Helioseismology with Solar Orbiter

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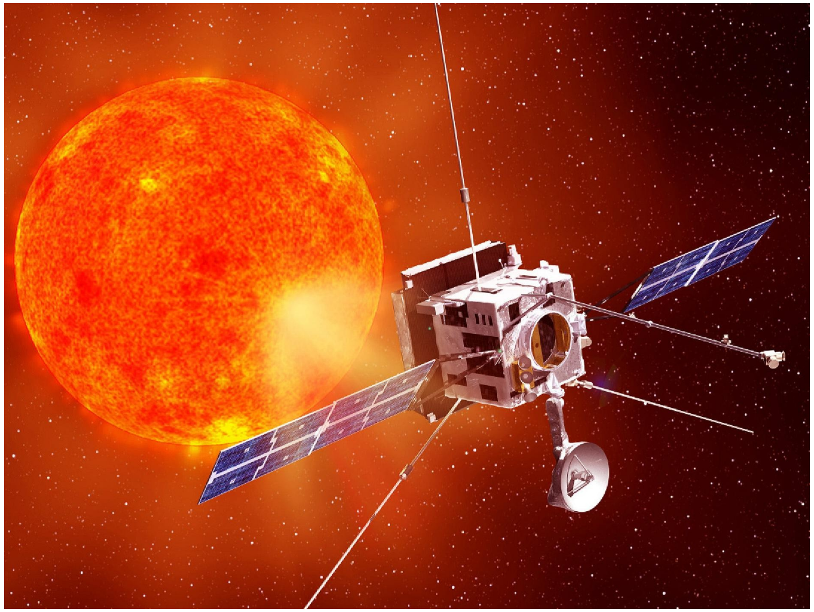
SOLAR SYSTEM SCHOOL

Solar Orbiter

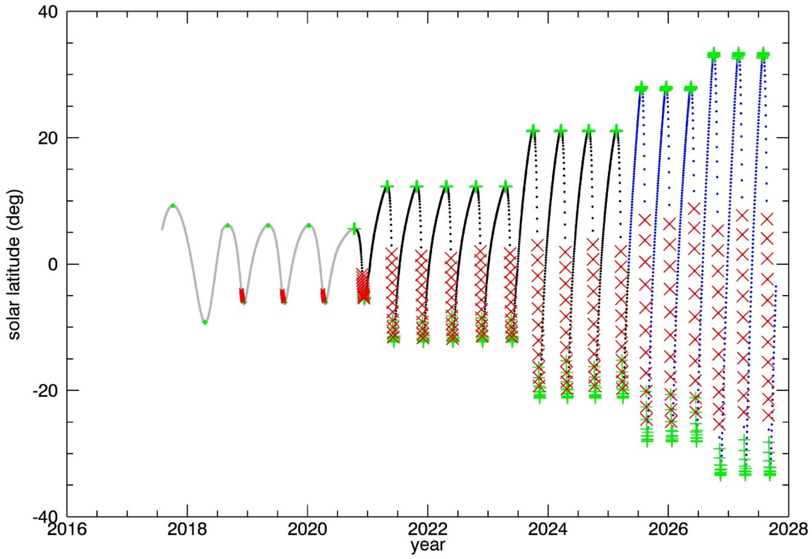
- Talk based on Löptien et al., 2014, Spac. Sci. Rev, published online
- ESA m-class mission
- Launch in July 2017
- Inclined and elliptic solar orbit
- Observation of solar poles at low angles
- Combination of 10 in-situ and remote-sensing instruments
  - For helioseismology:
    Polarimetric and Helioseismic Imager (PHI)



