DETECTION OF THE LONG-TERM MICROWAVE "DARKENING" BEFORE THE JULY 14, 2000 FLARE

Susanna Tokhchukova (susan@sao.ru) and Vladimir Bogod
Special Astrophysical Observatory of the Russian Academy of Sciences

Abstract. A gradual microwave darkening during several days on the preflare phase in the active region (AR) NOAA 9077, before the powerful proton event on July 14, 2000 was detected. The associated change of the circular polarization structure in the form of narrow-band double inversion of the sign was marked. The effects were revealed in a wide range radio observations at the RATAN-600 radiotelescope and were confirmed by data from the Nobeyama Radio Heliograph (NRH) at 17 GHz and Siberian Solar Radio Telescope (SSRT, Irkutsk) at 5.8 GHz. We propose an interpretation of the observed effects as an indication of gradual formation of a filament in the vertical structure of the AR. Destabilization of this filament apparently caused the major flare with a coronal mass ejection (CME).

1. Introduction

The pre-flare state of a solar active region (AR) magnetosphere at levels of chromosphere and corona (Lang et al., 1993) is investigated insufficiently until today. An emergence of a new magnetic flux (appearing of new loops), its interaction with the existing magnetic field (with old loops), formation of current sheets and filaments, eruption of filaments - all these effects are important reasons for to cause flares (Hanaoka, 1997, Heyvaets et al, 1977, Shibata, 1998). It is natural to presume, that the pre-flare activity at the photosphere should develop changes of magnetic structure and be accompanied by additional inflow of energy in the corona base, leading thus to the considerable increase of microwave emission intensity (Tanaka et al., 1975). But the latter is not always confirmed by observations. For example, there are short-term (during tens of minutes) depressions of radio emission before flares known for a long time from observations by small radio telescopes (see, for example, Covington, 1969, at 2800 MHz). Recent observations with high spatial resolution at 17 GHz with Nobeyama Radio Heliograph (NRH) also show, that both the depletions and enhancements of the AR radio emission on the pre-flare phase are possible (Fujiki and Nakajima, 2000). A long-term microwave darkening (the decrease of radio brightness temperature) before the rather weak flare in the AR 8038 on May 12, 1997 was noticed also in RATAN-600 observations (Bogod et al., 1999).

In this work, based on wide range (1.74 -30 cm) microwave RATAN-600 observations, with engaging of NRH data at 17 GHz and Siberian Solar Radio Telescope(SSRT) at 5.8 GHz, we present the analysis of the AR 9077 radio emission pre-flare dynamics, prior to the major flare on July 14, 2000. This region was undergoing steady and considerable decrease of microwave emission within 3 days prior to the flare.

In section 2, the observational data and methods used for the data processing are described.

In section 3 we give an interpretation of the phenomena observed at radio waves as an indication of a filament formation, which imply a gradual increase of its density and opacity.

2. Observations

On July 14, 2000 the large complex AR NOAA 9077 produced the powerful (X5.7/3B) flare, with the maximum at 10:24 UT. According the Huairou H_α observations (Yan et al., 2001) at this day a long filament with a triangular shape existed above the neutral magnetic field line. One day before the filament was visible on the images from Ramey observatory (Puerto Rico) (see
$http://www.sec.noaa.gov/solar_images/2000\_07/2000\_07\_14.html$)

The Solar and Heliospheric Observatory (SOHO) Michelson Doppler Imager (MDI)data with 96 minutes cadence were used for the study of the AR 9077 magnetic structure at the photosphere level. The magnetic fields ($H > 2000$ G) structure was very complex ($\beta\gamma\delta$), with fields of southern polarity located at the northern side of the sunspots group, and fields of northern polarity located at the southern side. The AR showed no significant changes of global magnetic morphology and fields strength from day to day, only small scale relative motions of different polarities. This is in disagreement with sharp changes of the AR radio emission intensity and spectral polarization pattern, which are described below. The data from three largest radio telescopes were used for the study.

