CORONAL DIAGNOSTICS WITH COORDINATED RADIO AND EUV/SOFT X-RAY OBSERVATIONS

Jeff Brosius

Catholic University
at
NASA's Goddard Space Flight Center

Preview of Selected Topics

- 2D coronal magnetography (Brosius *et al.* 1993)
- Coronal iron abundance (White *et al.* 2000)
- 3D coronal magnetography (Brosius *et al.* 2002)
  - Three-dimensional coronal magnetograms
  - Comparison with extrapolations
  - Alfven speeds
  - Implications for flare studies
- QT diagnostics (Schmelz *et al.* 1992)
- AIA on SDO (Title *et al.* 2002)
- FASR design characteristics

2D Coronal Magnetography

Brosius, Davila, Thompson, Thomas, Holman, Gopalswamy, White, Kundu, & Jones 1993, *ApJ* **411**, 410

EUV plage spectroheliograms from SERTS flight of 1991 May 7 yield T and CEM maps with

$2.3 \times 10^6 \leq T \leq 2.9 \times 10^6$ K

$2.5 \times 10^{27} \leq CEM \leq 1.3 \times 10^{28}$ cm^{-5}.

$\tau_{ff}^{X,O} = \tau_0(CEM, T)(1 \mp \frac{\nu_B}{\nu}\cos\theta)^{-2}$, where τ_0 is the optical depth of the unmagnetized plasma.

Using $T_B^{X,O;pred} = T[1 - \exp(-\tau_{ff}^{X,O})]$,

$B_z = B\cos\theta$, and

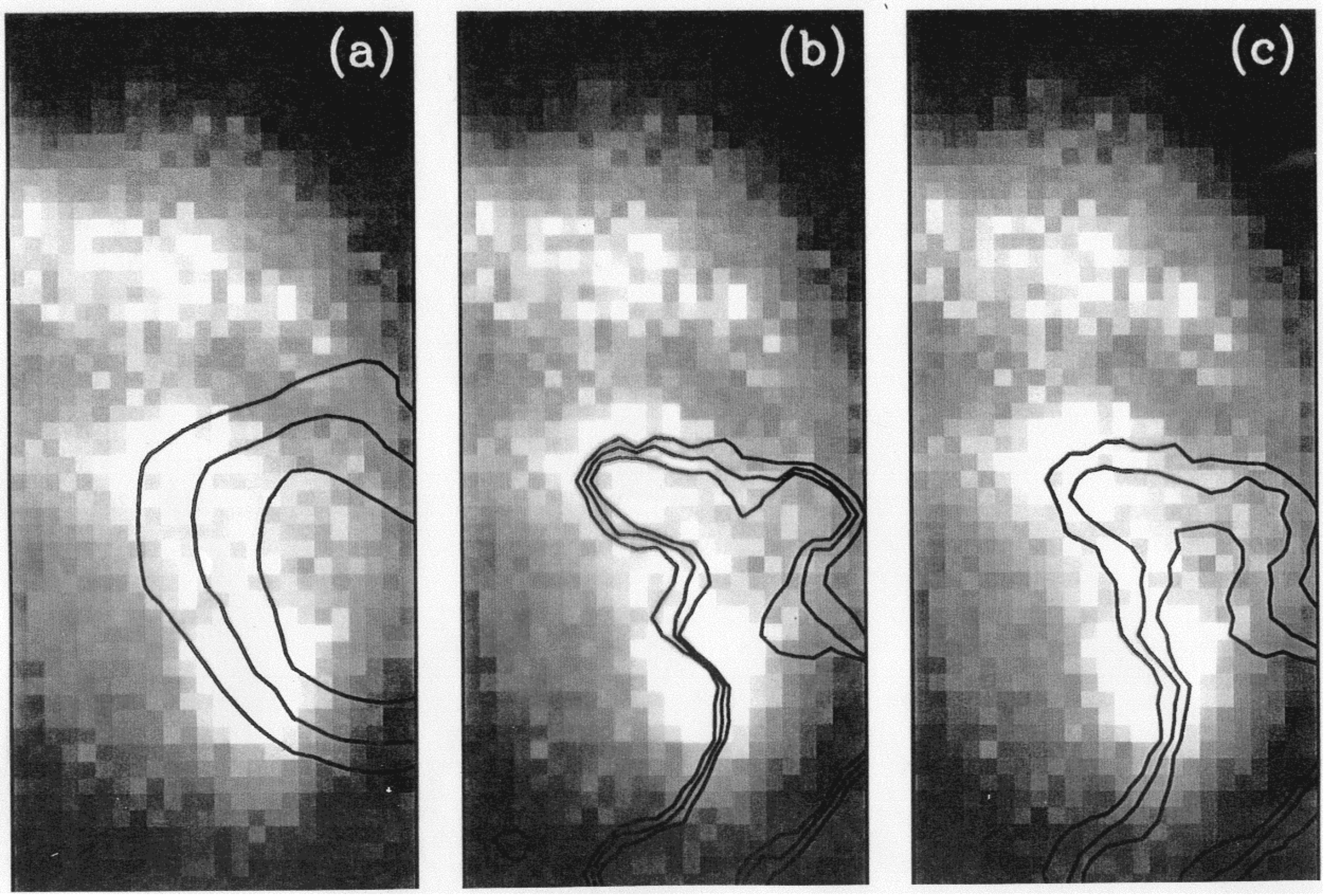
$P = V^{obs}/I^{obs}$

$= (T_B^{X;pred} - T_B^{O;pred})/(T_B^{X;pred} + T_B^{O;pred})$

can show

$$B_z = 258P[1 - \exp(-\tau_0)]/[\tau_0 \exp(-\tau_0)].$$

FE XVI 335.4 Å 1'.8 × 3'.8 SPECTROHELIOGRAMS FROM SERTS-91 WITH B_z = −30, −40, −50 G CONTOURS DERIVED FROM (a) EUV & RADIO OBSERVATIONS, (b) POTENTIAL EXTRAPOLATION TO 5000 KM, (c) POTENTIAL EXTRAP. TO 10,000 KM.



