THE ROLE OF ACTIVE GALACTIC NUCLEI IN GALAXY EVOLUTION

By

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Abstract

Irrespective of whether Active Galactic Nuclei (AGN) is cored with Supermassive Blackholes (SMBH)or not, there is a general consensus that observations indicate that the AGN plays role in hosting galaxy evolution. The accretion disc powered fueling of the AGN and counter-feedback on its environment in the form of stress-energy-momentum along the radial component and an associated polodial jets seems viable model. On the theoretical ground there is no unified theory that compromise the observations. But there are pull of such diverse physics simulated to describe the observational works. So, there is unsettled theoretical framework how the activity of the AGN plays role in the evolution of host galaxy. Motivated by this we studied the role of AGN on its host galaxy evolution where General relativistic (GR) Magnetohydrodynamics (MHD) equation is considered to derive radial pressure that invokes star forming cold gases. Methodologically the central engine of the AGN is considered with SMBH/pseudo-SMBH. Locally, around the AGN, Reissner - Nordstrom de-Sitter metric is considered that reduces to the Schwarzschoild-de Sitter (SdS) background. Geometrically, a simple spherical geometry is superimposed with central disc structure assumed by cored void mass ablating model. The results of the work indicates that the AGN plays role in galaxy evolution, especially in the nearby environment. Also we report that the adjacent envelope to the AGN seems quiet with no activity in formation.

Key words: Accretion, AGN, GR, MHD, Metric, Radial-Pressure, SMBH.

Chapter 1

Introduction

1.1 Scheme of the thesis

In this introductory chapter we provide the detail background of the work including literature reviews/issues thereof, objectives and methods. In chapter 2 the background physics, General Relativity theory (GR) is previewed. This chapter is intended to enrich the method and model going to be implemented. Chapter 3 is devoted to derive analytical dynamic equations from the GR with presumed boundary condition detailed in the methodology. In chapter 4 we discuss the results of our work. The final chapter, chapter 5 goes to summary and conclusion.

1.2 Background

Observationally, the discovery of Active Galactic Nuclei (AGN) goes back to more than a century ago where the first spectroscopic detection of emission lines from the nuclei of NGC 1068 and Messier 81 was reported by Edward Fath [1] and the discovery of the jet in Messier 87 by Heber Curtis [2]. Then, a number of further spectroscopic studies were carried out by astronomers in the presence of unusual emission lines in some galaxy nuclei with less understanding. However, the systematic study of galaxies with nuclear emission lines began with the work of Seyfert [3]. Seyferts spectroscopic work include NGC 1068, NGC 4151, NGC 3516, and NGC 7469. Today, active galaxies such as these are known as Seyfert galaxies in honor of Seyferts pioneering work. Furthermore, the development of radio astronomy during 1950s was one of the key initiatives in understanding AGN including the detected active elliptical radio source galaxies such as Messier 87 and Centaurus Bolton [4]. Consequently, further progress in radio survey led to the discovery of new radio sources as well as identifying the visible-light sources associated with the radio emission [5]. In photographic images, some of these objects were nearly point-like or quasi-stellar objects (QSOs) in appearance, and were classified as quasi-stellar radio sources (later abbreviated as quasars,). Also, further advances in the discovery of AGNs were stepp ed up in optically strong ultraviolet continuum through and later in infrared and X-ray surveys during the 1960s [5],[6]. In fact this period was a breakthrough in the spectrum analysis where an accurate position of certain quasars like 3C 273 were obtained observationally [7]. Remarkably, during 1970s b oth ground-based and sky-based observational techniques were develop ed to analyse wide range of the QSOs spectral distribution that covers almost all spectrum of the electromagnetic radiation. Conclusions were drawn that the spectrum of QSOs is just identical to that of the nuclei of the Seyferts. Later studies vastly have shown that both objects are recognized as the nuclei of hosting galaxies, the AGN. Moreover, all massive galaxies are likely to have hosted AGN activity during their lifetimes. As of the current understanding AGNs are among the most powerful energy sources in the Universe with extreme luminosity over the whole electromagnetic spectrum. However, pioneering literature reviews point out that in order to fully prob e the critical role of the AGN in galaxy formation/evolution, the need of new capabilities, specifically, sub-milliarcsecond (sub-mas) optical/UV imaging that can only be achieved with space-based, long-baseline observatories, such as the generic Ultraviolet Optical Interferometer (UVOI) under consideration for the decade of the 2020s and beyond On the other hand, the theoretical work have moved AGN to the forefront of extragalactic astronomy research. The observed widely varying appearances of the AGN s apparently required unification of diverse fields of study for theoretical models. The present computing standard theories are appealing AGNs with Super-Massive Black Holes at their centers powered with accretion, see [8] and the references therein. Their evolutionary scenario have been studied both with and without effects on the hosting galaxies. Most of the literatures support the co-evolutionary scenario while some reports also consider independent evolutionary scenario of the host, for instance see the review by [9], and the references therein. A plethora of literatures point out that the AGNs are considered to influence the evolution of its host galaxy, for example see [10], [11], [12]Radiation pressure and momentum injection by AGN play important role in models of feedback in star-forming galaxies, for instance see [13].There are implications for the dynamics of dusty shells in a number of contexts, including giant molecular cloud disruption around forming star clusters, outbursts from massive stars, galactic winds driven by star formation, and fast dusty outflows driven by AGN. However, the theoretical framework is yet not so fully developed. There remain a number of issues to be addressed. Partly, due lack of sophisticated observational instrumentation required to test the theories. And partly, the way the theories are being implemented in analysing observations. For instance, the widely accepted co-evolution of galaxies and black holes (at the core of AGN) lacks detail description and understanding. On the other hand, the ideas of fuelling the AGN with barred disc generated by internal instabilities which can lead the gas to the centre of galaxies and the presence of more than one sup er-massive black hole which seems likely in the nucleus of merger remnants cannot b e overlooked, see [14]and the references therein. In fact, the natural complication of the physical system cannot be ruled out in modeling even within the limit of the existing theories. Consequently, it is not difficult to recognize a numb er of debates among the scientific communities. So motivated by this scientific rationale we are interested to study the role of AGN activity in the evolution of galaxies with simple spherical geometry under Einstein General Theory of Relativity(GRT) in the Schwarzschild-de Sitter background being super imposed with central disc structure.

1.3 Literature Review

General relativity is a beautiful scheme for describing the gravitational field and the equations it obeys. Nowadays this theory is often used as a prototype for other, more intricate constructions to describe forces between elementary particles or other branches of fundamental physics. There are encouraging past success of GR and the hopes ahead there is an outstanding debates on GR field equations dated back to their origin. After completing his theory of GR, Einstein was interested to find a static solution of his field equations with the idea of incorporating Mach's principle[19]. As the consequence, Einstein himself introduced a positive cosmological constant Λ with the belief of constructing a static solution. The idea is that, the constant introduces a repulsive force which can counterbalance the attractive force of gravity leading to the static Einstein universe. The modified Einstein's field equations with the cosmological constant is:-

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + g_{\mu\nu}\Lambda = kT_{\mu\nu} \tag{1.3.1}$$

But at the same year that Einstein introduced the cosmological term, de-Sitter (1917) presented solutions to static Einstein universe, with $T_{\mu\nu} = 0$ and $\Lambda > 0$, which had both static and dynamic features, that allows a red-shift-distance relation. The de Sitter's prediction is considered as the first step towards the theoretical discovery of expanding universe. In the presence of a repulsive cosmological constant (positive) the spacetime geometry exterior to a static spherically symmetric gravitating system is Schwarzschild-de Sitter (SdS), in a spatially inflated Universe, rather than Schwarzschild. But the general perception is that owing to its tiny value, cosmological constant does not lead to any significant observable effects in a local gravitational phenomenon. However, the contribution of repulsive Λ could be significant (larger than the second order term) even in a local gravitational phenomenon when kiloparsecs to megaparsecs-scale distances are involved, such as the gravitational bending of light by cluster of galaxies .Probably, a local effect of cosmological constant is claimed to be observable from relativistic accretion phenomena around massive BHs which involve distance-scale of the order of hundreds of parsecs or even more and the references therein. So the current standard Λ CDM model that is consistent with observation shall be exploited to study the effect of cosmological constant on dynamical systems including MHD instabilities around massive objects like BHs where they are mostly hosted by AGNs. The first recorded observational evidence for the existence of (what are now referred to as) active galactic nuclei came from Edward A. Fath in 1908 who was obtaining spectra of star clusters and spiral nebulae at the Lick Observatory (Fath 1909) Ionising photons that escape the central regions of the

AGN can ionise gas in lowdensity regions that extend beyond the inner BLR (with electron densities $n_e \leq 10^6 cm^{-3}$; see Fig. 1.1). Here the emission lines produced have narrower widths (i.e.,$250 \leq FWHM \leq 2000 kms^{-1}$) and this region is referred to as the narrow-line region (NLR; Fig. 1.1). Unlike the BLR both permitted lines and forbidden lines are produced in the NLR, which can extend over large scales (i.e., $\approx 10^2 - 10^4$ pc;)[20]. Surrounding the central BH is an accretion disk that resides

