Stratification of physical parameters in a C-class solar flare using multi-line observations

*Rahul Yadav, C. J. Díaz Baso, J. de la Cruz Rodríguez, F. Calvo, and R. Morosin
Institute for Solar Physics, Dept. of Astronomy, Stockholm University, AlbaNova University Centre, SE-10691 Stockholm, Sweden
*Email : rahul.yadav@astro.su.se

Stockholm University

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Abstract

We present high-resolution and multi-line observations of a C2-class solar flare, occurred in NOAA AR 12740 on May 6, 2019. The rise, peak, and decay phases of the flare were recorded continuously and quasi-simultaneously in the Ca II K line with the CHROMIS instrument, the Ca II 8542 Å and Fe I 6173 Å lines with the CRISP instrument at the Swedish 1-m Solar Telescope. A non-LTE STiC inversion code was employed to infer the temperature, magnetic field, line-of-sight (LOS) velocity, and microturbulent velocity stratification in the flaring atmosphere. The temporal analysis of the inferred temperature at the flare footpoints shows that the flaring atmosphere from log(τ) ~ −2.5 to −3.5 is heated up to 7 kK, whereas from log(τ) ~ −3.5 to −5 the inferred temperature ranges between ~ 7.5 kK and ~ 11 kK. During the flare peak time, the LOS velocity shows both upflows and downflows around the flare footpoints in the upper chromosphere and lower chromosphere, respectively. Moreover, the temporal analysis of the LOS magnetic field at the flare footpoints exhibits maximum change of ~ 600 G. After the flare, the LOS magnetic field decreases to the non-flaring value, exhibiting no permanent or step-wise change. Our analysis suggests that a fraction of the apparent increase in the LOS magnetic field at the flare footpoints may be due to the increase in the sensitivity of the Ca II 8542 Å line in the deeper layers, where the field strength is relatively stronger. The rest can be due to magnetic field reconfiguration during the flare. In the photosphere, we do not notice significant changes in the physical parameters during the flare and non-flare time. Our observations illustrate that even a less intense Cclass flare can heat the deeper layers of the solar chromosphere, mainly at the flare footpoints, without affecting the photosphere.

Overview of observations

- Flare (SOL2019-05- 06T08:47) occurred in NOAA AR 12740 on May 6, 2019.
- Location: N08E48
- Time of observations: 08:34 to 09:33 UT
- Simultaneous observations performed with the CHROMIS and the CRISP instruments at the Swedish 1-m Solar Telescope (SST).
- The CRISP recorded full polarimetric observations in the Ca II 8542 Å and Fe I 6173 Å lines at 17 and 15 wavelength positions, respectively.
- The CHROMIS recorded Ca II K intensity profiles at 28 wavelength positions.
- The CRISP and CHROMIS data obtained with a cadence of 21 sec and 15 sec, respectively

