RATAN-600. UPGRADE AND DEVELOPMENT OF SOFTWARE FOR PRESENTATION OF THE DATA

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ABSTRACT

The radio telescope RATAN-600 has been upgraded in order to provide multiple observations during a day. This is due to new engine with high accuracy movement on railway tracks, which allows to realize multi azimuth regime. With one side it also allows to observe dynamic solar phenomena, from the other side to receive 2-D map daily.

Key words: telescope; solar; solar; emission; data.

1. INTRODUCTION

One of large reflector radio telescopes of the world RATAN-600 already more than two tens years is used as the tool for radioastronomical studies. The parameters of the radio telescope has appeared unique for solar observations. It has the good resolution about 5 angular seconds on short wavelength edge of a working range (at the 8 mm). On the long wavelengths the working range of the radio telescope reaches to 30 . Thus, the radio instrument covers the range of 5,5 octave and it is unique in practice. RATAN-600 represents the telescope, in which the various combinations of parameters for the analysis of radio emission are possible. For solar observations the most effective regime is a mode of use 1/4 parts (Southern sector) of Main circular mirror together with a Flat mirror (Periscope - similarly in Nancay system). The observations of the Sun are carrying out in monitoring mode also already more than 20 years, thus the work of improving the efficiency of the observations prolongs to go in a part of complete covering of the frequency range, detailed spectrum analysis, improving the accuracy of polarization measurements and flux calibration in a wide wavelength range, increasing of the number of observations per day, constructing of two-dimensional maps etc. This year the instillaling of new precision equipment allows to carry out about 20-22 observations per day. The data of observations are represented in Internet regularly. The work will be carried out also on presentation of physical parameters data of solar radio emission, in particular, magnetic fields data.

2. DESCRIPTION RATAN-600 AS RADIO TELESCOPE FOR SOLAR STUDY

The total description of the radio telescope is given in the papers (Korolkov&Parijskij,1979; Parijskij, 1993). The diagram of the radio telescope is formed with the help of calculated placing of a plenty of separate reflective elements. Each element (on the telescope there are 895 and they are placed on circle with 600m of diameter) has three degrees of freedom: on angle, azimuth and radius, and has high accuracy of placing (up to 0.1 mm) and high quality of a surface (root mean square is not worse than 0.26 mm on all elements). Such flexibility allows to construct the radio telescope with the various form of a diagram pattern directional in any point of the sky, to build the two-dimensional maps, to develop the tracking regime etc. Control of reflective elements is carried out from the computer. On Southern sector of the radio telescope there is a Flat periscope mirror, consisting from 124 flat reflecting elements (8,5 m 3 m). The Flat mirror together with the Main mirror (which elements form the vertical parabolic cylinder) and focusing "Receive Mirror" (in the form of the nonsymmetrical parabolic cylinder) construct the diagram in the form of a vertical knife. Inside Southern sector there are circular rail-way tracts for moving of "Receive Mirror" (third mirror together with a receive cabin) in multi azimuth regime and tracking. The radiation from celestial object struck to Flat mirror and is reflected as a plane wave to a Main circular mirror of Southern sector. The range of azimuth angles is about $\pm 20 degree$, that it is enough for realization of continuous observations in a time interval $\pm 2 hours$ from a central meridian. Mean time of the culmination is about 9-00 UT. The receive horns are in focus of "Receive Mirror". The "Receive Mirror" and room for the equipment are located on a uniform platform, which can move in any azimuth.

In 1999 on the platform the precise engine with computer control was installing, that allows to carry out multiple observations in different azimuths and to use tracking mode for chosen active region.

The control of reflective elements by computer of all Southern sector recently is completed. The new opportunity has appeared to study dynamics of a solar radioemission. It opens a new period in solar observations on -600.

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3. RECEIVE COMPLEX RATAN-600 FOR SOLAR OBSERVATIONS

The optimal combination of antenna and receivers parameters is very important for study of the Sun, which impose the specific requirements. Among which it is important the following: - the high dynamic range (from several Jy up to 10^5Jy,
- the big useful surface of a radio telescope from $500m^2$ for a short wavelength part to $1000m^2$ for a decimeter range,
- High flux sensitivity about 2.5 -5 Jy,
- High position stability of the telescope up to 0.3",
- the regularity of observations.

