**Star Forming Longitudinal Jeans Instability of Self-Gravitating Partially-Ionized Radiative Plasma with Hall Current and FLR Corrections**

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**Abstract**

The study of Jeans’s gravitational instability has been investigated for a partially ionized plasma with Hall current parameter and FLR corrections, which has connection in astrophysical condensations. An overall general dispersion relation has been inferred with the assistance of important linearized perturbation equations, utilizing the normal mode analysis investigation. Impacts of viscosity, radiative heat-loss function and collisions with neutrals on the unsteadiness of the system are considered. The states of instability are determined for a temperature-dependent and density-dependent heat-loss function with thermal conductivity. Mathematical estimations have been performed to examine the reliance of the growth rate of the gravitational instability on the different physical parameters. The viscosity, magnetic field, temperature-dependent heat-loss function, thermal conductivity and neutral collision have balancing out impact while density-dependent heat-loss function has a destabilizing influence on the growth rate of the gravitational instability. Based on Routh-Hurwitz's criterion, the steadiness of the system is examined. Results completed in this study are useful for the formation of star in interstellar medium (ISM).

**1. Introduction**

The fragmentation of the interstellar gas is an important phenomenon for star formation. It is generally assumed that stars are formed as a result of the gravitational contraction of fragments of interstellar clouds. In this connection the problem of gravitational instability was first given by Jeans [1], about the formation of astronomical bodies by the fragmentation of interstellar matter, where it is showed that there exists a critical size above which a uniform self-gravitating matter becomes unstable to small fluctuations in density. An important assumption made in Jeans analysis is that the interstellar medium is made up of a single stationary medium, which is by no means so, and further it is assumed that the fluctuations in density and pressure follow an adiabatic law, thereby leaving out the effects of thermal conduction and radiation. It is therefore of interest to see how the results of self-gravitational instability of interstellar matter are affected by the thermal conductive and radiative effects.

The problem of magneto-gravitational instability of interstellar matter is of considerable importance in connection with protostar and star formation in dust clouds. Presence of magnetic field in interstellar clouds inhibits the contraction and fragmentation of interstellar clouds. In addition to this, the influence of various dissipative processes like finite electrical resistivity, viscosity and thermal conductivity is well recognized as it can cause the energy to flow by perturbations. The effect of viscosity, electrical resistivity and thermal conductivity has been considered independently or jointly in a number of hydromagnetic models by several authors (Kato and Kumar [2], Kossaki [3], Nayyer [4], Shivamoggi[5], Sharma & Singh[6], Wu *et al.*[7] and El-Sayed & Mohamed[8]). The importance of finite electrical conductivity and thermal conductivity has been described by many investigators in the astrophysical context (Vyas & Chhajlani[9], Vaghela & Chhajlani[10], Chhajlani & Parihar[11]). Recently Dhiman & Mahajan [12] have explored the importance of finite electrical resistivity with viscosity on Jeans instability in magnetized viscoelastic fluid. From all the above studies it is clear that the impacts of viscosity, finite electrical resistivity and thermal conductivity are significant to discuss with Jeans-gravitational instability.

In above mentioned studies none of the authors has incorporated the radiative effects in their studies. All these authors have studied the problem with different parameters, but none has studied the joint influence of all the parameters together with radiative effects.

 In addition to this, it is well known that thermal and radiative effects do play an important role in the stability investigations. The thermal instability arising owing to various heat-loss mechanisms in a dilute plasma may be a probable reason of astrophysical condensations and the configuration of prominences via condensation of material (Field[13], Hunter[14], Cook *et al.*[15]). Beside these, there are varieties of astrophysical circumstances where the impact of thermal instability is significant. Van Hoven & Mok[16] have analyzed the effect of thermal instability in a sheared magnetic field. The various works have been done on the roles of thermal instability in the fragmentation of gravitational fluids (Hunter[17], Aggarwal & Talwar [18]). Thermal instabilities in matter in active galactic nuclei have been studied by Beltrametti[19]. Gupta *et al.*[20] have investigated the thermal instability in a high temperature rotating and gravitating plasma. Bora & Talwar[21] have considered the effect of thermal instability in resistive plasma. Renard & Chieze[22] have assumed the classical Jeans analysis of gravitational stability to a molecular gas focused to thermal exchanges of the interstellar medium. Dwivedi *et al.*[23] have investigated the effect of radiative condensation on Jeans instability. Talwar & Bora[24] have investigated the thermal instability in a star-gas system. Prajapati *et al.*[25] have carried out the problem of self-gravitational instability of rotating viscous Hall plasma with arbitrary radiative heat-loss functions and electron inertia. Recently Kaothekar *et al.* [26] have explored the importance of radiative heat loss function in the problem of effect of finite ion Larmor radius (FLR) corrections on thermal instability of rotating radiative porous astrophysical plasma in interstellar medium (ISM). No one of the researchers has considered the problem of thermal and radiative instability with the joint influence of viscosity and finite electrical resistivity in a partially-ionized plasma medium.

