Is AD Leo entering a polarity reversal?

Long-term monitoring of the large-scale magnetic field with ESPaDOnS, NARVAL and SPIRou

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Stellar magnetic cycles

With a long-term monitoring of the large-scale magnetic field, we can search for temporal evolution of the topology and uncover stellar dynamo theories. The Sun is an important benchmark: the magnetic cycle is characterised by a 11-yr variation in sunspot number, size and latitude of emergence, and magnetic polarity reversal [1,2]. Spectropolarimetric observations revealed analogous polarity flips also on other stars [3,4].
At the lower end of the main sequence, M dwarfs represent excellent laboratories to study non-solar dynamo mechanisms underlying the generation and preservation of magnetic fields.

The magnetic field generation occurs under different interior physical conditions, as the transition between partly - and fully-convective occurs at spectral type M3. Observational constraints for M dwarfs have been set by high-resolution spectroscopy field measurements in unpolarised light [5] and by tomographic inversion techniques (Zeeman-Doppler Imaging, [6]), revealing a dichotomy in the full-convective regime: strong, dipolar axisymmetric and weak, complex non-axisymmetric fields [7,8]. To explain this phenomenon, either dynamo bistability [9] or magnetic cycles [10] are invoked, but no definite conclusion has been reached so far.

Target star: AD Leo

Spectral type = M3.5
P_{rot} = 2.23 ± 0.01 d
$v_{eq}\sin(i)$ = 3 km/s
Inclination = 20°
Mass = 0.42 $M_\odot$
Main topology: dipolar and axisymmetric [7,11]
Dipole strength: ~1 kG

Longitudinal magnetic field

- Disk-integrated, line-of-sight component of the magnetic field (B_l)
- Stellar north pole is dominated by negative dipole all the time
- Global decrease in field strength over 14 years
- Reduced axisymmetry indicated by varying amplitude in the phase-folded time series

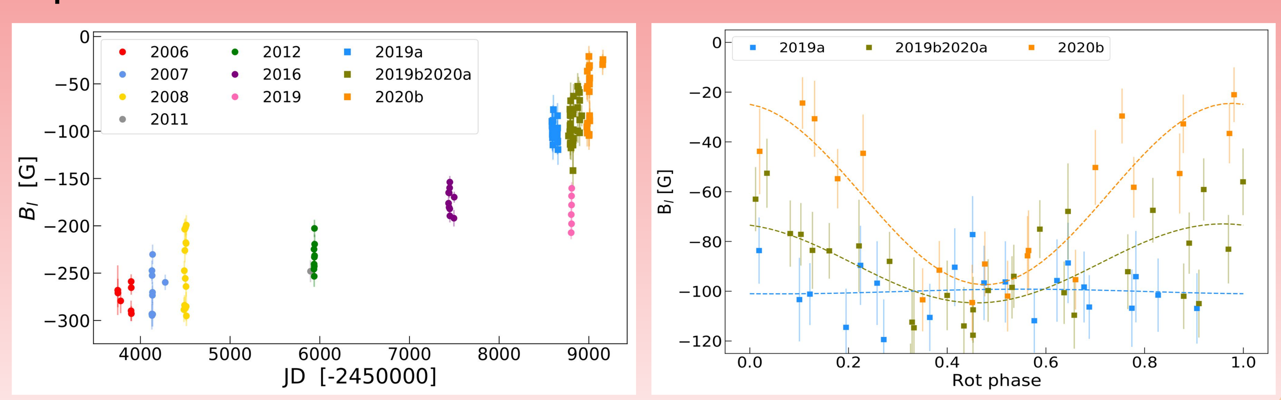


Fig 1. Evolution of B_l. *Left*: optical (circles) and near-infrared (squares) time series between 2006 and 2020. *Right*: near-infrared time series phase-folded at the stellar rotation period.

