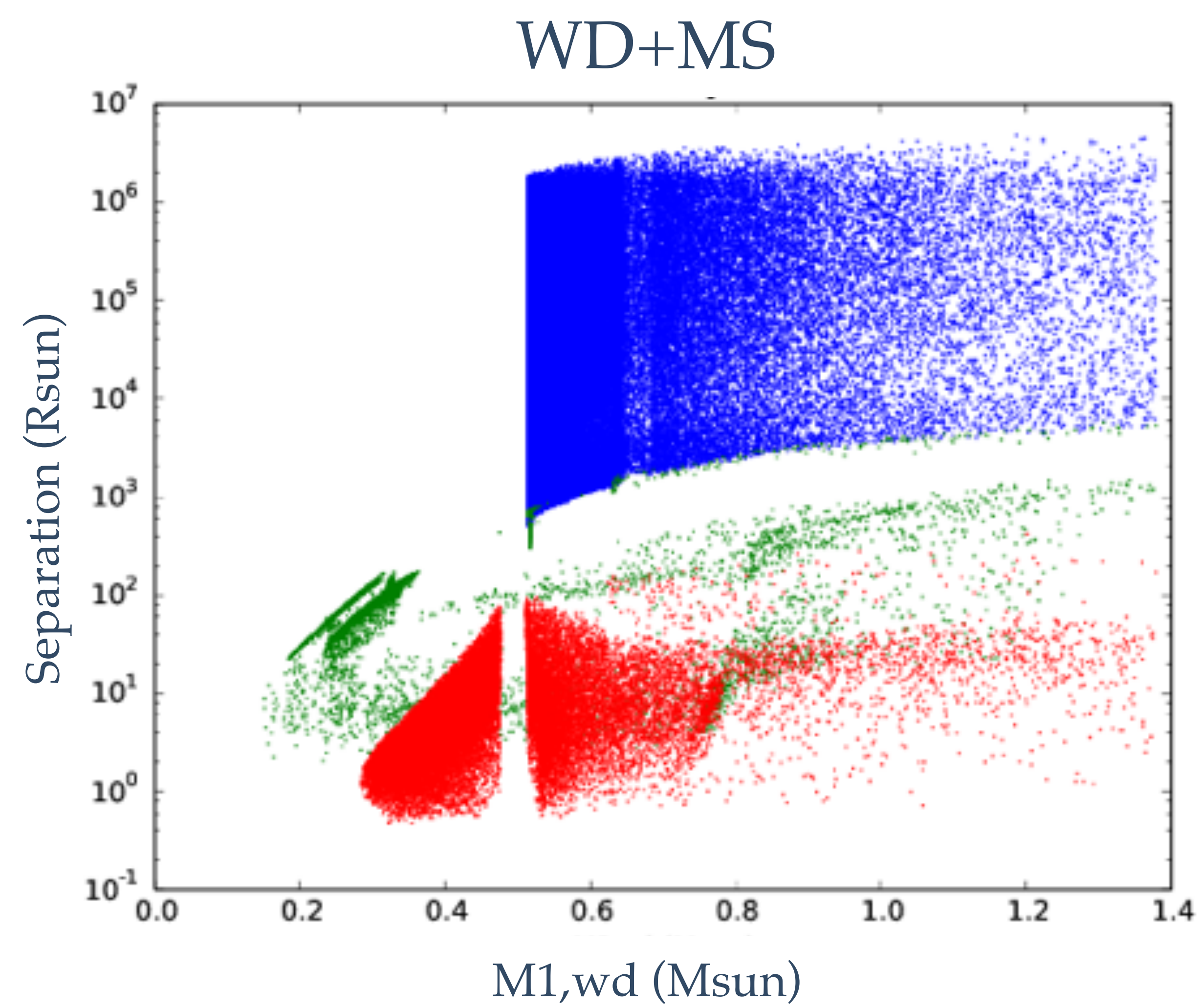




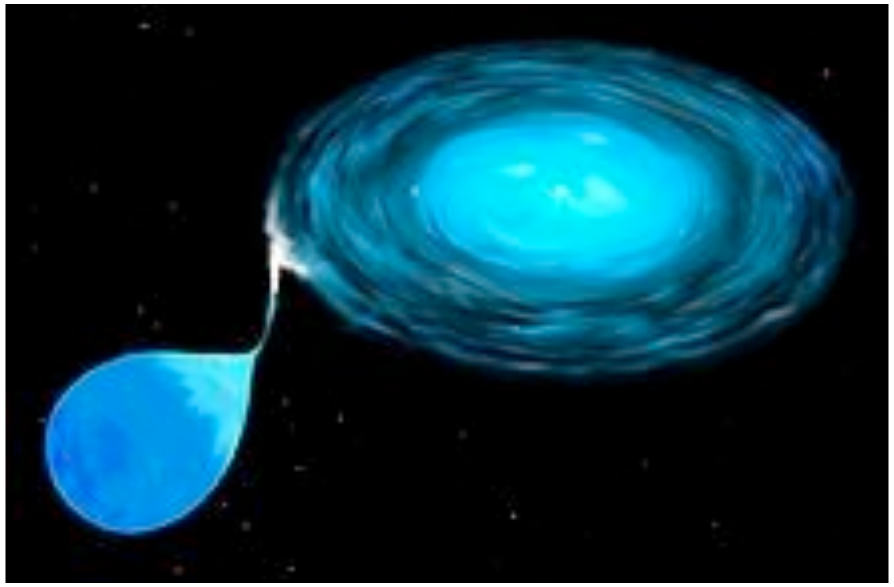
No interaction
Stable mass transfer
Unstable mass transfer / Common-Envelope

Mass transfer

- What happens at Roche Lobe OverFlow (RLOF)?
  - Tricky: mass transfer → change of donor radius → redistribution mass, i.e separation + mass loss from system → change separation → change in Roche lobe

- Compare donor's & Roche lobe's radial response to mass loss
  - Donor star: difference between radiative and convective envelopes
  - Roche lobe depends on mass ratio and angular-momentum loss

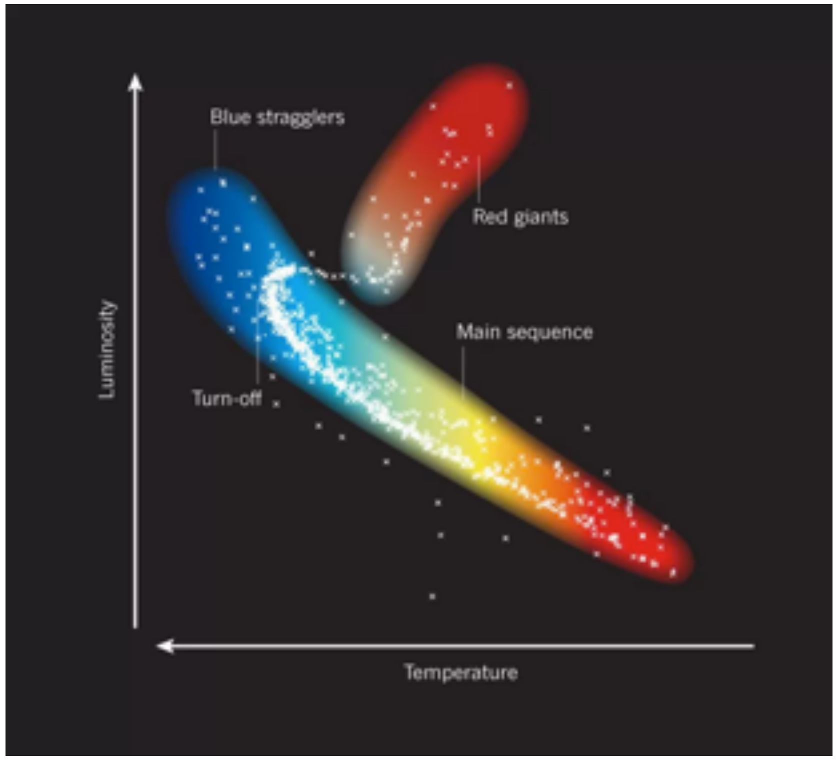
- Boundary between stable/unstable mass transfer
  - Not all giants expand upon mass loss (Passy+ 12)
    - Globally $t_{dyn} < t_{thermal}$, but locally $t_{dyn} \sim t_{thermal}$
  - Mass accretion important (Soberman+ 97, Woods+11, 12)
    - Non-conservative mass loss can stabilize the mass transfer



Stable mass transfer

- Simplest assumption: “conservative” mass transfer in a circular system from a synchronized spherical Roche-lobe-filling donor

- Significant accretion:
  - Algol variables (low-mass giant companion eclipsed by young massive MS)
  - Blue stragglers (MS more luminous & blue than turnoff point in cluster)



- However, mass transfer is often non-conservative (e.g. Han ea ’02,’03)
  - Accretor star easily spun up to critical surface rotation (Packet 1981)
    - What happens to the angular momentum?
      - Winds, tides? (de Mink+ 14)
  - Angular-momentum loss affects orbital evolution
    - Different prescriptions give very different outcomes

