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ROTATION OF SPLIT COMETARY NUCLEI

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Abstract

A simple model for the rotational motion of split cometary nuclei is studied. A large-amplitude precession is easily excited due to the change of the moments of inertia even if the perturbation is small at the splitting. The damping timescale of the excited precession is widely ranged because of the uncertainty of the physical parameter of cometary nuclei. We also discuss another possibility for clarifying the evolution of the short period comets by studying the split cometary nuclei.

1 Introduction

The rotation of split cometary nuclei is important for studying the internal structure of nuclei. The split nuclei may experience two phases; excitation of the precession, and its damping. The precession may be excited due to the change of the moments of inertia, or to mechanical forces in the splitting, or to the torque caused by the repulsive forces of jets from newborn active regions. Because the situation is too complicated to be modeled, no theoretical work has been done for the rotation of the split cometary nuclei. We model the excitation of the precession by considering only the change of the moments of inertia in this paper, and show high probability of the large precession. The damping of this precession is also discussed in this paper.

2 Excitation of the Precession

We consider a simple model for studying the effect of the change of the moments of inertia at the splitting, assuming a small perturbation. Considering that a nucleus of the axial ratio $1 : b : c$ with a homogeneous density ρ splits by a plane at the position P in the x-axis, new moments of inertia of the spilt nucleus are

$$I_x = K(b^2 + c^2)(8 - 15P + 10P^3 - 3P^5), \quad (1)$$

$$I_y = K[8(1 + c^2) - 15c^2P - 10(2 - c^2)P^3 + 3(4 - c^2)P^5] - M\delta x, \quad (2)$$

$$I_z = K[8(1 + b^2) - 15b^2P - 10(2 - b^2)P^3 + 3(4 - b^2)P^5] - M\delta x, \quad (3)$$

where $K = \rho\pi bc/60$, M is the mass of the fragment as $\rho\pi bc(1 - P)^2(2 + P)/3$, and δ is the distance between the new and old centers of gravity as $\delta x = 3(1 + P)^2/4(2 + P)$. According to the observational suggestion(Sekanina 1982), we take the parameter P so that the mass ratio does not exceed 0.05.

2.1 Spherical Nucleus($b = c = 1$): The split makes drastic change in the moments of inertia. For example, the fragment mass ratio 0.05 gives $P = 0.7$, and the resulted ratio of the moments of inertia is 1.0:0.9:0.9. The trace of the angular momentum on the nucleus is shown in figure 2. The bold arrow is the original direction of the angular momentum vector, and the circular curves indicate the traces on which the angular momentum vector moves along. Because the angular momentum vector is constant in the inertia space, the nucleus could be up-side-down. This means the large amplitude precession. It should be noted that all the cases in the spherical nucleus is the same situation even if the fragment is small.
2.2 Prolate Nucleus($b = c$): The original nucleus has a tendency to be precessing in a large amplitude. In case of Comet P/Halley, the trace of the angular momentum is long and slender, then we have a relation indicating that a small perturbation causes the large amplitude precession(Watanabe 1989). Because this characteristic holds generally after splitting in the prolate nucleus, the large amplitude precession is easily excited.
2.3 Oblate Nucleus($b = 1$): The nucleus with higher oblateness such like Comet P/Tempel 2(Sekanina 1987) is more stable for the precession. In the low oblateness nucleus like Comet P/Encke (Whipple and Sekanina 1979), the precession is easily excited.

Even if we consider the effect of the change of the moments of inertia only, the first conclusion is that split nuclei would have a large precession unless it was highly oblate one. It should be noted that the particular precession staes are entirely dependent on the particular assumption allowing this calculation. Other effects at the splitting would increase the possibility of the large precession.

3 Damping of the Precession

The damping timescale τ is derived by considering the internal energy dissipation (Burns and Safronov 1973) as $\tau \sim k\mu Q/\rho R^2\omega^3$, where μ is the shear modulus, Q the quality factor, R the radius, ω the rotation angular verocity, and k is the shape factor of $O(10)$. The damping time scale depends on the internal physical condition. Although we do not know such infromation, some experimental data on the ice are used for this estimate. However, the published data for shear modulus and the quality factor are widely ranged(Peale and Lissauer 1989). The damping timescale ranges several $10^4 (Q \sim 10, \mu \sim 10^{11})$, up to $10^7 (Q \sim 10^3, \mu \sim 10^{12})$ yrs. Therefore, it is reasonable that split cometary nuclei are in the precession states.

In this point of view, we observed Comet P/Taylor, which is one of survived split cometary nuclei, during the apparition of 1990-1991 by using the CCD direct imaging technique. Preliminary result for the light curve is, however, too sparce to say anything about the rotational state because of the poor observational condition.

4 Discussion

There are some further possibilities for the nucleus rotation of the split cometary cuclei. If the damping time scale is not short, it may give information not only on the internal structure, but also the evolution of the short period comets. If other short period comets have precession as same as the known split nuclei, then there may be a possibility that short period comets comes from the split orgin(Clube and Napier 1984). Otherwise, it means that the split evolution may be impossible, and we need other model, for example, the inner Oort cloud or Kuiper belt(Weissman 1991), to explain the unbalance of the number flux between the short and long period comets. It should be noted that this argument is not so strong because we must study the effect of the torque originated from jets, which is neglected in this paper(Belton 1991).

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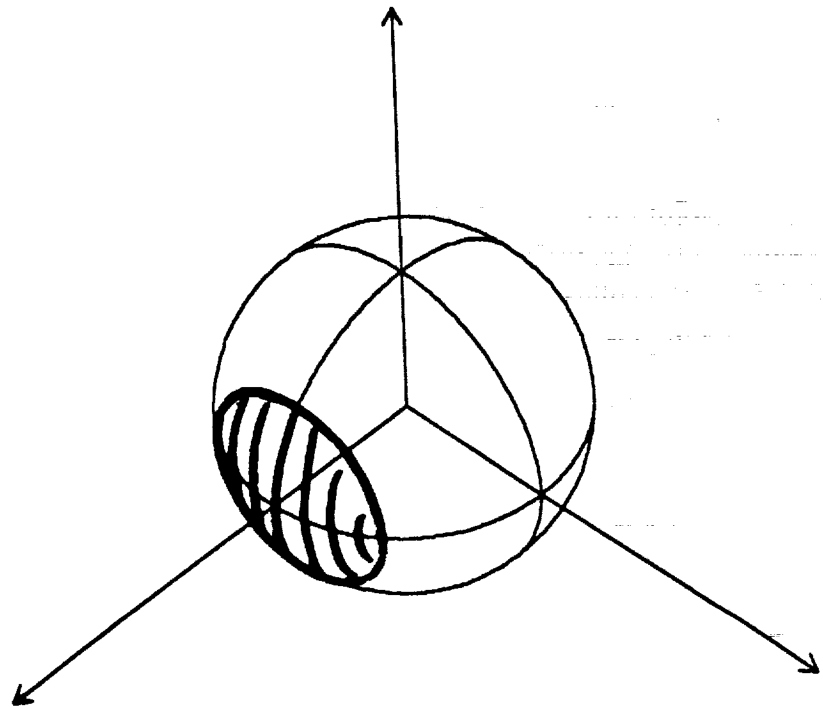

Figure 1: Split model of the spherical nucleus in case of the mass ratio 0.05

Figure 2: Traces of the angular momentum vector on the remnant nucleus of splitting in figure 1. The traces are concentric circles. Note the original angular momentum vector(bold arrow) become unstable for the perturbation.