

ACOUSTIC HALOS IN THE SOLAR ATMOSPHERE



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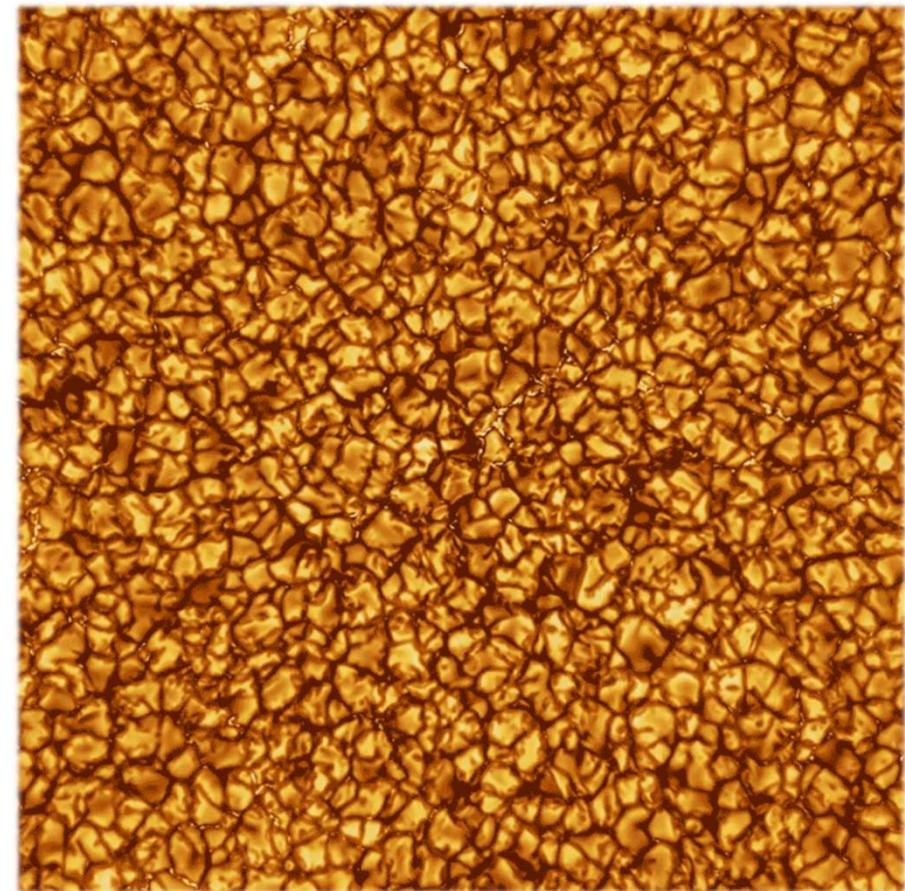
INTRODUCTION

CHARACTERISTICS

RESULTS

CONCLUSION

DISCUSSION



(Swedish 1-m Solar Telescope/Institute for Solar Physics/Luc Rouppe van der Voort, Oslo)

INTRODUCTION



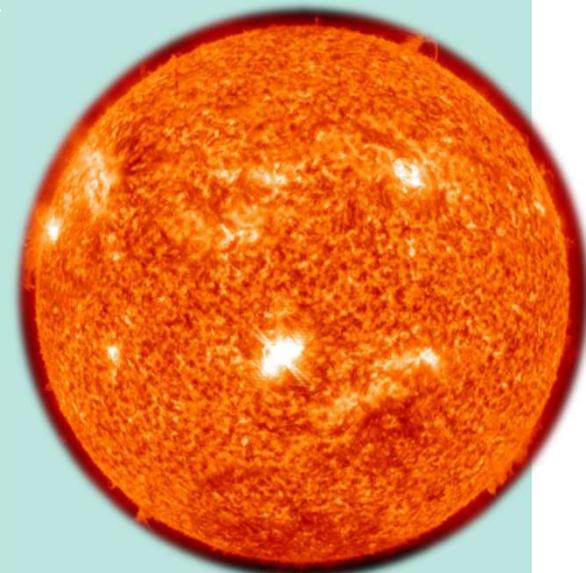
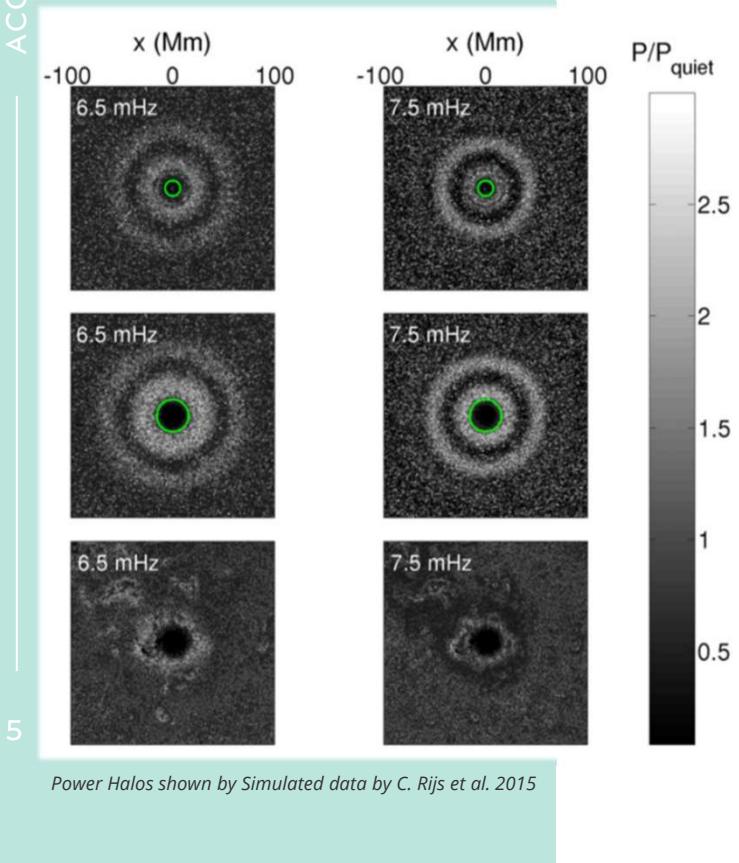


Image source: NASA

INTRODUCTION

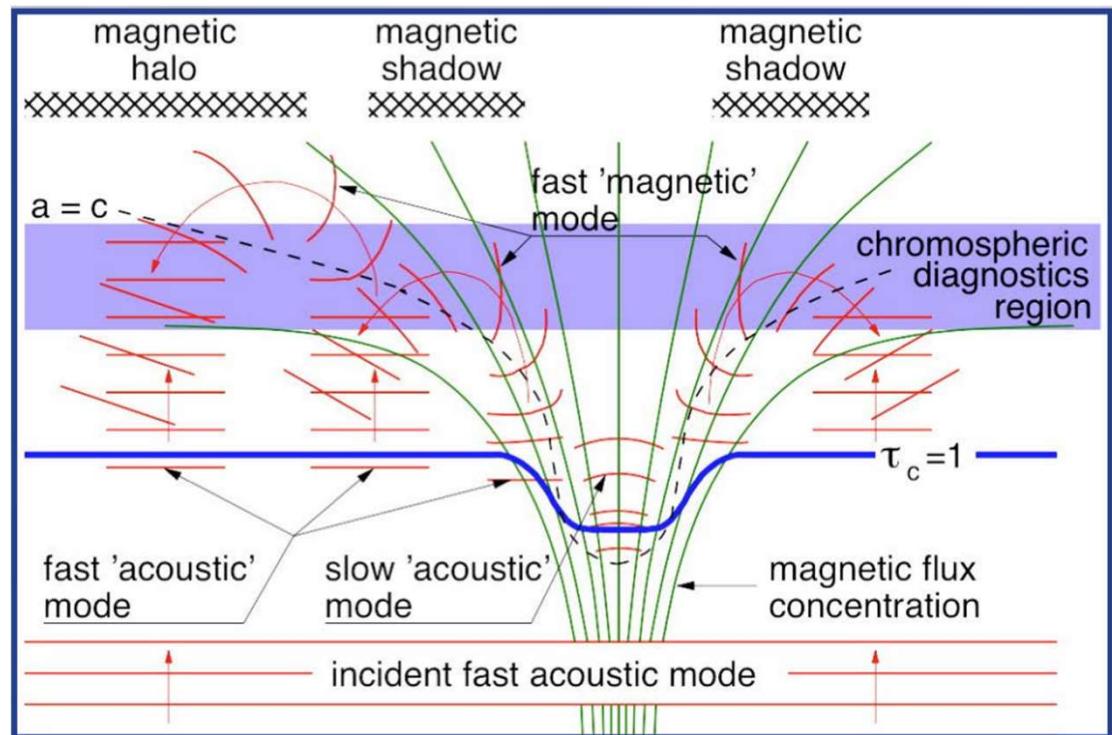
- 1) The power enhancement observed around Sunspots and active regions at frequencies above the local acoustic cutoff is known as “Acoustic Halo Effect”.
- 2) The acoustic halos were first observed in Dopplergrams as a power enhancement around 6 mHz (Braun et al., 1987), acoustic power maps as a diagnostic tool for local helioseismology, they not only well observed reduction of power at around 3 mHz, but also a high frequency enhancement at around 6 mHz extending many arcseconds radially.
- 3) Significant reflection of the upcoming acoustic waves at 5–6 mHz is detected in active regions, unlike the behavior of such high-frequency waves in the Quiet Sun (Braun & Lindsey 2000).



