Investigating the young AU Mic system with SPIRou: stellar magnetic field and close-in planet mass

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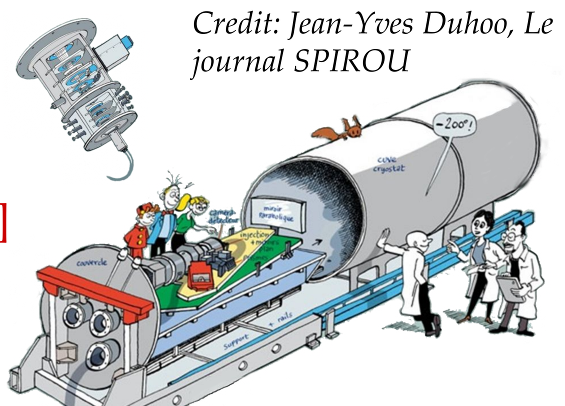
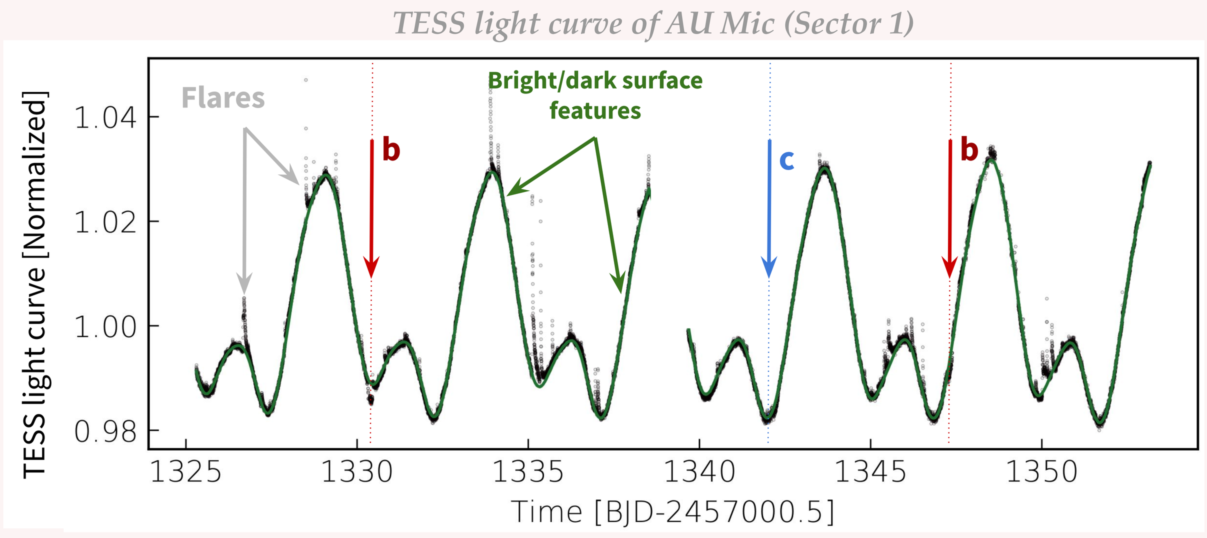
Goals: Velocimetric mass measurement for the 22 Myr-old planet AU Mic b with SPIRou
Spectropolarimetric analysis of the stellar magnetic field and activity

Interest of observing AU Mic with SPIRou



Name: SpectroPolarimètre InfraRouge [1]
Spectral Band: YJHK (0.98 - 2.35μm)
Resolution: 70 000
RV precision: <2 m/s (goal: 1 m/s)
Observations started in Feb. 2019
Location: Canada France Hawaii Telescope (CFHT)
Targets: M dwarfs, Pre-Main Sequence stars (PMS)

TESS light curve of AU Mic (Sector 1)



