Comparison of bisectors with inversions based on response functions to infer line-of-sight velocities of the Si I 10827 Å line

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Abstract

We compare two methods to compute Doppler shifts and infer line-of-sight (LOS) velocities of the largely used photospheric Si I 10827 Å line. This line is formed in the upper photosphere. The first method consisted of computing the height-depend bisectors of the line. For the second method we used the Stokes inversion based on response function (SIR) code, which provided height-dependent information, in an optical depth scale, of the LOS velocities. Thirty consecutive maps observed on 2015 April 17 between 08:16 and 08:45 UT were exploited for this study. The bisectors were computed in 10%-steps of the line depth using linear interpolation in both line wings. The output model from the SIR code covered 55 optical depth positions between 1.4 ≥ log τ ≥ -4.0. These LOS velocity maps from SIR at different log τ were compared with those originated from the bisector method at different percentages. The comparison between both methods allowed us to associate the bisector percentages to a specific optical depth. High linear correlations in the range of 94-99% were found. Bisector velocities obtained deeper in the line correspond to lower optical depths. The inferred correspondence between bisector percentage and optical depth can be used to quickly obtain information about the LOS velocity stratification versus optical depth without using inversions.

Introduction

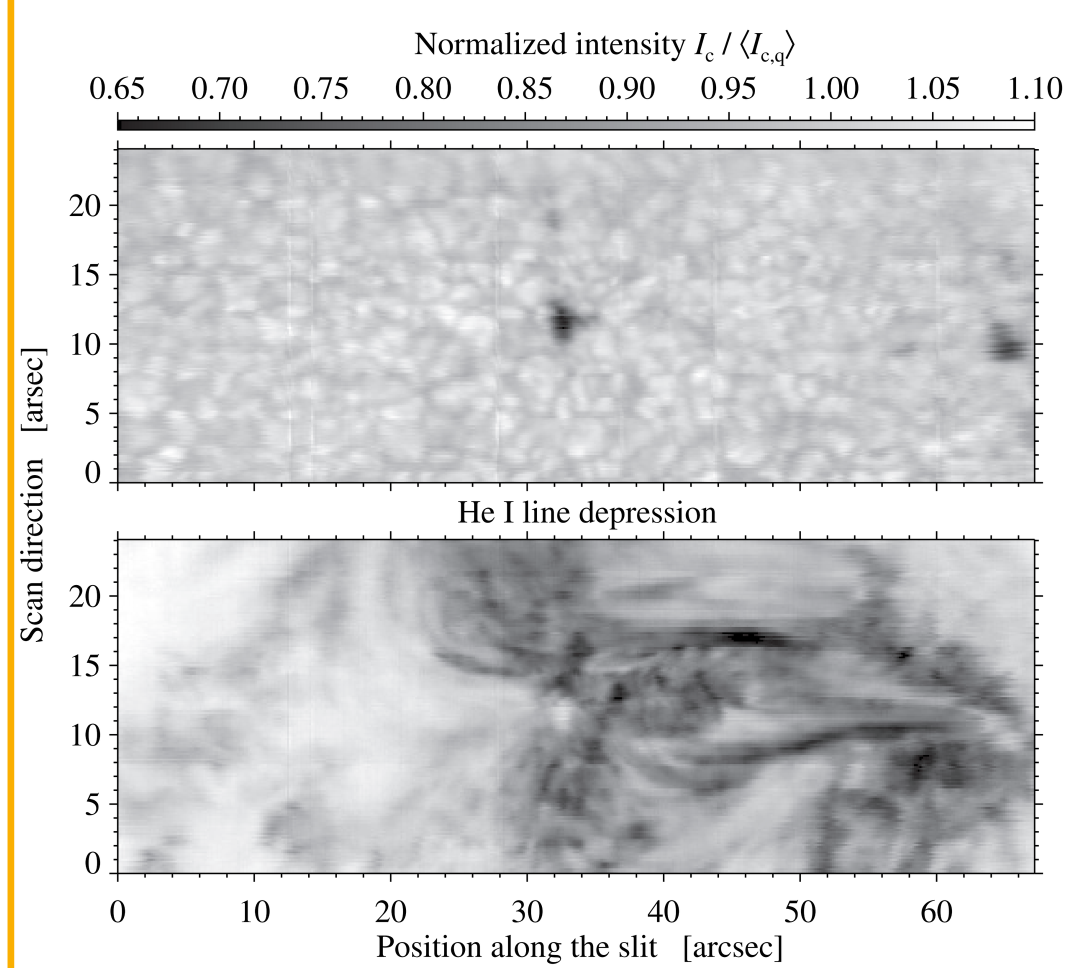

Fig. 1: Slit-reconstructed GRIS images at 08:43:21 UT on 2015 April 17 of the EFR. Continuum intensity (top) and He I line depression (bottom). The region is located at heliographic coordinates S19 and W4 (μ = 0.97).

Spectral lines often show asymmetries in their profiles. They are usually associated to velocity gradients along the line-of-sight (LOS). In addition, the line core is formed at a greater height than the wings, which can result in different Doppler shifts (Stix 2004). The line asymmetry can be represented by the bisector, which in turn gives the Doppler shift at a given percentage with the depth of the line. The bisector spans between the line core (0%) and the outer wings (100%). The wavelength positions of the bisectors can be quickly computed using linear interpolation in both line wings. The middle position between these two positions yield the Doppler shifts at different heights of the atmosphere. A more sophisticated way to infer height-dependent velocities is using an inversion code. It has been widely used the SIR code (Ruíz Cobo et al. 1992) for photospheric lines. SIR is based on response functions and solves radiative transfer equation assuming local LTE and hydrostatic equilibrium. The LOS velocity stratification is inferred as a function of the optical depth (log τ at 5000 Å). While bisectors can be computed in minutes for one map, SIR requires days for the same map.

