Bioastronomy 2002: Life Among the Stars
IAU Symposium, Vol. 213, 2004
R.P.Norris and F.H.Stootman (eds.)

Radio Emission from Extrasolar Planets

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Abstract. By virtue of their planetary-scale magnetic fields, the Earth and all of the gas giants in our solar system possess solar-wind deformed magnetospheres. The magnetic polar regions of these "magnetic planets" produce intense, aurora-related radio emission from solar-wind powered electron currents. Simple scaling laws suggest that Jovian-mass planets close to their host stars should produce radio emission; detecting such emission would be the first direct detection of many of these planets. We describe searches using the Very Large Array (VLA) for radio emission from the planets orbiting HD 114762, 70 Vir, and τ Boo. Our limits are just above those predicted for the planetary emissions. We discuss the possibilities for more stringent limits and the implications that the existing observations have for the planets' radio emissions, and hence on the planetary magnetic fields and stellar wind environments.

1. Introduction

The Earth and gas giants of our solar system are referred to commonly as "magnetic planets" since they contain internal dynamo currents that are capable of generating a planetary-scale magnetic field. Blackett (1947) demonstrated that dynamo-driven fields are scalable, with a functional dependence on body mass, radius, and angular frequency. Since that time and with the inclusion of the Voyager magnetic field observations at the outer planets, numerous planetary magnetic field scaling laws have been derived, each expanding upon but maintaining some similarity to Blackett's Law.

A planet's magnetic field is immersed in the high-speed electrical gas emitted by the planet's star (Chapman & Ferraro 1931, 1932). This stellar wind deforms the shape of the planetary magnetic field, compressing the field on the front side and elongating the field on the backside, forming a "tear-dropped" shaped planetary magnetosphere aligned with the solar wind flow.

The incident stellar wind is also an energy source to the planetary magnetosphere. Via magnetic field reconnection, the magnetic field embedded in the solar wind can cancel the planetary magnetic field at the magnetospheric front and back sides. Generally the merging magnetic fields generate electrical currents (viz. Faraday's Law). Part of these reconnection-generated currents (i.e., electrons) flow along the planet's magnetic field lines, depositing their energy in the planetary auroral region. Approximately 1% of the energy in the current is dissipated through the emission of visible and IR aurorae, and 0.1–1% of the energy is dissipated via the generation of long-wavelength radio emission.

The magnetic polar regions of the Earth and solar gas giants are well-known sites of intense, aurora-related radio emission. The auroral radio power from Earth is of order 10^8 W while for Jupiter it can exceed 10^{10} W. The "radiometric Bode's Law" describes the correlation between the stellar wind input power and the planetary radio emission:

$$P \sim 4 \times 10^{11}\,\mathrm{W} \left(\frac{\omega}{10\,\mathrm{hr}}\right)^{0.79} \left(\frac{\mathrm{M}}{\mathrm{M_J}}\right)^{1.33} \left(\frac{\mathrm{d}}{5\,\mathrm{AU}}\right)^{-1.6} \tag{1}$$

Here P is the *median* output radio power, ω is the planet's rotation period, M is the planet's mass, and d is the planet-star distance; the quantities ω and M are surrogates for the planetary magnetic moment. We have normalized all quantities to those of Jupiter. In this form, the radiometric Bode's Law describes the median radio emission from the Earth and all of the solar gas giants, including the *non-Io driven* Jovian decametric radio emission (Zarka et al. 2001). Variability in the solar wind input power can increase these planetary radio power levels by a large factor ($> 10^3$).

2. Extrasolar Planets

The current census of extrasolar planets numbers over 100 (Schneider 2002) and includes an estimate of planetary mass and star-planet distance for each case. With one exception, however, all of the known extrasolar planets have been detected only indirectly, via their gravitational influences on their parent stars.

As can be seen from equation (1), a considerable enhancement of the radio power is expected from massive, rapidly-rotating planets close to their parent stars. By analogy to the magnetically-active planets in our solar system, we predicted therefore that these extrasolar planets may have electrically-active, steller-wind driven magnetospheres that are capable of emitting long-wavelength radio emission (Farrell et al. 1999; Zarka et al. 2001).

