A Hidden Planet in the Outer Solar System: The Case for Planet 9

Right on the heels of Pluto's demotion from planet to dwarf planet, over the last few years evidence has been mounting in support of another icy, distant body's existence in the far reaches of the solar system. Nicknamed "Planet 9" for now, this mysterious body has yet to be detected or directly observed with any telescope, yet a steadily growing list of its indirect influences on the solar system have made it an increasingly intriguing prospect in recent years. What is Planet 9, and is it really out there? Hopefully by the end of this article you'll have a good answer to the first question, but as to the second? The short answer is that we really don't know yet, but this is one secret of the cosmos that may be unraveled much sooner than you might think.

To truly understand the significance of a potential Planet 9 discovery, placing it within the historical context of the solar system is vital. Let's wind the clocks back to the year 1781, when William Herschel discovered the seventh planet Uranus. Thought to be nothing but a background star in previous observations, this first major addition to the solar system since ancient times incited a flurry of interest as astronomers painstakingly monitored its motion over the next six decades. The physical laws governing the motion of the planets – namely, the laws of gravity – were deeply understood even back in Herschel's time, and it very quickly became clear that something wasn't quite right: observations of Uranus' position on the sky differed slightly from where it "should" have been from calculations. This discrepancy led Urbain Le Verrier to propose the existence of an eighth planet, beyond even the orbit of Uranus – gravitational perturbations from this outer planet could explain these irregularities in Uranus' orbit. In the year 1846, Le Verrier was vindicated when astronomer Joseph Gottfried Galle's observations confirmed the predicted existence of the newly christened Neptune. The focus of this article is not at all on Urbain Le Verrier's prediction of Neptune's existence, but let's take a moment to pause and remark on the gravity of this discovery - Le Verrier had correctly predicted (to remarkable accuracy) the existence and orbital position of a previously unknown body through nothing but mathematics. For the time, this was an absolutely incredible feat and confirmation of the remarkable accuracy of Newton's laws of gravitation – proof that the universe could be described and understood through math, reason and logic. It was also the first successful prediction of a celestial body through its subtle impacts on its surroundings; throughout the rest of our journey, this concept will remain important.

Le Verrier had opened the floodgates – the scientific discourse of the next century would be dominated by talk of unseen planets, near and far, subtly manipulating the framework of the solar system. The vast majority of these seeds failed to bear fruit; the search for the so-called "Planet X" championed by Percival Lowell in the early 18^{th} century remains the only exception. Motivated as Le Verrier was by continued slight discrepancies in the orbits of the giant planets, Lowell Observatory in Arizona was founded in search of Planet X. After Lowell himself died suddenly in 1916, Clyde Tombaugh took over the search and, in 1930, discovered Pluto in Planet X's predicted location. Things did not go as smoothly for Tombaugh as they did for Le Verrier, however, as not all was right with Pluto. To explain the irregularities in the orbits of the giant planets, Lowell demanded a fairly large planet, about seven times the mass of the Earth. Uranus and Neptune, for reference, are both approximately 15 times the mass of the Earth. An object of this size should not have presented a challenge for the telescopes of the time to resolve – Tombaugh's discovery of a dim point an order of magnitude fainter than expected did not jive with expectations. Pluto was there, yes, but it was *tiny* – today, we know Pluto sits at a measly 0.2% of Earth's mass; less than a quarter the mass of our moon. A planet of this size surely could not have been responsible for the discrepancies Lowell had noted, and indeed it was not – it was in fact a slight overestimation of Neptune's mass (verified by the Voyager 2 probe's flyby in the 1990s) that had thrown Lowell off. Pluto showing up exactly where the non-existent Planet X should have been? Nothing but coincidence.