FWHM of Stokes *I*

- FWHM useful activity tracer sensitive to Zeeman effect → high Landé factor (g_{eff}) lines can reveal activity signal
- Full vs high-g_{eff} mask [12]: all FWHM values are larger in the latter case
- Constant vs sine fit: the variations of the 2020b epoch are better described by sinusoid fit (22% decrease in residual RMS)
- Increased FWHM variations imply lower degree of axisymmetry
  - FWHM phase variations are reflected by ZDI maps

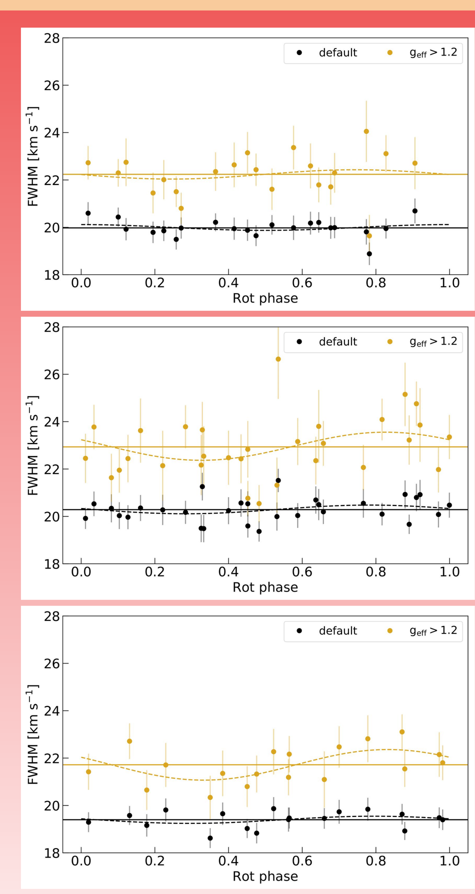
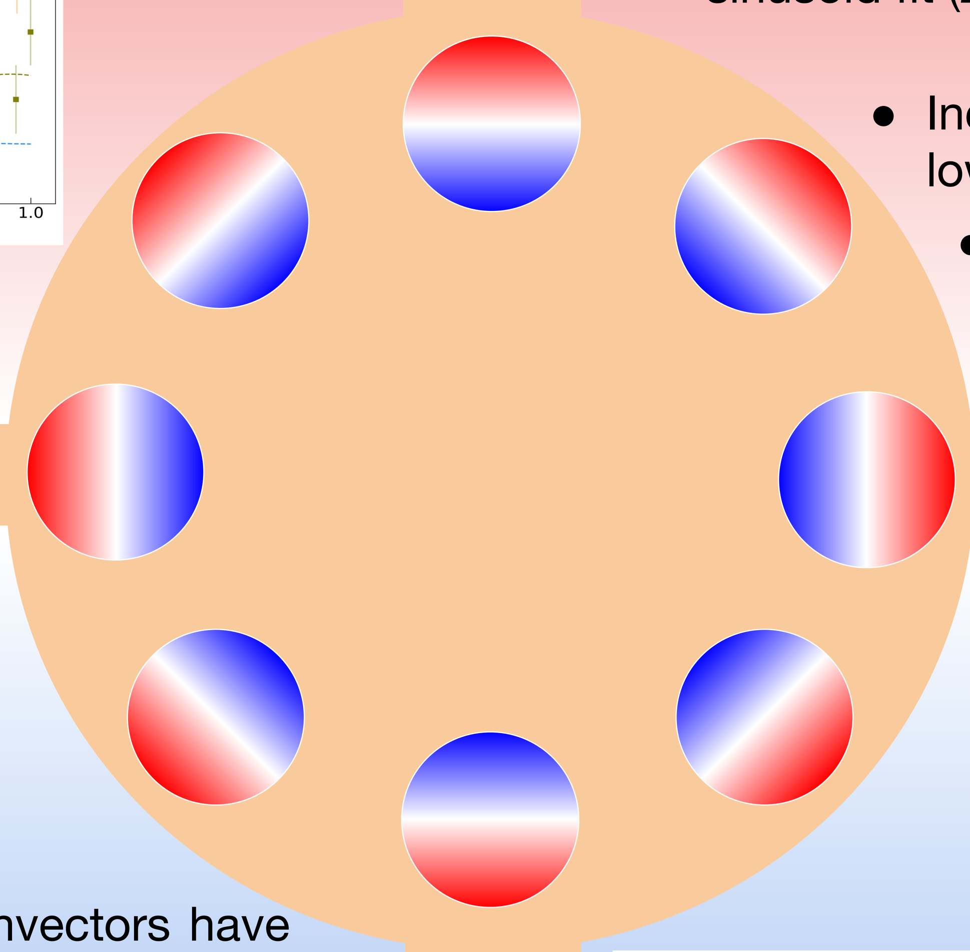
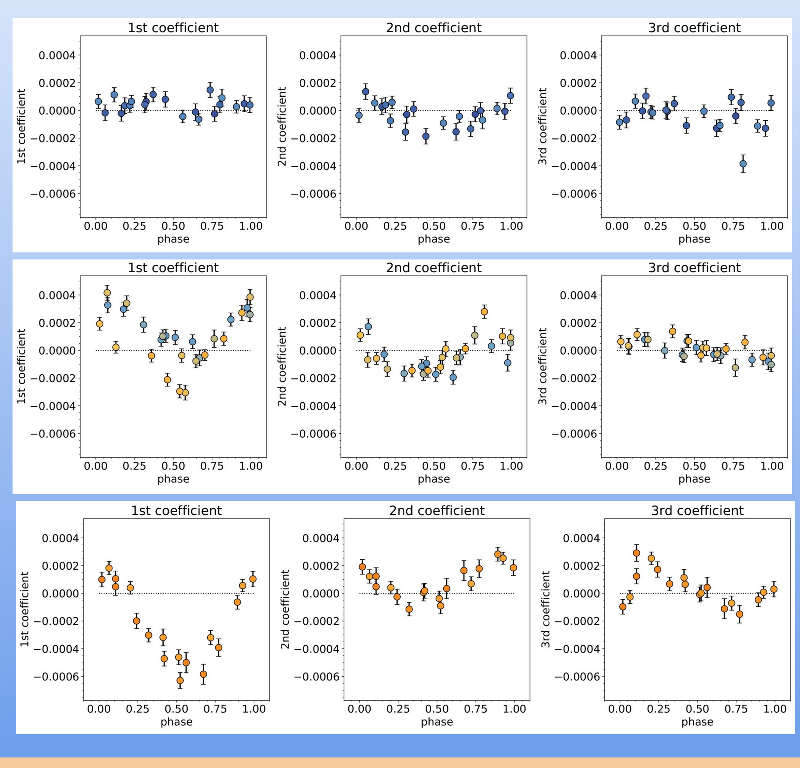


