Part II
Primordial CMB Observations: Ground based

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The Very Small Array

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Abstract.

The VSA is a 14-element aperture-synthesis telescope for mapping structure in the Cosmic Microwave Background which is now being commissioned at the Teide Observatory, Tenerife. It operates at frequencies between 26 and 36 GHz, with a bandwidth of 1.5GHz. Its elements track the sky, providing fringe-rate discrimination of any instrumental effects such as antenna cross-talk or ground radiation. The instrument incorporates a single-baseline interferometer comprising two large (3.7m) dishes, which is used to provide concurrent (and same frequency) pointed flux measurements of point sources in the VSA fields, the positions of these source having been obtained previously from survey observations made with the Cambridge Ryle Telescope at 15 GHz. The VSA is now completing its commissioning programme and it will start routine observations in September 2000.

1. Introduction

The Very Small Array (VSA) is a 14-element interferometer designed for mapping anisotropies in the Cosmic Microwave Background (CMB) over the range of angular scales, $10'$ to $2.5°$. The instrument is located at the Teide Observatory, Tenerife and the project is a collaboration between the Cavendish Astrophysics group (Cav AP), Cambridge, the Jodrell Bank Observatory (JBO), Manchester and the Instituto de Astrofisica de Canarias (IAC), Tenerife. The basic design of the VSA is a development of the Cosmic Anisotropy Telescope (CAT), which operated in Cambridge between 1992 and 1998 (Robson et al. 1993), and comprises corrugated horn-reflector antennas, rotation of the reflectors providing tracking in one of the coordinates. In order to cover the required range of angular scales while retaining a well-filled array, two different array configurations are used, with primary elements having beamwidths of $4.5°$ (compact array) and $2°$ (extended array); the compact array is described here. Some of the basic parameters of the telescope are shown in Table I.

The frontend receivers are 26-36 GHz cryogenically-cooled HEMT amplifiers, providing a typical overall system temperature of $\sim 25 - 30$K and an instantaneous observing bandwidth of 1.5 GHz. By combining observations at the upper and lower ends of the tuning range, an estimate of the galactic contribution can be obtained. The frontends, cryostats and 1st LO systems have been the provided by JBO, the remainder of the system being the responsibility of the Cavendish Laboratory, Cambridge. The site, support services and laboratory accommodation are provided by the IAC, Tenerife.

No. of elements	14	
Location	Teide Observatory, Tenerife	
Frequency	26 - 36 GHz, 1.5 GHz bandwidth	
	Compact array	Extended array
Element Aperture	143 mm	350 mm
Primary Beam (36 GHz)	4.5°	2°
Sensitivity (200h integn.)	24 mJy	4 mJy

Table 1. Basic VSA Parameters

2. Design Considerations

Both the CAT and the VSA are aperture synthesis interferometers employing phase-switching receivers. Such systems have the advantages of (i) having a precisely zero response to total power and (ii) providing a direct measurement of Fourier components of the sky brightness $B(\theta)$. To reduce the level of cross-coupling, the interferometer elements must have a very low response in directions away from the main beam. The VSA antennas have a response of less than -55 dB in directions more than about 30° from the primary beam.

The use of individually tracking elements has the important advantage that the rate of change of phase of the astronomical signals with HA (the source fringe rate) makes these signals easily distinguishable from the effects of ground radiation or any residual cross-talk between the interferometer elements. (When converted to a map of the sky, these latter signals will appear close to the celestial pole.) Atmospheric signals also generally have a completely different periodicity from the astronomical data. In return for these advantages, the use of tracking antennas makes it less easy to achieve close-packing of the elements and requires the use of 'path compensation' to maintain coherence of the wanted signals over the observing band.

To eliminate the need for the 'cable-rotator' used in the CAT, the VSA horns/reflectors are mounted in a North-South orientation on a tiltable table, the reflectors providing pseudo-HA tracking and the table providing pointing in elevation. Improved packing is achieved by tilting the horn/cryostat at an angle of 35° to the table. The tracking range is $\sim \pm 35^\circ$ and the range of accessible declinations, $\sim -7^\circ$ to $+63^\circ$. To eliminate ground radiation, the complete array is surrounded by a 3m high octagonal enclosure (Figure 1).