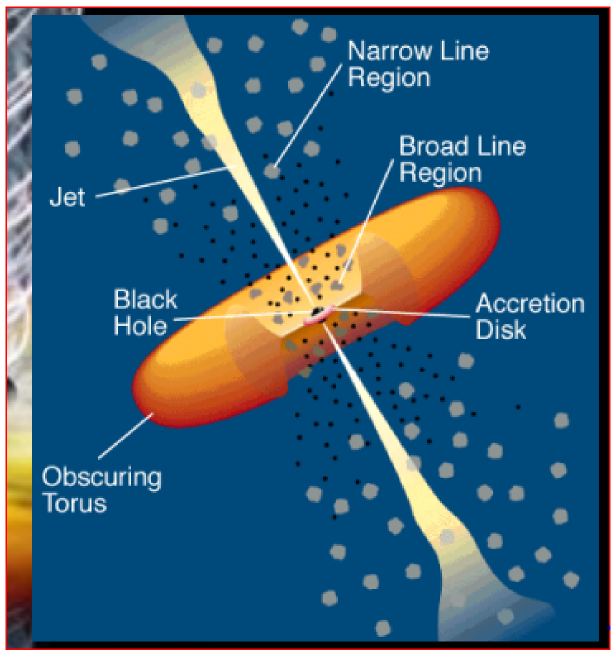

Figure 1.1: A schematic diagram of the currently most accepted model of the structure of AGN(credit to Planck collaboration;2016)

inside a geometrically thin and optically thick dusty structure called the torus. Above and below the accretion disk is a hot corona.The differential rotation of plasma in the accretion disk or black hole magnetosphere causes the polar component of magnetic field lines to win dup into a helix. The toroidal component of the magnetic field provides a force directed toward the jet axis that allows the jet confinement. This effect is complemented by the pressure provided by an external (high relative pressure) envelop of dense material such as a wind from the accretion disk. The expansion of the magnetic field with distance from the black hole reduces the magnetic pressure, hence creating a pressure gradient along the jet that drives the flow. Such outflow can become relativistic if the magnetic energy density exceeds the rest mass energy density. There are several observational and theoretical results that imply BH growth and galaxy growth are intimately connected, which seems incredible because there are nine orders of magnitude difference in the physical size scale of a BH and its host galaxy (equivalent to the difference between the size of a coin and the Earth!). This section explores three observational results that imply that BH growth and galaxy growth are linked: (1) the cosmic evolution of BH growth and star formation look very similar; (2) most BH growth occurs in star-forming galaxies; (3) BH masses correlate with galaxy bulge mass and velocity dispersion. Current theoretical and observational results imply that AGN activity (i.e., BH growth) can directly impact upon the evolution of their host galaxies. Fundamentally, the rates of star formation and BH growth (i . e. , AGN activity) in galaxies will be down to the balance between feeding (i.e., a supply of cold gas) and feedback (i.e., the prevention of the cold gas supply). A simple explanation for the co-evolution of star formation and BH growth and the observed relationships between galaxies and BHs, is that they grow from a common fuel supply. However, both star formation and AGN activity are known to be a source of energy and momentum (due to radiation pressure and the expulsion of material through winds or jets). If these winds, jets or radiation pressure are able of significantly suppress the supply of cold gas they will be the cause of negative feedback (see Fig.2)[21]. If either one of these processes injects energy or momentum into their surroundings (i.e., provides the source of heating or outflows)

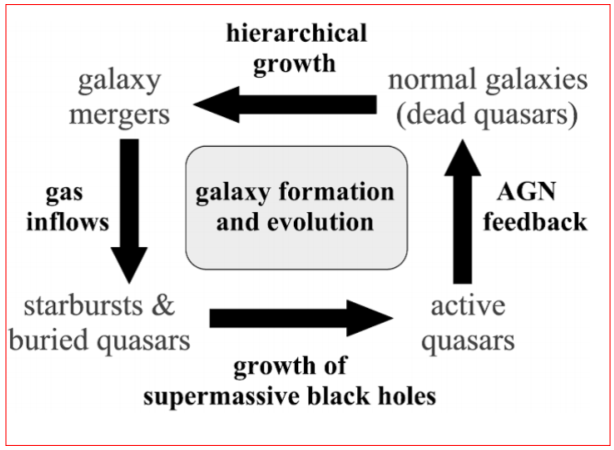

Figure 1.2: A schematic diagram to illustrate how AGN activity (BH growth) and star formation (galaxy growth) could be connected
[22].

future AGN activity and star formation could be enhanced or suppressed (i.e., the impact). The overall results of these processes could affect the observed properties of galaxies, BHs and the gas in the larger scale environment (i.e., the IGM and the ICM). The influence of AGN activity (i.e., AGN as the source) on the evolution of galaxies.Thick accretion discs (or tori) are probably orbiting the central black holes of many astrophysical objects such as quasars and other active galactic nuclei (AGNs), some X-ray binaries, and microquasars. The most promising processes for producing relativistic jets like those observed in AGNs, microquasars, and GRBs involve the hydromagnetic centrifugal acceleration of material from the accretion disk , or the extraction of rotational energy from the ergosphere of a Kerr black hole. The galaxies that we observe in the universe at the present time exhibit a remarkable variety of properties, such as morphology, colors, luminosity and dynamics.The morphology of the luminous component of galaxies,namely stars, gas and dust, is probably the most obvious manifestation of the diversity of galaxy properties. The earliest stage in the evolution of galaxies is the formation. When a galaxy forms, it has a disk shape and is called a spiral galaxy due to spiral-like ”arm” structures located on the disk. There are different theories on how these disk-like distributions of stars develop from a cloud of matter: however, at present, none of them exactly predicts the results of observation. On scales smaller than 1Mpc, it is much more difficult to explain and predict the nature of structures, because it requires the understanding of various baryonic processes like gas cooling, star formation, feedback and mergers, which occur during galaxy formation and evolution. The CDM scenario provides the initial conditions and the evolutionary framework for modelling structure growth while the baryonic processes in addition to gravity dictate the evolution of visible matter on small scale.Galaxies form from gas which cools from the hot halo observing conservation of angular momentum. As the temperature decreases, thermal pressure stops supporting the gas which therefore settles in a disk. This gives rise to rotating disks.

1.3.1 Introduction to Galaxy

A galaxy is a self-gravitating system composed of an interstellar medium, stars, and dark matter. Galaxies and their nuclear Super Massive Black Holes (SMBH) appear to be intimately related components of the same fundamental formation and evolutionary process. When the host galaxy contrives to feed its nuclear monster, it unleashes a torrential energy output that can far outshine the gentler and,apart from the occasional supernova, more constant shining of the stellar populations . The observed proportionality between the masses of the black hole and the galaxy bulge suggests a close coupling a negative feedback loop that limits SMBH growth. One of our more important goals is to understand the nature of this mechanism . To do this, we must look at the galaxy and its larger environment, not at the nuclear regions alone . A brightly shining AGN has a useful service by illuminating its host galaxy with an ionizing radiation field. The fluorescent emission that this produces can be studied to tell us about the some rather fundamental galaxy properties such as , via emission line kinematics, the mass and, via line ratios and ionization modelling, the chemical composition of the interstellar medium(ISM). With a luminosity that can far exceed that of its host, an AGN will not only illuminate its surroundings, it will push material around. Radiation pressure will affect dust clouds , ambient gas will be shocked in the presence of the particle jets , flows will be driven and the ISM will be generally mixed and redistributed. All these processes have to be recognised and understood if we are to generate a complete picture.

Galaxies are thought to have begun from large irregular clouds of hydrogen and helium. This gas was created in the first few minutes of the universe. Certain sections of the clouds were probably slightly more dense than others. Because of this higher density, gravity caused them to collapse. As the large cloud collapsed, it cooled. On an even smaller scale, pieces of the collapsing cloud, also collapsed into even smaller pieces. These smaller denser regions created the first stars. When the first stars reached the end of their life cycle, they exploded, heating the surrounding gas and slowing the collapse of the galaxy cloud. These explosions also introduced heavier metals, such as carbon and nitrogen, into the galactic cloud. Eventually, this process of collapse, star formation, and slowing, balanced, giving us stable galaxies. How this process created elliptical and spiral galaxies, is yet another question. There are two main theories. The first theory is: as the cloud collapsed to form a galaxy, it's spin is what determined what type of galaxy it became. Some theorists believe that spiral galaxies were formed from clouds that had a significant spin. As the cloud collapsed the spin got even faster still, this is a feature of the principle of angular momentum. As this the spin increased, it flattened the material in the cloud along the spin axis, forming the characteristic disk of spiral galaxies. Elliptical galaxies were simply formed from clouds that didn't have this spin. They therefore formed a more round structure, which has no particular axis of rotation. The second theory is that elliptical galaxies were formed from collisions of spiral galaxies. This theory is supported by a couple of interesting facts. First, in the early universe galaxies were much closer together then they are now. Since they were closer together, especially in galaxy clusters, collisions were probably very common. So if collisions of spirals made ellipticals, the process of elliptical galaxy creation was definitely present. Second, large elliptical galaxies typically occur in rich galaxy clusters, where collisions most likely happen. Third, ellipticals don't have much interstellar gas, when compared to spirals. Why? In the context of this theory, the collision of spirals would have ignited much of the gas, turning them into stars. This process can be seen today in galaxy collisions. Elliptical galaxies do show evidence of this "new" population of star formation, even though they currently have very low formation rates. Newer stars have a different metal composition than older stars, since they were created later in the galaxy's evolution (i.e. after several star life cycles). Astronomers can measure the amount of "heavy" metals in a star through a process called spectrophotometry. In some elliptical galaxies, there are two distinct populations of globular clusters an "old" and a "new."

The 'pressure effects' that density enhancements experience are due to the expanding Universe. The space itself between particles is expanding. So each particle is moving away from each other. Only if there is enough matter for the force of gravity to overcome the expansion do density enhancements collapse and grow. Structure could have formed in one of two sequences: either large structures the size of galaxy clusters formed first, than latter fragmented into galaxies, or dwarf galaxies formed first, than merged to produce larger galaxies and galaxy clusters[23].

1.3.2 Galaxy formation conditions and progenitors

We have already seen that galaxies were more numerous, but smaller, bluer, and clumpier, in the distant past than they are today, and that galaxy mergers play a significant role in their evolution. At the same time, we have observed quasars and galaxies that emitted their light when the universe was less than a billion years oldso we know that large condensations of matter had begun to form at least that early. Also in Active Galaxies, Quasars, and Supermassive Black Holes that many quasars are found in the centers of elliptical galaxies. This means that some of the first large concentrations of matter must have evolved into the elliptical galaxies that we see in todays universe. It seems likely that the supermassive black holes(SMBH) in the centers of galaxies and the spherical distribution of ordinary matter around them formed at the same time and through related physical processes. In Active Galaxies, Quasars, and Supermassive Black Holes, the more massive a galaxy is, the more massive its central black hole is. Somehow, the black hole and the galaxy know enough about each other to match their growth rates. There have been two main types of galaxy formation models to explain all those observations. The first asserts that massive elliptical galaxies formed in a single, rapid collapse of gas and dark matter, during which virtually all the gas was turned quickly into stars. Afterward the galaxies changed only slowly as the stars evolved. This is what astronomers call a top-down scenario. The second model suggests that todays giant ellipticals were formed mostly through mergers of smaller galaxies that had already converted at least some of their gas into stars which is called a bottom-up scenario. In other words, astronomers have debated whether giant ellipticals formed most of their stars in the large galaxy that we see today or in separate small galaxies that subsequently merged. Observations also indicate that most of the gas in elliptical galaxies was converted to stars by the time the universe was about 3 billion years old, so it appears that elliptical galaxies have not formed many new stars since then. They are often said to be red and dead that is, they mostly contain old, cool, red stars, and there is little or no new star formation going on. These observations (when considered together) suggest that the giant elliptical galaxies that we see nearby formed from a combination of both top-down and bottom-up mechanisms, with the most massive galaxies forming in the densest clusters where both processes happened very early and quickly in the history of the universe. The situation with spiral galaxies is apparently very different. The bulges of these galaxies formed early, like the elliptical galaxies. However, the disks formed later (remember that the stars in the disk of the Milky Way are younger than the stars in the bulge and the halo) and still contain gas and dust. However, the rate of star formation in spirals today is about ten times lower than it was 8 billion years ago. The number of stars being formed drops as the gas is used up. So spirals seem to form mostly bottom up but over a longer time than ellipticals and in a more complex way, with at least two distinct phases[24]

