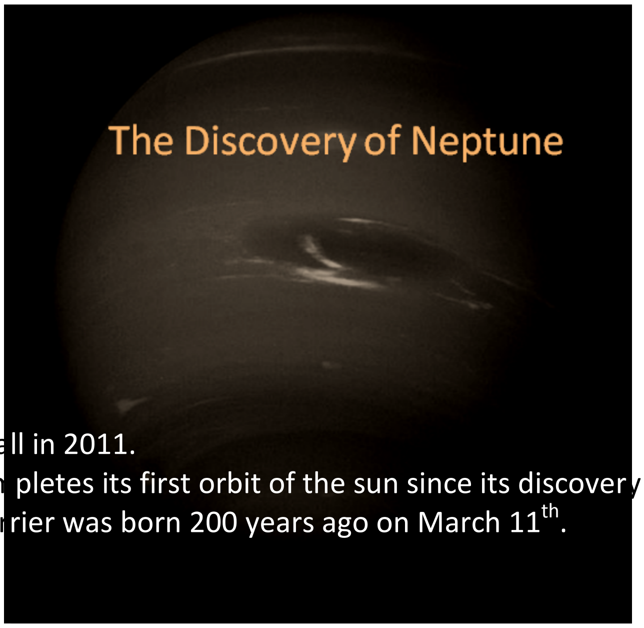
LE VERRIER'S PLANET FOUND!

The Times 1st October 1846



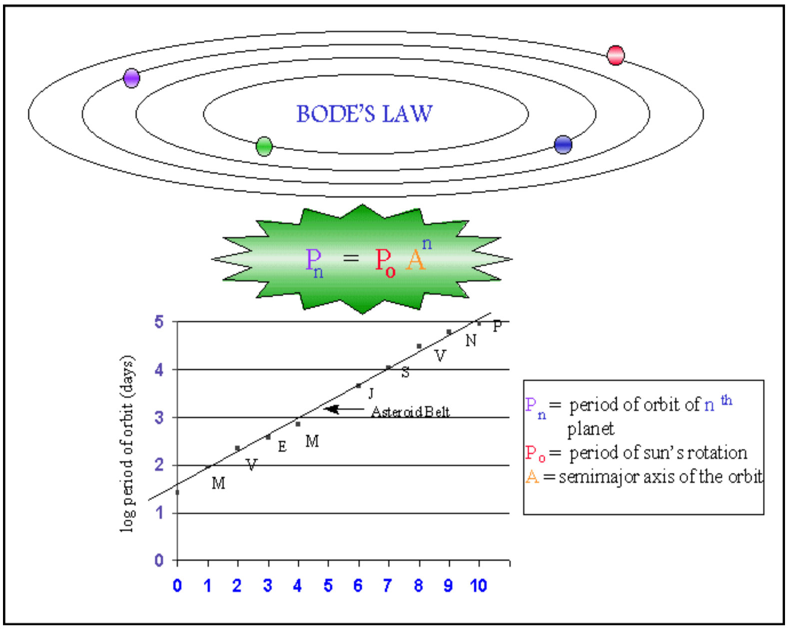
Two anniversaries fall in 2011.

- Neptune completes its first orbit of the sun since its discovery in 1846.
- Urbain le Verrier was born 200 years ago on March 11th.

So the subject for my talk to the Bridgwater Astronomical Society on March 9th 2011 was the discovery of Neptune.

Neptune is unique in our solar system in that it is the only planet not discovered by observation alone.
Neptune was actually discovered telescopically by Johann Galle, but it was a letter from le Verrier that persuaded him to look for it and told him where to look. Because Neptune was found by mathematical prediction.
Neptune wasn't actually the first solar system body to be discovered in a similar way.

In 1772 Johann Bode published a reference to the possibility of a law governing the position of planets within our solar system. It's known as Bode's law, but the idea had been around for a while. Like a lot of things in this story, it wasn't new and no-one's too sure where it came from.
Bode's law states that the major axis of the orbits of the planets follows a mathematical sequence. At this time, the solar system stopped at Saturn. In 1781 William Herschel discovered Uranus – not by following mathematics, but just by plain old fashioned looking through a telescope.

