Hot Jupiter Detection Experiment (HJUDE)

Jake Hartman (JPL)

PIs: G. Hallinan, G. Taylor, S. Ellingson

Caltech SURF: Lin Cheng
Targeted sources
Suitability of the LWA1
Observations to date
To-do list
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Observations to date
To-do list
Exoplanets are hot

- All known exoplanets
Exoplanets are hot

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- Hot Jupiters ($M > 0.5 \, M_J$, $a < 0.5 \, \text{AU}$)
  - orbital periods of 3 – 120 days
  - eccentricities of 0 – 0.97
Exoplanets are hot

- All known exoplanets
- Hot Jupiters ($M > 0.5 \, M_J$, $a < 0.5 \, AU$) orbital periods of 3 – 120 days eccentricities of 0 – 0.97
- Nearby HJs (within 50 pc)
Exoplanets are hot

- All known exoplanets
- Hot Jupiters ($M > 0.5\ M_J,\ a < 0.5\ AU$) with orbital periods of 3 – 120 days and eccentricities of 0 – 0.97
- Nearby HJs (within 50 pc)
- Nearby HJs in the northern sky

![Graph showing the number of exoplanets discovered over time](chart.png)
List of targets

<table>
<thead>
<tr>
<th>Planet</th>
<th>$d$ (pc)</th>
<th>$a$ (AU)</th>
<th>$P_{\text{orb}}$ (d)</th>
<th>$M$ ($M_J$)</th>
<th>Coordinates (J2000)</th>
<th>Best month</th>
<th>Num. days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot Jupiters likely to be tidally locked:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\upsilon$ And b</td>
<td>13.49</td>
<td>0.059</td>
<td>4.62</td>
<td>1.4</td>
<td>01$^h$37$^m$ +41°24'</td>
<td>Sep</td>
<td>37</td>
</tr>
<tr>
<td>$\tau$ Boo b</td>
<td>15.62</td>
<td>0.048</td>
<td>3.31</td>
<td>6.5</td>
<td>13$^h$47$^m$ +17°27'</td>
<td>Mar</td>
<td>43</td>
</tr>
<tr>
<td>HD 189733 b</td>
<td>19.45</td>
<td>0.031</td>
<td>2.22</td>
<td>1.13</td>
<td>20$^h$01$^m$ +22°43'</td>
<td>Jun</td>
<td>29</td>
</tr>
<tr>
<td>HD 187123 b</td>
<td>48.26</td>
<td>0.042</td>
<td>3.10</td>
<td>&gt; 0.51</td>
<td>19$^h$47$^m$ +34°25'</td>
<td>Jun</td>
<td>31</td>
</tr>
<tr>
<td>HD 209458 b</td>
<td>49.63</td>
<td>0.047</td>
<td>3.52</td>
<td>0.69</td>
<td>22$^h$03$^m$ +18°53'</td>
<td>Aug</td>
<td>32</td>
</tr>
<tr>
<td>Hot Jupiters less likely to be tidally locked:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55 Cnc b</td>
<td>12.34</td>
<td>0.116</td>
<td>14.65</td>
<td>&gt; 0.84</td>
<td>08$^h$53$^m$ +28°20'</td>
<td>Dec</td>
<td>30</td>
</tr>
<tr>
<td>$\rho$ CrB b</td>
<td>17.24</td>
<td>0.226</td>
<td>39.84</td>
<td>&gt; 1.06</td>
<td>16$^h$01$^m$ +33°18'</td>
<td>Apr</td>
<td>30</td>
</tr>
<tr>
<td>70 Vir b</td>
<td>17.99</td>
<td>0.484*</td>
<td>116.69</td>
<td>&gt; 7.46</td>
<td>13$^h$28$^m$ +13°47'</td>
<td>Mar</td>
<td>30</td>
</tr>
<tr>
<td>HD 195019 b</td>
<td>38.52</td>
<td>0.137</td>
<td>18.20</td>
<td>&gt; 3.58</td>
<td>20$^h$28$^m$ +18°46'</td>
<td>Jun</td>
<td>30</td>
</tr>
<tr>
<td>HD 114762 b</td>
<td>38.65</td>
<td>0.363*</td>
<td>83.89</td>
<td>&gt;11.68</td>
<td>13$^h$12$^m$ +17°31'</td>
<td>Mar</td>
<td>30</td>
</tr>
<tr>
<td>HD 38529 b</td>
<td>39.28</td>
<td>0.131*</td>
<td>14.31</td>
<td>&gt; 0.86</td>
<td>05$^h$47$^m$ +01°10'</td>
<td>Nov</td>
<td>30</td>
</tr>
<tr>
<td>HD 178911 Bb</td>
<td>42.59</td>
<td>0.345*</td>
<td>71.48</td>
<td>&gt; 7.29</td>
<td>19$^h$09$^m$ +34°36'</td>
<td>Jun</td>
<td>30</td>
</tr>
<tr>
<td>HD 37605 b</td>
<td>43.98</td>
<td>0.261*</td>
<td>54.23</td>
<td>&gt; 2.86</td>
<td>05$^h$40$^m$ +06°04'</td>
<td>Nov</td>
<td>30</td>
</tr>
</tbody>
</table>

