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The Magnetic Sun: From the Solar Dynamo to Sunspot Forecasting

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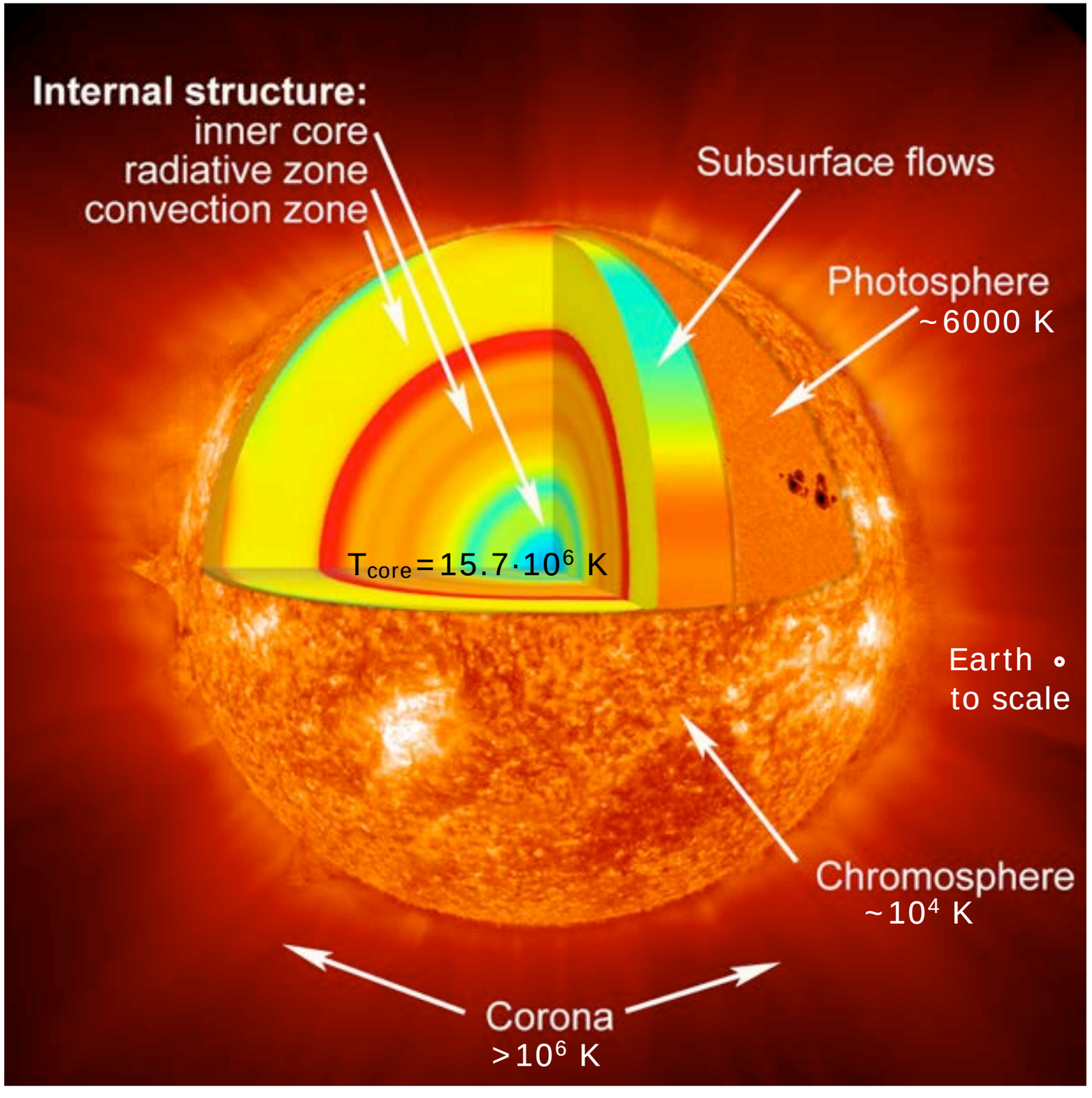
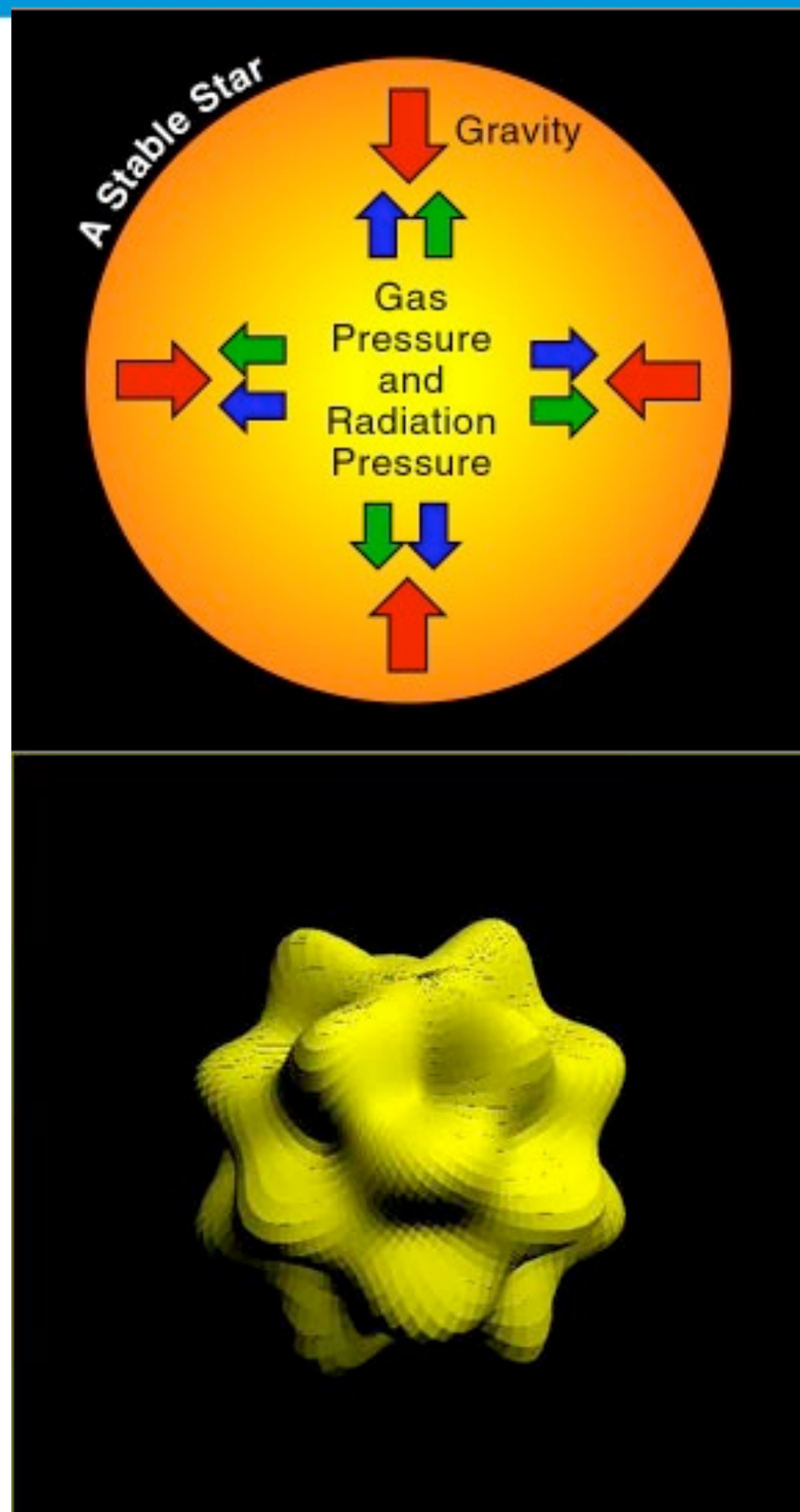
The Sun in a Nutshell



