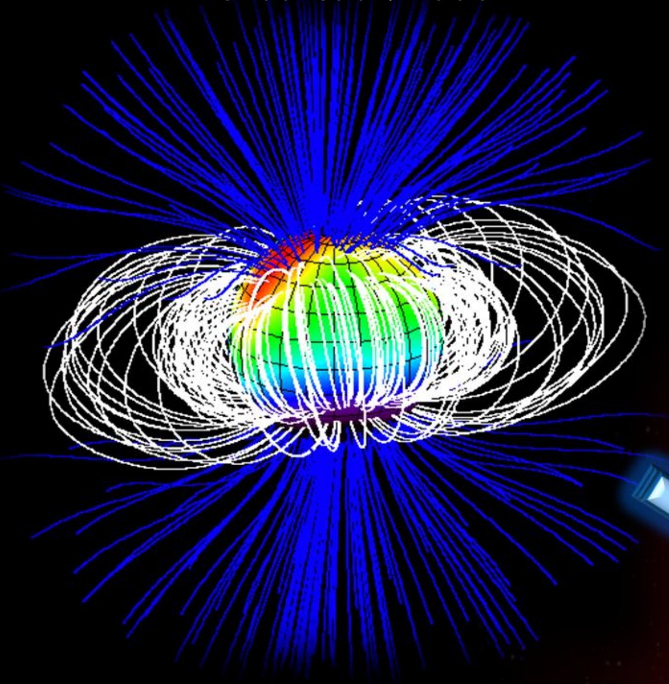
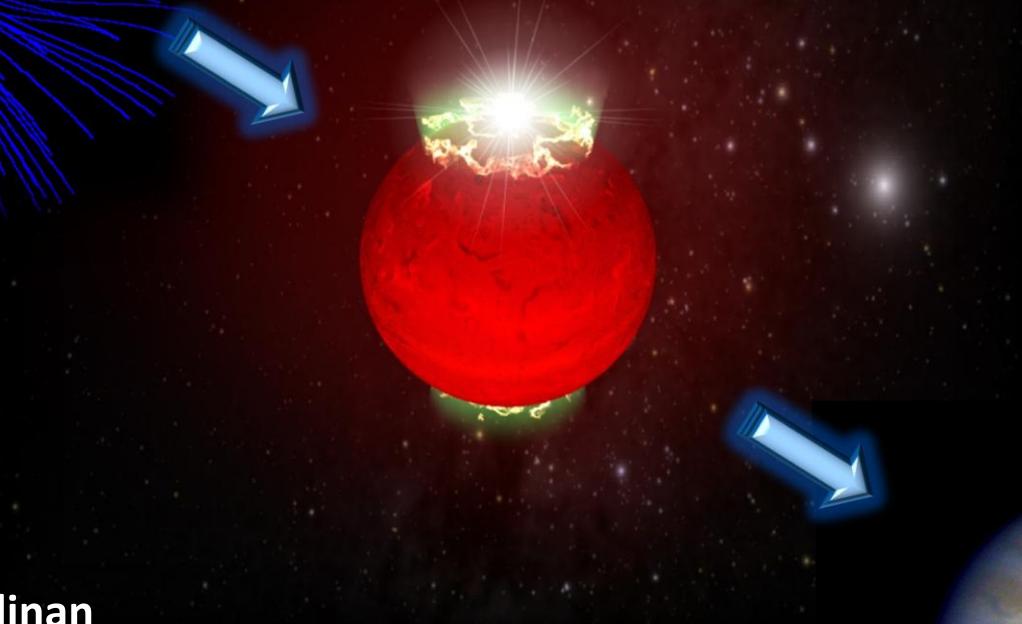
Auroral Emissions from Ultracool Dwarfs

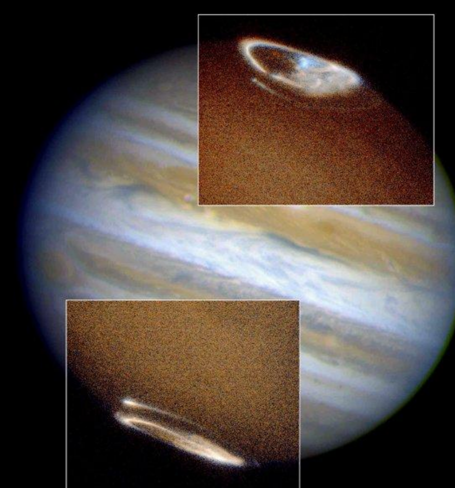
Donati et al. 2006



Hallinan et al. 2007



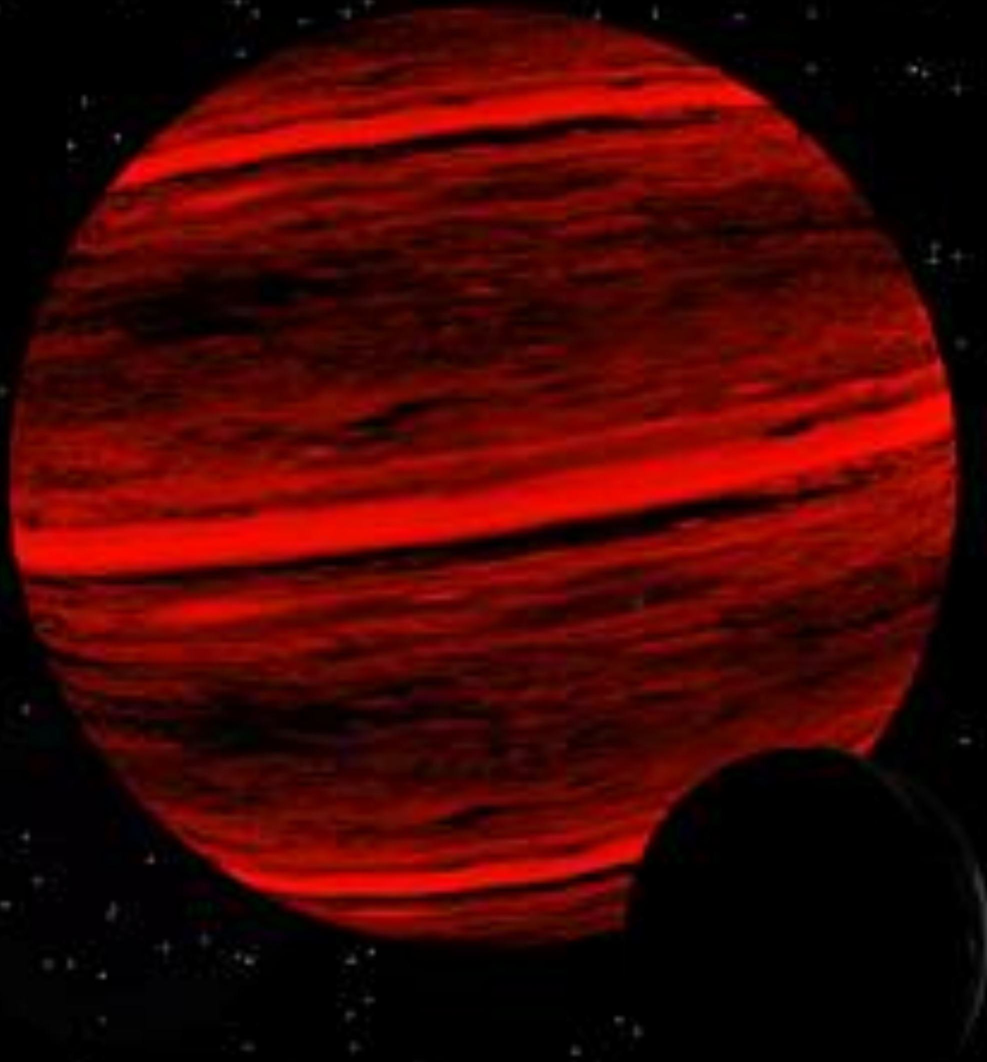
Clarke et al. 1998



Gregg Hallinan
National Radio Astronomy Observatory
& University of California Berkeley

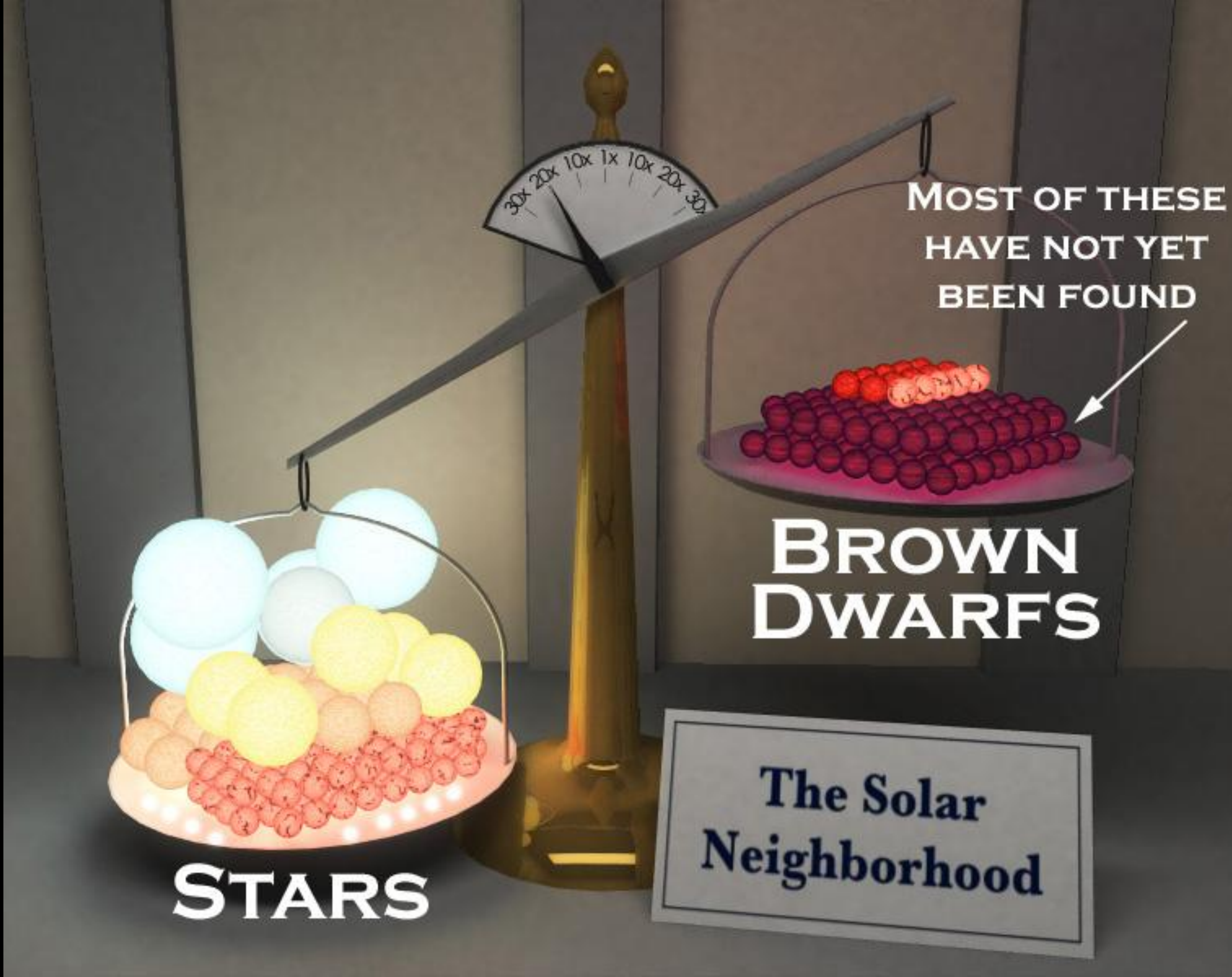
Southern Cross Astrophysics Conference Series
Kiama 10th June 2010

Brown Dwarfs

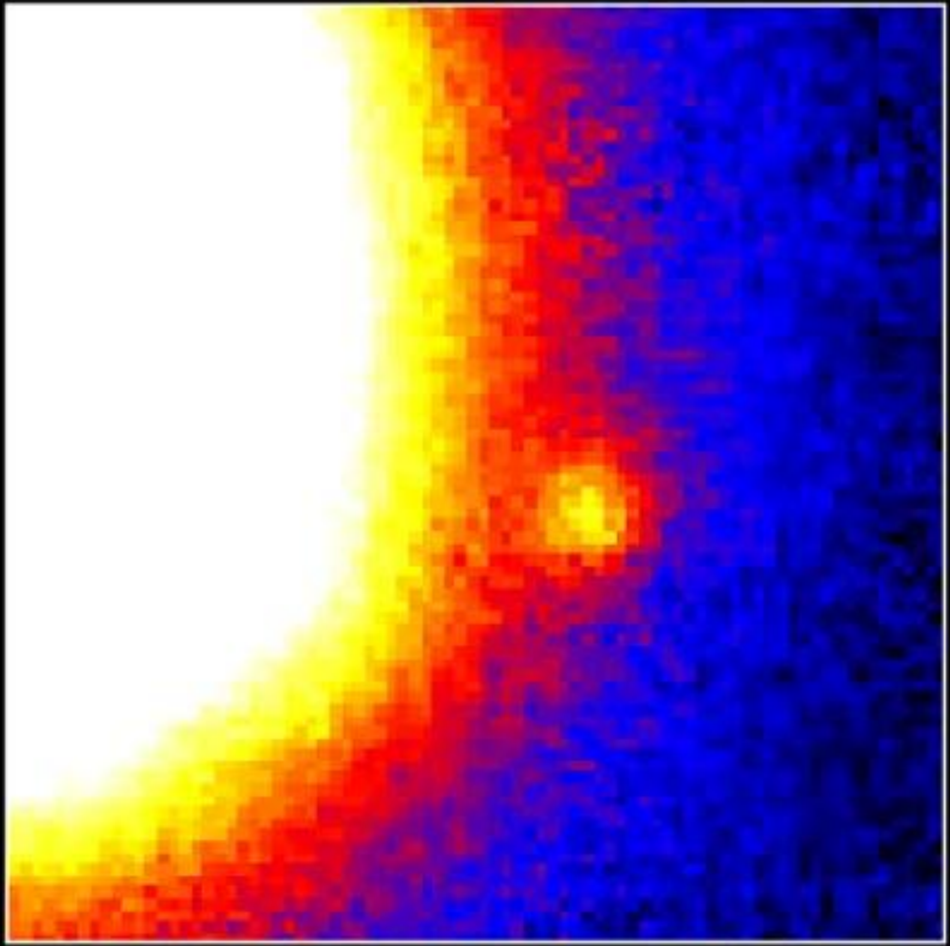


Very cool dense objects about the size of Jupiter, with mass from below 13 Jupiter masses to 75 Jupiter masses.

