DOWNLOAD PDF THE COSMIC MICROWAVE BACKGROUND RADIATION

Chapter 1 : What is the cosmic microwave background radiation? - Scientific American

The cosmic microwave background radiation is an emission of uniform, black body thermal energy coming from all parts of the sky.

For thousands of years, human being have been contemplating the Universe and seeking to determine its true extent. And whereas ancient philosophers believed that the world consisted of a disk, a ziggurat or a cube surrounded by celestial oceans or some kind of ether, the development of modern astronomy opened their eyes to new frontiers. By the 20th century, scientists began to understand just how vast and maybe even unending the Universe really is. And in the course of looking farther out into space, and deeper back in time, cosmologists have discovered some truly amazing things. For example, during the s, astronomers became aware of microwave background radiation that was detectable in all directions. Known as the Cosmic Microwave Background CMB , the existence of this radiation has helped to inform our understanding of how the Universe began. The CMB is essentially electromagnetic radiation that is left over from the earliest cosmological epoch which permeates the entire Universe. It is believed to have formed about , years after the Big Bang and contains subtle indications of how the first stars and galaxies formed. While this radiation is invisible using optical telescopes, radio telescopes are able to detect the faint signal or glow that is strongest in the microwave region of the radio spectrum. The CMB is visible at a distance of However, it is not an indication of the true extent of the Universe. Given that space has been in a state of expansion ever since the early Universe and is expanding faster than the speed of light , the CMB is merely the farthest back in time we are capable of seeing. Relationship to the Big Bang: As the theory goes, when the Universe was born Due to the extreme heat and density of matter, the state of the Universe was highly unstable. Suddenly, this point began expanding, and the Universe as we know it began. At this time, space was filled with a uniform glow of white-hot plasma particles â€" which consisted of protons, neutrons, electrons and photons light. Between , and million years after the Big Bang, the photons were constantly interacting with free electrons and could not travel long distances. As the Universe continued to expand, it cooled to the point where electrons were able to combine with protons to form hydrogen atoms aka. In the absence of free electrons, the photons were able to move unhindered through the Universe and it began to appear as it does today i. Over the intervening billions of years, the Universe continued to expand and cooled greatly. These photons fill the Universe today and appear as a background glow that can be detected in the far-infrared and radio wavelengths. This theory was based on their studies of the consequences of nucleosynthesis of light elements hydrogen, helium and lithium during the very early Universe. Essentially, they realized that in order to synthesize the nuclei of these elements, the early Universe needed to be extremely hot. The Big Bang timeline of the Universe. Cosmic neutrinos affect the CMB at the time it was emitted, and physics takes care of the rest of their evolution until today. They further theorized that the leftover radiation from this extremely hot period would permeate the Universe and would be detectable. This was the result of American astronomers Arno Penzias and Robert Wilson using the Dicke radiometer, which they had intended to use for radio astronomy and satellite communication experiments. However, when conducting their first measurement, they noticed an excess of 4. Initially, the detection of the CMB was a source of contention between proponents of different cosmological theories. However, by the s, a scientific consensus had emerged that favored the Big Bang interpretation. ESA During the s, ground-based instruments placed increasingly stringent limits on the temperature differences of the CMB. Many experiments followed over the next decade, which consisted of ground and balloon-based experiments whose purpose was to provide more accurate measurements of the first acoustic peak. The second acoustic peak was tentatively detected by several experiments, but was not definitively detected until the Wilkinson Microwave Anisotropy Probe WMAP was deployed in Between and , when the mission was concluded, WMAP also detected a third peak. Since , multiple missions have been monitoring the CMB to provide improved measurements of the polarization and small scale variations in density. Future of the CMB: According to various cosmological theories, the Universe may at some point cease expanding and begin reversing, culminating in a collapse followed by another Big Bang â€" aka. In another scenario, known as the

Big Rip , the expansion of the Universe will eventually lead to all matter and spacetime itself being torn apart. If neither of these scenarios are correct, and the Universe continued to expand at an accelerating rate, the CMB will continue redshifting to the point where it is no longer detectable. At this point, it will be overtaken by the first starlight created in the Universe, and then by background radiation fields produced by processes that are assumed will take place in the future of the Universe.

Chapter 2 : Cosmic Background Radiation - The Big Bang and the Big Crunch - The Physics of the Univers

Cosmic Microwave Background Revealed by Planck Observatory (Gallery) Gallery: Planck Spacecraft Sees Big Bang Relics The CMB was created at a time in cosmic history called the Recombination Era.