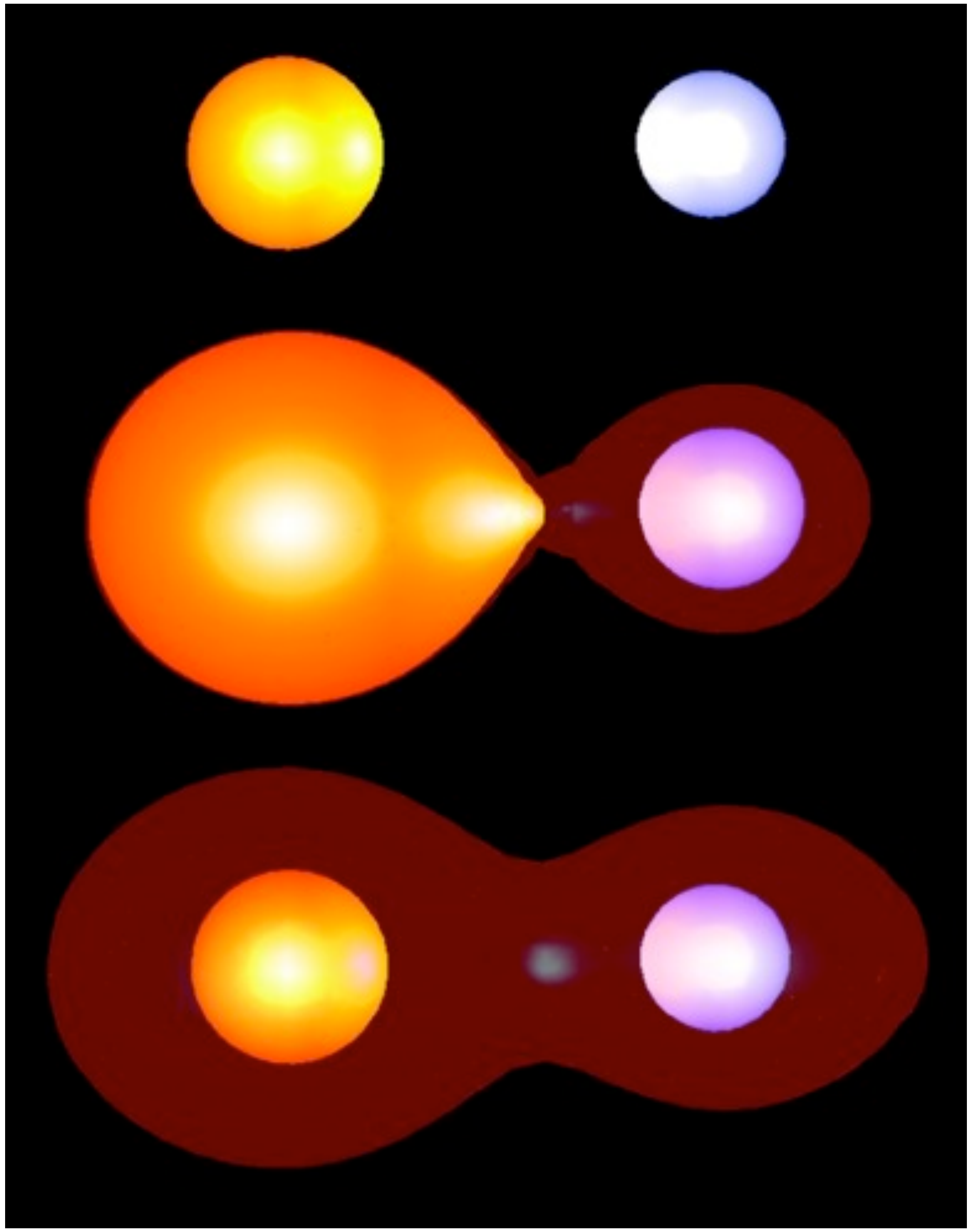
Stable mass transfer

- Mass-driving mechanisms
  - Evolutionary-driven mass loss
    - Nuclear evolution
    - Thermal evolution
    - Irradiation-driven evolution

- Evolution driven by systemic angular momentum loss
  - Gravitational radiation (well understood)
  - Magnetic braking (poorly understood)
  - e.g. low-mass X-ray binary, Cataclysmic variables (mass transfer to compact objects)

Common-envelope evolution

- Unstable mass transfer



Motivation

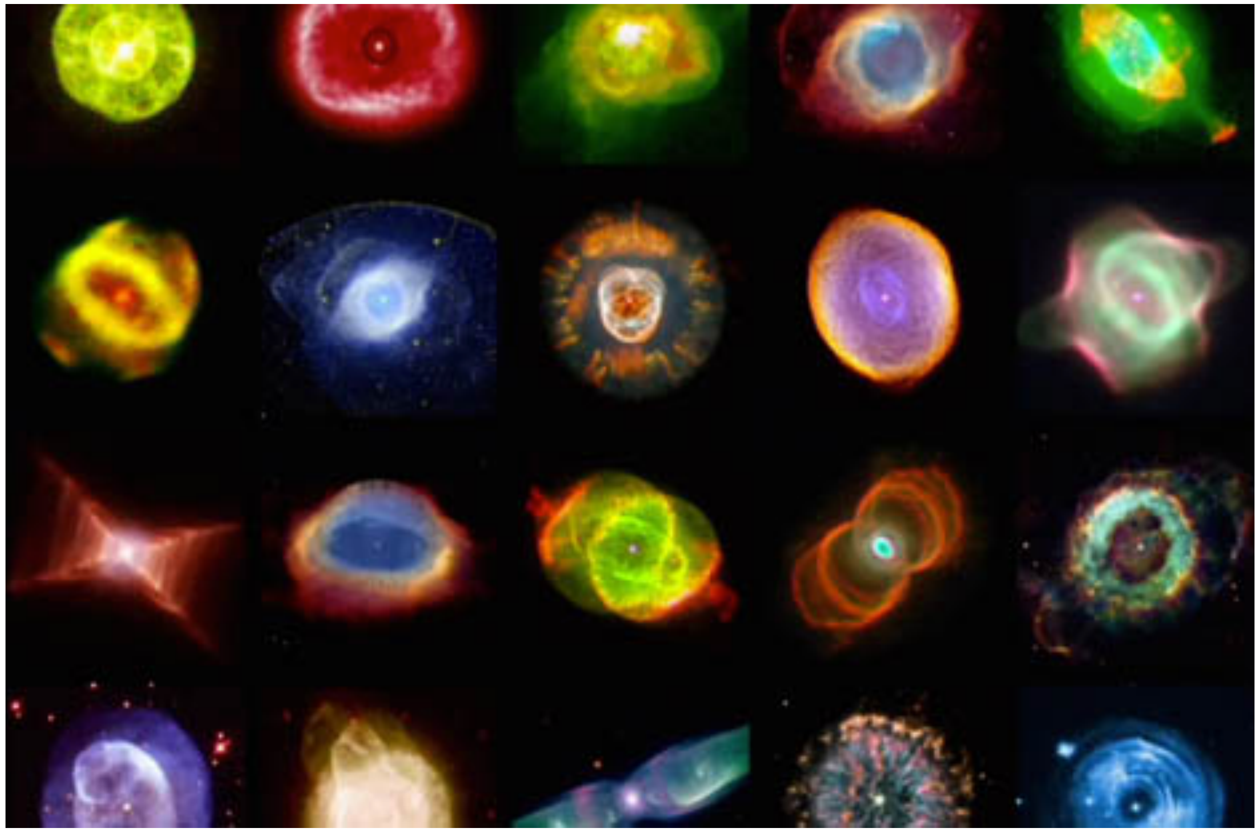
- Compact stars in close orbits observed
- Reduction of orbit needed

- Mayor source of uncertainty in binary evolution
- Steady progress:
  - 3D hydro simulations (review Ivanova+ 13)
    - recombination energy (Livio ‘89, Nandez+ ‘15,16, Iaconi+ ‘17, ’18)
  - Empirical constraints (Nelemans 00, 01, van der Sluys+ 06, Zorotovic+ 10, Toonen+ 13, Portegies Zwart 13, Camacho+ 14)

Common-envelope evolution

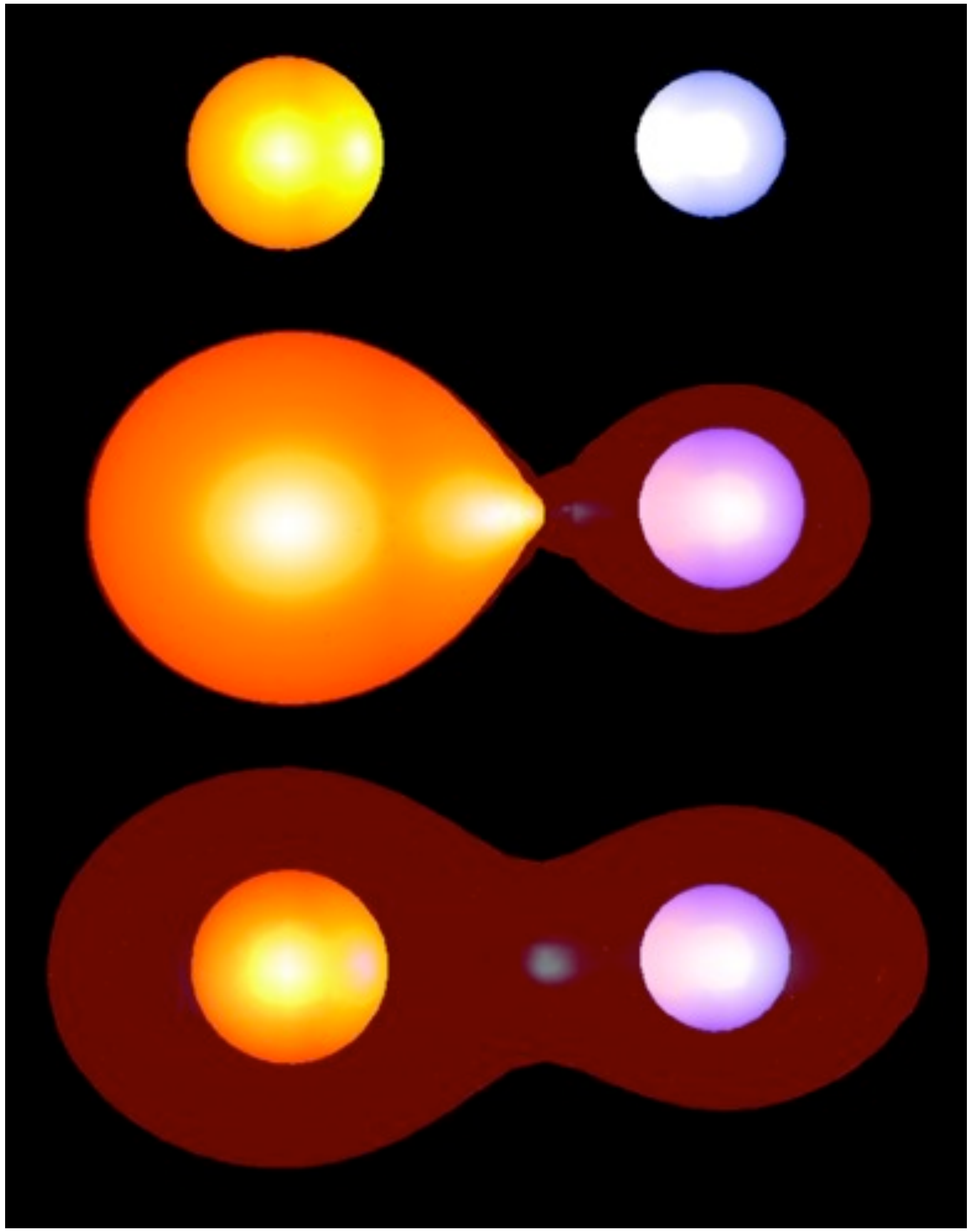
Importance

- Transients
  - V838 Mon, V1309 Sco, Eta Carinae
- Mergers
  - 10-30% of single WDs come from mergers (Toonen+ 17)



