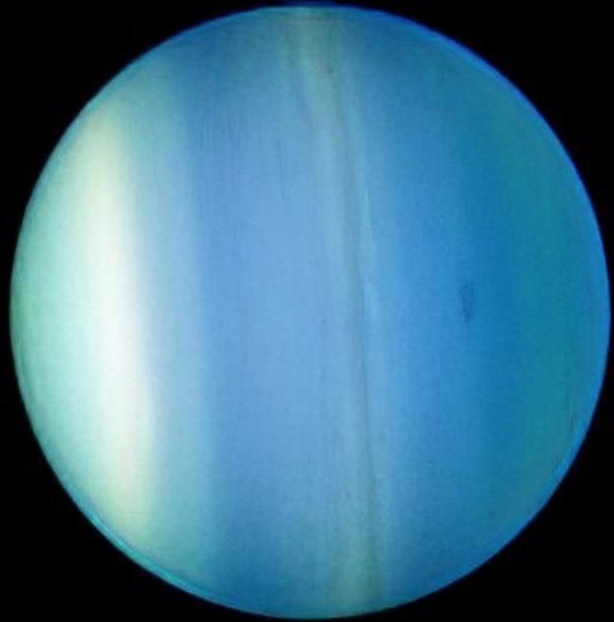
URANUS



the odd planet

Darryl WL Ward

This book is dedicated to my late brother Trace,

who taught me to love the stars.

Special thanks to Natalya, Amanda, Maria, and Polly for their patience and understanding. Environmental Protection Authority Te Mana Rahuī Taiao (EPA). Edwin, Dennis, and John, for astronomical community support. Lloyd and the SCOM 433 Class of 2022 at the University of Otago. Maria, for being a sounding board. Paul and Kel, for teaching me design and layout, and much of what I know about printing and publishing. And the late Murray Moorhead, for letting me write an astronomical column for his newspaper when I was a teenager.

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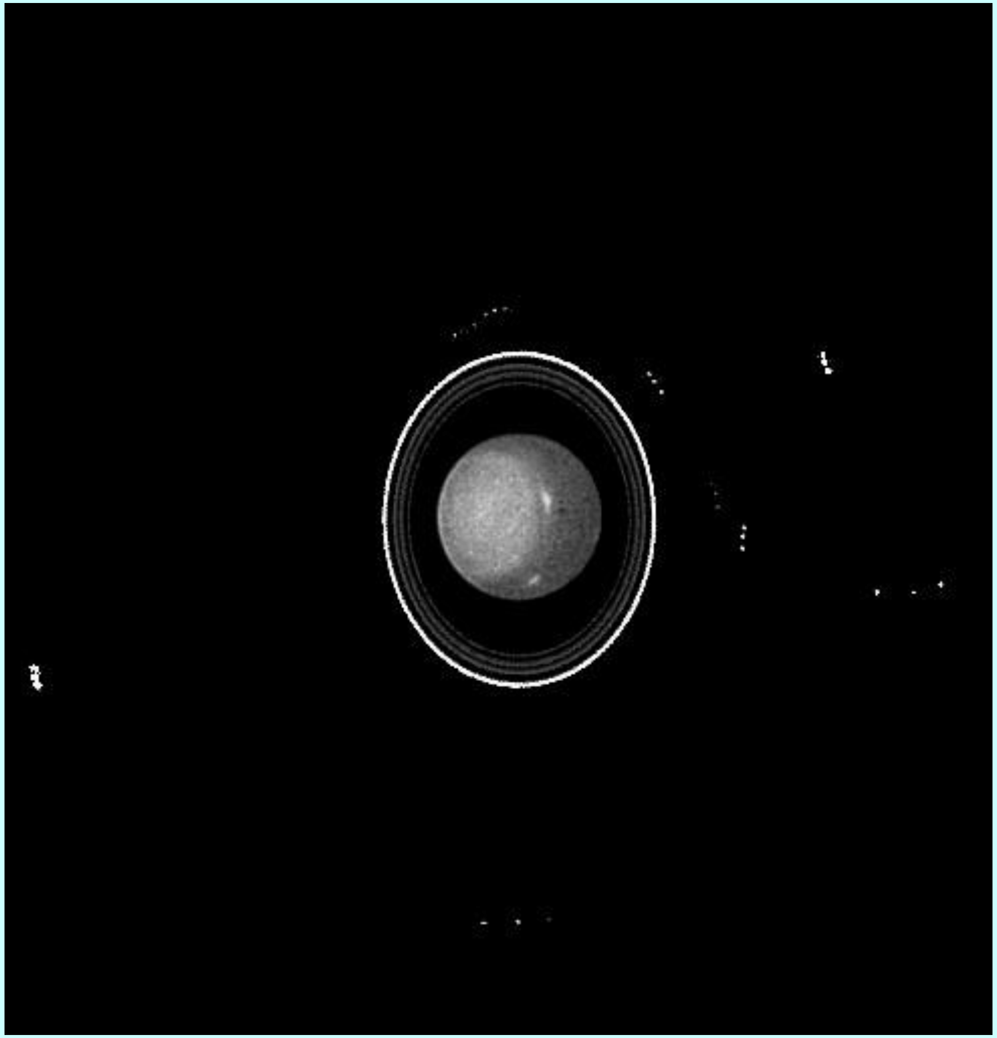


Hubble Space Telescope image of Uranus, courtesy NASA/JPL-Caltech

Introduction

Earlier this year, I saw Uranus for the first time.

There was not much to look at, only a pale blue disc. But it was still Uranus.

I had somewhat expected Uranus to be green, because that was how Uranus and Neptune were depicted in books I read in my childhood. But it was pale blue.

Everyone has heard of Uranus, and English speakers anyway will be quite familiar with the very infantile jokes that are so often made about it. But Uranus does not seem to inspire people in the same way other planets do. It was never a serious contender for harbouring life, like Mars has been. It does not have the

Uranus, Darryl WL Ward, 2022

hellish surface of Venus, a prominent ring system like Saturn, or easily observable features like Jupiter. And it does not have a sob story to garner public sympathy, like Pluto does because of its demotion to dwarf planet status.

However, the sheer oddity and uniqueness of Uranus more than make up for its relative obscurity, and it is arguably the most interesting planet in the Solar System. It was the first new planet to have been found since antiquity. And after its unexpected discovery, things just got weirder.

Uranus is the only planet named after a Greek god instead of a Roman one. Its tilt is so extreme it is like a giant marble rolling through space, instead of spinning like a top, like the other planets do. Uranus is the coldest planet in our Solar System. Its featureless icy structure holds many mysteries. It has even been proposed that it rains diamonds on Uranus!

You are about to read the story of the odd planet. You will learn about the discovery of Uranus, the bizarre saga of how it got its name, and what we have learned while observing it. Including how it led us to discover another new planet. You will join past and proposed spacecraft visits to this strange new world. And you will discover why Uranus is like nowhere else in the Solar System.

Darryl WL Ward

October 2022

Strange new world

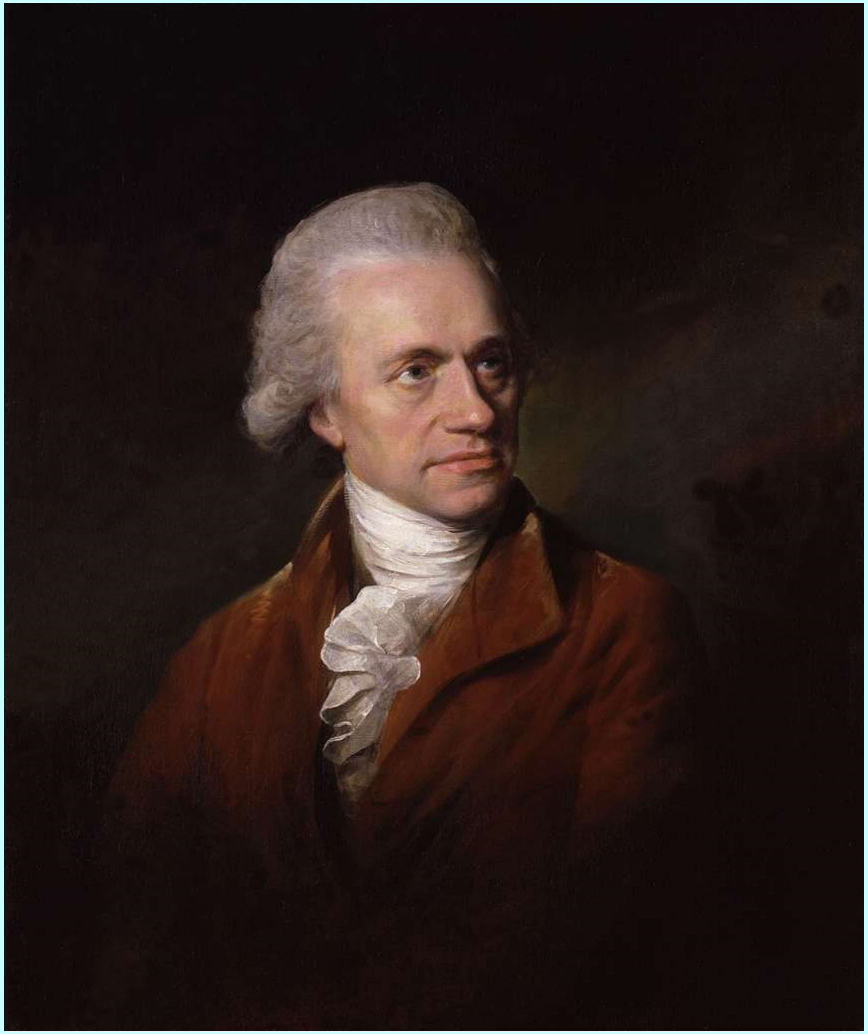
We did not know Uranus even existed until 1781.

Up until then, humankind knew of only five planets (not counting Earth - or the Moon or Sun - which used to be considered planets), and they had been known since antiquity.

