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Bode’s Law, also commonly known as the Titius-Bode’s Law, is a rule which predicts the spacing of the planets in the Solar System in astronomical units. The relationship was first discovered by Johann Daniel Dietz (a German teacher of physics at the University of Wittenberg), also known as Titius of Wittenberg, in 1766 and was published by Johann Elert Bode (a German astronomer and Director of the Observatory of Berlin) in 1772. The law states that if 4 is added to the sequence 0, 3, 6, 12, 24, 48, 96, 192 (where a new number is twice the previous number) and the totals divided by 10 to form the series 0.4, 0.7, 1.0, 1.6, 2.8, 5.2, 10.0, 19.6, 38.8, 77.2, . . . the result is the average distance of the planets from the Sun. This observation was then formulated as a mathematical expression, which is as follows:

\[ 0.4 + 0.3 \cdot 2^n \]
The relationship was tabulated as follows:

<table>
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<tr>
<th>Planets</th>
<th>Bode’s Law</th>
<th>Actual Distance</th>
</tr>
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<tr>
<td>Mercury</td>
<td>0.4</td>
<td>0.39</td>
</tr>
<tr>
<td>Venus</td>
<td>0.7</td>
<td>0.72</td>
</tr>
<tr>
<td>Earth</td>
<td>1.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Mars</td>
<td>1.6</td>
<td>1.52</td>
</tr>
<tr>
<td>Ceres</td>
<td>2.8</td>
<td>2.77 (Discovered after the establishment of Bode’s Law)</td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.2</td>
<td>5.20</td>
</tr>
<tr>
<td>Saturn</td>
<td>10.0</td>
<td>9.54</td>
</tr>
<tr>
<td>Uranus</td>
<td>19.6</td>
<td>19.19 (Discovered after the establishment of Bode’s Law)</td>
</tr>
<tr>
<td>Neptune</td>
<td>38.8</td>
<td>30.07 (Discovered after the establishment of Bode’s Law)</td>
</tr>
<tr>
<td>Pluto</td>
<td>77.2</td>
<td>39.46 (Discovered after the establishment of Bode’s Law)</td>
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Fig. 3 Table of Bode’s Law

An astronomical unit is the average distance between the Earth and the Sun, approximately 93 million miles.

The second column in the table is supposed to be the calculation from the formula of the distance of each planet; the third column shows the actual average distance from the sun for each planet.

As we can see, there is good agreement with the actual mean distances of the planets that were then known. Mercury (0.39), Venus (0.72), Earth (1.0), Mars (1.52), Jupiter (5.2), and Saturn (9.55). Uranus, discovered in 1781, has mean orbital distance 19.2, which also agrees. The asteroid (meaning “star-shaped”) Ceres, discovered 1801, has mean orbital distance 2.77, which fills the apparent gap between Mars and Jupiter. However, when Neptune and Pluto were discovered, they were found to have a mean orbital distance of 30.1 and 39.5 respectively. There is a large discrepancy from the positions 38.8 and 77.2 as predicted by Bode's law. Since then, there has been an
argument as to whether Bode’s law is just something that happens by chance or it is an undiscovered force that plays a part in the creation of the solar system.

However, because of the way that planets are believed to accrete themselves from the primordial dust cloud, planets act like gravitational vacuum cleaners, sweeping out bands of gas which eventually come into contact with their neighbors so that the sweeping process stops. The first planet to reach a critical size, grows the fastest and largest. A number of computer simulations have, over the years, revealed that planetary systems ought to eventually stabilise into a regular pattern of planetary distances as a consequence of both their initial formation spacing, and billions of years of gravitational perturbations, but Bode's Law is not a law which can be generalized to describe these other systems. This means that you are more or less free to hypothesize just about any spacings for planets which does not conflict with their masses. Large planets should not have nearby neighbors, for example. You would not expect to find a Jupiter-sized planet wedged in between the orbits of planets like the Earth and Mars, because the growth of such a large planet would have created a sweeping zone extending from the orbit of Venus to the orbit of Mars and so, Venus, Earth and Mars-like planets would never have had the chance to grow.
THE BODE’S LAW

HOW THE BODE’S LAW SATISFIED URANUS?

Uranus was discovered on March 13, 1781 by English astronomer William Herschel at his observatory in Bath. It is found to be at a distance of 19.2AU from the sun. This is very close to the distance of 19.6AU as predicted by an extrapolation of Bode’s Law.

![Bode's Law Graph](image)

The extrapolation can be seen from fig.4. When we extend the line, we can see that at the position of the planet numbered 8, which is at a distance 19.6AU from the sun is approximately the distance of 19.2AU, the distance of Uranus from the sun. The closeness of the predicted and actual distance clearly shows the validity of Bode’s Law. This discovery also prompted the search for the missing planet that lies between Mars and Jupiter as predicted by Bode’s Law.

![Graphical representation of Bode’s Law](image)
HOW THE BODE’S LAW LED TO THE DISCOVERY OF CERES AND THE ASTEROIDS?

Introduction

Asteroids are rocky bodies about 1,000 kilometres or less in diameter that orbit around the sun primarily between the orbits of Mars and Jupiter. Asteroids are often known as 'minor planets', since they are too irregular in size, too numerous and too small to be considered as proper planets. The term planetoid is sometimes used as well. There are thought to be billions of these rocky objects orbiting the Sun.

Asteroids are thought to be the remnants of an exploded planet that orbit around the sun between Mars and Jupiter by some. However some also believed that asteroids are debris in the space that failed to coalesce into a planet due to the gravitational influence of massive Jupiter.

Since they can only be seen as points of light in telescopes, British astronomer William Herschel coined the term ‘asteroid’ - from a Greek word meaning ‘starlike’ - to describe this new class of celestial objects. Earlier this century, astronomers coined a less poetic term for them - ‘vermin of the skies’ - as they regularly appeared in photographs of distant galaxies and nebulas, spoiling the sensitive observations.

Origin

Uranus was discovered in 1781, by William Herschel, from his observatory in Bath, in the west of England. The location in which Uranus is found appeared to be consistent with an extrapolation of Bode's Law. Thus if Titius and Bode were correct, then there should be a planet between Mars and Jupiter. Searches were organized and prizes offered to the first person to find the missing planet. Astronomers were convinced that the intermediate planet will soon be found. However for two decades, the astronomers failed to make any progress and were at a loss.

Finally in 1st Jan 1801, there was a breakthrough as Italian Giuseppe Piazzi discovered the first asteroids at Palermo. Giuseppe Piazzi was observing for a new star catalogue, a collection of the precise location of all stars visible in the sky. While observing stars in the constellation Taurus, he saw a small, starlike object that was not listed on any of his star maps. He carefully recorded its location, but on the next night, he noticed that the object had moved slightly to the east. Stars don't do such a thing. Over the next six weeks he recorded its motion, and discovered that it was moving relative to the background stars. Its rapid motion indicated that the object was not a star, but rather an object in the solar system. At first, Piazzi thought that he had discovered a comet. However, after the orbital elements of the object had been computed, it

Fig.5 Giuseppe Piazzi
became clear that the object moved in a planet-like orbit between the orbits of Mars and
Jupiter. However due to illness, Piazzi was only able to observe the object until 11\textsuperscript{th}
February. Since no one was aware of its existence, the short period of observation by
Piazzi was insufficient to compute where the object would appear in the night sly after
sometime and the object was “lost”.

The matters might have stood there if not for the fact that this object was located
at the heliocentric distance as predicted by Bode’s Law. Titus and Bode believed that
Piazzi had found and then lost the planet. Thus both Titus and Bode make used of the
discovery made by Piazzi and embarked on a journey to look for the “missing” planet
that lies between Mars and Jupiter to verify their theory.

**Ceres and the asteroids**

The search for the “missing planet” led to the development of a new method of
computing orbit which requires only a few observation by German mathematician Carl
Friedrich Gauss. Using his method, German astronomer Franz von Zach recovered the
missing planet on 1\textsuperscript{st} Jan 1802. Piazzi then named his object Ceres after the ancient
Roman grain goddess and patron goddess of Sicily, thereby initiating a tradition that
continues to the present day: asteroids are named by their discoverers (in contrast to
comets, which are named for their discoverers).

At first, the discovery of Ceres seems to confirm the Bode’s Law. At a distance of
2.77AU, Ceres was only 0.3AU off the predicted distance of 2.8AU as of Figure 3.
However, something was not right. Ceres was only 940 kilometres in diameter only about
¼ the size of Earth’s moon, far too small to be considered as a planet. The situation was
made more confusing when another minor planet, Pallas was discovered not far away
from Ceres. Shorter after that, 2 more minor planets, Juno and Vesta followed.
Eventually more and more were discovered and they became known as the asteroid belt
lying between Mars and Jupiter. Thus the asteroid belt that lies between Mars and Jupiter
partly owed their discovery to the Bode’s Law.
HOW NEPTUNE AND PLUTO DEFY THE BODE’S LAW?

After the discovery of the Ceres and the asteroids, it seems that the Bode’s Law had been verified, however, this was only until the discoveries of Neptune and Pluto.

Neptune was discovered by John Couch Adams and Urbain Le Verrier through mathematical calculations in 1840s and was first sighted by Johann Galle and Henrich d’Arrest in September 1846. Neptune is found to be 30.1AU instead of 38.8AU as predicted by Bode’s Law. This is the first time that a planet does not agree with Bode’s Law which was substantially off from the predicted value.

Bode’s Law was further dealt a blow when Pluto was discovered in 1930. Pluto was found to be at a distance of 39.6AU from the sun instead of the 78AU as predicted by Bode’s Law. The predicted value was about twice the actual distances and therefore the validity of the Bode’s Law was put under question. Pluto was almost around the distance as predicted by the Bode’s Law at where Neptune should have been.

Upon the discovery of Neptune and Pluto, both substantially off the predicted values, the law began to lose its credibility. For the next 200 years, there has been a debate in astronomy as to whether Bode’s Law is simply a coincidence or if it is really some important law that guides the solar system.
THE APPLICATIONS AND VALIDITY OF BODE’S LAW

CAN WE EXPLAIN BODE’S LAW USING GRAVITY?

We shall begin looking at some of the basic ideas of gravity and their mechanisms in the working of the solar system. Understanding gravity’s effects and applications will help us to understand Bode’s Law better. Then we will look into the underlying assumptions which allow Bode’s Law to work correctly, up to a certain extend. Finally, we will identify the factors that Bode’s law had not considered which makes the law flawed and thus seemingly inapplicable.

Law of Gravitation

In 1687, Newton wrote in the Book of Principia that masses have gravitational fields which cause bodies to attract each other with a force proportional to the product of their masses but inversely proportional to the square of the distance between them.

However, since the planets have much smaller masses than that of the Sun and are relatively well separated, the combined gravitational force between two planets is small, giving only slight effects on the planet’s orbit.

Centre of Mass

As a planet moves around its star, both the planet and the star must be exerting gravitational forces on one another. In fact, both planet and star are moving in orbits around the center of mass of the system (Fig.7 a, b, c, d), the planet’s orbit being far larger than the star’s.

In the Solar System, the planets cause the Sun to follow a small orbit around the centre of mass of the system which is the point that accelerates under the action of a force external to the system as if all the mass in the system were concentrated at that point. Thus if the external forces are negligible then the centre of mass is unaccelerated.