2.1. RATAN-600 DATA

In this work we used routine RATAN-600 observations which are carried out daily in the transit mode in a wide frequency range from 17.2GHz (1.74 cm) up to 1 GHz (30 cm). The registration of the intensity and circular polarization emission was made using the multi channel Panoramic Analyzer of Spectrum ($Korol'kov \& Parijskij$, 1979, $Bogod et. al$, 1993) simultaneously at 36 frequencies. The radiotelescope in the mode of

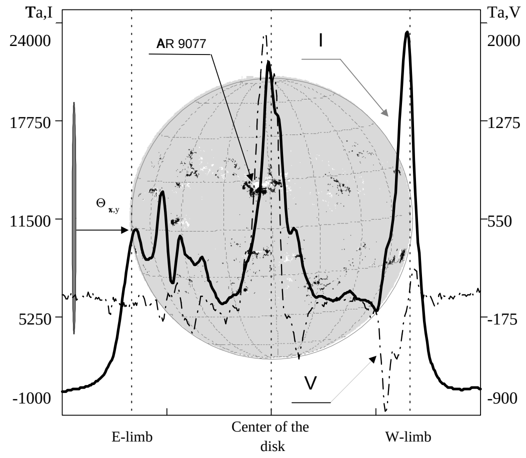

Figure 1. An example of RATAN-600 one-dimensional solar scan record in intensity I = I(L)+I(R) and circular polarization V = I(L)-I(R) for July 14, 2000, 9:00 UT. The AR 9077 is located at the center of the disk. On the left the sizes of the beam pattern for the wavelength 6.06 cm are shown.

observations together with a Periscope reflector has one-dimensional beam, with the sizes determined by formulae:
$\Theta_x[arcsec] = 0.85\lambda[mm], \Theta_y[arcmin] = 0.75\lambda[mm]$. An example of the one-dimensional image of the Sun at the wavelength ($\lambda = 6.06$ cm) in intensity $I = I(L) + I(R)$ and circular polarization $V = I(L) - I(R)$ is shown in the Figure 1, superposed on MDI magnetogram.

The long vertical size of the beam allowed us to observe practically all AR's available on the Sun for the research. The AR NOAA 9077 was isolated enough and had the dominant emission in comparison with other small sources captured by a vertical diagram. At short wavelengths the vertical beam size is smaller than the diameter of the Sun. For the calibration of scans we used the data from Nobeyama Radio Polarimeters (NoRP) Station. It is recording daily the total flux from the full Sun disk at 5 frequencies
(ftp://solar.nro.nao.ac.jp/pub/norp/data/daily/). For the other intermediate frequencies of RATAN-600 we used the cubic spline interpolation. This method provides an accuracy of a flux measurement better than 10% relative the quiet Sun level. Applying the calibration procedure to all frequencies for each day, we have studied the temporal behavior of a relative antenna temperature with a cadence of 1 day. In Figure 2 the dynamics of radio brightness temperature at 3 different wavelengths during the period from July 11 up to July 16,

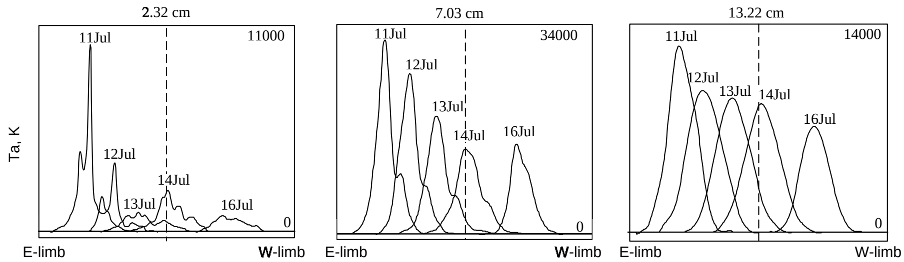

Figure 2. RATAN-600 scans of the AR 9077 at wavelengths 2.32 cm, 7.03 cm and 13,22 cm. The emission of the quiet Sun is subtracted. The picture demonstrates the "darkening" effect of the AR radio emission during its passage on the solar disk from July 11 till July 16. We see, that the effect decreases with a wavelength. The observations were carried out at the local noon, about 9:00 UT.

