Abstracts for Tuesday 27th May

Mechanisms of coherent radio emission in the MHz range

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Bursty solar radio emission was detected decades ago and often has high brightness temperature, greatly exceeding the source's plasma temperature and indicating coherent emission mechanisms. The exciter is non-thermal electrons, and emission results either directly, or via some other wave mode with subsequent conversion into escaping radio waves. Electron-cyclotron maser emission (ECME) is the first type and was proposed as the origin of type I emission, but as it occurs at the electron cyclotron frequency, MHz emission requires a very strong magnetic field and it is of more interest in kHz ranges. Plasma emission is a common example of the second type, involving Langmuir waves produced by beam-type or loss-cone distributions of fast electrons. The former may explain fast drifting type II and III bursts, due to acceleration in propagating shocks and in flares themselves respectively. The latter may explain type I emission. Moreover in moderate magnetic fields, the double-plasma-resonance effect where upper-hybrid waves are produced in layers where the plasma frequency is an integer multiple of the cyclotron frequency, is key for type IV bursts and the associated zebra patterns. We will begin with a brief overview of history and type classifications, then discuss each mechanism, and also some lesser explored possibilities.

Resonance broadening due to particle scattering and mode-coupling in the quasi-linear relaxation of electron beams

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Of particular interest for radio diagnostics of accelerated electrons during solar flares is the understanding of the basic non-linear mechanisms regulating the relaxation of electron beams propagating in turbulent plasmas. In this work, it is shown that in addition to scattering of beam electrons, scattering of the beam-generated Langmuir waves via for instance mode-coupling, can also result in broadening of the wave-particle resonance.

We obtain a resonance-broadened version of weak-turbulence theory with mode-coupling to ion-sound modes. Resonance broadening is presented here as

a unified framework which can quantitatively account for the reduction and possible suppression of the beam instability due to background scattering of the beam electrons themselves or due to scattering of the beam-generated Langmuir waves in fluctuating plasmas. Resonance broadening being essentially equivalent to smoothing of the electron phase-space distribution, it is used to construct an intuitive physical picture for the stability of inverted populations of fast electrons that are commonly observed in-situ to propagate in the solar-wind.

Dynamics of flare processes and variety of the fine structure of solar radio emission in new events

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24 cycle of activity continues to remain poor to the major flare phenomena. However, small flares presented a number of enigmas in the radio emission of fine structure. From several recent events the most interesting is the April 11, 2013 event, 07:00 , 07:26 UT. The first time the fine structure was observed simultaneously in 4 observatories: SBRS/Huairou, Ondrejov, SSRT and spectrograph/Badary and IZMIRAN/Moscow, Troitsk. Zebra Pattern and fast pulsations were observed during flare maximum at tops of loop arcade according the Solar Dynamics Observatory / Atmospheric Imaging Assembly (SDO/AIA) 335 √Ö images. The flare of M6.5 class taken place at 06:58 ,Äì 07:26 UT in solar active region NOAA 11719 located very close to the center of solar disk. The ZP stripes appeared as high frequency boundary of pulsations, and their spectra observed in Huairou and Ondrejov coincided in details. The future analysis must clarify whether a radio source of ZP really related with a closed magnetic loop, lower than source of pulsations. On the impulsive phase of the event the strong narrow-band radio burst of the zebra structure occurred with the moderate left handed circular polarization. Then a series of the pulsations and zebras were observed almost in the unpolarized emission. After 07:00 UT zebra appeared with the moderate right-handed polarization. On the decay phase (to approximately 07:25 UT), the zebra and fiber bursts appeared in the strong right-handed polarization. According to Badary spectral data the background emission was in left handed circular polarization (as at around 3 GHz in Huairou spectra). But the fine structure appeared in right-handed polarization. This dynamics of the polarization will be coordinated with the motion of the flare processes, which were being observed in the line 335 Angstrom by SDO/AIA.