Jupiter is the most massive planet but it has a mass of only 0.0955% of that of the Sun, thus the centre of mass of a Jupiter-Sun system is only 740,000 km from the Sun’s centre which means that if Jupiter is the only planet in the Solar System, the Sun’s centre will move around a nearly circular orbit of radius 740,000km (not much more than the solar radius). The effects of the other planets will be to make the Sun’s motion complicated.
Circular Velocity

Circular velocity is the speed of a satellite in a circular orbit about a primary body. The circular velocity decreases with increasing distance because the pull of gravity declines with distance.

Fig. 7 A planet and its star are both moving around the center of mass of the solar system: (a) face-on view, (b) edge-on view. Note that the size of the star relative to the size of the planetary orbit has been greatly exaggerated.
Fig. 7b The centre of mass of a star-planet system does not wobble; however, both the planet and the star revolve around it.

Fig. 7c If viewed from afar, the Sun itself would wobble – primarily in response to the gravitational tugs of the two largest planets, Jupiter and Saturn.
Fig. 7d Earth and moon orbit about the centre of mass of the Earth-moon system which is located 1,630 km deep inside Earth.

Three-Body Problem

The three-body problem is to describe the motions of three bodies when they are big enough to influence one another or at least when two of them are big enough to influence the third.

Each planetary body in the solar system is affected not only by the sun but also by the other planets and other smaller bodies. The sun dominates, but the interplanetary forces cause small effects, called perturbations. A planet’s motion may be perturbed by another but the satellite of a planet may also be perturbed by the sun and the planet itself. An asteroid’s motion may also be perturbed by Jupiter. This is important as we will be able to understand why there is no planet at the location where the asteroids are even though Bode’s Law had predicted that there would be one.

Effects of perturbations are interesting and varied. The elements of a perturbed orbit change with time. The changes may be periodic (varying smoothly between limits) or secular (tending to change in a certain direction). Perturbations of satellite orbits inclined to planets’ equators typically react on a smaller time scale.

In many cases the perturbations cause only minor fluctuations in the orbital elements that look more or less random. For an asteroid whose period is $\frac{1}{2}$ of Jupiter’s period, on every second trip of the asteroid around the sun, it will find itself again next to Jupiter (positions 1 and 9), and the perturbations of the asteroid by Jupiter will repeat, this is a condition in which the two bodies are said to be commensurable (Fig 8a).
Commensurability causes a condition called resonance, the repetition of perturbations. Similarly, some resonances can have a dramatic pumping-up effect on a planetary orbit, causing a drastic change in the orbital elements, usually markedly increasing the eccentricity.

Some asteroids have been forced out of certain zones in the asteroid belt by their resonances with Jupiter, creating gaps called the Kirkwood gaps (Fig. 8b) and presumably forcing these asteroids into adjacent parts of the belt that can apparently throw asteroids clear out of the belt into orbits that can approach Mars and subsequently Earth, possibly explaining the supply of meteorites that fall on Earth.
Fig. 8b Kirkwood Gaps and Jupiter resonances. Between Mars and Jupiter are the asteroids. The asteroid belt is punctuated by gaps, known as Kirkwood Gaps. These are areas of the belt that are in orbital resonances with Jupiter, and repeated, identical gravitational perturbations have cleared these zones of asteroids.

Other types of resonances can apparently have a stabilizing effect on orbits. Rotations can also be affected by resonance. An example is Mercury (Fig. 8c).
Important applications of gravity in Bode’s Law

As we can see here, the principal force for planets is gravity, thus, the distances of the planets from the sun is also controlled by the sun in the sense that they are “bounded” by the sun and their distances are affected by the gravitational pull of the sun on them, and their gravitational resistance against the sun. Also, it is this gravitational pull of the sun that keeps the planets in their orbits.

We understand from this too that a planet’s gravity may affect another planet’s orbit too and vice versa. Thus, the distance of the planet from the sun takes into account these two factors of gravity.

It is important to note though that the Bode’s Law did not state the conditions in which to apply the law. Bode’s Law was a simple rule which explained only the distances with no relation to their gravity. However, it is understandable that planets are affected by gravity and thus we can assume that Bode’s Law made an assumption that the planets’ distances from the sun are affected by gravity, which allows them to follow Bode’s Law.

However, there is much simplicity in assuming only this as we understand from the law of gravity too that the planets are not only affected by the gravity but that their masses also do have effects on their gravity, and thus their distances in that a planet with a stronger mass will have stronger gravitational force and will thus exert more force on another planet than that planet has on it.
Thus one flaw of Bode’s Law is that even though it is plausible that an assumption of gravity can be used to make clearer the idea of Bode’s Law, it does not take into account at all the masses of the planets. The simple assumption is that a planet has to be twice the distance from that of the previous planet’s distance. However, we can assume that this is true only if the masses of all the planets were of the same size (Fig.9a). Yet if all the planets were indeed of the same size, would it not have made better sense to think that they would be spaced equally apart. Thus, we may be led to think that if the planets were to abide by Bode’s Law, they would either have to be bigger and bigger or smaller or smaller as they go further out into space. If they were to go bigger and bigger, would it not be that the distances of the planets from the sun would be very big when they are near the sun, and smaller when they are in the outer fringes? Thus, in order for Bode’s Law to be accurately applied to, it may be necessary for the planets do be bigger and bigger as they reach out into space (Fig.9b).

**Neptune**

Indeed, if we look at the planet of Neptune, it did not appear at the position where Bode’s Law had estimated it to be. Could we then attribute this to the fact that Neptune’s size and thus mass is smaller than the Jupiter and Saturn (even though its mass is slightly greater than that of Uranus), which would mean a shorter distance in essence of its size? Yet, it would be very speculative to assume this as we only understand the solar system as it is and it is unthinkable how Neptune’s size can grow such that we can actually understand whether Bode’s Law will be true.

Also, applying the three-body problem, could Neptune’s orbit, and thus its distance from the sun be affected by another two planet, possibly Uranus and Jupiter (taking only the known planets of the solar system), or it may be also affected by Saturn, since these three planets all have higher or similar masses than Neptune and can thus affect Neptune more. But it may be far-fetched to include Jupiter and Saturn in consideration of Neptune’s orbit, since they are relatively far away from Neptune (though not denying their importance in their solar system). Thus, a three-body problem may actually involve Uranus, Neptune and another planet. It should be noted that Uranus’s mass is smaller than Neptune and thus if Uranus were to be the only planet affecting (or affected by) Neptune, Neptune’s effect on Uranus would be comparatively higher than otherwise, (Fig.10) which would not explain the distance and orbit of Neptune insofar as it is dealt with only in relation to Uranus.
Fig. 9a (Left) Planets are spaced uniformly and Fig. 9b (Right) The inner planets bunch together and the outer ones spread apart.

With Pluto out of the question, because of the obvious fact that it is too small to be of any consequent, the only contender would be an undiscovered planet which has an exerting force on Neptune, together with Uranus. It is however quite impossible that these two planets may actually alter Neptune’s orbit such that its distance from the sun is so much reduced from Bode’s Law’s prediction of its distance, unless Planet X is indeed so massive that it has such a strong gravitational force on Neptune, but even so, A planet that massive will pull Neptune towards it, and thus further and further away from the sun. Thus, the existence of a Planet X can only be in the explanation of why Uranus and
Neptune seem to wobble in their orbits than in explanation of why Neptune’s distance is so much different from the estimation.

![Diagram of Neptune and Uranus orbiting the Sun](image)

Fig.10 Neptune’s gravity perturbs Uranus, at times pulling it forward faster (top) and at other times slowing it down (bottom).

Thus, a constant pattern such as this can exist but without knowing exactly the workings of the solar system and its formation, we can only make hypotheses. If we may even go as far as to say, it would be assumptive to think the planets follow a mathematical pattern such as the Bode’s Law. However, it is undeniable that the planets do follow the Bode’s Law, whether it was coincidental or if the planets do follow a certain mathematical formulation.

One mistake that we make too is the assumption that Bode’s Law is supposed to be carried out throughout the whole of the solar system. Is it possible, however, that Bode’s Law can only be applied to as far as Uranus? Is it possible that there is a certain distance whereby Bode’s Law would not be applicable or that the sun’s gravitational force may not work as equally as it did within the inner limits?
Circular velocity states that the circular velocity of a planet decreases with increasing distance because the pull of gravity declines with distance. If indeed the application of Bode’s Law was to be applied to as far as Uranus only, and consequently meaning that the gravitational pull of the sun may be weaken beyond, would it not mean then that Neptune should be further away then its predicted distance? Even if Bode’s Law held true, the understanding is that the sun exerts constant diminishing gravitational energy outwards of the solar system, which could be the reasoning of Bode’s Law (thus not taking into account the masses of the planets instead). However, it may be possible that there is a Planet X which constrains Neptune into its current orbit because it prevents Neptune from leaving its orbit. This may be possible but such a planet will need to have a weird orbit and it would need to exert a lot of energy onto Neptune. Thus, Neptune’s impossible application into the Bode’s Law may be most efficiently dealt with in terms of an explanation of the planets’ masses, which is not looked into in the law.

A lot of astronomers have questioned Pluto’s role as a planet, yet it fits itself into Bode’s Law quite perfectly (if not including Neptune). Why then would Neptune, a planet which has more probability of being one than Pluto, not fit into the law? One explanation could be that the law had not taken into account the masses of the planets and thus with a calculations of the masses and their inclusions, we may be able to draw up a different set of Bode’s Law, with the two basic underlying assumptions being that a planet’s distance from the sun is affected by the gravitational pull of the sun and that of the planets and how these gravitational forces act upon each other; and that these gravitational forces are in turn affected by their masses, a planet with a greater mass having greater gravitational force.

Yet, could there be other forces other than gravity which results in Neptune not satisfying Bode’s Law. It may be probable to look at the Kupier Belt and the gravitational forces of these that act on Neptune. Could Neptune’s mass had prevented it from going further as going further would have caused it to enter the Kupier’s Belt? It could be that if Neptune had reached further into space, it would affect the orbits of the asteroids in this belt, and thus it is prevented from extension. Yet, this would be conceptually wrong since we understand that a planet’s mass is larger and thus, if any body was to exert any force on another, it would have to be that a planet with a larger mass will be the dominant exerting force, meaning that instead of the asteroids of the Kupier Belt affecting Neptune, it should be the other way round, and if the Kupier Belt was in danger of being affected by Neptune, it would be that their orbits were pushed further into space.

Moreover, if we look at the example of Jupiter on the asteroids between Mars and Jupiter, Jupiter’s large mass during formation had caused some of the asteroids to be flung into the inner system of the solar system, resulting in collisions such as the one which caused Mercury to lose its crust (as dealt with later on). It could also be that these asteroids, flung out of their orbits because of Jupiter’s mass, caused Venus and Earth to grow larger in size because of accretion. However, we know too that Neptune does not have a mass such as that of Jupiter, and any effect that Neptune has would be far diminished, compared to that of Jupiter, and thus it is questionable as to whether Neptune could indeed have any effect on the Kupier’s Belt.
We know that the mass of all the asteroids in the Kupier Belt combined would have a mass much lower than that of Neptune, so their effect on Neptune would be far limited yet even if they have a collective mass which could be greater than that of Neptune, could their gravitational exertion on Neptune resulted it in its present orbit? Yet to assume this would be an exaggeration somehow since Neptune’s distance from the sun is far off that of the predicted distance, and for it to be so different would require another body with too large a mass. Even if the Kupier Belt had any effect on Neptune, it would be to cause slight wobbles.

