Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Quantifying weak non-thermal meterwave solar emission using non-imaging techniques

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An improved understanding of the solar corona is crucial for making progress on long-standing problems like coronal heating and the origin of the solar wind. Metrewave radio emissions arise in the coronal regions and form a unique diagnostic probe of this, otherwise hard to study region. The background radio emission at these wavelengths comes from the slowly varying thermal free-free emission and on it are superposed a variety of nonthermal emissions arising from a range of plasma emission processes. The latter are coherent in nature and hence lead to a much larger observational contrast, as compared to that in EUV or X-ray, for emissions involving similar energetics. One of the prevalent hypotheses for explaining coronal heating is based on the presence of an energetically weak population of 'nanoflares' (Parker 1988). A necessary requirement for nanoflares based coronal heating to be effective is that their occurrence rate slopes must be $<$-2 (Hudson 1991). There is hence a lot of interest in studies of weak nonthermal emissions. Existing studies in EUV and X-ray bands have detected 'microflares' with slopes $>$-2 (e.g. Hannah *et al.* 2011). Some of the weak meterwave emissions detected are, however, believed to correspond to energies in the 'picoflare' range (Ramesh *et al.* 2013). It is hence, very interesting to study weak nonthermal emissions at metric wavelengths.

Though the importance of metric solar observations has been known for a long time, the Sun is a challenging radio source to study. The metric solar emissions show structures at small spectral (order MHz) and temporal (sub-second) scales, which are accompanied by corresponding changes in the solar images. To follow the details of these emissions in their full glory, one needs a high-fidelity spectroscopic snapshot imaging capability, which had till recently simply not been available. The new generation of interferometers, like the Murchison Widefield Array (MWA), represents a significant step forward in meeting the needs of solar imaging (Tingay *et al.* 2013). MWA observations have already demonstrated the presence of numerous weak, narrow-band and short-lived impulsive emission features, even during quiet times (Oberoi *et al.* 2011). Here we briefly describe our non-imaging investigations of these weak emission features. A complete overview of solar science efforts with MWA data is described in Oberoi *et al.* (this volume). The new generation arrays produce very large data volumes ($\sim$1 TB/hr) and traditional interferometric analysis is very human effort and computation intensive. An automated imaging pipeline for harnessing these science-rich data is described by Mondal *et al.* (this volume).

The first requirement for characterising these weak features is a robust flux calibration. The highly variable solar emission and the Sun being much brighter than typical calibrator sources make this a non-trivial task. We have devised a computationally lean flux calibration technique (Oberoi *et al.* 2017) to meet these challenges. It uses <0.1% of the total interferometric dataset and enables us to estimate the integrated solar flux densities across the 100–300 MHz band with uncertainties comparable to, or better than, most existing techniques. This technique has been implemented as a Python-based pipeline and its output forms the starting point for further analysis discussed here. We briefly summarise our attempts to characterise a few different aspects of these weak nonthermal features. Sharma *et al.* (2018) quantify the flux density and prevalence of these features. The observed dynamic spectra (DS) were first decomposed into impulsive and slowly varying components using a median filter. During periods of low solar activity, one expects the slowly varying emission to be dominated by thermal coronal emission, while the impulsive emissions must arise from nonthermal processes. We analysed an hour of MWA data under conditions of moderate solar activity using a method based on a class of statistical data models called Gaussian mixture models (GMM). GMM modelled the distribution of impulsive flux densities as a superposition of one thermal component and multiple components corresponding to nonthermal emissions. Using this to estimate their flux densities we found, somewhat surprisingly, that the flux densities of the impulsive components were very similar to those for the slowly varying component. The impulsive features were found to have a prevalence, or fractional occupancy, ranging from 17–45%, even during moderately quiet times. Going down to 0.2 SFU, the nonthermal emissions identified here are the weakest reported yet. Estimates of occurrence rate slopes of the impulsive emissions lie between -1.47 and -2.35. Though more data needs to be analysed to arrive at statistically stable estimates, we note that for some of the frequency bands, these slopes meet the criterion for nanoflare based coronal heating.

We have also characterised the morphology of these weak nonthermal features in the observed DS. This was accomplished using a robust automated wavelet-based feature detection technique developed by Suresh *et al.* (2017). A total of 14,177 impulsive features were detected in about 4.5 hours of observations. Their typical bandwidths and durations lie between 4–5 MHz and 1–2 s respectively. The occurrence slopes of their peak flux densities were found to be -2.23 in the range 12–155 SFU.

The data from the MWA have enabled us to explore new and interesting phase space. Our work has lead to the detection of the weakest nonthermal emissions yet, and the realisation that the energy radiated in the nonthermal impulsive emissions can be comparable to that of the slowly varying thermal emissions. The characterisations of weak nonthermal features in terms of their morphology in the DS, flux density distributions and prevalence should serve as useful clues for their origin. We are now pursuing imaging studies of such emissions to explore their associations with other solar features. We hope that our work will spur greater interest in the community to work on studying such emissions.

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