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Acoustic Oscillations in the Early Universe and Today

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During its first ≃100,000 years, the universe was a fully ionized plasma with a tight coupling by Thompson scattering between the photons and matter. The trade-off between gravitational collapse and photon pressure causes acoustic oscillations in this primordial fluid. These oscillations will leave predictable imprints in the spectra of the cosmic microwave background and the present-day matter-density distribution. Recently, the BOOMERANG and MAXIMA teams announced the detection of these acoustic oscillations in the cosmic microwave background (observed at redshift ≃ 1000). Here, we compare these CMB detections with the corresponding acoustic oscillations in the matter-density power spectrum (observed at redshift ≃ 0.1). These consistent results, from two different cosmological epochs, provide further support for our standard Hot Big Bang model of the universe.

The standard model of cosmology is the Inflationary Hot Big Bang scenario. A key aspect of this model is the ease with which it explains some critical observational facts about the universe. For example, the existence of the cosmic microwave background (CMB) radiation that fills all space is simply the radio remnant of a hot early phase of the universe, i.e., when it was only ≃100,000 years old. The model also provides a natural explanation for Hubble's famous expansion, large-scale coherent structures in the mass distribution (caused by quantum effects in the early universe), as well as producing a flat global geometry for the universe (*1*). In this scenario, the distribution of matter on the largest scales is connected, through well-established physics, to the temperature fluctuations in the CMB. Thus, any independent agreement between the CMB (at redshift ≃ 1000) and the matter-density distribution (at redshift ≃ 0.1) is naturally explained by the Hot Big Bang Inflationary model.

The early universe was a plasma made up of photons, electrons, and protons, along with the so-called Dark Matter. During this period, the gravitational force from potential wells (created as a result of local curvature pertubations or dark matter clumps) causes compressions in this fluid. As the plasma collapses inward, it meets resistance from photon pressure, reversing the plasma direction and causing a subsequent rarefaction. This cycle of compression and rarefaction results in acoustic oscillations, where baryons act as a source of inertia. Compression (rarefaction) of the plasma creates hot (cold) spots in the temperature of the plasma. Because the photons and baryons are coupled through Thompson scattering, the matter-density power spectrum will also exhibit these oscillations. As the universe cooled and the photons and matter decoupled, the acoustic oscillations became frozen as oscillatory features in both the temperature and matter-density power spectra. These acoustic oscillations are a general prediction from gravitational instability models of structure formation (*2*, *3*).

The recent results from the MAXIMA and BOOMERANG CMB balloon experiments provide evidence for the first two acoustic peaks (*4*–*8*). These acoustic oscillations are the peaks and valleys in Fig. 1A. The location and amplitude of the first peak indicate that

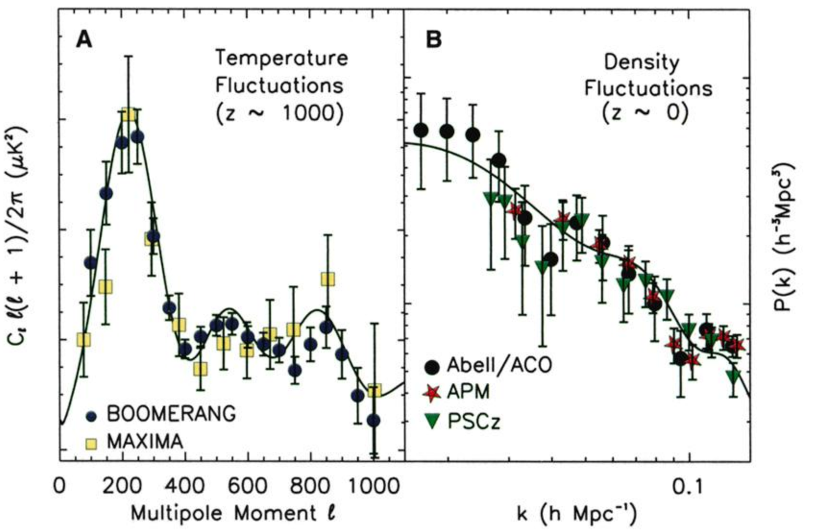

Fig. 1. We plot the CMB data from the MAXIMA and BOOMERANG experiments (**A**) alongside the matter-density data (**B**). The solid line is the best fit model (Ω_{matter} = 0.24, $\Omega_{baryons}$ = 0.06, and n_s = 1.08 with H_0 = 69) using the matter-density data alone. The amplitudes in both plots remain a free parameter. The solid line in (A) is not a fit to the CMB data (although the χ^2 is 34 for 32 data points). It is the resultant cosmological model using the best fit parameters from (B) and Ω_{vacuum} = 0.8, consistent with the Type Ia supernovae results (*18*).