CHARACTERISTICS

- 1) Form in moderate magnetic field strength (150 – 350 G) and near horizontal ($\pm 30^\circ$) magnetic field.
- 2) The acoustic power measured in **halos** is **higher** than in the nearby **Quite Sun** by about **40–60%**.
- 3) The peak frequency **increases** with the **field strength**. (*Schunker, H., & Braun, D. C. 2011*)
- 4) Decreasing in amplitude as the field becomes more vertically aligned. (*Rajaguru et al. 2013*)
- 5) The presence of the **halo** is extremely dependent on **height**.
- 6) The **enhancement** is also visible in the **chromosphere** in intensities, no enhancement is present in the **continuum** intensity power.

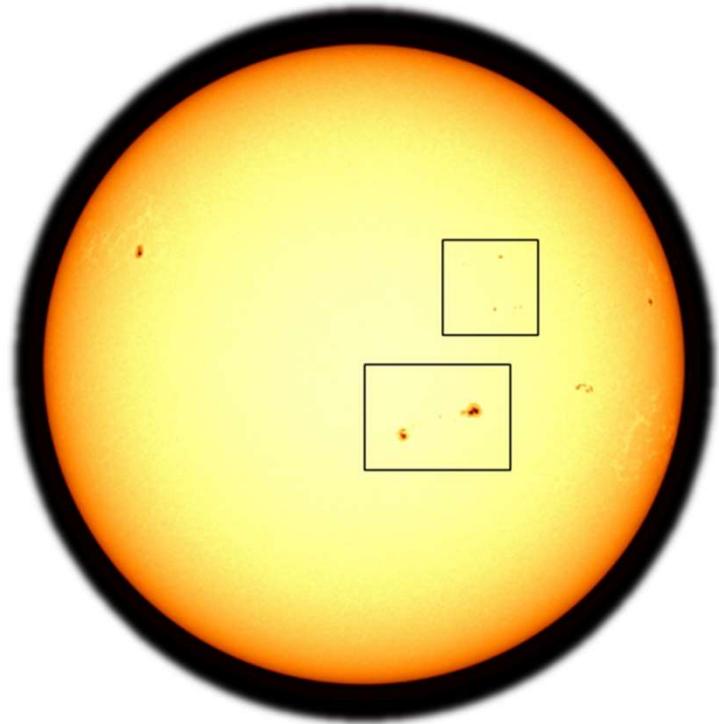
- Sketches the physics behind the Magnetic shadow and Halo. In the peripheral region of the Magnetic flux concentration (green), acoustic waves enter the region above the dashed curve where the Magnetic field dominates the thermal gas pressure (low β , region).
- There, they convert to fast, predominantly magnetic waves, which refract further above because of the steep increase in the Alfvén speed with height.
- After refraction, the waves travel back into the Sun again, and convert back to acoustic waves. Three such refractive wave paths are indicated in red.
- The downward traveling refracted waves interfere with the continuing incident fast acoustic waves within the diagnostics region, which leads to excess power, hence the Acoustic halo.



Poster: Revealing the nature of magnetic halos and shadows with radiation MHD simulations. Komm et al. (2013)

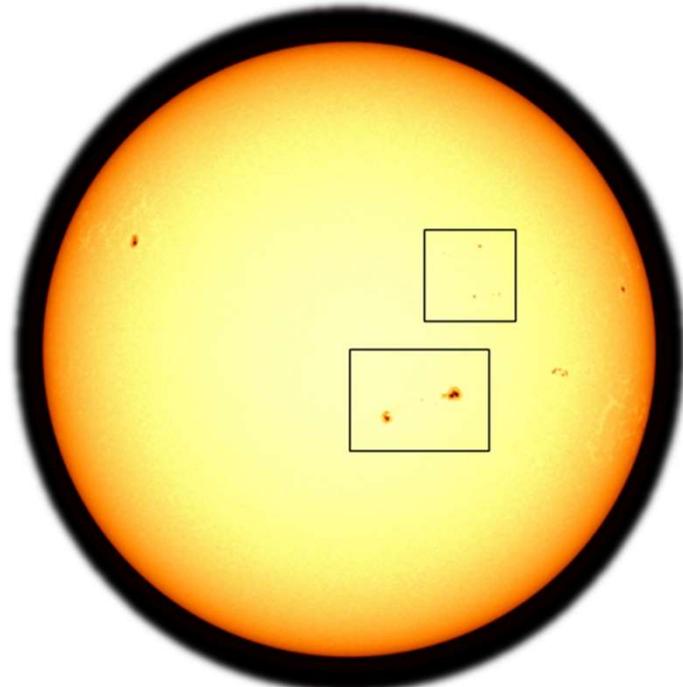
DATA

- SDO data product.
- We have considered 2 active regions for our analysis.
- The Sunspot NOAA 12381 and Solar Pore NOAA 12378 belongs to $\beta\gamma$ and $\alpha\gamma$ classes respectively.
- The time of observation is 2015-07-10, 07:00:40 to 07:59:55.
- Dataset used: HMI Continuum (Fe I 617.3 nm), HMI Dopplergram, AIA 170nm and 160nm and Vector Magnetogram.
- Cadence = 45 sec for HMI and 24 sec for AIA, No. of images = 80 and 149
- Employ Discrete Fourier Transform algorithm to map the Power Spectrum at each pixel of the image data.



DATA

- Details on line formation height
 - AIA 160nm, $z = 430\text{km}$ (Lower Chromosphere)
 - AIA 170nm $z = 360\text{km}$ (Upper Photosphere, Fossum and Carlsson 2005)
 - HMI Continuum $z = 0\text{km}$, $\tau = 1$ (Photosphere, Norton et al. 2006)
 - Dopplergram, $v \approx 140\text{km}$ (Fleck, Couvidat 2011)
- We are looking for the presence of excess power in high frequency range in the vicinity of active regions, at 4 different heights
- AIA 170nm and 160nm lines are known to capture the oscillations in Chromosphere due to p-modes. (Howe et al. 2010)
- FOVs: Sunspots = 218Mm x 363Mm, Solar Pore = 218Mm x 218Mm.



METHODS OF ANALYSIS

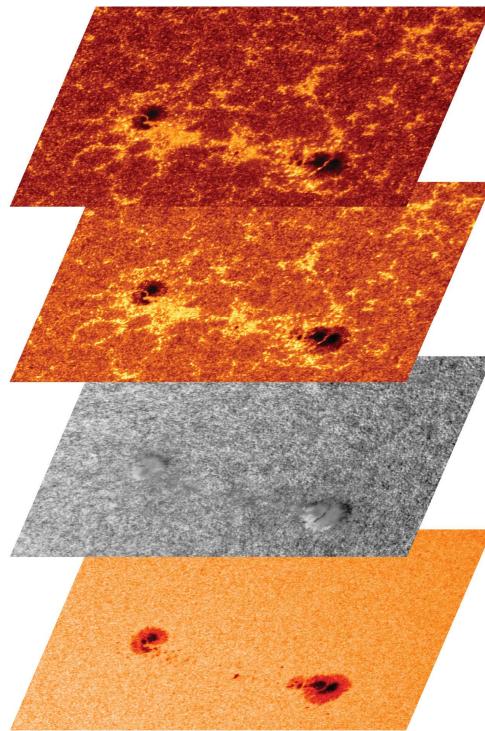
- De-rotate the disk data to compensate for the rotation of the Sun in the selected active regions
- Use Fourier analysis to determine the amplitudes of respective frequencies present in the signal.

$$\hat{x}_n = \sum_{k=0}^{N-1} x_t e^{2\pi i k n / N} \quad k_n = \pm 0, \pm 1, \dots, \pm \left(\frac{N}{2} - 1\right)$$

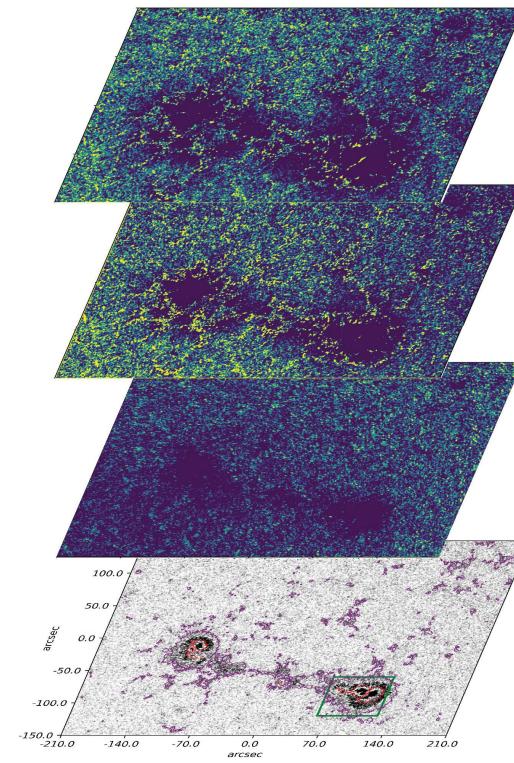
- Select a sub portion and apply thresholding to isolate the active regions with some portion of Quite Sun.
- Selected frequency band 1) Low frequency band = 3-5mHz
2) High frequency band = 7-11 mHz
- Make Power maps for particular frequency bands and repeat for comparison between low and high frequency power. Repeat this for data at different height to study the recombination of power as a function of height.
- Study the scatter plot of Field strength vs Power and Inclination vs Power.

