ORIGIN OF 1I/'OUMUAMUA: A TIDAL DISRUPTION FRAGMENT

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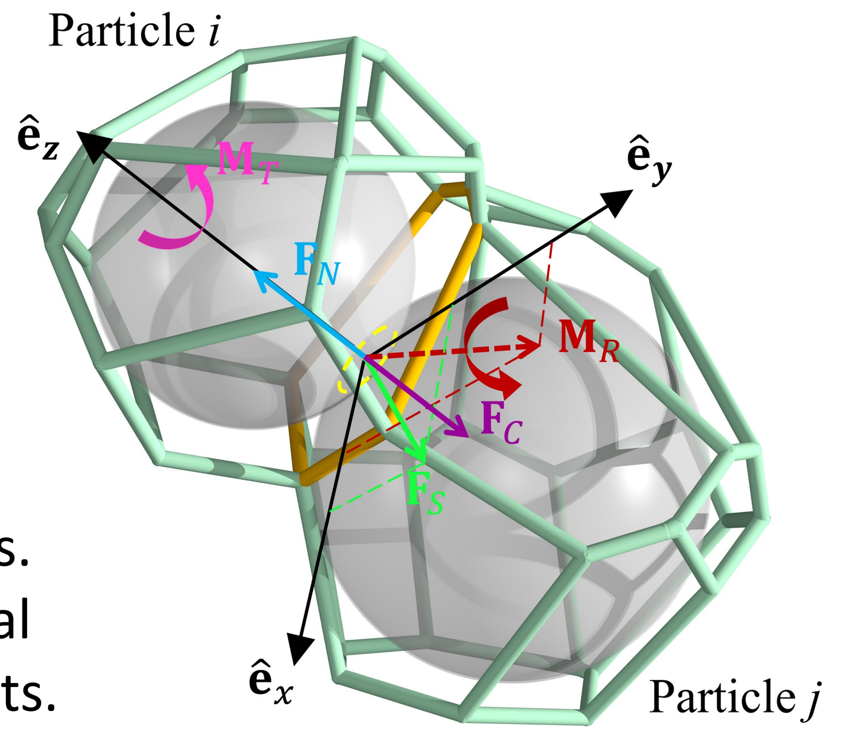
INTRODUCTION

The first discovered interstellar interloper, 'Oumuamua (1I/2017 U1) exhibits a more unusual axis ratio $c/a < 1/6$ and many other puzzling characteristics [1]. Among all the possibilities, collisional events are unlikely to produce an object with an axis ratio $c/a < 1/3$ [2], as are thermal YORP-induced rotational deformations [3], which leaves tidal disruption as the most probable mechanism [4]. Here we show by numerical simulations that 'Oumuamua-like interstellar objects (ISOs) can be prolifically produced through tidal fragmentation and ejected during close encounters of their volatile-rich parent bodies with their host stars.

METHODOLOGY

- **PKDGRAV: "Parallel *k*-D tree GRAVity code"**
  - Combine parallelism and hierarchical tree code to compute forces rapidly, $O(N \log N)$
- **Can exploit tree to find nearest neighbors quickly**
- **Comprehensive interparticle contact physics [5, 6]**
  - Normal force $\mathbf{F}_N$
  - Sliding force $\mathbf{F}_S$
  - Rolling torque $\mathbf{M}_R$
  - Twisting torque $\mathbf{M}_T$
  - Cohesive force $\mathbf{F}_C$
  - ✓ Capable of precisely adjust material shear and cohesive strengths.
  - ✓ Calibration with several laboratory experiments.



