Solar Physics with Radio Observations (SPRO2016)

Sep 9 (Fri) – Sep 10 (Sat), 2016 @ Nagoya U.

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Nobeyama Radioheliograph

First Circular

Solar Physics with Radio Observations
- Continued Operation of Nobeyama Radioheliograph -

http://st4a.stelab.nagoya-u.ac.jp/SPRO2016/

Date: September 9 (Fri.) and 10 (Sat.), 2016

Venue: Nagoya University

Access: http://en.nagoya-u.ac.jp/access/index.html

Campus map: http://en.nagoya-u.ac.jp/map/index.html

SOC: K. S. Cho, N. Gopalswamy, M. Ishii, S. Masuda, K. Shibasaki (chair), and Y. Yan

LOC: S. Masuda (chair), ISEE staff

Objective of the meeting:

Nobeyama Radioheliograph (NoRH) has been observing the Sun since 1992. After March 2015, International Consortium for the Continued Operation of Nobeyama Radioheliograph (ICCON) took over the operation from NAOJ and operated successfully for more than one year. To enhance science output from NoRH, we wish to organize a symposium to discuss new science results from NoRH and future targets of NoRH. Recently, many new radio telescopes started solar observations. This symposium is also a good chance to learn about them and to discuss collaboration with NoRH.

Deadlines for abstract submission and registration:

July 31, 2016

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Program

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Sep 9 (Fri) – Sep 10 (Sat), 2016 @ Nagoya U.

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Date	Time	Session (Chair)	Paper #	Title	Presenter
Sep 9 (Fri)	8:45 – 9:00	**Registration and Welcome**			
		I. Radio Telescopes for Solar Observations			
	9:00 – 9:30	**Gopalswamy**	I – 1	Continued operation of Nobeyama Radioheliograph	Masuda, S.
	9:30 – 10:00		I – 2	Solar Physics with NoRH	Shibasaki, K.
	10:00 – 10:30		I – 3	Recent Progress of MUSER	Yan, Yihua
				Coffee Break / Poster	
	11:00 – 11:20		I – 4	Recent Operational and Scientific Activities of Nobeyama Radio Polarimeters	Asai, A.
	11:20 – 11:40		I – 5	Absolute calibration of Nobeyama Radio Polarimeters	Iwai, K.
	11:40 – 12:10		I – 6	What Solar Data will ALMA Provide to Us in Cycle 4 and Beyond?	Shimojo, M.
	12:10 – 12:30		I – 7	Hiraiso to Yamagawa: A Japanese new solar radio spectrograph	Kubo, Y.
	12:30 – 12:50		I – 8	Solar flares THz photometers on a stratospheric transantarctic balloon flight	Raulin, J.-P.
				Lunch Break	
		II. Radio Studies of High Energy Phenomena			
	14:00 – 14:30	**Masuda**	II – 1	Diagnostics of the electron pitch-angle anisotropy in flaring loops using polarization measurements with Nobeyama Radioheliograph	Melnikov, V.
	14:30 – 14:50		II – 2	Microwave imaging of a hot flux rope structure during the pre-impulsive stage of an eruptive M7.7 solar flare	Wu, Zhao
	14:50 – 15:10		II – 3	Temporal and spatial distributions of microwave emission in flaring loop and the implication of nonthermal electrons	Kawate, T.
	15:10 – 15:30		II – 4	Microwave Diagnostics of Solar Flaring Loop Parameters by the Forward Fitting Method	Melnikov, V.
				Coffee Break / Poster	
	16:00 – 16:20		II – 5	Radio and EUV Imaging Observations of Particle Acceleration Associated with Plasmoid Motions	Takasao, S.
	16:20 – 16:40		II – 6	Erupting Sigmoid and Associated Flare with Parallel and Large-Scale Quasi-Circular Ribbons	Joshi, N. C.
	16:40 – 17:00		II – 7	Solar microwave Zebra pattern burst and its source region	Tan, Baolin
	17:00 – 17:30		II – 8	Coronal Magnetic Field of the 2011 August 09 Flare Source Inferred from the KSRBL Microwave Spectra	Lee, Jeongwoo
Sep 10 (Sat)	**9:00 – 9:30**	**Shibasaki**	II – 9	A comparison of eruptive and confined flares in microwaves	Yashiro, S.
	9:30– 10:00		II – 10	Solar Flare Observations in Millimeter, Sub-millimeter and THz range	Raulin, J.-P.
	10:00 – 10:20		II – 11	Implications of new Mid-IR Observations for mm/cm Flare Research	Hudson, H.
				Coffee Break / Poster	