Helioseismology: Looking Inside the Sun

The Sun can be excited to resonance oscillations
around a hydrostatic equilibrium

The Sun acts as resonator
for small pressure perturbations caused by sound waves
→ Fundamental mode and higher harmonics are excited



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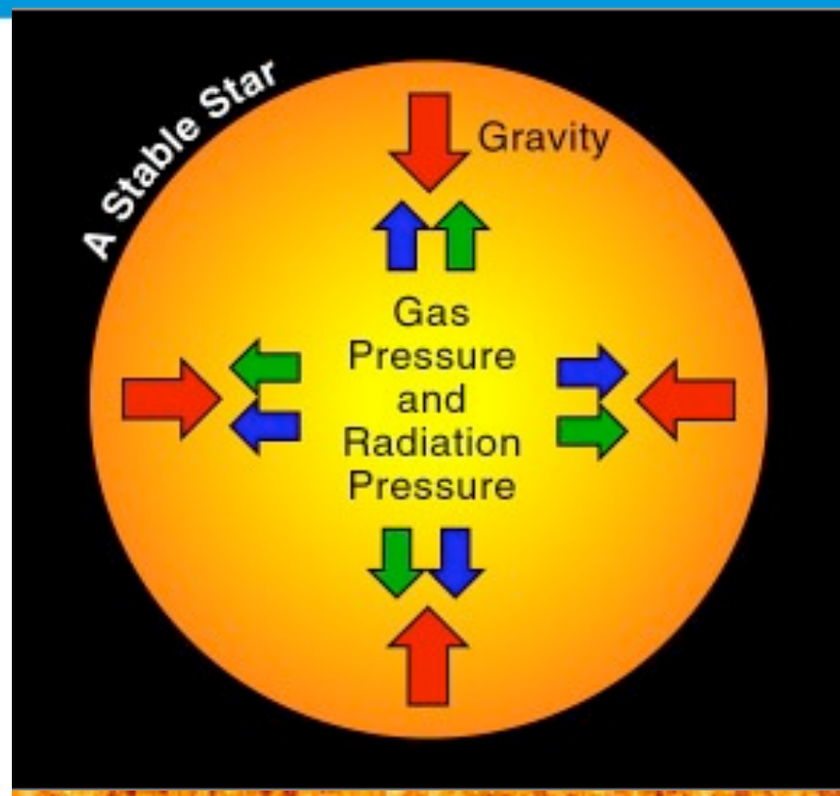
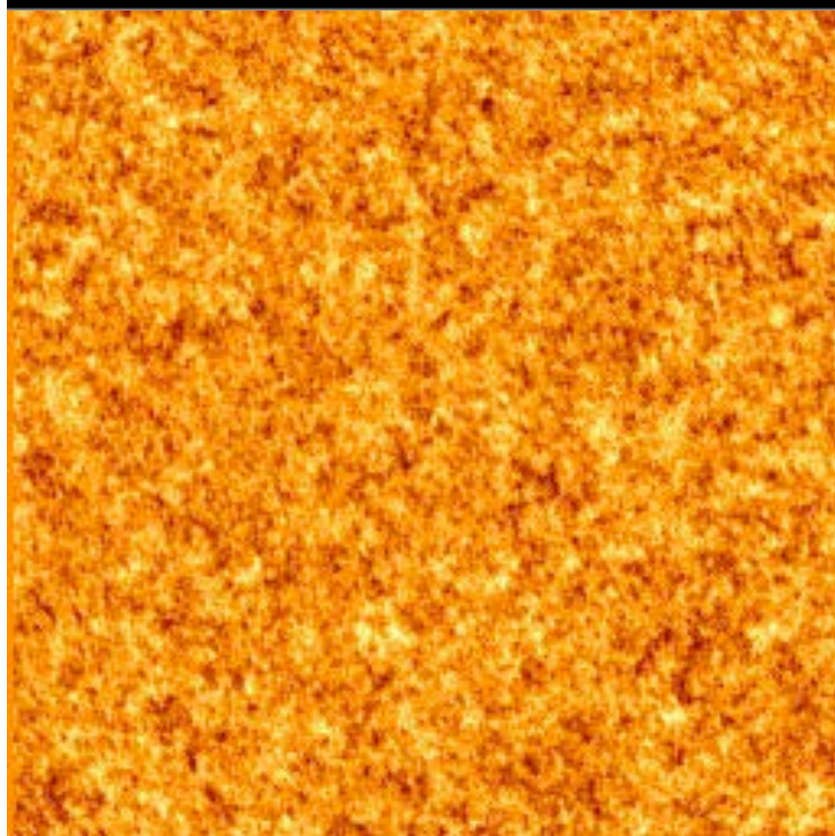


SOHO/MDI Dopplergram showing vertical surface motions



Helioseismology: Looking Inside the Sun

The Sun can be excited to resonance oscillations
around a stable hydrostatic equilibrium

The Sun acts as resonator
for small pressure perturbations caused by sound waves
→ Fundamental mode and higher harmonics are excited

