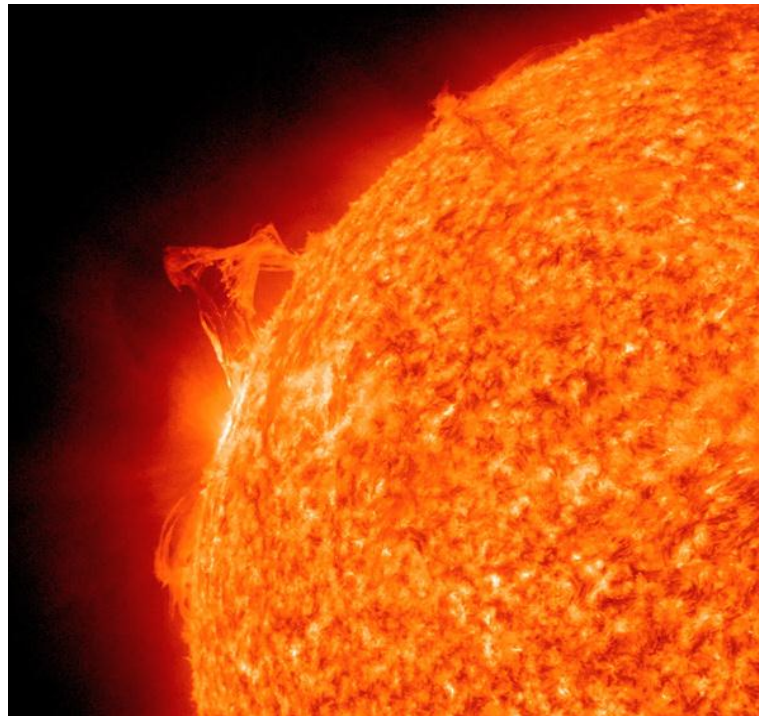
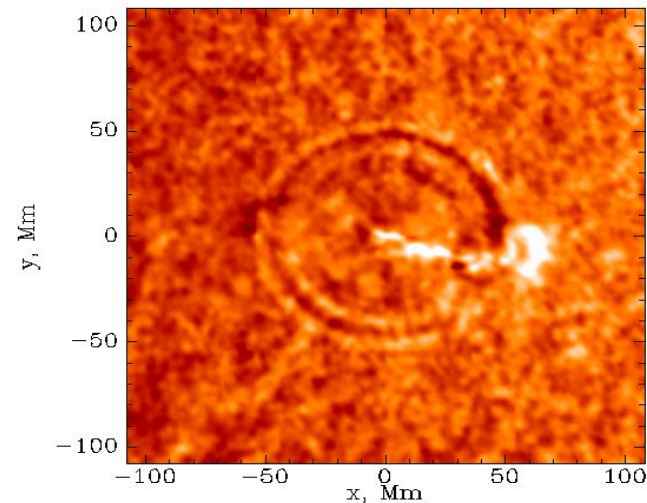
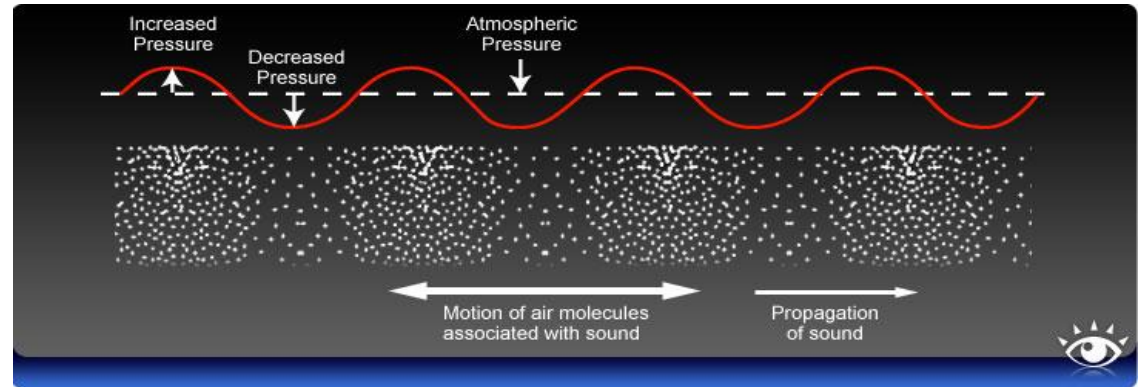
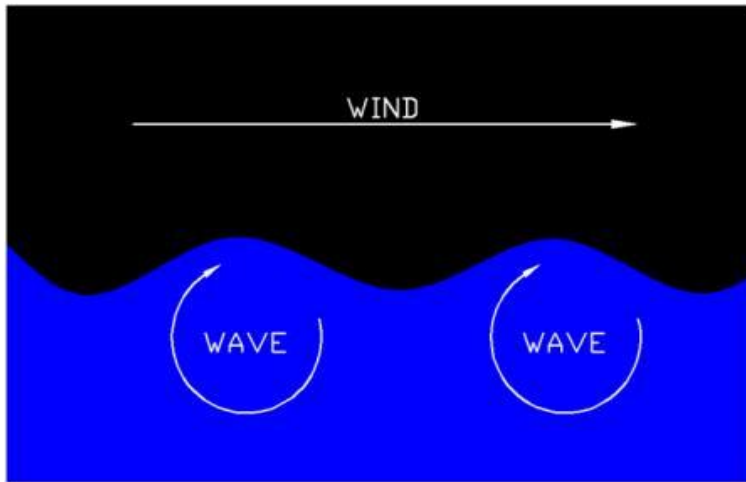


