Solar and Heliospheric Measurements

Polar and Far Side Measurements

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Space Weather Operations and Research Infrastructure

- What do we need?
- What can we do now?
- What are the gaps?

Three (Four) SWX Time Scales

- Radiation
  - Immediate – Event Prediction
- Energetic Particles
  - Hours – Prediction, Observations, Generation & Transport Models
- Magnetic Field and Solar Wind Structure and Disturbances
  - Days/Months – Remote Observations, Transport Models, *In Situ*, Local 3D

- Space Climate: Solar Cycle & GCRs
  - Decades – Models, Observations, Hope and Hard Work

Measurement requirements may differ depending on location

Requirements –Space Weather Drivers

- Dynamic Photosphere, Corona & Heliosphere
  - Flares, Active Regions, CMEs, SEPs, Solar Wind (Global)
- Situational Awareness of Evolving Global Heliosphere
  - Global solar and *in situ* measurements and models
- Solar Cycle Prediction
  - Flows, Interior, Poles (Irradiance)

Others are talking more about *in situ* measurements, models, and validation

Forecasting Eruptive Events

Models Require

- Regular, frequent photospheric magnetic field measurements in Active Regions
- Regular, frequent images in EUV for flares, coronal events, and CME initiation
- Regular, frequent observations of Corona for CMEs
- Synchronous Events – Hemispheric Scale Connections

The Global Heliosphere

- Full Sun ($360^{\circ}/4\pi$) magnetic field (line of sight)
- Full Sun EUV imagery
- Multipoint Coronagraph Observations
- Multipoint In situ measurements for validation
- Out-of-ecliptic vantages desirable

Solar Cycle

- More theory
- Meridional Flow
- Convection
- Differential Rotation
- Variation with Depth
- High latitudes

Related to Farside and Polar Vantage Points

Far Side (and Polar) Measurements

- L3/Polar measurement requirements essentially the same as L5 & L4 (and L1 minus science) with lower resolution, sensitivity, and cadence, but similar latency
  - M, EUV, corona / heliospheric imager, in situ package
- Challenge is telemetry (mostly latency)
  - Resolution/cadence can be addressed with processing and compression
- Polar capable of coronal measurement of ecliptic plane
- Polar gives hemispheric view, polar field/missing flux
- Polar gives convection/flows/discovery

Present capabilities – Solar Observations

- (On/Near Earth) Synoptic – GONG, SOLIS, MLSO, SOON, RSTN, WSO, Other GB, SDO, GOES, DSCOVR, ACE
- Returning STEREO (70°), Proba 2, other
- Non-synoptic: Various including SPP, Solar Orbiter, Hinode, DKIST, GST, other GB

