Tracking flare chromospheric ionisation in the infrared

The space environment around the Earth is mainly determined by Solar Coronal Mass Ejections, which are harmful for technology and in particular (GPS or communication) satellites. The team led by Dr. P. Simoes have detected the launch of the ejections for the first time in the infrared, and have constructed novel models for explaining their observations.

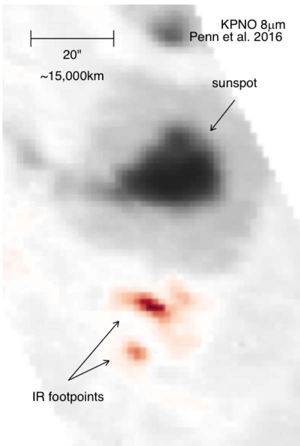

Illustration 1: First IR flare observed at 8 micron, showing two IR sources near a sunspot.

During a solar flare, rare infrared (IR) observations show intense emission arising from the same locations of flare hard X-ray and white-light sources. The IR gives a direct view into the rapid energisation of the chromosphere - similar to the much better known flare optical observations – but recent observations have shown that the IR is much easier to detect. Figure 1 shows a snapshot of recent IR flare obtained with the McMath-Pierce telescope. In anticipation of flare IR observations with the Daniel K. Inouye Solar Telescope, we have used radiation hydrodynamic simulations of a heated flare chromosphere to investigate the generation of the flare IR, and investigate what it tells us about the evolution of the flare chromosphere.

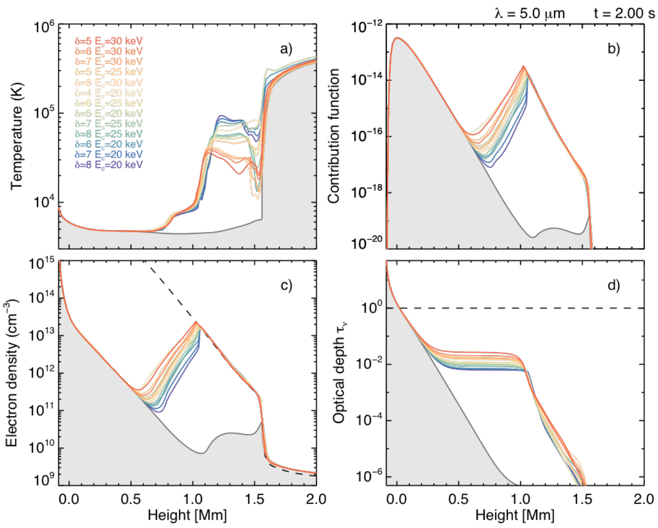

Illustration 2: Atmospheric variations of the peak of the simulated flare for different beam parameters showing (a) electron temperature, (b) contribution function at 5 microns, (c) electron dencity and (d) optical depth at 5 mirons, as a function of height above the photosphere. Grey shows the pre-flare atmosphere.

In a flare the rapid energisation of the chromosphere leads to heating and, primarily, rapid changes in ionisation. We model the flaring atmosphere, subject to heating by a beam of electrons. In Figure 2 we show part of our results, where each coloured line represents a different test of our idea.
As you can see, the details of the atmosphere vary with beam parameters, because all the coloured lines vary slightly. However, all show an increase in temperature, electron density and emission between 0.7Mm and 1.5Mm. The emission shows where the infrared originates. From Figure 2(b) it is clear that the biggest *change* in the IR emission, i.e. the IR flare excess, is from the higher altitude chromospheric layer. It is caused by the

rapid increase in flare temperature (Figure 2a) and electron density (Figure 2c), the latter due to ionisation primarily of hydrogen (and, to a lesser extent, helium). The chromosphere is transparent (optically thin) where this emission is formed. These simulations show a remarkable agreement with the recent observations at 5 and 8 µm (see Figure 1).

Infrared observations of solar flare chromospheric sources can provide useful flare diagnostics, being both a prompt response to the energy input, and directly related to the evolution of ionisation in the chromosphere. We have also been able to show that as the flare IR intensity offers the possibility to track something like the chromospheric 'total electron content'. Flare observations in the infrared continuum are rare at present, but this will change with the Daniel K. Inouye Solar Telescope which will be able to observe parts of the IR. Our results also show that at longer wavelengths, towards the radio domain, the flare emission can be used to directly measure the temperature of the flaring plasma in the chromosphere – which can be done in the future with solar flare observations with *Atacama Large Millimetre/sub-millimetre Array* (ALMA).

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Contact: Paulo Simões (Paulo.Simoes@glasgow.ac.uk)