Observations and data reduction

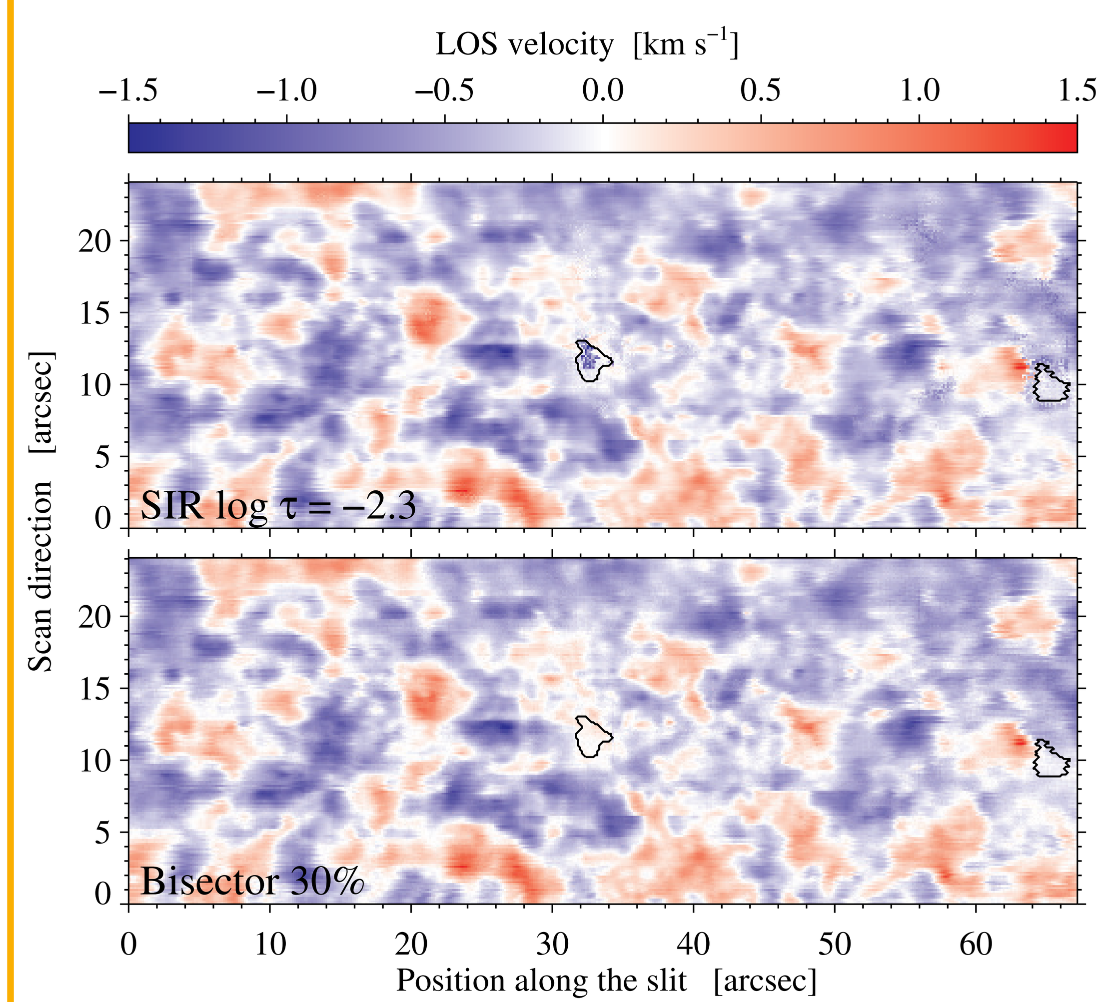

Fig. 4: LOS velocity maps inferred from the Si I line using two different methods: SIR code (top) and bisectors (bottom). The maps refer to the same time as shown in Fig. 1. The highest linear correlation between both methods is 99.2% and corresponds to the bisector velocity at 30% and log τ = -2.3 from SIR. The contours outline the pores in the continuum image (≤0.89I_c). These areas were not included when computing the correlation between the bisector and SIR velocities.

An emerging flux region was observed at 08:16 UT on 2015 April 17 using the GREGOR Infrared Spectrograph (GRIS) (Collados et al. 2012) placed at the 1.5-meter GREGOR solar telescope (Schmidt et al. 2012) at Observatorio del Teide, Tenerife, Spain. The field of view contained two small pores with opposite polarities as seen in the photosphere and an arch filament system connecting the opposite polarities in the chromosphere (see Fig 1). GRIS was used in the very fast spectroscopic mode (Gonzalez Manrique et al. 2016, 2017) and its spectral range spectral range covered around 18 Å in the He I 10830 Å spectral region. The cadence was around one minute for each map.

