

GABRIELA ARAUJO AND RICARDO PERES

GABRIELA ARAUJO loads a crystal into a light-sheet fluorescent microscope to create a 3D image of defects. She is studying tracks from known sources to facilitate analysis of ancient minerals. During data acquisition, an arm moves the crystal into an oil immersion chamber (the transparent container at the center). Lenses on either side of the chamber provide the light sheet, and a camera at the back of it captures the fluorescence signals.

melts the signals. Likely sources of minerals are existing mines and bore holes. Scientists also talk about grabbing minerals from beneath the ocean floor and the surface of the Moon.

Sorting out the tracks and handling the vast amounts of data will be hard. Artificial intelligence will be needed, says Freese. For example, it could be trained to identify and sort tracks. "I hope to work on that," she says.

"There are a lot of challenges," says Pieter Vermeesch, a geochronologist at University College London who has a hand in paleo-detection. But, he notes, all the existing enormous detectors are extremely expensive compared with paleo-detection. "Even if the chances of success are low with minerals, it's worth it." And developing new readout techniques not only would offer huge benefits to physics but may, he says, "revolutionize geology" by increasing the precision of fission track and alpha-recoil track dating by several orders of magnitude.

Toni Feder

What's up with Planet Nine?

The question of whether it exists may soon be resolved.

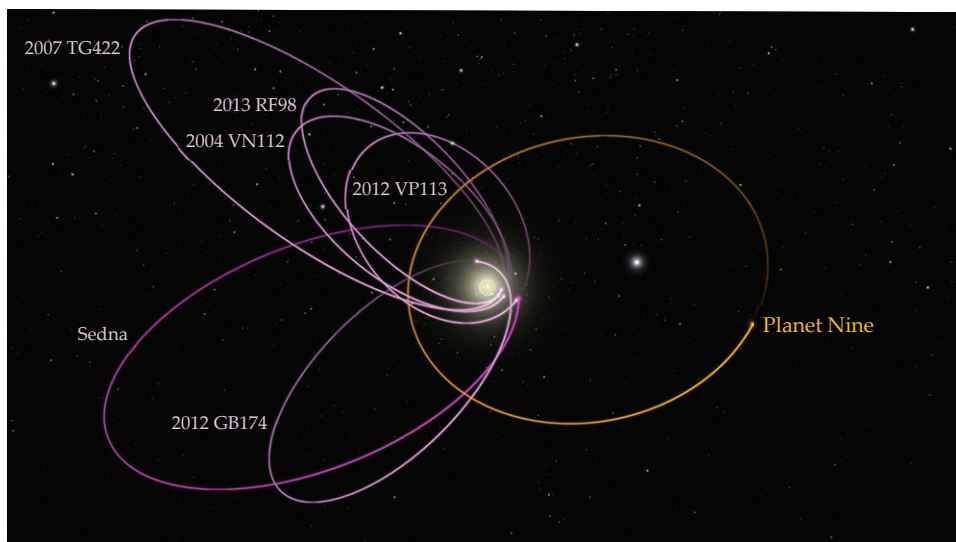
A decade ago, astronomers Scott Sheppard and Chad Trujillo hypothesized the existence of a sizable planet beyond Neptune. Dozens of papers have since come out with arguments both pro and con and sparked conversations among astronomers and the public alike. Discovery of the planet's existence would raise questions about the solar system's formation and the processes that produced its distant orbit. An additional planet would also explain the behaviors—the paths of the extreme trans-Neptunian objects (ETNOs) that orbit the Sun with trajectories that can't be explained by Neptune's gravitational pull—that led to the initial hypothesis.

Following the 1846 discovery of Nep-

tune, whose existence was predicted before it was directly observed, astronomers wondered if another faraway planet perturbs Uranus's and Neptune's orbits. In 1880, astronomer George Forbes was the first to formally propose the existence of trans-Neptunian planets. Nearly 150 years later, one may be found with the

help of the Vera C. Rubin Observatory in Chile, which is slated to begin operations next year.

