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ARC CENTRE OF EXCELLENCE FOR ALL-SKY ASTROPHYSICS

Chasing Low Frequency Radio Bursts from Magnetically Active Stars

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+ MWA Transients Collaboration

THE UNIVERSITY OF SYDNEY

MWA MURCHISON WIDEFIELD ARRAY

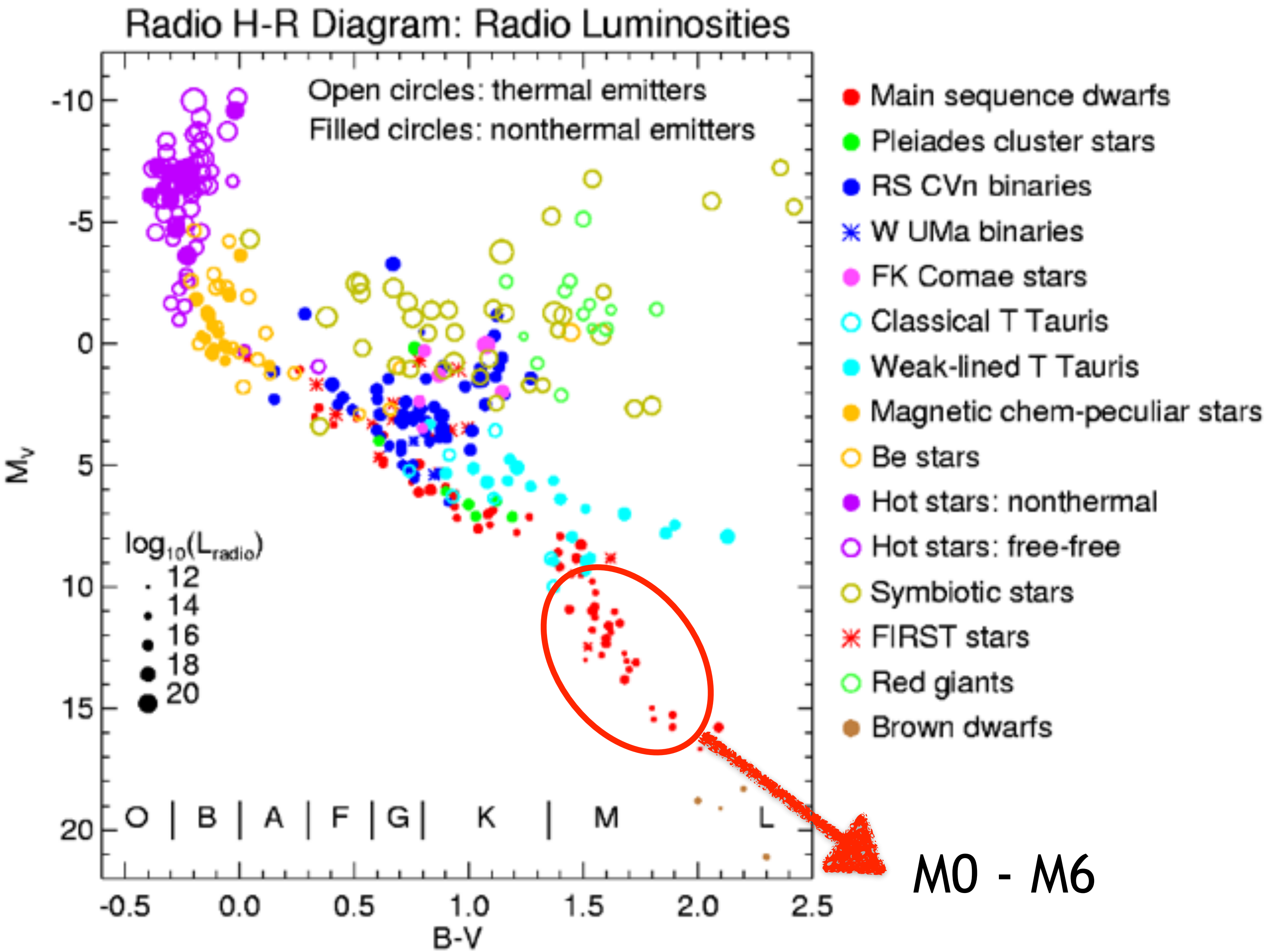
Stellar Flares:

Flaring is a common characteristic of magnetically active stars.

Observations of stellar flares:

- Provide constraints on stellar magnetic properties
- Solar - Stellar connection
- Habitability of discovered exoplanets

https://blogs.stsci.edu/universe/2015/11/15/follow-the-photons-to-understand-the-effects-of-stellar-flares/



