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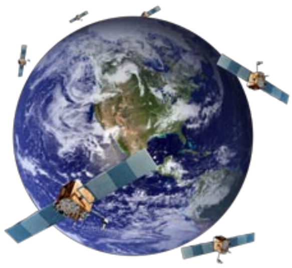

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Dr Tim Wetherell

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For Bode-ing

I've said this before, but hey, I'm the Editor so I can say it again. In science, observation is king and any theory that doesn't fit the observations, however cherished, is wrong!

I can't deny it irritates me when I hear people proclaim that something is impossible because their pet theory precludes it, even though the phenomena has been clearly observed. So I've enjoyed covering a piece of research in this edition that's given some credibility back to a centuries old idea; Bode's law or more correctly the Titus-Bode relation.

It's just a rule of thumb that predicts the spacing of planets orbiting a star which was popular in the 18th century but rapidly fell out of favour largely because there's no good theoretical justification for it.

A couple of my colleagues up at Mt Stromlo Observatory have just shown that this old rule of thumb actually works superbly well for many other solar systems outside our own. Yeah for Bode's law!

When you think about it, any given spinning accretion disc around any forming star is likely to have very similar properties to any other. Gravity's the same, angular momentum and the impact dynamics too. Planets can't form too close to each other or inevitably they collide and make new planets until everything's stable. So it makes sense that most planetary systems will be broadly similar.

As to the precise reason that all the complex mathematics of swirling protoplanetary discs, accretion and orbital path clearing should boil down to a simple sequence - well no one knows at this point. But there will be a reason and some smart cookie will find it one day. In the meantime, as scientists we are students of nature, not its master. Nature is never wrong. We frequently are!

Johann Daniel Titius - In this portrait he looks resigned to the fact that his observations will be rejected!

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Cover Image: 19th century orrery manufactured by Newton and Son, London. Image: Christoph Braun

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How did we get here?

Can the mathematics of waves explain the origin of life?

One of the fascinating questions about life on Earth is how did it get here in the first place? There are a vast number of theories ranging from the mundane to the outright fanciful, but most scientists gravitate to what they see as elegant ideas. That is, scenarios which don't require anything "special" to have happened.

But can things simply create themselves out of nothing? Professor Nail Akhmediev from the Australian National University believes they can and indeed did in the case of life on Earth. Professor Akhmediev's background is solitons; a special class of wave which can persist for long periods.

"You might not think that solitons would have anything to do with life on Earth," Professor Akhmediev says, "But think about a single celled organism such as an algae for a moment. It takes in energy in the form of sunlight, it takes in materials in the form of food and so long as the flow of these two things persist, it's alive. The dissipative solitons have very similar properties, they consume energy and materials and whilst the supply of these two things continues, the localized soliton wave remains 'alive'."

But one thing that does distinguish dissipative solitons from cells, is that solitons can be completely described by mathematics. "Something as complicated as a cell has so many parts and processes describing it in an exact mathematical way would be almost impossible." Professor Akhmediev explains, "But with solitons we can do just that."

The importance of an exact mathematical treatment is that the results you get are certain. With numerical models like those used in climate research, the answers you get out are statistical and as we see every week in the media, open to debate. With an exact model, the result is an answer, not a probability. If 3X=6 then X=2 and not 2.2, not 1.8 just 2.

"We have seven parameters in our equations that we can vary and what we find is that over a surprisingly broad range of values, dissipative solitons will simply spontaneously create themselves. There's no need for any special external input, you just provide the energy and matter then self sustaining solitons will just happen."

The similarities between solitons and living things don't end there. Solitons can bifurcate, essentially reproducing themselves. Amazingly enough, they can also get sick. "If the flow of energy or matter is reduced what we see is the soliton begin to oscillate and if it is interrupted, just like cells, they die." The nature of the solitons also changes in response to changes in their environment in a process very like evolution.

