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A new dynamical solution of (45) Eugenia's satellites

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Abstract

(45) Eugenia and its satellites are one of the few triple asteroid systems discovered. Eugenia's shape is far from spherical, with a theoretical J_2 estimated to 0.19 assuming an homogenous distribution of mass in its interiour. We have adapted the numerical model we developped for Pluto's system to Eugenia's case, adding the second harmonics of Eugenia's gravity field. Previous study by [4] found a lower value of the coefficient J_2. We present here our results after fitting the satellites observations to our model using new observations of the system done in 2010 . We confirm that the value of J_2 is about three times lower than its theoretical value. We find a similar pole direction for Eugenia and similar orbital elements for Petit-Prince.

1. Introduction

The main-belt asteroid (45) Eugenia is one of the four triple asteroid systems in the main-belt known today (Marchis et al., DPS, 2010). The primary, Eugenia, is a large irregular body with a mean diameter of 217 km, and a shape estimated by combining lightcurve inversion method and high resolution adaptive optics observations. Its outermost satellite, Petit-Prince, was discovered in 1999 [6], the second one, S/2004 (45) 1, closer to Eugenia, was discovered in 2007 [2]. Both satellites have a direct orbit with respect to their primary, but recent studies [3][4] suggest that they do not orbit in the equatorial plane of Eugenia, making this triple asteroid system a puzzling one, since it is not expected for satellites orbiting well inside the Hill sphere not to be damped by tidal effects (Petit-Prince's semi-major axis is only 3% of Eugenia's Hill radius). A recent dynamical solution of the system [4] confirmed the apparent high inclination of the satellites. The authors also found a value of the second order polar oblateness of Eugenia J_2 of 0.06, while the theoretical value estimated from Eugenia's shape was 0.19 assuming an homogeneous distribution of material in the interior of the primary. We present in Section 2 a new dynamical model based on a more complete set of observations presented in Section 3. Section 4 summarized the results obtained with our more refined model.

2. Dynamical model

We have adapted to Eugenia's case the numerical model developed for Pluto's system [1]. We compute the motion of both Eugenia and its satellites in the inertial reference frame J2000 centered on the Solar System barycenter. The positions of the Sun, the eight planets and the Moon are computed by using the planetary ephemeris DE405 [5]. We include the second order polar oblateness of Eugenia J_2. We use the following notation: i an integrated body from Eugenia's system, j the Sun or a planet, m_i the mass of the body i, $\mathbf{r}_j$ the position vector of the body j with respect to Solar System barycenter, r_{ij} the distance between bodies i and j, R_l the equatorial radius of body l, $J_2^{(l)}$ the polar oblateness of body l, $U_{\bar{i}\,\hat{l}}$ the potential of the l body's oblateness on the i body's center of mass. We then obtain the following equation of motion :

$$\begin{aligned}\ddot{\mathbf{r}}_i = \;& \sum_{j=1}^{10} -\frac{Gm_j(\mathbf{r_i}-\mathbf{r_j})}{r_{ij}^3} \\ & + \sum_{l=1,\ l\neq i}^{3} \Big(-\frac{Gm_l(\mathbf{r_i}-\mathbf{r_l})}{r_{il}^3} + Gm_l \nabla_l U_{\bar{l}\,\hat{i}} \\ & -Gm_l \nabla_i U_{\bar{i}\,\hat{l}} \Big)\end{aligned} \tag{1}$$

where $U_{\bar{i}\,\hat{l}}$ is a function of the oblateness of l, and ϕ_i the latitude of i with respect to l equator :

$$U_{\bar{i}\,\hat{l}} = -\frac{R_l^2}{r_{il}^3} J_2^{(l)} \left(\frac{3}{2}\sin^2(\phi_i) - \frac{1}{2} \right) \tag{2}$$

Then we adjust orbital elements of the satellites, the polar oblateness and the direction of Eugenia's pole through a least-square method.

