Numerical simulations of particle acceleration & low frequency radio emission in stellar environments

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Why Radio?

✓ Characterizing exoplanetary environments
✓ Promising for stellar CME observations
✓ Favorable atmospheric window
✓ Plethora of astronomical radio sources
✓ Produced by a wide range of mechanisms
✓ New low frequency regime from space
Follow the energy for particle acceleration

Flares v<100MHz CMEs

Flares

CME Shocks
Solar EPs

Reames, 1999, SSR

<table>
<thead>
<tr>
<th>SEP Classes</th>
<th>Gradual (CMEs)</th>
<th>Impulsive (flares)</th>
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<tbody>
<tr>
<td>Duration</td>
<td>Days</td>
<td>Hours</td>
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<tr>
<td>X-rays</td>
<td>Gradual</td>
<td>Impulsive</td>
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<tr>
<td>Radio-bursts</td>
<td>Type II</td>
<td>Type III, IV</td>
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</table>
Radio emission mechanisms

Bremsstrahlung radiation \( (\propto n_e^2 T_e^{-1/2}) \)

Gyromagnetic radiation  
  (gyroresonance, gyrosynchrotron, synchrotron)

Plasma radiation \( (v_p, 2v_p \propto n_e^{1/2}) \)

N.E. VDFs \( \rightarrow \) Langmuir waves \( \rightarrow \) E/M

a) e- beams (Type III)
  
b) MHD shocks (Type II)
Radio solar atmosphere

source: web.njit.edu, Prof. D. Gary
Radio bursts

Green Bank Solar Radio Burst Spectrometer (GBSRBS)

Impulsive phase
flare rise
Type III

CME
Type II

flare decay
Type IV
Refraction of Radio waves

Mercier + Chambe, 2015  Dulk + Gary, 1983

Models & Simulations
Simulations of type II radio bursts

BATS-R-US + WSA + analytic Kappa VDFs

Schmidt et al., 2012, 2014
Flare particle acceleration

Chen et al., Science, 2015

MHD reconnection simulation of Termination Shock

Chen et al., Science, 2015
Towards a realistic radio corona

BATS-R-US + AWSoM/R+
Radio Synthetic Imaging:
Bremsstrahlung + Refraction

Moschou et al. 2018a (submitted)
Towards a realistic radio corona

Moschou et al. 2018a (submitted)
Towards a realistic radio corona

(b) Nancay 164 MHz

C2-2

10:13:23 UT

2011-03-07

100 MHz

500 MHz

5 GHz

10 GHz

Bastian et al. 2001

Moschou et al. 2018a (submitted)
LOS vs. Refracted

$I_v (W \text{ m}^{-2} \text{ sr}^{-1} \text{ Hz}^{-1})$

Moschou et al. 2018a (submitted)
Next: include kinetic physics

BATS-R-US & MFLAMPA

Videos: D. Borovikov

Moschou et al. 2018b, in prep
Radio Stellar flares
Radio stellar flares

- Incoherent stellar flares in both Sun-like (FGK)-stars (e.g. Gudel+, '98) & M-dwarfs (e.g. Bastian, '90)

- Coherent stellar flares in M-dwarfs (e.g. van den Oord & de Bruyn, '94)
Radio stellar flares

- **Incoherent** stellar flares in both Sun-like (FGK)-stars (e.g. Gudel+, '98) & M-dwarfs (e.g. Bastian, '90)

- **Coherent** stellar flares in M-dwarfs (e.g. van den Oord & de Bruyn, '94)

\[ N(E) = KE^{-\alpha} \] (Dulk 1985)

\( Osten+, 2005 \)
Stellar radio bursts

YZ CMi

Campaigns for Type II
VLA, New Mexico

Credit: NRAO

Type III

Jackie Villadsen, 2017, PhD thesis
Stellar radio bursts

YZ CMi

Campaigns for Type II
VLA, New Mexico

No Type II detection

Credit: NRAO

Jackie Villadsen, 2017, PhD thesis
Conclusions

- **Ground-based radio observations** have been a valuable tool for years.
- **Multiple radio emitting processes**
- **Particle acceleration through CMEs and flares in low frequencies**
- **Refraction needs to be examined systematically.**
What do we need?

- Low frequency radio observations from space
- Modeling: include kinetic physics consistently
- Synthetic imaging tool + capabilities to examine different emission mechanisms in different setups
Thank you!
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