SEARCH FOR POSSIBLE EXOMOONS WITH FAST TELESCOPE

D. V. LUKIĆ
Institute of Physics, University of Belgrade, P.O. Box 57, 11001 Belgrade, Serbia
E–mail: lukic@ipb.ac.rs

Abstract. Our knowledge of the Solar System, encourage us to beleive that we might expect exomoons to be present around some of the known exoplanets. With present hardware we shall not be able to find exomoons with existing optical astronomy methods at least 10 years from now and even then, it will be hard task to detect them. We suggest radio astronomy based methods to search for possible exomoons around these exoplanets. Using data from the Exoplanet Orbit Database (EOD) we find 2 stars with Jovian exoplanets within 50 light years fully accessible by the new radio telescope, The Five-hundred-meter Aperture Spherical radio Telescope (FAST).

1. INTRODUCTION

Discovery of the 51 Pegasi b (Mayor & Queloz 1995), exoplanet orbiting the Sun-like Main Sequence star, was only the first in the series of many exoplanets discovered thenceforth. The progress is made thanks to advanced detection techniques and instrumentation. Nowadays, the result is hundreds of confirmed and thousands of potential exoplanets, the most of them identified by the NASAs Kepler space telescope. Every prudent connoisseur of the Solar System would expect the presence of the exomoons close to the known exoplanets. The Solar System's planets and dwarf planets are known to be orbited by 182 natural satellites. In our solar system, Jovian planets have the biggest collections of moons and we expect similar position for gas giants planets in extrasolar systems. Nonetheless, contemporary techniques for observation haven't made a single detection of any exomoon so far. One of the leading models describing planetary satellites formation is the actively supplied gaseous accretion disk model (Canup & Ward 2006). In this model, the final total mass of satellite system, approximately $10^{-4} M_P$ (M_P mass of planet) is given by a balance of the supply of material to the satellites, and satellite loss through orbital decay driven by the gas.

2. SELECTION OF DATA AND METHOD OF ANALYSIS

Many of the detected exoplanets are the gas giants located in the habitable zone of their stars. These big planets cannot support life, but it is believed that some of their exomoons could be habitable. In our analysis, assuming that scaling law (Canup & Ward 2006) observed in the solar system also applies for extrasolar super-Jupiters (Heller & Pudritz 2014), we used planet's data from the Exoplanet Orbit

Database catalog (Wright et al. 2011 and Han et al 2014). We selected only exoplanets closer than 50 light years which have comparable mass or are more massive than Jupiter within declination limits of full sensitivity of new radio telescope in China. Approximately a half of them are hot or warm Jupiters. According to (Heller & Pudritz 2015) if these planets migrated in to the stellar habitable zones from beyond a few AU, they could be orbited by large, water rich satellites. The liquid water on surface is possible on sufficiently massive satellites.

Besides telescopes explained in (Griessmeier et al. 2011, Noyola 2015) we have additional radio telescope in final phase of construction, The Five-hundred-meter Aperture Spherical radio Telescope (FAST) (Nan et al. 2011) and latter SKA telescope. FAST is located at a great depression with a diameter of about 800 m at $25^o.647$N and $106^o.856$E, near the village of Dawodang, in Guizhou Province. FAST will be capable of covering the skywithin 40^o from the zenith with full sensitivity. Set of nine receivers covers a frequency range from 70 MHz to 3 GHz. It has an illuminated aperture of 300 m diameter. FAST is an order of magnitude more sensitive than 100-m telescopes at Green Bank, USA, and Effelsberg, Germany and about two times more than Giant Meterwave Radio Telescope (GMRT), India.

We count on interaction of magnetic field of extrasolar planets with plasmas from exomoons (Zarka 2007). In Solar system, e.g. the particles from Io's volcanic eruptions interact with the Jupiter's magnetosphere to produce intense decameter radio waves. From the ground, these radio waves are detectable in the frequency range from 10 to 40 MHz (Zarka 1998). The generation mechanism is the cyclotron-maser instability (Wu et al. 1979). Listed frequencies in Table 1 are maximum values reported in (Griessmeieret al. 2007). In Table 2 we compare frequencies f_{mG} calculated by (Griessmeier et al. 2007), with other models of extrasolar planets radio emission f_{mL} (Lazio et al. 2004) and f_{mR} (Reiners & Christiansen 2010) and expected radio fluxes. Other radio telescopes with the most suitable frequency range are: super LOFAR extension (NenuFAR, 10-80 MHz) in France, 1-2 mJy at 4MHz bandwidth, Giant Meterwave Radio Telescope (GMRT, 153 MHz) in India, 0.2 $mJy/(t/15minutes)^{0.5}$ in a 4 MHz bandwith, and Ukrainian T-shaped Radio telescope (UTR-2, 8-40 MHz).

