

# Towards a unified observational view of cool-star magnetism

**Oleg Kochukhov**

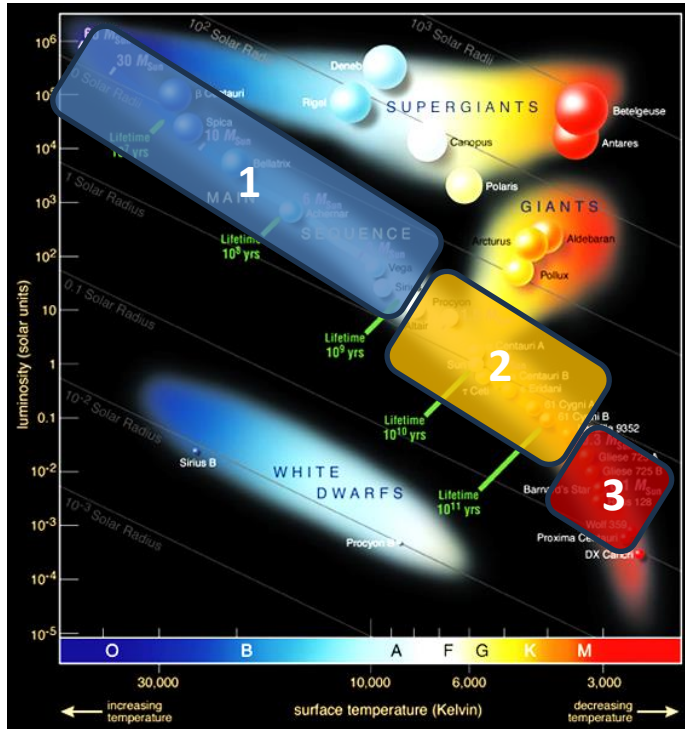
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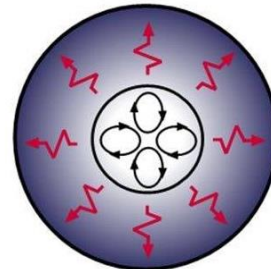
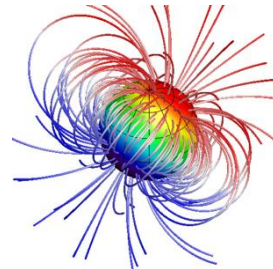
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# Stellar magnetism

