Project Title: Testing the Extrapolation of Coronal Magnetic Fields

Investigator(s): K. D. Leka, S. M. White, J. Lee and Z. Mikić  Date: 1999 Jan 15

Brief Statement of Project:
We propose a stringent test of nonlinear force-free coronal magnetic field extrapolations by combining observations from the photosphere, chromosphere, and corona. High-quality magnetic field observations from the ASP of solar active regions will be used to calculate coronal magnetic fields via state-of-the-art nonlinear extrapolation methods. Using direct radio observations of those coronal fields along with independent observations of the thermal state of the corona, the most accurate comparison of computed vs. measured coronal fields will be performed.

QUARTER: 2nd

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<th>NSO/Sacramento Peak</th>
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<td>Dunn Solar Telescope</td>
<td>McMath-Pierce Main</td>
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<th>Type of Scheduling:</th>
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<tr>
<td>X Firm Dates</td>
<td>X One quarter only</td>
<td>12 Days</td>
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<td>Nights</td>
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<td>Stand-by</td>
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<td>Bumping</td>
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Specify: _______________________

Preferred Dates: May - to be advised

Dates you will be unable to observe:

Observing Requirements:
Conditions: X Good Seeing  □ Sky Clarity  □ Specific Solar or Stellar Activity  □ Low Water Vapor  □ Not Critical  □ Other  _______________________

Time of Day: X All Day  □ Sunrise to Noon  □ Noon to 4pm  □ 4pm to Sunset  □ All Night  □ Partial Night  □ Conditions Permitting  _______________________

For NSO Use:
Project Number ______________________  Time Requested ______________________
Host ______________________  Time Granted ______________________
### NSO/Sacramento Peak

- **Dunn Solar Telescope**
  - Echelle Spectrograph
  - Universal Spectrograph
  - Horizontal Spectrograph
  - Universal Birefringent Filter
  - Fabry-Perot Interferometer
  - Advanced Stokes Polarimeter
  - Branch Filters
  - Arrays: Type __________________
  - Film: Type __________________
  - Tracker
  - Other Mg prism and cameras

### Evans Solar Facility

- Coelostat
- Coronagraph
- Littrow Spectrograph
- Universal Spectrograph
- Spectroheliograph
- Coronal Photometer
- Arrays: Type
- Film: Type
- Other

### Hilltop Facility

- N/A
- Flare Patrol
- Emission-line Coronagraph
- Multi-band Patrol
- White-light Patrol

Estimate magnetic tape/film usage: 4 cameras, 2 tapes each per day, average, 10 days of observing (80 tapes).

### NSO/Kitt Peak

- **Main Spectrograph**
  - Photometry
  - CCD
  - Infrared Camera
  - Near Infrared Magnetograph (*NIM*)
  - 1968 Magnetograph
  - Other

- **FTS**
  - 6-meter White Cell
  - Polarimeter

Wavelength Range: (list regions of interest in order of priority, so that an optimum beam splitter can be scheduled.)

### Stellar Spectrograph

- Echelle
- Cross-Dispersed Echelle
- Milton-Roy
- Order Sorting Filter
- Wavelength Region
- Other

### Vacuum Telescope

- Spectromagnetograph
- High-/Helioseismometer
- 10830 Video Filtergraph
- 1968 Magnetograph
- Other
Part III: TECHNICAL REQUIREMENTS

At Either Site

To allow the reviewers and the observing staff to understand your requirements, please detail your anticipated observing procedures, including the approximate number of observations you plan to make, their duration, calibration procedures, need for quick-look displays, etc.

The primary observing tasks will be to obtain high-resolution spectropolarimetry in both the \( \lambda \lambda 6301.5, 6302.5 \) Å Fe-I photospheric lines and the \( \lambda \lambda 5172.8, 5183.6 \) Å Mg-I chromospheric lines. The target will be a sunspot selected according to the observing requirements of the VLA and SoHO instruments. A fairly large field of view, including the entire active region in question will be required, hence multiple ASP scans will be rastered for the required spatial coverage.

Numerous calibration procedures will be performed, including the normal dark/flat sequences, “Gang-of-Four” polarization sequences, and laser profiles. If a sunspot is located close to disk center, the requisite observations for a telescope matrix will be obtained, for which good seeing is not required (although sunrise – sunset clear skies is).

The P.I. is familiar with the ASP setup, observing procedures, calibration and quick-look requirements. Assistance will be required during set up, for which two days prior to the start of the coordinated campaign have been requested. Should the observations be scheduled beyond 27 May, none of the scientists will be on-site.

Will you bring any equipment? Give details:

List any additional equipment or expendable supplies that you will need:
[Note—please bring appropriate magnetic tapes; otherwise NSO will provide tapes at cost.]

Tapes will be supplied.

