AMiBA: Array for Microwave Background Anisotropy

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Abstract.   As part of a 4-year Cosmology and Particle Astrophysics (CosPA) Research Excellence Initiative in Taiwan, AMiBA − a 19-element dual-channel 85-105 GHz interferometer array is being specifically built to search for high redshift clusters of galaxies via the Sunyaev-Zeldovich Effect (SZE). In addition, AMiBA will have full polarization capabilities, in order to probe the polarization properties of the Cosmic Microwave Background. AMiBA, to be sited on Mauna Kea in Hawaii or in Chile, will reach a sensitivity of $\sim 1\,\mathrm{mJy}$ or $7\mu\mathrm{K}$ in 1 hour. The project involves extensive international scientific and technical collaborations. The construction of AMiBA is scheduled to starting operating in early 2004.

1. Introduction

The Academia Sinica Institute of Astronomy & Astrophysics and the National Taiwan University Physics department in Taipei, Taiwan are jointly developing experimental and theoretical Cosmology.

The idea of a ground-based millimeter-wave interferometric array (MINT) to study the primary anisotropy of the Cosmic Microwave Background (CMB) was first suggested by Lyman Page of Princeton University at a workshop on Cosmology held in Taiwan in December 1997. Subsequently, the ASIAA focussed on designing an instrument specifically for observing the Sunyaev-Zel'dovich Effect (SZE) to study clusters of galaxies and to search for high redshift clusters to take advantage of the distance-independent nature of the SZE. The resulting specifications consist of a high sensitivity 19-element 90 GHz interferometer that can achieve one arc-minute resolution.

In response to the Research Excellence Initiative of the Ministry of Education and the National Science Council in Taiwan, a proposal on Cosmology and Particle Astrophysics (CosPA) was jointly submitted by the NTU Physics department, the ASIAA, the National Central University and the National Tsinghua University during the Spring of 1999, with the goals of developing cosmological research and Optical/Infrared Astronomy. CosPA consists of five interrelated projects: (1) construction and use of the Array for Microwave Background Anisotropy (AMiBA); (2) theoretical work in Cosmology; (3) access to large Optical/Infrared (OIR) facilities; (4) improving the infra-structure at the Lulin observatory site in the Jade Mountains in Taiwan; (5) a feasibility study of cold dark matter detection.

During December of the same year, the 4-year US$15M CosPA proposal was funded in full. In February 2000, a science and engineering specification meeting on AMiBA was held in order to define an instrument that will have unique scientific capabilities when completed in late 2003. The important conclusion was reached to achieve full polarization capability for AMiBA in order to probe the polarization properties of the CMB, in addition to observing the secondary anisotropy of the CMB.

2. Science Goals

There are three principal science goals for AMiBA: (1) a survey for high z clusters via the SZE; (2) in search of the missing baryons in large scale structures via the SZE; and (3) the polarization of the CMB.

2.1. High z Cluster Survey

The formation history of clusters depends on Ω_m, the matter density and Λ, the cosmological constant (e.g. Barbosa et al. 1996), as well as σ_8, a measure of the initial fluctuation amplitude (Fan & Chiueh 2000). What is needed observationally to define the history is a survey of high z clusters over a sufficiently large area of the sky, so that the cosmic variance does not affect the results significantly. Because the SZE is distance independent, surveying for the SZ decrement in the CMB is very well suited to search for clusters at high z (Sunyaev & Zel'dovich 1972; Birkinshaw 1998).

To optimize the sensitivity of the survey, AMiBA is designed for maximal sensitivity, by maximizing the number of elements, adopting dual channel for the receivers and to have a 20 GHz bandwidth. The choice of the 90 GHz range is to minimize the foreground and point source confusion, and to minimize the scale of the array.

