Bivariate mass-size distribution with Galaxy Zoo 2 morphologies

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Abstract

It is well known that the mass-size relation evolves as a function of cosmic time and that this evolution is different between passive and star-forming galaxy populations. Recent work suggests that early types have grown by a factor of 5 in size since z~2 with little change in mass. In contrast, disk systems have remained relatively unchanged since z~1.5. In order to reproduce the slow evolution of disk galaxies, theoretical models require galaxies should grow along the relation with time, i.e., the rate at which galaxies move along the mass-size relation should equal the rate at which large, star-forming galaxies move out of the sample either via merging or quenching through secular evolution. *Such models clearly predict that the growth rate of star-forming galaxies must be accompanied by an increasing number of large spheroids at lower redshift.*

Testing this requires tracking galaxy number densities not only as a function of size and stellar mass, but also by morphological type. This can be achieved by computing the bivariate (i.e. joint probability distribution) mass-size function for galaxy samples morphologically selected in a consistent way as a function of time. Bivariate distribution functions are the only way to properly account for selection effects. Here we present the first step by considering galaxies visually classified from Galaxy Zoo 2 as our z~0 sample. We quantify the mass-size distribution using the well-known parametric Maximum Likelihood estimator.

Sample Selection

Final sample size: 120,015 galaxies

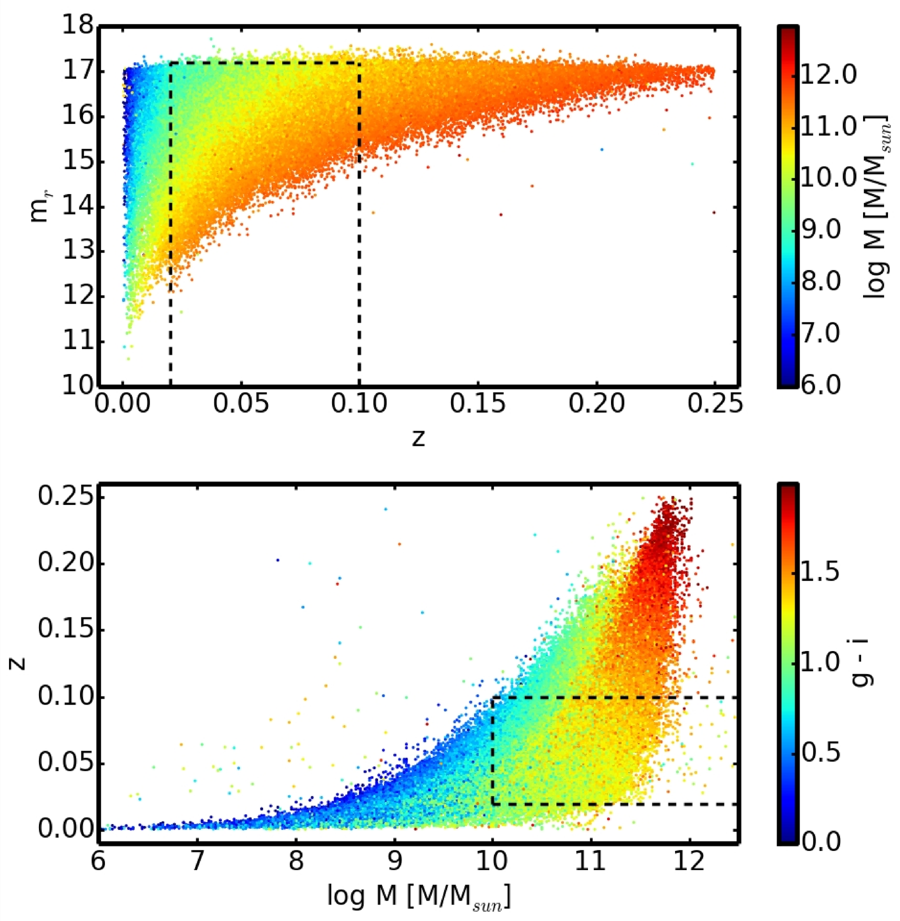

Figure 1. We use the GZ2 spectroscopic Main Sample which contains ~250K objects (data.galaxyzoo.org). We use stellar masses as calculated from multi-band photometry from the MPA-JHU catalog. Since GZ2 is magnitude-limited we make cuts in redshift and mass to obtain a complete sample shown by black dashed rectangles.