A group of 13 ETNOs—whose orbits have a semimajor axis of at least 150 astronomical units (AU)—ignited interest in Sheppard, of the Carnegie Institution for Science, and Trujillo, of Northern



THE ORBITS OF SIX EXTREME TRANS-NEPTUNIAN OBJECTS (rendered in magenta) are aligned in one direction, which could suggest the existence of Planet Nine (orbit rendered in orange). (Courtesy of Caltech/R. Hurt/IPAC; diagram created using WorldWide Telescope.)



THE VERA C. RUBIN OBSERVATORY in Chile will take images of the Southern Hemisphere over the next 10 years, starting in 2025. It will access around 10 billion objects and is poised to detect Planet Nine—if it exists.

Arizona University. They observed that the ETNOs had elongated orbits around the Sun that were too distant to be affected by Neptune's gravitational pull. The pair suggested that another planet was tugging on the orbits.

The puzzle inspired Caltech astronomers Konstantin Batygin and Michael Brown to take a closer look. They published research in 2016 detailing how 6 of the 13 identified ETNOs' orbits point in the same direction in space and tilt about 30° downward from the plane of the solar system. They calculated the chance of both those behaviors occurring randomly to be about 0.007%. After testing and fine-tuning their models, Batygin and Brown supported the idea that a planet herds the ETNOs. They dubbed the hypothetical object Planet Nine. (See the Quick Study by Brown, *PHYSICS TODAY*, March 2019, page 70.)

Their models put the planet somewhere between 5 and 10 Earth masses and position it near the outer Kuiper belt, 400–800 AU from the Sun. The small size and great distance mean that very little light would reflect off the planet, making it difficult to detect.

Presenting the evidence

The astronomy community is divided about Planet Nine. David Nesvorny, an astronomer at the Southwest Research Institute in Colorado, says he was skeptical at first. But, he says, "none of my ideas could explain what's going on besides Planet Nine." A ninth planet could

be responsible for the retrograde motions observed in some Kuiper belt objects as well as the ETNOs' clustered orbits, Nesvorny says. Using solar-system simulations, he has found that Planet Nine could also explain why some objects make their way inside Neptune's orbit from beyond the Oort cloud, which is located far beyond the edges of the Kuiper belt.

Samantha Lawler, an astronomer at the University of Regina in Canada, remains skeptical about Planet Nine. "I am convinced there are strong observational biases in the ETNOs that we need to be very careful about," she says. Because ETNOs reflect very little light at such great distances, they have been observed only when they are in certain areas of the sky and close to the Sun, she says. Lawler worked on the Outer Solar System Origins Survey, which detected more ETNOs with high perihelion distances. With the added ETNOs, according to the survey's study published in 2017 in the *Astronomical Journal*, there's no evidence of clustered orbits.

Others attribute the ETNO orbits to a dark-matter effect or a misunderstanding of how gravity works, but both theories are "very complicated explanations" for what is likely going on, says Lawler.

Astronomer David Tholen at the University of Hawaii says he is "in the gray area" when it comes to Planet Nine. He says that astronomers use different sets of ETNOs to measure clustering and alignments. Because the "cutoff for

which objects are chosen is arbitrary," more data are needed for him to support or reject the hypothesis. "I'm not sure if the evidence is leaning one way or another right now," says Matthew Holman, a Smithsonian astrophysicist and lecturer at Harvard University. But, he adds, the possibility of Planet Nine is compelling enough to warrant research time.

This past April, Batygin and Brown published more evidence that Planet Nine exists. Their study focused on a new set of low-inclination trans-Neptunian objects with orbits that reach the inside of Neptune's orbit. According to the study, those objects could only make their way into the inner solar system if another planet were there to slingshot them. A planet could also explain how the objects were pulled into the solar system and how their orbits were formed.

Planet Nine hunters have their sights set on the Rubin Observatory. It boasts an 8.4-meter telescope and the largest camera ever built for astronomy research. The camera will scan the Southern Hemisphere sky every night over the next decade and is expected to access around 10 billion objects. Planet Nine's estimated brightness and distance fall into the observatory's capabilities. "If we find something moving out around 500 to 600 AU, it will be Planet Nine," says Brown. If Rubin doesn't find Planet Nine within a few years, he adds, "we'll try using radio telescopes."

Hannah H. Means