To detect clusters more massive than $2.5 \times 10^{14}\,\mathrm{M}_\odot$ at z $\gtrsim 0.7$, the AMiBA will be more sensitive compared to X-ray detection by satellites such as the XMM (fig. 1). A comparison of the sensitivity of AMiBA with other existing and planned instruments that can be applied to such a survey is also shown in fig. 1. We plan to survey for 50 square degrees of sky at a speed of 1.2 square degree per month.
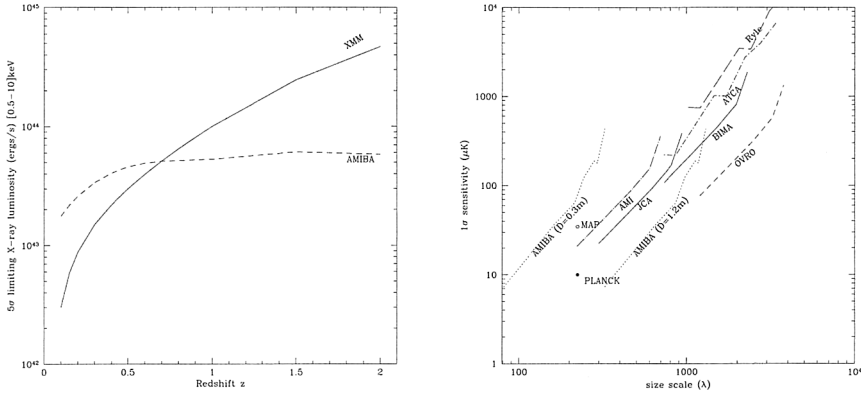
Figure 1.   LEFT:A comparison of the limiting sensitivity of AMIBA (dot-
ted curve) and XMM (Solid curve) for detecting clusters at various redshifts.
AMIBA is more sensitive than XMM at detecting clusters beyond a red-
shift of $z \gtrsim 0.7$. Limiting X-ray luminosity in ergs s^{-1} for a 5σ detection
in 20 ksec for both telescopes for a typical cluster of core radius $r_c = 250$
kpc, shape parameter $\beta = 2/3$ and gas temperature $T_e = 8$ keV, assuming
an average galactic neutral hydrogen column density of $N(H) = 6 \times 10^{20}$
cm^{-2} for the X-ray observation. (XMM sensitivities provided by Monique
Arnaud) RIGHT: A comparison of brightness sensitivities (in 1hr) of various
ground based aperture synthesis telescopes for the SZE either in operation
or planning. The telescopes plotted is by no means a complete list of tele-
scopes capable of detecting the SZE. The brightness sensitivity in μK over
1hr's observation is plotted against the uv-spacing (or size scale) expressed in
terms of the number of wavelengths (multiplied by 2π gives l). A hexagonal
close packed configuration is assumed for AMIBA, and a scaled version of a
standard BIMA D-array configuration is assumed for the non-platform arrays
BIMA, OVRO, AMI and JCA.

2.2. Super-clusters, Filaments - Missing Baryons ?

In addition to the hot gas in highly collapsed objects such as rich clusters, a weaker SZ effect should be produced when CMB photons scatter off warm baryons in lower-density environments such as filaments and inter-cluster regions in superclusters. There is a growing consensus that a significant fraction (from 1/3 to 1/2) of the present-day baryons from big bang nucleosynthesis may be in the form of warm to hot gas with $10^5 < T < 10^7$ K which has mostly eluded detection thus far (cf. Fukugita et al 1998). Both gravitational and non-gravitational (such as supernova feedback) heating mechanisms have been discussed for this gas component (Dave et al. 2000; Cen & Ostriker 1999; Pen 1999; Wu et al. 1999) The gravitational case is due to shock heating as intergalactic gas flows along dark matter in filaments and the large scale structure. The dark matter in these regions are at moderate overdensities with a mean of 10 to 30, and the expected SZ distortion is of order 10 μK. Detection of signals from sensitive, non-targeted SZ surveys over large regions of the sky may be feasible, but it will be challenging to separate out the warm gas component from the primary anisotropy and the hot gas in clusters. We are currently carrying out more detailed studies to assess this exciting possibility.

2.3. Polarization of the CMB

The CMB polarization contains a wealth of information about the early Universe. It provides a sensitive test of the reionization history as well as the presence of non-scalar metric perturbations, and improves the accuracy in determining the cosmological parameters (Zaldariaga et al 1997). The degree of polarization is of order a few μK at $l \sim 1000$ (Bond and Efstathiou 1984).

