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МОДЕЛИРОВАНИЕ ЗАТУХАНИЯ МЕДЛЕННЫХ МАГНИТОЗВУКОВЫХ ВОЛН В ВЫСОКОТЕМПЕРАТУРНОЙ ПЛАЗМЕ

A MODELING OF A DAMPING OF THE SLOW MAGNETOACOUSTIC WAVES IN A HIGH-TEMPERATURE PLASMA

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Аннотация

В линейном анализе до сих пор используется упрощенное локальное представление функции радиационных потерь плазмы как степени температуры [1], что, на наш взгляд, приводит к большим ошибкам в результатах. Поведение магнитозвуковых волн сильно зависит от параметров плазмы; поэтому необходимо более точное аналитическое выражение для функции радиационных потерь. Мы используем новые данные о функции радиационных потерь [2]. Мы строим локальные аналитические выражения с помощью кубических сплайнов и изучаем затухание волн в широком диапазоне параметров плазмы и магнитного поля.

Ключевые слова: Компьютерное моделирование, физика плазмы, функция излучения, магнитная гидродинамика, астрофизика.

Abstract

Linear analysis still uses a simplified local representation of the plasma radiative loss function as a degree of temperature [1], which, in our opinion, leads to large errors in the results. The behavior of the magnetoacoustic waves strongly depends on the parameters of the plasma; therefore, a more precise analytical expression for the radiatiave loss function is needed. We use new data on the radiative loss function [2]. We build local analytical expressions using cubic splines and study wave attenuation in a wide range of plasma and magnetic field parameters

Key words: Computer modeling, plasma physics, radiation function, magnetic hydrodynamic, astrophysics.

Introduction

In this paper, we study the behavior of magnetosonic waves under the influence of two often considered effects, thermal conductivity and heating/radiative losses. The temperature range of interest is 1-10 MK, which is typical for the lower corona of stars. The coronal plasma radiation function is used, which is determined using the CHIANTI 10 code (www. chiantidatabase.org). To obtain its analytical expression, cubic spline interpolation is used. The calculations are carried out in the approximation of one-dimensional hydrodynamics.

If, near the extremum points, the radiation function is represented as a degree of temperature, then such an approximation will give a large error comparable to the wave amplitude, so we obtained a more accurate expression by cubic spline interpolation

$$\tilde{\Lambda}(\tilde{T}) = \tilde{A}_i(\tilde{T} - \tilde{T}_i)^3 + \tilde{B}_i(\tilde{T} - \tilde{T}_i)^2 + \tilde{C}_i(\tilde{T} - \tilde{T}_i) + \tilde{D}_i, \quad (1)$$
$$\tilde{T}_i < \tilde{T} < \tilde{T}_{i+1}, \qquad i = 0, \ldots, 28,$$

the tilde sign means a dimensionless quantity. For case T_0 =1 MK, the scale $m(T) = 10^6$ K, that is $\tilde{T}_i = 1$, the interpolation coefficients will be as follows: $\tilde{A}_i = 6.1576166, \tilde{B}_i = -2.7325371, \tilde{C}_i = -0.1518774, \tilde{D}_i = 2{,}3168278$.Scale for the radiation function $m(\Lambda) = 10^{26}$ эрг·гр$^{-2} \cdot$ см$^3 \cdot$ с$^{-1}$.

