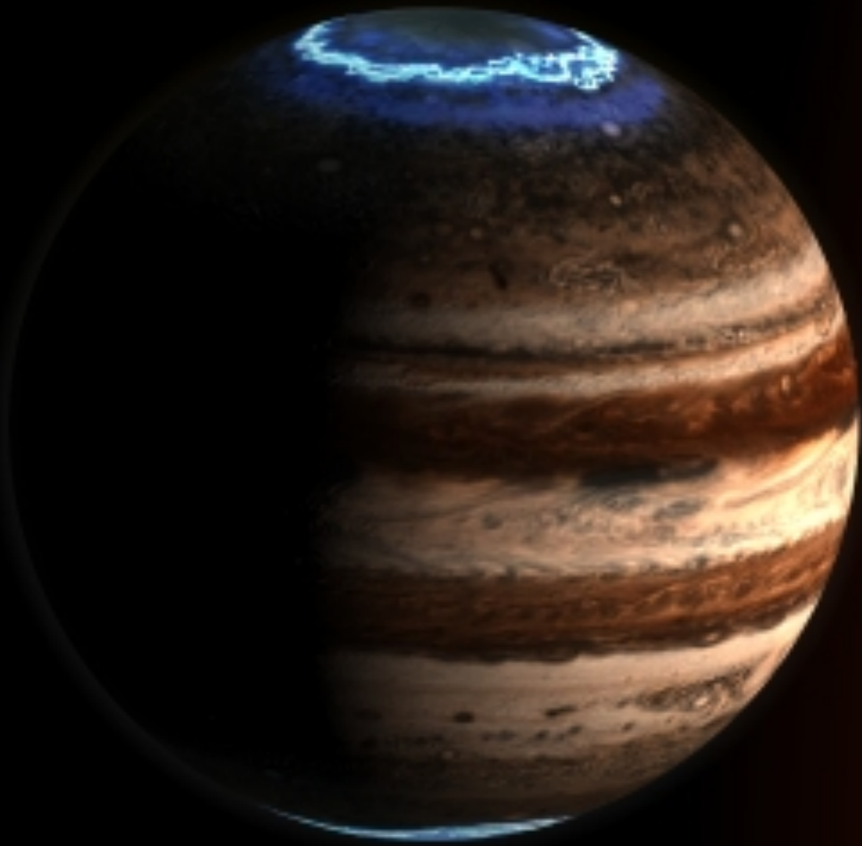
Looking for a Pulse: The Search for Hot Jupiters with the LWA



Jake Hartman
Eureka Scientific
E-mail: ***jakehartman@gmail.com***

Gregg Hallinan
NRAO & UC Berkeley
E-mail: ***gregg@astro.berkeley.edu***

LWA
Long Wavelength Array

1955 - Radio Emission from Jupiter

Bernard Burke and Kenneth Franklin serendipitously discovered radio emission from Jupiter.

This radio emission confirmed that Jupiter had a magnetic field and firmly established the rotation rate of 9.925 hours.

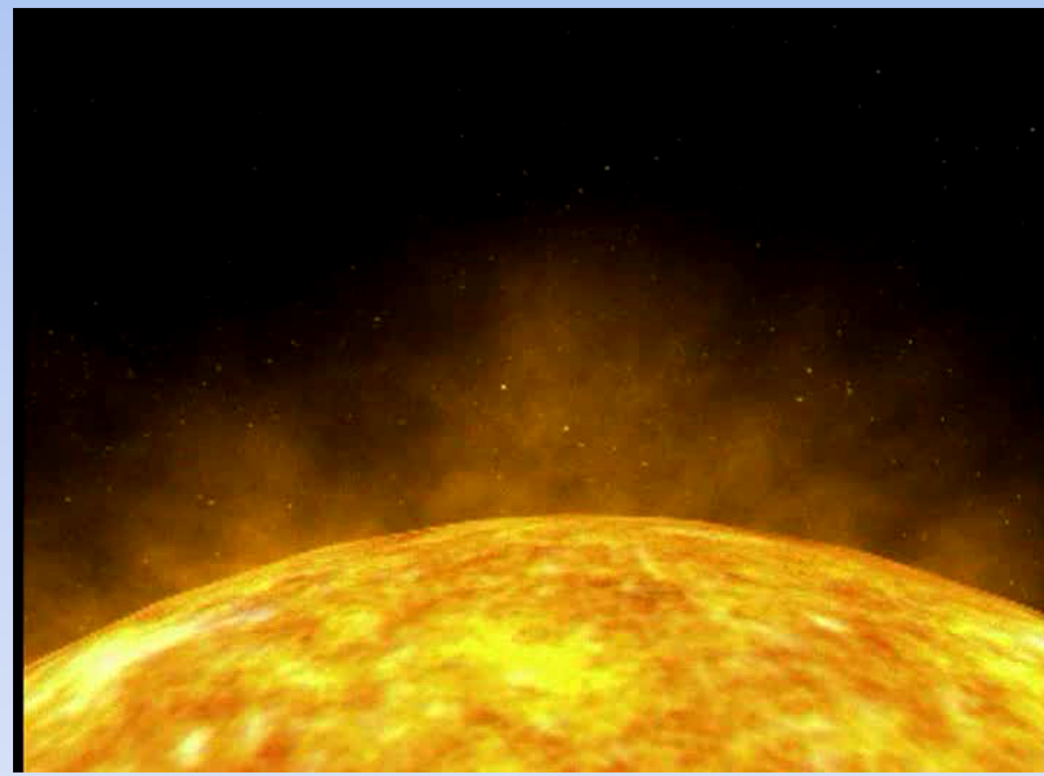
Radio Emission from Solar System Planets

All the magnetized planets in our solar system produce extremely bright radio emission at low frequencies (MHz and kHz)

1-5 % of auroral input energy converted into electron cyclotron maser emission.

