CAPTURE OF THE COMET P/BOETHIN BY JUPITER.

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ABSTRACT

The possible effects of non-gravitationnal forces on the motion of the comet P/Boethin are investigated for various values of the orbital period. A time interval of 2000 years backward and forward is treated. The authors find in all cases that the comet librates temporarily around the 1/1 resonance with Jupiter as a remote jovian satellite during at least two centuries.

1. INTRODUCTION

Comet P/Boethin (1975 I) has been previously shown to librate around the 1/1 resonance with Jupiter during at least a few centuries, and to have a very remote satellite motion around this planet (Benest et al., 1980; see also Benest et al., 1981). More recently, the authors began to study the influence of non-gravitationnal forces upon this behaviour, first using a restricted four-body model (Sun-Jupiter-Saturn-comet; Benest et al., 1982).

We present here the results obtained for a more complete set of conditions with the restricted three-body model, integrated with a Runge-Kutta method with variable step, where we combine the influence of varying orbital period with non-gravitationnal forces.

2. CALCULATION

In a rotating-pulsating frame centered on Jupiter, the motion of a remote satellite is composed of a fast motion along a bean-shaped curve

V. V. Markellos and Y. Kozai (eds.), Dynamical Trapping and Evolution in the Solar System, 107–114.

which librates slowly around the planet (see figure 1a). Before capture and after escape, the comet can be still in 1/1 resonance with Jupiter, but the bean-shaped curve either librates around a point approximately symmetric to Jupiter with respect to the Sun (which we call an "anti-satellite libration"; see figure 1b), or circulates continuously around the Sun.

We have computed 25 orbits for the comet over 2000 years backward and forward. One of these, hereafter referred to as the "central orbit", is based on the elements in Marsden's (1979) catalogue and corresponds to purely gravitationnal motion. Besides, we have treated four different gravitationnal orbits varying the orbital period P at the starting epoch (1974 Dec. 19) by $\Delta P = \pm 8$ d and ± 16 d. We have also treated 20 non-gravitationnal orbits, 4 for each starting period. As for the four-body calculation, we adopted the standard expression for the non-gravitationnal force (Marsden, 1974) with the same set of values for A_2: ± 1.5 and $\pm 3.\ 10^{-9}$ a.u./day^2.

For each orbit, we have plotted a (semi-major axis of the orbit of the comet), $l-l_J$ (cometary mean longitude minus Jupiter's mean longitude) and d_{CJ} (minimum distance between Jupiter and the comet over one period of the comet) versus time (see figure 2, here for the central orbit). On these plots, the libration motions correspond to oscillations of a around the value of a_J (Jupiter's semi-major axis) and of $l-l_J$ around 0 (satellite) or $\pm 180°$ (anti-satellite); during a circulation, a stays always greater or less than a_J and $l-l_J$ varies monotonously.

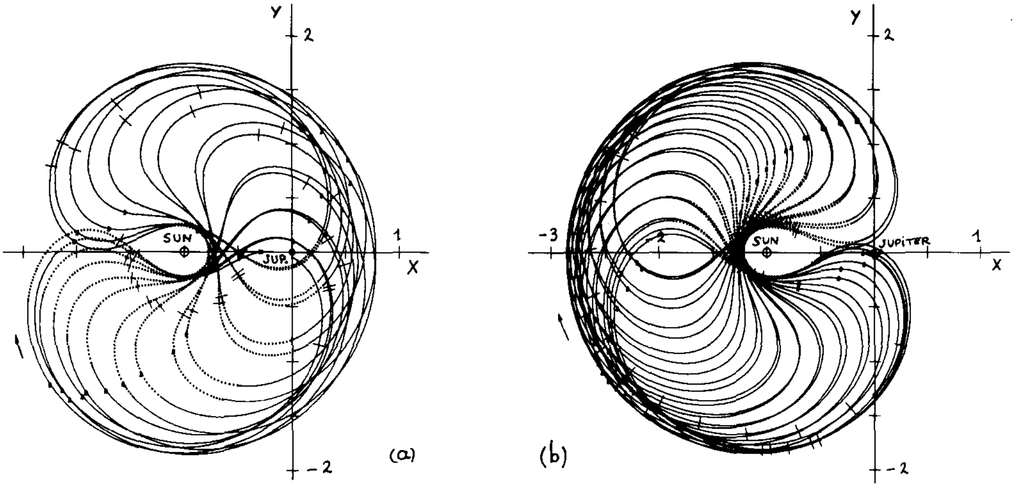

Figure 1. Satellite (a) and anti-satellite (b) motion for P/Boethin in a rotating-pulsating frame. Full (resp. dotted) line: part of the orbit above (resp. below) Jupiter's orbital plane; the perpendicular slashes indicate when the comet is at a maximum distance from this plane; the little open marks indicate when Jupiter is at perihelion or aphelion. The arrow on the left side indicates the direction of motion.

