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Spectroscopy of Cosmic Waves

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Abstract : When the universe began to form 13.8 billion years ago, the big bang triggered an enormous number of mutations. 40,000 years after the Big Bang, cosmologists discovered the cosmic microwave background, also known as the CMB. Once thought to be merely some heat radiation left over from the Big Bang, or the moment the universe originated, the cosmic microwave background (or CMB) was discovered. The universe is filled with a very faint glow of light, or radiation, known as Cosmic Microwave Background radiation, or CMB radiation for short. The CMB radiation falls on Earth from all directions with a remarkably uniform intensity.

The maximal energy of cosmic rays accelerated in supernova remnants is limited and is determined by the size and strength of the acceleration region's magnetic field. The origin of these ultra-high energies is a major outstanding subject in astronomy because cosmic rays have been recorded at energies that are substantially greater than those produced by supernova remnants. They might originate from quasars, gamma-ray bursts, or active galactic nuclei that are outside of the galaxy.

A mathematical procedure known as "blackbody radiation inversion" uses the determined power radiation spectrum to estimate the temperature probability distribution. To determine the temperature distribution of the producing medium, this inversion approach is used to invert the blackbody radiation field corresponding to the cosmic microwave background, which is the hot big bang's residual radiation. The key characteristics of this distribution are examined, and the study of this distribution suggests that the cosmic microwave background spectrum contains distortion.

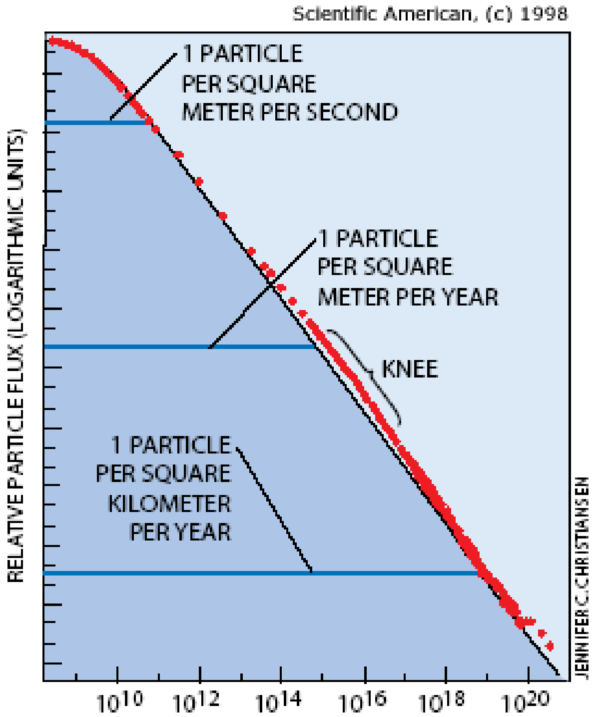
***IndexTerms* – Cosmic Microwave Background, Blackbody Radiation Inversion.**

INTRODUCTION

Representation of the energy spectrum of cosmic rays, which has been recorded up to 10^{21} electron volts. The energy of cosmic rays at their maximum energies is comparable to that of a well-hit tennis ball, but it is contained within a single atomic nucleus or particle.

Up to 10^{18} eV, the energy spectrum of cosmic rays has been comparatively well investigated. According to a preliminary estimation, the spectrum has an overall index of around 2.8 and follows a fast-dropping power law in energy, dN/dE. The spectrum does, however, exhibit some discernible structure, as evidenced by the rise in inflation of the spectral index beyond 10^{15} eV (from =2.7 to =3.0). The "knee" refers to this shift in the spectral index. A harsher spectral index (=2.7) above $5x10^{18}$ eV is followed by a second steepening at around $5x10^{17}$ eV (=3.3).

It is believed that variations in the particle's makeup and origins are connected with disruptions in the cosmic ray spectrum. Most cosmic rays are thought to be protons that have been speeded up in leftovers of supernovae inside our galaxy, below the "knee." A shift throughout the magnetic confinement of the cosmic rays can be inferred from the drop in flux near the "knee" in this image. The cosmic rays above a specific energy can traverse the magnetic fields in the Galaxy as their energies and gyro radii rise.