Electron maser emission produced at the electron cyclotron frequency

Field strength (Gauss) = Frequency (MHz) / 2.8



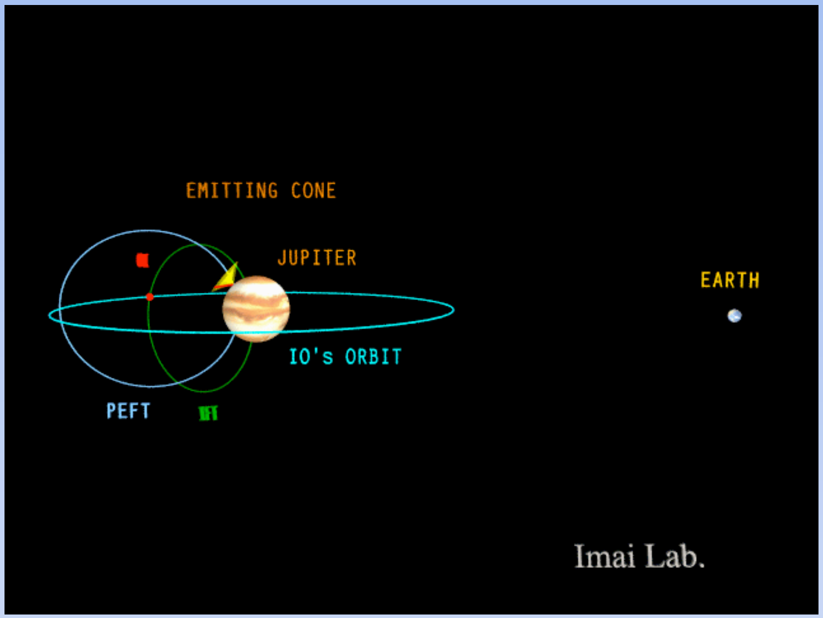
Credit: Soho

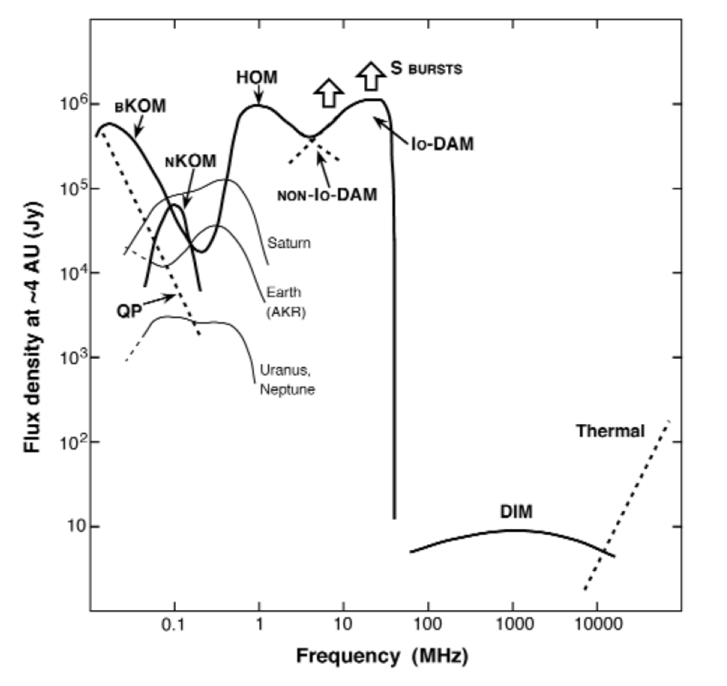
Radio Emission from Jupiter

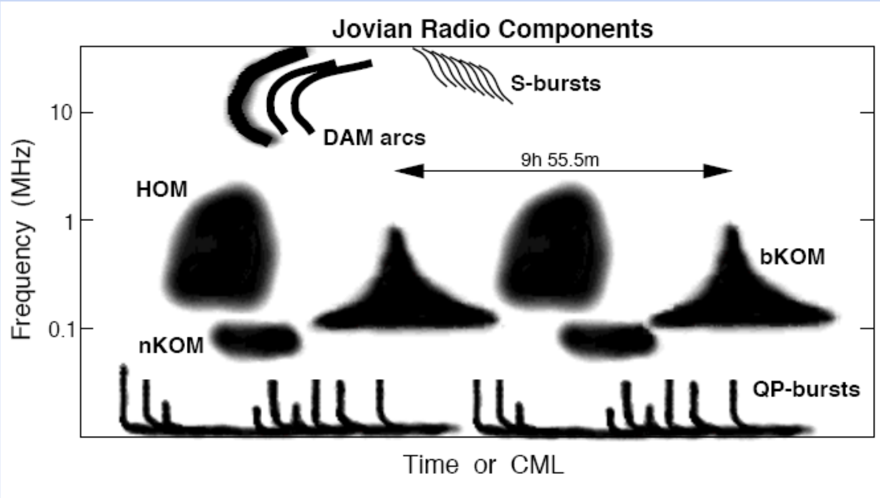
The radio emission is extremely bright, T_B up to 10^{20} K and highly polarized.

It is beamed into conical patterns ranging from as large as 60˚ to as thin as 5˚ in beam width.

Jupiter can outshine the Sun at low frequencies.







Zarka (1998)

Why look for radio emission from exoplanets?

• It's a direct detection

• Allows measurement of rotation rate

• Possible use as a detection method for exoplanets

• The only method currently viable for measurement of magnetic field strengths for exoplanets...

a)Leads to constraints on scaling laws based on magnetic fields of solar system planets. May eventually allow magnetic field estimation for planets with ecosystems – crucial for life?

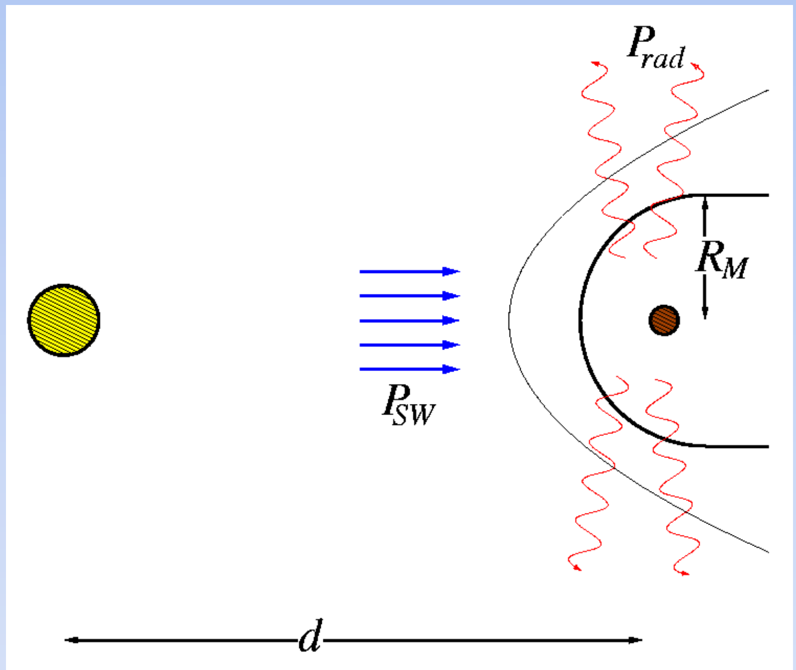
b)Provides insight into internal structure of planet.

Expected Flux…

• Strong correlation between Solar Wind (P & V) and auroral radio emissions.

