Abstract

A local property of standard cosmology — growth of primordial perturbations — implies at least six different formation mechanisms of dwarf galaxies. A global property — the topology of the Universe — may enable direct observational study of the aging of individual galaxies.

Dwarfs (by mass) can form by star formation in low mass dark matter haloes, which generally collapse early in hierarchical galaxy formation scenarios. However, several other formation paths exist, including that of low redshift, recently collapsed, low mass dark haloes containing low metallicity stellar populations. The latter possibility is purely a property of gravitational collapse — no special mechanisms to retard star formation are required. Dwarfs by “nurture”, as opposed to “nature”, are also possible.

1 Introduction

In principle, we are here to talk about “Dwarf Galaxies and Cosmology”.

Dwarf galaxies can be defined either as galaxies of low luminosity or as galaxies of low mass. “Cosmology”, as an observational science, should be taken to mean the study (a) of global properties of the Universe, to the extent that properties appear to be global, or (b) of local properties of the Universe which are significantly affected by global properties.

The formation of galaxies and large scale structure from primordial fluctuations in the early Universe is a local property, i.e., an example of (b), while the study of the topology of the Universe (e.g., [3], [4]) is a global property, i.e., an example of (a).

Within a decade, both the curvature and the topology parameters of the Universe are hoped to be known to within a few percent accuracy to the limits possible within the observable horizon. Once these are known, and if the size of the Universe is small enough, then for a
given dwarf galaxy, multiple topological images of the same dwarf galaxy at different epochs (probably by several Gyr) will be observable at predicted positions.

So, statistical studies of dwarf galaxy evolution may be complemented by that of the studies of individual dwarf galaxy aging.

2 Hierarchical galaxy formation and dwarf galaxies

The most popular scenarios of galaxy formation from small density perturbations within a cosmological context (e.g., [12, 8]) are termed “hierarchical”, since small length scale (i.e., small mass scale) perturbations generally collapse first, and later merge together to form dark matter haloes of successively higher and higher masses. Subsequent to gravitational collapse, cooling processes in the baryonic components enable star formation.

2.1 Obvious dwarfs

Dwarf galaxies defined either by mass or by luminosity can therefore be expected in three categories:

(i) galaxies in low mass haloes, at high $z$, (dwarfs by mass);

(ii) galaxies formed in low mass haloes at high $z$, which have escaped merging and so are seen at low $z$, (dwarfs by mass); and

(iii) galaxies in high mass haloes at low $z$, which have had much less star formation than other galaxies in high mass haloes (dwarfs by luminosity).

Dwarfs (i) are likely to be difficult to observe, in particular because of (bolometric) surface brightness dimming of $(1 + z)^4$ (cf. [2, 6]).

Dwarfs (ii) are probably the main observational target of this meeting, although some of them are detected in studies intended for the study of the high $z$ galaxies (e.g., the HDF [2]).

Dwarfs (iii), i.e., defined by luminosity, include dwarf spheroidals such as DDO154 (e.g., [7]) and high mass, low surface brightness galaxies (though because of the high mass, the term “dwarf” tends not to be preferred for these).

Since dwarfs of types (ii) and (iii) are those observed, these are of immediate interest for detailed hierarchical galaxy formation models. Since relative isolation is probably necessary to avoid either merging of dark matter haloes [for dwarfs (ii)] or to avoid interaction-induced star formation [for dwarfs (iii)], simulations based on statistical analytical approximations (e.g., [11]) may be sufficient to correctly model dwarf galaxy formation and evolution.

