The Case for Exoplanet Surveys at Radio Wavelengths

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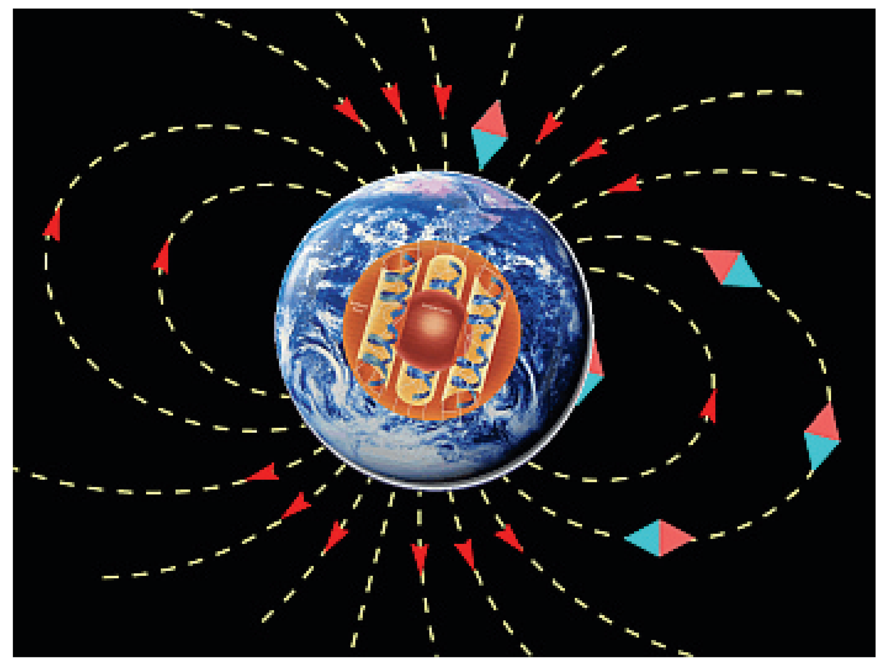
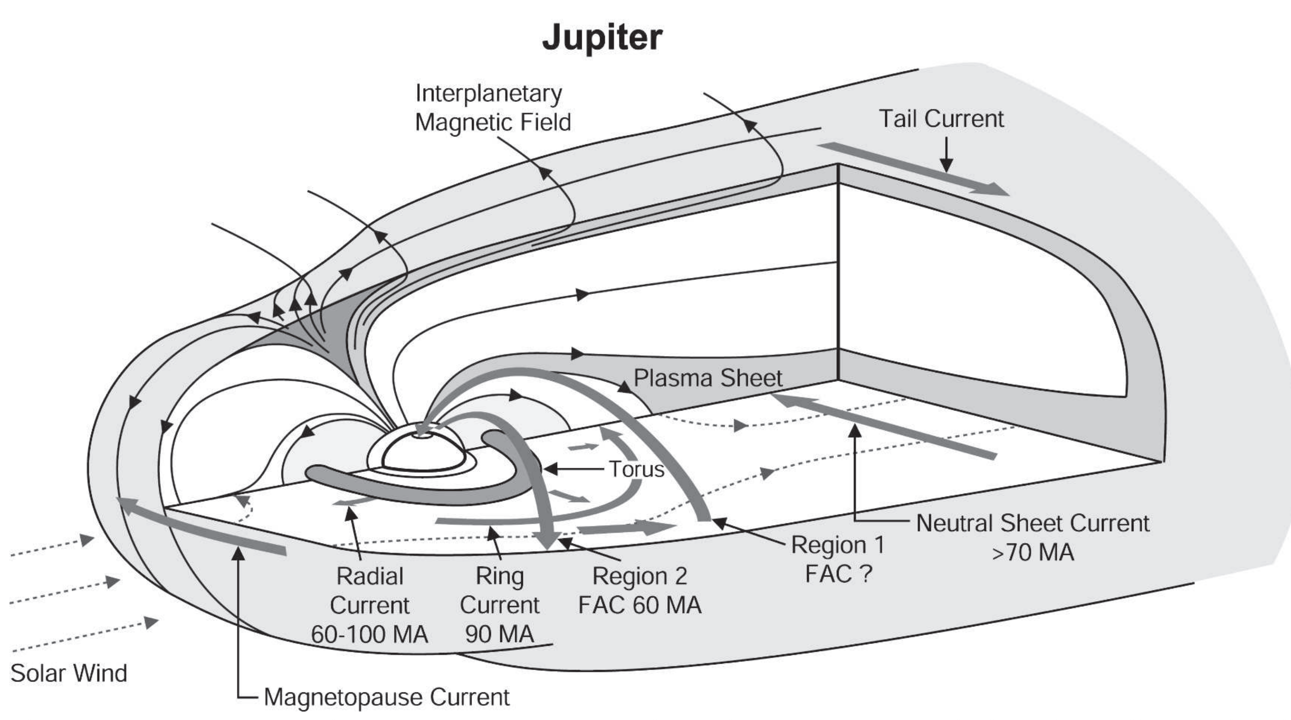
The Stakes

