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Mapping the Sound Speed Structure of the Sun's Atmosphere

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Abstract. We describe an instrument for seismically probing the acoustic properties of the Sun's lower atmosphere. The instrument, which is based on magneto-optical filter technology, acquires full-disk Dopplergrams simultaneously in the K D1 (770 nm) and Na D2 (589 nm) Fraunhofer lines. The Dopplergrams have a spatial resolution of ≈5 arc secs and are recorded at a cadence of one frame every 10 seconds, average from 16 frames per second. These data allow us to use acoustic waves with frequencies beyond the cut-off frequency for the solar atmosphere ($\approx 5mHz$) to map the spatial and temporal changes in the vertical wave travel time between the mid-chromosphere and the low-photosphere. These types of maps will provide a strong constraint for models of the solar atmosphere and possibly study early warnings for explosive phenomena. We present some preliminary results from observations made at the geographical South Pole during the 2002/2003 Austral summer. We also discuss our program for the next campaign with instrumental improvements as far as a third level Dopplergram and magnetographic capability. We also consider cloning the instrument for Dome C in order to further minimize atmospheric noise and gaps in the data string due to bad weather.

Key words. MOF – Time distance analysis – Helioseismology – Solar Atmosphere Diagnostic

1. The instrument

The instrument used at South Pole is made of two optical parallel benches, each carrying a MOF (Filter + Wing Selector; for a complete description, see Cacciani et al., 1990 and 1994, JPL #D 11900, in www.phys.uniroma1.it /Dipw /serverdip.htm clicking G28). One MOF is tuned in the Sodium D2 line (5889.97 Å) while the other is tuned in the Potassium D1 line (7698.98 Å). The system separates the red and blue components of each solar line with the help of a $\lambda/4$ plate followed by a beam splitter feeding them into 4 digital 12 bit cameras. A schematic layout of the optical instrument is shown in Fig. 1, while Fig. 2 shows a picture of the over-

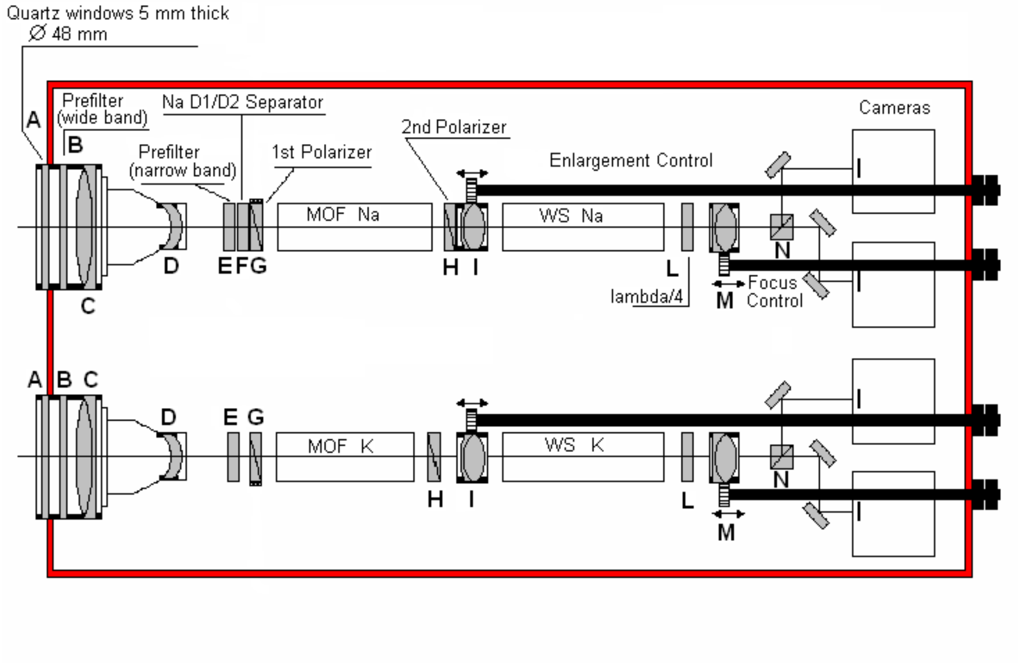

Fig. 1. Scheme of the optical components of the instrument.