If we approach this issue by looking at the orbit of Neptune and Pluto, would it be possible to come out with an idea as to why Neptune does not satisfy Bode’s Law? The orbit of Pluto crosses into that of Neptune’s for 20 years. This is the only occurrence in the solar system. Could we analyse them from this point of view? Why could Pluto not have formed an orbit similar to that of the rest of the planets? One of the reasons was of course that Pluto was a captured planet or that it used to be one of the moons of Neptune. If this was the case, could Pluto be a representative of Neptune? Since Neptune should be at the position where Pluto is, as predicted, and since it has not reached its “full potential”, could it have made use of Pluto in helping it achieve its “full potential”. This may be stretching it too far but as Pluto and Neptune are “linked” by their orbits, Neptune could have a controlling force over Pluto and could have guided its motion in a sense since it has a relatively much greater mass and could have effects on Pluto. It could be that since its full gravitational force has not been realized, Neptune thus makes use of this on Pluto by using what is left of its “unused” gravitational force to guide Pluto to its needs. However, this being speculative without any scientific basis can only be a hypothesis and does not explain Bode’s Law necessarily, though it would be useful to understand why Bode’s Law cannot be applicable from a different perspective. Ultimately Bode’s Law is unsatisfying in that it had not made clear its basic assumptions and most importantly that it had neglected the mass of a planet and its influence.

Mercury
It would be necessary too to look at the other planets and their gravitational energy in order to have a better understanding of the Bode’s Law. It is quite limited in only analysing Neptune, though not denying that it is the major problem in the law, for other planets seemingly follow the law. However, on closer observation, we notice that Mercury’s distance from the sun is also not in accordance with the law to an extent. Mercury is closer to the sun than the law predicts.

In the past, some astronomers had speculated that there could have been an extra inner planet, which they named as Vulcan, that could have affected the orbit and distance of Mercury. They had based this on the idea as a comparison with that on the understanding that since an undiscovered planet could be affecting Neptune’s movement, this could be the case for Mercury. However, what was forgotten was that Mercury is a very close planet to the sun, and indeed, the closest planet to the sun by far, and thus the sun would be almost the only other body which is capable of exerting any influence on Mercury, such that the mass of the sun could be far too strong for any other effect of any
other planet to affect Mercury. Even Venus, the closest known planet to Mercury, would not suffice to be of any use.

On first thought thus, it would be imaginable that Mercury is closer to the sun because it is nearest the sun, and being so, the sun’s attraction on it would be much stronger than on any other planet. That is also in view that Mercury is a small planet (the second smallest in the solar system) and thus, the sun’s gravitational strength on it would be very assertive, moving Mercury closer to the sun than it would be if it had a mass which may be slightly bigger, which may cause it to be relatively closer to Venus instead.

However, we know that the mass of a planet is small, and considering Mercury’s size, its mass would be slight and negligible. Thus, even if Mercury had a mass that of Venus or the Earth, its orbit should not have changed much. It is important to note that Mercury has a very thick iron core, which is relatively larger than that of any of the interior planets (Fig.10a). One possible explanation is that an asteroid could have hit Mercury during the stage of formation, which caused Mercury to lose much of its surface material and crust, depleting Mercury of a sizeable mass which could be as that of Earth and Venus. In view of this, we may be led to wonder that if Mercury had a mass of that of the two largest terrestrial planets, would it have fitted itself into Bode’s Law perfectly? This may not be as major a problem as that of Neptune’s as the variation of the distance of Mercury is not as great as that of Neptune’s.

![Fig.10a Interior structures of the terrestrial worlds.](image)

Thus to understand how Bode’s Law can work in application to the solar system, we need to understand the sizes (and masses) of the planets and why their distances are at their present positions. To understand this, we will need to look at the solar system’s formation and how it was formed that resulted in the planet’s present conditions. Through the understanding of the formation of the solar system, we can thus come up with an idea of why there is no planet at the position where the asteroids are. Also, Bode’s Law had predicted that there would be a planet at 77.2 astronomical units (AU) from the sun. We will look at the predictions of other astronomers and scientists and their analysis and get an idea if such a planet can exist. It is also useful to look at other planetary systems to see if our planetary system is “normal” and whether they follow Bode’s Law. Also, by looking at the satellite systems of the giant planets, we can also understand our solar system through their similarities and differences. With an understanding of other planetary systems and the satellite systems, we can better understand Bode’s Law applications into our solar system.
CAN BODE’S LAW BE EXPLAINED THROUGH THE FORMATION OF THE SOLAR SYSTEM?

Formation of the Solar System

Stars form from the interstellar medium (ISM) - the thin gas with a trace of dust that pervades interstellar space. The density and temperature of the ISM vary considerably from place to place. Star formation occurs in the cooler, denser parts of the ISM, because low temperatures and high densities each favour the gravitational contraction that must occur to produce a star from diffuse material. Low temperatures favour contraction because the random thermal motions of the gas that promotes spreading is then comparatively weak. High densities favour contraction because the gravitational attraction between the particles is then relatively strong. The cooler, denser parts of the ISM are called dense clouds.

The only way for a dense, cool interstellar cloud to contract from nebular to stellar dimensions is to be dense enough so that the gravitational attraction of its particles for each other is strong enough to start it contracting or to keep it contracting if it gets compressed by external forces. The complete contraction process is called by astrophysicists’ gravitational collapse because once the process has begun, the cloud usually collapses to stellar sizes (less than a millionth of its initial size) in a relatively short time. During its collapse, but prior to onset of nuclear reactions, the object is called a protostar.

In a given cloud at a given temperature, the atoms are darting about, colliding with each other. This exerts an outward thermal pressure. If gravity is inadequate to hold the cloud together, the cloud rapidly expands away into space. The cloud can collapse only if the density of the gas becomes great enough for interatom gravitational attractions to overcome the outward pressure.

As it contracts, it becomes denser towards its central regions. But the fragment is rotating, and so it is to be expected that only the material on or near the rotation axis falls fairly freely towards the centre; the infall of the remainder is moderated by its rotation. A circumstellar disc should thus form in the plane perpendicular to the axis of rotation. We have noted that such discs are thought to be the birthplace of a planetary system (Fig.11a, b).
Fig.11a A circumstellar disc should thus form in the plane perpendicular to the axis of rotation.

Fig.11b This sequence of paintings show the collapse of an interstellar cloud. In our nebula, the hot, dense central bulge became the sun, and the planets formed in the disk. The original cloud is large and diffuse, and its rotation is almost imperceptibly slow (Left). The cloud heats up and spins faster as it contracts (Middle). The result is a spinning, flattened disk, with mass concentrated near the centre (Right).

The disc temperatures are generally lower, the further we are from the Sun (Fig.12a). Therefore as the disc cools a substance condenses rather in the manner of a wave spreading inwards to some minimum distance within which the temperature is always too high. In the innermost part of the disc the temperatures are probably always too high at the dust-condensation stage for anything much less refractory than iron-nickel to condense. At greater distances less refractory dust components appear.

This slow growth is accompanied by an increasing tendency for grains to settle to the mid-plane of the disc (Fig.12b), a result of the net gravitational field and gas drag. The sheet gets thicker with increasing distance from the Sun, i.e. with increasing heliocentric distance. As the heliocentric distance increases, the mass of dust per unit
volume of the sheet must decrease. This is mainly because the dust grains are further apart, and not because they are smaller.

The concentration of the dust into a sheet leads to a greatly increased chance of a collision between two grains. Neighbouring grains tend to be in similar orbits and therefore a significant fraction of the collisions is at sufficiently low relative speeds for the grains to stick together in a process called coagulation. Coagulation is more likely when one or both grains have a fluffy structure, and it is aided when the two grains have opposite electric charges, or when they contain magnetised particles.

Fig.12a Disc temperatures are generally lower, the further we are from the Sun.

Fig.12b The sheet gets thicker with increasing heliocentric distance from the sun.

The outcome of coagulation is the gradual build-up of bodies of order 10mm across. The time required for this to happen depends on the relative speeds of grains in slightly different orbits, the lower the relative speeds, the lower the collision rate and the slower the coagulation. If the relative speeds are lower, the smaller will be the orbital speeds, and so there will be a tendency for the coagulation time to increase with increasing heliocentric distance. But the coagulation time also depends on the average spacing of the grains, the greater the spacing, the slower the coagulation. This spacing increases as the column mass or the disc decreases, and so the coagulation time is further
increased with increasing heliocentric distance, except at the ice line, here the step-up in column mass causes a significant reduction in the coagulation time in the Jupiter region. Broadly speaking, the coagulation times are of the order of thousands of years out to about 5 AU, increasing to many hundreds of thousands of years at 30 AU. The times for dust condensation and settling were shorter.

By the time bodies 10mm or so in size are appearing at 30 AU, the bodies out to about 5 AU have grown to 0.1 - 10 km across. These are called planetesimals – ‘little planets’, rocky within the ice line, icy-rocky mixtures beyond it. There are at least two means of producing planetesimals, both of which might have been significant. The first is a continuation of coagulation, promoted by the continuing thinning of the dust sheet with the corresponding increase in its density. The second is a different consequence of this density increase. At a sheet thickness of order 100 km it is possible that the gravitational attraction between the bodies constituting the sheet leads to gravitational instability, the sheet breaking up into numerous fragments, each fragment forming a planetesimal.

A planetesimal about 10km across has sufficient mass for it to exert a significant gravitational attraction on neighbouring planetesimals (Fig.13a). This increases the collision rate between planetesimals, and models show the net effect to be growth of the larger planetesimals at the expense of the smaller ones. An essential condition for net growth is that the collisions are at low speed, thus requiring neighbouring planetesimals to be in low-eccentricity, low-inclination orbits (Fig.13b, c). Such orbits could have been promoted by nebular gas drag. The acquisition by a larger body of smaller bodies is called accretion.

Fig.13a A planetesimal about 10km across has sufficient mass for it to exert a significant gravitational attraction on neighbouring planetesimals
Fig. 13b Collisions between particles in the solar nebula average out their random motions and flatten the cloud into a disk. The green arrow represents the path of a particle that originally had a tilted orbit. After the collision, its orbit lies closer to the plane of the other particles. If the particles had started on an eccentric orbit, collisions would have made its orbit more circular.

Fig. 13c A low-energy collision between planetesimals. Planetesimals in similar orbits collide with low relative energy, which allows them to coalesce into a single, larger object rather than destroy each other, as could easily happen in a high-energy collision.
Fig.13d Planetesimals gradually accrete into the terrestrial planets. Early in the accretion process, there are many moon-size planetesimals on crisscrossing orbits (left). As time passes, a few planetesimals grow larger by accreting smaller ones, while others shatter in collisions (center). Ultimately, only the largest planetesimals avoid shattering and grow into full-fledged planets (right).

As a planetesimal gets more massive its accretional power increases, and consequently there is a strong tendency for a dominant planetesimal to emerge that ultimately accretes most of the mass in its neighbourhood (Fig.13d). The outcome is runaway growth, in which the population of planetesimals in a neighbourhood evolves to yield a single massive planetesimal called an embryo that accounts for over 90% of the original planetesimal mass in the neighbourhood, plus a swarm of far less massive planetesimals, the largest being perhaps a million times less massive than the embryo. The neighbourhood of an embryo is an annular strip covering a small range of heliocentric distances, and so we get a set of embryos each at a different heliocentric distance.

