SF2A 2021
A. Siebert, K. Baillié, E. Lagadec, N. Lagarde, J. Malzac, J.-B. Marquette, M. N'Diaye, J. Richard, O. Venot (eds)

THE SEARCH FOR RADIO EMISSION FROM EXTRASOLAR PLANETS USING LOFAR BEAM FORMED OBSERVATIONS

J.-M. Grießmeier[1,2], J. D. Turner[3,4] and P. Zarka[2,5]

Abstract. Observing planetary auroral radio emission is the most promising method to detect exoplanetary magnetospheres and magnetic fields, the knowledge of which will provide valuable insights into the planet's interior structure, atmospheric escape, and habitability. We present LOFAR (LOw-Frequency ARray) Low Band Antenna (LBA: 10-90 MHz) circularly polarized beamformed observations of three exoplanetary systems which are usually considered to be among the best candidates for exoplanetary radio emission. We tentatively detect circularly polarized bursty emission from the τ Boötis system in the range 14-21 MHz with a statistical significance of 3 σ. Assuming the detected signal is real, we discuss its potential origin. A possible explanation is radio emission from the exoplanet τ Boötis b via the cyclotron maser mechanism. Assuming a planetary origin, we derived limits for the planetary polar surface magnetic field strength, finding values compatible with theoretical predictions. Follow-up observations will allow to confirm this possible first detection of an exoplanetary radio signal. We will discuss such follow-up observations that have recently been performed on LOFAR-LBA, NenuFAR and UTR-2.

Keywords: Planets and satellites: magnetic fields, Radio continuum: planetary systems, Magnetic fields, Planet-star interactions, Planets and satellites: aurorae, planets and satellites: gaseous planets

1 Introduction

This proceeding article is a summary of recent work. The full article (Turner et al. 2021) contains more details on the observational setup, data processing, and the interpretation of the observations.

All the planets in our Solar System (except Venus), have or used to have a magnetic field, and many exoplanets are expected to have magnetic fields as well. Measuring the magnetic field of an exoplanet would give valuable information to constrain its interior structure, its atmospheric escape, and the nature of any star-planet interaction (e.g. Grießmeier et al. 2007; Hess & Zarka 2011; Zarka et al. 2015; Grießmeier 2015, 2017; Lazio 2018; Grießmeier 2018; Zarka 2018). For these reasons, many methods have been proposed to study the magnetic fields of exoplanets. By contrast to all other suggested methods, radio observation can constrain the magnetic field amplitude directly without invoking complex model assumptions, and is much less susceptible to false positives (Grießmeier 2015). Still, despite decades of search, the direct detection of exoplanetary magnetic fields has so far remained elusive (e.g. Grießmeier 2017).

2 LOFAR beamformed observation campaign

We have performed beam-formed observations with LOFAR (van Haarlem et al. 2013), observing three planets which were selected based on theoretical predictions: 55 Cancri, υ Andromedae, and τ Boötis. The available observing time (between 20 and 45h per target) was spread as evenly as possible over the planetary orbital period. We used multiple beams (at least one 'ON' beam and two 'OFF' beams) to allow to search for rapid bursts. The pipeline has been tested and calibrated with Jupiter data (Turner et al. 2017; Turner et al. 2019).

[1] Laboratoire de Physique et Chimie de l'Environnement 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 and Carl Sagan Institute, Cornell University, Ithaca, NY, USA
[4] Department of Astronomy, University of Virginia, Charlottesville, VA, USA
[5] LESIA, Observatoire de Paris, CNRS, PSL, Meudon, France

3 A radio burst from τ Bootis b?

For one or the observations of the τ Bootis system, our analysis found an excess of circularly polarized bursts of a duration of the order of 1 second in the ON beam. The frequency range of the emission was 14-21 MHz. This detection is significant at 3.2 σ. The most likely cause for this emission is the planet τ Bootis b, via cyclotron maser emission. For this, the planet requires a surface magnetic field strength of 5-11 G, which is roughly comparable to Jupiter's magnetic field. With a measured intensity of 900 mJy, the emission would be 4-5 orders of magnitude stronger than Jupiter's emission, which is be consistent with current models. Figure 1 compares the observed emission to Jupiter's emission and upper limits derived during other observation campaigns.

