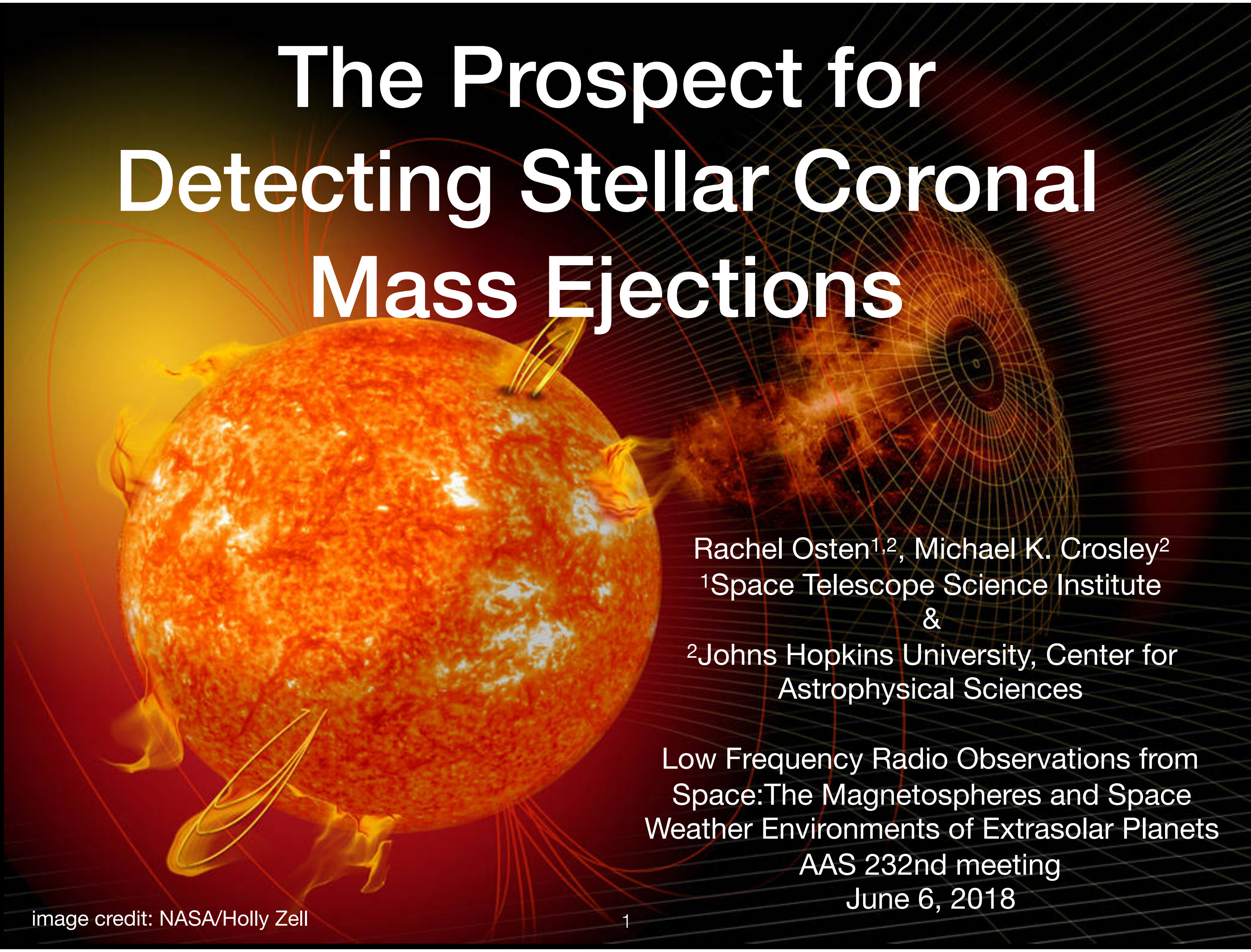

The Prospect for Detecting Stellar Coronal Mass Ejections

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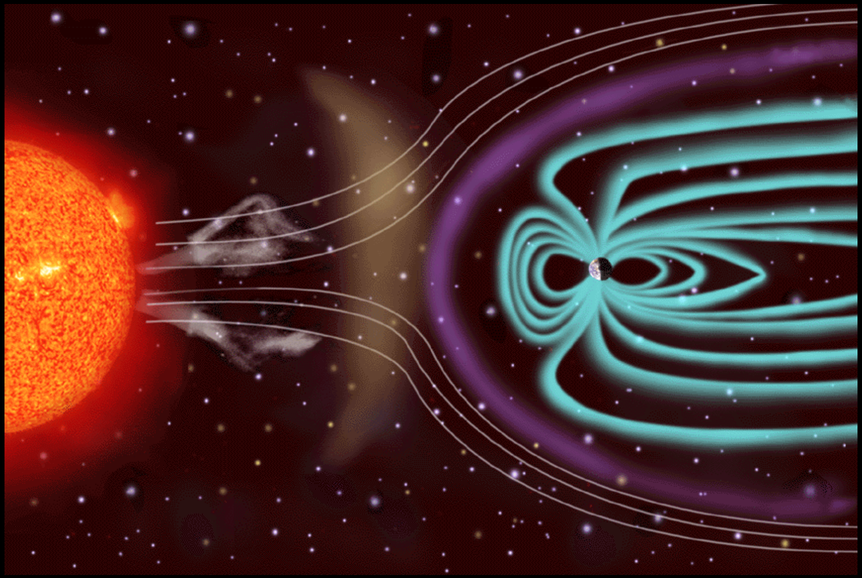
Low Frequency Radio Observations from Space:The Magnetospheres and Space Weather Environments of Extrasolar Planets
AAS 232nd meeting
June 6, 2018

image credit: NASA/Holly Zell

To Find a Habitable Extrasolar Planet. . .

- My (biased) perspective:
  - We need to understand planets
  - We need to understand stars
  - We need to understand star-planet interactions
  - We need to understand the solar-stellar, planet-exoplanet connection
- These topics are all interconnected, require scientists to work across their divisions

Star’s magnetic field helps to set the environment for planets and life