1.3.3 Galaxy Formation and Evolution

On scales smaller than $\sim 1Mpc$, it is much more difficult to explain and predict the nature of structures, because it requires the understanding of various baryonic processes like gas cooling, star formation, feedback and mergers, which occur during galaxy formation and evolution. The ΛCDM scenario provides the initial conditions and the evolutionary framework for modelling structure growth while the baryonic processes in addition to gravity dictate the evolution of visible matter on small scales. Theoretically, the standard picture of galaxy formation was first put forward by White and Rees (1978). The basic idea is that the initial density fluctuations grow by gravity and form dark matter haloes which acquire angular momentum via tidal torques from neighbouring protohaloes. Then the bayonic matter (i.e. gas) falls into these dark matter potential wells. The fraction of the baryonic matter that is bound to dark matter haloes depends on the depth of the potential wells and the pressure of the gas. For example, when the Universe reionizes, the temperate and hence the pressure of the baryons increase, which results in a lower baryon fraction in low mass galaxies . When the gas does accrete the infalling gas experiences an accretion shock and is heated to the virial temperature of the halo. The shock heated gas then cools through radiative processes. At typical densities of the astrophysical plasma two-body radiative processes are the most important such as free-free emission or bremsstrahlung, radiative recombination, collisional ionization and collisional excitation. However, the flux density of the incident radiation field can also have a large effect on the gas cooling rate . The photon matter interactions can either reduce the cooling of the gas through photoionization(thereby reducing the amount of atoms available for collisional excitation) or increase the temperature of the gas through photoheating. The angular momentum of the gas in the halo arises in the same way as that of the dark matter halo, i.e., tidal torques from large scale structure. Since radiative cooling is an angular momentum conserving process the gas forms self-gravitating disc like structures after cooling. Gravitational instabilities of the cold gas clouds triggers cloud collapse and eventually the formation of stars. It was realized very early that star formation in the dark matter haloes is very inefficient. This inefficiency was attributed to feedback from stars and active galactic nuclei (AGN). Stars inject energy and momentum back into the gas in form of stellar winds, photoheating, radiation pressure and supernova (SN) feedback. There are two kinds of SN feedback mechanism currently considered, kinetic feedback and thermal feedback. Kinetic feedback models concentrate on imparting momentum to the surrounding gas and ejecting it out of the disc and maybe the halo itself, while thermal feedback models focus on heating the surrounding gas and relying on gas pressure to generate galactic scale outflows. Modelling these processes remains quite a challenge for modern galaxy formation theories. In addition to processes discussed above, due to the hierarchical nature of structure formation, galaxies accrete other galactic systems. The merging satellite galaxies lose energy through dynamical friction, falls to the center and merges with the central galaxy. Such merger events change the morphology of galaxies. For example, an elliptical galaxy is thought to be formed by a merger of two, approximately equal mass, spiral galaxies. In addition to changing the morphology, there might also be a spike in the star formation rate, as the merger induces torques which drives gas to the center and forms stars. After such a merger event, a disc can reform by accreting high angular momentum gas from its halo.

Although the distinction now seems artificial, most models for the formation of individual galaxies have been based on either the collapse picture or the merger picture. We mention first some results of collapse calculations based on the hypothesis that galaxies form by the collapse of discrete protogalactic clouds. The role of the dark matter has usually been neglected in these generalizations; in effect, it has been assumed that the protogalactic clouds have already formed at the centers of dark halos and that the dark matter plays no further important role in the ir evolution. The simplest type of collapse model is one that treats only the collapse of a system of stars formed with high efficiency from the gas at an early time. Such models clearly cannot address chemical enrichment processes or account for the formation of disks, but they may nevertheless be able to account for the gross structure of typical elliptical galaxies. When viscosity is included, models that are otherwise realistic tend to produce too large a central ac cumulation of gas , leading to rotation curves that peak too strongly in the inner regions of the resulting galaxy. The heating and expulsion of residual gas by the effects of supernovae may in fact be of quite general importance for galaxy formation , and will almost certainly b e very important for the smallest galaxies, causing them to lose most of their heavy elements at an early stage of evolution and thus end up with low metallicities.[25]

One explanation of the low star formation efficiency in massive halos is that a supermassive black hole at the center releases vast amounts of energy when it absorbs mass from its surroundings, and this suppresses cooling and star formation in its host galaxy(AGN feedback). The abundance of low mass halos could be reduced by replacing cold dark matter with warm dark matter , but the adoption of warm dark matter is challenged by the requirement to form relatively massive structures at high redshfit, within which galaxies could form to produce high energy photons to account for the reionization of the intergalactic medium. White and Rees (1978) argued that in the hierarchical paradigm, feedback can help expel gas from small galaxies, making them less successful at forming stars, thus reducing the stellar masses of faint galaxies. Cosmic reionization, which could inhibit gas collapsing into shallow potential well and suppress gas cooling in low mass halos, could also affect galaxy formation in very small halos. Galaxies form in the centers of dark matter halos and gain stars by formation from their interstellar medium (ISM) and by accretion of satellite galaxies. The dense ISM is assumed to form a disk and may be replenished by infall from the surrounding halo, and by gas from accreted satellite galaxies. The interaction between these processes and the feedback driven by supernovae and by active galactic nuclei drives the overall evolution of galaxies, which thus cannot be followed realistically without considering a complex network of baryonic physics. The main modifications here include mass-dependent supernova feedback, gradual stripping and disruption of satellite galaxies, a model that follows the angular momentum accumulation history of gas disks and stellar disks, and a model to calculate bulge sizes. At the end stage of evolution of a massive star, an enormous amount of energy is released during a supernova (SN) explosion. The radiation and the blast-waves from supernovae may heat the interstellar medium and blow them out of the host galaxy. This effect is of particular importance in the formation of low-mass galaxies where the potential well is shallower. White and Rees (1978) first proposed that supernova feedback can help to reproduce the proper abundance of dwarf galaxies. If gas is ejected from the main subhalo, it will contribute to the mass Mejec in the ejecta reservoir of the main subhalo, from which it might be reincorporated into the cooling cycle as the halo grows. If gas is ejected from a subhalo, on the other hand, it will contribute to the hot atmosphere of the main subhalo, and will never fall back into the subhalo. In low-mass halos, the hot gas is much more weakly bound than in massive halos and gas is thus easier to eject to give high kinematic energy relative to the binding energy.

1.4 Statement of the problem

Irrespective of whether AGN is cored with SMBHs or not, there is a general consensus that observations indicate that the AGN plays role in hosting galaxy evolution. The accretion disc powered fueling of the AGN and counter-feedback on its environment in the form of stress-energy-momentum along the radial component and an associated polodial jets seems viable model [15],[16],[17]. On the theoretical ground there is no unified theory that compromise the observations. But there are pull of such diverse physics simulated to describe the observational works. So, there is unsettled theoretical framework of how the activity of the AGN plays role in the evolution of hosting galaxy **??**.

Research questions

- Has the dynamism of AGN role in its host galaxy evolution **??**?
- What key parameters are involving in the dynamical counter-feedback of the AGN on its environment?
- How and in what way do the parameters significantly determine the effect of the AGN on host?

1.5 Objectives

1.5.1 General objective

The main objective of this thesis is to study the role of AGN on its host galaxy evolution where General relativistic MHD equation is considered.

1.5.2 Specific objectives

- To develop general relativistic MHD equations around AGN environment.

- To derive relevant dynamical parameters from the developed equations.
- To study the effect of the derived parameters on the host.

1.6 Methodology

Mainly General relativistic MHD equation is considered. The central engine of the AGN is considered with SMBH. It is hoped to work for both in the presence or absence of such real object, where in the later case a pseudo SMBH is assumed. The rational behind is that, the AGN is presumably sufficiently massive whether it is cored with such objects or not to appeal for strong gravity around its environment. On top of this the internal activity of the AGN doesn't matter on gravitation as long as the mass is being kept constant. However, the activity of the AGN is supposed to play role on the evolution of the host galaxy. In the meantime, the feedback is expected to have counter-effect on it. Locally, around the AGN, the Reissner - Nordstrom de-Sitter spacetime is being considered that reduces to the SdS background to retain the concordance cosmological model ΛCDM represents the current best fit to a number of various observations across a wide range of physical scales and cosmic time [16],[18] the references therein. Moreover, a simple spherical geometry being superimposed with central disc structure is assumed by the cored void mass ablating model which still holds for the spherical symmetry.

