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SPIRAL MAGNETO-ELECTRON WAVES IN THE INTERSTELLAR GAS DYNAMICS

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We discuss possible observational consequences resulting from the propagation of transverse magneto-electron waves in the interstellar medium. We briefly describe the magnetohydrodynamics model for the cyclotron waves with the emphasis on their analogy with hydrodynamical inertial waves. It is shown that the cyclotron waves are heavily damped in the interstellar medium, and therefore, cannot affect the gas dynamics of star-forming molecular clouds. We developed an analytic model of helicoidal magneto-electron waves based on the electromagnetic induction equation for the magnetic flux density driven by the Hall and Ohmic components of the electric field generated by flows of thermal electrons. We find that the helicons can propagate in the interstellar medium without a noticeable attenuation. The presented numerical estimates for the group velocity of the intercloud helicons suggest that spiral circularly polarized magneto-electron waves of this type can be responsible for the broadening of molecular lines detected from dark interstellar clouds.

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1. INTRODUCTION

The gas dynamical processes in star-forming molecular clouds are primarily determined by a strong coupling of the gas–dust interstellar medium (ISM) to magnetic fields. The electrons, both relativistic and thermal, are one of the most abundant and mobile charged components of the ISM, and their small mass provides the most strong coupling to the intercloud magnetic fields. Therefore, it is natural to expect that the collective behavior of electrons may essentially affect the interstellar gas dynamics.

According to the available data on the pulsar dispersion measure, the average density of interstellar electrons evaluated throughout the Galactic disc is estimated as $n_e \approx 0.03\,\mathrm{cm}^{-3}$ [1]. On the one hand, an extensive analysis of the thermodynamic state of interstellar medium in our Galaxy reported by Heiles and Kulkarni [2] implies that the warm diffusive clouds might be the regions of the most dense accommodation of thermal electrons where their density can attain a sufficiently high value $n_e \approx 1\,\mathrm{cm}^{-3}$ [3]. On the other hand, highly ionized HII regions of the warm interstellar medium occupy only 25% of the Galactic volume [4]. Therefore, they give a significant contribution to the dispersion measure for only a small fraction of pulsars. The latter observation was made long ago by Manchester and Taylor [5] and led them to suggest that dispersing electrons can basically be located in denser interstellar clouds highly obscured for the ionizing ultraviolet radiation and soft X-rays. However, if the thermal electrons reside in the central region of a molecular cloud at some stage of the star formation, their detection becomes a highly formidable problem. The progress in searching for their presence could then be achieved by inspecting observational consequences caused by highly coherent electron gasdynamical processes.

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This paper discusses two wave processes associated with collective motions of interstellar electrons in the presence of a uniform magnetic field. The first process is the well-known cyclotron waves originating from the inertial collective motions of electrons driven by the Lorentz force. These waves are briefly discussed in Sec. 2. Emphasis in this paper is placed on the second wave process, the helicoidal magneto-electron waves inherently related to the Hall drift of the magnetic flux density by the flows of thermal electrons. The model of interstellar helicons is developed in Sec. 3. For a deeper insight into the physics of these spiral circularly polarized waves, we confine our consideration to the idealized model of a gaseous magnetically supported cloud whose gas dynamics is dominated by thermal electrons in the regime of strong coupling between the densities of the electron current and the magnetic flux threading the cloud; the mobility of ions and neutral molecules is assumed to be heavily suppressed. In doing this, we clearly realize that ignoring the dusty component of the intercloud medium and assuming immobility of ions and neutrals, thereby eliminating the ambipolar diffusion effect, can be a matter of controversy. Nevertheless this does not affect the interest in the problem of the wave gas dynamics of inetrstellar electrons as such. To the best of our knowledge, the problem of the wave transport of magnetic field by thermal electrons in the interstellar medium has not been considered in the literature. In Sec. 4, based on the electromagnetic induction equation for the transport of the magnetic flux density by the Hall and Ohmic components of the electric field generated by flows of thermal electrons, we derive the dispersion relation for helicons and evaluate their group velocity. We show that the helicoidal magneto-electron waves can propagate in the interstellar medium without a noticeable attenuation. This leads us to suggest that the helicons could be responsible for the observed widths of molecular lines detected from dark interstellar clouds. In Sec. 5, a brief outlook is given of the wave process considered here and another wave process in dark interstellar clouds affecting the broadening of molecular lines.

