Chasing Low Frequency Radio Bursts from Magnetically Active Stars

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Stellar Flares

Flaring is a common characteristic of magnetically active stars.

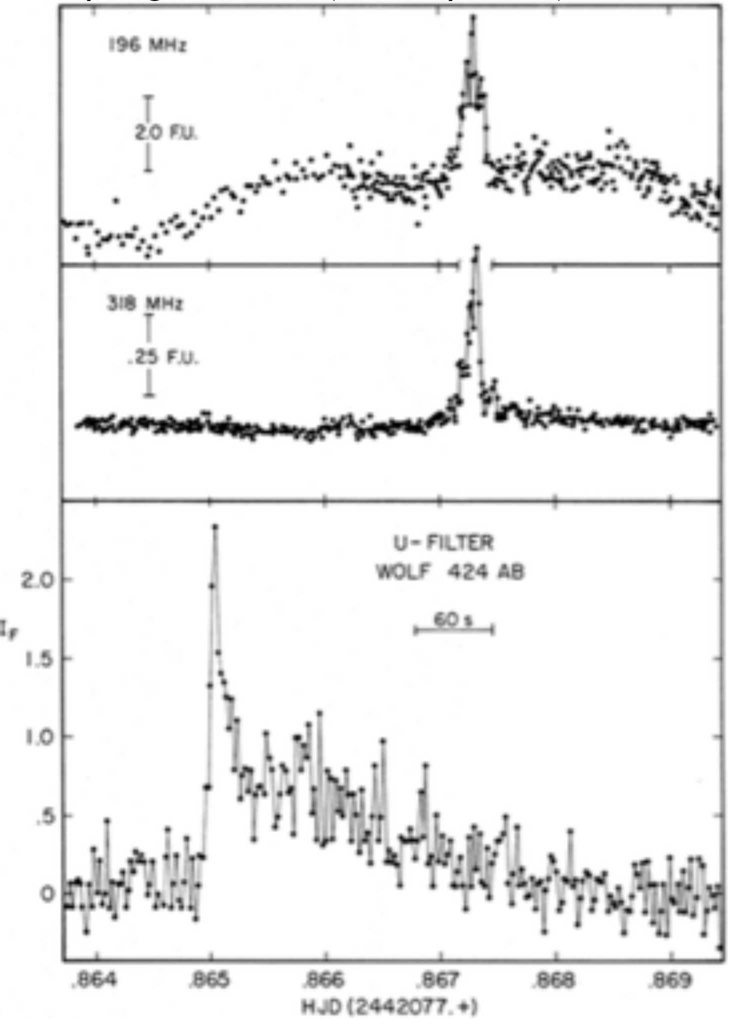
Observations of stellar flares:

- 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/

MHz Flares

Spangler et al. (1976 ApJ 203)



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:

  $\nu_c \sim 2.8\ \mathrm{MHz}\ (B_{Gauss}) \rightarrow$ 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:

  $\nu_p \sim 9.0\ \mathrm{kHz}\ (n_{cm^{-3}})^{1/2} \rightarrow$ 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, 5σ ~ 0.5 Jy
- Rowlinson et al. (2016 MNRAS 458): 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?

Try targeted observations to assess behaviour

Murchison Widefield Array

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).