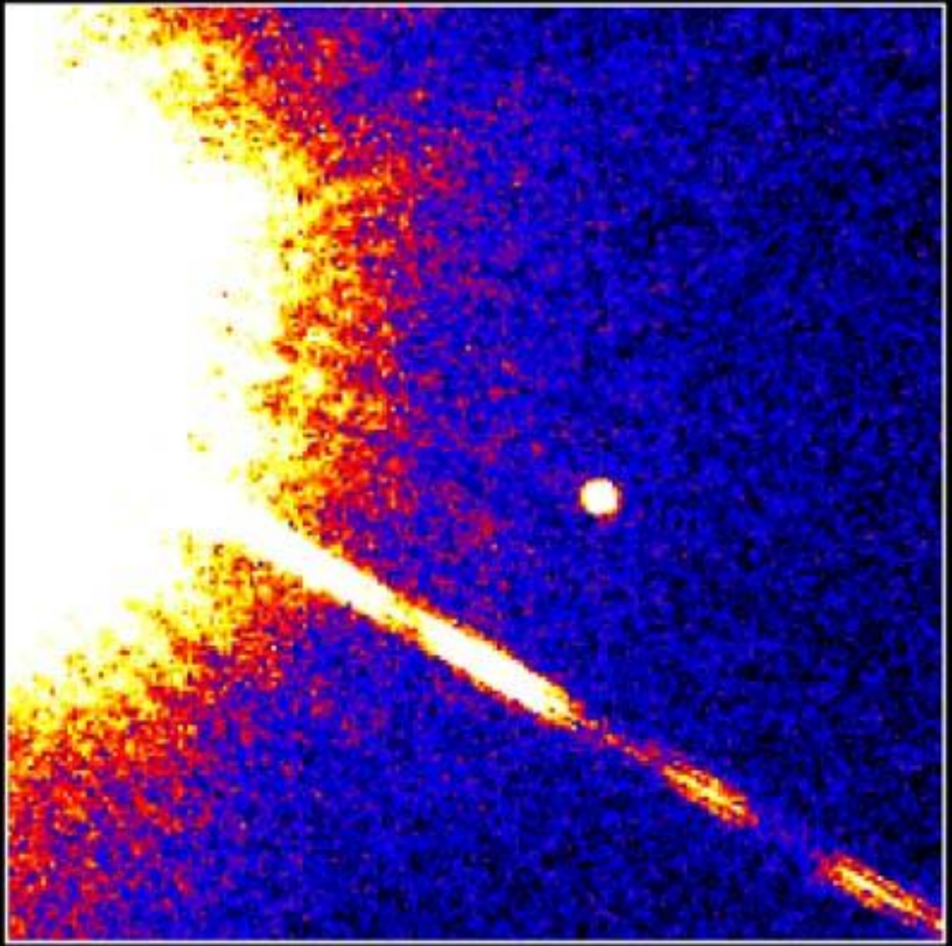
Can't burn hydrogen but can burn deuterium.


30x 20x 10x 1x 10x 20x 30x
MOST OF THESE
HAVE NOT YET
BEEN FOUND
BROWN
DWARFS
STARS
The Solar
Neighborhood

Brown Dwarf Gliese 229B

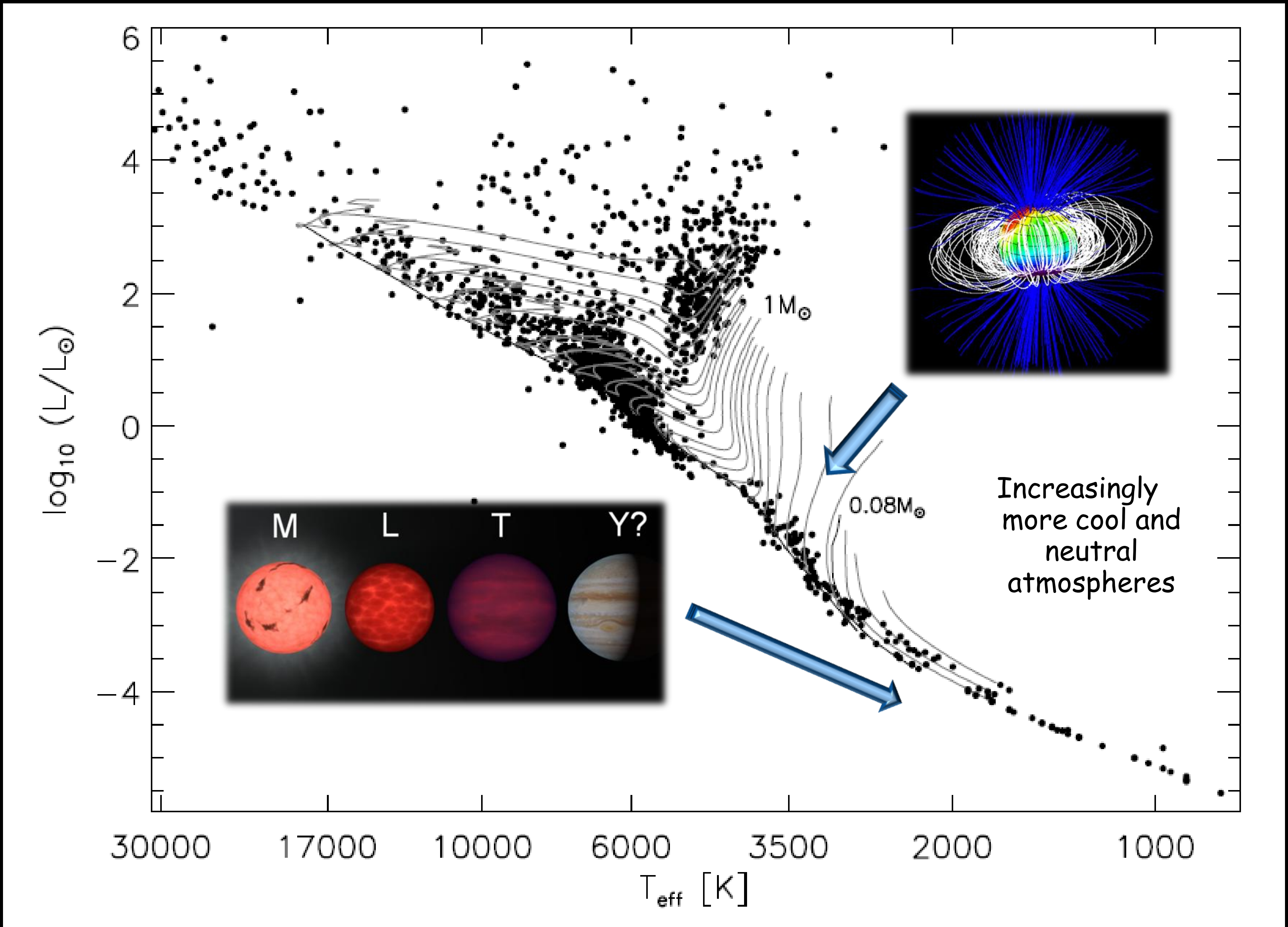


Palomar Observatory
Discovery Image
October 27, 1994



Hubble Space Telescope
Wide Field Planetary Camera 2
November 17, 1995

PRC95-48 • ST ScI OPO • November 29, 1995
T. Nakajima and S. Kulkarni (CalTech), S. Durrance and D. Golimowski (JHU), NASA

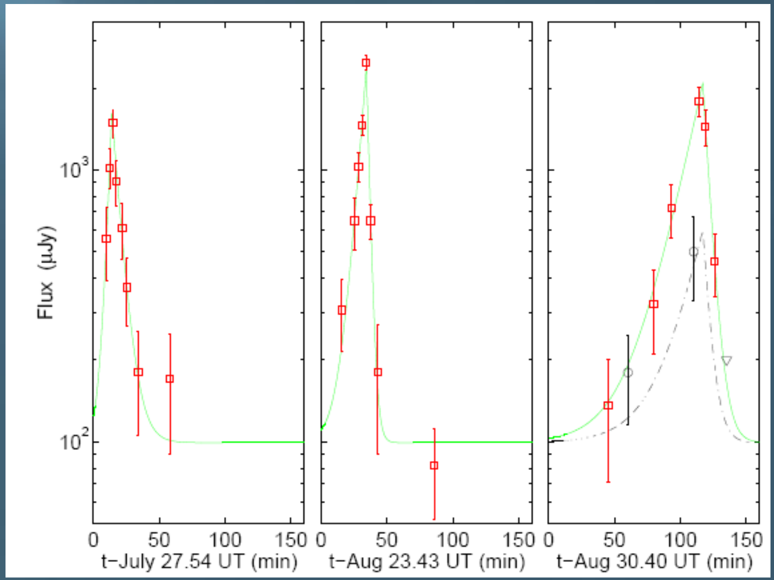


Adapted from Reiners (2007)

First Radio Brown Dwarf : LP 944-20

• NRAO Summer School at the VLA, Class of 2000 -> Berger et al. *Nature* **410**, 338-340 (2001)

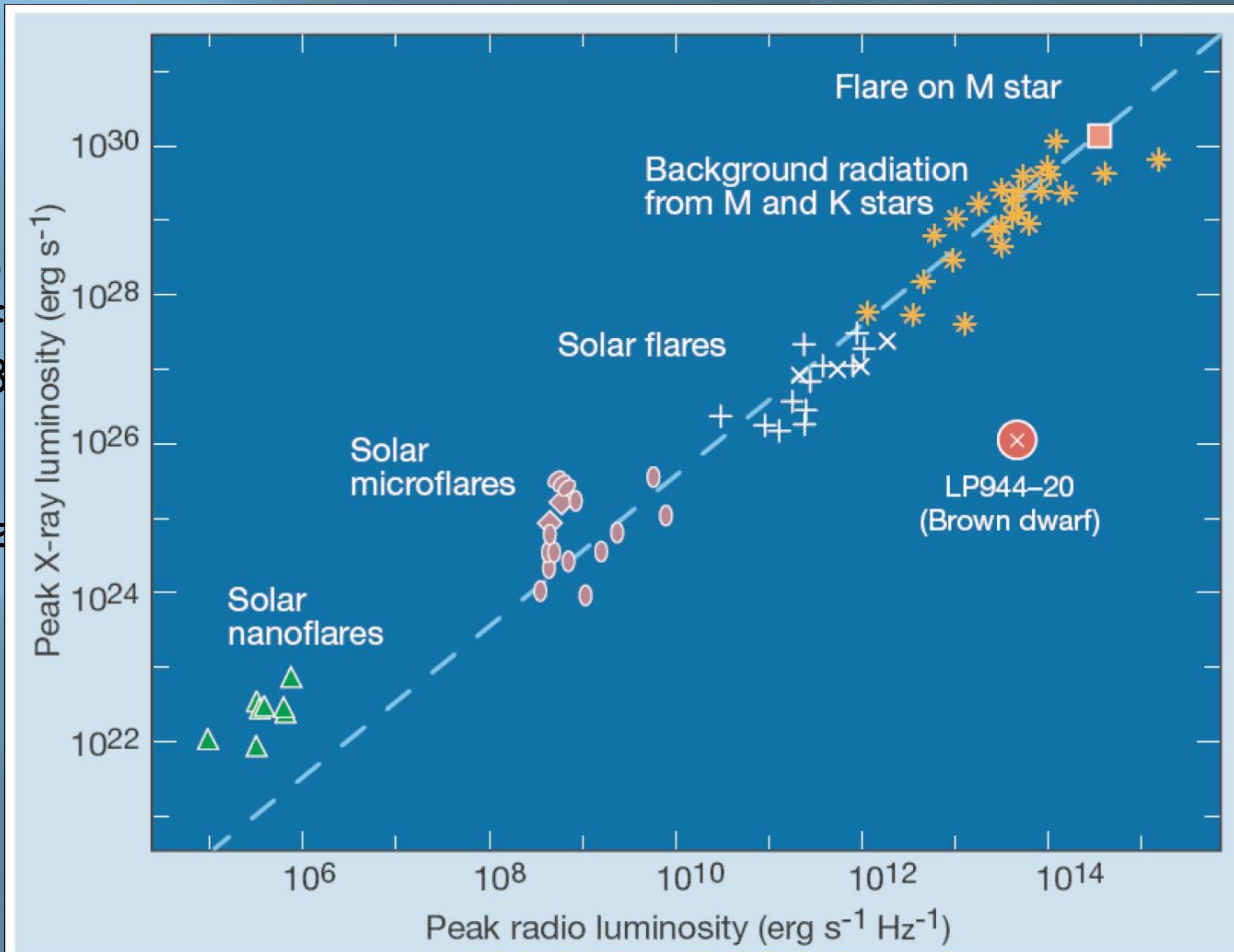
• Further detections followed...

