ORIGIN OF 1I/'OUMUAMUA: A TIDAL DISRUPTION FRAGMENT. Y. Zhang[1], [1]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, CS 34229, 06304 Nice Cedex 4, France, yun.zhang@oca.eu.

Introduction: 'Oumuamua (1I/2017 U1) was the first macroscopic object observed to traverse the inner Solar System on an unbound hyperbolic orbit [1]. It has an unusually elongated shape with a short-to-long axis ratio < 1:6 and is experiencing rotational tumbling and showed no evidence of cometary activity, while its optical colors are similar to those of cometary nuclei, and non-gravitational acceleration probably due to outgassing was detected in its motion [2]. Its discovery, despite its low detection probability, implies a vast population ($\sim 3.5 \times 10^{13} - 2 \times 10^{15}$ pc^{-3}) of similar-size interstellar objects (ISOs) with rocky surface [3]. These extraordinary properties pose challenges to any scenario which attributes their origin to 1) scattering by gas giant planets, 2) liberation of comets by stellar encounters, or 3) non adiabatic loss during their host stars' post main sequence evolution [4]. While the hypothesis of tidal disruption followed by ejection remains an option [5, 6], its viability in producing the predicted amount of asteroidal ISOs is uncertain and the causes for 'Oumuamua's extreme shape, surface composition, tumbling motion, remain enigmatic [2].

Based on a series of numerical simulations, we show that ISOs with all 'Oumuamua's characteristics can be prolifically formed and readily ejected through the tidal disruption of their volatile-rich parent bodies induced by their common, low-mass, main-sequence host stars.

Methodology: We use a high-efficiency SSDEM code, *pkdgrav*, to investigate the dynamical behaviors of self-gravitating rubble piles during close stellar encounters [7, 8]. A soft-sphere discrete element model including four dissipation/friction components in the normal, tangential, rolling, and twisting directions is applied for computing particle contact forces [9, 10]. These quantities determine the magnitude of the material shear strength.

Simulation setup: Similar to most small bodies in the Solar System, 'Oumuamua and its parent body are likely to be rubble piles. We physically simulate the disintegration of self-gravitating rubble piles that approach a half-solar-mass star on a parabolic orbit with various perihelion distances. The rubble-pile object is modeled as a spherical granular assembly consisting of ~20,000 particles with a –3-index power-law particle size distribution. The initial bulk density is set to 2 g/cc and radius to 100 m. As the tidal failure limiting distance $d_{\rm limit}$ is proportional to the bulk density ρ_o of the object and the stellar bulk density ρ and size R as $d_{\rm limit} \propto R(\rho/\rho_o)^{1/3}$, the simulation results can be scaled to different rubble-pile bodies and star types.

Results: The simulation results show that, as approaching the host star, the parent body is spun up, heavily distorted and then disrupted by the stellar tides, during which numerous fragments are produced. In general, larger fragments have more extreme axis ratios (~1:5) and longer rotation periods. All the fragments are not principle-axis rotators (especially for the small ones), and the damping time scale is usually longer than 5 Gyr. The orbital-energy increment for some fragments is adequate for them to escape from the gravitational potential of their host star plus additional, if any, Jupiter-like planets.

The structural stability and dynamical behaviors of a rubble pile in response to a certain external effect mainly depend on the material shear and cohesive strengths. Our numerical experiments show that extremely elongated fragments with axis ratios of 1:4 can be produced even using a material friction angle as low as 27 degrees. This result implies that the production of elongated fragments through the tidal disruption process is robust.

Furthermore, the thermal analyses of the encounter process show that the material cohesive strength of the parent body and the fragments could be changed by the thermal effect during their perihelion passage. In the proximity of the original host star, their exposed surface is briefly heated by the intense stellar radiation to temperature above the melting point of silicates, and the solidification of their surface facilitates the formation of sintering bonds between surface particles. The enhanced cohesive strength inhibits subsequent break-apart and enables the formation and survival of some very elongated fragments. The phase-transition simulations show that the tidal encounter under such circumstances can produce fragments with axis ratios < 0.1, providing a possible formation scenario for the reported shape of 'Oumuamua.

The intensive heating of the host star also causes excessive volatile loss of the parent body and the resulting fragments. Our thermal analyses show that, temperature reaches 28 K (i.e., CO's sublimation temperature) at a depth of 3 m. So, a large fraction of volatiles in an 'Oumuamua-size body can be sublimated, leading to a desiccated crust. This provides an explanation to account for ‘Oumuamua’s spectroscopic properties. However, volatiles of high sublimation temperatures, such as H_2O, buried at tens of centimeters subsurface remain condensed. Vaporization of this additional inventory of volatiles during its recent passage through the inner Solar System may lead to the reported non-gravitational acceleration.

Conclusions: In our attempt to address plausible causes of all aspects of the ‘Oumuamua conundrum, we construct a scenario which focus on conventional physical processes. This formation mechanism also highlights the high occurrence rate of tidal encounter processes around stars. Studying and monitoring the close approach of Apophis with the Earth would be largely beneficial for understanding similar dynamical processes in other planetary systems.

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