Detailed equilibrium and dynamical tides

Impact on circularization and synchronization in open clusters

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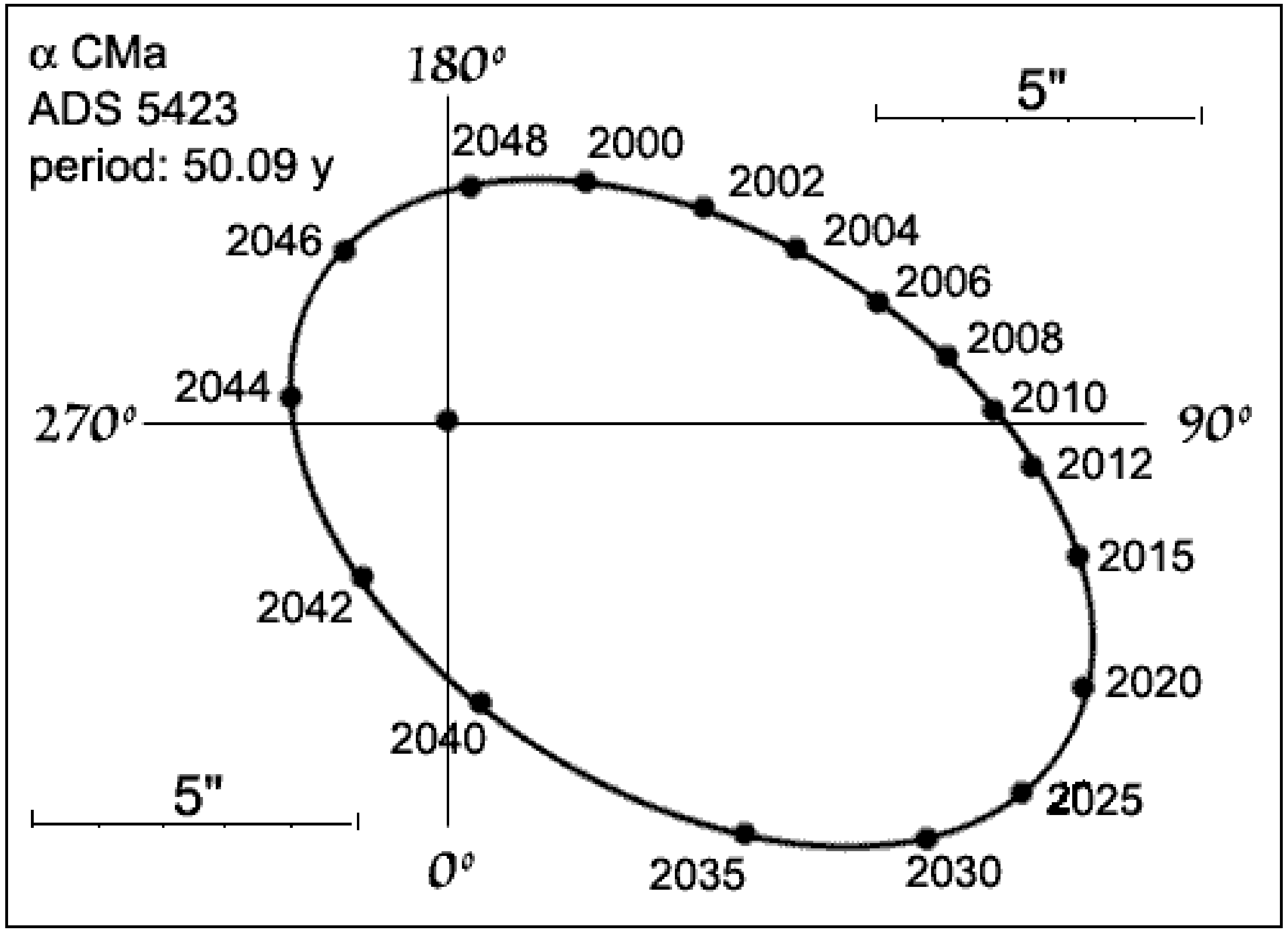
Atelier codes stellaires – June 24th, 2022

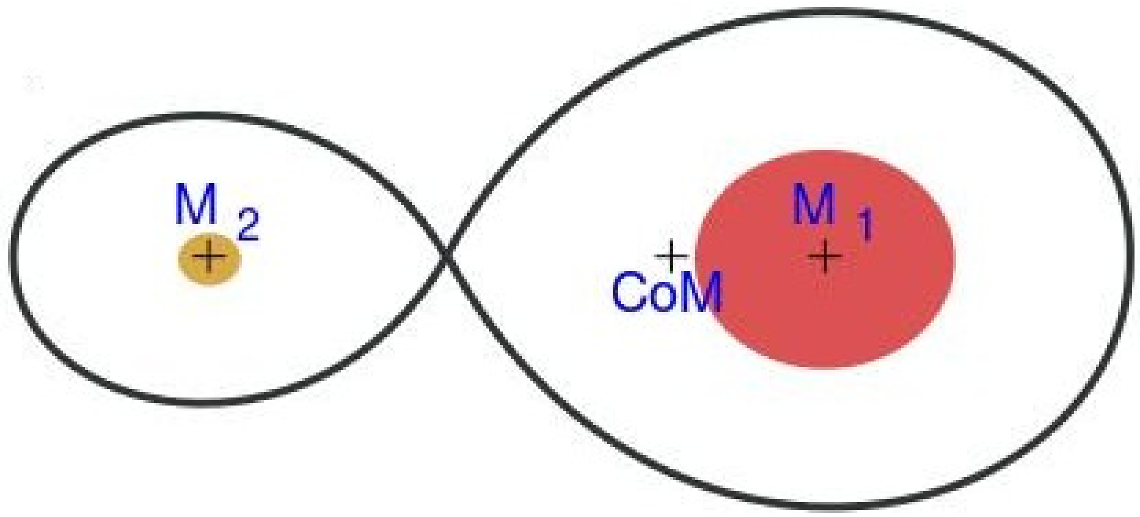
Binary-star evolution : interactions

For binary systems you need
- → a model of star 1
- → a model of star 2
- → orbit and

interactions between stars

Credit Sam Wormley





Close detached binaries :
- → **tides** dissipating energy
- → orbit **circularization**
- → spin **synchronization**

