Active Region Scale Flux Emergence with the SWMF

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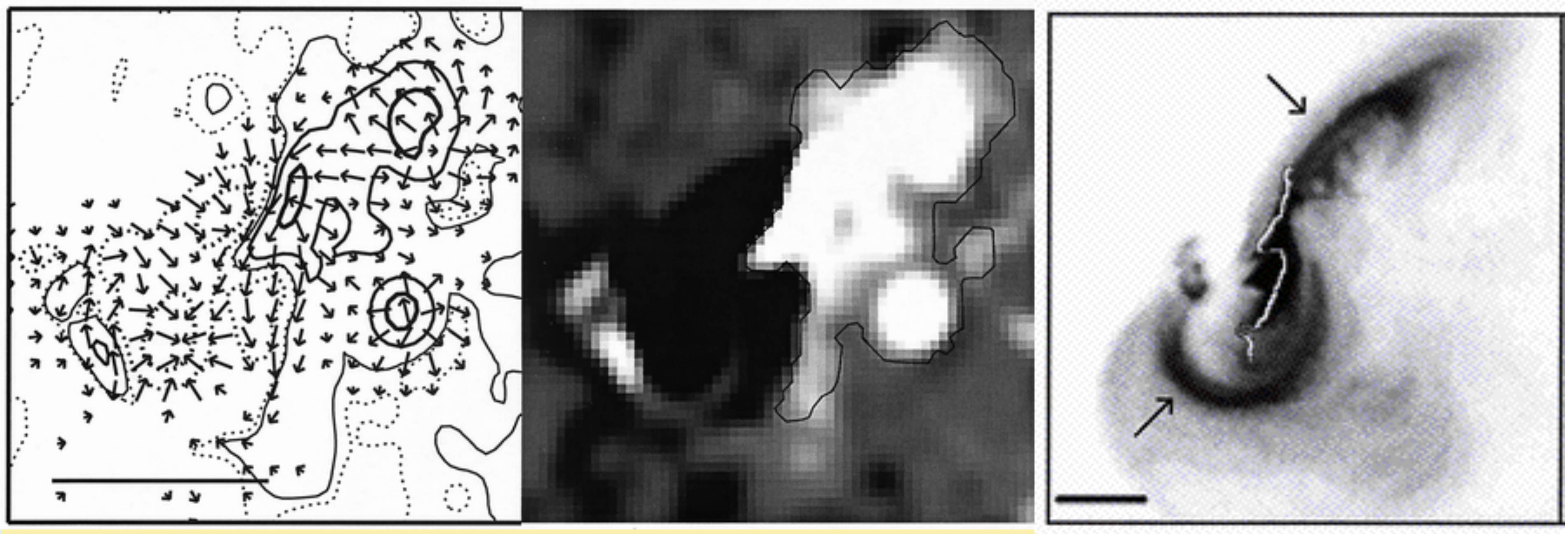
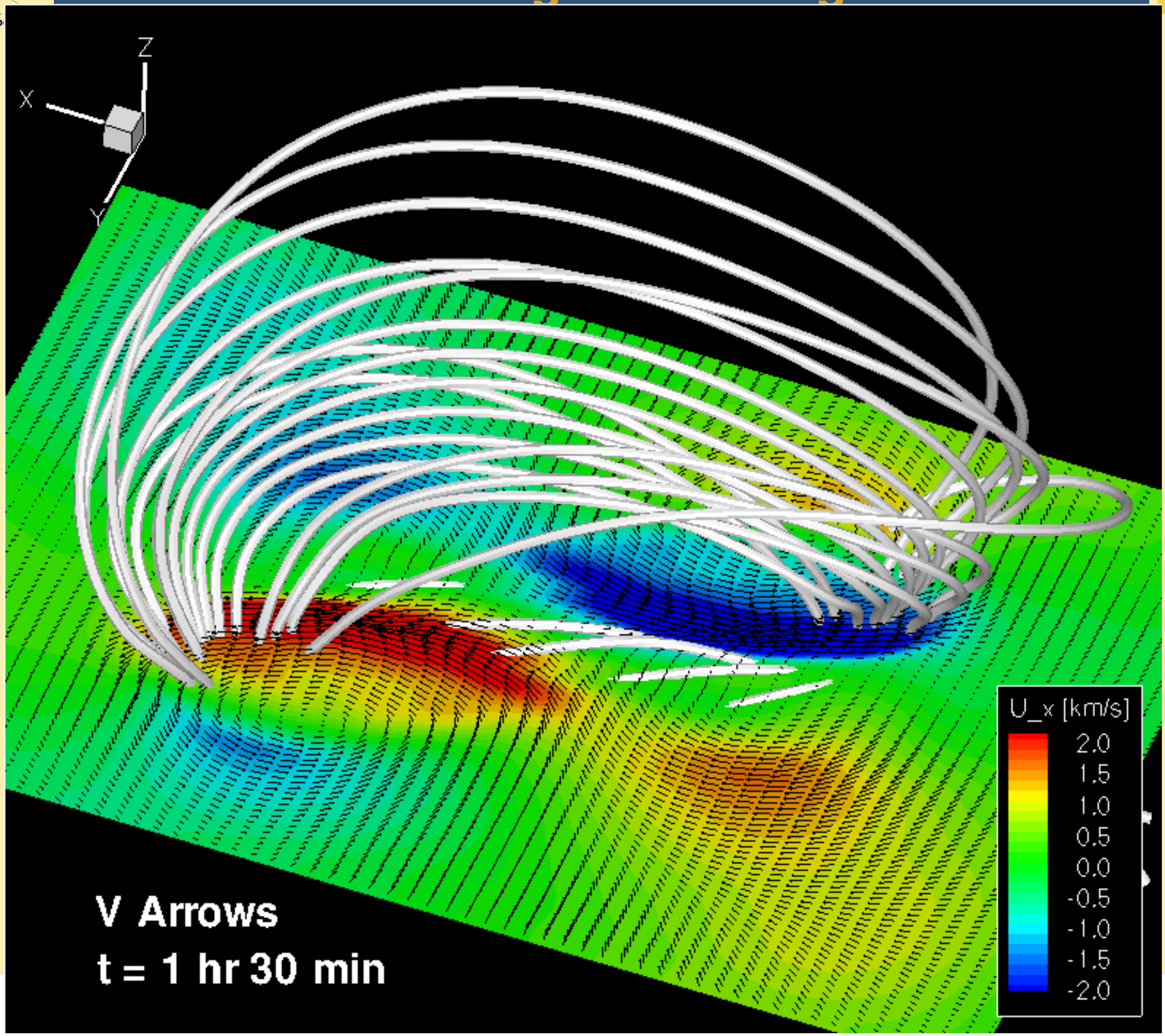
CCMC Meeting 2016, Annapolis MD