We do not know who first discovered the other planets were different from the background stars, but we can safely assume it would not have been long after our ancestors began to observe the heavens, that they would have noticed that some star-like objects appeared to wander across the seemingly fixed backdrop of the sky, and waxed and waned in brightness along the way.

And we can be quite certain that ancient peoples would have seen Uranus, as it is visible to the unaided eye. But it would have looked just like a faint star among all the others in the dazzling pre-industrial sky.

It was the Babylonians who made the earliest known systematic recording of observations of the planets. But, like ancient European civilisations, they believed the Earth lay motionless at the centre of the universe, and the Sun, Moon, and planets orbited around it.



William Herschel, oil painting by Lemuel Francis Abbot, Wikimedia Commons

Although Uranus was not one of the planets known since antiquity, it had in fact been observed and recorded on many occasions - possibly early as 128 BCE by Greek astronomer and mathematician Hipparchus - although its first confirmed observation was by English astronomer and the first Astronomer Royal John Flamsteed in 1690. (Flamsteed actually saw it six times, in 1690, 1712, and 1715, but failed to realise it was not a star.) German astronomer Tobias Mayer observed and catalogued it in 1756. And twelve observations made by French astronomer Pierre Charles Le Monnier between 1736 and 1780 would later be used to help calculate the planet's orbit.

But those who had seen Uranus before it was discovered to be a planet had not made observations on different nights and compared them, so failed to see it was a moving object. (Although to be fair to Le Monnier, he had observed Uranus at a near stationary point in its orbit.)

The discovery was finally made by German-English composer, musician, and astronomer William Herschel.

Astronomy was not originally Herschel's day job. He was born in Hanover but migrated to England in 1757. He initially settled in Bath, where he earned his living as a composer, musician, music teacher, and choirmaster. But astronomy became Herschel's great passion.

Using a series of home-made telescopes, built with the assistance of his brother Alexander and his sister Caroline (who would become an acclaimed astronomer in her own right), Herschel followed the usual path of novice astronomers of observing easy objects like Saturn and its rings and the Great Orion Nebula. He then focused on searching for double star systems. This was an important astronomical activity at the time, as it was considered that observing the apparent distances between a pair of stars over time could be used to calculate their distance.

And it was on 13 March 1781, during a survey of 8^{th} magnitude stars (these are stars that are a bit too faint to be seen with the unaided eye) he noticed an object in the constellation of Taurus that took on a disc-like appearance when subjected to increasing magnification. Stars do not behave like this when magnified; they remain points of light. But planets do. And not only did this object take on a disc-like appearance, it appeared to move relative to the background stars over subsequent observations.

The discovery of a new planet was unprecedented. So, it should come as no surprise that Herschel at first thought he had found either a 'nebulous star' (which could be anything from an actual nebula – a gas or dust cloud – to a galaxy) or a comet, eliminating the first option upon discovering that it moved.

However, this was quite unlike any other comet that ever been seen. Comets typically have highly elliptical orbits. Planets also have elliptical orbits, but they tend to be far less extreme and closer to circular. The orbit of this newly discovered object was first calculated in 1781 by Anders Johan Lexell, a Finnish-Swedish astronomer who mostly worked in Russia, and his calculations showed that it followed a path that more closely resembled that which would be followed by a planet. Further calculations of its orbit were made by the French scholar Pierre-Simon Laplace in 1783.

The conclusion that it was a planet was also reached by German astronomer Johann Elert Bode, who is best remembered for developing the Titius-Bode Law, a mathematical formula concerning the distance of respective planets from the Sun, which essentially expanded on the work of Johann Daniel Titius, another German astronomer. In its simplest terms, the Titius-Bode Law proposed that the distance from a planet to the Sun would roughly double for each successive planet away from the Sun. And this new planet was in the orbit that this formula predicted a planet one out beyond Saturn would occupy.

However, it would take about two years for it to be generally accepted by astronomers that a new planet had in fact been discovered.

Silhouette portrait of Anders Johan Lexell, artist unknown, public domain

Pierre-Simon Lapalace, public domain

Herschel's telescopes

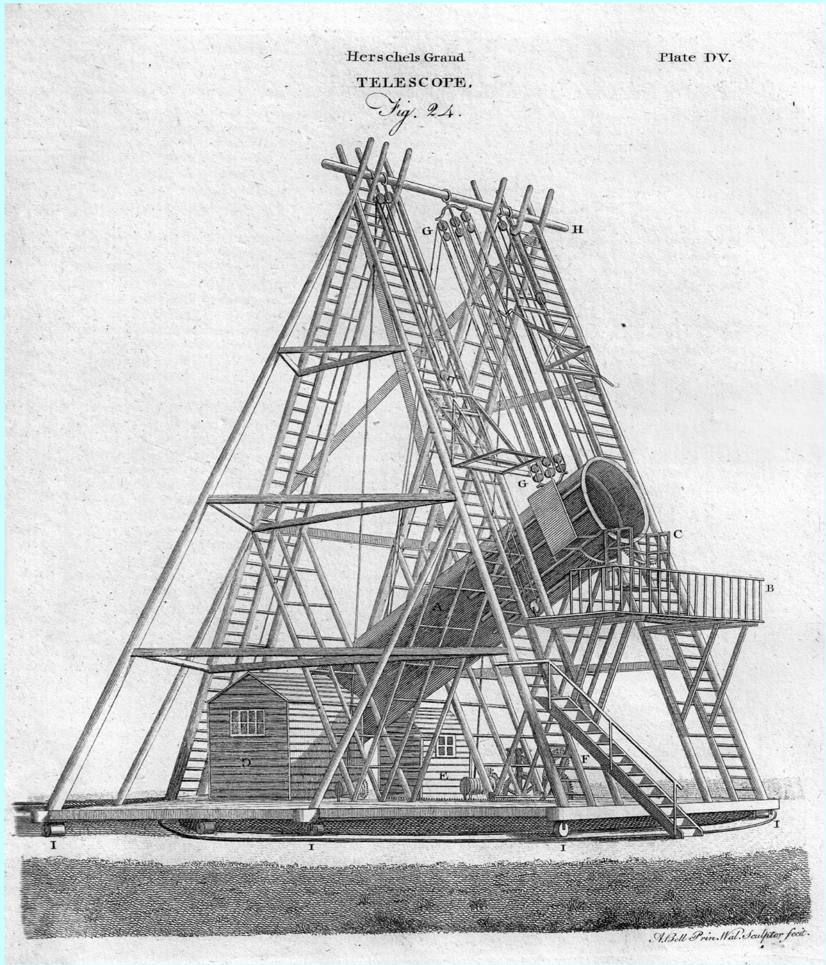
William Herschel's mirror polisher, Mike Peel, Creative Commons

William and Caroline Herschel, colour lithograph by A. Diethe, Wellcome, Creative Commons

Replica of the telescope Herschel used to discover Uranus, Alun Salt Wikimedia Commons

Reflecting telescopes in Herschel's day did not use glass mirrors like modern ones do. Instead, they relied on an alloy of copper and tin called speculum metal. Other elements such as arsenic were often added. Speculum metal was a difficult material to work with. It tarnished easily, meaning mirrors had to be repolished frequently. And it could only reflect 60% of incoming light. But it was the best option available, until a chemical process for applying silver onto glass was invented in the 19th Century.

Herschel could not initially afford a telescope. So, he taught himself how to make them, and became quite skilled at the art; by 1776, he was building telescopes whose quality was said to surpass those of the Royal Observatory at Greenwich. He created a new design of



40 foot telescope, public domain


Remaining section of the 40 foot telescope, Mike Peel, Creative Commons

telescope, now known as the Herschelian reflector, and he built some very large instruments, including a monstrous 48 inch aperture telescope, which was completed in 1789. (A telescope's aperture is the diameter of primary mirror or lens and determines its light-gathering capacity.) Its tube was 40 feet long and it became known as the 40 foot telescope. It was the largest telescope that had been built to date, and it would not be until 1845 that a larger one would be built.

What's in a name?

A planet has to have a name.

But there was no established procedure for naming a planet; you could not just walk into a registry office and register it like you would register a birth. Discovering a planet was unprecedented. And there was no international body governing astronomical matters; the International Astronomical Union would not be formed until 1919.

Nevil Maskelyne, the Astronomer Royal of the day, approached William Herschel and asked him to propose a name for his newly discovered planet. Herschel had been granted an annual stipend of £200 per annum by George III of Great Britain and Ireland, although he was required to move to Windsor to give the Royal family access to his telescopes. He decided to honour the king by naming the planet after him and calling it Georgium Sidus, which means George's star in Latin. Herschel felt that the previously known planets had names that reflected the era in which they were named, and he proposed this new planet should have a name that would proclaim it was discovered during the reign of George III.

Portrait of George III when Prince of Wales by Jean-Étienne Liotard, Royal Collection, public domain

Proposing a royal name for an astronomical body was not without precedent; Galileo had initially named the four largest moons of Jupiter, which he had discovered, the Medicean Stars in honour of Cosimo II de' Medici, the Grand Duke of Tuscany.

Another Italian astronomer (but later naturalised Frenchman), Giovanni Domenico Cassini, had discovered four moons of Saturn. He had named them Sidera Lodoicea, which means the stars of Louis, acknowledging his patronage by Louis XIV of France. (However, these names had also been replaced with classical ones by the time Herschel discovered his planet.)

And Polish astronomer and local politician Johannes Hevelius had given the constellation Scutum (the shield) its initial name of Scutum Sobiescianum (the shield of Sobieski), in honour of John III Sobieski, the King of Poland and Grand Duke of Lithuania, because he had led the forces that defeated the Ottoman Empire at the Battle of Vienna in 1683. This victory more or less coincided with a return of Hayley's Comet, so celestial recognition seemed appropriate.

Perhaps not surprisingly, Herschel's suggestion was not met with much enthusiasm in Europe, with the probable exception of Hanover, given George III was also the Prince-Elector of Hanover. National identity aside, the newly discovered object was a planet, not a star, and even though Herschel modified his proposed name to mean George's planet, it did not win international favour. And the feeling seemed to be clear in Central and Eastern Europe that the same should have some kind of mythological significance, along with the other planets.