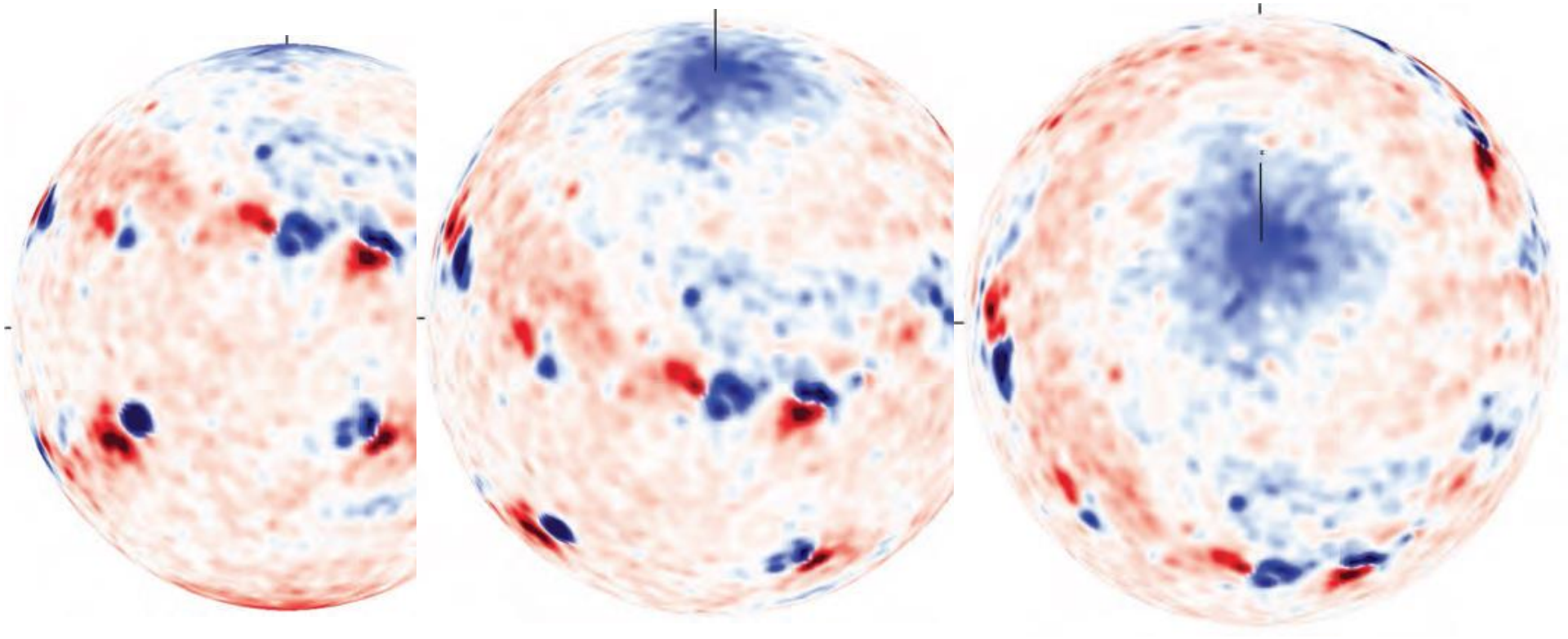
Some Planned/Proposed Solar Observations

- NG-GONG
- COSMO
- SWFO-L1
- L5 – Lagrange
- Aditya, Punch, Other
- Polar: SOLARIS, SPOC

What is Unique About the Poles?

- **The poles are very poorly and sporadically observed. In addition to seasonal obscuration, observational difficulties also include foreshortening, resolution, center-to-limb effects, reduced sensitivity, and small signals. Important for models.**
- High latitudes likely have different convection and rotation patterns that influence the solar cycle. What happens to converging poleward flows?
- The magnetic field is different in the polar regions (e.g. largely unipolar, small flux concentrations with no active regions, structured by surges from low latitudes), difficult to measure due to line-of-sight projection, home to long-lived coronal holes, and potentially important for 'flux deficit' concerns and solar cycle generation.
- High-latitude observations provide leverage for meridional flow measurements, helioseismology in unexplored subsurface regions above 60 degrees, tracking of surface features for longer times over a range of latitudes, hemispheric connections, and visibility of heliospheric structures in the whole ecliptic plane for extended times.
- Only *in situ* measurements have been made from high latitudes by Ulysses

