PLANETARY CLOSE ENCOUNTERS: AN INVESTIGATION ON TEMPORARY SATELLITE-CAPTURE PHENOMENA

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This research is part of a wider one (Carusi & Pozzi,1978a,b) concerning a detailed study of the dynamics of close encounters between a giant planet and a minor object. A special result of that investigation was the recognization of some satellite-capture events,already found by Everhart (1973). An important remark about this previous work is that all satellite-captures occurred with low inclination objects which orbits were initially near-tangent to the Jupiter's one. Starting from this consideration,a hundred fictitious orbits have been generated in order to study the phenomenon in greater detail. Their initial distribution is shown in fig.1. The initial angular parameters i,ω,Ω,were chosen to be equal to those of the most interesting case of the previous research. Eccentricities were selected regularly in the range .01-.5,with a step of .01, giving the same value to an object of the upper band and to the next of the lower. The semimajor axes were chosen at random between limits computed so that the aphelion for the lower band,or the perihelion for the upper band,would lie within a distance of 10^8km from Jupiter's orbit. As the orbital planes do not coincide with that of Jupiter,the minimum distance point between the two orbits does never coincide with the object perihelion or aphelion,but is always close to them. Fig.2 shows the final situation of this population:we note that in no case a permanent binding occurred. We can do some remarks on this picture. First of all we note that 56% of objects experienced a temporary binding to the planet. Secondly,67% of objects,bounded or not,had a final orbit lying, on the a-e diagram,on the opposite band with respect to their initial one. This kind of transition is especially significant if compared with the case of observed comets,because it gives a simple mechanism to transform long-period comets in short-period ones, and to transfer comets from one family to another. Actually,on the basis of the computations of Kazimirchak-Polonskaya (1972),we can say that a similar process has been experienced, for example,by comets Whipple,Oterma,Brooks 2,Lexell,Kearns-Kwee and o-

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thers. A third remarkis that,between the initial and final situations, small eccentricities are increased,as a consequence of the encounter, whilst the great ones are decreased. This phenomenon leads to a clustering of final orbits in the eccentricity range .1-.2.

It is quite interesting to analyze,just to give an example, the path of object 24 in a jovicentric rotating frame,as shown in fig.3 This object binds itself to Jupiter at point a,then becomes temporary unbounded from the Sun between the points b and c,and finally it unbinds itself from the planet at point d. The maxima and minima of semiaxis occur in correspondance of the conjunctions. We call inner conjunction the one in which the object is located between Jupiter and the Sun,the other situation representing an outer conjunction. Then,we note that a maximum of semiaxis always occurs during an inner conjunction on a retrograde planetocentric orbit,or during an outer conjunction on a direct planetocentric orbit. The minima of semiaxis occur in the remaining two cases. In order to get a better understanding of these occurrencies we can use the formulas for heliocentric energy and angular momentum:

$$E = mv^2/2 - GmM/r = - GmM/2a$$

$$|\underline{L}| = mvr \sin\varphi = m\sqrt{GM}\sqrt{a(1-e^2)}$$

It is easy to see that we have relative maxima of E and $|\underline{L}|$,and then of a, in a direct outer conjunction,and relative minima in a direct inner conjunction. From an exam of our objects we have seen that,for a retrograde planetocentric orbit,things go the opposite way. It follows,for instance,that an object can unbind itself from the Sun only in inner retrograde or in outer direct conjunction. Fig.4 clearly explains what we said. In this picture the energy and angular momentum with respect to the Sun are plotted. The abscissa gives the number,to be multiplied by 50,of the integration time steps,and so it is a not linear time scale. We can note that the positions of maxima and minima are in good agreement with what we said. Moreover,in these points the object is always near to its osculating perihelion or aphelion. Referring to the "mirror theorem" demonstrated by Roy & Ovenden (1955),we note that in the case of number 24 we have three instants in which a configuration of this kind is quite well verified,that is in the 3rd,5th and 6th conjunctions. The mirror theorem,however,is not completely satisfied,because in none of these conjunctions Jupiter is located on its aphelion or perihelion,and the lines of nodes are not aligned. Now a comparison with a really observed case is quite interesting:that is the case of comet Oterma,which orbital evolution has been analyzed by Kazimirchak-Polonskaya (1967). An inspection of the orbital history of this comet shows that,with respect to July 1950,

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the evolution was almost symmetric for a period of about 17 years forwards and backwards. Fig.5 shows this symmetry for the semiaxis and the eccentricity. Let's now spend some words about another quite interesting experimental evidence, that is the case of the objects 25 and 28. The trajectories of these two bodies are shown in figs.6 and 7: they can overlap by a rotation of π about z-axis. In fact, the maxima and the minima of E and $|L|$ of number 25 coincide with the minima and the maxima respectively for number 28. Similar cases occur even when the objects, although bounded to Jupiter, do not close any orbit about it.

