The shape of the universe and it's density parameter; the ratio of the actual density of the universe to the critical density that would be required to cause the expansion to stop

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This paper overviewing the answer to a reasonable question to wonder what the shape of the Universe is. Is it a sphere? A torus? Is it open or closed, or flat? And what does that all mean anyway? Is it doubly curved like a western saddle? What can determine the entire fate of the Universe. Does the Universe go on forever? If not is there some kind of giant brick wall at the edge of the Universe? As it turns out, the answer is both simpler and weirder than all those options. What does the Universe look like is a question we love to guess at as a species and make up all kinds of nonsense.

Shape of the universe | Flat universe | Expanding universe

Introduction

Hindu texts describe the Universe as a cosmic egg, the Jains believed it was human-shaped. The Greek Stoics saw the Universe as a single island floating in an otherwise infinite void, while Aristotle believed it was made up of a finite series of concentric spheres, or perhaps its simply turtles all the way down.

There are three main flavors we consider: positively-curved, negatively-curved, and flat. We know it exists in at least four dimensions, so any of the shapes we are about to describe are bordering on Lovecraftian geometry.

A positively curved Universe would look somewhat like a four-dimensional sphere. This type of Universe would be finite in space, but with no discernible edge. In fact, two distant particles traveling in two straight lines would actually intersect before ending up back where they started.

Method

Grab a balloon and draw a straight line with a sharpie. Your line eventually meets its starting point. A second line starting on the opposite side of the balloon will do the same thing, and it will cross your first line before meeting itself again.

This type of Universe, conveniently easy to imagine in three dimensions would only arise if the cosmos contained a certain, large amount of energy.

To be positively curved, or closed, the Universe would first have to stop expanding, something that would only happen if the cosmos housed enough energy to give gravity the leading edge.

Present cosmological observations suggest that the Universe should expand forever. So, for now, were tossing out the easy to imagine scenario.

A negatively curved Universe would look like a four dimensional saddle. Open, without boundaries in space or time. It would contain too little energy to ever stop expanding.

Here two particles traveling on straight paths would never meet. In fact, they would continuously diverge, getting farther and farther away from each other as infinite time spiraled on.

If the Universe is found to contain a Goldilocks-specific, critical amount of energy, teetering perilously between the extremes, its expansion will halt after an infinite amount of time, this type of Universe is called a flat Universe. Particles in a flat cosmos continue on their merry way in parallel straight paths, never to meet, but never to diverge either.

Sphere, saddle, flat plane. Those are pretty easily to picture. There are other options too like a soccer ball, a doughnut, or a trumpet. A soccer ball would look much like a spherical Universe, but one with a very particular signature a sort of hall of mirrors imprinted on the cosmic microwave background. The doughnut is technically a flat Universe, but one that is connected in multiple places As large warm and cool spots in the CMB could actually be evidence for this kind of tasty topology.

Method to visualize a negatively curved cosmos

We made a saddle curled into a long tube, with one very flared end and one very narrow end. Someone in the narrow end would find their cosmos to be so cramped, it only had two dimensions. Meanwhile, someone else in the flared end could only travel so far before they found themselves inexplicably turned around and flying the other way. **Based on the most recent Planck data, released in February 2015, our Universe is most likely Flat. Infinitely finite, not curved even a little bit, with an exact, critical amount of energy supplied by dark matter and dark energy.**

Overview

Thinking about the shape of the Universe is in itself a bit absurd. When you consider the shape of anything, you view it from outside, yet how could you view the universe from outside? We generally approach two concepts:

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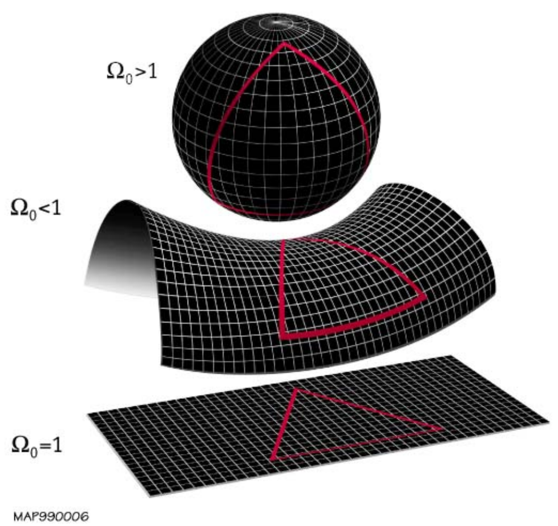

Fig. 1. The three possible options of the shape of the Universe

The local geometry. This concerns the geometry of the observable universe, along with its curvature. The global geometry. This concerns the topology, everything that is, as opposed to everything we can observe.