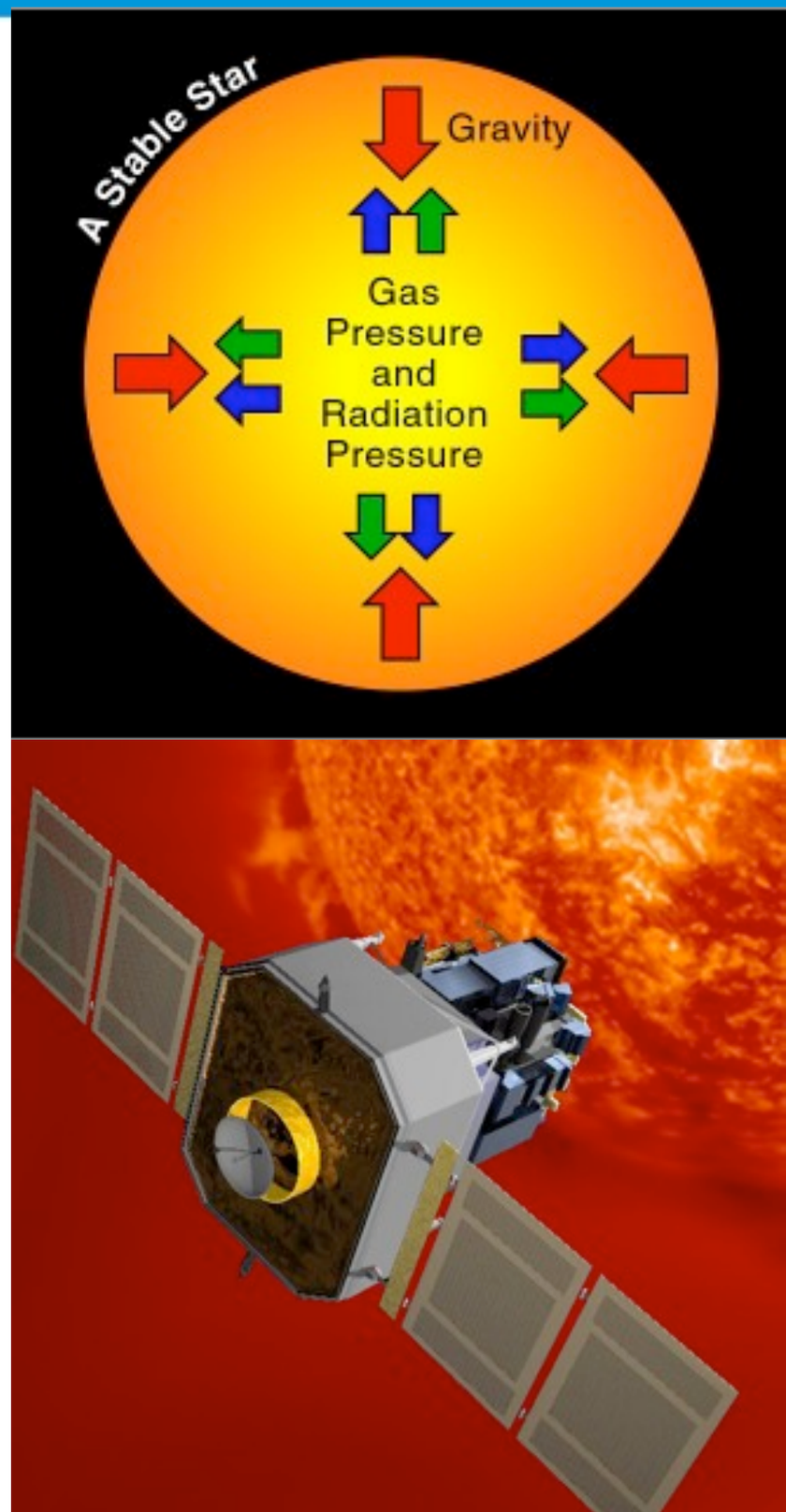
Frequencies of eigenmodes depend on conditions inside the Sun
Inversion of frequencies → structure of the solar interior

Frequency resolution: $\Delta\nu = \frac{1}{T}$

→ Need long and uninterrupted measurements for global helioseismology

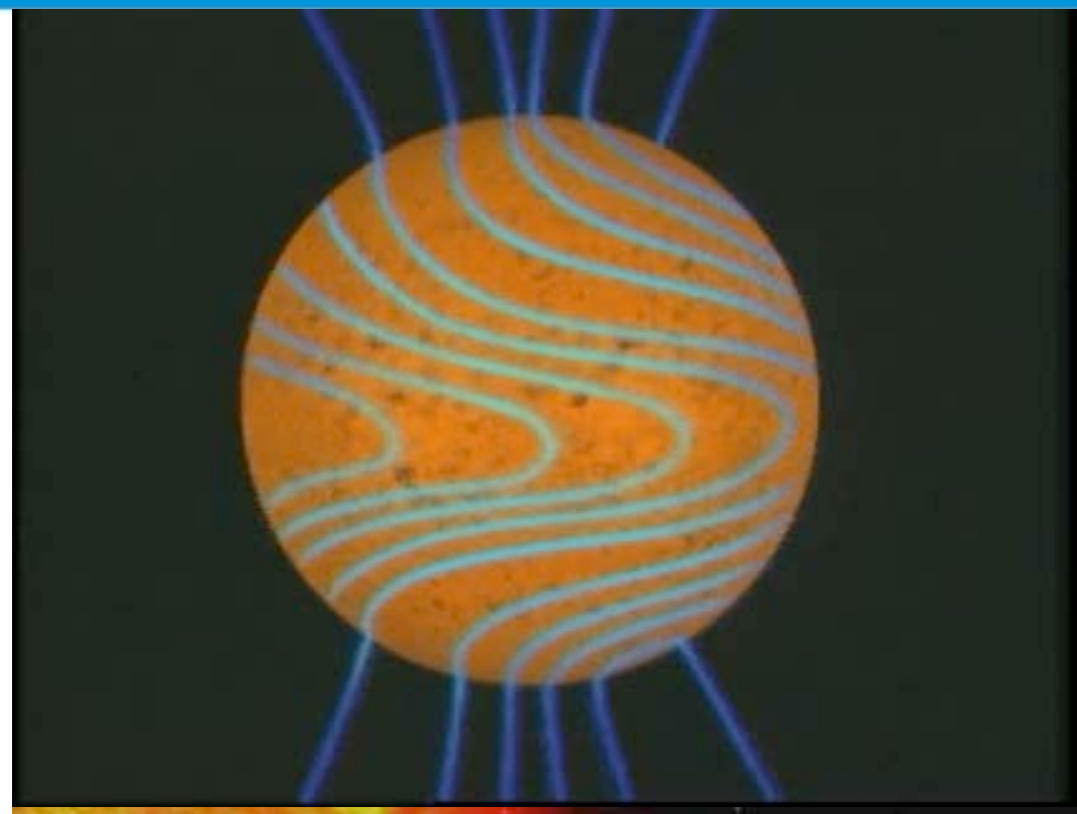
SOHO - Solar and Heliospheric Observatory
ESA/NASA mission, launched in 1995:

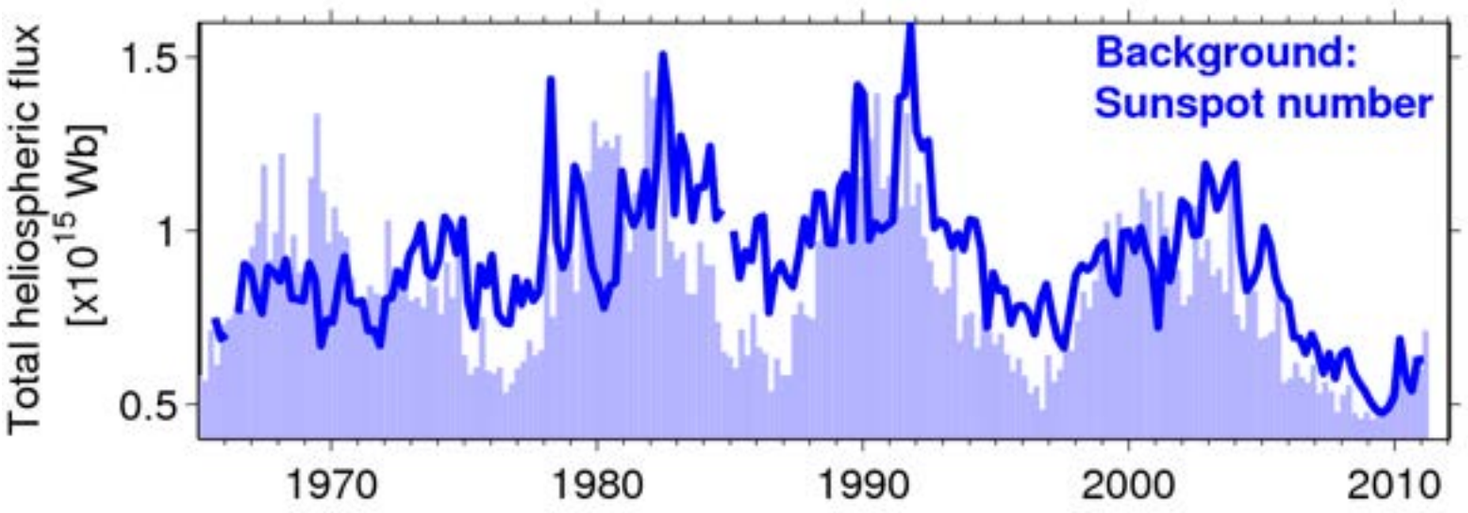
> 15 years of data with high duty cycle



The Solar Dynamo

- Inside the Sun, moving charges generate magnetic field
- Solar Dynamo:Field amplification at the base of the convection zone
- Bundles of intense magnetic field rise to the Sun's surface due to magnetic buoyancy
  → Sunspots
- Sunspot Cycle: Period of ~11 years - but why?