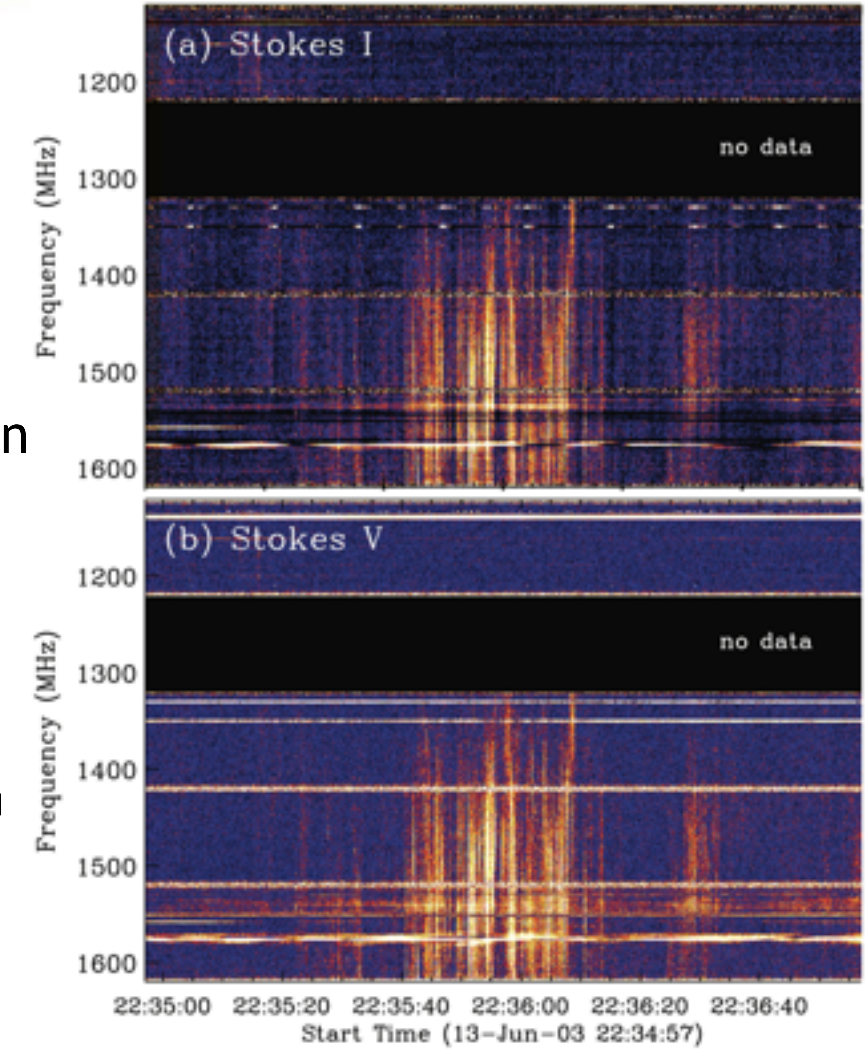
Radio H-R Diagram: Radio Luminosities
Open circles: thermal emitters
Filled circles: nonthermal emitters
Main sequence dwarfs
Pleiades cluster stars
RS CVn binaries
W UMa binaries
FK Comae stars
Classical T Tauris
Weak-lined T Tauris
Magnetic chem-peculiar stars
Be stars
Hot stars: nonthermal
Hot stars: free-free
Symbiotic stars
FIRST stars
Red giants
Brown dwarfs
$\log_{10}(L_{radio})$
12
14
16
18
20
O | B | A | F | G | K | M L
M_V
-10
-5
0
5
10
15
20
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
B-V
M0 - M6

1 & 5 GHz Flares

Radio emission dominated by coherent emission:

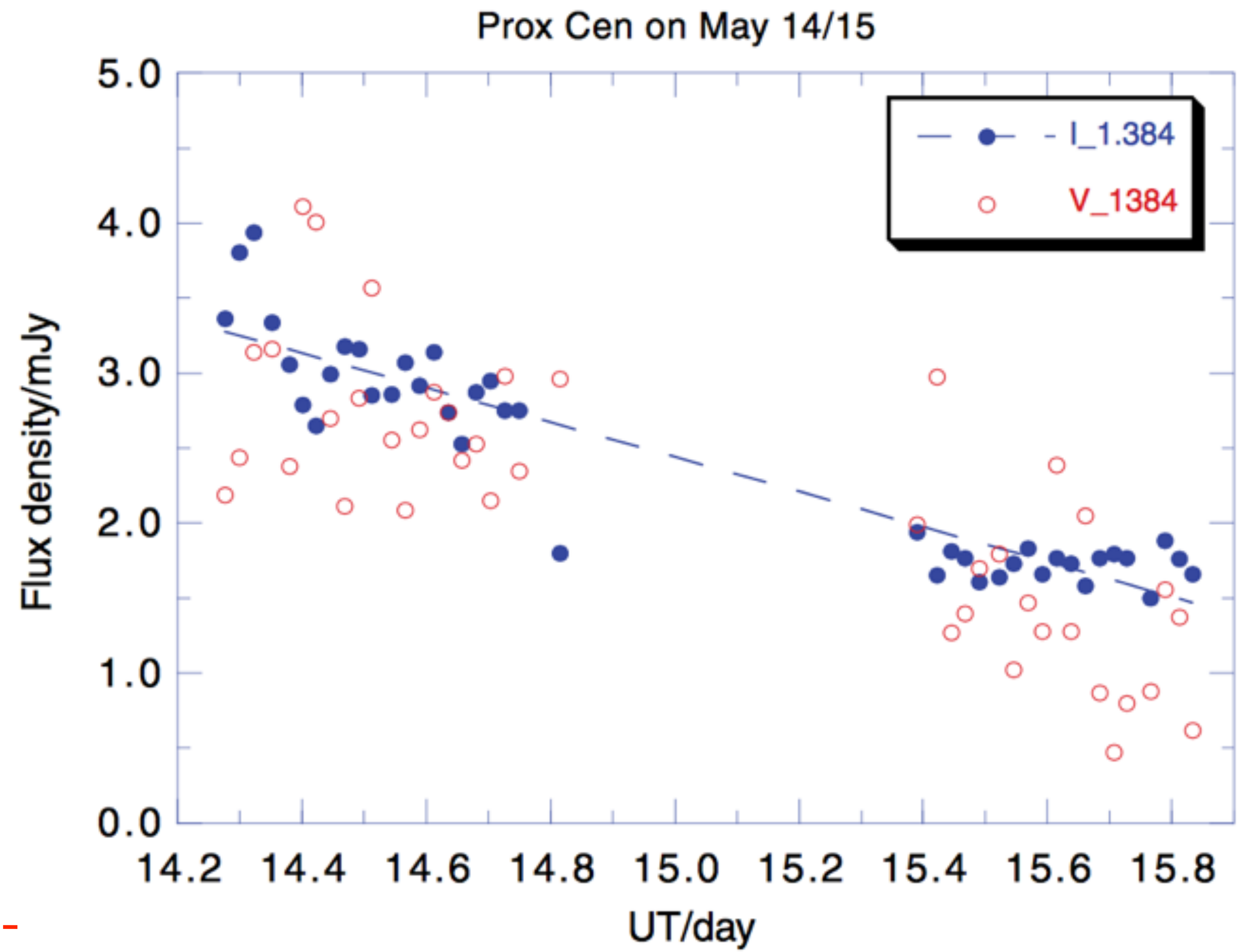
- Duration = ~x10 seconds – x10s minutes (Proxima Cen outlier)
- Intensities = 0.3 - 600 mJy
- High fractional circular polarisation (>70%)
- milli-sec time structure