See my copyright notice for fair use practices. Select the photographs to display the original source in another window. Links to external sites will be displayed in another window. George Gamov lived predicted in that there should be a faint glow left over from when the universe was much hotter and denser. Since the universe is observed to be expanding, it means that the galaxies were originally right on top of each other. Also, the energy of the universe was concentrated in a smaller volume. The entire universe would have glowed first in the gamma ray band, then the X-ray band, then to less energetic bands as the universe expanded. By now, about The expansion rate has slowed down over time because of the force of gravity. This means that the early expansion was faster than it is now. At the start of the expansion, the expansion rate was extremely rapid. The early large expansion rate and very hot temperatures made Fred Hoyle lived - call this theory of the birth of the universe, the Big Bang. At the time he coined the term, Hoyle was advocating another theory that used the perfect cosmological principle called the Steady State theory. However, the Big Bang proponents liked the term and used it from then on. Observation Arno Penzias and Robert Wilson observed in a radio background source that was spread all over the universethe cosmic microwave background radiation. The radiation has the same intensity and spectral character as a thermal continuous source at 3 K more precisely, 2. To a high degree of precision the sky is uniformly bright in radio. The uniformity of the background radiation is evidence for the cosmological principle. The error bars in the figure below are too small to be seen. Interpretation This background radiation is interpreted to be the relic of the early universe. If this is correct, then the early universe was very uniform. Since the further out in space you look means the further back in time you look, the microwave radiation is coming from the universe as it was a few hundred thousand years after the Big Bang when the universe was much hotter. The glow from the early hot universe has been redshifted by times! The early universe both the matter and the radiation was much more compact. The radiation density was so great that it dominated the expansion rate and the conditions of the universe for the first 10, years. The early universe was hot and opaque photons could not move very far before being absorbed. The freely-moving electrons, protons, and neutrons scattered the photons all about making the dense gas opaque. Dense hot gases will produce a continuous spectrum that depends only on the temperature a thermal spectrum. The universe cooled off as it expanded. Eventually, the early universe cooled to where the electrons and protons could combine to form neutral hydrogen atoms and not be blown apart by energetic photons. The process of the electrons becoming bound to the protons to make atoms is called recombination. Okay, "recombination" is not really correct since this was the first time that the electrons combined with the protons, but the term also describes processes that occur today. Extrapolating the expansion rate and the temperature of the universe backward in time, one finds that at the temperature of K, the universe was about , years old. That meant the photons could travel further without hitting some kind of unit particle. Also, the expansion of the universe spread the matter out. In addition, the coolness of the universe only K at the time of recombination meant that longer wavelengths of light were present. Instead of the gamma rays and X-rays of earlier times, the predominant form of radiation was the longer wavelength visible light and infrared. Longer wavelengths of light are able to more easily to pass through gas. For all of these reasons the photons could then travel long distances without running into some particle. The universe became transparent when the universe was glowing at the temperature of the surface of a cool star. The photons from this time are now reaching our radio telescopes. They are by far the oldest radiation that can be detected. The universe could not have been perfectly uniform, though. The universe must have been slightly lumpy to form galaxies and people later on from the internal gravity of the lumps. Gravity is symmetrical so it needed some initial density variations to provide some direction to where surrounding matter could be attracted. The COBE satellite found slight variations in the brightness of the background radiation of about 1 part in , The slight variations exist because some parts of the universe were slightly denser than other parts. The slightly denser regions had more gravity and attracted more material to them while the expansion occurred. Over time, the denser regions got even denser and eventually formed galaxies about 1 billion years after the Big Bang. The slightly less dense places got even emptier as gravity increased the contrast between the denser places and less dense places. See the figure at the end of the superclusters section for a simulation of this process. The galactic equator runs horizontally through the center of each map. The range of temperatures for each map is given in the caption. The colors for the temperatures range from blue for 0 K to red for 4 K yes, the color scheme is backwardblue should be hot and red should be cool. Notice that the background appears completely uniform at a temperature of 2. The colors for the temperatures range from blue for 2. The double-lobe pattern shows the doppler effect from the motion of the Sun with respect to the background radiation. The faint microwave contribution of the Milky Way is clearly seen along the center. The Cygnus constellation is at left center, the Sagittarius constellation is at the center, and the Orion constellation is at right center. With that greater resolution WMAP enabled us to learn the composition, geometry, and history of the universe, amount of matter in the universe, as well as, it provided much tighter constraints on the models. Selecting the map below will take you to the WMAP homepage in another window. The first data release in early confirmed the standard cosmology model derived from the COBE and WMAP missions but it did show some surprises at the really large scales 6 to 90 degrees across with slightly weaker than expected fluctuations at those scales and also an asymmetry in the temperature fluctuations across the two halves of the sky, where one hemisphere has a wider variation in the fluctuations than the other hemisphere. In the past, advances in technology led to breakthroughs in our understanding of the nature of the universe and the high-precision measurements of Planck may be indicating a need to modify the standard cosmology model. The time period between when the universe became transparent about , years after the Big Bang and formation of the first stars in the galaxies and the large black holes in the quasars began flooding the universe with powerful ultraviolet is called the "Dark Ages" or "Dark Era" in cosmological models. The ultraviolet light re-ionized the gas, freeing a lot of electrons. The light from the cosmic background would scatter off these newly freed electrons and become "polarized" so that the light waves tend to oscillate in a particular direction. How the light is polarized can tell you when the electrons were being freed again, i. WMAP has detected the polarization of the microwave background and derived a time of about million years after the Big Bang for the first stars. The visible light from these first stars will now have been redshifted into the infrared. The Hubble Space Telescope has detected near-infrared light from galaxies shining about million years after the Big Bang in the " Hubble Ultra Deep Field " and even further back million years after the Big Bang with the new WFPC3 camera and the Spitzer Space Telescope may have spotted infrared light from early galaxies of about that time in other areas of the sky see also link. One galaxy whose light was magnified by gravitational lensing by a foreground galaxy cluster appears to have formed a mere million years after the Big Bang. However, it will take the much larger light-gathering power and resolution of the infrared James Webb Space Telescope to study these objects in detail.

