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LIFETIME OF BINARY ASTEROIDS VS. GRAVITATIONAL ENCOUNTERS AND COLLISIONS

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Abstract : In this paper we investigate the effect on the dynamics of a binary asteroid in the case of a near encounter with a third body. The dynamics of the binary is modelled as a two-body problem perturbed by an approaching body in the following ways: near encounters and collisions with a component of the system. In each case, the typical value of the two-body energy variation is estimated, and a random walk for the cumulative effect is assumed. Results are applied to some binary asteroid candidates. The main conclusion is that the collisional disruption is the dominant effect, giving lifetimes comparable to or larger than the age of the solar system.

Introduction

The first indirect observations of binary asteroids have been made between 1977 and 1980. These observations are compiled in the article by Van Flandern et al in the 1979 *Asteroids* book. More recently, new observational evidence has been obtained. The secondary event observed during a stellar occultation by 146 Lucina (Arlot et al., 1985), peculiar light curves analysis by Leone et al. (1984), Cellino et al. (1985) and the spectacular observation by Ostro et al. in August 1989 (Ostro et al., 1990) increase the plausibility of the existence of binary asteroids.

This increasing number of observations has raised questions as to the stability and dynamical evolution of putative binary asteroids. Whipple and White (1985) and Zhang and Innanen (1988) have numerically investigated the effects of solar and Jovian perturbations on the relative motion of a binary asteroid over durations of the order of thousand years. More recently, Chauvineau and Mignard have obtained an estimation of the lifetime of a binary asteroid versus solar and Jovian tidal perturbations (1990a,b) and find that Jupiter causes a destabilizing effect over timescale comparable to the age of the solar system if the components are separated by a distance exceeding a few tens of radii of the primary.

In this paper, we present estimates of the typical lifetime of a binary asteroid versus close encounters and collisions.

I. Principle of the estimation

We do not present here the detailed study of close approaches and collisions, but only the main ideas of the developments together with the major results. See Chauvineau et al. (1992) for the detailed derivations. One must distinguish approaches, either close or distant, from the physical collisions.

1) Encounter cases

In case of encounters, the typical energy variation is estimated in three cases:

a) penetrating encounters: the impact parameter of the third body is comparable to the separation of the binary components. In this case, the effects of the encounter are different on each component of the binary asteroid;

b) close encouters: the impact parameter is larger than the orbital radius of the binary, but the encounter duration is short compared with its period. In this case, the effects on the two components of the binary system are comparable and the Hill's formalism is used (Chauvineau and Mignard, 1990c);

c) far encounters: here again, the impact parameter is much larger than the orbital radius, but the system completes several revolutions during the encounter time. For the same reasons, the Hill's formalism is used in this case too.

The cumulative effect in these three cases are estimated using the number of encounters per time interval dt:

$$d^3N = f(m)dm 2\pi b\, db \frac{P_i}{\pi} dt$$

where $f(m)dm$ is the number of asteroids in the masse range $[m, m+dm]$ and b is the impact parameter. A power law ($f(m) \propto m^{\gamma}$) is assumed for f. P_i is a probability of encounter per unit surface and per unit time (Wetherill, 1967; Farinella and Davis, 1991) and d^3N is the number of asteroids of mass $[m, m+dm]$, passing at the distance $[b, b+db]$ of the binary system in the time interval $[t, t+dt]$. The energy diffusion is computed from a one-dimensional random walk. The binary asteroid is destroyed when its binding energy becomes positive. We find that the cumulative effect of far encounters is always negligible compared to the cumulative effects of close encounters.

2) Collision cases

In this case, the third body impacts with one of the two binary asteroid components. The effect of such an event can be sufficient to destroy the system. Two cases are considered:

a) Ejection: in this case, the anelastic asumption is made. The impacting and the impacted bodies are assumed to stick to each other after the collision. There is ejection if the energy of the new binary system is positive after the impact. Assuming here again a power law for f of exponent γ, it is found that the satellite ejection is more probable than the primary one because $\gamma \simeq 1.83 > 5/3$.

b) Collisional disruption: we consider in this case that the impacted asteroid (target) is broken up by the impacting object. This phenomenon occurs if:

$$\frac{M_{proj}}{M_{target}} > \frac{4S}{\rho V^2}$$

where V is the impact velocity, ρ the typical asteroidal density and S the impact strength (Davis et al., 1989; Davis and Ryan, 1990; Housen and Holsapple, 1990).

II. Results

We give here typical lifetimes of some binary candidates versus the different phenomenons listed previously. τ_1, τ_2, $\tau_{c.ej.}$ and τ_{dis} are respectively lifetimes for penetrating and close encounters, collisional ejection and disruption. Lifetimes are given in years.

146 Lucina

For this asteroid, one finds $\tau_1 = 1.7\ 10^{12}$, $\tau_2 = 1.4\ 10^{11}$, $\tau_{c.ij.} = 1.8\ 10^{10}$ and $\tau_{dis} = 2\ 10^9$.

216 Kleopatra

For this asteroid, one finds $\tau_2 = 9\ 10^{11}$, $\tau_{c.ij.} = 1.2\ 10^{11}$ and $\tau_{dis} = 3\ 10^{10}$. In this case, τ_1 has no significance because collisions occur before cumulative effects of penetrating encounters are efficient.

532 Herculina

For this asteroid, one finds $\tau_1 = 1\ 10^{13}$, $\tau_2 = 1.4\ 10^{12}$, $\tau_{c.ij.} = 1.3\ 10^{11}$ and $\tau_{dis} = 9\ 10^9$.

1220 Crocus

For this asteroid, one finds $\tau_2 = 1\ 10^{10}$, $\tau_{c.ij.} = 7\ 10^9$ and $\tau_{dis} = 3\ 10^9$. In this case again, τ_1 has no significance.

The conclusion is that these lifetimes are generally greater or of the order of the age of the solar system, and that binary stability in the present solar system is limited by collisional disruptions.

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