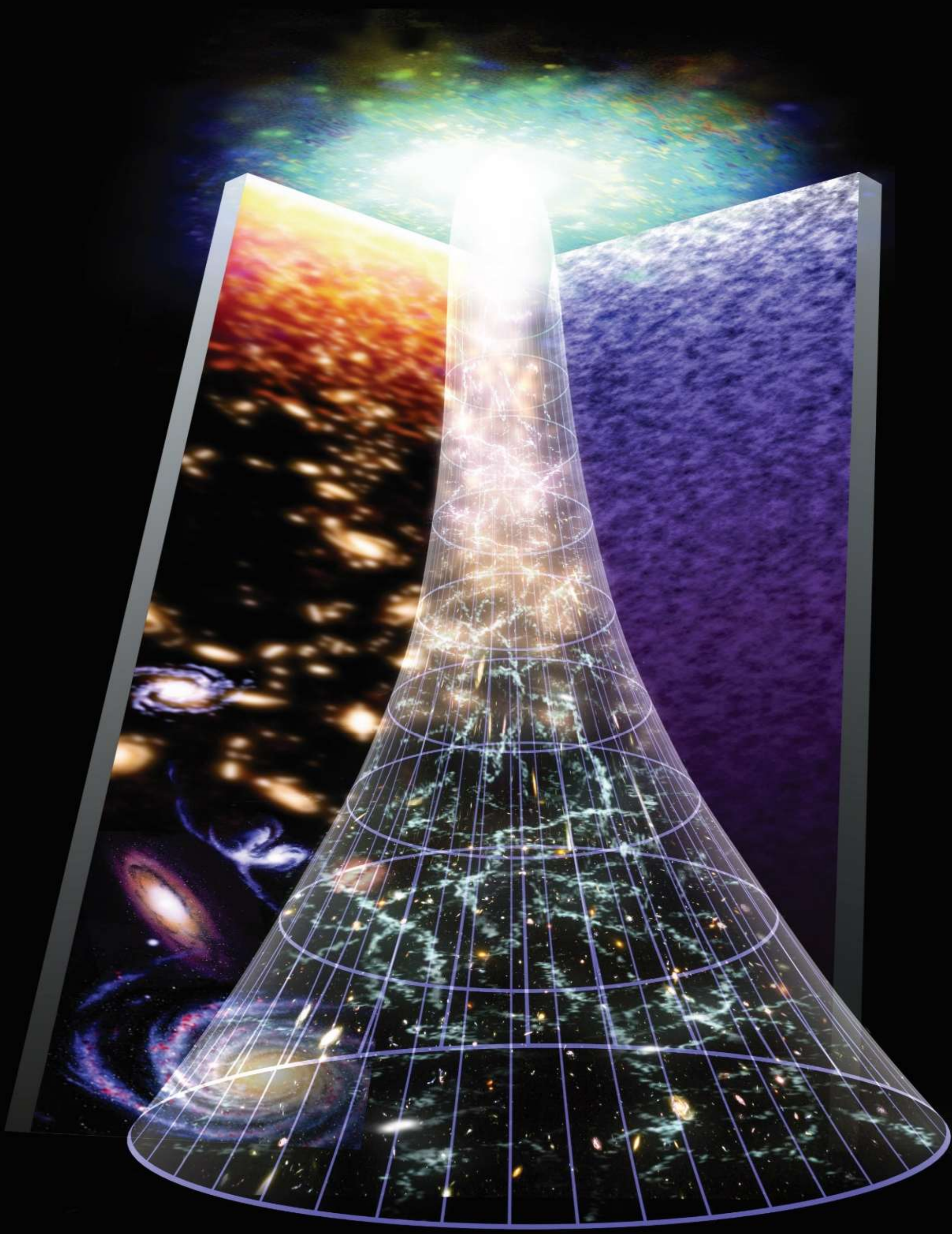
Understanding the Big Bang



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First Web Edition

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Endorsement

"An excellent, up-to-date, examination of Big Bang cosmology in light of its underlying philosophical assumptions, observational evidence, and alternative models. Highly recommended for anyone wanting to learn about the current state of cosmology and its worldview connections."

John Byl
PhD in Astronomy
Emeritus Professor, Trinity Western University, Langley, British Columbia, Canada
June 2021

Two very different opinions from cosmologists:

"The big-bang model … provides a reliable and tested accounting of the history of the Universe from about 0:01 sec after the bang until today, some 15 billion years later."[1]

Professor Michael S. Turner, University of Chicago

"The big bang … is not the ultimate model of the Universe. There are several cosmological models which are based on other fundamental hypotheses and give different interpretation of observable phenomena."[2]

Professor Yurij V. Baryshev, Saint Petersburg State University

According to the Big Bang model, the universe is said to have begun around 14 billion years ago as a 'singularity', an unimaginably hot, dense, 'point'. This, it's said, contained all the matter and energy of the planets, stars and galaxies that now fill space. At the moment of the 'Big Bang' this 'exploded', or more accurately, started to expand. (That is, there wasn't an explosion *within* space, but an expansion *of* space.) As the universe grew in size it started to cool, enabling quarks and electrons to form, these being the building blocks of atoms. The quarks then combined to form protons and neutrons and these, along with the electrons, combined to produce hydrogen and helium gas, together with small amounts of deuterium and lithium. These are referred to as 'light elements' because they have very little mass. (This is why hydrogen and helium are used in airships. Being lighter than air, they provide the lift needed to raise the ship off the ground. See fig. 1.)

Fig. 1. Airships can be filled with either hydrogen or helium gas. Although hydrogen is lighter and produces more lift, helium is preferred for safety reasons (hydrogen being flammable).

The first stars then formed as pockets of these gases came together under the influence of gravity. This is said to have happened because some gas regions were slightly more concentrated than others, this 'lumpiness' becoming the 'seeds' of galaxies and stars. The hot interiors of these stars then provided the furnaces in which carbon, oxygen, iron and other elements were forged. As stars aged, some of them exploded, producing yet more elements such as uranium and gold. The gas and dust from these star explosions provided the materials from which other stars and planets formed.

Supporters of Big Bang theory say that many observations support this model, particularly, measurements of the 'redshifts' of galaxies, the existence and characteristics of a 'cosmic microwave background radiation' and the relative amounts of the light elements found throughout the universe.

Galaxy redshifts

A motorcycle sounds different when moving towards us and when moving away from us. This is because, when moving towards us, the sound waves are compressed and produce a higher note; when moving away, they are stretched and produce a lower note. This is known as *Doppler shift*. There is a similar effect with electromagnetic radiation. Objects moving towards us have their light waves compressed, making them appear bluer; those moving away from us have their light waves stretched, making them appear redder. Hence, light emitted by objects moving away from us is said to be *redshifted*. The expansion of space would have a similar effect as it would stretch light waves.

In the 1920s, Edwin Hubble discovered that the greater the distance of a galaxy from the earth, the more its light is redshifted. This effect is seen in whatever direction ones looks, and many scientists interpret this as indicating that the universe is expanding and that the galaxies we observe through our telescopes are receding (i.e. moving away from us). Supporters of Big Bang theory point out that these observations are consistent with the claim that the universe expanded from a singularity.

According to *Hubble's Law*,

$$v = H_0 D$$

where v is the recession velocity, and D is the distance from the observer. H_0 is the *Hubble constant* and its value is determined by the rate of expansion. The greater the distance, D, the greater is the recession velocity, v. The Hubble constant is sometimes referred to as the *Hubble parameter* because, in the Big Bang model, the rate of expansion has varied over the course of the universe's history.

Big Bang cosmologists assume that, on large scales, the universe is the same in all locations. As such, it is said to have the same average density everywhere, for example, with every galaxy surrounded by similar numbers of galaxies. Hence, the universe is said to be *homogeneous*—from Greek, *homos* (same) and *genos* (kind). They also assume that, whatever the location of an observer, the structure and expansion of the universe would appear the same, and in whatever direction he looked. As such, Hubble's law is understood to apply in all places in the universe as shown in fig. 2. Hence, the universe is also said to be *isotropic*—from Greek, *isos* (equal) and *tropos* (a turn).

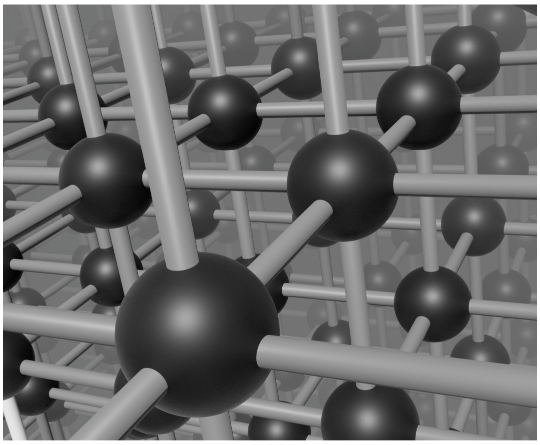

Fig. 2. A structure made up of balls connected by rods. If each rod started to grow at the same rate, the balls would recede from one another according to Hubble's law. Moreover, wherever an observer might be positioned, and in whatever direction he looked, he would see the structure expanding in the same way.

The assumption that the universe is characterised by homogeneity and isotropy is known as the *cosmological principle*. According to this view, no place is special and the universe has no centre. These assumptions are fundamental to the mathematics describing Big Bang theory. They have not, however, be proven. Cosmologist Professor George F.R. Ellis remarked, "People need to be aware that there is a range of models that could explain the observations. For instance, I can construct you a spherically symmetrical universe with Earth at its center, and you cannot disprove it based on observations. … You can only exclude it on philosophical grounds. In my view there is absolutely nothing wrong in that. What I want to bring into the open is the fact that we are using philosophical criteria in choosing our models. A lot of cosmology tries to hide that."[3]

Cosmic Microwave Background Radiation

In the 1960s, Arno Penzias and Robert Wilson, detected what appeared to be a low level of electromagnetic radiation coming from all directions in space. Further studies confirmed this and showed that it could be detected across a range of short ('micro') wavelengths. Subsequently, instruments in satellites have measured and mapped this in great detail (see fig. 3). Big Bang cosmologists believe that, if these satellites were to travel to distant places in the universe, they would observe this everywhere. Hence, they have named it the *Cosmic Microwave Background* (CMB) and interpret it as the 'after-glow' of the original Big Bang 'explosion', a residual background heat that fills the whole cosmos (i.e. whole universe).[4] The Big Bang model predicts that the CMB would have certain characteristics, particularly that a graph of its frequency vs the intensity of the radiation would rise and fall as shown in fig. 4. Since this is what is observed, Big Bang cosmologists argue that measurements of the CMB provide strong evidence for their theory.

