Importance of Measuring Expansion History

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Cosmology today is becoming a healthy, energetic blend of an empirical and theoretical science, combining concepts and tools from astrophysics and particle physics. The most recent results have already brought surprises: the universe's expansion is apparently accelerating rather than decelerating as expected due to gravity. This implies that the simplest model for the universe – flat and dominated by matter – appears not to be true, and that our current fundamental physics understanding of particles, forces, and fields is likely to be incomplete.

The clearest evidence for this surprising conclusion comes from the recent supernova measurements of changes in the universe's expansion rate that directly show the acceleration. These measurements indicate the presence of a new, exotic energy component that can cause acceleration. This conclusion is supported by current measurements of the mass density of the universe, of the cosmic microwave background radiation, and from inflationary theory.

To address this new puzzle and begin to establish a solid cosmological picture, we propose a satellite experiment to carry out a definitive supernova study that will determine the values of the cosmological parameters and the history of the expansion back to 30% of the age of the universe. Since this experiment is sensitive to the redshift range in which the accelerating energy is dominant, it will provide a nearly unique window on the properties of this piece of fundamental physics.

The cosmological parameters describe the constituents of our universe – matter, cosmological constant, dark energy – and determine its curvature and fate. These are fundamental questions: how is field theory manifest today in the form of dark energy? will the acceleration continue without end in a new inflationary epoch or does the dark energy fade and gravity decelerate the expansion?

Cosmological Parameters

Cosmology is certainly no longer – and never could have been – a search for two numbers, H_0 and q_0. We have moved far beyond the great Hubble/Sandage program where one can see no great distinction between the state of the field in Sandage's comprehensive summaries of 1961 and 1988. The present expansion rate H_0 and deceleration q_0 are merely the first two derivatives of the expansion factor $a(t)$, representing only a very partial parametrization of the full behavior. This clearly shows the insufficiency of these two model parameters to reconstruct the cosmology. One requires an infinite number of derivatives or, of course, the function $a(t)$ itself.

This is what the supernova program hopes to measure over the range $0.1 < z < 1.7$ critical to determining a transition from matter decelerated expansion to dark energy accelerated expansion. Dark energy is mostly indistinguishable from a cosmological constant at higher redshifts, such as the cosmic microwave background probes, and is mostly invisible to low redshift large scale structure measurements. (However, probing the expansion and curvature of the universe at all these different epochs is important both for consistency and the possibility that they will disagree and teach us something about the evolution of dark energy or missing fundamental physics.)

Furthermore note that there is a essential difference in the fate of a universe dominated by dark energy rather than matter. The unstable future behavior of the density Ω is well known for ordinary matter: it goes asymptotically to zero (the Big Emptiness) or infinity (the Big Crunch), depending on whether the curvature is negative or positive. But for exotic equations of state the critical density $\Omega = 1$ instead represents an attractor solution: $w < -1/3$ components approach flatness in the future.