• The emitted power scales with the received stellar wind power - $P_{rad} \propto P_{SW}^{x}$

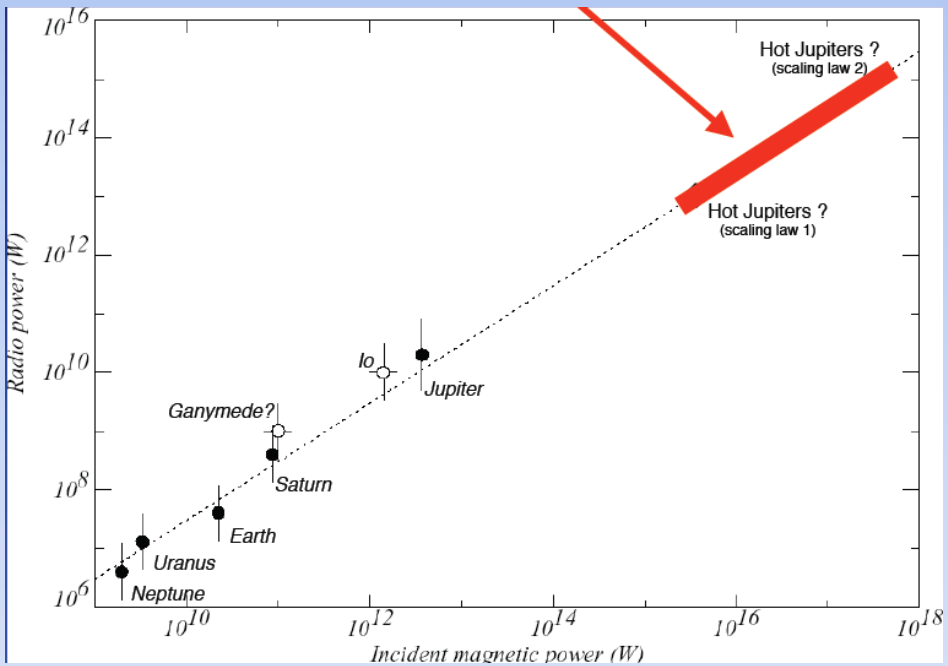
•The received stellar wind power depends on the distance and the cross-section of the magnetosphere - $P_{SW} \propto R_M^2 d^{-2}$



Zarka et al, ApSS. 2001

Radiometric Bode's Law

- 'Hot Jupiters' with expected radio luminosities many thousands of times brighter than Jupiter.
- Should theoretically outshine the parent star.
- Predicted detectable fluxes from a number of planets up a few hundred mJy in some cases.



Zarka et al, ApSS. 2001

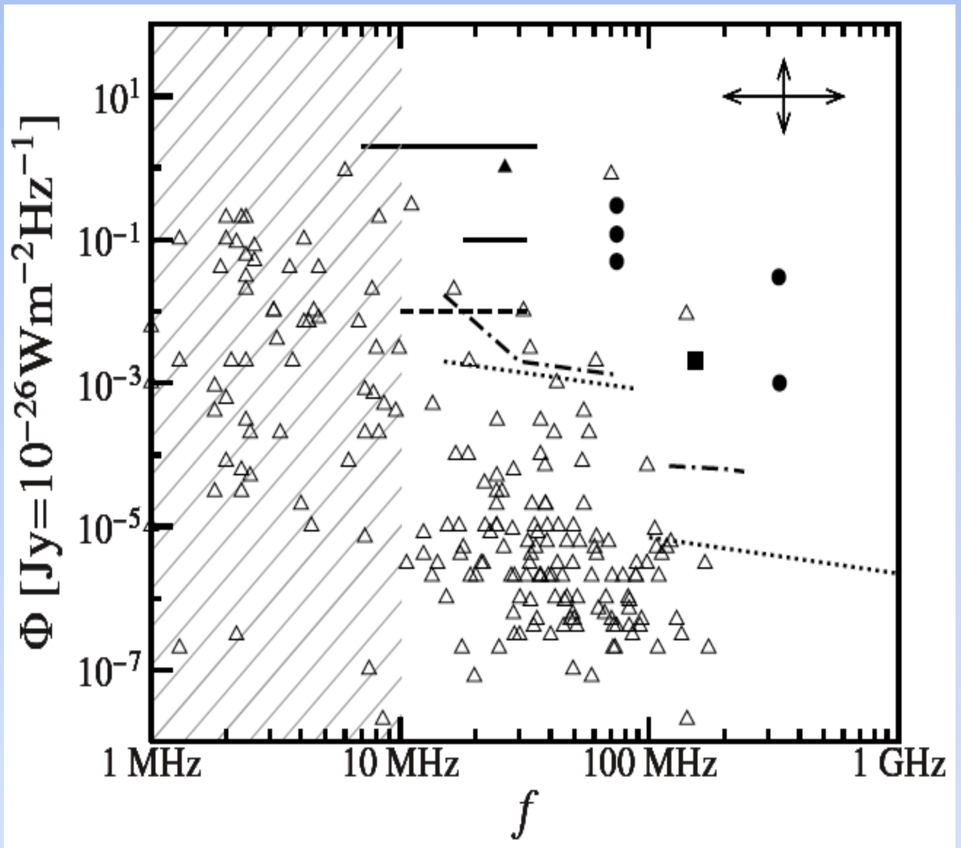
What frequency to observe?

- Frequency cut off dependent on maximum magnetic field strength.

- Therefore dependent on magnetic dipole moment. Number of scaling laws have been applied starting with Blackett (1947). Order of magnitude disagreement between some models.

-Christensen et al. Nature (2009) suggest the energy flux available for generating the magnetic field sets the field strength - suggest magnetic field strengths of > 100 Gauss are possible.

- Predictions are useful but observations are vital to constrain these models.



Eg. Lazio et al. (2004); Zarka (2004); Griessmeier et al. (2007)

Searches Thus Far…

- Searches have been ongoing for > 30 years

- Involve targeted pointings of small sample of Hot Jupiters (<10)

- No detections!

- See Lazio et al. 2009 for review – 2010 Decadal Survey White Paper

Limits on Extrasolar Planetary Magnetosphere Emission

Frequency	Limit	Telescope	Reference
150 MHz	0.3–2 mJy	GMRT	Hallinan et al. 2009; Winterhalter et al. 2009
74 MHz	135–300 mJy	VLA	Lazio & Farrell 2008
25 MHz	100–1600 mJy	UTR-2	Zarka 2007