Helioseismology

Kyle DeGrave
New Mexico State University
15 April 2011

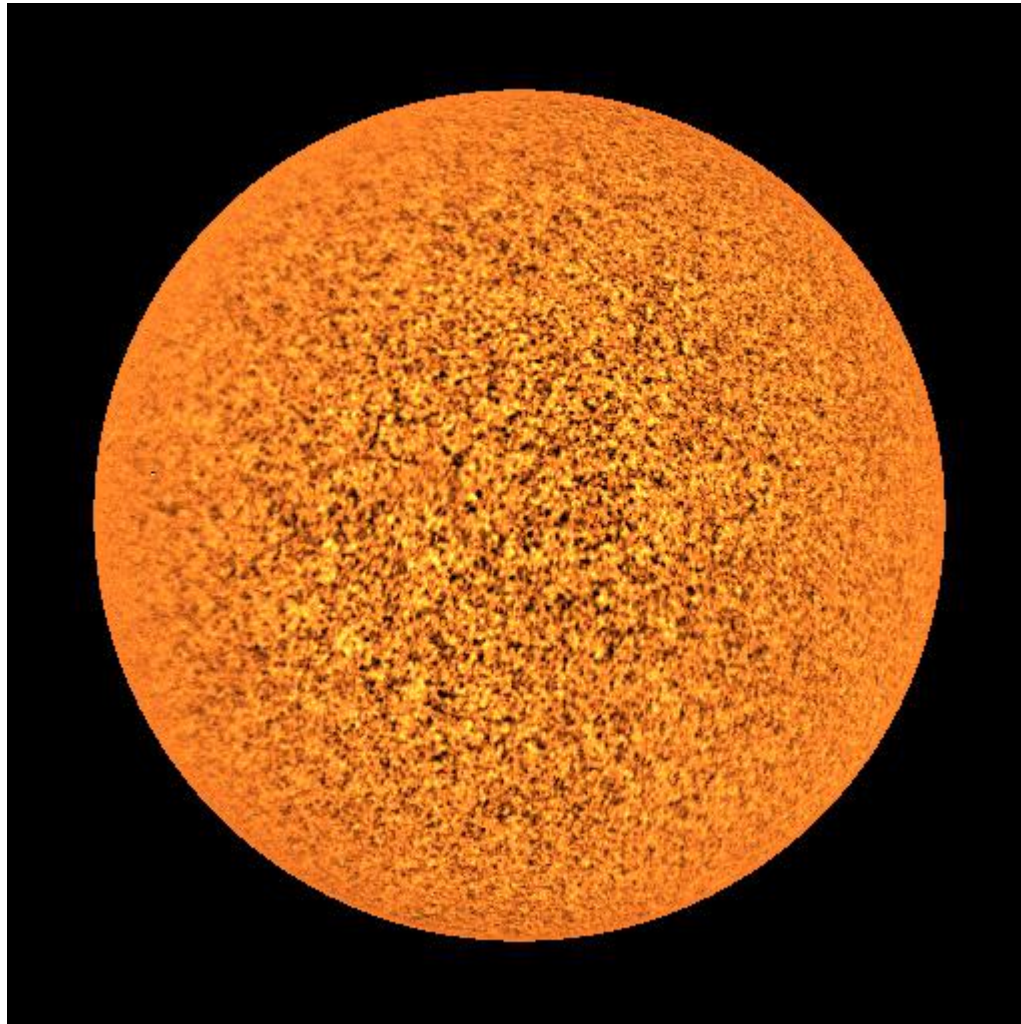