White et al. (1989) find 40% of flare stars within 10 pc exhibit GHz emission (likely due to flares).



Osten et al. 2006

Slee et al. 2003



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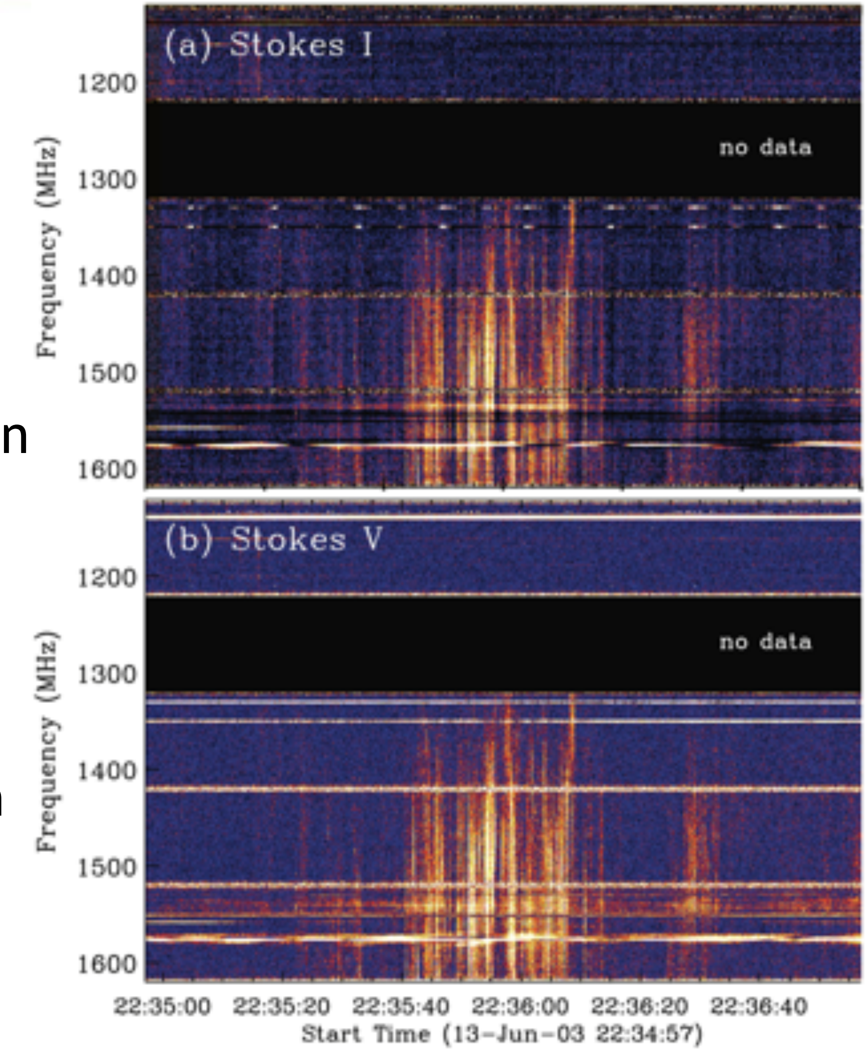
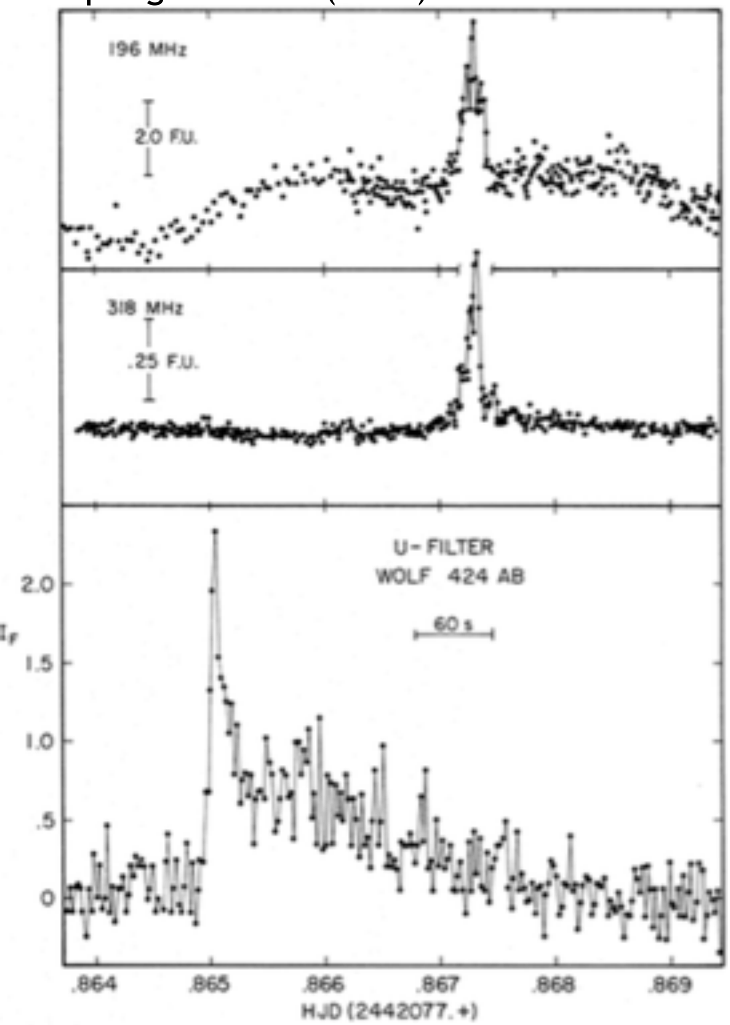