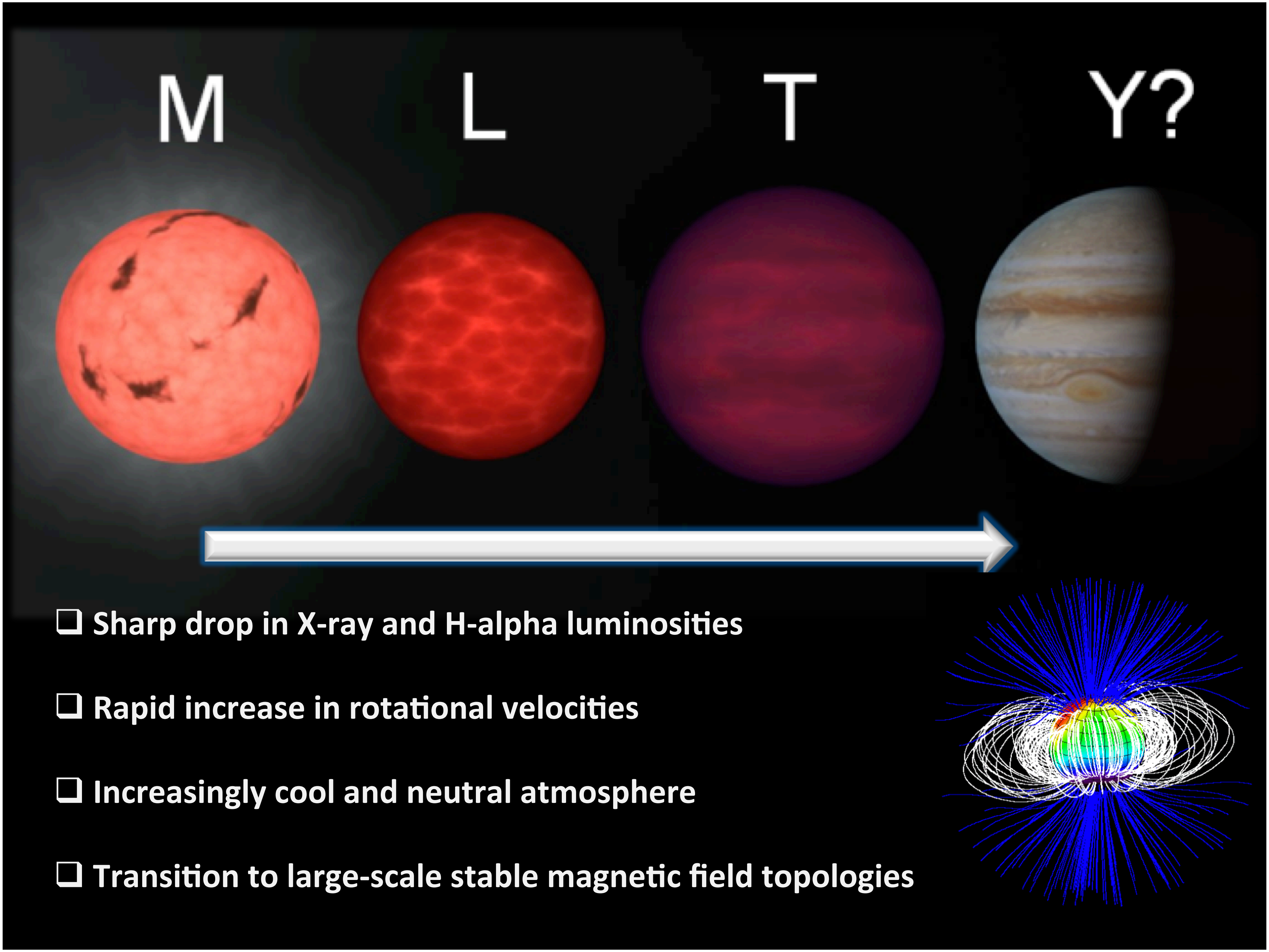
Why No Detection?

1) Low Frequency AND high sensitivity required. New generation of telescopes such as the LWA will meet this requirement.

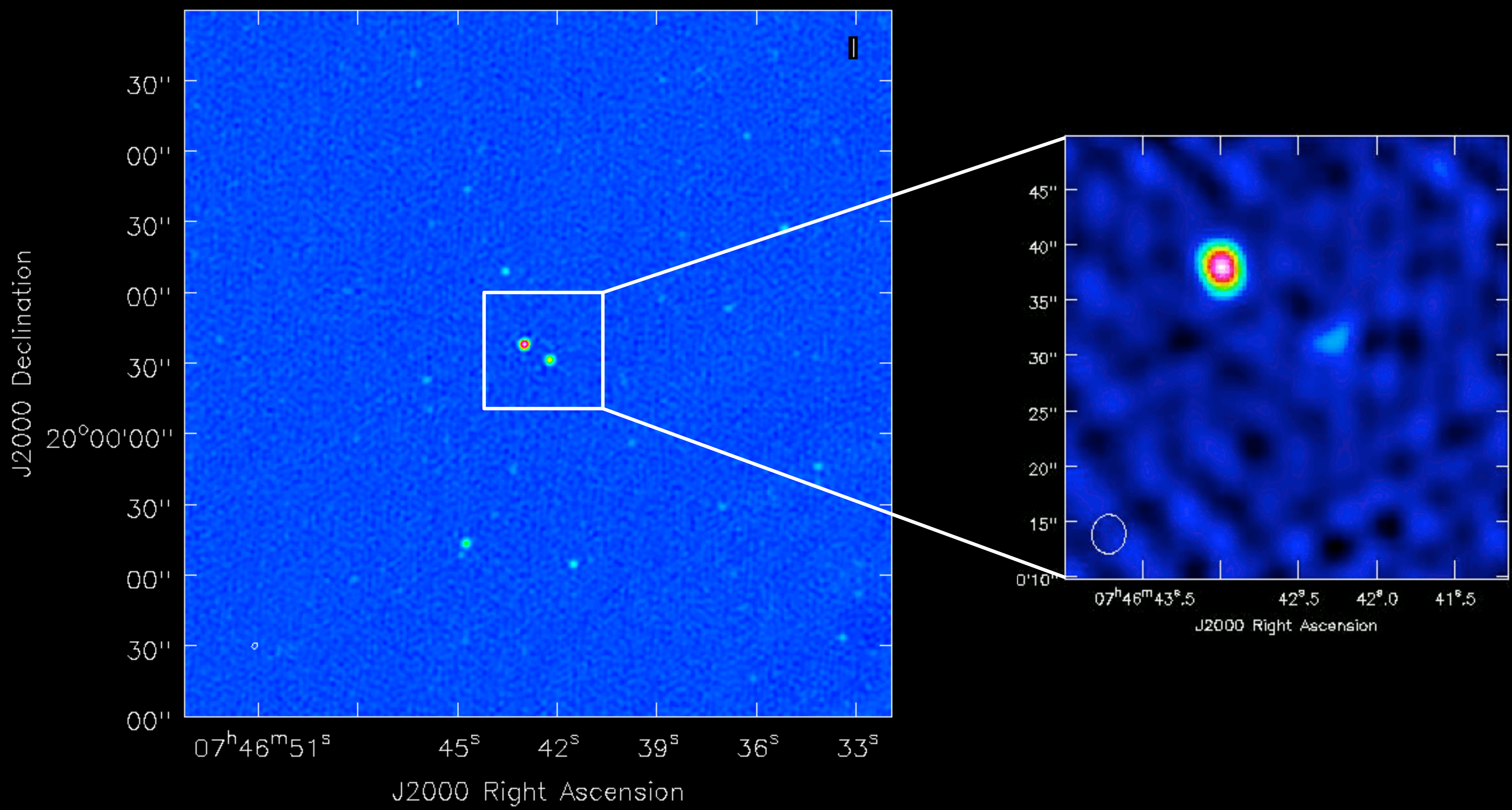
2) Emission may be tightly beamed.

