# Scalar Field Dark Energy

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## Aims:

The primary objective of this project was to model Dark Energy as a scalar field and demonstrate the tracking behaviour of the Energy Density Distribution.

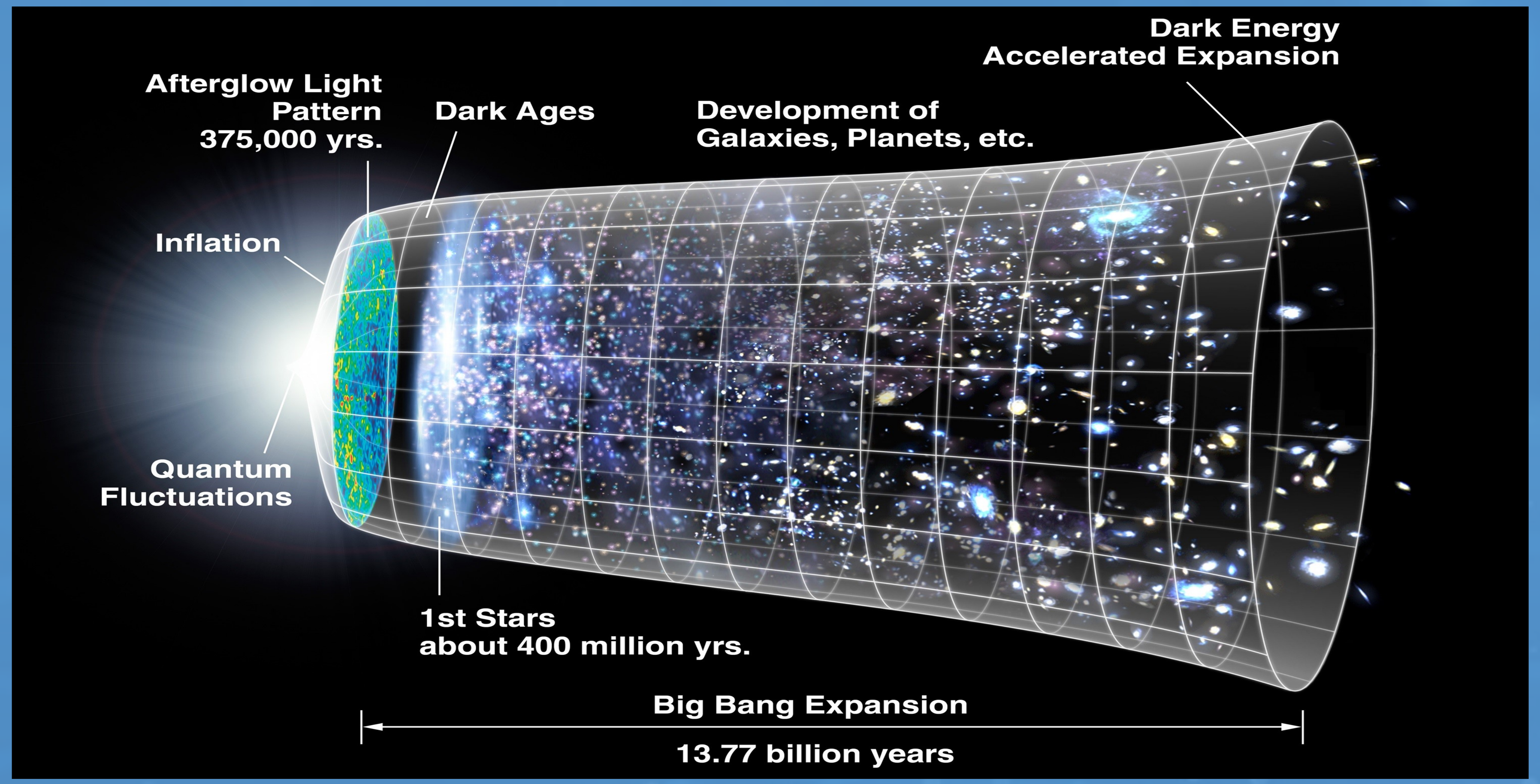


***Fig. 1:*** *Observed expansion history of the universe from initial Big Bang (Left) to the Dark Energy acceleration at the present (Right) [1].*

## What is Dark Energy?

The universe's expansion was recently discovered to be accelerating from observational evidence of supernovae [2]. This is believed to have begun when Dark Energy became dominant around 5 billion years ago [3]. This accelerated expansion can only be explained by the existence of a positive 'Vacuum Energy', dubbed *Dark Energy.* At the present time, Dark Energy currently dominates the Energy Density of the universe - the Universe is roughly 70% Dark Energy and 30% matter and Dark Matter [4].