Owing to the scarceness of the allowed space, we have limited ourselves to a few comments. A more complete discussion of our results will be published elsewhere.

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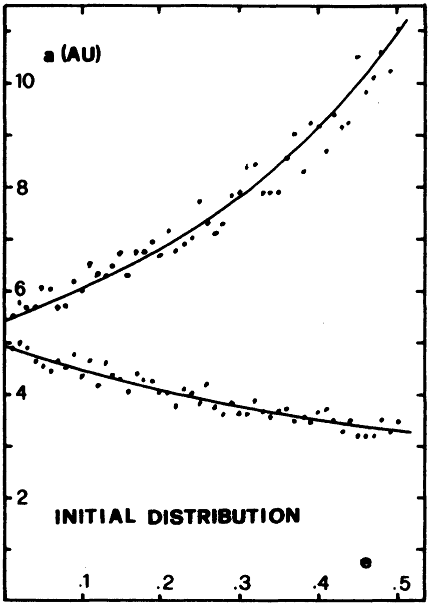

Fig. 1

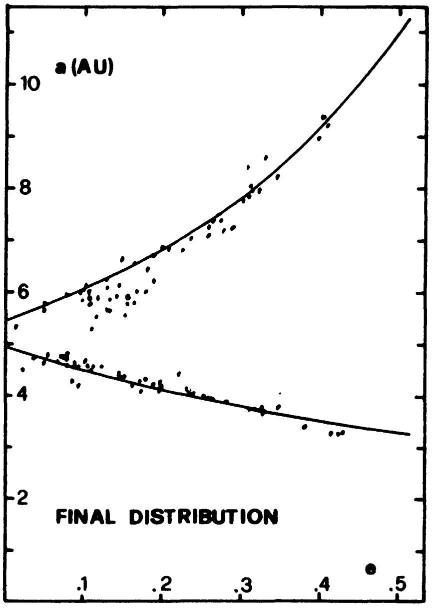

Fig. 2

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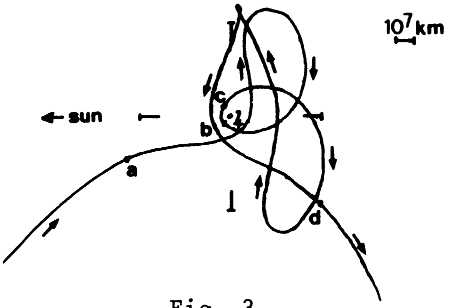