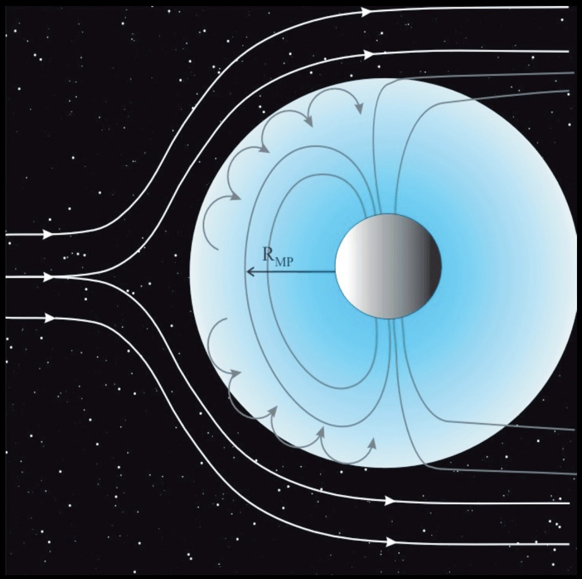
A star’s magnetic field:

- Heats plasma to temperatures up to several tens of millions of degrees (chromosphere, corona)
- Expels material (wind, coronal mass ejection)
- Accelerates particles to very high energies (energetic particle events)

How do Flares and Associated Events Affect Habitability, Space Weather?

- ➡ We can study stellar flares, see (gross) similarities to solar flares
- ➡ The coronal mass ejections and energetic particles are of most concern for habitability and/or space weather
- ➡ For now, astrobiological investigations of stellar flares extrapolate from solar flares by orders of magnitude: unclear if these scalings apply!

How do Flares and Associated Events Affect Habitability, Space Weather?



