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A SEMI-ANNUAL PROGRESS REPORT

FOR

NASA SMM GUEST INVESTIGATOR GRANT NAG 5-501

ENTITLED

SIMULTANEOUS SOLAR MAXIMUM MISSION (SMM) AND VERY LARGE ARRAY (VLA) OBSERVATIONS OF SOLAR ACTIVE REGIONS

for the period from 1 February 1985 to 30 January 1986

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I. INTRODUCTION

The purpose of this grant is to obtain and analyze simultaneous observations of solar active regions with the Solar Maximum Mission (SMM) satellite and the Very Large Array (VLA). The combined results have and will enhance the scientific return beyond that expected from using either the SMM or the VLA alone.

We have now obtained a total of two weeks (14 days) of simultaneous SMM-VLA data (see Section II for greater detail). The multiple wavelength VLA observations have been used to determine the temperature and magnetic structure at different heights within coronal loops. These data are now being compared with simultaneous SMM-XRP observations. Additional simultaneous SMM-VLA observations of the Sun will be carried out during the rest of 1985 and in 1986.

The Principal Investigator of this grant has presented three papers at workshops during the first half of 1985. These workshops are described in greater detail in Section III where the abstracts of these papers are reproduced. The paper presented at the CESRA workshop in Duino, Italy will be published in a special issue of Solar Physics, whereas the review paper presented at the Solar Maximum Analysis (SMA) workshop at Irkutsk, Siberia will be published as a contribution to a book.

A review article entitled "The Sun and Nearby Stars : Microwave Observations at High Resolution" was published in the April 15, 1985 issue of Science. This article is reproduced in Section IV.

The final Section V describes several papers that are now in progress. They include VLA observations of compact, transient sources in the transition region; simultaneous SMM-VLA observations of the coronal loops in one active region and the evolution of another one; and sampling of the coronal plasma using thermal cyclotron lines (magnetic field - VLA) and soft X-ray spectral lines (electron density and electron temperature - SMM/XRP).

II. SIMULTANEOUS SMM-VLA OBSERVATIONS

Although this SMM Guest Investigator Grant (NAG 5-501) is for a one year period beginning 1 Feburary, 1985, we had begun collaborative SMM-VLA observations in the summer of 1984. As a result, we have obtained a total of two weeks of simultaneous microwave and SMM measurements. These data are listed in Table 1.

Table 1. Simultaneous Microwave and SMM Observations of Solar Active Regions Taken Under the Support of NASA SMM Guest Investigator Grant NAG 5-501.

Date	Active Region Observed	Time (U.T.)	Wavelength (cm)
June 4, 1984	AR 4508	1400-2300	2,20
July 8, 1984	AR 4532	1800-2200	20
July 14, 1984	AR 4537	1600-2400	6,20
July 15, 1984	AR 4539	1600-2400	6,20
July 22, 1984	AR 4545	1500-2400	6,20
July 23, 1984	AR 4545	1500-2400	6,20
June 7, 1985	AR 4663	1500-2330	6,20
June 8, 1985	AR 4663	1500-2330	6,20
July 14, 1985	Whole Sun	1500-1700	21
July 15, 1985	Whole Sun	1500-1700	21
July 16, 1985	Whole Sun	1500-1700	11,21
July 19, 1985	Whole Sun	1500-1700	11,21
July 20, 1985	Whole Sun	1500-1700	11,21
July 21, 1985	Whole Sun	1500-1700	11,21

Because of operational difficulties with the UVSP, most of these simultaneous observations are being compared with XRP data from the SMM. Dr. Kermit Smith at the NASA Goddard Space Flight Center has spent considerable time developing the computer software needed to maximize the signal-to-noise of relatively weak soft X-ray signals. As a result, we are only now beginnning papers that describe the simultaneous VLA-SMM (XRP) observations. The fruitful comparisons are described in the following Section I on Papers in Progress. The relevant papers include:

A. June 4, 1984 Data:

VLA OBSERVATIONS OF COMPACT, TRANSIENT SOURCES IN THE SOLAR TRANSITION REGION.

B. July 8, 1984 Data:

SIMULTANEOUS SOLAR MAXIMUM MISSION AND VERY LARGE ARRAY OBSERVATIONS OF A SOLAR ACTIVE REGION.

C. July 15, 1984 Data:

EVOLUTION OF A SOLAR ACTIVE REGION AT MICROWAVE AND SOFT X-RAY WAVELENGTHS.

D. JUNE 7-8, 1985 Data:

SMM-VLA OBSERVATIONS OF CORONAL LOOPS: PHYSICAL PARAMETERS INFERRED FROM THERMAL CYCLOTRON LINES AND SOFT X-RAY SPECTRAL LINES.

The VLA beam on June 7, 8 also included a filament that was simultaneously observed at the Big Bear Solar Observatory. Comparisons of filament activity and eruption can therefore be made at optical and microwave observations. Moreover, preburst activity can also be studied at microwave wavelengths for the adjacent AR 4663 that emitted several bursts detected by the SMM-XRP on these days.

