Correcting Dopplergrams in active regions

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Abstract

MDI Dopplergrams are produced by using four out of five measured filtergrams which are sensitive to intensity fluctuations in the wings of the Ni I absorption line at 6768 Å. The line of sight velocity is calculated onboard SOHO from a lookup table which is based on the shape of the line in the quiet sun at disk center. In magnetic regions, however, the line shape changes with the strength and the inclination of the magnetic field, and with the different thermal stratification.

Based on high spectral resolution images of magnetic regions obtained by the ASP (Advanced Stokes Polarimeter) instrument we show that the MDI Doppler velocities are systematically underestimated in magnetic regions, and suggest a first order correction based on a proxy of the line's width and the line asymmetry.

Special campaigns on MDI provide all five filtergrams. For such a campaign, we present Dopplergrams and their first order correction.

We calculate the difference in the travel time maps, power maps, and phases for the corrected and the uncorrected version.

Observations with the MDI

MDI-like algorithm — We use the Fourier transform of the filtergrams to estimate parameters describing the line profile:

$$f_k = \sum_{j=0}^{N-1} F_j e^{2\pi \mathrm{i} kj/N} \tag{1}$$

$$v \approx k \arg(f_1)$$

MDI uses the phase of the first Fourier component together with a lookup table to determine the line-of-sight velocity.

Polarization

MDI measures velocity in linear polarization (mostly used in full disk mode), and in circular polarization (mostly used in high res. mode). Circular polarization measurements are the average of the velocity from the left hand (LCP) and right hand (RCP) circular polarized component. Averaging is done to cancel out the Zeeman splitting which is present in the single polarized components.

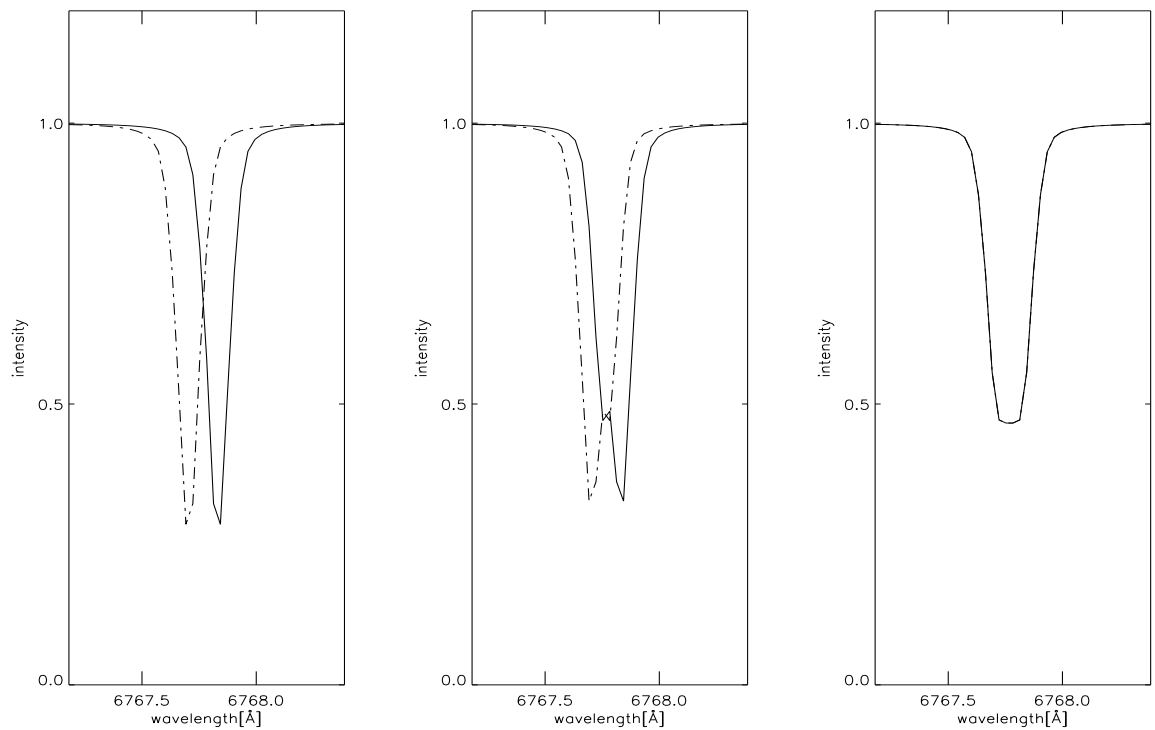


Figure 1: Line shape of Ni I 6768 in LCP, RCP for magnetic field inclinations of 0° (left), 45° (middle), and 90° (right).