Much like parents trying to conjure up a name for their new child, various ideas came into the mix. Professor Erik Prosperin from Upsla in Sweden proposed the name Neptune. (He also put forward Astraea and Cybele.) Anders Johan Lexell suggested two compromises between Neptune and the royal names we met earlier: Neptune de George III and Neptune de Grande-Bretagne. Even Neptune Great Britain was suggested! But, of course, the name Neptune would eventually be bestowed upon another planet.

Various other names also derived from classical mythology, such as Austäa were put forward. Then Johann Elert Bode proposed the name Uranus, a Latin transliteration of the name of the Greek sky god Ouranos. This was something of a break from tradition; all the other planets had been named after Roman gods. While these Roman gods had Greek counterparts, it was the Roman deities that were used for planets, so it was a little surprising that Bode did not come up with Caelus, the Roman equivalent of Ouranos.

There was particular aptness for suggesting this deity's name. In Roman mythology, Jupiter was the father of Diana (who was associated with the Moon), Mercury, Venus, Apollo (who was associated with the Sun), and Mars; Saturn was the father of Jupiter; and Caelus was the father of Saturn. The Romans believed the Earth, specifically their empire, was at the centre of the ordered universe, orbited by the Moon in the innermost circle, then Mercury, Venus, the Sun, Mars, Jupiter, and finally Saturn.

So just as Jupiter, the first planet beyond the inner planets was named after their father, and Saturn, the next planet beyond Jupiter, was named after Jupiter's father, it seemed appropriate to many for the next planet beyond Saturn to be named after Saturn's father.

Abbe Maximilian Hell, the director of the Vienna Observatory, not only picked up Bode's suggestion, he even wrote a long poem in Latin to promote the acceptance of the name Uranus among astronomers!

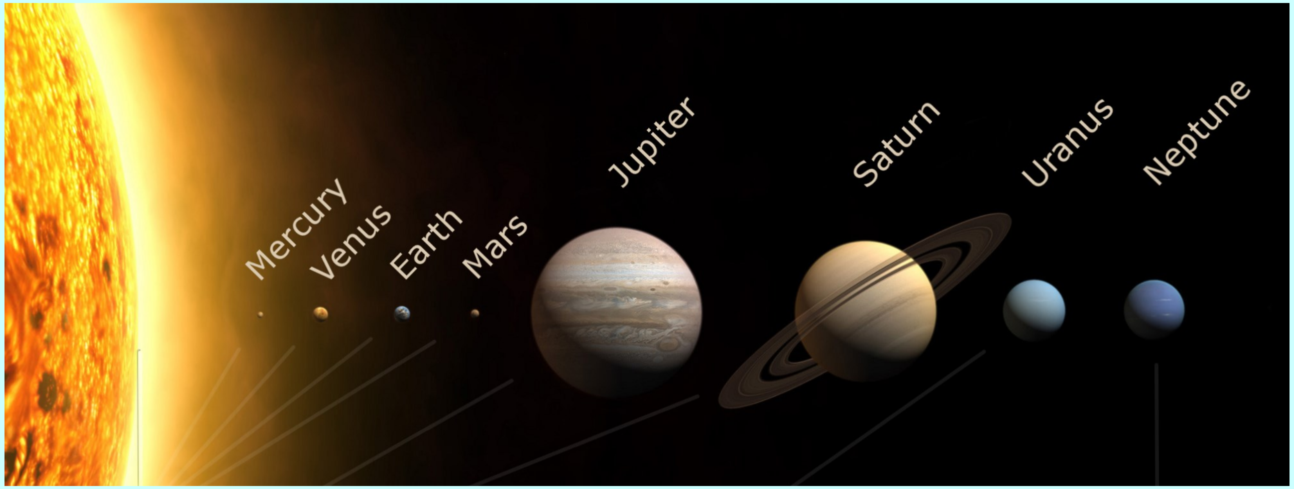
Ouranos statue, Versailles, Travail Personnel, Creative Commons

However, it would take some time for consensus to be reached. Influential French astronomer Joseph Jérôme Lefrançois de Lalande strongly lobbied for the new planet to be named Herschel, in honour of the person who had discovered it. He also argued that “mythological names” were now “inept”. But in spite of de Lalande’s vigorous campaigning and Herschel’s own views (as discoverer, these held some weight), the name Uranus slowly but surely became accepted by the international astronomical community. And in 1789, a newly discovered element was called uranium, in honour of the newest planet in the Solar System.

Great Britain held out though and continued to refer to Uranus as the Georgian Planet in its almanacs for another half century.

Planet *	**Roman deity**	**Greek deity**
The Moon	Diana	Artemis, Hecate
Mercury	Mercury	Hermes
Venus	Venus	Aphrodite
The Sun	Apollo	Helios
Mars	Mars	Ares
Jupiter	Jupiter	Zeus
Saturn	Saturn	Cronus
Uranus	Caelus	Ouranos
Neptune	Neptune	Poseidon

* The Moon and Sun used to be considered planets, with the Moon being the innermost planet orbiting the Earth, then Mercury, Venus, and the Sun etc.



The Sun and the eight planets of the Solar System, Tdadamemd, Creative Commons

Calculated discoveries

While debate continued to rage on Earth about what name would be given to the planet we now know as Uranus, astronomers got on with the task of observing and tracking its apparent movement across the sky.

William Herschel discovered the first two moons of Uranus, Titania and Oberon, in 1787, and while observing their orbit around the planet, he discovered the extreme axial tilt of Uranus. (Herschel also claimed to have found four additional moons, but there was insufficient evidence to substantiate this.)

In the meantime, Uranus took a strange turn. Literally. The planet was observed to be wandering off course. The French astronomer Alexis Bouvard is best remembered for his creation of tables plotting the predicted orbits of Jupiter and Saturn in 1808, and Uranus in 1821. While his tables for Jupiter and Saturn worked well, that was not the case with Uranus.

Although he had the records of many observations of Uranus to work with, the long orbital period of Uranus (84 years) meant he needed to use pre-discovery

Bouvard, lithograph by J. Boilly, 1821 , Wellcome, Creative Commons observations (that is, observations made before it was known to be anything other than a background star) to have a longer period of data to work with. Bouvard had records of eleven pre -discovery observations of Uranus, including three by Pierre Charles Le Monnier. Bouvard searched through fifteen folio volumes of Le Monnier's observations from 1736 and 1780. These records were not exactly very orderly; Le Monnier purportedly recorded some of his observations on a paper bag that had previously contained hair powder! But Bouvard was able to find a further nine observations by Le Monnier, giving him twenty pre-discovery options he could work with.

They were not much help at first. Bouvard found it impossible to calculate an orbit for Uranus that fitted both with both its pre-discovery and post-discovery observations. So, he dispensed with the pre-discovery observations he had worked so hard collating and used post-discovery observations only to calculate his table.

But his dismay, his table soon failed. As more time passed, Uranus was further and further behind where it was supposed to be in its predicted orbit. Yet in the years prior to 1821, Uranus had been ahead of where it should have been.

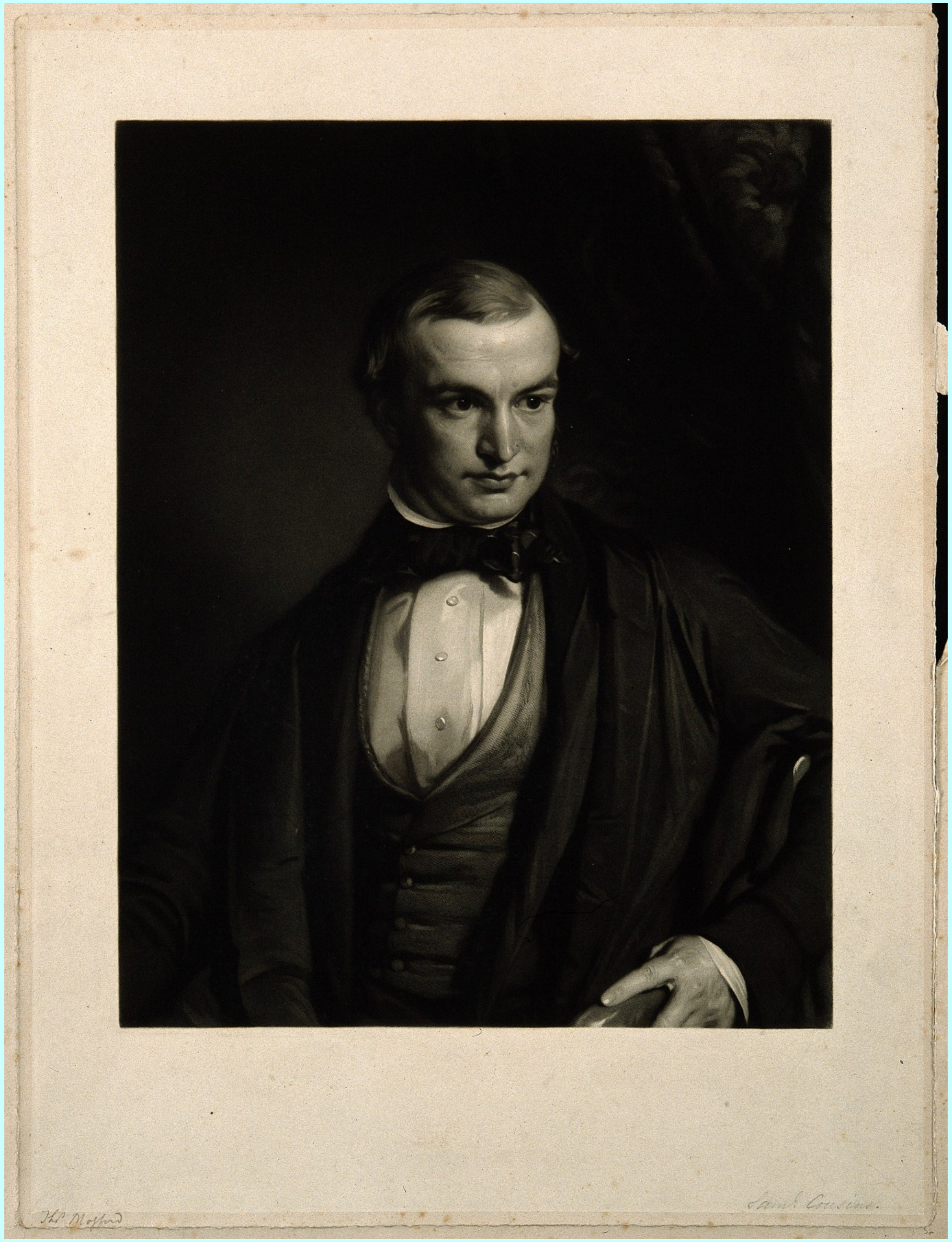
'The Astronomer', oil painting of Le Monnier by Nicolas Bernard Lépicié, Creative Commons

Then Bouvard had an epiphany. There were two possible explanations for the strange behaviour of Uranus. Either Newton's laws of motion were fundamentally flawed, or some as yet undiscovered body was perturbing the orbit of Uranus, accelerating then decelerating it. And the latter was the only viable explanation.

