

Searching for Moving Magnetic Features at 1565 nm

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We are particularly interested in moving magnetic features outside of the spot and how these motions are related to magnetic field fit parameters inside the spot produced by the Milne-Eddington inversion. Relationship between line of sight magnetic field strength variations at the penumbral boundary and the moving magnetic features seen in the photosphere is investigated in Harvey & Harvey (1973). Zhang, Solanki, and Wang (2003) observed that 7 of 144 MMFs appear first within the penumbral boundary. Both inward and outward movements of g-band bright points were observed by Bovelet and Wiehr(2003). Bonet *et al.* (paper I 2004) found that G-band bright points cross the penumbral boundary, these continuum features had speeds of 0.74 km/s, 0.51 km/s, mean radial outflow. For the first time we show magnetic features which start in penumbra and cross into quiet sun, appearing as familiar MMFs in the quiet sun we also see magnetic field strength features moving in the penumbra. Based on the fact that the motions observed have similar velocities to the G-band bright points in Bonet *et al.*, we hypothesize that these G-band bright points have a relation with the magnetic field.

The observations of NOAA active region 10663 commenced at 16:35 and ended at 20:50 UT with a cadence of 15 minutes on 26 August 2004. Seeing was good to fair and the McMath-Pierce main mirror was used with the CSUN-NSO IR camera. In addition to the Milne-Eddington results maps of the magnetic field have been made from the Stokes V spectrum using the strongest Fe I line near 1564.8 nm. Maps of the sunspot continuum were made with averages of the continuum spectrum. The completed maps are 256x240 pixels and each pixel corresponds to 0.1 arcsec.