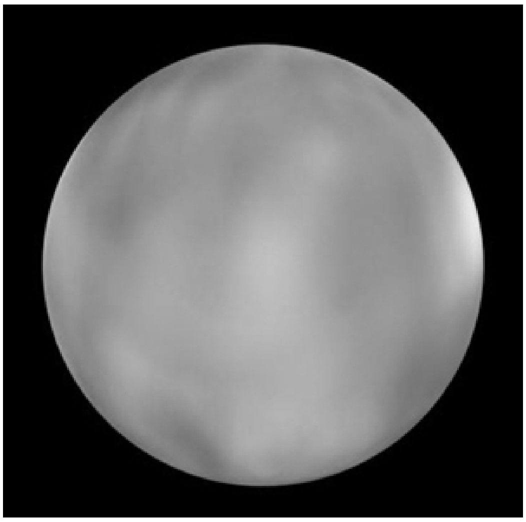


However, if you take Bode's law out past Saturn to Uranus, it still works pretty well. It goes a bit wonky beyond Uranus, but pretend for now we still don't know anything's out there. In fact the discovery of Uranus at the 'right' distance increased the credibility of the law. Except for the gap between the orbits of Mars and Jupiter. According to the law, there should have been something there, but it seemed there wasn't.

Planet	k	T-B rule distance (AU)	Real distance (AU)	% error (using real distance as the accepted value)
Mercury	0	0.4	0.39	2.56 %
Venus	1	0.7	0.72	2.78 %
Earth	2	1.0	1.00	0.00 %
Mars	4	1.6	1.52	5.26 %
Ceres	8	2.8	2.77	1.08 %
Jupiter	16	5.2	5.20	0.00 %
Saturn	32	10.0	9.54	4.82 %
Uranus	64	19.6	19.2	2.08 %
Neptune	128	38.8	30.06	29.08 %
Pluto	256	77.22	39.44	95.75 %

In 1800 a search began. 24 experienced astronomers were invited to combine forces to search the heavens. One of those was Giuseppe Piazzi, however back in those days before the internet and email was invented news travelled slowly, and on the 1st January 1801, while his invitation to join the group was still in the post, he discovered the asteroid we call Ceres. Even more ironically, it was an accidental discovery. He was looking for something else at the time and found that what he was looking for had a companion that shouldn't have been there. Like Herschel with Uranus, he initially thought it might be a comet, but its movement didn't seem right. He hoped for something better, and he made a number of observations over about five weeks, but was slow in reporting it because he became ill. By the time the information was published, in September, the object was too close to the Sun to observe.

It might have been lost except that a youngster named Carl Gauss reckoned he had found a way of applying Keppler's laws of motion to predict the position of a solar system body from only a few observations. His technique was actually a bit iffy, but in this case, happily, it worked, and nearly 11 months after its first discovery Ceres was rediscovered. At first Ceres was thought to be the 'missing' planet. Although it was clearly very small, it did fit Bode's law.



The asteroid Ceres – first to be discovered

The group of astronomers, however, went on to discover more dwarf planets or asteroids at the same distance, and although in some books and tables Ceres remained listed as a planet (along with Pallas, Juno and Vesta) for some fifty years, it was soon acknowledged that the missing planet was an asteroid belt, almost certainly a planet that had been prevented from forming by the massive gravitational effect of Jupiter.

There is no theoretical basis for Bode's law, and although the spacing of bodies in other systems, for example the satellites of Jupiter, do follow a pattern, it's not the same one. It appears that every system might have its own variation on Bode.

At this time there was still a lot of work being carried out on computing the orbits of the known planets, the Moon and comets. This was work that dated back to Charles Messier's time, when the laws governing the movement of planets and other solar system bodies were relatively newly discovered. Newton's Principia, outlining his laws of motion, had been first published in 1687, but over the next fifty years or more others were taking Newton's principles, applying them and refining them.

In 1792 Jean Baptiste Joseph Delambre published his tables on the Sun, Jupiter, Saturn, Uranus and the moons of Jupiter. Delambre had studied under Lalande, who in turn had studied under Delisle, who was Messier's first boss. His credentials were good. Predicting orbits worked both ways, and once Uranus had been discovered it was possible to work backwards to where it had been, and it was realised that several previous observations had been made. John Flamsteed had observed Uranus at least six times as far back as 1690. He mistook it for 34 Tauri. Pierre Le Monnier had observed it at least a dozen times between 1750 and 1769. Even William Herschell had at first assumed it to be a comet.