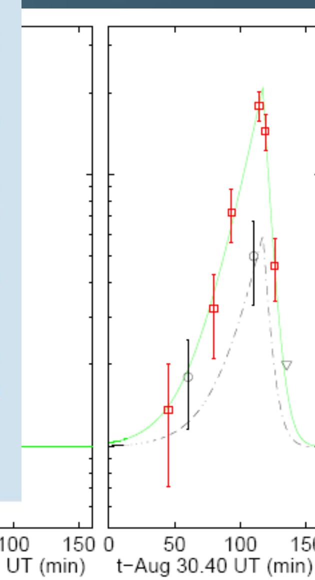


First Radio Brown Dwarf : LP 944-20

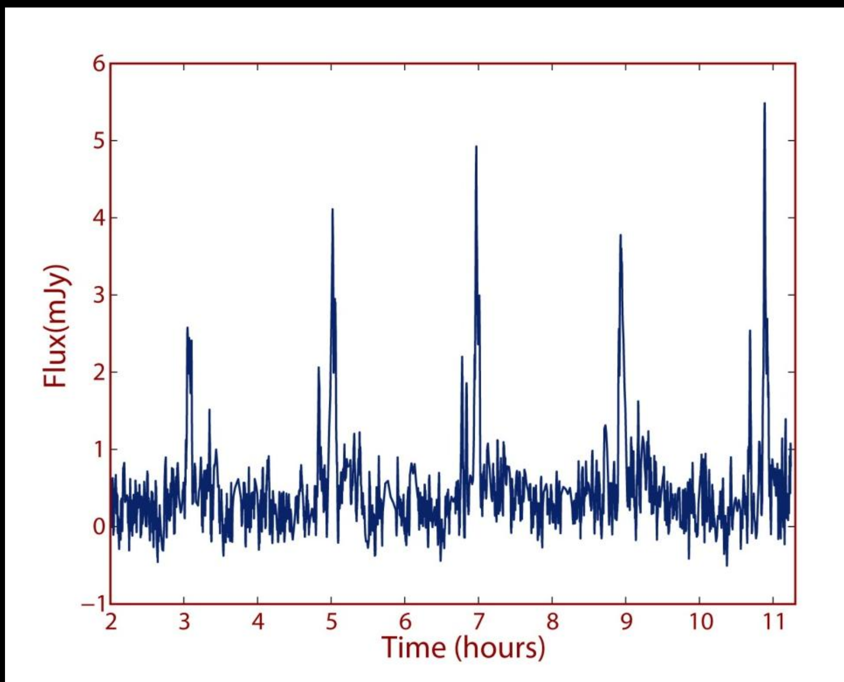
- NRAO
Class of
410, 33

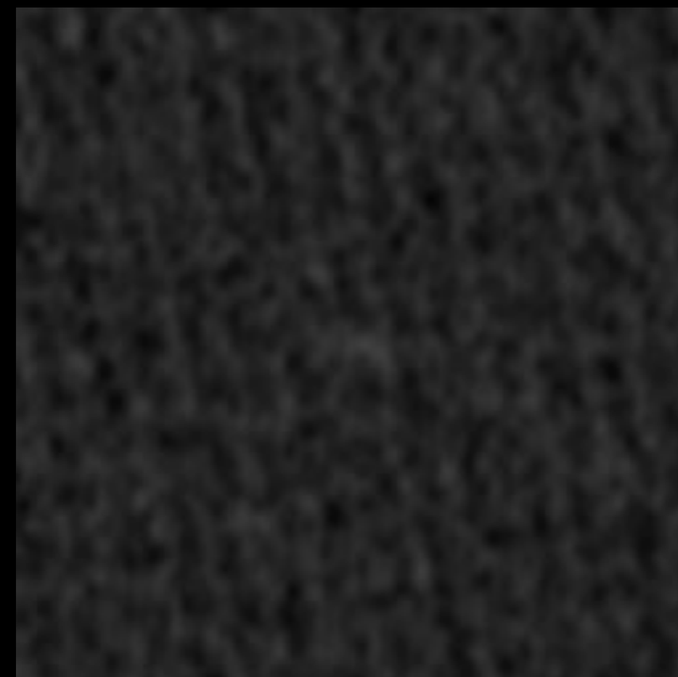
- Furthe





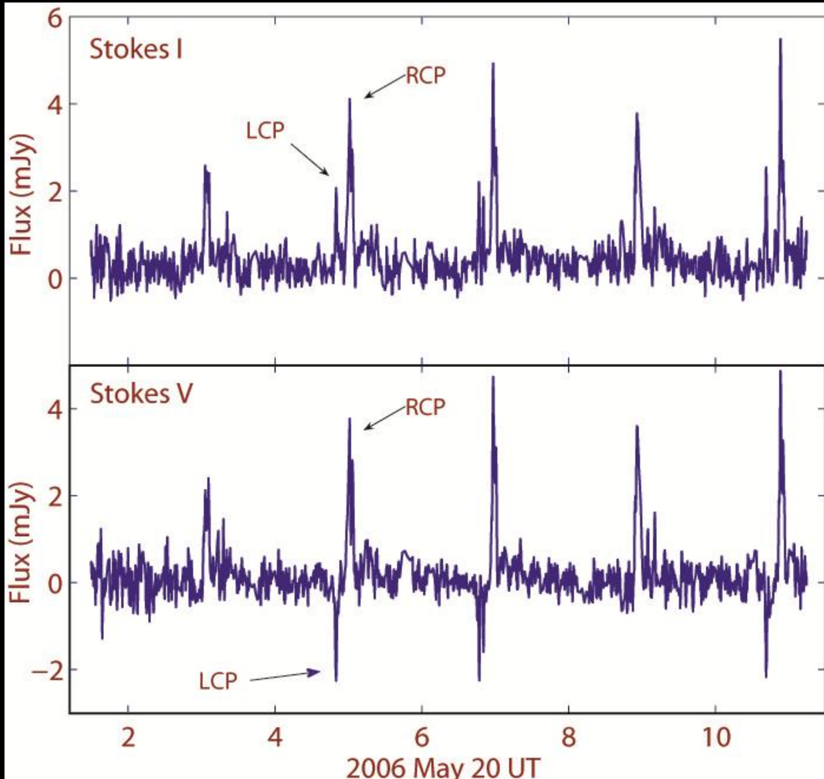
Radio Pulses!

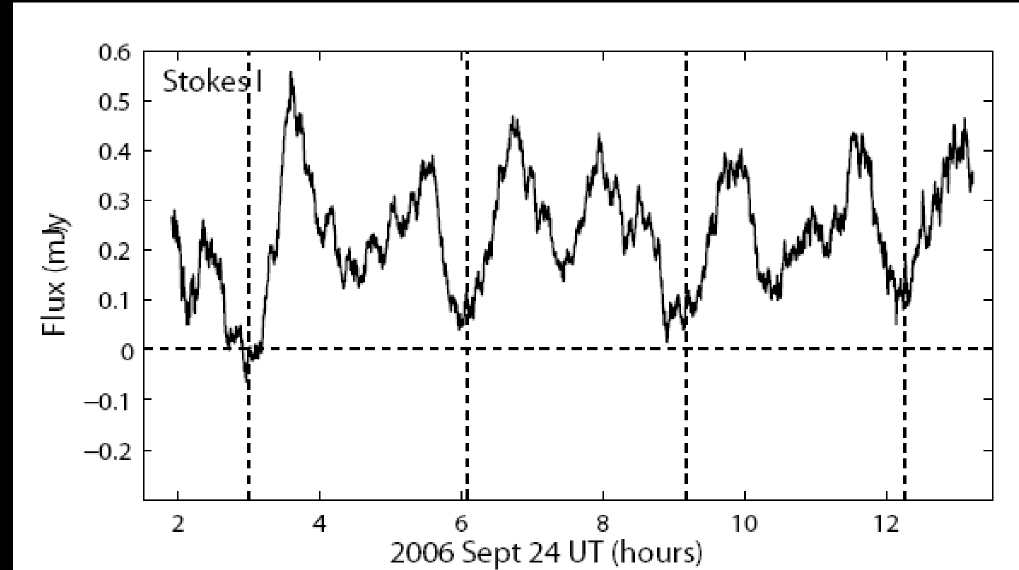


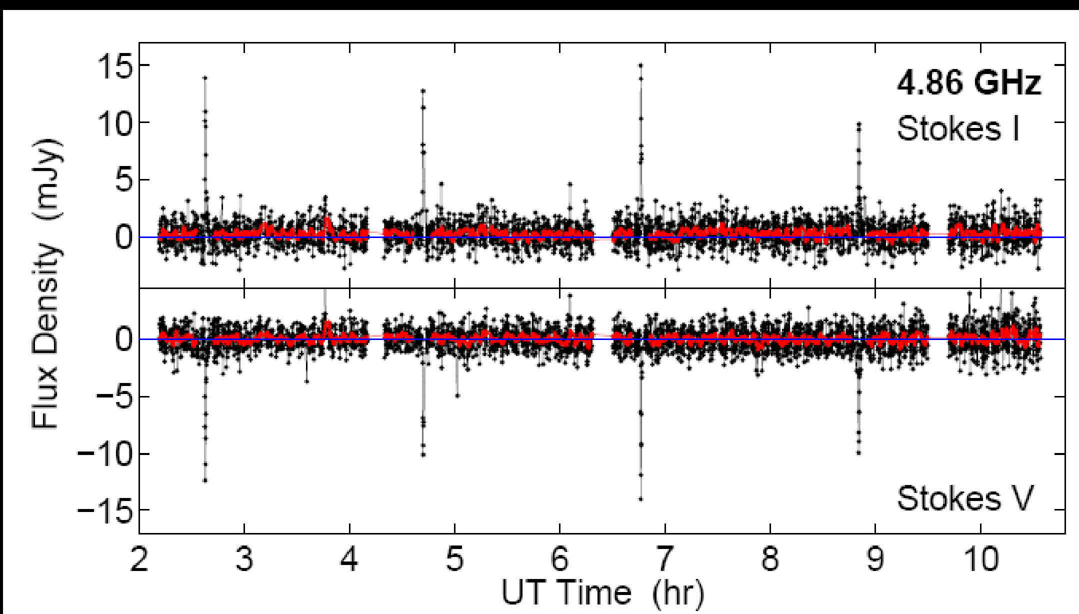


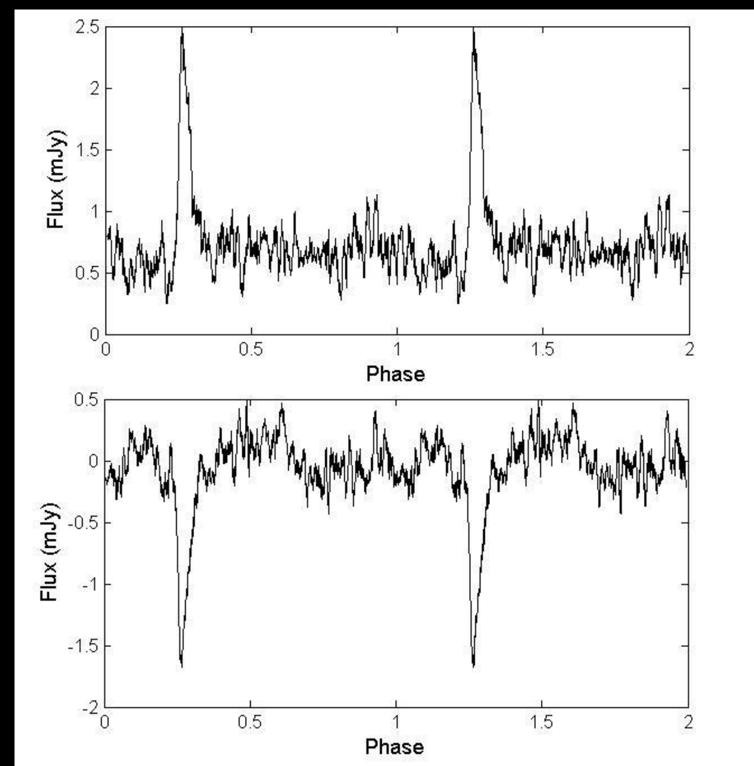
The M9 dwarf TVLM 513-46546 - Hallinan et al. (2007)

Allows very accurate measurement of magnetic field strengths for ultracool dwarfs


Stokes I
RCP
LCP
Stokes V
RCP
LCP
Flux (mJy)
Flux (mJy)
2006 May 20 UT


Stokes I
Flux (mJy)
2006 Sept 24 UT (hours)


4.86 GHz
Stokes I
Stokes V
Flux Density (mJy)
UT Time (hr)


Flux (mJy)
Phase
Flux (mJy)
Phase

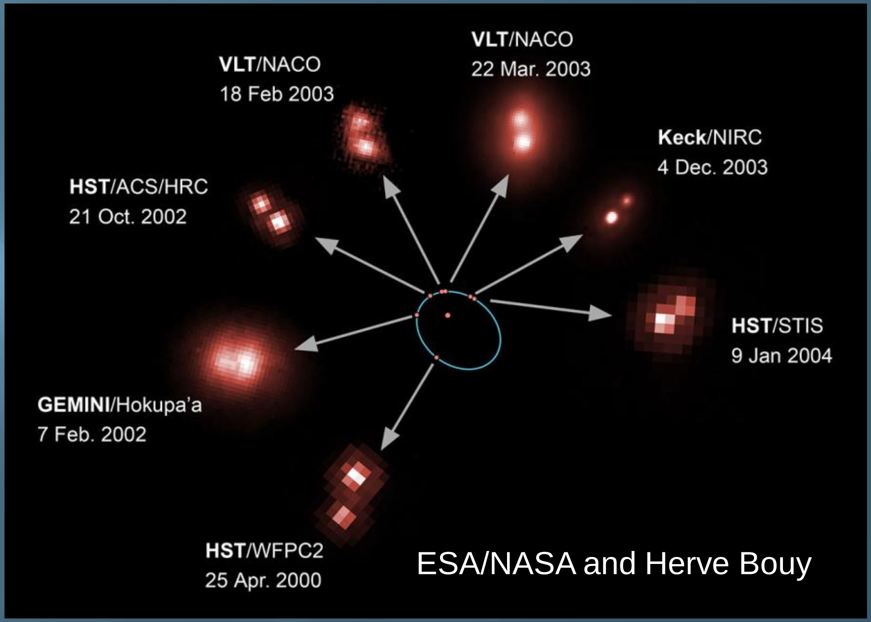
Why are only a fraction of dwarfs detected?