The data taken in July 1985 and simultaneous SMM-VLA data taken during the rest of 1985 will not be fully analyzed until 1986. Our 1986 SMM Guest Investigator Proposal therefore includes a request for support to complete the analysis of all the 1985 data and publish it in reputable journals.

The abstract of our 1985 SMM Guest Investigator Program also includes related observations of microwave bursts from nearby stars. These observations may lead to a better understanding of solar bursts. We have therefore carried out extensive VLA observations of dwarf M flare stars that are listed in Table 2. These observations have generally been taken simultaneously with the International Ultraviolet Explorer (IUE) Satellite.

Table 2. VLA and IUE Observations of Nearby Dwarf M Flare Stars and RS CVn stars.

Date	Star	VLA Time (UT)	IUE Time (UT)
Sept. 30, 1984	YZ CMi	0945-1435	0742-1330
Nov. 7, 1984	AD Leo	0831-1202	0754-1053
Nov. 8, 1984	AD Leo	0827-1207	0801-1015
Nov. 9, 1984	AD Leo	0823-1157	0735-1054
Nov. 10, 1984	AD Leo	0821-1051	0745-1059
Dec. 10, 1984	YZ CMi	0450-0925	0205-0845
June 10, 1985	λ And	1330-2051	1310-2058
June 10, 1985	UX Ari	1052-1256	--
July 15, 1985	AD Leo*	1730-1900*	--
Sept. 23, 1985	HR 1099	0400-1700	0600-1400
Sept. 26, 1985	UX Ari	0400-1700	0600-1400
Nov. 11, 1985	λ And	0300-1100	0300-1100

* This interesting observation was carried out at the Arecibo Observatory in Puerto Rico.

III. WORKSHOP PRESENTATIONS

The Principal SMM Guest Investigator presented papers at three workshops in 1985. They were the Coronal and Prominence Plasma (CPP) Workshop held at the Airlie Conference Center in Virginia on April 9 to 11, 1985; the workshop on Radio Continua During Solar Flares held at the Duino Castle near Trieste, Italy on May 27 to 31, 1985; and the Solar Maximum Analysis (SMA) Workshop held at Irkutsk, USSR on June 17 to 21, 1985. We next provide a brief description of each workshop together with an abstract of the relevant paper presented by the Principal Investigator.

Coronal and Prominence Plasma (CPP) Workshop

The SMM PI's have sponsored a series of two topical meetings on Coronal and Prominence Plasmas (CPP). The first meeting was held at Airlie, Virginia on April 9 to 11, 1985 where the Principal Investigator presented the paper entitled:

THERMAL AND NONTHERMAL EMISSION FROM CORONAL PLASMAS.

The abstract for this paper is:

Multiple wavelength VLA and SMM observations are used to determine the three dimensional structure of solar active regions by specifying the temperature and magnetic structure at different heights within coronal loops. Thermal emission from quiescent (non-flaring) coronal loops is detected at soft X-ray and 20 cm wavelengths. Other coronal loops emit nonthermal radio emission. The legs of most coronal loops emit thermal gyroradiation at radio wavelengths, but the X-ray emission is not normally detected above sunspots.

VLA observations at 21 and 92 cm can bridge the gap between the visible solar surface and the outer solar corona. They may provide

important information on the early stages, driving mechanism and initiating source of coronal mass ejections.

Observations of coronal loops at 20 cm wavelength also provide information on preburst coronal heating and changes in the topology of the coronal magnetic field that precede radio bursts. The preburst heating may be related to current sheets in the coronal plasma. Narrow-band 100% circularly polarized radio emission provides evidence for electron-cyclotron maser emission during solar bursts. The X-ray emitting plasma may be heated by this plasma.

One outcome of this meeting was a collaboration involving filament observations on June 7 and 8, 1985 by the SMM-UVSP, the VLA, Pic du Midi, the Sacramento Peak Observatory, and the Big Bear Solar Observatory. Our contribution to this collaborative investigation was briefly described in the preceding section.

A CPP subgroup on Coronal Diagnostics was formed in order to describe various diagnostic tools and to specify different research plans for the coming year. The Principal SMM Guest Investigator is serving as the chairman, or focal point, for that subgroup. Research plans have been delineated by subgroup members, and we all look forward to the second CPP meeting in 1986. One outcome of that meeting will be a book edited by Art Poland that contains papers by individual subgroup members and perhaps a summary review of coronal diagnostics by the Principal Investigator of this SMM-NASA grant.

Radio Continua During Solar Flares

The Committee of European Solar Radio Astronomers (CESRA) organized a Workshop on Radio Continua During Solar Flares that was held at the Duino Castle, Italy on May 27 to 31, 1985. The meeting was sponsored by the CESRA, the Italian

Research Council (CNR) and SISSA (the International School for Advanced Studies) at Trieste.