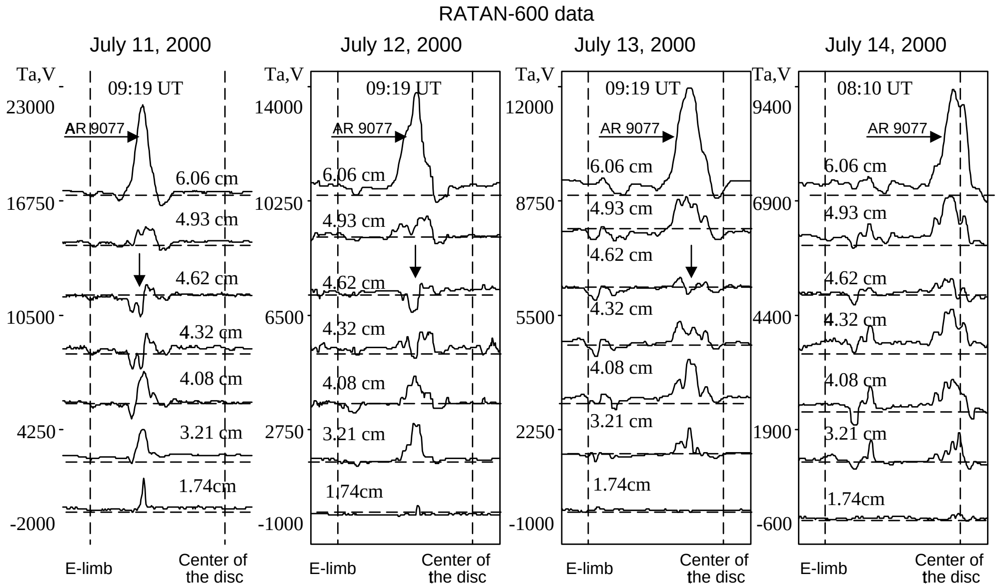

Figure 3. RATAN-600 scans of the AR 9077 circular polarization emissions V = I(L)-I(R) made at several wavelengths in the range of 1.74 cm - 6.06 cm during the period from July 11 to July 14. One can see the complicated reconstruction in the AR structure at wavelengths 4.32 cm and 4.62 cm. The place of polarization inversion is marked by arrows.

2000 is shown. One can see that the emission drops violently at shorter wavelengths. Generally, the darkening was detected in the centimetric range from 1.7 cm up to 8 cm. At longer wavelengths the depression is relatively small, if any. An analysis of the circular polarization structure revealed associated changes which are shown In Figure 3.

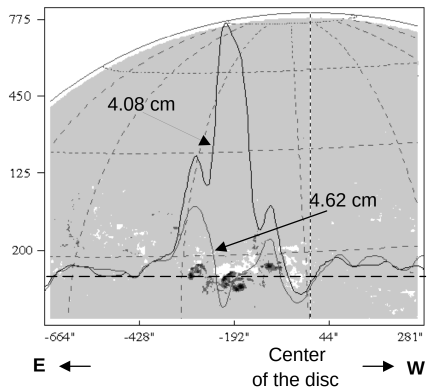

Figure 4. Detailed comparison of circular polarization structures of the AR 9077 at neighboring wavelengths 4.08 and 4.62 cm with the magnetic structure for July 13, 2000. The sharp changes of the structure and polarization sign are visible in the place of magnetic polarity changes. The left circular polarization directed to up and the right one directed to down.

