Near-IR spectropolarimetry of the strongly accreting T Tauri star RU Lup with SPIRou

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with Jean-François Donati, Hugo Nowacki, Karine Perraut
ANR YRISS

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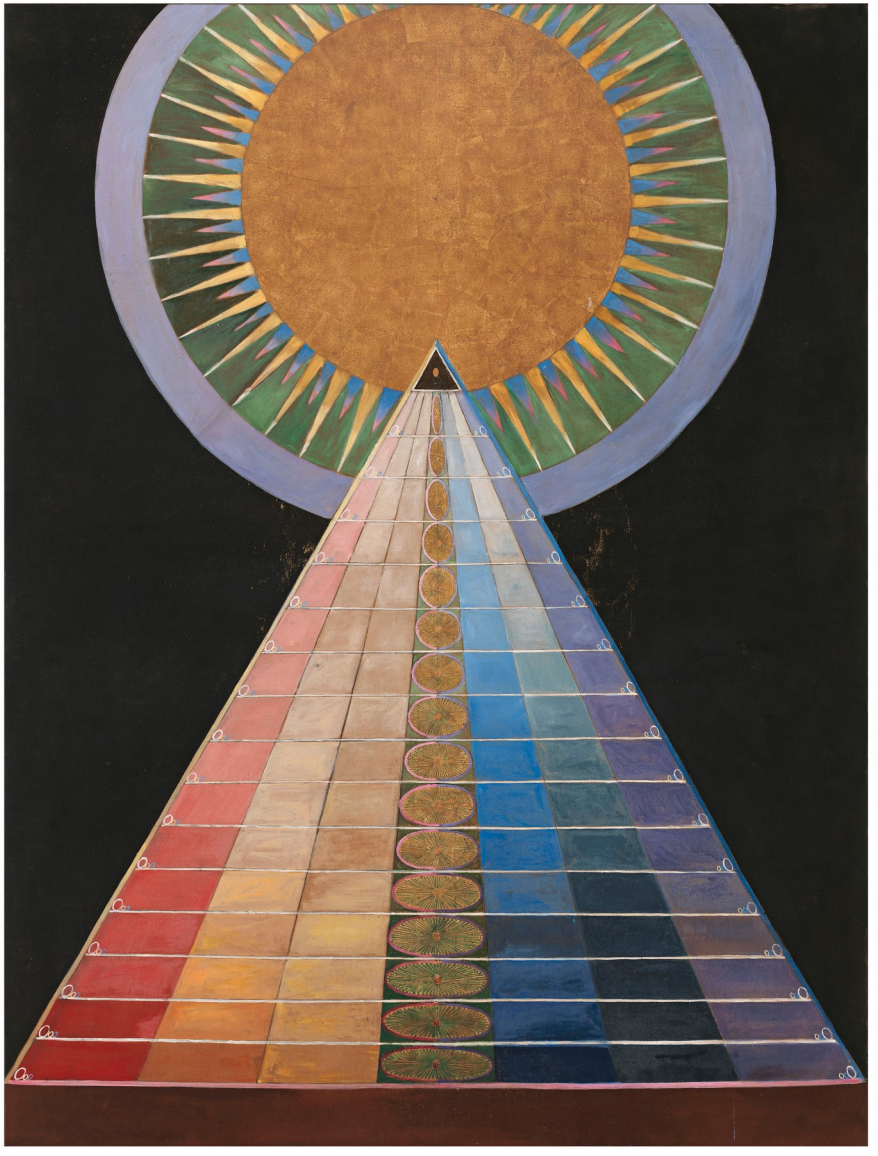

Hilma af Klint
Altarpiece, No. 1, Group X, Altarpieces, 1907

RU Lup – why do we care?

RU LUP

A classical T Tauri star

Age	**1-3 Myr**
SpT	K7
d	158.9 ± 0.7 pc
$M_\star$	0.55 ± 0.13 $M_\odot$
$i_\star$	16 ± 5°
v sin i	8.6 ± 1.4 km s^{-1}

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strongly accreting

$\dot{M}_{acc}$	**3 – 17 × 10^{-8} Msun/yr**

e.g Herczeg et al. (2005), Alcalá et al. (2014), Alcalá et al. (2017), Stock et al. (2022), Wojtczak et al. (2023), Wendeborn et al. (2024)

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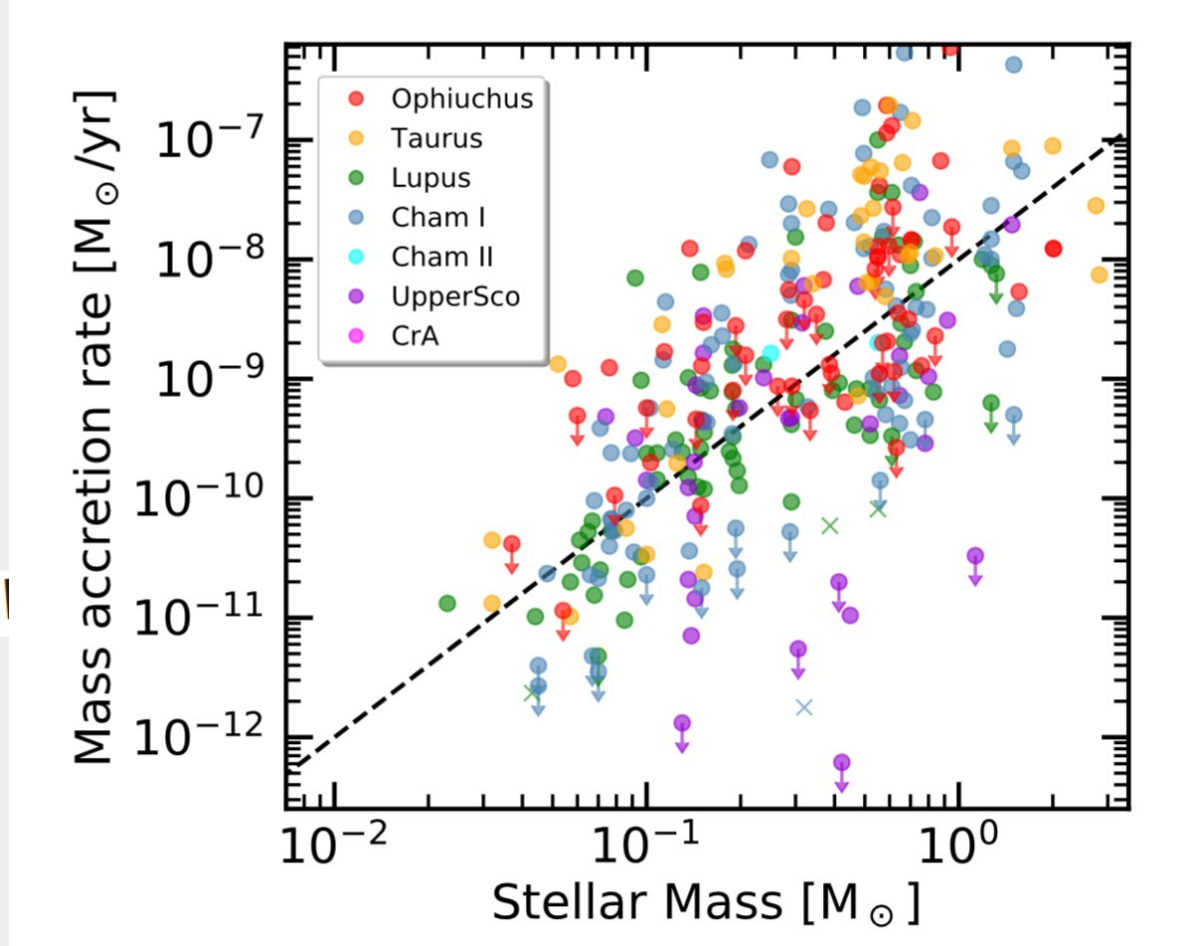

Manara et al. 2023

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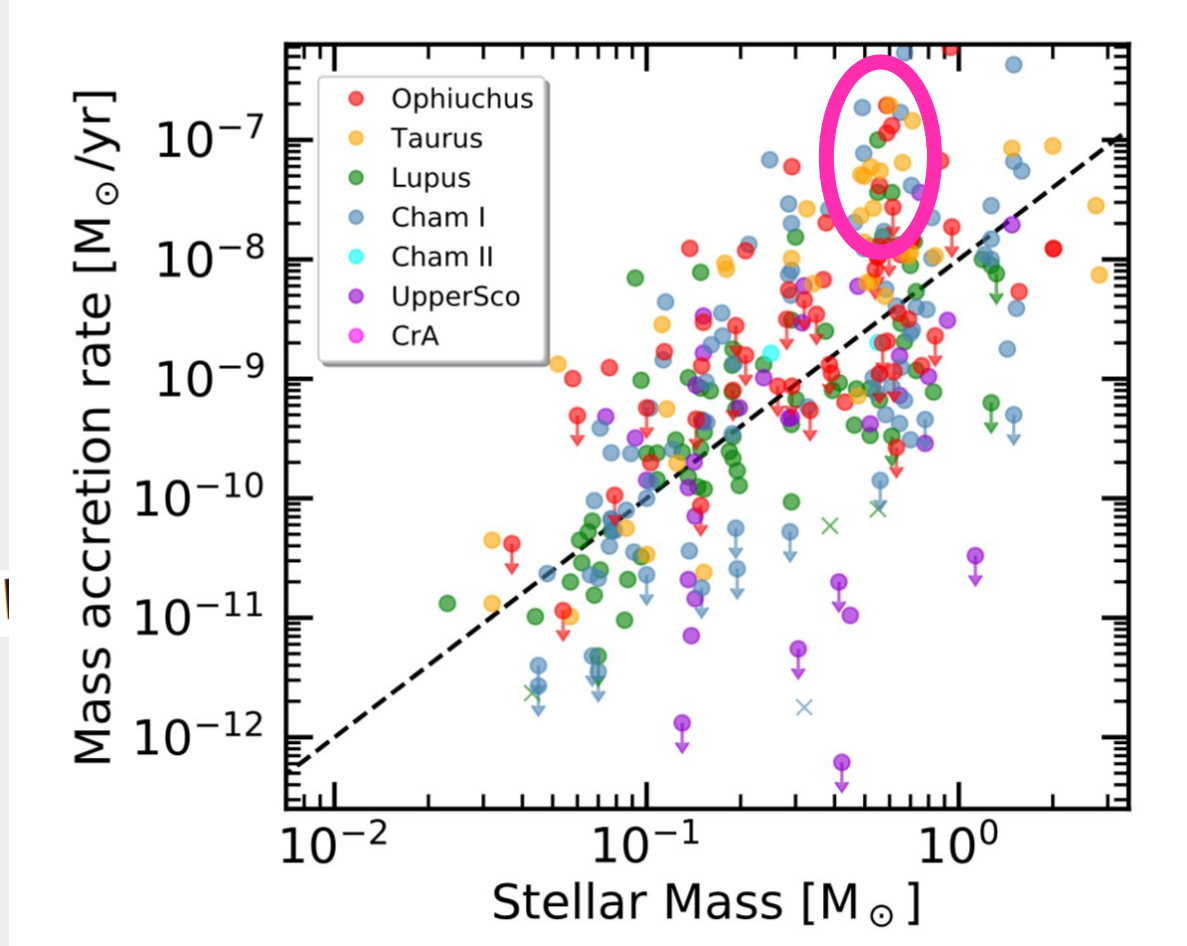

