A STUDY OF "THERMAL" AND "NONTHERMAL" S-COMPONENT EMISSIONS GENERATED OUTSIDE SUNSPOTS

Sh.B. Akhmedov[1], V.M. Bogod[2], G.B. Gelfreikh[1],
J. Hildebrandt[3], A. Krüger[3]

[1]Acad. Sci. USSR, Main (Pulkovo) Observatory,
SU-196140 Leningrad, USSR

[2]Acad. Sci. USSR, Special Astronomical Observatory,
SU-196140 Leningrad, USSR

[3]AdW der DDR, Zentralinstitut für Astrophysic,
DDR-1500 Potsdam, Telegrafenberg, GDR

ABSTRACT. Starting with a classification of different types of the sources of the slowly varying (S-) component of solar radio emission, the radiation from regions outside sunspots has been considered by means of RATAN-600 observations. Firstly, three examples of microwave sources above plage regions were analysed. Spectra of flux density and polarization characteristics were discussed in comparison with model computations. Secondly, the radiation from the space between bipolar sunspots was investigated on the base of further RATAN observations. Special attention was paid to the phenomenon of high emission peaks which cannot be explained in the frame of traditional models of thermal emission. Three kinds of outstanding source characteristics have been specified which require a quantitative analysis by future loop models.

ИССЛЕДОВАНИЕ "ТЕПЛОВОГО" И "НЕТЕПЛОВОГО" ИЗЛУЧЕНИЯ S-КОМПОНЕНТЫ ВНЕ СОЛНЕЧНЫХ ПЯТЕН: Исходя из классификации различных типов источников медленно изменяющейся (S)-компоненты солнечного радиоизлучения, излучение от областей вне солнечных пятен было рассмотрено, на основе наблюдений на РАТАН-600. Во первых были проанализованы три примера микроволновых источников над флоккулными областями. Спектры потока и поляризационнх характеристик были изучены в сравнении с модельными расчетами. Во вторых, излучение из пространства между биполярными структурами пятен были изучены на основе дальнейших наблюдений на РАТАН-е. Следует обратить особое внимание наявление пиков с высокой эмисией, которые нельзя объяснить в рамках традиционных моделей теплового излучения. Три вида необыкновенных характеристик источников вне пятен были специфицированы и они требуют количественное описание с помощю арковых моделей.

VÝSKUM "TEPELNÉHO" A NETEPELNÉHO" RÁDIOVÉHO ŽIARENIA S-ZLOŽKY, KTORÉ VZNIKÁ V OBLASTIACH MIMO SLNEČNÝCH ŠKVŔN: V práci sú klasifikované rôzne typy zdrojov pomaly sa meniacej (S)-zložky slnečného rádiového žiarenia. Na základe pozorovaní, uskutočnených na RATAN-e, bola skúmaná S-zložka vznikajúca v oblastiach mimo slnečných škvŕn. 1/ Boli analyzované tri prípady mikrovlnných zdrojov nad flokulovými poľami. Spektrum rádiového toku a polarizačné charakteristiky boli porovnané s modelovými výpočtami. 2/ Žiarenie z priestoru medzi bipolárnymi štruktúrami škvŕn bolo skúmané na základe ďalších pozorovaní na RATAN-e. Obzvlášť treba upozorniť na výskyt maxím, vyznačujúcich sa vysokou hodnotou emisie, takže sa vymykajú z rozsahu tradičných modelov tepelného žiarenia. Boli špecifikované tri druhy zvláštnych charakteristík zdrojov, ktoré sa nachádzajú mimo oblasť slnečných škvŕn a kvantitatívne si vyžadujú riešenie pomocou slnečných modelov.

1. INTRODUCTION

During the last decade high-resolution microwave observations made significant contributions to the knowledge of the structure of solar active regions. Different sub-component of the S-component could be distinguished which are related to different parts of the active regions. These concern

(i) radiation from source regions above the core of sunspots at high magnetic fields,

(ii) radiation from sources related to plage regions, and

(iii) radiation from magnrtic loops and/or filaments between sunspots.

Presently best understood is the emission from the sources above sunspots. Here the magnetic field is believed to be rather regular and model calculations of gyromagnetic (g-r) radiation from deep coronal levels are in accordance with the observations (Gelfreikh and Lubyshev, 1979; Alissandrakis et al., 1980; Akhmedov et al., 1983; Krüger et al., 1985). The present communication therefore draws the attention on the other sub-components (ii) and (iii) on the basis of selected RATAN-observations.

