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What Have Dwarf Planets Taught Us About the Solar System?

Classrooms across the world received some bad news on 24 August 2006. Pluto—the celestial body discovered in 1930 and named by an 11-year-old girl, the “pizzas” in the planet mnemonic “My very educated mother just served us nine pizzas”—had been officially stricken from the solar system’s family of planets and reclassified as a “dwarf planet.”

The discovery of the slightly more massive object Eris inspired the International Astronomical Union’s (IAU) decision. Proponents of the change insisted that if Pluto got to keep the label “planet,” so too should similarly sized objects—like Ceres, for instance, which was then considered a large asteroid.

A dwarf planet, by IAU’s new definition, must directly orbit the Sun. It must be massive enough for gravity to pull it into a roughly spherical shape. But unlike regular planets, dwarf planets haven’t cleared other smaller celestial debris out of their orbital paths.

As more objects got discovered, Pluto’s new label “dwarf planet” stuck. Then the jokes began.

Facebook group pages popped up, with snarky titles of “When I was your age, Pluto was a planet!” Angry Pluto enthusiasts wrote hate mail to astronomer Mike “Pluto Killer” Brown, one of the scientists who found Eris (see <http://bit.ly/PlutoKiller>). Astrophysicist Neil deGrasse Tyson, a strong proponent of the dwarf planet label, received his own stream of hate mail from crushed 6-year-olds (see <http://bit.ly/NDGTLeters>). To this day, Twitter users occasionally hurl insults at both.

Although some consider the reclassification a “demotion,” Pluto and its cousins Ceres, Makemake, Eris, Haumea, and others continue to dazzle scientists with their strange features and surprising geology. But perhaps more critical, these dwarf planets also trace a trail of scientific breadcrumbs that scientists can follow back in time to understand the origins of the solar system.

“I like to think of Pluto being the dwarf planet that showed us how the solar system’s architecture came to be,” said Renu Malhotra, a planetary scientist at University of Arizona’s Lunar and Planetary Laboratory.

Here are six such revelations about the solar system that we gained from studying dwarf planets.

1 Dwarf Planets Are as Complex as Regular Planets. When the New Horizons probe passed by Pluto more than a year ago, scientists found a complex system with areas of geologically young surface and evidence of active geology. Pluto, the images revealed, wasn’t just a chunk of rock orbiting in space. “Even I underestimated what we would find,” said Alan Stern, principal investigator of the New Horizons mission.

Pluto continues to stun scientists with its unexpected surface features, but its newly revealed complexity is just the beginning. Makemake has no atmosphere. Haumea spins faster than any other known large object in the solar system. Eris might have a thin, icy surface. Ceres hosts mysterious bright spots.

“The fact that these objects can be every bit as complicated as terrestrial planets is a headline,” Stern said. “It should be written in as big a point size as we can write it, because it was completely unexpected.”

2 Dwarf Planets Reveal Neptune’s Orbital Origins. By studying the particular orbital relationship between Pluto and Neptune, scientists figured out how Neptune got to its current position in the solar system. The two bodies are inextricably locked in an orbital resonance: Every time Neptune orbits the Sun three times, Pluto orbits twice, which means that even though Pluto may occasionally cross Neptune’s orbital path, they will never meet.

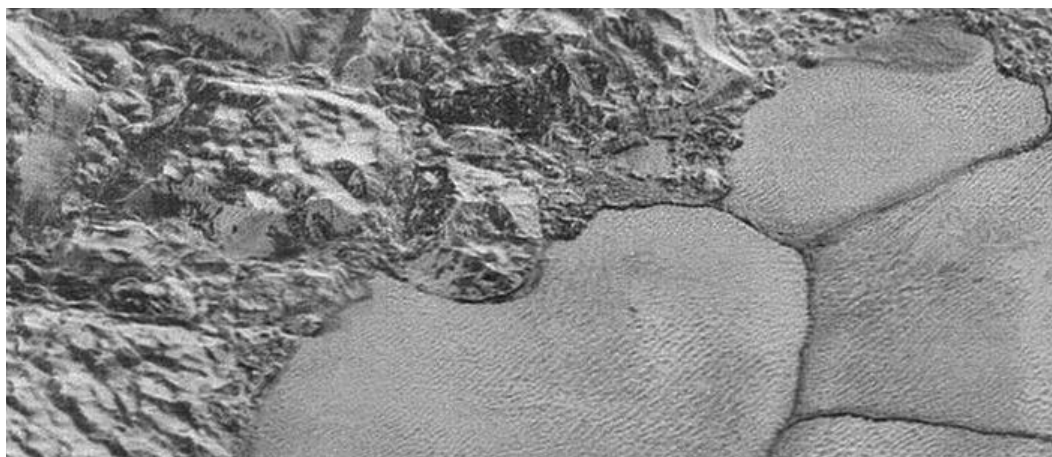


NASA/JHUAPL/SRI

On 14 July 2015, NASA’s New Horizons probe snapped the first ever close-up images of Pluto. Scientists continue to be stunned by its unexpectedly complex surface features.