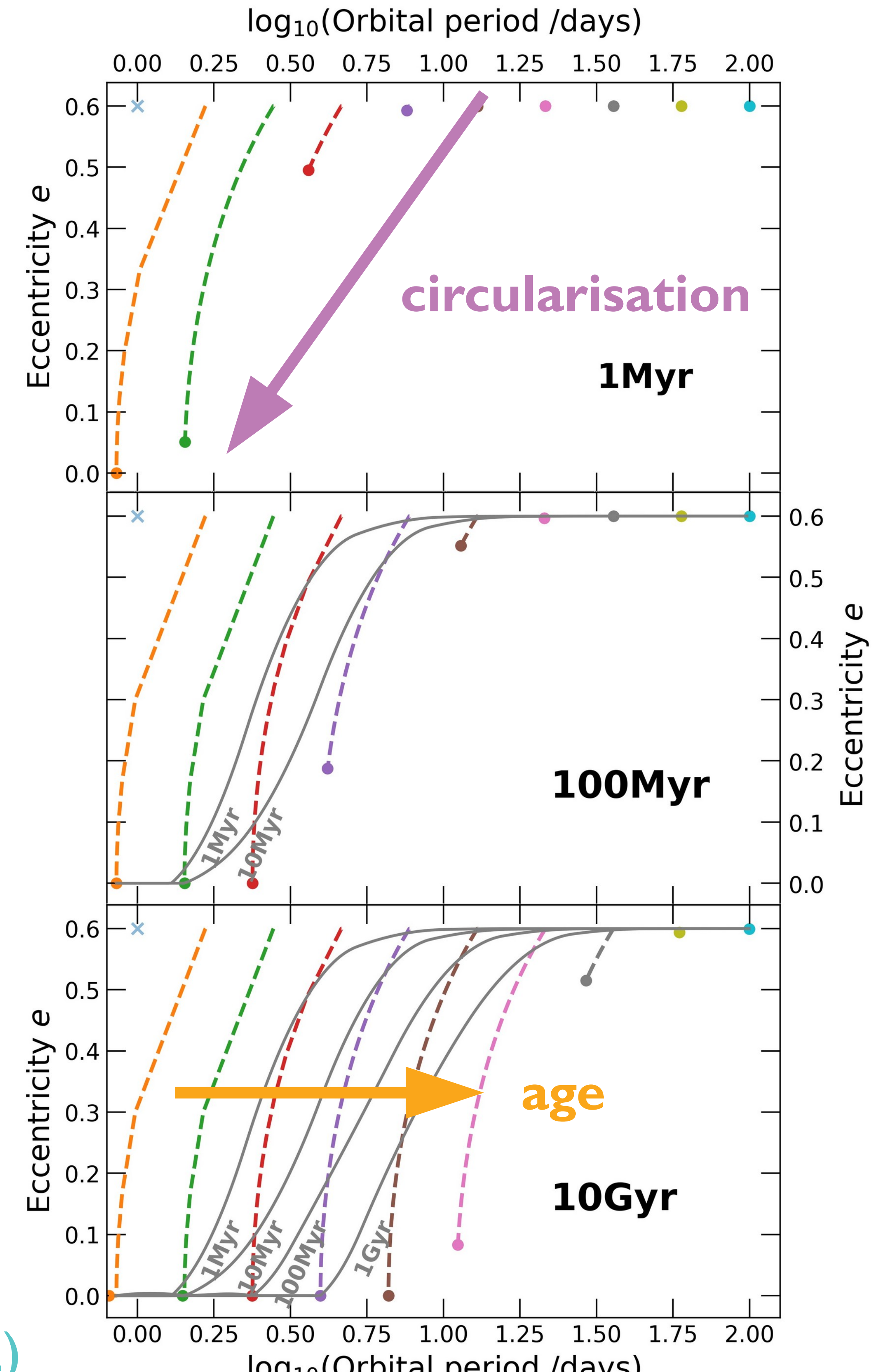
Izzard et al. (2012)

Tidal circularization in clusters

Tides circularize orbits :
in a population of
originally-eccentric systems

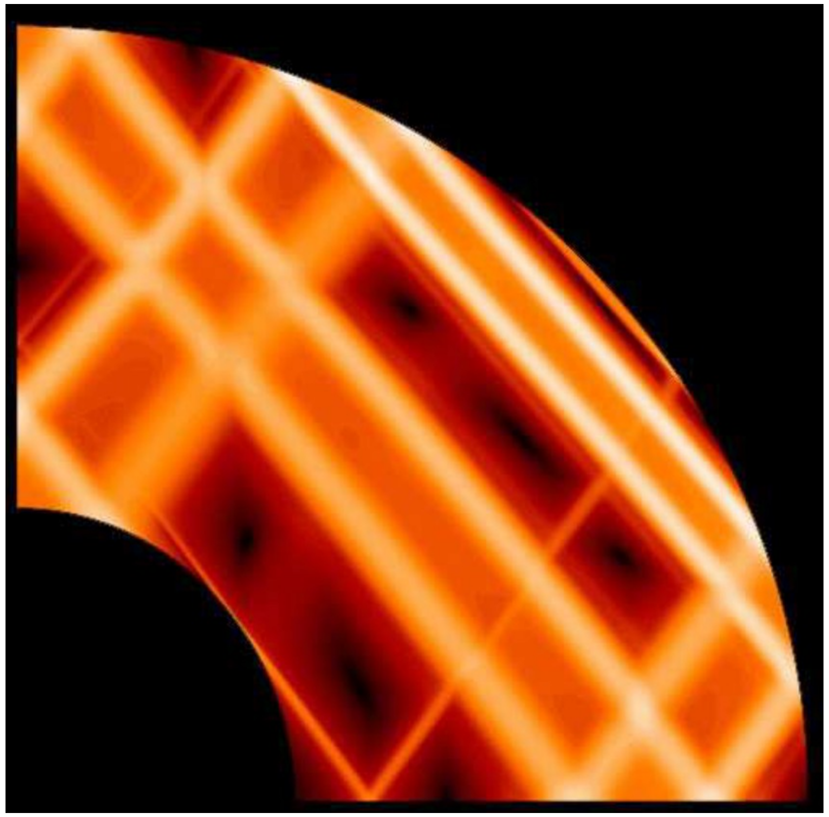
close systems become circular
→ **cutoff period**

cutoff period increases with age
→ provides an **age estimate**
for the cluster



Witte & Savonije (2002)

The two kinds of tides



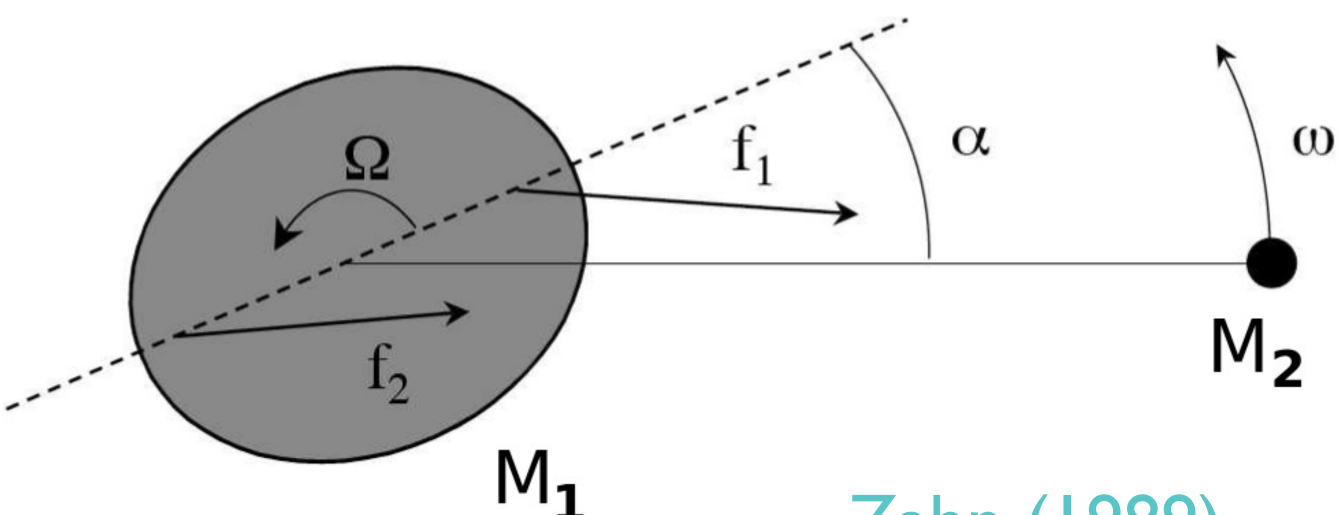
Rieutord & Valdettaro (2010)

