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

G. D. Soni,1,[[1]](#footnote-2)a Sachin Kaothekar2 and R. K. Chhajlani3

1Maharani Puspamala Raje Panwar Government Girls College, Dewas, M. P.-452004, India.

2Department of Physics, Govt. Madhav Science P. G. College, Ujjain, M. P. - 456010, India.

3Retired from School of Studies in Physics, Vikram University Ujjain, M. P.-456010, India.

amail: gdsoniphysics@gmail.com

**Abstract**

The study of Jeans’s gravitational instability has been examined for a partially ionized plasma with Hall current parameter and FLR corrections, which has correlation in astrophysical compressions. An overall general dispersion relation has been inferred with the assistance of important linearized perturbation equations, utilizing the normal mode investigation. Impacts of viscosity, radiative heat-loss function and collisions with neutrals on the unsteadiness of the organization 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 executed to examine the reliance of the growth rate of the gravitational instability on the different physical limitations. 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 weakening influence on the growth rate of the gravitational instability. Based on Routh-Hurwitz's criterion, the steadiness of the organization is examined. Results completed in this study are useful for the configuration of star in interstellar medium (ISM).

**1. Introduction**

The breakup of the interstellar gas is a significant observable fact for star configuration. It is generally supposed that stars are formed as a consequence of the gravitational reduction of sections of interstellar clouds. In this connection the difficulty of gravitational instability was primary argued by Jeans [1], concerning the arrangement of astronomical ruminants by the separation of interstellar material, where it is represented that there survives a critical size above which a consistent self-gravitating substance turn out to be unstable to tiny 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 supplementary it is presumed that the fluctuations in density and pressure pursue an adiabatic law, thus departing out the impacts of thermal conduction and radiation. It is therefore of interest to see how the consequences of self-gravitational instability of interstellar substance are influenced by the thermal conductive and radiative effects.

The problem of magneto-gravitational instability of interstellar substance is of considerable importance in connection with protostar and star formation in dust clouds. Presence of magnetic field in interstellar clouds inhibits the reduction and breakup of interstellar clouds. In this association, the impact of different dissipative progressions like finite electrical resistivity, viscosity and thermal conductivity is well recognized as it can cause the energy to flow by perturbations. The consequence of viscosity, electrical resistivity and thermal conductivity has been believed autonomously or together in a number of hydromagnetic models by quite a few authors (Kato & Kumar [2], Kossaki [3], Nayyer [4], Shivamoggi[5], Sharma & Singh[6], Wu *et al.*[7] and El-Sayed & Mohamed[8]). The significance of finite electrical conductivity and thermal conductivity has been described by a lot of 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 over stated studies no one of the authors has incorporated the radiative effects in their learning’s. All these authors have studied the difficulty with dissimilar limitations, but no one has studied the joint authority of all the limitations jointly through radiative effects.

 In addition to this, it is well known that thermal and radiative effects do play an important role in the stability examinations. The thermal instability arising owing to a variety of heat-loss mechanisms in a dilute plasma might be a probable reason of astrophysical concentrations and the configuration of prominences via condensation of material (Field[13], Hunter[14], Cook *et al.*[15]). Beside these, there are diversities of astrophysical circumstances where the impact of thermal instability is significant. Van Hoven & Mok[16] have examined the effect of thermal instability in a sheared magnetic field. The a variety of works have been done on the roles of thermal instability in the disintegration of gravitational fluids (Hunter[17], Aggarwal & Talwar [18]). Thermal instabilities in substance in energetic galactic nuclei have been considered 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 explored the impact of radiative condensation on Jeans instability. Talwar & Bora[24] have investigated the thermal instability in a star-gas system. Prajapati *et al.*[25] have explored the difficulty 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 difficulty of thermal and radiative instability with the combined impact of viscosity and finite electrical resistivity in a partially-ionized plasma system.

In all the over stated learning’s, a fully ionized plasma has been believed. It is well recognized that a minute portion of interstellar gas subsists in the form of shining, ionized and tenuous gas known as H I and H II area and other than this 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 survive near to each other in a variety of areas in the universe. A logically easy estimate may be that the interstellar plasma is assumed as a combination of hydromagnetic (ionized) constituent and a neutral constituent, the two acts together via common collisions. In cosmic region such circumstances take place in the solar photosphere, chromospheres and in cool interstellar clouds. The problem of gravitational instability and thermal conductivity has been investigated in few 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 difficulty with dissimilar limitations, but no one studied the joint impact of all the limitations jointly with radiative effects.

Thus the plasma replica might be improved by comprising the impact of viscosity, neutral particles, thermal conductivity, finite electrical resistivity and radiative effects. Additional, in the preceding studies, in common, it is only the situation of instability which is being studied to discover the impact of a variety of aspects on gas strengthening in gravitational instability difficulty. However, for better insight steadiness of the organization must also be argued. The reason of the nearby work in this paper is to argue instability as well as stability of an infinite homogeneous, self-gravitating, and uniformly magnetized, thermally conducting, partially-ionized viscous plasma containing finite electrical resistivity and radiative effects. The stability of the organization is argued 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  infused with neutral particles of densityflowing via porous medium in the attendance of homogeneous magnetic field ***H*** (0, 0, *H*). We suppose that the two components of partially ionized plasma (the ionized fluid and the neutral gas) behave as a continuum and their stable condition velocities are identical. The magnetic field act together only with the ionized component of the plasma. The density of the neutral particles is supposed to be little sufficient to abandon its contribution in Poisson's equation of self-gravitation and pressure gradient of the neutrals. Also we abandon 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 believed only with the permeability of the porous medium. The impacts of the neutral component consequent from the fields of self-gravity and pressure are abandoned in the momentum transfer equation. Thus we believe 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, limited 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 unbalanced. The instability will develop when power relocated to the organization 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, estimated 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 indistinguishable 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 indistinguishable 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 impacts are not considered. Equation (31) convinces the essential and enough condition. According to which it cannot have a real positive root. All its roots posses negative real parts and, hence, the organization is a viscous type of damped constant mode modified 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 over equation represents the dispersion relation for self-gravitating system representing the impacts 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 impact of each limitation may be argued sovereignty.