Alexis Bouvard, director of the Paris Observatory, updated Delambre's work using these earlier observations and published new tables on Uranus in 1821, predicting its orbit and future position using Newtonian laws of motion and gravitation. However he felt that all was not as it should be, or to be more precise, Uranus was not quite where he thought it should be.

Subsequent observations confirmed this. By 1840 the discrepancy was one and a half minutes. Now this is tiny – the unaided eye would not be able to distinguish between

Uranus in its actual position and Uranus in its theoretical position. However, the discrepancy was there and was greater than for anything else observed.
There were several possible explanations for this. The most obvious was that some of the observations were not correct. Uranus had not completed an orbit since its discovery, which is why the 'pre discovery' observations were useful, but in assuming it was a star, some of those old observations might have been in error. Another possibility was that the laws of motion, the work of Keppler and Newton, might not hold in the same way so far from the Sun. There was a third option, and that was there was something else out there, something exerting its own gravitational influence on Uranus. This third option was the one that Bouvard proposed. He wrote -

> '... I leave it to the future the task of discovering whether the difficulty of reconciling [the data] is connected with the ancient observations, or whether it depends on some foreign and unperceived cause which may have been acting upon the planet.'

He put the idea forward to George Airy, the Astronomer Royal. Again, he wasn't the only one with the idea. The theory needed someone to work in reverse, to determine the position of an unknown body from the effect it had on something else, on Uranus, but it seems no-one was trampled in the rush to be the first to find it. It was by no means easy work. It wouldn't be difficult now, with the benefit of fast computers and another one hundred and seventy years of knowledge, but at the time the formulae would have to be derived and the complex calculations done by hand.
The technique was to use Bode's law to predict where the unknown body should be and calculate the effect on Uranus, check that against the observed position and adjust the characteristics of the unknown body. Then calculate it all again, and again, and again, until the effect on Uranus matched the observations. Then the position and characteristics of the unknown body would be known. That was half of the problem. The other half was to confirm its existence by observation.
Two men in particular went to work on the problem, independently of each other, as so often happened. One was John Couch Adams, a young Cambridge undergraduate, who seems to have taken on the task off his own bat. The other was a young Frenchman by the name of Urbain le Verrier, who was directed towards the problem by Francois Arago, the head of astronomy in France.

In October 1845 Adams wrote to Airy, claiming that he had solved the problem of Uranus's orbit, and stating the position in which the unknown body would be found. Now if Airy had pointed a telescope at that spot, he might have found Neptune – not at the exact spot that Adams had pinpointed, but not far away. But it wasn't that simple. Adams was an unknown, a youngster working on his own initiative, with unproven credentials. Airy would have had plenty of people like him making claims on his time and resources. It wasn't easy to take the one telescope he had to work with off whatever project it was engaged on when the object in question might not be easy to find. When Herschel discovered Uranus, he did not immediately recognise it for what it was. The new object might be so far distant that it might appear star like, in which case a prolonged program of observation would be required, looking for movement against the background stars. In any case, Airy wasn't impressed by what Adams had given him. Airy seems to have suffered what one might call a bit of an inferiority complex. His rise to the post of Astronomer Royal had been largely driven by financial considerations. He was a good mathematician – that is not in doubt – but he didn't like competition and wasn't noted for encouraging up and coming talent. But by

