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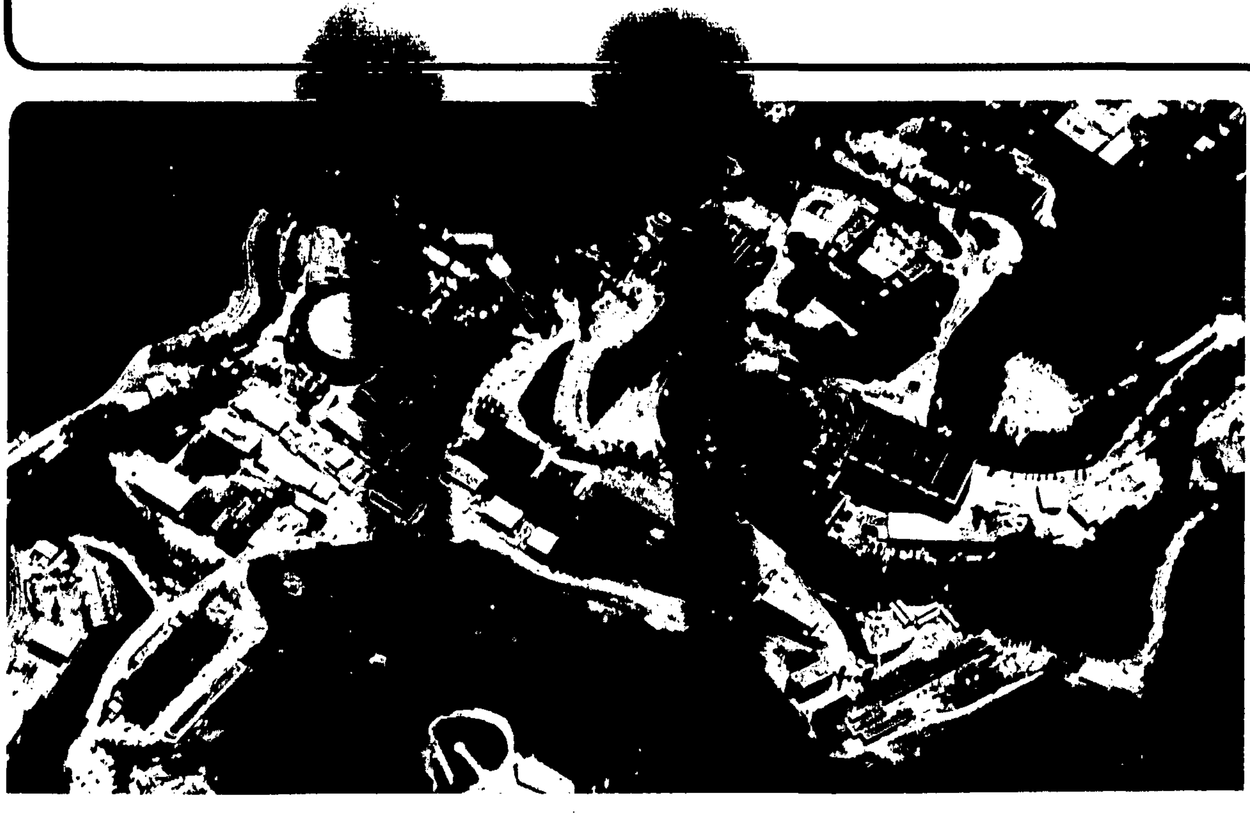

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COSMIC QUADRUPOLE?

from Richard A. Muller

"The truly marvelous thing about science is the great return in theory that one obtains for such a meager investment in fact." —Mark Twain

In no other field of science is Mark Twain's perception as true as in Cosmology. There are so few "facts" that constrain cosmology that the discovery of a new one is a major event. One of the most recent such discoveries is the anisotropy (variation in intensity with direction) in the cosmic microwave background radiation. It is now well established[1,2] that the intensity of the radiation varies by about 0.2% (6 mK of the 3K signal), with maximum intensity towards the Virgo cluster of galaxies, and minimum in the opposite direction. The intensity of the modulation varies smoothly between these extremes as the cosine of the angle in the sky, suggesting that the anisotropy is due to a Doppler shift from motion of the Milky Way galaxy with respect to the radiation. This cosine modulation has recently been observed[3,4] to have a blackbody spectrum in the frequency range from 19 to over 100 GHz. This observation has eliminated lingering fears that the anisotropy might be a spurious effect due to interference by galactic synchrotron emission.