Manara et al. 2023

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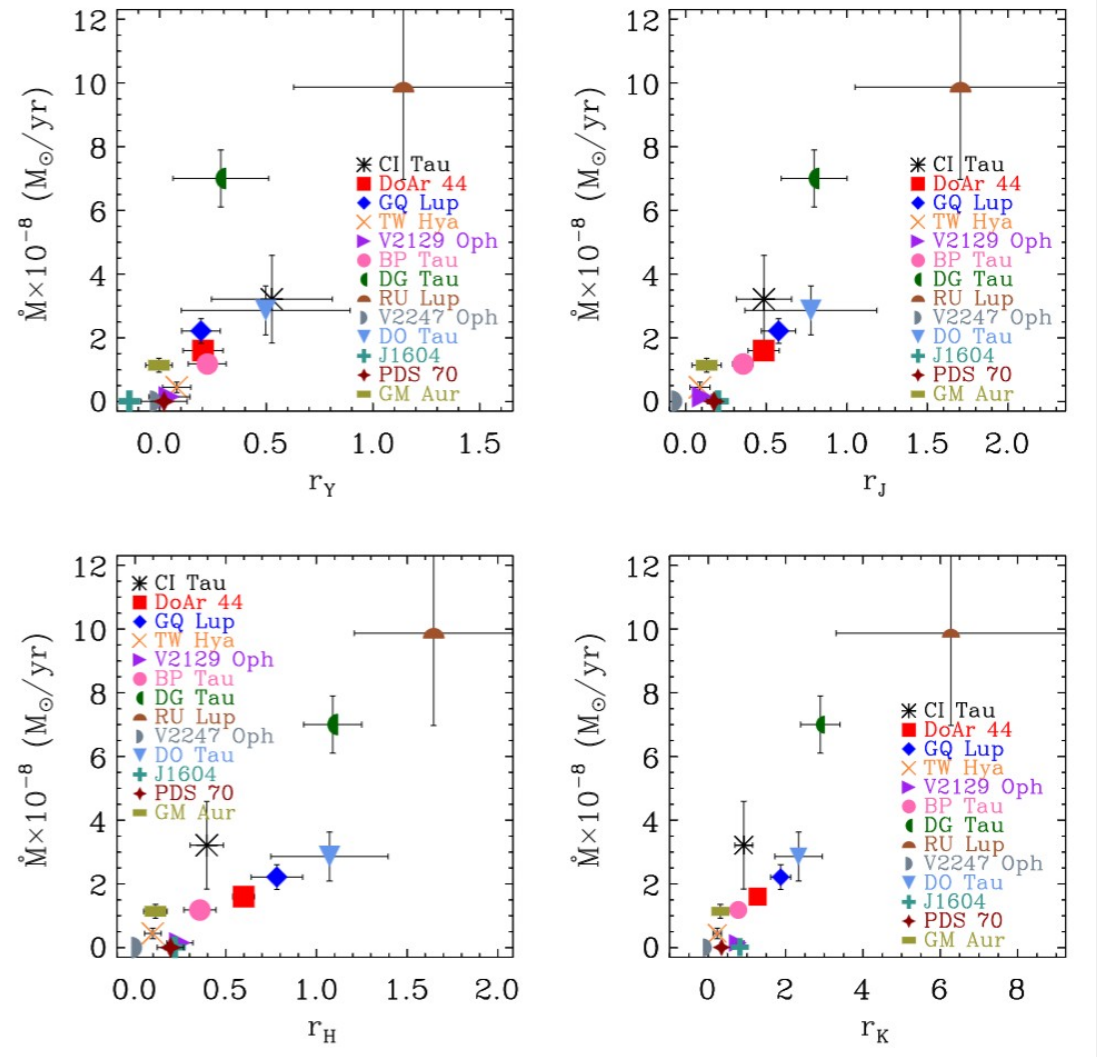
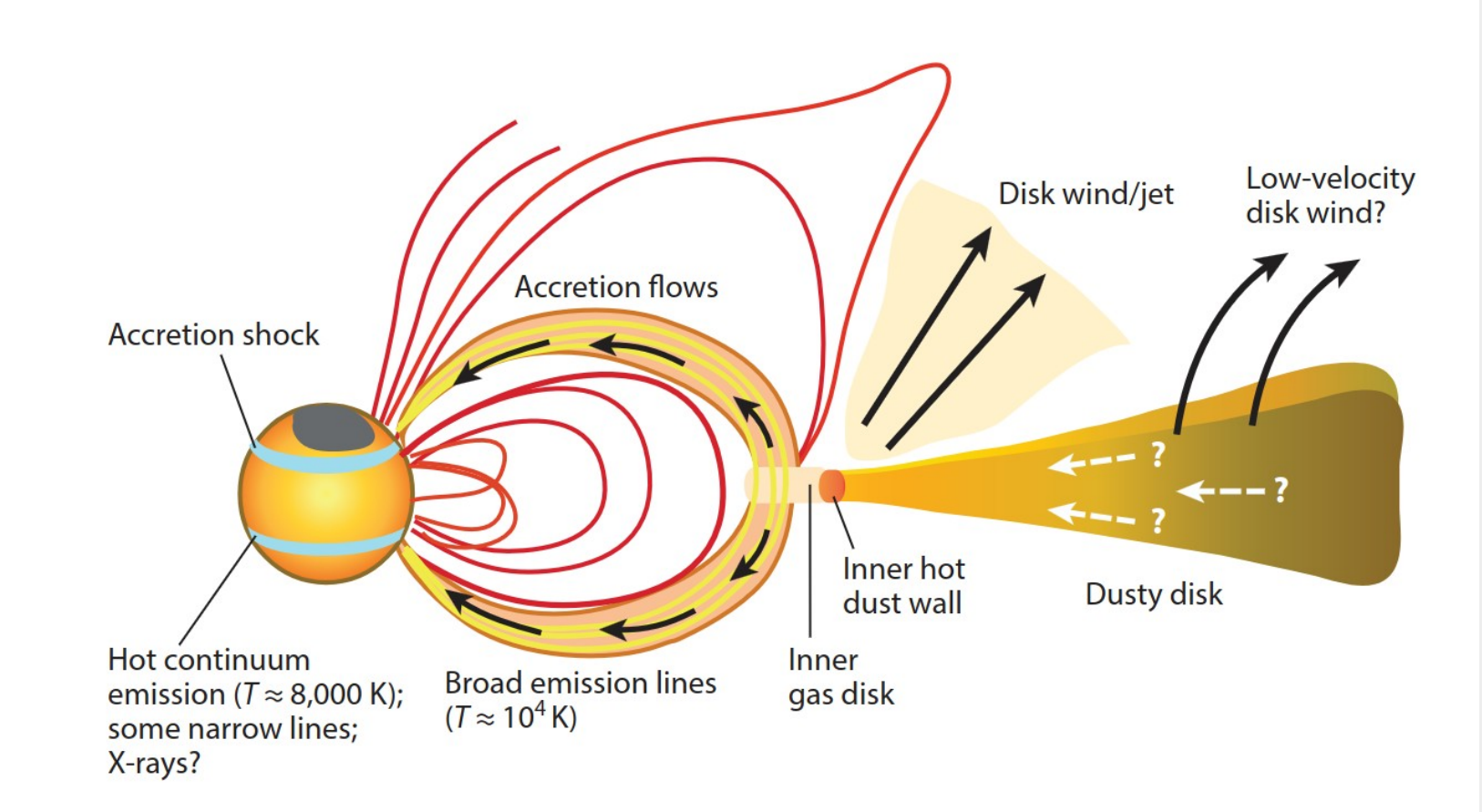
R_K	**6.3 ± 3**

Sousa et al. 2024



RU Lup – what about the magnetic field?



