

e-VLBI: Applications for Active Stars and Brown Dwarfs

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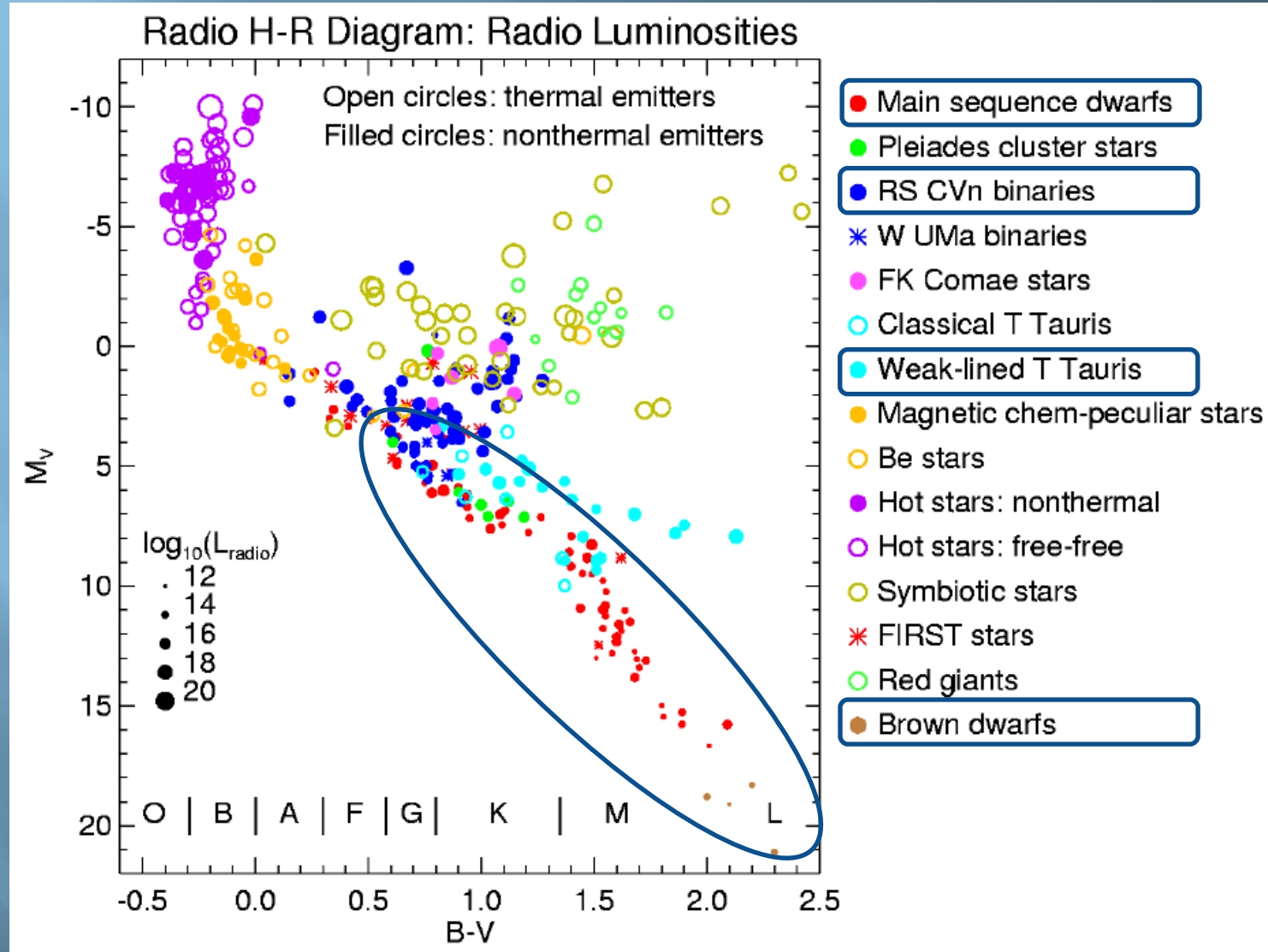


National University of Ireland, Galway
Ollscoil na bÉireann, Gaillimh

e-VLBI Workshop
23rd June 2009



The Radio H-R Diagram



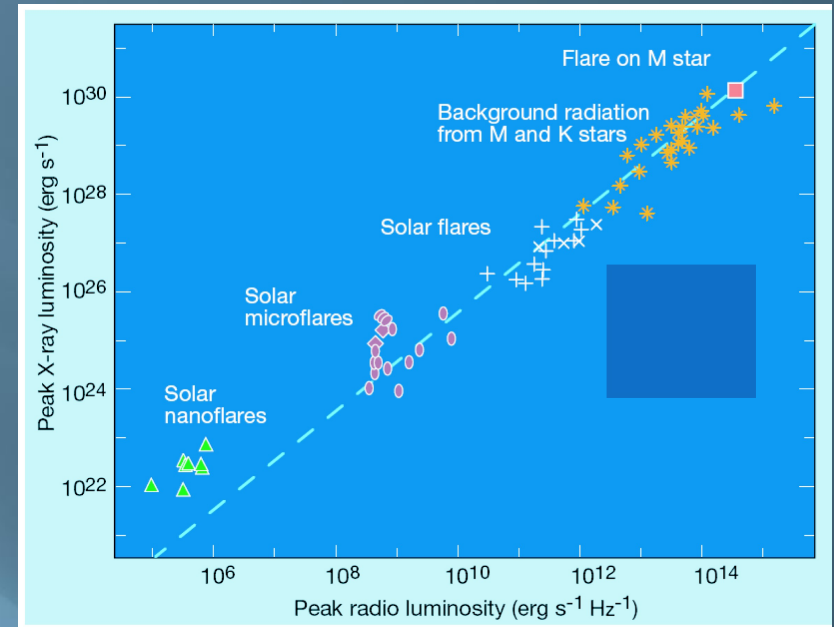
- Non-thermal radio sources are invariably rapidly rotating and strong X-ray sources and hence very active.

- In fact the radio emission and X-ray emission are tightly correlated.

- Similar relationship observed for solar flares.

- Sun -> Bulk of the radio emission due to electrons accelerated during flares producing gyrosynchrotron emission.

- Background radio emission from cool stars due to continuous flaring?



Arnold Benz, Nature (2001)



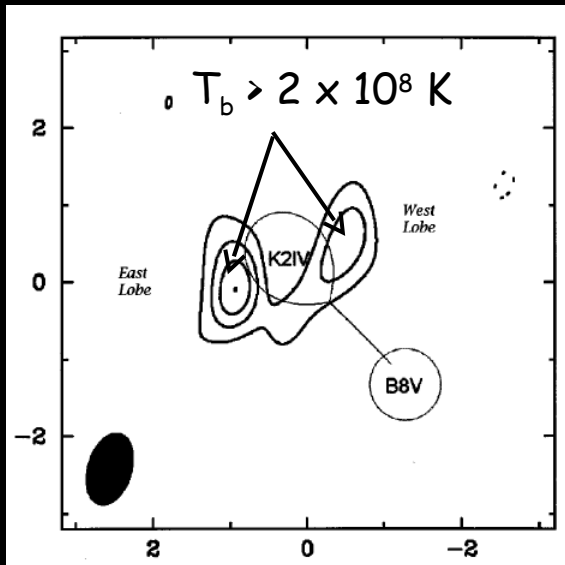
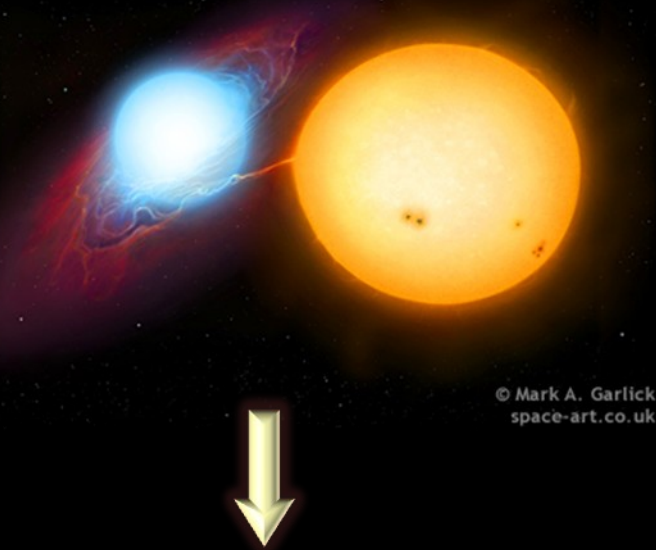
Credit: Soho