For carrying out of solar observations at RATAN-600 was designed and continue to develop a panoramic spectrum analyzer (PAS). The main aim was to cover the all working range of frequencies of the telescope (0,8 - 30) and behind its limits (in the short waves up to 5 mm and in the long waves up to 50-100 cm). Now, the coverage from 18 GHz up to 0, 95 GHz is realized.

3.1. Coverage of frequency range and spectrum analysis

PAS ideology consists in use of a parallel spectrum analysis in all frequency range. For this purpose all frequency range parted to the set subranges (receivers). The amplification part of each receiver is made in the schema of direct amplification with output frequency filters. The input amplifiers are executed on low noise microwave transistors. On the input of the PAS the special combined multi wavelength horn for all wavelengths is used. Such combined horn has one phase center for all frequencies with precision 1-2 angular seconds. It is provided the reception of the right and left-hand polarization in a modulation mode. Now the all frequency range (from 0.9 GHz to 18 GHz) covered by 7 receivers with next bands: 1) 12 - 18 GHz, 2) 8 - 12 GHz, 3) 5.5 - 8 GHz, 4) 3.5 - 5.5 GHz, 5) 2.5 3.5 GHz, 6) 1.5 - 2.5 GHz, 7) 0.9 - 1.1 GHz. Each frequency band is divided for 6-8 channels. So, the receiver complex PAS consists of 48 channels with registration both intensity and circular polarization with about 5% frequency resolution.

In the Fig. 1 and 2 the observation of the Sun at microwaves is presented. On the Fig 1 the previous representation of the data in the form of the separately chosen wavelengths. On the Fig.2 the new representation of the data for intensity (on the right) and circular polarization (on the left) is shown. Data acquisition system is based on use of digital processing and provides total automation of observation process, recording of multi-channel data, high time resolution (several millisecond).

3.2. Sensitivity, calibration and dynamic range

In case of observations of radio sources on a solar disk with determined frequency band and time constant, the flux sensitivity is completely determined in antenna noise temperature of about 10000 K. Nevertheless, the high flux sensitivity is necessary for realization of calibrations on observations of radio sources with a known flux spectrum. The several selestial sources Crab, 273, Moon, Sagitarius A are used. The realized sensitivity for selestial sources achieves to 0.1 - 0.3 Jy. On the other hand, the high dynamic range of receive system is necessary for recording the powerful bursts. Achieved value is equal to 5×10^4 .

3.3. Accuracy of polarization measurements

The problem of improving of polarization accuracy always was at centre of attention of solar radio astronomers. This problem is especially important at observations with the high spatial resolution, where usually operate with accuracy of a polarization degree in some percent (VLA, OVRO, WSRT etc.). In the antenna system of Southern sector and Periscope mirror the polarization distortions are small about (0,5 - 1.0)%, that allows to study thin polarization effects. However, the structure of such errors is rather nonregular (complicate dependencies on frequencies and diagram position) and limits the study of weak polarization solar sources. Especially such measurements are important on the solar limb (height structure of active region, prominencies etc.). The testing of antenna parameters have shown, that the polarization distortions are stable on the interval in several weeks. It allows to separate the systematic errors on circular polarization on each frequency channel and to take into account them at the treatment of observations.

In the Fig.3 the scan of the Sun in intensity and circular polarization after the procedure of antenna errors cleaning is shown. The limiting measurement accuracy of a degree of polarization, which is 0,02-0,03 % at the observations on solar disk and 0,1 % at the limb observations. Such high accuracy is realized practically in all wavelength range of PAS. The particular perspectives in fine limb sources study exist in use as a reference the Moon. Thus at enough good statistics becomes to possible also the study of large-scale magnetic field of the Sun etc.

3.4. Analysis of the temporal characteristics of solar emission

RATAN-600 is the telescope, in basic, transit type, therefore analysis of dynamics of a solar radio emission was possible only on a daily interval earlier. Due to new technical achievements (mentioned above) the mode of multiple observations in azimuths (see Fig.4) within $\pm 2 hours$ from a central meridian (9-00 UT) get possible.

The testing of the tracking mode have shown, that there are some irregularities about 0.1 % , which can be still decreased (up to 10 times). Technical opportunities of data acquisition system of PAS provide the time resolution up to several millisecond of time per channel. Thus, the problems on localization and analysis of bursts at an initial stage (processes such as spikes) in a wide wavelength range and search of structural, time and frequency relations become possible (Bogod et al, 1999).

