Identification of Vortex Flows in the Lower Solar Atmosphere

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Abstract

Traditionally photospheric intensity flow fields have been traced using local correlation tracking of magnetic bright points and the revealed vortex flows have been identified by eye. This manual approach has two major shortcomings. First, it introduces observational bias and second a large number of vortex flow fields are most likely missed due to the sheer scale of the task, which also has adverse effects on the variance of the statistical analysis. Small-scale vortices in the quiet Sun regions are widely accepted to form due to turbulent convection **[1-3]**. Solar photospheric vortex flows have drawn the attention of researchers as they have the potential to excite a wide range of MHD waves, e.g. slow and fast magneto-acoustic as well as Alfven **[4]**. In this work we present an automated approach to identify intensity vortex flows on the photosphere and perform a statistical analysis of their properties.

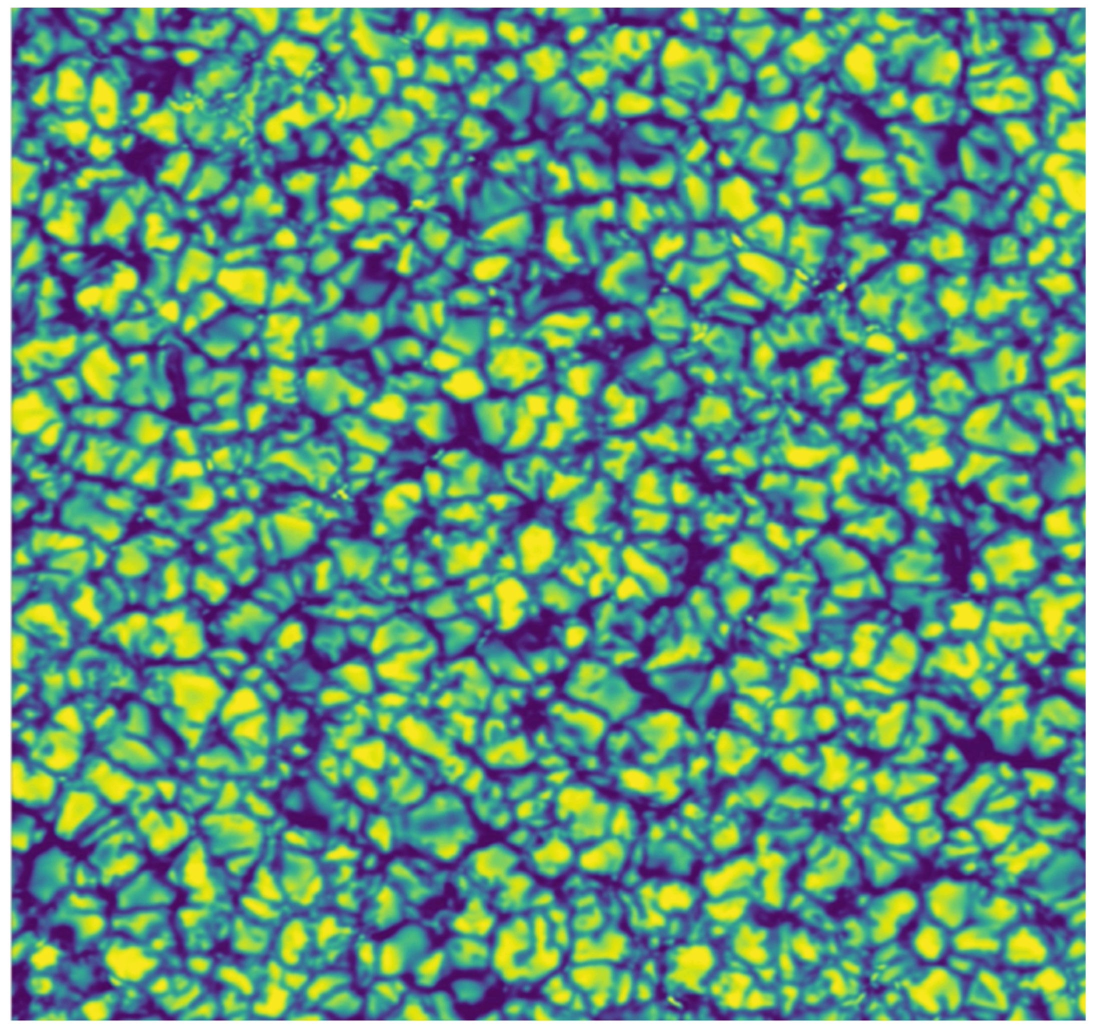


Fig. 1. Post-processed Fe I continuuum. Observations using the Crisp Imaging SpectroPolarimeter (CRISP) at the Swedish 1-m Solar Telescope.

