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Study of the wave-instabilities due to a temperature gradient in a self-gravitating MHD medium and its role in producing decelerated mass-outflow from the central region in AGN

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Abstract. The wave-instabilities due to a temperature gradient in an infinitely conducting self-gravitating, non-relativistic MHD medium have been studied. It has been found that : (1) the temperature gradient is able to produce two types of instabilities viz., sinusoidal and exponential of longitudinal MHD waves, (2) the presence of self-gravitation reduces the lower limit of the frequencies of the stable and unstable longitudinal waves. (3) sinusoidal instability is due to amplification or damping in the direction of negative or positive gradient of temperature respectively. Further, the sinusoidally unstable longitudinal MHD waves have been found to be of two types viz., supersonic and subsonic. This supersonic wave-flow, when in the direction of negative temperature gradient, suffers amplification as well as deceleration provided $T_{01} / T_{02} > 2$, T_{01} and T_{02} being the temperatures at the two end points in the direction of increasing distance, respectively.

The above theory may be applied to the hot and ionised gas medium of the Region (5 lt-day $\lesssim r \lesssim$ 1 lt-yr) within the central 1-parsec of NGC 4151, because the medium in this region appears to be roughly similar to the medium which is considered in this paper. It has been seen that in the presence of a poloidal magnetic field the amplification of sinusoidally unstable longitudinal MHD waves due to temperature gradient could be one of the triggering factors for mass-outflow in the Z-direction where $\partial T_0 / \partial Z < 0$. However, the effect of self-gravitation of the plasma medium in the central region (5 lt-day $\lesssim r \lesssim$ 1 lt-yr) of NGC 4151 does not appear to be significant. Further, the numerical estimation of wave parameters using basic parameters of the medium reveals that the mass-outflow could be supersonic and decelerated from Z_1 = 5 lt-day to Z_2 = lt-yr. The velocities (V_{ph}) of mass-outflow and the sound speeds (C_s) at the ends Z_1 = 5 lt-day and Z_2 = 1 lt-yr come out to be approximately in the following range :

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$$170 \text{ km s}^{-1} (\sim C_{s2}) < 210 \text{ km s}^{-1} (\sim V) < V_{ph2} < C_{s1} < V_{ph1}.$$

Whereas the observed $V_{ph2} = 800$ km s^{-1} and $V_{ph1} = 4000$ km s^{-1} in the central region which, in turn, are in agreement. Using above inequality it has been obtained that at $Z_1 = 5$ lt-day the hot gas temperature (T_{01}) should satisfy the following range : 10^8 K $\lesssim T_{01} < 5.7 \times 10^8$ K.

Key words. MHD wave-instability — AGN — mass-outflow — NGC 4151

1. Introduction

Over the past few decades many attempts have been made to explore the mechanisms for the activities in the central part of galaxies, e.g., in Seyfert galaxies and other AGNs. In our previous paper (see Chakraborty and Bondyopadhaya 1993; hereafter called paper-I) also we have discussed the same (a number of references have been given there).

Recent observations have suggested that

(1) In AGNs there exists two major structural components viz, the Broad Line Region (BLR) and the Narrow Line Region (NLR) (see e.g., Clavel et al. 1987; Osterbrock 1988; Netzer 1990 etc.)

(2) The existence of an intermediate or transition region in between BLR and NLR in AGNs may not be ruled out (see e.g., Osterbrock and Mathews 1986; Clavel et al. 1987; Van Groningen and de Bruyan 1989; Roos 1992 etc.)

(3) Almost a continuous outflow of hot ionized gaseous materials at high velocities has been observed to occur from BLR in AGNs including Seyferts (see e.g., Guilbert et al. 1983; MacAlpine 1986; Osterbrock and Mathews 1986; Clavel et al. 1987; Osterbrock 1991 etc.)

(4) The mass-outflow from BLR in AGNs appears to be supersonic (see e.g., Mathews and Ferland 1987; Blandford 1990 etc.) and

(5) The mass-outflow from BLR in AGNs decelerates outwardly (see e.g., Osterbrock and Mathews 1986; Clavel et al. 1987 etc.)

These outflows could be described by non-relativistic MHD theory (see e.g., Blandford 1990; Lovelace and Contopoulos 1990; Woltjer 1990; Chakraborty and Bondyopadhaya 1993 etc.).

In this paper we shall make an attempt to explain these aspects of the mass-outflow from the BLR in an AGN known as Seyfert galaxy NGC 4151.

2. Basic theory

Our main motivation is to investigate the mechanism of mass-flow phenomena from astrophysical bodies like the central region of galaxies or Seyfert galaxies. We shall, first of all, consider a medium which is infinitely conducting, self-gravitating and of non-relativistic hydromagnetic nature with a temperature gradient. The basic equations which could describe such a medium are as follows (vide paper-1) :

(i) Equation of Motion :

$$\rho \frac{\partial \underset{\sim}{U}}{\partial t} = \frac{\mu}{4\pi} (\underset{\sim}{\nabla} \times \underset{\sim}{H}) \times \underset{\sim}{H} - \rho (\underset{\sim}{\nabla} \times \underset{\sim}{U}) \times \underset{\sim}{U} - \underset{\sim}{\nabla} p - \rho \underset{\sim}{\nabla} (\tfrac{1}{2} U^2 + \phi) ,$$

(ii) MHD - Field Equation :

$$\frac{\partial \underset{\sim}{H}}{\partial t} = \underset{\sim}{\nabla} \times (\underset{\sim}{U} \times \underset{\sim}{H}) ,$$

(iii) Mass - Conservation Equation :

$$\frac{\partial \rho}{\partial t} = - \underset{\sim}{\nabla} \cdot (\rho \underset{\sim}{U}) ,$$

(iv) Magnetic Flux Conservation Equation :

$$\underset{\sim}{\nabla} \cdot \underset{\sim}{H} = 0 ,$$

(v) Poisson's Equation :

$$\nabla^2 \phi = 4\pi G \rho_t ,$$

(vi) Equation of State :

$$p = R \rho T ,$$

(vii) Heat Equation :

$$\frac{\partial p}{\partial t} = \frac{\gamma p}{\rho} \left[\frac{\partial \rho}{\partial t} + (\underset{\sim}{U} \cdot \underset{\sim}{\nabla}) \rho \right] - (\underset{\sim}{U} \cdot \underset{\sim}{\nabla}) p + \epsilon (\gamma - 1) ,$$

(viii) Heat Energy transport Equation :

$$\epsilon = \chi \nabla^2 T ,$$

where

$\underset{\sim}{U}$ = Fluid velocity vector,

$\underset{\sim}{H}$ = Magnetic field intensity vector,

$\rho_t = (\rho_F + \rho)$ = Total mass-density,

ρ_F = Fixed mass density (e.g., in the case of a galactic system it may be regarded as stellar density),

ρ = Gas density, G = Gravitational constant, ϕ = Gravitational potential,

p = Hydrostatic pressure,

T = Temperature, γ = Ratio of specific heats (assumed to be constant),

R = Gas constant (obtained by dividing Universal gas constant by mean molecular weight of the gas),

$\in$ = Increase in heat energy per cm^3 per second due to heat conduction, radiation processes,

χ = heat conductivity, μ = Permeability,

and all the other symbols have their usual meaning. Here, Gaussian system of units have been taken to measure all the variables.

Next, we have considered this medium which was at equilibrium initially but subsequently perturbed. Using rectangular Cartesian co-ordinate system and linear perturbation of the variables $\underset{\sim}{U}$, $\underset{\sim}{H}$, ρ, ρ_F, p, T, $\in$, ϕ, the wave propagation in such a medium has been discussed, in general, in secs. 2-5.2 in paper-I (vide Appendix). Wave propagations under some specific conditions as prescribed below are very relevant with the medium in the central region of galaxies.

Specific Conditions : (i) $\partial T_O/\partial Z \neq 0$ but $\partial T_O/\partial t = 0$ (i.e., the basic temperature is non-uniform only along Z-direction and is steady). (ii) $\partial \rho_O/\partial \ell = 0$ where ℓ =x,y,z (i.e., the basic density is uniform in all directions), (iii) $\chi = 0$ (i.e., the absence of heat flux), (iv) $\eta = 0$ (i.e., the electrical conductivity is infinite). The wave propagation in such a medium had been discussed in sect. 6 in paper-I. It was found that the wave propagations along Z-direction in the above type of medium are guided by the following two Dispersion Relations (D.R.) : For Transverse Waves : $\omega = \pm k_Z V_A$ (1)

For Longitudinal Waves : $\omega^2 = C^2_s k_Z [k_Z - (i/\gamma T_O)(\partial T_O/\partial Z)] - \omega_g^2$ (2)

where (as in sect. 5.1 in paper-I)

$C_S = (\gamma R T_O)^{1/2}$: Adiabatic Sound Speed

$\omega_g = (4\pi G \rho_O)^{1/2}$: Gravitational Frequency

$V_A = (\mu/4\pi\rho_O)^{1/2} H_{Oz}$: Alfven Velocity

3. Wave instability : Types and conditions

Now, the D. R. (2) (see Eq. (19) in paper-I) in the previous section can be rewritten as

$$k_Z C_S = iW \pm (\omega^2 + \omega_g^2 - W^2)^{1/2} \tag{3}$$

where $W = (C_S/2\gamma T_O)(\partial T_O/\partial Z)$ (3.1)

Evidently for longitudinal waves

$$\left.\begin{array}{ll}\text{(i) The exponential instability requires} & \omega^2 \le W^2 - \omega_g^2\ (=\omega_C^2),\\ \text{(ii) The sinusoidal instability requires} & \omega^2 > \omega_c^2,\\ \text{(iii) The insignificant instability on stability requires} & \omega^2 \gg 2W^2 - \omega_g^2\ (=W^2+\omega_c^2)\end{array}\right\} \quad \text{(C–1)}$$

where ω_C may be called the critical wave frequency [see sect. 6.1 in paper-I].

