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Parametric interaction of coronal loops with p modes

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Abstract

Parametric resonance between p modes and eigenoscillations of coronal loops is studied. Observations of solar radio bursts revealed this effect in simultaneous excitation of loop oscillations with periods corresponding to the pumping-up frequency (5 min), subharmonic (10 min), and to the first upper frequency of parametric resonance (3.3 min). An interpretation in terms of a coronal magnetic loop as an equivalent electric circuit is given. Parametric resonance can work as a channel for transfer of energy from photospheric motions to stellar coronae.

Individual Objects: Sun

Introduction

The heating of solar (up to 10^6–10^7 K) and stellar coronae (10^7–10^8 K) has been explained by a variety of mechanisms. In particular acoustic heating, reconnection, damping of MHD-waves, topological dissipation, microflares were discussed in this context, but without an obvious solution in sight. We consider here another possible origin of coronal heating dealing with parametric resonance between coronal loops and p modes.

Parametric excitation of loop oscillations by p modes

There is quite a lot of evidence of 5-min oscillations in the solar corona as inferred from TRACE and SOHO data (see e.g. De Moortel et al. 2002; De Pontieu et al. 2005) and Metsähovi observations at 11 and 37 GHz (Kislyakov et al. 2006; Zaitsev & Kislyakov 2006). Figure 1 presents the example of spectral analysis of the solar flare event on March 20, 2000 which revealed 10, 5, and 3.3 min oscillations. Why are p-mode oscillations driven by photosphere convection observed at the coronal level?

De Pontieu et al. (2005) suggested a tunneling or direct propagation of photospheric oscillations into the outer atmosphere via slow MHD and shock waves. We interpret such kinds of events using the electric circuit model for a coronal loop (Zaitsev et al. 2000) and parametric resonance between acoustic eigenmodes of a loop and p modes. Indeed, 5-min velocity oscillations of the photosphere modulate the electric current in a coronal loop foot point. Parametric resonance between photosphere oscillations and sound oscillations $\omega_0 = k_{||} c_s$ of the loop appears. This effect reveals itself in the excitation of loop oscillations with periods of 5 min (pumping-up frequency ω), 10 min (sub-harmonic $\omega/2$), and 3.3 min

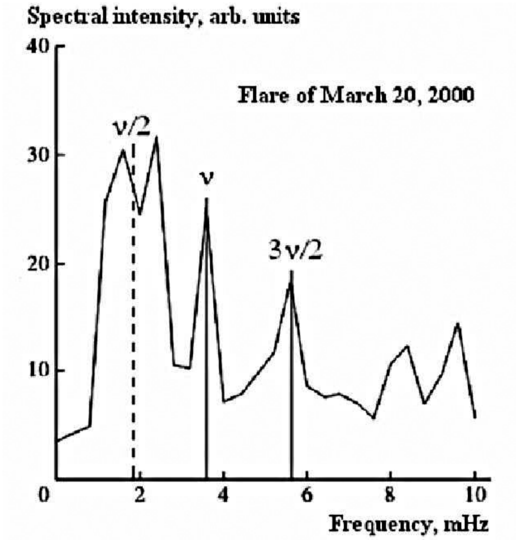

Figure 1: Spectrum of pulsations in the flare event on March 20, 2000 observed with the Metsähovi radio telescope at 37 GHz. The dashed line shows the frequency of the 1.8 mHz (10 min period), while the solid vertical lines indicate the frequencies of 5-min (3.6 mHz) and 3.3-min (5.6 mHz) oscillations.

(corresponding to the first upper frequency of parametric resonance $3\omega/2$). Modulation of electric current leads to modulation of sound velocity in a loop (Zaitsev & Kislyakov 2006):

$$c_s = \left(\frac{2\gamma k_B T}{m_i}\right)^{1/2}\left(1+\frac{\Delta T}{2T}\right) = c_{s0}(1+0.5q\cos\omega t), \qquad q = \frac{4}{3}\frac{\gamma-1}{\gamma}\frac{I^2}{\pi c^2 r^2 p}\frac{I_\sim}{I}.$$

Here p is the gas pressure, r is the loop radius, $k_{||} = s\pi/L$, L is the loop length, $s = 1, 2, 3, \dots$, $I \gg I_\sim$. Deviations of loop plasma parameters can be written as

$$\frac{d^2y}{dt^2} + \omega_0^2(1+q\cos\omega t)y = 0$$

Here the parameter q is determined by the width of zones near the frequencies of a parametric resonance $\omega_n = n\omega/2$, $n = 1, 2, 3, \dots$ where the parametric instability occurs (Landau & Lifshitz 1976). The width of the first instability zone $(-q\omega_0/2 < \omega/2 - \omega_0 < q\omega_0/2)$, where ω_0 is close to $\omega/2$, is larger. So, the amplitude of variations of sound speed under action of photospheric oscillations is higher compared to the second considerably narrowed zone $\omega \approx \omega_0$ if $q \ll 1$ (Fig. 1). Since p modes cannot directly penetrate into the corona, the parametric resonance may work as an effective channel for transfer of energy of photospheric oscillations to the upper layers of the atmosphere. It offers the challenge to understanding the heating mechanism of stellar coronae. Estimations made for solar loops have shown that if the current exceeds 7×10^9 A, the energy flux of sound oscillations arising in the coronal magnetic loop as a result of parametric resonance exceeds losses due to optical radiation.

Conclusions

Hindman & Jain (2008) proposed recently that loop oscillations are generated due to the buffeting excitation of loop magnetic fibrils by p modes. They supposed however that magnetic fields are potential and no electric current exists. Our mechanism suggests the interaction of p modes with electric currents in coronal loop and the heating of loop foot points due to the dissipation of the electric currents. Because p modes do not penetrate into the corona, the parametric resonance is a good way for transfer of energy of photosphere oscillations to stellar coronae.

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