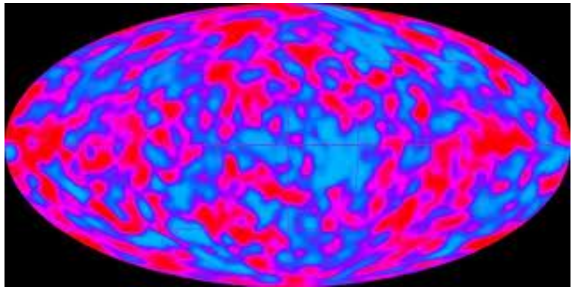
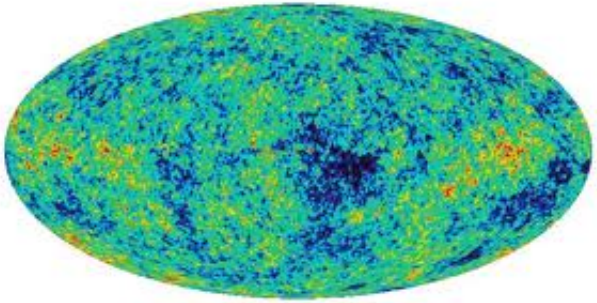
The Cosmic Microwave Background Radiation

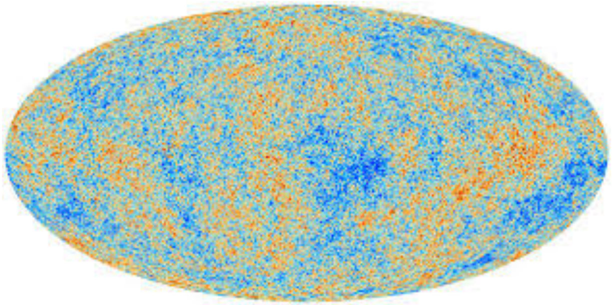
1978 Nobel Lecture
Robert Wilson



COBE



WMAP



Planck

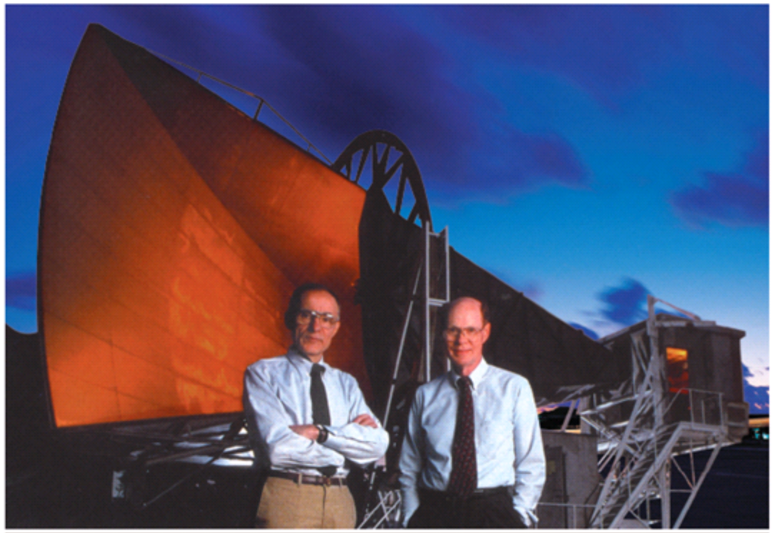


그림 4-2 | 마이크로파 안테나로 우주 배경 복사를 발견한 펜지어스(왼쪽)와 윌슨(오른쪽)

Radio Astronomy has added greatly to our understanding of the structure and dynamics of the universe. The cosmic microwave background radiation, considered a relic of the explosion at the beginning of the universe some 18 billion years ago, is one of the most powerful aids in determining these features of the universe.

A radio telescope pointing at the sky receives radiation not only from space, but also from other sources including the ground, the earth's atmosphere, and the components of the radio telescope itself.

In 1963, when the 20-foot horn-reflector was no longer needed for satellite work, Arno Penzias and I started preparing it for use in radio astronomy.

My interest in the background measuring ability of the 20-foot horn-reflector resulted from my doctoral thesis work with J. G. Bolton at Caltech. We made a map of the 31 cm radiation from the Milky Way and studied the discrete sources and the diffuse gas within it.

Previous low frequency measurements had indicated that there is a large, radio-emitting halo around our galaxy which I could not measure by that technique. The 20-foot horn reflector, however, was an ideal instrument for measuring this weak halo radiation at shorter wavelengths. One of my intentions when I came to Bell Labs was to make such a measurement.

We wanted to make accurate measurements of antenna temperatures. To do this we planned to use the radiometer to compare the antenna to a reference source, in this case, a radiator in liquid helium.

… Unless we could understand our ‘antenna problem’ our 21 cm galactic halo experiment would not be possible.

A pair of pigeons was roosting up in the small part of the horn where it enters the warm cab. They had covered the inside with a white material familiar to all city dwellers. We evicted the pigeons and cleaned up the mess, but obtained only a small reduction in antenna temperature.

