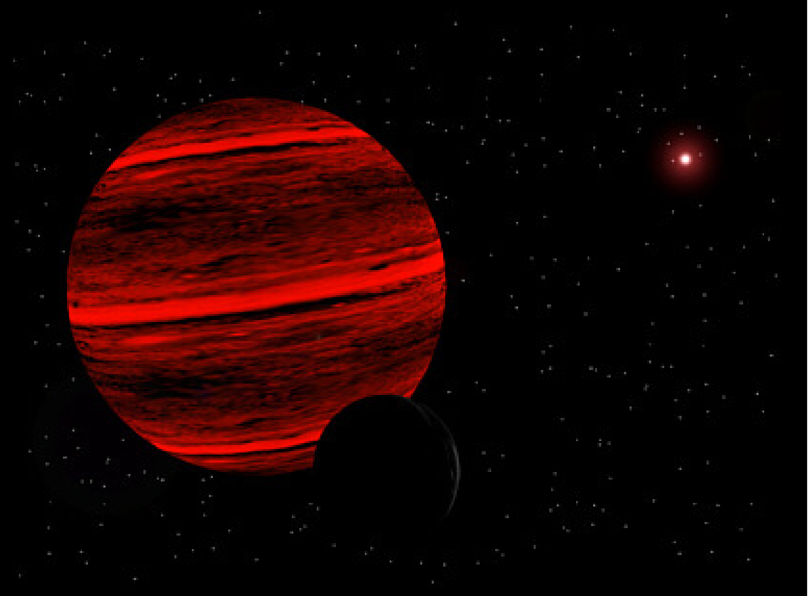
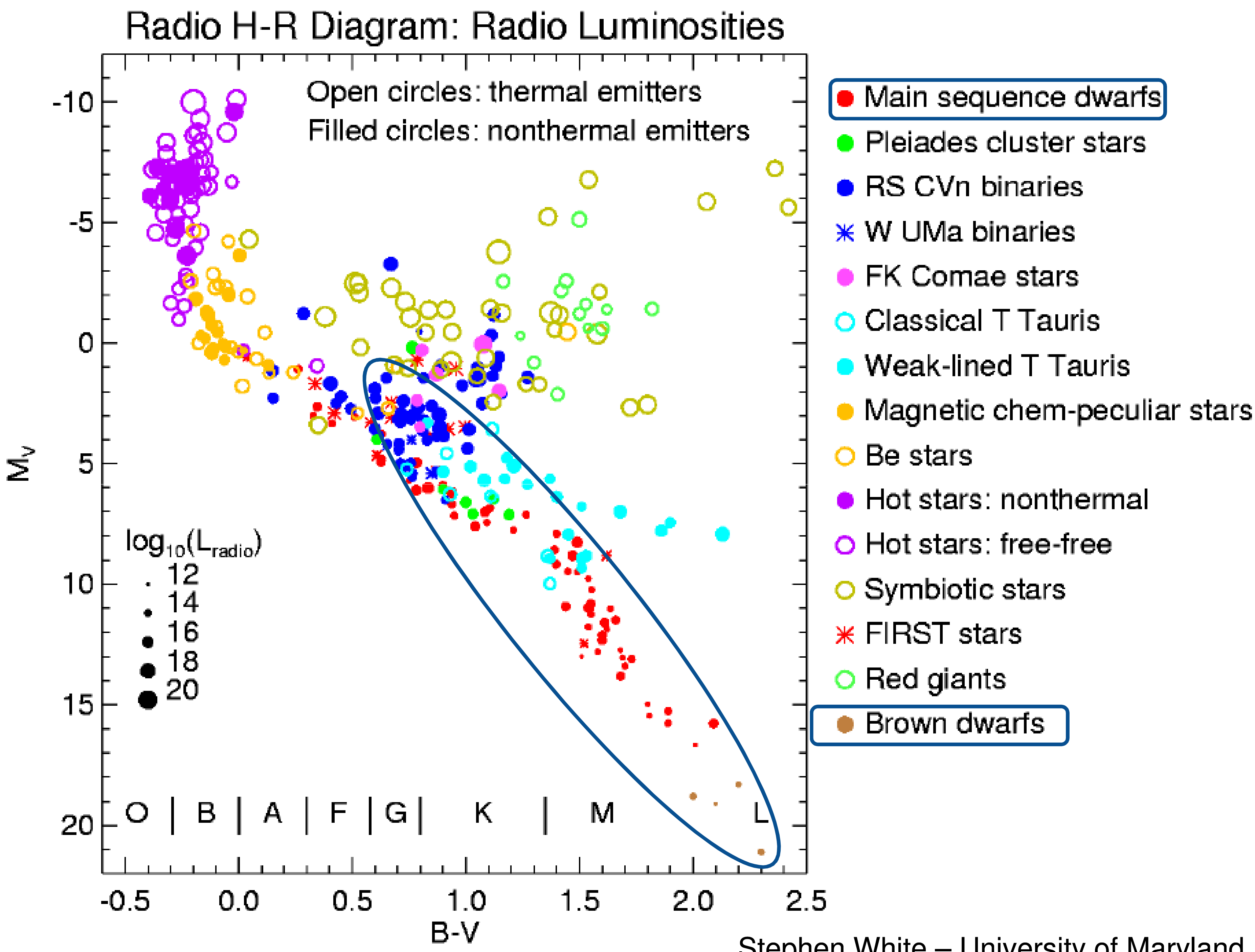


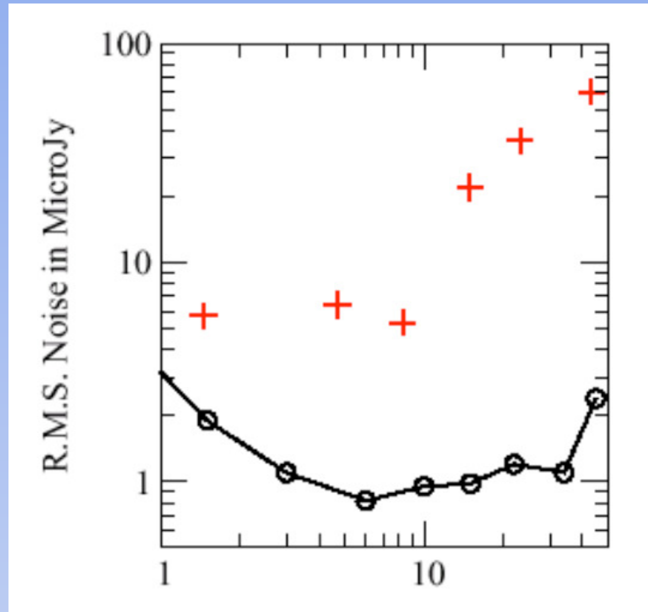
Probing Stellar and Substellar Magnetospheres with Next Generation Radio Instruments

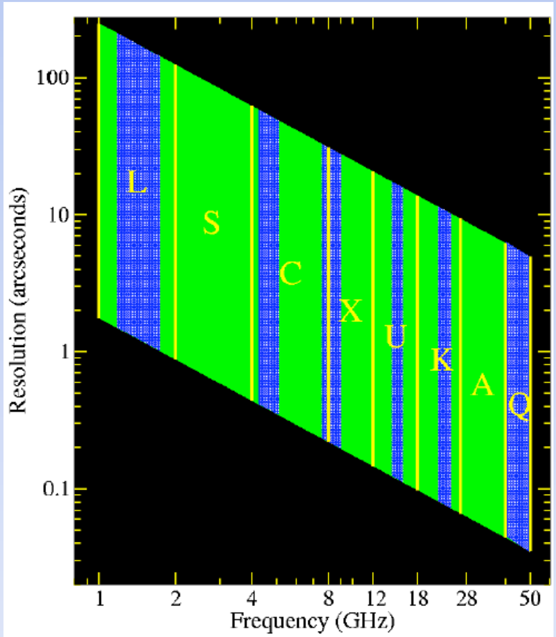
Gregg Hallinan
National Radio Astronomy Observatory
& UC Berkeley
E-mail: gregg@astro.berkeley.edu



Stephen White – University of Maryland

The EVLA: A New Era in Stellar Radio Astronomy





- EVLA – Continuum point-source sensitivity better than 1 microJy between 2 and 40 GHz.

- Operation at any frequency between 1.0 and 50 GHz, with up to 8 GHz bandwidth per polarization and a minimum of 16,384 channels.