The dynamical tide

modes at core/envelope boundaries
→ shear layer in envelope
→ **dissipation**

Zahn (1977)

In stars with **convective core + radiative envelope**



Zahn (1989)

The equilibrium tide

Pull from companion
→ large-scale flows
→ **dissipation** through friction

In stars with a **convective surface**

Modelling cluster populations

Stellar population synthesis requires **many** stellar models, about **1 million stellar systems**

We need

→ adequate **initial conditions** for stars and orbits

→ a **rapid** evolution algorithm

→ a prescription for **tides**

We compute stellar populations using the binary_c code (**open source**) to model open clusters

https://gitlab.surrey.ac.uk/ri0005/binary_c/

Populations : initial distributions

We use two sets of initial distributions :

→ Kroupa (2001) IMF

+ Gaussian eccentricities and periods Duquennoy & Mayor (1991)

→ **DM91**

or

→ Kroupa (2001) IMF

+ empirical distributions from bias-corrected obs for eccentricities and periods Moe & di Stefano (2017)

→ **MS17**

Populations : rapid algorithm

Binary_c can rely on one of two algorithms

BSE *Binary-star evolution* Hurley et al. (2000, 2002)

→ fitting formulae derived from "old" models

→ widespread and simple

→ outdated and based on imposed physics

MINT *Multi-object INTerpolation* Mirouh et al., in prep.

→ based on grids of MESA models Paxton et al. (2019)

