Emission of Exoplanets in the GHz Range

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We estimate possible radio emission of massive exoplanets and brown dwarfs. We assume that such radiation originates in processes similar to those observed in the Jupiter system. Therefore, we analyse two possible emission scenarios. The first scenario assumes interaction between the stellar wind and the planetary magnetosphere. The second mechanism needs a moon orbiting close to the planet, and is similar to the Jupiter-Io interaction. We show that the emission of exoplanets and brown dwarfs, in young systems (age < 0.1 Gyr) can be observed even at GHz frequencies. Therefore, VLBI networks could possibly detect such radiation. Moreover, an excellent angular resolution of VLBI should also allow to observe orbital movement in nearby (distance < 30 pc) systems.

Keywords: VLBI, Exoplanets, Astrometry.

1 Introduction

Possibility of detection of radio emission from exoplanets was already discussed by several authors (for a review see Griessmeier, Zarka & Girard [1]). Most of the publications suggested that such emission may originate in processes similar to those observed in the Solar system, especially in the Jupiter neighbourhood. However, there is no confirmed detection of the radio emission from an exoplanet, so far. The reason for this can be quite simple, the emission was expected in the MHz range, by analogy to the radiation observed in the Jupiter system. The non-thermal emission observed in this system extends form the kHz range up to 40 MHz. Where, the maximum frequency is limited by the magnetic field strength, which is ~ 9 G on average in this particular case. The fact that most of the theoretical models predicted the emission at MHz frequencies, leads to the observations in this particular range (eg. Winglee, Dulk & Bastian [2]; George & Stevens [3]; Lazio et al. [4]). The observations made by the instruments that may operate in this range (eg. VLA, GMRT). Unfortunately sensitivity of such interferometers is relatively low in comparison to the global networks, where also big antennas can significantly contribute to the observations. This may be the main reason for no detection, so far. On the other hand global interferometric networks operate in the GHz range. Therefore, the main question is if we can expect any emission form exoplanets at GHz frequencies?

2 Emission scenarios

Radiation of exoplanets and also brown dwarfs is probably powered by the electron cyclotron maser instability, where the maximum frequency of the emission is the cyclotron frequency. Therefore, the key parameter for this radiation process is the magnetic field strength. To estimate value on this parameter, we adopted approach proposed by Reiners & Christensen [5]. They proposed a simple scaling law, where the magnetic field depends on three parameters: mass, size and luminosity of a planet or brown dwarf. These parameters are derived in turn from the evolutionary models proposed by Burrows et al. [6], [7]. Simple calculations show that emission at 1.4 GHz requires the magnetic field above 500 G. Our estimations show that such relatively large value of the magnetic field can be generated only by massive ($M > 6 M_{\rm J}$, where $M_{\rm J}$ the Jupiter mass) and young planets (age $< 2 \times 10^8$ yr). On the other hand, the magnetic field produced by brown dwarfs ($15 < M/M_{\rm J} < 80$) can exceed a few kilo Gausses. This allows for the emission even above 5 GHz. Moreover, such large magnetic field can be produced also in old objects (age $> 10^9$ yr).

The first criterion that must be fulfilled, if we want to use Very Large Baseline Interferometry (VLBI) for search of exoplanets, is the frequency of the emission. This frequency must be higher than 1.4 GHz. The second criterion is the observed flux density. The flux must be at the level of about $20 \mu {\rm Jy}$, if we want for example to detect it with European VLBI Network (EVN), in five hours of integration, with 1GB recording rate. To estimate the flux density we have to analyse specific emission scenarios. In this work we focus on two scenarios that are observed in the Jupiter system.

The first mechanism assumes dissipation of the kinetic energy of stellar wind in the planetary magnetosphere. We calculated expected emission produced by this process for a wide range of masses and ages of planets, assuming typical wind parameters. We adopted for these calculations the approach proposed by Griessmeier et al. [8]. Our calculations show that detectable emission of planets, can be produced only by very young (age $< 2 \times 10^8$ yr) and massive object ($M > 11\ M_{\rm J}$), located a the distance not higher than 30 pc. Moreover, this radiation will be produced at the frequencies not higher than 3 GHz. On the other hand emission of brown dwarfs is not significantly limited by mas and age, but is also strongly constrained by the distance. A the distance higher than 30 pc such emission will also be difficult for detection.

The second emission scenario assumes an interaction between a moon and a planet, and is similar to the interaction observed between Jupiter and Io. It requires a moon that through volcanic activity fills the planetary magnetosphere with matter. The matter is ionized and accelerated by electric currents induced by the moon. This process may produce emission that could possibly be observed. We also analysed this radiation process calculating expected fluxes for a wide range of masses and ages. Our estimations show that this particular emission scenario gives radiation that is order or even two orders of magnitude weaker than the emission produced by the first scenario. Therefore, in the further discussion we focus on the first emission scenario.

