Helioseismic Monitoring of the Sun's Far Hemisphere for Applications in Space Weather Forecasting

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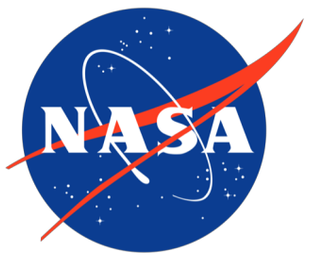


NWRA
Since 1984

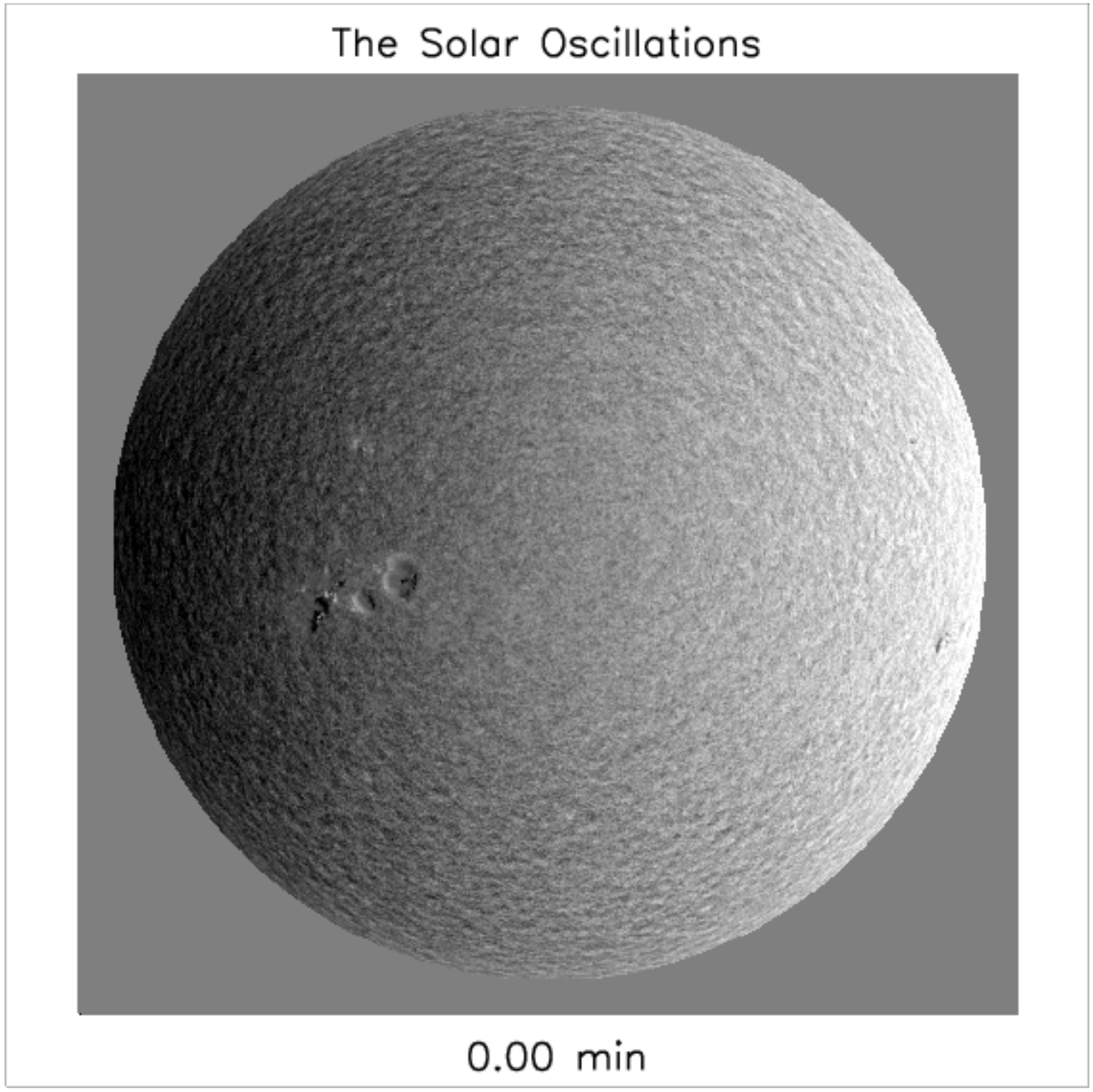
- In the future far-side magnetic activity will be directly monitored.

- Until then, we will use everything available to deduce it.

- Helioseismic monitoring is an important tool in our toolbox.

“The Solar Oscillations”

- Doppler observations of the Sun (Fe I 6173) show its surface to be constantly oscillating
- +/-10 km amplitude
- T ≈ 300 seconds
- Discovered by Leighton, Noyes and Simon, and independently by Evans, Michard and Servajean, in the early 1960s.

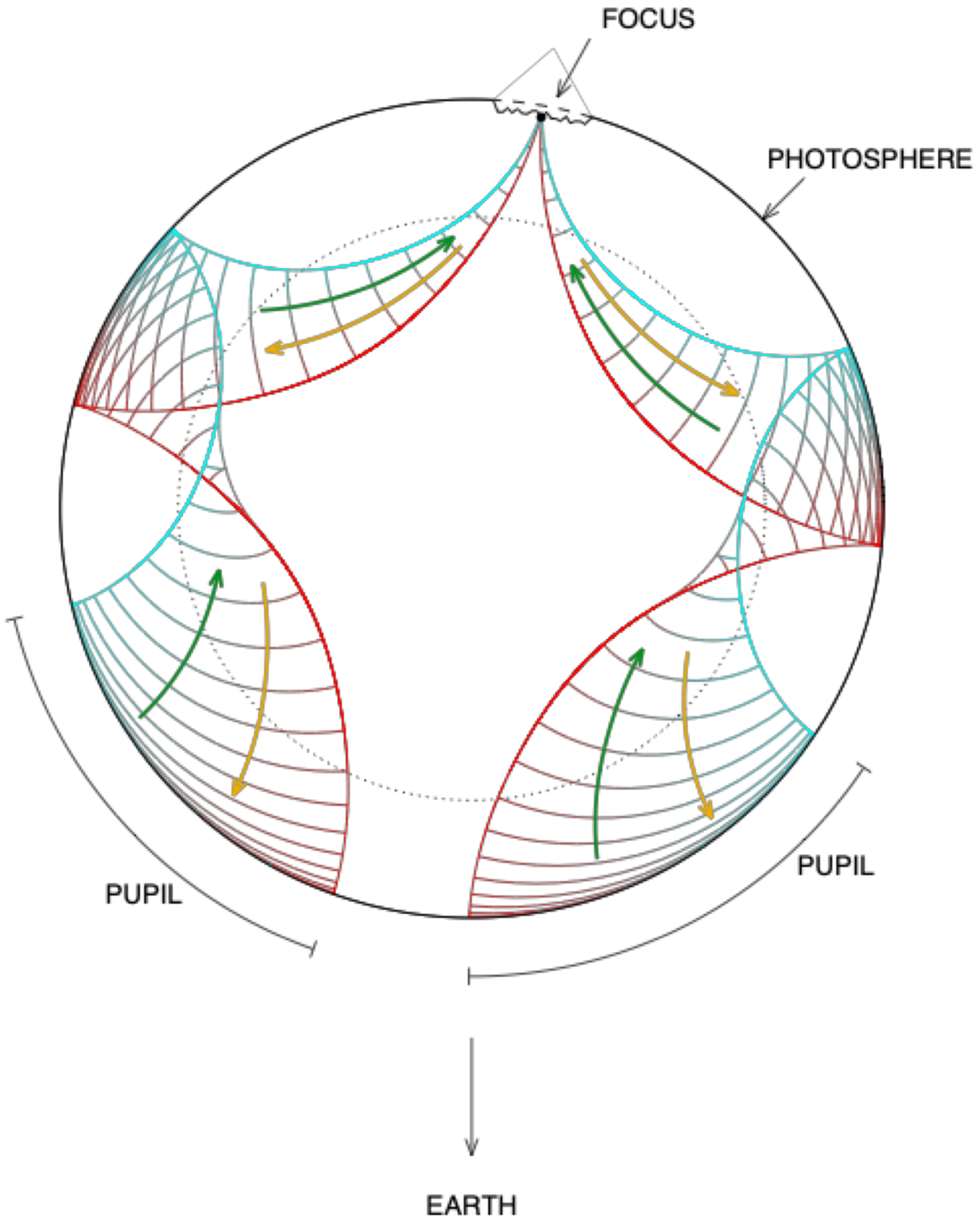


Wave Diagram for 2x2-Skip Helioseismic Holography

Oscillations result from acoustic waves that fill the solar interior.

