All the Sky, All the Time:

Searching for Extrasolar Planets with the Owens Valley LWA

Gregg Hallinan, Jake Hartman, Stephen Bourke, Marin Anderson, Michael Eastwood, Jackie Villadsen, Melodie Kao, Lincoln Greenhill & Joe Lazio

Magnetic Fields as Magnetic Shields

- Habitability may need to be redefined based on magnetic activity (stellar age and mass dependent).
- During stellar flares, higher X-ray and ultraviolet can result in photochemical reactions leading to significant atmospheric loss (eg. Segura et al. 2010).
- Possible associated coronal mass ejections (CMEs) can severely affect atmospheric retention – eg. ion pick-up of a CO2-rich atmosphere (eg. Lattimer et al 2007).
- Planetary magnetic fields shield against such activity. How can we measure magnetic fields in extrasolar planets?

Radio Emission from Extrasolar Planets

The magnetized planets in our solar system produce extremely bright, highly polarized, coherent radio emission at low frequencies attributed to electron cyclotron maser emission .

- ***Allows accurate measurement of magnetic field strength as produced at the electron cyclotron frequency***
- ***Can be used to measure true rotation rate of planet***
- ***Provides insight into the dynamics and composition (indirectly) of the planetary interior***

The detection of similar emission from an extrasolar planet represents the most promising method for directly measuring their magnetic fields. Hot Jupiters are a particularly promising population for first detection (Fig. 1).

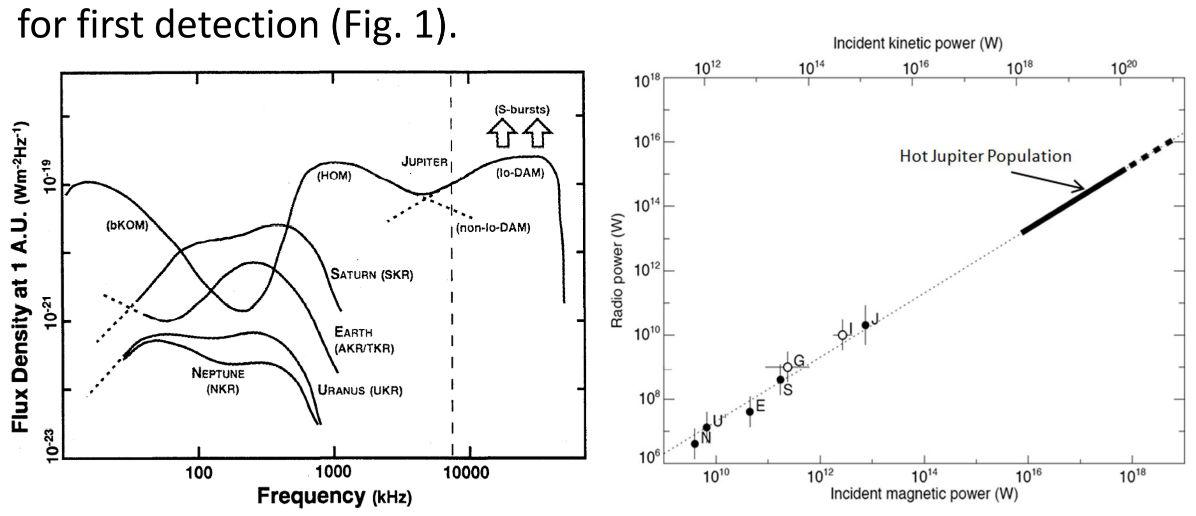


Fig 1 *Left: Radio Spectra of the auroral radio emissions from all of the magnetized planets. Average emission levels are sketched as they would be detected from 1 AU. The high frequency cut-off is determined by the maximum magnetic field strength near the planetary surface. Right: Generalized radio-magnetic Bode's law showing the proportionality between output planetary radio powers and the solar/stellar wind power incident on the magnetopause. E, J, S, U, N are the initials of the 5 radio planets; open dots show the correlation between induced radio emissions from Io and Ganymede. Extrapolation for the Hot Jupiter population suggests flux densities up to 5 orders of magnitude brighter than detected from Jupiter (Zarka 2006).*