But how like-life can a wave really be? "Obviously cells are far more complex, but what we've proved mathematically is that when the conditions are right, localized self sustaining entities can be spontaneously created." Professor Akhmediev says.

What this all tells us is that in a situation where you have energy and matter localized entities that consume, excrete and multiply are essentially an inevitability. So on any planet like the Earth with benign conditions, if you wait long enough, you'll get life.

What makes this work especially interesting at the moment is that with advances in spaceflight and massive new generation telescopes we may soon be able to test the idea directly. If Professor Akhmediev and his solitons are right, the universe should be teeming with microbial life!

Inspired

Better pathways to new medical compounds

For thousands of years humans have known that certain plants hold medicinal properties and have gathered those plants to treat a variety of ailments. Many modern medicines, such as aspirin derived from the bark of willow trees, have natural origins too. If a plant is commonly available and the active molecule works well in its natural form, then there's no problem. But what if we need to modify a natural product to increase its efficacy and reduce undesirable side effects, or what if a clinically important agent is only found in an endangered species? In situations like these synthetic chemists are frequently called upon to develop methods to access these important molecules in an economically and ecologically sustainable manner.

The kingianin natural products were recently isolated from the bark of the rare Medang tree found in Malaysia and Borneo, and have great promise as lead compounds in the development of novel cancer therapies. Frustratingly, the bark of an entire tree only produces a vanishingly small quantity of these complex and biologically active compounds. This has hindered further medicinal studies, due to a lack of supply.

Driven by a demand for a more sustainable route to these kingianin molecules, a team of chemists from the Australian National University elected to confront this challenge head-on, by investigating whether the kingianins could be prepared in the laboratory from scratch.

"Just because something is natural doesn't automatically make it safe, or a good medicine" Professor Mick Sherburn explains, "More often than not, molecules in their natural form have undesirable or even fatal side effects, so very few of them go to market unchanged. But what these natural products often do, is provide us with a raw material which we can modify into something really useful through synthetic manipulations in the laboratory."

A group of researchers, led by Professor Mick Sherburn and Dr Andrew Lawrence, have recently developed a novel technique for the synthetic production of the kingianins, which has pushed at the boundaries of what was traditionally thought possible.

Synthetic chemists usually construct molecules one new bond at a time: reagents are introduced to a reaction vessel and specific conditions are applied to form just one new chemical bond. What the ANU group has developed is what's known as a domino reaction, wherein lots of bonds are all formed in a single reaction – this is far more efficient, but also far more challenging to successfully execute.

by nature

“With a domino reaction, everything is designed to automatically happen selectively in the right sequence without any additional changes needed. The molecule essentially assembles itself.” Dr Andrew Lawrence says, “The really tricky bit is creating the right precursor molecule for the domino reaction.”

To achieve this the researchers produced a molecule that contained a long straight chain of eight carbon atoms. They then used a process to add many hydrogen atoms to the chain – something that has not previously been done on such a long carbon chain.

“Nature is a master chemist, so it’s a great place to seek inspiration.” Dr Lawrence adds, “What we have done is combine state-of-the-art synthetic technology, which is available to us in the laboratory, with a synthetic strategy that mimics the processes actually used by nature to assemble these kingianin molecules in the tree. This so-called ‘biomimetic’ approach has resulted in a uniquely efficient synthesis.”

The researchers discovered that the tree utilized free radicals to make the kingianin molecules. “Free radicals are well known to break down biological molecules,” Professor Sherburn says. “Our work shows that nature has actually harnessed free radicals to create rather than destroy.”

But why is it that so many useful medical compounds are found in nature in the first place?

“Nature doesn’t create these molecules for it’s own amusement, if it goes to the considerable trouble of doing so, there must be a good biological reason.” Dr Lawrence says.

