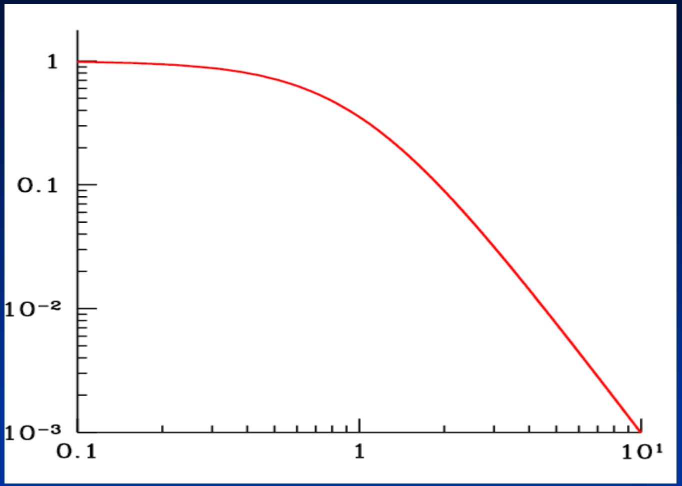
Triples Formation in Dense Clusters

extracts from simulations with no much of deep thoughts

attention: no analytics involved, but an extended zoo excursion

Population synthesis with dynamics



- Static cluster background
  core density n_c
  dispersion velocity σ
  escape velocity v_{esc}
- Mass segregation (Fregeau et al. 2004)
  $t_{sc}(m) \approx \langle m \rangle / m \; t_{rh}$
- Recoil

"+" : large populations, up to 2×10^6 stars
"–" : cluster dynamics is not self-consistent

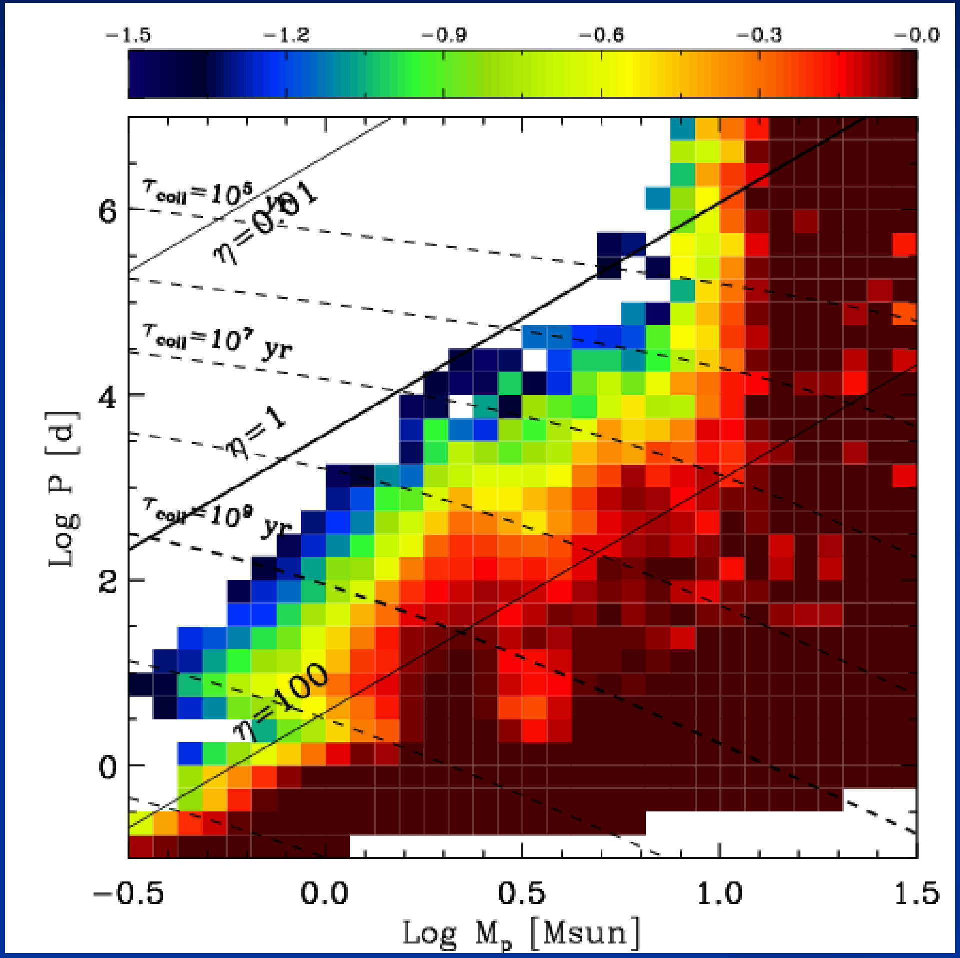
Stellar evolution

- Single stars: analytic fits provided by Hurley et al. 2000
- NS formation: cc, kicks, ECS
- Binary stars: (Belczysnki et al. 2002, 2005, 2008)
  - Magnetic braking
  - Mass transfer events
  - Common envelope events
  - Tidal circularization and synchronization
  - Accretion on WDs, Ia SN and subCh Ia
- Triples: dynamical formation, but no evolutionary treatment yet

“Typical” cluster model

- $2 \bullet 10^6$ stars give 500,000 $M_\odot$, 50–100% binaries
- IMF for primaries from $0.05M_\odot$ to $100M_\odot$ (triple power law by Kroupa 2002); $Z=0.001$
- Binaries
  - Flat mass ratio distribution
  - Periods from 0.1 d to 10^7 days
  - Thermal e distribution
- Core characteristics:
  - $n_c=10^5$ per pc^3
  - $\sigma_1 = 10$ km/s
  - $t_{rh}=10^9$ yr

Binaries destruction: role of the evolution



Destructions of only soft binaries (~60% of primordial binaries) & evolutionary destructions:

Upper limit

30% if <m> ≈ 0.5 M⊙

24% if <m> ≈ 1 M⊙

50% of all hard binaries will undergo an encounter in 10Gyr, about half of them will be destroyed

Only 22% of binaries will be left, and among binaries with a primary companion > 0.5 M ⊙ only 13%

Triples: formation rate

A typical dense cluster of 500 000 Msun has about 10000 hier. stable triples formed throughout its evolution in its core

$$\Delta N_{tr}/N_{bin} \approx 0.05\ f_b <m_b> <a> \text{ per Gyr}$$

At 10 Gyr : $<m_b> \approx 1.0 M_\odot$, $<a> \approx 10 R_\odot$, $f_b \approx 10\%$

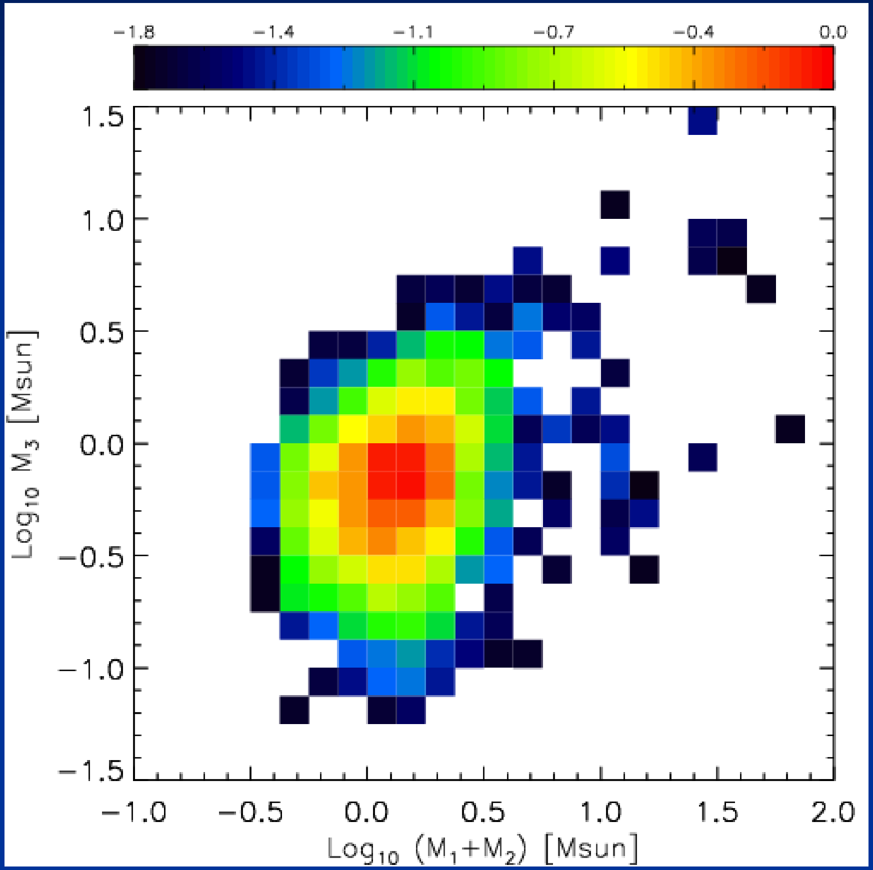
$$\Delta N_{tr}/N_{bin} \approx 5\% \text{ per Gyr in the core}$$