Fig.14 shows the embryo mass versus distance calculated from one model, the results from which must be regarded as illustrative and not definitive - for example, the step at the ice line is smaller in some other models. In this model the orbits of the embryos within the ice line are spaced by about 0.02 AU, and the time taken for the full development of a single embryo from a swarm of planetesimals is about 0.05 Ma at I AU, and increases with heliocentric distance. These times are very uncertain, though a general increase in time with increasing heliocentric distance emerges in all models, largely because of the decrease in column mass. Another common feature is an increase in embryo spacing with increasing solar distance.
At greater heliocentric distances it also takes longer to form the embryos from planetesimals - about 0.5 Ma at 5 AU, and even longer further out. However, the time required is shorter for smaller planetesimals, and so if there is a trend whereby the greater the heliocentric distance, the smaller the planetesimals, then this would partly offset the increasing embryo formation times. In any case, many planetesimals are left over after the embryos have formed.

The embryos are so few and far between beyond the ice line that embryo collisions are unlikely. and so the slow embryo-to-final-planet phase that operates in the terrestrial region does not occur. Instead the embryos are massive enough to act as kernels that gravitationally capture large quantities of the considerable mass of gas that still dominates the solar nebula.

Hydrogen and helium together account for about 98% of the mass of the nebula, and for nearly all of the gas component. At first, the rate of capture of gas by the kernels is low, and it is estimated that it takes several times the kernel-formation time for the capture of a mass of gas equal to the initial kernel mass. At this point, the capture rate is much higher and it is rising rapidly with further mass increase there is a runaway.

As nebular gas is captured it undergoes self-compression, to yield an envelope with an average density that grows as its mass increases. As well as gas, the growing giants also capture a small but significant proportion of the surviving planetesimals, which still account for nearly 2% of the mass of the nebula. These icy - rocky bodies partially or wholly dissolve in the envelope, particularly in its later, denser stages. Icy materials
dissolve more readily than rocky materials, so some preferential accretion of rocky materials onto the kernel might occur. On the other hand, convection in the envelope opposes core growth, so the further central concentration of icy–rocky materials might be slight. The (runaway) capture of gas is halted by the T Tauri phase of the protoSun, when the high radiation and particle fluxes sweep the remaining nebular gas into interstellar space.

We can thus account for the presence of giants in the outer Solar System. However, some critical timing is seen to be essential when we look at the differences between the giants, notably the decrease in mass with increasing heliocentric distance.

If the T Tauri phase had been much later, then all the giants would now be more massive than Jupiter. After the T Tauri phase the giants must have captured further icy–rocky planetesimals. These will have added only very slightly to the total mass, but could have a significantly enriched the envelopes in icy and rocky materials.

The formation of giant embryos leaves behind large numbers of icy—rocky planetesimals, most of them less massive than the rocky planetesimals in the asteroid zone. The gravitational fields of the giant planets leads to the capture of some of these planetesimals by each of the planets and by the Sun, but these fields cause most of the planetesimals to be flung far outwards. Most of these escape from the Solar System, but a few percent do not. The effects of Uranus and Neptune are less energetic than those of Jupiter and Saturn, and so the Uranus–Neptune region is a particularly copious source of icy—rocky planetesimals that are flung out but do not escape.
How the Formation of the Solar System helps to explain the masses of the planets and their distance from the sun.

From the formation of the solar system, we understand that the masses of the planets and their distances from the sun were formed due to initial conditions of the developments of the solar system. It would be fair to conclude thus that if the formation of the interstellar cloud had formed from different conditions, with different reactions which would occur in the cloud, then a solar system with a substantially different pattern, with different masses and distances may have developed.

However, if we were to identify a flaw, it could that Bode’s Law has generalised too quickly the distances of the planets. The law had simply stated that planets were to be twice as far out as from the previous. This, as stated, would be reasonable, with an explanation that the sun’s gravity weakens as a planet is further out. However, from a comparison with the moons system of the planets and one other solar system that has 3 planets, it would seem that this may not be necessarily the case, as Neptune had proven. The planets may actually become closer instead. The probability of Bode’s Law inconsistency with these actual observations could be that Bode had overgeneralised his discovery of the law.

The solar system is divided into the inner planets, the outer planets and Pluto. Perhaps it would have been fair if Bode had instead divided his law to fit into these 3 categories, thus being able to qualify for the different sizes and masses of the planets as well as the different relative effect they have on each other. He could have perhaps thought it unnecessarily as the planets do, as it seems, move further and further out, until the occurrence of Neptune.

From the formation of the solar system, we may be led to think that since the particles in the interstellar disc were extended outwards and become bigger as it extend outwards, that the planets should also increase in size outwards, yet their sizes were concentrated towards the middle of which Jupiter is the largest planet and in the middle of the planets, and Earth is the largest interior planet and it is in the middle of the interior planets. A possible explanation had been that because of Mars proximity to Jupiter, Jupiter’s massive mass had dislocated some of the asteroids which caused them to be flung inwards into the solar system, thus colliding into Mars, causing accretion to be quite impossible. Also, because of Jupiter’s mass, the asteroids which were initially flung would have moved too fast. Even if there had been a large number of asteroids in the space around Mars, their speed would be too high to facilitate accretion.

Around 3 AU from the protoSun, there are expected to have been several embryos with huge masses. Today this region is occupied by the asteroids, with a very small combined mass, the most massive being Ceres. The asteroids in independent orbits about the Sun represent material that was left over from the planet formation process. The answer to this seeming contradiction is the effect of Jupiter, the most massive planet, which is in orbit just beyond this region. In the theory, as Jupiter grows, its gravitational field ‘stirs’ the orbits of the planetesimals and embryos, producing a range of
eccentricities and inclinations, so that most collisions occur between two bodies occupying substantially different orbits, with huge relative speed, as in Fig. 14.

The result is fragmentation and dispersal of the fragments, rather than accretion. Some of the dispersed fragments are flung into huge orbits, some are lost from the Solar System, and some are captured by the Sun and planets. The gravitational effect of nearby Jupiter removed most of the planet-forming material from the region of the asteroid belt before it could accumulate into a full-size planet. As said, the gravitational influence of Jupiter was also responsible for the circumstance that Mars is so much smaller than Earth and Venus. Only a small fraction remains around 3 AU. This population has continued to evolve, and we see the survivors today as the asteroids, with perhaps only 0.1 % of the original mass in this region. Alternatively, the asteroids may simply represent a case of planetesimal growth that was halted at an early stage, when planetesimals had reached only a maximum size of 100 – 1000 km.

Fig. 14 Jupiter’s gravitational field ‘stirs’ the orbits of the planetesimals and embryos, producing a range of eccentricities and inclinations, so that most collisions occur between two bodies occupying substantially different orbits, with huge relative speed.

The growth of Mars must also have been stunted by the stirring of the planetesimal and embryo orbits by Jupiter. Nearer the Sun, the effect of Jupiter might have been to speed up the final stages of growth of the Mercury, Venus, and the Earth, partly through the provision of material from outside the terrestrial zone, and partly by increasing the eccentricity of the embryo orbits, thus increasing their collision producing the huge relative speeds of the asteroid region.

On why the last 2 outer planets were of smaller masses as they reach outwards, an explanation could be related to the concept of the T Tauri phase. It was thought that if the
T Tauri phase had been much later, the planets would have enough time to accumulate in size from the rocky particles instead of the icy materials.

The giant planets consist of cores of rocky and icy material surrounded by huge envelopes of gas. All four of these planets have cores amounting to 10 – 15 Earth masses (Fig.15). These massive cores are apparently the key to the further attraction of gas from the solar nebula to make up the hydrogen and helium atmospheres observed today.

![Fig.15 All four of these planets have cores amounting to 10 – 15 Earth masses.](image)

For reasons not yet understood, Uranus and Neptune were not able to capture as much hydrogen and helium from the solar nebula as their more massive cousins closer to the Sun.

In explanation of why the distances of the planets extend further and further out into space, it can be looked into through an understanding of the formation of the solar system. There are 3 factors we can look into in the formation: the temperature, speed and spacing. Since the temperatures towards the centre of the sun is higher than further out, the innermost part of the disc would have a higher incidence of iron-nickel condensing, which allowed for the inner planets to form first. Also, at the innermost areas, the particles have higher speeds than the outmost areas, which allowed the particles to collide more often than in the outer areas, thus increasing opportunities for accretion and coagulation. Thirdly, the spacing of the particles from one another is closer in the innermost areas due to a higher density, The particles are further apart in the outermost areas. This contribute to the faster formation of the planets in the innermost area, and also why, with a huge abundance of particles available within each planetesimals’ area, they were able to form closer to each other.
However, for the outer planets, because there were fewer particles, they had to be separated further apart so as to accumulate enough particles for themselves to evolve as planets. Thus, from here, it seems that the distances of the planets does not seem to be based on gravity alone. It seems that the idea is that their distances depended on the number of particles available, where the planetesimals will then situate themselves in the middle of each concentration so as to evolve. It would thus seem strange if we were to attribute the distances of the planets to Bode’s Law since Bode’s Law description of the planet’s distances with respect to an underlying suggestion of their gravity would not fit in adequately with their initial formation. Bode’s Law was formulated with an analysis of the planets in their present state, without analysing their formulative state. It would be more appropriate if a law had been used to describe where the planetesimals would situate themselves instead of explaining the planets’ distance.

It has almost always been thought that Pluto is not a true member of the family of the solar system since it falls into one category of its own, not as a terrestrial planet or a giant gas planet. Indeed, its weird orbit also seemed too out-of-the-world, in comparison to even the eccentricities of Mercury, Venus and Uranus. The idea of the capture of Pluto into the solar system seems to suggest that the sun has enough gravitational reach till that distance but since Pluto is a small body, it cannot explain adequately why the distances of the giant planets are as where they are in relation to the sun’s gravitational strength. Another planet of a mass at least equivalent to that of Neptune would be able to help explain effectively Neptune’s seeming irregularity to Bode’s law. Indeed, some moons of some of the planet’s moons system were also captured. These can be seen as reflection to the processes of the solar system.
DO THE MOON SYSTEMS FOLLOW AND EXPLAIN BODE’S LAW?

With the exception of Triton, all of the massive satellites of the giants, and nearly all of their less massive satellites, orbit the planet in the same direction as the planet rotates, and in a plane tilted at only a small angle with respect to the equatorial plane of the planet. This orderly arrangement is strong evidence against separate formation and capture, and strong evidence for formation in a disc of dust and gas around each planet, called a protosatellite disc. In some ways this mimics the formation of the planets from the disc of gas and dust around the protoSun.

In the models, the protosatellite disc is composed of material attracted to the growing giant, but that fails to be incorporated into it. The material forms a cloud of gas, dust, and planetesimals. Interactions within the cloud and between the cloud and the planet cause the cloud to evolve into a thin disc in the equatorial plane of the planet, and orbiting in the same direction as the planet is rotating. Though much of the icy-rocky material in the disc is lost to interplanetary space, coagulation and accretion occur, building up the satellites. Remnant gas is lost during the T Tauri phase of the protoSun.

A few other small satellites are probably captured asteroids or icy-rocky planetesimals. Any satellite in a peculiar orbit might be a captured body, particularly if it is in a large orbit, capture being easier into large orbits than into small orbits—large orbits require the captured body to lose a smaller fraction of its orbital energy than do small orbits. A retrograde orbit (one in the opposite direction to the rotation of the planet) is also suggestive of capture.

Triton, one of the largest satellites, and by far the largest satellite of Neptune, is unique among the large satellites in that it orbits its planet in the retrograde direction. Indeed, there are very few satellites of any size that orbit in this manner, and none of the other satellites of Neptune does so. This is strong evidence that Triton was indeed captured. Initially its orbit would have been eccentric and perhaps inclined at a large angle with respect to Neptune’s equatorial plane. Once captured its gravitational interaction with Neptune would have reduced the eccentricity and inclination.

