Probing coronal magnetic field at the TR level using microwave gyroresonant techniques

Sergey Anfinogentov[1]

[1]Institute of Solar-Terrestrial Physics, Russia

ISSI team meeting

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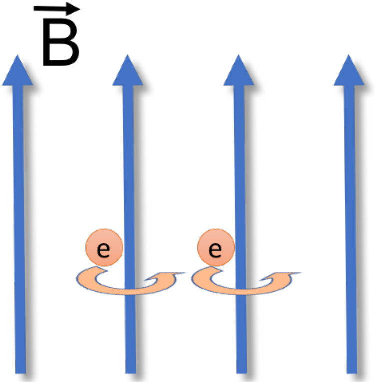
Measuring magnetic field in the corona

- Extrapolation from the photospheric magnetograms
  - Potential field
  - Non-linear force free field
  - Data-driven modelling
- Coronal seismology (from kink oscillations)
- Hanle effect (from UV spectropolarimetry)
- Measurements from radio emission
  - Free-free (LOS component)
  - **Gyro-resonant** (absolute value)

To reconstruct a complete picture of the 3D magnetic field, we need to combine all available information.

Gyroresonance emission



Gyration frequency

$$\omega_B = \frac{eB}{m_e c}$$

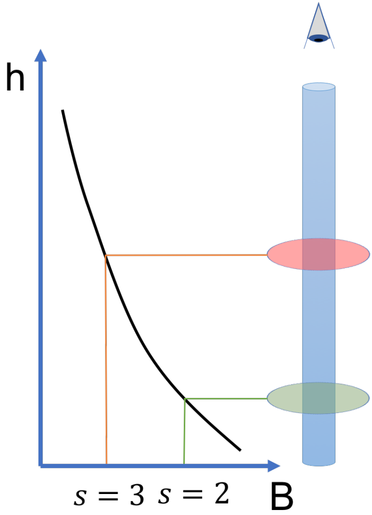
Efficient EM waves emission/adsorption

$$f = s\omega_B, s = 1, 2, 3...$$

EM emission modes

- Ordinary
- Extraordinary

Gyroresonance layers, 1D



Ordinary mode

$$s = 2,$$

$$B_o = \frac{2\pi f m_e c}{2e}$$

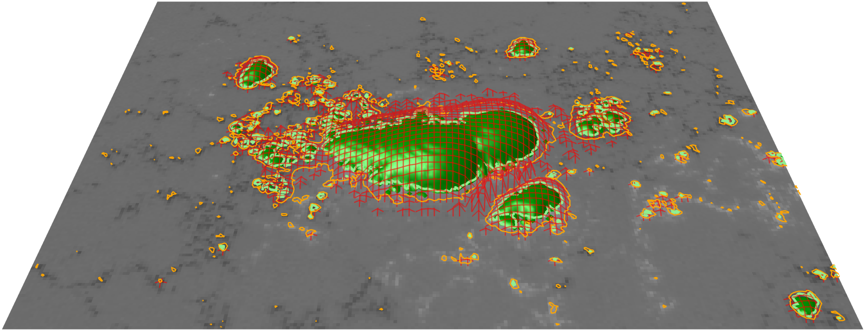
Extraordinary mode

$$s = 3,$$

$$B_e = \frac{2\pi f m_e c}{3e}$$

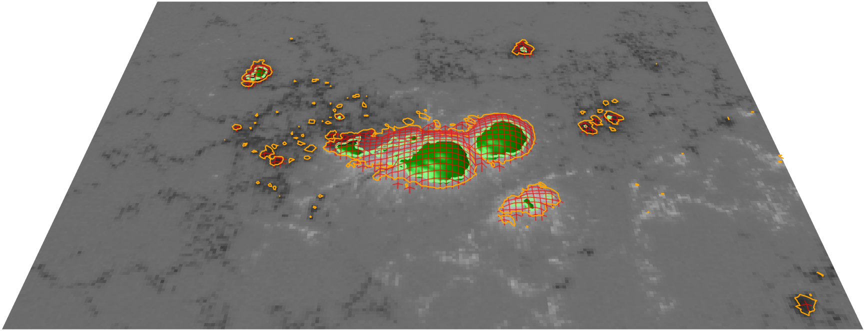
Gyroresonance layers, 3D

NOAA 11520, potential field, $f = 5.7$ GHz



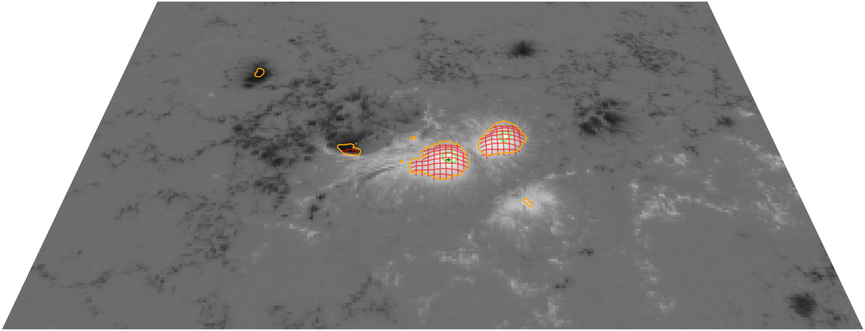
Gyroresonance layers, 3D

