SEARCH FOR RADIO EMISSIONS FROM EXTRASOLAR PLANETARY MAGNETOSPHERES

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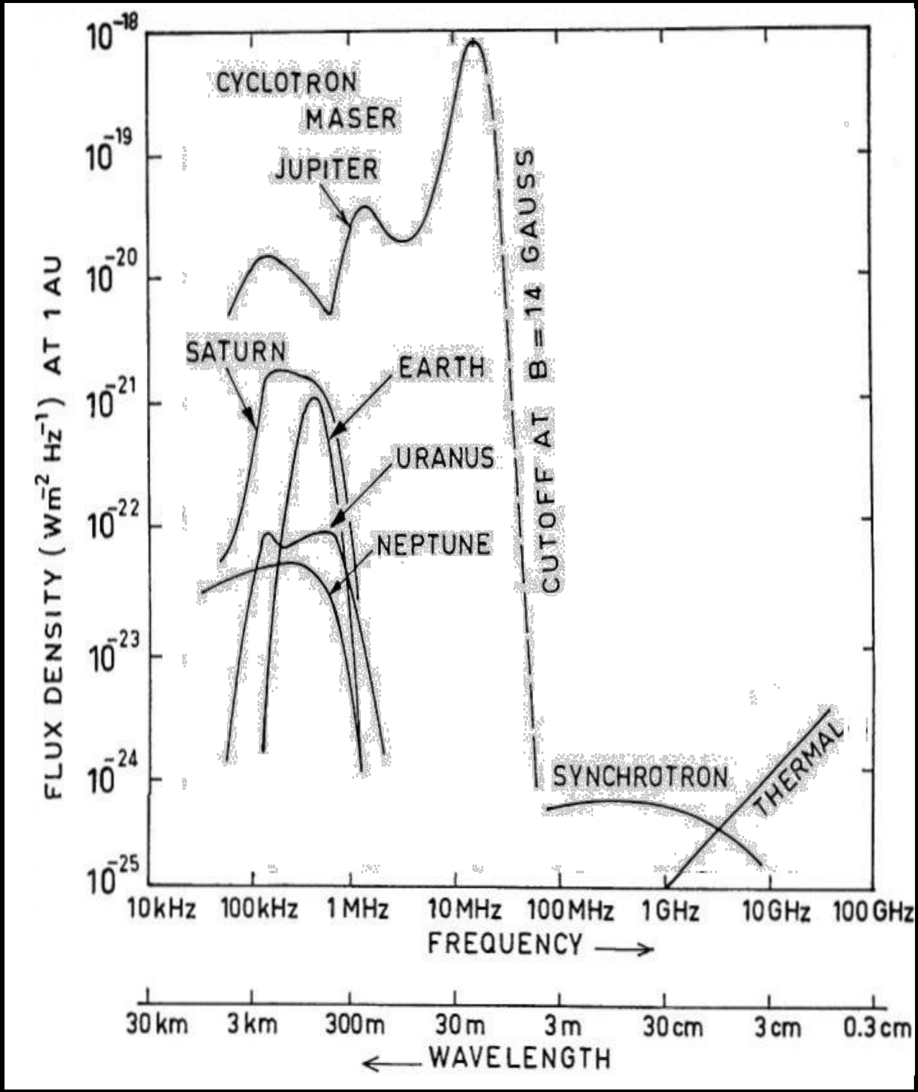
WHY RADIO?

- **Alternate way to search for extrasolar planets (much prefers stellar activity, whereas optical requires quiet stars).**
- **Better planetary/stellar flux intensity ratio:**
  - **visible: 10^{-9}**
  - **Infrared: 10^{-6}**
  - **Radio: 10^{4} (quiet sun); 10^{-3} (strong radio bursts).**
- **Emissions will quantify planetary B; gain info re thermal state and composition of planetary interior.**
- **Information on planetary rotation (modulation of the emission with the rotation frequency).**
- **Star/Planet interaction; Magnetospheric characteristics.**

Search for Radio Emissions…

Planetary Radio Emissions:
Our Solar System



Thermal (black-body) and non-thermal emission of our solar system's radio planets (normalized to a distance of 1AU).

[Bastian, Dulk, Leblanc, ApJ, 545, 1058, (2000)]

The emission mechanism probably is the Cyclotron Maser Instability (CMI), a wave-particle-interaction involving electrons gyrating in a magnetic field.