Here now we arrive at part of the tale many of you will know all too well – Pluto's tragic demotion from planet to dwarf planet. The precise astronomical definition of "planet" is and always will be, to some degree, arbitrary and contested – but if we were to distill it down to one reason, Pluto was demoted because *it was not alone*. 15760 Albion was the first of these "trans-Neptunian objects (TNO)", or objects beyond the orbit of Neptune, to be discovered in 1992. A deluge of discoveries followed shortly, including Sedna, Orcus, Haumea, and Makemake. The final nail in the coffin came in 2005, when astronomer Mike Brown discovered Eris, a TNO larger than Pluto. Now infamously known as "the man who killed Pluto", Brown argued that Pluto did not deserve its planet status on grounds that other bodies of similar mass were close to its orbit. The decision was far from popular and I could write several more articles on its nuance and controversy – for now, let's table it and move on.

So where does that leave us now? Pluto, along with the large TNOs Eris, Makemake and Haumea (as well as the asteroid Ceres) are considered dwarf planets. More importantly, they are members of the *Kuiper Belt*, a huge collection of icy TNOs just beyond the orbit of Neptune. Thousands of Kuiper belt objects have been found to date – the true census is believed to lie in the range of the hundreds of thousands, the vast majority nothing more than tiny, icy rocks. The object I'd like to draw your attention to next, however, is neither one of the five dwarf planets nor a tiny iceball. Rather, Sedna is not remarkable for its size – rather, it boasts one of the most intriguing orbits in the solar system. A common measure of distance in astronomy is the average distance from the Earth to the Sun: this is called the *astronomical unit*, or AU for short. Earth obviously orbits the Sun at an average distance of 1 AU – Neptune, the most distant planet, averages 32 AU. Sedna never exactly gets close to the sun – separated from the sun by 76 AU at closest approach, the sun never appears as more than a pinprick in Sedna's sky. The truly remarkable aspect of Sedna's orbit is revealed when we consider its *furthest* distance from the sun – a massive 937 AU. It would take light over five days to traverse such a distance, and it takes Sedna itself over 10,000 years to orbit the sun once. Understanding Sedna's incredibly eccentric and elongated orbit is key to unlocking many secrets of the solar system.

Planet 9

It is now finally time to turn our attention to Planet 9. Sedna, while certainly an abnormality, is not exactly alone either. A handful of these incredibly long-period, stretched out TNOs have been observed along with Sedna. This exclusive group carries numerous monikers – *extended-scattered disk objects, detached objects, long-period TNOs*, etc. In this article I will call them long-period TNOs, or LP-TNOs, and thirteen LP-TNOs were known as of 2016 when Konstantin Batygin and Mike Brown, astronomers at Caltech, noticed once again that something was not quite right. Consider Sedna's orbit a template for all LP-TNO orbits – one side (relatively) close to the sun, one side astronomically far. Draw a line from the far side of the orbit to the near side – in astronomy, this is the planet's *line of apsides*. Batygin and Brown noted that the lines of apsides of these thirteen bodies showed a striking and unusual degree of clustering – essentially, all the orbits pointed in the same direction. This phenomenon is termed *apsidal confinement*, and immediately is cause for suspicion – all things equal, there's no reason to suspect these LP-TNOs to favor any region over another. We would expect to see a fairly uniform distribution of their orbits across the entire globe of the solar system – instead we see one hemisphere essentially empty, the other relatively packed with objects. Something must have influenced our LP-TNOs – something must have dragged the whole population to one side, or ejected everything in the opposite. What mysterious agent could be responsible? The answer, as I'm sure you've guessed by now, is Planet 9[1].

Audacious of Brown, so quick on the heels of killing the previous 9th planet, to propose the existence of another. You'd think that on first glance, but Planet 9 is no Pluto. Planet 9 influences the orbits of these LP-TNOs through a complex process of angular momentum transfer. Due to the vast distances involved, these effects happen slowly over millions of years – ensuring that orbital distances are unaffected but orbital orientations may be. A crude way to envision this is to think of Planet 9 as an energy well of sorts – over time, each LP-TNO will draw from this well to slowly march towards the most favorable orientation, which works out to be in the opposite orientation from Planet 9 itself. To influence the orbits of so many TNOs to such a degree, something far more substantial than your typical dwarf planet is needed. Brown and Batygin have recently run Monte-Carlo Markov-Chain simulations[2], which assess the probability of observing the present-day solar system given different orbital configurations of Planet 9. Their results suggest that the body responsible is indeed both very large and very distant. Clocking in at about six Earth masses and orbiting the sun at around 400 AU, Planet 9 is 3000 times more massive and ten times further from the sun than Pluto.

