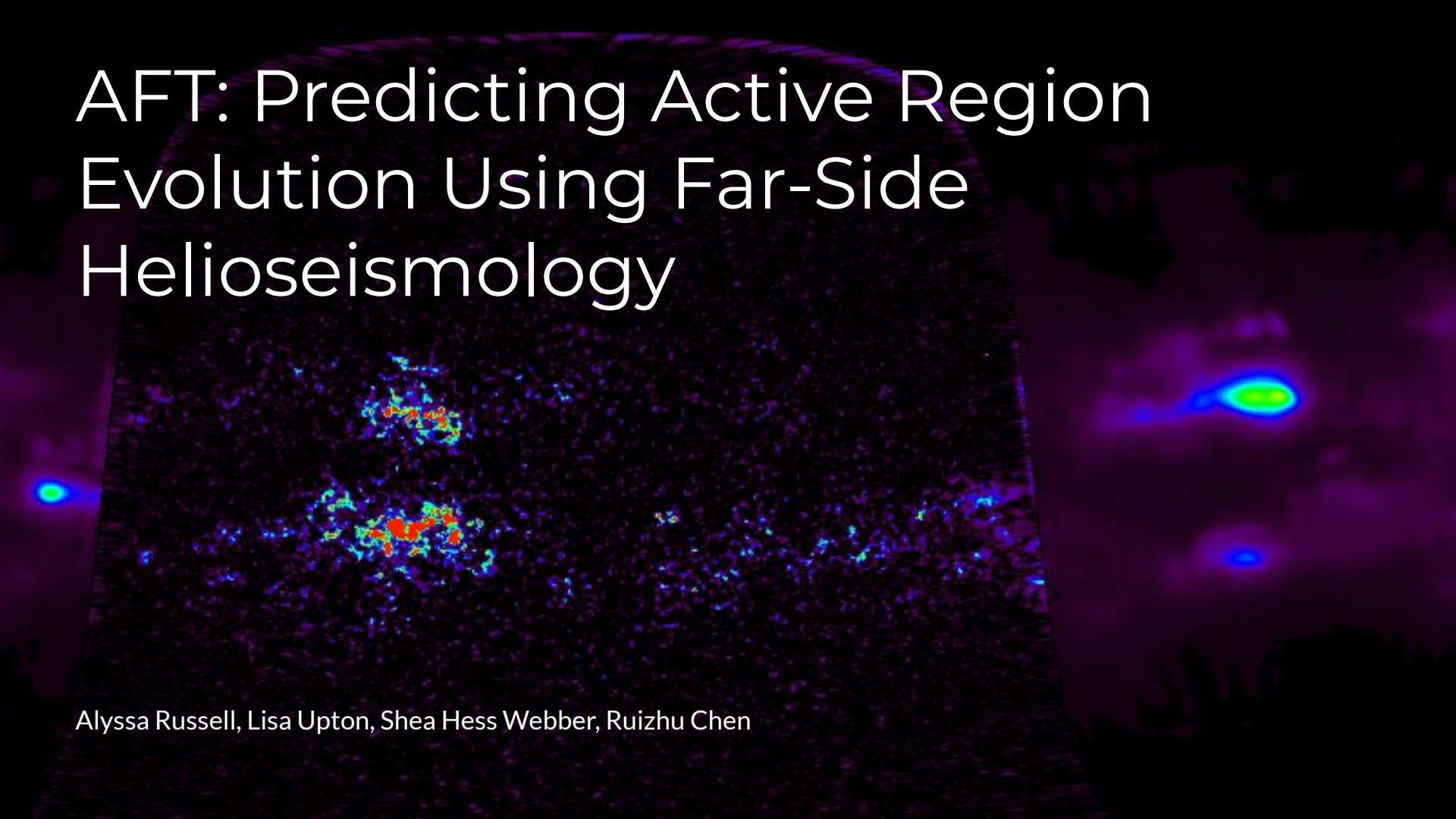
AFT: Predicting Active Region Evolution Using Far-Side Helioseismology



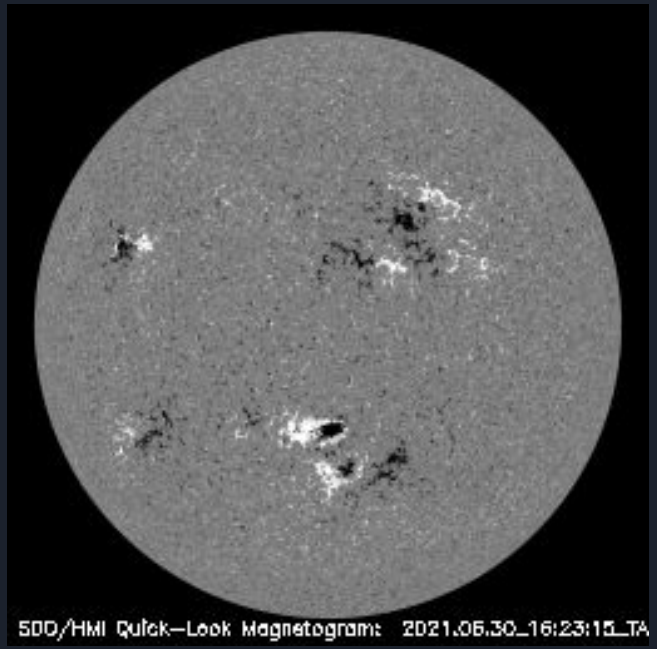
Alyssa Russell, Lisa Upton, Shea Hess Webber, Ruizhu Chen

Motivation: Space Weather

- Harms satellites, communications, computers, astronauts, etc.
- Active regions are good indicators of where harmful space weather may occur

NOAA - Space Weather

Science background: Near Side Data

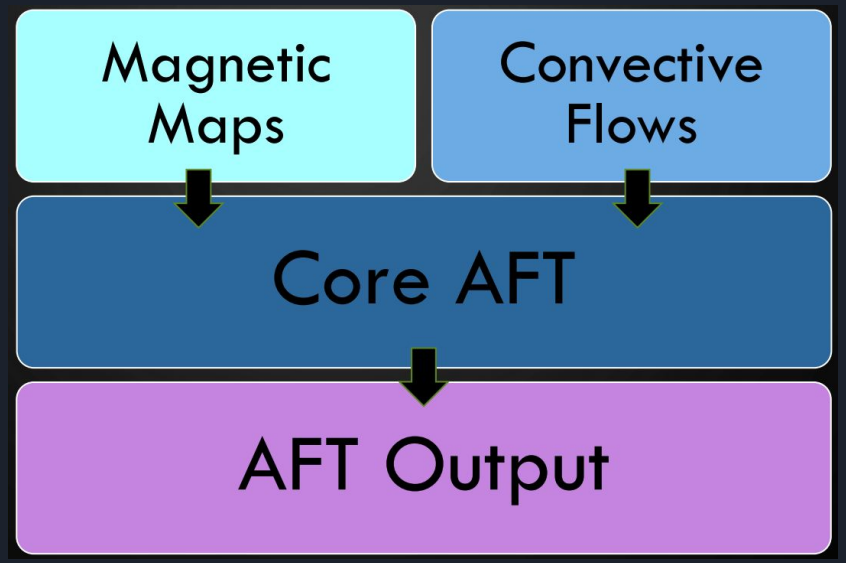


Near-side HMI/SDO magnetogram

- Helioseismic and Magnetic Imager (HMI) on the Solar Dynamics Observatory (SDO)
- Geosynchronous orbit
- Active regions are determined by areas of higher magnetic field strength