Here the Principal Investigator presented the paper entitled:

FLARE STARS AND SOLAR BURSTS; HIGH RESOLUTION IN SPACE, TIME, AND FREQUENCY

The abstract for this paper is:

Coronal loops on the Sun and nearby stars are investigated using observations at 20 cm wavelength with high resolution in space time and frequency. VLA observations with high angular, or spatial, resolution enable studies of the evolution and interaction of coronal loops on the Sun, thereby providing new insights to the triggering mechanisms of solar bursts. Observations with high time resolution using the Arecibo Observatory have placed stringent limits to the size of the burst emitter on AD Leo; related observations at Arecibo or the VLA may place similar size limits for stellar bursts from other dwarf M flare stars or RS CVn stars. Observations at closely spaced wavelengths, or high frequency resolution, provide evidence for coherent emission mechanisms on the Sun and Flare stars. The scientific potential of these discoveries may be best fulfilled by the construction of a solar-stellar synthesis radiotelescope.

This paper will be published in a special issue of Solar Physics devoted to the proceedings of this workshop.

One outcome of this meeting was a plan for a United States Solar-Stellar Synthesis Radio Telescope that would be dedicated to solar observing during daylight hours. A proposal for the construction of this instrument is being developed by participants of the CESRA workshop and presented to the

appropriate study group of the National Academy of Sciences.

Solar Maximum Analysis (SMM) Workshop

The Solar Maximum Analysis (SMA) Workshop held at Irkutsk, USSR on June 17 to 25, 1985 was organized by a steering committee that invited the Principal SMM Grant Investigator to present a half-hour review entitled:

HIGH-RESOLUTION MICROWAVE OBSERVATIONS

OF THE SUN AND NEARBY STARS

The abstract for this paper is:

Multiple-wavelength VLA observations uniquely specify the three-dimensional structure of the magnetic field and the plasma in the coronal atmosphere above solar active regions. Synthesis maps at 20 cm wavelength specify the density, temperature, and fields of the ubiquitous coronal loops that are the dominant structural element of the solar corona; the 6 cm maps delineate the magnetic structure of the legs of coronal loops that radiate at the second or third harmonic of the gyrofrequency. Individual cyclotron lines have been detected at 20 cm wavelength at the apex of a coronal loop where the magnetic field strength is relatively constant and neutral current sheets may lead to enhanced emission from a relatively thin coronal layer. Although thermal bremsstrahlung and/or thermal gyroresonance emission dominate the quiescent microwave emission from solar active regions, some plage-associated microwave sources require nonthermal emission mechanisms in the presence of weak magnetic fields. Intense filament-associated sources might be attributed to the nonthermal gyrosynchrotron emission of subrelativistic electrons.

Snapshot synthesis maps for time intervals as short as ten seconds have led to a new understanding of the excitation and eruption of solar bursts. The impulsive phase of 20 cm bursts is released near the apex of coronal loops located at a height of about 40,000 km above the solar photosphere. Solar bursts are triggered by preburst heating and/or magnetic changes that precede the bursts on time scales of 10 minutes to an hour. The preburst changes can occur within single coronal loops or arcades of coronal loops. Magnetic triggering can also be caused by current sheets that develop during the emergence of coronal loops or the interaction of preexisting coronal loops. Successive bursts can be excited in adjacent coronal loops. Observations of microwave bursts at closely spaced wavelengths provide evidence for narrow-band, highly circularly polarized bursts that may be attributed to gyrosynchrotron masers or electron-cyclotron masers.

Observations of nearby stars with high time resolution provide stringent limits to the size of the stellar bursting sources; highly circularly polarized emitters with very high brightness temperatures suggest coherent emission mechanisms. The slowly varying emission from one nearby flare star also exhibits narrow-band microwave emission characteristic of a coherent mechanism.

This paper will be published as a contribution to a book by a publisher in Holland.

The SMA Workshop was sponsored by the USSR Academy of Sciences and organized by a group of scientists closely involved with the analysis of data obtained with the Solar Maximum Mission (SMM) satellite.

V. PAPERS IN PROGRESS

During the first half of 1985 we have published one paper, had three papers accepted for publication, and begun work on four additional papers. The published paper entitled:

THE SUN AND NEARBY STARS; MICROWAVE OBSERVATIONS AT HIGH RESOLUTION

by Mukul R. Kundu and Kenneth R. Lang

appeared in Science 228, 9-15(1985) - April. It is reproduced in the preceding section.

Two papers have been accepted for publication in the proceedings of workshops. These papers are entitled:

FLARE STARS AND SOLAR BURSTS: HIGH RESOLUTION IN SPACE, TIME AND FREQUENCY

by Kenneth R. Lang

and

HIGH-RESOLUTION MICROWAVE OBSERVATIONS OF THE SUN AND NEARBY STARS

by Kenneth R. Lang.

The abstracts for these papers are given in the preceding section on workshop presentations.