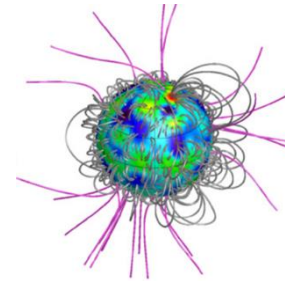


**Fossil (10%)**  
Large-scale fields

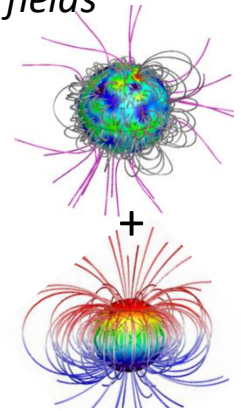


**1**  
 $M > 1.5$   
Convective Core  
Radiative Envelope

**Dynamo (100%)**  
Multi-scale fields



**2**  
 $0.5 < M < 1.5$   
Radiative Core  
Convective Envelope



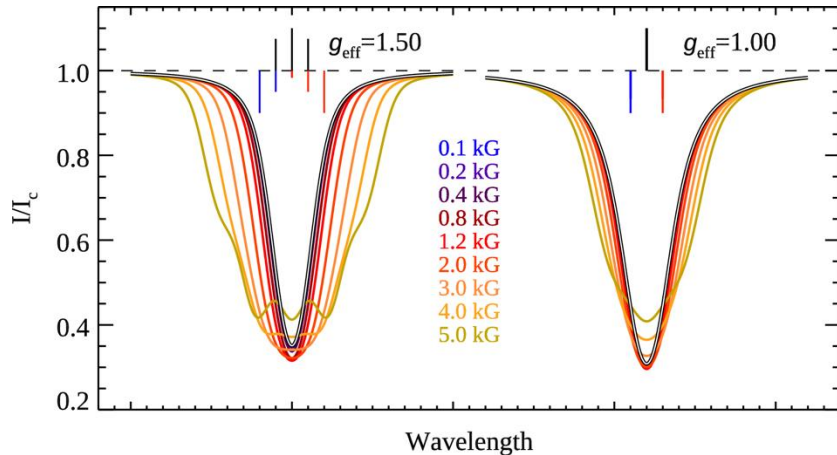
**3**  
 $M < 0.5$   
Fully Convective

# Stellar magnetometry: principles

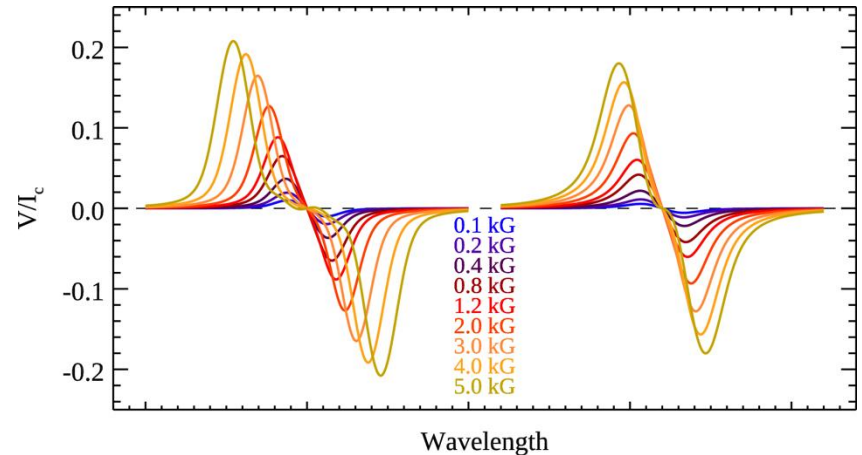
**Zeeman broadening and intensification:** total field strength ( $\gtrsim 100$  G), no topology

**Spectropolarimetry:** global field topology ( $\gtrsim 1$  G), local field cancellation

$$\Delta\lambda_Z \propto |B|g_{\text{eff}}\lambda_0^2$$

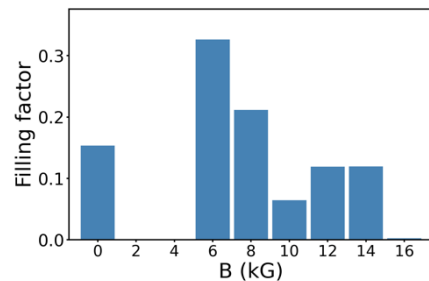
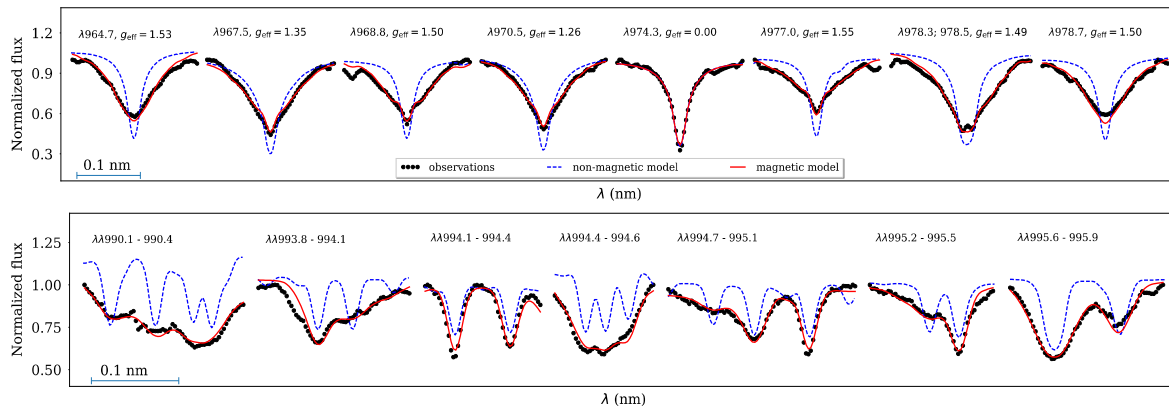


