Radio Observations of HD 80606 Near Planetary Periastron

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Summary

This paper reports Very Large Array (VLA) observations at 325 and 1425 MHz during and near the periastron of HD 80606b on 2007 November 20. We obtained 3σ limits of 1.7 mJy and 48 μJy at 325 and 1425 MHz, respectively, equivalent to planetary luminosity limits of 2.3 x 10^{24} erg/s and 2.7 x 10^{23} erg/s. Unfortunately, these are orders of magnitude above the Jovian value (at 40 MHz) of 2 x 10^{18} erg/s. The motivation for these observations was that the planetary magnetospheric emission is driven by a stellar wind-magnetosphere interaction so that the planetary luminosity should be elevated near periastron. In the case of HD 80606b, it might be as much as 3000x more luminous than Jupiter. Transit observations of HD 80606b provide stringent constraints on the planetary mass and radius, and, because of the planet's highly eccentric orbit, its rotation period is likely to be "pseudo-synchronized" to its orbital period, allowing a robust estimate of the former. Consequently, we find that the cutoff frequency for HD 80606b is likely to be 60–90 MHz. While lower than our observations, we compare HD 80606b to other high eccentricity systems and assess the detection possibilities for both near-term and more distant future systems. Of the known high eccentricity planets, only HD 80606b is likely to be detectable, as the others (HD 20782Bb and HD 4113) are both lower mass and have longer rotational periods, which imply weaker magnetic field strengths. Both the forthcoming "EVLA low band" system, which will operate as low as 65 MHz, and the Low Frequency Array (LOFAR) may be able to improve upon our planetary luminosity limits for HD 80606b, and do so at a more optimum frequency.

Future Prospects

- Electron cyclotron maser emission is quenched when local plasma frequency exceeds cyclotron frequency; above ν_c, no emission. For Jupiter, $\nu_c \approx 40$ MHz; for Earth, $\nu_c \approx 1$ MHz.
- Estimate ν_c from solar system scaling laws for planetary magnetic moments,

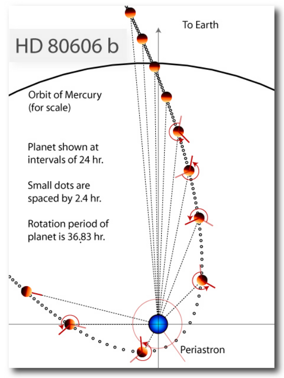
  $$\nu_c \approx 24 \text{ MHz } (\omega/\omega_J)\,(M/M_J)^{5/3}\,(R/R_J)^3$$

  for planetary mass M, rotation ω, and radius R; 50% uncertainties in scaling laws
- Previous estimates for ν_c of HD 80606b have varied wildly:
  - 180 MHz by Lazio et al. (2004)
  - 0.8 MHz by Greissmeier et al. (2007)
- HD 80606b is a **transiting** planet so M and R now well constrained
- Key difficulty has been ω; rotation of HD 80606b now recognized as likely **pseudo-synchronous** with orbital period ⇒ 39 hr rotation
- For HD 80606b, **$\nu_c \approx$ 60–90 MHz**

- **Future observations** must be more sensitive *and* at a lower frequency than those that we report here.
- Current projects well matched to HD 80606b:
  - **Expanded Very Large Array (EVLA)** being outfitted with "low-band" receivers covering 65–80 MHz, funded by NRL and NRAO
  - **Low Frequency Array (LOFAR)** being commissioned in the Netherlands and other European countries; includes "low band" stations (LBA) covering 30–80 MHz, with peak sensitivity around 60 MHz
- Noise levels of 25 mJy beam^{-1} obtained with previous 74 MHz VLA
- Ansatz—both algorithmic improvements and larger bandwidths result in 10× sensitivity improvement, i.e., 3 mJy beam^{-1}
  - EVLA "low band" and LOFAR-LBA will have 3–10× larger bandwidths
  - Continuing algorithmic improvements in RFI identification & excision and ionospheric calibration
- Luminosity limit (3σ) ≈ 10^{23} erg s^{-1}; comparable to more stringent limit (Table 1), but at a frequency at which emission more likely to be detected

- Limiting factor in imaging sensitivity might not be thermal noise, but factors such as ionospheric calibration.

