Investigating stability of triple and quadruple stellar systems

Diganta Bandopadhyay

University of Birmingham

Supervisor: Silvia Toonen

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Motivation

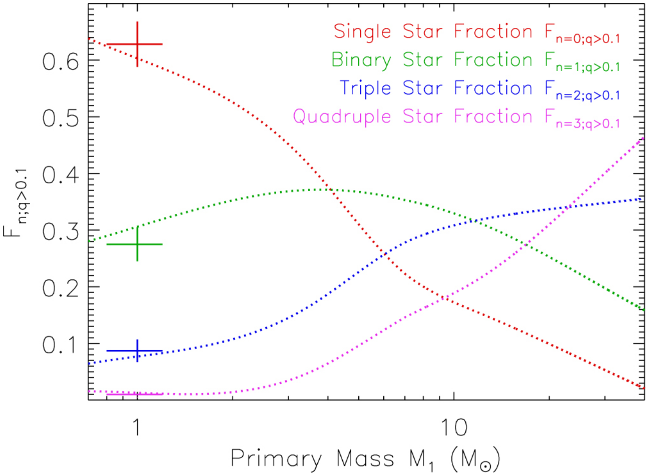

Figure 1: Multiplicity fraction as a function of primary mass (Moe and Di Stefano [2016])

Introduction

- Initial orbits for long term evolution of triples.
- Effects of picking orbital elements from different models.
- Observational evidence shows massive stars have more companions and are found in more compact orbits.
- Biases within stable distributions of orbital elements.

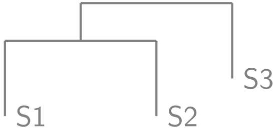

Figure 2: Triple hierarchical System

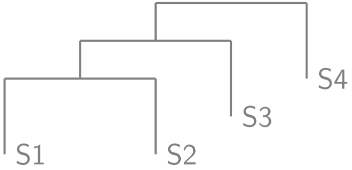

Figure 3: Quadruple hierarchical System

Parent distributions

- Orbital separation:
  - T14 model: Log normal distribution in orbital period with parameters $\mu = 5, \sigma = 2.3$ (days).
  - OBin model: Uniform distribution in log of orbital separation in the range $[5, 5 \times 10^6] R_\odot$.
- Mass ratios ($\frac{M3}{M1+M2}$):
  - Uniform.
  - $\frac{1}{q}$.
- Thermal eccentricity distribution ($f(e) = 2e$).
- Uniform cosine distribution in inclination.

Parent distributions

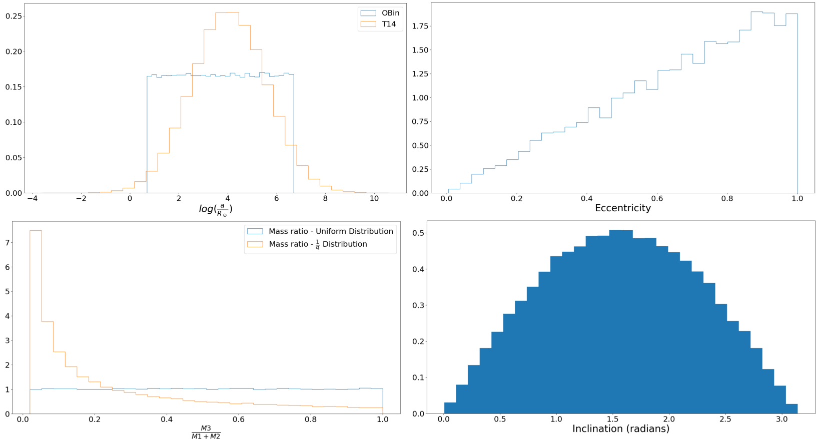

Figure 4: Orbital parameter parent distributions

Stability testing

$$\left.\frac{a_{out}}{a_{in}}\right|_{crit} = \frac{2.8}{1-e_{out}}\left(1-\frac{0.3i}{\pi}\right)\left(\frac{(1+q_{out})(1+e_{out})}{\sqrt{1-e_{out}}}\right)^{\frac{2}{5}} \tag{1}$$

Mardling and Aarseth [2001]

Orbital separation & Eccentricity

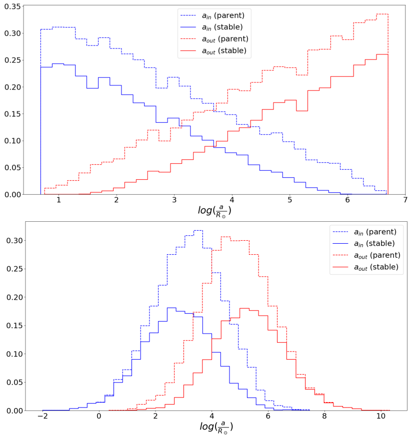

Figure 5: Orbital separation distributions (Top: OBin, Bottom: T14)