NOAA 11520, potential field, $f = 10$ GHz

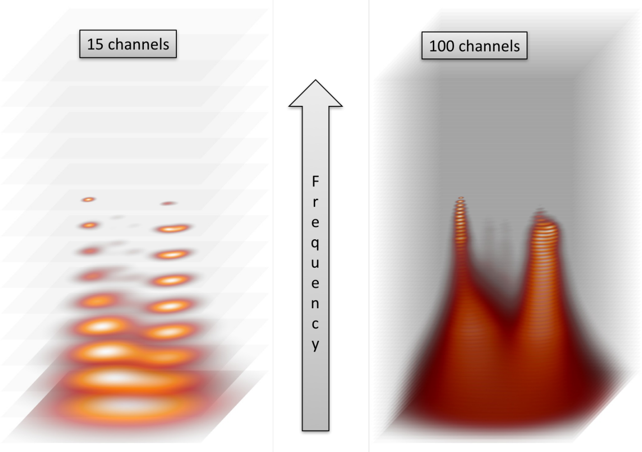


Gyroresonance layers, 3D

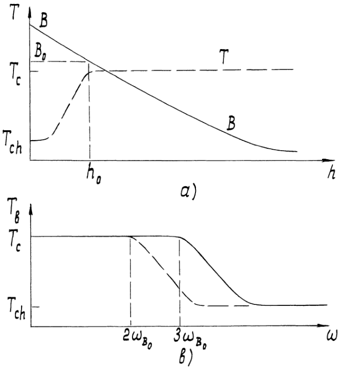
NOAA 11520, potential field, $f = 17$ GHz



Multi-frequency observations



Gyroresonance emission is a thermometer for the solar corona [1]



- GR emission comes mainly from the highest optically thick layer
  - $T_{br} = T$
- The height of this layer depend upon the EM wave frequency
  - $T(\mathbf{B})$
  - Magnetic field in the transition region

[1] Figure adopted from Zhelezniakov and Zlotnik (1980)

Gyroresonance emission applications

Different approaches

- **Stereoscopy (Magnetic field upon height)**
  Bogod and Yasnov (2009); Zlotnik et al. (1998)
- **Reconstructing Field-Temperature dependence in 3D assisted with EUV methods**
  Mok et al. (2005)
- **Mapping magnetic field in the transition region**
  Gelfreikh and Shibasaki (1999); White (2004)
  - Additional constraint for reconstruction of coronal field in 3D

GR magnetography

Different approaches

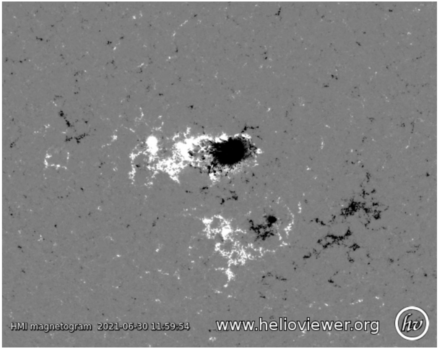
- Simple thresholding: $B = B_f H(I_f - I_{thr})$
- Forward fitting 1D models: $B(z), n(z), T(z)$
- Forward fitting 3D models: $B(x, y, z), n(x, y, z), T(x, y, z)$

Radioheliographs in the microwave range

- MingantU SpEctral Radioheliograph (MUSER)
- Expanded Owens Valley Solar Array (EOVSA)
- Siberian RadioHeliograph (SRH)