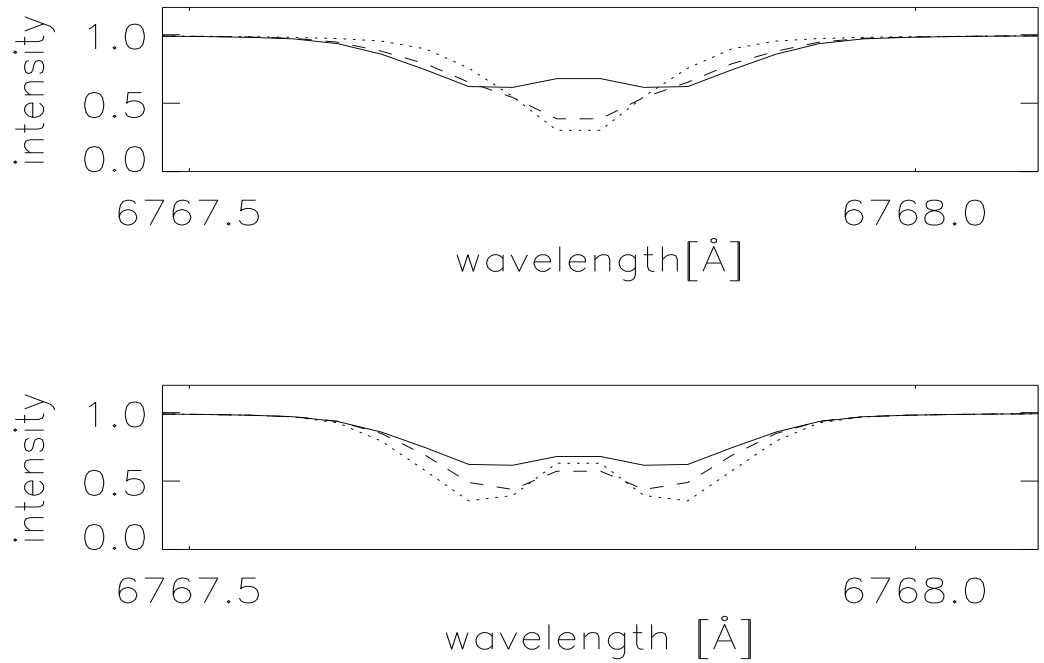


Figure 2: Line shape of Ni I 6768 in horizontal linear polarization (upper panel) and vertical linear polarization (lower panel) for inclinations of $0°$, $45°$, and $90°$, and a strength of 2000 Gauss.

Line width and asymmetry from MDI filtergrams

For a Gaussian profile:

$$I = I_c(1 - Ae^{-(\lambda-\lambda_0)^2/(2\sigma^2)}) \tag{2}$$

we get:

$$\sigma \approx \sqrt{\frac{2a^2}{3} \ln \frac{|f_1|}{|f_2|}} \tag{3}$$

The difference between two Fourier velocities

$$\alpha := k(\arg f_1 - \arg(f_2)/2)$$

will be taken as a measure of line asymmetry.

NOAA 10752, Apr. 13 through Apr. 17th 2005

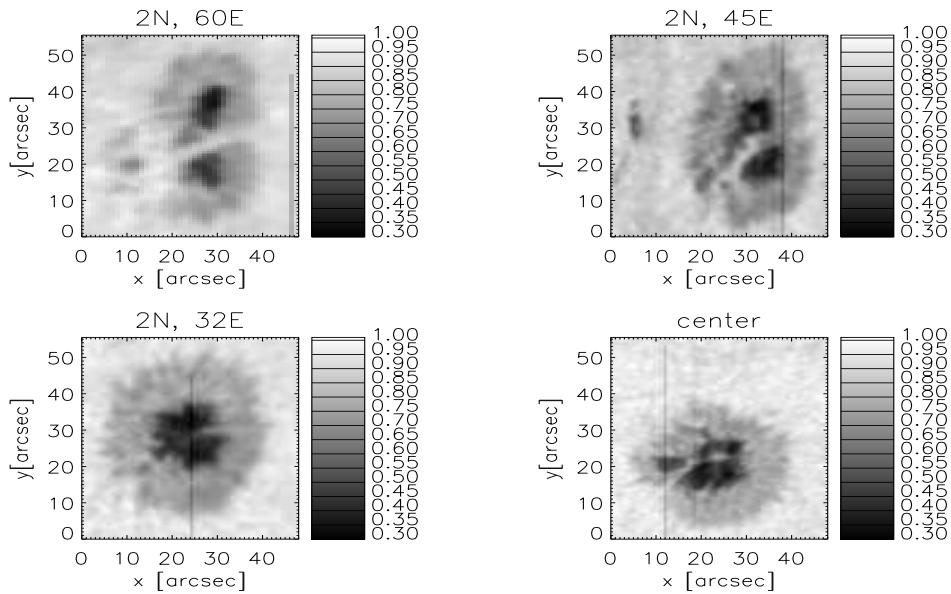


Figure 3: NOAA 10750 in continuum intensity. The spectral resolution for our ASP observations is 17.1 mÅ, the spatial resolution is (0.6 $\times$ 0.37) arcsec / pixel. We observed the spot rotation from the east limb to the center.

Velocity sensitivity factor

We take the absorption line in each particular polarization state as they are observed by the ASP instrument and shift it in wavelength according to a Doppler shift corresponding to velocities from -3 km / s to + 3 km /s in steps of 0.1 km /s. This corresponds to a vertically homogeneous velocity. Before doing so, we estimate the real velocity for each pixel by performing Milne-Eddington inversions and shift the line back to represent zero velocity. We apply the MDI filters to the line to obtain the "measured" velocity. We fit a straight line to the input-velocity – output velocity graph:

$$v_{out} = s_f(\{p\})v_{in} + c_f(\{p\}) \tag{4}$$

Here, s_f is the velocity sensitivity factor, which is derived for each pixel. We look for parameters which can be derived from MDI filtergrams and which correlates well with s_f, independent from the particular shape of the active region.

