Ultra-weak magnetic fields and atmospheric dynamics of Am stars

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Magnetic dichotomy in A stars

- Only 5-10 % of A stars exhibit strong magnetic fields ($B_l > 100G$).
  - Ap stars: simple field topology (dominated by dipole)

- Weak magnetic fields ($B_l < 1G$):
  - Normal A stars, Am stars
Weak magnetic fields in A/B stars

- Weak magnetic field discovered in normal A star Vega (Lignières et al. 2009, Petit et al. 2010)

- No similar detection in two normal B stars (Neiner et al. 2014, Wade et al. 2014)

- Stokes V signatures in Am star Sirius A (Petit et al. 2011). Zeeman effect?
Targets

- Two bright Am stars: β UMa and θ Leo
- Am stars: chemically peculiar (metal rich) stars
- Target parameters:

<table>
<thead>
<tr>
<th></th>
<th>β UMa</th>
<th>θ Leo</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectral type</td>
<td>A1V</td>
<td>A2V</td>
</tr>
<tr>
<td>$T_{\text{eff}}$</td>
<td>9600K$^a$</td>
<td>9350K$^b$</td>
</tr>
<tr>
<td>log g</td>
<td>3.83$^c$</td>
<td>3.65$^b$</td>
</tr>
<tr>
<td>Mass</td>
<td>2.7 $M_{\odot}^d$</td>
<td>2.5 $M_{\odot}^d$</td>
</tr>
<tr>
<td>Radius</td>
<td>3.0 $R_{\odot}^a$</td>
<td>4.3 $R_{\odot}^a$</td>
</tr>
<tr>
<td>vsini</td>
<td>46 km/s$^e$</td>
<td>23 km/s$^e$</td>
</tr>
<tr>
<td>$L_{\odot}$</td>
<td>63$^a$</td>
<td>141$^d$</td>
</tr>
<tr>
<td>Age (Myr)</td>
<td>500$^f$</td>
<td>550$^g$</td>
</tr>
</tbody>
</table>

$^a$ Boyajian et al. (2012)  
$^b$ Smith & Dworetsky (1993)  
$^c$ Monier (2005)  
$^d$ Royer et al. (2002)  
$^e$ Wyatt et al. (2007)  
$^f$ Palous & Hauck (1986)  
$^g$ Zorec & Royer (2012)
Observations

• Data taken with NARVAL spectropolarimeter:
  – β UMa: 149 spectra (2010-2011)
  – θ Leo : 171 spectra (2012-2014)

• Least-Squares Deconvolution (LSD) technique
  – No signal in individual LSD V line profiles
    (using ≈1100 photospheric spectral lines)

• Co-addition of all LSD profiles of a same star
  – Final SNR ≈500000
Results

Signature shapes similar to Sirius A: prominent positive lobe.
Results

• What is the physical origin of V signatures in line profile?
  - Zeeman effect?

• Tests to ascertain magnetic origin:
  - Magnetic field \( \rightarrow \) amplitude of V profiles depends on line parameters (line depth, Landé factor, wavelength,..).
  - I compute LSD profiles from two line lists (extracted from our original list) with one line parameter varied in the two sub-lists.
  - Compare results with same test applied to standard, strongly magnetic Ap star \( \alpha^2 CVn \).
Test: Low vs high Landé Factors

\[ \alpha^2 CVn \]
Test: Low vs high Landé Factors

\[ \alpha^2 \text{CVn} \]

\[ \beta \text{UMa} \]

\[ \theta \text{Leo} \]
Test: blue vs red Wavelengths
Test: blue vs red Wavelengths

\[ \alpha^2 \text{CVn} \]

\[ \beta \text{UMa} \]

\[ \theta \text{Leo} \]
Test: low vs high line depth

\[ \alpha^2 \text{CVn} \]

\[ \alpha_2 \text{CVn} \]

![Graph showing low vs high line depth comparison with two curves: one for low depth and another for high depth. The x-axis represents velocity (km/s) ranging from -200 to 200, and the y-axis represents V ranging from -0.01 to 0.01.](image)
Test: low vs high line depth
Test: low vs high line depth

Magnetic origin: confirmed!
Strong asymmetry in V profiles

- Stokes V profiles with non-zero integral: not expected in standard Zeeman effect.

- In solar observations, similar shapes interpreted as a combination of vertical gradients in both velocity and magnetic fields.

- Detection of a microturbulence contribution in Am stars (Landstreet et al. 2009) convection.

- Models predict the widespread presence of shocks in the superficial layers of Am stars (Kupka et al. 2009).
Fossil field or Dynamo?

- Fossil field:
  - Failed fossil field (Braithwaite & Cantiello 2013, Aurière et al. 2007)

- Dynamo:
  - Surface dynamo
  - In convective core
  - In iron convective zone
  - In radiative zone

Problem: timescale to carry magnetic flux to stellar surface
Conclusion

- New observations and LSD tests confirm magnetic origin of Stokes V signatures.

- 100% magnetic detection rate in Am stars so far.

- Stokes V asymmetry: new information on photospheric dynamics of Am stars?

- New observations are currently being carried out to identify physical origin of weak magnetic fields in A stars.
Thanks for your attention!