COSMIC RAYS

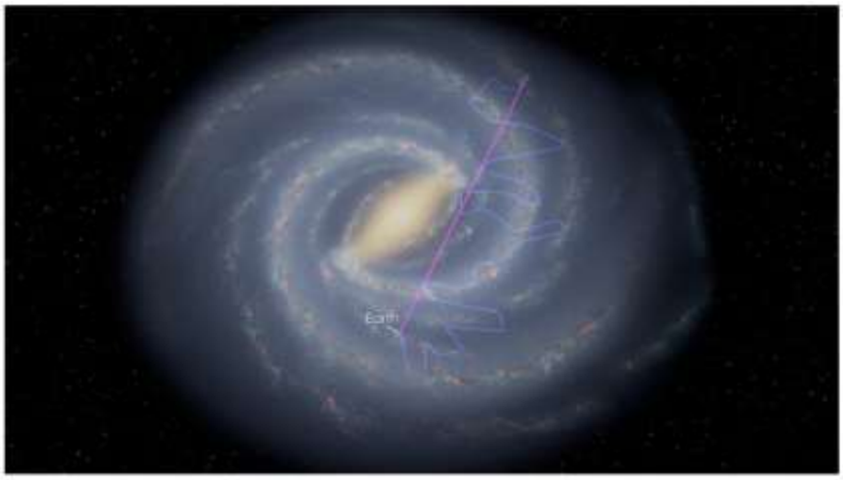
One of the few direct samples of material from outside the solar system that we have is from cosmic rays. These are very energetic particles that travel through space almost as swiftly as light. The majority of cosmic rays are made up of atomic nuclei that have lost their atoms, with protons (hydrogen nuclei) being the type that is most prevalent. But measurements have been made of nuclei of elements as heavy as lead. However, additional sub-atomic particles like neutrons, electrons, and neutrinos are also present in cosmic rays.

Magnetic fields have the ability to alter the direction of cosmic rays since they are charged particles with positively charged protons or nuclei or negatively charged electrons (except for the highest energy cosmic rays). We are unable to determine their precise origin because the magnetic fields of the solar system, the galaxy, and the Earth substantially obscure their flight patterns as they travel to Earth. So, we must use indirect methods to ascertain the origin of cosmic rays.

Studying the composition of cosmic rays is one method we can learn more about them. Electrons, protons, or other periodic table-aligned elemental nuclei are used in fraction computation. Protons are also referred to as hydrogen nuclei. As the various charges of each nucleus have quite different characteristics, determining the concentration of each separate element is rather simple. The isotope composition is a better signature because it is more difficult to measure (nuclei of the same element but with different numbers of neutrons). It amounts to analyzing each nucleus that passes the cosmic ray detector in order to distinguish the isotopes. Cosmic rays contain every natural element listed in the periodic table. This includes elements heavier than iron that are created in violent situations, such as a supernova near the conclusion of the life of a large star, as well as components lighter than iron that are created in stars.

We can learn more about the cosmic ray origins and their journey around the galaxy from the specific variances in their abundances. Protons make up around 90% of the cosmic ray nuclei, followed by helium (alpha particles) at 9% and all other elements at 1%. Although heavier elements are far rarer in cosmic radiation than iron, measuring them gives crucial insight into how cosmic rays accelerate and the material they are derived from.

The majority of galactic cosmic rays are most likely accelerated in supernova remnant blast waves. Cosmic rays are accelerated in these exploding remains, which are enormous masses of gas and magnetic fields which may persist for thousands of years. Randomly bouncing back and forth within the remnant's magnetic field causes certain of the particles to accumulate energy and develop into cosmic rays. They eventually pick up speed to the point where the remnant could no further confine them, and they burst into space.