Magnetic Shear in AR6982

- Falconer 2001 JGR 106, 25185



Formation of Shear Flows and Sheared Fields During Flux Emergence



How the Lorentz Force Forms

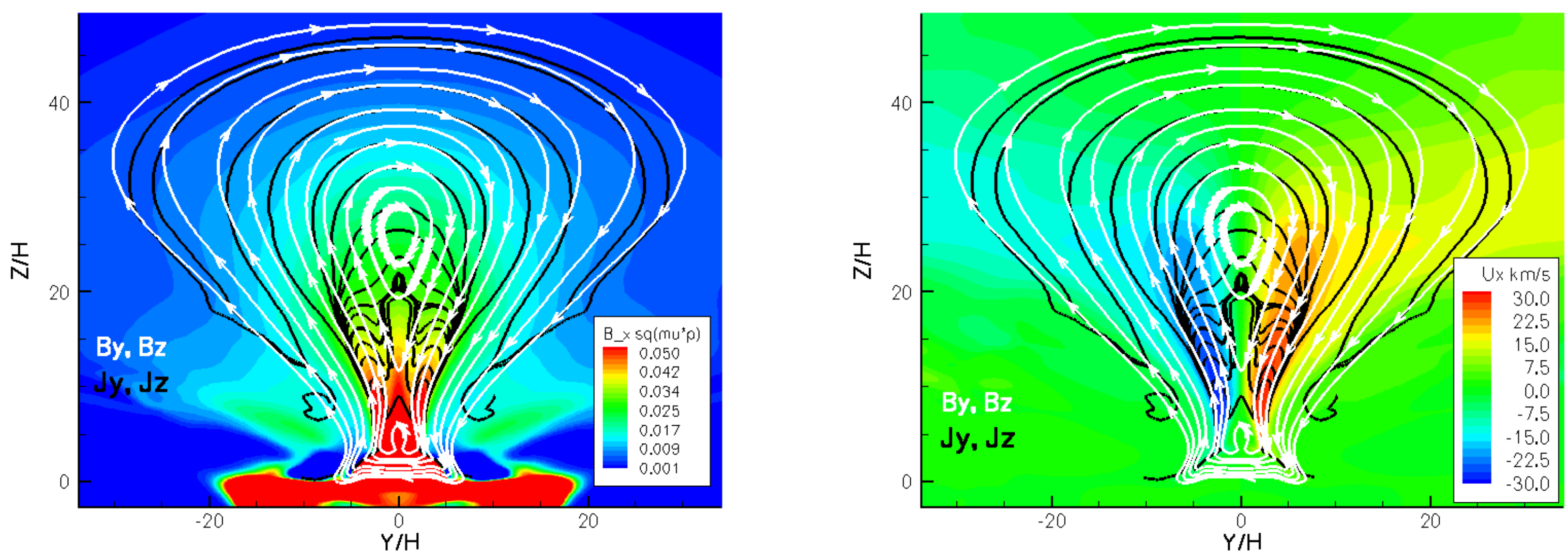
- **Shearing motions transport Bx flux into the expanding portion of the flux rope and tends to return Bx to constant values along field lines to restore force balance (Manchester 2001, 2003, 2007, 2008, Manchester et al. 2004)**

$$F_x = \nabla B_x \cdot (B_y, \quad B_z)$$

$$\frac{\partial B_x}{\partial t} + \nabla_{yz} \cdot (B_x(V_y, \quad V_z)) = \frac{\partial}{\partial y}(V_x B_y) + \frac{\partial}{\partial z}(V_x B_z)$$