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

. (33)

In addition, if we don’t take into deliberation, we have

  (34)

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

,

 or , where  (35)

, (36)

where  is the Jeans wave number and  is the Jeans length. The organization is unbalanced for all Jeans lengths or wave numbers. Hence the medium does not influence the circumstance of instability and we may finish that the Jeans criterion of instability stays unaffected for self-gravitating medium independent 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 state of instability from steady expression of this equation is

, (38)

, (39)

where  is the adapted Jeans wave number for thermally conducting intermediate. The amended Jeans length because of addition of thermal conduction is

. (40)

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

. (41)

Since, the Jeans length is decreased because of thermal conduction and weakens the system. If we believe viscous, radiating, thermally non-conducting, self-gravitating porous medium with neutral particles, then we discover that the organization is unstable for all wave numbers  and, consequently, commences to rupture into sections of size analogous to  where is the altered critical Jeans wave number because of addition of radiative expressions and given by

. (42)

Thus the critical Jeans wave number  is extremely dissimilar from the classical Jeans value and depends on derivatives of the heat-loss function with admiration to local temperature and density in the arrangement. It is obvious that the critical Jeans wave number stays unchanged if the heat-loss function is autonomous of density of the medium  and relies only on temperature. Obviously, the critical Jeans wave number disappears if the heat-loss function is autonomous of temperature.

Now believing the joined impact of all the limitations agreed by the dispersion relation (32). The circumstance of instability from steady term of this equation is given by

. (43)

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

The condition (43) propose 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 situation (43) propose a monotonic instability if . Though, if in its place, the heat-loss function reduces with temperature, the instability happens for  lying connecting the values  and. Alternately, if we presume the heat-loss function to be autonomous of temperature and relying only density, the circumstance (43) recommend and instability if

  (45)

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

 We currently believe the dynamical stability of the organization 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 adequate condition we establish the principal diagonal minors of Hurwitz matrix figured by these coefficients. The principal diagonal minors are

 as







 (46)

These are all positive, there by pleasing the Hurwitz criterion according to which equation (32), will not acknowledge any positive real root of  or a complex root whose real part is positive. Thus, the organization 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 observe the impact of diverse physical parameters on the growth rate of unbalanced mode, we have executed arithmetical computations of the dispersion relation (47) and place the roots of (growth rate) beside (wave number) for quite a few values of the limitations. 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 belief 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 functionHence the outcome of temperature dependent radiative heat-loss function is stabilizing, while as of fig. 2 we finish that growth rate enhances with augmenting density dependent radiative heat-loss function. Hence 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. Hence the outcome of collision frequency is stabilizing. From fig. 4 we bring to a close that growth rate diminishes with enhance in thermal conductivity of the system. Thus the outcome of thermal conductivity is stabilizing. It is easy to estimate from fig. 5 that on growing the value of permeability  growth rate of the organization increases. So we conclude that permeabilitytries to destabilize the organization.

Now we converse the third feature of dispersion relation (30). On resolving that we get

 (49)

where

 ,

 







(50)

The dispersion relation (49) engages viscosity, magnetic field, finite electrical resistivity, Hall current, FLR corrections, and the impacts of neutral particles, but it doesn’t 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 essential circumstance only.

 For ease, we believe the case of stability of the organization symbolized by the dispersion relation (49) in the nonattendance of neutral particles. After replacing () in the equation (49) we gained fourth degree equation of the form

 





 (51)

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









  (52)

These 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 impact 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 in attendance difficulty we have discussed the impacts of FLR corrections, Hall effect, finite electrical resistivity, thermal conductivity, radiative effects in the occurrence 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 influence the instability circumstance in all the situations. It is set up that Hall current affects the wave propagation down the track of magnetic field by changing 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 path of wave propagation. The magnetic field and FLR corrections do not affect the Jeans condition in longitudinal route.

 We observe 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 decreased due to thermal conductivity and destabilizes the system. Due to the addition of radiative effects the critical Jeans wave number is extremely a large amount dissimilar from the classical Jeans value, and depends on derivatives of the heat-loss function with esteem to local temperature and density in the arrangement.

 From the different figures we see that temperature dependent radiative heat-loss function , thermal conductivityand collision frequencyhave stabilizing consequence 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 organization.

**Acknowledgements**

The author (S. K.) is thankful to Prof. V. K. Gupta, Principal, Government Madhav Science P. G. College, Ujjain for continuous support and guidance.

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 doi.org/10.1016/j.matpr.2023.05.596

1. a mail: gdsoniphysics@gmail.com [↑](#footnote-ref-2)