The 1st mixer is integrally mounted with the cryostat and phase-switching is provided by 180° switching of the LO signal to each aerial using orthogonal Walsh functions having effective frequencies in the range $\sim 150-2000$ Hz. Low-level noise signals, modulated at $\sim$ 2400 Hz are injected into each antenna to monitor variations of system temperature arising, for example, from changes in atmospheric opacity. Each 1st IF signal is converted to baseband (0.25 - 1.75 GHz) by two second mixers fed with 8 GHz LO signals which are in phase quadrature, providing the required in-phase and quadrature components of each antenna signal. Path compensation is provided, in increments of $\sim$ 7 mm,

Figure 1. 11 antennas on the tilt-table in test configuration

by a binary sequence of stripline elements controlled by solid-state microwave switches. Appropriate pairs of signals are fed by a series of splitters to 182 correlators, providing the real and imaginary components of the correlated signal from each of the 91 interferometer baselines. The outputs of the correlator are recorded every second, together with the noise calibration signals from each antenna.

3. Construction Programme

The array, with a subset of 6 antennas, and associated LO, IF, correlator and control systems, was initially assembled and partly commissioned at the Mullard Radio Astronomy Observatory, Cambridge in the period Mar-Oct 1999. Within the limitations set by the (generally) poor atmospheric conditions prevailing at this site, the system performed substantially as expected. Low-level spurious correlated signals which were present on some baselines, particularly towards the ends of the HA tracks, were attributed to incomplete shielding from ground radiation or atmospheric emission. (See later section describing system performance.)

In November 1999 the system was dismantled and everything (over 20 tonnes of equipment) shipped to Tenerife. The site work in Tenerife, including foundations and laboratory extension, were completed at about the same time. By early January 2000, assembly of most of the system, now including 9 antennas and cryostats, was completed and the first fringes were obtained in mid-January. Commissioning of the complete array, including all 14 antenna

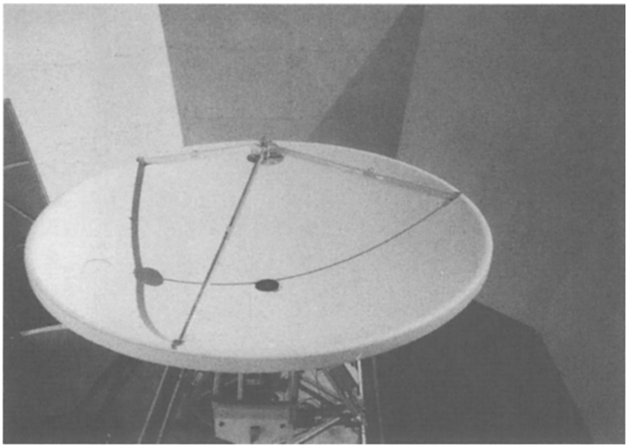

Figure 2. One of the source-subtraction dishes

elements, will be finished in September 2000 and routine observations started shortly afterwards.

4. Source-subtraction Strategy

Foreground point-sources are a significant component of maps made at the frequencies around 30 GHz and the VSA has an explicit two-stage strategy for their removal. In the first stage the relevant region is mapped with the Ryle Telescope (Jones et al. 1991) at 15 GHz, down to a flux level such that all sources which might significantly affect the VSA map - including those with inverted (i.e. rising) spectra - are detected. During the VSA observations the sources so detected are measured, at the same frequency as the main array, using pointed observations with a single-baseline interferometer (the 'source-subtraction' system) consisting of two 3.7m dishes (Figure 2), and their contributions subsequently subtracted, in the UV plane, from the VSA observations. Since the source observations are made concurrently with the main observations, the known time variability of many of the sources does not introduce any errors. The Cassegrain source-subtraction antennas are each situated in an enclosure identical to that of the main array, separated 9m on a North-South baseline, and are fitted with identical horn-reflector feeds and cryostats as are used on the main VSA array. The Ryle source surveys are described in more detail by Taylor (these Proceedings) and Waldram (ibid).

5. System Performance

5.1. The spurious signal

It was apparent from the earliest tests of the system in Tenerife that the spurious signal noted during the initial Cambridge observations was still present.