The emission from plage regions (so far not superimposed by the loop component) exhibits a more or less flat intensity spectrum which can be generally ascribed to Coulomb bremsstrahlung from the chromosphere-corona transition region (CCTR). Although not resolved by present-time observations, an additional contribution of (g-r) radiation from small bright plage elements seems likely.

The S-component emission from the loop component between sunspots (and covering also filaments) is associated by soft X-rays. Owing to our still inadequate knowledge of magnetic fields and energy release processes in the corona, this sub-component is worse understood. The radio loop emission appears to be complex in nature and also its terminology is not unified (there are, e.g., the labels interspot and halo emission in different use by different authors). Nevertheless, a point of principal interest is the occasional occurrence of an excessive radiation at high temperatures (T 5 10^6 ^oK) in apparent absence of burst events (Akhmedov and Gelfreikh, 1981; Webb et al., 1983; Kaverin et al., 1983).

2. PLAGE REGIONS

Three cases of S-component sources related to plage regions have been selected being located not very far from the central meridian of the Sun on March 3, 1977, July 15, 1982, and July 28, 1984. These examples demonstrate a great range of possible variations: The source sizes vary between about 4 and 10 arc min, and corresponding fluxes between 1 and about 15 sfu at 15 GHz for the present sample.

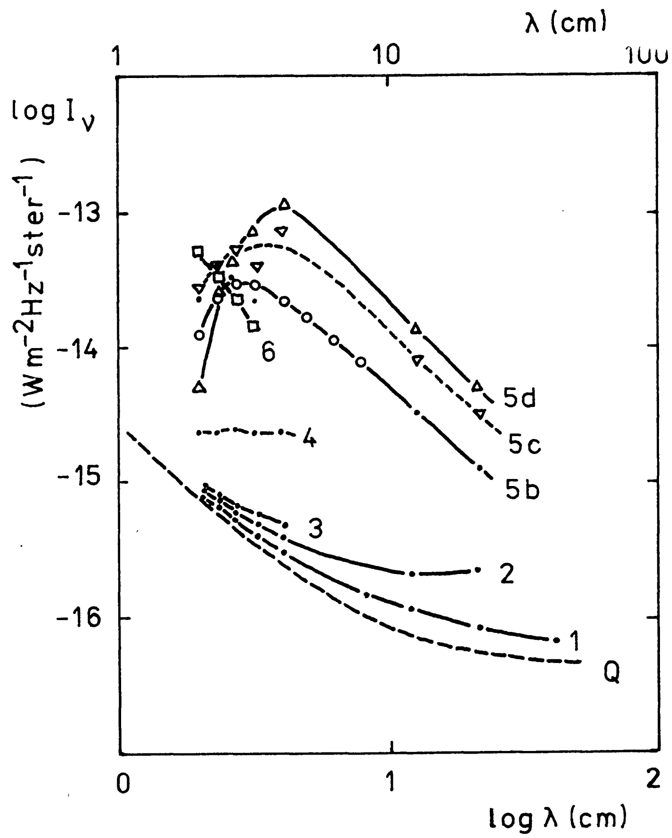

Fig. 1: RATAN-observations of I -spectra. Q - quiest Sun, plage regions: 1 - 28.07.1984; 2 - 15.07.1982; 3 - 02.03.1977, interspot regions: 4 - 01.05.1979; 5 - 15.07.1982 (sources "b", "c", and "d"); 6 - 27.05.1980, o - o : model calculations of a strong sunspot component.

The observed spectra of the intensity I are shown in Figure 1. The corresponding brightness temperatures T_b for the above three cases are 14.5×10^3, 12.4×10^3, and 11.3×10^3 K at 15 GHz and 27.6×10^3, 23.3×10^3, and 16.8×10^3 K at 7.5 GHz, respectively. Towards lower frequencies (= dm-wavelenghts) the brightness temperatures continue to increase, and also the differences between individual plage regions become greater. At 1.4 GHz, e.g., the values of T_b reach 13.9×10^4 and 37.8×10^4 K on July 28, 1984 and July 15, 1982, respectively.

The difference in brightness can be principally explained by the assumption of a different (number) density of bright plage elements embedded in the quasi-quiet background and/or by variations of the electron density/temperature profiles in the CCTR. The bright plage elemnets are a characteristical feature in optical observations, but their sizes (≤ 1 arc sec) are yet below the resolution of the radio observations.

As a further characteristical feature, medium-size inhomogeneities of dimensions of about 20 arc sec are displayed by the RATAN observations. The flux pattern and, even better, the polarization pattern exhibit a wealth of fine structures of different scales. This feature heavily empedes the application of simple models (cf. Kruger and Hildebrandt, 1985). Nevertheless, a superposition of g-r emission (at B_{max} = 0.1 ... 0.2 T with different scale heights and a not too steep CCTR) with filling factors of, roughly saying, less than 20 per cent is expected to be consistent with the RATAN observations.