SDO Geosynchronous orbit

AFT: Advective Flux Transport Model



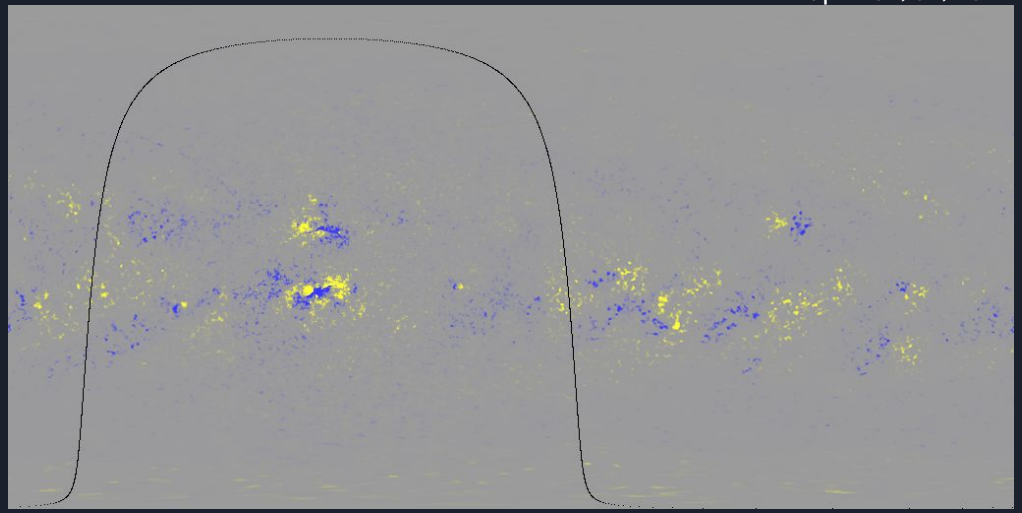
Upton, AFT design flow

- Near side magnetic fields input
  - Magnetograms from direct observations
  - Inputs active regions on near side
- Convective flows input
  - Simulates the convective motion, producing the magnetic network on the far side
  - Evolves active regions on far side
- AFT is unable to predict where new active regions will arise on the far side

AFT: Advective Flux Transport Model

- AFT Output: Full-sun map of magnetic field strength
- Near side is in the black outline
    - Data assimilation occurs here
- Active regions evolve on far side
- No new flux is added to the far side

Map of 02/01/2014

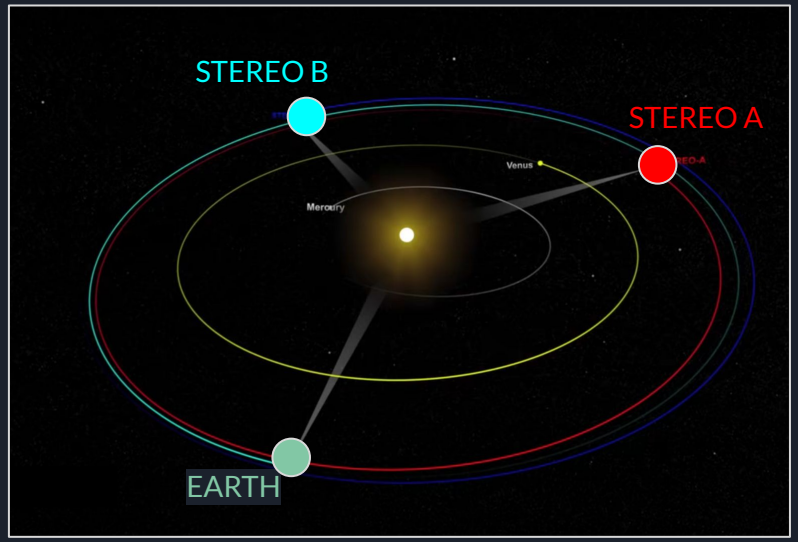


Full-sun map of magnetic field strength

Yellow: Positive, Blue: Negative

STEREO: Full-Sun Data

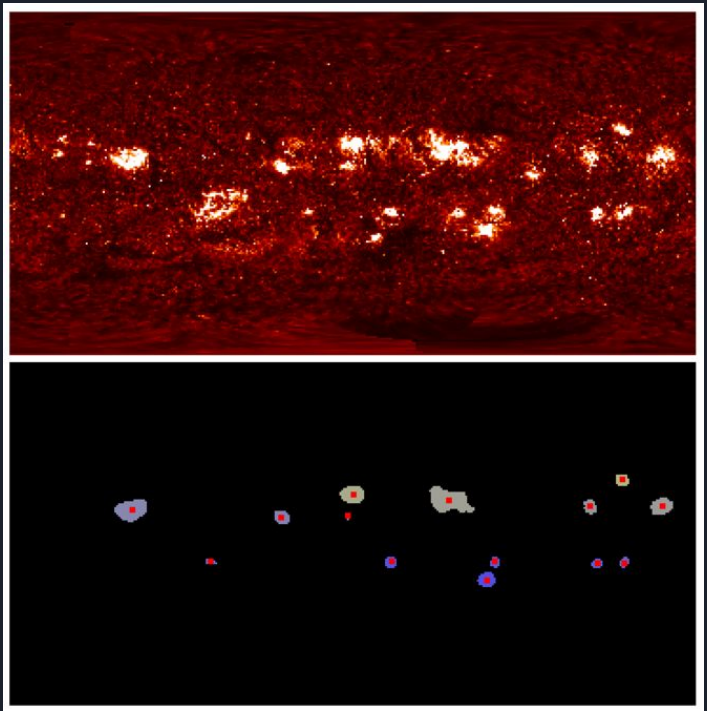
- Full sun images in various wavelengths
- 2+ years of far-side data (2012-2014)
- Lost contact with stereo B in 2014
- Now satellites are almost back to Earth



NASA, STEREO paths

STEREO data

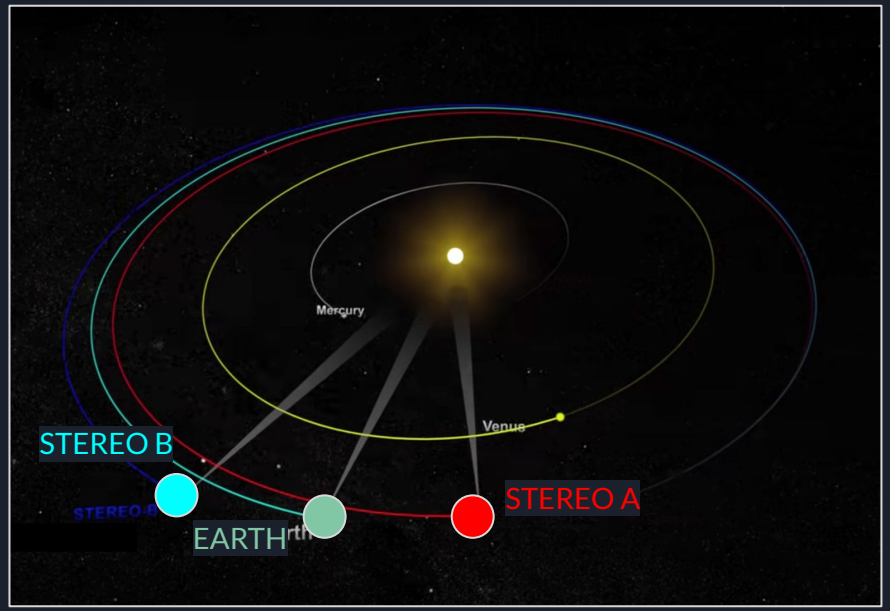
- For 2012-2014, far-side 304 data is assimilated into the AFT model
- STEREO 304 maps are used to find and map active regions
- Luminosity is used to calculate magnetic flux strength
- Far-side active region locations and flux strength are added into AFT



