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Microwave sources with anomalous polarization and high temperature of complex active regions on the Sun

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Abstract. The spatial structure and evolution of the radio emitting region in the solar corona above the complex group of sunspots (SD No 24/1976) at the stage of violent activity is studied. Polarization observations with a high spatial resolution (about 10 arcsec) in the wavelength range 1.35 cm – 18.0 cm have been used for this purpose. From the data obtained a qualitative model of the three–dimensional structure of the radio emitting region is constructed. A hot flare–like loop (peculiar source) which existed quasistationarily for about 5 days and a source of cyclotron nature radiation with predominant ordinary wave are the most prominent details of the model. Both phenomena are related to anomalous and prolonged energy release in the region of radiation origin. Joule dissipation of electric current in the circuit "coronal magnetic loop – photosphere" may be such a source of energy, electric current being generated by subphotospheric motions of solar matter, and the high resistance is due to collisions of ions and neutrals in a way similar to that it occurs during solar flares.

Key words: Sun: activity – Sun: corona – Sun: radio

1. Introduction

Active regions (AR) on the Sun, as it follows from observations, are extremely diversified in any range of electromagnetic radiation. In the radio wavelength range, for instance, the brightness and other characteristics of local sources (l.s.) of radio emission located in the solar atmosphere above AR vary over a very wide range. This refers to all basic components of the structure of l.s.: sunspot associated (nuclear) details, halo and peculiar sources. The variability of the latter can be explained by the fact that non-thermal processes are likely to play an important (if not decisive) part in generation of their radiation. The nuclear component of l.s., as one of thermal nature of radiation, must be more stable, however, its brightness varies occasionally or in the process of evolution by more than one order. What determines the degree of heating and where are the sources that heat up the atmosphere above ARs, and which is the mechanism transporting this heat? This question remains one of the main problems of physics of the solar atmosphere.

Due to the great variety of ARs on the Sun they have long been studied by way of classifying the characteristics. The regular observations at RATAN–600, owing to which a wealth of observational data have been accumulated, allows proceeding to statistical investigation of the l.s. structure. Peterova (1994) has attempted to develop a certain classification of l.s. based on the type of their halo. The paper seeks to search for common features of the structure and evolution of radio radiation of sunspot groups with the same type morphology.

First we have chosen a sample of complex vigorously active ARs, when a new bipolar group of young sunspots is formed near the old isolated sunspot. This type of ARs are characterized by high flare activity, which creates favourable conditions for detection of sources heating the atmosphere above ARs. The work has been done on the basis of observational data of AR SD No. 24/1976. The results of analysis are compared with the observations of a similar AR SD No. 259/1980 (Peterova et al., 1996). In both cases above one of the young sunspots a region with an excess of ordinary mode radiation has been detected. This phenomenon is likely to be associated with the negative temperature gradient due to the increased energy release above the sunspot. This regularity, which is confirmed in a number of other cases, provides grounds for selection of a new subclass of sunspot associated details — the sources with inverse polarization of radiation. Investigations of evolution confirm once again that radio observations can be efficiently used for the study of active processes on the Sun, the onset of which is more distinct here than in other ranges of the electromagnetic spectrum.

2. Description of the AR SD No. 24/1976

The indicated AR (SD is the number label of the bulletin "Solnechnye Dannye", McM No. 14179 is that of the bulletin SGD) was observed in its third rotation (CMP=IV-27.4). In the first rotation (SD No. 10/1976) this was a bipolar sunspot group of small area (Sp=20–50 m.s.h.) which turned up on the visible side of the Sun and existed only three days. In the second rotation (SD No. 16/1976) the AR represented a large and complex sunspot of class H (Sp=600–800 m.s.h.) of inverse magnetic polarity surrounded with a very bright flocculus. According to Akinian et al. (1983) in the third rotation this AR was observed as a sufficiently bright middle-sized flocculus. Until 27/IV a unipolar regular sunspot of S-magnetic polarity (Sp=200–240 m.s.h.) was situated in its eastern part. Beginning from 29/IV a new bipolar group of sunspots of inverse polarity appears to the north of this sunspot, the area of the main old sunspot being diminished. The maximum development of the young part of the group is observed on 30/IV – 01/V 1976, after that the AR breaks down quickly.

On the whole the AR was characterized by enhanced flare activity. It gave rise to two powerful events: in the second rotation the flare of 28/III (T_{max} = 19.5UT) of class 1B, X1, while in the third rotation the flare of 30/IV (T_{max} = 21.0UT) of class 1B, X2. These were proton flares accompanied by a number of helio and geophysical effects. Hedeman (1981) has noted this AR to be the most significant event on the Sun in 1976. It was observed in a period of minimum solar activity just at the border between the 20th and 21st cycles. By its location on the solar disk (latitude S 07–08) it must be referred to the old-cycle ARs, however, the sign of polarity alternation in it corresponded to the new cycle.

3. The observation and the procedure of analysis

The basic observational material for the investigation of the AR SD No. 24/1976 was obtained in the observations carried out during the solar eclipse of 29/IV at the wavelengths 4.0 cm (near Zelenchukskaya, D=3 m) and 4.85 cm (near Kislovodsk, D=3 m) with an effective resolution of 8–12 arcsec and at the RATAN–600 in the period from 26/IV to 01/V at the wavelengths 2.08 cm, 3.90 cm and 6.52 cm with a resolution of $14'' \times 1.2', 28'' \times 2.3'$ and $47'' \times 3.9'$, respectively. The preliminary results of the observations are available in the papers by Gelfreikh et al. (1978), Korzhavin (1979), Boldyrev et al. (1978).

For AR SD No. 24/1976 we used a great body of additional data owing to the fact that this AR was observed during the STIP–interval. These observations were systematized and published in "Collected Data Reports for STIP–interval II", 1977 (Report UAG-61), where the principal solar, interplanetary and geophysical phenomena for the period (20/III – 05/V) 1976 are described in details. To widen the spectral range of investigations, the results of the eclipse observations of this AR at 1.35 cm (Efanov et al., 1977) and 18 cm (Gosachinsky et al., 1977) as well as the observations with the Large Pulkovo Radiotelescope (LPR) in March – April, 1976 at 4.4 cm and 9.0 cm (Akhmedov et al., 1991) are also included into consideration.