* Sources with eccentricities greater than 0.1.
Targeted sources

➤ **Suitability of the LWA1 Observations to date**

To-do list
Emission from Hot Jupiters

- Low frequency: \( eB / 2\pi m_e = 28 \text{ MHz at 10 G} \)
- Bright! ~100 mJy fluxes predicted (but less than confusion)
- High circular polarization: LWA1 is very good at this!
- Predictably time-variable:
  - pulsar-like emission
  - secondary eclipses
  - periastron passages of high-eccentricity HJs
- However, substantial observing time is required for good upper limits
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Phase coverage of known-period HJs

For the five sources for which the rotational periods are likely known, the observation are daily and are generally centered around the times of transit. In some cases, a shift of a few minutes per day is added to maximize coverage of rotational phase. Figure x shows the resulting phase coverage, which has no gaps.

For the eight sources with unknown rotational periods, we adopt a logarithmically spaced observing schedule to maximize the likely phase coverage. These programs total w/t observations per source, spreading these observations unevenly over v months with daily observations around the time of best observation. To improve coverage of rotational periods close to v/h, pseudo-random offsets of order u/h are added to the times of observation. These offsets were chosen using a Monte Carlo simulation to maximize the coverage of random rotational periods between u and w/t h. Figure y shows the distributions of phase coverage for the optimal offsets. 9/10 of orbital periods less than w/t hr will have at least 9/10 phase coverage.

For the sources with eccentric orbits (marked with asterisks in Table x), the time of best observation accounts for the time of periastron in addition to the time of early morning transit. Their radio flux at periastron should be at least a factor of v greater than at apastron, using the standard assumption that the electron cyclotron maser emission is linearly proportional to the incident radiation from the parent star. For the highly eccentric exoplanet HD w–z, the radio flux should be x/t times greater at periastron than at apastron. In most cases, including HD w–z, a periastron serendipitously occurs within a week of early morning transit during the year starting Apr v/tu.

We will use the widest available tuning, ≈v kHz, and stack the usable bandwidth of a beam's two tunings to give ≈v kHz bandwidth per beam. This strategy accommodates the unknown cutoff frequencies and expected broadband emission. One beam will cover u–v MHz, the other v–w MHz. We request that the other two LWAu beams that...
Targeted sources
Suitability of the LWA1
➤ Observations to date
To-do list
Observations processed to date

429 beam hours taken

Tau Boötes b
- HJ: 90 beam hours
- Ref: 90 beam hours

HD 189733 b
- HJ: 21 beam hours
- Ref: 21 beam hours
Early Tau Boo observation

Avg spec: 50 – 90 dB
Early Tau Boo observation

Light curves

Frequency: 8 – 75 MHz


Avg spec: 25 – 85 dB

Tau Boo, Stokes V
Early Tau Boo observation

Avg spec: 25 – 90 dB
Later Tau Boo observation

Time: 02:25 – 05:25 MDT, March 10, 2012
Avg spec: 50 – 95 dB

Light curves

Tau Boo, Stokes I

Frequency: 8 – 75 MHz
Later Tau Boo observation

Time: 02:25 – 05:25 MDT, March 10, 2012
Avg spec: 25 – 90 dB

Light curves

Frequency: 8 – 75 MHz

Tau Boo, Stokes V
Later Tau Boo observation

Time: 02:25 – 05:25 MDT, March 10, 2012
Avg spec: 25 – 95 dB
Deep integration

Work in progress!

Integration of Tau Boo b field, 58 – 74 MHz, from March 8.

- **Total intensity**
- **Circular polarization**
- **1 / T**

Credit: Lin Cheng (Caltech)
Deep integration

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- Total intensity
- Circular polarization
- \( \frac{1}{T} \)

Credit: Lin Cheng (Caltech)
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Observations to date
➢ To-do list
To-do list for deep integration of Stokes V

- Circular pol calibration
  - sign: RH or LH?
  - correction for ant pattern
- Live testing of beam levels
  - what is the best level?
  - automatic gain control
- Optimal zeroing of DRX data around clipped samples
- RFI flagging and excision
- Bandpass calibration
  - bootstrapped
  - modeled
- Flux calibration

Polarization leakage for Cyg A in TBN data, as measured by PASI

Uncorrected: $-10.2$ dB rms
Corrected: $-16.5$ dB rms
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http://www.phys.unm.edu/~lwa/lwatv/beam_status.html
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Too high (Tau Boo; March 13; 8 – 44 MHz)

Too low (HD 189733; June 25; 8 – 44 MHz)
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Options:

- Power thresholding
- Kurtosis thresholding
  (lsl.statistics.kurtosis)
- CASA algorithms
  (tflagdata, mode = “tfcrop” or “rflag”)
- LOFAR algorithm(s)
- other?
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