Other astronomers began to think the same way, and the hunt was on for a new planet. But while Uranus was discovered by accident, this new planet would be discovered through mathematics.

A young Cambridge mathematician and mathematician, John Couch Adams, believed he could calculate the mass, orbit, and position of this new planet using the observations that had been made of Uranus, and Newton's laws of motion. He also figured that this new planet would be 38.8 Astronomical Units (an Astronomical Unit or AU is the mean distance between the Earth and the Sun: 149,597, 871 kilometres), based on the Titius-Bode Law.

This is where things start to get murky, and it is difficult to sort fact from fiction and reality from legend. Adams completed his work in 1845 and purportedly sent his predictions to the then Astronomer Royal George Biddell Airy, urging him to check a particular part of the sky. But Airy appeared to showed little interest. It has also been suggested he had independently sent predictions to James Challis,



John Couch Adams, Wellcome, Creative Commons the Director of Cambridge Observatory, who had previously supplied Adams with observational data about Uranus, which he had in turn obtained from Airy, but that cannot be determined with confidence due to the difficulty of ascertaining the authenticity of some documents.

But whatever had transpired, Adams' work was not given the attention or treated with the urgency it should have been. And independently from and unbeknown to Adams, French astronomer and mathematician Urbain Le Verrier was also calculating the position of the new planet.

Airy became aware of Le Verrier's work and soon realised that this was very similar to what Adams had done. He immediately understood its significance and asked Challis to start searching. Adams laboriously and hurriedly worked on new calculations, which at one point resulted in Challis searching in the wrong place. (And one occasion, Challis actually saw the new planet, but failed to recognise it as one, because he lacked a recent start chart.)

Meanwhile, Le Verrier was facing similar issues with the powers that be in French astronomical circles. He was unaware of the frantic search that was now being carried out across the English Channel.

Grave of Le Verrier, Carcharoth, Wikimedia Commons

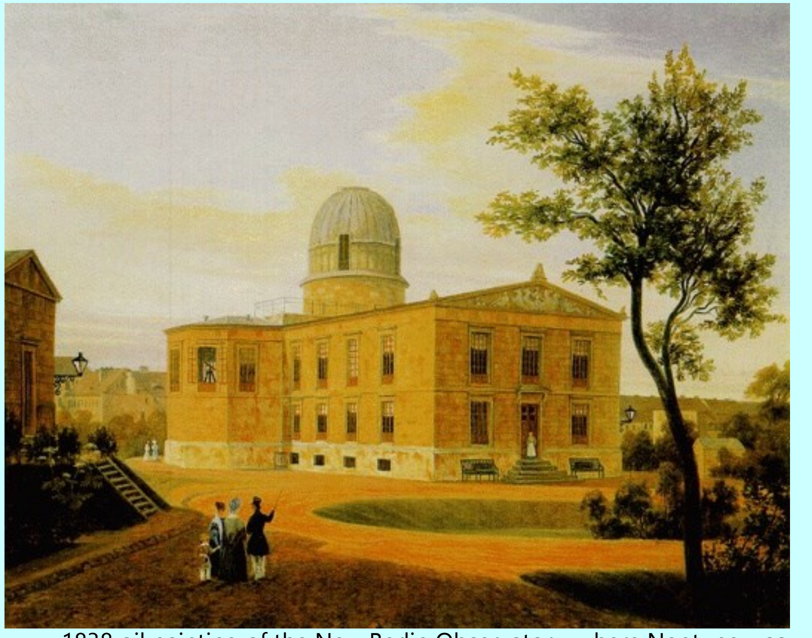
But after becoming frustrated with slowness in Paris, he sent his calculations to Berlin Observatory.

Unlike their French and British counterparts, German astronomer Johann Gottfried Galle and his assistant, student Heinrich Louis d'Arrest did not waste any time. They turned their telescope to the region of the sky where Le Verrier had calculated the new planet would be, and within half an hour, just after midnight on 24 September 1846, they became the first people to see a world that had been discovered through mathematics.

The humiliation faced by the British astronomical establishment failing to properly act on Adams' calculations (there can be no doubt he made his initial predictions prior to Le Verrier) was enormous, and the repercussions are still felt to this day.

That new world was the planet we now know as Neptune. A name that had been previously proposed for Uranus. Like Uranus, it had been observed before it was discovered to be a planet, including – it would appear – by none other than Galileo himself.

The discovery of Neptune doomed the credibility of the Titius-Bode Law, because its prediction of what the next planet's distance from the Sun would be was wildly out. And perturbations in Neptune's orbit would in turn lead to the discovery of another planet, Pluto (which, of course, would later be demoted to the status of dwarf planet). But that is another story.



1838 oil painting of the New Berlin Observatory, where Neptune was discovered, by Carl Daniel Freydanck. public domain.

The Nine Inch Fraunhofer Refractor, the refracting telescope Neptune was discovered with, Deutsches Museum, Munich, H Raab, Creative Commons

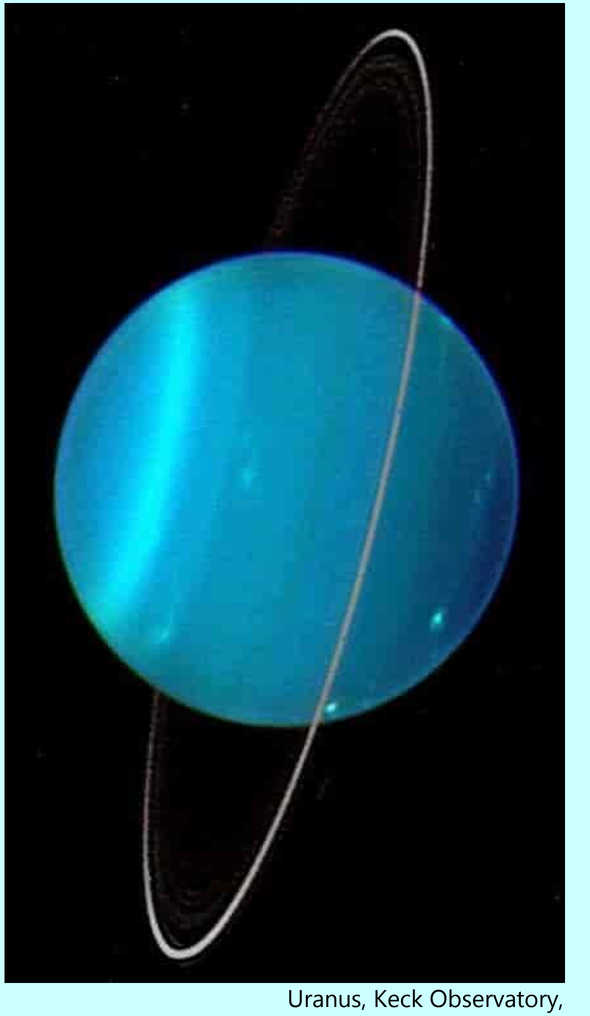
Rolling through the cosmos

Uranus is the seventh planet from the Sun.

Like Neptune, the next planet out, and the closest in terms of size, mass, and composition, Uranus is classified as an ice giant (as opposed to the gas giants Jupiter and Saturn, and the terrestrial, or rocky, planets Mercury, Venus, Earth, and Mars). Indeed, Uranus and Neptune have been described as the 'twin planets'. Like all planets, they formed from accretion of mass left over from the formation of the Solar System

Topped with dense clouds that mask what lies underneath, Uranus has an atmosphere that primarily consists of hydrogen, helium, and methane, as well as some acetylene and other hydrocarbons. The methane absorbs light near the red end of the spectrum, which is why Uranus has been observed to be pale blue, blue-grey, and greenish in appearance to various observers, although more recent observations and photographs have shown it to be closer to pale blue than anything else.

Underneath the atmosphere of Uranus is an icy mixture of water, methane, and ammonia. (There is also some hydrogen sulphide, which is responsible for the smell of rotten eggs you get at geothermally active places on Earth.) And at the centre there is believed to be a rocky core.



