

## Sounds from the Infant Universe

Abstract for talk at AAS session on public outreach (6/3/04)  
Two paragraph summary of the Big Bang Acoustics Project

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One of the most impressive developments in modern cosmology has been the measurement and analysis of the tiny fluctuations seen in the cosmic microwave background (CMB) radiation – the omni-directional wall of hot glowing gas which dates from when the universe was only 400,000 years old. When discussing these fluctuations, cosmologists frequently refer to their acoustic nature – sound waves move through the hot gas and are seen as peaks and troughs when they cross the glowing wall. As is now well known, the most recent observations (culminating with the February 2003 WMAP results) quantify the amplitudes of these waves, revealing both a fundamental tone and several harmonics, whose relative strengths have played a key role in determining a number of fundamental cosmological parameters. Not surprisingly, these recent results have wonderful pedagogical value in educating and inspiring both students and the wider public, and indeed many excellent non-specialist articles have already been written about the CMB. To further enhance this opportunity to communicate the field, I have attempted what might seem rather obvious: to reproduce the CMB power spectrum as an audible sound, preserving both volume and sound quality while shifting the frequency up by the necessary 50 or so octaves to bring it into the human range. By choosing the fundamental to fall at 200 Hz (matching its harmonic “ $\ell$ ” value), the resulting sound is a rather loud hissing roar, of about 90 decibels volume.

Matching the progress in observational results has been an equally impressive development of the theoretical treatment of CMB fluctuations, culminating in highly sophisticated computer simulations which can accurately reproduce the observations, once the various fundamental parameters are set. Using these simulations it is possible to recreate the sound generated by various types of universe with, for example, different curvature (yielding sounds of different pitch) or different baryon content (yielding different higher harmonics). Pushing further, one can generate the “true” sound, characterized by  $P(k)$ , rather than the “observed” sound, characterized by  $C(\ell)$ . From  $P(k)$ , we learn that the fundamental is offset from the higher harmonics, yielding a chord somewhere between a major and minor third. Finally, tracking  $P(k)$  forward in time one can listen to the development of cosmic sound from the Big Bang, through recombination, and beyond. This sound sequence can be loosely described as a descending scream, changing into a deepening roar, with subsequent growing hiss, nicely matching the increase in wavelengths caused by universal expansion, followed by the post recombination flow of baryons into the small scale potential wells created by dark matter. This final sound, of course, sets the stage for all subsequent growth of cosmic structure, from stars (hiss) through galaxies (mid-range tones) to large scale structure (bass notes).

Although popular presentations of CMB studies already make use of many visual and conceptual aids, introducing sound into the pedagogical mix can significantly enhance both the intellectual and the emotional impact of the subject on its audience, without sacrificing scientific honesty.