The identification of separate details of the l.s. structure was performed with high accuracy (2 arcsec) by means of comparison of radio images with the photoheliogram on the day of the eclipse, 29/IV, using coordinate measurements by Matveev and Yurovsky (1977). For the other days the photoheliograms kindly made available from L.Dezhe (Debretsen, Hungary) were used. In the given case the observational material is noted for its fair completeness and high quality. The analysis of our own data and of those obtained at the RATAN–600 was performed by well-developed methods (Gelfreikh et al., 1974; Akhmedov et al., 1987). The preliminary results published earlier are specified and reconsidered taking into account the present–day knowledge of the structure of l.s.

4. The structure of the l.s. of AR SD No. 24/1976

The characteristic properties of multicomponent structure of this AR reflect best the radio observations in the eclipse. In Fig. 1 is shown the one-dimensional brightness distribution of the l.s. of this AR during the eclipse at 4.85 cm. A very like distribution was obtained at a close wavelength, 4.0 cm.

To demonstrate the peculiarities of the structure, Fig. 2 displays in more detail the image of the AR from the observations at this wavelength. In the structure of the l.s. 5 details can be noted. Three of them are related to the main sunspots of the group: detail A is associated with the old largest area sunspot, details B and C are situated above the young sunspots of the new bipolar group of N and S magnetic polar-

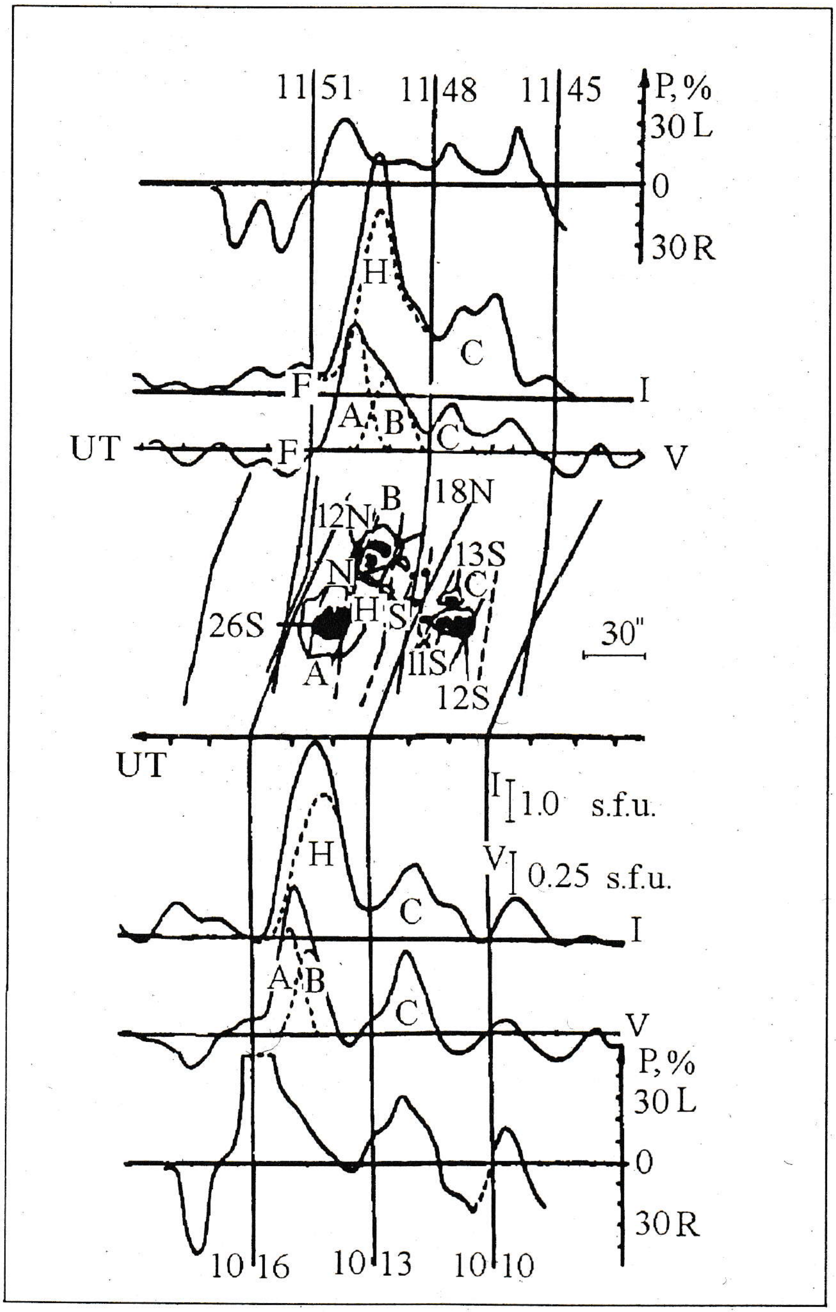

Figure 1: *The structure of the l.s. and the group of sunspots of the AR SD No.24/1976 from observations of the 29/IV solar eclipse at 4.85 cm at the moments of contacts with the Moon limb.*

ity, respectively. The distribution of the degree of polarization over the l.s. indicates that the radiation of the three details was strongly polarized. This helped to resolve the unpolarized radiation of this compact l.s. into separate details.The division was performed under the assumption that all polarized radiation of the l.s. is due to the sunspot associated details and the degree of polarization of this radiation is 100 % at the wavelength 4.0 cm and 50 % at 4.85 cm. After subtraction of these details from the total radiation, weakly polarized details H1 and H2 are revealed.

