6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Magnetohydrodynamic seismology of solar coronal plasmas

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Processes operating in the outer part of the atmosphere of the Sun, the fully-ionised and magnetically-dominated plasma of the solar corona, remain one of the major puzzles of the Solar System physics. The intensively debated research topics are enigmatic problems of coronal heating, rapid release of a huge amount of magnetic energy in solar flares and coronal mass ejections, microphysical processes responsible for effective acceleration of charged particles, anomalous values of transport coefficients, and the nature of the fine perpendicular structuring. The solar physics research community is well supported by a number of ground-based and spaceborne observational facilities providing us with a wealth of high-precision data throughout the electromagnetic wave spectrum, from radio to gamma-rays. However, several key parameters of the solar corona, such as the magnetic field and coronal heating function, as well as effective coefficients of thermal conduction, viscosity, and resistivity, as well as the fine perpendicular structuring, are not open to direct observations. The method of magnetohydrodynamic (MHD) seismology, based on probing plasma parameters by MHD waves, provides us with a paradigm changing diagnostic tool for studying the plasma in the corona [1].

Modern MHD seismology utilises several ubiquitous and confidently detected MHD modes of various plasma structures. In the talk, we concentrate on the seismology with the kink mode which appears as transverse repetitive displacements of coronal plasma loops [2]. The loops are the enhancements of the EUV emission brightness, elongated along the apparent direction of the closed magnetic field lines. Loops are believed to be the main building blocks of the magnetically-closed corona. The perpendicular non-uniformity of the plasma makes loops to act as effective fast magnetoacoustic waveguides, in particular, for the kink mode waves.

Kink oscillations of the decayless class are detected as small amplitude (< 1 Mm) persistent displacements of the loops in the plane of the sky, occurring without any association with solar flares, eruptions, or other impulsive energy releases. The observed duration of the oscillations reaches up 50 oscillation cycles without any apparent systematic variation of parameters of the oscillating loop. Typical oscillation periods range between 2–11 minutes. It is likely that kink oscillations outside this range are not detected because of the instrumental resolution limitation and the loops' observability lifetimes.

Oscillation periods of decayless kink oscillations are established to correlate linearly with the lengths of the oscillating loops, indicating that the oscillations are natural modes of the loop, similarly to transverse oscillations of a string. Together with the oscillation wavelengths estimated by imaging observations, we determine the kink phase speed. This information allows for constructing Alfvén speed maps in the host active regions (Figure 1). Further development of this technique addresses the estimation of the free magnetic energy available for a release in a flare or eruption [4].

The statistical distribution of oscillation amplitudes with the periods shows no pronounced peaks associated with a certain period, suggesting the lack of a periodic driver. We discuss two main mechanisms responsible for the decayless behaviour: the self-sustained oscillatory process based on the interaction of steady flows with the oscillating loop via the phenomenon of negative friction; and a randomly driven oscillatory process based on granulation flows near footpoints of the loop. Revealing the mechanism is expected to provide us with the information vital for understanding the energy balance in the upper part of the solar atmosphere.

References
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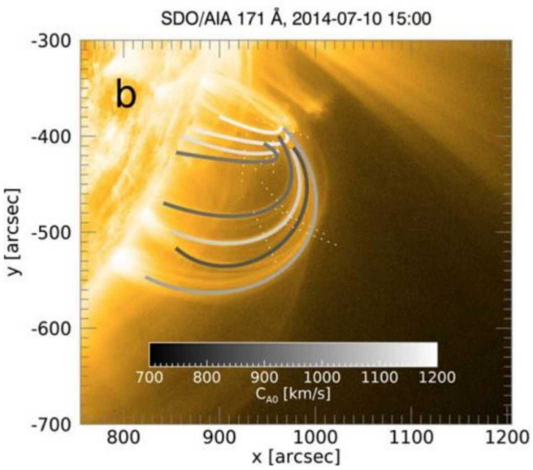

Figure 1. Mapping the Alfvén speed in AR 12107. The color of the broad curved lines following the coronal loops shows the internal Alfvén speed estimated from the observed decayless kink oscillations. The EUV image of AR12107 observed by SDO/AIA at 171 Å on 2014 July 10 at 14:32 UT is used as the background. Artificial slits used for creating time–distance plots are marked with the straight dotted lines. (From [3])