Analysis of the Density Evolution of In-falling Prominence Material from the 7th June 2011 CME

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Overview

The June 7th 2011 eruption was a spectacular event; the amount of matter flung into the heliosphere appears to be much larger than any other on record, but even more interestingly, ended with much of the ejected material falling back to the solar surface. This suggests unusually high densities, as erupted prominence material is usually driven out into interplanetary space by magnetic pressure gradients (Chen 2011). As the matter fell back to the Sun, cohesive "blobs" were seen to form, some of which traced what appear to be magnetic Rayleigh-Taylor (RT) instabilities along their descent (Innes et al. 2012).

The Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) captured the event with full-disc, high resolution and cadence images in multiple passbands, allowing us to apply an interpolative approach to determine the column density of the cool filament material when in absorption against the disc of the Sun (Williams et al. 2013). By achieving a quantitative assessment of the in-falling material, the physical conditions for such RT instabilities may be investigated.

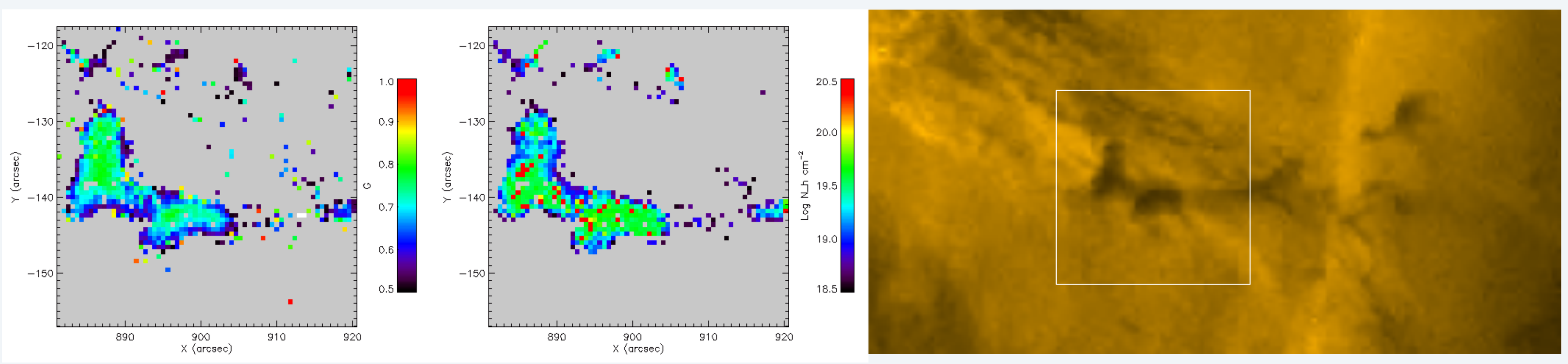

Figure 1 – Blob A at 07:15; fitted G, $\log_{10}N_H$ and 171 Å image.

