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Interstellar Object Rotation with the Mechanical Torque Produced by Interstellar Medium

Wenhan Zhou (1)
(1) Department of Physics, HKU, HK, China (u3006384@connect.hku.hk)

Abstract

1. Introduction

The first interstellar object (ISO) was discovered in 2017, which is in an excited rotation around non-principal axis, or say tumbling[2]. Interstellar objects are still mysterious to us since no sufficient information is revealed by the observation data. Studying its rotational dynamic is beneficial to understand its origin and history. The damping time of its tumbling is estimated to be around 10 billion years due to its internal energy dissipation caused by inelastic deformations[1]. However, Considering such a large timescale, some tiny effect, collision with interstellar medium, can potentially cause considerable change in its rotation state. This study explored the influence of ISOs' collision with interstellar medium when they travel through interstellar space.
The mechanism of collision with interstellar medium is similar to YORP effect. As the starlight in interstellar space is dim, the YORP effect is not significant during the ISO's interstellar travel. However, interstellar medium will be reflected after colliding with ISOs, and produce a continuous mechanical torque on the body, causing the changes in angular momentum of the body relative to its center of mass. As this process lasts for ten billion years, the changes will integrate to a large amount.

2. Equations

The total angular momentum transferred to the interstellar object in one time interval can be obtained by summarizing that of all the faces:

$$\delta\vec{L} = \sum_i m n_p (\vec{v}\cdot\vec{n})^2 \delta t S_i (\vec{r}_i \times \vec{n})\gamma_R \tag{1}$$

The rotation of interstellar object obeys Euler's motion equation:

$$\frac{d\vec{L}}{dt} = \frac{d'\vec{L}}{dt} + \vec{w}\times\vec{L} \tag{2}$$

The shape model is Gaussian random sphere, where the distance on the surface is the function of the polar angle and azimuthal angle:

$$r_s(\theta,\phi) = a(1+\sigma^2)^{-1/2} e^{\omega(\theta,\phi)}, \tag{3}$$

$$\omega(\theta,\phi) = \sum_{l=1}^{l_max}\sum_{m=0}^{l} P_l^m(cos\theta)(a_{lm}cosm\phi + b_{lm}sinm\phi) \tag{4}$$

$$\beta_{lm}^{-\alpha} = (2-\delta_{m0})\frac{(l-m)!}{(l+m)!}c_l ln(1+\sigma^2) \tag{5}$$

$$c_l = l^{-\alpha}\left(\sum_{l=1}^{l_max} l^{-\alpha}\right)^{-1} \tag{6}$$

3. Summary and Conclusions

This study builds different shapes of the interstellar objects. It is found that the irregularity of the body and direction of the incoming gas are the two prime factors of the effect of collision. The collision effect may compete with the body's internal energy dissipation as a mechanism of changing small ISO's rotation state. What's more, we estimate a maximum distance Oumuamua' travels since its last collision or other event that changed its rotation.

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