Fig 2. Phase-folded FWHM curves using full and high-g_{eff} masks for near-infrared epochs: 2019a (top), 2019b2020a (middle), 2020b (bottom)



Principal Component Analysis

- Apply PCA to mean-subtracted near-infrared Stokes *V* (2019-2020) to infer details on non-axisymmetric field [13, see also poster of L. T. Lehmann]



- First three eigenvectors have signals → on average field is non-axisymmetric
- Variations in the coefficients are more sinusoidal and amplified → large-scale field is dipolar and its axisymmetry decreases over time

Fig 3. Evolution of PCA coefficients for the first three eigenvectors over the near-infrared epochs: 2019a (top), 2019b2020a (middle) and 2020b (bottom).

Zeeman-Doppler Imaging

- Reconstruction of the large-scale magnetic field topology by means of a maximum-entropy algorithm
  - The geometry is poloidal (magnetic energy fraction >90%) and dipolar (>70%), as in 2006-2016 observations
  - Axisymmetry decreases from >85% to 48% in 2020b and tilt angle increases from 15° to 56° accordingly

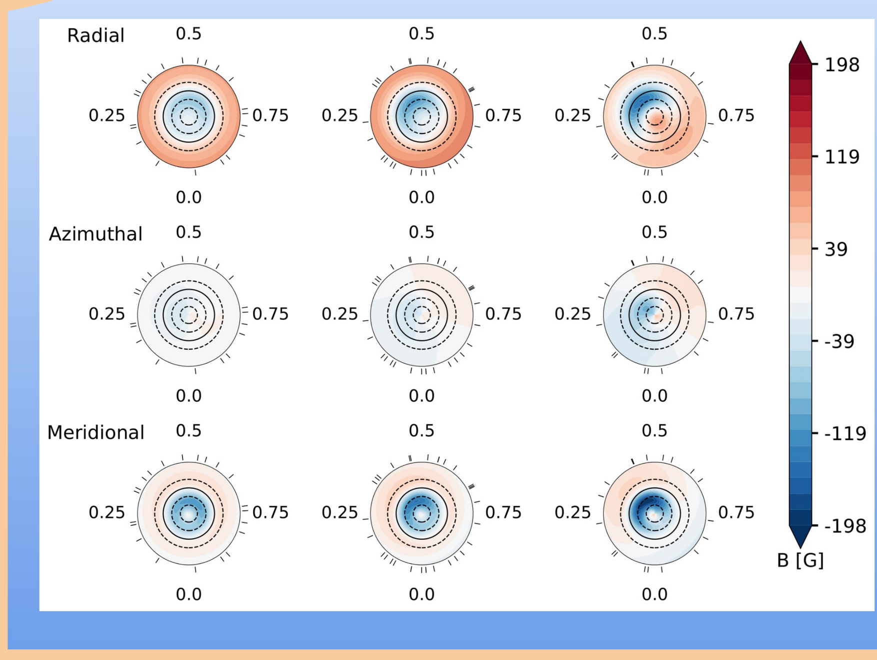


Fig 4. Evolution of ZDI map over near-infrared epochs: 2019a (left), 2019b2020a (middle) and 2020b (right). The magnetic maps are in flat polar view, with the north pole at the center and the equator marked by a solid line

Conclusions

- Decreasing axisymmetry of the large-scale field confirmed by different techniques
- Global evolution of the large-scale field of AD Leo possibly suggesting a magnetic cycle, in the strong aligned dipole category
- Difference of longitudinal and ZDI field strength between near-infrared and optical domains, to be further investigated

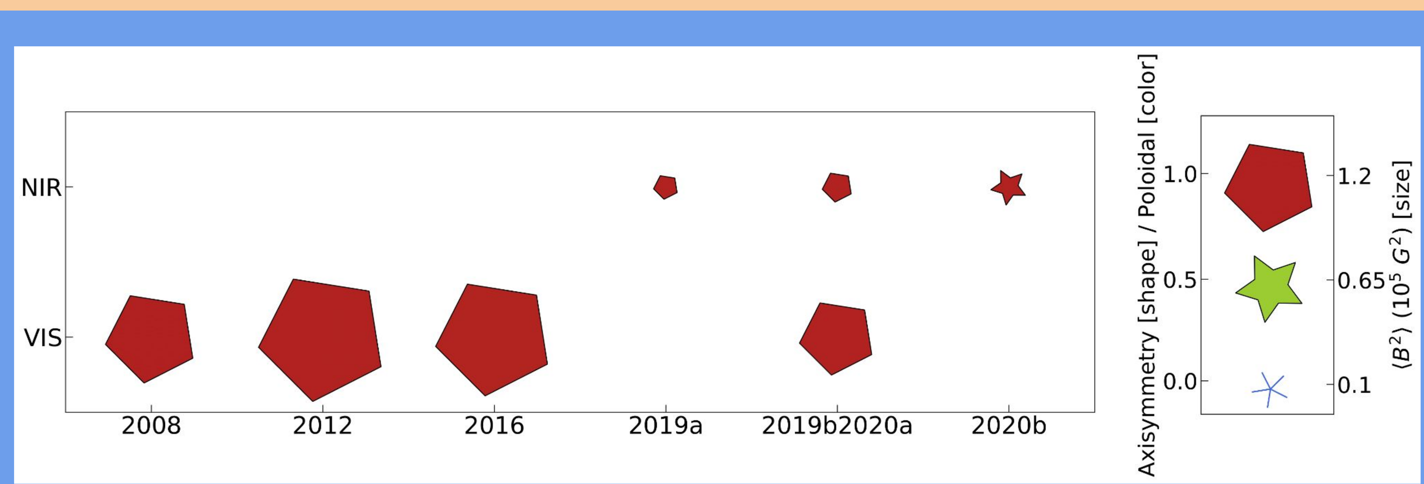


Fig 5. Evolution of the magnetic field topology over 14 years. While the field remains poloidal and dipolar, its secular variation is manifested by a reduced axisymmetry and changing field strength

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