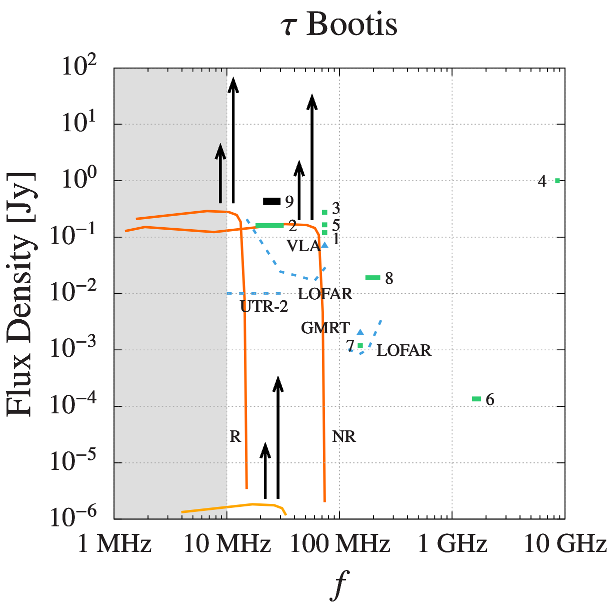

Fig. 1. Predictions and observations for the exoplanet τ Boötis b. Grey area: Emission below 10 MHz is not detectable for ground-based observations (ionospheric cut-off). Lower solid line (light orange): Typical spectrum of Jupiter's radio emissions at 15.6 pc distance. Two upper solid lines (orange): Jupiter's radio emission scaled for values expected for τ Boötis b according to models R (left) and NR (right) from Grießmeier (2017). For Jupiter, the radio flux increases by up to two order of magnitude during periods of high activity. The same variability is assumed for exoplanetary emission, as indicated by the vertical black arrows. Dashed lines and triangles show the theoretical sensitivity limit of the radio-telescopes UTR-2, LOFAR (low band), VLA, LOFAR (high band), and GMRT (for 1 h of integration time and a bandwidth of 4 MHz). Black line (9): this study. Other numbered lines and points: upper limits derived in previous observations of τ Bootis. See Turner et al. (2021) for details.

4 Conclusions

While promising, the result if not yet fully conclusive. In particular, we cannot rule out stellar flares as the source of the emission. In order to confirm that the source of the detected signal is indeed the planet τ Boötis b, we have performed a follow-up campaign using four different radio telescopes (LOFAR, LWA, UTR-2 and NenuFAR). We have increased the number of observations, with an improved orbital coverage. The data of this follow-up campaign are currently under analysis.

References

Grießmeier, J.-M. 2015, in Astrophysics and Space Science Library, Vol. 411, Characterizing stellar and exoplanetary environments, ed. H. Lammer & M. Khodachenko (Springer), 213–237

Grießmeier, J.-M. 2017, in Planetary Radio Emissions VIII, ed. G. Fischer, G. Mann, M. Panchenko, & P. Zarka (Austrian Academy of Sciences Press, Vienna)

Grießmeier, J.-M. 2018, in Handbook of Exoplanets, ed. H. J. Deeg & J. A. Juan Antonio Belmonte (Springer)

Grießmeier, J.-M., Zarka, P., & Spreeuw, H. 2007, Astron. Astrophys., 475, 359

Hess, S. L. G. & Zarka, P. 2011, Astron. Astrophys., 531, A29

Lazio, T. J. W. 2018, in Handbook of Exoplanets, ed. H. J. Deeg & J. A. Juan Antonio Belmonte (Springer)

Turner, J. D., Grießmeier, J.-M., Zarka, P., & Vasylieva, I. 2017, in Planetary Radio Emissions VIII, ed. G. Fischer, G. Mann, M. Panchenko, & P. Zarka (Austrian Academy of Sciences Press, Vienna), 301–313

Turner, J. D., Grießmeier, J.-M., Zarka, P., & Vasylieva, I. 2019, Astron. Astrophys., 624, A40

Turner, J. D., Zarka, P., Grießmeier, J.-M., et al. 2021, Astron. Astrophys., 645, A59

van Haarlem, M. P., Wise, M. W., Gunst, A. W., et al. 2013, Astron. Astrophys., 556, A2

Zarka, P. 2018, in Handbook of Exoplanets, ed. H. J. Deeg & J. A. Juan Antonio Belmonte (Springer)

Zarka, P., Lazio, J., & Hallinan, G. 2015, Advancing Astrophysics with the Square Kilometre Array (AASKA14), 120