Helioseismology

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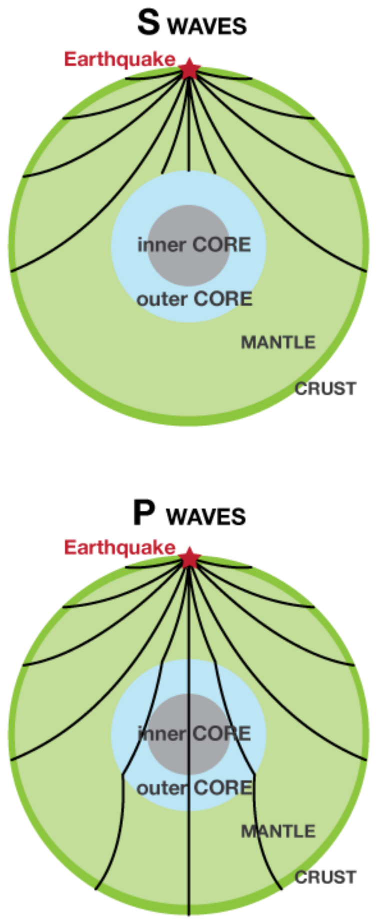
*(Helio)*Seismology

The same way that geologists use seismic waves from earthquakes to probe the inside of the earth, waves propagating throughout the inside of the sun can be used to study its internal structure.

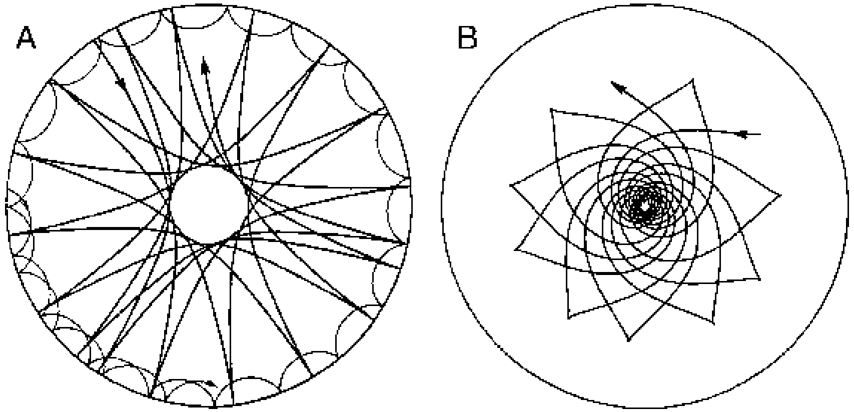
The lack of solid structure within the sun, its physical distance from earth, and the effects of magnetic and gravitational fields means that the problems within helioseismology are unique



P-wave and S-wave paths through the earth [9]

Helioseismology

- Some of these waves travel right through the center of the sun. Others are bent back toward the surface at shallow depths.
- Helioseismologists can use the properties of these waves to determine the temperature, density, composition, and motion of the interior of the sun *[5]*



p modes (A) and g modes (B) paths through the earth. [10]

