Calibration of SOT Dopplergrams

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Abstract

Narrowband Filter Imager (NFI) on SOT provides Dopplergrams (DGs) which are images of Doppler (LOS) velocities. Observations with DGs are critically important in studies of photospheric dynamics and helioseismology. The primary photospheric line used for DGs is Fe I 5576 Å which is a line insensitive to Zeeman effect. We made a LUT for the 5576 Å DGs to get actual Doppler velocities from velocity indexes using an atlas spectrum and simulated transmission profiles of the tunable filter (TF) on SOT. Using data sets taken in the real Sun-light test, we evaluated accuracy of the DGs by comparing the rotational speed of the Sun with the predicted one. There was a little systematic error in the velocity obtained by SOT, but the error was less than 20% of the predicted rotational velocity.

Fe I 5576Å Dopplergram

NFI on SOT takes four filtergrams (F1, F2, F3, and F4) at 4 wavelengths uniformly spaced through the line to make DGs. The nominal wavelength samplings for the 5576Å line are F1 at -90mÅ , F2 at -30mÅ , F3 at +30mÅ , and F4 at +90mÅ . The velocity index R is calculated from the 4 images:

$$R = \frac{F1 + F2 - F3 - F4}{F1 - F2 - F3 + F4}$$

The denominator and numerator are calculated on board and sent to the ground separately. The Doppler velocity is obtained from the velocity index R by a look-up table.

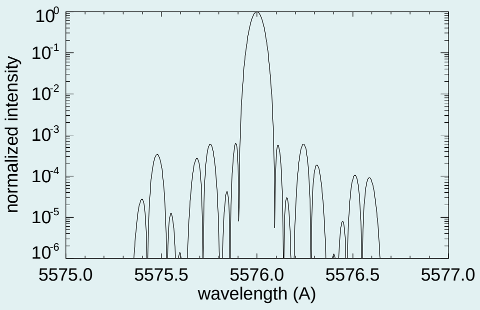


Fig. 1: Theoretical spectral profile of the tunable Lyot filter at 5576Å.

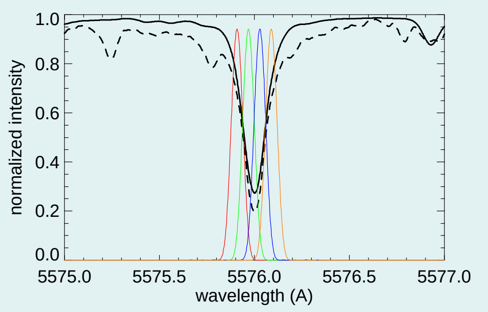


Fig. 2: Fe I 5576Å spectra in the quiet sun (solid line) and in an umbra (dashed line). The four TF profiles are at {-90, -30, +30, +90} mÅ from the line center.

LUT for the 5576A DGs

We made a LUT to convert the velocity index R to Doppler velocity from the atlas spectrum at the quiet sun (solid line in Fig. 2) and the theoretical transmission profile of the TF. This LUT can be used for the velocities within ± 3kms.

We also made a LUT using the spectrum in an umbra (dashed line in Fig. 2). The difference is very small as shown in Fig. 3. The LUT in QS can be used even in an sunspot with better than 100m/s accuracy.

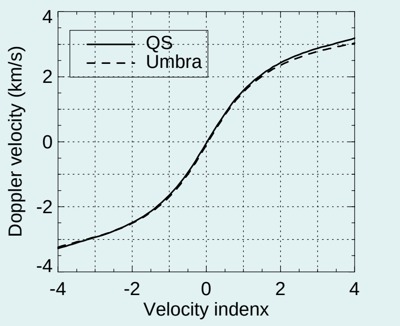
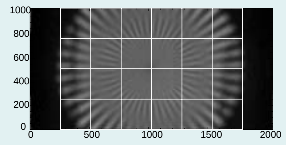


Fig. 3: Theoretical LUT to make a DG. The atlas spectra in QS (solid line) and an umbra (dashed line) are used.

Intensity ripple of TF

Intensity profiles obtained by wavelength scan showed periodic modulation of the observed intensity as a function of wavelength offset (Fig. 4). The dominant component is a ripple in a period of 560mÅ. The amplitude of the ripple is smaller than 10% and slightly depends on positions over FOV.



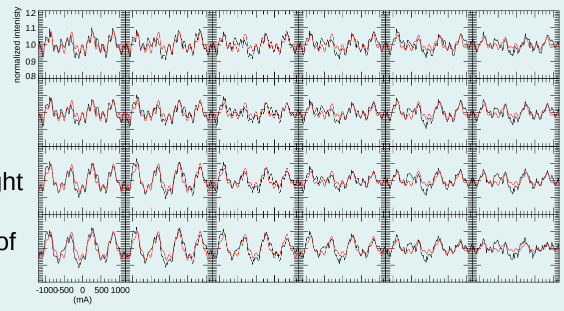


Fig. 4: Intensity ripples obtained by the wavelength scan around 5576Å. The light source was a lamp emitting continuous light. The red lines show superposition of 3 sinusoidal modulations.

Effects of the intensity ripple

The intensity ripple was simulated by including some errors in the setting of the wide field elements in TF (Fig. 5). The relation between the velocity indexes and the Doppler velocities is reexamined using the TF profiles. The deviation from the ideal LUT shown in Fig. 3 is 1 km/s in the worst case.

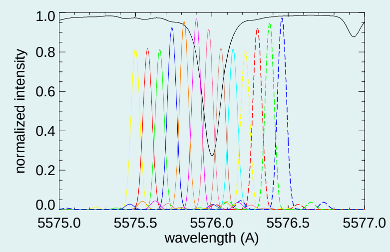


Fig. 5: Fe I 5576Å spectrum and the TF transmission profiles reproducing the intensity ripple.