Computational analogies of standard wave optics are applied to helioseismic observations of the near hemisphere to image active regions in the Sun's far hemisphere.

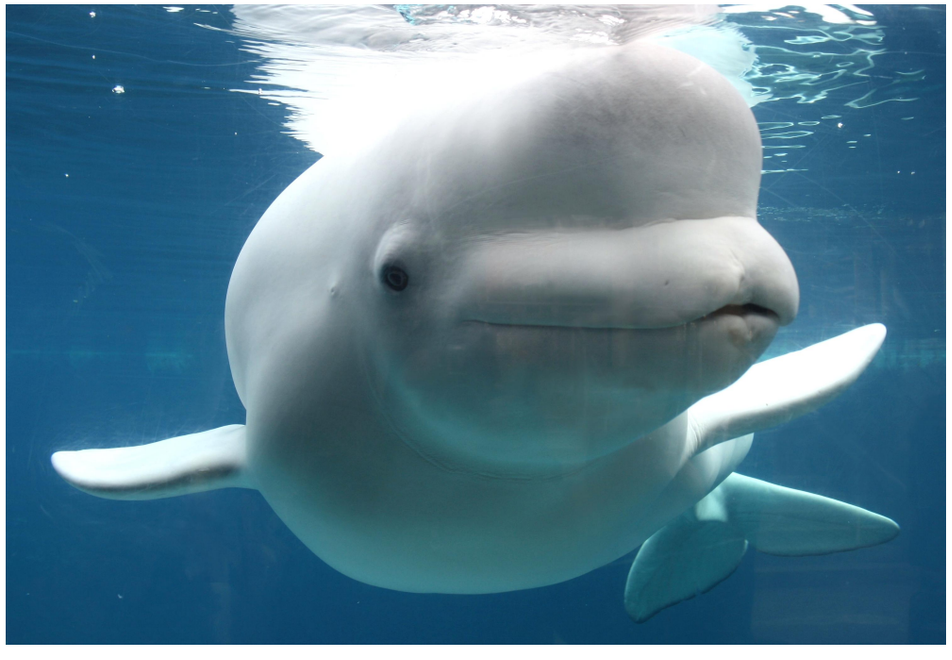
Seismic monitors that extend to the antipode of solar-disk center from Earth depend on waves that take two or more skips.