Lammer et al. (2007)

Need to test the assumption that a high flaring rate = a high rate of CMEs

This is particularly true for planets around M dwarfs

Observing Flares on Stars is Easy

Observational Signature	Sun	Stars
coherent radio emission, m-dm-cm wavelengths	✔	✔
radio gyrosynchrotron/synchrotron, dm-cm-mm wavelengths	✔	✔
optical/UV continuum (photosphere)	✔	✔
optical emission lines (chromosphere)	✔	✔
FUV emission lines (transition region)	✔	✔
EUV/soft X-ray emission (corona)	✔	✔
non thermal hard X-ray emission	✔	?

Osten 2016

Observing CMEs on Stars is Hard

Observational Signature	Sun	Stars
Thompson scattering via coronagraph	✔	✘
type II burst	✔	?
non thermal emission from CMEs	✔	
scintillation of point radio sources	✔	
coronal dimming during a flare	✔	
high velocity outflows in emission lines during a flare	✔	?
pre-flare “dips”	✔	?
increase in N_H during flare		?
effect of CMEs on stellar environment	✔	?
association with stellar flares	✔	?

Osten & Wolk (2017)

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

- ➡ Just starting to explore whether we can see stellar CMEs in a systematic way, thanks to new generation of low frequency radio telescopes
- ➡ Flare-associated transient mass loss implies large $\dot{M}$ (Aarnio et al. 2012, Drake et al. 2013, Osten & Wolk 2015)

Recent work (Crosley et al. 2016, Crosley et al. 2018 ab) is utilizing observations to detect and constrain the rate of stellar coronal mass ejections

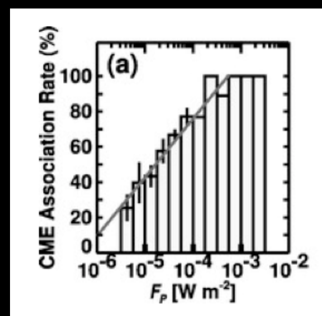
Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

Flare

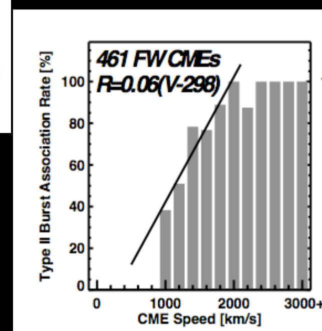
CME

v>v_A

Type II burst



Yashiro et al. (2006)

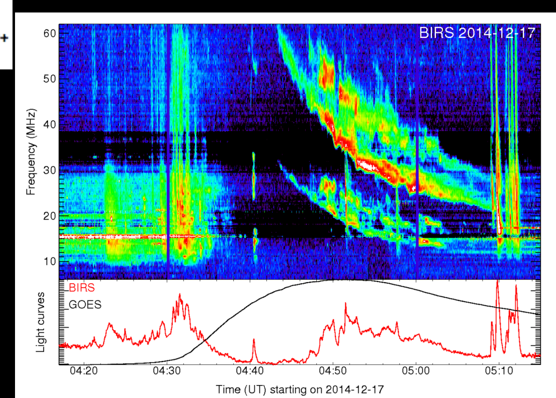


Gopalswamy et al. (2008)

What We Expect

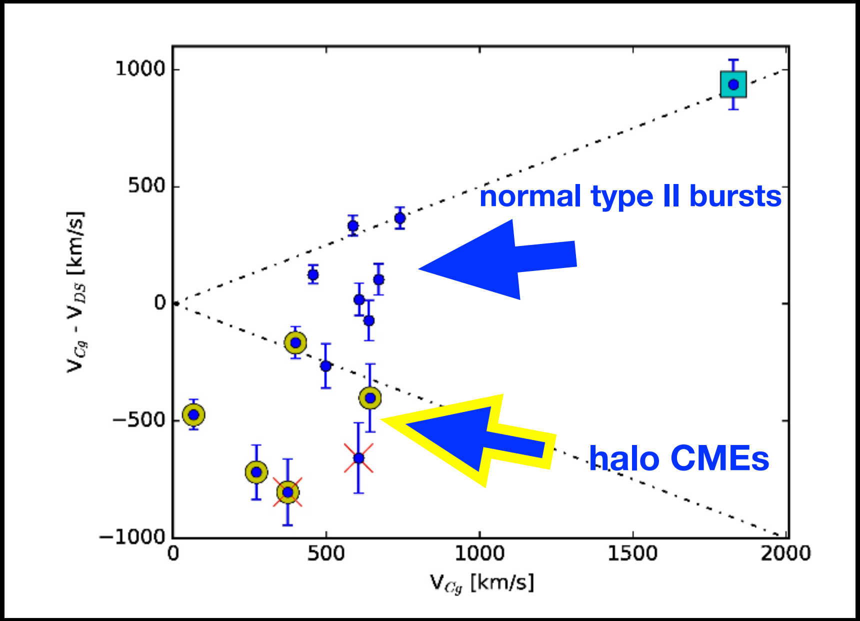
$$\frac{d\nu}{dt} = \frac{\partial \nu}{\partial n_e}\frac{\partial n_e}{\partial h}\frac{\partial h}{\partial s}\frac{\partial s}{\partial t}$$