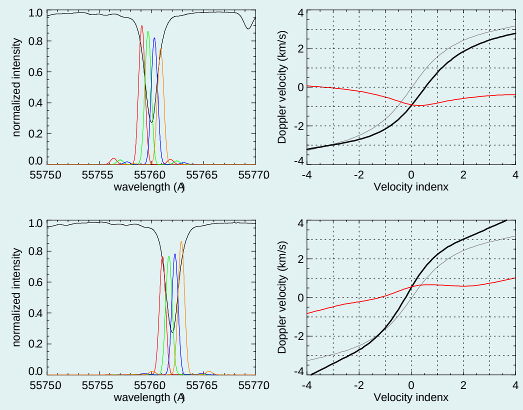


Fig. 6: Relation between the vel. indexes and the Doppler velocities including the effect of the intensity ripple (black line). Their deviations from the ideal LUT (gray line) are drawn by red lines.

Doppler shift compensation

Fine tuning of the wavelength against solar originated absorption lines is important for deriving physical parameters from the obtained data by NFI. Adjustment of TF wavelength is performed in FPP by using Doppler velocities value calculated in MDP.

The largest velocity is caused by the revolution of the satellite around the earth. The maximum velocity is 3.9 km/s in a period of about 95min.

Fig. 7 shows the error of DGs caused by the satellite revolution and the intensity ripple. In the worst case, about 1 km/s velocity offset occurs in the range between -2 and 2 in the velocity index.

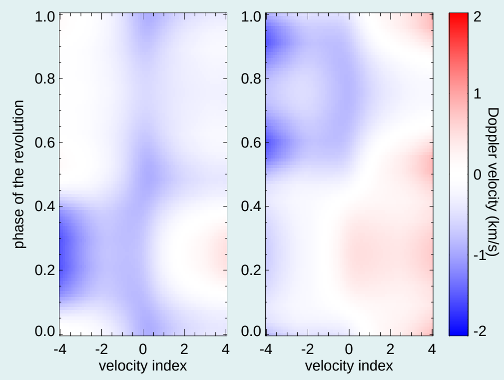


Fig. 7: Simulated error of the Doppler velocities caused by the intensity ripple and the Doppler motion of the satellite. We assume ±3.9 km/s as the satellite motion.

Quantitative evaluation of DGs

Using data sets taken in the natural sun-light test performed in Palo Alto, we evaluated accuracy of the DGs quantitatively. We derived rotational speeds of the Sun from the DGs, and compared it with the theoretical prediction.

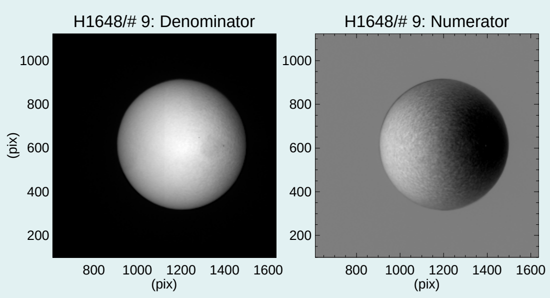


Fig. 8: Example of the data sets used to evaluate the accuracy of DGs. The image of the full solar disk was located near the center of FOV.

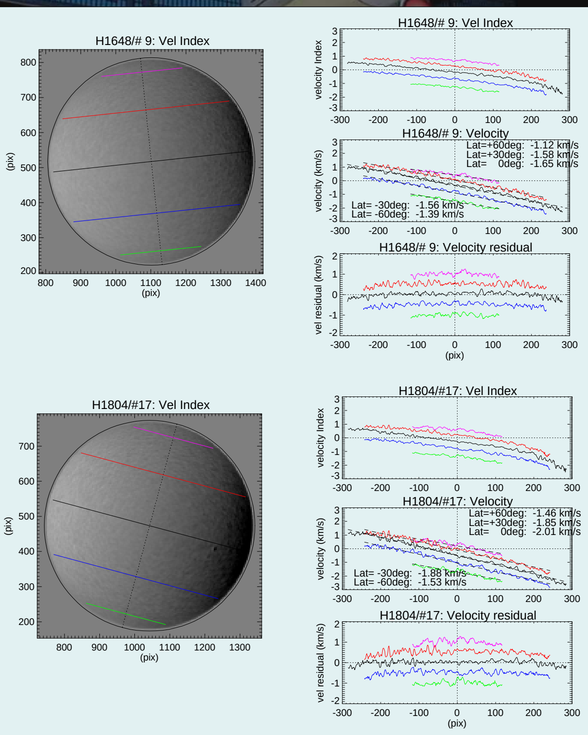


Fig. 9: Doppler velocities were examined along the latitudinal lies at 0°, ±30 °, and ± 60 °. The LUT made from the ideal TF profiles (shown in Fig. 3) was used to get the Doppler velocities from the velocity indexes. The theoretical velocities of the solar rotation are 1.98 km/s, 1.89 km/s, and 1.56 km/s at 0°, 30 °, and 60 ° respectively.

The velocities of the solar rotation obtained by the DGs are roughly consistent with the theoretical prediction. But there was time variation in the obtained velocities from data to data. The deviation from the theoretical prediction is about 400 m/s in the worst case.

Further improvement

The most probable cause of the error in the rotational velocities here obtained is the intensity ripple as shown in Fig. 4. We are now modeling the variation of the TF profile as a function of motor positions in TF which can be known by telemetry outputs during actual observations.