New formation theory explains the mysterious interstellar object 'Oumuamua

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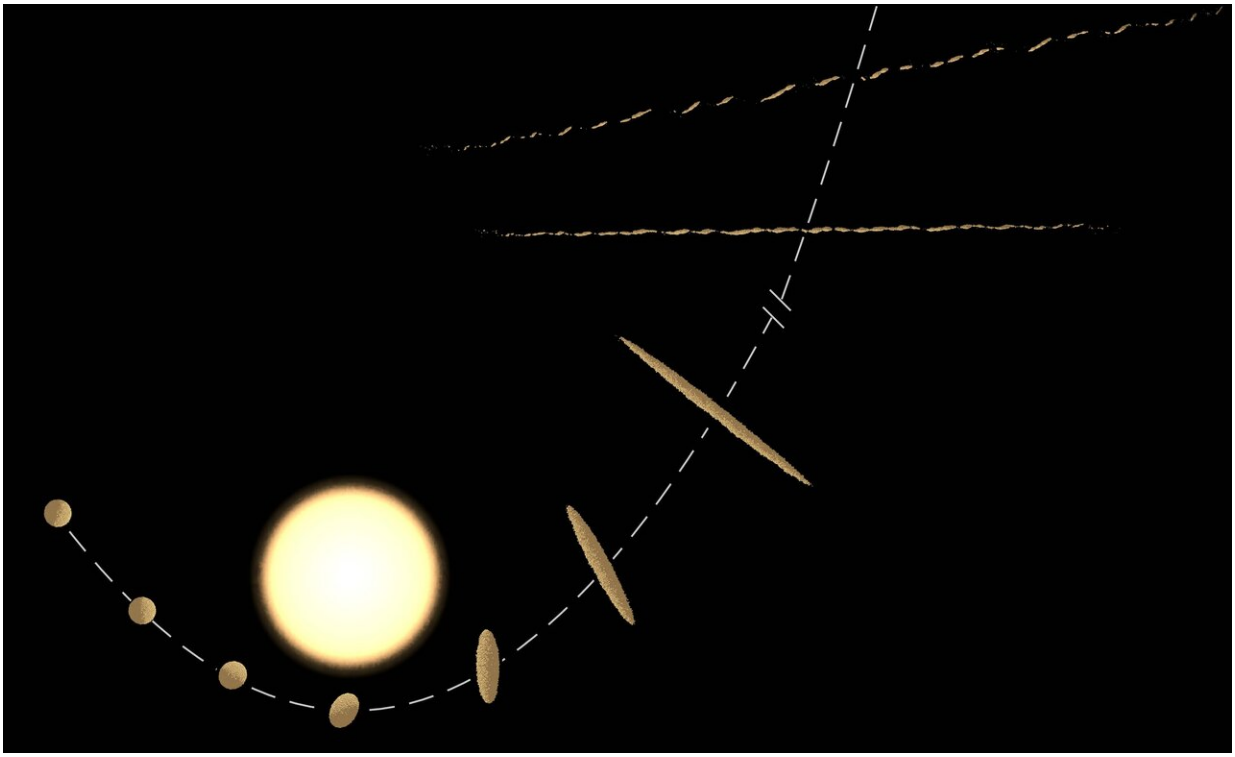


This illustration shows the tidal disruption process that can give rise to 'Oumuamua-like objects. Credit: NAOC/Y. Zhang

Since its discovery in 2017, an air of mystery has surrounded the first known interstellar object to visit our solar system, an elongated, cigar-shaped body named 'Oumuamua (Hawaiian for "a messenger from afar arriving first").

How was it formed, and where did it come from? A new study published April 13 in *Nature Astronomy* offers a first comprehensive answer to these questions.

