A New Type of Small-Scale Downflow Patches in Sunspot Penumbrae

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It has been known that high-speed outward flows, called Evershed flows, take place along magnetic field lines in a sunspot penumbra. High resolution and high precision spectro-polarimetric observations with Hinode have provided lots of knowledge on relationship between filamental magnetic structures and the Evershed flows in penumbrae, which helps to understand how the highspeed flows are driven by strong interaction between inclined fields and convection. In contrast, Hinode has revealed that there are small-scale flows in and around a sunspot that cannot be explained by the Evershed flows and has not been realized before.

The penumbral flow studied in this paper is one of the flow structures newly discovered with Hinode. Observations with the Spectro-Polarimeter (SP) aboard the Solar Optical Telescope (SOT) clearly show existence of patchy downflow structures in a penumbra which are different from the Evershed flows[1]. Sunspot magnetic fields consist of vertical and horizontal magnetic components with respect to the solar surface, and they form interlaced magnetic field configuration. The patchy structures associated with the downflow have a size of 300–400 km, and are located within the vertical magnetic component. While the flow structures associated with the Evershed flow typically have duration of tens of minutes to one hour, the newly discovered downflows are relatively transient phenomena and have duration of only a few minutes. The small size and short duration probably made it difficult to find the downflow patches in previous observations. Analysis of polarized spectrum line profiles reveals that the velocity of the downflow is about 1 km/s in the lower photospheric layer, and is almost zero in the upper photosphere.

The penumbral downflows have importance because some of the downflows are temporally and spatially coincident with the chromospheric brightenings above the penumbra. It is expected that magnetic reconnection between the vertical and horizontal magnetic fields generates bi-directional jets; the downward flow is observed in the photosphere, and the upward flow is observed in the chromosphere as a transient brightening. In this case, the finding of the downflows strongly supports that magnetic reconnection takes place in the photosphere. On the other hand, no counterpart is detected in the chromosphere for some of the downflows. One reason is that the observation does not have enough temporal resolution to detect temporal coincidence of the transient downflows and the brightenings. Some of the downflows are observed to appear after disappearance of the Evershed flows, which suggests that cooled materials drain down along magnetic fields after interruption of heat transport by the Evershed flow. The process is possibly related with the disappearance of the filamental magnetic fields[2]. It is required to acquire a simultaneous observation of the photosphere and the chromosphere with high temporal resolution to get a better grasp on the cause of the downflows.

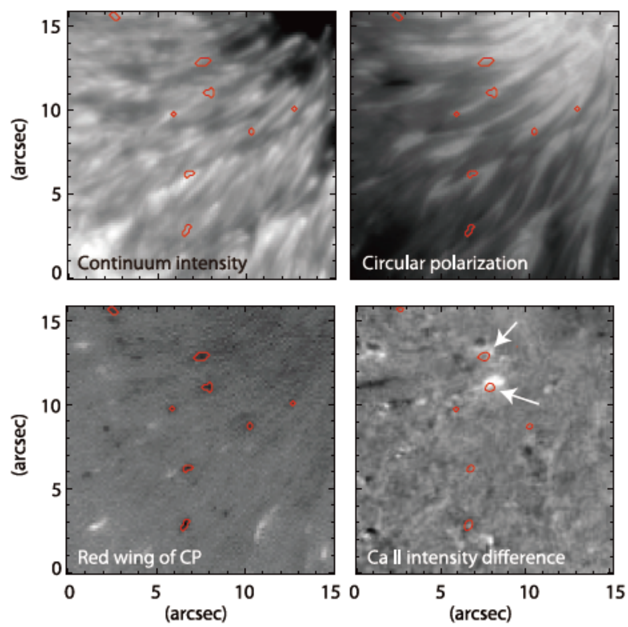

Figure 1: Sunspot penumbra observed with the Hinode Spectro-Polarimeter (SP). Here are shown maps of contin- uum intensities (*left top*), intensities of circular polarization (*right top*), red shifts of the circular polarization (*left bottom*), and chromospheric brightenings seen in Ca II H ltergrams (*right bottom*). The red contours indicate down ow patches, and the arrows indicate the chromospheric brightenings coin- cident with the down ows.

References

[1] Katsukawa, Y., Jurčák, J.: 2010, *A&A*, **524**, A20.
[2] Jurčák, J., Katsukawa, Y.: 2010, *A&A*, **524**, A21.