3. Method

We use astrometric positions derived from adaptive optics observations recorded from various 8-10 class telescopes and Hubble Space Telescope (HST), taken from 1998 to 2007, composed for Petit-Prince, of 3 observations from Canada France Hawai Telescope (CFHT), 9 observations from W.M. Keck II Telescope and 25 observations from the VLT-UT4, with respective uncertainties of 70, 6 and 9 mas. For Princess, we have used 3 observations from the VLT in 2004, and 3 observations from Keck in 2007, with respective uncertainties of 17 and 20 mas. In this study, we also included one observation of Petit-Prince from the HST collected in 2001, 2 recent observations from Keck and 3 from Gemini North telescope, both sets recorded in 2010, as well as 2 observations of S/2004 (45) 1 from the Keck, and 2 from the Gemini telescope.

4. Results

In a first step, we have fitted the orbital parameters of Petit-Prince as well as Eugenia's J_2 and its pole direction. Then, we fit S/2004 (45) 1's elements. The post-fit residuals for both satellites are presented in Fig. 1, and the osculating elements for both satellites in Table 1. We also find $J_2 = 0.0581 \pm 0.0004$, $\lambda = 121.1 \pm 0.4$ and $\beta = -20.6 \pm 0.3$, which are consistent with those in [4]. For both satellites, the observations from the Gemini are not consistent with those from the Keck. We seem to have the same kind of problem with the HST image, but the very small amount of observations prevent us from knowing whether it comes from the system's dynamic or from the reduction of the data.

Table 1: Osculating elements of Petit-Prince and S/2004 (45) 1 at epoch JD=2452980.0

Parameter	Petit-Prince	S/2004 (45) 1
Semimajor axis	1164.42	610.79
(km)	± 0.01	± 0.05
Eccentricity	0.0004	0.078
	± 0.0012	± 0.013
Inclination	107.1	126.7
in ICRF (deg)	± 0.27	± 0.65
Longitude of	201.9	209.5
ascending node (deg)	± 0.3	set
Argument of	142	95
periapse (deg)	± 15	set
Mean anomaly (deg)	1	-186
	± 15	set

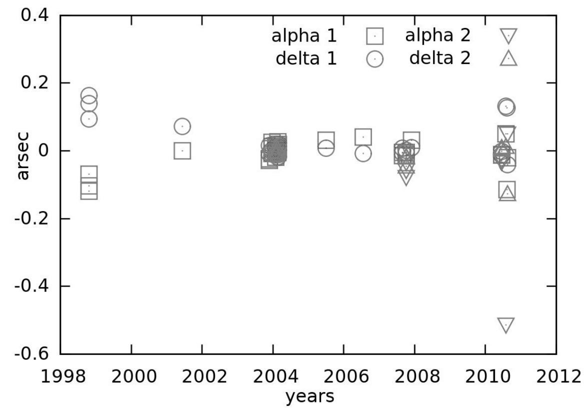

Figure 1: Astrometrical residuals of Petit-Prince and S/2004 (45) 1, 1 refers to Petit-Prince, 2 refers to S/2004 (45) 1.

5. Conclusion

We find orbital elements consistent with the previous dynamical study of the system [4] and confirm the low value of J_2. We still have to cope with the fact that Gemini's observations do not seem coherent with those taken with Keck Telescope and to achieve a satisfying orbital solution for S/2004 (45) 1, the most recent points coming from the Gemini telescope. We will also study the cause for the discrepancy between the detected and theoretical value of J_2. We are planning to use the same approach to develop a dynamical study of the multiple asteroid (87) Sylvia.

References

[1] Beauvalet, L. et al. : Dynamical parameter determinations in Pluto's system, submitted to A&A

[2] Marchis, F. et al. : S/2004 (45) 1, IAU Circ., 8817, 2007.

[3] Marchis, F. et al. : Main belt binary asteroidal systems with circular mutual orbits, Icarus, Volume 196, Issue 1, pp. 97-118, 2008.

[4] Marchis, F. et al. : A dynamical solution of the triple asteroid system (45) Eugenia, Icarus, Volume 210, Issue 2, pp. 635-643, 2010.

[5] Standish, E. M. : JPL Planetary and Lunar Ephemerides, DE405/LE405, Jet Propulsion Laboratory Interoffice Memorandum 312.F-98-04, 1998.

[6] Merline, W. J. et al. : Discovery of a moon orbiting the asteroid 45 Eugenia, Nature, Volume 401, pp. 565, 1999.