Few-Body Problem: Theory and Computer Simulations
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Dynamics and stability of multiple stars

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Abstract. We consider the problem of the dynamical stability of multiple stars. The stability criteria for triple systems are reviewed. A new classification scheme for multiple stars is given: non-hierarchical systems (probably unstable); high-hierarchical systems (probably stable); low-hierarchical systems (intermediate class of objects). We discuss methods to study the dynamical stability of concrete multiple star systems, taking into account the uncertainties in orbital elements and masses of the components. The analysis of dynamical stability for actual multiple stars has been used to find some candidates in unstable systems.

1. Introduction

Historically, configurations of multiple stars have been separated into two types. These are Trapezium-like (non-hierarchical) systems and ϵ Lyrae-like (hierarchical) systems. Systems of the first type are usually unstable (with some rare exceptions — for example, eight-like orbit, see Fig. 1). Hierarchical systems are usually stable and motions in those are Keplerian in nature.

In this work we introduce a new intermediate type of multiple star — which we term 'low-hierarchical systems'. As one example we consider the probably quadruple system HD 40887 (see Fig. 2). The stability of such systems is always a special question and requires special investigation for each individual case.

A natural question which arises in the theoretical/numerical study of the stability of multiple stellar systems is the correspondence with actual, observed systems. There are several low-hierarchical systems in the solar neighbourhood. It would be interesting to study these from this point of view. Are they stable? If not, what are the mechanisms involved in their origin?

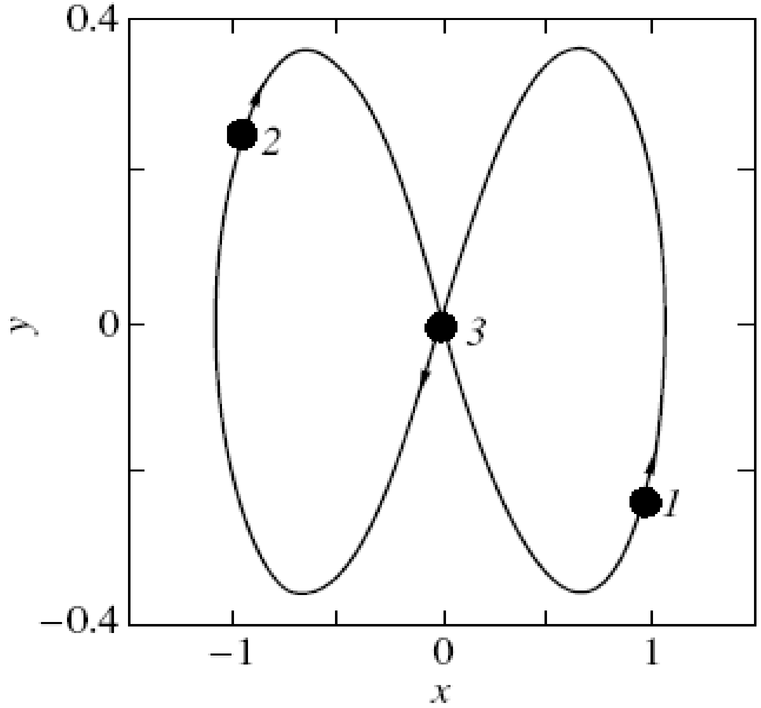

Figure 1. Eight-like stable orbit in the three-body problem. This system is non-hierarchical.

2. Studying Stability

We have used several stability criteria to examine the stability of the triple systems (see Golubev 1967, 1968; Harrington 1972, 1977; Eggleton and Kiseleva 1995; Mardling and Aarseth 1999; Tokovinin 2004; Valtonen and Karttunen 2006).

At the same time, we have used numerical simulations to examine the types of motion and stability and also to estimate the life-time of unstable systems. To make the numerical simulations, we used three codes — the code *TRIPLE* for triplets, as well as the code *CHAIN* by Sverre Aarseth and a similar chain-regularization code by one of authors (Alexey Rubinov) for quadruple systems. Numerical integration of the equations of motion was made over periods of 10^6 (sometimes 10^7) years into both the past and the future.

This approach gives us an opportunity to compare several stability criteria and numerical results and choose the best criterion for particular purposes.

To take into account the uncertainties in observational data, we utilise Monte-Carlo simulations, running 1000 realizations for each system. A Gaussian distribution function was used for the input parameters for the realizations, with mean values and dispersions corresponding to observed quantities and their associated errors.