$$\dot{\nu} = \nu \cos\theta v_B/(2H_n)$$



Crosley et al. (2017)

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?



Crosley et al. (2017)

- Pretend the Sun is a star: solar type II dynamic spectra, X-ray flares, scaling relations

$$\frac{1}{2}M_{CME}v^2 = \frac{E_{rad}}{\epsilon f_{rad}}$$

$$M_{CME} = AE^{\gamma}\ [\mathrm{g}]$$

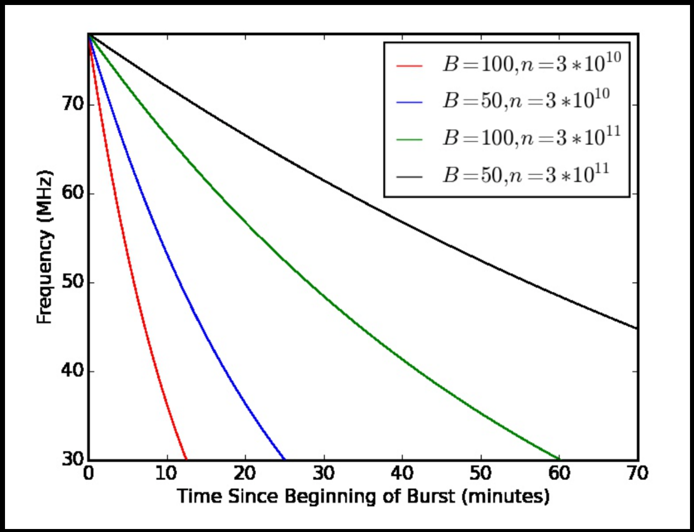
- Compare with coronagraphic measurements

- CME velocities good to about 50%, masses to an order of magnitude, kinetic energies only ~3 orders of magnitude

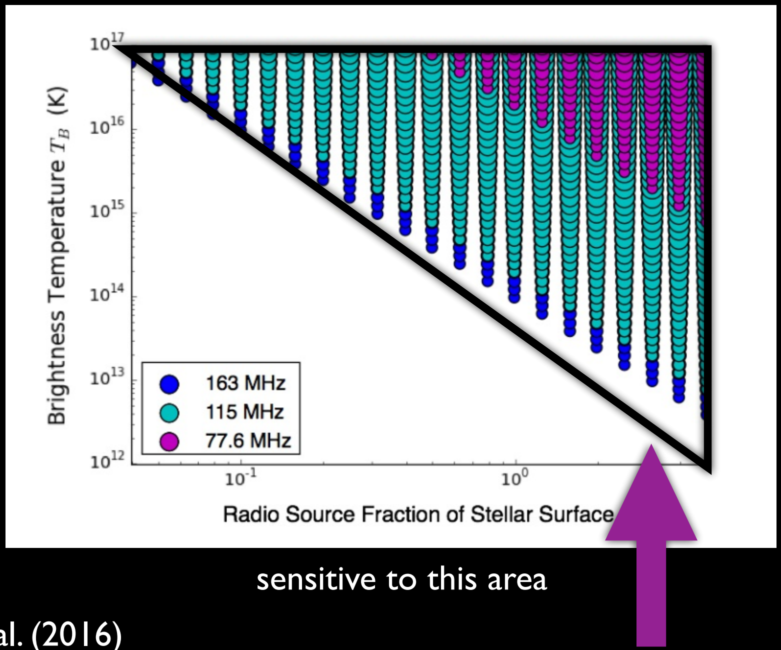
Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