Chapter 3 : Cosmic Microwave Background - Introduction

Cosmic microwave background (CMB), also called cosmic background radiation, electromagnetic radiation filling the universe that is a residual effect of the big bang billion years ago. Because the expanding universe has cooled since this primordial explosion, the background radiation is in the microwave region of the electromagnetic spectrum.

This article looks at what the CBR is, how it was detected and why it is important for cosmology. While working with microwave communication technology Penzias and Wilson discovered a background noise, uniform in all directions, which they could not account for. Dicke and Peebles of Princeton University were at the time working on the hot Big Bang theory and realised that this "noise" was the radiation left over from the Big Bang. The radiation detected was measured at a temperature of 2. These slight variations are evidence of the conditions in the early universe and have been interpreted as evidence of a "lumpy" universe, also predicted by the Big Bang theory. These variations are thought to be the origin of galaxies and large structures in the universe. The CBR shows very strong evidence for the hot Big Bang theory as it suggests that the early universe was once very hot. COBE microwave measurements show redshift and blueshift indicating that our galaxy is travelling through space. From these readings, we can deduce that the speed of our galaxy relative to the CBR is around km s-1 towards the Virgo cluster. Cosmic Background Radiation map from COBE The slide above shows a false colour image of the entire sky projected onto an oval similar to a map of the Earth. The Milky Way extends horizontally across the centre of the image and has been subtracted from the results. The variations in the CBR temperature are shown as different colours. These variations are the "lumps" technical term: As the early universe expanded these clumps of matter went on to form galaxies and other large structures. What is the Cosmic Microwave Background Radiation? The microwave background radiation is believed to be the "visible" remnant from the Big Bang. In the very early stages of the universe the energy density was far greater than the mass density there was more energy per unit volume than matter. During the radiation era, photons were flying around with so much energy that they ionised any matter that tried to form. As the universe expanded, the radiation cooled and the matter was able to form without ionisation, causing the matter density to increase and became dominant. The stage is known as the matter era. The transitional phase between the two eras is called the age of recombination in which the universe expanded and cooled to around K. During this time photons could exist without ionising atoms and instead began travelling across the universe. The speed of light is finite and takes a time to reach us, for example when we look at the Sun, we see it as it was 8 minutes ago. When we look at the Andromeda galaxy, the light has taken about 2. In exactly the same way, when we look at the CBR we see the universe as it was Due to the extremely rapid expansion of the universe, the CBR is observed in the microwave spectrum because the original light emitted has been redshifted into the microwave wavelengths. Because the universe is expanding, we can express the temperature of the universe through time as a function of the scale factor. Equation 32 - Temperature scale factor This can also be simplified to become a factor of redshift like so: Equation 33 - Temperature redshift. Where T0 represents the current temperature of the universe. This is a far more useful function because we do not always know a time, but we can measure redshift from observations of spectra. This polarisation was an important discovery because it was initially predicted by the gravitational instability theory. This theory predicts that slight variations in density of the early universe will, over time, form larger structures. This not only verified results recording tiny lumps in the CBR, but it also validates our current understanding and theories of the universe. The Wilkinson Microwave Anisotropy Probe WMAP probe, a successor to COBE, has extended the original measurements with an even greater resolution, which allow us to see greater detail in the variations in the temperature of the CBR and provide accurate data for models of the shape, content and evolution of the universe. This data can then be used to test the Big Bang theory, inflation theory and any other theory of the formation of the universe. These peaks have been attributed to dark matter and have given evidence to support the inflationary theory of the universe. Combined sky images of microwave radiation commected by the WMAP satellite. The existence of the CBR is not only confirmation that our models for the evolution of the early universe are valid, but also through its analysis we are able to refine values for cosmological constants and ultimately move one step closer to understanding the universe in which we live. We eagerly await the first results from Planck Surveyor and the implications for Cosmology!

