Properties of Spiral and Elliptical Galaxy Progenitors at $z > 1$

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Abstract. We present the results of a Hubble Space Telescope and ground based optical and near infrared study to identify progenitors of spirals and ellipticals at $z > 1$. We identify these systems through photometric and spectroscopic redshifts, deep K-band imaging, stellar mass measurements, and high resolution imaging. The major modes of galaxy formation, including: major mergers, minor mergers, and accretion of intergalactic gas, and their relative contribution towards building up the stellar masses of galaxies, can now be directly measured using these data.

1 Introduction

The generally accepted modern hierarchical galaxy formation picture consists of galaxies forming in dark matter halos that later merge to form larger halos and more massive galaxies. The end result of this evolution is the morphological and stellar population mix in the nearby universe. This picture however remains largely untested. Understanding how the modern galaxy population was put into place requires understanding when and how stars (and hence galaxies) formed. Based on several decades of observations and modeling of stellar evolution we know that the stars in nearby galaxies contain a wide diversity of ages and metallicities. To first order these differences correlate with galaxy type and environment. Generally, early-types or elliptical galaxies are dominated by old stars and are found in dense environments, while later type galaxies have a mix of young and old stellar populations and are found in lower density areas.

Directly measuring the galaxy mass assembly and star formation history has now been accomplished out to $z \sim 3 - 6$. However, these measurements do not tell us *how* galaxies formed. One way to address this question is to include high resolution imaging, such as from deep Hubble Space Telescopes images. Imaging surveys with Hubble show that galaxies evolve into normal systems from peculiars between $z \sim 1 - 2$ ($\sim$ 10 Gyrs ago) (Figure 1; e.g., van den Bergh et al. 2001; Conselice et al. 2003). At redshifts higher than $z \sim 1.5$ most galaxies are distorted and asymmetric (Abraham et al. 1996; Conselice et al. 2003). Deep NICMOS observations of the Hubble Deep Field North, which samples the rest frame B-band morphologies of galaxies at $z > 1.2$, demonstrates that these galaxies are intrinsically distorted in the rest-frame optical, and that we are not witnessing morphological k-correction effects (Papovich et al. 2003).

These high redshift galaxies are also undergoing large amounts of star formation (e.g., Madau et al. 1998), creating the normal bright galaxies we see today.

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What causes the structural peculiarities in these galaxies, and presumably also the induced star formation? If we can answer this it will reveal the formation modes of galaxies, and allow us to quantify the relative contributions of different formation processes.

2 Mass Assembly as a Function of Morphology

The first step towards understanding the formation mechanisms of galaxies is to have a robust determination of how the structures of galaxies change with redshift, and how these changes relate to the star formation and mass assembly history. Figure 1 shows co-moving number, luminosity, and stellar mass densities of ellipticals, spirals, and peculiar galaxies as a function of redshift. One interesting trend from this figure, besides the dominance of spirals and ellipticals at $z < 1.5$ and peculiars at $z > 1.5$, is the that there exists an equilibrium point at $z \sim 1.5$ where the relative fraction of luminosity, mass and number densities for normal galaxies (disks/ellipticals) and peculiars are nearly equal. In all regards this is the redshift in galaxy evolution where modes of forming galaxies are rapidly transitioning. This trend is also seen when studying the NICMOS observations of the Hubble Deep Field North and in the Hubble Deep Field South.

There is a growth in both the stellar mass density and number density of spirals and ellipticals at $z < 1$, with a corresponding decrease in the number of peculiars (see also Brinchmann & Ellis 2000). Star formation is still occurring in disks and ellipticals at $z < 1$ as the stellar mass densities for these types grows by a factor of two or more (Figure 1). The luminosity density for both ellipticals and spirals also peaks at $z \sim 1$, and mass to light ratios for these systems increase with lower redshift at $z < 1$. At $z > 2$ peculiar galaxies consistent with major merging (Conselice et al. 2003) are dominating the luminosity and stellar mass density, suggesting that this is the dominate star formation process at early times.

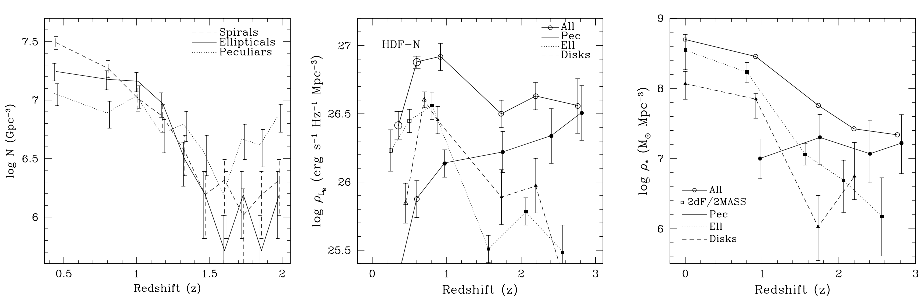

Fig. 1. The relative co-moving number, rest-frame B-band luminosity, and stellar mass density of galaxies as a function of redshift from deep NICMOS images of the Hubble Deep Field North (Conselice et al. 2004, in prep). Points at redshifts $z < 0.5$ are taken from Brinchmann & Ellis (2000), Fukugita et al. (1998) and the 2dF/2MASS survey.