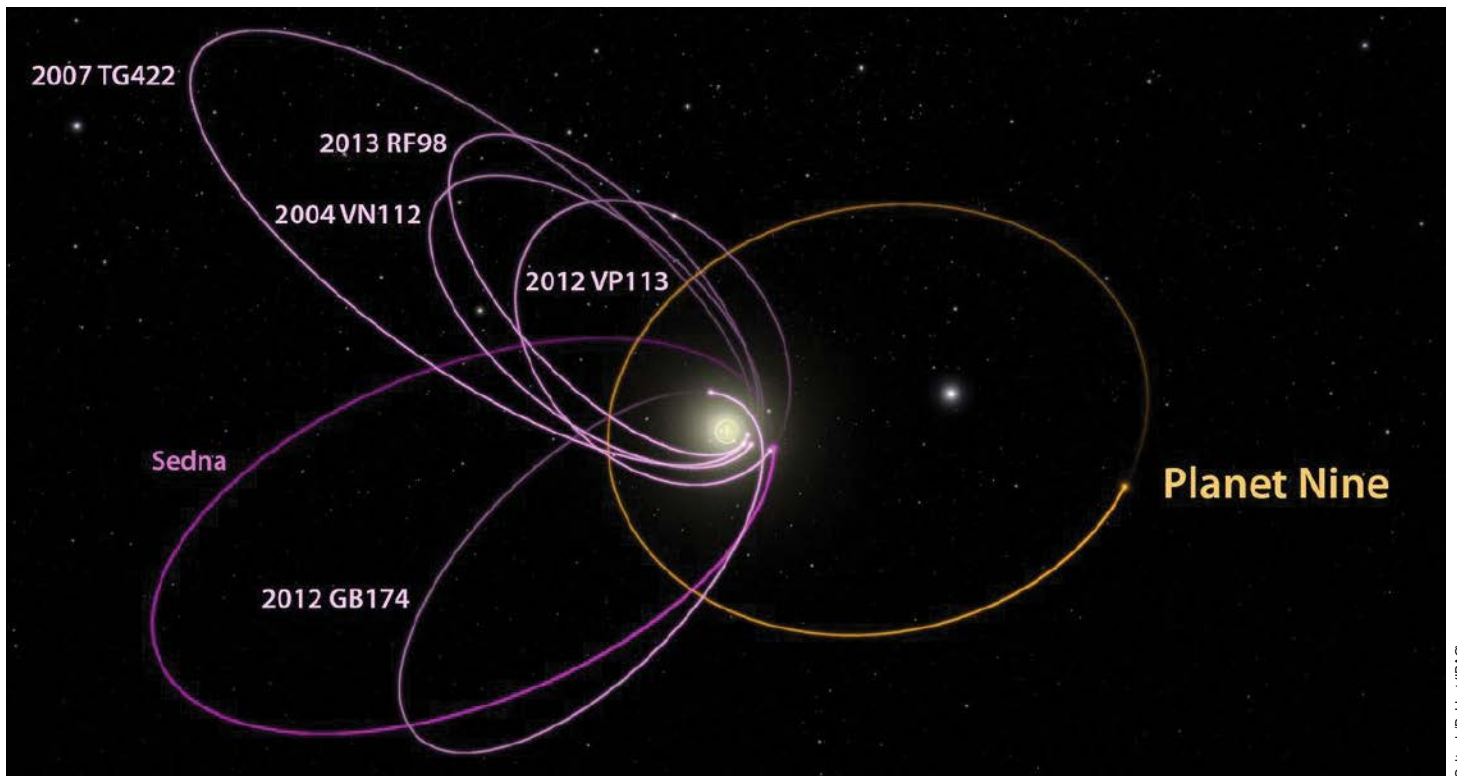
Scientists have always known about this resonance, but it was Malhotra who realized its significance. In a 1995 paper, Malhotra calculated that the only way Neptune and Pluto could have ended up in this resonance was if they both had formed closer to the Sun, then migrated outward (see <http://bit.ly/MalhotraPluto>).