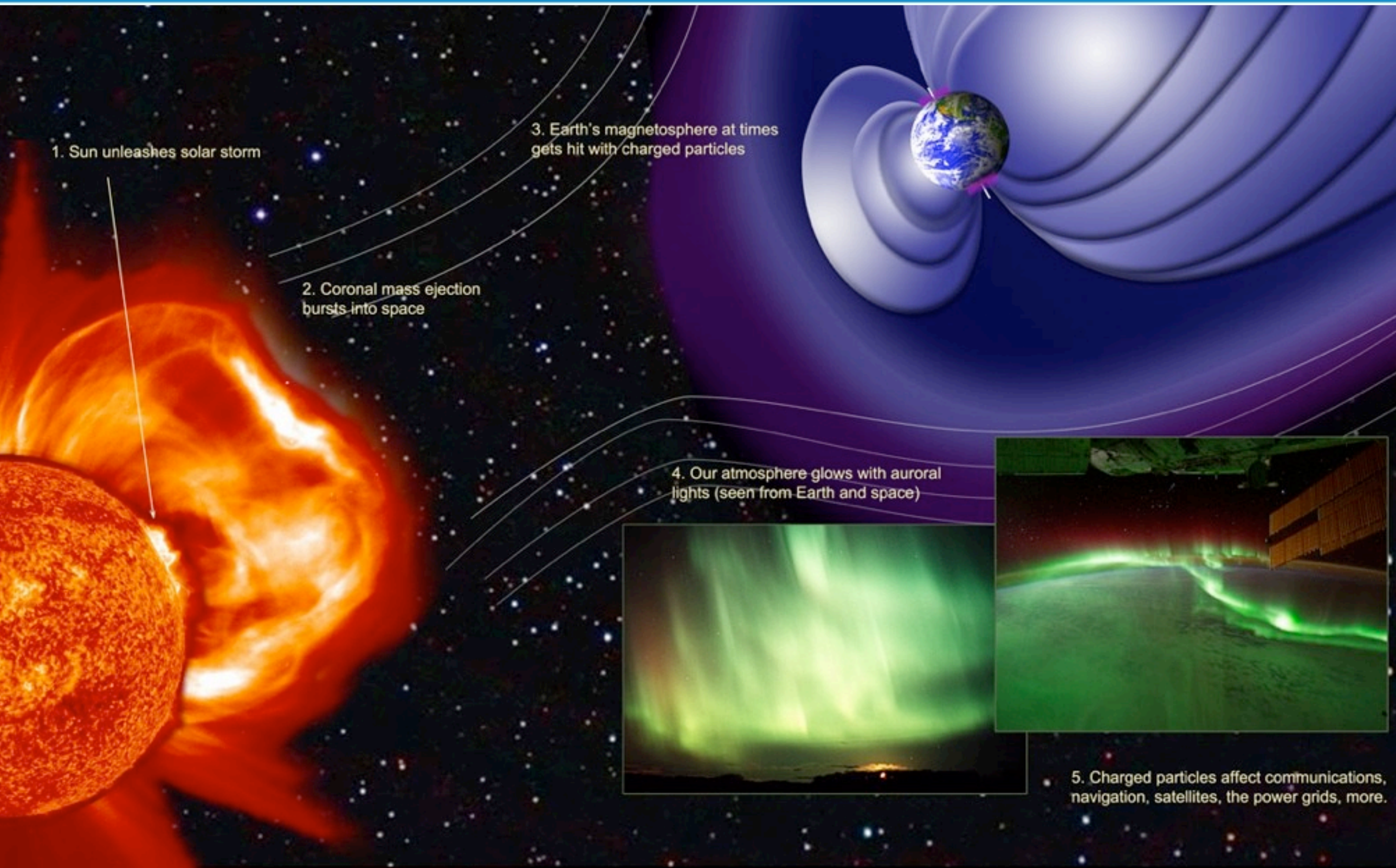




M. Owens, University of Reading

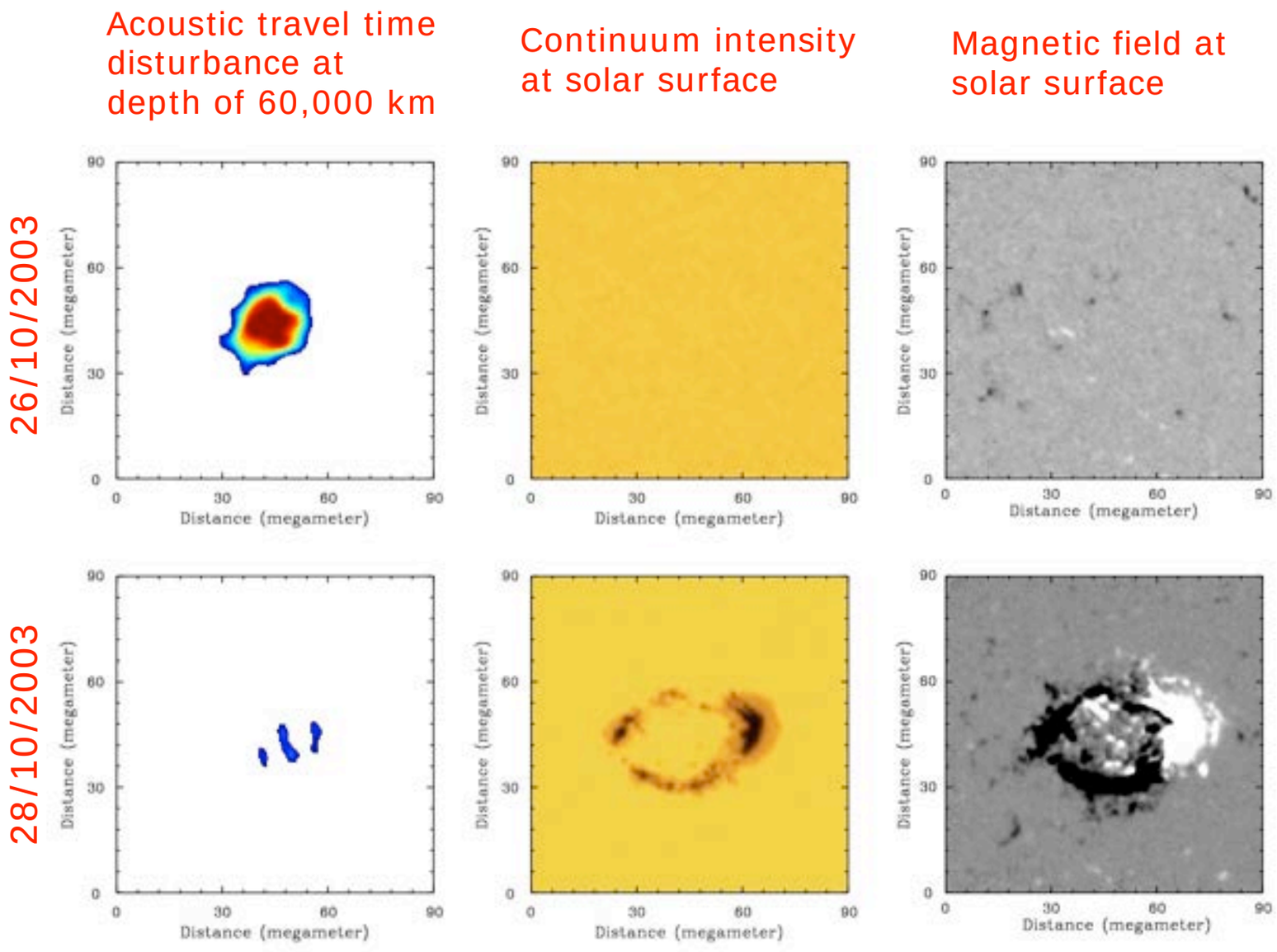
SST/Royal Swedish Academy of Sciences/ V. M. de Jorge Henriques

The Sun’s Magnetic Field:
Main Driver of Space Weather



Detection of Emerging Sunspots in the Solar Interior

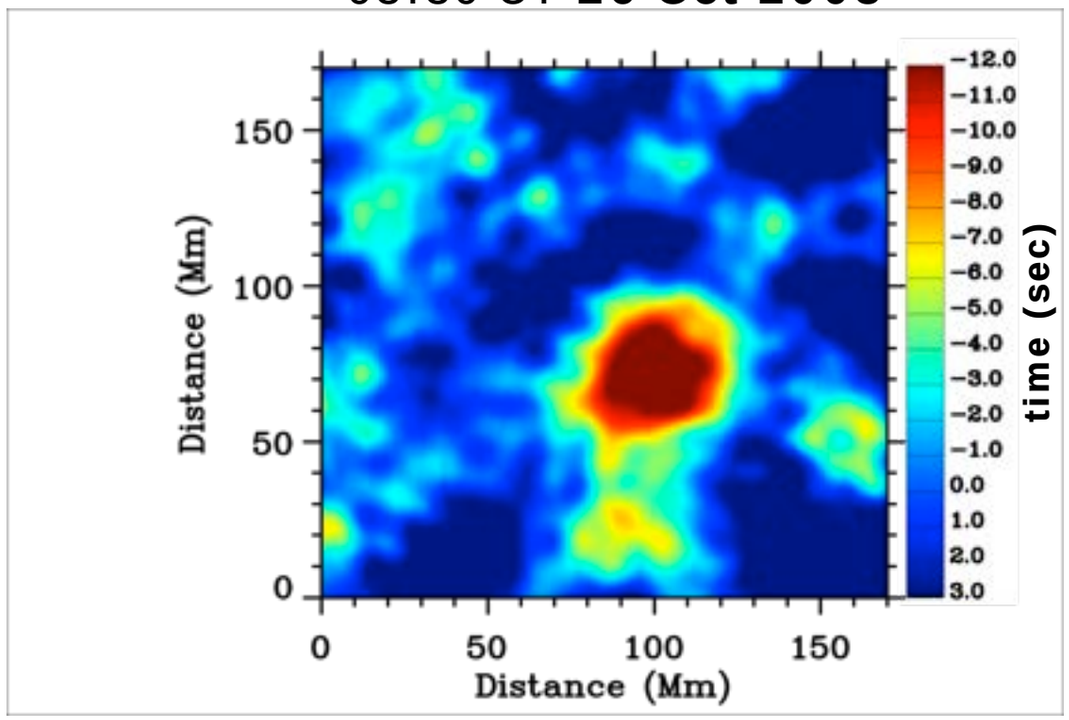
- First detection of sunspot regions in deep interior of Sun, 1-2 days before they appear at the solar surface
- Data from SOHO/MDI
- Technique: time-distance helioseismology (similar to approach widely used in earthquake studies)
- Sunspots generated at least 60,000 km below the surface and emerge from this depth with an average speed of 0.3-0.6 km/s