It may further be noted that

(1) any non-uniformity of temperature (i.e., for $W \neq 0$) will always lead to some instability and, (2) generally the stable waves are of very high frequency (i.e., $\omega \gg (W^2 + \omega_c^2)^{1/2}$), sinusoidally unstable waves are of high frequency (i.e., $\omega > \omega_c$), and exponentially unstable waves are of low frequency (i.e., $\omega \le \omega_c$).

Role of self-gravitation of the medium : It is clear from the D.R.(3) that for stable propagation of longitudinal waves in a medium of non-uniform temperature we must require the imaginary part must be negligible in comparison to real part of the right hand side of D.R.(3) i.e.,

$$\omega \gg (2W^2 - \omega_g^2)^{1/2} \tag{3.2}$$

which, in turn, implies that the presence of self-gravitation reduces the lower limit of the frequencies of propagating longitudinal waves (see also remarks in sect. 6 later). One may also note that above inequality (3.2) can also be interpreted as 'self-gravitation tends to reduce the influence of temperature gradient'. This becomes apparent as soon as we replace $W^2 - \omega_g^2$ by ω_c^2 . Naturally in all subsequent discussion the effect of self-gravitation will be just to oppose the action of temperature gradient whatever be its magnitude.

Instability Factor (I.F.) : From D.R.(3) it is evident that the Instability Factor (I.F.) [i.e., the non-harmonic amplitude of the wave structure for the sinusoidally unstable longitudinal waves is $(-W/C_S)$.

Hence, for $W<0$ i.e., in the direction of negative gradient of basic temperature (T_O) the sinusoidally unstable longitudinal waves will undergo amplification. Similarly, for $W>O$ i.e., in the direction of positive gradient of basic temperature (T_O) such waves will undergo damping (see sect. 6.1 in paper-I).

Also, from D.R.(3) we get for the exponentially unstable waves the Instability Factor as

$$\text{I.F.} = -(W/C_S) \mp (1/C_S)\,[W^2 - (\omega_g^2 + \omega^2)]^{1/2}$$

$$= -(W/C_S)\left[1 \pm [\,1 - \{(\omega_g^2 + \omega^2)/W^2\}]_{1/2}\right]\left\{\begin{array}{l}< 0 \text{ if } W > 0\\ > 0 \text{ if } W < 0\end{array}\right\} \tag{C-2}$$

Evidently, for exponential instability the conclusions regarding the amplification and damping of the waves are same as in the case of sinusoidal instability.

Phase Velocity (Vph) : From the D.R.(3) we get

$$\frac{Vph}{C_S} = \frac{1}{C_S}\,\frac{\omega}{\text{Real part of } k_Z} = \frac{1}{\left[1-\left(\frac{W^2-\omega_g^2}{\omega^2}\right)\right]^{1/2}} = \frac{1}{\left(1-\frac{\omega_c^2}{\omega^2}\right)^{1/2}}$$

This shows that the sinusoidally unstable longitudinal wave is supersonic if $W^2 > \omega_g^2$ and subsonic if $W^2 < \omega_g^2$. Evidently, if self-gravitation is absent then sinusoidally unstable longitudinal waves are always supersonic (of course $\omega > W$) and it is the self-gravitation which may convert the supersonic wave into subsonic waves.

When $\omega^2 \leqslant \omega_c^2 = W^2 - \omega_g^2$, then $V_{ph} \rightarrow \infty$,

When $\omega^2 \gg \omega_c^2 = W^2 - \omega_g^2$, then $V_{ph} \rightarrow C_S$ (sonic waves),

When $\omega^2 > \omega_c^2 = W^2 - \omega_g^2$, then ***either*** $V_{ph} > C_S$ (supersonic waves) provided $W^2 > \omega_g^2$ including the case of absence of self-gravitation (i.e., $\omega_g = 0$) ***or***, $Vph < C_S$ (Subsonic waves) provided $W^2 < \omega_g^2$. (C-3)

Supersonic and subsonic wave-flow : It is clear from the expression of phase velocity for the sinusoidally unstable longitudinal waves in (C-3) that the longitudinal MHD wave-flow could be supersonic or subsonic according as

$$W^2 > \text{or}, < \omega_g^2 \tag{C-4}$$

which implies [by using $W = (C_S/2\gamma T_O)\,(\partial T_O/\partial Z)$, see Eq.(3.1)]

$$\partial T_O/\partial Z > \text{or}, < [\partial T_O/\partial Z]_C \tag{C-5}$$

where $[\partial T_O/\partial Z]_C = (2\gamma\omega_g)\,(T_O/C_S)$ (C-6)

may be called the critical temp. grad. (see sec. 6.1 in paper-I). Further, these types of flows undergo amplification along the increasing Z-direction where $\partial T_O/\partial Z$ decreases.

Now, in the following section we shall make an attempt to understand how a longitudinal MHD wave-flow (i.e., sinusoidally unstable longitudinal MHD waves) behaves mainly in the direction of negative gradient of temperature in the medium by using the above conditions for wave-instability.

3.1 Nature of longitudinal wave-flow in the direction of negative gradient of temperature

Now, let **R** be the region $Z_1 \leq Z \leq Z_2$ where

(i) the basic temperature (T_O) decreases from T_{01} at $Z=Z_1$ to T_{02} at $Z=Z_2$ i.e., $T_{02} < T_{01}$,

(ii) the basic density (ρ_0) remains uniform, and

(iii) the ratio of specific heats [viz., $\gamma \simeq 5/3$; see Woltjer 1965] remains constant and all the other basic parameters of the medium in **R** as the same as what was considered in sect. 2.

Evidently, in the medium in **R** the sound speed viz., $C_S = (\gamma RT_O)^{1/2}$ (see sect. 2) and the critical temp. grad. viz., $[\partial T_O/\partial Z]_C = (2\gamma\omega_g)(T_O/C_S)$ (see (C-6) in sect. 3) decrease from Z_1 to Z_2 because T_O decreases from T_{01} to T_{02} in that direction i.e.,

$$C_{S2} = (\gamma RT_{02})^{1/2} < (\gamma RT_{01})^{1/2} = C_{S1} \quad \text{(C-7)}$$

and

$$\left[\frac{\partial T_O}{\partial Z}\right]_{c2} = \frac{2\gamma\omega_g T_{02}}{C_{S2}} = 2\omega_g\left[\frac{\gamma T_{02}}{R}\right]^{1/2} < 2\omega_g\left[\frac{\gamma T_{01}}{R}\right]^{1/2} = \frac{2\gamma\omega_g T_{01}}{C_{S1}} = \left[\frac{\partial T_O}{\partial Z}\right]_{c1} \quad \text{(C-8)}$$

Now, let us assume (1) $\partial T_O/\partial Z \simeq (T_{01} - T_{02})/L$ where L [$= Z_2 - Z_1$] denotes the length scale of the medium in **R** , and (2) the magnitude of $\partial T_O/\partial Z$ viz., $(T_{01} - T_{02})/L$ is constant throughout in **R**.

Therefore, the parameter $W\left[= \frac{C_S}{2\gamma T_O}\left(\frac{\partial T_O}{\partial Z}\right)\right.$; see in Eq. (3.1) in sect.3$\left.\right]$

increases from Z_1 to Z_2 in **R** because

$$W_2 = \frac{C_{S2}}{2\gamma T_{02}}\left(\frac{\partial T_O}{\partial Z}\right) = \frac{1}{2}\left(\frac{R}{\gamma T_{02}}\right)^{1/2}\left(\frac{T_{01} - T_{02}}{L}\right) > \frac{1}{2}\left(\frac{R}{\gamma T_{01}}\right)^{1/2}$$

$$\frac{T_{01} - T_{02}}{L} = \frac{C_{S1}}{2\gamma T_{01}}\left(\frac{\partial T_O}{\partial Z}\right) = W_1 \quad \text{(C-9)}$$

Now, in view of the conditions (C-1), (C-4) & (C-5) (see sect. 3) it follows that the sinusoidally unstable longitudinal waves will undergo amplification in the direction of decreasing temperature from Z_1 to Z_2 in **R** provided

$$\omega_1^2 > W_1^2 - \omega_g^2 \text{ and } \omega^2 > W_2^2 - \omega_g^2 \quad \text{(C-10)}$$

where ω_1 and ω_2 are the frequencies of the waves at $Z = Z_1$ and at $Z = Z_2$ respectively.

3.1.1 Features of Supersonic Wave-Flow

Let us find out the necessary condition for the wave-motion in the **R** to be always supersonic. Evidently, using (C-9), we get from (C-4)

$$\omega_g^2 < W_1^2 < W_2^2$$

which can be written as [by using (C-8)]

$$(T_{O1} - T_{O2}) / L > 2\gamma\omega_g (T_{O1} / C_{S1} > 2\gamma\omega_g (T_{O2} / C_{S2}) \quad \text{(C-11)}$$

where $\partial T_O / \partial Z \simeq (T_{O1} - T_{O2}) / L$.

Now, writing (C-11) as

$$\left(\frac{V}{C_{S2}}\right)\frac{T_{O2}}{T_{O1}} < \frac{V}{C_{S1}} < 1 - \frac{T_{O2}}{T_{O1}} \quad (\text{where } V = 2\gamma L\omega_g)$$

we get the following

$$\frac{V}{C_{S1}} < 1 - \frac{T_{O2}}{T_{O1}} < 1 \qquad \text{i.e., } V < C_{S1} \quad \text{(C-11.1)}$$

and

$$\frac{V}{C_{S2}} < \frac{T_{O1}}{T_{O2}} - 1 \quad \text{(C-11.2)}$$

Now, when the necessary condition (C-11) holds in **R** , then wave-motion from Z_1 to Z_2 will be supersonic.