Using an estimate of the line width and asymmetry, we can perform a correction on the tracked Dopplergrams:

$$v_{corr}(x, y, t) = (v - c_f) / s_f$$

The correction should be time independent or have a slow time dependence to account for the time evolution of the active region because the line shape parameters depend in reality somewhat on the central wavelength. A minute-by-minute correction can represent a worst-case-scenario for the phase distortions due to an oscillating line shape.

Obtaining the velocity sensitivity factor from ASP

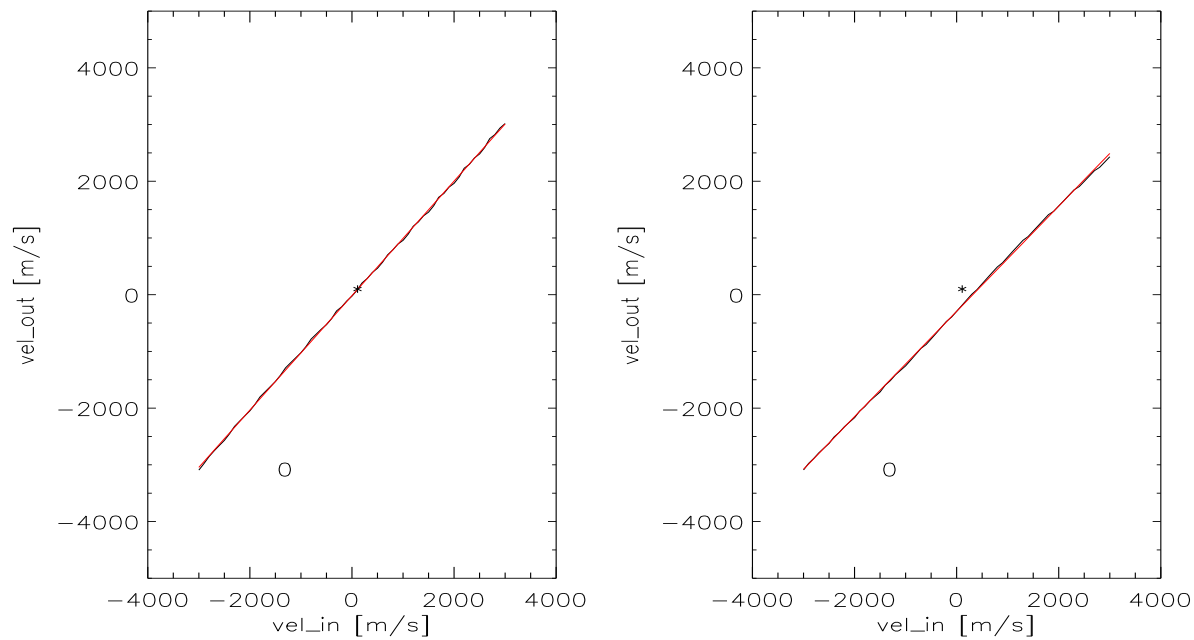
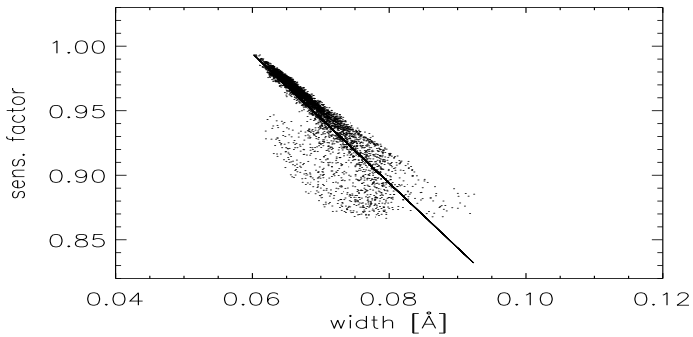


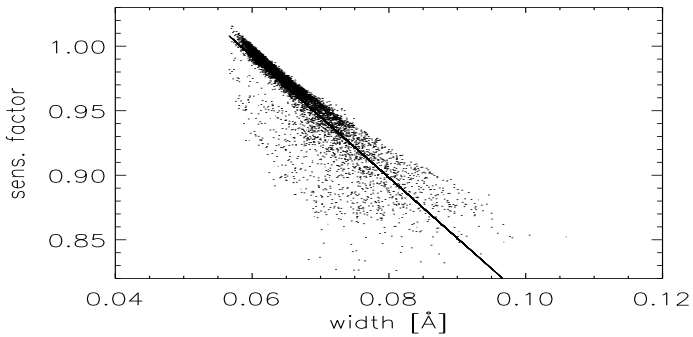
Figure 4: Input (Doppler shift) versus output (detected by MDI) velocity, and a linear fit to the curve for the quiet sun (left) and an umbral line (right).