Fig. 3

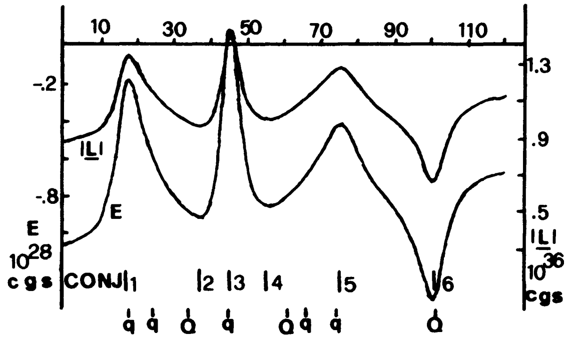

Fig. 4

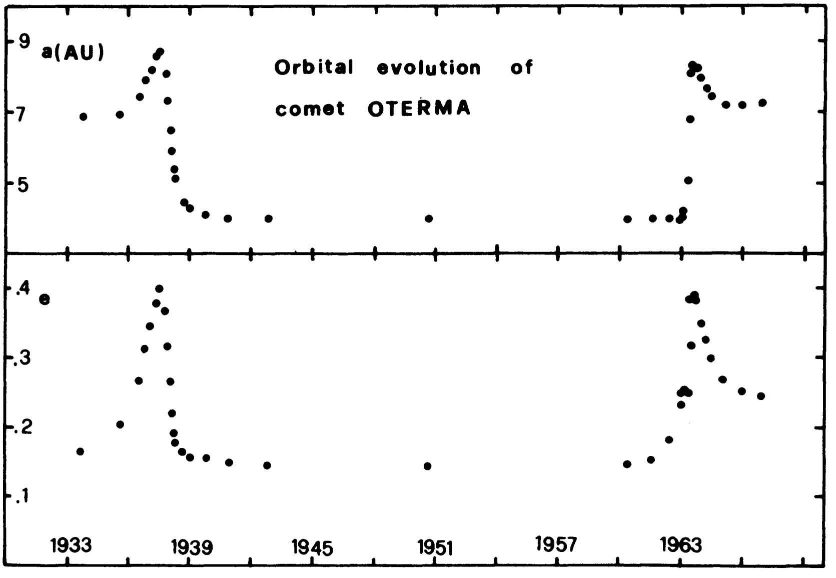

Fig. 5

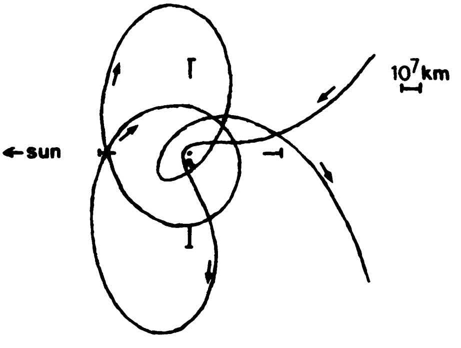

Fig. 6

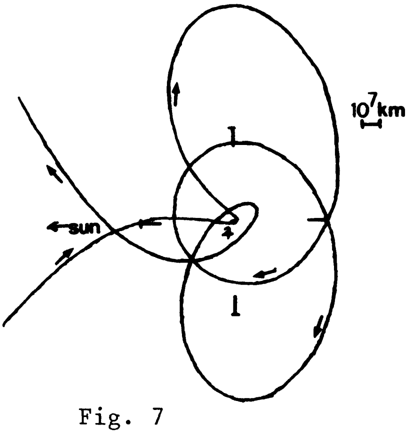

Fig. 7

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DISCUSSION

Szebehely: What equations did you integrate, the circular or the elliptic restricted problem? In the first case, did the Jacobian constant have a constant value? Did you use regularization at the close approaches?

Carusi: I have used the Greenspan's "discrete mechanics" (LeBudde & Greenspan:1976,Numer.Meth.25,323; 1976,Numer.Meth.26,1) which consists in recursive formulas giving positions and velocity components for all bodies. The main feature of that method is the exact conservation of the invariants of motion for any n-body system, without restrictions on the initial mass distribution. During the close approach the integration time step is automatically scaled, proportionally to the relative distance of the two bodies, which cannot become less than 7×10^5 km (~ Jupiter's radius). In this case a collision occurs. Positions and velocities are computed in a heliocentric ecliptical reference frame; in its last version the computer program supplies, at every time step, the osculating heliocentric and jovicentric parameters, together with other useful quantities, such as heliocentric and jovicentric energies, angular and linear momenta, components of the Landau vector, Tisserand and Collenbreau-Motukume invariants, and so on. The computation is fast: 100 close encounters (mean time length about three years) are computed in about ten minutes of a UNIVAC 1106.

Kresak: This is just a nice example of the difference in the behavior of the Jacobi integral and Tisserand invariant. While both of them remain approximately constant before and after the perturbation, the Tisserand value may change appreciably during the approach. This is due to the neglected term containing the reciprocal distance from Jupiter. However, even the Tisserand criterion resumes its original value after the encounter, except for a small deviation produced by Jupiter's orbital eccentricity.

Carusi: This is true: the Tisserand constant may change even on the first decimal digit, during the close encounter. It must be noted, however, that the variations between initial and final values are not so small. We have found variations of the order of ± 1% or 2% with respect to the initial value.

Dvorak: Did you use Tisserand's criterion in your numerical calculations?

Carusi: My numerical method consists in solving the Newtonian equations of motion directly, by means of the "discrete mechanics" method of Greenspan (LeBudde & Greenspan,1976: Numer.Meth.25, 323; Numer.Meth.26,1), so I can use the actual positions and velocities of all objects. I can compute the Tisserand invariant, but I've found that it is not invariant when the objects are very close (~10^8 km).

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