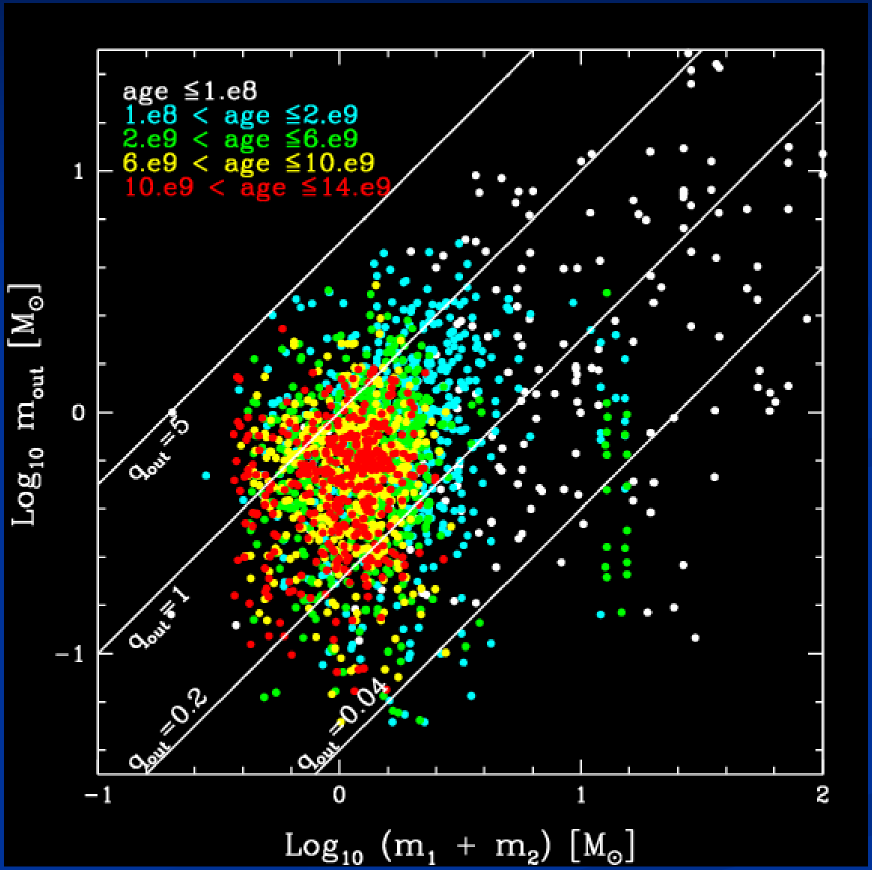
Stability criterion as in Mardling & Aarseth (2001)

$$\Delta N_{tr} \approx 1200/t_9^{1/3} \text{ per Gyr, at ages} > 1 \text{ Gyr}$$

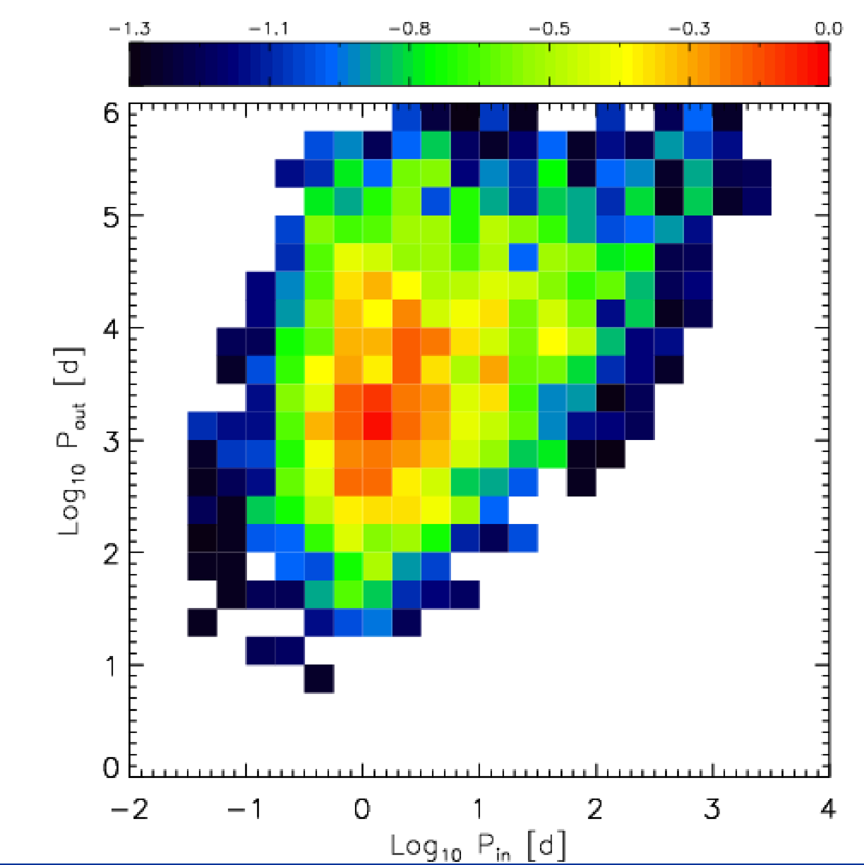
(for fixed n_c and σ)

