The Starburst Program: Exploring a Threat to Foreign Worlds



Detecting, Monitoring and Imaging Coronal Mass Ejections on Nearby Stars

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Image Credit: NASA/Steele Hill

Motivation

- M dwarfs are an attractive target in the search for nearby habitable-zone planets
- But most M dwarfs remain magnetically active (high rate of strong flares) for >1 Gyr (West et al 2008)
- Strong flares are most likely frequently accompanied by coronal mass ejections (CMEs)
- Properties of CMEs of active stars are unknown
- CMEs pose an unknown threat to exoplanet atmospheres
- Planetary magnetospheres provide protection from CMEs - is it enough?

Theory

- CMEs compress magnetosphere (Khodachenko et al 2007)
- Flares expand atmosphere beyond magnetosphere, where it is swept away (Lammer et al 2007)
- Charged particles from CMEs may deplete ozone for years at a time (Segura et al 2010), allowing harmful UV radiation to reach the planet's surface
- Current theoretical work assumes that many properties of solar CMEs extend to other stars

Stellar Radio Bursts

- Wide variety of radio flares observed in Sun
- Long-duration bursts trace bulk motion of electrons energized by magnetic reconnection
- Such long-duration bursts are frequently associated with coronal mass ejections
- 2 emission mechanisms for coherent long-duration bursts:
 - electron cyclotron maser emission: frequency determined by magnetic field strength
 - plasma emission: frequency determined by electron density
- Only a few coherent radio bursts have been observed in other stars (Güdel et al 1989, Osten & Bastian 2006)
- We are developing the first facility dedicated to radio observation of coherent stellar bursts, recording spectra with ultra-wide bandwidth and fast cadence

The Starburst Program: Purpose

Use dynamic spectra of stellar radio bursts and complementary observations to constrain properties of CMEs around active stars:

- mass
- velocity
- energy
- dependence of direction on star's magnetic field configuration

Goal: provide observational constraints to determine the impact of coronal mass ejections on planetary habitability

Observing Program

- 3 years of nighttime observing (2014-2016) with single-baseline correlation from two 27-meter telescopes at the Owens Valley Radio Observatory (OVRO)
- New wideband receiver installed by Owens Valley Solar Array (OVSA)
 - $T_{sys} < 25 K$
- Full polarization measurements
- Dedicated Starburst correlator:
 - 5 GHz bandwidth (I to 6 GHz)
 - I MHz channels
 - 10 ms cadence
- Automatic real-time burst detection pipeline



The 27-meter telescopes from the Owens Valley Solar Array, available for nighttime observing for the Starburst program for 3 years.

Sample

- 8 active M dwarfs (inc. UV Ceti, AD Leo)
- 2 young solar analogs
- 2 young stellar objects
- 3 close binaries (Algol + 2 RS CVn binaries)

Complementary Observations

Once the radio flare luminosity distribution and rate in Starburst targets are well measured, we will follow up with coordinated observing campaigns:

Meter-Wavelength

- Long Wavelength Array (LWA) station at OVRO currently in commissioning
- Images full sky simultaneously with 1-sec cadence
- 29 to 88 MHz, ~I degree resolution
- Full Stokes
- Sensitivity: 0.4 Jy in one second (whole band)
- Search Stokes V for high circular-polarization bursts in direction of stars in Starburst sample

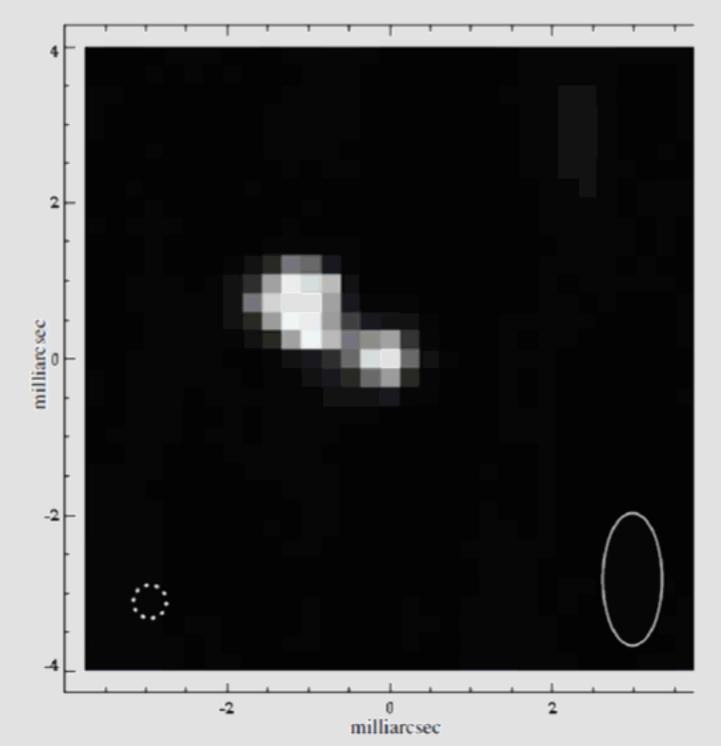


Optical Photometry

- A small optical telescope will observe targets simultaneously to the 27-meter dishes
- Photometric monitoring will start within the first year of Starburst observing

