Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Universidad de La Laguna

Solar-cycle and Latitude Variations in the Internetwork Magnetism.

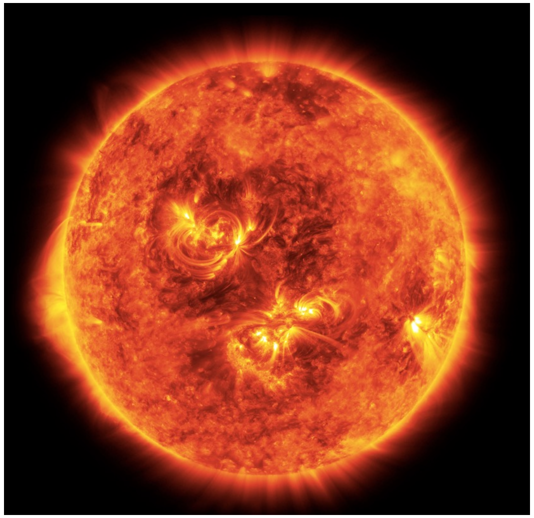
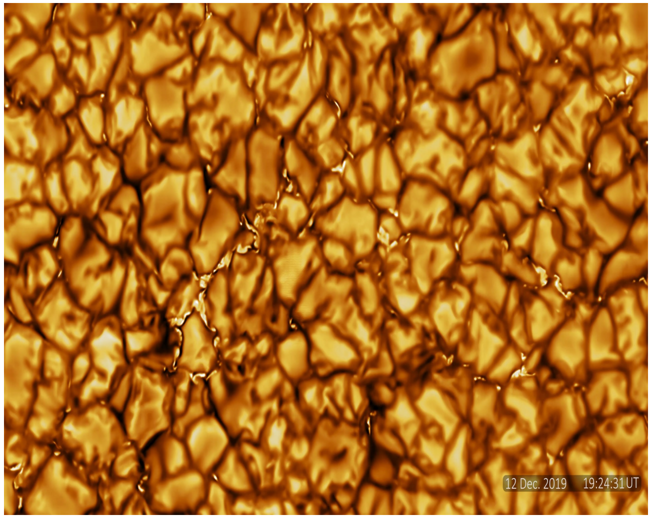


Image by NASA's Solar Dynamics Observatory



Movie by The Daniel K. Inouye Solar Telescope (NSO/AURA/NSF)

Dr. Juan Carlos Trelles Arjona

Dr. María Jesús Martínez González

Dr. Basilio Ruiz Cobo

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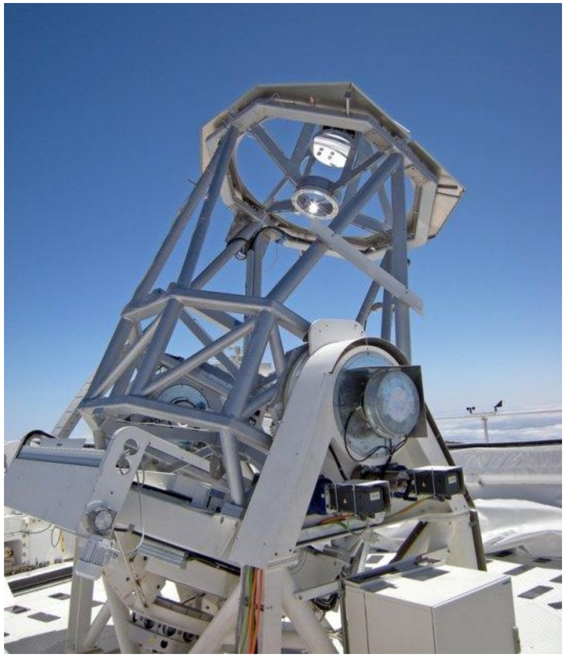
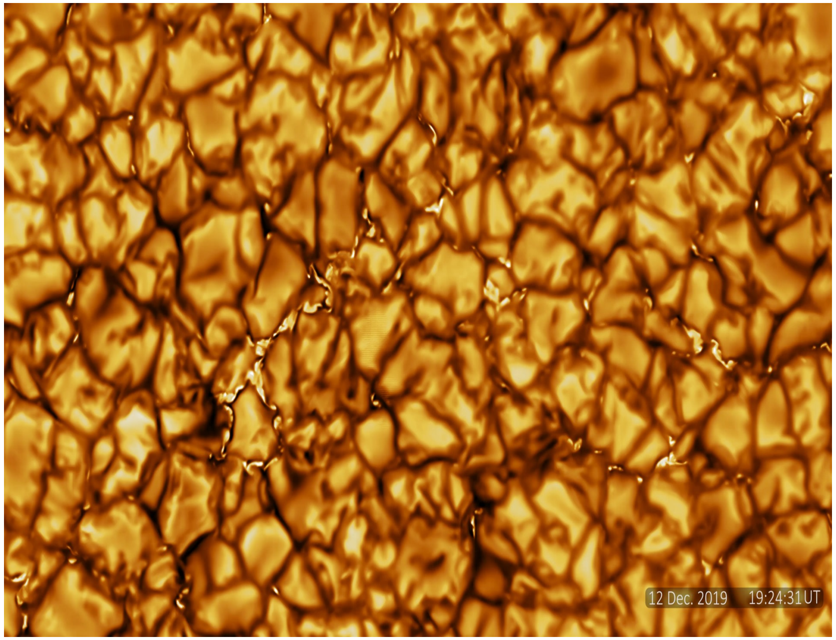


