NASA-CR-192135

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Final Technical Report

For the period 10/1/88 through 11/30/91

"Microwave Spectroscopy of the Active Sun"
Grant NAGW-1706

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13 March 1992

(NASA-CR-192135) MICROWAVE SPECTROSCOPY OF THE ACTIVE SUN Final Technical Report, 1 Oct. 1988 - 30 Nov. 1991 (California Inst. of Tech.) 6 p

N93-20571

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1 Final Report

In studies of solar active regions and bursts, the ability to obtain spatially resolved radio spectra (brightness temperature spectra) opens a whole new range of possibilities for study of the solar corona. For active regions, two-dimensional maps of brightness temperature over a wide range of frequencies allows one to determine temperature, column density, and magnetic field strength over the entire region in a straightforward, unambiguous way. For flares, the time-dependent electron energy distribution, number of accelerated electrons, and magnetic field strength and direction can be found.

In practice, obtaining complete radio images at a large number of frequencies is a significant technical challenge, especially while keeping costs down. Our instrument at Owens Valley Radio Observatory provided the starting point for a modest attempt at meeting this goal. We proposed to build three additional, very low-cost 2-m antennas which, when combined with our existing two 27-m dishes, expands the array to 5 elements. This modest increase in number of solar dedicated antennas, from 2 to 5, increases our maximum number of physical baselines from 1 to 10, and allows the instrument to do true imaging of solar microwave sources, both bursts and active regions. Combined with the technique of frequency synthesis, the new array has up to 450 effective baselines, giving imaging capability that approaches that of a sub-arrayed VLA.

This SR&T grant was a three-year grant to provide funds to build two 2-m antennas, using an in-house design, and two frequency-agile receivers. An additional 2-m antenna was built as a prototype, and is now employed in the 5-element array with a spare receiver that was used previously on the 40-m antenna at Owens Valley. There was also money in the third year for partial support for a post-doc.

The prototype antenna design was finalized and the antenna put into operation in November 1989. A photograph of this antenna is shown in the Figure. The antenna is shielded from the wind on the north side by an 8-foot high chain-link fence, and protected from grazing cows on the south by a cattle-guard. The reflector is a 2-m parabola ($f/d = 0.4$) with a broadband (1-18 GHz) log-periodic linear dipole feed mounted at the prime focus. The antenna mount is an equatorial design, to match the previously existing 27-m antennas. The mount is driven with a stepper-motor in both axes ($6''$ per step) under computer control. Optical sensors detect when range limits are hit and also mark north-south and east-west sectors to aid in zeroing the stepper-motor counters.

After installation, the operation of the prototype dish was found to be nominal, and continuous 3-element data have been taken since late-1989. After check-out of the prototype, work on the two additional dishes was begun simultaneously with the design of the new frequency-agile receivers. Although the new receivers follow the design of the three existing receivers, some design work was required to repackage the receiver components into a more compact configuration. The new receiver package sits on the ground at the base of the antenna, rather than being placed at the prime focus as the existing receivers were designed to do.

The final two antennas and their receivers were constructed largely in parallel. The first of these antennas was completed in November 1990, and checked out with the receiver moved from the prototype 2-m antenna. This antenna also operated without difficulty. Near this time, control software was written to allow driving four dishes, switching delays, and