→ still under development

→ modular, bespoke physics

Populations : rapid algorithm

MINT introduces various improvements wrt **BSE**

→ more physical clocks for stellar evolution

→ **updated tides**

→ wider parameter range

Main sequence extended

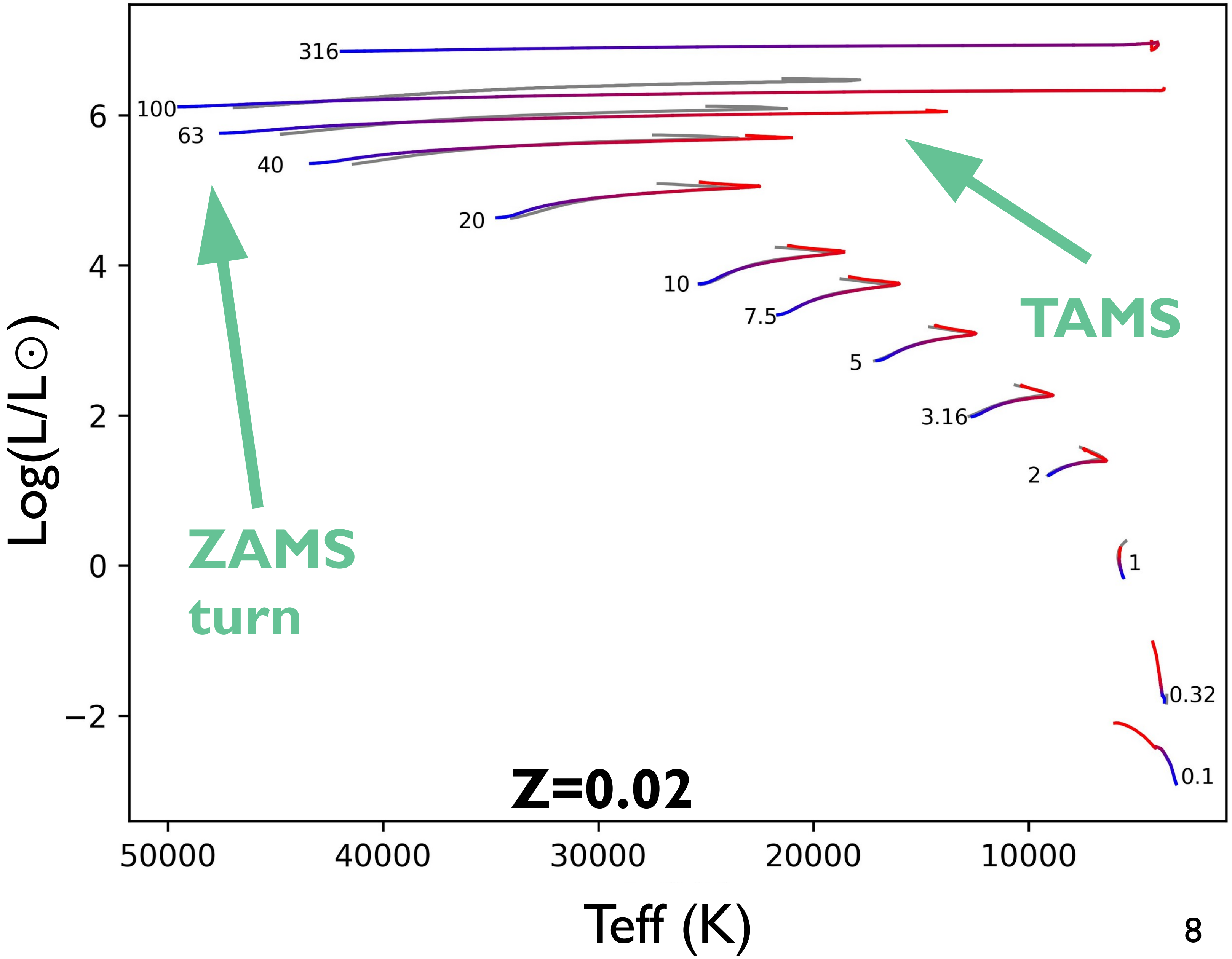
$0.5 \leq M \leq 80\ M_\odot$

$10^{-4} \leq Z \leq 0.03$

↓

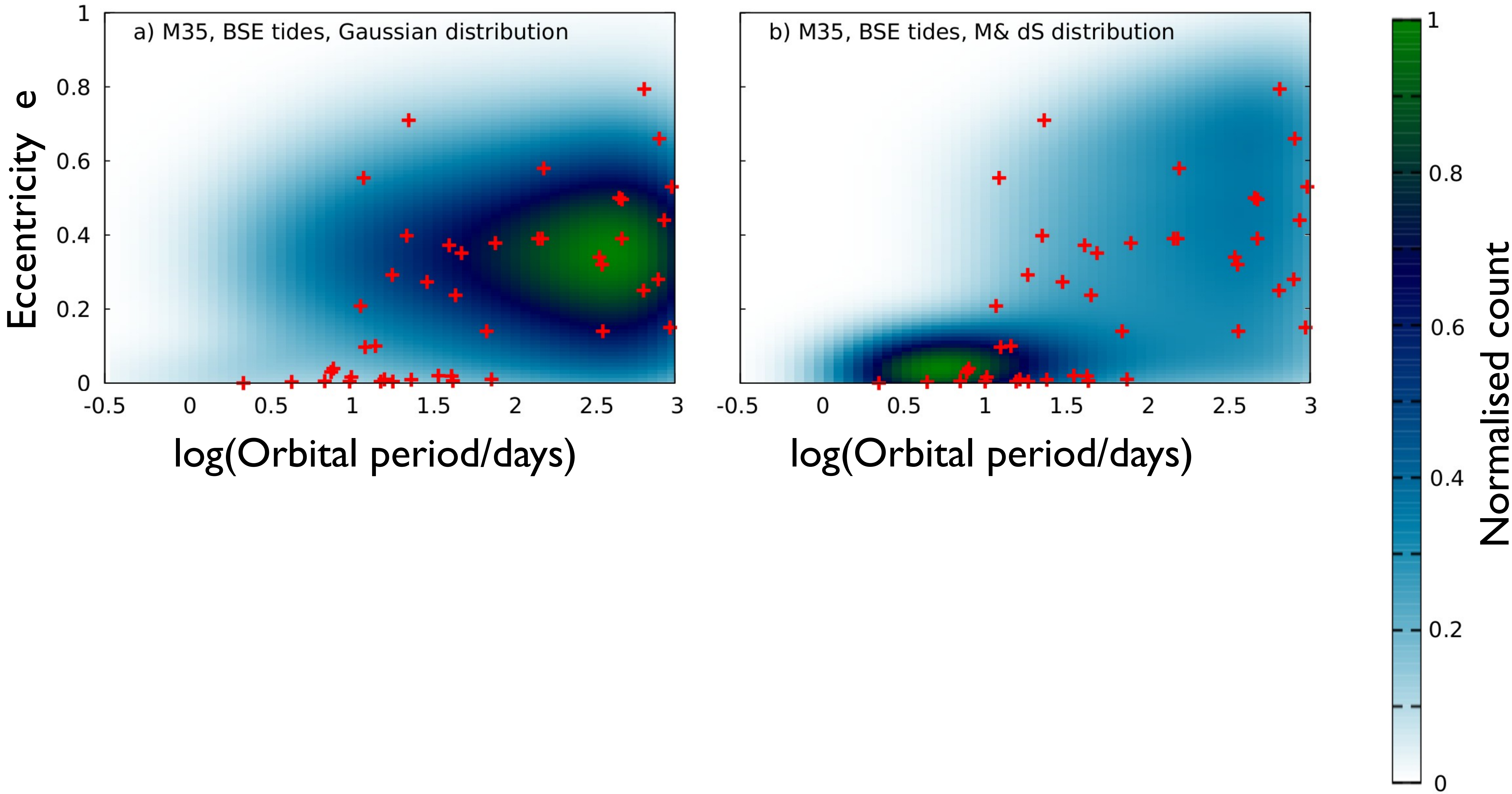
$0.3 \leq M \leq 1000\ M_\odot$

$0 \leq Z \leq 0.04$



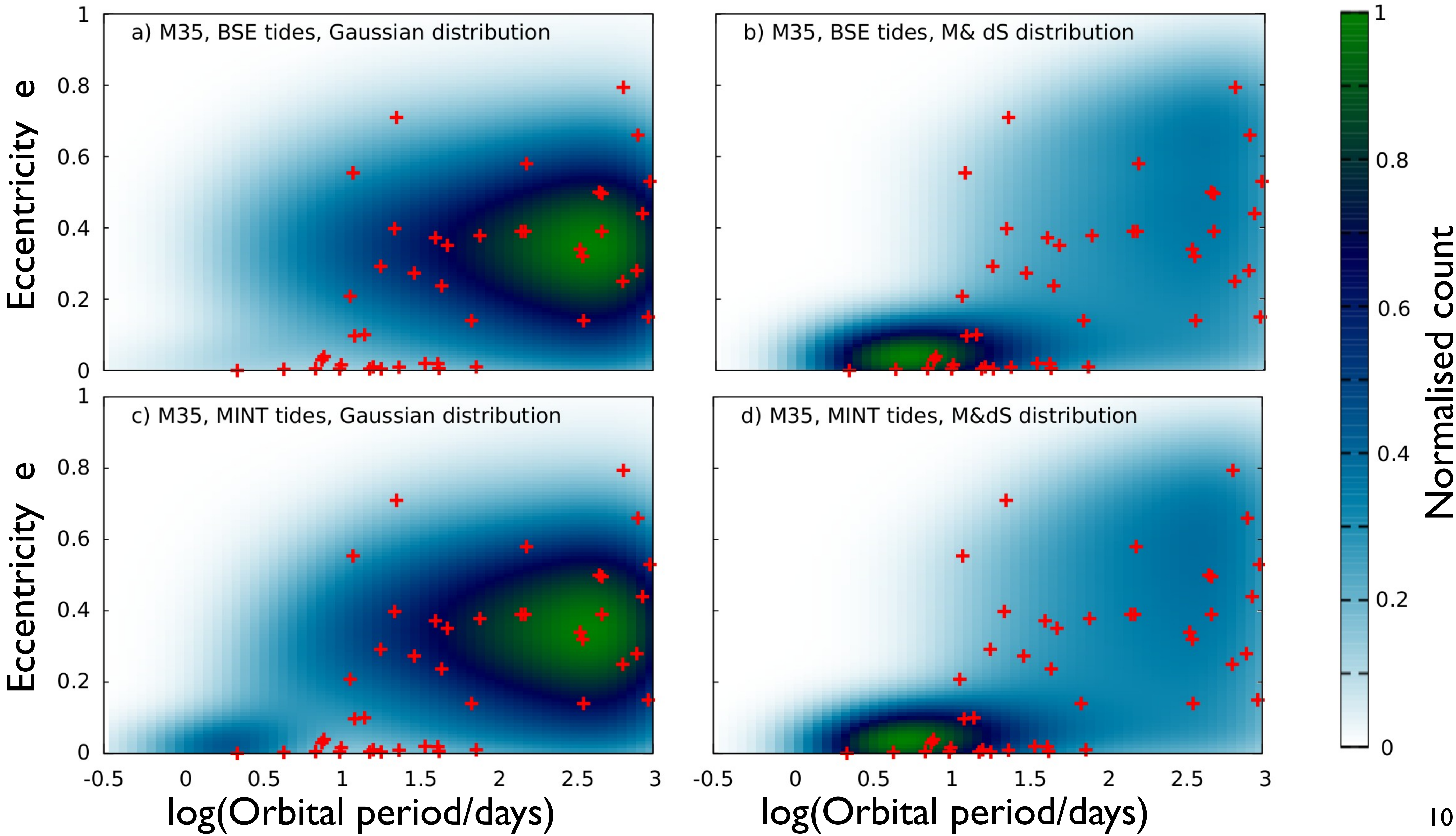
Solar-like star cluster : M35

Initial distributions → Gaussians (DM91) vs. empirical (MS17)