Time	Chair	No.	Title	Speaker
	III. Radio Studies of Waves and Oscillations			
11:00 – 11:30		III – 1	Multi-mode quasi-periodic pulsations in a solar flare	Nakariakov, V.
11:30 – 11:50		III – 2	MHD oscillations or periodic reconnection? The advantages of multi-wavelength approach.	Kupriayanova, E.
11:50 – 12:10		III – 3	Quasi-periodic acceleration of electrons in solar flares	Huang, Jing
			Lunch Break	
	IV. Radio Studies of the Quiet Sun, Solar Activity Cycle, and Others			
14:00 – 14:30	**Yan**	IV – 1	Long-term Variation of the Polar Magnetic Field of the Sun Indicated by Polar Brightening and Prominence Eruptions in Microwaves	Gopalswamy, N.
14:30 – 14:50		IV – 2	Daily 17 GHz Circular Polarization Maps	White, S.
14:50 – 15:10		IV – 3	Chromospheric Sunspots in the Millimeter Range as Observed by the Nobeyama Radioheliograph	Iwai, K.
15:10 – 15:30		IV – 4	Radio Emission Diagnosis of Solar Atmospheric Model	Tan, Chengming
			Coffee Break / Poster	
16:00 – 16:20		IV – 5	Solar Radio Physics and MHD	Shibasaki, K
	V. Discussion			
16:20 – 17:20		V – 1	Future of NoRH and Science	Panelers
	Posters			
		I – P1	Expanded Owens Valley Solar Array	(Gary, D.)
		I – P2	HF – UHF Solar radio telescopes in Tohoku Univ. : Introduction of the system and science results	Misawa, H.
		II – P1	Search for signs of electron pitch-angle anisotropy using the observed polarization degree distribution along microwave flare loops: a statistical study	(Morgachev, A.)
		II – P2	Modeling the Distribution of Circular Polarization Degree of Microwave Emission along the Flaring Loop in the event of July 19, 2012	(Kuznetsov, S.)
		II – P3	Properties of Gyrosynchrotron Emission in a Shrinking Flaring Loop	(Filatov, L. V.)
		II – P4	Polarization Characteristics of Zebra Patterns in Type IV Solar Radio Bursts and a Possible Mechanism of Depolarization	Kaneda, K.
		III – P1	Spatio-temporal evolution of sources of HXR and microwave pulsations in a solar flare observed with the RHESSI, NoRH and AIA/SDO	(Kuznetsov, S.)
		III – P2	Microwave observations of a large-scale coronal wave with the Nobeyama radioheliograph	(Warmuth, A.)
		IV – P1	Coronal Magnetic Fields Derived from Simultaneous Microwave and EUV Observations and Comparison with the Potential Field Model	(Miyawaki, S.)
Sep 11 (Sun)	**Excursion to Nobeyama**			

I-1. Continued Operation of Nobeyama Radioheliograph

S. Masuda (Nagoya University), K. Shibasaki (Solar Physics Research Inc.), N. Gopalawamy (NASA), Y. Yan (NAOC), K. S. Cho (KASI), and M. Ishii (NICT)

Nobeyama Radioheliograph (NoRH) is a radio interferometer specially designed to observe the full disk of the Sun at 17 and 34 GHz. Eighty-four antennas with a diameter of 80 cm were installed along a T-shape baseline (North - South: 250 m, East - West: 500 m). The spatial resolution is about 10 arcseconds and 5 arcseconds in 17 GHz and 34 GHz, respectively. The time resolution of NoRH is typically 1 second and 0.1 second for the event mode. The National Astronomical Observatory of Japan (NAOJ) has successfully operated NoRH since 1992. From April 2015, the Solar-Terrestrial Environment Laboratory (now, Institute for Space-Earth Environmental Research), Nagoya University is operating NoRH as a representative of the International Consortium for the Continued Operation of Nobeyama Raidoheliograph (ICCON). We report the operating system of ICCON and the current status of NoRH.

I-2. Solar Physics with NoRH

K. Shibasaki (Solar Physics Research Inc

Recent scientific results from NoRH are reviewed.

I–3. Recent Progress of MUSER

Yihua Yan, Wei Wang, Fei Liu, Zhijun Chen, Lihong Geng, Linjie Chen, Donghao Liu, Jing Du, Cang Su, Baolin Tan, Chengming Tan, Jing Huang

The recent progress of MUSER will be reported. Initial results of MUSER-I and MUSER-II arrays will be presented, including MUSER-II for 23 July 2016 M-class flare.

I–4. Recent Operational and Scientific Activities of Nobeyama Radio Polarimeters

A. Asai, S. Nozawa, K. Ichimoto, M. Shimojo, T. Sakurai, Y. Suematsu, T. Minamidani, N. Shinohara, S. Kawashima, M. Saito, H. Shinkai, M. Takemura, K. Iwai, Y. Kubo, K. Shibasaki, S. Masuda

After the closure of Nobeyama Solar Radio Observatory, NAOJ in 2015 April, the scientific data verification of Nobeyama Radio Polarimeters (NoRP) has been performed by a data verification team of Japanese scientists, while the operation and maintenance of NoRP are taken over by Nobeyama Radio Observatory, NAOJ. We report recent activities of the data verification and the operation of NoRP and scientific applications of the data.

I-5. Absolute calibration of Nobeyama Radio Polarimeters

K. Iwai (NICT), N. Shinohara (NAOJ) and NRO NoRP team

The solar radio emission in the micrometer range is thought to be generated between the upper chromosphere and the corona. Hence, the total flux of the solar radio emission in this wavelength range has been widely used as an indicator of the solar activity. The Nobeyama Radio Polarimeters (NoRP) have been continuously observed the total solar flux at 1.0, 2.0, 3.75, and 9.4 GHz for more than 60 years which should be a useful data to study the variation of the solar activity and its influence to the upper atmosphere of the Earth. The total solar flux monitors are usually optimized to the solar observation. Hence, it is difficult to calibrate the system by using the radio standard sources. In this study, we developed standard horn antennas and evaluated the accuracies of the total flux provided by NoRP. The developed horn antenna was calibrated in the large-scale anechoic chamber of NICT. This anechoic chamber is a fully anechoic room (FAR) and its room size is 23.4m and 11.9m. This large-scale chamber enables us to approximate the experimental condition as a far-field. Then, we examined the gain of the NoRP antennas by solar observation using the horn antenna. The experimental result indicates that the NoRP antennas still keep the original gain which was measured more than 20 years ago. This result suggests that the NoRH has maintained high quality data for the solar total flux.

I-6. What Solar Data will ALMA Provide to Us in Cycle 4 and Beyond?