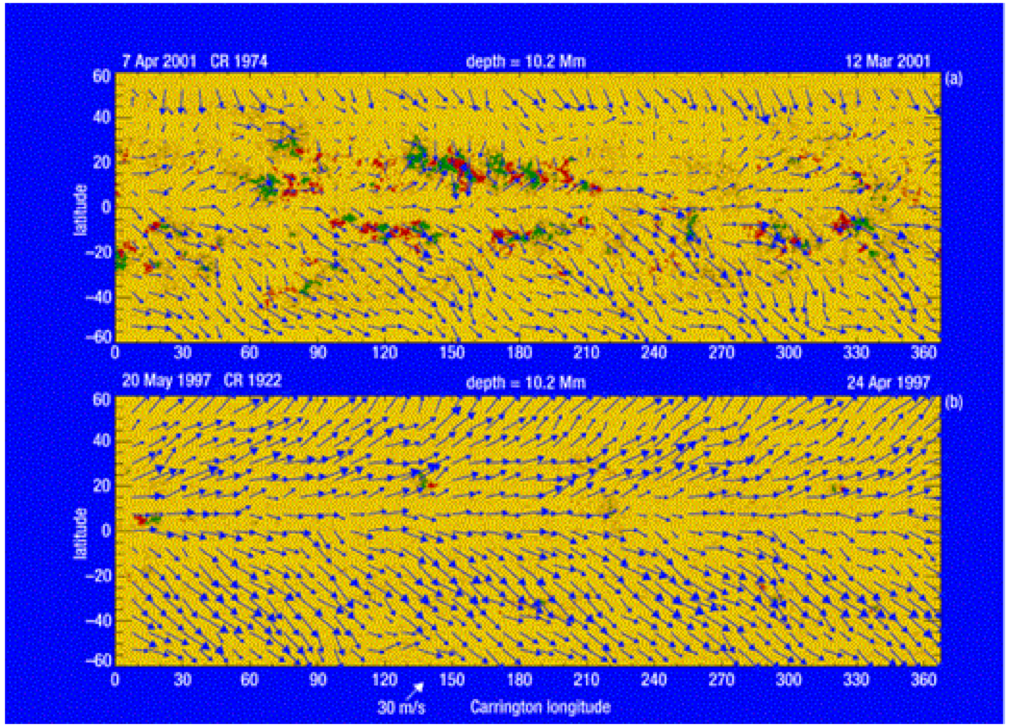
In practice, helioseismology is split into two separate, but collaborative, fields of study.

Local Helioseismology

Global Helioseismology

Local Helioseismology

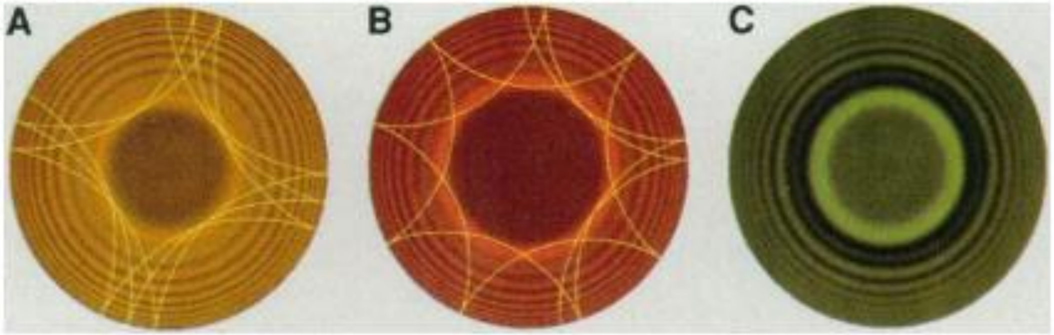
- Focused on observations of local motion near the surface of the sun.
- Velocity measurements in well defined areas.
- Analogous to methodologies employed in earth-seismology
- High-resolution Doppler images of the Sun's surface in combination with maps of the Sun's magnetic field



Synoptic maps of horizontal flow at 10×10^6 m depth below the photosphere. [3]

Global helioseismology

- Studying the normal modes, resonant acoustics of the Sun
- Inwards-propagating waves get refracted back to the surface at some depth because the temperature and hence sound speed increase with depth. Near the surface, outwards-propagating waves also get deflected by the sharply changing stratification in the near-surface layers. Hence the **acoustic waves are trapped in a resonant cavity and form modes**, with discrete frequencies. *[3]*
- Allows for Deep inferences/deduction into much of the internal structure