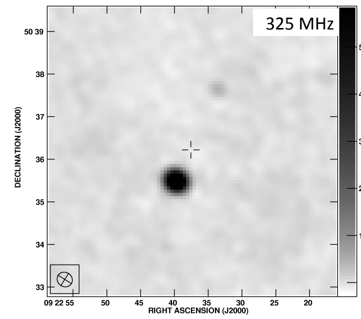
- HD 80606b appears the most promising for future observations, as pseudo-synchronous rotation is coupled to orbital period
  - HD 20782b: 1.9 M_J (minimum mass) planet in an orbit with e = 0.97 and orbital period of 592 days ⇒ 64 hr rotation
  - HD 4113b: 1.6 M_J (minimum mass) planet in an orbit with e = 0.903 and orbital period of 527 days ⇒ 14 day rotation
- Combined with their lower masses, ν_c < 20 MHz for both



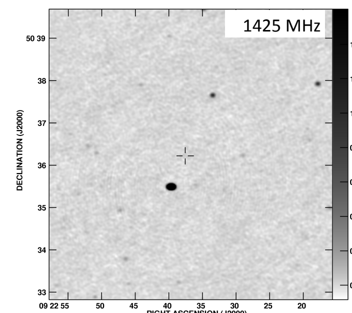
Orbit of HD 80606b near periastron. Figure courtesy of G. Laughlin.

HD 80606b
- e = 0.9366, one of the most eccentric planets known
- Transiting planet
- M = 3.94 ± 0.11 M_J
- R = 0.921 ± 0.03 R_J
- P = 111.43637 days
- a = 0.449 AU

HD 80606
- G5 star
- D = 58.4 pc



Field around HD 80606 at 325 MHz, just before periastron. The cross marks the location of the star. The beam is 22.1" × 20.1" and is shown in the lower left corner; the noise level is 0.58 mJy beam^{-1}; and the gray scale is logarithmic between −2.3 mJy beam^{-1} and 58 mJy beam^{-1}. The source to the southeast of the star is FIRST J092239.6+503529.



Field around HD 80606 at 1425 MHz, during periastron. The cross marks the location of the star. The beam is 5.49" × 4.35", the noise level is 16 μJy beam^{-1}, and the gray scale is logarithmic between −80 μJy beam^{-1} and 1.6 mJy beam^{-1}. The area shown is approximately that of the 325 MHz figure.

Table 1: Observational Summary

Frequency	Wavelength	Epoch	Orbital Phase	Flux Density Limit (3σ)	Luminosity Limit (3σ)
1425 MHz	20 cm	HJD 2454424.74–2454425.07 (2007 November 20 05:46–13:44 UT)	0.94–0.12	48 μJy	2.7 × 10^{23} erg/s
325 MHz	90 cm	HJD 2454423.89–2454424.22 (2007 November 19 09:20–17:17 UT)	0.69–0.73	1.7 mJy	2.3 × 10^{24} erg/s

Analysis

Planetary radio emission driven by stellar wind-magnetosphere interaction.

Table 2: Planetary radio luminosity scales approximately as $L \propto d^{-1.6}$

	Jupiter	HD 80606b (apastron)	HD 80606b (periastron)
d	5 AU	0.87 AU	0.028 AU
L/L_J	1	16	3000

- Near periastron, HD 80606b might be 3000× brighter than Jupiter.
- Luminosity of Jupiter L_J ~ 2 × 10^{18} erg s^{-1} (near 40 MHz)
- Predict that $L_{HD80606b}$ ~ 6 × 10^{21} erg s^{-1}

∴ Boost in luminosity due to HD 80606b's plunge into the stellar wind is unlikely to be enough to make it detectable. (See also Future Prospects.)

[The age of HD 80606 is uncertain, with estimates ranging from 0.3 Gyr to greater than 14 Gyr, but many favor approximately 7 Gyr. We take the age of HD 80606 to be comparable to that of the Sun, with a comparable stellar wind strength. Thus, a Jovian planet, with an orbital semi-major axis comparable to that of Jupiter (≈ 5 AU), should have a radio luminosity similar to that of Jupiter.]

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