2. INTERSTELLAR CYCLOTRON WAVES

The model of intercloud cyclotron waves can be developed on the basis of hydrodynamical equations for the collective motions of electrons in a permanent magnetic field $\mathbf{B}$. Modeling the interstellar electron gas as a viscous uniformly charged fluid whose flows are governed by the Lorentz force, we can write

$$\frac{d\rho_e}{dt} + \rho_e \nabla\cdot\mathbf{u} = 0, \quad \frac{d}{dt} = \frac{\partial}{\partial t} + \mathbf{u}\cdot\nabla, \tag{1}$$

$$\rho_e \frac{d\mathbf{u}}{dt} = \frac{e n_e}{c}\mathbf{u}\times\mathbf{B} + \eta\Delta\mathbf{u}, \quad \rho_e = n_e m_e, \tag{2}$$

where m_e is the mass of the electron, n_e is the electron density, $\mathbf{u}$ is the directed velocity of the electron flow, and η stands for the dynamical viscosity of the electron fluid effectively accounting for all the dissipative effects of elastic collisions of electrons with other microparticles of the cloud. Viewing the electrons as an incompressible fluid, we linearize the above equations around the homogeneous undisturbed state with $\mathbf{u}_0 = 0$ and $\mathbf{B}_0 = B\mathbf{e}_z$. As a result, we obtain[1)]

$$\nabla\cdot\delta\mathbf{u} = 0, \quad \frac{\partial\delta\mathbf{u}}{\partial t} = \frac{e}{m_e c}\delta\mathbf{u}\times\mathbf{B} + \frac{\eta}{\rho_e}\Delta\delta\mathbf{u}. \tag{3}$$

Using the plane-wave form for

$$\delta\mathbf{u} \approx \exp[i(\mathbf{k}\cdot\mathbf{r} - \omega t)]$$

in the first of equations (3), we have

$$\mathbf{k}\cdot\delta\mathbf{u} = 0,$$

which implies that the wave is transverse. Inserting the plane-wave form of $\delta\mathbf{u}$ into equation of motions in (3), after some algebra we obtain the dispersion relation

$$\omega = \pm\omega_c\,(1 \pm i\Gamma_c)\,, \quad \omega_c = \frac{eB}{m_e c}, \quad \Gamma_c = \frac{\eta k^2}{\omega_c \rho_e}. \tag{4}$$

It thus follows that the interstellar cyclotron waves are transverse, circularly polarized, and damped. Their group velocity is given by

$$\mathbf{V}_c = \frac{\partial\omega}{\partial\mathbf{k}} = \pm\frac{e}{m_e c}\,\frac{\mathbf{k}\times[\mathbf{B}\times\mathbf{k}]}{k^3}. \tag{5}$$

To describe the effect of cyclotron waves on the molecular linewidths, we consider the case where $\mathbf{k}\perp\mathbf{B}$. Recalling the mean electron density $n_e = 10^{-3}$ cm^{-3}, the average magnetic field intensity $B \sim 10^{-5}$ Gs, and the average electron temperature T_e = 10–200 K in dark molecular clouds [7] and putting $V_c \approx$ 0.3–0.5 km/s (the realm of observed molecular linewidths),

[1)] It worth noting that cyclotron waves can be considered as an analog of inertial waves in the rotating incompressible fluid governed by the equations [6]

$$\nabla\cdot\delta\mathbf{u} = 0, \quad \frac{\partial\delta\mathbf{u}}{\partial t} = 2\delta\mathbf{u}\times\mathbf{\Omega} + \nu\Delta\delta\mathbf{u},$$

where $\nu = \eta/\rho$ is the kinematic viscosity.

we can evaluate the wavelength of a cyclotron wave as $\lambda_c \approx 10^2 - 10^3$ cm. The viscosity coefficient in the interstellar electron fluid can be evaluated as [8]

$$\eta \approx \frac{n_e k_B T_e}{\nu_c} \text{ g/cm} \cdot \text{s}.$$

The frequency of the elastic collisions of electrons is typically in the interval $\nu_c \sim 10^{-3}$–10^{-1} s^{-1} [7]. With the above parameters, the magnitude of the damping coefficient $\Gamma_c \approx 10^3 - 10^4$ is in strong conflict with the propagation criterion $\Gamma_c \ll 1$ following from Eq. (4). The same can be said about diffusive clouds. Thus, the cyclotron waves of the Larmor gyration of the electron flow about the direction of the equilibrium magnetic field threading the cloud are highly damped. Therefore, they cannot produce any essential effect on molecular linewidths detected from interstellar molecular clouds.

