PART I. A non Mathematical Introduction

Lecture 1. What is cosmology?

CONTENT

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1.1. About this course

This course is an Introduction to the modern cosmology, including recent developments. The concepts and techniques described in this course are used to explain the evolution of our Universe. The course shows how mathematical techniques can be combined to answer questions of fundamental interest. The course introduces the basic constituents and observational features of the Universe, including the Cosmic Microwave Background. Cosmological models based on both Newtonian and general relativistic equations are developed. The history of the Universe is described including inflationary models and the formation of large-scale structure. The mathematical features of observational cosmology and formation of structure are introduced. [See Fig.1.0.]

The Universe is large and strange, enjoy just looking, for example, at the galaxy Andromeda (Fig.1.1), or the whole cluster of galaxies, where gravitational lenses magnify images of galaxies (Fig.1.2).

1.2. The Universe as a whole

Cosmology studies the large scale properties of the Universe as a whole: the origin, evolution and ultimate fate of the entire Universe. In cosmology the theory of the origin and evolution of the Universe is confronted with observations. Depending on the outcome of the observations, the theories will need to be abandoned, revised or extended to accommodate the data.

The Universe denotes everything that is or ever will be observable, so that we can never hope to study another universe. The scale of the Universe observable now is about

$$L_{obs} \sim 10^4 \text{ Mpc.} \tag{1}$$

In order of magnitude this scale is the product of the age of the Universe and the velocity of light.

Uniqueness of the Universe

Unlike other branches of science, cosmology deals with an unique object, since there is only one Universe available for study. We can never know how unique is our Universe, for we have no other universe with which to compare. [Nevertheless, recently some cosmologists started a discussion about Multiverse in contrast to the Universe.]

The laws of physics.

The laws of physics which are locally measured in the laboratory have more general applicability. Cosmology is developed by extrapolation of locally verified laws of physics to remote locations in space and time.

Simplicity in average.

In Cosmology, simplicity is sought on sufficiently large scales. Later we will see that this scale is about 100 million pc.

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1.3. What is known about the Universe?

The Universe contains everything and at first sight it should be too complicated to be successfully studied in a one term course. Fortunately, as we will see later, the Universe as a whole turns out to be simple enough. What is known at the present moment about the Universe as a whole? We know that

(i) The Universe is expanding from a hot and dense initial state called the Big Bang.

(ii) In the Big Bang the light elements were synthesized.

(iii) We believe that there was a period of inflation which led to many observable properties of the Universe.

(iv) Any observable large scale structure was seeded by some small perturbations which are the relics of quantum fluctuations.

(v) This structure is dominated by cold dark matter.

(vi) At the present moment the Universe seems to be expanding with an acceleration rather than a deceleration as cosmologists used to think in the 20th century.

1.4. The Big Bang Model

The Big Bang Model is a broadly accepted theory for the origin and evolution of our Universe. According to this model, 14 billion years ago, the portion of the Universe we can observe at the present moment was, say, just a few millimeters across. The Universe has since expanded from this hot dense state into the vast and much cooler cosmos we currently inhabit. We can see remnants of this hot dense matter as the now very cold cosmic microwave background radiation which is also called "relic radiation". This radiation can be "seen" by microwave detectors as a uniform glow across the entire sky.

1.5. Cosmological Principle

The simplicity of the Universe is based on the following cosmological principle:

The Universe, on average, looks the same from any point.

If the universe is locally isotropic, as viewed from any point, it also should be uniform. So the cosmological principle states: Our Universe is approximately isotropic and homogeneous, as viewed by any observer at rest. More accurately, the matter in the Universe is homogeneous and isotropic when averaged over very large scales.

This assumption is being tested continuously as we actually observe the large scale distribution of galaxies. Fig.1.3 shows the distribution of measured galaxies over a 30^o swath of the sky.

In cosmology the simplicity of the Universe appears on sufficiently large scales. A few decades ago it was assumed that homogeneity applies on scales above 10 Mpc.

$$1 \text{ Mpc} = 10^6 \text{ pc} = 3 \times 10^{22} \text{ m}. \qquad (2)$$

According to the definition of 1 parsec (pc)

$$L = 1 \text{ pc}, \text{ if } \alpha = 1 \text{ arcsec}, \qquad (3)$$

where α is parallax, see Fig. 1.4, where

$$l = 1 \text{ AU (astronomical unit), 1 AU=150 000 000 km}. \qquad (4)$$

In cosmology we deal mostly with distances measured in Mpc's

$$1 \text{ Mpc} = 10^6 \text{ pc} = 3 \times 10^{22} \text{ m}. \qquad (5)$$

However, the recent discovery of giant filaments and voids, as well as large-scale streaming motions, suggests that one may need to go to scales of order 100 Mpc. Since the scale of the observable Universe is around 6000 Mpc, this is only a factor of 60 larger, still it gives about $60^3 \approx 2 \times 10^5$ cells, which is large enough number to apply statistics.

A long time ago cosmologists believed in a much stronger principle, called the perfect cosmological principle, which says that the Universe appears the same from all points and at all times. In other words, there can have been no evolution. This contradicts the observations which show that the real Universe does not satisfy this principle because we now have evidence that the Universe evolves (expansion of the Universe).

Another principle, the status of which remains ambiguous, is the so-called Anthropic Principle. This principle claims that certain features of the Universe - such as the values of the physical constants - are determined by the requirement that life should arise, because otherwise we could not be here asking questions about it.

1.6. Astronomical time-machine

It is inevitable that an astronomer studies objects remote in time as well as in space. Light travels a distance of 300,000 kilometers in one second, or ten thousand billion kilometers in a year. The nearest star, Alpha Centauri, is 3 light years from us: we see it as it was three years ago. The nearest galaxy comparable to our own Milky Way is at a distance of two million light years; we are seeing the Andromeda galaxy, a naked eye object in a dark sky, as it was when homo sapiens had not yet evolved. A large telescope is a time-machine that can take us part way to creation, to examine regions from which light emanated more than five billion years ago, before our sun had ever formed. To a cosmologist, the issue of creation is inevitable.

In cosmology we really can observe the remote past of our Universe!!!