RESULTS

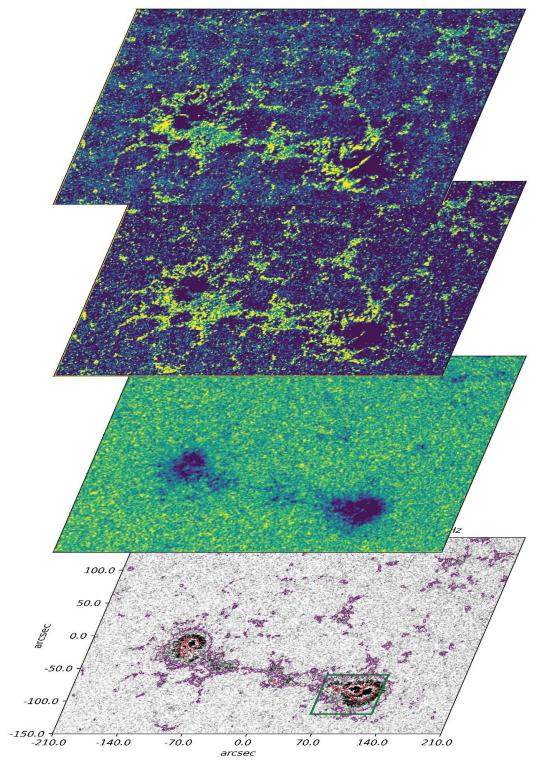
Sun Spots at different heights



Power Maps of Sun Spot at various heights (4mHz)

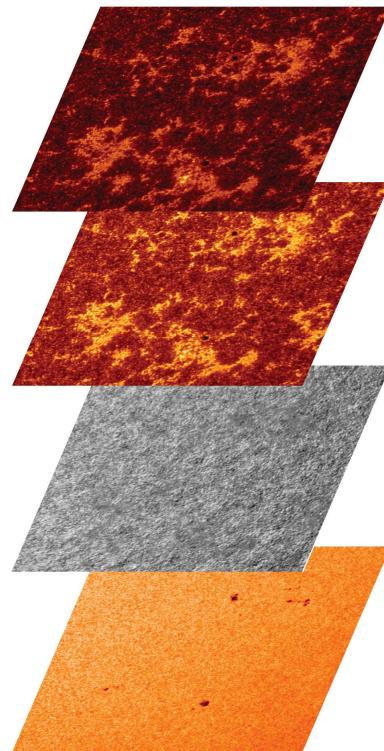


Power Maps of Sun spots at various heights (8mHz)



RESULTS

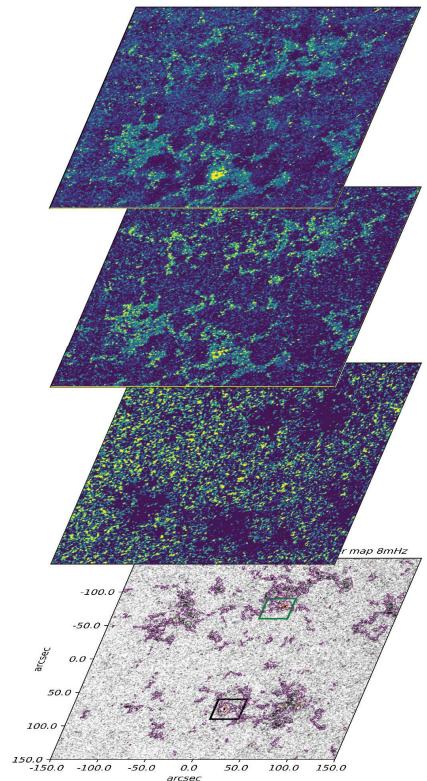
Solar Pore at different heights



Power Maps of Solar Pore at various heights (4mHz)



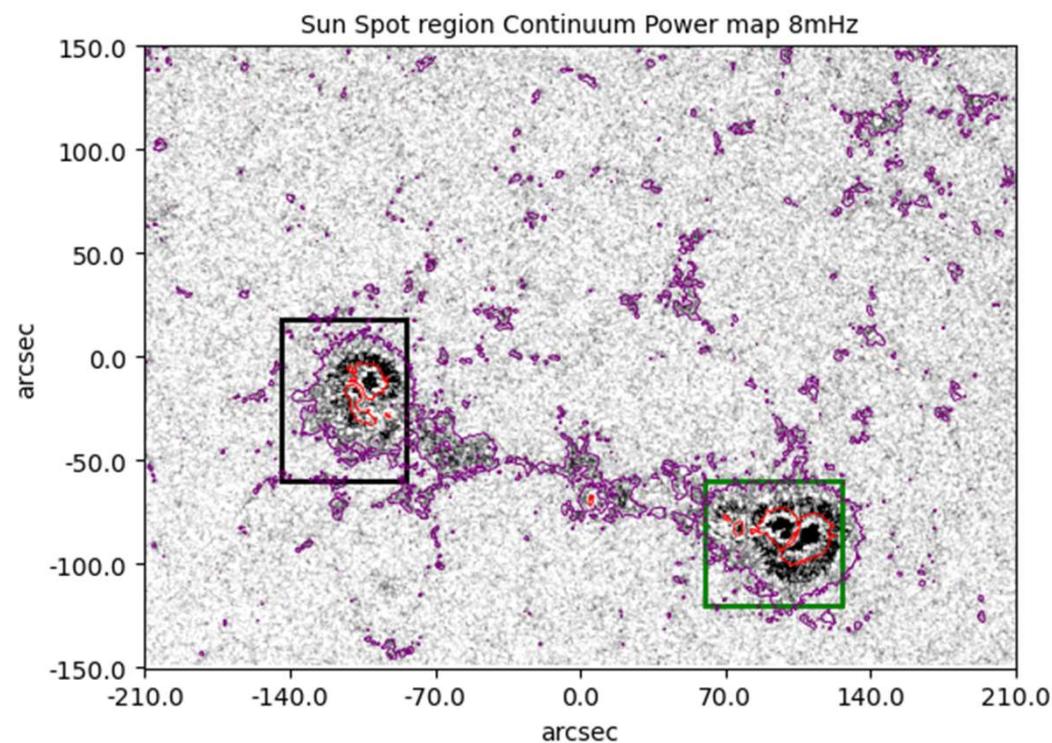
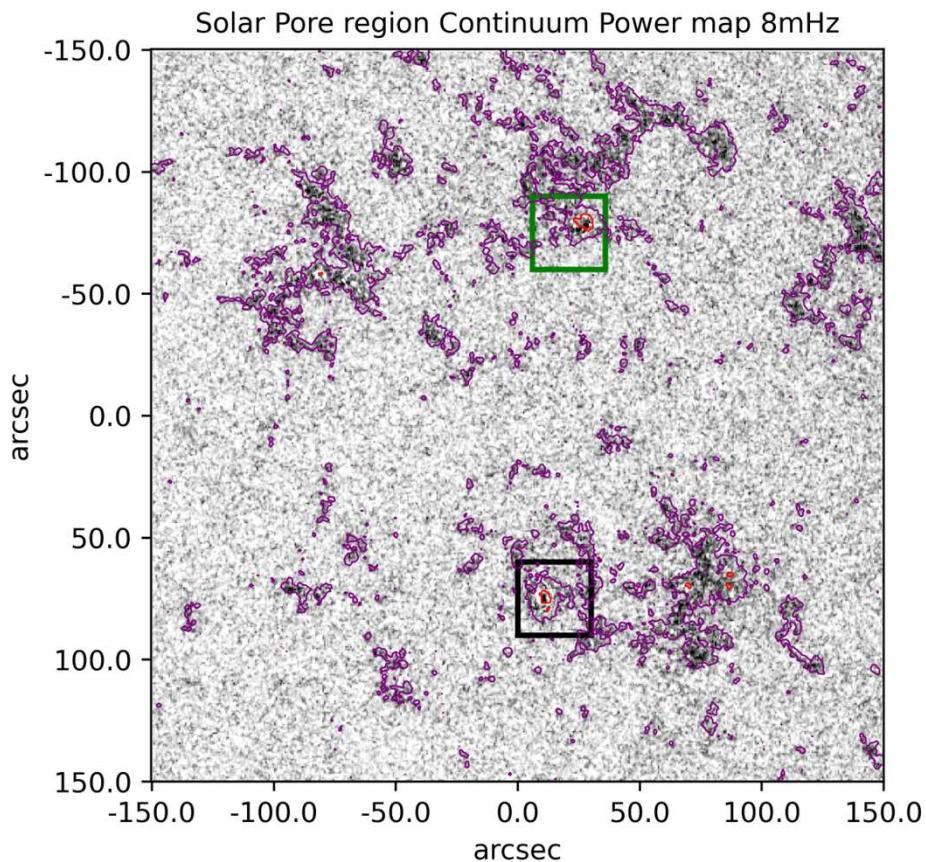
Power Maps of Solar Pore at various heights (8mHz)