In this figure one-dimensional scans of the AR 9077 circular polarization emission at several centimetric wavelengths for the period from July 11 to July 14, 2000 are presented. One can see a narrow band (5-10%) circular polarization inversion in the middle of the centimetric range (around wavelength 4.62 cm). Note that these peculiarities were conserving during 4 days before the flare and disappeared after it. On July 14 observations were made two hours before the flare. At this day we can see some restoration of the polarization spectrum at the wavelengths 4.32 cm and 4.62 cm. Moreover, the radio intensity source of the AR at short wavelengths (see scan in the Figure 2 at 2.32 cm) became slightly brighter. In Figure 4 the sharp slope of spectrum at two neighboring wavelengths 4.08 cm and 4.62 cm for July 13, 2000 is shown on a large scale and compared with photospheric magnetic fields structure. It is necessary to mark, that both microwave darkening and the polarization sign inversion are connected to flare activity of the NOAA 9077 and reflect their joint nature. Other non-flaring AR's recorded at this period on the disk demonstrated a steady monotonic growth of circular polarization spectrum.

2.2. NRH DATA

For confirmation of the darkening detected at RATAN-600 spectral data, we used regular data from NRH at 1.76 cm, published on the web site:

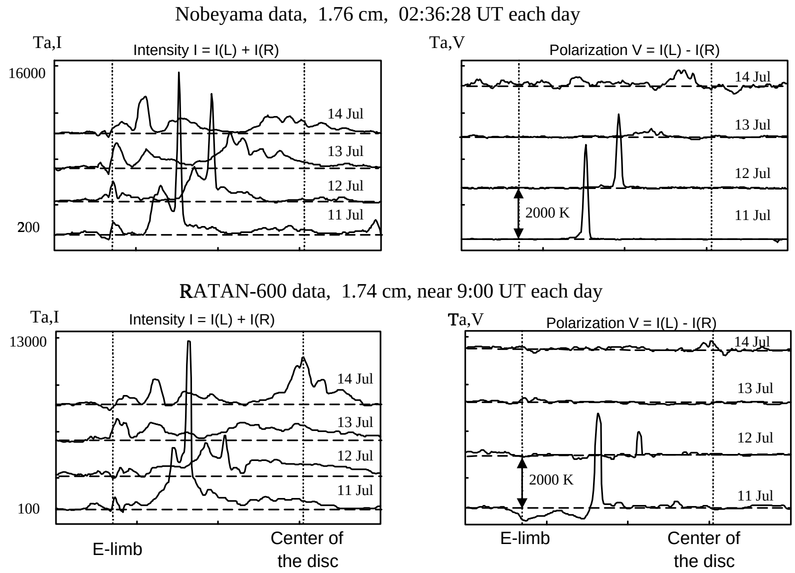

Figure 5. Comparison of the Nobeyama and RATAN-600 data at the nearest wavelengths for the period from July 11 to July 14. The NRH maps were convolved with the RATAN-600 beam. Left: the scans of intensity. Right: the circular polarization scans. Darkening of the AR 9077 on time is clearly manifested both in intensity (I) and circular polarization (V) channels.

ftp://solar.nro.nao.ac.jp/pub/norh/images/daily/2000/07/. The two-dimensional NRH maps have been rotated by a position angle and convolved with the one-dimensional RATAN-600 beam at the corresponding wavelength 1.76 cm. The obtained one-dimensional scans of solar disk are shown in the Figure 5. Comparison of the observations shows a good correspondence between RATAN and NRH data both in intensity and circular polarization emission. At this wavelength we observe a strong depression (up to 90%) during 3 pre-flare days. On July 13 and 14 the AR emission both in I and V has the minimum values. Some difference in amplitudes of the radio source for July 11 and 12 on two instruments can be explained by a difference (about 6.5 hours) in the time of observations .

2.3. SSRT DATA

Comparison of RATAN-600 data with two-dimensional radio maps from the SSRT (Irkutsk, Russia,
*ftp://iszf.irk.ru/pub/ssrt_data/fits/*2000/07/) at wavelength 5.2 cm was also made. SSRT maps also were convolved with the one-dimensional RATAN-600 beam at the corresponding wavelength. The