Source: ESA

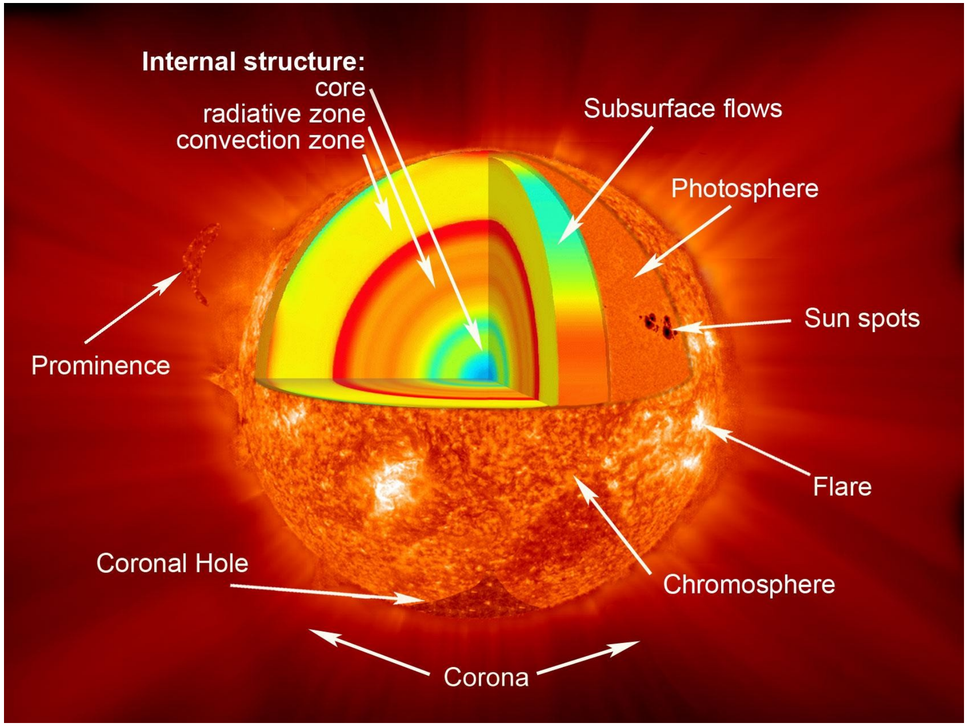
Orbit

- Inclined and elliptic solar orbit (max. latitude: 34°, min. distance: 0.28 AU)
- 3 year cruise phase, 4.5 year nominal mission, 3.5 year extended mission
- Cruise phase:
  - GAMS with Earth and Venus
  - Final orbit in resonance with Venus (p ≈ 180 days)
- Nominal and extended mission:
  - Increase inclination using Venus GAMs
  - At perihelion: low angular velocity relative to the Sun



General Scientific Goals

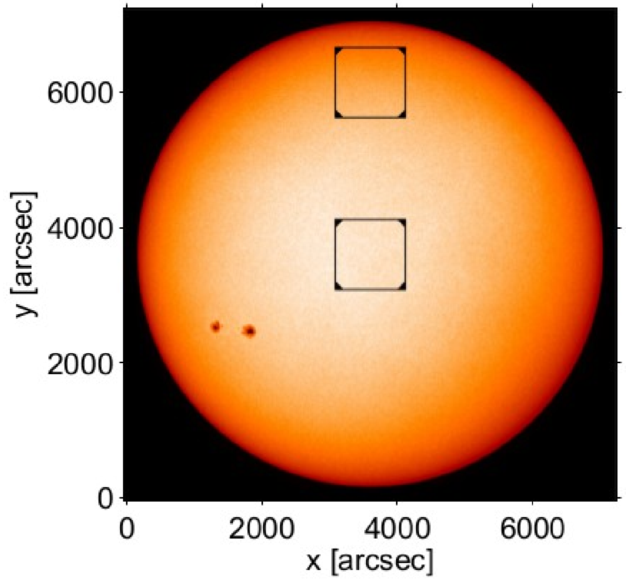
- Connect measurements at different heights in atmosphere with results from helioseismology and in-situ measurements
- Top level science question:
  How does the Sun create and control the heliosphere
- Helioseismology:
  - Subsurface flows near poles
  - Deep interior using stereoscopic helioseismology