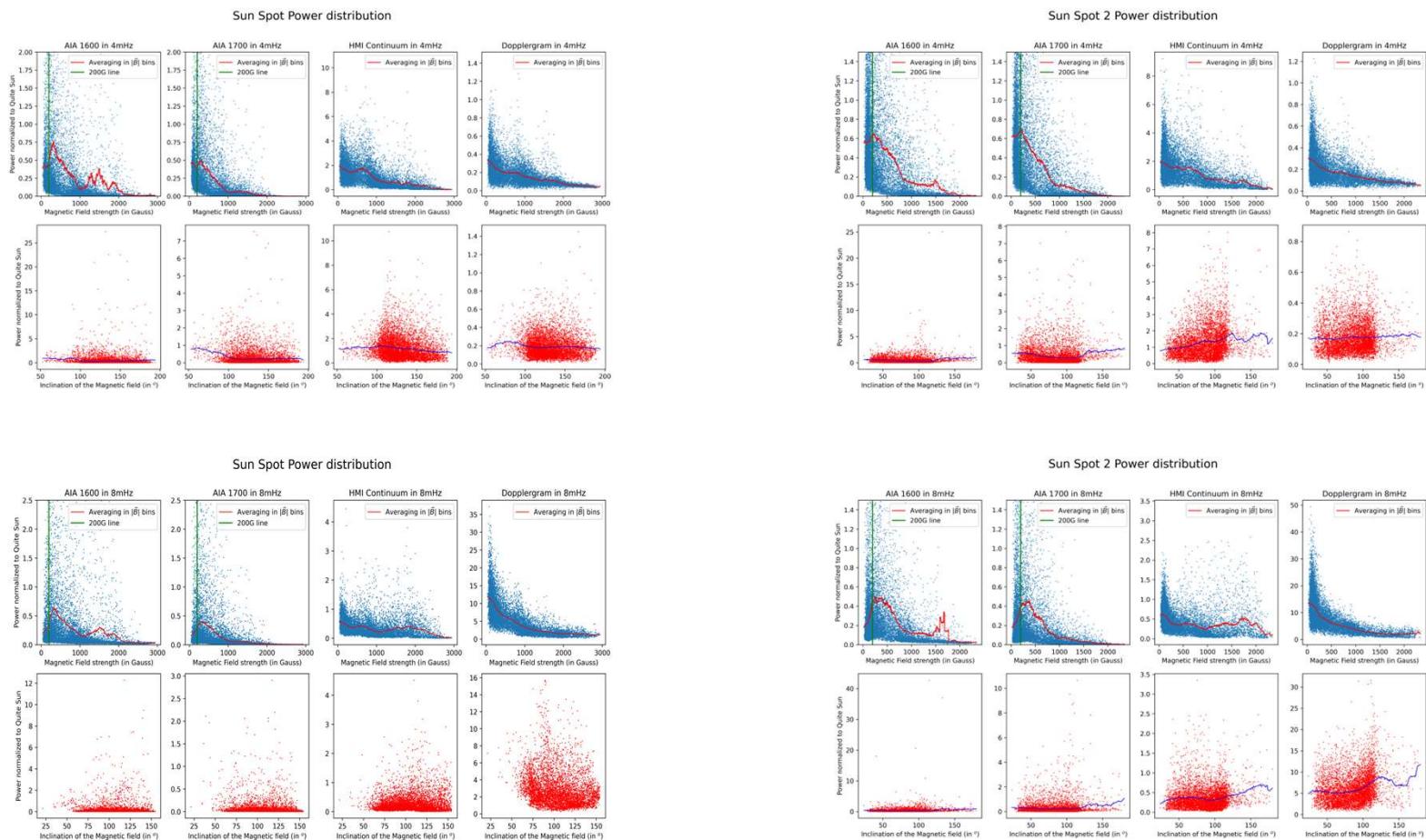
DEPENDENCE ON THE FIELD STRENGTH AND INCLINATION



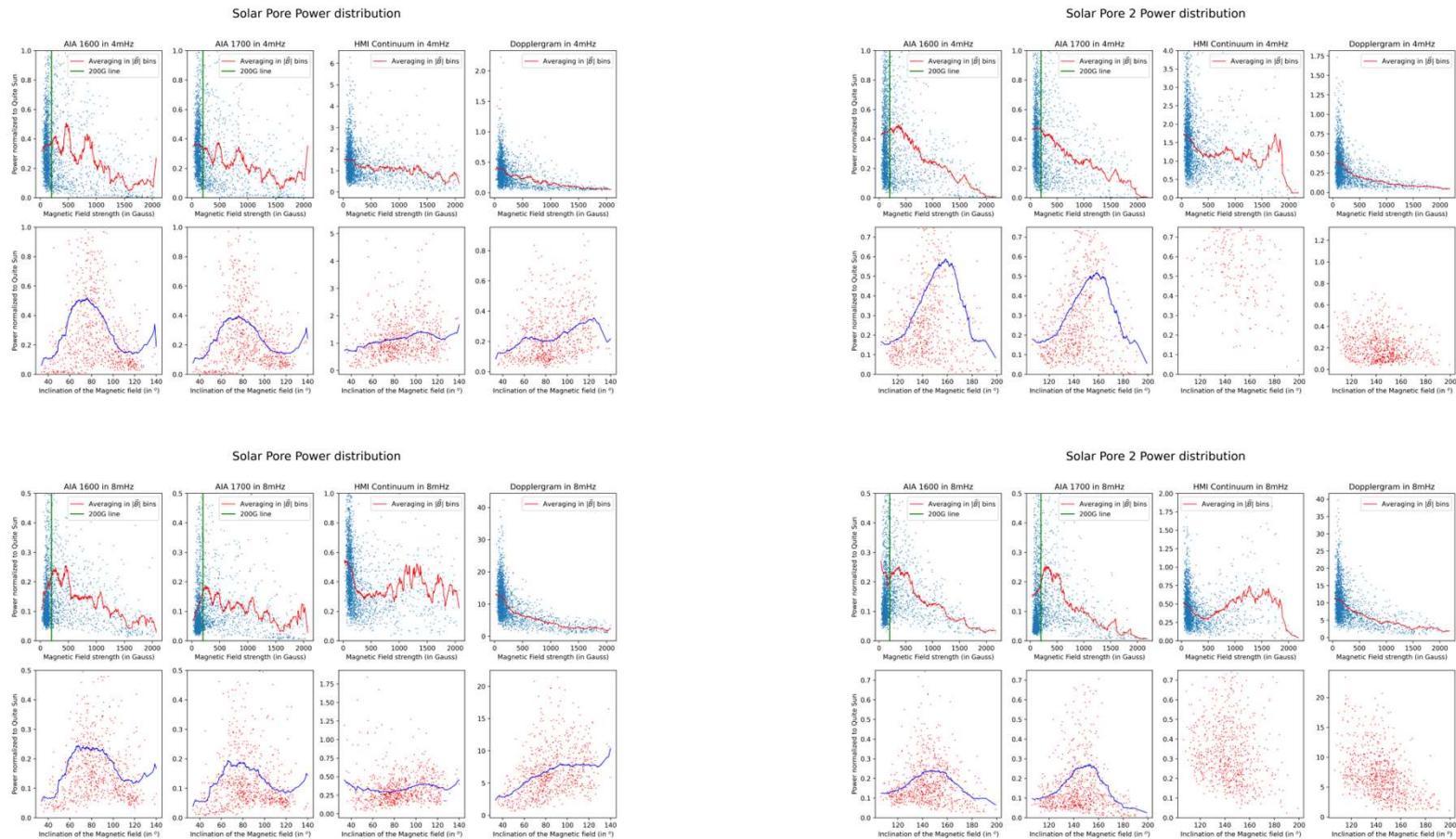
ACTIVE REGIONS



For Sun Spots



For Solar Pores



CONCLUSIONS AND DISCUSSION

- Spatial reorganization of the otherwise uniform distribution of Power above the Photospheric cut-off by the overlying Magnetic field of active regions is clearly shown by our analyses of wave power distribution in different frequency and heights.
- The formation of a Power enhanced Halo region around the active region is evident in the Power maps, with it showing suppression of low frequency wave in the same region.
- Scatter plots of Power vs Field Strength show a distinct peak in the 250G region (S.P. Rajaguru et al. 2012 for an α Sun Spot).
- Decrease in Power in High Magnetic field strength region is evident in the scatter plots.
- Further analysis needs to be done with the Field inclination vs Power plots to make a conclusion with it.
- The fact that the chosen Active regions were off from the Solar disk center by 23° and 19° respectively, the Dopplergrams didn't reveal much structure in it as the limb effects started to interfere in the Power Maps.
- An α class Sun Spot with simple structure that is close to the disk center might reveal more details in the Acoustic Halo's structure.

