Measurements of Mg II Doppler velocities at two heights in the chromosphere

M. Sobotka and V. Abbasvand

Astronomical Institute of the Czech Academy of Sciences, Ondřejov, Czech Republic

Abstract: We present a method of Doppler velocity measurement in the Mg II k and h lines observed with IRIS. Velocities of the k and h emission cores are measured by means of the "double-slit" method at the half-intensity of the emission maximum. This part of the emission core is formed in the middle chromosphere. Velocities of the central reversals, formed in the upper chromosphere, are measured using a parabolic fit. The effective formation heights are estimated by means of Mg II k and h contribution functions calculated from model atmospheres.

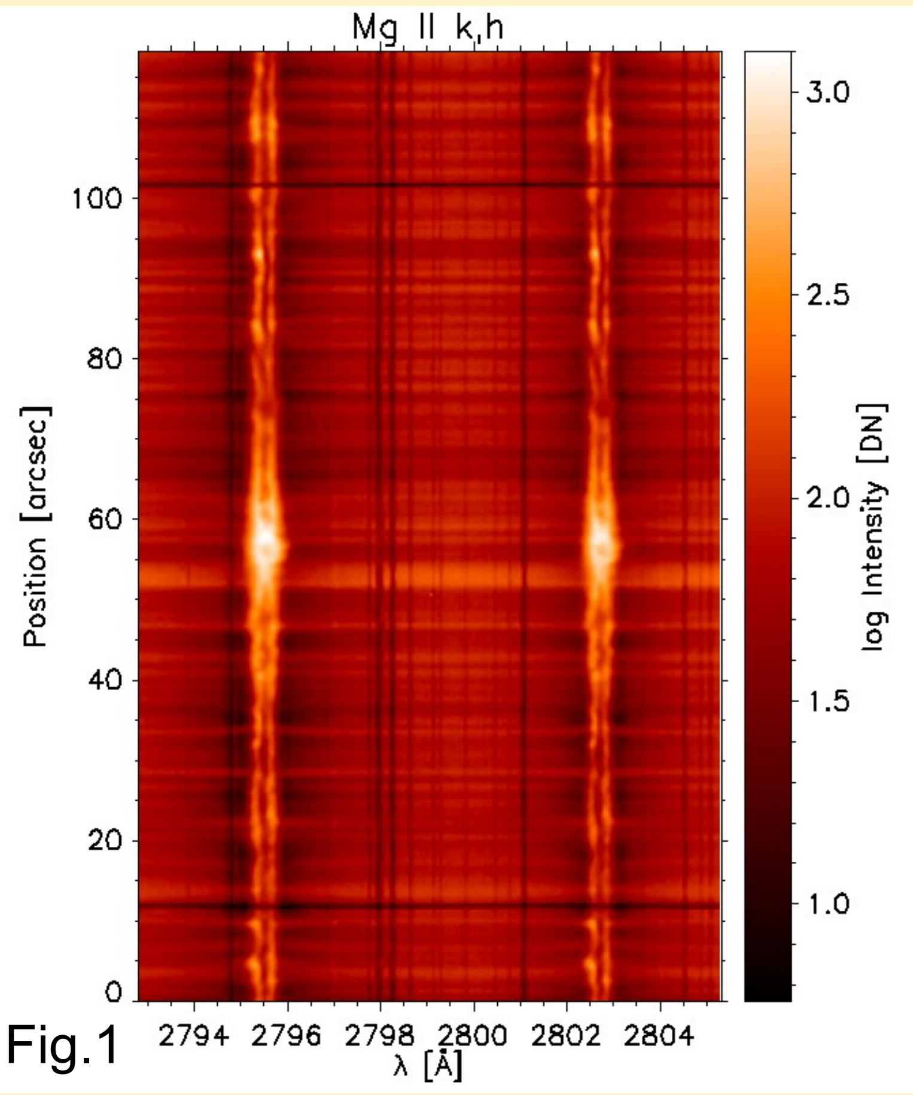


