# Microwave magnetograms at the corona base

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## Introduction

Circular polarization of microwave radiation of solar plasma is due to free-free emission mechanism at high frequencies $\nu > 3\nu_B$, thus measurements of observed polarization degree $\rho = V/I$ open ways to study magnetic fields $B$ at chromosphere-corona (Grebinskij and Moltchanov, 1964). First implementations of such techniques (Bogod and Gelfreikh, 1980) were unconclusive, because estimations of magnetic field ($B \sim \rho/n$), require the spectral observations to find a spectral index $n$ for brightness temperature spectrum $T_b(\lambda)$. Recently, a new techniques were proposed (Grebinskij et al., 1999a), which may be used in both spectral (RATAN 600) and single frequency (Nobeyama Radioheliograph at 17 GHz) observations, with a taking into account single frequency data of Metsähovi observations at mm-wavelengths (Urpo et al., 1987). Here we report a practical methods for construction of the full-disk solar magnetograms of longitudinal fields at corona base by converting $I$, $V$ images with Nobeyama Radioheliograph. Details and first results of such studies for typical ARs are described by Grebinskij et al. (1999b). Proposed techniques may be a useful check in the problems of 3D extrapolations of magnetic fields from the photosphere to the corona.

## Single frequency techniques for microwave measurements of magnetic fields

Observed brightness spectra for Stokes parameters $I(\lambda)$ and $V(\lambda)$ are well reproduced with two-layer model atmosphere with optically thin corona and near-isothermic chromosphere with power-law electron temperature distribution along the depth (Grebinskij et al., 1999a)

$$I_{obs} = I_{chr} + I_{cor},\ V_{obs} = qI_{chr}\beta_{chr} + I_{cor}\beta_{cor},\ \beta \equiv B\lambda/5350 \qquad (1)$$

where $B_{chr}$, $B_{cor}$ are magnetic fields at the top of the chromosphere and corona base, $2q \equiv d\log I_{chr}/d\log\lambda$ is spectral index of the chromosphere microwave brightness. For a mean magnetic field at transition region ($B_{TR} \simeq B_{chr} \simeq B_{cor}$) we have

$$B_{TR}[G] = \frac{5350}{\lambda_{cm}} Q \frac{V_{obs}}{I_{obs}},\ Q \equiv \frac{1 + I_{chr}/I_{cor}}{1 + qI_{chr}/I_{cor}} \qquad (2)$$

Factor $Q$ gives correction for reduction of chromosphere contribution to the polarization by factor $q$ relative to the corona (see Eq. 1), thus $Q \simeq 1$ for the corona only, but $Q >> 1$ at shortest wavelengths with $I_{chr}/I_{cor} >> 1$.

In order to implement estimate the values in Eq. 2, one should know the parameter $q$, and partial contributions $I_{chr}$, $I_{cor}$ to the total (i.e. observed) brightness $I_{obs} \equiv I_{chr}+I_{cor}$. This is possible with spectral observations by tomography techniques (Bogod and Grebinskij, 1997), but regular spectral imaging the short cm-mm wavelengths is absent now. Thus, we should use some additional information for interpretation of single-frequency Nobeyama observations at 17 GHz.

Here we propose, as a first approach to the problem, to use as parameters $q$, $I_{chr}$ in Eq. 2 expected model values which are typical for plage and spot areas at 17 GHz. Such values may be found from atmosphere model, based on compilation of different observations for the different ARs (see Urpo et al., 1987; Grebinskij et al., 1999a), which leads to empirical spectra $I_{\mathbf{mod}} \equiv I_{\mathbf{mod},chr} + I_{\mathbf{mod},cor}$ with $I_{\mathbf{mod},chr} = T_o(t_o\lambda^2)^q$, $I_{\mathbf{mod},cor} =< tT >_c \lambda^2$. We found parameters $t_o$, $T_o$, $q$ and $< tT >_c$ for a typical plage atmospheres matching Metsähovi mm-wave spectra (Urpo et al., 1987):

$$t_o = 10^{-1.9},\ T_o = 15000K,\ q = 0.095,\ \ < tT >_c = 800 \tag{3}$$

which gives at 17 GHz (Nobeyama): $I_{\mathbf{mod},chr} = 11000\ K$. As parameter $I_{cor}$ in Eq. 2, we use $I_{cor} \equiv I_{obs} - I_{\mathbf{mod},chr}$ (i.e. any observed brightness enhancements in $ff$ emision are due to corona mainly, but not due to chromosphere (Bogod and Grebinskij, 1997).