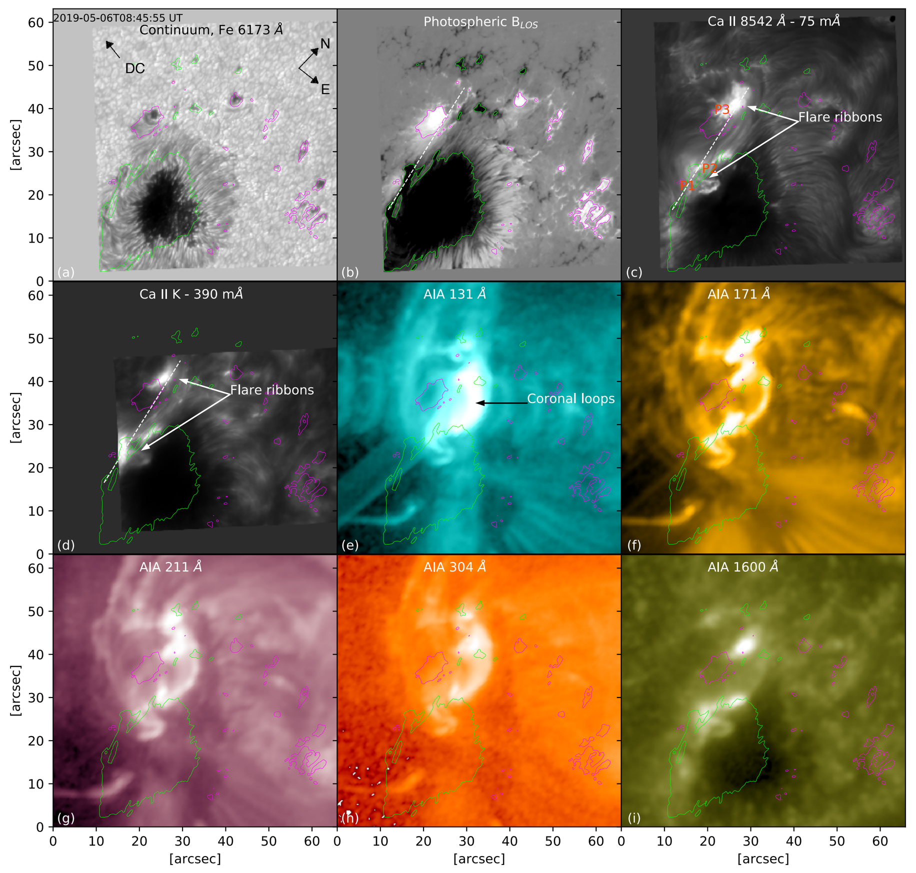

Figure 1. An overview of the C2-class flare observed at 08:45 UT on May 6, 2019 with the SST and SDO/AIA channels.

Inversion of Stokes Profiles

- The physical parameters such as temperature, magnetic field, line-of-sight velocity, and microturbulent velocity are inferred by inverting three lines (Fe I 6173 Å, and Ca II K and Ca II 8542 Å) using the STiC code.