Masumi Shimojo(NAOJ), Tim Bastain(NRAO), Antonio Hales(JAO), Akihiko, Hirota(JAO), Stephen White(AFRL), Kazumasa, Iwai(NICT), Neil Phillips(JAO), Roman Brajša(Univ, of Zagreb), Richard Hills (Cavendish Lab.), and the ALMA Solar Development Team

The procedures of 5th ALMA science operation (Cycle 4) were started from the announcement of “Call for Proposal” in March 2016. Solar observations are offered from Cycle 4, and first scientific solar observations will be started in this winter according to the solar observing proposals evaluated to high grade by the ALMA proposal review panels. To verify the solar observing modes used in Cycle4, the ALMA solar development team, which is consisted of solar radio physicists and the staffs of the ALMA observatory, held the commissioning campaign in December 2015. Although the usage of 50 antennas is guaranteed for scientific observations in Cycle4, we could use only 30 antennas for the campaign. Nevertheless, we succeeded in obtaining the marvelous mm-wave solar images from the commissioning data as shown below. Due to increase the number of usable antennas to 50, the quality of images obtained in Cycle 4 will be surely better than the images below. In this paper, we present the data obtained at the campaign in 2015, and discuss the quality of mm-wave images obtained in Cycle4. Moreover, the candidates of new functions for solar observations in future Cycles are discussed.

I-7. Hiraiso to Yamagawa: A Japanese new solar radio spectrograph

Yûki Kubo, Kazumasa Iwai, Hiromitsu Ishibashi, and Takahiro Naoi (NICT)

"In Hiraiso Solar Observatory, National Institute of Information and Communications Technology (NICT), we have been operating solar radio spectrograph called HiRAS for over twenty years. But, radio wave environment at Hiraiso has been getting worse and the system has been decrepit. Also, it has already decided due to political reasons that Hiraiso Solar Observatory will be shut down within a couple of years. Because of this, HiRAS will also be shut down in this autumn. So, we have developed a Japanese new solar radio spectrograph in Yamagawa radio observation facility, NICT.

While the MHz solar radio bursts, especially type II and III bursts, are radiated via mode conversion of Langmuir waves excited by high energy electrons, the GHz solar radio bursts are synchrotron radiation emitted by high energy electrons at lower corona. These high energy electrons are accelerated at reconnection regions in solar flare and shock waves in solar corona. Therefore, MHz and GHz solar radio waves are closely related each other through the accelerated high energy electrons. So, wide frequency range (MHz to GHz) radio wave observations with high time resolution are required to comprehensively understand high energy phenomena in solar corona.

Our Japanese new solar radio spectrograph has the widest frequency range (70MHz-9GHz), high time resolution (8ms), and high frequency resolutions (31.25kHz for MHz band and 1MHz for GHz band). The construction of the system is almost finished and now the system is in test observation. The observation will transit to routine operations in this year. The observation data of the system will be distributed by FITS format near future.

Finally, we would like to thank all the solar radio astronomers for having been supporting Hiraiso Solar Observatory, NICT."

I-8. Solar Flares THz Photometers on a Stratospheric Transantarctic Balloon Flight

P. Kaufmann (CRAAM, CCS), A. Abrantes (Propertech), E.C. Bortolucci (CCS), A. Caspi (SRI), L.O. Fernandes (CRAAM), G. Kropotov (Tydex), A. Kudaka (CRAAM), G. Laurent (SRI), N. Machado (Propertech), A. Marun (ICATE), R. Marcon (IFGW, OSBL), V. Nicolaev (Tydex), R.F. Hidalgo (CRAAM), J.-P. Raulin (CRAAM), P. Saint-Hilaire (SSL), C.M. Silva (Neuron), T. Timofeevsky (Tydex)

Sub-THz and 30 THz solar burst observations revealed a new spectral component, with fluxes increasing towards THz frequencies, simultaneously with the well known component peaking at microwaves, bringing challenging constraints for interpretation. The THz flare spectra can be completed with measurements made from space. A new system of two photometers was built to observe the Sun at 3 and 7 THz named SOLAR-T. An innovative optical setup allows observations of the full solar disk and detects small bursts with sub-second time resolution. The photometers use two Golay cell detectors at the foci of 7.6 cm Cassegrain telescopes. The incoming radiation undergoes low-pass filters made of rough surface primary mirrors and membranes, 3 and 7 THz band-pass filters, and choppers. The system has been integrated to redundant data acquisition system and Iridium short-burst data services telemetry for monitoring during the flight. SOLAR-T has been flown coupled to U.C. Berkeley solar hard X-ray and gamma-ray imaging spectro-polarimeter GRIPS experiment launched on a NASA CSBF stratospheric balloon from U.S. McMurdo base on January 19, 2016, on a trans-Antarctic flight. The mission ended on January 30. The SOLAR-T on-board computers were recovered from the payload that landed in the Argentina Mountain Range, nearly 2100 km from McMurdo. The SOLAR-T performance was successfully attained, with full space qualification of instrumentation. Calibrations, pointing and tracking conditions are described. Solar disk brightness temperatures were determined, 5300K at 3 THz and 4700K at 7 THz. The burst data reduction is in progress, with sensitivity of the order of 1 % of the full solar disk emission level at both frequencies. A first impulsive event analyzed in more detail was detected on January 28, 2016, at 3 and 7 THz, peaking at 12:12:10 UT, time coincident with impulsive burst detected at 0.2 and 0.4 THz by ground-based Solar Submillimeter Telescope, SST, in Argentina, while tracking AR14289 (N10E25). Simultaneous bursts were detected in Ha by HASTA (Argentina) and in EUV by SDO. One EUV bright arch feature "falls" towards the solar surface hitting the footpoint precisely at the same time of the burst. Other detections are being analyzed. Spectral trends in the sub-THz and THz bands indicate fluxes increasing with frequency at both ranges, with a possible break in intensity somewhere between 0.4 and 3 THz.