Waves and Oscillations in Sunspot Atmosphere

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Temporal, spatial and frequency evolution of 3-min wave fronts detected in the atmosphere of sunspot NOAA 11131 on 08/12/2010 in 02:00-04:00 UT in the 1700 A, 1600 A, 304 A, 171 A, 193 A, 211 A, 131 A and 335 A channels of SDO/AIA is analysed with the use of the time-distance plots and the pixelised wavelet filtration (PWF). It is found that there are time intervals when the angular symmetry of the 3-min wave fronts, with respect to the centre of the umbra, changes. The power of 3-min waves is found to correlate with the shape of the wave. In the power maxima the 1D wave fronts are symmetric, while in the minima the fronts loose the symmetry and split. PWF analysis revealed that the wave fronts have a two-armed spiral spatial structure with the centre at the centre of the umbra. The spiral rotates anti-clockwise each cycle of the 3-min oscillation. The arms diverge up to the boundary of the umbra. The spiral spatial structure is found at all heights above the sunspot. The phase delays found with the cross-correlation technique (with respect to the 1700A, it is 7.2 s for 1600 A, 16.8 s for 304 A, 28.8 s for 193 A and 45 s for 171 A), reveal that the signal propagates upwards. Thus, the phase speed is 90-100 km/s. The spectrum is found to have a fine structure with different spectral peaks coming from different spatial locations. The shorter-period (about 1.8 min) part has a point-like source at the umbra centre, while the longer-period (2.6-3.1 min) part comes from the propagating wave fronts. Together with the spiral wave-fronts, in the corona there are also radial wave-motions. We associate the spiral spatial structure of 3-min oscillations in the umbra with the combined effect of the localisation of slow magnetoacoustic waveguides across the umbra, and different heights of the excitation of the oscillations. Thus, the frequency cut-off mechanism forms spatially distinct narrowband sources that together create the observed spiral-like shape.

Decay-less oscillations of EUV coronal loops

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Thanks to the high spatial and temporal resolution observations of the solar corona from the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO), a new type of kink waves is found, in addition to the well-know rapidly decaying oscillations. This new regime is characterised by low-

amplitude and undamped oscillations, and for this reason defined as ""decay-less"". Typical periods are measured between 2.5 to 12 min in both regimes and are different for different loops, increasing with the loop length. Estimates of the loop lengths are supported by three dimensional reconstruction of the loop geometry. The amplitude for the decay-less regime is typically lower than in the decaying regime, and usually do not exceed 1 Mm, close to the spatial resolution of the AIA instruments. The oscillation phase, measured by the cross-correlation method, is found to be constant along each analysed loop, and the spatial structure of the phase of the oscillations corresponds to the fundamental standing kink mode. We show that the observed behaviours are consistent with the empirical model of a damped linear oscillator excited by a continuous low-amplitude harmonic driver, in addition to an eventual impulsive high-amplitude driver. Any irregularity in the kink oscillations may be associated with the stochastic nature of the driver. The observed life-time of the oscillations is likely to be determined by the observational conditions rather than any physical damping. However, the balance between the driving and damping is a necessary ingredient of this model. The properties of this type of transverse oscillations make them interesting object of study in the framework of resonant absorption theory and coronal heating process.

Oscillations in a sunspot with light bridges

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Solar Optical Telescope (SOT) onboard Hinode observed a sunspot (AR 11836) with two light bridges (LBs) on 31 Aug 2013. We analysed a 2-hour CaII H emission intensity data set. We detect strong 5-min oscillation power on both LBs and in the inner penumbra. The variation of 5-min oscillation power along the bridges does not exhibit any obvious pattern that may imply its origin. Nevertheless, the time-distance plot reveals that 5-min oscillation phase does not vary significantly along LBs, indicating that the oscillations are likely to originate from underneath the LBs. The narrowband power map of the sunspot constructed at the 3.5+-0.5 min band looks very similar to the original emission intensity image: the bright area, corresponding to the enhancement of 5-min oscillations power, highlights the penumbra and both LBs. The 5-min oscillations are suppressed in the umbra, while the 3-min oscillations occupy all three cores of the sunspot's umbra, separated by the LBs. The 3-min oscillations were found to be in phase at both sides of the LBs. It may indicate that either LBs do not affect umbral oscillations, or umbral oscillations at different umbral cores share the same source. We found that umbral flashes (UFs) follow the life cycles of umbral oscillations with much larger amplitudes. They cannot propagate across LBs and dominate the 3-min oscillation power within each core, however, they do not disrupt the phase of umbral oscillation.