Problem 1: Emission Bandwidth/Cut-Off

$$\Delta f = f_c^{\max} = \frac{eB_p^{\max}}{2\pi m_e}$$

JUPITER AT 10 pc

	Jupiter's Flux Density (~ 30 MHz)
4.5 AU	~ 50,000 Jy (~ 50 kJy)
10 pc	~ 0.0000002 Jy (~ 0.2 μJy)

(1 Jy = 10^{-26} W/m^2/Hz)

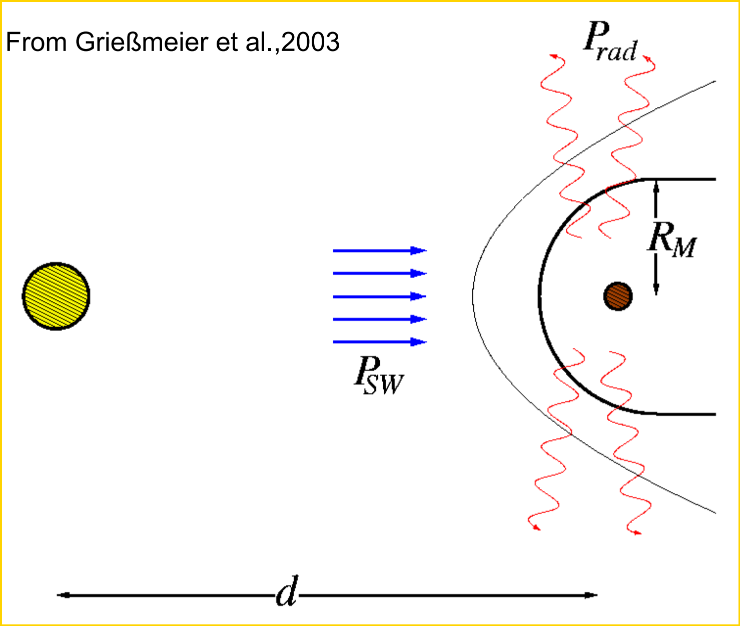
B.Gary and S. Gulkis, *JPL IOM*, 1974.

(BIG) Problem 2: VERY weak signal

Is there any hope?

PLANETARY RADIO FLUX

All strongly magnetized planets of the solar system are sources of non-thermal radio emission. The source region is close to the auroral field lines at distances of 2 to 4 planetary radii. For the total emitted power, simple scaling laws can be applied:



For close-in extrasolar giant planets (i.e. small ***d***), a <u>much stronger radio emission</u> is expected than for Jupiter as long as they are not tidally locked (this would lead to smaller magnetic moments???).

- The emitted power scales with the received stellar wind power [Farrell et al., JGR, 104, 14025, (1999)]:

  $$\mathbf{P_{rad} \propto (P_{SW})^{1.2}}$$

- The received solar wind power depends on the cross-section of the magnetosphere:

  $$\mathbf{P_{SW} \propto (R_M)^2 d^{-2}}$$

- The size of the magnetosphere depends on the planetary magnetic moment:

  $$\mathbf{R_M \propto M^{1/3} d^{1/3}}$$

- For the magnetic moment, different scalings are in use [e.g. Grießmeier et al., A&A, 2003]:

  $$\mathbf{M \propto (\rho_c)^{1/2} \omega^{\alpha} (r_c)^{\beta}}$$

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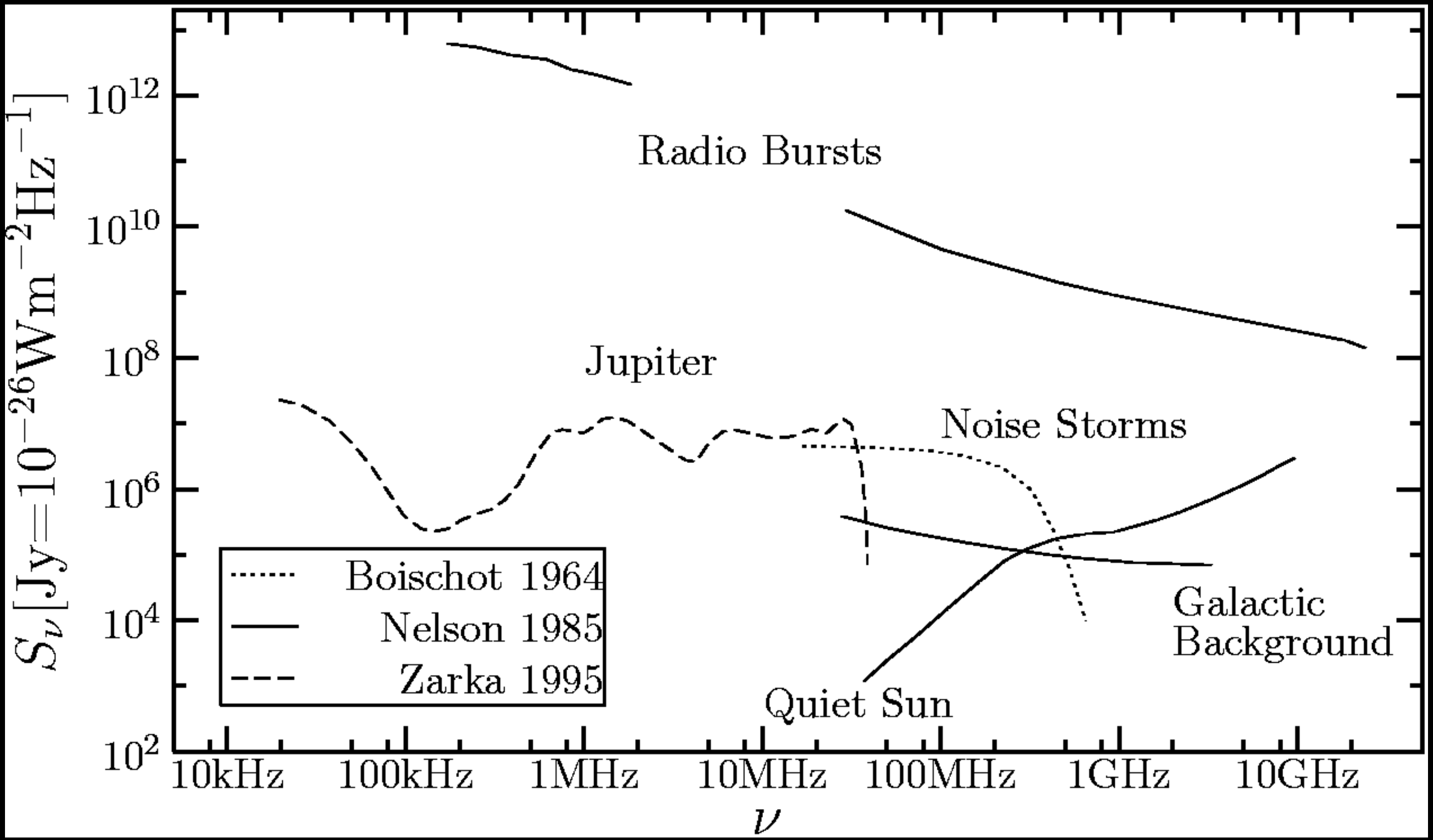
(BIG) Problem 2: VERY weak signal

… What about Variability?

Search for Radio Emissions…

COMPARISON OF SOLAR AND AVERAGE PLANETARY FLUX DENSITIES

(in our solar system)



The **quiet sun** emission is due to thermal emission of ionized plasma close to the (local) electron plasma frequency. It is randomly polarized.

During solar maximum, **noise storms** frequently occur (about 10% of the time). The typical duration is between a few hours and several days. The emission consists of a broadband continuum plus short-lived bursts. The emission is circularly polarized.

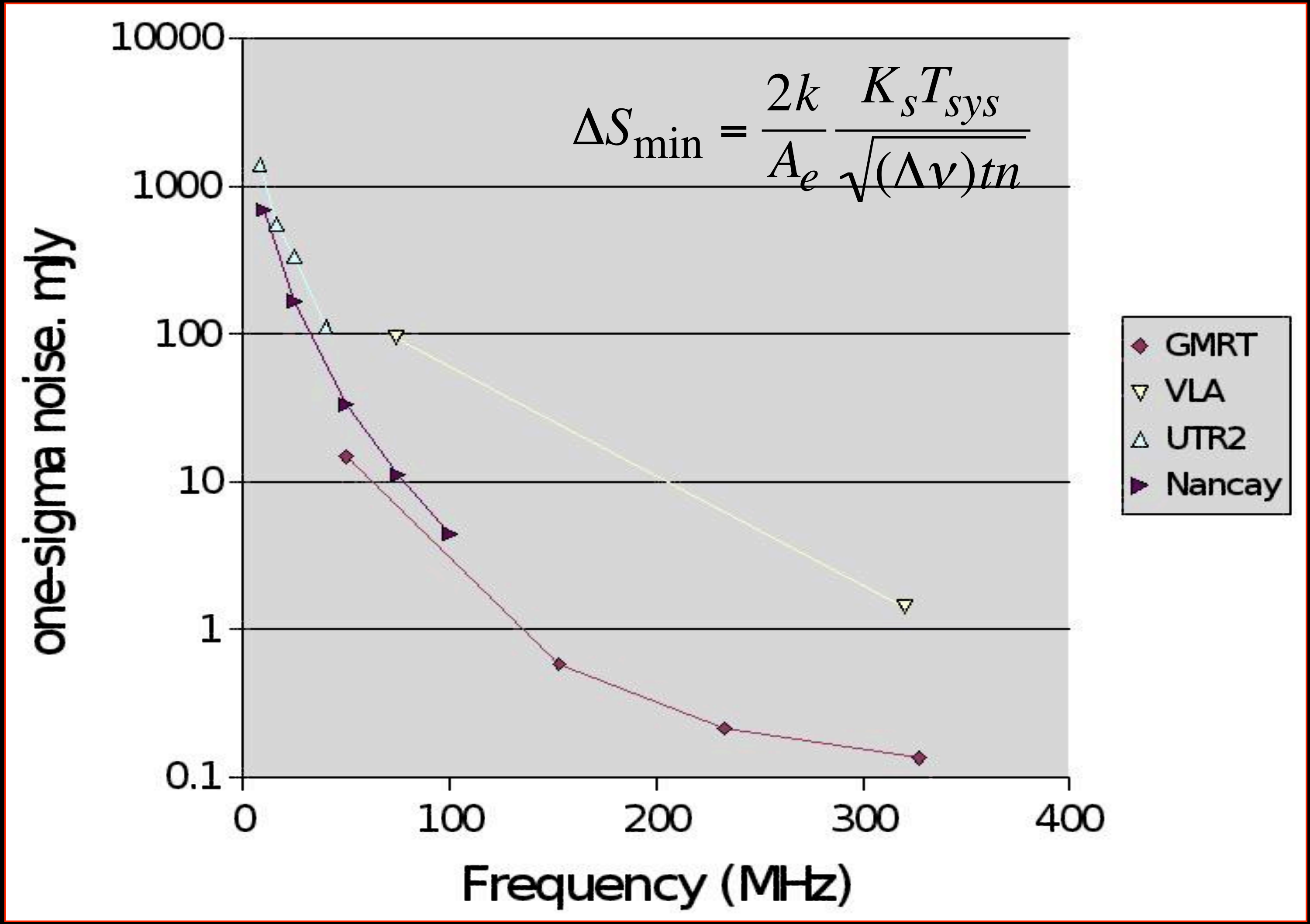
Radio bursts are generated by high-energy particles originating from solar flares or shock fronts. Typically, their frequency drifts. Their flux densities are much higher than that of the quiet sun or of noise storms. Different kinds of radio bursts exist.