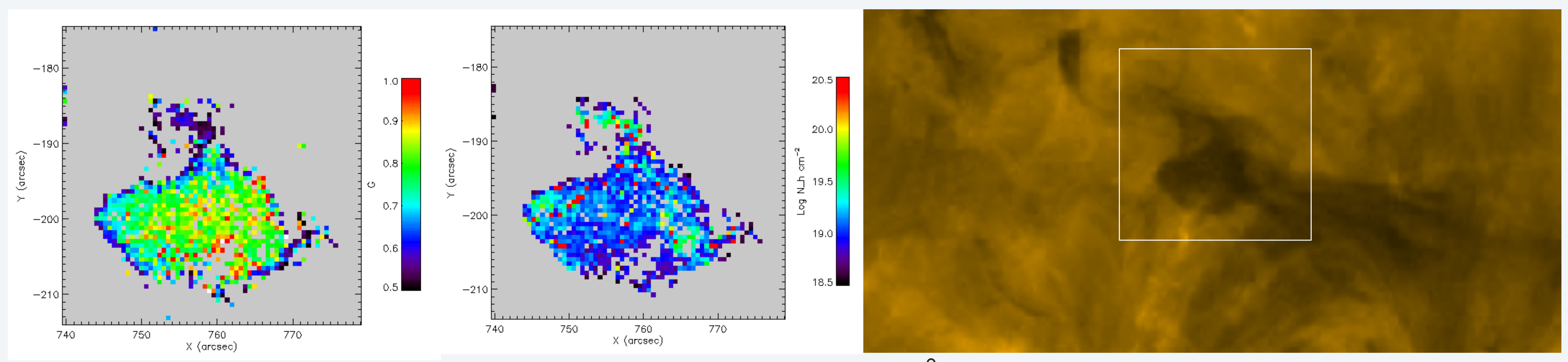

Figure 3 – Blob C at 07:32; fitted G, $\log_{10}N_H$ and 171 Å image.

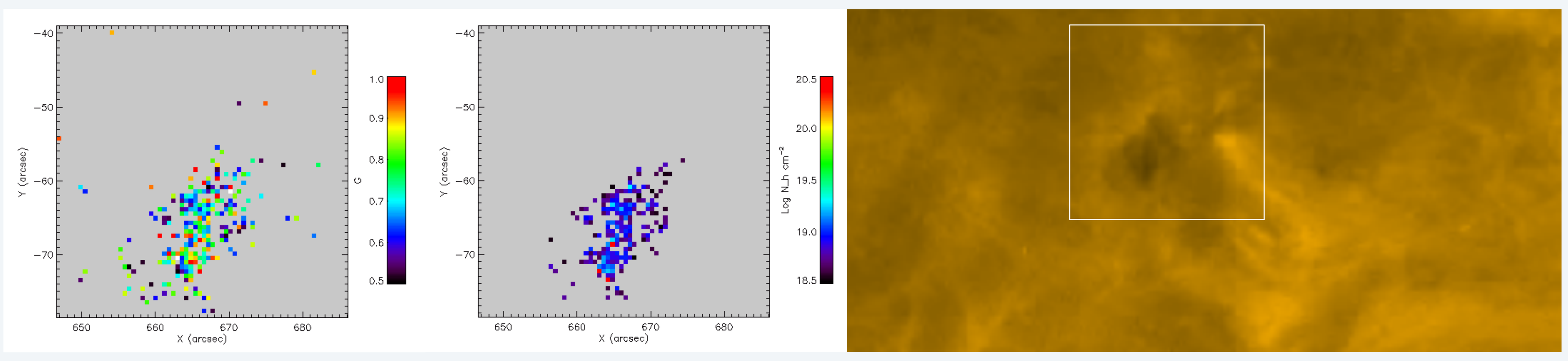

Figure 5 – Blob E at 08:17; fitted G, $\log_{10}N_H$ and 171 Å image.

Results

- All five blobs display a core with column densities of $\log_{10}N_H$ between 19.2 and 19.7 for their entire descent.
- The blobs all break up and, visually, become smaller and less defined, however the N_H values remain remarkably constant.
- The range of N_H fluctuates slightly for each blob, however they do not consistently decrease; blob E, for example, appears to start with $\log_{10}N_H$ of ~19.2, which rises to ~19.5, falling back to ~19.2 and then rising to ~19.5 again before splashing down on the solar surface!
- The value of G appears to slowly decrease over the descent of all blobs.

Method

This investigation assumes that photo-ionisation is the dominant process by which cool prominence material removes photons from the line of sight when viewed against the solar disc (Williams et al. 2013). By comparing an image of a blob to an image of the same location some minutes before (typically 2 – 5, specific to each blob) to act as an unocculted background image, the absorption by the blob in each wavelength is found. These absorption measures are then combined and fitted to an equation with two variables (see Details section): G, a combination of pixel filling factor and ratio of background-to-unattenuated emission; and N_H, the column density of the material. A best-fit value for each of these variables may then be calculated for each pixel in the image.