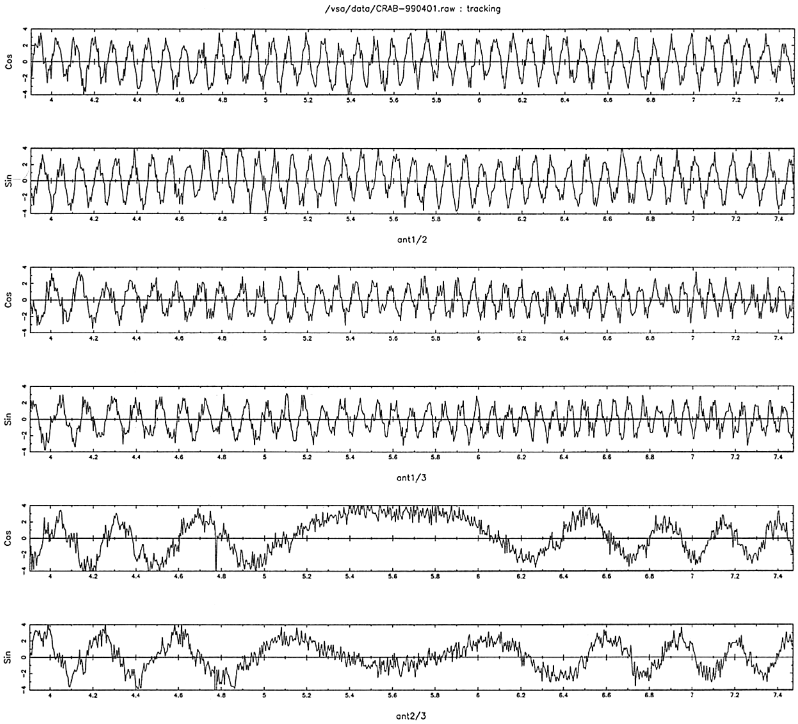

Figure 3. Sample fringes from a VSA observation of Tau A

Exhaustive tests have failed to indentify the source of this signal unambiguously since it is an order of magnitude larger than can be attributed to the noise from one receiver entering another, given the measured level of coupling between the feed horns (which is similar to that deduced with the far-field horn response patterns). It possibly arises from coupling of small thermal signals through higher-order excitation modes of the feed horns. Fortunately, the signals are mostly confined to the shorter baselines and the ends of the HA tracks and generally have a fringe rate which is very different from (i.e. lower than) that of the astronomical signal. In order to remove these unwanted signals, the data are passed through a high-pass filter having a 7×10^{-4} Hz cut-off frequency. Those samples for which the astronomical signal has a calculated fringe frequency below this value are omitted from the subsequent analysis. This process proves to be extremely effective in reducing any effects of the unwanted signal to such a level as to be undetectable, even after the addition of 30 days observations.

5.2. System Tests

The main array has been undergoing commissioning tests since February 2000, the last of the 14 antennas being added in August 2000. Sample fringes, of the calibration source Tau A, are shown in Figure 3. Observing conditions over this period have been extremely good, with less than 5 % of the data being

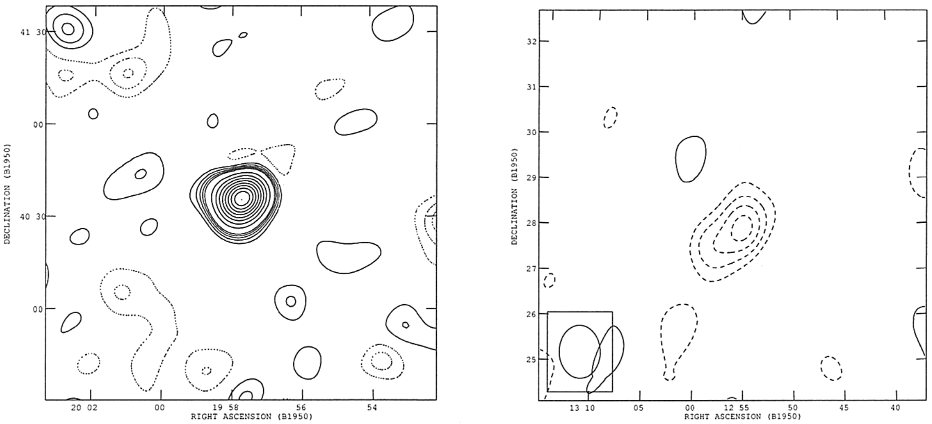

Figure 4. VSA observations of (left) Cygnus A, calibrated on an observation of Tau A, and (right) the S–Z effect in the Coma cluster (Rusholme, these Proceedings).

significantly affected by the atmosphere. The system has also demonstrates very good phase stability, with a typical rms phase variation of ~ 6° over a 13 day period. A VSA observation of Cyg A, calibrated on an observation of Tau A, is shown in Figure 4; the dynamic range is greater than 100:1, with no self-calibration. A map of the SZ effect in the Coma cluster (Rusholme, these Proceedings), taken in May 2000, is also shown.

It is important to test the behaviour of the telescope over extended periods of integration, to confirm that its performance is not limited by any systematic effects, such as cross-talk or residual ground radiation. A combination of 30 days VSA observations shows the expected $t^{-1/2}$ reduction in noise level, indicating that, for this period at least, no systematic effects are detectable.

The VSA is scheduled to start routine measurements in September 2000 when three fields, selected to contain small numbers of foreground sources and low galactic emission, will be observed.

6. Acknowledgments

The VSA project has involved contributions from a large number of people at each of the three collaborating institutions and these are gratefully acknowledged.

References

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