If we can observe the entire universe and were not limited somehow by its geometry or another characteristic, then the two coincide. But theres a good chance that the two dont coincide, and our observations are limited somehow by an intrinsic characteristic of the universe.

We expect the universe in its entirety to be symmetrically round a sphere-like shape, sort of like the Earth. Speaking of the Earth, lets consider it for a while. We know the Earth is not flat, but what does that mean? Geometrically, it means that parallel lines on its surface arent really parallel. All lines, even if they do start parallel, would end up uniting at one of the Poles, and the distance between them will not be constant.

So a flat Universe would mean that drawn parallel lines remain parallel and herein lies the key. Broadly speaking and simplifying things, we noted that the light from several galaxies remains parallel to each other, across large distances of the universe. The Baryon Oscillation Spectroscopic Survey telescope gave some very strong evidence that the observable universe is indeed flat. [1]

Finite vs Infinite

If the Universe is infinite, then the sky wouldnt be dark because in any direction youd look, there would be infinite space and eventually, youd encounter a star which would send its light. The night sky doesnt completely light up so voila, the universe isnt infinite, its not as simple as that. There could be a number of explanations for Olbers paradox, and none are simple. The universe is expanding rapidly, so distant stars are red-shifted into obscurity. Or light from other stars simply hasnt reached us yet.[4]

Universe in an expanding sphere. The galaxies farthest away are moving fastest and hence experience length contraction and so become smaller to an observer in the center.

The diameter of the observable Universe is 91 billion light-years. The distance the light from the edge of the observable universe has traveled is very close to the age of the Universe times the speed of light, 13.8 billion light-years, but this does not represent the distance at any given time because the edge of the observable universe and the Earth have since moved further apart. Because we cannot observe space beyond the edge of the observable universe, we cant know directly whether the Universe is infinite or not. Modern measurements, including those from the Cosmic Background Explorer (COBE), Wilkinson Microwave Anisotropy Probe (WMAP), and Planck maps of the CMB, suggest that the Universe is infinite in extent, but its still an ongoing debate. But what about the Big Bang?

A representation of the evolution of the universe over 13.77 billion years. The far left depicts the earliest moment we can now probe, when a period of inflation produced a burst of exponential growth in the universe.

The Big Bang is a connection, and this is where the most misconceptions lie. Because thats when space came into existence, we can't say the universe is expanding in all directions equally but thats likely not how things went down. Before the Big Bang, there was no space or time. So, there is nothing outside the Big Bang in which the universe to expand to. The Universe simply expanded from a very small volume into a huge volume, and this expansion is occurring even today but theres no guarantee that the expansion took place symmetrically, in all directions.

So, in the end, were left with a potentially flat, potentially infinite universe, but what is its global shape? Even if lines are parallel and the observable universe is flat, it doesnt mean that the whole universe is flat. It could be a Mbius strip for all we knowa shape where space bends and distorts, but lines stay parallel, ultimately connecting one end of space to another.

There are three distinct possibilities, all with their own distinct implications:

Universe with zero curvature. A flat universe. Not necessarily infinite, and not necessarily looking like a sheet of paper. It could also have a shape like a torus. Universe with positive curvature. A sphere-like shape. Universe with negative curvature. A three-dimensional analog of an infinitely extended saddle shape.