- **EVLA will revolutionize stellar radio astronomy.**

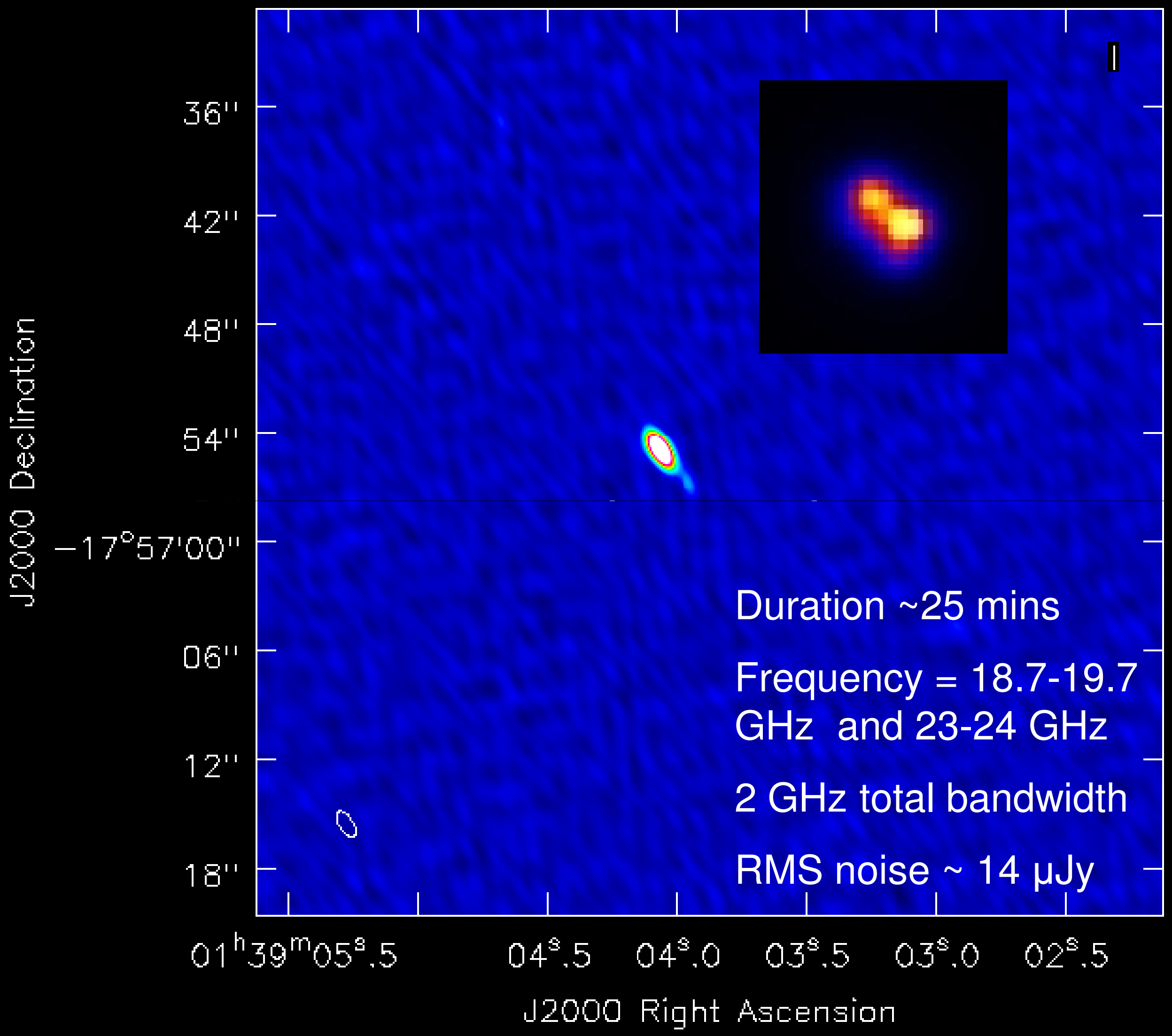
RSRO – Resident Shared Risk Observing

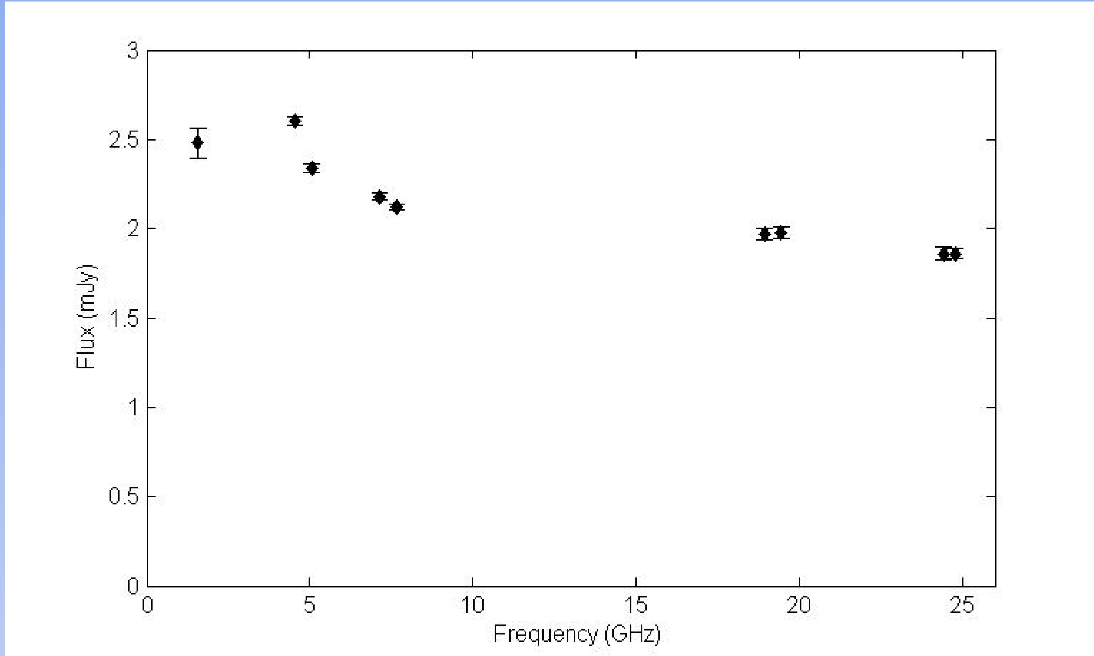
Early access to the growing capabilities of the EVLA as it is being commissioned, in exchange for a period of residence in Socorro to assist with the commissioning.

RSRO 10B-209: '*Broadband Periodic Dynamic Spectra of Ultracool Dwarf Pulsars*' - 38 hours on two brown dwarfs

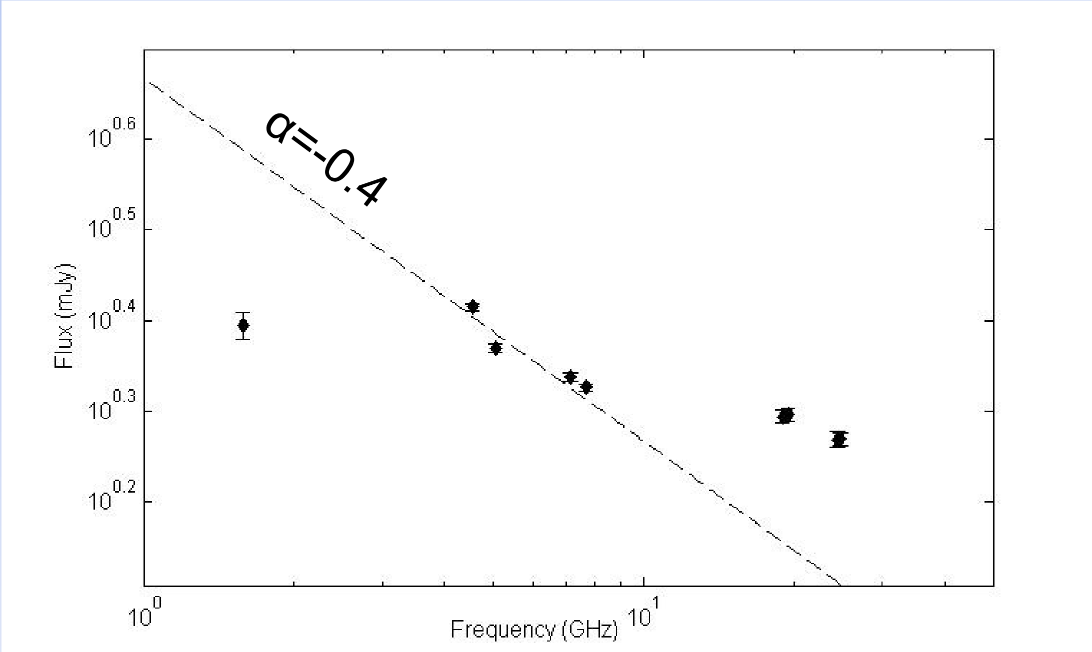
RSRO 10C-210: '*Broadband Spectra of Radio Emission from M Dwarf Stars and Brown Dwarfs*' - 16 hours on 2 flare stars and two brown dwarfs

UV Ceti


I
36''
42''
48''
54''
−17°57'00''
06''
12''
18''
J2000 Declination
01h39m05s.5
04s.5
04s.0
03s.5
03s.0
02s.5
J2000 Right Ascension
Duration ~25 mins
Frequency = 18.7-19.7 GHz and 23-24 GHz
2 GHz total bandwidth
RMS noise ~ 14 μJy