Combining Global and Local Helioseismology

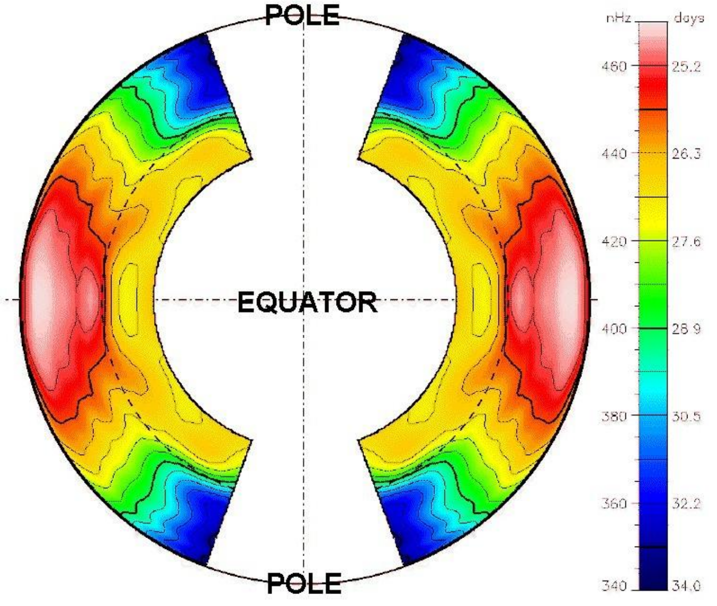
- It was discovered in the 1960s that patches of the Sun's surface were oscillating with a period of about five minutes.
- Initially these were thought to be entirely manifestation of **local** convective motions,
- by the 1970s it was understood that the observed motions are the superposition of many **global** resonant modes of oscillation within the Sun.
- The modes in which the Sun is observed to oscillate are predominantly acoustic modes – (pressure waves)
  - Though the acoustic wave propagation is modified by gravity and the Sun's internal stratification, and by bulk motions and magnetic fields

[3]

What can helioseismology tell us?

- The angular velocity inside the Sun
- Throughout the convection zone velocities are larger at the equator than at the poles
- The radiative interior rotates nearly uniformly.

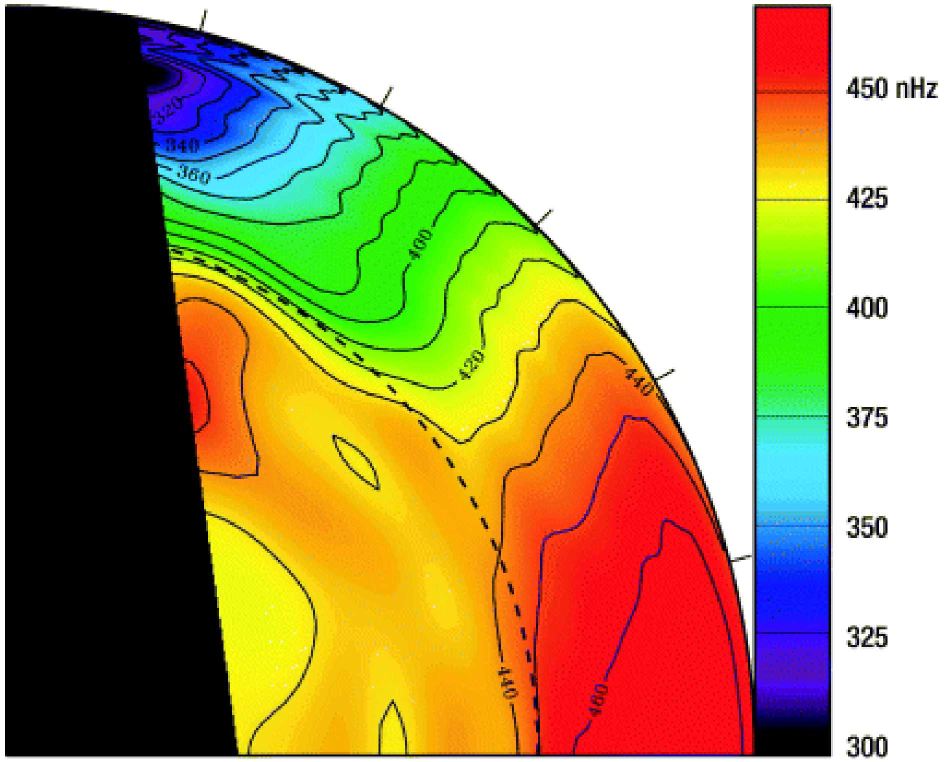
[1]



The internal rotation rate of the sun with red for fast and blue for slow. [5]

What can helioseismology tell us?