Requirements	**YZ CMi**	**EQ Peg**
Star w/high flaring rate for close association with CMEs	0.4 flares/hour	~1.2 flares/hour
Nearby, for sensitivity	5.9 pc	6.2 pc
Constraints on coronal T, n_e	✔	✔
Photospheric magnetic field measurements	✔	✔
Previous evidence of radio bursts	✔	✔

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?



expect a burst of this shape



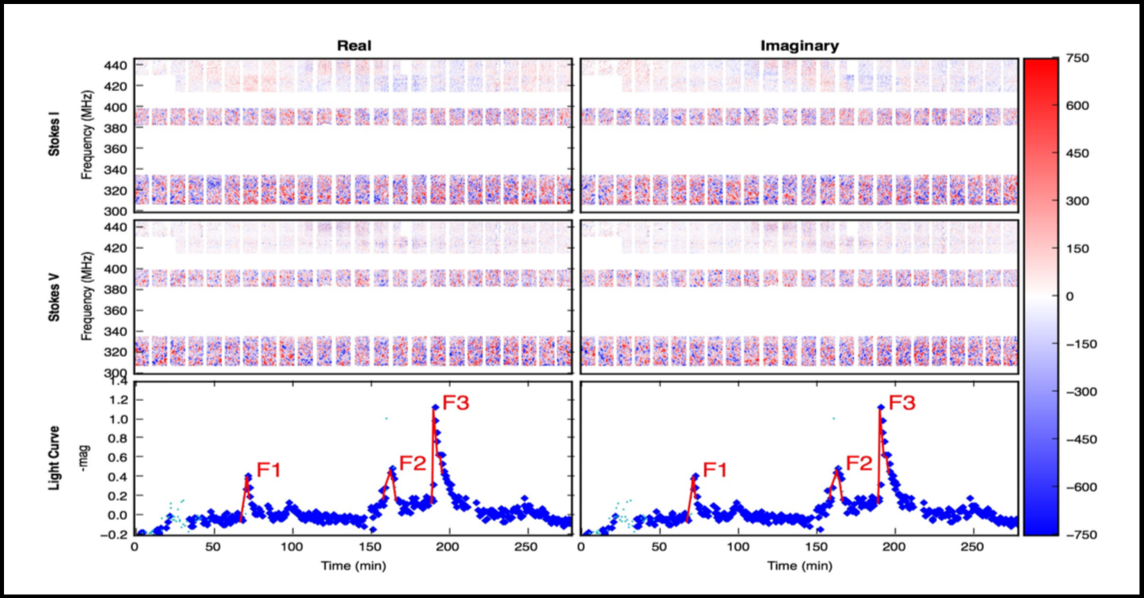
sensitive to this area

Crosley et al. (2016)

➡Constraints on the rate of stellar CMEs from LOFAR observations of a well-studied nearby M dwarf (YZ CMi)

➡ Optical flare rate is 1.2 flares every 3 hours; expect a CME to accompany each powerful flare. For 15 hours of radio observations we expected several flares/CMEs to have occurred

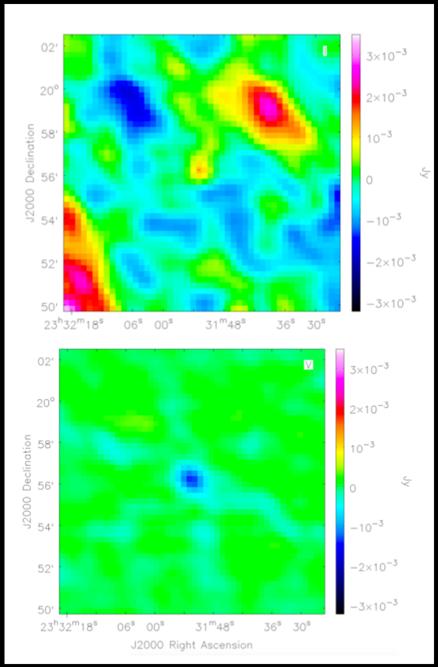
Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