$$V \approx B_{\text{los}}g_{\text{eff}}\lambda_0 \frac{dI}{d\lambda}$$



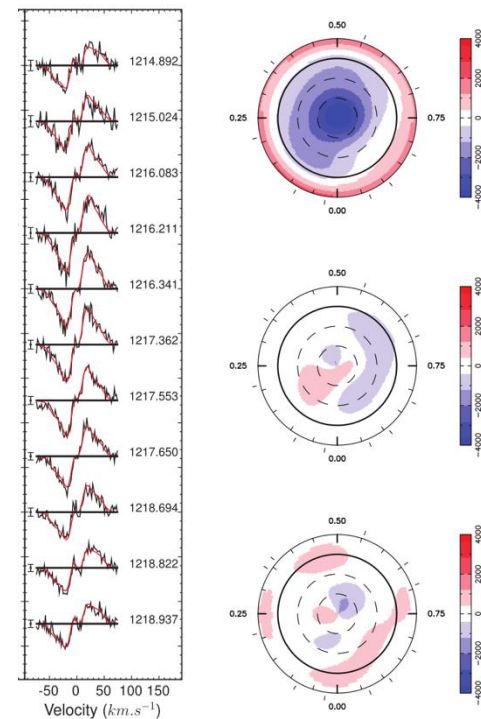
# Stellar magnetometry: examples

## Small-scale field (Shulyak+ 2017)



M6 dwarf WX UMa (GJ 412B):  
Small-scale:  $\langle B \rangle = 7.5$  kG  
Large-scale: 1.4 kG dipole

## Large-scale field (Morin+ 2010)

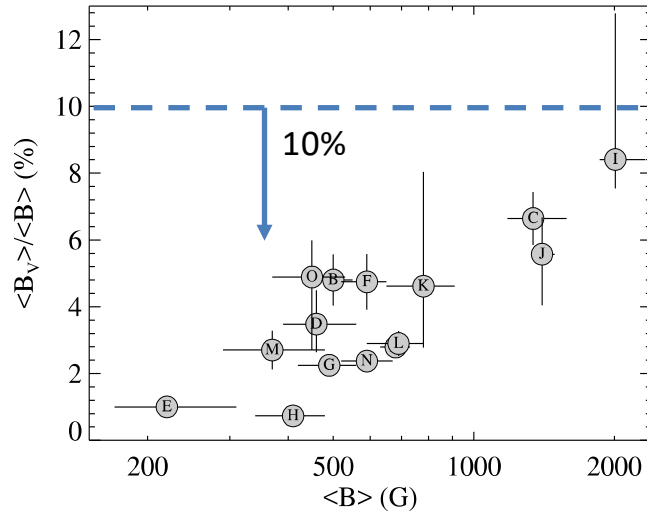


# Discrepant Zeeman diagnostics

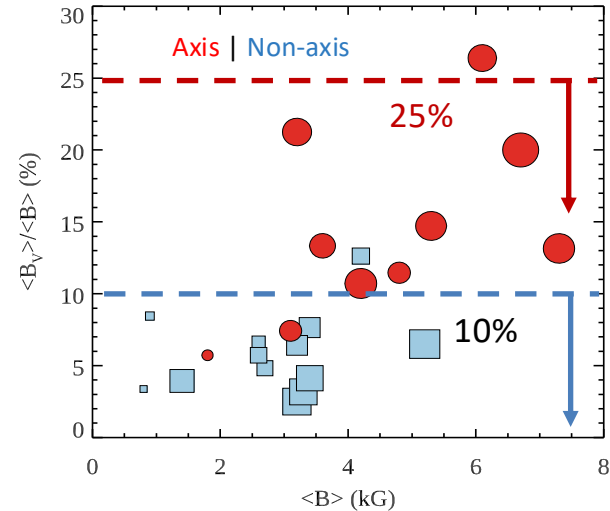
Small-scale fields are the dominant contributors to cool-star magnetism:

$$B_{\text{global}} \text{ (polarimetry)} < 0.1 \times B_{\text{total}} \text{ (Zeeman broadening)}$$