Table 1. Possible exomoons.

Planet Name	*Mass*	*Star type*	*Semimajor Axis*	*Distance* [pc]	*Satellite mass*	*Declination*	Frequency
eps Eridani b	$1.55\ M_J$	K2V	3.4 AU	3.22	$0.049\ M_\oplus$	$-09^o\ 27'\ 29.7312''$	33.2 MHz
Gliese 876 b	$2.27\ M_J$	M4V	0.2 AU	4.69	$0.072\ M_\oplus$	$-14^o\ 15'\ 49.32''$	38.2 MHz
Gliese 876 c	$0.7\ M_J$	M4V	0.13 AU	4.69	$0.022\ M_\oplus$	$-14^o\ 15'\ 49.32''$	16.4 MHz
Gliese 849 b	$0.91\ M_J$	M3.5V	2.39 AU	9.1	$0.0289\ M_\oplus$	$-4^o\ 38'\ 26.62''$	21.8 MHz
Gliese 849 c	$0.94\ M_J$	M3.5V	4.82 AU	9.1	$0.0298\ M_\oplus$	$-4^o\ 38'\ 26.62''$	
HD 62509 b	$2.9\ M_J$	K0III	1.64 AU	10.3	$0.092\ M_\oplus$	$+28^o\ 01'\ 35''$	49.5 MHz
55 Cnc b	$0.8\ M_J$	G8V	0.11 AU	12.3	$0.025\ M_\oplus$	$+28^o\ 19'\ 51''$	18.9 MHz
55 Cnc d	$3.878\ M_J$	G8V	5.74 AU	12.3	$0.123\ M_\oplus$	$+28^o\ 19'\ 51''$	61.4 MHz
HD 147513 b	$1.21\ M_J$	G1VH-04	1.32 AU	12.9	$0.038\ M_\oplus$	$+39^o\ 11'\ 34.7121''$	24.5 MHz
ups And A b	$0.62\ M_J$	F8V	0.059 AU	13.47	$0.019\ M_\oplus$	$+41^o\ 24'\ 19.6443''$	2.4 MHz
ups And A c	$13.98\ M_J$	F8V	0.832 AU	13.47	$0.44\ M_\oplus$	$+41^o\ 24'\ 19.6443''$	38.4 MHz
ups And A d	$10.25\ M_J$	F8V	2.53 AU	13.47	$0.33\ M_\oplus$	$+41^o\ 24'\ 19.6443''$	61.4 MHz
ups And A e	$0.96\ M_J$	F8V	5.25 AU	13.470	$0.031\ M_\oplus$	$+41^o\ 24'\ 19.6443''$	
47 UMa b	$2.5\ M_J$	G1V	2.1 AU	14.06	$0.079\ M_\oplus$	$+40^o\ 25'\ 27.97''$	46.6 MHz
HIP 79431 b	$2.00\ M_J$	M3V	0.36 AU	14.4	$0.064\ M_\oplus$	$-18^o\ 52'\ 31.8''$	40 MHz
HD 176051 b	$1.5\ M_J$	F9V	1.76 AU	15	$0.047\ M_\oplus$	$+32^o\ 54'\ 5''$	

A selected planets are presented in Table 1. We can see that the selected planets orbit stars from M to F star type. Since these planets most likely were not formed at those distances, but have migrated from larger ones, posibble exomoons could also be captured rocky planets. Now if the possible exomoons are captured they can survive enough time for all stars presented in Table 1 (Barnes & O' Brien 2002). These captured satellites can be more massive than formed ones (Porter & Grundy 2011) but we do not consider them. Even if 50 percent planets are falsely detected (Santerne et al. 2015) we still have enough candidates. We will have most likely high mean plasma density between ρS$\sim 10^6$amu cm^{-3} and ρS$\sim 10^7$amu cm^{-3} due to the presence of some exomoons in star's habitable zone and closer to stars (Schunk & Nagy 2009). The main problem is that the distances of the possible exomoons we are suggesting are greater than one selected in the previous radioastronomy searches (George & Stevens 2008, Noyola 2015). The closest planets are eps Eridani b at 3.22 pc and Gliese 876 b and c at 4.69 pc distance.