Image by Kiepenheuer-Institut für Sonnenphysik (KIS).

- **Introduction and motivation of this work**
- **Methodology**
- **Results**
- **Conclusions**

Introduction

Quiet Sun



Movie by The Daniel K. Inouye Solar Telescope (NSO/AURA/NSF)

Active region

Active region 2993-94. Image taken by KARZAMAN AHMAD/LANGKAWI NATIONAL OBSERVATORY OF MALAYSIA.

Introduction

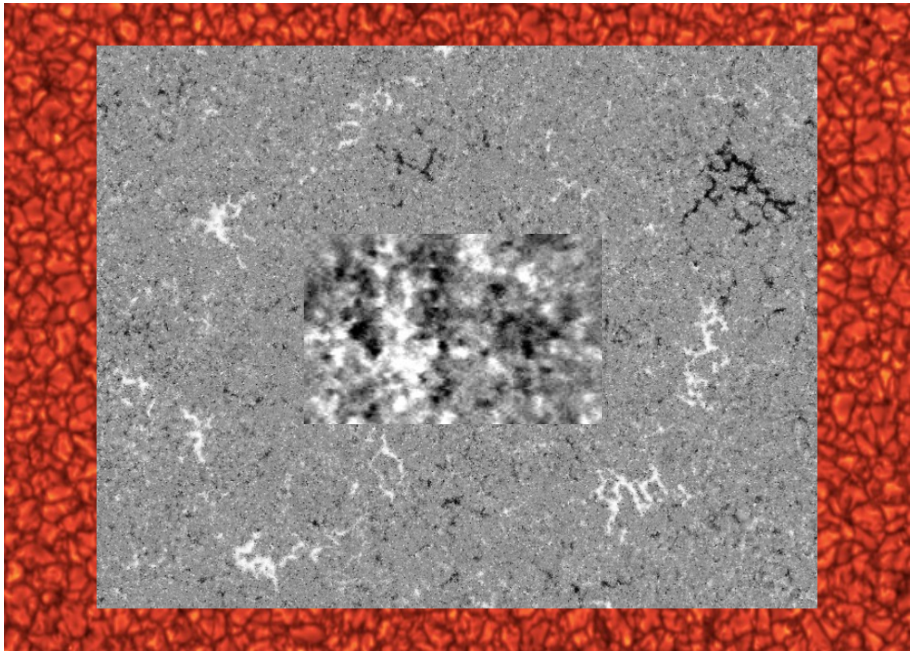


Image created using HINODE/SOT data

Quiet Sun magnetism

- **Network: strong magnetic fields (of the order of kG) located at super granular cells borders.**
- **Internetwork: much weaker magnetic fields (of the order of hG) located at the interior of super granular cells.**

Motivation

Importance of quiet Sun magnetism

- **Amount of magnetic energy stored**

Still to know

- **Origin? Small-scale dynamo?**
- **Distribution?**
- **Long-term variations?**
- **Latitude variations?**

Aims of the thesis

To deepen the knowledge about quiet Sun magnetism

Empirical determination of spectral lines parameters

Trelles Arjona et al. 2021b

Mapping quiet Sun magnetism using multiline intensity profiles inversions

Trelles Arjona et al. 2021a

Long-term and latitude variations of quiet Sun magnetism

Trelles Arjona et al. 2023

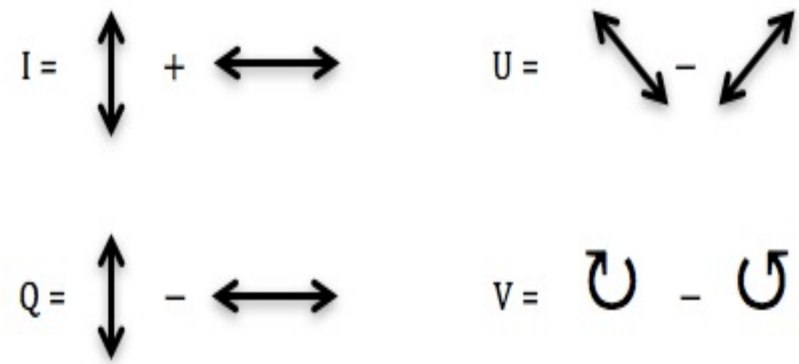
Methodology I: fundamental physics

Zeemen effect

Polarization of light
(Stokes Parameters)