Coronal Iron Abundance

White, Thomas, Brosius, & Kundu 2000, *ApJ* **534**, L203

Procedure:

• Observe a weak, optically thin AR (8105 on 1997 Nov 11) with VLA-D (1.4, 4.8, 8.4 GHz) to obtain $T_{B,ff}$. (Free-free: EUV and radio images match; pol. is low.)

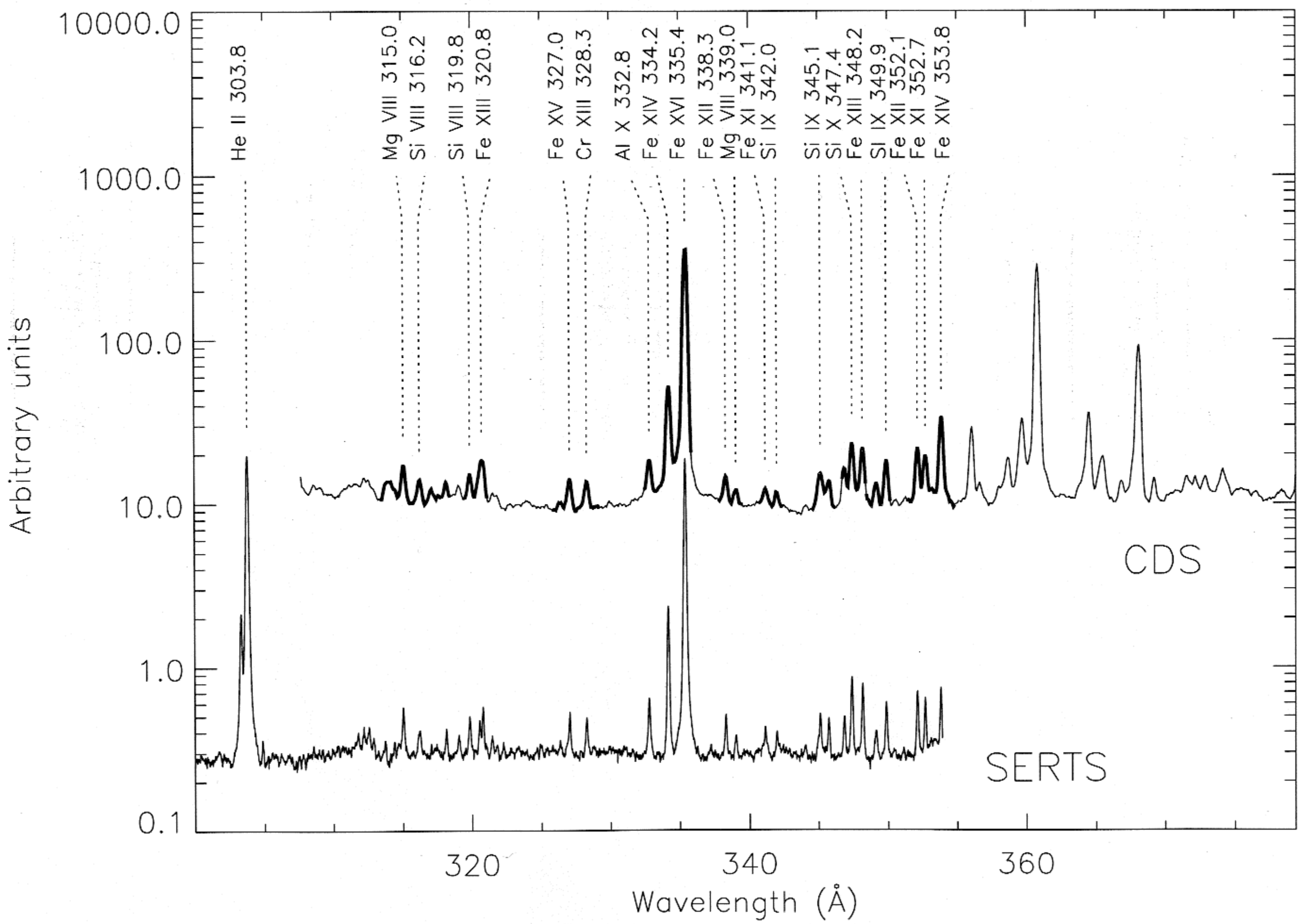
• Obtain Fe line intensities with CDS. Use these and CHIANTI database to calculate the DEM.

• Use the DEM to calculate the expected radio flux, varying the iron abundance so that the calculated value matches the observed.

Result:

Fe/H $= 1.56 \pm 0.31 \times 10^{-4}$, i.e., log A $= 8.19$. This is 4X photospheric.

Spectrum from Solar EUV Rocket Telescope and Spectrograpl (SERTS). Well calibrated in lab before launch. Enables cross calibration with CDS and EIT on SOHO.



3D Coronal Magnetography

Brosius, Landi, Cook, Newmark, Gopalswamy, & Lara 2002, *ApJ* **574**, in press

What's New

• First time that CDS and EIT data have been used for coronal magnetography. These data enable us to measure the pixel-by-pixel (2D)