If you are a visitor, do you plan to reduce or analyze data at NSO/SP or NSO/KP? Due to restrictions on resources, we can no longer provide programmer support for this purpose.

Only quick-look analysis will be performed; access to exabyte tape drives and temporary disk space on SPO computers will be needed.
If this is a new proposal: Discuss in reasonable detail the scientific basis and objectives of your observing program. If you are requesting a long-term program, justify its duration. Attach extra sheets if necessary. In concluding, list publications completed or in preparation resulting from observations obtained at NSO during the past two years. The reviewers are interested in how effectively you have used previous observing time.

If this is a request for renewal: Please give a progress report on your activities to date, including any publications submitted or in preparation. Attach extra sheets if necessary.

This proposal requests observations with the Advanced Stokes Polarimeter on the Dunn Solar Telescope in order to acquire high-quality vector magnetic field measurements in the solar photosphere and chromosphere. These will be used as the basis for an extrapolation of the photospheric fields into the corona using a state-of-the-art nonlinear force-free extrapolation technique developed by Zoran Mikić (Mikić & McClymont 1994; McClymont, Jiao & Mikić 1997). Once we have a coronal magnetic field model, we will compare it with simultaneous radio measurements of the magnetic field in the corona to be acquired with the Very Large Array in New Mexico. In addition, we have an approved SOHO program to carry out observations simultaneously with the Coronal Diagnostic Spectrometer which will be used to characterize the thermal state of the corona.

The overall goal of this program is to test the accuracy of current extrapolation methods for determining the coronal magnetic field from measurements in the photosphere or chromosphere. Radio emission from the strong magnetic fields in the corona above active regions is optically thick in very narrow layers of constant magnetic field strength corresponding to a resonance between the observing frequency and a low harmonic of the local electron gyro-frequency (Figure 1). The observing frequency determines the value of the magnetic field strength: essentially at a frequency $f$ GHz we see emission from the surface in the corona on which the magnetic field strength is $120 f$ G. At all points on this surface where the magnetic field direction is not close to the line of sight, the surface will be optically thick and we measure a brightness temperature which should correspond to the electron temperature in the layer (e.g., see the review by White & Kundu 1997). Since the opacity arises from a resonance, the thickness of the optically-thick layer is very small (of order 100 km) and this makes the radio temperature measurement very specific.

In principle, given the magnetic field distribution in the corona and the thermal state of the corona (density and temperature), the radio images in regions of strong magnetic field above active regions, where radio opacity is dominated by gyro-resonance emission, can be predicted as a function of frequency. The coronal magnetic field is the dominant influence on the appearance of the radio images. The success of the magnetic field extrapolation can then be determined by several tests applied to the comparison of the radio images predicted on the basis of the extrapolation with the observed images. We have demonstrated the power of this technique for region NOAA AR6615 observed in May 1991 (Figure 2) using vector magnetic field data from the Haleakala Stokes Polarimeter (“HSP”) at Mees Solar observatory, with the following results:

- We showed that a potential field extrapolation was unable to produce the field strength required in the corona above a magnetic neutral line to explain a strong radio source observed there. However, the vector magnetic field data did indicate the presence of vertical currents near the magnetic neutral line, and this non-potential morphology was able to explain the stronger magnetic field in the corona required by the radio data (Lee et al. 1997).
- We showed that temperatures in the corona measured from the radio images were correlated with the presence of currents (Lee et al. 1998)
- We showed that if we used the field lines derived from the nonlinear force-free extrapolation, then the temperature at different points on a field line (measured at different frequencies in the radio observations) were well correlated. This is in contrast to field lines derived from a potential field approximation where there was no correlation between the temperature measured at different points on a field line (Lee et al. 1999).

The Need for ASP Data

The example described above is incomplete in several ways: (a) No X-ray measurements were available, so the thermal state of the corona could not be determined independently of the radio data.
This deficit was not disastrous, since we were able to use the radio measurements of temperature, and the temperature and density of the corona are less important than the coronal magnetic field for determining the overall morphology of the radio emission. However, in the proposed program we will correct this problem by obtaining images of the corona above the target active regions with the CDS aboard SoHO, in a number of EUV lines sensitive to coronal temperatures. (b) The magnetic field data used were from the BBSO vector magnetograph and the HSP, mentioned above. The former is a filter-based instrument with high spatial and temporal resolution but poor spectral resolution, which results in either saturation at higher field strengths (e.g. in sunspot umbrae) or an overestimation of the mid-strength fields (e.g. if the umbrae fields are matched to other magnetograph data). The latter instrument is based upon a spectrograph which returns high spectral resolution but extremely limited spatial resolution and a very limited field of view.