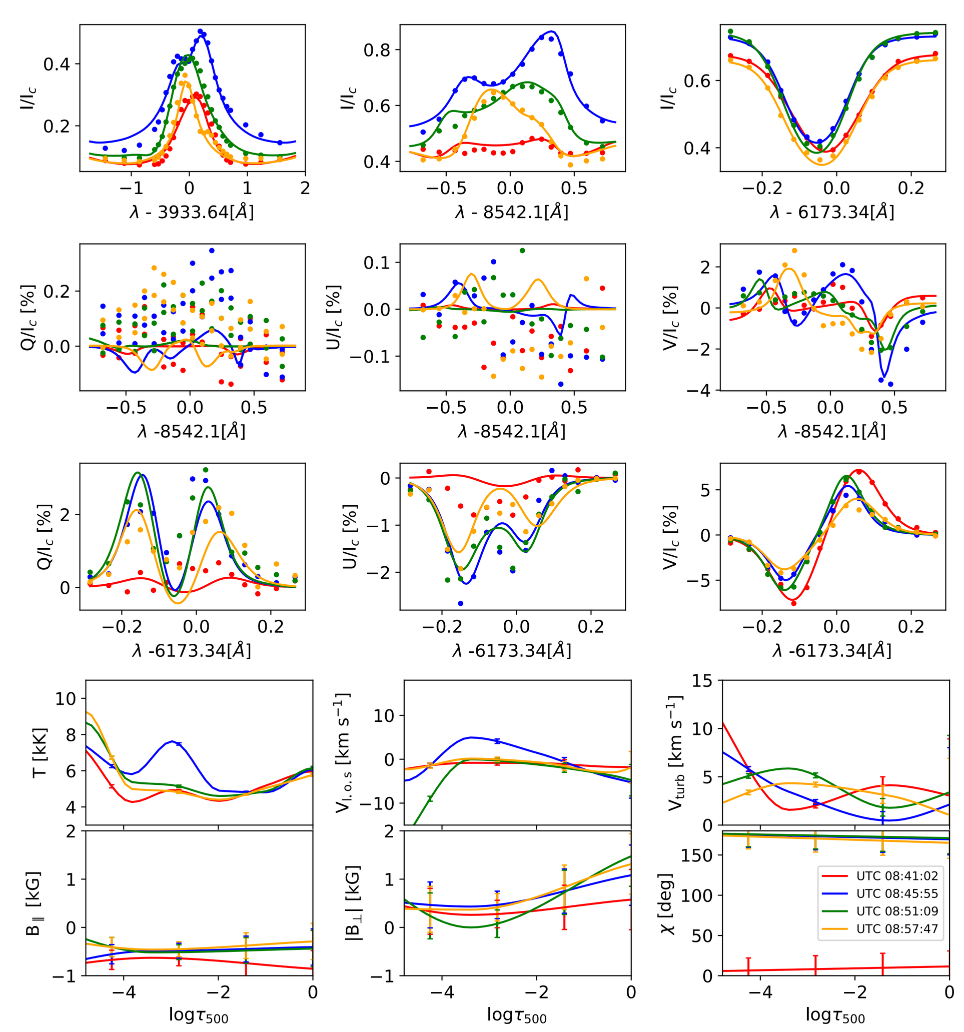

Figure 3. Top three rows: observed (dotted lines) and best fits of the Stokes profiles (solid lines). Bottom two rows: the inferred model atmosphere retrieved from the inversion with the STiC code. Different colors indicate the time of the observations during a flare. The observed profiles are located at 'P3', which is indicated in Fig. 1.