All stars fully accessible by the FAST are: eps Eridani, Gliese 876, Gliese 849, HD 62509, 55 Cancri, HD 147513, Upsilon And A, 47 UMa b, HIP 79431 and HD 176051, have enough lifetime to be listed in HabCat (Turnbull & Tarter 2003). If, as we can see in Table 1, these stars do not have exomoon emitters with frequency above 70 MHz our next chance is the low-end Low-Frequency Array (LOFAR). Present LOFAR has frequency range 10−240 MHz which is the best for exomoons and exoplanets detection. The super LOFAR extension (NenuFAR, 10-80 MHz) has frequency range of our interest. Sensitivity in this range is a few mJy. We can see that most suitable radio telescope for search for the closest possible exomoons is NenuFAR, the super LOFAR extension and FAST telescope especcialy for two extrasolar planets, 55 Cancri d and υ And A d, where it can be very useful. As we can see in Table 2. for other models of extrasolar planets radio emission (Lazio et al. 2004), and (Reiners & Christiansen 2010) second set of FAST receivers (Nan et al. 2011) is also suitable for these two extrasolar planets and plans for radioastronomy methods search for exoplanet (Li et al. 2012). To our best knowledge we do not know for exoplant detection by radioastronomy methods.

Table 2. Possible maximum frequencies for exomoons and exoplanets.

Planet Name	*Star type* [M_J]	*SemiMajor Axis*	f_{mG} [MHz]	R. flux [mJy]	f_{mL} [MHz]	R. flux [mJy]	f_{mR} [MHz]	R. flux [mJy]
eps Eridani b	K2V	3.4 AU	33.2	0	53	6.3	18.3	6
Gliese 876 b	M4V	0.2 AU	38.2	6.3	66	3.1	68	160
Gliese 876 c	M4V	0.13 AU	16.4	61.7	16	2.1	8.9	630
Gliese 849 b	M3.5V	2.39 AU	21.8	0	-	-	-	-
Gliese 849 c	M3.5V	4.82 AU	-	-	-	-	-	-
HD 62509 b	K0III	1.64 AU	49.5	0	68	0.1	-	-
55 Cnc b	G8V	0.11 AU	18.9	3	-	-	17.6	80
55 Cnc d	G8V	5.74 AU	61.4	0	-	-	242	0
HD 147513 b	G1VH-04	1.32 AU	24.5	2	43	4.1	23.5	0.2
ups And A b	F8V	0.059 AU	2.4	178.5	27	41.8	2.2	200
ups And A c	F8V	0.832 AU	38.4	0	84	2.8	68	2.5
ups And A d	F8V	2.53 AU	61.4	0	163	0.1	213	0.3
ups And A e	F8V	5.25 AU	-	-	-	-	-	-
47 UMa b	G1V	2.1 AU	46.6	0	-	-	111	0.5
HIP 79431 b	M3V	0.36 AU	40	0	-	-	-	-
HD 176051 b	F9V	1.76 AU	-	-	-	-	-	-

3. CONCLUSION

Since we shall not be able to find exomoons with existing optical astronomy methods at least 10 years from now (Kipping 2014), and even then it will be hard task to detect them (Hippke & Angerhausenet 2015, Heller et al. 2016), we suggest to search for exomoons around these planets with radio astronomy based methods (see Noyola et al. 2014, Noyola 2015). The main problem is that the distances of the possible exomoons we are suggesting are greater than one selected in the first searches (George & Stevens 2008, Noyola 2015). The closest promising planets are 55 Cancri d at 12.3 pc and υ And A d at a distance of 13.47 pc. At present such sensitivity can be expected only from the radio telescope the super LOFAR extension (NenuFAR, 10-80 MHz) and the just finished radio telescope FAST.

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