Velocity Fields in Sunspots Derived from Observations with the GREGOR Fabry-Pérot Interferometer

H. Balthasar[1], C.Denker[1], A. Diercke[1,2], S.J. González Manrique[1,2], C. Kuckein[1], R.E. Louis[1], M. Verma[1], J. Löhner Böttcher[3] and M. Sobotka[4]

1 Leibniz-Institut für Astrophysik Potsdam (AIP), Germany
2 Institut für Physik und Astronomie, Universität Potsdam, Germany
3 Kiepenheuer-Institut für Sonnenphysik Freiburg, Germany
4 Astronomical Institute of the Czech Academy of Sciences, Ondřejov, Czech Republic

Observations at GREGOR

Two sunspot groups have been observed on 2014 August 24 with the GREGOR Fabry-Pérot Interferometer (GFPI, Puschmann et al. 2012) at the GREGOR telescope in Tenerife (see Schmidt et al. 2012). Here we concentrate on NOAA 12146, which consisted of two major spots of opposite polarity. The lower one in Fig. 1 emerged during the previous days next to the pre-existing upper one. We used the magnetically insensitve spectral line Fe I 709.04 nm with an excitation potential of 4.23 eV probing the mid photosphere. In addition, we took images in the blue continuum at 450 nm with the Blue Imaging Channel (BIC, Puschmann et al. 2012) and restored them with a speckle technique (Wöger & v.d. Lühe 2008).

For the basic reduction of the GFPI-data, we use the sTOOLS package (see Kuckein et al. 2017). Velocities were determined from the minimum of a parabola fit to the line profile. The most prominent result is the velocity contrast in the penumbra of the new spot (see Fig. 2). Here we find velocities of more than +2 and -2 km s^{-1} next to each other. This result is confirmed by the HMI-Dopplergram. The separation line is not obvious in the intensity image in Fig. 1.
The disk center is to the left, so one does not expect a strong blueshift from the Evershed effect for the lower spot.

Horizontal velocities were derived with the local correlation tracking (LCT) method described by Verma & Denker 2011, applying it to the BIC-data. Results are shown in Fig. 3. We detect several locations in the quiet Sun with high velocities of about 1 km s^{-1}, but close to the neutral line, values are small, indicating that the Doppler velocities in Fig. 2 correspond to vertical motions rather than to horizontal ones. The group was at θ = 22° (cos θ = 0.927). Keep in mind that LCT follows intensity structures, and their movements are not necessarily identical with matter motions.

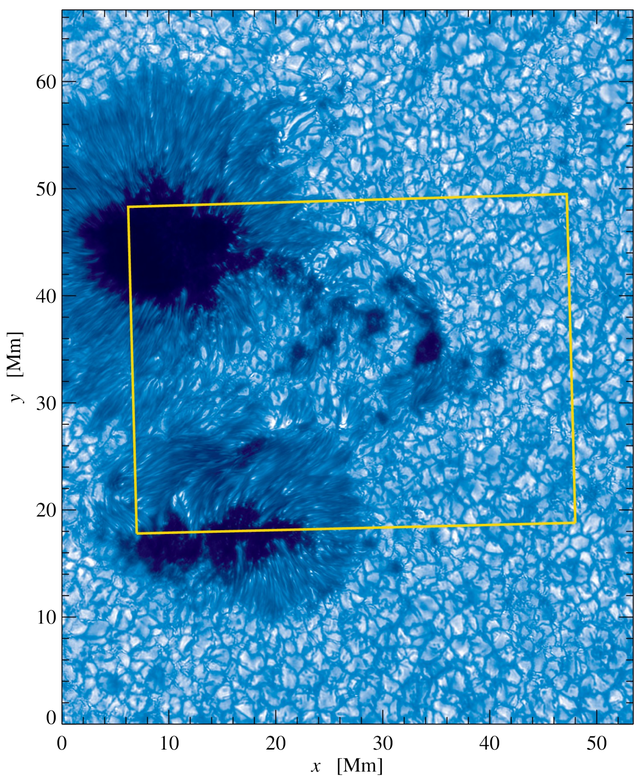

Fig. 1: Restored image of NOAA12146 in the blue continuum obtained with BIC. The yellow box marks the range covered by the GFPI.