Hartmann, Herczeg,and Calvet (2016)

Our SPIRou spectropolarimetric observations

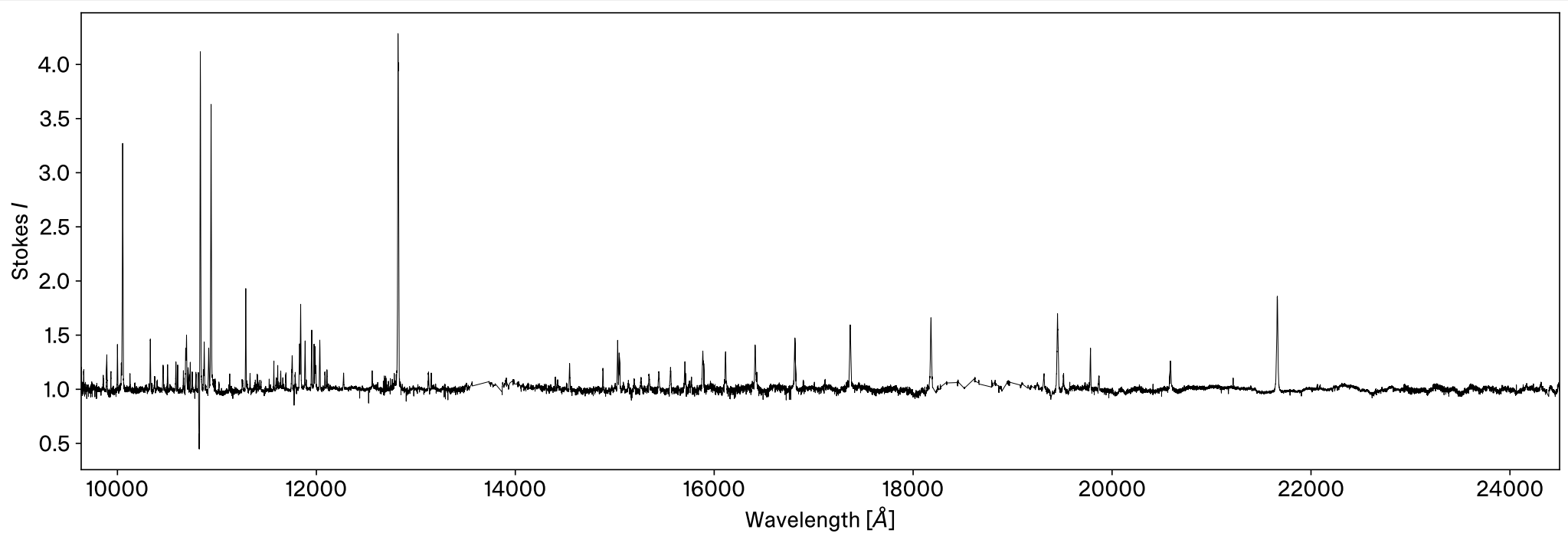
RU Lup was observed with **SPIRou** at CFHT

SPIRou: high-resolution spectropolarimeter in the near-infrared (950-2500 nm)

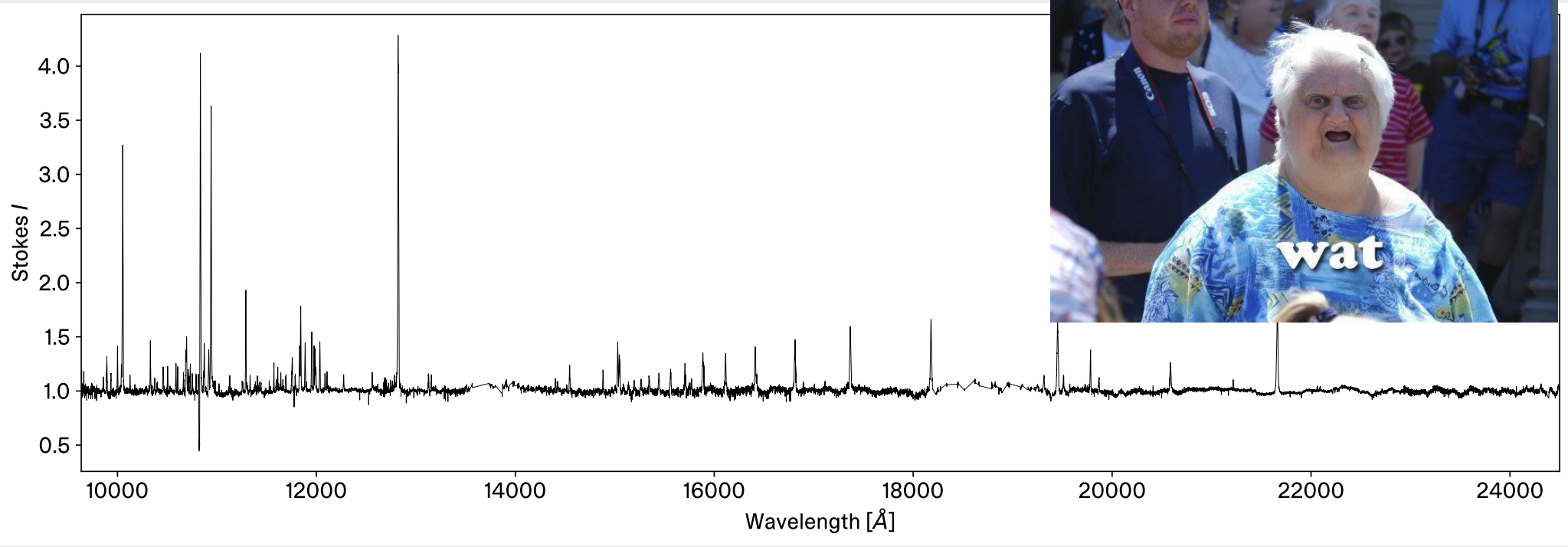
3 observing epochs:

- 2020: **9** visits between May 31 → Jul 10
- 2021: **30** visits between Jun 19 → Aug 26
- 2022: 1 visit on May 15