The expanding universe. The fate of the universe is determined by a struggle between the momentum of expansion and the pull of gravity. The rate of expansion is expressed by the Hubble Constant, Ho, while the strength of gravity depends on the density and pressure of the matter in the universe. If the pressure of the matter is low, as is the case with most forms of matter of which we know, then the fate of the universe is governed by the density. If the density of the universe is less than the "critical density", which is proportional to the square of the Hubble constant, then the universe will expand forever. If the density of the universe is greater than the "critical density", then gravity will eventually win and the universe will collapse back on itself, the so called "Big Crunch". However, the results of the WMAP mission and observations of distant supernova have suggested that the expansion of the universe is actually accelerating, which implies the existence of a form of matter with a strong negative pressure, such as

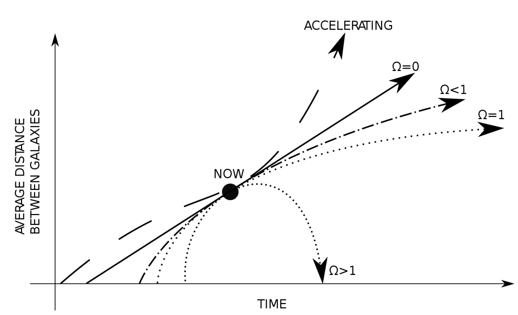

Fig. 2. The expansion of the universe proceeds in all directions as determined by the Hubble constant.

the cosmological constant. This strange form of matter is also sometimes referred to as "dark energy". If dark energy in fact plays a significant role in the evolution of the universe, then in all likelihood the universe will continue to expand forever.[5]

How Fast is the Universe Expanding

The expansion or contraction of the universe depends on its content and past history. With enough matter, the expansion will slow or even become a contraction. On the other hand, dark energy drives the universe towards increasing rates of expansion. The current rate of expansion is usually expressed as the Hubble Constant. But the universe is expanding faster according to the detecting of variable stars in several nebulae by using the newly constructed 100 telescope at Mount Wilson Observatory in the 1920s and with the evolutionary of Hubble discovery because we couldn't detect the distance of those stars because nebulae are diffuse objects so were they interstellar clouds in our own Milky Way galaxy, or whole galaxies outside our galaxy it is notoriously difficult to measure the distance to most astronomical bodies since there is no point of reference for comparison. Hubble helped to answer the question because these variable stars had a characteristic pattern resembling a class of stars called Cepheid variables. Earlier, Henrietta Levitt, part of a group of female astronomers working at Harvard College Observatory, had shown there was a tight correlation between the period of a Cepheid variable star and its luminosity (intrinsic brightness). By knowing the luminosity of a source it is possible to measure the distance to that source by measuring how bright it appears to us: the dimmer it appears the farther away it is. Thus, by measuring the period of these stars (and hence their luminosity) and their apparent brightness, Hubble was able to show that these nebula were not clouds within our own Galaxy, but were external galaxies far beyond the edge of our own Galaxy.

Hubble's second revolutionary discovery was based on comparing his measurements of the Cepheid-based galaxy distance determinations with measurements of the relative velocities of these galaxies. He showed that more distant galaxies were moving away from us more rapidly:

v = Hod

where v is the speed at which a galaxy moves away from us, and d is its distance. The constant of proportionality Ho is now called the Hubble constant. The common unit of velocity used to measure the speed of a galaxy is km/sec, while the most common unit of for measuring the distance to nearby galaxies is called the Megaparsec (Mpc) which is equal to 3.26 million light years or 30,800,000,000,000,000,000 km! Cepheid variables remain one of the best methods for measuring distances to galaxies and are vital to determining the expansion rate (the Hubble constant) and age of the universe. Hubble found that the universe was not static, but rather was expanding!

The Inflation Theory proposes a period of extremely rapid (exponential) expansion of the universe during its first few moments. It was developed around 1980 to explain several puzzles with the standard Big Bang theory, in which the universe expands relatively gradually throughout its history.

Imagine living on the surface of a soccer ball (a 2-dimensional world). It might be obvious to you that this surface was curved and that you were living in a closed universe. However, if that ball expanded to the size of the Earth, it would appear flat to you, even though it is still a sphere on larger scales. Now imagine increasing the size of that ball to astronomical scales. To you, it would appear to be flat as far as you could see, even though it might have been very curved to start with. Inflation stretches any initial curvature of the 3-dimensional universe to near flatness.

The density of the universe also determines its geometry. If the density of the universe exceeds the critical density, then the geometry of space is closed and positively curved like the surface of a sphere. This implies that initially parallel photon paths converge slowly, eventually cross, and return back to their starting point (if the universe lasts long enough). If the density of the universe is less than the critical density, then the geometry of space is open (infinite), and negatively curved like the surface of a saddle. If the density of the universe exactly equals the critical density, then the geometry of the universe is flat like a sheet of paper, and infinite in extent. The simplest version of the inflationary theory, an extension of the Big Bang theory, predicts that the density of the universe is very close to the critical density, and that the geometry of the universe is flat, like a sheet of paper.