Temporal evolution of physical parameters

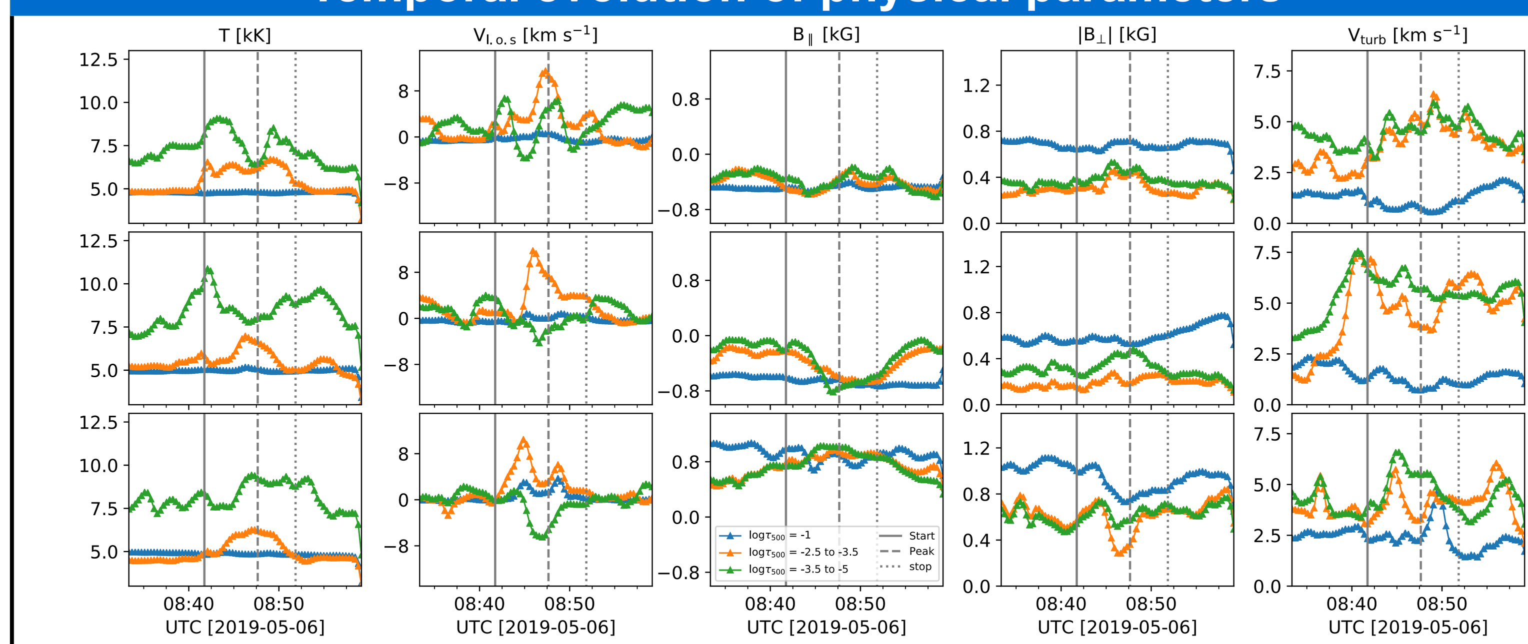

Figure 5. The temporal evolution (from left to right) of the temperature, line-of-sight velocity, longitudinal and transverse magnetic field, and micro- turbulent velocity obtained from the inversion with the STiC code at 'P1' (top panels), 'P2' (middle panels) and 'P3' (bottom panels) locations highlighted in Figure 1. The vertical solid, dashed, and dotted lines refer to the start, peak and end time of the flare, respectively.

- The mean temperature increases from ~ 5 kK up to ~ 11 kK at the footpoint in the upper chromosphere, whereas in the lower chromosphere it changes from ~ 5 kK to ~ 7 kK.
- The upper chromosphere is dominated by upflows (evaporation) and the lower chromosphere by downflows (condensation), mainly at the flare footpoints.
- The LOS magnetic field in the chromosphere show changes at the flare peak time, but that change is not permanent or step-wise. No significant change observed in the photosphere.

Temporal evolution of the observed Stokes profiles

- The intensity profiles of Ca II lines are broad and asymmetric around flare peak time.
- Enhancement in the Stokes V signal of Ca II 8542 due to strong change in the intensity profiles.
- Highly asymmetric profiles suggest the presence of a strong gradient in the LOS velocity in the chromosphere.