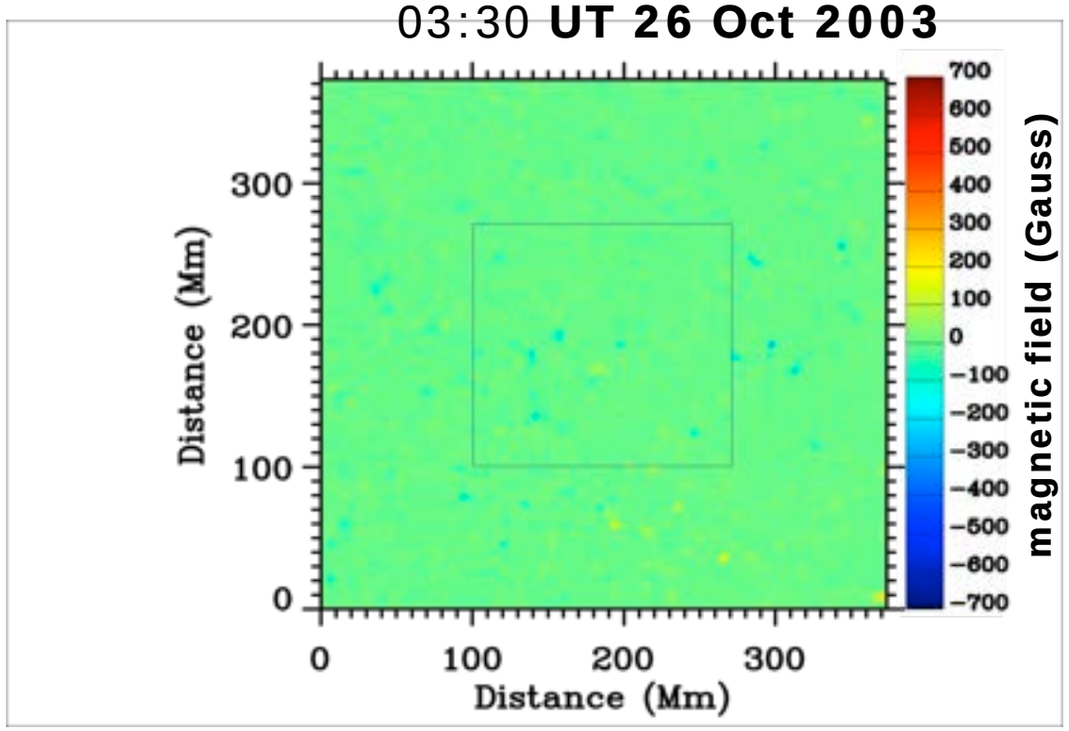
Ilonidis et al.: 2011, Science 333, 993

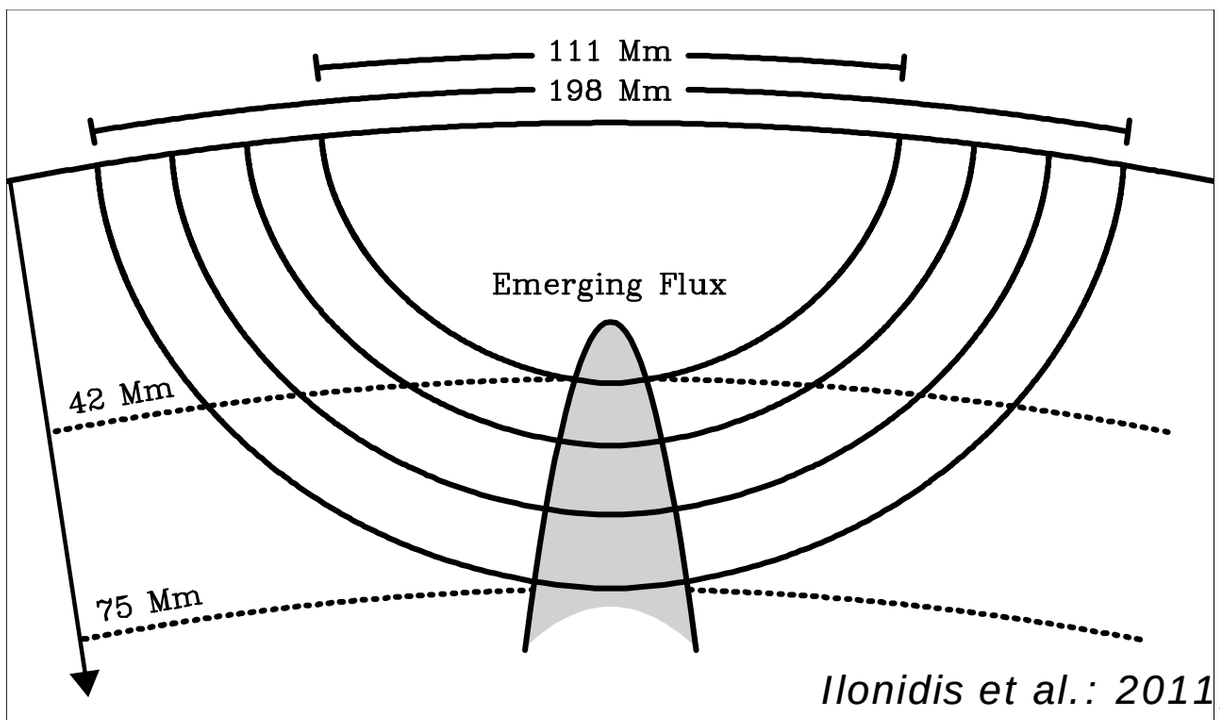
Detection of Emerging Sunspots in the Solar Interior

