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Regularity and chaos for planetary orbits in binaries

D. Benest

Observatoire de Nice, Nice, France

1. Introduction

Cosmogonical theories as well as recent observations allow us to expect the existence of planets around many stars other than the Sun; moreover, several planets have been detected around one of the components in binaries, 16 Cyg B or Gliese 86 A for example. On the other hand, double and multiple star systems are established to be more numerous than single stars (such as the Sun), at least in the solar neighborhood. We are then faced to the following dynamical problem: assuming that planets can form in a binary early environment (we do not deal here with, although observations have been made recently of which is interpreted as protoplanetary disks, included in binary systems: BD+31^{o}643 or L1551 for example), does long-term stability for planetary orbits exist in double star systems?

2. The model

The dynamical model is the elliptic plane restricted three-body problem; the phase space of initial conditions for the planet of negligible mass (X_o, V_o) is systematically explored for given physical parameters of the binary (the reduced mass μ of the 'sun' of the planet and the orbital eccentricity e of the binary), and limits for stability are established.

Previous papers showed that stable planetary orbits, around either the lightest or the heaviest component of several nearby binary systems, exist up to distances from their primary of the order of more than half the binary's periastron separation. Moreover, among the stable planetary orbits found, in binary systems where $\mu = 0.45$ for the lightest and 0.55 for the heaviest (and are nearly of solar type), i.e. the α Centauri ($e = 0.52$), η CrB ($e = 0.28$) and ADS 12033 ($e = 0.83$) systems, nearly circular orbits ($e_3 < 0.1$, and even $e_3 < 0.05$, where e_3 is the eccentricity of the planet around its 'sun') lay inside the habitable zone – as defined by Hart; but, in the ADS 11060 system, not any such nearly circular orbits were found; we may conjecture that the high eccentricity of this binary (0.96) is at least one of the causes of this miss, although a verification is desirable.

The systematic study of stable planetary orbits in nearly binaries is to be continued, the final goal being to establish the general rules of existence of such orbits as function of the parameters μ and e.

But our definition here of the stability is: an orbit is called stable if there has been neither collision with a star nor escape during a given time, here chosen – by a criterium depending on the computing time – to 100 orbital revolutions of the binary. Can we be sure that a longer integration will give the same result?

3. Chaos: bounded or sticky?

It is now well-known that planetary dynamics may include some proportion of chaos. During the previous studies, several indices have revealed that a difference in the initial conditions, even as little as 10^{-6} in X_o, may induce in some cases an orbital destiny completely different, not only at the border of the stability zone but even inside this latter.

The next step is naturally the use of indicators of chaos (such as Lyapunov coefficients or frequency analysis, for example) to try to determine, among the stable orbits (stable in the sense defined above), how many are chaotic: are they all chaotic, or does a 'strong nucleus' of regular orbits remain? Note that, fortunately, chaos does not always mean lethal destiny: we know for example that the orbit of the Earth is chaotic, i.e. we cannot know the exact position and velocity of the Earth over millenia, but this is 'confined' chaos because the Earth orbit stays inside a bounded region of the phase space. Nevertheless, an orbit may look like such a confined chaos configuration during a very long time (up to several billions years) and then blow up: such an orbit is called 'sticky'.

This communication will present our latest results about the evolution during long time spans of the orbital elements, together with the greatest Lyapunov coefficient, for some fictitious planets orbiting a component of a binary.