Imaging with sound is not new …

e.g., medical imaging …

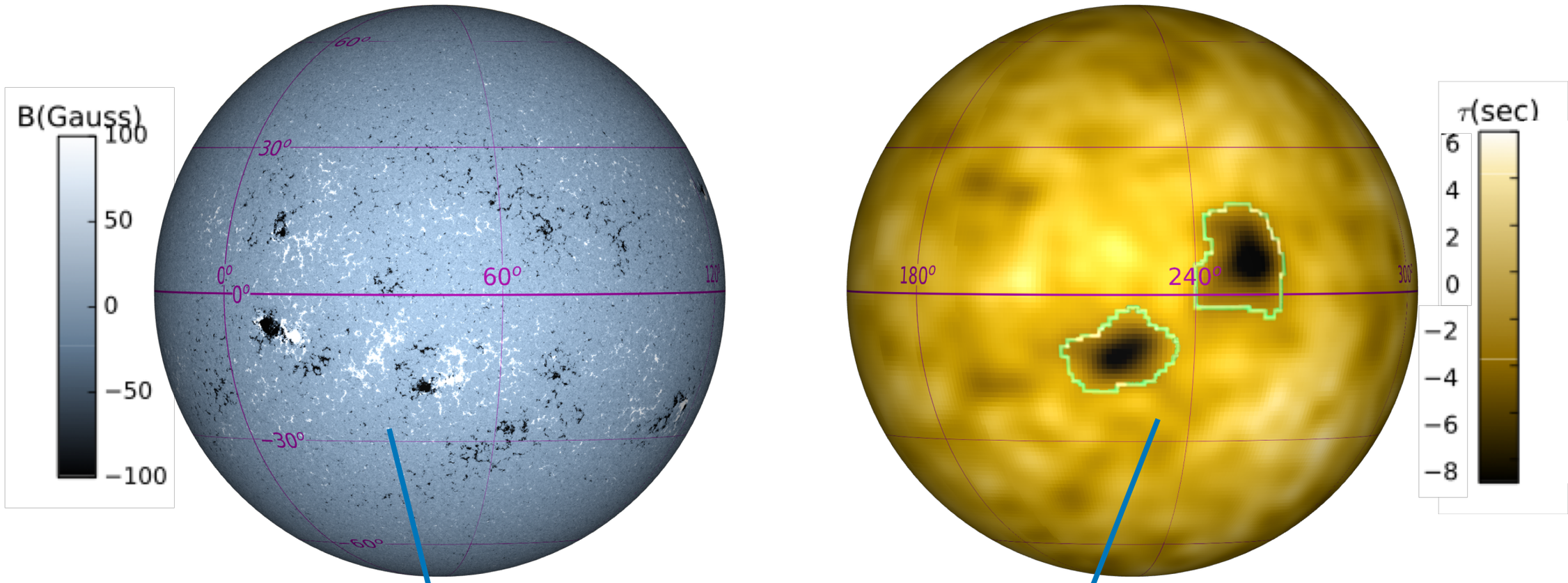
geo-exploration …

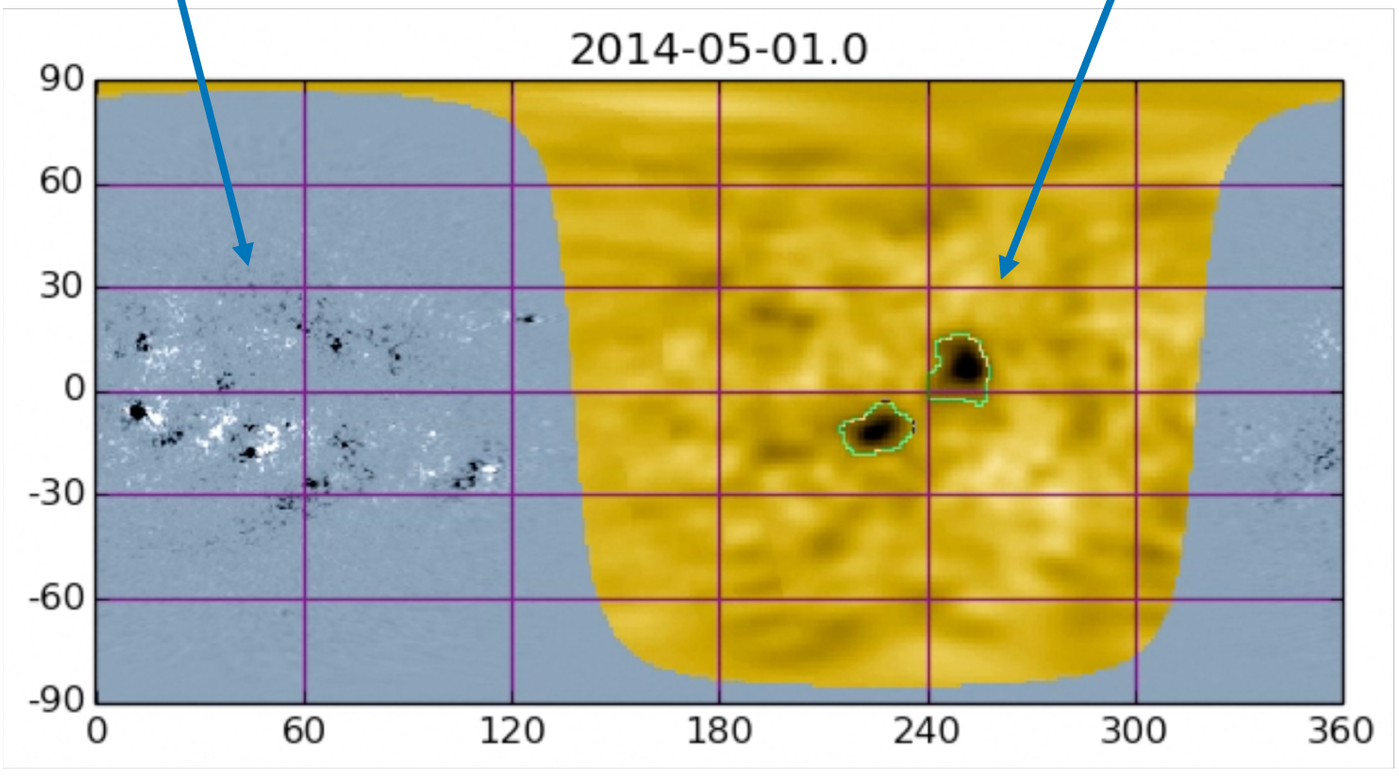


… and we're not the only ones who do it

earth side

far side





Operational Far-side Maps

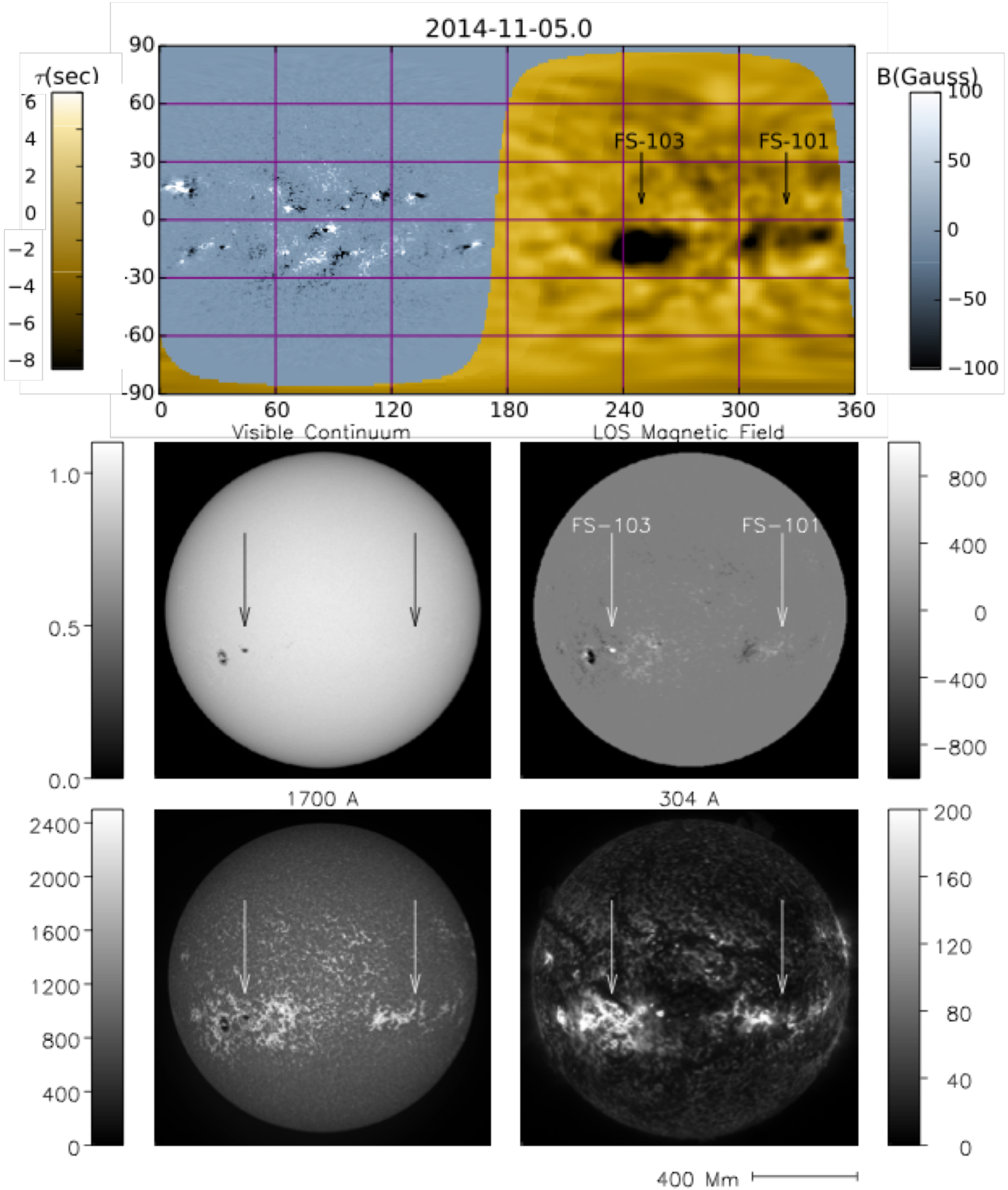
The Joint Science Operations Center (JSOC) for the Solar Dynamics Observatory (SDO) posts twice-daily synoptic images of the Sun's far Hemisphere computed from HMI:

http://jsoc.stanford.edu/data/farside

Strong helioseismic signatures generally indicate regions that will be emitting strong excess UV and EUV when they subsequently transit to the near hemisphere. The He II-304 A irradiance from the active regions designated FS-101 and FS-103 is a factor of 1.8 greater than the quiet He II-304-A irradiance.

The first far-side synoptic monitor was produced in 2001 by Phil Scherrer, using images computed from SOHO/MDI observations.