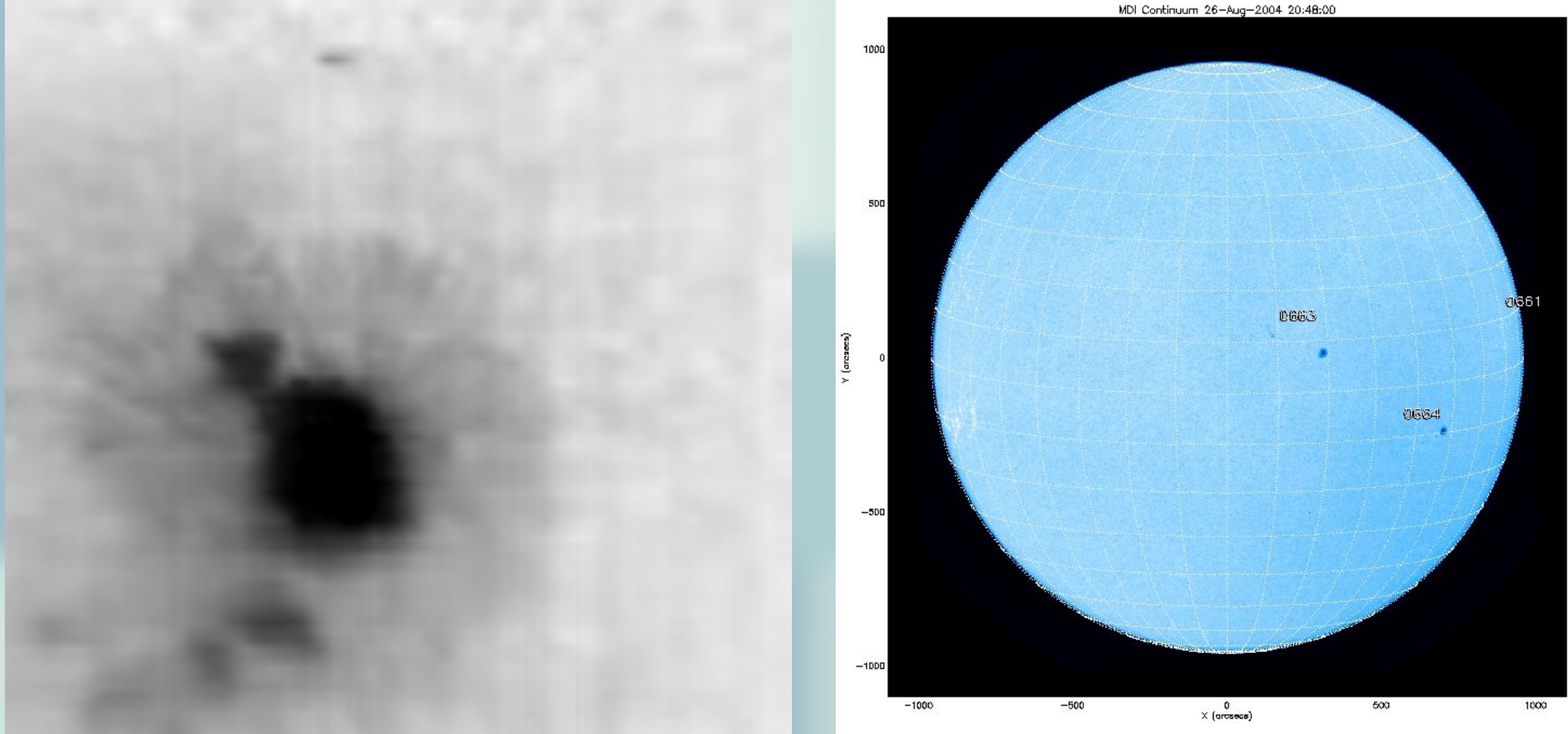


Figure 1. A continuum map of one component of the time sequence, provided for context is a full disk continuum image from BBSO's Active Region Monitor. The continuum map is shown correctly oriented, other such maps on the poster are horizontally inverted.

Results of the Milne-Eddington Inversion

A Milne-Eddington inversion was performed on the spectropolarimetric observations. Noise limits at 5×10^{-3} in polarization restrict successful fits to