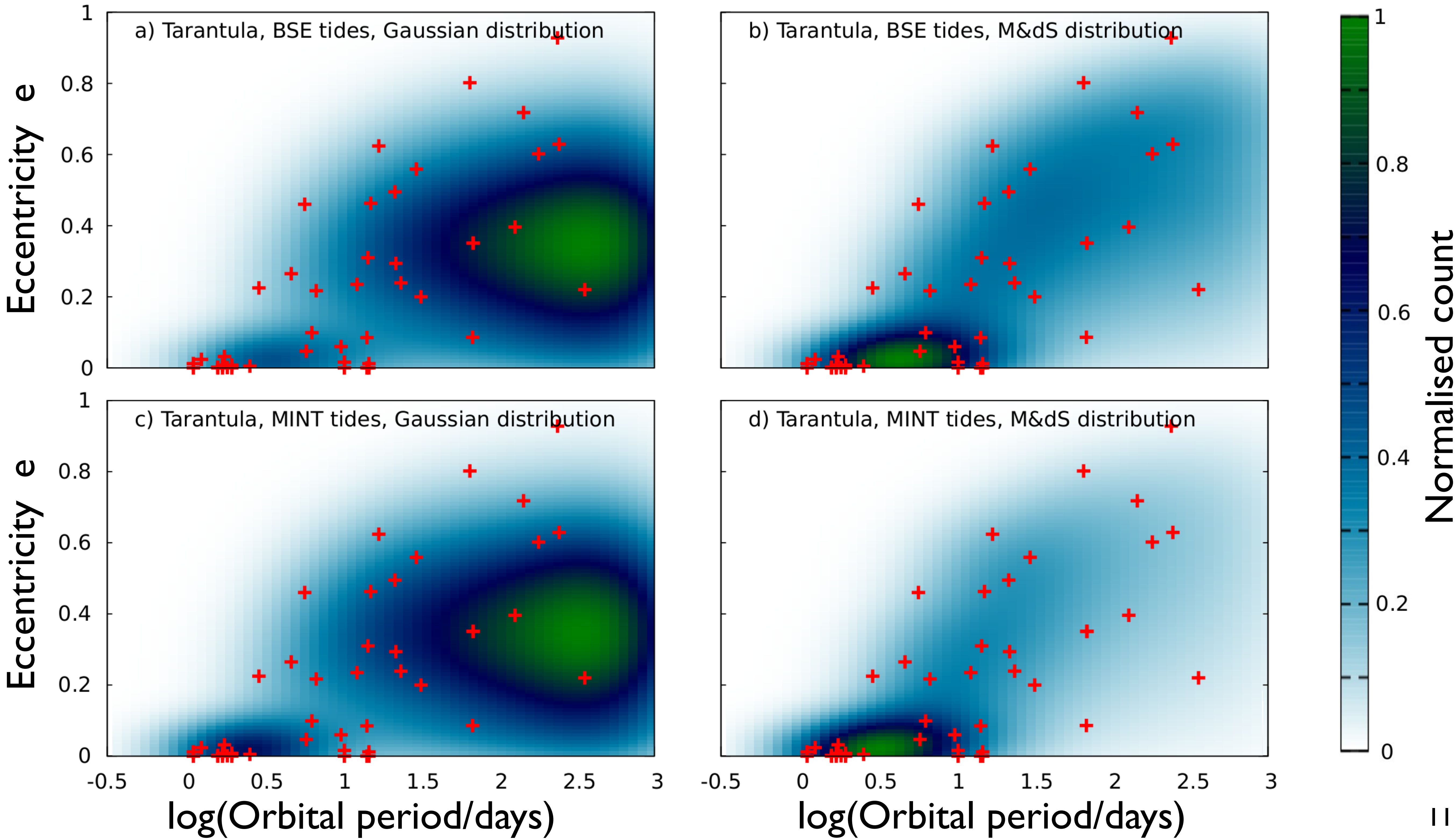
Solar-like star cluster : M35

Equilibrium tides → MINT vs. BSE



O-star cluster : Tarantula

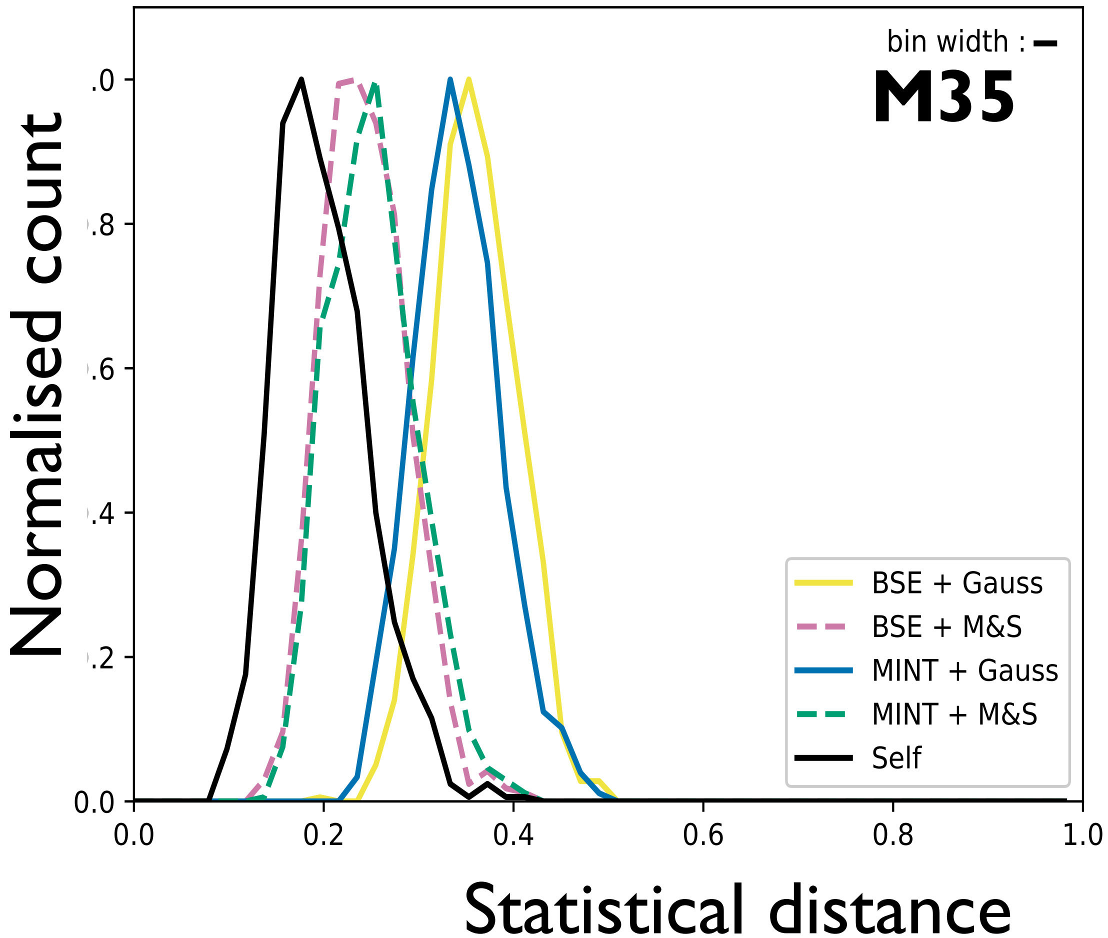
Dynamical tides → MINT vs. BSE
Initial distributions → DM91 vs. MS17