- Compact binaries with an compact object/stripped star
- Planetary nebulae
  - >20-80% of PN central course in binary (Mizsalski+ 09, De Marco+ 04, Douchin+ 15)

Common-envelope evolution



Binary populations → effect on orbit

- close WD-MS → strong contraction
  (Zorotovic+ 10, 14, Toonen & Nelemans '13, Portegies Zwart '13, Camacho+ '14)
- close WD-WD (Nelemans+ 00, 01,vd Sluys+ '06)
  - forming first WD → modest widening
  - forming second WD → modest contraction

What we need:

- large & uniform populations of compact binaries
- well-understood selection effects

Common-envelope evolution

Eclipsing populations

- ~70 WD-MS known (Parsons +15)
  - period~hours-days
- ~7 WD-WD known
  - period~min-hours

- Mass-radius relation (e.g. Parsons+ 10)
- Supernova type Ia progenitors (e.g. Wang+ 12)
- Tides / WD viscosity (e.g. Piro 11)
- Circum-binary planets (Beuermann+ 10,12, Marsh+ 14)

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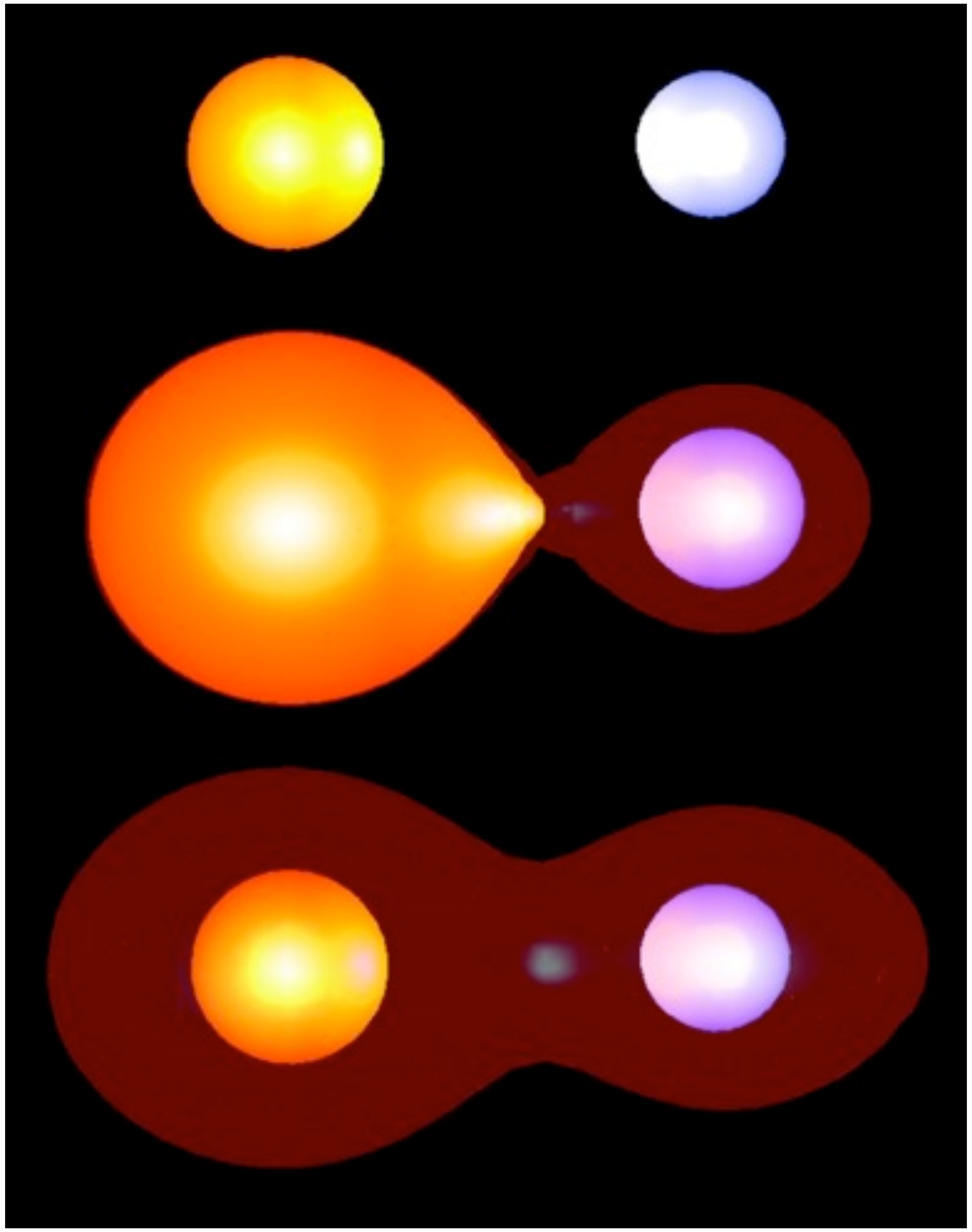
Common-envelope evolution

- Unstable mass transfer



What happens to a planetary companion?

(e.g. Soker+ 98, Nelemans & Tauris+ 98)

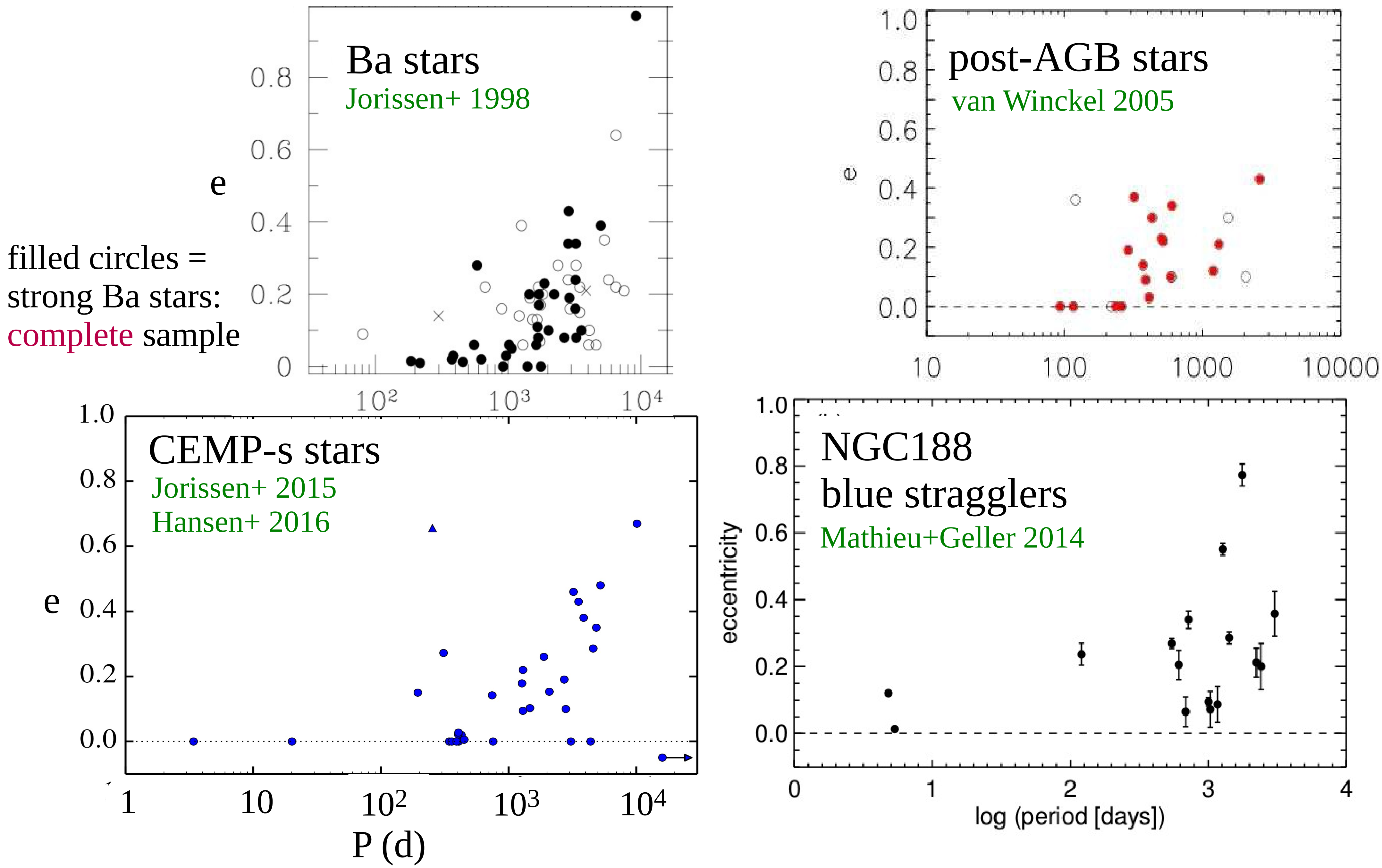
- Evaporation
- Merger with core
- Survivial

- Second generation planets?