Radio emission is the only direct observational probe of planetary magnetic fields. These fields are generated by dynamos operating below the surface, so **radio observations probe planetary interior structure**. Dynamo action needs vigorous convection and hence efficient heat loss; in terrestrial planets, this seems to require active geology. **Radio data could potentially trace the difference between outwardly similar active and inactive rocky planets, e.g. between Earth and Venus.**



The Earth's magnetic field is an external manifestation of its internal dynamo. (Conrad Observatory)

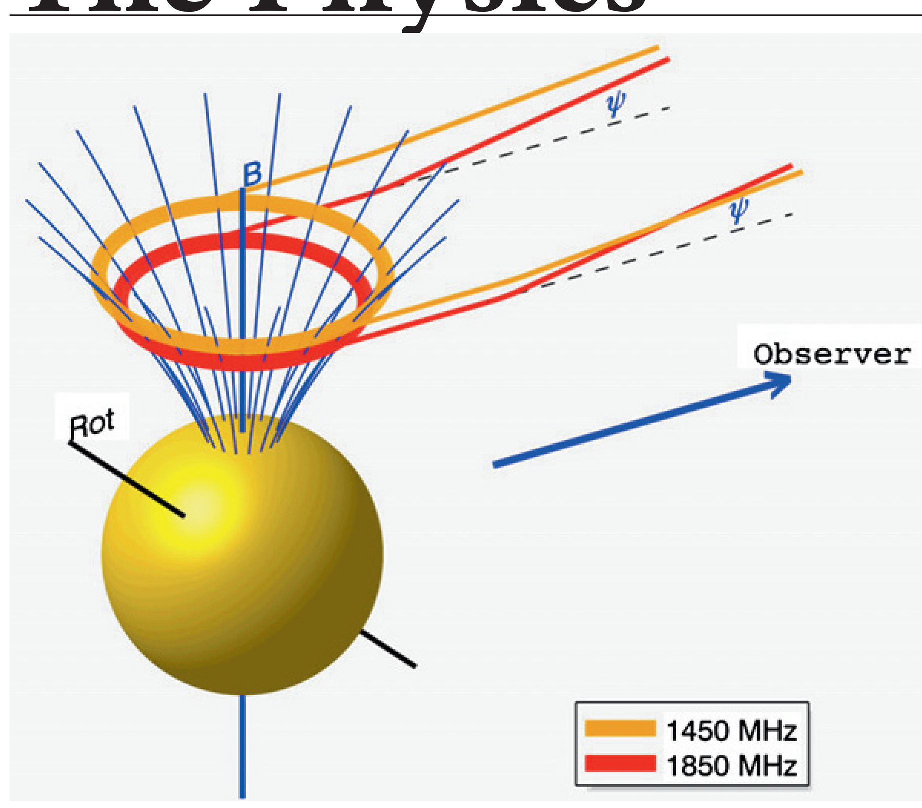


Planetary magneto/ionospheric current systems are driven by interactions with the solar/stellar wind and have a rich phenomenology, as seen in this schematic of the jovian environment (Khurana et al., 2004)

Energetic radio-emitting particles come from magneto/ionospheric current systems, which have rich phenomenologies and are **key constituents of the planetary near-space environment**. Since it defines how a planet interacts with the solar/stellar wind, **the magnetosphere is vital to understanding habitability**, especially around active stars such as M dwarfs.

