# Detecting Exoplanet Magnetic Fields

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*Abstract*—**Planetary magnetic fields shield life from harmful radiation, but current terrestrial exoplanet magnetic field strength estimates predict signals too weak and too low frequency to detect. However, timely coronal mass ejections may boost signal strengths enough, and a radio telescope array placed on the Moon could detect the low frequencies emitted. Once built, this telescope should monitor exoplanets Gliese876 d, 55Cnc e, and GJ1214 b.**

## I. Introduction

Earth-sized exoplanets in their habitable zones are prime suspects for finding life outside our planet. However, the planet must have certain properties conducive to life besides its orbital location. Among these, a magnetic field strong enough to shield the planet from harmful stellar radiation is suspected to be required. This paper explores a current exoplanet magnetic field modeling effort and investigates ways to improve detection of these fields.

## II. Exoplanet Model

Before considering detecting an exoplanet's magnetic field, its field strength should be estimated to see if detection is even possible. Since the focus is on finding habitable exoplanets, the model makes certain idealistic assumptions based on assumed requirements for life. In particular, the model assumes a differentiated planetary interior with Earth-like compositions. This interior contains convecting mantle layers and convecting cores as this presents optimal heat flow conditions [1]. The model framework and results are borrowed from Driscoll and Olson [1] and termed the Driscoll Model.

The Driscoll model consists of three parts: a structural model, a temperature model, and a magnetic field model. The structural model solves physical equations to find the equations of state. Boundary conditions are assumed Earth-like. For example, the surface pressure, density, and temperature are assumed to be 1 atm, 3.226 g/cm$^3$, and 300 K, respectively. At the center, the mass and gravity drop to zero while the density and temperature must remain finite. The temperature model combines convection and advection to produce an Earth-like profile. The two variables in the model are the planetary mass and the core-mass fraction (CMF), which represents the percent of total mass contained in the core.

The magnetic field model assumes an internal dynamo similar to Earth's, and scales the field strength based on the convective energy flux through the dynamo region. The core's field strength is projected to the surface based on the size of the planet's differentiated layers.

## III. Magnetic Field Detection

Detecting an exoplanet's magnetic field requires an observable signature. This signature comes from cyclotron emissions, which are radio frequencies emitted when solar wind electrons interact with the exoplanet's magnetic field. The emission frequency is given by the cyclotron frequency,

$$f_c = \frac{eB}{2\pi m_e} \tag{1}$$

where $e$ and $m_e$ are the electron charge and mass, and $B$ is the surface field strength. The emission power is estimated by fitting emissions from the Sun's planets to an empirical power-law model (the "Radiometric Bodes Law"), and is given by

$$P_{rad} = \left(\frac{a_j}{a_x}\right)^{1.18} \left(\frac{M_x \rho_x}{M_j \rho_o}\right)^{0.59} \left(\frac{V_x}{V_o}\right)^{2.06} 4 \times 10^9 \tag{2}$$

where the solar wind properties have been explicitly included [2], [3]. In the equation, $a$ is planet's semi-major axis, $M$ is the planet's magnetic moment, $\rho$ is the solar wind density at 1 au, and $V$ is the solar wind speed. The subscripts j, x, and o represent properties of Jupiter, the exoplanet of interest, and the Sun, respectively. The constant $4 \times 10^9$ normalizes the equation to Jupiter's emission power. Finally, this emission is attenuated as it travels to

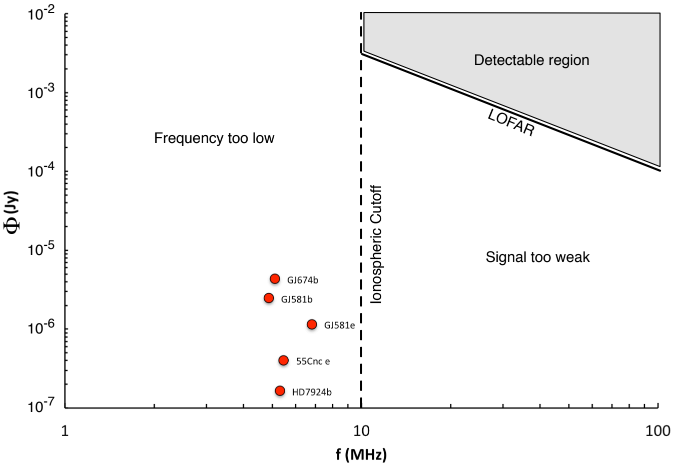


Fig. 1. Estimated magnetic field radio signatures at Earth for several exoplanets using the Driscoll Model [1].