Under this situation we consider that a supersonic wave-motion takes place from Z_1 to Z_2 in **R** having V_{ph1} and V_{ph2} as the magnitudes of phase velocities at Z_1 and Z_2 respectively. Evidently, we get

$$V_{ph1} > C_{S1} \text{ and } V_{ph2} > C_{S2} \quad \text{(C-11.3)}$$

Now, using (C-7), (C-11.1), (C-11.2) we get from (C-11.3) respectively the following as :

$$V_{ph2} > C_{S2} < C_{S1} < V_{ph1}, \quad \text{(C-11.4)}$$

$$V < C_{S1} < V_{ph1}, \quad \text{(C-11.5)}$$

and

$$\frac{V}{V_{ph2}} < \frac{V}{C_{S2}} < \frac{T_{O1}}{T_{O2}} - 1, \quad \text{(C-11.6)}$$

The above conditions (C-11.4) to (C-11.5) indicate that a relation between V_{ph1} and V_{ph2} may help us to understand the nature of supersonic wave-motion from Z_1 to Z_2 in **R**, which can be determined provided the relations among V, V_{ph2}, C_{S2}, C_{S1} are known. To obtain such relationships, we notice that

$$\left(\frac{V}{V_{ph2}}\right)^2 = \left(\frac{V}{C_{S2}}\right)^2 \left(\frac{C_{S2}}{V_{ph2}}\right)^2 = \left(\frac{V}{C_{S2}}\right)^2 \left\{1-\left(\frac{W_2^2-\omega_g^2}{\omega_2^2}\right)\right\}$$

$\left[\because, \left(\frac{C_{S2}}{V_{ph2}}\right)^2 = 1-\left(\frac{W_2^2-\omega_g^2}{\omega_2^2}\right)\right.$ obtained from the expression of phase velocity of sinusoidal waves in (C-3) by using $W_2^2 > \omega_g^2$ for supersonic waves having frequency ω_2 at $Z = Z_2\left.\right]$

Now, V could be $\gtreqless V_{ph2}$

$$\text{if} \quad \left(\frac{V}{C_{S2}}\right)^2 \left\{1-\left(\frac{W_2^2-\omega_g^2}{\omega_2^2}\right)\right\} \gtreqless 1$$

$$\text{i.e., if} \quad \omega_2^2 \gtreqless \frac{W_2^2-\omega_g^2}{1-\left(\frac{C_{S2}}{V}\right)^2}$$

($\because$, $\omega^2 > W^2 - \omega_g^2 > 0$. So far as the wave-motion is supersonic, therefore the quantity $1-\left(\frac{C_{S2}}{V}\right)^2$ must be a positive quantity).

Hence, so far as the supersonic wave-motion is concerned in **R** we notice that

$$V \gtreqless V_{ph2} \text{ provided } \omega_2^2 \gtreqless \frac{W_2^2-\omega_g^2}{1-\left(\frac{C_{S2}}{V}\right)^2} \quad \text{(C-12)}$$

$$\text{and } 1-\left(\frac{C_{S2}}{V}\right)^2 > 0 \text{ i.e., } C_{S2} < V \quad \text{(C-12.1)}$$

Further, from (C-11.6) we have

$$\frac{V}{C_{S2}} < \frac{T_{O1}}{T_{O2}} - 1 = \frac{\Delta T_O}{T_{O2}} \quad \text{(C-12.2)}$$

where $\Delta T_O = T_{O1} - T_{O2}$.

Here, both (C-12.1) and (C-12.2) may hold simultaneously provided $T_{O1} - T_{O2} = \Delta T_O > T_{O2}$

i.e., $T_{O1} / T_{O2} > 2$ (C-12.3)

Case 1 : When $T_{O1} / T_{O2} > 2$, and $\omega_2^2 \geq \dfrac{W_2^2 - \omega_g^2}{1 - \left(\dfrac{C_{S2}}{V}\right)^2}$:

In this situation, we get from (C-12) that

$$V_{ph2} \leq V \text{ when } \omega_2^2 \geq \frac{W_2^2 - \omega_g^2}{1 - \left(\frac{C_{S2}}{V}\right)^2} .$$

Using this condition along with (C-11.1) and (C-11.3), we get

$$C_{S2} < V_{ph2} \leq V < C_{S1} < V_{ph1} \tag{C-12.4}$$

Case 2 : When $T_{O1} / T_{O2} > 2$, and $\omega_2^2 < \dfrac{W_2^2 - \omega_g^2}{1 - \left(\dfrac{C_{S2}}{V}\right)^2}$:

In this situation, we get from (C-12) that

$$V < V_{ph2} \text{ for } \omega_2^2 < \frac{W_2^2 - \omega_g^2}{1 - \left(\frac{C_{S2}}{V}\right)^2} .$$

Evidently, $$\frac{V}{C_{S1}} < \frac{V_{ph2}}{C_{S1}} \tag{C-12.5}$$

From (C-11.1), we have the following

$$\frac{V}{C_{S1}} < 1 - \frac{T_{O2}}{T_{O1}} < 1.$$

Both (C-11.1) and (C-12.5) may hold simultaneously provided

$$\frac{V_{ph2}}{C_{S1}} \leq 1 \text{ i.e., } V_{ph2} \leq C_{S1} \tag{C-12.6}$$

Now, we get the following [by using (C-11.3), (C-12), (C-12.1), (C-12.6)] :

$$C_{S2} < V < V_{ph2} \leq C_{S1} < V_{ph1} \tag{C-12.7}$$

Case 3 : When $T_{O1} / T_{O2} > 2$ and $(C_{S2} / V)^2 \ll 1$:

In the situation where C_{S2} / V (<1) is such a small quantity that $(C_{S2} / V)^2 \ll 1$ and can be taken as ≈ 0, then we get the following from (C-12) :

$$\frac{W_2^2 - \omega_g^2}{1 - \left(\frac{C_{S2}}{V}\right)^2} \approx W^2{}_2 - \omega_g^2,$$

and hence (C-12) can be written as

$$V \gtreqless V_{ph2} \text{ provided } \omega_2^2 \gtreqless W_2^2 - \omega_g^2 \tag{C-12.8}$$

Now, so far as the supersonic wave-motion in **R** is concerned we notice that ω_2^2cannot be $\leq W_2^2 - \omega_g^2$ [since $\omega_2^2 \leq W_2^2 - \omega_g^2$ cannot occur at Z_2 as the condition (C-10) holds at Z_2 in **R**] which, in turn, removes the possibility of $V \leq V_{ph2}$ as shown in (C-12.8) in this case.

Thus, for $(C_{S2} / V)^2$ [$\ll 1$] being a negligible quantity in comparison to unity, we shall get the following only as

$$V_{ph2} < V$$

$$\text{where } \omega_2^2 > W_2^2 - \omega_g^2 \tag{C-12.9}$$

Therefore, we get the following [by using (C-11.1), (C-11.3) & (C-12.9)] :

$$C_{S2} < V_{ph2} < V < C_{S1} < V_{ph1} \tag{C-12.10}$$

Observations : (1) From all the cases 1, 2 and 3 it follows that the supersonic wave-motion takes place from Z_1 to Z_2 in **R** only when $T_{O1} / T_{O2} > 2$ which, in turn, gives $C_{S2} < V$ i.e., $C_{S2} < 2\gamma L\omega_g$. (2) From all the cases 1, 2 and 3 we see that $V_{ph2} < V_{ph1}$ i.e., in **R** the supersonic wave-motion will behave like a decelerative wave-motion in the direction of decreasing temperature from Z_1 to Z_2. This is an important feature of supersonic wave-motion in **R**.

3.1.2 Features of Subsonic Wave-Flow

Let us first find out the necessary condition for the wave-motion in R to be always subsonic.

Using (C-9), we get from (C-4)

$$W_1^2 < W_2^2 < \omega_g^2$$

which can be written as

$$(T_{O1} - T_{O2}) / L < 2\gamma\omega_g (T_{O2} / C_{S2}) < 2\gamma\omega_g (T_{O1} / C_{S1}) \tag{C-13}$$

where $\partial T_O / \partial Z \simeq (T_{O1} - T_{O2}) / L$.

From (C-13), we get

$$\frac{T_{O1}}{T_{O2}} - 1 < \frac{V}{C_{S2}} < \frac{V}{C_{S1}} \left(\frac{T_{O1}}{T_{O2}}\right) \tag{C-13.1}$$

where $V = 2\gamma L\omega_g$.

Thus, when necessary condition (C-13) holds in **R**, then wave-motion from Z_1 to Z_2 in **R** will be subsonic.

Now, under this situation we consider that a subsonic wave-motion takes place from Z_1 to Z_2 having V_{ph1} and V_{ph2} as the magnitudes of phase velocities at $Z = Z_1$ and $Z = Z_2$ respectively.

Evidently, we get

$$V_{ph1} < C_{S1} \text{ and } V_{ph2} < C_{S2} \tag{C-13.2}$$

From (C-13.1) and (C-13.2), we get

$$\frac{T_{O1}}{T_{O2}} - 1 < \frac{V}{C_{S2}} < \frac{V}{C_{ph2}} \tag{C-13.3}$$

Here, we notice that

$$\left(\frac{V}{V_{ph2}}\right)^2 = \left(\frac{V}{C_{S2}}\right)^2 \left(\frac{C_{S2}}{V_{ph2}}\right)^2 = \left(\frac{V}{C_{S2}}\right)^2 \left\{1 + \frac{\omega_g^2 - W_2^2}{\omega_2^2}\right\}$$

[$\because$, $\left(\frac{C_{S2}}{V_{ph2}}\right)^2 = \left\{1 + \frac{\omega_g^2 - W_2^2}{\omega_2^2}\right\}$ obtained from the expression of phase velocity of sinusoidal waves in (C-3) by using $\omega_g^2 > W_2^2$ for the subsonic waves having frequency ω_2 at $Z = Z_2$ in **R**

Now, V could be $\gtreqless V_{ph2}$

$$\text{if} \quad \left(\frac{V}{C_{S2}}\right)^2 \left\{1 + \frac{\omega_g^2 - W_2^2}{\omega_2^2}\right\} \begin{matrix} > \\ = \\ < \end{matrix} 1$$

$$\text{i.e., if } \omega_2^2 \begin{matrix} < \\ = \\ > \end{matrix} \frac{\omega_g^2 - W_2^2}{\left(\frac{C_{S2}}{V}\right)^2 - 1}$$

[$\because$, $\omega_g^2 - W_2^2 > 0$ so far as the wave motion is subsonic, therefore $\left(\frac{C_{S2}}{V}\right)^2 - 1$ must be a positive quantity.]