Methodology I: Stokes Parameters

- **I:** **sum of the intensities transmitted through perfect linear polarizers whose transmission axes are mutually orthogonal.**
- **Q:** **difference between the intensities transmitted through the linear polarizers at angles $\theta = 0^{\circ}$ and $\theta = 90^{\circ}$.**
- **U:** **difference between the intensities transmitted through the linear polarizers at angles $\theta = 45^{\circ}$ and $\theta = 135^{\circ}$.**
- **V:** **difference between right and left circularly polarized light.**



Methodology II: tools

Process to achieve results

- GREGOR Solar Telescope
- Data reduction
- Stokes Inversion based on Response functions (SIR)
- Simulation (MANCHARAY)

Methodology II: tools

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Methodology II: GREGOR solar telescope

Schmidt et al. (2012)

Berkefeld et al. (2016)

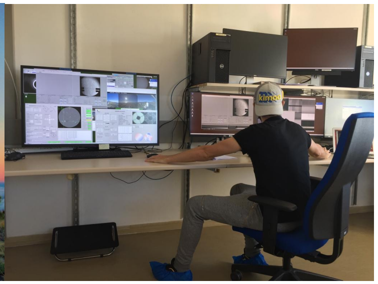
Image by Leibniz-Institut für Sonnenphysik (KIS)

- **Aperture of 1.5 m**
- **Open telescope**
- **Adaptive optics**
- **Grating Infrared Spectrograph (GRIS)**

Methodology II: data

Data collection

- 7 observing campaingns (2018, 2019, 2020, 2021, and 2022)
- Targets: disk center, poles, and maps along the central meridian and equator of Sun.



Observation set up

- Exposure time: 30ms
- Accumulations: 10
- Espectral range: 15635-15675 Å
- Slit-Jaw: continuum and Hα image
- Slit: 0.135 ″ x 60 ″
- IFU: 3 ″ x 6 ″