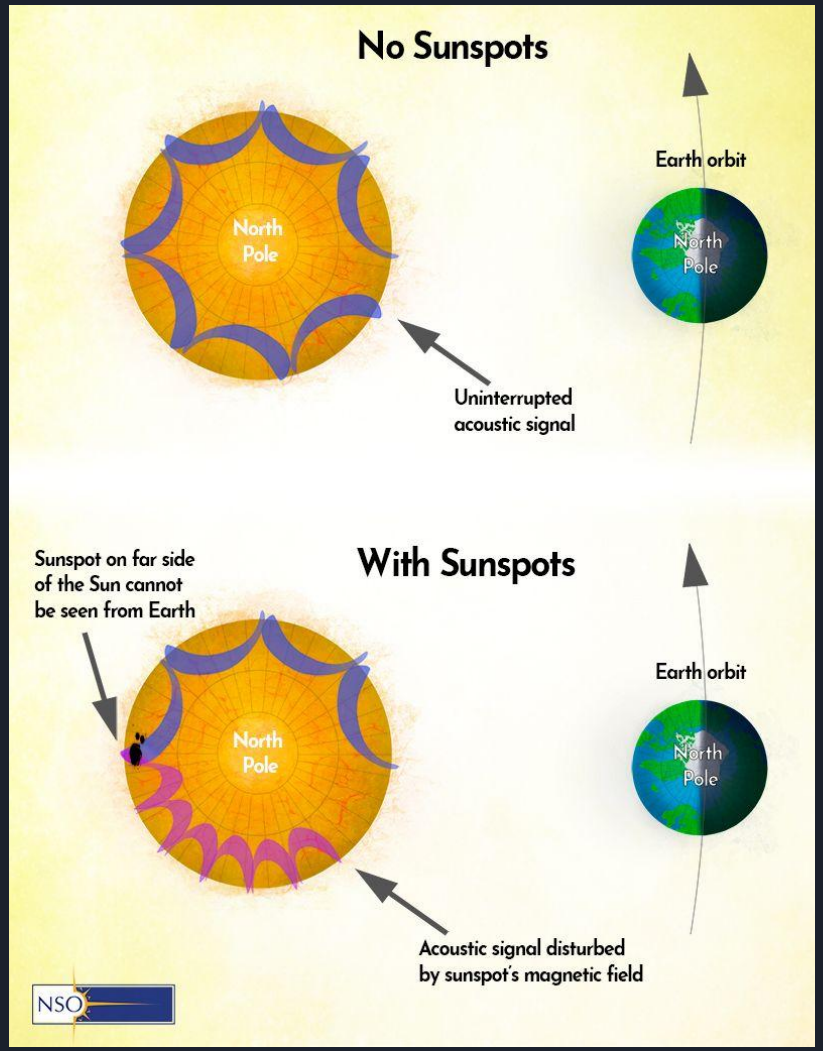
Upton, AFT 304

STEREO data is great, but unfortunately both satellites have returned to the near-side.

Where do we go from here?



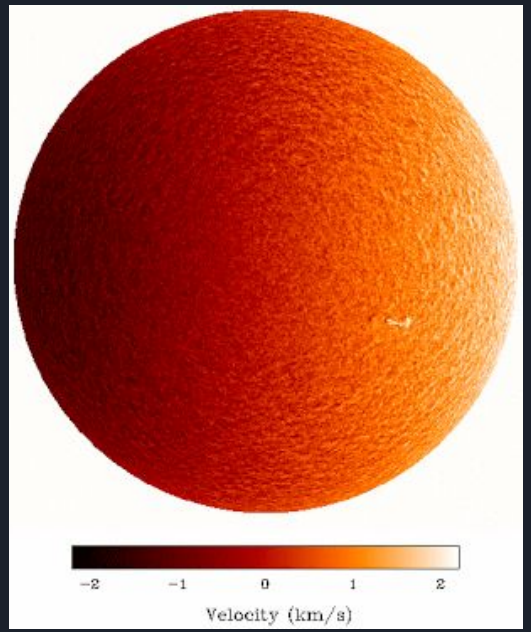
NASA, STEREO paths



Helioseismology

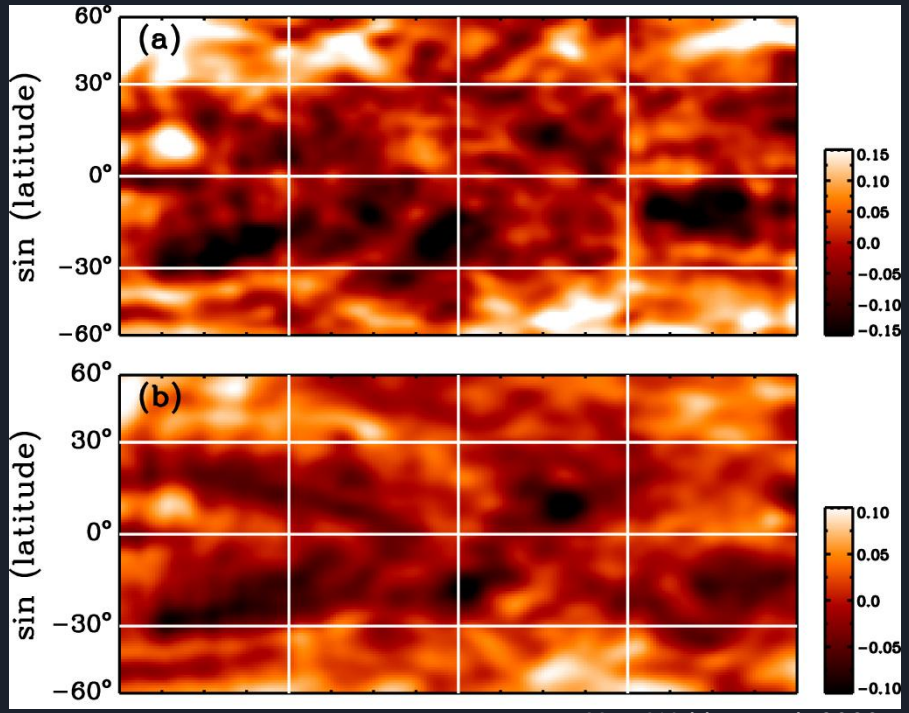
- Sun has inner sound waves
- Active regions disturb those waves
- Determine approximate active region location and size