WHAT WE NEED FOR THE OBSERVATIONS:

1. **A telescope with frequency as low as possible, or a target with a large magnetic field (both).**

2. **A telescope with very large effective aperture.**

Minimum Detectable Flux Density

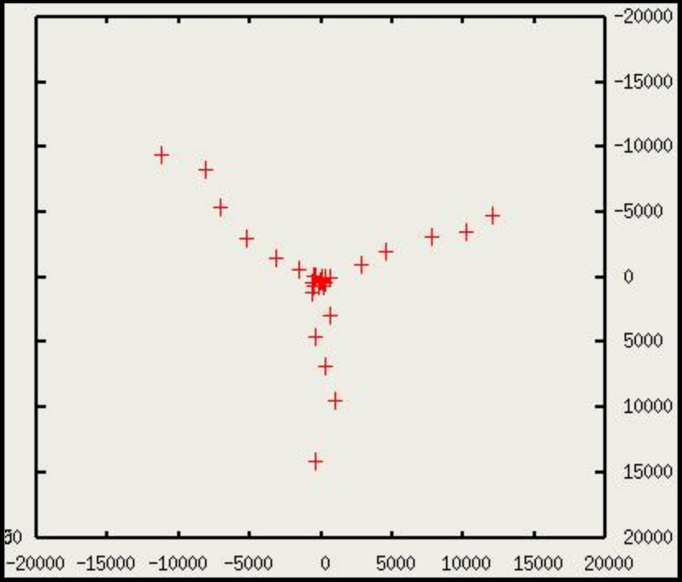


Search for Radio Emissions…

THE GIANT METERWAVE RADIO TELESCOPE (GMRT)

GMRT is the largest fully steerable telescope operating at meter wavelengths. Currently, its lowest operating frequency is 150 MHz.

The facility, located near Pune, India, consists of 30 individual 45 meter dishes.



