Flux Emergence Prediction Tool (FEPT)

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Flux Emergence Prediction Tool (FEPT)

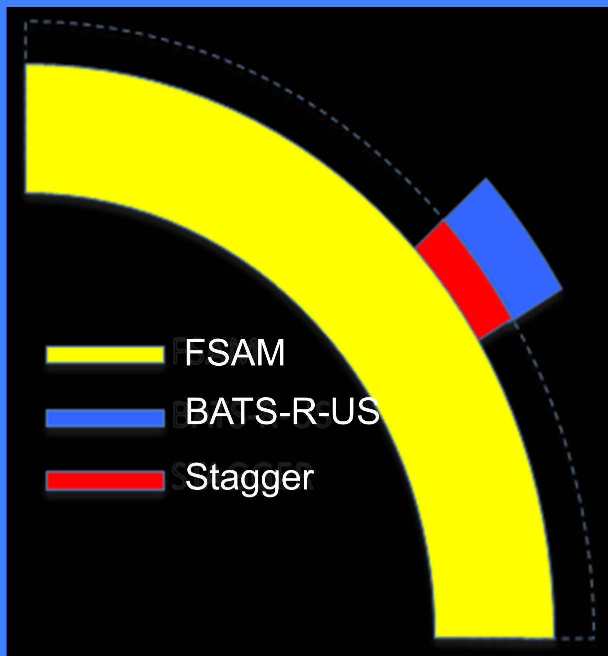
Motivation

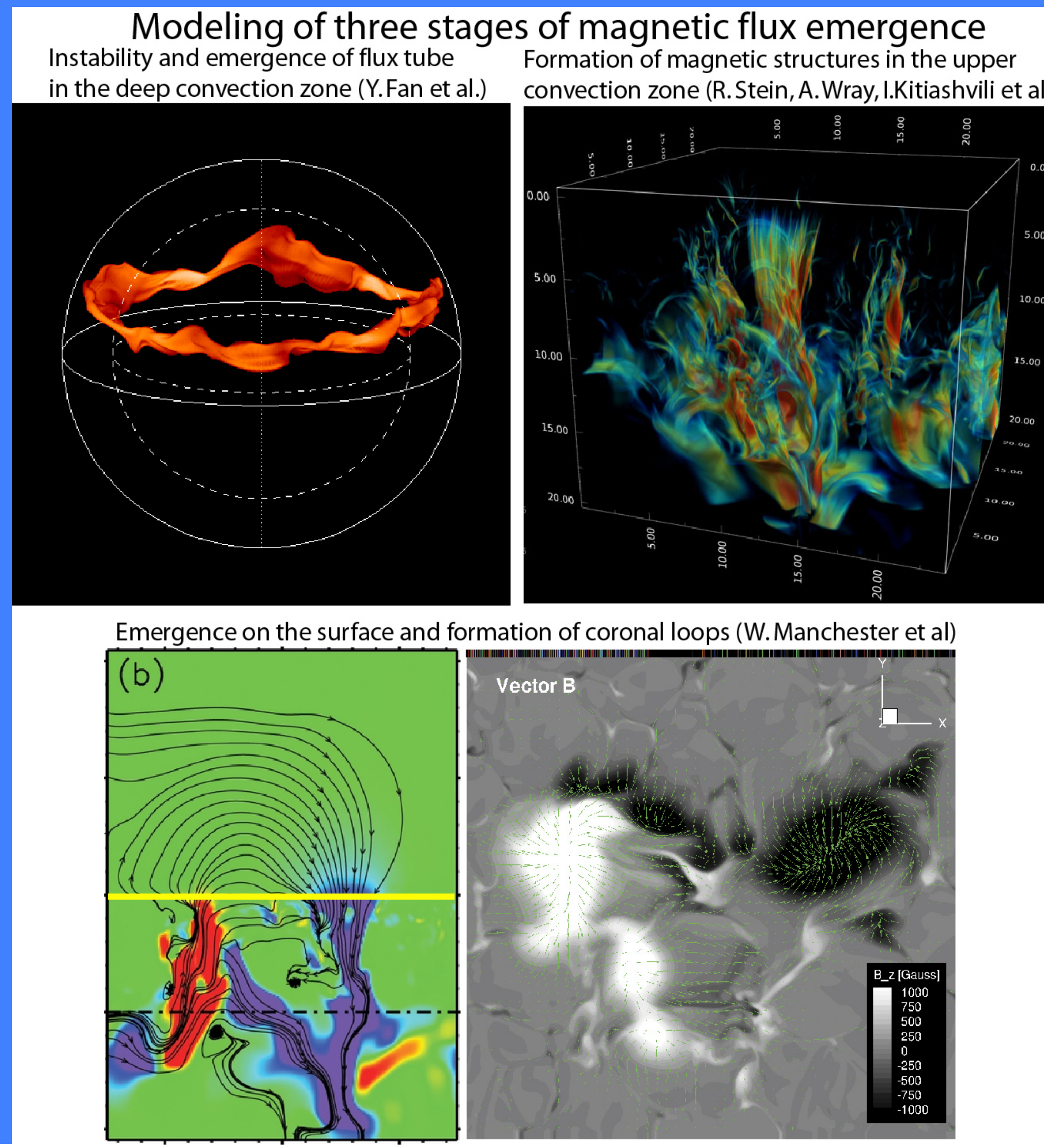
The Sun lies at the center of space weather and is the source of its variability. The primary input to coronal and solar wind models is the activity of the magnetic field in the solar photosphere.

Goal

Develop physics-based models for the dynamics of the magnetic field from the deep convection zone of the Sun to the corona with the goal of providing robust near real-time boundary conditions at the base of space weather forecast models .

Approach

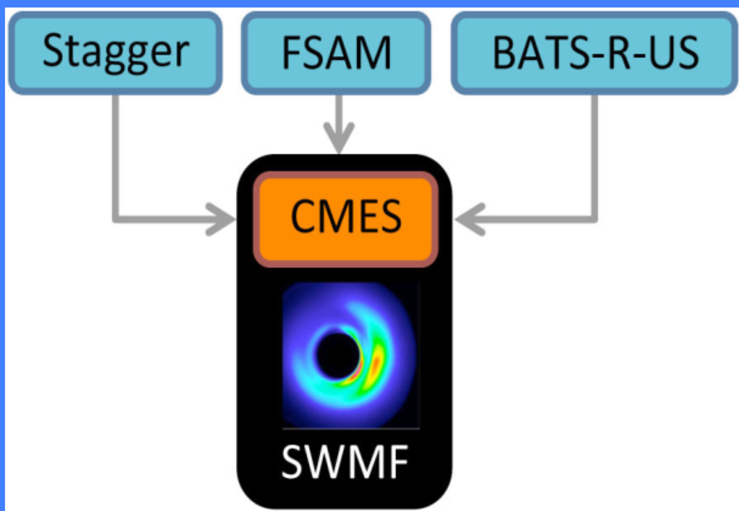


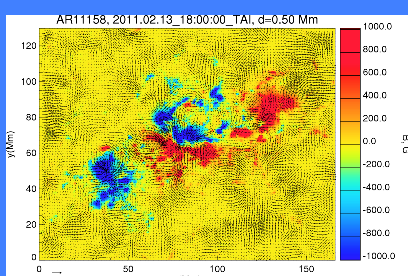


- Schematic of the optimal physical domains for FASM, BATS-R-US, and Stagger. The anelastic MHD code, FASM, is optimal below 20Mm. The MHD code with realistic radiative transfer, Stagger, is optimal from 30 M to the photosphere. The MHD code with approximate radiative transfer, Near Surface Convection Zone (SWMF), is optimal from 30Mm to the corona.

Flux Emergence Prediction Tool (FEPT)

Coupled Models for Emerging flux Simulation (CMES)





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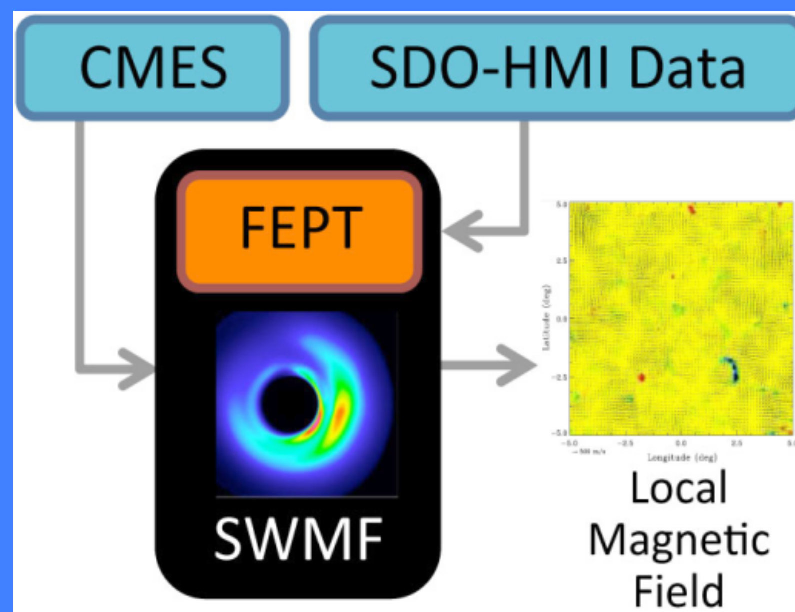