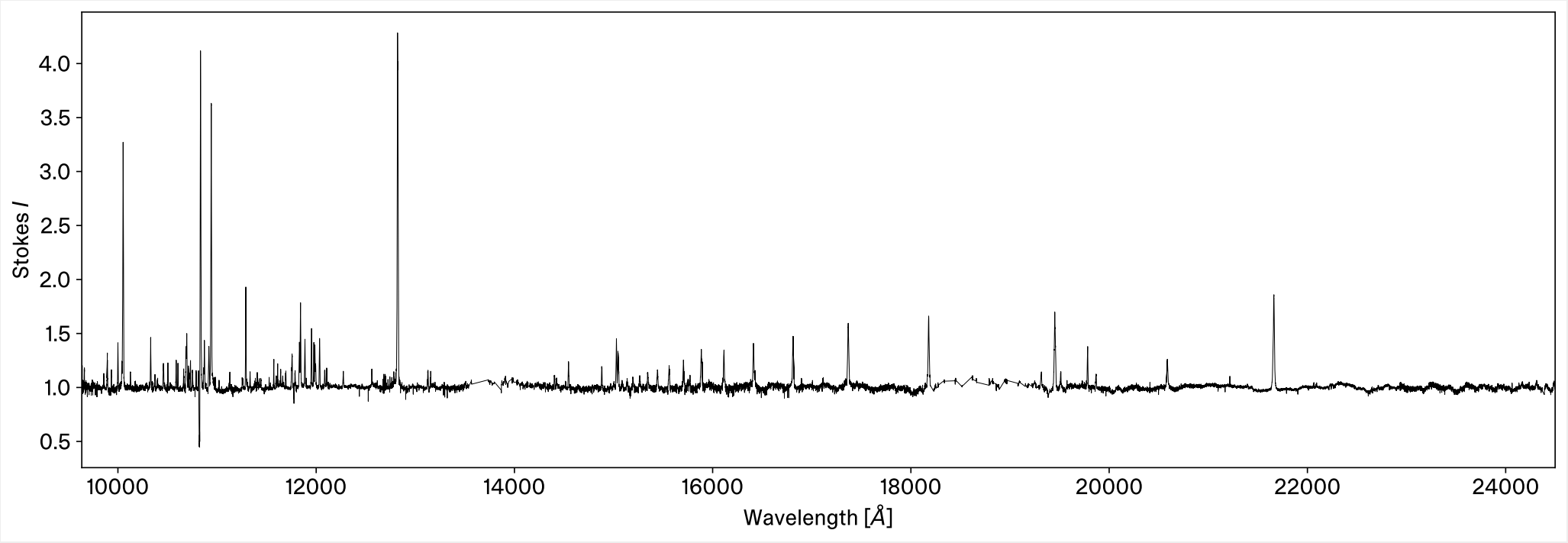
Intensity spectrum



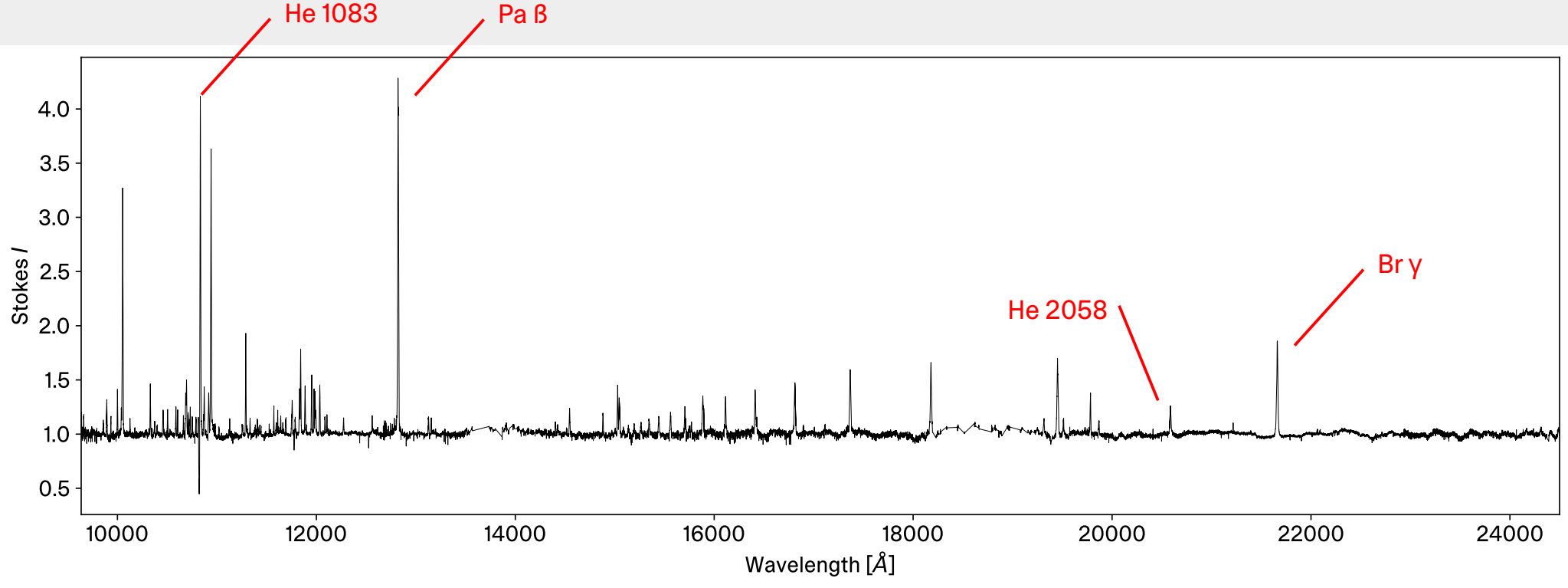
Intensity spectrum



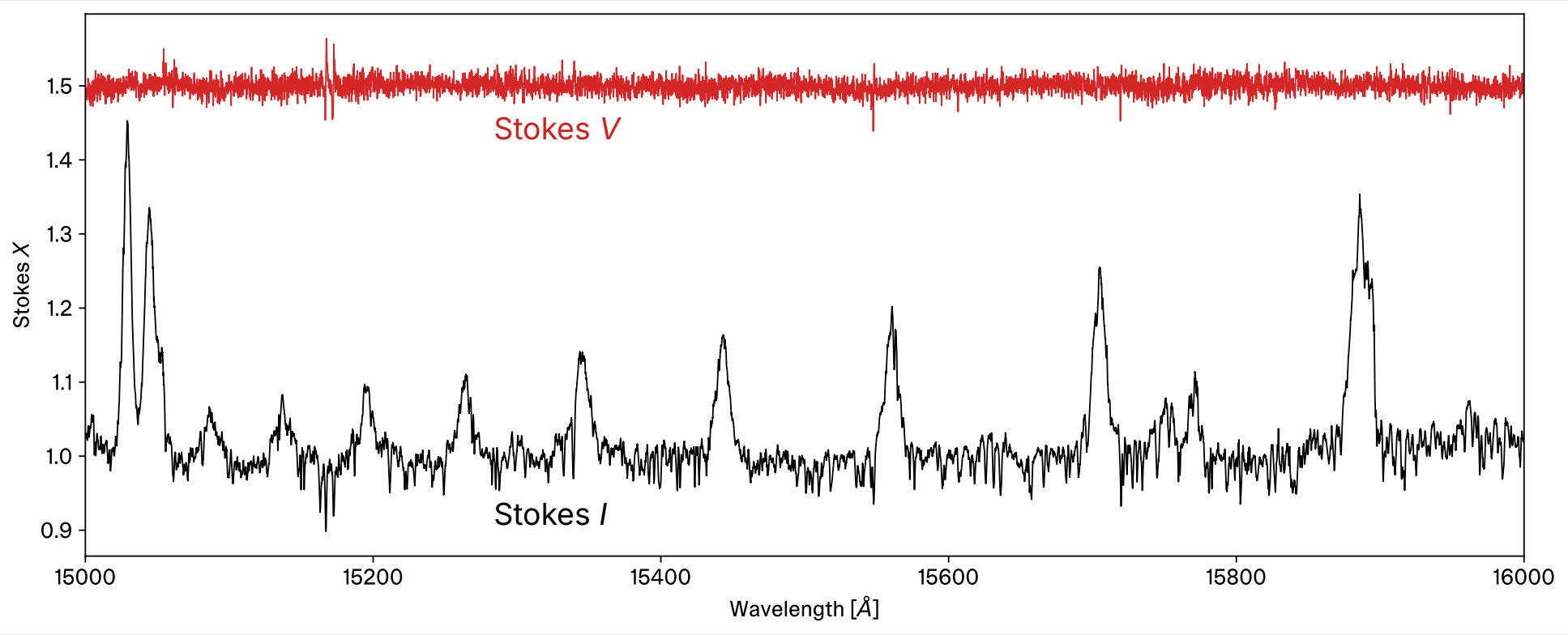
Intensity spectrum



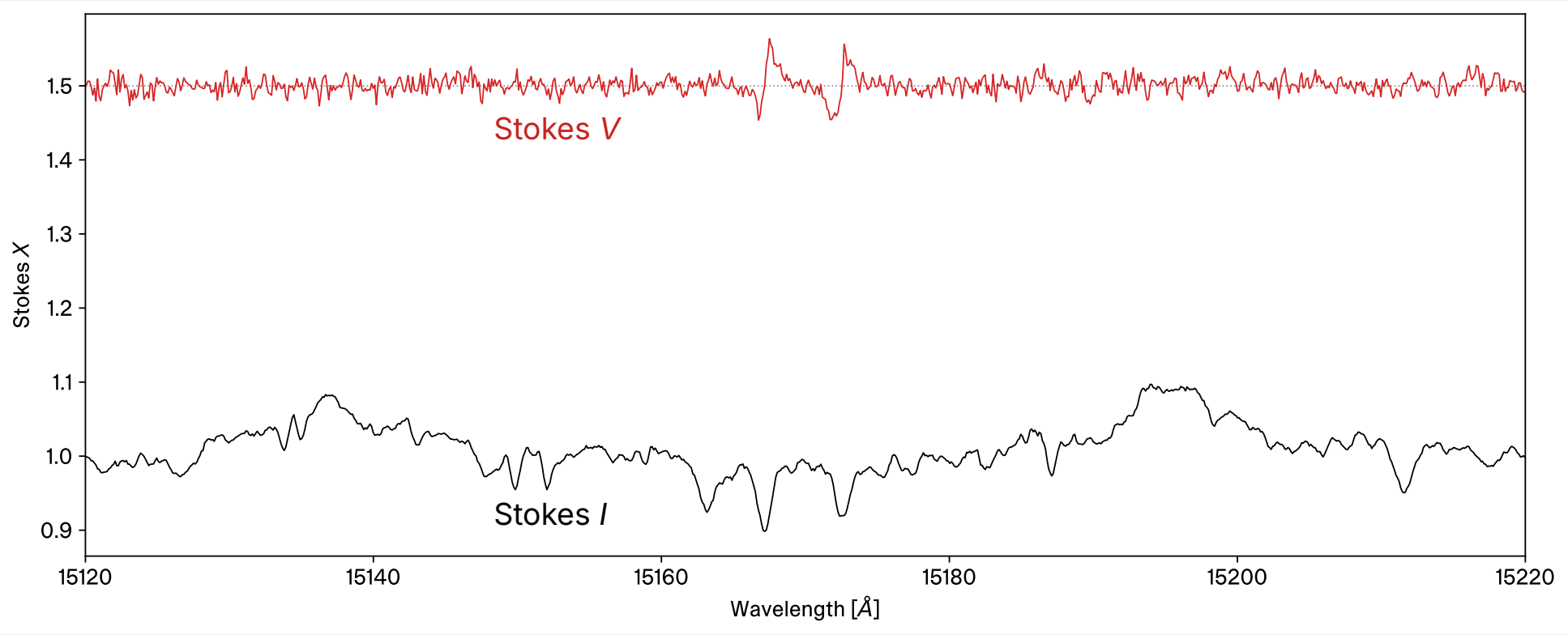
Intensity spectrum – emission lines



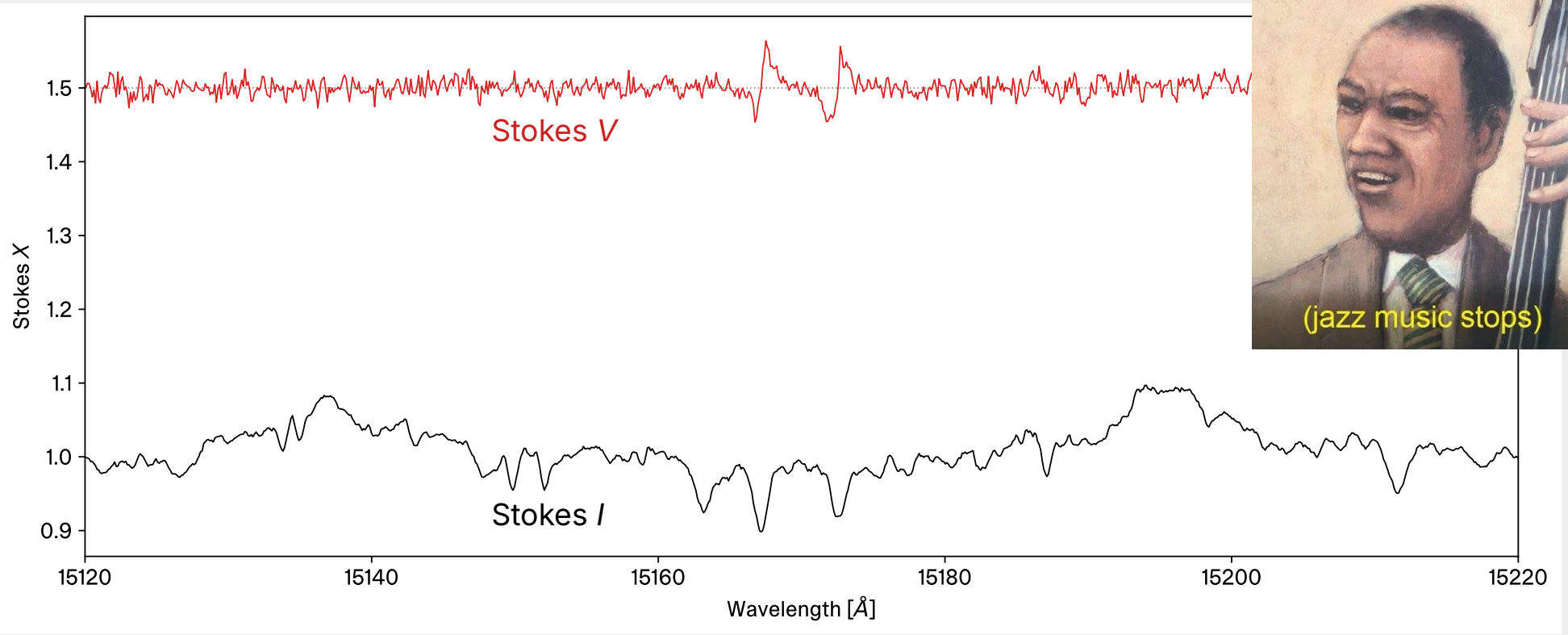
Polarized spectrum



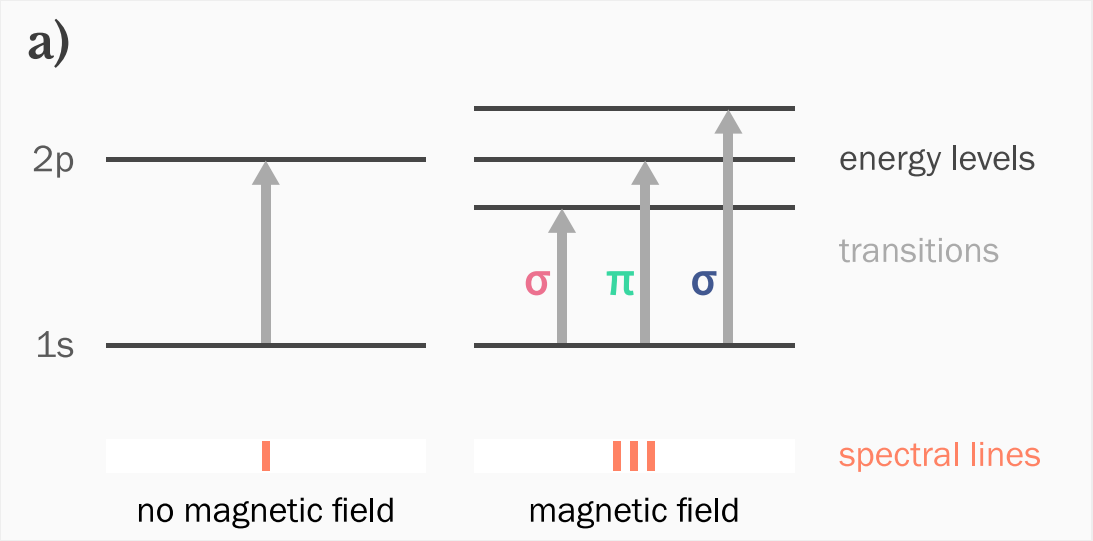
Polarized spectrum

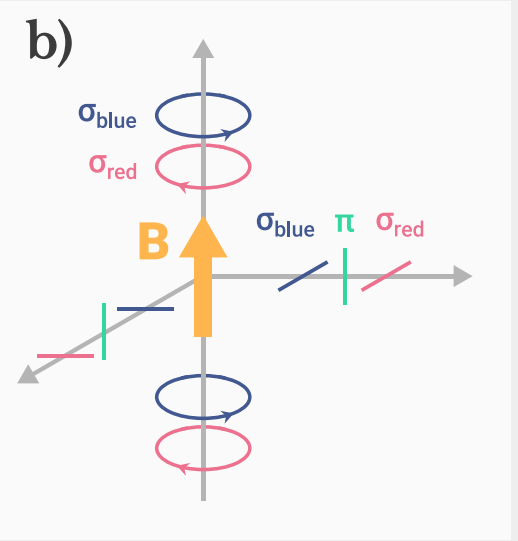


