CHAPTER 8
DARK MATTER CANDIDATES AND Λ As DARK ENERGY

8.1 INTRODUCTION

It is now universally accepted by the cosmologists that the universe consists not just of visible celestial bodies, stars, planets and galaxies. It also has a mysterious material known as dark matter as discussed details in chapter 7. This material is responsible for providing the gravitational attraction that enables objects such as galaxies to form and hold them together once they have formed. Dark matter interacts with the normal matter by gravity, but does not absorb or emit radiation, and thus cannot be seen [170].

As per Big bang cosmology, Dark matter and Dark energy (detail is on the next page) account for the vast majority of the mass in the observable universe. According to observations of structures larger than galaxies, as well as Big Bang cosmology interpreted under the Friedmann equations and the FLRW metric, the universe appears to consists of approximately 23% dark matter (in section 7.4 of previous chapter as per [162] it is (24 ± 0.02)% which clusters and drives the formation of large-scale structure in the universe, while the ordinary matter – stars, planets, gas, dust and all the rest accounts for nearly 4% of the universe [171].

![Figure 8.1: Structure of universe](image)
In the recent research [172] of cosmology, cosmological constant ‘Λ’ has been interpreted as the angular power spectrum of the clustering of galaxies. In the above referred paper, the author have urged that there were more structures on large scale than expected in pure cold dark matter universe. During the investigations it has been noticed that the above problem was in fact opposite, it is on small scales and the amplitude of matter fluctuation in a critical density dark matter universe is too high relative to observations as established by White et al. [173].

8.2 DARK ENERGY

As per the investigations we believe that the expansion of the universe is due to certain energy inside it and that may be called ‘Dark Energy’. From literature survey, Existence of dark matter in universe may be established by its gravitational effect on the matter and this provides the idea about the kinds of components in the universe. The observations suggest that the total amount of matter in the universe including dark matter accounts for just one-third of the total energy as shown in figure-8.1. This has been confirmed by survey & various projects, which have mapped the positions and motion of galaxies and confirm the fact that the remaining part of the universe is filled by a mysterious force called ‘Dark Energy’. As this mysterious force is invisible and its exact nature is unknown, so cosmologists called it ‘Dark Energy’.

Dark energy is introduced theoretically to explain the accelerating expansion of the universe and as stated above the word ‘dark’ implies, only few of its properties are known:

**First aspect** : According to Friedmann’s equation without the cosmological constant

\[
\frac{\dot{R}}{R} = -\frac{4\pi G}{3c^2}(3p + \rho c^2)
\] (8.1)

where equation of state is \( \beta = \frac{p}{\rho c^2} \); \( \beta < -\frac{1}{3} \), where \( \rho \) is the energy density and \( p \) is the pressure, should be satisfied in order to make the ‘anti-gravity’ \( \dot{R} > 0 \) becomes possible on the large scale of the universe.
Second aspect: The repulsive properties of dark energy require its distribution to be highly homogeneous and isotropic.

Third aspect: Observations show its density to be roughly $10^4 eV/cm^3$ [174].

Fourth & final aspect: Finally we may conclude that there is still no evidence to suggest that it interacts with matter through any of the fundamental forces other than gravity.

8.3 REGARDING DARK MATTER CANDIDATES

During the research reviews it has been noticed that the cosmological observations provide strong evidences for dark matter other than in form of massive neutrinos and low mass called cold dark matter (CDM) [163].

8.4 STUDY REGARDING COLD DARK MATTER (CDM) AND X-COLD DARK MATTER (XCDM)

a) CDM: The current observations and estimates of dark matter is that 20% of the dark matter is probably in form of massive neutrinos. Another 5 to 10% is in the term of stellar remnants and low mass. The rest of the dark matter is called CDM.

b) XCDM: In XCDM parameterization of dark energy, the equation of state of the dark energy component is given by

$$ p_x = \beta(z)\rho_x $$

Where usually $\beta(z)$ varies with some powers of the redshift, say,

$$ \beta(z) = \beta_0 (1 + z)^n $$

Models with constant $\beta$ are the simplest ones and their free parameters can easily be constrained from the main cosmological tests. From the research findings, we can tabulate the comparative study of recent constraints; here $\Omega_m$ is the density parameter of CDM.
Table 8.1: Comparative study regarding $\Omega_m$ and $\beta$

