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50 Years of the CMB

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The cosmic microwave background radiation, measured with CN molecules but unrecognized by 1941, predicted in 1948, detected in 1964, and published in 1965, is now the basis for precision cosmology, a phrase that would once have been an oxymoron. With confirmation of its blackbody spectrum, and the statistics of its hot and cold spots and polarization, the CMB tells us that the expanding universe can be described very simply. With just 6 parameters, we match the measured statistics and enjoy the "standard model" of cosmology with percent-level accuracy, but we require two mysterious substances that only astronomers have detected: dark matter and dark energy. Gravity alone, acting on the primordial perturbations, explains the growth of cosmic structures, though we argue about the detailed properties of the dark matter. And the idea of cosmic inflation, propelled by a hypothetical field, fits the measurements and explains why the universe is flat and uniform, and filled with nearly scale-invariant primordial fluctuations. The development of instruments and theory has been spectacular, and I will summarize the breakthrough concepts. But after 50 years the job is not done: new equipment could measure the spectrum, anisotropy, and polarization even better. At long wavelengths, the spectrum could be different from a blackbody, due to electrons or redshifted hydrogen 21 cm emission, and it could be either hotter than the CMB (from energy release) or colder (from adiabatic cooling). At intermediate wavelengths, the spectrum could show traces of the hydrogen recombination lines, and we know that recombination was delayed by trapping of Lyman α photons. Moreover, the statistics of the polarization tell us about the nature of the forces during the first moments of the universe, and whether there were propagating gravitational waves in equipartition with other fluctuations. Discoveries await!