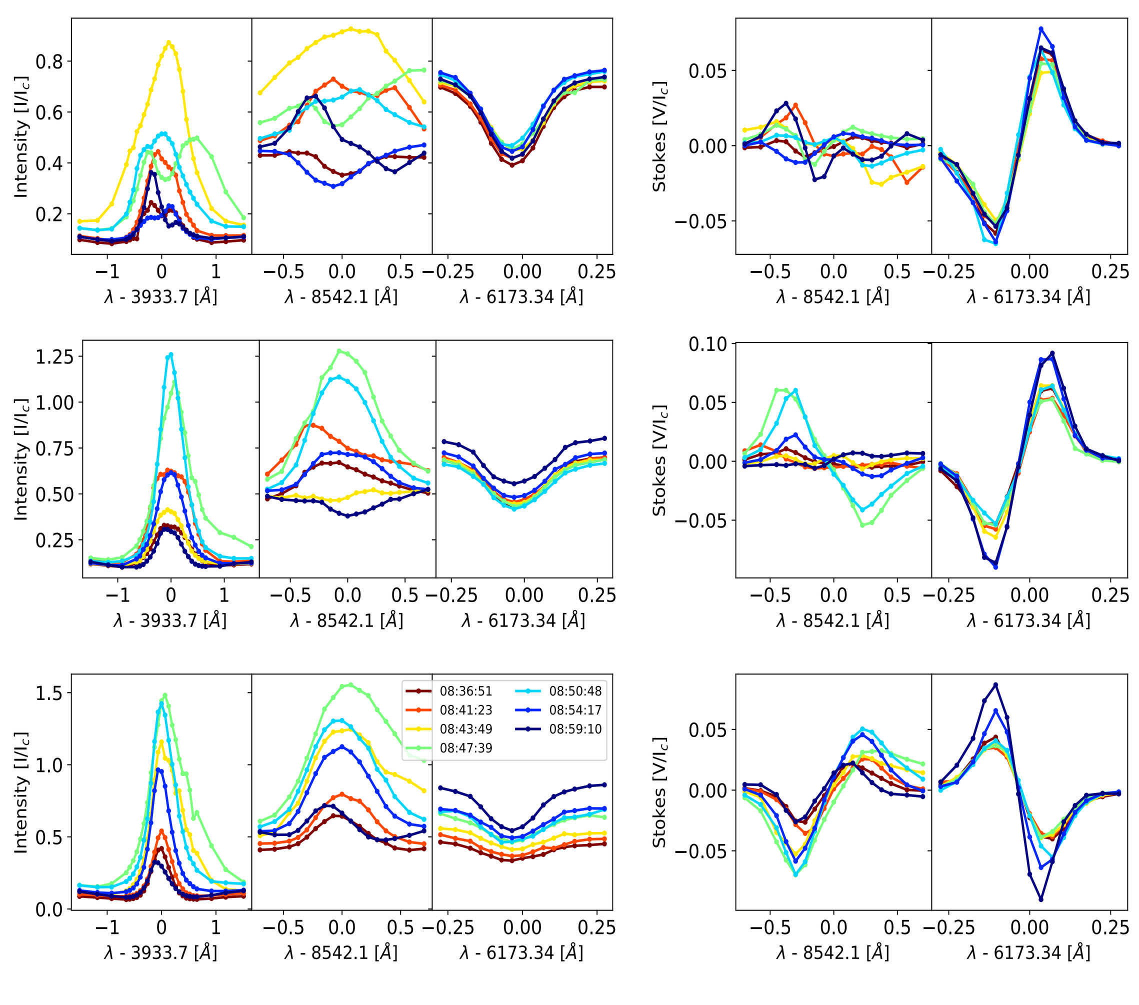

Figure 2. The temporal evolution of the observed Stokes I (Ca II K, Ca II 8542 Å and Fe I 6173 Å) and Stokes V profiles (Ca II 8542 Å and Fe I 6173 Å lines) around the flare start, peak and end time at the locations of 'P1' (top panels) , 'P2' (middle panels) and 'P3' (bottom panels) shown in Fig. 1. Different colors depict different times