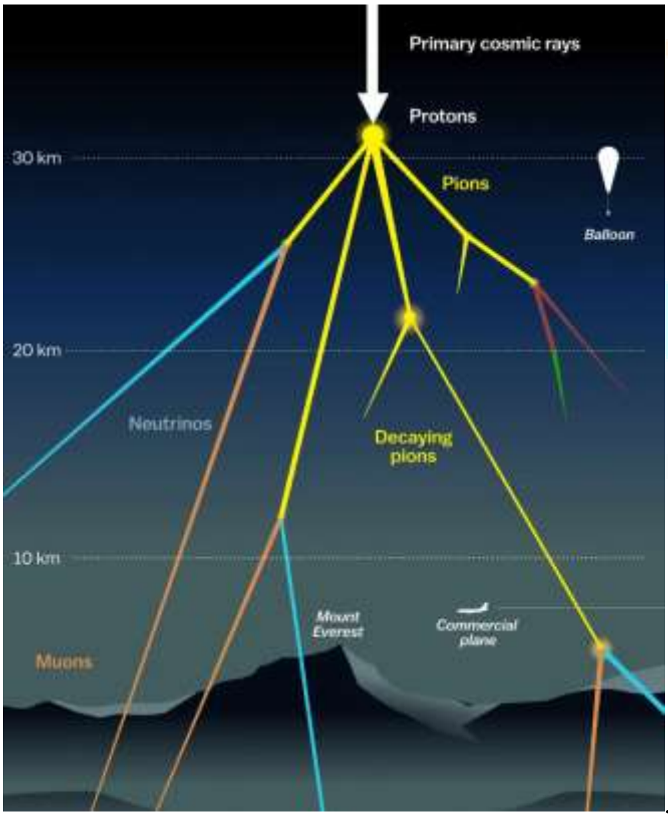


Because cosmic rays carry electric charge, their direction changes as they travel through magnetic fields. By the time the particles reach us, their paths are completely scrambled, as shown by the blue path. We can't trace them back to their sources. Light travels to us straight from their sources, as shown by the purple path. (Credit: NASA's Goddard Space Flight Center)

The historic balloon voyage undertaken by Austrian scientist Victor Hess in August 1912 provided a new perspective on the nature of the matter in the universe. He monitored the rate of ionization in the atmosphere as he rose to a height of 5300 meters and discovered that it increased to around three times that at sea level. He concluded that piercing radiation was coming from above. Cosmic rays were something he had found.

These high-energy comets are composed primarily (90%) of protons, the hydrogen (the universe's lightest and most prevalent element) nuclei. But they also contain nuclei of helium (9%) and heavier meteors (1%), all the way up to uranium. They clash with the atomic nuclei in the upper atmosphere when they reach Earth, producing more particles, primarily pions.
The charged pions can quickly decay and release muon-like particles. These, in contrast to pions, do not interact with matter very strongly and can travel through the atmosphere to pierce the ground. A volume the size of a person's head is traversed by around one muon each second as they arrive at the Earth's surface.

At its discovery in 1912, cosmic rays became a mystery. When Victor Hess, a physicist, went up in a hot air balloon at that time, he discovered that radiation levels rise with altitude. To shield his experiment from radiation, he was aboard the balloon. Further up, however, it was simply louder. Because of this, he concluded that space was the source of the radiation and not radioactivity in the earth's rocks.



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During a total solar eclipse, he also went on this balloon ride. The sun should have been shielded from cosmic radiation by the moon. Yet, he continued to record some. He gained the understanding as a result that the radiation was coming from further into space and not the sun. He received the physics Nobel Prize in 1936 for his discovery of cosmic rays.

Galactic Cosmic Rays (GCR) originate largely from inside our Milky Way galaxy however they also come from outside the solar system. Charged particles with energy ranging from 10^{10} to 10^{15} eV are known as galactic cosmic rays. Many astronomers think that they come from the shocks of supernova remnants because of their helical velocity around the magnetic field lines of the Galaxy, which makes their distribution appear isotropic (they are observed equally in all directions). These shocks and the magnetic fields they produce can endure for tens of thousands of years, however, over time the particles can be accelerated to energies high enough to allow them to escape the remnant as they bounce around the shocked area. Galactic cosmic rays have maximum energy that depends on the size of the acceleration region and the strength of the accompanying magnetic field because once they reach a certain energy, they do escape into the Galaxy. Galactic cosmic rays differ significantly from solar cosmic rays and anomalous cosmic rays in terms of their composition since they have a little enrichment in heavy elements, as well as lithium, beryllium, and boron. Observations of these latter elements' compositions allow us to infer their age (3–10 million years) as well as the amount of material that was transported to the Solar System. These latter elements are assumed to be the product of heavy nuclei fragmenting through interactions with interstellar debris.