Scientists theorize that in the early days of the solar system, the gas giants, Jupiter, Saturn, Neptune, and Uranus, migrated inward toward the Sun and knocked out leftover debris. This gravitational push on planetary debris ended up changing the planets’ orbits as well, sending Neptune farther out. Nep-



NASA/JHUAPL/SRI

A mosaic of Pluto’s complex surface taken by the New Horizons probe from about 15,000 kilometers away as it approached Pluto on 14 July 2015. Scientists are working to understand the origins of these unexpectedly diverse features.

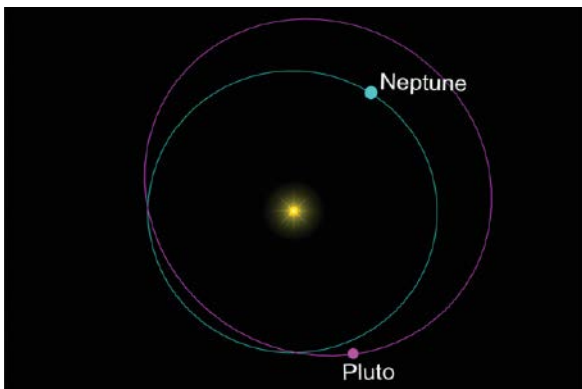


The orbits of Planet 9 and the dwarf planets it supposedly influences. Scientists calculated that only a Neptune-sized planet could keep these objects in their peculiar, angled orbits. The diagram was created using the WorldWide Telescope.

Caltech/R. Hurt (IPAC)

tune's gravitational force encountered Pluto's, and the two bodies pushed and pulled at each other until they fell into a resonance orbit. Astronomers detected the same effect in other bodies, including a new dwarf planet named 2015 RR245 announced to the world this year (see <http://bit.ly/new-dwarf-planet>).

3 Dwarf Planets Give Us a Peek into the Early Solar System. Dwarf planets are handy guides to the ancient solar system.



NASA/JPL

Scientists calculated that in the early solar system, Neptune migrated out to its current position and nudged Pluto into a resonance orbit. Although Pluto sometimes crosses Neptune's orbital path, the resonance prevents the two planets from colliding.

For instance, all the Kuiper belt dwarf planets—Pluto, Haumea, Makemake, and Eris—have moons that scientists suspect formed from high-impact collisions, said Scott Sheppard, an astronomer at the Carnegie Institution for Science in Washington, D. C. Haumea in particular is the only known Kuiper belt object to have a “family” that orbits along with Haumea and its moons, meaning that the debris kicked off by an impact long ago didn't have enough energy to escape Haumea's gravitational pull.

The presence of such moons is further evidence of an early period of “late heavy bombardment” of objects in the solar system. Scientists think that during this time, about 3.8–4 billion years ago, gravitational interactions among Jupiter, Saturn, and Neptune sent comets and asteroids sprawling across the solar system to collide with planets.

In the past 2 years, Ceres has also provided various windows into the past. In 2015, NASA's Dawn probe headed to the dwarf planet after visiting the asteroid

Vesta. There, scientists detected ammonia-rich clays in Ceres's surface.

Ammonia itself isn't stable at the temperatures found on Ceres (130–200 kelvins), but it is plentiful in the outer solar system. So how did the molecule get there? Scientists have formulated different hypotheses, said Carol Raymond, deputy principal investigator for Dawn. Either Ceres formed in the outer solar system, during its early days, and got kicked inward by a chaotic migration of the gas giants, or Ceres formed in the asteroid belt, and somehow ammonia-rich material from the outer solar system made its way inward.

Further study of Ceres will help clarify details of solar system formation, Raymond said.

4 Dwarf Planet Candidates Helped Scientists “Find” Planet 9. Thanks to a handful of debris orbiting farther away than Pluto, scientists this year found evidence that a rocky, Neptune-sized planet may lurk beyond the gaze of even our most powerful telescopes (see <http://bit.ly/Eos-Planet9>).

The story began in 2003, when Brown and his team at the California Institute of Technology (Caltech) discovered Sedna, a dwarf planet candidate that orbits far beyond the

Kuiper belt, Pluto's neighborhood of large, icy bodies 30 astronomical units (AU) away. Sedna maintains a steady orbit and comes within only 76 AU of the Sun at its closest approach.

Since then, scientists have spotted several more objects near Sedna, including 2012 VP113, found by Sheppard and colleague Chad Trujillo of Hawaii's Gemini Observatory. The pair noticed that their new object and the rest of these far-away objects had similar, steady orbits.

Back at Caltech, after reading Sheppard's and Trujillo's work, Brown and his colleagues set out to find the cause of such clustering, and after many hours of poring over models and simulations, they officially proposed that only a planet-sized body could exert enough gravitational pull to keep the far-away cluster of dwarf-planet-sized objects in steady orbits. This hypothesized planet was deemed Planet 9 (sometimes called Planet X).