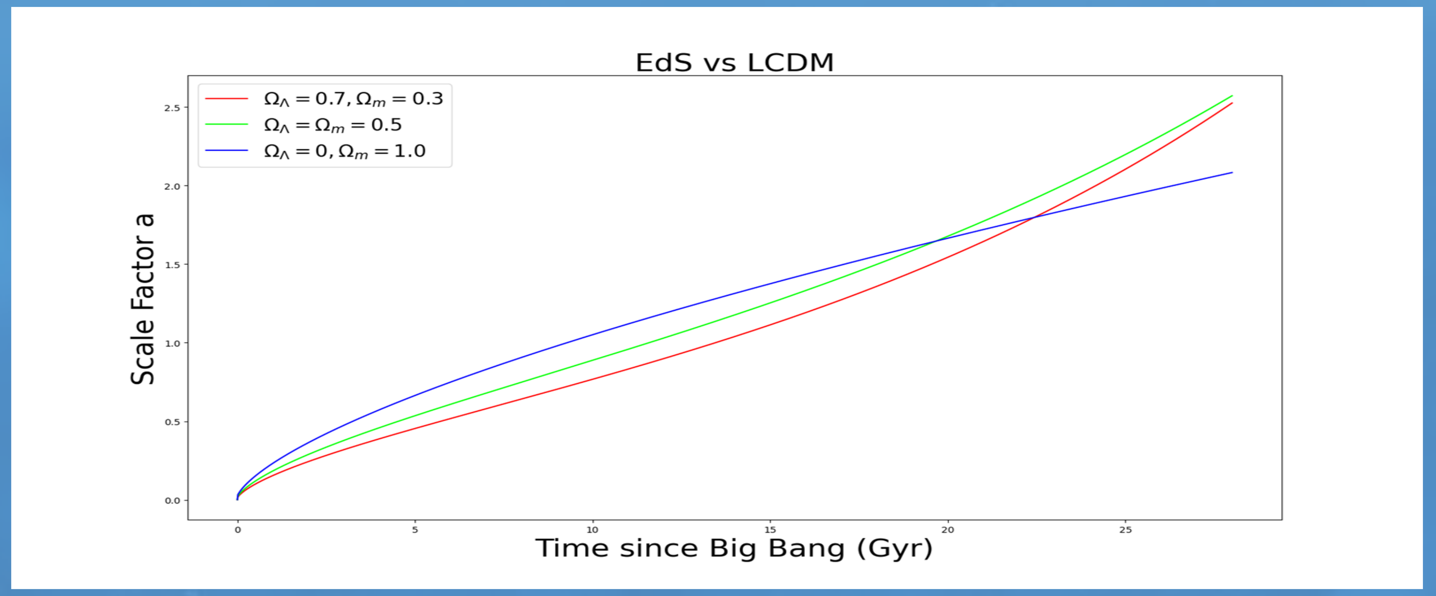


***Fig. 2:*** *Evolution of the scale factor against time for the Einstein-de Sitter model (blue), LCDM model (red), and for an equivalence of matter and dark energy (green).*

## Scalar Fields:

Scalar Fields assign a scalar value to every point in space, and must give the same result no matter the chosen frame of reference.

In this project, the scalar field equation considered was:

$$\ddot{\phi} + 3H\dot{\phi} = -V'(\phi)$$

Where $\phi$ is the scalar field, 3H is the *Hubble Drag*, and V is an arbitrary scalar potential.