Osten et al. 2006

MHz Flares

Spangler et al. (1976)



Early single dish observations (1960’s - 1980’s) measured:

- Flare rates = 0.03 - 0.8 flares/hour
- Duration = 0.5 - 3 hours
- Intensities = 0.8 - 20 Jy
- High fractional circular polarisation (>70%)

Interferometric detections of YZ CMi at 408 MHz:

1. Davis et al. (1978, Nature)
2. Kundu et al. (1988, ApJ)

Total number of sources with MHz emission = 11

Coherent Emission Types:

1. **Electron Cyclotron Maser**
   - Emitted at local cyclotron frequency:

     $\nu_c \sim 2.8$ MHz (B_{Gauss}) → Constrain B-field

   - Confirmed emission mechanism for radio bursts of brown dwarfs + Solar System planets.
   - Possibly responsible for Solar spike bursts (Melrose et al. 1982, 2016)

2. **Plasma Emission**
   - Emitted at local plasma frequency:

     $\nu_p \sim 9.0$ kHz $(n_{cm^{-3}})^{1/2}$ → Constrain Density

   - Different types of Solar flares due to plasma emission

Murchison Widefield Array

Frequency range = 80 - 300 MHz

Field of view (@150 MHz) = 600 sq. deg

Bandwidth = 30 MHz

Max baseline = 3 km (original)
1km/5 km (2017)

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Murchison Widefield Array

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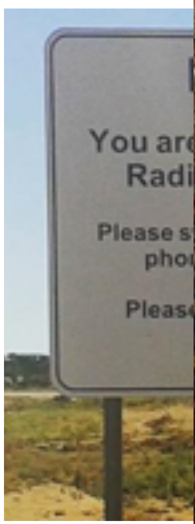

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Recent Surveys for Transients

Non-detections in long-duration, widefield surveys for transients:

- Tingay et al. (2016): Kepler K2 field, 5.9 hours, 5σ ~ 0.5 Jy
- Rowlinson et al. (2016): 100 hrs of MWA EoR field, 5σ ~ 0.235 Jy

➡ 2375 M dwarfs within 25 pc expected (Winters et al. 2015)

➡ 70 nearby M dwarf stars per MWA pointing

➡ < 2% have 100 - 200 MHz flare emission

Where are all the flare stars?