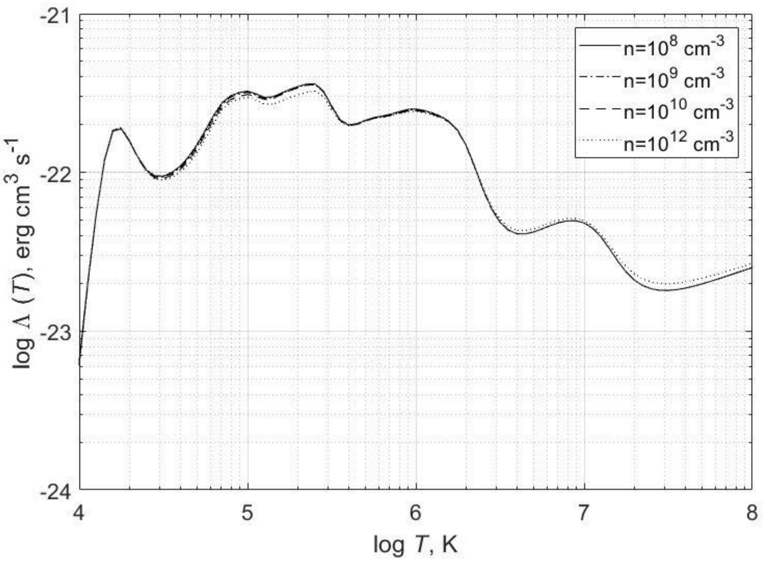

Figure 1. Radiation function

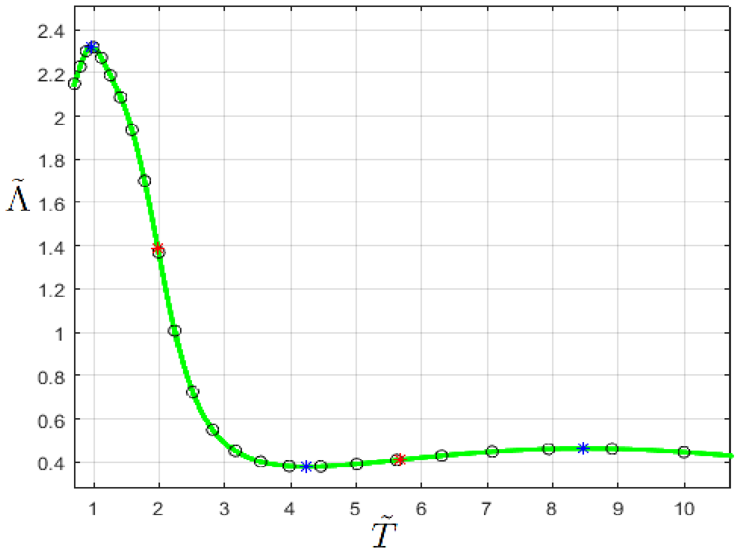

Figure 2. Radiation function approximation

Model

We study waves in the approximation of one-dimensional hydrodynamics. We write the initial equations in the MHD approximation in terms of density and temperature, since they are considered basic thermodynamic parameters:

$$\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} = -\frac{R}{M}\left(\frac{\partial T}{\partial x} + \frac{T}{\rho}\frac{\partial \rho}{\partial x}\right),$$
$$\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} = -\frac{B_{0x}}{4\pi\rho}\frac{\partial B_y}{\partial x},$$
$$\frac{\partial \rho}{\partial t} + v_x\frac{\partial \rho}{\partial x} + \rho\frac{\partial v_x}{\partial x} = 0,$$
$$\frac{\partial B_y}{\partial t} = B_{0x}\frac{\partial v_y}{\partial x} - \frac{\partial}{\partial x}\left[(B_{0y}+B_y)v_x\right],$$
$$\frac{\partial T}{\partial t} + v_x\frac{\partial T}{\partial x} + (\gamma-1)T\frac{\partial v_x}{\partial x} = -\frac{(\gamma-1)M\cos^2\theta}{R\rho}\frac{\partial}{\partial x}\left(\varkappa(T)\frac{\partial T}{\partial x}\right) - \frac{(\gamma-1)M}{R}\left[\rho\Lambda(T) - H\right], \quad (2)$$

T- temperature, ρ- density, M- molar mass, R- universal gas constant, $\varkappa(T)$- thermal conductivity, $\vec{v}$- speed, $\vec{B}$- magnetic field induction vector, $\Lambda(T)$- radiation function, H- coronal heating. Coronal heating is a very complex function that depends on many factors, so it is most often given as a constant value.