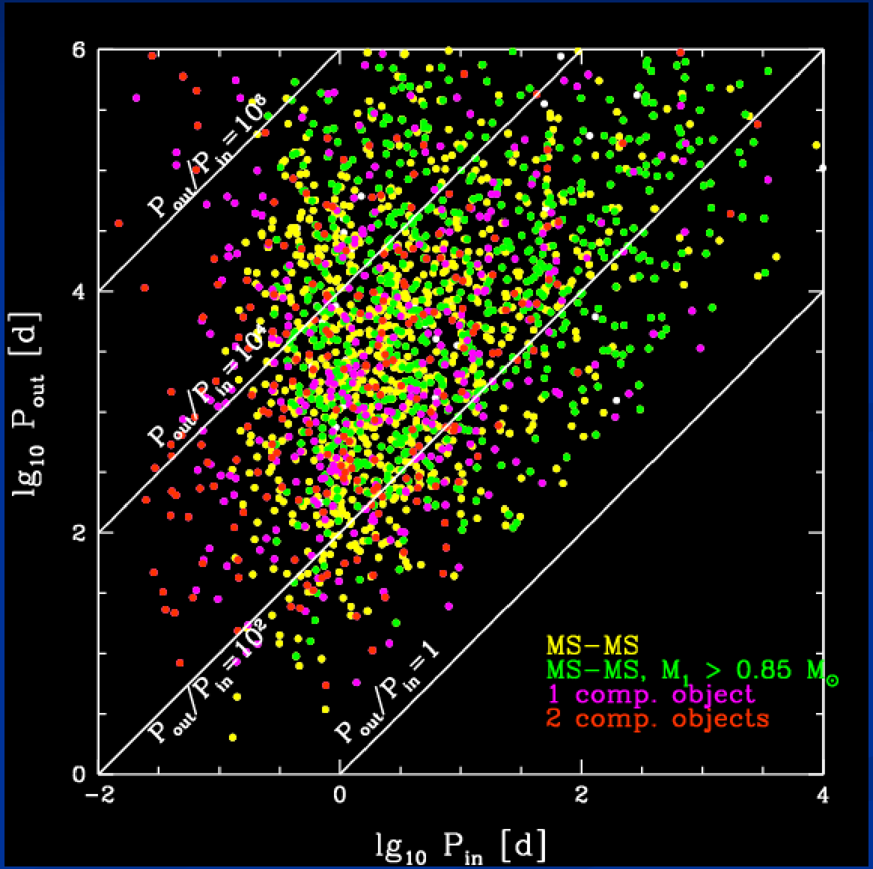
Triples: masses



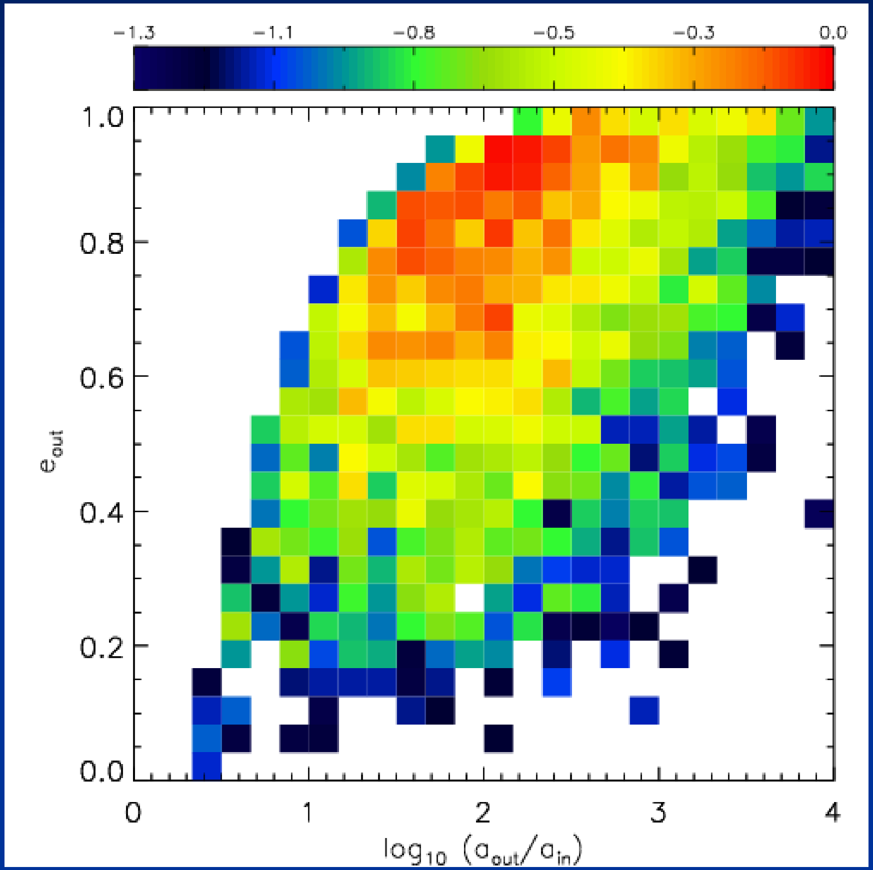


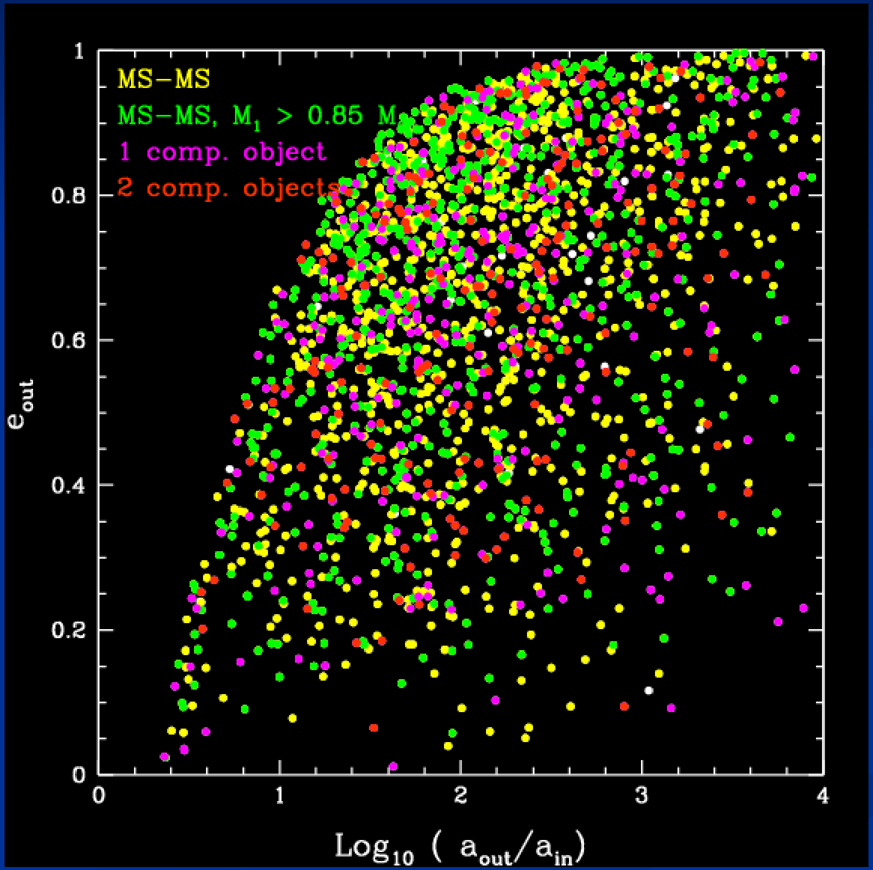
Triples: periods



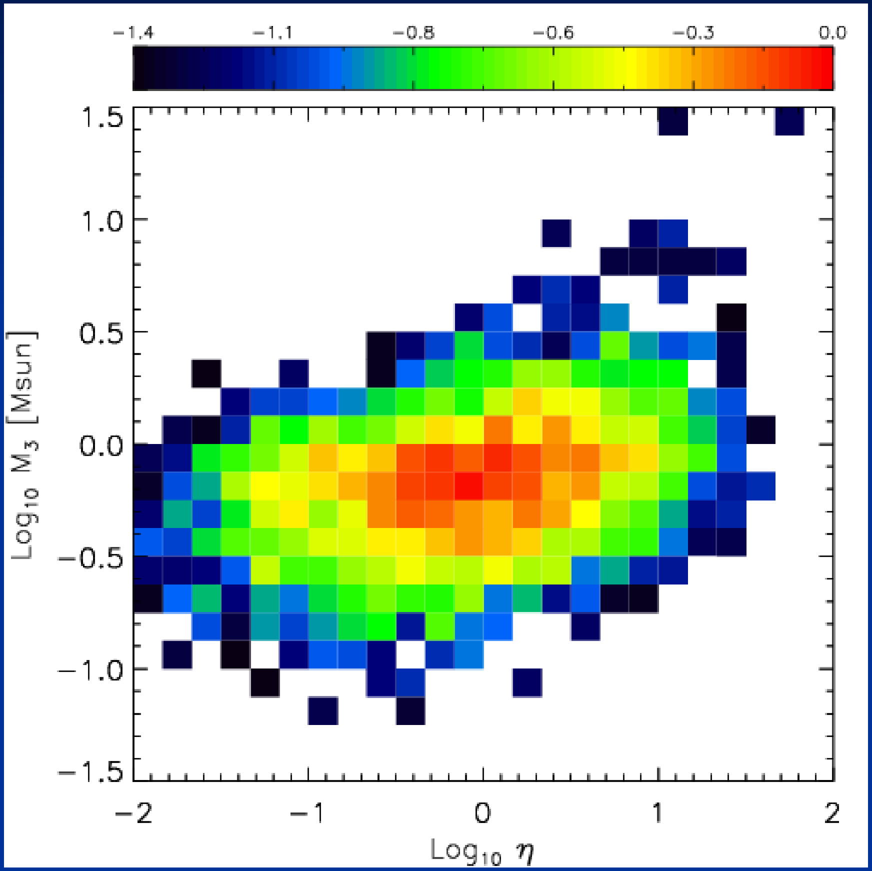


Triples: eccentricities





Triples: hardness



45% with η > 1kt and only 7% with η > 10kt

~half of hard triples have small mass outer companion

Triples and Kozai mechanism

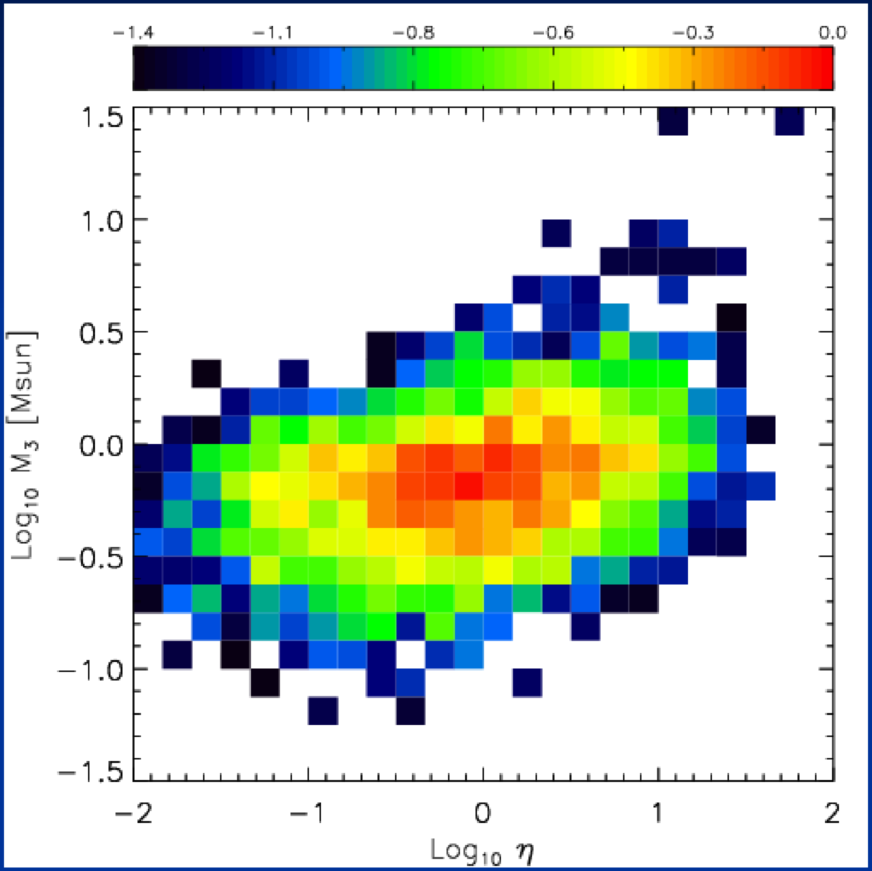
Kozai mechanism causes large variations in the eccentricity and inclination of the stars orbits and, especially if coupled with tidal friction, could drive the inner binary of the triple system to merge or RLOF before next interaction with other stars.