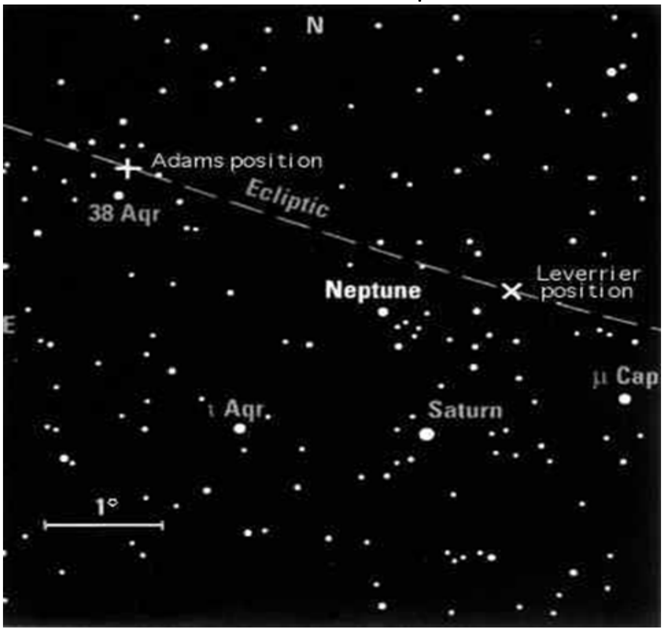
the same token, Adams seems to have been a bit unprofessional in his presentation of both himself and his conclusions.
Airy didn't ignore Adams. Airy, incidentally, wasn't a subscriber to the undiscovered planet theory. He was more inclined towards the breakdown of the laws of gravity with distance. What Airy did was ask Adams a technical question in relation to his calculations, which was designed to try to distinguish between the two conflicting theories. Adams could have given a simple reply, but for whatever reason, he didn't. So Airy, not surprisingly, took no notice of his claim.
In June the following year, 1846, le Verrier published his own prediction of the position on the unknown body. It was within a degree of that claimed by Adams. However Airy was still cautious. He asked le Verrier the same question he had asked Adams, and from le Verrier received a prompt reply. So did he turn the Greenwich telescope to the spot? No, he didn't. Instead he contacted Professor Challis at Cambridge University, who had access to a suitable telescope of 11 ¼ inch diameter. Challis did conduct a search, but unfortunately what he didn't do was compare his observations. He actually saw and recorded what he was looking for twice, a week apart. If he had compared the two observations he might have seen movement against the true stars. If he had had a star atlas down to 10th magnitude, the discovery might have been made on August 4th. But he did not compare his observations, and neither did he have the 10th magnitude star atlas. Such a thing was in preparation, in Germany, but was neither complete nor published. However the portion of the sky where the new body was at this time was complete. Challis had no way of knowing this.
Le Verrier tried to interest the Paris Observatory in a search for the possible new planet, but was met with a lack of any real interest.
Challis wrote later –

> 'It was so novel a thing to undertake observations in reliance upon merely theoretical deductions; and that while much labour was certain, success appeared very doubtful.'

What you don't get is any sense that anyone's imagination was fired by the idea of discovering a new planet at the outer reaches of the solar system. Even though Halley had used Newtonian theory to predict the return of a periodic comet in 1758, nearly ninety years earlier, the whole Idea still seemed to be deemed too new and uncertain – too much work for too little chance of success.
Perhaps knowing that Germany was to the forefront of mapping at the time, and almost certainly because of his failure to persuade anyone in France to undertake a search for his planet, le Verrier contacted Johann Galle of the Berlin Observatory. By now both le Verrier and Adams had further refined their calculations.

Galle received le Verrier's letter on 23rd September. He pointed his telescope skywards that same evening – luckily it was clear – and there was the new planet, found after less than an hour of searching and less than a degree from le Verrier's computed position, using a 9 inch achromatic refractor, a very fine telescope for its day. Galle thought there was a disk there rather than a point of light which would have signified a star, but it could have been wishful thinking. He, however, had the new star chart for the area of sky he was looking in, drawn up by the observatory director Johann Encke, and it showed no star in that position. Two further observations – luckily it obviously stayed clear – confirmed it.
Galle replied to le Verrier - 'The planet whose place you have computed really exists.'

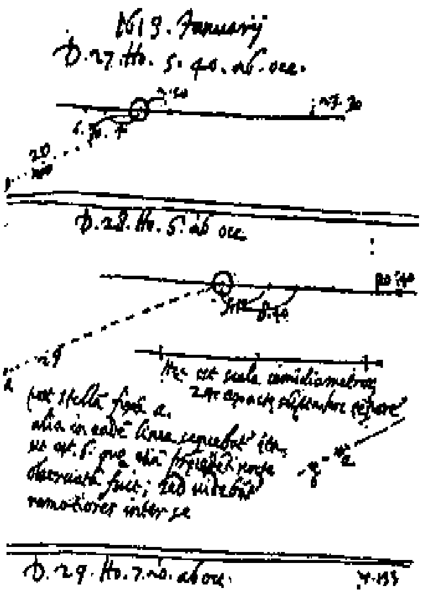
News of the discovery flashed around Europe with lightning speed. Lightning speed for the mid nineteenth century – Challis heard about it on October 1st, hence the headline from The Times of that date – le Verrier's planet found!