<table>
<thead>
<tr>
<th>Method</th>
<th>Reference</th>
<th>$\Omega_m$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMB + SNe Ia........</td>
<td>[175]</td>
<td>$\approx 0.3$</td>
<td>$\approx -0.6$</td>
</tr>
<tr>
<td>SNe Ia + LSS.....</td>
<td>[176]</td>
<td>~</td>
<td>$&lt;-0.6$</td>
</tr>
<tr>
<td>GL................</td>
<td>[177]</td>
<td>~</td>
<td>$-0.55$</td>
</tr>
<tr>
<td>X-ray GC .........</td>
<td>[178]</td>
<td>$\approx 0.32$</td>
<td>$-1$</td>
</tr>
<tr>
<td>X-ray GC$^a$ .......</td>
<td>[178]</td>
<td>$\approx 0.31$</td>
<td>$-1.32$</td>
</tr>
<tr>
<td>SNe Ia.................</td>
<td>[179]</td>
<td>~</td>
<td>$&lt;-0.55$</td>
</tr>
<tr>
<td>SNe + X-ray GC$^a$ ...</td>
<td>[180]</td>
<td>0.29</td>
<td>$-0.95^{+0.30}_{-0.35}$</td>
</tr>
<tr>
<td>SNe Ia + GL............</td>
<td>[181]</td>
<td>0.24</td>
<td>$&lt;-0.7$</td>
</tr>
<tr>
<td>OHRO’s ..................</td>
<td>[182]</td>
<td>0.3</td>
<td>$&lt;-0.27$</td>
</tr>
<tr>
<td>$\theta (z)$ ...............</td>
<td>[183]</td>
<td>0.2</td>
<td>$\approx -1.0$</td>
</tr>
<tr>
<td>$\Delta \theta$ ............</td>
<td>[184]</td>
<td>0.2 - 0.4</td>
<td>$\leq -0.5$</td>
</tr>
<tr>
<td>CMB</td>
<td>[185]</td>
<td>0.3</td>
<td>$&lt;-0.5$</td>
</tr>
<tr>
<td>CMB + SNe + LSS</td>
<td>[186]</td>
<td>0.3</td>
<td>$&lt;-0.85$</td>
</tr>
<tr>
<td>CMB + SNe + LSS$^1$</td>
<td>[187]</td>
<td>~</td>
<td>$&gt;-2.68$</td>
</tr>
</tbody>
</table>

Some authors have studied models with constant $\beta$ by considering two different cases:

Case-i) The standard XCDM, for $-1 \leq \beta < 0$.

Case-ii) The extended XCDM (named “phantom energy” [188] in which the $\beta$ parameter violates the null energy condition and may assume value $\beta < -1$).

8.5 DARK MATTER AND ASTRONOMICAL EVIDENCES

There is a great deal of astronomical evidences for dark matter, galaxy rotational curves and dynamical studies. Laboratories & accelerator tests are also necessary to establish the linkage between astrophysics and particle physics. During the study, it
has been noticed that all the related research work is very much in the proper scientific spirit. Dark Matter searches and test are thriving and we will continue our study in this direction in future. In this chapter it has been tried to highlight the Dark Matter in connection with cosmological constant ‘Λ’. Astronomical observations are being refined in many sophisticated way and used to confirm the acceleration and test equations of state of hypothetical Dark energy. It is therefore important to highlight some more evidences here from peer research findings.

**8.6 POSSIBILITY OF LABORATORY TEST**

From the peer research findings we can say that there are many proposals by scientists for laboratory testing or accelerator detection of Dark Matter, but perhaps, no one has attempted for Dark Energy. This may be because in a lab or even in solar system such types of tests are not phsible for Dark Energy usual conception as Cosmological Constant ‘Λ’.

It has been also noticed that in many cases, the evidences for Dark Matter are also evidences for Dark Energy. Without lab test we have to believe on theoretical explanation for its nature whether constant or varying as discussed in detail in the thesis. Now here we feel necessity to discuss limits on Λ and some facts about space or in other words the chemistry of space expansion.

**8.7 LIMITS ON COSMOLOGICAL CONSTANT**

Here we wish to present the constraints on ‘Λ’ since on the basis of the observations, we can say that the cosmological constant ‘Λ’ is investigated only by large scale structure observations as a choice for dark energy together with dark matter. This may be explained on the basis of cosmological investigations. In principle, the cosmological constant so take part in phenomena on every physical scale but due to its small size a local independent detection of its existence is still lacking. Till date no
convincing method for constraining ‘$\Lambda$’ in the laboratory situated on the earth has been proposed [90]. The effect on perihelion precision of solar system planet has been considered to limit the cosmological constant ‘$\Lambda$’ due to extra precision of the inner planet of solar system namely Mercury, Venus, Earth & Mars.

Limits on the cosmological constant due to extra precision of the inner planets of the solar system [189].