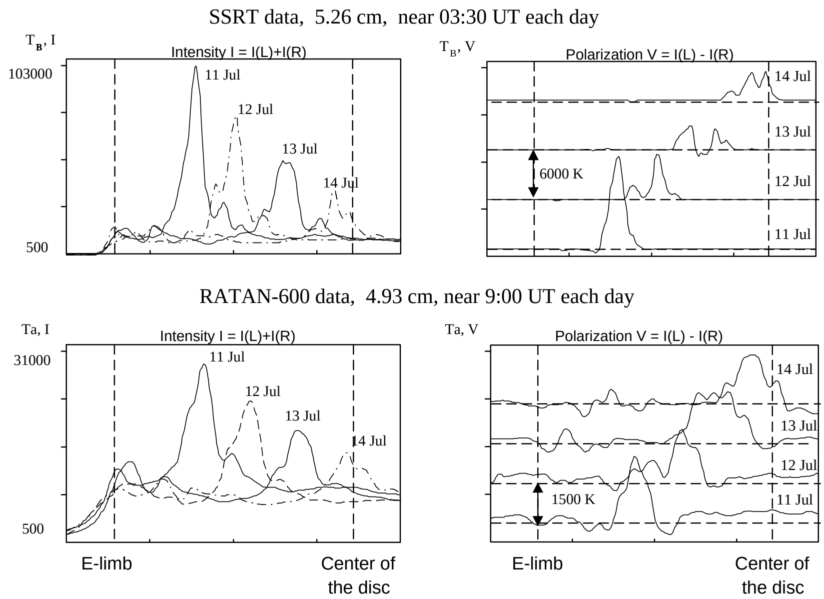

Figure 6. Comparison of the SSRT 5.2 cm and RATAN-600 data at the nearest wavelength 4.93 cm for AR 9077 during the period from July 11 to July 14. The two-dimensional brightness temperature SSRT images were convolved with the RATAN-600 beam. RATAN data are presented in antenna temperature scale. Left: the scans of intensity. Here, for clarity, the 12 and 13 July scans are plotted by dotted lines. Right: the circular polarization scans. Darkening effect is evident in intensity channel. On July 13 the effect of circular polarization sign inversion is seen at SSRT data. Similar behavior was detected at the spectral data of RATAN-600 at more short wavelengths 4.62 cm and 4.32 cm (see Figure 4).

comparison of the data is shown in Figure 6. Here we note also a good concordance of RATAN and SSRT data in the intensity channels for all the period. However, we see a considerable difference in the circular polarization channels for the data on July 13. At this day SSRT has recorded an emission drop at the center of the source down to the appearance of the opposite sign of polarization. However, RATAN-600 has not marked any change of the polarization sign at the nearest wavelength 4.93 cm. But the change of the polarization sign at this day occurred at shorter wavelengths 4.62 and 4.32 cm (see Figure 4). Probably this distinction is due to the significant time difference in the moments of observations about 5.5 hours.

2.4. Discussion of the data

Our discussion will concern mainly Figures 3, 5, 6 and 7. In Figure 7 the comparisons of photospheric magnetic fields according the SOHO MDI