Tight Binaries

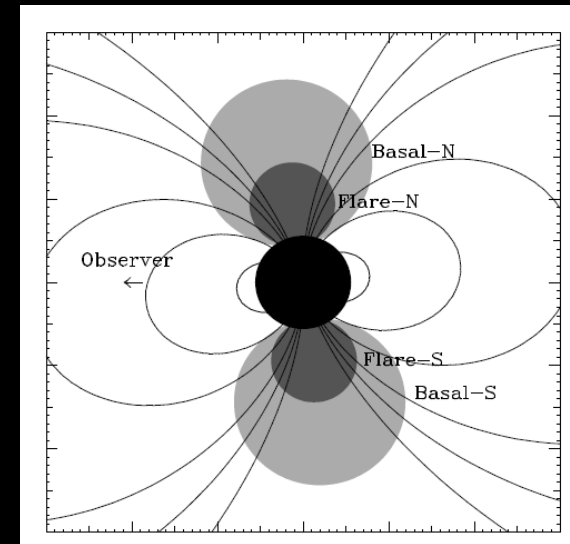
Algol...

Primary -> B type main sequence star

Secondary -> Lower mass K type subgiant



Mutel et al. (1998)



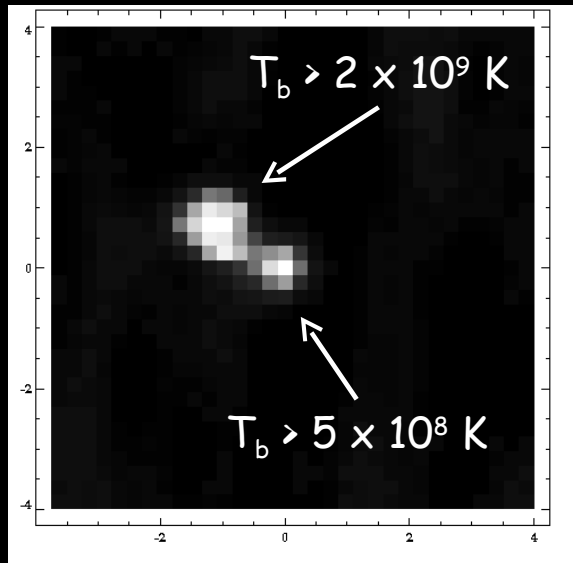
dMe Flare Stars



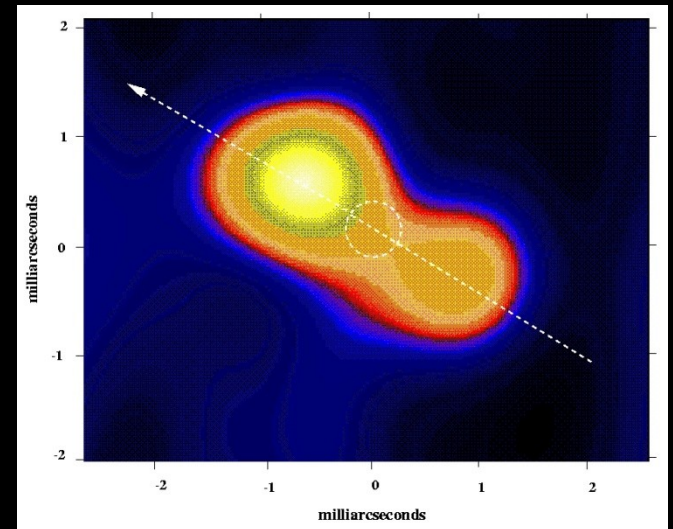
UV Ceti B...

The archetypal flare star

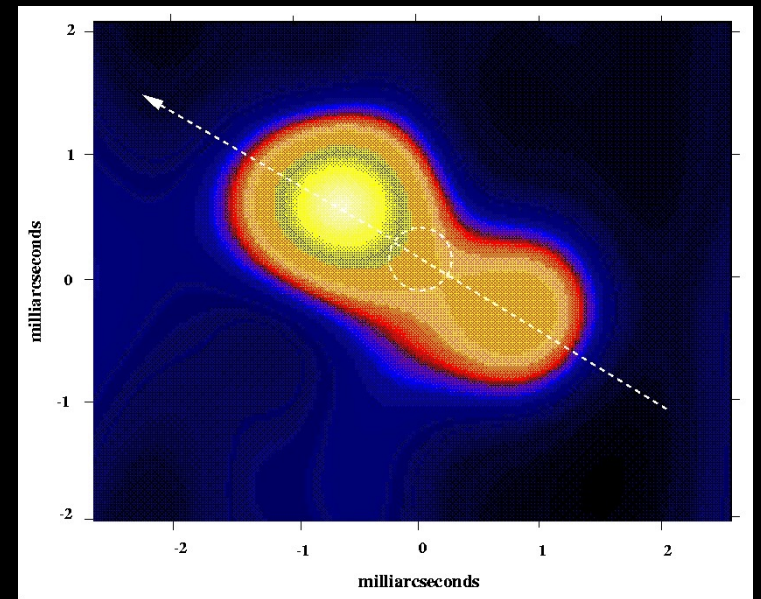
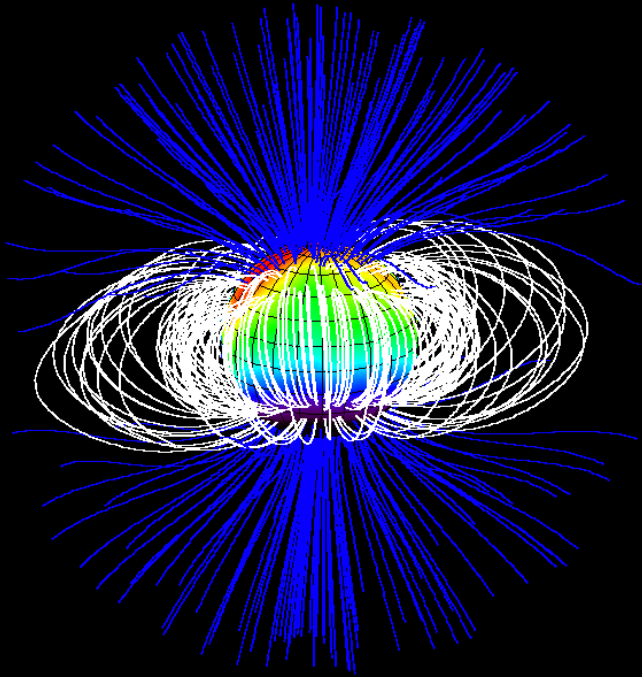
M5.5



Benz, Conway and
Gudel (1998)