### Table-8.2: Limits on Cosmological Constant

<table>
<thead>
<tr>
<th>Name</th>
<th>$\delta \dot{\omega}$ (arcsec/year)</th>
<th>$\dot{\omega}_\Lambda$ (deg/year)</th>
<th>$\Lambda_{\text{lim}}$ (cm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>-0.36(50)x10$^{-4}$</td>
<td>9.61x10$^{-5} \Lambda/(1\text{km}^{-2})$</td>
<td>4x10$^{-45}$</td>
</tr>
<tr>
<td>Venus</td>
<td>0.53(30)x10$^{-2}$</td>
<td>2.51x10$^{-6} \Lambda/(1\text{km}^{-2})$</td>
<td>9x10$^{-43}$</td>
</tr>
<tr>
<td>Earth</td>
<td>-0.2(4)x10$^{-3}$</td>
<td>4.08x10$^{-6} \Lambda/(1\text{km}^{-2})$</td>
<td>1x10$^{-46}$</td>
</tr>
<tr>
<td>Mars</td>
<td>0.1(5)x10$^{-5}$</td>
<td>7.64x10$^{-6} \Lambda/(1\text{km}^{-2})$</td>
<td>2x10$^{-46}$</td>
</tr>
</tbody>
</table>

where $\dot{\omega}_\Lambda$ is angular velocity due to cosmological constant ‘$\Lambda$’.

It may be defined as

$$\dot{\omega}_\Lambda = \frac{\Lambda c^2 P_b}{4\pi} \sqrt{1-e^2}$$

(8.1)

where $e$ is the eccentricity and $P_b$ is the Keplerian period of the unperturbed orbit.

$\Lambda_{\text{lim}}$ indicates the limiting value of $\Lambda$ in the particular solar system.

$\delta \dot{\omega}$ indicates the probable error in arcsec/year.

From the above table it is clear that the best constraints come from Earth & Mars observations with the value of $\Lambda$ approximately $10^{-46} \text{cm}^{-2}$. Major sources of symmetric errors come from uncertainty about solar oblateness and from gravito-magnetic contributions to secular advanced perihelion but their effect could be in principle accounted for [190]. The accuracy in determining the planetary orbital motions will further improve with data from future space-missions.
8.8 SOME IMPORTANT FACTS ABOUT SPACE

Now we feel necessity to discuss some facts about space or in other words the chemistry of space expansion as published in our paper [157]. Space expansion or contraction is a type of balance between the ratios of photons to photon holes in a given quantity of space. In a region where photons are dominant, the negative pressure space is more uniform and becomes repulsive. The cosmological term then becomes a ratio of photons to photon holes. Another way to picture this is that the space-grid expands when it vibrates or oscillates too much or contract where there is a lack of vibrations. It means,

Space expands when:
- Photons & photon holes are spontaneously generated.
  ie. Photons + Photon holes = 0
- The vibrations in the space foam dominate; this may happen when ordinary photons are emitted or where relatively less photon holes are present. This can be seen as the so called “Dark Energy”

Space contracts when:
- The Photon holes are filled by photons of identical energy.
- When a photon hole's negative attraction in the space foam dominates grid vibrations. Commonly, contraction occurs in gravitational field as well as in lines of electromagnetic force. The overall dominance of photons in the space foam mix over gravity takes place because gravity of missing mass ie. dark matter, cannot halt the expansion.

8.9 DARK ENERGY COULD BE EINSTEIN’S COSMOLOGICAL CONSTANT

As shown in fig 8.1, Dark Energy which forms almost three-quarters of the universe, is the most mysterious stuff known to us. A new set of Chandra X-Ray observatory
data, however has given scientists few information on what dark energy might actually be. In our opinion it looks suspiciously like Einstein’s Cosmological constant ‘Λ’ (a factor he added to his theory of General Relativity).

8.10 CONCLUDING REMARKS

- From the above comparative study of recent constraints on the dark energy parameter $\beta$ in section (8.4), it is easy to see that the estimates of $\Omega_m$ and $\beta$ are compatible with the results obtained from many independent methods.
- One of the important detection of the existence of Dark Matter & Dark Energy is based on the assumption that universe has a Robertson Walker geometry spatially homogeneous and isotropic on a large scale. The observation can at least in principle be accounted for, without the presence of any Dark Matter & Dark Energy. If we consider the possibility of inhomogenity then this may happen in two ways:
  i) Locally via back reactions.
  ii) Observational effects via large scale inhomogenity.
- The standard model of cosmology suggests that the total energy density of the universe is presently dominated by the density of two components:
  i) Dark Matter components
  ii) Dark Energy components
The nature of both components remain unknown and in future we may hope that the large hadrons colloidal (LHC) or any other proposal may be able to provide hint on the nature of Dark Matter. During last few years the cosmological observations have greatly improved precisely in number where their analysis are generally performed with in the standard model of cosmology considering Dark Matter & Dark Energy.