Flux Emergence Project

FEPT is an element of the Flux Emergence Project under the LWS NASA/NSF Strategic Capabilities

Objective 1: Forecast (Technology) - Enhance the Air Force Data Assimilation Photospheric flux Transport model (ADAPT) by assimilating SDO-HMI data

Objective 2: Understanding (Science) - Develop Coupled Models for Emerging flux Simulations (CMES) within the Space Weather Modeling Framework (SWMF) by coupling:

Co-Investigators

Air Force Research Laboratory
- C. Henney, Nick Arge

University of Michigan
- W. Manchester

New Jersey Institute of Technology
- A. Kosovichev

Stanford University
- P. Scherrer, J. Zhao

National Center for Atmospheric Research/HAO
- Y. Fan

Michigan State University
- R. Stein

NASA Ames Research Center
- A. Wray, D. Hathaway

Los Alamos National Laboratory
- H. Godinez, J. Koller

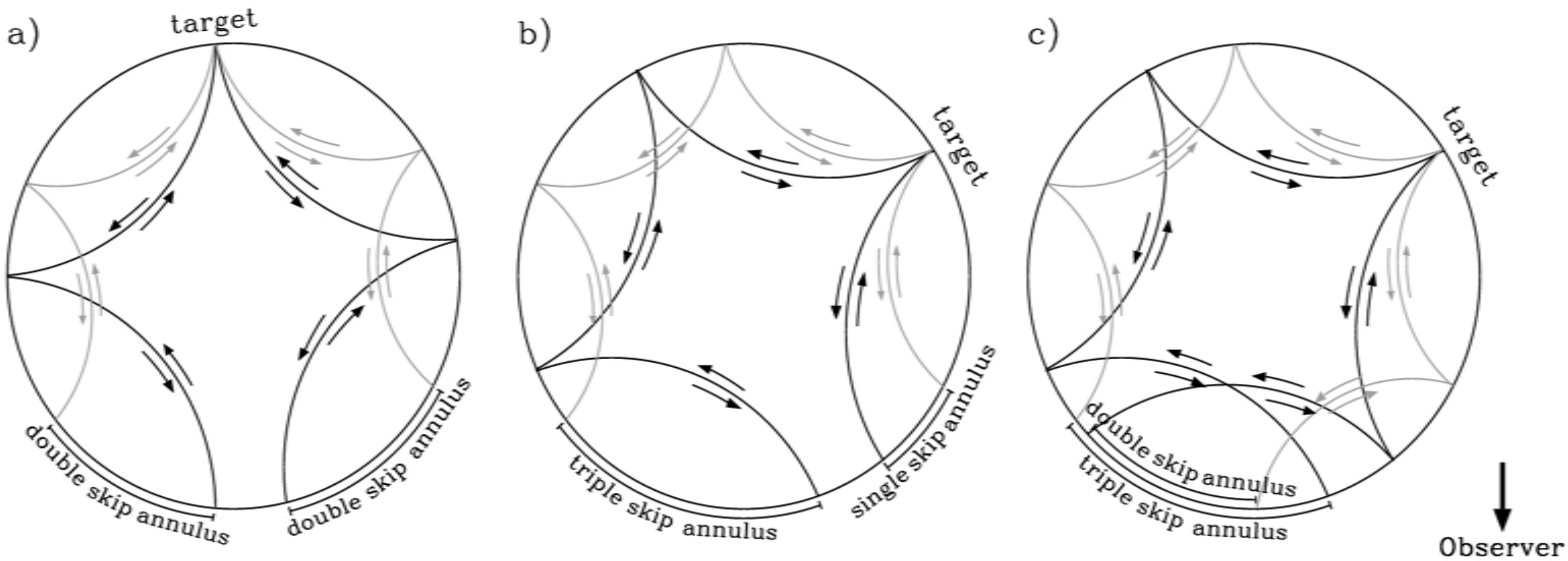
Advancements in Observation Methods

Key element of the Flux Emergence project is to assimilate SDO-HMI data

- Doppler data
- Far-side imaging
- Detection of large solar active regions in acoustic travel-time signals before their emergence (from several hours to two days in advance.)
- Detection of the meridional flow by helioseismology methods.
- Mapping solar subsurface flow fields down to more than 20 Mm below the photosphere (discovery of strong shearing flows associated with flaring and CME activity.)
- …

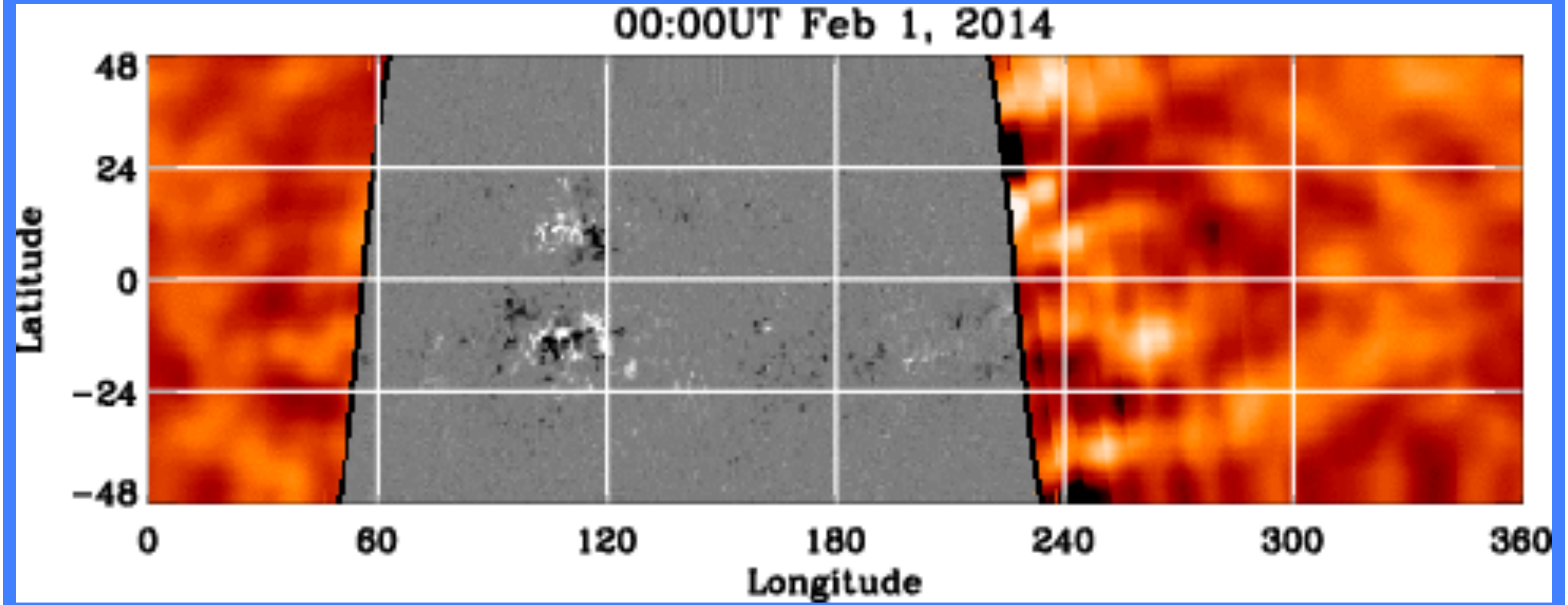
Far-Side imaging

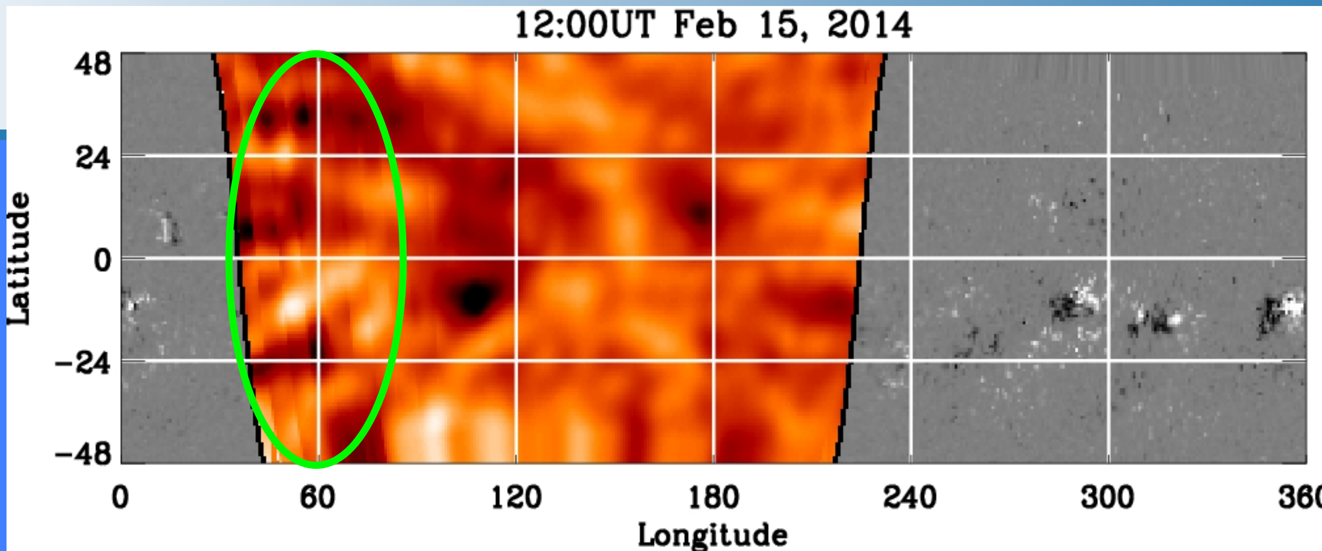
Time distance scheme implemented for HMI data
(J. Zhao)