So far, the current upper limit on the CMB linear polarization is 16 μK (Netterfield et al 1995). A handful of new experiments, adopting low-noise receivers as well as long integration time per pixel, are underway or being planned (Staggs et al 2000). The MAP mission, launched in 2001, will be sensitive to the temperature-polarization correlation. The balloon-borne Boomerang and Maxima experiments are scheduled flights in 2001 to measure polarization with an angular resolution of $l < 800$ and pixel sensitivity of a few μK. The ESA space mission Planck will have sensitivity to CMB polarization, but the mission is not scheduled for launch until 2007.

An interferometer array is very attractive for CMB observations in that it directly measures the power spectrum. In addition, many systematic problems that are inherent in single-dish experiments, such as ground and near field atmospheric pickup, and spurious polarization signal, can be reduced or avoided in interferometry (cf. White et al 1999). Balloon-borne experiments are usually plaqued by pointing accuracy.

The AMiBA, with dual-channel receivers and 4 correlators, will be able to measure all four Stokes parameters simultanesously, so that the array will be much more sensitive to detecting CMB polarization than existing arrays, such as the Very Small Array (VSA), Degree Angular Scale Interferometer (DASI), Cosmic Background Imager (CBI). The AMiBA, when used with the 0.3 m apertures, will be sensitive to CMB polarization over the range $700 < l < 2000$. The S/N ratio in polarization in 24 hr is about 4 at $l \sim 700$, and about 2 at $l \sim 1150$.

3.   AMiBA Specifications

Frequency (ν)	85-105 GHz
Bandwidth ($\delta\nu$)	20 GHz
Polarisations (N_p)	2-linear (XX,YY)
Receiver type	HEMT, cooled to 15 K
System Temperature	70 K
Number of Antennas (N)	19
Size of antennas (D)	2 sets; 0.3m,1.2 m
Number of Baselines	171
Primary beam	$11'$,$44'$ FWHM
Synthesized beam (full range)	$1'$ - $19'$
Fequency bands	8 chunks over 20 GHz
Flux Sensitivity	1.3mJy, 20.5 mJy in 1hr
Brightness sensitivity	7μK in 1hr
Mount	Hexapod Mount: 3 rotational axes used
Platform	CFRP structure - 3 fold symmetry

4.   Organization of AMiBA

The AMiBA project is a collaboration principally between ASIAA/NTU and the Australia Telescope National Facility (ATNF), with important participation by scientists elsewhere. K. Y. Lo is the PI, with Robert Martin as the project manager, T. H. Chiueh as the project scientist, Paul Shaw (NTU/ASIAA) as the project administrator, Michael Kesteven (ATNF) as the system scientist. The other science and engineering team members include Ron Ekers, R. Sault, M. Sinclair, Ravi Subrahmanyan and W. Wilson from the ATNF, M. T. Chen, Y. J. Hwang, Kin-wang Ng from the ASIAA, T. D. Chiueh, T. Chu, and H. Wang from NTU, Haida Liang (Bristol), Chung Pei Ma (Penn/ASIAA), Ue-li Pen (CITA/ASIAA), Jeff Peterson (CMU), and John Payne (NRAO).

5.   Some AMiBA Technical Details

The dual channel 85-105 GHz receievers will be based on the MIC InP HEMT amplifiers supplied by the National Radio Astronomy Observatory, with similar specifications built for the MAP project (Popieszalski 2000). The local oscillator system will be based on photonic devices with fiber-optic transmission lines, which will minimize component counts and make the distribution more stable. The 20 GHz bandwidth poses considerable technical chanllenges that are being met by a 17-lag analog correlator. There will be four correlators built to provide full polarization capabilities for AMiBA. The 19 apertures will be mounted on three 2.5m platforms supported on hexapod mounts.

As the project is also funded to develop the research capabilities of the universities in Taiwan, there are parallel development projects on the InP and GaAs MMICs that are aimed at satisfying the requirements of the AMiBA.

However, these development efforts are not placed on the critical paths of the AMiBA construction.

6. Schedule of events

A preliminary design review meeting was held in July 2000 in Taipei, where the decision was made to build a prototype by September 2001 to test the basic concepts and specifications. After the proving of concepts, the full system will be built to be completed in late 2003 and to start observations in early 2004.

To further review the science goals and to keep up with the latest development in this rapidly evolving field, an international workshop in Taiwan on AMiBA-related science goals is being planned for June 2001.

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