Width and velocity sensitivity factor

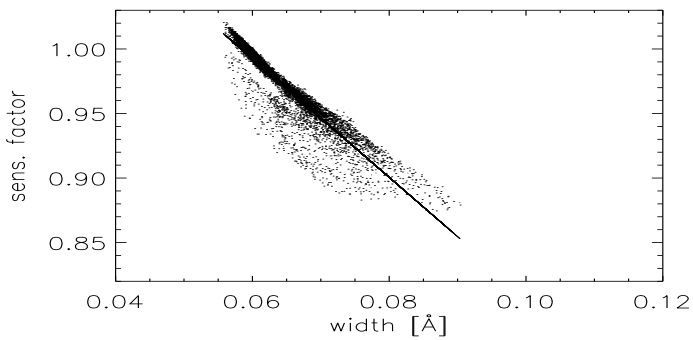
(2N, 60E)



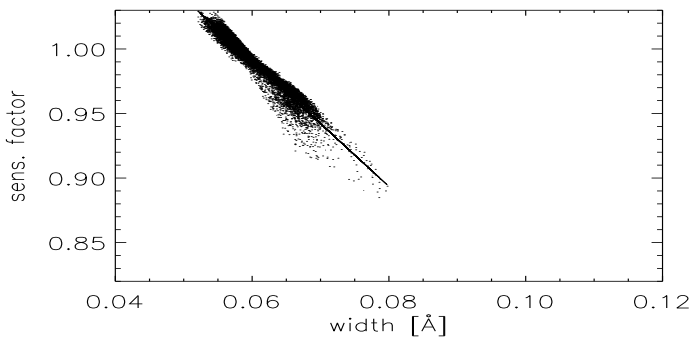
(2N, 45E)



(2N, 32E)



(2N, 5E)



Line width and velocity sensitivity factor at disk center

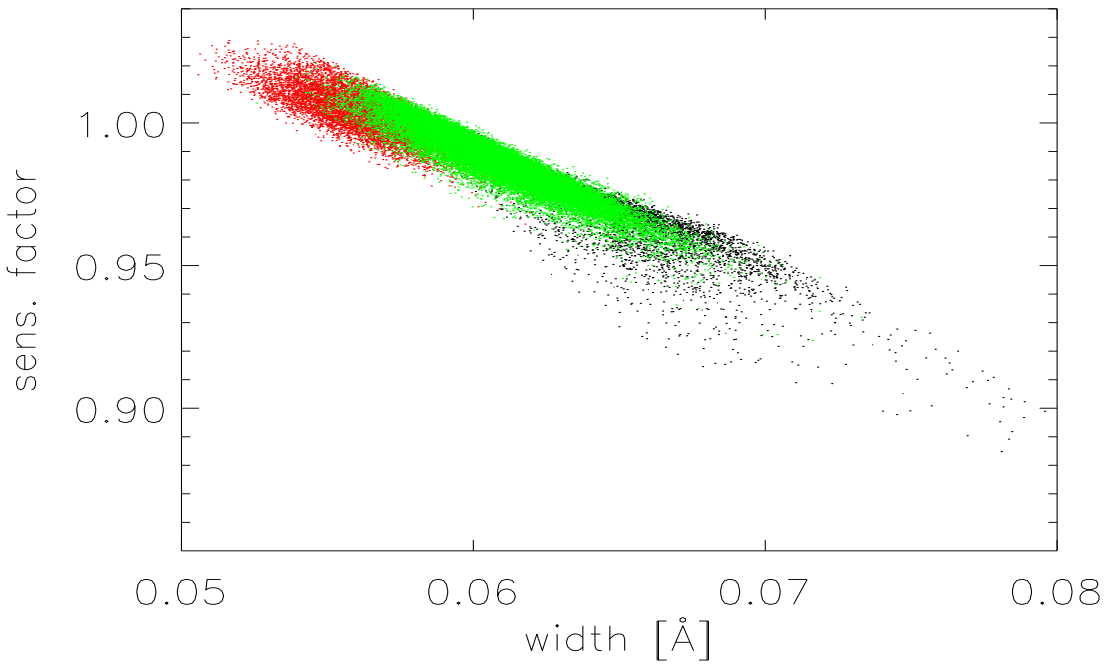


Figure 5: Combined scatter plot for different active regions, observed with different instrumental setups at disk center. The black dots represent a sunspot, the green dot represent a plage region, and the red dots a quiet sun region.