MWA Observations

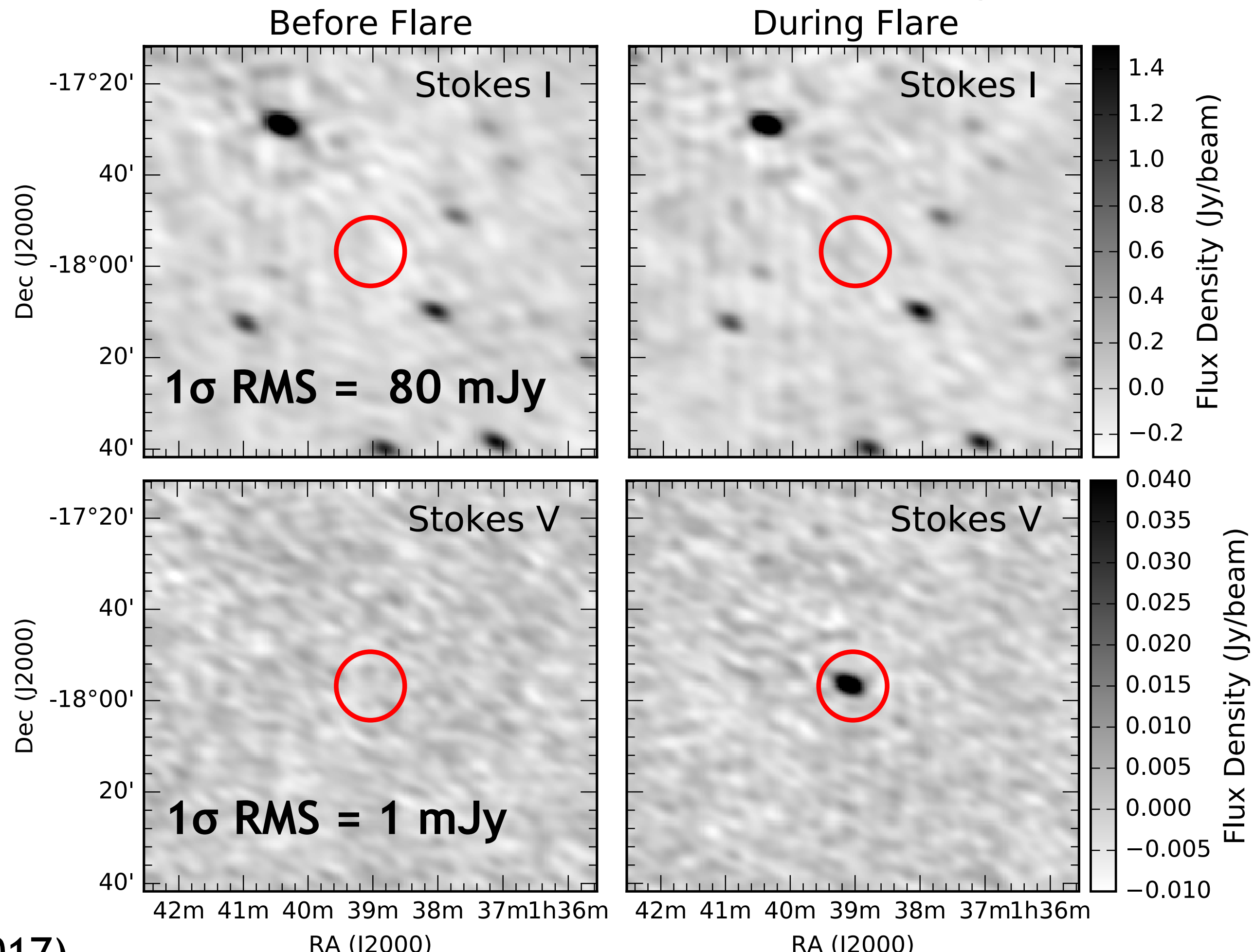
UV Ceti:

- Binary system w/ 26 yr period — both exhibit radio flares
- Spectral types = M5.5 (BL Cet) + M6 (UV Cet)
- BL Cet P=5.86 hr; UV Cet P= 5.45 hr
- Distance = 2.7 pc

- Total observation time = 8.8 hours — split over 4 days in Dec 2015
- Frequency = 154 MHz
- Focus in Stokes V (circular polarisation)