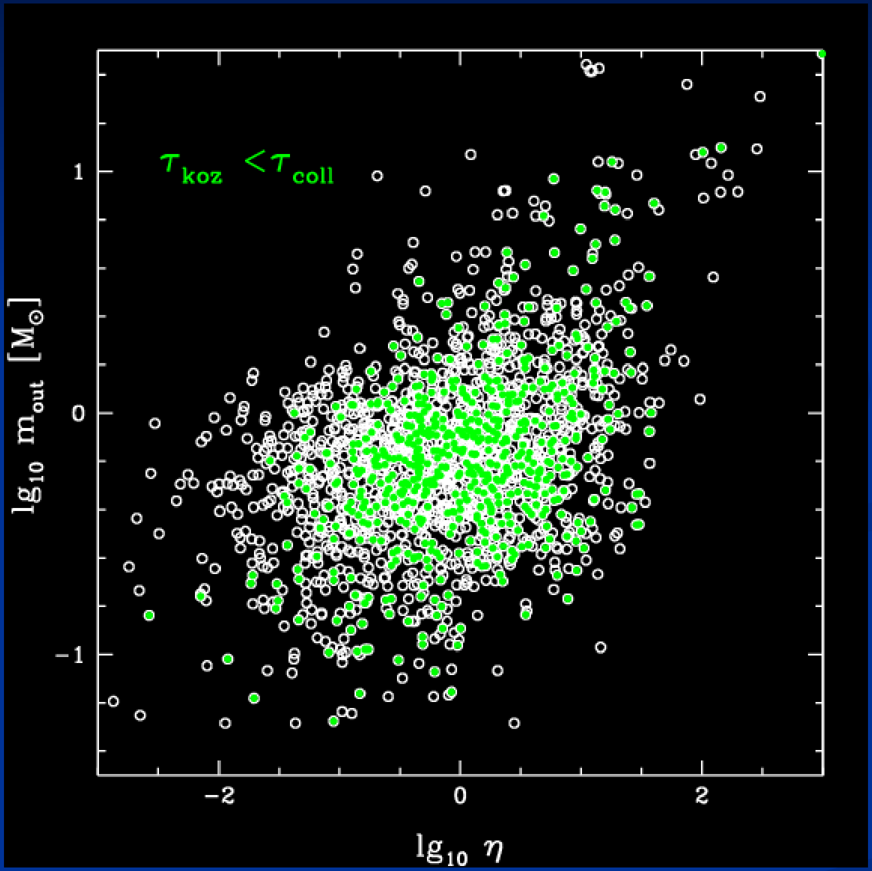
Kozai time-scale τ_{koz} as in Innanen et al. (1997) "Kozai triple" if $\tau_{koz} < \tau_{coll}$

KCTF – "Kozai Cycle with Tidal Friction"

Eggleton & Kiseleva (2006), Fabrycky & Tremain (2007)