In all the over stated learning’s, a fully ionized plasma has been believed. It is well recognized that a small fraction of interstellar gas subsists in the form of luminous, ionized and tenuous gas known as HI and HII region and the rest is mostly neutral hydrogen. Thus the interstellar gas is not entirely ionized and it is infused with neutral atoms. HI region and molecular clouds are weak ionized medium. Weakly and fully ionized plasmas normally exist side by side in a variety of regions in the universe. A logically easy estimate may be that the interstellar plasma is assumed as a mixture of hydromagnetic (ionized) component and a neutral component, the two interacting via mutual collisions. In cosmic physics such situations occur in the solar photosphere, chromospheres and in cool interstellar clouds. The problem of gravitational instability and thermal conductivity has been investigated in some studies (Ali & Bhatia[27], Bhatia & Hazarika[28], and Shaikh *et al.*[29]). Recently Kaothekar et al. [30] have explored the importance of partially ionized plasma in the problem of transverse thermal instability of partially-ionized plasma with impact of radiative heat-loss function, neutral collisions and finite electron inertial effects in ISM. All these authors have studied the problem with different parameters, but no one studied the joint effect of all the parameters jointly with radiative effects.

Thus the plasma model might be improved by comprising the impact of viscosity, neutral particles, thermal conductivity, finite electrical resistivity and radiative effects. Further, in the preceding studies, in common, it is only the condition of instability which is being studied to discover the impact of a variety of aspects on gas condensation in gravitational instability problem. However, for better insight stability of the system should also be discussed. The purpose of the nearby work in this paper is to argue instability as well as stability of an infinite homogeneous, self-gravitating, uniformly magnetized, thermally conducting, partially-ionized viscous plasma including finite electrical resistivity and radiative effects. The stability of the system is discussed by applying Routh-Hurwitz criterion.

**2. Equations of the Problem**

Let us assume an infinite homogeneous, viscous, thermally conducting, radiating, self-gravitating finitely conducting fluid of density  permeated with neutral particles of densityflowing through porous medium in the presence of uniform magnetic field ***H*** (0, 0, *H*). We assume that the two components of partially ionized plasma (the ionized fluid and the neutral gas) behave as a continuum and their steady state velocities are equal. The magnetic field interacts only with the ionized component of the plasma. The density of the neutral particles is assumed to be small enough to neglect its contribution in Poisson's equation of self-gravitation and pressure gradient of the neutrals. Also we neglect the contribution of ion-neutral resistivity in induction equation. The collisional force of neutrals with the ionized fluid is of the order of pressure gradient of ionized component. The contribution of viscosity is considered only with the permeability of the porous medium. The effects of the neutral component resulting from the fields of self-gravity and pressure are neglected in the momentum transfer equation. Thus we are considering here only the mutual frictional effects between the neutral gas and the ionized fluid. The equations of the problem are written as

 (1)

 (2)

, (3)

, (4)

 (5)

, (6)

 , (7)

 , (8)

where *,* *, p,* *, T, G, K,, R, N, e, , ,* and denote respectively the ionized fluid velocity, neutral gas velocity, pressure, gravitational potential, temperature, gravitational constant, kinematic viscosity, permeability, thermal conductivity, electrical resistivity, gas constant, electron number density, charge of electron, ratio of two specific heats, velocity of light, heat-loss function, and collisional frequency between two components. The heat-loss function is the net loss of energy per unit mass of material per unit time, exclusive of thermal conduction, and in general is a function of the local density and temperature of the gas. The FLR corrections have been add in via the stress tensor **P**in the equation of motion Operator  is the substantial derivative given by

*,* (9)