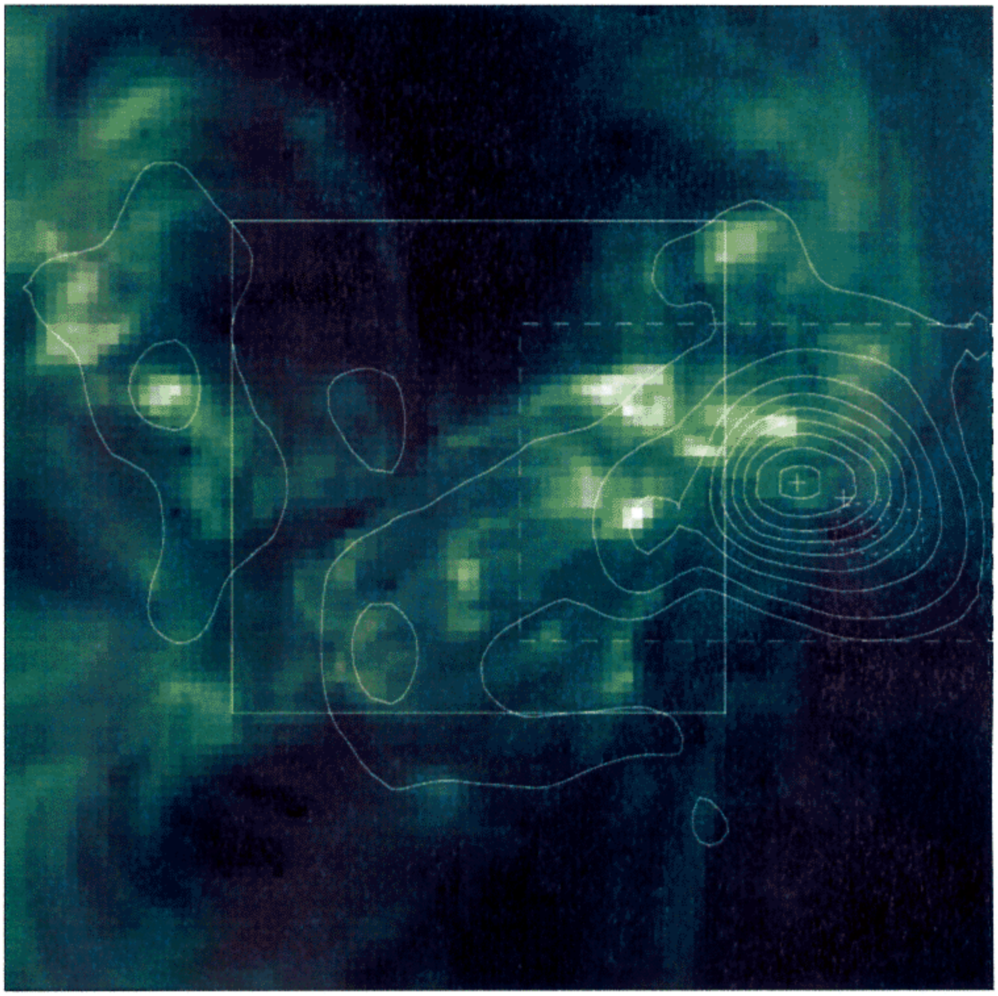
— DEM

— n_e

• Development and application of a new algorithm that iteratively selects the T-intervals into which the harmonics of the various radio observing frequencies must be placed in order to reproduce the observed brightness temperatures.

• Radio observations provide a direct measure of (an upper limit on) magnetic scale height L_B.

3D Coronal Magnetography



Fe XII 195 Å $4' \times 4'$ EIT image of NOAA AR 8108 around 1940 UT on 18 Nov 1997, with

- VLA T_B^R(5 GHz) contours:
  0.1, 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 MK
- MDI B_z contours: +1000, +1500 G
- CDS and SERTS $2' \times 2'$ sub-FOV (solid)
- Radio centroids of T_B^R(5 GHz) and T_B^R(8 GHz)
- $1'.9 \times 1'.3$ area for magnetography (dashed)

3D Coronal Magnetography

For multiple emitters along a given line of sight, the contribution to the radio brightness temperature from the i'th interval is

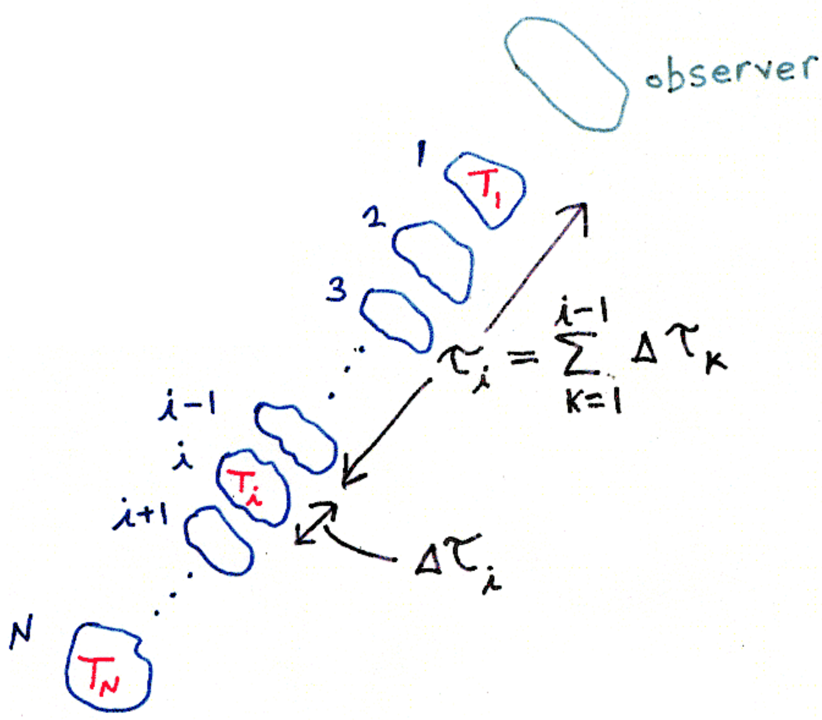
$$\Delta T_{B,i}^{X,O} = T_i[1 - \exp(-\Delta\tau_i^{X,O})]\exp(-\tau_i^{X,O}),$$