Young Sun-like stars (Kochukhov+ 2020)

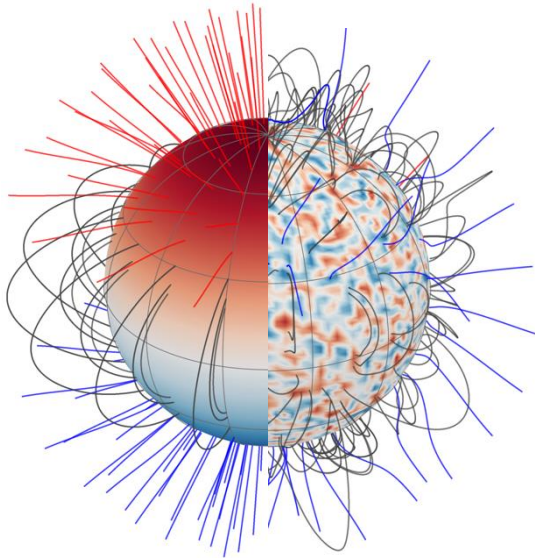


Active M dwarfs (Kochukhov 2021)



# Unified approach to cool-star magnetism

Developing new observational, modelling, and theoretical interpretation frameworks to treat multi-scale nature of cool-star magnetic fields



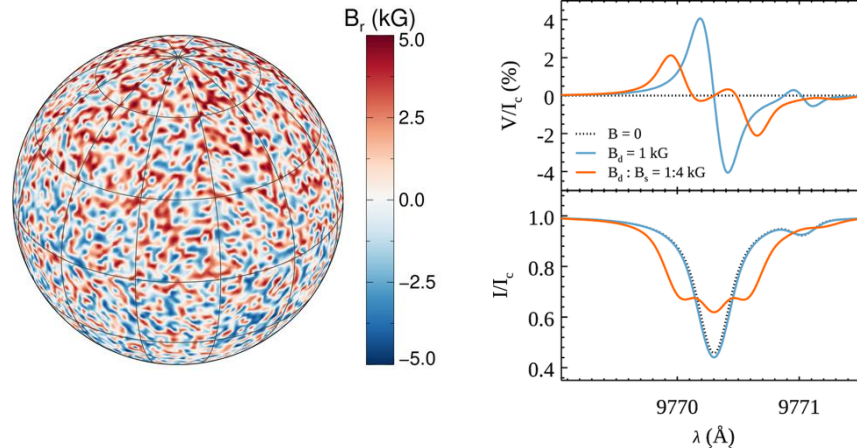
- **Observations:** Zeeman broadening and polarization analysed simultaneously in the same spectral lines
- **Modelling:** inferences based on composite field structure morphologies combining large- and small-scale fields
- **Theory:** calculating synthetic observables from realistic 3D magneto-hydrodynamic simulations of magnetic fields

Talk by I. Amateis

# Impact of small-scale fields on polarimetry

- Polarization signals corresponding to small-scale fields are cancelled out in disk-integrated stellar spectropolarimetric observations
- Small-scale fields can still have a large impact on the shape of remaining polarization signals corresponding to large-scale fields

Kochukhov (2026)

