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Неустойчивость акустических колебаний под действием излучения

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Аннотация. Введение. *Интенсивность излучения высокотемпературной плазмы солнечной короны существенно зависит от температуры, причем эта зависимость носит сложный характер, поскольку вклад различных источников излучения крайне неоднороден, особенно в линиях излучения элементов, входящих в состав короны.* ***Результаты и обсуждение.*** *Например, в диапазоне температур 0,5–1 МК наблюдается сильный рост функции излучения, а в диапазоне 1–4,5 МК наблюдается столь же быстрый спад. В области затухания возможна адиабатическая неустойчивость колебаний плотности плазмы, обусловленная быстрым затуханием.* ***Заключение.*** *С использованием ранее полученной кубической сплайн-интерполяции функции излучения исследована адиабатическая неустойчивость и определены границы интервала неустойчивости, которые подтверждаются другими расчетами.*

Ключевые слова: компьютерное моделирование, физика плазмы, функция излучения, магнитная гидродинамика, Солнце, колебания и волны

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Research article

Instability of acoustic oscillations under the influence of radiation

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Abstract. Introduction. *The radiation intensity of the high-temperature plasma of the solar corona depends strongly on temperature, and this dependence is complex, as the contributions of various radiation sources are highly nonuniform, particularly in the emission lines of elements inhabiting the corona.* ***Results and discussion.*** *For example, in the temperature range of 0.5-1 MK there is a strong increase in the radiation function, and in the range of 1-4.5 MK there is a similarly rapid decline. In the damping range, adiabatic instability of plasma density oscillations is possible, due to the rapid damping rate.* ***Conclusion.*** *Using previously obtained cubic spline interpolation of the radiation function, the adiabatic instability was studied, and the boundaries of the instability interval were determined, which are confirmed by other calculations.*

Keywords: computer modeling, plasma physics, radiation function, magnetic hydrodynamic, Sun, oscillations and waves.

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Introduction. In astrophysics, two types of instability associated with the phenomenon of superadiabatic temperature drop are widely known. The first is known as the Schwarzschild instability; it occurs when the temperature inside a star decreases with distance from the center faster than the threshold at which the plasma's adiabatic properties can be preserved. That is, the temperature has time to equalize due to heat transfer from the lower, hot layers to the upper layers. As a result, convective motion arises under the influence of the Archimedes force, which occurs more often in the upper layers of the star, where the plasma temperature drops sharply [1]. The second example is radiative instability, when the adiabatic threshold is exceeded during plasma density fluctuations. The increase in temperature during plasma compression causes increased radiative losses, as a result of which the compression is not slowed down, but, on the contrary, intensifies. This phenomenon is called the adiabatic instability of compression waves [2]. Adiabatic instability is determined by the properties of the plasma's radiative loss function and can be realized under certain conditions, such as those found in the high-temperature plasma of the solar corona. The attenuation and instability of compression waves in the coronal system are currently being studied due to their possible connection to the solution of the coronal heating problem [3, 4]. In this paper, these conditions are sought by interpolating the radiative loss function, whose values are typically calculated numerically using known codes. The analytical expression obtained with a good approximation allows for a more accurate calculation of the radiative instability conditions than previously known estimates.

Coronal plasma emission function. The solar corona is an optically thin medium. This means that, due to low absorption, virtually all radiant energy is lost by the gas. The specific energy loss function, the amount of energy lost due to radiation per unit time per unit plasma mass, is written as $Q(\rho,\ T) = \rho\Lambda(T)$, where $\Lambda(T)$, called the emissivity function, is found using various models as a function of temperature alone (Figure 1).