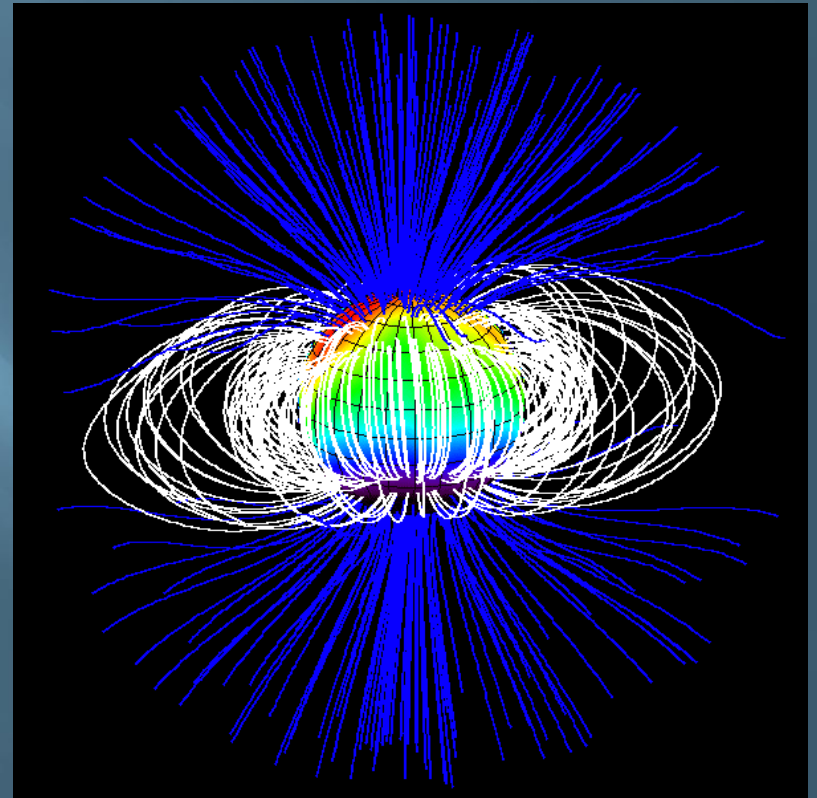


The Future: Simultaneous e-VLBI and Zeeman Doppler Imaging

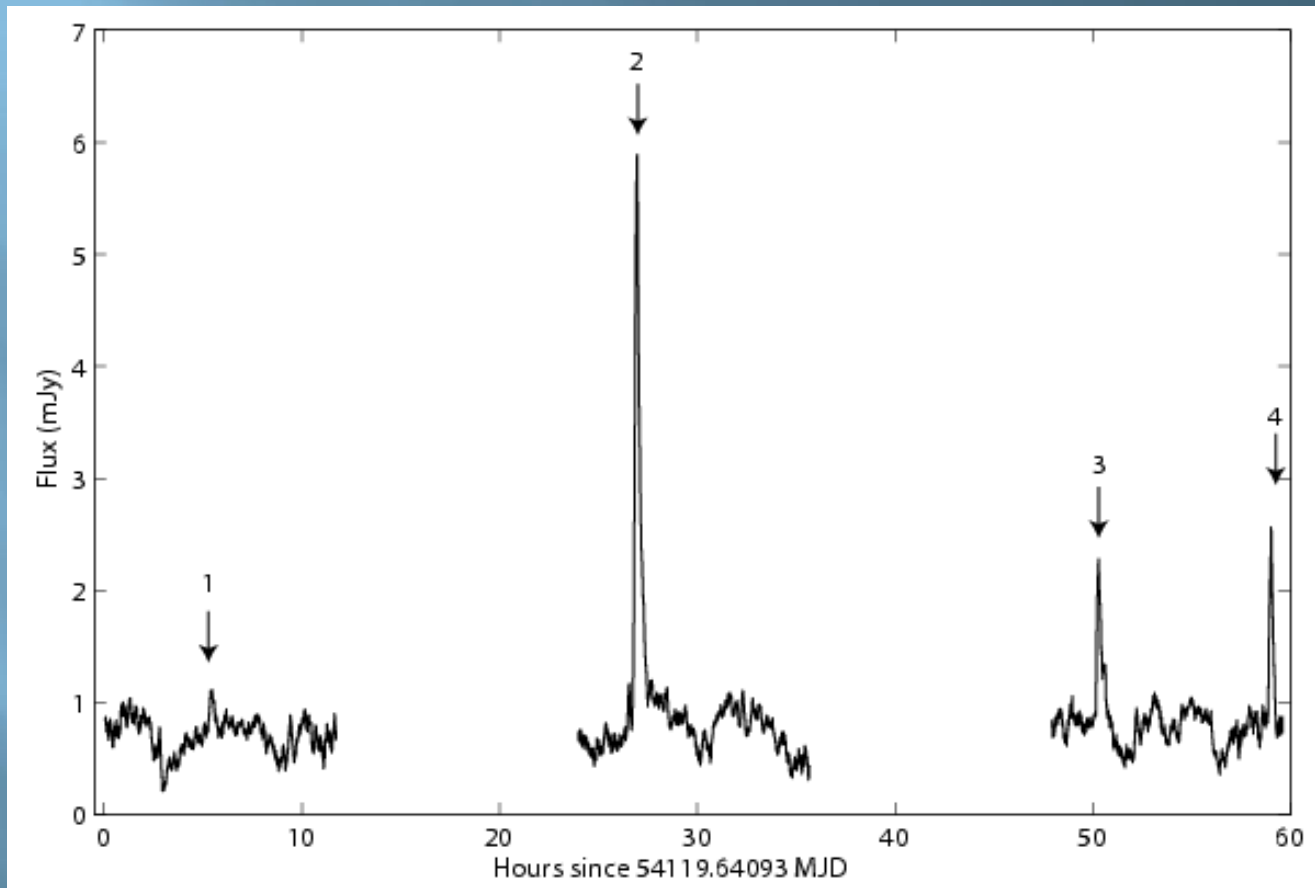


Radio Corona of V374 Peg

- V374 Peg....
- Rapidly rotating flare star ✓
- Saturated X-ray and H α emission ✓
- Correlated X-ray and Radio Luminosities ✓
- Observed for 3 nights with the VLA...
- Most importantly, ZDI data allows correlation of the radio light curve to the orientation of the large-scale magnetic field.
- Work done in collaboration with Moira Jardine, J.F. Donati & Julien Morin.