II-1. Diagnostics of the electron pitch-angle anisotropy in flaring loops using polarization measurements with Nobeyama Radioheliograph

V.F. Melnikov (Pulkovo Observatory), A.S. Morgachev (Pulkovo Observatory, RRI), S.A. Kuznetsov (Pulkovo Observatory, RRI)

In this paper we apply our technique for microwave diagnostics of properties of the pitch angle distribution of energetic electrons in flare loops using model simulations of the gyrosynchrotron emission and Nobeyama Radioheliograph observations to specific single loop and arcade flares. We found that the single loop and arcade flares have different spatial distributions of their microwave brightness, polarization degree, and frequency spectral slope. In particular, the single flare loops often have their brightness maximum at the top of a loop. On the contrary, the arcade flare loops are often characterized by two brightness maxima localized near their footpoints. Moreover, in some arcade flares, the polarization degree changes its sign along the loop indicating on the change of the polarization mode of gyro-synchrotron emission from the extraordinary to ordinary one. Our comparison of model and observed distributions of the microwave emission characteristics along flaring loops show that the longitudinal anisotropy of accelerated electrons is a characteristic feature of the arcade flare loops, and the perpendicular anisotropy is most often realized in the single flare loops.

II-2. Microwave imaging of a hot flux rope structure during the pre-impulsive stage of an eruptive M7.7 solar flare

Z, Wu, Y, Chen, G, Huang(PAO), H, Nakajima(NAOJ), H, Song(SDO), V, Melnikov(ACOPR), W, Liu(Stanford), G, Li(UAH), K, Chandrashekhar(SDU), and F, Jiao(SDU)

Corona structures and processes during the pre-impulsive stage of solar eruption are crucial to understanding the physics leading to the subsequent explosive energy release. Here we present the first microwave imaging study of a hot flux rope structure during the pre-impulsive stage of an eruptive M7.7 solar flare, with the Nobeyama Radioheliograph at 17 GHz. The flux rope is also observed by the SDO/AIA in its hot passbands of 94 and 131 Å. In the microwave data, it is revealed as an overall arcade-like structure consisting of several intensity enhancements bridged by generally weak emissions, with brightness temperatures (TB) varying from ~10,000 K to ~20,000 K. Locations of microwave intensity enhancements along the structure remain relatively fixed at certain specific parts of the flux rope, indicating that the distribution of emitting electrons is affected by the large-scale magnetic configuration of the twisted flux rope. Wavelet analysis shows a pronounced 2 minute period of the microwave TB variation during the pre-impulsive stage of interest. The period agrees well with that reported for AIA sunwardcontracting loops and upward ejective plasmoids (suggested to be reconnection outflows). This suggests that both periodicities are controlled by the same reconnection process that takes place intermittently at a 2 minute timescale. We infer that at least a part of the emission is excited by non-thermal energetic electrons via the gyro-synchrotron mechanism. The study demonstrates the potential of microwave imaging in exploring the flux rope magnetic geometry and relevant reconnection process during the onset of solar eruption

II–3. Temporal and spatial distributions of microwave emission in flaring loop and the implication of nonthermal electrons

T. Kawate (ISAS/JAXA), V. F. Melnikov (Pulkovo Observatory)

"Electrons accelerated in solar flaring loops generate microwave (MW) and hard X-ray (HXR) emissions through the gyrosynchrotron and bremsstrahlung mechanisms, respectively. First emission is mostly generated by trapped electrons with large pitch-angles, and the second one predominantly by electrons with small pitch-angles precipitating into the dense chromosphere. The relative amounts of those electrons depends on the initial pitch-angle distribution of the accelerated electrons. Therefore, comparative studies of MW and HXR emissions are important for examining the particle acceleration problem in solar flare since different acceleration mechanisms are expected to produce different pitch-angle distributions.

We analyzed flares observed simultaneously with Nobeyama Radioheliograph (NoRH), Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) statistically. It is shown that the MW sources tend to be located at the looptop in impulsive flares, while they tend to be located at the footpoint in gradual flares. To explain the spatial evolution and temporal behavior of the observed emission characteristics, we did numerical simulations of the electron distribution function and corresponding MW/HXR characteristics in a model magnetic loop. It was done under various types of the electron injection, in particular, for its different position in the loop (looptop or footpoints), initial pitch angle distribution (isotropic or longitudinal), and electron spectral index time behavior (constant or changing with time).

In this presentation, we show our observational and numerical results and discuss the spatial and temporal behavior of nonthermal electrons. "

II–4. Microwave Diagnostics of Solar Flaring Loop Parameters by the Forward Fitting Method

A. Morgachev (Pulkovo Observatory, RRI of Lobachevsky University), V. Melnikov (Pulkovo Observatory)

Numerical methods for solving the inverse problem of determining solar flaring loop physical parameters are developed. This problem can be solved by fitting theoretically calculated radio emission characteristics (intensity and circular polarization) to the corresponding observed characteristics. Such a fitting is reduced to the solution of a system of equations with the observed and theoretically calculated radio emission characteristics on the right- and left-hand sides, respectively. For the fitting, we use the genetic algorithm which demonstrates good accuracy and relatively short calculation time in the case when five parameters of a model flaring loop are recovered. After testing this method on the model sources, the algorithm has been used to recover four parameters of the real flaring loop using the Nobeyama Radioheliograph data.