Therefore, so far as the subsonic wave motion is concerned at $Z = Z_2$ in **R**, we notice that

$$V \gtreqless V_{ph2} \text{ provided } \omega_2^2 \lesseqgtr \frac{\omega_g^2 - W_2^2}{\left(\frac{C_{S2}}{V}\right)^2 - 1} \tag{C-14}$$

along with the condition

$$\left(\frac{C_{S2}}{V}\right)^2 - 1 > 0 \text{ i.e., } V < C_{S2} \quad \text{(C-14.1)}$$

Further, from (C-13.3) we have

$$\frac{V}{C_{S2}} > \frac{T_{O1}}{T_{O2}} - 1 = \frac{\Delta T_O}{T_{O2}} \quad \text{(C-14.2)}$$

where $\Delta T_O = T_{O1} - T_{O2}$.

Here, (C-14.1) and (C-14.2) may hold simultaneously provided

$$T_{O1} - T_{O2} = \Delta T_O < T_{O2} \text{ i.e., } T_{O1} / T_{O2} < 2 \quad \text{(C-14.3)}$$

Further, using (C-7) and (C-14.1), we get

$$V < C_{S2} < C_{S1} \quad \text{(C-14.4)}$$

Again, at $Z=Z_1$ we notice that [using (C-13.2) & (C-14.4)]

$$V < C_{S2} < C_{S1} > V_{ph1} \quad \text{(C-14.5)}$$

which indicates that V_{ph2} may be $\gtreqless$ C_{S2}.

Now, we get

$$\left(\frac{C_{S2}}{V_{Ph1}}\right)^2 = \left(\frac{C_{S2}}{C_{S1}}\right)^2 \left(\frac{C_{S1}}{V_{ph1}}\right)^2 = \left(\frac{C_{S2}}{C_{S1}}\right)^2 \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\}$$

$[\because, \left(\frac{C_{S1}}{V_{ph1}}\right)^2 = \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\}$ obtained from the expression of phase velocity of sinusoidal waves in (C-3) by using $\omega_g^2 > W_1^2$ for the subsonic waves having frequency ω_1 at $Z = Z_1$ in **R**].

Here, C_{S2} could be $\gtreqless V_{ph1}$

if $\left(\frac{C_{S2}}{C_{S1}}\right)^2 \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\} \gtreqless$.

i.e., if $\omega_1^2 \gtreqless \dfrac{\omega_g^2 - W_1^2}{\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1}$

$[\because, 0 < \left(\dfrac{C_{S1}}{C_{S2}}\right)^2 = \dfrac{T_{O1}}{T_{O2}} < 2$ obtained form (C-14.3) and since

$1 < T_{O1}/T_{O2} < 2$, therefore, $0 < \left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1 < 1]$.

Therefore, so far as the subsonic wave-motion is concerned at $Z = Z_1$ in **R**, we notice that

$$V_{ph1} \gtreqless C_{S2} \text{ provided } \omega_1^2 \gtreqless \frac{\omega_g^2 - W_1^2}{\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1} \quad \text{(C-15)}$$

$$\text{where } \frac{\omega_g^2 - W_1^2}{\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1} > \omega_g^2 - W_1^2 \quad \text{(C-15.1)}$$

Case-1 : When $T_{O1}/T_{O2} < 2$, $\omega_2^2 \gtreqless \dfrac{\omega_g^2 - W_2^2}{\left(\dfrac{C_{S2}}{V}\right)^2 - 1}$ and $\omega_1^2 \geq \dfrac{\omega_g^2 - W_1^2}{\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1}$

In this situation, we get from (C-14) that

$$V_{ph2} \gtreqless V \text{ provided } \omega_2^2 \gtreqless \frac{\omega_g^2 - W_2^2}{\left(\dfrac{C_{S2}}{V}\right)^2 - 1}$$

Again, we get from (C-15) that

$$C_{S2} \leq V_{ph1} \text{ provided } \omega_1^2 \geq \frac{\omega_g^2 - W_1^2}{\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 - 1}$$

Therefore, using these and (C-13.2) & (C-14.1) we get the following as :

$$V < V_{ph2} < C_{S2} \leq V_{ph1} < C_{S1} \text{ and } V_{ph2} \leq V < C_{S2} \leq V_{ph1} < C_{S1}$$

which, in turn, indicate

$$V_{ph2} < V_{ph1} \quad \text{(C-15.2)}$$

Case-2 : When $T_{O1}/T_{O2} < 2$, $\omega_2^2 \begin{matrix} > \\ = \\ < \end{matrix} \dfrac{\omega_g^2 - W_2^2}{\left(\frac{C_{S2}}{V}\right)^2 - 1}$ and $\omega_1^2 < \dfrac{\omega_g^2 - W_1^2}{\left(\frac{C_{S1}}{C_{S2}}\right)^2 - 1}$

In this situation we first notice that the condition

$$\omega_1^2 < \frac{\omega_g^2 - W_1^2}{\left(\frac{C_{S1}}{C_{S2}}\right)^2 - 1} \text{ implies that} \left(\frac{C_{S1}}{C_{S2}}\right)^2 < 1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2} \qquad \text{(C-15.3)}$$

But from (C-14.3) we have $\left(\dfrac{C_{S1}}{C_{S2}}\right)^2 = \dfrac{T_{O1}}{T_{O2}} < 2$

Now, these two may hold simultaneously provided

$$1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2} \leq 2 \qquad \text{i.e., } \omega_g^2 - W_1^2 \leq \omega_1^2$$

Hence, from above we get the following :

$$\omega_g^2 - W_1^2 \leq \omega_1^2 < \frac{\omega_g^2 - W_1^2}{\left(\frac{C_{S1}}{C_{S2}}\right)^2 - 1} \qquad \text{(C-15.4)}$$

Next, we see that $V < C_{S2}$ and $V_{ph1} < C_{S2}$ [as it follows from (C-15)].

Hence, we get

$$\left[\frac{V_{ph1}}{V}\right]^2 = \left[\frac{V_{ph1}}{C_{S1}}\right]^2 \left[\frac{C_{S1}}{C_{S2}}\right]^2 \left[\frac{C_{S2}}{V}\right]^2$$

i.e., $$\left[\frac{V_{ph1}}{V}\right]^2 < \left[\frac{C_{S1}}{C_{S2}}\right]^2 \left[\frac{C_{S2}}{V}\right]^2 \qquad \text{[using (C-13.2)]}$$

i.e., $$\left[\frac{V_{ph1}}{V}\right]^2 < \left[\frac{C_{S2}}{V}\right]^2 \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\} \qquad \text{[using (C-15.3)]}$$

$\therefore$, $$\left(\frac{C_{S2}}{V}\right)^2 \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\} > \left(\frac{V_{ph1}}{V}\right)^2 \qquad \text{[using (C-15.5)]}$$

$\because$, $C_{S2} > V$ and $1 + \dfrac{\omega_g^2 - W_1^2}{\omega_1^2} > 1$ so far as the subsonic wave-motion

is concerned, therefore, we must have always the following :

$$\left(\frac{C_{S2}}{V}\right)^2 \left\{1 + \frac{\omega_g^2 - W_1^2}{\omega_1^2}\right\} > 1 \tag{C-15.6}$$

Now, the conditions (C-15.5) and (C-15.6) may hold simultaneously in **R** provided

$$\left(\frac{V_{ph1}}{V}\right)^2 \geq 1 \quad \text{i.e., } V \leq V_{ph1}$$

Thus, from (C-13.2), (C-14.1) and $V \leq V_{Ph1}$, we get

$$V \leq V_{ph1} < C_{S2} \tag{C-15.7}$$

Further, from (C-14) we have the following two conditions :

$$V_{ph2} < V \text{ when } \omega_2^2 < \frac{\omega_g^2 - W_2^2}{\left(\dfrac{C_{S2}}{V}\right)^2 - 1} \tag{C-15.8}$$

$$\text{and } V \leq V_{ph2} \text{ when } \omega_2^2 \geq \frac{\omega_g^2 - W_2^2}{\left(\dfrac{C_{S2}}{V}\right)^2 - 1} \tag{C-15.9}$$

Case-2(a) : When $V_{ph2} < V$ and $V \leq V_{ph1} < C_{S2}$:

In this situation we get the following

$$V_{ph2} < V \leq V_{ph1} < C_{S2} < C_{S1} \tag{C-15.10}$$

[as $C_{S2} < C_{S1}$ in **R** ; vide condition (C-7)] corresponding to wave- frequencies ω1 and ω_2 satisfy (C-15.4) and (C-15.8) respectively

Now, (C-15.10) gives

$$V_{ph2} < V_{ph1} \tag{C-15.11}$$

Case-2(a) : When $V \leq V_{ph2}$ and $V \leq V_{ph1} < C_{S2}$:

In this situation, by using (C-7) and (C-13.2), we get the following

$$V \leq V_{ph2} < C_{S2} < C_{S1}$$

and (C-15.12)

$$V \leq V_{ph1} < C_{S2} < C_{S1}$$

provided the frequencies of the waves ω_1 at $Z = Z_1$ and ω_2 at $Z = Z_2$ satisfy (C-15.4) and (C-15.9) respectively.

From (C-15.12) we see that the subsonic wave-motion could be either an accelerative or a decelerative motion, or could be a constant flow.

Observations : (1) From all the cases 1 and 2 it is clear that the subsonic wave-motion takes place from Z_1 to Z_2 in **R** only when $T_{01}/T_{02} < 2$ which, in turn, gives $C_{S2} > V$ i.e., $C_{S2} > 2\gamma L\omega_g$. (2) From the cases 1 and 2(a) we see that $V_{ph2} < V_{ph1}$ i.e., in **R** the subsonic wave-motion in the direction of decreasing temperature from Z_1 to Z_2 will behave like a decelerative wave motion. But in the Case-2(b) the subsonic wave-motion could be either an accelerative or a decelerative motion, or could be a constant flow in the direction of decreasing temperature from Z_1 to Z_2.