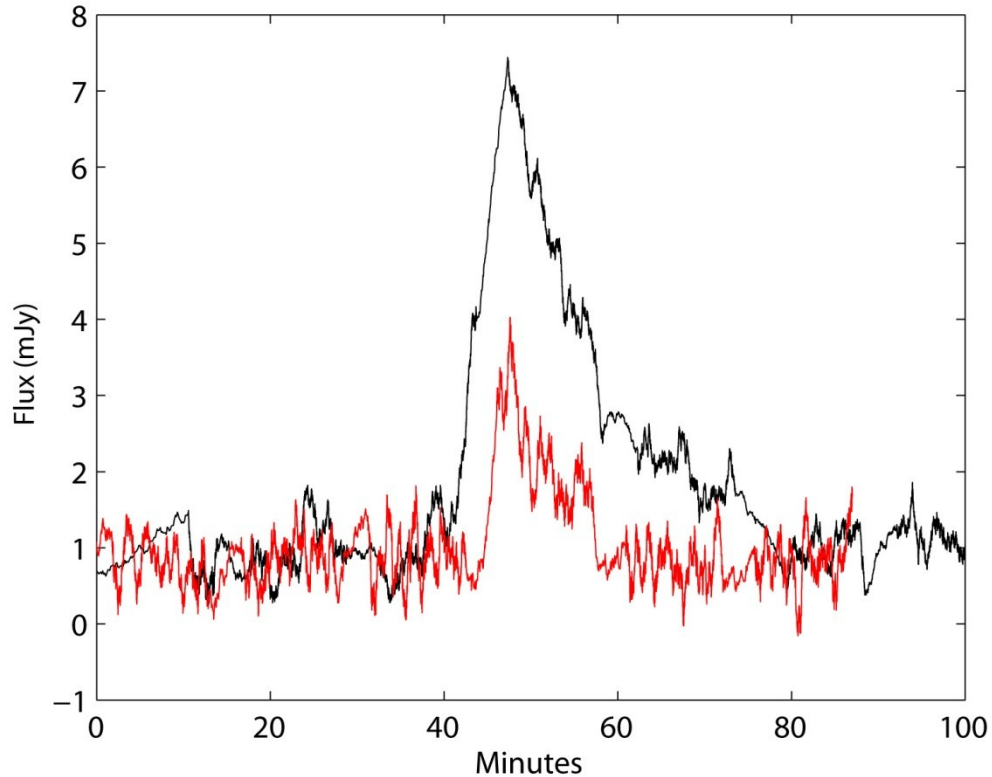


Radio Corona of V374 Peg



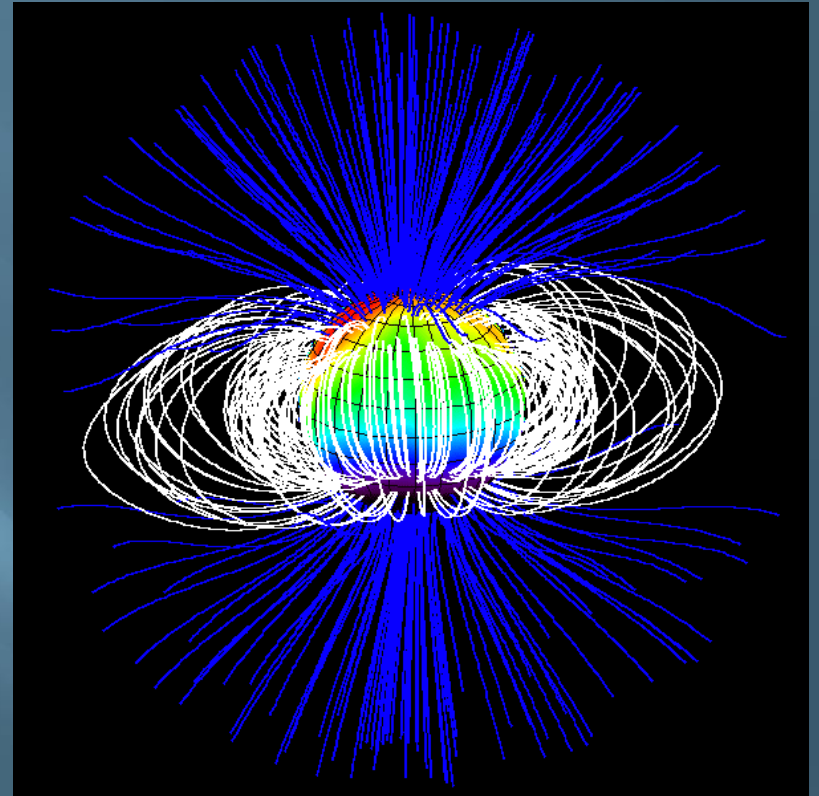
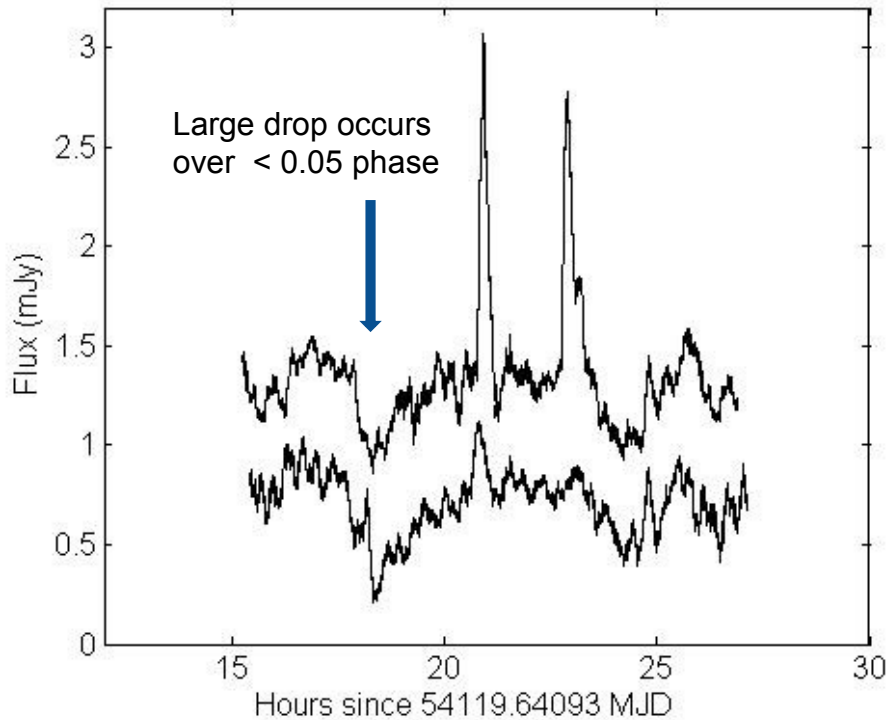
- Both quiescent emission and 'flares' detected.

Radio Corona of V374 Peg

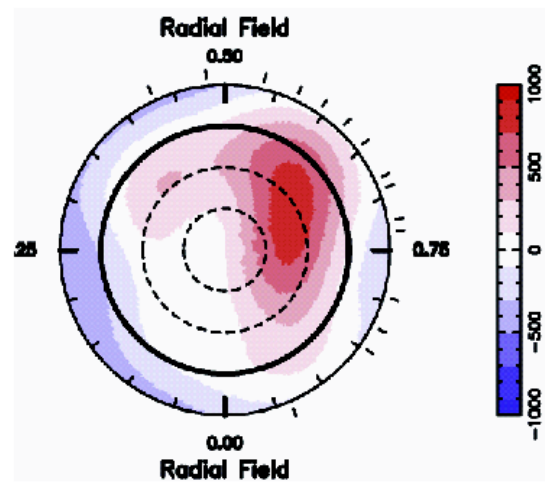
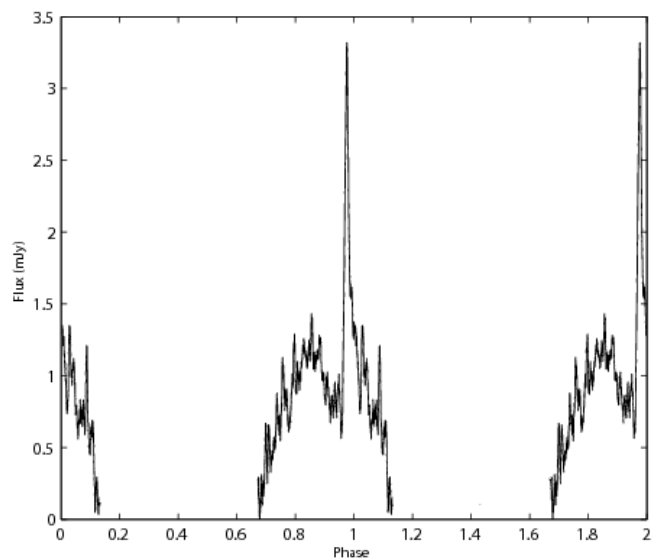
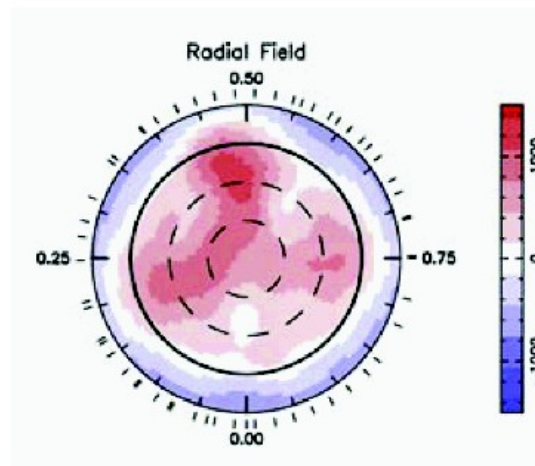
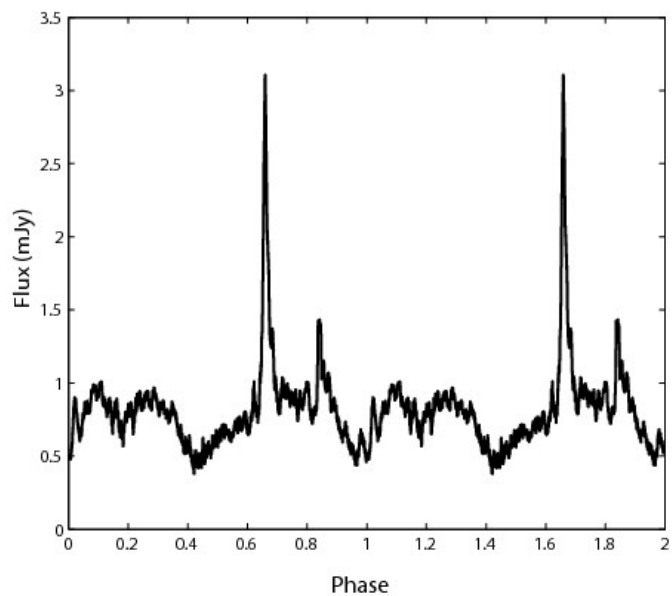