Two of our radio dwarfs are tight binaries.

Which one is pulsing? The faster rotator? The higher mass dwarf?

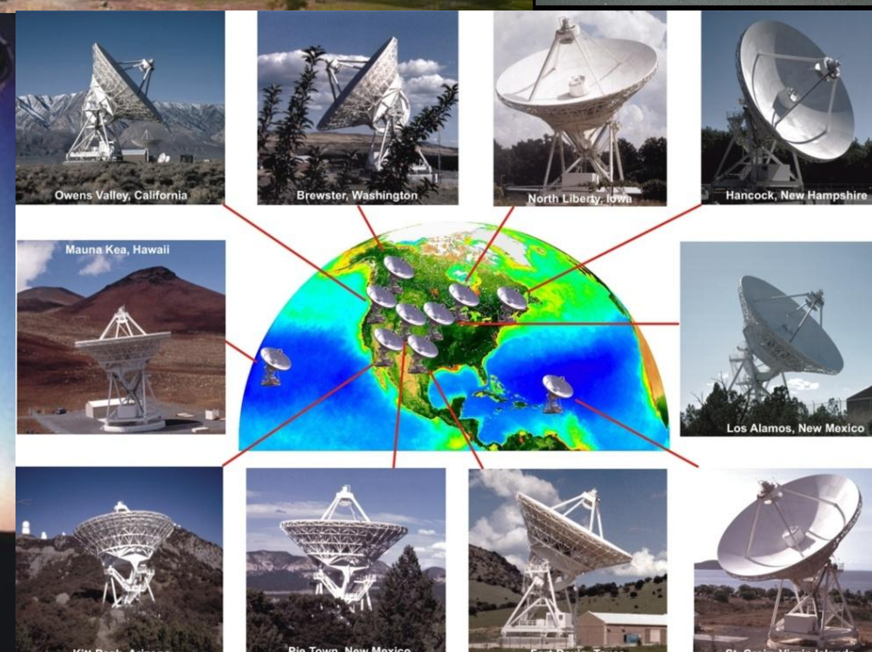
Separation only 0.1 arcsecond.

We need Very Long Baseline Interferometry (VLBI).



Dynamical mass measurement of 2MASS J07464256+2000321 using HST/VLT/Keck/Gemini: Bouy et al. A&A 2004

The High Sensitivity Array



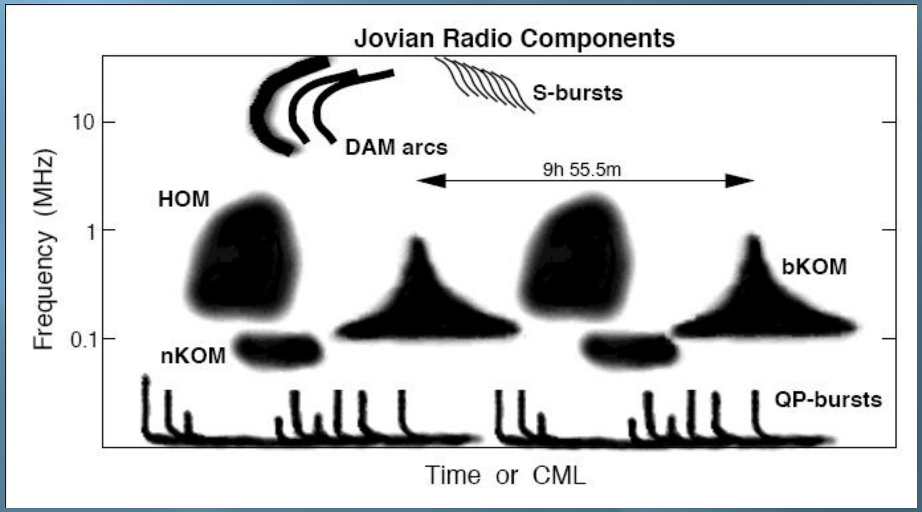
How is stable electron acceleration maintained in the magnetospheres of ultracool dwarfs?

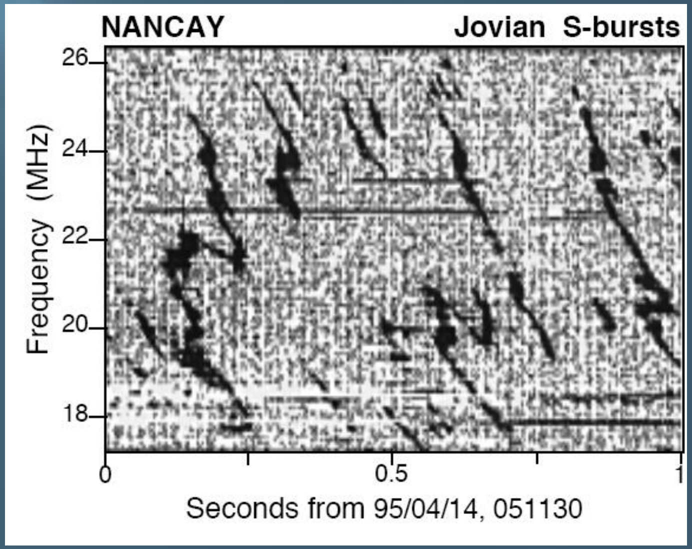
Persistent electron acceleration implies stable electric fields within the magnetosphere of the dwarf.

Such electric fields may be a fundamental source of electron acceleration, and hence radio emission, for plasma trapped in a large-scale magnetic field.

How do we answer this question?

Need to characterize the location, extent, and morphology of the source regions of the bursts, through wideband observations with high temporal and spectral resolution.





Adapted from Zarka, P. 1998, J. Geophys. Res., 103, 20159

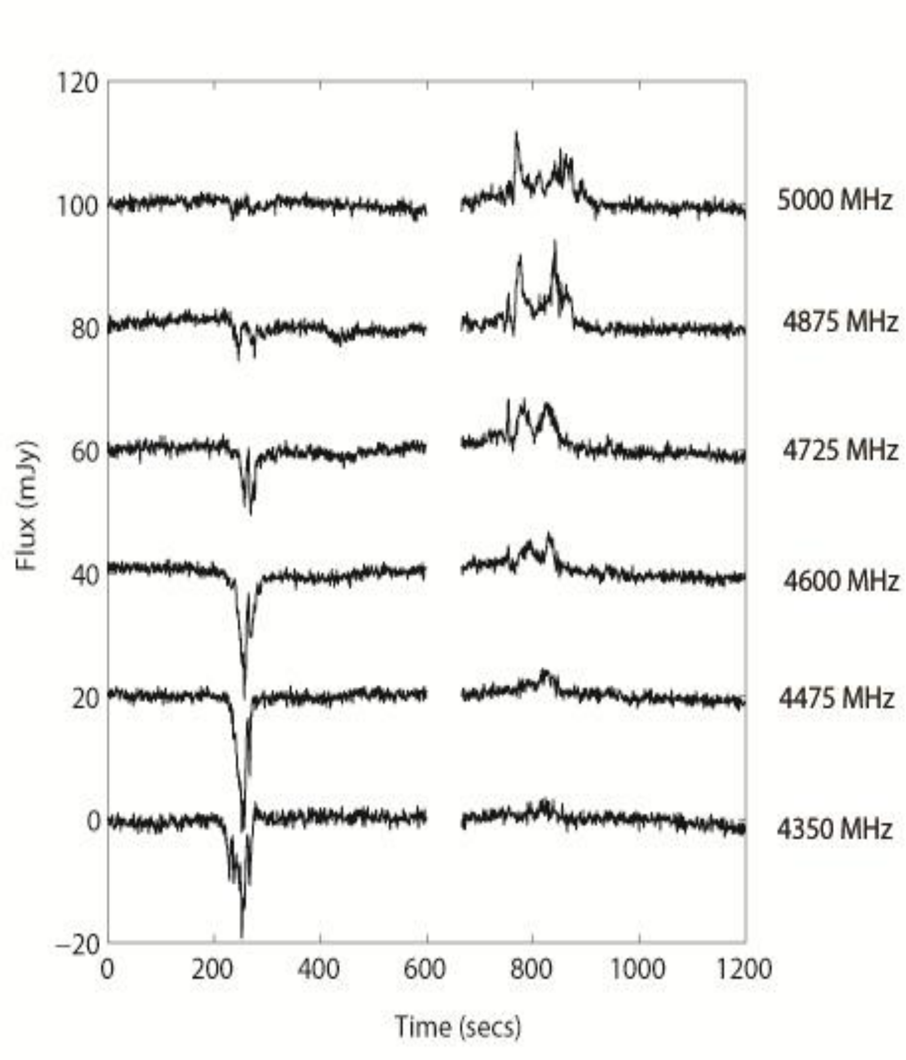
Arecibo

• We use Arecibo to try and produce dynamic spectra of the pulses.

• The first Arecibo observations consisted of 3 successive nights on the pulsing ultracool dwarf TVLM 513-46546 using the Wideband Arecibo Pulsar Processor (WAPP).

Broadband Dynamic Spectra of Individual Pulses

- Brightest radio emission yet detected from an ultracool dwarf.
- Brightness temperatures > 10^{15} K
- Requires quasi- stable current systems within the magnetosphere of the dwarf.
- What kind of emissions can be produced by this current system?



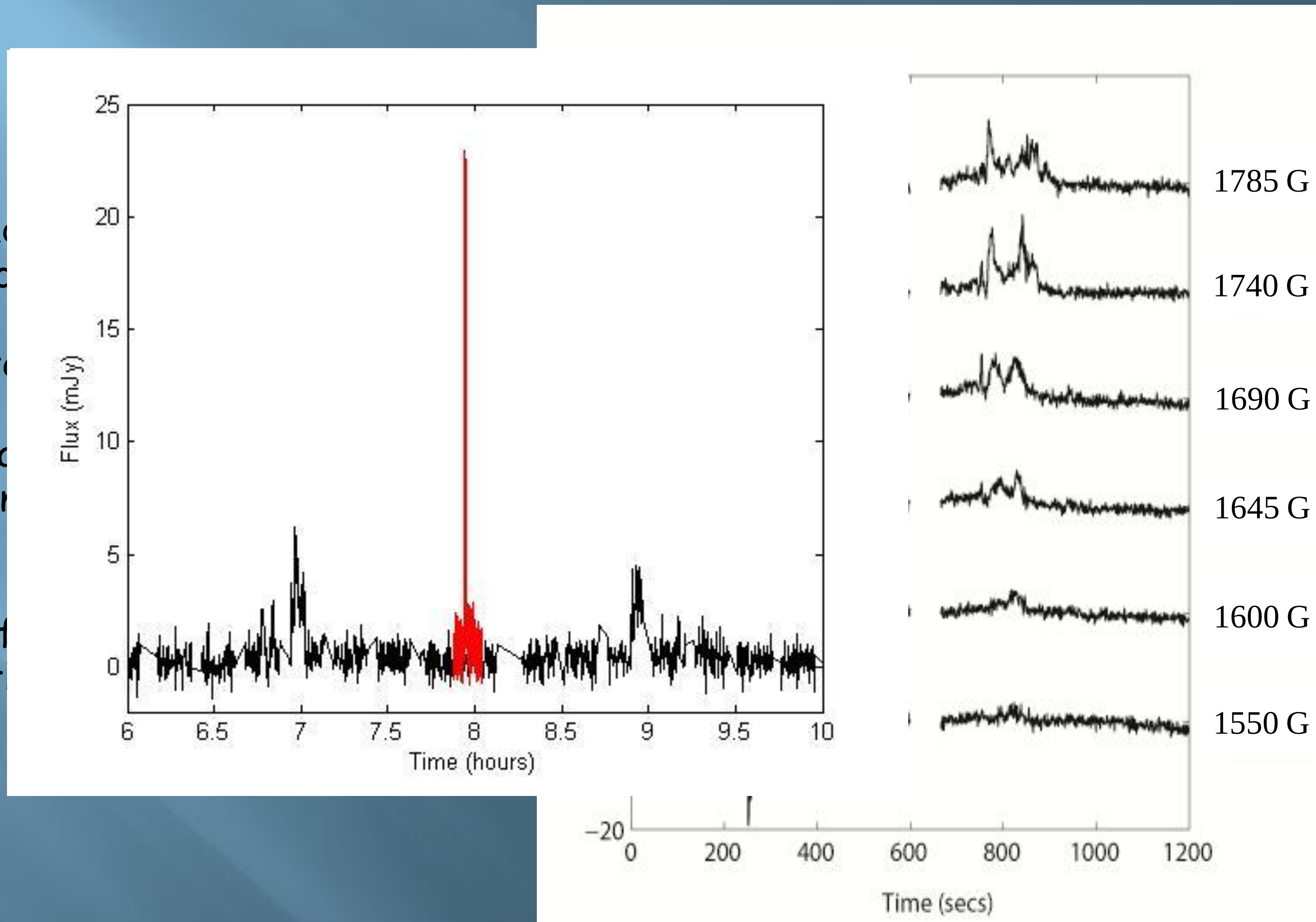
Broadband Dynamic Spectra of Individual Pulses

