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# Radio Observations for Space Weather

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## Abstract

Observations of radio emissions from physical processes occurring in the Heliosphere provide fundamental tiles for building up the phenomenological scenario of Space Weather perturbations. In this context, we will briefly review solar and heliospheric radio emissions by focussing on the role of dedicated and non-dedicated new-generation radio instruments.

## 1 Introduction

Space Weather at the Earth and in planetary environments is determined by a complex series of nonlinearly coupled physical phenomena, that occur at different spatial, temporal, and energy scales. Hence, the perspective of Space Weather science must include multi-scale observations and modelling from the Universe to the Heliosphere and Solar System [1]. In fact, Heliospheric Weather and Climate, i.e., the short- and long-term behaviour of the physical state of the Heliosphere, are determined both by inner sources and by outer ones like, e.g., Cosmic Rays and Gamma Ray Bursts (Figure 1). The relevant plasma processes originate a set of radio emissions (Figure 2), which can be fruitfully used as plasma probes by reverse modelling. Solar Radio Weather is the most studied phenomenology (see, e.g., [3, 4, 5]). Possible radio diagnostics for Space Weather were considered, e.g., in [6] as schematised in Figure 3.

## 2 Radio Observations for Space Weather

Figure 3 makes evident that radio emissions span an extended range of frequencies from a few kHz to tens GHz. In fact Solar Radio Weather manifests from 37 Ghz to 10 MHz, whereas Interplanetary Radio Weather from 1 MHz to 50 kHz. Hence, as stressed in [6], diachronic radio observations from the ground and from space that cover these frequency bands are a must both for Space Weather science and for Space Weather operations. For monitoring purposes, solar radio observations must be carried out by dedicated solar radio instruments that operate a continuous surveillance, providing radio indices, single-frequency radio flux density and polarisation, radio spectra [6] and radio images time series in near-real-time. In fact, only this approach can provide a timely and comprehensive Solar and Interplanetary Radio Weather scenario, characterised by the identification of radio precursors (if any), radio proxies for X and UV radiation to the planetary thermospheres, and solar radio frequency interferences to radio communications and GNSS receivers. Most of these impacts are relevant to both civil and military frameworks (see, e.g., [6, 8]).

## 3 Radio Observatories for Space Weather

As an update of what reported in [6], Figure 4 depicts the geographical distribution of dedicated solar radio spectrometers, spectrographs, multi-channel radio polarimeters, and interferometers. The USAF Radio Solar Telescope Network sites are indicated as well. To avoid an excessive crowding, the e-Callisto solar radio spectrograph network [9], constituted by more than 70 instruments, is not reported in this figure, despite that it is an excellent distributed facility for solar radio monitoring. Despite the large number of facilities and the good frequency band coverage, they do not represent an optimal set because of their specific features, like, e.g., no circular polarisation measurement, and non-homogeneous distribution in longitude. To have a better performing system for effective Solar Radio Weather monitoring, these limitations have to be overcome by national efforts under international collaboration. Figure 5 depicts the geographical distribution of dedicated solar spectropolarimetric and imaging instruments and non-dedicated radio instruments that can be used for solar imaging and spectropolarimetry. The Atacama Large Millimeter/Submillimeter Array has been used for solar radio observations [10], but is not reported in this figure. Non-dedicated facilities, like the Italian INAF-ASI single dish instruments can provide synoptic images and high resolution region mapping [11]. The Low-Frequency Array (LOFAR) has been explored for Space Weather observations and its upgrade for this purpose is in progress. The Square Kilometre Array (SKA) is being considered for Space Weather observations as well. Anyway, such large instruments can certainly be used for Radio Weather science, but it is quite complex to set up them for Radio Weathering monitoring.