Linear Polarization

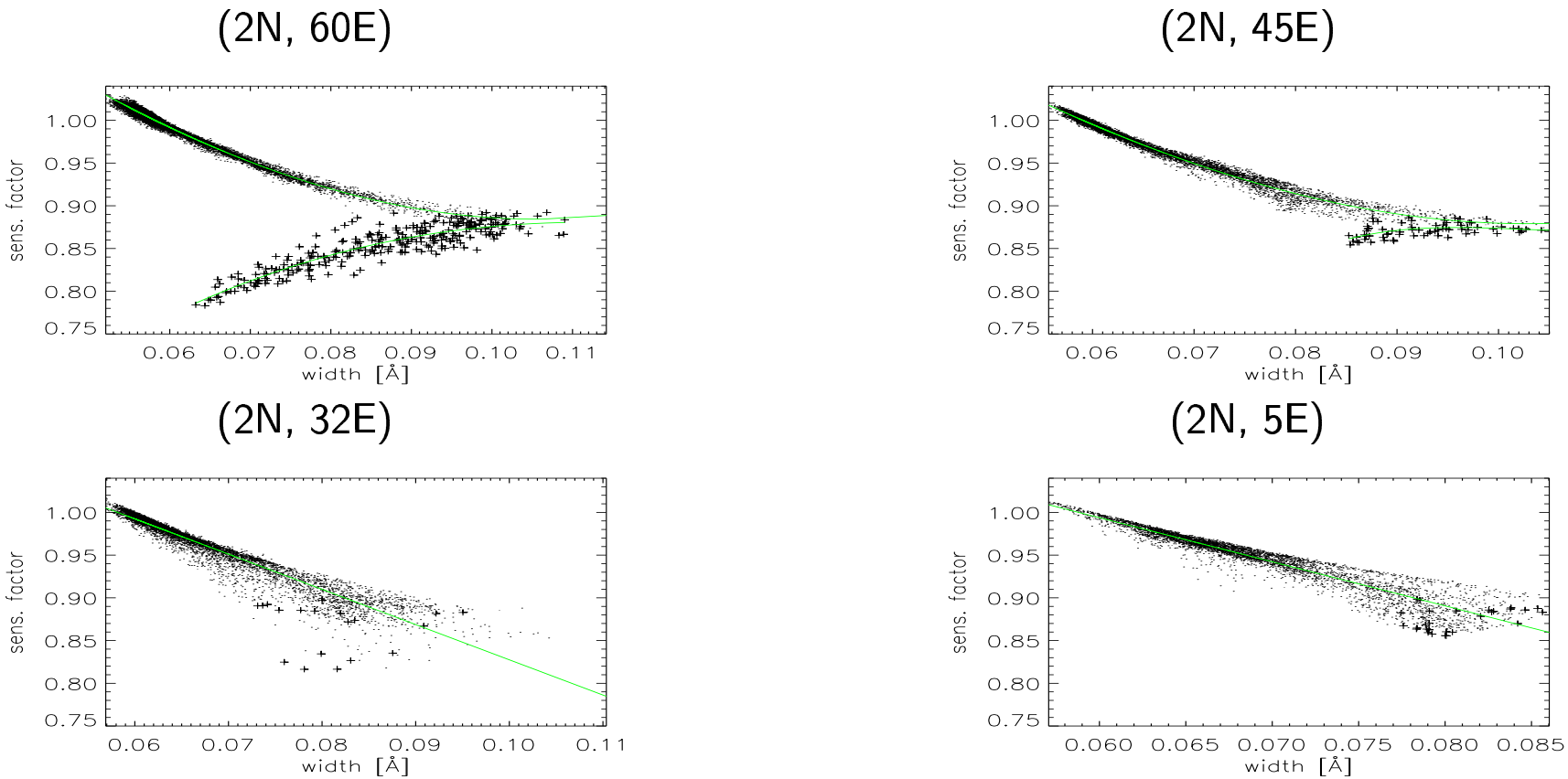


Figure 6: Scatter plots for linear polarization. A kink occurs at the transition from Zeeman broadening to Zeeman splitting.

NOAA 10750 Active Region

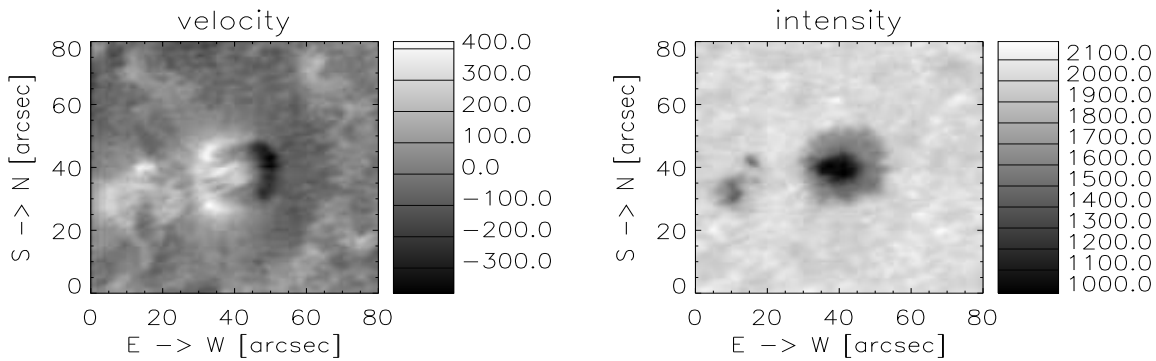


Figure 7: Average velocity and continuum intensity map for the active region for which we calculate the corrected Dopplergrams.