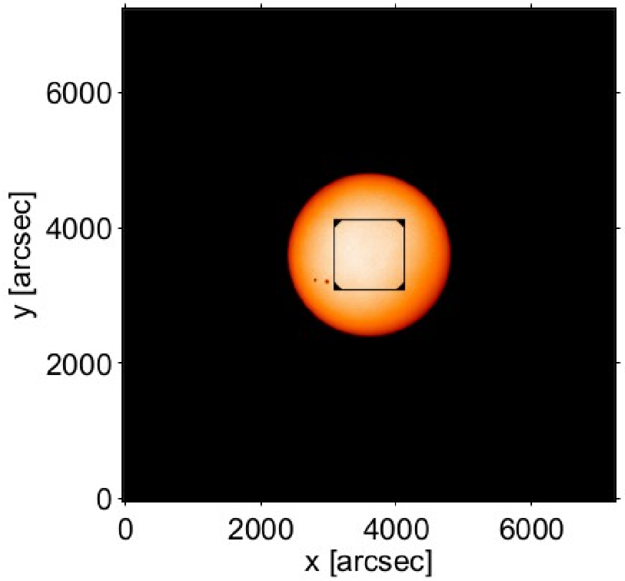
Source: NASA

PHI Instrument

- Observation of Fe I 6173 Å line (same as HMI) with 60 s cadence
- 2 telescopes (FDT and HRT, cannot be used simultaneously)
  - HRT: FOV: 16.8', res.: 1" (200 km at perihelion)
  - FDT: FOV: 2° (full disk), res.:9 " (1800 km at perihelion, max. ell = 200)
- One filtergraph and one detector (2048 x 2048 pixel)



FOV at perihelion (0.28 AU)



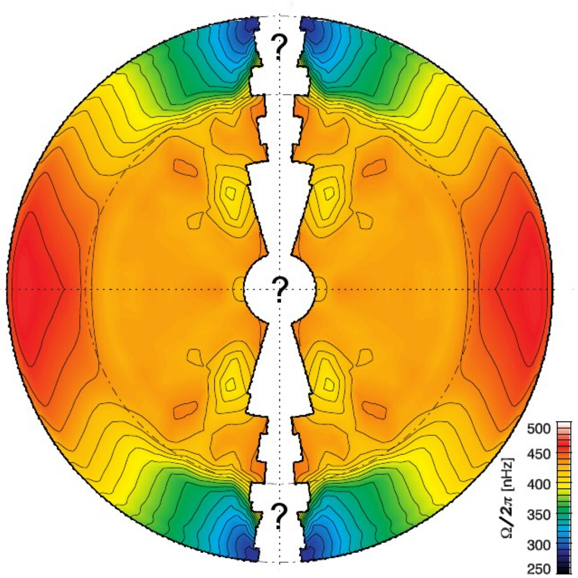
FOV at 0.8 AU

PHI: Operations

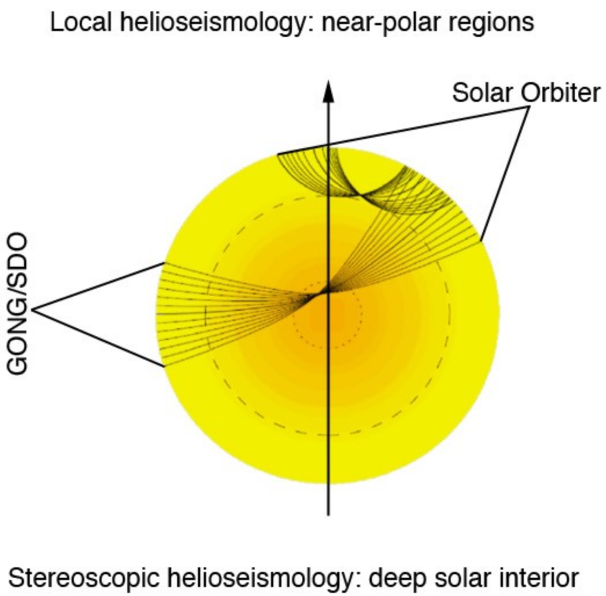
- Observe during 3 science windows (length: 10 days)
  - Maximum/minimum heliographic latitude
  - Perihelion
- Limited telemetry (51 Gbit per science orbit)
  - On-board inversion for LOS velocity and magnetic field vector
  - Classical estimate (MDI-like) of velocity possible for helioseismology
  - Data compression necessary for helioseismology
- PHI important instrument for Solar Orbiter mission as a whole
  - Synoptic magnetograms