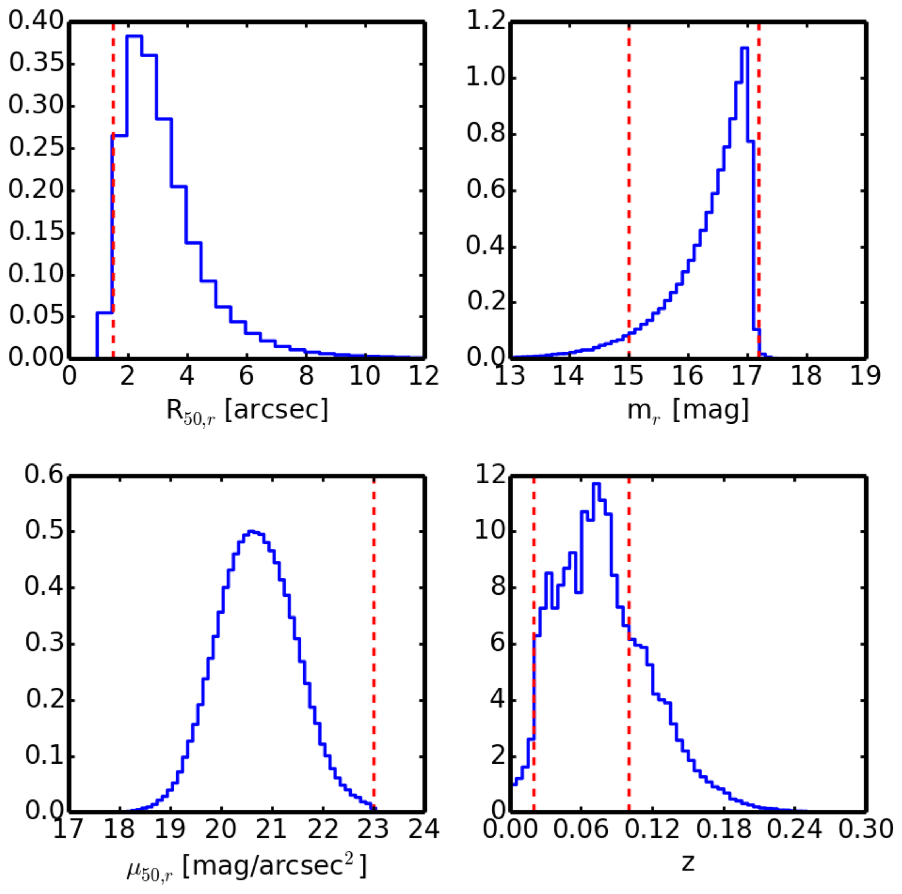

Figure 2. Various distributions of the full GZ2 sample. In addition to redshift and magnitude cuts we also make a cut on galaxy radius. Very small galaxies have size measurements which can be highly affected by their PSFs. We choose a conservative value of 1.6" as SDSS has a PSF of 1.5".