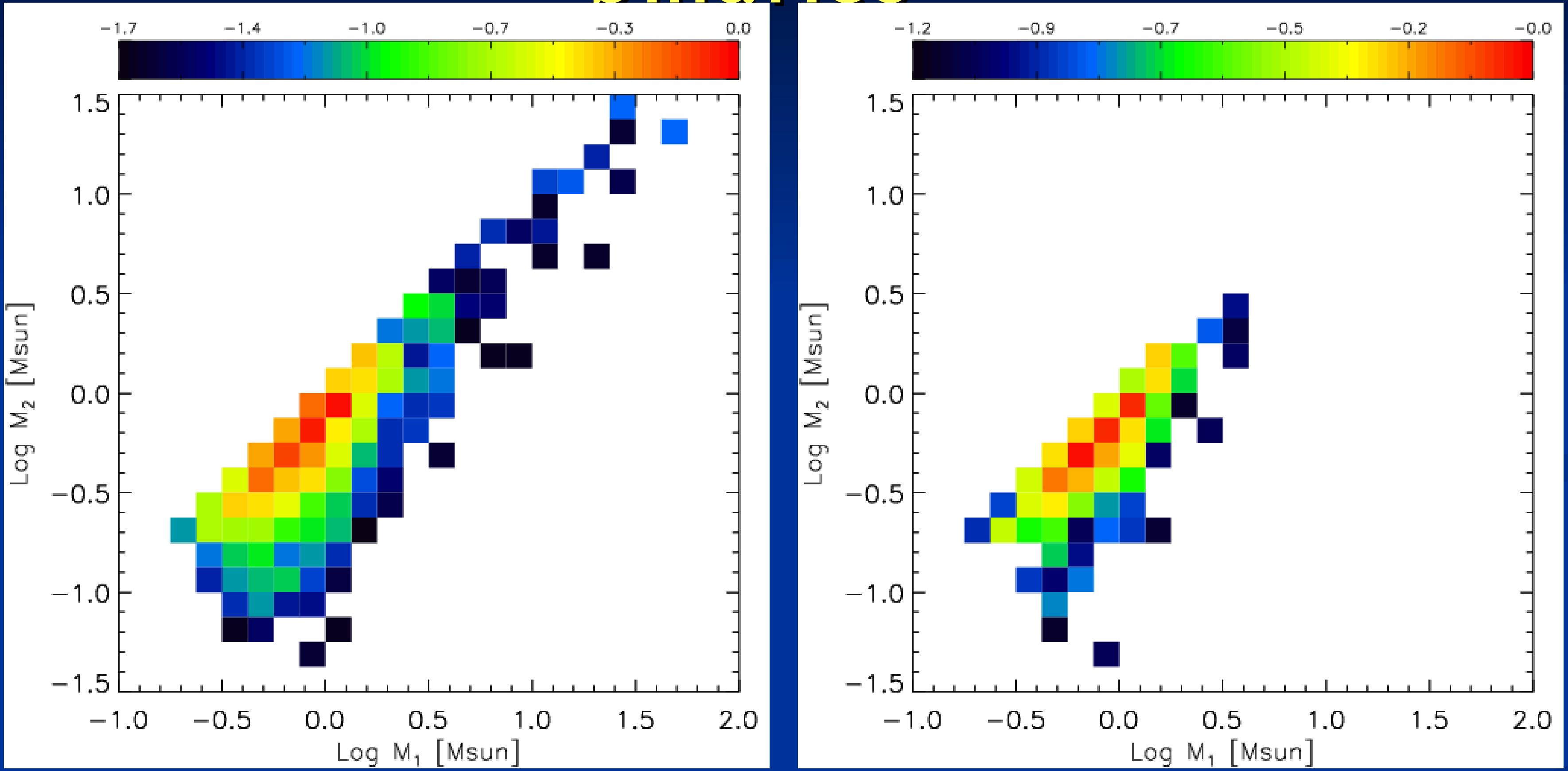
Triples: hardness and Kozai





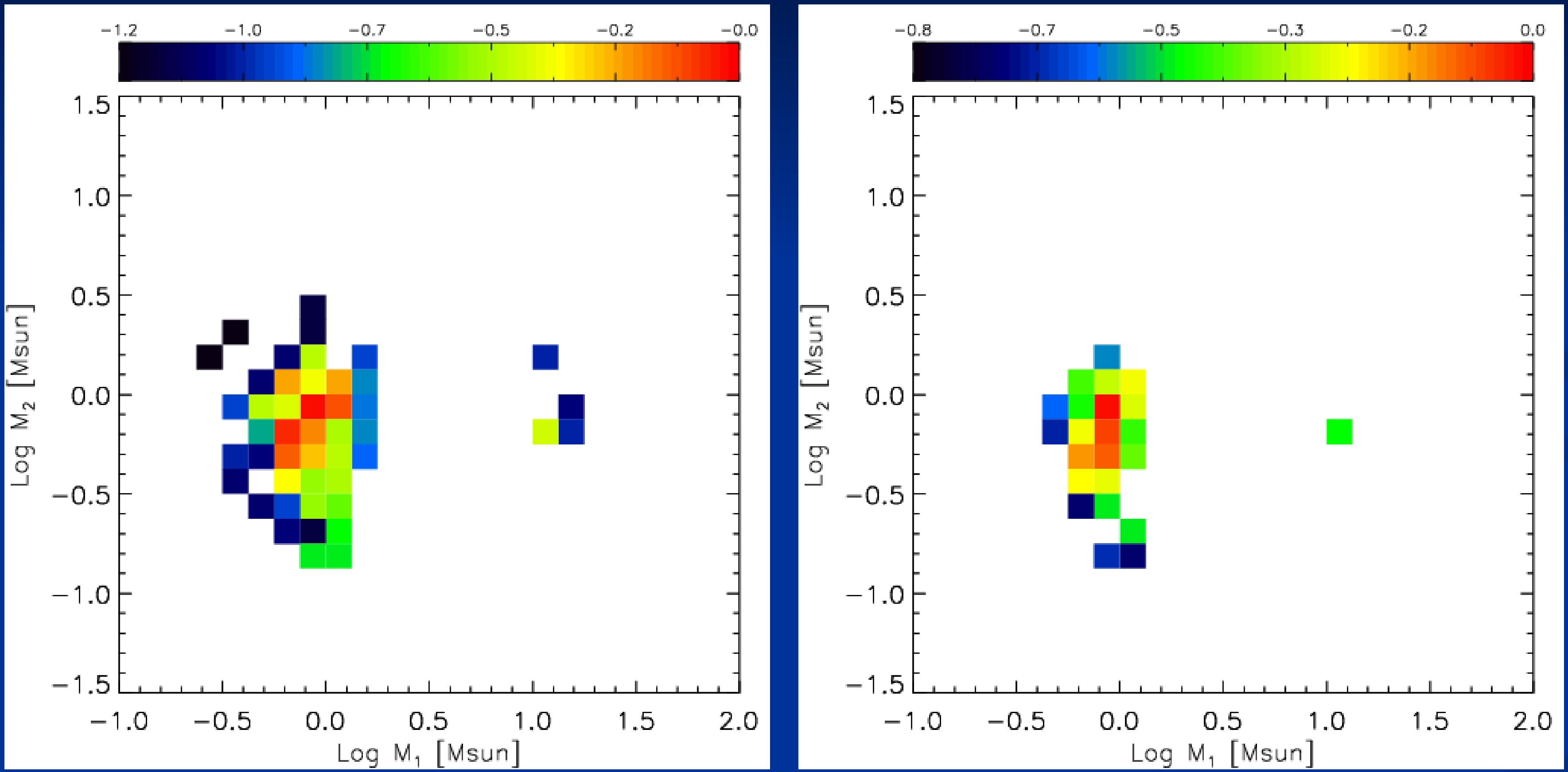
1/3 of all triples – Kozai systems

Triples: Kozai & MS-MS inner binaries



73% of all triples have MS–MS inner binary, 30% of them are Kozai binary. Overall can provide ~10% of all BSs.

Triples: Kozai & inner binaries with a compact companion



23% of all triples have inner binary with a CO (8% –two CO), 40% of them are Kozai binary. If Kozai binaries merge, the number of CVs (observed at 10Gyr) is reduced by 1/3.

Binaries vs triples (at 10 Gyr)

Core binaries

	MS	WD
MS	80%	13%
RG	0.7%	0.3%
WD	13%	7%
NS	0.3%	0.3%

Inner binaries in triples

	MS	WD
MS	60%	20%
RG	2%	1%
WD	20%	15%
NS	1%	0.7%

Outer star

MS	80%
RG	0.7%
WD	20%
NS	0%

Triples Zoo Summary

- Hierarchically stable triples are formed at the rate of about $1200/t_9^{1/3}$. ~ 10000 triples are formed throughout entire evolution in a cluster of 500 000 Msun.
- 1/2 are short lived soft triples, 1/4 are hard and stable with respect to further encounters and 1/4 are hard and will possibly undergo an exchange interaction if one occures
- 75% of them have MS-MS inner binary and in 25% of them the inner binary containing a compact object
- A "typical" triple: $M_3/(M_1+M_2)\approx 0.6$, $M_1+M_2\approx 1.2M_\odot$, $P_{in}\approx 1$ day, $P_{out}/P_{in}\approx 1000$, $a_{in}/a_{out}\approx 100$, $e_{out}\approx 0.8$, $\eta\approx 1$ kT
- An inner binary of a triple is more likely to contain a compact object than a core binary. Outer star follows the binaries population.
- 1/3 of all triples are affected by Kozai mechanism
- A typical BS – product of KCTF – is 1.1 $M_\odot$, could provide 10% of all BSs
- A typical WD-MS binary merged due to KCTF contains $0.8M_\odot$ WD and $0.8M_\odot$ MS. Number of CVs is reduced by 1/3

Triples: formation rate for NS triples

$\Delta N_{tr,ns}/N_{bin,ns} \approx 0.05$ per Gyr (47 Tuc–type)

$\Delta N_{tr,ns}/N_{bin,ns} \approx 0.15$ per Gyr (Ter 5–type)

~1/3 of the are Kozai triples

NGC 6623: 4U 1820-303

- Binary orbital period is ~685s (Stella, Priedhorsky & White 1987; Anderson et al. 1997).
- Secondary star is a He WD 0.06-0.08 M☉ (Rappaport 1987).
- Stability of the period of Pdot/P=(3.5+-1.5)10^{-8} yr^{-1} makes certain that 685s period is the orbital period (Chou & Grindlay 2001).
- Formation scenario of 4U 1820-303 is a direct collision of a neutron star and a giant (Verbunt 1987; Ivanova et al. 2005).

4U 1820-303 has the luminosity variation by a factor of ~2 at a superorbital period P~170d (Chou & Grindlay 2001).

- X-ray busts take place only at the flux minima ⇒ the observed variability is due to intrinsic luminosity/accretion rate changes and not obscuration or changes of the projected area of the source due to precession.
- Ratio between superorbital and orbital periods (~22000) is too high for any kind of the disk precession at the mass ration of the system (Larwood 1998; Wijers & Pringle 1999).

a hierarchical triple?

(Chou & Grindlay 2001)

- The third body mass < 0.5M☉, based on the lack of its optical detection.
- The third body orbital period P_{out}~1.1d .

In a hierarchical triple, a distant third body exerts tidal forces on the inner binary. As a result, there is a cyclic exchange of the angular momentum between inner binary and third body, causing variations in the eccentricity and inclination of the stars orbits (Kozai 1962; Ford, Kozinsky & Rasio 2000; Blaes, Lee & Socrates 2001).

NGC 6623: 4U 1820-303

Prodan & Murray 2008:

- perturbation from a third body on a longer period orbit
- the quadrupolar distortion of stars due to their intrinsic spins
- the further quadrupolar distortion due to their mutual gravity
- tidal friction in the equilibrium tide approximation
- General Relativity
- mass transfer
- gravitational radiation

Initial parameters are: M_1=1.29M⊙ (primary NS), M_2=0.07M⊙ (secondary WD), M_3=0.5M⊙,

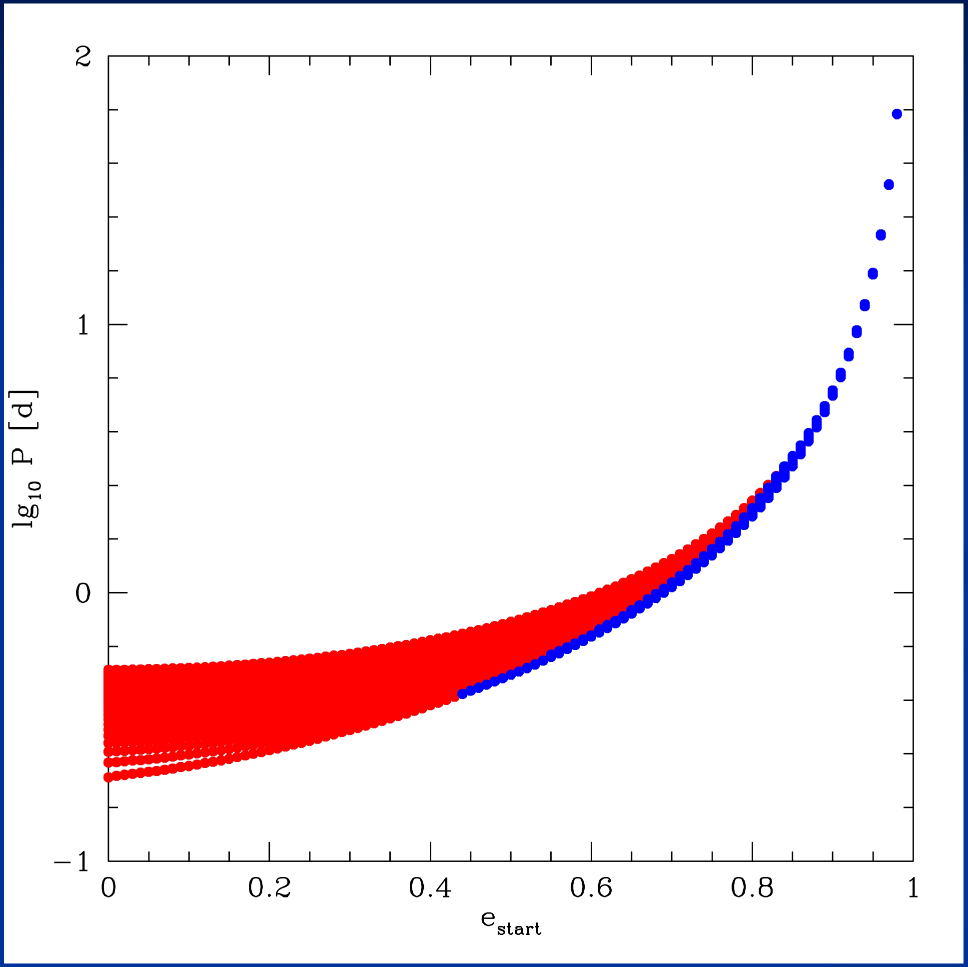
e_{in}=0.0001, e_{out}=0.0001, i=40°.044 (initial mutual inclination),

a_{out}=8.66a_{in} = 1.6 R⊙ (outer binary semi-major axis), P_{out}=4.1h

a companion is not a MS star

This model reproduces observed P_{super}=170d and e_{max}=0.004.