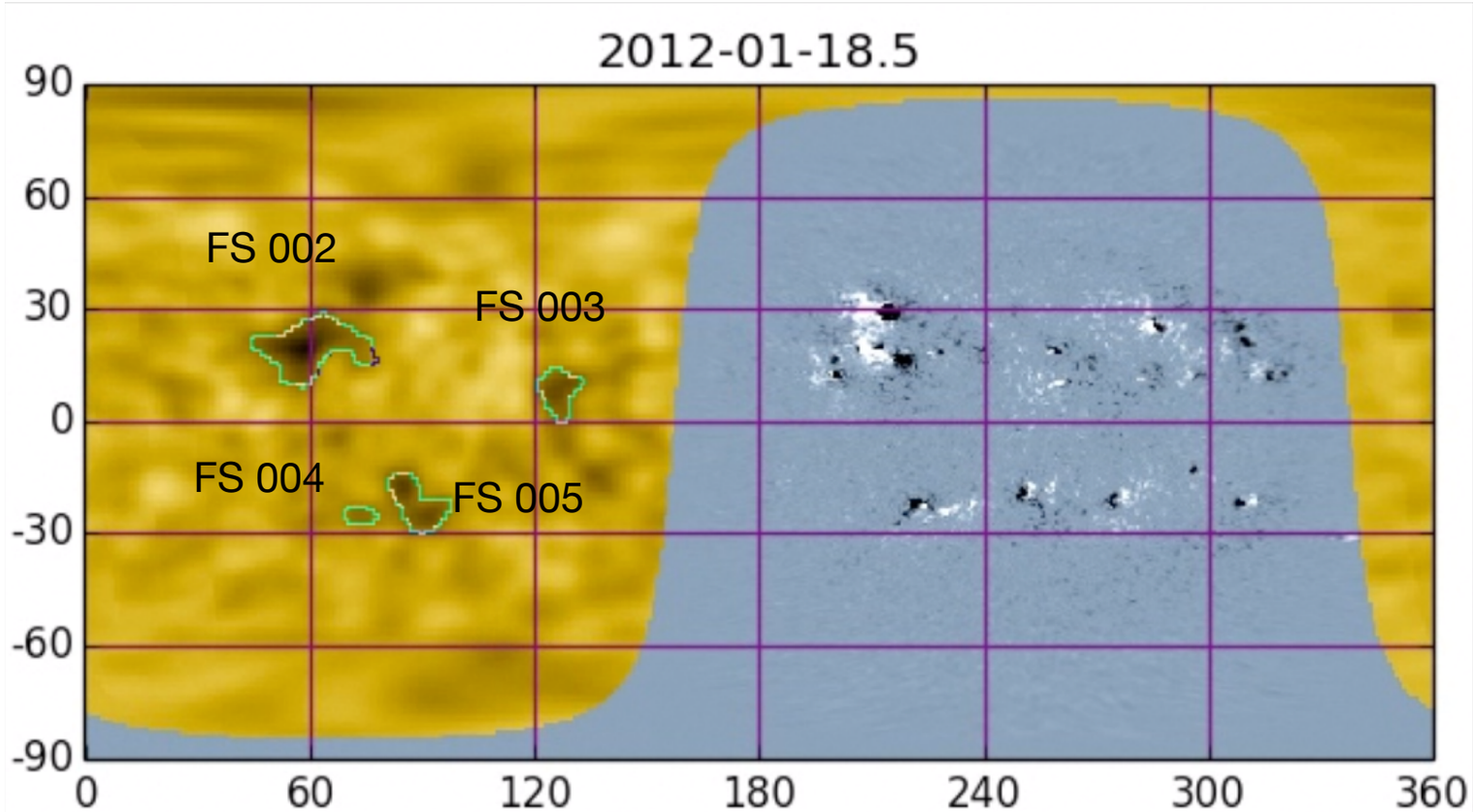
Frank Hill and Irene Gonzalez Hernandez (NSO/GONG) implemented a synoptic far-side seismic monitor shortly afterwards.



Comparison between Helioseismic and STEREO EUV-Intensity Maps

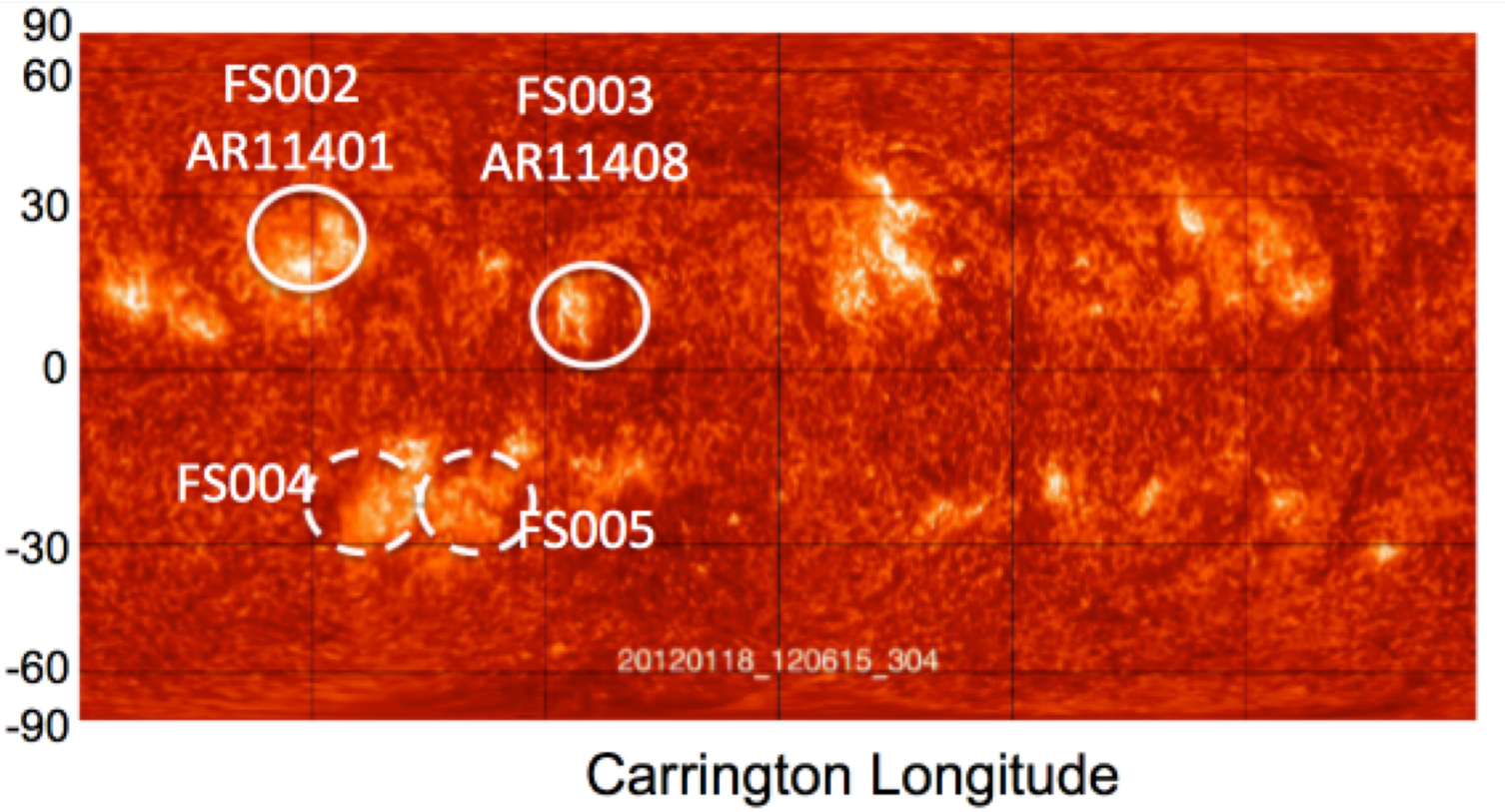
The SDO JSOC has a Strong Active Region Discriminator (SARD).

The SARD gives designations to signatures it believes to be a reliable indicator of an active region that could have a significant space-weather impact when it transits the near hemisphere.