pixels inside the sunspot. The time sequence of inversion results shows moving features in magnetic field strength and magnetic field inclination as does the time sequence of magnetograms made from Stokes V. Fits to two pixels, one inside an enhanced region of magnetic field strength, and one pixel in a weaker region, are shown below.

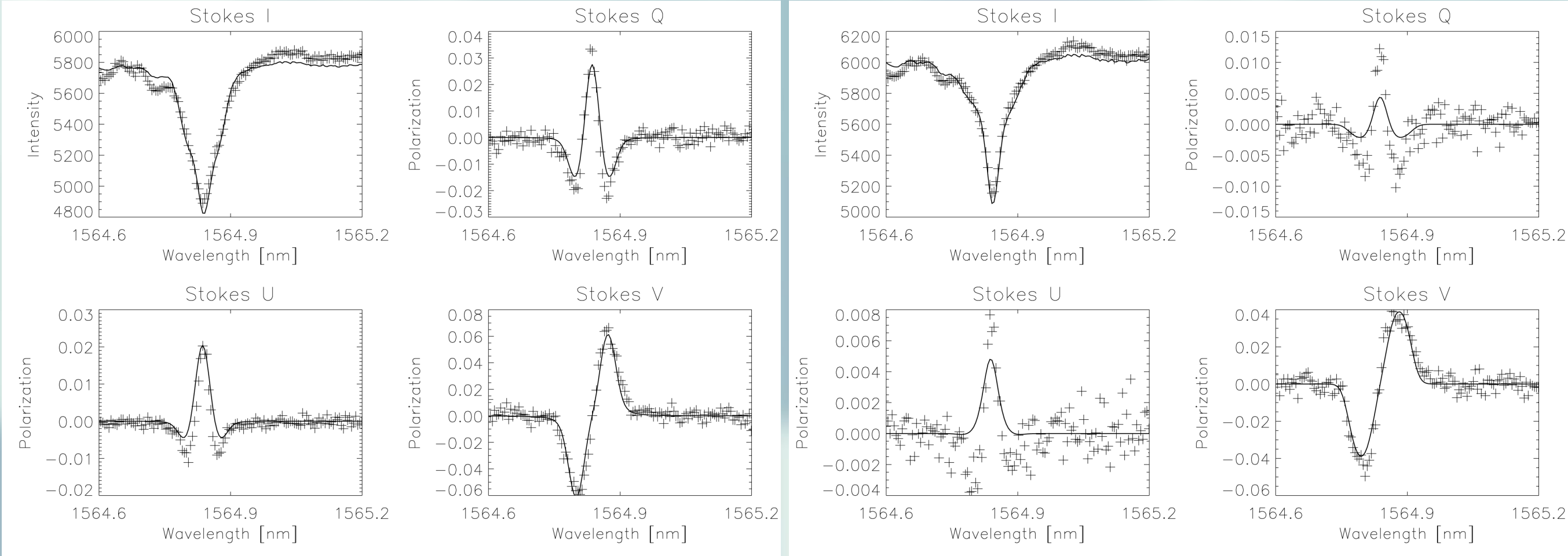


Figure 2. Examples of the Milne-Eddington fit for points behind(left) and within(right) the bright arc in figure 5.