• Brightest ra
from an ultrac

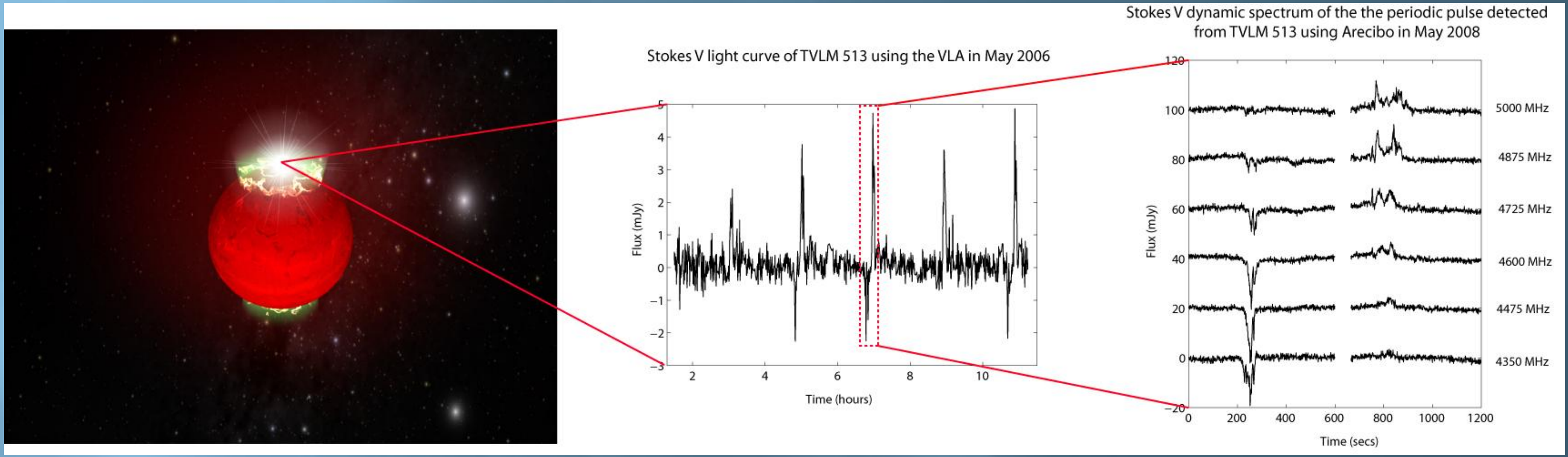
• Brightness t

• Requires qu
systems withi
the dwarf.

• What kind o
produced by t



Ongoing Radio Observations

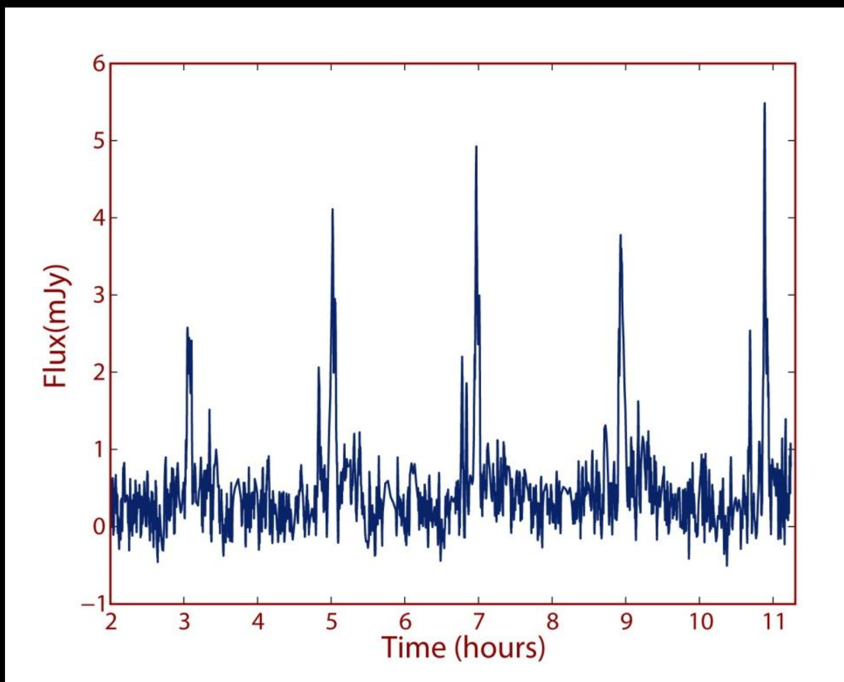


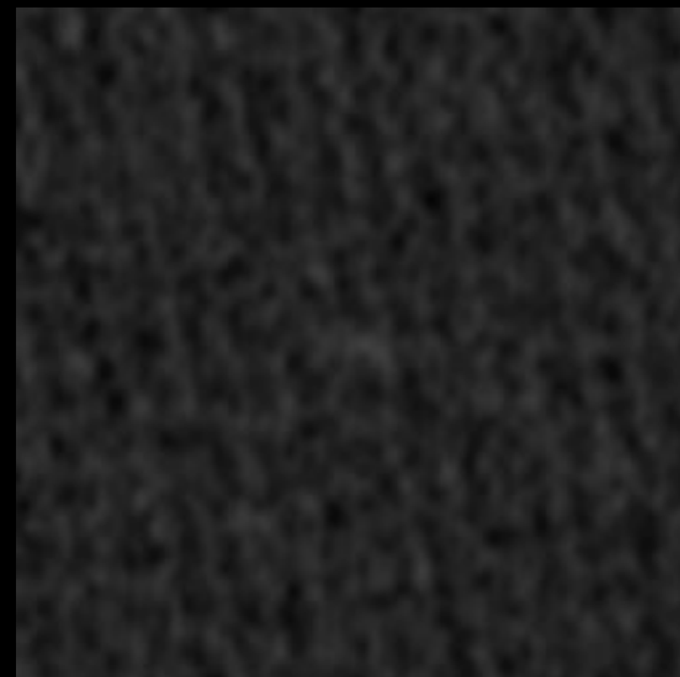
• Arecibo observations of 3 ultracool dwarf pulsars completed.

• A VLA survey of 35 more targets is completed with a view to increase the sample of known pulsars and to extend the study to cooler late L and T type dwarfs.

•VLBI observations to find out which ultracool dwarfs pulse?

Ultracool Dwarf Pulsars

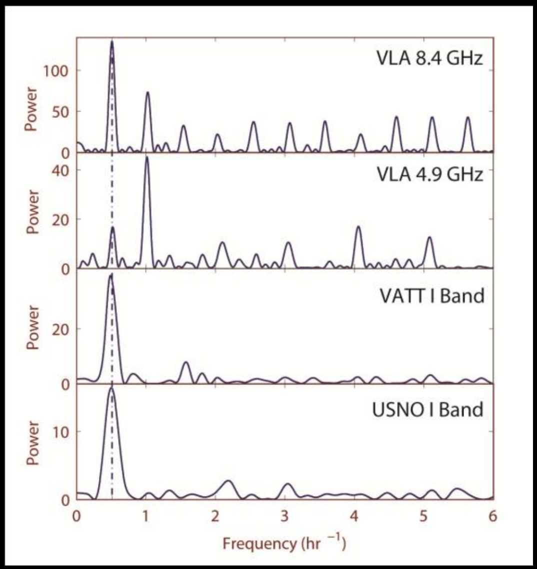


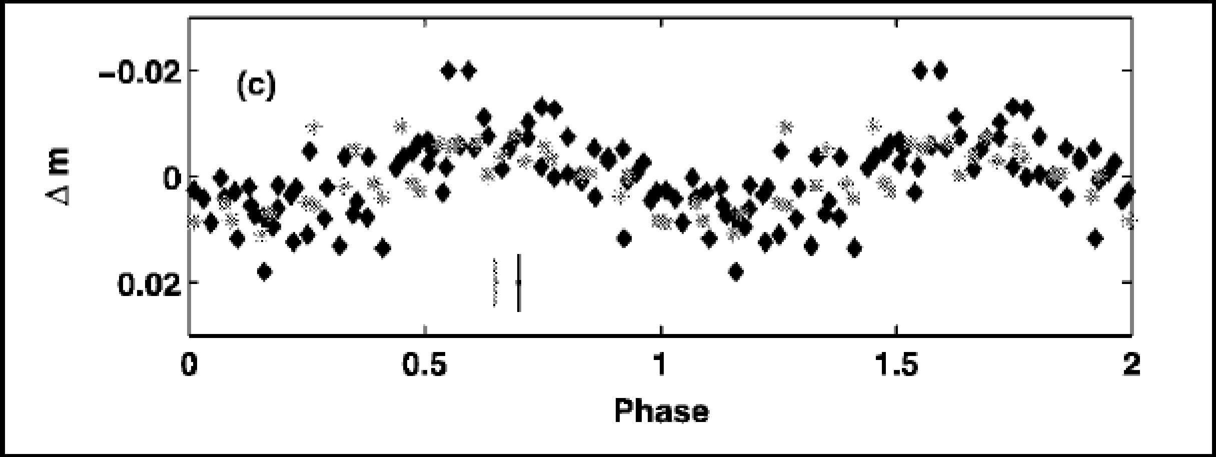


Exemplar Object – TVLM 513-46536

Unusual Behaviour at other wavebands...

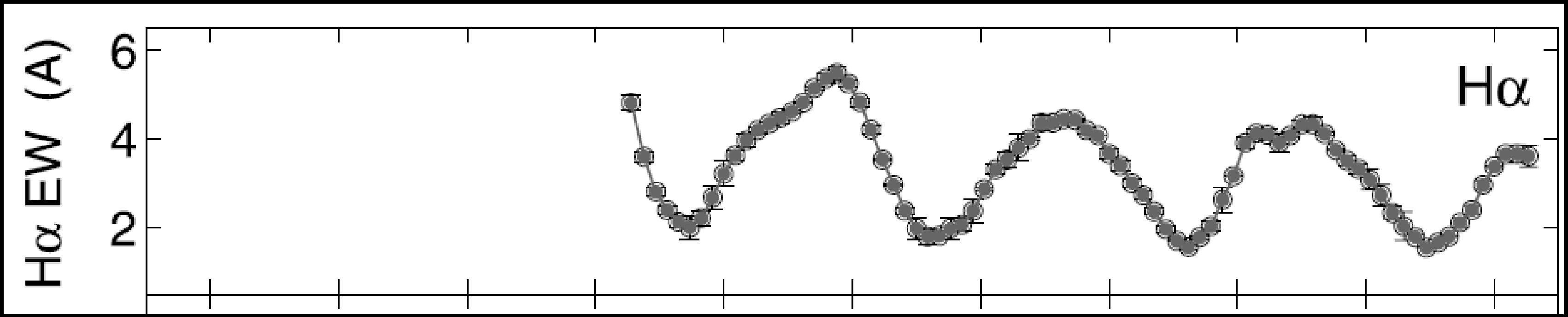
Periodicity in I band photometric monitoring





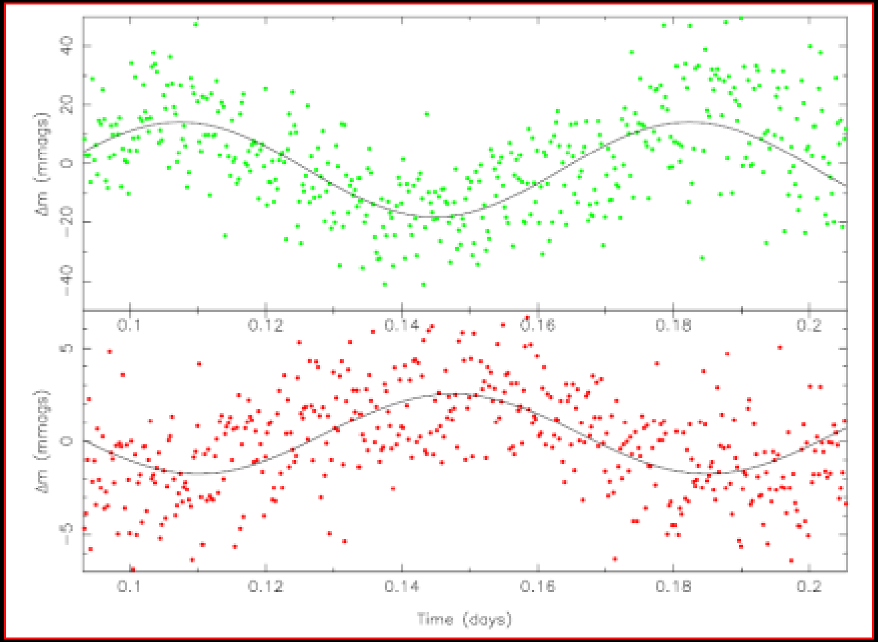
• The same period is retrieved in optical observations – Lane et al 2007