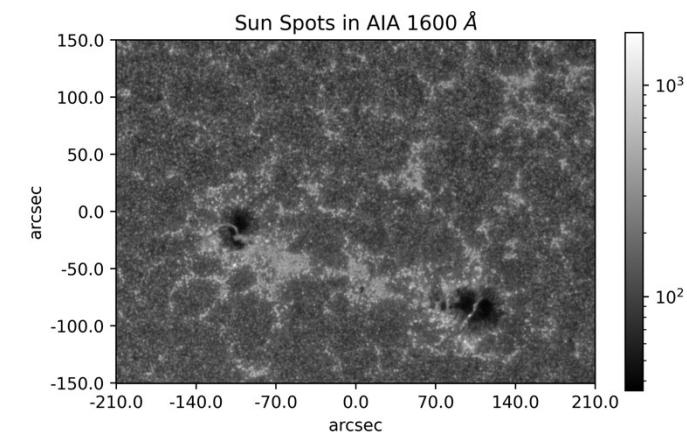
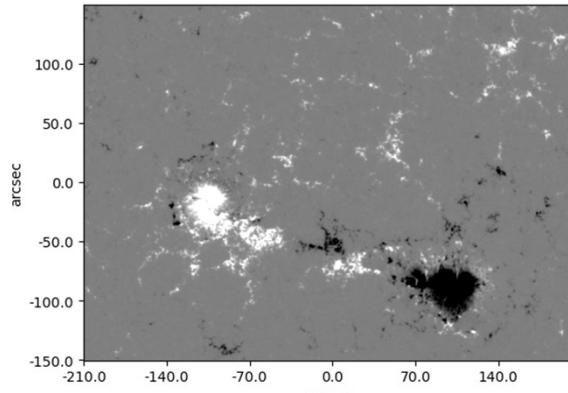
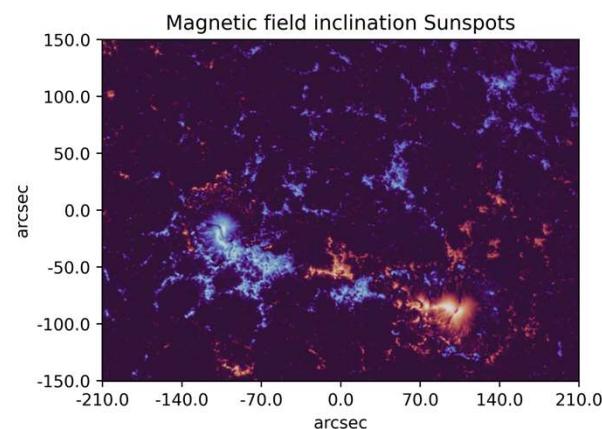
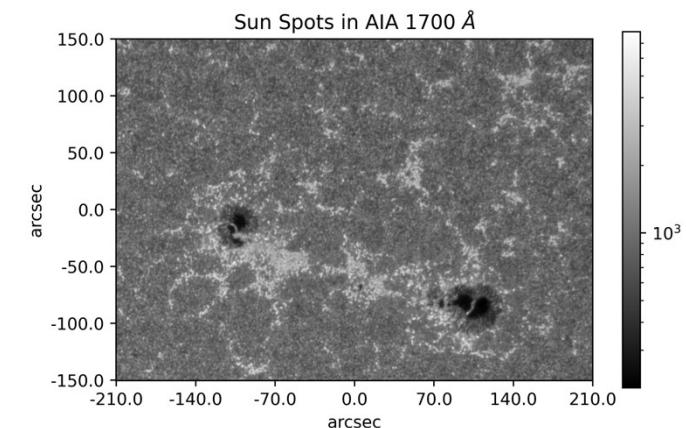
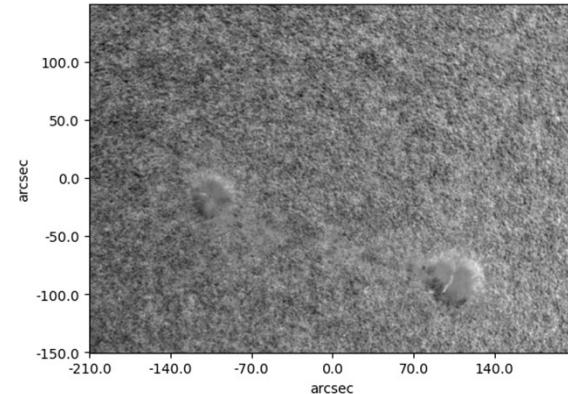
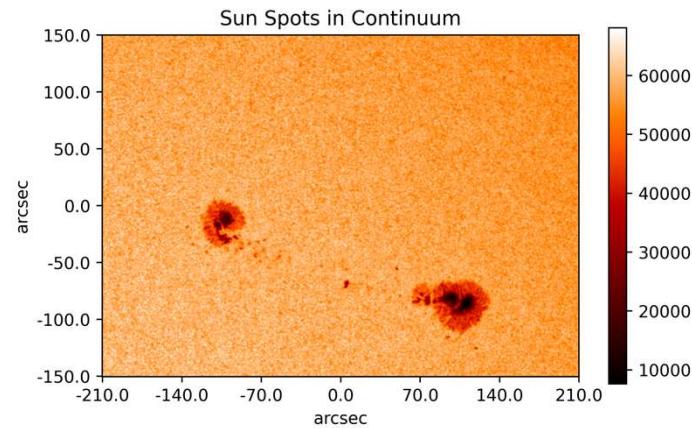
REFERENCES

- Revealing the nature of magnetic shadows with numerical 3D-MHD simulations - C. Nutto et al. 2012
- Properties of High-Frequency Wave Power Halos around Active Regions – S. P. Rajaguru et al. 2012
- Sunspot seismic halos generated by fast MHD wave refraction – Khomenko et al. 2009
- 3D SIMULATIONS OF REALISTIC POWER HALOS IN MAGNETOHYDROSTATIC SUNSPOT ATMOSPHERES – Carlos et al. 2015
- A Study of Acoustic Halos in Active Region NOAA 11330 using Multi-Height SDO Observations - S. C. Tripathy et al. 2017
- Wave properties in the low solar atmosphere - Julia M. Riedl
- Revealing the nature of magnetic halos and shadows with radiation MHD simulations Poster - Oskar Steiner et al.

Thank you

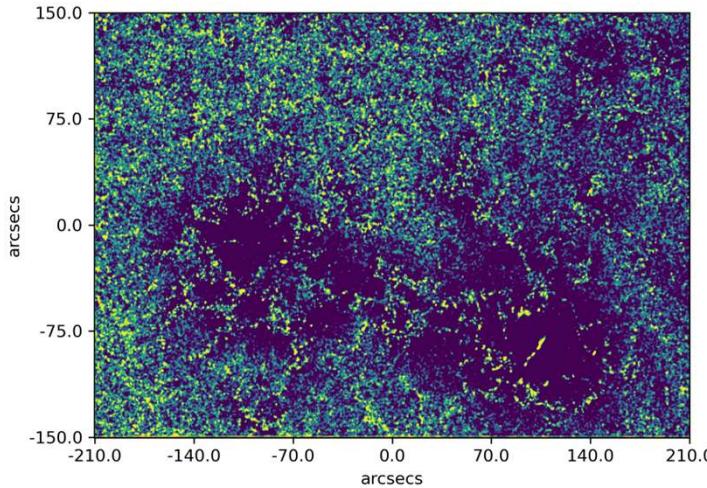
Any question? !?

