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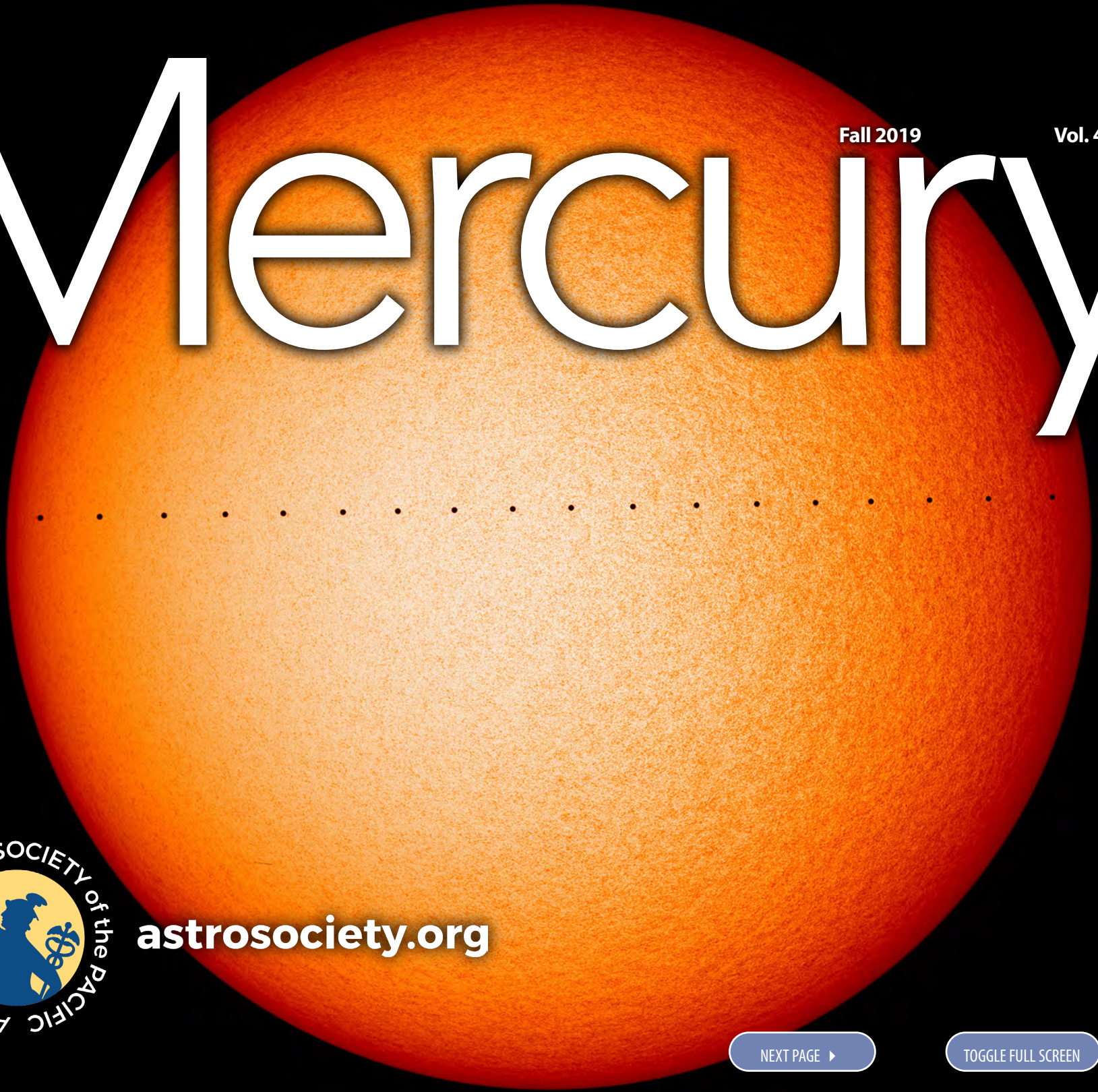

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The November 11, 2019, transit of Mercury as seen by NASA's Solar Dynamics Observatory. This year's transit of the solar system's smallest planet will be the last until 2032. [NASA/SDO]

Passing Through

Two interstellar travelers have visited the solar system in as many years—how many more are out there?