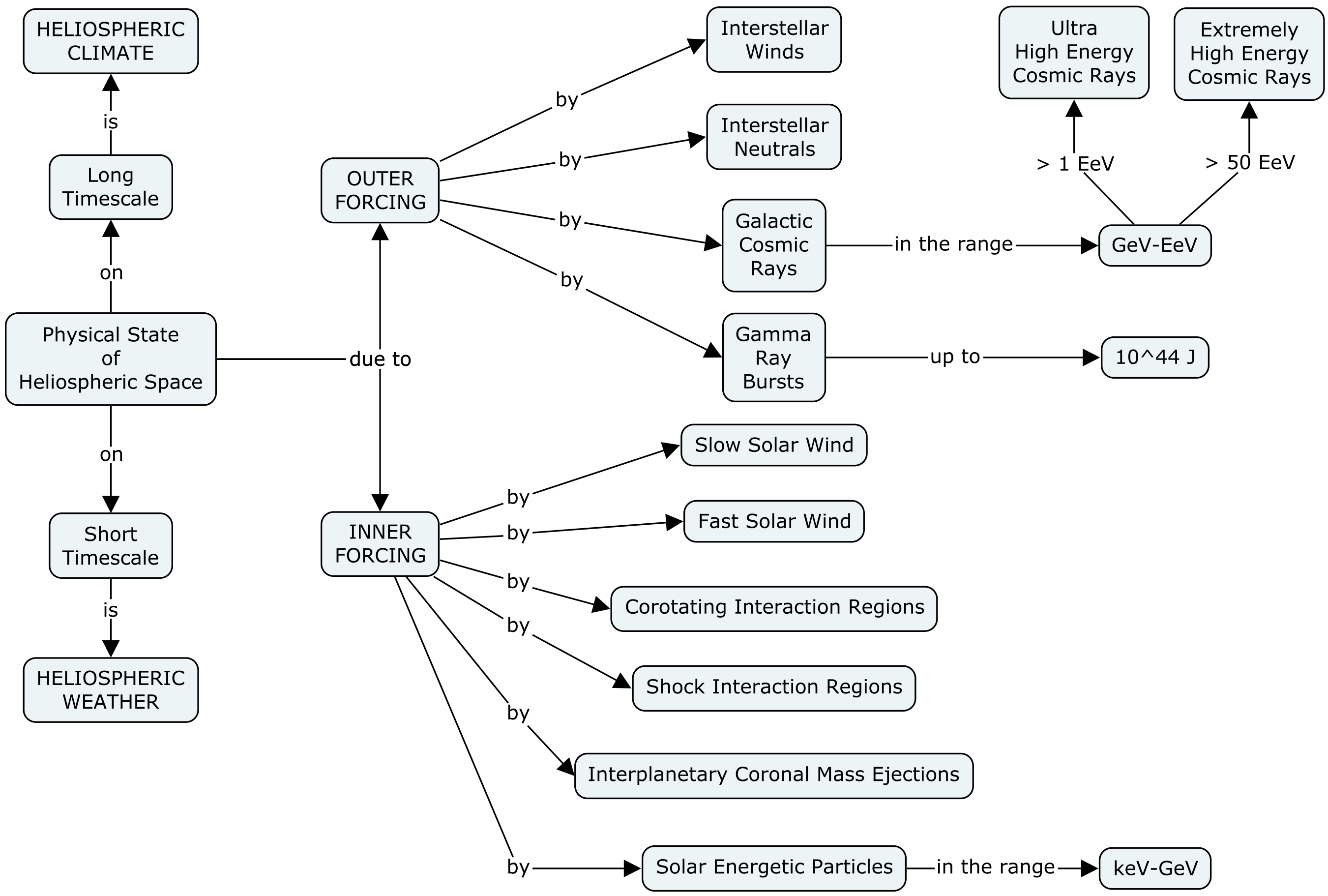


**Figure 1.** Inner and outer forcing of Heliospheric Weather and Climate [1].

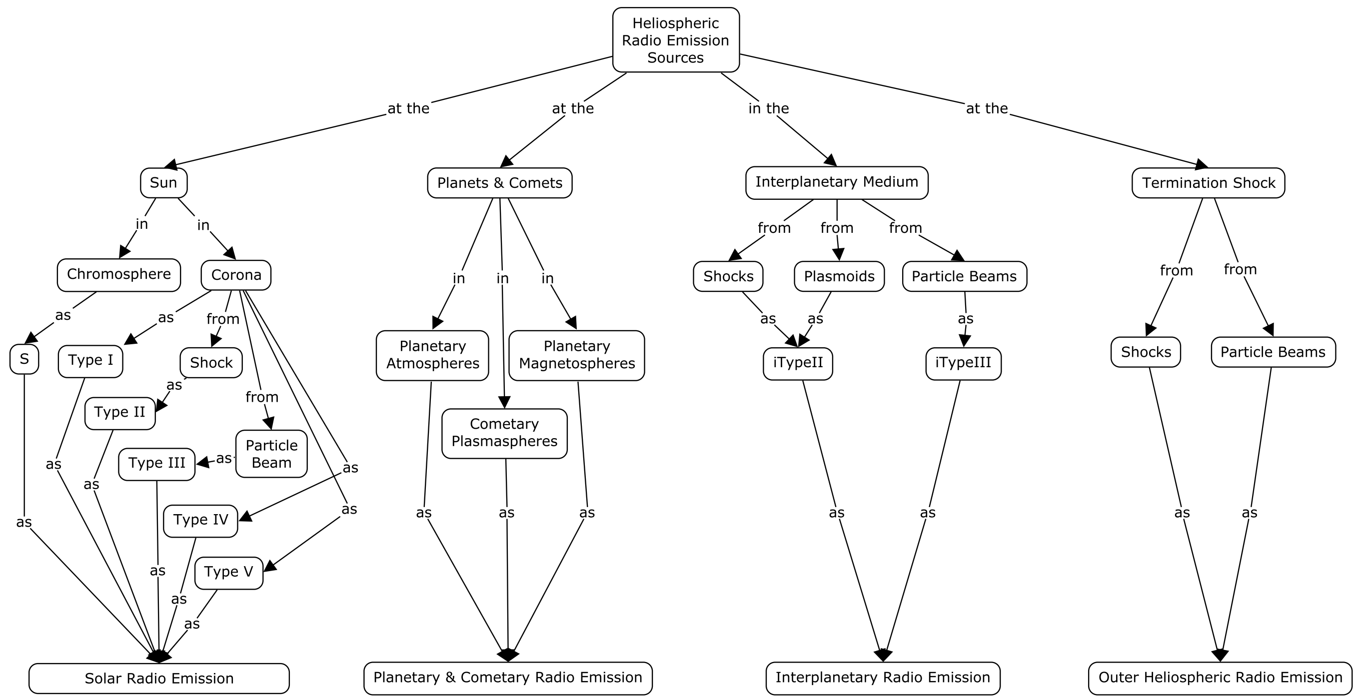


**Figure 2.