Rapid Growth of Massive Galaxies: A Paradox for Hierarchical Formation Models

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Abstract. On behalf of the survey teams I summarize the designs and results of the Las Campanas Infrared Survey and Gemini Deep Deep Survey, both of which were initiated to understand the nature of red galaxies and to study the history of stellar mass assembly. Our results from luminosity function analysis, ISM absorption line measurements, and spectral synthesis modeling show that near-infrared selected galaxies at $1 < z < 2$ are not only massive and abundant but also old and metal enriched, indicating rapid formation of massive systems at higher redshifts.

1 Background

Various galaxy surveys in the optical, near-infrared, and sub-mm have uncovered different galaxy populations at redshift $z > 2$ (see Steidel, Cimatti, and Chapman in these proceedings for discussions), but whether these galaxies are representative of the galaxy population at high redshifts or how they are related to the present-day population is not clear. For example, rest-frame UV-selected samples are presumably sensitive to active star-forming galaxies and biased against evolved, quiescent systems, while sub-mm samples select mostly dusty star-forming galaxies. In contrast, near-infrared based surveys are sensitive to early-type galaxies at $z = 0 - 3$ that are known to dominate the total stellar mass at $z = 0$. A complete sample of massive systems at different epoch allows us to study the history of stellar mass assembly and offers important clues for discriminating between different galaxy formation scenarios (e.g. [1]).

But past studies based on near-infrared surveys have yielded inconsistent space density measurements of red galaxies at $z \geq 1$ (see [2] for a list of references). Early-type galaxies are strongly clustered and have no prominent narrow-band spectral features at UV wavelengths. If these red galaxies are progenitors of early-type galaxies we see in the local universe (rather than dusty star-forming galaxies), then a wide-field infrared survey is required to minimize the effect of surface density variation between fields due to strong clustering (e.g.[3,4]). Furthermore, deep galaxy spectroscopy is required to obtain a complete sample of these massive systems for spectral diagnostics of their ISM and stellar content.

The Las Campanas Infrared Survey (LCIRS) and Gemini Deep Deep Survey (GDDS) are complementary studies designed to probe the nature of red galaxies and to determine mass assembly history using near-infrared selected galaxies. In the following section I summarize the goals and results of the surveys.

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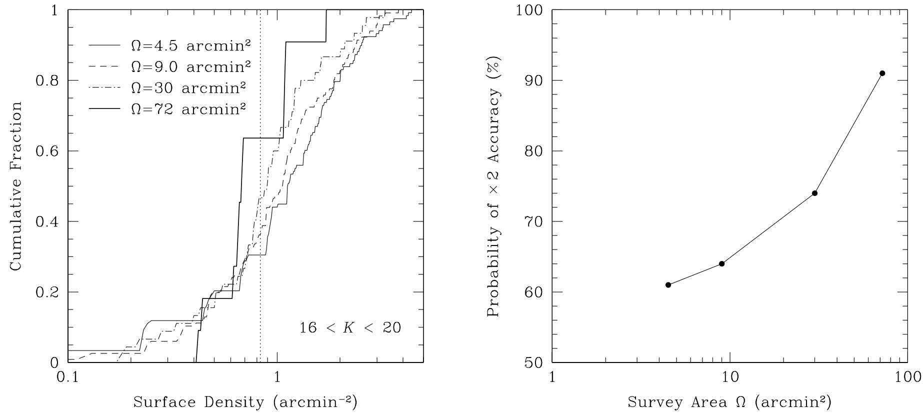

Fig. 1. Uncertainty of surface density measurements of red $I - K \geq 4$ galaxies with $16 < K < 20$ in different survey areas Ω. The surface densities were determined empirically within separate sub-areas randomly selected from the LCIRS fields. The left panel shows the cumulative probability of different surface density measurements for $\Omega = 4.5 - 72\,\text{arcmin}^2$. The vertical dotted line indicates the mean surface density of 0.83 arcmin^{-2} determined over the entire LCIRS K-band selected red galaxies. Based on these curves, we show in the right panel the probability of obtaining a measurement within a factor of two accuracy of the nominal value versus Ω.

2 The Las Campanas Infrared Survey

The LCIRS is a deep, wide-field near-infrared and optical imaging survey, designed to identify a large number of red galaxies at $1 < z < 2$, while securing a uniform sample of galaxies of all types to $z \sim 2$ using photometric redshift techniques ([2,4,5]). The primary objectives are: (1) to examine the nature of the red galaxy population and identify evolved galaxies at redshifts $z > 1$; (2) to study the space density and luminosity evolution of early-type galaxies at redshifts $z \leq 2$; and (3) to measure spatial clustering of massive galaxies, thereby inferring merger rates of these galaxies for constraining theoretical models.

We have completed the phase-I H-band survey to $H = 20.5$ over 1.1 deg^2 and are completing the phase-II K-band survey to $K = 20.6$ over 0.75 deg^2. The size of our survey area was determined in order to obtain a representative measure of the surface density of red galaxies and a significant signal in clustering analysis [4]. Five random fields have been chosen and each field covers $\approx 26 \times 26\,\text{arcmin}^2$, corresponding to a projected co-moving distance 20 h^{-1} Mpc. This is twice the correlation length observed for early-type galaxies at $z = 0$ (see [4] for references). The large survey area of the LCIRS allows us to estimate empirically the uncertainties in the surface density measurements of red galaxies identified in smaller-area surveys, assuming that the LCIRS galaxy sample are representative of these systems at $z \geq 1$. Figure 1 shows the results based on red galaxies with $I - K \geq 4$ found in non-overlapping, random sub-areas within the LCIRS fields,