Recent Insights into the Physics of the Sun and Heliosphere
- Highlights from SOHO and Other Space Missions -
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Seismic Holography of the Solar Interior and Far Side

D. C. Braun

Colorado Research Associates Division, Northwest Research Associates, Inc., 3380 Mitchell Ln, Boulder, CO, 80301, USA

C. Lindsey

Solar Physics Research Corp., 4720 Calle Desecada, Tucson, AZ, 85718, USA

1. Active Region Holography

The development of solar acoustic holography over the past decade has opened a major new diagnostic avenue in local helioseismology (Lindsey & Braun 1990; 1997; 2000b). Its application to SOI-MDI data from *SOHO* has revealed "acoustic moats" surrounding sunspots, "acoustic glories" surrounding complex active-regions, and "acoustic condensations" suggesting the existence of significant seismic anomalies up to 20 Mm beneath active-region photospheres. It has given us the first seismic images of a solar flare, and has uncovered a remarkable anomaly in the statistical distribution of seismic emission from acoustic glories. A review of these and other accomplishments is given by Braun & Lindsey (2000a).

Phase-sensitive seismic holography, described by Lindsey & Braun (1997; 2000a) has produced high-resolution maps of sound travel-time anomalies caused by magnetic forces in the immediate subphotosphere of complex active regions. Braun & Lindsey (2000b) demonstrate that the reduced sound travel-times in sunspots, acoustic moats, and isolated plages increase approximately in proportion to the logarithm of the surface magnetic flux density, for flux densities above 10 Gauss. This is consistent with an interpretation of the travel-time anomalies, observed with holographic and other local-helioseismic procedures, as caused by acoustic Wilson-like depressions in photospheres of magnetic regions. Compared with isolated plages, however, the acoustic moats have an additional sound travel-time reduction on the order of 3-5 seconds which may be explained by a thermal excess due to the blockage of convective transport by the sunspot photosphere.

Seismic holography applied to global modes, such as those used to image the far side, has directly demonstrated the influence of active regions on these modes (Lindsey & Braun 2000a). The combined effect of the Wilson depression in plages, acoustic moats, and sunspots may explain the observed variation of global p-mode frequencies with the solar cycle. There is now a growing consensus that reduced sound travel times in magnetic regions explain the entirety of the solar cycle variations (Howe, et al. 1999; Hindman, et al. 2000). Cunha et al. (1998) suggested that local travel-time perturbations within sunspots alone could account for one-third of the solar cycle frequency variations. We find that plages, which cover approximately 20 times more surface area than sunspots,

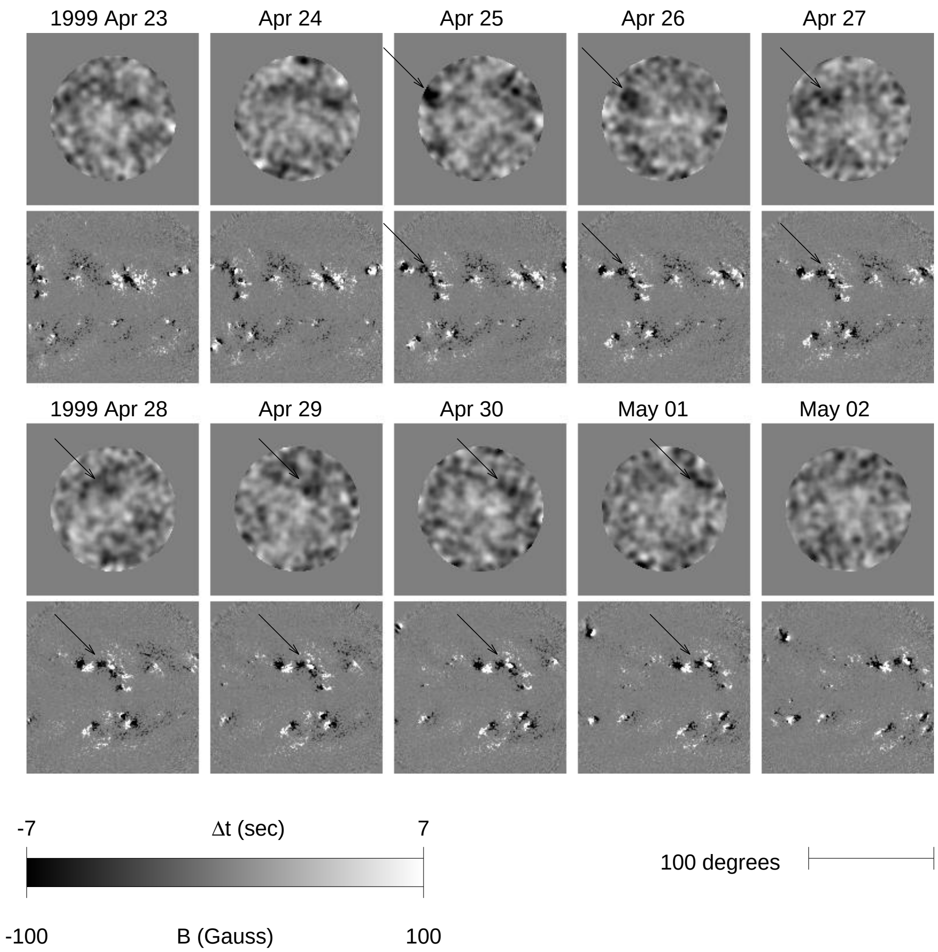

Figure 1. A series of seismic images of the far side of the Sun, derived from SOI-MDI observations. Each day is represented by a pair of images: the upper frame shows a travel-time perturbation map of the solar far side, integrated over a 24 hour period beginning on the date indicated above each frame pair, while the bottom frame shows a magnetogram of the same region after it has rotated to the near side two weeks later. The reduced travel-times in plages, which are the primarily signatures of active regions in these images, are very likely the major source of the global p-mode frequency variations with the solar cycle. The spherical-harmonic degrees of the p-modes contributing to these images range from approximately 20 to 40. The images are Postel's projections, centered on the antipode of disk center at the midpoint of each day.

are likely the principal source of the global frequency shifts (Braun & Lindsey 2000b).

2. Far-side Imaging

Computational seismic holography is now providing us with images of active regions on the far side of the Sun (Lindsey & Braun 2000a), the possibility of which was first proposed ten years ago (Lindsey & Braun 1990). Figure 1 illustrates a series of images of the far side of the Sun over a ten day period, derived from SOI-MDI observations. The images show seismic signatures of several active regions, including one, marked by arrows, which is clearly visible on the far side for seven consecutive days. Substantial effort has been invested towards the prediction of flares and coronal mass ejections, based on the presence of active regions on the near solar surface. Active regions can rise rapidly from beneath the photosphere or appear on the east limb with relatively little warning. Because of this, the ability to anticipate the appearance of active regions will contribute significantly to forecasts of space weather on time scales of more than a day. In collaboration with Dr. Phil Scherrer and the MDI group at Stanford University we are currently deriving far-side images from the lower resolution "medium-ℓ" SOI-MDI Dopplergrams, which are obtained continuously throughout the year and arrive at MDI headquarters within 24 hours of their acquisition by the *SOHO* spacecraft. We are therefore already capable of imaging large far-side active regions and predicting their appearance on the east solar limb to within a few hours more than a week in advance. Moreover, ground-based sites such as the Global Oscillations Network Group (GONG+) will soon have the capability for "real-time helioseismology", and will be routinely monitoring the far surface of the Sun, and beneath the near surface, for emerging solar activity.

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