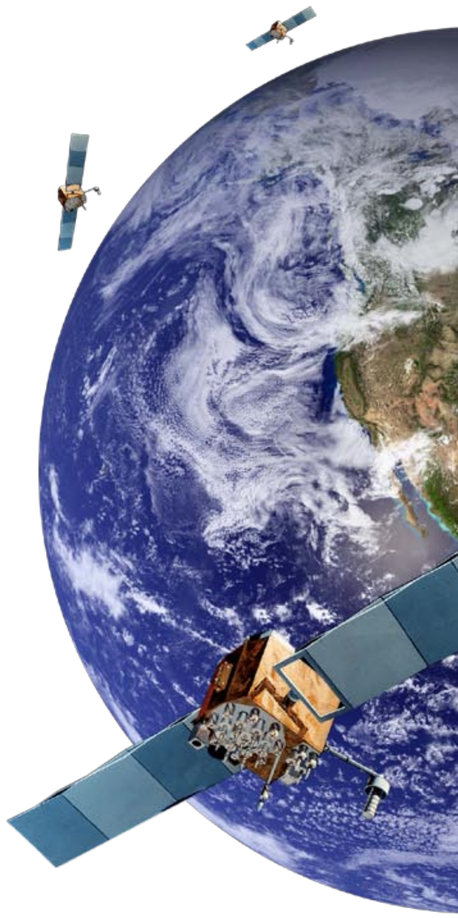
Samuel Drew, the PhD student who actually conducted the experiments in the lab, says “Our research isn’t directly involved in medical applications, what we’re really interested in is developing the science and art of synthetic chemistry. Our results show that by working smarter, chemical synthesis can be made more efficient, take less time and cost less money. We can also reduce energy consumption and waste production. So if the kingianins turn out to be the next hot thing in medicine, then our research will mean we don’t need to endanger the tree or destroy the environment to harness the biological activity of these intriguing molecules.”

This research was funded by the Australian Government through the Australian Research Council. It is published in the leading international chemistry journal, *Angewandte Chemie*.

Drifting off

The GPS navigation system in your car calculates your location by timing the arrival of signals from four or more of a constellation of satellites in orbit around the Earth. It's a tricky feat to pull off because the signals travel at the speed of light so if your electronics is a hundred millionth of a second off, the position is out by three meters – easily enough to put you in the wrong lane!

In spite of the technical difficulty, the GPS system works superbly well for most purposes, providing navigation with an accuracy of a metre or so. But what if you're a scientist wanting to study the tiny creep in the movement of tectonic plates, or measure the rate of sea level rise? In those cases, plus or minus a metre simply isn't good enough.



Dr Paul Tregoning from the ANU Research School of Earth Sciences was a member of a scientific team using GPS to study the movement of tectonic plates in the Papa New Guinea region. "When you're looking for movements smaller than a few millimetres per year, standard GPS isn't good enough." Dr Tregoning says, "So we have to throw away the usual coded time signals and instead make use of the phase of the microwave beam that they're carried on."