Chapter 2

An Overview of General Relativity Theory

General theory of relativity is a theory of Gravitation where one recognises the power of geometry in describing the physics. The pivotal point in the theory is that a gravitational field implies in the background of spacetime and conversely, a curve space time satisfying the laws of general relativity indicates the possible existence of an intrinsically associated real gravitational field . General theory of relativity and Newton's gravitational theory make essentially identical predictions as long as the strength of the gravitational field is weak. However for the case of strong gravitational field both differ in their predictions. Further Einsteins General Theory of relativity successfully explains the phenomena taking place in the presence of strong gravitational field. Thus Einsteins theory of relativity has important astrophysical implications. For the mathematical formulation of this theory Einstein field equations play very important role. The deflection of light rays in the gravitational field of massive stars, the gravitational red-shift, gravitational time delay e.t.c,can be most successfully explained by General theory of relativity [28]. General relativity is the relativistic theory of gravity that is consistent with experimental data.Under the normal conditions the general relativistic effects are very small and extremely difficult to detect.In the neighbourhood of an object of mass M and radius R general relativistic effects are of the order of $\frac{GM}{Rc^2}$, G being the Gravitational constant , c the speed of light. The ratio is equal to $\sim 10^{-6}$ in the case of sun, hence it is very difficult to detect these effects. For the massive and compact objects for which $\frac{GM}{Rc^2} \sim 1$ the general relativistic effects can be easily detected.Neutron star, White Dwarf, Black Hole are very compact objects in which the relativistic effects come into existence and can not be ignored. The dominant role of gravitation and general relativity became very much evident with the discovery of pulsars and their identification as fast rotating neutron stars. Non-static solutions of Einsteins field equations are very important while discussing gravitational collapse , very high energy events like quasars, and supernova bursts.At every layer within a stable star, there must be balance between the inward pull of gravitation and the gas pressure [29].Any stellar structure is in equilibrium under the influence of two forces: (a) The gravitational force, (b) The pressure of gas and radiation. The equation of hydrostatic equilibrium is given by:-

$$\frac{dP}{dr} = -\frac{GM(r)\rho(r)}{r^2} \tag{2.0.1}$$

, Where M(r) is the mass interior to radius r and $\rho(r)$ is the density at r. P represents the total pressure due to both gas and radiation. Thus within any given layer of a star there must be hydrostatic equilibrium between the outward pressure due to both gas and radiation from below and the weight of the material above pressing inward. The relativistic equilibrium between Pressure and gravity for a spherical and static star is expressed by the generalized TOV equations written as:-

$$\frac{dP(r)}{dr} = -\frac{G}{r^2}[\rho(r) + \frac{P(r)}{c^2}][m(r) + \frac{4\pi r^3 P(r)}{c^2}][1 - \frac{2Gm(r)}{rc^2}]^{-1} \tag{2.0.2}$$

The neutral solutions of Einsteins field equations have very important astrophysical implications. The Various compact stellar objects like neutron star,white Dwarf, pulsar can be explained theoretically by studying the physically realizable solutions of Einsteins field equations. But many solutions of Einsteins field equations are not well behaved , hence can not be used for modeling of astrophysical objects. The solutions of Einsteins field equations which are not well behaved in neutral arena can be made well behaved after including charge in them . The charged interior solutions of Einstein field equations are normally found very useful to predict or explain the various properties of massive compact objects. It is observed that in the presence of charge, the gravitational catastrophic collapse of a spherically symmetric material ball to a point singularity can be avoided by virtue of the Columbian repulsive force along with the thermal pressure gradient. Exact solutions of Einstein-Maxwell field equations are important in the modeling of relativistic astrophysical objects. Such models successfully explain the characteristics of massive objects like Neutron stars, Pulsars, Quark stars, or other super-dense objects.

2.1 Spherically symmetric solutions of EFEs and their roles in Astrophysical application

The Minkowski, de-Sitter and anti de-Sitter spacetimes are the simplest solutions in the sense that their metrics are of constant (zero, positive, and negative) curvature. They admit the same number (ten) of independent Killing vectors, but the interpretations of corresponding symmetries differ for each spacetime. Together with the Einstein static universe, they all are conformally flat, and can be represented as portions of the Einstein static universe.

2.1.1 The Choice of Solutions

Since most solutions, when properly analyzed, can be of potential interest, we are confronted with a richness of material which puts us in danger of mentioning many of them, but remaining on a general level, and just enumerating rather than enlightening. In fact, because of lack of space (and of our understanding) we shall have to adopt this attitude in many places. However, we have selected some solutions, hopefully the fittest ones, and when discussing their role, we have chosen particular topics to be analyzed in some detail, and left other issues to brief remarks. Among various astrophysical implications of the Schwarzschild solution we especially note recent suggestions which indicate that we may have evidence of the existence of event horizons, and of a black hole in the centre of our Galaxy. The main focus in our treatment of the Reissner-Nordstrom metric is directed to the instability of the Cauchy horizon and its relation to the cosmic censorship conjecture.

2.1.2 Spherically Symmetric Spacetimes

In the early days of general relativity spherical symmetry was introduced in an intuitive manner. It is because of the existence of exact solutions which are singular at their centres (such as the Schwarzschild or the Reissner-Nordstrom solutions), and a realization that spherically symmetric, topologically non-trivial smooth spacetimes without any centre may exist. Relativistic effects will, of course, play a role in many astrophysical situations involving spherical accretion, the structure o f accretion disks around compact stars and black holes , their optical appearance etc. They have become an important part of the arsenal of astrophysicists.

2.2 Shwarzschild de-Sitter solution of EFEs(SdS space geometry)

The basic properties of Spherically symmetric SdS space-time describing combined effects of an attracting central object and cosmic repulsion determined by the cosmological constant(Λ). The SdS geometry describes Black Hole space-time but it can be used to describe the space-time outside any matter configuration at a distances where the distributions from spherical symmetry can be abandoned(e.g Well outside elliptical and Spiral galaxies of characteristic extension R). The Einstein Field equations in vacuum are:-

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = 0 \tag{2.2.1}$$

For non-vacuum space-time, it can be shown that EFEs take the forms of:-

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = -\frac{8\pi G}{c^4}T_{\mu\nu} \tag{2.2.2}$$

Here $T_{\mu\nu}$ is the stress-Energy tensor .The indices in the above equation(2.2.1) can be contracted to give:-

$$g^{\mu\nu}[R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu}] = g^{\mu\nu}[\frac{-8\pi G}{c^4}T_{\mu\nu}] \tag{2.2.3}$$

$$R - \frac{1}{2}R(4) + 4\Lambda = \frac{-8\pi G}{c^4}T \tag{2.2.4}$$

Then

$$R = \frac{8\pi G}{c^4}T + 4\Lambda \tag{2.2.5}$$

Now using equation (2.2.5) in equation (2.2.2) above we can rewrite as

$$R_{\mu\nu} - \Lambda g_{\mu\nu} = -\frac{8\pi G}{c^4}(T_{\mu\nu} + \frac{1}{2}Tg_{\mu\nu}) \tag{2.2.6}$$

This is called trace-reversed Einstein equation. The EFEs are nonlinear second order differential equations; therefore, it is notoriously difficult to find solutions in closed form. However, with a few additional requirements, a solution can be found. First, we neglect any mass terms, so we obtain an empty universe. Therefore, we take the stress-energy tensor and the contracted stress-energy tensor in equation (2.2.6)to be zero. The Einstein equation then becomes:-

$$Rg_{\mu\nu} = \Lambda g_{\mu\nu} \tag{2.2.7}$$

2.2.1 Static coordinates

The space around a spherically symmetric body with a vacuum energy described by the repulsive cosmological constant($\Lambda > 0$) is of the form :-

$$ds^2 = -f(r)dt^2 + g(r)dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.8}$$

Here, f(r) and g(r) are real functions of r. We take the signature of the metric (- + + +). It is therefore necessary to specify in each calculation the signature used. The signature of the metric specifies that f(r) and g(r) ≥ 0; this means we can write the metric as:-

$$ds^2 = -e^{A(r)}dt^2 + e^{B(r)}dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.9}$$

The components of the Ricci tensor are calculated to be:-

$$R_{tt} = -e^{(A-B)}\frac{1}{2}A'' - \frac{1}{4}A'B' + \frac{1}{4}A'^2 + \frac{A'}{r} \tag{2.2.10}$$

$$R_{rr} = \frac{1}{2}A'' - \frac{1}{4}A'B' + \frac{1}{4}A'^2 - \frac{B'}{r} \tag{2.2.11}$$

$$R_{\theta\theta} = e^{(-B)}[1 + \frac{1}{2}r(A' - B')] - 1 \tag{2.2.12}$$

$$R_{\phi\phi} = R_{\theta\theta}\sin\theta^2 \tag{2.2.13}$$

where $A' = \frac{dA}{dr}$ and $B' = \frac{dB}{dr}$. All other components are equal to zero. Setting these components equal to $\Lambda g_{\mu\nu}$ gives for the (tt) and (rr) components:

$$Rg_{tt} = \Lambda g_{tt} \tag{2.2.14}$$

$$Rg_{rr} = \Lambda g_{rr} \tag{2.2.15}$$

$$Rg_{\theta\theta} = \Lambda g_{\theta\theta} \tag{2.2.16}$$

By the aid of equation(2.2.9), (2.2.10) and (2.2.11) above we can write as :-

$$\Lambda g_{tt} = -e^{(A-B)}\frac{1}{2}A'' - \frac{1}{4}A'B' + \frac{1}{4}A'^2 + \frac{A'}{r} \tag{2.2.17}$$

but

$$g_{\mu\nu} = -e^A, g_{\mu\nu} = e^B, g_{\theta\theta} = r^2 and g_{\phi\phi} = r^2 \sin\theta^2 \tag{2.2.18}$$

By equations (2.2.17) and (2.2.18) we can write the combined equation as:-

$$\Lambda(-e^A) = -e^{(A-B)}\frac{1}{2}A'' - \frac{1}{4}A'B' + \frac{1}{4}A'^2 + \frac{A'}{r} \tag{2.2.19}$$

Since $R_{rr} = \Lambda g_{rr}$ and $g_{rr} = e^B$, we get

$$\Lambda(e^B) = \frac{1}{2}A'' - \frac{1}{4}A'B' + \frac{1}{4}A'^2 - \frac{B'}{r} \tag{2.2.20}$$

A little calculation shows that from this

$$A' = -B' \Rightarrow A = -B. \tag{2.2.21}$$

The integration constant is taken zero here; otherwise, it would result in a factor in the dt^2 terms. By a rescaling(changing the physical properties) of t, this factor could be absorbed anyway. The (tt) equation now gives:-

$$e^A(1 + rA') = 1 - \Lambda r^2 \tag{2.2.22}$$

Substituting $\alpha = e^{A(r)}$ equation (2.2.22) gives the differential equation $\alpha + r\alpha' = 1 - \Lambda r^2$,this can be written as

$$\frac{d}{dr}(r\alpha) = \frac{d}{dr}(r - \frac{\Lambda}{3}r^3) \tag{2.2.23}$$

giving

$$(r\alpha) = (r - \frac{\Lambda}{3}r^3 + M) \tag{2.2.24}$$

where M is the integration constant. Putting this equation(2.2.24) in the metric in equation (2.2.9) i.e $ds^2 = -e^{A(r)}dt^2 + e^{B(r)}dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2)$ as $\alpha = e^{A(r)}$ and $e^{B(r)} = \frac{1}{\alpha}$ From equation (2.2.24) we get

$$e^{A(r)} = \alpha = 1 - \frac{\Lambda}{3}r^2 + \frac{M}{r} \tag{2.2.25}$$

and

$$e^{B(r)} = \frac{1}{\alpha} = \frac{1}{(1 - \frac{\Lambda}{3}r^2 + \frac{M}{r})} \tag{2.2.26}$$

By equations (2.2.9) , (2.2.25) and (2.2.26) we ca conclude that:-

$$ds^2 = -e^{A(r)}dt^2 + e^{B(r)}dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.27}$$

since $\alpha = e^{A(r)}$ and $\frac{1}{\alpha} = e^{B(r)}$

$$ds^2 = -\alpha dt^2 + \frac{1}{\alpha}dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.28}$$

Using the values of α and $\frac{1}{\alpha}$ from equations (2.2.25) and (2.2.26) respectively in equation(2.2.28) we get

$$ds^2 = -(1 - \frac{\Lambda}{3}r^2 + \frac{M}{r})dt^2 + (\frac{1}{(1 - \frac{\Lambda}{3}r^2 + \frac{M}{r})})dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.29}$$

This equation(2.2.29) is called the Schwarzschid -de-Sitter metric [31]. **Note** :- The parameter M corresponds to a spherical mass in the origin. For $\Lambda = 0$, we obtain the

Schwarzschild solution to the EFEs , this metric models the curvature of spacetime under the influence of a mass M in the origin of the coordinate system. For M=0 , this metrc reduces to the de-Sitter metric ,

$$ds^2 = -(1 - \frac{\Lambda}{3}r^2)dt^2 + (\frac{1}{(1 - \frac{\Lambda}{3}r^2})dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.2.30}$$

The coordinates in this metric are also called static because they do not depend explicitly on the time coordinate.