advection in the yz plane

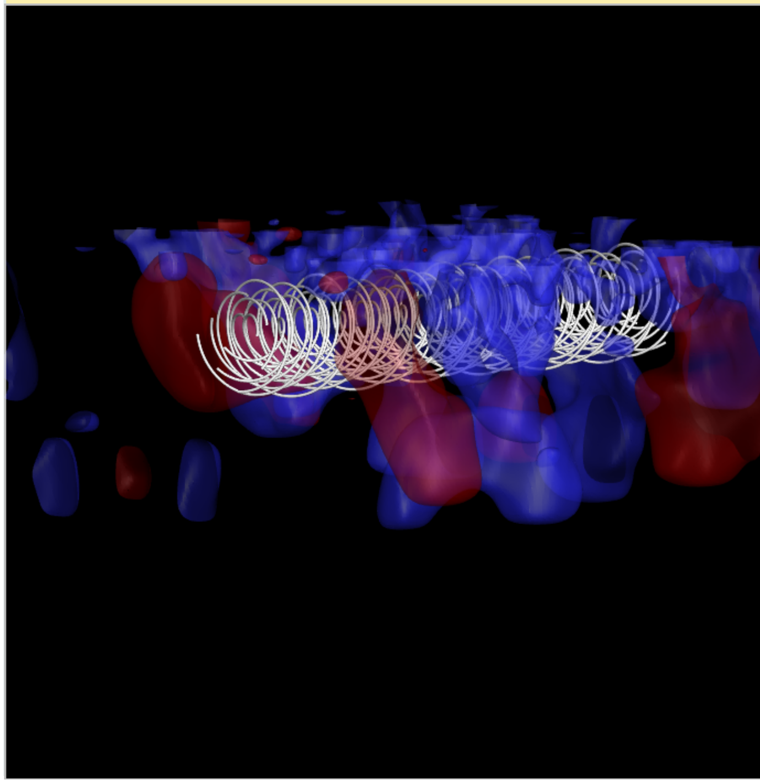
shearing displacement

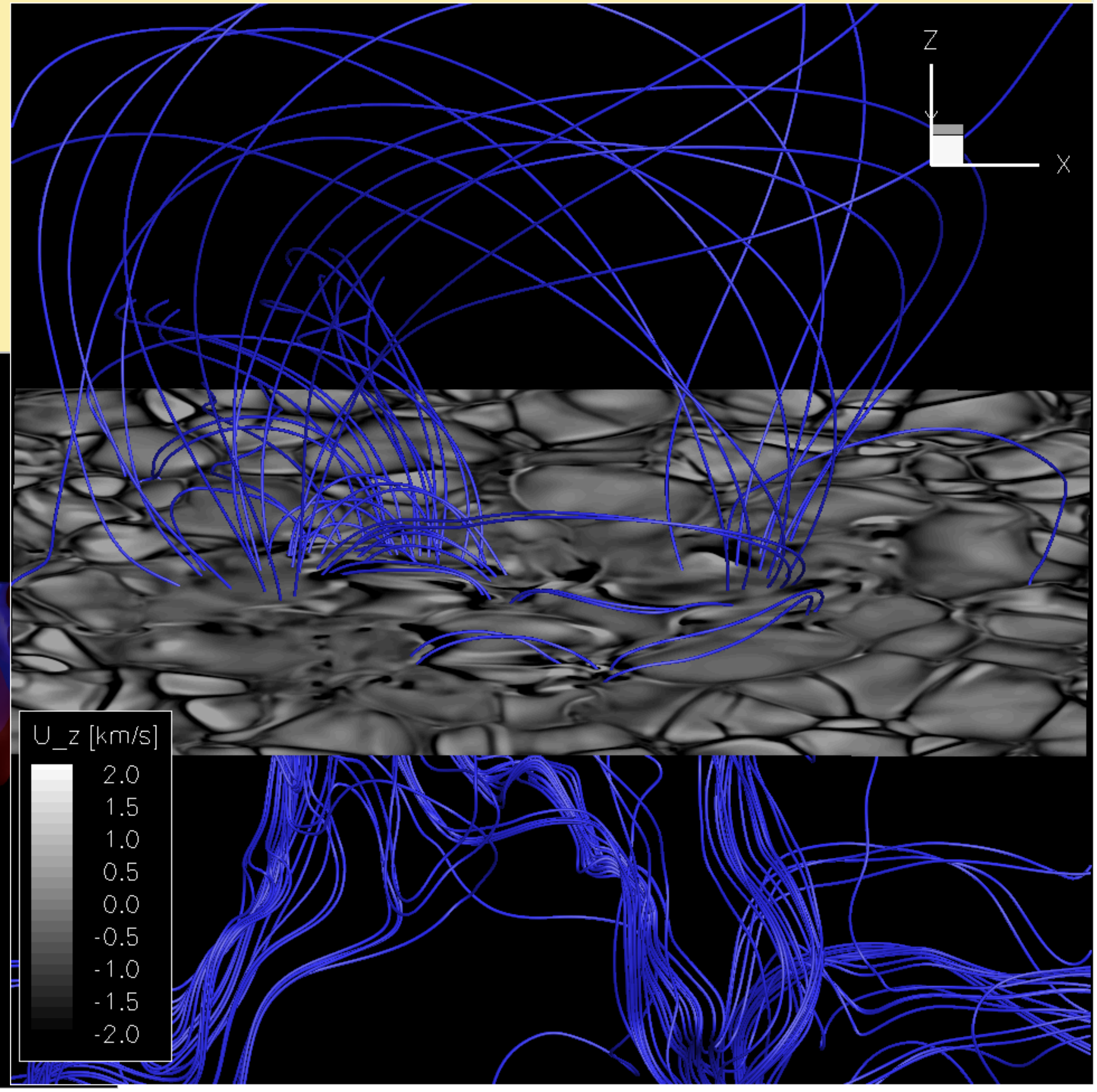


Magnetic Flux Emergence

- Small scale 30x30 Mm
- Cartesian Geometry
- ~10^{20} Mx

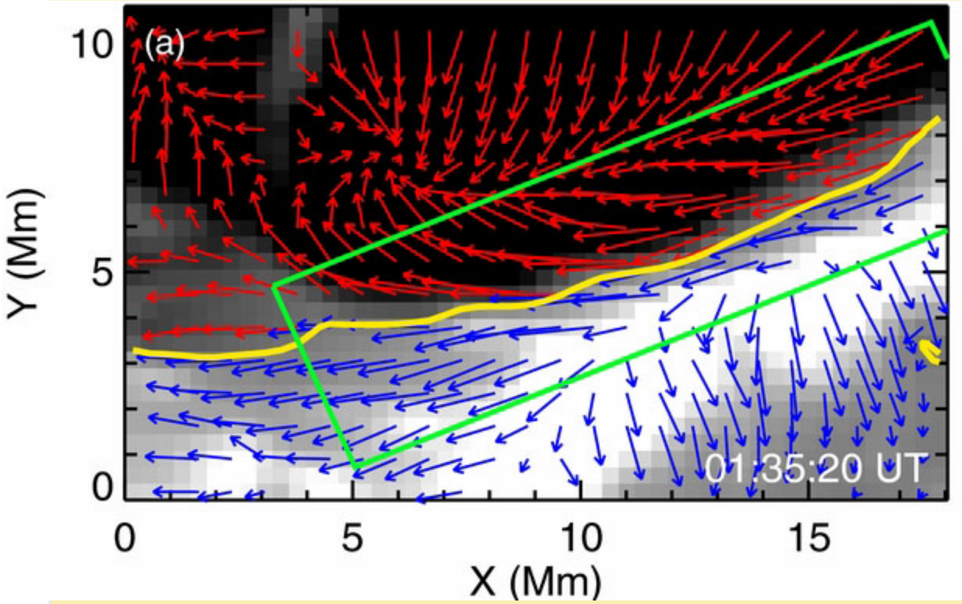
Fang et al. 2012

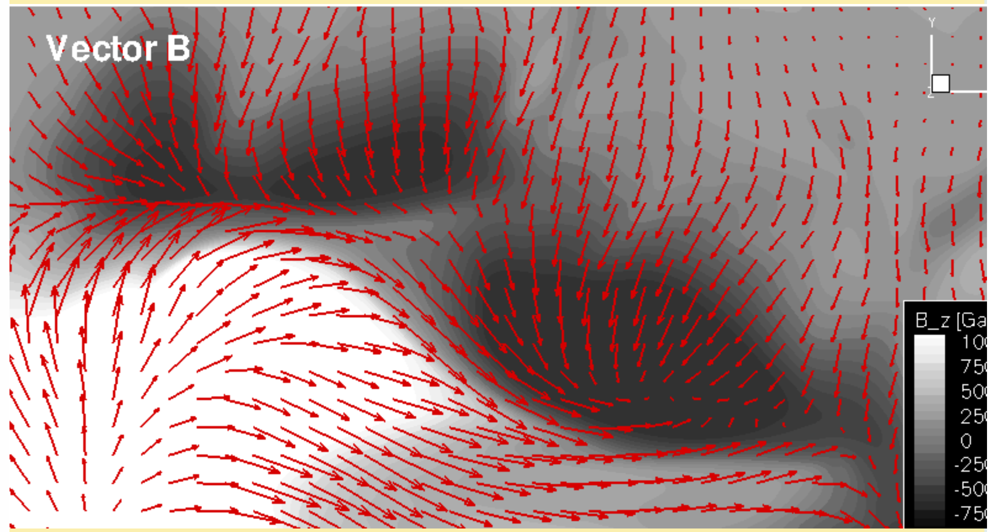




Photospheric B Field

- AR11158 Sun et al. 2012