Helioseismology Science Objectives

- Solar Orbiter allows science that is not possible with current missions, e.g.,
  - Near-surface flows at high latitudes
  - Deep flows using stereoscopic helioseismology



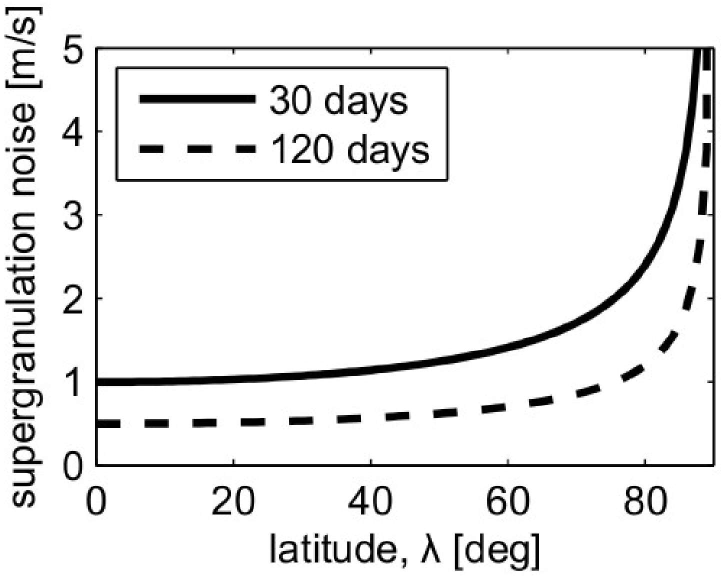
Source: Korzennik & Eff-Darwich (2011)



Source: Roth (2007)

Planning Observing Strategies

- Several parameters need to be fixed:
  - Observable (mostly v_{LOS})
  - Duration
  - Telescope (FDT or HRT)
  - Spatial sampling
  - Compression ratio



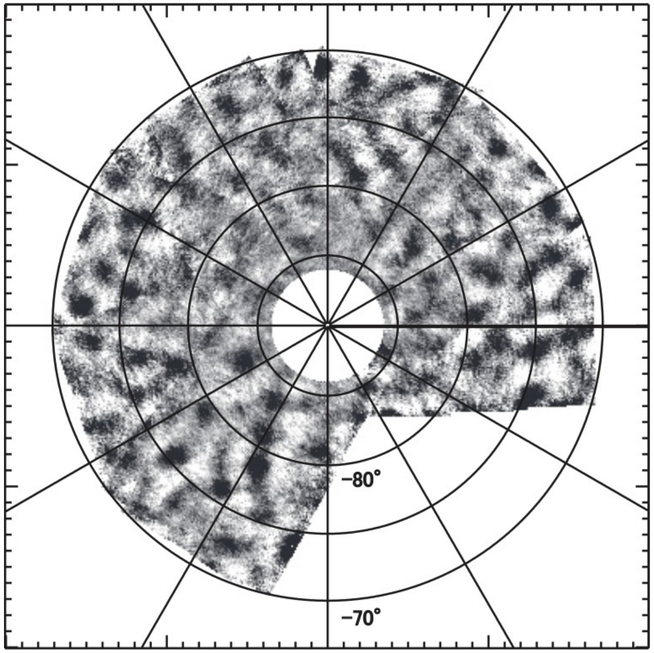
- Main source of noise: supergranulation noise (decreases as $1/\sqrt{T}$)
- Other issues:
  - Limited telemetry (51 Gbit/orbit)
  - Observing time (3 science windows @ 10 days)
- Some science goals could be achieved using local correlation tracking

Near-Surface Flows at High Latitudes

- Large-scale flows:
  - Differential rotation and meridional circulation near poles important for dynamo
  - Torsional oscillations at high latitudes
  - T ≈ 30 days, likely to exceed allocated telemetry

- Convection at high latitudes:
  - Alignment of supergranules
    (Lisle et al. 2004, Nagashima et al. 2011)
  - Effect of Coriolis force on supergranules
    (Gizon et al. 2010)
  - Wavelike properties of supergranulation
    (Gizon et al. 2003, Schou et al. 2003,
    Green & Kosovichev, 2007)
  - T ≈ 7 days, telemetry probably within allocation