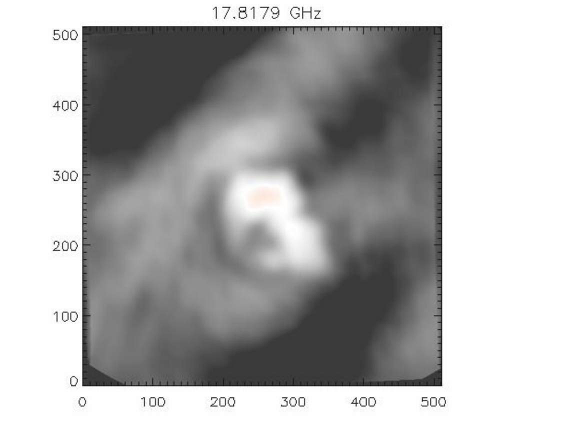
EOVSA and SRH observations

2021-06-30, NOAA 12835



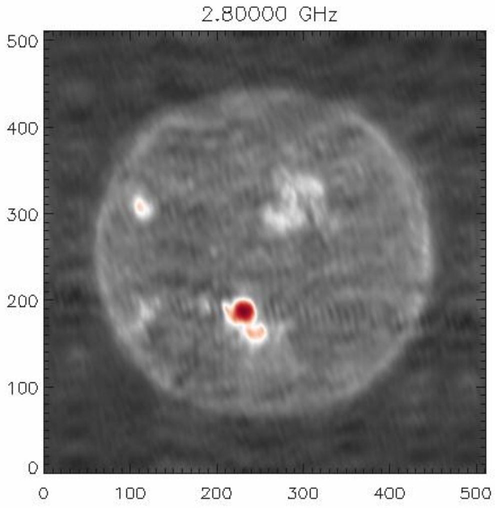
EOVSA observations

2021-06-30, NOAA 12835



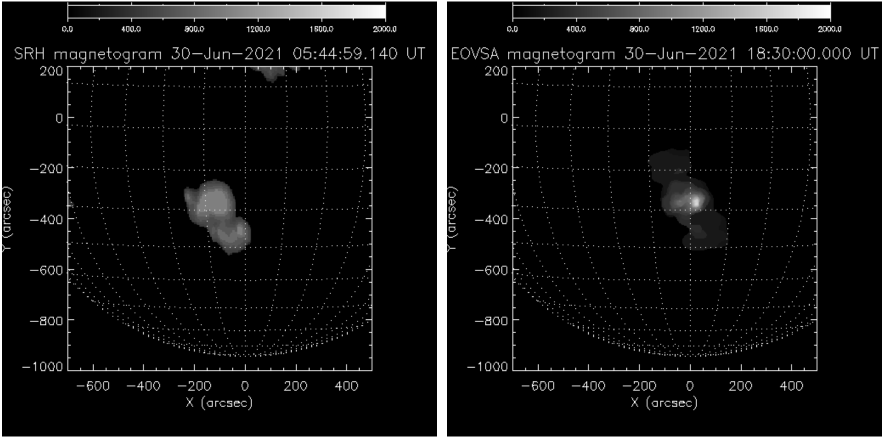
SRH observations

2021-06-30



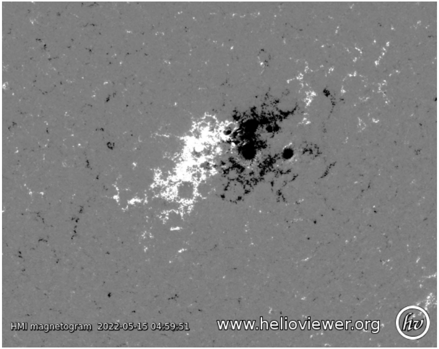
GR-magnetogramms obtained from EOVSA and SRH (3-6 GHz) observations

