Air and Space this Week

Item of the Week

THE *COSMIC BACKGROUND EXPLORER* SATELLITE

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The Big Bang Theory is more than a goofy TV show, it's actually the dominant theory of the earliest days of our Universe. Research into it has been a tour de force *of Physics, with a little luck, and some poop, thrown in. So far, the research has resulted in four people sharing two Nobel Prizes, and many other awards. And the* COBE *spacecraft was in the middle of it all.*

PENZIAS AND WILSON

COSMOLOGICAL DEBATE

The nature of galaxies, part of the Milky Way or vastly distant from the Milky Way, was largely resolved by 1930, when Edwin Hubble made spectroscopic observations of galaxies and found the wavelength of a galaxy's light is shifted red-ward, meaning the galaxy was moving away from us. Further observations showed that the more distant the galaxy, the faster it was receding.

After WWII, attention to cosmology resumed. The implications of Hubble's discovery were far-reaching. If everything is moving apart today, then everything must have been closer together in the past. When taken to the ultimate, all the mass in the Universe had to be in one place and then something happened to make the matter fly apart as observed. This not only had scientific implications, it had philosophical and even theological implications. The Universe had to have had a "Beginning!" This has evolved into the present "Big Bang" Theory. What came before? Was the gravity of the exploded masses strong enough to halt, even reverse, the expansion?

The alternative view was that the Universe is eternal, essentially unchanging. In order to have that be true in a Universe where everything is flying apart requires the continuous spontaneous generation of intergalactic matter. This is the "Steady-State" Theory. Was spontaneous creation of even a little bit of matter possible?

Either model was somewhat unsettling, but that was the state of cosmological knowledge in the 1950s.

THE BIRTH OF COMMUNICATIONS SATELLITES

The US and the USSR were on the way to building rockets capable of putting a payload in low-Earth orbit in the time of the International Geophysical Year (7/1/1957 to 12/31/1958). The USSR surprised everyone with the launch of *Sputnik 1* on October 4, 1957; the US would follow, after several spectacular public failures, on February 1, 1958. For more on this pivotal time period, see the past Item of the Week on *Explorer 1*.

Many of the scientists participating in the IGY knew of the advantages of the highest of "high ground" for meteorology, communications, and military activity, some well before the IGY began. Arthur C. Clarke, yes, the science fiction writer, had published a paper in 1945 about putting communications relays in geostationary orbits (meaning that they would stay in the same spot in the sky as seen from the Earth, making reception of their signals much easier; see here for the math involved). But the altitude needed for geosynchronous/geostationary orbit was much higher than the early rockets could reach.

Radio communications from the time of Marconi were pretty-much line-of-sight only. But Marconi discovered that some longer-wavelength signals seemed to follow the curvature of the Earth, at least at times. Transcontinental radio transmissions were, in fact, possible. We know now that those signals can be reflected by ionized particles in the ionosphere, the upper atmosphere of the Earth. at least when conditions were favorable.

The longer wavelengths used in the early days of radio required large antennas and had lower data-rates than desirable. R.A. Fessenden figured out a way to use shorter wavelengths that could carry more information, but were line-of-sight.

But if shorter-wave radio signals couldn't bounce off the ionosphere, perhaps something could be put aloft that would reflect the signals over the horizon, something in low-Earth orbit, perhaps. It would have to be a large something, to give enough signal strength at the receiving end.

Why not bounce a radio signal off the Moon? That was tried, and it actually worked (Operation Moon Bounce; see here)! But the Moon stubbornly refused to be in a convenient position for needed-now communications, or to receive clandestinely the radio signals of others.

A big target was needed in low-Earth orbit, but rockets were puny back then. NASA engineers came up with the idea of launching a large aluminized balloon (over 100' across when inflated), and bouncing the signals off that. Thus were born the *Echo 1* and *Echo 2* satellites. When they were in the right spot, radio signals bounced off them beautifully. However, they had to be in the right spot, and atmospheric drag on a huge, low-mass balloon limited their time on orbit to only a few years. Besides, the Echo satellites were passive reflectors, and advances in the 1960s in both rocketry and electronics allowed the use of active relay satellites such as those of the Telstar family to be developed. The Echo concept was obsolete.