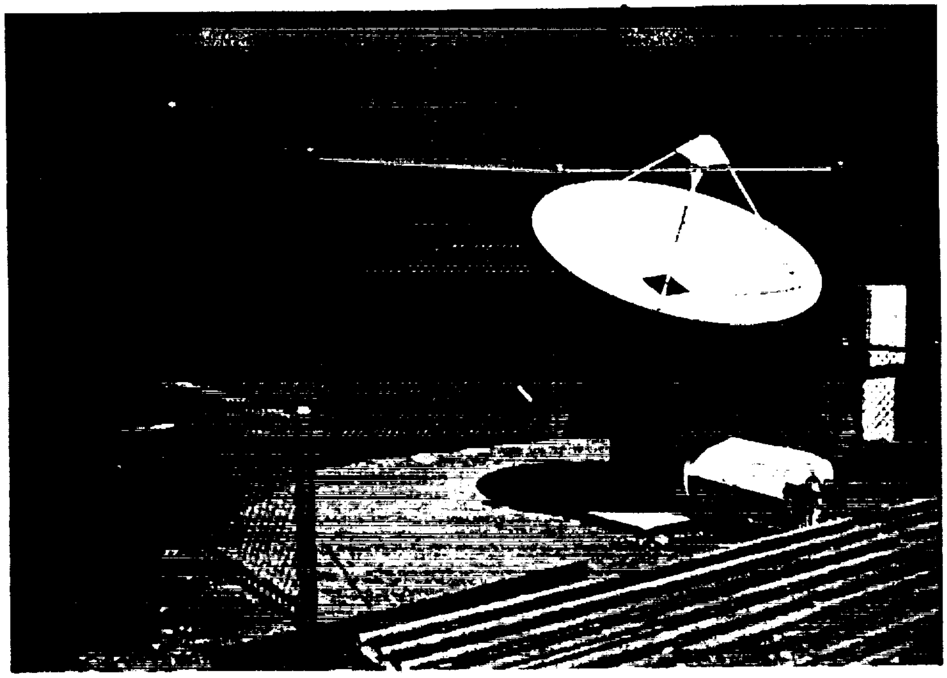

Figure 1: *A 2-m dish in operation at the Owens Valley site. The receiver sits on the ground at the base of the antenna.*

processing and recording data from four receivers. In early February 1991, the first of the new receivers was completed and our first 4-element observations began. The last antenna was completed in early April 1991, and checked out with the original receiver. At this time, the control software was generalized for controlling the five dishes. The final receiver was then completed and put into operation on 5 June 1991, completing the main construction phase of the project. Some additional signal switching hardware (IF and delay line multiplexers) were completed and installed in September 1991, making it possible to take data on all 10 baselines. The array has been operated in its full-up, 5-element mode since then.

Although we were given money in partial support of a post-doctoral fellow in the final year of the SR&T grant, reduced funding from the NSF made it appear impossible to find the additional support to allow hiring one. We are fortunate that a visitor from Brazil, Dr. J. Costa, was able to obtain a fellowship from the Brazilian government so that he required only partial support from us. Dr. Costa joined us in March 1991, for a 12 month stay, and is currently analyzing OVRO data taken during the HIREGS balloon flight period in December 1990.

Dr. Costa, working with Gary and Dr. T. Bastian, has completed a paper entitled "Complex Diffusion of Microwave Emitting Electrons in a Solar Flare." The event seen at OVRO was also observed with the new 5-feed radiometer system at Itapetinga, Brazil, operating at 48 GHz, and mapped at 15 and 23 GHz at the VLA. We use the OVRO spectral data to clarify the relationships among three spatially distinct sources seen with the VLA and Itapetinga. At least two of these sources appear to be related as footpoint and loop-top sources of a single loop system, indicating trapping of electrons at the loop-top plus precipitation in the high-field region at one of the footpoints.

Hurford, Gary, and Dr. R. Read have begun work on an instrumental paper that will give a full technical description of the 2-m antenna design and the signal multiplexing system, and will illustrate the capabilities of the 5-element array as a solar instrument. The paper will be illustrated with early observations with the instrument.

Another paper, to be presented at the June 1992 meeting of the AAS, will present observations of an active region and three flares that occurred on 1991 October 24. This is the first analysis of solar data using the completed 5-element system, and shows for the first time the imaging capability of the array for both earth-rotation-synthesis and snapshot imaging of flares. Figure 2 shows brightness temperature maps of the 24 October active region at a number of frequencies from 1 to 7 GHz. The reduction of the size of the source is dramatic, due to the free-free emission from coronal loops at low frequencies becoming optically thin at higher frequencies. The power of multifrequency mapping becomes obvious when the spectrum is determined for each point in the map. The frequency where the emission becomes optically thin gives a unique measurement of (i) the ambient electron density when the emission is due to bremsstrahlung (free-free) or (ii) the magnetic field strength when the emission is due to gyroresonance emission. Whether the emission is due to free-free or gyromagnetic processes can be determined directly from the shape of the optically thin part of the spectrum. Thus, these maps contain the information necessary to make a coronal density map and a coronal magnetic field map in the vicinity of the active region.

Gary, along with Dr. G. Dulk and Dr. Y. Leblanc, are working on a paper describing observations of an active region observed during the (partial) eclipse seen at OVRO on 1991 July 11. By using the motion of the lunar limb as a "knife-edge," spatial resolution of 1-2″ in one dimension can be achieved simultaneously at 20 frequencies. The result is a one-dimensional scan across the active region showing the spectral variation of the emission in two polarizations. From an analysis of the spectra, we can determine the sense and strength of the coronal magnetic field, and the coronal temperature and density. We compare this with the structure of X-ray emission observed with the Normal Incidence X-ray Telescope (NIXT) rocket experiment of the Harvard Smithsonian Center for Astrophysics, which occurred shortly before the observations.

