A summary of Springel, Frenk, and White's <u>The Large Scale Structure of the Universe</u>

The Large Scale Structure of the Universe is a summary which takes the reader up-to-date on the current ideas about the composition, evolution, and representation of our universe. Beginning as a tribute to recent informational and technological advancements, it then delves into the theories that have thus been postulated and are supported by a variety of independent perspectives. We have seen many of these ideas discussed in our former articles, and here, Springel et al uses them to chart the development large scale structure analysis and formulate a summarization of our standard model. However, although these authors highly support their presented standard model, they also present some unresolved inconsistencies between the theoretical models and observed universe structure. Alternative theories are mentioned, and the pros and cons are weighed. In all, the article assures the reader that new research will continue to change the way we think of large scale structure, and very few areas can be regarded as completely understood or explained by our simulations and models.

The great informational advancements of the last few decades have been achieved through our analyses of quasar absorption, gravitational lensing, and the CMB radiation. Moreover, with our massive galaxy surveys and computer capabilities, we have learned much more about the necessary composition for our universe and simulated evolution of such large scale structure with numerical and semi-analytical techniques. From our research and simulation, the "standard model of cosmology" is now known as the *lambda cold-dark-matter* model, which independently matches with the constraints imposed by a flat universe with increasing expansion rate. We therefore look to dark matter and dark energy to explain the majority of our universe's large scale structure, although we cannot actively see/detect the particles that account for these forces and effects. However, analysis of galactic rotation curves, galaxy groups and clusters, large scale cosmic flows, and gravitational lensing highly support the dark matter cause and dark energy is needed as Einstein's cosmological constant. Also, such theories support the idea of inflation, where our universe briefly expanded at an incredible rate, explaining how such uneven distribution of mass in our current state could have arisen from a beginning of practically complete homogenous density distribution.

In regards to the composition and characteristics of our universe's matter, research has shown dark matter to be very different from the matter we know and are used to interacting with. Dark matter is thought to be non-baryonic and only responsive to the gravitational force. Therefore, while visible galaxy clusters have held their large-scale structure for a significantly large portion of our universe's history (redshifts of up to 8.5), dark matter structure has only recently developed (within redshifts of less than 5). Therefore, while our visible baryonic matter has remained reasonably stable in it structure for a very long time, dark matter has played a much more dynamic role in the molding of universe large scale structure.

However, there are flaws in the standard model that need addressing in order cosmologists to be truly satisfied with the current hypothesis. We still don't know what dark matter and dark energy actually are, and our models do not exactly match our experimental findings. Numerical simulations and semi-analytical models both still need a multitude of constraints in their equations to match observation, and we don't understand enough about dark matter to know exactly what these constraints are. Also, dark energy poses a problem of its own. Quantum mechanics and cosmology do not agree on gravitational effects and interplay with the other three fundamental forces at such a large scale, and the dark energy field should be much larger than it is postulated to be. In addition, from a phenomenological perspective, we are not certain about the accuracy of our standard candle supernovae luminosity method, which could change the value for the cosmological constant.

The alternate theory of MOND (modified Newtonian dynamics) is discussed in the article, which explains galaxy rotation curves very well. However, the authors do not think that MOND does a good job of explaining all the other observational evidence for dark matter, and therefore, they stick to their support of the "standard model." However, the standard model does not explain small-scale structure nearly as well as it explains large scale structure, which is a challenge that future research and modeling must face and hopefully mend. Therefore, there are many prospects for the future in the field of cosmology and astrophysics. The article supports the possibility of finding a dark matter particle in the near future. Explaining dark energy will be a much more challenging task; however, NASA is in its first stages of the Joint Dark Energy Mission, which will measure the equation of state parameter of the dark energy. Hopefully, this will give us some constrains on the quality of dark energy and allow us to begin to understand more about its characteristics and effects on large scale structure. Ideally, we would find some sort of interaction between dark matter and dark energy, as dark matter does not seem to interact with much except for itself, and we currently don't know what dark energy interacts with.

Future testing hopes to reach new findings through observations of high-redshift type Ia supernovae, weak lensing tomography, and the study of baryon oscillations (aka baryonic wiggles).