An additional paper entitled:

VLA OBSERVATIONS OF SOLAR ACTIVE REGIONS AT CLOSELY SPACED FREQUENCIES; EVIDENCE FOR THERMAL CYCLOTRON LINE EMISSION

by Robert F. Willson

has been accepted for publication in the Astrophysical Journal. The abstract for this paper is

VLA observations of a solar active region at 10 closely spaced frequencies between 1440 and 1720 MHz are presented. THe synthesis maps show, on two successive days, significant changes in the brightness temperature within this narrow frequency range. We show that these changes cannot be due to either thermal bremsstrahlung or gyroresonance emission from a coronal loop in which the temperature, density, or magnetic field varies monotonically with height. Instead, we attribute the brightness spectrum to cyclotron line emission from a narrow layer where the temperature is elevated above the surrounding part of the loop.

The four papers that are now being written are briefly summarized as follows:

VLA OBSERVATIONS OF COMPACT, TRANSIENT SOURCES

IN THE SOLAR TRANSITION REGION

by Robert F. Willson and Kenneth R. Lang

The draft abstract for this paper is:

Very Large Array observations of a solar active region at 2 cm wavelength reveal the presence of compact (angular size ϕ 5"), hot (brightness temperature T_B 0.5 to 3 $\times 10^5$) highly circularly polarized sources (degrees of circular polarization ρ_c 8.0 to 90%) sources which vary in brightness on timescales of less than 30 seconds to several hours. This emission apparently originates in regions of low magnetic fields. It may be attributed to gyrosynchrotron emission from mildly relativistic electrons with a power law spectrum. The more rapidly varying sources have temperatures, sizes and lifetimes characteristic of rapid brightenings seen at ultraviolet wavelengths in the transition region.

A representative illustration for this paper is shown in Figure 1.

SIMULTANEOUS SOLAR MAXIMUM MISSION AND VERY LARGE ARRAY OBSERVATIONS OF SOLAR ACTIVE REGION

by Kenneth R. Lang, Robert F. Willson and revelvant SMM-XRP scientists.

As Illustrated in Figure 2, simultaneous SMM(XRP) and VLA observations of a solar active region reveal the presence of coronal loop plasma that is detected at both 20 cm and soft X-ray wavelengths. The SMM data, which are from the lowest energy channel O VIII at 18.9 A, have been made by adding four Earth-orbits of data using a new procedure developed a comparison of the electron densities and electron temperatures inferred from the SMM and the VLA data indicate that the electron temperatures suggested by the 20 cm data are a factor of two higher than those inferred from the soft X-ray data in regions of intense X-ray emission. In addition, there are regions of intense 20 cm emission where there is no detectable X-ray radiation. Both results suggest the presence of an additional source of opacity at 20 cm wavelength such as gyroresonant absorption.

EVOLUTION OF A SOLAR ACTIVE REGION AT MICROWAVE AND SOFT X-RAY WAVELENGTHS

by Kenneth R. Lang, Robert F. Willson and relevant SMM-XRP scientists.

As illustrated in Figure 3, sequential VLA maps made at 5 minute intervals at 6 cm wavelength show evolution of the plasma and/or magnetic field in a coronal loop on time scales of about 10 minutes. This may be the first time that such evolution has been detected during quiescent periods when no solar bursts occurred. Ongoing investigations with the SMM-XRP data are expected to reveal similar evolutionary characteristics. The VLA data will provide estimates for changes in the magnetic field strengths, electron temperature, and electron density. The SMM-XRP data will provide independent estimates for changes, or the lack of change, in the electron density. The combined data will provide new insights into the evolution of quiescent, or non-flaring, coronal loops.