MWA Observations

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

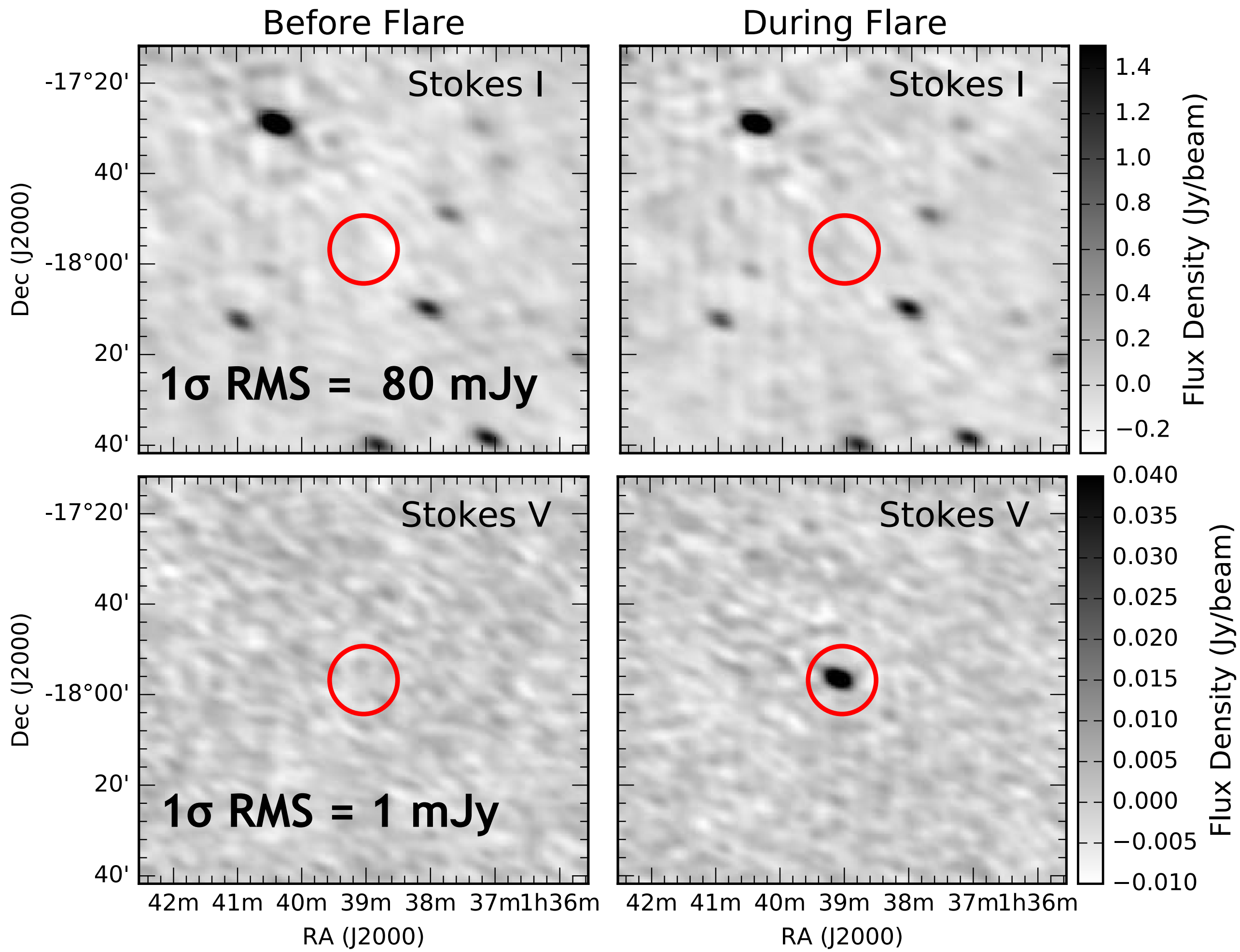
- Total observation time = 8.8 hours — split over 4 days in Dec 2015

- Frequency = 154 MHz

- Focus in Stokes V (circular polarisation)

