The long-term oscillations in sunspots and related inter-sunspot sources in microwave emission

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Abstract. This work presents the microwave long-term oscillations with periods of a few tens of minutes obtained from Nobeyama radioheliograph (NoRH) at frequency 17 GHz. In two active regions the fluctuations of radio emission of different types of intersunspot sources (ISS) (compact and extended) were compared with the fluctuations in magnetic fields of sunspots. Common periods in variations of microwave emission of different type of sources and magnetic field of sunspots were discovered. The delay of 17 minutes was revealed for oscillations of the extended ISS with respect to variations of magnetic field of its tail sunspot. The model of the sunspot magnetic structure based on the concept of three magnetic fluxes for explanation of this fact is discussed.

1. Introduction

An analysis of long quasi-periodic oscillations (LQPO) in the microwave emission generated at different sunspots, detected by different techniques with the use of different, spatially separated instruments, Siberian Solar Radio Telescope (SSRT) and Nobeyama Radioheliograph (NoRH) performed in [1] revealed significant LQPO with periods 30–170 min in both SSRT (5.7 GHz) and NoRH (17 GHz) data for several sunspots during different days of observations with non stable periods at both frequencies. The detection of the same or similar periods in the time series of different radio-parameters (intensity, polarization and degree of circular polarization) recorded at different frequencies and so at different heights in the sunspot’s magnetosphere, suggest a global nature of long-term oscillations. In particular, the oscillations may be present in variations of sunspot’s magnetic field. In this case the slow variations of the magnetic field can be explained by global eigen oscillations of sunspots [2].

In [3] a significant correlation between fluctuations in radio sources above sunspots and variations of strengths of their magnetic fields according NoRH and SDO/HMI are shown and common periods were discovered as: 30–40 min, 60–70 min, 100–110 min and 150–200 min. The typical shifts between the time series of the maximum magnetic field strength in spots and the overlying radio source, were found of about 50 min [4].

The attempt to study surroundings of spots on the subject of LQPO was made in [5, 6] where data on the variations of millimeter (37 GHz) radio emission of solar active regions were analyzed in comparison with data on the variations of the magnetic field strength of sunspots and there was shown the presence of a slow quasi-periodic oscillations of flux density radio emission.
of near-sunspot and intersunspot radio sources and oscillations of the magnetic field strength of photospheric sunspots with equal periods 200–400 min. It was also noted that temporal variations in the series of radio emission fluxes are with respect to the corresponding variations of the magnetic field strength of the closest spot, and the delay time consists 15–35 min. The observed delay times in this paper are not associated with the times of Alfvén wave propagation or fast magnetoacoustic wave propagation from the photosphere to the radio source (if they were related, the delay times would be no larger than 1–2 min), but variations of the millimeter radiation source with respect to variations of the magnetic field and time delay between them are associated with the eigen oscillations of the lower-lying sunspot and their physical interpretation based on a novel concept of the magnetic structure of sunspots (the model of three magnetic fluxes) which explains the formation of intersunspots sources [7].

In [7] ISS were divided into two groups: radio sources that can exist during one day or even more over the neutral line of the photospheric magnetic field in the intersunspot area (extended ISS) and ISS above the neutral line which passes through the umbra of a complex sunspot (compact ISS). Although the latter sources are in fact above-sunspots sources, it was used a single name for all sources above the neutral line, namely intersunspot (microwave) sources, or ISS [7].

In the present study data on the fluctuations of centimeter (17 GHz) radio emission of solar active regions are analyzed in comparison with data on the variations of the magnetic field strength of photospheric sunspots. The radio observations were carried out with the Nobeyama Radioheliograph (NoRH, Japan) [8]. Data on the sunspot magnetic fields were provided with the Michelson Doppler Imager (MDI) [9] instrument onboard the Solar and Heliospheric Observatory (SOHO) [10]. We focus on comparison the fluctuations of radio emission of different types of sources: compact and extended intersunspot sources (ISS) with respect to the sunspot’s magnetic field oscillations.

2. Data analysis and results
2.1. Oscillations in the compact ISS
Consider the compact ISS above complex sunspot. As a rule, the emergence of such ISS is accompanied by a series of powerful flares. Investigating the fluctuations in such ISS is extremely difficult because of the ambiguous interpretation - there is a lot of radio bursts in ISS of such type, it often ”noises” before a powerful flare, it is difficult to distinguish the quiet period of its existence.

Compact ISS in AR 09415 10.04.2015 was observed at frequency 17 GHz in the head part of the active region above the leading sunspot of dual magnetic polarity (see figure 1, left panel). Figure 2 (right panel) demonstrates significant magnetic field oscillations with periods of 15 and 128–200 minutes.

Figure 2 for the right part of the north polarity of the complex sunspot doesn’t show significant common periods for the variations of ISS’s radio emission and magnetic field, but figure 3 shows the behavior of the magnetic peak strength of the south polarity with a period of about 3 hours and a similar oscillations of the degree of circular polarization of radio emission for the part of ISS which is located above the magnetic field of south polarity of the head sunspot. The delay about 60 min is observed for the radio-emission with respect to oscillations of magnetic field.

2.2. Oscillations in the extended ISS
Consider the example of an extended ISS in AR 09455, 12.05.2001 (Figure 1, right panel).

Figure 4 demonstrates significant fluctuations of magnetic field with periods of 16, 64 and ~200 min.