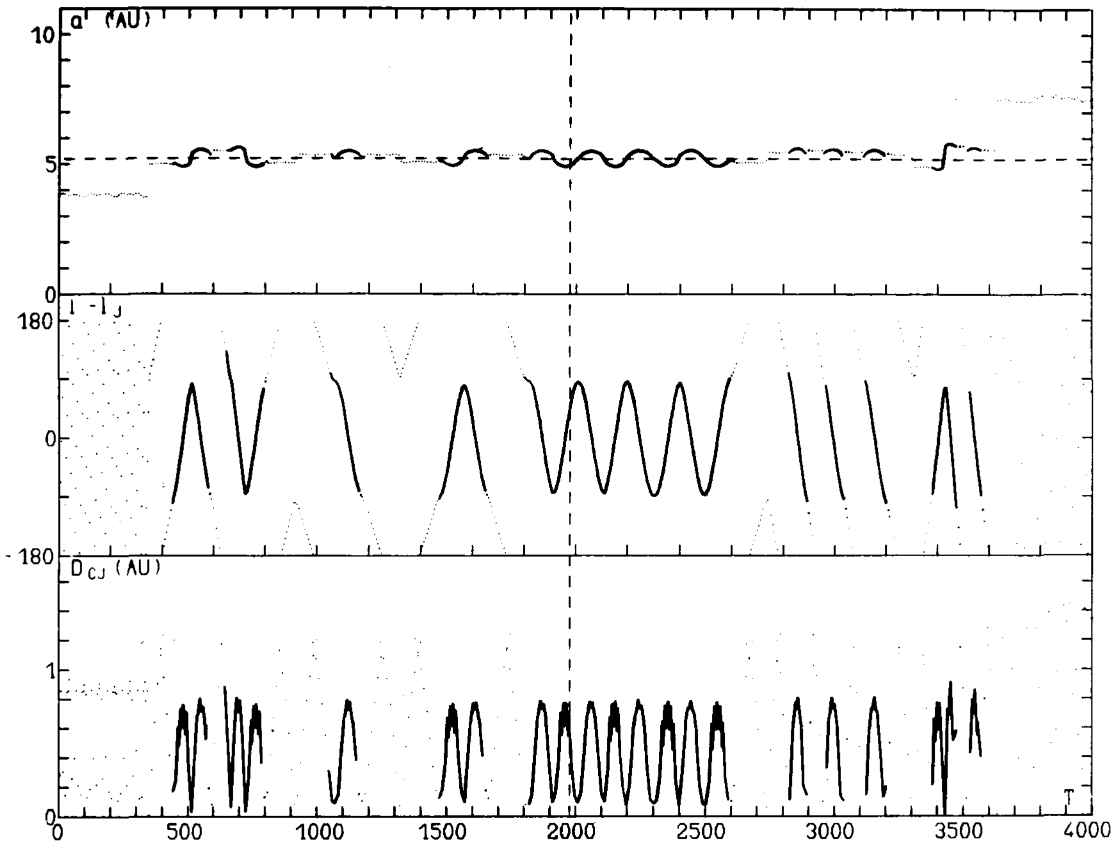

Figure 2. Semi-major axis $\underline{a}$ (in a.u.), mean longitude of the comet $\underline{l}$ minus Jupiter's mean longitude l_J (in degrees) of the orbit of P/Boethin and the minimum distance D_{CJ} between Jupiter and the comet over one period of the comet, from 0 to 4000 A.D. for the central orbit. Full line: satellite libration; dotted line: other types of motion (anti-satellite libration or circulation).

https://doi.org/10.1017/S0252921100096998 Published online by Cambridge University Press

3. RESULTS

All our 25 orbits show temporary satellite librations enclosing the starting date (see Table 1). The minimum duration is about 200 years (for $\Delta P < 0$ and $A_2 < 0$), slightly less than one complete libration period; the maximum of stability is obtained when ΔP and A_2 increase.