Morphological Subdivisions

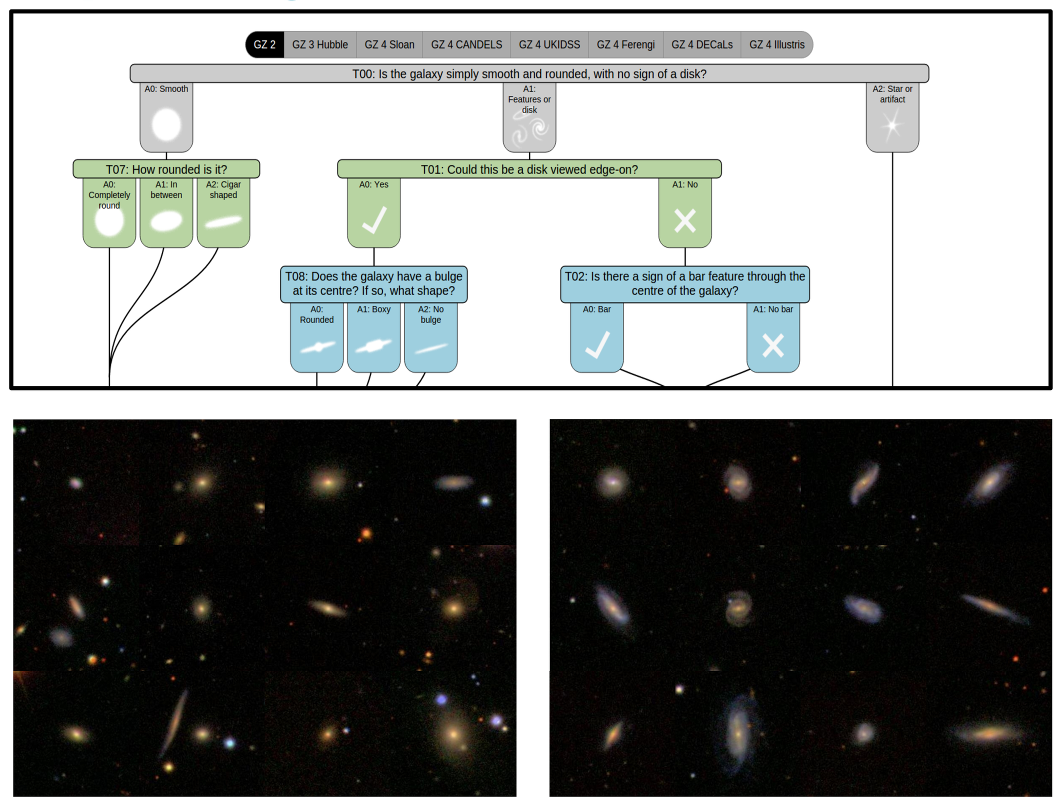

Figure 3. Visual morphological classifications were made by volunteers who answered increasingly detailed questions. In this work we consider only the top level question. "Smooth" galaxies ($p_{smooth} \geq 0.5$, i.e. where 50% of GZ users identified the galaxy as smooth) are found to roughly correlate with early-types, while "Featured" objects ($p_{features} \geq 0.5$) include disks, edge-on galaxies, and mergers.

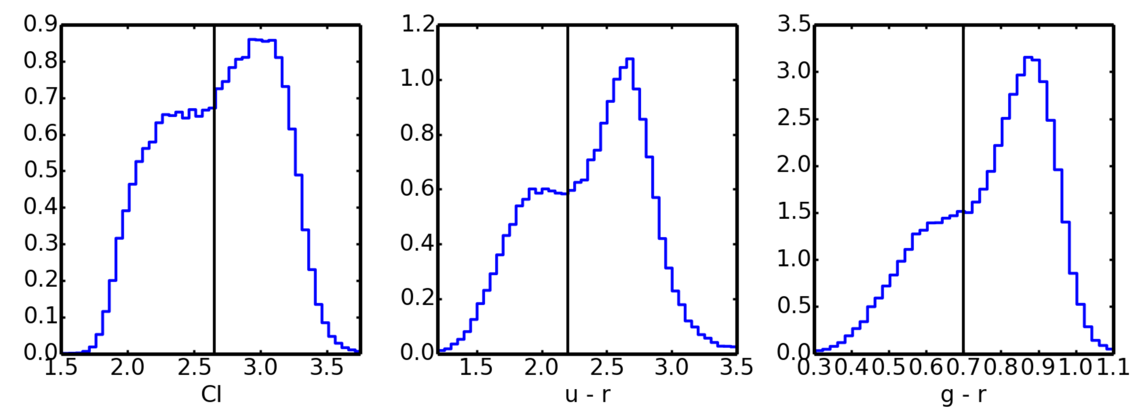

Figure 4. In addtion to visual morphologies we explore other traditional morphological indicators like Concentration Index ($CI = R_{90} / R_{50}$), u – r color, and g – r color in order to examine how these indicators compare. Solid black lines show the separation value used to distinguish between late-types (left-sides) and early-types (right sides).