Polar View – Ecliptic, 35 (SO) and 75



Simulation from J. Linker and C. Downs

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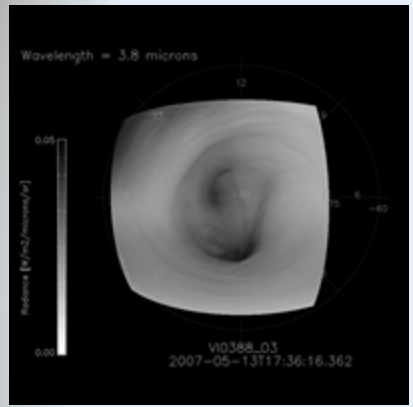
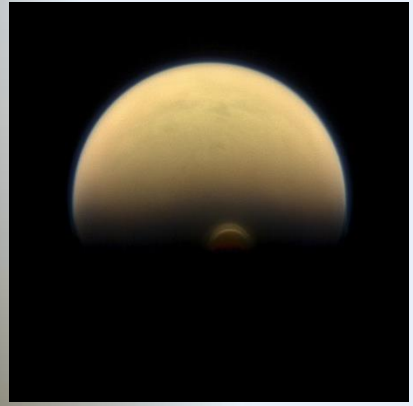
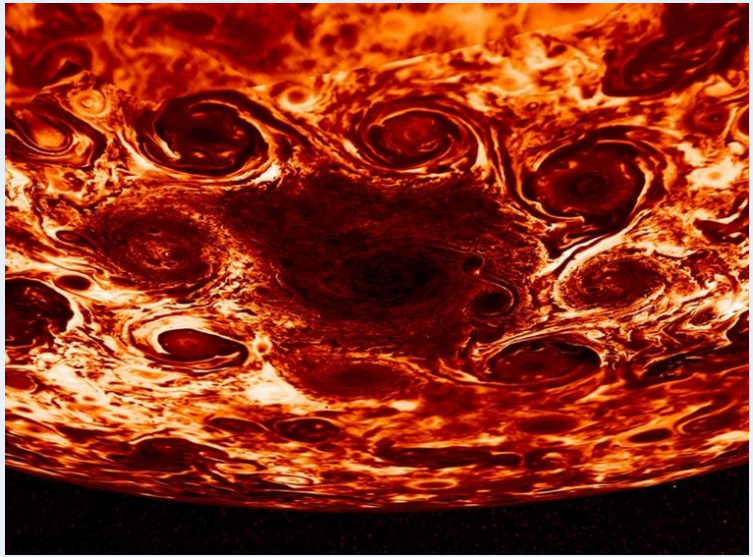
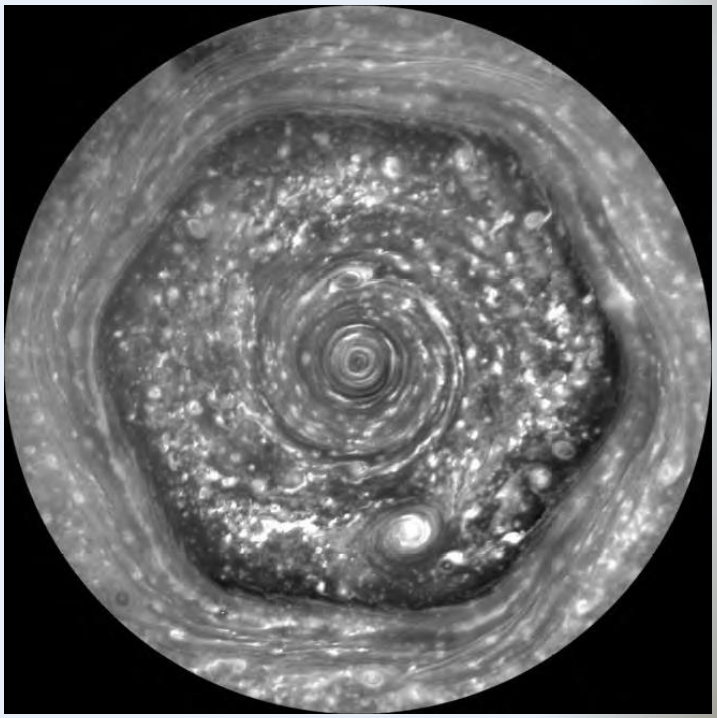
Polar Vortices – Venus, Titan, Jupiter, Saturn