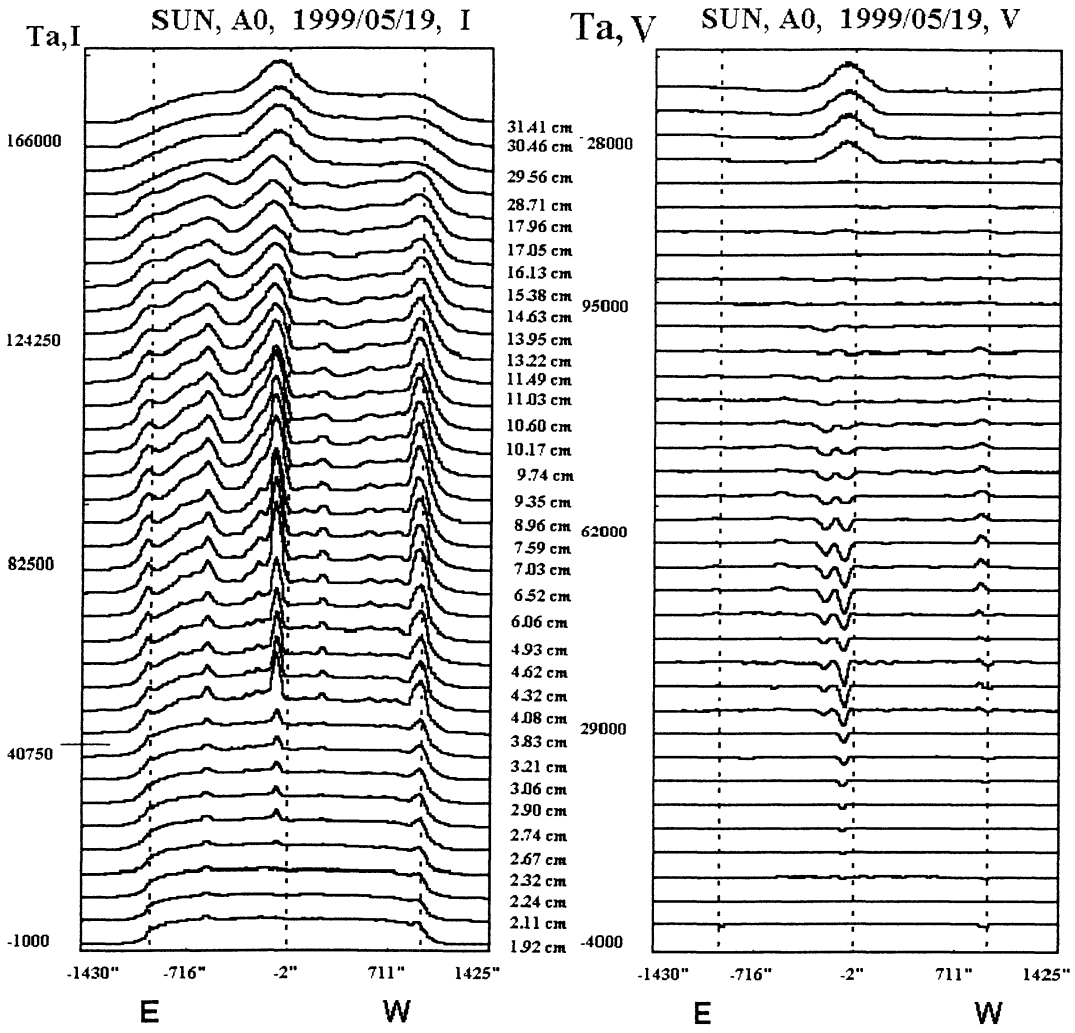

Figure 1. The multi-wavelengths observations in the form of multiple scans in intensity and circular polarization.

3.5. 2-D mapping

The creation of two-dimensional maps of solar active regions on Southern sector with Periscope was shown in (Nindos et al, 1966). Representation of such radio maps daily on the many wavelengths of centimeter and decimeter ranges will be realized in the nearest future. Simultaneously there is in development a method of a radioheliograph RATAN-600 (Bogod et al, 1998). The first image of source 3C84 is obtained.

4. THE SOFTWARE OF TREATMENT AND REPRESENTATION DATA IN INTERNET

The program of treatment for multi-channel solar observations with RATAN-600 named "Work Scan" is realized in medium Win32 in language C ++. It is represented on home page htpp://www.sao.ru/~sun. The new software "*ws_fits*" for looking through the data by IDL is created. All programs are in free usage.