Radio data are a unique probe that provides essential insight as we seek to characterize exoplanets in detail.

The Physics



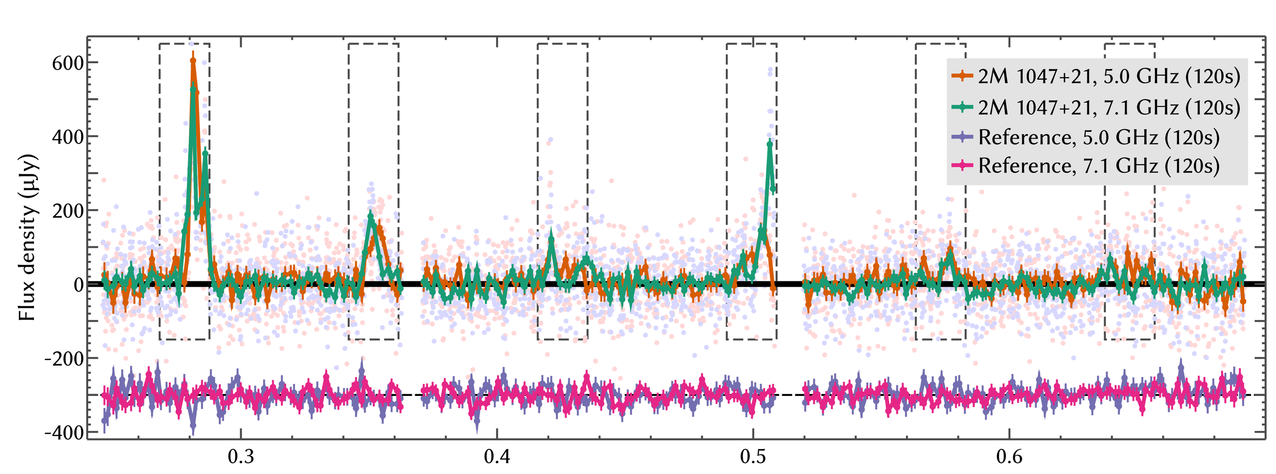
Schematic of the radio emission site. The beaming occurs axisymmetrically, so the overall emission pattern is a broad cone. (Trigilio et al., 2011)

The expected signal is **long-wavelength auroral radio emission** from the **electron cyclotron maser instability**. This emission is **bright and distinctive**; **planet-star flux ratios exceed unity** (Zarka, 1998):

- Brightness temperatures reaching 10^{20} K
- 100% circularly polarized
- Beamed in broad cone
- Emission at electron cyclotron frequency

Extensive Solar System observations including *in situ* particle measurements support theoretical models of the emission process.