SELECTION OF TARGETS

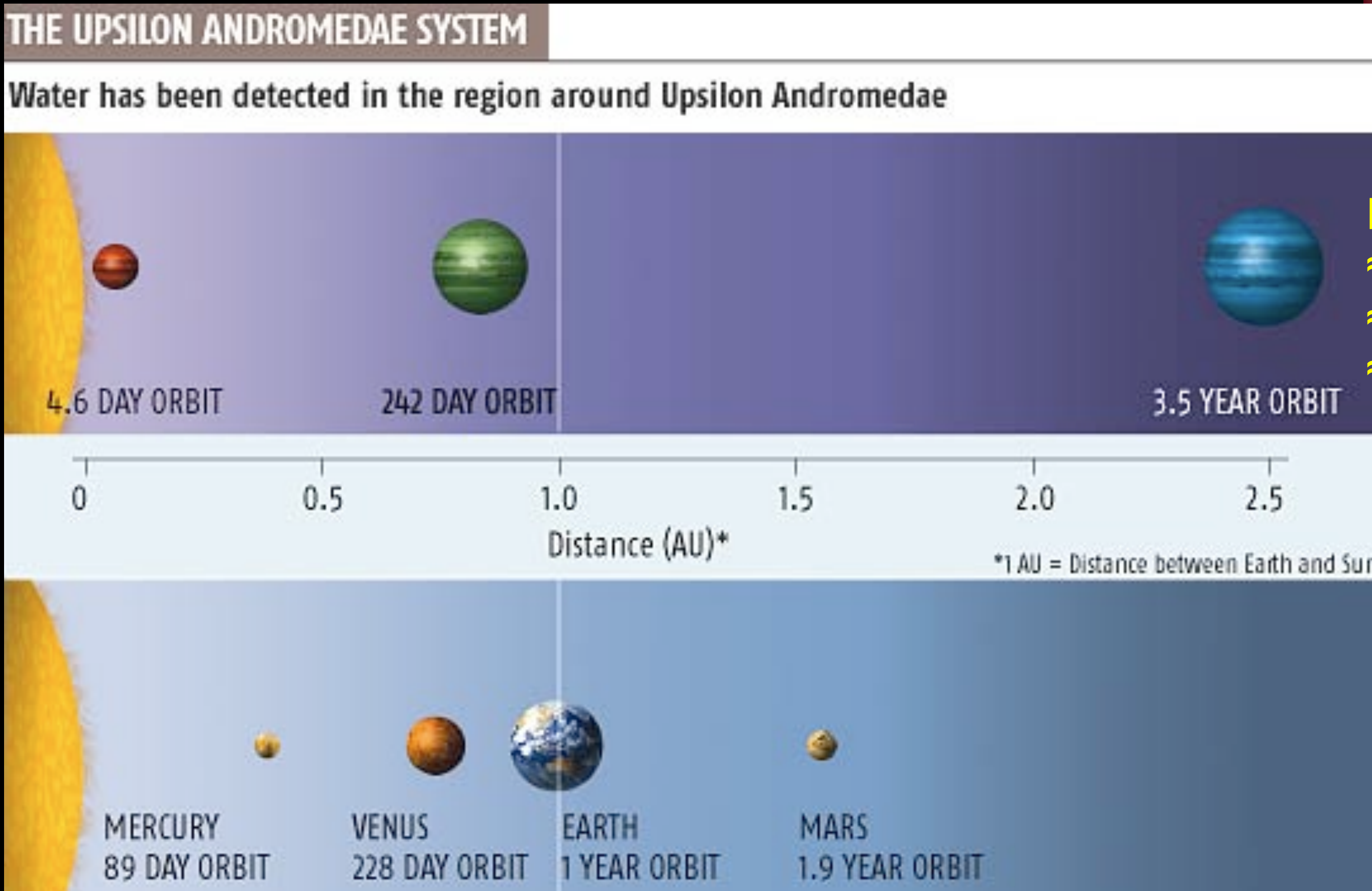
Theoretical studies have proposed scaling "laws" to estimate the radio power (P_r) emitted from solar (stellar) wind driven cyclotron emissions*:

$$P_r \propto \left(\frac{m}{m_j}\right)^{1.33} \left(\frac{d}{d_j}\right)^{-1.60} \left(4X10^{11}\right) W$$

Priority	name	M (Jup)	a (AU)	dist (pc)	Flux1 (mJy)	Gal Lat
1	tauboo	***5.2***	0.05	15.6	***717.8***	***-73.9***
2	HD162020	2.4	0.21	***4.7***	43.6	59.6
3	HD179949	1.2	0.04	27.0	211.1	15.8
4	70vir	9.3	0.48	18.1	1.6	-74.1
5	Upsandb	0.9	***0.06***	13.5	147.3	20.7

*Desh. M. D., and M. L. Kaiser, *Nature, 310*, 755, 1984;
Farell, W. M., et al., *Geophys. Res. Lett.,*, 2003;
Zarka, P., R. A. Treumann, B. P. Ryabov, and V. B. Ryabov, *Astrophys. and Space Science, 277*, 293, 2001.
Lazio, T.J.W., W.M. Farrell, J. Dietrick, E. Greenlees, E. Hogan, C. Jones, and L.A. Hennig, *Astrophys. J.,* 2004.

Search for Radio Emissions…



Distance:
≈ 13.5 pc
≈ 44 LY
≈2.8×10^6 AU

- The first main sequence star with an extrasolar planetary ***system*** was found in 1999.
- *Upsilon Andromedae b*: a = 0.059 AU, T = 4.6 days, M = 0.69 MJ.
- *Upsilon Andromedae c:* a = 0.83 AU, T = 242 days, M = 11.6 MJ.
- *Upsilon Andromedae d:* a = 2.55 AU, T = 1302.6 days, M = 10.3 MJ.