Next, we consider small perturbations, that is, $\rho = \rho_0 + \rho_1, T = T_0 + T_1, \rho_1 \ll \rho_0, T_1 \ll T_0$. ρ_0, B_{0x}, B_{0y} and T_0 are unperturbed background external conditions, and small perturbations of density, temperature, and magnetic field arise inside the volume under consideration ρ_1, T_1, B_y. Thus, we linearize the system of equations (2) and look for a solution of unknown functions in the form: $f(\vec{r},t) = \bar{f}(\vec{r}) \cdot e^{i(\vec{k}\vec{r}-\omega t)}$, where $\vec{k}$ is the wave vector, ω is the frequency. As a result, we obtain a system of linear equations that has parameters ω and k (we set it), based on the system of linear equations - the dispersion relation [3]:

$$\omega^5 + i\omega^4 A(k) - \omega^3(C_s^2 + V_A^2)k^2 - i\omega^2 B(k) + \omega C_s^2 V_A^2 k^4\cos^2\theta + iC(k) = 0, \quad (3)$$
$$A = a_1k^2 + a_2,$$
$$B = (a_1k^2 + a_2 - a_3)C_s^2k^2/\gamma + (a_1k^2 + a_2)V_A^2k^2,$$
$$C = (a_1k^2 + a_2 - a_3)C_s^2V_A^2k^4\cos^2\theta/\gamma,$$
$$a_1 = \frac{\gamma(\gamma-1)}{\rho_0C_s^2}T_0\bar{\kappa}(T_0)\cos^2\theta,$$
$$a_2 = \frac{\gamma(\gamma-1)}{C_s^2}\rho_0\Lambda'(T_0)T_0^2,$$
$$a_3 = \frac{\gamma(\gamma-1)}{C_s^2}\rho_0\Lambda(T_0)T_0.$$