2.3 Reissner-Nordstrom de-Sitter spacetime

The Reissner-Nordstrom de-Sitter metric is a known exterior, electro-vacuum solution of the Einstein-Maxwell equations. Einsteins field equation was given by equation:-

$$G_{\mu\nu} + \Lambda g_{\mu\nu} \equiv R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi T_{\mu\nu} \tag{2.3.1}$$

where $T_{\mu\nu} = M_{\mu\nu} + E_{\mu\nu}$ and $M_{\mu\nu}$ is Matter stress-Energy momentum tensor, where as $E_{\mu\nu}$ is Electromagnetic stress-Energy-momentum tensor . With these terms equation(2.3.1)above can be written as :-

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi(M_{\mu\nu} + E_{\mu\nu}) \tag{2.3.2}$$

The electromagnetic energy-momentum tensor $E_{\mu\nu}$ is given in terms of the electromagnetic field strength tensor $F_{\mu\nu}$, which is often referred to as the Faraday tensor:-

$$E_{\mu\nu} = \frac{1}{4\pi}(F_{\mu}^{\sigma}F_{\nu\sigma} - \frac{1}{4}g_{\mu\nu}F^{\sigma\rho}F_{\sigma\rho}) \tag{2.3.3}$$

where $F_{\mu\nu}$ is an anti-symmetric rank-two tensor so that $F_{\mu\nu} = -F_{\mu\nu}$. This tensor is defined in terms of the spatial three-vectors $\vec{E}$ and $\vec{B}$ which represent the electric and magnetic fields respectively. The Faraday tensor is then given by the relation $\vec{F_{\mu\nu}} = \partial_\mu \vec{A_\nu} - \partial_\nu \vec{A_\mu}$, thus in Cartesian coordinates this tensor becomes:-

$$\tilde{F_{\mu\nu}} = \begin{pmatrix} 0 & E_x & E_y & E_z \\ -E_x & 0 & E_z & -B_y \\ -E_y & -B_y & 0 & B_x \\ -E_z & B_y & -B_x & 0 \end{pmatrix}$$

To obtain this tensor in spherical coordinates, consider the transformation $r = \sqrt{x^2 + y^2 + z^2}$, $\cos\theta = \frac{z}{r}$, $\tan\phi = \frac{y}{x}$ with inverse $x = r\cos\phi\cos\theta$, $y = r\sin\theta\sin\phi$, $z = r\cos\theta$. Now the electromagnetic field strength tensor can be given in spherical coordinates, using the tensor transformation law $F^{\mu\nu} = \frac{\partial X^\mu}{\partial \tilde{x^\rho}} \frac{\partial X^\nu}{\partial \tilde{X^\sigma}} \tilde{F^{\rho\sigma}}$ we can convert each component of (2.3.3) and simplifying the resulting expressions. This yields for instance, $F^{tr} = \sin\theta(\cos\varphi E_x + \sin\phi E_y) + \cos\theta E_z = E_r = -F^{rt}$ and $F^{t\theta} = \frac{\cos\theta}{r}(\cos\phi E_x + \sin\phi E_y) - \frac{\sin\theta E_z}{r} = \frac{E\theta}{r} = -F^{\theta t}$. Computing the remaining components yields the Faraday tensor in spherical coordinates:- $F_{\mu\nu} = \begin{pmatrix} 0 & E_r & \frac{E_\theta}{r} & \frac{E_\phi}{r\sin\theta} \\ -E_r & 0 & \frac{B_\phi}{r} & \frac{-B_\theta}{r\sin\theta} \\ \frac{-E_\theta}{r} & \frac{-B_\phi}{r} & 0 & \frac{B_r}{r^2\sin\theta} \\ \frac{-E_\phi}{r\sin\theta} & \frac{B_\theta}{r\sin\theta} & \frac{-B_r}{r^2\sin\theta} & 0 \end{pmatrix}$

then indices can be lowered with $F_{\mu\nu} = g_{\sigma\mu} F^{\sigma\rho} g_{\rho\nu}$, using the spherically symmetric metric $g\mu\nu = (-e^a, e^b, r^2, r^2\sin^2\theta)$. This gives for example $F_{tr} = -e^{a+b}E_r = F_{rt}$, and the remaining components can be calculated similarly. The electromagnetic field strength tensor $F_{\mu\nu}$ must satisfy Maxwells equations, which can be written as:-

$$\partial_\mu(\sqrt{-g}F^{\mu\nu}) = \sqrt{-g}J^\nu \tag{2.3.4}$$

,

$$\partial_\mu(F^{\nu\sigma}) = 0 \tag{2.3.5}$$

$J^\mu = 4\pi\sigma U^\mu$ is the four-current density and is a product of the proper charge density σ and the four-velocity $U^\mu = \frac{dx^\mu}{dt}$ which satisfies $U^\mu U_\mu = -1$. The definition of the electromagnetic field strength tensor, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$, implies that Maxwells equation is automatically satisfied. Since we are working in a static and spherically symmetric spacetime with line element of the form:-

$$ds^2 = -e^a dt^2 + e^b dr^2 + r^2 d\Omega^2 \tag{2.3.6}$$

, where $d\Omega^2 = d\theta^2 + \sin\theta^2 d\phi^2$ is the line element for the two-sphere with unit radius, this implies J^μ is independent of the temporal and angular coordinates so that the only contribution is the radial component J^r. Thus equation (2.3.6) reduces the components of the field strength tensor to just the $F^{\mu r}$ entries in (2.3.5). Since we consider solutions in the absence of a magnetic field $\vec{B}$, this means the only non-zero components of $F^{\mu\nu}$ in a static and spherically symmetric spacetime are $F^{tr} = -F^{rt} = E_r$. Using Maxwells equation we obtain $e^{(a+b)/2} r^2 \sin\theta J^r = \partial_t [e^{(a+b)/2} r^2 \sin\theta F^{tr}]$, where $J^r = 4\pi\sigma U^r = 4\pi\sigma \frac{dr}{dt}$ therefore

$$F_{tr} = 4\pi e^{-(a+b)/2r^2} \int_0^r (e^{\frac{a+b}{2}} \tilde{r}^2 \sigma \frac{d\tilde{r}}{dt}) = \frac{e - (\frac{a+b}{2})}{r^2} q(r) \tag{2.3.7}$$

, or equivalently $F_{rt} = e^{\frac{(a+b)}{2}} \frac{q}{r^2} = -F_{tr}, q = q(r)$. Here q = q(r) is the total charge in the region [0, r] and is defined in terms of the charge density σ. Thus q(r) is given by:-

$$q(r) = 4\pi \int_0^r e^{\frac{(a+b)}{2}} \tilde{r}^2 \sigma d\tilde{r} \tag{2.3.8}$$

Using this we can compute the components of the electromagnetic energy-momentum tensor (2.3.3), the non-zero entries are the four diagonal elements $E^t_t = E^r_r = -E^\theta_\theta = -E^\phi_\phi = -\frac{q^2}{8\pi r^4}$. The matter energy-momentum tensor for a perfect fluid is given in terms of $T_{\mu\nu} = (\rho + P)U_\mu U_\nu + p g_{\mu\nu} = diag(e^a\rho, e^b P, r^2 P, r^2 \sin^2\theta P)$, with an anisotropic pressure this becomes:- $M^\nu_\mu = diag(-\rho, P, P_\perp, P_\perp)$ This can be put together to yield the components of the total energy momentum tensor :-

$$T^\nu_\mu = diag(-\rho - \frac{q^2}{8\pi r^4}, P - \frac{q^2}{8\pi r^4}, P_\perp + \frac{q^2}{8\pi r^4}, P_\perp + \frac{q^2}{8\pi r^4}) \tag{2.3.9}$$

$$T^{\mu}_{\nu} = \begin{pmatrix} -\rho - \frac{q^2}{8\pi r^4} & 0 & 0 & 0 \\ 0 & P - \frac{q^2}{8\pi r^4} & 0 & 0 \\ 0 & 0 & P_{\perp} + \frac{q^2}{8\pi r^4} & 0 \\ 0 & 0 & 0 & P_{\perp} + \frac{q^2}{8\pi r^4} \end{pmatrix}$$

Note that for non-zero charge **q** and pressures **p** , $p_{\perp}$, the condition of isotropy in the total energy momentum tensor $T^r_r - T^{\theta}_{\theta} = 0$ becomes $p - p_{\perp} = \frac{q^2}{4\pi r^2}$. Now the field equations can be written in component form:-

$$8\pi\rho + \frac{q^2}{r^4} = b'\frac{e^{-b}}{r} + \frac{1}{r^2}(1 - e^{-b}) - \Lambda \tag{2.3.10}$$

$$8\pi P - \frac{q^2}{r^4} = a'\frac{e^{-b}}{r} - \frac{1}{r^2}(1 - e^{-b}) + \Lambda \tag{2.3.11}$$

$$8\pi P_{\perp} + \frac{q^2}{r^4} = \frac{e^{-b}}{2}[a'' + (\frac{a'}{2} + \frac{1}{r})(a' - b')]\Lambda \tag{2.3.12}$$