Details

Opacity is related to column density and intensity respectively by the following equations: $\tau(\lambda) = N\sigma(\lambda)$ (1) & $I = I_0 e^{-\tau}$ (2)
Equation (2) may be re-written using observed intensity in the presence of the blob, I_{obs}, background intensity, I_b, foreground intensity, I_f, the unattenuated intensity, I_0, and f, the pixel-filling factor: $I_{obs} = I_b[fe^{-\tau} + (1-f)] + I_f$ (3)
Rearranging, we are left with the following equation:

$$1 - \frac{I_{obs}}{I_0} = f\frac{I_b}{I_0}(1-e^{-\tau}) \quad \text{or} \quad d(\lambda) = G(1-e^{-\tau(N,\lambda)}) \quad (4)$$

On the LHS of equation (4) are observables, and the RHS is an equation to which the calculated absorption depths from the five wavelengths may be fitted, with only two variables: G and N_H. This is done using a Levenberg-Marquardt least-squares minimisation algorithm.

Observations

The data used in this investigation were gathered by the Solar Dynamics Observatory's Atmospheric Imaging Assembly (SDO/AIA) and focus mainly around NOAA active region 11226 between 06:00 and 09:00 UT. Five distinct targets of infalling prominence material ("blobs") which traced coherent descent paths were chosen, and between three and five time steps were picked out for each. The most suitable data was taken at wavelengths below 228 Å, (above this the photo-ionisation cross-section for He^+ goes to zero) (Gilbert et al. 2010), and in order to maximise accuracy, all available passbands which fit this criterion were used: 94, 131, 171, 193 and 211 Å.

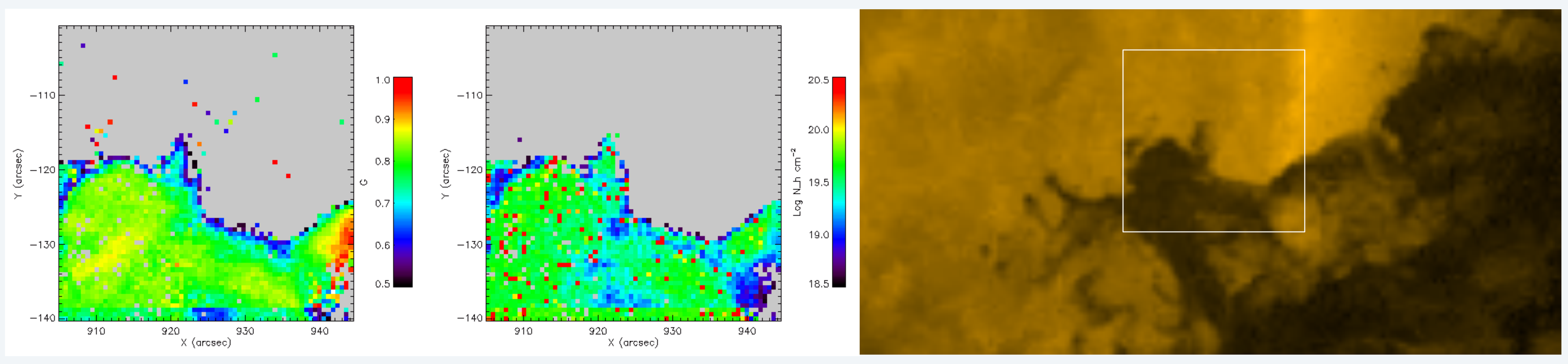

Figure 2 – Blob B at 06:45; fitted G, $\log_{10}N_H$ and 171 Å image.