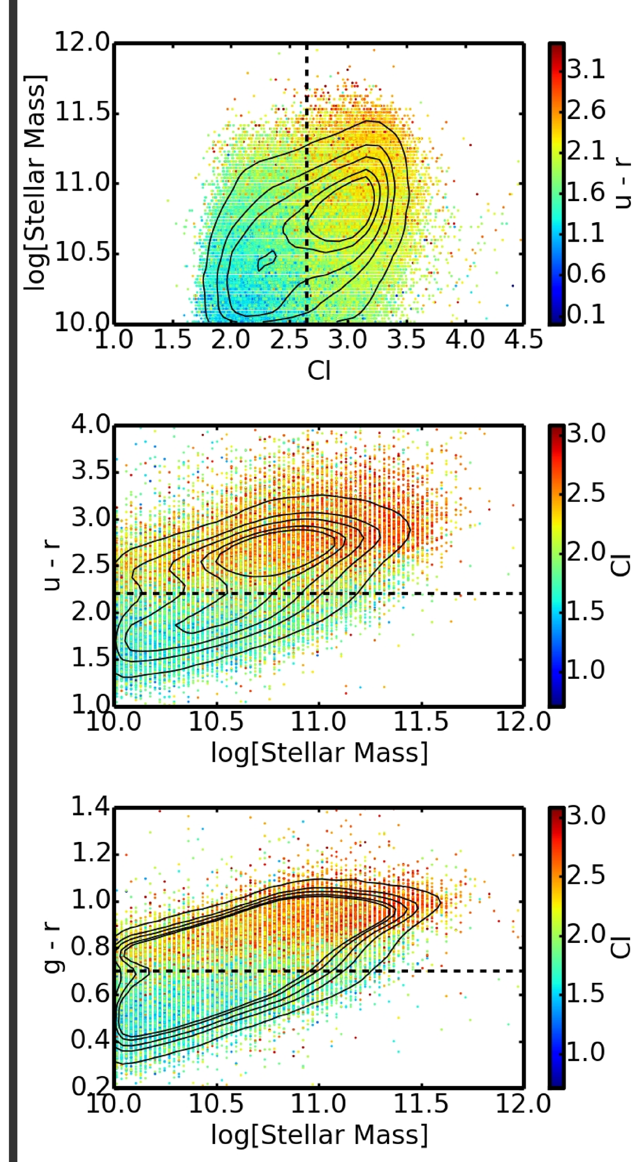

Figure 5. Multi-dimensional look at our sample. Dashed lines denote the traditional morphological cuts from Figure 4. We see that they indeed split the sample into broad categories and that each of these has mild correlations with stellar mass.