The capture of Triton would have wreaked havoc with any emerging or fully formed satellite system. The orbit of another satellite of Neptune, Nereid, might bear witness to this. Its large eccentricity could be the result of the capture of Triton. Nereid’s orbit would have remained peculiar because of its large average distance from Neptune. If Triton was captured, then its broad similarity in size and density to Pluto suggests that it might initially have been a large member of the Kupier belt.

Of the terrestrial planets only the Earth and Mars have satellites. The two tiny satellites of Mars are probably captured asteroids. The Moon is far too massive for capture to be likely. In recent years widespread support has grown for the view that the Moon is the result of an embryo at least twice the mass of Mars colliding with the nearly
formed Earth at a grazing angle. All but the core of the embryo, and some of the outer part of the Earth, is scattered along an arc, predominantly as a gas produced by vaporisation during the impact. Much of this material returns to Earth, some escapes, but a small fraction goes into orbit around the Earth, from where, in only a year or so, it forms the Moon (Fig.16a, b).

Fig.16a The Moon is the result of an embryo at least twice the mass of Mars colliding with the nearly formed Earth at a grazing angle.
Recently, there was a newspaper report that another moon, J002E2, may be orbiting Earth and it may have only just arrived. It could be passing chunk of rock captured by the Earth’s gravity. It was in a 50-day orbit around the Earth. Calculations suggests it may have been captured earlier this year. J002E2 would be Earth’s third natural satellite. Earth’s second one is called Cruithne (Fig.17). It was discovered in 1986 and it takes a convoluted horse-shoe path around the planet as it is tossed about by the gravity of the Earth and the moon.
Fig. 17 The yellow line indicates the path of Cruithne in one of its oddly shaped circuits around the solar system.

In the 1800s many theorists thought that satellite systems were merely scaled-down versions of the solar system, formed in just the same way and perhaps holding the key to planet formation. Indeed, Fig. 18 gives considerable support to the idea that similar underlying processes may be involved.

Fig. 18 Many theorists thought that satellite systems were merely scaled-down versions of the solar system, formed in just the same way and perhaps holding the key to planet formation.
Fig. 19 The distances of the moons from the giant planets.
Inferences which can be made of the Solar System from the moon systems of the Jovian planets

From the analysis of the third moon of Earth and Triton, we know that it is possible that moons can be captured into the moon system of a planet, given enough gravitational strength and also, if the mass of the captured object is relatively small enough for capture. This can be made to suggest that Pluto could also have been a captured planet or as some astronomers claim, to be a moon of Neptune which escaped. This may not explain the inconclusive nature of Bode’s Law since Pluto supposedly abides by Bode’s Law. But that Pluto is sometimes not recognized as a planet makes it quite inapplicable to the law at times.

An analysis of the moon systems and the solar system show that there are irregularities. The moons are supposed to have form in a similar manner to that of the solar system yet the distances of the moons from their planets do not seem to follow that of the planets. Since the moon systems are said to be similar to that of the solar system, they would thus have to abide by Bode’s Law too, yet, they do not. The distances of the planets are irregular. There seem to be more complexities at work than distances.

However, the first few moons of the planets seem to follow Bode’s Law pretty alright, suggesting that Bode’s Law does apply to systems of moons or planets, but that they are only applicable to the first few moons suggest that outside a certain distance, or outside a certain gravitational sphere of a planet, Bode’s Law may no longer apply. The question then is how much Bode’s Law is applicable. Where should we draw the line? Already, we have suggested that Bode’s Law could be applied from after Mercury onwards, since the sun’s gravitational pull on Mercury or no first planets will be so strong as to pull them into the spatial influence of the sun, from their original assumed orbits. This first break may now be added on by another.

As shown by the systems of the moons, the distances do not double by each moon but some actually become nearer. This can be an explanation for Neptune as well, on why Neptune would seem to become closer. As stated, Neptune could be nearer because of its smaller mass, compared to Jupiter and Saturn. What it seems to suggest here is that the gravitational pull of a planet or a star may not have an even stretch such that the planets do not get spaced evenly based on the gravity, but it could be probable that at places where the gravitational pull of the planet is stronger, the moon may actually be drawn closer. However, we do not have enough planets in the solar system to test out this hypothesis.

Another idea then could be that there is an interplay between the masses of the planets and the gravity of the sun.

It would seem quite impossible to accurately find a law which would suit the planets or the moons sufficiently. The different gravitational strength of the planets and the different masses would make for harder generalisations. What we could formulate
instead of Bodes’ Law, could be to formulate a mathematical relationship of the mass of a body and the effect of its gravitation pull on that of another body orbiting it. A generalisation of a number of bodies orbiting a single body may be hard to qualify due to the differences. Thus, if Bode’s Law were to even be perfect, it would only be based on our solar system and the accuracy of Bode’s Law would only be for our solar system. Other systems which may fit into it but may have slight alternations, depending on changes made to their masses and gravity.

Many small planetary satellites are likely captured bodies that did not form along with the parent planet in the early solar system. To apply Bode’s Law in this instance, it would be advantageous to analyse only the larger moons of the planets. However, even large satellites may not have formed directly along with the parent planet or may have their orbits changed drastically during early solar system evolution. Jupiter is the most obvious planet to analyse since its four large Galilean satellites stand apart from Jupiter’s other much smaller orbiting bodies. Uranus also has five satellites that stand out from its other smaller satellites. However, both Saturn and Neptune each have only one large satellite (Fig.20a, b).

Bode’s Law seem to be applicable to the large moon systems of these two planets, though not perfectly (Fig.21). Other astronomers may argue otherwise. However, it is not enough to simply apply Bode’s Law to only the larger moons of the planets. It is only fair to apply the law to all the planets which had formed together with the planet during the formation of the solar system. By excluding them, we cannot have a proper understanding of Bode’s Law. Also, to exclude the captured moons also deprive Bode’s Law of some understanding too. The captured moons would have to be affected by the planet’s gravity by some way, though differently from those which formed together with the planet. Perhaps Bode’s Law could have another component, which is to divide the law which is applicable both to natural bodies of the solar system and does which are captured.
Fig. 20a Sizes of the moons compared with the Earth
Fig. 20b The larger moons of the Jovian planets, with sizes shown to scale. Mercury, the Moon and Pluto are included for comparison.

**Bode’s Law works for moons around planets**

![Bode's Law Graph]

Fig. 21 Bode’s Law works for Uranus’s moons
PLANET X AND ITS INVOLVEMENT WITH BODE’S LAW

Long-term calculations of the stability of orbits in the outer solar system have shown that planetesimals have a great chance to survive at distances greater than 33 to 50 AU against becoming Neptune crossers and short-period comets, or from being ejected from the solar system over its life-time. Surveys aimed to search for Kuiper-belt bodies discovered 24 of 100 – 200 km-size bodies. Statistical extrapolation based on this survey gave the total estimation of the number of bodies up to 35,000. Space Hubble Telescope found 29 objects with radii ranging from 5 to 10 km in the orbits. A total of 0.02 Earth masses of 5 to 10 km comets are confined in this region of the Kuiper belt. These observations revealed that the total mass of the Kuiper-belt objects is much less than the mass of the size of that of a possible planet.

It has been discussed recently that the Kuiper belt was more massive in the early history of the solar system. The Kuiper belt is currently eroding away due to collisions and remarkable fraction of the mass has been lost. Also, it was suggested that the hypothetical early outward migration of Neptune would cause its mean motion resonances to sweep through the region of the inner Kuiper belt (heliocentric distances < 41 AU thereby sweeping most objects into the mean motion resonances.

Computer simulations of Planet X to explain Triton’s, Pluto’s and Charon’s orbits

In 1976, computer simulations of planets of different sizes intruding into the Neptunian system at different distances, speeds, and angles. Computations suggest that a planet could have a mass of two to five times that of Earth, be in a highly inclined and elliptical orbit 50 to 100 astronomical units from the Sun with an orbital period of about 800 years. This planet could have reversed the motion of Triton, warped the orbit of Nereid, and cast the moon Pluto out of the Neptune family onto a planetary orbit of its own. Charon could be an additional satellite of Neptune expelled along with Pluto so that they captured one another; or, alternatively, the intensity of the intruding planet’s tidal strain could have caused Pluto to break in two, with Charon as the smaller fragment. Charon might even be a former satellite of the Planet X, that was transferred to Pluto’s control.

Some astronomers think that Planet X should be a frozen methane, ammonia, and water world somewhat like Uranus and Neptune but of lower mass – perhaps two to five times the mass of Earth (Fig.22). To remain so far unseen, Planet 10 must be nearing aphelion on its highly elliptical orbit, so that it is near minimum brightness. Still, for an icy body its size, this tenth planet should be some six times brighter than Pluto but could be dark in color, reflecting light so poorly that it would be no brighter than 16th or 17th magnitude – fainter than Pluto at its discovery.
Can Planet X explain the extinction events of Earth?

The extinction that claimed the dinosaurs and so much of life 65 million years ago was only one of the many extinctions that the Earth has experienced in the last 250 million years. Large scale obliterations of life on our planet have occurred approximately every 28 million years. Researchers immediately recognised that asteroid collisions with Earth are too infrequent to cause mass extinctions every 28 million years and that there was no mechanism to get asteroids to hit the Earth with regularity. But comets could, if something was disturbing them. They proposed that the periodic mass extinctions were triggered by an unseen star within our solar system, bound to our Sun by gravity, just as the planets are. After all, a majority of the stars in the universe are binary or multiple star systems.
The sun’s companion had to be a star of low mass and hence low brightness to remain unidentified when it was by far the closest star to the Sun. This star had an elliptical orbit that carried it in as close as 0.5 light-year (about 30000 astronomical units) to the Sun and then out to a distance of 2.4 light-years (more than halfway to the nearest star) in a period of 28 million years.

In the course of its travels, this star would at perihelion careen through the densest portion of the Oort Cloud of comets, accelerating millions of them out of the solar system but decelerating millions of others, forcing them to fall in closer to the Sun so that some hit the Earth with momentous consequences for the evolution of life.

There is, however, no consensus among paleontologists and geologists about the causes of mass extinctions and whether mass extinctions and cratering episodes occur at regular intervals. The controversy continues at a lively pace into the present.

Were mass extinctions caused by comet showers triggered by a companion star for our Sun? One of the early attacks on this hypothesis came from analyses of the stability of a companion star on such an elliptical orbit that carried it more than half the distance to the nearest star. It was doubtful that it could survive in such an orbit from the beginning of the solar system because the Sun’s gravity at that distance is very weak. Stars and clouds of interstellar gas and dust passing near the solar system would have disrupted the regularity of the twin star’s period and, rather quickly, would have torn it away from the Sun.

Since there is a problem of a companion star’s orbital stability, this companion could be a planet instead. Instead of Sun 2 scattering comets with a plunge from the fringes into the densest regions of the Oort Cloud, a Planet X could disrupt comet orbits by scratching the innermost portion of the Oort Cloud from inside, in particular a disk of comets thought to lie in the plane of the solar system with orbits not far beyond Neptune and Pluto (Fig.23).

Fig.23 Planet X could disrupt comet orbits by scratching the innermost portion of the Oort Cloud from inside, in particular a disk of comets thought to lie in the plane of the solar system with orbits not far beyond Neptune and Pluto.
Yet Pluto takes only 248 years to orbit the Sun. How could a planet not too far beyond Pluto take 28 million years to complete a circuit? According to the law of gravity, it couldn’t. Even a planet several times the distance of Pluto cannot revolve around the Sun that slowly. But the entire orbit of a planet will revolve due to the gravity of neighboring planets, and this precession can proceed very slowly.