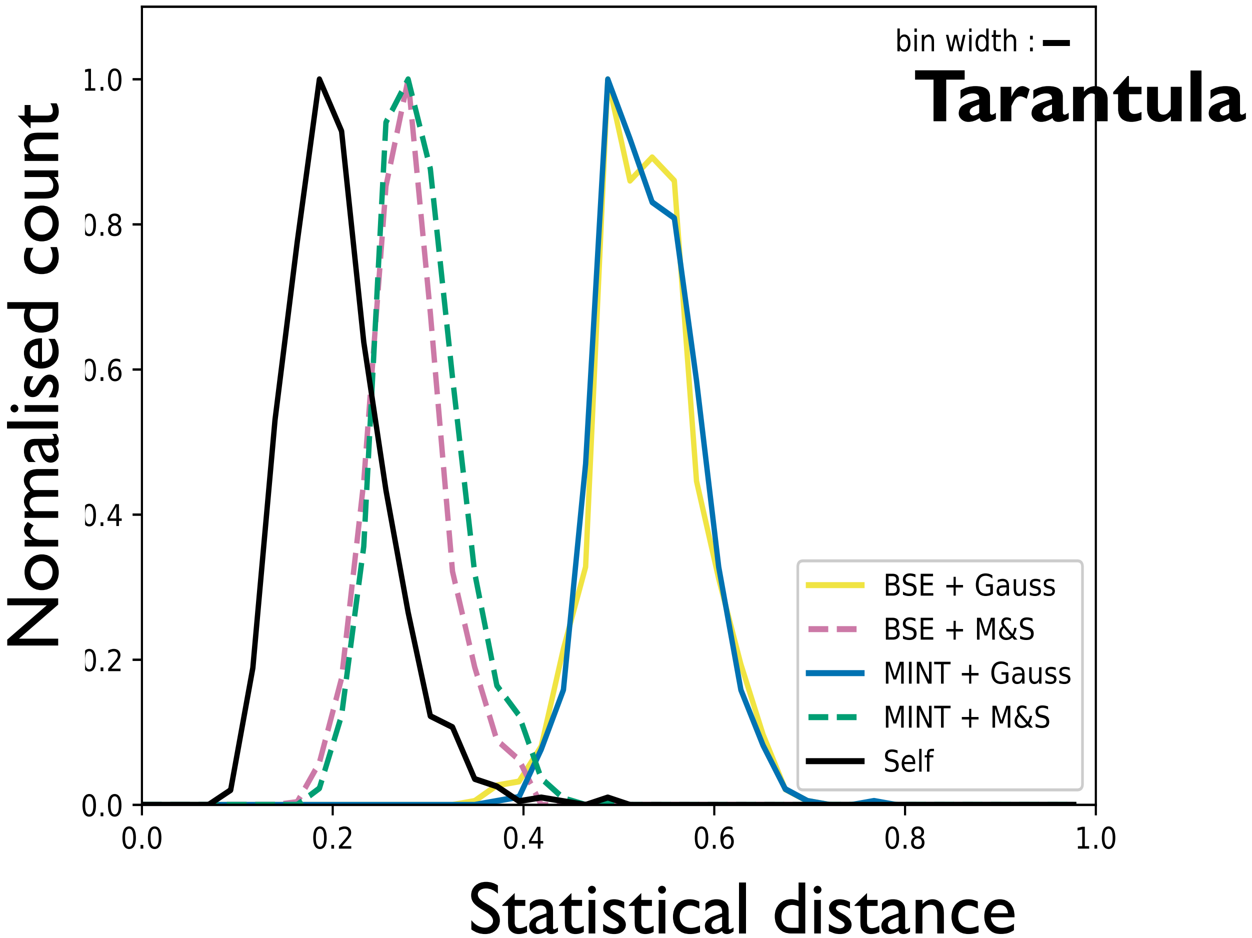


Statistical agreement obs-model

Test for statistical match:

1) bootstrap two samples from model population
2) measure distance to each other and with obs through a 2D KS test
3) repeat 1000 times, compute mean and standard deviation