NGC 6623: 4U 1820-303

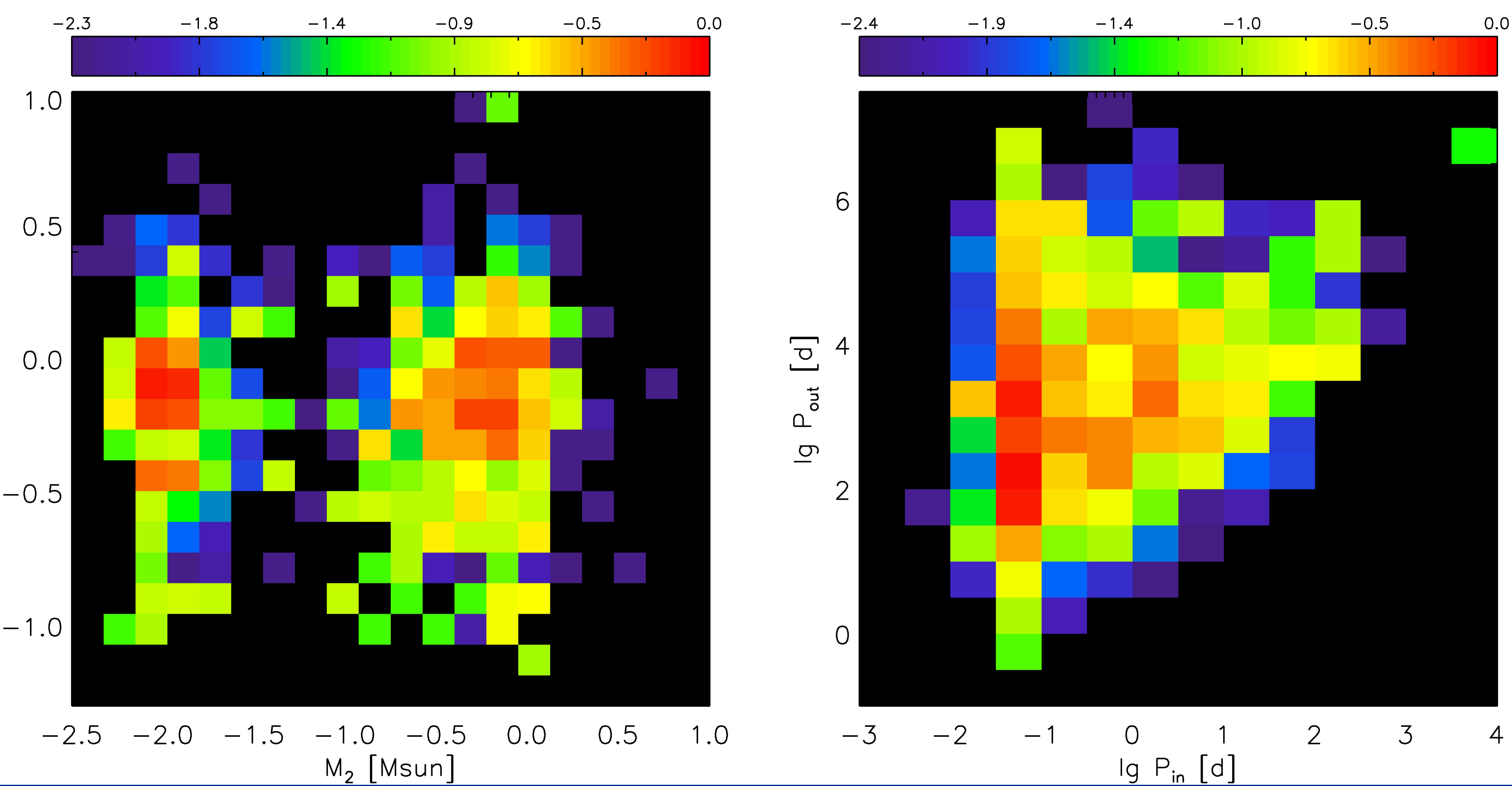


dynamical tides are mandatory to bring e_{out} down!