Earth, and we observe a power spectral density given by

$$\Phi = \frac{P_{rad}}{4\pi s^2 \Delta f} \tag{3}$$

where $s$ is the total distance to Earth and $\Delta f$ is the observational bandwidth, assumed to be $f_c/2$.

Combining the magnetic field strengths from the Driscoll Model with the emission power and frequency equations for known exoplanets results in the frequency and magnitude plot shown in Figure 1. Note that this assumes stellar wind properties equal to our Sun's. Earth's ionosphere blocks most radio signals below about 10 MHz. Also shown on the plot is LOFAR's detection range and sensitivity. As seen, all estimated signals are both too weak and too low frequency to be detected currently.

## IV. Improving Detection Likelihood

As stated in the previous section, both the estimated signal strength and signal frequency are below detectable levels. This paper proposes two methods to measure exoplanet magnetic fields in the future. The first accounts for coronal mass ejections (CMEs) to increase peak signal strength. The second requires constructing a new telescope on the Moon to remove the ionospheric limitation.

### A. Signal Strength Boosts

The previous analsys from Driscoll assumed stellar wind characteristics similar to our Sun's. A more accurate analysis would estimate stellar wind density and speed and apply them to Equation 2. Stellar wind values were derived using the method in Section 5.1.4 of Griessmeier [4]. These values take stellar age and orbital distance into account. The combined methods of Griessmeier [4] and Driscoll [1] were tested on Kepler exoplanet data, both from kepler.nasa.gov and exoplanet.eu. The results were similar to those in Figure 1, with some values even lower than predicted by Driscoll. This is because stellar wind accellerates as it travels away from the star, making it weaker for closer-in planets. Distances were assumed to be 100 pc, and stellar age was assumed 1 Gyr when missing.

CMEs are similar to stellar wind, but with faster velocities and higher densities. Velocity and density values were taken from Griessmeier [4], included in Equation 2, and tested on the Kepler exoplanet data mentioned. The results, shown in Figure 2, suggest CMEs produce much stronger signals which might be detectable from Earth in the future. However, the frequencies are still masked by Earth's ionosphere.

### B. Improving Detection Range

The Driscoll Model estimates cyclotron emissions less than 10 MHz, and CMEs will not change the emission frequencies. Earth's ionosphere blocks signals below 10 MHz, making detection of even strong magnetic field radio signals impossible. To overcome this barrier, this paper proposes placing a

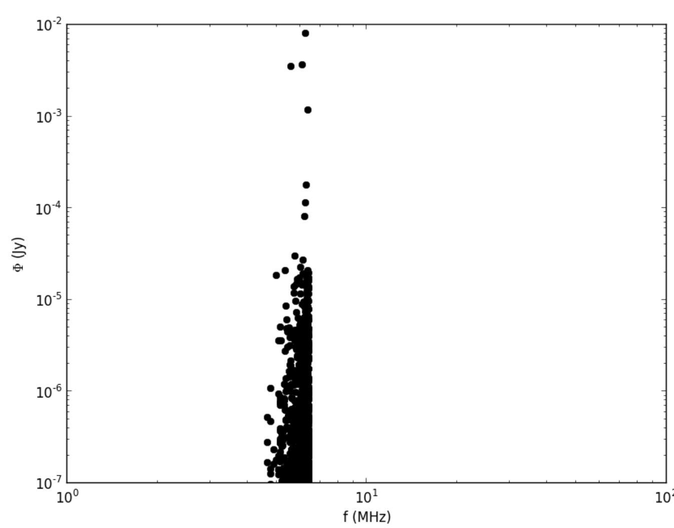


Fig. 2. Estimated magnetic field radio signatures at Earth for exoplanets using the CME Model. Most are weak because their distance was conservatively estimated at 100 pc when missing.

radio telescope array on the Moon. The advantages and disadvantages are discussed here.