- Fang et al. 2012

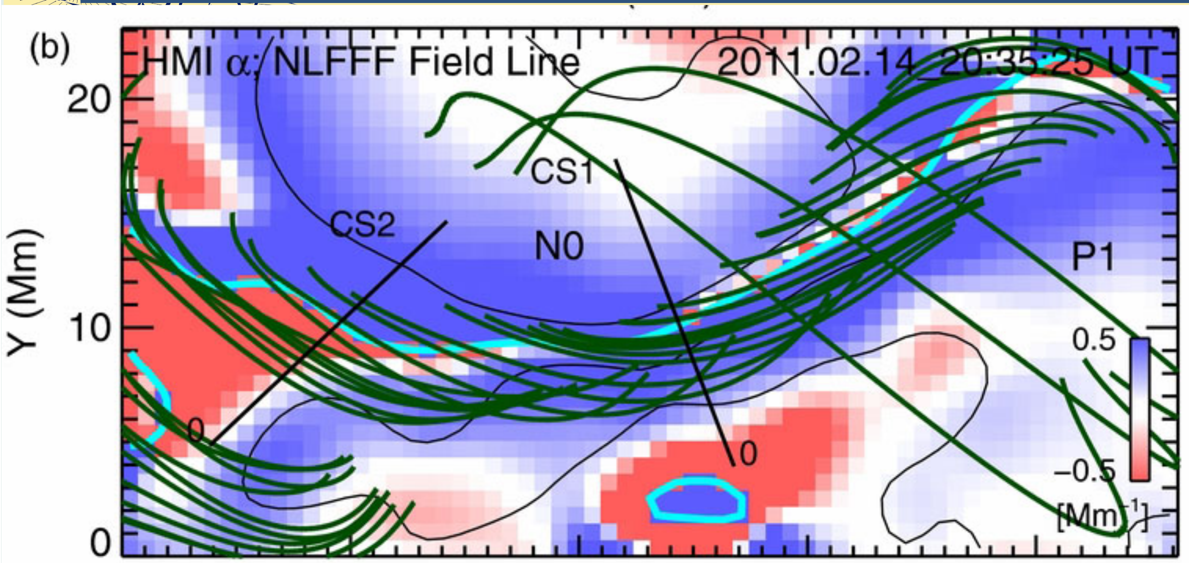


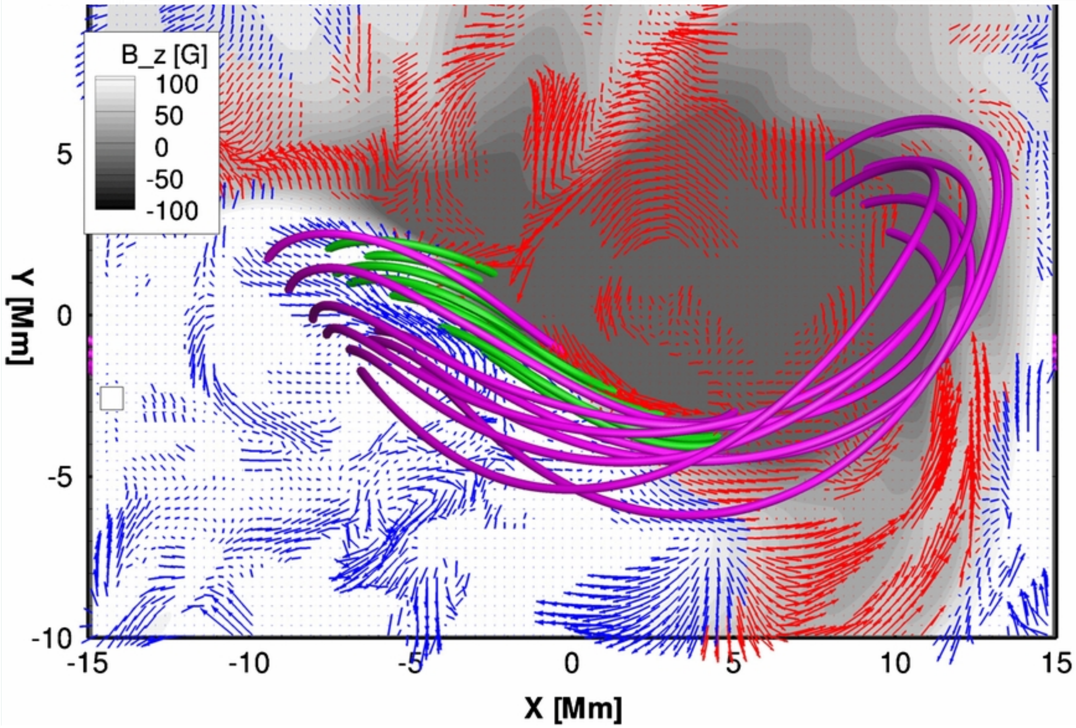


The observed vector magnetic field for AR11158 (left) and the simulation of flux emergence (right) produce high degrees of magnetic shear in close proximity to the polarity inversion line.

For data driven models, we need vector B observations in the chromosphere where B is FF