Wave Propagation in the Sun



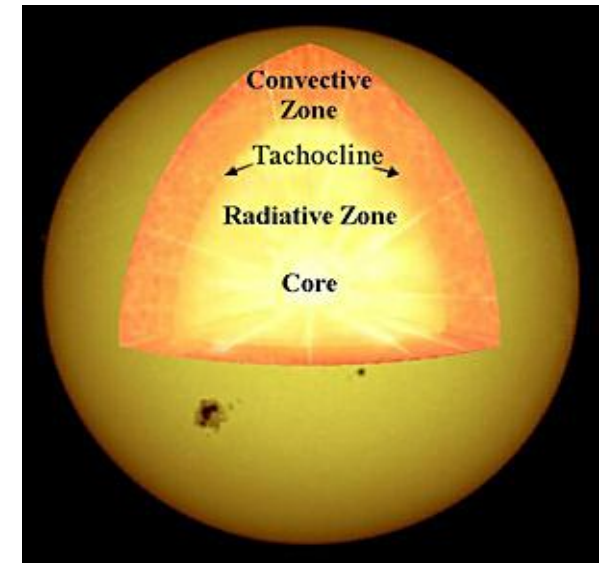
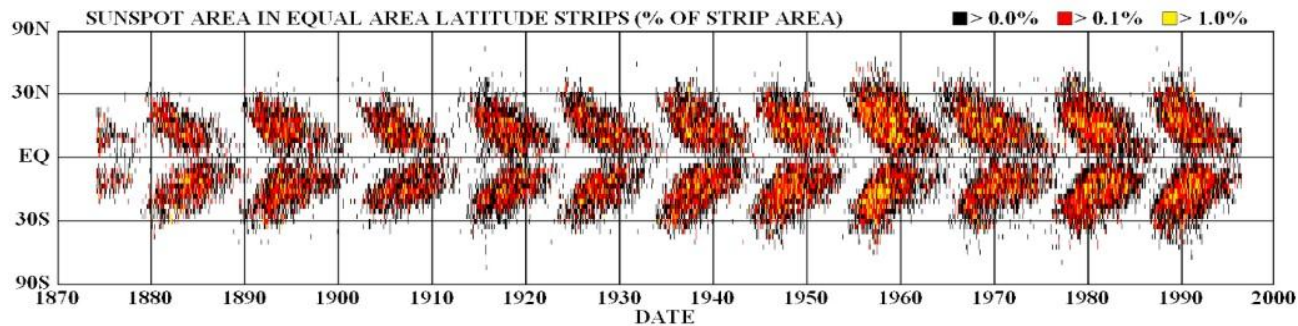
Solar Waves

