Abstract

The rotation curve of galaxies and a few other observations suggest that a major part of the matter in disc galaxies is non-luminous or dark. On the other hand the discovery of the accelerating expansion of Universe has led inclusion of a new dominant component into the energy-momentum tensor of the universe having negative pressure, the so called dark energy component. Several other observations which include the cosmic microwave background (CMB) measurements, baryon acoustic oscillations (BAO), lensing in clusters support the existence of dark energy and/or the presence of dark matter halo surrounding the Galactic disc. Consequently on large distance scales, astrophysical and cosmological phenomena are governed mainly by dark matter and dark energy.

There are several proposed candidates for dark matter but despite extensive experimental searches no direct evidence of dark matter has been found so far. There are also proposals for modifications of relativity theory at the fundamental theoretical level which include Modified Newtonian dynamics (MOND), the conformal gravitational theory (based on Weyl symmetry), Grumiller's modified gravity model etc all of which can explain flat rotation curves of galaxies without the need of dark matter. The simplest candidate for dark energy is the cosmological constant (Λ) *and the* Λ*CDM model where CDM refers to cold dark matter, is in accordance with all the existing cosmological observations. But it has a big theoretical problem - the magnitude of* Λ ($\sim 10^{-52}\ m^{-2}$) *is many orders of magnitude smaller than the expected vacuum energy density in the standard model of particle physics. Hence many other theoretical explanations for the DE have been proposed in the literature in which the parameter* w *evolves with time or different from* -1. *A few alternative theories also have been proposed other than the General Theory of Relativity to explain the dark energy consequences, like f(R) gravity model, DGP model which is based on Strings theory etc.*

Dark matter/energy is supposed to affect the gravitational phenomena in all distance scales including the local scales. As the evidences of dark sector so far are found only in large distance scale observations, the study of effects of dark energy/matter on local gravitational phenomena may provide important observable

signature of dark sector and may assist to understand the nature of the dark sector. Already some analysis have been performed so far in this direction. In the present thesis work, the influences of dark matter and dark energy on different local gravitational phenomena have been examined theoretically considering different models of dark matter/energy. Emphasis has been given to examine the viability of different models of dark matter and dark energy by comparing the theoretical predictions based on the models with the observations.

In first chapter, the introduction of the thesis work has been given including the basics of dark matter and energy. After outlining the objective of the thesis work, the current status of the local gravitational effects of dark sector has been reviewed.

In second chapter, the effect of dark matter/energy on gravitational time advancement (negative effective time delay) has been studied considering few dark energy/matter models including cosmological constant. It is found that presence of dark energy field gives only (positive) gravitational time delay irrespective of the position of the observer whereas pure Schwarzschild geometry leads to gravitational time advancement when the observer is situated at relatively stronger gravitational field point in the light trajectory. Consequently, there will not be any time advancement effect at radial distances where gravitational field due to dark energy is stronger than the gravitational field due to Schwarzschild geometry.

In third chapter, the expression of gravitational time advancement (negative time delay) for particles with non-zero mass in Schwarzschild space-time geometry has been obtained. The influences of the gravitational field that explains the observed rotation curves of spiral galaxies and that of dark energy (in the form of cosmological constant) on time advancement of particles have also been investigated in this chapter. The present findings suggest that in presence of dark matter gravitational field, the gravitational time advancement may take place irrespective of gravitational field of the observer, unlike the case of pure Schwarzschild geometry where gravitational time advancement takes place only when the observer is situated at stronger gravitational field compare to the gravitational field encountered by the particle during its journey. When applied to the well known case of SN 1987a, it is found that the net time delay of a photon/gravitational wave is much smaller than quoted in this chapter. In the presence of dark matter field, the photon and neutrinos from SN 1987a should have been suffered gravitational time advancement rather than the gravitational time delay.

In fourth chapter, gravitational deflection of light rays due to the space-time metric of global monopole and a Schwarzschild black hole that swallowed a global monopole have been studied considering the asymptotically non-flat behavior of the space-time geometries of the stated configurations. It is found that so obtained gravitational bending angles differ considerably from those obtained from conventional approach, which is essentially applicable to asymptotically flat space time geometries. More importantly the bending angle is obtained negative when the lensing system contains global monopole which is a clear signature of a global monopole system. Implications of the present analysis on the viability of global monopole as an alternative to dark matter hypothesis is discussed.

In fifth chapter, space-time geometry of the halo region in spiral galaxies is derived using the observed galactic flat rotation curve feature and considering the characteristics of cold dark matter in the galaxy. Gravitational lensing due to the derived space time has been studied. The total mass of Abell 370 galaxy clusters estimated from the derived space-time is found to agree well with the gravitational lensing observations.

In sixth chapter, Grumiller's quantum motivated modified gravity model, which modifies the Newtonian potential at large distances and describes the galactic rotation curves of disk galaxies in terms of a Rindler acceleration term, has been tested through the baryonic Tully-Fisher relation. We estimate Rindler acceleration parameter from observed rotation velocity versus baryonic mass data of a sample of sixty galaxies. It has been found that the Rindler parameters describes the observed data reasonably well.

And the last (seventh) chapter, we conclude our findings.

The material/results reported in this thesis have been published/communicated in different journals as shown below:

1. *"Influences of dark energy and dark matter on gravitational time advancement"*, Samrat Ghosh and Arunava Bhadra, The European Physical Journal C volume 75, Article number: 494 (2015).

2. *"Probing dark matter and dark energy through gravitational time advancement"*, Samrat Ghosh, Arunava Bhadra and Amitabha Mukhopadhyay, General Relativity and Gravitation volume 51, Article number: 54 (2019).

3. *"Gravitational lensing by global monopole"*, Kabita Sarkar, Samrat Ghosh and Arunava Bhadra, communicated for publication.

4. *"Space-time geometry of spiral galaxy halo"*, Samrat Ghosh, Arunava Bhadra and Amitabha Mukhopadhyay, communicated for publication.

5. *"Baryonic Tully-Fisher test of Grumiller's modified gravity model"*, Samrat Ghosh, Arunava Bhadra and Amitabha Mukhopadhyay and Kabita Sarkar, communicated for publication.

The conference presentations out of the thesis work are given below

1. *"Influence of dark matter and dark energy on gravitational time advancement"*, Samrat Ghosh, Arunava Bhadra, National Conference on "Exploring the Relativistic Universe", University of North Bengal, West Bengal, December 15-16, (2015).

2. *"Probing Dark Energy through Gravitational Wave Lensing"*, Samrat Ghosh, Arunava Bhadra and Amitabha Mukhopadhyay, National Conference on "Exploring the Cosmos: 2016-17", University of North Bengal, West Bengal, January 16-17, (2017).

3. *"Effect of Dark Energy and Dark Matter on Gravitational Time Advancement for a Relativistic Particle of Non-zero mass"*, Samrat Ghosh, Arunava Bhadra and Amitabha Mukhopadhyay, National Conference on "Exploring the Cosmos: A national Conference on Relativistic Universe", University of North Bengal, West Bengal, February 27-28, (2020).