Helioseismology Acoustic Maps



Solar Center Stanford, MDI SOHO

Near-side dopplergram of surface velocities



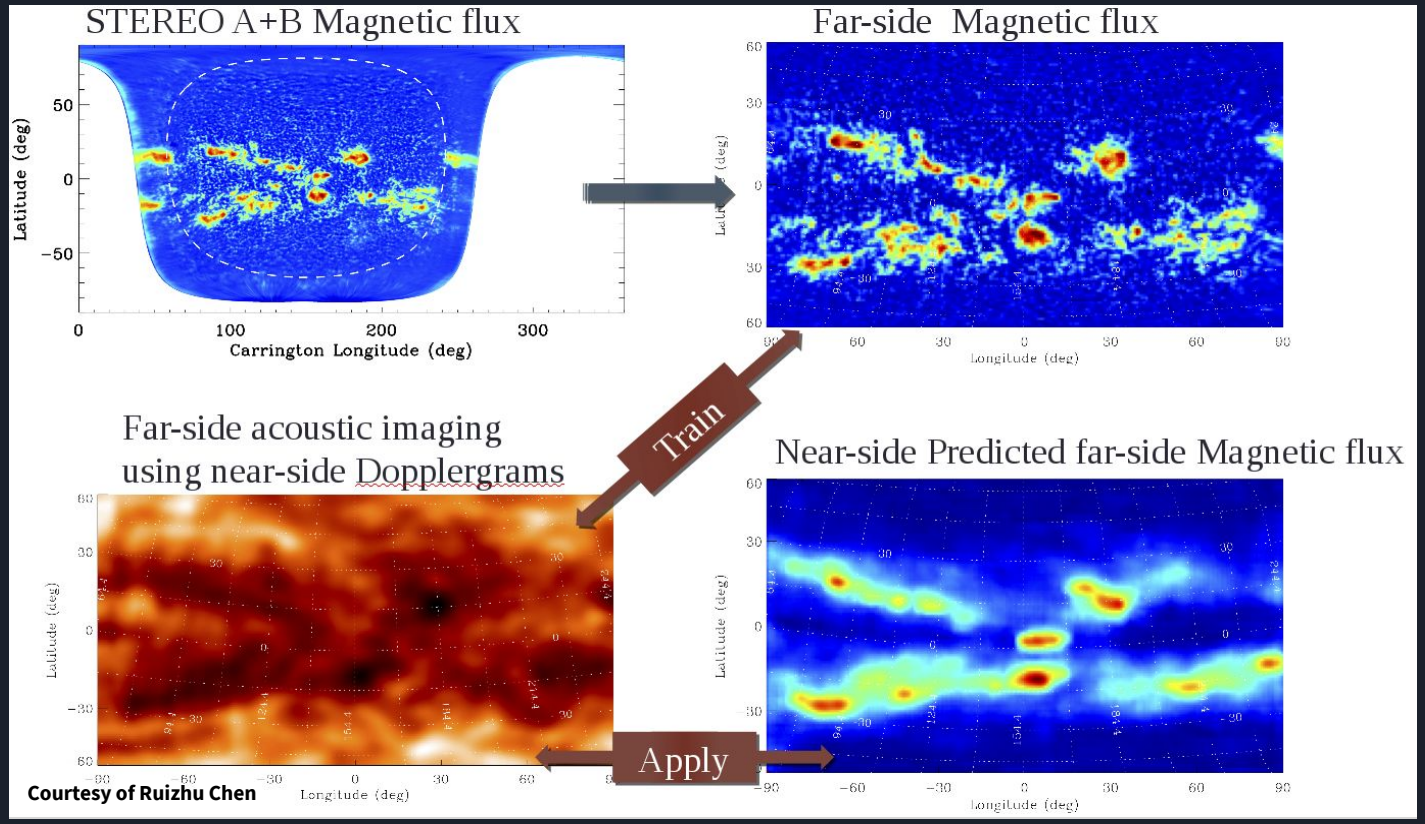
Hess Webber, et al., 2020

Far-side acoustic maps

(a) 31 hour period

(b) Three days of overlapped maps

Machine Learning for Dopplergrams



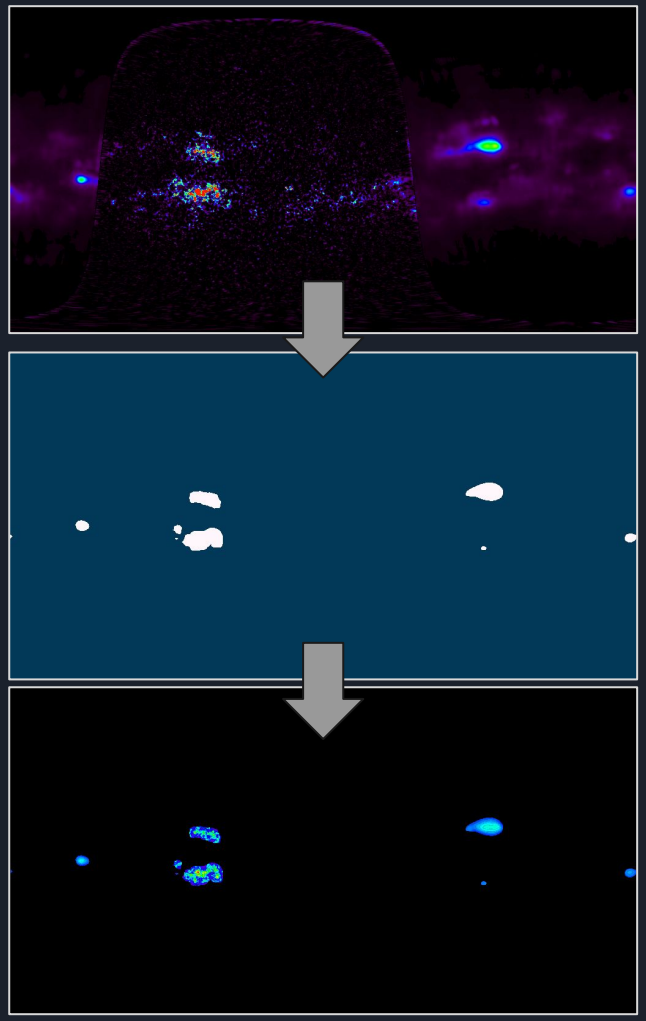
Hess Webber et al., lecture, 2019

Analyzing Helioseismology Data

Full-sun magnetic flux strength map calculated from helioseismology magnetic field strength data