An unusual planet, to be sure, and an absolute outlier in our solar system. What do we know about this mysterious world, other than that it *might* be out there? Unfortunately, other than its most basic physical parameters such as mass and distance, not much at all – we've never even seen it as a pinprick of light on the sky, much less its surface to make any sort of assumption about its composition. We do know that it shouldn't be where it is: our current understanding of planet formation has each planet gradually forming via gravitational collapse out of a massive disk of dust and gas that would have encircled the primordial Sun. The issue here is one of mass: these disks generally have the vast majority of their material concentrated close to their host star, and six Earth masses is a lot to ask for being so far away from the Sun. It's generally agreed, then, that if Planet 9 is out there it didn't form there; rather, it moved there. Theories and speculation abound for formation mechanisms, and discussion has largely settled on one of two possible origins. One possibility is capture from a passing star: while the Sun is fairly isolated today, it's not entirely outlandish to think that sometime in the distant past, a near encounter with a quick-moving star in our stellar neighborhood could have detached one of its planets, only to find a new home in our solar system. Planet 9 would then be an interloper, an alien to our solar system. Another intriguing possibility is migration: many astronomers posit that Planet 9 formed much closer to the Sun, where the circumstellar disk was plentiful enough to support its formation, and was scattered out to its present-day orbit via gravitational interactions with the much larger Jupiter or Saturn. Planetary migration is well understood and accepted as a vital mechanism in the formation of our present-day solar system: in fact, the well studied "Nice Model" is the current paradigm that seems to best explain the solar system's present-day configuration[3], and relies on migration to explain Uranus and Neptune's orbits. So migration is not as far-out an idea as it might seem, at first blush. And if a body of Planet 9's significance had moved through the solar system in this manner, it certainly would have left a mark gravitationally; astronomers have theorized a myriad of possible side effects of this migration, from a slight twist in the orbit of the Sun[4] to Uranus' unusual axial tilt[5].

Excitement around Planet 9 is at an all-time high as scientists and astronomers consider the implications and ramifications of such a body in the outer solar system. Sadly, it would be remiss to plow on ahead without noting the counterevidence against Planet 9. So if Planet 9 isn't actually out there, what is causing this clustering of LP-TNOs? This is a bit of a trick question – while a few alternative suggestions have been brought forth, the most compelling argument against Planet 9 is that the orbital clustering *does not exist*. This may be a bit tricky to grasp, but ultimately comes down to the argument that all the data we have on the outer solar system has some sort of systematic bias attached. Imagine, for instance, taking a helicopter and hovering far above the Amazon rainforest. You would probably see a vast expanse of huge, tall trees before you. Does that mean the Amazon rainforest only has tall trees? Maybe, but not necessarily – it's more likely that you see only the huge trees because they are *easier to see* – the smaller trees may be obscured by the larger ones, for example, or they may simply vanish into the distance in contrast to the larger trees you'd see from miles away. This is observational bias, and some astronomers argue that the evidence for Planet 9 may be tainted by it. So why would it be easier to detect LP-TNOs in a specific direction? It's certainly not as clear-cut as our tree example, and at the moment we don't have a perfect understanding – astronomers simply hypothesize that such a bias exists. One notable study was recently performed at the University of Michigan, where a vast statistical survey was run simulating observations from relevant surveys of LP-TNOs[6]. These simulations were taken assuming certain biases in the surveys in which the analysis for Planet 9 is based. The study concludes that it is still possible for simple observational bias to explain the unusual orbital clustering we see, rather than Planet 9. The study was careful to not explicitly rule for or against the existence of Planet 9, and this cautious attitude encapsulates the community's approach to Planet 9 thus far. Keep in mind that the current data is based on the orbits of just a handful of outer solar system bodies, and astronomers are extrapolating these observations to make assumptions about the much larger population that must exist. While the evidence we see is indeed extremely compelling, we cannot forget that it is just a snapshot of the bigger picture – and given the difficulty of detecting these LP-TNOs, this is a bigger picture that will be painstakingly revealed, if at all. The discourse regarding the true nature of Planet 9 will be tough to resolve via indirect means – of course, the only way to truly know for sure is a direct detection.