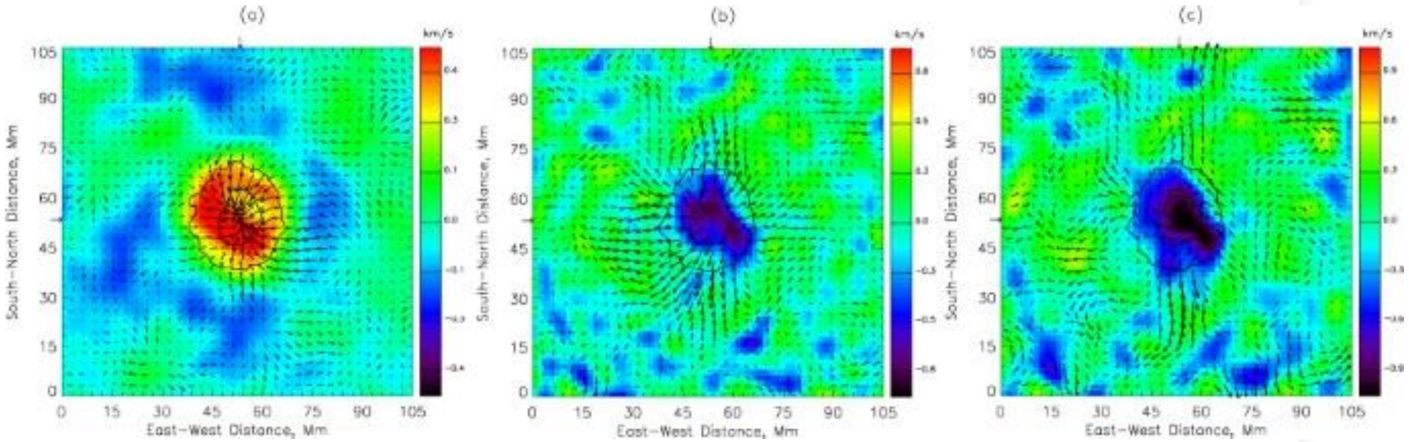
- It is widely believed that the point between these two inner and outer zones of rotation, called the tachocline, is where the Sun's large-scale magnetic field is generated
- This may be the cause of the 11-year solar cycle of sunspots and the large-scale dipole field *[3]*



The rotation rate inside the Sun inferred from MDI data [3]

What can helioseismology tell us?

- Local Helioseismology is particularly good at studying the flow of material in and around sunspots
- The very first success of local helioseismology was the **detection of acoustic absorption by sunspots** - Spruit and Bogdan (1992) suggested that the partial conversion of the incoming acoustic waves into slow magnetoacoustic waves that propagate downward, channeled by the magnetic field, may explain the observations. *[1]*



Flow maps around a sunspot at depths of (a) 0–3 Mm, (b) 6–9 Mm, and (c) 9–12 Mm [2]

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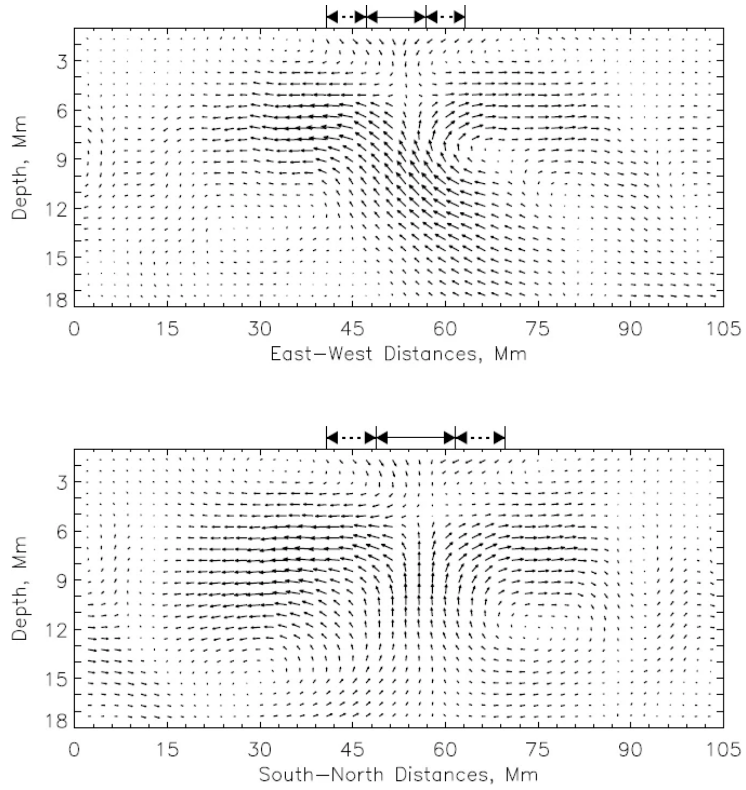