II-5. Radio and EUV Imaging Observations of Particle Acceleration Associated with Plasmoid Motions

S. Takasao (Nagoya University), A. Asai, H. Isobe, and K. Shibata (Kyoto University)

We report a strong association between the particle acceleration and plasmoid motions found in the 2010 August 18 flare. The plasmoid motions are tracked in the EUV images taken by AIA/SDO and EUVI/STEREO-A, and the signature of the particle acceleration is investigated by using Nobeyama Radioheliograph data. We discovered impulsive radio bursts associated with the dynamic plasma motions such as ejection, coalescence of plasmoids, and collision of plasmoids with the post-flare loops. The radio bursts are considered as the gyrosynchrotron radiation by nonthermal high energy electrons. We believed that our observation provides clear evidence of the particle acceleration associated with the plasmoid motions. We will discuss possible acceleration mechanisms on the basis of our results.

II-6. Erupting Sigmoid and Associated Flare with Parallel and Large-Scale Quasi-Circular Ribbons

N. C. Joshi, C. Liu (NJIT/BBSO), X. Sun(Stanford University), Haimin Wang (NJIT/BBSO), Tetsuya Magara (KHU), and Y.-J. Moon (KHU)

In this paper, we present observations and analysis of an interesting event with sigmoid formation, eruption and the consequent solar flare with standard and large–scale quasi–circular ribbons that occurred on 2014 April 18 using multi–wavelength data sets. We divide the event into two phases. During the first, pre–flare phase, a sigmoid forms above the central magnetic polarity inversion line. The second, main phase, features the eruption of the sigmoid, the subsequent double flare ribbons, and a quasi–circular ribbon along the periphery of the active region. The circular ribbon and nonlinear force–free field (NLFFF) extrapolation both suggest the existence of a large–scale fan–spine type magnetic configuration. We propose the following scenarios. First, tether–cutting reconnection is responsible for the formation of the sigmoid under a section of the fan dome. Second, the reconnection occurred in the wake of the erupting sigmoid produces the standard, double flare ribbons. Third, the null–type reconnection higher in the corona, possibly triggered by the erupting sigmoid, leads to the large quasi–circular ribbon.

II-7. Solar microwave Zebra pattern burst and its source region

Baolin Tan (NAOC)

Microwave spectral zebra pattern structures (ZPs) are frequently observed in solar flares and the Crab pulsar. This talk will report an unusually strong ZP burst at the beginning of a solar flare. It is a very short and super strong explosion whose intensity exceeds several times of the underlying flaring broadband continuum emission, lasting for about 18 s. EUV images show that the flare starts from several small flare bursting points. There is a sudden EUV flash with extra enhancement in one of these points during the ZP burst. Analysis indicates that the ZP burst accompanying a EUV flash is an unusual explosion revealing a strong coherent process with rapid particle acceleration, violent energy release, and fast plasma heating simultaneously in a small source region with short duration just at the beginning of the flare.

II-8. Coronal Magnetic Field of the 2011 August 09 Flare Source Inferred from the KSRBL Microwave Spectra

J. Lee (Nagoya University)

The 2011 August 09 flare is one of the largest flares of Solar Cycle 24, observed with limited spatial information due to its location close to the western limb. We attempt to derive its magnetic field information from the microwave spectra obtained with the Korean Solar Radio Burst Locator (KSRBL). The KSRBL spectra exhibit significant fluxes at low frequencies, which implies high energy electrons residing in a large coronal volume with rapidly decreasing magnetic fields with height. We demonstrate such a magnetic structure with a model in which the volume and thickness of the microwave source are described as functions of magnetic field strength, and adjusted to reproduce the observed spectra. Information on energetic electrons derived from the hard X-ray spectra of the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) is used as a model constraint. The model developed in this study is adequate for analyzing spatially-integrated, broad-band microwave spectra.

II-9. A comparison of eruptive and confined flares in microwaves

S. Yashiro (CUA/NASA), S. Akiyama (CUA/NASA), S. Masuda (Nagoya University), M. Shimojo (NAOJ), A. Asai (Kyoto University), S. Imada (Nagoya University), and N. Gopalswamy (NASA)

We report on the different characteristics of eruptive and confined flares in microwave images obtained by the Nobeyama Radioheliograph (NoRH). Out of the 2181 GOES soft X-ray flares (M and above) reported during 1996 – 2014, NoRH observed 663. Using the coronal mass ejection (CME) observations made by SOHO/LASCO and STEREO/SECCHI, we found 215 flares were eruptive and 202 flares were confined. The remaining 146 flares whose CME association is unclear are excluded from the analysis. We compared the microwave flare properties between eruptive and confined flares and found that the spatial flare size in microwaves does not show significant difference. On the other hand, the microwave brightness temperature of eruptive flares is approximately 3 times higher than that of the confined ones on average. In other words, the CME association rate of flares clearly increases with increasing radio brightness temperature, similar to soft X-ray intensity. Combinations of X-ray and microwave flare observations show a better score in predicting the CME association rate of flares.

II-10. Solar Flare Observations in Millimeter, Sub-millimeter and THz range

Jean-Pierre RAULIN (CRAAM)

We will review solar flare observations detected up to 400 GHz, most of them observed by the Solar Submillimeter Telescope (SST). A recently published statistical analysis on the spectral trends of such events detected by the SST will also be presented and discussed. Few recent events were also observed and their study complemented by EUV, H-alpha and 30 THz (10 microns) data. It comes out from these recent analysis that a thermal interpretation cannot be excluded, at least for part of the high frequency flare emission.

II-11. Implications of new Mid-IR Observations for mm/cm Flare Research

H. Hudson (UCB and U. of Glasgow), L. Fletcher (U. of Glasgow), G. Kerr (U. of Glasgow), P. Simoes (U. of Glasgow), and M. Penn (NSO Kitt Peak)

In a recent observational breakthrough it has become possible to obtain high-quality images of solar flares in the 10 micron (30 THz) band. These observations, coupled with RADYN radiation-hydrodynamic signatures, significantly clarify the evolution of the lower solar atmosphere during the impulsive phase of a solar flare. We discuss the new data in the context of existing and future mm/cm observations.