Visualize Planet X on an elliptical orbit perpendicular to the plane of the solar system. If the plane of the solar system is a table top, then the orbit of Planet X is standing on its head. We see the table top at eye level edge on and the orbit of Planet X face on. In that headstand position, Planet X does not disturb any disk of ancient comets that lie in the plane of the solar system not far beyond Neptune and Pluto. But eventually it will disturb the comets in the disk because the gravity of the outer planets causes the entire orbit of Planet X to precess (Fig.24). The tilt of the orbit will stay inclined to the plane of the solar system by, say, 90 degrees, but the orbit will gradually pivot around like a very fat hour hand on a clock. It will pivot through the plane of the table and down, then back up through the plane of the table and back to its initial headstand position. In a multiple-exposure photograph, the ellipses of Planet X’s orbit would form a rosette.

In the course of that precession, the outer portion of the orbit (the end of the fat hour hand) would slide through the comet disk only at the nine and three o’clock positions, sending swarms of comets in all directions only during those two relatively brief periods when the planet’s aphelion is in or near the plane of the comet disk. If the orbit of Planet X completes one precession cycle in 56 million years, it will cause two periods of comet showers for the inner solar system – one every 28 million years.
The size of the orbit of a planet with an orbital precession of 56 million years could have an average distance of this planet from the Sun which is about 80 astronomical units (about twice the distance of Pluto). Its 700-year orbit would be substantially inclined (perhaps 45 degrees) and elliptical (slightly more than Pluto’s). It would range far enough to chop through the comet disk when precession placed it in the proper position, but it was also close enough to the Sun to be detectable. The orbit of this Planet X would be stable.

This hypothetical planet was practically identical to the one done through computations but they explain completely different set of problems. The computer simulations were intended to solve the irregularities in the positions of Uranus and Neptune, the strange orbits of Neptune’s satellites, and the peculiar orbit of Pluto. Yet the two planets were essentially the same.

Some astronomers think that even with a mass of five Earths, Planet X could not cause comet showers, a possible cause of mass extinctions on Earth. Pointing to other studies, they concluded that the purported inconsistencies in the motions of Uranus and Neptune do not indicate a tenth planet, that a planet of equal or greater mass than Earth would be so bright that it could hardly have escaped previous discovery, and that a planet larger than Earth would be unlikely to have formed beyond Pluto. Other astronomers counter that their by saying that a Planet X with five Earth masses could cause comet showers, that a planet with low reflectivity or one located deep in the southern sky could have escaped detection, and that the study that indicated an Earth-size planet could not form beyond Pluto also cannot account for the existence of Uranus and Neptune.

**Other Calculations of Planet X**

**Calculations of Jet Propulsion Laboratory**

The Jet Propulsion Laboratory had calculated highly accurate orbits for Uranus and Neptune by including only observations from 1910 to the present and by excluding earlier observations. An unseen outer planet could have been disturbing Uranus and Neptune before and during the nineteenth century but the planet could now be too far away for its gravitational effects to be noticeable on the planets.
Planet X must then have a highly elliptical orbit that carries it far enough away to be undetectable now but periodically brings it close enough to leave its disturbing signature on the paths of the outer planets, with an orbital period at 700 to 1,000 years. The planet must have a mass of about five Earths to create the planet perturbations. This Planet X is now far away, nearing aphelion, where its gravitational effects are unnoticeable. Its perturbations on the outer planets won’t be detected again until about the year 2600.

**Calculations of Powell**

Powell’s calculations showed Planet X with 2.9 Earth masses at a distance from the Sun of 60.8 astronomical units, giving a period of revolution of 494 years. He was intrigued that this number was approximately twice the period of Pluto and three times the period of Neptune – suggesting that the planet could have an orbit stabilized by mutual gravitational resonance with its nearest neighbours despite their vast separation.

His calculations for a tenth planet also provided an orbit inclined by only 8.3 degrees (less than Pluto’s) and only slightly eccentric (but not firm enough to warrant a number). The orbital resonance of Planet X and the unspectacular nature of its derived orbit gave him confidence that this unseen planet was real.

Later, he calculated a Planet X which was now smaller, closer, and brighter. His new solution predicted a planet with 87 percent the mass of Earth. With a mean distance of 39.8 astronomical units, a period of 251 years, and an eccentricity of 0.26, Powell’s planet would follow almost exactly the path of Pluto. Like Pluto, it would even spend part of its circuit inside the orbit of Neptune. Powell is fascinated by the similarities between his new prediction and the final predictions for a ninth planet by Lowell and Pickering.

**Calculations of Lowell and Pickering**

Pickering’s 1908 prediction for Planet O gave it a distance of 51.9 astronomical units, a period of 373.5 years, and a mass twice that of the Earth. Lowell, in 1908, thought that it laid 47.5 astronomical units from the sun, had an orbital period of 327 years, and a mass of two-fifths of Neptune’s. These calculations were done before Pluto was discovered.

Most concepts of Planet 10 envision a body between the size of Earth and Uranus at a distance of 60 to 250 astronomical units. To have avoided detection, the tenth planet must be distant and faint, most likely in a highly inclined orbit so that it is far from the plane of the solar system where the most intensive surveys have been conducted.

Problems in fitting Uranus and Neptune to orbits may be due to the way the data were taken and that too much reliance has been placed on the accuracy of older prediscovery observations. Neptune has not yet completed one revolution around the sun since it was discovered and Uranus is only halfway through its third. It is too early to rule out errors of observation or data transcription as an explanation for the disparities. The
orbits are not yet known with enough precision to permit the conclusions that the gravity of an undiscovered planet is disturbing them.

![Orbits of Planets Diagram](image)

**Fig.25 Another predicted orbit of Planet X**

**Implications of the Calculations of Planet X and Bode’s Law**

According to Bode’s Law, the 10th planet will be at a distance of 77.2 A.U. from the sun, the 11th planet will be at 154.0 A.U. and the 12th planet will be at 307.6 A.U. However, none of the calculations seem to suggest this. However, it would be very difficult to speculate on the distance of a planet until it is found. So, as it stands, the predictions of Bode’s Law on the 10th planet puts it at 77.2 A.U. but astronomers are free to believe otherwise, since a few flaws of the law have already been pointed out.

Moreover, Neptune has already deviated from the law, showing thus that a 10th planet need not follow Bode’s Law if Bode’s Law is faulty. Possibly, with the discovery of a 10th planet, our understanding of Bode’s Law could be enhanced. If the distance of this planet were to be at 77.2 A.U., it may actually suggest that Neptune’s orbit is the problematic source to Bode’s Law instead of the other way round. However, if the 10th planet is not at where it is predicted to be, there could be two possibilities. It could be that either Bode’s Law is not simply useless as a law or that after Uranus, Bode’s Law needs to be altered to tailor for the needs of planets after that distance.

A few astronomers had predicted that the orbit of Planet X be inclined such that it rotates around the poles of the Sun. This seems highly improbable since the gravitational pull of the Sun lies around its equatorial plane. It is also in the formation of the solar system that the planets formed around this plane. It would seem absurd that Planet X would actually rotate around the poles. Yet, if Planet X rotates around the equator of the sun, it would be in the midst of the Kupier belt, which would cause it to be constantly massacred by the asteroids. Already, a suggestion had been made that Neptune was
pushed into its orbit towards the sun to avoid collision with the Kuiper Belt. It is thus probable that for Planet X to escape this incident, it was made to rotate around the poles but because the gravitational pull of the sun and the planets will get it back into a plane around the equator, the planet, as stated by some astronomers, would occasionally cause comets to be dislocated.
Direct detection of planets is beyond present instrumental capabilities, because a planet is a very faint object with a very small angular separation from a far brighter object – its star. Therefore, up to now, successful techniques have been indirect, in that astronomers have detected planets through their influence on the star they orbit, or on any disc of gas and dust around the star. Generally, massive unseen companions to stars are easier to detect than less massive companions, even if none of them are luminous. In our Solar System the planets cause the Sun to follow a small (complicated) orbit around the centre of mass of the system. Therefore, if small orbital motion of other stars can be detected we can infer the presence of one or more planets even if they are too faint to be seen.

Though our knowledge of other planetary systems is sparse, it is beginning to give us some guidance about the origin of our own system. Many scientists have concluded that we will never be able to gain a full understanding of our own system without having some additional examples. We would begin by examining several different planetary systems to see what common properties they exhibited. These properties would help us determine which aspects of our own system are truly fundamental, requiring a common theory for their explanation, and which are random, the result of chance events. Do all systems consist of small planets close to their star and massive planets farther out? Do the planets always revolve around the star in the same direction? Are comets and asteroids always “left behind” when solar systems form?

Nature’s preference for forming systems of small bodies in orbit around more massive ones is well illustrated by our own system’s giant planets with their satellites and
rings. On the other hand, the excess material may have been lost during the early stages of the star’s formation and the star may truly be a single object in space.

Nevertheless, recent results suggest that our understanding of solar system formation may not be as good as we have thought. In 1995 the patient measurement of stellar radial velocities finally paid off with the discovery of the first “real” planet outside our own solar system. This planet orbits a faint nearby star called 51 Peg, which is very similar to the Sun in mass, luminosity, temperature, and rotation rate—quite different from the pulsars. The planet has an orbital period of 4.22 days, placing it at a distance from the star of only 1/20 of an AU, about five times closer than the distance of Mercury from the Sun. The mass of the planet, inferred from the observed radial velocity variations of the star, is 0.45 times the mass of Jupiter. The planet is therefore what we would call a giant planet, intermediate in mass between Jupiter and Saturn, but located in a very unjovian orbit. (It is the closeness of the planet to its star and the short period of revolution that made it relatively easy to discover; the same techniques would not have detected this planet in jovian orbit.) In January 1996, two larger planets were found (3 and 6 times the mass of Jupiter). One is in a circular Mars-size orbit around the star 47 UMa, the other in an eccentric Mercury-size orbit around 70 Vir. Based on these discoveries, it seems to suggest that giant planets will be found in such short-period orbits for something like 5% of the nearby solar-type stars. These results demonstrate that other planetary systems may be common, but they are not necessarily constructed like our own.

How the differences of other solar systems seem to debunk Bode’s Law as useful in application

Though Bode’s Law seems to fit into the Solar System almost perfectly, there is now another basic underlying assumption to it, other than the initial idea of gravity, that the initial formation of any solar system in the universe would have to have the same composition and structure of that of ours so as to be able to follow Bode’s Law. This is not to conclude that Bode’s Law is deemed useless but Bode’s Law had been formed only with an adequate knowledge of one solar system. Without an adequate understanding of the other solar systems, since none, with a substantial number of planets could be found and studied effectively for a comparison, we cannot come up with proper formulae. Bode’s Law would seem to be as good as it gets.

One mistake to this is that there has been no other comparison to back the law up, or even to prove the law incomplete. In the past, other planetary systems had not been thought to be inexistence but with present technological advances and the idea of that possibility, Bode’s law has thus been seen redundant. But the truth is there need to possibly be changes made so as to fit into the law a knowledge of gravity, masses and the different categories which it could be analysed in.