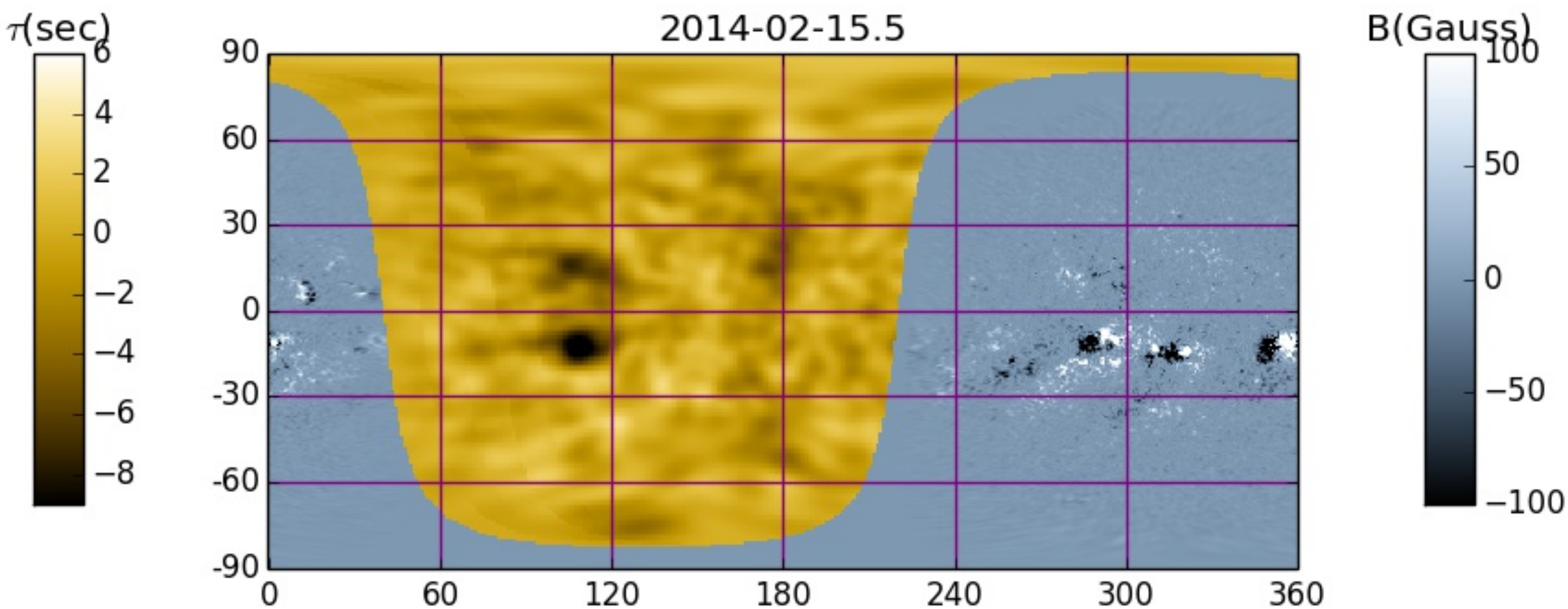


Panel (a) shows the measurement scheme using a 2 by 2 skips on either side of the target region; panel (b) shows the measurement scheme using a 1 by 3 skips on either side; and panel (c) shows the scheme using a 2 by 3 skips on either side. [Adapted from Zhao 2007 ApJ Lett.]

Far-side imaging from HMI (Zhao)





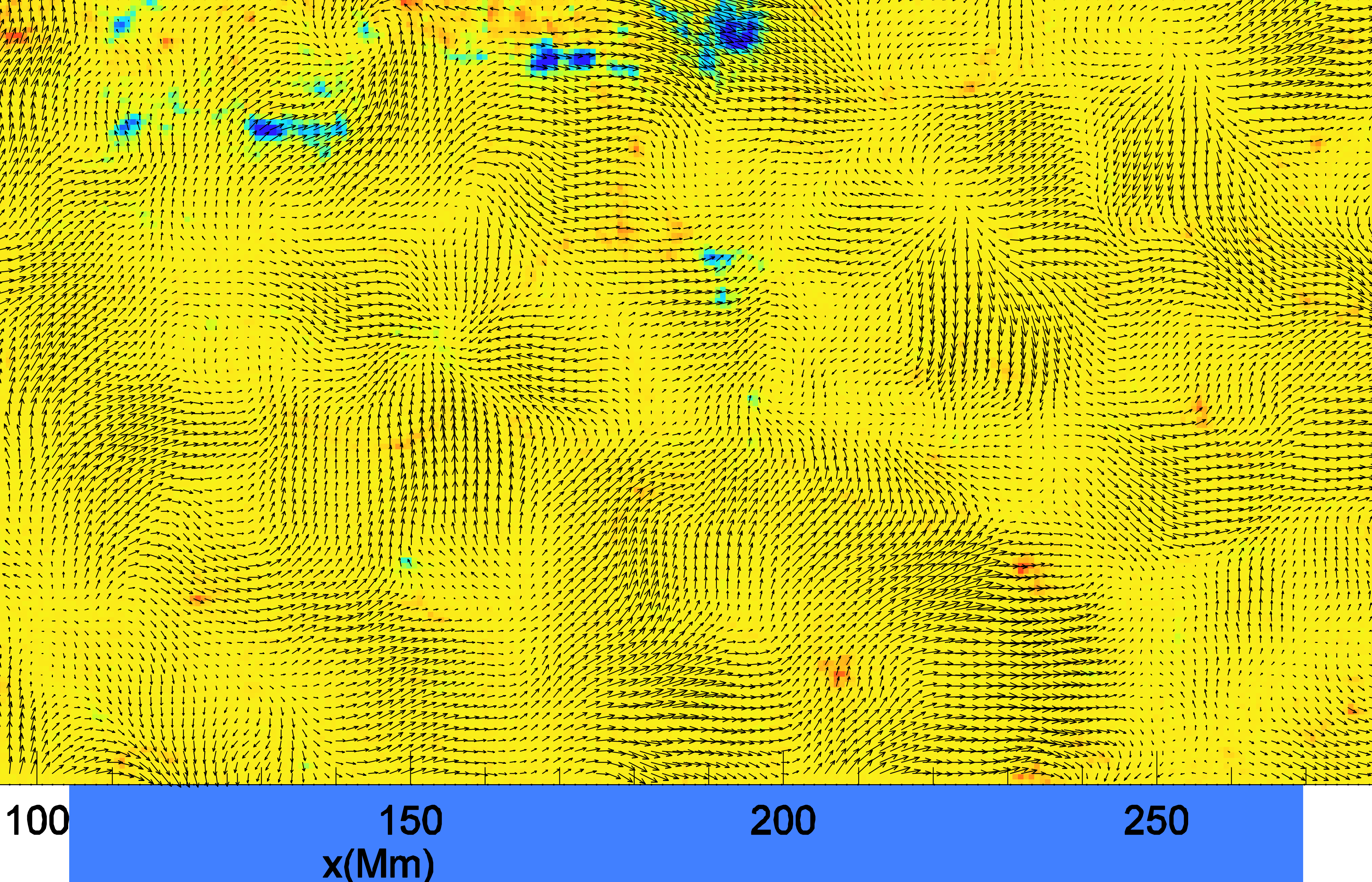


Courtesy: J. Zhao (2016)