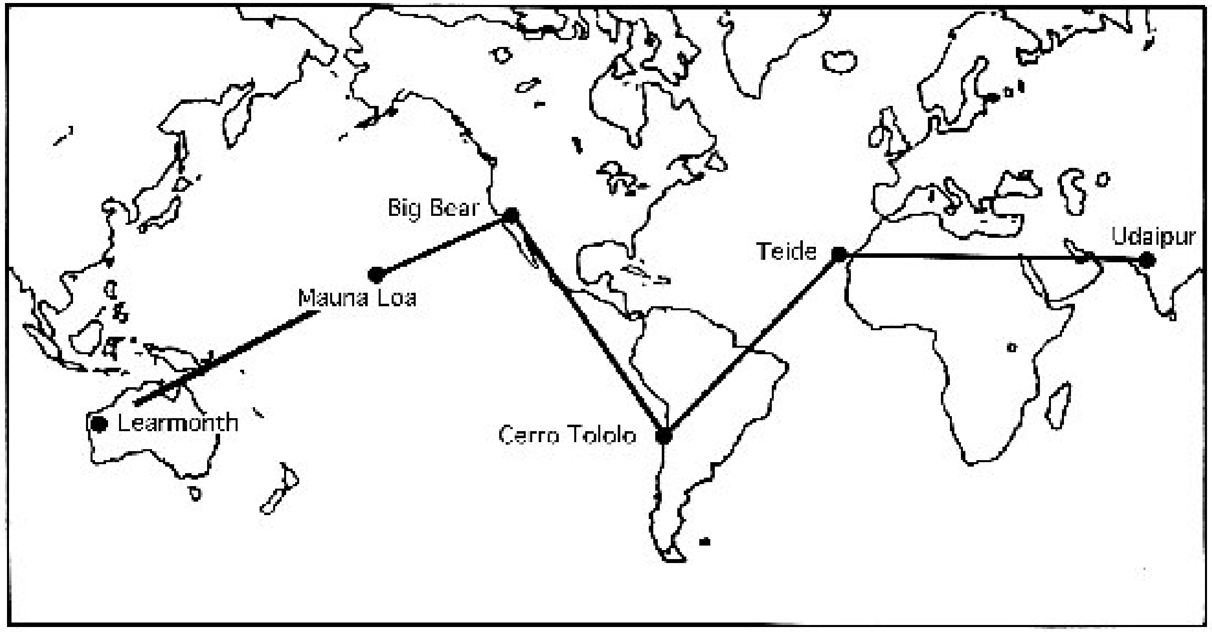
Experiment and measurement

- Magnetic imaging paired with high-resolution doppler images of the Sun's surface
- Today, the development of local helioseismology is fueled by high-quality data from space and ground-based networks.
  - the Global Oscillation Network Group (**GONG**)
  - and the Helioseismic & Magnetic Imager (**HMI**)

[1]

GONG

- 6 sites – nearly 24hr observation
- Uses a tunable interferometer to measure the shift in frequency of known solar absorption lines – produces doppler images of the suns surface



[6]