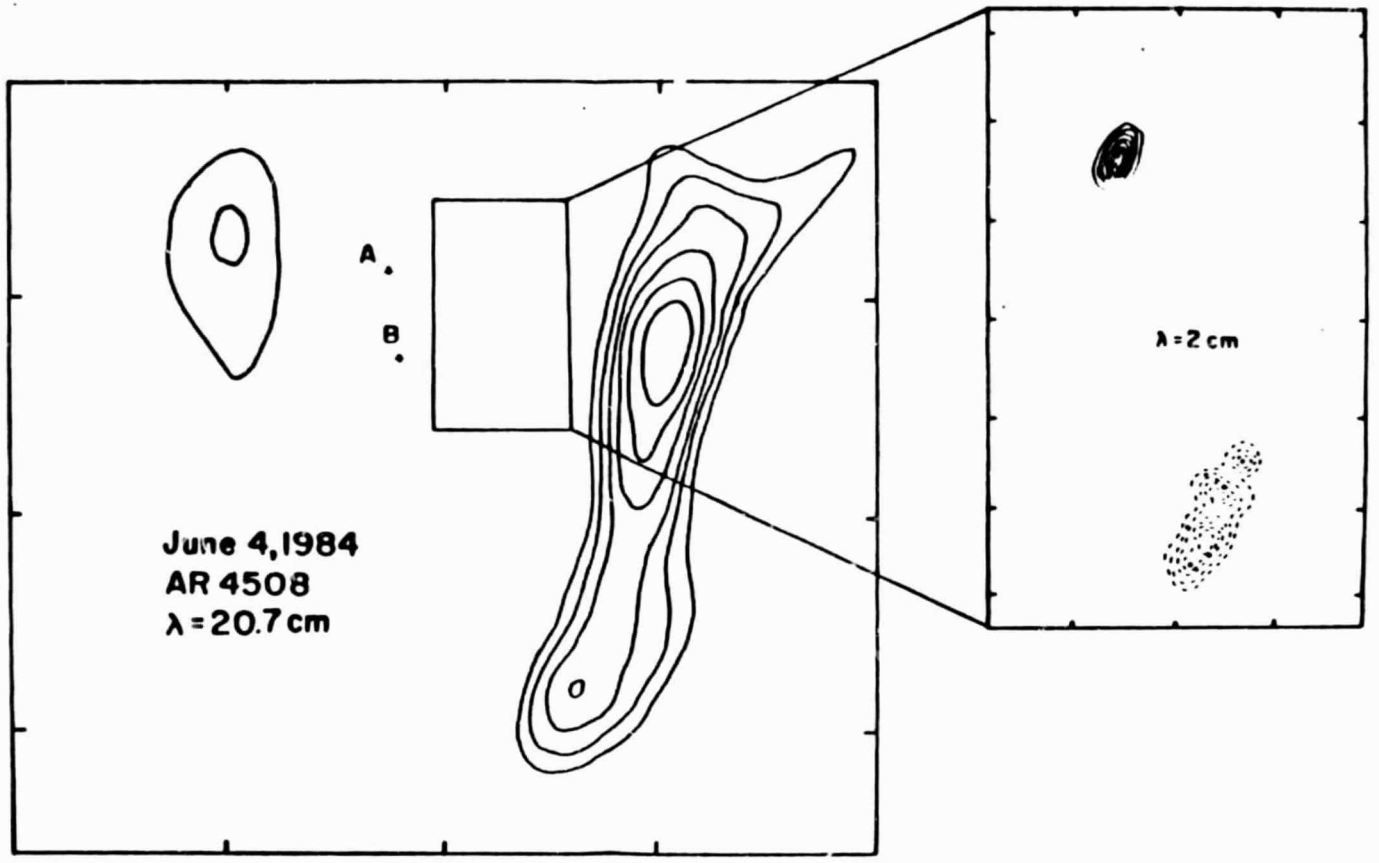

Fig 1. VLA synthesis maps of total intensity at λ =20.7cm and λ =2cm (insert). The solid and dashed contours of the 2cm emission correspond to left and right-hand circular polarization, respectively. The most intense 20.7cm source is unpolarized with a peak brightness temperature of $\sim 10^6$ K, and coincides with a magnetic neutral line. The 2cm sources are ~ 80% circularly polarized and have brightness temperatures of $\sim 3 \times 10^5$ K. They are also located above regions of weak magnetic fields and vary on timescales of a few hours. A and B denote the locations of two 2cm sources which lasted less than 30 seconds. The angular scales on the 20.7 and 2cm maps may be inferred from the respective 60" and 10" spacings between the fiducial marks on the axes.