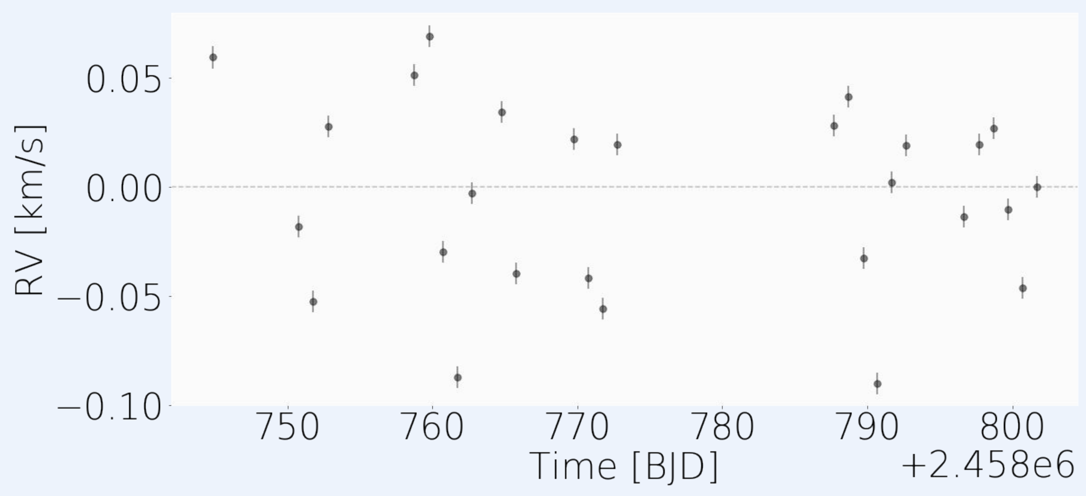
AU Microscopii / AU Mic
Second closest PMS star

→ 22 Myr-old M1 dwarf in the β-Pic moving group
→ Resolved edge-on disk with fast moving structures
→ Intense magnetic activity: quasi-periodic fluctuations of 5% in TESS photometry and **>100 m/s** in HARPS velocimetry [2]
→ 2 close-in transiting Neptune-sized planets from TESS/Spitzer light curves ([2],[3]). **Mass unknown for both planets.**

SPIRou velocimetric capabilities → Measure close-in planet mass (bright star + stellar activity signals weaker in the nIR than in the optical)
SPIRou spectropolarimetric capabilities → Investigate large- and small-scale magnetic fields and associated activity

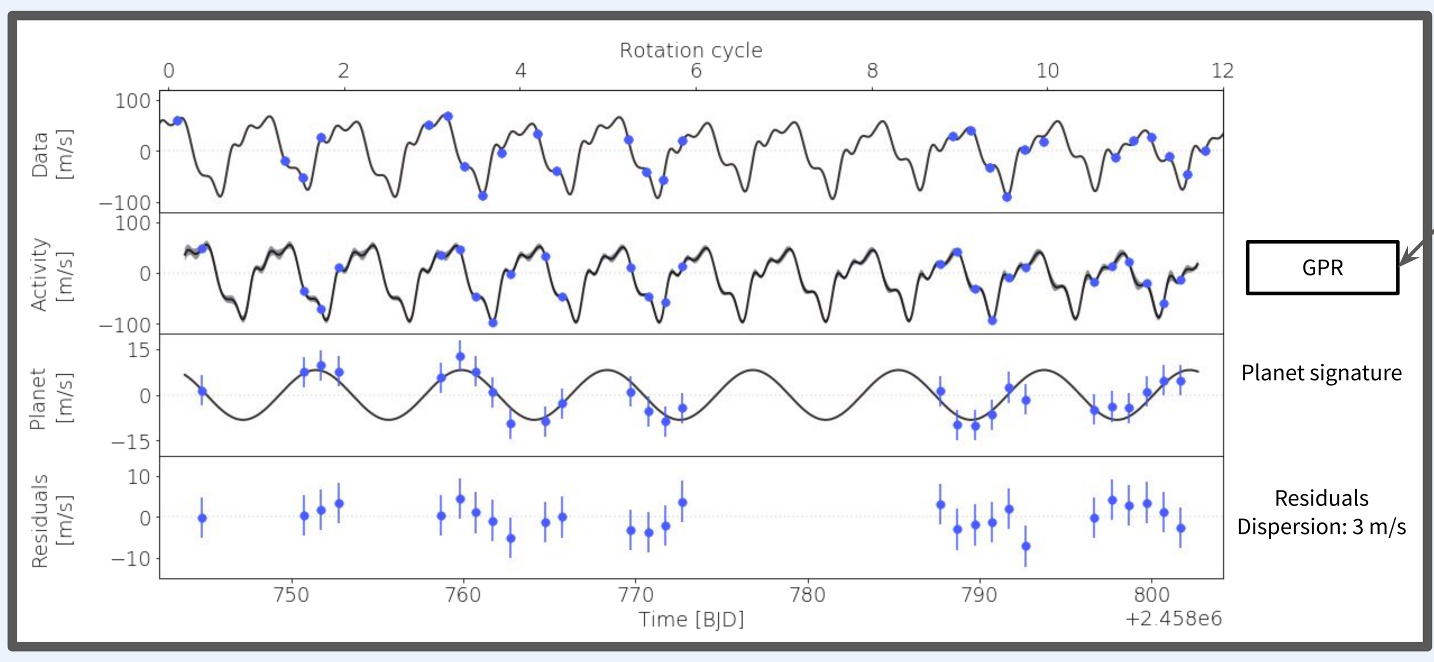
Velocimetric analysis of AU Mic with SPIRou