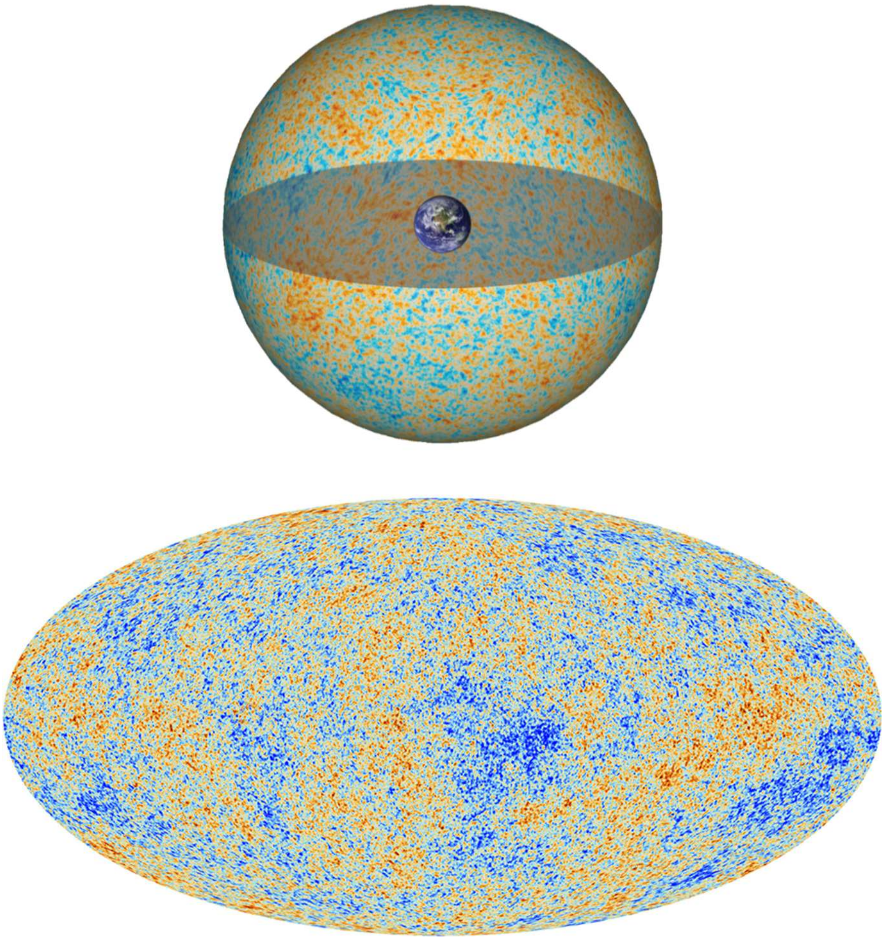

Fig. 3. The Cosmic Microwave Background Radiation (CMB) as measured by the Planck satellite. The different colours represent different temperatures. Redder regions are warmer and bluer regions cooler. Above: The CMB shown as celestial sphere around the earth. Below: Projected so as to show the whole sky as a 2-dimensional map. The average temperature is around 2.725 K. The temperature variation is very small, in most places measuring only around 0.0002 K above and below the average. In the Big Bang model, these temperature fluctuations are understood to be a result of the small fluctuations in the density of matter in the early universe.

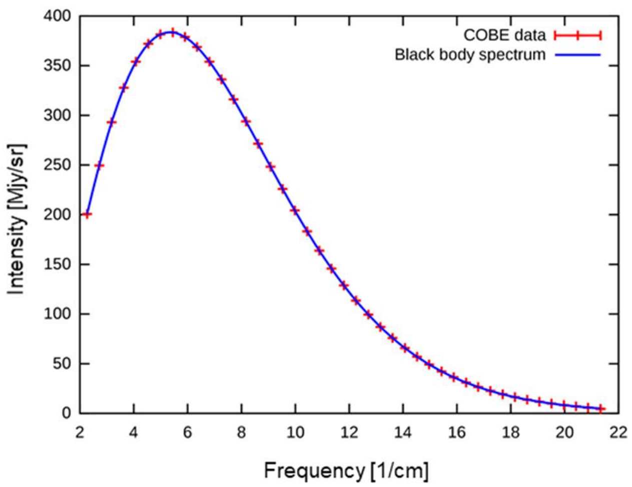

Fig. 4. Graph showing the relationship between CMB frequency and intensity. The blue line shows what is known as a ‘blackbody spectrum’ and is the relationship expected if the Big Bang model is correct and the early universe was in a hot, dense state. The red crosses are data measured by the COBE satellite and fit perfectly with the Big Bang prediction.

Light elements

According to the Big Bang model, the 'light elements'—hydrogen, helium, deuterium and lithium—would have been produced within the first few minutes following the start of the initial 'bang'. This is known as *Big Bang nucleosynthesis*. Since the model successfully predicts the relative amounts of hydrogen, helium and deuterium actually observed in the universe, this is said to provide further confirmation that Big Bang theory is correct.

'Dark matter' and 'dark energy'

The motions of the planets that orbit our sun are well understood. The law of gravity dictates that those furthest from the sun should move more slowly than those which are nearer. If they didn't, they would fly off into space. Stars also orbit around the centres of their galaxies and, as with the planets of our solar system, it would be expected that those furthest from the centre would move more slowly than those which are nearer. This, however, is not what is observed. This is often illustrated by what's known as a galaxy rotation curve, an example of which is shown in fig. 5.

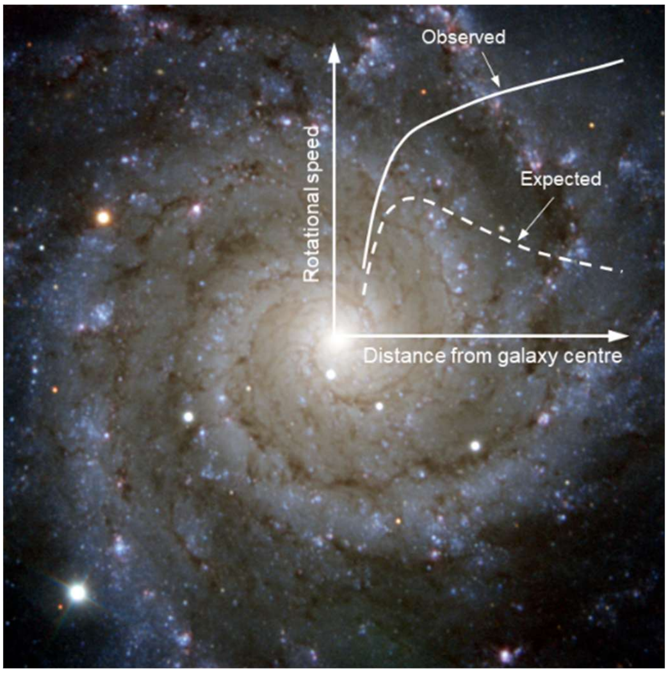

Fig. 5. A spiral galaxy with stars rotating about the galaxy centre and its rotation curve. The dashed line shows how stars would be expected to move more slowly with increasing distance from the galaxy centre; the solid line shows what is actually observed.

In order to resolve this problem, some have concluded that large amounts of additional mass reside in galaxies which are invisible to us. This, they say, provides the additional gravity needed to hold the galaxy together despite the high rotation speeds of the outer stars. It is often referred to as 'dark matter', not because it has a dark colour, but because it cannot be seen and we don't understand it. If it exists, it is a different type of matter to that with which we are generally familiar, being made up of something different to the baryons (protons and neutrons) making up 'normal matter'. 'Dark mater' has the peculiar characteristic of not absorbing, reflecting or emitting light. Indeed, light seems to passes straight through it. Moreover, it appears only to interact gravitationally and can, largely, pass though 'normal matter' and through itself.

Evidence for the reality of 'dark matter' is also seen in galaxy clusters—groups of galaxies bound together by gravity. Here calculations of gravitational force based on the observed amounts of matter indicate that this would be insufficient to keep the cluster together. Again, additional ‘dark matter’ is needed to prevent the individual galaxies flying off into space. Further confirmation of ‘dark matter’ is said to be found in the way the passage of light is bent as it passes by these clusters. This is known as *gravitational lensing*. Again, large amounts of unseen matter are needed to obtain agreement between theory and observations.

Perhaps the strongest evidence for ‘dark matter’ is seen when two galaxy clusters collide, as shown in fig. 6. Galaxies (shown in orange and white) and gas clouds (shown in pink) make up the ‘normal matter’, with the gas comprising most of this. The putative ‘dark matter’ is shown in blue and its presence is inferred from gravitational lensing. Before the collision, the gas clouds surrounded their respective stars and galaxies but, as one cluster passed through the other, the gas clouds were separated from them. This is because, as the gas clouds met, one got in the other’s way and their motion was slowed. Meanwhile, the paths of the stars and the ‘dark matter’ associated with each galaxy cluster were largely unaffected. Being thinly distributed, the stars passed each other by, and the clusters of ‘dark matter’, interacting only gravitationally, had little effect on the motions of either the stars or each other. Despite the gas clouds comprising most of the ‘ordinary matter’ the gravitational lensing is centred on the regions containing the stars. This suggests that, around the stars, there is additional mass—the ‘dark matter’.