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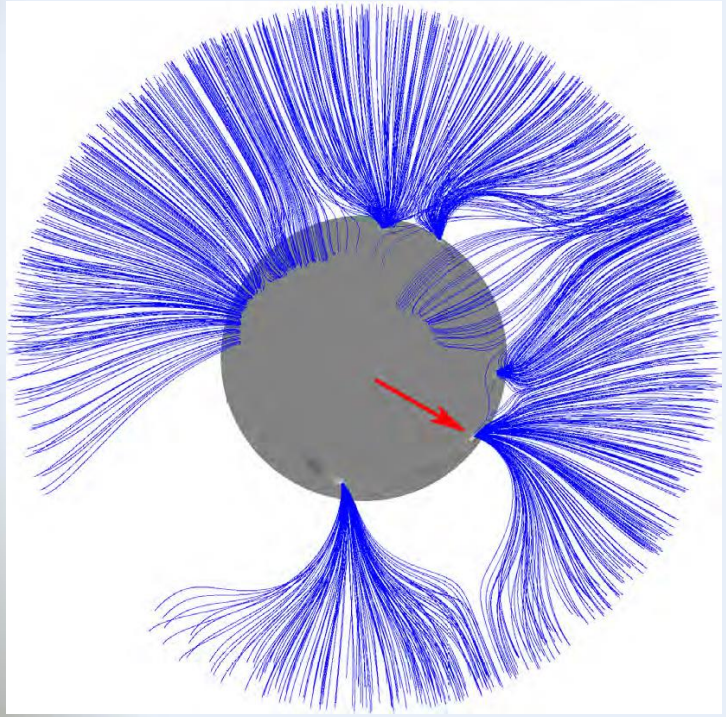
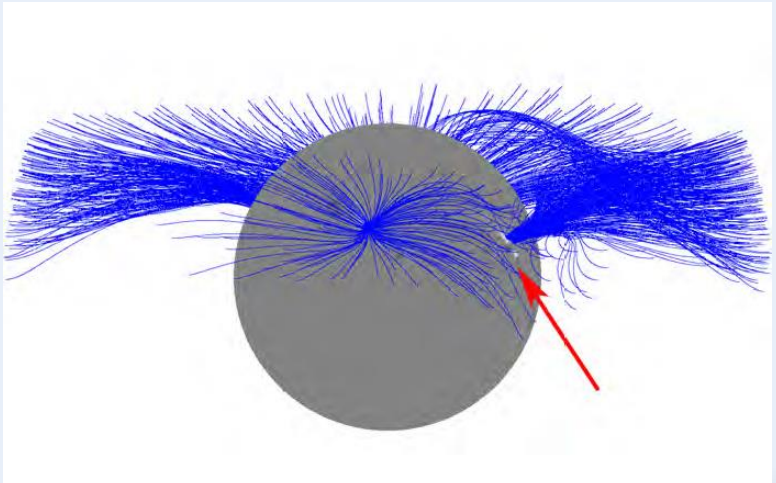
Views of Heliospheric Structures from Pole and Ecliptic

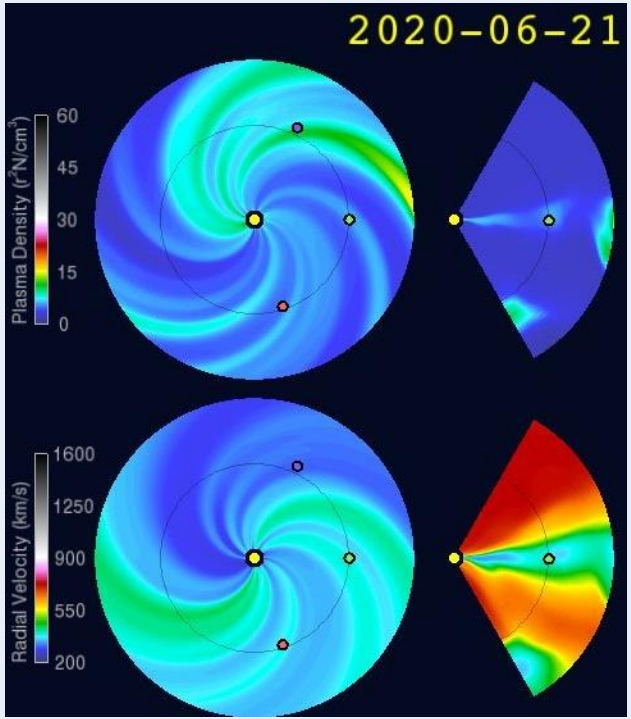


Pseudostreamer belt (PFSS) for the wide SEP event on 2010 Aug 14 (red arrows indicate a source of SEP, blue – open magnetic field of negative polarity)



Courtesy O. Panasenco

Polar Vantage Shows Ecliptic Plane Evolution of Heliospheric Structure



Why do we care about the Farside?

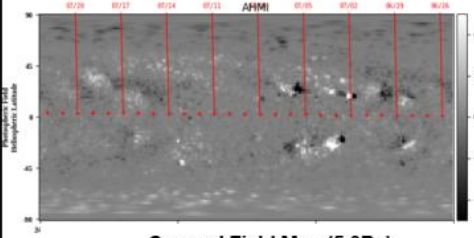
- Need situational awareness of magnetic configuration of entire heliosphere
  - More detail in L5/L4 discussion
- Space Weather not near Earth
- What can we do until we have Farside observations?