Wave travel time anomaly
03:30 UT **26 Oct 2003**

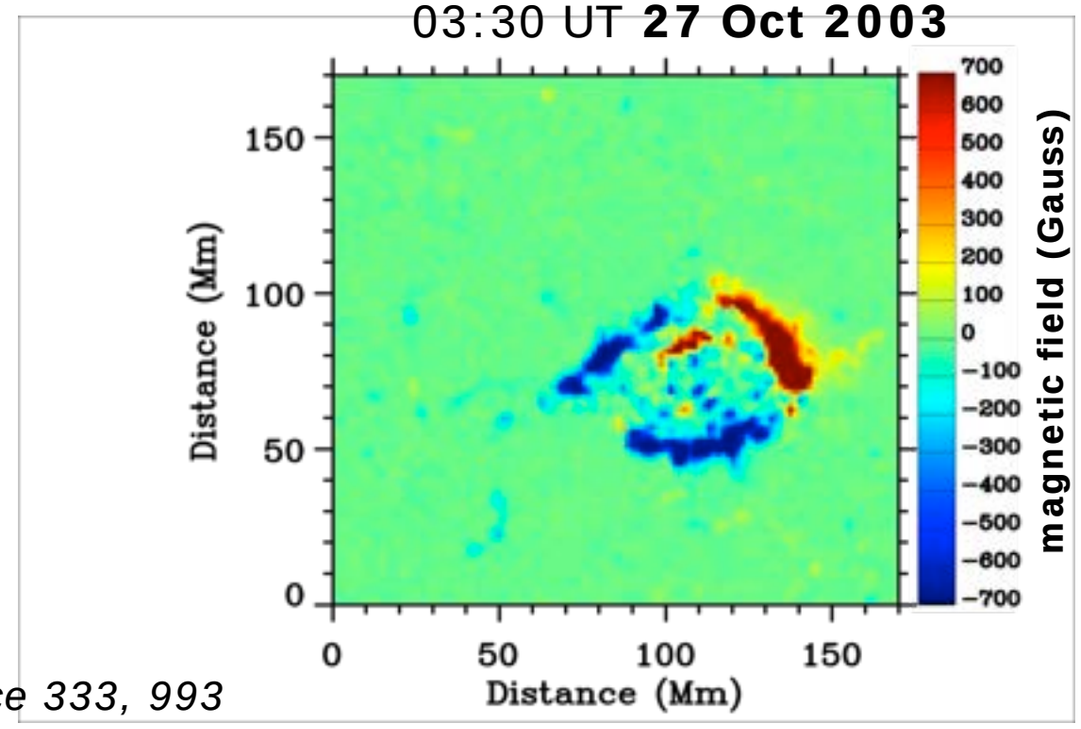


Magnetogram
03:30 **UT 26 Oct 2003**





03:30 UT **27 Oct 2003**



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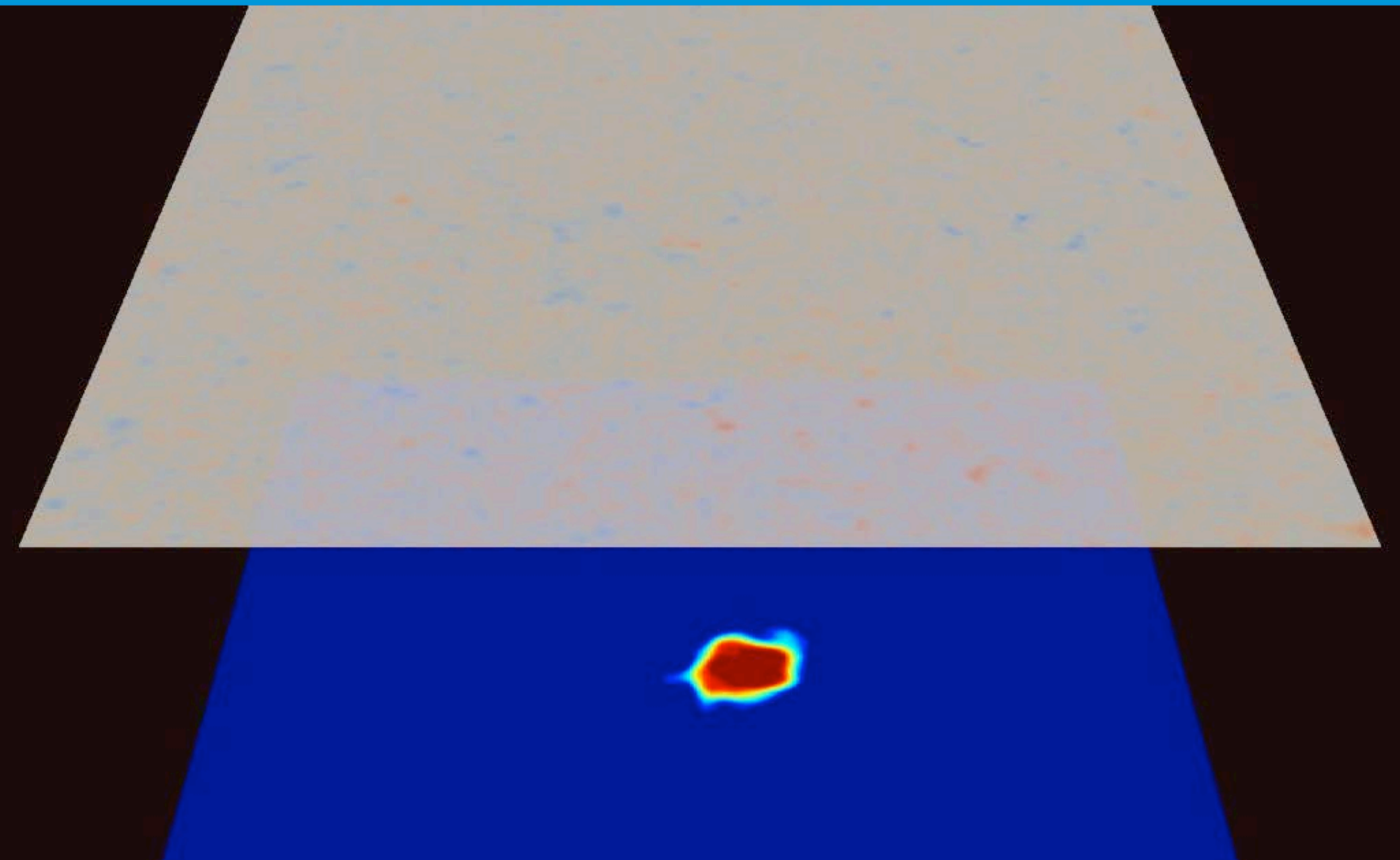