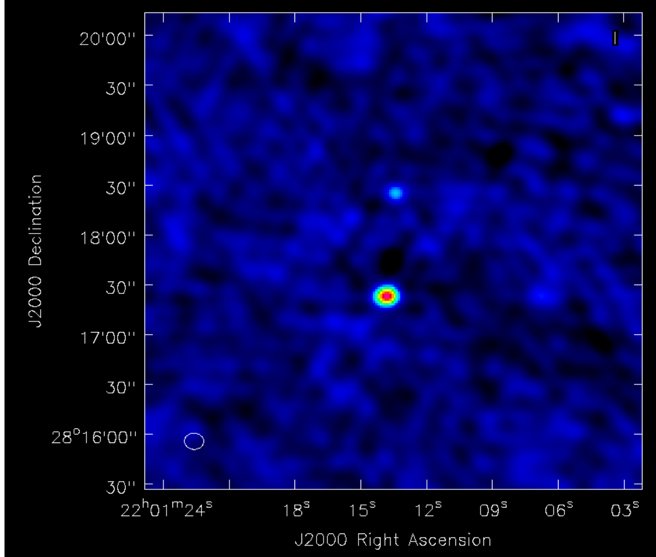


3
2.5
2
1.5
1
0.5
0
Flux (mJy)
0
5
10
15
20
25
Frequency (GHz)

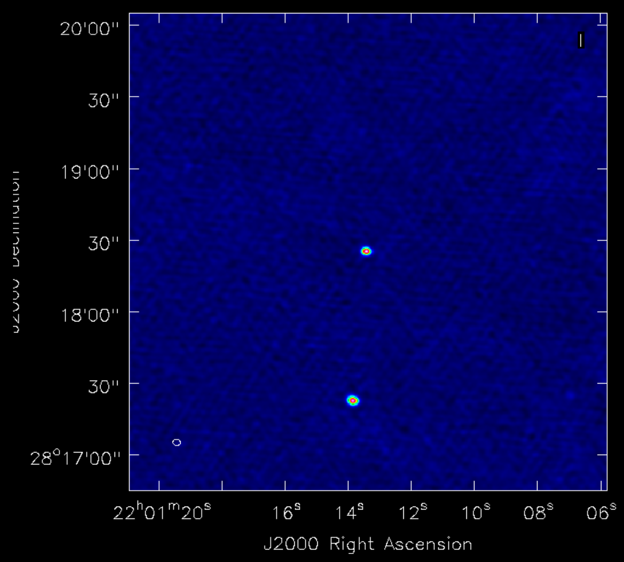


α=-0.4
$10^{0.6}$
$10^{0.5}$
$10^{0.4}$
$10^{0.3}$
$10^{0.2}$
Flux (mJy)
10^{0}
10^{1}
Frequency (GHz)

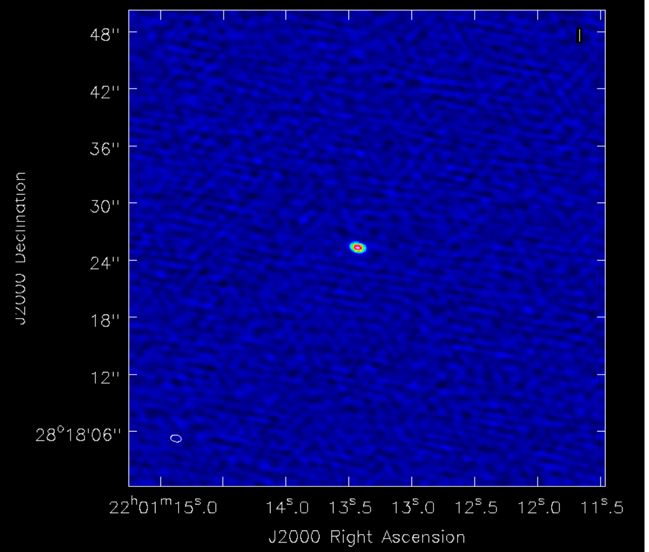
V374 Peg



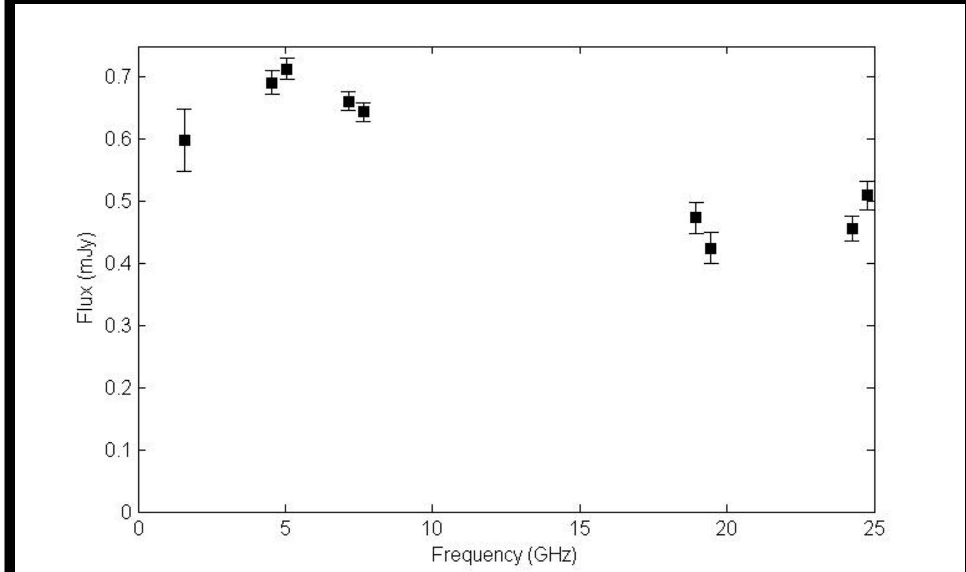
J2000 Declination
J2000 Right Ascension



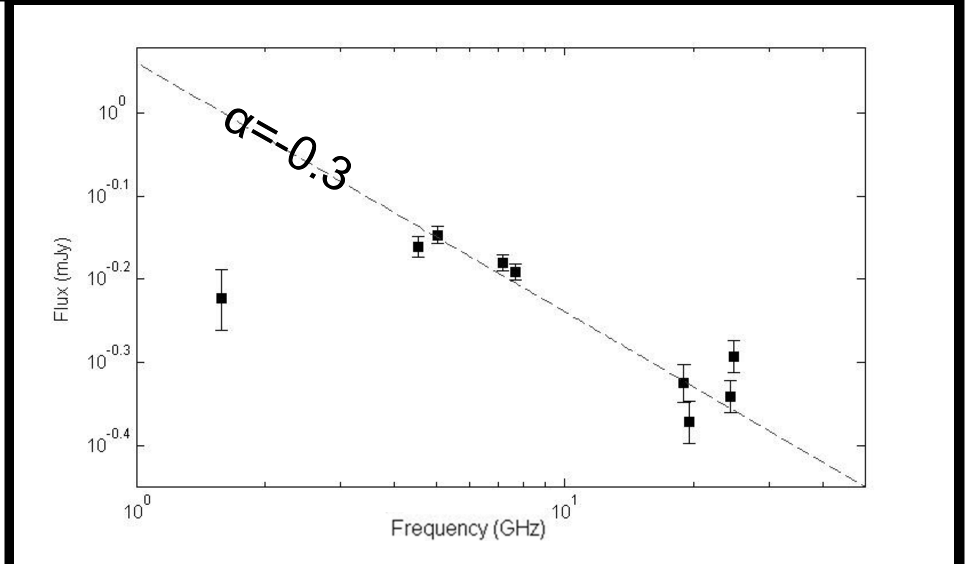
J2000 Right Ascension



J2000 Declination
J2000 Right Ascension



Flux (mJy)
Frequency (GHz)

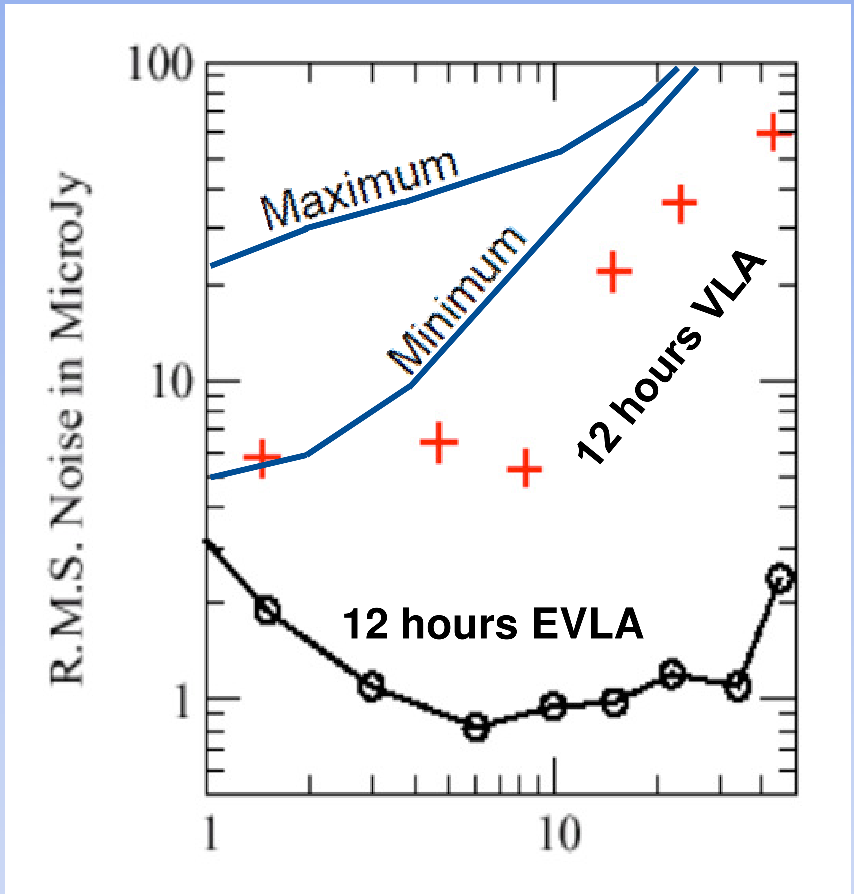


α=-0.3
Flux (mJy)
Frequency (GHz)

From flare stars to Solar-type stars and everything in between...