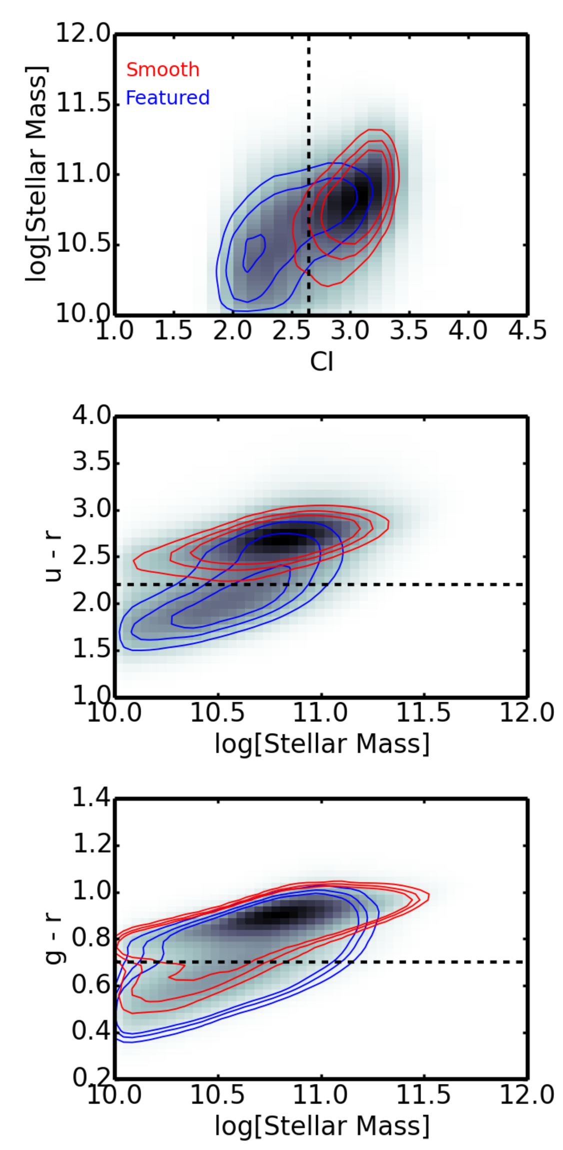

Figure 6. Same as Figure 5 but with red and blue contours corresponding to "Smooth" and "Featured" morphologies from Galaxy Zoo 2. Color cuts alone are not adequate for selecting clean morphological samples as there exist red disks and blue spheroids.