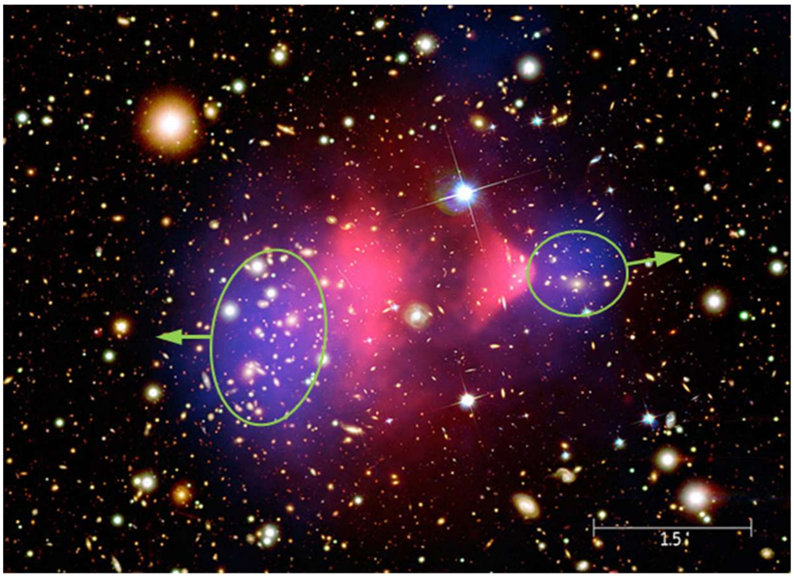

Fig. 6. The *Bullet cluster*, the result of a collision between two separate galaxy clusters. These are ringed in green with their galaxies shown in orange and white. Areas of gas are shown in pink. The cluster on the right has passed through the one on the left, with the green arrows showing their current directions of motion. Before the collision, the two clouds of gas would have surrounded their respective clusters, remaining largely within the green outlines. Now they lag behind the clusters. Observations of gravitational lensing suggest that most of the mass exists in the blue areas.

Many people see empty space as being nothing, but there are good reasons for seeing it differently, and as having a ‘fabric’ that can be deformed. Albert Einstein, for example, argued that mass and energy have the effect of warping space (or more accurately ‘space-time’) and that this produces what we refer to as gravity. Hence, the moon orbits the earth because the earth’s mass curves the space around it and the moon’s path follows this curvature. Similarly, the warping of space around a galaxy cluster is understood to explain why light beams appear to bend as they pass by it, giving rise to gravitational lensing.

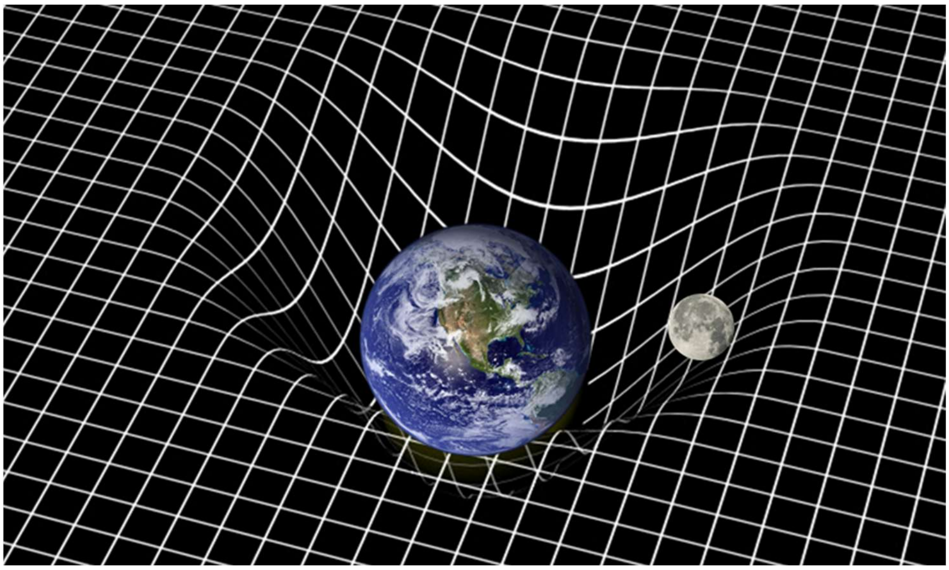

Fig. 7. The mass of the earth warps the space around it causing the moon's orbit.

In a homogeneous, isotropic universe—as required by Big Bang theory—space, overall, can be curved—positively or negatively. In positively curved space, initially parallel lines will converge; in negatively curved space, they will diverge; in uncurved space, they will remain parallel. Due to the difficulty of imagining a curved-space universe in three dimensions, the effect is often illustrated in terms of the deformation of an initially two-dimensional surface. With reference to fig. 8, a universe with uncurved space is said to be 'flat'; a universe with positively curved space is said to be 'closed'; and a universe with negatively curved space is said to be 'open'. The matter-energy density that leads to a flat universe is known as the *critical density*. A universe with a higher density will be 'open'; one with a lower density will be 'closed'.

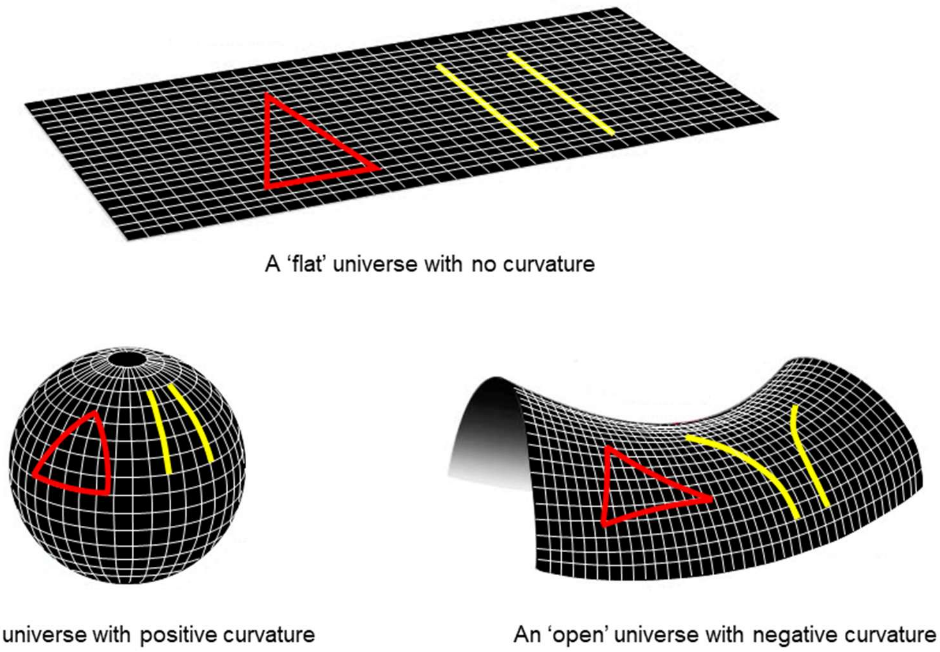

Fig. 8. Representations of the different shapes of the universe that could arise from the Big Bang. In a 'flat' universe, parallel lines remain parallel and the angles of a triangle add up to 180°; in a 'closed' universe, parallel lines converge and the angles of a triangle add up to more than 180°; in an 'open' universe, parallel lines diverge and the angles of a triangle add up to less than 180°.

Until recently, Big Bang cosmologists held that the universe is 'closed'. Although, everyday experience indicated that parallel lines remain parallel, it was believed that, over very large distances they would, in fact, be seen to converge. This created a problem because there didn't appear to be enough matter in the universe to bend space in this way.[5] In addition, it was realized that Big Bang nucleosynthesis put a limit on the total amount of normal (i.e. baryonic) matter that could exist—above this value, the model would fail to predict the observed amounts of light elements.[6] To overcome these problems, the Big Bang model was modified to accommodate a universe comprising 5% normal matter and 95% 'dark matter'.[7]

In Big Bang theory, dark matter is also needed to explain how galaxies formed. Even though the universe is said to be billions of years old, there has not been enough time for gravity to cause gases to clump together to form the many galaxies found throughout space. 'Dark matter' is said to solve this problem by providing the additional gravity needed to speed up this process. It is understood to have acted as the 'scaffolding' of the universe, around which normal matter accumulated and merged into stars.

In the 1990s, studies of distant exploding stars known as type 1a supernovae led cosmologists to conclude that the expansion of the universe is accelerating. This, however, was not a prediction of the Big Bang model as, in a homogeneous and isotropic universe, the gravitational attraction of all its matter would be expected to cause the rate of expansion to decrease over time. To accommodate this discrepancy, 'dark energy' was added to model, a kind of anti-gravity force which provides the required 'outward push' on the universe. As with 'dark matter', the existence of 'dark energy' is inferred from its effects on the universe, as it has never been observed in a laboratory.

Generally, Big Bang cosmologists now interpret the available data as indicating that, on very large scales, the universe is flat[8] (although some data suggest otherwise).[9] To accommodate this and an accelerated expansion, the Big Bang model was again adjusted so as to be based on a universe comprising 5% normal matter, 27% 'dark matter' and 68% 'dark energy'.

Some problems and a proposed solution—Inflation

Although the temperature of the CMB does vary (fig. 3), the variations are very small, making it almost uniform, in whatever direction it is measured. This, however, would not be expected from a Big Bang. An 'explosion' would produce an uneven distribution of temperature—areas of extreme heat along with patches of cold—rather than the very even pattern actually observed. Even allowing billions of years for the temperature to even out, due to the very large size of the universe, it would still not have reached its present, essentially uniform state. To come to the same temperature, different regions of space must exchange energy with one another which is done with photons that move at the speed of light. Although light moves very fast, it is not fast enough to have brought the most distant regions of the universe into thermal equilibrium, as they are—and always have been throughout the expansion history of the universe—beyond their 'horizons'. This is known as the *horizon problem*.[10]

A 'flat' universe would, again, not be expected from a Big Bang. The problem here is that any deviation from perfect 'flatness' in the early stages of the expansion would be greatly amplified over time. The mass-energy density of the early universe would have had to be just right—exquisitely fine-tuned—to result in an essentially 'flat' geometry today. Moreover, if soon after the initial 'bang' the actual density had been less than the critical density by just one part in 10^{60}, space would have expanded so rapidly that no stars or planets could have formed; if greater than one part in 10^{60}, after a while space would have stopped expanding and the universe then collapsed into a 'big crunch', again, leaving no stars and no planets.[11] Hence, the initial density would need to be fine-tuned to 60 decimal places, 10^{60} being 1 followed by 60 zeros. This is known as the *flatness problem*.