Impact of Far-Side Fields

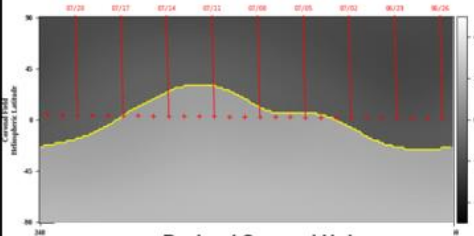
(WSA Predictions at *ACE* With & Without Far-Side Included)

Coronal & Solar Wind Predictions *without* Active Region

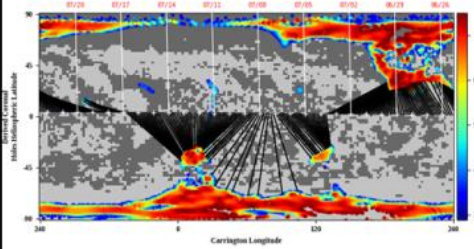
Photospheric Field Map



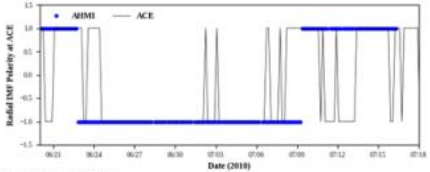
Coronal Field Map (5.0Rs)



Derived Coronal Holes

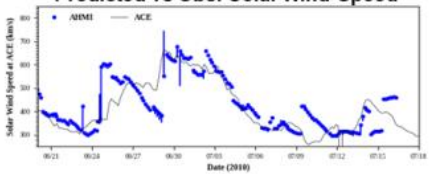


Predicted vs Obs. IMF Polarity



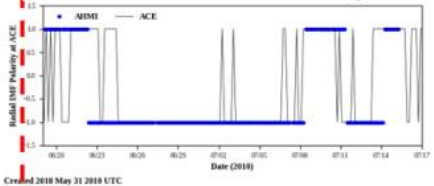
Created 2010 June 5 2051 UTC

Predicted vs Obs. Solar Wind Speed



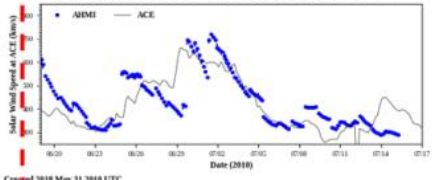
Created 2010 June 5 2052 UTC

Predicted vs Obs. IMF Polarity



Created 2010 May 31 2010 UTC

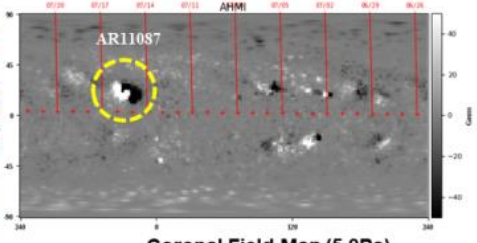
Predicted vs Obs. Solar Wind Speed



Created 2010 May 31 2010 UTC

Coronal & Solar Wind Predictions *with* Active Region

Photospheric Field Map



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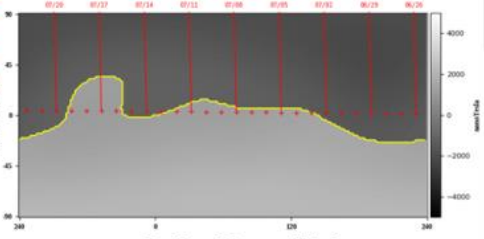

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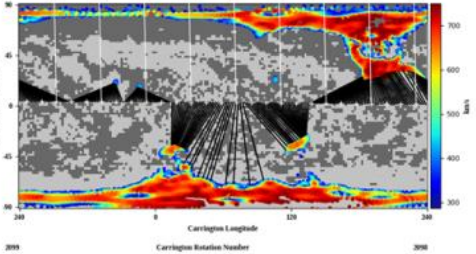