- Dopplergrams



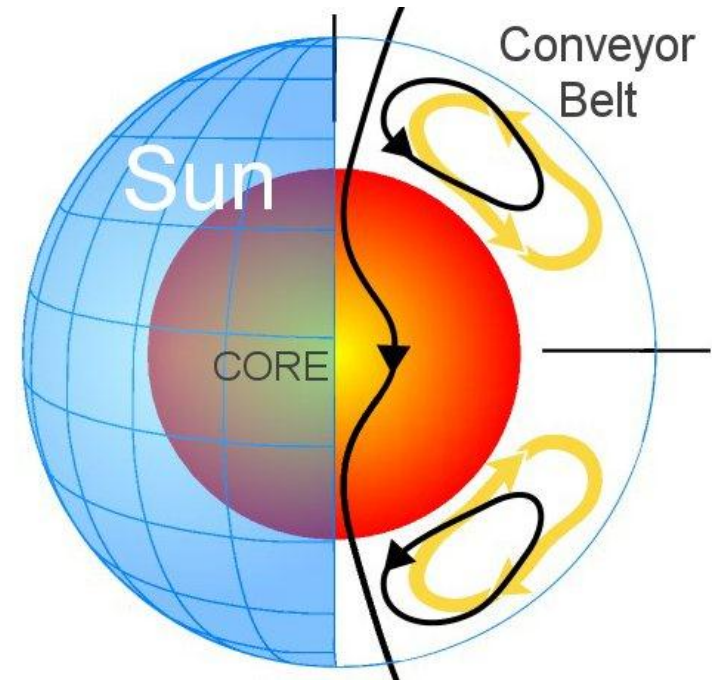
Outstanding Questions

- Sunspots – regions of ~kilogauss
- What is happening around sunspots?
 - Formation, subsurface structure, deep magnetic field topology
- Sunspots alter acoustic waves
- What keeps them together?
- Region of formation – surface or tachocline?



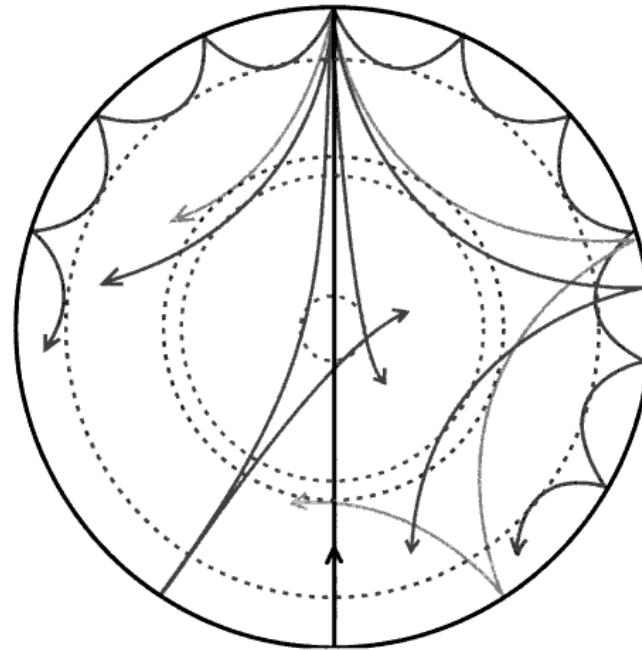
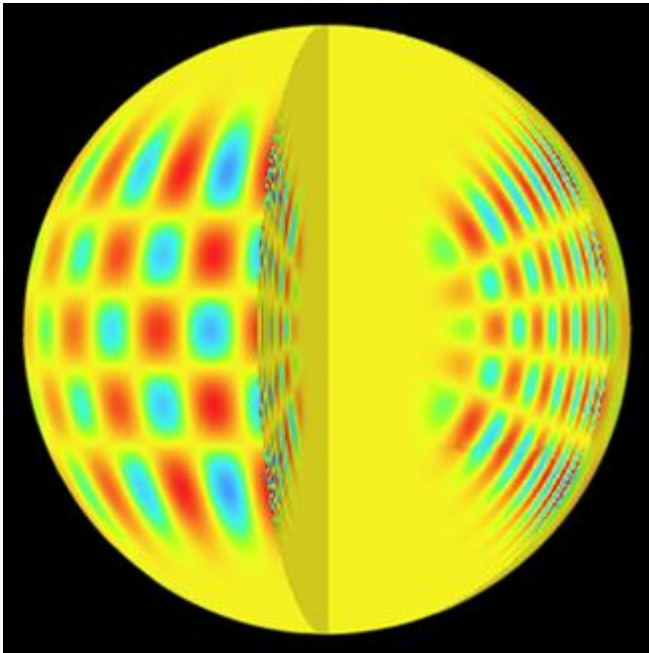
Outstanding Questions