A_2 ($\times 10^{-9}$ a.u./d^2) \ ΔP(d)	−16	−8	0	8	16
3.	<u>622–2007</u> (1400)	1152–1318 1473–1660 <u>1818–> 4000</u> (> 2200)	1473–1648 <u>1807–> 4000</u> (> 2200)	283–463 583–761 1013–1164 <u>1401–> 4000</u> (> 2600)	<u>< 0–3474</u> 3723–3901 (> 3600)
1.5	<u>1710–2005</u> (300)	1509–1660 <u>1818–2125</u> (300)	1473–1648 <u>1807–2501</u> 2647–2834 (700)	<u>29–3544</u> 3651–3795 (3500)	<u>965–2975</u> (2000)
0.	<u>1710–2005</u> (300)	774–1056 1485–1660 <u>1818–2137</u> 3679–3821 (300)	442–581 652–796 1473–1648 <u>1807–2597</u> (700)	<u>1236–3366</u> 3521–3688 (2100)	<u>< 0–2975</u> (> 3000)
−1.5	1485–1662 <u>1807–2005</u> (200)	1509–1660 <u>1818–2017</u> 2172–2335 (200)	133–452 784–973 1461–1648 <u>1807–2311</u> (500)	823–962 <u>1332–3462</u> (2100)	<u>< 0–2975</u> (> 3000)
−3.	1497–1660 <u>1807–2005</u> 2910–3073 (200)	349–629 905–1660 <u>1818–2017</u> 2160–2326 (200)	345–511 784–962 1461–1648 <u>1807–2299</u> (500)	<u>1343–2798</u> 3074–3237 (1400)	478–639 <u>752–2975</u> (2200)

Table 1. Periods of jovian satellite motion for comet P/Boethin, when ΔP and A_2 vary. Underline: periods enclosing the starting date (1974 Dec. 19); parenthesis indicate the duration of these periods.

A_2 ($\times 10^{-9}$ a.u./d^2) \ ΔP(d)	−16	−8	0	8	16
3.	516–2434 3640–3806 (1100)	<0–> 4000 (> 4000)	1343–> 4000 (> 2700)	<0–> 4000 (> 4000)	<0–> 4000 (> 4000)
1.5	1569–2434 (900)	1104–> 4000 (> 2900)	1233–> 4000 (> 2800)	<0–3866 (> 3800)	785–3117 (2300)
0.	107–465 831–1281 1569–2375 (1400)	466–2350 3679–3821 (1100)	348–3381 (3000)	1018–> 4000 (> 3000)	<0–3192 (> 3200)
−1.5	1367–2446 (1100)	1317–2446 (1100)	<0–2597 (> 2600)	823–3747 (2900)	<0–3105 (> 3100)
−3.	1379–3217 (1900)	<0–2422 (> 2400)	<0–2540 3735–> 4000 (<2800)	620–3521 (2900)	382–3093 (2700)

Table 2. Periods of 1/1 resonance with Jupiter for comet P/Boethin. Same notations as for Table 1.

Moreover, before and after this satellite libration, the comet stays in 1/1 resonance over a longer interval, at least 900 years (see Table 2); during this time, there can be one or several satellite and anti-satellite librations with sometimes intervals of circulation. Generally, the transition between these three types of motion correspond to close encounters with Jupiter, as do the definitive departures from the 1/1 resonance.

As examples, figures 3 a and b show two orbits with a very short interval of 1/1 resonance ($\Delta P=-16$, $A_2=-1.5\ 10^{-9}$) and a very long one ($\Delta P=16$, $A_2=3\ 10^{-9}$).

4. CONCLUSION

We have here confirmed the main result of the previous calculation. We must now determine the interval of time during which the three-body model is sufficient, that is to compare these results with same calculations by four- and nine-body models. In fact, we have as yet compared