Uranus, Keck Observatory,
Courtesy NASA/JPL-Caltech

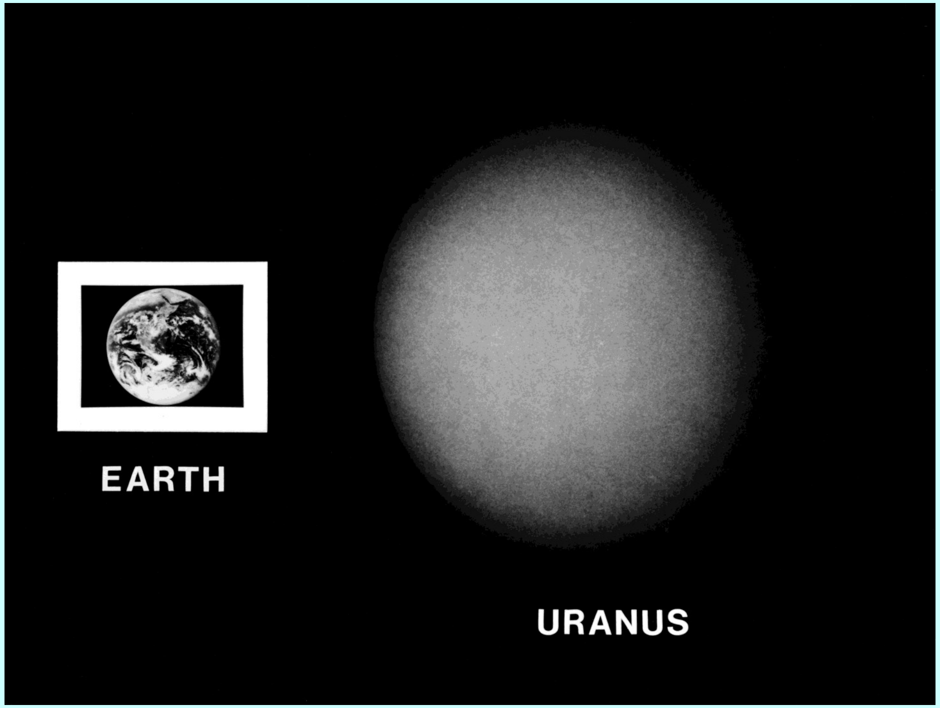
Uranus is the third largest planet in the Solar System after Jupiter and Saturn, and it is the fourth most massive (although Neptune is slightly smaller than Uranus, it has more mass). It has a mean radius of 25,362 km – four times that of earth – and about 63 Earths would fit inside it. And it has 14.5 times the mass of Earth.

A year (the time it takes to orbit the Sun) on Uranus is 84 Earth years. It orbits at an average distance of 2.9 billion km, or 19.8 Astronomical Units. A day (the time it takes to rotate) on Uranus is taken to be 17 hours and 14 minutes, its slushy nature means that it can rotate at different speeds at different latitudes, and some parts are believed to rotate in as few as 14 hours!

Uranus has 27 known moons, all named after characters from the works of William Shakespeare and Alexander Pope. It also has a ring system, but we will discuss that in more detail in the next section.

One of the oddest features of Uranus is its extreme axial tilt. This is the angle between the axis the planet rotates on and the axis at the centre of its orbit around the Sun. Earth has an axial tilt of 23.44 degrees. This gives rise to the seasons, because during the course of the year, the northern and southern hemispheres respectively point more towards and more away from the Sun, meaning the amount of Sunlight received (and thus the length of days) varies.

Mercury has the smallest axial tilt of any planet in the Solar System: just 0.03 degrees! But that is still a tilt. But Uranus has an axial tilt of 97.77 degrees, meaning it almost rolls on its side like a giant marble



Lunar and Planetary Institute from Houston, TX, USA, CC BY 2.0, Wikimedia Commons

instead of spinning like a top as the other planets do. (You may be wondering why we say Uranus is tilted at 97.77 degrees instead of 82.23 degrees, given that it would be intuitive to give the equivalent version of the same angle that is fewer than 90 degrees instead of more.)

The reason is that a planet's axial tilt is measured from what is known as its positive pole, which is the one that appears to rotate anticlockwise when looking down on it; the opposite - or negative - pole appears to rotate anticlockwise. And the positive pole of Uranus points slightly south, instead of north like all other planets in the

Solar System, except for Venus. In other words, Uranus really has an 82.23 degree axial tilt, but we say it is 97.77 degrees, because it is rotating in an opposite, or retrograde, direction, when compared with all the other planets bar Venus, another of its oddities.

The exact reason for the extreme tilt of Uranus is not known, but the most likely explanation is that an Earth-sized protoplanet about the size of Earth collided with Uranus and knocked it over. Although it has also been suggested that the gravitational fallout from the migration of an ancient satellite was responsible.

Given a year on Uranus is 84 Earth years, its extreme axial tilt means that the seasons on Uranus are nothing short of extreme, if we were to divide the Uranian year into four seasons, they would each be 21 Earth years long, and during summer and winter, that would mean 21 earth years of endless day and endless night respectively for anywhere on the planet outside its equatorial regions.

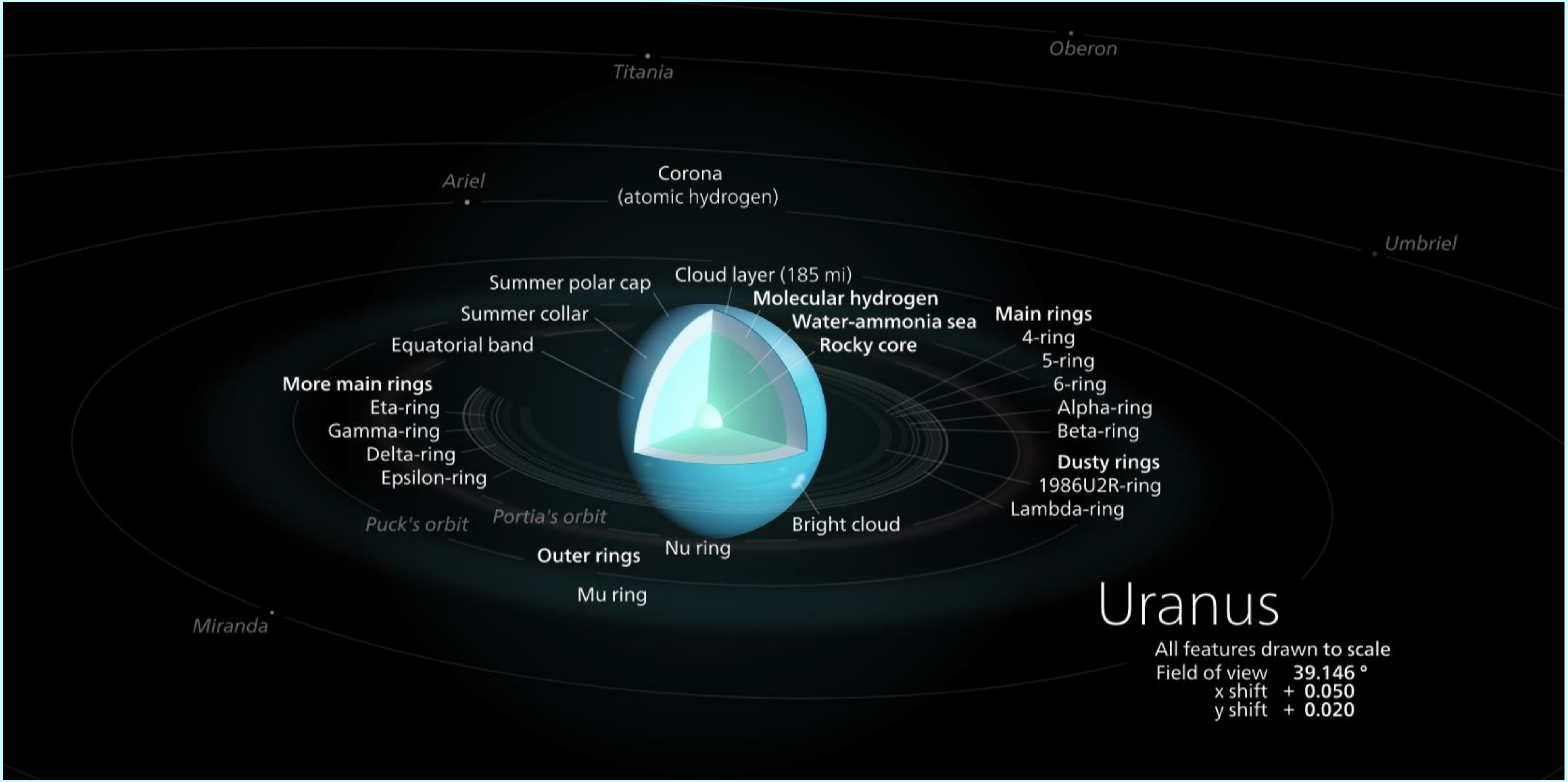
Perhaps not surprisingly, Uranus has an extreme climate. Despite not being the furthest planet out from the Sun, it is the coldest planet in the Solar System; the lowest temperature recorded on Uranus is -224.2 degrees Celsius or 49 Kelvin. That is just 49 above degrees above absolute zero. (In contrast, the temperature of its core is believed to be around 5,000 degrees Celsius!) Uranus can also get incredibly windy, with wind speeds of up to 900 kilometres per hour recorded!

And if the extreme axial tilt of Uranus is not strange enough, its magnetic field is a staggering 60 degrees out of alignment from its rotational axis! Again, nobody knows why.

Some astronomers believe enormous seas of liquid salts could be responsible; others believe liquified diamonds could be the cause. There is even evidence that it rains diamonds on Uranus. And that is my favourite hypothesis about the odd planet. Watch this video to learn more: https://www.youtube.com/watch?v=bX-NWhsjEtY

The Hope Diamond, Smithsonian, public domain

What's inside Uranus?