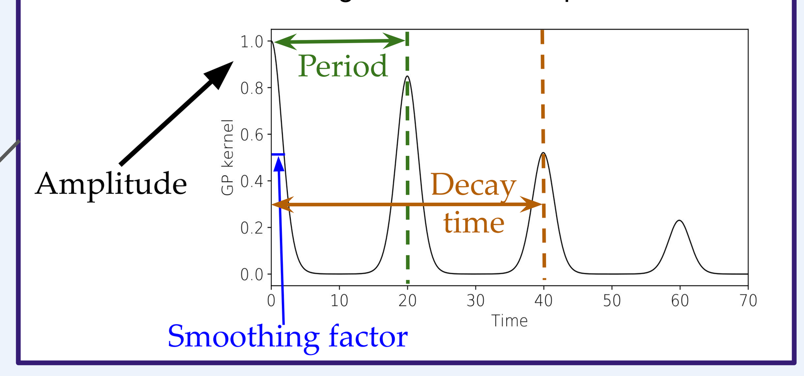
27 observations → Sep. - Nov. 2019
Dispersion of the RVs: **45 m/s**
RV uncertainty: 5 m/s
2.5x lower than HARPS !



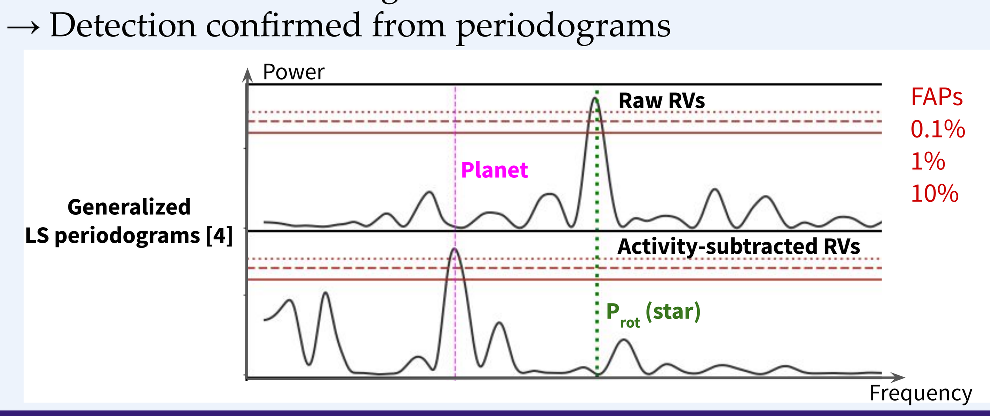
Model $V_r(t) = V_j(t) + V_p(t) + \epsilon(t)$

Stellar activity RV signal; Planet signature — Circular orbit phased with transit; Uncorrelated noise $\sigma_{rv} = 5$ m/s