4. How is the central region of Active Galaxies like NGC 4151 ?

Central Region (C.R.) of Active Galaxies is a bed of hot plasma.

The galaxy NGC 4151 is of Seyfert type (Seyfert, 1943) and the active nucleus of it is a prominent member of AGN families (vide Clavel et al. 1987). In the central 1-parsec of it a decelerated outflow (velocity of which drops from 4000 kms^{-1} at 5 lt-day to 800 kms^{-1} at 1 lt-yr) of ionised gas has been observed to emanate from BLR (vide Clavel et al. 1987).

However, with a view to explain the activities like mass-outflow we shall make an attempt to estimate in the following numerically the magnitude of some basic parameters characterising AGN like NGC 4151 depending on the available data [see also paper-I].

(i) **Composition :** We can safely consider the medium in the region concerned as mainly consisting of hydrogen gas and abundance of elements in the medium as solar [vide Ferland & Mushotzky 1982].

(ii) **Density :** Recent reviews on AGNs (vide e.g., Krolik et al. 1981; Osterbrock & Mathews 1987; Netzer 1990; Osterbrock 1991; Roos 1992 etc.) suggest that in BLR and NLR the cool ($T \approx 10^4$ K) gas clouds are confined by a hot, low density ambient gas medium. The ambient medium occupies over 99% of central 1-parsec or so (leaving aside any molecular tori).

Within Central 1-parsec of NGC 4151 the number density of electrons in the clouds of the region (5 lt-day $\lesssim r \lesssim$ 1 lt-yr) increases by a factor 10000 from 1 lt-yr to 5 lt-day and it could be $\gtrsim 10^{11}$ cm^{-3} at radius ~ 5 lt-day (vide clavel et al. 1987). If these clouds are confined by hot ambient gas medium, then the implication of the above run of density of clouds, as suggested by Clavel et al. (1987), is that the temperature of hot ambient medium increases faster than virial temperature within C.R. (5 lt-day $\lesssim r \lesssim$ 1 lt-yr). This, in turn, indicates that a negative gradient of temperature is present and presumably it would be sufficiently energetic in hot ambient medium along outward direction in C.R. Now, when the gas clouds are in pressure equilibrium with hot ambient medium, then we must have

$$N_e T_e \approx N_c T_c$$

where N_c & T_c denote the electron density and temperature of clouds respectively. While N_e & T_e denote electron density and temperature of the ambient medium. At radius ~ 5 lt-day in C.R., we have $N_c \gtrsim 10^{11}$ cm^{-3}, $T_c \sim 10^4$ K (vide Clavel et al. 1987) and $T_e \sim 10^8$ K [vide Krolik et al. 1981; Shields 1986 etc. and discussions in (iii) in this section] which, in turn, give $N_e \gtrsim 10^{7.5}$ cm^{-3}. Again, at radius ~ 1 lt-yr, we have $N_c \gtrsim 10^7$ cm^{-3}, $T_c \sim 10^4$ K (vide Clavel et al. 1987) and $T_e \sim 10^6$ K [vide Perola et al. 1986 and discussions in (iii) in this section] which give $N_e \gtrsim 10^5$ cm^{-3}. These indicate that the ambient density (N_e) varies much slowly than the internal density of the clouds in C.R. of NGC 4151.

We, in this paper, assume that the ambient medium has a density $N_e \approx 10^{7.5}$ cm^{-3} at the inner C.R./BLR of NGC 4151. This density, however, much lower than the internal density of clouds ($N_c \gtrsim 10^{11}$ cm^{-3}) at the inner region of C.R. and also 2 order of magnitude lower than the canonical density $\approx 10^{9.5}$ cm^{-3} of BLR clouds in AGNs (vide Clavel et al. 1987).

We assume ambient density $N_e \approx 10^{7.5}$ cm^{-3} as same throughout the C.R. of NGC 4151.

The assumption of uniformity of density is definitely an idealisation. This will, however, make the mathematics to be used simpler and should be treated one step forward for the more generalisation.

However, while studying the BLR one must note the following :

1) BLR is a small shell like region sandwitched between nucleus and large NLR, whereas there is continuous inflow of matter and energy from the nucleus to the BLR (vide e.g., Netzer 1990 etc.),

2) There are observations indicating clouds while moving from inner surface to outer surface looses material and takes spherical shape (vide e.g., Netzer 1990 etc.),

3) There is a possibility of magnetic inhibition (i.e., attempt to confine).

Noting these informations, and noting that the many observations are yet to be confirmed, the BLR is taken to be uniform, at least for the sake of first approximated results.

Now under this assumption the uniform volume density (ρ_0) of the hot ambient medium in C.R. may be taken as of the order of the product of mean mass per proton of hydrogen and number density (N_e) $\approx 5.3 \times 10^{-17}$ gcm^{-3}.

(iii) Temperature : From the observations the hot gas temperature at radius ~1 lt-yr in C.R. of NGC 4151 may be ~ 10^6 K (vide Perola et al. 1986).

Now, as per suggestion of Krolik et al. (1981), the temperature of hot gas could be $\gtrsim 10^8$ K in BLR of AGNs. While it is suggested by Shields (1986) that the gas temperature could be $\sim 10^8$ K at the radii, very close to the centre of AGNs, where gases are driven out with velocity $\gtrsim 10^{3.5}$ kms^{-1}. Whereas approximately same magnitude of outflow velocity has been reported at the radius ~ 5 lt-day in the C.R. of NGC 4151 (vide clavel et al. 1987). So, for the purpose of approximate numerical estimation let us take the hot gas temperature $\sim 10^8$ K at the radius ~ 5 lt-day.

The discussions made above and in 2nd para in (ii) in this section it reveals that a negative temperature gradient of magnitude $\sim 10^8$ K/lt-yr is present throughout the hot ambient medium along outward direction within C.R..

(iv) Gas characteristics within C.R. (5 lt-day $\lesssim$ r $\lesssim$ lt-yr) of NGC 4151 :

(a) Fully ionised : Following the discussions made in (ii) and (iii) above we see that the medium in C.R. from 5 lt-day to 1 lt-yr in NGC 4151 have temp. $\sim 10^8$ K to temp $\sim 10^6$ K, uniform density of ambient medium (n_e) – $10^{7.5}$ cm^{-3}. Therefore, it can be regarded as a fully ionised hydrogen gas (vide Woltjer 1965). Also, for fully ionised gas, the ratio of specific heats (γ) can be taken as 5/3 (vide Woltjer 1965).

(b) Non-relativistic and non-degenerate : In an ionised gas when an electron with an average energy kT moves with relativistic speed ($C=3\times10^{10}$ cms^{-1}), then $T = m_e C^2 k^{-1} \approx 5.9\times10^9$ K, T and m_e being temp & mass of an electron and k is the Boltzmann constant (vide Uberoi 1988). The corresponding number density (n_e) for which quantum degeneracy occurs is given by (Uberoi 1988).

$$n_e = (2k\, m_e)^{3/2}\,(3\pi^2\hbar^3)^{-1}\, T^{3/2}$$

$$\approx 1.7 \times 10^{30}\ \text{cm}^{-3} \text{ if } T \approx 5.9 \times 10^9\ \text{K}$$

where $\hbar = h/2\pi$ and h is the Planck's constant.

Now, from Table 1 it is clear that in C.R. the gas temperature and uniform number density of the charged particles are both lying below the limit of relativistic temperature and the limit of the quantum degeneracy respectively.

Thus, the ionised gas medium in the C.R. may be treated as a non-relativistic and non-degenerated gas medium.

(c) Self-Gravitation : Volume of the C.R. = $(4\pi/3)[(1\text{ lt-yr})^3 - (5\text{ lt-day})^3] \approx 3.6 \times 10^{54}$ cm^3

Therefore, mass of the ambient medium = (Volume of the C.R.) × (uniform density of the ambient medium) $\approx 1.9 \times 10^{38}$ g $\approx 10^5\ M_\odot$. Thus, due to this mass $\approx 10^5\ M_\odot$ the ambient (and ionised) medium in C.R. is treated as a self-gravitating medium.

Table 1. Physical parameters in the gas in the central region of NGC 4151.

Medium	T ($\times 10^6$ K)	n_e (cm^{-3})	λ_D† (cm)	N_D† ($\times 10^8$electrons)	Λ† ($\times 10^8$)	λ_m† ($\times 10^8$cm)	η† ($\times 10^{-5}$ohm-cm)
At radius ~5 lt-day	100*	$10^{7.5}$***	12.3	2.45×10^3	7.35×10^3	9×10^4	0.02
At radius ~1 lt-yr	1**		1.23	2.45	7.35	9.0	15.0

* Krolik et al. (1981) ** Perola et al. (1986) *** Clavel et al. (1987) † Uberoi (1988)

(v) Plasma characteristics : For fully ionised gases the Debye length is given by $\lambda_D = 6.9 \times (T/n_e)^{1/2}$ where n_e is the electron density and T is the kinetic temp. in degrees Kelvin (vide e.g., Spitzer, Jr. 1956; Chen 1974; Uberoi 1988 etc.). From the Table 1, in C.R. we find $\lambda_D \ll L$, L being the linear dimension of the region i.e., the distance from 5 lt-day to 1 lt-yr. Further, the number of electrons in this Debye sphere (N_D) of radius λ_D comes out to be much greater than unity i.e., $N_D \gg 1$ (vide Table 1)

Now, since $\lambda_D \ll L$ and $N_D \gg 1$, therefore the ionised gas medium in C.R. may be treated as plasma (vide Parks 1991). In that region no electric field occurs beyond the distance λ_D and the concentration of the oppositely-charged particles beyond the distance $\gg \lambda_D$ are almost equal i.e., the plasma is quasi-neutral. Further, since the "plasma parameter" g [$= N_D^{-1}$] $\approx$ 0 (vide Table 1), the binary collisions could be rare and consequently it may be treated as a collisionless plasma. Furthermore, g is also a measure of the ratio of the interparticle potential energy to the mean kinetic energy of the plasma particle. Hence, $g \ll 1$ implies that interparticle forces could be neglected and the said plasma is almost like an ideal gas (vide e.g., Chen 1974; Uberoi 1988; Parks 1991 etc.).