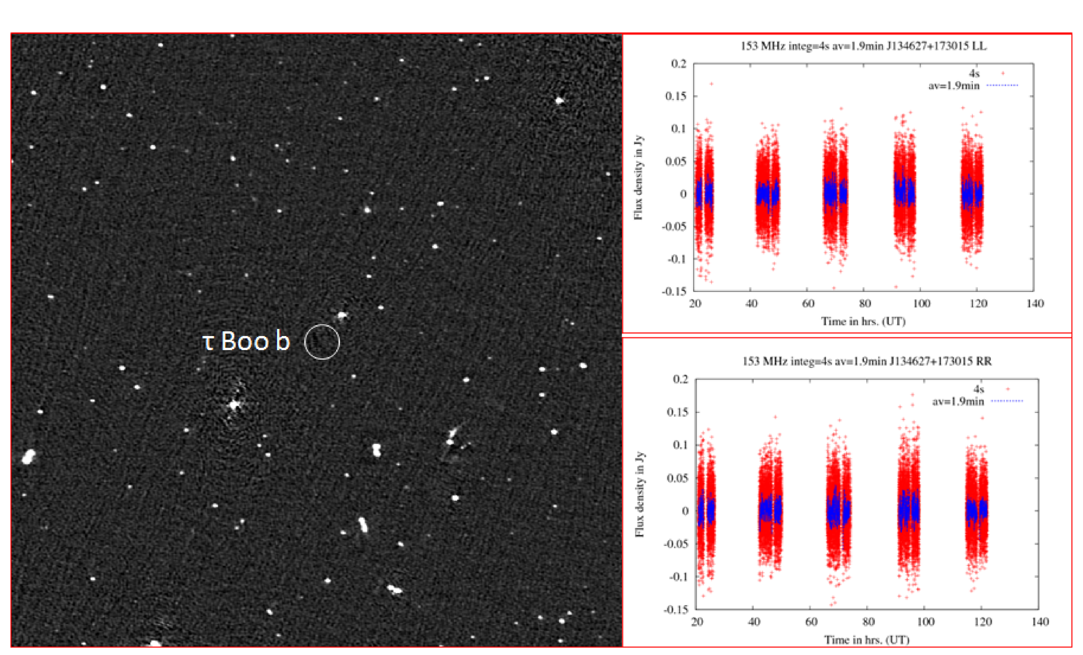


Fig 2: *The 150 MHz field of the hot Jupiter τ Boo b produced using 40 hours of monitoring observations with the GMRT scheduled over 5 nights to allow maximal phase coverage. The RMS noise in much of the image is ~0.3 mJy/beam. No source is detected at the position of the planet. Time series for the left and right circularly polarized also reveal no evidence for the detection of any polarized bursts (Hallinan et al 2013).*

Radio emission is narrowly beamed:

- Need to monitor a large number of planets to account for geometrical selection effects
- Need to observe for > a rotation period to detect the rotationally modulated emission.

Tidally locked hot Jupiters can have rotation periods of a few days! Need very large amount of observing time, eg. Fig 2. However, observations of brown dwarfs indicated that this kind of radio emission is detectable (Fig. 3)