Detecting thermal radio emission from solar type stars (F8V-K2V) with activity levels comparable to the Sun is now possible.

Excellent method to measure coronal magnetic field strengths low in the corona and chromosphere.



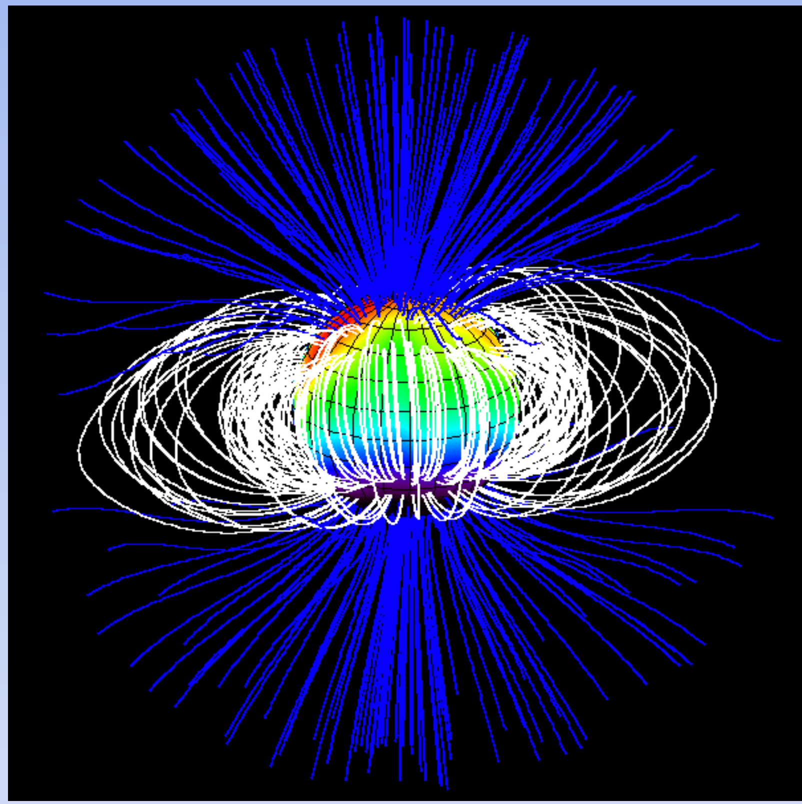
Solar radio flux at distance of Alpha Centauri compared to VLA and EVLA sensitivity.

Combining Radio and Zeeman Doppler Imaging

Zeeman Doppler Imaging (ZDI) enables the mapping of the large-scale magnetic fields of stars.

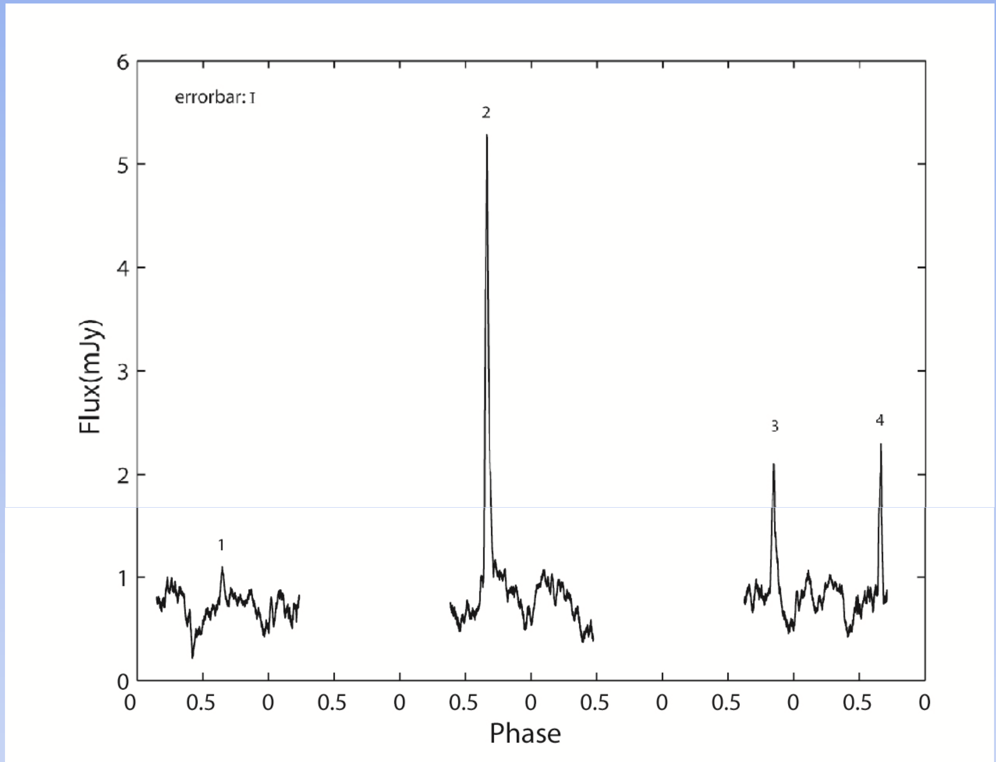
Donati et al. (2006) – Fully convective dwarf stars have large-scale axisymmetric dipolar fields.

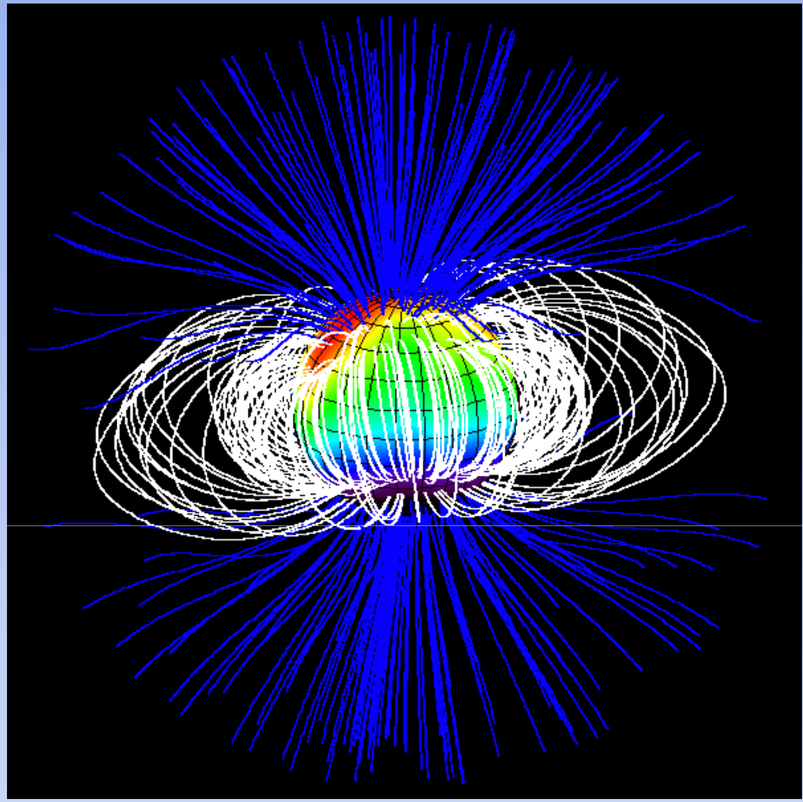
Simultaneous observations can map the radio corona to the stellar magnetic field.



- Work done in collaboration with Julien Morin, J.F. Donati & Moira Jardine.

