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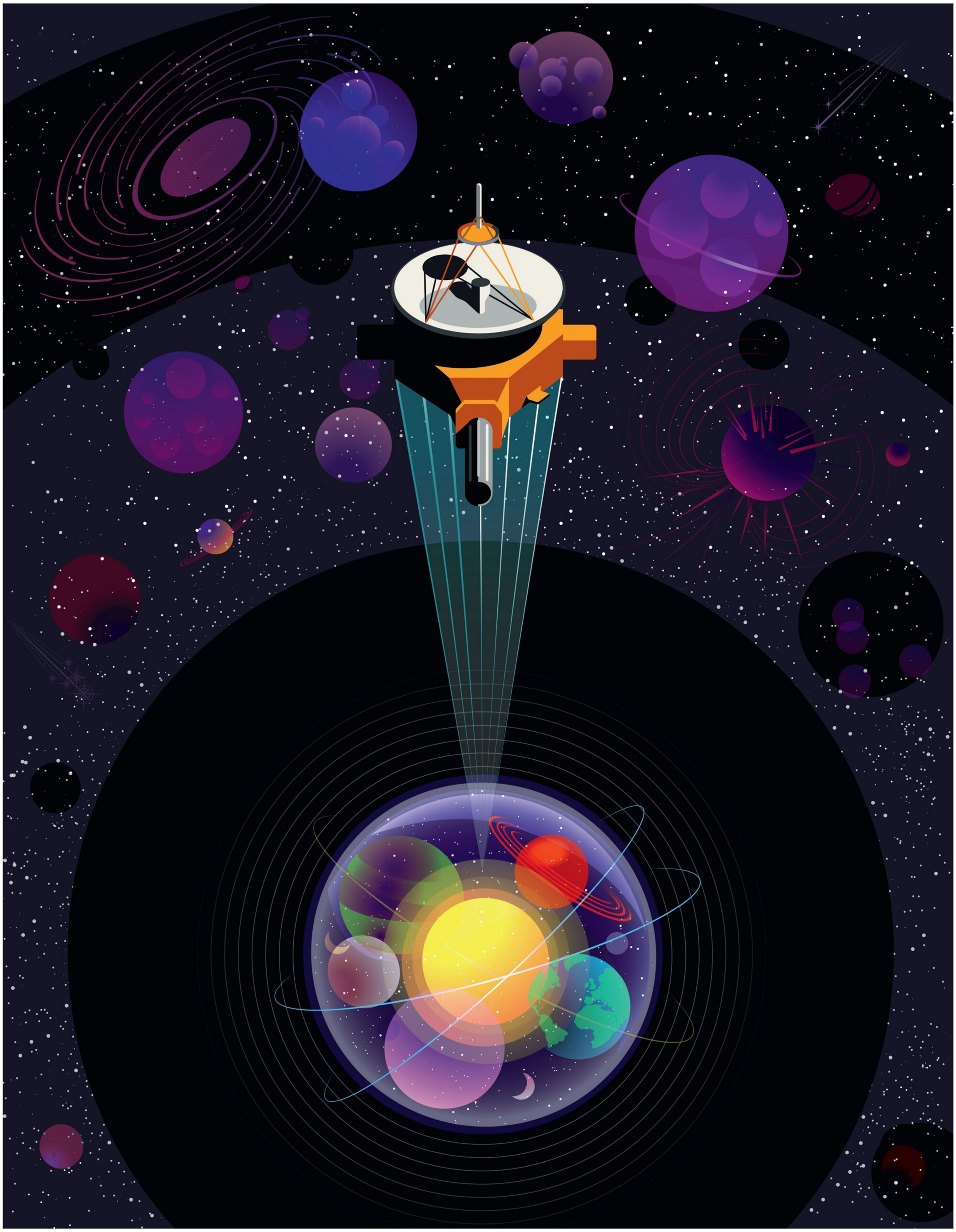


PETER GREENWOOD

Pushing the boundaries

A plucky space probe could be about to redraw the frontiers of our solar system, finds **Becca Caddy**

NASA's New Horizons spacecraft is hurtling out of the solar system at an incredible speed. It is currently about 8 billion kilometres from the sun, and by the time you finish reading this story, it will have sped thousands of kilometres further into the frigid gloom. It is lonely out there. Even the giant planet Jupiter is but a tiny speck.