Width for MDI and ASP for NOAA 10750

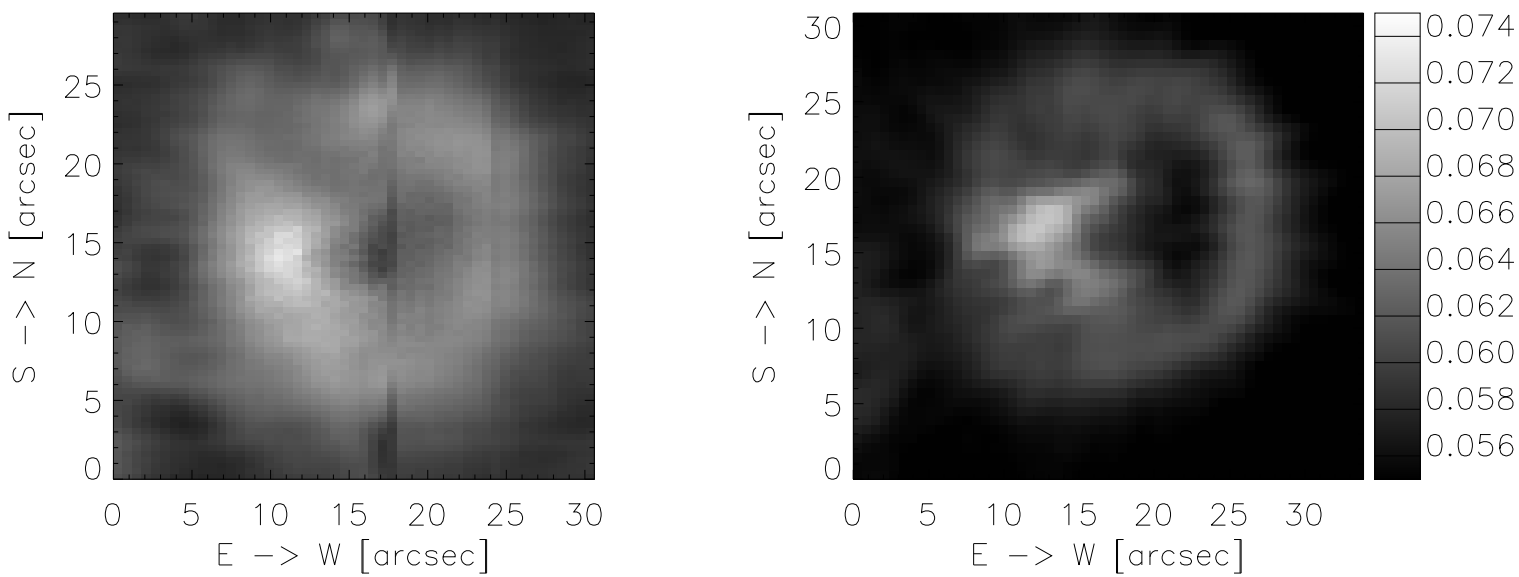


Figure 8: Simultaneously observed line width (LCP, RCP averaged) using expression 3 for NOAA 10750 from ASP (left panel) and MDI (right panel). The spot is close to disk center. We see the enhanced width along a ring-like structure where the fields are horizontal.

