17.5: Summary

Learning Objectives

- You will reflect on what you have learned about cosmology

Helped are those who love the entire cosmos... for to them will be shown the unbroken web of life and the meaning of infinity...

- Alice Walker

WHAT DO YOU THINK: THE FATE OF COSMOLOGY STUDENTS

Some students are relaxing after their final exam in cosmology, reflecting on what they learned.

- **Julianna:** I never knew the Universe was so complicated. I'm glad I don't have to keep all that stuff straight anymore.
- **Teresa:** I don't know. I think it all fit together pretty well. I wish I could keep learning about it.
- **Luca:** I think it's cool that I can understand some of the news reports about space now. I never could before. Maybe I'll take another astronomy class sometime.

Do you agree with any or all of these students and if so whom?

Teresa

Julianna

Luca

None

Explain.

With this chapter we end our exploration of the modern ideas in cosmology. Our species' ideas concerning the cosmos began with attempts to explain the nature and motions of the stars and planets. Eventually those early notions led to mathematical laws describing the motion of falling bodies, the nature of electromagnetic waves and the structure of atoms. Over the past century we have seen our grasp of Nature extend to theories of the ultimate nature of matter, in which all of its interactions and constituent parts are explained by a single standard model of particle physics. Our understanding of the three of the four forces of nature fit into an orderly, if as yet incomplete, structure based on quantum theory. Yet the most familiar force, gravity, is understood in terms of the geometry of a four-dimensional spacetime within the framework of general relativity, a decidedly non-quantum theory. Unifying gravity with the other three forces in a single mathematical framework, a "Theory of Everything," is still an unrealized ambition of many physicists.

In these modules we have presented the story of cosmology, how our understanding of the cosmos developed, and how early developments led to later ones. But more than that we have attempted when possible to let you discover the story for yourself, feeling that it is best if you understand what the data have to say about the nature of our Universe. It is the data that are the ultimate authority in science, and it is an understanding of these data, both their strengths and their limitations, that is required by anyone who wants to know how scientists go about exploring reality.

We hope you have come to appreciate both the simplicity and complexity of the underpinnings of the Big Bang theory. At its most fundamental level, it is composed of some very simple ideas: expanding gases cool, so the Universe was hotter (and denser) in the past and will be cooler (and less dense) in the future; the Universe was simpler in the past, and has evolved complex structures over time as the result of small deviations from homogeneity early in its history; basic gravitational, thermal, atomic and nuclear physics acted on these early seeds to form the structures we see now; this process of evolution continues, and will continue, into the future.

These ideas have led to some truly startling conclusions. The first, that the material Universe that we see is only a small fraction of the matter that exists, has its origins in the study of the dynamics of galaxies and galaxy clusters, and it is bolstered by Big Bang explanations of structure formation. Furthermore, the matter in the Universe makes up less than a third of its total energy content, and that fraction is shrinking as the expansion continues; the Universe is now dominated by a form of energy, called dark energy for lack of a better name, that is completely mysterious at the moment, and it is also almost completely unexpected.

We do not yet know how the story will end. Current evidence suggests that the dark energy will become more dominant over time. In any event, its mere presence demonstrates that the Universe is likely destined to expand forever, cooling and becoming ever less dense. The stars will go out and darkness will reign. Eventually black holes will evaporate, and perhaps even some of the "fundamental" particles might decay into simpler forms. On the longest timescales it seems that the Universe ends not with a bang, but a whimper. In the meantime, there is a vast amount to explore, learn about and come to understand. Our explorations have barely started.