Very high energy particles known as **Extragalactic cosmic rays** enter the Solar System from regions outside the Milky Way galaxy. At high energies, extragalactic cosmic rays predominate over low-energy cosmic rays, which often come directly from the Galaxy (such as supernova remnants). Despite being in the 10^{17}–10^{18} eV range, the precise energy at which the change from galactic to extragalactic cosmic rays takes place remains a mystery.

ULTRA-HIGH ENERGY COSMIC RAYS

Very energetic subatomic particles with energies more than 10^{15} eV are known as ultra-high energy cosmic rays (UHECRs). These particles are primarily protons, but they can also include heavier atomic nuclei. A UHECR now holds the record with an energy of 3×10^{20} eV, or perhaps the energy of a baseball thrown at 160 km/hour!

Presently, the only way to monitor UHECRs is through the cosmic ray showers they cause when they collide with the Earth's atmosphere. Because of the extremely small amounts of penetrating cosmic rays at such energy, this indirect technique of observation is necessary. The most sophisticated ground-based experiments to identify cosmic ray showers span several kilometers and include both fluorescence detectors used to trace the radiance of the particle as it travels through the atmosphere and Cherenkov detectors that monitor the light created by high-energy particles in a number of big water tanks.

As with the method used to elevate particles to high energy, the origin of UHECRs is still unknown. The majority of astronomers, however, assume that UHECRs are of extragalactic origin since they have enough energy to bypass the normal magnetic field of a spiral galaxy. Active galaxies, inactive quasars with supermassive black holes nearby, galaxy mergers, and dormant quasars are other potential sources.

Uncertainty still exists over how we are capable of identifying UHECRs at such high energy, even if they are produced in severe interstellar conditions. Cosmic rays should impact with the cosmic microwave background radiation at energies more than 5×10^{19} eV within 150 million light years, bringing their energy below this limit. The Greisen-Zatsepin-Kuzmin limit (GZK limit) is the theoretical upper limit to the energy of a cosmic ray, and the fact that we detect cosmic rays at energies higher than this appears to contravene special relativity's predictions.

COSMIC MICROWAVE BACKGROUND

Infrared and afterward microwave radiation would first appear when the light had redshifted and traveled far enough to lose its ability to be seen. This is how a very strong light from the big bang was created. After traveling for around 13.8 billion years, light is now observable and is recognized as a type of microwave emanating from just about every aspect of space. The Cosmic Microwave Background Radiation, which is a pretty imposing moniker for this light, is nothing less than the glow left over from the big bang.

The cosmos' background radiation is one of the finest discoveries. The Cosmic Microwave Background (CMB), which was discovered by astronomers in the 1960s and is observable in all directions of space, has contributed to our knowledge of how the Universe came into being.