New Horizons is mainly known for giving us our first proper look at the dwarf planet Pluto in 2015. Until then, we had only seen it as a blurry smudge. It has also taught us much about the solar system's outer reaches and the small, frozen worlds that float there. "It's really been an Alice in Wonderland kind of story," says Alan Stern, the principal investigator of the mission. "It's been dreamlike and we've discovered wonderful things."

However, the dream isn't over yet because New Horizons may be poised for a surprise final act. In early 2024, one of its detectors recorded an unexpected uptick in the amount of dust it was encountering. Since that material could have been created in collisions between rock fragments, astronomers now wonder if there are many objects beyond the rubble-strewn Kuiper belt often considered the edge of the solar system. If so, our system's boundaries will need to be redrawn and our models of how it formed thrown into doubt.

Stern and his colleagues are obviously keen to take advantage of their probe's unique position to learn more about this unexplored wilderness while they still can. "It's an ongoing detective story," he says.

We have known of the Kuiper belt , a vast doughnut-shaped region teeming with cold rocks and icy bodies, for decades. Its nearest edge is just past Neptune's orbit, at about 30 times the distance from the sun to the Earth, or 30 astronomical units (AU). We assumed the farthest edge of the belt was at about 50 AU.

Perhaps its most famous inhabitant is the dwarf planet Pluto. "When I was a kid, there were nine planets and Pluto was one of them," says Carly Howett at the University of Oxford. But we knew very little about what it looked like. "Every time you looked in a book about space, [Pluto] was just a fuzzy photo. No one knew anything."

New Horizons launched in 2006, the same year that Pluto was downgraded by the International Astronomical Union to a dwarf planet. When the craft flew close by this world nine years later, our impression of it was transformed. It went from an indiscernible smudge to a fascinating place with an atmosphere and signs of volcanic activity.

The mission revealed mountains and plains, and gave us a close look at its incredible moons, such as Charon with its complex surface of canyons. "To be on the team that finally brought Pluto into focus was just astounding," says Howett, who worked on one of the mission's imaging instruments.

But the voyage of discovery didn't end there. Before the spacecraft had even reached Pluto, the New Horizons team had set its sights on finding another target to study. We are aware that there are plenty of icy bodies known as Kuiper belt objects (KBOs) out there (see "Far-flung worlds", p42). But ground-based telescopes couldn't find any within the spacecraft's reach. For a while, it seemed as though there would be no plausible candidates to explore. Then the Hubble Space Telescope took over the search and in August 2015, a target was finally chosen. In January 2019, New Horizons flew past the asteroid of choice, a strange rock about 35 km long named Arrokoth.

The aim of the flyby was to learn more about its composition and surface, to gain some clues to how it may have formed. Arrokoth is a contact binary, meaning it consists of a pair of lobes stuck together, a bit like the sections that make up a snowman.

Not only did we get a better look at Arrokoth, but, coupled with observations that many other objects are binaries, it taught us about the early solar system's building processes. Astronomers had thought that planetesimals – large rocky bodies on their way to becoming planets – grew through high-speed collisions. But Arrokoth's binary nature, two parts that ›

must have come together at a fairly slow speed, showed it was probably a gentler merging process instead. "The discovery that many of these objects in the Kuiper belt are binaries has completely rewritten our understanding of how the seeds of planets, the so-called planetesimals, are formed," says Stern.