The (t, t) field equation, given by equation (2.3.10), can be used to obtain the **total gravitational mass** is defined to be :-

$$m_g(r) = \underbrace{4\pi \int_0^r \tilde{r}^2 \rho d\tilde{r}} + \underbrace{4\pi \int_0^r e^{\frac{a+b}{2}} \tilde{r} \sigma q d\tilde{r}} \tag{2.3.13}$$

In the presence of a cosmological constant and charge, m_i can be obtained by inserting (2.3.13) in place of the energy density ρ. This yields:-

$$m_i = \frac{1}{2}\int_0^r \{\frac{d}{dr}(\tilde{r} - \tilde{r}e^{-b}) - \frac{q^2}{\tilde{r^2}} - \Lambda\tilde{r^2}\} d\tilde{r} \tag{2.3.14}$$

$\Rightarrow$

$$m_i = r(\frac{1 - e^{-b}}{2}) - \frac{\Lambda}{6}r^3 - \int_0^r \frac{q^2}{2\tilde{r^2}} d\tilde{r} \tag{2.3.15}$$

Next, in order to obtain the **exterior Reissner-Nordstrom de- Sitter line element**, the electromagnetic mass m_q must be written as:-

$$m_q = \int_0^r [\frac{q2}{2\tilde{r^2}} d\tilde{r}] + \frac{q^2}{2r} \tag{2.3.16}$$

Substituting m_i and $m_q$into the definition of m_g in equation (2.3.13) and rearranging gives $e^{-b} = 1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2$. In the Reissner-Nordstrom de- Sitter exterior, we have $r \geq R$, where R is the boundary of the matter distribution and is often referred to as the total radius. This implies the metric coefficient

$$e^{-b} = 1 - \frac{2M_g}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2 \tag{2.3.17}$$

where $M_g = m_g(R)$ and $Q = q(R)$ represent the total gravitational mass and charge respectively. To fix the remaining metric coefficient e^a, consider the (r, r) component of the electro-vacuum field equations, that is when $r \geq R$. Rearranging for a' yields:-

$$a' = \frac{2e^b}{r}(\frac{M_g}{r} - \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2) \tag{2.3.18}$$

Note, taking the derivative of equation (2.3.17) and comparing with the equation above yields the relation $b' = -\frac{2eb}{r}(\frac{M_g}{r} - \frac{Q^2}{r^3} - \frac{\Lambda}{3}r^2) = -a'$, this implies $e^a = e^{-b}$. Therefore the remaining metric coefficient for the **exterior solution** can be written explicitly as:-

$$e^a = 1 - \frac{2M_g}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2 \tag{2.3.19}$$

.In the **interior**, the metric coefficients can be written as

$$e^a = 1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2 = e^{-b} \tag{2.3.20}$$

The solution (2.3.6) with metric coefficients (2.3.19) and (2.3.20) gives the exterior Reissner-Nordstrom de Sitter solution [32].The line element is:-

$$ds^2 = -(1 - \frac{2M_g}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2)dt^2 + (1 - \frac{2M_g}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2)^{-1}dr^2 + r^2(d\theta^2 + \sin\theta^2 d\phi^2) \tag{2.3.21}$$

Chapter 3

The dynamics of systems around AGN

Boundary conditions

In studying the dynamism of AGN on its surrounding system(host galaxy)we applied GR and the governing EFEs solutions in different mechanisms, MHD and hydrodynamic equilibrium in two different conditions(rotating and non-rotating cases).

1. We have selected the SdS geometry because it allows us in describing the combined effects of an attracting central object and cosmic repulsion determined by cosmological constant(Λ).

2. We have used Reissner-Nordstrom de-Sitter spacetime because it is a solution to EFEs that describes the spacetime around a Spherically Symmetric non-rotating body with mass M and an electric charge Q (specially for the case of TOV equations for charged massive body).

3. We make also use of MHD to describe electrically conducting fluids in which a magnetic field($\overrightarrow{B}$) is present.

4. Finally we also solved TOV equations for the uncharged object because the presence of magnetic field($\overrightarrow{B}$) addresses Magneto-Rotational-instablities(MRI) around

the disc of AGN then stars in torus rotates around the axis of central SMBH.

An active galaxy possesses are an intrinsic axial symmetry due to the spin of the SMBH. This symmetry leave sits imprint on the host in the form of an anisotropic illuminating radiation field and the effects of the jets that initially trace the AGN spin axis. This has the important consequence that active galaxies appear quite different when viewed from large and small angles to the AGN spin axis. The host galaxy feels the presence of its nuclear SMBH through the gravitational effect of its mass, through the ionizing and non-ionizing radiation field emitted by the AGN and by the particle flows in the jets and radiation pressure driven winds with any associated magnetic fields . In this chapter, our concern lies principally with the radiation field and with the AGN-related flows. The primary radiation source associated with the SMBH is assumed to be more or less isotropic. However, beyond the scale of 100pc, this intrinsic isotropy may have been destroyed by absorption, most notably by the presence of an optically thick equatorial torus surrounding the black hole . Such a structure can produce sharply defined shadows and it is thought to be responsible for most, if not all, of the ionization cones first seen in the emission line images of Seyfert galaxies. The radiation field affects the material within these ionization cones in a number of ways, each of which produces characteristic observable phenomena. The photo ionization process results in a spatially extended emission line region which is variously known as the Extended Emission Line Region (EELR) or the (Extended) Narrow Line Region (ENLR). The term narrow is use d to contrast this region with the much smaller and much less massive Broad Line Region (BLR) surrounding the nucleus . The emission line widths actually extend over a broad range of values from the relatively quiescent interstellar medium of the galaxy which happens to be illuminated by the nucleus , to material that may be shocked by AGN-driven winds or jets. In many objects, there appears to be a correlation be tween line width and ionization state that may reflect either differences in density or the presence of alternative ionization mechanisms. A notable characteristic of the NLR is the wide range of ionization levels present in the gas. The presence of dust within the ionization cones has a number of consequences . AGN photons can ionize dust grains , donating high kinetic energy electrons to the gas and so affecting the thermal balance . The photons can also efficiently transfer momentum to grains and thus, by dragging the gas along with them , pro duce radiation pressure driven winds . The presence of the se winds can be inferred from the emission line shifts and widths . Another consequence of dust is the result of its high cross section for scattering. Dust clouds can act as mirrors that allow us to see the AGN along indirect sightlines in sources where the AGN is obscured. The presence of scattered light can be most directly inferred by measuring linear polarization. In the axisymmetric bi-conical geometry of an AGN, a net line ar polarization with the E-vector perpendicular to the cone axiscan remain even after the spatial averaging by the polarimeter of unresolved sources. Hot electrons can also Thompson scatter and, hence, polarize, AGN radiation although electrons are far less efficient scatters than dust grains, and clouds with sufficient Thompson optical depth appear quite rare away from the immediate nuclear environment. Electron-scattered spectra will be significantly smeared in wavelength due to high Doppler velocities in a hot, highly ionized plasma. The process of accretion onto the SMBH results in the generation of substantial amounts of kinetic energy. This is transported both in the form of highly collimated jets , seen predominantly in radio- loud sources , and as more isotropic winds . The evidence from some (radio quiet) Broad Absorption Line (BAL)

QSOs suggests that fast winds can carry a substantial fraction of the AGN power, perhaps even approaching that of its radiative output. While the AGN radiation field produce s its dominant effects on the ISM of the host galaxy, the winds and jets probably transport their energy to larger scales and dissipate it in the tenuous and already hot intergalactic medium (IGM). The passage of this kinetic energy through the galaxy can, however, influence the way the ISM is distributed and, by driving shocks , increase the gas density in some regions. Both the shocks themselves , and the density changes they produce, an influence the line emission from the gas in the galaxy. The reaction of an AGN, in the form of its radiative and kinetic output, to the rate and form of accretion onto the SMBH constitutes a potential feedback loop that can limit growth and, perhaps, establish the apparent observed relationship between the black hole mass and that of the host galaxy bulge . The correlations measured between black hole masses and the velocity dispersions and/or masses of their host galaxies bulges suggest a direct relationship between supermassive black hole(SMBH) formation and galaxy formation [30].

3.1 TOV equations for charged massive Objects

In a static and spherically symmetric spacetime with line element of the form:-

$$ds^2 = -e^a dt^2 + e^b dr^2 + r^2 d\Omega^2 \tag{3.1.1}$$

, where $d\Omega^2 = d\theta^2 + \sin\theta^2 d\phi^2$ is the line element for the two-sphere with unit radius, or equivalently $F_{rt} = e^{\frac{(a+b)}{2}} \frac{q}{r^2} = -F_{tr}, q = q(r)$. Here q = q(r) is the total charge in the region [0, r] and is defined in terms of the charge density σ. Thus q(r) is given by:-

$$q(r) = 4\pi \int_0^r e^{\frac{(a+b)}{2}} \tilde{r}^2 \sigma d\tilde{r} \tag{3.1.2}$$

Using this we can compute the components of the electromagnetic energy-momentum tensor (3.1.3), the non-zero entries are the four diagonal elements $E_t^t = E_r^r = -E_\theta^\theta = -E_\phi^\phi = -\frac{q^2}{8\pi r^4}$. The matter energy-momentum tensor for a perfect fluid is given in terms of $T_{\mu\nu} = (\rho + P)U_\mu U_\nu + pg_{\mu\nu} = diag(e^a\rho, e^bP, r^2P, r^2\sin^2\theta P)$, with an anisotropic pressure this becomes:- $M_\mu^\nu = diag(-\rho, P, P_\perp, P_\perp)$ This can be put together to yield the components of the total energy momentum tensor :-

$$T_\mu^\nu = diag(-\rho - \frac{q^2}{8\pi r^4}, P - \frac{q^2}{8\pi r^4}, P_\perp + \frac{q^2}{8\pi r^4}, P_\perp + \frac{q^2}{8\pi r^4}) \tag{3.1.3}$$

For non-zero charge q and pressures p , $p_\perp$, the condition of isotropy in the total energy momentum tensor $T_r^r - T_\theta^\theta = 0$ becomes .

$$p - p_\perp = \frac{q^2}{4\pi r^2} \tag{3.1.4}$$

$\Rightarrow$

$$p_\perp = p - \frac{q^2}{4\pi r^2} \tag{3.1.5}$$

Now the field equations can be written in component form:-

$$8\pi\rho + \frac{q2}{r4} = b'\frac{e^{-b}}{r} + \frac{1}{r^2}(1 - e^{-b}) - \Lambda \tag{3.1.6}$$

$$8\pi P - \frac{q2}{r4} = a'\frac{e^{-b}}{r} - \frac{1}{r^2}(1 - e^{-b}) + \Lambda \tag{3.1.7}$$

$$8\pi P_\perp + \frac{q2}{r4} = \frac{e^{-b}}{2}[a'' + (\frac{a'}{2} + \frac{1}{r})(a' - b')]\Lambda \tag{3.1.8}$$