The identification of detail H2 is apparent — this

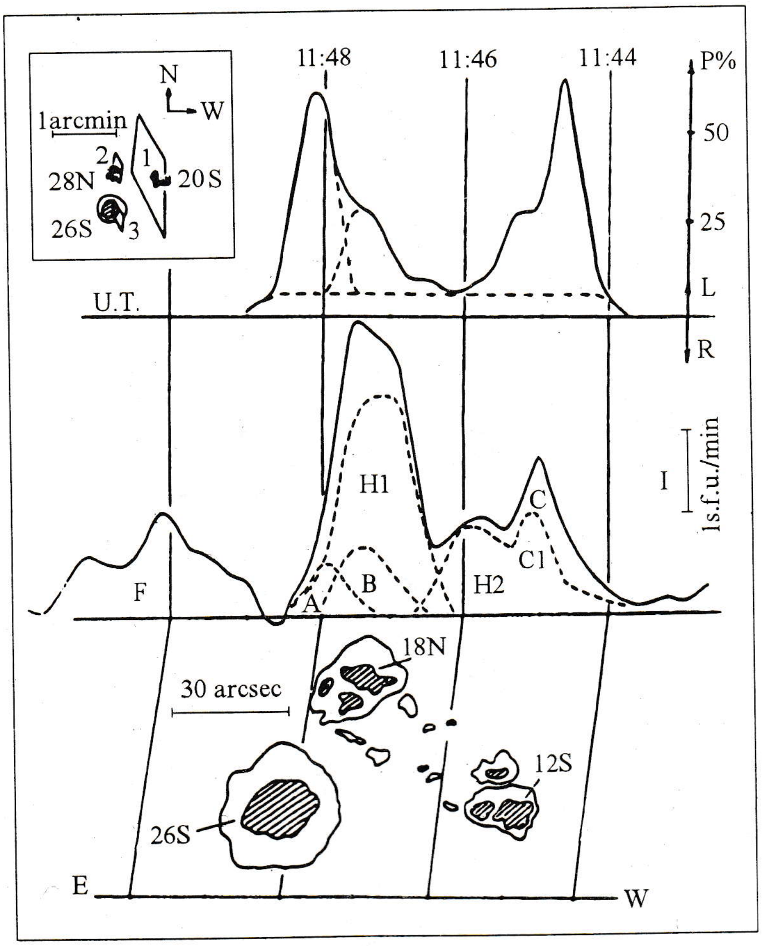

Figure 2: *The brightness distribution of non-polarized radiation (I) and degree of polarization (P) for the l.s. AR SD No. 24/1976 obtained by the eclipse method on 29/IV at 4.0 cm. The dashed line shows the division of the total flux into separate details (A,B,C, H1 and H2, F). The lower part displays the sketch of a photoheliogram with indication of sign and strength (100 Gs) of the maximum magnetic field in the main nuclei of the sunspots. Enframed at the top is the position of individual details of this l.s. with respect to the main sunspots from the eclipse observations at 1.35 cm (Efanov et al., 1977).*

is the magnetosphere of the young part of the group, which forms a halo-type source. This is suggested by both the position of the source whose coordinate falls within the interspot space B–C and its size comparable with the separation between the young sunspots of opposite magnetic polarity. Detail H1 has like characteristics (halo or peculiar source) too, although the identification in this case is not as apparent. However, this may be supposed to be a magnetic loop formed as a result of interaction between old sunspot A and neighbouring young sunspot B of opposite polarity. The displacement of the coordinate of detail H1 towards W with respect to sunspots A and B may be considered as an effect of elevation of source H1 located at the top of the loop that connects spots A and B. The existence of magnetic loops related to details H1 and H2 is supported by observations of this AR in the H_α line. According to Gaizauskas et al. (1977) on 29/IV two arch systems of fibrilles which connect spots A–B and B–C are observed.

As it will be shown below, to understand active processes that have occurred in the AR, observations in the short–wave part of the spectrum are of exceptional importance. In this connection in Fig.2 we represent the structure of this l.s. obtained by the eclipse method at 1.35 cm, following Efanov et al. (1977). According to these observations the total flux of the l.s. was concentrated on three details. Two of them having small sizes, about 10 arcsec, coincide with sunspots A and B. By the way detail 2 (sunspot B) has the highest brightness temperature (T_B = 314kK). Detail 1 contributes half of the to-

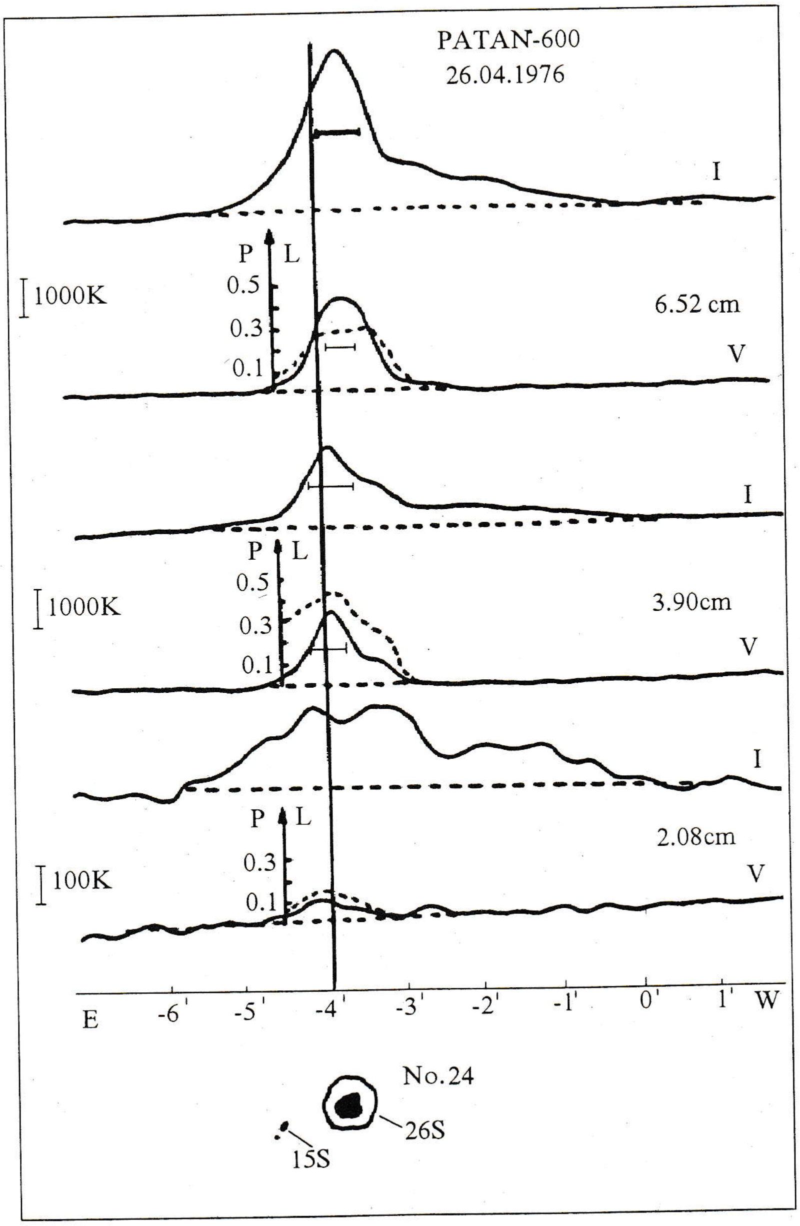

Figure 3: **(a–f)**. *Dynamics of the l.s. AR SD No. 24/1976 from the RATAN-600 observations in the range (2.08–6.52) cm. I and V are the Stokes parameters presented in antenna temperatures (the scale is given on the left). The degree of polarization P=V/I is shown by the dashed line. For some bright details of the l.s. structure the estimate for the effective size of the radiation region along the day parallel (E–W axis) is presented. At the bottom the sketches from photoheliograms are displayed.*

tal flux of l.s. at the wavelength 1.35 cm. By position and size this detail coincides with halo H2 observed at longer wavelengths.