- The 'flares' are periodic, therefore not flares but pulses.
- Notably, the pulses are unpolarized -> indistinguishable from incoherent flares.

Radio Corona of V374 Peg

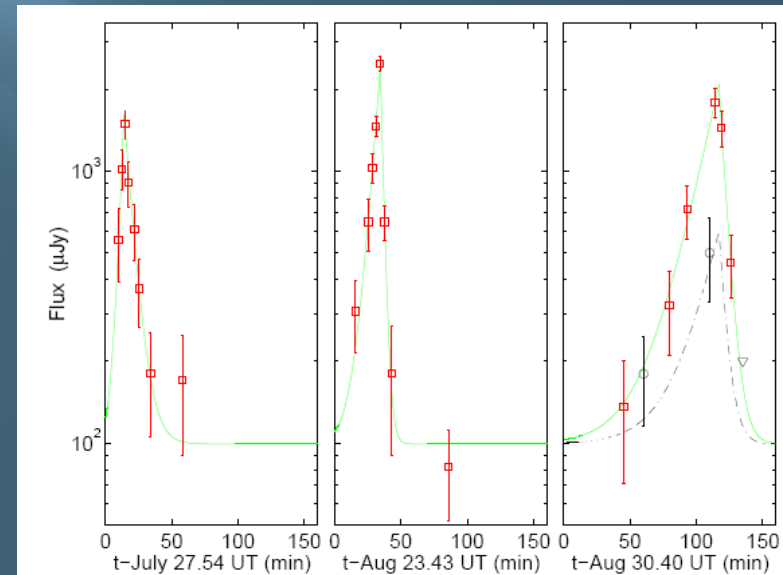


- Quiescent emission is strongly periodic with rotation of the dwarf.
- Two peaks per period if rotation when the large-scale magnetic field is perpendicular to our line of sight.



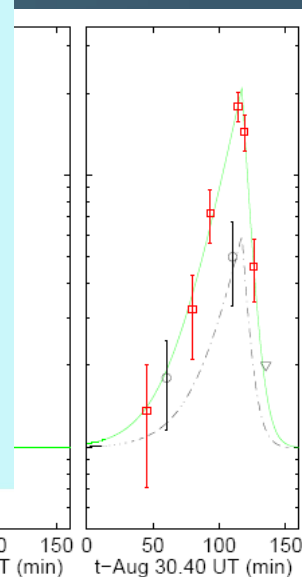
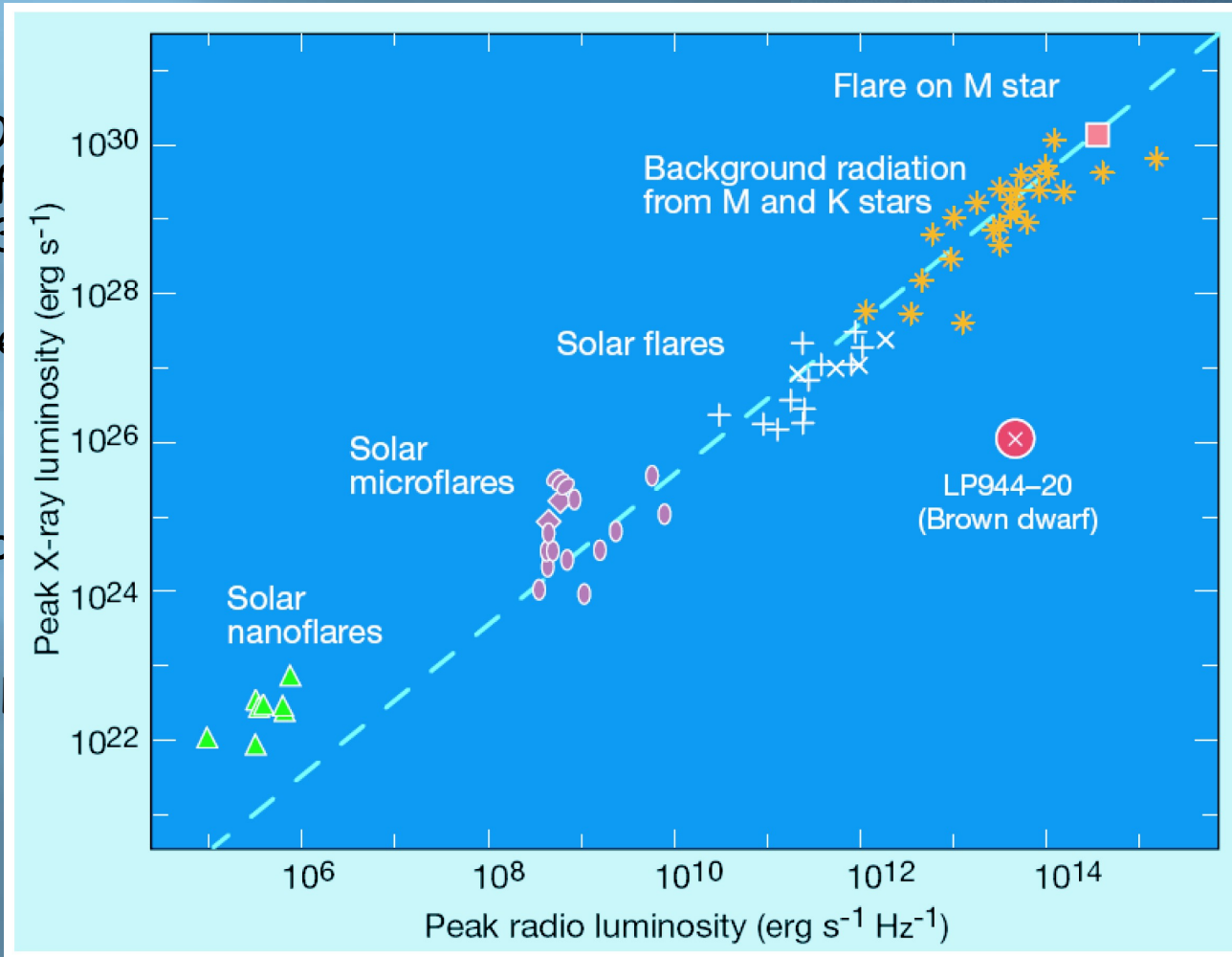
First Radio Brown Dwarf : LP 944-20

- NRAO Summer School at the VLA, Class of 2000 -> Berger et al. *Nature* 410, 338-340 (2001)
- Further detections followed.
- What mechanism produces this anomalous radio emission?
- Same as that detected from coronally active stars?