The (t, t) field equation, given by equation (3.1.6), can be used to obtain the total gravitational mass is defined to be :-

$$m_g(r) = \underbrace{4\pi\int_0^r \tilde{r}^2\rho d\tilde{r}} + \underbrace{4\pi\int_0^r e^{\frac{a+b}{2}}\tilde{r}\sigma q d\tilde{r}} \tag{3.1.9}$$

In the presence of a cosmological constant and charge, m_i can be obtained by inserting (2.3.15) in place of the energy density ρ. This yields:-

$$m_i = \frac{1}{2}\int_0^r \{\frac{d}{dr}(\tilde{r} - \tilde{r}e^{-b}) - \frac{q2}{\tilde{r^2}} - \Lambda\tilde{r^2}\}d\tilde{r} \tag{3.1.10}$$

$\Rightarrow$

$$m_i = r(\frac{1 - e^{-b}}{2}) - \frac{\Lambda}{6}r^3 - \int_0^r \frac{q^2}{2\tilde{r^2}}d\tilde{r} \tag{3.1.11}$$

Next, in order to obtain the exterior Reissner-Nordstrom de- Sitter line element, the electromagnetic mass m_q must be written as:-

$$m_q = \int_0^r [\frac{q2}{2\tilde{r^2}}d\tilde{r}] + \frac{q^2}{2r} \tag{3.1.12}$$

Substituting m_i and $m_q$into the definition of m_g in equation (3.1.9) and rearranging gives $e^{-b} = 1 - \frac{2m_g}{r} + \frac{q^2}{r2} - \frac{\Lambda}{3}r^2$. In the Reissner-Nordstrom de- Sitter exterior, we have $r \geq R$, where R is the boundary of the matter distribution and is often referred to as the total radius. This implies the metric coefficient

$$e^{-b} = 1 - \frac{2M_g}{r} + \frac{Q^2}{r2} - \frac{\Lambda}{3}r^2 \tag{3.1.13}$$

where $M_g = m_g(R)$ and $Q = q(R)$ represent the total gravitational mass and charge respectively. To fix the remaining metric coefficient e^a, consider the (r, r) component of the electro-vacuum field equations,equation(2.3.19) that is when $r \geq R$. Rearranging for a' yields:-

$$a' = \frac{2e^b}{r}(\frac{M_g}{r} - \frac{Q^2}{r^2} - \frac{\Lambda}{3}r^2) \tag{3.1.14}$$

Now taking the the derivatives of equation(3.1.14)w.r.t "r" and comparing it to equation(3.1.13) yields the relation $b' = -a' \Rightarrow e^a = e^{-b}$

$\therefore$

$$b' = \frac{-2}{r} e^b \left(\frac{M_g}{r} - \frac{Q^2}{r^2} - \frac{\Lambda}{3} r^2 \right) = -a' \tag{3.1.15}$$

Then

$$e^a = 1 - \frac{2M_g}{r} + \frac{Q^2}{r^2} - \frac{\Lambda}{3} r^2 \tag{3.1.16}$$

for the exterior solution. In the interior, the metric coefficients can be written as:-

$$e^a = 1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3} r^2 = e^{-b} \tag{3.1.17}$$

Here we can construct a TOV-like conservation equation which governs the hydrostatic equilibrium of a charged spherically symmetric solution in de Sitter space. Given the SdS spacetime with anisotropic pressure $P \neq P_{\perp}$, first we differentiate p with respect to r using equation (3.1.7), this becomes:-

$$\frac{d}{dr}[8\pi P - \frac{q^2}{r^4} = \frac{a' e^{-b}}{2} - \frac{1}{r^2}(1 - e^{-b}) + \Lambda] \tag{3.1.18}$$

this results that:-

$$8\pi P' = \frac{e^{-b}}{r}(a'' - a'b' - \frac{1}{r}(a' + b')) + \frac{2}{r^3}(1 - e^{-b}) - \frac{4q^2}{r^5} + \frac{2qq'}{r^4} \tag{3.1.19}$$

If we combine equations (3.1.6) and (3.1.19) we get :-

$$8\pi(\rho + P) = \frac{e^{-b}}{r}(a' + b') \tag{3.1.20}$$

and combining equations (3.1.8)and(3.1.19) we get :-

$$8\pi(P - P_{\perp}) = \frac{e^{-b}}{2}(a'' + \frac{a'}{2}(a' - b') - \frac{1}{r}(a' + b') - \frac{1}{r^2}(1 - e^{-b}) + \frac{2q^2}{r^4}) \tag{3.1.21}$$

If we multiply equation(3.1.20) by $\frac{a'}{2}$ yields :-

$$\frac{a'}{2}[8\pi(\rho + P) = \frac{e^{-b}}{r}(a' + b')] \tag{3.1.22}$$

$\Rightarrow$

$$4a'\pi(\rho + P) = \frac{a'e^{-b}}{2r}(a' + b') \tag{3.1.23}$$

Again multiplying (3.1.21) by $\frac{2}{r}$ yields:-

$$\frac{16}{r}\pi(P - P_\perp) = -\frac{e^{-b}}{r}(a'' + \frac{a'}{2}(a' - b') - \frac{1}{r}(a' + b') - \frac{2}{r^3}(1 - e^{-b}) + \frac{2q^2}{r^5}) \tag{3.1.24}$$

Adding equations (3.1.23)and (3.1.24)yields that:-

$$4\pi a'(\rho + P) + \frac{16\pi}{r}(P - P_\perp) = \frac{4q^2}{r^5} - \frac{e^{-b}}{r}[a'' - a'b' - \frac{1}{r}(a' + b') - \frac{2}{r^3}(1 - e^{-b})] \tag{3.1.25}$$

Now we can use (3.1.23) to eliminate some terms in (3.1.19) Which yields the conservation equation:-

$$P' + \frac{a'}{2}(\rho + P) + \frac{2}{r}(P - P_\perp) - \frac{qq'}{4\pi r^4} = 0 \tag{3.1.26}$$

If we make use of the expression for e^{-b} in the interior given by :-

$$e^{-b} = 1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2 \tag{3.1.27}$$

and inserting (3.1.26) in (r,r)field equation (3.1.7), From (3.1.26)

$$P = -\frac{1}{\frac{a'}{2} + \frac{2}{r}}(P' + \frac{a'}{2}\rho - \frac{2}{r}P_\perp - \frac{qq'}{4\pi r^4}) \tag{3.1.28}$$

Using this equation directly in(3.1.28) results:-

$$\frac{a'}{2} = \frac{4\pi rP + \frac{m_g}{r^2} - \frac{q^2}{r^3} - \frac{\Lambda}{3}r}{1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2} \tag{3.1.29}$$

If we put (3.1.29) in place of **a'**in equation(3.1.19)t yields that:-

$$P' + \frac{4\pi rP + \frac{m_g}{r^2} - \frac{q^2}{r^3} - \frac{\Lambda}{3}r}{1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2}(\rho + P) + \frac{2}{r}(P - P_\perp) - \frac{qq'}{4\pi r^2} = 0 \tag{3.1.30}$$

This equationis the **TOV** -like conservation for charged massive object in **de-Sitter** space [33].

3.2 Magnetohydrodynamics(MHD)

Magnetohydrodynamics describes electrically conducting fluids in which a magnetic field is present. A high electrical conductivity is ubiquitous in astrophysical objects. Many astrophysical phenomena are influenced by the presence of magnetic fields, or even explainable only in terms of magnetohydrodynamic processes. The atmospheres of planets are an exception. Much of the intuition we have for ordinary earth-based fluids is relevant for MHD as well, but more theoretical experience is needed to develop a feel for what is specific to MHD. The equations of magnetohydrodynamics are a reduction of the equations of fluid mechanics coupled with Maxwells equations. Compared with plasma physics in general, MHD is a strongly reduced theory. Of the formal apparatus of vacuum electrodynamics with its two **EM** vector fields, currents and charge densities, MHD can be described with only a single additional vector : the magnetic field. The MHD approximation that makes this possible involves some assumptions :

1. The fluid approximation : Local thermodynamic quantities can be meaningfully defined in the plasma, and variations in these quantities are slow compared with the time scale of the microscopic processes in the plasma. This is the essential approximation. 2. In the plasma there is a local, instantaneous relation between electric field and current density (an Ohms law). 3. The plasma is electrically neutral:This statement of the approximation is somewhat imprecise. The first of the assumptions involves the same approximation as used in deriving the equations of fluid mechanics and thermodynamics from statistical physics. It is assumed that a sufficiently large number of particles is present so that local fluid properties, such as pressure, density and velocity can be defined. It is sufficient that particle distribution functions can be

defined properly on the length and time scales of interest. In 2. it is assumed that whatever plasma physics processes take place on small scales, they average out to an instantaneous, mean relation (not necessarily linear) between the local electric field and current density, on the length and time scales of interest. The third assumption of electrical neutrality is satisfied in most astrophysical environments, but it excludes near-vacuum conditions such as the magnetosphere of a pulsar. Electrical conduction, in most cases, is due to the (partial) ionization of a plasma. The degree of ionization needed for 2. to hold is generally not large in astrophysics. The approximation that the density of charge carriers is large enough that the fluid has very little electrical resistance : the assumption of perfect conductivity, is usually a good first step. Exceptions are, for example, pulsar magnetospheres, dense molecular clouds or the atmospheres of planets. **Note:-** In astrophysics fluid is used as a generic term for a gas, liquid or plasma.

