# COMMISSIONING THE VERY SMALL ARRAY

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The Very Small Array (VSA) is a fourteen-element interferometer for sensitive measurement of CMB anisotropies on scales of three degrees to ten arc-minutes. The telescope was assembled and tested in Cambridge and is now undergoing commissioning observations on site in Tenerife. As each antenna in the array tracks quasi-independently this provides a fringe rate per baseline which attenuates systematics such as cross-talk. This possible contaminant has been modelled on measurements of antenna cross-coupling and shown to be under the thermal noise.

## 1 Introduction

The Very Small Array is an interferometric experiment for mapping anisotropies in the the CMB. The power spectrum of these fluctuations is cosmology-dependent and sensitive to fundamental parameters such as $H_0$, $\Omega_{\rm M}$ and $\Omega_{\rm b}$. The current paradigm of inflation and CDM predicts Gaussian-distributed fluctuations on the sky with a strong peak in the power spectrum at about one degree scales with subsequent peaks of declining amplitude at smaller angular scales.

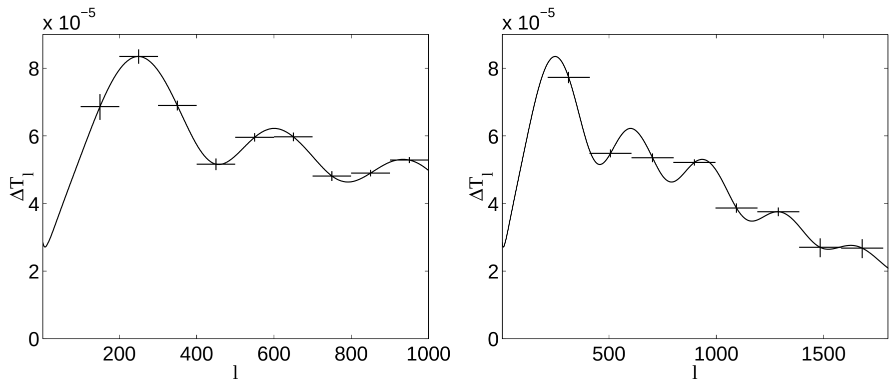
An interferometer is well-suited to measuring such a signal as it directly samples the Fourier modes of the sky which can be readily converted to a power spectrum. In addition interferometers provide excellent rejection of systematic noise due to filtering of unwanted signals which do not move with the celestial sky, and by switching and correlating of the signal from each antenna which removes instrumental drifts.

The range of angular scales sampled is determined by the spacing of the elements of the array. In its most compact configuration the VSA has fourteen close-packed antennas of 143mm diameter for sensitivity on angular scales of up to three degrees (the observing band is the $26 \leftrightarrow 36$GHz atmospheric window). For mapping finer angular scales the antenna diameter

Table 1: Observational parameters of the two configurations of the VSA

| | *Compact* | *Extended* |
|---|---|---|
| Mirror Size / mm | 143 | 350 |
| Primary Beam (30GHz) | $4.0°$ | $1.6°$ |
| Synthesised Beam (30GHz) | $34'$ | $11'$ |
| Range of $l$ | $120 \leftrightarrow 900$ | $300 \leftrightarrow 1900$ |
| Flux Sensitivity (in 28x7hrs) / mJy | 24 | 4 |
| $\Delta$T (in 28x7hrs) / $\mu$K / beam | 30 | 30 |

Figure 1: Simulated power spectrum recovery for two years observation on twelve separate fields.




will be increased to 350mm to maintain the temperature sensitivity of the larger array. The specifications of these two configurations are given in table 1.

The simulated power spectrum recovery for each configuration is given in fig 1[2]. The data are binned such that the noises in each are uncorrelated. The number of independent bins can be increased by mosaicing the fields together. Increasing the continuous sky coverage reduces the width of the convolution in the aperture plane, allowing finer binning without correlation.