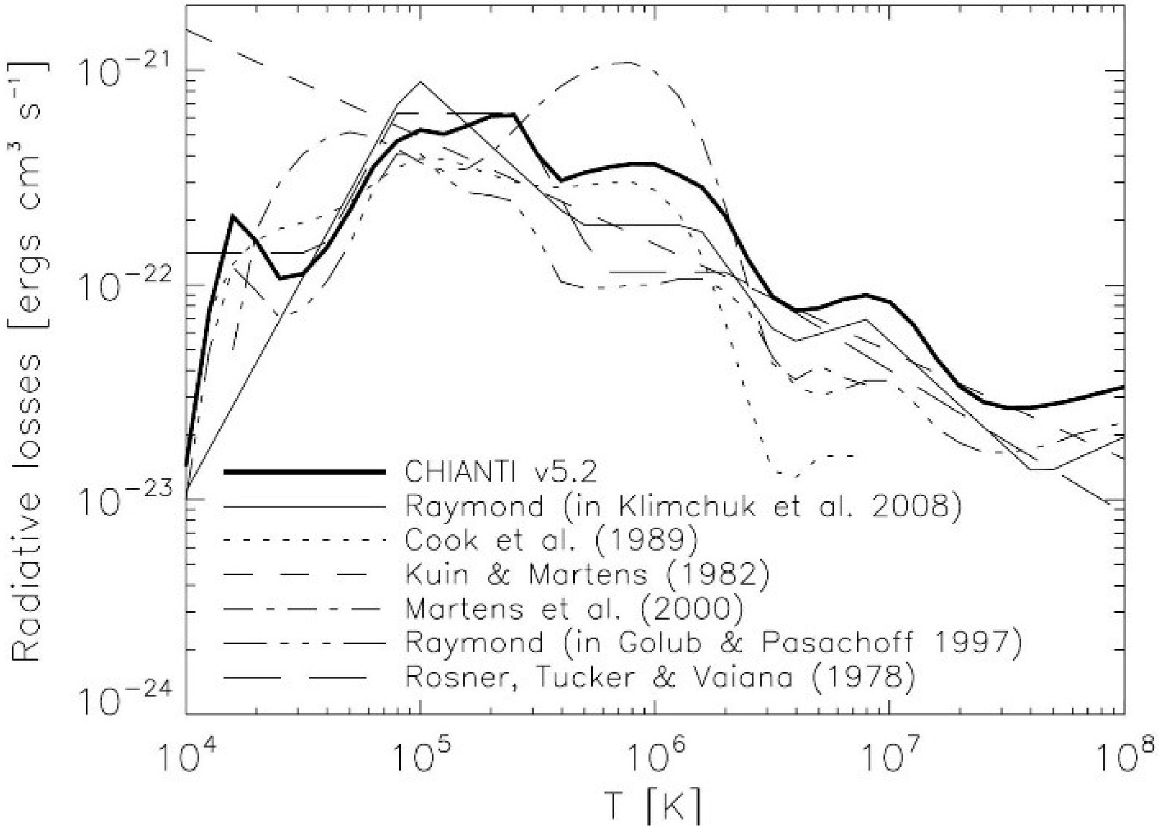

Figure 1. Various variants of the power-law approximation of the coronal plasma emission function [6]. For comparison, a curve obtained based on numerical calculations using the CHIANTI code is shown (bold line). In the vicinity of 1 MK, they have a significant deviation from the original distribution.

The starting point here is the values $\Lambda(T)$for a series of temperature values that are currently found using the CHIANTI code taking into account a particular set of possible sources, including electron bremsstrahlung and ion radiation in a number of spectral lines [5, 6]. A local power-law approximation of the radiation function of the form $\Lambda(T) = \chi T^{\alpha}$with certain constants $\chi$and is traditionally used, which is convenient for calculations α. Over a wide temperature range, several approximations are used, constructed separately on several successive subintervals [7]. As can be seen from the figure, a significantly larger number of subintervals is required to obtain a more accurate global approximation.

The situation can be significantly improved by using interpolation even with a relatively small number of points. Figure 2 shows cubic spline interpolation over the 0.5-10 MK interval, constructed using 29 points marked in red [8]. The resulting suitable analytical expression for the function $\Lambda(T)$allows for a thorough study of the attenuation and instability properties of the compression wave. In particular, we find intervals of increase and decrease in the radiation function, as well as an instability interval of 1.83-3.15 MK. It turns out that the likelihood of instability is highest at a temperature of 2.17 MK.