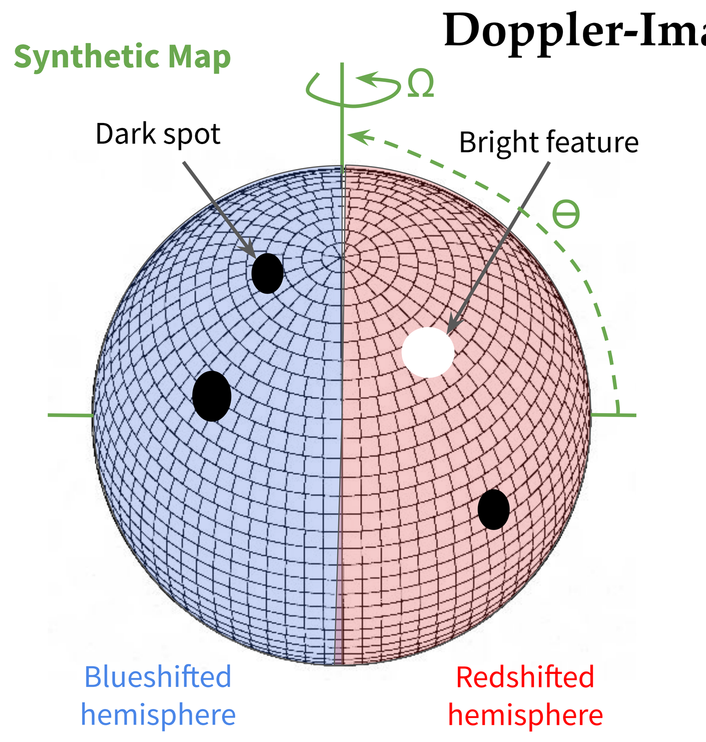


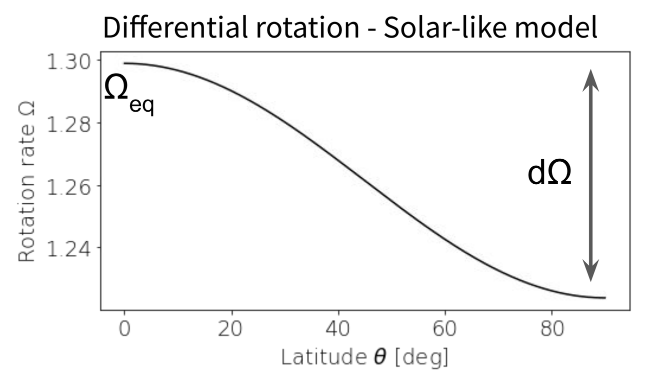
3.9σ detection of AU Mic b -- Mass: $17.1^{+4.7}_{-4.5}\,M_\oplus$ ~ Neptune
→ Phased with transit signal
→ Detection confirmed from periodograms



Unveiling the close-in planet using Doppler Imaging

Doppler-Imaging (DI, [5])



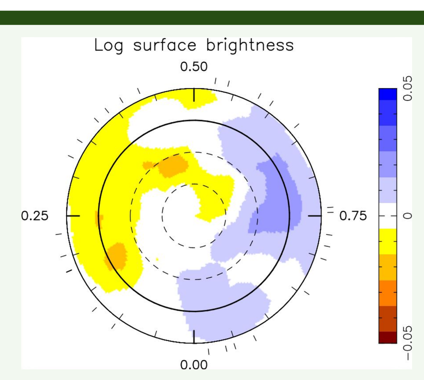


General principle

→ DI inverts time series of line profiles into brightness distribution

→ Maximum entropy regularization: **Synthetic map with the minimum information**

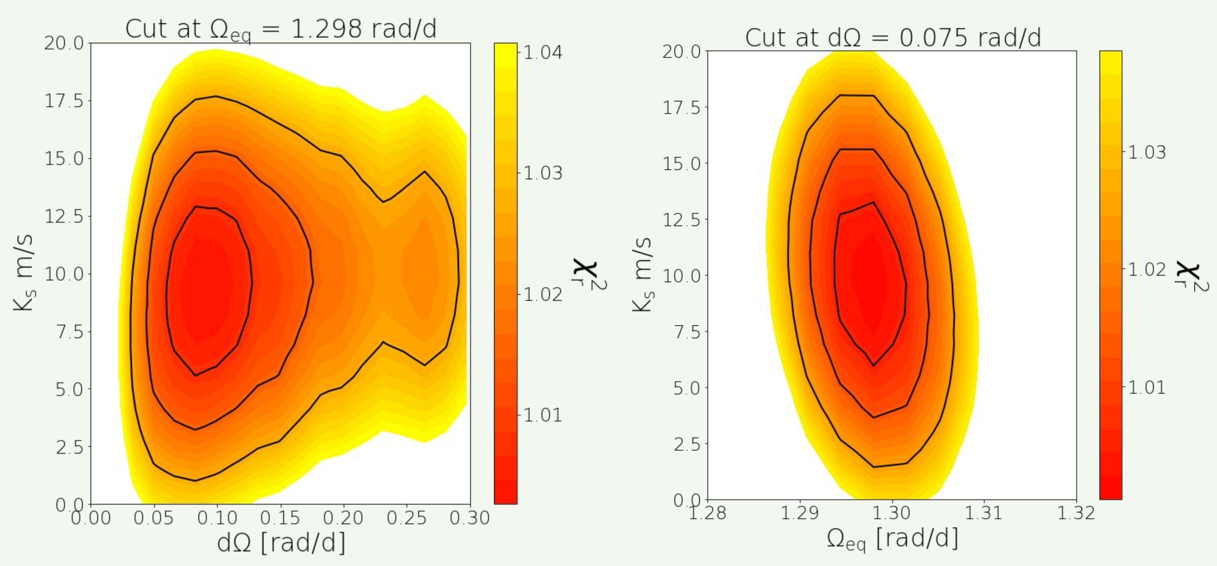
Goal: independent planet detection from the average line profiles
→ Couple Doppler Imaging (profile distortions) and planet model (profile shift)
→ Grid of DR parameters and semi-amplitude K_s of planet RV signature
→ Shift profile + DI reconstruction to given entropy level → **χ^2 map**