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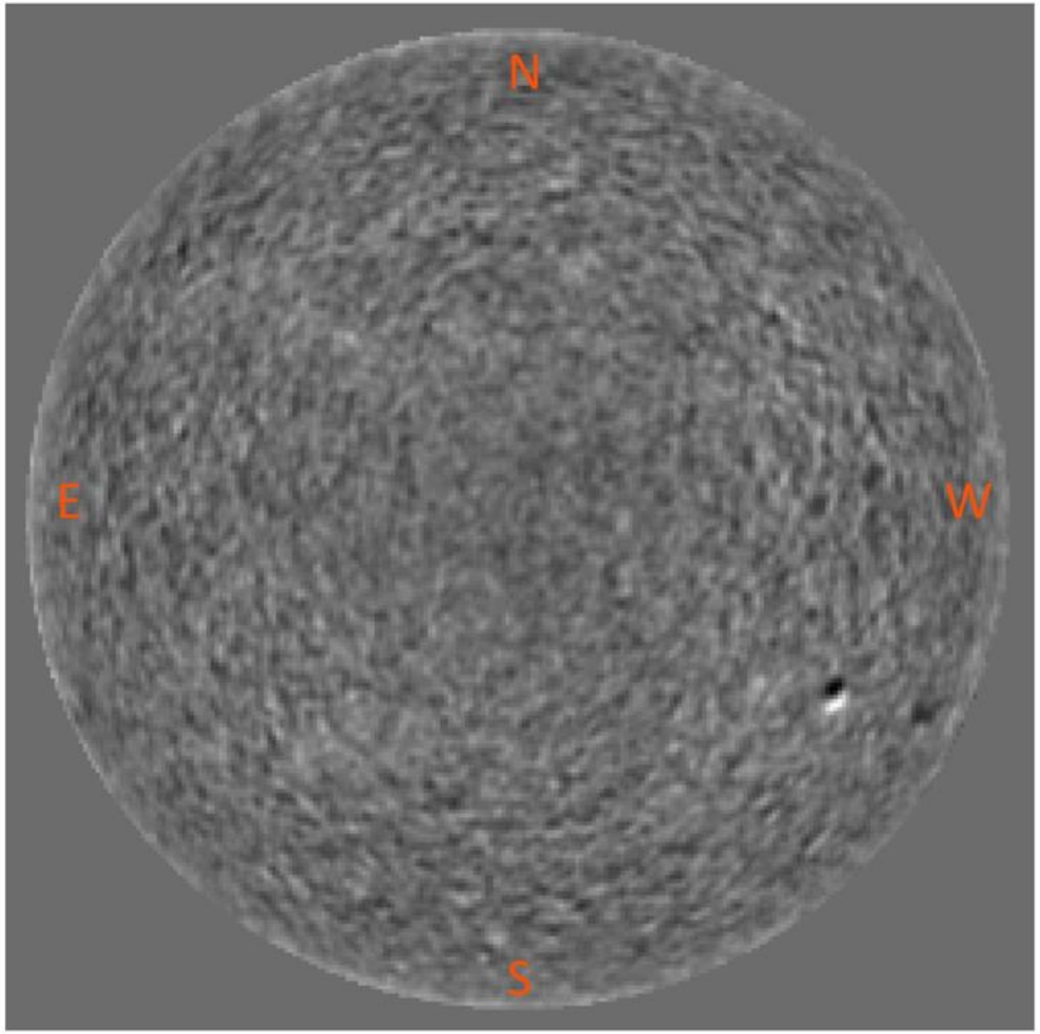
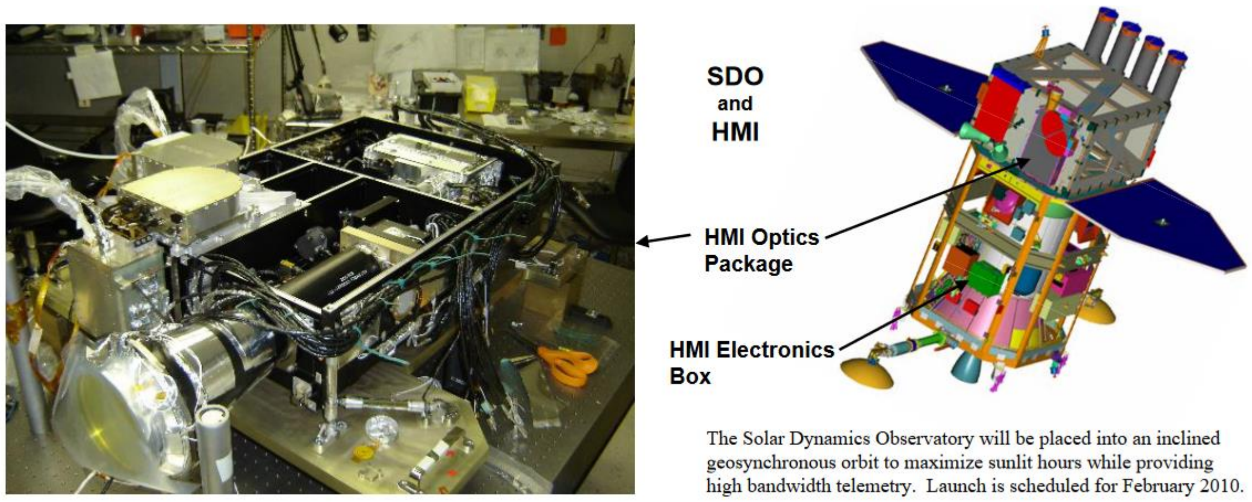