Methodology II: data

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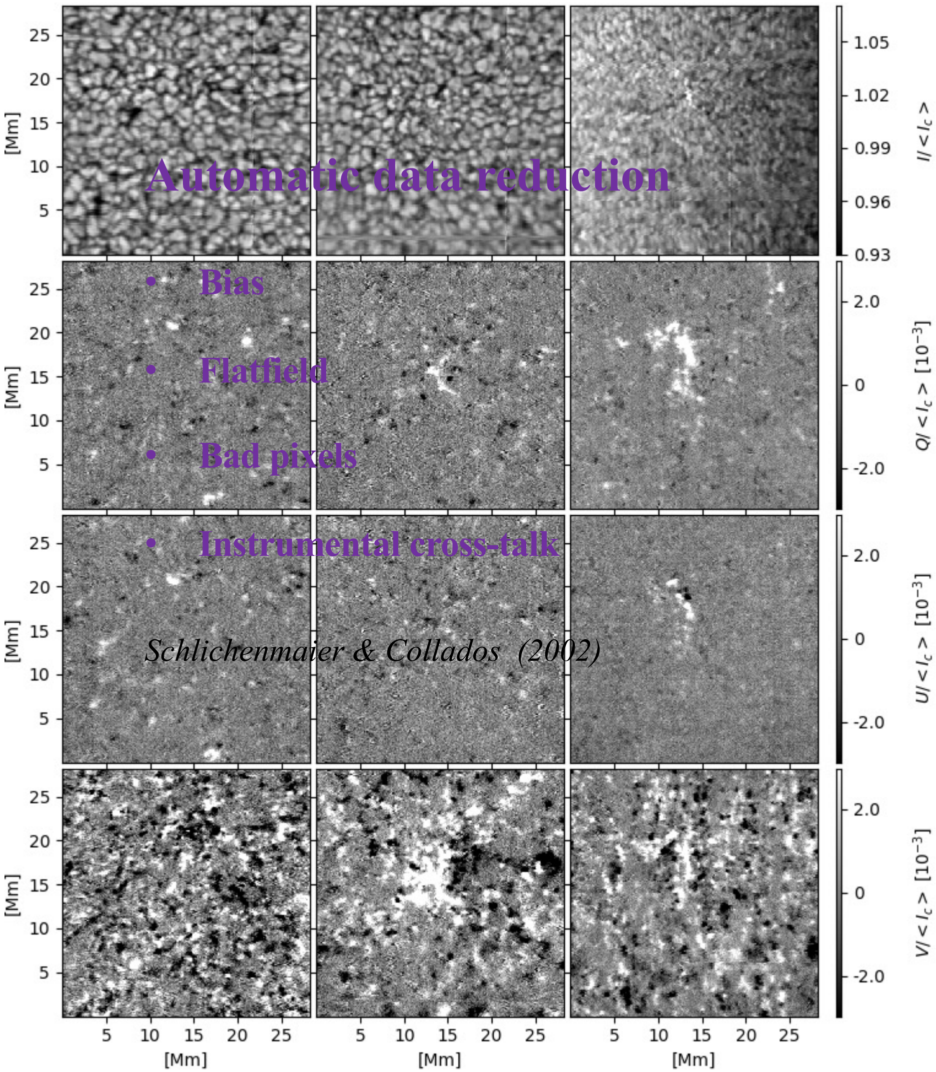
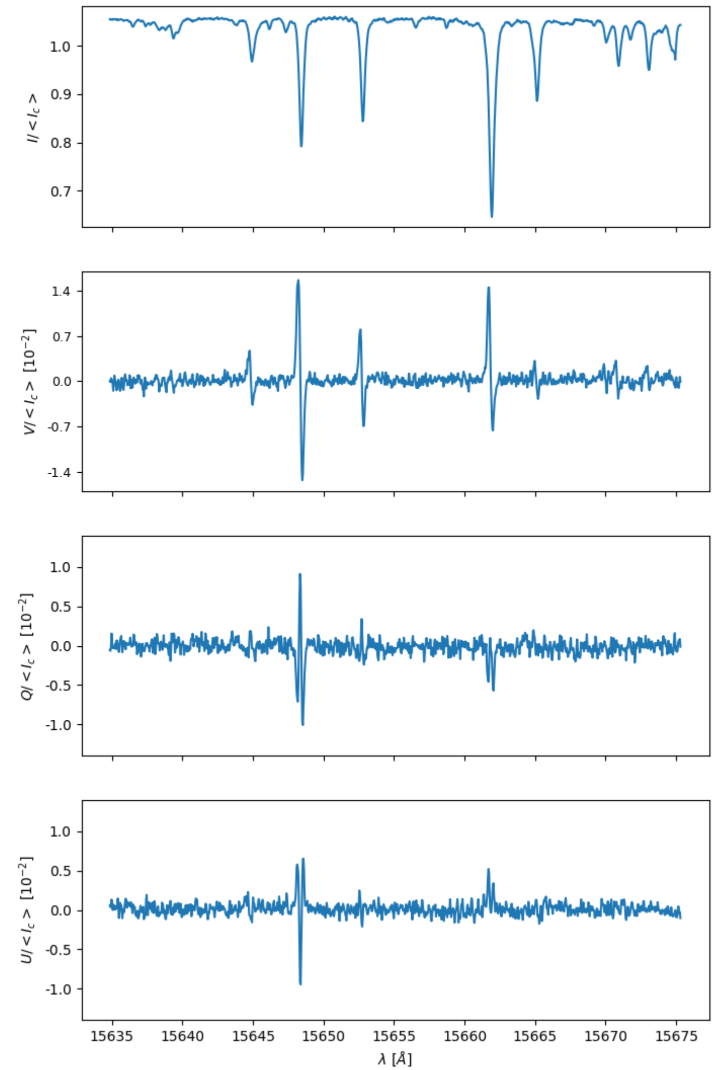


Automatic data reduction

- Bias
- Flatfield
- Bad pixels
- Instrumental cross-talk

Schlichenmaier & Collados (2002)



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Results

I. Empirical determination of atomic line parameters of the 1.5 μm spectral region

J. C. Trelles Arjona et al. (2021). Astronomy & Astrophysics. Volume 648, id.A68

C. Kuckein et al. (2021). Astronomy & Astrophysics. Volume 653, id.A165

II. Mapping the hidden magnetic field of the quiet Sun

J. C. Trelles Arjona et al. (2021). The Astrophysical Journal Letters. Volume 915, id.L20

III. Solar-cycle and latitude variations of the internetwork magnetism

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Results II: Mapping the quiet Sun magnetism