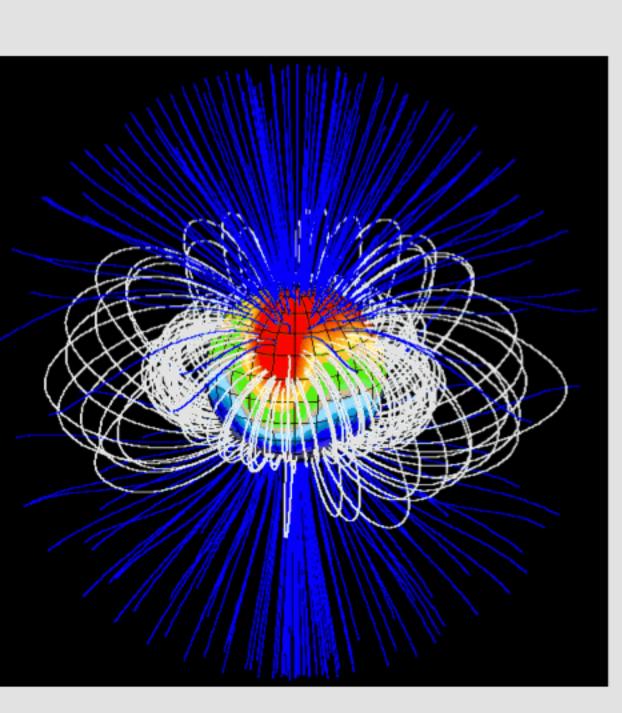
Very Long Baseline Interferometry

- Step I: Simultaneous observations with Starburst and the Very Long Baseline Array (VLBA)
- Identify time dependence of coronal structure during flares
- Step 2: Trigger VLBA observations when Starburst detects large flares
- Determine if the direction of coronal mass ejections depends on the star's magnetic field topology (as determined by Zeeman Doppler Imaging)



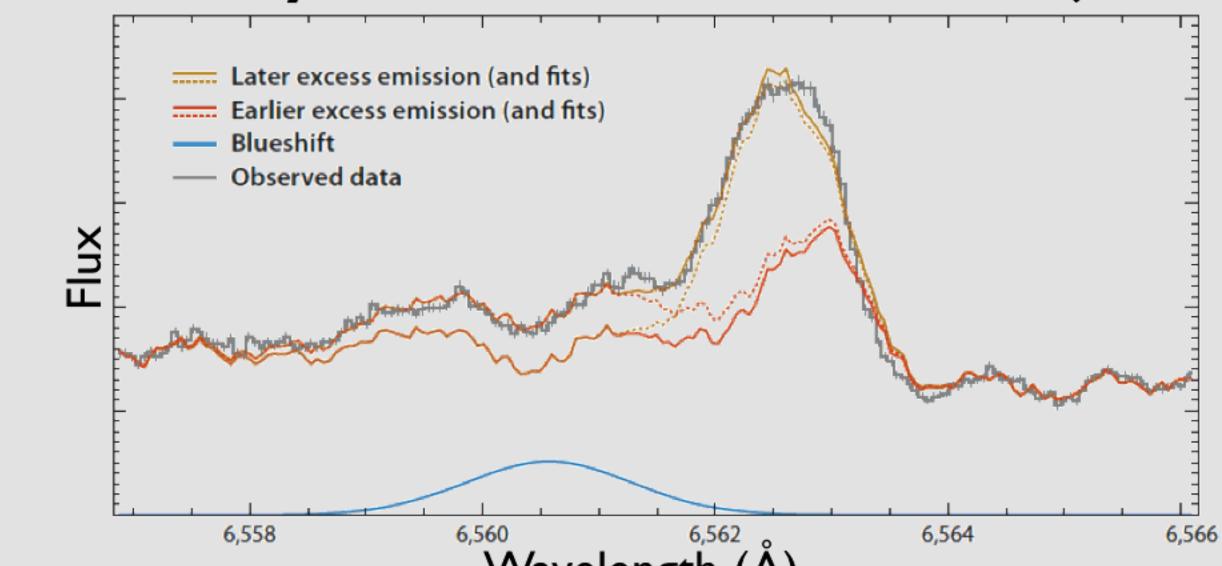
Left:VLBI image of UV Ceti's post-flare radio corona (Benz et al 1998).

Right: Dipolar magnetic field structure of M4 dwarf V374 Peg, as measured by Zeeman Doppler Imaging (Donati et al 2006).