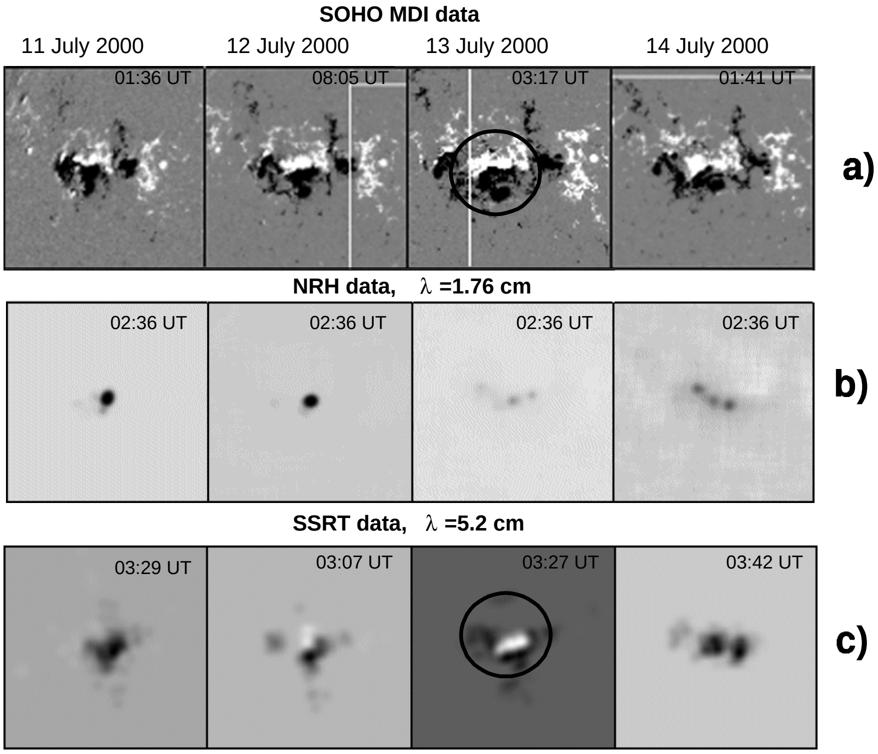

Figure 7. NOAA AR 9077 images from the SOHO/MDI (a), NRH (b) and SSRT (c) for the period from July 11 to July 14, 2000. A horizontal size of each picture is about 480 arcsec. Top (a): MDI photospheric magnetic fields. Middle (b): NRH circular polarization maps at 1.76 cm. Bottom (c): SSRT circular polarization maps at 5.2 cm. Note the considerably strong changes of circular polarization structure from day to day at radio waves in comparison with small changes of the photospheric magnetic field structure. Especially sharply the difference is exhibited on July 13. At this day the sign of the circular polarization emission above the magnetic field of northern polarity changed (marked by circles) as compare with the data for July 11. Also note that the NRH data demonstrate the sharp decrease of polarized emission flux during all period.

data with circular polarization maps at radio waves obtained with NRH (at 1.7 cm)and SSRT (at 5.2 cm) are presented. It is noticeable that the photospheric magnetic field structure (upper picture) underwent not so much drastic changes as the polarization structure at radio waves did, during 4 preflare days (middle picture for NRH and bottom picture for SSRT).

At the longer wavelength 5.2 cm during July 12 a new source with right circular polarization (white colour) associated to o-mode emission appeared inside the region with opposite sign. On July 13 it became dominant, so on the one-dimensional scan (see Figure 6) we see the drop of emission at the center of the AR. The overlay of the SSRT and SOHO MDI maps shows, that this source was located above the large spot of northern polarity (black colour) at the photosphere (see circles in Figure 7a and 7c). The region of the right polarization (the white spot in the circle in Figure 7c) has coincided on the line of sight with the region of northern polarity (dark spot in Figure 2a) as opposed to polarized emission of x-mode. It corresponds to the o-mode polarization of cyclotron radio emission. The same behavior of polarized emission structure, but at more short wavelengths (4.62 - 4.32 cm), was observed at RATAN-600 (see on the Figure 3 the places marked by arrows). At this narrow frequency range we have observed the prevalence of the o-mode emission in the central part of the source during the 3-day pre-flare period.

3. Interpretation

Flare productive AR's have very complex magnetosphere structure not only on the photosphere level but at the low corona levels. This is the place where the scenario of the future flare usually begins. Filaments available at these levels are often considered as tracer ways above the magnetic neutral lines and now it is well known that they are being cause of CME's (Gopalswamy et al., 1998, Hudson, 1999). Also note that the long-term microwave darkening effect most probably has nothing in common with different types of short-term dimmings, marked in X-ray/EUV ranges, which sometimes happen before CME.

It is also known that filaments are generally much wider in radio waves and EUV (Kundu et al., 1986, Heinzel et al., 2001) than on H_α images. Proper emission of filaments is well studied by other authors (Schmahl et al., 1981, Kundu et al., 1986 and Chiuderi- Drago et al., 2001) who determined their thermal nature. Here we present other manifestation of filament existence, in the form of absorption of the transmitted thermal gyroresonance (cyclotron) radiation coming from lower levels of atmosphere.

