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Future missions for helioseismology

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Abstract. In this paper I provide basic information on the scientific objectives of upcoming helioseismology missions. The launch of NASA's Solar Dynamics Observatory (SDO) in 2008 is an important opportunity for helioseismology. SDO will carry the Helioseismic and Magnetic Imager (HMI), which will have a 1″ resolution over the whole visible solar disc and is especially designed for local helioseismology. ESA's Solar Orbiter, to be launched ten years from now, will allow the study of the subsurface structure and dynamics of the Sun at high latitudes. Just recently, Hinode (Solar-B) was launched. It is designed to deliver Dopplergrams at 0.3″ resolution. Ground-based observations are also expected to complement space projects.

1 Introduction

Helioseismology has been tremendously successful over the last two decades at probing the solar interior, especially since the establishment of the GONG (Global Oscillation Network Group) and the launch of SOHO (Solar Heliospheric Observatory). The GONG runs a network of six observatories distributed around the world to provide nearly continuous time series of solar oscillations. The SOHO spacecraft, in a halo orbit around the L1 Sun-Earth Lagrange point, carries the MDI (Michelson Doppler Imager) instrument. Both experiments detect solar oscillations in images of the line-of-sight velocity at the Sun's surface. These data now cover a full sunspot solar cycle. Helioseismology has provided a very good estimate of the sound speed and the large-scale differential rotation inside the Sun as function of radius and latitude and has contributed to solving the neutrino problem. Current investigations focus on the study of seismic variations that are connected with the solar magnetic cycle. In the future, helioseismology will address important question related to the origin of the solar dynamo.

Important space missions for helioseismology are planned. They will enable us to study long-standing problems in solar physics. These missions include the Japanese mission Hinode (Solar-B), the NASA space mission Solar Dynamics Observatory (SDO), and the ESA mission Solar Orbiter. In this short contribution, I gather basic information about these missions and other projects.

2 Future missions

2.1 Hinode

Hinode (Solar-B) is equipped with three advanced solar telescopes, an X-ray telescope (XRT), an EUV imaging spectrometer (EIS) and a solar optical telescope (SOT). Hinode was successfully launched on 22 September 2006. The Sun-synchronous orbit of Solar-B allows a downlink of data nearly every orbit, hence observations will be possible 24 hours a day for about 8 months of the year. The SOT system is optimized for accurate measurements of the vector magnetic field in the photosphere and dynamics of both the photosphere and chromosphere associated with the magnetic fields. This makes the SOT instrument interesting for helioseismology, especially as SOT was designed to deliver Dopplergrams with a resolution of 0.3 arcsec. Such a resolution is unprecedented for helioseismology. The field of view of up to $328'' \times 164''$ is, however, a limitation for probing the deep solar interior. Further information can be found at the Solar-B (2006) website.

2.2 SDO

The Solar Dynamics Observatory is a major component of NASA's Living With a Star (LWS) Program, designed to understand the causes of solar variability and its impacts on Earth. Besides the Atmospheric Imaging Assembly (AIA) and the Extreme Ultraviolet Variability Experiment (EVE) instruments, SDO will carry the Helioseismic and Magnetic Imager (HMI). The HMI will provide data for helioseismology. It will make measurements of the motion of the solar photosphere (at least every 50 sec) to study solar oscillations. Moreover, it will measure the polarization at 5 points in a spectral line to study all three components of the photospheric magnetic field (at least every 90 sec). It will deliver nearly continuous full-disk images at $1''$ spatial resolution (this resolution is available with MDI only during short periods in a limited field).

Foreshortening makes it difficult to measure oscillations close to the limb with MDI. With HMI the foreshortening effect is reduced. This allows, e.g. better measurements of the Doppler signal at higher latitudes and longer tracking of active regions during their transit. Longer contiguous runs are then possible for local helioseismology.

The science goals of HMI are: the relations of convection-zone dynamics to the solar dynamo, the origin and evolution of sunspots, active regions and activity complexes, links between the internal processes and dynamics of the corona and heliosphere (together with AIA), and precursor measurements of solar disturbances for space-weather forecasts. For further information see the HMI (2006) website.

