Vera Rubin's keen eye on our solar system will inspire future missions

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View of Rubin Observatory at sunset in December 2023. The 8.4-meter telescope at Rubin Observatory, equipped with the highest-resolution digital camera in the world, will take enormous images of the southern hemisphere sky, covering the entire sky every few nights. Rubin will do this over and over for 10 years, creating a timelapse view of the Universe that's unlike anything we've seen before. What new Solar System exploration missions will of these observations inspire? Image Credit: RubinObs/NSF/AURA/H. Stockebrand

When the interstellar object (ISO) 'Oumuamua appeared in our solar system in 2017, it generated a ton of interest. The urge to learn more about it was fierce, but unfortunately, there was no way to really do so. It came and went, and we were left to ponder what it was made of and where it came from. Then, in 2019, the ISO comet Borisov came for a brief visit, and again, we were left to wonder about it.

There's bound to be more of these ISOs traversing our solar system. There's been talk of having missions ready to go to visit one of these interstellar visitors in the future, but for that to happen, we need advance notice of its arrival. Could the Vera Rubin Observatory tell us far enough in advance?

No mission leaves the launch pad without detailed planning, and detailed planning depends on observations. Ground-based observations laid the foundation for our forays into the solar system. NASA missions like OSIRIS-REx, Lucy, and Psyche are simply impossible without detailed ground observations preparing the way.

Soon, one of our most powerful and unique observatories will begin operations, the Vera Rubin Observatory. Its main activity will be the Legacy Survey of Space and Time (LSST.) The LSST will image our solar system in far more detail than ever before, and it'll do it continuously for a decade. The wealth of data that flows from those observations will be a massive benefit to mission planning and will probably inspire missions that we haven't dreamed of yet.

The VRO's Legacy Survey of Space and Time is based on the observatory's 8.4 meter, wide-angle primary mirror and its ability to change targets in only five seconds. Attached to it is the world's largest digital camera, a 3.2 gigapixel behemoth. The VRO will image the entire available night-time sky every few nights.

The LSST is aimed at detecting transients like supernovae and gamma-ray bursts. It's also going to study dark energy and dark matter and will map the Milky Way. But it will also map small objects in our solar system like near-Earth asteroids (NEA) and Kuiper Belt Objects (KBOs).

"Nothing will come close to the depth of Rubin's survey and the level of characterization we will get for solar system objects," said Siegfried Eggl, Assistant Professor at the University of Illinois Urbana-Champaign and Lead of the Inner Solar System Working Group within the Rubin/LSST solar system Science Collaboration. "It is fascinating that we have the capability to visit interesting objects and look at them close-up. But to do that we need to know they exist, and we need to know where they are. This is what Rubin will tell us."

It's difficult to overstate how the VRO and its LSST will advance our understanding of the solar system. There are other survey telescopes, like Pan-STARRS (Panoramic Survey Telescope and Rapid Response System.) Pan-STARRS has detected huge numbers of astronomical transients. Its job is to detect them and alert astronomers so other telescopes can observe them.

Pan-STARRS is based on two telescopes with 1.8-meter mirrors and is our most effective detector of Near-Earth Objects (NEOs), but once the VRO is operational, it will be relegated to a distant second place.

Intriguingly, the VRO will also detect ISOs. In a 2023 paper, researchers estimated that the VRO will detect up to 70 interstellar objects every year. If the VRO can see them far enough in advance, it could give us time to launch a mission to one.

"Rubin is capable of giving us the prep time we need to launch a mission to intercept an interstellar object," said Eggl. "That's a synergy that's very unique to Rubin and unique to the time we're living in."

It's unclear how many ISOs visit our solar system every year, and will be detectable. While some researchers suggest the VRO can detect 70 per year, others say the number will be lower. The VRO isn't magic. Objects that are too dim and/or are moving too quickly can escape detection. But it seems certain that the LSST will detect some ISOs. It may even discern patterns in their trajectories that make it easier to detect more of them.

As our knowledge of ISOs grows, the urge to visit one of them will grow alongside it. The appearance of 'Oumuamua and Borisov shows that opportunities will keep presenting themselves. There are already preliminary plans on how to visit one.

The ESA's Comet Interceptor is designed to visit a long-period comet. The Interceptor mission has three spacecraft, and each one will study the comet from a different angle, giving a 3D view. Advance notice is critical to the Comet Interceptor mission, and the ESA specifically mentions the LSST as enabling the mission by alerting us to an appropriate target soon enough.

But the target doesn't need to be a comet. It could be anything traveling through the inner solar system.

The unique thing about the Comet Interceptor is that it'll already be lying in wait for its target. After launch, it'll travel to the sun-Earth Lagrange 2 (L2) point. It'll enter a halo orbit there and await further instructions. The ESA can bide their time until the VRO detects a desirable target on the right trajectory, and they can activate the Comet Interceptor.

NASA's Lucy mission shows how advanced knowledge of objects in the solar system enables powerful missions. Lucy relies on exacting observations of solar system objects and will visit several asteroids by looping its way through the inner solar system, using Earth as a gravity assist on three separate occasions. Detailed knowledge of the solar system inspired and allowed Lucy's mission.

The Comet Interceptor, or another mission like it, won't need a path this complex. But just like Lucy, it will rely on keen observations, something the VRO and the LSST will provide in great depth.

The LSST won't just enable missions like the Comet Interceptor. It'll inspire new ones we can't envision yet. That's because we don't know what the Survey will reveal yet. It might uncover regions of objects that behave in a way we haven't seen yet or types of objects clustered together that have remained unseeable.

"If you think of Rubin as looking at a beach, you see millions and millions of individual sand grains that together constitute the entire beach," said Eggl, "There might be an area of yellow sand, or volcanic black sand, and a space mission to an object in that region could investigate what makes it different. Often, we don't know what's weird or interesting unless we know the context it's in. With our current telescopes, we've essentially been looking at the big boulders on the beach," says Eggl, "but Rubin will zoom in on the finer grains of sand."

The Jupiter Trojan asteroids that Lucy will visit are a good example of this. This type of asteroid was predicted to exist back in the 1770s, but the first one wasn't seen until more than a century had passed. Even then, nobody was sure it was actually a Trojan asteroid until almost another century had passed. Now, astronomers know that there are thousands of them.

In a similar way, our knowledge of ISOs could become much more complete once the LSST gets going. A whole new window into ISOs could open. Astronomers may discern patterns in their trajectories and in their makeup that lead to new understandings of their origins. If the

Comet Interceptor or a similar mission is dispatched to one, we'll learn more about how planetary systems form, including our own.

Not everything in our solar system formed where we see it today. Some bodies have been captured, like Neptune's moon Triton, which is likely a captured Kuiper Belt Object. Astronomers think it's highly likely that some of our solar system's objects are captured ISOs. The VRO and the missions it inspires could identify these objects.

New observations lead to new questions and new missions designed to answer them. That's a long-standing pattern in our quest to understand nature.

Who knows what the VRO will see and what future missions its findings will lead to?

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