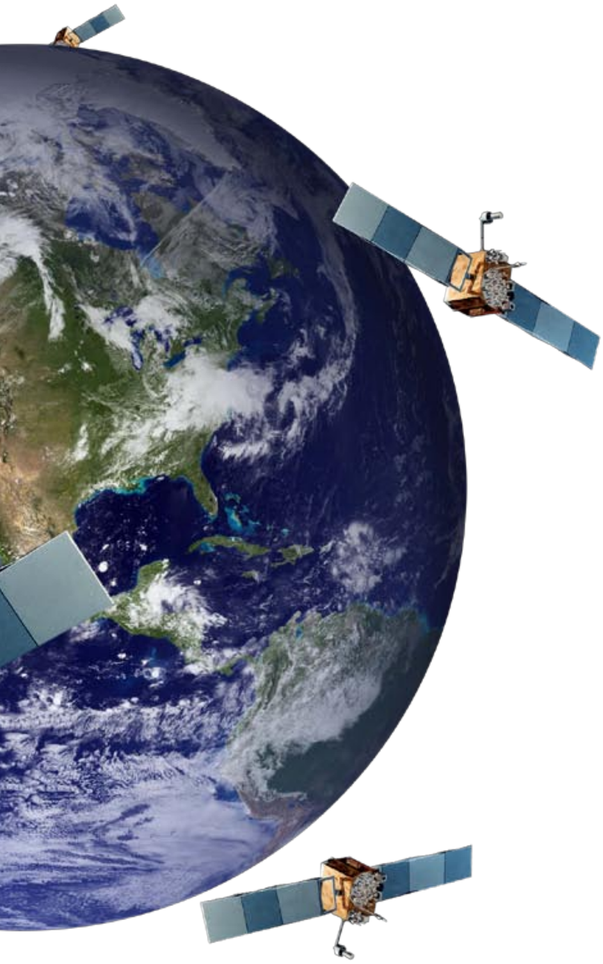
Any wave has peaks and troughs so, in principle, you can work out how far along a microwave beam you are by counting those. Obviously it isn't possible to count every peak right back to the satellite because the distance is too great and the wave is hurtling along at the speed of light. But if you stand in one place and count the peaks going past, you can work out how fast the satellite is moving relative to you. You can then estimate the satellite's orbit, how many peaks and troughs there were between you and the satellite when you started counting and your own position. From 24 hours of continuous measuring, the position can be worked out to better than 5 mm.

"It's quite amazing that we're able to do this since the satellites are travelling at thousands of kilometres per hour and tectonic plates are crawling along at less than 70 millimetres per year, but by using several satellites at the same time and keeping careful electronic count of the trillions of wave peaks we can do exactly that."

But, as is often the case in science, when the team studied the PNG plate movements they discovered a lot more than they bargained for. "We had expected to see a steady linear drift as the plates slowly moved around," Dr Tregoning explains, "But the data were all over the place and it was a real puzzle to work out what was happening."

It turns out that the scientists could see a number of significant shifts in the land caused by 17 massive earthquakes that have occurred this century. At the moment of the fault slip during an earthquake there's a sudden violent shift in the crust at that point, but the subsequent deformation effects can extend right across the surrounding continents. And whilst the initial quake is very rapid, the deformation and relaxation of the entire region can take many years to complete.

Are GPS coordinates shifting beneath our feet?



One of the complicating factors in identifying tiny land movements is that there are other forces involved which are far larger. The combined gravitational pull of the Sun and the Moon causes the Earth's crust to rise and fall by as much as 40cm – a phenomena called the Earth tide. Although the majority of this movement is vertical, there is also a daily horizontal cycle of up to 50mm that would swamp any tectonic plate movement if not corrected for.

Then there's the effect of ocean tides. Because eastern Australia has a long continental shelf there's a colossal mass of additional seawater pressing down on it at high tide, which moves most of the continent. Incredibly, when the tide is in at Batemans Bay, Canberra 250km inland, moves down by about 8mm!

Even the weather changes the position of the land. A high-pressure system contains millions of tonnes of extra air, which pushes down the Earth's surface by as much as 15 mm.

"One of the most difficult parts of this work are the many corrections that have to be applied to the measurements before we can tease out the tiny signals corresponding to tectonic plate movement or local shifts dues to earthquake processes." Dr Tregoning says, "The more you understand about these measurements the more you realize how difficult it is to identify a fixed frame of reference from which to measure."

The GPS satellites all orbit about the centre of gravity of the Earth but even that shifts with the Earth tide and changing distributions of ocean and air. "The best we can do is to try to identify the most stable parts of the Earth on which to place reference stations and that's where the earthquake work becomes so important."

All parts of the Earth move with tectonic plate drift. But that's generally smooth, linear and easy to compensate for. However the unexpected horizontal shifts caused by massive earthquakes greatly reduce the value of any reference station located in such an area. "By creating global maps of earthquake shifts we've been able to identify which regions are prone to such motion and which simply follow smooth continental drift. From this we've selected eight measuring stations that can create a good base line for all such studies."