NOAA 12835, 2021-06-30, observations



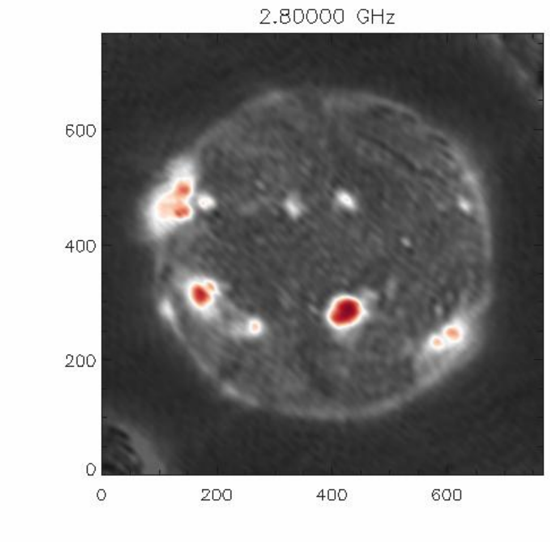
SRH observations

NOAA 13007, 2022-05-15



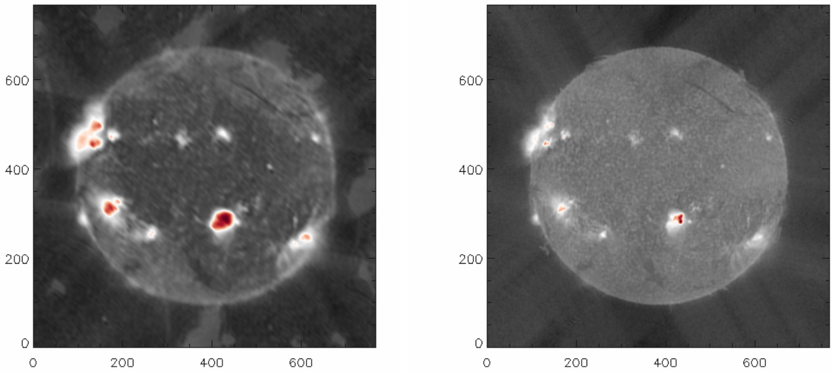
SRH observations

2022-05-15, 3–12 GHz



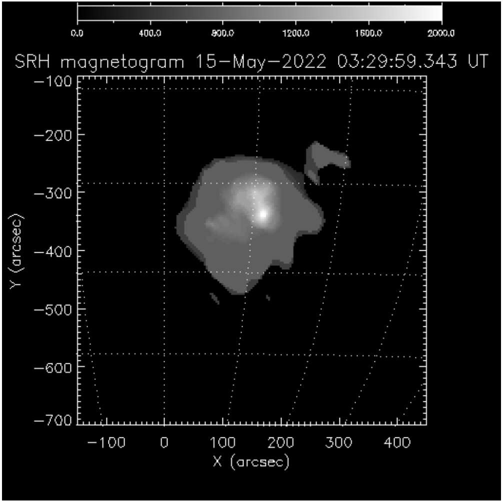
SRH broadband images

3–6 GHz and 6–12 GHz



GR-magnetogramm, SRH 3-12 GHz

NOAA 13007, 2022-05-15



Topics to discuss

Spatial resolution is low and frequency dependent

Possible workarounds:

- **Ignore**: spectra at individual pixels are not correct
- **Degrade resolution for high frequency**: some information is lost

Topics to discuss

Where do we measure magnetic field?

Possible workarounds:

- **Let it be 2000 km**: Average atmosphere, may be not correct in some cases
- **Couple with 3D or 1D models**: different effective heights for different pixels

Topics to discuss

Real MW emission at a certain frequency comes from several gyro-layers

Possible workarounds:

- **Forward fitting 1D or 3D models**

Topics to discuss

Brightness temperature calibration

Possible workarounds:

- **Quiet Sun as reference**: QS brightness temperature depends upon the activity level especially at lower frequencies
- **Total flux calibration**: Spectrometers with absolute calibrations are needed

Topics to discuss

Comparison of the observations of different instrument

Possible workarounds:

- SRH vs EOVSA vs RATAN-600 vs ...

Summary

GR magnetography:

- Direct mapping absolute value of the magnetic field in TR
- Constraints for the 3D field reconstruction
- Constraints for thermal 3D models

Current RadioHeliographs (MUSER, EOVSA and SRH):

- SRH and EOVSA allow for precise GR-magnetography
- SRH testing observations of the Sun in 3–6 GHz and 6–12 GHz ranges were performed from January 2021 till June 2022
  - Browse images and light curves: `http://badary.iszf.irk.ru/srhDailyImages.php`
  - Download data: `ftp://ftp.rao.istp.ac.ru/`

Thank you for your attention!

References

Bogod, V. M. and Yasnov, L. V. (2009). On the comparison of radio-astronomical measurements of the height structure of magnetic field with results of model approximations. *Astrophysical Bulletin*, 64:372–385.

Gelfreikh, G. B. and Shibasaki, K. (1999). Radio Magnetography of Solar Active Regions Using Radio Observations. In Wilson, A. and et al., editors, *Magnetic Fields and Solar Processes*, volume 448 of *ESA Special Publication*, page 1339.

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White, S. M. (2004). Coronal Magnetic Field Measurements Through Gyroresonance Emission. In Gary, D. E. and Keller, C. U., editors, *Astrophysics and Space Science Library*, volume 314 of *Astrophysics and Space Science Library*, page 89.

Zheleznyakov, V. V. and Zlotnik, E. I. (1980). Thermal cyclotron radiation from solar active regions. In Kundu, M. R. and Gergely, T. E., editors,