Bisectors vs. SIR inversions

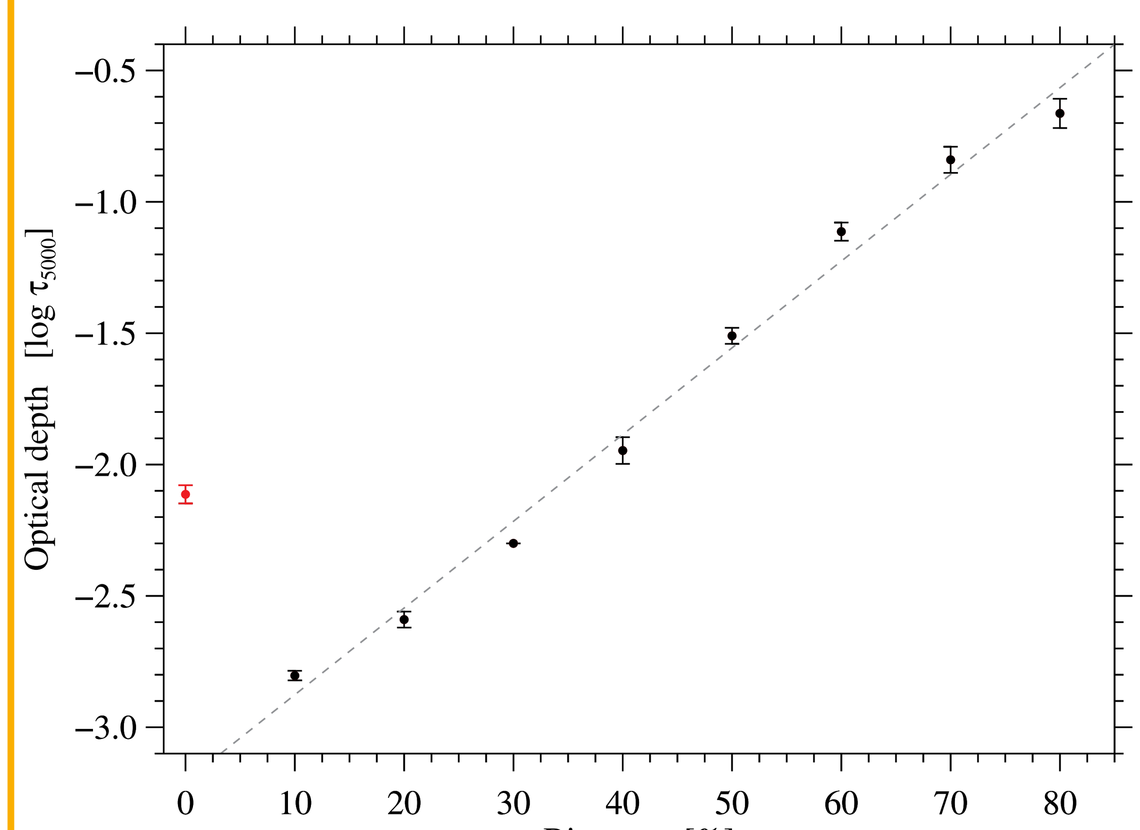

Fig. 2: The filled circles depict the highest correlation for each bisector map at a given line depth. The value of the optical depth for every bisector is the mean value of the 30 maps. The red filled circle indicates the results at the line core. The bars depict the standard deviation (for the 30 maps). The line represents the linear fitting between all the bisectors except at the core.

There is a clear linear correlation between the bisectors and the optical depth except at the core.

$$y = 0.033x - 3.206$$

Best match between the inferred velocities with the bisector´s method and the SIR inversions (black circles in Fig. 2). The correlation percentages between both maps are shown in Fig. 3. The extreme wings of the Si I line near the continuum are almost flat and contain small intensity perturbations producing large bisector shifts. Therefore, bisector maps close to the continuum (>80%) are strongly affected by noise and are consequently discarded leading to our choice for the upper value. The value of 0% refers to the line core of each spectral line. The Doppler velocity map corresponding to the line core was calculated by a Gaussian fit. The comparison between the two techniques allows us to associate the bisectors for a specific line depths to a specific optical depth inferred with the SIR code. The bisector and SIR velocity maps were compared using Pearson's linear correlation coefficient.