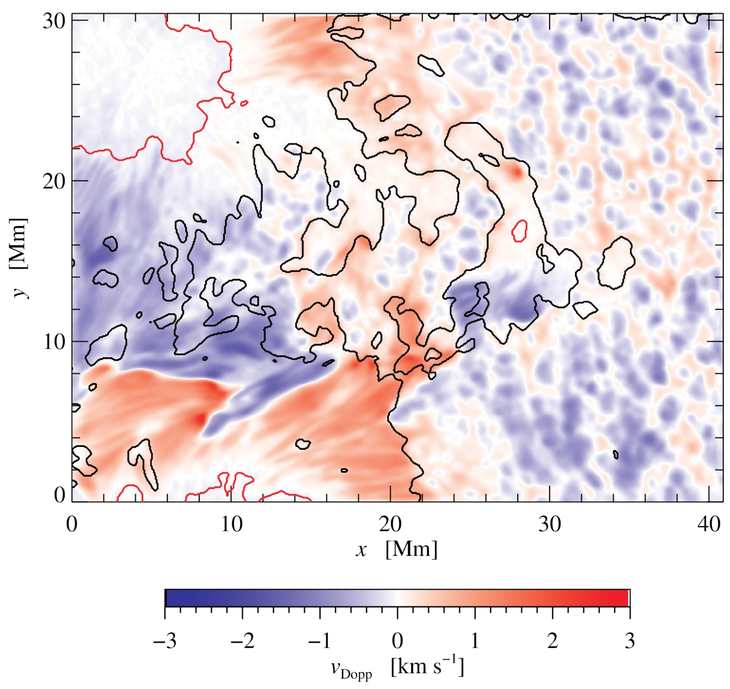

Fig. 2: Doppler velocities derived from Fe I 709.04 nm recorded with the GFPI. Contours indicate the outline of umbrae (red) and penumbrae (black).

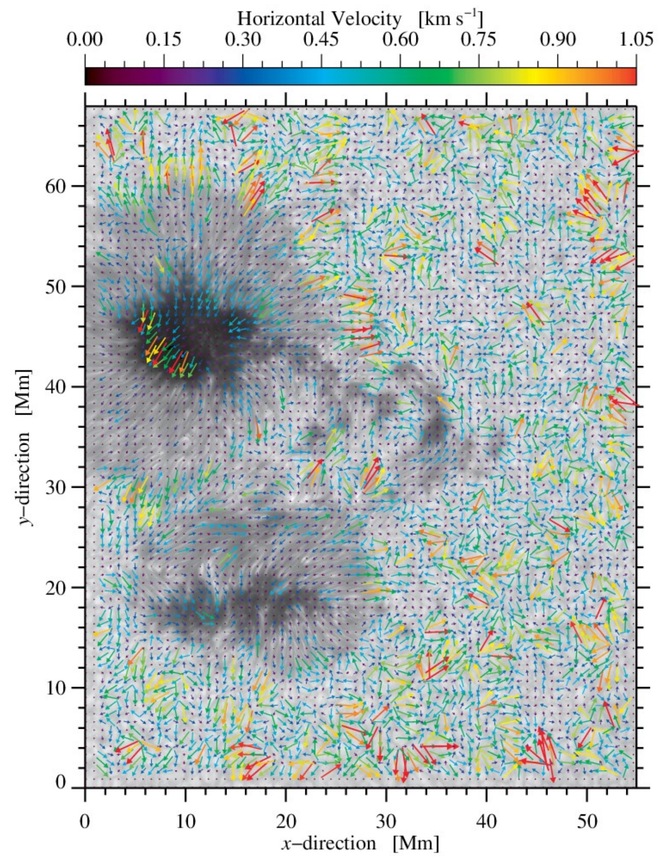

Fig.3: Horizontal velocities displayed as colored arrows with the BIC intensity image as background. The amount of the velocities is given by the color-scale bar above.

HMI Data and Magnetic Field

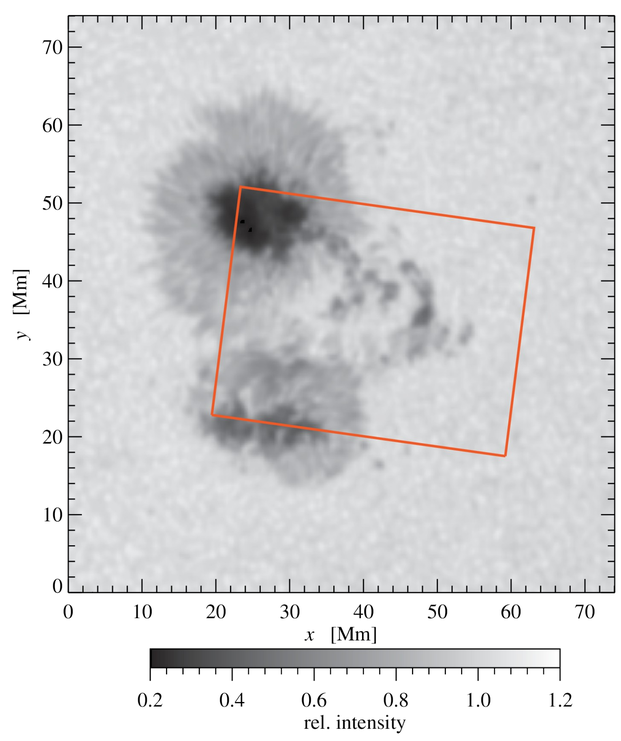

Fig.4: Intensity image of the group from HMI. The red box marks the range covered by the GFPI.