Shear Coronal Field Lines

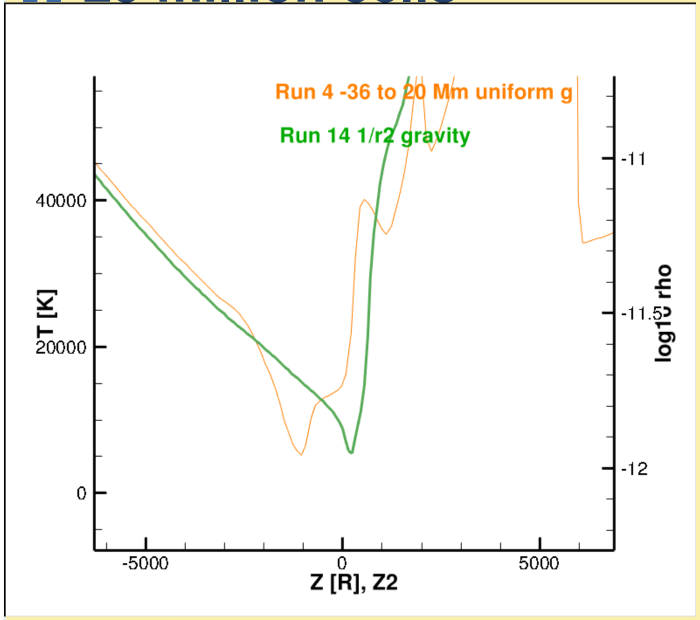


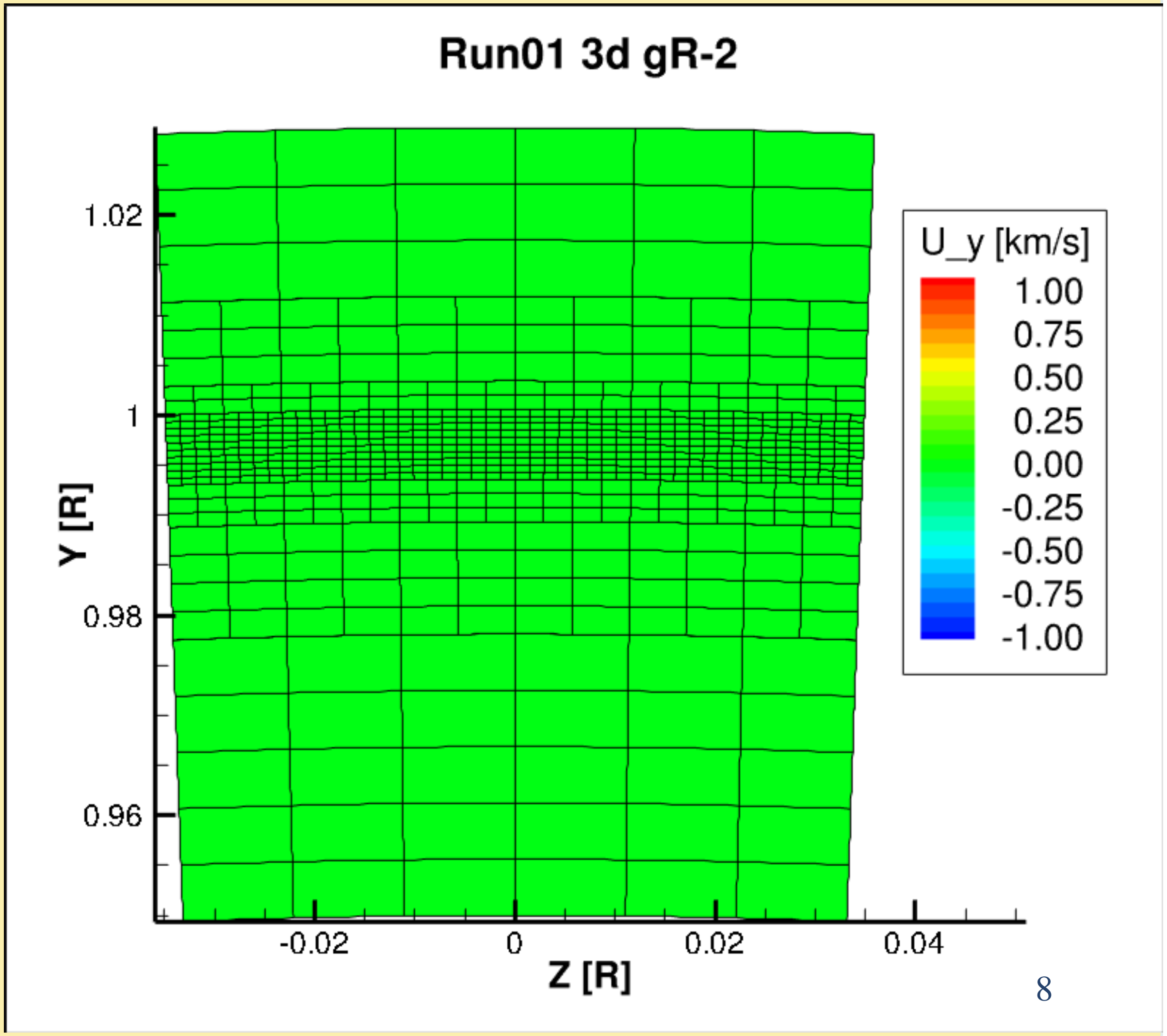


- Sun et al. 2012: NLFFF for AR 11158
- Fang et al. 2012

Near Surface Confection Zone Simulation