At the wavelength 1.35 cm all three details had excess left-polarized radiation. The same was observed at 4.0 and 4.85 cm. Attention is attracted by the unusual sign of polarization in the source situated above sunspot B since the sunspot had the magnetic field of northern polarity. To explain the polarization sign inversion, one frequently uses the effect of interaction of normal waves in the region of transverse magnetic field. In the case of AR SD No. 24/1976 the influ-

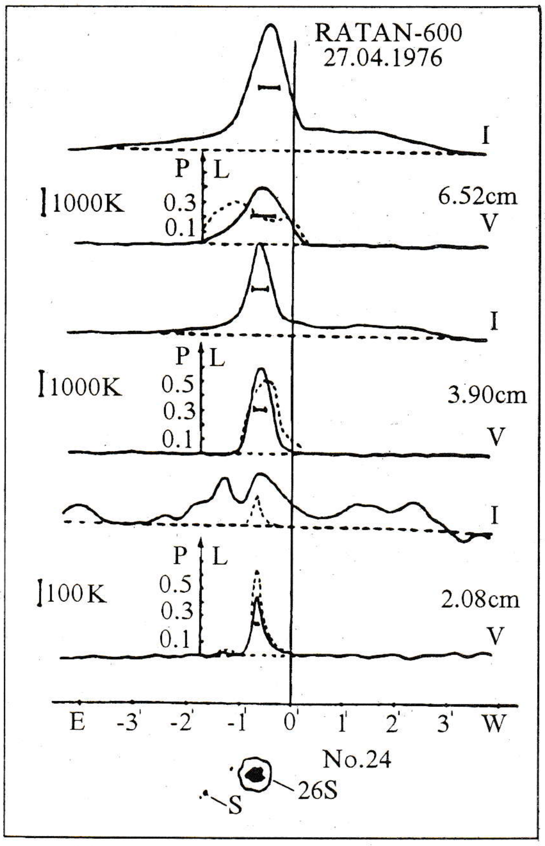

Figure 3: b

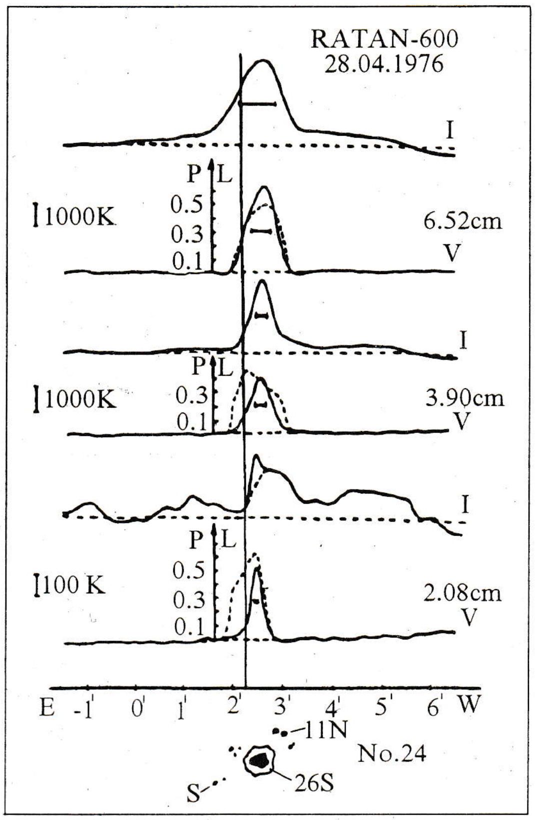

Figure 3: c.

ence of the magnetoactive plasma on the polarized radiation, propagating through it, has been examined by Ryabov (1982). A model calculation shows that a 20 % variation of the free model parameter causes essential change of magnetic field strength in the region of inversion screen. That is why in this case the inversion of polarization sign is difficult to explain by this means in a wide wavelengths range.

Weakly polarized detail F located east of the sunspot group has no apparent identification. Its radiation is likely to be short-lived, for this detail is absent on the RATAN-600 scans. A similar short-lived extended region situated aside from the sunspots and having no clear identification was detected also in the case of AR SD No. 259/1980 (Peterova et al., 1996). All this suggests that the structure of the subphotospheric magnetic field of this type ARs was much more complex than one can judge from the strong fields of the sunspots at the level of photosphere. The presence of fast-variable details also indicates that the magnetic field of these ARs, as a whole, is extremely unstable.

5. Evolution of the l.s. AR SD No. 24/1976

The development of this l.s. according to the observations with the RATAN-600 is represented in Fig. 3a–f. The structure and intensity of radiation start to change with the short wavelengths in the period between 26 and 27/IV: at 2.08 cm a strongly polarized (100 %) source of radiation of very small size (about 5 arcsec) appears above the stable old sunspot which had much larger sizes (20–25 arcsec). At longer wavelengths the variations are not as significant, however the effective size of the radiating region above this sunspot is somewhat reduced too. At the photosphere level the area of the sunspot and the magnetic field strength remain practically unchanged. The radio observations show that the atmosphere above the old sunspot as if begins to "feel" more than 48 hours in advance the subphotospheric processes, which will eventually give rise to new activity in close proximaty to it.