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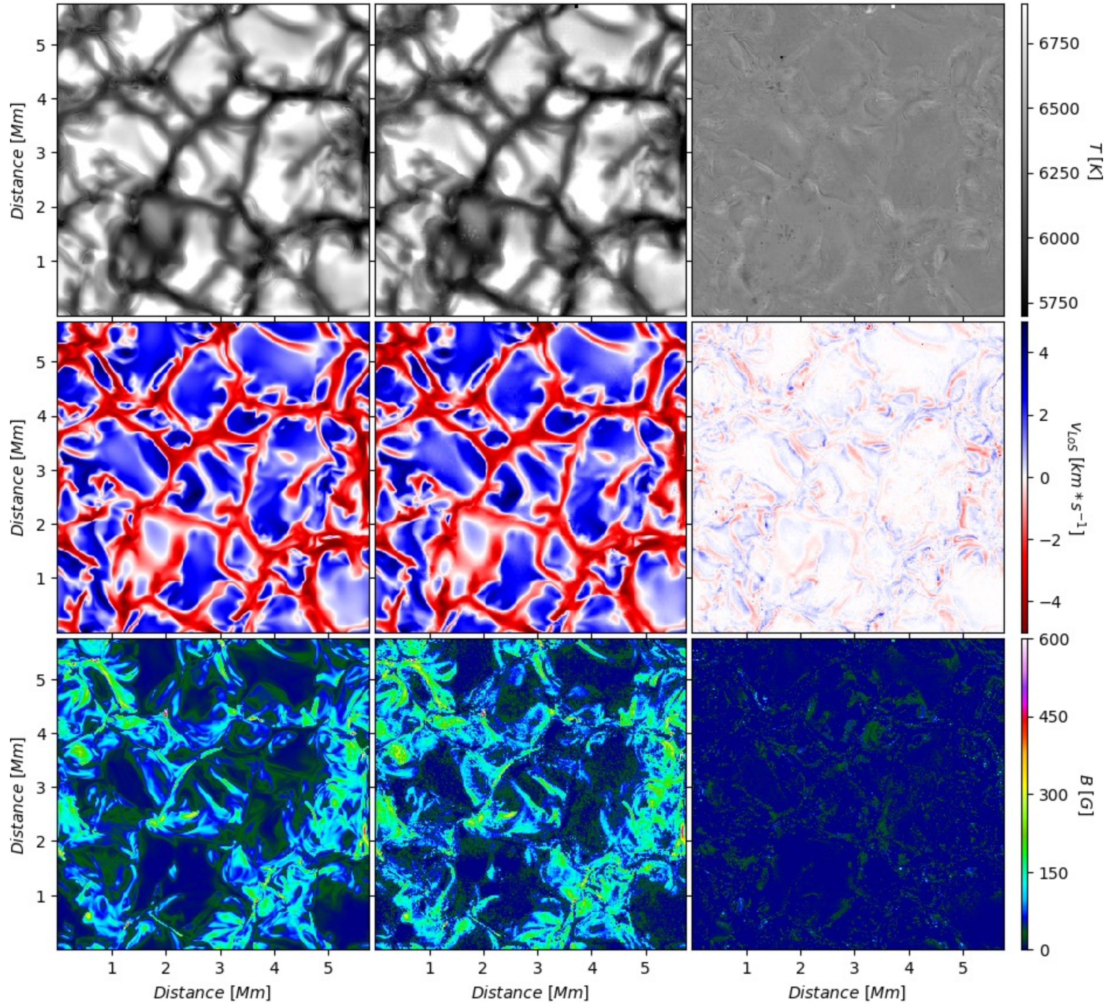
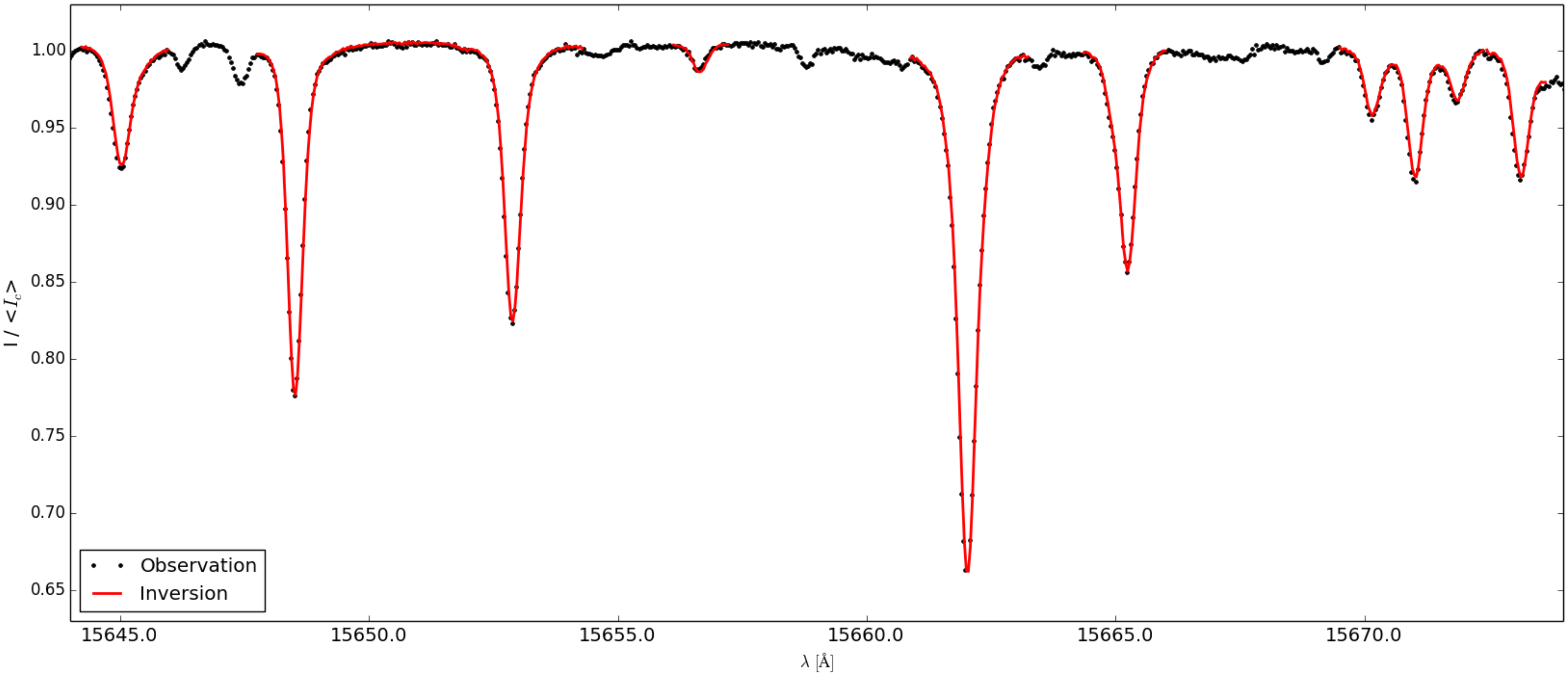
Full resolution, noiseless case. Inversion strategy