Binary map of active region location and size from smoothed flux strength map

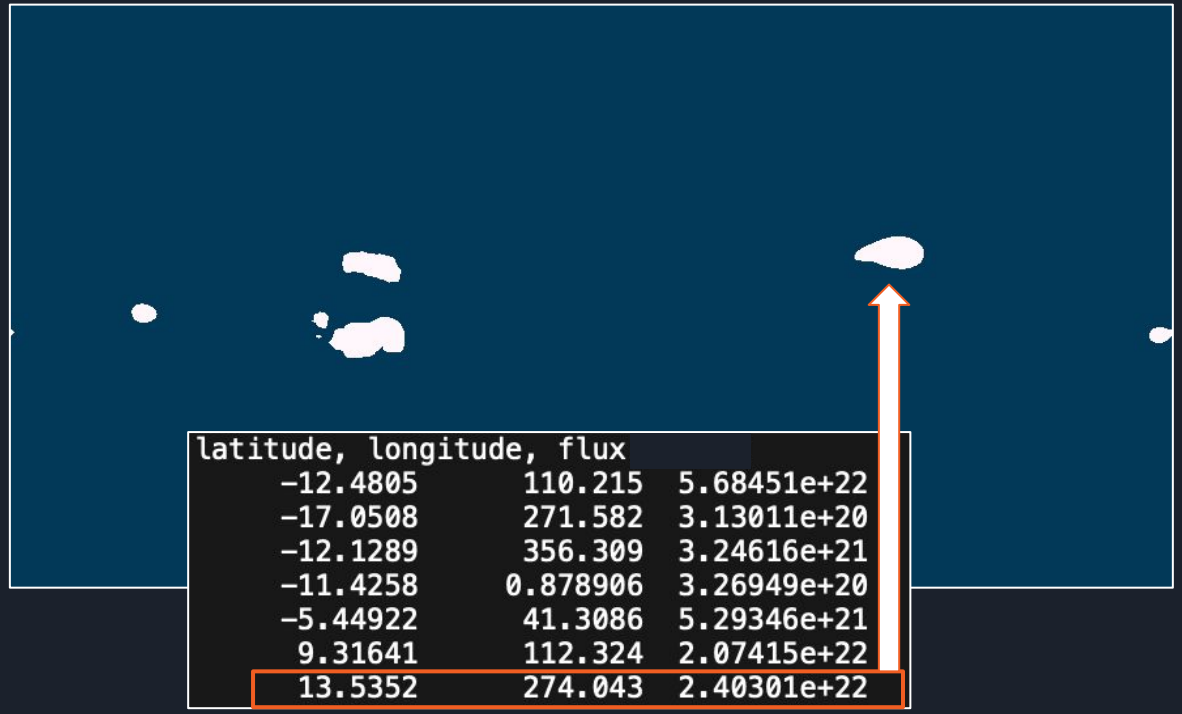
Magnetic flux strength map of only active regions using AFT data



Maps of 02/2014

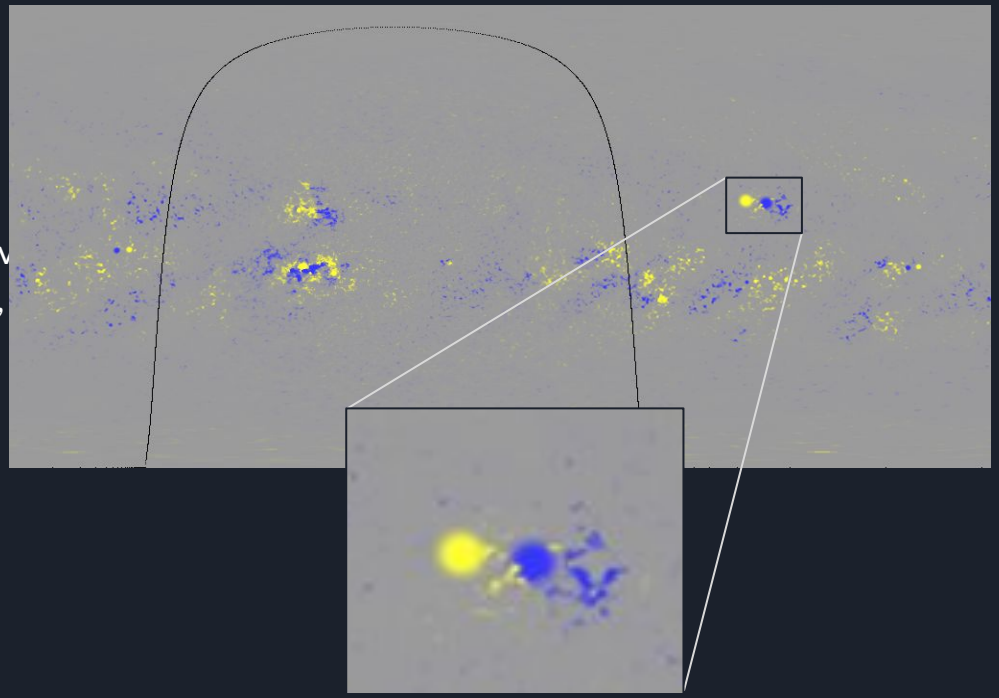
Active Region data

- Active region Latitude and longitude degree positions recorded
- Active region magnetic flux strength calculated
- Helioseismology data compared with AFT data



Adding Helioseismology into AFT

- Add polarity by Hale's Law
  - Leading polarity in the Northern hemisphere is opposite that of the Southern hemisphere
  - Assumes all Northern hemisphere activ regions have the same leading polarity, and all Southern hemisphere active regions have the opposite polarity
- Add tilt by Joy's Law
  - Active regions' characteristic tilt
  - Tilt is proportional to the latitude