** Synopsis of heliospheric radio emission sources [2].

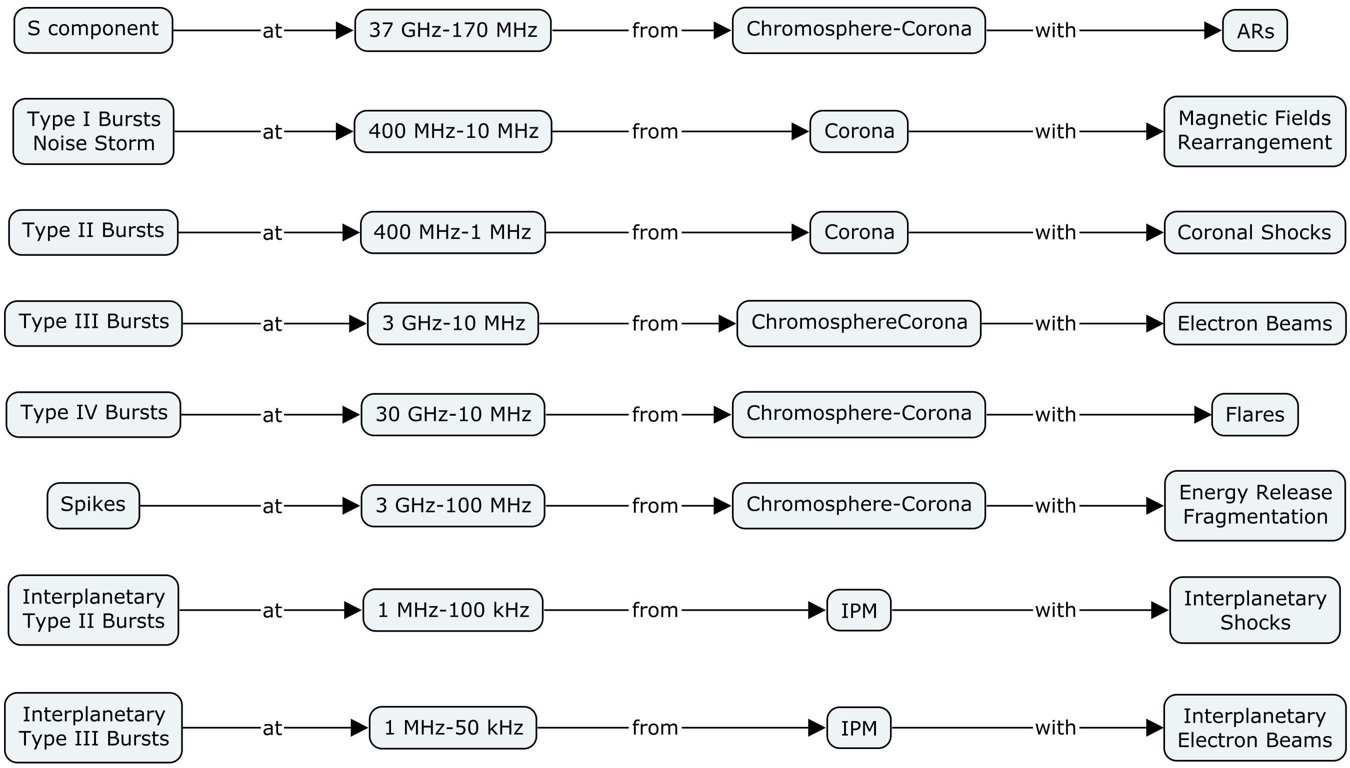


**Figure 3.** Scheme of solar and interplanetary radio emission and the relevant diagnostics [6].

## 4 Conclusions

Existing solar