Prospects for Detection

A direct detection of Planet 9 would be the holy grail to astronomers – even the most skeptical critics would be silenced if they could look through a telescope and see Planet 9 in the sky. This is easier said than done though, as the vast distances involved make a direct detection a daunting prospect. Planet 9 is bigger than Pluto, to be sure – far bigger. This doesn't particularly matter, though – planets produce very little of their own light. The vast majority of the light we see when we look at a planet is actually light reflected from its host star, in our case the Sun. At Planet 9's distance, the Sun would appear as merely a pinprick in the sky. A tiny, faint object and the entire sky's expanse in which to look; it's no wonder that when the Planet 9 hypothesis was first put forth, Batygin likened a direct detection to finding a needle in a haystack, except you only have a vague idea of where the haystack itself is. Luckily for us, that was five years ago, and things look less bleak today. A direct detection of Planet 9 has two prerequisites: we need to know where it will be on the sky, and we need a highly sensitive instrument to follow up.

Let's first explore Planet 9's location. When Brown and Batygin first proposed Planet 9 they predicted its location, but with generous error bars. It was better than a vague "it's somewhere over there", but for the purposes of a direct detection not by much. In the ensuing five years this prediction has been greatly refined. In particular, the previously mentioned Monte-Carlo Markov-Chain models not only predict physical characteristics of Planet 9, but also its orientation in physical space – after some calculation, this can be translated to a position on the sky. As it happens, we now have a pretty good idea of where to look for Planet 9: Brown and Batygin predict its position to trace the ecliptic plane of the Earth, or the plane of the Earth's orbit around the Sun.

We have a location – important to be sure, but you could look exactly there for years and never see it given how dim Planet 9 is. The next piece of the puzzle is a powerful instrument to actually detect Planet 9. Meet TESS, the Transiting Exoplanet Survey Satellite[7]. As the name suggests, TESS is a space telescope primarily designed to detect exoplanets, or planets around other stars. While it's not explicitly in TESS's mission to find Planet 9, it takes an incredibly powerful telescope to detect exoplanets and TESS is more than powerful enough to directly detect Planet 9, if it's indeed out there. Furthermore, the predicted area on the sky in which Planet 9 is expected to be found just so happens to fall neatly within TESS' next mission run parameters. TESS' most recent run started up in November of 2021, and astronomers all around the world are gearing up to analyze the wealth of data that will shortly be available to them. Planet 9 has eluded detection since its genesis into the scientific community, but it appears to be running out of places to hide: if it's out there, TESS is powerful enough. It's entirely possible that within a year of you reading this article, the question of Planet 9's existence is finally put to rest.

Where does that leave us now? The saga of Planet 9, from its inception in 2016, seems likely to come to a close in the very near future. Whether that ending is confirmation of a giant planet in the distant outreach of our solar system, or a non-discovery and some introspection on the biases of our past telescope surveys? Only time will tell. No matter the result, however, it must be said that the putative Planet 9 has had a positive impact on the field as a whole, not only for kicking off a brief era of intense interest and scientific curiosity, but also for the very real advancements in observational techniques that have come about as a means of discovery[8]. For now, as Brown would put it, the search continues.

References (and good further reading)

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