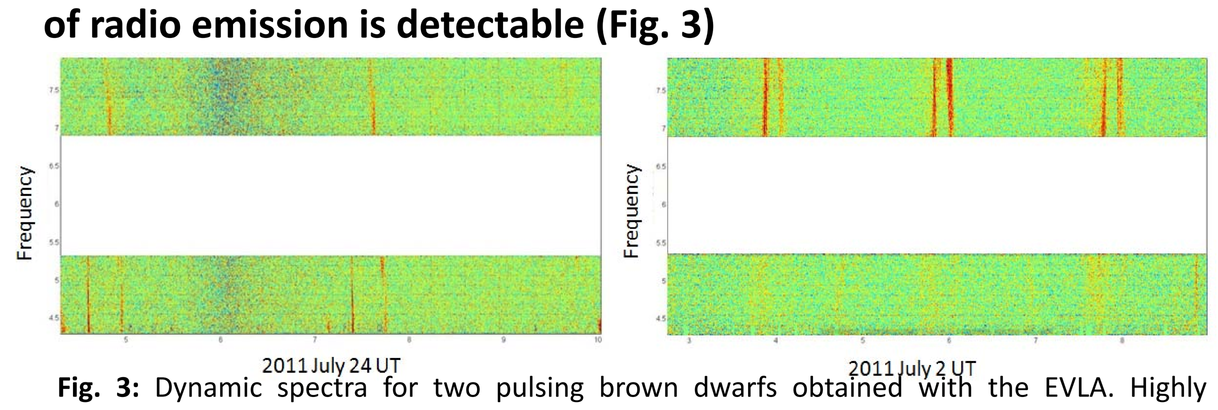


Fig. 3: Dynamic spectra for two pulsing brown dwarfs obtained with the EVLA. Highly circularly polarized emission is detected pulsing on the periods 2.84 hours (left) and 1.96 hours (right), similar to planetary radio emission.

Owens Valley LWA: A New Approach

Fig. 4: *The newly constructed Owens Valley LWA*

The Owens Valley LWA is a new array of 256 antennas at Caltech's Owens Valley Radio Observatory (OVRO). The array will host the NSF-funded LEDA correlator (PI: Lincoln Greenhill), which provides full cross-correlation capability of all 33,000 baselines enabling instantaneous, snapshot imaging of most of the viewable sky. Bandwidth of 60 MHz (28-88 MHz) is correlated simultaneously, giving <10 mJy RMS noise in 1 hour integration. Primary science cases are the study of high redshift HI and monitoring for low frequency transients, particularly exoplanets.