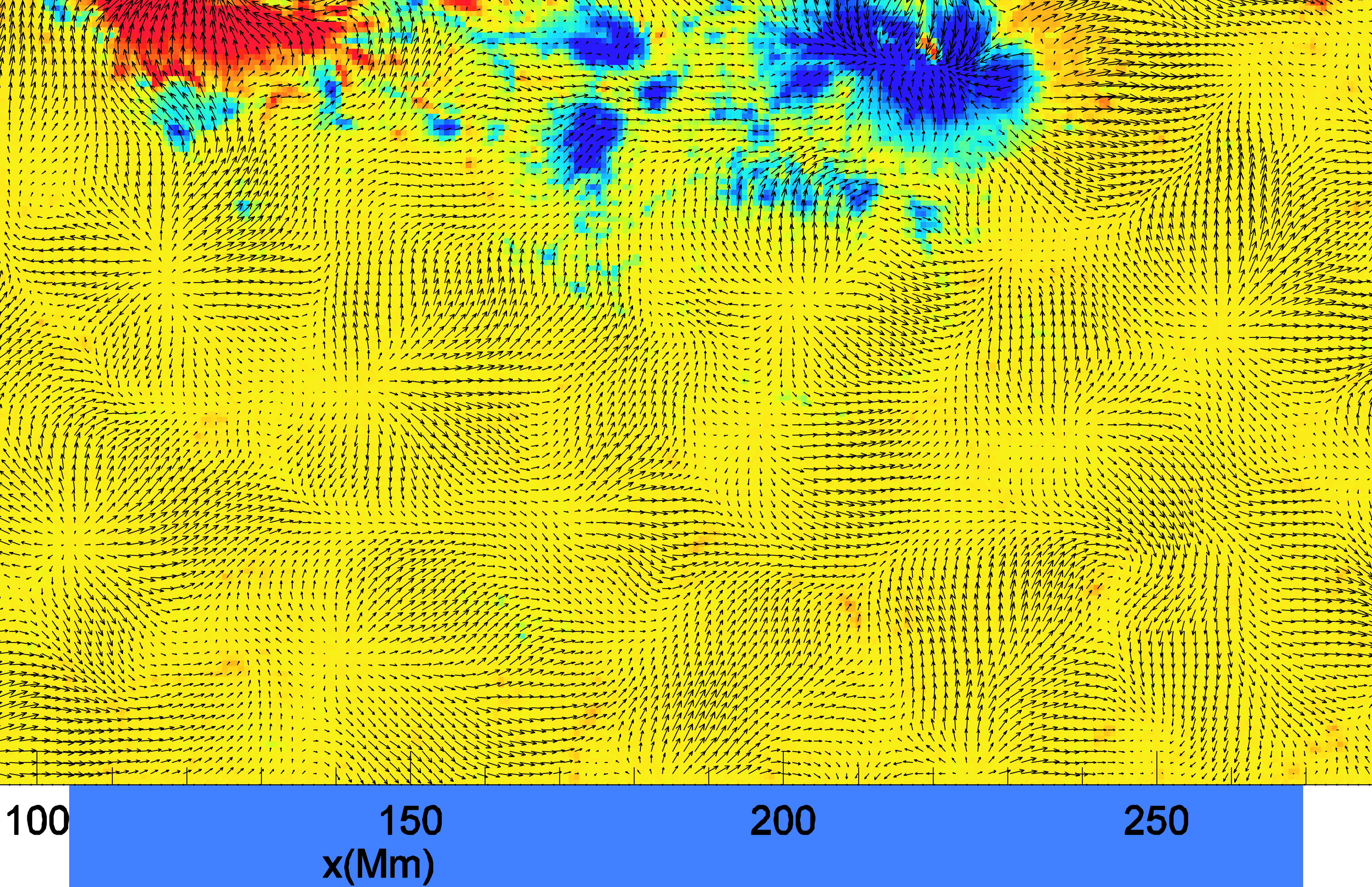
Far-side imaging from HMI (Zhao)

Time-distance far-side images have some advantages over the holography images in identifying smaller active regions, but have some systematic problems near the west-limb of the far-side.

Few parts of the codes have been identified that can improve significantly the technique.



.G. Kosovichev, J. Zhao (2016)



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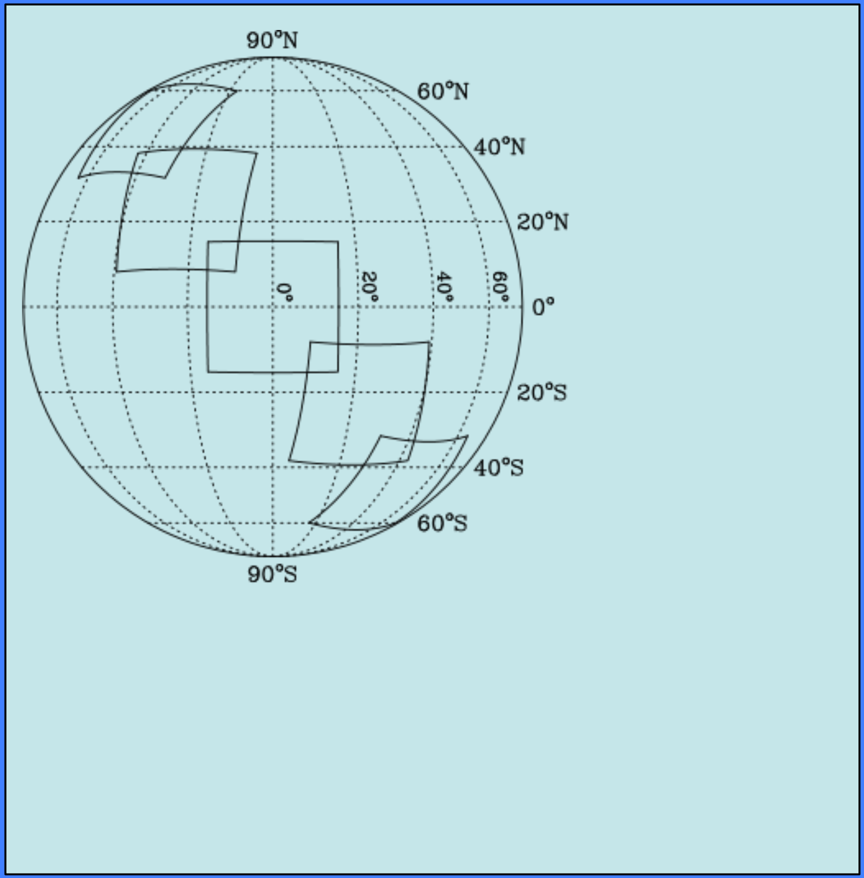
Surface Flow Maps

Measurement scheme: 25 30x30 degree areas are remapped onto heliographic coordinates and tracked with the differential rotation at the center of these areas



Parallel Surface Flux Transport Code(I)

Solve an advection-diffusion equation for the radial magnetic field, B_r, on the solar surface

– The field is advected by a flow that consists of
  - – Differential rotation
  - – Meridional flow derived from solar observation
  - – And a cellular flow **W** that mimics supergranules (Hathaway et al., JFM 2010) which itself is advected with the axisymmetric flow

Flux transport with Giant cells and surface granulation

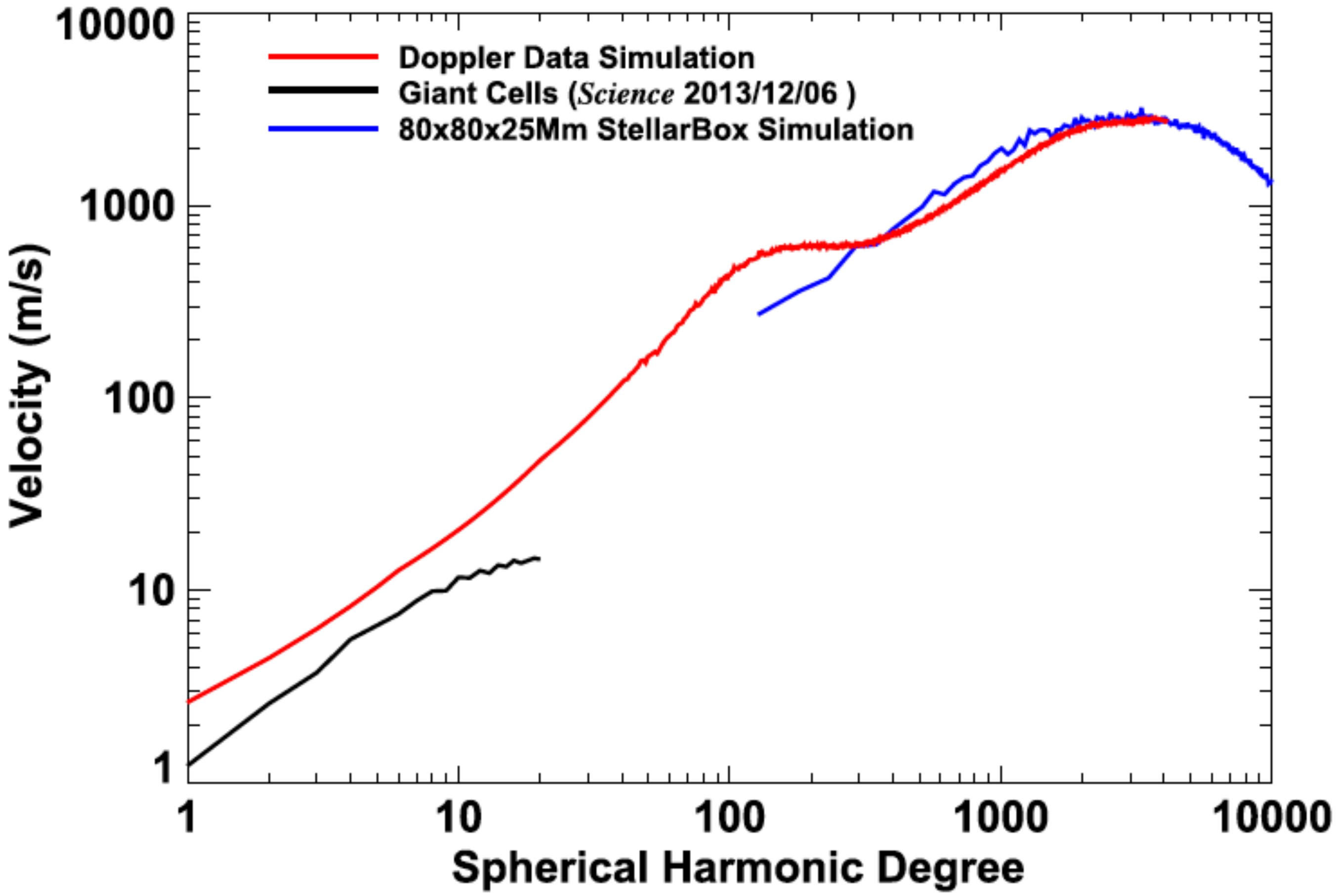


Figure 13. Total velocity spectrum (red line) from the data simulation is plotted for comparison with the spectrum from the vector velocities found for giant cells (Hathaway et al. 2013) and the spectrum from the vector velocities in the StellarBox simulation of solar granulation.