Observation Strategy

Summary
- Observation using the 150 MHz feed in phased array mode
- Both interferometric and pulsar mode.
- 22-23 of 30 antennas in the array used

Interferometry Mode
- for maps
- time resolution 512 msec
- bandwidth 8 MHz - 5.5 MHz
- 256 spectral channels
- spectral resol. 15-31 KHz

- spatial resolution ≈ 20”

Pulsar Mode
- for dynamic spectra
- CSQ antennas
- time resol. 512 μsec
- bandwidth 4-8 MHz
- spectral resol. 15 - 31 KHz
- synthesized beam size 7'

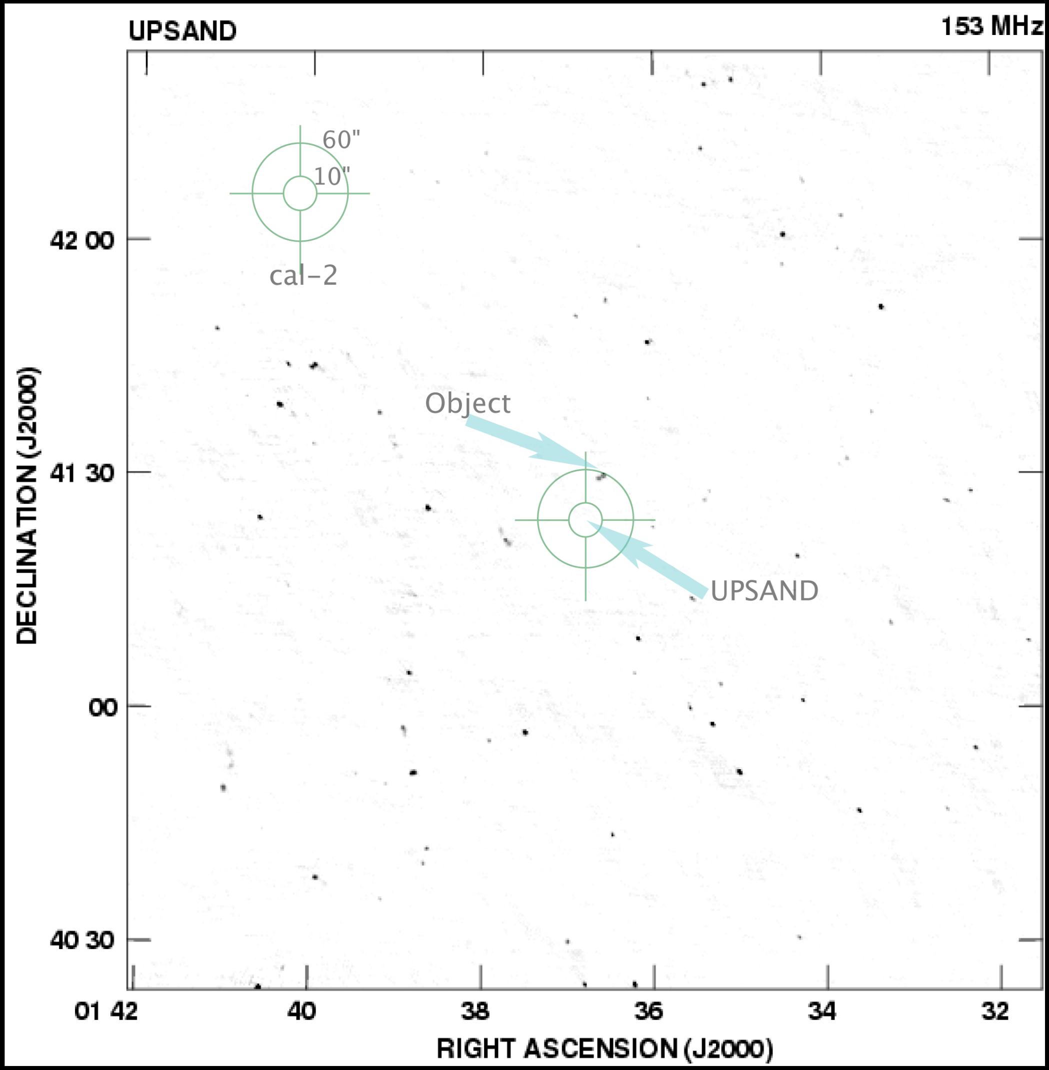
Strategy

Because of RFI:

- split the array into two subarrays
  - point one subarray at target source
    - simultaneously point second subarray 5˚ away
    - loss of sensitivity
- recorded front end terminated data with both subarrays
- observed pulsar calibrators with both subarrays
- observed pulsar calibrator with one subarray, while pointing second subarray to off position
- switched subarray 1 with subarray 2

Search for Radio Emissions…

Radio Map of the Upsilon Andromedae Region



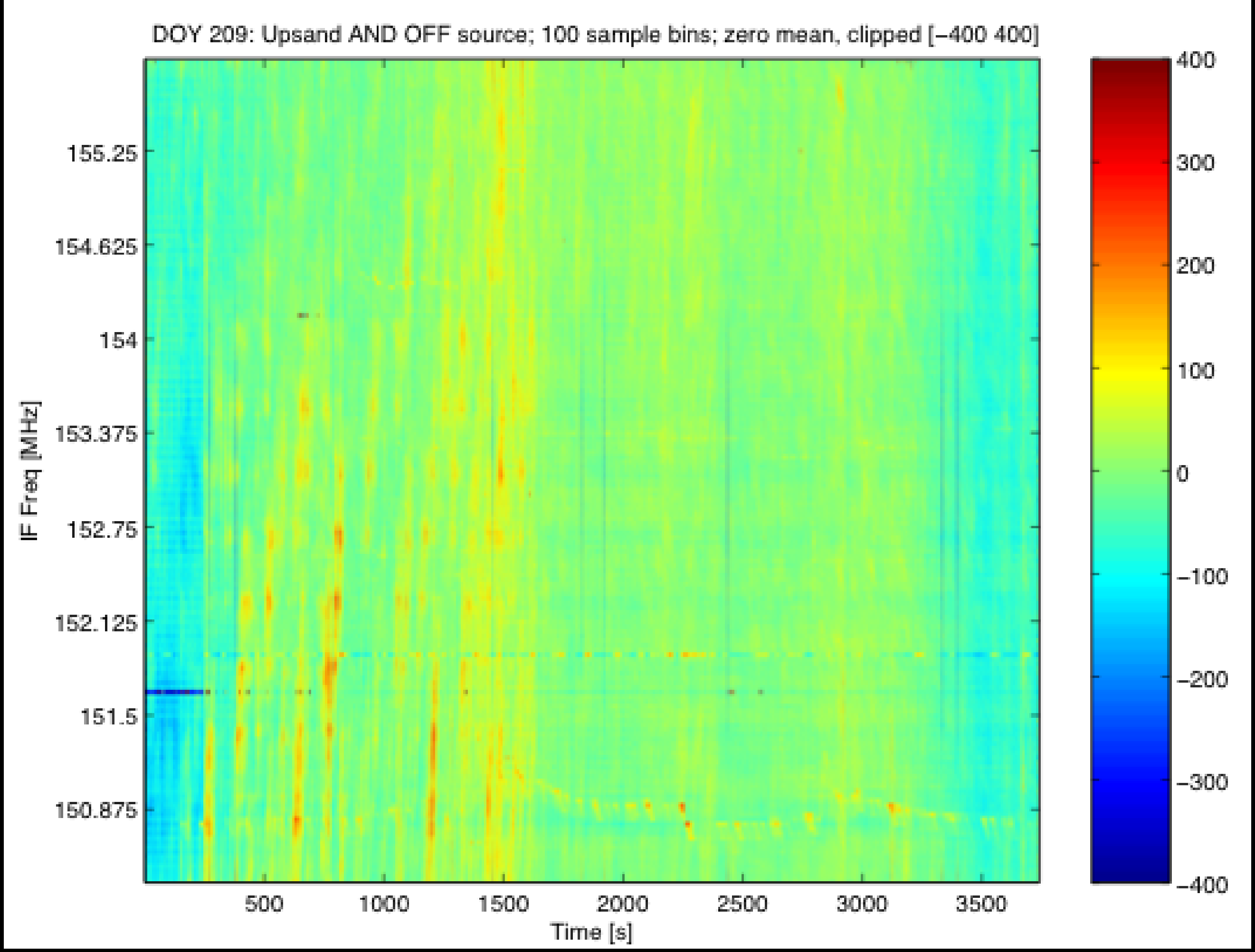
***Interferometry Mode** (for maps)*

- time resolution 512 msec
- bandwidth 8 MHz - 5.5 MHz
- 256 spectral channels
- spectral resolution 15-31 KHz
- spatial resolution ≈ 20” (250 AU)

- **GMRT map of UPSAND region in 153 MHz.**
- **Beam size ≈ 60 arcseconds.**
- **1 hr integration, 5 MHz bandwidth.**
- **RMS Noise: 3 mJy *(expected signal 147 mJy)***
- **Nothing seen.**

Search for Radio Emissions…

Dynamic Spectra for Upsilon Andromedae



Pulsar Mode (for dynamic spectra)