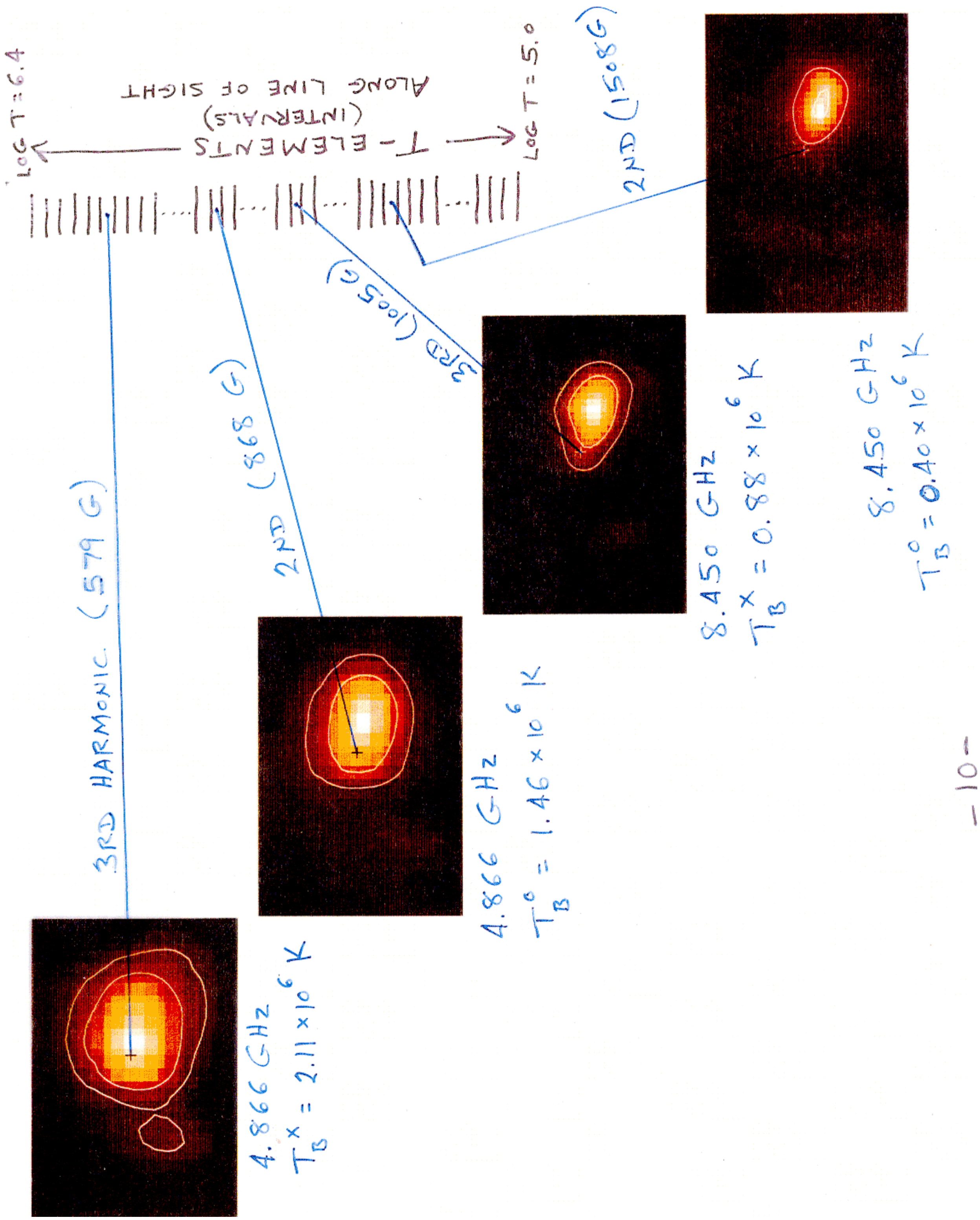
where

$$\Delta\tau_i^{X,O} = \Delta\tau_{ff,i}^{X,O} + \Delta\tau_{gr,i}^{X,O}.$$

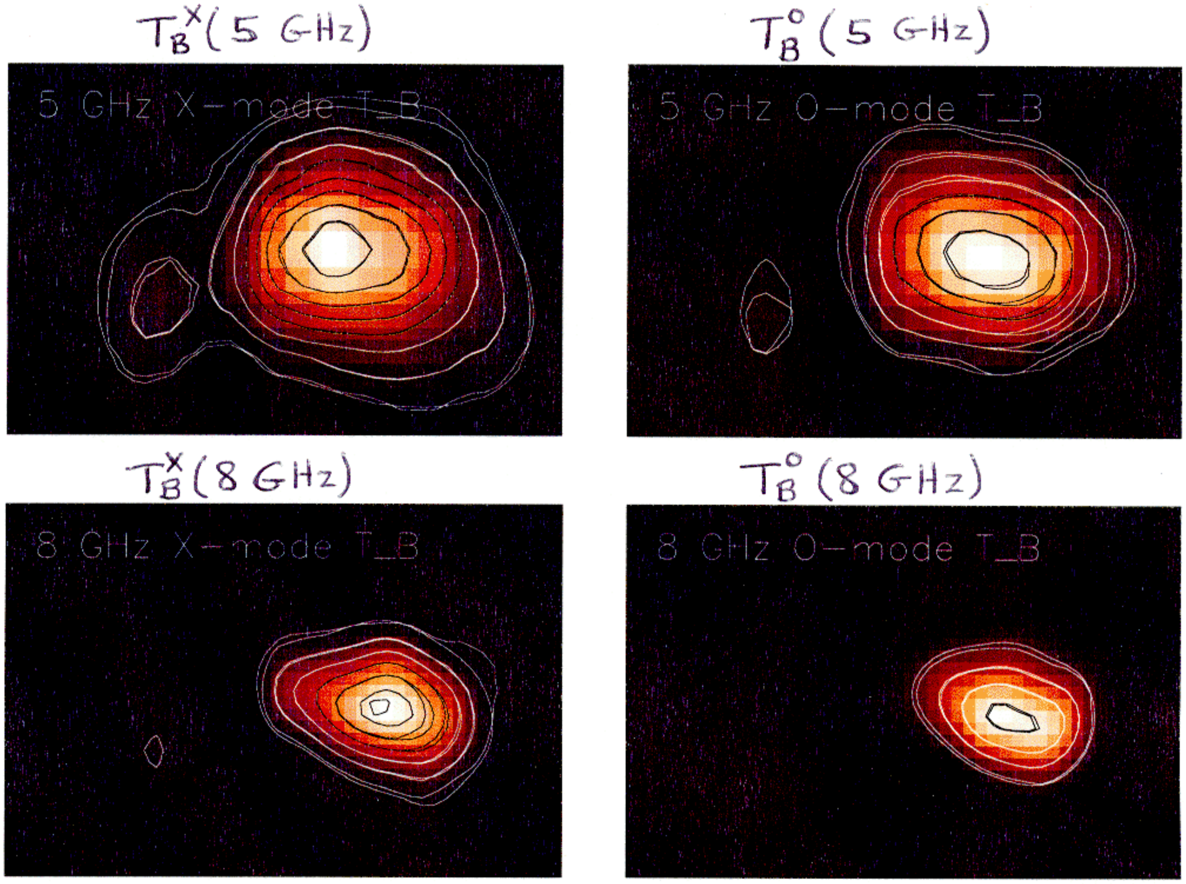
The total observed radio brightness temperature at a given frequency for a given line of sight is