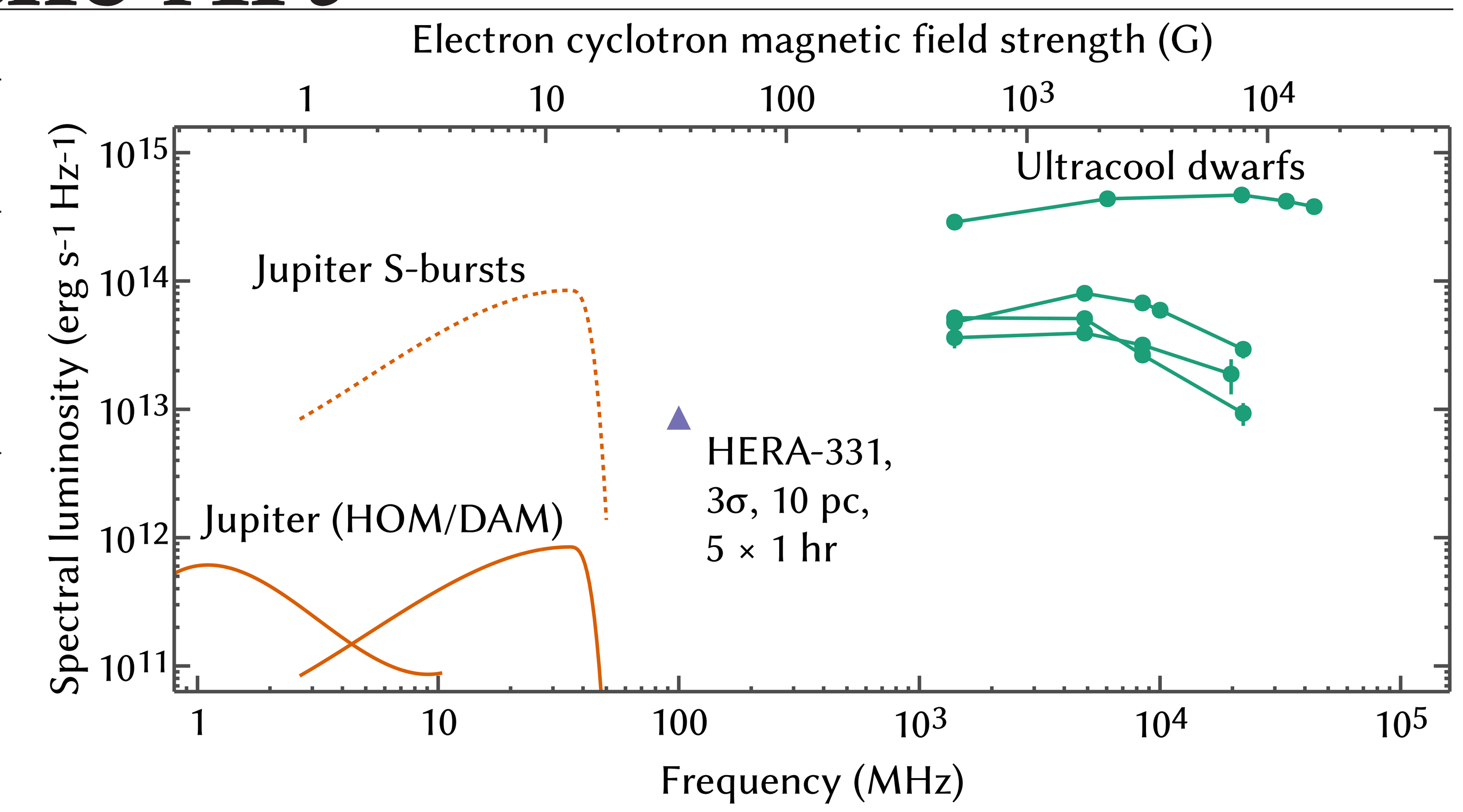
The beaming leads to periodic radio bursts. **The local magnetic field strength and rotation period can be read straight off of the data.** Bursts with telltale auroral characteristics have been detected from the magnetic Solar System planets, brown dwarfs, and very low-mass stars.



Example auroral radio burst light curve from a ~900 K (T6.5) brown dwarf. (Williams & Berger, 2015)

The State of the Art

No convincing detection of exoplanetary radio emission has yet been achieved. However, studies of brown dwarfs have revealed that their magnetic properties seem to closely resemble those of the gas giant planets, scaled up significantly, so **we can do physics today**. Predictions of exoplanetary radio fluxes vary widely (e.g., Murphy et al. 2015). **We have shown that very strong magnetic fields (~3 kG) are generated in brown dwarfs far cooler — 900 K! — than expected** (Williams & Berger, 2015).