- See also Leen Decin's talk tomorrow

Mass transfer?

- Period - eccentricity distribution not understood (e.g. Vos+15)
- Also seen in SdB stars (stripped stars) & symbiotics



- Courtesy: Onno Pols

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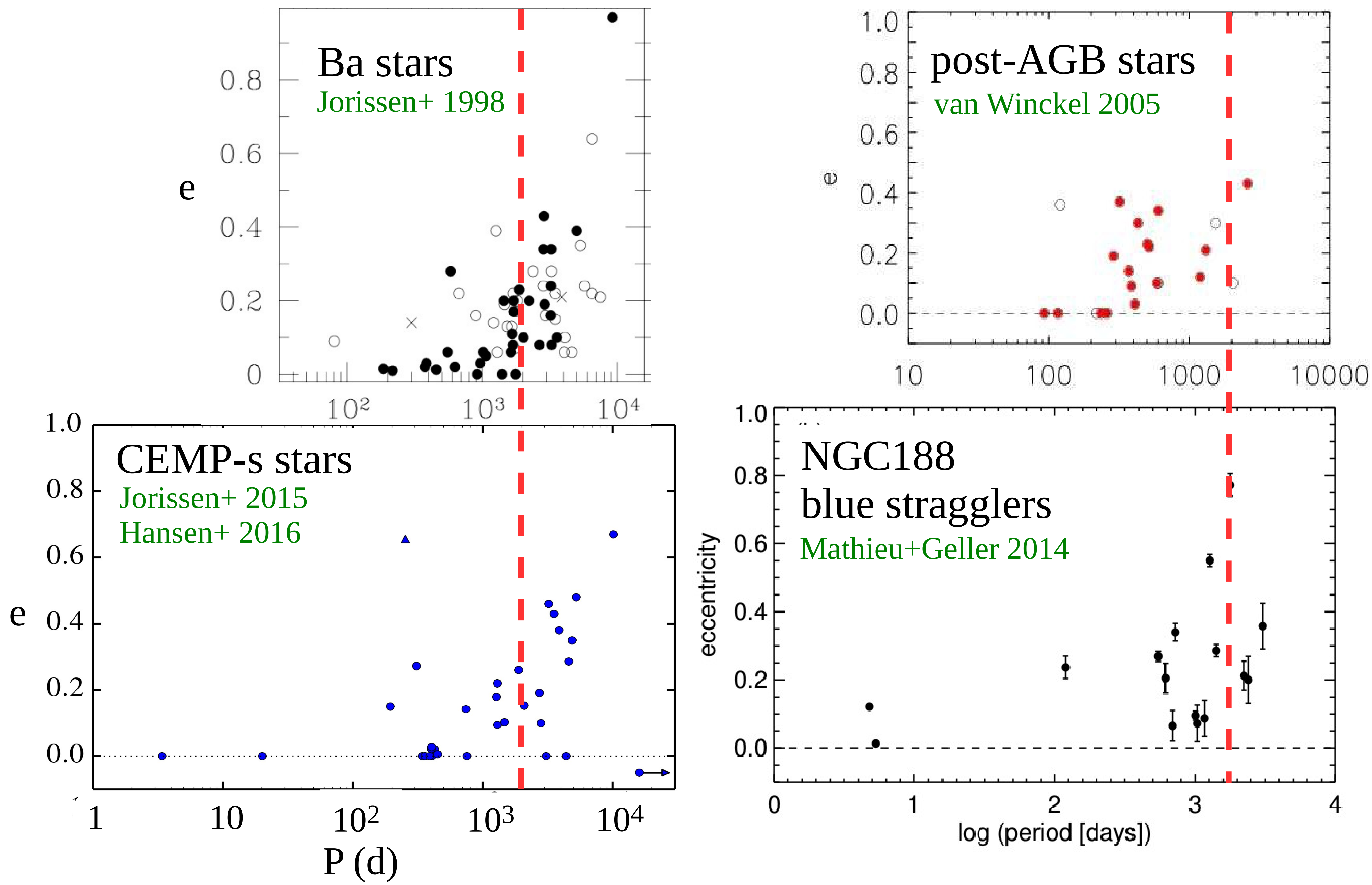

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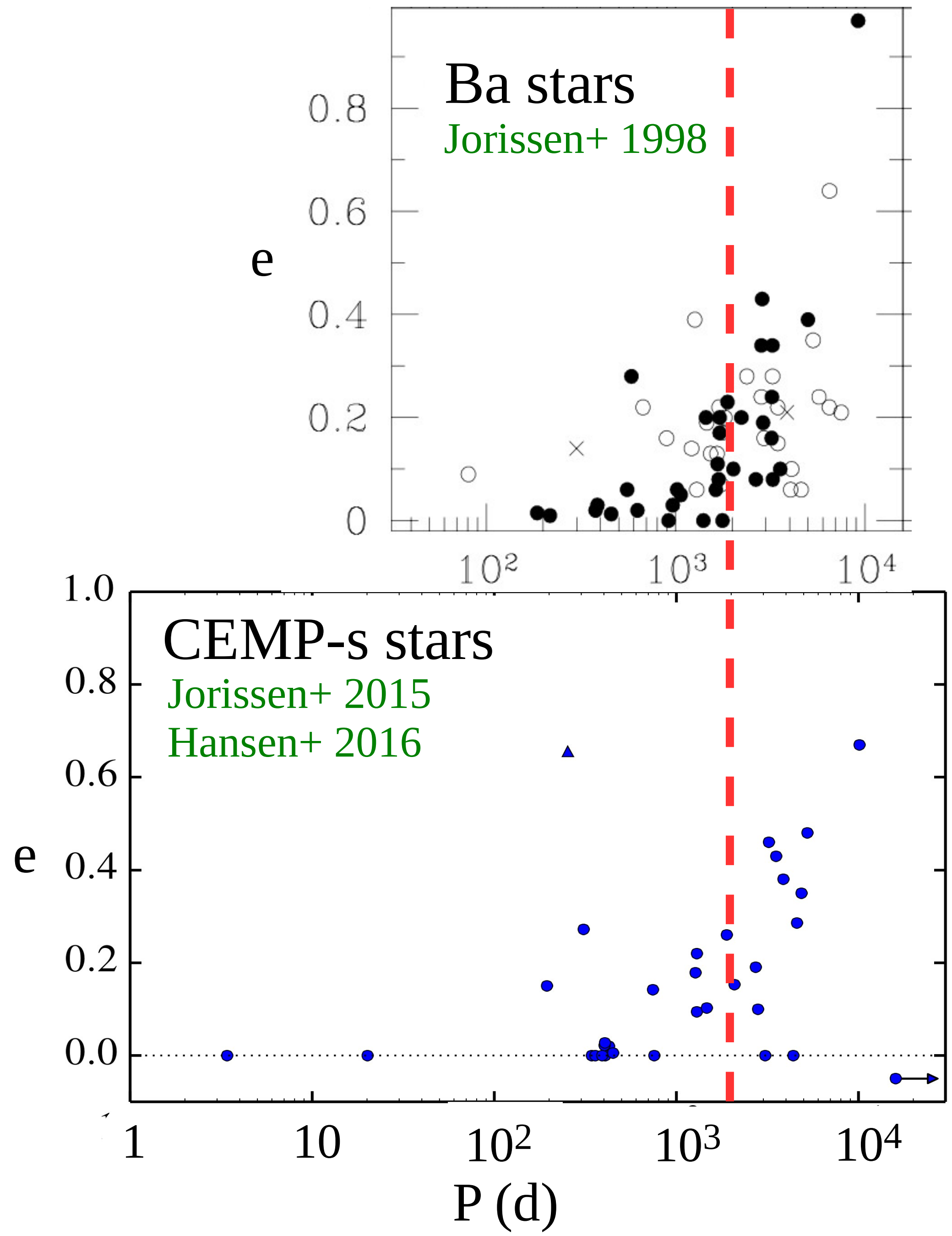