Kelvin Song, Creative Commons

A giant unmasked

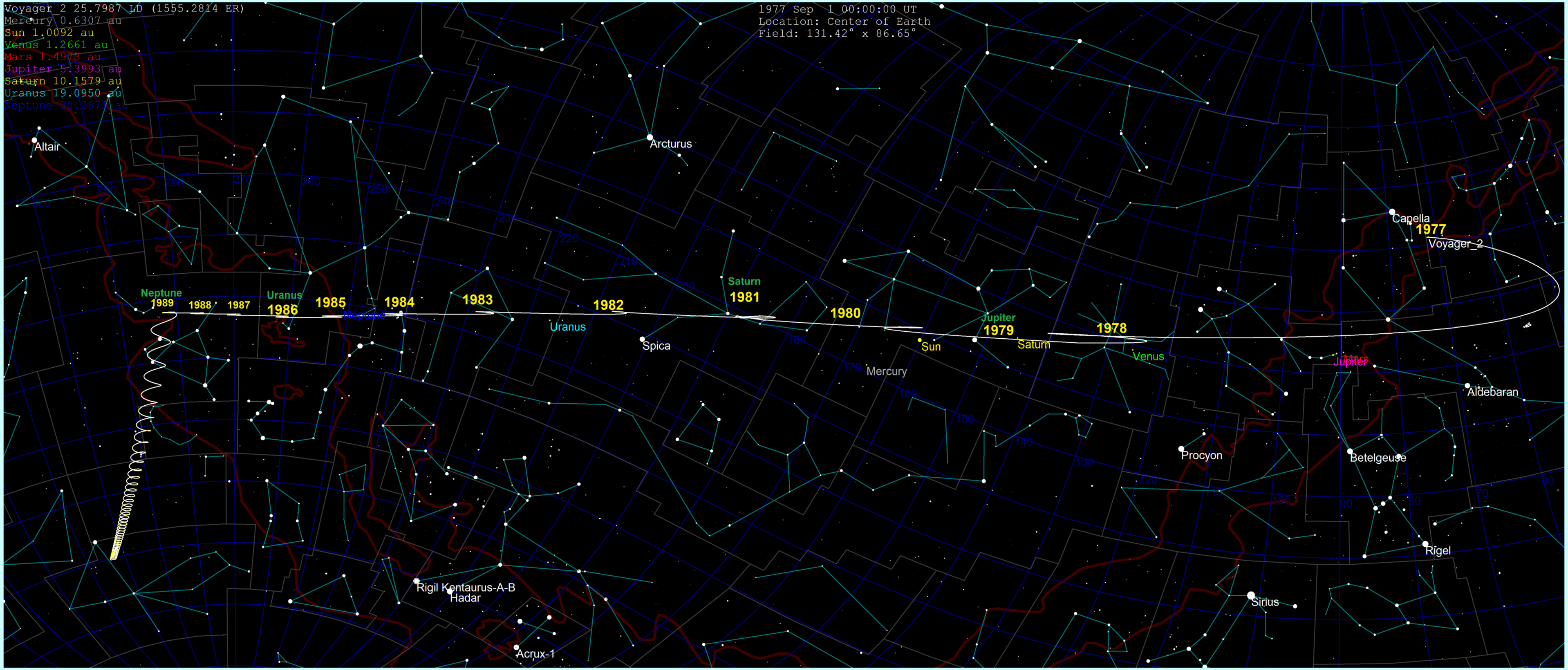
At first glance, Uranus looks pretty uninspiring.

If you were to look at Uranus through a small to medium sized telescope, all you would be likely to see is a tiny pale blue disc. If you were to look at it through a much larger instrument, you would probably see nothing more than a slightly larger pale blue disc. And photos taken by the Voyager II probe as it flew by Uranus in 1986 showed nothing more than an even larger pale blue disc that was almost completely featureless.

However, Uranus is not totally devoid of detail; faint clouds and bands are sometimes seen, especially when viewed at the near infrared part of the spectrum. (Coincidentally, infrared radiation was another discovery of William Herschel, which he made in 1800.) White spots have been seen, and a great dark spot was observed in 2006. The polar areas can also appear distinctive. But for the most part, Uranus looks deceptively bland.

No other planet is so modest about its appearance; its sibling Neptune, shows some clearly visible atmospheric features, especially in photos taken by [Voyager 2](), when it made its final visit to any planet in the Solar System, in

The final image of Uranus from Voyager 2 as it headed towards Neptune, courtesy NASA/JPL-Caltech



Sky path of Voyager 2 1977—2030, Tom Ruen, Wikimedia Commons

1989, and more recently, in photos taken by the James Webb Space Telescope.

Its relative lack of detail did not of course prevent astronomers from calculating the orbit of Uranus, complete with perturbations, or discovering its moons. We have already noted the discovery of its first two moons, Titania and Oberon, in 1787, by Herschel, which also revealed its major axial tilt. Ariel and Umbriel were discovered by English astronomer William Lassell in 1851, and Miranda was found by Dutch astronomer Gerard Kuiper in 1948. The other moons would have to wait a bit longer to be found.

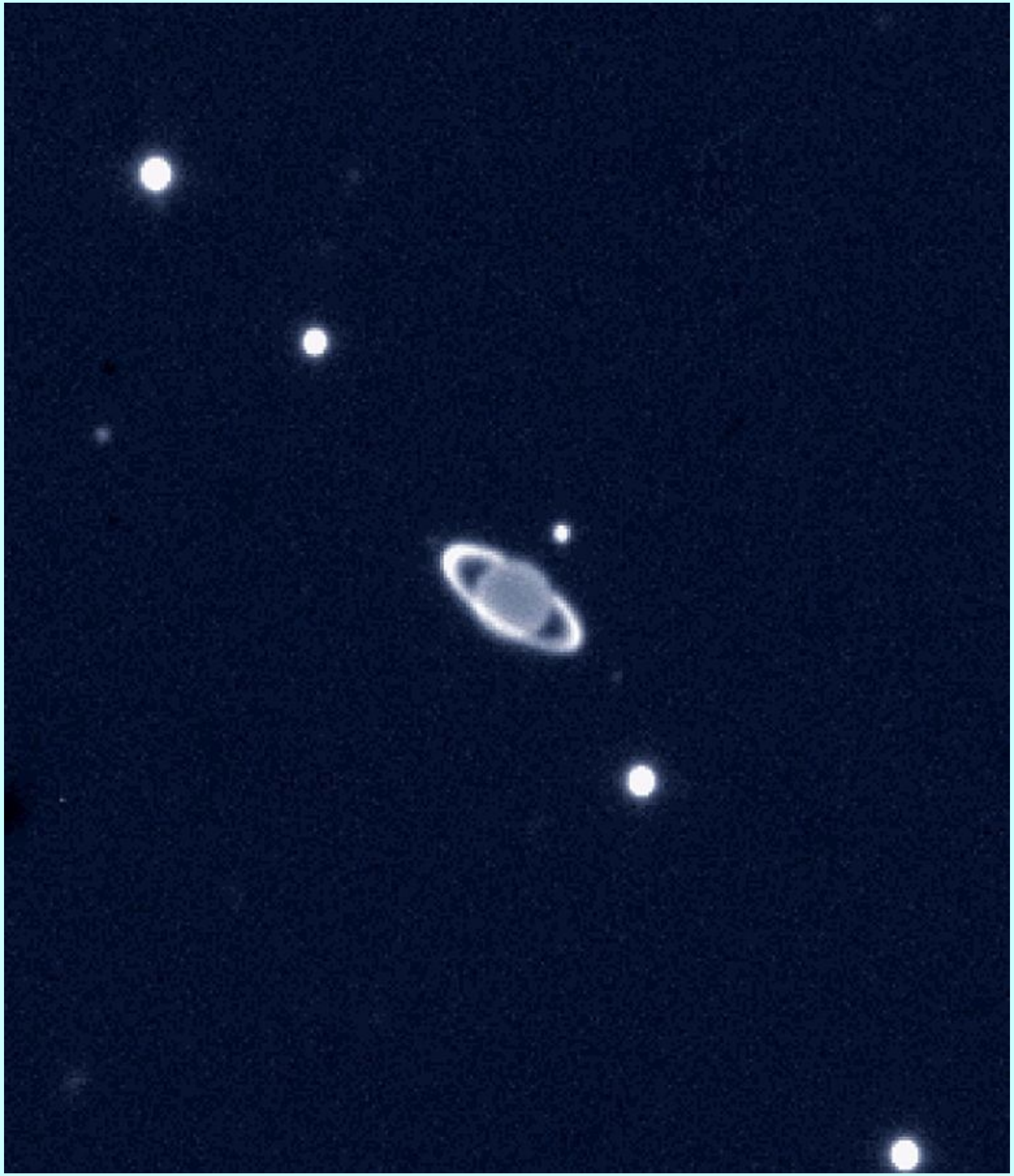
While its distance and lack of detail hid most of its features, Uranus was not able to hold onto all of its secrets. In the second half of the 19th Century, spectroscopy began to reveal what Uranus was comprised of. For the most part Uranus has primarily been observed with Earth-based instruments like telescopes and spectroscopes.

A standout moment of the 20^{th} Century was the discovery of the planet's ring system. This is nowhere near as grandiose as the famous ring system of Saturn, but it is more substantial than the simple ring systems of Jupiter and Neptune, and its rings were the next to be discovered after Saturn's.

It is likely they are primarily comprised of frozen water with some dust and other material and were formed by the collision and fragmentation of former moons.

Herschel had reported seeing rings around Uranus in 1789, but that is extremely unlikely. Even though Herschel's telescopes were state of the art at the time, they were quite primitive by today's standards. But we cannot completely rule this out, especially when there was an astronomer of Herschel's genius involved.

The existence of rings around Uranus was confirmed by Americans James L. Elliot, Jessica Mink, and Edward W. Dunham. They were observing an occultation (which is when the Moon or a planet passes in front of



Uranus with rings and moons, European Southern Observatory, Creative Commons a star or other object) of a star by Uranus in 1977, when the star in question briefly disappeared from view five times before and five times after the actual occultation. This was because the ring system had obscured it.

Uranus is now known to have at least 13 separate rings, and while most of them are very dark, observations of the two most newly discovered outer rings showed them to be red and blue respectively. The rings are accompanied by two ‘shepherd moons’; small moons orbiting close to the ring system whose gravitational influence helps keep the rings together.

The single most significant exploration of Uranus to date has been the visit of the Voyager 2 space probe in 1986 (this link is a video). Launched on 20 August 1977, it visited Jupiter in 1979, then Saturn in 1981, before flying past Uranus on 24 January 1986. It was helped along its way by ‘gravity assists’ from Jupiter and Saturn. Also known as gravitational slingshot, this is a technique whereby a spacecraft has its speed or trajectory altered by passing by another object. The technique was first used by the USSR in 1959, to enable the Luna 3 spacecraft, which had photographed the far side of the Moon for the first time, to return close enough to Earth to transmit the images to ground based receiving stations.