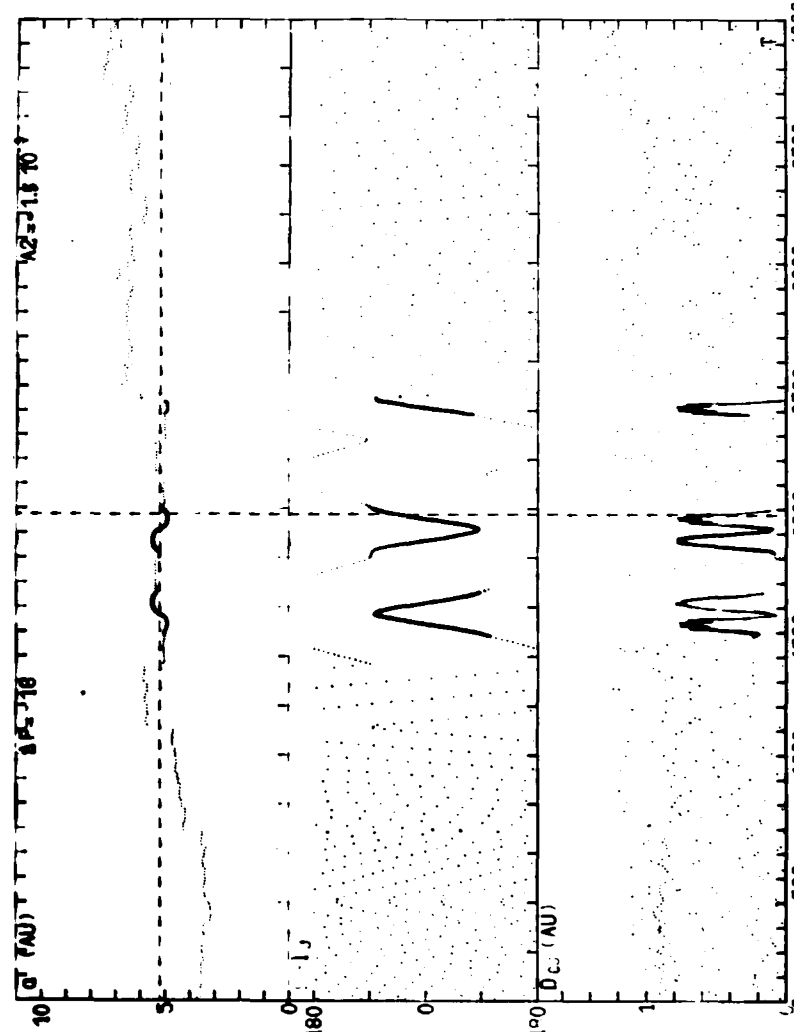

Figure 3a. Elements a, $l-l_J$ and D_{CJ} for P/Boethin when $\Delta P=-16$ and $A_2 = -1.5\ 10^{-9}$, showing a very short interval of 1/1 resonance with Jupiter. Same notations as for Figure 2.

https://doi.org/10.1017/S0252921100096998 Published online by Cambridge University Press

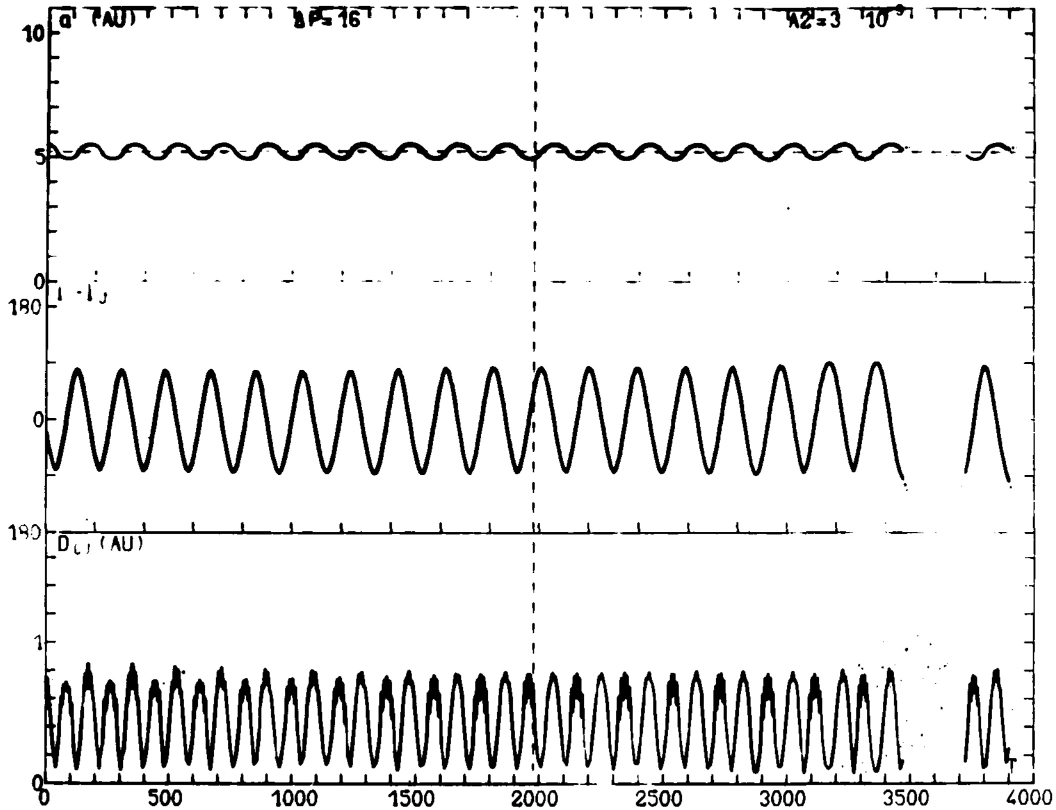

Figure 3b. Elements $\underline{a}$, $l-l_J$ and D_{CJ} for P/Boethin when Δ P=16 and A_2= 3 10^{-9}, showing a very long interval of 1/1 resonance with Jupiter. Same notations as for Figure 2.

the results for three- and four-body models for the 9 orbits where ΔP and A_2 are varied separately, and we have found that a moderately close encounter with Saturn in 1836-37 (Benest et al., 1982) causes an appreciable divergence between the orbits before this date; however, for the future, the two models seem in good agreement during a longer interval of time.

Finally, we must wait for the next perihelion passage of the comet in 1986 to establish the real value of ΔP and for yet another perihelion passage ($\sim$ 1997) to determine the value of A_2.

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