Travel time map

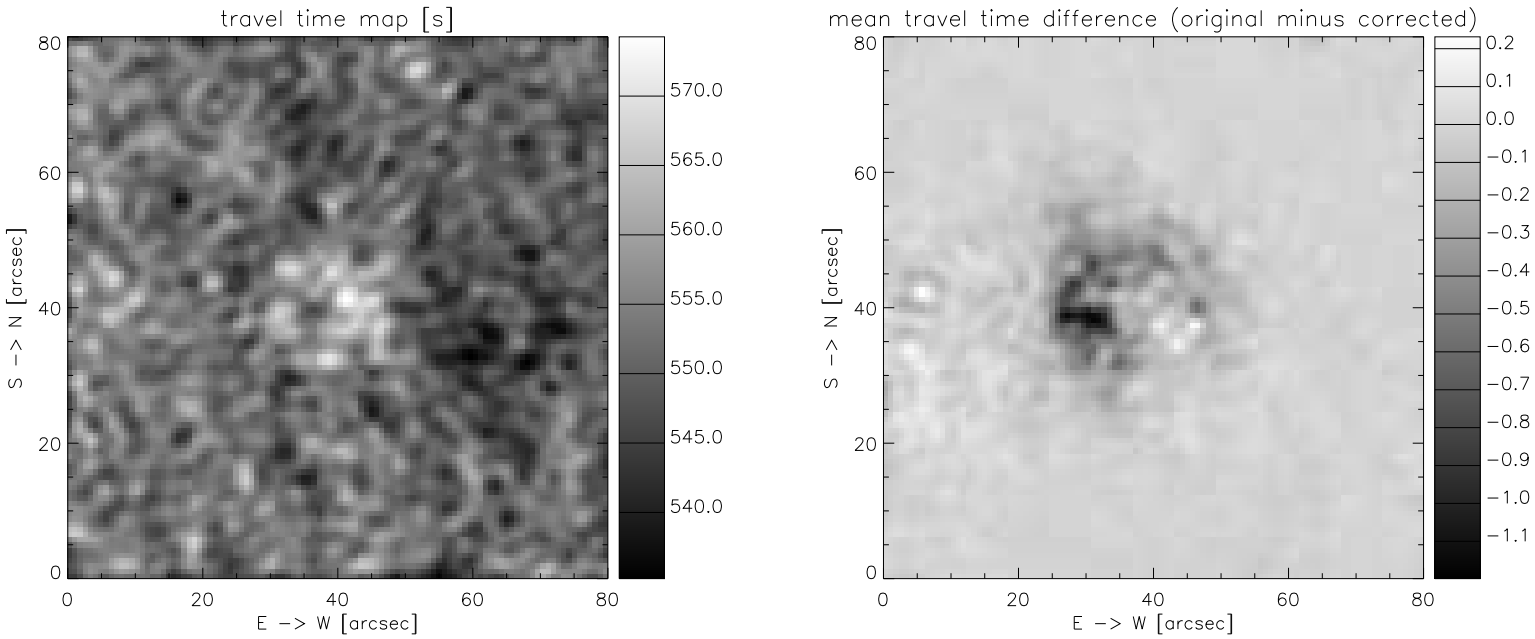


Figure 9: Center-to-annulus travel time map for the uncorrected data cube of Dopplergrams for NOAA 10750 (left panel), and the difference between travel time maps from corrected and uncorrected Dopplergrams.

Power maps (NOAA 10750)

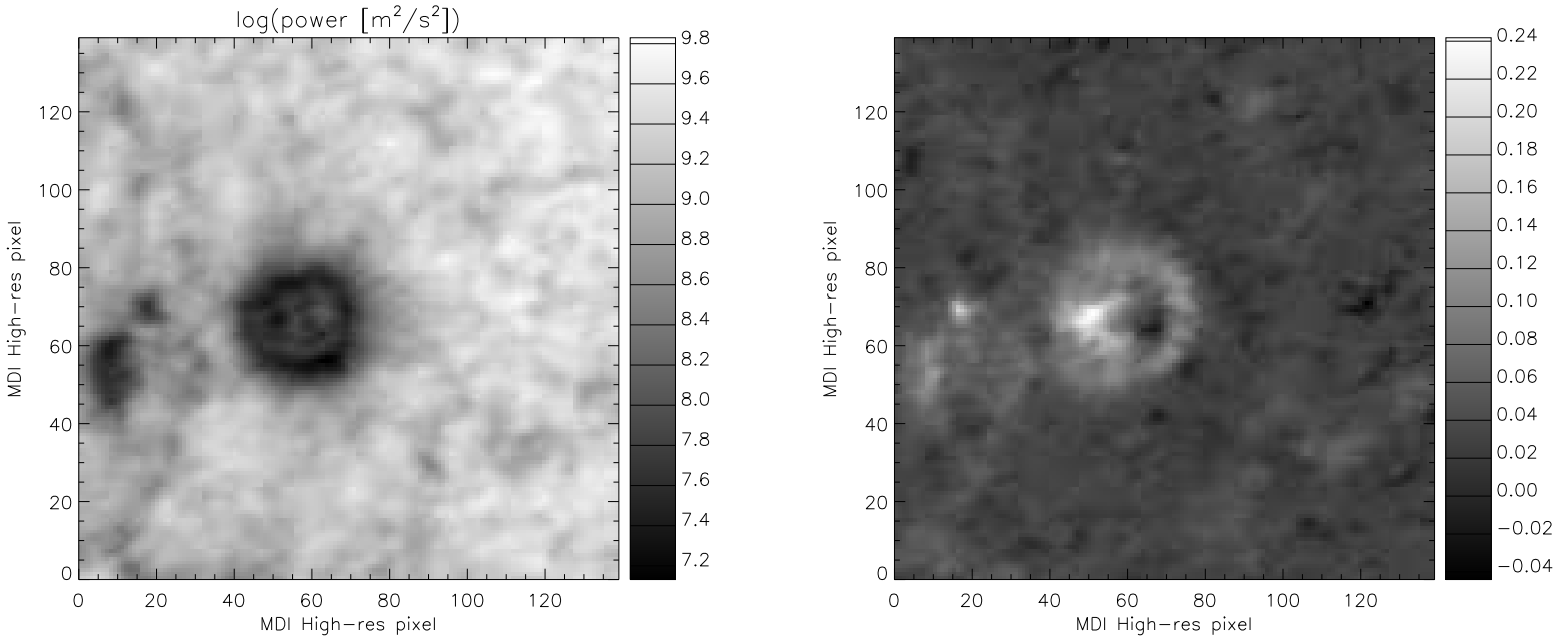


Figure 10: Corrected powermap (left) for NOAA 10750 and the difference between the corrected and the uncorrected powermap for an average correction.

Power map (NOAA 10822)