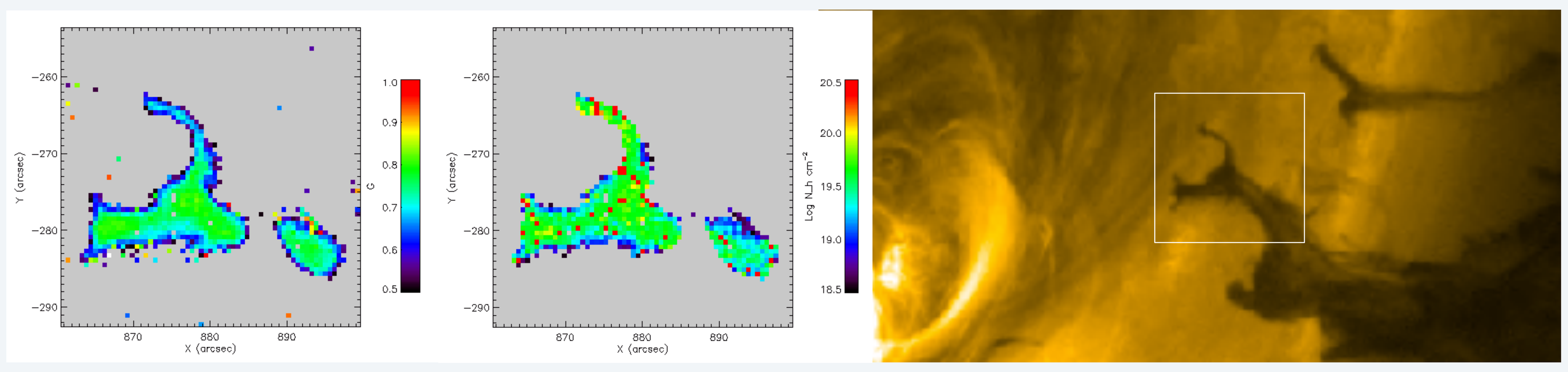

Figure 4 – Blob D at 07:11; fitted G, $\log_{10}N_H$ and 171 Å image.

Discussion

- The fact that the density stays reasonably constant over the whole descent suggests that the blobs are being held together somehow, most likely by magnetic field lines which are frozen in to the cool filament plasma.
- The visual edge of the blobs appears remarkably consistent with a G value of between 0.5 and 0.6 (Williams et al. 2013). Pixels with G < 0.5 were not displayed in Figures 1 – 5 (f > 0.5 pixels can be said to be *dominated* by filament material).
- The fall in G is most likely due to a greater proportion of the emission being in the foreground as the height of the blobs decrease.
- The mass of each blob is estimated to be of the order 10^9 kg, however the blobs differ in size quite dramatically, which changes as they fall. This is a rough estimate for the blob shown in Figure 1.

Summary and Future Directions

- The results of this work provide an interesting insight into the 7 June 2011 event, and the dynamics of infalling chromospheric material in the corona; this technique suits the data well (i.e. the material studied is fast-moving across quiet patches on the solar disc).
- The stray-light point spread function, especially in the 131 Å channel, is thought to be appreciable in SDO/AIA observations, and this will be investigated. This should minimise calculated errors on G and N_H.
- The next aim of this work is to apply the method to other solar features seen in absorption against the solar disc, including quiescent filaments, as well as erupting filaments, in order to provide mass estimates from multi-wavelength imaging data.

References:
P.F. Chen 2011, Living Reviews in Solar Physics
D. Innes et al. 2012, A&A, 540, L10
D. Williams et al. 2013, ApJ 764, 165

Acknowledgements:
The authors wish to thank UCL and the Max Planck Institute for an Impact Studentship award, STFC for support via a MSSL Consolidated Grant and the Hungarian Government for grant OTKA K-081421. The research leading to these results has received funding from the European Commision's Seventh Framework Programme under the grant agreement No. 284461 (eHEROES project). We also would like to thank the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA), led from the Lockheed Martin Solar and Astrophysics Laboratory (LMSAL), for providing the data used in this study.