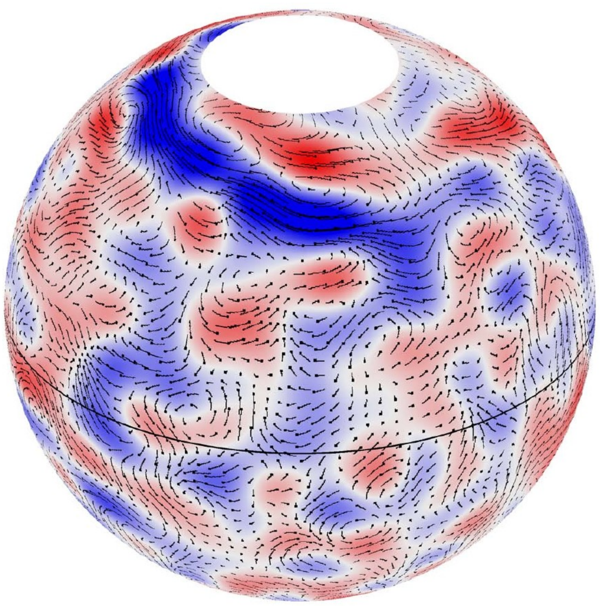
Source: Nagashima et al. (2011)



Stereoscopic Helioseismology

- Deep large-scale flows
  - Deep flows only poorly understood
  - 2-cell meridional circulation (Zhao et al. 2013)?
  - 1.3 year oscillations in tachocline (Howe et al. 2000)?
  - New discoveries?

Source: Hathaway et al. (2013)

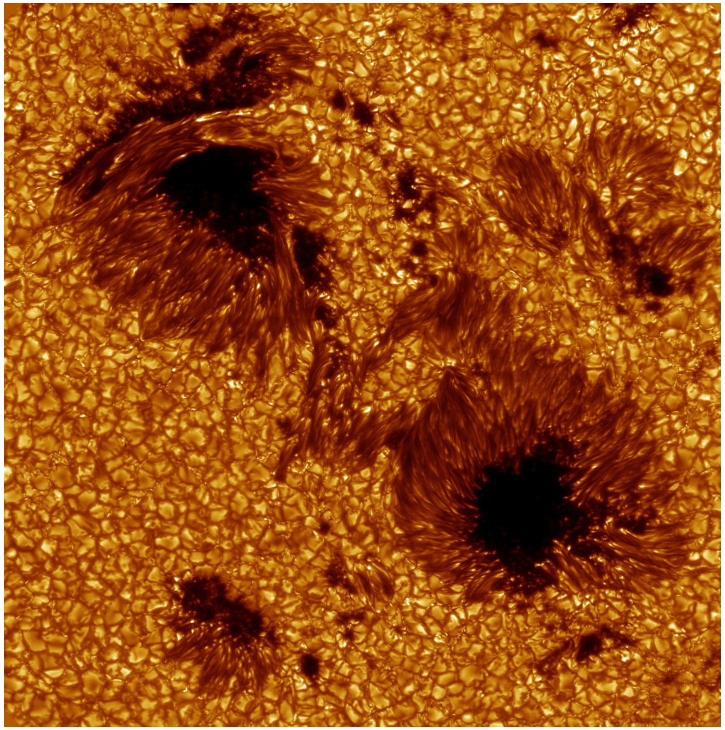


- Deep convection
  - Giant cells (Hathaway et al. 2013) ?