"Right now we're doing surveys trying to find more dwarf planets," Sheppard said. "If we find more and more of these, they can lead us to the much bigger, major Planet X."

5 Ceres (We Hope) Will Help Us Understand Icy Ocean Moons. Kuiper belt dwarf planets aren't the only thing keeping scientists busy. Dawn mission scientists recently discovered that regions of Ceres contain higher concentrations of carbonate minerals than anywhere outside of the Earth's ocean floor. These minerals reveal that Ceres is like a "fossilized" ocean world, Raymond explained. They could be the



There may be only six officially designated dwarf planets (missing from the image is 2015 RR245, announced this year), but many more dwarf-planet-sized objects exist. They may even be the dominant class of objects in the solar system.

remnants of a vast ocean that once existed on the dwarf planet.

Scientists figured out that mysterious bright patches in Ceres's geologically young Occator crater come from sodium carbonate, a highly reflective mineral found in hydrothermal environments under Earth's oceans. This means that at some point in Ceres's history, hydrothermal processes must have pushed this material to the surface, Raymond said.

If hydrothermal processes are confirmed, Ceres's surface may be analogous to the current seafloors underneath the solar system's ice-covered moons. Astrobiologists yearn to

peek below the icy shells of Jupiter's and Saturn's moons Europa and Enceladus because there are vast oceans underneath, and life needs water to proliferate.

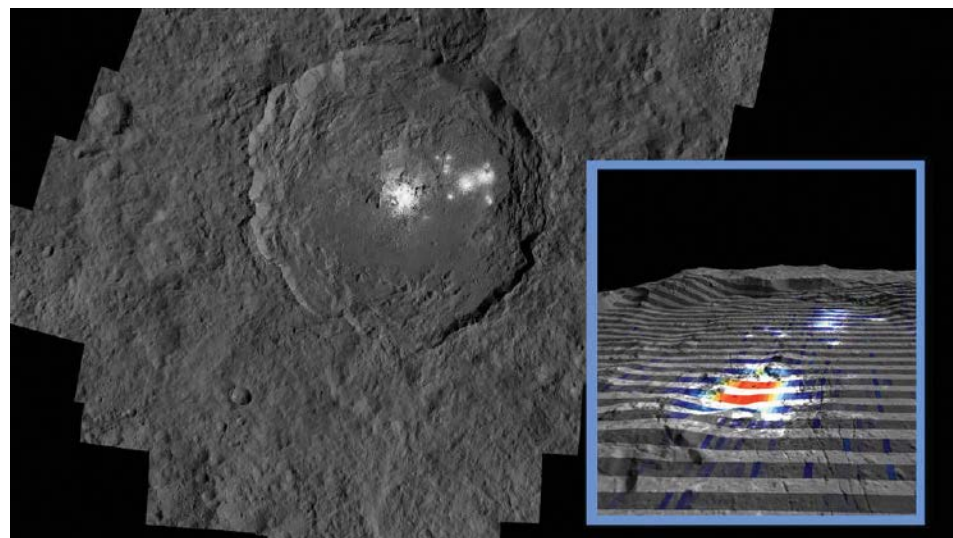
Ceres is similar to these moons because 25% of the dwarf planet is water ice. Plus, its seafloor-type conditions are "where all of the elements necessary for habitability occur together," Raymond said.

6 Dwarf Planets Are Prolific. Pluto holds a special place in the Internet's collective heart but may not be so special in the solar system. Currently, there are six dwarf planets officially designated by IAU: Pluto, Ceres, Eris, Makemake, Haumea, and 2015 RR245, discovered in July. Since scientists started looking deeper into the Kuiper belt, they have found at least 20 more similarly sized objects, Sheppard said.

And there may be dozens more out there. "We discovered that dwarf planets are the most populous class in the solar system," Stern said. Other solar systems may be like ours too, he added.

This population revelation, along with the surprising geological and atmospheric complexity found on dwarf planets, means that the field could be "at the very beginning of a paradigm shift and a revolution," Stern said. Perhaps, he continued, it's the classic large planets that are the "oddballs" of planetary formation.

He wonders, "Who's the misfit now?"



Scientists found evidence of carbonate minerals in the bright spots of dwarf planet Ceres's Occator crater. Stripes on the inset represent where the spectrometer frames lie, whereas red signifies a high abundance of carbonates and gray indicates a low abundance. These carbonate minerals mean that Ceres may have been covered once by an ocean.