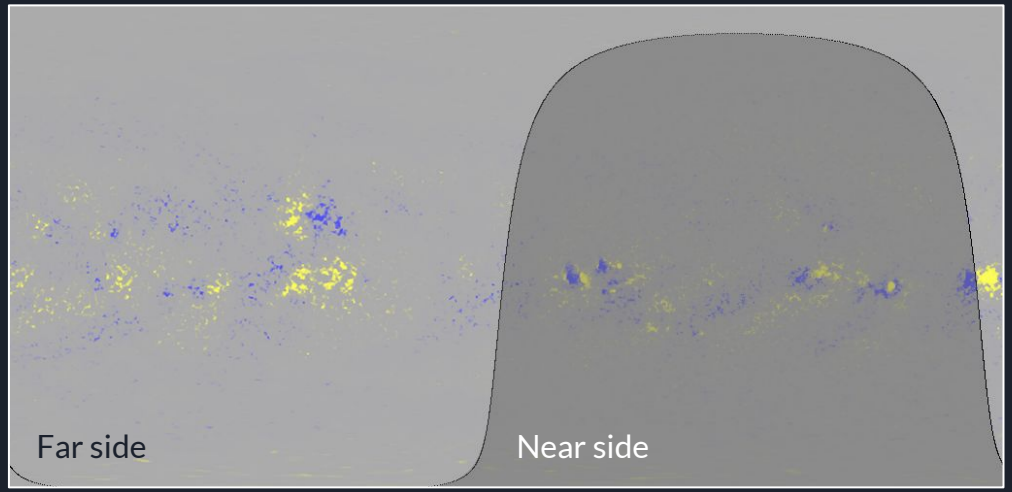


Yellow: Positive, Blue: Negative

Results

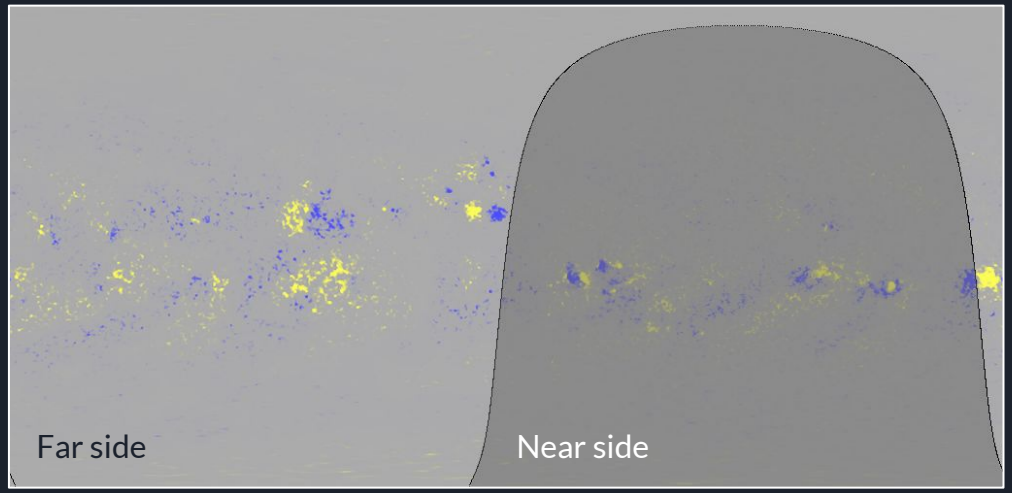
AFT without far-side data

- Near side is detailed
- Far side misses new flux



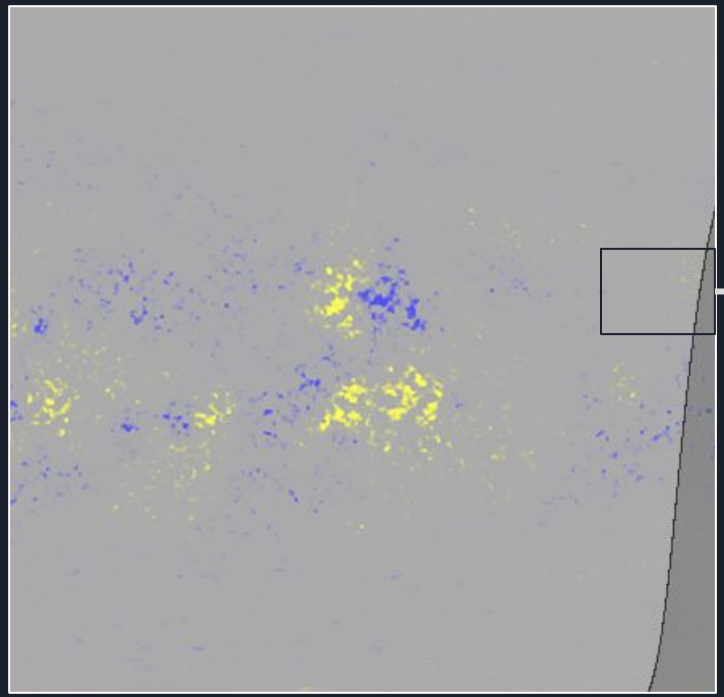
AFT with far-side data

- Both near and far side are detailed
- Far-side flux added in

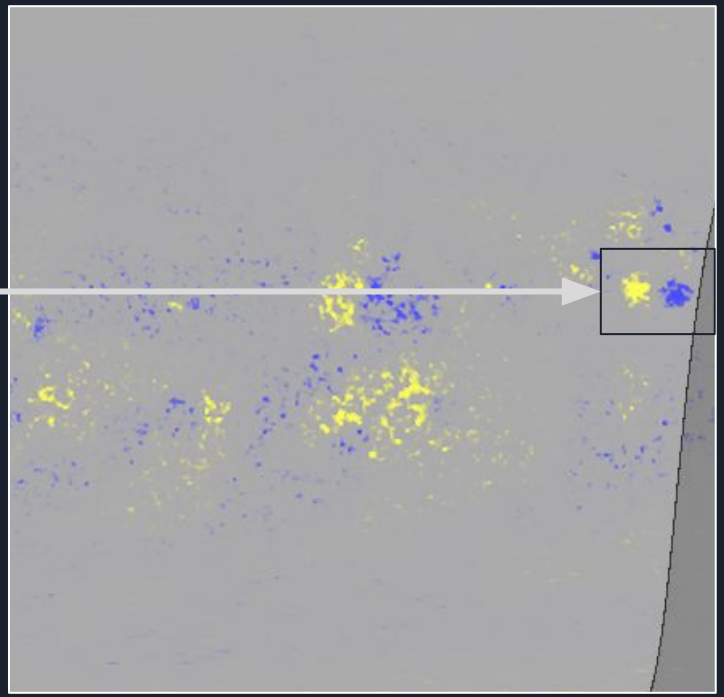


Maps of 02/18/2014

Results: Adding in new active regions

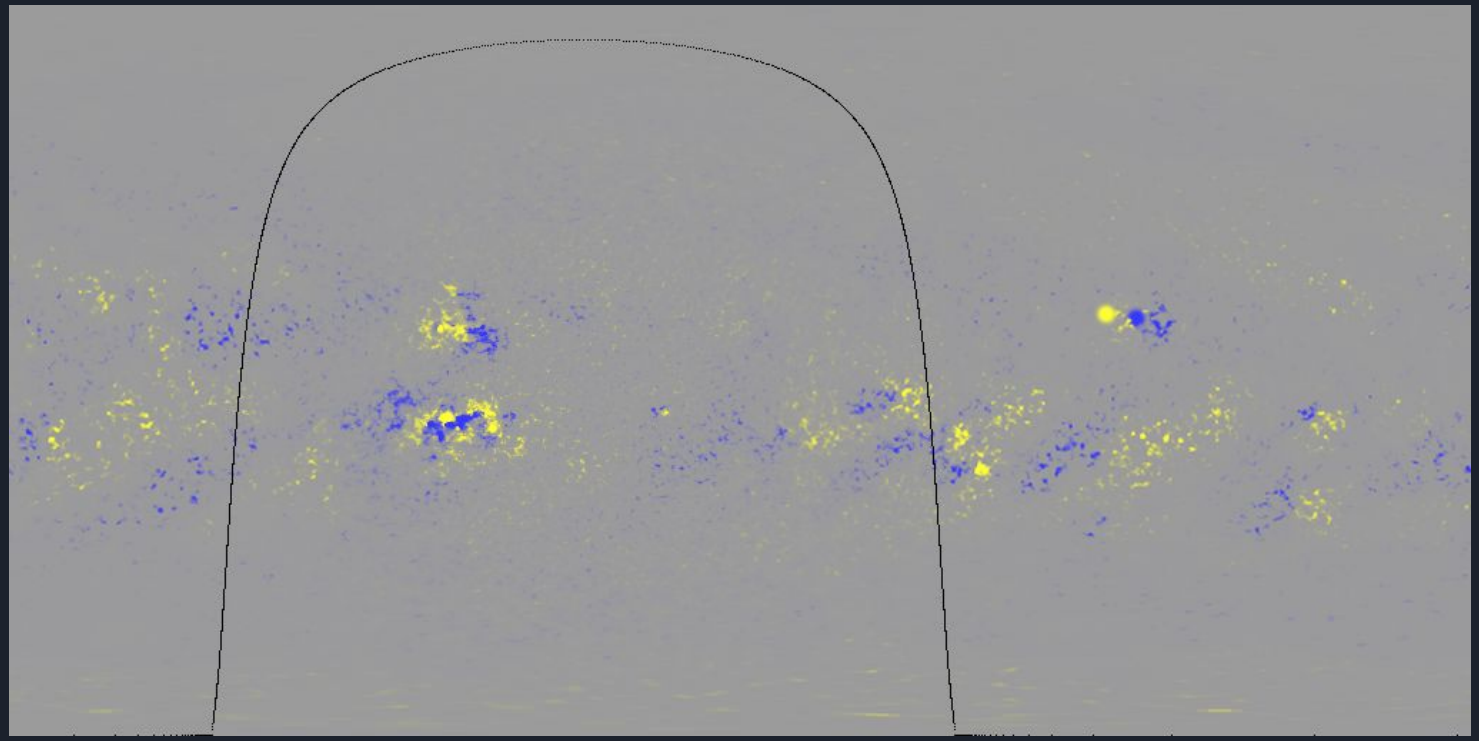


AFT only: Far side



AFT with helioseismology: Far side

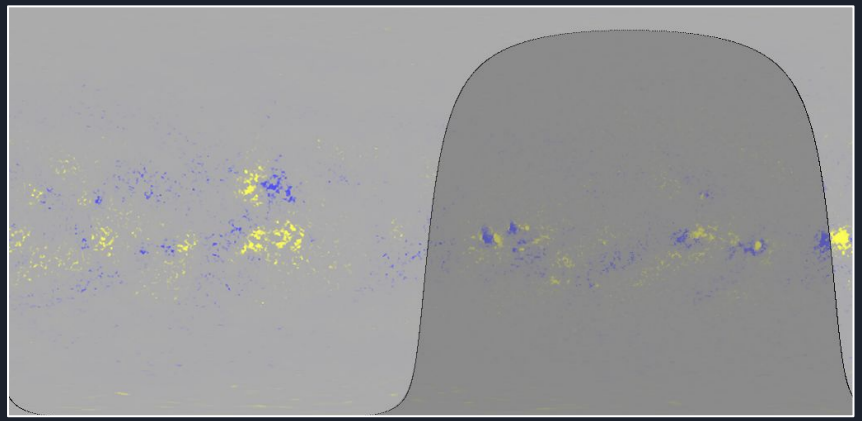