We need the best magnetic field data we can acquire. The ASP provides the most accurate measurements of magnetic fields available, in part due the high-resolution spectropolarimetry which is obtained. The least-squares inversion technique does not saturate at high field strengths (Skumanich & Lites 1987) and can detect weak fields as well (e.g. Lites et al. 1996). The nominal 1″ is quite suitable for the extrapolations, and the ASP scans can be rastered to include the entire active region flux in approximately one hour, again quite suitable for the tests we propose here. In addition, by taking advantage of the ability of the ASP to obtain simultaneous spectropolarimetry in a chromospheric line, a most thorough test of the extrapolation program developed by Zoran Mikić is possible.

![Figure 1](image.png)

Figure 1. Magnetic field lines derived from a state-of-the-art extrapolation of a photospheric vector magnetogram, together with gyro-resonant surfaces corresponding to 5 GHz (600 G), 8 GHz (960 G) and 11 GHz (1320 G). The two upper surfaces (respectively) are those where the 5 and 8 GHz emission shown in Figure 2 arise.
The combination of ASP data to quantify the photospheric and chromospheric vector magnetic field, CDS data to characterize the thermal state of the corona, and VLA data to measure the temperature on isogauss layers in the corona, will provide a powerful test of our ability to model coronal magnetic fields. The data set will also be used to investigate coronal heating using the technique developed by Lee et al. (1998) of propagating quantities along magnetic field lines.

Scheduling Constraints

Four days of VLA observations have been approved for this program, and the SOHO/CDS observations are also part of an approved and funded NASA proposal; we are presently negotiating the optimal dates for the observations between CDS and the VLA. We anticipate that this will be sometime in May; our plan is to proceed and inform NSO as soon as those dates are known (most likely before this proposal is considered). The VLA/CDS dates will not be contiguous in order to optimize the chances of observing an active region with suitably strong magnetic fields. We therefore request 12 days of observations with the Dunn Solar Telescope/ASP combination, including 2 days for set-up. The P.I. will be available to travel to SPO until 27 May; the Co-I (White) will also travel to SPO as his scheduling allows.

PI Leka will be responsible for the ASP observations and analysis. Co-I White is responsible for the overall coordination and the VLA and CDS observations. Co-I Mikić will carry out the extrapolation of the photospheric magnetic fields into the corona, while Co-I Lee will be responsible for comparing the radio data and magnetic field extrapolation.

References


Figure 2. Radio images at different frequencies of active region AR6615 on 1991 May 7 made with the Very Large Array radiotelescope. The radio emission represents a surface of constant magnetic field strength in the corona, with each frequency corresponding to a different value of field strength. (a) A white light picture of AR6615 obtained at BBSO. (b) Total intensity contours at 4.9 GHz overlaid on the white light picture; the 4.9 GHz emission comes from the surface where the magnetic field strength is 600 G, and brightness variations are dominated by temperature differences across the corona. Total intensity contours at (c) 8.4 GHz (field strength of 960 G) and (d) 15 GHz (1500 G) overlaid on the longitudinal magnetogram also from BBSO. The maximum radio brightness temperatures are $4.4 \times 10^6$ K at 4.9 GHz, $4.6 \times 10^6$ K at 8.4 GHz, and $1.8 \times 10^6$ at 15 GHz. Contours begin at 10% of the maximum intensity and then are 10% apart. The resolution of the radio images is 8'' at 5 GHz, 5'' at 8 GHz and 2.5'' at 15 GHz.
Please supply the following information. This section must be filled in completely for a proposal to be processed.

Principal Investigator:

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Will you travel to the observatory for the observations? [X] Yes [ ] No
New Observer? [ ] Yes [X] No
PhD (or equivalent) [X] Yes [ ] No
Graduate Student [ ] Yes [ ] No
Thesis? [ ] Yes [ ] No
Other [ ]

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Will you travel to the observatory for the observations? [X] Yes [ ] No
New Observer? [X] Yes [ ] No
PhD (or equivalent) [X] Yes [ ] No
Graduate Student [ ] Yes [ ] No
Thesis? [ ] Yes [ ] No
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Will you travel to the observatory for the observations? [X] Yes [ ] No
PhD (or equivalent) [X] Yes [ ] No
Graduate Student [ ] Yes [ ] No
Thesis? [ ] Yes [ ] No
Other [ ]

Travel Support: Travel support is normally limited to graduate students affiliated with U.S. institutions who require the requested observations for their thesis research. NSO will reimburse the cost of economy-class U.S. air fare (or its equivalent sum if ground transport is chosen) and accommodations during the observing run; only one student can be supported per run. The responsible thesis advisor must indicate in a letter accompanying the proposal that the student is planning to use the observations for her/his dissertation; the letter should certify that the student is in good academic standing and is capable of carrying out the program.

Name of graduate thesis student who will request support: ____________________________

Name of graduate thesis student who will request support: ____________________________