From an analysis of the three inner planets with a comparison of three planets of another solar system, PSR B1257+12, we see that here is a similarity between these two solar systems in that the orbital distances of the three pulsar planets when doubled, would
nearly line up with the positions of Mercury, Venus and Earth around the sun. This suggests that pulsar planets, and perhaps solar systems in general, obey the Bode’s Law of planetary distances (Fig.26).

Fig.26 The distances of the sun’s three innermost planets (top) resemble those of the pulsar planets (middle); if the pulsar planets’ distances are doubled (bottom), they line up almost perfectly with Mercury, Venus and Earth.

However, there are two ways we can look at this. From the diagram, it seems that just by comparing the first 3 planets, they do not seem to follow Bode’s Law, since their distance seems to become closer but Bode’s Law had determined it to be otherwise. From our own solar system, we would know then that the other planets would fit into the law. Moreover, it would be in this case here that mercury does not follow the law, since it is nearer to the sun than its would be predicted position. From the solar system, PSR B1257+12, the lack of planets makes it difficult for us to make an adequate comparison. We cannot know how the gravitational pull of the star would affect the distances of the planets, if there were any.
Moreover, as mentioned, the mass of a planet should be taken into account to have a full understanding of how gravity and mass interplay to produce the distances. The pulsar planets’ mass resemble those of Mercury, Venus, and Earth. In both systems, the innermost world is a featherweight. Mercury has 0.055 Earth mass, and the first pulsar planet is 0.02. The next two pulsar planets are more massive, like Venus and Earth. In our solar system, the third planet, Earth, is slightly more massive than the second, Venus; in the pulsar system, the second planet is the one slightly more massive. Both of these pulsar planets are more massive than Venus and Earth, though having around four Earth masses each.

It seems that the patterns of the masses of these pulsar planets are similar to ours, yet they are not enough to explain Bode’s Law. We still cannot understand why the first planet would not seem to adhere to Bode’s Law. The reasoning can only be that Bode’s Law is inadequate in explanation for the first planet. In the solar system, PSR B1257+12, the first planet is significantly smaller than the second and third planet, which would imply that the gravitational pull of the sun on it would be comparatively much stronger than it would have on Mercury. Thus, we are still shown why the first planet will always be nearer than its predicted position (with a comparison of two solar systems).

Another conclusion we can make thus of this is that Bode’s Law may only be achievable from a certain distance onwards to a certain distance, meaning, since the first planets of both solar systems seem to be closer, it can be explained by saying that if Bode’s Law were to be applied from a further distance onwards (thus a distance after Mercury, such that the gravity of the sun would not be as strong and would be more even), then the planets’ distance would fit perfectly into the law. Thus, this would be an example of how we can break Bode’s Law up so that different parts of the law need to be modified so as to have a better fit.
However, we can only do justice to Bode’s Law if we compare it with other planetary systems too. By comparing it with 55 Cancri System (Fig.27) and HD168443 (Fig.28), we can have a better understanding of Bode’s Law. The similarity of 55 Cancri with our solar system is that at the distance where Jupiter is, there is also a planet in that system. In HD168443, there are two planets located at the distance between that of Mars and Jupiter. It is necessary to note that these planets which have been found are of sizes which are about the masses of the giant planets or are at least a few times the mass of the Earth (in order for them to be discovered). Thus, there may be smaller planets in these planetary systems which have not been discovered. To have a good understanding of Bode’s Law, it would be ideal if we can have all the planets of a planetary system. In our solar system, it is not a certainty that all the planets have been discovered. Moreover, the definition of a planet is not too clear (as to whether Pluto should be classified as a planet or not or if there are other smaller bodies which can be classified as planets too). Thus, to apply Bode’s Law with our limited knowledge and understanding will not suffice to be enough. Ultimately, we will be able to fit Bode’s Law into a planetary system adequately or even to formulate a fully adequate law only when we have a proper understanding of how a planetary system works and the mathematical formulations and mechanisms that “rule” the systems.

Moreover, to understand Bode’s Law through other solar systems, it would be necessary for a system to have at least 3 planets so as to have a comparison but as yet, only a very few planetary systems have been discovered which have at least 3 planets. Also, these systems cannot give us a clear understanding of Bode’s Law because we do not understand their structure and composition. Bode’s Law have been formulated based
on our solar system. If we do want to have a law which can be applied to all solar systems, it may have to be re-looked into, after examining at least some planetary systems qualitatively.

![Fig.28 The planetary system of HD168443 compared to our solar system.](image)

In a number of the planetary systems where planets were found, these planets were approximately of a mass like that of Jupiter, and most of them were found very near to their suns, within a distance of Mercury’s orbit. There are four possibilities why gas giant planets form so close to their suns when we have seen from our solar system, how through the formations of the solar system, that is unlikely.

1. The gas giant formed in the outer limits during the planet formation and then migrated inwards.
2. The gas giants formed in its present positions.
3. It is a giant terrestrial planet.
4. It was originally a brown dwarf or a companion of the star which has been driven, in some way, to loss its mass.

If the gas giants did indeed formed in the outer limits and migrated in, this poses a serious problem to Bode’s Law. If planets do migrate into the solar system, that would imply that the planets of our solar system may also migrate into the solar system as time goes by. However, that is assuming that our solar system works the same way as that of the other solar systems. However, there is no evidence to prove that this is so. Yet, even if the planets were to migrate inwards, they may still adhere to Bode’s Law if they migrated inwards constantly.

A question to ask would be that if the planets were to migrate inwards, would they get swallowed up by their suns in future? The problem is to understand how the planet stops, before it plunges into its sun. This had been discussed by astronomers by analyzing a planetary system’s formation. It could be that a natural gap prevents the star during formation from dragging the planet in or that tides raised on the planet by its sun halt the advance of the planet. Some astronomers had suggested that not all planets will stop; instead they will plunge into its sun. This could mean that the planets were all in a constant process of forming and spiraling to destruction. Thus only the last to form will survive when migratory forces are removed.
Bode’s Law had not taken into consideration these factors. Though not immediately a concern for planets in our solar system since they do not appear to be as the forms of other planetary systems, yet for Bode’s Law to sufficiently be a law meant for the planets, it would have to consider planetary migration as well. However, as yet, astronomers are not too sure as to whether planets could have migrated into the inner parts of the solar system. Thus, it is still a hypothesis. What could be implied then could be that our solar system may not be a representative planetary system, and thus Bode’s Law may be useless as a law for planetary distance unless the system has similar traits to ours. We could counter this claim by saying that due to these discovered planetary systems’ distance from us, we could only discover the giant planets, thus the law seems to be inapplicable. However, even if we discover the smaller planets, Bode’s Law does not seem to take into consideration the sizes and masses of the planets in relation to their distances.

Bode’s Law had assumed our solar system as being representative as a planetary system, and thus our system’s formation will be seen as characteristic of most planetary systems. However, as the second point had pointed out, if gas giants had formed in the inner regions, this would be vastly different with what our solar system formation advocates. It was hypothesized that the gas giants could form in the inner regions of the solar system. Studies of nearby star-forming regions are beginning to show that protoplanetary discs may contain very different amounts of material from the few tenths of a solar mass often assumed.

Thus, if our solar systems are discovered, Bode’s Law would have to be revisited and reconsidered. As it is, it seems to fit into our solar system fairly representatively, with exceptions which we can try to explain away. Alternatively, we can conclude that Bode’s Law is not comprehensive enough and too general. The solar system could be more complex than Bode had envisaged it to be. There may be a need for several subsets of Bode’s Law so as to properly define the distances of the planets as they are in their positions. Also, a complete law to explain the distances would take into account their masses, their formation and their composition.
CONTRACTION OF SPACE

According to the theoretical study of physics—Electrodynamics of Energy and Matter, there is contraction of space at the solar system. The reason why the Neptune and Pluto are out of positions according to the Bode’s law is because of the supposition that space at the solar system would be isotropic. That is, space is homogeneous in all directions.

But the study on the Electrodynamics of Energy and Matter suggest the problem of Bode’s law with respect to Pluto and Neptune can be explained.

Fig. 29 A diagram and a graphical representation of the contraction of space.

From Fig. 29, we can see that from the contraction of space, the light is bent thus the position of Pluto is brought much closer than the actual position. If this theory is correct, then Bode’s law prediction will therefore correctly predict the distance of Neptune and Pluto.
RECENT DISCOVERIES

Observations over the last decade have revealed the existence of a large number of bodies orbiting the Sun beyond Neptune. Known as the Kuiper-belt objects (KBOs), they are believed to be formed in the outer reaches of the protoplanetary disk around the young Sun, and have been little altered since then. They are probably the source of short-period comets. The KBOs are, however, difficult objects to study because of their distance from earth.

In addition to the planets and their moons, the Sun has two belts and a clouds of tiny bodies. The innermost is the familiar Asteroid Belt that lies between Mars and Jupiter for the most part. It is made up of many irregular bodies and a few small worlds all composed largely of iron and rock like the inner planets. The next out is the Kuiper Belt composed of comets and comet like small worlds all composed of icy materials. The outermost region far from the Sun contains a second halo of comets called the Oort Cloud. The Asteroid Belt was discovered in 1801 when its largest member (Ceres) was spotted for the first time. The Oort cloud is too distant to see with telescopes but we know it is there from the frequent long period comets which can be backtracked to this region.

Pluto is a typical KBO. It is the largest such object discovered to date, but its satellite Charon and two other large KBOs (Ixion and Varuna) rival it in size. Many KBOs have been pulled into rings surrounding the solar system with large gaps between the rings. The source of these gaps is tidal forces created by Neptune. Quaoar and other Kuiper belt objects are believed to be leftover remnants from when icy fragments of matter coalesced to form the outer planets billions of years ago.

Recently, a massive object half the size of Pluto – a distant, dark reddish, icy, sphere called Quaoar (Fig.30), is the largest body discovered in the solar system since Pluto was spotted in 1930. It is about 6.5 km, or 43.45 A.U., from the sun. It is estimated to be 1,287 km across, the larger than the size of Pluto’s moon, Charon, which is 1,200 km in diameters. Superimposed on America, it would blot out several Midwestern states (Fig.31). It takes 288 years to orbit the sun. But because Pluto’s 248-year orbit around the sun is not circular, parts of it extend beyond the orbit of Quaoar (Fig.32). It completes one rotation every nine hours. Its discoverers said Quaoar is too small to be a planet, although they note it is quite planet-like in its behavior and acts far more like a planet than Pluto does. Other Plutonian peers found in recent years include Varuna, Ixion, an object estimated to be nearly as large as Quaoar, and Rhadamantus, a smaller object. Varuna was in 2000 and is 560-mile-across, about 40 percent as big as Pluto (Fig.33, 34a, b). Varuna was the record-holder for size in the far-out belt until now. Ixion was found in 2001, is estimated to be 1,200 kilometers, nearly the same size as Quaoar. Quaoar and other Kuiper belt objects are believed to be leftover remnants from when icy fragments of matter coalesced to form the outer planets billions of years ago.
Fig. 30 An artist's conception shows the newly discovered world Quaoar, which orbits beyond Pluto. Astronomers consider Quaoar to be a
"Kuiper Belt object" rather than a planet, and they say its discovery may weaken the case for considering Pluto a planet.

Fig.31 One-tenth the size of Earth, Quaoar, the biggest object found in the solar system since Pluto was discovered in 1930, is superimposed over a satellite view of North America in this artist’s image.