The original reasoning behind the fast collisions idea hinges on a description of the evolution of the solar system known as the Nice model. Named after the French city where it was developed, this proposes that the giant planets started out much closer together before migrating to their current positions. These planetary movements would have stirred up the solar system, sending debris zipping around.

But the gentle formation of Arrokoth, along with the unexpectedly stable orbits of many KBOs, suggests Neptune's migration was less disruptive than the Nice framework predicts. The model is valuable for understanding some parts of the solar system's evolution, says Stern, but the insights from New Horizons mean it may need some adjustments.

Mysterious dust

New Horizons gathered such a swathe of data about Arrokoth that it is still being sent back from the spacecraft to Earth for analysis, and it continues to lead to new discoveries. But there were no plans to study any more KBOs up close. The Arrokoth flyby was meant to be the probe's swansong.

Since it left that location, New Horizons has been travelling in hibernation mode, with most of its instruments switched off. It has traversed the Kuiper belt and is encountering new territory, almost 60 AU away from us. Only NASA's Pioneer and twin Voyager spacecraft have ventured further, but their trajectories took them out of the plane the Kuiper belt sits in, whereas New Horizons stayed within it.

The only instrument that remains switched on, a dust detector, has recently picked up something strange. Between 55 and 60 AU, it started to spot more of this material than expected. This is an important indication that there are larger bodies out there that might be smashing together. The presence of all that dust suggested the Kuiper belt may be bigger than we thought.

To better understand what is going on, the New Horizons researchers used a ground-based observatory, the Subaru Telescope in Hawaii, to look at the region beyond the Kuiper belt. Their results, presented at a conference in March 2023, show a surprising number of very distant objects beyond the suspected outer edge of the belt.

"We expected to encounter the Kuiper cliff, where the density of objects drops off sharply," says Anne Verbiscer at the University of Virginia, who is co-investigator of the New Horizons mission. Instead, they found this measure dropped between 50 and 60 AU, but beyond that there were far more objects than expected. Verbiscer says this means there could be a second Kuiper belt.

If that is the case, it would be an enormous discovery. "It would make us rethink many of the properties we see today in the trans-Neptunian region and in the formation of our solar system," says Pedro Bernardinelli at the University of Washington in Seattle. For example, he says, we explain the position of the edge of the Kuiper belt with the hypothesis that another star and our sun had a close encounter in their youth that wiped out any objects beyond that distance. If the Kuiper belt doesn't end there, perhaps that never happened.

While Bernardinelli is excited about the prospect of a second Kuiper belt, he urges caution. The Subaru Telescope results have yet to be peer reviewed – and other studies of the region beyond 60 AU with other ground-based telescopes have come up short. As well as confirmation of the initial results, we would need more detail on the orbits of these objects beyond 60 AU to say whether they are just part of the same Kuiper belt we know of or if they form a second one.

One possible explanation is that the Kuiper belt "just happens to be more extended in the direction New Horizons is flying", says Stern. "Or it could be that others missed it." However, he points out that other studies published in the past 10 years also found evidence in agreement with his team's results.

Whether there really is a second Kuiper belt comes down to the way the objects that populate it move around the sun. When the New Horizons researchers began mapping the Kuiper belt, they discovered significant variations in the distribution and stability of KBOs. Some have what are known as non-resonant orbits, meaning they do their own thing, without being subject to the gravitational influence of nearby Neptune. From this, astronomers can deduce that these KBOs formed where they are right now.

But data from New Horizons has revealed that many more KBOs than expected are in orbital resonance with Neptune. This means that these KBOs precisely line up with Neptune at regular intervals, a bit like the minute and

Far-flung worlds

The New Horizons spacecraft has changed our understanding of the Kuiper belt and the outer reaches of the solar system (see main story). "One of the first real surprises of New Horizons was that very large objects [in this region], like Pluto, are abundant," says Alan Stern, principal investigator of the mission. "It could have been Pluto was an oddball, but it was just brighter and more easily discovered."