Here there is an archive of observation data for period from May 1997 to the present time in formats *gif* and *fits*. In case of necessary questions to be e-mailed to addresses: gvi@ratan.sao.ru vbog@ratan.sao.ru

4.1. Representation data in digital formats

Since May 1, 1999 the data of observations are represented in 3-D view (see Fig.2). Intensity of emission is presenting in coordinates: amplitude I=I (L) +I (R), frequency, one-dimensional coordinate of solar disk. Circular polarization emission is presenting in coordinates: parameter of Stokes V=I (L) -I (R) (dark colour for right-hand) and (light colour - for the left-hand polarization), frequency, one-dimensional coor-

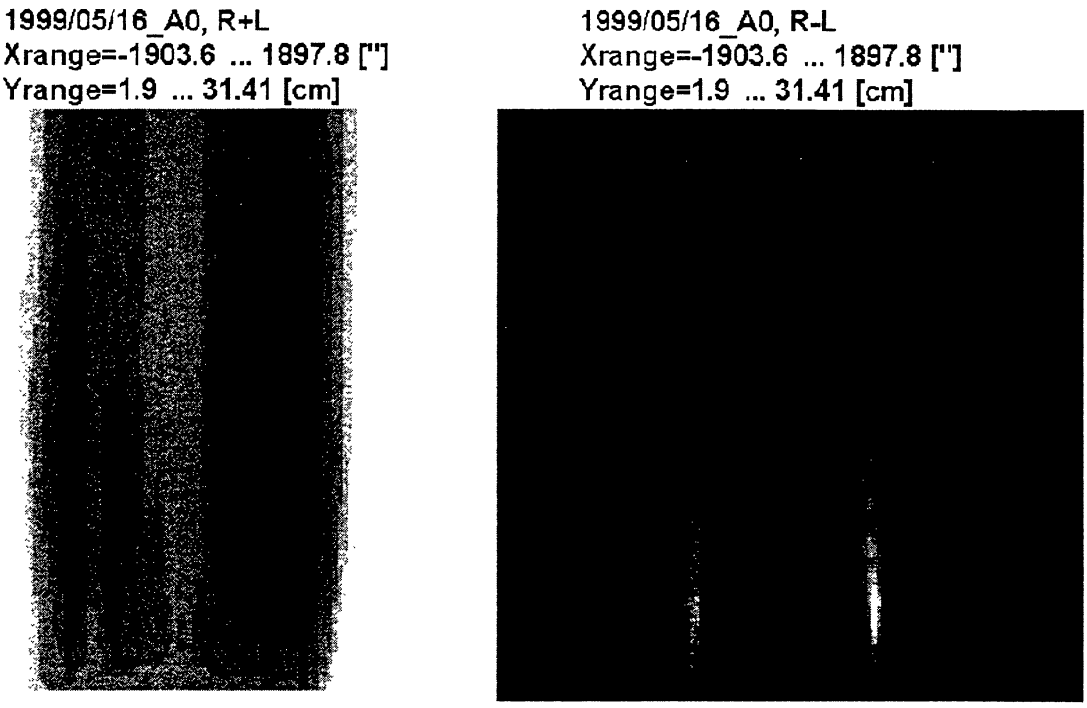

Figure 2. The multi-wavelengths observations in 3-D presentation also in intensity and circular polarization.

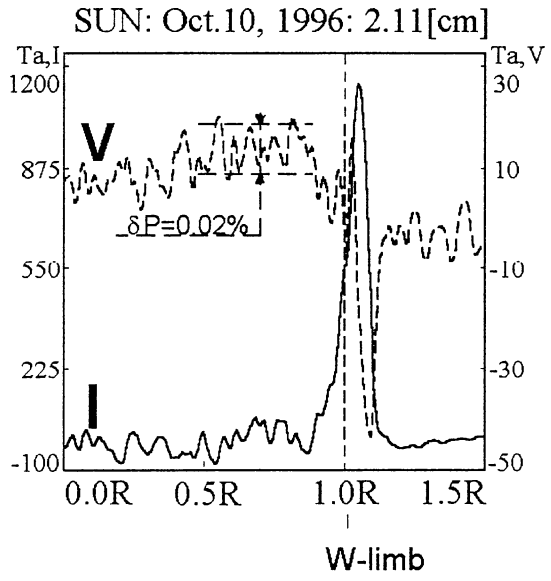

Figure 3. To the accuracy of polarization measurements.

dinate of solar disk. With the help of the program *ws_fits* it is possible to look through the data of observations both as in right, and left-hand polarizations, and also in intensity I and circular polarization V=I(L) - I(R) by IDL medium.