Stratification of physical parameters

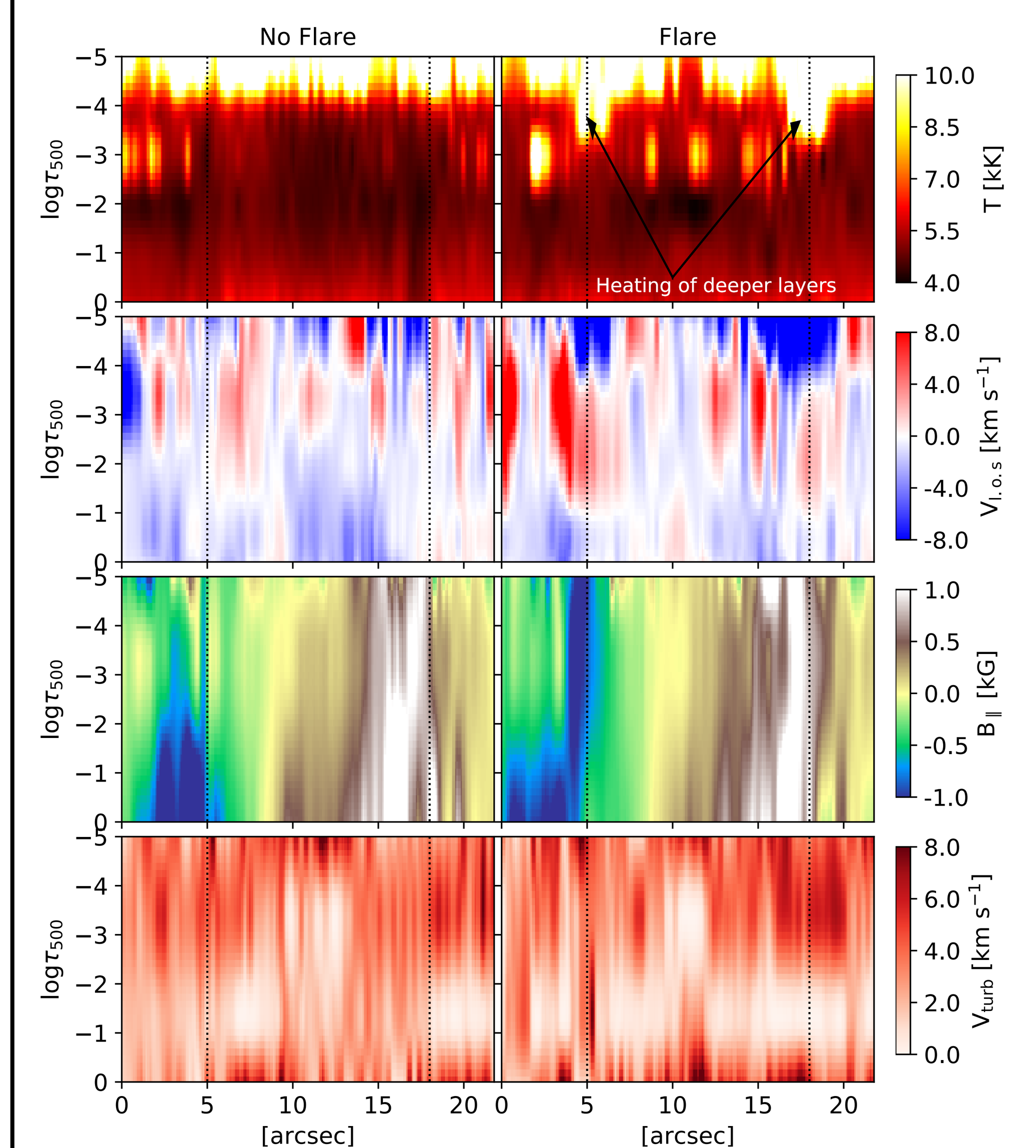

Figure 4. The stratification of temperature, line-of-sight velocity, line-of-sight magnetic field and microturbulent velocity obtained from the inversion of the pixels located on the dashed line shown in Fig. 1. The left column shows the parameters retrieved around the no-flare time (~ 09:30 UT), whereas the right column refers to the flare time (~ 08:46 UT). The dotted vertical lines refer to the possible locations of the flare footpoints.

- The flare heats the deeper layers at and around the flare footpoints.
- The presence of chromospheric evaporation and condensation can be noticed near the footpoints.

Summary

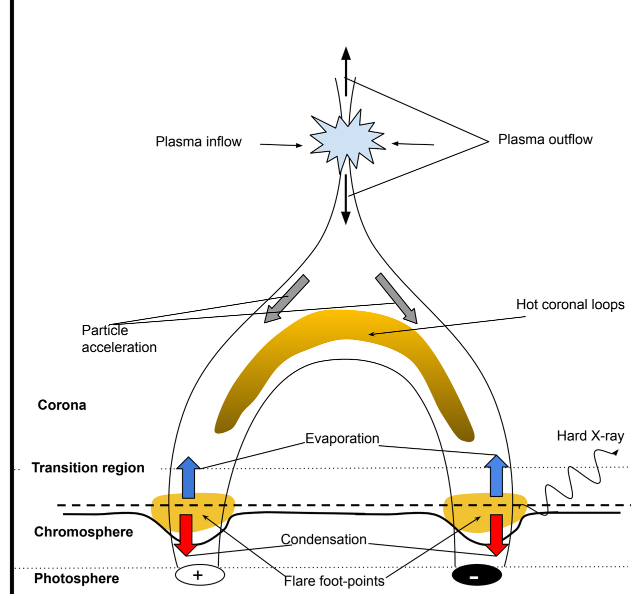

Figure 6. A sketch of the standard flare model. A plausible scenario in the chromosphere explaining our observations.

- A C-class flare was observed simultaneously in the Ca II K, Ca II 8542 Å and Fe I 6173 Å lines, with the CRISP and CHROMIS instruments at the SST.
- State-of-the-art inversion code employed to infer the physical parameters during the flare.
- In the footpoints, we reconstruct the simultaneous presence of chromospheric condensation and evaporation. At that location the temperature rises up to approximately 11 kK.
- The sensitivity of the Ca II lines analyzed in this study shifts to larger optical depth in the footpoints and their surroundings. However, the Fe I 6173 Å line show insignificant changes during the flare.
- The time evolution analysis yields changes in the magnetic field stratification, mostly above the photosphere, but those changes are not step-wise as reported in previous studies

References

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