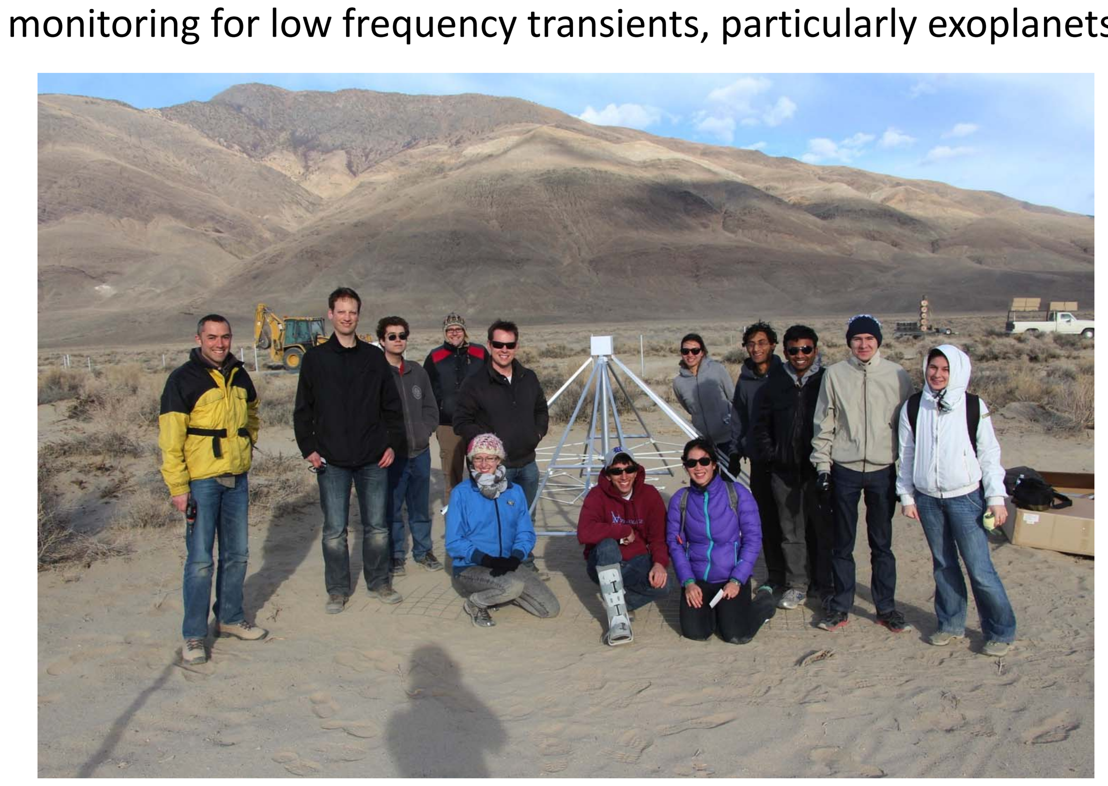


Fig. 5: *The Owens Valley LWA team after construction of the first