4.2. Representation data in physical formats

Multi-channel spectral - polarization data RATAN-600 have formed the basis for development of various methods of measurements of magnetic fields in solar active regions (Akhmedov et al, 1984; Bogod and Gelfreikh, 1982; Ryabov et al 1999).

For sunspot associated sources it is stated, that they are good described within the frames of thermal cyclotron emission on the first three harmonics of a gyrofrequency. It has allowed to develop on the basis of spectral and polarization observation methods of magnetic field measurements at the level of transition region chromosphere - corona. On the Fig.5 the model of sunspot associated source on 2 and 3 harmonics of a gyrofrequency is presented.

The o-mode emission is obliged to radiation on the second harmonic, as it has the big optical thickness. Depending on magnetic field strength the x-mode line can be displaced to the short waves (for strong fields) or long waves (for weak fields). The interpolation of this line on an axis $F \times \lambda^2 = 0$ gives value of a magnetic field at a level of a chromosphere - corona transition region under the formula:

$$B[Gs] = \frac{3570}{\lambda[cm]},$$

RATAN-600 data, May 19, 1999; at 31.41 cm (azimuthal observations)

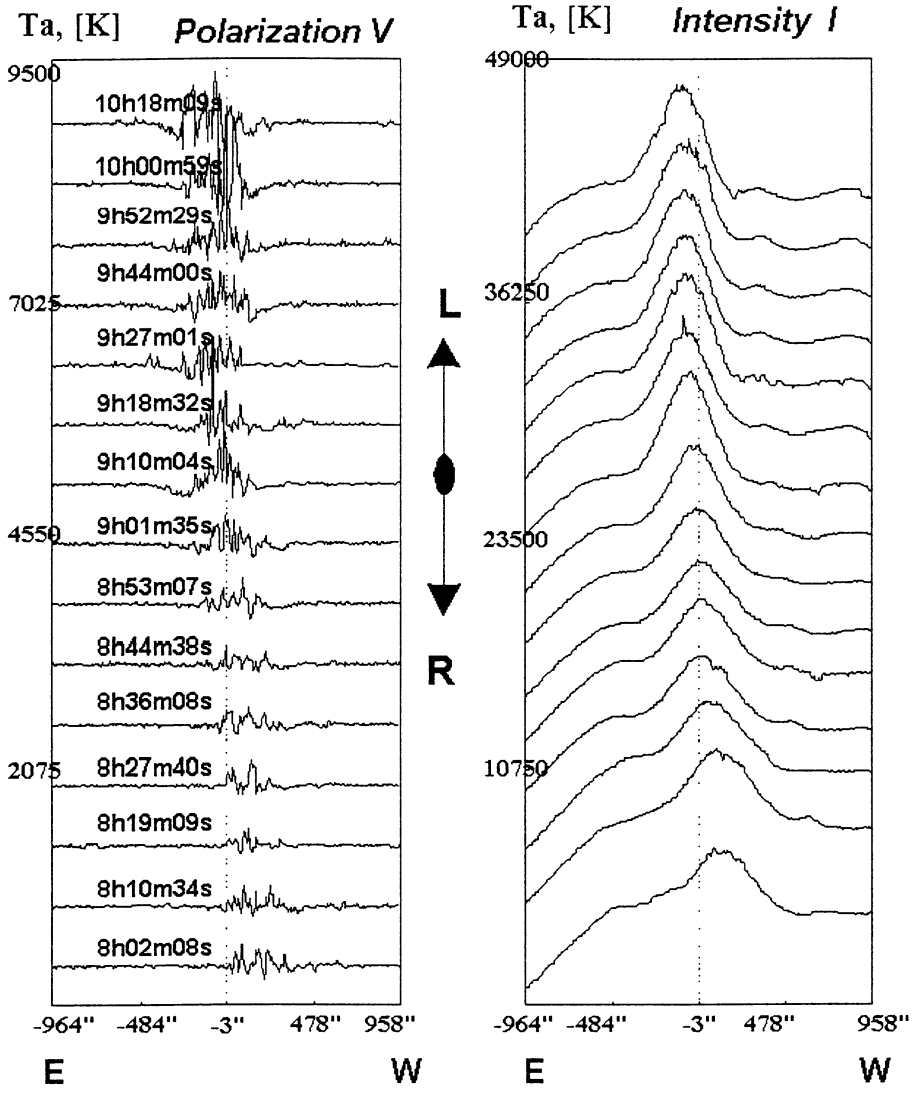

Figure 4. An example of multiple azimuth solar observations from 8-10 UT 10-18 UT at wavelength 31.41 cm. Practically the instant registration in all spectral range is achieved

