CHAPTER OVERVIEW

1: Workbook

It has been quite a century for our understanding of the cosmos. As I write these words at the beginning of 2017 it was just over 100 years ago, in November 1915, that Albert Einstein finished development of his general theory of relativity. Among many other things, this theory provided the proper context for interpreting Edwin Hubble's distance-redshift law, published in 1929, as due to the expansion of the Universe. In the 40s, Gamow and Alpher speculated that the dense conditions that must have existed earlier in this expanding universe could provide another site, in addition to the cores of stars, for the fusion of light elements to heavier ones. In fact, to avoid over-production of the elements, this earlier, denser phase would have to be very hot. In the 1960s Bell Labs scientists accidentally stumbled upon the thermal radiation left over from that heat, that exists in the current epoch as a nearly uniform microwave glow. With that discovery, the idea that the universe used to be hot, dense, and expanding very rapidly became the dominant cosmological paradigm known as the "Big Bang."

The subsequent fifty years of the past century saw much progress as well. We now know that we do *not* know what constitutes 95% of the mass/energy in the universe. Only 5% of the mass/energy is composed of constituents in the particle physicist's standard model. Most of the rest is "dark energy" which smoothly fills the universe and dilutes only slowly, if at all, as the universe expands. The rest is "dark matter" that, like George Lucas's mystical Force, "pervades us and binds the galaxy together." Measurements of light element abundances, combined with modern, precision, version's of Gamow and Alpher's big bang nucleosynthesis calculations, give us confidence we understand the expansion back to an epoch when the presently observable universe was 10^{27} times smaller in volume than it is now. A speculative theory, known as cosmic inflation, has met with much empirical success, giving us some level of confidence we may understand something about events at yet higher densities and even earlier times.

In this quarter-long course we will at least touch upon all the topics in the above two paragraphs. We will learn how to think about the expanding universe using concepts from Einstein's theory of general relativity. We will use Newtonian gravity to derive the dynamical equations that relate the expansion rate to the matter content of the universe. Connecting the expansion dynamics to observables such as luminosity distances and redshifts, we will see how astronomers use observations to probe these dynamics, and thereby the contents of the cosmos, including the mysterious dark energy.

We will introduce some basic results of kinetic theory to understand why big bang nucleosynthesis leads to atomic matter that is, by mass, about 25% Hydrogen, 75% Helium with only trace amounts of heavier elements. We'll use this kinetic theory, applied to atomic rather than nuclear reactions, to explore perhaps the most informative cosmological observable: the cosmic microwave background. Finally, we will study how an early epoch of inflationary expansion, driven by an exotic material with negative pressure, can explain some of the otherwise puzzling features of the observed universe.

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- 1.9: A Newtonian Homogeneous Expanding Universe
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- 1.17: Cosmological Data Analysis

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1.22: Overview of Thermal History
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1.24: Big Bang Nucleosynthesis - Observations
1.25: Introduction to the Cosmic Microwave Background
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1.27: Cosmic Microwave Background Anisotropies
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1.31: Galaxy Formation
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Thumbnail: This modification of the Flammarion Engraving is an enigmatic woodcut by an unknown artist. The woodcut depicts a man peering through the Earth's atmosphere as if it were a curtain to look at the inner workings of the universe. The original caption below the picture (not included here) translated to: "A medieval missionary tells that he has found the point where heaven and Earth meet...".

Contributor

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