By Steve Murray

The interstellar comet 2I/Borisov as imaged by the Hubble Space Telescope. *[NASA/ESA]*

As giant planets orbit through the disks of young protoplanetary systems, their gravity can eject some pieces of disk material into interstellar space. Over the eons, chunks of planet-building debris (known as planetesimals) should have drifted through our galactic neighborhood, and astronomers have wondered where it was. All the asteroids and comets we had discovered to date seemed to be native to our solar system.

Now, in the span of only two years, we've spotted two extrasolar visitors and a new analysis predicts that we can expect many more. The first was detected late in its visit and scientists hurried to study it while they could. The second was found earlier in its journey and offers more time for a detailed examination. Armed with what they've learned so far, astronomers believe we could be awash in extrasolar visitors.

"This is the material that makes up planets around other stars," says Malena Rice, a Yale researcher involved in exoplanet formation and evolution, "and it's here for us to examine up close. It's a new way for us to study extrasolar systems."

First Detection

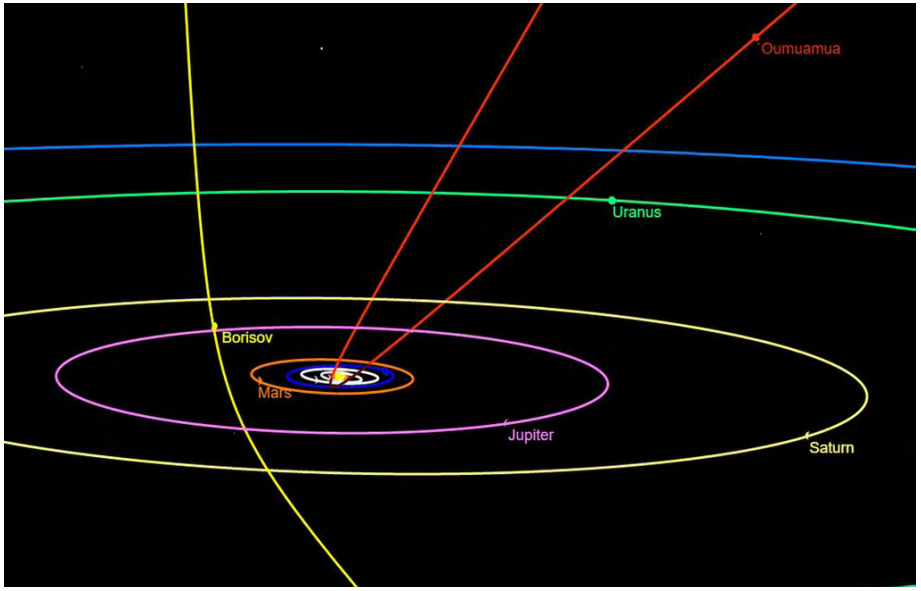
Astronomers found the first object on October 19, 2017 using Pan-STARRS1, a survey telescope located at Haleakala Observatory in Hawaii. They weren't sure what it was at first and labeled it a comet (C) before changing it to an asteroid (A). That changed yet again, once its speed (clocked at an incredible 196,000 miles per hour, or 87.3 kilometers *per second*) and hyperbolic path through the solar system pegged its extrasolar origin. The International Astronomical Union (IAU) assigned its first formal interstellar designation (I) to 1I/2017 U1, but people soon used the more popular name: 'Oumuamua, a Hawaiian term meaning "scout."

The rocky surface of 1I/'Oumuamua appeared to have a deep red color characteristic of many Kuiper Belt objects, and was highly elongated—astronomers estimated its length between 330 and 3,280 feet (100 and 1,000 meters).

