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HF CHARACTERISTICS OF THE ASTROPHYSICAL PLASMAS

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Abstract. The values of electrical conductivity of plasma of stars with a magnetic field or moving in the magnetic field of the other component in a binary system could be of significant interest, since they are useful for the study of thermal evolution of such objects, cooling, nuclear burning of accreted matter, and the investigation of their magnetic fields. So, on the basis of numerically calculated values for the dense plasma conductivity in an external HF electric field, we determine the HF characteristics of astrophysical plasmas under extreme conditions. The examined range of frequencies covers the IR, visible and near UV regions and consider electronic number density and temperature are in the ranges of $10^{21}\mathrm{cm}^{-3} \leq Ne$ and 20 000 $\leq T$, respectively. The method developed here represents a powerful tool for research into white dwarfs with different atmospheric compositions (DA, DC etc.), and for investigation of some other stars (M-type red dwarfs, Sun etc.).

1. INTRODUCTION

In this paper a highly ionized plasma in a homogenous and monochromatic external electric field $\vec{E}(t) = \vec{E}_0 \exp\{-i\omega t\}$ is considered. According to Sreckovic et al. (2010) and Sakan et al. (2007), the dynamic electric conductivity of a strongly coupled plasma $\sigma(\omega) = \sigma_{Re}(\omega) + i\sigma_{Im}(\omega)$ is represented by the expressions:

$$\sigma(\omega) = \frac{4e^2}{3m}\int_0^\infty \tau(E)\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{1}$$

$$\sigma_{Re}(\omega) = \frac{4e^2}{3m}\int_0^\infty \frac{\tau(E)}{1+(\omega\tau(E))^2}\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{2}$$

$$\sigma_{Im}(\omega) = \frac{4e^2}{3m}\int_0^\infty \frac{\omega\tau^2(E)}{1+(\omega\tau(E))^2}\left[-\frac{dw(E)}{dE}\right]\rho(E)EdE, \tag{3}$$

where $\rho(E)$ is the density of electron states in the energy space and $w(E)$ is the Fermi-Dirac distribution function, $\tau(E)$ is the relaxation time

$$\tau(E) = \frac{\tau(E)}{1 - i\omega\tau(E)}, \tag{4}$$

$\tau(E)$ being the 'static' relaxation time. The method of determination of $\tau(E)$ is described in the previous papers (Adamyan et al. (2006), Tkachenko et al. (2006) and Sreckovic et al. (2010a,b)) in detail.

Other HF plasma characteristics can be expressed in terms of the quantities $\sigma_{Re}(\omega)$ and $\sigma_{Im}(\omega)$.

Thus the plasma dielectric permeability is

$$\varepsilon(\omega) = 1 + i\frac{4\pi}{\omega}\sigma(\omega) = \varepsilon_{Re}(\omega) + i\varepsilon_{Im}(\omega), \tag{5}$$

where $\varepsilon_{Re}(\omega)$ and $\varepsilon_{Im}(\omega)$ are given as

$$\varepsilon_{Re}(\omega) = 1 - \frac{4\pi}{\omega}\sigma_{Im}(\omega), \quad \varepsilon_{Im}(\omega) = \frac{4\pi}{\omega}\sigma_{Re}(\omega). \tag{6}$$

The coefficients of refraction, $n(\omega)$, and reflection, $R(\omega)$, are determined as

$$n(\omega) = \sqrt{\varepsilon(\omega)} = n_{Re}(\omega) + in_{Im}(\omega), \tag{7}$$

$$R(\omega) = \left|\frac{n(\omega) - 1}{n(\omega) + 1}\right|^2 \tag{8}$$

where, bearing in mind that

$$|\varepsilon(\omega)| = \sqrt{\varepsilon_{Re}^2(\omega) + \varepsilon_{Im}^2(\omega)}, \tag{9}$$

the real and imaginary part of refractivity, $n_{Re}(\omega)$ and $n_{Im}(\omega)$, are given by

$$n_{Re}(\omega) = \sqrt{\frac{1}{2}(|\varepsilon(\omega)| + \varepsilon_{Re}(\omega))}, \quad n_{Im}(\omega) = \sqrt{\frac{1}{2}(|\varepsilon(\omega)| - \varepsilon_{Re}(\omega))}. \tag{10}$$