2.2 Less obvious dwarfs

However, there remain some less obvious categories of dwarfs (by mass) expected in a hierarchical model, at least the first two for which the modelling requires the inclusion of non-linear effects absent in “semi-analytical models”:

(iv) galaxies formed in high mass haloes at low $z$, with a “normal” star formation rate, but which are stripped of both dark and luminous matter by interactions with other galaxies or the inter-galactic medium inside of a cluster;

(v) galaxies formed in the tails of major galaxy mergers; and
Figure 1: The left panel shows perturbations, with amplitudes drawn from a Gaussian distribution, shown in the right panel. The perturbations are shown as overdensity $\delta \equiv (\rho - \bar{\rho})/\bar{\rho}$ as a function of distance, scaled to a fixed wavelength (arbitrary units) and shifted to a fixed phase. The Gaussian probability density function and the perturbations are shown in units of r.m.s., i.e., “1-σ” fluctuation amplitudes (vertical axes). Amplitudes less than 0.25-σ are shown in bold. If the collapse epoch of 1-σ perturbations is $z_{\text{coll}} = 3$, then 0.25-σ perturbations should collapse at $z_{\text{coll}} = 0$, (for $\Omega_0 = 1, \lambda_0 = 0$), forming “type (vi)” dwarfs.

(vi) galaxies in low mass haloes formed at low $z$.

In principle, the non-linear effects are included in full-scale hydro-gravitational $N$-body simulations (e.g., [14]). Alternatively, pure gravity $N$-body simulations can be combined with analytical formulae using the method of [11], which is being updated into a user-friendly software package, ARFUS (“arbres de fusions”, [10]).

If dwarfs (iv) exist, then they have probably already been observed and need to be distinguished from dwarfs (ii).

At least some dwarfs (v) exist ([1]),

At least some dwarfs (vi) also exist ([13, 3]), and these are not in contradiction with the standard hierarchical galaxy formation scenario.

2.3 Low amplitude fluctuations: dwarfs of “type (vi)”

Fig. 11 of [14] shows that the formation of dwarfs (vi) is apparent in $N$-body derived merging history tree simulations of galaxy formation: the “merging histories” of low $z$, low mass galaxy haloes show recent birth and little or no merging.

The explanation for this provides a useful reminder about “primordial Gaussian fluctuations”.

“Gaussian” does not refer to the shape of the fluctuations; it refers to the probability distribution of the amplitudes of the fluctuations. Fig. 1 shows an example of some fluctuations, at a fixed length scale and fixed phase, drawn from a Gaussian distribution of amplitudes.

In fact, the most common fluctuations are of zero amplitude and so do not collapse to form structure! Of course, the majority of fluctuations have amplitudes $A$ with, say, $|A| > 0.25$,
in units of the r.m.s. amplitude $\sigma$. So a majority of small length scale perturbations, whose amplitudes have $|A| \sim 1$, generate the low mass haloes which should collapse early and provide the low mass dwarfs [types (i) and (ii)].

Nevertheless, some small length scale fluctuations have low, but non-zero amplitudes. These fluctuations, according to “linear theory”, should only collapse at recent epochs. If $z_{\text{coll}}$ is the collapse epoch of haloes of a given mass generated from $1-\sigma$ fluctuations, then fluctuations of $[1/(1 + z_{\text{coll}})]-\sigma$ amplitude will only just be collapsing now, forming dwarfs of type (vi) [for $\Omega_0 = 1, \lambda_0 = 0$, in which case amplitude growth is $\delta \propto 1/(1 + z)$].

Of course, some of the small length scale fluctuations expected to collapse at the present may be inside of large length scale fluctuations, i.e., they merge before they have a chance to collapse, and end up in a higher mass halo.

Alternatively, the small length scale fluctuations may contain fluctuations on yet smaller scales (above the recombination epoch Jeans mass), which mostly collapse earlier. In this case, the low $z$ newly formed halo would be partly composed of these smaller haloes which could already be metal-enriched via star formation. Hence, type (vi) dwarfs should not be too much greater than the Jeans mass if they are to contain zero metallicity matter and no old stars.

The existence of some low $z$, low $Z$, low mass galaxies is not surprising in hierarchical galaxy formation. This property does not require any special assumptions regarding star formation — it is simply gravitational.

Moreover, precise statistics on the numbers, masses and metallicities of such galaxies, combined with the recombination epoch Jeans mass, might provide an independent method of constraining the cosmological metric parameters, $\Omega_0$ and $\lambda_0$, in the sense that a high number density of low $z$-$Z$-$M$ galaxies would provide a constraint against a low density of the Universe (since perturbation growth slows near the present in a low density universe).

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