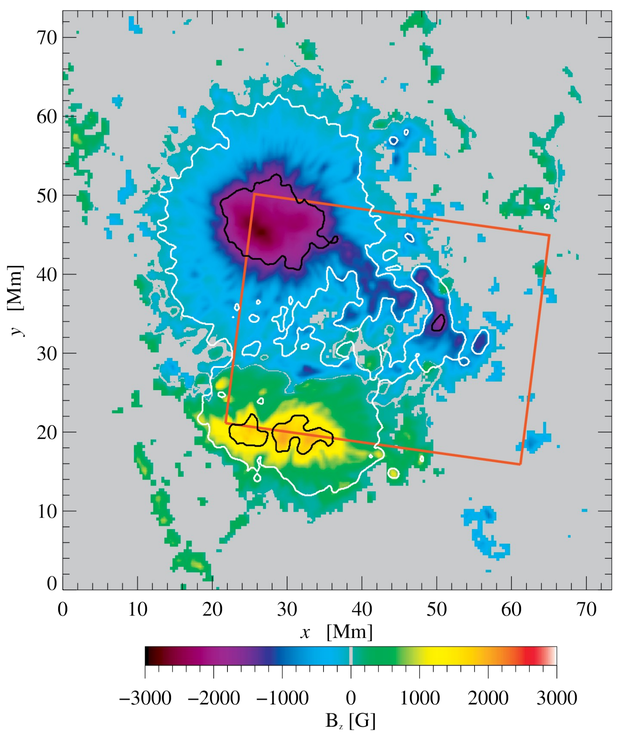

Fig. 5: Vertical component of the magnetic field from HMI. The polarity inversion is recognizable as a thin grey line. White and black contours mark the intensity structures in Fig. 4, and the red box is the range covered by the GFPI.

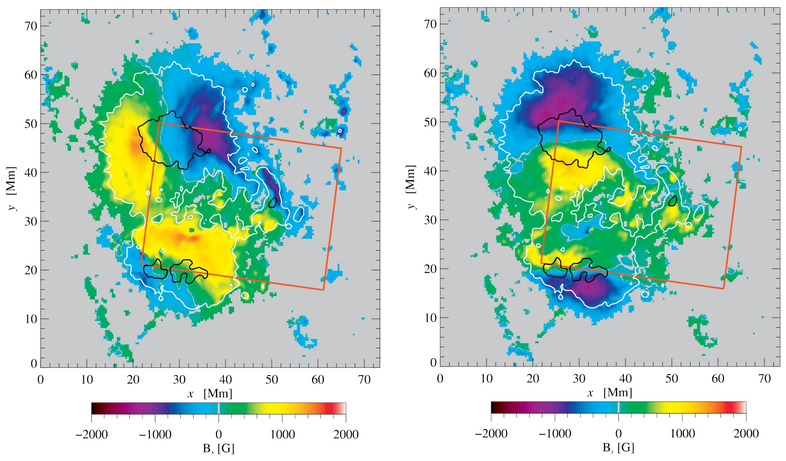

Fig. 6: Horizontal components of the magnetic field.

As magnetic information we use the magnetic vector from HMI. We solved the azimuth ambiguity assuming two azimuth centers for the two spots and did local manual corrections where needed. Finally we rotated the vector to the local frame of reference. Now we see that Doppler blueshifts appear where the magnetic polarity is still negative (the polarity of the main spot), and in the range of the positive polarity of the new (lower) spot, we encounter redshifts. In Fig. 5, we display the vertical component of the magnetic field indicating the negative polarity in bluish colors and the positive in green-to-red colors.

Velocities opposite to the Evershed effect have been reported in the literature, see Kleint & Sainz Dalda (2013), Louis et al. (2014), Balthasar et al. (2016), but for much smaller areas than in the present case. Obviously, this is related to the magnetic configuration of two larger spots of opposite polarity rather close to each other and the ongoing emergence of magnetic flux.
Nevertheless, the overall configuration along the polarity inversion line is not fully understood. The magnetic field is more horizontal here (see Fig. 6), and one does not expect a flow of matter perpendicular to the magnetic field.

References:
Balthasar, H. et al.: 2016, AN 337, 1050
Kleint, L. & Sainz Dalda, A.: 2013, ApJ 770:74
Kuckein, C. et al. 2017, ArXiV 1701.01670
Louis, R.E. et al.: 2014, A&A 570, A92
Puschmann, K.G. et al.: 2012, AN 333, 880
Schmidt, W. et al.: 2012, AN 333, 796
Verma, M. & Denker, C.: 2011, A&A 529, A153
Wöger, F. & von der Lühe, O.: 2008, SPIE 7019, id. 70191E

Acknowledgements: The 1.5-m GREGOR solar telescope was built by a German consortium under the leadership of the Kiepenheuer-Institut für Sonnenphysik in Freiburg (KIS) with the Leibniz-Institut für Astrophysik Potsdam (AIP), the Institut für Astrophysik Göttingen (IAG) the Max-Planck-Institut für Sonnensystemforschung Göttingen (MPS), and the Instituto de Astrofísica de Canarias (IAC), and with contributions by the Astronomical Institute of the Academy of Sciences of the Czech Republic (ASCR). SDO HMI data are provided by the Joint Science Operations Center – Science Data Processing.