Radio Corona of V374 Peg

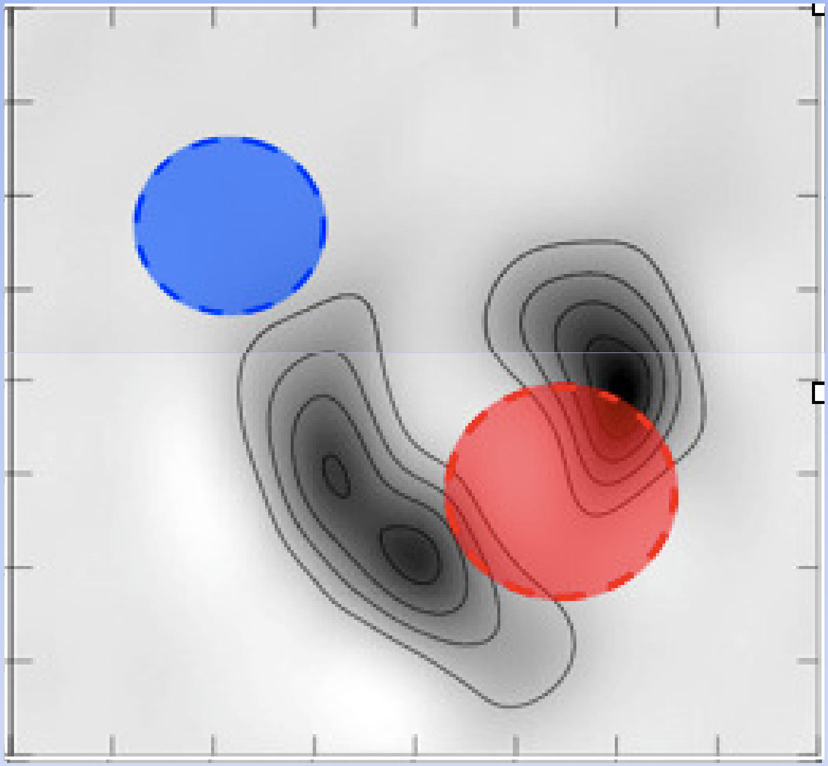




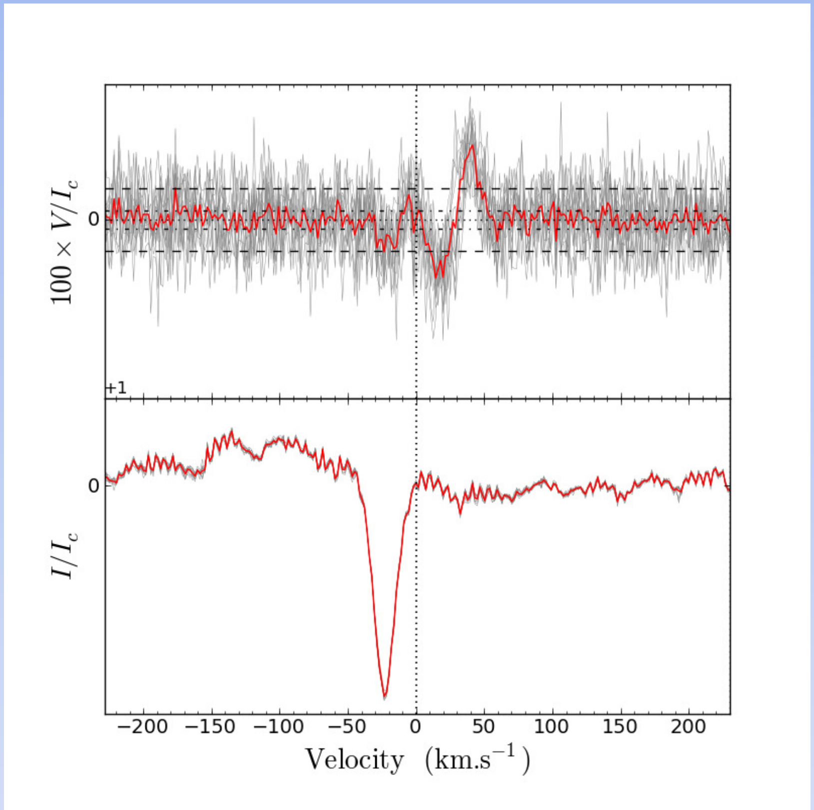
- Quiescent emission is strongly periodic with rotation of the dwarf.

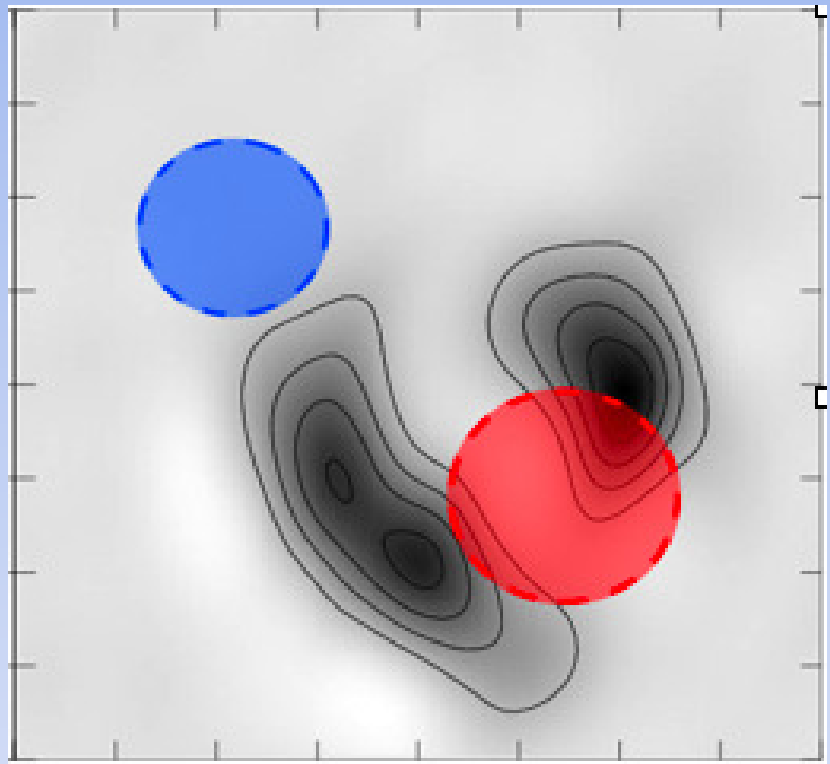
-Two peaks per period if rotation when the large-scale magnetic field is perpendicular to our line of sight.

Peterson et al. Nature 2010: Coronal Loop on Algol

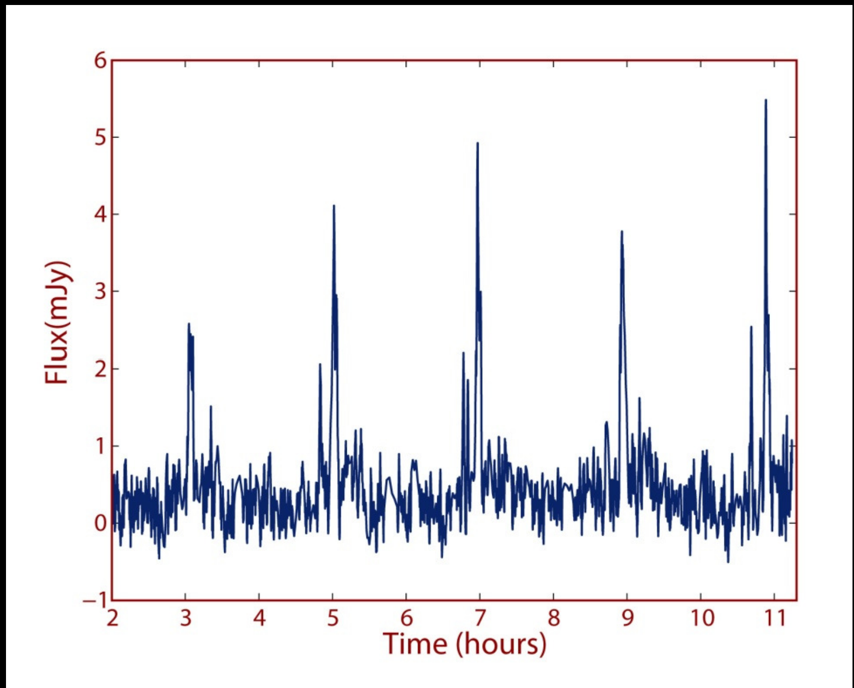


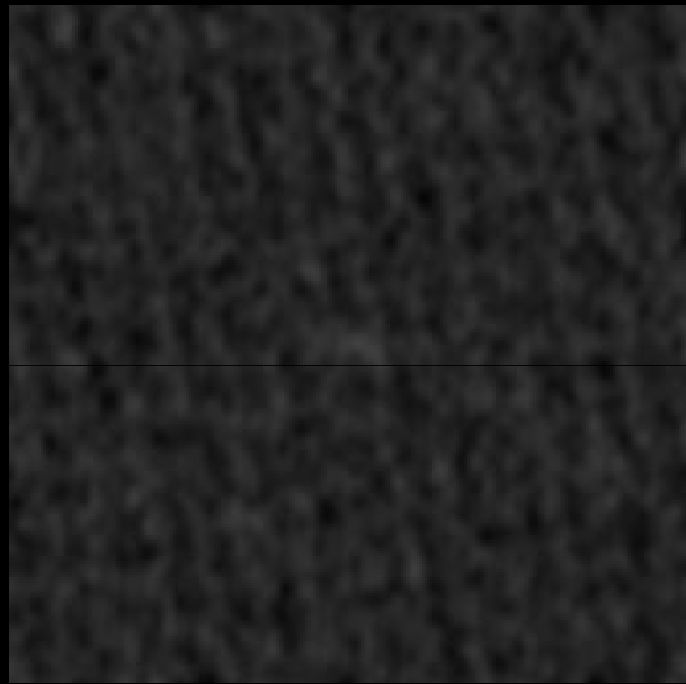
Simultaneous Zeeman Doppler Imaging and VLBI





Brown Dwarfs Pulses!