Known planetary-like radio emissions and estimated HERA limit. Current limits reach ~10^{14} erg/s/Hz at 150 MHz.

$$\sigma \approx \frac{2k_B(T_{\rm sky}+T_{\rm rest})}{A_{\rm eff}\sqrt{\tau\cdot\delta\nu}}$$

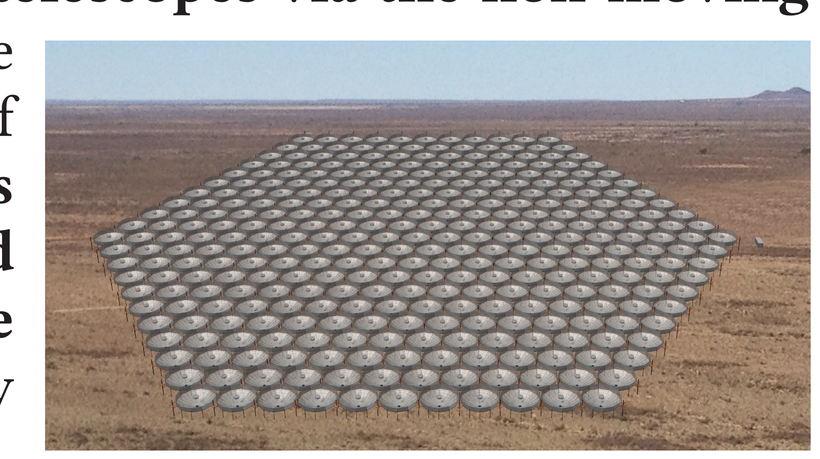
Sensitivity and time-on-the-sky appear to be the limiting factors as we progress toward true exoplanets. At long radio wavelengths, sky noise (T_{sky}) dominates the telescope. The optimal integration time τ and bandwidth δν are set by physics, so to improve sensitivity, larger telescopes (A_{eff}) are required.

A Path Forward

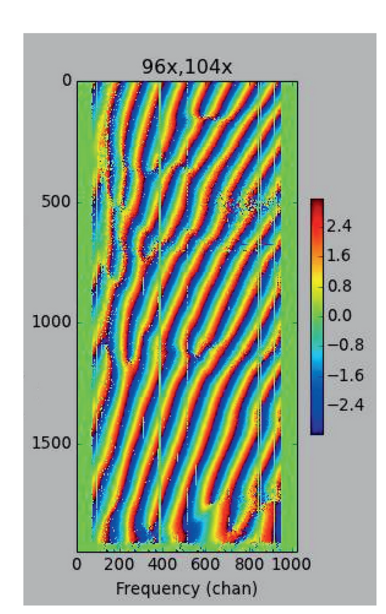
The HERA site as of late August, 2015. HERA dishes are in the background; dipoles from the PAPER array are in the foreground. (HERA Project; photo by David DeBoer).

The Hydrogen Epoch of Reionization Array, **HERA, is a long-wavelength radio telescope currently under construction in the Karoo desert, South Africa**. Although it is engineered for EoR science, its data stream is perfectly suited to searches for exoplanetary radio emission at ~100 MHz.

HERA will consist of 331 close-packed 14-meter dishes fixed to point at zenith. **HERA achieves a larger A_{eff} (~84,000 m²) than competing telescopes via the non-moving dishes.** It will continuously monitor the same declination strip, providing nightly coverage of ~10% of the sky (~220 stars within 25 pc). **We judge that this is a promising survey strategy since the expected signal is faint and intermittent, but planets are common** — extensive coverage of an unbiased, nearby stellar sample is ideal.



Visualization of the planned HERA-331 array. (HERA Project)



"First fringes" plot showing successful correlation. (HERA Project; plot by Danny Jacobs)

It is not yet fully funded but **HERA was named the top EoR instrumentation priority in the 2010 decadal review.** Interferometric "first fringes" were achieved <5 months after construction began thanks to simple designs and reuse of electronics. Routine data taking will begin in months.

References

Khurana et al., 2004, in "Jupiter: The Planet, Satellites, and Magnetosphere" (Cambridge), pp. 593–616.
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Trigilio et al., 2011 ApJL 739 L10.
Williams & Berger, 2015, ApJ 808 189.
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This work is supported by the NSF through grant AST-1008361.