Parallel Surface Flux Transport Code

Numerics:

– Pseudo-spectral using spherical harmonic decomposition

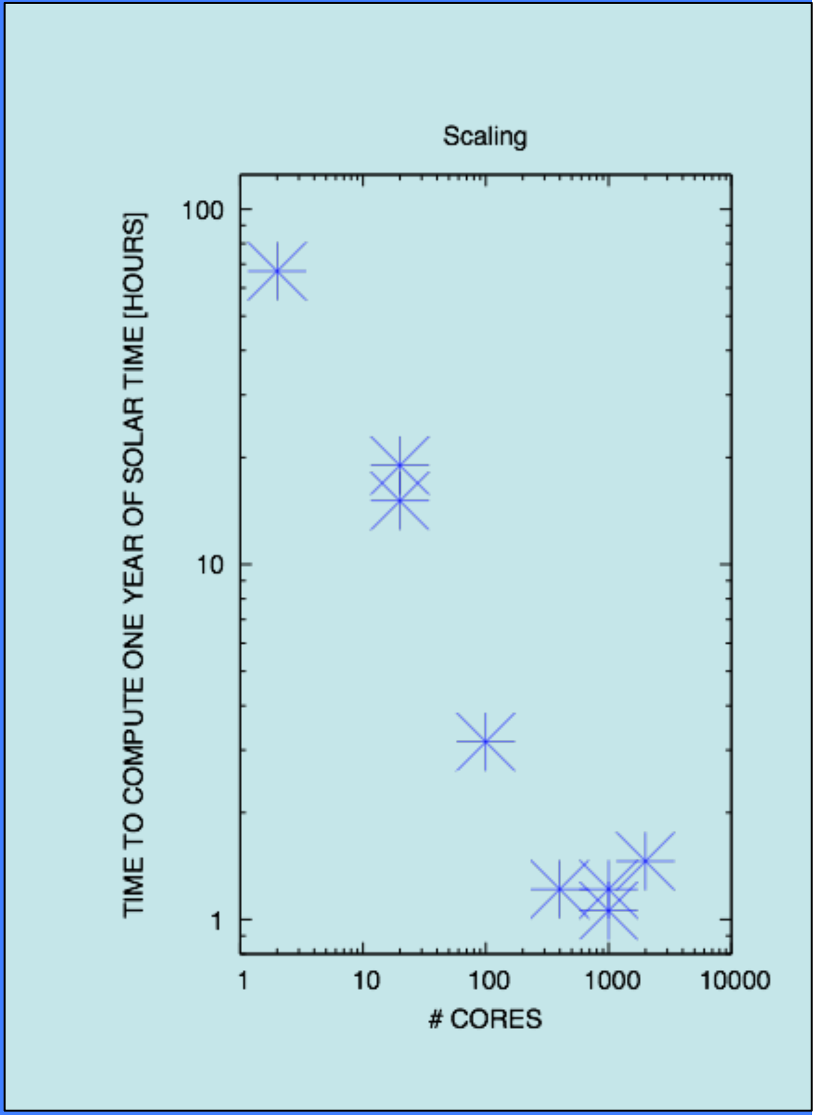
– 4th-order Rugga-Kutta time advancement

– Resolution:

- Physical space (latitude x longitude Gauss grid): 2,048 x 1,024

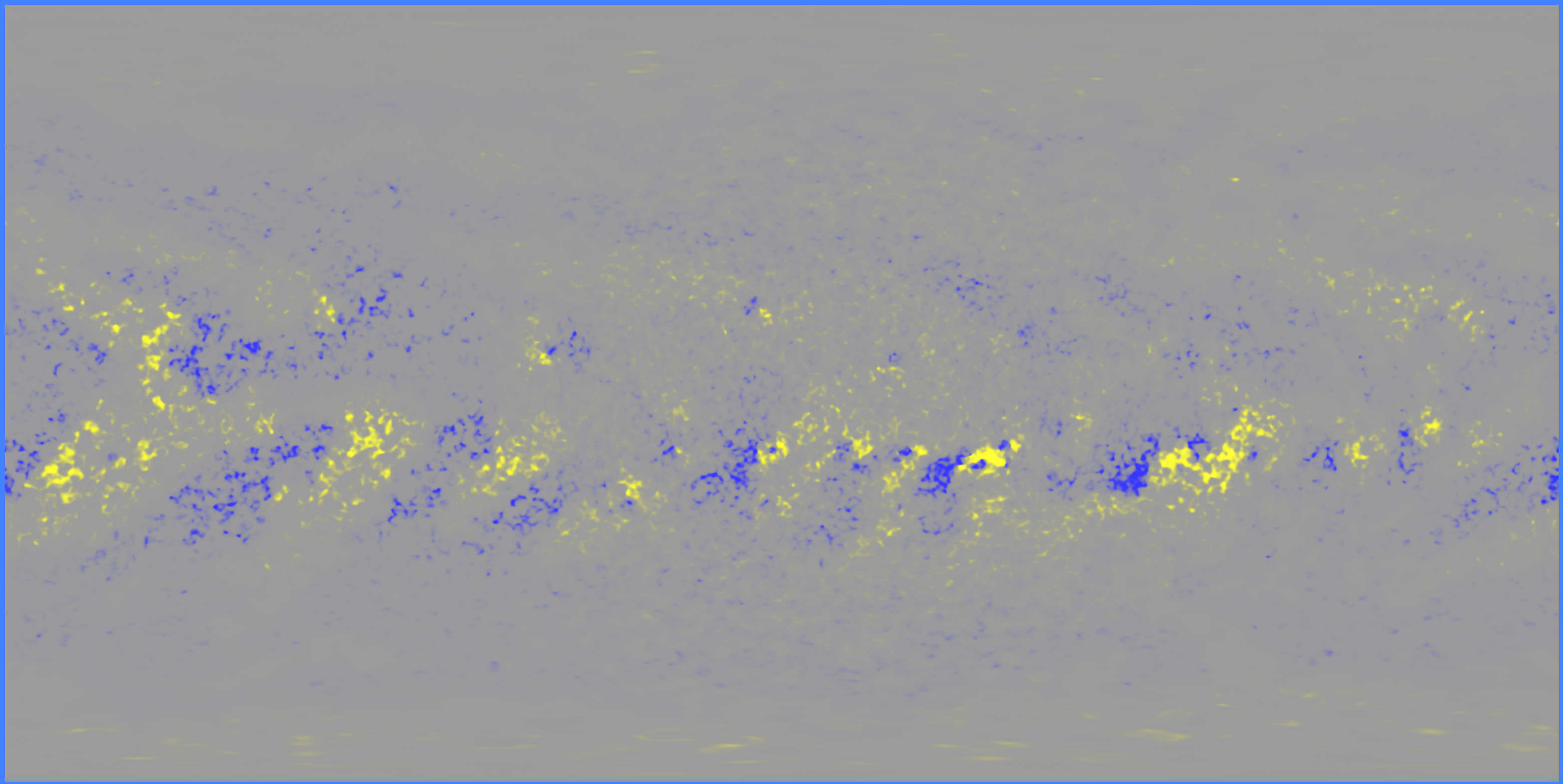
- Spectral space (spherical harmonic degree): 0 <= l <= 683

– Parallelization: Hybrid OpenMP + MPI; At given resolution efficient to ~400 cores -> Computing 1 year of solar time takes little over 1 hour on NASA's Pleiades supercomputer