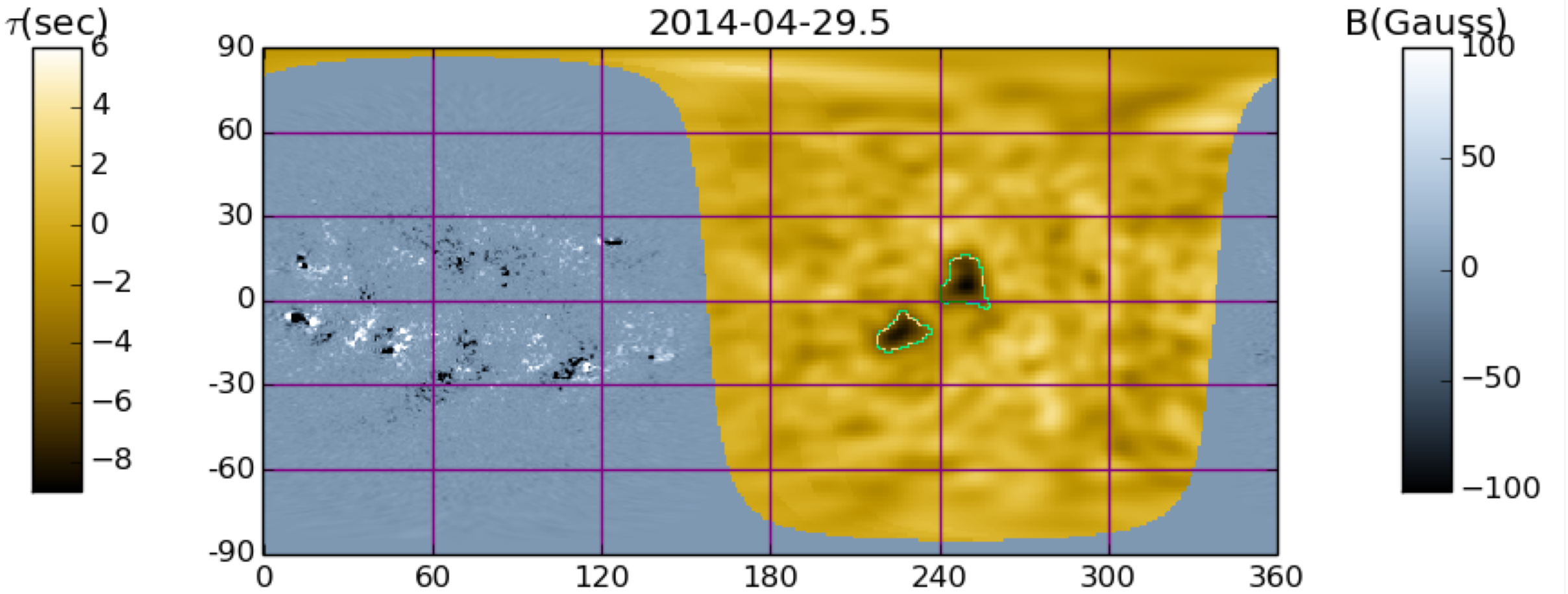


FS02 - AR11041 (AR11384)
FS03 - AR11408 (AR11290)
FS04 - AR11389 remnant
FS05 - AR11388 remnant

NASA's twin STEREO spacecraft have given us EUV coverage of the far hemisphere for the past decade. Image complements of Paulett Liewer.



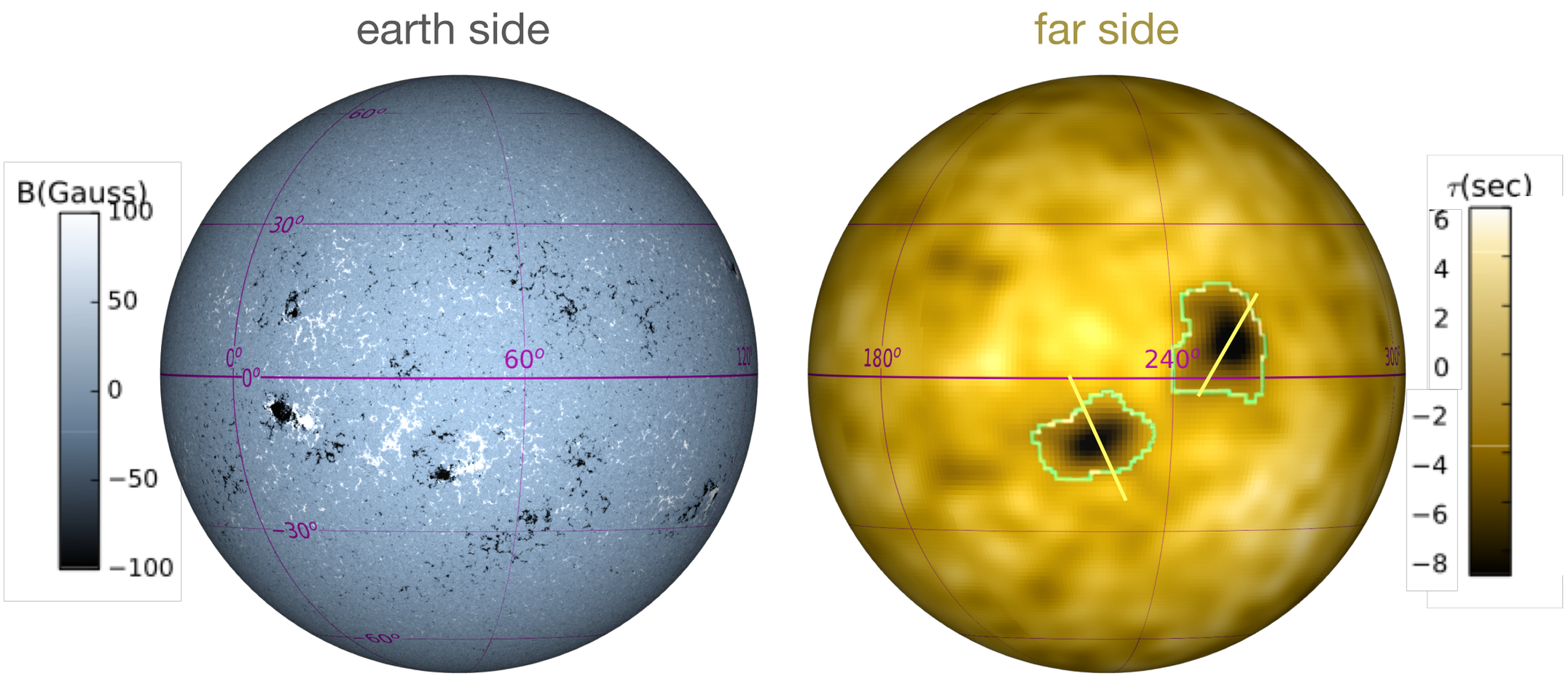
Far-Hemisphere Helioseismic Holographic Monitoring 2013 - 2016



1. Strong active regions can be identified on the Sun's far-side from earth-side observations
2. Simultaneous STEREO-EUV observations concur with helioseismic monitoring results
3. Identified far-side strong active regions square with near-side AR identifications
4. Identified far-side strong active regions nearly always manifest as near-side ARs

What about the sign of B?