In the unperturbed state the fluid is supposed to be at rest. A small amplitude perturbation encourages an oscillatory motion and as this perturbation produces in time the system is supposed to be unstable. The instability will grow when power relocated to the system surpass the dissipation. The perturbations in density, pressure, magnetic field, ionized fluid velocity, temperature, gravitational potential, and the heat-loss function are given as *δρ, δp*, ***h***(*hx****,*** *hy****,*** *hz*), ***u***(ux, uy, uz)*, δT, δU* and  respectively. The perturbed state is given by

 *ρ = ρ0 + δρ,* *p = p0 + δp,* ***H= H0 + h****,* ***=*** 

 *T = T0+ δT,* =*,* (with  = 0*,),*  (10)

where the suffix '0' represents the initial equilibrium state.

**3. Linearized Perturbation Equations**

Replacing equation (10) along with equation (9) in equations (1) to (8) and linearizing them by ignoring advanced order perturbations, we get the linearized perturbation equations of the system. Suffix '0' is dropped from the equilibrium quantities for simplicity.

The linearizing perturbation equations overseeing the motion of mixture of the hydromagnetic fluid and a neutral gas are

 (11)

 *,*(12)

 ,  (13)

 , (14)

  (15)

 , (16)

 , (17)

 , (18)

where  and  respectively denote partial derivatives  and  of the heat-loss function, evaluated for the initial (unperturbed) state. The stress tensor ***P*** has the following components for a given magnetic field along z-axis ([Robert & Taylor [11]).

 (19)

where , is ion-gyration frequency and , and denotes the number density, ion temperature and Boltzmann constant, respectively. is the gyroviscosity.

**4. Dispersion Relation**

We look for solutions of equations (11) to (18) in which reliance of perturbed quantities is given by

, (20)

where  is the frequency of harmonic disturbance and **k =** () in x and z directions respectively is the wave number of perturbation making angle  with z-axis, such that

.

Equations (15) and (16) yield a relation between and written as

, (21)

 where

, is the adiabatic velocity of sound in the medium.

 ,  (22)

Using equations (12) to (23) in equation (11), we obtain the following algebraic equations for the perturbed components



 (23)



 (24)

 (25)

 where,

 (26)

is the Alfven velocity, is the condensation of the medium

Taking divergence of equation (11) and using equation (13) and other above used equations, we find that



 (27)

Equations (23) to (25) and (27) can be written in matrix form as

  (28)

Where is the fourth order square matrix and is a single column matrix whose elements are and . For a nontrivial solution of the equation (28) the determinant of the matrix should disappear, leading to the general dispersion relation

 

 











 (29)

The equation (29) symbolizes the general dispersion relation for an infinite homogeneous, viscous, uniformly magnetized, self-gravitating, radiating, partially-ionized plasma flowing through a porous medium of finite electrical and thermally conductivity with FLR corrections and Hall effect. The over dispersion relation can be easily verified with other previous result obtained. In the nonattendance of neutral particles, Hall current, and radiative effects the dispersion relation (29) is alike to that of Vaghela & Chhajlani [10]. This dispersion relation is also identical to that of Chhajlani & Parihar [11], if we neglect the contribution of neutral particles, FLR corrections and radiative effects. If we ignore the effect of radiative heat-loss function, FLR corrections, Hall current and permeability the dispersion relation (29) is identical to Shaikh *et al.*[29].

**V. Discussion**

For the sake of generalization this general dispersion relation is discussed for longitudinal mode and transverse mode of propagation separately.

**A. Longitudinal Mode of Propagation** ()

Taking perturbations in parallel direction to magnetic field we have,  and the dispersion relation (29) diminishes to



 (30)

This equation has three autonomous factors, each symbolizing the modes of propagation integrating diverse parameters, the first factor when equate to zero gives

 (31)

The over equation (31) is identical to equation (17) of Ali & Bhatia [27] when permeability effects are not considered. Equation (31) satisfies the necessary and sufficient condition. According to which it cannot have a real positive root. All its roots posses negative real parts and, hence, the system is a viscous type of damped stable mode amended by the impacts of viscosity, collision frequency, and permeability of the medium. It is autonomous of the magnetic field, electrical resistivity, thermal conductivity, self-gravitation and radiative effects.