3 A-type stars

Strong magnetic field — the main condition required for the emission of exoplanets at GHz frequencies can be generated only in relatively young objects. Therefore, searchings for star candidates, where possible emission can be detected, we selected main sequence A-type stars. A-type stars evolve relatively fast. Therefore, the main-sequence objects are usually younger than 10^9 yr. The selection of this particular type of stars, gives opportunity to estimate more precisely their stellar wind parameters. We assumed that A-type stars have winds driven by the radiation pressure, where the force that accelerates the wind comes from the photon scattering on free electrons and also from the interception of photons by ions. To estimate possible emission from the planetary systems around such stars, we selected 26 objects located in the Solar neighbourhood (distance < 30 pc). To calculate wind parameters required for the estimation of expected fluxes we used: luminosity, mass, size and metallicity of each star. We found that the mass-loss rate for the most of stars in our sample is in the range from 10^{-14} to 10^{-13} $\mathrm{M}_\odot/\mathrm{yr}$, which is close to the Sun mass-loss rate (2×10^{-14} $\mathrm{M}_\odot/\mathrm{yr}$). The density of the wind (n) at the distance of 1AU is in range $0.1 < n/n_\odot < 10$, where $n_\odot = 6.6 \times 10^6 \mathrm{m}^{-3}$ is the density observed in the Solar system. The significant difference appears only in the terminal velocity (maximum velocity) of the wind that is in the range from 1100 to 1550 km/s, which is 2–4 times higher than in the solar wind. This may be related to the fact that the solar wind is accelerated by different processes. Note that higher velocity allows for more efficient emission, because the wind has more kinetic energy.

Maximum frequencies and fluxes estimated for our sample of stars are presented in Fig. 1. We assumed in our calculations two different masses of hypothetical planets ($M_\mathrm{p} = 10$ or 20 M_J) and three different distances between these objects and their stars (d = 0.5, 1 and 5 AU). The most promising is the case, where very massive planet ($M = 15 M_\mathrm{J}$) is orbiting relatively close to the star (d < 1 AU). The expected level of the emission form all objects in such case, is well above the threshold of 20 μJy. On the other hand the maximum frequency of the emission for most of these hypothetical planets is around 1 GHz, below the 1.4 GHz threshold. Only four stars (β Leo, β Pic, 59 Dra, ζ Lep) may host planets young enough to produce emission above 1.4 GHz, that can be detected by VLBI. The reason why these four stars are different from the other objects in the sample, is the age. The age of all these stars is lower than 100 Myr. Note that a planet was already discovered around β Pic (Lagrange et al. [9]). This planet has mass 4–11 M_J and is located around 8 AU from the star. Unfortunately, β Pic has declination $\delta = -51°$, and therefore is below the operating range of EVN and VLBA.

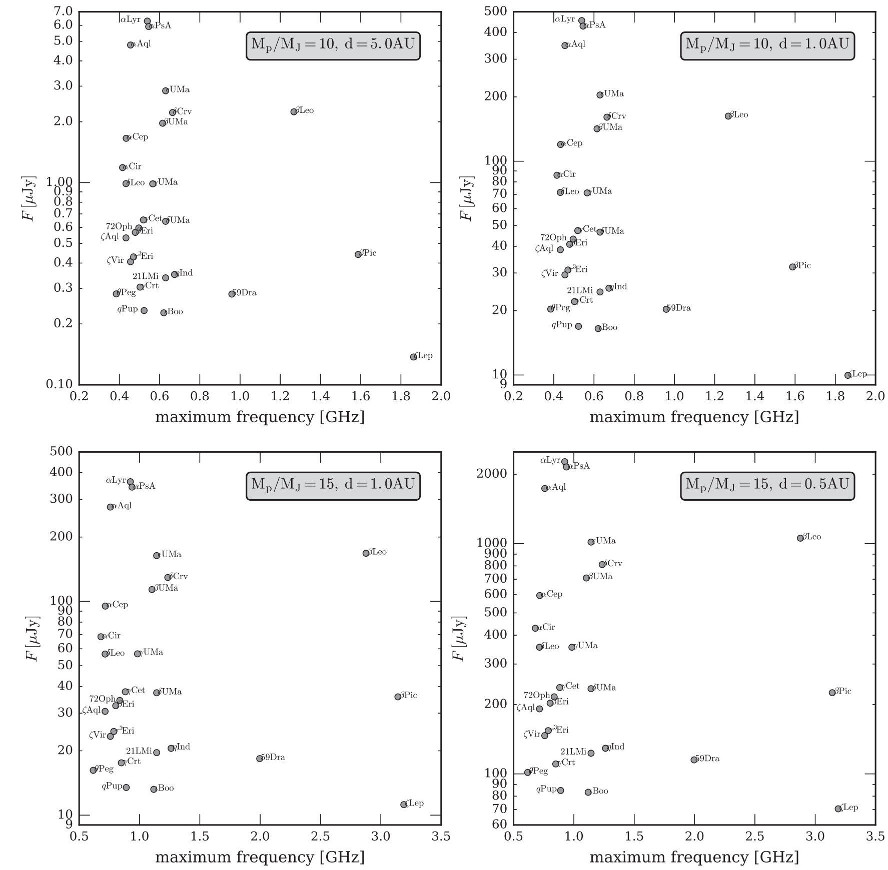

Fig. 1. Maximum frequencies and fluxes estimated for hypothetical planets located around A-type stars in solar neighbourhood (distance < 30 pc). Figures show values calculated for objects width different masses (M_p) and for different distances between stars and planets (d)

4 Summary

Our theoretical investigations demonstrate that radio emission of exoplanets can be generated also at GHz frequencies. Moreover, we show that such radiation can be detected by present VLBI instruments, but only in the case of very massive ($M > 10 M_{\rm J}$) and young planets (age < 100 Myr). Therefore, we suggest to search for such objects around main–sequence A-type stars, which are usually relatively young. Moreover, such stars should be located in the solar neighbourhood. This will not only increase the chance for the detection but may also allow for direct observations of planetary motions.

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