Chasing Low Frequency Radio Bursts from Magnetically Active Stars

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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

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


MHz Flares

Interferometric detections of YZ CMi at 408 MHz:
1. Davis et al. (1978, Nature)

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

Total number of sources with MHz emission = 11
Coherent Emission Types

1. Electron Cyclotron Maser
   - Emitted at local cyclotron frequency:
     \[ \nu_c \sim 2.8 \text{ MHz (B}_{\text{Gauss}}) \rightarrow \text{Constrain B-field} \]
   - 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:
     \[ \nu_p \sim 9.0 \text{ kHz } (n_{\text{cm}^{-3}})^{1/2} \rightarrow \text{Constrain Density} \]
   - Different types of Solar flares due to plasma emission
Recent Surveys for Transients

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

- Tingay et al. (2016 ApJ 152): Kepler K2 field, 5.9 hours, $5\sigma \sim 0.5$ Jy
- Rowlinson et al. (2016 MNRAS 458): 100 hrs of MWA EoR field, $5\sigma \sim 0.235$ 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?

Try targeted observations to assess behaviour
Field of view ~ 600 sq. deg

Frequency range = 80-300 MHz
- radio stations & cell phones

Telescope noise not thermally dominated in total intensity (confusion limited).
GJ 65 AB:

- Binary system w/ 26 yr period
- 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

Before Flare

Stokes I

$1\sigma$ RMS = 80 mJy

During Flare

Stokes I

$1\sigma$ RMS = 1 mJy

Lynch et al. (2017 ApJL 836)
Light-curve analysis

PERIODICITY:

- P ~ 5.45 hrs (95% confidence)

Lynch et al. (2017 ApJL 836)
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 A&A 331)
Emission Type?

Polarisation:
A. Circular: Both right & left handed; >27%
B. Linear: >18%; $\phi = + 3 \text{ rad m}^{-2}$; Faraday rotation $\sim 12 \text{ rad}$

→ Elliptically Polarised → Electron cyclotron maser

$\nu_{\text{obs}} = (B)$ 2.8 MHz → $B = 28 \text{ G}$

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

Lynch et al. (2017 ApJL 836)
Further Observations @ 154 MHz

UV Ceti:

1. Dec 2016: 13.7 hours of observation (Hex)
   - $5\sigma \sim 0.1$ Jy
   - Single bright (440 mJy), short duration (~4 min) burst

2. Oct 2017: 18 hours of observation (extended)
   - $5\sigma \sim 0.03$ Jy
   - Single dim (35 mJy), short duration (~2 min) burst
   - No periodic long-duration signal (not persistent)
   - Observations on-going (80 hours total)

Other M Dwarfs:

1. YZ CMi: 11.1 hours of observation, $5\sigma \sim 0.03$ Jy, no detection

2. CN Leo: 7.4 hours of observation (Hex), $5\sigma \sim 0.1$ Jy, no detection
modified from Lynch et al. (2017 ApJL 836)
1. The radio emission at frequencies < 5GHz is dominated by coherent bursts for flare stars of spectral type M.

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 2016
   ‣ Dim, short duration flare 2017, no periodic bursts

4. Flare distribution not well constrained — need more detections