DOWNLOAD PDF THE COSMIC MICROWAVE BACKGROUND RADIATION

Chapter 4 : Cosmic microwave background radiation Facts for Kids

The Cosmic Microwave Background Radiation is the afterglow of the Big Bang; one of the strongest lines of evidence we have that this event happened. UCLA's Dr. Ned Wright explains. "Ok, I'm.

The temperature differences indicated by colour are about one part in ten thousand of the average 2. Matter was instead distributed as a highly ionised plasma which was very efficient at scattering radiation. As the Universe expanded, however, its temperature and density dropped to a point where the atomic nuclei and electrons were able to combine to form atoms. This is known as the epoch of recombination , and it is at this time that photons were finally able to escape the fog of the early Universe and travel freely. The data from COBE match the theoretical blackbody curve so exactly that it is impossible to distinguish the data from the curve. In particular, Big Bang theory predicts certain characteristics for the radiation left over from the birth of the Universe, all of which are confirmed by the CMB: The multiple scattering of photons by a hot plasma in the early Universe should result in a blackbody spectrum for the photons once they have escaped at the epoch of reionisation. This is exactly what is observed for the CMB. The agreement is so good that it is impossible to distinguish the data from the theoretical curve. The photons of the CMB were emitted at the epoch of recombination when the Universe had a temperature of about 3, Kelvin. This agrees well with what Big Bang theory predicts. In particular, once we remove the dipole that arises due to our motion in the Universe, the CMB is incredibly uniform across the sky, varying by no more than one part in ten thousand. However, this is not possible given standard Big Bang theory, the age of the Universe, and the finite speed of light. A period of inflation is also necessary so that regions of the early Universe are close enough to thermally equalise. Big Bang theory therefore makes it impossible for the whole Universe to have equalised its temperature at these early times, as not all the Universe was in communication. In everyday life we cannot receive information beyond our horizon, so this is known as the horizon problem. To resolve the horizon problem, astronomers introduced an inflationary period into the Big Bang model blue region in figure. This sudden increase in the rate of expansion of the Universe soon after the Big Bang, resolves not only the horizon problem, but also the flatness problem. It has therefore been accepted as part of the current concordance model of cosmology. The presence of a background radiation which has a temperature, spectrum and uniformity consistent with Big Bang cosmology and inflation, is extremely difficult to produce by any other means. Therefore, astronomers believe that by studying the properties of the CMB, they are in fact studying the conditions of the early Universe.

Chapter 5 : Cosmic Microwave Background | COSMOS

The cosmic microwave background (CMB) is thought to be leftover radiation from the Big Bang, or the time when the universe began. As the theory goes, when the universe was born it underwent a.