As marked by several observers (Yan et al., 2001), (Liu & Zhang, 2001) a big triangular prominence was located above the neutral line of the AR 9077. We have two observational results: 1) a wide range microwave darkening and 2) a narrow band (5 – 15%) polarization peculiarity in the form of double inversion.

As a first approximation one can explain the microwave darkening by absorption in thermal plasma in accordance with a transfer equation:

$T_B = T_s exp(-\tau_p) + T_p(1 - exp(-\tau_p))$,
where T_B is the observed brightness temperature, T_s is the temperature of cyclotron source, T_p and τ_p are the temperature and optical depth of the filament.

Taking into account $T_s >> T_p$, for the case of $\tau_p < 1$, one can write: $T_B \approx T_s exp(-\tau_p)$

As follows from Fig.2 the weakest depression is at 13.22 cm and increases to short waves. On assumption of stability of the cyclotron source emission we need to consider the variation of prominence opacity τ_p. Our estimations of depression in the wavelength range from 1.7 cm to 8 cm give the values of $\tau_p = (0.5 - 2)$. Such method based on wide range observations may be very sensitive to small variations of matter opacity for transmitted emission. Note, that according to H_α line data (Yan et al., 2001), the filament was registered only since July 13.

For the explanation of narrow-band polarization peculiarities, at first we should note that considerable values of circular polarization ($p > 30\%$) at short wavelengths specify the cyclotron mechanism of radio emission with predominance of extraordinary mode (Zheleznyakov, 1970). It allows us to make the estimation of longitudinal magnetic field $H = 2000G$ for a wavelength 1.7 cm, and $H = 700G$ for 5.2 cm (Gelfreikh et al., 1993). From the regular observations we know that cyclotron emission from sunspot associated sources for simple magnetic field configuration usually has monotonous growth with wavelength. But in the case of the AR 9077 we see the double inversion of the circular polarization sign in the 4-5 cm wavelength range.

According to model calculations done by Zlotnik (2001), such a double inversion of polarization is possible at a presence of a cold filament in the atmosphere above sunspot. This result in the local change of the sign of kinetic temperature gradient. The existence of a region with negative temperature gradient in a certain height interval leads to the prevalence of the ordinary wave at certain frequency interval and thus to the appearance of the double polarization spectrum inversion. One should note that this effect is a long-term event and was observed both in RATAN-600 and SSRT observations. Our understanding of the filament location is shown in Figure 8.

At last, we would like to draw an attention to the observations in Figure 3 for July 14, 2000, which were made 2 hours before the flare. The data indicate that the process of restoring of relative contribution of the extraordinary wave has started. It apparently points to the beginning of processes, related to the filament moving. As a consequence, its eruption and ejection as a CME, and also triggering of the powerful flare became possible. It is known that for the event of July 14, 2000 both of two events occurred with big intensity.

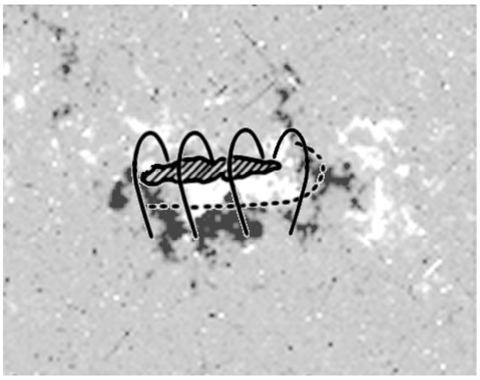

Figure 8. Schematic representation of the filament located above the neutral magnetic field line, and arcades structure.

4. Conclusion

This work promotes the understanding of active region nature before big flares. Two effects at microwaves were detected: 1) long-term (during 4 days) gradual depression of radio emission ("darkening"), which is most effective at short wavelengths; 2) the effect of double polarization inversion of a cyclotron radio emission on spectrum (from the e- mode to o-mode and back) in the central part of centimetric range. These effects are well explained by a model of gradual accumulation of a cold mass of filament located above the AR and its sharp disappearance before the flare. We suggest that the microwave darkening in combination with frequency dependent peculiarities of polarized radio emission could be used as a long-term signature of the preflare state of AR.