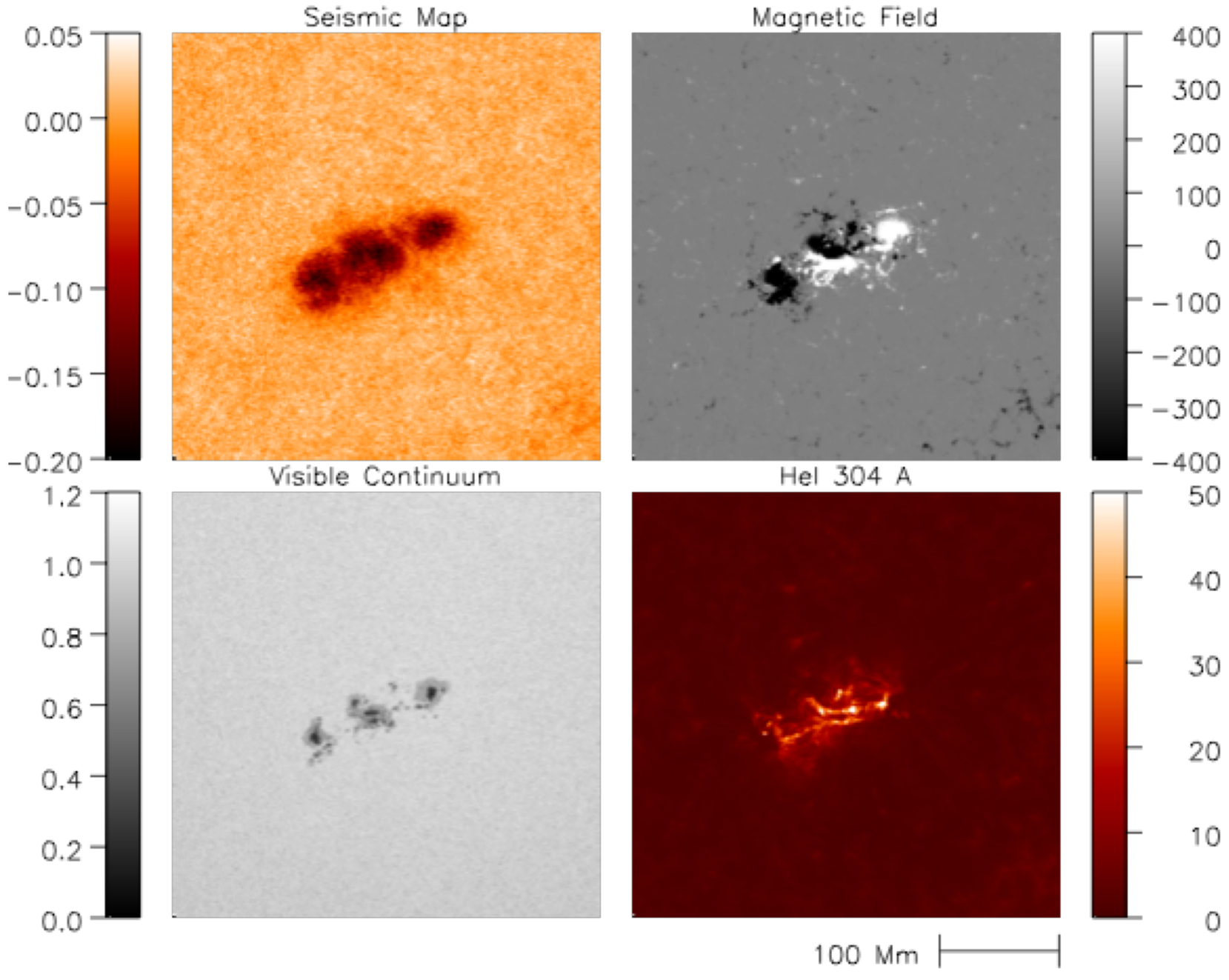
Arge, Henney, Gonzalez Hernandez, Toussaint, Koller, Godinez, “Modeling the Corona and Solar Wind using ADAPT Maps that Include Far-Side Observations”, AIP Conference Proceedings 1539, 11 (2013); https://doi.org/10.1063/1.4810977



Empirical ‘laws’ (i.e, the Hale-polarity law and Joy’s law) are used to ascribe net-flux-neutral magnetic polarities to far-side active regions in ADAPT; the result is improved downstream coronal-hole and solar-wind predictions.

Near-side holography and direct observations help us refine these ideas

1. Magnetic-flux distributions and seismic signatures have very similar morphologies, unlike the chromospheric EUV images



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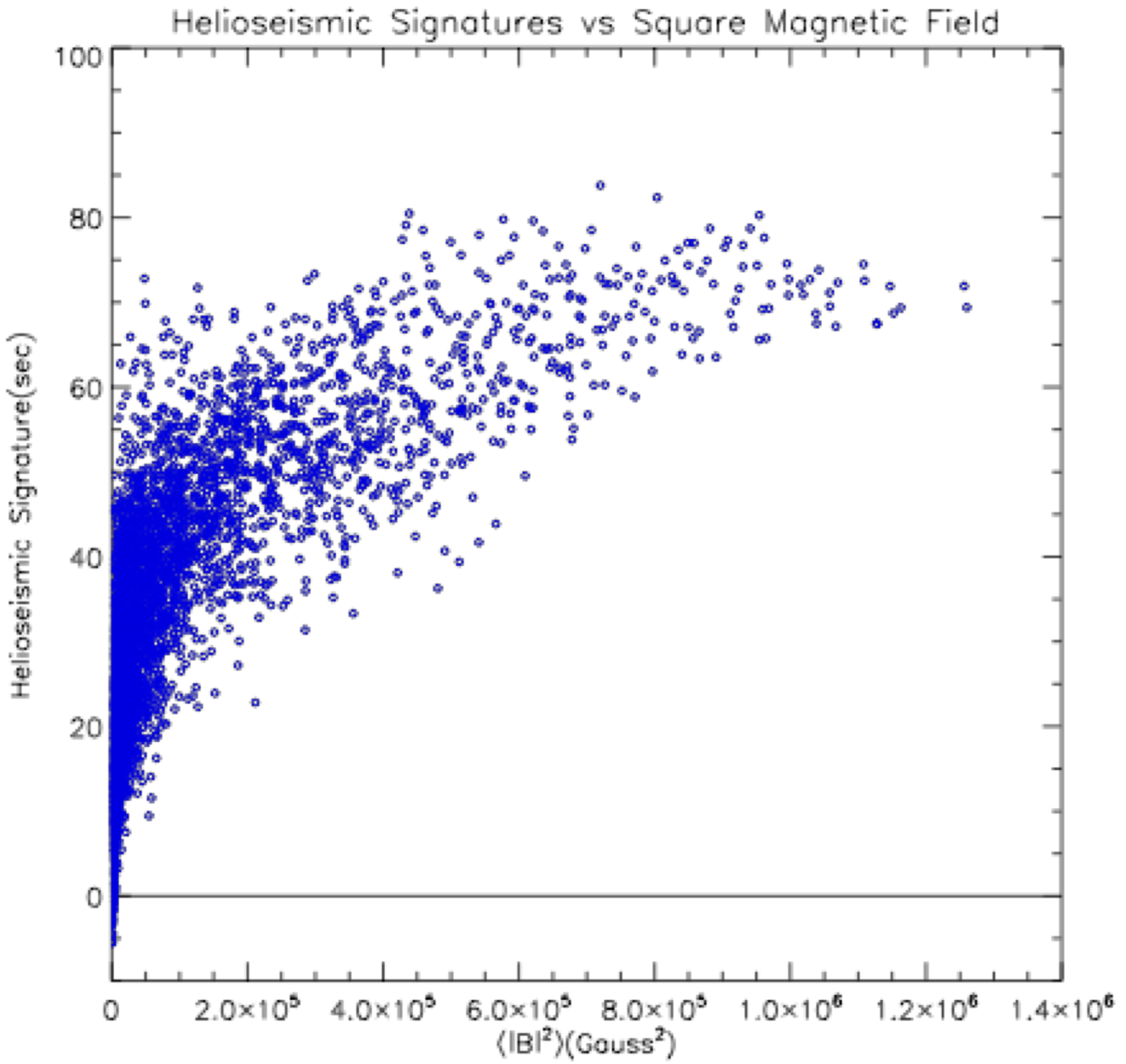