Sun Spots images and Power Maps

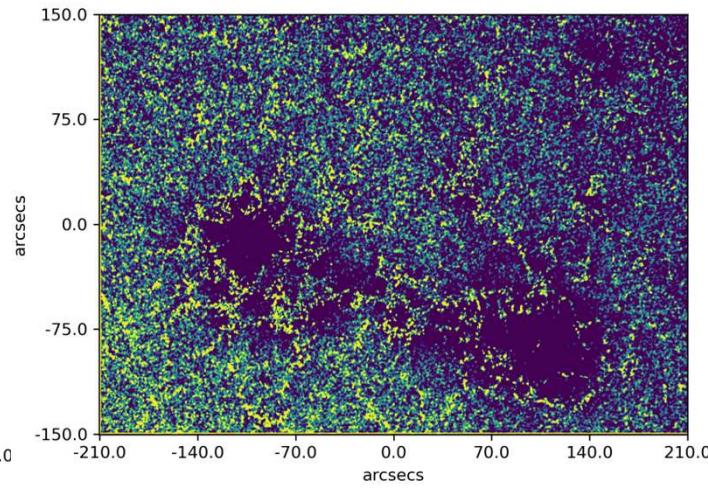


Sun Spots images and Power Maps

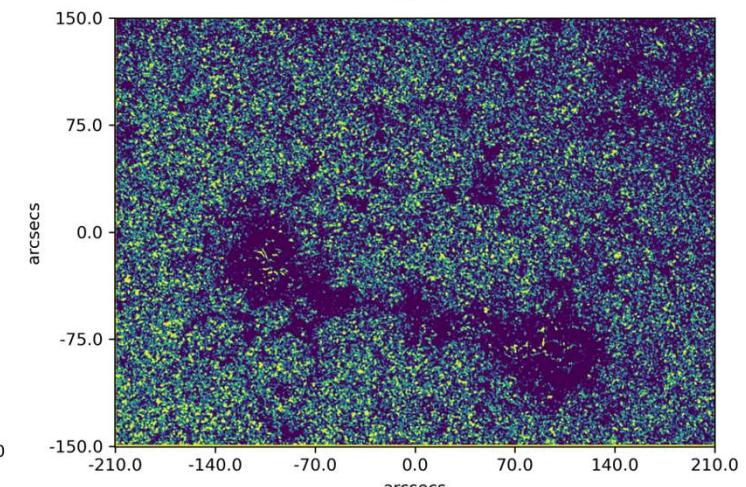
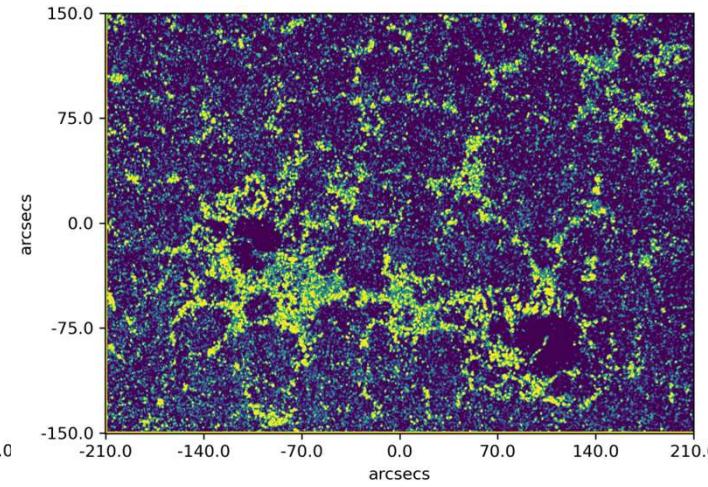
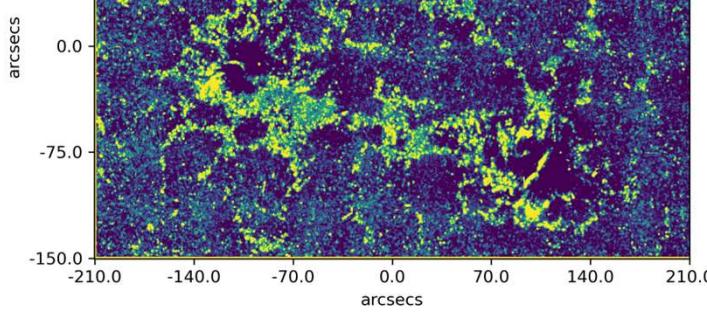
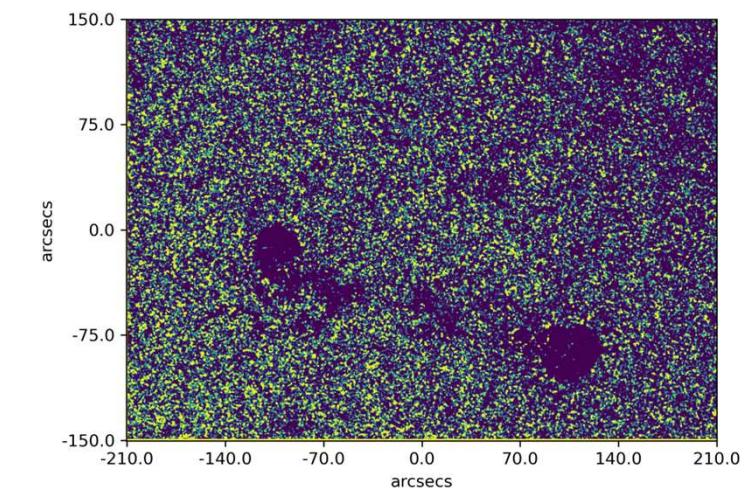
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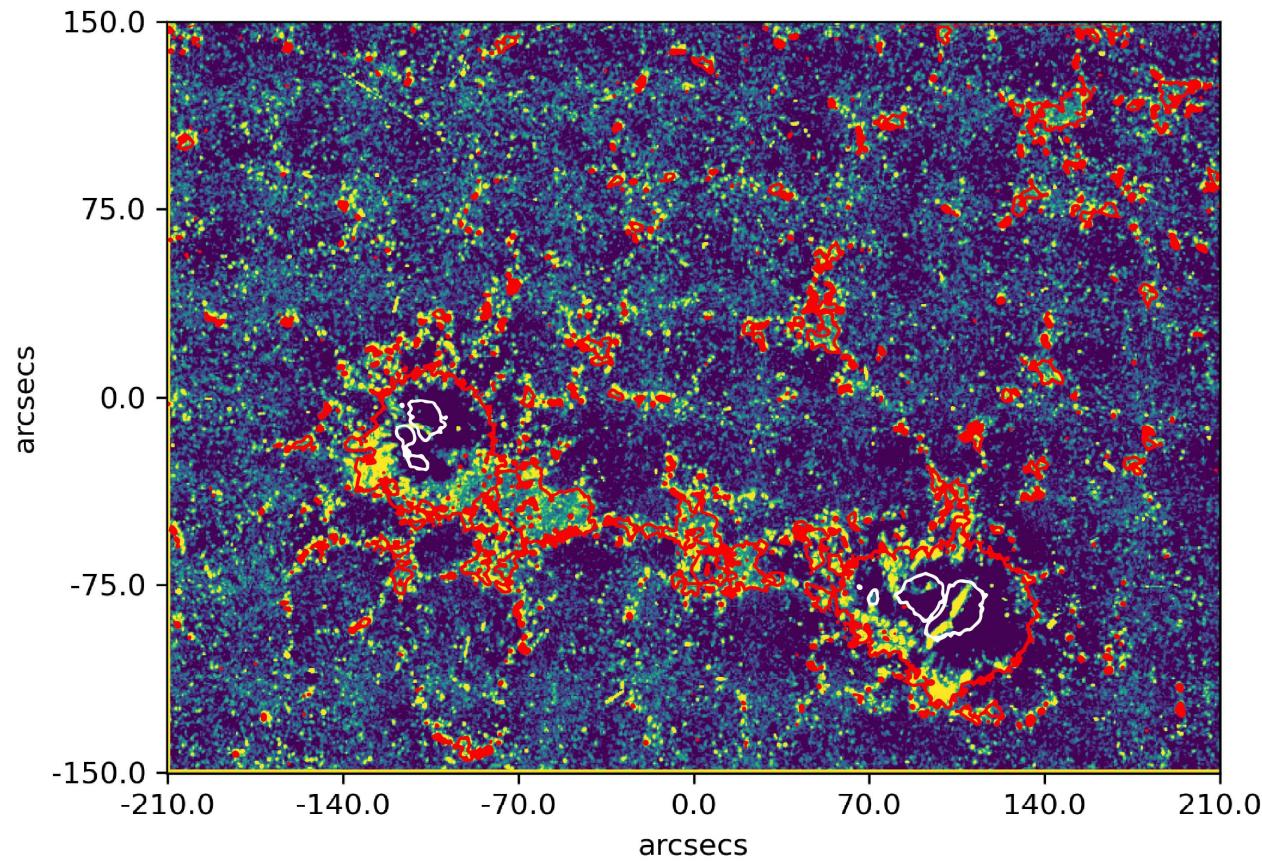


AIA 1700 A

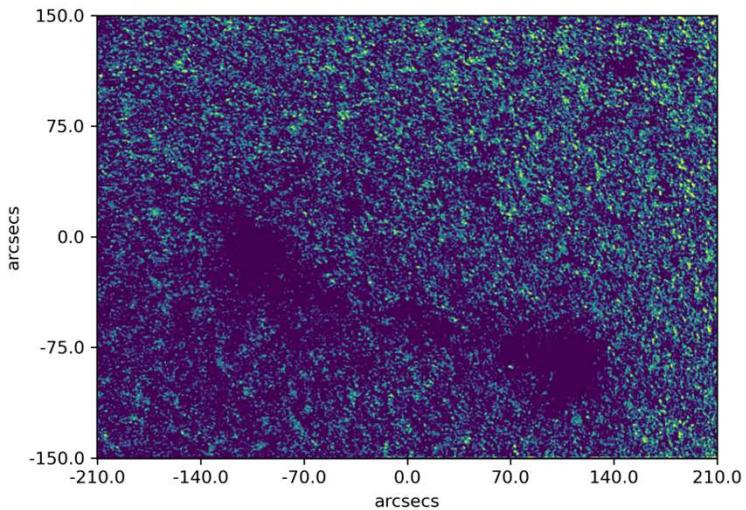


HMI Continuum Fe I 6173 A

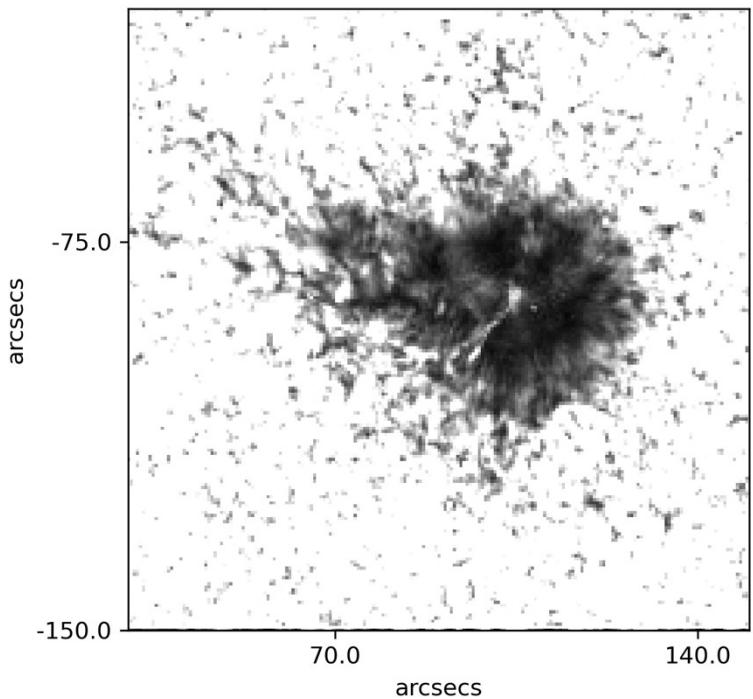
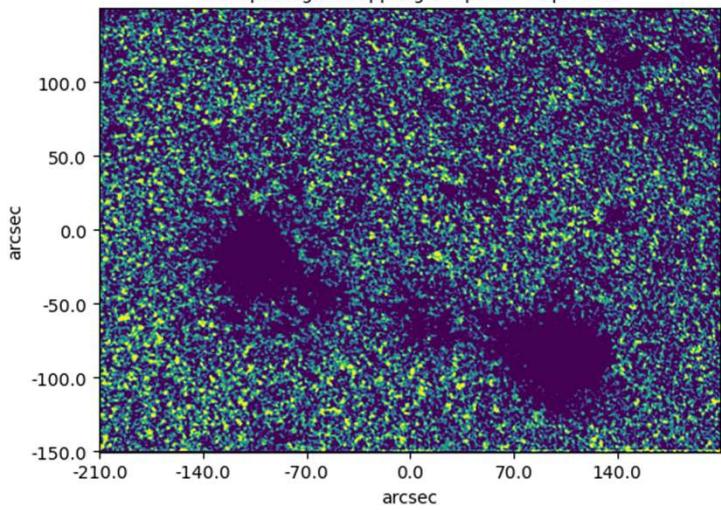