- Sun contains many flows (meridional, moat, etc)
- Interaction with B-fields – conflicting methods
- What drives sunspot cycle?
 - Recent minimum
 - Lack of understanding
- Meridional – only top 50 Mm and lower latitudes
- Why does meridional change speed?



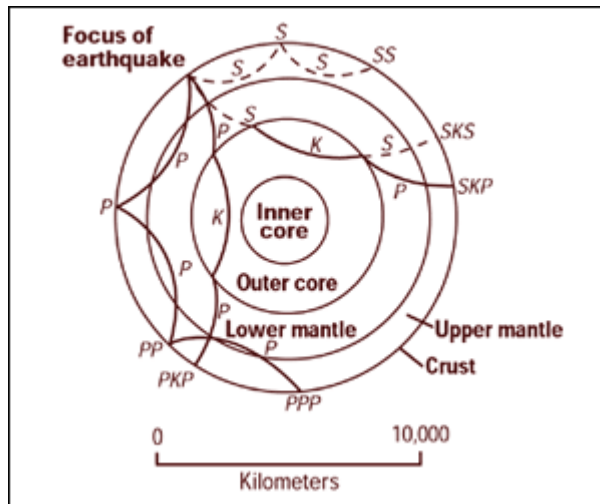
Helioseismology

- Many oscillation modes
- Resonance cavities – sound speed gradient
- Two main types – global and local