ACKNOWLEDGMENTS & REFERENCES

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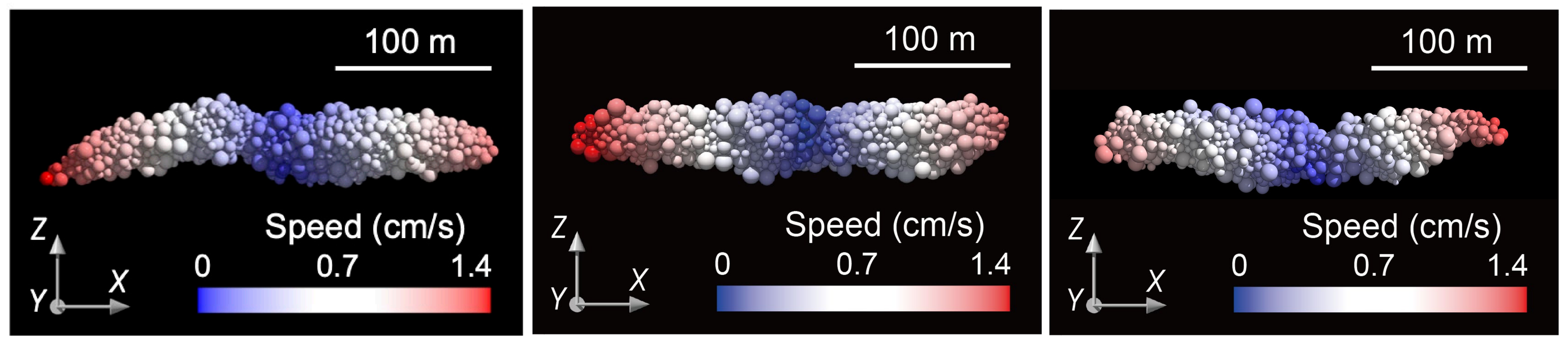
[1] Meech, K. J. et al. (2017) *Nature*, 552, 378–381. [2] Schwartz S. R. et al. (2018) *NatAs*, *2*, 379. [3] Zhang Y. et al. (2018) *ApJ*, *857*, 15. [4] Richardson D. C. et al. (1998) *Icar*, *137*, 47–76. [5] Schwartz S. R. et al. (2012) *Granular Matter*, *14*, 363–380. [6] Zhang Y. et al. (2017) *Icar*, *294*, 98.

