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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22. This research was supported by the Natural Sciences and Engineering Research Council of Canada and by NSF-9802362.

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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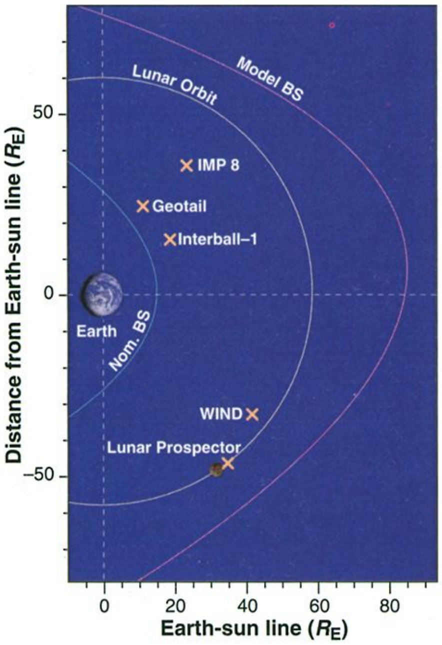

A sunward shift. Positions of various spacecraft at the time when they encountered the outward moving shock front, the "bow shock" (BS). The horizontal axis is the spacecraft distance along the Earth-sun line in units of R_E. The vertical axis is the distance perpendicular to the Earth-sun line. The spacecraft positions have been rotated into the ecliptic plane; spacecraft on the dawn side of Earth are plotted with negative perpendicular distance. White line: lunar orbit. Blue line: nominal (Nom.) position and shape of the bow shock, Pink line: model calculation of the maximum extent of the bow shock during this time period. Earth and the moon are shown at about 3 times their real size.

SOURCE: A. STABO/NASA/GSFC

lar wind electrons (confined to the field lines) direct access to the north polar region. Normally, the solar electron distribution is broadened by collisions; all but the most field-aligned electrons are turned back by the increasing magnetic field as the polar regions are approached. But on this day, a particular part of the solar wind electron velocity distribution (known as the "strahl" because it forms a beam or ray that streams in a narrow cone along the field lines) dominated the distribution. Because the solar wind density was so low, the strahl electrons were relatively unscattered by collisions in the solar wind, and they arrived near Earth in an unusually intense and narrow beam that was able to penetrate into the polar region. The electron collisions with the atmosphere generated "the strongest x-ray emissions ever seen from the polar cap" (D. Chenette, Lockheed-Martin, Palo Alto, CA). The x-rays were observed from the Polar spacecraft, which can view both poles as it orbits Earth. The field polarity was such that electron access to the southern polar region by incoming electrons was not expected, and indeed no x-rays were observed from the south polar regions.

The strahl electrons provided an exciting opportunity to observe the electron distribution deep within the sun's corona. J. Scudder (University of Iowa) suggested that the strahl electrons indicated that substantial electron energy may have been deposited in the lower corona rather than higher up (a situation that is theoretically expected to produce low-mass flux solar wind), resulting in the normal speed but anomalous low-density condition we saw.

The strahl electrons also provided a chance to estimate the temperature at the base of the corona where the electrons were last in collisional equilibrium. The temperature in that region could be deduced from the overly energetic strahl distribution, seen by Wind and by the Hydra experiment on the Polar spacecraft in the tail of Earth's stretched field. Ordinarily, the energy spectrum of the strahl electrons coming into the polar regions decreases above about 1 keV, but in this case the energies exceeded 20 keV, corresponding to temperatures at the coronal base of 10^6 K.

The low solar wind had other effects in regions near Earth. D. Baker and his colleagues (University of Colorado) used data from near-Earth spacecraft to characterize conditions in Earth's Van Allen radiation belts, which are deeply embedded in the magnetosphere. The radiation belts became much more symmetric during the event, with the cometlike tail of the radiation belts apparently disappearing in the process.

Although the density of energetic electrons in the solar wind returned to normal on the following day, the density of very high-energy electrons in the magnetosphere dropped once again the next day and remained severely depleted for nearly 2 months, despite the fact that the solar wind flux had returned to its usual value. This raises interesting questions about the refilling of the radiation belts.

Why periods of very low density wind occur remains unknown. It is interesting to note, as N. Crooker (Boston University) pointed out, that such low wind flux periods tend to appear on the ascending portion of the solar activity cycle, a period in which we are in now (*2*). Discussions of low solar wind flux periods will undoubtedly occupy solar physicists for years to come.

References and Notes

1. American Geophysical Union Fall Meeting, San Francisco, CA, 13 to 17 December 2000, sessions SM11A, SM21E, and SM22C.
2. See, for example, www.oulu.fi/~spaceweb/textbook for general background on solar physics.
3. I wish to thank J. Scudder at Iowa and A. Szabo at NASA/Goddard Space Flight Center for their help with this Perspective.

PERSPECTIVES: GENOMICS

The End of the Beginning

Sydney Brenner

In classical experimental genetics, where many of us began, we could not assert the existence of a wild-type gene until a mutant version with an altered function had been isolated. For Mendel to say that there was a factor for tallness, he first had to find heritable dwarf variants that suffered from a lack of tallness. This genetics began with inherited changes in phenotype that provided, if not knowledge, then at least a classification of the functions of genes, and it used genetic complementation experiments to discover how many genes were involved in dictating each phenotype. But, if one asked how many genes were required to make a bacteriophage or a bacterium or a fly or a mouse, no answer could be given.

A quarter of a century ago, the advent of new methods to analyze genomes directly changed the field of genetics. When the genome of bacteriophage lambda was first sequenced, it allowed the enumeration of all of the open reading frames (DNA sequences that potentially can be translated into protein). Some of these were in genes that encoded proteins whose functions had been thoroughly explored, whereas others encoded new proteins that were not essential for the growth of bacteriophage in the laboratory.

Proteins are the workhorses of biological systems, and deepening functional analyses of organisms requires that their proteins be purified and characterized. By sequencing the genome of a complex organism, the amino acid sequences of all of the proteins are obtained, so to speak, in one blow, thus avoiding the terrifying prospect of separating and purifying all of the proteins, and sequencing them by laborious methods. Cloning the genes into expression vectors allows us to make large amounts of the proteins for study and, what is more, we can make mutations in them and study the consequences without ever going back to the original genome.

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