Bell Labs was involved in the Echo program, and it had built several 20' horn-shaped antennas to be used in the communications testing. One of them was in Holmdel, New Jersey.

FROM ECHO TO PIGEON POOP…

Astrophysicists had come to realize that there was an observational test that could help decide about the Big Bang vs. Steady-state Models of the Universe. One of the byproducts of the Big Bang would be a very low level of residual heat would be pervasive throughout the expanding Universe. The first hint of a little heat in the interstellar realm came in 1941, when observations of the spectrum of a B-type star with cyano radical (CN) showed a background temperature of 2.3K, (mis)interpreted as the "rotational temperature of interstellar molecules."

Two Bell Labs physicists, Arno Allan Penzias and Robert Woodrow Wilson, realized that the horn antenna at Holmdel would be ideal for looking for residual heat in interstellar Space. The antenna needed refurbishing, and our heroes had to use liquid helium to cool the interference caused by their equipment, but they began to see a steady noise with a wavelength of 7.35 cm no matter where they looked. They eliminated New York City and other human-caused sources as the cause, and they also found that the interference was not coming from the Sun or any other object in the sky. They went to great lengths to eliminate any source of interference, even to the point of cleaning the antenna of droppings from the pigeons that liked to roost in the antenna. The faint signal at 7.35 K was coming from everywhere.

Meanwhile, Robert Dicke and colleagues at Princeton were modeling the Big Bang theory and the potential nature of any residual heat from it, and they began looking for it. Penzias and Wilson heard of Dicke's search and got in touch with him. A short trip brought Dicke to Holmdel, and he quickly confirmed P&W's observations as being caused by the residual temperature from the Big Bang. The peak wavelength of 7.35 cm would be emitted by a blackbody with a temperature of 3 K. Dicke was excited, but he knew he'd been "scooped" as thoroughly as the pigeons had.

… AND ON TO STOCKHOLM

Penzias and Wilson, and Dicke and his team, both published papers in the *Astrophysical Research Letters*. The Steady-state Theory immediately fell out of favor. Due to their priority, Penzias and Wilson got the lion's share of the credit for this great discovery of what now is called the "Cosmic Microwave Background" radiation (CMB), and would be awarded the **Nobel Prize in Physics for 1978**. The horn antenna that led them to the discovery became a National Historic Landmark in 1990. Even the pigeons got recognition; the now-defunct Explore the Universe gallery at the National Air and Space Museum used to have one of Penzias and Wilson's pigeon traps on exhibit!

And then a wrinkle in the theory arose. Subsequent observations with ever-more sensitive equipment showed that the CMB, while pervasive, was not strictly uniform. Confirming the slight variations and making sense of them required a new tool…

THE *CO*SMIC *B*ACGROUND *E*XPLORER SATELLITE (*COBE*)

A blackbody with a temperature of 3 K radiates energy whose wavelength peaks (weakly) at 7.35 cm. However, a lesser amount of energy is radiated at wavelengths somewhat less and somewhat more than that. To investigate the CMB in more detail required instruments more sensitive to a range of wavelengths, and with higher spatial resolution, than previously possible. Better shielding from interfering signals was important, too. Those constraints required a Space-based observing platform.

The USSR beat us to the punch. They launched the *Prognoz 9* satellite carrying the RELIKT-1 instrument designed to investigate the CMB and its variations ("anistotropy") on July 1, 1983.

The RELIKT-1 observations lasted only six months, but it made successful observations of the CMB dipole, the Galactic plane, and provided constraints on the quadrupole moment. An improved successor was being built in 1992, with a planned launch in mid-1993, but a variety of delays postponed the launch until 1996, but was ultimately cancelled with the dissolution of the USSR.