Two groups are now reporting a new "fact", a second harmonic in the cosmic background anisotropy. R. Fabbri, I. Guidi, F. Melchiorri and V. Natale[3] in Italy have observed a second harmonic with amplitude 0.9 (+0.4, -0.2) mK, ~~with~~ and axis consistent with that of the first harmonic. S. Boughn, E. Cheng, and D. Wilkinson[4] at Princeton report a "quadrupole moment" Q_5 (i.e. a second harmonic proportional to $\cos^2 d \cos 2a$ where d is declination and a is right ascension) of magnitude -0.54 (+- 0.14) mK. Observations of second and higher order harmonics are particularly exciting because unlike the cosine anisotropy, they are not easily explained by local effects such as proper motion. Rather they give us information about the the state of the Universe at very early times.

The existence of the cosmic microwave radiation was predicted by G. Gamow, P. Alpher, and R. Hermann,[5] and independently by R. Dicke, P. Peebles, P. Roll, and D. Wilkinson[6] before the radiation was discovered by A. Penzias and R. Wilson[7] in 1965. Their theories have formed the basis for what is now referred to as the "standard model" of the early universe. In this model, the microwave radiation was once thermal radiation in equilibrium with the hot plasma that filled all space. About a half million years after the big bang, expansion of the Universe caused the previously opaque plasma to cool sufficiently to become transparent to the radiation, and since that time the signal has been travelling essentially unimpeded through the universe. When one observes the radiation, one is literally looking at the shell of matter that last scattered it. The radiation comes from a more distant region of space, and was emitted earlier in time, than any other observed signal. The microwave radiation literally forms the spatial "background" in front of which all other astrophysical objects lie.

There are many effects that could give rise to anisotropy in the radiation, including long-wavelength gravitational radiation, an overall rotation to the Universe, an anisotropic Hubble expansion, and nonuniformity in the density of the Universe at the time of decoupling. Only the cosine or "dipole" term (so termed because a dipole distribution is proportional to the first spherical harmonic) can come from the Doppler shift due to the velocity of the observer with respect to the distant matter that last scattered the radiation.

Calculations indicate that the reported quadrupole anisotropy is consistent with that expected, based on observed inhomogenieties in the distributions galaxies, and extrapolations in scale and in time to distributions at the time of decoupling.[8,9] In fact theorists were beginning to become uncomfortable with the absence of high harmonics in the anisotropy, since it was difficult to see how the present very lumpy Universe could have evolved from a highly uniform one in the short period of 10 to 20 billion years.

Our sigh of relief may be premature, however, because the experimental status is not totally resolved. Anisotropy measurements are very difficult, for they require measurement of millikelvin signals in the presence of system noise of typically several hundred Kelvin. Galactic emission and earth-shine are highly anisotropic, and difficult to eliminate. The history of anisotropy measurements is not reassuring, for published data has shown large nonstatistical fluctuations subsequently shown to be due to systematic error. And most importantly, the present experiments do not agree within statistical errors. In 1979 G. Smoot and P. Lubin[10] at Berkeley published a measurement of Q_5 consistent with zero: +0.06 (+-0.2) mK. This value differs with the Princeton value by several standard deviations. Even the Princeton dipole terms differ significantly from those of Berkeley. No one doubts the reality of the dipole anisotropy, but the disagreement does show that one must be wary of accepting statistical errors as the true errors. The three experiments are very different in design, and the systematics could be very different. The Berkeley experiment sampled regions of the sky in both the northern and southern hemispheres. The Princeton experiment had continuous sky coverage, but only in the northern sky. The Italian experiment had the poorest sky coverage of all; their high frequency makes them insensitive to synchrotron background, but more sensitive to thermal radiation from galactic dust. Since galactic emission can be pointlike as well as diffuse, it is impossible to guess which experiment is most sensitive to unknown backgrounds. Smoot and Lubin are cautious, and willing to give as their final upper limit 1 mK for a quadrupole term. Fabbri et al. are similarly cautious. They consider their effect, 4.5 standard deviations from zero, to be only "suggestive" of a quadrupole anisotropy. Only the Princeton group is convinced that they have been able to take all systematic errors into account.

If their quadrupole term is verified, then the Princeton group will deserve credit for their unambiguous announcement of its discovery. But I think it is premature to accept the effect as proven. Caution is called for, in part because the experiments are difficult, in part because of the discrepancies between the existing experiments, and in part because the results are close to those expected. Fortunately we may not have long to wait for verification. The Princeton group has already flown in their balloon gondola a maser receiver with considerably improved sensitivity, and the Berkeley group is about to fly a 90 GHz cryogenic system. The frequency behavior of the quadrupole term will clearly identify it as cosmic background or as galactic interference. And in a few years we should obtain a detailed map of the 3K signal, including higher harmonics, from NASA's Cosmic Background Explorer satellite (COBE). The coverage and sensitivity of COBE are likely to give cosmologists a whole handful of new facts to inspire and constrain their theories.

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