Whereas a bar magnet has a north and a south pole, a monopole has only one pole. The Big Bang model predicts that a very large number of magnetic monopoles would have been produced in the early universe—but we don't observe these. This is known as the *monopole problem.*

To solve these problems, the original Big Bang model was modified so as to include a brief period of extremely rapid expansion, very soon after the initial 'bang'. This is known as *inflation*. With the inflation model, the observable universe comprises only a small part of the whole universe, and came from a small portion of the original universe that had reached a uniform temperature before inflation began. Hence, according to this model, while there is considerable variation in temperature across the whole universe, the part we can see has essentially the same temperature. This also results in the appearance of a 'flat' universe, just as blowing up a football until it is the size of the earth would remove its apparent curvature. Inflation also allows for magnetic monopoles so long as they arose before the inflationary period. This is because, with a very large expansion of the universe, they would have become 'lost in space'.

More on the Cosmic Microwave Background Radiation (CMB)

In the Big Bang model, the CMB is understood to reflect the state of the universe a few thousand years after the initial 'bang'. At this time, no stars, planets or even atoms had formed, and space was filled with atomic nuclei (protons and neutrons), electrons, photons (bundles of light energy), 'dark matter' and 'dark energy'. The concentration of this 'soup' varied across space, with the density in different regions increasing and decreasing over time as gravity tended to pull it together into pockets and the resulting increased pressure tended to push it back out. These density fluctuations, occurring at all scales, are said to have been recorded in the temperature fluctuations seen in the CMB, as measured by instruments in satellites.

Big Bang cosmologists have analysed these temperature fluctuations and argue that their results demonstrate that the Big Bang model accurately predicts the amounts of normal matter, 'dark matter' and 'dark energy' found in the universe today. First, the data are analysed so as to obtain values of temperature variation at different scales (i.e. different levels of detail). Some examples are given in fig. 9.

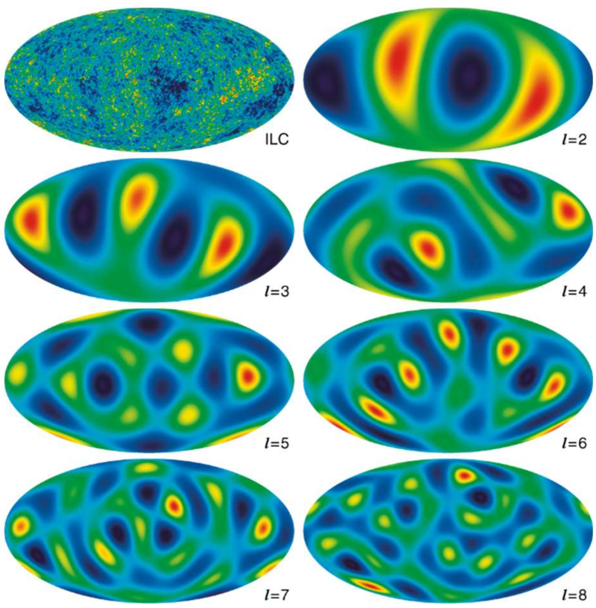

Fig. 9. The CMB temperature fluctuations anaylsed at different scales (i.e. levels of detail), with the multipole moment, l, indicating the scale. The higher the value of l, the smaller the angle between points on the sky over which measurements are being compared. $l \approx 180/\theta$ where θ = angle in degrees.

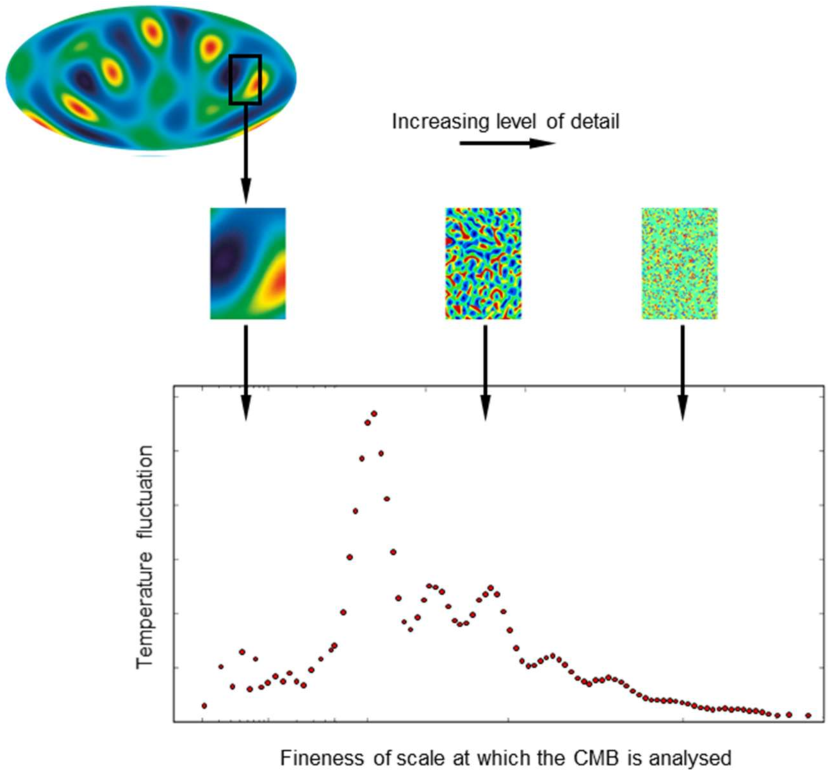

Fig. 10. CMB temperature variation as analysed at different scales. The warmest areas are shown in red and the coldest in blue. The graph shows data points measured by the Planck satellite.

The temperature fluctuation at each scale is then plotted as shown in fig. 10. This is often referred to as the *CMB power spectrum*. Fig. 11 shows the measured data points along with a theoretical prediction based on the Big Bang model (the green line). Since these correlate to a high degree of accuracy, Big Bang cosmologists argue that these analyses again demonstrate that the Big Bang model is correct.

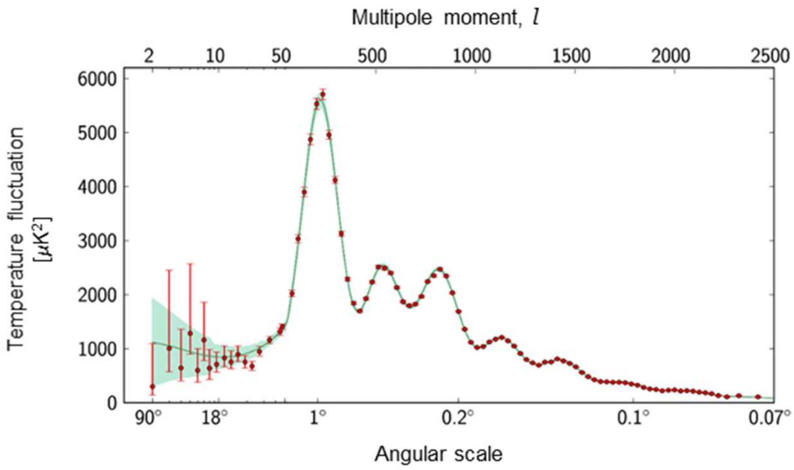

Fig. 11. The CMB power spectrum. The 'angular scale' along the horizontal axis refers to the angle in the sky over which the temperature fluctuations are analysed. The larger the multipole moment, l, the smaller the angle and the more detailed the analysis. The red dots are the data points obtained from satellite measurements (fig. 10) and their 'error bars' are shown as red vertical lines. The green curve shows how the Big Bang model can be adjusted to fit these.[12] By analysing these data, Big Bang cosmologists claim to be able to estimate the amounts of normal matter, 'dark matter' and 'dark energy' present in the universe. The position of first peak is understood to indicate the curvature of the space. Occurring at around l = 200, this indicates a 'flat' universe as predicted by 'inflation'. Assuming the Big Bang model is correct, analysing the heights of the first, second and third peaks enables the densities of normal matter and 'dark matter' to be established.

The LCDM model

The history of the universe according to the current Big Bang model is shown graphically in fig. 12. This is often referred to as the LCDM model, where CDM is an abbreviation for 'cold dark matter'. (Here the term 'cold' means slow-moving rather than low in temperature.) L is an abbreviation for 'lambda', the Greek letter denoted (in upper-case) by Λ, and refers to the incorporation of 'dark energy' into the model in the late 1990s. Supporters of LCDM Big Bang model argue that it provides a 'precision cosmology', with measured data confirming its predictions with a high degree of accuracy.