Artist's concept of interstellar object 1I/2017 U1 ('Oumuamua) as it passed through the solar system. *[ESO/M. Kornmesser]*

1I/'Oumuamua didn't stick around very long, however. The interstellar object (ISO) was already 40 days past its closest point to the Sun at the time it was detected and was already heading back out of the solar system. "We effectively had only a week to observe it," says Karen J. Meech, at the Institute for Astronomy at the University of Hawaii. Meech and her colleagues conducted some of the first measurements of the object, employing a variety of instruments. "We were part of the team that discovered 'Oumuamua," she adds, "and we had a huge campaign to characterize it quickly."

Useful observations ended about mid-December 2017, when distance and speed put 1I/'Oumuamua beyond the capability of most telescopes, but its passage had energized planetary scientists around the world. Extrasolar objects were in our midst and were detectable after all.



Trajectories of comet 2I/Borisov and 1I/'Oumuamua as they passed through the solar system. *[NASA/JPL-Caltech]*

Act Two

That's where things stood until August 30, 2019 when Gennady Borisov, an amateur astronomer and telescope maker in Crimea, detected a second visitor. When first detected, the object was about three astronomical units (AU) from the Sun, where big telescopes don't perform well. In fact, Borisov found it with a small instrument: a 2.1 foot (0.65 meter) telescope he built himself.

This time, the object was found still on its way into the solar system. There will be about a one year window to study the visitor and telescope time is in high demand. "People are excited," says Meech. "Basically every asset that astronomers can get will be looking at it."

The new object, now designated 2I/Borisov, is much larger than 1I/'Oumuamua—1.2 to 10 miles (2 to 6 kilometers), and it will be traveling over 98,000 mph (44 kilometers per second) relative to the Sun when it reaches perihelion in early December.

And because 2I/Borisov has a coma, the fuzzy envelope of gases that surround a comet, astronomers are focusing a lot of spectrographic attention on it. "You want to see if the chemistry is the same," says Meech, "and if its size, color, and shape are the same across all solar systems." So far, that seems to be the case. Meech and her colleagues reported their detection of cyanide gas (CN) around 2I/Borisov in September, and October observations from the Hubble Space Telescope (see the cover of this issue of *Mercury*) showed that the object shares its structure and chemical composition with comets in our own solar system. It's still early, though, and there's much more to learn. "We're just scratching the surface as far as spectroscopy goes, because those observations are still taken pretty close to the horizon. It will also be getting brighter as it comes to perihelion [its closest approach to the Sun] around December 7th."

Telescopes in the Northern Hemisphere should be able to study the comet until January, and then Southern Hemisphere instruments will come into play. Meech estimates that by October 2020 it will be nearly impossible to spot as it speeds out again from the solar system.

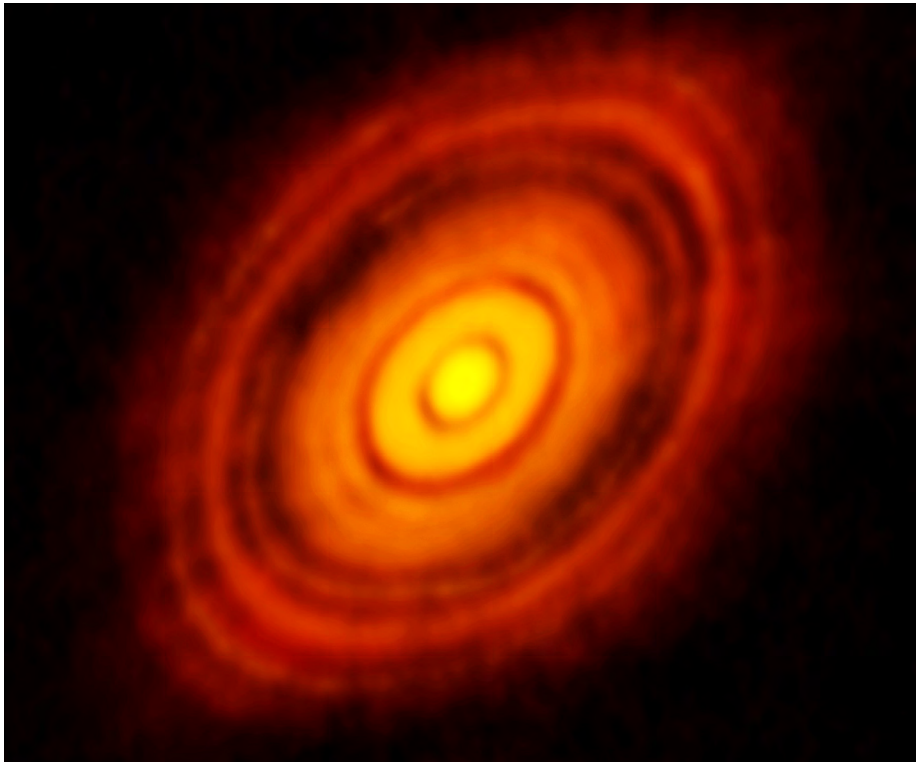
More at the Door?