Polarized spectrum



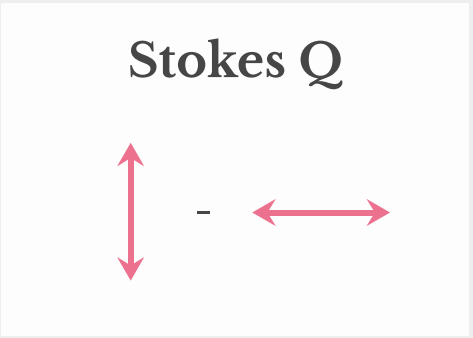
Zeeman effect

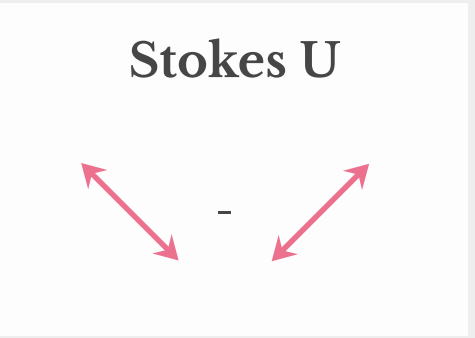


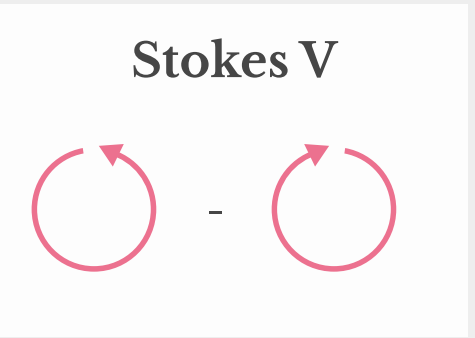


SMALL SCALES

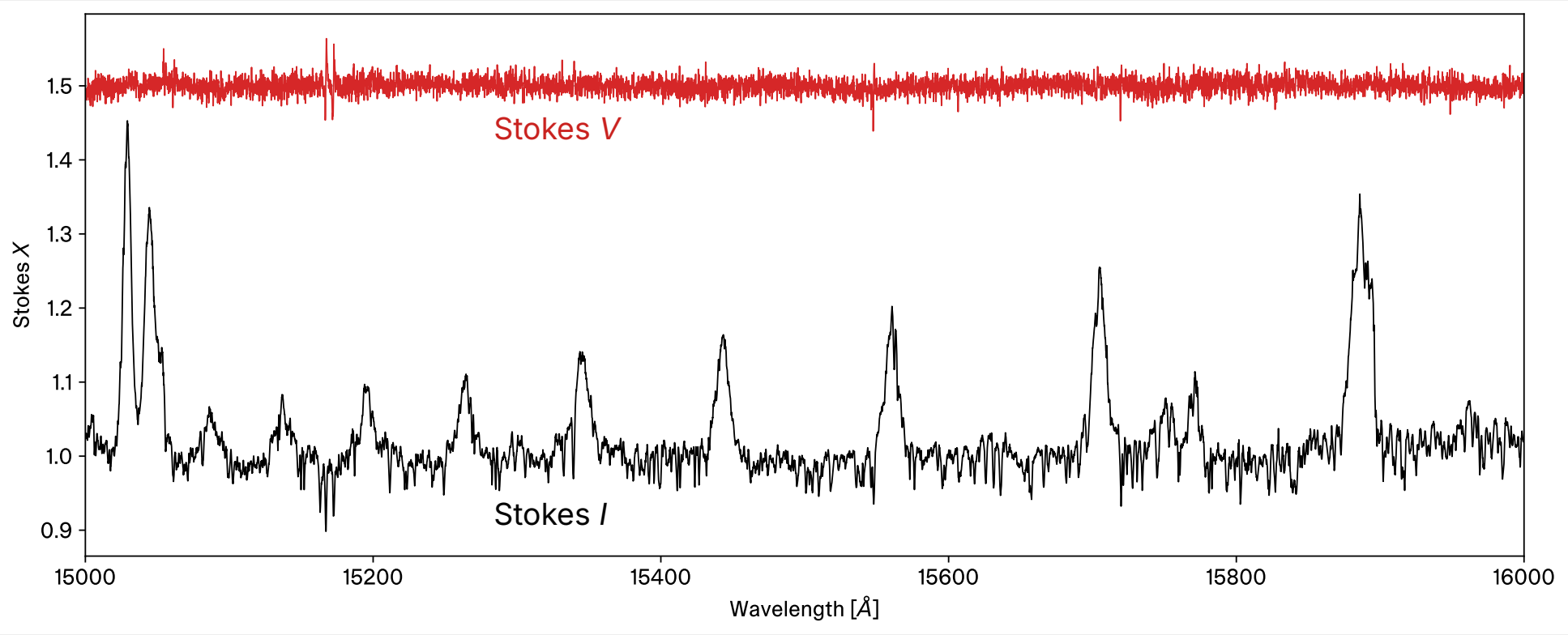
LARGE SCALES







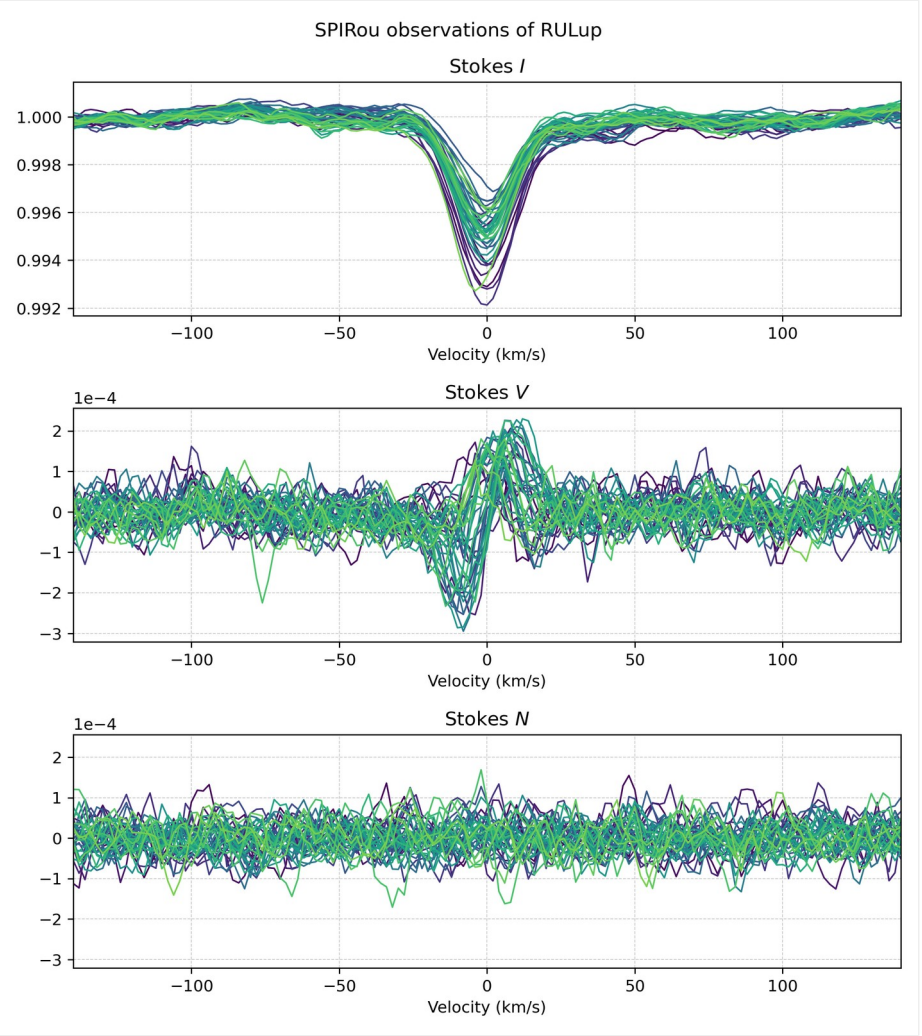
Our spectropolarimetric observations



Least squares deconvolution

Clear magnetic field detection for most epochs

