Numerical analysis of particle distribution with collisions around an asteroid

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Abstract

In "Hayabusa 2" project, it is planned to make a crater on a target asteroid by an impactor. Then, in order to operate the spacecraft safely, it is important to analyze the motions of particles ejected from the asteroid. In this study, the orbit motions of particles around the asteroid are analyzed by numerical simulation which contains collisions between particles treated by statistical method.

衝突を考慮した小天体まわりの粒子分布解析

要旨

現在開発が進んでいる「はやぶさ２」プロジェクトでは，小惑星に衝突体を突入させクレーターを作るということが計画されている．その際に舞い上がる粒子の振る舞いを知ることは，探査機を安全に運用するために重要である．そこで本研究では，舞い上がった粒子の小惑星周りの軌道運動を，粒子同士の衝突を統計手法により取り入れながらシミュレーションを行った．

1. Introduction

In "Hayabusa 2" project, it is planned to make a crater on a target asteroid 1999JU3 by an impactor. According to the 2-body problem, an ejected particle, whose velocity is under the escape velocity, falls to the surface of asteroid without exception. In actual situation, however, the applied force to the particles is not only the gravity of asteroid, i.e. gravity ununiformity, solar radiation pressure (SRP), tidal force, and collisions between particles. By these perturbations, it is probable that the ejected particles remain on orbits around the asteroid. These particles may have harmful effect to the Hayabusa 2 mission if these particles collide against the spacecraft or choke thrusters. Then it is necessary to simulate the motion of these ejected particles. In this paper, this particle simulation is provided with statistically method diverted from computational fluid dynamics.

2. Calculation Model

2.1 Target Asteroid

Target asteroid is the 1999JU3 in this paper.

Table1 gives the physical geometries and Table2 shows Keplerian Elements of the 1999JU3. The parameters using in numerical simulations are based on these properties.

ID	1999JU3 (C-type asteroid)
Diameter	0.87±0.03 km (axial ratio 1.0 : 1.1: 1.3)
Volume	3.4×10^{8} m^3
Density	500 ～ 4000 kg / m^3 (nominal 1400 kg / m^3)
Mass	1.7×10^{11}～1.4×10^{12} kg
μ	11～92 m^3 / s^2 (nominal 32 m^3 / s^2)
Period of rotation	7.5 hours

Table 1 physical geometries of 1999JU3

Epoch	55400 TDB MJD
a	1.1896 AU
e	0.19022
i	5.8832 deg
ω	251.63 deg
Ω	211.43 deg
M	338.86 deg

Table 2 Keplerian Elements of 1999JU3
(J2000EC ecliptic coordinate)

2.2 Calculation Model

In numerical simulations, following perturbations are considered;

1) Gravity Ununiformity (only oblateness)
2) Solar radiation pressure
3) Tidal force
4) Collisions between particles

Dissolution of particles by collisions is not considered for simplicity.

Table3 shows the numerical conditions.

Coordinate	Asteroid-centered inertial frame
Δt	10 sec
Integration	4^{th} order Runge-Kutta method
Computational Mesh	r $40\times$ θ $40\times$ ϕ 80
Sample numbers	1000000
Location of crater	On the equator

Table 3 numerical conditions

2.3 Model of Collisions

In this paper, the collisions between particles are treated statistically. This method is frequently used when rarefied flows are simulated.

By kinematical analysis, at first, mean free time τ is given as follow;

$$\tau = \frac{1}{\pi d^2 n v_{rel}}$$

where d is diameter of particle, n is particle number density, and v_{rel} is mean relative velocity of particles. By this equation, a number N, which one particle collides within one second, is estimated as

$$N = \frac{1}{\tau}$$

In the simulation, the collisions are treated as perfectly elastic collision, i.e. the energy is not dissipated by collisions

2.4 Initial Condition

This simulation needs the initial conditions of ejected particles such as

1) Distribution of direction vector
2) Distribution of velocity magnitude
3) Distribution of mass

The purpose of this paper is to simulate the particle motions pessimistically. Hence, it is enough that the initial condition in computation contains the initial condition in actual situation. Then, the initial condition of ejected particles is defined as follow:

1) Distribution of direction vector: uniform within 2π sr
2) Distribution of velocity magnitude: uniform within 0~43 cm/s (plus rotational velocity of asteroid 10 cm/s)
3) Distribution of mass: shape of particles is sphere. Size of particle is d = 1mm or d = 0.1mm.