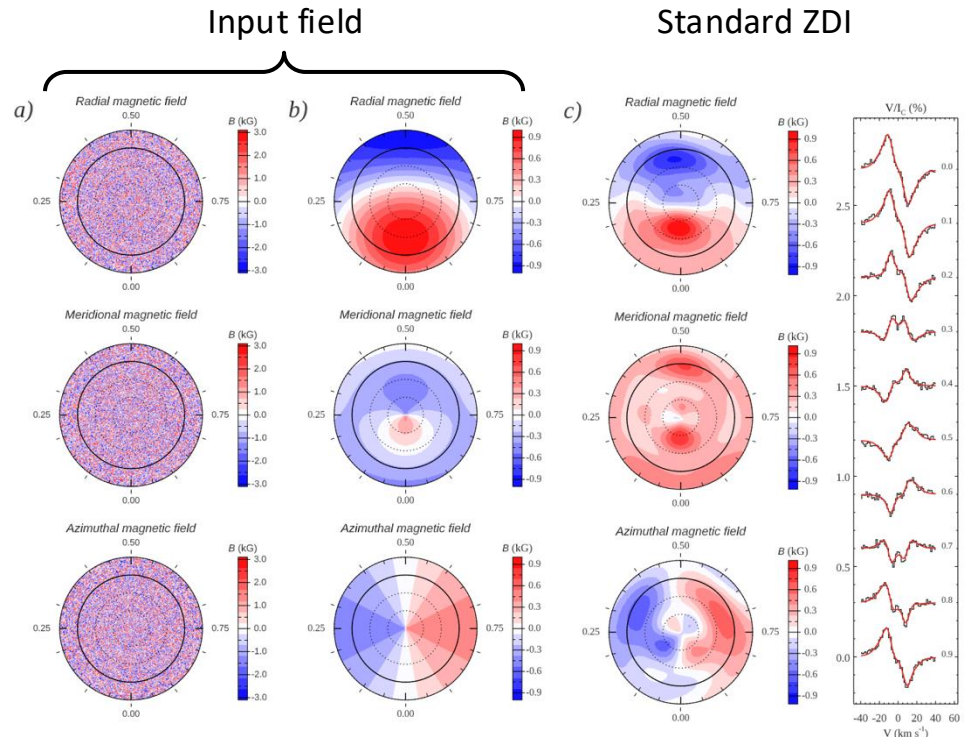


# Impact of small-scale fields on ZDI

## Testing LSD + ZDI inference pipeline

1. Adopt small-scale + global field
2. Calculate full Stokes  $IQUV$  spectra in the 0.9-2.5 micron range
3. Calculate LSD profiles
4. Run ZDI inversions with/without accounting for small-scale field

Kochukhov (2026)