Back in the s, Stephen Hawking described the COBE discovery of temperature variations in the afterglow of the big bang as "the most important discovery of the century, if not of all time. He is the senior project scientist for this mission. JWST will be the greatest telescope launched into space. Its infrared cameras will detect the faint light from the first stars and galaxies to form in the universe, over 13 billion years ago. The observatory is also fine-tuned to search for extra-solar planets, dark matter and dark energy. Back in the s, Stephen Hawking described the COBE discovery of temperature variations in the afterglow of the Big Bang as "the most important discovery of the century, if not of all time. Each of these experiments zoom in on the temperature variations that COBE discovered. COBE is like the face that launched a thousand ships. Balloon experiments are important because they are relatively inexpensive to fly and they can utilize the latest technology. Because they are airborne for a maximum of about 40 days per year, however, the amount of data they can collect is limited. The space-based WMAP mission has been in orbit since , collecting remarkable data that very well may lead to another Nobel Prize--or two or three. Microwaves are a low-energy form of radiation but higher in energy than radio waves. The cosmic microwave background blankets the universe and is responsible for a sizeable amount of static on your television set--well, before the days of cable. From studying the temperature variations--a millionth of a degree hotter here, a millionth of a degree cooler there--the WMAP team could deduce fundamental properties of the universe, including its age and shape, the ratio of matter to energy, the era when stars first ignited, and rate at which the universe continues to expand. The universe is The team found evidence to support the concept of inflation, which poses that the universe expanded many trillion times its size faster than a snap of the fingers at the outset of the Big Bang. The first set observations had focused on the temperature differences. In that crucial split second, changes occurred that allowed for the creation of stars and galaxies many million years later. WMAP has revealed that the first stars--the forebears of all subsequent generations of stars and of life itself--were fully formed remarkably early, only about million years after inflation. Polarization is affected by the environment through which the light passes, such as the polarized glare of sunlight reflecting off of a shiny object. With a richer temperature map and the new polarization map, WMAP data favor the simplest versions of inflation. Generically, inflation posits that, at the outset of the Big Bang, quantum fluctuations--short-lived bursts of energy at the subatomic level--were converted by the rapid inflationary expansion into fluctuations of matter that ultimately enabled stars and galaxies to form. The simplest versions of inflation predict that the largest-sized fluctuations will also be the strongest. The most recent results from WMAP favor this signature. So What Powered the Big Bang? To understand what powered the Big Bang, scientists need to probe this fleeting, explosive moment called inflation. There are two types of polarization signals from the microwave background, which scientists call E and B modes. The E mode points to the era of reionization, when the universe, after cooling down for millions of years, became warm again with new stars. These first stars ionized hydrogen atoms, liberating electrons from the protons, which scattered and polarized the big bang afterglow. The new WMAP data indicate that reionization, and thus star formation, occurred million years after the Big Bang, the most accurate assessment to date. B modes point way back to the inflationary epoch, the calling card of the Big Bang. Inflation attempts to resolve two problems with the Big Bang theory: The universe is flat and uniform. Sure, any space will reach equilibrium given enough time. But the universe was at a uniform temperature at age , years. Energy would have had to move over times the speed of light to make things that uniform that early. Inflation provides the speed. Inflation also expands the universe quickly enough to flatten out any wrinkles in spacetime that could have been created by gravity or would have caused the nascent universe to implode. But the temperature map and the E-mode polarization map can make specific statements about inflation, such as an upper limit on its energy. Hearing the Big Bang Itself The European Space Agency plans to launch a mission called Planck in that will study microwave background polarization. The race is on. One route could be a highly advanced polarization detector. But other ideas might emerge as well. Theory predicts that we can directly detect the Big Bang, the very moment of the creation of space and time as we know it. This would be a remarkable achievement for humankind, and with dedication this visionary goal can be attain within two decades. No ordinary telescope will do. Light, or electromagnetic radiation, can only allow us to view the moments after the Big Bang. But the Big Bang made a rumble, a vibration in the fabric of space and time called a gravitational wave that is still ringing today. The ground-based LIGO experiment , now in operation, and the space-based LISA mission , proposed for launch next decade, hope to detect gravitational radiation from objects in the universe, such as black holes. There is overwhelming indirect evidence for their existence, though. The "Big Bang observer" would build upon LISA; this would be an ultra-sensitive detector tuned to the low, faint frequency of that primordial Big Bang gravitational wave. This is the Holy Grail of cosmology, to witness the birth of the universe. So as you can see, COBE was just the beginning of great science to come.

DOWNLOAD PDF THE COSMIC MICROWAVE BACKGROUND RADIATION

Chapter 6 : Cosmic Microwave Background: Remnant of the Big Bang

In cosmology, the cosmic microwave background radiation is a form of electromagnetic radiation discovered in that fills the entire universe. It has a thermal kelvin black body spectrum.