(vi) Fluid characteristics : It is well known that the fluid (or hydrodynamic) behaviour of an ionised gas medium requires the mean free path (λ_m) of the charged particles to be less than L, the linear dimension of the medium (vide Woltjer 1965). Now, $\lambda_m = \lambda_D \times \Lambda$, Λ being the Coulomb logarithmic parameter with $\Lambda = 3N_D$ (vide Uberoi 1988).

From Table 1, we find that corresponding to temperature and number density at radii 5 lt-day and 1 lt-yr the mean free paths have been found to be much less than the linear dimension of the ionised gas medium considered i.e., $\lambda_m \ll L$. Hence, the hydrodynamic description for the medium in the region considered may be taken as more or less justified. That is to say that the medium in C.R. may be treated as a continuous media or a fluid.

Further, the ionised gas medium in C.R. can be treated as a fully ionised hydrogen plasma (vide sects. 4(iv)/a & 4(v)). We have seen that this plasma is quasineutral (vide sect. 4(v)) which implies that in the macroscopic motion of this plasma, the electrons and protons are constrained to move without separating appreciably (vide Uberoi 1988). The electrical conductivity (σ) of this fully ionised and macroscopically neutral plasma can be obtained from $\sigma = [(kT)^{3/2}]/[4\pi m_e^{1/2} e^2 \ln\Lambda]$, e being the charge of an electron (vide uberoi 1988).

From Table 1, the values of the resistivity η [$= \sigma^{-1}$] appear to be less than that of copper [$\eta \simeq 2 \times 10^{-6}$ Ohm-cm] and comparable to Mercury [$\eta \simeq 10^{-4}$ Ohm-cm] at the radii 5 lt-day and 1 lt-yr respectively. Therefore, we see that η is very small in the plasma medium in C.R. and so the macroscopic motion will be remarkably independent of υ/ω_{ce}, the ratio of collisional frequency (ν) to the electron cyclotron frequency (ω_{ce}) (vide Spitzer Jr. 1956) i.e., low frequency phenomena, which are related mainly to heavier particles (ions or neutral particles) of the plasma, become more dominant. Thus, the plasma medium in C.R. of the active galaxy NGC 4151 may be treated as a single fluid plasma in C.R., while though it behaves macroscopically as a neutral gas, is a highly electrically conducting medium where $\sigma = \propto$ as $\eta \approx 0$.

(vii) Magnetic fields : From radio observations Osterbrock and Mathews (1986) suggested that the magnetic forces may quite possibly be an important factor in determining the structures and velocities observed in AGNs. Rees (1987) suggested the existence of magnetic field of strength - 1G in the environment of the line-emitting clouds of BLR in AGN. Sofue (1990) also suggested the ejection features perpendicular to the disc plane and/or central radio sources may be the manifestation of a vertical magnetic field running across the nuclei of spirals. Woltjer (1965, 1971, 1990) always stressed the need of taking into account the effect of a magnetic field on the activities in the regions like spiral arms, nuclear regions of galaxies etc., particularly in the case of ejection phenomena. The evidences for the existence of a poloidal magnetic field in the nuclei of galaxies including our Galaxy have been reported by many astronomers (e.g., Wielebinski 1990; Morris 1990 etc.). Osterbrock (1991) suggested that most probably magnetic fields are prevalent in AGNs, especially in the BLRs close to their centers and they viz., magnetic fields, may have an important effect on the velocity field. Thus, it appears that the magnetic field (particularly poloidal type) may have some important role on the activities of the central region of Active Galaxies like NGC 4151.

Further, since the length scale of the medium in C.R. is very large (i.e., L at the order of 10^{18} cm) the dissipative phenomena associated with magnetic field, kinematic viscosity and heat conduction, are not significant (vide Woltjer 1965). In this situation a magnetic field will be frozen in the single-fluid plasma and will be carried by the plasma. The description of this medium requires a single-fluid MHD equation (vide e.g., Woltjer 1965; Chen 1974; Parks 1991 etc.).

5. Mass-outflow in the Central Region (C.R.) of NGC 4151

As mentioned earlier in section 4, a strong decelerative outflow of ionised gas has been observed in the C.R. of NGC 4151. While many researchers (e.g. Clavel et al. 1987) have tried to show that radiation pressure cannot be the cause of this outflow, some others (e.g., Ferland and Mushotzky 1982) maintained the opposite view. There are some others also who held the opinion that the wave-instability as "one of the most responsible elements" for this type of mass-flow (e.g., Woltjer 1965, 1971; Bondyopadhaya 1972, 1976; Osterbrock & Mathews 1986; Blandford 1990 etc.). In this paper we shall follow the path of wave-instability to see the phenomenon of mass-outflow from C.R. of NGC 4151.

In the theory of wave-instability (as discussed in sect.3) we have seen that the gradient of temperature could be a cause of instability of longitudinal waves (i.e., material waves) and hence of mass-flow in a typical MHD medium. In fact, the negative temperature gradient makes sinusoidally unstable longitudinal waves amplified along the direction of decreasing temperature. The energy absorbed by the wave-amplification actually amounts to an increase of the kinetic energy of the fluid flow.

Let us now divide our task into two parts : (I) To compare and see whether C.R. of NGC 4151 has a medium roughly similar to the typical medium considered in the discussion in sect. 2, and (II) Whether the numerical values of the different basic parameters required for the said instability are consistent with the observation.

Part-I : This part has already been discussed in sect. 4 where it has been seen that the medium in C.R. of NGC 4151 (and possibly many other AGNs) can approximately behave as a single-fluid, infinitely conducting, self-gravitating, non-relativistic (in the sense of STR viz., Special Theory of Relativity) and non-degenerate hydromagnetic medium having temperature gradient and heat energy transport. This medium is also assumed to be non-relativistic in the sense of General Theory of Relativity.

It is suggested that in C.R. the observed outward gas flow (mentioned in sect. 4) possibly occurs above and below the Accretion Disc (vide e.g., Clavel et al. 1987), in the direction perpendicular to the Accretion Disc (vide Sofue 1990). The Kinematic models which suggest outward radial flow from BLR of AGNs as mainly along the axes perpendicular to the plane of rotation through a conical region (vide Osterbrock and Mathews 1996) are in good agreement with the observations. Thus, plasma outflow from the center/and BLR in AGNs or in particular from the C.R. of NGC 4151 can be considered to be conical or axial i.e., with reference to Rectangular Cartesian Co-ordinate system the direction of this outflow in C.R. can be taken as the Z- direction (used in the discussion in sect. 2).

On the basis of the discussions made in sect. 4 (vii) the basic magnetic field (H_{oz}) can be taken as poloidal and nearly along the direction of mass-outflow in C.R. i.e., along Z-direction. Further, it should be practicable to take the gradient of this basic field only along Z-direction i.e., $\partial H_{0z}/\partial Z \neq 0$ (as observations suggest the presence of a gradient of physical conditions across the BLR of NGC 4151 (vide Clavel et al. 1987)).

It follows from the discussions made in sect. 4 (iii) that a gradient of basic temperature ($\partial T_0/\partial Z \neq 0$ as used in sect. 2) is present in the medium of C.R. only along the direction of outflow and hence along Z-direction [as follows from previous para], and it decreases along outward Z-direction in C.R. i.e., $\partial T_0/\partial Z < 0$ there.

Following the discussions made in last para in sect. 4 (vii) we take the coefficient of heat conductivity (χ) as nearly zero because the dissipative effect due to it becomes negligible in C.R. as the C.R. has a large linear size(L) ~ 10^{18} cm.

Perhaps the assumption of homogeneity of BLR does not correspond very well to the reality, especially given the present data, but we believe it is helpful to have an approximate scenario. Nevertheless, the discussions regarding density and temperature of the ambient medium in C.R. of NGC 4151 made in sect. 4 should be kept in mind.

In this paper we take the density $(n_e) \sim 10^{7.5}\ cm^{-3}$ of the ambient gas medium as uniform in C.R. of NGC 4151. Further, we assume the steadiness of basic temp. viz., $\partial T_O/\partial t = 0$ [as used in sect. 2] in C.R. of NGC 4151. Thus, it is seen that the medium in C.R. of NGC 4151 is roughly similar to the typical medium considered in sect. 2.

Part-II : In this part we shall first estimate the numerical values of the basic parameters and thereafter find the values of the same which are consistent with the observations.

Table 2. Numerical estimation of the values of the basic parameters in the Central Region of NGC 4151.

Regional at Z_1=5 lt-day				Region at Z_2=1 lt-yr				Central Region (5 lt-day $\lesssim r \lesssim$ 1 lt-yr)		Region at Z_1=5 lt-day	Region Z_2=1 lt-yr
Temperature (T_{01}) $(\times 10^8$ K)	Sound Speed (C_{s1}) $(\times 10^8$ cms^{-1})	Critical Temp. Grad. $(\partial T_0/\partial Z]_{C1})$ $(\times 10^7$ K/lt-yr)	Observed Phase Velocity (V_{ph1}) $(\times 10^8$ cms^{-1})	Temperature (T_{02}) $(\times 10^6$ K)	Sound Speed (C_{s2}) $(\times 10^7$ cms^{-1})	Critical Temp. Grad. $(\partial T_0/\partial Z]_{C2})$ $(\times 10^7$ K/lt-yr)	Observed Phase Velocity (V_{ph2}) $(\times 10^7$ cms^{-1})	$\mid \partial T_0/\partial Z \mid \approx \frac{T_{01} - T_{02}}{Z_2 - Z_1}$ $(\times 10^7$ K/lt-yr)	Gravitational Frequency (ω_g) $(\times 10^{-12}$ S^{-1})	W_1* $(\times 10^{-11}$ S^{-1})	W_2* $(\times 10^{-11}$ S^{-1})
1	1.70	1.24						10.0		5.44	54.00
2	2.40	1.76						20.2		7.80	109.08
3	2.90	2.20						30.3		9.40	163.62
4	3.35	2.52						40.4		10.83	218.16
5	3.74	2.82	4.0	1.0	1.70	0.124	8.0	51.0	6.7	12.21	275.40
6	4.10	3.10						61.0		13.34	329.40
7	4.43	3.33						71.0		14.40	383.30
8	4.73	3.57						81.0		15.32	437.40
9	5.02	3.80						91.1		16.30	491.94

* $W_1 \approx \omega_{C1}$ and $W_2 \approx \omega_{C2}$.

