Observations of the Sunyaev-Zeldovich Effect Towards ROSAT Clusters with SEST and the Italian Double-Channel Photometer

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Scientific Aims

A double-channel (1.2 and 2 mm) photometer has been installed at the focus of the SEST antenna to perform measurements of the Sunyaev-Zeldovich effect towards X-ray ROSAT clusters. Here we report the performance of the instrument and the first results obtained during the August-September 1994 observing run.

The Sunyaev-Zeldovich effect (Sunyaev and Zeldovich, 1972) is a shift of the Cosmic Microwave Background spectrum by the inverse Compton scattering of microwave photons by the hot electron gas present in rich clusters of galaxies. The resulting cluster signal shows a decrement at wavelengths longer than 1.4 mm and an enhancement at shorter ones relative to its planckian value. After many attempts to detect this effect (see e.g. the review paper Birkinshaw, 1990) radio observations seem finally to show the expected decrement at centimetre wavelengths towards A2218, A665, 0016+16 and A773 (Birkinshaw, 1991; Klein et al., 1991; Jones et al., 1993; Grainge et al., 1993) and more recently even at 2.2 mm towards A2163 (Wilbanks et al., 1994). However, a more definitive detection of the S-Z effect requires the measurement of both the decrement and the enhancement. In order to minimize systematic errors and to eliminate spurious signals, simultaneous detections of the decrement and enhancement are mandatory.

The Italian group of the III University of Rome have therefore built a photometer with two channels centred at 1.2 and 2 mm to feed the O.A.S.I. (Osservatorio Antartico Submillimetrico Infrarosso) telescope installed at the Italian base in Antarctica (Dall'Oglio et al., 1992). This photometer has been adapted to be placed at the focus of the SEST antenna in Chile.

The Instrument

The photometer uses two Si-bolometers cooled at 300 mK by means of a single stage ^{3}He refrigerator. They are located inside the cryostat orthogonal to each other. With this configuration the radiation coming from the telescope is split by a dichroic mirror (beam-splitter) onto two interference filters centred at 1.2 and 2 millimetres with bandwidth 350 and 560 μm respectively. The central wavelengths have been chosen to match the atmospheric transmission windows and to maximize the ratio between the expected signal from the S-Z effect and that from the atmosphere, I_{SZ}/I_{atm}. Note that the 2 mm band includes the peak brightness of the decrement in the S-Z effect: $\Delta I \sim -56.3\, y$ Jy (or in temperature: $\Delta T \sim -2.53\, y$ K), while in the 1.2 mm band we expect a positive signal of $\sim + 32.3\, y$ Jy (or $\Delta T \sim + 1.33\, y$ K), where y is the Comptonization parameter depending on the electron gas temperature and density. It ranges between 2 and 6 10^{-4} for the chosen clusters. More details on the characteristics of the photometer and the refrigerator system can be found in Pizzo et al. (1994a, 1994b).

Before installing the photometer in the receiver cabin, we measured the r.m.s. values of the responsivities (the detector output signals in Volts per degree Kelvin or per Watts falling onto the detectors): we find 5.9 μV/K (or 2 10^7 V/W) at 1.2 mm and 2.8 μV/K (or 3.8 10^7 V/W) at 2 mm. The noise equivalent temperatures (N.E.T., i.e. the brightness temper-