Periodicity in H-alpha emission



• Same periodic signal also present in H-alpha emission – Berger et al. 2008

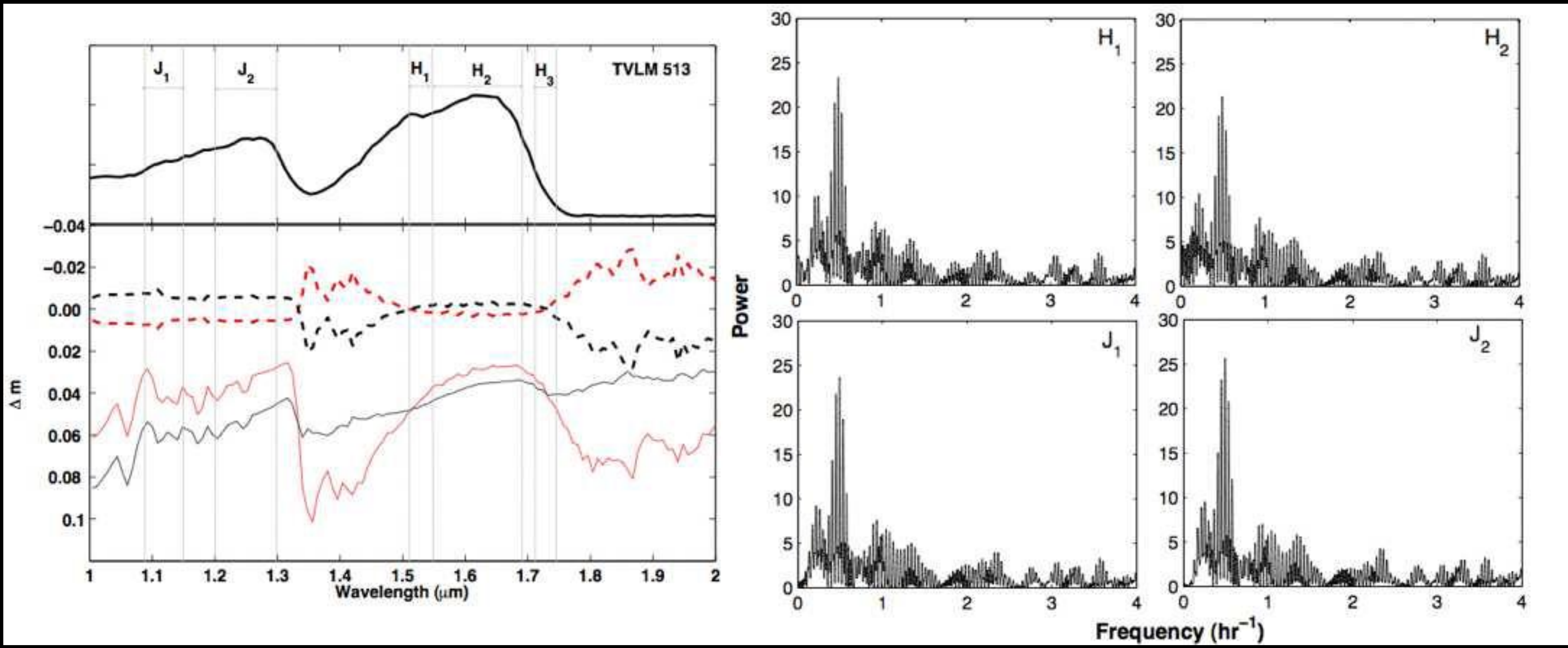
Anti-correlation in g′ and i′ photometric monitoring



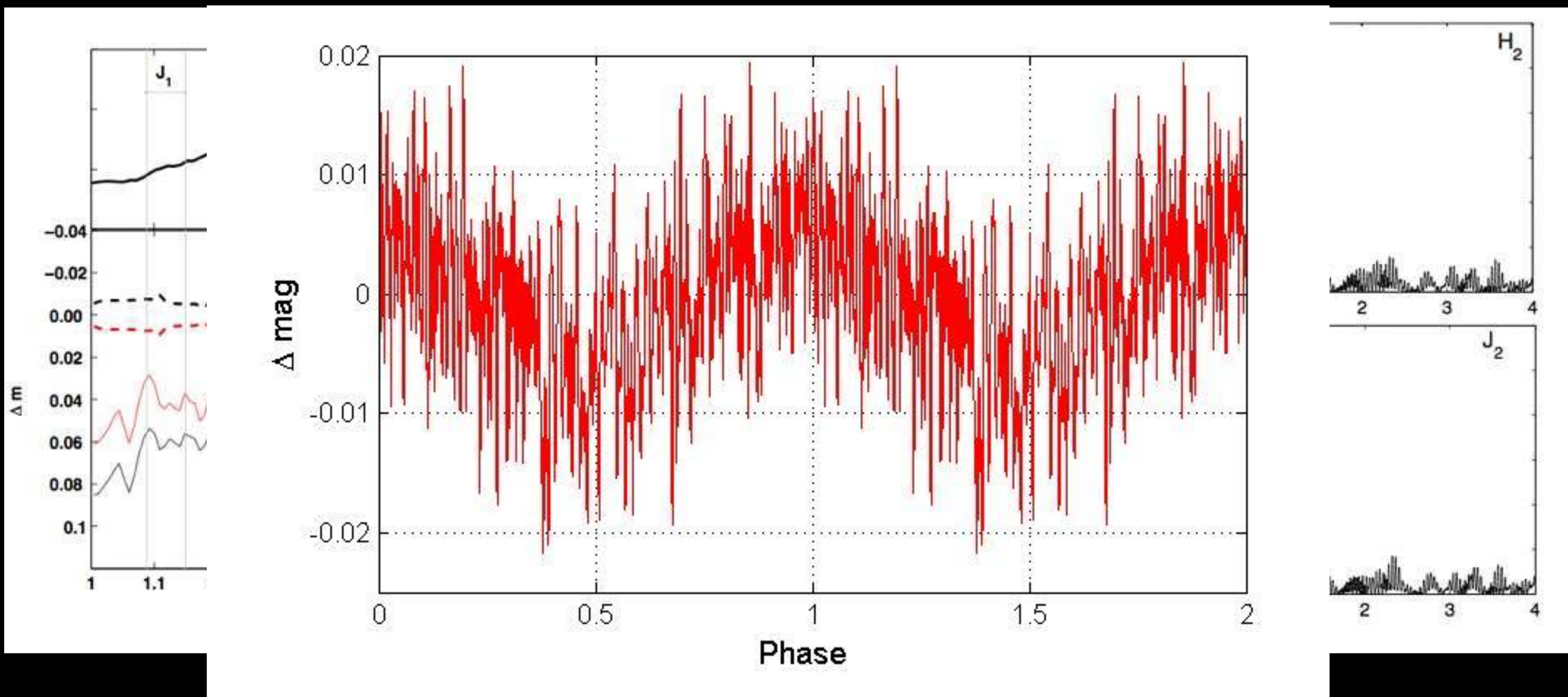
Littlefair et al. 2008: Anti-correlation in g′ and i′ photometry, rules out spots as the sole cause of the variability. Consistent with dust.

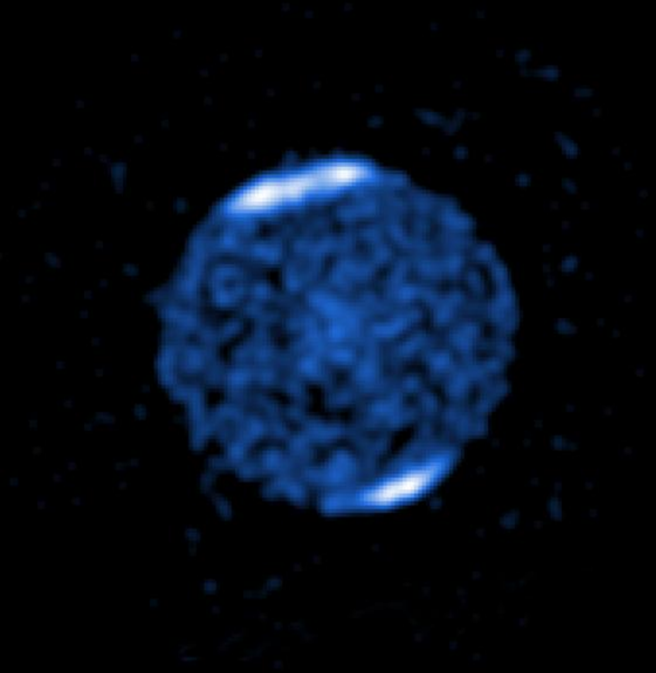
•Change in variability amplitude greatly diminished.

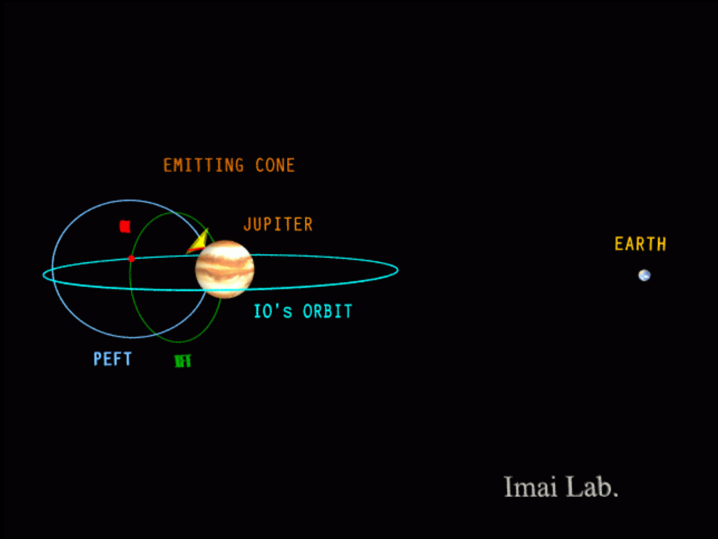
Periodicity in JHK Spectrophotometry



Periodicity in JHK Spectrophotometry

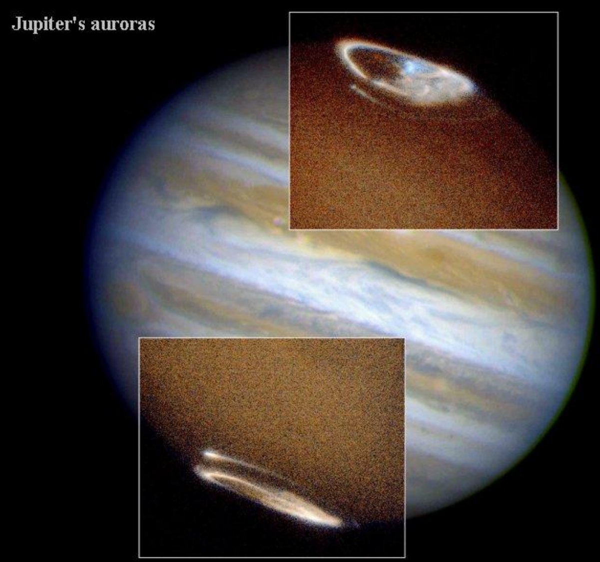


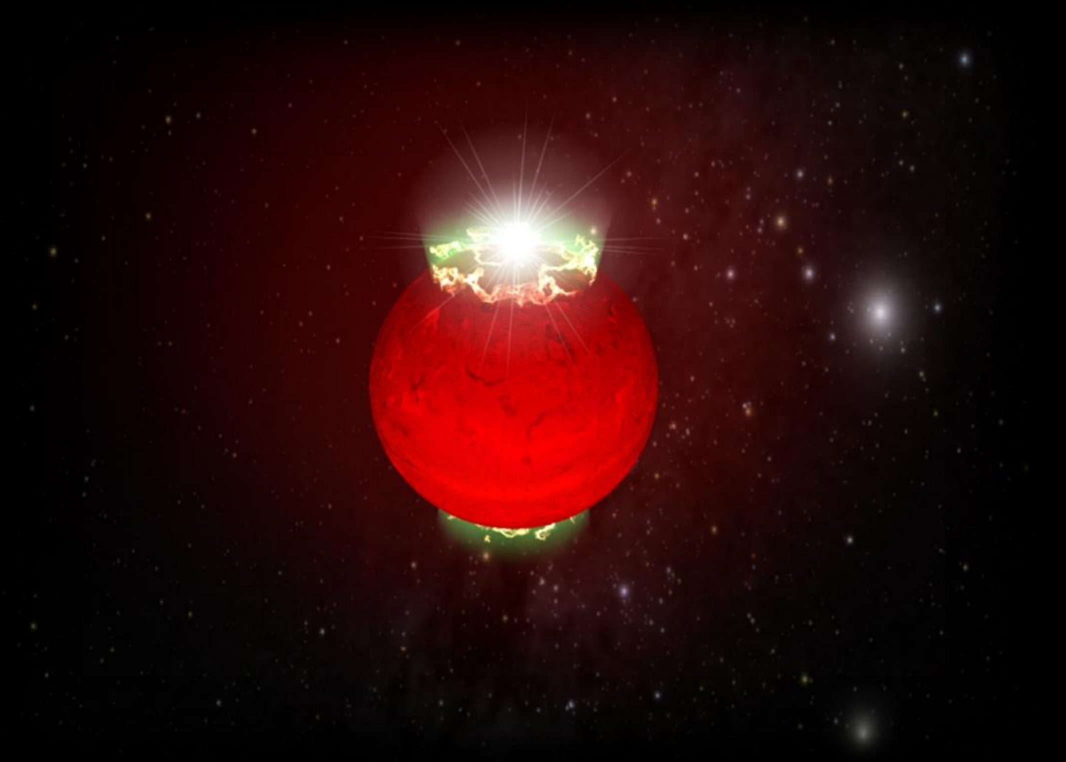




Emission	*Jupiter*
X rays (0.1–3 keV)	~1–4 GW[a]
FUV[b] (80–180 nm)	2–10 TW
Visible (385–1000 nm)	~10–100 GW
IR (H_3^+) (3–4 μm)	4–8 TW
IR (hydrocarbons) (7–14 μm)	~40 TW
Radio (10 kHz to a few megahertz)	~10 GW[c]

Bhardwaj and Gladstone (2000)