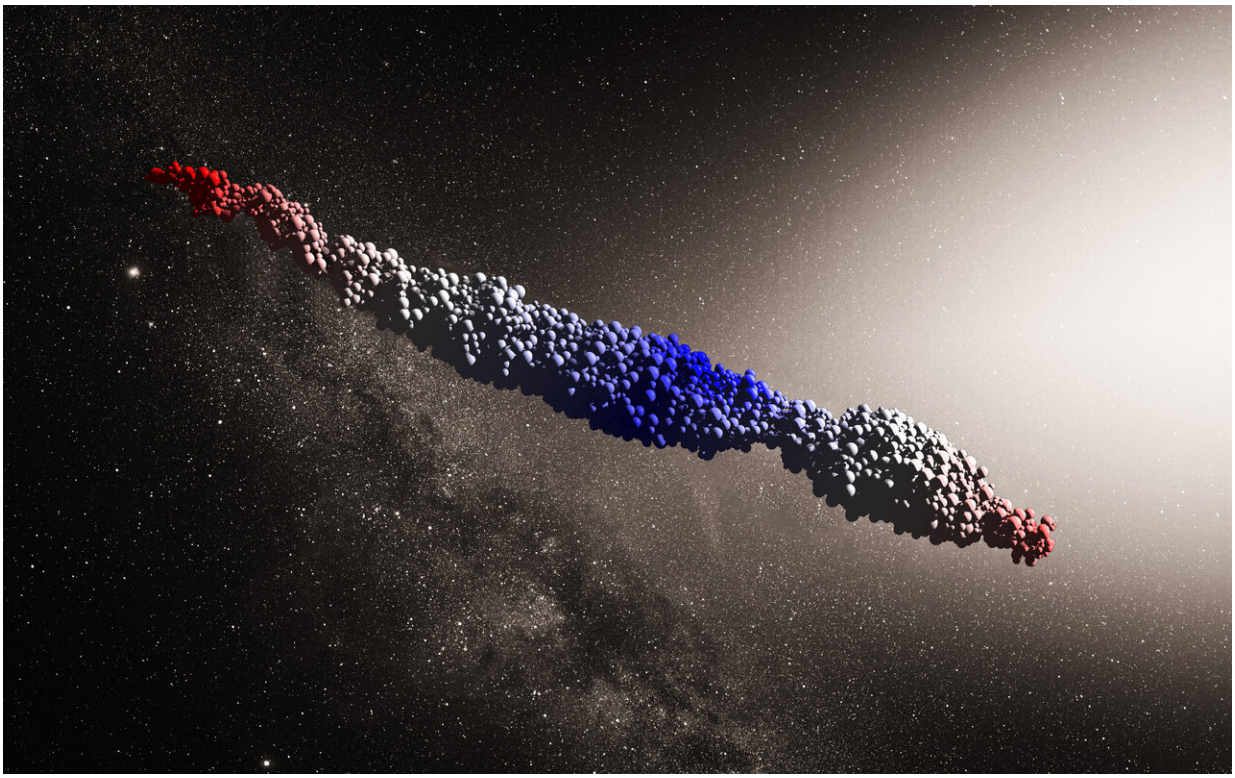
First author Yun Zhang at the National Astronomical Observatories of the Chinese Academy of Sciences and coauthor Douglas N. C. Lin at the University of California, Santa Cruz, used computer simulations to show how objects like 'Oumuamua can form under the influence of tidal forces like those felt by Earth's oceans. Their formation theory explains all of 'Oumuamua's unusual characteristics.

"We showed that 'Oumuamua-like interstellar objects can be produced through extensive tidal fragmentation during close encounters of their parent bodies with their host stars, and then ejected into interstellar space," said Lin, professor emeritus of astronomy and astrophysics at UC Santa Cruz.

Discovered on October 19, 2017, by the Panoramic Survey Telescope and Rapid Response System 1 (Pan-STARRS1) in Hawaii, 'Oumuamua is absolutely nothing like anything else in our solar system, according to Zhang. Its dry surface, unusually elongated shape, and puzzling motion even drove some scientists to wonder if it was an alien probe.