On the next day, 28/IV, north–west of the old sunspot pores of opposite magnetic polarity appear, while in radio radiation the intensity of the source above the main spot continues to rise, and at 2.08 cm it is already clearly noticed not only in polarization

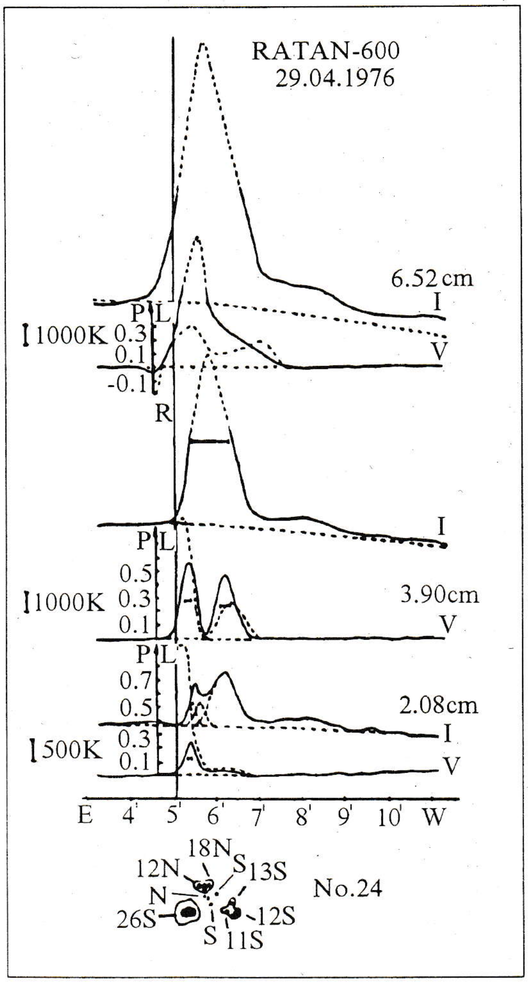

Figure 3: **d.**

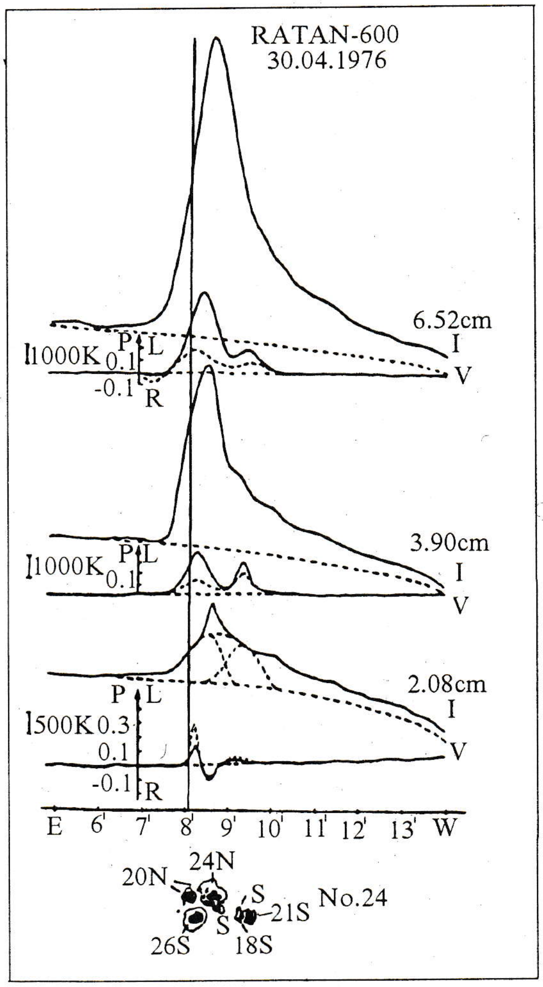

Figure 3: **e.**

but also in intensity (Fig. 3c), preserving the small size.

Sudden activization of the group of sunspots is observed during the next 24 hours. On 29/IV the emerging loop forms new sunspots of both polarities at the photosphere level, which is accompanied by a considerable (two-fold at all the wavelengths) increase of flux and complication of the l.s. structure. If previously only one bright detail above the main sunspot was observed against the background of the extended low-contrast source of about 5 arcmin, now the l.s., as indicated in the previous section, consists of five details.

The day of 30/IV was noted in the history of this AR for its powerful flare of class 1B, X2. The observations at the RATAN-600 and LPR were performed 12–13 hours before the flare. On this day the radiation flux from the AR reaches its maximum value: according to the LPR observations in the range 4.4 cm–9.0 cm (Akhmedov et al., 1991) it increases twice as compared with the day before. From the RATAN-600 observations it is seen that at the short wavelength, 2.08 cm, the atmosphere above the AR becomes turbulent: the sunspot associated sources are poorly discerned in the general structure of the l.s. In the intensity only one detail is visible, its position approximately coincides with the nucleus of a weak flare that is to occur in this AR about three hours later (Gaizauskas et al., 1977). On the other hand, however, in the polarization the sources above all the sunspots are visible well enough, the structure of the polarizational image being more "normal": above the sunspot with the magnetic field of N polarity a source of right sign is first recorded.

A similar structure of the polarization image was observed on the next day, 01/V, at a longer wavelength, 3.90 cm. From this day the l.s. begins to degrade: the total flux decreases, the source formed by the plasma of magnetic loop H2 weakens considerably. As is frequently the case, the development of active processes ends in a powerful flare after which the AR returns to its quasiquiet state.

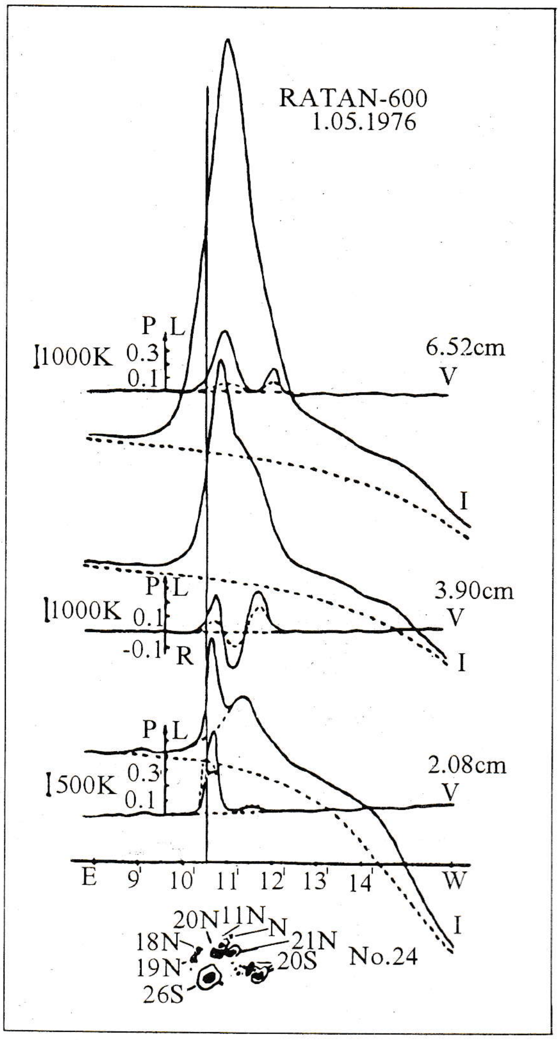

Figure 3: **f.**

6. Discussion of results

1. The spectra of radiation of the main details of the l.s. structure of AR SD No. 24/1976 from the observations on the day of the eclipse are presented in Fig. 4a–b. It must be kept in mind that the l.s. structure has been divided up into separate details under the assumption of high polarization degree of sunspot associated sources, therefore the radiation flux value at wavelengths longer than 4 cm for detail B may be underestimated, while for detail H1 it may be overestimated. However, the character of the spectrum must conserve qualitatively assuming a lower degree of polarization.