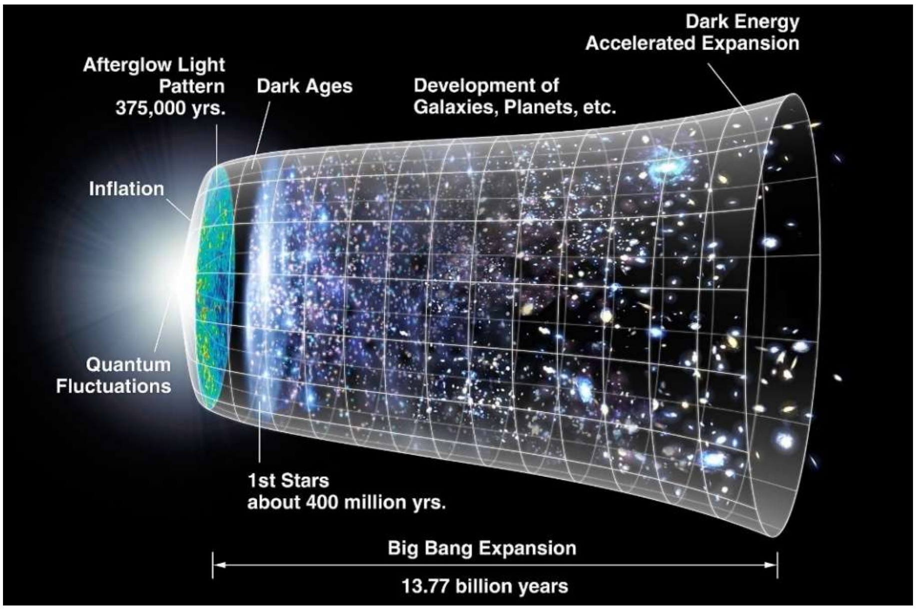

Fig. 12. The history of the universe according to the LCDM Big Bang model.

Problems with 'dark matter' and 'dark energy'

Some argue that 'dark matter' and 'dark energy' are not part of science because they have never been detected in the laboratory. In the case of 'dark matter' much money has been spent seeking to prove its existence but to no avail. In the case of 'dark energy' it is even questionable as to whether an experiment could be devised to do this.[13] Such are the problems with 'dark matter' and 'dark energy', some scientists are searching for other explanations for the effects said to be explained by them.[14] Of particular concern is that these unobserved, 'dark' phenomena must be present in just the right quantities and have just the right characteristics to solve the problems they are said to address.

In the case of 'dark matter', to solve the problem of galaxy rotation speeds, it has to be arranged in just the right way, with the right amounts in the right places. For a particular galaxy with a particular rotation curve (fig. 5), the density of the 'dark matter', and how this varies with distance from the galaxy centre, is adjusted to give the right result.[15] For some, this requirement for 'fine-tuning' (or 'fudging') casts considerable doubt on the validity of the theory. There is also a lack of consistency, as different observations lead to different conclusions about how much 'dark matter' is needed. For example, a certain amount of 'dark matter' might be required to obtain the right rotation curve but a different amount might be needed to keep the galaxy stable.[16,17] The degree of gravitational lensing observed around galaxy clusters has also been found to be inconsistent with the predicted amounts of 'dark matter'.[18]

To play its role, 'dark matter' must, very largely, interact only gravitationally. Hence, it must have very strange—some say 'exotic'—properties. It must not absorb, reflect or emit light, and must pass through normal matter and itself. Also, to play its role in galaxy formation, it must be 'cold', i.e. slow moving.

Even given this, however, simulations of galaxy formation fail to predict what is actually observed. These indicate that our galaxy should be surrounded by hundreds or thousands of 'dwarf galaxies', but these are not to be found. This is known as the *dwarf galaxy problem*.[19]

As with 'dark matter', 'dark energy' must have just the right properties and must behave in just the right ways so as to make Big Bang theory work. For example, by adjusting two parameters (energy density and pressure) the model is made to produce just the right expansion history of the universe.[20] Unless the magnitude of 'dark energy' had been just right, no galaxies could have formed. In the mathematical equations that describe the universe's expansion, this is determined by the 'cosmological constant', Λ. Remarkably, it must be adjusted to a precision of one part in 10^{120}, i.e. 120 decimal places. In the Big Bang model, it cannot be zero as otherwise the universe's expansion would not be accelerating; but nor can it be much greater than zero as, if it were, the matter in the universe would have just flown apart, never being drawn together by gravity to form stars and planets. For some scientists, the requirement to 'fine-tune' the cosmological constant to such a degree stretches the credibility of the model far too far.

Equally embarrassing for Big Bang theory is that calculations indicate that the cosmological constant should be many, many times greater than the model requires.[21] This is known as the *cosmological constant problem*. According to Professor Mike Hobson, the magnitude of this discrepancy is so great that it is "probably the worst theoretical prediction in the history of physics! Nobody knows how to make sense of this result."[22] Given the discrepancy between estimated and actual value of lambda, and central role that 'dark energy' plays in the theory, some ask how the Big Bang model can be considered to be part of science.

Neptune, Vulcan and 'dark matter'

In the early part of the nineteenth century, Alex Bouvard published tables which accurately predicted the positions of Jupiter and Saturn as they orbited the sun. Similar calculations, however, failed to work for Uranus. Bouvard suggested that this might be explained by there being another planet (a 'dark planet' which couldn't be seen) whose gravity was interfering with Uranus's natural orbit. Subsequently, Urbain-Jean-Joseph Le Verrier calculated the size and path of this hypothetical planet, which turned out to be the planet Neptune, first observed by Johann Galle in 1846. Mercury was another planet that did not follow its expected orbit as predicted by Newton's laws of motion. Again, Le Verrier suggested that another planet must exist that was causing the discrepancy and gave it the name Vulcan. In 1876, one popular science journal declared:

> "Our text books on astronomy will have to be revised again, as there is no longer any doubt about the existence of a planet between Mercury and the sun. The celebrated French astronomer Le Verrier … proved the existence of … Vulcan. … The passage of this planet has already been observed … at the New Haven observatory by the late Prof. Hubbard. … There is no longer the least doubt about the existence of this planet."[23]

In the same year, *The New York Times* reported:

> "… there is an end of all discussion. Vulcan exists, and its existence can no longer be denied or ignored. The Earth must henceforth be ranked as the fourth planet from the sun, and the children in the public schools who have been taught to recite their planets after the old-fashioned order, must be required to commit Vulcan to memory and insert it in its proper place."[24]

In reality, Vulcan doesn't exist, and the true explanation for Mercury's orbit necessitated a more precise understanding of Newton's law of gravity. This was provided by Albert Einstein and his theory of relativity.[25]

Advocates of 'dark matter' make much of Le Verrier's successful prediction of Neptune. Opponents of 'dark matter' make much of his failed prediction of Vulcan. Some 'dark matter' sceptics believe that, just as the orbit of Mercury was explained by a modification of Newton's law of gravity rather than a 'dark planet', so the behaviour of galaxies will one day be explained by another modification of gravity, rather than 'dark matter'. One such hypothesis is known as Modified Newtonian Dynamics (MOND).

Missing anti-matter

In the Big Bang model, as the very early universe expanded and cooled, some of its energy was converted into matter. According to the laws of physics, for every particle of matter created, a particle of 'anti-matter' should also have formed—and herein lies one of the greatest difficulties for Big Bang theory. While enormous amounts of matter fill the universe—billions of galaxies each containing billions of stars—the corresponding anti-matter is not to be found. This is known as the *matter-antimatter asymmetry problem*.

A constantly changing model

In the 1970s the Big Bang model was declared to be good science with cosmologists "insisting that the major problem of the correct cosmological model had been cracked and only superficial details needed sorting out."[26] Despite this bold claim, by the 1980s the model had been discarded in favour of a new version, based on a universe comprising 95% 'dark matter'. This was termed the Standard Cold Dark Matter model (SCDM). Again, the general public were assured that they could have great confidence in this latest Big Bang theory as it had now "developed into a mature and believable physical model."[27] By the end of the twentieth century this too had been discarded in favour of another radically different model based on normal matter, 'dark matter', and 'dark energy', the Lambda CDM (LCDM or ΛCDM). At the time of writing, Big Bang theory requires a universe markedly different to the one envisaged in earlier models, 95% of which is 'dark matter' and 'dark energy'. Some have remarked that, according to this model, only 5% of the universe is known!

Big Bang sceptics ask how anyone can be confident of the current model, given how much previous models had to change to accommodate the latest data. These modifications, they point out, are not trivial, but fundamental. For example, the 1970s model included no 'dark matter' and no 'dark energy'. It also had no inflationary period needed to solve the 'flatness problem', the 'horizon problem' and 'monopole problem'. Some ask what would happen to the Big Bang theory if it were demonstrated that dark matter and dark energy do not exist. Would it then be abandoned or would the model, again, be modified to make it work without them? If the latter, would this then demonstrate, beyond all possible doubt, its unscientific nature, being flexible to the point of being able to accommodate any data?

> According to Professor Stacy McGaugh, "It is hard to overstate the fervor with which the SCDM paradigm was believed. … we should remember that we once endowed SCDM with the same absolute certainty we now attribute to ΛCDM."
> McGaugh, S., A personal recollection of how we learned to stop worrying and love the Lambda, 28 January 2019; tritonstation.com.

A model that can be endlessly adjusted to fit observations

For sceptics, the primary weakness of the Big Bang model is its flexibility, that it can be modified where needed to fit the data. Good scientific models, they say, work without such 'fudge factors'. To illustrate the problem, they refer to way that Claudius Ptolemy's incorrect model of the universe could be adjusted to fit with observations of the movements of the heavenly bodies (the sun, the moon and the planets).

In the thinking of Ancient Greeks, the earth was placed at the centre of the universe and the sun, along with all the other stars and planets, moved in perfect circles around it (fig. 13). This is known as a geocentric model—from Greek, *ge* (the earth) and *kentron* (centre). Over time, doubts about this model arose as observations showed that it failed to accurately predict their movements. Planets seemed to slow down and speed up, even at times appearing to go backwards (known as *retrograde motion*). They also appeared larger and smaller over time, and their brightness varied, none of which seemed to make sense.

In the second century AD, Ptolemy modified this model, introducing various features that could be adjusted to make theory and observations agree (fig. 14). For example, he added what are known as *epicycles* where the planets move in smaller circles which themselves rotate about a much larger circle known as a *deferent*. This enabled him to explain retrograde motion. His model also allowed him to offset the centre of a deferent from the centre of the earth, generating an *eccentric orbit*. This enabled him to account for changes in a planet's brightness. Introducing an *equant* enabled him to vary the speed with which an epicycle moved around the deferent over time. Hence, there were many parameters that could be adjusted to produce the motion needed: the relative positions of the earth, the eccentric and the equant, the diameter of the deferent and the diameter of the epicycle. The planets each had these parameters set for them so that they would behave as required. Their values were not (and could not be) measured and then used to test the model. They were chosen so as to make the model work. As such they are described as *free parameters*.