$$T_B^{X,O} = \Sigma\Delta T_{B,i}^{X,O}.$$



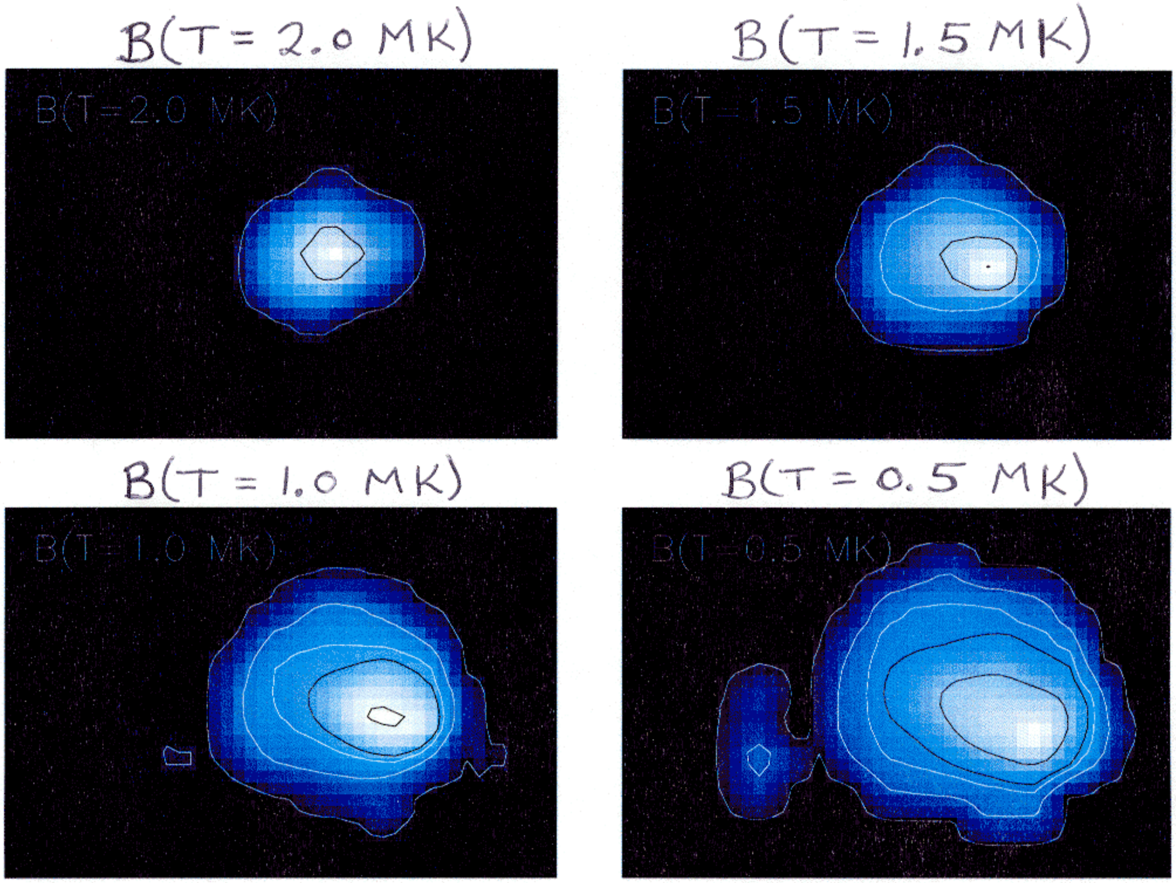

ALONG LINE OF SIGHT
(INTERVALS)
T - ELEMENTS
LOG T = 6.4
LOG T = 5.0
3RD HARMONIC (579 G)
2ND (868 G)
3RD (1005 G)
2ND (1508 G)
4.866 GHz
$T_B^x = 2.11 \times 10^6$ K
4.866 GHz
$T_B^o = 1.46 \times 10^6$ K
8.450 GHz
$T_B^x = 0.88 \times 10^6$ K
8.450 GHz
$T_B^o = 0.40 \times 10^6$ K
-10-