In accordance with moving to long waves the optical thickness for o-mode is increased and the emission on the second harmonic is growing. In a resulting spectrum of circular polarization the break is observed which also is possible to be used for an estimate of magnetic field strength under the formula

$$B[Gs] = \frac{5400}{\lambda[cm]},$$

Calculations of a magnetic field for each radio source also are treated regularly and represented in the following view (see the Fig.6).

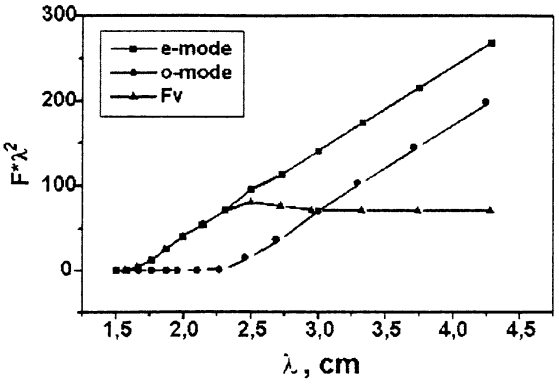

Figure 5. Model of cyclotron emission on 2 and 3 gyrofrequencies. The result curve is observed in radio spectral observations as Stokes parameters V. Two methods of magnetic field measurements based on 2 and 3 harmohics are used.

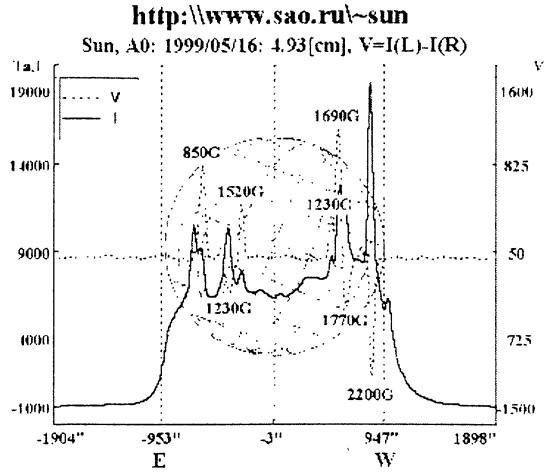

Figure 6. Radio measurement of coronal magnetic field. Because the diagram pattern is 1-D, the values of magnetic field above each sunspot is calculated according formula (1). The polarization curves shows the point with maximal values of magnetic field.

The comparison of coronal magnetic fields measured by a radioastronomical method with fields on photosphere shows, that $H_{rad}/H_{opt} = 0.8$ in a wide range of values of a magnetic field.

From our study it was stated, that H_{rad}/H_{opt} can be a coefficient of activity of active region magnetosphere and pointed to about the additional currents in corona (for larger values) and about possible turbulence of plasma in a corona (for smaller values).

In a case, when $f > f_H$, i.e. the magnetic field strength is not enough for formation of gyrofrequency harmonics (polarized emission on a first harmonic is absorbed itself) we develop the method of magnetic field measurements using free-free emission. It can be used in short centimeter and millimeter ranges for measurements of magnetic field in plages of active region.

It is important also the method of an estimate of a magnetic field at big heights in the corona (100 - 200 Mm) based on effect of change of a sign of circular polarization emission of a sunspot associated sources in the quasi-transverse magnetic field region (Ryabov et al, 1999).

5. SUMMARY

The parameters of a radio telescope RATAN-600 as the tool for solar observations are described. The spectral - receive panoramic analyzer PAS for ground-base observations of solar radio emission in a multi wavelength monitoring mode is represented. The instillment of new technical improvements allows to expand a time interval of observations up to $\pm 2 hours$ from the culmination 9-00 UT. Besides it will allow in the near future to represent daily the multi wavelength maps of a solar radio emission. Regular data of magnetic fields on spectral polarization observations are regularly represented in Internet for solar community.

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Joint Discussion on Databases

Convenor: M. Messerotti