3. MAGNETIC FLUX EVOLUTION DUE TO THE HALL AND OHMIC CONDUCTIVITIES OF THERMAL ELECTRONS

The cyclotron waves characterize a high-frequency branch of the collective oscillatory behavior of electrons in the interstellar magnetoplasma. In this section, we focus on the low-frequency magneto-electron waves whose origin is in the transport of the magnetic flux density by thermal electrons, or in other words, in the Hall electron conductivity. It should be mentioned that the magneto-electron waves under consideration were first discovered in the solid-state plasma physics. The name helicons [9–11] was coined because of the spiral character of these circularly polarized waves. By sayng that the helicons represent a low-frequency branch of electromagnetic excitations in a non-compensated electron-dominated magnetoplasma, we imply that the frequency of electron oscillations in this wave is less than the cyclotron frequency (see, e.g., [12]). Waves of a similar nature are observed in planetary magnetospheres. In particular, the propagation of helicons in the Earth's ionosphere causes the whistling audio noise on radio; this is why these waves are often called whistlers [12, 13]. A similar Hall mechanism of the wave transport of a magnetic flux density by electrons was recently discussed in Refs. [14] and [15] in the context of the magnetic field evolution in the radio pulsars and magnetars.

In what follows, we confine our consideration to the idealized model of the isothermal intercloud medium whose gas dynamics is dominated by thermal electrons. The magnetic field is considered to be frozen into the ions; the mobility of the ions and of the neutral molecules is assumed to be heavily suppressed, and these latter are therefore regarded as immobilized. This suggests that the collective behavior of intercloud electrons in the presence of a permanent magnetic field has some common features with the behavior of conducting electrons in a metal solid, where the immobility of ions is taken for granted. Following this line of arguments, we use of the constitutive equation for the electron conductivity in the form of the generalized Ohm law

$$\mathbf{E}(\mathbf{r},t) = \frac{\mathbf{j}(\mathbf{r},t)}{\sigma_C} + \frac{1}{ecn_e}\mathbf{B}(\mathbf{r},t) \times \mathbf{j}(\mathbf{r},t) = \\ = \frac{\mathbf{j}}{\sigma_C} + \frac{\mathbf{n}_B \times \mathbf{j}}{\sigma_H}, \quad \mathbf{n}_B = \frac{\mathbf{B}}{B}, \quad (6)$$

$$\sigma_C = \frac{n_e e^2}{m_e \nu_c}, \quad \sigma_H = \frac{e n_e c}{B}, \quad (7)$$

where the Ohmic conductivity σ_C is given by the Drude formula and σ_H stands for the Hall conductivity. We let $\mathbf{j}(\mathbf{r},t)$ denote the electron current density that is given by

$$\mathbf{j}(\mathbf{r},t) = \frac{c}{4\pi}\nabla \times \mathbf{B}(\mathbf{r},t) \quad (8)$$

in accordance with the Ampére law. Because the magnetic flux density satisfies the Maxwell equation for the Faraday induction,

$$\frac{\partial \mathbf{B}(\mathbf{r},t)}{\partial t} = -c\nabla \times \mathbf{E}(\mathbf{r},t), \quad (9)$$

inserting Eqs. (6) and (8) in (9) gives

$$\frac{\partial \mathbf{B}(\mathbf{r},t)}{\partial t} = -\frac{c}{4\pi e n_e}\nabla \times [\mathbf{B}(\mathbf{r},t) \times \nabla \times \mathbf{B}(\mathbf{r},t)] + \\ + \frac{c^2}{4\pi\sigma_C}\Delta\,\mathbf{B}(\mathbf{r},t). \quad (10)$$

We note that this model can be considered as an idealized version of the model motivated by Mouschovias [7] in the context of the magnetic flux redistribution in cores of the interstellar magnetically supported clouds with the ions frozen into the magnetic field threading the cloud. The first term in the right hand side of Eq. (10) is due to the Hall electron conductivity and the second term describes the Ohmic diffusion of the magnetic field. Obviously, the diffusion-free regime of the magnetic flux transport is realized if

$$\sigma_C \gg \sigma_H. \quad (11)$$

In this regime, Eq. (10) supplemented by the solenoidality condition for $\mathbf{B}(\mathbf{r},t)$ becomes

$$\begin{aligned}\frac{\partial \mathbf{B}(\mathbf{r},t)}{\partial t} &= -\frac{c}{4\pi\, en_e}\,\nabla\times[\mathbf{B}(\mathbf{r},t)\times[\nabla\times\mathbf{B}(\mathbf{r},t)]],\\ \nabla &\cdot \delta\mathbf{B}(\mathbf{r},t) = 0,\end{aligned} \tag{12}$$

