

Research Interests of
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How did the Universe come into existence? How was the matter we observe around us created, and why does it exist in the state we observe? Has it existed like this forever, or was there some dramatic creation event? These are questions that have excited and perplexed ordinary people and professional philosophers alike ever since records began, and no doubt long before that. But can science possibly have anything to say about these questions, or are these questions so out of reach that they are destined to be the subjects of endless unresolved debate? It was a keen skepticism about this point that made me very uncomfortable with the field of Cosmology when I started Graduate School in 1979. Despite my skepticism, I wound up writing my Ph.D. thesis on Cosmology, fully expecting that my transgression would be remedied by subsequent work in "pure" particle physics.

Since that time, the field of Cosmology has undergone an amazing transformation, and I have come around to the view that to do cosmology in this age is to participate in one of the great scientific events of all time. What has caused this transformation? One of the key driving forces is new technology, which is opening up many new possibilities for gathering data. Today we know the positions of a about one hundred million galaxies, a number which has gone up by two orders of magnitude in just a few years (and by many more orders of magnitude since I started my Ph.D.). Dedicated satellites are being built that will probe the Universe to greater depths than ever before, and thus reveal detailed facts about the Universe in areas about which we can only speculate today.

But the new data is only half the story. In the last couple of decades we have also seen dramatic developments on the theoretical side. In particular, a host of specific models have emerged which describe how the Universe evolved in the first stages of the Big Bang, and how the Galaxies and other structures began to form. It is already clear that these models have numerous characteristic observable signatures that will allow them to be tested by the new data. In fact, a large range of models has already been ruled out. One of the great challenges currently facing the theorists is to make predictions to the level of precision commanded by the observations. This task involves digging deep into the astrophysical issues that affect the observations as well as understanding the high energy physics which is needed to describe the ultra-hot early stages of the Big Bang. There are even links with condensed matter physics, due to the key role that phase transitions are expected to have had in the early Universe. Modern technology is contributing crucially to the theoretical side of the effort as well, by providing ultra-fast computers of ever-increasing speed.

It is a great thing that some of our theories have been so successful, but without a doubt the most exciting parts of our field are the areas we do not understand. To make our theories work, we need to postulate that 95% of the universe is comprised of "Dark Matter" and "Dark Energy", things we have so far been unable to see directly in laboratories. We may indeed be close to a better understanding of the Dark Matter: Many theories suggest that over the next several years the Dark Matter will reveal itself

as a new elementary particle as new laboratory experiments come on line. The Dark Energy (at around 70% of the mass-energy of the Universe) is more problematic. The Dark Energy is needed to explain why, despite the decelerating force of gravity, the cosmic expansion is observed to be *accelerating* today. Every existing theoretical explanation of the acceleration has serious fundamental problems. Most experts believe that nothing short of a revolution will be required before the cosmic acceleration can be incorporated into our understanding of fundamental physics.

The fundamental challenge for cosmologists of our time is to make the most of the tremendous opportunities that we are faced with. This is an epoch where our understanding of the Universe can deepen very rapidly. Are we up to the challenge? Will people look back on this era as one in which we used our precious new data to sow confusion or to reveal great truths about the Universe? My personal research goal is to do as much justice as possible to the opportunities that lie before us.

At any given time, my main research focus might be on a very astrophysical problem, aimed at carefully establishing the link between the complex astrophysical objects we observe today (such as galaxies) and the early Universe. Or it could be on some fundamental problem in early Universe theory, which typically involve deep connections with high energy physics. The diversity of physics that is relevant to modern cosmology certainly adds to the challenge, but ultimately also adds to the sense of adventure as one explores one of the great frontiers of human knowledge.

Specific research problems currently include: Fundamental issues with the theory of cosmic inflation, the formation of cosmic structure (both the basic origins of cosmic structure, and the use of precision measurements to test physics of the early universe), and the searching for an understanding of the “dark energy” that current data suggests is accelerating the Universe.