So 1I/'Oumuamua and 2I/Borisov are pretty different in size, color, and chemical characteristics. Are they typical of other ISOs or could they be outliers in a bigger population of wandering planetesimals? Astronomers will need to find many more examples before they can make firm statements. Fortunately, some clever analyses are indicating that many more objects may be waiting discovery.

A team headed by Toni Engelhardt, of the Institute for Astronomy at the University of Hawaii, used historic data from three sky surveys to model confidence limits on the likely abundance of interstellar objects. Based on about 20 years of accumulated telescope time,

what, they asked, was the likely population density of these objects given that we had not seen one? They made one prediction for "easy to see" objects such as comets with bright tails and another prediction for "hard to see" objects like asteroids. Their paper was published in 2017, however, before 1I/'Oumuamua was discovered. When our first ISO detection was a "hard to see" object, the research team determined that the original modeling estimates were probably too conservative and revised their estimates upward in a subsequent paper.

A more recent study tackled the same question in a different way. Malena Rice, a PhD student at Yale University, and her advisor Greg Laughlin modeled planetesimal ejection rates by looking at new data collected by the Disk Substructures at High Angular Resolution Project (DSHARP) project at the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile.



The sharpest image ever taken by ALMA, showing the protoplanetary disk surrounding the young star HL Tauri, and an example of a possible origin of interstellar comets. *[ALMA (ESO/NAOJ/NRAO)]*

The idea that small objects are launched into space from giant planets in young, forming solar systems is the predominant theory for the origin of ISOs. "We even expect that a huge fraction of material in our own solar system got tossed out early in its formation," Meech tells Mercury, "as the giant planets were being built and moving around. This ought to be a universal process that happens everywhere."

Not every young planet meets the necessary conditions to pull this off, however. "Most of the planets we've discovered in other systems are too small or too close to their host star," says Rice, lead author of the new Yale paper. "Any material perturbed by these planets would probably remain in the system, trapped by the gravity of that star."

The problem for astronomers is that giant planets further out than 5 AU are extremely hard to detect with current planet hunting methods. Stellar transits much beyond 1 AU from their star are almost impossible to sense, and the long orbital periods of distant planets make radial velocity effects too slow to pick out of most data records.

The DSHARP project provided an alternate perspective on the phenomenon. Headed up by Sean Andrews, of the Harvard-Smithsonian Center for Astrophysics, researchers gathered high resolution images of 20 large protoplanetary disks to characterize the emission ring and depleted gap structures related to planetary formation. "You're not seeing the planets directly in these gaps," explains Andrews. "You're seeing what could be the interaction of the planets being born and their birth environments [adjacent

disks]."

