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Where do running penumbral waves emerge in chromosphere?

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Abstract. The earlier work on the oscillatory phenomena in sunspot structures have supported in validating the detection of long-period oscillations, which are generated by the photospheric umbral response to the five minute p-mode global oscillations. We report here on the events of 3-min umbral oscillations which are detected within a duration of one hour from a single-polarity sunspot of active region NOAA 12132. The umbral oscillations that appear first around umbral boundaries is speculated to be excited by the wavefronts at the umbral-penumbral boundaries due to sub-photospheric or photospheric granular buffetings. The appearance of the wavefronts in spiral structures suggests that the wave guides are twisted. In addition, the newly formed running penumbral waves (RPWs) appears to be connected with the preceding RPWs.

Keywords. Sun: chromosphere, Sun: oscillations, Sun: sunspots

1. Running penumbral waves and Umbral Oscillations

Zirin *et al.* (1972) and Giovanelli *et al.* (1972) first observed the Running penumbral waves (RPWs). Usually the RPWs have periods of 3-5 min and they propagate more or less uniformly outwards and becomes gradually invisible while approaching the outer boundary of the penumbra. The physical nature of the RPWs is controversial. Some studies show that they are waves originating from oscillating elements inside the umbra. The RPWs and umbral oscillations appear to belong to the same traveling wave system and probably the underlying driving physical mechanisms are same. There is also evidence that umbral oscillatory events of the chromosphere are not the source of RPWs (Giovanelli *et al.* 1972; Jess *et al.* 2013). However, Su *et al.* (2016) suggested the association of the running waves with the chromospheric umbral oscillations . Also, there are several theoretical models to explain the nature of the umbral oscillations. But, the question that arises is where do the RPWs initially emerge in chromosphere, in the inner umbra or umbral boundary of sunspots? What is the linkage between umbral oscillations and RPWs?

2. Analysis, Results and Discussion

We revisited the issue with RPWs using the spectra of TiO, Hα, and 304 Å for various atmospheric heights from the photosphere to lower Corona. TiO and Hα observations of umbral oscillations in sunspot of active region NOAA AR12132 are conducted on August 5, 2014, using Goode Solar Telescope (Cao *et al.* 2010) operating at Big Bear Solar Observatory. Observations cover the umbral oscillations and RPWs at different

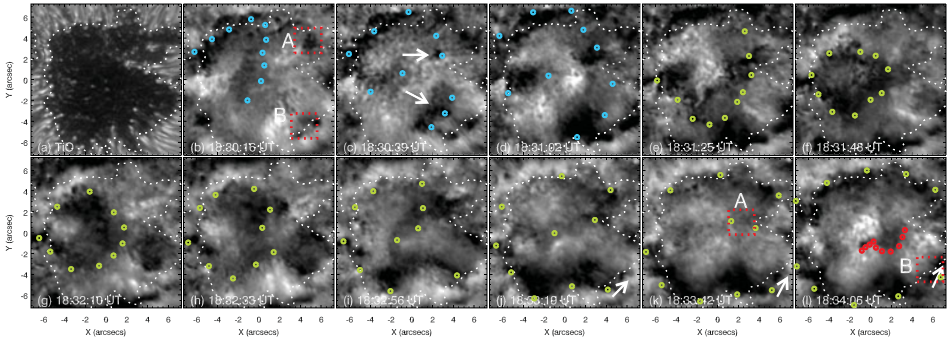

Figure 1. (*a*) is a TiO map for reference and white dotted contours in it and the other panels mark umbral boundaries. (b)-(l) is the time series of filtered H$\alpha - 0.4$ Å images with phase speeds > 4 km s^{-1}, on which circle symbols are superposed to highlight the trajectories of running wavefronts. Red squares at A and B mark initial emerging locations of the next umbral oscillations.

heights in solar atmosphere. The filtering method has been introduced and tested in Su *et al.* (2016) to distinguish between the umbral and penumbral waves. We have utilized a high-speed ($v > 14$ km s^{-1}) filtered images to investigate the properties of umbral oscillations and get a clear picture of the propagating RPWs. Our analysis show that the power in passbands of Hα -0.4Å accounts for only about 5% of that in the passband of TiO, suggesting that there is only 5% transmission rate for 5-min oscillation power from TiO to Hα -0.4 Å. It is noticed that most of the umbral oscillations originates close to the boundaries of umbra. Also, it is observed that the wavefronts which are part of the already emerged RPWs detaches itself from the RPWs and jumps into the center of the umbra where it appears to expand radially and starts a new oscillations as shown in Fig. 1 (see Priya *et al.* 2018 for more details). Along the edges of the wavefront, the periods of running waves show a large spread. Since umbral oscillations probably appear first around umbral boundaries, we speculate that they are excited at umbral-penumbral boundaries due to sub-photospheric/photospheric granular buffetings. Moreover, it is suggested that the wavefronts in spiral structures is due to the twisting of the waveguides. If both of the two speculations are real, then we should first see wavefront at umbral boundaries with high latitude, then at umbral centers with lower latitude. The twisting motion of waveguides opens a new window to understand the nature of waveguides, and potentially of small-scale magnetoconvection and penumbral energy transport. MHD simulations by Khomenko *et al.* (2008) suggests there is possibility of 5 minute oscillations leaking up into the chromosphere all inside the magnetic flux tubes.

References

Cao, W., Gorceix, N., Coulter, R., *et al.* 2010, *Astronomische Nachrichten*, 331, 636

Giovanelli, R.-G. 2013, *solphys*, 27, 71

Jess, D. B., Reznikova, V. E., Van Doorsselaere, T., Keys, P. H. *et al.* 2013, *ApJ*, 779, 168

Khomenko, E., Centeno, R., Collados, M., & Trujillo Bueno, J. 2008, *ApJ*, 676, L85

Priya, T. G., Wenda, Cao, Jiangtao, Su., Jie, Chen., Xinjie, Mao., Yuanyong, Deng., & Robert, Erdlyi. 2018, *ApJ*, 852, 15

Su, J. T., Ji, K. F., Cao, W., Banerjee, D., Priya, T. G., *et al.* 2016, *ApJ*, 817, 117

Zirin, H. & Stein, A. 1972, *ApJ* (Letters), 178, L85

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