First Radio Brown Dwarf : LP 944-20

- NRAO Class of 410, 33
- Further
- What anomalous
- Same coronal



0 50 100 150 0 50 100 150 0 50 100 150
 t-July 27.54 UT (min) t-Aug 23.43 UT (min) t-Aug 30.40 UT (min)

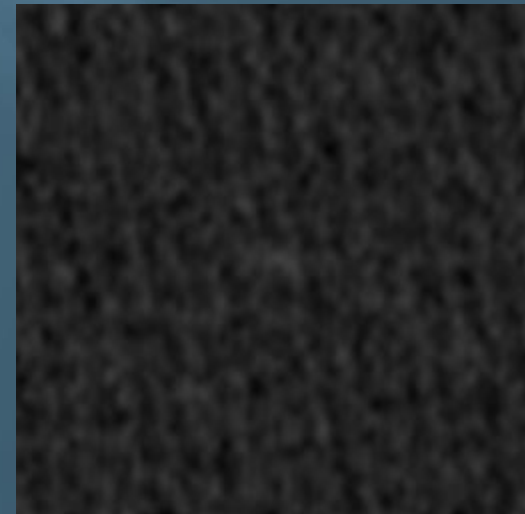
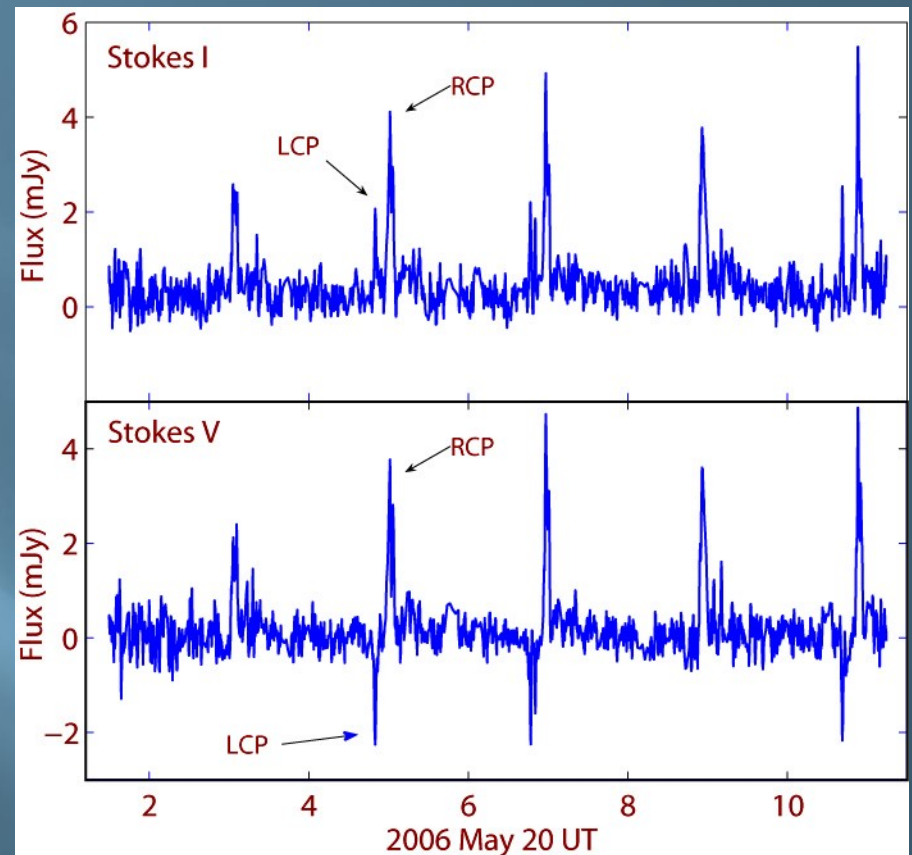
VLA observation of M9 dwarf
TVLM 513-46546

Hallinan et al. ApJ, 663, L25 (2007)

Detection of extremely bright periodic bursts of radio emission (p=1.958 hours).

- 1) Bursts of both left and right 100% circularly polarized emission
- 2) Narrowly beamed
- 3) Brightness temperature $> 2.4 \times 10^{11}$ K

-> Emission is conclusively coherent.



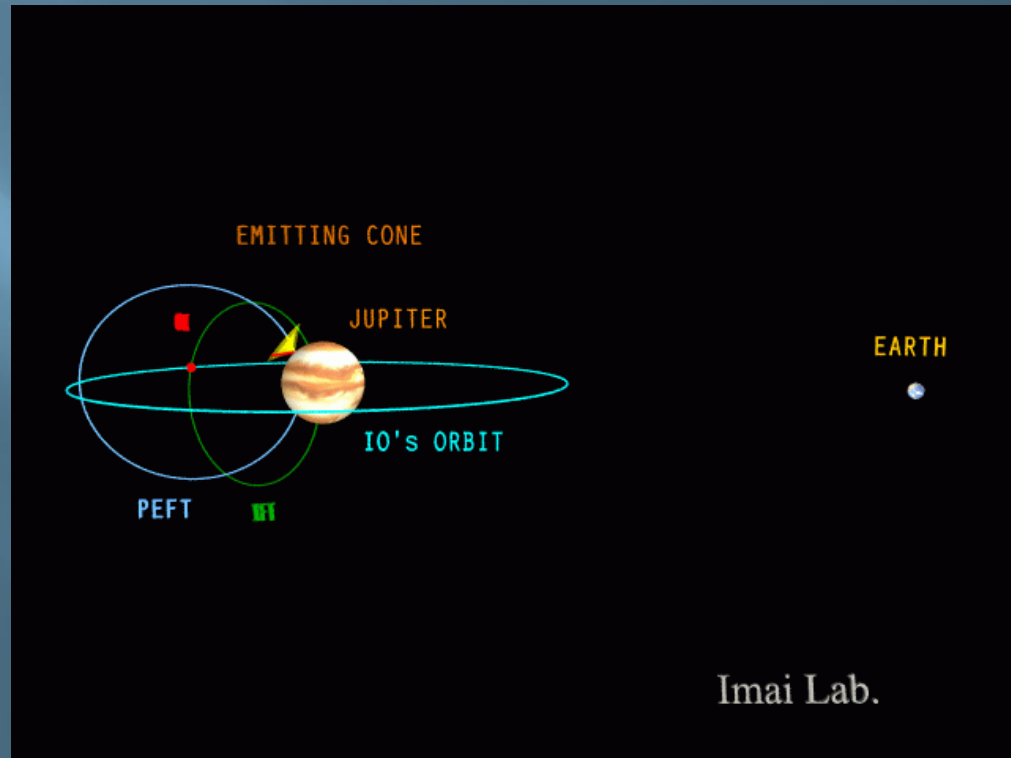
Brown Dwarfs Behave like Planets...

Jupiter produces highly beamed, 100% polarized radio emission.

Can outshine the Sun at low frequencies.

The radio mechanism is the electron cyclotron maser instability.