Possible e-pumping mechanisms

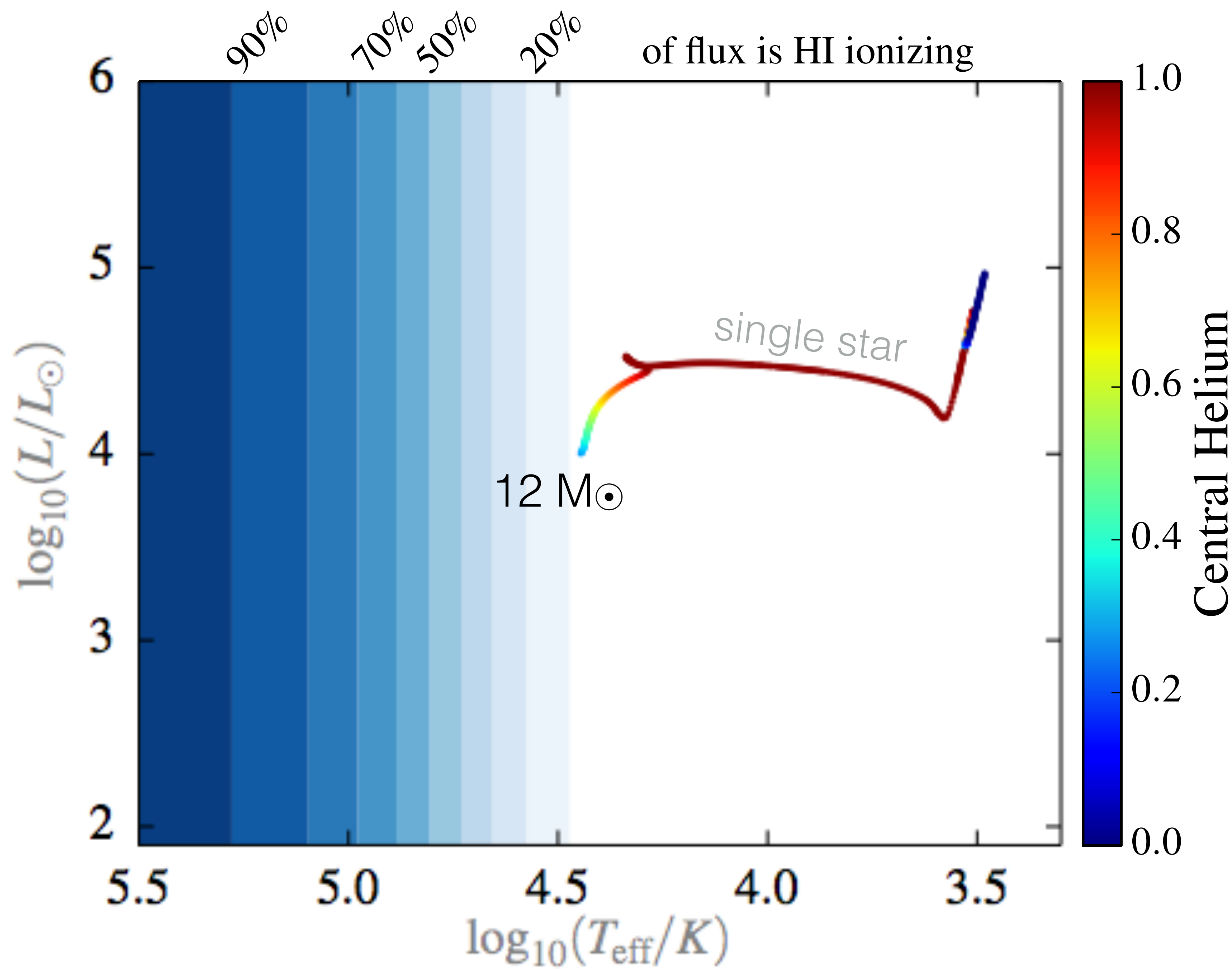
- Enhanced wind-mass loss at periastron (van Winckel+ 95, Bonanic+ 08)
- Mass transfer at periastron (Soker+ 00, Vos+ 15)
- Circumbinary disks (Waelkens+ 96, Dermine+ 13, Vos+ 15)
- Wind-RLOF (Mohamed+ 07, Mohamed+ 10, Abate+ 15)
- Triple companion (Perets & Kratter 12)

- Courtesy: Onno Pols

Stripped stars

- Why interesting?
  - Proof of binary interaction
  - Progenitors of SN Ibc
  - Ionizing photons

- From: Gotberg+ 2017



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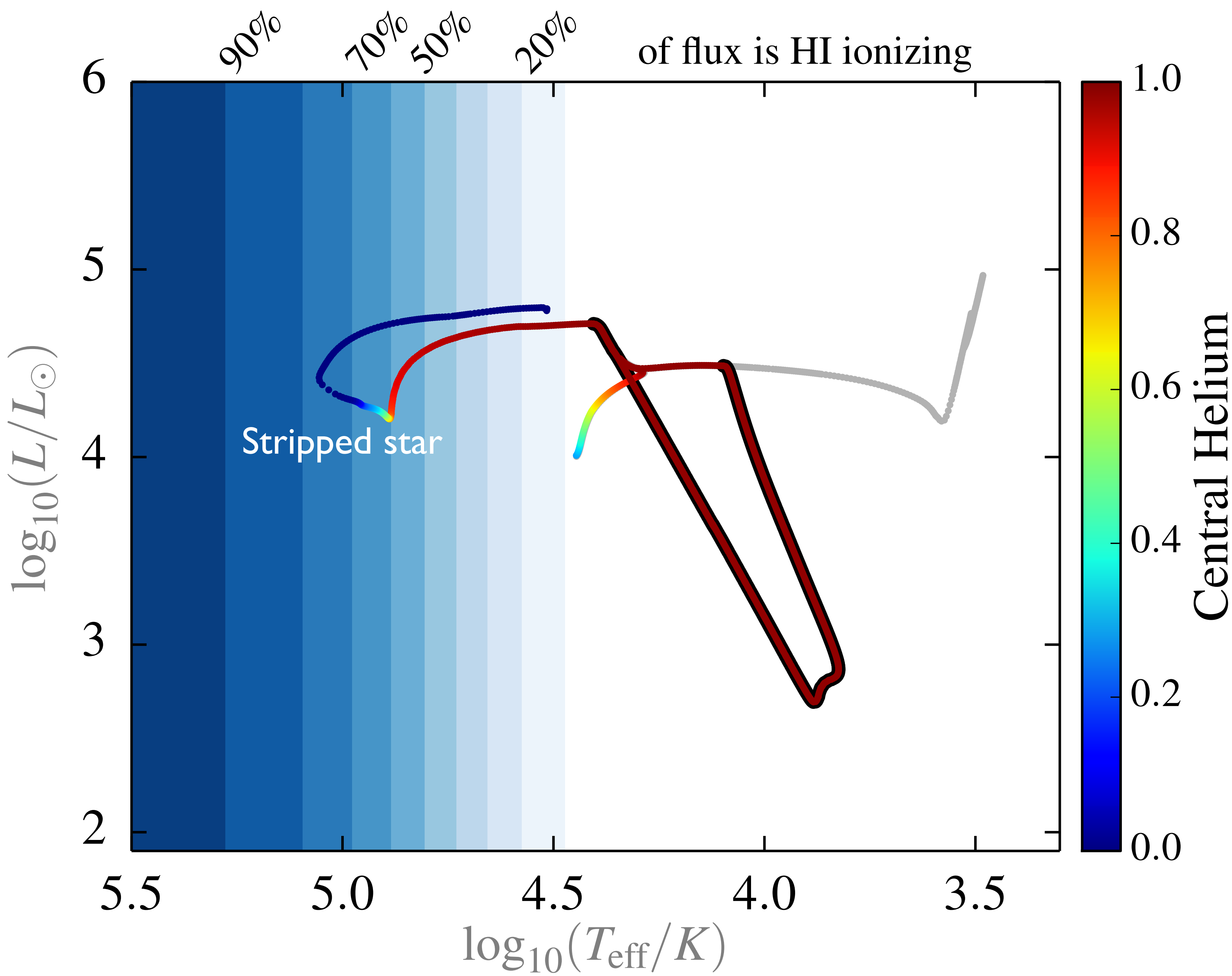
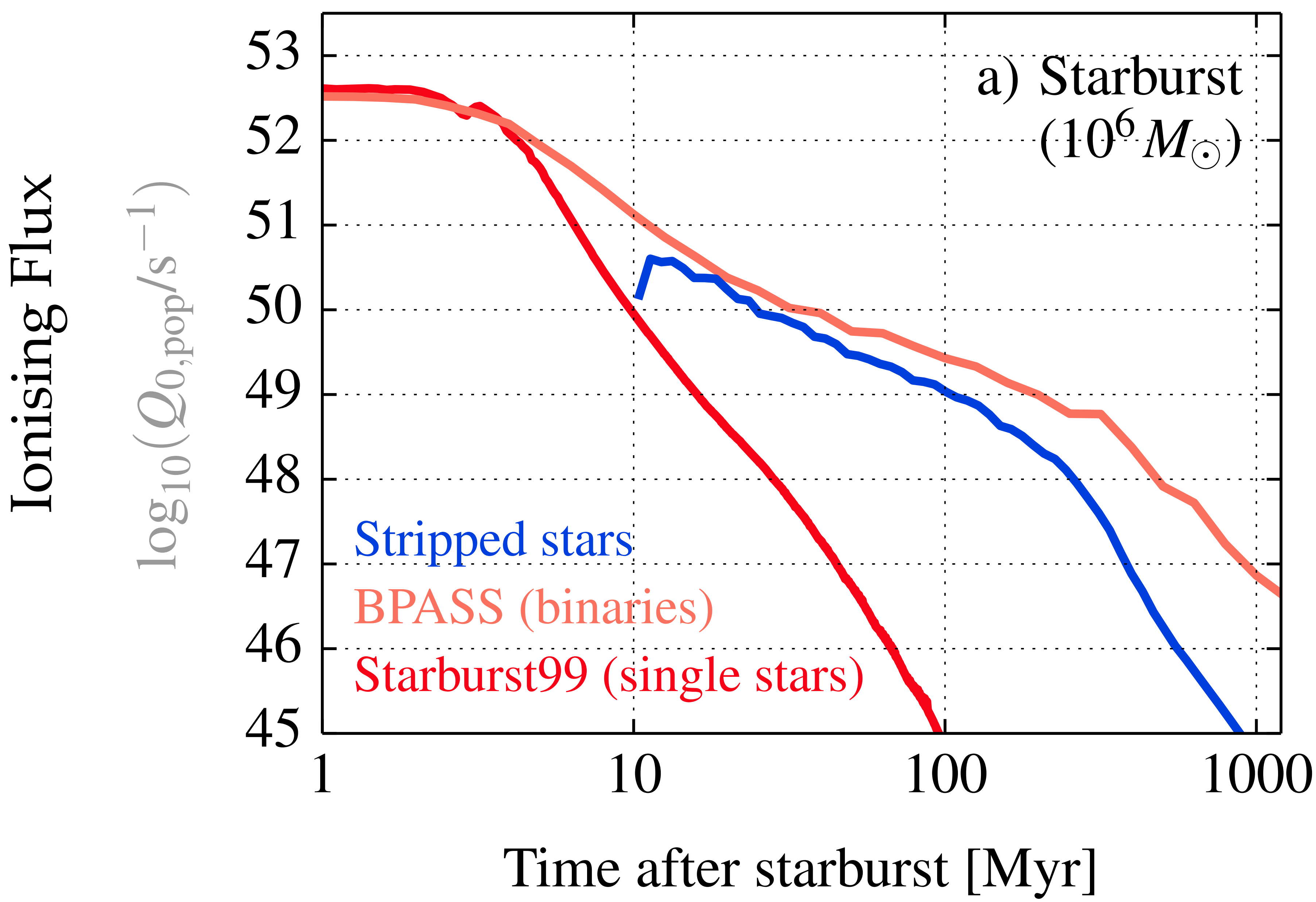