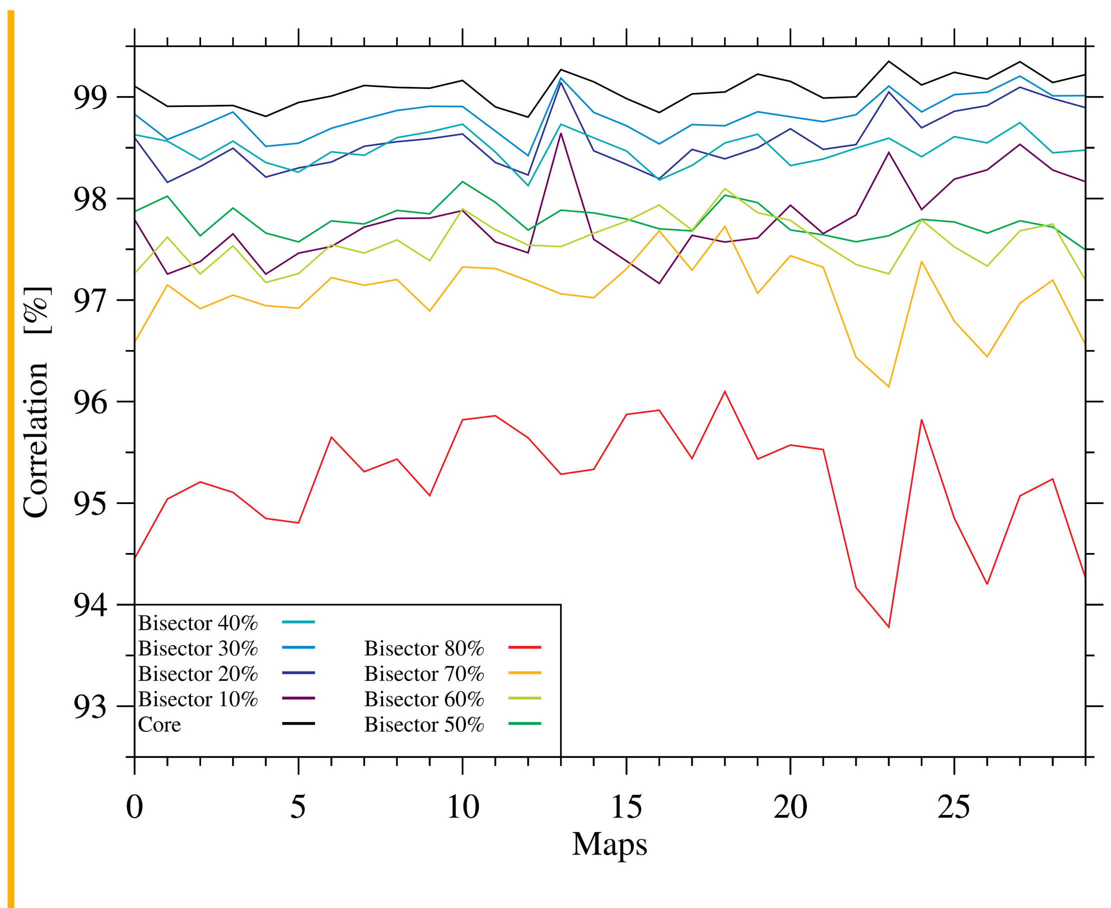

Fig. 3: Best correlation between velocity maps derived with the bisector method and with the SIR inversions. The x-axis enumerates the maps. Every color shows a different bisector percentage.

High correlations in the range of 94–99% between velocity maps derived with the bisector method and with the SIR inversions (see Fig. 3) are found. As expected, bisector velocities obtained deeper in the line correspond to lower optical depth. As an example, the bisector at 30% above the line core shows correlations between 98.4% and 99.2% with an average of 98.8% with SIR maps at log τ = -2.3. The two LOS velocity maps for which the best correlation was achieved (99.2%) are shown in Fig. 4. Visually, both maps are very similar except in the area of the pores.

Conclusions

The bisectors method is suitable to quickly infer Doppler velocities from the Si I line at different heights. In addition, using the SIR code, we have associated the bisectors for a specific line depth to a specific optical depth of the atmosphere. We have demonstrated this with spectroscopic data taken with the GRIS instrument at GREGOR and achieved correlation values above 94% between the bisector maps and the inferred SIR velocity maps (Fig 3). We have characterised the relation between bisector percentage and optical depth (y = 0.033x - 3.206). These results are only valid avoiding areas with very strong magnetic fields where the line splits. The advantage of using the bisector method instead of the SIR code is the much faster computing time. The inferred velocity maps using the bisector method applied to all 30 maps were computed in about 60 minutes (with one Intel Core i7-4770 CPU at 3.40 GHz and 32 GB of RAM). On the other hand, in serial, SIR would need about 108 days.

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