AFT with Helioseismic Data



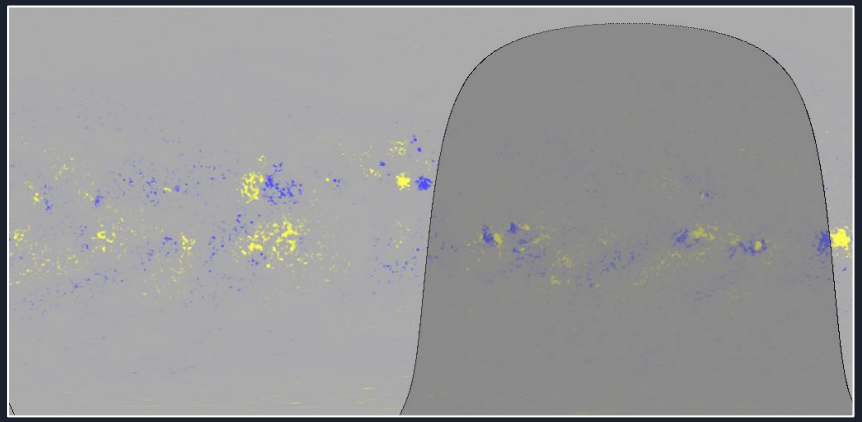
02/2014

Next steps

- Graphical comparisons between AFT and Helioseismic data
  - Compare individual active region magnetic flux strength over time
  - Make any necessary improvements
- Incorporate helioseismology into more data
  - Currently only one month has been run, February 2014
  - Next: The full year of 2011 data
  - Long term: Near real time assimilation

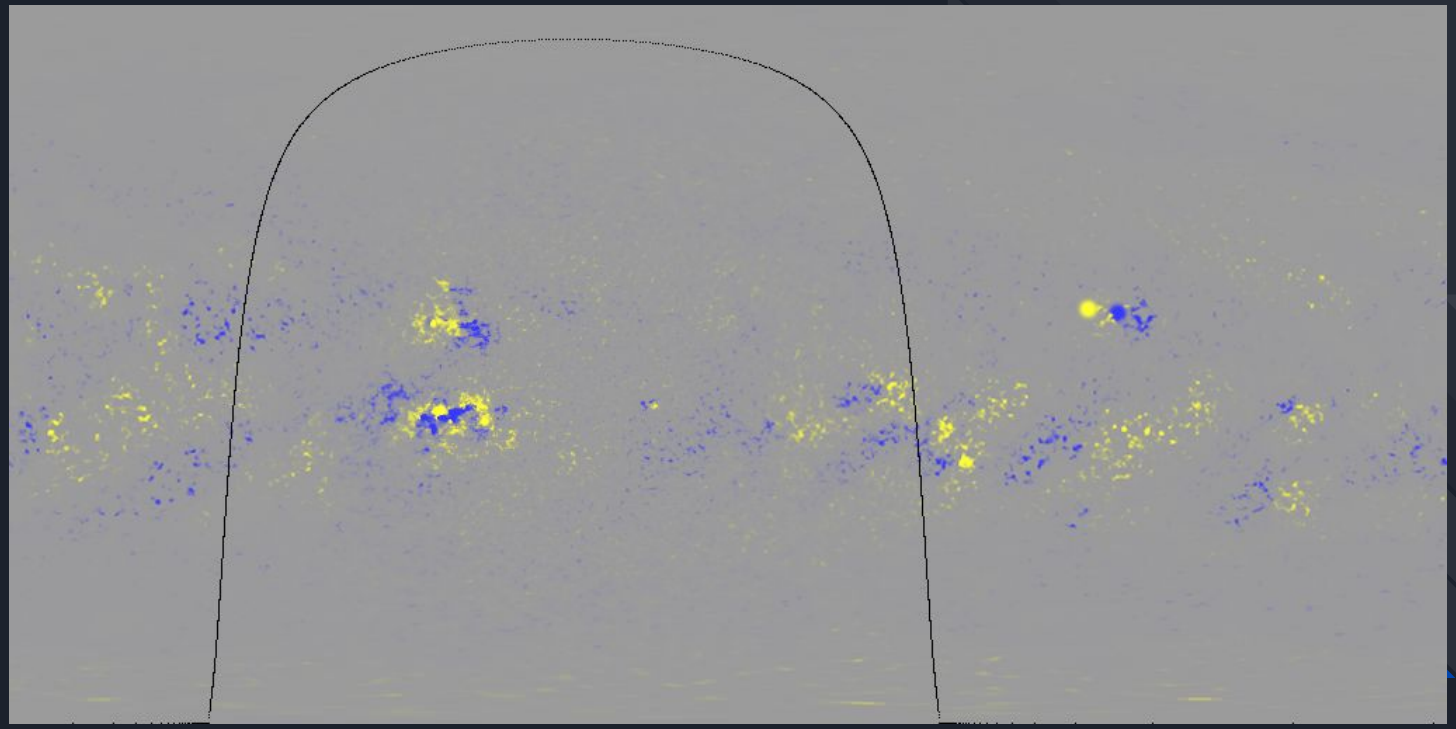


AFT without helioseismology



AFT with helioseismology

Questions?