III-1. Multi-mode quasi-periodic pulsations in a solar flare

V.M.Nakariakov, D. Y. Kolotkov (University of Warwick), K.Shibasaki (NAOJ)

We study QPP of the microwave emission generated in an X3.2-class solar flare on 14 May, 2013, observed with the Nobeyama Radioheliograph (NoRH), aiming to reveal signatures of the non-linear,non-stationary, and multi-modal processes in the signal. The NoRH correlation signal obtained at the 17 GHz intensity has a clear QPP pattern. The signal was analysed with the Hilbert-Huang transform (HHT) that allows one to determine its instant amplitude and frequency, and their time variation. It was established that the QPP consists of at least three well-defined intrinsic modes, with the mean periods of 15, 45,

and 100 s. All the modes have quasi-harmonic behaviour with different modulation patterns. The 100 s intrinsic mode is a decaying oscillation, with the decay time of 250 s. The 15 s intrinsic mode shows a similar behaviour, with the decay time of 90 s. The 45 s mode has a wave-train behaviour. Dynamical properties of detected intrinsic modes indicate that the 100 s and 15 s modes are likely to be associated with

fundamental kink and sausage modes of the flaring loop, respectively. The 100 s oscillation could also be caused by the fundamental longitudinal mode, while this interpretation requires the plasma temperature of about 30 million K and hence is not likely. The 45 s mode could be the second standing harmonics of the kink mode.

III–2. MHD oscillations or periodic reconnection? The advantages of multi-wavelength approach.

E. G. Kupriyanova (KU Leuven, Pulkovo Observatory), L. K. Kashapova (ISTP), Z. Xu (Yunnan Observatory), H. A. S. Reid (University of Glasgow), I. N. Myagkova (MSU)

The most discussed explanations of quasi-periodic pulsations observed during solar flares are MHD waves and periodic reconnection. Good objects for testing the different models are solar flares showing clear quasi-periodicities in optic and EUV emissions, X-rays, microwaves and followed by type III radio bursts. We use methods of the correlation, Fourier, and wavelet analyses to examine the temporal fine structures and relationships between the time profiles at different wave bands. We tested our method on two flares. The periods 40-50 s and 140-170 s are found at the most of the wave bands. We interpret the results as a quasi-periodic injection of non-thermal electrons, produced by magnetic reconnection.

III–3. Quasi-periodic acceleration of electrons in solar flares

Jing Huang (NAOC), Eduard P. Kontar (School of Physics and Astronomy, University of Glasgow), Valery M. Nakariakov(Physics Department, University of Warwick), Guannan Gao(YNAO)

Quasi-periodic pulsations (QPPs) of nonthermal emission in an M7.7 class flare on 2012 July 19 are investigated with spatial resolved observations at microwave, HXR band and with dynamic spectra at decimetric, metric waves. Microwave emission at 17 GHz of south footpoint and loop leg, HXR emission at 20-50 keV of north footpoint and loop top and type III bursts at 0.7-3 GHz show prominent in-phase oscillations at 270s. The microwave emission of north loop leg and footpoint has smoother but stronger emission than the other regions. By estimation of plasma density around loop top, we find that the emission of type III bursts covers vide region from above loop top to loop top and loop legs. Quasi-periodic acceleration or injection of energetic electrons is proposed to be reasonable for this in- phase QPPs of nonthermal emission from foot points, loop top and above, while the smoother emission of loop leg is dominated by accumulated trapped electrons. In overlying region, drifting pulsations (DPS) at 200-600 MHz oscillate at a distinct period (200s). Its global structure drifting towards low frequency is closely related to the upward ejection of plasmoid observed simultaneously from EUV emission. Thus, two systems of quasi-periodic acceleration of electrons at different altitudes coexist in the same flaring process. MHD oscillations originated by bi-directional outflows from reconnection region may modulate the acceleration processes to produce oscillatory number of energetic electrons, which dominates accordingly the nonthermal emission in underlying flare loop region and overlying plasmid.

IV–1. Long-term Variation of the Polar Magnetic Field of the Sun Indicated by Polar Brightening and Prominence Eruptions in Microwaves

N. Gopalswamy (NASA), S. Yashiro (CUA/NASA), S. Akiyama (CUA/NASA), and P. Makela (CUA/NASA)

It is well known that the microwave enhancement in coronal holes is an important indicator of the strength of the magnetic field at the chromospheric level. When applied to the polar coronal holes, the microwave enhancement faithfully tracks the solar cycle variation of the polar field strength. High-latitude prominence eruptions also track the evolution of the polar field because they occur between the incumbent flux and plumes of insurgent flux from the active region belt. Cessation of high-latitude prominence activity thus marks the epoch of reversal of the polar field. By combining prominence eruptions detected automatically (Nobeyama Radioheliograph and SDO), the polar microwave brightness (Nobeyama Radioheliograph), and the magnetic butterfly diagram (SDO and NSO) we show that the evolution of the polar field is very different from that in cycle 23. During several recent cycles, the north pole reversed first, followed by the south. During cycle 24, the south pole reversed first. Even though polar prominences started appearing as early as 2011, the polar microwave brightness remained near the quiet Sun level for unusually long time. This indicates an extended period of near-zero field in the north polar region and the reversal happened at the end of this period, which occurred about a year after the reversal in the south pole. We suggest that the weak north polar field should result in very weak and delayed sunspot activity in the northern hemisphere in cycle 25. On the other hand the south polar region behaved as in previous cycles and reversed over a shorter time scale, indicating a normal onset of activity in the south.