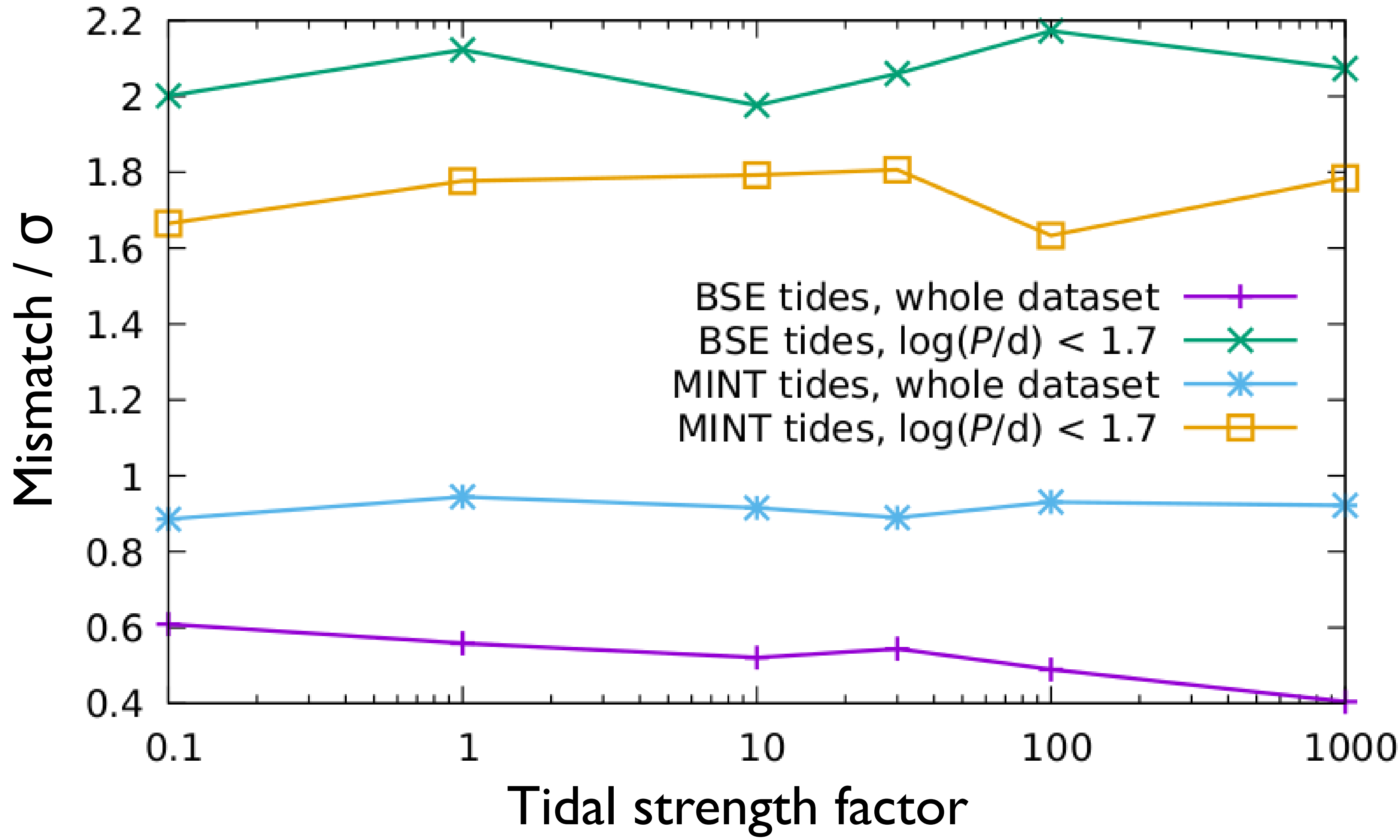
No difference between **MINT** and **BSE** tides with MS17 ?

Modulating tides

Initial distributions dominate the agreement

even when considering circularizing systems only

and even when modulating tides by a factor 0-1000 !



→ Circularisation and the study of e-logP distributions **cannot offer constraints on tidal efficiency**

Tidal synchronization in clusters

Tides synchronize stellar spins with the orbital period

Starting from various **initial rotation prescriptions**

→ we test DM91 v. MS17 parameters

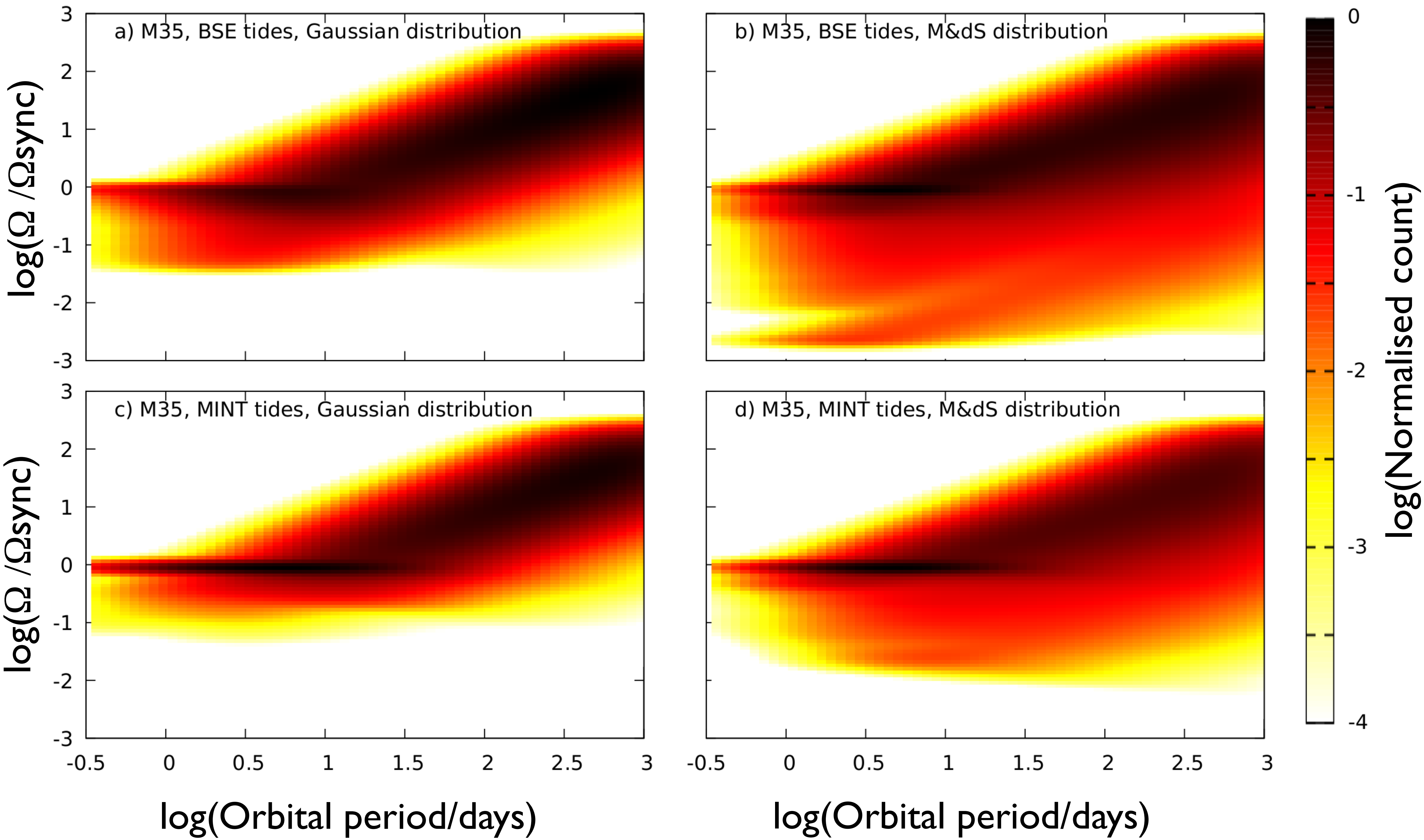
→ we test **BSE** v. **MINT** tides

Observational constraints are rare :

