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The Future of Theoretical Cosmology

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Over the course of the twentieth century, we went from knowing essentially nothing about the large-scale structure of the universe to knowing quite a bit: that it is expanding from a Big Bang, that it is approximately 14 billion years old, that there are perhaps 100 billion galaxies spread uniformly throughout the observable universe. Theory has progressed along with observation: general relativity now forms the basis for all our discussions about cosmology, and advances in quantum field theory and particle physics have allowed us to talk sensibly about nucleosynthesis, dark matter, and primordial inflation. In the twenty-first century, two obvious candidates stand out: the nature of the dark sector, and the beginning of time. With 95% of the energy density of the universe apparently residing in dark matter and dark energy, the issues to be addressed by theorists span a wide range: What are these substances? Do they interact, with each other or with ordinary matter? Can they be detected in the lab? Why do they have the abundances we observe? Do they really exist, or are we being fooled by the behavior of gravity on large scales? Meanwhile, we will continue to stretch our theoretical models further into the past. Did the dark matter decouple from thermal equilibrium at early times? Do phase transitions in the early universe produce observable gravitational-wave backgrounds? Did inflation occur, and if so what were the dynamics of the inflaton field? Why did inflation start? Are there distinct domains within the universe, possibly with different properties? Can quantum gravity resolve the initial singularity, and connect us with a pre-Big-Bang phase? Why is the early universe different from the late universe – what is the origin of time asymmetry? It's impossible to predict what the answers to any of these issues will turn out to be, but we can be confident that we won't be running out of interesting questions.