Belting it out among the planets

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**How far apart are the planets spaced?**

Put the Sun at 0 and the Earth at 1. This astronomical unit (AU) stands for about 1.5 crore kilometres. Then Mercury is at 0.4 AU, Venus is at 0.7 AU, Earth is at 1.0 AU and Mars is at 1.6 AU. Jupiter is at 5.2 AU and Saturn is at 10.0 AU. When Uranus was discovered in 1781, it was found to be at 19.6 AU.

This is exactly true for the Sun and Earth. The numbers are almost correct for the other planets, being less than 5% off from the correct value.

**Is there a pattern to these numbers?**

Astronomer **Johannes Kepler** at Prague (today in the Czech republic), who first calculated these distances, thought there was.

You can try your hand at the puzzle if you want, but here is a hint. Take the differences from Mercury onwards. From Mercury to Venus it is 0.3, then to Earth it is 0.3, then to Mars it is 0.6.

Now take the differences from Jupiter onwards. To Saturn it is 4.8, then to Uranus it is 9.6.

Kepler was a mathematician. In 1596 (before Uranus was discovered) he predicted, “Between Mars and Jupiter, I place a planet.” Call this planet A. Place it at a distance of 2.8 AU from the Sun.

Now take the differences from Mercury onwards. To Venus it is 0.3, then to Earth it is 0.3, then to Mars it is 0.6, then to A it is 1.2, then to Jupiter it is 2.4, then to Saturn it is 4.8, then to Uranus it is 9.6. Do you see the pattern?

German astronomer **Johann Titius** wrote out this pattern in 1766. This was popularized by another German astronomer **Johann Bode** later, and sometimes it is called *Bode's law*. Earlier in 1702, Scottish mathematician **James Gregory** had written the *geometric progression* of numbers*:* 4,7,10,16,28,52,100. He was an astronomer too, a telescope design of his is known as a *Gregorian telescope*.

After the discovery of Uranus, Bode urged astronomers to search for a missing planet between Mars and Jupiter. The planet *Ceres* was found by the Italian priest and astronomer **Giuseppe Piazzi** at the predicted distance in 1801.

Except that Ceres wasn't very big, and it wasn't just Ceres. Hundreds of tiny planets at about 2.8 AU from the Sun were found. Today lakhs are known, they are together called the *asteroid belt*. The name was given by English astronomer **William Herschel** who discovered Uranus.

Today's theories say that when the solar system formed 460 crore years ago, there wasn't enough mass of material in this region, so instead of the material coalescing to form planet A, it just formed a belt of asteroids.

Why does this geometric progression give the location of planets? This is not known. Statistics seems to suggest that if planets were arranged at different distances, they would have a better chance of changing each other's orbits.

**Nice story, can we continue it further?**

After Uranus the new planet must be at 19.2 and at 38.8 AU (close enough) we find *Pluto*, discovered by American businessman turned astronomer **Percival Lowell** in 1930. Bu that's not good! We missed *Neptune* which is at 30 AU, but its turn will come a paragraph below.

It's not just Pluto. Pluto has a large moon, *Charon*, so large that we should call them both a double planet. American astronomers **David Jewitt** and J**ane Luu**, and following them others, found thousands of tiny planets in this region, which is now called the **Kuiper belt** after Dutch-American astronomer **Gerard Kuiper.** On 1 January 2019, the American *New Horizons* spacecraft flew by *Arrokoth*, a tiny KBO (Kuiper belt object) less than 40 km in size. It does seem as though when the solar system formed, the mass in this region did not coalesce into planet K, but just remained as the Kuiper belt.

In 2005, four astronomers from **Nice** (a city in France), Brazilian **Rodney Gomes**, American **Hal Levison**, Italian **Alessandro Morbidelli** and Greek **Kleomenis Tsiganis**, put forward the theory that earlier in the history of the solar system, Neptune and Uranus were closer to Saturn.

The combined gravity of Jupiter and Saturn led to them, especially Neptune, being pushed out to where it is today. In turn Neptune pushed out the mass in this region to form the Kuiper belt. Indian-born American astronomer **Renu Malhotra** had earlier predicted in 1995 that migration of Neptune would mean that other objects with orbits similar to Pluto would be found in the Kuiper belt. Such *Plutinos* have been found.

Lots of nice things in this story. Can we continue it further? Near about 77.2 AU, the next in our geometric progression, American astronomers **Mike Brown**, **Chad Trujillo** and **David Rabinowitz** found *Eris* in 2005.

Eris is bigger than Pluto! It has a moon. And it's not just Eris. By now we know around 200 such SDO (*scattered disk objects*). Unlike the "belt" of KBOs, the word "disk" suggests that orbits of SDOs are more elliptical and more inclined to the plane of the solar system. These SDO may come into the Kuiper belt when closest to the Sun (Eris comes to 38 AU) but go far out when farthest (Eris is nearly 100 AU when farthest).

The most famous comet, **Halley's comet**, is in the scattered disk region when at its farthest from the Sun. Not just Halley. Many comets are of this kind. It is thought that because this region preserves icy objects, comets may originate from here.

Let's continue with the story. Nothing at 77.2+76.8 = 154 AU. Nothing at 307.6 AU. The trail is getting cold.

At 614.8 AU the story springs back to life again. Brown, Trujillo and Rabinowitz discovered *Sedna* in 2003 at around this distance. Well, sort of. Its orbit around the Sun is very elliptical (it goes from 76 AU to nearly 1000 AU) and takes more than 11000 years to go around the Sun! At these distances it cannot be affected by the gravity of Neptune, unlike Kuiper belt objects. And it's not just Sedna. There are other such *Sednoids* known.

Sednoids and farther objects are known as DDO (*distant disk objects*). **Konstantin Batygin** and **Mike Brown** found Sednoid orbits aligned in a peculiar way. In 2016 they calculated that there may be another *planet* out there, about 5 to 10 times the size of Earth, orbiting the Sun at around 600 AU, which may be aligning them. Even after a systematic search, no planet has been found so far.

On the other hand, **David Gerdes** and colleagues argued in 2021 that the evidence for alignment of the Sednoids is not strong enough, a careful look at other bodies is needed.

Irish-born American astronomer **Ann-Marie Madigan** and colleagues came up with a different explanation. Based on the accumulating evidence for the Nice model, and a 2019 theory of **Antranik Sefilian**, a Lebanese student in England and **Jihad Touma**, a professor in Beirut, Lebanon, they proposed in 2020 that when Neptune pushed out the Kuiper belt, it in turn pushed out a large number of icy bodies which then occupied the scattered disk. They say the SDO which remain today are a fraction of that number. The entire mass of Batygin and Brown's supposed "planet" could be made up of a lot more DDO than the 200 SDO, scattered more widely and more haphazardly, when farthest from the Sun forming a distant "disk", but when nearest to the Sun coming right into the Kuiper belt.

Their 2020 calculations can account for the alignment of the Sednoids. One argument is that if there were a Batygin-Brown planet, SDO should have been found at 154 AU and 307.6 AU since statistics says these are relatively safe orbits. That nothing is found suggests that during planetary history, DDO with very elliptical orbits have swept out the intermediate region. This leaves few SDO and suggests there are a lot more DDO.

Our picture of a planetary system is changing. It looks like the material around a star forms not just planets, but planets and belts and disks, depending on whether there is enough material to form a planet or not. "If our disk is not there," Madigan optimistically said in an interview, "it has to be the planet. It is one or the other." She has recently been awarded the prestgious *Vera Rubin Early Career Prize* for her work on exploring objects in space.