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## Combined Radio and Space-based Solar Observations: From Techniques to New Results - Preface

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**Abstract** The phenomena observed at the Sun have a variety of unique radio signatures that can be used to diagnose the processes in the solar atmosphere. The insights provided by radio observations are further enhanced when they are combined with observations from space-based telescopes. This special issue demonstrates the power of combination methodology at work and provides new results on i) type I solar radio bursts and thermal emission to study active regions; ii) type II and IV bursts to better understand the structure of coronal mass ejections; iii) non-thermal gyro-synchrotron and/or type III bursts to improve characterization of particle acceleration in solar flares. The ongoing improvements in time, frequency, and spatial resolutions of ground-based telescopes reveal new levels of solar phenomena complexity and pose new questions.

**Keywords:** Radio Bursts; Flares; Active Regions; Corona; Coronal Mass Ejections

CESRA, the Community of European Solar Radio Astronomers<sup>1</sup>, organizes triennial workshops on the investigations of the solar atmosphere processes using radio and other observations. The 2016 workshop<sup>2</sup> had a special emphasis on the complementarity of the current and future space-based observations with the ground-based radio observations. It was the place to discuss the new exciting science opportunities that arise from the radio instruments like the Atacama Large Millimeter/submillimeter Array (ALMA<sup>3</sup>), the Expanded Owens Valley

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<sup>1</sup>See webpage <http://cesra.net>.

<sup>2</sup>See <http://cesra2016.sciencesconf.org>.

<sup>3</sup>See <http://www.almaobservatory.org>.

Solar Array (EOVSA<sup>4</sup>), the Expanded Very Large Array (EVLA<sup>5</sup>), the Low Frequency array (LOFAR<sup>6</sup>), the Mingantu Spectral Radioheliograph (MUSER, see Yan *et al.*, 2009, for details), and the developments of the Square Kilometer Array (SKA<sup>7</sup>). The workshop discussions have focussed on particle acceleration and transport, the radio diagnostics of coronal mass ejections, fine structures in solar radio bursts and the radio aspects of space weather and this volume provides a snapshot of the developments and challenges discussed during the workshop. This topical issue covers four sub-topics:

1. Solar Radio Emission Modelling (Lyubchik *et al.*, 2017; Rodger and Labrosse, 2017; Stupishin *et al.*, 2018; Zaitsev and Stepanov, 2017)
2. Solar Flares and Solar Energetic Particles (Anastasiadis *et al.*, 2017; Benz, Battaglia, and Güdel, 2017; Altyntsev *et al.*, 2017)
3. Fine Structures in Solar Radio Emission (Mohan and Oberoi, 2017; Mugundhan, Hariharan, and Ramesh, 2017)
4. Coronal Mass Ejections (Al-Hamadani, Pohjolainen, and Valtonen, 2017; Kumari *et al.*, 2017; Long *et al.*, 2017; Melnik *et al.*, 2018; Miteva, Samwel, and Costa-Duarte, 2018)

### Solar radio emission modelling

The complexity of the solar atmosphere as well as the increasing quality of solar radio observations necessitates the development of new more complex models. The modeling of solar atmosphere parameters above sunspots using RATAN-600 microwave observations (Stupishin *et al.*, 2018) inferred the upper transition-region structure of sunspots. The method presented is based on iterative correction of the temperature-height profile in the transition region and lower corona allowing to test time-independent models of density and temperature as a function of height. Anticipating the future observations in the sub-THz range, Rodger and Labrosse (2017) studied how the ratio of brightness temperatures at two frequencies can be used to estimate the optical thickness and the emission measure for prominences. Highlighting that there is no generally accepted theory explaining high brightness temperatures in type I storms, Lyubchik *et al.* (2017) proposed a new model to explain type I solar radio bursts associated with active regions. The model is based on the turbulence of kinetic-scale Alfvén waves that produce an asymmetric plateau in the electron velocity and a high level of Langmuir waves leading to plasma emission. The model proposed by Zaitsev and Stepanov (2017) suggests that the electron acceleration and storage of energetic particles in solar magnetic loops can be better explained by a mechanism based on oscillations of the electric current. Specifically, the model aims to explain synchronous pulsation in a wide frequency interval that is hard to achieve by the sausage and kink MHD modes.