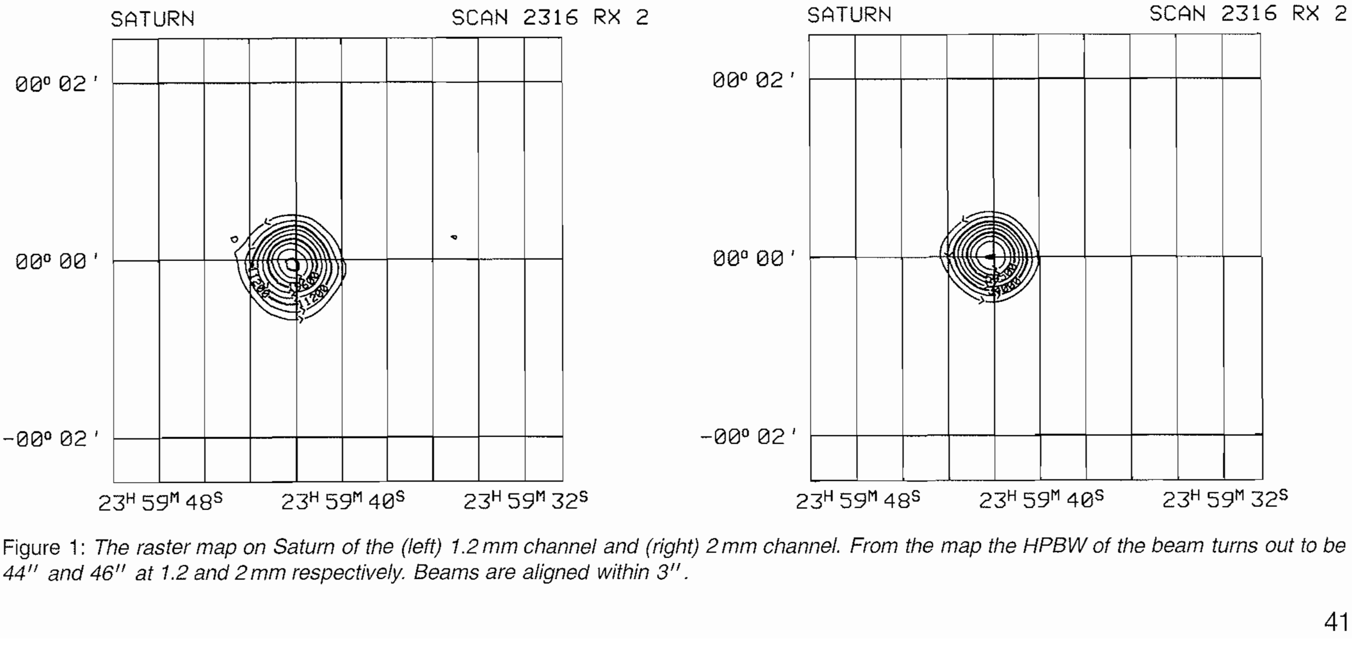

Figure 1: *The raster map on Saturn of the (left) 1.2 mm channel and (right) 2 mm channel. From the map the HPBW of the beam turns out to be 44″ and 46″ at 1.2 and 2 mm respectively. Beams are aligned within 3″.*

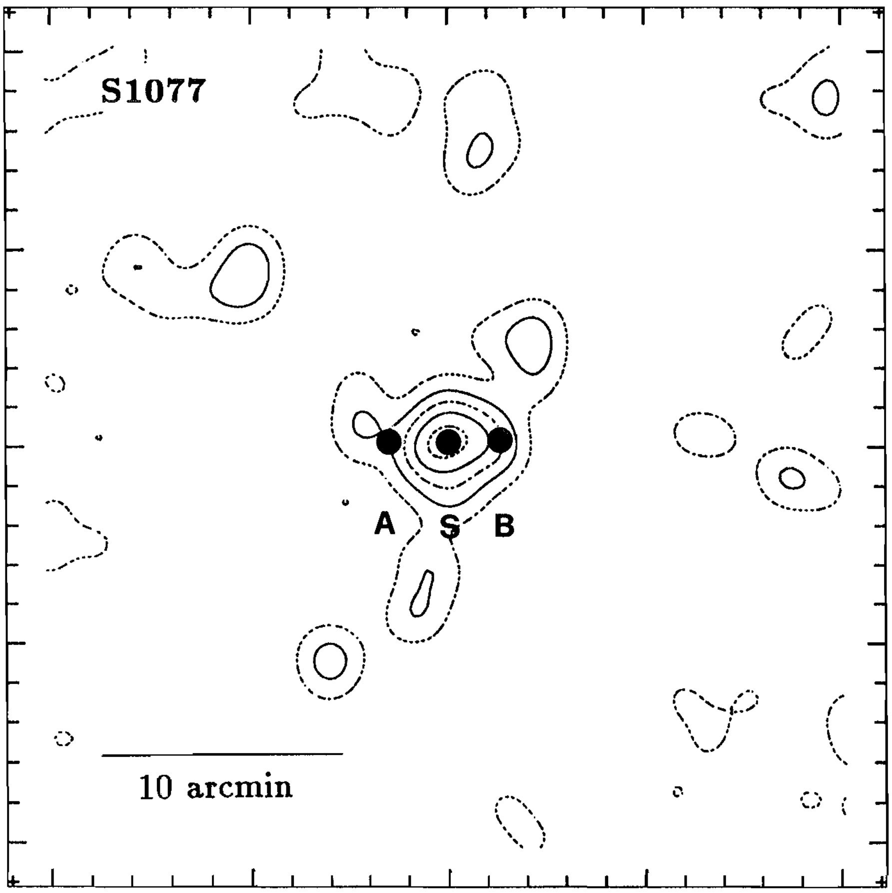

Figure 2: *The ROSAT all-sky survey image of S1077. The central beam (S) and the reference beams (A and B) are shown as filled circles superposed on the X-ray isophotes.*

ature producing a signal with a signal-to-noise ratio of 1) are: 4.2 and 9 mK/$\sqrt{Hz}$ at 1.2 and 2 mm respectively. Since we expect a cluster signal of the order of 1 mK (see above), this means that in principle to get a 1σ value of 1 mK we have to integrate for 5 and 20 seconds at 1.2 and 2 mm respectively.

The coupling between the optics of the telescope and that of the photometer is provided by a PTFE lens converting the F/d = 5.1 beam from SEST to the F/d = 4.3 configuration of the photometer. The lens focal length of 570 mm gives the optimum coupling at both 2 mm and 1.2 mm and it is fixed on the cryostat window. The lens was designed and built at Onsala.