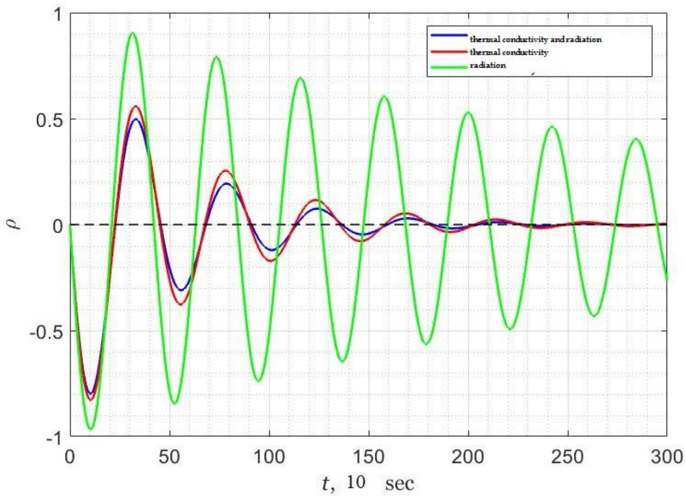

Figure 3. Wave attenuation in the case of dominance of thermal conductivity

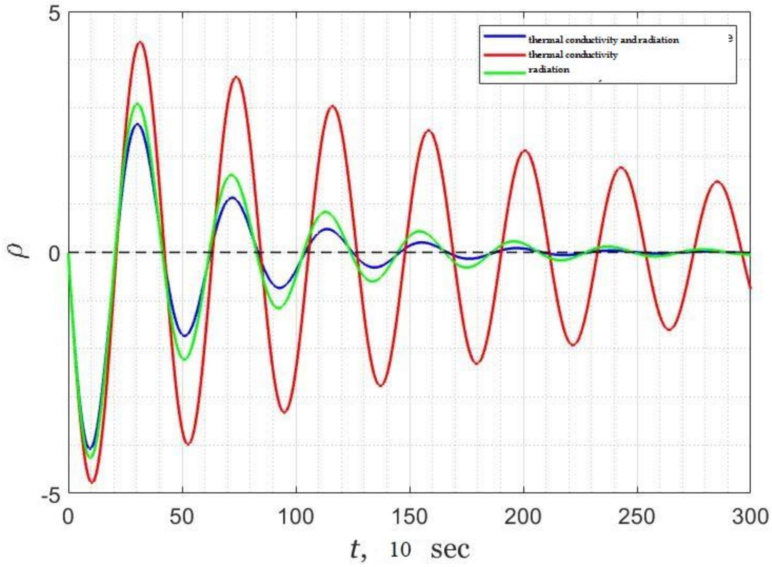

Figure 4. Wave attenuation in the case of radiation dominance

If the external conditions are such, then $\tilde{\rho} = 1$, $\tilde{T} = 1$and $\tilde{k} = 0.2$, is the complete predominance of thermal conductivity (Fig. 5). But, there is a case when thermal conductivity and heating/radiation make almost the same contribution to the attenuation of magnetosonic waves in the corona of stars $\tilde{\rho} = 5$, $\tilde{T} = 1$and $\tilde{k} = 0.2$(Fig. 6).

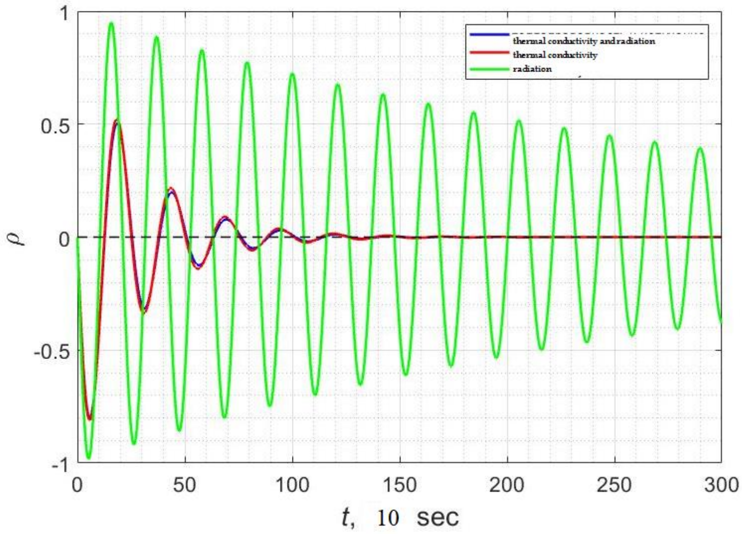

Figure 5. Radiation does not affect attenuation

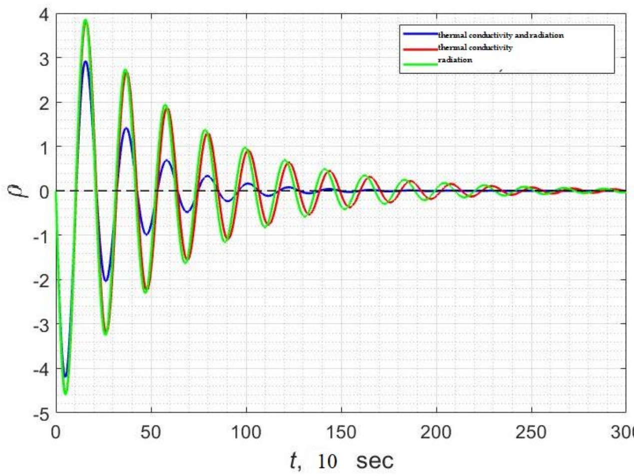

Figure 6. Radiation and thermal conductivity contribute almost identically to attenuation

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Conclusion

The attenuation of the MMSM in plasma is greatly influenced by the physical parameters, so the behavior of the waves in each case has to be considered locally. For example, if $\tilde{\rho} = 1$, $\tilde{T} = 1$and $\tilde{k} = 0.1$are the density, temperature and wave number in a dimensionless form, then it turns out that the radiation contribution is very small, thermal conductivity prevails (Fig. 3), if we increase the density by a factor of 5, that is $\tilde{\rho} = 5$, then the picture changes absolutely, and the thermal conductivity fades into the background (Fig. 4).

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