## 2 Project Overview

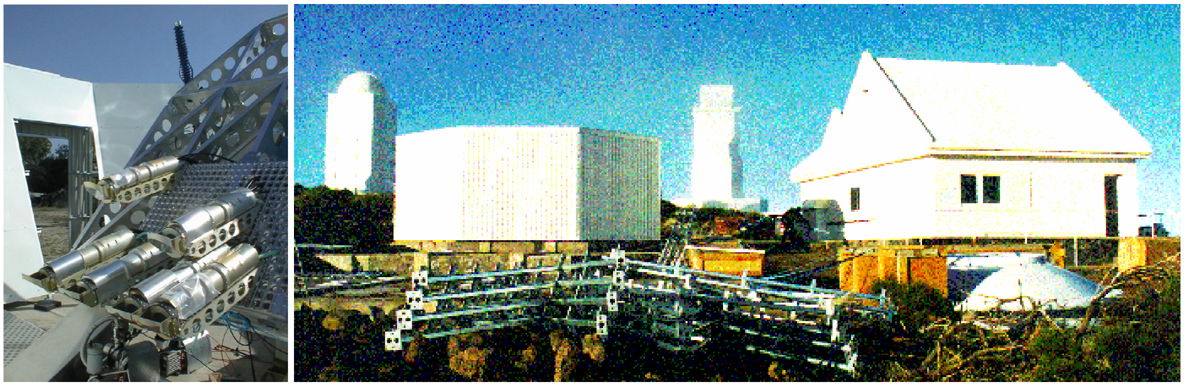
The telescope was assembled and tested at the Mullard Radio Astronomy Observatory, Lord's Bridge, near Cambridge, between February 1998 and November 1999, prior to being shipped to the Observatorio de Teide, Tenerife, where it is currently undergoing commissioning observations.

Data from the new site show that the design sensitivity is being achieved and that atmospheric contamination is negligible. Experience from the Jodrell Bank 33GHz interferometer (D. Harrison, these proceedings) on the same site show that correlated emission from the atmosphere is undetectable for $> 80\%$ of the time and that the atmospheric contribution to the noise temperature is $\sim$5K.

## 3 Rejection of Systematics

The telescope has been designed for the best possible rejection of systematics[3]. Interferometers naturally provide a great deal of rejection of spurious signals via several effects:

Figure 2: Snapshots of the VSA under construction. *Left* Inside the ground shield, Cambridge, September 1999. Six antennas can be seen mounted on the table, which drives in elevation. The mirrors on the end of the cryostats rotate to track in pseudo-hour angle. Note the blinders around the mirrors which further attenuate side-lobes and cross-coupling between the corrugated horn antennas. *Right* The VSA on site in Tenerife, January 2000. The control room and correlator (in screened room) are located in the building on the right. The source subtraction foundations and dishes can be seen in the foreground (see K. Grainge, these proceedings)



- Fringe Rotation: A feature of the VSA that distinguishes it from the other current interferometric CMB experiments such as CBI[4] and DASI[1] is that the antennas track quasi-independently. This results in a varying path to each antenna during an observation and thus a *fringe rate*. The complex visibilities are multiplied by the inverse of this expected fringe rate at to give a quasi-constant signal. This is equivalent to applying a matched filter and moves all signals not varying at the expected fringe rate outside the map; eg. constant offsets appear at the North Pole.

- Delay Beam Smearing: For sources away from the pointing centre the path difference between antennas causes the interference fringes wash out due to white light de-coherence.

- Sample Averaging: Fringes of periods close to and faster than the sample integration time (typically 16 sec for the VSA) average out. This assists in rejecting bright sources far from the pointing direction, and also residual correlated emission from the atmosphere which tends to have quite fast ($0.1 \leftrightarrow 1$Hz) fringe rates.