Results

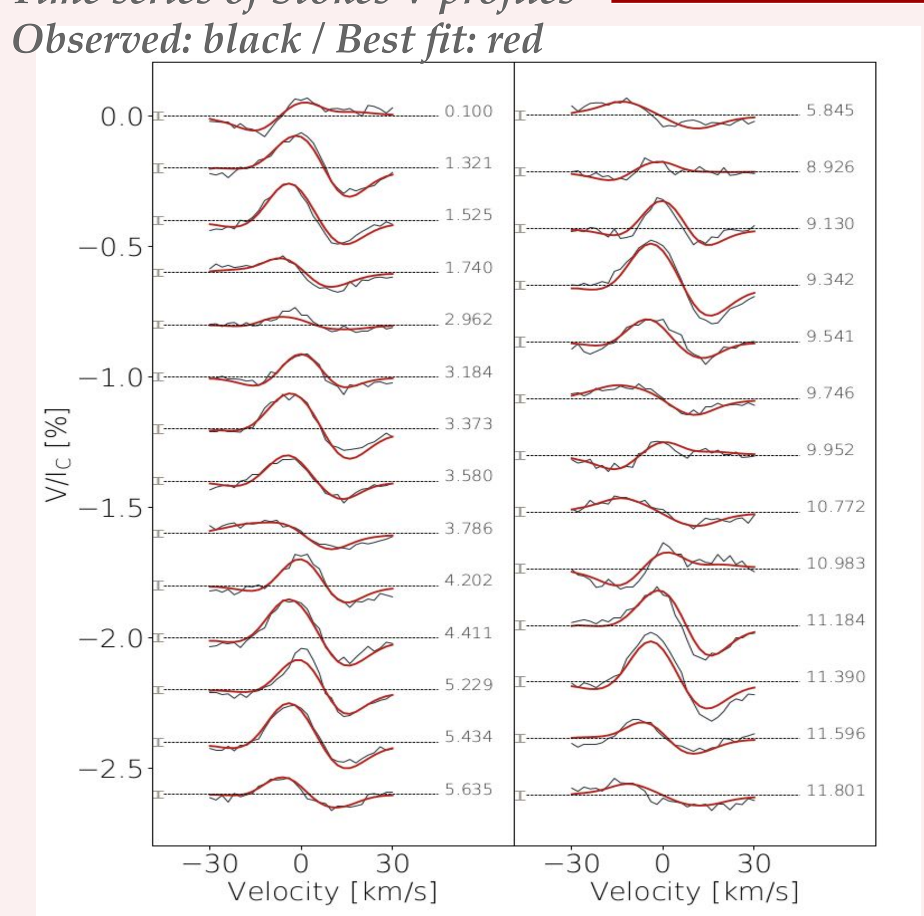
→ Detection of AU Mic b → Mass: **19.1+/-5.1 $M_\oplus$**
Mass consistent with RV detection !

→ Solar-like DR at the solar level
Ω_{eq} = 1.298 +/- 0.003 rad/d
$d\Omega$ = 0.075 +/- 0.031 rad/d