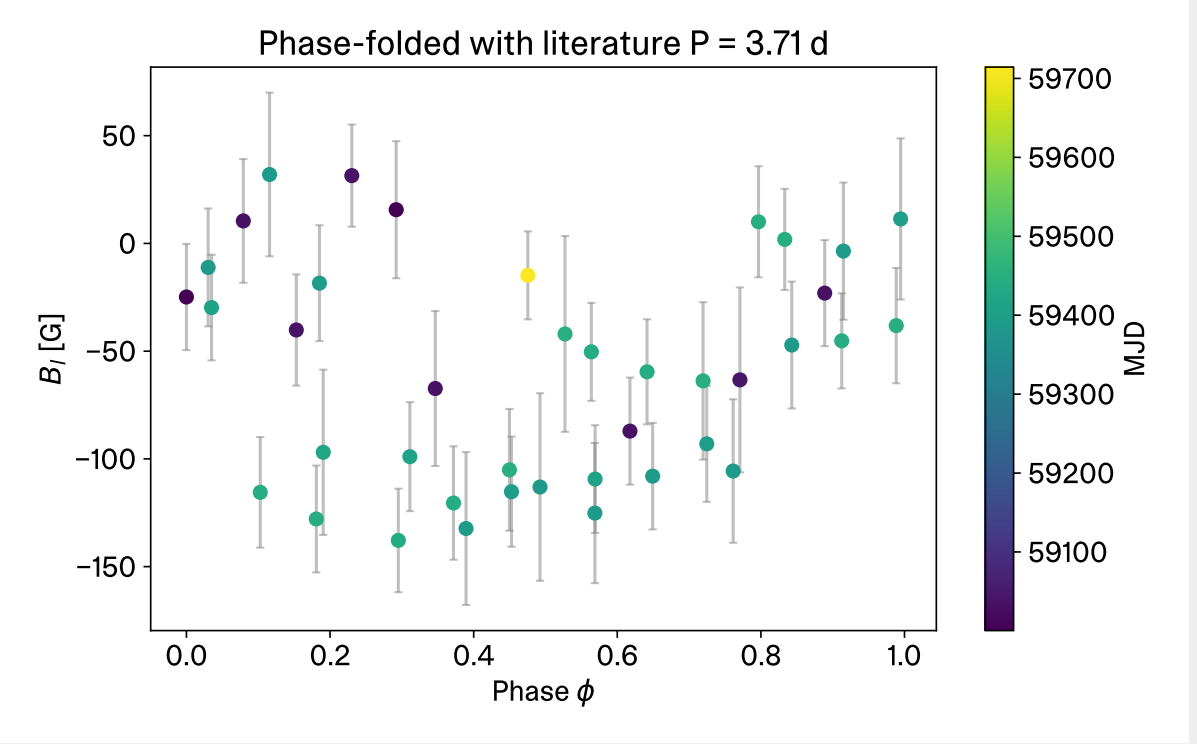
~1400 atomic lines deeper than 10% of the continuum



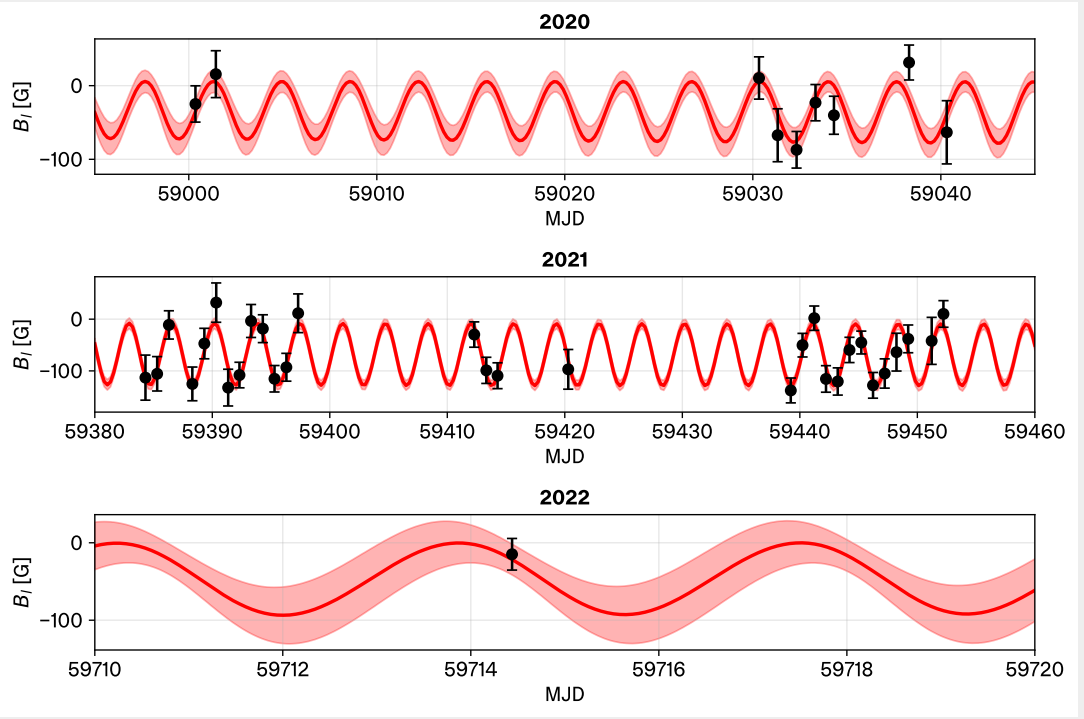
Mean longitudinal magnetic field

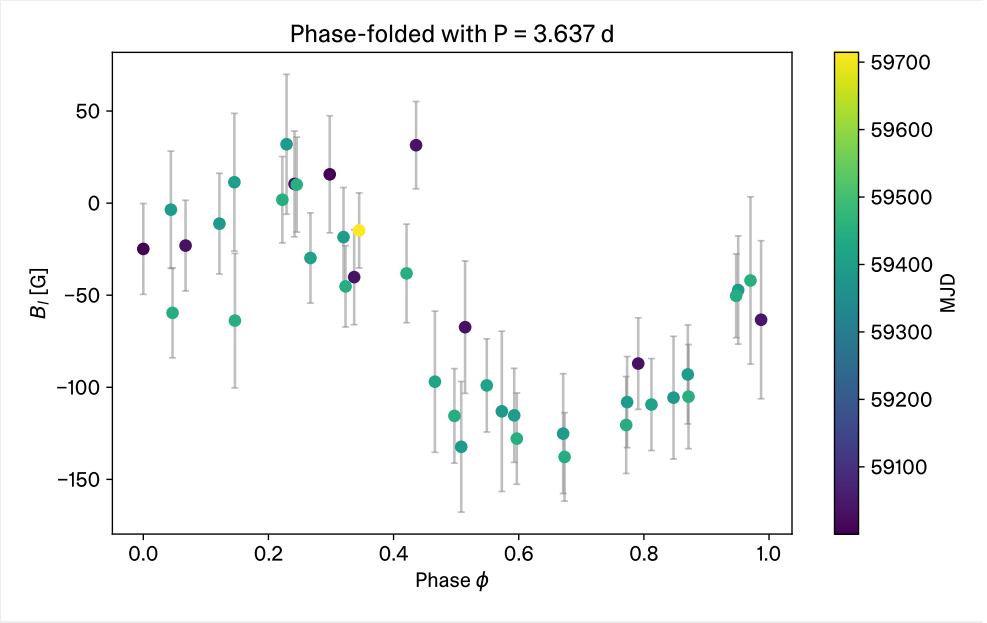
Integrating Stokes V and Stokes I, we can compute the **mean longitudinal magnetic field**

Folding with period from the literature, P = 3.71058 ± 0.0004 days (Stempels et al. 2007), is not great