Courtesy: N. Arge

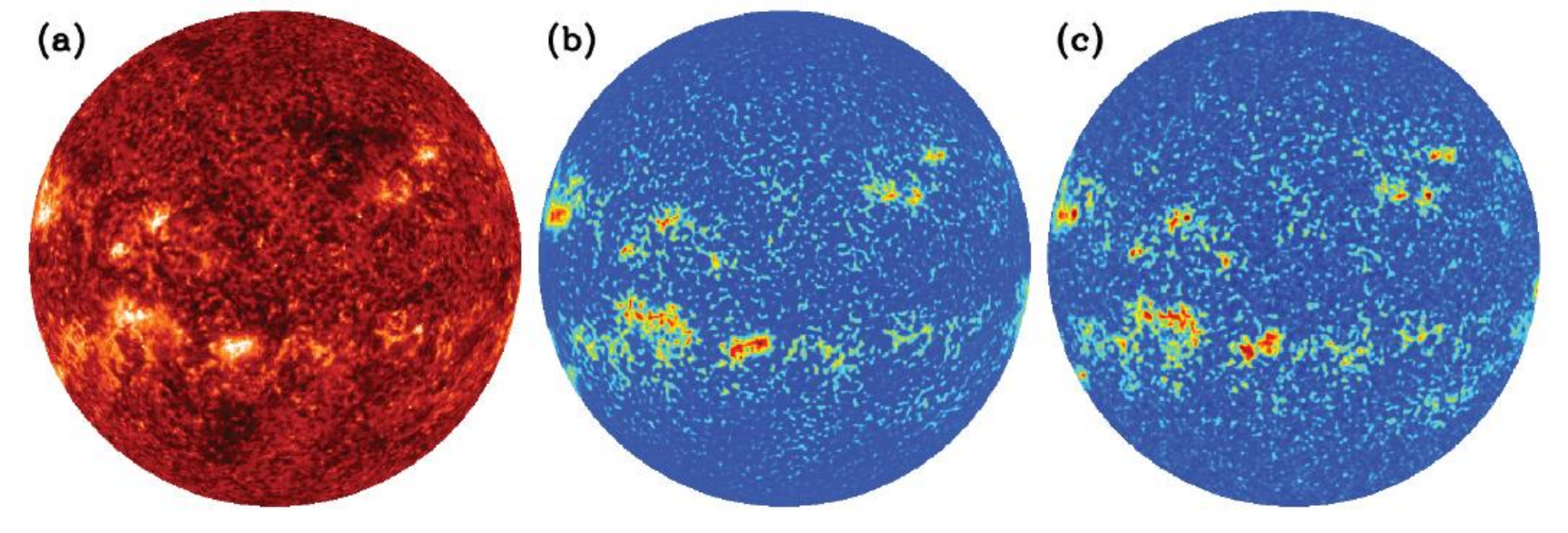
Current Capabilities – Farside

- Farside Helioseismology – AR Measurement
  - Capabilities – flux map
  - Limitations – no magnetic configuration / orientation
- STEREO EUV & Coronagraph & in situ
- Limited Lyα scattering

Farside Active Region Measurement

- Helioseismology gives Farside ‘time delay’ maps
  - Time delays are related to presence of magnetic flux
- STEREO provides Farside EUV images
  - EUV is related to magnetic flux
- SDO nearside magnetic maps used to train translation of EUV into a magnetic flux proxy
- Farside EUV used to train translation of Farside delays into magnetic flux