 The second factor of equation (30), when equate to zero, gives



 (32)

The above equation represents the dispersion relation for self-gravitating system symbolizing the effects of neutral particles, viscosity, thermal conduction and radiation. This is autonomous of magnetic field, Hall current, electrical resistivity, and FLR corrections. The dispersion relation (32) is a fourth degree equation which may be decreases to particular cases so that the effect of each parameter may be discussed independently.

 For inviscid, fully-ionized, thermally non-conducting, non-radiating, self-gravitating, porous medium we have () and the dispersion relation (32) decreases to

. (33)

Furthermore, if we don’t take into consideration, we have

  (34)

 For both the cases of equation (33) and (34), the condition of instability is

,

 or , where  (35)

, (36)

where  is the Jeans wave number and  is the Jeans length. The system is unstable for all Jeans lengths or wave numbers. Hence of the medium does not influence the condition of instability and we may finish that the Jeans criterion of instability stays unaffected for self-gravitating medium irrespective of it being porous or purely gaseous.

For viscous, non-radiating, but thermally conducting self-gravitating porous medium with neutral particles (), equation (32) becomes



 (37)

where,,,is the isothermal velocity of sound.

The condition of instability from constant term of this equation is

, (38)

, (39)

where  is the adapted Jeans wave number for thermally conducting medium. The amended Jeans length due to addition of thermal conduction is

. (40)

Evaluating equations (35) and (39) we find that due to thermal conduction the sonic velocity is altered from adiabatic to isothermal one in Jeans expression. From equation (36) and (40) we have

. (41)

Since, the Jeans length is reduced because of thermal conduction and destabilizes the system. If we believe viscous, radiating, thermally non-conducting, self-gravitating porous medium with neutral particles, then we find that the system is unstable for all wave numbers  and, therefore, begins to break into fragments of size comparable to  where is the modified critical Jeans wave number due to inclusion of radiative terms and given by

. (42)

Thus the critical Jeans wave number  is very much dissimilar from the classical Jeans value and depends on derivatives of the heat-loss function with respect to local temperature and density in the arrangement. It is clear that the critical Jeans wave number stays unchanged if the heat-loss function is autonomous of density of the medium  and depends only on temperature. Clearly, the critical Jeans wave number disappears if the heat-loss function is independent of temperature.

Now believing the joined effect of all the parameters agreed by the dispersion relation (32). The condition of instability from constant term of this equation is given by

. (43)

This is the tailored condition of instability. Thus we see that the Jeans condition of instability is tailored because of inclusion of radiative and thermal conductive effects. The condition (43) is the same as gained earlier by Bora & Talwar [21], for an finitely conducting fluid and by Hunter [17] for and electrically non-conducting gas subjected to a general heat-loss function and thermal conduction.

In general the condition (43) suggest a range of critical wave numbers, given by



  (44)

It may be remaindered that for a density independent heat-loss functionwhich augments with temperature, the condition (43) propose a monotonic instability if . However, if instead, the heat-loss function reduces with temperature, the instability happens for  lying between the values  and. Alternately, if we presume the heat-loss function to be autonomous of temperature and depending only density, the condition (43) recommend and instability if

  (45)

so that the critical wave number is expanded or diminished depending on whether the heat-loss function is an expanding or condensing function of density.

 We now consider the dynamical stability of the system, by relating the Routh-Hurwitz criterion on the dispersion relation (32). If and then all the coefficients of the equation are positive, gratifying the essential condition of stability. For the sufficient condition we determine the principal diagonal minors of Hurwitz matrix formed by these coefficients. The principal diagonal minors are

 as







 (46)

which are all positive, there by pleasing the Hurwitz criterion according to which equation (32), will not admit any positive real root of  or a complex root whose real part is positive. Hence, the system symbolized by equation (32) is stable if and 

The dispersion relation (32) may be symbolized in non-dimensional form on dividing it by  and assuming so that, gives







 (47)

where the a variety of non-dimensional parameters are definite as

 

  (48)

To see the impact of diverse physical parameters on the growth rate of unstable mode, we have executed arithmetical computations of the dispersion relation (47) and place the roots of (growth rate) against (wave number) for quite a few values of the parameters. The value of  in arithmetical computations is taken as ().