The most apparent is the nature of radiation of sources C and H2 which are genetically related to the young part of the AR (sunspot system B–C). Detail C has all the features of a typical source of cyclotron nature: the flux growing with encreasing wavelength, sizes comparable with those of sunspots, high degree of polarization. A certain excess of non–polarized radiation (detail C1) suggests that the degree of polarization was actually less than 100 %. This can be explained by the assumption that the magnetic field, necessary for generation of emission at the second harmonic of gyrofrequency, partially extends to the region of high coronal temperature values. On the other hand, detail C is most likely a superposition of radiation of smaller sources belonging to separate sunspots. Earlier it was shown by observations that in the region of aggregation of closely spaced pores or small sunspots the non–polarized radiation, often with non–thermal spectrum, is nearly always detected to increase. The radiation of detail C1 may be of the same nature, its contribution to the total flux is small — at 4 cm it amounts to 0.3 s.f.u.

The polarization sign of detail C throughout the whole wavelength range corresponded to the excess of extraordinary wave, i.e. there was no influence of the transverse field on the polarized radiation, although this phenomenon might qualitatively be expected proceeding from the geometry of the AR at the moment of observations. The corona above sunspot C sank apparently sufficiently low, however, the conditions for generation of radiation at the short wavelength, 2.08, cm were not realized (the source was extremely faint), possibly due to low strength of magnetic fields. The fields of the order of 1.7 kGs necessary for generation of radiation at this wavelength were in the region of the cold chromospheric plasma.

The radiation of halo H2 was of bremsstrahlung character — flat spectrum with minor polarization.

In contrast to the sources related to the young loop, the sources located in the system of sunspots A – B had peculiarities both in intensity and in polarization. The spectra of details A and B is given separately in Fig. 4b to emphasize their peculiarity, namely the presence of the short–wave radiation excess. From Fig. 4b it is seen that in both details the spectrum is a superposition of spectra of two types — thermal bremsstrahlung and cyclotron emission. These border at a wavelength of 2 cm: at higher frequencies bremsstrahlung predominates. For detail B the spectrum of this radiation drops abruptly with increasing wavelength, while for A it remains flat or also drops towards long waves. The degree of polarization of detail B at the shortest wavelength, 1.35 cm, is not high, P=(3-4) % (Efanov et al., 1977). At wavelengths larger than 2 cm cyclotron emission appears: the flux increases with wavelength, the degree of polarization rises.

The most remarkable feature of the polarized radiation of detail B is the predominance of the ordinary mode of radiation in a wide wavelength range (1.35 – 4.85) cm. The inversion of the temperature gradient in the source of radiation is a preferable interpretation in this case. For this a source or a mechanism of

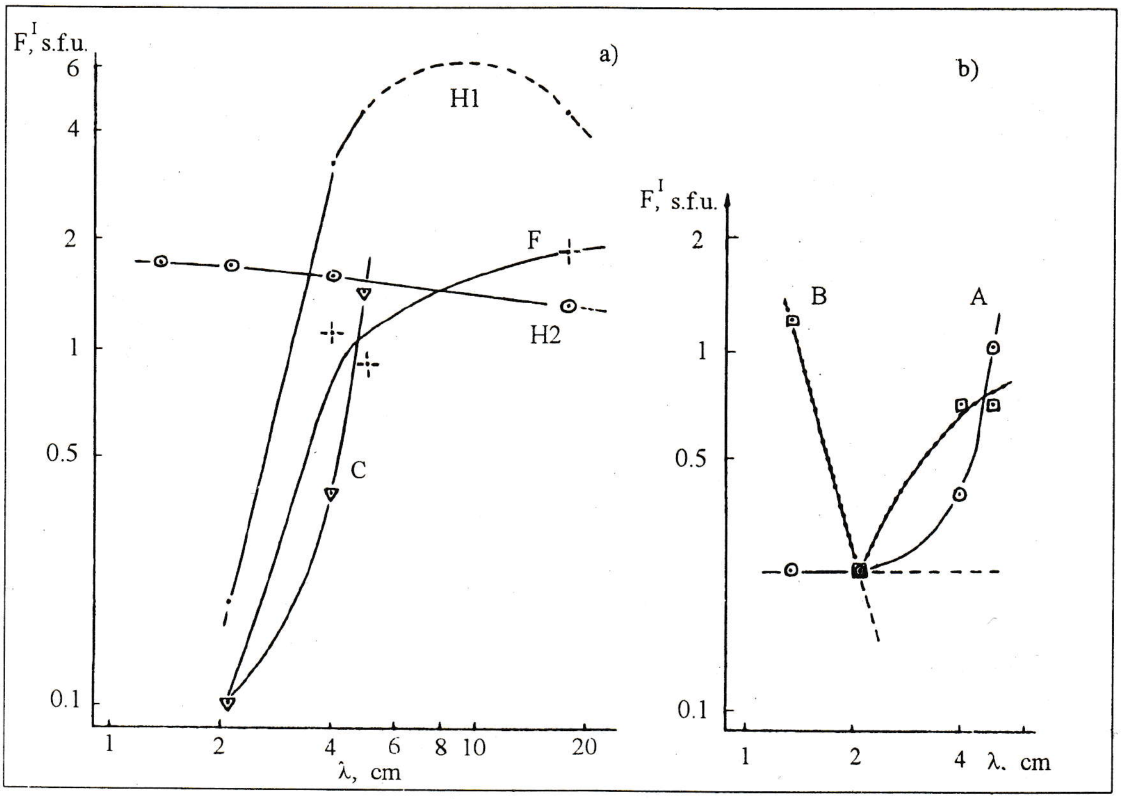

Figure 4: *The spectra of the fluxes F^I of separate details of the l.s. structure (A,B,C, H1,H2 and F) for 29/IV obtained from the RATAN-600 and eclipse observations. Detail A — circles, detail B — squares. The dashed line is extrapolation of the bremsstrahlung spectrum to the long-wave part of the spectrum.*

heat transport must exist for the additional heating of the coronal plasma in the solar atmosphere above sunspot B. The features of radio emission of detail H1 described above are believed to be related to a mechanism of anomalous release of energy.