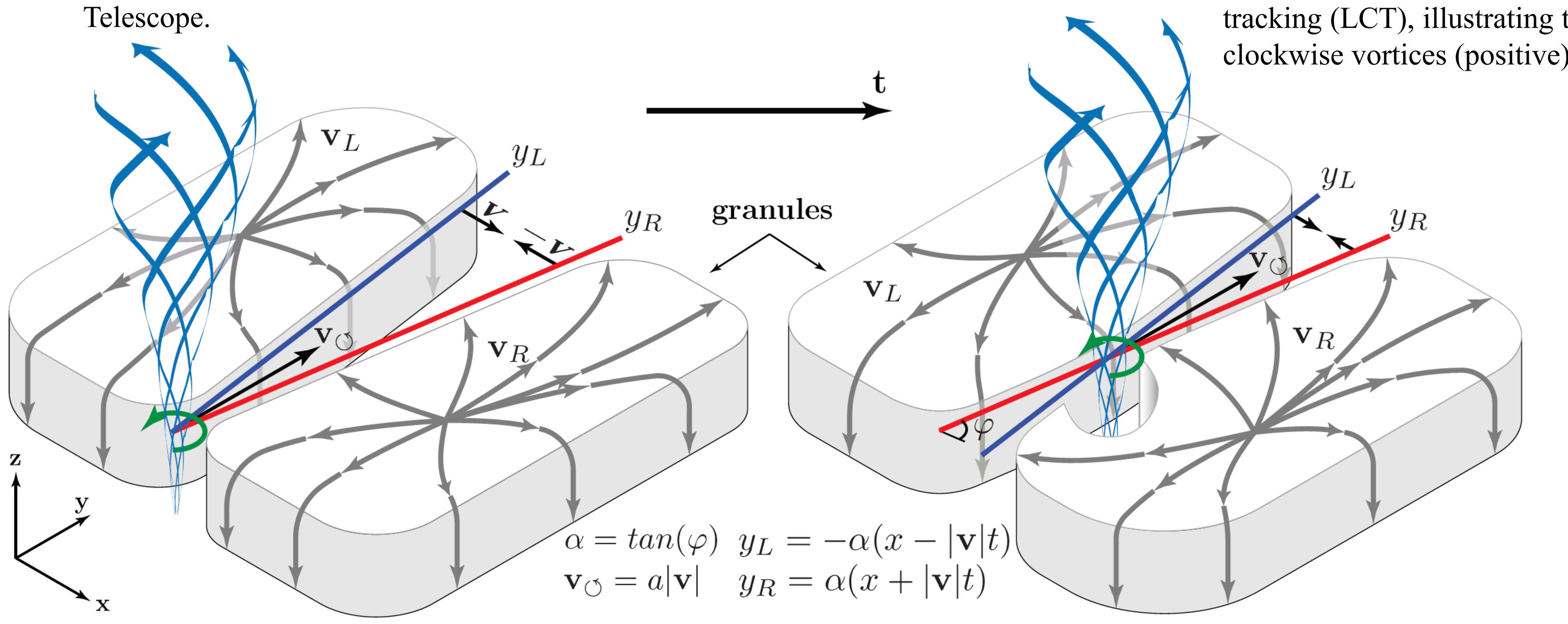


Fig. 2. Illustration of a possible physical mechanism explaining the apparent high velocity of vortex centers. The line segments y_L and y_R, shown in blue and red color respectively, represent the edges of two neighboring granules. In this instance the two edges are moving towards each other with speed |v|. The streamlines in the plane represent the velocity field near the edges of the granules, with v_L and v_R representing the velocity field in the left and right granule respectively. The velocity of the vortex center is labeled v_{circ}. The blue streamlines in the z-direction represent magnetic field lines above the vortex center.