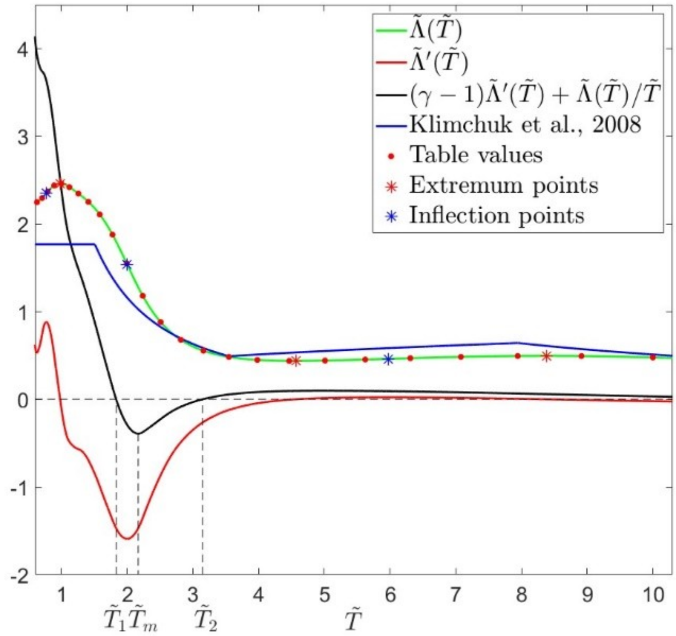

Figure 2. The radiation function obtained by cubic interpolation (green line) over a series of its numerical values (red dots) [12]. The red line denotes the derivative and shows the intervals of increase and decrease. The black line gives the criterion for adiabatic instability, which occurs in the interval where it lies in the lower half-plane.

The influence of radiation and heating on compression waves

To study the instability, we use a hydrodynamic approach that takes into account the thermal conductivity properties of the plasma, as well as the effects of heating and radiative loss. We use thermal conductivity in its well-known form for the thermal conductivity coefficient of high-temperature plasma [9], and to describe the heating, we use a simplified approach in which the energy gain per unit plasma mass per unit time is assumed to be constant. This so-called constant heating approximation is supported by observational data [10, 11]. This yields a set of hydrodynamic equations with fully defined physical effects that can influence the behavior of the compression wave. Thermal conductivity is taken into account because it is the most important physical effect, and heating is necessary to establish equilibrium with radiation in the steady state.

The analysis is carried out on the basis of the dispersion equation for acoustic waves [8]

$$\widetilde{\omega}^3 + iA\widetilde{\omega}^2 - \widetilde{\omega}\tilde{C}_s^2\tilde{k}^2 + iB = 0, \quad (1)$$

$$A = A_1\tilde{k}^2 + A_2, B = \frac{1}{\gamma}\left(-A_1\tilde{k}^2 - A_2 + A_3\right)\tilde{C}_s^2\tilde{k}^2, \quad (2)$$

the coefficients of which are determined through the thermal conductivity coefficient $\varkappa(T_0)$and the radiation function$\Lambda(T_0)$

$$A_1 = \frac{(\gamma-1)Mm(k)^2}{R\rho_0 m(\omega)}\varkappa(T_0), \quad (3)$$

$$A_2 = \frac{(\gamma-1)M}{Rm(\omega)}\rho_0\Lambda'(T_0),$$

$$A_3 = \frac{(\gamma-1)M}{RT_0 m(\omega)}\rho_0\Lambda(T_0).$$

The tilde denotes dimensionless quantities; the following scales are chosen for physical quantities in the solar corona conditions

$$m(T) = 10^6\ K, m(C_s) = 10^5 \text{ м с}^{-1}, m(\omega) = 0.1 \text{ с}^{-1}, m(k) = 10^{-6} \text{ м}^{-1}, \quad (4)$$
$$m(x) = 10^6 \text{ м}, m(t) = 10 \text{ с}.$$

Plasma is described by the equation of state of an ideal gas, the adiabatic index is $\gamma = 5/3$, the molar mass is equal to $M = 0.62 \times 10^{-3}$ кг моль$^{-1}$.For a fully ionized plasma at a temperature, $T_0 \sim 10^6$ Kthe thermal conductivity coefficient is determined by the expression [9]

$$\varkappa(T_0) = 2.28 \times 10^{-11}\, T_0^{5/2} \text{ (Вт м}^{-1} \text{ К}^{-1}). \quad (5)$$

In the graph from Figure 2, the values of the radiation function are given to scale

$$m(\Lambda) = 10^{26} \text{ эрг г}^{-2} \text{ см}^3 \text{ с}^{-1}. \quad (6)$$

Adiabatic instability is possible when the following condition is met:

$$(\gamma - 1)\Lambda'(T_0) + \Lambda(T_0)/T_0 < 0, \quad (7)$$

which is shown in Figure 2 using the function $(\gamma - 1)\Lambda'(T_0) + \Lambda(T_0)/T_0$.. Its graph is highlighted in black. Condition (7) defines the temperature range (1.83 MK, 3.15 MK) where instability occurs for certain wavelength values. Field's criterion for adiabatic instability of acoustic waves [2]

$$(\gamma - 1)A_1\tilde{k}^2 + (\gamma - 1)A_2 + A_3 < 0 \quad (8)$$

can be rewritten as

$$k > k_c, \quad (9)$$

$$\tilde{k}_c = \sqrt{-\frac{(\gamma - 1)A_2 + A_3}{(\gamma - 1)A_1}}. \quad (10)$$

The critical wavenumber $\tilde{k}_c$reaches its maximum at the minimum of the function $(\gamma - 1)\Lambda'(T_0) + \Lambda(T_0)/T_0$, i.e., at a temperature of 2.17 MK. For a typical particle concentration in the corona 10^{15} м$^{-3}$(Figure 3), this corresponds to a value of $\tilde{k}_c = 0.0063$and the smallest possible wavelength 10^9 м, which, under coronal conditions, is on the verge of reality.