5. Acknowledgements

The authors thank A.Grebinskij for critical remarks and for drawing of our attention to this topic and V.N.Borovik for useful discussion. We are also much obliged to SSRT and Nobeyama radioheliograph groups for high quality Internet data. This work is supported by the grant RFBR (No 02-02-16430a and 01-02-06040), and INTAS grant YSC 4315.

References

Akhmedov, Sh. B., Borovik, V.N., Gelfreikh, G.B., Bogod, V.M., Korzhavin, A.N., Petrov, Z.E., Dikij, V.N., Lang, K.R., and Willson, R.F.: 1986, *Astroph. J.*, **301**, 460.

Bogod V., Grebinskij A., Garaimov V., Urpo S., Fu Q.J., Zhang H.: 1999, *Bull. Spec. Astrophys. Obs.*, **48**, 17.

Bogod V.M., Garaimov V.I., Korzhavin A.N.: 1999, *in Magnetic Fields and Solar Processes*, **ESA SP-448**, 1253.

Chiudery Drago F., Alissandrakis C.E., Bastian T., Bcchialini K., Harrison R.A.: 2001, *Solar Phys.*, **199**, 115.

Covington, A. E.: 1973, *Solar Physics*, **33**, 439.

Gelfreikh G.B., Bogod V.M., Abramov-Maximov V.E., Tsvetkov S.V.: 1993, *ASP Conference Series*, **46**, 271.

Gelfreikh G.B.: 1998, *ASP series*, **155**, 110.

Gopalswamy, N.; Yashiro, S.; Kaiser, M. L.; Thompson, B. J.; Plunkett, S.: 1999, in T. S. Bastian, N. Gopalswamy, and K. Shibasaki (eds), *Solar physics with radio observations. Proceedings of the Nobeyama Symposium*, NRO Report **479**, 207.

Fujiki, K.; Nakajima, H: 2000, *Advances in Space Research*, **26**, Issue 3, 477.

Hanaoka Y.: 1997, *Solar Phys.*, **173**, p. 319.

Heinzel P., Schmieder B., Tziotziou K. : 2001, *APJ*, **561**, 223.

Heyvaerts J., Priest E.R., Rust D.M.: 1977, *APJ*, **216**, 123.

Hudson, H.,: 1999, *Solar Phys.*, **190**, 91.

Yihua Yan, Yuanyong Deng, Marian Karlicky, Qijun Fu, Shujuan Wang, and Yuying Liu: 2001, *Astroph. J.*, **551**, 115.

Korol'kov D.V., Parijskij Yu.N.: 1979, *Sky and Telescope*, **57**, 329.

Kundu M., Melozzi M, Shevgaonkar R.: 1986, *Astroph. J.*, **167**, 166.

Lang K.R., Willson R.F., Kile, J.N., Jemen, J., Strong K.T., Bogod V.M., Gelfreikh G.B., Ryabov B.I., Hafizov S.R., Abramov V.E., Svetkov S.V.: 1993, *Astroph. J.*, **419**, 398.

Liu Y., Zhang H.: 1986, *A&A*, **372**, 1019-1029.

Shibata K.: 1999, in T. S. Bastian, N. Gopalswamy, and K. Shibasaki (eds), *Solar physics with radio observations. Proceedings of the Nobeyama Symposium*, NRO Report **479**, 381.

Schmahl E.J., Bobrowsky M., Kundu M.R.: 1981, *Solar Phys.*, **71**, 311.

White, S.M., Kundu, M.R., and Gopalswamy, N.: 1992, *APJ Suppl Ser*, **78**, 599.

Zheleznyakov V.V.: 1970, *Radio Emission of the Sun and the planets*, Pergamon Press Ltd., Oxford.

Zlotnik E.Ya.: 2001, *Radiophysics and Quantum Electronics*, **44**, 53.

Address for Offprints: Special Astrophysical Observatory, Pulkovskoe shosse 65/2 St. Petersburg, 196140, Russia.