radio facilities provide a good frequency coverage. The use of large instruments has to be elaborated on.

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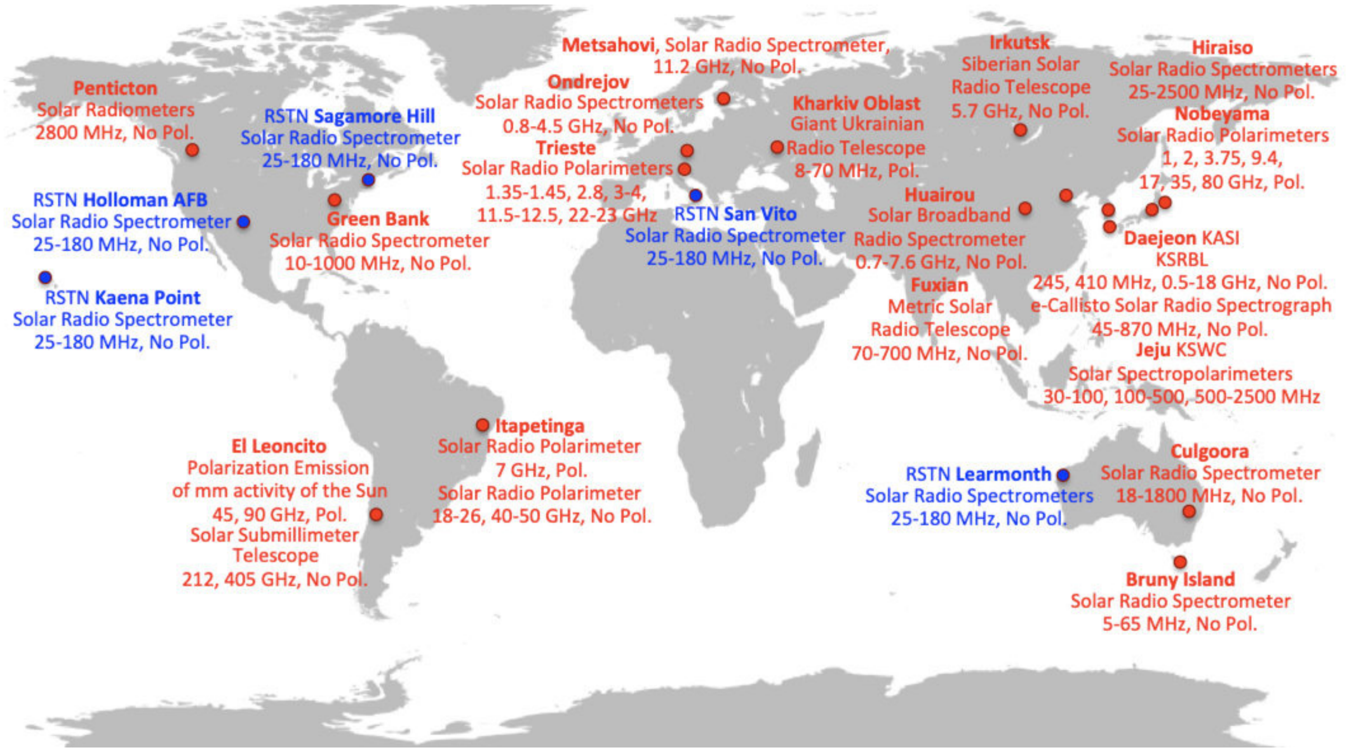