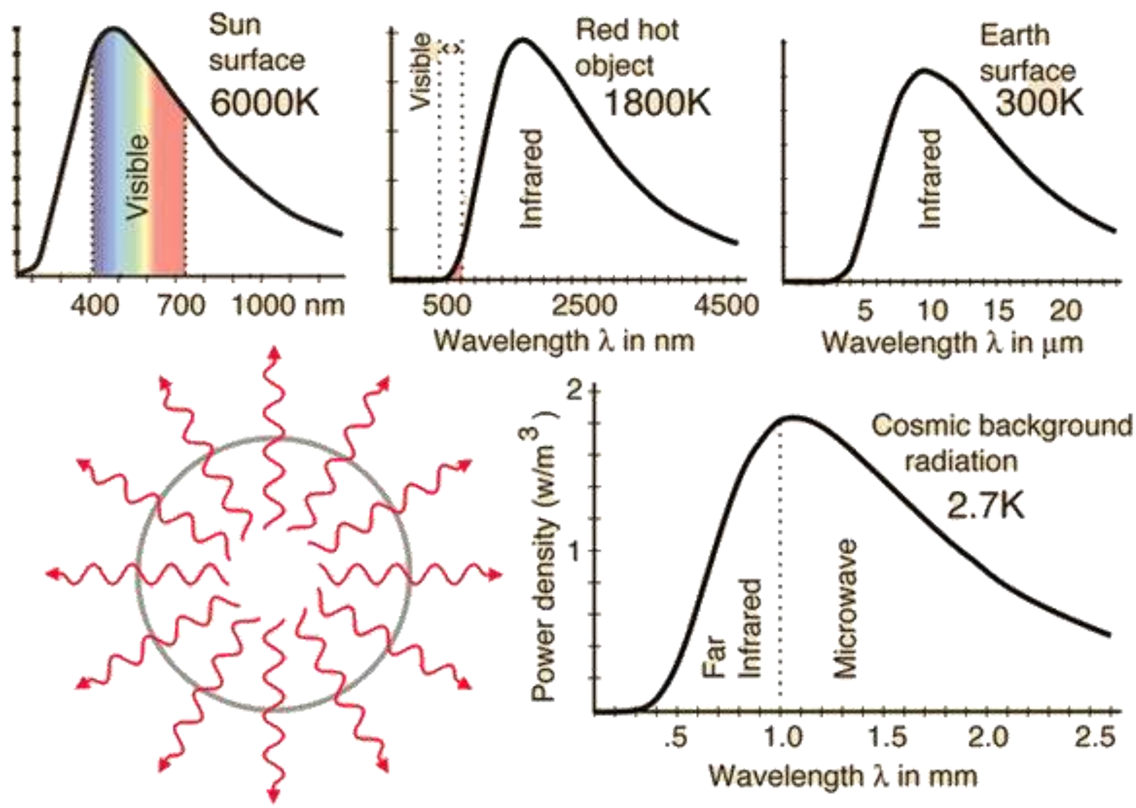
Because it is invisible to the human eye, cosmic background radiation is prevalent across the entire cosmos. Its low temperature, which is barely 2.725 degrees above absolute zero, or about minus 459.67 degrees Fahrenheit or minus 273.15 degrees Celsius, makes cosmic background radiation undetectable to humans. This explains why it is also referred as the Cosmic Microwave Background Radiation and why its emission is most noticeable in the microwave region of the electromagnetic spectrum.

One of the strongest arguments in favor of the Big Bang is the CMB, which was discovered for the first time by Arno Penzias and Robert Wilson in 1965. The CMB specifically confirms the following Big Bang theory predictions for the energy left behind from the creation of the Universe:

1. When photons escape at the moment of reionization after being repeatedly scattered by high energy particles in the early Universe, they should have a blackbody spectrum. For the CMB, this is precisely what is seen. The Cosmic Background Explorer (COBE) satellite's CMB measurements are plotted beside a hypothetical blackbody curve in the figure. Since the agreement is so strong, it is impossible to tell the difference between the observations and the theoretical curve.

2. The CMB photons were released during the recombination period when the temperature of the universe was approximately 3,000 Kelvin. They have been found in the microwave part of the electromagnetic spectrum at an average temperature of 2.725 Kelvin, but they have been cosmologically redshifted to longer wavelengths throughout their 13-billion-year transit through the expanding Universe. Big Bang theory predictions and this are in good agreement.

COMPARING COSMIC MICROWAVE RADIATION WITH BLACKBODY RADIATION



In all directions of the sky, constant background radiation in the microwave part of the spectrum is visible. These days, it is referred to as the Cosmic Microwave Background, or simply CMB, about its Wien peak in the microwave band spectrum. It displays the "blackbody" radiator's wavelength dependence at a temperature of roughly 3 Kelvin. It is believed to be a leftover from the radiation that the expanding universe released when it reached a temperature of about 3000 K and started to become transparent. The calculation of the conventional "Big Bang" model of cosmology required several key stages, one of which was the initial identification of the 3K microwave background radiation, which served as a proxy for relative particle and photon populations. The temperature measured by the COBE satellite's FIRAS (Far Infrared Absolute Spectrophotometer) was 2.725 +/- 0.002 K. However, COBE's data collection revealed fluctuations in the background, contradicting earlier experiments that had indicated certain distortions of the background radiation caused by the solar system's motion.