- Long observing times (years), low spatial resolution and telemetry

Other Science Objectives

- Observe evolving active regions for longer time than currently possible
- Observe 2 velocity components of MHD waves
- Evaluate center-to-limb effects using stereoscopic helioseismology
- Calibrate far-side helioseismology
- Sun-as-a-star observations outside of the ecliptic (for asteroseismology)
- Shape of the Sun



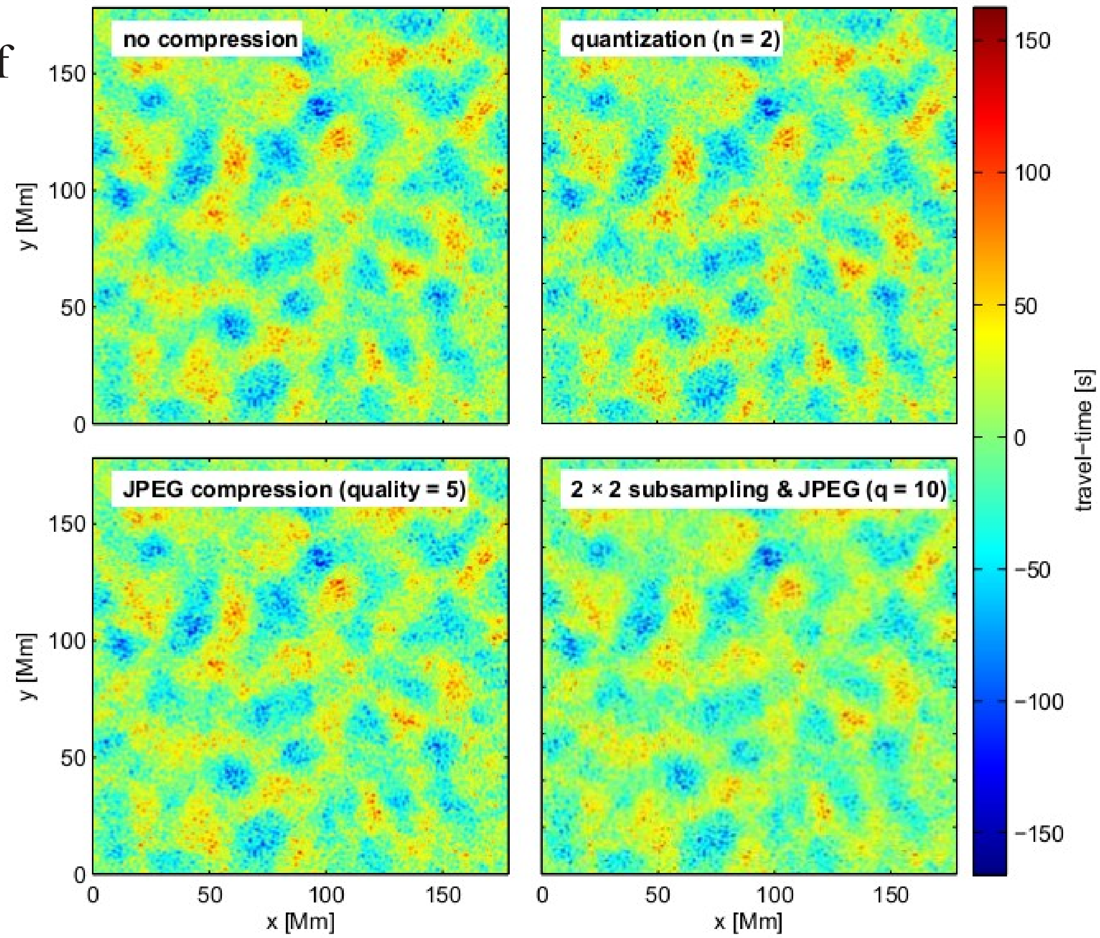
Source: SST

Compression

- Motivation: Reduce telemetry
- Image compression methods:
  - Lossless compression (limited efficiency)
  - Binning, subsampling & cropping (reduction of spatial resolution, limited efficiency, can be combined with other methods)
  - Bit truncation + lossless compression
  - Spatial transformation of data + quantization and compression of coefficients (e.g., JPEG)
  - In helioseismology: add time dimension (e.g., MPEG)?
- Influence of lossy compression
  - Additional noise
  - Compression bias

Compression Study for Supergranulation

- Test influence of data compression on time-distance helioseismology of supergranulation
- Apply different compression methods to tracked and mapped HMI Doppplergrams
- Supergranulation flows very robust to data compression



For more information see my poster and Löptien et. al. (2014, accepted by A&A)

Thank you for your attention!