In a paper nearing completion, Gary, along with Drs. T. Bastian and M. Aschwanden, are studying a pulsation event that occurred on 1990 Dec 21, during the Max '91 Campaign #2. The paper includes observations from OVRO at 0.2 s time resolution at 5 frequencies in the range 1.2-2.0 GHz, where rapid, spikey pulsations are seen, and observations at 1.4 and 5.0 GHz with the VLA. The OVRO data allow the bandwidth of the pulsations to be measured, while the VLA data allow the locations of the pulse and interpulse sources to be distinguished for the first time.

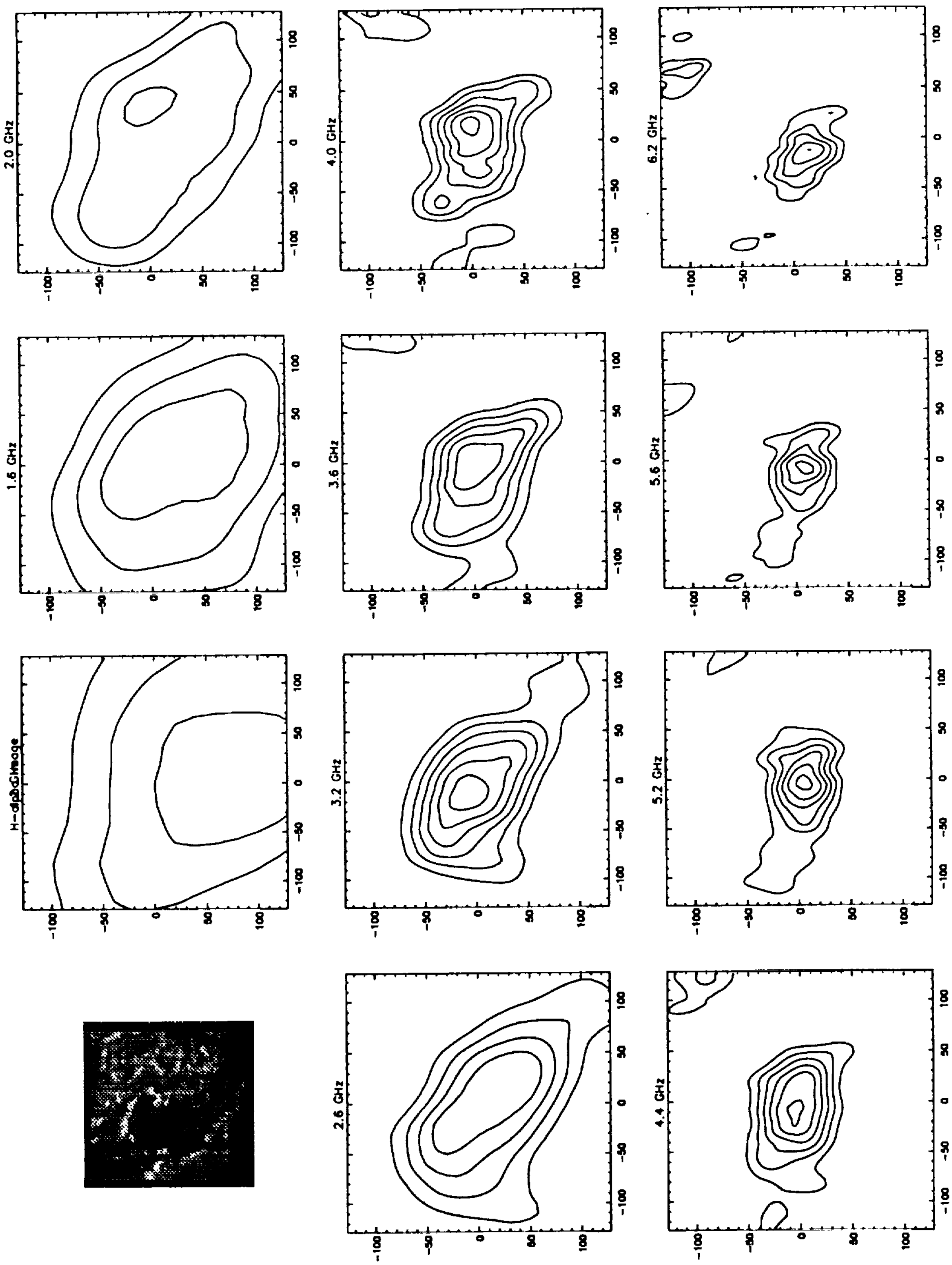

Figure 2: *OVRO rotational synthesis maps of an active region observed on 1991 October 24. The first panel shows the region in H-alpha, to the same scale as the following maps. Each map covers a* $256'' \times 256''$ *region of the Sun. Each contour represents* 5×10^6 *K. We actually have twice as many frequencies as shown, and find a smooth variation in source structure with frequency.*

2 Other Papers Appearing in Refereed Journals

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