Jupiter

Radio ~ 10^{10} W

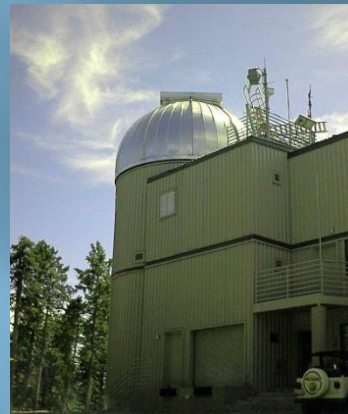
Balmer Line emissions ~ 10^{10} - 10^{11} W

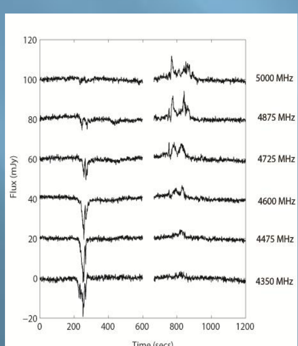
TVLM 513

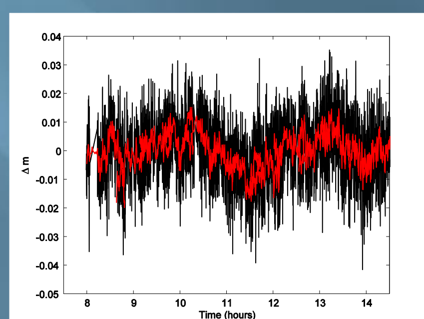
Radio ~ 10^{16} W

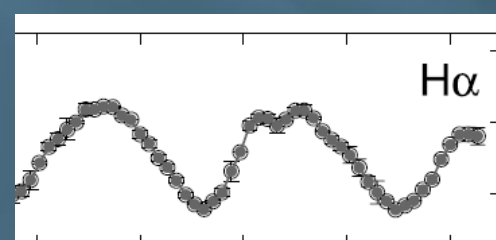
H-alpha ~ 10^{17} W

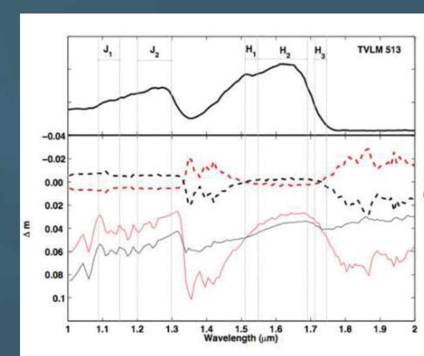
Scaling factor of 10^6




5000 MHz
4875 MHz
4725 MHz
4600 MHz
4475 MHz
4350 MHz
Flux (mJy)
Time (secs)


Δ m
Time (hours)


Hα


TVLM 513
Wavelength (μm)
Power

What about detecting magnetic fields on exoplanets?

Radio emission from exoplanets

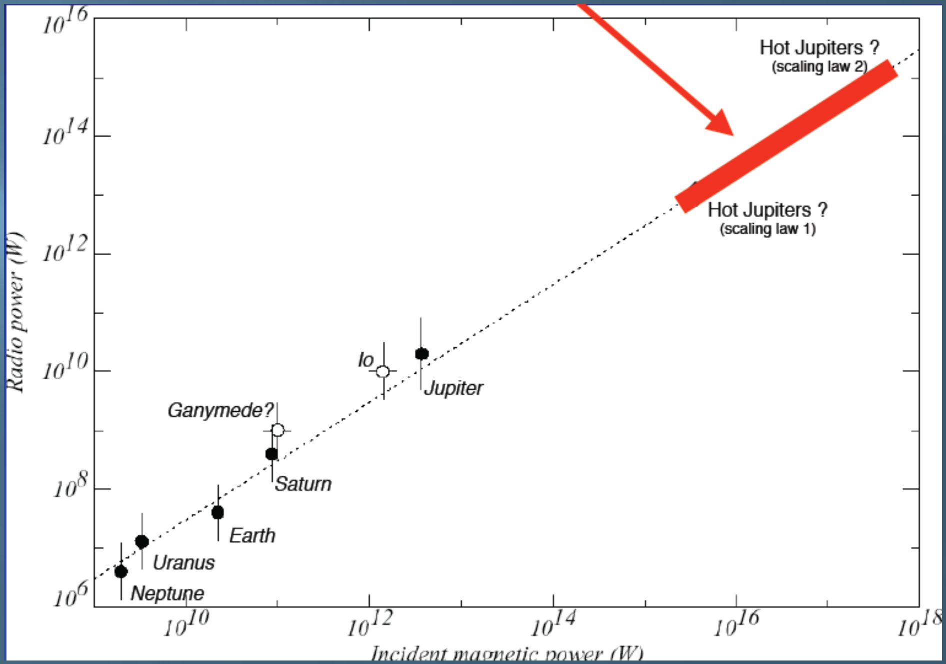
- It's a direct detection
- Allows measurement of rotation rate
- Possible use as a detection method for exoplanets
- The only method currently viable for measurement of magnetic field strengths for exoplanets…

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.

Radiometric Bode's Law

- 'Hot Jupiters' with expected radio luminosities many thousands of times brighter than Jupiter.
- Should theoretically outshine the parent star.
- Detectable with current generation of telescopes - GMRT.

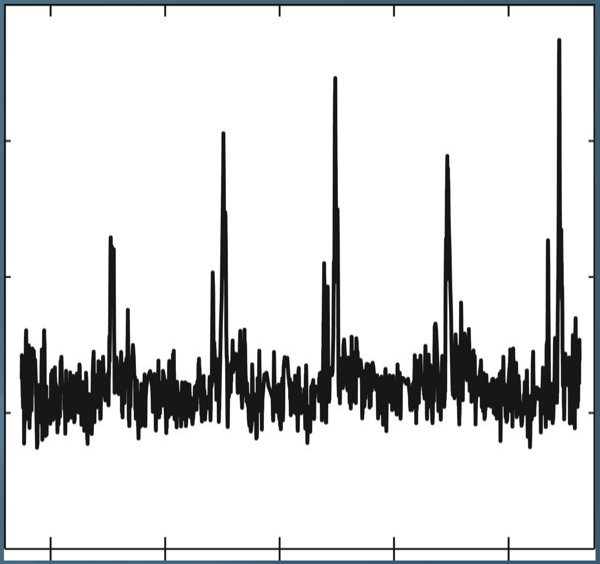


Zarka et al. 2001

What have we learned from Brown Dwarfs…

Why has there been no detection?

- 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.
- We have commenced observations with the GMRT to look for a pulse.



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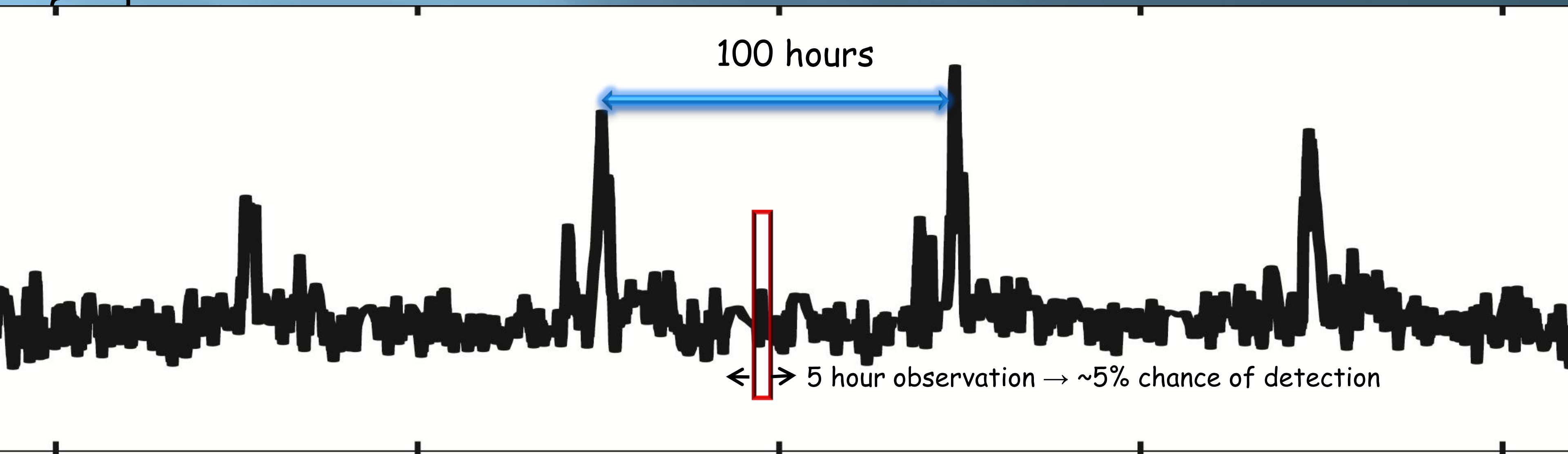


Target 1: Tau Boötis b

- Tau Boötis b: > 4 Jupiter masses.

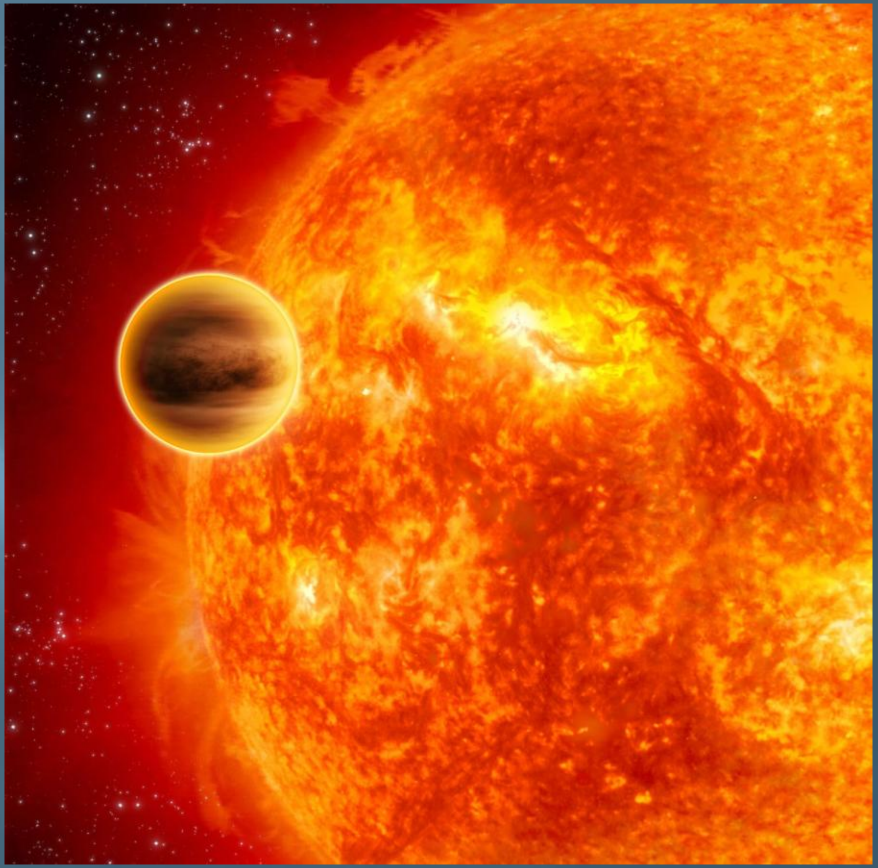
- Semimajor axis ~0.05 AU - Only 1/7 the distance of the Mercury to the Sun – 'torch orbit'.

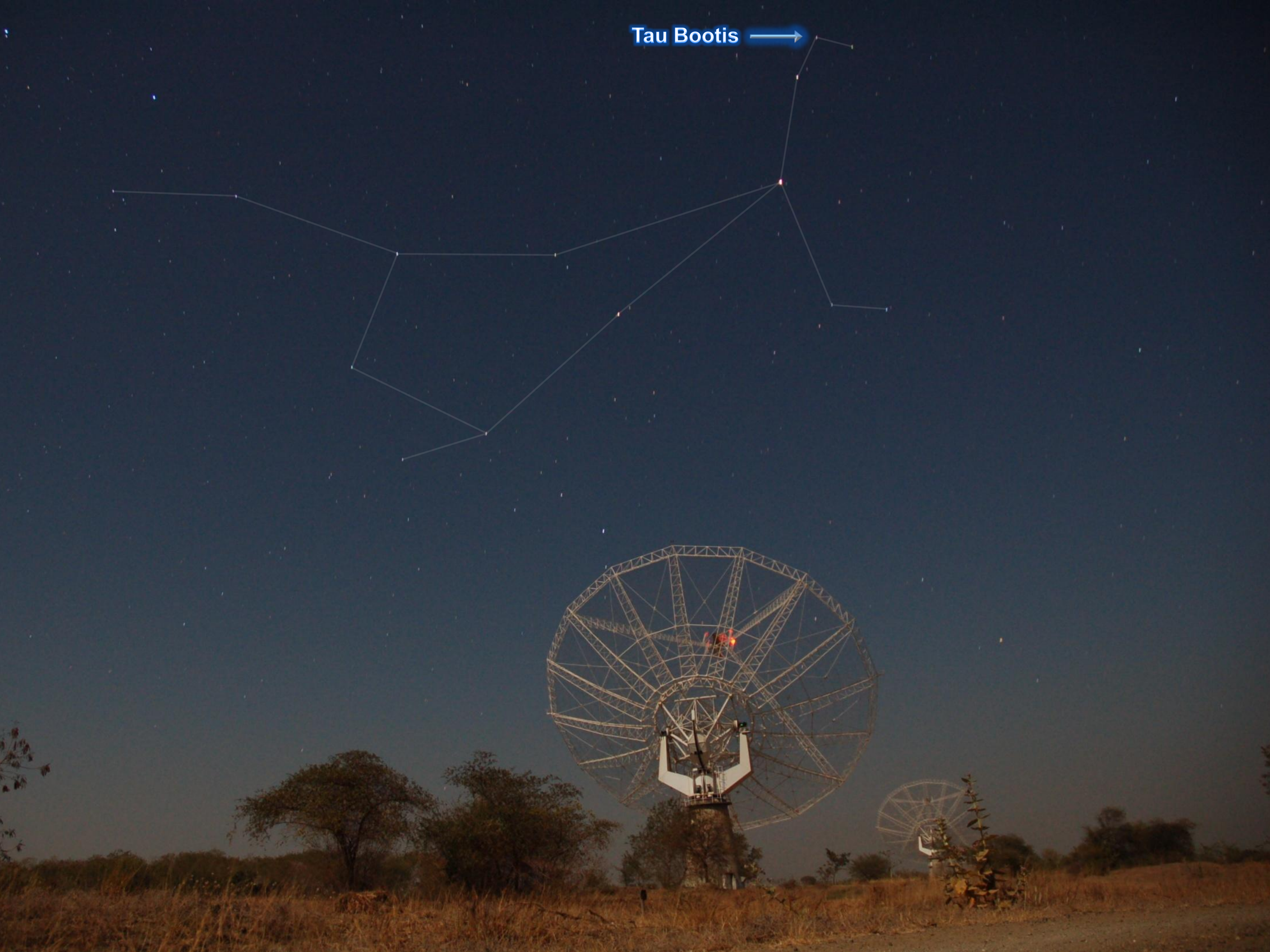
- Distance of 50 light years.