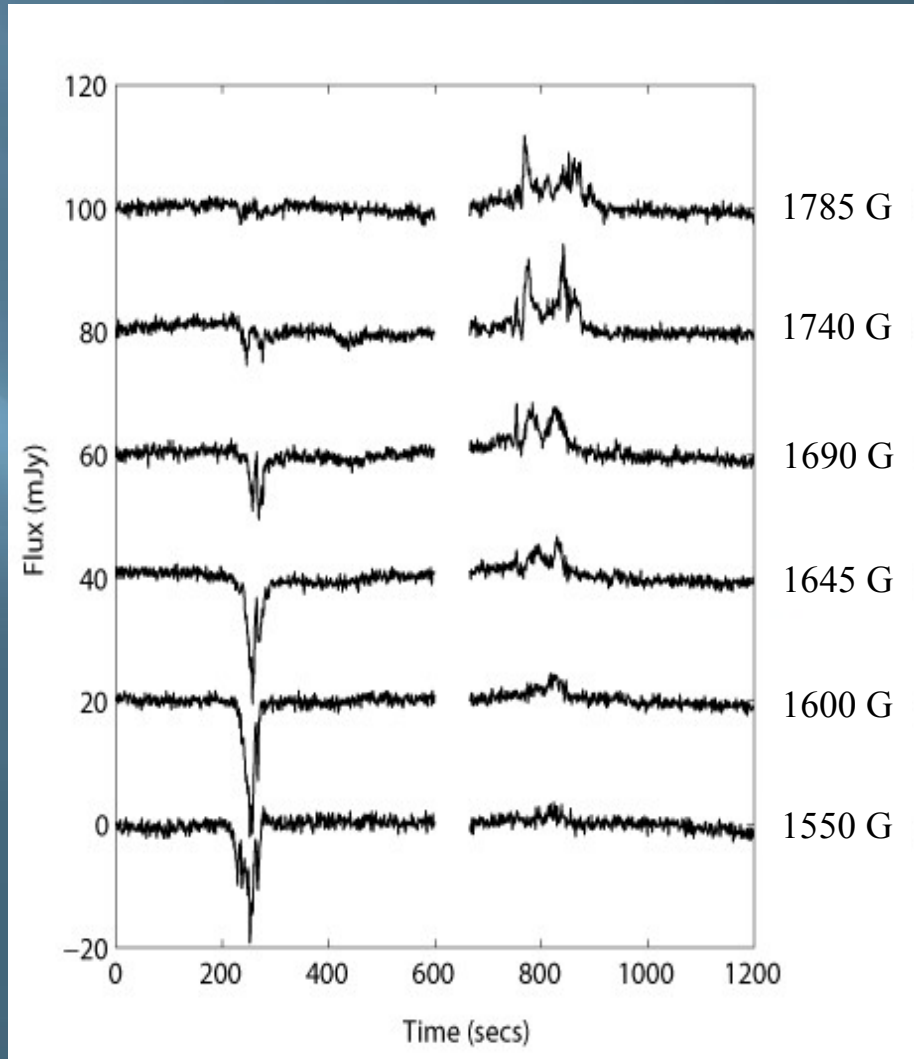
Confirms magnetic fields of 3 kG.



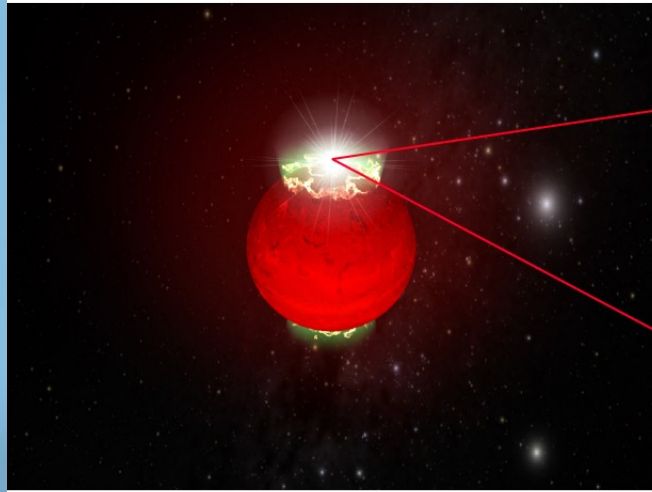
Imai Lab.

Broadband Dynamic Spectra of the Periodic Pulses

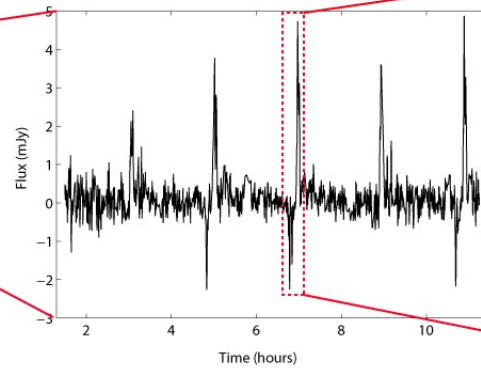
- Pulses detected every night.
- Brightest radio emission yet detected from an ultracool dwarf.
- Brightness temperatures $> 10^{15}$ K
- Double peaked structure to pulses that broadens with increasing frequency.
- Possibly indicative of inverted-V electron distributions associated with field-aligned electric fields.



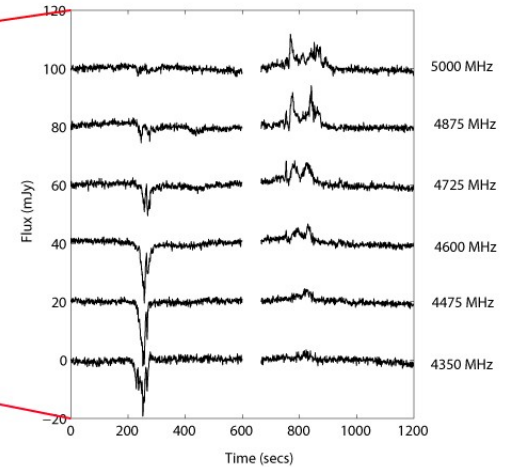
Radio Observations are Ongoing...



Stokes V light curve of TVLM 513 using the VLA in May 2006



Stokes V dynamic spectrum of the the periodic pulse detected from TVLM 513 using Arecibo in May 2008



Why are only a fraction ultracool dwarfs detected in the radio?

Why are only a fraction of dwarfs detected?

3. Correlated with $v \sin i$ - possible factor

May indicate that high rotation velocities are necessary to generate the required high strength magnetic fields.

Our results do indeed show very short rotation periods.

May indicated a geometrical selection effect.