Fig.1

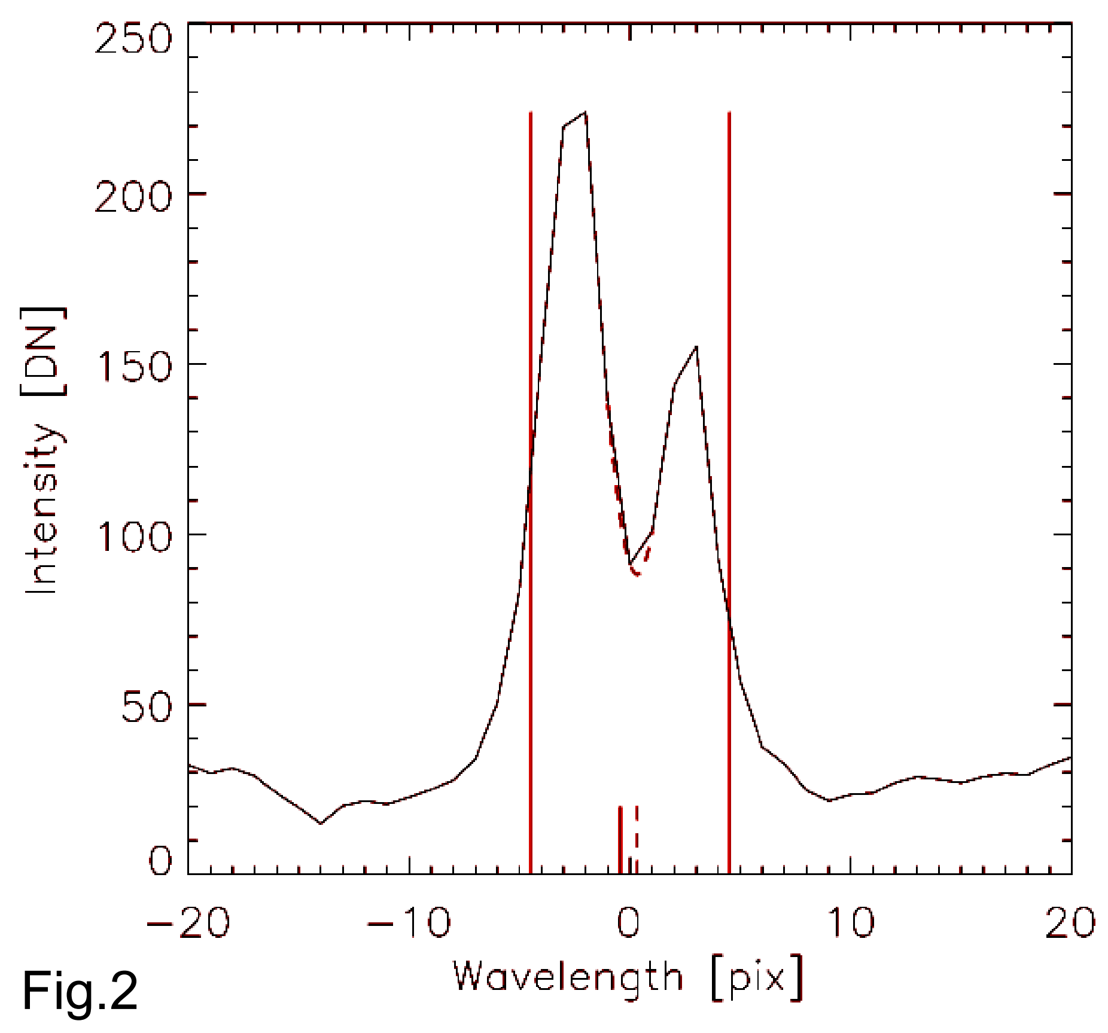


Fig.2

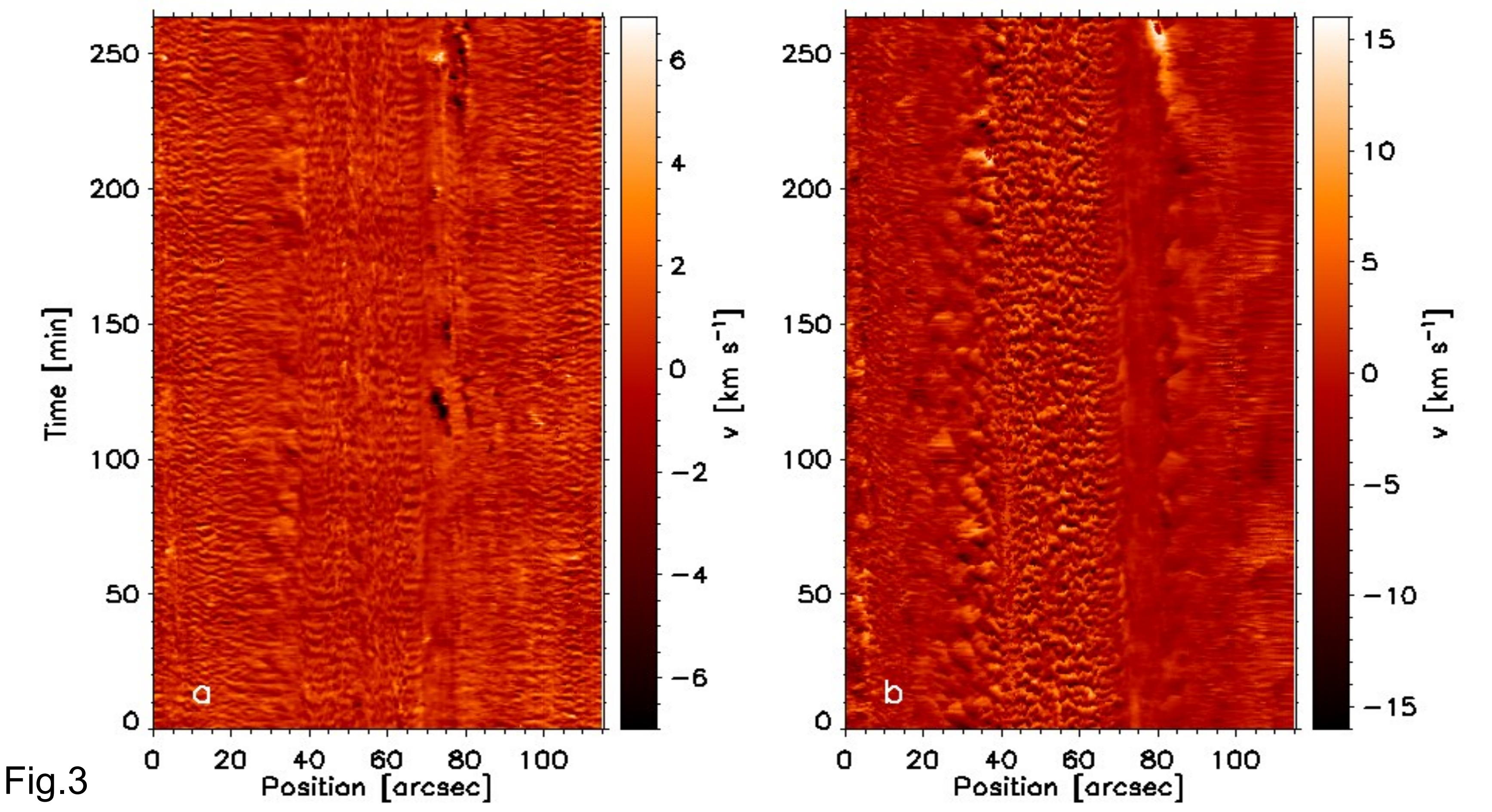


Fig.3

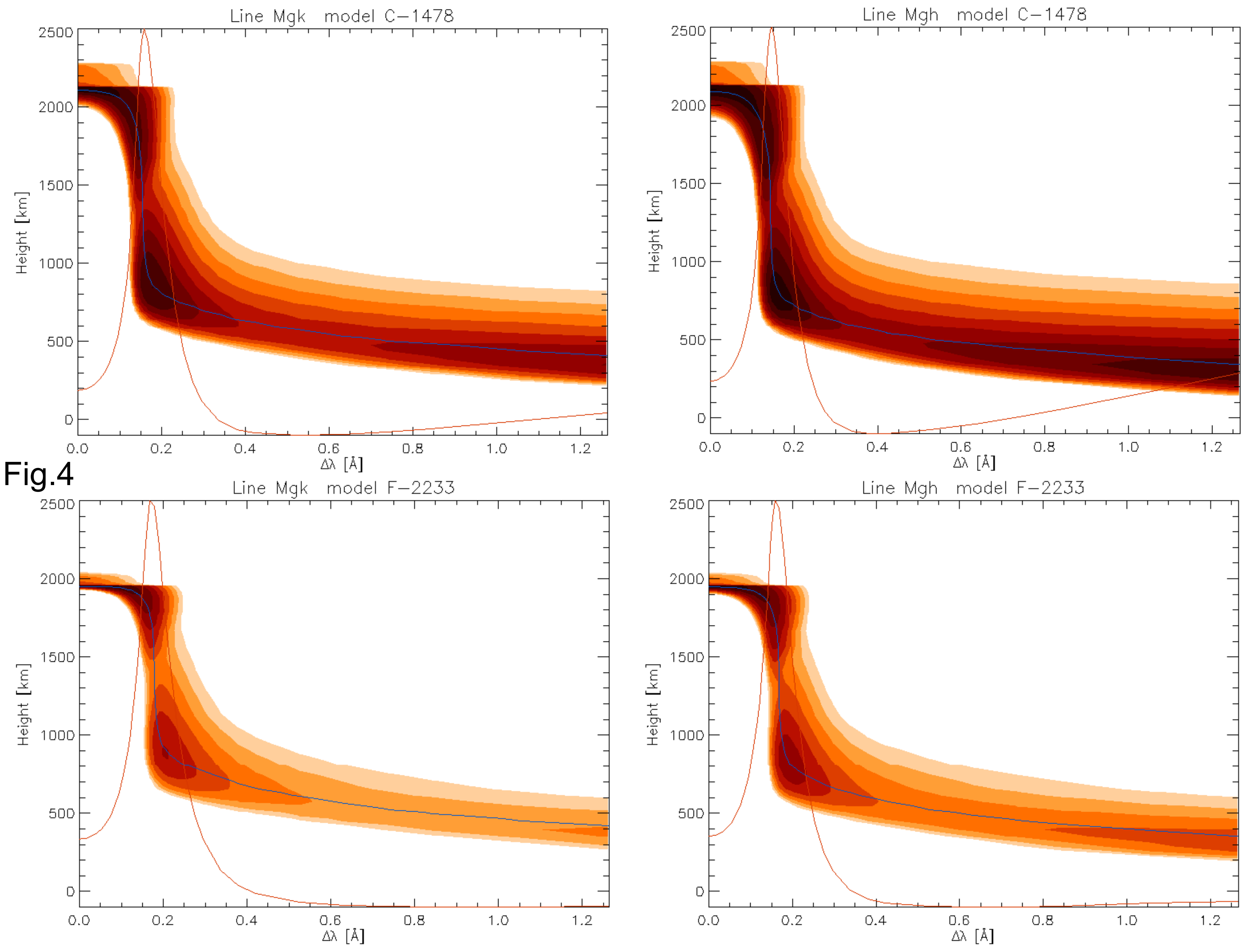


Fig.4

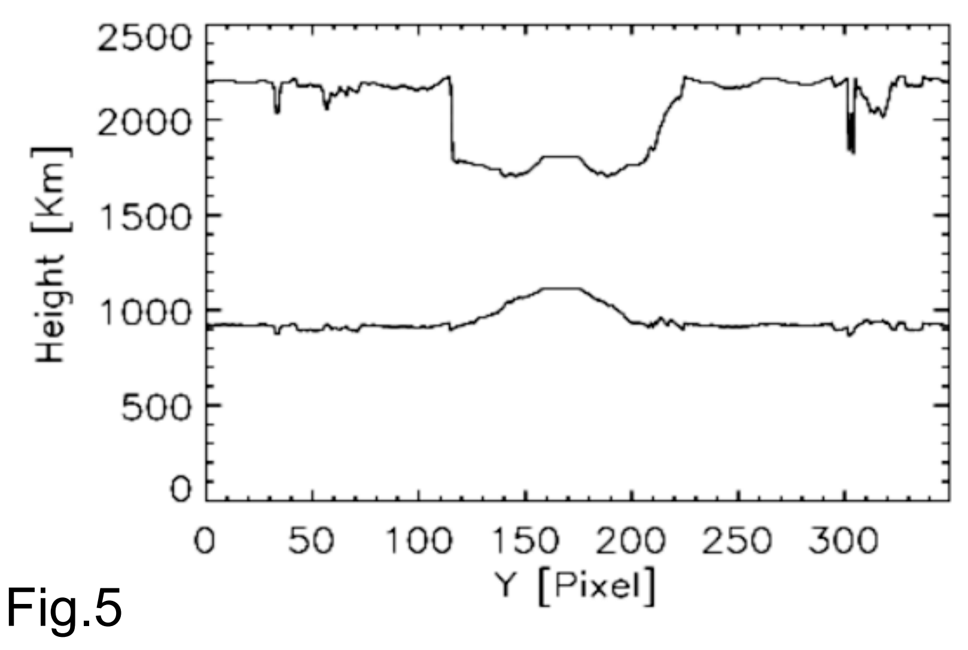
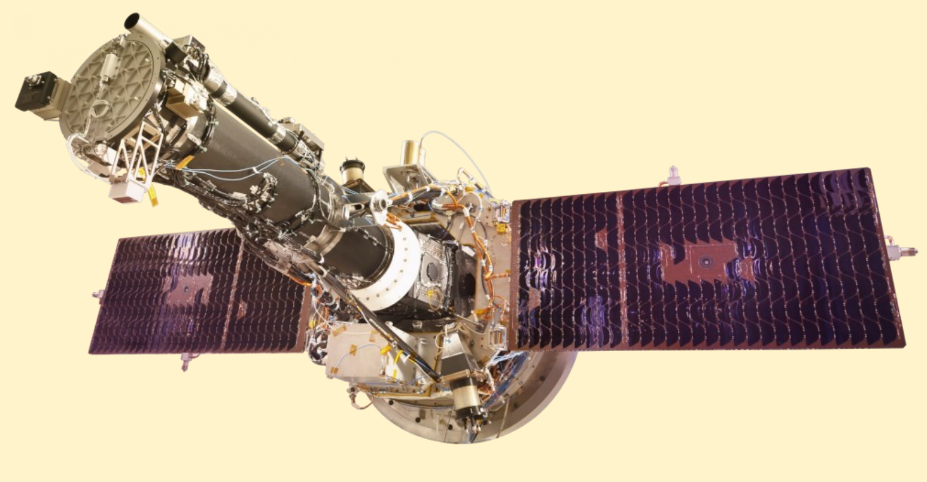