August 23, As the theory goes, when the universe was born it underwent a rapid inflation and expansion. The universe is still expanding today, and the expansion rate appears different depending on where you look. It is invisible to humans because it is so cold, just 2. This means its radiation is most visible in the microwave part of the electromagnetic spectrum. Origins and discovery The universe began Any atoms present at that time were quickly broken apart into small particles protons and electrons. The radiation from the CMB in photons particles representing quantums of light, or other radiation was scattered off the electrons. About , years after the Big Bang, the universe was cool enough that hydrogen could form. Because the CMB photons are barely affected by hitting hydrogen, the photons travel in straight lines. Cosmologists refer to a "surface of last scattering" when the CMB photons last hit matter; after that, the universe was too big. So when we map the CMB, we are looking back in time to , years after the Big Bang, just after the universe was opaque to radiation. The team was doing research related to Big Bang nucleosynthesis, or the production of elements in the universe besides the lightest isotope type of hydrogen. Wilson and Penzias won the Nobel Prize in physics for the find. They shared the award with Soviet scientist Pyotr Kapitsa. In , two researchers with Bell Telephone Laboratories Arno Penzias and Robert Wilson were creating a radio receiver, and were puzzled by the noise it was picking up. They soon realized the noise came uniformly from all over the sky. Later, Penzias and Wilson both received the Nobel Prize in physics. Studying in more detail The CMB is useful to scientists because it helps us learn how the early universe was formed. It is at a uniform temperature with only small fluctuations visible with precise telescopes. The Cosmic Microwave Background CMB radiation tells us the age and composition of the universe and raises new questions that must be answered. See how the Cosmic Microwave Background works and can be detected here. They also saw a strange asymmetry in average temperatures in both hemispheres of the sky, and a "cold spot" that was bigger than expected. Scientists uncovered another mystery with this information: Fluctuations in the CMB at large angular scales did not match predictions. Planck also confirmed what WMAP saw in terms of the asymmetry and the cold spot. Other research efforts have attempted to look at different aspects of the CMB. One is determining types of polarization called E-modes discovered by the Antarctica-based Degree Angular Scale Interferometer in and B-modes. B-modes can be produced from gravitational lensing of E-modes this lensing was first seen by the South Pole Telescope in and gravitational waves which were first observed in using the Advanced Laser Interferometer Gravitational Wave Observatory, or LIGO. In , the Antarctic-based BICEP2 instrument was said to have found gravitational wave B-modes, but further observation including work from Planck showed these results were due to cosmic dust. As of mid, scientists are still looking for the signal that showed a brief period of fast universe expansion shortly after the Big Bang. At that time, the universe was getting bigger at a rate faster than the speed of light. If this happened, researchers suspect this should be visible in the CMB through a form of polarization. A study that year suggested that a glow from nanodiamonds creates a faint, but discernible, light that interferes with cosmic observations. Now that this glow is accounted for, future investigations could remove it to better look for the faint polarization in the CMB, study authors said at the time.

Chapter 7 : Cosmic microwave background radiation - Simple English Wikipedia, the free encyclopedia

The Cosmic Microwave Background Radiation Perhaps the most conclusive, and certainly among the most carefully examined, piece of evidence for the Big Bang is the existence of an isotropic radiation bath that permeates the entirety of the Universe known as the "cosmic microwave background" (CMB).

As one measures the relative speeds of galaxies by using the Doppler shift of characteristic radiation emissions, one finds that all galaxies are moving away from one another. Those that are moving the fastest are systems that are the farthest awayâ€¦ Discovery of the cosmic background Beginning in , the American cosmologist George Gamow and his coworkers, Ralph Alpher and Robert Herman, investigated the idea that the chemical elements might have been synthesized by thermonuclear reactions that took place in a primeval fireball. As the universe expanded, the temperature would have dropped, each photon being redshifted by the cosmological expansion to longer wavelength, as the American physicist Richard C. Tolman had already shown in In the early s physicists at Princeton University , N. When they consulted Bernard Burke of the Massachusetts Institute of Technology , Cambridge, about the problem, Burke realized that Penzias and Wilson had most likely found the cosmic background radiation that Robert H. Peebles, and their colleagues at Princeton were planning to search for. Put in touch with one another, the two groups published simultaneously in papers detailing the prediction and discovery of a universal thermal radiation field with a temperature of about 3 K. Precise measurements made by the Cosmic Background Explorer COBE satellite launched in determined the spectrum to be exactly characteristic of a blackbody at 2. The velocity of the satellite about Earth , Earth about the Sun , the Sun about the Galaxy , and the Galaxy through the universe actually makes the temperature seem slightly hotter by about one part in 1, in the direction of motion rather than away from it. The COBE satellite carried instrumentation aboard that allowed it to measure small fluctuations in intensity of the background radiation that would be the beginning of structure i. The satellite transmitted an intensity pattern in angular projection at a wavelength of 0. Bright regions at the upper right and dark regions at the lower left showed the dipole asymmetry. A bright strip across the middle represented excess thermal emission from the Milky Way. To obtain the fluctuations on smaller angular scales, it was necessary to subtract both the dipole and the galactic contributions. An image was obtained showing the final product after the subtraction. Patches of light and dark represented temperature fluctuations that amount to about one part in ,â€”not much higher than the accuracy of the measurements. Nevertheless, the statistics of the distribution of angular fluctuations appeared different from random noise, and so the members of the COBE investigative team found the first evidence for the departure from exact isotropy that theoretical cosmologists long predicted must be there in order for galaxies and clusters of galaxies to condense from an otherwise structureless universe. The conditions at the beginning of the universe left their imprint on the size of the fluctuations. Today the universe is Although neutrinos are now a negligible component of the universe, they form their own cosmic background , which was discovered by WMAP. WMAP also showed that the first stars in the universe formed half a billion years after the big bang. On the one hand, it provides a strong justification for the assumption of homogeneity and isotropy that is common to most cosmological models. In the context of the cosmic microwave background, the problem can be expressed as follows. Consider the background radiation coming to an observer from any two opposite sides of the sky. Clearly, whatever are the ultimate sources hot plasma of this radiation, the photons, traveling at the speed of light since their emission by the plasma, have only had time to reach the Earth now. What accounts for the high degree of angular isotropy of the cosmic microwave background? The basic idea is that at high energies, matter is better described by fields than by classical means. The contribution of a field to the energy density and therefore the mass density and the pressure of the vacuum state need not have been zero in the past, even if it is today. After at least 85 doublings, the temperature, which started out at or K, would have dropped to very low values near absolute zero. Inflation provides a mechanism for understanding the overall isotropy of the cosmic microwave background because the matter and radiation of the entire observable universe were in good thermal contact within the cosmic event horizon before inflation and therefore acquired the same thermodynamic characteristics. Rapid inflation carried different portions outside their individual event horizons. When inflation ended and the universe reheated and resumed normal expansion, these different portions, through the natural passage of time, reappeared on our horizon. Through the observed isotropy of the cosmic microwave background, they are inferred still to have the same temperatures. Given the measured radiation temperature of 2. Thus, the current universe is matter-dominated. Thus, the radiation energy density becomes comparable to the energy density of ordinary matter at a redshift of about 1, At redshifts larger than 10,, radiation would have dominated even over the dark matter of the universe. Between these two values, at a redshift of about 1,, radiation would have decoupled from matter when hydrogen recombined. It is not possible to use photons to observe redshifts larger than this, because the cosmic plasma at temperatures above 4, K is essentially opaque before recombination. These photons from a redshift of 1, form the cosmic microwave background.