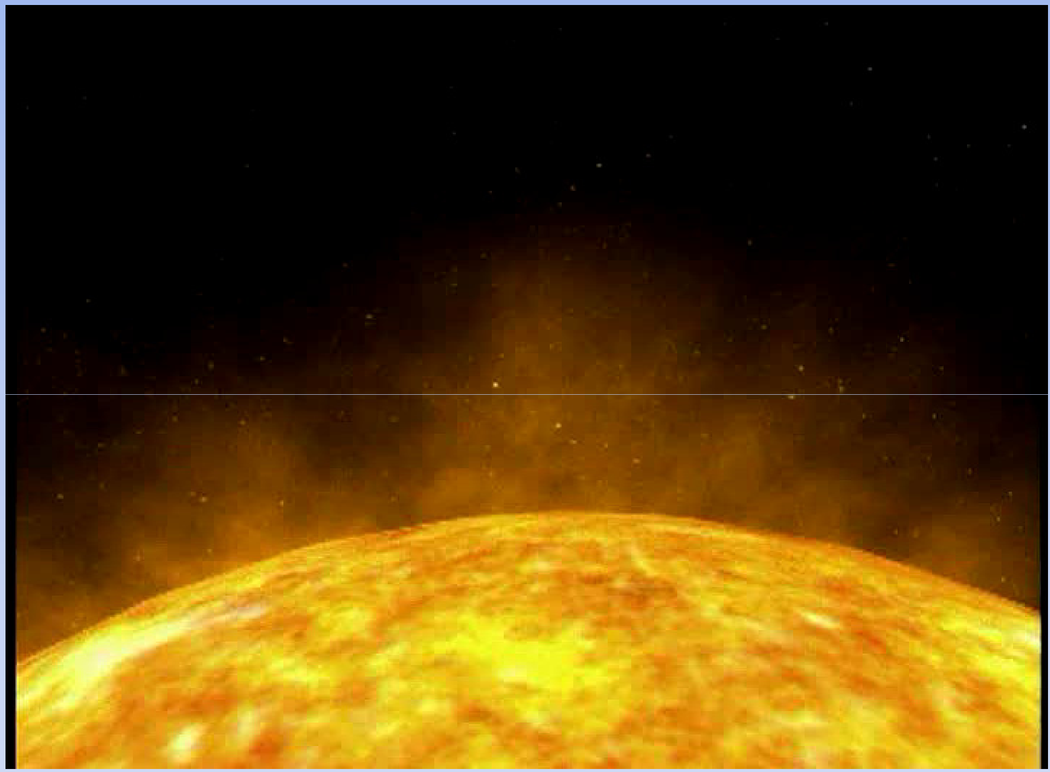
The M9 dwarf TVLM 513-46546 - Hallinan et al. (2006, 2007)

Radio Emission from Solar System Planets

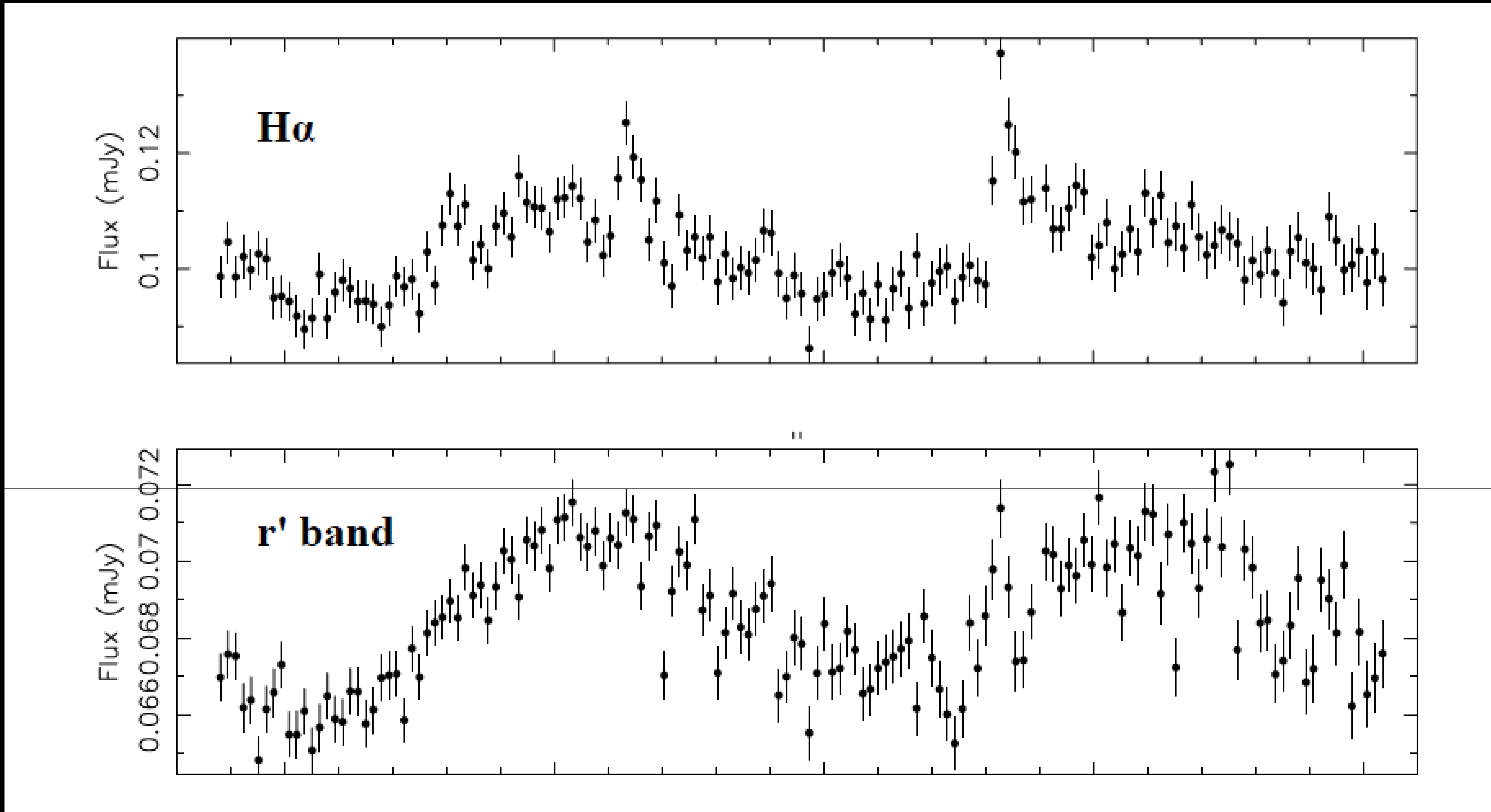
- All the magnetized planets in our solar sytem produce extremely bright radio emission at low frequencies (MHz and kHz)

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

- Produced at the electron cyclotron frequency - Field strength (Gauss) = Frequency (MHz) / 2.8



Credit: Soho



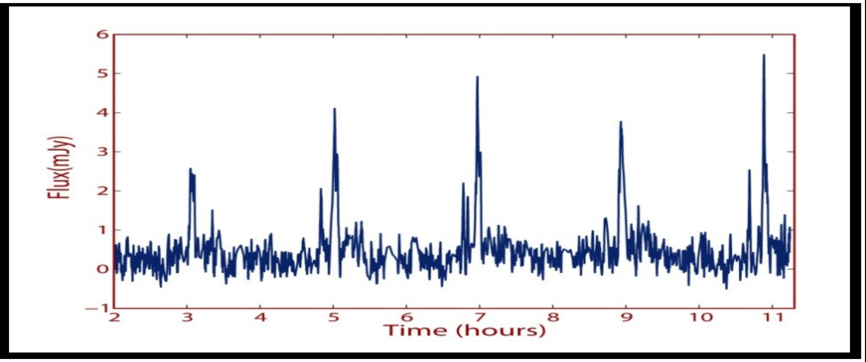
Peak to peak amplitude variation in r′ band is ~ 7%

TVLM 513-46546 -> M8.5

Period: 1.96 hours

Surface B > 3015 G

$Log(L_{H\alpha}/L_{bol}) = -4.8$
$Log(L_X/L_{bol}) = -5.1$ (marginal)