The ideal object is a blackbody, which can completely absorb incoming radiation of all frequencies. Planck's law can be used to express the total power emitted by a blackbody emitter at a given frequency and solid angle over a given region.

$$P(\nu) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Where ν= frequency

T= absolute temperature of body

h = Planck’s constant

k = Boltzmann's constant
c = the speed of light

Any celestial object's power spectrum is typically measured using telescopes. However, because of its limited field of view, a telescope can only ever observe a small sky area simultaneously. These tiny sections are made up of various blackbody radiators with various T temperatures, each in thermal equilibrium. The total radiated power per unit area for a group of black bodies with a probability distribution (T) and temperature T is determined by the integration of the distribution as

$$W(\nu) = \frac{2h\nu^3}{c^2}\int_0^\infty \frac{\alpha(T)}{e^{\frac{h\nu}{kT}}-1}\,dT$$

where W(v) = radiated power per unit frequency per unit area and per unit solid angle and
α (T) = probability distribution of temperature of the blackbody

The objective of the blackbody radiation inversion issue is to determine the temperature probability distribution from the radiated power spectrum.
In real fact, an empirically available set of discrete W(v) values is available. This set of data can be used to calculate (T) using the blackbody inversion method.
A dimensionless parameter is used in mathematics for ease.

$$G(\nu) = \frac{c^2}{2h\nu^3}W_{(\nu)}$$

$$G(\nu) = \int_0^\infty \frac{\alpha(T)}{e^{\frac{h\nu}{kT}}-1}\,dT$$

The limit ranges from zero to infinity since Equation considers all possible temperature levels.
Here, it is assumed that a group of black body radiators operate within a bounded frequency range of v and a temperature range of T_1 to T_2 that varies from black body to black body. Consequently, equation can be expressed as expressed as

$$G(\nu) = \int_{T_1}^{T_2} \frac{\alpha(T)}{e^{\frac{h\nu}{kT}}-1}\,dT$$

$$T = T_1 + (T_2 - T_1)\,t$$

$$G(\nu) = \int_0^1 \frac{\alpha(T_1 + (T_2 - T_1)t)}{e^{\frac{h\nu}{kT_1+(T_2-T_1)t}}-1}\,dT$$

$$G(\nu) = \int_0^1 K(\nu, t)\,a(t)\,dt$$

$$K(\nu, t) = \frac{(T_2 - T_1)}{e^{\frac{h\nu}{kT_1+(T_2-T_1)t}}-1}$$

$$a(t) = \alpha(T_1 + (T_2 - T_1)t)$$

$$a(t) = ke^{-k_2t^2}\sinh(k_3^2 t)$$

$$a(t) = ke^{-k_2t^2}\,\frac{e^{k_3^2t^2} - e^{-k_3^2t^2}}{2}$$

The distribution of the probability for the temperature is the information we are attempting to acquire using this approach. Probability distributions typically have characteristics that resemble Gaussian distributions.

