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Radio emission from the Sun, planets, and the interplanetary medium

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Abstract. A brief review is given of radio phenomena on the Sun, the planet Jupiter, and the interplanetary medium and its outer boundary. A brief aside is made to draw parallels between radio emission from Jupiter and extrasolar planets.

Keywords. instrumentation: interferometers, instrumentation: spectrographs, radio continuum: solar system, Sun: radio emission, Sun: activity, solar system: planets (Jupiter), interplanetary medium

1. Introduction

Radio emission from the Sun, planets, and the interplanetary medium (IPM) have been studied for decades. Indeed, early solar observations formed the underpinnings of modern radio astronomy. Interest in low frequency radio emission from the solar system remains strong. A lack of space prevents more than a passing mention of several topics of current interest; citations likewise draw attention to only a very small part of the relevant literature.

2. Instrumentation

A large number of both ground and space based low-frequency instruments are available for observations of the Sun, planetary emissions, and the IPM. Ground-based interferometric arrays include the Ukrainian T-shaped Radiotelescope (UTR-2, 10 - 25 MHz; Ukraine), the Nançay Radioheliograph (150 - 450 MHz; France), the Guaribidanur Radioheliograph (40 - 150 MHz; India), the Giant Meter-wavelength Radio Telescope (150, 235, 327 MHz; India), and the VLA (74, 327 MHz; USA). Spectrographs too numerous to list individually are available around the world and provide dynamic spectra of active solar phenomena. The most recent addition (White *et al.* 2006) is the Green Bank Solar Radio Burst Spectrometer (10 - 1050 MHz; USA). In space, both the Ulysses URAP instrument, operating from 1.25 - 940 kHz, and the WIND/WAVES spectrometers, operating from 20 kHz to 13.8 MHz, continue to provide dynamic spectroscopy. In the near future, the Frequency Agile Solar Radiotelescope (50 MHz to 20 GHz), the Miluera Widefield Array (80 - 300 MHz), and the Long Wavelength Array (20 - 80 MHz) will become available on the ground and STEREO/WAVES (10 kHz to 16.1 MHz, plus 50 MHz) will be available in space.

3. Relevant emission mechanisms

There are several emission mechanisms relevant to low frequency radio observations in the solar system that provide unique access to physical processes in the solar, planetary, and interplanetary (IP) environments (e.g., Bastian *et al.* 1998). These are thermal free-free emission (the quiet solar corona and planetary disks), plasma radiation (solar and IP radio bursts), synchrotron radiation (solar flares, coronal mass ejections, and magnetospheric emission), cyclotron maser emission (magnetospheric emissions), as well as other less well-established mechanisms.

4. Radio emission from the Sun and interplanetary medium

Radio emission from the in the meter and decameter wavelength range is particularly rich phenomenologically. It is in this wavelength range that the 'classical' solar radio bursts of Types I - V occur (e.g., McLean & Labrum 1985) in the solar corona. Bursts of Type II/IV and III have received particularly close attention in recent years due to their association with space weather phenomena. Type II bursts result from plasma radiation driven by a fast MHD shock propagating in the solar corona whereas Type IV emission is due to either plasma radiation and/or synchrotron radiation. The shock exciter may be flare ejecta (e.g., Gopalswamy *et al.* 1997), a flare blast wave (e.g., Vršnak *et al.* 2006), or a coronal mass ejection (CME, e.g., Cliver *et al.* 1999). Type III radio bursts, associated with coronal energy release, are due to plasma radiation driven by suprathermal elecron beams and are used as probes of particle acceleration in the IPM (e.g., Krucker *et al.* 1999). Long-duration IP Type IIIs are correlated with solar energetic particle events (Cane *et al.* 2002). Similarly, there are interplanetary analogs to coronal Type II radio bursts that are driven by fast CMEs. Recent theoretical work has emphasize their analogy to planetary bowshocks (e.g., Knock *et al.* 2001, 2003). Progress has been made in detecting thermal free-free (Kathaviran & Ramesh 2005) and synchrotron radiation signatures (Bastian *et al.* 2001; Maia *et al.* 2007) from CMEs in their nascent stages.

5. Radio emission from Jupiter

While all planets are thermal radio emitters, all magnetized planets are nonthermal radio emitters as well, with Jupiter the most prominent source among them. Since its discovery by Burke & Franklin (1955), Jupiter's radio emission has been studied through remote and *in situ* instrumentation. In addition to thermal emission from its planetary disk, there is synchrotron radiation from energetic electrons trapped in its magnetosphere (DIM), and complex, transient radio emissions caused by cyclotron maser emission at decameter wavelengths (DAM), the latter modulated by interactions between the magnetosphere and the Galilean satellites (chiefly Io), and the solar wind (Gurnett *et al.* 2002). Zarka (2004) presents a detailed review.

6. An aside: radio searches for exoplanets

Winglee *et al.* (1986) first pointed out possibility of detecting cyclotron maser emission from magnetized exoplanets and performed a blind search at 327 and 1400 MHz using the VLA. With discovery of *bone fide* planets by Mayor & Queloz (1995), Bastian *et al.* (2000) targeted six known exoplanets and two brown dwarfs at 74, 327, and 1400 MHz with the VLA. On the basis of the 'radiometric Bode's Law' (Desch & Kaiser 1984; Farrell *et al.* 1999), Zarka *et al.* (2001) suggested interaction of 'hot Jupiters' with stellar winds could produce emissions orders of magnitude stronger than Jupiter's (see also Lazio *et al.* 2004). Subsequent attempts to detect exoplanets (e.g., Farrell *et al.* 2003; Lazio *et al.* 2004), have failed. Nevertheless, if detections are eventually made the payoff would be high, for they could be used to measure the planet's rotation period, magnetic field, presence of satellites, their orbital periods, and more.

7. Radio emission from the outer limits

Radio emission from 2 - 3.4 kHz was detected by the Voyager-1 and -2 spacecraft during the period from 1983 - 1984 (Kurth *et al.* 1984), again from 1992 - 1994 (Gurnett *et al.* 1993), and most recently from 2002 - 2003. These emissions have been interpreted as plasma radiation from the heliopause beyond the termination shock of the heliosphere (Cairns & Zank 2002).

8. Concluding remarks

Low frequency observations of solar, planetary, and interplanetary phenomena allow a variety of phenomena – particle acceleration and transport, shock initiation and propagation, emission mechanisms, plasma physics – to be studied in detail. An exciting new generation of instrumentation will be constructed in the coming decade. The future of low frequency radiophysics of the solar system therefore looks extrementy promising.

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