IV–2. Daily 17 GHz Circular Polarization Maps

S. White (AFRL)

The creation of sensitive 17 GHz daily circular polarization maps is described. Under good conditions, noise levels as low as 15 K are achieved; limitations to the process are described.

IV−3. Chromospheric Sunspots in the Millimeter Range as Observed by the Nobeyama Radioheliograph

K. Iwai (NICT), H. Koshiishi (JAXA), K. Shibasaki (Sol. Phys. Res. Inc.), S. Nozawa, S. Miyawaki, T. Yoneya (Ibaraki University)

We investigate the upper chromosphere and the transition region of the sunspot umbra using the radio brightness temperature at 34 GHz (corresponding to 8.8 mm observations) as observed by the Nobeyama Radioheliograph (NoRH). Radio free-free emission in the longer millimeter range is generated around the transition region, and its brightness temperature yields the temperature and density distribution of the emission region. We use the NoRH data at 34 GHz by applying the Steer-CLEAN image synthesis. These data and the analysis method enable us to investigate the chromospheric structures in the longer millimeter range with high spatial resolution and sufficient visibilities. We also perform simultaneous observations of one sunspot using the NoRH and the Nobeyama 45 m telescope operating at 115 GHz. We determine that 115 GHz emission mainly originates from the lower chromosphere while 34 GHz emission mainly originates from the upper chromosphere and transition region. These observational results are consistent with the radio emission characteristics estimated from current atmospheric models of the chromosphere. On the other hand, the observed brightness temperature of the umbral region is almost the same as that of the quiet region. This result is inconsistent with current sunspot models, which predict a considerably higher brightness temperature of the sunspot umbra at 34 GHz. This inconsistency suggests that the temperature of the region at which the 34 GHz radio emission becomes optically thick should be lower than that predicted by the models.

IV−4. Radio Emission Diagnosis of Solar Atmospheric Model

Chengming Tan (NAOC)

Study of solar atmospheric model at radio waveband is shortage for the reason of lacking of observation and complexity of theoretical treatment. Especially there is still discrepancy between the theoretical prediction and the observation, such as the discrepancy of radio flux spectrum, discrepancy of radio brightness temperature spectrum, and discrepancy of limb brightening. The studies on this topic are focused on several single frequencies, thus narrowed the explanations. The new construction of the Chinese solar radio heliograph will provide more observations on the 2D image of the Sun at a wide frequency range of 400 MHz–15 GHz. This study will combine the theoretical prediction of radio emission with observation and carry out the research on two topics: 1) Study the flux spectrum, brightness temperature spectrum, and distribution across the solar disk of radio quiet-Sun, in using of the standard solar model plus spicules model, and consider the refraction and scattering; 2) Based on the first topic, we go on study the relationship between the radio emission and ultraviolet observation of the different region on the solar disk by using the differential emission measure. The report will give primary result of our study.

IV-5. Solar Radio Physics and MHD

K. Shibasaki (Solar Physics Research)

Circularly polarized radio waves interact with charged particles in magnetic field even under highly collisional chromosphere. This nature is used to measure chromospheric magnetic field. However, the standard MHD theory assume that charged particles are not magnetized due to frequent interruption of gyration. Hence, magnetic moment of plasma is not included in MHD. In this talk, it is shown that magnetic moment does not disappear even under highly collisional condition and that a new MHD is needed to understand behavior of plasma in the solar atmosphere.

I-P1. Expanded Owens Valley Solar Array

D. Gary (NJIT)

I–P2. HF - UHF Solar radio telescopes in Tohoku Univ. : Introduction of the system and science results

H. Misawa, F. Tsuchiya, K. Iwai, K. Kaneda, Y. Katoh, S. Masuda, Y. Miyoshi and T. Obara

We have made observations of solar radio bursts using AMATERAS in the VHF-UHF range since 2010 and a newly developed radio telescope in the HF-VHF range since 2014, both of which are located in the Tohoku district, Japan. In this presentation, we will introduce instrumental characteristics of the radio telescopes and some science results observed with them.

II–P1. Search for signs of electron pitch-angle anisotropy using the observed polarization degree distribution along microwave flare loops: a statistical study

A. Morgachev, S. (Pulkovo Observatory, RRI of Lobachevsky University), V. Melnikov (Pulkovo Observatory), S. Kuznetsov (Pulkovo Observatory, RRI of Lobachevsky University)

We have performed an analysis of the polarization degree and radio brightness distributions for more than 40 events using data of Nobeyama Radioheliograph. It is shown, that in six flares the observed microwave emission is polarized in the ordinary mode in some parts of the flare loops. A combined analysis of photosphere magnetic field maps from HMI/SDO, MDI/SOHO instruments and radio emission dynamics in different parts of the flare loops is fulfilled. On the basis of this analysis, we have concluded that, in the selected events, the ordinary mode domination can be associated with the longitudinal pith-angle anisotropy of emitting electrons.

II–P2. Modeling the Distribution of Circular Polarization Degree of Microwave Emission along the Flaring Loop in the event of July 19, 2012

S.A. Kuznetsov (Pulkovo Observatory, RRI), A.S. Morgachev (Pulkovo Observatory, RRI), F.V. Melnikov (Pulkovo Observatory)

The distribution of the degree of circular polarization of microwave emission along the solar flare loops during the event on July 19, 2012 observed with the Nobeyama Radioheliograph has been analyzed. It is found that the polarization degree in the loop footpoints remains negative (R–L < 0) during the entire burst. At the upper part of the flare loop, the polarization is inverse with respect to the footpoints (R–L > 0) and also does not change over time. In the northern and southern legs of the loop, the polarization degree sign changes over time. The proposed explanation of this effect is based on modeling the kinetics of nonthermal electrons and the calculation of their gyrosynchrotron (GS) emission for the model loop located on the solar limb. It is shown that the observed change of the polarization sign in space and time can be caused by the presence of longitudinal anisotropy of energy electrons in the upper part of the flare loop.