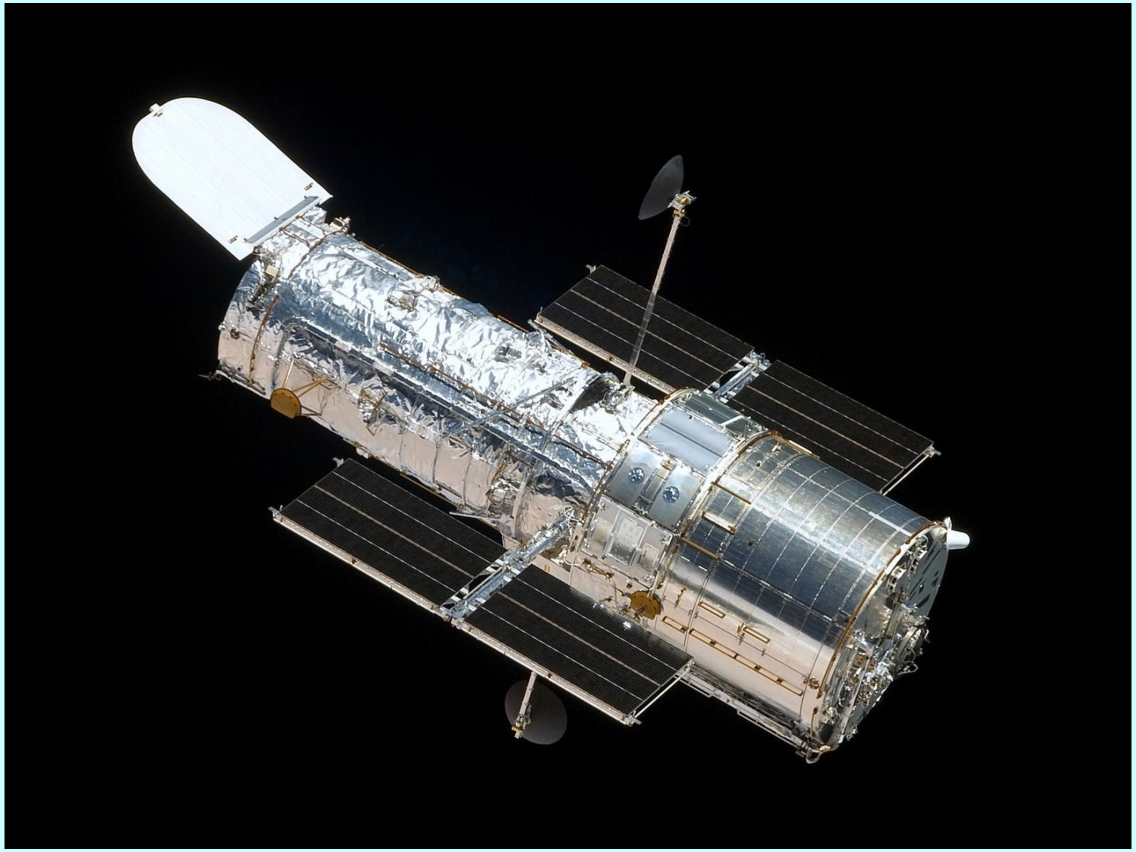
Voyager 2 passed within 81,500 kilometres of the clouds obscuring Uranus. It gave us the best photos we have to date of the planet, but they still revealed virtually no detail. However, Voyager 2 made some interesting discoveries, including the planet’s lopsided magnetic field, and the discovery of ten new moons, bringing the known total up to 15. (The 12 moons that have been subsequently discovered were found using Earth-based telescopes.)

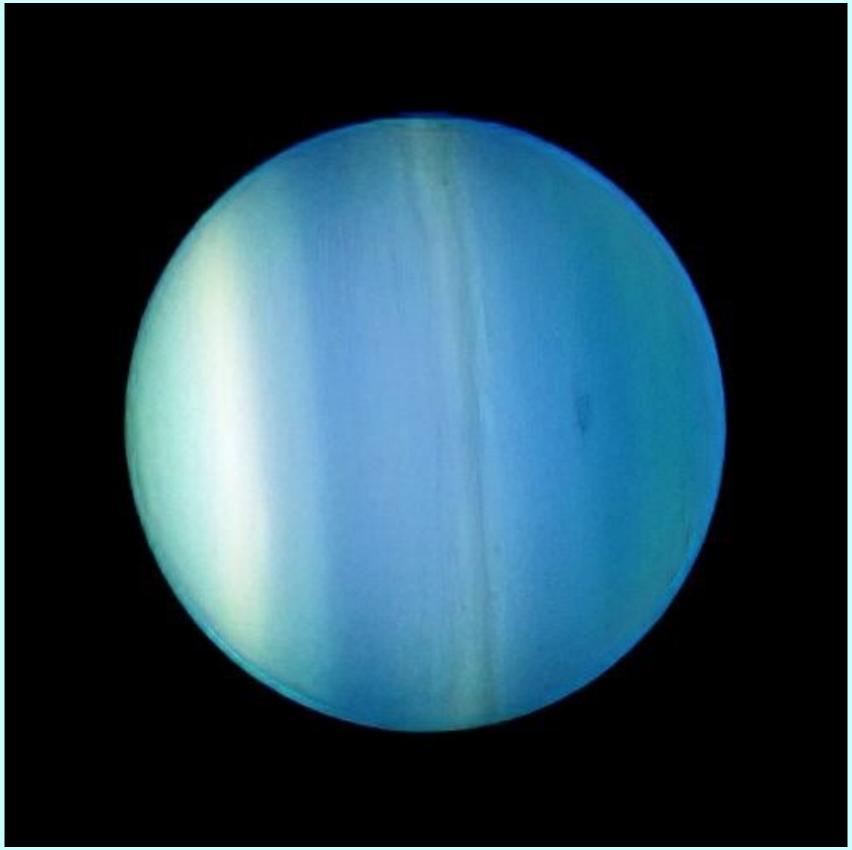
Voyager 2 found two new rings. And some oddities such as an ocean of boiling water some 800 kilometres below the clouds! It also made detailed examination of the five previously known moons.

The visit of Voyager 2 coincided with the summer solstice for the southern hemisphere of Uranus, but the temperature at its Sun-facing south pole was found to be similar to that at its equator, an anomaly that remains a mystery.

And after a few short hours in the Uranian neighbourhood, Voyager 2 went on to visit Neptune in 1989 and then left the Solar System for good and went into interstellar space.

These are the only visits that have ever been made by spacecraft to either of the two outer planets. Voyager 2’s sibling Voyager 1 was unable to accompany it to Uranus, because a visit to Saturn’s largest



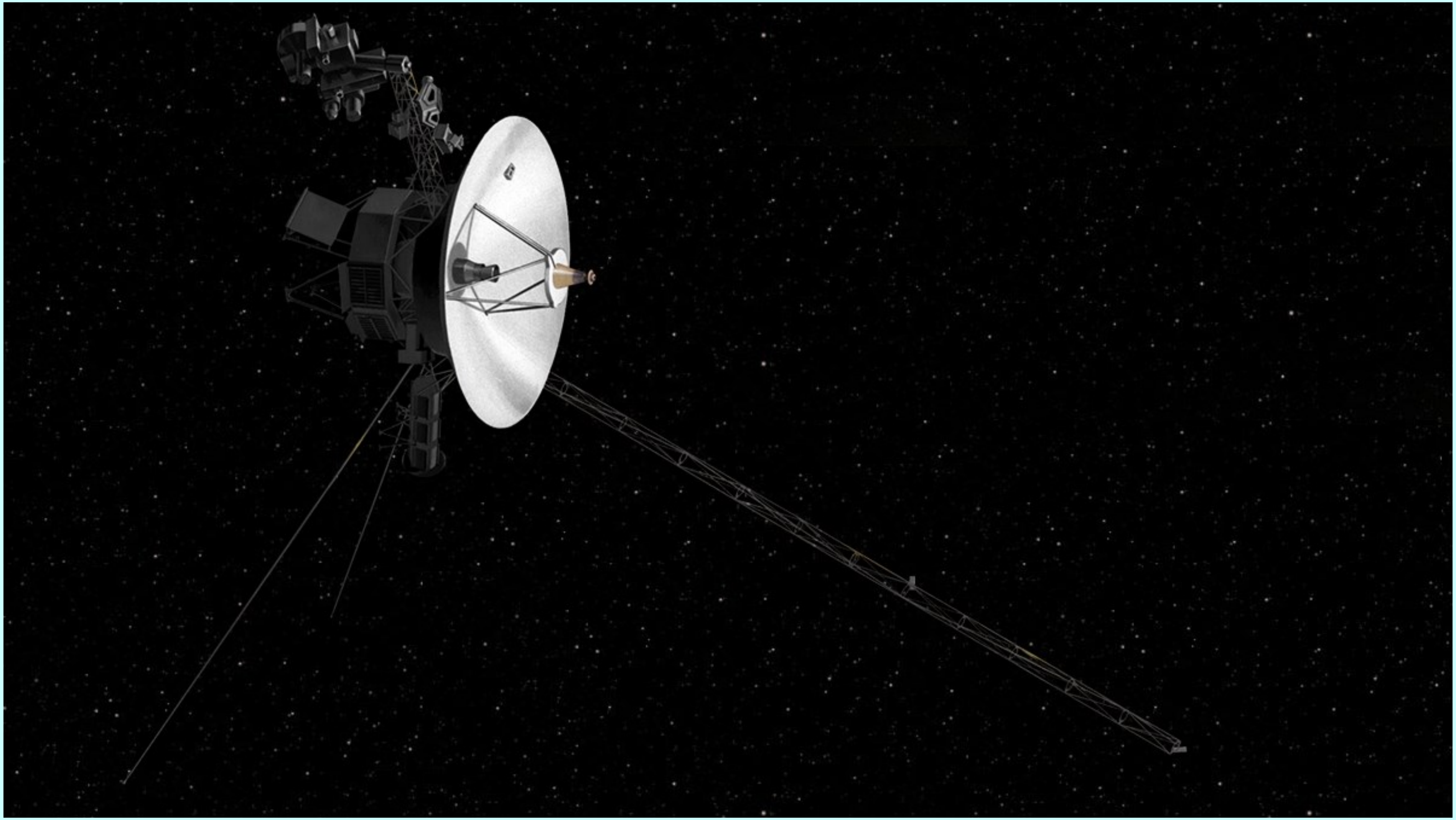


Hubble Space Telescope and an image it took of a dark spot on Uranus in 2006, courtesy NASA/JPL-Caltech

moon Titan was deemed a priority, and it was not possible for it to go to both. The possibility of sending the Cassini probe onto Uranus after it had visited Saturn was considered, but that idea was dropped in favour of a suicide mission into Saturn's atmosphere.