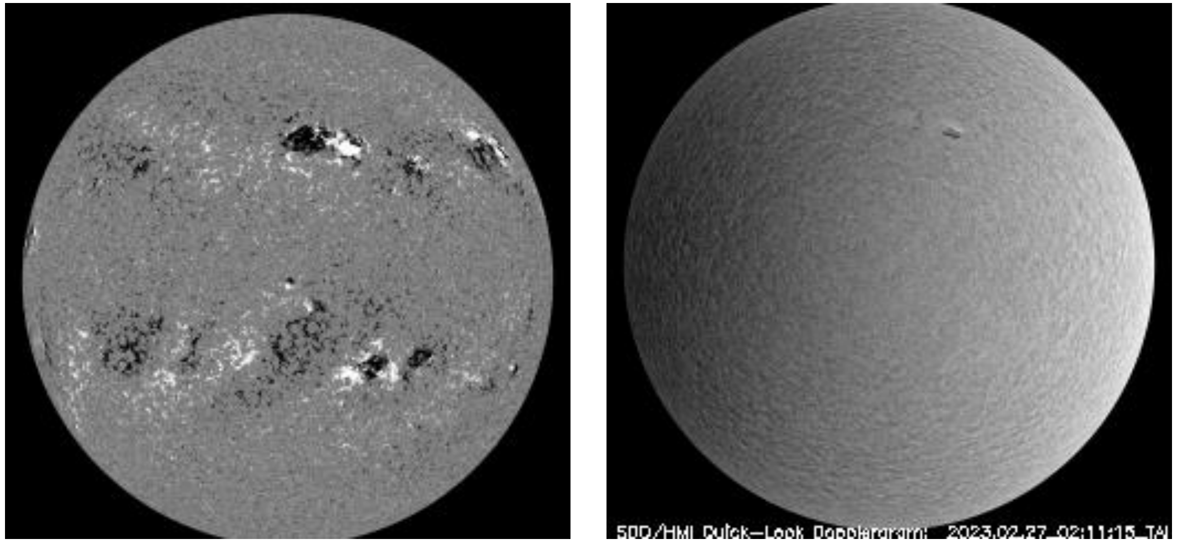
GONG Dopplergram with overall rotational velocities accounted for [13]

HMI

- Produces Dopplergraph and Magnetogram
- Aboard the ESA/NASA SOHO spacecraft in a halo orbit around the L1 Sun-Earth Lagrange point

[12]





Magnetogram and Dopplergraph taken by HMI *[7]*

HMI Dopplergram from Today:

http://sdo.gsfc.nasa.gov/assets/img/latest/

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