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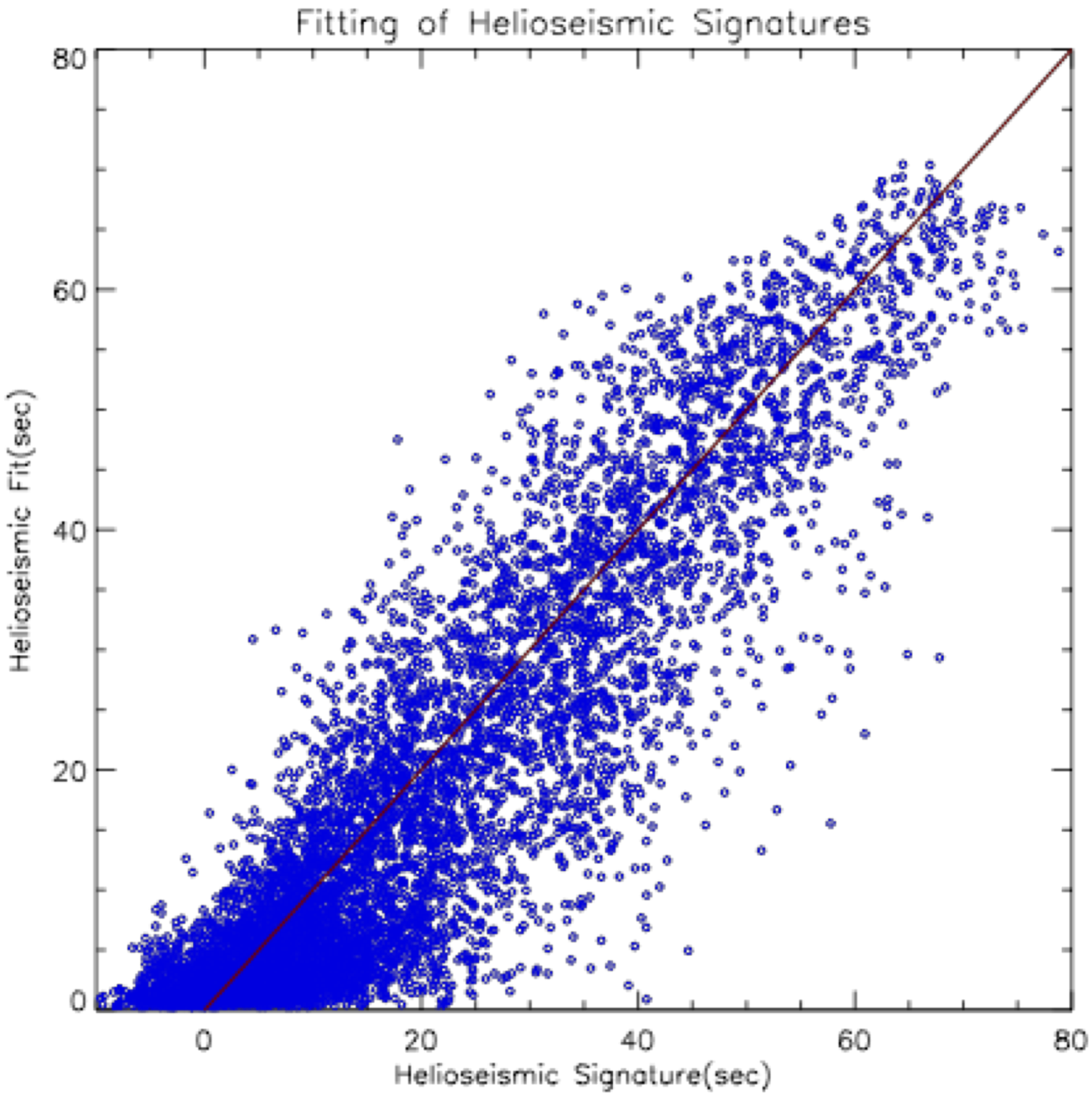
3. Travel-time deficit has the form:

$$\tau = h_0 \ln(1+B^2/B_0^2)$$

with h_0 = -15 sec, B_0 = 75 Gauss

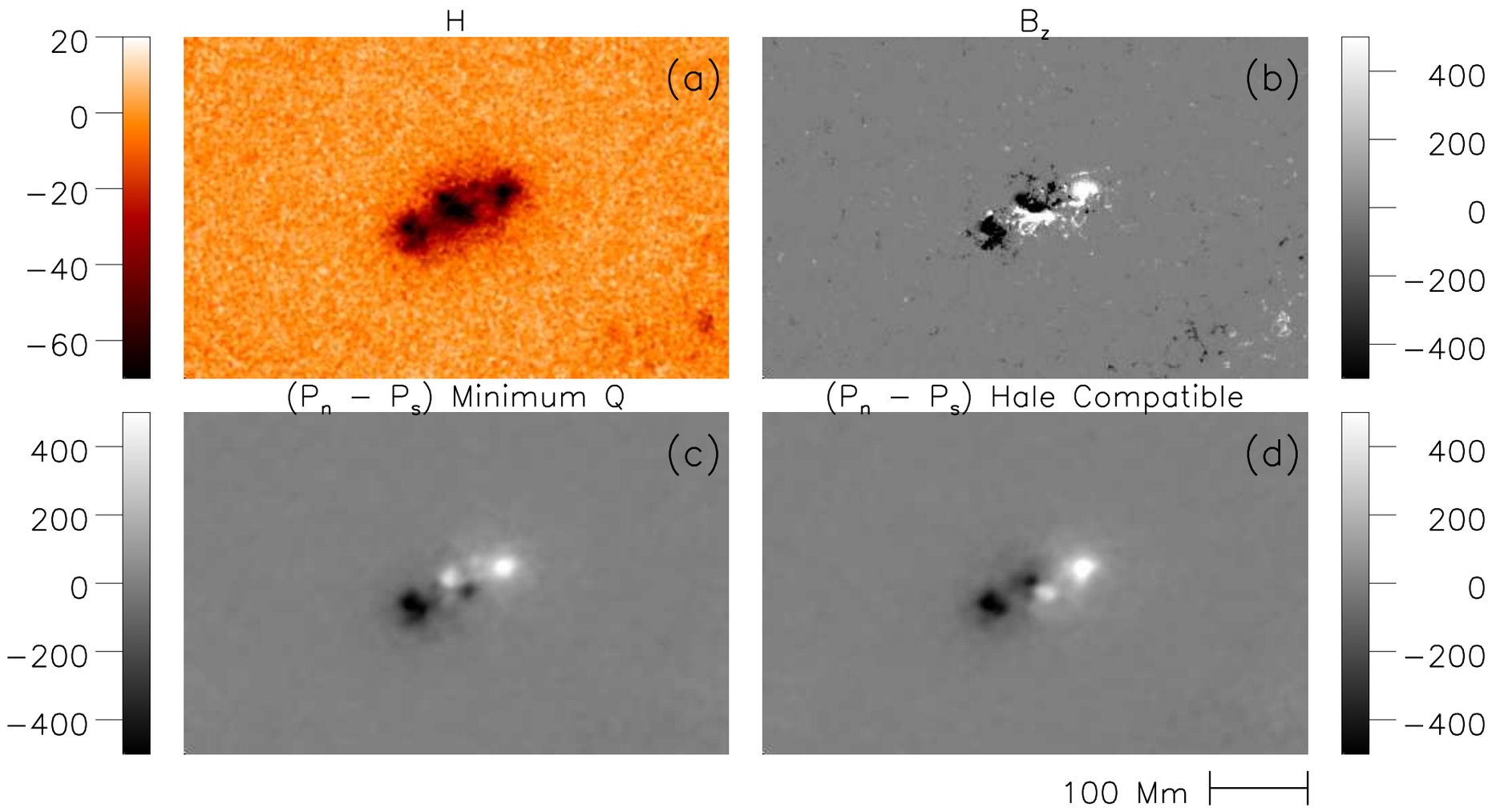


Refined Parsing of Helioseismic Signatures for Magnetic Polarity

Donea & Lindsey (2019) “Modeling magnetic polarity distributions of solar activity from its helioseismic signature”

Using near-side diagnostics, Donea & Lindsey recently extended the results of Arge, Henney, et al. to ascribe magnetic polarity to more complex ARs identified by their seismic signatures.