II–P3. Properties of Gyrosynchrotron Emission in a Shrinking Flaring Loop

V.F. Melnikov (Pulkovo Observatory),L.V. Filatov (NNGASU)

Shrinking flaring loops recently became a popular topic in the solar flare physics. The flare loop shrinkage has not been predicted by so called the standard solar flare model. The standard model predicts just the opposite behavior, namely the expansion of a system of flaring loops during the flare development. The purpose of our work is modeling the microwave emission of such loops and comparing the obtained properties with the observed ones.

First of all we model the dynamics of various parameters of nonthermal electrons injected into a non-stationary shrinking magnetic trap. The electron energy and pitch angle non-stationary spatial distributions in an extensive inhomogeneous magnetic trap have been obtained by numerically solving the non-stationary Fokker–Planck kinetic equation. It is shown that the high energy electrons are effectively accumulated and accelerated at the top of the shrinking trap due to the first order Fermi and betatron acceleration mechanisms. Spatial and temporal properties of gyrosynchrotron emission characteristics have been calculated for the obtained electron distributions. Specifically, the obtained solutions make it possible to explain the radio brightness peak that is frequently observed at the top of solar flare loops. Also, we found unexpectedly long time delays between emission light curves from the looptop and footpoint regions. The properties obtained are compared with the properties of the shrinking microwave loops for some flares observed with Nobeyama Radioheliograph.

II-P4. Polarization Characteristics of Zebra Patterns in Type IV Solar Radio Bursts and a Possible Mechanism of Depolarization

K. Kaneda, H. Misawa, K. Iwai, F. Tsuchiya, T.Obara, Y. Katoh, and S. Masuda

Zebra Patterns (ZPs) are one of the fine structures observed in type IV solar radio bursts. We investigated the polarization characteristics of 21 ZP events observed with AMATERAS. In this presentation, we will show the obtained results and suggest a possible mechanism of depolarization.

III-P1. Spatio-temporal evolution of sources of HXR and microwave pulsations in a solar flare observed with the RHESSI, NoRH and AIA/SDO

S.A. Kuznetsov (Pulkovo Observatory, RRI), I.V. Zimovets (Space Research Institute), V.F.Melnikov (Pulkovo Observatory)

Spatial dynamics of sources of HXR and microwave pulsations for SOL2011-06-07 06:25UT event has studied using the RHESSI and NoRH data. We have found that HXR sources change their positions from peak to peak of HXR pulses. The character of movement of HXR sources is predominantly longitudinal relatively to magnetic polarity inversion line (MPIL). EUV images made with the SDO/AIA data show appearance and evolution of two ribbons in the flaring region and eruption of a magnetic flux rope. The results of analysis of spatio-temporal evolution of sources from radio images at 34 GHz (NoRH) are in a good agreement with the results of analysis of HXR and EUV images. It has been shown that the center of radio brightness temperature at 34 GHz changes the position along the MPIL during the event. Our observational results put some constraints on the models of HXR and microwave pulsations in solar flares. One of the possible explanations of the dynamics of the emission sources is a successive involvement of new flux tubes (loops) into the energy release process due to the interaction of different parts of an eruptive flux rope with the ambient magnetic field.

III−P2. Microwave observations of a large-scale coronal wave with the Nobeyama radioheliograph

A. Warmuth, K. Shibasaki, K. Iwai, and G. Mann

Large-scale globally propagating waves in the solar corona have been studied extensively, mainly using EUV observations. In a few events, corresponding wave signatures have been detected in microwave radioheliograms provided by the Nobeyama radioheliograph (NoRH). Several aspects of these observations seem to contradict the conclusions drawn from EUV observations. We investigate whether the microwave observations of global waves are consistent with previous findings.

We revisit the wave of 1997 Sep 24, which is still the best-defined event in microwaves. We obtain radioheliograms at 17 and 34 GHz from NoRH and study the morphology, kinematics, perturbation profile evolution, and emission mechanism of the propagating microwave signatures.

We find that the NoRH wave signatures are morphologically consistent with both the associated coronal wave as observed by SOHO/EIT and the Moreton wave seen in H alpha. The NoRH wave is clearly decelerating, which is what is typically found for large-amplitude coronal waves associated with Moreton waves, and its kinematical curve is consistent with the EIT wavefronts. The perturbation profile shows a pronounced decrease in amplitude. Based on the derivation of the spectral index of the excess microwave emission, we conclude that the NoRH wave is due to optically thick free-free bremsstrahlung from the chromosphere.

The wavefronts seen in microwave radioheliograms are chromospheric signatures of coronal waves, and their characteristics support the interpretation of coronal waves as large-amplitude fast-mode MHD waves or shocks.

IV−P1. Chromospheric Sunspots in the Millimeter Range as Observed by the Nobeyama Radioheliograph

S. Miyawaki(Ibaraki University), K. Iwai(Nict), K. Shibasaki, D. Shiota(Nagoya University), and S. Nozawa(Ibaraki University)

We estimated the accuracy of coronal magnetic fields derived from radio observations by comparing them to potential field calculations and the differential emission measure measurements using EUV observations. The upper limits of the coronal longitudinal magnetic fields were determined as 100-210 G. We also calculated the coronal longitudinal magnetic fields from the potential field extrapolation using the photospheric magnetic field obtained from the Helioseismic and Magnetic Imager. This discrepancy between the potential and the observed magnetic field strengths can be explained consistently by two reasons: (1) the underestimation of the coronal emission measure resulting from the limitation of the temperature range of the EUV observations, and (2) the underestimation of the coronal magnetic field resulting from the potential field assumption.