- Large sample required to negate possible geometrical selection effect.
- Full rotational phase coverage required.

Consider the example of brown dwarfs...

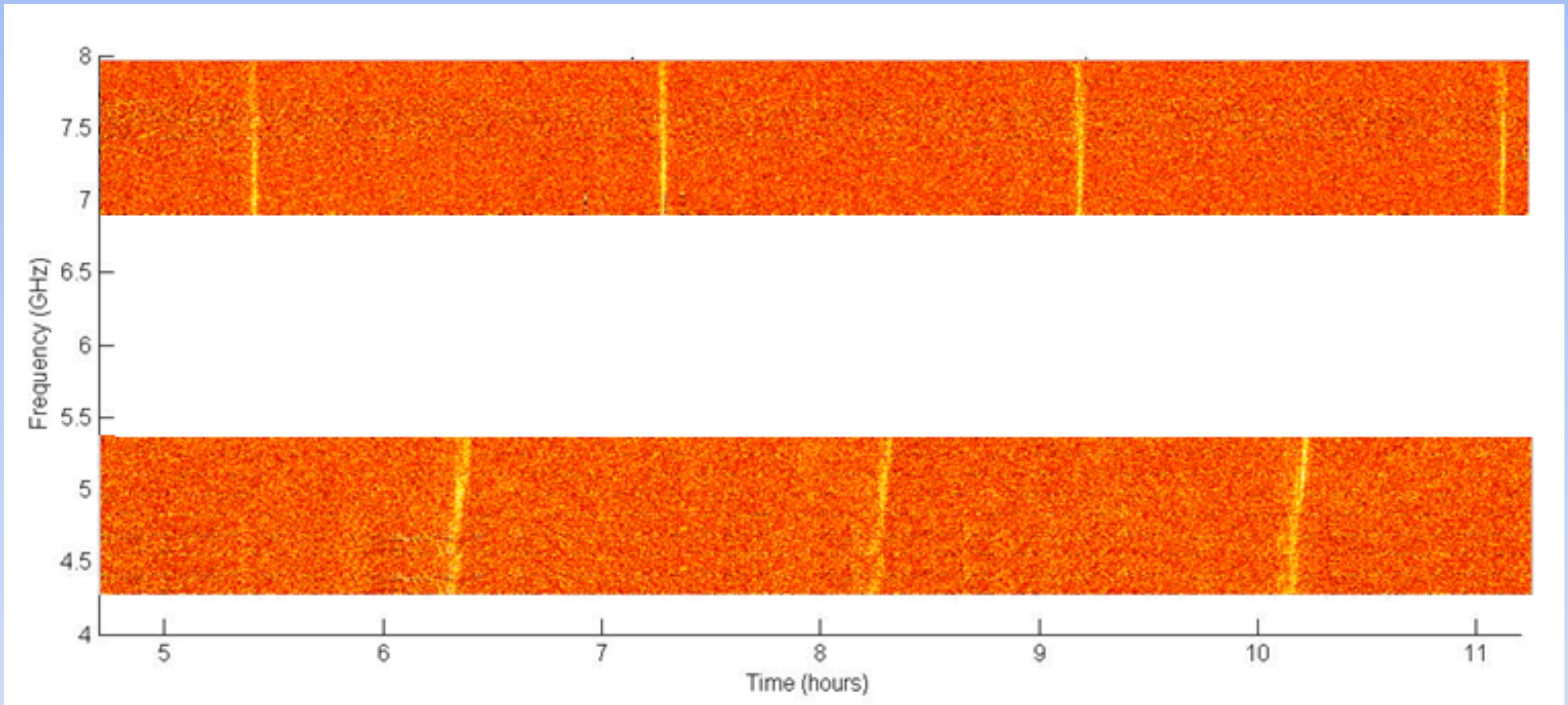

M
L
T
Y?
❑ Sharp drop in X-ray and H-alpha luminosities
❑ Rapid increase in rotational velocities
❑ Increasingly cool and neutral atmosphere
❑ Transition to large-scale stable magnetic field topologies

Brown Dwarfs Pulse



- **12.5 hours of EVLA data with 2 GHz bandwidth.**
- **RMS noise <1.5 μJy. Deepest radio image yet...**