- Intensity profiles of 15 spectral lines.
- One single magnetic atmosphere
- Free atmospheric parameters: temperature, line-of-sight velocity, and magnetic field strength and inclination.
- 45 initializations. The one with the lowest χ2 was chosen.

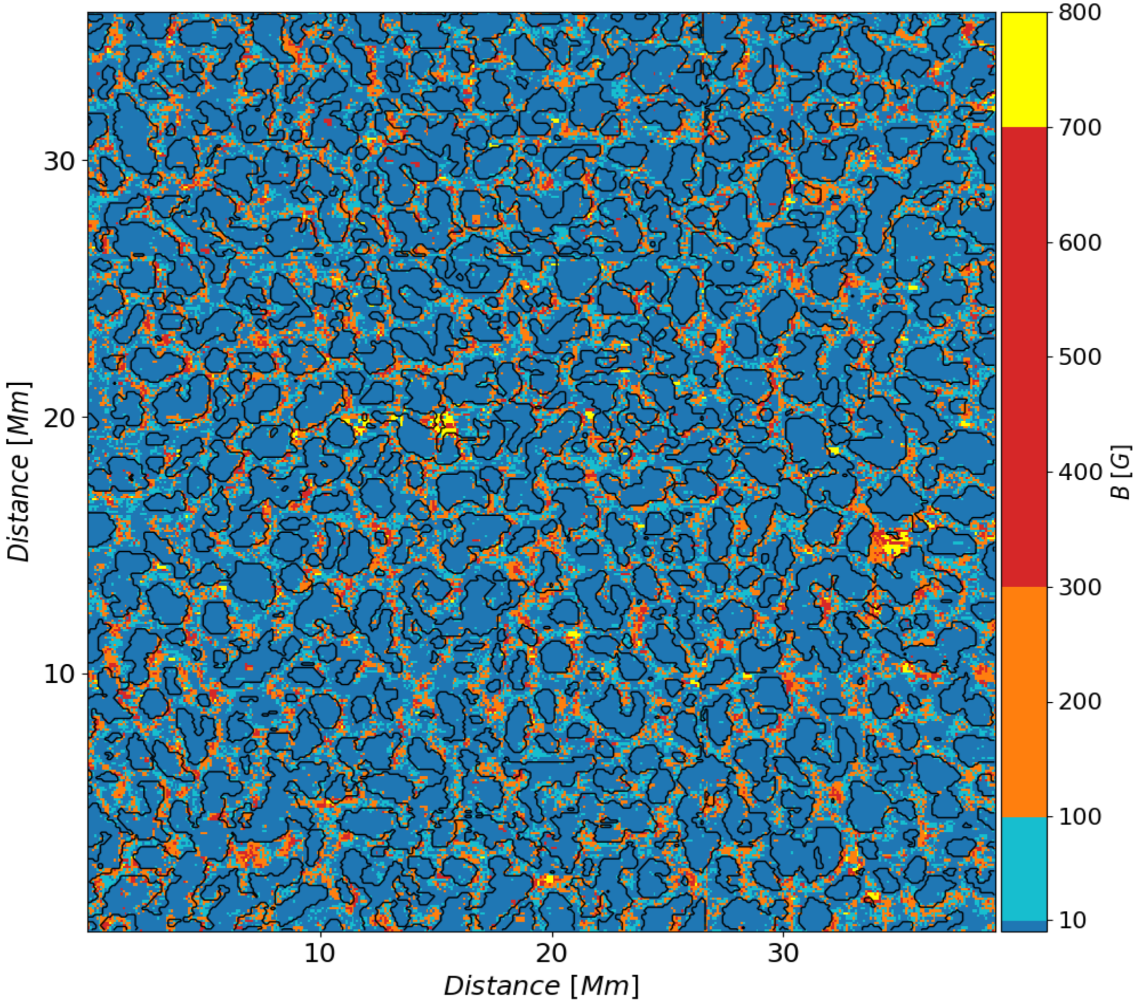


Results II: Mapping the quiet Sun magnetism

Real observations (GRIS data). Inversion strategy