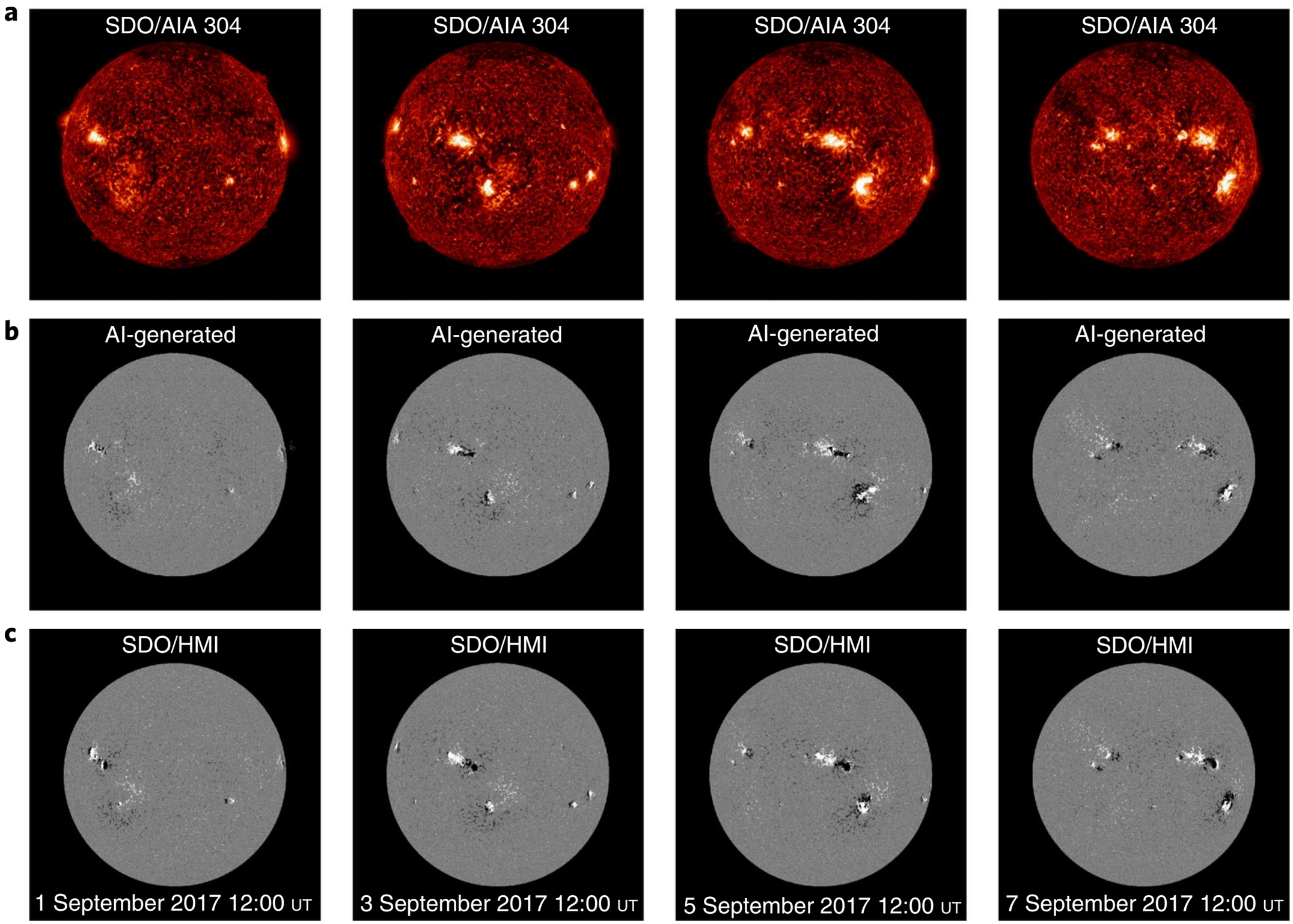
In this example deviating from Hale/Joy’s laws is required to minimize the model cost function



Improved cost functions can produce better agreement with direct observations

Recent deep-learning algorithms with automated cost-function specification produce errant magnetogram estimates

Kim et al. (2019) “Solar farside magnetograms from deep learning analysis of STEREO/EUVI data” Nature Astronomy Letters



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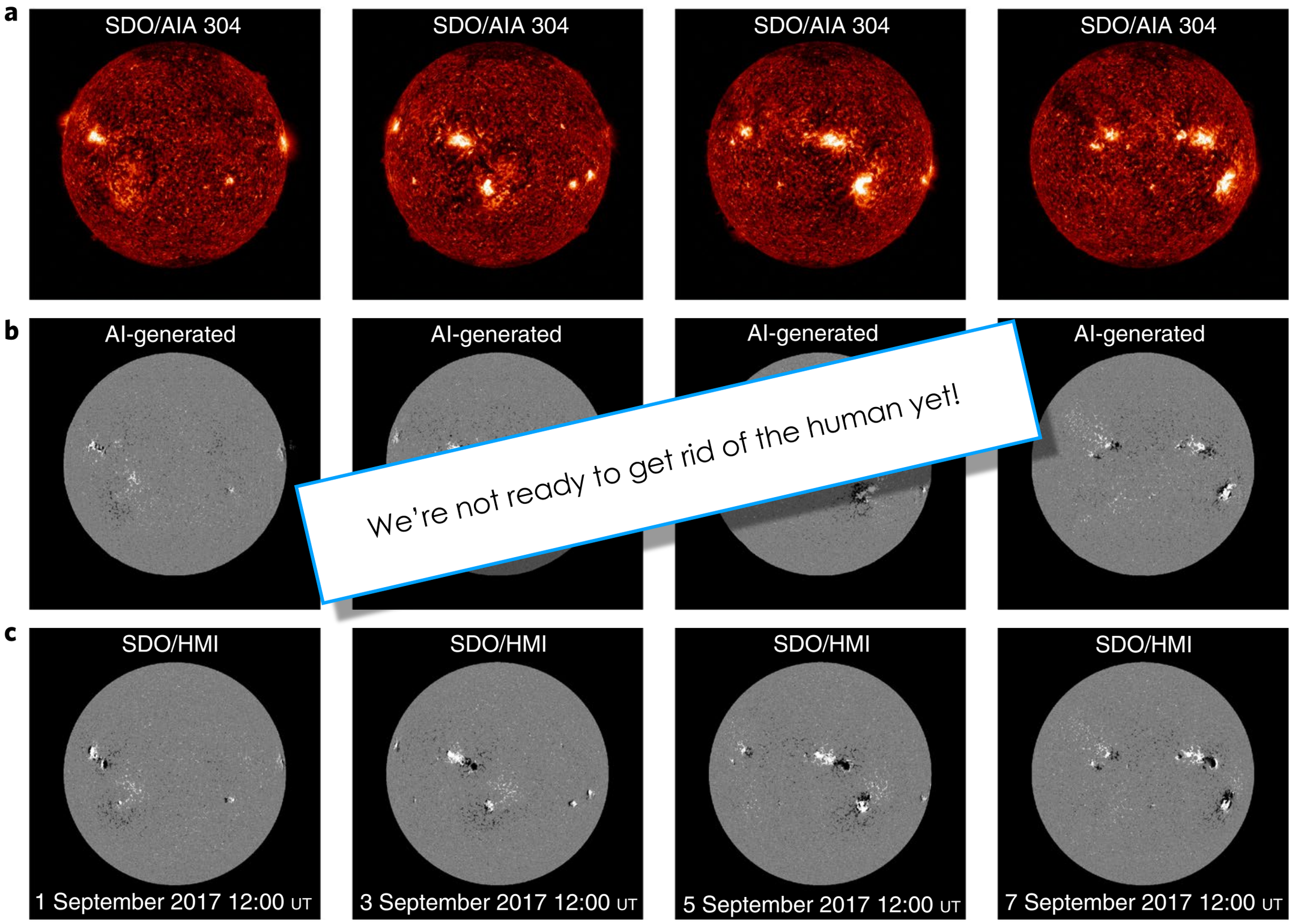

Questions?


$X_k = \frac{1}{2\pi} \int_{-\pi/T}^{\pi/T} \left[\sum_n \right.$
$\int_{-x}^{x} h^*(h) k(t + kT)\, dt$
$\Phi_{nn}(\omega)\, d\omega = \frac{TN_0}{2\pi}$
$= \left(\frac{TN_0}{2\pi}\right)$
$X(e^{j\omega T})$