which implies that the total magnetic energy

$$W_m = \frac{1}{8\pi}\int \mathbf{B}^2\, dV \tag{13}$$

is conserved:

$$\frac{dW_m}{dt} = \frac{1}{4\pi}\int \mathbf{B}\cdot\frac{\partial \mathbf{B}}{\partial t}\, dV = \frac{c}{16\pi^2\, en_e}\times \times\int [[\nabla\times\mathbf{B}]\times\mathbf{B}]\cdot[\nabla\times\mathbf{B}]\, dV = 0. \tag{14}$$

It is the major purpose of the remainder of this paper to show that the interstellar magnetoplasma of molecular star-forming clouds can transmit low-frequency perturbations in the magnetic flux density by weakly damped helicoidal circularly polarized waves owing their existence to the Hall drift of the magnetic field by flows of thermal electrons.

4. HELICONS IN THE INTERSTELLAR MEDIUM

We consider the evolution of small-amplitude magnetic flux density perturbations $\delta\mathbf{B}$ superimposed on the permanent magnetic field $\mathbf{B}$,

$$\mathbf{B}(\mathbf{r},t)\to\mathbf{B}+\delta\mathbf{B}(\mathbf{r},t),\quad \mathbf{B}=\text{const}. \tag{15}$$

The corresponding linearization of Eq. (10) leads to

$$\frac{\partial\delta\mathbf{B}}{\partial t} = \frac{c}{4\pi\, n_e e}\,(\mathbf{B}\cdot\nabla)\,[\nabla\times\delta\mathbf{B}] + \frac{c^2}{4\pi\sigma_C}\Delta\delta\mathbf{B}. \tag{16}$$

Inserting

$$\delta\mathbf{B} = \mathbf{b}\exp\left[i(\omega t - \mathbf{k}\cdot\mathbf{r})\right], \tag{17}$$

in the right-hand side of Eq. (16), we obtain

$$\frac{\partial\delta\mathbf{B}}{\partial t} = -\frac{c^2}{4\pi\sigma_H}(\mathbf{k}\cdot\mathbf{n}_B)[\mathbf{k}\times\delta\mathbf{B}] + + \frac{c^2}{4\pi\sigma_C}[\mathbf{k}\times[\mathbf{k}\times\delta\mathbf{B}]]. \tag{18}$$

We let the permanent field $\mathbf{B}$ be directed along the z axis, $\mathbf{B}=[0,0,B]$, and consider a one-dimensional plane-wave perturbation along the z axis ($\mathbf{k}=k\mathbf{e}_z$) that does not affect the intensity of the magnetic field in this direction, but only along the x an y directions. This means that the fluctuating magnetic field components depend only on z and t:

$$\begin{aligned}\delta B_x(z,t) &= b_x \exp[i(\omega t - kz)],\\ \delta B_y(z,t) &= b_y \exp i(\omega t - kz),\quad \delta B_z = 0.\end{aligned} \tag{19}$$

The Cartesian components of Eq. (18) can be represented in the equivalent form

$$\frac{\partial\delta B_x}{\partial t} = +\frac{c^2k^2}{4\pi\sigma_H}\delta B_y - \frac{c^2k^2}{4\pi\sigma_C}\delta B_x, \tag{20}$$

$$\frac{\partial\delta B_y}{\partial t} = -\frac{c^2k^2}{4\pi\sigma_H}\delta B_x - \frac{c^2k^2}{4\pi\sigma_C}\delta B_y. \tag{21}$$

To see the circularly polarized character of the wave motions in question, we omit the Ohmic diffusion term for the moment. The resulting equations (20) and (21) then become

$$\delta\dot{B}_x = -\Omega\,\delta B_y,\quad \delta\dot{B}_y = \Omega\,\delta B_x.$$

These are the Cartesian components of the vector equation

$$\delta\dot{\mathbf{B}} = [\Omega\times\delta\mathbf{B}]$$

describing the precession of the vector $\delta\mathbf{B}$ about the z axis with the angular frequency

$$\boldsymbol{\Omega} = -\frac{cB}{4\pi\, n_e e}k^2\mathbf{e}_z.$$

Wave motions of this type are customarily described in terms of the right-hand (δB_+) and the left-hand (δB_-) circularly polarized wave fields

$$\begin{aligned}\delta B_+ &= \delta B_x + i\delta B_y = b(z)\exp(-i\omega t),\\ \delta B_- &= \delta B_x - i\delta B_y = b(z)\exp(i\omega t).\end{aligned} \tag{22}$$