Figure 5 shows time profiles both the maximum of intensity of magnetic field and maximum of intensity of ISS and cross-correlation function for them. One can see good cross-correlation
Figure 1. Left: NoRH,17 GHz, partial image, AR 09415 10.04.2001. Right: Extended ISS in AR 09455 12.05.2001. ISS observed at frequency 17 GHz above neutral line of magnetic field of the whole AR. NoRH,17 GHz, partial image. Grey map (background) shows SOHO/MDI magnetograms (black - S-, white - N-polarity of the magnetic field). Contours of red color - negative circular polarization, blue - positive (TV, brightness temperature in a circular polarization); green contours - TI (brightness temperature in intensity).

Figure 2. Left: Time profile a) of the intensity flux FI of radio emission, b) of the circular polarization flux FV, c) the degree of circular polarization FV/FI above the head of AR 09415 (the right part of the head spot), April 10, 2001, with 10 minute cadence. Start time is 00:00:03 UT, End time is 06:20:03 UT. Right: Time profile and wavelet spectrum of the peak strength of the magnetic field of north polarity (in Gs) at the head of AR 09415 (the right part of the head spot), April 10, 2001, according to the data of SOI MDI/SOHO with 1 minute cadence. Start time is 22:00:30 UT, end time is 07:42:30 UT.

with coefficient ~0.6 with the time-delay of 17 min. It is in a good accordance with the results described in [5, 6].
3. Discussion and conclusions

The model of ISS suggested in [11] and based on the model of the shallow spot [2] suggests that the nearspot and interspot radio sources are originally connected to a spot by the magnetic field...
Figure 5. Left: cross-correlation function for the maximum of intensity of magnetic field of positive polarity of the following sunspot and maximum of intensity of ISS 12.05.2001. Right: Time profiles both the maximum of intensity of magnetic field of positive polarity of the following sunspot and maximum of intensity of ISS 12.05.2001.

Figure 6. Magnetic structure of sunspot and formation of intersunspot microwave radiosources [11].

lines coming from the spot umbra and are formed due to thermalization of accelerated particles produced in small scale current layers at the periphery of the spot. Quasiperiodic variations of the magnetic field of the spot as a slowly oscillating massive coherent object [2] are transferred from the spot to the radio source along the magnetic field lines with the speed of sound and modulate the radiation of the source.

As can be seen from the figure 6, the magnetic pipe-loop in the top of which ISS is situated, formed from about half of the lines of force of the flux F1, originating in the sunspot’s umbra and lines of force of the flux F2, reconnected with the flux F3. Thus, ISS initially closely linked to the spot, and quasi-periodic variations in the magnetic field of the spot, as an integral object, appear as quasi-periodic boundary conditions changings in the basis of the magnetic loop of ISS.

These changes are transmitted along the magnetic field lines in two ways: by means of fast magnetoacoustic waves with a speed that in the chromosphere is very high, about $1 \text{ Mm/second}$, and slow magnetoacoustic waves traveling along the magnetic field with the speed of sound which is about $10 \text{ km/s}$, i.e. 100 times less than the velocity of Fast Magnetic Sound Waves (FMSW). When there is the gyro-cyclotron or gyrosynchrotron emission of radio waves, which depends on the magnetic field, the source will feel changings of the magnetic field in the spot very quickly, in a time of the order

$$L \over V(FMSW) = \frac{2 \times 10^9}{2 \times 10^8} = 10\text{s}$$

For changes of thermal radio emission of an extended ISS the temperature, density
characteristics of ISS have to be changed. And this is possible only when the Slow Magnetic Sound Waves comes up from the outer boundary of the spot, and along the magnetic loop a new hydrostatic distribution will be installed. This time is 100 times longer, i.e. 15–17 minutes.

These delays are found in millimeter radio emission for ISS in [5, 6].

We considered microwave radiation at a frequency of 17 GHz for two active regions of 23 cycle of solar activity (compact (AR 09415) and extended (AR 09455) ISS) and the magnetic field of related sunspots on the magnetograms SOHO/MDI. ISS at 17 GHz considered in the current study demonstrate commonly identified periods with the magnetic field in 16, 64 and 200 minutes. This is in agreement with the works [6] and [3]. We found the time delays for compact ISS for radio emission with respect to magnetic field of about 60 min and it is approximately the same as for sunspot’s microwave sources [4]. We found that the time delay for extended ISS is 17 min and it is agreed with time delays found in [5, 6] for millimeter ISS (18–35 min).

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References

[1] Bakunina I A et al. 2013 Publ. Astron. Soc. Japan 65 S13
[2] Solov’ev A A and Kirichek E A 2014 Astrophys. Space Sci. 352 23
[3] Abramov-Maximov V E et al. 2013 Publ. Astron. Soc. Japan 65 S12
[4] Nagovitsyn Yu A, Nagovitsyna E Yu and Abramov-Maximov V E 2013 Astronomy Reports 57(8) 636 (original Russian text: Astronomicheskii Zhurnal 2013 90(8) 692)
[5] Smirnova V V et al. 2013 Astron. Astrophys. 552 23
[6] Smirnova V V et al. 2015 Geomagnetism and Aeronomy 55(7), in press
[7] Bakunina I A et al. 2015 Sol. Phys. 290 37
[8] Nakajima H et al. 1994 Proc.IEEE 82 705
[9] Scherrer P H et al. 1995 Solar Phys. 162 129
[10] Domingo V, Fleck B and Poland A I 1995 Solar Phys. 162 1
[11] Solov’ev A A 2015 Geomagnetism and Aeronomy 55(7), in press