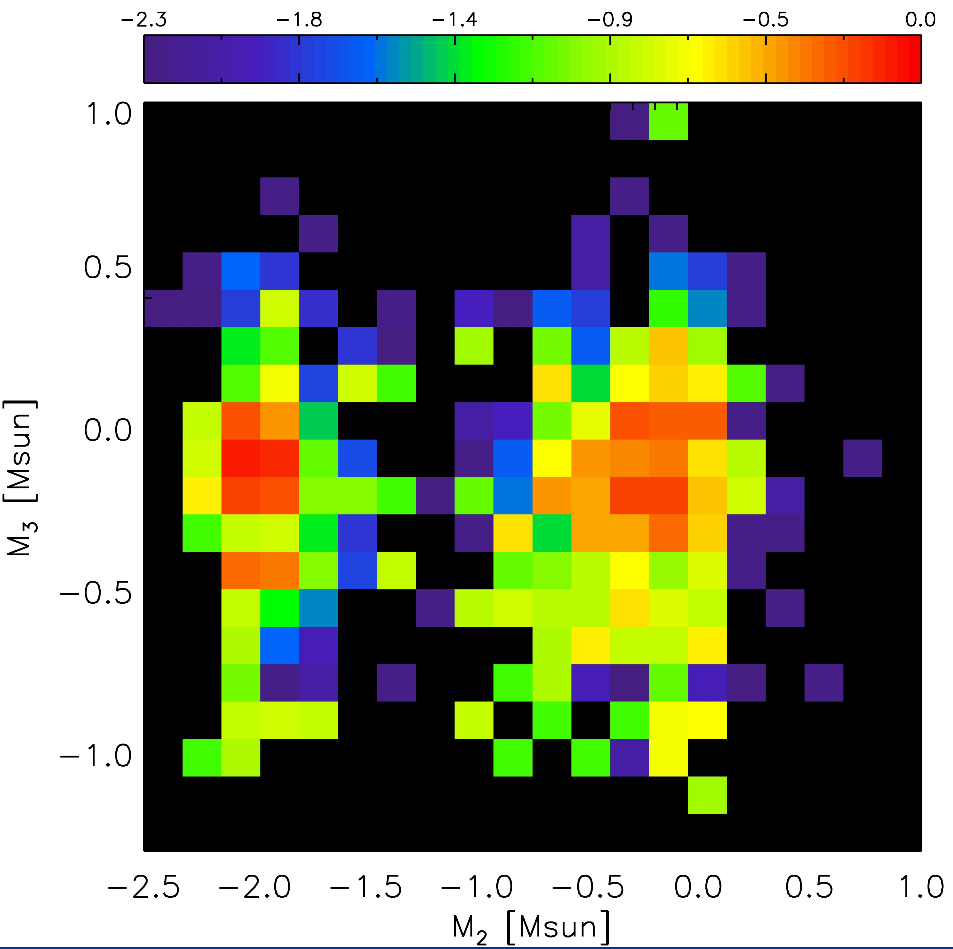
P_{out}<1.6 d

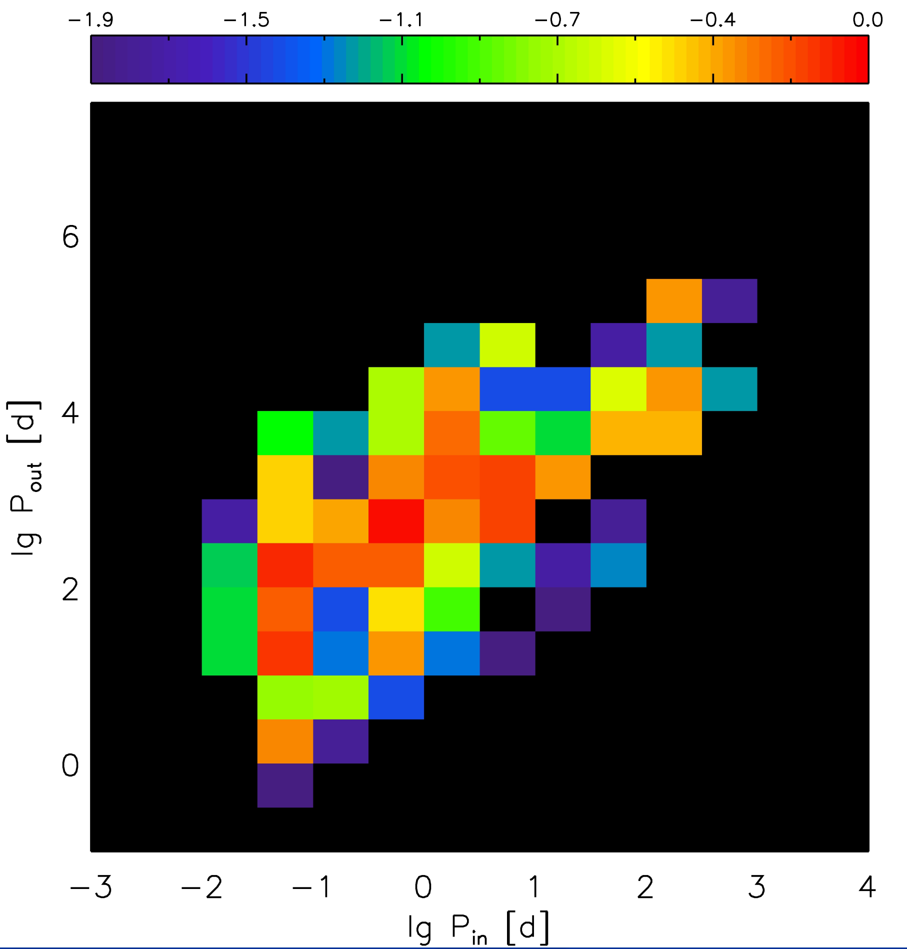
e_{out}<0.8

NS-Triples: properties



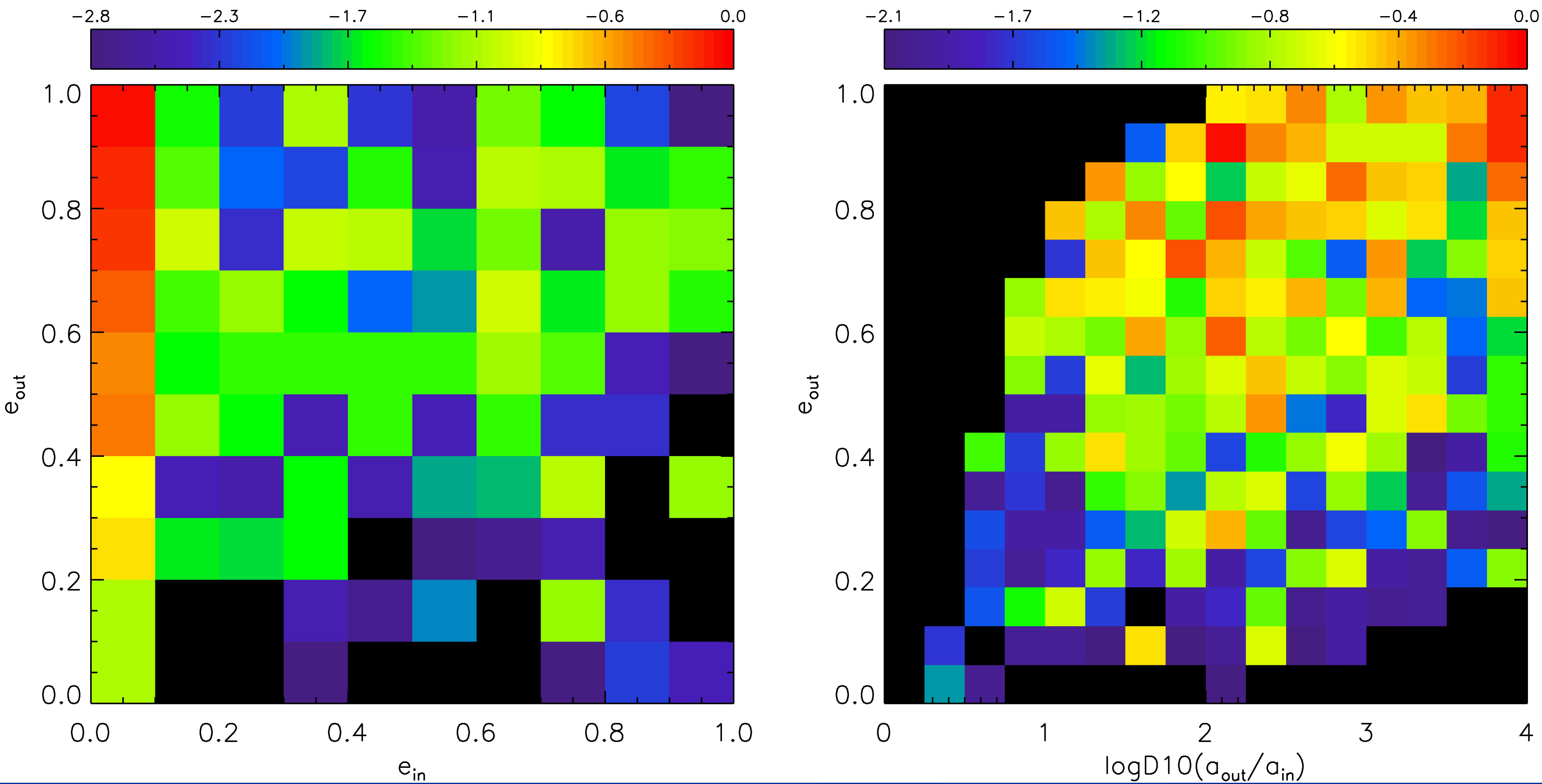
NS-Triples: properties





Kozai triples only

NS-Triples: properties



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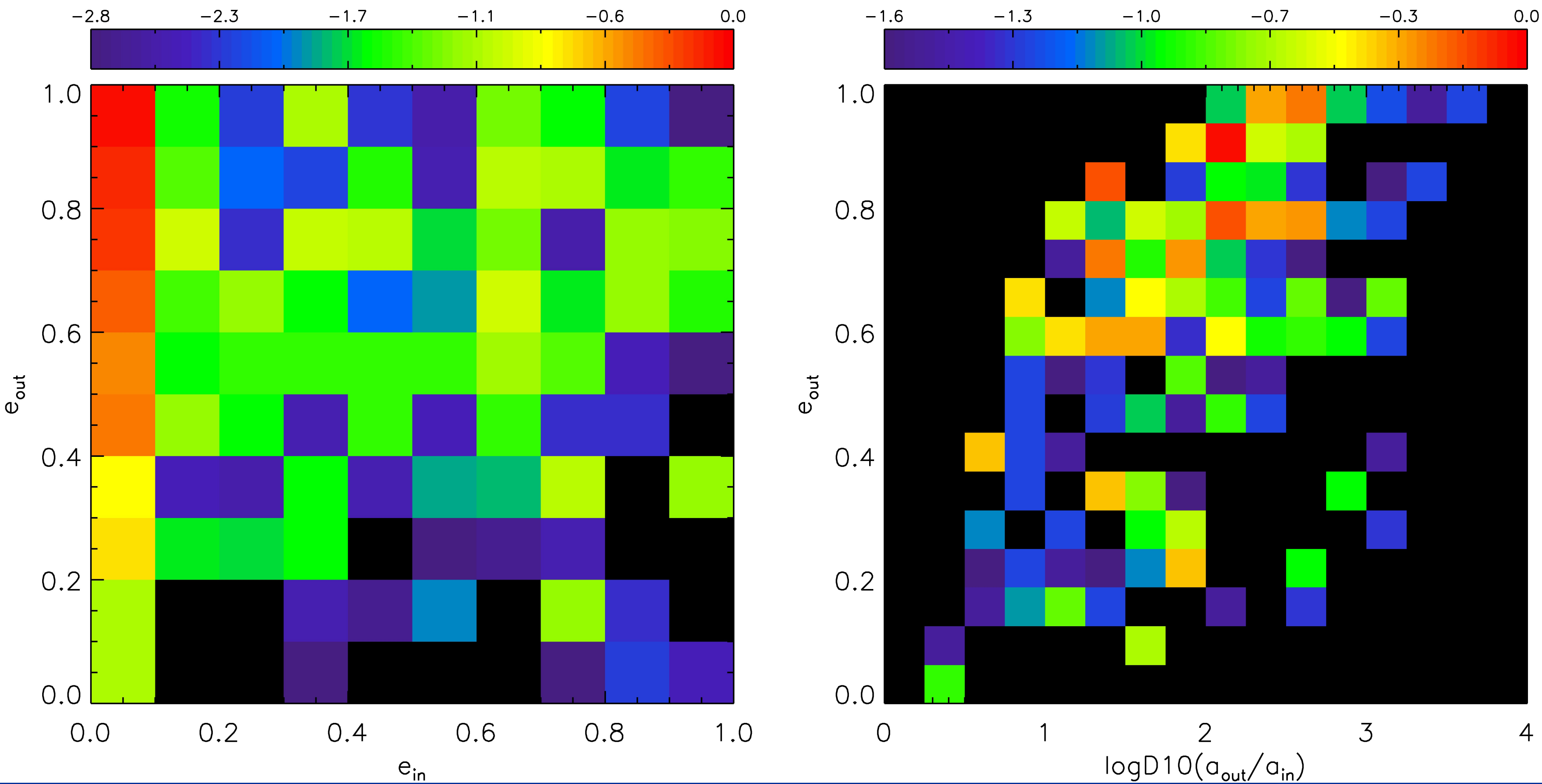