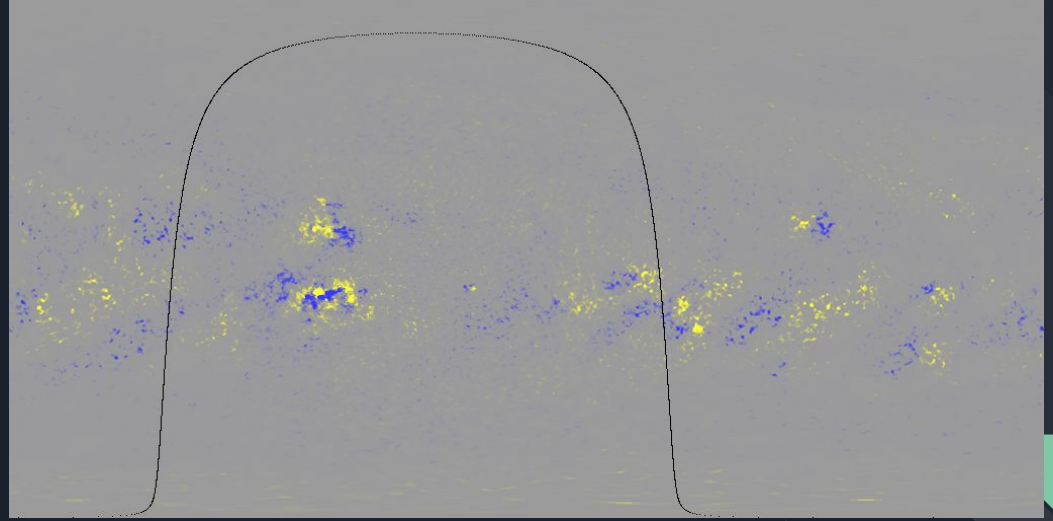
Resources

Hathaway, D.H. 2015. Living Rev. Sol. Phys. 12(1).
Hathaway, D.H. 2020. Solar Cycle Science. Lecture.
Ugarte-Urra, I., et al. 2015. ApJ. 815(2), 90.
Upton, L., et al. 2013. ApJ. 780(1), 5.
Upton, L. 2021. HAO. Lecture.
Upton, L. 2021. WAS. Lecture.
Upton, L. 2018. Solar Cycle Predictions. Lecture.
Hess Webber, S. 2020. SWPC. Lecture.
Hess Webber, S. 2019. L5 Consortium. Lecture.

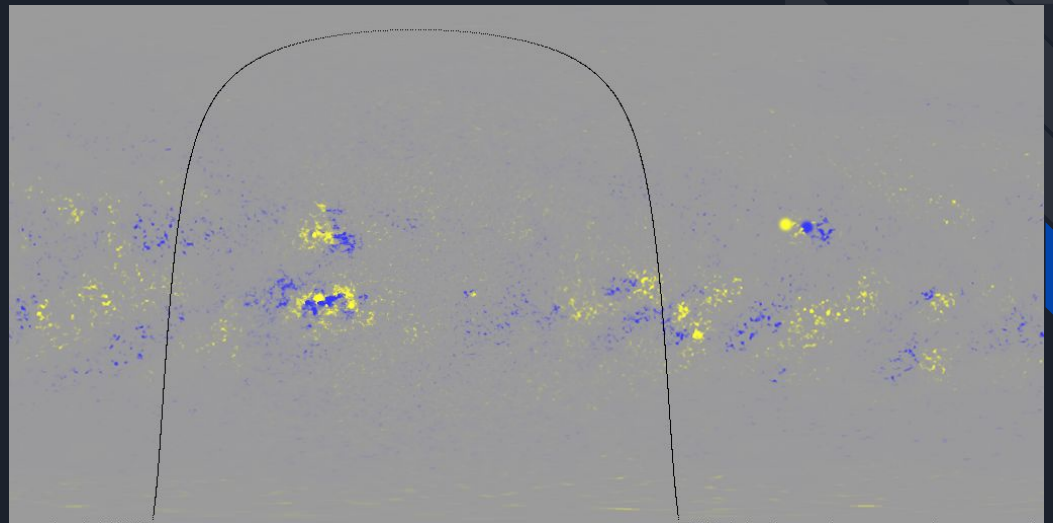
This research was supported by the National Science Foundation REU program, award #1659878.

Additional material

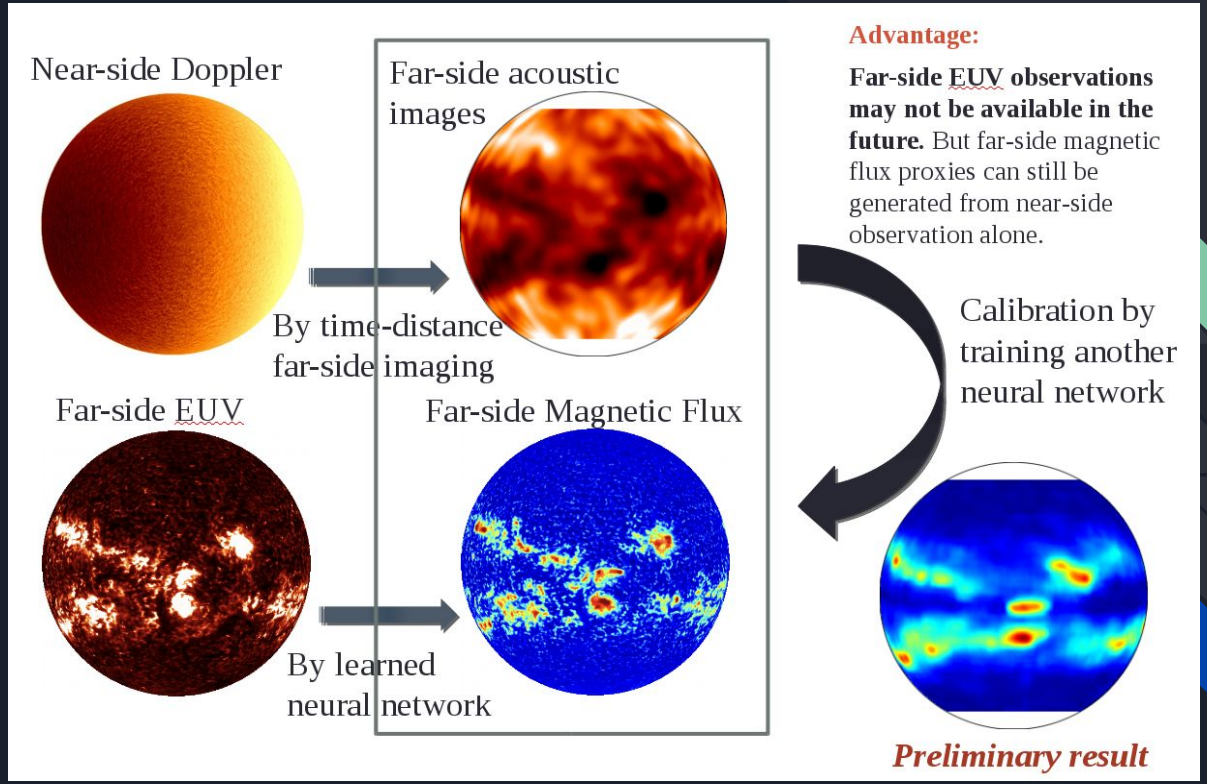
AFT without helioseismology



AFT with helioseismology



Machine learning for helioseismology



Hess Webber et al., lecture, 2019

AFT and Helioseismology sample comparison