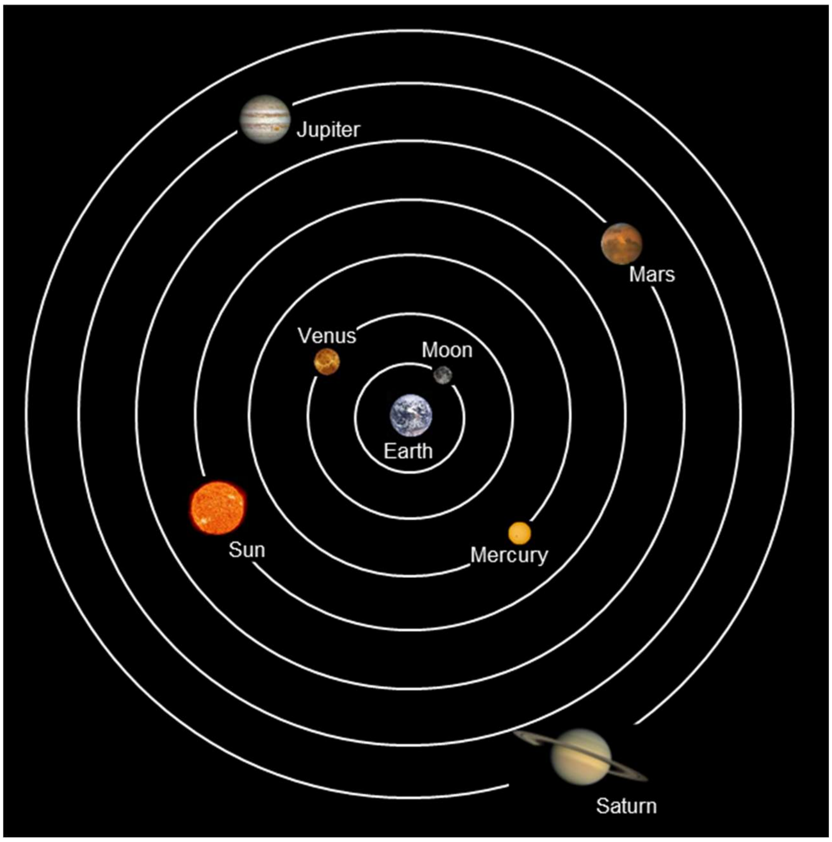

Fig. 13. Aristotle's model. The earth is at the centre and the planets move around it in perfect circles. However, the model fails to accurately predict the positions of the planets over time.

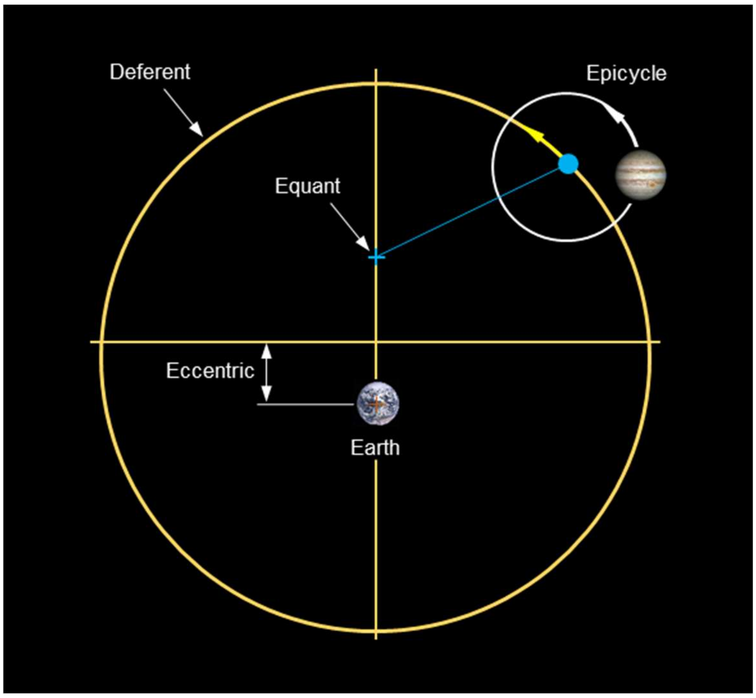

Fig. 14. Ptolemy's model incorporating an eccentric, an epicycle and an equant. Each planet rotates around an epicycle which itself rotates around a deferent. The centre of the deferent is eccentric to the centre of the earth. The angular speed of the epicycle around the equant is constant but, because the equant is offset from the deferent, the angular speed of the epicycle around the deferent varies over time. By choosing appropriate values for each of these 'free parameters' the model can be made to accurately predict the position of a planet over time.

Many people accepted Ptolemy's geocentric model because it appeared to be successful, accurately predicting the positions of the heavenly bodies over time. It was, however, wrong and an important lesson was learnt from this: *A model can produce the right result and still be incorrect.*

According to Professor M.J. Disney, "Scientific history is littered with theories which once fitted many facts."
Doubts About Big Bang Cosmology, 9 September 2011, DOI: 10.5772/intechopen.84025.

Sceptics see the Big Bang in a similar way. They say that, just as Ptolemy assumed the geocentric model to be correct and then modified it wherever required to match observations, so Big Bang cosmologists assume their model to be correct and modify it as and when needed. Sceptics argue that Big Big theory is unscientific because there are just too many free parameters that can be varied to make the model work.[28] These, they say, can be likened to 'sticking plasters' that are used to keep the model together when observations indicate that it is falling apart. These 'fudges' include, for example, the amounts of normal matter, 'dark matter' and 'dark energy'. One particular target for the sceptics is 'inflation' which they view as unscientific because it makes no firm observational predictions and, again, can be adjusted to give whatever results are needed to make the Big Bang model work. In addition, it has no established theoretical explanation for its cause. Professor Paul Steinhardt, a strong critic of 'inflation' stated:

> "inflation is very flexible … [and] can be adjusted to give any result … any outcome is possible. … [Hence] it is not possible to find evidence to support or refute inflation"[29]

> "… inflationary cosmology, as we currently understand it, cannot be evaluated using the scientific method."[30]

Another critic is Professor Roger Penrose who describes it as "fundamentally fallacious" and contrary to the second law of thermodynamics.[31] Sceptics point out that, if 'inflation' is untenable, then so is the Big Bang model because it then has no answer to the flatness, horizon and magnetic monopole problems.

Sceptics argue that the Big Bang model's successes (predictions that have come true) are more than countered by its failures (observations that seem to contradict it) and point out that there are other models that can explain the data. Such concerns were expressed by a number of scientists in an open letter to the scientific community published in *New Scientist* magazine. Referring to what they regard as 'fudge factors' such as 'dark matter', 'dark energy' and 'inflation' they wrote:

> "In no other field of physics would this continual recourse to new hypothetical objects be accepted as a way of bridging the gap between theory and observation. It would, at the least, raise serious questions about the validity of the underlying theory."[32]

Another major problem with Big Bang theory is that it is impossible to do experiments to test it. As argued by Professor Richard Lieu, "Cosmology is not even astrophysics: all the principal assumptions in this field are unverified (or unverifiable) in the laboratory."[33] Fundamentally different models can explain the same observations and it is very difficult—some would say impossible—to determine whether a particular model is correct.[34,35] For example, the Lemaitre-Tolman-Bondi model, which does not assume that the universe is homogeneous, explains the type 1a supernovae data without resorting to 'dark energy'.[36]

Are galaxy redshifts really strong evidence for the Big Bang?

Nobody has actually observed the expansion of the universe; rather, this is *inferred* from data, particularly the way the light from galaxies is redshifted. Some have suggested that this redshifting can be explained by the 'tired light' hypothesis, rather than the expansion of space. Here photons are understood to lose energy as they travel the great distances across space giving rise to a frequency shift. Several mechanisms have been proposed that might give rise to this.[37] Many Big Bang sceptics, however, accept that the universe is expanding, but point out that doesn't prove that the universe began as a singularity. It could be expanding from an initially much larger state.

The concept of a singularity is fraught with problems as there is no known physics which can describe it or explain how it might birth a universe. For some, this invalidates any claim that Big Bang theory is part of science. Professor Alan Guth admitted;

> "In spite of the fact that we call it the Big Bang theory … it really says absolutely nothing about the Big Bang. … it doesn't tell us what banged, why it banged, what caused it to bang. … it doesn't really allow us to predict what the conditions are immediately after this Big Bang."[38]

Is the CMB really strong evidence for the Big Bang?