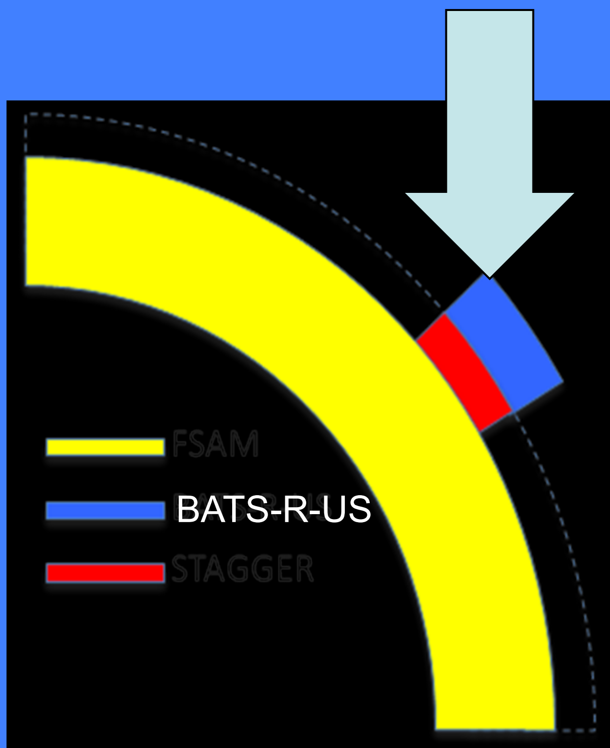


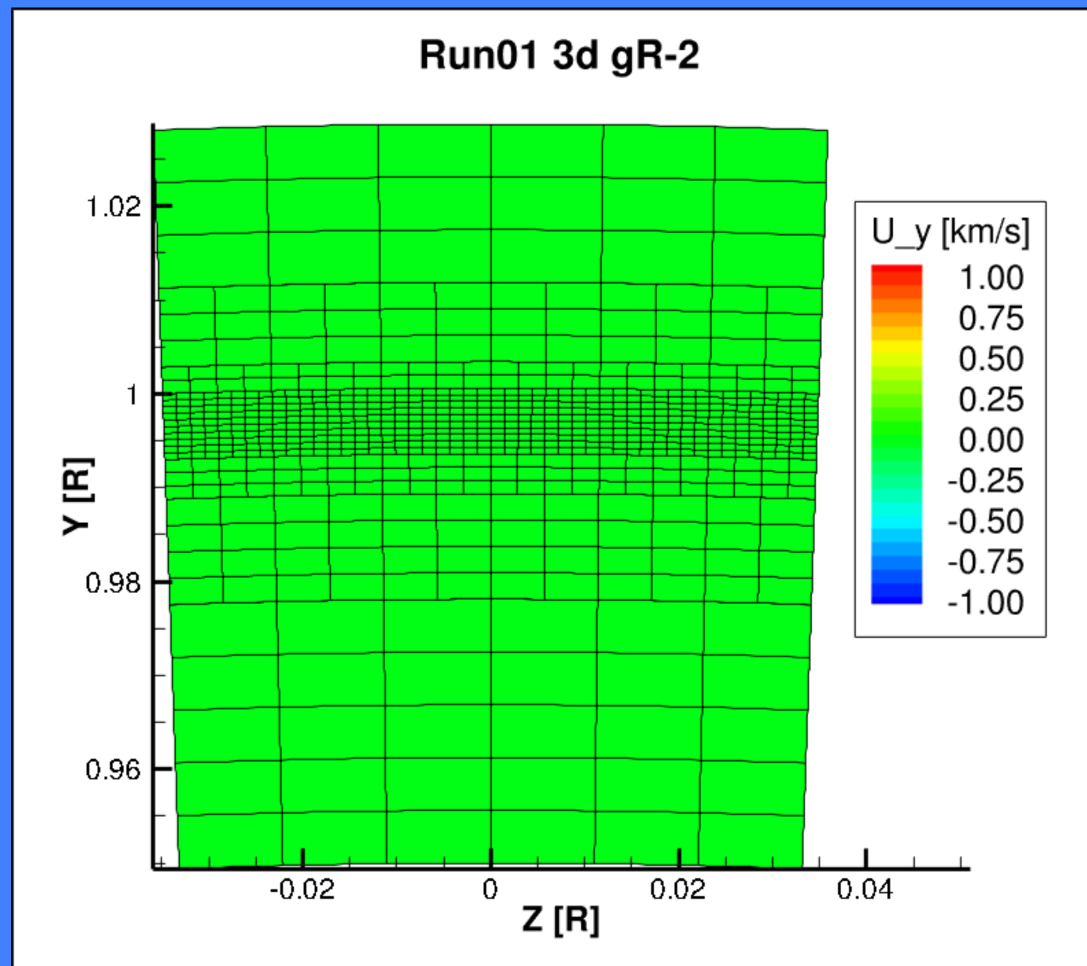
Parallel Surface Flux Transport Code

Snapshot

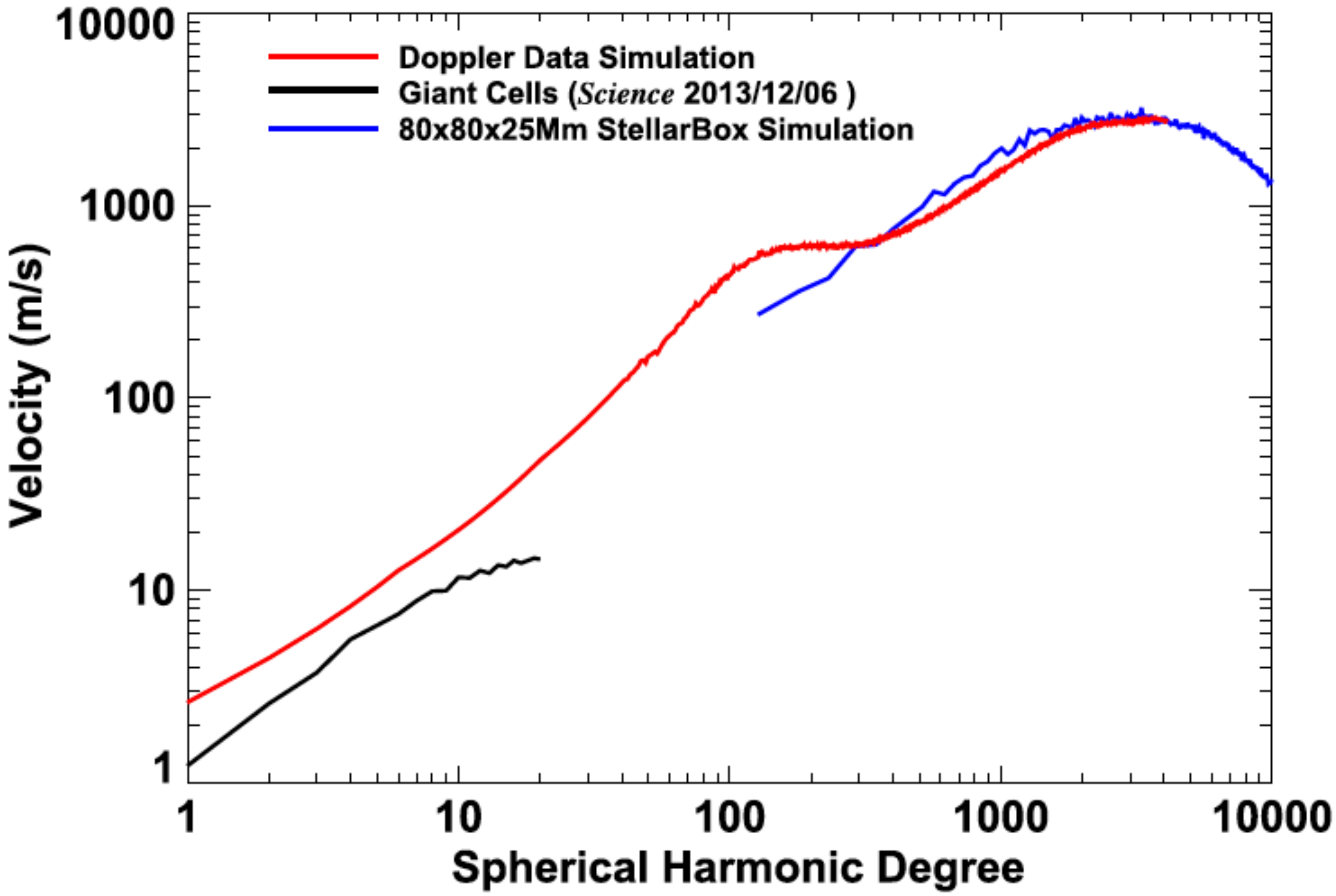


EEGGL in SWMF (W. Manchester)





Flux transport with Giant cells and surface granulation



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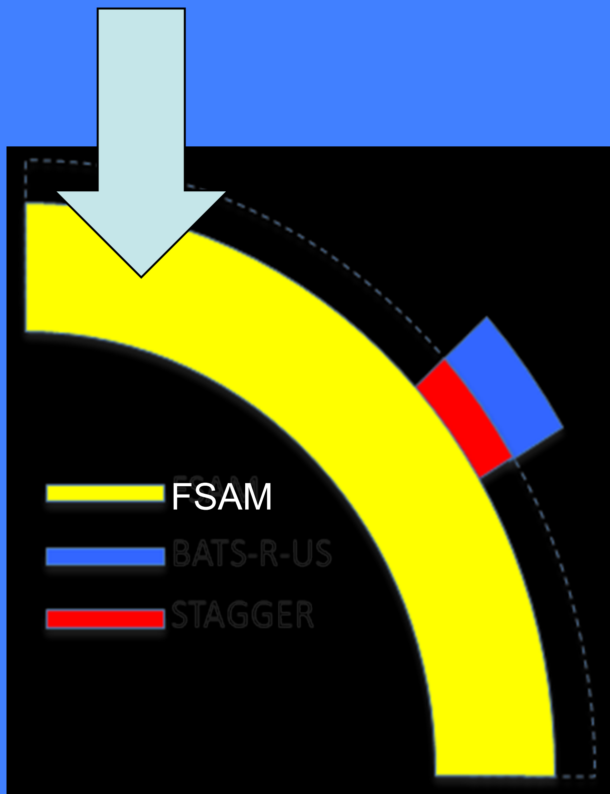
FSMA: Convective dynamo and emerging flux in the solar convective envelope (Y. Fan)