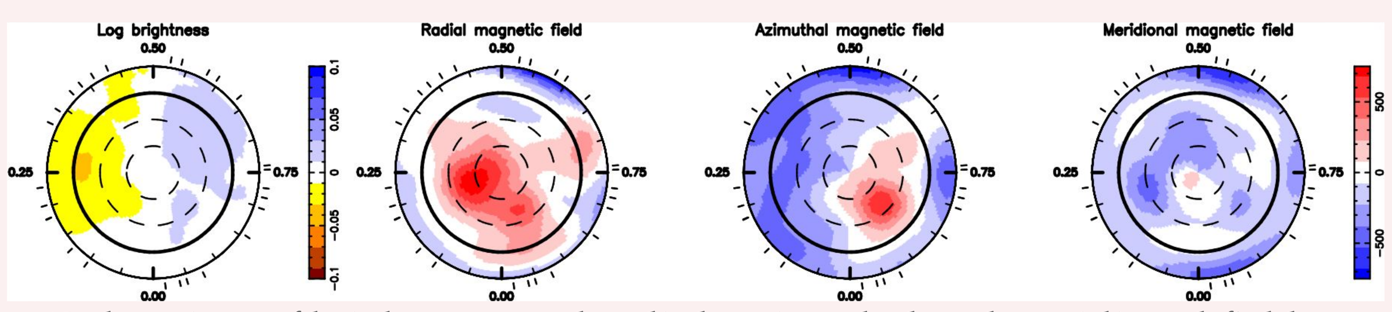
Spectropolarimetric analysis of AU Mic with SPIRou

Time series of Stokes V profiles
Observed: black / Best fit: red



Zeeman-Doppler Imaging (ZDI, [5])

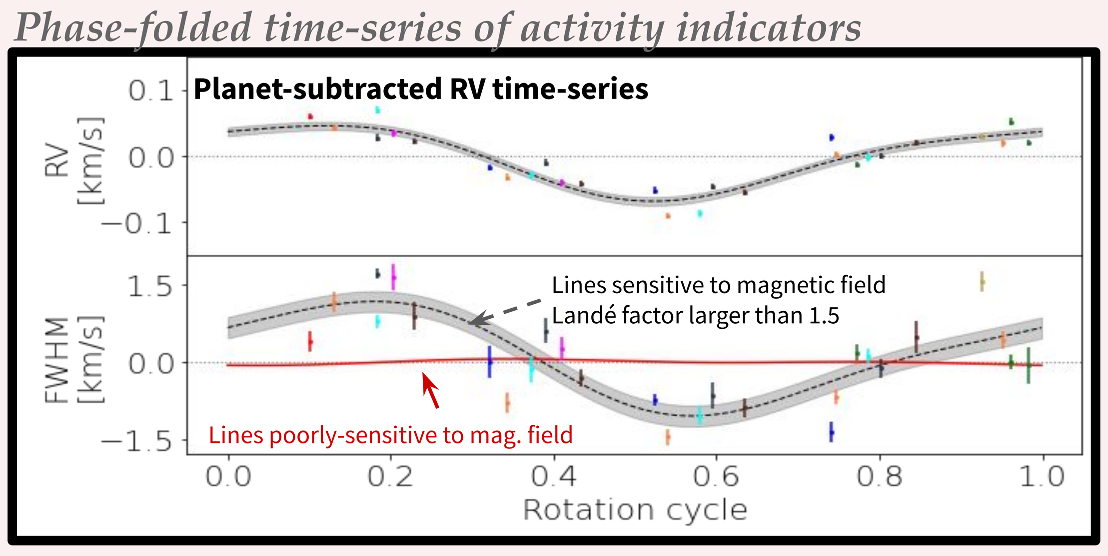
→ Inverts circularly-polarized Zeeman signatures into maximum entropy distribution of large-scale magnetic field vector
→ **Field of 475 G, mainly poloidal and axisymmetric**
→ Extended magnetosphere dipolar → Input for stellar wind geometry computation with MHD simulations (Kavanagh+, submitted)
→ **Differential rotation detected** from large-scale magnetic field:
$d\Omega$ = 0.167 +/- 0.009 rad/d (2x larger than in DI)
Ω_{eq} = 1.344 +/- 0.002 rad/d (different layer in brightness / field mag)



Polar view of brightness, and radial, azimuthal and meridional field

Magnetic activity of AU Mic

Phase-folded time-series of activity indicators



→ **Detection of Zeeman-broadening** (small-scale field)
→ Small-scale field correlates well with RVs (ρ = 0.7)
Results compatible with the Sun [6]
→ Width of lines poorly sensitive to mag. field barely modulated with P_{rot}
Stellar activity RV signals mostly of magnetic origin

Results published in MNRAS: Klein et al. 2021, MNRAS, 502, 188K / Access to the Press Release

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References: [1]Donati et al. 2020, MNRAS, 498, 5684 [2]Plavchan et al. 2020, Nature, 582, 497P [3] Martioli et al. 2021, eprint arXiv:2012.13238 [4] Zechmeister & Kürster 2009, A&A, 496, 577Z [5] Donati & Brown 1997, 326, 1135D [6] Haywood et al., 2020, eprint arXiv:2005.13386