Meanwhile, NASA was making plans for a satellite to observe the CMB in detail. It would be called the "*COsmic Background Explorer*" (*COBE*). "The *COBE* satellite was developed by NASA's Goddard Space Flight Center to measure the diffuse infrared and microwave radiation from the early universe to the limits set by our astrophysical environment. It was launched November 18, 1989 and carried three instruments, a Diffuse Infrared Background Experiment (DIRBE) to search for the cosmic infrared background radiation, a Differential Microwave Radiometer (DMR) to map the cosmic radiation sensitively, and a Far Infrared Absolute Spectrophotometer (FIRAS) to compare the spectrum of the cosmic microwave background radiation with a precise blackbody. Each *COBE* instrument yielded a major cosmological discovery." (source of quote above and immediately below: https://lambda.gsfc.nasa.gov/product/cobe)

Just because the wavelength of the *peak* energy radiated by the CMB is 7.35 cm doesn't mean that the CMB energy is restricted to that particular wavelength. Lesser amounts of energy are radiated in wavelengths ranging from longer radio waves to infrared. A lot could be learned by detecting a wider spectrum of energy from the CMB, just as your eyes get more info from a range of colors than one single wavelength. Further, there were hints in earlier data that the CMB was not perfectly uniform everywhere; variations in it could be related to the details of the conditions of the Big Bang. COBE carried the three instruments named above to further the investigation.

***COBE* INSTRUMENTS**

DIRBE: The Cosmic Infrared Background "represents a "core sample" of the Universe; it contains the cumulative emissions of stars and galaxies dating back to the epoch when these objects first began to form. The *COBE* CIB measurements constrain models of the cosmological history of star formation and the buildup over time of dust and elements heavier than hydrogen, including those of which living organisms are composed. Dust has played an important role in star formation throughout much of cosmic history."

DMR: The hints about anisotropy of the CMB turned out to be true, even though it was very small (1 part in 100,000). "These tiny variations in the intensity of the CMB over the sky show how matter and energy was distributed when the Universe was still very young. Later, through a process still poorly understood, the early structures seen by DMR developed into galaxies, galaxy clusters, and the large-scale structure that we see in the Universe today."

FRIAS: A Planck wavelength curve for a blackbody that was 3 K was well-understood from theory. FRIAS could determine both the wavelength of the peak of the curve as well as how well the CMB conformed to blackbody radiative characteristics. FRIAS data from *COBE* showed that the CMB spectrum conformed very closely to "that of a nearly perfect blackbody with a temperature of 2.725 +/- 0.002 K. This observation matches the predictions of the hot Big Bang theory extraordinarily well, and indicates that nearly all of the radiant energy of the Universe was released within the first year after the Big Bang."

STOCKHOLM AGAIN!

The *COBE* satellite delivered amazing results that revealed the mechanisms and conditions of the Universe immediately after the Big Bang. 'Twas a BIG DEAL, indeed. So important that two of the scientists deeply involved in the mission, John Mather of NASA Goddard and George Smoot at UC Berkeley, were awarded the **2006 Nobel Prize in Physics**. [George Smoot is a distant relative of Oliver Smoot of "Smoot Unit" fame!]

COBE score (so far): Two Nobel Prizes, Four Nobel Laureates! Eat your heart out, other Kobe!

AFTERMATH

The issue of CMB anisotropy is fundamental to understanding the earliest time in the Universe. *COBE*'s DMR showed that the CMB was mottled, but additional precision of the data was crucial to understanding the details of the aftermath of the Big Bang. Electronics and instrumentation were making great advances technologically, so it only makes sense that a follow-up mission to *COBE*, maybe two, would be desirable.

WILKENSON MICROWAVE ANISOTROPY PROBE

WMAP was launched on June 30, 2001, and used a gravitational assist from the Moon to reach the L2 libration point (where JWST and other spacecraft reside now). Its data collection was planned for 2 years, but it actually worked for nine.

WMAP deserves a full Item of the Week treatment of its own. Someday.

Meanwhile, here's a brief summary: "*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 years 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." Source: https://map.gsfc.nasa.gov/news/index.html

Note the difference in detail between the COBE anisotropy map and the *WMAP* version!

The WMAP team won the Gruber Foundation's 2012 Cosmology Prize and the 2018 Fundamental Breakthrough Prize for Fundamental Physics.

ESA's PLANCK SATELLITE

The European Space Agency also launched a *COBE* follow-on mission of their own, *Planck*, named after the famous German physicist, Max Karl Ernst Ludwig Planck, who won the Nobel Prize for Physics in 1918 for his development of quantum theory. His work on blackbody radiation was fundamental to the underpinnings of the science used by COBE, WMAP, and PLANCK. The Planck Mission website is here: https://www.cosmos.esa.int/web/planck.

RESOURCES

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