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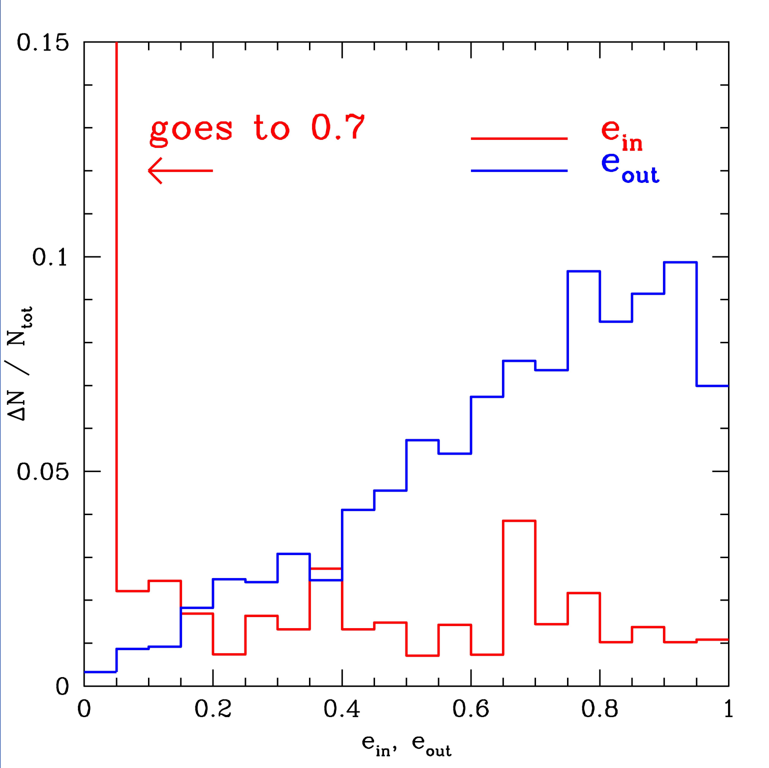

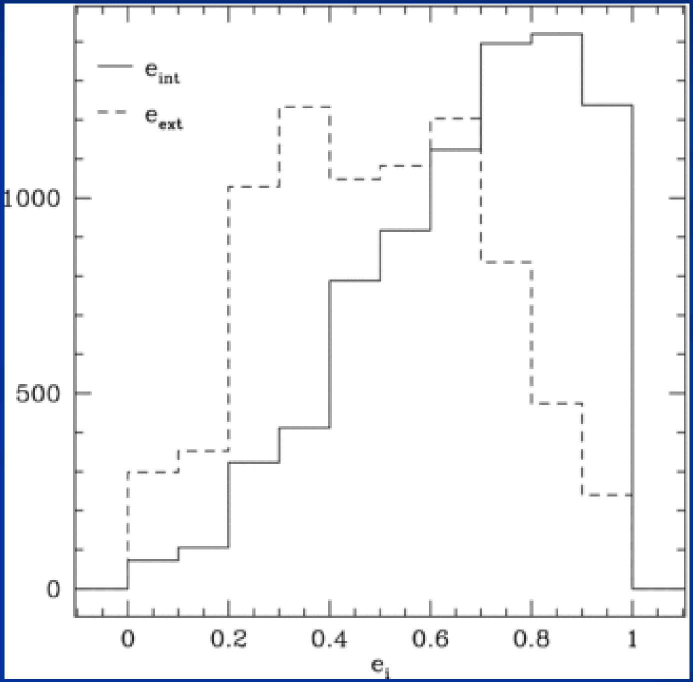

Trenti et al 2008

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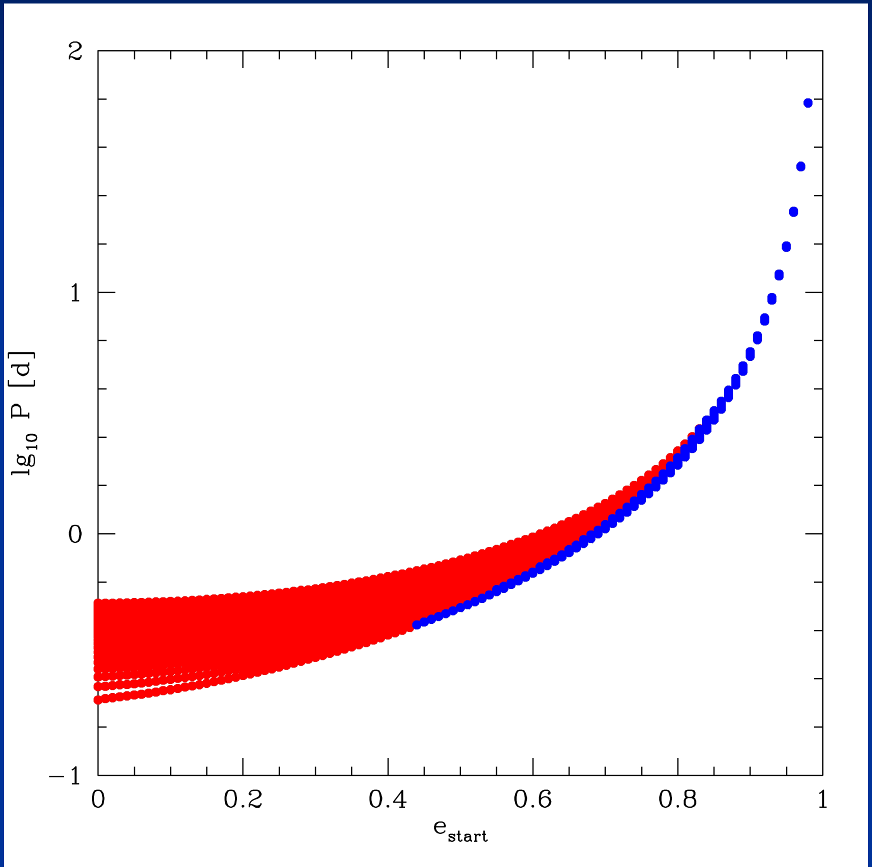

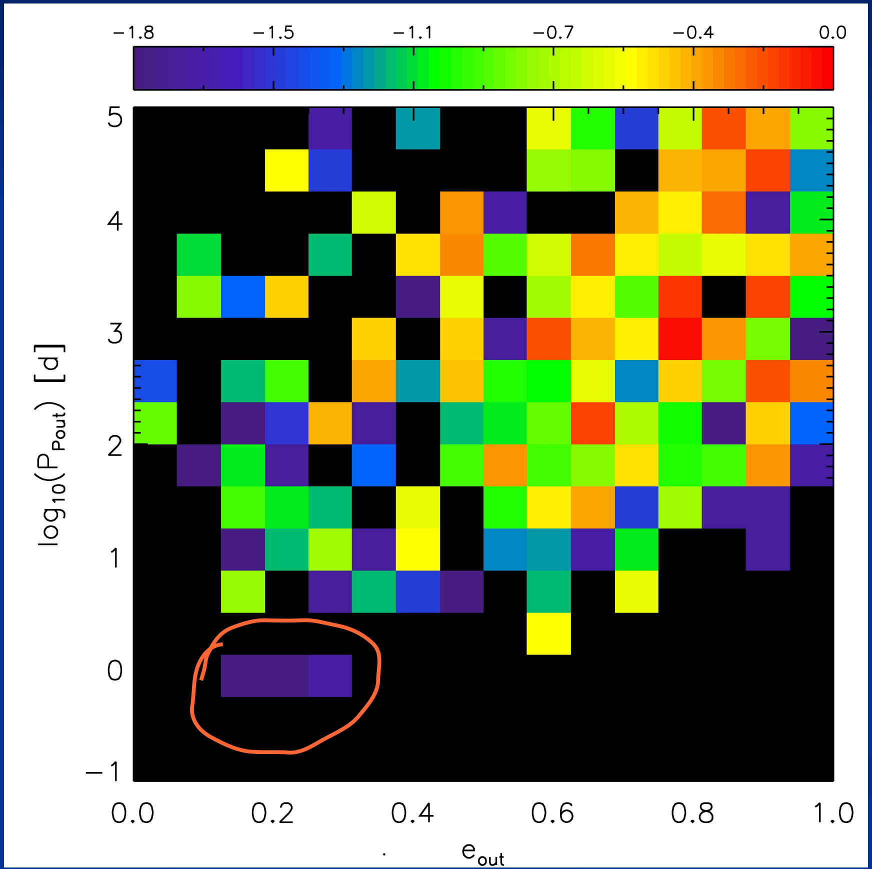

Summary

- Triple systems with a NS are expected to be formed
- Half of LMXBs were members of some hierarchically stable triples in the past
- the only observed likely triple LMXB 4U 1820-303 is one of the hardest to make theoretically. *Outer common envelope?...*