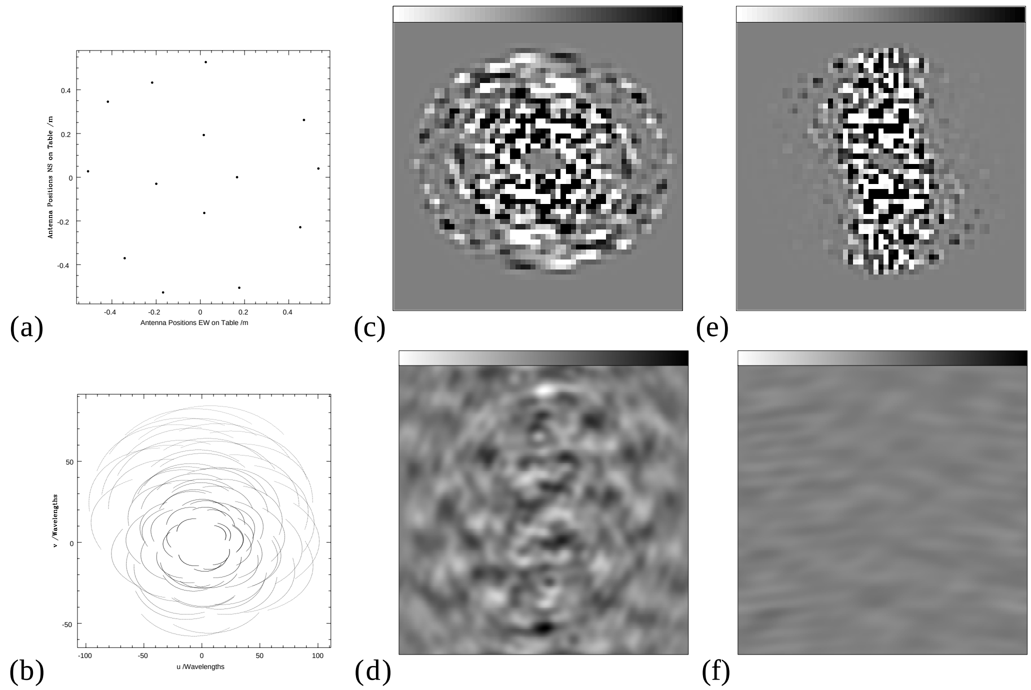
### *3.1 Simulations of Cross-Coupling Contamination*

A good example of the benefit of fringe rates is in the reduction of any cross-coupling contamination. This is potentially a serious problem in a close-packed array when noise generated in an antenna can be picked up by a neighbour and correlated.

We measured the near-field coupling between VSA antennas at varying separations, orientations and mirror angles by mounting a modulated transmitter in an antenna assembly and detecting the switched power via a second VSA antenna. Even at the shortest spacings the antenna coupling was no worse than $-100$dB. These data were then interpolated and scaled for an compact 2D array and used to produce a simulated observation, including all of the above interferometer effects. To calibrate the cross-talk signal, we assumed that the emitted power was 10% of the amplifier noise power, ie. about 3K. VSA antennas are fitted with a 20dB isolator.

The cross-coupling signal drops with distance, and delay beam smearing also has a greater effect on longer baselines, so that the signal is largest on the shortest baselines. Fringe rotation only applies to the E-W component of a baseline. Thus the cross-talk is least rejected on the

Figure 3: Simulations of cross-coupling contamination. (a) The (unoptimised) compact Kogan array used in the simulations (b) *uv* coverage for the array tracking a near overhead source from Tenerife. (c) Result of cross-coupling simulation gridded on the aperture plane. (d) 14.2 degree$^2$ map of this data. Noise level 3.5mJy. (e) Aperture plane after fringe rotation and flagging of low fringe rate data (3.1% reduction in sensitivity). (f) Map of fringe rotated and flagged data. Noise level is 0.6mJy.




short N-S baselines. For these simulations the simplest solution of flagging out data with the lowest fringe rates was used. Removing a small fraction of the data results in a large reduction in the cross-talk signal in the map, equal to the effect of fringe rotation - see fig3.

The cross-talk flux calculated before fringe rotation was an order of magnitude under our thermal noise. The fringe rate effects increased this by a further factor of five. Fringe rate/ interferometer effects are a significant aid to the accuracy of the experiment.

## 4 Conclusions

The Very Small Array is beginning scientific observation from a good site after extensive design verification. We have accurately modelled the possible contamination from cross-coupling, a possibly serious systematic for a close-packed interferometer, and have found it to be under our expected thermal noise limit. The effects of interferometer fringe rates assist in the rejection of non-astronomical sources. The contamination due to astronomical sources is discussed by K. Grainge (these proceedings).


## Acknowledgments

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**References**


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2. M. Hobson and S. Bridle. Private communication.
3. M. Jones and P. Scott on pg. 233 of *Proceedings of XXXIIIrd Recontres de Moriond*, ed. J. Trân Thanh Vân *et al.* (Editions Frontièrs, 1998).
4. http://astro.caltech.edu/ tjp/CBI/