Combining the coupled equations (20) and (21) to obtain one equation for either δB_+ or δB_-, we arrive at

$$\frac{\partial\delta B_\pm}{\partial t} = \mp i\frac{c^2k^2}{4\pi\sigma_H}\delta B_\pm \pm \frac{c^2k^2}{4\pi\sigma_C}\delta B_\pm. \tag{23}$$

Eliminating the time derivative with the help of (22), we obtain

$$\begin{aligned}\omega &= \omega_h(1\mp i\Gamma_h),\quad \omega_h = \frac{c^2k^2}{4\pi\sigma_H} = \frac{\omega_c}{\omega_p^2}\, c^2\, k^2,\\ \Gamma_h &= \frac{\sigma_H}{\sigma_C} = \frac{\nu_c}{\omega_c},\end{aligned} \tag{24}$$

where

$$\omega_c = \frac{eB}{m_e c},\quad \omega_p^2 = \frac{4\pi e^2 n_e}{m_e},$$

$$\sigma_C = \frac{n_e e^2}{m\nu_c}, \quad \sigma_H = \frac{e n_e c}{B},$$

the omegas stand for the cyclotron and the plasma frequencies, and the sigmas for the Ohmic and Hall conductivities. Dispersion relation (24) implies that the helicon is a transverse circularly polarized and damped wave in which the densities of the magnetic flux and of the electron current undergo coherent oscillations in the plane perpendicular to the direction of propagation. In the diffusion-free regime, $\Gamma_h \ll 1$, we have

$$\omega_h = \frac{\omega_c}{\omega_p^2} c^2 k^2 = 4.97 \cdot 10^{18} \frac{B}{n_e} k^2. \qquad (25)$$

The corresponding group velocity is given by

$$V_h = \frac{2c^2\omega_c}{\omega_p^2} k \approx 9.58 \cdot 10^{18} \frac{B}{n_e} k \text{ cm/s}. \qquad (26)$$

Using (25), we can represent this formula in terms of ω as

$$V_h = \frac{2c\sqrt{\omega_c}}{\omega_p}\sqrt{\omega} \approx 4.46 \cdot 10^9 \sqrt{\frac{B}{n_e}}\sqrt{\omega} \text{ cm/s}. \qquad (27)$$

In the electron magnetohydrodynamics (MHD) [16], the helicons play the same role as the transverse Alfvén waves in the single-component magnetohydrodynamics [17]. In both kinds of these MHD waves, the oscillatory motions of the conducting fluid are strongly coupled to the magnetic field fluctuations. The essential kinematic difference between them is that the group velocity of a helicoidal magneto-electron wave depends on the frequency, whereas the Alfvén wave is characterized by the dispersion-free propagation law

$$\omega = V_A k, \quad V_A = \frac{B}{(4\pi\rho)^{1/2}}.$$

We now briefly discuss inferences that could be made from the propagation of helicoidal magneto-electron waves in the interstellar medium. As mentioned above, the average density of electrons evaluated in the Galactic disc is estimated to be $n_e \approx 0.03\,\text{cm}^{-3}$ and $B \approx 10^{-5}$–10^{-6} Gs [1]. With these parameters, we find that the cyclotron frequency ω_c (which sets the upper frequency limit for the dissipation-free propagation of helicons) falls into the interval $10 < \omega_c < 100\,\text{s}^{-1}$. Taking $\omega \approx 1\,\text{s}^{-1}$ as a representative example, which is typical of pulsar activity, we can estimate the velocity of interstellar helicons as $V_h \approx 10^7$–10^8 cm/s; the corresponding wavelength is $\lambda_h = 2\pi/k \approx 1000$ km. Because the frequency of elastic collisions is of the order $10^{-3}\,\text{s}^{-1}$ or less, it seems plausible that the helicons can freely travel in the interstellar space and give a contribution to the observed effect of scintillations of the pulsar signals.