"It is really a mysterious object, but some signs, like its colors and the absence of radio emission, point to 'Oumuamua being a natural object," Zhang said.

"Our objective is to come up with a comprehensive scenario, based on well understood physical principles, to piece together all the tantalizing clues," Lin said.



An 'Oumuamua-like object produced by a simulation of the tidal disruption scenario proposed by Zhang and Lin. Credit: NAOC/Y. Zhang; (background: ESO/M. Kornmesser)

Astronomers had expected that the first interstellar object they detected would be an icy body like a comet. Icy objects like those populating the Oort cloud, a reservoir of comets in the outermost reaches of our solar system, evolve at very large distances from their host stars, are rich in volatiles, and are often tossed out of their host systems by gravitational interactions. They are also highly visible due to the sublimation of volatile compounds, which creates a comet's coma (or "tail") when it is warmed by the sun. 'Oumuamua's dry appearance, however, is similar to rocky bodies like the solar system's asteroids, indicating a different ejection scenario.

Other researchers have calculated that there must be an extremely large population of interstellar objects like 'Oumuamua. "The discovery of 'Oumuamua implies that the population of rocky interstellar objects is much larger than we previously thought," Zhang said. "On average, each planetary system should eject in total about a hundred trillion objects like 'Oumuamua. We need to construct a very common scenario to produce this kind of object."

When a smaller body passes very close to a much bigger one, tidal forces of the larger body can tear the smaller one apart, as happened to comet Shoemaker-Levy 9 when it came close to Jupiter. The tidal disruption processes can eject some debris into interstellar space, which has been suggested as a possible origin for 'Oumuamua. But whether such a process could explain 'Oumuamua's puzzling characteristics remained highly uncertain.

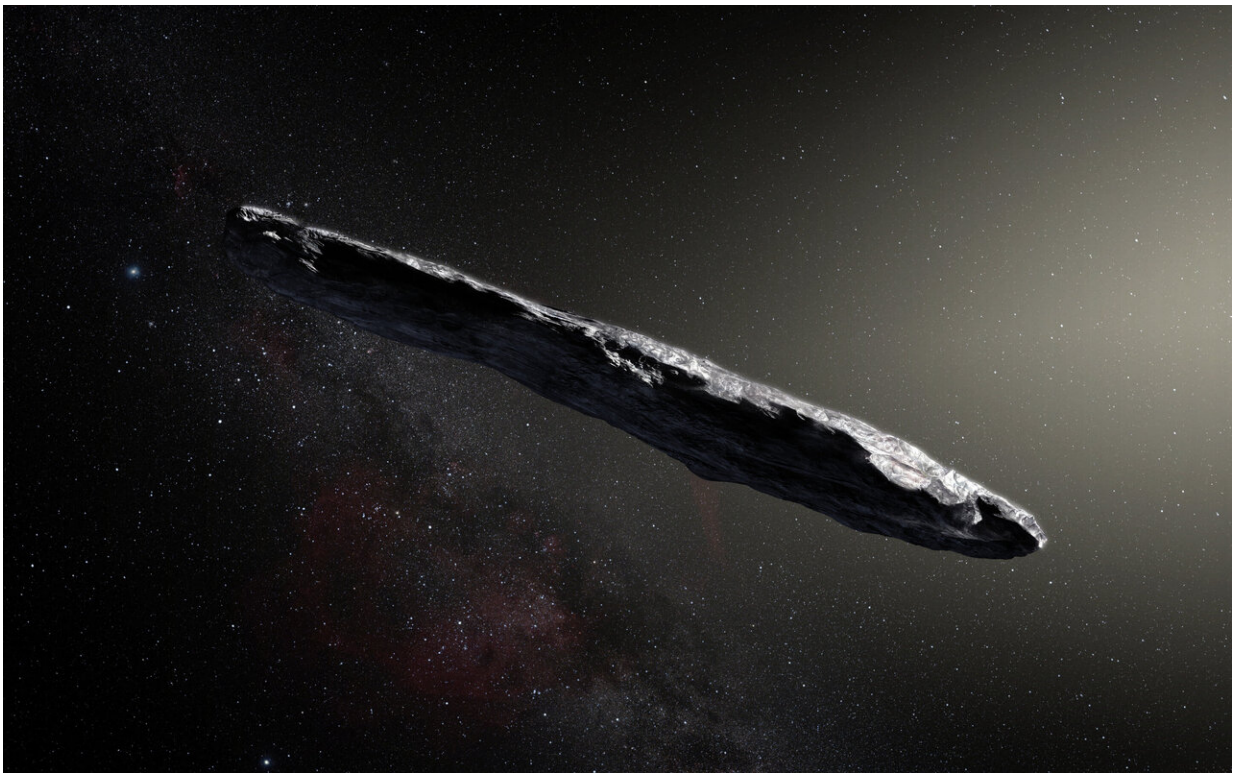
Zhang and Lin ran high-resolution computer simulations to model the structural dynamics of an object flying close by a star. They found that if the object comes close enough to the star, the star can tear it into extremely elongated fragments that are then ejected into the interstellar space.