The Inversion

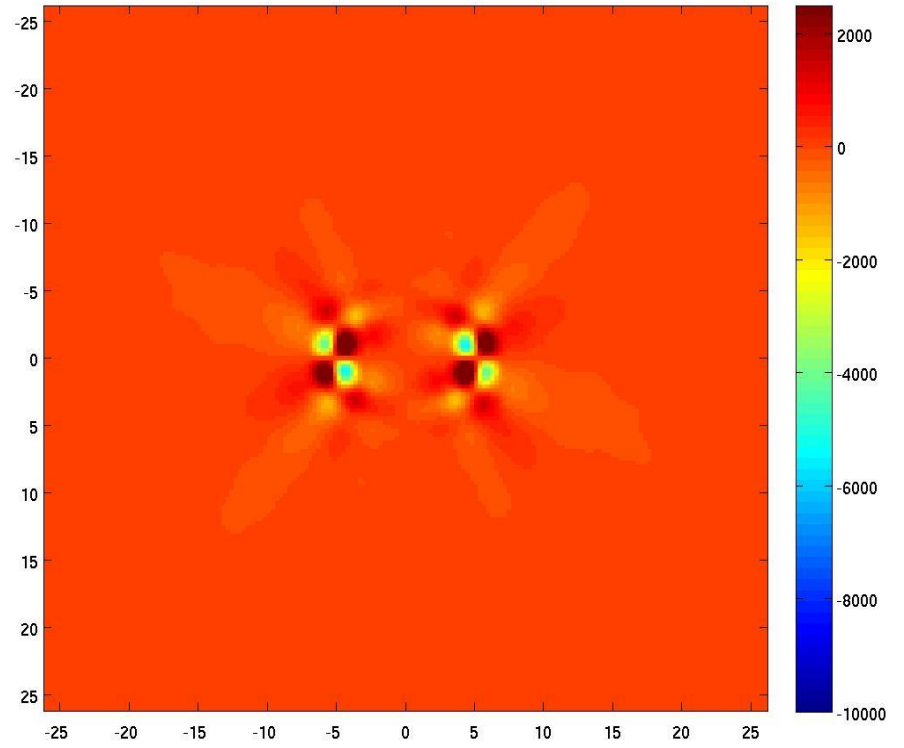
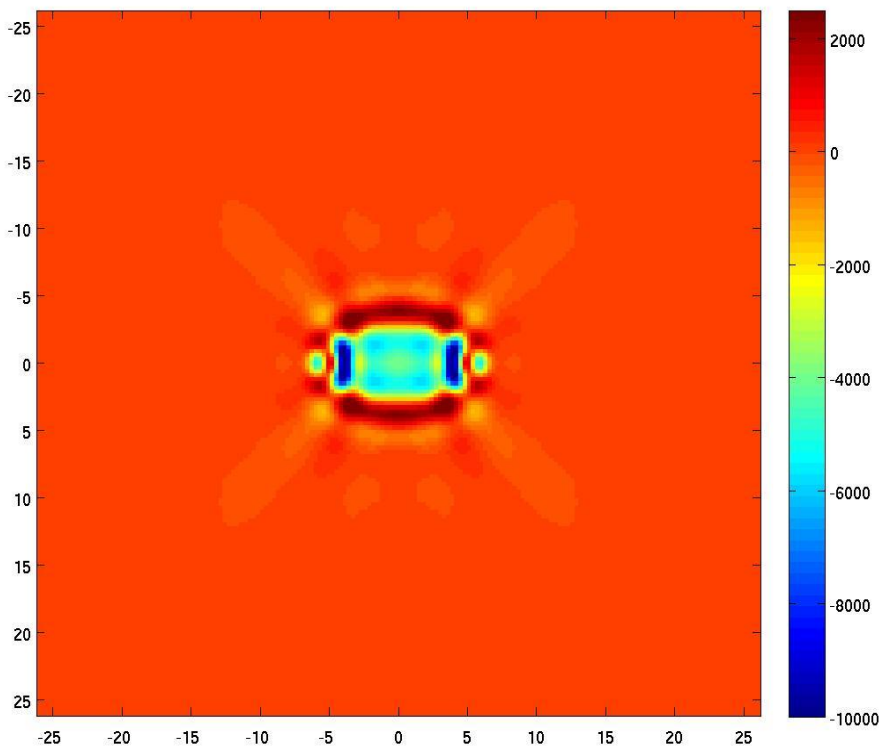
- “Inversion” is a mathematical tool for interpreting indirect scientific measurements
- Geophysics (seismology), medical imaging (computed tomography), mass distribution in moons, etc.



$$\tau_{diff}(\mathbf{x}_1, \mathbf{x}_2) = \iint \mathbf{K}(\Delta; \mathbf{x}) \cdot \mathbf{u}(\mathbf{x}) d^2 \mathbf{x} + noise$$

Sensitivity Kernels

- Represents local sensitivity of travel time perturbations to perturbations in the model (flows)



$$\tau_{diff}(\mathbf{x}_1, \mathbf{x}_2) = \tau_+(\mathbf{x}_1, \mathbf{x}_2) - \tau_-(\mathbf{x}_2, \mathbf{x}_1)$$

What's next?

- SDO – data for 10 years (about a solar cycle)
- A terabyte per day
 - Image every 10 seconds
 - Image processing (grouping similar objects)
- Set up a helioseismology pipeline – travel times, kernels, etc.
 - Inversion

References

- Gizon, L. and Birch, A. C. (2002). “Time-Distance Helioseismology: The Forward Problem For Random Distributed Sources.” *The Astrophysical Journal*.
- Jackiewicz, J. *et al.* “A Procedure for the Inversion of f-Mode Travel Times for Solar Flows.”
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- Jackiewicz, J. *et al.* (2007). “Time-Distance Helioseismology: Sensitivity of f-Mode Travel Times to Flows.” *The Astrophysical Journal*.