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New Approach to Teaching Cosmology

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Abstract

We have prepared an innovation course, with topic Introduction to Cosmology, for our university students - especially future teachers. In this paper, we have conducted research into student understanding of cosmological ideas. Our research study uses open-ended questions and interviews to ascertain what students know regarding modern cosmological ideas, what common misunderstandings and misconceptions they entertain, and what sorts of materials can most effectively overcome difficulties in learning this material.

Keywords: Cosmology education, misconception, teaching.

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Introduction

In the past few decades the progress of experimental technology has led to many important discoveries in cosmology. We can expect further discoveries and progress in theoretical sciences arising from a close relation of cosmology and particle physics. These discoveries and perspectives attract public and students' interest, but so far have not been really reflected in teachings of physics. It’s believed, that foundations of cosmology are too complicated to be easily explained in such a way that the student would really grasp the concept and would be able to actively use it. That leads to a conviction that the pedagogical benefits of deepening the study of cosmology would be disproportionately low compared to the effort. We tried to change this deeply-rooted attitude.

The Pedagogical Institute of Masaryk University in Brno has been offering for some years a one-semester one-hour course of cosmology. This course offers the basic topics of cosmology: homogeneous and isotropic cosmological models, the fundamental cosmological parameters accessible to measurement, physical processes in the Universe from its early stages to the present state, including prospects for future development of cosmology as a field of application of fundamental physical theories. We are trying to gradually make the course as accessible and interesting as possible, with a stress on students’ active participation in the acquisition of new knowledge.

Innovation

The main innovation of the course lies in the fact that it shows how basic cosmological equations for the universe expansion can be deduced both from the general theory of relativity, and from the Newtonian concepts, into which you can include the effect of dark energy which in the context of the general theory of relativity is explained as a cosmological constant. The cosmological evolution can then be interpreted as a "contest" of three factors - inertia, attractive Newtonian gravitational force, and repulsive influence of dark energy.

Some basic information about the behavior of a homogeneous and isotropic universe can then be obtained from a single differential equation. Its solution can be qualitatively described based on the graphical analysis. Progressively we try to find the simplest way to process several other parts of cosmology.

We conducted a study to observe the influence of our new course. The study compared questions and answers from the field of cosmology, astronomy and its history. We asked the students who finished the course and also students who did not take the course. The study found significant differences in individual indicators, suggesting a positive influence of the course not only directly on students’ knowledge, but also on their ability to respond actively and critically.

The course now includes questions which were mostly inspired by misconceptions that could come from TV programs and media reporting, or from reading popular science magazines and books. We formulate questions reflecting these misconceptions, we encourage students to solve these questions and then we scrutinize the responses during a debate. We don’t avoid any questions, we even address open problems. A deep understanding consists of logically and meaningfully interconnected concepts.

Sample Problems

It is also important for lecturer to assure that the most basic terms and concepts are profoundly understood and connected. Students would prove brief explanations and definitions of the most important terms and key concepts used throughout this course. Let us give you several examples:

Newton or Einstein?

Einstein's theory of gravity is based on a significantly different basis than Newton's theory. How is it possible, that according to these theories the Universe behaves in the same manner?

We can say that it behaves in the same manner after certain idealization which basically never happens and is inapplicable to early phases of cosmos evolution or for solution of problem of development of structures of the Universe.

Key terms and concepts that student needs to know:

Idealization in physics, the relationship between old and new theories, model and reality, absolute space and time, interactions, assumptions of Einstein Theory of Relativity

ACenter or Homogeneity?

The fundamental cosmological relations are derived from assumption that the Universe is expanding isotropically around our position, as if that was the center of the Universe. That seems to be in conflict with “Copernican principle” which states, that our position in the Universe is not exceptional in any sense.

The truth is that any place could be considered as the center of the Universe expansion. The original question could be used to demonstrate, how physical phenomena could be viewed from different frames of reference, while cosmology changes the view of their relation.

Key terms and concepts:

Anisotropy, isotropy, homogeneity, reference system, inertial system, the Copernican principle-K, Hubble's law.

Flat or Curved?

Even in a conventional printed material we can time to time read that the Universe is to a great precision flat, not curved. How does it relate to Einstein theory which states, that matter, space, and time are curved.

The truth is, that we have to distinguish between the curvature of spacetime which is nonzero and curvature of three-dimensional slice of spacetime, which represents space as a set of events that are, from cosmological perspective, happening at the same time. These conclusions, which seem to be contradicting each other, become clear, when students gain deeper understanding of the issue.

Key terms and concepts:

Curvature, flatness, space-time metric and topological properties of solids, dimensions, geodesics, motion description.

Accelerating or Stationary?

One of the greatest cosmological discoveries of recent decades was the discovery of accelerating expansion of the universe. On the other hand to this discovery, many cosmology papers state, that if “the cosmological constant” is really a constant, the Universe is asymptotically approaching stationary state. Aren’t these facts contradicting each other? How could permanent expansion be stationary?

The truth is that we have to distinguish between the speed of an object in the Universe (a galaxy) and the speed of objects passing gradually in a given distance from the observer. This kind of difference is well known from math (partial and total derivative), and from hydrodynamics (example of a stationary waterfall). Knowledge of mathematical or hydrodynamic problems could help solve problems that are seemingly very different.

Key terms and concepts:

Graphs, stationary, static process, cosmological constant, geometry, asymptotic course, hydrodynamic analogy.

How far could we see?

Information about how far in the Universe we can see considering the level of technological progress essentially differ even in credible books. How could these contradictions be explained?

To answer these questions it is necessary to take into account the fact, that the objects we observe now, were at that place at the time they emitted light we now receive. It’s fundamental to consider what is meant by distance. It became obvious, that seemingly straightforward definitions could lose their clarity when subjected to a thorough analysis.

Key terms and concepts:

Object distance in a given time, distance events, velocity of recession, finite speed of light, cosmic scale factor, light year, the units

Conclusion

Understanding of some aspects of cosmology is fundamental for the process of deeper understanding of the world we live in, and these aspects also help understand problems from other fields of physics. Cosmology allows formulating interesting, well-defined problems, that could be managed by students and which help to develop thinking ability that is both creative and critical.

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