As a practical method of magnetic fields estimations with Nobeyama $I-V$ maps, we use here Eq. 2 with a'priory parameters

$$I_{chr} = 11000K,\ I_{cor} = I_{obs} - I_{chr},\ q = 0.095 \tag{4}$$

For construction of the full-disc magnetograms we should kept in mind several limitatations.

a) For the quiet Sun regions (with $I_{obs} \simeq 10000$ K) outside ARs, we would have from Eq. 4 an artefact $I_{cor} < 0$, but here $V_{obs} \simeq 0$, thus we put $B_{TR} = 0$ there.

b) For the regions with $I_{obs} \geq I_{chr}$ which only slightly above adopted $I_{chr}$ value, we would have artificially low $I_{cor} << I_{chr}$ from Eq. 4, and an excessive estimate for $Q$-factor with $Q >> 1$ in Eq. 2, thus we restrict $Q$ at $Q_{\max} = 5.3$.

c) At the spot regions with the strongest fields, gyroresonance emission can be important at 17 GHz, thus any estimated value of $B_{TR} \geq 2000$ G (i.e. with $3\nu_B \geq \nu$) looks like artifacts (Grebinskij et al., 1999b).

To avoid this limitations, we should use high-resolution spectral imaging observations in the future.

### Observations and data reduction for magnetogram reconstruction

Daily Nobeyama Radioheliograph data are published since June 1992 as clean images in calibrated brightness at 17 GHz for Stokes parameters $I \equiv (T_b^+ + T_b^-)/2$, $V \equiv (T_b^+ - T_b^-)/2$, where $T_b^+$ / $T_b^-$ are observed brightness temperatures $T_b$ at left / right circular polarization. We used data at FITS-format 512×512 pixels with even spacing of 4.91 arcs in both directions, aligned with S - N, E - W solar axes. For most observations near local culmination of about 03:00 UT, synthesized beam resolutions are $\Theta_{N-S} \simeq 15\ /\cos z$ and $\Theta_{E-W} \simeq 15$ arcs.

