Proposal for Joint MDI/GOLF Data Analysis

Organizer: R.K. Ulrich (UCLA)
Participants: Carl Henney (UCLA), Scott Evans (UCLA), John Beck (UCLA & NSO), Rick Bogart (Stanford), Todd Hoeksema (Stanford) and Ted Tarbell (Lockheed)

Unconfirmed Participants: Patrick Boumier (IAS/Orsay), T. Roca Cortés (IAC), J.M. Robillot (Bordeaux)

1 Scientific Objectives

1. Removal of Active Region Effects
The MDI instrument provides 128×128 arrays of line depth proxy and continuum proxy time averaged on 12 minute centers. The spatial resolution has been degraded from 1024×1024 by boxcar binning. A low pass gaussian temporal filter with a standard deviation of 204 seconds has been applied to these images to remove high frequency aliases. The combined information from the line depth and continuum proxies allows an estimation of the magnetic field in each binned-pixel of the image. ¿From the estimated field strength, the change in the solar brightness at the GOLF working points of the NaD lines can be estimated allowing a correction to the GOLF signals. Pervious work has shown that the signals with periods of days due to active regions traversing the apparent solar disk can be explained by such models (Edmonds and Gough [1983]; Andersen and Maltby [1983]; Herrero, Jiménez and Roca Cortés [1984], Ulrich*et al.*[1993]).

2. Calibration of the MDI integrated signal.

The MDI instrument does not contain an atomic wavelength reference and relies on the thermal stability of the filter system to provide a velocity reference. In addition to the continuum intensity and line depth parameters, MDI will also provide steady-flow velocity images in the same 128×128 array on 12 minute time centers format. The integrated sunlight velocity measurement from GOLF does not weight all parts of the solar disk evenly. By integrating over the steady-flow velocity images, we should be able to provide a simulation of the GOLF image as derived from MDI. Comparison of this simulation to the real GOLF signal may reveal drifts in the MDI instrument and allow an effective atomic calibration of the MDI signal to the GOLF atomic reference. This will allow us to study the velocity signal from the center of the solar image which has proven to have a different spectral shape than does integrated sunlight. John Beck has recently obtained the spectrum shown in Figure 1 from a central circle 10 pixels across on the solar image from the GONG instrument where the solar disk diameter is 248 pixels. A report on this work is in press in the proceedings of the Asilomar conference.

Although disk center is a poor place to find low frequency or high ℓ $g-$modes, for $\ell = 1$ and 2, and for periods shorter than about 2 hours, the modes are as visible at disk center as anywhere on the solar image. Christensen-Dalsgaard and Gough (1982) have discussed the relationship between vertical and horizontal velocity using an isothermal atmosphere model. Ulrich and Evans (1992) have given results for both globally coherent $g-$modes and a supergranulation induced response. Figure 2 shows the result from Ulrich and Evans (1992). The vertical velocity is greater than the horizontal velocity for modes with periods less than 180 minutes. Consequently, it is clear that there is a good range of modes accessible to observation at the the disk center and in addition the cancellation of parts of the oscillation mode with opposite velocities which cuts off the full-disk visibility of the higher ℓ modes is not a factor at disk center. Thus, a wider range of ℓ may actually be observable this way.

2 Calculation of Magnetic Darkening from MDI Data

Both GOLF and MDI must be well understood. Good calibration of both will be required. Calibration of MDI is not required for the $p-$mode oscillation studies and an adequate calibration to carry out the Magnetic Darkening correction for GOLF may not benefit any other aspect of the MDI program.

- a) MDI observes $\alpha(x,y)$. An on-board lookup table will convert $\alpha(x,y)$ to $v(x,y)$: $v(x,y) = f(\alpha)$. Averages of $v(x,y)$ to a spatial array 128×128 $\overline{v}(x,y)$ are calculated and sent down on a cadence of one image every 12 minutes. The look-up table can only apply to one point of the solar image and is inappropriate for all other points of the solar surface. The actual relation between α and v has temporal and spatial dependence due to magnetic effects and the center-to-limb dependence of the λ676.8nm line profile.

- b) The original $\alpha(x,y)$ must be recovered from the inverse f transform f^{-1}. However, these α's refer to the averages so we have:

$$\overline{\alpha} = f^{-1}\Big(\overline{v}(x,y)\Big)$$

- c) The MDI data includes $I_{\rm depth}(x,y)$ and $I_{\rm cont}(x,y)$ which are averaged over the same grid as $v(x,y)$. The combination of $I_{\rm depth}$ and $I_{\rm cont.}(x,y)$ depends on the magnetic field in a way which has not yet been fully explored. It should be possible to derive a magnetic proxy from $I_{\rm depth}(x,y)$ and $I_{\rm cont}(x,y)$.