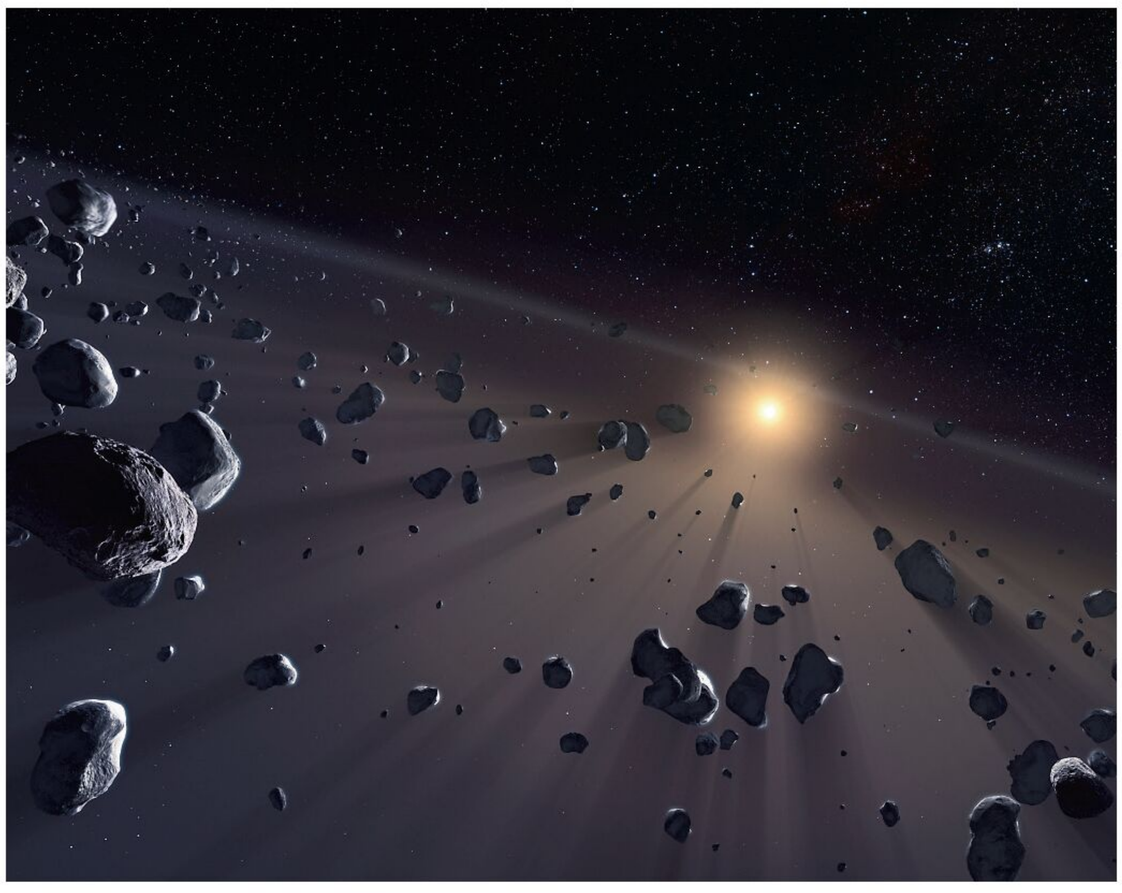
There are plenty of strange objects within the icy Kuiper belt. Notable among these are Makemake, a reddish-brown dwarf planet. Scientists have detected frozen methane and ethane on its surface. There is also Eris, which astronomers believe is one of the largest dwarf planets in our solar system. It has a rocky surface.

Anne Verbiscer, a co-investigator on New Horizons, is particularly interested in the dwarf planet Haumea. It is an oddity in that it is shaped like a rugby ball and rotates every 4 hours. Verbiscer says this rapid rate of tumbling could be because there was an intense collision between Haumea and a larger body.