The electronic chain consists of a preamplifier and a variable gain amplifier for each detector. The signal from each channel is fed to two separate acquisition systems: (a) by means of a two-channel Voltage-to-frequency converter, the outputs from the variable gain amplifiers are integrated with counters and stored on the HP computer controlling the antenna. The acquisition software has been modified by Roland Lemke of the SEST team in La Silla in order to store the two outputs of our photometer. (b) The secondary outputs from the variable gain amplifiers are fed to Stanford Research Lock-In amplifiers. The analogue outputs from the lock-in amplifiers are measured in a DI-200 data-acquisition system which is controlled by a 80386 PC through a parallel port. The programme uses the serial port COM1 to read the data from the antenna HP control computer. The data-acquisition programme was implemented by Angel Otàrola of the SEST team at La Silla.

Measured Performance

We used the dual-beam mapping programme adapted by Roland Lemke for the two-channel photometer to perform raster scans on planets. These scans provide a measurement of the beam shapes and dimensions and the beam separation in the sky. Figure 1 shows the two-dimensional appearance of the beams of the two channels. As it is clear from the figure, the beams are symmetric around the optical axis. Planet scans at the two wavelengths overlap well (within 3″), indicating the good alignment of the two beams. The Half Power Beam Width turns out to be 44 and 46″ at 1.2 and 2 mm respectively as we expect from the dimensions of the Winston cone entrance. Note that we are not working in a diffraction limited configuration and therefore the beams at the two different frequencies are comparable. We have set the chop throw in order to have a beam separation in the sky of 135″.

The detector noise in the receiver cabin turned out to be twice as large as that measured in the laboratory. In particular, because of its mounting inside the cryostat, the 2 mm channel suffered microphonics very likely caused by vibrations of the mechanical devices cooling the heterodyne receivers. In order to measure the N.E.T.s, sky noise and responsivities must be evaluated: the former is obtained during each night by looking at blank sky, the latter with calibration on planets. The average values of the N.E.T. measured at the focus were 28 and 70 mK/$\sqrt{Hz}$, i.e. 14 and 35 mK in one second integration time. To compare these values with those expected from the effect we have estimated, the magnitude of the latter by convolving $\Delta T = T\,y\,(x \coth(x/2) - 4)\ K$ (T is the CMB temperature, $x = h\nu/kT$ and $y = \int kT_e/mc^2 n_e \sigma_T d\ell$ is the comptonization parameter, n_e, T_e being the electron density and temperature) with the spectral filter response, the atmospheric transmission and the cluster core radius. We find: $\Delta T \sim 1.3\,y\,K$, $\Delta T \sim -2.7\,y\,K$ at 1.2 and 2 mm respectively. For a typical cluster in our list we estimate a comptonization parameter of $y \sim 4\ 10^{-4}$, therefore we get $\Delta T \sim 0.5\,mK$ and $\Delta T \sim -1.1\,mK$ at 1.2 and 2 mm respectively. This means that 3σ values can be reached in 2÷3 hours with the present instrumentation.

Observations of X-Ray Clusters A2744, S1077 and S295

Candidate sources were selected from the ROSAT southern clusters according to the following prescriptions: (a) high X-ray luminosity and (b) redshift larger than 0.25. This choice matches the two fundamental requirements: a small apparent angular dimension of the cluster core and a large Comptonization parameter. The cluster angular dimensions should not largely exceed the instrument beam width and they must be smaller than the maximum chop throw otherwise the amplitude of the signal cannot be correctly estimated. A large y parameter enhances the amplitude of the effect and therefore its detectability. Figure 2 shows superposed to the X-ray map of S1077 the location of the main beam (at the centre) with the reference beams (position A and B). Beam switching + nodding provides the real-time comparison between the emission from the cluster centre and that from the reference beams A and B.

The effect we are looking for is very weak. We have therefore to check carefully all the systematics which could affect the measurements. Spill-over from the ground, difference in temperature from one side to the other of the main mirror and other effects could certainly plague the observations. Since it is hard to identify and quantify each effect, we have measured them according to the following observing strategy: each source was integrated over time chunks of 600 s, this time interval plus the needed overheads gives a total tracking time on the source of 15 minutes. The same time was spent on a blank sky located with equatorial coordinates 15 minutes larger in right ascension. This means that the antenna tracks twice the same sky position in horizontal coordinates: once ON the source and the second time on the reference blank sky position. This enables us to compare the two different measurements and eliminate the spurious signals.

Because of the time spent for installation and tests and that lost due to bad weather, the number of useful observations in our August-September run was small. Some observations were obtained towards the clusters A2744, S1077 and S295. Careful data analysis is in progress: the real signal will be compared with a template one obtained by simulating the observational setup on the X-ray map of the source. A rough analysis gives some preliminary positive results: we find a 3σ value for the decrement towards S1077 of -2.5 ± 0.8 mK. This result makes us confident that with some improvements and the acquired knowledge of the system a next observing run will be successful in detecting the effect. We foresee changing the bolometer mounting by building a more robust cryostat and a different adapter. Both improvements will damp vibrations in the receiver cabin thus largely reducing microphonics and enhancing the detector sensitivity.

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