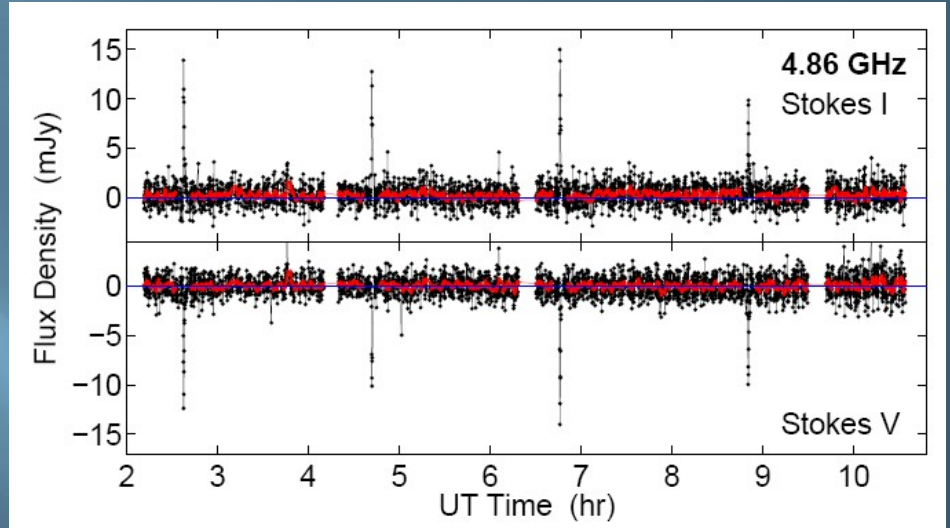
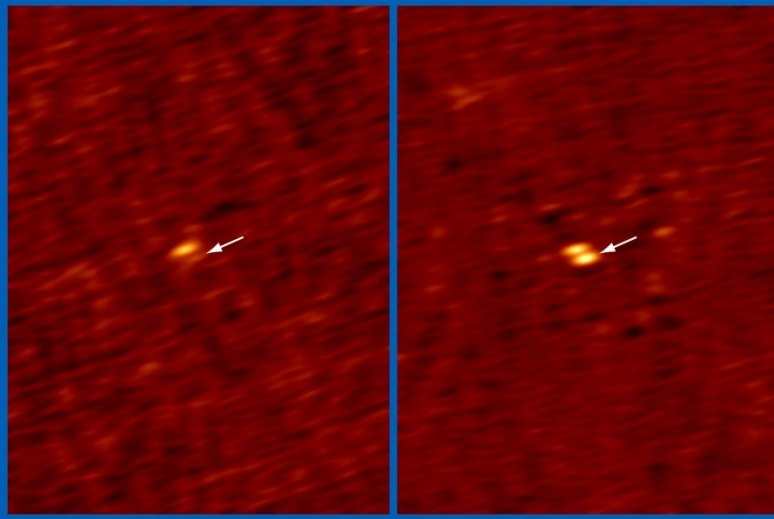
ECM emission is very narrowly beamed.

Our results show very high inclination angles for the axis of rotation.

Table 1. Confirmed Sources of Electron Cyclotron Maser Emission

	TVLM 513-46546	2MASS J00361617+1821104	LSR J1835+3259
Spectral Type	M9	L3.5	M8.5
Distance (pc)	10.6	8.8	5.7
$\log(L_{bol}/L_{\odot})$	-3.59	-3.98	-3.51
Lithium	No	No	?
Est. Mass	0.06 - 0.08	0.06 - 0.074	< 0.083
Est. Age (Gyr)	> 0.4	> 0.8	?
$v \sin i$ (km s ⁻¹)	60	37	50 ± 5
Rotation Period (hours)	1.958	3.08	2.84
Radius (R/R_{\odot})	0.097 - 0.109	0.092 - 0.098	0.105 - 0.129
i (°)	62.5 - 90	70 - 90	~ 90

VLBI observations of Tight Binaries



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

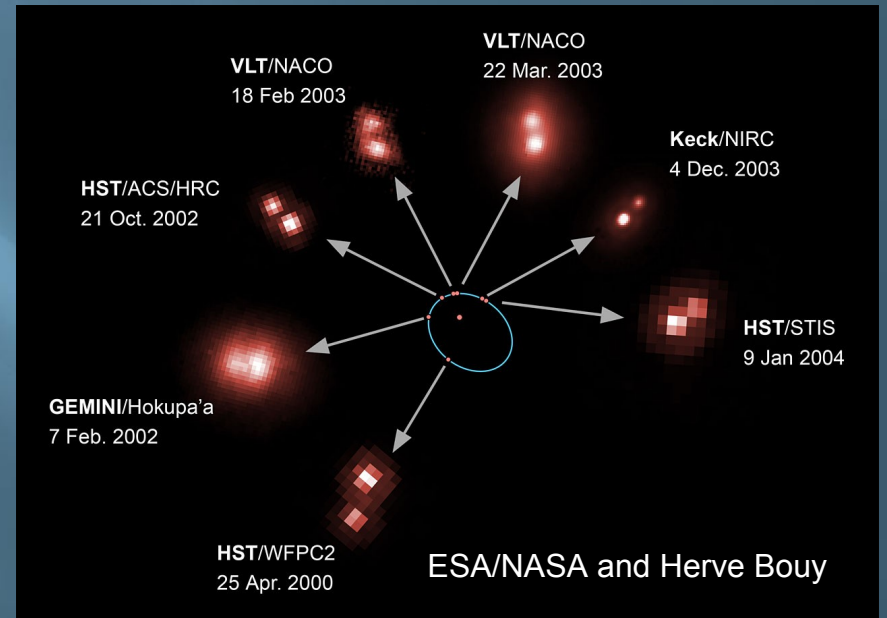
Separation only 0.1 arcsecond!

We need Very Long Baseline Interferometry (VLBI).

What if we detect both dwarfs?

If both brown dwarfs in a single tight binary, the potential is there for a new kind of VLBI campaign.

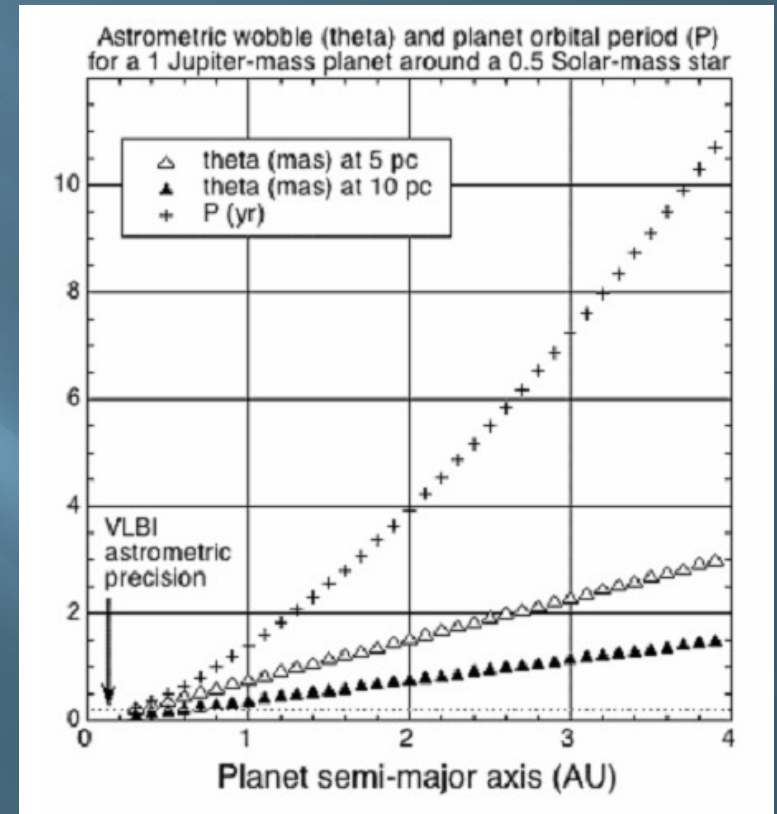
Dynamical mass measurement of brown dwarfs is a very active field, as the degeneracy in the mass-luminosity relationship or brown dwarfs makes it difficult to pin down their physical properties.



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

RIPL: Radio Interferometric Planet Search

- Opportunity to discover planets around nearby active M dwarfs at large radii;
- Ability to fully characterize orbits of detected planets
- Sensitivity to long-period planets with sub-Jovian masses;
- Complementary with existing planet searching techniques



Bower et al...

<http://astro.berkeley.edu/~gbower/RIPL/>

- Guirado et al. 1997:
 - dedicated pre-Hipparcos VLBI study of pre main sequence star, AB Doradus solved for the accurate distance
 - also detected AB Dor C for the first time
 - subsequently confirmed in infrared observations