"We think it might still be spinning from that collision," she says. It also has plenty of satellites to explore. "It's got at least two moons that we know of and a ring system," says Verbiscer. "It's a very, very interesting world."

The New Horizons probe is hurtling out of our solar system

JOE OLMSTED/STSCI



ESO/M. KORNMESSER

Left: An artist's impression of the Kuiper belt. Below: The Vera C. Rubin telescope that will help us discover more Kuiper belt objects like Pluto (also pictured)

hour hands on a clock. For instance, a KBO in a 2:3 resonance with Neptune completes three orbits of the sun for every two orbits Neptune makes. This means the KBO's orbit is fairly stable, largely preventing any collisions. And in this case, astronomers can tell the objects must have formed elsewhere, perhaps in the inner solar system, before being gravitationally tugged outwards and slotting into a synchronised orbit with Neptune. "In its early days, the solar system was rearranging itself," says Stern.

Cliff or canyon?

The New Horizons exploration of the Kuiper belt has already challenged our existing ideas about how the solar system formed, including the Nice model. But discovering objects from a second Kuiper belt would really raise eyebrows.

The exact implications would depend on whether these entities were resonant or not, says Wes Fraser at the Herzberg Institute of Astronomy in Canada. "That detail is important because if distant bodies were entirely resonant, they would be most likely transported bodies, originating from closer regions," he says. If this is the case, it would require a revamp of our models of solar system formation, he says, but not a complete rewrite.

On the other hand, if they were non-resonant, this would be a tremendous discovery. "A disc of material at 70+ AU would make our solar system much more in line with the sizes of some of the other known old debris discs [of other star systems]," says Fraser. "Hence the importance of the discovery."

If we do have two Kuiper belts, it would mean that instead of a Kuiper cliff, the gap between the two belts would form more of a Kuiper canyon. This gap, at about 50 to 60 AU from the sun, would make our solar system much more like other systems than we had thought. This will help to put our system into context. "We don't know the extent to which our solar system is unique," says Stern. And it could teach us about our past. Other, younger star systems often have gaps at around 100 AU, so if ours turns out to have a gap too, says Verbiscer, then studying these younger systems might teach us about the history of our own.

> "There could be a second Kuiper belt. If so, this would be an enormous discovery"

RUBIN OBSERVATORY/NOIRLAB/NSF/AURA/STOCKEBRAND

DOTTED ZEBRA/ALAMY

Why these gaps should exist isn't completely clear. In other planetary systems, gaps in the disc are sometimes taken as a sign of a fledgling planet, hoovering up dust as it orbits. "But those are pretty young stellar systems, not like our current solar system," says Verbiscer. Instead, she suggests the gap in the Kuiper belt, if it does exist, could be influenced by gravitational forces. Such gaps are already known in our solar system. For example, there are "Kirkwood gaps" in the asteroid belt between Mars and Jupiter, caused by asteroids being affected by Jupiter's gravity.

There is plenty more to learn, then. And luckily, New Horizons might get an encore. Towards the end of 2023, NASA extended the mission into the late 2020s, and the team is currently exploring whether there are any KBOs ahead of it that it could conceivably fly past and observe.

"The spacecraft is in perfect health, has power in its nuclear battery and a communication range that could allow it to operate until around 2050," says Stern. Plans are now in place to use upcoming telescopes, such as the Vera C. Rubin Observatory and the Nancy Grace Roman Space Telescope, to discover new KBOs for future flybys.

Although we need to find these new targets before New Horizons goes too far, the longer the wait, the more technology advances. "The machine learning, AI and computing power we now have are growing exponentially," says Howett, stressing that these tools are enabling deeper insights into the Kuiper belt.

Ultimately, the craft's journey is a voyage into the unknown. "The Kuiper belt is a puzzle," says Verbiscer. "We just need to put the pieces together." ▮

Becca Caddy is a freelance writer based in London