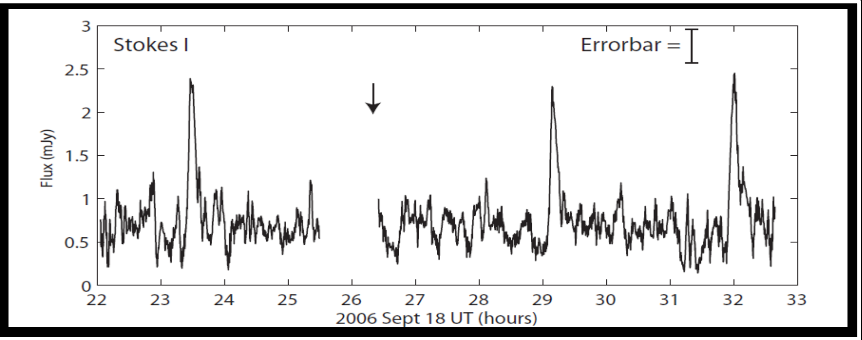


LSR J1835+3259 -> M8.5

Period: 2.84 hours

Surface B > 3015 G

$Log(L_{H\alpha}/L_{bol}) = -4.85$
$Log(L_X/L_{bol}) < -5.7$

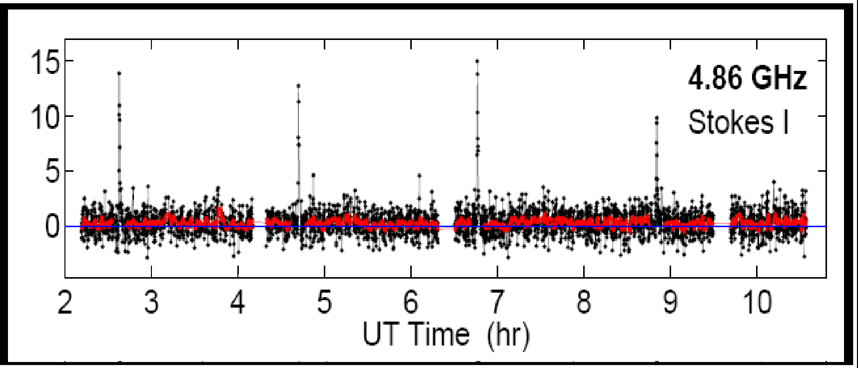


2MASS J0746+20 -> L0+L1.5

Period: 2.07 hours

Surface B > 1735 G

$Log(L_{H\alpha}/L_{bol}) = -4.85$
$Log(L_X/L_{bol}) < -4.7$

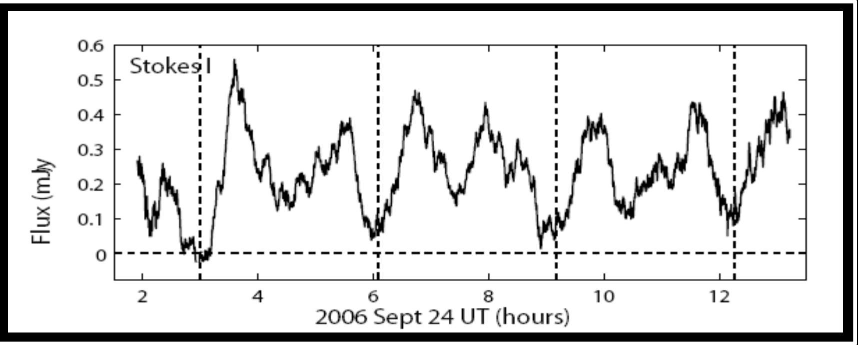


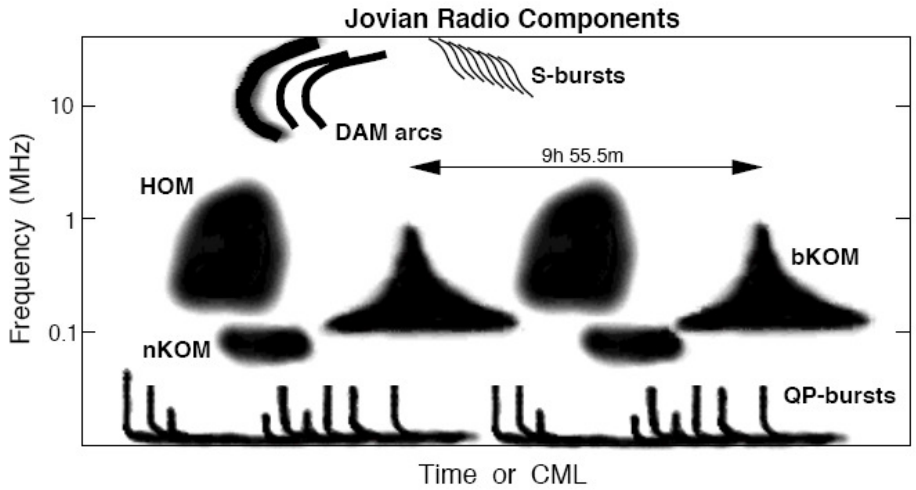
2MASS J0036+18 -> L3.5

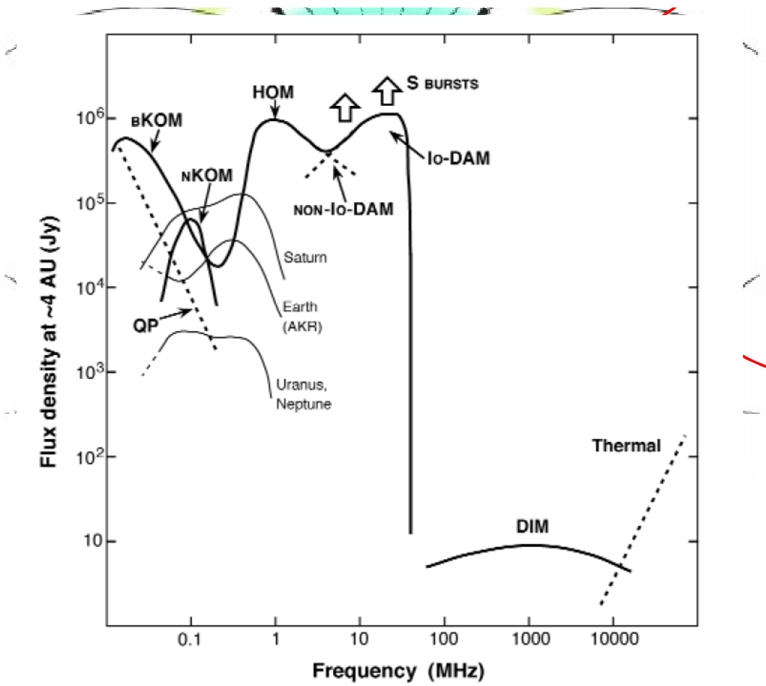
Period: 3.08 hours

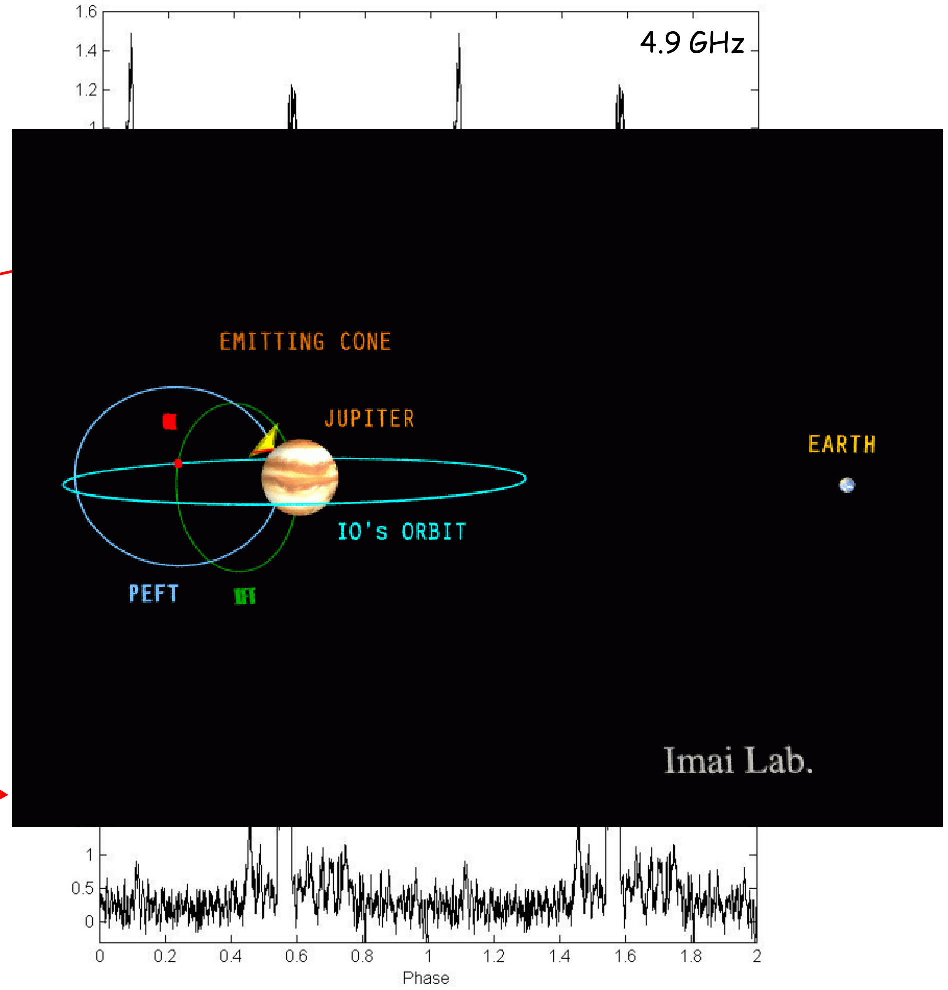
Surface B > 1735 G

$Log(L_{H\alpha}/L_{bol}) = -4.7$
$Log(L_X/L_{bol}) < -6.65$

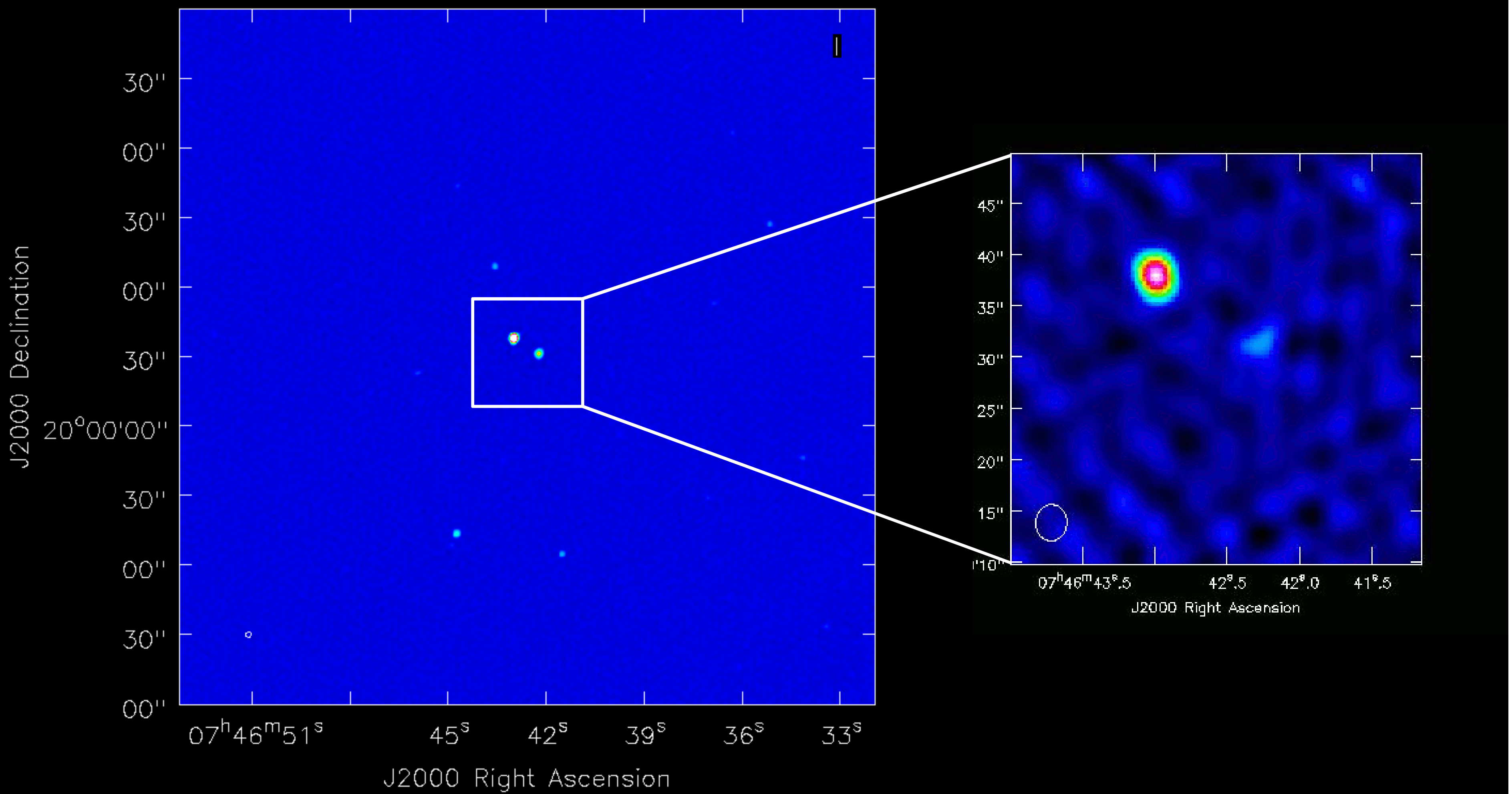



Jovian Radio Components
S-bursts
DAM arcs
9h 55.5m
HOM
bKOM
nKOM
QP-bursts
10
1
0.1
Frequency (MHz)
Time or CML


HOM
S BURSTS
bKOM
nKOM
Io-DAM
NON-Io-DAM
Saturn
Earth (AKR)
QP
Uranus, Neptune
Thermal
DIM
10^6
10^5
10^4
10^3
10^2
10
0.1
1
10
100
1000
10000
Flux density at ~4 AU (Jy)
Frequency (MHz)

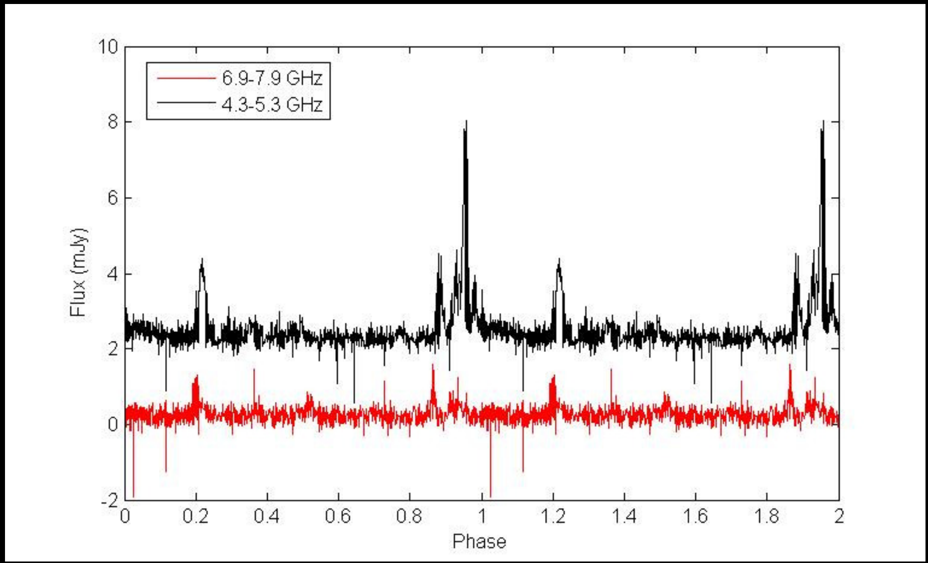

4.9 GHz
1.6
1.4
1.2
EMITTING CONE
JUPITER
EARTH
IO's ORBIT
PEFT
Imai Lab.
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Phase

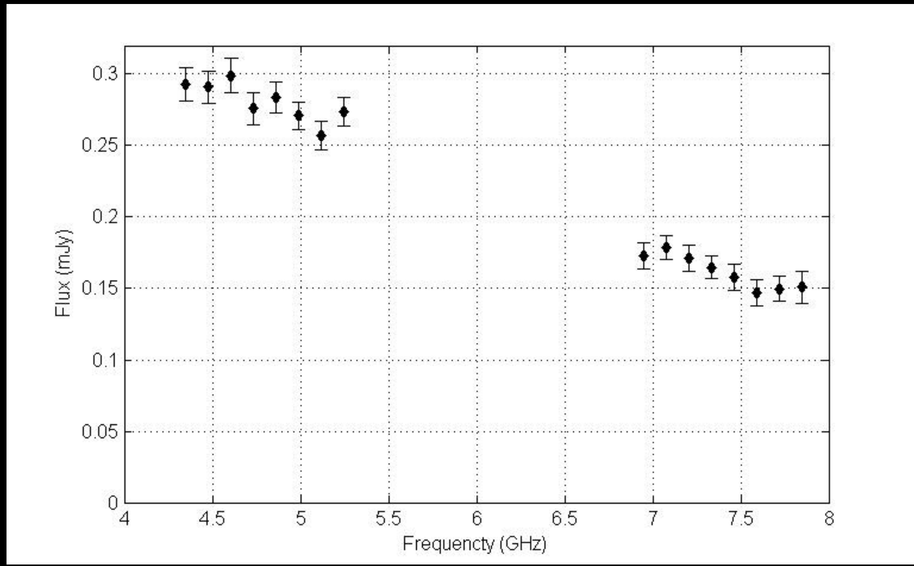
EVLA: First results...



- 5 hours of test data with 2 GHz bandswidth.