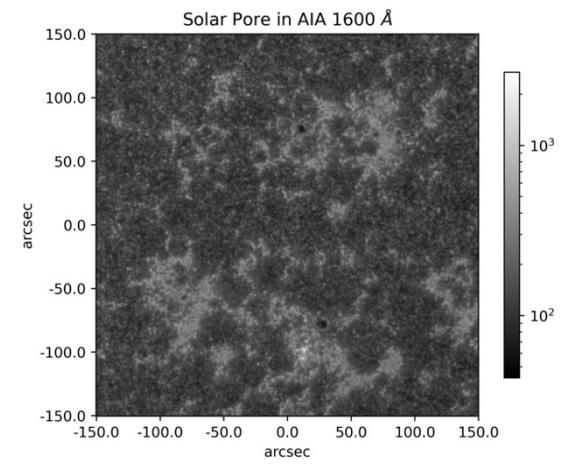
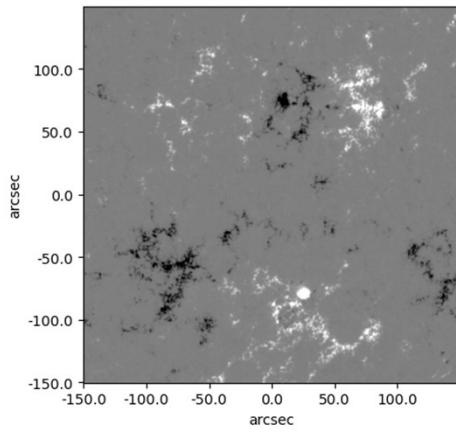
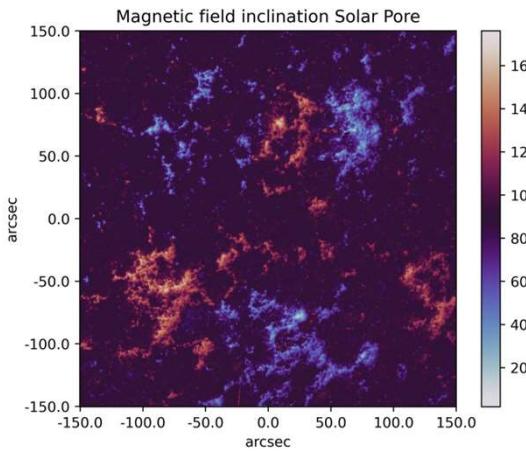
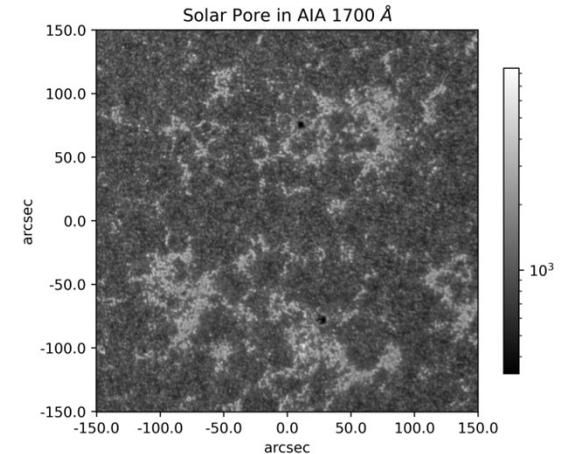
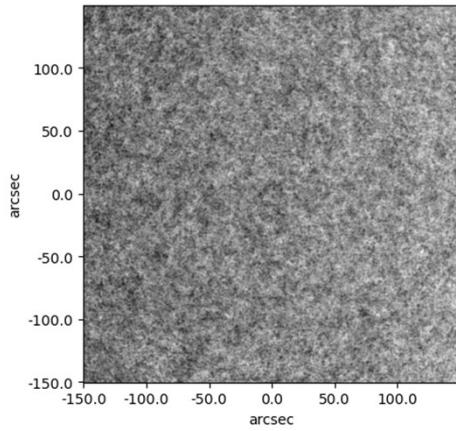
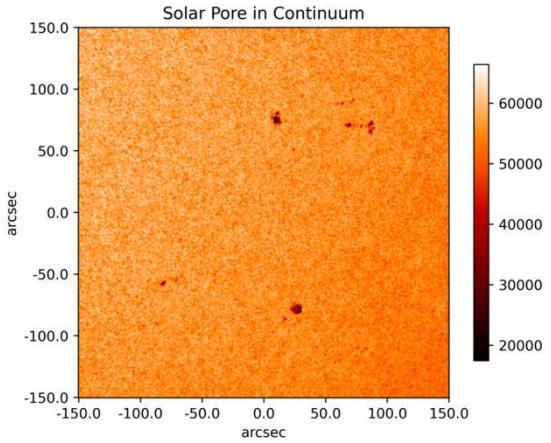
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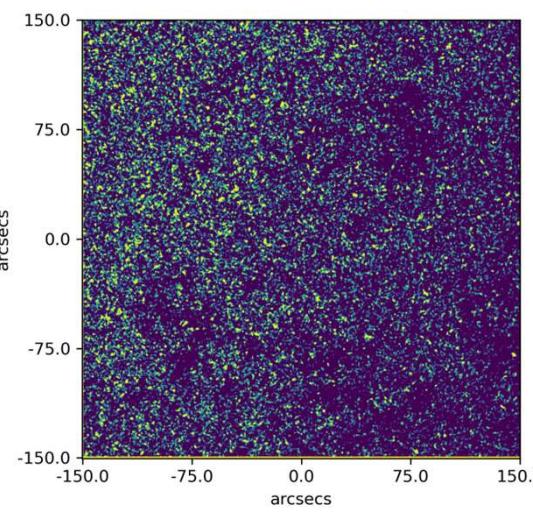
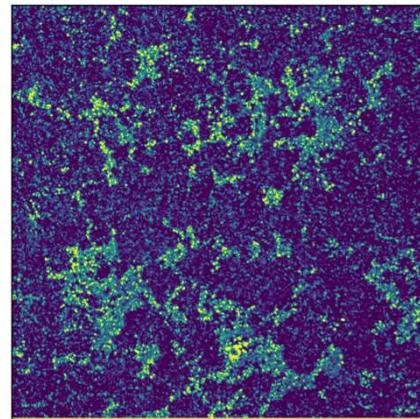
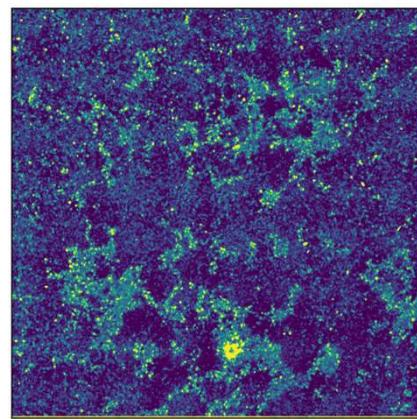
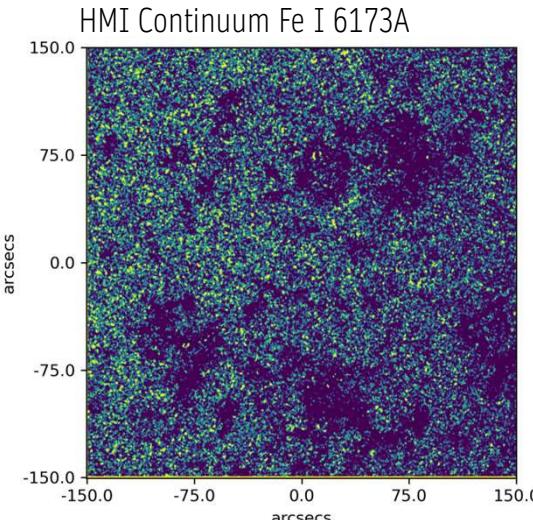
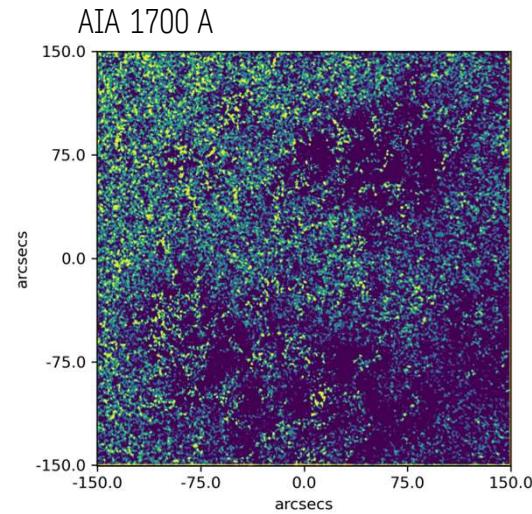
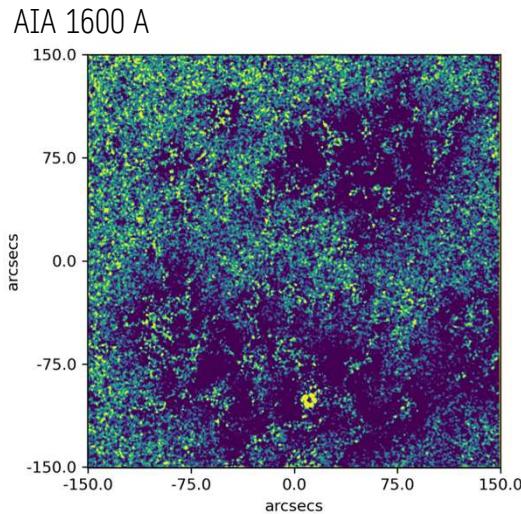
Sun Spot region Dopplergram power map 8mHz

