Dynamical stability in the habitable zone of binaries and multiple planetary systems

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Abstract: The main goal of this study is to investigate the long term stability of orbits of terrestrial like planets in the habitable zone (HZ) of extrasolar systems. The habitable zone is defined as the region, where liquid water can exist on the surface of a terrestrial planet. The most interesting planetary systems from the dynamical point of view are double stars and multiple planetary systems, from the more than 100 detected extrasolar systems 14 are binaries, from which we selected those with close stellar components (Gamma Cephei [2], HD 41 004 and Gliese 86 [6]). The second part of our study is concerned with the stability of some of the 13 known multiple planetary systems like HD 74 156 [1], HD 38 529, HD 16 9830, HD 16 8443, 47 Uma. In Table 1 all investigated systems are shown; in the last column their possibility for hosting additional planets inside the habitable zone is marked either by a green point for stable motion inside the HZ or by a orange point, which means that stable orbits have been found under certain circumstances, e.g. for eccentricities lower than the given one. To study the orbital behaviour in the different systems we used (a) direct numerical computations (Lie-Integration Method), where we determined the escape-times and the maximum eccentricity (MEM) and (b) for the long term stability we used two chaos indicators (Fast Lyapunov Indicator [3] and Relative Lyapunov Indicator [7]). Examples for both methods are given below. We have to point out that the study of the mean motion resonances is very important in exoplanetary systems, since the detected planets are very massive and move on high eccentric orbits. Some of the systems show quite stable habitable zones, while others are more or less chaotic.

Close Binaries

Table 1: The map of all observational data for the, until now, investigated systems is summarised. The symbols in the last column show the possibility for additional planets to move inside the habitable zone: The green point means that stable motion inside the HZ is possible for the given data and the orange point means, that only under certain circumstances stable orbits are possible.

![Multiple planetary systems](image)

Figure 5: Shows the habitable zone in three multiple planetary systems, where the habitable zones lies between two of the observed planets. In the case of Ups And one can see, that one of the observed planets lies inside the HZ and the other is very close to it, so that additional planets inside the HZ would be unstable.

![Figure 6](image)

Figure 6: The right upper figure shows the planetary orbits and the mean motion resonances in the system HD 38 529. The blue region gives the position of the HZ and the hatched region shows the region of influence from the outer planet. One can see that a lot of inner systems with the outer planet are inside the HZ. For a few systems we integrated some test-planets inside these resonances, which is shown in the lower right plot. Black circles means stable motion and white circles stable motion. So one can see, that just a few test-planets sufficiently far away from the known planet have stable orbits. In the left picture a RL plot for this system is shown for different eccentricities values of the test-planets (yellow means stable), where one can see, that there are just a few orbits left of the inner edge of the HZ.

![Figure 7](image)

Figure 7: Shows a maximum eccentricity plot of the multiple planetary system 55 Cnc, which is additionally part of a far binary system. Red and orange colors show stable motion, thus it is clearly seen, that nearly all initial conditions lead to stable orbits. Furthermore some mean motion resonances are visible.

![Figure 8](image)

Figure 8: The upper picture shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 9](image)

Figure 9: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 10](image)

Figure 10: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 11](image)

Figure 11: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 12](image)

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![Figure 14](image)

Figure 14: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 15](image)

Figure 15: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 16](image)

Figure 16: The right upper plot shows the stability regions in the binary system Gliese 86 depending on the unknown eccentricity of the binary; the blue region marks the habitable zone. Thus, stable motion inside the HZ is possible for nearly all binary-eccentricities, only for high eccentricities of about 0.8 the HZ lies in the mixed region where stable as well as unstable motion is possible. This is also shown in the right upper plot, where additional planets inside the HZ would be unstable.

![Figure 17](image)

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References:
7) Sándor, Z., Erdi, B., Efthymiopoulos, C.: 2000, CMDA. 78, p.113-123
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