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► **To cite this version:**

Jean-Mathias Griessmeier, Jake Turner, Philippe Zarka, Iaroslavna Vasylieva. The search for exoplanetary radio emission: Jupiter as an exoplanet. EPSC-DPS Joint Meeting 2019, Sep 2019, Vienne, Switzerland. p.401-418. hal-03563829

HAL Id: hal-03563829

<https://hal.science/hal-03563829>

Submitted on 10 Feb 2022

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The search for exoplanetary radio emission: Jupiter as an exoplanet

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Abstract

In the solar system, the magnetized planets are strong radio emitters, the strongest emission being that generated at Jupiter. Theoretical studies suggest that the radio emission from nearby exoplanets could reach intensity levels 3-6 orders of magnitude higher than Jupiter's emission. Several campaigns have been led to search for this emission, but no confirmed detection has yet been reported. Published upper limits are usually based on the theoretical sensitivity of the radio telescope and do not take into account the sporadic nature of the emission. In this paper, we use the radio emission from Jupiter re-scale it for different emission intensity and planetary distance. With this, we determine at what emission intensity and distance our detection pipeline can still detect the emission. This allows us to realistically determine the detection limits for a given telescope and observation setup.

1. Introduction

The detection and characterization of exoplanetary magnetic fields would open a new window for exoplanet studies, allowing a better understanding of their formation and their evolution. For this reason, several methods have been suggested which could potentially detect magnetic fields of extrasolar planets. However, most of these methods are prone to false positive detections. This is not the case for planetary auroral radio emission. Therefore, the detection of exoplanetary radio emission can be considered to be one of the few methods which can unambiguously detect exoplanetary magnetic fields ([2]). Over the past decades, this has sparked a number of observational campaigns (see e.g. [3] for an overview), none of which has achieved a confirmed radio detection yet.

In parallel, a number of articles have attempted to estimate the radio flux density that can be expected for different types of exoplanets (starting with [6] and [1]). Indeed, according to most recent estimates, emission frequencies are compatible with the frequencies at which some radio telescopes of latest generation operate, and estimated flux densities are close to the sensitivity of these instruments. In particular, [3] find that the flux densities of 15 exoplanets are above the theoretical detection limit of LOFAR as given by [4]. With such encouraging radio predictions, radio observations of exoplanets are undertaken by most low-frequency radio telescopes.

2. Method

In this work, we concentrate on beam-formed observations using LOFAR (the Low-Frequency Array) in the LBA band (≤ 90 MHz). These observations have the advantage of a high time resolution, which can be used to localize and excise short and sporadic RFI precisely. They cannot reliably detect continuous or slowly varying emission, but excel at the detection of short bursty signals. In order to differentiate a physical signal from RFI, we use one ON-beam and two OFF-beams ([4]).

We record radio emission from Jupiter (the ON beam), scale it down in intensity and add it to one of the OFF beams. This combined beam ("Jupiter beam") is then compared to the second OFF beam ("OFF-Beam 2"). After RFI cleaning and data reduction (using the pipeline described by [4]), we produce a set of observables which allow us to search for exoplanetary radio emission (see Fig. 1 for an example).

We determine by how much we can attenuate Jupiter's signal before the detection pipeline does not detect any statistically significant difference between the "Jupiter beam" and the "OFF-Beam".

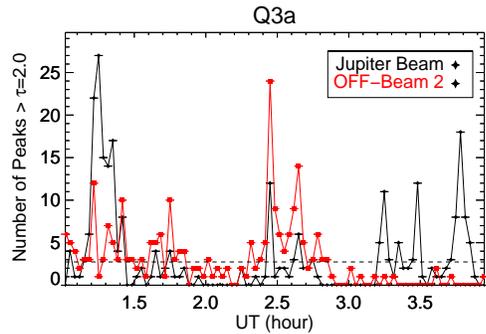


Figure 1: Number of radio emission peaks, compared between the ON-beam (Jupiter) and OFF-beam. Jupiter’s emission is mainly localized between 1.2–1.4 UT and 3.2–3.9 UT, whereas the bright emission between 2.3–2.8 UT can be seen in the ON and the OFF beam simultaneously.

3. Result

Applied to LOFAR beam-formed observations, we find that radio bursts from a planet at 5 pc could be detected if its radio flux is 10^6 times stronger than the typical level of Jupiter’s radio bursts during active emission events. Equivalently, planets at a distance of 20 pc can be detected assuming the level of emission is 10^6 times stronger than the peak flux of Jupiter’s decametric burst emission. We will describe how this detection limit can be improved by a modified observation setup.

4. Summary and Conclusions

Most published upper limits on exoplanetary radio emission are based on the theoretical sensitivity of a radio telescope, and do not take into account the

sporadic nature of the emission. We have developed a method to derive upper limits for a realistic situation and apply it to the case of beam-formed observations with LOFAR. We observe Jupiter, divide its signal by a fixed factor before adding it to an observation of “sky background”, thereby creating an artificial dataset best described as “Jupiter as an exoplanet”. We then run our data processing and signal detection pipeline and check whether the (attenuated) radio signal from Jupiter is detected. The maximum factor by which we can divide Jupiter’s signal and still achieve a detection gives the sensitivity of our setup (i.e. telescope plus processing chain).

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