According to the Big Bang model, since the universe is isotropic, the CMB should be isotropic. That is, it should show the same patterns of temperature variation in whatever direction we look. Detailed studies of the satellite data, however, do not support this view, with some features indicating a clear anisotropy as shown in fig. 15. There is also a 'cold spot', a part of the map that is unexpectedly large and cold, which is, again, very difficult for Big Bang cosmologists to explain.[39] Some studies of galaxy clusters similarly challenge the assumption that the universe is isotropic.[40]

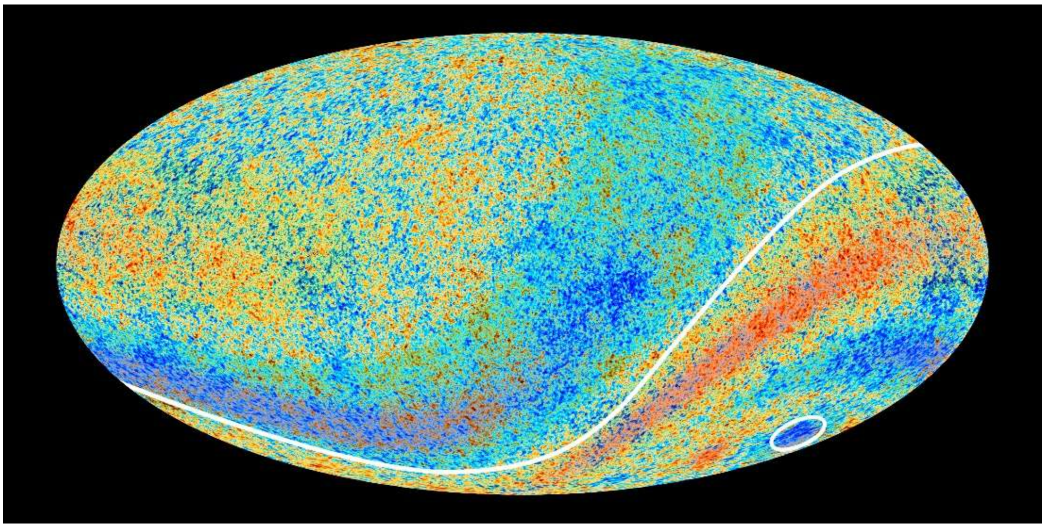

Fig. 15. Image of the CMB with its asymmetry highlighted. The patterns of temperature variation are different on the left and right hand sides. Also there is 'cold spot' circled in the bottom right-hand corner. If the CMB reflects conditions in the early universe—as Big Bang cosmologists maintain—it was neither homogeneous nor isotropic.

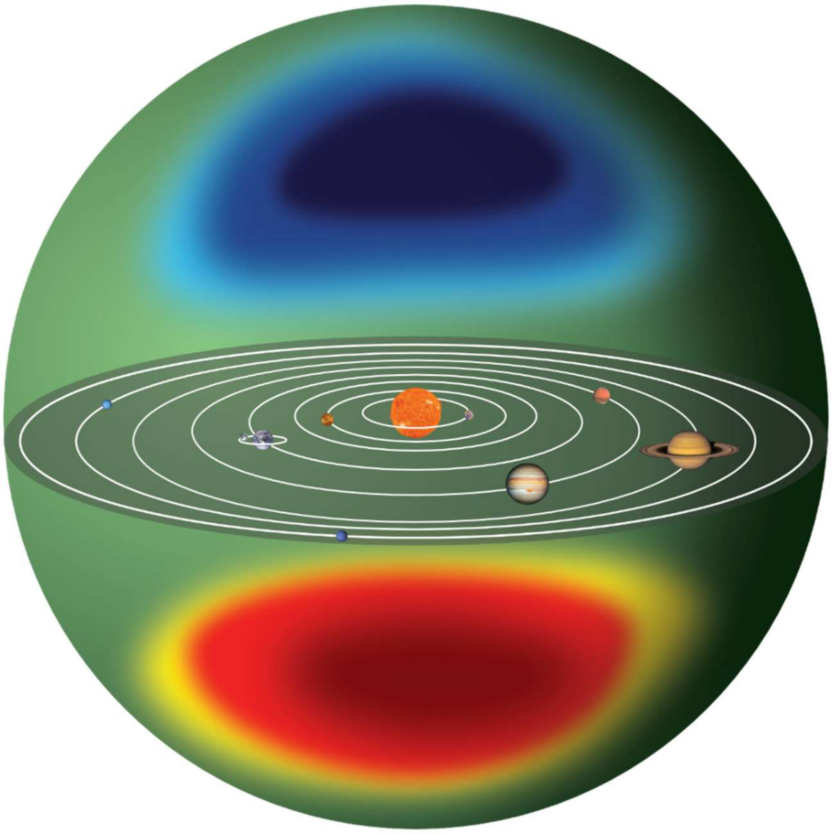

Fig. 16. In some analyses, the pattern of CMB temperature variation can be seen to be aligned with the plane of the solar system. Here two of the maps in fig. 9 (l = 2 and l = 3) are combined and the data shown as a 'celestial sphere'. The largest cool and warm regions are seen on opposite hemispheres of the sky.

An even bigger surprise for Big Bang cosmologists was the discovery that some patterns of CMB temperature variation line up with the plane of our solar system, as illustrated for example in fig. 16.[41] In fact, generally, there is greater temperature variation in the southern hemisphere than the northern hemisphere. Studies of spiral galaxies also show a similar anisotropy. These can have left-handed or right-handed spirals, and a clear pattern has been observed which is, again, aligned with the plane of our solar system.[42,43,44]

Professor Lawrence Kraus commented:

> "… when you look at CMB map, you also see that the structure that is observed, is in fact, in a weird way, correlated with the plane of the earth around the sun. … That's crazy. … That would say we are truly the center of the universe."[45]

Being an atheist, Professor Kraus does not believe that the earth has such a special position; but he accepts that CMB data imply that it does. Another possible explanation is that what we are observing is not a *Cosmic* Microwave Background Radiation, i.e. something associated with the whole 'cosmos' (the whole universe), but a *Local* Microwave Background Radiation, something associated with our solar system. Either way, the Big Bang model is left with a major problem. If the microwave background is cosmic, this suggests that the universe is not isotropic; if so the mathematical models describing the Big Bang and the evolution of the universe come into question. If the microwave background is local, this invalidates much of the evidence for the Big Bang.

For many Big Bang cosmologists, the strongest evidence in support of their model comes from its good fit with the measured CMB power spectrum shown in fig. 11. From this, the case for dark matter and the figure for its density are said to have been established beyond doubt. Sceptics respond that this good fit is unremarkable because it is achieved by adjusting free parameters. For example, it has been demonstrated that the green line shown in fig. 11 can be obtained using an alternative model that does not include 'dark matter'.[46] Significantly, for a particular model, various combinations of parameters can be made to fit the data.[47] Sceptics point out that these different versions of Big Bang cosmology cannot all be right and that this demonstrates, yet again, that a model—and indeed all proposed models—can be wrong even though they give the 'right results'.

Analysis of these Planck satellite data (assuming the Big Bang model) yields a value for the Hubble constant, $H_0 = 67.4$ km/s/Mpc.[48] The value based on studies of stars known as cepheids is $H_0 = 74.03$ km/s/Mpc.[49] Other methods yield different values.[50] This discrepancy is known as the *Hubble tension* and various solutions have been proposed to address this. These include the introduction of another type of 'dark matter' which no longer exists[51] and variations in 'dark energy' in the early universe.[52] These provide additional 'free parameters' that can be varied to make the theory agree with observations. Unsurprisingly, they are regarded by sceptics as yet more 'sticking plasters', akin to epicycles, used to rescue a failing model.

Are successful predictions of amounts of light elements really strong evidence for the Big Bang?

In order for the Big Bang model to predict the amounts of the light elements generated by 'Big Bang nucleosynthesis', it is necessary to have an estimate of the total amount of normal (baryonic) matter that was produced. For many years Big Bang cosmologists had no way of estimating this so they calculated what would be needed for the model to give the right result.[53] In other words, the parameter was given the 'right value' so that the calculation gave the amounts of hydrogen, helium and deuterium believed to exist in the universe today. Subsequently, it was claimed that analyses of the CMB power spectrum (fig. 11) confirmed this value to be correct.

As discussed above, sceptics point out that other models with different values of the free parameters can also be made to fit the satellite data and therefore Big Bang cosmologists cannot claim that their model—including the amount of normal matter—has been demonstrated to be correct. Hence, sceptics say, the Big Bang only 'predicts' the amounts of light elements by using a 'fudge factor'. Moreover, even with this 'fudging', the model fails to predict the observed amount of lithium. This is known as the *lithium problem.* This is such a major failing of the model that some have suggested that the discovery of 'new physics' will be required to explain it.[54] Sceptics respond that such an appeal to 'unknown scientific laws' again demonstrates that Big Bang theory is more about faith than science.

The Big Bang and fine-tuning

Unless certain free parameters are set so as to have just the right values, the Big Bang model doesn't work. Perhaps the most obvious is the cosmological constant discussed above, which must be fine-tuned to 120 decimal places. To solve the horizon and flatness problems, the process of inflation must also be fine-tuned in various ways and must be adjusted so as to leave the density fluctuations of post-inflation universe in just the right state to birth stars and galaxies.[55]

According to the Big Bang model, the first stars were formed as pockets of gas came together under the influence of gravity. This is said to have happened because some regions of space were slightly denser than others, this 'lumpiness' becoming the 'seeds' of stars and galaxies. This lumpiness would have had to be just right. (See fig. 17.) Had it been insufficiently lumpy, gravity would not have been strong enough to draw the gas together to begin to form stars. Had it been too lumpy, the universe would have become a violent place, with whole galaxies collapsing into 'black holes' and stars packed too closely together to function as suns which could provide stable orbits for planets.

To give rise to stars and ultimately planets suitable for life, this initial lumpiness—the departure of the density of the universe from its average density known as 'Q'—would have had to be just right, approximately 0.00001 (5 decimal places). Less than 0.000001 (6 decimal places) and no stars would form; more than 0.0001 (4 decimal places) and the universe would have become chaotic. The inflation model can achieve practically any value of 'Q' and its free parameters are chosen to the give the right result.[56]

There are many other examples of values that would have had to be just right, exquisitely fine-tuned for the Big Bang model to work[57] and some argue that all this can be explained by a multiverse. This is discussed in chapter 11 of *Evolution, Creation and Science*.[58]

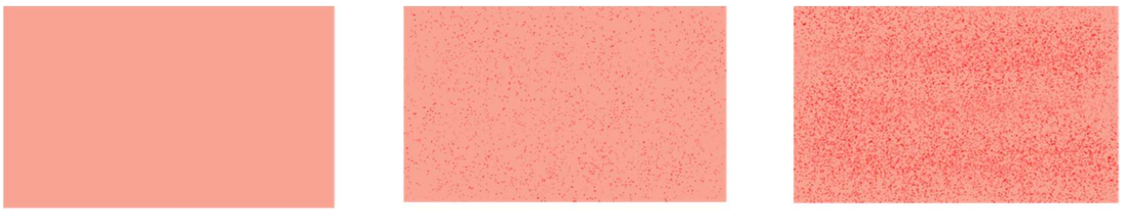

Fig. 17. Smoothness and lumpiness of the early universe. On the left the density of matter and radiation is perfectly even and smooth; in the middle it is slightly lumpy; on the right it is very lumpy. In Big Bang theory this lumpiness is the seedbed of galaxies, providing gravity with the potential to draw matter together to form stars. In a perfectly smooth universe, no stars could form; in a very lumpy universe, they would form in a chaotic way; only with just the right lumpiness could a stable galaxy form with a sun and planet Earth that could support life.