antenna (Mar 8 2013)*

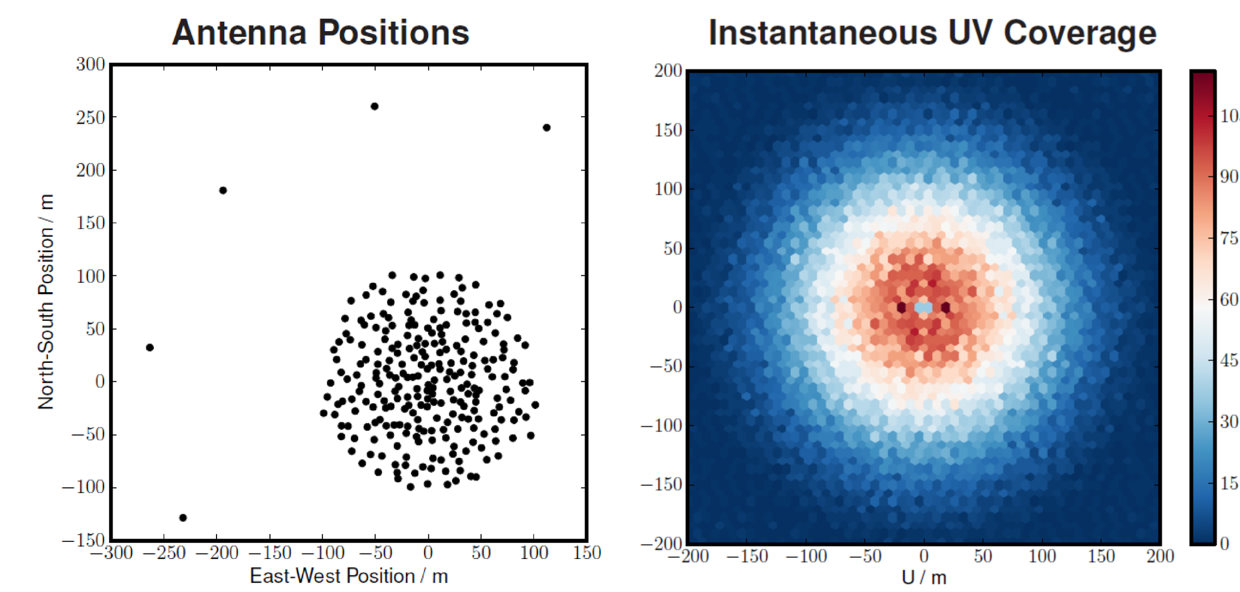
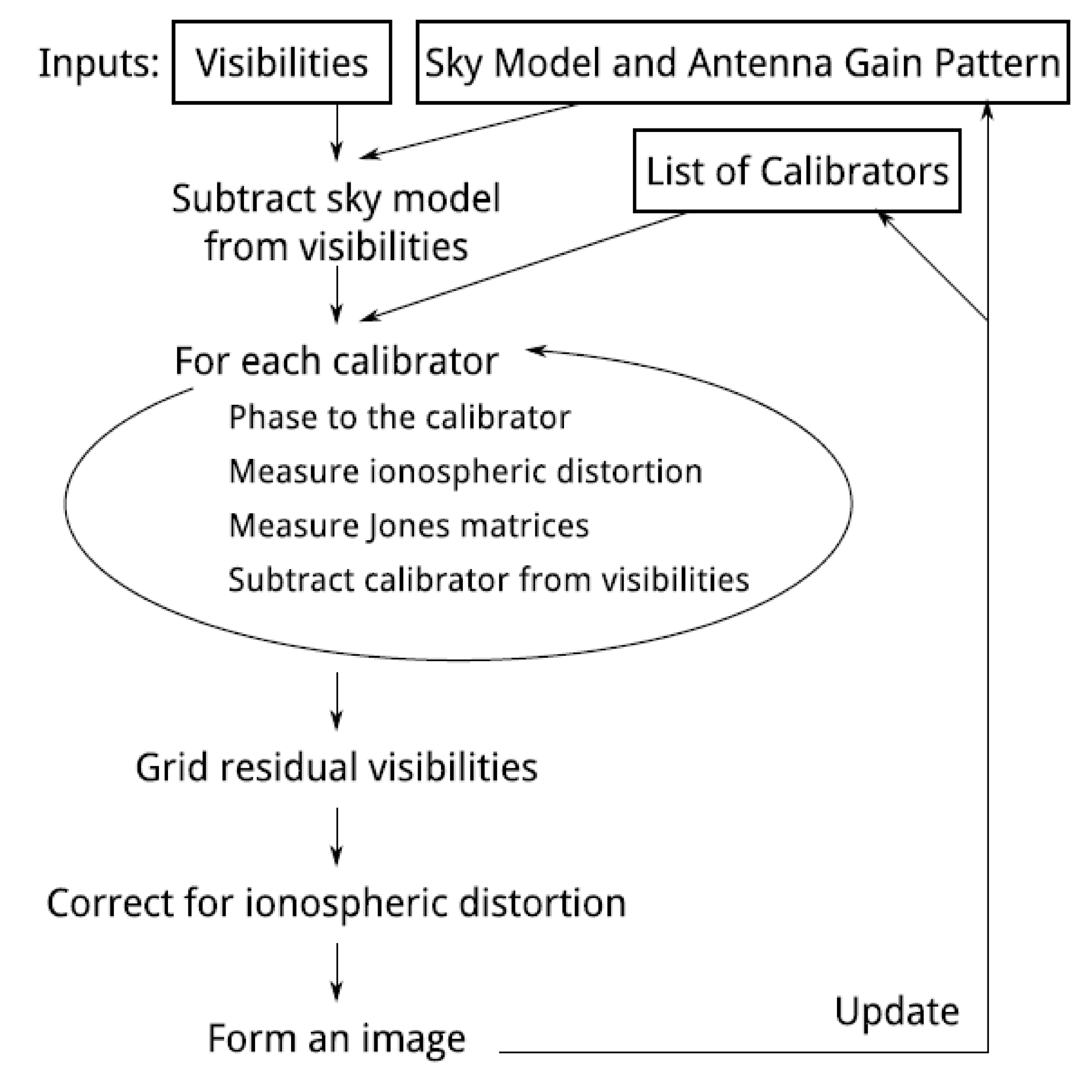