Detection of UV Ceti

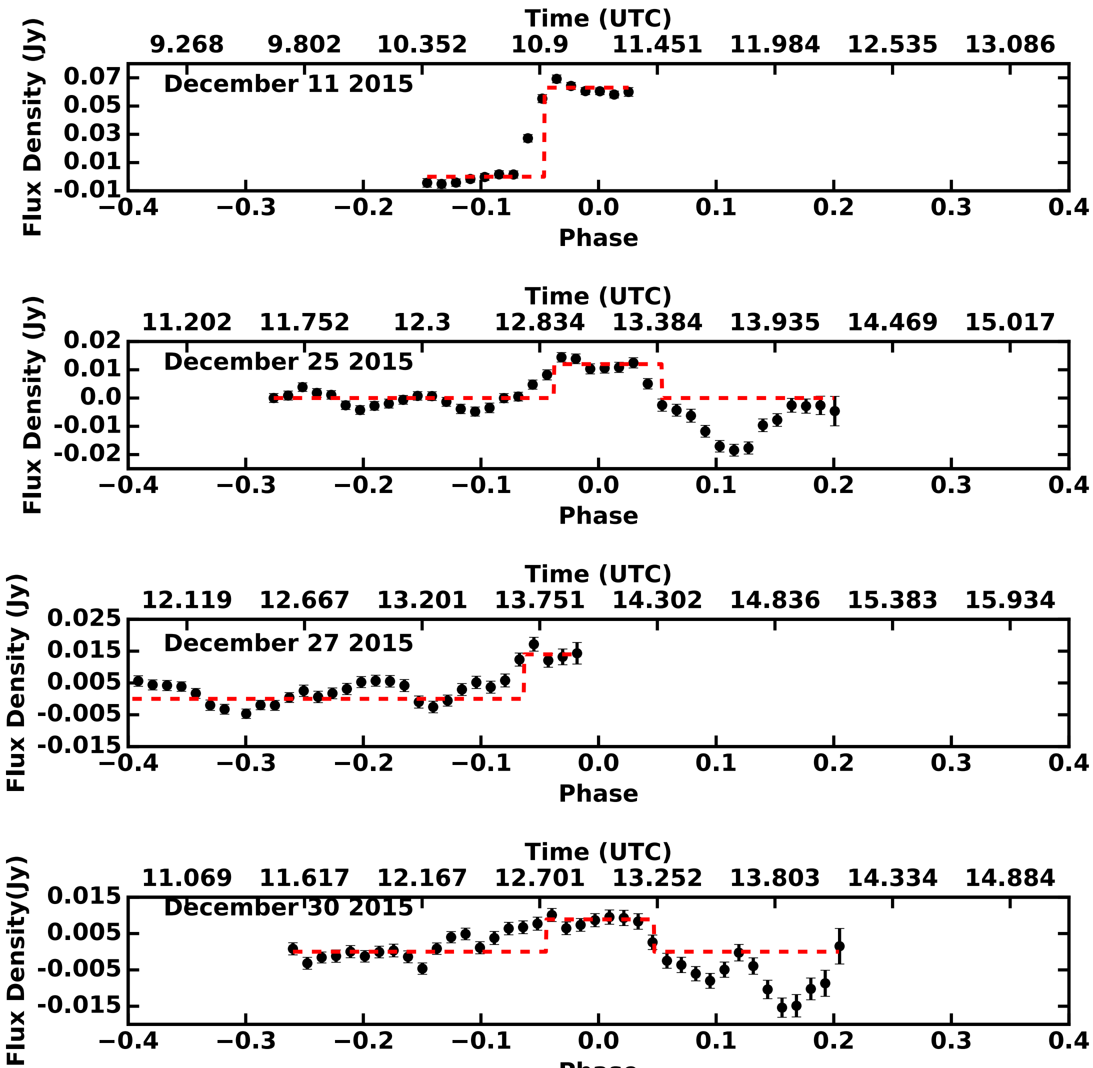
December 11 2015: 30 min integrations



Lynch et al. (2017 ApJL 836)

Light-curve analysis

STOKES V (pos = RH, neg = LH)



PERIODICITY:

- P ~ 5.45 hrs (95% confidence)

Lynch et al. (2017 ApJL 836)

Emission Type?

