Philosophy and the Sciences

Introduction to the Philosophy of the Physical Sciences

EIDYN

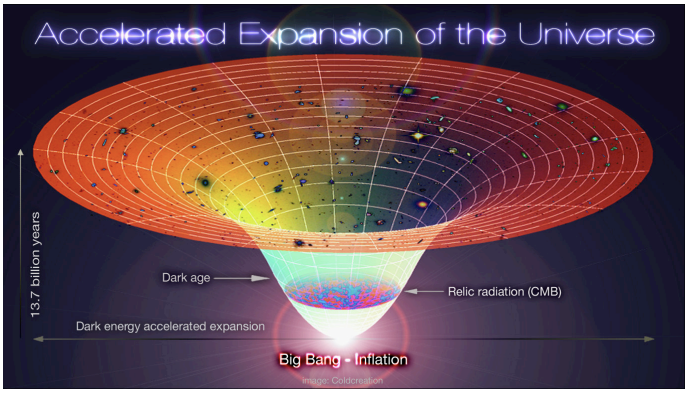
Dark Matter and Dark Energy

What kind of entities are dark matter and dark energy?
What is the rationale for choosing between rival research programs?

The 'concordance model' or ΛCD

This asserts that we live in an infinite universe, with approximately 5% ordinary matter (baryons), 25% Cold Dark Matter, and 70% Dark Energy.

It builds on Einstein's general relativity (GR) and the so-called Friedmann-Lemaître-Robertson-Walker (FLRW) models.



Lambda-Cold Dark Matter by Coldcreation (CC-BY SA 3.0)

What are dark matter and dark energy?

• Evidence from Supernova Ia shows that not only is the universe expanding but it is also accelerating in the expansion. The currently most accepted hypothesis for this accelerated expansion is dark energy.

• Dark energy means giving weight to the vacuum. If empty space can have density, it can also have anti-gravitational properties.

• Why do galaxy clusters, and superclusters exist? The simplest answer is: because gravity can amplify density irregularities.

• By mapping the three dimensional distribution of galaxies, we're able to infer the density of the universe.

• The majority of the clumpable matter in the universe is of a form that we only see through gravity. The matter we see from radiation is **dark matter** (DM). Evidence for Dark Matter comes from galaxies' flat rotation curves.

Thomas Kuhn on the rationality of theory-choice

In The Essential Tension (1977), Kuhn pointed out that theory choice seems governed by the following criteria:

• **accuracy** (i.e. the theory is in agreement with experimental evidence);

• **consistency** (i.e., the theory is consistent with other accepted scientific theories);

• **broad scope** (i.e., the theory has to go beyond the original phenomena it was designed to explain);

• **simplicity** (i.e., the theory should give a simple account of the phenomena);

• **fruitfulness** (i.e., the theory should be able to predict Novel phenomena).

• Kuhn: these criteria are either imprecise (e.g., how to define 'simplicity'?); or they conflict with one another (e.g., while Copernicanism seems preferable to Ptolemaic astronomy on the basis of accuracy; Ptolemaic astronomy fares better on the score of consistency with the Aristotelian- Archimedean tradition of the time).

• These five joint criteria are not sufficient to determine theory choice.

• Instead, external, sociological factors seem to play a decisive role in how scientists gather consensus around a given theory.

Going back to cosmology…

What is the current evidence for the concordance model, with dark matter and dark energy?

Are there viable alternatives to the concordance model?

How do cosmologists make their rational decision of endorsing the concordance model?

Alternatives to ΛCDM

Going back to Duhem and the underdetermination problem. Does underdetermination loom in contemporary cosmology?

Two possible rivals to Dark Energy

1. **Inhomogeneous Lemaitre-Tolman-Bondi (or LTB) models** (rather than the standard FLRW model, which assumes, with the Cosmological Principle, that the Universe is roughly homogeneous and isotropic, namely it has the same uniform structure in all spatial positions and directions).

2. LTB denies homogeneity (but retains isotropy), and assumes that there are spatial variations in the distribution of matter in the Universe, and that we live in an underdense or 'void' region of the Universe (a 'Hubble bubble'), which is expanding at a faster rate than the average.

• Instead of modifying FLRW models, we could try to modify General Relativity itself (to avoid DE).

Possible rivals to Dark Matter:

Modified Newtonian Dynamics or MOND, first proposed by Milgrom (1983), and in its relativistic form by Bekenstein (2010).

Is theory-choice underdetermined in cosmology?

The underdetermination argument challenges the rationality of theory-choice.

Was Kuhn right in claiming that neither simplicity, nor any of the other criteria, will ever be sufficient to determine the rationality of theory choice? Philosophers of science have sometimes appealed to the notion of empirical support as a more promising way of thinking about theory choice.

The concordance model is empirically supported not just when there is direct experimental evidence for some of its main theoretical assumptions, but when the model is integrated / embedded into a broader theoretical framework.

In this way, the model receives indirect empirical support from any other piece of evidence, which although not a direct consequence of the model itself, are nonetheless consequences of the broader theoretical framework in which the model is embedded.

Anomaly	Reject a main theoretical assumption?	Add a new auxiliary hypothesis?
Galaxy flat rotation curves	Modify Newtonian dynamics (MOND)?	Halos of dark matter?
Accelerating expansion of the universe	Modify general relativity (GR)? Retain GR but modify FLRW?	Dark energy?

Credit: Lahav, O., Massimi, M. "Dark Energy, Paradigm Shifts, and the Role of Evidence" (2014)