3D Coronal Magnetography



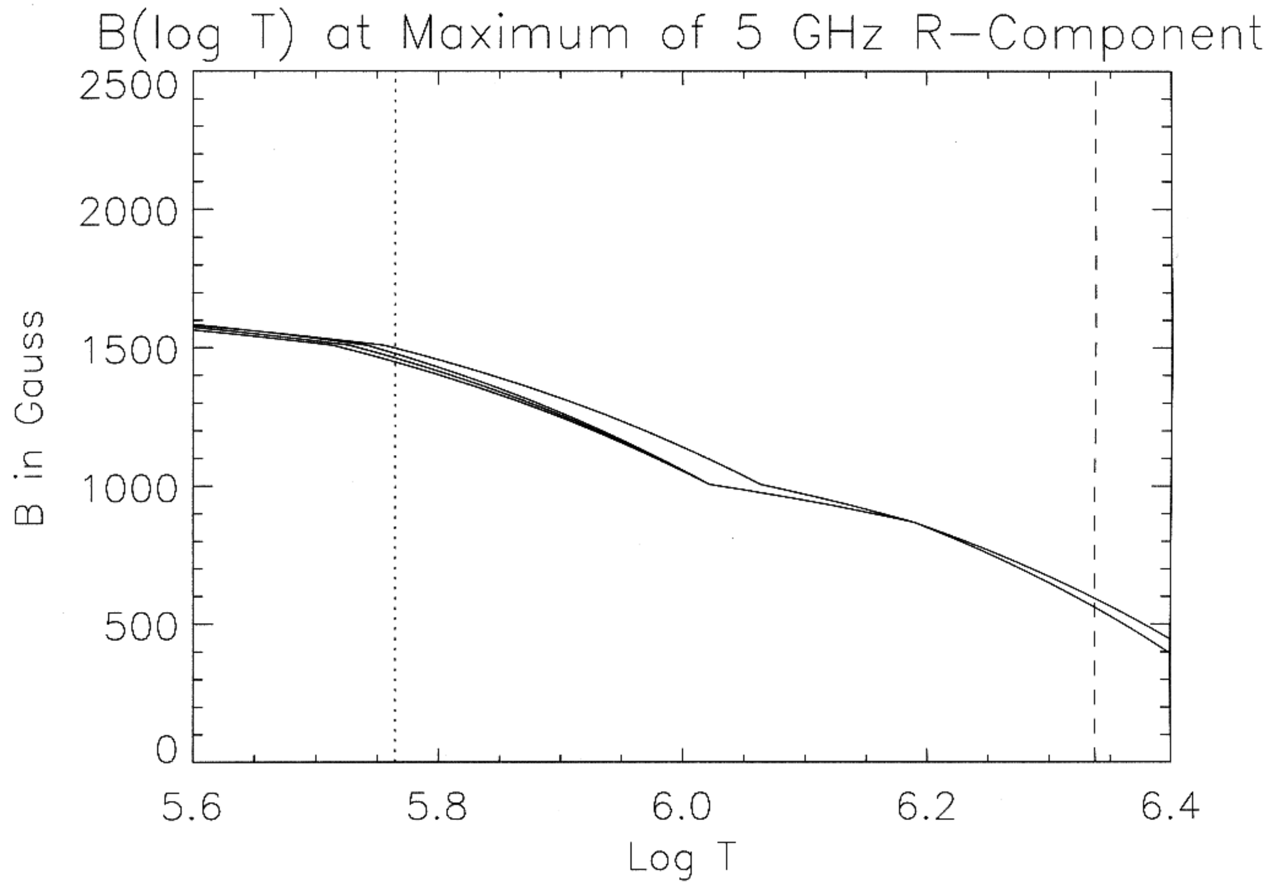
Observed radio maps, with observed *and calculated* brightness temperature contours at 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, 2.0 MK. The close agreement between the observed and calculated contours supports the reliability of our derived 3D coronal magnetogram B(x,y,T).

3D Coronal Magnetography



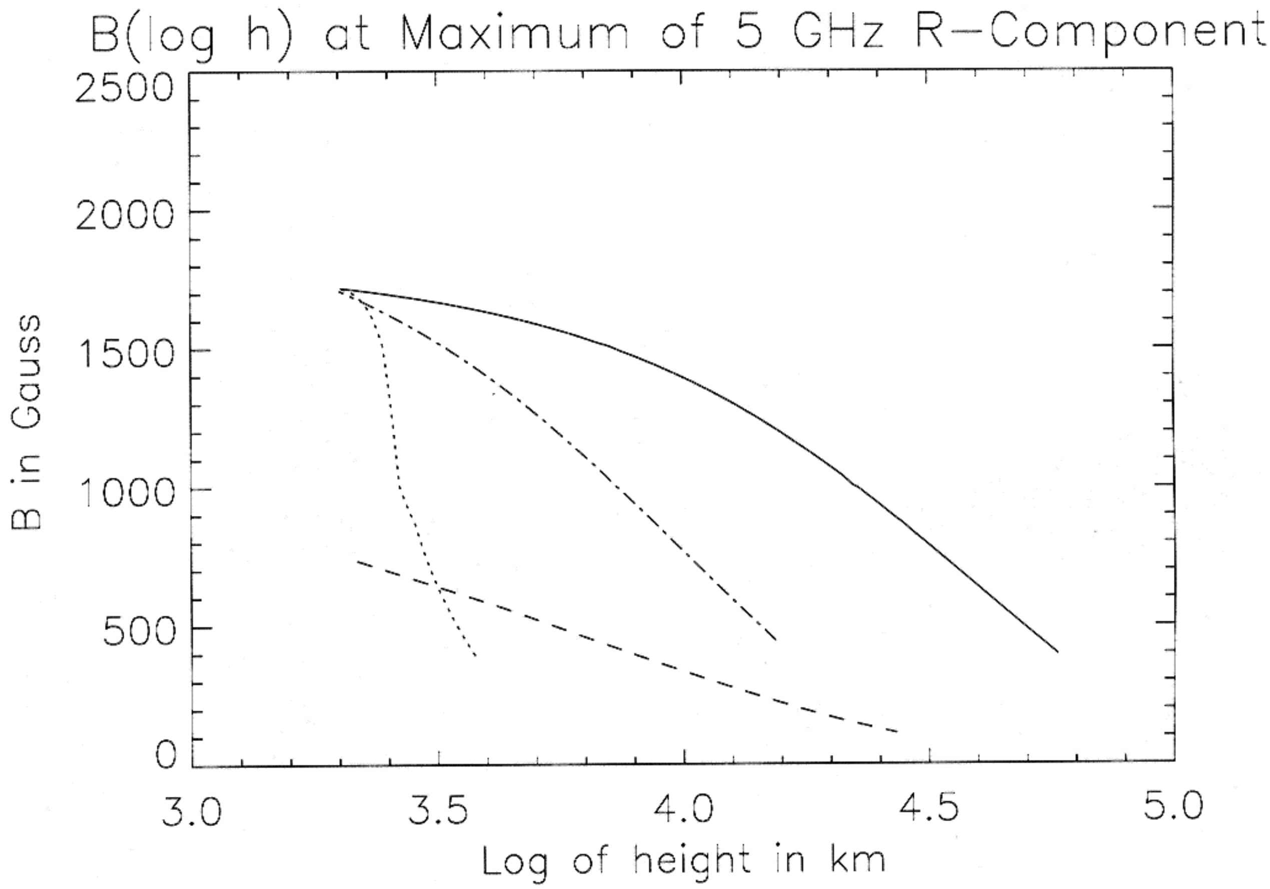
"Slices" of B(x,y,T) along isothermal surfaces. Contour levels are 100, 580, 870, 1000, and 1500 G. Last four values correspond to 3rd & 2nd harmonics of 4.87 GHz, and 3rd & 2nd harmonics of 8.45 GHz.