Fig.5



The ultraviolet lines of ionized magnesium Mg II k (2796.35 Å) and h (2803.52 Å) are important tools to study the solar chromosphere, sampling layers from the temperature minimum to the upper chromosphere. Their profiles are often characterized by a central emission reversal surrounded by two emission peaks. The Interface Region Imaging Spectrograph (IRIS) provides high-quality spectra of these lines (Fig. 1).

Doppler velocities can be derived from measured wavelength shifts of the two emission peaks and the central reversal. The shift of the central reversal is determined by means of a three-point parabolic fit of the profile minimum between the emission peaks (Fig. 2, red dashed line). However, the intensities and shifts of the emission peaks can be strongly influenced by the depth and shift of the central reversal. For this reason, we consider the two peaks to be a single emission core and measure its overall shift.

We utilize a "double-slit" method, consisting in the minimization of the difference in intensities of light passing through two "slits" located at a certain distance *s* in the opposite wings of the emission core. The two slits are shifted by sub-pixel distances with respect to the profile to find the minimum of intensity difference (Fig. 2, red solid lines). The distance *s* between the slits determines the depth of the profile, for which the shift is measured. We use *s* matching the half intensity difference between the emission maximum and the line-profile minimum, so that shifts of the emission core are measured independently of the emission peaks and central reversal. Because the widths of the k and h emission cores change with physical conditions, *s* is automatically adapted to the emission-core width.

The shifts are converted into Doppler velocities, defining the reference zero as the time-average of measurements for each position along the slit. Failures of measurements are replaced by interpolated values obtained by median filtering. Because the Dopplergrams in the k and h lines are almost identical, we use their average. The resulting Dopplergrams of the emission core (a) and the central reversal (b) are shown in Fig. 3. The IRIS slit intersects a small plage located between the positions 30" − 80". Velocity oscillations with various frequencies can be observed. Their characteristics in (a) and (b) clearly differ thanks to different heights of formation.

To know at which heights in the atmosphere the velocities are measured, we use contribution functions retrieved from our public database of chromospheric models and line profiles of H, Ca II, and Mg II − https://www.asu.cas.cz/~sdsa/VAL-database/. Synthetic line profiles were calculated using a grid of 17934 non-LTE models obtained by scaling the set of 1D semi-empirical models VAL A−F by Vernazza et al. (1981, ApJS 45, 635). Example plots of Mg II k, h contribution functions versus wavelength and height above $\tau_{5000} = 1$ are shown in Fig. 4. The upper row corresponds to the quiet chromosphere (model VAL−C) and the lower one to a plage (scaled model VAL−F). Red lines depict the synthetic profiles and the blue ones optical depths in the lines.

Effective formation heights can be calculated as mean heights weighted by the contribution function at the given wavelength: Δλ = 0 Å for the central reversal and Δλ ≈ 0.2 Å for the emission core (the exact Δλ depends on the model atmosphere). Because the k and h lines form practically at the same heights, we use their average. An example of effective formation heights is shown in Fig. 5. The IRIS slit intersects a small plage between the positions Y = 110 and 220 pixels. According to the applied models, the velocity of the Mg II emission is measured at the height of 900 km in the quiet Sun and 1100 km in the plage, while the central-reversal velocity originate at 2200 km and 1800 km, respectively.

This work was done thanks to the institutional support ASU:67985815 of the Czech Academy of Sciences. The VAL-database construction was supported by the project SOLARNET that has received funding from the European Union Horizon 2020 research and innovation programme under grant agreement No. 824135. IRIS is a NASA small explorer mission developed and operated by LMSAL with mission operations executed at NASA Ames Research Center and major contributions to downlink communications funded by ESA and the Norwegian Space Centre.