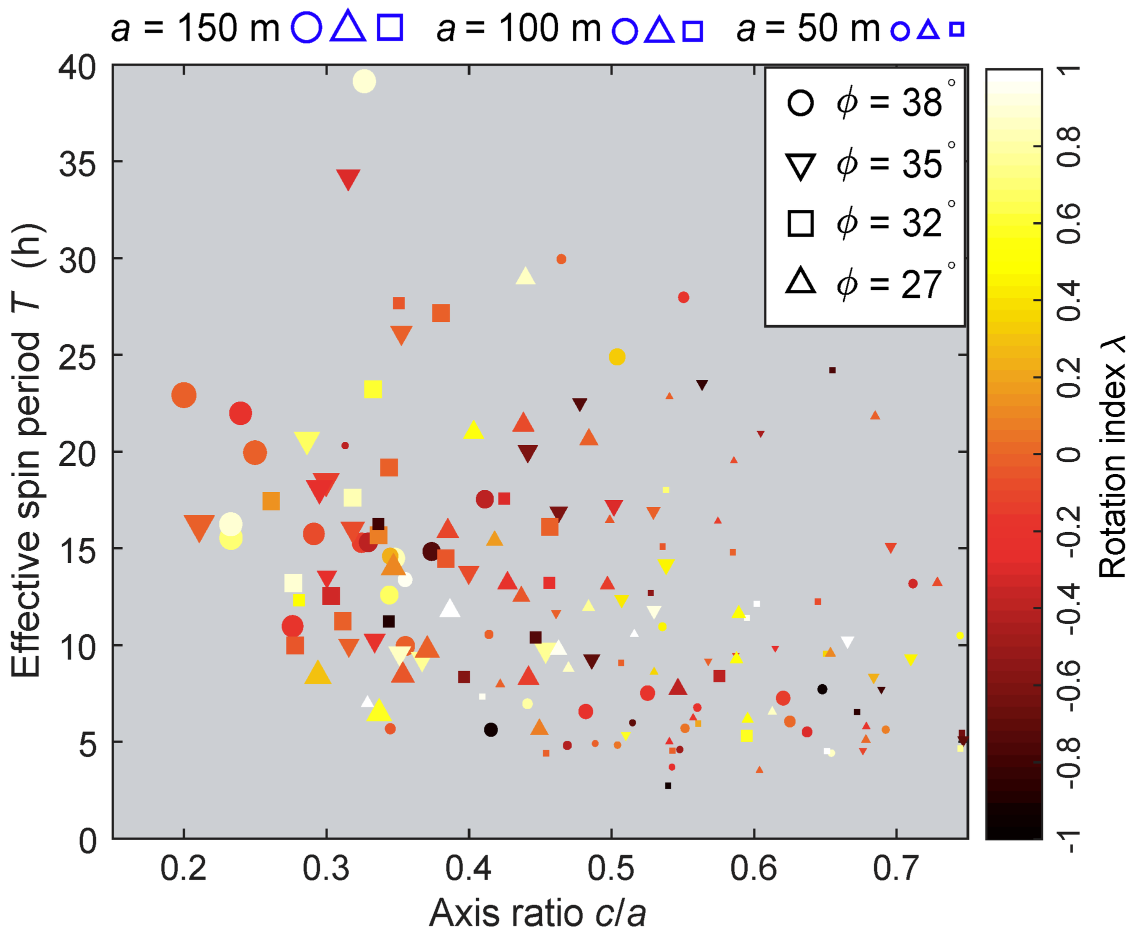
SIMULATION SETUP

- **Rubble-pile model**
  - Spherical granular assembly consisting of ~20,000 particles with a −3-index power-law particle size distribution
  - Radius: 100 m, bulk density: 2 g/cc, initial no spin
  - Friction angle: 27, 32, 35, and 38 deg
  - Cohesive strength: 0, 0.8, 2.1, 5.2 Pa.
- **Tidal encounter scenario**
  - Stellar tides: $0.5M_{\odot} = 9.942 \times 10^{29}$ kg with radius of 3.5×10^8 m
  - Encounter orbit $e = 0.999999$, perihelion distance 4.0×10^8 m.