Further discoveries about Uranus have been made by the Hubble Space Telescope, including new rings, and atmospheric dynamics. It also gave us some revealing new images. But nowhere near enough to give us much insight into the secrets that lie below the clouds that obscure the surface of Uranus.

Launch of Voyager 2



Watch this video to see the launch: https://www.youtube.com/watch?v=SmIPMhKyiY0

Image courtesy NASA/JPL-Caltech

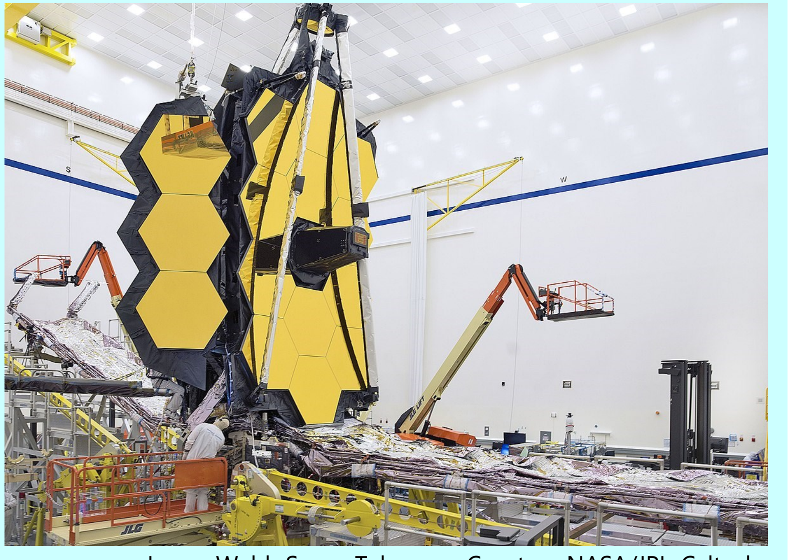
Probing the future

Much has changed in our knowledge of the universe since Voyager 2 paid its fleeting visit to Uranus back in 1986.

Apart from the photos taken by Hubble, Uranus has not been paid a huge amount of attention by anyone other than ground-based observers since then.

But that is about to change. In 2022, the James Webb Space Telescope was deployed, and its agenda includes paying careful attention to Uranus and Neptune. A major task will be observing the weather patterns on these planets. Scientists want to learn more about the composition and temperature of their atmospheres, and this help us understand more about circulation patterns and meteorological systems. Uranus and Neptune are further from the Sun than Jupiter and Saturn, have different atmospheric compositions, are smaller, and rotate more slowly, and all of these factors mean their conditions are quite different from their gas giant neighbours.

Unlike optical telescopes, Webb operates in the infrared rather than the visible light part of the spectrum, which makes it better suited to this task. Not only is infrared useful for studying weather systems, given heat is infrared, this will enable Webb to peer into the upper atmosphere of Uranus and peer behind its clouds.



James Webb Space Telescope Courtesy NASA/JPL-Caltech

Deployment of James Webb Space Telescope:
https://www.youtube.com/watch?v=RzGLKQ7_KZQ

First images from James Webb Space Telescope:
https://www.youtube.com/watch?v=IC3LcELkSDU

NASA's page on Uranus:
https://solarsystem.nasa.gov/planets/uranus/overview/

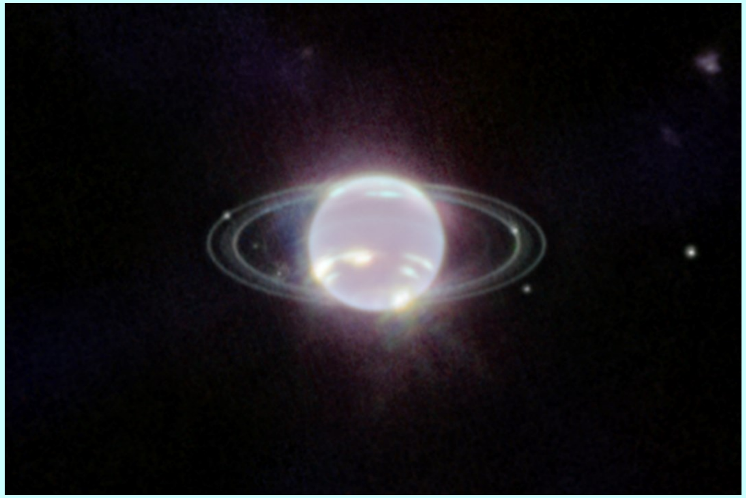
At the time of writing, stunning new images of Neptune taken from Webb had just been released. Admittedly, these were false colour images, which was necessary for us to be able to perceive the infrared spectrum, given it is invisible to us. And I am eagerly anticipating what it is going to show us of Uranus.

However, there are even more exciting possibilities in the pipeline. There have been proposals to send another spacecraft to Uranus, although at the time of writing, none of them have been formally approved, so there is no guarantee that any of these will come to fruition.

So why all the sudden interest in Uranus? This is partly because the ice giants have been relatively ignored; Voyager 2 is the only spacecraft to have visited Uranus and Neptune, while Jupiter and Saturn and the inner Solar System have hosted a plethora of probes. Probing the mysteries of Uranus will give us more insights into the infancy of the Solar System.

But there is another, more compelling, reason. As astronomers discover more and more planets outside the Solar System, they have found that ice giants like Uranus and Neptune are incredibly common in our galaxy. So, by learning more about the two ice giants in our neighbourhood may help unlock mysteries of the universe. Neptune has an average distance from the Sun of 4.5 billion kilometres, while Uranus has an average distance of a mere 2.8 billion kilometres, which makes it an easier target.

The European space Agency has proposed launching a spacecraft called MUSE (Mission to Uranus for Science and Exploration) in 2026. This would arrive at Uranus



Images of Neptune from the James Webb Space Telescope, courtesy NASA/JPL-Caltech. The bright object just above Neptune in the top image is Triton, it's largest moon.

in 2044, with a variety of instruments, and a special atmospheric probe that would be sent into the atmosphere of the planet. Each of the five major moons of Uranus would have nine flybys. This proposal was still on the table at the time of writing.

Another proposed European mission to Uranus was the Uranus Pathfinder, which was put to the European Space Agency by the UK. This involved a launch date in 2025 and arrival at Uranus in 2037. This was seriously considered but was ultimately dropped, partly because it would have only involved a flyby and not time in orbit.

ODINUS (Origins, Dynamics, and Interiors of the Neptunian and Uranian Systems), a mission comprising twin probes to be sent to both Uranus and Neptune has also been proposed to the European Space Agency. The proposed launch date would be 2034.

The USA is also considering some potential missions. Every ten years, the USA's National Academy of Sciences produces a report of priorities for planetary exploration, and NASA takes these reports very seriously. And this year (2022), the Academy published its most recent decadal report, which requested that NASA should make the Uranus Orbiter and Probe mission concept its highest priority for the next decade. With a proposed launch date of 2031, the spacecraft would arrive at Uranus in 2044, where it would study the planet and its environs, including its five major moons, for four and a half years. And a launch date of 2031 for a mission to Uranus would be most fitting, because it would coincide with the 250th anniversary of Herschel discovering the planet in 1781. (See also 'Patience for Uranus' by The Planetary Society.)

Another potential American mission to Uranus is OCEANUS (Origins and Composition of the Exoplanet Analog Uranus System) a joint project between NASA and the Jet Propulsion Laboratory. The suggested launch date is 2030 and it would arrive at Uranus in 2041. It would study the atmosphere, internal structure, and magnetic field of Uranus. And, to add to the mix, China has plans to send a probe to Jupiter and Uranus.

There is no guarantee which – if any of these missions – will eventuate. At this stage, Uranus Pathfinder has been dropped, and ODINUS and OCEANUS appear still largely conceptual. Which leaves MUSE and the Uranus Orbiter and probe mission looking the most likely at this stage. (Not enough is known about the Chinese mission concept to know what stage this is at.) Hopefully some of them will come to fruition, because Uranus is long overdue for another visit.

Conclusion

When William Herschel compared his observations back in 1781 and determined that the object we now know as Uranus was not a star, it is understandable that he did not immediately realise it was a planet but instead thought it was a 'nebulous star' or a comet. Because discovering a new planet was unprecedented. But Herschel's discovery was one of the most important astronomical milestones ever achieved, because it proved there were worlds beyond those known by the ancients, and in doing so opened up the outer Solar System.

Nearly 250 years later, we have come to realise that the secrets of Uranus may not only help us unlock some of the mysteries of the Solar System but give us a better understanding of the universe beyond.

Uranus may be the odd planet. But it is also the most interesting of our neighbours. And it may also be the one that has the most to teach us.

Uranus from Voyager 2, courtesy NASA/JPL-Caltech

About the author

Darryl Ward has been writing for many years. He wrote a weekly column about astronomy for Ngāmotu New Plymouth's Sunday Express for over three years and he is a former winner of the winner of the Royal Astronomical Society of New Zealand's Kingdon-Tomlinson Trust Essay Competition. He also writes about tramping, the outdoors, and faith and society, and he used to write a cooking column.

Darryl has degrees in communication and theology and is currently studying postgraduate science communication at the University of Otago. He works as a Senior Advisor in the Engagement team at the Environmental Protection Authority Te Mana Rahuī Taiao. And when he is not working or writing, he enjoys tramping, camping, and observing the night sky.

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Darryl Ward, photo by Maria Ward