Measurements from WMAP. The WMAP spacecraft can measure the basic parameters of the Big Bang theory including the geometry of the universe. If the universe were flat, the brightest microwave background fluctuations (or "spots") would be about one degree across. If the universe were open, the spots would be less than one degree across. If the universe were closed, the brightest spots would be greater than one degree across.

Recent measurements (c. 2001) by a number of ground-based and balloon-based experiments, including MAT/TOCO, Boomerang, Maxima, and DASI, have shown that the brightest spots are about 1 degree across. Thus the universe was known to be flat to within about 15 percent accuracy prior to the WMAP results. WMAP has confirmed this result with very high accuracy and precision. We now know (as of 2013) that the universe is flat with only a 0.4 percent margin of error. This suggests that the Universe is infinite in extent; however, since the Universe has a finite age, we can only observe a finite volume of the Universe. All we can truly conclude is that the Universe is much larger than the volume we can directly observe.

One of the most profound insights of General Relativity was the conclusion that mass caused space to curve, and objects traveling in that curved space have their paths deflected, exactly as if a force had acted on them. If space itself is curved, there are three general possibilities for the geometry of the universe. Each of these possibilities is tied to the amount of mass (and thus to the total strength of gravitation) in the universe, and each implies a different past and future for the universe.

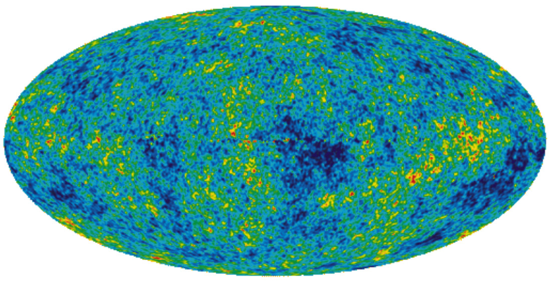

Fig. 3. WMAP image of background cosmic radiation

General Relativity asserts that space itself (not just an object in space) can be curved, and furthermore, the space of General Relativity has 3 space-like dimensions and one time dimension, not just two as in our example above. This IS difficult to visualize! Nevertheless, it can be described mathematically by the same methods that mathematicians use to describe the 2-dimensional surfaces. So what do the three types of curvature - zero, positive, and negative -mean to the universe?

If space has negative curvature, there is insufficient mass to cause the expansion of the universe to stop. In such a case, the universe has no bounds, and will expand forever. This is called an open universe.

If space has no curvature (i.e, it is flat), there is exactly enough mass to cause the expansion to stop, but only after an infinite amount of time. Thus, the universe has no bounds and will also expand forever, but with the rate of expansion gradually approaching zero after an infinite amount of time. This is termed a flat universe or a Euclidian universe (because the usual geometry of non-curved surfaces that we learn in high school is called Euclidian geometry).

If space has positive curvature, there is more than enough mass to stop the present expansion of the universe. The universe in this case is not infinite, but it has no end (just as the area on the surface of a sphere is not infinite but there is no point on the sphere that could be called the "end"). The expansion will eventually stop and turn into a contraction. Thus, at some point in the future the galaxies will stop receding from each other and begin approaching each other as the universe collapses on itself. This is called a closed universe.

The geometry of the universe is often expressed in terms of the "density parameter", which is defined as the ratio of the actual density of the universe to the critical density that would be required to cause the expansion to stop. Thus, if the universe is flat (contains just the amount of mass to close it) the density parameter is exactly 1, if the universe is open with negative curvature the density parameter lies between 0 and 1, and if the universe is closed with positive curvature the density parameter is greater than 1.

The density parameter determined from various methods such as calculating the number of baryons created in the big bang, counting stars in galaxies, and observing the dynamics of galaxies both near and far. With some rather large uncertainties, all methods point to the universe being open (i.e. the density parameter is less than one). But we need to remember that it is unlikely that we have detected all of the matter in the universe yet.