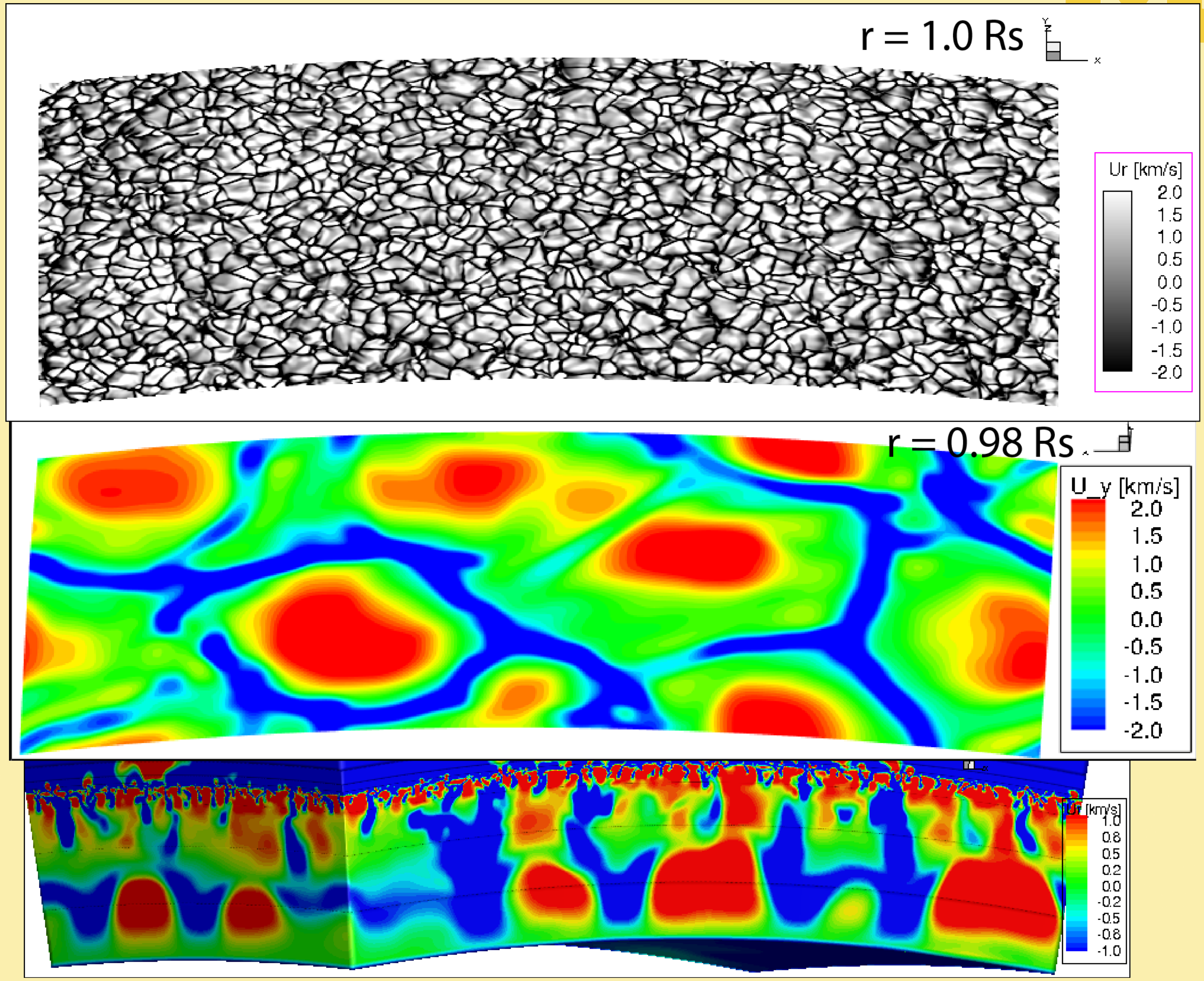
- Spherical Wedge
- Gravity 1/r^2
- 35 Mm deep (0.95 Rs)
- 50x50Mm
- 4 levels of refinement
- 10x10x10 cell blocks
- 25 million cells





Spherical Wedge Active Region Model (SWARM)

