A MODEL FOR THE SEQUENCE OF ELLIPTICAL GALAXIES

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We present a simple model for the formation of elliptical galaxies, based on a binary clustering hierarchy of dark matter, the chemical enrichment of the gas at each level being controlled by supernovae. The initial conditions for the non-linear phases of galaxy formation are set by the post-recombination power spectrum of density fluctuations. We investigate two models for this power spectrum – the first is a straightforward power law, $|\delta_k|^2 \propto k^n$, and the second is Peeble's analytic approximation to the emergent spectrum in a universe dominated by cold dark matter. The normalisation is chosen such that on some scale, say $M \sim 10^{12} M_\odot$, the objects that condense out have properties – radius and velocity dispersion – resembling 'typical' galaxies. There is some ambiguity in this due to the poorly determined mass-to-light ratio of a typical elliptical galaxy — we look at two normalisations, $\sigma_{1D} \sim 350\mathrm{kms}^{-1}$ and $\sigma_{1D} \sim 140\mathrm{kms}^{-1}$. The choice determines which of Compton cooling or hydrogen cooling is more important during the galaxy formation period. The non-linear behaviour of the perturbations is treated by the homogeneous sphere approximation.

Each power spectrum model is investigated by two techniques. A simple binary hierarchy which considers only *typical* 1σ fluctuations is compared with a more realistic approach where the amplitudes of the fluctuations on any scale are randomly sampled from a Gaussian of zero mean and variance set by the power spectrum. In the latter approach, the amplitudes of the fluctuations on all scales smaller than that destined to become a galaxy are self-consistently assigned from the largest scales down through the smallest, the technique being formally equivalent to a Hadamard decomposition of the density irregularities in that region. The amplitudes assigned to each level of the hierarchy enable us to calculate collapse times, and hence to know whether a spherical lump on a given level has time to complete its collapse before the next level turns around and collapses on top of it. We follow heating and cooling, and the chemical evolution, of lumps of gas due to the cumulative effect of supernovae in removing gas, or by the next level falling in on top. We allow for dissipation of energy as stars form by increasing the velocity dispersion of a given perturbation by an amount proportional to the mass of newly formed stars.

The simple model of a merging hierarchy presented here can account for the observed correlations between global properties of elliptical galaxies – metallicity, velocity dispersion, luminosity, surface brightness – perhaps favoring a flat spectrum of initial fluctuations, as predicted by models where the universe is dominated by cold, dark matter. Low luminosity (mass) ellipticals result from truncation of the hierarchy. The nature of the last merger (gaseous or stellar) and the stage along the hierarchy at which it took place are very important in determining the ultimate character of a galaxy. These are controlled in part by the statistical spread about the mean initial density fluctuation on a given scale, and on larger and smaller scales. If there is little gas around, either because the earlier stages have consumed it all or because it has been swept away in a cluster environment, the galaxy is an elliptical. If gas remains, but cannot cool rapidly to form stars, the galaxy will aquire a disk-structure.

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