3D Coronal Magnetography



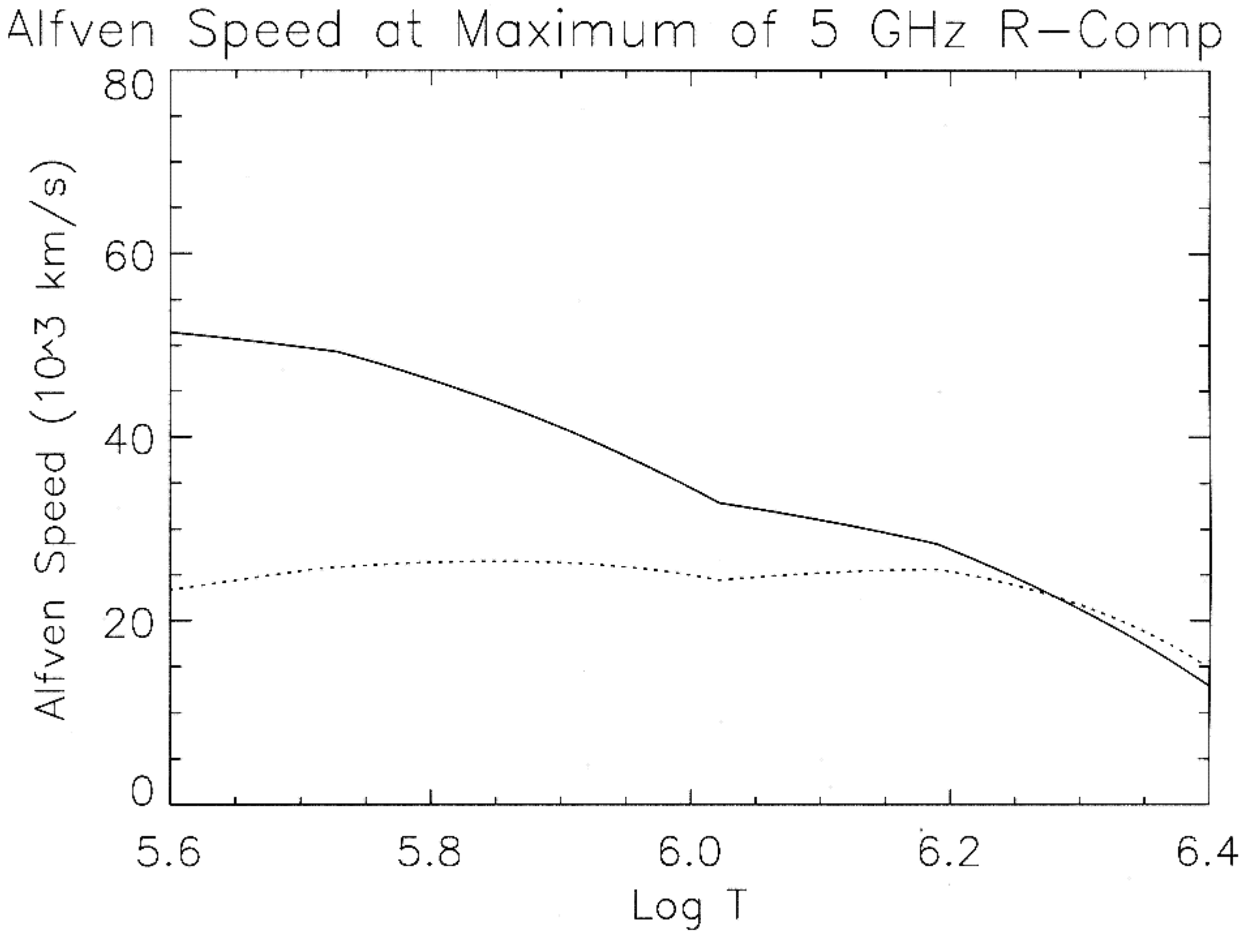
B(T) for all four combinations of density model (n_e=constant or p_e=constant, based on Fe XIV) and L_B (1.0 or 3.8 $\times 10^9$ cm). Evident blending of the curves indicates that our solution is relatively insensitive to L_B and the plasma density model. Dotted and dashed vertical lines bound the T-range within which B can be reliably determined at this location. Similar figures can be plotted for every spatial pixel in the region.

3D Coronal Magnetography



B(h) derived with n_e=constant and *(solid curve)* $L_B = 3.8 \times 10^9$, *(dash-dotted curve)* $L_B = 1 \times 10^9$, and *(dotted curve)* CEM/n_e^2. The dashed curve shows the potential field derived from the MDI photospheric longitudinal magnetogram with the Sakurai (1982) code.

3D Coronal Magnetography



Alfven speed $V_A(T) = B(T)[4\pi\rho(T)]^{-1/2}$ derived with *(solid curve)* n_e=constant and *(dotted curve)* p_e=constant. L_B has very little effect on $V_A(T)$.

Diagnostics of a Quasi-Transverse Layer

Schmelz, Holman, Brosius, & Gonzalez 1992,
ApJ **399**, 733

SMM/XRP observations of AR 4899 on 1987 Dec 4 yield T and CEM maps.

$T_B^{calc}(20cm) > T_B^{obs}(20cm) \longrightarrow$ cool absorbing plasma with $T_c < 0.5 \times 10^6$ K.