The study of the l.s. fine structure over the last few years has shown (see e.g. Akhmedov et al., 1987; Peterova, 1994) that the sunspot associated component in a number of cases gives rather a small contribution to the total flux of ARs. The sources above the sunspots come second in brightness temperature ($T_B = 1 - 3$ MK) after the peculiar details ($T_B = 5 - 10$MK), however, in contribution to the total flux (less than 50 %) they may be at a considerable disadvantage in relation to the halo-type sources. This result is confirmed by the investigation of the AR SD No. 24/1976.

2. The three-dimensional structure of the l.s. is represented schematically in Fig. 5. All the observations have shown that most likely the l.s. of the investigated AR consisted of a system of three-loop structures (arches). The outermost arch H is based on a floccule whose magnetic field was bipolar. This arch held the plasma whose radiation on the RATAN-600 scans manifests itself as a low-contrast extended (4-6 arcmin) source especially visible at short waves during the first period of evolution of the AR (till 27/IV). In all probability the radiation of this plasma was of bremsstrahlung character because in the observations of the eclipse at 18 cm source H was not recorded (Gosachinsky et al., 1977).

The foundations of the arch H2, located below, were fixed in the sunspots of opposite polarity of the young part of the AR. Most likely the plasma circulating in the loop was in equilibrium state: its radiation (source H2) was of thermal bremsstrahlung nature, above sunspot C a typical source of cyclotron radiation was situated.

All distinguishing features of the AR are related to loop H1. The loop is supposed to have originated as a result of interaction between the old and new magnetic fluxes and reconnection of part of magnetic force-lines. The interaction began two days before the apparent activization of the AR at the photosphere level and is considerably intensified at the moment the strong magnetic fields extended into the corona and new sunspots were formed (29/IV). Concerning phenomenology, arch H1 closely resem-

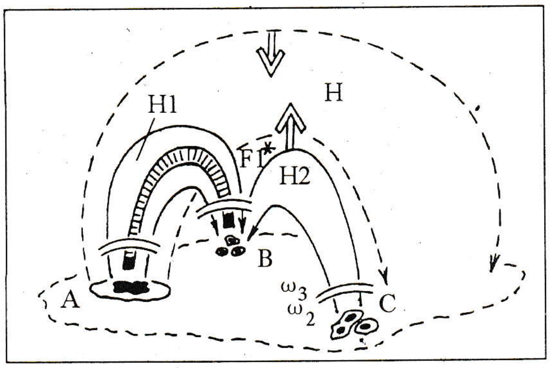

Figure 5: *The scheme of the three-dimensional structure of the radiation region above the sunspot group SD No. 24/1976. The brighter regions of arch H1 are cross-hatched. The footpoints of this loop, which were observed as sources of higher brightness in the short-wave part of the spectrum. are shown black.*

bles a flare loop: at its foundations (legs) are observed low-positioned bright footpoints that manifested themselves as compact bremsstrahlung sources. The brightness of their radiation at the short wave, 1.35 cm, is more than an order of magnitude higher than that of a quiet atmosphere of the Sun. The footpoint above the young sunspot is three times hotter than the footpoint above the old sunspot (300 kK and 100 kK, respectively). The above-situated plasma was also heated as a result of which the cyclotron sources became brighter (in Fig. 5 they are shown as two gyrolevels). It may be assumed that the heating above the footpoint B was so great that inversion of the temperature gradient in the region of generation of cyclotron emission took place, which explains the reversal of the polarization sign. The reduction of the effective sizes of the cyclotron source A in the course of evolution (the period after 26/IV) may be regarded as formation of a thin hot tube, "cord", along the centre line of the loop (in Fig. 5 it is hatched). At the top of loop H1 hot plasma was held, whose weakly-polarized radiation was non-thermal (see the spectrum of detail H1 in Fig. 4a).

Though arch H1 resembles in morphology a flare loop the region of radiation of H_α flares, however, does not coincide in this case with arch H1. According to Gaizauskas et al. (1977) the nucleus of the subflare of 30/IV was observed north-west of the sunspot B, the flare itself was preceded by emergence of a small filament related to the other loop, arch H2. A possible position of the filament in the three-dimensional AR structure is indicated by the mark Fl in Fig. 5.

We can judge of location of the 30/IV powerful flare in this AR on the basis of indirect evidence only. When observing its associated outburst (Akhmedov et al., 1991) with a low resolution, the polarization of its radiation in the range (3–5) cm was found to be right-signed. Nefed'ev et al. (1969) have observed that the outburst polarization sign is determined in some cases by polarity of the nearby sunspot. If this is the case, the flare must then be luminous near sunspot B, that is the coordinates of the powerful flare were coincident with those of the subflare whose position we know exactly from the observations in H_α.

From the comparison of the results of l.s. AR SD No. 259/1980 and of l.s. AR SD No.24/1976 observations it follows that in the region of H_α flares emission the long-lived detail of considerable intensity was absent in the structure of the latter as it was the case for the former. This may qualitatively be related to the difference in conditions for the emerging loop in the system of AR large-scale magnetic fields. In the case of AR SD No 259/1980, interaction between the arch that existed earlier and the young loop emerging near it took place, both had normal polarity alternation. The interaction occurred on the demarcation line between these magnetic islands and showed itself as a strong halo-type source. In the same region chromospheric flares were registered, a very powerful one occurred too. The indicated region coincided in position with neither of the loops that assumingly composed the three-dimensional structure of the l.s. AR SD 259/1980.

In the AR SD No 24/1976 the young loop emerges inside the old, both having anomalous order of polarity alternation. In this case the region of H_α radiation of the flares lies outside the arches that constitute the l.s. structure and outside the most active flare-like arch too. However, the conditions here are, probably, such that the flare process has no long-duration (several days) quasistationary phase with formation of a long-lived source of enhanced radio emission. The results obtained here suggest that actually not one but several mechanisms of flare formation may exist and the experimentator must be concerned with ascertaining the conditions under which a particular mechanism is operative rather than with choosing between them.