"The elongated shape is more compelling when we considered the variation of material strength during the stellar encounter. The ratio of long axis to short axis can be even larger than ten to one," Zhang said.

The researchers' thermal modeling showed that the surface of fragments resulting from the disruption of the initial body would melt at a very short distance from the star and recondense at greater distances, thereby forming a cohesive crust that would ensure the structural stability of the elongated shape.

"Heat diffusion during the stellar tidal disruption process also consumes

large amounts of volatiles, which not only explains 'Oumuamua's surface colors and the absence of visible coma, but also elucidates the inferred dryness of the interstellar population," Zhang said. "Nevertheless, some high-sublimation-temperature volatiles buried under the surface, like water ice, can remain in a condensed form."



An artist's impression of 'Oumuamua. Credit: ESO/M. Kornmesser

Observations of 'Oumuamua showed no cometary activity, and only water ice is a possible outgassing source to account for its non-gravitational motion. If 'Oumuamua was produced and ejected by the scenario of Zhang and Lin, plenty of residual water ice could be activated during its passage through the solar system. The resulting

outgassing would cause accelerations that match 'Oumuamua's comet-like trajectory.

"The tidal fragmentation scenario not only provides a way to form one single 'Oumuamua, but also accounts for the vast population of asteroid-like interstellar objects," Zhang said.

The researchers' calculations demonstrate the efficiency of tidal forces in producing this kind of object. Possible progenitors, including long-period comets, debris disks, and even super-Earths, could be transformed into 'Oumuamua-size pieces during stellar encounters.

This work supports estimates of a large population of 'Oumuamua-like interstellar objects. Since these objects may pass through the domains of habitable zones, the possibility that they could transport matter capable of generating life (called panspermia) cannot be ruled out. "This is a very new field. These interstellar objects could provide critical clues about how planetary systems form and evolve," Zhang said.

An artist's impression of 'Oumuamua formation. Credit: YU Jingchuan from Beijing Planetarium

According to Lin, "'Oumuamua is just the tip of the iceberg. We anticipate many more interstellar visitors with similar traits will be discovered by future observation with the forthcoming Vera C. Rubin Observatory."

U.S. Naval Academy astronomer Matthew Knight, who is co-leader of the 'Oumuamua International Space Science Institute team and was not involved in the new study, said this work "does a remarkable job of explaining a variety of unusual properties of 'Oumuamua with a single,

coherent model."

"As future interstellar objects are discovered in coming years, it will be very interesting to see if any exhibit 'Oumuamua-like properties. If so, it may indicate that the processes described in this study are widespread," Knight said.

More information: Tidal fragmentation as the origin of 1I/2017 U1 ('Oumuamua), *Nature Astronomy* (2020). DOI: 10.1038/s41550-020-1065-8 , www.nature.com/articles/s41550-020-1065-8

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