A few millimetres here or there in the GPS system won't cause you much hassle driving your car down the highway, but to science that can be very significant. For example when we talk about rising sea levels what do we measure that relative to? A tide gauge fixed to the pier is fine but how do you know that the pier isn't moving up or down over the years?

The GPS system contributes to monitoring sea level changes, but again, you have to be able to calibrate that system accurately if you want to see changes of the order of millimetres.

Science magnet

How a unique facility is attracting scientists to Australia

A series of massive slabs of iron are lined up on the floor of the mechanical workshop at the ANU Research School of Physics and Engineering. They're waiting to be machined into a housing for a powerful solenoid funded by the Federal Government Superscience Initiative. Together, these will form part of a unique physics instrument, located at the ANU Heavy Ion Accelerator Facility.

Watching the gantry crane heave a ton of solid iron from the floor onto one of the biggest lathes you're likely to see in Australia, it's hard to imagine that the vast majority of the space within that colossally heavy metal ingot is actually filled by lightweight electrons.

Most of the 1000kg mass comes from the nuclei of the iron atoms, but those nuclei occupy only the smallest imaginable fraction of the total volume. If you could get rid of the electrons and pack the nuclei together you'd have something smaller than a particle of dust, but that still weighed almost 1000kg!

The tiny size of nuclei creates a problem for scientists like Professors David Hinde and Mahananda Dasgupta. They study the processes of nuclear collision and fusion in order to understand how the heavy elements found on Earth were formed in ancient supernova explosions.

"We study fusion by bombarding a target with a beam of very energetic nuclei, but because the nuclei are so tiny, the chances of a direct hit on a target nucleus by a beam nucleus are very small indeed. We may only get a few fusion events for billions of ions hitting the target." Professor Dasgupta says.

When a direct hit does happen the impact is enormous. So large in fact that not only do the two nuclei fuse, but the newly formed heavier nucleus is blown right out of the back of the target. The scientists need to isolate these newly formed nuclei so that they can be identified and characterised. However the problem is that for every fusion product leaving the back of the target, there are literally billions of beam particles that have passed through. Somehow, the scientists have to separate the two and fortunately nature has provided a way.

Immediately after fusion, the new heavy nucleus is incredibly hot and emits energetic particles such as neutrons. These emissions perturb its trajectory, just like little rocket thrusters firing to the side, so the jet of fused nuclei leaving the back of the target isn't all along the beam direction. Instead it forms a cone more like the spray from a shower head.

Using an enormously powerful magnetic field it's possible to re-focus this cone of fused particles and collect them all in one place with excellent efficiency. The difficulty is that the field required to do this is truly enormous – 250,000 stronger than the Earth's magnetic field.

To generate a field of that strength over a large volume requires a superconducting electromagnet. When cooled close to absolute zero, the coils of special wire within the solenoid have no resistance, so once a large current is set up, it will circulate forever, or until the coil is allowed to warm up at the end of the experiment.

The massive iron housing being manufactured in the workshop encloses the superconducting coil and serves a double purpose. Firstly it improves the uniformity of the magnetic field within the instrument. But it also prevents that field spilling out into the surrounding lab. "When you're dealing with strong magnetic fields, 8 Tesla in this case, you really have to look at the safety aspects too," Professor Hinde explains, "In a lab full of nuts, bolts and spanners, turning on an uncontained field of this magnitude would trigger a hail of metal!"

"There are very few workshops in the country that could handle the fabrication of such massive and complex parts. The Research School's mechanical workshop has always been one if its great strengths and the expertise of our technical staff is what makes so much of the science we do here possible." Professor Hinde says.

The ANU accelerator is one of the highest Voltage Van de Graff accelerators in the world attaining over 15 million Volts. Scientists are attracted from around the world to make use of the laboratory's unique capabilities. The new solenoid system will enhance both the Accelerator Facility and Australia's global scientific reputation.