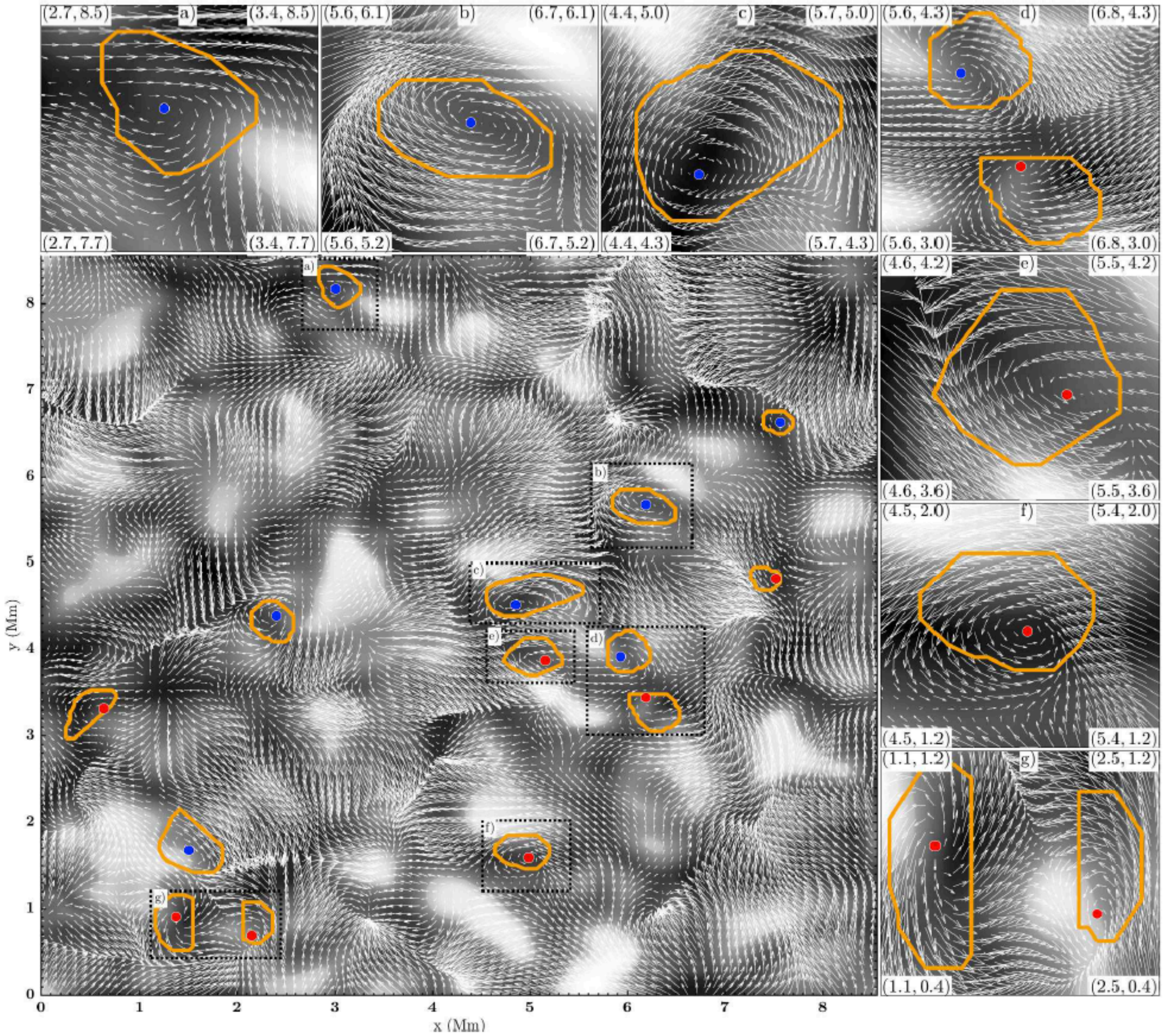
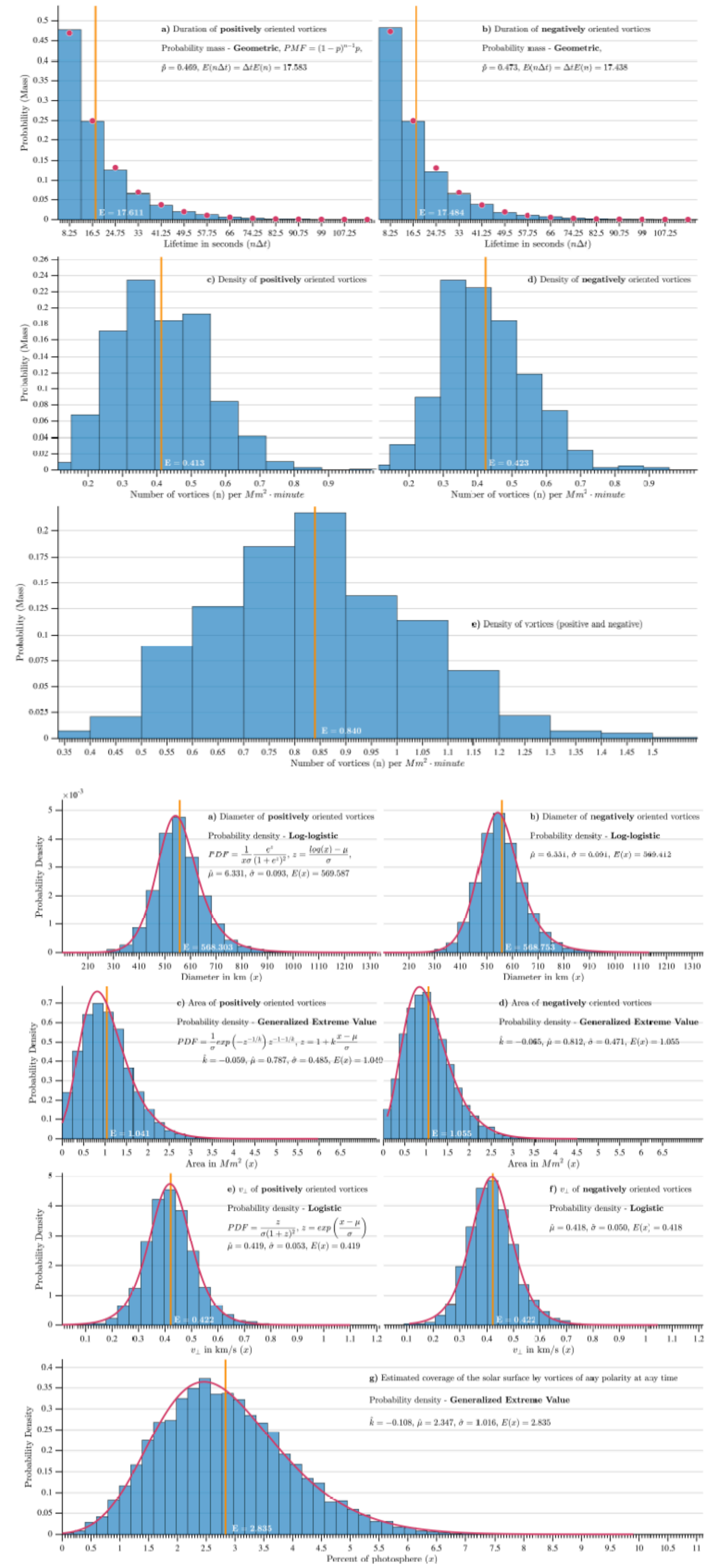


Fig. 3. A snapshot of the estimated velocity field based on the Fe i continuum (intensity shown here in grayscale) using local correlation tracking (LCT), illustrating the identified vortices and their boundaries. The circles denote the vortex center, with red referring to counter clockwise vortices (positive) and blue clockwise vortices (negative). The orange border line denotes the vortex boundary.

The automated vortex identification methodology we present splits into four stages: i) pre-processing, ii) velocity field estimation, iii) vortex identification and, iv) vortex lifetime estimation. The intensity maps obtained from observations have varying intensity at different times that appears to be due to atmospheric effects, given that the magnitude of the intensity variation is a few standard deviations from the mean, and, the effect is global, i.e. affects almost equally the entire image and disappears in subsequent frames. To counter these effects image histogram equalization **[5]** was used in the following way:

- First, the expected distribution of intensities is estimated by means of averaging the histogram distributions across all frames. The rationale for this is that the Sun is not expected to change its general power emission spectrum during the time of the observation.
- Once the expected intensity distribution has been obtained, histogram equalization is applied to all frames using that distribution as a reference.

This procedure is fast and efficiently removes inter-frame flickering, and, improves the numerical stability of the LCT method.



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