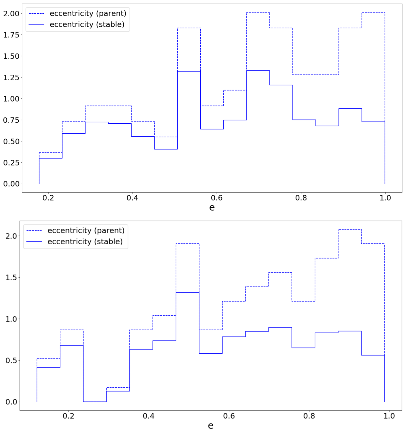

Figure 6: Eccentricity distributions (Top: OBin, Bottom: T14)

Mass ratio & Periapasis distance

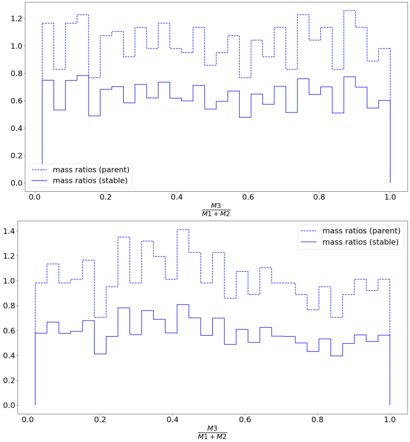

Figure 7: Mass ratio distributions (Top: OBin, Bottom: T14)

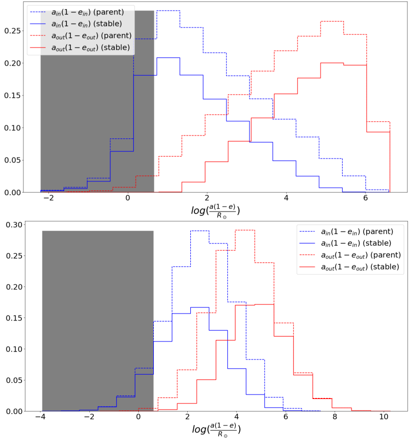

Figure 8: Periapsis distributions (Top: OBin, Bottom: T14)

Circular orbit assumption

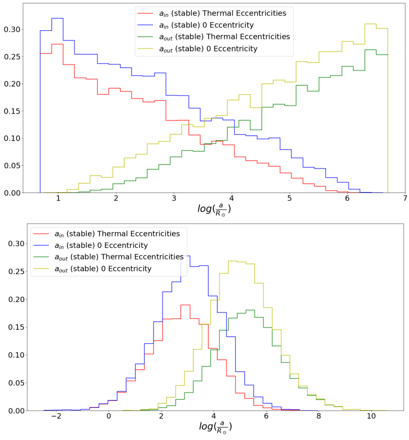

Figure 9: Orbital separation distributions (Top: OBin, Bottom: T14)

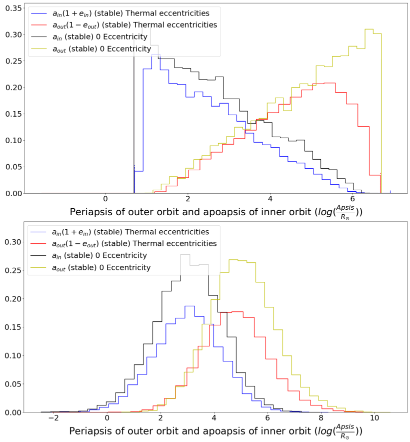

Figure 10: Apsis distributions (Top: OBin, Bottom: T14)

Mass ratio distribution comparison

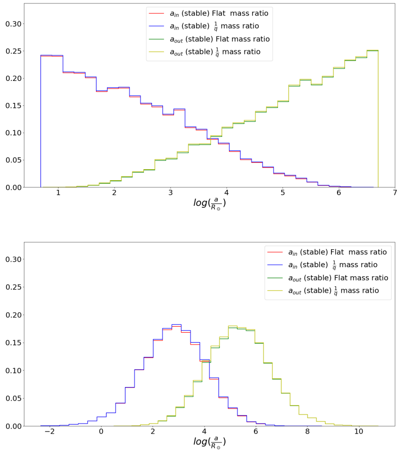

Figure 11: Orbital separation distributions (Top: OBin, Bottom: T14)

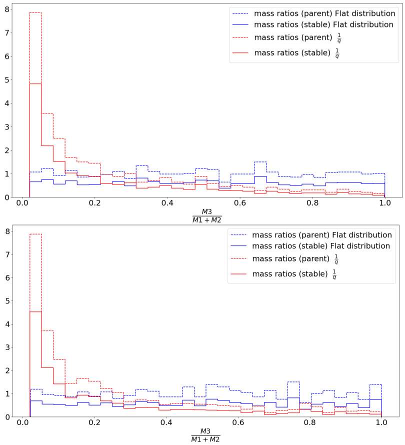

Figure 12: Mass ratio distributions (Top: OBin, Bottom: T14)

Triple results summary

- Aim: Study the initial orbit distributions of triples as an input to studies simulating further evolution.
- OBin model produces more triple systems with interacting binaries.
- Circular orbits are more stable than orbits with eccentricities picked from a thermal distribution.
- Orbits with eccentricities picked from a thermal distribution are more likely to undergo interactions between the inner binary and the triple star.
- T14 distribution produces more systems with binary-triple interactions than OBin.
- Mass ratio distributions flat and $\frac{1}{q}$ produce very similar numbers of stable orbits (Variation of mass distribution model does not significantly affect stability curves across other orbital elements).