CHARACTERISTICS OF FRAGMENTS

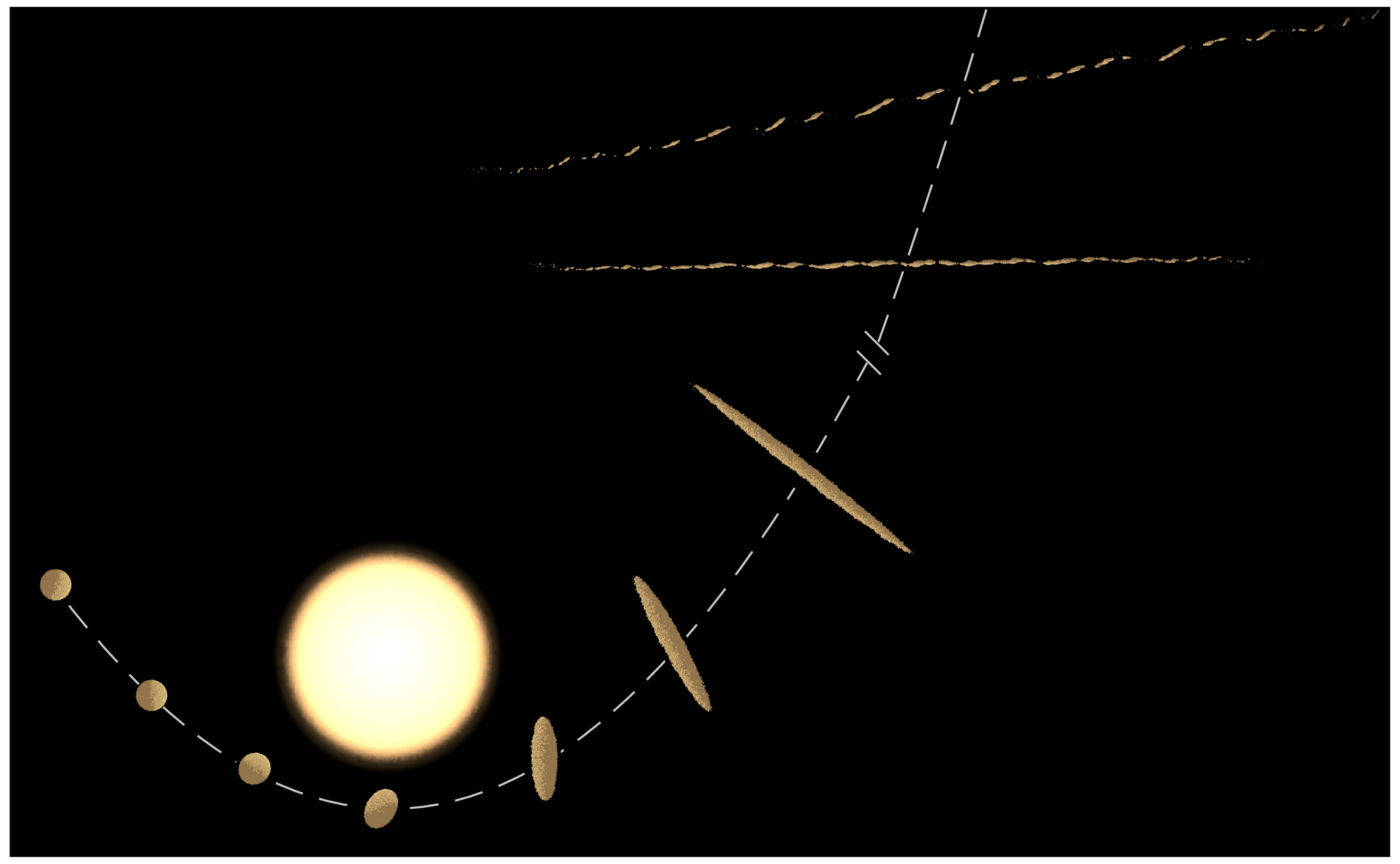


- **Shape distribution**
  - Extremely prolate
  - Larger fragments are more elongated
  - Higher friction angle enhance elongation
- **Rotation state**
  - Tumbling ($\lambda \neq \pm 1$)
  - Smaller fragments spin faster
- **Volatile depletion**
  - Low-sublimation temperature volatiles (like CO, NH_3) are depleted by the extensive heating during close encounter
  - H_2O ice buried ≳0.2 m and CO_2 ice buried ≳0.5 m beneath the surface can be preserved

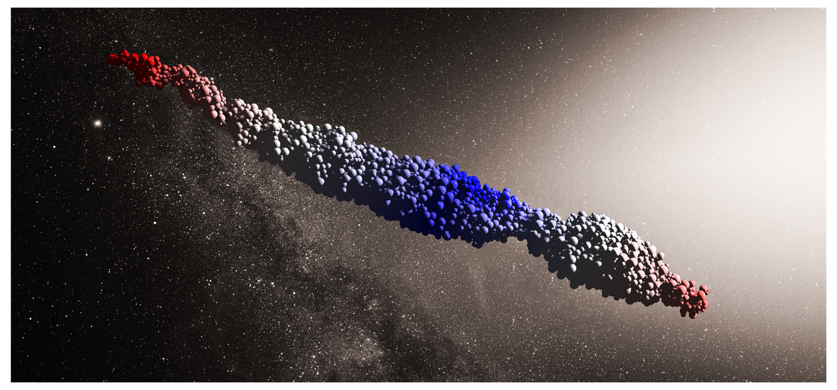


For additional details, please check out the published article in Nature Astronomy: Zhang, Y., & Lin, D.N.C. Tidal fragmentation as the origin of 1I/2017 U1 ('Oumuamua). Nat Astron 4, 852–860 (2020). https://doi.org/10.1038/s41550-020-1065-8

STELLAR TIDAL ENCOUNTER PROCESSES



SOLVE PUZZLES OF 1I/'OUMUAMUA



- **Puzzles:**
  - Shape and tumbling rotation state
  - No cometary activity is observed
  - Non-gravitational acceleration probably due to outgassing
  - Required number density
- **Stellar tidal disruption can account for all these puzzles**
  - Elongated and tumbling fragments are the natural outcomes of tidal disruption, and the energy injected into these fragments can lead to ejection from their original planetary system
  - Close encounter with the host star causes sublimation of volatiles and melting of surface material. The enhancement of cohesion due to sintering of silicates in the crust leads to more extreme shape (as shown above)
  - High-sublimation-temperature volatiles, like water, can be preserved and serve as the outgassing source
  - Two populations of potential progenitors, super-Earths and km-size planetesimals around low-mass main-sequence stars or to a lesser extent white dwarfs, provide abundant reservoirs to account for the discovery of `Oumuamua