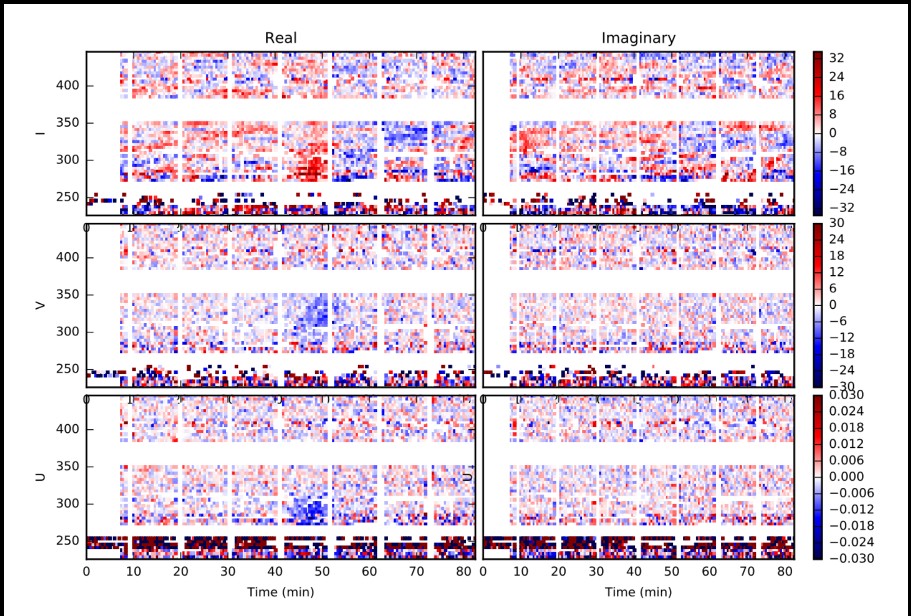


Crosley & Osten (2018a)

- JVLA, APO simultaneous measurements of EQ Peg
- Each pixel in the dynamic spectrum image is 15 s by 500 kHz (total span is 4 hours and ~240 MHz)
- 20 hours of overlapping radio/optical data, several moderate flares
- No features identifiable as type II bursts (no features in the dynamic spectrum, period)