What have we learned from Brown Dwarfs…

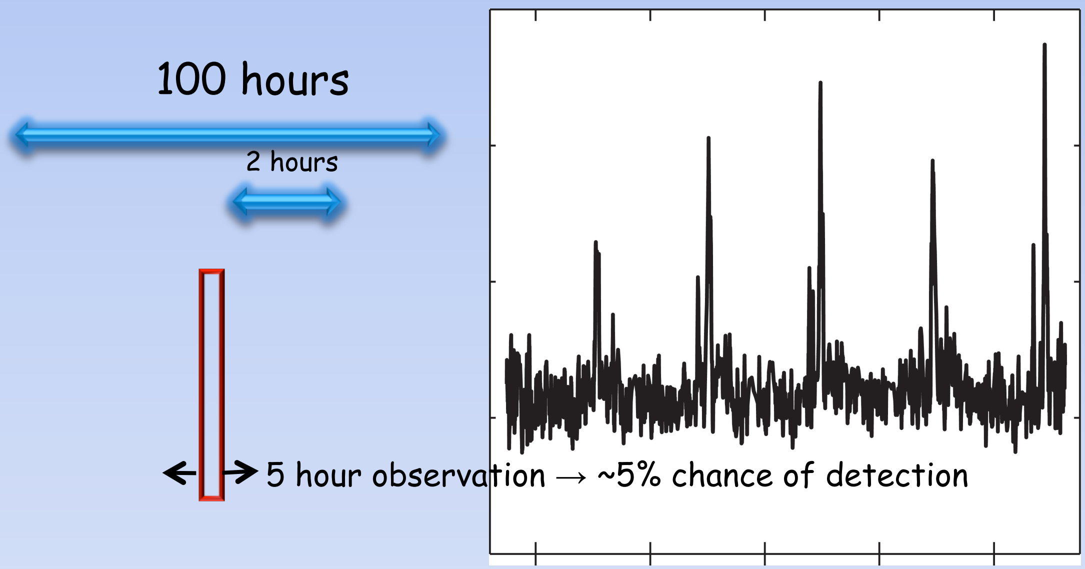


Dynamic Spectrum - RR

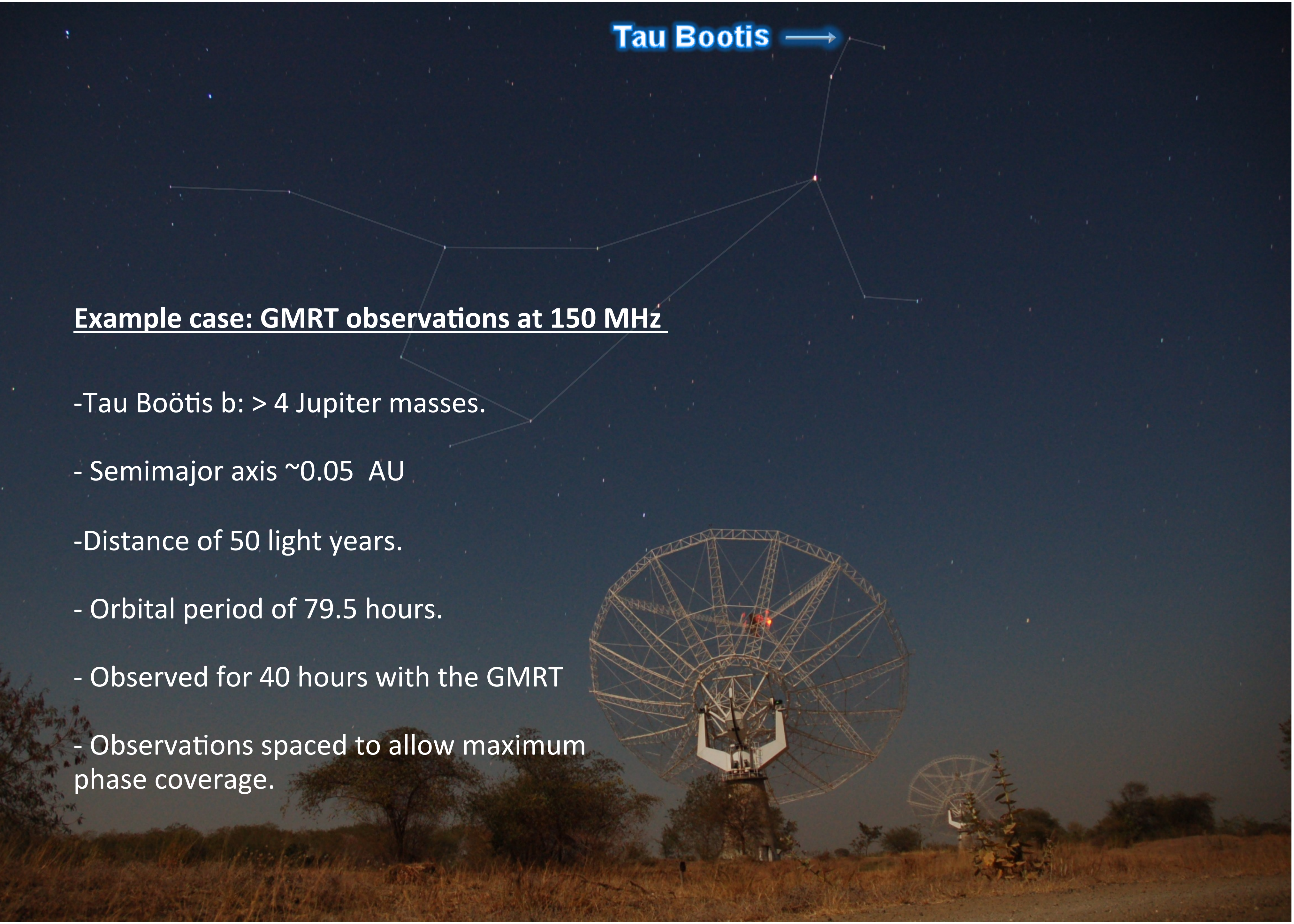
- 10% of brown dwarfs detected – geometrical selection effect?
- Emission is 100% circularly polarized electron cyclotron maser emission – same as planets.
- Confined to narrow ranges of rotational phase.


Observing in the radio is still more reliable than in the optical!

What have we learned from Brown Dwarfs…



- Most observations have been short, of order a few hours.
- However, need to monitor for entire rotation period to detect 'pulse'…
- Hot Jupiters typically have rotation periods of 3-5 days.



Example case: GMRT observations at 150 MHz

-Tau Boötis b: > 4 Jupiter masses.

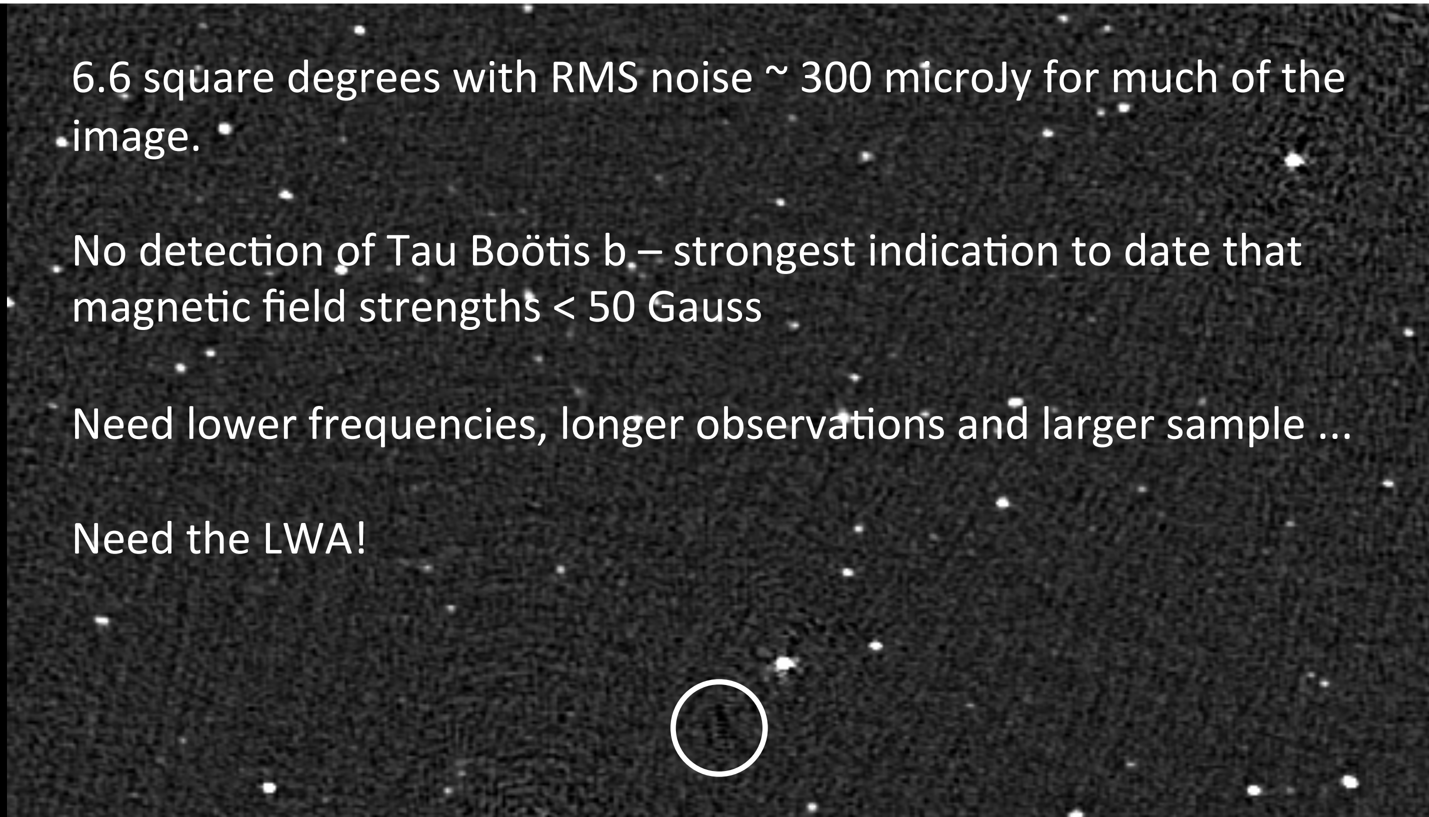
- Semimajor axis ~0.05 AU

-Distance of 50 light years.

