The Origin of Large Scale Structure in the Univers

Scientific Context and Questions

Exquisitely sensitive all sky maps made at millimeter wavelengths by the COBE (Cosmic Background Explorer) and WMAP (Wilkenson Microwave Anisotropy Probe) satellites record the intricate patterns manifest in the relic radiation emanating from the cosmic explosion that gave birth to the universe. These patterns – miniscule fluctuations in the temperature of the all pervasive 3 K background radiation produced by the 'big bang' -- encode the basic physics of the universe and the origin of visible structures in the universe: galaxies and the gas between them.

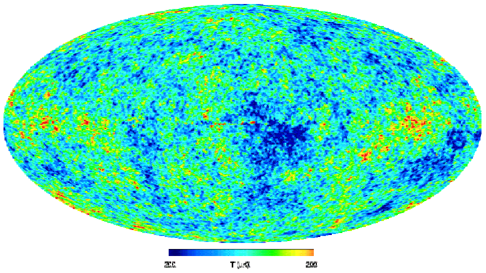

Figure 1: A color-coded representation of temperature fluctuations (typically 1 part in a million) about the otherwise uniform 3 K radiation emanating from the cosmic explosion – the 'big bang' – that gave rise to the universe and its constituents. This all-sky picture derives from recent observations made with WMAP.

Cosmologists are busy decoding these maps and have already made enormous progress in defining the geometry, age and expansion rate of the universe, and inferring its likely fate. Physicists have developed new theories to explain the origin and statistical features of the WMAP temperature fluctuation patterns, and the mysterious combination of 'dark matter' and 'dark energy' that they imply. Over the next decade, more precise mm-wave maps, together with observations of the large scale distribution of galaxies, and precise distances to thousands of distant galaxies provided by supernovae, promise to refine both our understanding of the equations that govern the evolution of our universe in space and time, and constrain theories that seek the basic nature of dark matter and dark energy. It is possible that these observations will require a revolution in our understanding of basic physics rivaling that of the early 20th century.

Astronomers are equally excited by the challenge of understanding how in the context of a rapidly expanding, post big-bang universe, these microscopic variations in the uniformity of the universe built in at the instant of conception ultimately manifest themselves in the structures we can observe – the million light-year long 'webs' traced by galaxies and intergalactic gas. How do the largest structures in the universe evolve? What is the interplay between ‘ordinary’ matter (gas, dust, stars) and dark matter? How does large scale structure influence the formation and early evolution of galaxies? How do galaxies and their constituent stars take form from intergalactic gas, and how do galaxies enrich the gas?

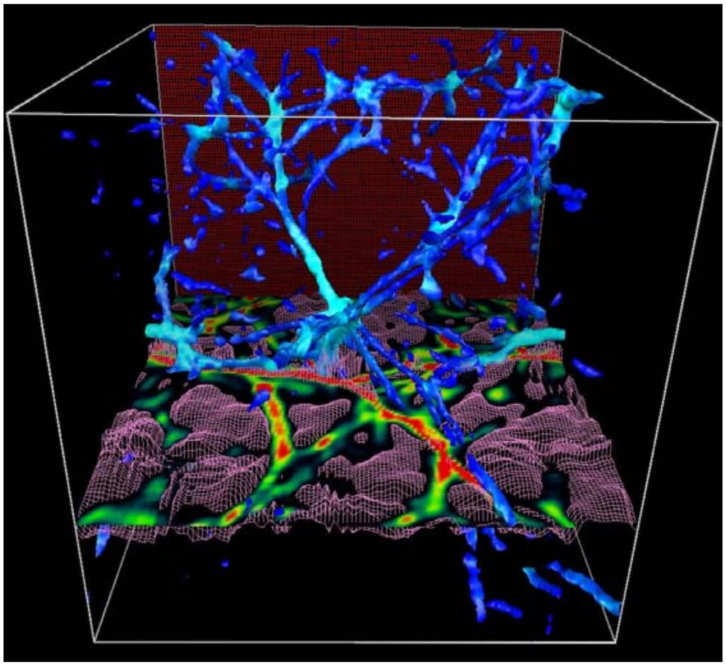

Figure 2: Results of a numerical simulation starting from a model universe whose basic parameters derive from analysis of COBE and MAP data. This representation illustrates the web of gas (blue) and nascent galaxies (red clumps mapping regions where agglomerations of dark matter have begun to capture intergalactic gas and form the first generation of stars). GSMT has the light gathering power to use faint, distant galaxies as probes to reveal both the large scale distribution of these systems, and to develop a tomographic map of how intergalactic gas is distributed and how star formation in just assembling galaxies affects the dynamics and chemical composition of the gas.