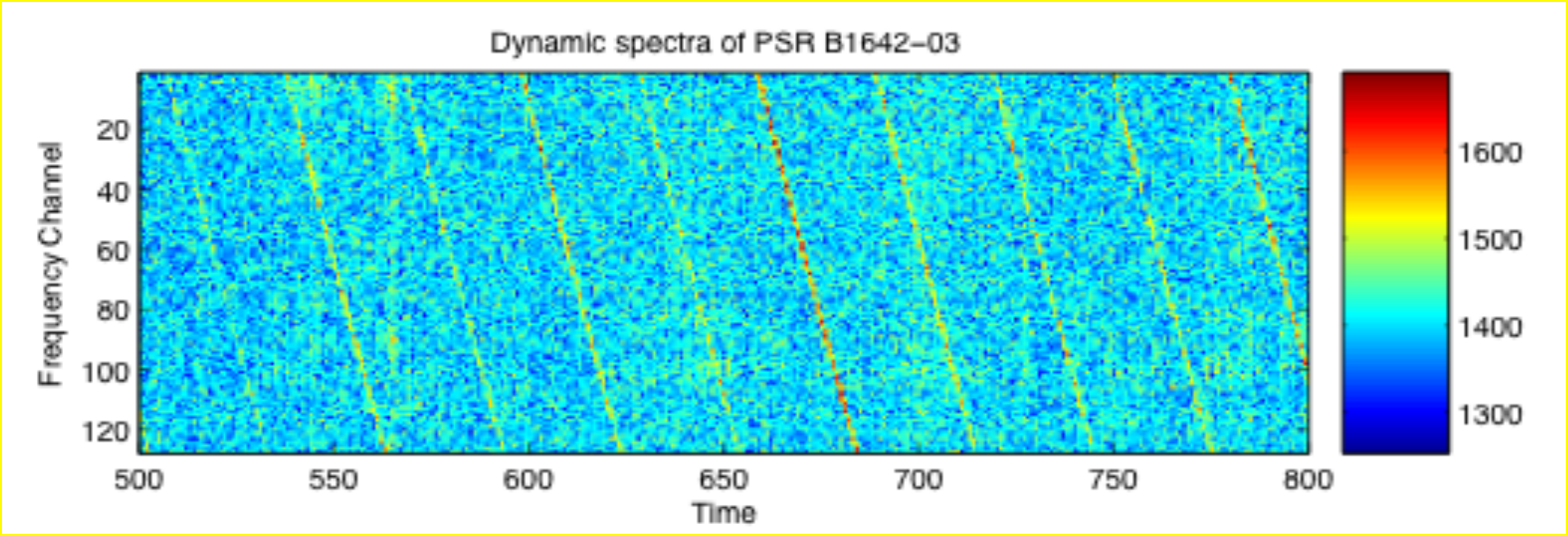
- CSQ antennas
- time resol. 512 μsec
- bandwidth 4-8 MHz
- spectral resol. 15 - 31 KHz
- synthesized beam size = 7' (5600 AU)

- **UpsAnd ON source and OFF source**
- **100 sample bins.**
- **Zero mean.**
- **Clipped [-400, 400].**
- **Signal??? (hmm.….)**

Calibrations

In Addition to Extrasolar Planets, other targets were:

- flux calibrators
- phase calibrators
- array phase calibrators
- pulsars



FUTURE WORK: DATA ANALYSES

Observations of the following targets were completed, but still need analyses:

UpsAnd b, c, d: New radio observations.

HD179949b: The chromosphere of the star HD 179949 shows a persistent hotspot, observed to keep pace with the planet in its 3-day orbit for more than a year (or 100 orbits)! The hotspot appears to be moving across the surface of the star slightly ahead of, but keeping pace with the planet. The best explanation for this traveling hot spot is an interaction between the planet's magnetic field and the star's chromosphere.

HD188753Ab: Discovered in August of 2005, this still controversial finding is of a **hot Jupiter in a triple star system**. The planet orbits the central star at very close range. In addition, a binary system orbits at about 11 AU.

HD209458b: Since 1999, it has been known that a Jupiter-mass planet orbits the star HD209458 every 3.52 days. Initial discovery was via spectroscopic radial velocity measurements; later in that year, it was found that a photometric dip occurred at the time expected from the spectroscopic orbital parameters. This was the first such detection (or more correctly, confirmation) of an exoplanet by photometric means. Since then, several groups and individual observers have observed these transits photometrically. **Sodium and hydrogen** have been observed in the planet's atmosphere.

Gliese876d: Two planets in orbit around a red dwarf which is only about 15 lightyears from Earth. In addition to a Jupiter-sized gas giant,the only known **earth-like planet (rocky)** orbits very close to its sun.

ACKNOWLEDGEMENTS

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