Stripped stars

Ionising contribution from stripped stars



- Fig. from Gotberg+ in prep.
- See also: Han+ 07, Van Bever+ 98, Van Bever & Vanbeveren 03

Stripped stars

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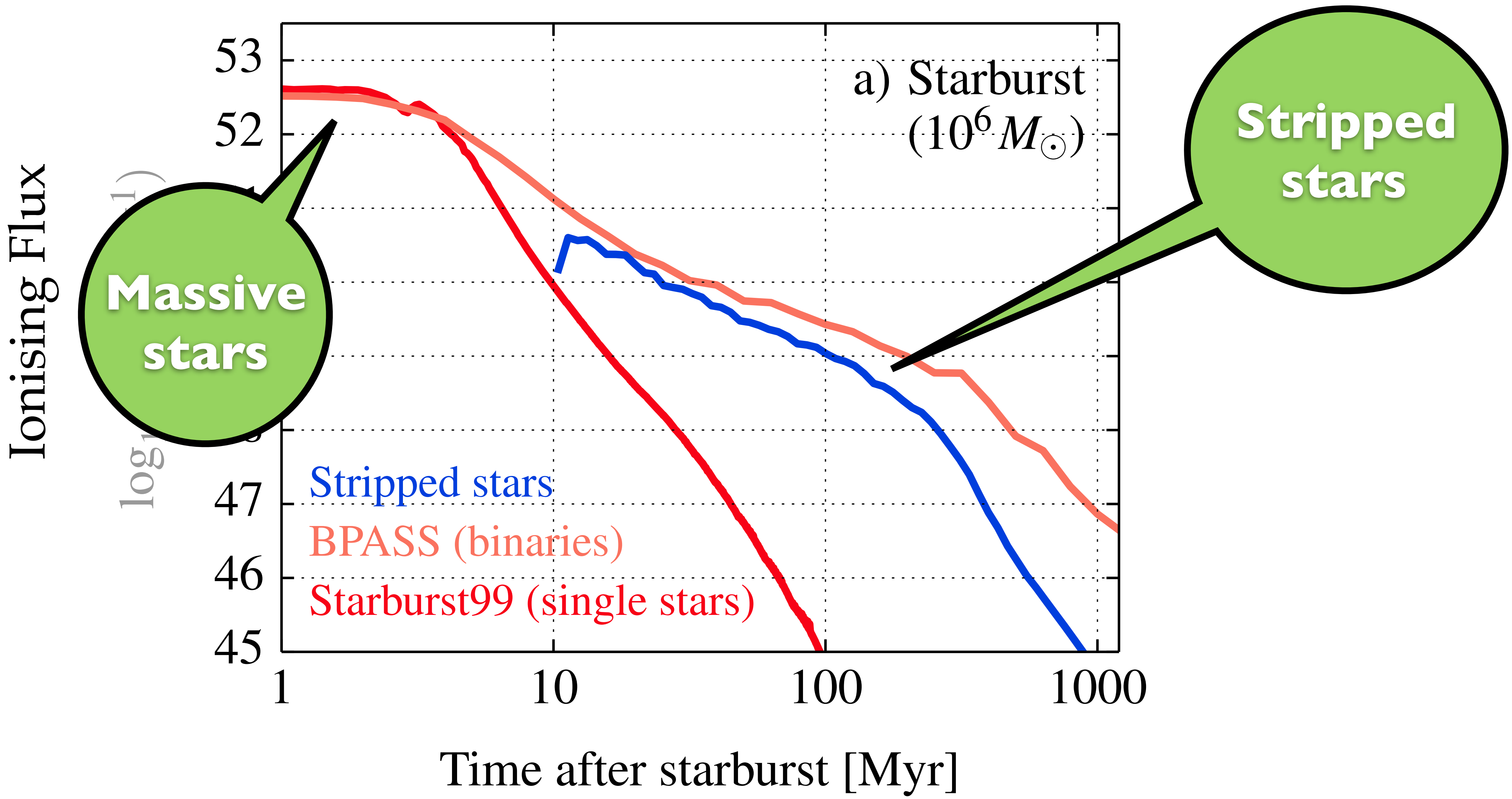

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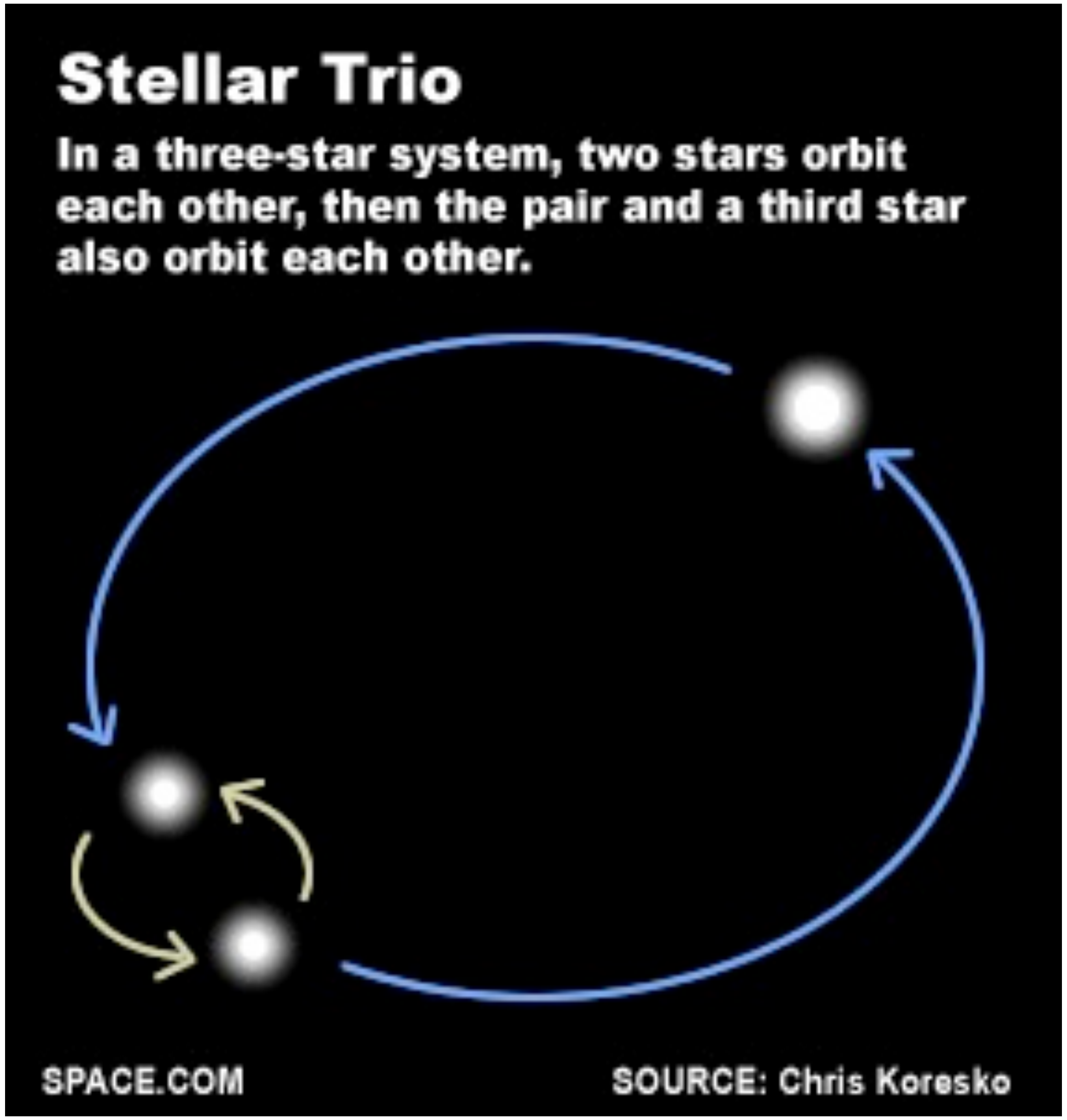
Triples