The Role of GSMT

The power of GSMT lies in its ability to obtain spectra of large numbers of galaxies at sufficiently high resolution to reveal – via their sharp‘shadows’ against galactic light – a forest of absorption features arising in intergalactic gas and diagnostic both of its distribution (via its Doppler-shifted velocity) and chemical composition (via the strength of a metallic feature compared to the strength of a corresponding hydrogen absorption feature at the same Doppler-shifted velocity). By using a large number of galaxies (on order a million probing a volume of 300 million light years on a side) and searching for features of common Doppler velocity along multiple lines of sight, it will be possible to produce a ‘tomographic’ map of the intergalactic medium as it looked during the first 10% of the lifetime of the universe. Combined with the distribution of galaxies, this map will provide the basis for confronting ‘model universes’ designed to predict large-scale structure from the fluctuations encoded in the cosmic background radiation.

These same observations will provide a direct probe not only of luminous matter (contained in galaxies and stars) and gas, but of dark matter as well – traced indirectly through its gravitational effect on the motions of both galaxies and gas. Hence we can learn how dark and luminous matter are distributed during the earliest evolutionary phases of the universe, and how dark matter influences the formation and evolution of galaxies.

Furthermore, the distribution, composition and motions of the intergalactic gas can be compared with the distribution of galaxies in order to learn how elements produced by exploding supernovae in young galaxies enter the intergalactic medium and enrich it.

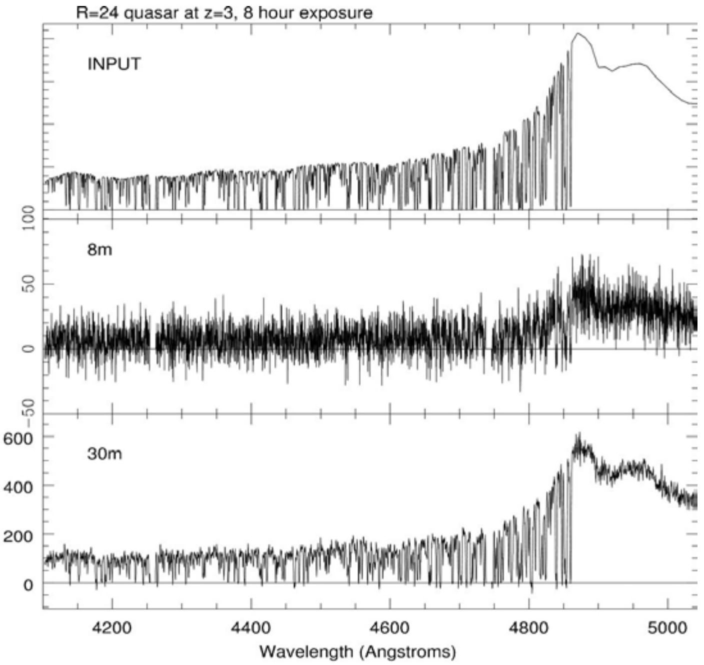

Figure 3. A plot depicting a simulation of the ‘forest’ of hydrogen and metal absorption lines as they might appear observed against the spectrum of a faint quasar (top). The middle spectrum reveals the best result we could expect for today’s 8-10m diameter telescopes even with an all night exposure. The bottom spectrum illustrates the potential of GSMT to deliver spectra capable of analyzing these absorption features and deducing the distribution, chemical composition and motions of intergalactic gas. To gather the million galaxy sample capable of providing a tomographic map of the intergalactic medium will require nearly two full years of observation with a 30m GSMT.