Fig. 2. The instrument assembly.

all mechanical assembly. The 4 black boxes visible on the right top side of Fig. 2 are modem transceivers that convert the camera outputs into a fiber optic data transmission. Images are then recorded on the hard disk of a personal computer housed in a container buried under the ice 30 meters away. The cameras can acquire images at the maximum rate of 16 frames per second, but the PC integrates the signals over 10 seconds, up to 16 bits, before recording. Therefore, four 512x512 pixel images, with a resolution of ≈ 5.3 arcsecond / pixel, are stored in a 1 Terabyte Raid hard disk system. While a one minute temporal resolution is acceptable to produce the Power Spectra of Fig. 4, we need 10 seconds velocity image cadence to detect the travel time shown in Fig. 5 (which was expected to be less than one minute).

2. The Data

The longest acquisition run lasted up to more than 100 hours, collecting 4 images every 10 seconds (Na red, Na blue, K red, K blue). Summing simultaneous red and blue images produces the Intensity sequence, while their difference, normalized to the local intensity, produces the Velocity sequence. In Fig. 3 samples of Intensity and Velocity images are shown for the two solar

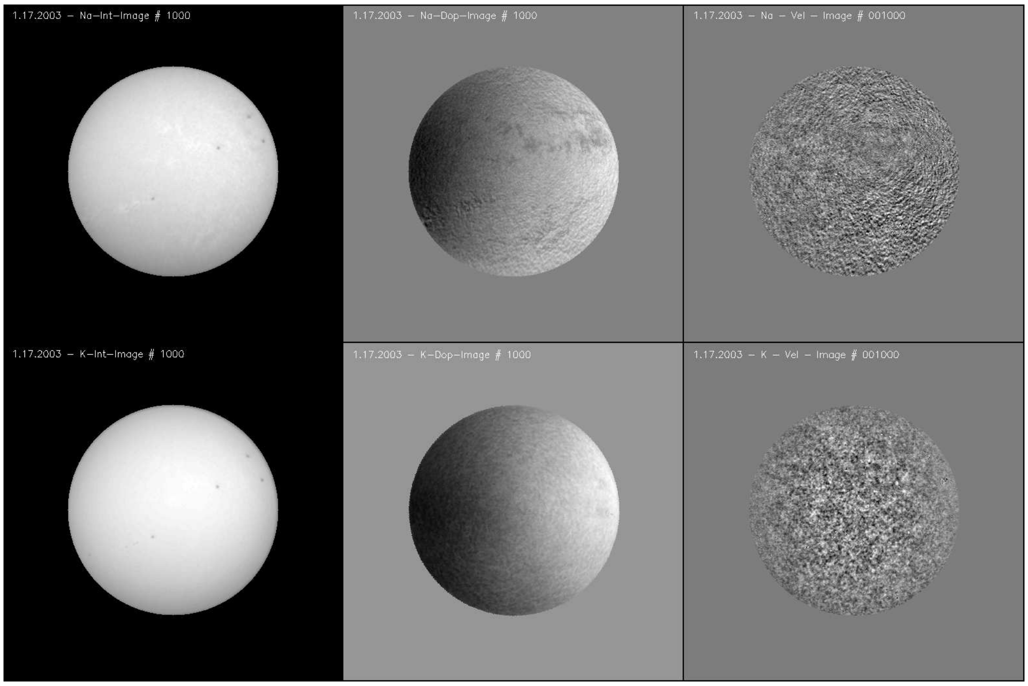

Fig. 3. Intensity(left), Velocity(middle) and rotation suppressed Velocity(right) sample images in the Na line (above) and in the K line (below).

lines. Local velocity images, obtained cancelling the solar rotation, are shown as well: they result from the difference between two Velocity images one minute apart. 3000 images of this kind have been used to obtain the Power Spectra of Fig. 4. Actually, because the expected value of our measured time delay for the acoustic p-waves between the K and the Na layers in the Sun's atmosphere is $\approx 20s$, we are currently processing velocity images taken with a time resolution of at maximum 10 seconds in order to obtain a reliable measurement of the acoustic travel time in the atmosphere. Moreover, to avoid confusion and unnecessary noise coming from the resonant waves reflected back into the solar interior, the Na and K signals have been first filtered to take out all the frequencies below the cut-off frequency ($\approx 5mHz$); then a time-distance analysis is applied to find the travel time by cross correlating the resulting signals.