- d) Using a multiple variable set of look-up tables we can calculate

$$V(x,y) = a(x,y)\overline{\alpha}(x,y) + b(x,y)I_{\rm depth}(x,y) + c(x,y)I_{\rm cont}(x,y)$$

$$B(x,y) = d(x,y)\overline{\alpha}(x,y) + e(x,y)I_{\rm depth}(x,y) + f(x,y)I_{\rm cont}(x,y)$$

  These relations are shown as linear on the grounds that the non-linear true conversion can be linearized around the spatial points. It will be important to hold the filter tuning to a relatively fixed position with respect to the solar line so that this linearity can be preserved. The full set of coefficients needs to be derived and this probably will require some special observations at the beginning of the mission.

- e) Using $B(x,y)$ and $I_{\rm cont.}(x,y)$ we can calculate a Magnetic Darkening Velocity (MDV) for the GOLF experiment. This correction can then be applied to the GOLF velocity.

3 GOLF–MDI Intercomparison

The purpose of this exercise will be to obtain a disk center velocity from MDI which takes advantage of the GOLF signal as a means of providing an atomic reference. The following steps are needed:

- a) Recalibrate MDI to remove filter defects and magnetic effects.

- b) Correct and calibrate GOLF signal to remove thermal and other environmental effects.

- c) Correct GOLF signal for magnetic effects using MDI images and the 4-point GOLF data. Any GOLF publication utilizing MDI data in this step will probably require the inclusion of some MDI investigators as co-authors.

- d) Compare Na D_1 and $\lambda 6768$ velocities on a point by point basis using Mt. Wilson observations. This will give line dependent offsets.

- e) Carry out a spatial integral of the MDI velocity using an appropriate GOLF response function $G(x,y)$ to provide a simulated GOLF signal:

$$v_{\rm GOLF}^{\rm sim} = \int_{x,y} G(x,y)V(x,y)\,dx\,dy$$

for the MDI instrument.

- f) Adjust the MDI simulation of the GOLF signal so that it agrees with the magnetic effects corrected GOLF velocity.
- g) Study the power spectrum of the disk center MDI velocities. This signal may be the least contaminated by solar noise available. Any publication resulting from steps e) and f) will have to be joint between the GOLF and MDI teams in a manner to be agreed upon by the two Principal Investigators.

4 Current Status

A few gound-based MDI images are available and have been used to begin deriving the coefficients $a(x,y)$ to $f(x,y)$. Most of these tasks cannot begin until a substantial data set is available. We will begin task e) of the GOLF–MDI Intercomparison this summer. During the early phase of the mission, probably before arriving on station, a special sequence of MDI images will be obtained in which the tuning of the Michelson filters will have smaller than nominal steps between them. This will allow a derivation of the coefficients relating $V(x,y)$ and $B(x,y)$ to the observable quantities.

5 References.

Andersen, B.N. & Maltby, P. 1983, *Nature,* **302**, 808.

Christensen-Dalsgaard, J. & Gough, D.O. 1982, *M.N.R.A.S.,* **198**, 141.

Edmunds, M.G. & Gough, D.O. 1983, *Nature,* **302**, 810.

Herrero, A., Jiménez, R. & Roca Cortés, T. 1984, *Mem. Soc. Astr. Ital.,* **55**, 331.

Ulrich, R.K. & Evans, S. 1992, in: *GONG 1992:Seismic Investigation of the Sun and Stars*, ed. T. Brown, (Astron. Soc. Pacific, San Francisco), 277

Ulrich, R.K., Henney, C.J., Schimpf, S., Fossat, E., Grec, G., Loudagh, S., Schmider, F.-X., Gelly, B., Pallé, P., Régulo, C., Roca Cortés, T. and Sanchez, L. 1993, *Astr. Ap.,* **280**, 268.

Figure 1 – The power spectrum of the GONG disk center velocity obtained from 6 days of data observed at Tucson. A circular aperture of radius $0.08R_\odot$ was used to select the disk center region. The lower panel gives the raw observations with the Ephermeris velocity subtracted.

Figure 2 – The ratio of vertical velocity U to horizontal velocity V for global $g-$modes (solid line) and for the atmospheric response to a supergranulation

perturbation (crosses). The ratio for the supergranulation is evidently an overestimate based on the observations from figure 1 which show the actual solar ratio to be very small. The global $g-$mode result is for $\ell = 2$. The ratio for the $g-$modes depends primarily on period and this solid line is appropriate for a range of ℓ with only small adjustment.