As a model source of high temperature plasma in the corona, one normally consideres the coronal heating due to rapid dissipation of magnetic fields in the process of reconnection. This mechanism finds confirmation in various observations (see, for instance, the survey by Somov, 1988). The results of the structure investigation of the l.s. AR SD No. 24/1976 presented here are not at variance with those concepts. However, some phenomenological peculiarities of this case as well the necessity to explain the most interesting facts of the investigation — the structure of radio emission of arch H1 and the polarization inversion of the source B — allow one to apply one more way of modeling flare processes – the Joule heating of plasma in the flare loop.

3. On the Joule heating of plasma. The phenomenology of the loop H1 suggests that at a certain stage of its development electric current heating the plasma in the loop could arise and exist quasistationarily for a certain time. For the first time a model of the energy release (for the flare) caused by Joule losses of electric current in the circuit "coronal arch–photosphere" has been proposed by Alfwen and Karlqvist (1967). One of the difficulties of this model for interpreting the flare heating is the long current build-up time. In the case of S-component of solar radioemission, requirements to certain parameters of this model may turn out to be less stringent.

To interprete the observations of loop H1, we have made use of one of the further developments of the above mentioned model — the work of Zaitsev and Stepanov (1991). In this work the magnetic loop with current is represented as an electric circuit consisting of the coronal and photospheric parts. The electromotive force in this circuit is induced by the motion of photospheric matter. The parameters of this model, both geometrical and physical, appear to be nearly coincident with those of loop H1, which we have measured from observations (the photospheric material motion velocity has been estimated in accordance with the papers by Rodrigues et al. (1996); Matveev and Yurovsky (1977). All the parameters differ not more than (1.5–2) times. This allows the estimates made by Zaitsev and Stepanov (1991) to be used directly. The calculations show that energy stored up in such a circuit is sufficient even for powerfull flares, $W = 10^{29} - 10^{31}$ erg, including the proton flare of 30/IV in the AR under investigation. However, the Joule heat turns out to be many orders lower because of the low resistance the circuit offers. The flare can occur if the resistance, for some reasons, rises by 8–10 orders of magnitude. Zaitsev and Stepanov have shown that such an increase in resistance occurs with penetration of neutral atoms into hot plasma, for instance, with interaction between the flare loop and the cool filament. The decisive part in energy release in this case is played by collisions of ions with neutrals. There are two regions of energy release: at the top of the loop where it comes in contact with the prominence, and at its legs, where the neutral component may be of chromospheric origin. The long-duration luminosity of loop H1 of higher brightness allows one to suppose the same mechanism of heating (Joule dissipation of electric current), but of lower power, to be effective at the out-of-flare phase of its existence too. The neutral component is likely to have penetrated into the loop from the chromosphere.

The observational fact that the heating of loop H1 begins first of all at the short wavelengths and shows itself much more effective in this range than at the longer wavelengths, or, in other words, in the higher solar atmospheric layers above the AR points out that the plasma of the loop is heated by Joule dissipation. The case is, that according to the estimate of Zaitsev and Stepanov (1991) the energy release at the chromosphere level must be much more powerful than in the corona.

The structure of AR SD No. 24/1976 and SD No. 259/1980 type is not unique. The significance of examining these cases consists only in that the phenomena observed in them were of large scale, and therefore, can be studied with a resolution of 10–30 arcsec. This kind of processes, but in smaller arches, are typical of most ARs, that is why the results of our research may be of more general importance for the solution of the problems concerned with the heating of plasma above ARs.

7. Principal conclusions

When studying two sunspot groups of the same type, SD No. 24/1976 and SD No. 259/1990, which were at the stage of violent activization and gave rise to powerful flares of class (1–2)B, the following results have been obtained.

1. It has been confirmed by radio observations that with the swimming up of a new magnetic flux tube near the old sunspot of opposite magnetic polarity a loop arises which connects the regions of the old and new field. In one of the cases the effects of reconnection are observed two days before the appearance of young sunspots at the photosphere level, which is indicative of the existence of subphotospheric interaction of magnetic fields. The interaction is accompanied by a considerable heating of coronal plasma held by this arch, which shows itself in a several-fold increase of radio emission brightness above the old spot and in formation of a halo-type radiation source with a non-thermal spectrum at the top of the arch. The process lasts 3–4 days.

2. In both cases a sunspot associated source of inverse polarization sign has been recorded above the young sunspot lying at one of the foundations of the newly formed active loop. The spectrum character of the polarized emission and its independence on the geometry of location of this detail in the structure of the AR allows us to suppose that in the given case the ordinary radiation mode excess is due to the peculiarities of the conditions under which this radiation is generated — the temperature gradient inversion — but not the effect of propagation conditions which are usually involved for interpreting such observational results. At least in one case this assumption is confirmed by the revelation above this sunspot of a low-situated bright compact source of radiation having a spectrum of bremsstrahlung character, which suggests the existence of elevated heating of the solar

plasma in the active loop, especially at its foundations.

It should be noted that similar sources with the excess of ordinary-mode radiation in a wide wavelength range have been observed as part of other active regions of complex structure too. These are, for instance, the AR SD No. 329+332/1981 (see Fig. 6 in the paper by Akhmedov et al., 1982) and the AR SD No. 228+229/1982 (Figs. 4 and 5, Akhmedov et al., 1987). All these facts permit a new subclass of sunspot associated details of the structure of local sources with anomalous characteristics — predomination of the ordinary mode of radiation, which is difficult to explain, the excess of short-wave radiation — to be introduced.

3. An essential difference has been found in the structure of the radio emission region in these two cases with respect to the region of radiation of powerful H_α flares. In one case it was associated with a long-lived (several days) intensive source of weakly polarized radiation in a wide wavelength range, in the other case with a hardly visible detail at the short waves (2 cm) only, which was observed for a short time just a few hours prior to the flare. The mutual orientation of the interacting arches was also noted to be different: in the first case the new arch emerged beside the old, in the second inside it.

4. Comparison of radio emission characteristics of the investigated AR in the quasiquiet state and during the flares shows that the heating of the atmosphere above the AR may be due to one and the same physical process for these two phases that are different only in the energy and time scale. It is pointed out that the phenomenology of out-of-flare events provides grounds to consider Joule dissipation of electric current as such a mechanism.

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