Fig. 5 shows a travel time map for a 100x100 pixel square in the centre of the disk. The resulting mean value is $\approx 27s$ and turns to be different pixel by pixel. The signals have been filtered with a gaussian filter centred at 7 mHz. The same computation using a filter centred on 3 mHz, gives zero mean value, that is, no travelling waves are present below the frequency cut off . The same appears to happen in magnetic regions above and below the cut off frequency. The analysis is in progress and more data are required to derive firm conclusions. In particular our plan is to implement a third level of Doppler measurements along with the magnetic capability of the instrument.

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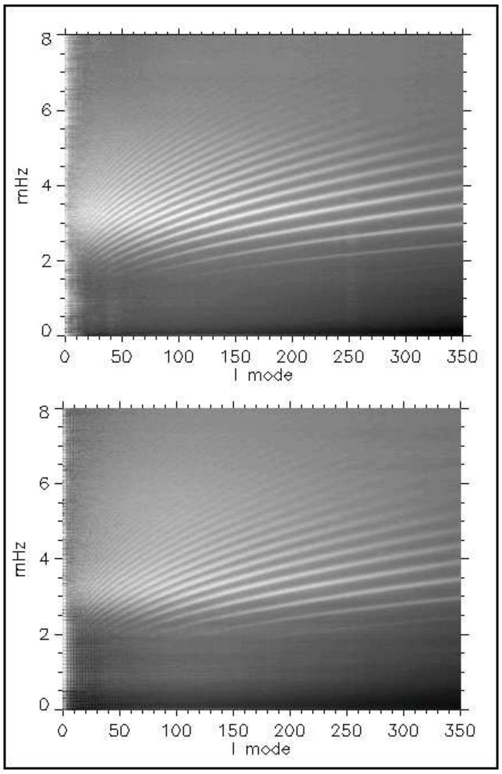

Fig. 4. K D1 line (above) and Na D2 line (below) Power Spectra.

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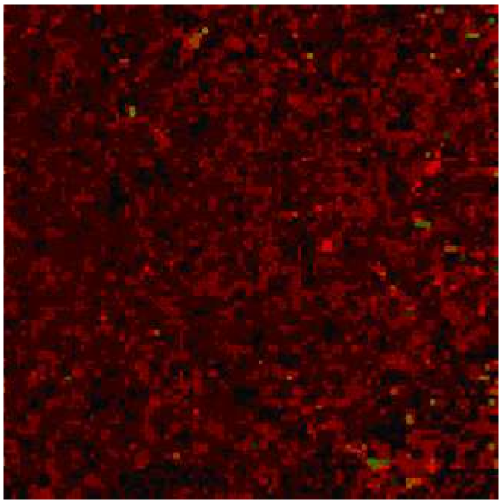

Fig. 5. Time Lag Map @ 7 mHz for 100x100 pixel square at the centre of the Sun (average: 27 seconds).

References

Cacciani, A. and Fofi, M., 1978, "The Magneto-Optical Filter, Velocity Field Measurements", Solar Phys., 59,179

Cacciani, A., Rosati, P., Ricci, D., Egidi, A., Appourchaux, T., Marquedant, R.J., and Smith, E.J., 1994, "Theoretical and Experimental Study of the Magneto-Optical Filter", JPL Report # D11900

Grossman-Doerth, U., 1994, "Height of formation of solar atmospheric spectral lines", Astron. Astrophys., 285, 1012

Jefferies, S.M., 1998, "High Frequency Solar Oscillations", New Eyes to See Inside the Sun and Stars, eds. F.-L. Deubner et al., Proc. IAU Symposium 185