Miro Peric machines one of the iron sections that will encase the completed solenoid

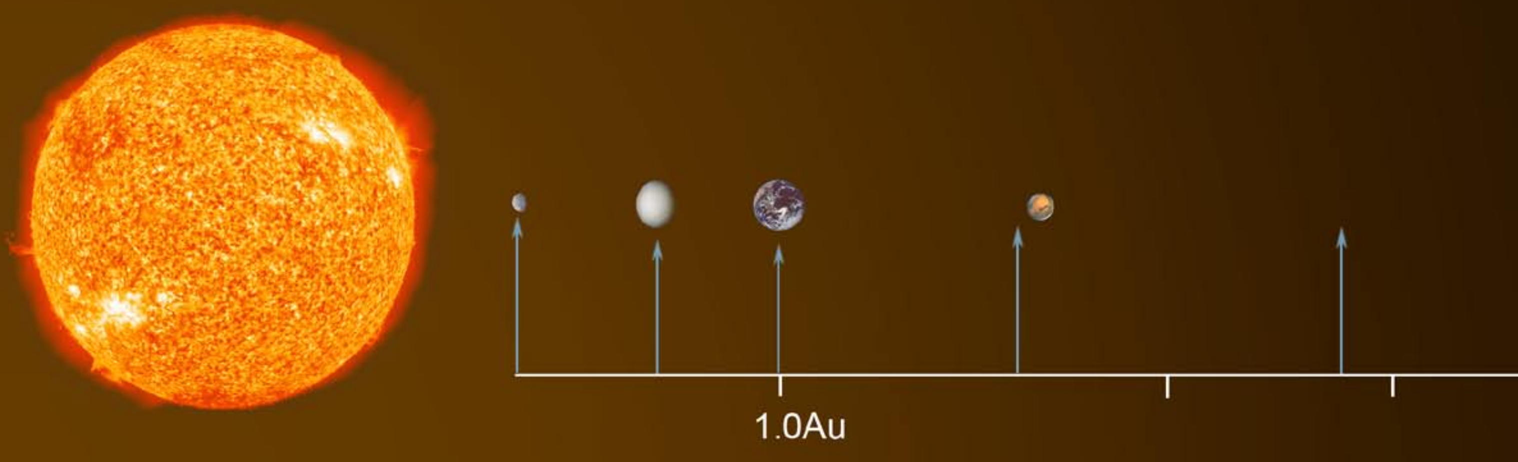
A mysterious sequence

Back in the 1600s telescopes had crude optics that offered very poor views of other planets, so relatively little was known about the nature of our neighbours in the solar system. However one thing that could be accomplished with considerable accuracy was the measurement of planetary position and thus the calculation of orbits. This meant that by the dawn of the 18th century astronomers had an excellent grasp of the relative distance of each planet from the sun.