From here the equation for the plasma reflectivity could be expressed as

$$R(\omega) = \left\{\frac{1 + |\varepsilon(\omega)| - \sqrt{2}\sqrt{|\varepsilon(\omega)| + \varepsilon_{Re}(\omega)}}{1 + |\varepsilon(\omega)| + \sqrt{2}\sqrt{|\varepsilon(\omega)| + \varepsilon_{Re}(\omega)}}\right\}^{1/2} \tag{11}$$

The other parameter of interest is the penetration depth of electromagnetic radiation into plasma, $\Delta(\omega)$. This quantity is just the skin-layer width determined as the inverse imaginary part of the electromagnetic field wave number

$$\Delta(\omega) = \frac{c}{\omega}\frac{1}{n_{Im}(\omega)}. \tag{12}$$

where c is the speed of light.

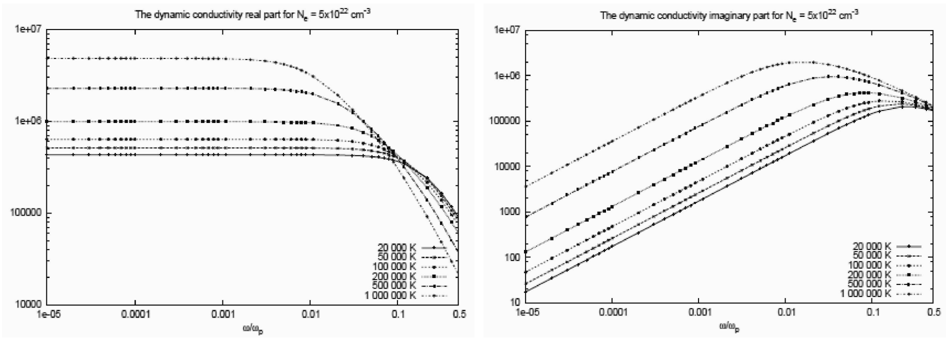

Figure 1: The dynamic conductivity real $\sigma_{Re}(\omega)$ and imaginary part $\sigma_{Im}(\omega)$ for $Ne = 5 \cdot 10^{22}$ cm^{-3} and $20,000\text{K} < T < 100,000\text{K}$.

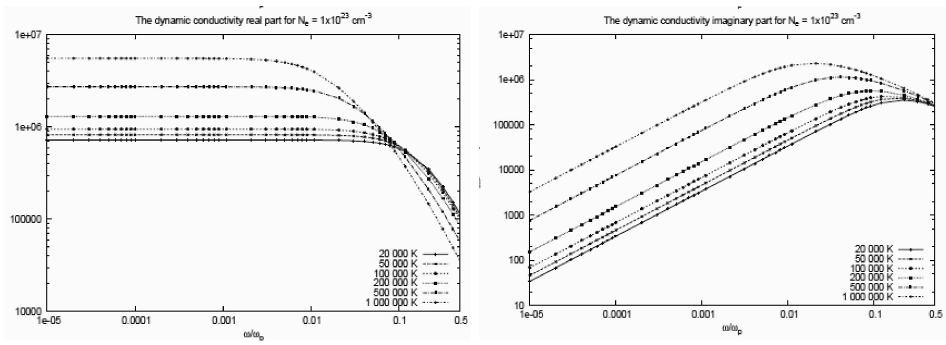

Figure 2: The dynamic conductivity real $\sigma_{Re}(\omega)$ and imaginary part $\sigma_{Im}(\omega)$ for $Ne = 1 \cdot 10^{23}$ cm^{-3} and $20,000\text{K} < T < 100,000\text{K}$.

2. RESULTS AND DISCUSSION

We here continue our previous investigations of plasma static electrical conductivity which are of interest for DB white dwarf atmospheres (see Sreckovic et al. (2010)b,c and Sreckovic et al. (2012)). So, in accordance with the aim of this work, we calculated HF plasma characteristics for vide plasma conditions in order to apply our results to the atmospheres of different stellar types.