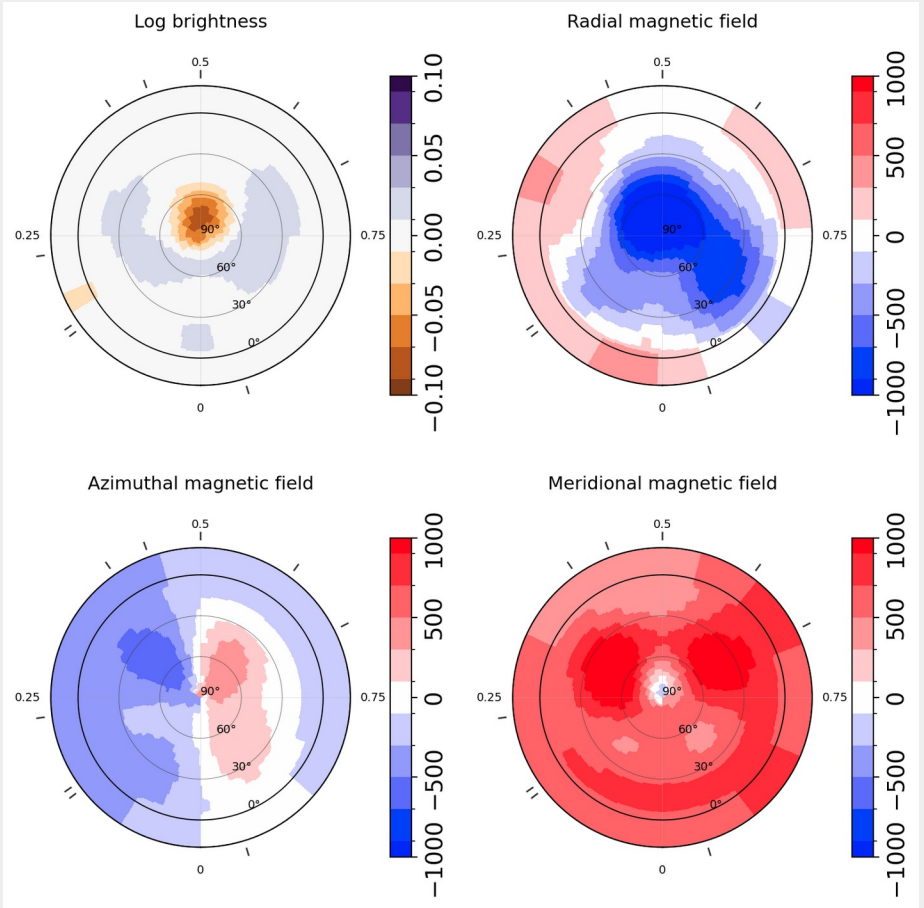
Rotation period determination

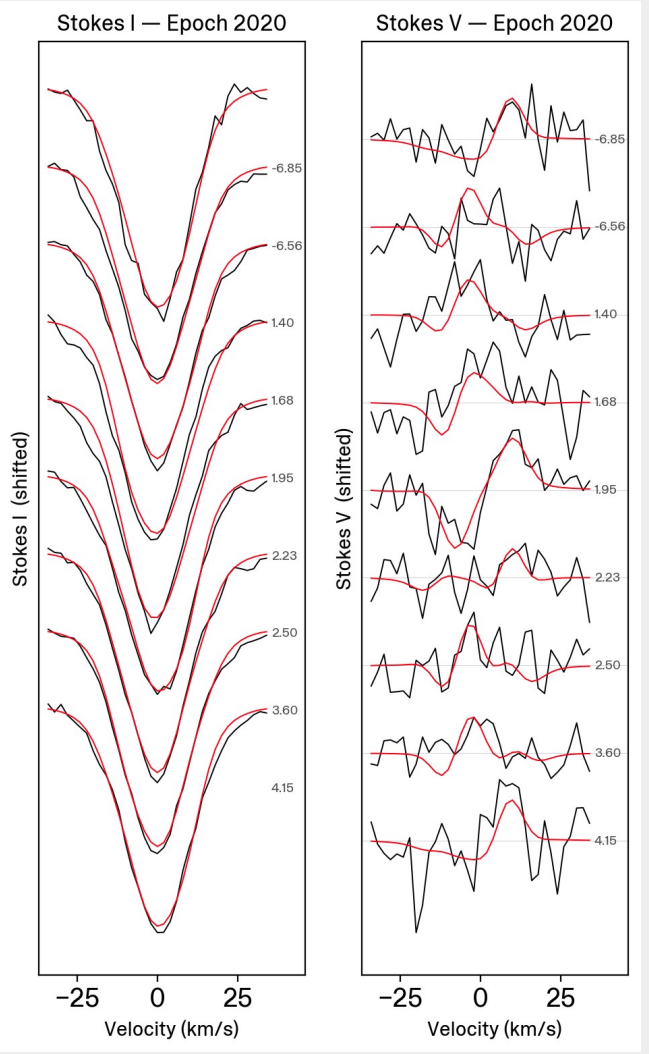




Zeeman Doppler Imaging

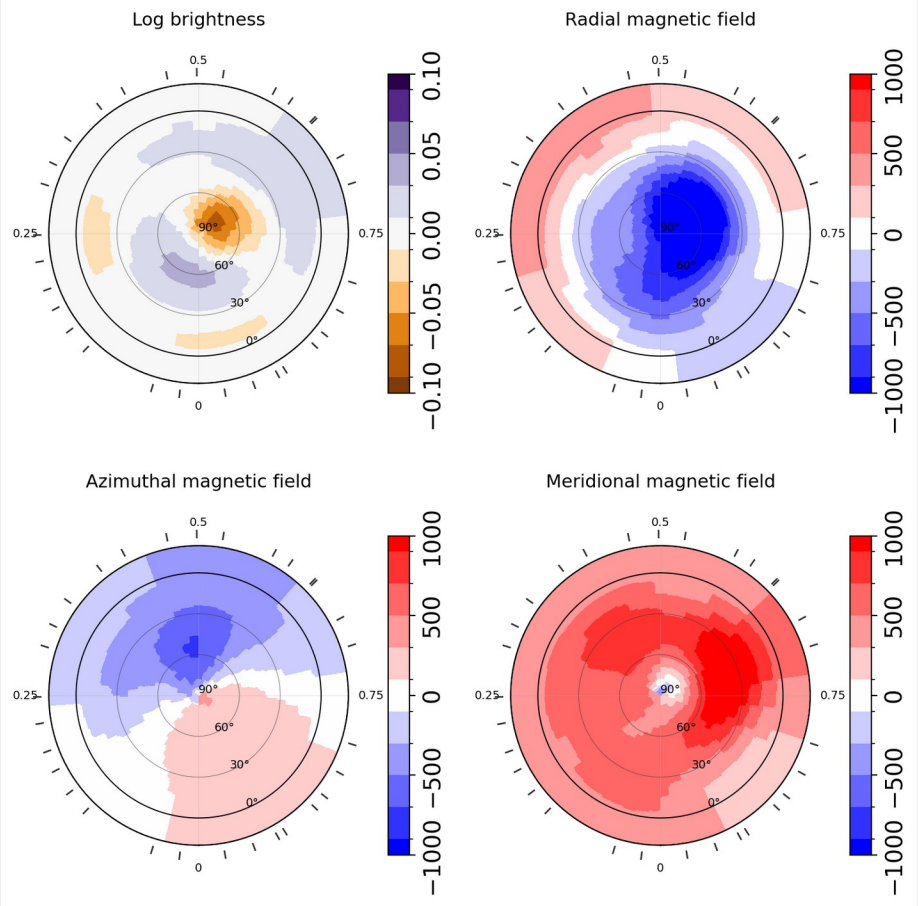
2020

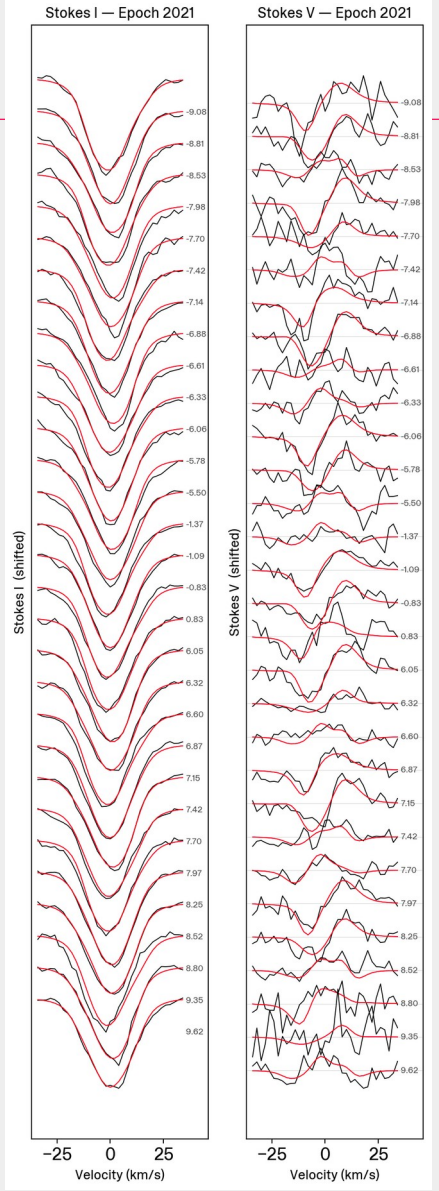




Zeeman Doppler Imaging

2021





Zeeman Doppler Imaging

Epoch 2020

Poloidal/Toroidal split:
Poloidal: 80%
Toroidal: 20%

Axisymmetric/Non-axisymmetric:
Axisymmetric (m=0): 69%
Non-axisymmetric (m>0): 31%

Energy per l (% of total):
l=1 76.1% (pol 64.7%, tor 11.4%)
l=2 10.4% (pol 6.8%, tor 3.6%)
L=3 6.4% (pol 3.3%, tor 3.1%)
l=4 3.8% (pol 2.4%, tor 1.4%)
l=5 3.3% (pol 2.8%, tor 0.5%)

Dipole properties:
Polar strength: 1729 G
Tilt angle: 16 deg from rotation axis

Epoch 2021

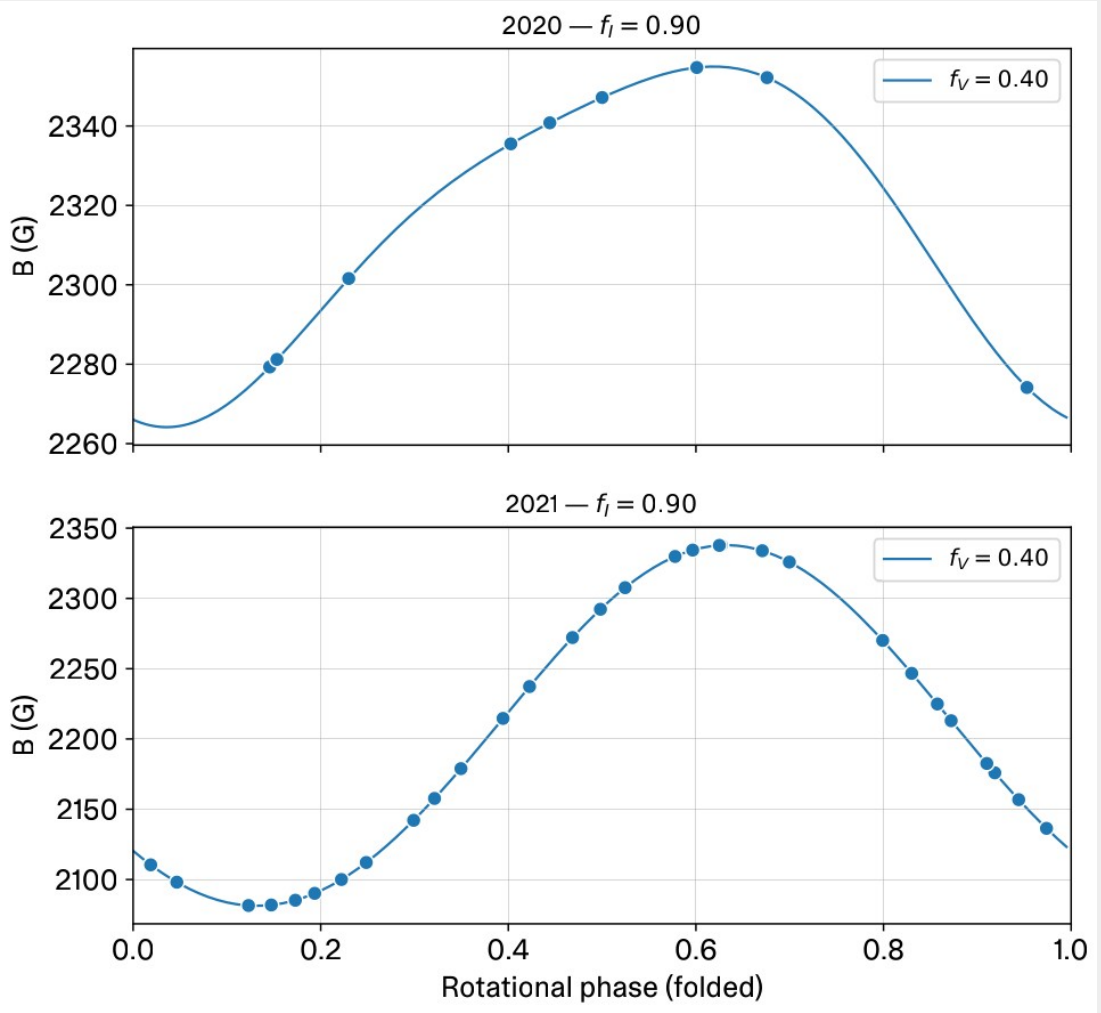
Poloidal/Toroidal split:
Poloidal: 87%
Toroidal: 13%