Results II: Mapping the quiet Sun magnetism



Results

- Magnetic fields concentrated in intergranules
- Granules almost devoided of fields
- Convection is probably behind this distribution
- Magnetic fields of hG

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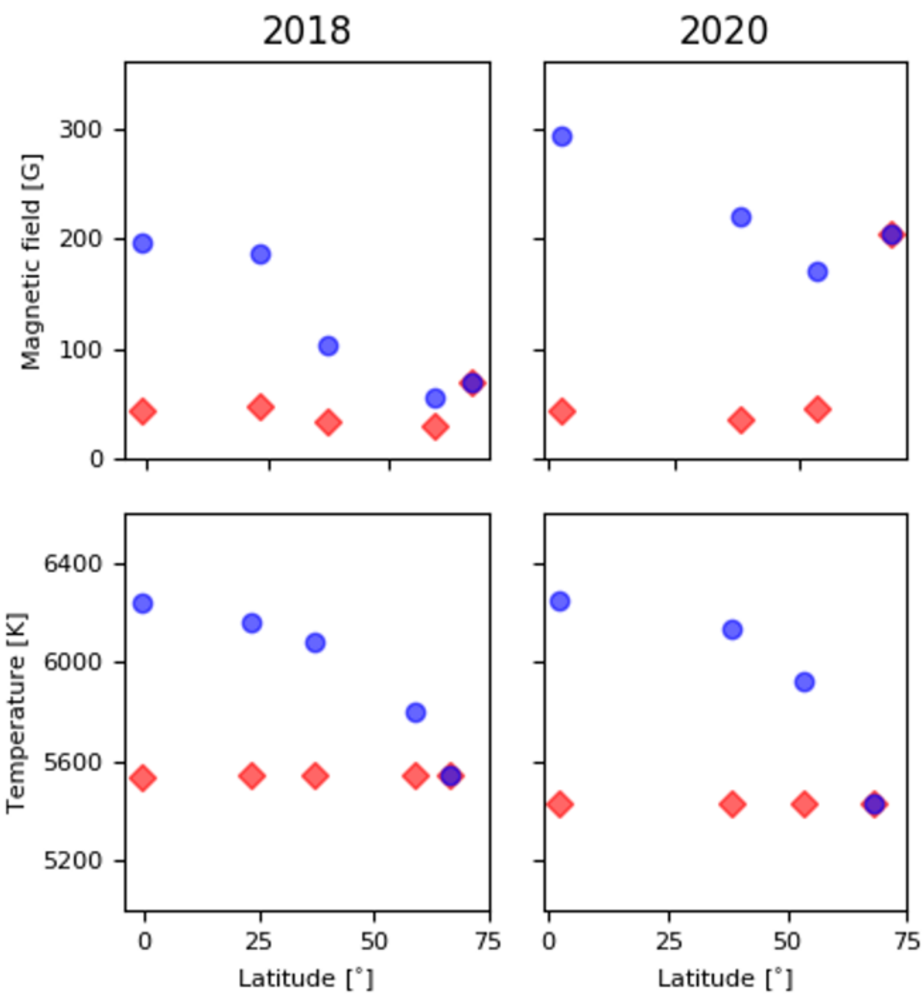
Results III: Long-term and latitude variations of quiet Sun magnetism