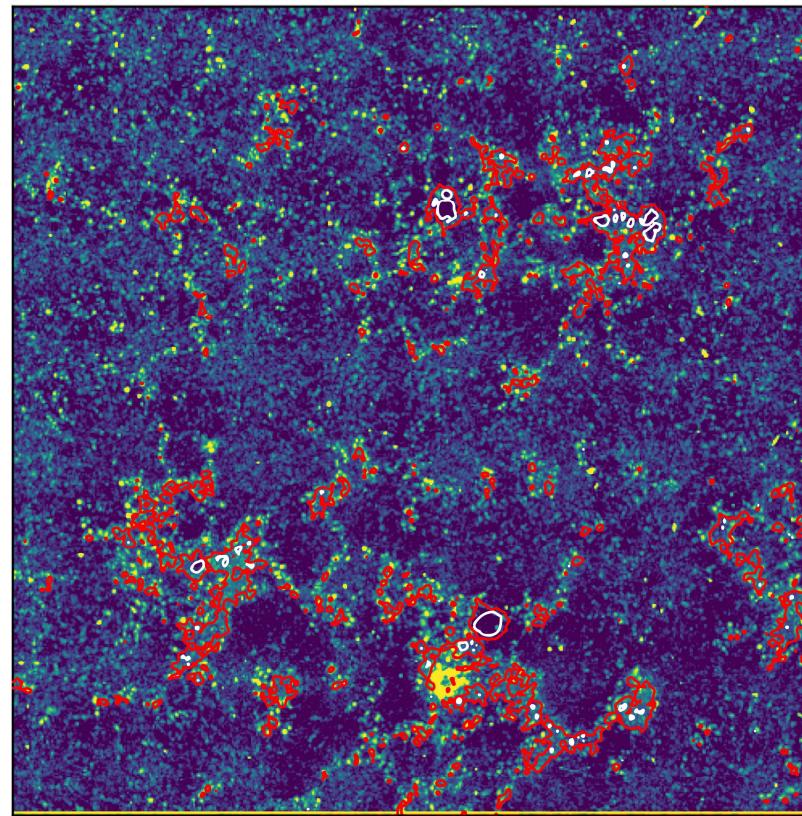


Solar Pore images and Power Maps

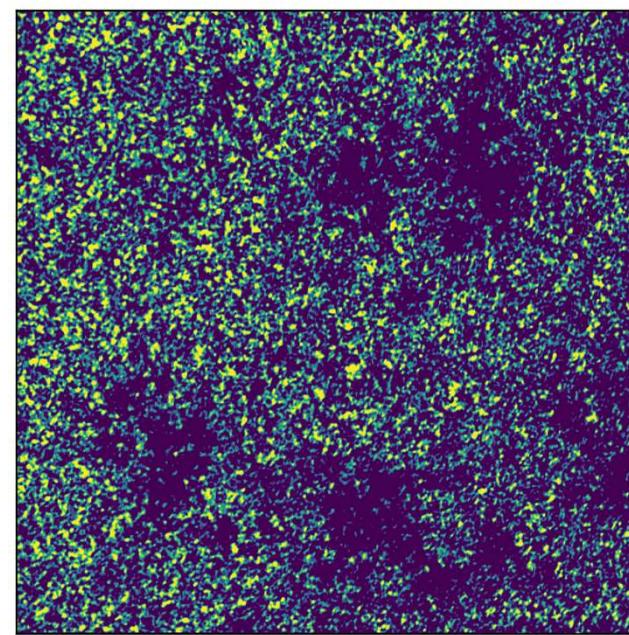
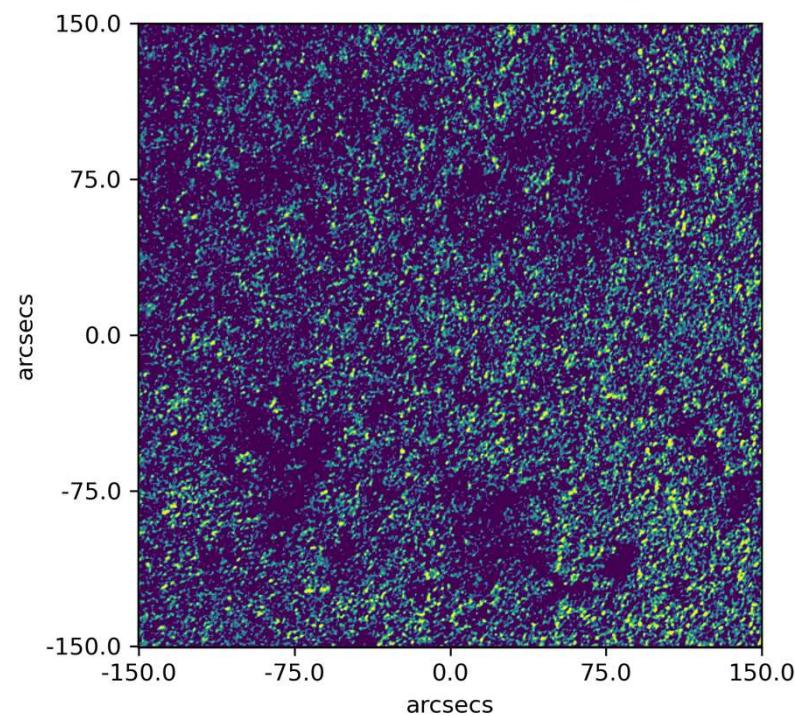


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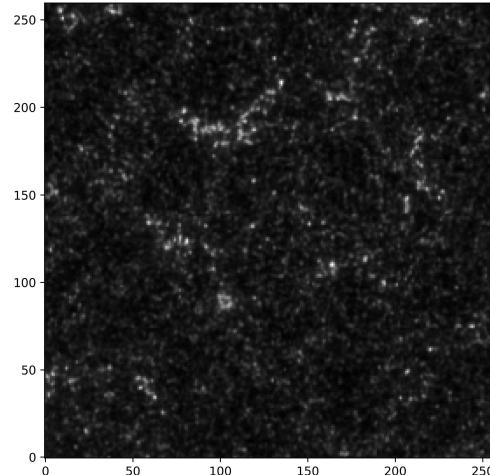
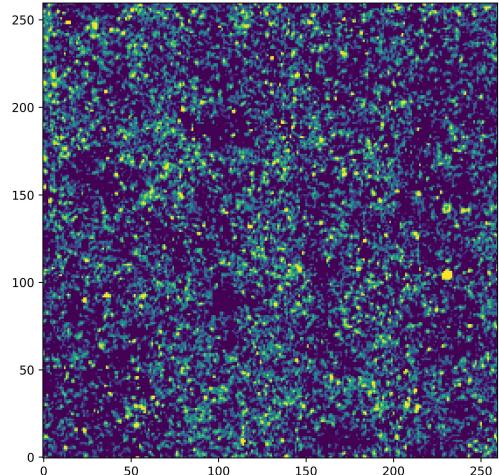


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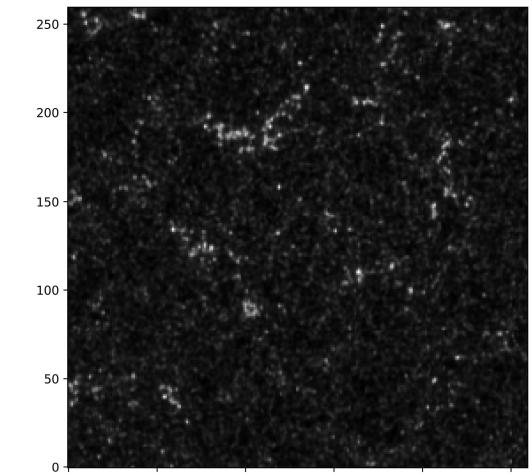
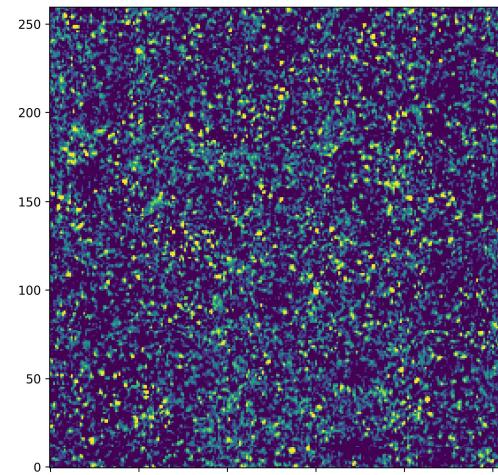


Quite Sun images and Power Maps

AIA 1600 Quite Sun



AIA 1700 Quite Sun



HMI Continuum Quite Sun