3.3 Tolman-Oppenheimer-Volkoff Equation for charge free massive objects

The equilibrium of a spherically symmetric star consisting of a perfect fluid in equilibrium with its gravitational field is determined by the Tolman-Oppenheimer-Volkoff(TOV)equations:-

$$\frac{dP(r)}{dr} = -\frac{G}{r^2}[\rho(r) + \frac{P(r)}{c^2}][m(r) + \frac{4\pi r^3 P(r)}{c^2}][1 - \frac{2Gm(r)}{rc^2}]^{-1} \tag{3.3.1}$$

where the P(r) and $\rho(r)$ are the pressure and density at radial coordinate r, and

$$m(r) = \int_0^r d^3r'\rho(r') \tag{3.3.2}$$

is mass contained within a sphere of **r**. It is convenient in astrophysical and cosmological calculations to use a Geometrized unit system to avoid arithmetic overflow or underflow in combining very large and small numerical values. For example, we can set:-

$$\hbar = c = G = \frac{1}{4\pi\epsilon} = 1 \tag{3.3.3}$$

by choosing appropriate units of mass, length, time, temperature, and electric charge. In relativity and cosmology all physical quantities are expressed in terms of a single unit of length (geometry). For example, time is measured in meters and $1s = 2.99 \times 10^8$m and the mass of the Sun is $M_{\odot} = 1.4766km$. SI units can always be recovered from the dimensions of the quantity and appropriate conversion factors. In high energy physics, quantities are expressed in terms of energy and the system is termed natural units. It can be shown that the most spherically symmetric metric can be written in terms of two metric functions $\Phi(r,t)$ and $\lambda(r,t)$ independent of the angular coordinates $\Omega = (\theta, \varphi)$:

$$ds^2 = -e^{2\Phi}dt^2 + e^{2\lambda}dr^2 + r^2 d\Omega^2 \tag{3.3.4}$$

For an isolated star, the density $\rho(r)$ is zero outside a finite radius r = R and the metric must reduce to the Schwarzschild metric.

$$ds^2 = -(1 - \frac{2M}{r})dt^2 + (1 - \frac{2M}{r})^{-1}dr^2 + r^2 d\Omega^2 \tag{3.3.5}$$

where M is the total mass inside of the star. According to Birkhoffs theorem this is actually also true for any spherically symmetric time-dependent density inside of the star! Einsteins equation

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu} \tag{3.3.6}$$

for spherically symmetric stars can now be written in terms of the metric functions Φ, λ. For stellar applications the cosmological constant Λ just contributes a constant background energy and can be dropped. In addition, for a static solution the metric functions do not depend on the time t. General covariance still leaves some freedom in choosing the form of the metric functions. A convenient choice is to related them to the mass within a radius r with the definition

$$e^{\lambda(r)} = \frac{1}{1 - \frac{2m(r)}{r}} \tag{3.3.7}$$

This is possible because the coordinate r is not the invariant distance measured by a meter stick from the center of the star. The invariant distance is determined by integrating ds once the metric is known.

Assuming zero temperature T = 0, the Equation of State(EOS) gives the pressure $P(\rho)$ and a function of the density $\rho(r)$ at radial coordinate r. Actually, P and ρ are not the pressure and density measured by an external observer, but the proper pressure and density in an inertial (freely falling) coordinate system at the point r. The TOV equilibrium equation is:-

$$\frac{dP}{dr} = -\frac{\rho m}{r^2}[1 + \frac{P}{\rho}][1 + \frac{4\pi r^3 P}{m}][1 - \frac{2m}{r}]^{-1} \tag{3.3.8}$$

The mass inside radius r is determined by the equation:-

$$\frac{dm}{dr} = 4\pi r^2 \rho \tag{3.3.9}$$

This is a system of 2 ordinary differential equations for 3 unknown functions with the EOS relating **P** and ρ.They can b e solved by integrating from r = 0 outward with starting values $\rho(0)$, P(0) = P($\rho(0)$) , m(0) = 0 , and integrating outward until the pressure drops to zero. P(R) = 0 , m(R) = M , to obtain the mass of the star M($\rho(0)$) as a function of the central density. This integration yields the pressure profile P(r), and the corresponding density profile $\rho(r)$ for given central density. The metric inside the star must match smoothly onto the Schwarzschild metric at the surface. The equation for the metric function is:-

$$\frac{d\Phi}{dr} = -\frac{1}{\rho}\frac{dP}{dr}(1 + \frac{P}{\rho})^{-1} \tag{3.3.10}$$

This can be integrated with starting condition :-

$$\Phi(r = R) = \frac{1}{2}\ln(1 - \frac{2M}{R}) \tag{3.3.11}$$

at the surface of the star, down to the center of the star.

Assuming a polytropic star makes the relativistic structure analysis easier and more interpretable. Solutions should satisfy appropriate boundary condition(s) in order to explain various astrophysical objects from compact stars to galactic objects . Almost all polytropic models assume an isotropic pressure. Here, we allow anisotropic cases by assuming different tangential and radial pressure components in the energy-momentum tensor. All principal pressures (stresses) are assumed to have double-polytropic equations of state . A number of authors have investigated anisotropic models . Assuming anisotropic stresses is by no means un-natural. For example, in a compact star, although the radial pressure vanishes at the surface one still could postulate a tangential pressure to exist. While the latter does not alter the spherical symmetry, it may create some streaming fluid motions. The Reissner-Nordstrom solution is another relativistic solution which is supported by anisotropic stresses. A charged black hole readily results in negative radial pressure, while the tangential pressure remains positive. This anisotropic pressure originates from the fact the phase space distribution function of the stars depends on coordinates and velocities only through the constants of motion (energy and angular momentum). If the distribution function depends on the magnitude of the angular momentum, this will lead to an anisotropic pressure, even if the system is spherically symmetric. In what follows, we first derive the TOV equation for an anisotropic fluid with spherical symmetry .

Note:- We started with generalizing the TOV equation for a gravitating relativistic sphere with an anisotropic, barotropic fluid. We adapted an equation of state which has a linear term plus a power-law term which is encountered in various polytropic fluids.

To progress toward a solution of the TOV Equation we assume a polytropic equation of state (EOS) for a relation between the isotropic pressure and the rest mass density [34].

$$P = K\rho^{\Gamma} \tag{3.3.12}$$

where Γ is the adiabatic index and K is a normalization constant. For adiabatic processes we may neglect heat transfer (i.e. dQ = 0) so the first law of thermodynamics is simply

$$dU = -PdV, \tag{3.3.13}$$

where$U = \epsilon V$ is the total energy of the fluid in a volume **V**, including both the rest energy and internal energy. However, we may write the rest mass density as $\rho = mN/V$, where **N** is the number of particles of mass m in the same volume V.

Chapter 4

Result and Discussion

By now we have developed a handful of tools with appropriate boundary conditions. Here, we use these tools (the boundary conditions and the derived equations in chapter 3) to discuss how the AGN plays role in hosting galaxy in the form of pressure feedback.

4.1 The radial radiation pressure

As derived in chapter 3, the conservation like generalized TOV equation is given by:

$$P' + \frac{4\pi r P + \frac{m_g}{r^2} - \frac{q^2}{r^3} - \frac{\Lambda}{3}r}{1 - \frac{2m_g}{r} + \frac{q^2}{r^2} - \frac{\Lambda}{3}r^2}(\rho + P) + \frac{2}{r}(P - P_\perp) - \frac{qq'}{4\pi r^2} = 0 \tag{4.1.1}$$

Integrating this equation we obtain the radial pressure dependent on the parameters: q, $M(r)$, $\rho(r)$, Λ, core parameters(void mass, density, radius, height) given by

$$P = \frac{[(\alpha\rho) + (q^2 + 16\pi r^4)\beta] \pm \sqrt{[\alpha\rho + (q^2 + 16\pi r^4)\beta]^2 - 512\pi^3 \rho r^6 \gamma \beta^2}}{16\pi r^2 \gamma\beta} \tag{4.1.2}$$

where we defined, α, β and γ as

$$\alpha = \frac{m_g}{r} + \frac{2q^2}{r^3} + \frac{\Lambda}{3}r^2 \tag{4.1.3}$$

$$\beta = \frac{2m_g}{r^2} - \frac{2q^2}{r^3} - \frac{2}{3}\Lambda r^2 \tag{4.1.4}$$

$$\gamma = \frac{2m_g}{r^2} - \frac{m_g}{r} - \frac{4q^2}{r^3} - \Lambda r^2 \tag{4.1.5}$$

Here we have generated a numerical result of the spectrum of pressure for some selected theoretically acceptable mass, mean density of the galaxy and void core parameters. As we learn from the pressure spectrum plot and its equation, we have

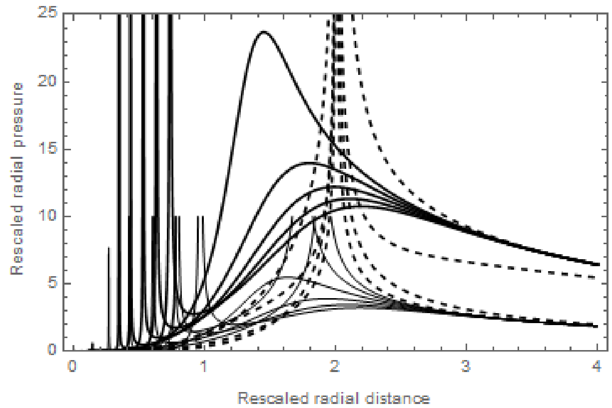

Figure 4.1: In the plot the dashed spectrum represents charge free AGN. The solid thick one represents low mass, low mean density galaxy where charge is being varied. Accordingly the higher peaks stand for higher charge value and so on. The black thin spectrum represents high mass with reasonably higher mean density galaxy where charge is being varied.

the following points and comments.

1) The AGN plays role on hosting galaxy evolution, especially closer to it. Because as pressure creates turbulence to trigger rotations that can possibly enhance star formation where there is sufficient cold gas cloud system. In fact the effect decreases with distance.

2) In confirmation with observations we draw a conclusion that just next to the AGN the environment is quiet and hence no star formation expected.

3) The charge also matters in terms of the level of effect of star formation and as well where to play role in the formation.

4) We have also learned that Λ has no significant effect in AGN role against the host galaxy.

5) The void parameters enter with significant role.

Chapter 5

Summary and Conclusion

In order to study the role of AGN evolution in galaxy evolution, we have successfully developed a technique that enables us to understand about it taking into account realistic merger and gas accretion histories. We also emphasize that gas accretion from filaments(a massive,thread like structure) can allow to rebuild a thin disk in a galaxy, which proves the absolute necessity to take this accretion into account to understand galaxy evolution. Moreover, we used more simplifying boundary conditions to conjuncture for the scientific communities to develop the technique whenever GR is in the vicinity.

On the other hand, we emphasise that even though the method we have adopted is so viable as we see from the results, a further comprehensive work is necessary to develop a model of this kind.

The following conclusions and Remarks are given:-

- The AGN plays role on hosting galaxy evolution, especially closer to it.
- The charge also matters in terms of the level of effect of star formation and as well where to play role in the formation.

- The void parameters enter with significant role.

- Finally, it is our hope that the scientific community will communicate this work for the conjuncture we have made here to enhance.

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