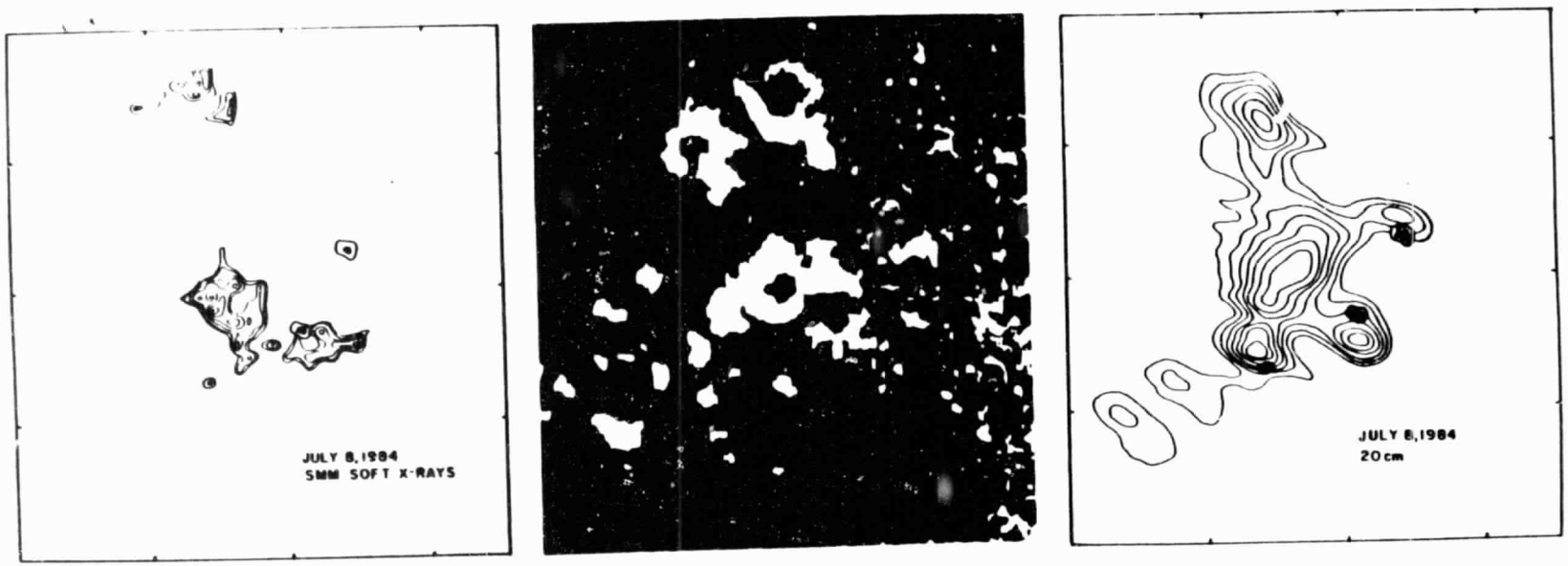

Fig. 2. PLots of the soft X-ray (1eft), Hα (middle), and 20cm (right) emission of an active region on the same day. Notice that the most intense radio emission is correlated with both the X-ray and Hα emission, but that there is also detectable radio emission associated with the sunspots. The angular scale is denoted by the 60" spacing between the fiducial marks on the axes.

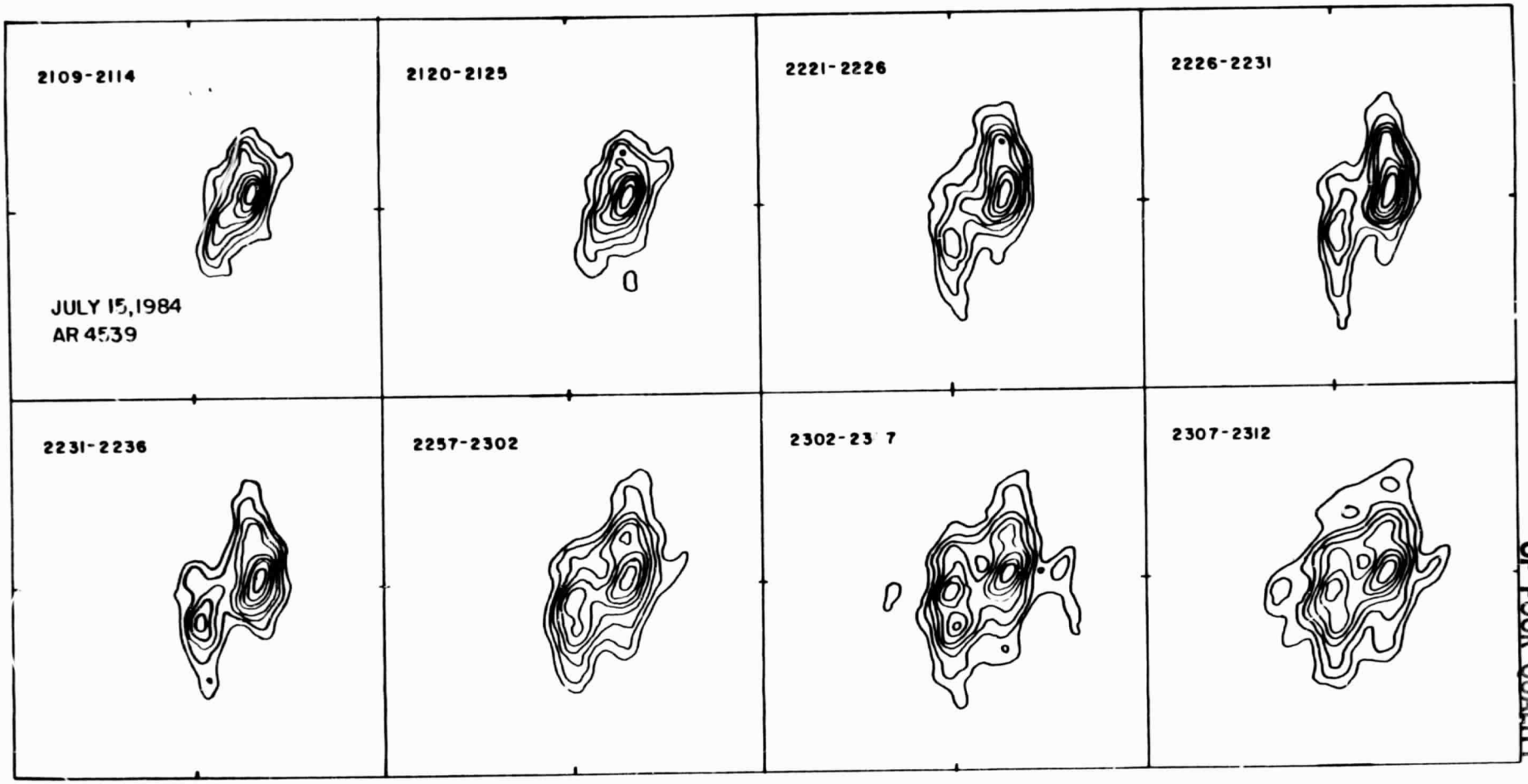

Fig. 3. A sequence of 5 minute VLA synthesis maps at 6cm wavelength which depict the evolution of active region AR 4539 on July 15,1984. The angular scale can be determined from the 2' spacing between the fiducial marks.