Fig.32 The orbit of Quaoar
Implications of the discovery of these new bodies on Bode’s Law

These findings immediately revived a debate among astronomers about whether Pluto should be stripped of its designation as a planet, and is forcing astronomers to reconsider even basic notions about the solar system as a whole, some think that Pluto should never have been labeled as a planet. The discovery of Quaoar also adds support to the argument Pluto itself is a Kuiper belt object rather than a planet, according to the researchers. Pluto is believed to be composed of rock and ice like other Kuiper belt objects, which is quite different to Pluto's neighboring giant gas planets Neptune and Uranus. Pluto also orbits the sun outside the orbital plane of all the other planets, like Kuiper belt objects. Pluto is closer to the Kupier Belt than to other members of the solar system, its orbit is not circular, and it is not on the same plane as the other planets. Moreover, Quaoar’s orbit is almost as circular as Earth’s and is close to the plane in which most of the other planets orbit, the researchers say. Pluto’s odd orbit is elongated and also inclined about 17 degrees to the main solar system plane. Planets are either rocky bodies with iron cores or large gas giants composed mainly of hydrogen and helium like the Sun. Pluto is unlike either type of planet. Pluto is a typical Kuiper belt object.
We are thus now faced with the dilemma of defining what a planet is. A few years ago the International Astronomical Union reclassified Pluto as "minor planet #1589". Today Pluto is officially both a major and a minor planet. One theory of a planet is of anything which is big enough to become round by gravitational forces. This would mean that anything more than 296 km across would be a planet, including Quaoar.

The first thought which comes to mind about this newly discovered “planet” would be whether it would follow Bode’s Law. As Bode’s Law had stated, a planet after Pluto should be at 77.2 A.U. but Quaoar is 43.45 A.U. away from the sun. However, this discovery also led astronomers to think that Pluto may not be a planet, as most astronomers agree. Thus, it would seem that Bode’s Law should only be applied to as far as Neptune is, it being the last planet. It would be impossible to explain why Neptune’s distance from the sun is different from that of Bode’s predicted distance, using Pluto. One idea could be that the Kupier belt could indeed have a mass which is so high that it prevents Neptune from extending outwards and traps Neptune in an orbit within the Kupier Belt. Moreover, Neptune lies at the edge of this belt. The mass of Quaoar is...
bigger than that of the masses of the known asteroids combined. Thus, even though Jupiter could exert its gravitational strength on the asteroids, being it that the mass of one single body is already representative of the asteroid belt, it could be that the combined mass of the Kuiper Belt may indeed have an effect on Neptune and thus keeping it in its orbit.

The orbit of Quaoar is more consistent with that of the planets in solar system. It is suggested that Quaoar is more like a planet than Pluto is. If Quaoar is indeed a planet, it would seem to suggest an even more weird irregularity of Bode’s Law since this “planet” would be also in an incorrect position as Bode’s Law had stipulated. One point that can be offered here is that there may indeed be a law which can be formulated (or the planets could have formed within a certain mathematical pattern) but as yet, we have limited knowledge of the solar system. Thus, even if there is a rule, there are a few issues we need to make clear. We need to have a proper clear definition of a “planet” so that we can decide on which planets can be described by Bode’s Law. But it seems that Bode’s Law may be discriminatory to the other bodies in the solar system since it neglects their
presence in the law. Even though the planets are the largest bodies in the solar system and their masses, other than the mass of the sun, would hold up to a very large proportion of all the mass in the solar system that these smaller bodies may not be significant in influence. But as we can see from our analysis, since Neptune does not seem to move out from Uranus with twice the distance, we can conclude that there are other factors at work. Even if Bode’s Law had not been formulated to indicate to us the prediction of Neptune’s distance, it is generally taken that a body moving out from the centre of gravity would weaken. Yet, Neptune does not follow this pattern.

From the discovery of Quaoar, thus, we have weakened Bode’s Law even further. It should not be concluded that Bode’s Law is useless. It should be taken that Bode’s Law is not comprehensive enough. Bode’s Law had generalized the distance of the planets too much. Also, Bode’s Law was formulated based on the simple observations of the planets as if they are not affected by any other mechanisms. The idea is that the planets are in the sky rotating and revolving only. But with a stronger foundation in our understanding now, we realise that there are other mechanisms at work which complicate the our understanding and these should be given more credit as well. Thus Bode’s Law should be not be discredited but should be added on and modified to our present increased understanding.
Fig. 29 Orbital distances and approximate masses of the first 55 planets discovered around the other stars. Most of the planets are closer to their stars and more massive than the planets in our solar system.
Another moon may be orbiting the Earth

Mystery surrounds the object, newly discovered, which could be a rock chunk or a piece of space junk

It was soon realised, however, that far from passing us, it was in a 50-day orbit around the Earth.

Mr Paul Chodas of National Aeronautics and Space Administration’s (Nasa) Jet Propulsion Laboratory in California said it must have just arrived or it would have been easily detected long ago by any of several automated sky surveys that astronomers were conducting.

Calculations suggest it may have been captured earlier this year.

When Mr Yeung detected the object, he contacted the Minor Planet Centre in Massachusetts, the clearing house for such discoveries, which gave it the designation J002E2 and posted it on its Near-Earth Object Confirmation Web page.

Soon, however, its motion suggested it was in an orbit around the Earth with its movements having all the hallmarks of being a spent rocket casing or some other piece of space junk.

But experts remain baffled by what exactly the object was.

Observations made in Europe have also failed to detect any variations in brightness that might be expected from a slowly spinning metallic object.

Its trajectory suggested that it may have been captured in April or May this year.

If it was determined that J002E2 is natural, it would become Earth’s third natural satellite.

Earth’s second one is called Cruithne. It was discovered in 1986 and it takes a convoluted horseshoe path around the planet as it is tossed about by the gravity of the Earth and the moon.

LONDON — Another moon may be orbiting the Earth and may have only just arrived, according to experts.

Much uncertainty surrounds the mysterious object, designated J002E2.

It could be a passing chunk of rock captured by the Earth’s gravity, or a discarded rocket casing coming back to our region of space, the BBC reported yesterday.

It was discovered by amateur astronomer Bill Yeung from his observatory in Arizona and reported as a passing Near-Earth Object.
Oddball sighting prompts new look at space

An object, half the size of Pluto and which resembles a planet, has raised new questions about the solar system.
BIRMINGHAM (Alabama)

Two California Institute of Technology astronomers, using an ageing telescope to scan the fringes of the solar system, have found a massive object half the size of Pluto—a distant, icy sphere they have dubbed Quaoar.

The scientists say the dark, reddish object is the largest body discovered in the solar system since Pluto was spotted in 1930.

Although precise measurements are impossible to make from Earth, Quaoar (pronounced kwa-wahr) is estimated at 1,287 km across, the size of Pluto’s moon, Charon.

It dances near the edge of the solar system 1.6 billion km beyond Pluto, 6 billion km from Earth.

The find by Caltech astronomers Mike Brown and Chad Trujillo, who have worked in relative obscurity to survey the outer reaches of the solar system, was announced on Monday at a meeting of planetary scientists in Birmingham.

Quaoar orbits in a region of space so cold and dark that our blazingly bright sun appears there as only another star in the night sky.

Until recently, most astronomers thought the region was a boring stretch of emptiness containing only Pluto, its moon and a long-sought entity called Planet X, whose theorized existence was disproved eventually.

Quaoar joins a handful of other strange, large objects found recently in Pluto’s neighbourhood, the Kuiper Belt, a swath of icy cosmic residue that extends from Neptune to the solar system’s outer limits.

Its discoverers say Quaoar is too small to be a planet, although they note it is quite planet-like in its behaviour.

“There’s a whole zoo of things out there that we ought to be exploring, but haven’t even been able to fit into our conceptual framework,” said Dr David Jewitt, an astronomer at the University of Hawaii who co-discovered the first object in the Kuiper Belt in 1992.

In this age of eagle-eyed space telescopes that can locate some of the most distant objects in our universe, the discovery of these startlingly large objects so close to home is something of a wake-up call.

Even veteran astronomers are calling it “awesome”, “spectacular” and “cool”.

At least seven waltz with satellites nearly their own size. None appear to have atmospheres. And as large as Quaoar is, scientists expect it will soon be surpassed.

Here is what is known about Quaoar: It takes 288 days to orbit the sun. It completes one rotation every nine hours. It is not much brighter than a piece of charcoal and is somewhat red.
Astronomers have since realised that the Kuiper Belt is swarming with unexpected objects. In the 10 years since Dr Jewitt’s discovery, scientists have found about 600 Kuiper Belt objects, or KBOs. Models suggest that there could be 10 billion objects there.

These are a motley collection that defy stereotype. Some have such distant, looping orbits that they remain invisible from Earth for hundreds, if not thousands, of years.

Save for Pluto, with its reflective ice surface, the objects found so far are all dark, their carbon-rich surfaces scorched by a constant bombardment of cosmic rays. Some give off a faint, reddish glow.

It is a magnitude 18.5 object — less than 1/100,000 the brightness of the faintest star visible to the human eye.

One side is brighter than the other. It is composed of some still unidentified dark material and water ice.

It has no satellites.

Although it sounds basic, this is hard-won information. Distant objects that do not give off their own light are difficult to study, or even find, from the vantage point of Earth.

These are so faint, they yield few clues even when studied by more powerful telescopes like the Hubble.

Only the biggest objects yield meaningful information.

— Los Angeles Times
Pluto's planet status under scrutiny again

THE discovery of Quaoar has once again called into question Pluto's status as a planet. The new object was found about 6 billion km from Earth in a region known as the Kuiper Belt, where Pluto is thought to have originated and later ejected into its current orbit by some form of disturbance.

To some astronomers, the discovery of an object as big as Quaoar means that Pluto should be classified as a Kuiper Belt object as they believe there are many objects as big as, if not bigger than, Pluto in the region.

Pluto is also closer to the Kuiper Belt than to other members of the solar system, its orbit is not circular, and it is not on the same plane as the other planets.

Some astronomers say that because of the number of objects found in the Kuiper Belt in recent years, Pluto should be considered just another one of those.

Also hurting Pluto's status is the fact that Quaoar's orbit is almost as circular as Earth's, and that it lies on the same plane as all the other planets, except — you guessed it — Pluto.

So what is a planet?

There is no proper definition, although a few scientists have tried to come up with some criteria.

One theory is that anything big enough to become round by gravitational force qualifies. This would mean that anything more than 296 km across would be a planet, including Quaoar.

For now, the International Astronomical Union's "working definition" is: "Any non-fusor object — an object that cannot emit light — that orbits a star."

Pluto’s peers

OTHER Plutonian peeks found in recent years include Varuna, named for the Vedic god of the oceans; Ixion, estimated to be nearly as large as Quaoar, named for the mythical Greek king who fathered the Centaurs; and Rhadamanthus, a smaller object named for one of three judges of the underworld in Greek mythology.

Quaoar takes its name from the creation myth of the original inhabitants of the Los Angeles Basin, the Tongva Indian tribe, also known as the Gabrielenos. According to tribal elder Mark Acuna, Quaoar is the formless, genderless creation force that sang into existence the other deities, namely, Sky Father, Earth Mother and Grandfather Sun.
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Tables includes the Sun, all major planets, and all other objects with estimated diameters of at least 700 km.

Explanations: Inclination is relative to the ecliptic for Sun-orbiting objects and irregular satellites, and is relative to the planet's equator for other satellites. In column for diameter, two figures indicate equatorial and polar diameters; three figures indicate triaxial ellipsoid dimensions. Diameters for trans-Neptunian objects are highly uncertain. Under rotation period, negative figures indicate retrograde rotation and "SYN" indicates synchronous rotation with respect to primary.
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