Results

- Detection of an increase in the average magnetic field at the solar poles

Yes

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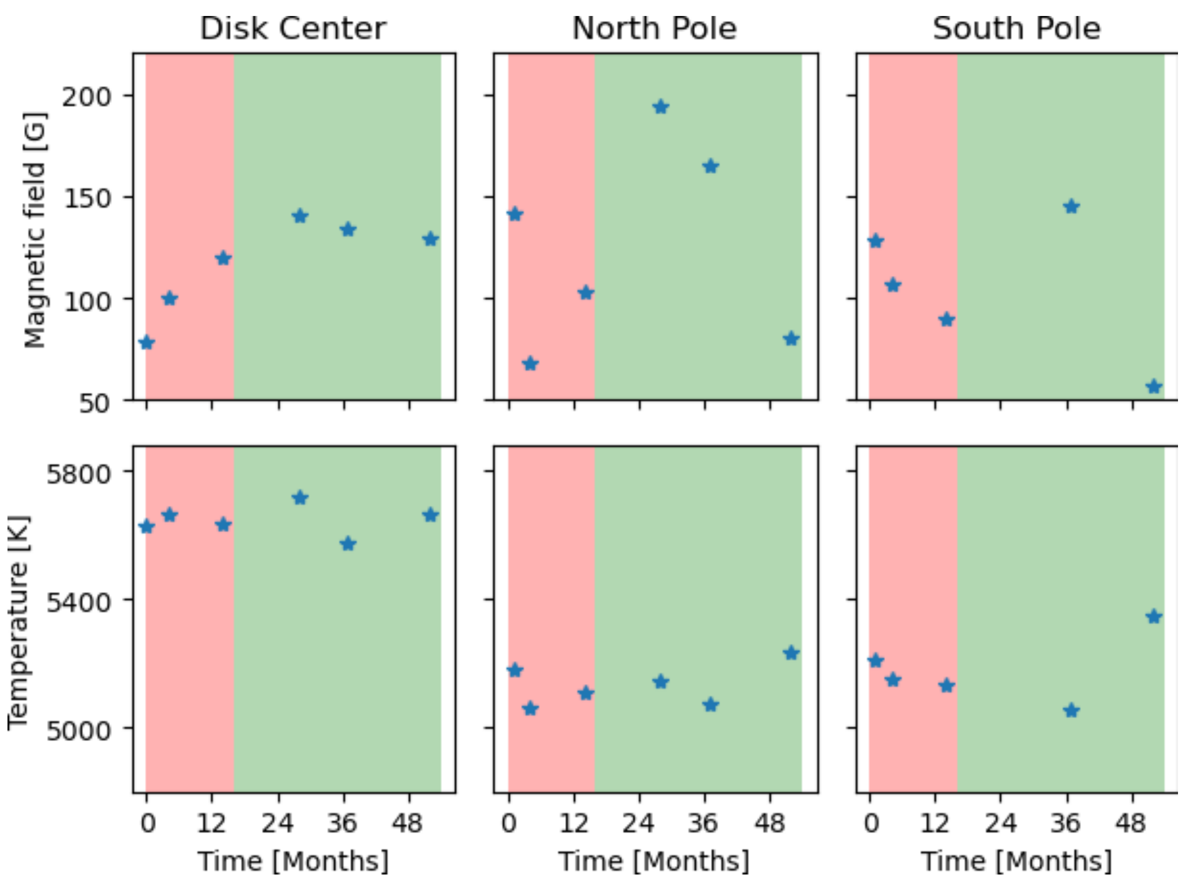
Results III: Long-term and latitude variations of quiet Sun magnetism



Results

Yes

- Variations … or of 2-3
- At disk center, the rising trend of the average magnetic field starts at least 1 year prior to the activity minimum
- At the poles, there is no clear trend in the average magnetic field strength

Conclusions

- **Quiet Sun magnetism is highly variable in the range between 40 and 200 G, with a mean value of 109 G. It depends on both time and location over the solar surface.**

- **We detect that the strength of the magnetic fields of the quiet Sun increases at solar poles.**

- **We present the first clear detection of the cycle variation of the internetwork magnetism. This variation depends on the solar latitude.**

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Thank you!