Naturalism and uniformitarianism

Many advocates of the Big Bang model will admit that it has deficiencies. Nevertheless, they still hold firmly to it, believing that future research will resolve its problems. Generally, at the heart of this view is a commitment to, or faith in, the doctrines of *naturalism* and *uniformitarianism*. Naturalists hold that only natural laws can be considered in seeking to explain the existence of all that we see around us. Atheists, for example, are 'materialists' believing that nothing exists outside of that which is material (matter/energy). For them any consideration of the supernatural must be excluded and therefore the universe must have arisen entirely by natural processes. Typifying this 'worldview' Professor Richard Lewontin wrote:

> "It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on the contrary, that we are forced by our *a priori* adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated. Moreover, that materialism is absolute, for we cannot allow a Divine Foot in the door."[59]

Many naturalists consider that, of all the proposed 'scientific' explanations for the universe, the Big Bang is the best and, for this reason, have concluded that it is valid. Others maintain that this thinking has two obvious flaws. Firstly, the view that everything can be explained by natural processes is not scientific as it cannot be deduced from any known scientific principles. There is no proof that the universe did or even could arise by natural laws. Secondly, just because a particular scientific model appears better than all the alternatives, this doesn't establish that it is correct. For example, for many years Ptolemy's model of the planetary system seemed to be the best; but it was still wrong!

Uniformitarianism holds that 'the present is the key to the past', i.e. that the natural processes known today reflect the processes that have generally operated throughout history. Hence, for example, the expansion of the universe observed in the present is interpreted as indicating that, from its inception, it has always been expanding, and in a similar way. Acceptance of this view inevitably leads to the conclusion that the universe began as a singularity. Others argue that assumptions about the past are simply that—assumptions—and cannot be known with any certainty. Moreover, some point out that 'inflation' is a significant departure from uniformitarianism.

The Big Bang and the Bible

Generally, biblical creationists who hold to a literal six-day creation reject Big Bang theory because it contradicts the order of events taught in Genesis. Whereas with the Big Bang model the first stars form before the earth, in Genesis the earth is created first. That is, the earth is created on Day 1 (Genesis 1:1) and the sun, moon and stars on Day 4 (Genesis 1:14–19). Creationists point out that neither naturalism nor uniformitarianism—the pillars of Big Bang theory—have been demonstrated to be valid; rather they are assumed or 'taken by faith'. Hence the view that the universe started as a singularity is not one that has been demonstrated to be true by science. See also chapter 2 of *Evolution, Creation and Science*.[60]

Some argue that six-day creation cannot be true because science has shown that the universe must be extremely old. For example, at the currently observed speed of light, it would take billions of years for light from distant stars to reach the earth. Hence, it's said, the universe must be billions of years old rather than just thousands of years old as the Bible indicates. Similarly, it's argued, 'young earth creationists' cannot explain ancient supernovae (stars that appear to have exploded billions of years ago) or galaxies which appear to have collided over very long periods of time.

Some creationists respond that the events of Creation Week were supernatural and therefore purely naturalistic explanations for them are not required (and nor are they appropriate). Hence, they would say that 'young earth creationists' have no more need to explain apparently ancient stars than they need to explain how Adam was made from the dust of the earth (Genesis 2:7). Another example of 'mature creation' is Christ's miracle at a wedding feast when he turned water into high quality wine (John 2:1–11).

Some have suggested that God rapidly brought into being an apparently ancient universe by speeding up processes that would normally have taken very long periods of time. Light travel, for example, could have been miraculously enhanced so that light from distant stars reached the earth in just hours. Some creation scientists are seeking to develop models which address these issues based on known physical laws, i.e. to explain how God might have used natural processes to produce the universe we know today in just six days.[61,62]

Some 'old earth creationists' say that God made the universe through the Big Bang and deal and the apparent contradiction with Genesis by arguing that the passage does not teach that the stars were *made* on 'Day 4', but simply *appeared* at that time. That is, they had been made previously, along with the 'heavens' (Genesis 1:1), but only became visible later. Others argue that this interpretation is difficult to justify. In Genesis 1:16, the Hebrew word translated 'made' is *asah*:

> "God made [*asah*] two great lights—the greater light to govern the day [the sun] and the lesser light to govern the night [the moon]. He also made the stars."

A review of over twenty major Bible translations reveals that all render *asah* as 'made' rather than 'appeared'.[63] Moreover, had the writer of Genesis 1 intended to convey the sense of 'appearing' rather than 'making' there is a much better Hebrew word he could have chosen, i.e. *ra'ah*. This is used, for example, in Genesis 1:9:

> "And God said, 'Let the water under the sky be gathered to one place, and let dry ground appear [*ra'ah*].' And it was so."

In the main, theistic evolutionists (also known as 'evolutionary creationists') subscribe to the generally accepted secular account of origins, beginning with the Big Bang and ending with the evolution of people through the Darwinian process. The required Big Bang fine-tuning, they say, arose through the divine hand.

Summary

Supporters of Big Bang theory say that their model provides a 'precision cosmology', with many carefully measured data confirming its predictions, and many independent lines of enquiry indicating it to be correct. Particularly, the redshifting of light coming from galaxies correlated with their distance is indicative of an expanding universe; the CMB is consistent with a universe that was once in a hot, dense state; and Big Bang nucleosynthesis accurately predicts amounts of light elements found today. Hence, they say, we can be confident that the Big Bang provides a true account of the history of the universe.

Sceptics say that, while the model makes some correct predictions, the same can be said of many failed models in the past. The Big Bang, they argue, only appears scientific because only the data supporting it are generally presented and little is said about its problems. These include missing anti-matter, the unexpected generally uniform CMB, the flatness of space and the absence of magnetic monopoles. Appeals to 'unknown science' and mysterious processes like 'inflation', they say, are just fudges, used whenever convenient to prop up a failing theory, and the need to adjust free parameters to make the model fit with observations makes it unscientific. Finally, the degree of fine-tuning required is thought to stretch its credulity beyond breaking point.

Biblical 'young earth' creationists reject Big Bang theory, arguing that the order of events and the timescales contradict the Genesis account of creation. They also point out that the assumptions of naturalism and uniformitarianism are imposed on the 'science' rather than derived from it. Generally, 'old earth' and 'evolutionary' creationists say that God used the Big Bang to create the universe and fine-tuned its parameters so as to make it work.

Update January 2025

Images from the James Webb Space Telescope (JWST) have raised more serious scientific problems for Big Bang theory. Being much larger than previous telescopes, the JWST can gather far more light allowing it to peer much deeper into space. In the thinking of Big Bang cosmologists this enables it to observe the universe as it was closer to the dawn of time—shortly after the Big Bang. The images, however, are not what they expected, being quite different from that which the Big Bang model predicted. So surprising are the data that one news article was titled, 'Has Webb broken cosmology?'[64]

In May 2024, it was reported that the JWST had observed the most distant galaxy ever seen, subsequently named JADES-GS-z14-0. According to Big Bang theory, due to its extreme distance from the earth, it must have formed around 290 million years after the Big Bang.[64] Yet it was fully formed and "shockingly large".[65] According to Big Bang theory, no such galaxy should have existed then as there wouldn't have been enough time for the stars to form. Even harder for Big Bang proponents to explain is the JWST's identification of large black holes 'dated' to 740 million years after the Big Bang. Again, according to their models, these could not have formed so quickly.[66]

In addition, a carbon cloud was observed 'dated' to 350 million years after the Big Bang. Again, according to Big Bang theory this should not exist as carbon only formed in large quantities around a billion years after the Big Bang.[67]

Big Bang sceptics argue that all this seriously undermines an already floundering model. Good scientific theories, they say, make predictions which are later confirmed by observations. In contrast Big Bang theory must be constantly adjusted to accommodate new data that would otherwise falsify it.

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Fig. 2: Expansion of the universe
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Fig. 3: CMB maps
thecmb.org, Damian P. George (celestial sphere)
ESA and the Planck Collaboration (projection)

Fig. 4: Blackbody frequency curve
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Fig. 8: Flat, closed and open universes
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Fig. 9: CMB power spectrum modes
lambda.gsfc.nasa.gov, NASA

Fig. 10
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Fig. 11: CMB power spectrum
esa.int/ESA_Multimedia/Images/2013/03/Planck_Power_Spectrum, ESA and the Planck Collaboration (modified)

Fig. 12: History of the universe according to the LCDM model
en.wikipedia.org/wiki/Big_Bang#/media/File:CMB_Timeline300_no_WMAP.jpg, NASAWMAP Science Team

Fig. 13: Aristotle's geocentric model
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en.wikipedia.org/wiki/Jupiter#/media/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg, NASA, ESA, and A. Simon (Goddard Space Flight Center)

Fig. 14: Ptolomy's model
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en.wikipedia.org/wiki/Jupiter#/media/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg, NASA, ESA, and A. Simon (Goddard Space Flight Center)

Fig. 15: CMB anisotropy (projected)
esa.int/ESA_Multimedia/Images/2013/03/Planck_enhanced_anomalies, European Space Agency and the Planck Collaboration

Fig. 16: CMB anisotropy (celestial sphere)
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en.wikipedia.org/wiki/Jupiter#/media/File:Jupiter_and_its_shrunken_Great_Red_Spot.jpg, NASA, ESA, and A. Simon (Goddard Space Flight Center)

Fig. 17: Lumpiness of early universe
Author