based on more realistic assumptions yields extinction of moas within a few decades. If you doubt it, think of the tameness of Galapagos birds even today, and think of Steller's accounts of how his men "hunted" sea cows. (Men paddled up to it, jabbed a hook into it, and pulled the unresisting beast ashore).

This study yields two conclusions specifically about New Zealand. First and foremost: yes, this was a blitzkrieg; yes, a few people could and did kill every moa. At a time when all moas had been eliminated from 270,000 km^2 of some of the world's most rugged territory, the Maori population probably still numbered under 1000. As for how they could have found every moa, it was easy: Within a generation, they had also found all sources of stones in New Zealand that were useful for toolmaking.

Second, it is often asserted that the colonization of New Zealand must have preceded the earliest known radiocarbon-dated sites by centuries, because the chances of finding the actual first sites are supposedly negligible. On the contrary, the conclusion is now that the first sites were the ones with the greatest archaeological visibility because of their piles of moa bones. What we see is everything that was there then; there wasn't an earlier, archaeologically invisible human population.

Where should we seek evidence for other blitzkriegs? Almost anywhere, except on the Eurasian and African mainlands, long inhabited by humans. Candidate victims include Cyprus's pygmy hippo, Hawaii's flightless geese, the Caribbean's bear-sized rat, Fiji's land-lubber crocodile—and, of course, all of the large animals that disappeared in Australia, North America, and South America around the time of human arrival (*2*).

Is archaeology a useless discipline, irrelevant to the present, and deserving of the late Senator Proxmire's Golden Fleece Award for wasted research money? Think of all those long-lived plants and animals still being harvested today at unsustainable rates. As Santayana said, those who do not remember the past are condemned to repeat it. Then, there were no more moas; soon, there will be no more Chilean sea bass, Atlantic swordfish, and tuna. I wonder what the Maori who killed the last moa said. Perhaps the Polynesian equivalent of "Your ecological models are untested, so conservation measures would be premature"? No, he probably just said, "Jobs, not birds," as he delivered the fatal blow.

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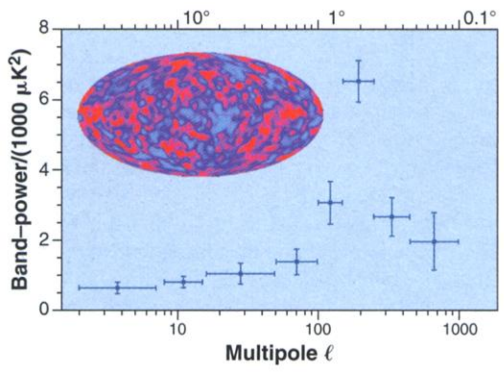
PERSPECTIVES: ASTRONOMY

How Flat Is the Universe?

Elena Pierpaoli, Douglas Scott, Martin White

The discovery of the cosmic microwave background (CMB) in 1965 (*1*) provided key evidence supporting the hot Big Bang model for the evolution of the universe. Tiny temperature variations in the CMB discovered in 1992 (*2*)—of just the right size for gravity to have created the observed large-scale structures over the age of the universe—established gravitational instability as the mechanism of structure formation. These first measurements of CMB anisotropy on an angular scale of tens of degrees have been followed by many experiments concentrating on smaller scales. Already in 1995 (*3*), indications for enhanced temperature variations on a scale of 0.5° were reported. Here we combine all existing observational data to show that the temperature variations decrease again below 0.5°. This observation has profound implications for the origin of structure in the universe and the global curvature of space.

The CMB sky is conventionally expanded into a set of functions labeled by a multipole number ℓ. Functions with higher ℓ probe smaller angular scales. The squares of the expansion coefficient amplitudes, as a function of ℓ or inverse angle, are referred to as the "anisotropy power spectrum" (*4*), which statistically describes how the temperature variations depend on angle—a high power spectrum at some ℓ means large variations in temperature on a scale $\theta = 1/\ell$. This power spectrum is easy to compute theoretically for model universes and contains essentially all of the cosmological information in the CMB. What remains to be done, however, is to obtain this power spectrum experimentally. Until now, individual experiments have had limited angular range, and each has provided only a small piece of the puzzle. Different CMB experiments can, however, be combined to provide an essentially model-independent estimate of the power spectrum (*5*). This estimate, provided that it is carefully calculated, can then be used to constrain models.



The power spectrum of cosmic microwave background anisotropies. This plot of temperature variations versus multipole ℓ, which is equivalent to an inverse angle, is a binned spectrum from all currently available data. A prominent peak is centered just below 1°. Top left: Map showing CMB fluctuations from the COBE satellite (*21*). This map only represents the first two points in the power spectrum.