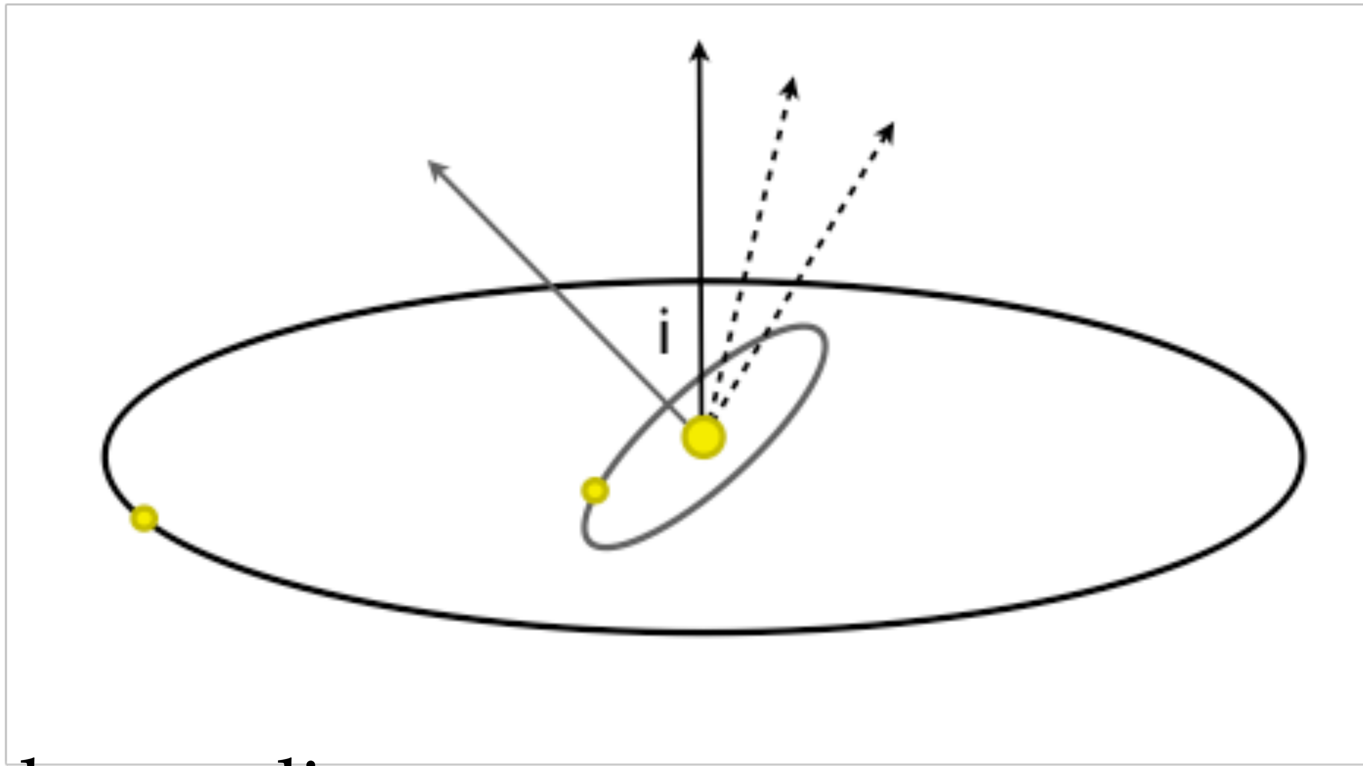


- Fairly common

	Binary fraction	Triple fraction
Low-mass stars	40-50%	10-15%
High-mass stars	>70%	>30%
Refs	Raghavan+ '10, Tokovinin '08, '14, Remage Evans '11, Duchene & Kraus '13, Sana+ '14, Moe+ '17	

Evolution of stellar triples

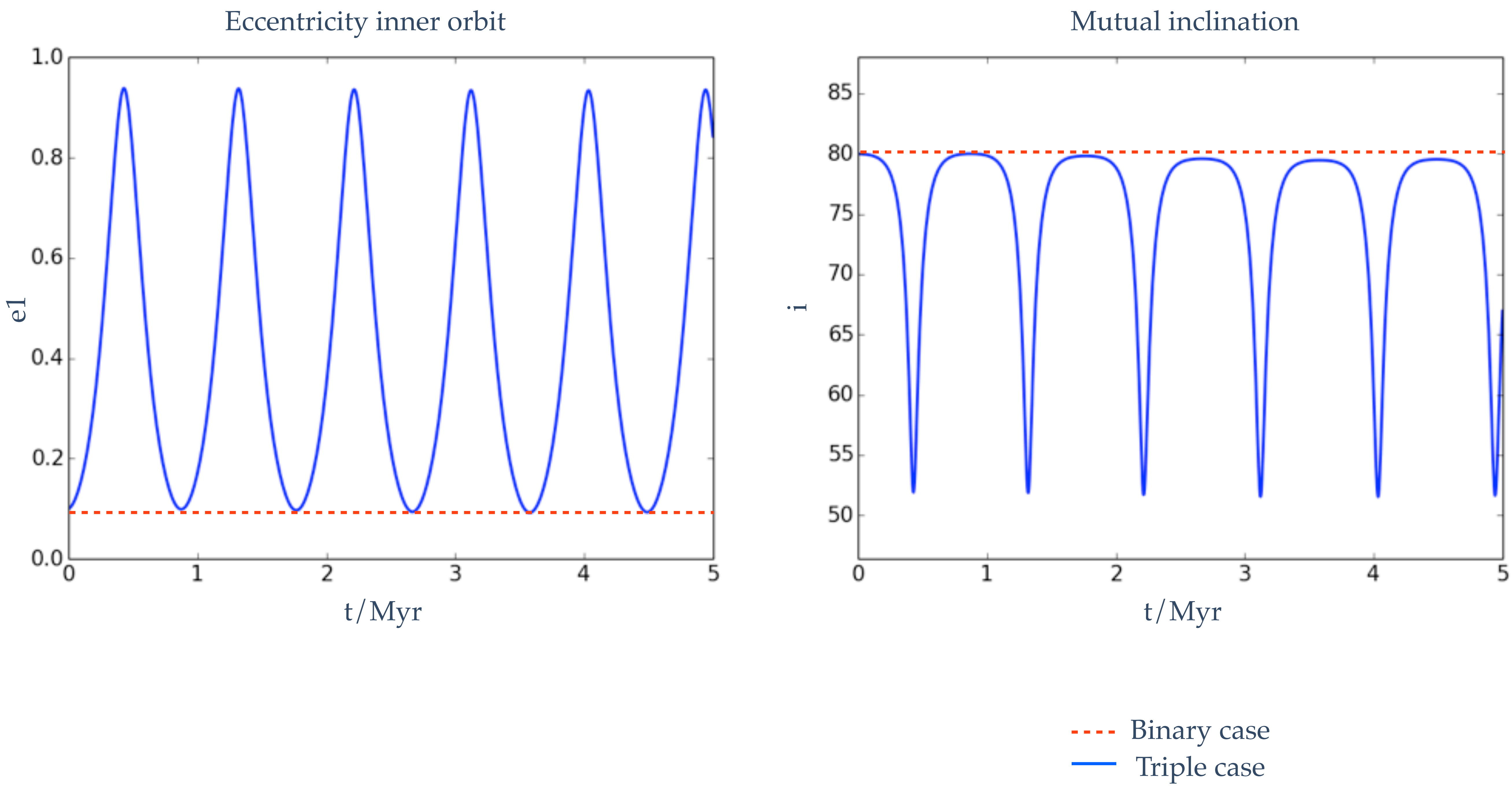
- Triple evolution provoked for:
  - Gravitational wave sources, supernova type Ia progenitors, mergers, blue stragglers, low-mass X-ray binaries etc. etc.



- Unique evolution
  - Three-body dynamics
  - Stellar (& binary) evolution
- Impressive recent progress, but little coupling
  - Rich interacting regime (Shappee+ '13, Hamers+ '13, Michaely+ '14, Toonen+16, Antonini+ 17)
  - New code **TRES** for (coeval stellar hierarchical) triple evolution (Toonen+ 2016 => also for review on triple evolution in stellar systems)

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



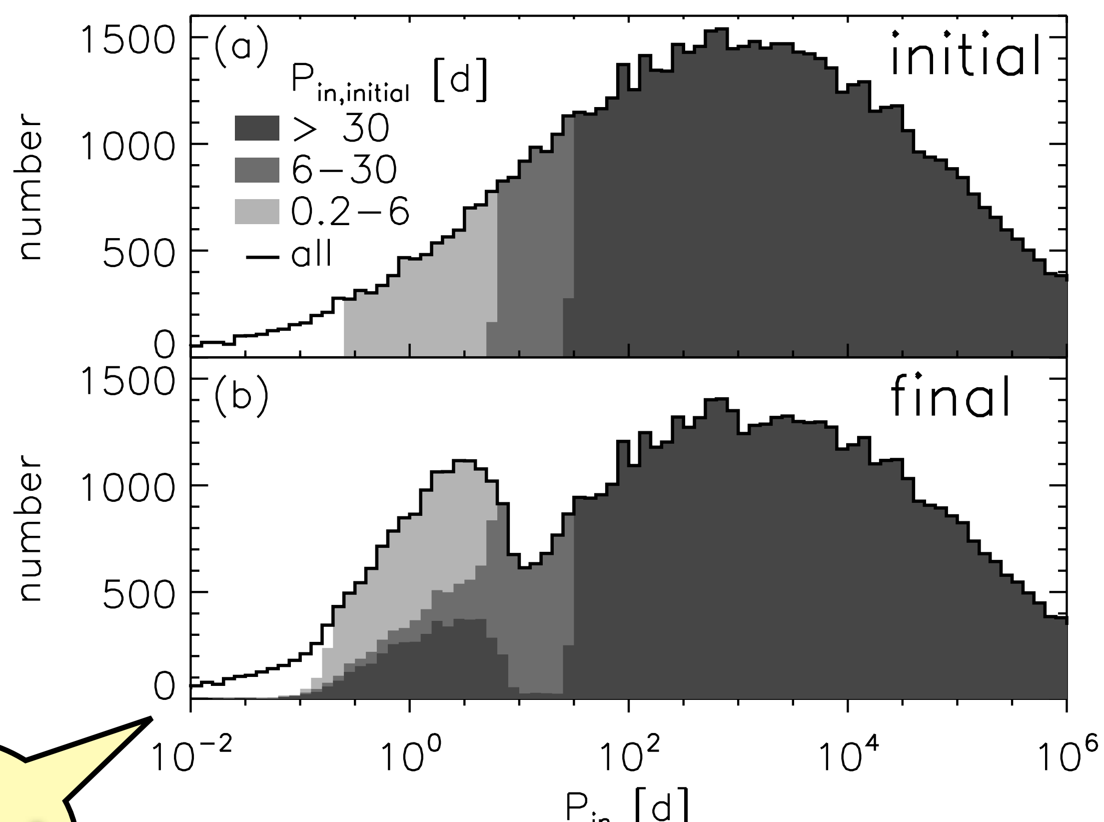
Triple evolution leads to...