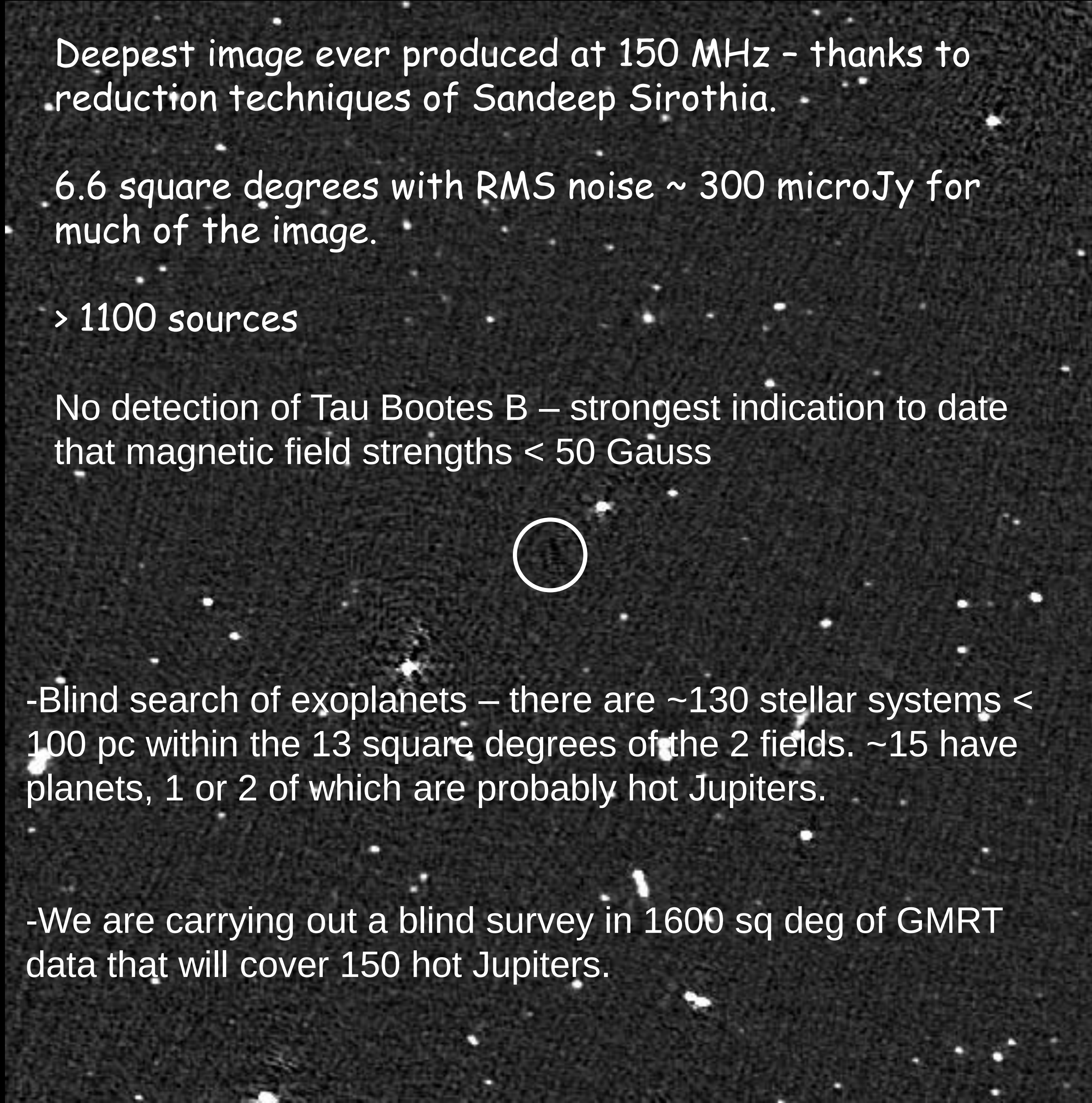
- Orbital period of 79.5 hours.

- Observed for 40 hours with the Giant Metre-Wave Radio Telescope (GMRT) in India.

- Observations spaced to allow maximum phase coverage.




Tau Bootis



Deepest image ever produced at 150 MHz – thanks to reduction techniques of Sandeep Sirothia.

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

> 1100 sources

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

-Blind search of exoplanets – there are ~130 stellar systems < 100 pc within the 13 square degrees of the 2 fields. ~15 have planets, 1 or 2 of which are probably hot Jupiters.

-We are carrying out a blind survey in 1600 sq deg of GMRT data that will cover 150 hot Jupiters.

Deepest image ever produced at 150 MHz – thanks to reduction techniques of Sandeep Sirothia.

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

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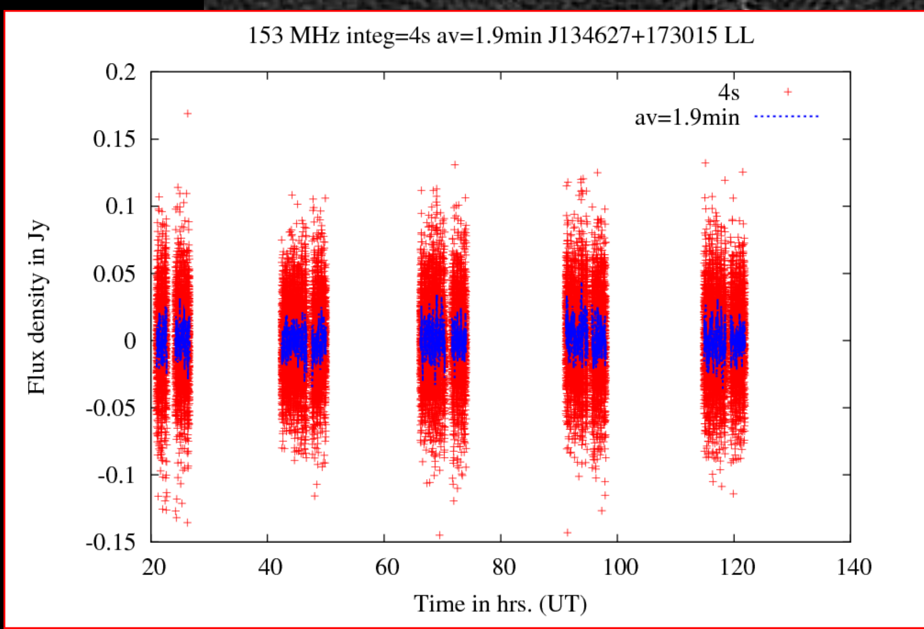
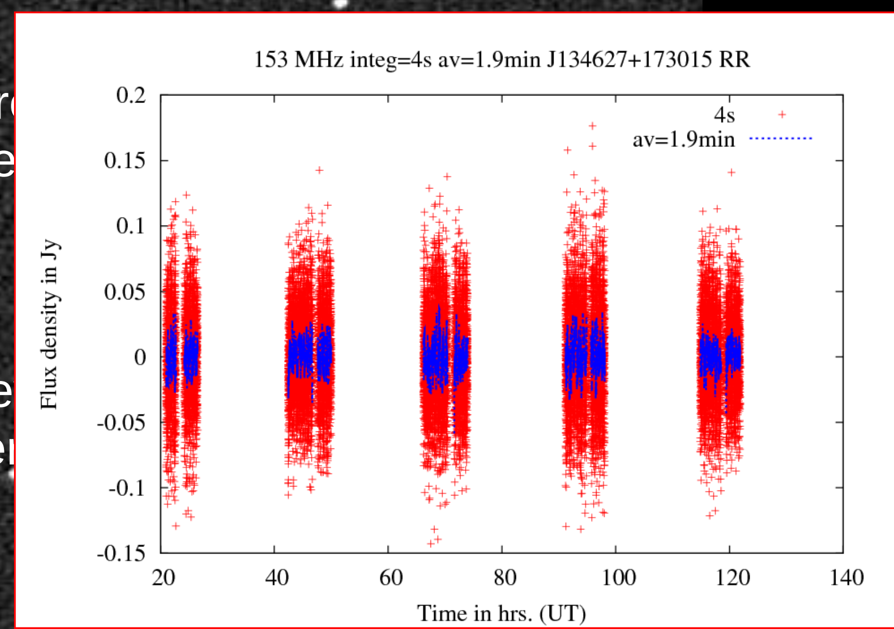
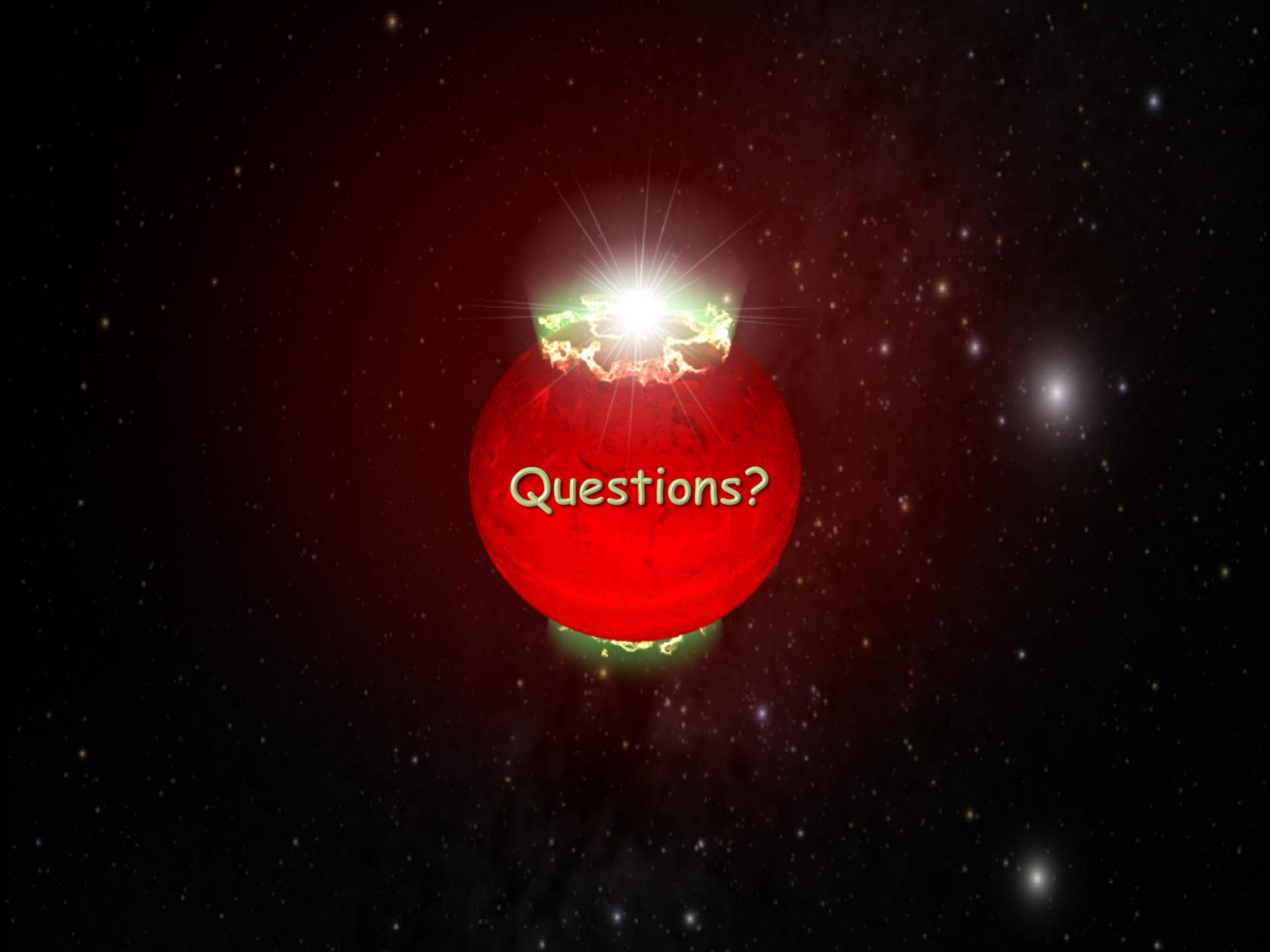
No detection of Tau Bootes B – strongest indication to date that magnetic field strengths < 50 Gauss






Questions?