Quadruple systems

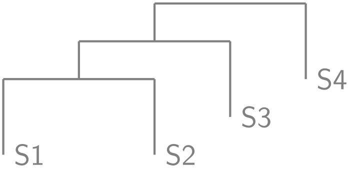

Figure 13: Quadruple Hierarchical System

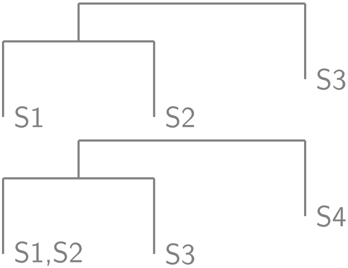

Figure 14: Application of centre of mass approximation to hierarchical structure

Orbital separations & eccentricities

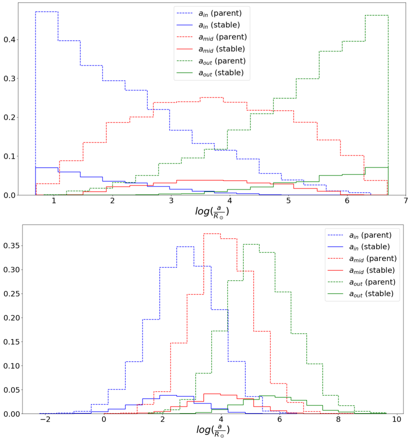

Figure 15: Orbital separation distributions (Top: OBin, Bottom: T14)

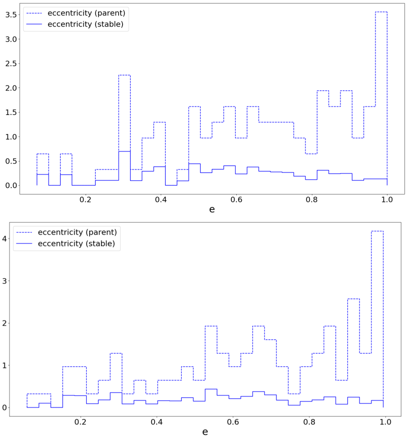

Figure 16: Primary eccentricity distributions (Top: OBin, Bottom: T14)

Primary and secondary mass ratios

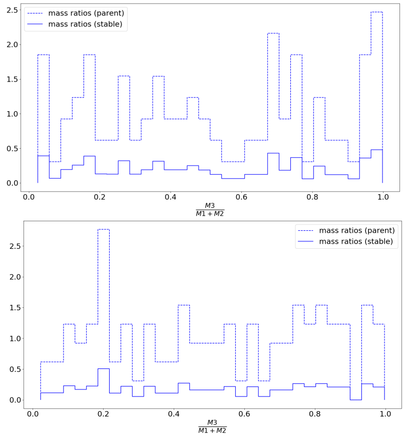

Figure 17: Primary mass ratio distributions (Top: OBin, Bottom: T14)

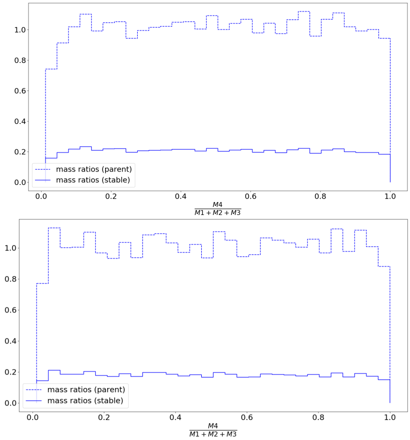

Figure 18: Secondary mass ratio distributions (Top: OBin, Bottom: T14)

Quadruple results summary

- Aim: Similarly to the triple case, we study the initial distributions of orbital elements for quadruple systems as an input to studies for further evolution.
- Aim: To compare the distributions of orbital elements of quadruples and triples.
- Flat distribution of stable eccentricity from the thermal parent distribution.
- Massive stars are observed to have more companions and tend to be in more compact orbits (observational evidence). There may be some link between the number of companions and the size of orbit, in the quadruple case both the OBin and T14 cases showed the inner binary orbital separation (stable) is pushed to lower orbital separations (more often) than in the triple case.

Code

- Written in Python and Fortran.
- Multiprocessing library.
- Separate triple and quadruple codes.
- All code ran on Hydra.
- https://github.com/dig07/Summer-project-triple-and-quadruple-stability.