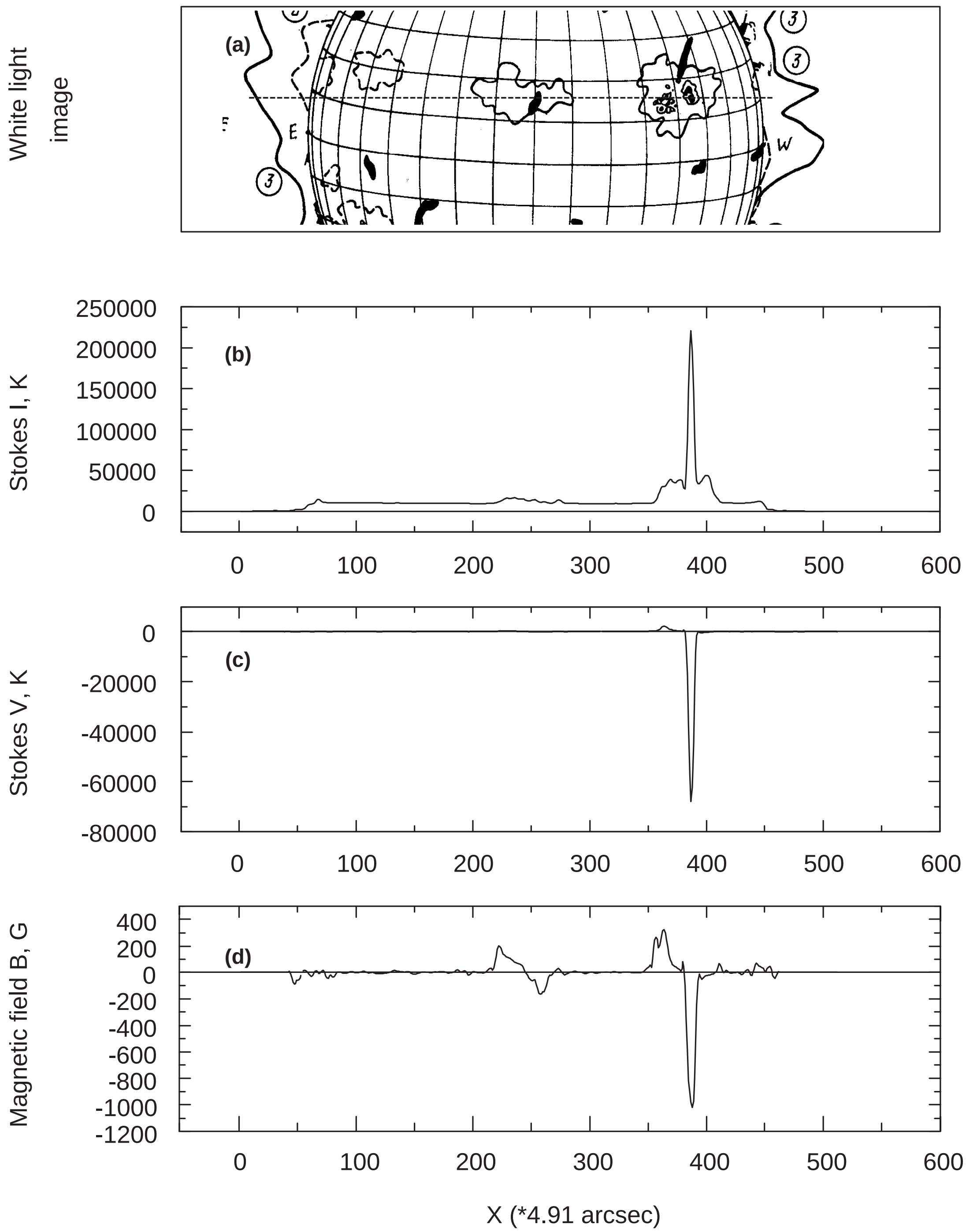


Figure 1: Observations of solar activity on August 21, 1992. (a) White light image, solid line shows position of cross-section scans; (b), (c) Microwave brightness cross-sections at intensity and polarization at 17 GHz; (d) Calculated magnetogram cross-section for longitudinal field at the corona base

To improve the quality of magnetogram calculations with Eq. 2, we have used two-step smoothing of FITS data. Each E-W line of pixels was replaced with a mean of 3 adjacent lines (3-pixel, linear vertical smoothing), and resulting line is smoothed with a nonlinear 7-point cubic running filter. Such filtration eliminates white noise and keeps angular resolution. That procedure decreases $V_{rms}$ to $\sigma_V \simeq 45$ K (versus $\sigma_V \simeq 60$ K for original images) and leads to magnetogram noise $B_{rms}$ about $\sigma_B \simeq 20$ G. Further noise reduction, by successive images average, is ineffective, due to presence of quasy-regular grids of spurious effects on clean $V$-images with $V_{spur} \simeq \pm 150$ K, aligned with position of strong local sources on $V$ - images.

An example of microwave magnetography is presented in Fig.1(a-d) shows the results of calculations of magnetic fields with Nobeyama Radioheliograph for observations on August 21, 1992, as a cross-sections of 2D full-disk images through the bipolar plage area (near disk center) and sunspot area NOAA 7260 with strong photospheric field. These results confirm a possibility of precise magnetic field measurements at corona base with Nobeyama imaging.

## Conclusions

We presented a new techniques for the measurements of magnetic fields in the solar chromosphere - corona, through a single-frequency imaging observations of its free-free emission in intensity and in polarization. Presented techniques can be a useful tool for study of magnetic field evolution at the upper layers of ARs (corona bottom), which are more directly connected with flare energy build up and release comparing to the photospheric measurements.

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