5.2 学位論文

Numerical Study of Plasma Instabilities to Investigate Fine-Scale Prominence Dynamics

The launch of SOT on the Hinode satellite revolutionised prominence observations. With spatial resolution of 0.2" (~ 140 km) and high temporal cadence (~ 10 s) combined with the seeing free observations provided by a satellite, it has given unprecedented observations of the fine-scale structure and dynamics of quiescent prominences. Through these observations, previously unobserved dynamics have been discovered that challenge our thinking on quiescent prominences.

The most striking of the observations has to be that of dark upflows that propagate from cavities that form at the base of the prominence through the dense prominence material. These observations show plumes of underdense material propagating through the dense prominence. These plumes are excited by the magnetic Rayleigh-Taylor instability, in what is arguably the best observation of this phenomena in an astrophysical system (Berger et al. 2011). As this is an observation, not an experiment, numerical simulations are necessary to complete our understanding of this phenomena.

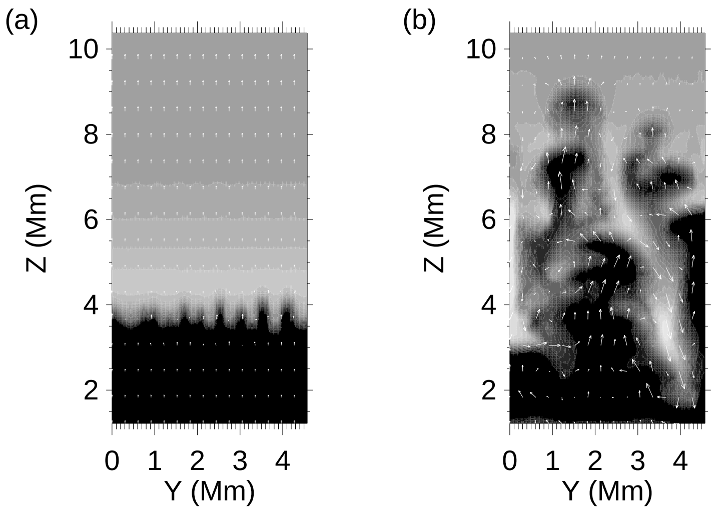

Fig.1: This figure shows a 2D slice along the centre of the 3D prominence. The initiation of the magnetic Rayleigh-Taylor plumes (panel a) and the nonlinear evolution (panel b) are shown. The simulated plumes are remarkably similar to those observed in prominences.

In my Ph.D. thesis, using 3D MHD simulations, we investigated the nonlinear stability of the Kippenhahn-Schlüter prominence model for the interchange mode of the magnetic Rayleigh-Taylor instability. The model simulates the rise of a buoyant tube inside the quiescent prominence model, where the interchange of magnetic field lines becomes possible at the boundary between the buoyant tube and the prominence. Upflows of constant velocity (maximum found $6\,\mathrm{km\,s^{-1}}$) and a maximum plume width ≈ 1.5 Mm which propagate through a height of approximately 6 Mm were found. Nonlinear interaction between plumes was found to be important for determining the plume dynamics (Hillier et al. 2011 ApJL). It was found that the 3D mode of the magnetic Rayleigh-Taylor instability grows, creating upflows aligned with the magnetic field of constant velocity (maximum found $7.3\,\mathrm{km\,s^{-1}}$) (Hillier et al. 2012). These results are in general agreement with the observations of the rising plumes.

These simulations have also shown that the Rayleigh-Taylor instability results in the formation of current sheets inside the prominence and that reconnection in these currents sheets triggers dense downflows in the prominence. These downflows are accelerated by gravity to reach supersonic velocities, resulting shearing and twisting of the prominence magnetic field. Matching these results to observations of bright descending blobs of plasma in prominences (know as prominence knots) have lead to the creation of a new dynamic model for this phenomenon which is presented in my thesis.

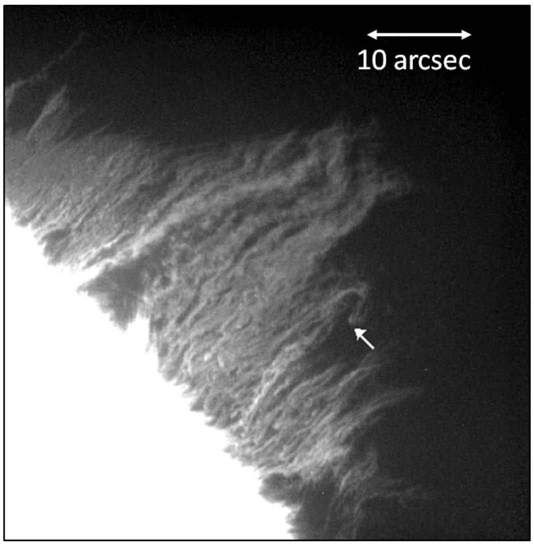

Fig.2: This figure shows a quiescent prominence, observed by Hinode SOT. The ejection from the top of the prominence is marked with the arrow. Over the 4 hours of the observations, 4 such ejections were observed. These ejections were launched against gravity, before falling under ballistic motion.

New Hinode observations of blobs of plasma were found that were ejected against gravity before undergoing freefall motion (Hillier et al. 2011 PASJ). To investigate this phenomenon, the development of a prominence current sheet under the crossfield diffusion of neutral particles was investigated for the first time. This lead to the discovery of a significantly increased growthrate for the tearing instability, that would be able to provide an explanation for the upward ejected plasma blobs.

These studies show that the local dynamics observed by Hinode are very important for our understanding of quiescent prominences, particularly in relation to the structure of the magnetic field inside the prominence.

Reference:

Berger, T., Testa, P., Hillier, A., et al. 2011, Nature, 472, 197

Hillier, A., Isobe, H., & Watanabe, H. 2011, PASJ, 63, L19

Hillier, A., Isobe, H., Shibata, K., & Berger, T. 2011, ApJL, 736, L1

Hillier, A., Berger, T., Isobe, H., & Shibata, K. 2012, ApJ, 746, 120

(Andrew Hillier)