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

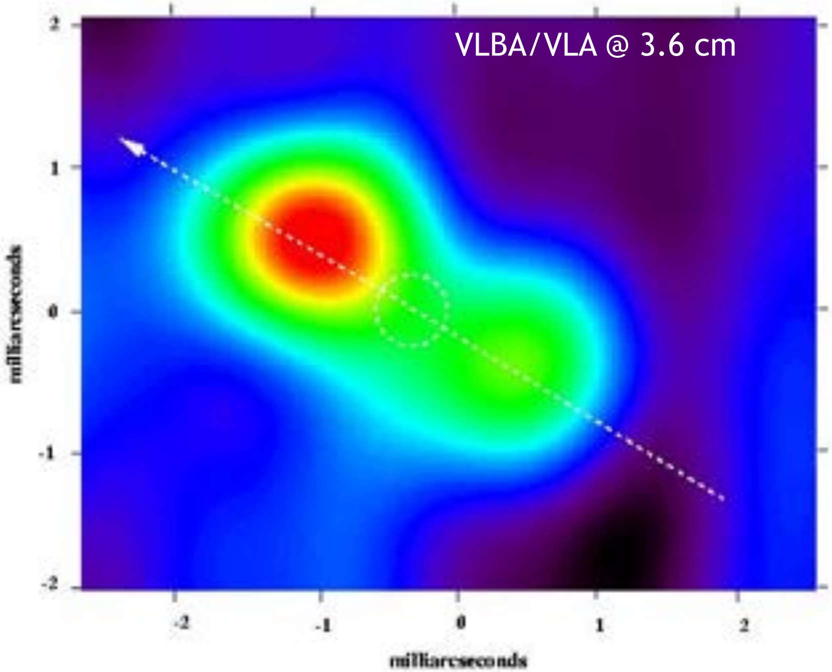
A. Source size constrained by assuming periodic persistent source:

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

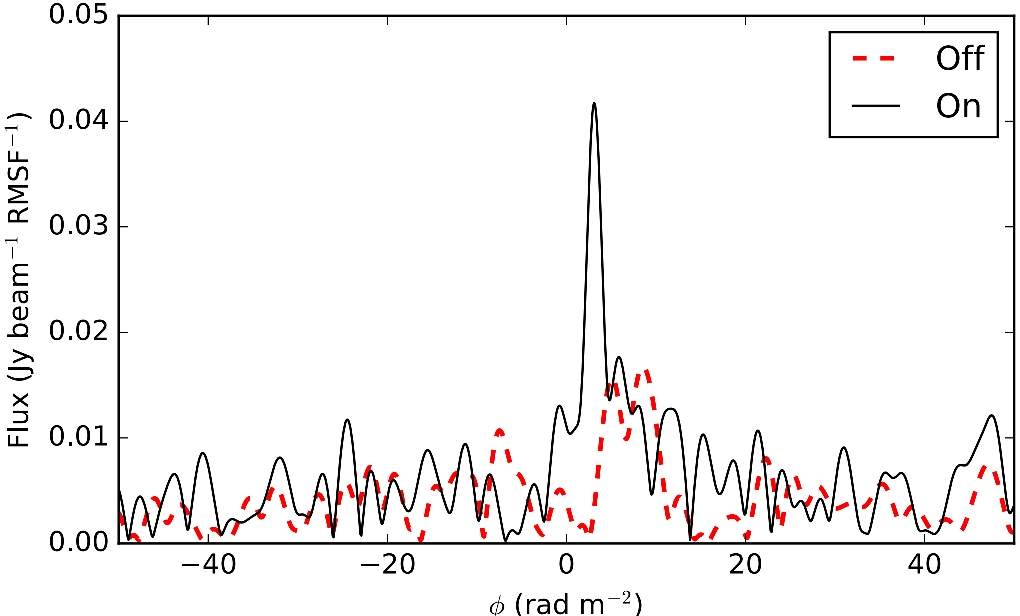
B. Source size constrained by VLBA:

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

Benz et al. (1998 A&A 331)



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}

Lynch et al. (2017 ApJL 836)

Further Observations @ 154 MHz

UV Ceti:

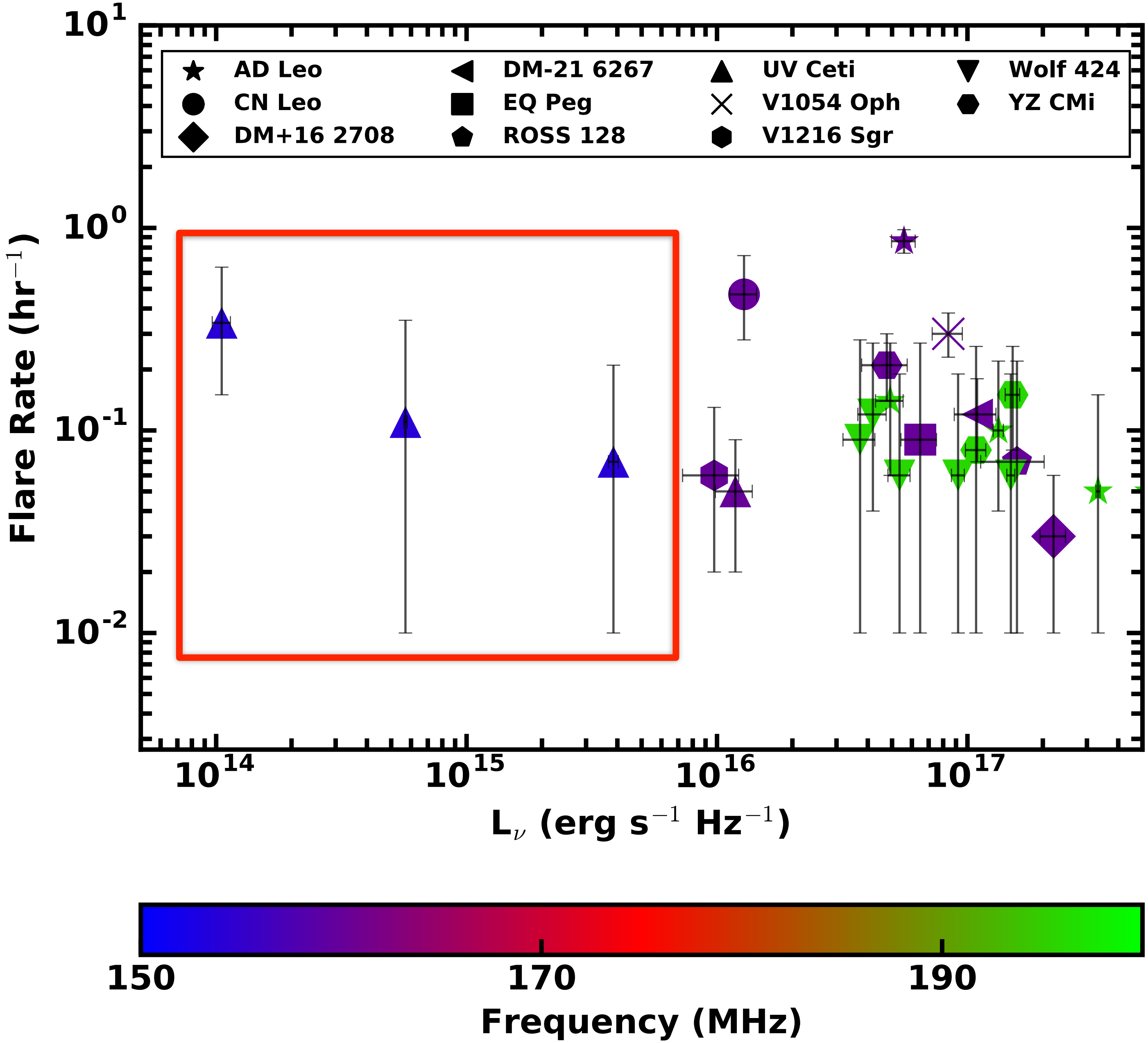
1. Dec 2016: 13.7 hours of observation (Hex)
   - 5σ ~ 0.1 Jy
   - Single bright (440 mJy), short duration (~4 min) burst

2. Oct 2017: 18 hours of observation (extended)
   - 5σ ~ 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, 5σ ~ 0.03 Jy, no detection

2. CN Leo: 7.4 hours of observation (Hex), 5σ ~ 0.1 Jy, no detection



modified from Lynch et al. (2017 ApJL 836)

Summary:

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