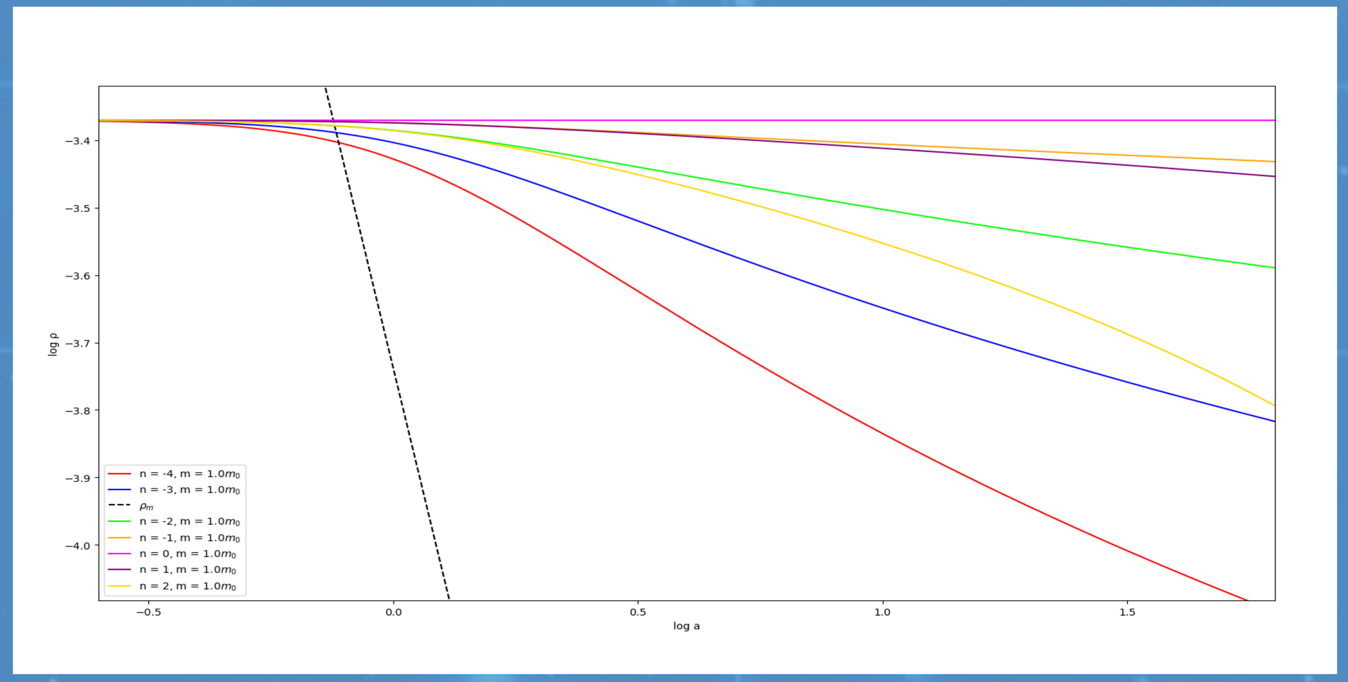

***Fig. 3:*** *Logarithmic plot of the evolution of the energy densities of the scalar field in the potential with varying n. Dashed line is the matter density evolution and $m_0$ denotes an arbitrary parameter.*

## Results:

Figure 2 shows the evolution of the scale factor of the universe against time since the Big Bang (0 Gyrs). It can be seen that an accelerated expansion is observed in the Lambda CDM model in which the universe is 70% Dark Energy, and a steady decelerating expansion is observed in the Einstein - de Sitter model for a matter dominated universe. This was to be expected as we know the universe's expansion to be accelerating due to observations of Type 1a Supernovae.

Figure 3 shows the evolution of the scalar field energy density against the scale factor for the new model with the scalar field equation. The potential in this case was chosen to be of the form

$$V = \frac{1}{2}\left(\frac{m}{m_{pl}}\right)^{4-n}\left(\frac{\phi}{m_{pl}}\right)^{n}$$

Where $m_{pl}$ is the Planck mass, such that the scalar field and m have units of Planck mass - i.e. V is dimensionless.

It can be seen that due to the short timescales when the scalar field density is less than that of matter, we get a flat distribution. When the densities become roughly equal, the field becomes dominated by the Hubble Drag, causing the density to track the matter density. At large timescales the field exhibits slow roll behaviour and flattens out again.

**References:**

*[1] NASA/WMAP Science Team http://map.gsfc.nasa.gov/media/060915/index.html, [2] Adam G. Reiss et al. https://arxiv.org/pdf/astro-ph/9805201.pdf, [3] Joshua A. Frieman et al. https://doi.org/10.1146/annurev.astro.46.060407.145243, [4] Planck Collaboration: N. Aghanim et al. https://doi.org/10.48550/arxiv.1807.06209*