(i) Numerical estimation for the values of the basic parameters : As mentioned earlier (vide sect. 4 and part-I) that along the outward Z-direction from the center the basic temperature (T_O) could be $\sim 10^8$ K [= T_{O1}, say] at 5 lt-day [= Z_1, say] and is $\sim 10^6$ K [= T_{O2}, say] at 1 lt-yr [= Z_2, say] in C.R. of NGC 4151. The basic density (ρ_O) is taken as $\approx 5.3\times10^{-17}$ g cm^{-3} (giving gravitational frequency $(\omega_g) \sim 6.7 \times 10^{-12}\ s^{-1}$) and the ratio of specific heats $(\gamma) \approx 5/3$ is assumed to be the same throughout the medium in C.R.

The above data implies that $\partial T_O/\partial Z < 0$ outwardly. The values of T_{O1} and T_{O2} are consistent with the non-relativistic temperature. i.e., $T_{O1}, T_{O2} < 5.9 \times 10^9$ K (vide sect. 4 (iv)/b).

Using these values of T_{O1}, T_{O2}, ρ_O and γ as mentioned above the corresponding numerical values of C_S, $[\partial T_O/\partial Z]_c$, W, ω_c (as per formula in sect. 3) at the distances Z_1 = 5 lt-day and Z_2 = 1 lt-yr have been calculated in Table-2. It is assumed, however, that the gradient of basic temperature is constant throughout C.R..

(ii) Numerical estimation of the values of basic parameters consistent and inconsistent with observations : During the discussions made in sect. 3 it has been found that temperature gradient could be a cause of longitudinal wave-flow (i.e., material-flow) and hence of mass-flow in a typical MHD medium. Further, we have seen that

(a) when $W > \omega_g$ holds due to $\partial T_0/\partial Z > \partial T_0/\partial Z_C$, then, in the direction of negative gradient of temperature in the medium, a supersonic wave-flow (i.e., supersonic mass-flow) occurs with a frequency ω such that $\omega^2 > \omega_C^2$ where $\omega_C^2 = W^2 - \omega_g^2 > 0$ and with a phase velocity $V_{ph} > C_S$, and

(b) when $W < \omega_g$ holds due to $\partial T_0/\partial Z < \partial T_0/\partial Z_C$, then in the direction of negative gradient of temperature in the medium a subsonic wave-flow (i.e., subsonic mass-flow) occurs with a frequency ω such that $\omega^2 > \omega_c^2$ where $\omega_c^2 = W^2 - \omega_g^2 < 0$ and with a phase velocity $V_{ph} < C_S$.

Now, from Table 2 we list up the numerical values of the basic parameters which are consistent and inconsistent with observation as shown in Table 3. From Table 3, we obtain that the numerical values of the basis parameters estimated for $T_{01} \sim (1\text{–}5) \times 10^8$ K at $Z_1 = 5$ lt-day and $T_{02} \sim 10^6$ K at $Z_2 = 1$ lt-yr along with uniform density $(\sigma_o) \approx 5.3\times10^{-17}$g cm^{-3} and constant $\gamma \approx 53$ are consistent with observation throughout the medium in C.R. having linear dimension (L) $\approx$ 360 lt-days ($\approx 9.33\times10^{17}$ cm) in NGC 4151. These values indicate the following :

(1) The temperature gradient obtained for $T_{01} \sim (1\text{–}5) \times 10^8$ K, $T_{02} \sim 10^6$ K and L = 360 lt-day exceeds the critical temperation gradient throughout the medium in C.R.,

(2) The mass-outflow takes place throughout the medium in C.R. at supersonic velocities which is also a feature of BLR of AGNs (vide e.g., Mathews & Ferland 1987; Clavel et al. 1987; Blandford 1990 etc.),

(3) At Z_1 = 5 lt-day in C.R. the temperature of hot gas ranges from 10^8 K to 5×10^8 K which makes a good agreement with the suggestion for hot gas temperature $\gtrsim 10^8$ K in BLR of AGNs [vide Krolik et al. 1981],

(4) In the presence of poloidal magnetic field the amplification of sinusoidally unstable longitudinal MHD waves due to a temperature gradient could be one of the triggering factors for mass-outflow in the Z-direction where $\partial T_0/\partial Z < 0$ in the C.R. of NGC 4151 (e.g., vide Fig 1). The reason being the fact that negative gradient of temperature is capable of amplifying the sinusoidally unstable longitudinal waves in the Z-direction. The energy absorbed by the wave-amplification actually amounts to increase of kinetic energy of fluid flow.

(5) The estimated numerical values of W_1, W_2, ω_g, ω_{c1}, ω_{c2} in Table-2 indicate that at Z_1=5 lt-day or at Z_2=1 lt-yr in C.R. the self-gravity of ambient plasma has practically no influence to reduce frequencies of longitudinal MHD waves.

Table 3. Consistency and inconsistency of the numerical values of the basic parameters with observation in the Central Region of NGC 4151

Region	Basic Temperature (T_o) (in K)	Relation between the Basic Parameters drawn from their Numerical values obtained in Table-2. W with ω_g	$\partial T_o/\partial Z$ with $\partial T_o/\partial Z]_c$	Types of flow as judged from theory by satisfying the Numerical values of the Basic Parameters obtained in Table-2.	Numerical value of C_s as obtained in Table-2 (in km s^{-1})	Observed value of Vph (in km s^{-1})	Relation between C_s and Vph drawn from the observation and corresponding type of flow.	Remark (regarding the consistency or inconsistency of the basic parameters with observation)
at Z_1=5lt-day	$T_{01}=(1\text{-}5)\times 10^8$	$W>\omega_g$	$\partial T_o/\partial Z>\partial T_o/\partial Z]_c$	Supersonic	1700-3740	4000	$C_s<V_{ph}$ Supersonic	Consistent
	$T_{01}=(6\text{-}9)\times 10^8$	$W>\omega_g$	$\partial T_o/\partial Z>\partial T_o/\partial Z]_c$	Supersonic	4100-5020		$C_s<V_{ph}$ Subsonic	Inconsistent
at Z_2=1lt-day	$T_{02}=10^6$	$W>\omega_g$	$\partial To/\partial Z>\partial T_o/\partial Z]_c$	Supersonic	170	800	$C_s<V_{ph}$ Supersonic	Consistent

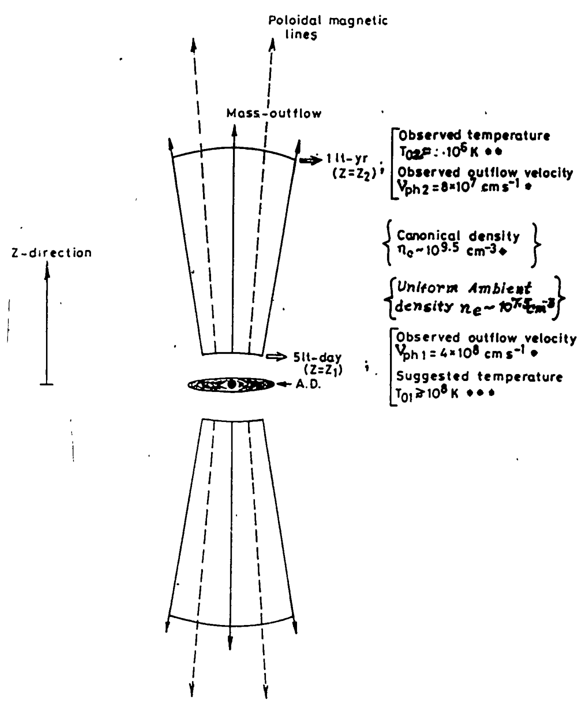

Figure 1. Rough sketch of mass-outflow in central region at NGC 4151

5.1 Nature of mass-outflow in C.R. of NGC 4151

Keeping in view of the discussions made in the previous sections and in part-I of sec. 5 we see that the C.R. of NGC 4151 can be treated as the region **R** (vide sect. 3.1) with $Z_1 = 5$ lt-day, $Z_2 = 1$ lt-yr, $T_{O1} \sim 10^8$K, $T_{O2} \sim 10^6$K, $\rho_o = 5.3 \times 10^{-17}$g cm^{-3} and $\gamma \approx 5/3$.

Now, from the analytical discussions made in sect. 3.1 we see that in the direction of decreasing temperature form Z_1 to Z_2 in **R** supersonic or subsonic wave-motion takes place under the situation when $T_{O1}/T_{O2} >$ or < 2 respectively.

Here, we find that $T_{O1}/T_{O2} \sim 10^8/(10^6) = 100 \gg 2$ holds in C.R.. Therefore, the mass-outflow from $Z_1 = 5$ lt-day to $Z_2 = 1$ lt-yr in C.R. is supersonic. This result is the same as what was obtained in part-II of sect. 5 earlier.

Again, as in sect. 3.1 we see that supersonic wave-motion from Z_1 to Z_2 in **R** is a decelerative wave-motion provided $T_{O1}/T_{O2} > 2$, therefore mass-outflow from $Z_1 = 5$ lt-day to $Z_2 = 1$ lt-yr in C.R. is also a decelerative outflow. This is what is suggested by Clavel et al. (1987) from the observational point of view.