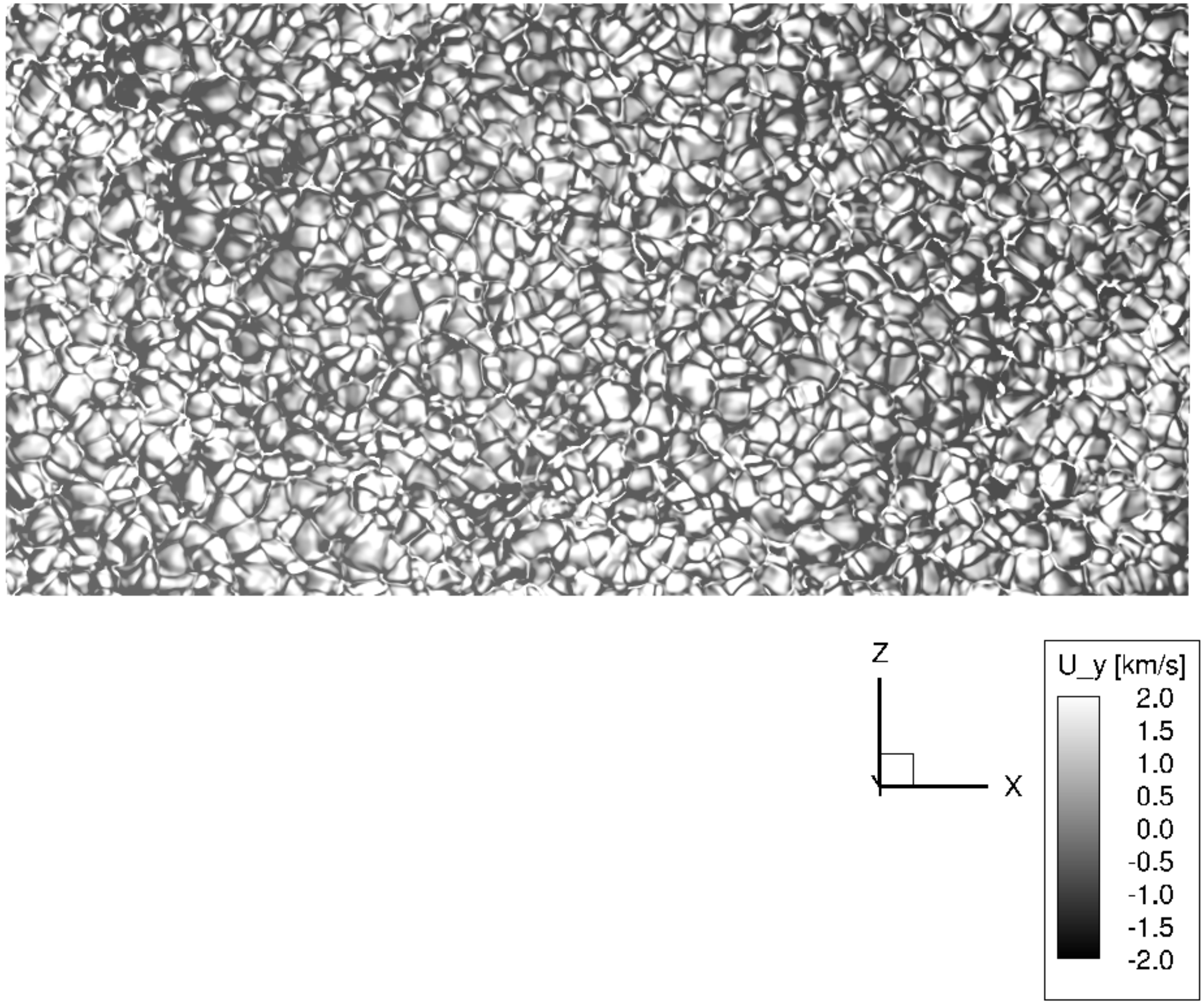
- Spherical Wedge
- Gravity 1/r2
- 35 Mm deep (0.95 Rs)
- 100x200Mm (8x16 deg)
- 4 levels of refinement
- 70 million cells



Active Region Scale Convection Simulation

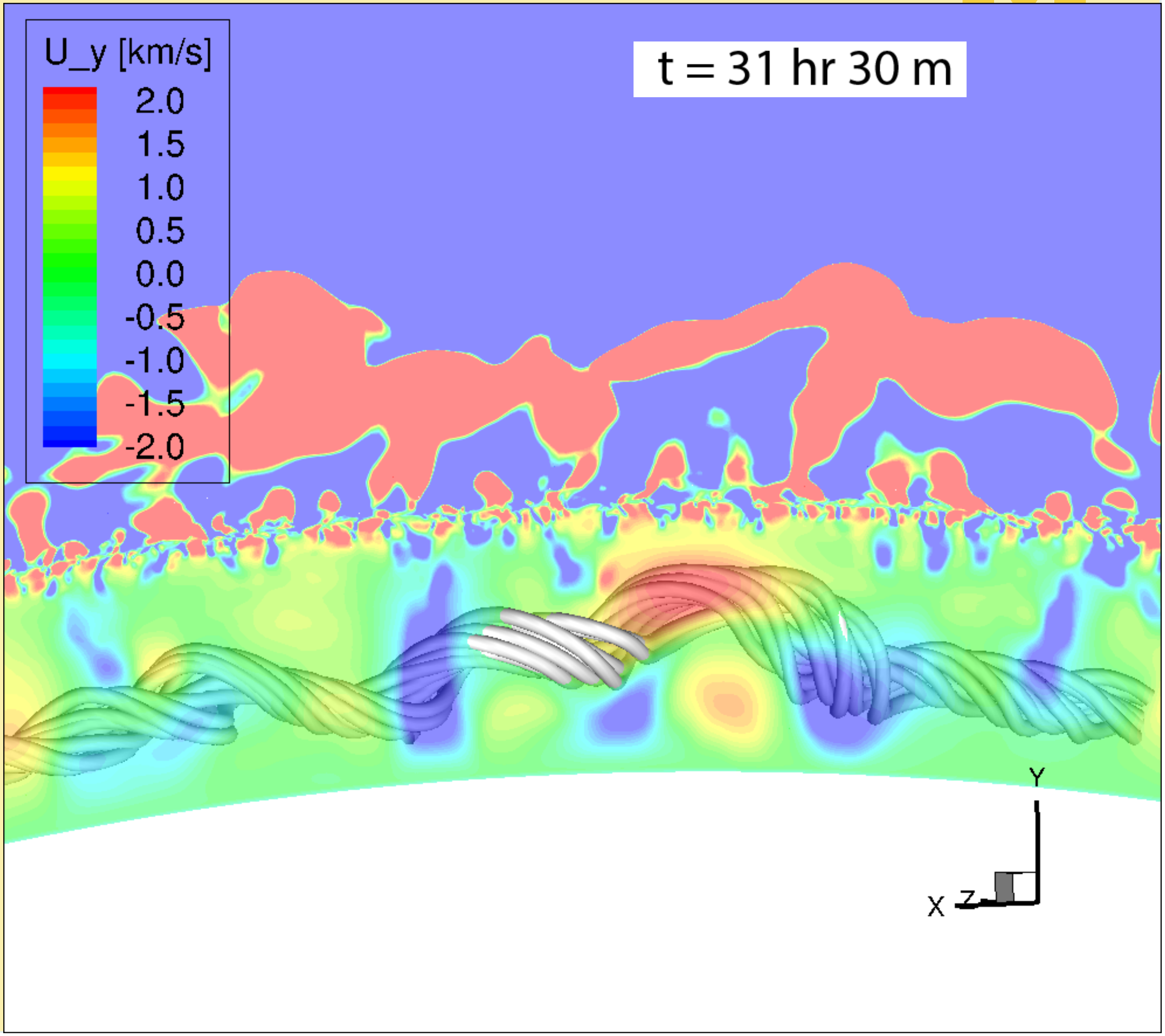
Space Weather Modeling Framework

- Spherical Wedge
- Gravity 1/r2
- 35 Mm deep (0.95 Rs)
- 100x200Mm (8x16 deg)
- 4 levels of refinement
- 70 million cells
- Structure of convection R=1 to R=0.970