Figure1 is the initial Keplerian Elements a (the semi-major axis) and e (eccentricity) of ejected particles obtained from this initial condition.

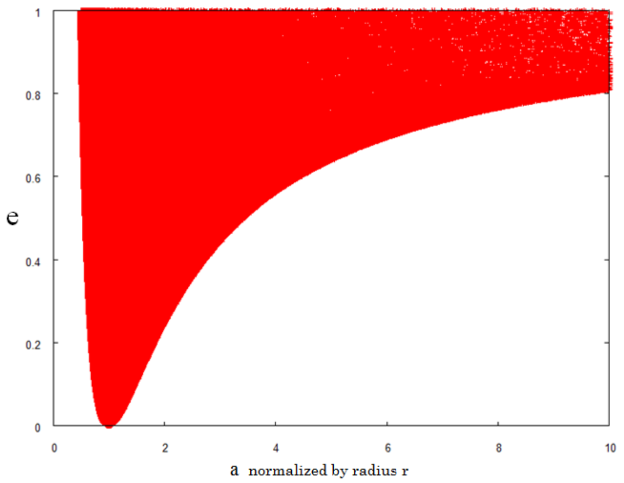

Figure 1 initial a and e of ejected particles

3. Result

3.1 gravity vs sun radiation pressure

At first, the magnitudes of the force delivered from gravity and solar radiation pressure are compared. Table4 shows that solar radiation pressure is greater than gravity when the size of particles fall below 1μm. Therefore the particles, which are smaller than 1μm, are blown away by solar radiation pressure so that these particles can not remain around asteroid.

diameter [m]	gravity [N]	SRP [N]	gravity / SRP
1	4.97E-02	3.53E-08	1.41E+06
1.00E-01	4.97E-05	3.53E-10	1.41E+05
1.00E-02	4.97E-08	3.53E-12	1.41E+04
1.00E-03	4.97E-11	3.53E-14	1.41E+03
1.00E-04	4.97E-14	3.53E-16	1.41E+02
1.00E-05	4.97E-17	3.53E-18	1.41E+01
1.00E-06	4.97E-20	3.53E-20	1.41E+00
1.00E-07	4.97E-23	3.53E-22	1.41E-01
1.00E-08	4.97E-26	3.53E-24	1.41E-02
1.00E-09	4.97E-29	3.53E-26	1.41E-03

Table 4 gravity vs sun radiation pressure
(a = 800 m and location of asteroid is AU)

3.2 Numerical Result

Numerical simulations are performed in 2 cases.

Case1: particle size is 1 mm

Case2: particle size is 0.1 mm

Figure.2-5 show the Keplerian Elements a and e of remaining particle after 1 day and 2 days. All figures show that the particles which have small a fall to the surface quickly. It is because the period of these particles is short.

The difference between case1 and case2 shown in figure 2-5 is induced by solar radiation pressure. That is, in case2, the magnitude of solar radiation pressure is relatively large compared to gravity (see in Table4) so that orbits are flown down and e becomes small.

Figure6 is a graph of time elapsed vs remaining particle. This figure indicates that perturbations have only a slight influence on how many particles remains around asteroid. Perturbations have only influence on remaining particle originally.