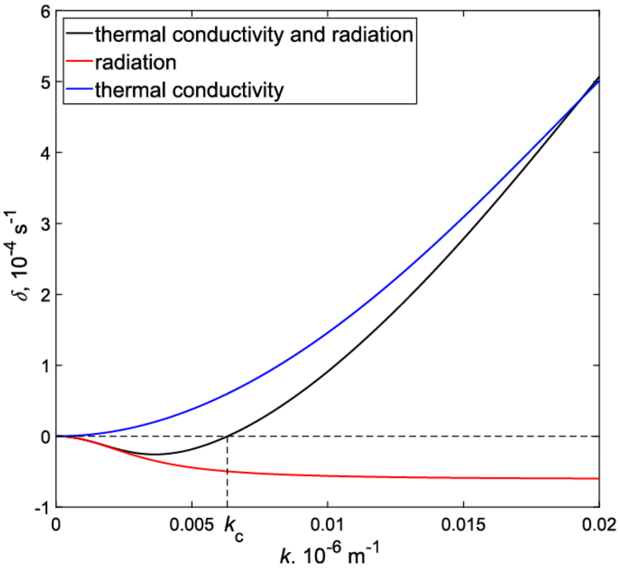

Figure 3. The attenuation coefficient for a temperature of 2.17 MK considering only thermal conductivity (blue line), only heating and cooling (red line), and considering both effects (black line). Thermal conductivity suppresses the instability at $k > k_c$.

Conclusion. It was found that the radiative instability of compression waves in the solar corona is most probable at a temperature of 2.17 MK. This temperature is close to the estimated value of 2 MK, previously found in a study of hot plasma condensation processes [12]. Let us consider the possibility of instability onset based on the observed oscillation periods, which usually vary from 3 to 30 min, but can sometimes reach values of 60-70 min. The plasma temperature in the coronal regions where compression waves are observed can vary widely from 0.5 to 14 MK, but the value of 2.17 MK was chosen, at which the acoustic wave velocity is

2.15×10^5 м $с^{-1}$. If the oscillation period is close to 70 min, the wavelength approaches 900 Mm, that is, close to the length of the unstable wave. For frequently observed periods, it will be far from the critical value. In other words, the radiative instability of compression waves is unlikely to be realized in the solar corona.

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ЛИТЕРАТУРА / REFERENCES

1. Priest E.R. *Magnetohydrodynamics of the Sun*, Cambridge University Press, Cambridge, 2014.
2. Field G.B. *Astrophys. J.* 142, 531, 1965.
3. Zavershinskii D.I., Kolotkov D.Y., Nakariakov V.N., Molevich N.E., Ryashchikov D.S. *Phys. Plasmas* 26, 082113, 2019.
4. Kolotkov D.Y., Zavershinskii D.I., Nakariakov V.M. *Plasma Phys. Control. Fusion* 63, 124008, 2021.
5. Dere K.P., Landi E., Young P.R., Del Zanna G., Landini M., Mason H.E. *Astron. Astrophys.* 498, 915, 2009.
6. Del Zanna G., Dere K.P., Young P.R., Landi E. *Astrophys. J.* 909, 38, 2021.
7. Klimchuk J.A., Patsourakos S., Cargill P.J. *Astrophys. J.* 682, 1351, 2008.
8. Derteev S.B., Shividov N.K., Bembitov D.B., Mikhalyaev B.B. *Physics* 5, 215, 2023.
9. Spitzer L.J. *Physics of Fully Ionized Gases*, Wiley, NY, 1962.
10. Warren H.P., Winebarger A.R., Brooks D.H. *Astrophys. J.* 711, 228, 2010.
11. Viall N.M., Klimchuk J.A. *Astrophys. J.* 828, 76, 2016.
12. Claes N., Keppens R. *Astron. Astrophys.* 624, A96, 2019.

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