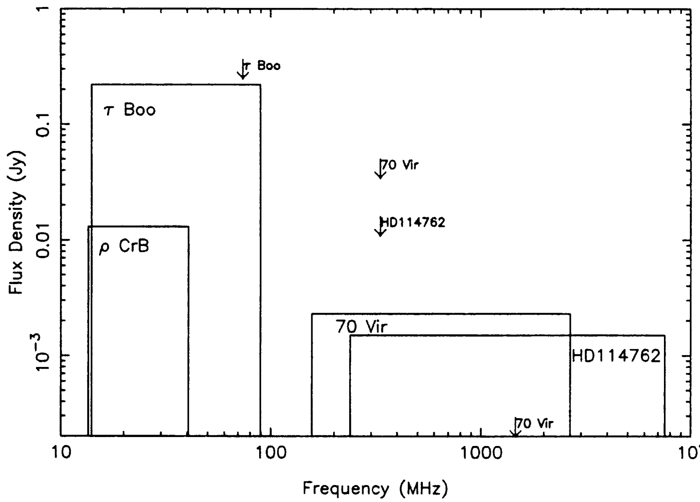

Figure 1. The model-predicted flux densities for the four planets with the largest predicted flux densities. Each rectangle represents the range of flux densities and frequencies due to possible variations in the stellar wind flux and uncertainties in the planetary magnetic moment. Also shown are the upper limits from Bastian et al. (2000, HD 114762 and 70 Vir) and this work (τ Boo); not shown is the upper limit of 7.8×10^{-5} Jy on the emission of HD 114762 at 1465 MHz. All of these upper limits are for the average emission on time scales of several hours; upper limits on short time scale bursts are typically 10–50 times higher. (1 Jy $\equiv 10^{-26}$ W m^{-2} Hz^{-1})

Unfortunately, in most cases the characteristic frequency of the emission (which is also related to the strength of the planet's magnetic field) is below the frequency at which the Earth's ionosphere becomes opaque to radio waves ($\approx$ 10 MHz). Figure 1 shows the predicted flux densities from the most likely candidates; these are the planets orbiting HD 114762, 70 Vir, and τ Boo.

3. Observational Results and Discussion

Based upon these predictions three observing campaigns have been carried out at the National Radio Astronomy Observatory's Very Large Array (VLA). The VLA consists of 27 radio antennas, each of 25 m diameter for the equivalent sensitivity of a 130-m single-dish antenna, aligned in a Y-shaped configuration with an effective resolution approaching that of an equivalent 36 km antenna.

Bastian et al. (2000) observed HD 114762 and 70 Vir, as well as a number of other stars with planetary companions for which our model does not predict measurable levels of emission. Their observations were primarily at 333 and 1465 MHz. In two observing campaigns (1999 June and 2002 May) we have observed τ Boo at 74 MHz.

https://doi.org/10.1017/S0074180900193003 Published online by Cambridge University Press

Figure 1 also shows the upper limits from these campaigns. In no case were any emissions detected, though, the upper limits are comparable to the levels expected.

The lack of detected emission may occur because the extrasolar planet was

- Not radiating when observed: Planetary radio emission in the solar system is sporadic and impulsive, in part due to solar wind variability. We have searched for bursts within our observations, though, the upper limits are less stringent than those in Figure 1. Nonetheless, if Jupiter were observed for a few hours at some arbitrary time, the probability of detecting it would be low.

- Radiating at drastically different frequencies: Assuming that the emission is strong enough to be detected, but occurs below the frequencies observed, we can infer a limit to the planetary magnetic dipole moment, m, of the extrasolar planet. Suppose that these planets do emit but below 74 MHz; this implies $m < 13$ G R_J, a limit similar to that for a Jovian planet.

- Too faint: For the planet orbiting τ Boo, the limit on planetary emission power is 10^{17} W. This upper limit is 10^5 times greater than that of Jupiter's emission. However, the planet has $M \simeq 4M_J$ and is 100 times closer to its parent star (0.05 AU). As such, we expect its nominal power to be roughly 10^4 times that of Jupiter or 10^{15} W. By analogy with solar wind variability, this nominal power can increase by another factor of 100. Our nondetection suggests that the measurements were made when τ Boo's stellar wind was quiescent.

Acknowledgments. The NRAO is a National Science Foundation facility operated under cooperative agreement by Associated Universities, Inc. Basic research in radio astronomy at the NRL is supported by the Office of Naval Research.

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