Fig. 1. Growth ratevs wave numberfor three values of parametermaintaining the additional parameters constant

 

Fig. 2. Growth rate vs wave numberfor three values of parameter  maintaining the additional parameters constant



Fig. 3. Growth rate vs wave numberfor several values of parameters maintaining the additional parameters constant 



Fig. 4. Growth rate vs wave numberfor several values of parameters maintaining the additional parameters constant 



Fig. 5. Growth rate vs wave numberfor several values of parameters maintaining the additional parameters constant

Out of the four modes only one mode is unstable for which the calculations are in obtainable in figs. 1-5, where the growth rate is plotted against the wave number to display the dependence of the growth rate on the different physical parameters. It is clear from fig. 1 that the growth rate decreases with elevating the temperature dependent radiative heat-loss functionThus the outcome of temperature dependent radiative heat-loss function is stabilizing, whereas from fig. 2 we finish that growth rate augments with augmenting density dependent radiative heat-loss function. Thus the outcome of density dependent radiative heat-loss function is destabilizing. One can monitor from fig. 3 that the growth rate diminishes with augmenting collision frequency. Thus the outcome of collision frequency is stabilizing. From fig. 4 we bring to a close that growth rate diminishes with augment in thermal conductivity of the system. Thus the outcome of thermal conductivity is stabilizing. It is easy to estimate from fig. 5 that on increasing the value of permeability  growth rate of the system increases. So we conclude that permeabilitytries to destabilize the system.

Now we discuss the third factor of dispersion relation (30). On solving that we get

 (49)

where

 ,

 







(50)

The dispersion relation (49) engages viscosity, magnetic field, finite electrical resistivity, Hall current, FLR corrections, and the effects of neutral particles, but it does not engage the self-gravitation, thermal conduction and radiative effects. This provides Alfven modes customized by the dissipative effects of viscosity, finite electrical resistivity, Hall current, FLR corrections, and the neutral particles. The coefficients of this equation are all positive counting the constant term: hence, the equation cannot have a positive root, means thereby that the system symbolized by the equation is stable, according to the necessary condition only.

 For simplicity, we consider the case of stability of the system symbolized by the dispersion relation (49) in the nonattendance of neutral particles. After substituting () in the equation (49) we obtained fourth degree equation of the form

 





 (51)

All the coefficient of this equation is positive, fulfilling necessary condition of stability. For the sufficient condition we find out the principal diagonal minors of the Hurwitz matrix, formed by the coefficients of the equation (51), as









  (52)

Which are all positive, so the Routh-Hurwitz criterion is satisfied. Thus the equation (51) shows a stable Alfven mode amended by the dissipative effects of viscosity, finite electrical resistivity, Hall current, and FLR corrections.

To see the effect of FLR corrections we put  in equation (49) to get the required equation as

 (53)

From equation (53), we have

  (54)

These are Alfven waves moving in reverse routes with velocity amended because of FLR corrections. Thus FLR corrections amended the mode by varying the growth rate.

**6. Conclusions**

In the present problem we have discussed the impacts of FLR corrections, Hall effect, finite electrical resistivity, thermal conductivity, radiative effects in the presence of neutral particles on an infinite homogeneous, self-gravitating plasma. The results may be summarized as follows:

The velocity has a damping impact but doesn’t influence the Jeans expression. Also the occurrence of collision with neutral does not affect the instability circumstance in all the cases. It is set up that Hall current affects the wave propagation along the direction of magnetic field by modifying the Alfven mode but it has no involvement in the condition of instability. The Alfven mode is unchanged by thermal conductivity and radiative effects.

 The attendance of neutral particles, viscosity, thermal conductivity and radiative effects influences the gravitational mode in the longitudinal direction of wave propagation. The magnetic field and FLR corrections do not affect the Jeans condition in longitudinal direction.

 We see that owing to the addition of thermal conductivity, the adiabatic velocity of the sound is being substituted by the isothermal one in different cases. The Jeans length is reduced due to thermal conductivity and destabilizes the system. Due to the addition of radiative effects the critical Jeans wave number is very much different from the classical Jeans value, and depends on derivatives of the heat-loss function with respect to local temperature and density in the configuration.

 From the different figures we see that temperature dependent radiative heat-loss function , thermal conductivityand collision frequencyhave stabilizing effect on the growth rate of the considered system. Whereas density dependent radiative heat-loss function and medium permeabilityhas a destabilizing impact on the growth rate of the system.

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