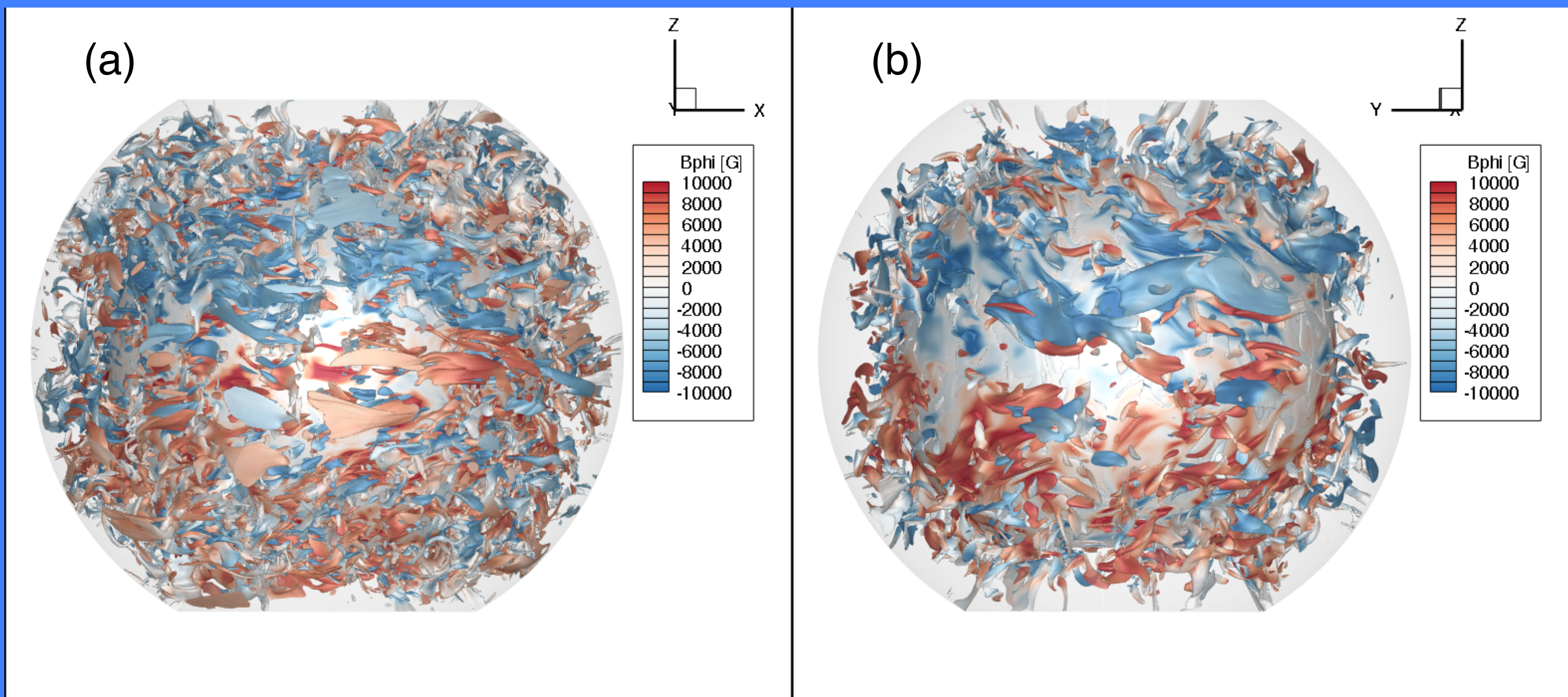
Committed an updated version of FSAM to the CZ component of SWMF, which includes the following revisions:

- Improved total energy conservation by incorporating the numerical dissipation of magnetic energy into the entropy
- Added the capability of including a sub-adiabatically stratified overshoot layer at the base of the CZ

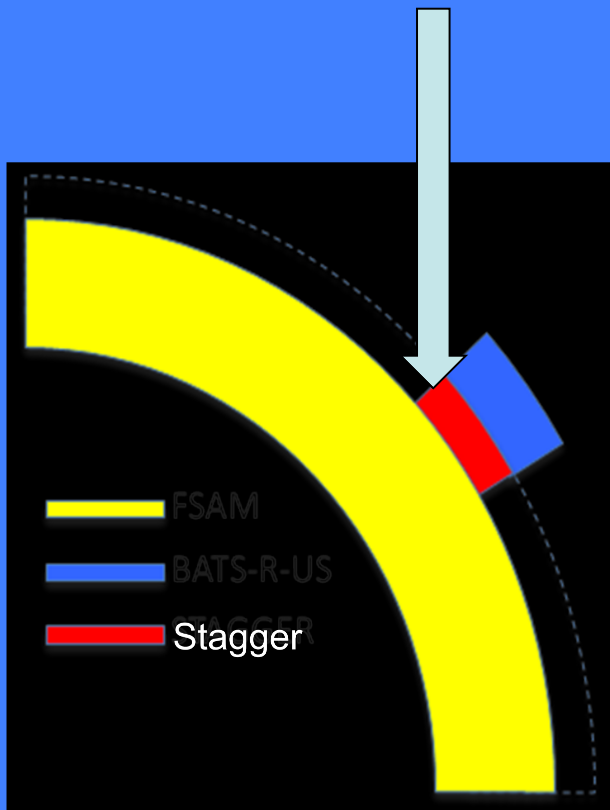
Convective dynamo and emerging flux in the solar convective envelope (Y. Fan)

Less diffusive dynamo

Previous model of Fan and Fang (2014)



Stagger: Realistic radiative MHD code (R. Stein)

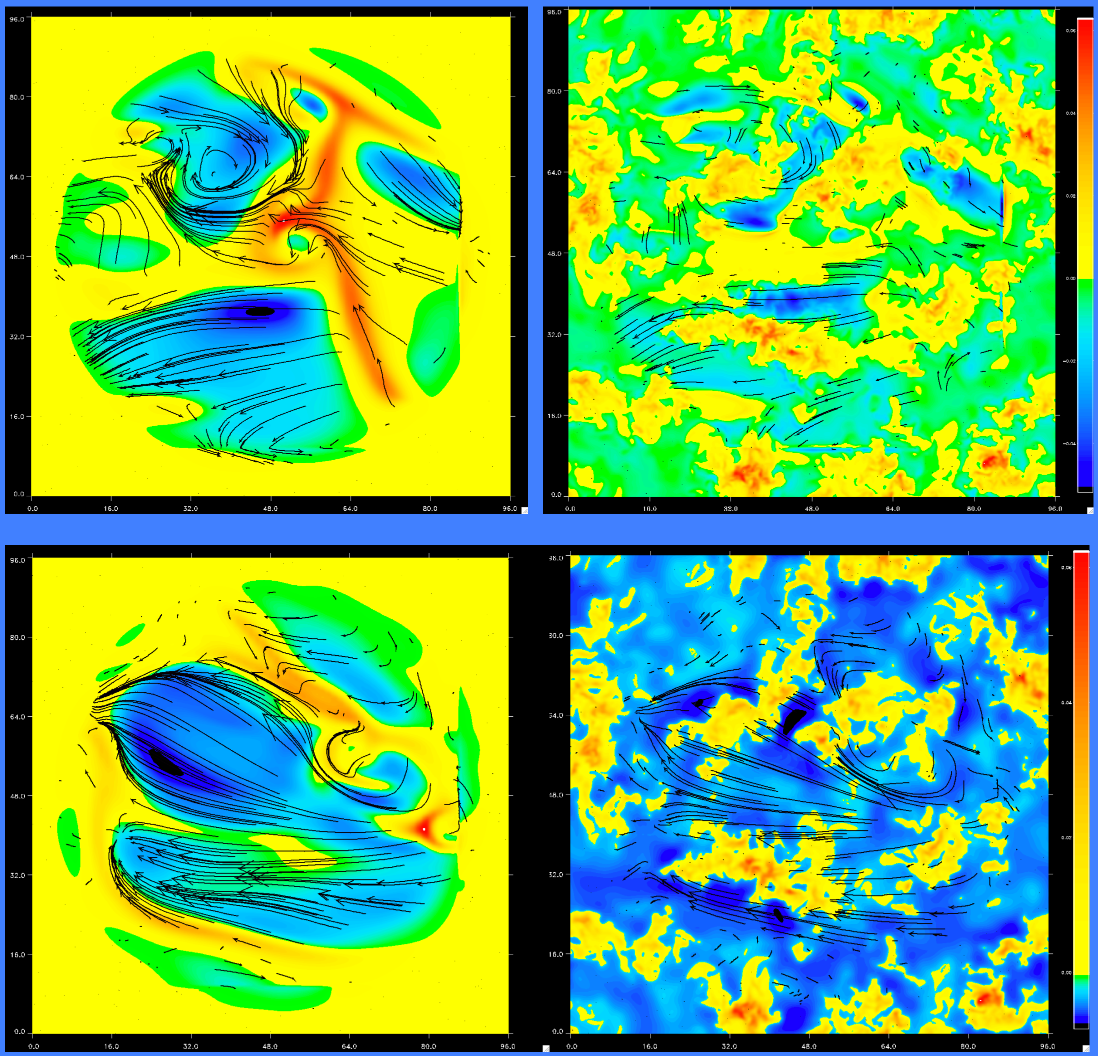


One way coupling to FSAM through Boundary Condition

- Initial testing outside SWMF
- No issues were identified in an initial effort to integrate Stagger into SWMF

Magnetic Field Boundary Condition (R. Stein)

Velocity image and horizontal magnetic filed lines. Left=dynamo input; Right=simulation. No boundary condition has been imposed on the velocity.