ESA's Next Solar Mission: Solar Orbiter

Summary

Launch Date: January 2017

Cruise Phase: 3 years

Nominal Mission: 3.5 years

Extended Mission: 2.5 years

Orbit: 0.28 – 0.91 AU

Out-of-Ecliptic View:
Multiple gravity assists with Venus to increase inclination out of the ecliptic to >24° (nominal mission),
>34° (extended mission)

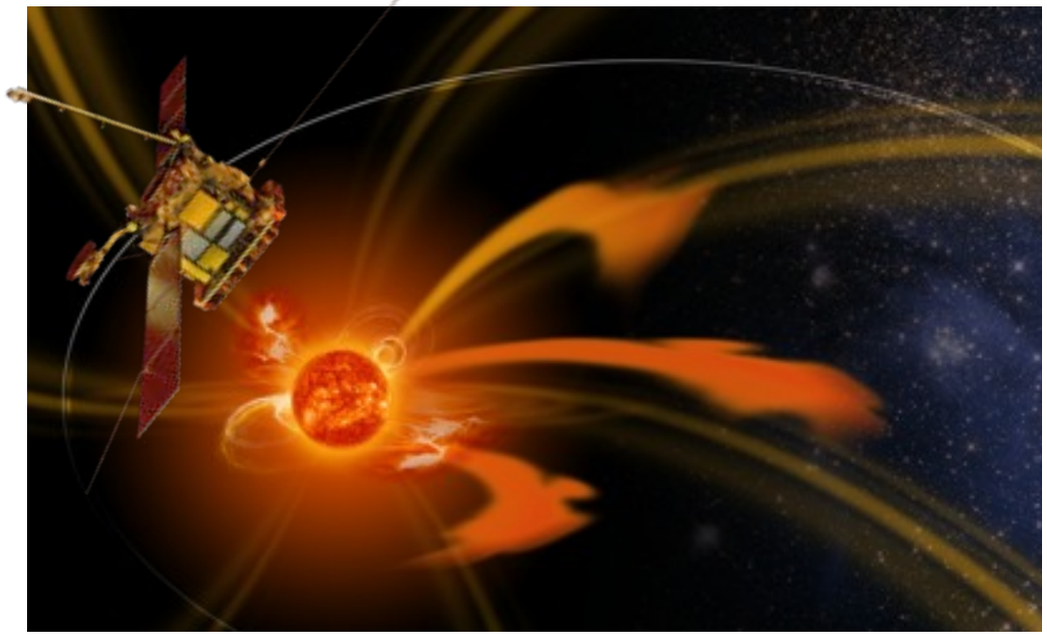
Reduced relative rotation:
Observations of evolving structures on solar surface & in heliosphere for almost a complete solar rotation

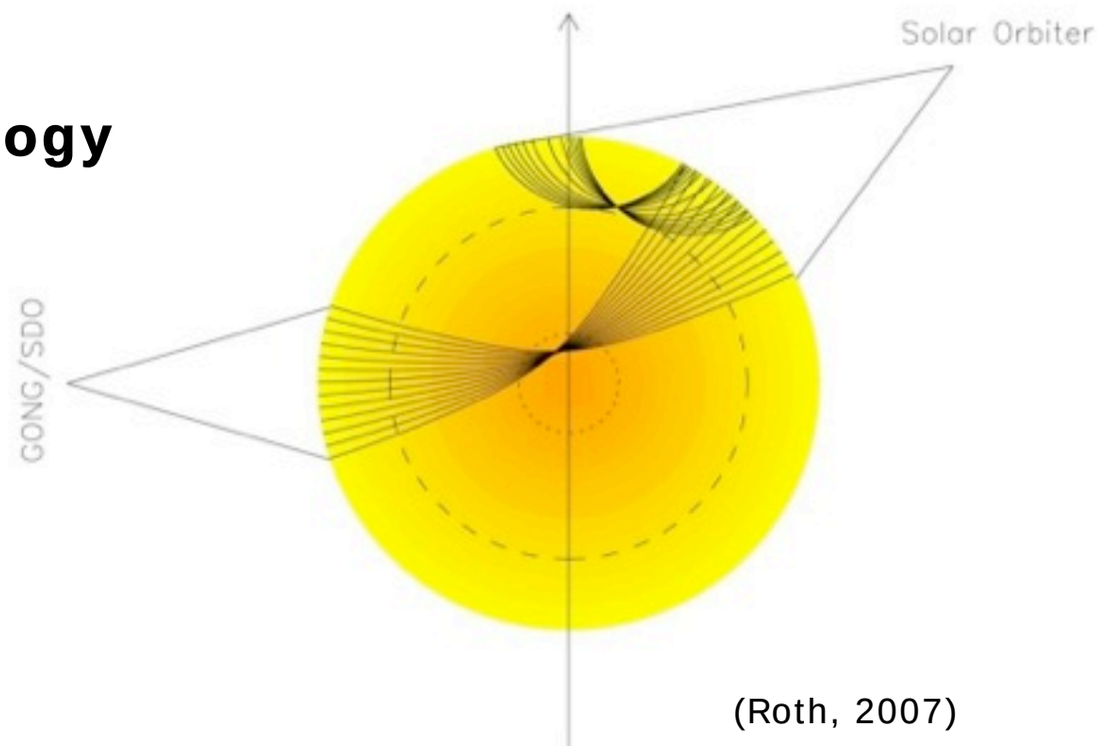
Solar Orbiter: New Frontiers in Helioseismology

- **Solar Orbiter will see the Sun's far side and higher latitudes**
  - Improved combined helioseismic data (back+front sides)
    - *Global helioseismology: reduced leakage effect*
    - *Local helioseismology: probing deeper layers*
  - Large- and small-scale flow patterns at poles

- **Probing of the deep solar interior**
  - Seismic estimates for the deep meridional return flow

- **Magnetoseismology / Atmospheric Seismology**
  - Sunspot seismology
  - Prediction of appearance of active regions
  - Space weather applications





(Roth, 2007)