- RMS noise ~2.3 μJy

EVLA: First results...





- Phase folded light curves.
- Clear difference in time of arrival at higher frequencies.

- First slice of the spectrum
- Spectral Index α~-2 : steep

Conclusions

- EVLA will enable the definitive detection of the thermal radio emission from the atmospheres of main sequence stars for the first time.

- Broadband spectra of individual active stars should establish the various mechanisms at work in non-thermal and thermal radio coronae.

- Combining radio observations with Zeeman Doppler Imaging is a powerful method for diagnostics of stellar coronae.

- The study of ultracool dwarf pulsars indicates the presence of planet-like behaviour at the lower end of the main sequence.

Acknowledgements

Joe McMullin, Michael Rupen and all the staff at the NRAO.

The RSRO 10B-209 team: Gregg Hallinan, Michael Rupen, Stephen Bourke, Rachel Osten, Gerry Doyle, Atoaneta Antonova, Gibor Basri, Brent Carlson, Aaron Golden.

The RSRO 10C-210 team: Gregg Hallinan, Michael Rupen, Stephen Bourke, Rachel Osten, Gerry Doyle, Atoaneta Antonova, Aaron Golden.

Optical Observations: Leon Harding, Ray Butler, Richard Boyle, Aaron Golden.

-**ZDI Group:** Julien Morin, J.F. Donati & Moira Jardine