The evidence for the existence of large-scale motions in dark star-forming molecular clouds is provided by the whidths of molecular lines. Therefore, searching adequte models of interstellar gas dynamics is one of the important parts in the current investigations of the ISM physics. By inspecting a possible effect of helicons on the widths of molecular lines, we note that in a typical dark molecular cloud, $\omega_c \approx 10^2\ \text{s}^{-1}$ and $\nu_c \approx 10^{-3}$–$10^{-1}\ \text{s}^{-1}$. The criterion for the dissipation-free propagation of helicons $\Gamma = \nu_c/\omega_c \ll 1$ is therefore well justified, and its validity remains quite robust to the changes in ν_c up to $\nu_c = 100\ \text{s}^{-1}$. By taking the group velocity of the helicons V_h to be equal to the velocity dispersion measured for molecular lines, $V \approx 0.3$–5.0 km/s, we find the wavelength of the intercloud helicon $\lambda_h \sim 10^{12}$–10^{13} cm. This space scale is much less than the linear size of clouds, $L \sim 10^{17}$ cm. For the same velocity, the period of oscillations of the electron flow in the helicoidal magneto-electron wave falls into the interval $P_h \sim 0.1$–10 years. These estimates unambiguously show that the intercloud medium can transmit the helicons without a significant attenuation and we conjecture that they can be responsible for the broadening of molecular lines.

5. DISCUSSION

Understanding gas dynamical processes governing the structure and the evolution of dense molecular clouds is one of the outstanding challenges in the current development of star formation astrophysics. While the central role played by magnetic fields in these processes was recognized many years ago, the major uncertainties regarding the motions follow from inadequate knowledge of the material composition of the intercloud medium. Over the years, convincing evidence has been obtained that the composition of dark molecular clouds is dominated by molecular hydrogen with some admixture of OH and CO molecules whose linewidths were found to exhibit the supersonic character of intercloud motions. The fact that the linewidths cannot be explained as a result of the propagation of isothermal sound waves has served as an impetus in searching for alternative models of interstellar gas dynamics and has led to the hypothesis that a sizable fraction of charged particles (primarily electrons and ions) are present in dark molecular clouds, with the collective flows of these particles strongly coupled to the intercloud magnetic field. On the assumptions that the magnetic field causes both electrons and ions to move with equal velocities and the friction then causes the neutral molecules to follow the ions with the same velocity, the single-component magnetohydrodynamics model was extensively exploited in interpreting supersonic broadening of molecular lines in terms of hydromagnetic waves of the Alfvén type [19–23]. On average, the model provides a reasonable account of data in CO regions of clouds where the temperature and the ionization factor are sufficiently high.

Together with this, recent Zeeman measurements of magnetic fields in dense cores of molecular clouds, highly obscured by the ionizing ultraviolet radiation, have revealed a predominately sub-Alfvénic character of the intercloud motions [24]. The latter circumstance can be regarded as an indication that the composition and the character of the motions in cores of the molecular clouds might be quite different from those implied by the single-component MHD model of interstellar gas dynamics. With this in mind, we recently investigated a model of a non-MHD type [25, 26]. Motivated by the observable filamentary structure of some of the dark molecular clouds, we argued that the filaments could be regarded as a manifestation of a superparamagnetic state of the gas–dust ISM considered by Jones and Spitzer [27] long ago in the context of the starlight polarization problem. The magnetically polarized, poorly conducting soft matter of this type can be thought of as a gas-based ferrocolloid (consisting of tiny ferromagnetic grains suspended in the dense gas of molecular hydrogen) capable of sustaining a long-range magnetic chains extending along the intercloud magnetic fields. Having assumed that the motions of the Jones–Spitzer matter are governed by the magnetoelastodynamics equations, we found in [25] that ferrocolloidal interstellar medium can transmit perturbations by shear magnetomechanical waves propagating with a sub-Alfvénic group velocity in accordance with observations [24].

In the meantime, several authors have argued that the ISM motions in star-forming molecular clouds can pass the regime in which the Hall conductivity may become important [28, 29]. In particular, it was recently shown [30] that the Hall conductivity can essentially affect the propagation of Alfvén waves in a dense weakly ionized molecular gas. In this paper, continuing investigation in this direction, we have explored two models of the pure electron interstellar gas dynamics. The focus was placed on the helicons — spiral magneto-electron waves owing their existence to the Hall drift of the magnetic flux by thermal electrons. The basic inference of this model is that in dark molecular clouds, the helicons can propagate without a noticeable attenuation. The observational consequence of their propagation might be the widths of molecular lines exhibiting the existence of large-scale intercloud motions. Our numerical estimates for the group velocity of the helicons suggest that these waves could be responsible for the broadening of molecular linewidths detected from dark star-forming clouds or, at least, provide a sizable contribution to this effect. As a conclusion, the problem of the interstellar electron wave dynamics considered here for the first time is interesting in its own right, and we hope that our analysis can find other useful physical applications.

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