The current theoretical belief (because it is predicted by the theory of cosmic inflation) is that the universe is flat, with exactly the amount of mass required to stop the expansion (the corresponding average critical density that would just stop the is called the closure density). Recent observations (such as the BOOMERANG and MAXIMA cosmic microwave background radiation results, and various supernova observations) imply that the expansion of the universe is accelerating. If so, this strongly suggests that the universe is geometrically "flat".

Measurements indicate that the universe is flat, suggesting that it is also infinite in size. The speed of light limits us to viewing the volume of the universe visible since the Big Bang; because the universe is approximately 13.8 billion years old, scientists can only see 13.8 billion light-years from Earth.

Measuring the cosmos

We are studying cosmology measure the expansion of the universe and its density to determine its shape.

While studying distant galaxies in the early 20th century, astronomer Edwin Hubble realized that they all seemed to be rushing away from the Milky Way. He announced that the universe was expanding in all directions. Since then, astronomers have relied on measurements of supernova and other objects to refine calculations of how quickly the universe is expanding.

Other instruments measure the background radiation of the universe in an effort to determine its shape. NASA's Wilkinson Microwave Anisotropy Probe (WMAP) measured background fluctuations in an effort to determine whether the universe is open or closed. In 2013, scientists announced that the universe was known to be flat with only a 0.4 percent margin of error.

Result

We observe the entire universe as a flat universe and by measurement of the cosmos and CMB using COBE, WMAP and Planck we live in a flat universe (the observable universe).

The whole universe shape goes under three possibilities:

- We live in an open universe where it contain infinite number of pi galaxies.
- We live in a closed universe as if you traveled along a straight path that extend without a beginning or an end, travel with out any turns, you can return back where you were started, and according to general relativity, the space curved itself so everything is following straight lines, but this happen if the density of the universe is high enough than the critical density, and we would be analogous to 2 dimensional being living on a sphere as we can only travel on the surface of this sphere and never go inside this sphere, this sphere is expanding and the expanding is accelerating faster than the speed of light, and according to General relativity, nothing can travel faster than the speed of light, and so objects get away from each others according to the expansion of the universe, and the faster the two galaxies are from one another the faster the distances between them increases, so the closed universe for us is like an open universe as we won't reach the limits of the universe if the speed of light will still faster than us

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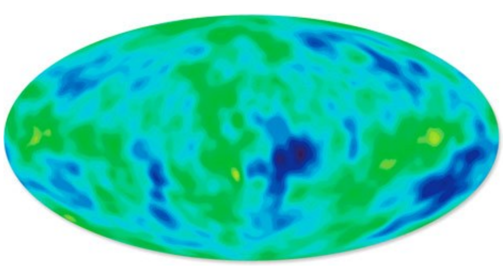

Fig. 4. The Cosmic Background Explorer Probe (COBE)

There are some missions that helped us to measure the shape and fate of the universe like COBE in 1992, WMAP 2003 and planck 2013.

COBE

The purpose of the Cosmic Background Explorer (COBE) mission was to take precise measurements of the diffuse radiation between 1 micrometer and 1 cm over the whole celestial sphere. The following quantities were measured: (1) the spectrum of the 3 K radiation over the range 100 micrometers to 1 cm; (2) the anisotropy of this radiation from 3 to 10 mm; and, (3) the spectrum and angular distribution of diffuse infrared background radiation at wavelengths from 1 to 300 micrometers.

COBE Highlights COBE revolutionized our understanding of the early cosmos. It precisely measured and mapped the oldest light in the universe – the cosmic microwave background. The cosmic microwave background spectrum was measured with a precision of 0.005 percent. The results confirmed the Big Bang theory of the origin of the universe. The very precise measurements helped eliminate a great many theories about the Big Bang. The mission ushered cosmologists into a new era of precision measurements, paving the way for deeper exploration of the microwave background by NASA's WMAP mission and ESA's Planck mission.

Wilkinson Microwave Anisotropy Probe WMAP

The Wilkinson Microwave Anisotropy Probe (WMAP) is a NASA Explorer mission that launched June 2001 to make fundamental measurements of cosmology – the study of the properties of our universe as a whole. WMAP has been stunningly successful, producing our new Standard Model of Cosmology. WMAP's data stream has ended.