**Figure 4.** Geographical distribution of dedicated solar radio spectrometers, spectrographs, multi-channel radio polarimeters, and interferometers (highlighted in red). The USAF Radio Solar Telescope Network (RSTN) is highlighted in blue. (Updated from [6].)

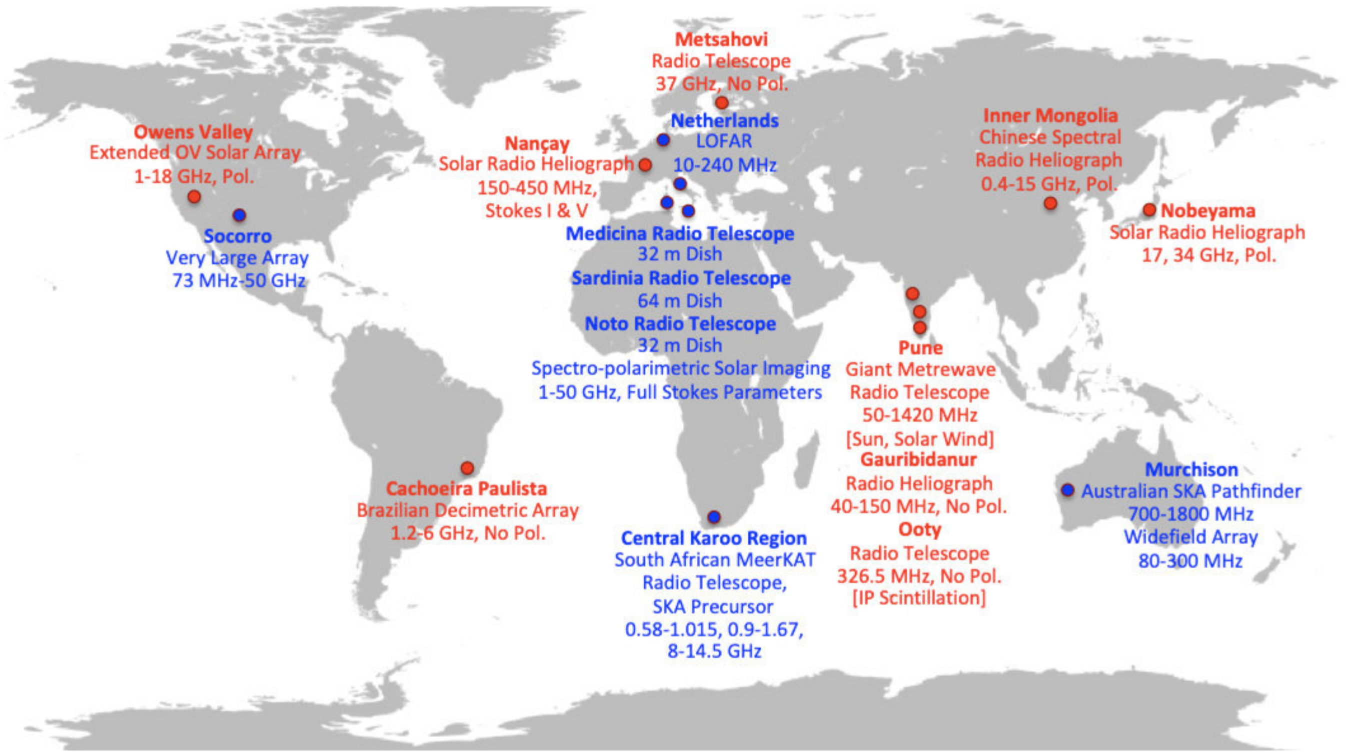


**Figure 5.** Geographical distribution of dedicated solar spectropolarimetric and imaging instruments (highlighted in red) and non-dedicated radio instruments that can be used for solar imaging and spectropolarimetry (highlighted in blue). (Updated from [6].)