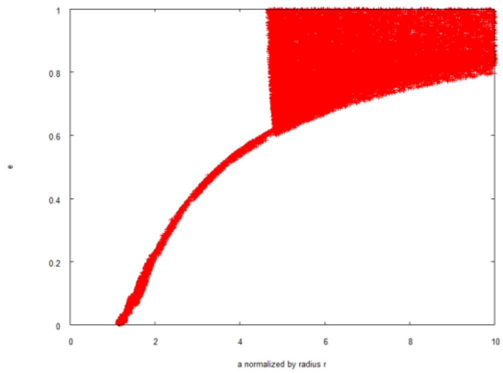

Figure 2

case1: 1 day later

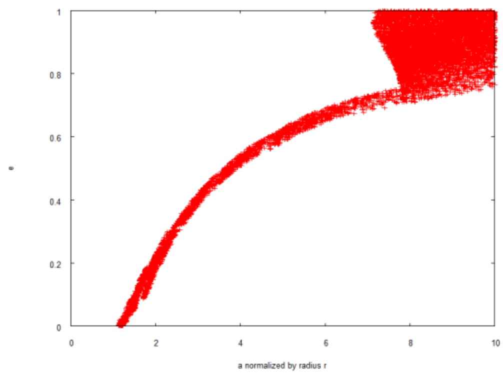

Figure 3

case1: 2 days later

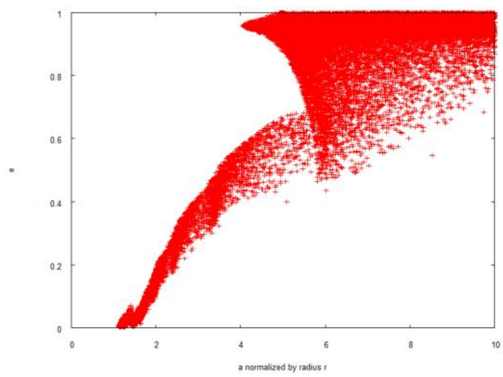

Figure 4

case2: 1 day later

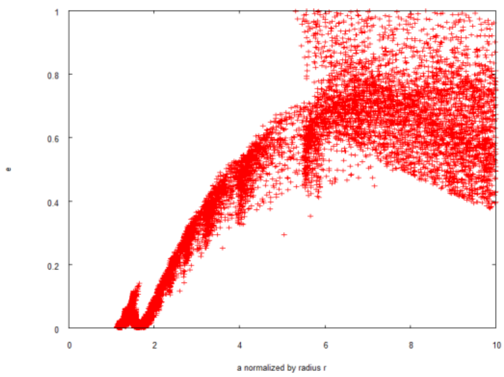

Figure 5

case2: 2 days later

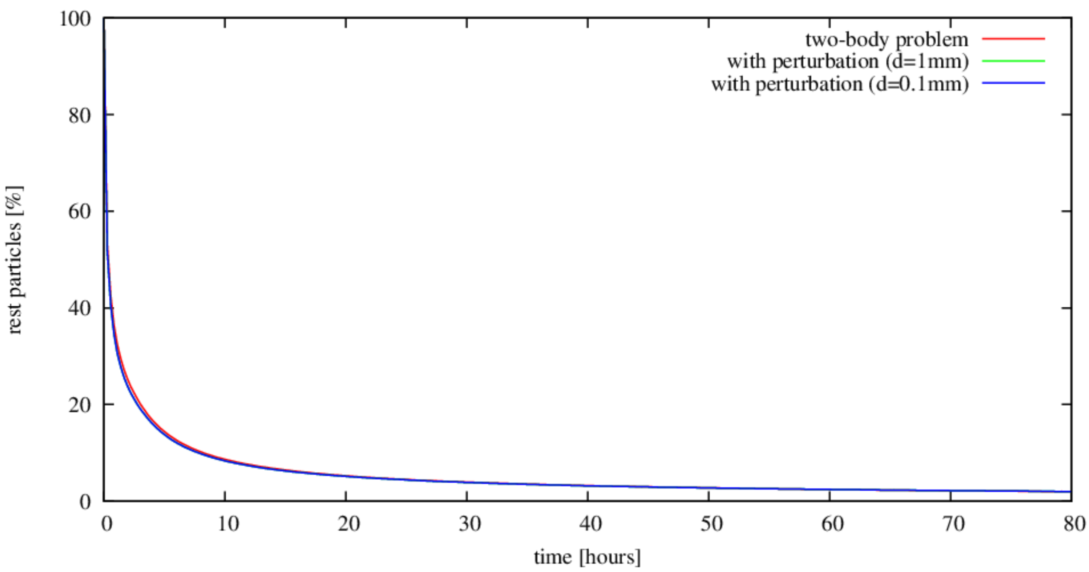

Figure 6 remaining particles around asteroid

Table5 shows time elapsed vs collision numbers. This table shows that collisions happen right after crater making. On numerical simulations, the effect of collisions can be absorbed into initial conditions, so that it is unnecessary to consider the collision effect in this simulation.

Time elapsed [min]	Collision numbers 1mm	Collision numbers 0.1mm
0.17	72431	732740
0.50	3302	37794
1.00	317	3702
1.50	65	698
2.00	25	229
2.50	6	82
3.00	2	24
3.50	0	15
4.00	0	12

Table 5

Time elapsed vs collision numbers

4. Conclusion

In this paper, the motions of ejected particles from 1999JU3 are simulated with collisions. These simulations show that perturbations, especially solar radiation pressure, have a great influence on small particles and show that collisions happen only right after crater making so that it is unnecessary to consider collisions between particles in this simulation.

References

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