There had been an element of luck involved. The analysis done by both Adams and le Verrier was not particularly good and both predicted different orbits. The positions, close to each other, only held good for the 1840s, but that was all that was needed.

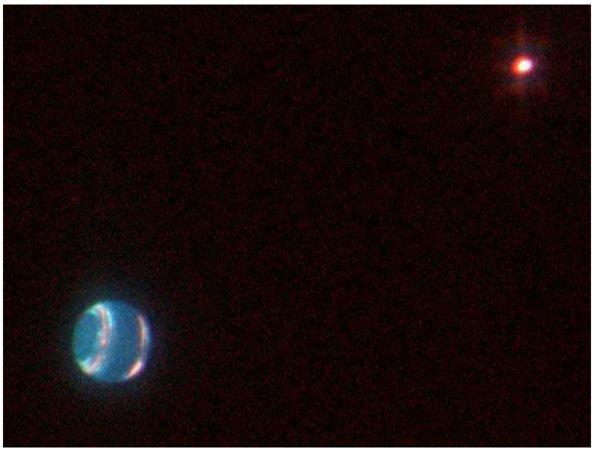
Le Verrier was awarded the Copley Medal by the Royal Society and the French Legion d'Honour. In spite of the fact that le Verrier had had to go to Germany to find someone willing to search on his behalf, the French were keen to claim the discovery. Arago wanted to call the new planet le Verrier, much as Uranus had first been named Georgium Sidus, or George's Star, by Herschel in honour of his patron King George III. This having been rejected as unacceptable to the French, the name Herschel was proposed. Interestingly, Neptune was also proposed before Bode argued that since Saturn was the father of Jupiter, so Herschel's new planet should be the father of Saturn, Uranus. Le Verrier was also very keen to donate his name to 'his' planet, but the name Neptune was adopted.

Le Verrier went on to discover a discrepancy in the motion of the perihelion of Mercury, which again was more than Newtonian theory predicted. Le Verrier attributed this to a second asteroid belt or another planet between the Sun and Mercury, so close to the Sun as to be invisible. He named this theoretical planet Vulcan. There is, of course no planet there, but subsequently this discrepancy became important evidence for Enstein's theory of general relativity.



It turned out that Challis had not been the only one to see the newly discovered Neptune without seeing it, as it were.
There is evidence that it was seen and recorded by Galileo as early as December 1612, and again in January 1613. His notes make mine look tidy, but presumably they made perfect sense to him.
LeLande recorded it in 1795, and John Herschel in 1830. All of them took it to be a star. Galileo, with two observations close together, might have noticed its movement, but unfortunately the planet was stationary as it had just turned retrograde. Herschel's telescope was certainly capable of resolving the planetary disk, but for some reason he failed to do so.

The work of le Verrier and Adams had caused some interest in the amateur world. 'Amateur' in the astronomical world in those days didn't quite have the same meaning as it does now. These were well educated men who had made, inherited or married into a great deal of money and had the leisure time to indulge in scientific pursuits. Professional astronomers were few and far between, and were usually dividing their time between programs of observation with whatever resources they managed to get funding for, and teaching. Not unlike today, but then the amateurs – the Grand Amateurs as they are sometimes dubbed - were an accepted and highly valued part of the scientific scene. William Dawes, a clergyman who was made Fellow of the Royal Astronomical Society for his work on double stars, had discussed the matter with his friend John Herschel, but as he only had a 6 ½ inch refractor, he felt it not to be worth his while conducting a search for the planet himself. He did, however, write to another friend, William Lassell, the telescope builder from Lancashire who had made his fortune in the brewing trade, and who was then working with his new 24 inch equatorially mounted reflector. It was his own design and no expense had been spared in its manufacture. It had been designed specifically for planetary observation. The story goes that Lassell was laid up with an ankle injury, and when he was sufficiently recovered to hobble out to his telescope he had lost the letter. The story is probably not true, but it does sound better than admitting that we just don't know why Lassell seems not to have made any observations from September 16th to October 2nd when he saw Neptune for the first time. Perhaps it was just cloudy in Liverpool.