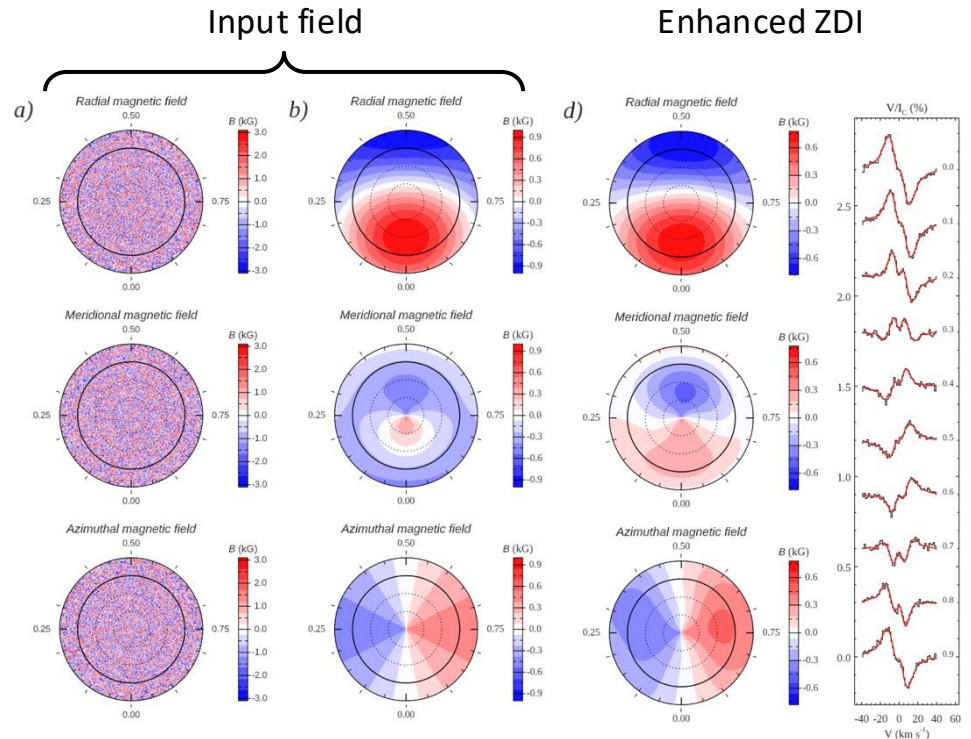
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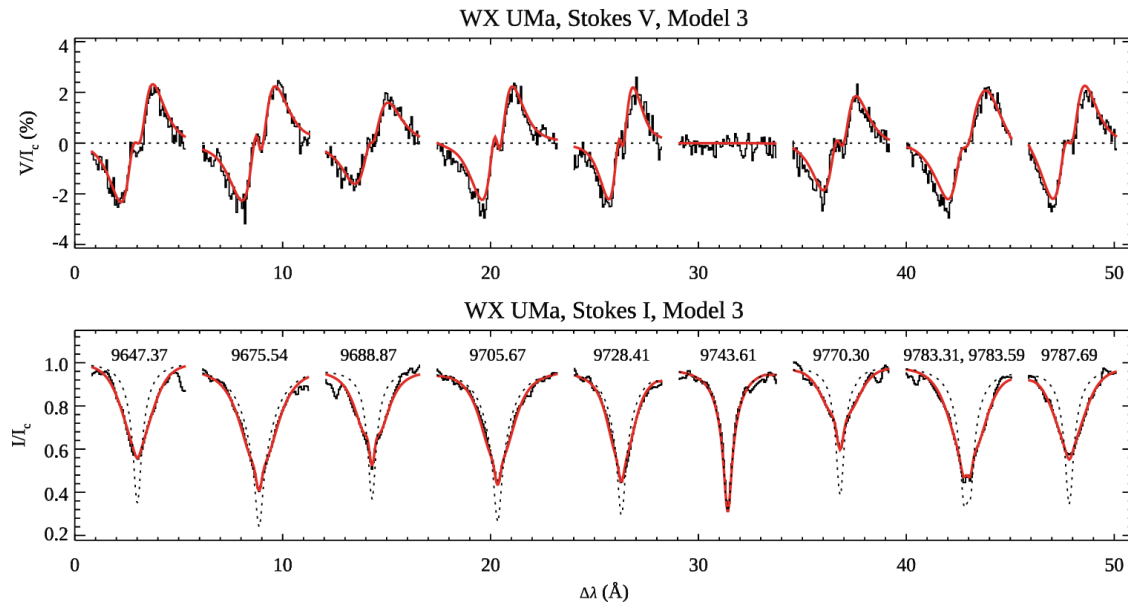
Kochukhov (2026)

Standard ZDI can lead to misleading results for active M dwarfs!

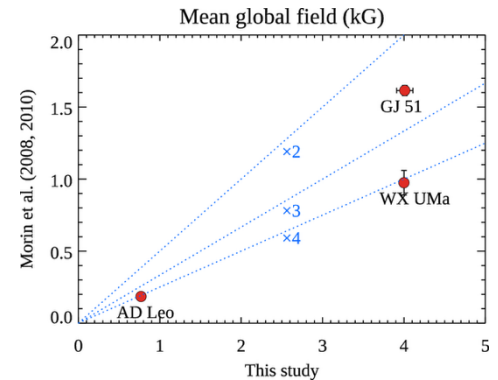


# Multi-model magnetic inference

Unified Stokes  $I$  and  $V$  inference for several M dwarfs with axisymmetric global fields yields 2-4 times stronger dipolar fields than in previous analyses



Small-scale:  $\langle B \rangle = 7.8$  kG  
Large-scale: 5.8 kG dipole



# Take-home message

- Cool-star magnetic fields have complex, multi-scale structure
  - Large-scale fields: measured with spectropolarimetry
  - Small-scale fields: dominate Zeeman broadening diagnostics
- Large-scale fields  $\ll$  small-scale fields
- Unified magnetic diagnostics are starting to be explored
  - Polarization profiles are strongly affected by small-scale fields in  $>1$  kG regime
  - ZDI accounting for small-scale fields is important for active M dwarfs