Consistent with the above picture, the average degrees of polarization p are rather low ($p \lesssim 0.04$), although the existence of not resolved fine structures of p at much higher values can be assumed.

3. RADIATION FROM THE INTERSPOT REGIONS

Aside plages, the S-component radiation from the space between opposite sunspots appears to be complex in nature. The source regions contain loops, filaments, and unspecified areas. Three examples of RATAN observations on May 1, 1979, May 27, 1980, and July 15, 1982 may be used to demonstrate these features.

The intensity spectrum of the interspot radiation on May 1, 1979 (Mac Math No. 15974) can be interpreted as an overlapping of plage associated radiation and loop radiation at moderate magnetic fields. This example shows, how the interspot radiation can result in comparatively large fluxes amounting more than the 18-fold of the flux of one large sunspot at 15 GHz! (cf. also below). However, due to the large area covered by the interspot emission, high flux density must not necessarily lead to very large brightness temperatures: T_b ranges from $33\cdot10^3$ to $137.3\cdot10^3$ K between 15 and 7.5 GHz, respectively. (For I_ν cf. Figure 1). The degree of plarization was rather low in the present case, the highest value (p = 0.05) occurred at 7.5 GHz.

Considering the very complex active region AR 3804 on July 15, 1982 (cf. Akhmedov et al., 1985), it can be concluded that the highest brightness temperatures and most anomalus spectral characteristics are just related to source regions between large sunspots. In this connection the sources labeled "b", "c", and "d" by Akhmedov et al. (1985) are of highest interest: Source "b" is bridging a filament in a phase of splitting up into two different brances (Bachmann, 1986). The radio flux spectrum shows a maximum at the shortest wavelength (2.3 cm). Such a spectrum is incompatible with usual model calculations of thermal g-r emission (cf. Krüger et al., 1985). On the other hand, due to the source size, T_b is not extreemely high (reaching 10^6 K at 7.5 GHz). Below 13 GHz the intensity does not exceed the theoretical flux spectrum of a strong spot-related S-component source (curve 0 in Figure 1).

Extreemely high temperatures (possibly up to about 8 10^6 K!) and intensities (cf. Figure 1) are indicated by the RATAN observations of the sources "c" and "d" by Akhmedov et al. 1 (1985). These sources cover the umbra of a large sunspot plus interspot region ("c") and the umbrae of two further spots (one of them belonging to a δ-configuration) together with a filament which devides both spots which have the same (!) S-polarity ("d"). The spectra of I_ν of both sources clearly exceed the emission of normal spot-related S-component models and require a description by loop models.

A further example of a very complicated source of S-component radiation concerns the observation of the active region 16863 on May 27, 1980. For this source already Webb et al. (1983) detected the presence of hot kernels which stimulated the assumption of a contribution of nonthermal radiation. The RATAN brightness spectrum (even without resolution of single hot kernels) is extreemely "hard" and likewise cannot be explained by thermal g-r emission at reasonable magnetic fields.

4. DISCUSSION

Two sub-components of S-component radiation from sources essentially outside the core region of sunspots have been considered here. In the first case, the radiation from plage regions corresponds to relatively low brightness temperatures signifying an origin at comparatively deep levels (CCTR). The observations are not incompatible with the assumption of an inhomogeneous source structure composed of bright (subtelescopic) plage elements and a quasi-quiet background. The observed range of individual spectral characteristics can be principally explained by local variation of population density of the plage elements as well as by variations of the distribution of thermodynamical parameters in the background medium.

The radiation from the regions between sunspots exhibits three outstanding features realised in different active regions:

a/ Excess of flux density at high frequencies (which must not necessarily result in high brightness),

b/ Excess of brightness over a broad spectral range especially at dm-waves,

c/ Excess of brightness at short cm-wavelengths.

Items b/ and c/ were already discussed in the literature either favouring (Gelfreikh et al., 1970; Akhmnedov and Gelfreikh, 1981; Webb et al., 1983;

Chiuderi Drago and Melozzi, 1984; Shibasaki et al., 1983) or denying (Zlotnik, 1983) a contribution of radiation from a nonthermal electron population. Our findings reveal the existence of a variety of "super" thermal S-component spectra. But it is argued that a final decision about their true nature must be postponed after the development of realistic loop models and chacking by two-dimensional high-resolution observations.

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