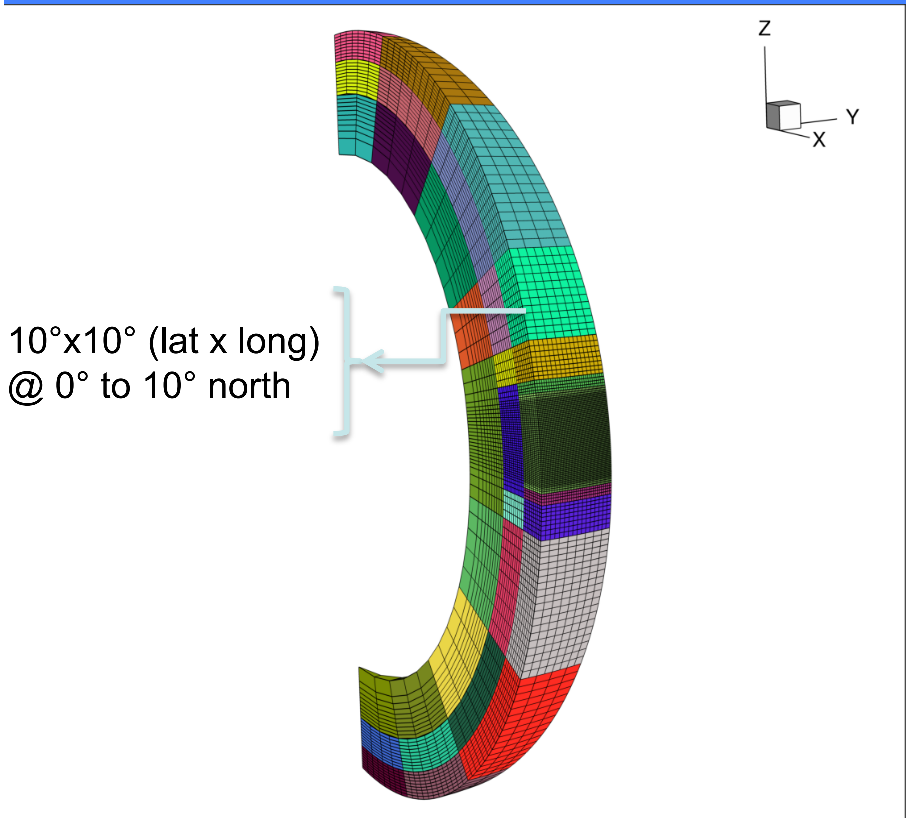


time=15 min

time=42 min

StellarSegment Code (Alan Wray, 2016)

- ✓ Fully conservative compressible
- ✓ Fully coupled radiation solver:
  - LTE using 4 opacity-distribution-function bins
  - Ray-tracing transport by Feautrier method
  - 18 ray (2 vertical, 16 slanted) angular quadrature
- ✓ Non-ideal (tabular) EOS
- ✓ 4th order Padé spatial derivatives
- ✓ 4th order Runge-Kutta in time
- ✓ LES-Eddy Simulation options (turbulence models):
  - Compressible Dynamic Smagorinsky model
  - MHD subgrid models



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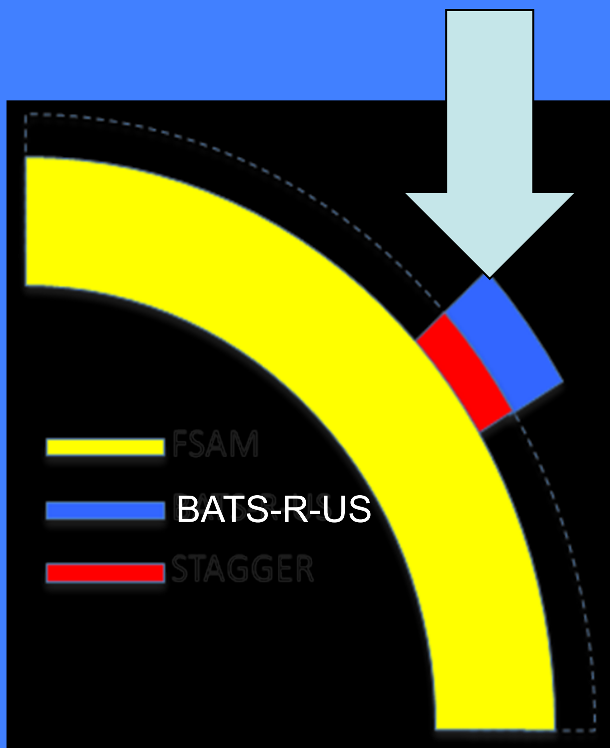

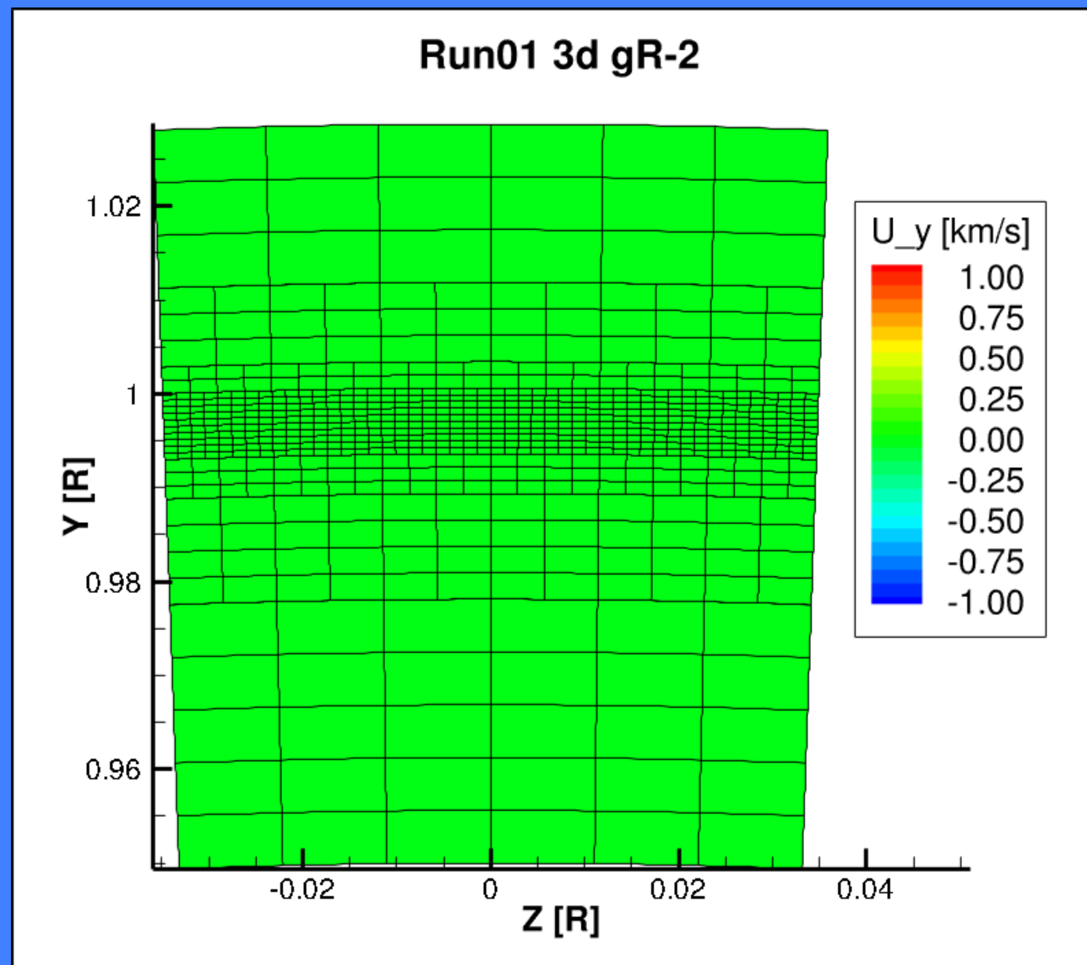

Future Plans

- *CMES: Coupled MHD models of flux emergence to enable modeling the 3D evolution of active region flux emergence from the bottom of the convection zone to the solar corona, connecting the properties of active region at the surface and in the corona to the deep convective zone.*

- *HMI time-distance helioseismology pipeline: provides 3D maps of solar flows covering almost the whole disk (within 60 degrees from the disk center) in the range of depths from 0 to 30 Mm, every 8 hours (Zhao et al, 2013).*

- *NEXT Challenge: Data assimilation of helioseismology-derived observations into realistic simulations.*