Results The WMAP science team has determined, to a high degree of accuracy and precision, not only the age of the universe, but also the density of atoms; the density of all other non-atomic matter; the epoch when the first stars started to shine; the "lumpiness" of the universe, and how that "lumpiness" depends on scale size. In short, when used alone (with no other measurements), WMAP observations have improved knowledge of these six numbers by a total factor of 68,000, thereby converting cosmology from a field of wild speculation to a precision science.

WMAP's "baby picture of the universe" maps the afterglow of the hot, young universe at a time when it was only 375,000 years old, when it was a tiny fraction of its current age of 13.77 billion years. The patterns in this baby picture were used to limit what could have possibly happened earlier, and what happened in the billions of year since that early time. The (mis-named) "big bang" framework of cosmology, which posits that the young universe was hot and dense, and has been expanding and cooling ever since, is now solidly supported, according to WMAP.

WMAP observations also support an add-on to the big bang framework to account for the earliest moments of the universe. Called "inflation," the theory says that the universe underwent a dramatic early period of expansion, growing by more than a trillion trillion-fold in less than a trillionth of a trillionth of a second. Tiny fluctuations were generated during this expansion that eventually grew to form galaxies.

Remarkably, WMAP's precision measurement of the properties of the fluctuations has confirmed specific predictions of the simplest version of inflation: the fluctuations follow a bell curve with the same properties across the sky, and there are equal numbers of hot and cold spots on the map. WMAP also confirms the predictions that the amplitude of the variations in the density of the universe on big scales should be slightly larger than smaller scales, and that the universe should obey the rules of Euclidean geometry so the sum of the interior angles of a triangle add to 180 degrees. Detailed Studied of Temperature and Polarization in the CMB Credit: NASA/WMAP Science Team / PNG(17 Kb) PNG(46 Kb) PDF(598 Kb)

The universe comprises only 4.6 percent atoms. A much greater fraction, 24 percent of the universe, is a different kind of matter that has gravity but does not emit any light — called "dark matter". The biggest fraction of the current composition of the universe, 71 percent, is a source of anti-gravity (sometimes called "dark energy") that is driving an acceleration of the expansion of the universe.

WMAP has also provided the timing of epoch when the first stars began to shine, when the universe was about 400 million old. The upcoming James Webb Space Telescope is specifically designed to study that period that has added its signature to the WMAP observations.

WMAP launched on June 30, 2001 and maneuvered to its observing station near the "second Lagrange point" of the Earth-Sun system, a million miles from Earth in the direction opposite the sun. From there, WMAP scanned the heavens, mapping out tiny temperature fluctuations across the full sky. The first results were issued in February 2003, with major updates in 2005, 2007, 2009, 2011, and now this final release. The mission was selected by NASA in 1996, the result of an open competition held in 1995. It was confirmed for development in 1997 and was built and ready for launch only four years later, on-schedule and on-budget.

Planck

Planck was a space observatory operated by the European Space Agency (ESA) from 2009 to 2013, which mapped the anisotropies of the cosmic microwave background (CMB) at microwave and infra-red frequencies, with high sensitivity and small angular resolution. The mission substantially improved upon observations made by the NASA Wilkinson Microwave Anisotropy Probe (WMAP). Planck provided a major source of information relevant to several cosmological and astrophysical issues, such as testing theories of the early Universe and the origin of cosmic structure; as of 2013, it has provided the most accurate measurements of several key cosmological parameters, including the average density of ordinary matter and dark matter in the Universe.

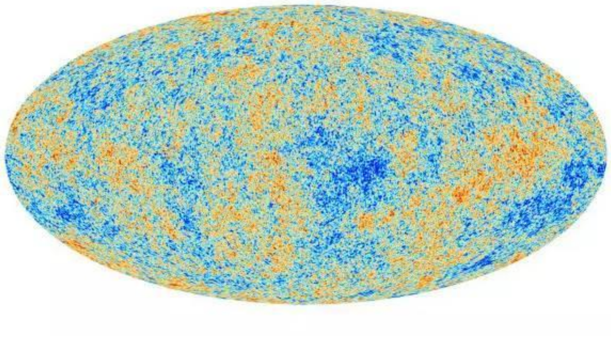

Fig. 5. The Cosmic Background from planck

The project was started around 1996 and was initially called COBRAS/SAMBA: the Cosmic Background Radiation Anisotropy Satellite/Satellite for Measurement of Background Anisotropies. It was later renamed in honour of the German physicist Max Planck (18581947), who derived the formula for black-body radiation.