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<sup>4</sup>See <http://ovsa.njit.edu>.

<sup>5</sup>See <http://www.aoc.nrao.edu/evla/>.

<sup>6</sup>See <http://www.lofar.org>.

<sup>7</sup>See <https://www.skatelescope.org>.

## Solar flares and Solar Energetic Particles

Solar flares are well-known for the efficient acceleration of non-thermal electrons and hence being a source of various solar radio bursts (see Nindos *et al.*, 2008, for a review). However, Benz, Battaglia, and Güdel (2017) have demonstrated that there are exceptions to this rule and presented observations of a radio-quiet solar pre-flare, which suggests that acceleration to relativistic energies, if any, should be occurring with low efficiency and does not lead to observable radio emission. Studying optically thin gyrosynchrotron emission, Altyntsev *et al.* (2017) reported an unusual flare, where the emission displays an apparently ordinary mode polarization in contrast to the classical theory that favors the extraordinary mode. This apparent ordinary wave emission in the optically thin mode has been attributed to radio wave propagation across the quasi-transverse layer that changes the radio-wave polarization.

Solar flares are often associated with the energetic particle events (SEPs) observed near the Earth. These SEP events are an important element of space weather and there is a growing interest in development of reliable forecasting systems. Anastasiadis *et al.* (2017) presented an integrated prediction system for solar flares and SEP events. The system is based on statistical methods and demonstrated promising results for the expected SEP characteristics.

## Fine Structures in Solar Radio Emission

The high frequency resolution solar radio telescopes have enabled the detailed imaging and spectroscopic studies of the fine structures of solar radio emission (Kontar *et al.*, 2017). For example, type III bursts that sometimes show fine structures (stria) in dynamic spectra (de La Noe and Boischot, 1972) can be used to study density fluctuations. Assuming that the individual stria bandwidth are determined by the amplitude of density fluctuations, Mugundhan, Hariharan, and Ramesh (2017) used the striations in a type III radio burst to determine the electron density variations along the path of the electron beams. The observations of solar bursts in time, frequency and two spatial coordinates naturally lead to 4D data. Using the Murchison Widefield Array (MWA<sup>8</sup>) radio telescope data, Mohan and Oberoi (2017) implement a formalism to generate 4D data cubes based on brightness temperature maps.

## Coronal Mass Ejections

Coronal Mass Ejections (CMEs) are often associated with type II and type IV radio bursts observed over wide radio frequency range. Simultaneous, radio and white-light observations of CMEs can be used to poorly constrained strength of the solar coronal magnetic field above  $\approx 2R_{\odot}$  (Kumari *et al.*, 2017). Assuming

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<sup>8</sup>See <http://www.mwatelescope.org/>.

plasma emission mechanism in type IV radio burst associated with a behind-the-limb CME, Melnik *et al.* (2018) have estimated the densities of plasma in the core of the CME. However, the relation between CMEs, global EUV waves and type II solar is not always clear. Long *et al.* (2017) studied over 160 global EIT waves observed in EUV and found no clear relationship between global waves and type II radio bursts. The relation between CMEs and type II is even more complicated when the Sun launches multiple CMEs. Al-Hamadani, Pohjolainen, and Valtonen (2017) studied type II solar radio bursts occurred during a multiple coronal mass ejection event and demonstrated that the last type II burst had enhanced emission in a wider bandwidth, which should be consistent with the CME-CME interaction. To understand the physics of the relation between the phenomena at the Sun and the satellite damaging proton events at 1 AU, identification of solar flares CMEs responsible for the proton events is required. The statistical relationships found by Miteva, Samwel, and Costa-Duarte (2018) serve as a useful tool to diagnose the dependencies and test solar flare and CME models.

The CESRA 2016 workshop took place in Orléans, France. The members of the Scientific Organizing Committee were M. Bartà (Czech Republic), K.-L. Klein (France; co-chair), E.P. Kontar (UK), M. Kretzschmar (France; co-chair), C. Marqué (Belgium), A. Nindos (Greece), S. Pohjolainen (Finland; co-chair), A. Warmuth (Germany), and M.K. Georgoulis (Greece; as president of the European Solar Physics Division). The workshop received financial support from the University of Orléans, the Observatoire de Paris, and the CNRS/INSU.

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