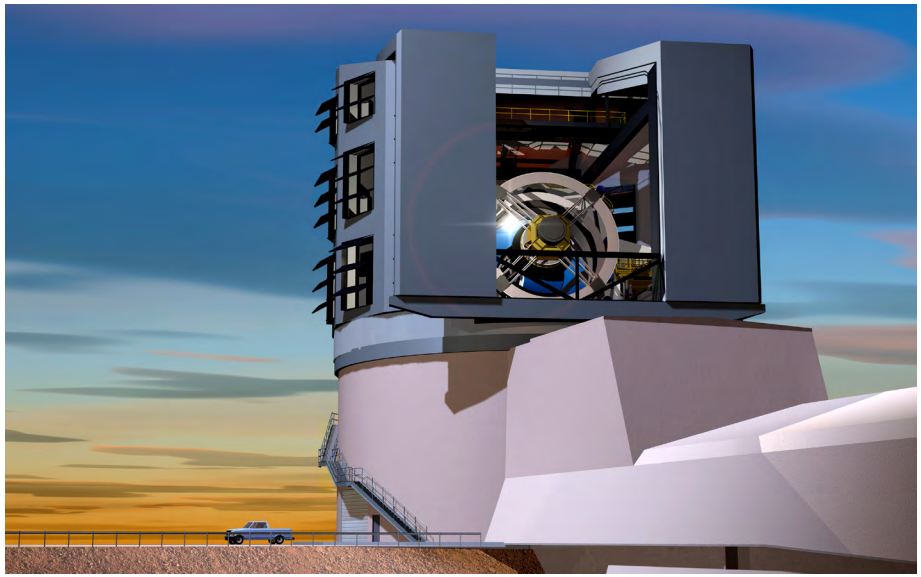
The Yale researchers examined the gaps in the disk images to estimate the prevalence of large, distant planets that could eject interstellar materials. "We focused on three representative systems," said Rice. "They had big gaps that likely indicated big planets. We were looking for planets of Neptune mass or greater, and more than about 5 astronomical units from their host star."

They then used data from these systems—number of candidate planets, planetary masses, and the mass of their surrounding dust—to seed a simulation model estimating how often these large bodies might eject planetesimals out of their systems over time. Their results fit the idea that 1I/'Oumuamua had been ejected from a DSHARP-type system, providing the first direct evidence that such objects could be ejected by large planets orbiting far from their sun in young protoplanetary systems.

Rice and Laughlin extended their analysis to forecast that powerful new sky surveys like those planned for the Large Synoptic Survey Telescope (LSST) should be able to detect over 100 ISOs 1 meter (3.3 feet) in radius or larger per year. "Every model includes some assumptions, of course, "said Rice. "But if these distant, giant planets are as common as we think, we'll be seeing a lot more of these interstellar objects soon."

Taking a Longer Look

It's a good bet that the LSST will begin finding more ISOs like 1I/'Oumuamu and 2I/Borisov when it comes on line in October 2023. With the biggest (3.2 gigapixel) digital camera in the world, the LSST will scan the entire southern sky every 3 days. One of its biggest strengths will be its ability to pick up transient events such as small, fast-moving ISOs and to quickly alert the astronomy community so that other instruments can be trained on them.



In this artist's rendition, the LSST primary mirror is seen through the slit of the dome at sunset. *[Todd Mason, Mason Productions Inc. / LSST Corporation]*

Without hard performance data, however, LSST scientists can only be cautiously optimistic about the rate of ISO detections. "Right now, it's difficult to predict based only on circumstantial evidence," says Mario Juric, Associate Professor of Astronomy at the University of Washington and lead of the Solar System processing group for the LSST. "We've seen two in the last two years just with current discovery instruments. With the emergence of the LSST, our detection rate should be a factor of 10 higher than that. We should find about a few each year, but we'll only know for sure when LSST is operating."

So the solar system might be busier than we thought even a few years ago. We should find out soon after the LSST begins operation. In the meantime, however, 2I/Borisov will be keeping astronomers very busy for some time. ✪

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