Built at the Cannes Mandelieu Space Center by Thales Alenia Space, and created as a medium-sized mission for ESA's Horizon 2000 long-term scientific programme, Planck was launched in May 2009,[2] reaching the Earth/Sun L2 point by July, and by February 2010 had successfully started a second all-sky survey. On 21 March 2013, the mission's first all-sky map of the cosmic microwave background was released, with an expanded release including polarization data in February 2015.

At the end of its mission Planck was put into a heliocentric orbit and passivated to prevent it from endangering any future missions. The final deactivation command was sent to Planck in October 2013.

Appendix: Flat universe

A remarkable finding of the early 21st century, that kind of sits alongside the Nobel prize winning discovery of the universes accelerating expansion, is the finding that the universe is geometrically flat. This is a remarkable and unexpected feature of a universe that is expanding let alone one that is expanding at an accelerated rate and like the accelerating expansion, it is a key feature of our current standard model of the universe.

It may be that the flatness is just a consequence of the accelerating expansion but to date this cannot be stated conclusively.

As usual, its all about Einstein. The Einstein field equations enable the geometry of the universe to be modelled and a great variety of different solutions have been developed by different cosmology theorists. Some key solutions are the Friedmann equations, which calculate the shape and likely destiny of the universe, with three possible scenarios:

closed universe with a contents so dense that the universes space-time geometry is drawn in upon itself in a hyper-spherical shape. Ultimately such a universe would be expected to collapse in on itself in a big crunch.

open universe without sufficient density to draw in space-time, producing an outflung hyperbolic geometry commonly called a saddle-shape with a destiny to expand forever.

flat universe with a just right density although an unclear destiny.

Table 1. Three possibilities of the shape of the whole universe

Closed universe	Open universe	Flat universe
High density	Law density	Equal
Sphere	Saddle	Flat
Greater than 180 degrees	Less than 180 degrees	Equal 180 degrees

The Friedmann equations were used in twentieth century cosmology to try and determine the ultimate fate of our universe, with few people thinking that the flat scenario would be a likely finding since a universe might be expected to only stay flat for a short period, before shifting to an open (or closed) state because its expansion (or contraction) would alter the density of its contents. Flat universe Although the contents of the early universe may have just been matter, we now must add dark energy to explain the universe's persistent flatness. Credit: NASA.

Matter density was assumed to be key to geometry and estimates of the matter density of our universe came to around 0.2 atoms per cubic metre, while the relevant part of the Friedmann equations calculated that the critical density required to keep our universe flat would be 5 atoms per cubic metre. Since we could only find 4 percent of the required critical density, this suggested that we probably lived in an open universe but then we started coming up with ways to measure the universes geometry directly.

Theres a You-Tube of Lawrence Krauss (of Physics of Star Trek fame) explaining how this is done with cosmic microwave background data (from WMAP and earlier experiments) where the CMB mapped on the sky represents one side of a triangle with you at its opposite apex looking out along its two other sides. The angles of the triangle can then be measured, which will add up to 180 degrees in a flat (Euclidean) universe, more than 180 in a closed universe and less than 180 in an open universe.

Krauss: Why the universe probably is flat (video).

These findings, indicating that the universe was remarkably flat, came at the turn of the century around the same time that the 1998 accelerated expansion finding was announced.

So really, it is the universes flatness and the estimate that there is only 4 percent (0.2 atoms per metre) of the matter density required to keep it flat that drives us to call on dark stuff to explain the universe. Indeed we cant easily call on just matter, light or dark, to account for how our universe sustains its critical density in the face of expansion, let alone accelerated expansion since whatever it is appears out of nowhere. So, we appeal to dark energy to make up the deficit without having a clue what it is.

Given how little relevance conventional matter appears to have in our universes geometry, one might question the continuing relevance of the Friedmann equations in modern cosmology. There is more recent interest in the De Sitter universe, another Einstein field equation solution which models a universe with no matter content its expansion and evolution being entirely the result of the cosmological constant.

De Sitter universes, at least on paper, can be made to expand with accelerating expansion and remain spatially flat much like our universe. From this, it is tempting to suggest that universes naturally stay flat while they undergo accelerated expansion because thats what universes do, their contents having little direct influence on their long-term evolution or their large-scale geometry.

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