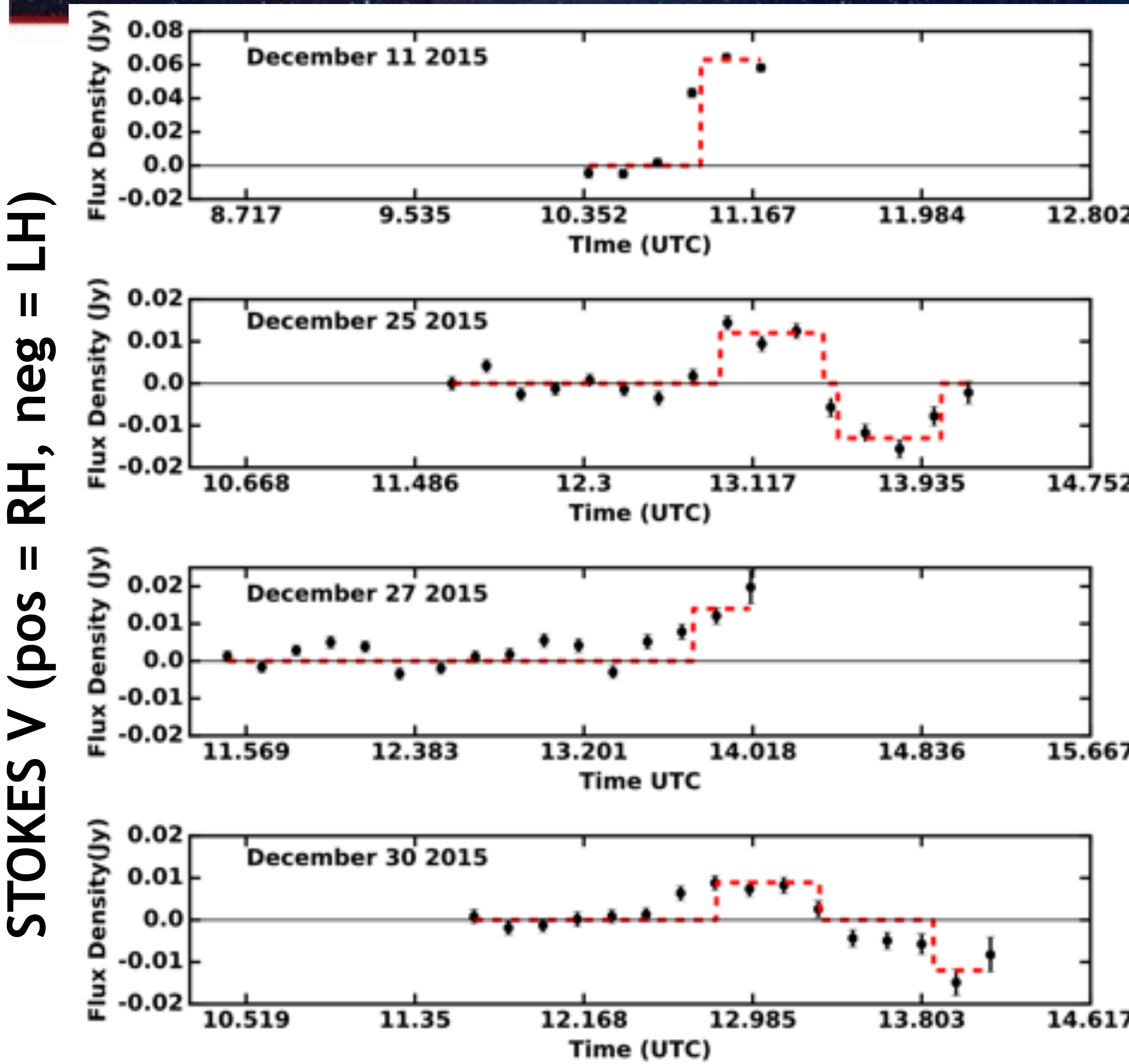
Detection of UV Ceti

December 11 2015: 30 min integrations



Lynch et al. (2017)

Light-curve analysis



PERIODICITY:

- P ~ 5.45 hrs (95% confidence)

Lynch et al. (2017)

Emission Type?

Brightness Temperature: $$S_\nu = 2k_B T_b \left(\frac{\nu}{c}\right)^2 \left(\frac{l}{d}\right)^2$$

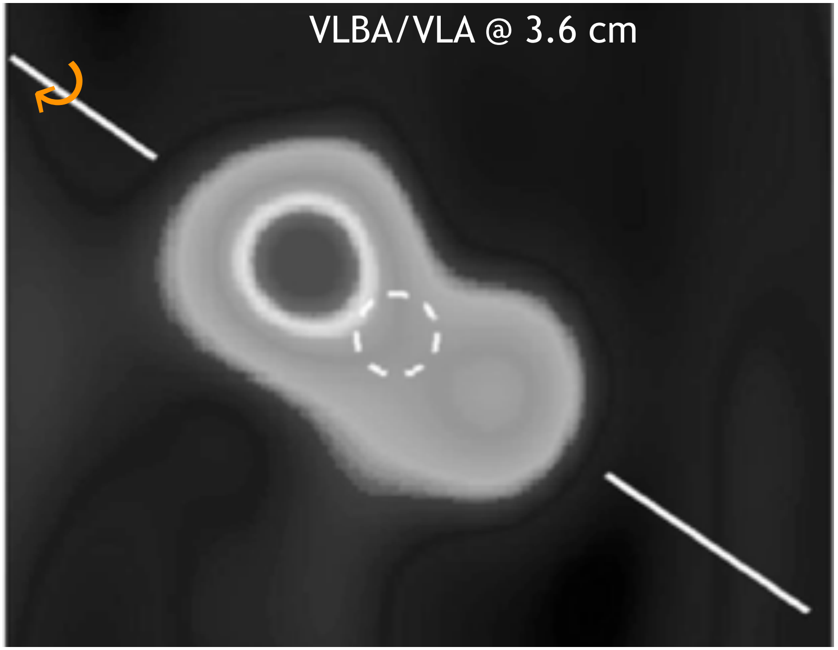
A. Source size constrained by assuming periodic persistent source:

- $l = \Delta t\ v\sin(i) \sim 10^9$ cm
- $T_b \sim 10^{14}$ K

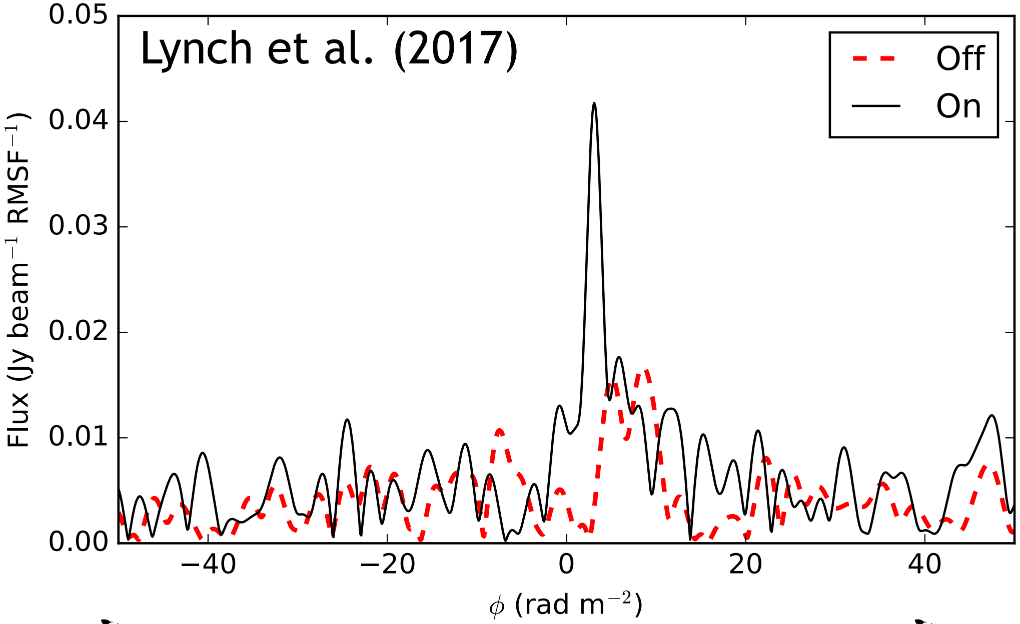
B. Source size constrained by VLBA:

- $l \sim 10^{10}$ cm ($\sim 0.14\ R_\odot$)
- $T_b \sim 10^{13}$ K

Benz et al. 1998



Emission Type?



Polarisation:

A. Circular: Both right & left handed; >27%

B. Linear: >18%; ϕ = + 3 rad m^{-2}; Faraday rotation ~12 rad

→ **Elliptically Polarised** → **Electron cyclotron maser**

ν_{obs} = (B) 2.8 MHz → B = 28 G

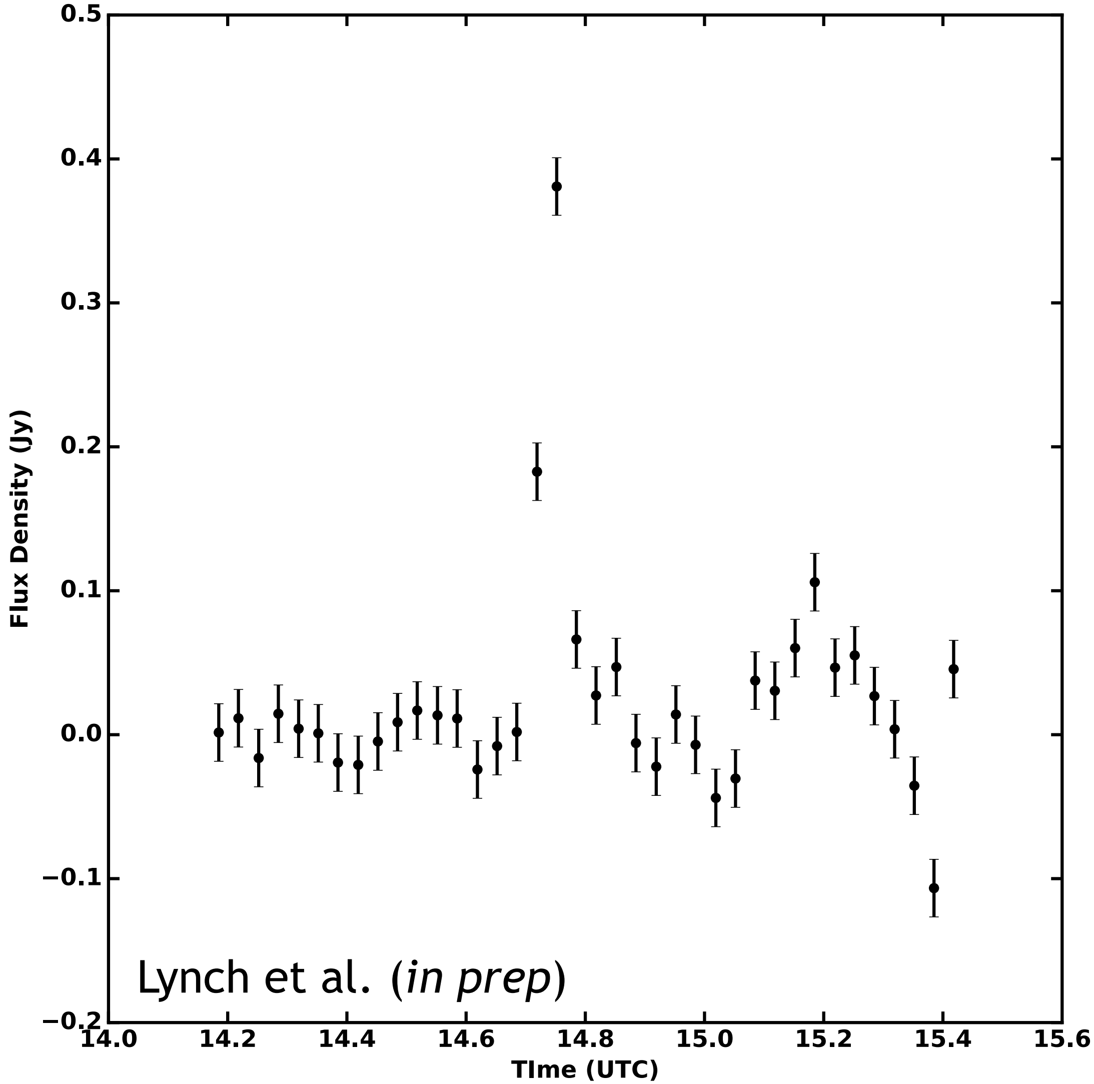
$\nu_{pe}^2/\nu_{ce}^2 << 1$ → $n_e \lesssim 7 \times 10^7$ cm^{-3}