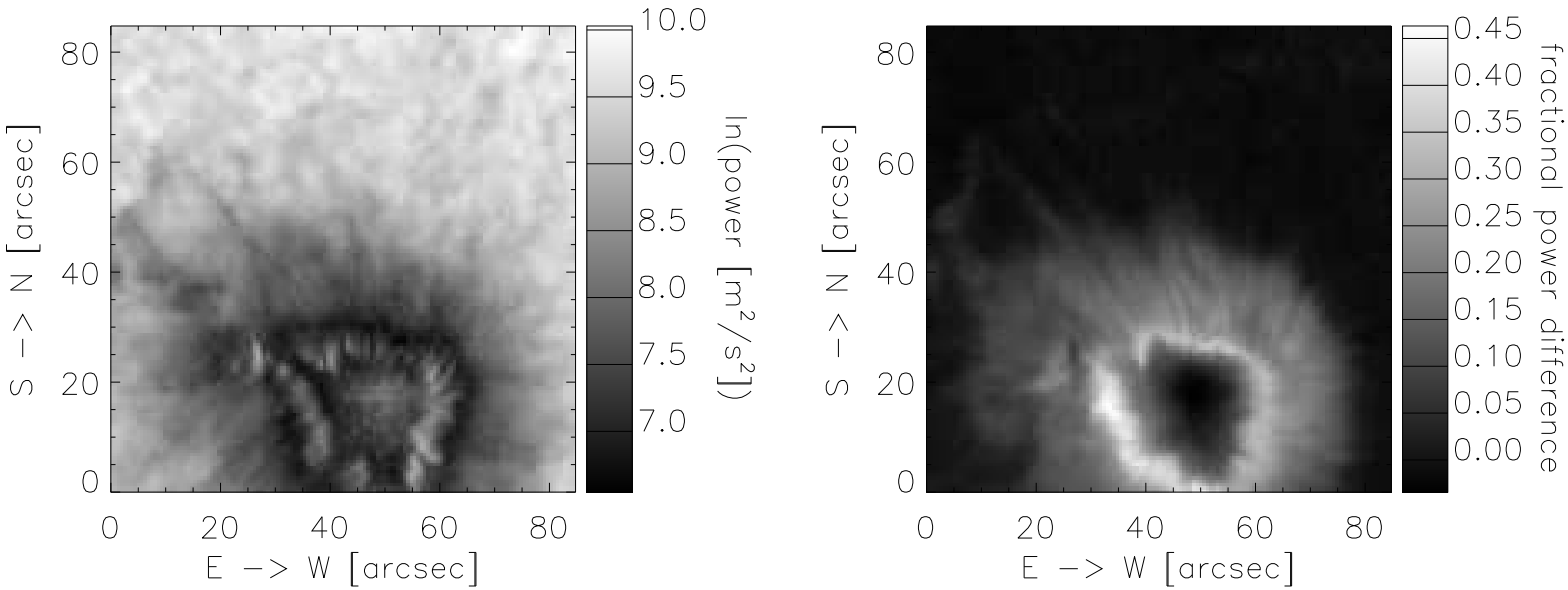


Figure 11: Same as Figure 10 for NOAA 10822. Although the power correction is quite substantial, the power depression can not be explained by measurement effects alone.

Phase correction

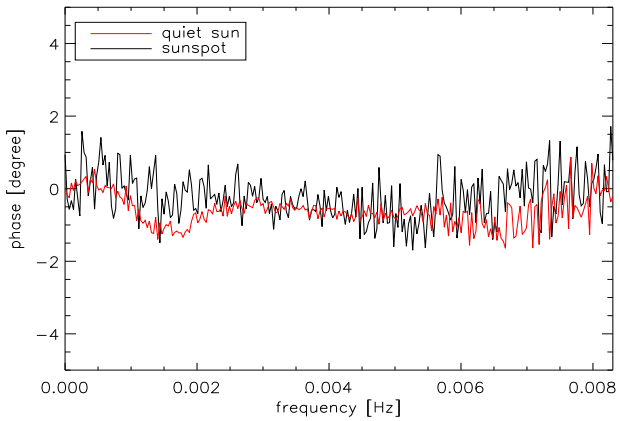


Figure 12: If we correct the Dopplergrams minute-by-minute, we can check the phase variation between the original and the corrected data cube. Here, the spatially averaged phase variation is shown as a function of frequency.

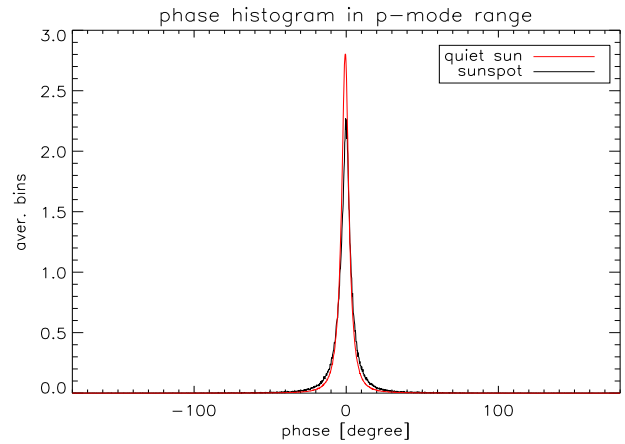


Figure 13: Histogram of the phases in the p-mode range (1.7mHz $< \nu < 5.2$ mHz). The histograms are made for the frequency bins of each pixel and averaged spatially.

No systematic phase shift!

Conclusions

MDI Dopplergrams of active regions can be corrected based on the information which is contained in the filtergrams. We can perform the correction for the so called "line profile campaigns" of MDI. The correction is model independent, and based on observations with the ASP instrument. The correction we suggest corrects the amplitudes of a tracked data cube for an active region. Although the correction for power maps is substantial, it doesn't change the well known features of active regions in powermaps.

For travel time maps the perturbation is marginal, because amplitude variations affect the center-to-annulus travel times only through the effects of annular averaging and phase speed filters.

A tentative minute-by-minute correction, which most likely results in an overcorrection because of the difficulty to estimate line profile parameter independent of the velocity, doesn't change the phases systematically.