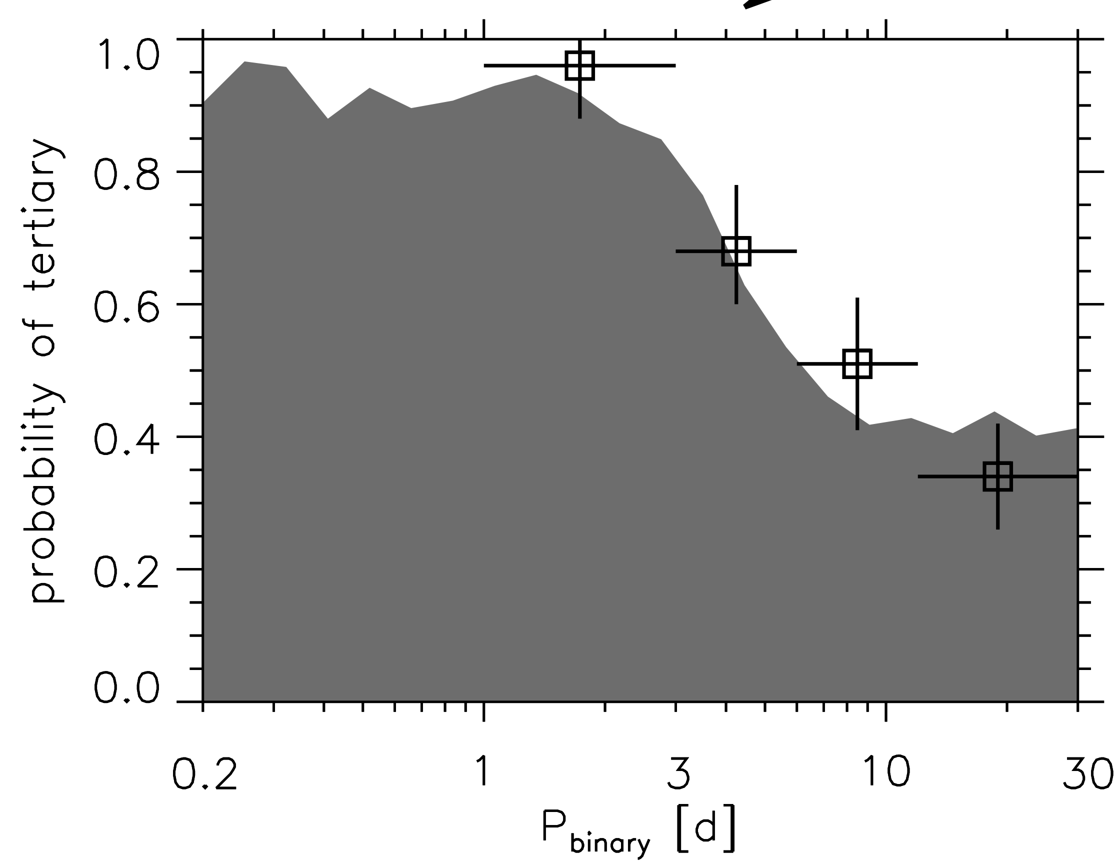
- Enhanced occurence rate of mass transfer
  - ~1.5x more often mass transfer compared to binaries (Toonen+ in prep.)
  - ~40% of onset mass transfer in an eccentric orbit (Toonen+ in prep.)
- Enhanced merger rate
  - Dominant source of collisions in the field (Perets & Kratter '12)
  - BH-BH mergers from initially very wide orbits:
    - 0.3-1.2 per year per Gpc^3 (Antonini, Toonen & Hamers '17)

Triple evolution leads to...

- ➡ Enhanced occurence rate of mass transfer
- ➡ Enhanced merger rate of compact objects
- ➡ Enhanced formation rate of compact binaries
  - Excess of close MS-MS (Fabrycky & Tremaine '07, Naoz+ '11)
    - 96% is part of a triple (Tokovinin+ '06)

Observed





Model

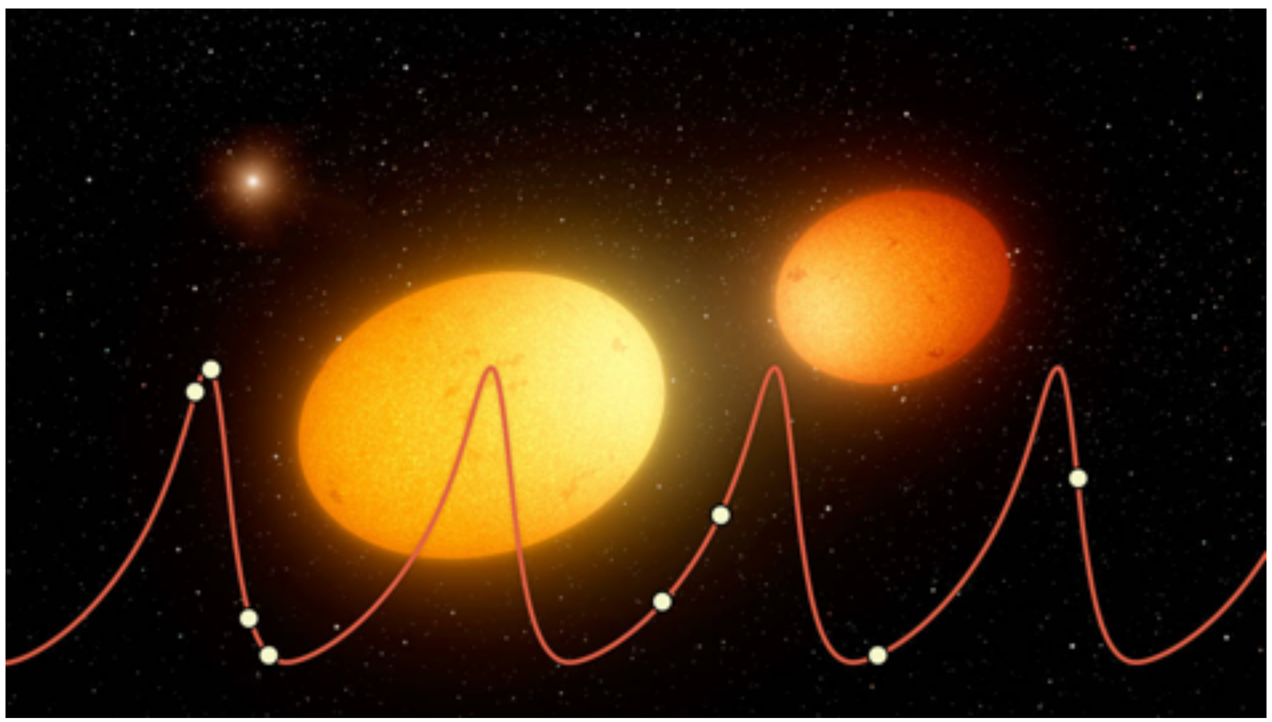
Tides important in triples!

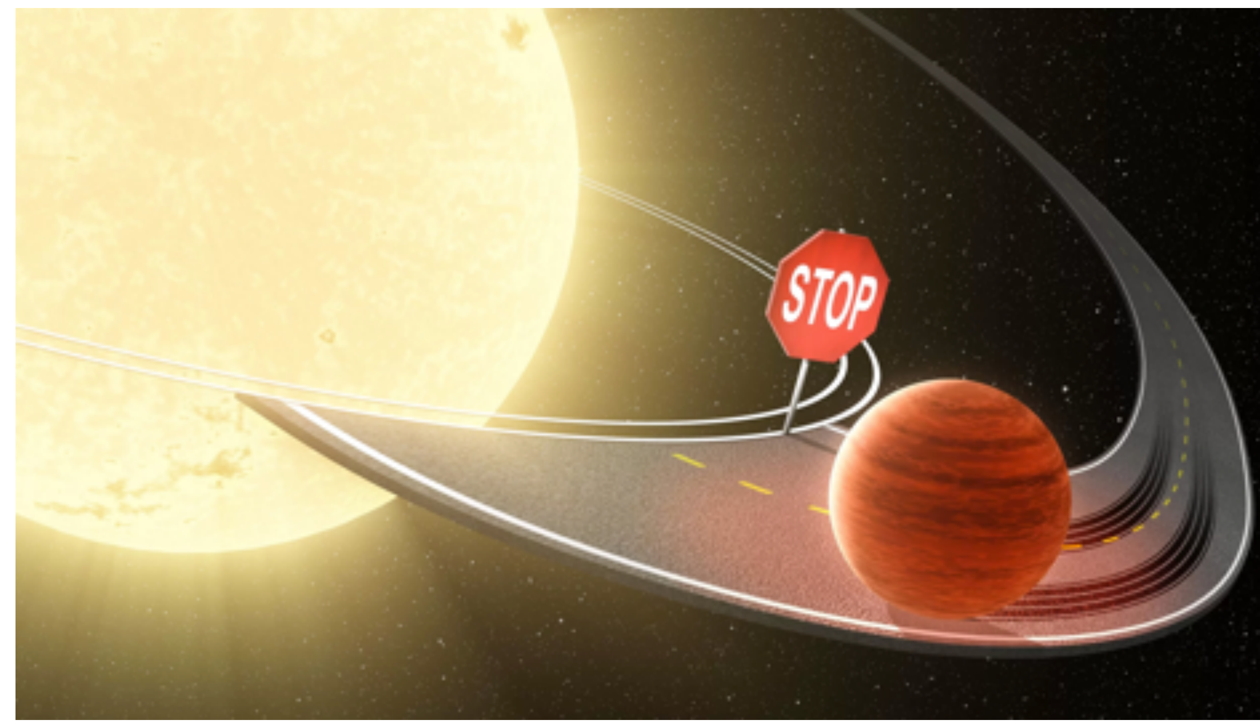
Triple evolution leads to...

Kozai-Lidov cycles with dissipation

- (tides, gravitational waves)

credit: Nasa/JPL





Heartbeat stars

- KIC 2835289, KIC 3749404, KIC 3766353 (Conroy+ 15, Hambleton+ '16, priv. comm.)

Hot Jupiters

- High-eccentricity migration (e.g. Wu+ '03, Ngo+ '16)

Conclusions

- Initial binary fraction: increases with primary mass
- Initial period distribution: more compact binaries as primary mass increases
- → More binary interactions as primary mass increases

- Stellar interactions change orbit, mass accretion, mass stripping
  - Ionizing flux from stripped stars

- The presence of a third star can have a strong effect on the evolution of the inner binary
  - New code TRES for (coeval stellar hierarchical) triple evolution (Toonen+ 2016 => also for review on triple evolution in stellar systems)

Conclusions

- Questions?