→ require **simultaneous measurements** of spins, orbits and stellar parameters

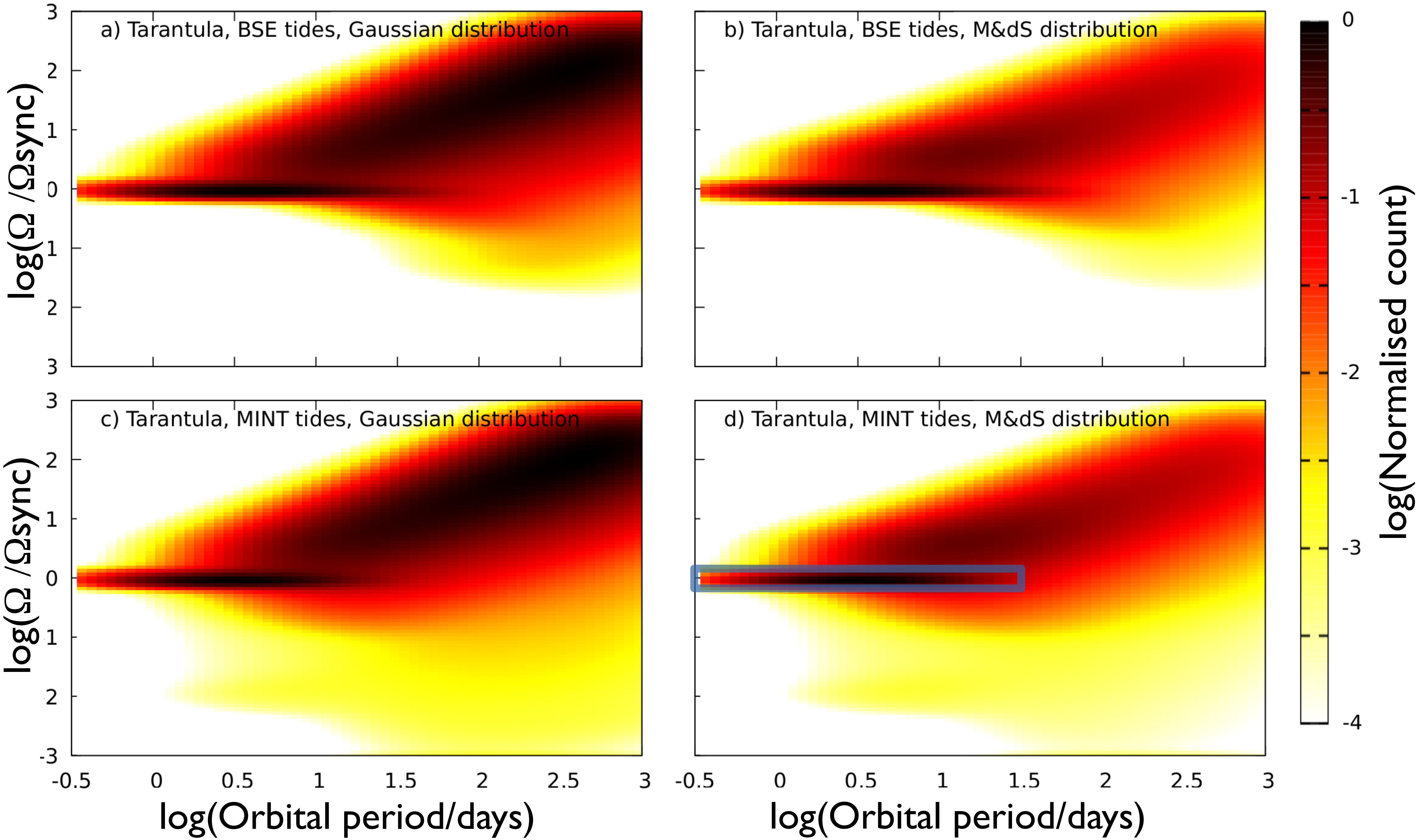
→ this is a proof-of-concept

Solar-like star cluster : M35



More efficient synchronisation with **MINT** equilibrium tides

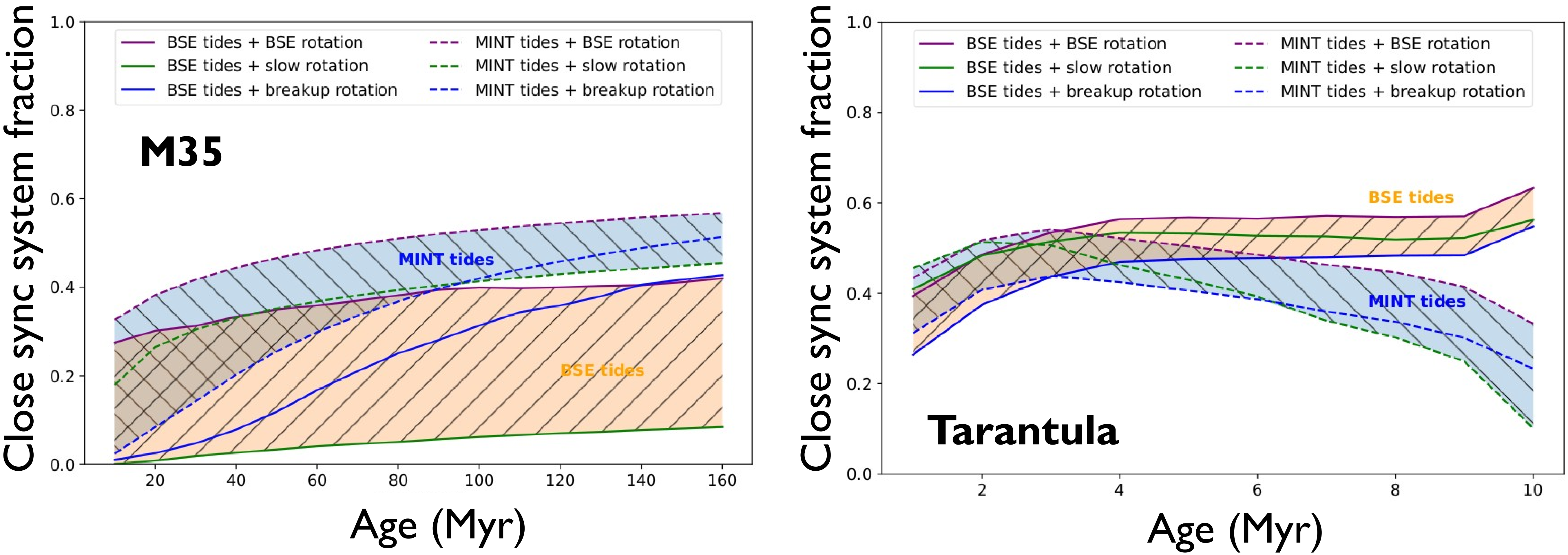
O-star cluster : Tarantula



Less efficient synchronisation with **MINT** dynamical tides

Rotation rate as an age indicator

We monitor the fraction of close systems $\log(P/d) < 1.5$
at synchronicity $|\log(\Omega/\Omega_{sync})| < 0.2$



The expected behaviour for tides is significantly recovered
→ synchronicity = measurable signature of tide efficiency

Conclusions

Impact of tides on **circularization and synchronization** in 7 open clusters

1) MS tides are inefficient on circularization

→ **circularization happens on pre-MS or post-MS**

2) signature of MS tides can be found on stellar spins

→ **synchronization can provide age estimates**

All these results → to appear in MNRAS, Mirouh et al. 2022

Applications galore

→ e.g. Pop III stars Gessey-Jones et al. subm., Sartorio et al. in prep.

→ your idea goes here