Active Region Scale Flux Emergence Simulation

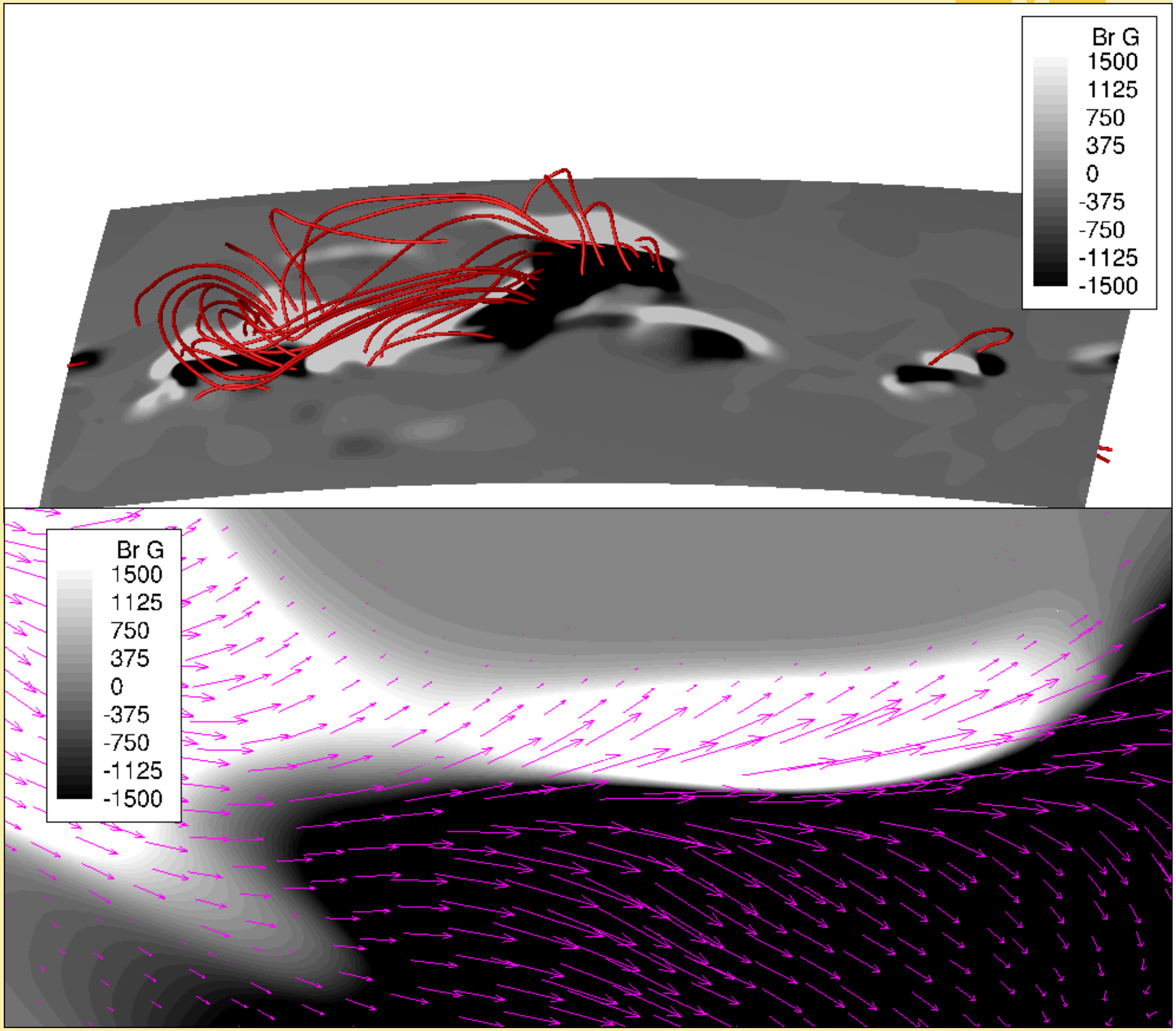
- Toroidal Rope
- 20 Mm deep (0.9714 Rs)
- 10^{23} Mx flux
- Twist factor =1



Magnetic Flux Emergence at 14 Mm below the Photosphere

Space Weather Modeling Framework

- R = 1 Rs
- Magnetic field distribution dominated by convection
- Flux concentrated in downdrafts
- Magnetic field evolves parallel to polarity inversion line
- Shear flows driven by the Lorentz force



Summary

1. Spherical Wedge Active Region Model (SWARM) 100x200Mm x35Mm deep
2. Realistically captures large scale convection structure
3. Emergence of a magnetic flux rope of 10^{23} Mx
4. Magnetic field fragmented by small-scale convection near the photosphere, confined in large deep convective downdrafts
5. At all depths, the magnetic field drawn parallel to the polarity inversion line by shear flows driven by the Lorentz force
6. Highly sheared filament channels form from emerging flux ropes: free energy for CMEs & flares &filament eruptions

Photospheric Signatures of Flux Emergence

- R = 1 Rs
- Flux confined in downdrafts
- Magnetic field fragmented by small-scale convection
- Magnetic field evolves parallel to polarity inversion line
- Shear flows driven by the Lorentz force