For some time we lived with the antenna temperature problem and concentrated on measurements in which it was not critical. In the spring of 1965 with our flux measurements finished, we thoroughly cleaned out the 20-foof horn reflector and put aluminum tape over the riveted joints. This resulted in only a minor reduction in antenna temperature.

By this time almost a year had passed. Since the excess antenna temperature had not changed during this time, we could rule out two additional sources: 1) Any source in the solar system should have gone through a large change in angle and we should have seen a change in antenna temperature.

2) In 1962, a high altitude nuclear explosion had filled up the Van Allen belts with ionized particles. Since they were at a large distance from the surface of the earth, any radiation from them would not show the same elevation-angle dependence as the atmosphere and we might not have identified it. But after a year, any radiation from this source should have reduced considerably.

The sequence of events which led to the unravelling of our mystery began one day when Arno was talking to Bernard Burke of M.I.T. about other matters and mentioned our unexplained noise. Bernie recalled hearing about theoretical work of P. J. E. Peebles in R. H. Dicke's group in Princeton on radiation in the universe. Arno called Dicke who sent a copy of Peebles' preprint.

The Princeton group was investigating the implication of an oscillating universe with an extremely hot condensed phase. Dicke had an important idea that if the radiation from this hot phase were large enough, it would be observable. In the preprint, Peebles, following Dicke's suggestion calculated that the universe should be filled with a relic blackbody radiation at a minimum temperature of 10 K. Dicke, Roll, and Wilkinson were setting up an experiment to measure it.

Shortly after sending the preprint, Dicke and his coworkers visited us in order to discuss our measurements and see our equipment. They were quickly convinced of the accuracy of our measurements. We agreed to a side-by-side publication of two letters in the Astrophysical Journal – a letter on the theory from Princeton and one on our measurements of excess antenna temperature from Bell Laboratories.

Arno and I were careful to exclude any discussion of the cosmological theory of the origin of background radiation from our letter because we had not been involved in any of that work. We thought, furthermore, that our measurement was independent of the theory and might outlive it. We were pleased that the mysterious noise appearing in our antenna had an explanation of any kind, especially one with such significant cosmological implications. Our mood, however, remained one of cautious optimism for some time.

While preparing our letter for publication we made one final check on the antenna to make sure we were not picking up a uniform 3 K from earth. From the total antenna temperature we subtracted the known sources with a result of 3.4 $\pm$ 1 K. We stated in the original paper that “This excess temperature is, within the limits of our observations, isotropic, unpolarized, and free of seasonal variations”.

After our meeting, the Princeton experimental group returned to complete their apparatus and make their measurement with the expectation that the background temperature would be about 3 K.

The first confirmation of the microwave cosmic background that we knew of, however, came from a totally different, indirect measurement. This measurement had, in fact, been made thirty years earlier by Adams and Dunhan. Adams and Dunhan had discovered several faint optical interstellar absorption lines which were later identified with the molecules CH, CH^+, and CN. In the case of CN, in addition to the ground state, absorption was seen from the first rotationally excited state. McKellar using Adams' data on the populations of these two states calculated that the excitation temperature of CN was 2.3 K. This rotational transition occurs at 2.64 mm wavelength, near the peak of a 3 K black body spectrum.

In December 1965 Roll and Wilkinson completed their measurement of 3.0 $\pm$ 0.5 K at 3.2 cm, the first confirming microwave measurement. By mid 1966, the intensity of the microwave background radiation had been shown to be close to 3 K between 21 cm and 2.6 mm, almost two orders of magnitude in wavelength.

I have mentioned that the first experimental evidence for cosmic microwave background radiation was obtained (but unrecognized) long before 1965. We soon learned that the theoretical prediction of it had been made at least sixteen years before our detection.

George Gamow had made calculations of the conditions in the early universe in an attempt to understand Galaxy formation. Although these calculations were not strictly correct, he understood that the early stages of the universe had to be very hot in order to avoid combining all of the hydrogen into heavier elements.

Furthermore, Gamow and his collaborators calculated that the density of radiation in the hot early universe was much higher than the density of matter. In this early work the present remnants of this radiation were not considered. However in 1949, Alpher and Herman followed the evolution of the temperature of the hot radiation in the early universe up to the present epoch and predicted a value of 5 K. In 1953 Alpher, Follin, and Herman reported what has been called the first thoroughly modern analysis of the early history of the universe, but failed to recalculate or mention the present radiation temperature of the universe.

In 1964, Doroshkevich and Novikov had also calculated the relic radiation and realized that it would have a blackbody spectrum.

Cosmology is a science which has only a few observable facts to work with. The discovery of the cosmic microwave background radiation added one – the present radiation temperature of the universe.

This, however, was a significant increase in our knowledge since it requires a cosmology with a source for the radiation at an early epoch and is a new probe of that epoch.

More sensitive measurements of the background radiation in the future will allow us to discover additional facts about the universe.