Two-dimensional observations of intersunspots microwave sources and their spectral features

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Data from the Nobeyama Radioheliograph, Siberian Solar Radio Telescope and the space magnetograph SOHO/MDI have allowed us to reveal the long-lived intersunspot sources (ISS) of two types: with their centers often located above the neutral line of the magnetic field separating leading and following parts of a whole active region (the first type of ISS) and with their centers above the neutral line separating magnetic polarities inside of complex sunspots (the second type of ISS). We try answering the question about the possible emission mechanisms of ISS using observations of the frequency spectrum slope between 17 and 34 GHz, as well as data on frequency spectra obtained with radio telescope RATAN, 600 and data from SOHO/EIT and TRACE. We show that ISS of the first type (extended) are mostly of bremsstrahlung nature. ISS of the second type (compact) most likely have gyroresonance or gyrosynhrotron nature.

Dynamics of microwave neutral line associated sources and of magnetographic parameters of sunspots as a factor in predicting large flares

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We present a study of evolution of five active regions (ARs) where strong X-class flares occurred in 2011--2012 (NOAA AR 11158, 11166, 11263, 11283 and 11520). The main aim of our study is a research of ARs on pre-flare phase (during a few days before flare) to reveal features in microwave radiation of AR and its magnetographic characteristics, which indicate that a power flare is preparing. One developed AR (NOAA AR 11654) has been also studied, which did not produce large flares. We used daily multiwavelength spectral-polarization solar observations in the range of 1.65--6.0~cm made with the RATAN--600 radio telescope and data obtained by Solar Dynamics Observatory/Helioseismic and Magnetic Imager (SDO/HMI). In all cases, when X-class flares occurred, we have found that new compact microwave source associated with the neutral line

of photospheric magnetic field (neutral line associated source - NLS), above the place with highest gradient of magnetic field, has been developed and in most cases became predominant in radio emission of AR one-two days prior to large flare. In considered AR, where no powerful flares occurred, such source has not been detected. An analysis of magnetigraphic characteristics of sunspots (based on SDO/HMI data) showed that large X-flares under investigation occured in ARs with great value of magnetic flux $\sim 10^{22}$ Mx and with growing magnetic field gradient. We first have identified positions of developing source (NLS) with location of large flares which has been registered in AR one-two days later. Radio characteristics and dynamics of NLS detected before large flare possibly reflects the current sheet formation in the corona above AR where energy necessary for a flare is stored. Thus, early detection of rapidly developing microwave source NLS and of magnetic field gradient increasing can be used as a factor in predicting large flares.

Study of the relationship between solar microwave spikes and type III bursts

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Generally, the solar microwave spike bursts are believed to produce from the electron cyclotron maser emission by some energetic electrons, and the type III burst is produced from the plasma emission mechanism when the energetic particles propagate across the background plasmas. Both of them are related to solar energetic particles. Therefore, there should be a closely relationship between these two kinds of microwave bursts. This work plans to reveal the relationships from the multi-wavelength observations, including the broadband microwave spectrograms (SBRS/Huairou and Ondrejov spectrometer) and EUV images of SDO, etc.

From GHz to MHz: A radio study of a solar flare

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Solar flares are known to accelerate electrons that travel through the magnetic field of the solar corona. Electron beams travelling downwards into the dense atmosphere of the Sun can create radio emission in the GHz frequencies through synchrotron emission. These electrons are also thought to produce X-ray emission in the solar chromosphere. Upward travelling electron beams are known to produce radio emission in the MHz frequencies through non-linear plasma processes. We use a combination of Russian and European radio instruments to simultaneously observe a solar flare in both GHz and MHz frequency ranges. We show, for the first time, simultaneous radio images of the synchrotron and plasma emission during the solar flare. Combining the analysis with X-rays, we deduce properties of the accelerated electrons and find the solar flare analysed displays many attributes of the "standard" solar flare.