Chapter 8 : Cosmic microwave background | electromagnetic radiation | calendrierdelascience.com

The 'Cosmic Microwave Background radiation' (CMB) is the record of these photons at the moment of their escape. The data from COBE match the theoretical blackbody curve so exactly that it is impossible to distinguish the data from the curve.

So it is an interesting historical anomaly that this prediction was not put forward and tested by the inventors of either theory, and that the first observers of the CMB were completely unaware of its cosmological significance. The CMB has the spectrum of a blackbody. A blackbody spectrum is produced by an isothermal, opaque and non-reflecting object. Usually a cavity with a small hole is used in the laboratory to make an opaque and non-reflective object. Radiation that enters the cavity through the hole will have to bounce off many walls before it returns to the outside, so even if the walls are only somewhat dark, the hole will appear to be completely black. The diagram at right shows such a cavity, with the blue incoming ray being absorbed completely while the red rays show the outgoing thermal radiation. A simple gedanken experiment shows that the spectrum emitted by a blackbody can only depend on its temperature T. The proof first assumes that two blackbodies have different spectra and then shows that this leads to a contradiction. Then use a filter and aperture stops to allow them to transfer heat only by radiation in a given passband. Then the radiation of A is entirely absorbed by B, and the radiation of B is entirely absorbed by A. Since heat transfer between objects of the same temperature does not occur, the spectra must be identical. The choice of filter passband was arbitrary, so the spectra must be identical at all frequencies. Because of the universality of the blackbody spectrum, we can convert any spectral measurement into a brightness temperature at the measured wavelength. The unique character of a blackbody spectrum is that the brightness temperature of a blackbody is the same at all wavelengths. The graph above shows the measured brightness temperature TB of the CMB at many different wavelengths. In order to make a blackbody spectrum, an object as to be opaque, non-reflective and isothermal. Thus a star, which is opaque, does not produce a blackbody spectrum because we can see both cooler outer layers and hotter deeper layers. There was only a small hole in the end of the horn to let the radiation into the instrument. No signifcant difference could be seen. The CMB is very close to a blackbody with temperature 2. The FIRAS results are shown below in units of intensity power per unit area per unit frequency per unit solid angle vs. The plot at top shows this residual added to the theoretical blackbody spectrum at the best fitting XCAL temperature, based on the function derived by Planck in The three curves in the bottom correspond to three fairly likely non-blackbody spectra: The image at right shows a spectrum of the star zeta Oph taken in which shows the weak R 1 line from rotationally excited CN. The significance of these data was not realized at the time, and there is even a line in the book Spectra of Diatomic Molecules by the Nobel-prize winning physicist Gerhard Herzberg, noting the 2. He measured the brightness temperature of the sky as a function of the elevation angle. As his antenna pointed closer to the horizon the brightness temperature went up and became closer to the air temperature. Dicke used a low sidelobe flared horn, and he invented a rapidly switching differential radiometer for this work, now known as a Dicke radiometer, that switched between the sky and an ambient temperature K load. Using this data Dicke determined the absorption of the atmosphere at 1 to 1. The short wavelength allowed radars to fit inside fighter planes and greatly aided the Allied war effort in WW II. Dicke was not interested in the temperature of the sky outside the atmosphere but in Dicke et al. By using a room temperature load Dicke had a large difference signal at the zenith, and a few percent uncertainty in his absolute gain calibration generated a several Kelvin uncertainty in the sky temperature. The plot on the left above is the actual data from Figure 3 of the Dicke et al. On the right is a hypothetical experiment that could have been done in with a cold reference at a wavelength not on the water vapor line. If Dicke had used a low temperature load and had observed from a mountaintop instead of Florida, he would have detected the CMB. Ironically, the paper by Gamow describing the hot Big Bang occurs in the same volume of the Physical Review. But none of the participants in this debate ever looked further into the interstellar CN data, and thus the CMB remained undiscovered until Ironically Dicke had forgotten about his old upper limit, but he knew how to do the measurement. After hearing about their data, Dicke said: Wilkinson went on to measure the

