In this paper, C.M. Baugh summarizes current galaxy formation research, and gives an introduction to semi-analytical modeling. I chose the paper (though it's a long one) because I feel like it's a pretty clear overview of a lot of the major structure formation questions on the galaxy scale, and also because it gives greater depth to the idea of semi-analytical modeling which we discussed a bit last week. Just as a note, I've had this paper assigned a couple of times in class and in research, and I still feel like there's more for me to get out of it, which is part of what makes it so good. On the downside, I've often felt as if there are a lot of the details which are hard to understand.

Baugh tries to motivate the problem of galaxy formation in several ways. First, he points out, we have determined fairly well the values of the major cosmological parameters, and we have found strong evidence to support a lambda CDM model of the universe. Second, increase in computing power has made semi-analytical or even gas dynamical N-body simulations of galaxy formation possible. We have better technology to study galaxy formation on a theoretical level than ever before. Of course, there is also simply the motivation that formation of galaxies is a rather mysterious astrophysical process; we really haven't made too much headway in describing a full theory of galaxy formation.

Baugh then describes our evidence for the current hierarchical theory of galaxy formation in a lambda CDM model. The evidence for the lambda CDM model is all pretty familiar, at least in the sense that we've heard of it before (though I wouldn't venture to say that that means we understand it): good agreement between theoretical simulation and observation, observations of the CMB power spectrum, redshift surveys of galaxies and galaxy clusters, and the Hubble diagram of type Ia supernovae. He points out that while he discusses semi-analytical models of galaxy formation in the context of a lambda CDM model, much of the formalism is based on physics, NOT any assumptions about the cosmological model used, and thus can carry over to any cosmological model of your choosing.

After this overview of the state of cosmology, he presents the hierarchical model of galaxy formation. In short, the idea is that overdense regions of the dark matter left over after the Big Bang will be gravitationally unstable and collapse. During this collapse, some overdense regions may merge with other overdense regions, or accrete material from the surroundings. By these two processes, perturbations in the matter distribution at early times grow into dark matter haloes. Modeling and observation in this field attempt to determine or predict the distribution of dark matter halo masses, the formation history of these haloes, and the internal structure of the haloes; Baugh describes some of what we know about all three. Of course, we are also interested in the luminous matter. As far as I can tell, in the model luminous matter is assigned to dark matter haloes on a somewhat ad hoc basis. It is believed that the luminous matter also follows a similar sort of formation process, with galaxy mergers playing a major role in galaxy formation and evolution.

Aside from simply presenting the theory, Baugh tries to compare semi-analytical modeling with gas dynamical simulations and present important questions for either of these approaches to answer. I honestly think that the paper is at its worst when Baugh gets on his high horse about people having an attitude about semi-analytical modeling, and also about how it must present its (debatably better-developed) science results without "the seductive power of a movie". He's trying to make his case to skeptics, and he makes some pretty good points. There's some good defense of the theory, but a lot of it is overshadowed for me by the tone he adopts.

More interesting for me are the questions he asks in section 1.5, and that he claims any theory of galaxy formation must explain. I think that they're good to keep in mind for the rest of the semester. He points to the observation of a sharp decline in the galaxy luminosity function beyond a certain threshold luminosity, which identifies characteristic mass and luminosity ranges for galaxies. I also think we should keep in mind his point that star formation is essentially inefficient. From my classes, I know that the relationship between the size of the bulge component of galaxies and their central black holes is thought to be pretty fundamental by a lot of the theorists working in this field, and yet it is not well understood. There are also lots of questions, here and elsewhere, relating to the specific details of the formation of different galaxy morphologies. While I don't propose any answers (and we haven't read enough of the paper to really get a sense of Baugh's answers, where he offers them), I think that the questions are very important.

In general, I think the most important things to carry away from this paper are the types of questions Baugh is asking about galaxy formation, and a bit about the approach he's taking to solve them. In particular, I think that it is important to realize that both semi-analytical modeling and dynamical simulation contribute to the study of structure formation, and especially that in a lot of ways semi-analytical modeling is a better-developed approach and one that will likely always exist simply because of limits on available computing power. The idea of the hierarchical model, though simple, is the last thing I would draw attention to; hierarchical models propose that smaller structures formed first and combined to create larger structures. The debate between this sort of "bottom-up" formation model, and models which propose that larger structures formed first, then fragmented through gravitational instability (so-called "top-down" formation models) is one that is still an active area of research and debate.