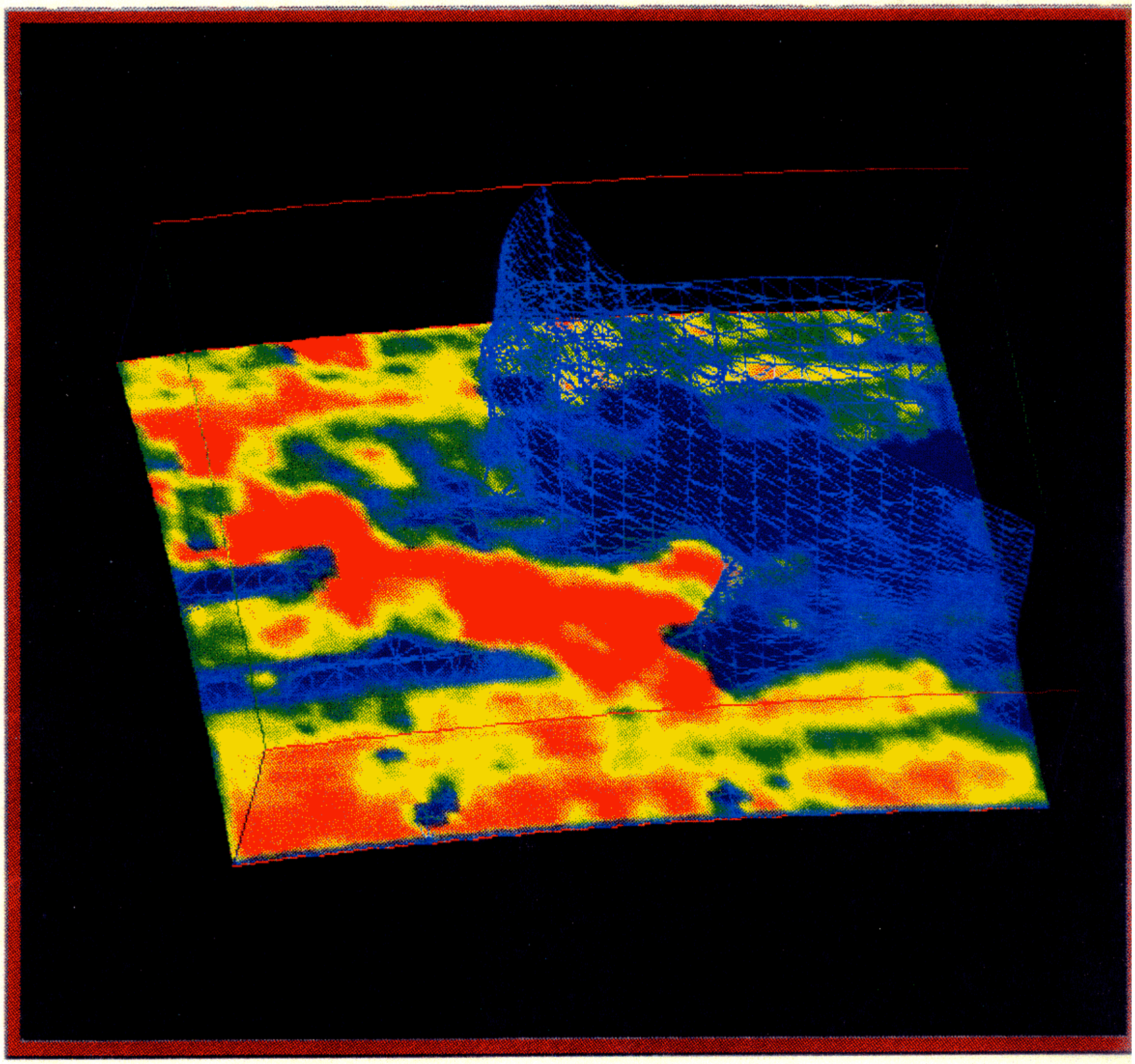
F-f absorption in cool plasma permeated by B-field introduces pol. opposite to that observed.

Polarization inversion in a QT layer will invert the polarization back to that observed:

$$C = \text{coupling parameter}$$
$$= 4.8 \times 10^{-18}(\nu^4/n_e B^3)(d\theta/ds) << 1.$$

For 20 cm emission $C_{20} << 1 \longrightarrow 10^7 << n_e$.
For 6, no inversion: $C_6 >> 1 \longrightarrow n_e << 10^9$.
Therefore, $n_e \approx 10^8$ cm^{-3} in the QT layer.

QT layer above AR 4899 (mesh) derived from potential field extrapolation.



AIA on *SDO*

The Atmospheric Imaging Array on the *Solar Dynamics Observatory*, Title *et al.* 2002

Instrument Properties:

- $1''.2$ spatial resolution
- $46.'0$ FOV
- 10 s cadence (2 s for partial CCD readout)
- $4 \leq \log T \leq 7$
- S/N $\sim$ 100
- dynamic range to 10,000

Wavelength Channels:

- white light continuum (log T = 3.7)
- 1700 Å continuum (3.7)
- 304 Å He II (4.7)
- 1600 Å C IV plus continuum (5.0)
- 171 Å Fe IX (5.8)
- 193 Å Fe XII, Fe XXIV (6.1, 7.3)
- 211 Å Fe XIV (6.3)
- 335 Å Fe XVI (6.4)
- 94 Å Fe XVIII (6.8)
- 133 Å Fe XX, Fe XXIII (7.0, 7.2)

Thoughts on *FASR* Characteristics

- Angular resolution: $20''/\nu_9$
  - — $4''.0$ @ 5 GHz
  - — $1''.2$ @ 17 GHz (comparable to AIA)
- FOV: $1125'/(\nu_9 D)$
  - — $D = 5$ m $\rightarrow$ FOV $= 46'$ @ $\nu = 4.9$ GHz
  - — $D = 2$ m $\rightarrow$ FOV $= 46'$ @ $\nu = 12.$ GHz
- Time resolution:
  - — $\sim \frac{1}{2}$ hour is adequate to look for changes in coronal B due to flare.
  - — $\sim$ 10 s will enable cotemporal EUV and radio sequences
- Dynamic range $\sim$ 1000 enables range of T_B comparable to that of AIA T-range
- Frequency range: $0.1 \leq \nu_9 \leq 30$ GHz
  - — $12 \leq B \leq 5400$ Gauss
  - — Enables measurement of B within non -flaring and flaring coronal loops.
  - — Enables search for change in coronal B due to flaring.
  - — May enable QS magnetography.