Analysis of the polarization degree distribution along limb flaring loops of July 19, 2012

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We have analyzed the polarization degree distribution along the limb flaring loops of July 19, 2012 using Nobeyama Radioheliograph data. Two flaring loops were observed simultaneously next to each other. The sense of polarization near both, southern and northern, footpoints of the two loops keeps the same (left handed: R-L<0) during the whole flare. On the other hand, in the upper parts of the loops, the inversion of the polarization (right-handed: R-L>0) has been found, and its sign also remains the same during the flare. Interestingly, in the two opposite legs of the loops, the polarization dynamics is opposite. From the rising phase to decay phase of the flare, the sense of polarization changes its sign from negative to positive for the northern leg, and from positive to negative in the southern leg. The origin of these peculiarities is discussed."

Spatial features of oscillations in the 2012 August 18 flare

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We analyze the dynamics of microwave spectrum and spatial characteristics of oscillation sources in the 2012 August 18 flare using the new unique complex of spectral imaging instruments (10-antenna prototype of the multifrequency Siberian radioheliograph, Badary BroadBand Microwave Spectrolarimeter and Spectropolarimeters 2-24 GHz).

We distinguished several stages in light profiles of this event. The first stage had a quasi-thermal character with gradually arising emission in X-rays at energies below 25 keV and in microwaves below 10 GHz. Also, there were several clusters of subsecond pulses at this stage. During other two stages, the emission sharply increased in X-rays channels at energies up to 25-300 keV and in microwaves at frequencies up to 35 GHz. Each stage began with prominent peak and then several oscillations with periods of several seconds were observed during these both stages.

There were well distinguished flare source. Spatial displacements of the sources were small relatively to the distance between them. In the first stage, the microwave source was extended and covered whole loop arcade, SXR source was observed near a footpoint, in the second and third stage microwave and HXR sources became compact and located near a loop footpoint. In all three stages, the sizes of the microwave source at 4.2, 4.9, 5.8, 6.9, 7.4 GHz decreased with the emission frequency. Dependencies of the X-ray and microwave flux oscillations on the source size were studied using direct observations. No correlation between flux oscillations and the source size was observed. A mode of the oscillations is discussed.

Energy release during the decay phase of long duration solar flares

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A long duration event (LDE) is a solar flare characterized by a slow decrease in soft X-ray (SXR) emission. The decrease may last from several hours to more than a day. This long lasting SXR emisson comes mainly from LDEs' coronal source(s). The sources are volumes of hot plasma (~10 MK) an they can last for many hours. It means that the sources need some efficient heating mechanism operating throughout the whole decay phase to sustain their high energy emission.

We selected a group of LDE flares observed by RHESSI and EUV imaging instruments like SoHO/EIT. Using such a complementary data we obtained detailed information on coronal sources. The analysis of size and location of observed coronal sources was made. Moreover, we performed RHESSI imaging spectroscopy for the sources. All collected information allowed us to solve energy balance of the coronal sources. Results from the energy balance can be used to define the heating mechanism responsible for long duration of LDE flares.

Atmosphere structure and the radio emission spectrum of the quiet Sun and the coronal holes according to UV observation

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SDO/AIA UV observations were used for definition of the quiet Sun atmosphere structure. It is found that temperature distributions of differential emission measure (DEM) obtained from AIA data were different for the quiet Sun and the coronal holes. In the assumption free-free radio emission of the quiet Sun from DEM distribution radio images at different frequencies were computed. Obtained as result of modeling the radio spectra qualitatively and quantitatively correspond with observed for the quiet Sun and the coronal holes in the 1-20 GHz range.

Joint observations of the circular polarization inversion in a solar microwave source by SSRT and RATAN

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with

Dr Kochanov A., Dr Myshyakov I., Dr Kaltman T., Dr Tokhchukova, S

We present radio observations of the solar active region NOAA 11734 during 2013 May 2-5. The observations include SSRT maps in the Stokes I and V parameters at 5.7 GHz and RATAN spectra at 3-18 GHz. It is found that the radio emission of the tail sunspot is anomalously polarized up to 16 GHz in the sense of the ordinary mode. To explain the observational data we performed reconstruction of the magnetic field structure above the active region in the nonlinear force-free approximation as well as simulation of the free-free and

gyroresonance radio emission. The results of our data analysis and calculations allow us to interpret the observed polarization feature as a result of the quasi-transverse propagation of microwaves in the complex magnetic field structure above the sunspot.