New Results in Microwave Background Anisotropy from WMAP

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NASA released on February 11, 2003 new data for the anisotropy of the microwave background radiation of the Universe, which will be used by cosmologists over the next few years to uncover the parameters important for the evolution and dynamics of the Universe. Preliminary results support the standard Big bang model of the Universe. They also support the idea that minute inhomogeneities in the mass distribution in the past grew into the structures that are found today, such as galaxies and galaxy clusters, through gravitational instability. Small clumps in the primeval soup of matter grew denser and bigger into giant structures of the present epoch.

Our Universe is filled with a radiation that has most of its energy in the microwave region (with wavelengths in the range of mm-cm), and whose spectrum is a perfect example of the blackbody spectrum. One expects such a radiation when matter and radiation are in thermal equilibrium, when the absorption and emission of radiation by matter are balanced. It is difficult to find an example for this ideal situation in reality; radiation inside a good oven can be cited as an approximate case.

The matter and radiation in the present day Universe are however not in thermodynamic equilibrium, since the timescale for interaction between them is much longer than other relevant timescales (the time taken by the expansion of the Universe, for example). The presence of the cosmic microwave background radiation (CMBR), therefore, suggests that matter and radiation must have been in equilibrium in the past. In the early Universe, the density and temperature were higher in the Universe, and matter and radiation could be in equilibrium. The present day CMBR would then just be a cooled down relic of the radiation in the early Universe.

The discovery of the CMBR in 1965 was a watershed event for cosmology. Since then the experiments have been providing finer details of the radiation. We now know that it has a temperature of 2.73 K. The radiation also provides a frame of reference in which the galaxies are expanding homogeneously, so that any deviation in the movement of our own Galaxy from the smooth expansion of the Universe (due to local graviational push and pull) would show up in the shift of frequency of this radiation, as a result of Doppler effect. In fact, measurements at high contrast show such a frequency shift, at a level of milli Kelvins, and our Galaxy is surmised to move towards the Virgo cluster of galaxies with a speed of about 600 km/s.

Working out the physics of the early Universe, one also comes to understand that the radiation which was in close interaction with matter very early on, lost touch with it when matter cooled down to form atoms. Photons do not interact as liberally with atoms as they do with free electrons. This happened when the size of Universe was 1100 times smaller than its size now. In the jargon of cosmology, one calls this the epoch of decoupling between matter and radiation as being 'at a redshift (z) of 1100'. The larger the redshift, the smaller and younger is the Universe.

Measurements at even higher contrasts in 1992 showed that there were patches in this radiation in the sky, in which the radiation appeared slightly hotter or colder, at the level of several micro Kelvin. In other words, the CMBR was found to be anisotropic at the level of one part in 10^5. This was theoretically anticipated from the ideas of formation of structures in the Universe such as galaxies, clusters of galaxies and so on. Such structures are believed to have formed from small fluctuations in matter density in the early Universe, which then grew into larger condensations of various sizes, being amplified by gravity. When matter and radiation decoupled (at $z \sim 1100$), any inhomogeneity in the matter density distribution would have changed the radiation frequency in its vicinity – since gravity changes frequency of photons. As some CMBR photons climb out of potential wells created by clumps of matter, they lose energy and their frequency is shifted towards red. This anisotropy, or the patchiness, of the CMBR therefore reflects the inhomogeneity in the matter density in the Universe at $z \sim 1100$, which were the seeds of the galaxies, clusters and superclusters today. Clearly, the analysis of such patches would yield the parameters that govern the evolution of the structures and of the Universe as a whole.

The analysis of the anistropy of the CMBR, and comparison with the large scale structure of the Universe today, have been perceived as one of the key tasks for cosmologists. Observations of 1992 had discovered only the large patches in CMBR, and later observations, mostly from ground based telescopes or balloon borne instruments, determined the patchiness to finer details for small parts of the sky. The satellite WMAP (Wilkinson Microwave Anisotropy Probe, named in honour of David Wilkinson, a pioneer in the study of CMBR anisotropy and who died recently) was launched by NASA in June 2001 primarily to provide a full sky map of CMBR in a few frequencies and with a resolution of around 0.3°. To achieve the goals, WMAP was set up at an orbit about the L2 Sun-Earth Lagrange point (which lies along the line connecting Sun and Earth, at a distance of 1.5 million km from Earth, in the direction away from Sun). From this point, WMAP could scan the sky all the time, unobstructed by Sun, Earth and Moon.

Analysis from the first full sky map from WMAP does not show much surprises. As expected, the fine details allow one to determine the cosmological parameters – expansion speed, densities of normal gas, dark matter and any other dominant form of energy in the Universe – to a high accuracy. Since these parameters govern the way the Universe has evolved, they allow one to determine the age of the Universe, which is found to be 13.7 ± 0.2 billion years. Such an accuracy was unthinkable even a few years ago. The expansion speed at the present epoch (called the Hubble constant, H_0) determined from this map matches well with previous measurements, at 71 ± 2 km/s per mega parsec (1 parsec equals about 3 light years). The densities of different form of matter (and energy) are usually expressed in the units of the critical density, which is given by $3H^2/8\pi G$. Density of normal gas is pegged at 4.4 % (of the critical density), density of dark matter at 22 % and the rest 73 % is believed to be contributed by something whose nature is still unknown, usually called the 'dark energy', and which provides a repulsive force counteracting the gravity of matter.

The surprising part of WMAP results came from its measurements of the polarization of the CMBR. Photons acquire polarization when scattered by electrons, which were available before the era of decoupling, *and* in the recent past, when the first stars in the Universe ionized the neutral gas around them. The measurements of the polarization tentatively show that the first luminous objects in the Universe appeared at $z \sim 20$ (that is when the Universe was twenty times smaller than now). From recent observations of the presence of neutral gas in the early Universe, astrophysicists had found that the gas is highly ionized only until $z{\sim}6$, and that before this era neutral gas could have been abundant. Simple models were computed in which the first stars appeared not much before $z{\sim}6$ and which then 'reionized' the Universe quickly. The difference in these two measurements ($z{\sim}6$ and $z \sim 20$ from WMAP) now shows that the history of gas and the emergence of luminous objects in the Universe was more complicated than previously thought. It is expected to be a hot area of research in the near future.

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This Swedish stamp was issued in honour of the discoverers of the microwave background radiation, Penzias and Wilson – the temperature of the radiation was then known to be approximately 3 degrees Kelvin.