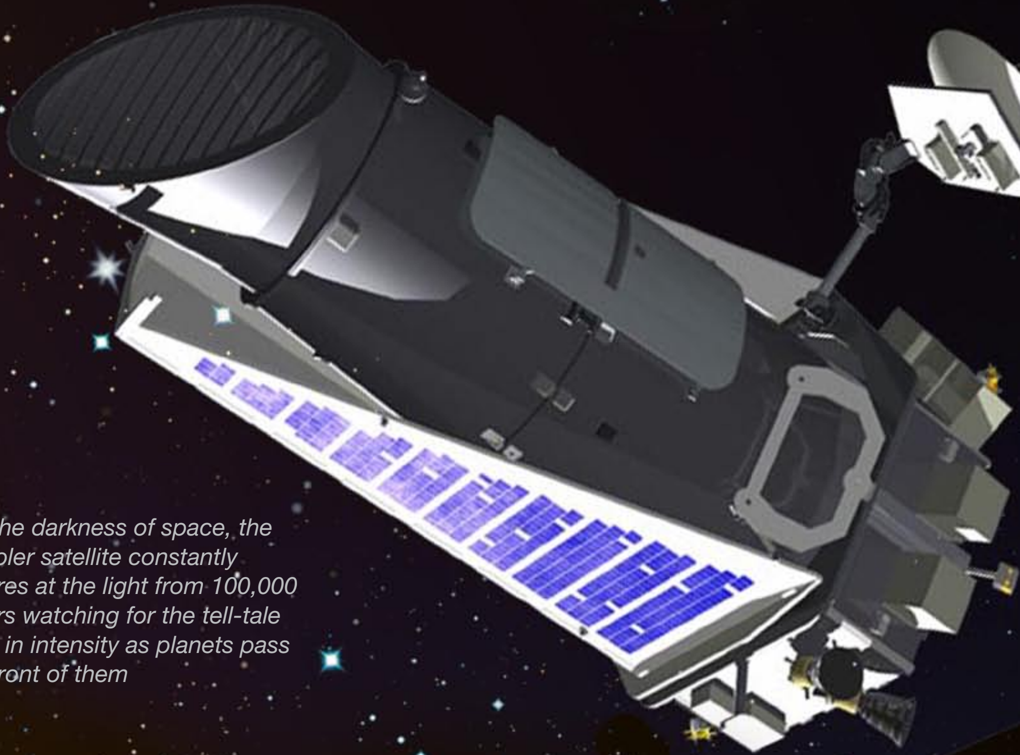
It wasn't long before people began to notice that many of those planetary distances fitted into a simple mathematical sequence $d = 4 + n$, where n doubled with each planet in the sequence 3,6,12,24 etc. There was no theoretical basis for this relation, it just seemed to be something that fit. In the middle of the 18th century, Johann Daniel Titius and Johann Elert Bode formalised what astronomers know today as the Titius Bode law. A rule of thumb that seemed to predict how far each planet would be from the sun.

It wasn't given that much thought until William Herschel discovered the planet Uranus in 1781 and it fitted almost perfectly into the sequence. This led astronomers to look for a missing planet that the Titius Bode law predicted should exist between Mars and Jupiter. In 1801, the dwarf planet Ceres was discovered right where it was predicted and the Titius Bode law was at the zenith of its credibility.

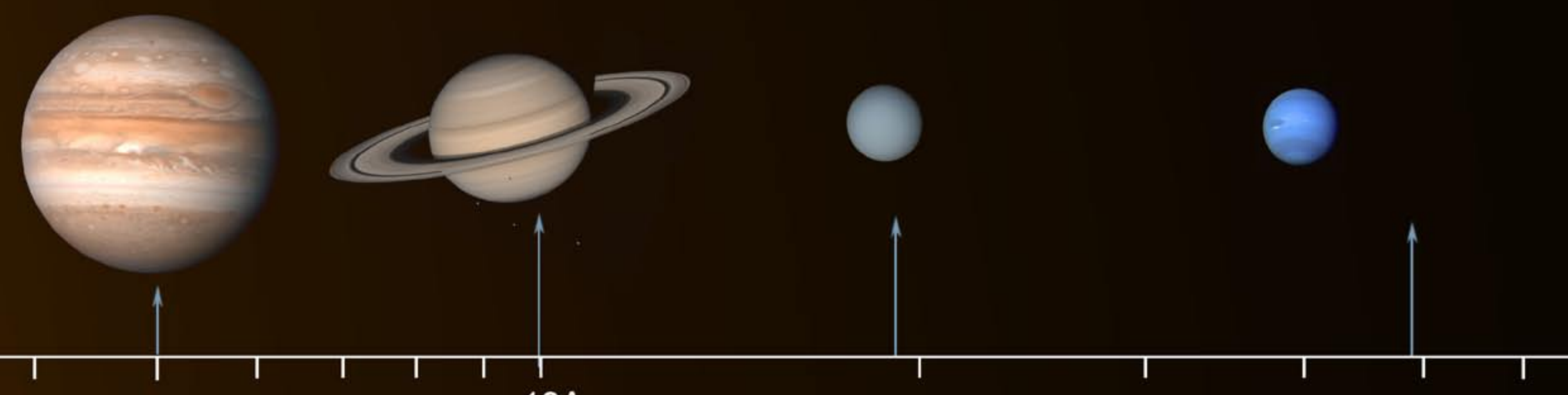
However in the coming years things became more complicated. Further objects were discovered in what we now know as the asteroid belt and perhaps most damning, the planet Neptune was discovered nowhere near the distance predicted by the Titius Bode law. This coupled with its lack of theoretical basis, saw it lose credibility with professional astronomers.