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

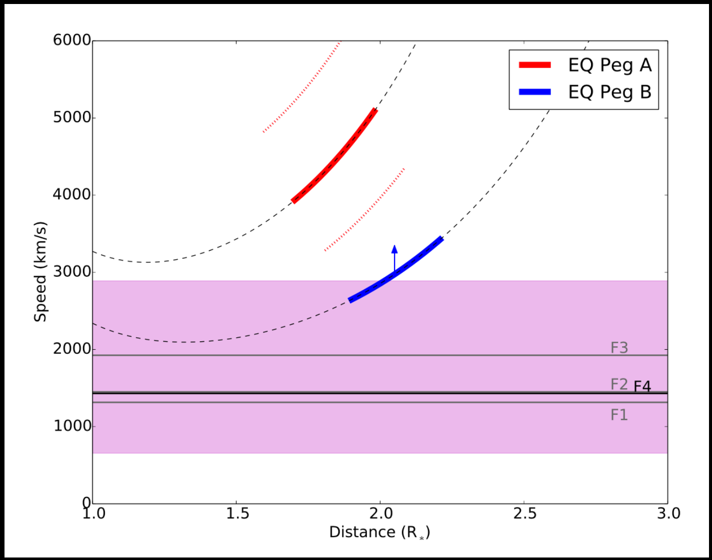


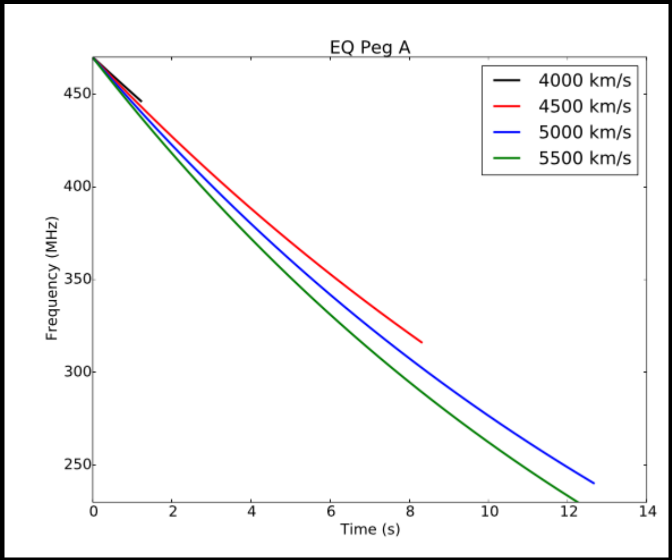


Crosley & Osten (2018b, subm.)

- 44 additional hours of JVLA only measurements
- Two low frequency radio bursts from EQ Peg!
- Features of the burst (bandwidth, drift rate, duration) not consistent with expectations for a type II burst

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?





Crosley & Osten (2018b, subm.)

Dynamic spectrum modeled from Zeeman Doppler Imaging photospheric magnetic field extrapolations, plus coronal T, n_e constraints (assuming barometric atmosphere)

Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

Flares but no CMEs?

↑

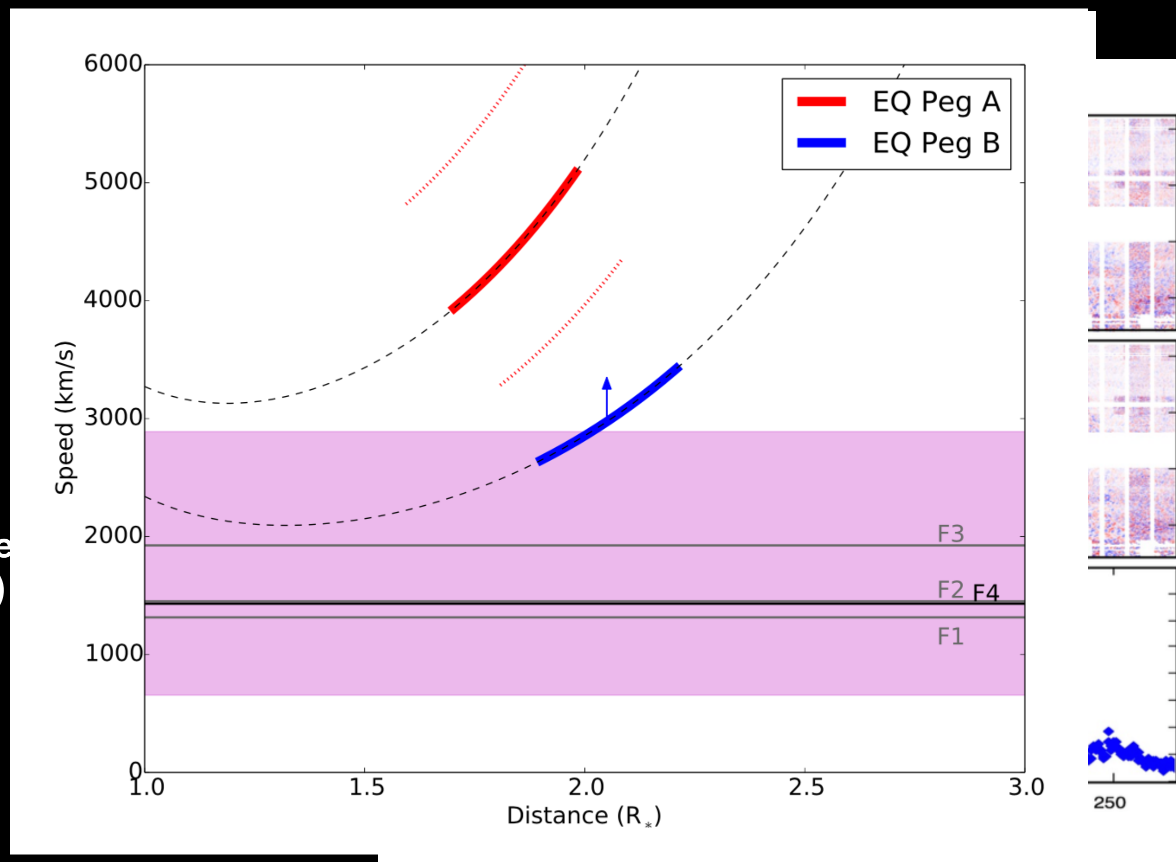
is $v > v_A$?