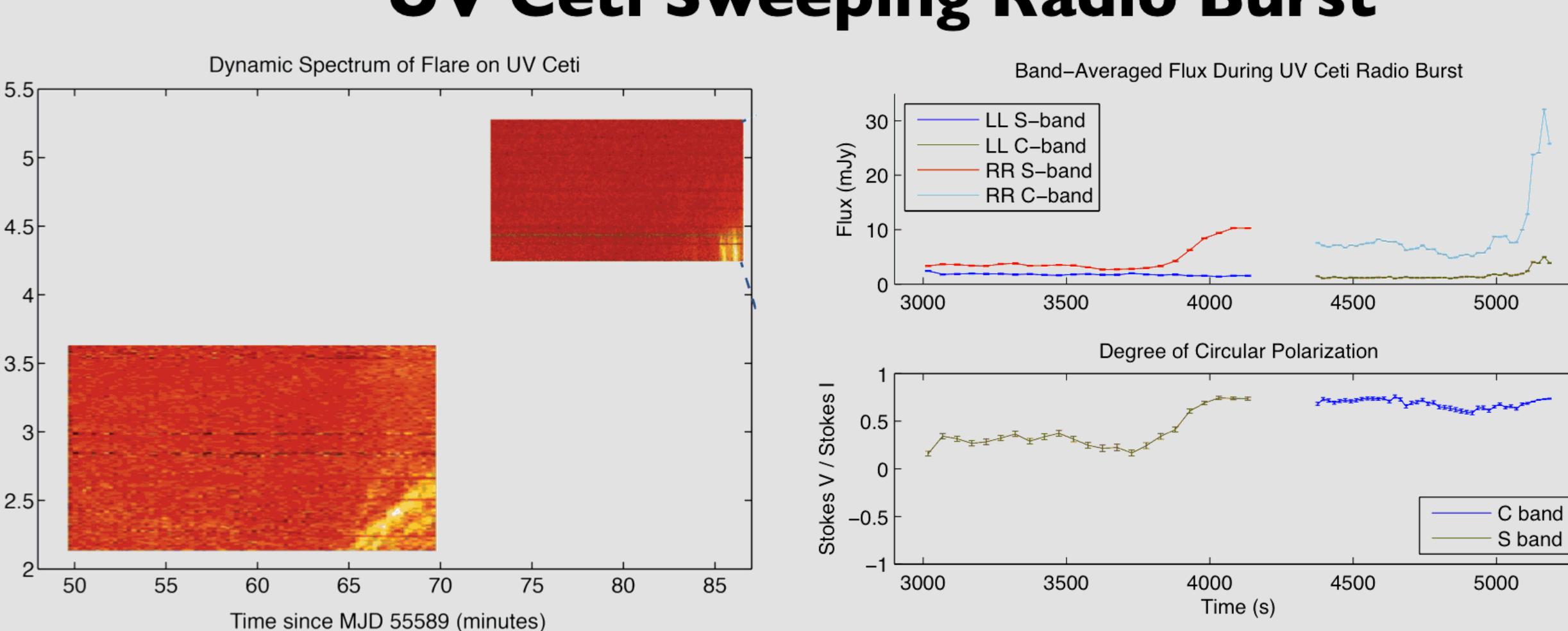
Optical Spectroscopy

- For stars with a high flare rate, obtain simultaneous optical spectroscopy with a large telescope
- Measure blueshifted component of $H\alpha$ line during flare to calculate velocity of coronal mass ejection



Blueshift of Hα during a flare on an M9 dwarf, showing the late flare emission (gray line). This emission is modeled (yellow line) by the sum of the pre-flare emission (red line) and two Gaussian components. The bottom blue curve shows the bluer Gaussian component, with a blueshift indicating a line-of-sight velocity of 100 km/s, suggestive of a coronal mass ejection (Fuhrmeister & Schmitt 2004; Benz & Güdel 2010).

UV Ceti Sweeping Radio Burst



Left: A coherent radio burst detected serendipitously during a VLA observation of UV Ceti (Hallinan, in prep). The first 20 minutes were observed in S band, the latter 15 in C band. Right: Band-averaged intensity and degree of circular polarization versus time.

- Serendipitous detection of radio burst during VLA observations of UV Ceti (active M6 dwarf)
- RR pol: 3.3 mJy quiescent flux, 157±9 mJy at flare peak
- Bright enough to be detected on all baselines (one VLA baseline ≈ Starburst sensitivity)
- Upwards sweep in frequency
 - implies bulk plasma motion downwards
 - plasma most likely falling along dipolar magnetic field lines downwards towards magnetic pole
 - \dot{v} = 1.75 MHz/s, implying v ~ H/(200 s), where H is the coronal density or magnetic scale height
- Coherent radiation:
- narrow BW; high degree of circular polarization
- $T_b \ge 7 \times 10^{10} \, \text{K}$ (given max source size of stellar disk)