Fig. 6: *The array configuration and instantaneous UV-coverage of the Owens Valley LWA station. The ~33,000 baselines are the largest number yet correlated.*



Calibration is achieved through an iterative self-calibration scheme Mitchell et al. (2008), designed specifically to support ultra wide-field, full polarization (IQUV) imaging with fixed dipole arrays via full implementation of the Measurement Equation formalism

Fig. 7: The Owens Valley LWA electronics shelter, capable of supporting 50 kW of back-end electronics, including th e LEDA correlator and the transient detection backend (Pulsing Planet Finder) developed at Caltech and JPL - 160 CPUs, 20 GPUs, 1 TB RAM, 200 TB Lustre storage.

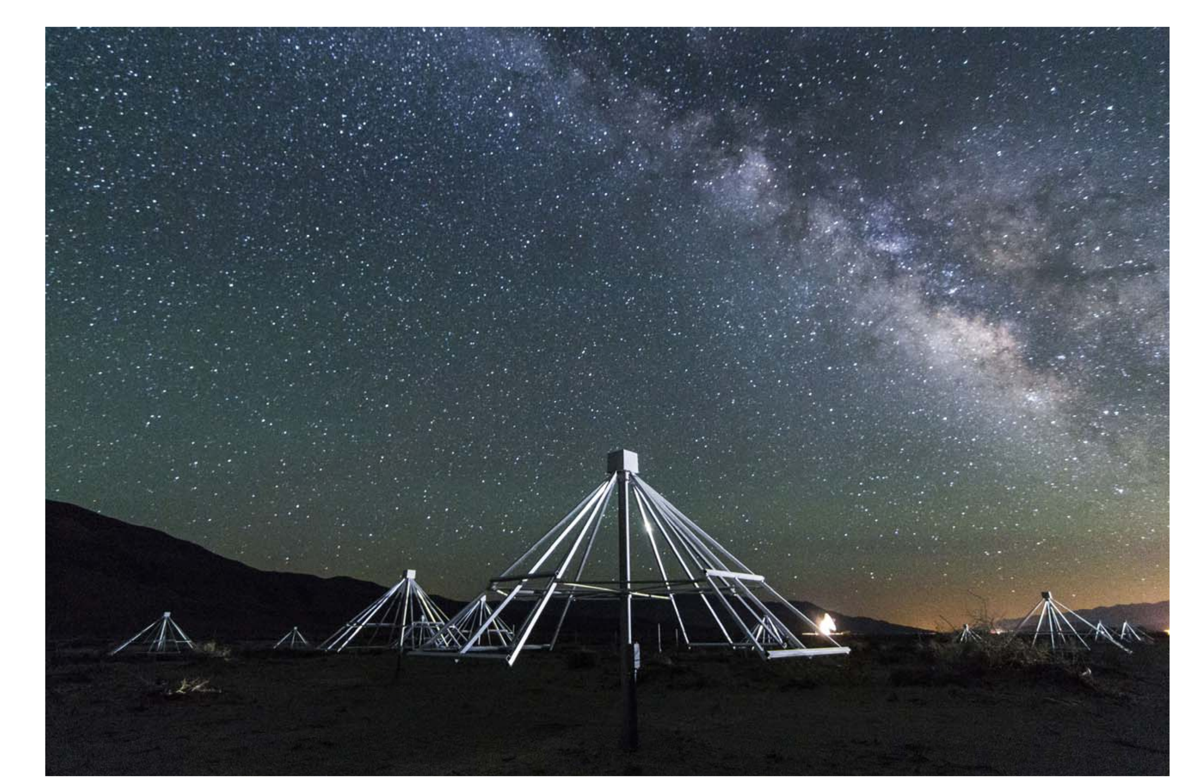
Fig. 8: *The array was built by OVRO staff with the assistance of students, postdocs and faculty*

The Pulsing Planet Finder

A dedicated backend will be installed in the electronics shelter with 160 CPUs, 20 GPUs, 1 TB RAM, 200 TB Lustre storage. This will image the output from the correlator (20 Gb/s) with 1 second time resolution in all 4 polarizations (IQUV).

The Pulsing Planet Finder will reduce and image the data from the LEDA correlator, yielding a map of the entire sky each second in Stokes IQUV. We will largely focus on the Stokes V data in our search for extrasolar planets, as these emissions are often highly circularly polarized and the sky is virtually empty of quiescent sources.

Via this means, we can monitor all known planets in the sky simultaneously, while also conducting blind searches for unknown planets. The presence of periodically pulsing sources in our all-sky data will be particularly indicative of extrasolar planets.



The Future: Over the next 12 months, 32 additional antennas are proposed to be installed, powered by solar panels with data transport via optical fiber, delivering longer baselines up to 2km and eventually yielding all-sky images of resolution 5' at the top of the band. This latter upgrade will allow better calibration, localization of transients and facilitate solar dynamic imaging spectroscopy observations.

Acknowledgements: The Owens Valley LWA project was enabled by the kind donation of Deborah Castleman and Harold Rosen.