↑

unlucky? (mismatch between type params & observing sensitivity)

↑

no type II burst



Crosley & Osten (2018ab)

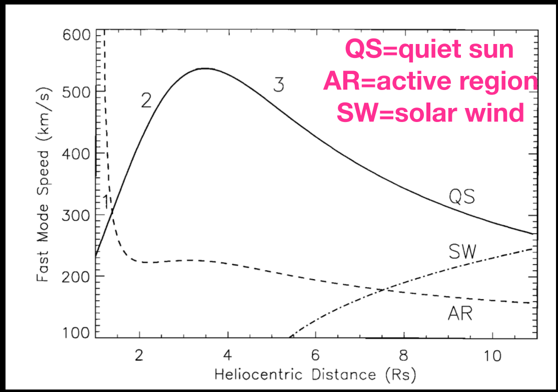
Does a High Flaring Rate Give Rise to a High Rate of Coronal Mass Ejections?

- Longest timescale search of one target for stellar type II bursts at low frequencies
- No type II bursts observed in 64 hours of monitoring of EQ Peg
  - Expected 1.2 flares/hr above flare energy where all solar flares have an associated CME
  - Using large-scale model corona, expect 1 flare every 27 hours to drive an observable shock

Do the large scale fields seen on M dwarfs prevent breakout?
Supporting evidence for weak stellar winds, in only a handful of active stars (Wood et al. 2004)

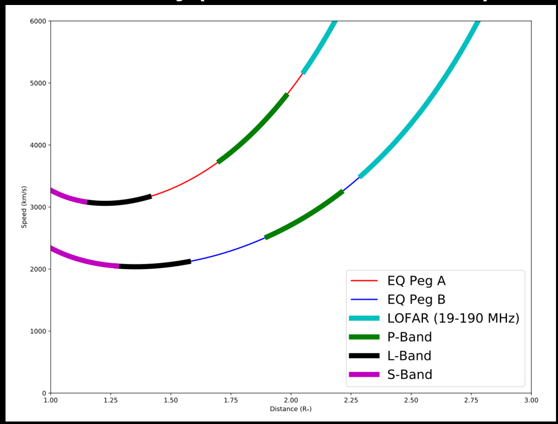
Considerations for Low Frequency Radio Observations from Space

- Frequency traces density traces distance (lower frequencies probe further distances from the star) we have only gross global characterizations of stellar ne(r), B(r)
- Importance of magnetic structures in forming shocks: weaker disturbances can drive shocks in quiet regions, while stronger disturbances have trouble exceeding the fast mode speed
- Lifetime of a shock depends on its initial speed, lifetime of the driver, location/origination on stellar surface



⬆ Gopalswamy et al. (2001)

Crosley (2018 PhD Dissertation) ⬇



Conclusions for Now

- **New low frequency observational capabilities enable the study of stellar transient mass loss.** A high rate of flaring does not appear to imply a similarly high rate of coronal mass ejections. Overlying coronal magnetic structures may prevent breakout of material from the stellar surface.

- **Stellar magnetic activity affects planetary environment.** Whether this is a space weather concern or habitability concern needs more detailed studies. We need to understand stars to place exoplanet discoveries in context as the search for life speeds up.