SMM-VLA OBSERVATIONS OF CORONAL LOOPS:PHYSICAL PARAMETERS INFERRED FROM THERMAL CYCLOTRON LINES AND SOFT X-RAY SPECTRAL LINES

by Robert F. Willson, Kenneth R. Lang and relevant SMM-XRP scientists

Previous observations discussed in the Astrophysical Journal paper on Thermal Cyclotron Lines (see abstract near the beginning of this section) have shown that these lines provide a sensitive measurement of the magnetic field strength in coronal loops. New unpublished data on thermal cyclotron lines are illustrated in Figures 4 and 5. This new data was taken simultaneously with SMM-XRP observations of the same coronal loops.

Previous work involved assumptions for the temperatures in order to infer a background level and the Doppler broadening of the cyclotron lines. The X-ray data can now provide independent measurements of these temperatures. They can also indicate whether or not the temperature is relatively constant across the coronal loop, while also providing electron density measurements that may confirm that the cyclotron line emission is enhanced above the thermal bremsstrahlung. Of course, the central frequency of the microwave lines will provide unusually accurate measurements of the magnetic field strengths.

The complete analysis of this work in progress may well extend into 1986. Moreover, additional observations will be carried out in 1985. Our 1986 SMM Guest Investigator Proposal therefore requests support for the continued analysis and publication of these results, while also requesting further observations that will enhance the scientific return of the SMM observations beyond that expected from the SMM alone.

