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Jean-Mathias Grießmeier (1,2), Jake D. Turner (3), Philippe Zarka (4,2), Iaroslavna Iaroslavna (5)
(1) Laboratoire de Physique et Chimie de l'Environment et de l'Espace (LPC2E) Université d'Orléans/CNRS, Orléans, France
(2) Station de Radioastronomie de Nançay, Observatoire de Paris, PSL Research University, CNRS, Univ. Orléans, OSUC, 18330 Nançay, France
(3) Department of Astronomy, University of Virginia, VA, USA
(4) LESIA, Observatoire de Paris, CNRS, PSL, Meudon, France
(5) Institute of Radio Astronomy, National Academy of Sciences of Ukraine, Kharkov, Ukraine

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, scale it down in intensity, and determine at what intensity our detection pipeline can still detect the emission. With this method, we can determine the sensitivity of a given telescope and observation setup for a realistic situation.

1. Introduction

The detection and characterization of exoplanetary magnetic fields would open a new window, allowing a better understand of exoplanets, including 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 be one of the few method to 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 ($\leq$ 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 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 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 2". In this way, we can measure the effective sensitivity limit for

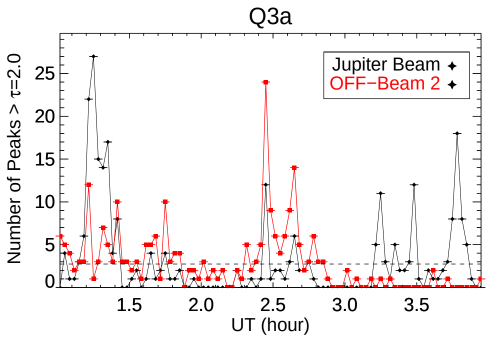

Figure 1: Number of radio emission peaks, compared between the ON-beam (Jupiter) and OFF-beam (observable quantity "Q3a"). Jupiter's emission is mainly localized between 1.2–1.4 UT and 3.2–3.9 UT, whereas the bright emission between 2.3–2.8 UT can be seen in the ON and the OFF beam simultaneously.

a given observational setup.

3. Result

Applied to LOFAR beam-formed observations, we find that radio bursts from a planet at 5 pc could be detected if the 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. This can probably still be improved by future modifications of our detection pipeline.

4. Summary and Conclusions

Usually, 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. In this paper, we describe a method how 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. the combination of the telescope and the processing chain).

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