Simulating Electron Cyclotron Maser Emission from Low Mass Stars

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How do we map stellar surface magnetic fields?

Doppler Imaging

Credit: J-F Donati
How do we map stellar surface magnetic fields?

Radial magnetic field

- Zeeman effect: Magnetic field splits lines
  
- $\text{stokes } V = \bigcirc - \bigcirc$

- Track Stokes $V \rightarrow$ get field along line-of-sight ($B_{\text{los}}$).

- Max amplitude at disk center

- Limitation: Only large scale field is detected

Credit: J-F Donati
How do we map stellar surface magnetic fields?

Radial magnetic field

Azimuthal magnetic field

Credit: J-F Donati
How do we map stellar surface magnetic fields?

- From Stokes V profile → use inversion techniques to derive $B_r, B_\phi, B_\theta$

Tau Boo (F7V)
Donati et al. (2008)
The *confusogram* of stellar magnetic fields

- **Size:** intensity
- **Color:**
  - poloidal
  - toroidal
- **Shape:**
  - axisymmetric
  - non-axisym.
- **Variety of intensities and topologies**

Modeling Stellar coronae and Winds

V374 Peg

Potential Field Source Surface Model

Altshuler & Newkirk (1969)
See et al. (2015, 2016, 2017)
Lang et al. (2012, 2014)
Lehmann et al. (2017)

3D MHD Modeling

Powell et al. (1999), Toth et al. (2012)
Cohen et al. (2011, 2014a, b, 2017)
Llama et al. (2013)
Garraffo et al. (2015, 2016)
Stellar Dipole: ECM Emission

- $B_* = 1000$ Gauss
- $\text{incl} = 45^\circ$
- $T_{\text{cor}} = 6 \times 10^6$ K

- For ECM emission:
  \[
  \sqrt{\frac{n_e e^2}{m_e e_0}} < \frac{eB}{m_e}
  \]

- and
  \[
  \beta = \frac{nk_B T}{B^2/(2\mu_0)} < 1
  \]
Stellar Dipole: ECM Emission
Stellar Dipole: ECM Emission

\[ \text{arccos} \left( \frac{\cos \theta_M - \cos \beta \cos i}{\sin \beta \sin i} \right) \]
Stellar Dipole: X-ray Emission

- Isothermal, hydrostatic corona:

\[ p = p_0 \exp \left( \frac{m}{T} \int g_s \, ds \right) \]

- Base-density scales with magnetic pressure:

\[ p_0(\theta, \phi) = KB_0^2(\theta, \phi) \]

Scales with observed Emission Measure
Stellar Dipole: X-ray Emission

- Graph showing X-ray intensity vs. phase.
- Image illustrating the phase behavior with a ring structure at phase 1.00.
X-ray and ECM light curves

ECM bright when X-ray dim
Simulating ECM emission from V374 Peg

- Size: intensity
- Color: poloidal, toroidal
- Shape: axisymmetric, non-axisym.
- Variety of intensities and topologies

Simulating ECM emission from V374 Peg

- Mass: 0.28 x solar mass
- Radius: 0.28 x solar radius
- Temperature: 3410 K
- Rotation Period: 0.44 days
- Log Lx = 28.44

\[ T_{\text{corona}} = 0.11 \times F_x^{0.26} \]

(Johnstone et al. 2015)

\[ T_{\text{corona}} = 6 \times 10^6 \text{ K} \]

(Morin et al. 2008)
Simulating ECM emission from V374 Peg

Llama and Jardine (in prep)
Simulating ECM emission from V374 Peg

Llama and Jardine (in prep)
Simulating X-ray emission from V374 Peg

Llama and Jardine (in prep)
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Extension to more ZDI stars

Llama and Jardine (in prep)
Planet induced ECM

Io Magnetic footprint

Main auroral oval

Ganymede Magnetic footprint

Europa Magnetic footprint

HST/STIS
NASA and J. Clarke (Michigan)
Planet induced ECM

Llama and Jardine (in prep)
Planet induced ECM

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Summary and Prospects

• Magnetic maps are a useful tool for predicting the radio emission from stars.

• X-ray and ECM light curves are anti-phased.

• Planet induced ECM can vary depending on the orbital configuration of the planet.

• Next steps: Predict light curves for the low-mass stars that have ZDI observations.