CMB at a large number of wavelengths and always found the same brightness temperature over a wide range of wavelengths. Le Roux used an ordinary parabolic dish, which is not designed for very low sidelobes, and used the horizon as an absolute temperature reference. He also observed at MHz where the galactic foreground is very bright. This is a more reasonable assessment of the precision of these data.

Chapter 9 : Planck and the cosmic microwave background / Planck / Space Science / Our Activities / ESA

The Cosmic Microwave Background Radiation (CMBR) or Cosmic Background Radiation (CBR) is the afterglow from the early universe and provides strong evidence for the theory of a hot Big Bang. This article looks at what the CBR is, how it was detected and why it is important for cosmology.

The cosmic microwave background radiation is an emission of uniform, black body thermal energy coming from all parts of the sky. The radiation is isotropic to roughly one part in , The CMB dipole as well as aberration at higher multipoles have been measured, consistent with galactic motion. The remaining irregularities were caused by quantum fluctuations in the inflaton field that caused the inflation event. As the universe expanded , adiabatic cooling caused the energy density of the plasma to decrease until it became favorable for electrons to combine with protons , forming hydrogen atoms. The intensity of the radiation also corresponds to black-body radiation at 2. According to the Big Bang model, the radiation from the sky we measure today comes from a spherical surface called the surface of last scattering. This represents the set of locations in space at which the decoupling event is estimated to have occurred [14] and at a point in time such that the photons from that distance have just reached observers. The CMB spectrum has become the most precisely measured black body spectrum in nature. Discovery of cosmic microwave background radiation The cosmic microwave background was first predicted in by Ralph Alpher and Robert Herman. This high estimate was due to a mis-estimate of the Hubble constant by Alfred Behr, which could not be replicated and was later abandoned for the earlier estimate. Although there were several previous estimates of the temperature of space, these suffered from two flaws. First, they were measurements of the effective temperature of space and did not suggest that space was filled with a thermal Planck spectrum. Next, they depend on our being at a special spot at the edge of the Milky Way galaxy and they did not suggest the radiation is isotropic. The estimates would yield very different predictions if Earth happened to be located elsewhere in the universe. The mainstream astronomical community, however, was not intrigued at the time by cosmology. The first published recognition of the CMB radiation as a detectable phenomenon appeared in a brief paper by Soviet astrophysicists A. Doroshkevich and Igor Novikov , in the spring of Penzias and Wilson received the Nobel Prize in Physics for their discovery. This was largely because new measurements at a range of frequencies showed that the spectrum was a thermal, black body spectrum, a result that the steady state model was unable to reproduce. RELIKT-1 , a Soviet cosmic microwave background anisotropy experiment on board the Prognoz 9 satellite launched 1 July gave upper limits on the large-scale anisotropy. Inspired by the COBE results, a series of ground and balloon-based experiments measured cosmic microwave background anisotropies on smaller angular scales over the next decade. The primary goal of these experiments was to measure the scale of the first acoustic peak, which COBE did not have sufficient resolution to resolve. This peak corresponds to large scale density variations in the early universe that are created by gravitational instabilities, resulting in acoustical oscillations in the plasma. Relationship to the Big Bang[edit].