Impact Conditions for the Formation of the Extremely Elongated Shape of 1I/’Oumuamua

*Keisuke Sugiura[1], Hiroshi Kobayashi[1], Shu-ichiro Inutsuka[1]

1. NAGOYA UNIVERSITY Graduate School of Science

1I/’Oumuamua is considered to be the first interstellar object observed by the Pan-STARRS telescope on October 2017. The eccentricity of 1I/’Oumuamua is about 1.2, which corresponds to the relative velocity with respect to the sun at infinity of 26 km/s. This relative velocity at infinity is comparable to the relative velocity of solar neighborhoods, and thus we consider that 1I/’Oumuamua came from a nearby planetary system. The absolute magnitude of this object is about 22 magnitude, which corresponds to the size of about 100 m with the albedo of 0.04. This object shows large light curve amplitude of at most 2.5 magnitude, and the shape of 1I/’Oumuamua is estimated to be the extremely elongated one with the ratio of the intermediate to major axis lengths less than 0.3.

To examine whether asteroidal impacts can form the extremely elongated shape of 1I/’Oumuamua or not, we conduct numerical simulations of collisions between asteroids. We use a Smoothed Particle Hydrodynamics code for elastic dynamics with the self gravity, a fracture model for rocky material, and a friction model for completely damaged rocks. We assume that impacting bodies do not have tensile strength of monolith bodies but have frictional forces of granular material. The diameter of target bodies is fixed to 100 m. We conduct impact simulations with various ratios of the masses of two impacting bodies, friction angles, impact angles, and impact velocities, and then we investigate the impact conditions required for the formation of the extremely elongated objects with the ratio of the intermediate to major axis lengths less than 0.3.

As a result of the impact simulations, we find that the formation of the extremely elongated bodies requires the mass ratio larger than 0.5, the friction angle larger than 40 degrees, the impact angle less than 30 degrees, and the impact velocity less than 40 cm/s. The most difficult condition to be realized among these conditions is the impact velocity; the required impact velocity is much smaller than the average impact velocity in the main belt ~ 5 km/s.

The impact velocities less than 40 cm/s require dynamically cold environments in protoplanetary disks. However, turbulent scattering due to gas or gravitational scattering due to larger bodies increase the relative velocities. We estimate required turbulent strength and the size of larger bodies and find that the Shakura-Sunyaev alpha parameter less than $10^{-4}$and the size of larger bodies less than 7 km realize the relative velocities between 100-m sized bodies less than 40 cm/s. This turbulent strength is realized at the places where magnetorotational instability is not active. The size of bodies less than 7 km is realized only in extremely young protoplanetary disks. Therefore,1I/’Oumuamua might have been formed in such an extremely primordial protoplanetary disk, then might have been ejected from the planetary system due to, for example, a stellar encounter, and then visited our solar system.

Keywords: 1I/’Oumuamua, extremely elongated shape, asteroidal impact, numerical simulation, SPH method