Further, from sect. 3.1 we see that the following conditions

$$C_{S2}/V \simeq 0.81 \text{ and hence } (C_{S2}/V)^2 \simeq 0.66 \not\ll 1$$

hold in **R** where $C_{S2} = 1.7\times10^7$ cm s^{-1}, $V=2\gamma L\omega_g = 2.1\times10^7$ cm s^{-1}, $\gamma=5/3$, $\omega_g=6.7 \times 10^{-12}$ s^{-1} and L = 360 lt-day. This indicates that the supersonic outflow velocities viz., V_{ph1} ($> C_{S1}$) at $Z=Z_1$ and V_{ph2} ($> C_{S2}$) at $Z=Z_2$ must be connected with C_{S1}, C_{S2}, V by the following relation (vide (C-12.7) in case-2 of sect. 3.1) as

$$C_{S2} < V < V_{ph2} \leqslant C_{S1} < V_{ph1}.$$

Now, from the observations (vide Clavel et al. 1987) we get in C.R. that the outflow velocities $V_{ph2} = 8 \times 10^7$ cm s^{-1} at $Z_2 = 1$ lt-yr and $V_{ph1} = 4\times10^8$ cm s^{-1} at $Z_1 = 5$ lt-day satisfy the above relation as

1.7×10^7 cms^{-1} (C_{S2}) $< 2.1 \times 10^7$ cm s^{-1} (V) $< 8 \times 10^7$ cm s^{-1} (V_{ph2}) $< C_{S1} < 4 \times 10^8$ cms^{-1} (V_{ph1}) provided $V < C_{S1}$ always hold in **R** (obtained analytically in sect. 3.1.1 for supersonic wave-motion) and $C_{S1} \gtrsim 1.7\times10^8$ cm s^{-1} as $T_{01} \gtrsim 10^8$K [vide sect. 4 (iii)]. Hence, from the above discussion we can say that in C.R. of NGC 4151 the mass-outflow from $Z_1 = 5$ lt-day to $Z_2 = 1$ lt-yr is supersonic and is a decelerated flow. The velocities of such flow viz., V_{ph1} at $Z_1 = 5$ lt-day and V_{ph2} at $Z_2 = 1$ lt-yr obey the following relation

$$C_{S2} < V < V_{ph2} < C_{S1} < V_{ph1}.$$

Hot gas temperature at $Z_1 = 5$ lt-day in C.R. :

Now from the above relation between the velocities of mass-flow at $Z_1 = 5$ lt-day and $Z_2 = 1$ lt-yr in C.R. with V, C_{S2}, C_{S1}, we get $V_{ph2} < C_{S1} < V_{ph1}$ where $V_{ph2} = 8 \times 10^7$ cms^{-1}, $C_{S1} \gtrsim 1.7\times10^8$ cms^{-1} and $V^{ph1} = 4\times10^8$ cms^{-1}. This, in turn, gives the following

$$10^8 \text{ K} \lesssim T_{O1} < 5.7 \times 10^8 \text{ K}$$

as a range of hot gas temperature at Z_1=5 lt-day in C.R. of NGC 4151. This range of temperature also confirms the range of hot gas temperature at Z_1=5 lt-day obtained in part-II in sect.5 earlier. This is an important result in connection with the hot gas temperature at 5 lt-day from where mass-outflow has been observed to originate from C.R. of NGC 4151 (vide Clavel et al. 1987).

6. Summary and Remarks :

(1) The present paper intends to explore the instability phenomena in a self-gravitating, infinitely conducting, non-relativistic MHD medium with temperature gradient by using rectangular Cartesian co-ordinate system (vide sect.2).

However, a similar analysis with both density and temperature gradients and using spherical polar co-ordinate system could be more interesting and more realistic.

(2) The temperature gradient is assumed to be only along Z-direction i.e., the direction of wave-flow (i.e., $k_Z \neq 0$; vide sect.2).

The more realistic analysis could be with temperature variations along both poloidal and radial directions.

(3) The dispersion relations obtained for propagation of waves have been found to be of two types viz., transverse and longitudinal. Only the longitudinal MHD waves are affected by the temperature gradient (vide sect.2).

(4) The temperature gradient is capable of producing two types of instability of longitudinal MHD waves viz., sinusoidal and exponential (vide sect.3).

(5) The sinusoidally unstable longitudinal MHD waves suffer amplification and damping in the direction of negative and positive gradient of temperature respectively. Conclusions regarding the amplification and damping of exponential waves are same as that of sinusoidal waves (vide sect.3).

(6) The longitudinal MHD wave-flow (i.e., sinusoidally unstable longitudinal MHD waves) has been found to be of two types viz., supersonic and subsonic (vide sect. 3).

(7) In the direction of negative temperature gradient supersonic wave-flow suffers amplification as well as deceleration which, however, is not always true for subsonic wave-flow (vide sect.3.1.1 & sect.3.1.2).

The behaviour of longitudinal wave-flow in the direction of positive temperature gradient could be interesting for investigation.

(8) In deriving D.R. (19) of paper-I or D.R. (3) in this paper (viz., paper-II), we have assumed that stellar mass density has remained constant. Therefore, the perturbed potential ϕ' is taken as due to the self-gravitation of perturbed medium only. There is no perturbation of stellar field and hence there is no effect on the perturbation of MHD waves.

(9) So far as the application of the theory is discussed we can mention the following :

(i) The hot and ionised ambient medium of the Region (5 lt-day $\lesssim r \lesssim$ 1 lt-yr) in the central 1-parsec of Seyfert galaxy NGC 4151 is roughly similar to the medium which is self-gravitating, infinitely conducting and of non-relativistic hydromagnetic nature with temperature gradient (vide sect.4). Also, the central regions in the other nuclei of active galaxies may have a medium similar to that of NGC 4151.

(ii) The amplification of sinusoidally unstable longitudinal MHD waves, in the presence of poloidal magnetic field, due to a temperature gradient could be one of the triggering factors for mass-outflow in the Z-direction where $\partial T_O/\partial Z < 0$ in the central region of NGC 4151 and in other AGNs. The reason being the fact that the negative gradient of basic temperature is capable to make sinusoidally unstable longitudinal MHD waves amplified in the direction of outflow. The energy absorbed by the wave-amplification actually amounts to increase in the kinetic energy of fluid flow.

(iii) The mass-outflow is supersonic and decelerated from Z_1=5 lt-day to Z_2=1 lt-yr in the central region of NGC 4151 as because the ratio of basic temperature (T_O) at both ends of that region viz., T_{O1}/T_{O2} is much greater than 2 where $T_{O1} \sim 10^8$ K at Z_1=5 lt-day and T_{O2} $\sim 10^6$ K at Z_2 = 1 lt-yr.

In the central region of other AGNs having medium roughly similar to that of NGC 4151 the mass-outflow could similarly be supersonic and decelerative in nature.

(iv) The velocities (V_{ph}) of mass-outflow and the sound speed (C_S) at the ends Z_1=5 lt-day and Z_2=1 lt-yr in the central region of NGC 4151 would be such that

$$170 \text{ kms}^{-1} (=C_{S2}) < 210 \text{ kms}^{-1} (=V) < V_{ph2} < C_{S1} < V_{ph1} \text{ and } C_{S1} \gtrsim 1700 \text{ kms}^{-1}.$$

We see that observed V_{ph2} (= 800 km s^{-1}) and V_{ph1} (= 4000 km s^{-1}) in the central region of NGC 4151. (vide Clavel et al. 1987) also confirm this result.

(v) From the above inequality in (iv) we get 1700 km s$^{-1} \lesssim C_{S1} < V_{ph1}$ where V_{ph1} = 4000 km s^{-1} obtained from observation. This inequality reveals that

$$10^8\text{K} \lesssim T_{01} < 5.7 \times 10^8\text{K}$$

where T_{01} is the temperature of hot gas at Z_1 = 5 lt-day in the central region of NGC 4151.

This range of hot gas temperature has been obtained by using the suggestion of Krolik et al. (1981) for the range of hot gas temperature $\gtrsim 10^8$ K in the BLR of AGNs.

This is an important result regarding the temperature of hot gas at Z_1=5 lt-day from where the mass-outflow has been observed to originate from the central region of NGC 4151 (vide Clavel et al. 1987). Again, this is to say that the results so obtained, following the path of wave-instability in a self-gravitating, infinitely conducting, non-relativistic MHD medium with temperature gradient, are making a good agreement with the observations.

(10) Numerical estimation of W, ω_g, ω_c (vide Table-2) for NGC 4151 shows that in C.R. of NGC 4151 the self-gravity of the plasma (ω_g) is found to be insignificant to diminish the effect of instability factor viz., temperature gradient.

Evidently, the more massive than NGC 4151 perturbed self-gravitating system may produce significant decrease of frequencies of MHD waves.

(11) Reduction of wave frequency due to self-gravitation is natural. Because whenever longitudinal waves (material or plasma waves are essentially longitudinal waves) move away from a self-gravitating system it has to expense some energy leading to diminishing of wave frequency due to gravitation of the system itself.

(12) It is usual to ask a question 'what could be the cause of perturbation ?' One of the causes of perturbation in the plasma medium of Central Region of galaxies is Supernova explosion inside the region.

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Appendix

The perturbation structure of the variables $\underset{\sim}{U}$, $\underset{\sim}{H}$, ρ, ρ_F, p, T, ∈, ∅ is as follows (vide sect. 3 in paper-I) :

$$\underset{\sim}{U} \equiv \underset{\sim}{U}_0 + \underset{\sim}{U}', \ \underset{\sim}{H} \equiv \underset{\sim}{H}_0 + \underset{\sim}{H}', \ \rho \equiv \rho_0 + \rho', \ \rho_F \equiv \rho_F + O,$$

$$p \equiv p_0 + p', \ T \equiv T_0 + T', \ \in \ \equiv \ \in_0 + \in', \ \phi \equiv \phi + \phi',$$

where suffix zero and prime are used to denote the equilibrium/unperturbed and perturbed states of the variables.

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