- Orbital period of 79.5 hours.

- Observed for 40 hours with the GMRT

- Observations spaced to allow maximum phase coverage.

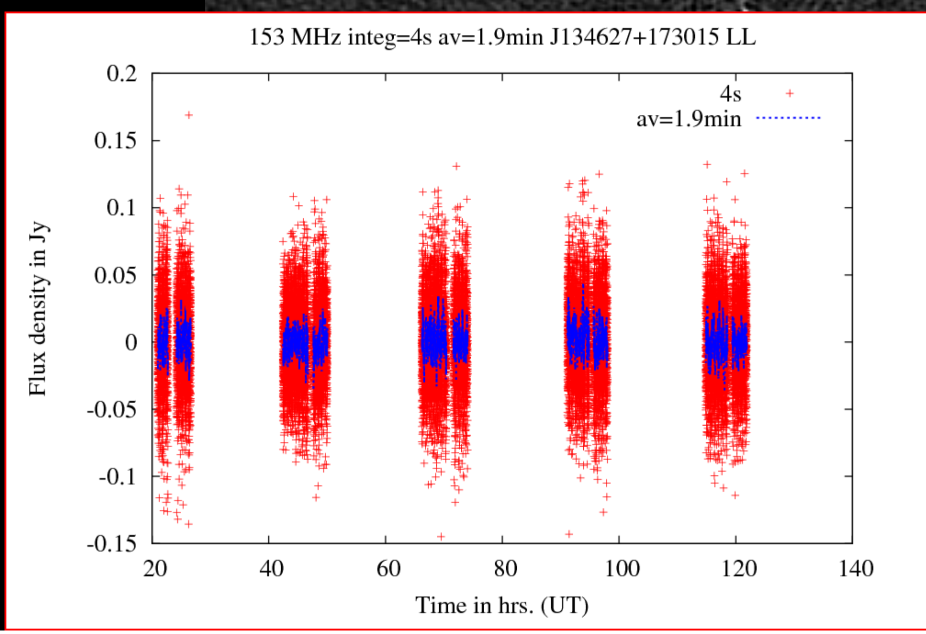


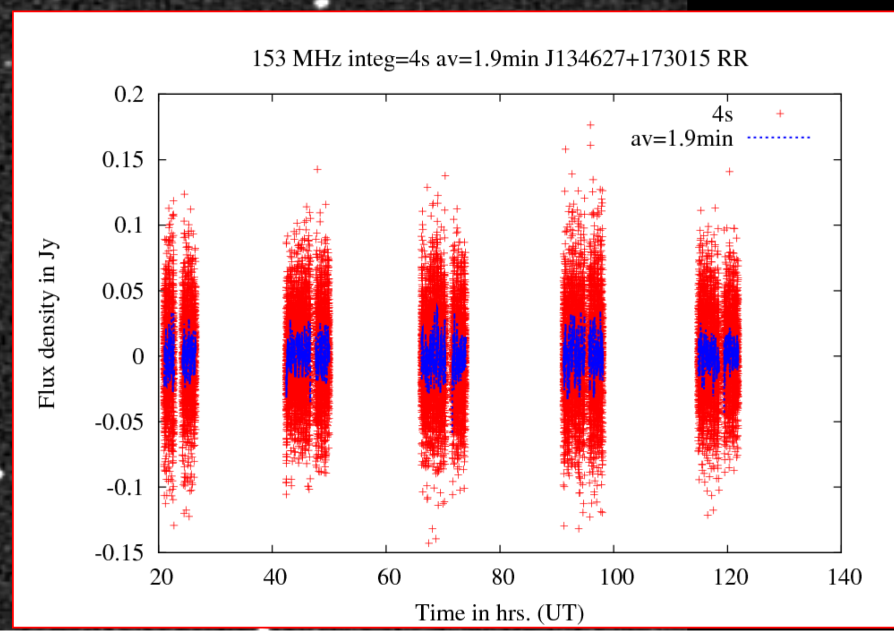
6.6 square degrees with RMS noise ~ 300 microJy for much of the image.

No detection of Tau Boötis b – strongest indication to date that magnetic field strengths < 50 Gauss

Need lower frequencies, longer observations and larger sample ...

Need the LWA!





Focus for the LWA

1) Large sample - Targeted and Blind Search

2) Volume limited

3) Full rotational phase coverage – lengthy observation plan!

4) Primary focus on Stokes V

5) Emphasis on close in, high mass Hot Jupiters

A volume-limited survey of known HJs

distance: $d < 50$ pc

semi-major axis: $a < 0.5$ AU

projected mass: $M \sin i > 0.5\ M_J$

location: northern sky

Planet	d (pc)	a (AU)	P_{orb} (d)	M (M_J)	Coordinates (J2000)	Best month	Num. days
Hot Jupiters likely to be tidally locked:							
υ And b	13.49	0.059	4.62	1.4	01^h37^m $+41°24'$	Sep	37
τ Boo b	15.62	0.048	3.31	6.5	13^h47^m $+17°27'$	Mar	43
HD 189733 b	19.45	0.031	2.22	1.13	20^h01^m $+22°43'$	Jun	29
HD 187123 b	48.26	0.042	3.10	> 0.51	19^h47^m $+34°25'$	Jun	31
HD 209458 b	49.63	0.047	3.52	0.69	22^h03^m $+18°53'$	Aug	32
Hot Jupiters less likely to be tidally locked:							
55 Cnc b	12.34	0.116	14.65	> 0.84	08^h53^m $+28°20'$	Dec	30
ρ CrB b	17.24	0.226	39.84	> 1.06	16^h01^m $+33°18'$	Apr	30
70 Vir b	17.99	0.484*	116.69	> 7.46	13^h28^m $+13°47'$	Mar	30
HD 195019 b	38.52	0.137	18.20	> 3.58	20^h28^m $+18°46'$	Jun	30
HD 114762 b	38.65	0.363*	83.89	>11.68	13^h12^m $+17°31'$	Mar	30
HD 38529 b	39.28	0.131*	14.31	> 0.86	05^h47^m $+01°10'$	Nov	30
HD 178911 Bb	42.59	0.345*	71.48	> 7.29	19^h09^m $+34°36'$	Jun	30
HD 37605 b	43.98	0.261*	54.23	> 2.86	05^h40^m $+06°04'$	Nov	30

* Sources with eccentricities greater than 0.1.