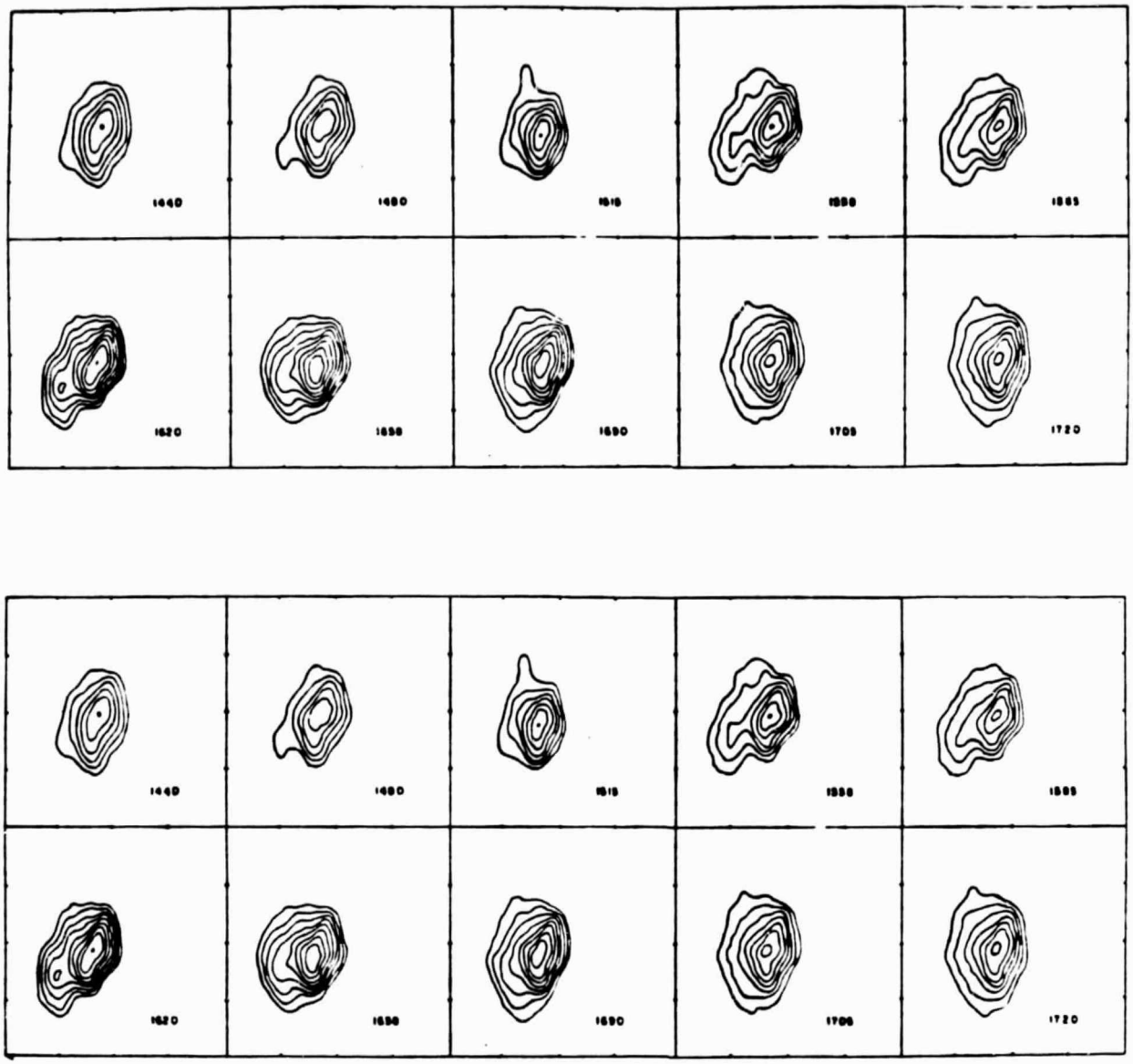

Fig. 4. VLA synthesis maps of total intensity, I, of active region AR 4663 at 10 closely spaced frequencies during a 10 hour period in June 7 (top) and 8 (bottom) 1985. The contours denote levels of equal brightness temperature. The outermost contour and contour interval are equal to 7.3×10^5 and 3.6×10^5 K. The angular scale can be determined from the 60" spacing between the fiducial marks.

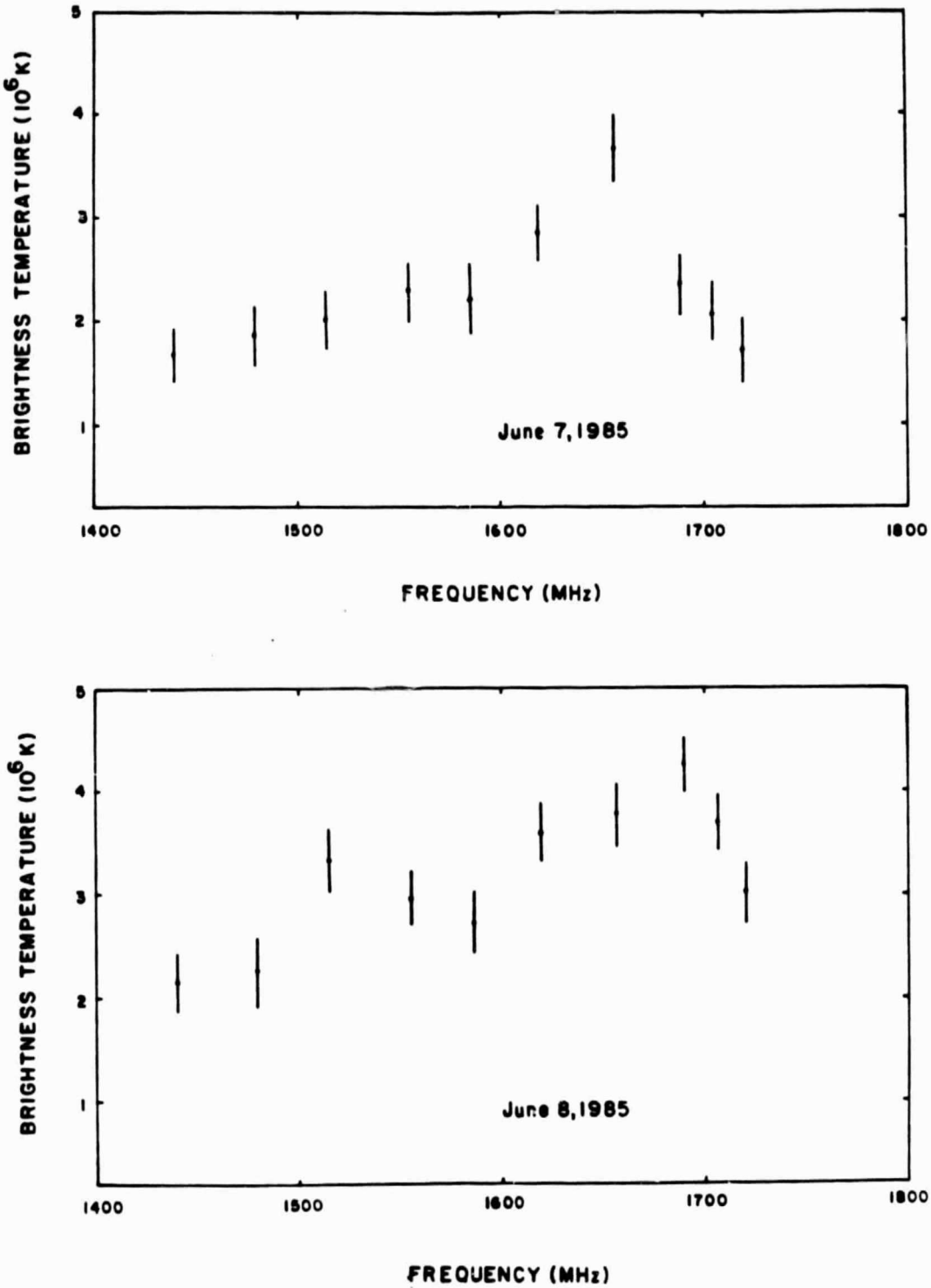

Fig. 5. Peak brightness temperatures observed at 10 different frequencies from active region AR 4663 on June 7 (top) and 8 (bottom) 1985.