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we live in a universe that is geometrically flat, with a fractional contribution of the total mass over the critical mass (required for a flat universe) of $\Omega_{matter}h^2 \simeq 0.2$, where the reduced Hubble constant is $h = H_0/100$ km s^{-1} Mpc^{-1}. The remaining contribution to the critical mass must come in some form of dark energy (specified as Ω_{vacuum}). The CMB data also indicate the detection of the second acoustic peak that, along with the first peak, can constrain the density of baryons in the universe ($\Omega_{baryons}$).

Until recently, the use of the local matter distribution in the universe has been limited to constraining just $\Omega_{matter}h$ because the data sets were not large enough to detect the acoustic oscillations. On scales smaller than $\sim 50h^{-1}$ Mpc, the oscillations will be wiped out by the individual motions of galaxies and clusters. Here, we examine the matter-density power spectrum on near-gigaparsec scales, where the imprint of the acoustic oscillations should be detectable. For our study, we use clusters of galaxies and individual galaxies as tracers of the matter in the universe and describe their distribution by the power spectrum, $P(k)$, of fluctuations in this density field, $\delta(\mathbf{r})$:

$$\delta(\mathbf{r}) = \frac{\rho(\mathbf{r}) - \langle\rho\rangle}{\langle\rho\rangle} \qquad (1)$$

The power spectrum is a function of wave number $k = 2\pi/\lambda$, where λ is the scale size in units of h^{-1} Mpc. We derived $P(k)$ from three cosmological redshift surveys: the Abell/ACO Cluster Survey (*9*, *10*), the IRAS Point Source redshift catalog (PSCz) (*11*, *12*), and the Automated Plate Measuring Machine (APM) cluster catalog (*13*, *14*). The volumes traced by these surveys are large enough to accurately probe the power spectrum to near-gigaparsec scales.

We find oscillatory features in the matter-density power spectrum (Fig. 1B), consistent with a cosmological model having $\Omega_{matter}h^2 = 0.12^{+0.02}_{-0.03}$, $\Omega_{baryons}h^2 = 0.029^{+0.011}_{-0.015}$, and $n_s = 1.08^{+0.17}_{-0.20}$, where n_s is the primordial spectra index (2σ confidence limits) (*15*, *16*). These fitted parameters provide almost enough information to independently predict the CMB temperature spectrum free of any CMB data. All that is needed is a choice for Ω_{vacuum}, which affects the temperature power spectrum but has no effect on the shape of the local matter-density power spectrum (*17*). Fortunately, the recent Type Ia supernovae results provide us with an independent measurement of Ω_{vacuum} (*18*, *19*). Thus, using the data at redshift $\simeq 0.1$ from galaxies and clusters of galaxies, along with the recent supernovae data at redshift $\simeq 1$, we can accurately predict the CMB temperature power spectrum (Fig. 1A) at redshift $\simeq 1000$, under the assumption of the standard cosmological model.

We see a direct concordance between the CMB, which originated $\simeq$100,000 years after the Big Bang, the supernovae data, measured at roughly half the age of the universe, and the matter-density distribution, which is measured today. Not only do these results provide support for the Hot Big Bang Inflationary model, they also show that we understand the physics of the early universe. This physics can take us forward in time, predicting the matter-density distribution from the CMB, or, as we have shown here, backward in time, "predicting" the CMB using the distribution of galaxies and clusters in our local universe.

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Conductance Switching in Single Molecules Through Conformational Changes

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We tracked over time the conductance switching of single and bundled phenylene ethynylene oligomers isolated in matrices of alkanethiolate monolayers. The persistence times for isolated and bundled molecules in either the ON or OFF switch state range from seconds to tens of hours. When the surrounding matrix is well ordered, the rate at which the inserted molecules switch is low. Conversely, when the surrounding matrix is poorly ordered, the inserted molecules switch more often. We conclude that the switching is a result of conformational changes in the molecules or bundles, rather than electrostatic effects of charge transfer.

Switches are among the most basic components for memory and logic, and some examples of molecules or nanostructures that might be used as switches have recently been demonstrated (*1–11*). We study such structures at the molecular scale to analyze and to understand mechanisms that cause conductance switching in single molecules. Stochastic switching of single-molecule fluorescence has been extensively studied spectroscopically (*12*, *13*). We study another multistate phenomenon, conductance switching, with the scanning tunneling microscope (STM) in order to test which of the hypothesized mechanisms, if any, explain the switching.

Conjugated phenylene ethynylene oligomers have interesting and practical electronic characteristics in ensembles of thousands in nanopore experiments (*6*, *7*, *11*). Derivatives of these molecules have exhibited negative differential resistance (NDR) (increased resistance with increasing driving voltage), bistable conductance states (memory), and controlled switching under an applied electric field (*6*, *7*, *11*). Such characteristics are often attributed to charge transfer effects (*14*). Theoretical studies that have complemented the nanopore work suggest that the NDR and conductance switching of the molecules originate from an internal conformational twist that is induced by charge

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