Time Slices

The most obvious MMFs were identified, their paths were plotted over the 18 temporal frames. Time slices of position versus time of two such features are shown in figure 3 and the position of these paths are shown in figure 5. Speeds for other features in the penumbra and quiet sun are plotted in figure 4.

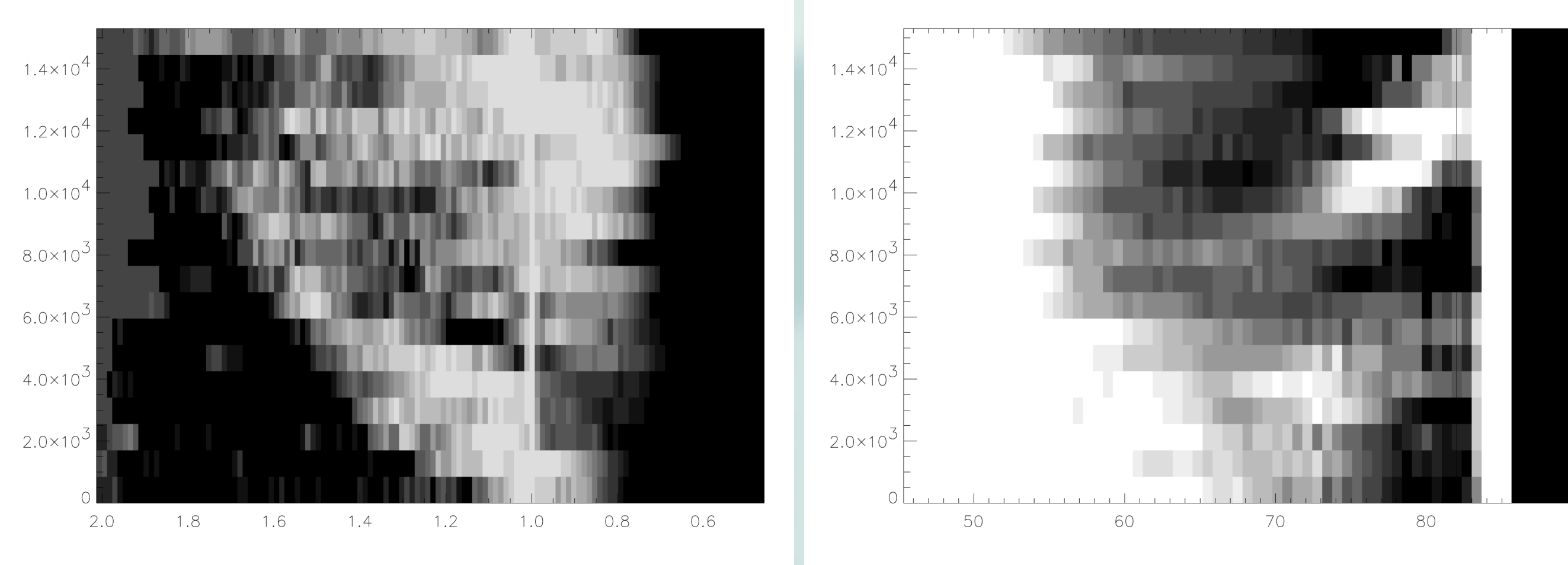
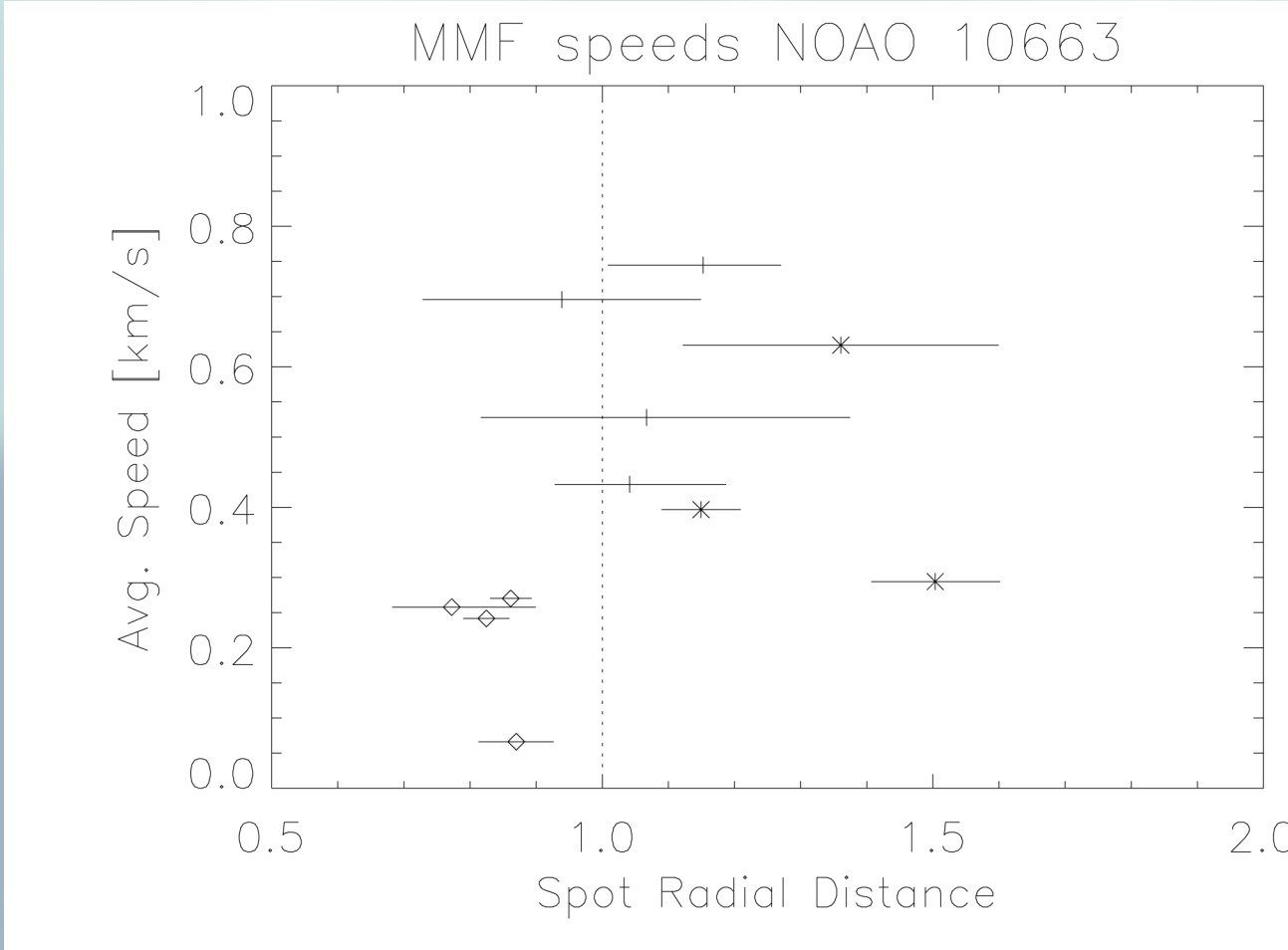