2.3 Solar Orbiter

Here we discuss the Solar Orbiter mission to be launched after 2015. More details on this topic can be found in Gizon (2006). The most interesting aspects of the Solar Orbiter mission clearly reside in the unique vantage points from which the Sun will be viewed. Although the exact orbit of the spacecraft is still under discussion, the orbit design will include two main characteristics, both of which offer novel perspectives for helioseismology. First, Solar Orbiter will make observations away from the ecliptic plane to provide views of the Sun's polar regions. The inclination of the spacecraft's orbit to the Ecliptic will incrementally

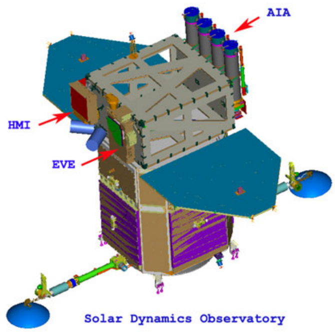

Figure 1. The Solar Dynamics Observatory (SDO) and its three instruments aboard (NASA illustration).

increase at each Venus swing-by manoeuvre to reach up to about 30° toward the end of the mission. Second, Solar Orbiter will cover a large range of spacecraft-Sun-Earth angles. In combination with data collected from the ground or near-Earth orbit, Solar Orbiter will mark the advent of stereoscopic helioseismology.

The picture of the solar interior is far from being complete at high heliographic latitudes. In particular, global mode frequency inversions for rotation cease to be accurate above 70° and local helioseismology above 50°. Out-of-the ecliptic observations will enable helioseismology to reach higher heliographic latitudes into the solar convection zone.

By definition, stereoscopy requires several observatories. Both SDO-HMI and GONG (or another ground-based facility) are expected to be operational at the time of Solar Orbiter operations. Combining Solar Orbiter with any one of them will open new windows into the Sun. Note that how well the data can be merged will depend critically on timing accuracy and geometry knowledge.

Looking at the Sun from two distinct viewing angles results in an increase of the observed fraction of the Sun's surface. Global helioseismology would naturally benefit from this situation, since the modes of oscillation would be easier to disentangle (reduction of spatial leaks).

With stereoscopic local helioseismology, new acoustic ray paths can be considered to probe deeper layers in the interior. Observations from two widely different viewing angles allow the probing of the solar interior at any depth, and in particular the solar tachocline (Ruzmaikin & Lindsey 2003). It even becomes possible to target regions in the solar core: this is illustrated in Figure 2. This aspect of seismic stereoscopy is very promising.

2.4 Other projects

The CNES mission PICARD will be launched at the end of 2008. It will measure the solar oscillations with a high resolution at the solar limb. The major objective is to measure solar gravity modes and the solar shape.

Ground-based observing facilities are needed to complement the observations made by SDO and other space missions. In particular, at least two instruments are required to understand systematic errors and sources of noise in the data. Historically, this has been demon-

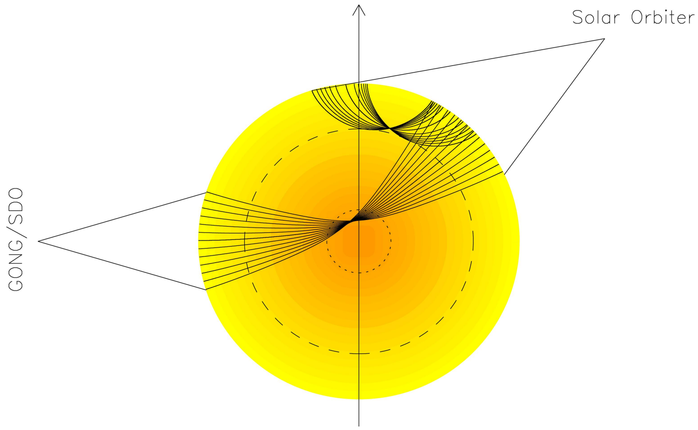

Figure 2. Sketch showing deep-focussing averaging schemes for local helioseismology. Solar Orbiter in combination with SDO or ground-based observatories will give access to local information very deep inside the Sun (stereoscopic helioseismology).

strated many times by comparing data from GONG and MDI (Schou et al. 2002, e.g.). Helioseismology needs uninterrupted time series: a second instrument guarantees continuous records. Ground-based instruments are also flexible, i.e. they can be upgraded more easily and fixed.

Other ground-based high-resolution solar observatories could turn out to be useful too, for the seismological study of the solar atmosphere by considering several lines formed at different heights in the atmosphere (Finsterle et al. 2004).

Acknowledgements. The information about the different projects was collected from the mission websites (see references below) and from Gizon (2006).

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