Lassell may have lost his chance of discovering the planet, but, encouraged by Herschel, he discovered Neptune's moon Triton on 10th October. He also recorded a ring, like that of Saturn, but this turned out to be due to a flaw in the telescope mount. When he fixed the mount, the ring vanished. Lassell's telescope was larger than that used by Galle and immediately revealed the 8th magnitude planet as a disk, needing no verification by subsequent observation of movement. Dawes had known that.

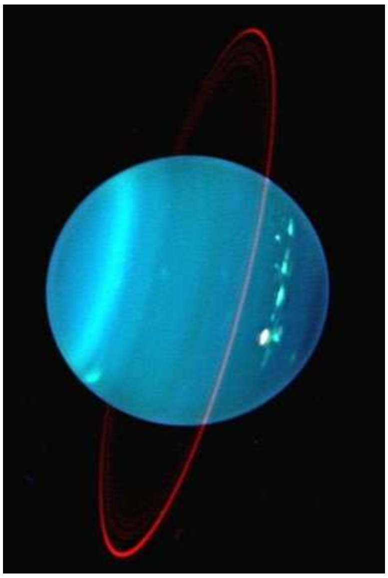
Johann Galle , Urbain Le Verrier, William Lassell, Francois Arago and John Couch Adams have given their names to each of the five rings of Neptune discovered by the Voyager 2 mission in 1989. It had been suspected for about twenty years that Neptune had a ring system. The rings around Uranus had been discovered and studied in some detail by observing stellar occultations. Although there seemed to be some evidence of rings round Neptune, it was inconclusive and could not be proven until the Voyager flyby. The reason is that the rings of Neptune are much thinner and sparser than those of Uranus. Lassell's telescope could not possibly have shown him the rings, but he had in fact been right in claiming their existence.

Four tiny Neptunian moons reside within the ring system, though unlike Saturn and its rings, the relationship between Neptune's rings and these four moons isn't really understood. The largest moon Triton, discovered by Lassell, is almost certainly a captured Kuiper Belt Object. Interestingly, for Neptune to capture it, something must have slowed it while it passed the planet. A possible explanation is that Triton demolished an existing satellite. It is the only large satellite in the solar system to have a retrograde motion around its planet. It's actually slightly larger than and similar in composition to Pluto. It's a frozen world, with a veneer of nitrogen and methane ice overlying water ice as strong as steel. Plumes of nitrogen gas have been observed at Triton's polar cap, possibly triggered by solar heating since they occur where the Sun is directly overhead.