Figures 1-3 illustrate the behavior of the HF conductivity for various plasma conditions which gives possibility to calculate other transport properties. Figures 1-3, demonstrate the regular behavior of $\sigma_{Re}(\omega)$, i.e. the convergence to the corresponding values of $\sigma_0(n_e, T)$ when $\omega \to 0$, and the existence of the interval of variation of ω where $\sigma_{Re}(\omega)$ is practically constant. We observe the tendency of this interval to decrease when temperature T increases. Similarly, Figures 1-3, demonstrate a regular behavior of $\sigma_{Im}(\omega)$, i.e. the convergence to zero when $\omega \to 0$, and the presence of a maximum in the interval $0 < \omega < 0.5\omega_p$.

The method developed in this paper represents a powerful tool for research white dwarfs with different atmospheric compositions (DA, DC etc.), and some other stars (M-type red dwarfs, Sun etc.). Finally, the presented method provides a basis for

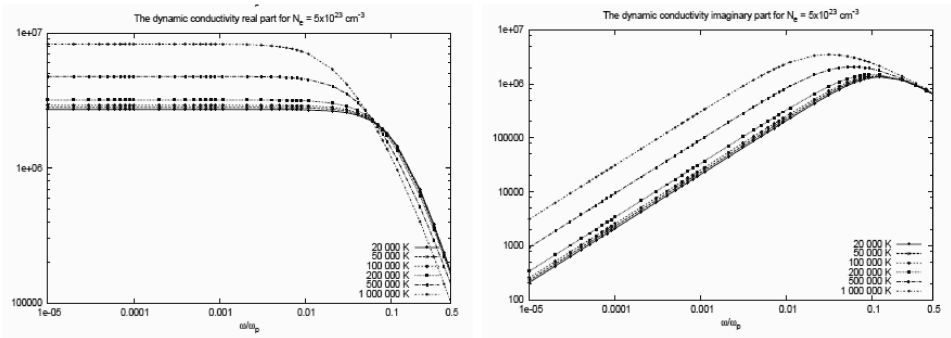

Figure 3: The dynamic conductivity real $\sigma_{Re}(\omega)$ and imaginary part $\sigma_{Im}(\omega)$ for $Ne = 5 \cdot 10^{23}$ cm^{-3} and 20000K $< T <$ 100000K.

the development of methods to describe other transport characteristics which are important for the study of all mentioned astrophysical objects, such as the electronic thermo-conductivity in the stellar atmosphere layers with large electron density, and electrical conductivity in the presence of strong magnetic fields.

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References

Adamyan, V. M., Grubor, D., Mihajlov, A. A., Sakan, N. M., Srećković, V. A., Tkachenko, I. M.: 2006 , *J. Phys. A*, **39**, 4401-4405.

Sakan, N. M., Sreckovic, V. A., Adamyan, V. M., Tkachenko, I. M., Mihajlov, A. A.: 2007, *Publications de l'Observatoire Astronomique de Beograd*, **82**, 171.

Srećković, V. A., Adamyan, V. M., Ignjatović, Lj. M., Mihajlov, A. A.: 2010, *Phys. Lett. A*, **374**, 754-760.

Srećković, V. A., Ignjatović, Lj. M., Mihajlov, A. A., Dimitrijević, M. S.: 2010, *MNRAS*, **406**, 590-596.

Srećković, V. A., Ignjatović, Lj. M., Mihajlov, A. A., Dimitrijević, M. S.: 2010 *American Institute of Physics Conference Series*, **1273**, 432-435.

Srećković, V. A., Ignjatović, Lj. M., Mihajlov, A. A. & Dimitrijević, M. S.: 2012, *PASRB*, **11**, 331.

Tkachenko, I. M., Adamyan, V. M., Mihajlov, A. A., Sakan, N. M., Šulić, D. M., Srećković, V. A.: 2006, *J. Phys. A*, **39**, 4693-4697.