When will we be able to detect exosatellites?

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Introduction

Once established that the existence of planets around other stars is a natural situation, as occurs in our solar system, we would also be able to consider that the presence of exosatellites or companions around them should not be rare. Moreover, the possible existence of other bodies moving around exoplanets relatively close to their host planets opens up a field of research of great interest, not only for astrodynamics but also for astrophysics and astrobiology due to the fact that said exosatellites may have sizes that are close to that of the Earth when, at least a part of them, may be located within the so-called zone of inhabitability.

In this sense, it seems logical to attempt to investigate not only the dynamics of said bodies, proposing models to that effect and calculating the perturbations that affect the orbits, but to also study their stability. Postulating the existence of Earth-type exosatellites around the giant planets located at approximately 1 AU of distance from a type G star (or closer for K or M stars), it appears to be appropriate to study the conditions in which life could be developed on such satellites. In this sense, checking the actual data, more than 200 of the discovered exoplanets may be in this situation.

Unfortunately, such satellites cannot be detected by the method of radial velocities, nor photometrically, at the moment. Nevertheless, the other hand, the timing method may be applicable in ideal conditions. In effect, studying the perturbations that affect the planetary orbits, it may be possible to detect indications of the existence of exosatellites whenever extremely precise orbital elements of the planets are available. On the other hand, the possible perturbations observed in the orbits would be masked by standard errors of the orbital elements themselves.

1. Previous studies

In recent years, we have begun to study some models of planetary orbits with satellites at the R. M. Aller Astronomical Observatory. First, around an isolated star, we have considered a double 4-(2,2) model that consists of a star with two planets, with the farthest away having a satellite that moves around it [2, 3] (see Figure 1).

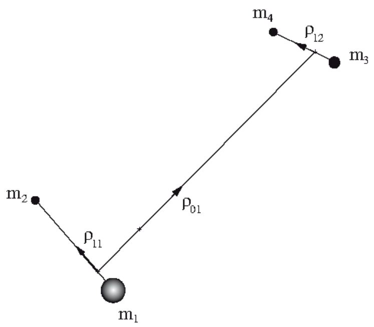

Figure 1: 4-(2,2) model

In said research, with the objective of clearly seeing the influence of the satellite, we have selected a case in which the mass of the satellite was greater than that of the interior planet (masses: inner planet, 0.02

M_J; outer planet, 0.05 M_J; satellite, 0.03 M_J) as an application. Comparing this case with another in which the exterior satellite does not have a satellite but it does have a mass that is equivalent to the sum of the exterior planet and the satellite of the first case, it turns out that the perturbation of the argument of the periastron of the interior planet's orbit does in fact present a behavior that is clearly different in both cases after 100 revolutions of the interior planet.

In a second investigation [5], we have studied the dynamics of exoplanets and exosatellites in double stars. In particular, considering that a planet moves around a component of the binary, the corresponding curve of radial velocity can be observed to be slightly distorted if the planet has a satellite that moves around it.

The curve of radial velocity of a double star with a planet is represented in Figure 2. The variations of the orbital elements of the planetary orbit, caused by the presence of a satellite moving around it, produce a distortion in said curve over a very long period of time. In effect, if we overlay the corresponding curves, said distortion could be observed. We have illustrated this in Figure 2.

In any case, the differences between the radial velocities of the overlaid curves is on the order of cm s^{-1} in the most favourable case.

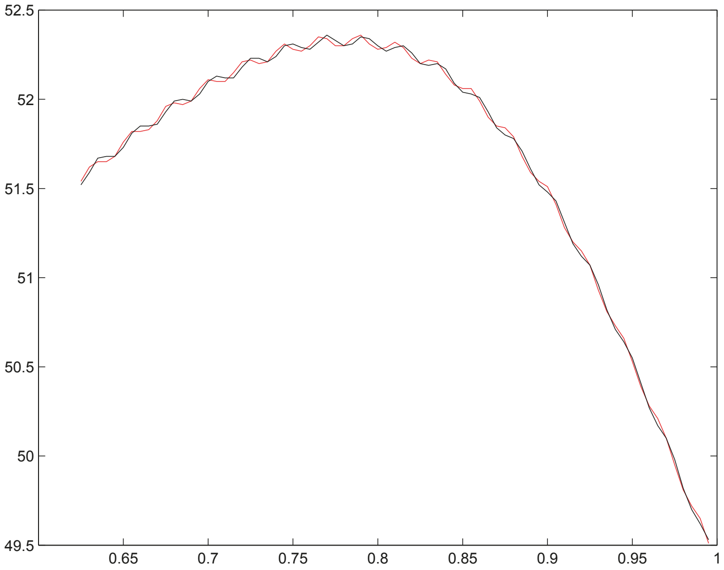

Figure 2: Comparions between the curves of radial velocity

Recently, a semianalytic method of the fourth order was developed in order to integrate the equations of this four-body case [4] (see Figure 3). In this study, a biparametric version of the method of Hori [1] was used in order to eliminate the angular variables, yielding a final result of a differential equation involving the star-planet distance to be integrated numerically.