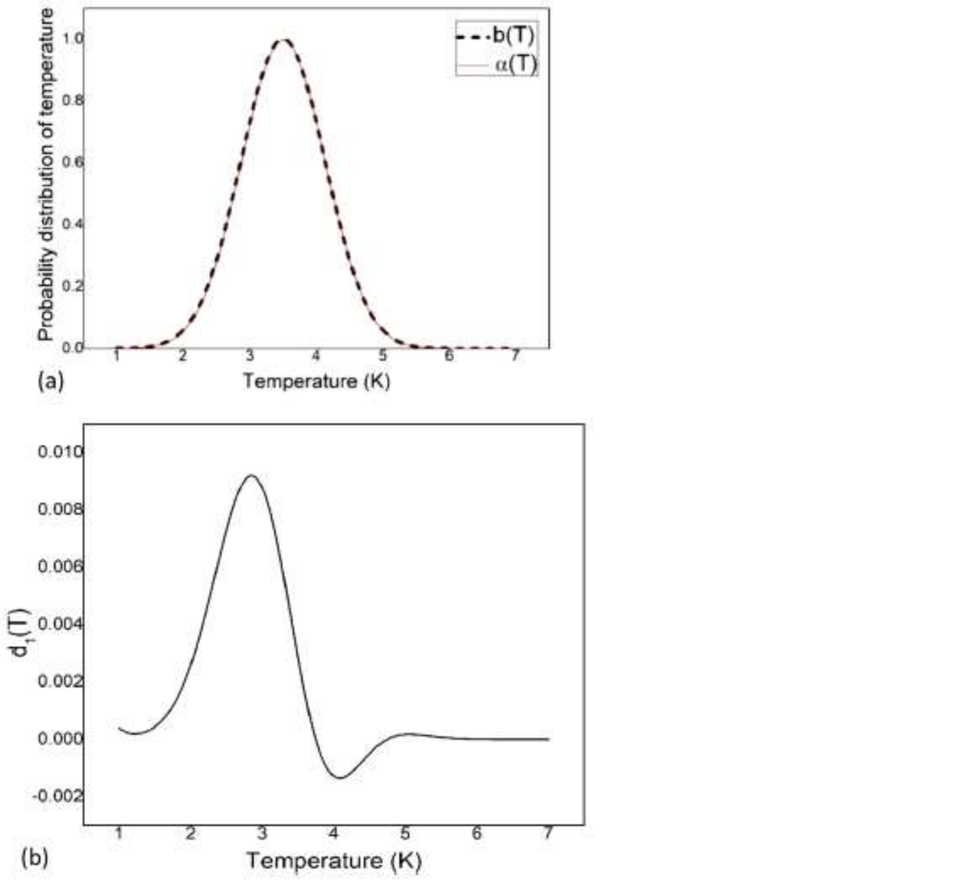


Figure 1. (**a**) Model function b(T) and reconstructed function α(T) are plotted against absolute temperature. Here $b(T)=e^{-\frac{(T-3.5)^2}{1}}$ and three frequencies of 5×10^{11} Hz, 6×10^{11} Hz and 7×10^{11} Hz are used to calculate α(T). (**b**) The difference between b(T) and α(T), $d_1(T)=b(T)-\alpha(T)$ is plotted against absolute temperature.

The initial detection revealed that the radiation was isotropic, or identical in all directions. However, later research revealed that radiation is anisotropic.

Studies that are more recent concentrate on the various CMB spectrum anomalies. It implies that the emission is a summation of various blackbodies with various temperatures rather than that of a blackbody with a single temperature. It produces various distortions when numerous blackbodies of various temperatures are combined.

CONCLUSION

The Big Bang theory states that the universe's initial 300,000 years of pressures and temperatures were insufficient for atoms to originate. A very ionized plasma that was exceptionally effective at scattering radiation was used to spread the matter alternatively. This had the effect of successfully trapping energy (photons) from the early Universe in an impenetrable "fog," which is still used today to conceal these earlier periods from investigators.
But, as the Universe grew, its temperature and density decreased to the point where atomic nuclei and electrons could come together to create atoms. Photons were eventually able to break free from the early Universe's obscuring fog and begin to move freely during this period, which is referred to as the epoch of recombination. These photons are captured in the "Cosmic Microwave Background radiation" (CMB), which is a record of their instantaneous escape.

The velocity of the celestial body through the radiation is thought to have generated a Doppler shift that results in an anisotropy of the background radiation from cosmic microwaves of about 0.1%. A differential microwave radiometer was employed by the COBE spacecraft to identify variations in the cosmic background of microwave radiation. The magnitude of the alterations is broader than what was known as the horizon at the moment when the background energy was transmitted, signifying that the fluctuations are fundamental and date from a period before the transparency point, which is the point at which radiation and matter are no longer mixed. The "horizon" is the area where causal relationships are possible, i.e., where they are separated by a distance equal to the speed of light.