LWA Long Wavelength Array

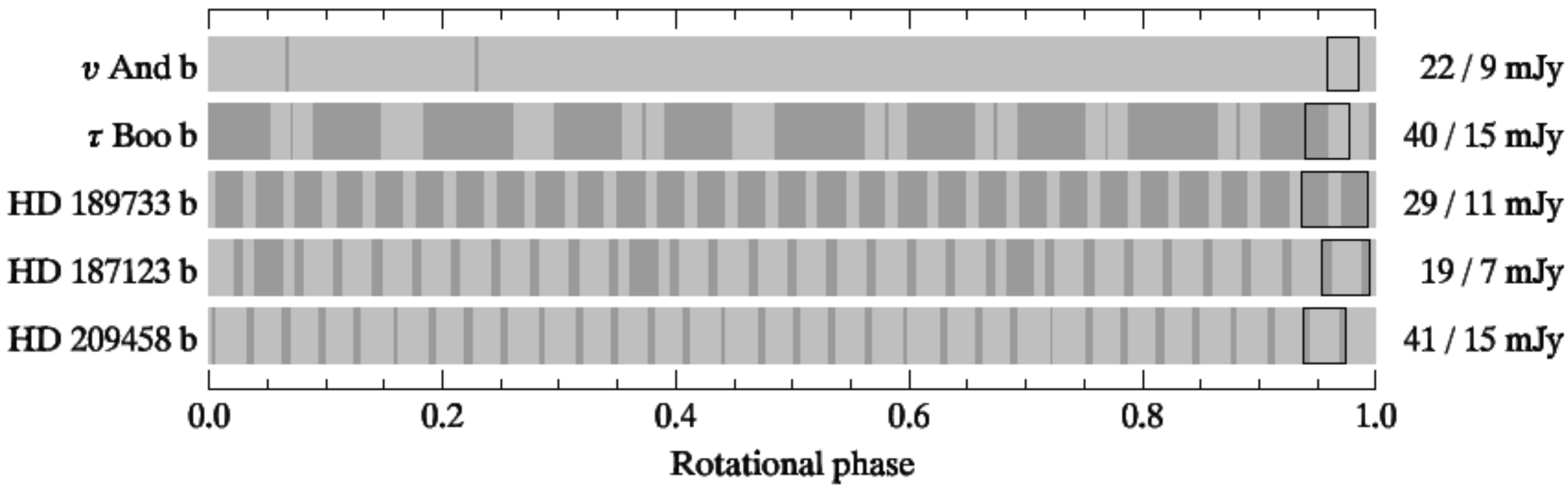
The Donald Rumsfeld Observation Strategy…

> “[T]here are known knowns; there are things we know we know.
> We also know there are known unknowns; that is to say we know there are some things we do not know.
> But there are also unknown unknowns – the ones we don't know we don't know.”

—Former United States Secretary of Defense Donald Rumsfeld

LWA
Long Wavelength Array

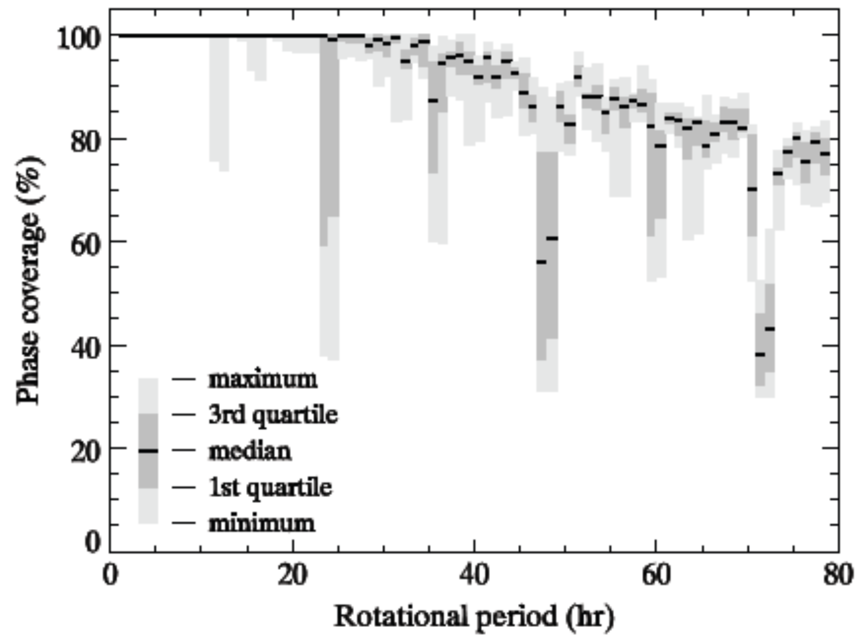
Known source, known period



- Sources with a < 0.06 AU probably are tidally locked
- Series of daily 3 hr observations, for 30–40 days
- 2 co-aligned beams with different tunings to cover 10–65 MHz
- Upper limits: if source emits up to $f_c = 36$ MHz: ~30 mJy
  $f_c = 65$ MHz: ~10 mJy

LWA
Long Wavelength Array

Known source, unknown period



- Sources with a > 0.11 AU may not be tidally locked
- Logarithmically spaced 3 hr observations over 2 months
- “Monte Carlo scheduling” gives >95% phase coverage for 96% of orbital periods less than 30 hr

Unknown source, unknown period

- 20 MHz beam of LWA is huge - (~5º × 5º)

- Every LWA beam will have ~75 stars within 100 pc. The frequency of Hot Jupiters is still uncertain : (0.1% – 1%). Kepler will refine this number.

- However, it is certain that every LWA beam will have planets within 100pc and some, if not all, will have Hot Jupiters.

- An algorithm will be added to search for bursty, highly polarized emission to the processing pipeline for ***ALL*** beamformed observations.

- Optical localization of radio counterparts difficult, but not impossible, primarily through identification of high proper motion stellar sources in the field.

LWA Long Wavelength Array

Summary

- The search for radio emission from exoplanets is an important one.

- The newest generation of low frequency telescopes is poised to commence the era of exoplanetary radio astronomy.

- The LWA should play an important role.

- Observation strategies have been informed from studies of planets in our own solar system, as well as studies of brown dwarfs.

- A large survey of Hot Jupiters will commence shortly, including targeted pointing of exemplary known candidates and blind surveys in all LWA data.

- Notable that brown dwarf pulses and stellar bursts should also be detected by the LWA.

LWA
Long Wavelength Array