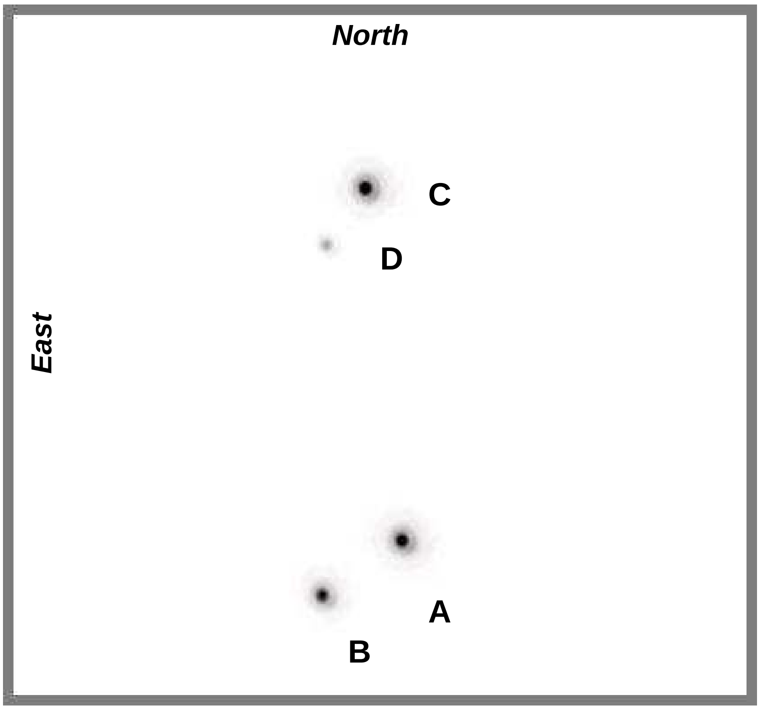

Figure 2. The probable low-hierarchical quadruple system *HD* 40887.

3. Results

In Fig. 3 we show the relationship between decay probability according to various stability criteria and the results of our numerical simulations. Two populations of multiple stars were found: probably stable and probably unstable. The gap between these two populations is rather wide (Fig. 3). For "stable" systems, we have estimated the decay probability $P_d < 0.1$. A non-zero value of P_d could be explained by overly large orbital parameter errors being taken into consideration. At the same time, for "unstable" systems we found $P_d > 0.9$ during a time interval of 1 Myr (more than $10^3 P_{ex}$, where P_{ex} is period of the external binary). We may suppose that the rest of systems will decay during a longer time. Here we give the list of probably unstable systems: HD 40887 (Gliese 225.2) — probably quadruple; HD 76644 (ι Uma = ADS 7114) — quadruple; HD 136176 (ADS 9578) — triple; HD 150680 (ADS 10157) — astrometric triple; HD 222326 (ADS 16904) — triple. Among them there are one quadruplet, one probable quadruplet, and three triplets.

Possible explanations of the unstable system phenomenon are:

1. errors of observations and interpretation,

2. physical youth of components,

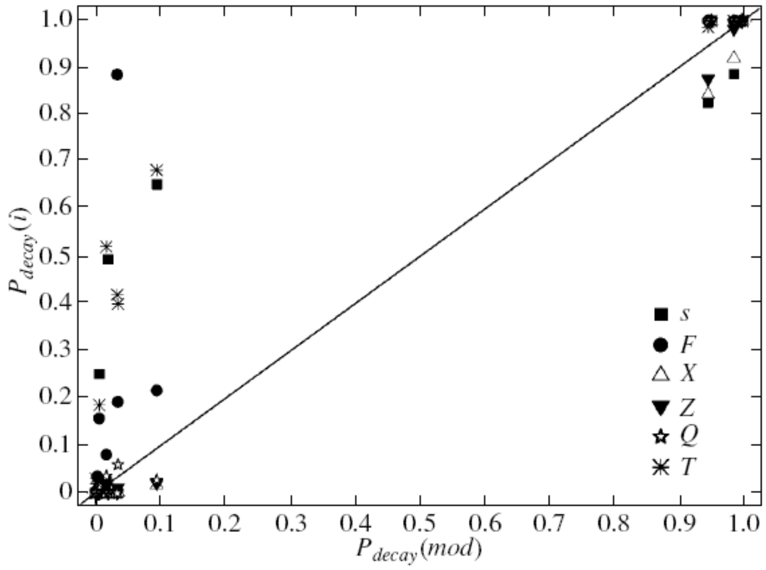

Figure 3. Relationship between the system decay probability according to various stability criteria ($P_{decay}(i)$) and the decay probability according to the numerical simulations ($P_{decay}(mod)$). Different symbols correspond to different criteria: s — Golubev; F — Harrington; X — Eggleton-Kiseleva; Z — Mardling-Aarseth; Q — Valtonen-Karttunen; T — Tokovinin. The solid straight line shows the plot diagonal. The inequality $P_{decay}(i) > P_{decay}(mod)$ for small decay probabilities indicates a shift of the instability boundary for some criteria.

3. additional effects responsible for the physical stability of the system (mass loss etc.),
4. additional effects which led to the formation of an unstable system (merging of components etc.),
5. temporary capture via the encounter of a binary (or multiple) system and a single (or multiple) star in the general star field,
6. stability loss via encounter of a stable multiple system and a massive object (molecular cloud, black hole etc.),
7. as a product of dissipation of a stellar group or cluster.

We have roughly estimated the expected numbers of unstable systems within the solar neighbourhood (here defined as two hundred parsecs) due to the last three of the mechanisms above. The expected number of unstable systems within a sphere of 200 pc around the Sun for the scenarios 5–7 is of order 1 to 10 ($P_{ex} < 10^3$ yr). This is non-negligible, and invites further investigation.

4. Conclusions

1. One can separate multiple stars into high-hierarchical, low-hierarchical, and non-hierarchical types.
2. High-hierarchical systems are long-term stable, non-hierarchical systems usually disrupt, and low-hierarchical systems may fall in either category.
3. Most of the *observed* multiple systems *are* stable, but some of them *might not* be so.
4. A few scenarios of unstable system origin are suggested.
5. The Valtonen-Karttunen and Aarseth-Mardling stability criteria showed the best correspondence to numerical simulations.

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