Figure 3. (Above) Examples of time slices for two interesting moving features. (a) is a time slice of in inclination(red circle) and (b) is a slice in magnetic field strength(red arc), positions of these features are noted in figure 5.

Figure 4. (Right) Speeds for some of the features.

Figure 5. (Left) The time sequence of selected merge maps, the outsides are magnetograms, insides in the left column are inclination and in the right column is magnetic field strength. The white circles indicate circular approximations to the umbra and penumbra.



Abstract: Spectropolarimetric data of the active region 10663 was taken with the CSUN-NSO IR camera and the McMath-Pierce telescope on August 26, 2004 from 16:35 to 21:02 UT. Utilizing the Zeeman split Fe I line near 1565 nm, the data is processed to remove instrumental polarization and a Milne-Eddington inversion technique is applied. The results of the inversion are used to examine the physical properties and radial motions of moving magnetic features which appear to originate in the sunspot umbra.

Conclusions

We observed penumbral MMFs and show that they are directly related to MMFs seen in the sunspot moat. This implies a formation method in the penumbra which was previously unsuspected. The resulting velocities observed were similar to those found in Bovelet *et al.* of g-band bright points and this leads us to believe that are related in some way.

Future Work: Wavelet Transforms

The analysis of features outlined above is quite tedious and time-consuming. An alternate method of analysis was using continuous wavelet transform to identify features and track their motions was utilized, losely based on analysis done by Malik & Subramaniam (1996). There were two flavors of wavelet transform used in our analysis. One was applied to magnetogram-style maps of the Stokes V component of the central Fe I line. The other flavor was used with the results of the ME inversion. However the analysis of the two differed only slightly, the method outlined below is the same for the two unless the differences are noted.

- Processed data was altered as needed, this included de-stretching the image and background fits to eliminate systematic scales.
- A two dimensional wavelet the same size as the data was computed.
- In the case of the magnetograms, this wavelet had two varied parameters, scaling and orientation. The wavelet was created by taking the difference of two normalized Gaussians. The full width of each Gaussian was scaled with the separation of the dipole. Orientation was done in of five degrees.
- The wavelet function used with the inversion results originated from the second derivative of a 1D normalized Gaussian which was rotated through 2π to give a symmetric 2D wavelet. Because of it's symmetry, no angle considerations needed to be made and scaling was achieved through adjusting the full width of the original Gaussian.

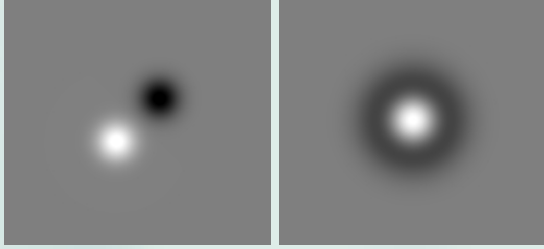


Figure 6. Examples of the dipole(left) and second-derivative Gaussian(right) wavelets applied in the wavelet analysis.

- The fft of the data and the complex conjugate of the wavelet fft were multiplied and sent through an inverse fft.
- This output was in turn sent to a continuous wavelet transform in time and the return was the "amplitude tracks".

Tests

A simulation of dipoles moving linearly in space was created during the development of the software method. The results of this test can be seen in figure x. Frames in row (a) show three of out of thirty-two of the simulated data frames for a chosen scale of wavelet. Frames in row (b) show the continuous wavelet transform of the corresponding three frames. The final row shows the continuous time wavelet transform results, amplitude, velocity, and position.

The amplitude map was totaled over the x dimension and the graph in figure x+1 is a plot of this totaled amplitude versus the scale of wavelet used. The peak corresponds to the best correlation of wavelet size.

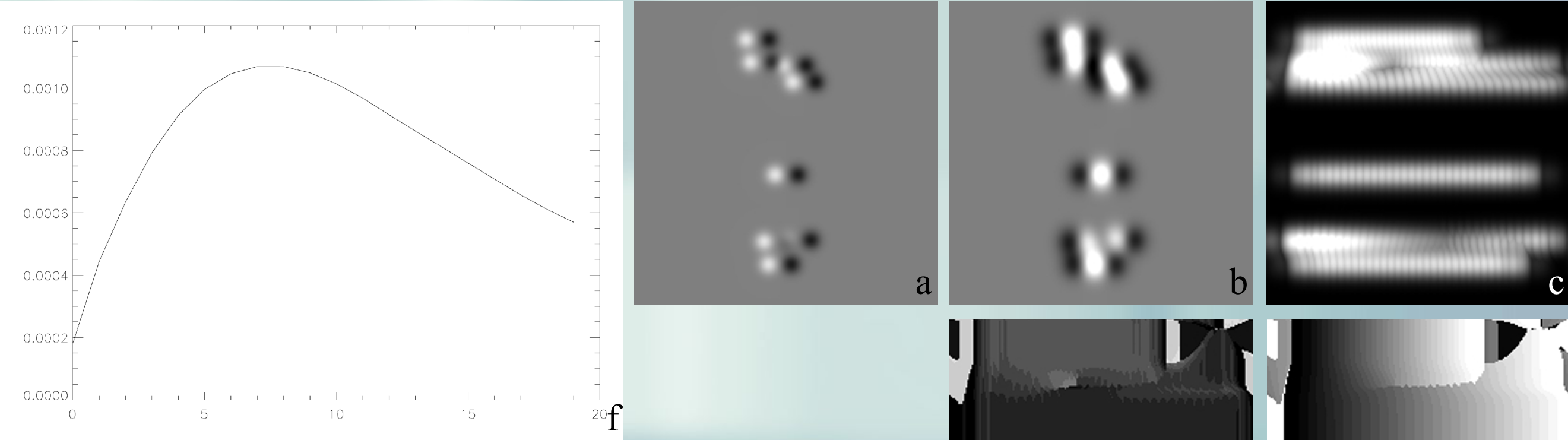


Figure 7. Wavelet analysis with simulated data. (a) Dipole features in the simulation travel from left to right with varying speeds. (b) The corresponding spatial CWT to (a). The amplitude(c), velocity(d), and position(e) resulting from the temporal CWT. (f) is a graph of the totaled amplitude.