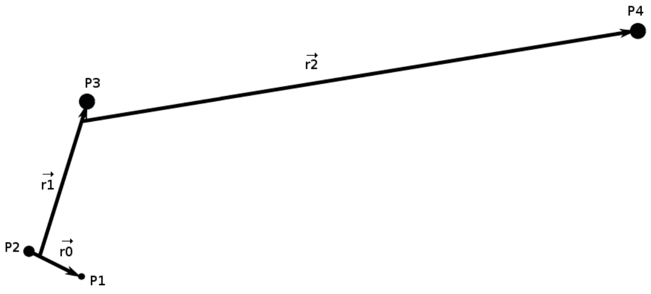

Figure 3: The four-body case

2. The study of a three-body model

In the present contribution, we consider a hierarchical three-body problem that corresponds to a planet with its satellite moving at a certain distance from the host star. It would be similar to the Sun-Earth-Moon system but with different mass ratios. We will attempt to see how the presence of the satellite perturbs the orbit that the planet describes around a star with a mass of 1 $M_\odot$ by numerically integrating the equations of the movement for a period of 1000 years.
We consider two cases with different planet-satellite mass ratios (in masses of Jupiter):

Case 1	
Planet mass:	7
Satellite mass:	7

Case 2	
Planet mass:	13
Satellite mass:	1

In Table 1, the initial values of both orbits are represented. First, the data of the planet with a subindex 1 and that of the satellite or companion with a subindex 2 (the mutual inclination is given by Δi). This figure also includes the final values of the orbital elements at the end of 1000 years. It can be proven that, in this time interval, only the variation of the argument of the periastron (ω) is significant.

Table 1: Initial and final orbital elements

ORBITAL ELEMENTS	INITIAL	FINAL	
		Case 1	Case 2
P_1 (yr)	1	0.999908	0.999962
T_1	2000	2000.38	1999.85
e_1	0.1	0.0991525	0.0998847
a_1 (AU)	1	1.00437	1.00441
i_1 (°)	2	1.95086	1.98674
ω_1 (°)	0	147.519	39.2651
Ω_1 (°)	0	359.216	359.908
P_2 (yr)	0.1	0.100007	0.102795
T_2	2000	1999.96	2000.00
e_2	0.05	0.139824	0.14095
a_2 (AU)	0.0511516	0.0517168	0.0520761
i_2 (°)	3	6.20382	6.13979
ω_2 (°)	300	197.975	86.2922
Ω_2 (°)	120	13.6774	7.16247
Δi (°)	4.4	4.3	4.2

Concretely, ω_1 increases on the order of 0.15 deg/year in Case 1 and only 0.04 deg/year in Case 2 (see Figure 4). ΔE and ΔL, that indicate the variation of the integral of the energy and the angular moment, are 10^{-12} and 10^{-3}, respectively.

3. Future projects

As future projects, we are considering the development of algorithms that permit the discrimination between perturbations caused by other planets or by satellites. We are also considering extending the

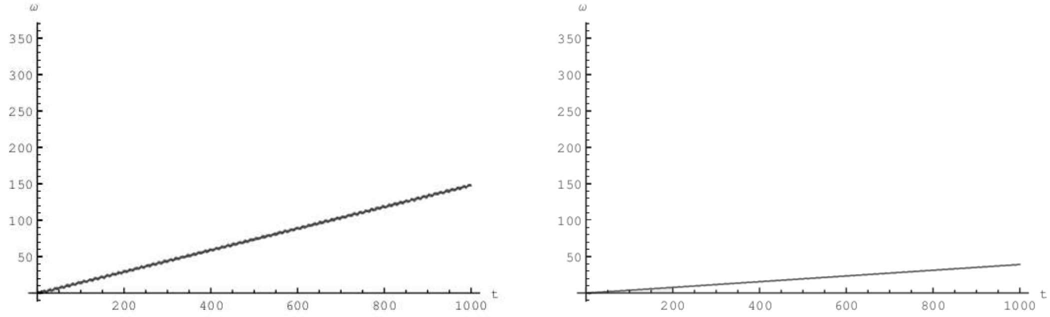

Figure 4: Evolution of the arguments of the periastron (left: Case 1; right: Case 2)

study of the movement of exoplanets and exosatellites in systems with P-type orbits. Finally, we are going to prepare a list of binary candidates that may have exoplanets with Earth-like satellites.

References

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