The proposed LOw frequency Lunar Array (LOLA) is simply LOFAR on the Moon. This allows for hardware and software reuse, with clear cost and time benefits. Another benefit is the lack of atmoshperic noise on the Moon, improving detection sensitivity. However, to achieve the same angular resolution as LOFAR, LOLA would require a larger diameter than LOFAR. At 6 MHz, LOFAR has a resolution of about 10" for its 1000 km diameter array of 20,000 telescopes. For reference, the Moon's diameter is about 3500 km.

The total cost for LOLA will likely be dominated by transportation costs. The low-band LOFAR antennas are 3m by 3m by 1.7m, with an estimated weight of 100 lbs [5]. Transporting 20,000 of these to the Moon aboard a Falcon Heavy (40,000 lb payload) would take 50 trips and cost \$150M per trip. Assuming another \$7.5B for a base station, construction and deployment of the antennas, power, and initial maintenance, the total cost is \$15B. This excludes the time cost of making 50 trips to the Moon, which might take tens of years without a reusable rocket.

See work by Jack Burns at UC Boulder for more on Lunar telescopes.

### C. Combined Efforts

With a telescope on the Moon observing the radio signature from a CME interacting with an exoplanet's magnetic field, detection is possible. Combining Figure 2 with an estimate of LOLA's capabilities produces Figure 3. The target exoplanets likely to produce detectable magnetic field signatures are Gliese876 d, 55Cnc e, GJ1214 b, GI581 e, 61Vir b, and GI581 c.

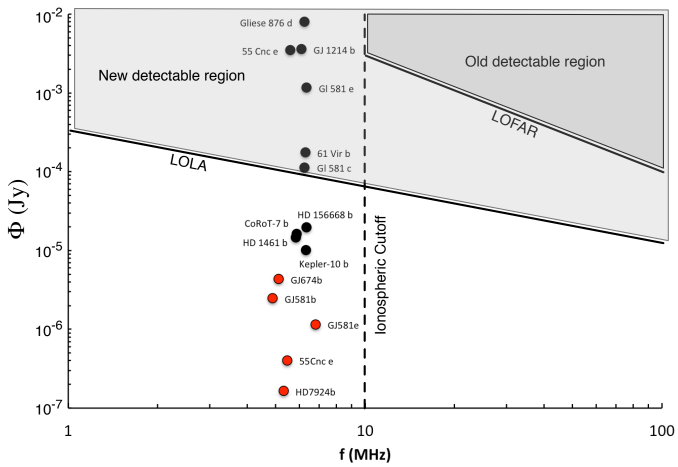


Fig. 3. Estimated magnetic field radio signatures at Earth for several exoplanets using the Driscoll Modle (red) and the CME Model (black). LOFAR and LOLA detection regions shown for scale.

## V. Conclusion and Future Work

Exoplanet magnetic field signatures are estimated to be too weak and too low frequency to detect. This paper proposed using a Lunar telescope to measure the signature of exoplanet magnetic fields interacting with a host star CME. It has several limitations and drawbacks. The Driscoll Model optimistically assumes these exoplanets are strongly convecting and have an active dynamo, which is likely untrue. Even if true, the host star's own magnetic field, or that of another, larger planet within the system, may emit stronger radio signals which mask those of the exoplanet of interest. Second, CMEs are infrequent and localized, giving them a low probability of interacting with a specific exoplanet. They are also temporal, reducing the benefit of long-term signal integration. Finally, putting a telescope on the Moon has a massive cost and time overhead.

Future work should remove assumptions made in this work. Namely, better exoplanet physical properties estimates would give better magnetic field strength estimates. Knowledge of the host star's activity and mangetic field should also be considered and factored in. Finally, research effort should go into lower-cost solutions to overcoming the ionosphere barrier. Perhaps a large array of telescopes in low-Earth orbit could jointly monitor a region of space.

## References


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