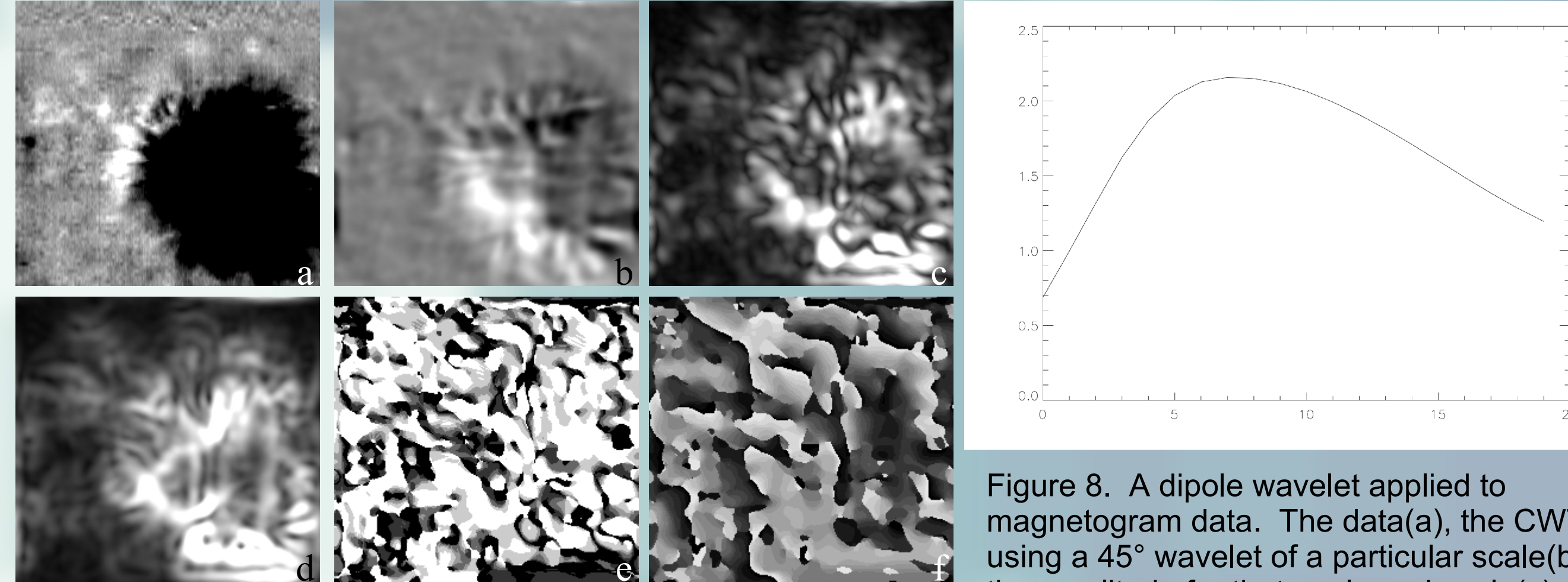


Figure 8. A dipole wavelet applied to magnetogram data. The data(a), the CWT using a 45° wavelet of a particular scale(b), the amplitude for that angle and scale(c), amplitude totaled over all angles(d), and the corresponding velocity(e), and position(f). (g) a graph of the amplitude vs. wavelet scale in a moving feature.

Sources

- J. Bonet *et al.* 2005. A&A 430,1089-1097.
- B. Bovelet and E. Wiehr. 2003. A&A 412, 249-255.
- K. Harvey and J. Harvey. 1973. SoPh 28, 61-71.
- R. Malik and K. Subramaniam. 1996. A&A 317, 318-327.
- A. Skumanich and B. Lites. 1987. ApJ 322, 473-482.
- J. Zhang, S. Solanki, and J. Wang. 2003. A&A 399, 755-761.