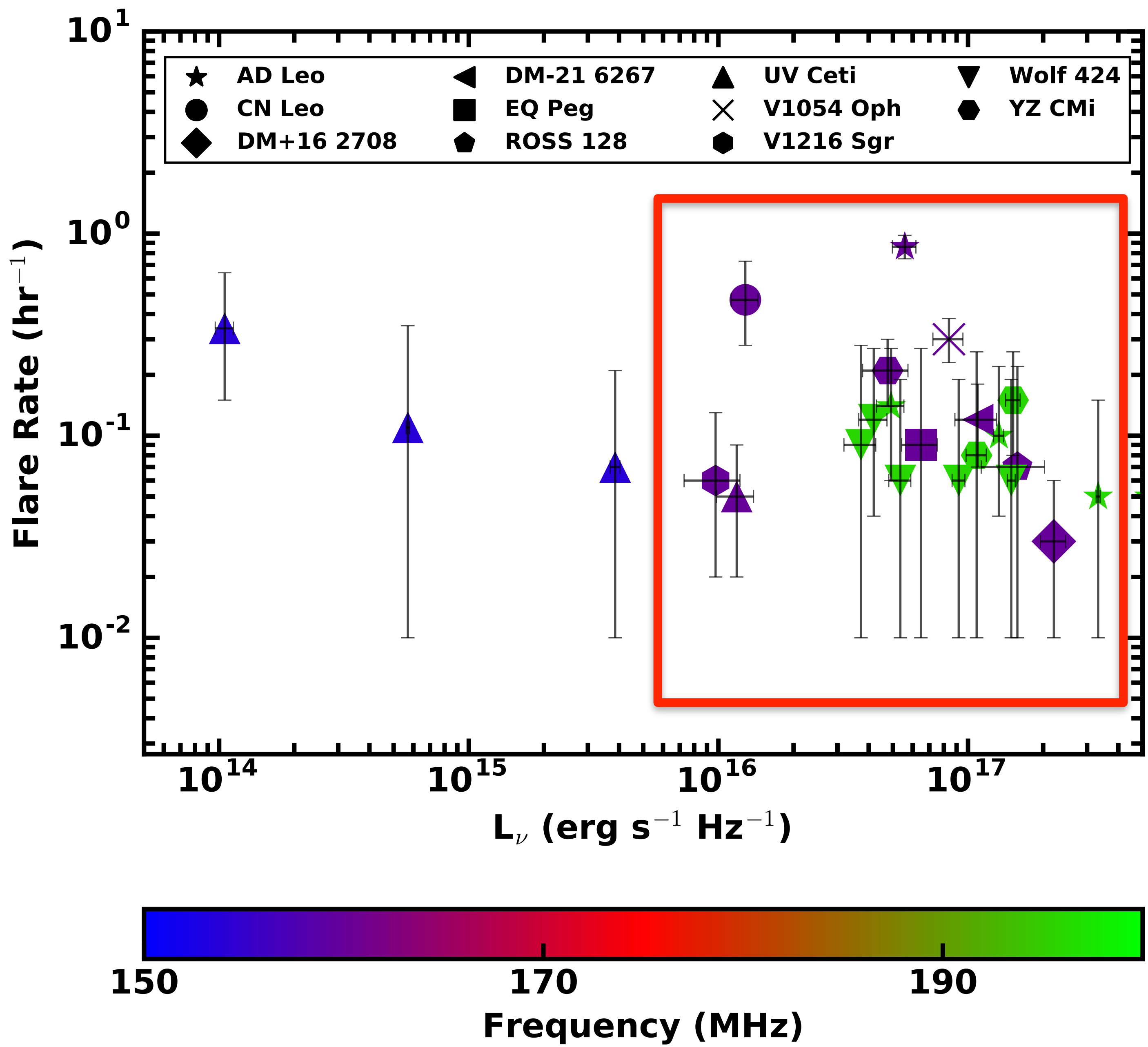
Follow up @150 MHz

15 hours follow-up observations of UV Ceti:

- 5σ sensitivity ~ 0.1 Jy
- Detect single flare
- S~ 0.4 Jy (7x brighter); lasts ~4 min

Preliminary!





Modified from Lynch et al. (2017)

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Summary:

1. The radio emission at frequencies < 5GHz is dominated by coherent bursts for flare stars of spectral type M. Radio properties can inform magnetic field studies.

2. Previous flare rates/intensities indicate that 100 - 200 MHz M dwarf flares should be easy to detect — blind surveys do not find the expected flares.

3. Targeted observation of UV Ceti reveal:
   - Low-intensity, periodic flares (30 min) — electron cyclotron maser
   - Bright, short duration flare >> **similar flares would be detectable within Rowlinson et al. (2016)!**

4. Flare distribution not well constrained — need more detections

Future Observing :

1. Current low-frequency interferometers (e.g. MWA, GMRT etc.) undergoing upgrades to be completed within 2018.

2. Coming online in 2018, two ~1 GHz telescopes: MeerKAT (900 - 1670 MHz, 2.7 sq. deg) + ASKAP (700 - 1800 MHz, 30 sq. deg).

3. SKA telescopes begin early science 2020.