Deriving Magnetic Flux from EUV



SDO/AIA 304 EUV image

HMI Magnetic Flux Map

ML Derived Flux from 304

Courtesy: J. Zhao, R. Chen, S. Hess Webber, R2O

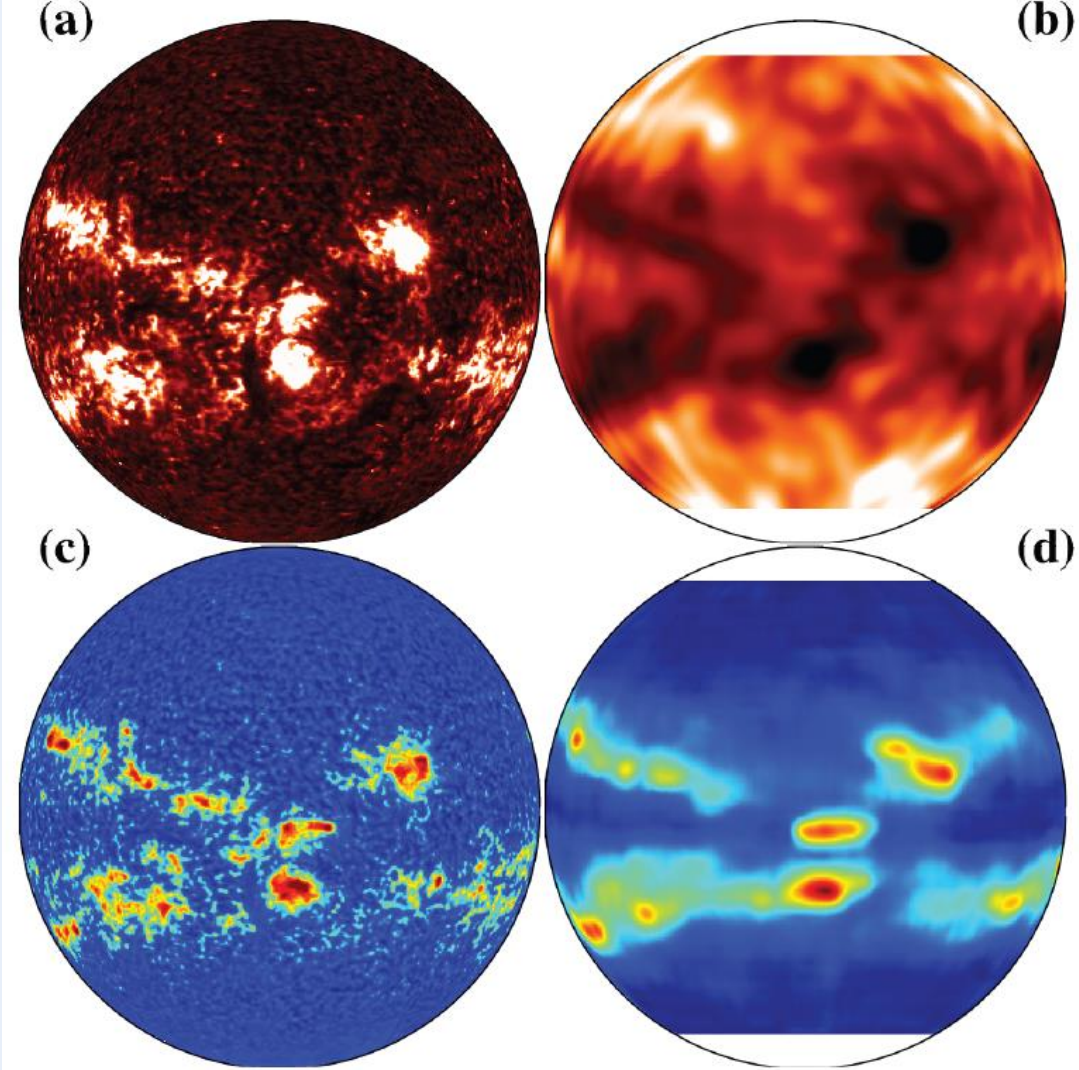
Farside Magnetic Flux Map Derived Using Nearside Helioseismology

A) Upper Left: Farside composite STEREO EUV Image

B) Upper Right: Farside Helioseismology time-delay map

C) Lower Left: EUV ML Derived Farside Magnetic Flux Map

D) Lower Right: Farside Helioseismic Magnetic Flux map



Courtesy: J. Zhao, R. Chen, S. Hess Webber, R2O

Farside Flux Maps

- Emerging ARs can be detected!
- **Flux is quantitatively determined, but configuration/orientation unknown and unknowable with helioseismology**
- All large ARs are visible in HS maps
- Smaller regions are more uncertain

Future Infrastructure

SHOES – Solar Heliospheric Operational Environmental Satellites

- Evolving series (constellation) of heliospheric spacecraft measuring essential space-weather quantities: LoS magnetograms, EUV, coronagraph, heliospheric imager, *in situ* package
- Spacecraft spread over multiple longitudes with as much heliographic latitude range as feasible to provide multiple vantage points and global coverage