CREDIT: NASA/GSFC

We used a maximum likelihood technique to obtain a power spectrum encompassing the knowledge gained from all currently available observational data of which we are aware. The data comprise those collected in (*6*), together with the more recent results of the QMAP (*7*), MAT (*8*), Viper (*9*), and BOOM97 (*10*) experiments, as summarized in the RADPACK package (*11*), with some minor corrections. We divided the range from $\ell = 2$ to $\ell = 1000$ into eight bins spaced at roughly equal logarithmic intervals, with slight adjustments to allow for regions where data are scarce (*12*). The power spectrum was approximated as a piecewise constant, and the values of that constant were fitted within each bin to the combined data, taking into account nonsymmetric error bars and calibration uncertainties in a manner similar to (*13*). We maximized the likelihood function for the eight parameters (plus 17 calibrations) using a simulated annealing technique (*14*). From the maximum likelihood position, we then used Monte Carlo integration to calculate the covariance matrix of the parameters. The final result is a power spectrum (see

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the figure) with realistic estimates of error bars and bin-to-bin correlations (*15*).

The data show a prominent peak in the angular power spectrum just below 1°. The distinct fall-off at high ℓ is indicated within the data sets of individual experiments [particularly Saskatoon (*16*), MAT, Viper, and BOOM97] but is more dramatically revealed in this data compilation, which is sensitive to different angular scales. Further confidence in the decrease in power comes from upper limits at even larger ℓ, not plotted or used in our fit. In other words, there is a particular angular scale—around $\ell = 200$, or just below 1°—on which CMB temperature fluctuations are highly correlated. It corresponds theoretically to the distance a sound wave could have traveled from the Big Bang to the time the CMB anisotropies formed. Such a characteristic scale was suggested in models of cosmological structure formation at least as far back as 1970 (*17*).

The prominent peak seen in the figure confirms our ideas of the early evolution of structure in our universe. Understanding the physical basis for the peak allows a constraint to be placed on the curvature of the universe (*18*, *19*). The overall geometry of space appears to be close to flat, indicating that something other than normal matter contributes to the energy density of the universe. Together with data from distant supernovae and other cosmological tests, this implies that models that include cold dark matter and Einstein's cosmological constant are likely to be correct (*20*).

The detailed structure of the CMB spectrum is expected to contain not just one peak, but a series of peaks and troughs. Finding such structure in the spectrum at the expected angular scales would be strong confirmation for adiabatic fluctuations (which perturb matter and radiation in a similar way) believed to have been produced when the universe was very young. Eventually this would lead to the possibility of proving inflation or stimulate research on other ways of generating similar fluctuations. In contrast, failure to see multiple peaks in the predicted locations would require substantial revisions in our cosmological theories.

If future observations verify our general cosmological framework, we need to determine precisely the parameters within our model, such as the amounts of matter of different types, the expansion rate, and the precise initial conditions. High-resolution maps of the CMB will also play a crucial role in understanding more recent epochs, carrying imprints, through reionization and gravitational lensing, of object formation in the recent universe.

The required high-resolution data may be available in the not too distant future. New results from a long-duration flight of the BOOMERANG experiment are expected in the very near future. Several ground-based experiments, including interferometric instruments, are also nearing completion. NASA's Microwave Anisotropy Probe is expected to return data in 2001, and the ambitious Planck satellite is scheduled for launch in 2007. Information from challenging CMB polarization measurements and the combination of CMB data with other cosmological probes will be even more powerful.

The history of CMB research can be split into five phases. Its mere existence showed that the early universe was hot and dense. The blackbody nature of the CMB spectrum and its isotropic distribution implied that the universe is approximately homogeneous on large scales. The detection of anisotropies confirmed the theory of structure formation through gravitational instability. We have now reached the fourth stage, the discovery of a characteristic (angular) scale on the CMB sky, which supports a model with adiabatic initial conditions and a universe with approximately flat geometry. Higher fidelity data will show whether or not our models are vindicated. And we are on the verge of the fifth phase, the determination of the precise fundamental cosmological parameters.

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PERSPECTIVES: SOLAR PHYSICS

The Day the Solar Wind Almost Disappeared

Alan J. Lazarus

The sun emits a constant flow of charged particles into interplanetary space. On 11 May 1999, the number density of this "solar wind" decreased to remarkably low values (~0.2 particles/cm^3, compared with an average value of 10/particles/cm^3). A special session of the American Geophysical Union 1999 Fall Meeting (*1*) was devoted to discussing this extraordinary event and its consequences.

Other instances of low-density wind have now been found, but this period of more than 27 hours was the longest having density below 1 particle/cm^3. At 360 km/s, the speed of the wind was near its typical value of about 400 km/s, but the pressure exerted by the wind was so low that the shock front formed by the interaction between the incoming, supersonic wind and Earth's magnetic field moved outward from its usual location (about 15 Earth radii R_E in front of Earth as measured along the Earth-sun line) to at least 60 R_E, near the moon (see the figure).

Normally, the completely ionized solar wind plasma compresses Earth's dayside magnetic field because of the wind's relatively high conductivity (*2*). The resulting pressure flattens the field on the sunward side and drags it out on the night side into a tail many Earth radii long. On 11 May 1999, the unusually low pressure resulting from the low-density wind allowed Earth's magnetic field to reassert its dipolar shape over a larger volume.

The solar magnetic field is carried outward by the solar wind as it travels to Earth. On 11 May 1999, it had the appropriate polarity to allow it to connect with the magnetic field from Earth's north pole, allowing so-

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