How an antiquated rule of thumb may identify new Earths



In the darkness of space, the Kepler satellite constantly stares at the light from 100,000 stars watching for the tell-tale dip in intensity as planets pass in front of them



Pretty close to the mark! The blue arrows show the positions predicted for the planets of the solar system compared to their true positions as shown by the planets themselves

However in the 21st century, astronomers Tim Bovaird and Charley Lineweaver from Mt Stromlo Observatory have scored another spectacular success for the Titius Bode law. Not in our own solar system, but in a distant system known as KOI-2722. “Even though there’s no current theoretical basis for the Titius Bode law, we were curious to see if it worked as well for other planetary systems as our own.” Tim says, “Until recently this would have been completely impossible because so few exoplanets had been identified. However since the Kepler mission, we have several systems with four or more planets to work with.”

The Kepler satellite launched in 2009, monitors the brightness of more than 100,000 stars watching for the tell-tale dip in intensity when an orbiting planet obscures a small proposition of their light. Earth based telescopes have detected such dips relating to very massive planets transiting but for tiny Earth sized planets that decrease in light is swamped by variations in the light curve caused by our own atmosphere. However from the crystal clear permanent darkness of space, Kepler can monitor the starlight for years on end with absolute precision.

“We looked at the KOI-2722 data and a best fit to the Titius Bode law predicted that there would be an additional smaller planet with a particular orbit. Two months later, the Kepler satellite spotted it! It’s really exciting because this is the first time in over two centuries the Titius Bode law has been successfully used to predict the location of an unknown planet.”

Since then, the scientists have fitted the old empirical law to orbital data in many star systems and incredibly, it fits most of them even better than our own solar system. “We don’t really know why this number sequence should fit planetary systems so well,” Tim says. “But the data fit too well for it to be just coincidence. In fact in 84% of the cases we examined the fit is significantly better than in our own solar system.”

If scientists can predict how far from their parent stars planets should be, they can easily calculate the orbital period for such a planet. Armed with this information they can examine the light curve for even a miniscule dip occurring regularly with that period.

“If we know how bright the star is, in other words how much energy it pours out, we can calculate the average temperature of a planet at any given distance. And we know the size of the planet from how much the light curve dips.” Tim explains. “What’s really exciting to me about this is that it may enable us to identify Earth like planets in the habitable zone of other stars.”

“You can be pretty sure that if and when we make a prediction for such a planet, I’ll be up all night scrutinising the light curve!” Tim says.

Artist's concept of the star Fomalhaut and the Jupiter-type planet that the Hubble Space Telescope observed. A ring of debris appears to surround Fomalhaut as well. The planet, called Fomalhaut b, orbits the 200-million-year-old star every 872 years. Image: ESA, NASA, and L. Calcada

ANSWERS

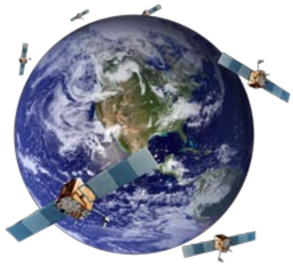
SCIENCEWISE

Could life on earth have spontaneously created itself?

What do you do if an important medical compound is only found in an endangered species?

What does a ton of iron have to do with nuclear physics?

Are GPS positions really that fixed?



How does an antique mathematical sequence help us find new Earths?