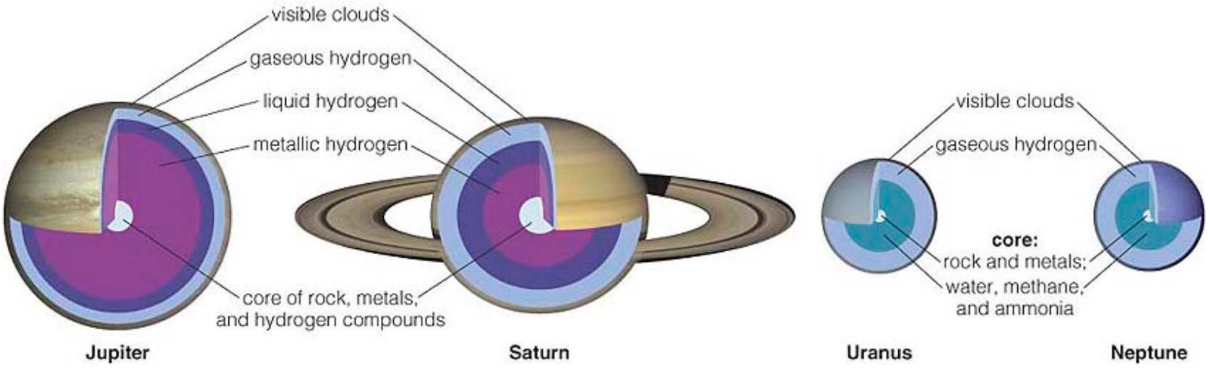
Uranus

Neptune

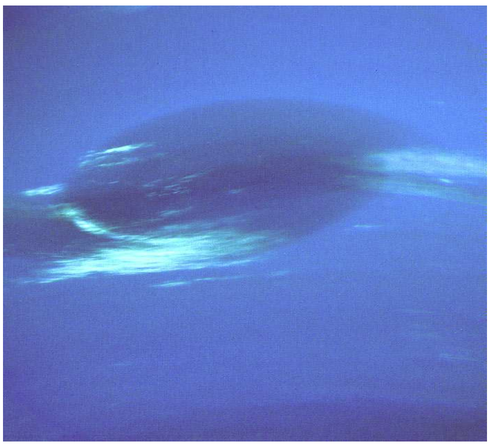
There are a lot of parallels between Neptune and its neighbour Uranus. Although the outer four planets in our solar system are referred to as the giant planets and sometimes gas giants, they are not all alike. Jupiter and Saturn certainly are gas giants. Uranus and Neptune are ice giants.
Both appear blue because of the methane in their atmospheres. In the Voyager images above Uranus appears rather featureless compared to Neptune, however it is thought that this is a seasonal effect.



In this image from the Keck telescope Uranus shows a marked similarity to Neptune, if you put aside the remarkable axial tilt of Uranus that is far greater than that of any another planet in our solar system. Uranus rolls around the Sun on its side.
Both planets are about the same size, although Uranus is less dense. The composition of the two is thought to be the same – with a small rocky core, a thick icy mantle and a gaseous upper atmosphere.



The gas giants Jupiter and Saturn are thought to have a layer of metallic hydrogen, and indeed are thought to be composed mainly of hydrogen. Compared to Jupiter and Saturn, Uranus and Neptune contain comparatively little hydrogen and helium except in their outer atmospheres, but far more methane and ammonia. Possibly, because they are so much further from the Sun, the disk of material left from the Sun's formation was less dense there and their cores took longer to form, so that by the time they had, Jupiter and Saturn had hoovered up most of the hydrogen for themselves.



High winds in the thick atmospheres of the giant planets cause immense storm systems like Jupiter's Red Spot. So Neptune has its Dark Spot, or rather spots, because Neptune's atmosphere is much more dynamic than that of Jupiter, and spots form, fade and reform.
However, although both Uranus and Neptune have faint ring systems, the rings of Neptune and Jupiter contain far more dust than those of Uranus and Saturn. This does not mean that any other comparisons can be drawn. Although all the outer giant planets have rings, they are all quite different.

In late 1993 Uranus and Neptune made a close pass of each other in Sagittarius, the first since Neptune's discovery.

Although the discrepancy in the orbit of Uranus led to the discovery of one missing planet in our solar system, it is a fact that the outer planets – Saturn, Uranus and certainly Neptune – do not behave entirely as predicted. As soon as a couple of years after Neptune's discovery, a case was being built for at least one, and possibly as many as three, planets beyond Neptune. At the beginning of the twentieth century Americans William Pickering at Harvard then Percival Lowell at the Flagstaff Observatory began a hunt for 'Planet X', as Lowell called it. Everyone knows that this culminated in 1930 in the discovery of Pluto, once planet and now demoted to a Kuiper Belt Object along with its moon Charon. This discovery wasn't made by calculation, but by painstakingly taking multiple photographic images of the same area of sky and comparing them.
Pluto and Charon together are in no way large enough to account for the irregularities of the outer planets, and this prompted a brief search for a tenth planet, but data from the Voyager mission suggests that the irregularities can probably be explained by inaccuracies in the estimation of the Neptune's mass.
Numerous 'tenth planets' have been found – all Kuiper Belt Objects around the size of Pluto, and this was almost certainly one of the factors that led to Pluto being stripped of its planetary status. Some of these have very irregular orbits, and some scientists believe that along with other oddities about the Kuiper Belt, this could be explained by another distant planet. If Planet X is still out there somewhere, it will be found with the benefit of computer simulation and possibly off Earth telescopes that le Verrier and Adams could never have envisaged one hundred and sixty five years ago.

A hundred years after Neptune's discovery the Second World War had given birth to the technology that would put men on the Moon and space craft into orbits around distant planets in our solar system, and give us this stunning image of Voyager's farewell to Neptune and Triton.