Axisymmetric/Non-axisymmetric:
Axisymmetric (m=0): 65%
Non-axisymmetric (m>0): 35%

Energy per l (% of total):
l=1 73.5% (pol 69.5%, tor 4.0%)
L=2 13.9% (pol 9.0%, tor 4.9%)
l=3 7.3% (pol 4.3%, tor 3.0%)
l=4 3.3% (pol 2.5%, tor 0.8%)
l=5 2.0% (pol 1.7%, tor 0.3%)

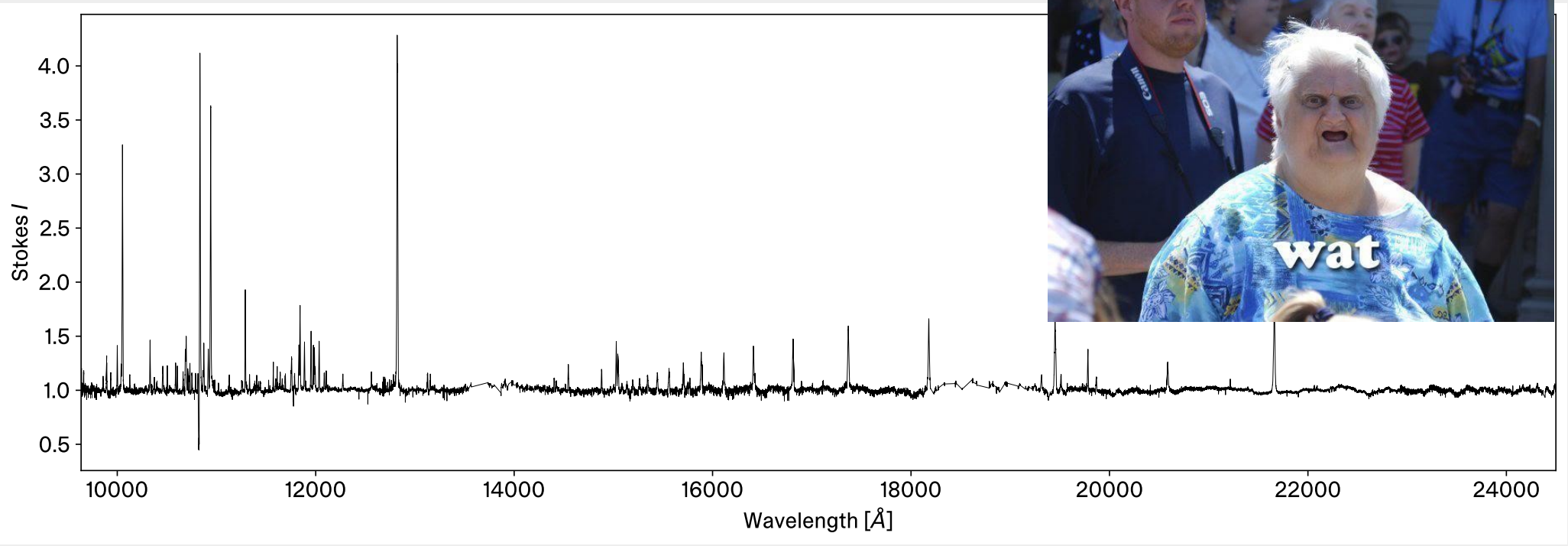
Dipole properties:
Polar strength: 1787 G
Tilt angle: 24 deg from rotation axis

Zeeman Doppler Imaging

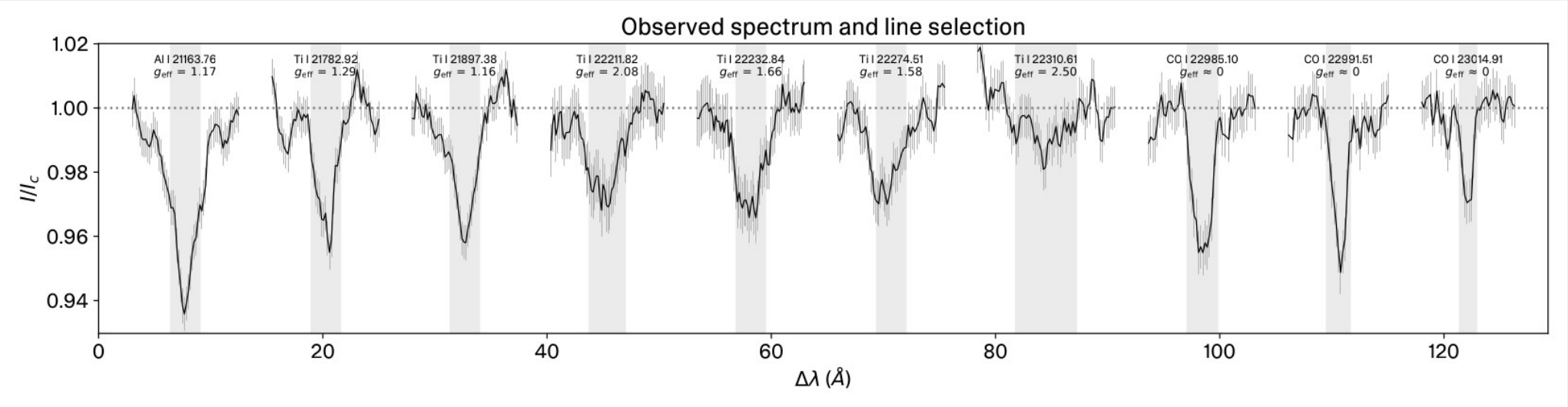


From our ZDI map, we can predict the small-scale field recoverable from Zeeman broadening.

Zeeman broadening



Zeeman broadening



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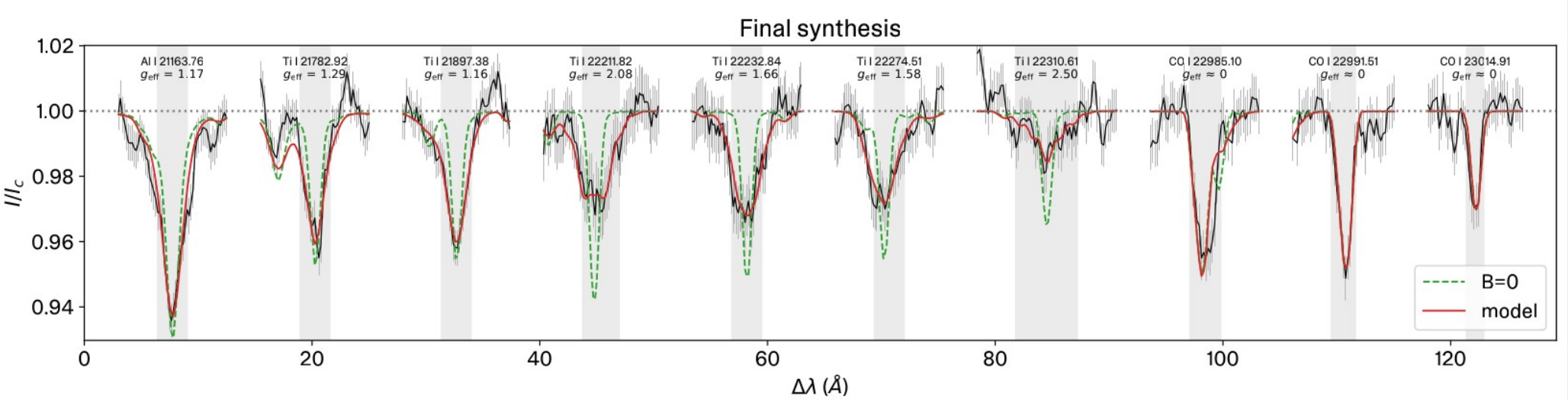

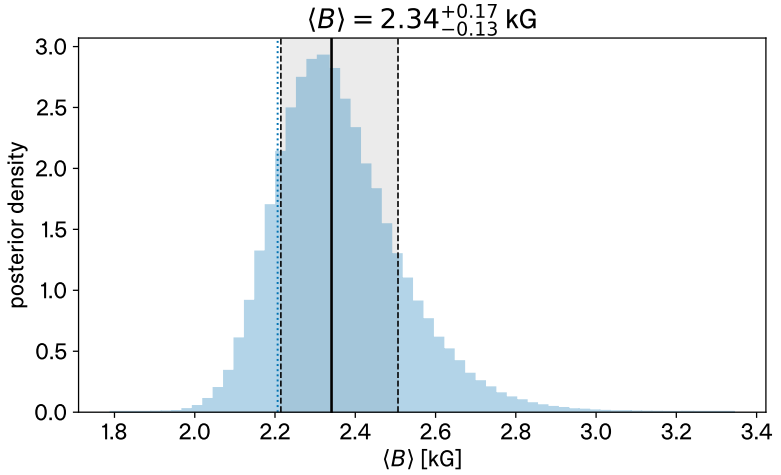

Conclusion

RU Lup (**strongly accreting** cTTS): 3 seasons of **SPIRou** spectropolarimetry (2020-2022)

- Clear Zeeman detections
- Rotation period refined to **P = 3.637 d**
- Large-scale field (ZDI): mainly **poloidal** (80-87%) and **axisymmetric** (~65-70%), **dipole-dominated**
- Field topology **stable** between the 2020 and 2021 epochs
- Total (small-scale) field from Zeeman broadening **~2.3 kG** (Zeeman broadening)

Outlook

- Connect field topology to accretion; link with GRAVITY observations (Hugo Nowacki)
- Extend to more epochs / cTTS