Results

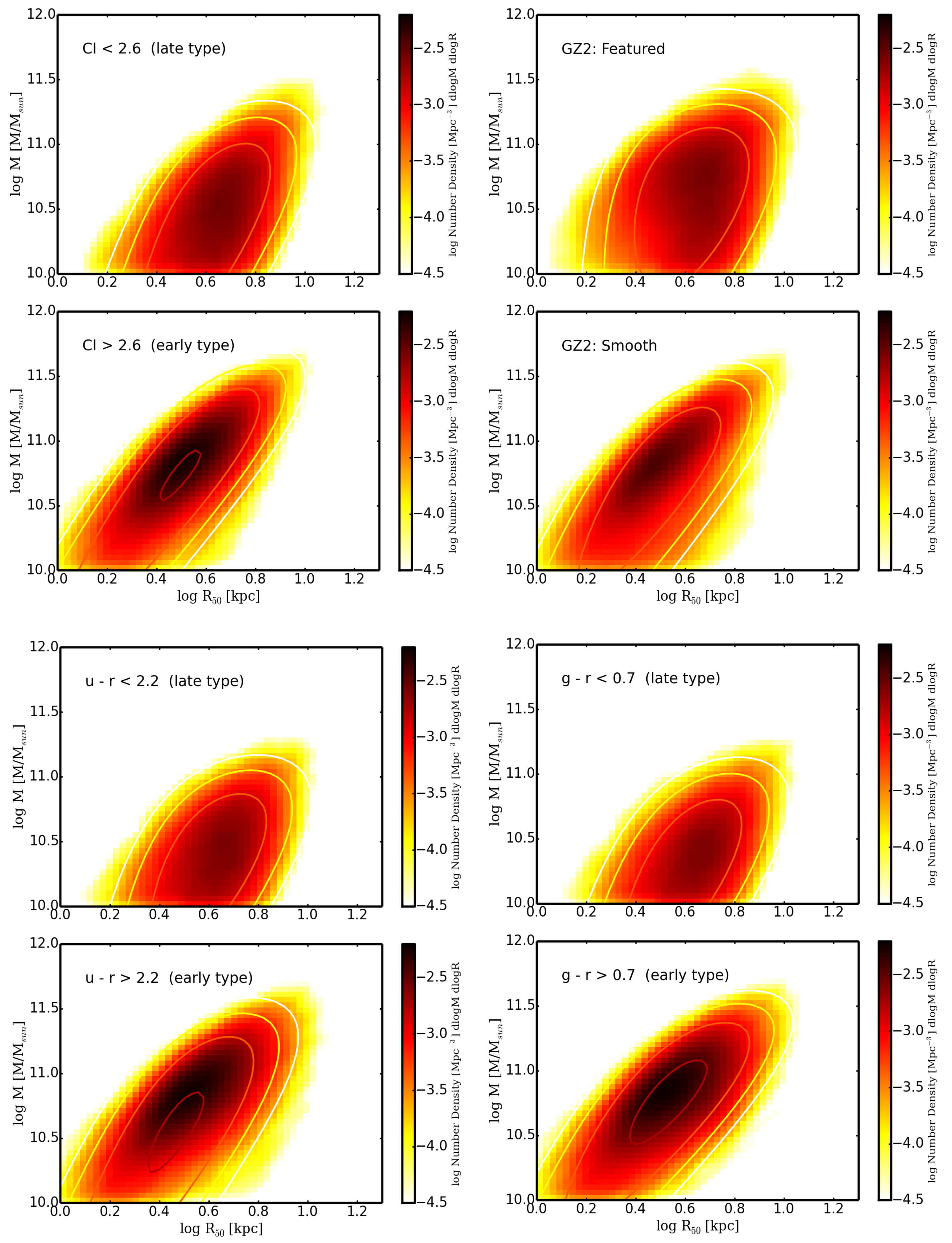

Figure 7. Preliminary results of our best fit bivariate mass-size distribution shown by contours. The completeness corrected Kernel Density Estimate (KDE) map of our data is plotted in color. We see that different morphological indicators don't seem to have a strong impact on the shapes of either the early or late type distributions.

Method: We adopt the Schecter function as our model mass function which describes the volume number density of galaxies within the mass range (M, M+dM). We adopt a log-normal distrubution for our size model which describes the probability density that a galaxy with mass M has a half-light radius between (R_{50}, R_{50} + dR_{50}). A power law relation then connects the mass and the peak of the size distribution. After converting to log units, the full bivariate distribution is thus:

$$\Psi(x,y;\mathbf{P})\,\mathrm{d}x\,\mathrm{d}y = \ln 10\left(\frac{10^y}{\mathrm{M}^*}\right)^{\alpha+1}\exp\left[-\frac{10^y}{\mathrm{M}^*}\right]\frac{\ln 10}{\sigma_{\ln \mathrm{R_e}}\sqrt{2\pi}}\exp\left[\frac{-[x-\langle x\rangle]^2}{2(\sigma_{\ln \mathrm{R_e}}/\ln 10)^2}\right]\mathrm{d}x\,\mathrm{d}y$$

where $x = \log(R_{50})$, $y = \log(M)$ and $\langle x\rangle = \log R_0 + \beta y$ is the power law relation. This distribution is characterized by five free parameters: $\mathbf{P} = [\alpha, M^*, \beta, R_0, \sigma_{\ln R_{50}}]$ (we determine ϕ^* after determining the shape of the distribution). We use the maximum likelihood estimator to recover the best fit parameters. This requires calculating the log probability of detecting a given galaxy with log(M) given **P**. The log likelihood function is then the sum of the log probabilities for all galaxies in the sample. This function is maximized to yield the best fit parameters, **P**.

We will perform this analysis on **Galaxy Zoo: Hubble** (Kyle Willett, poster 342.41) and **Galaxy Zoo: CANDELS** (Brooke Simmons, poster 342.42)

to obtain galaxy number densities over cosmic time selected in a morphologically consistent way to test the prediction that the growth rate of star-forming galaxies is accompanied by an increasing number of large spheroids at low redshift.

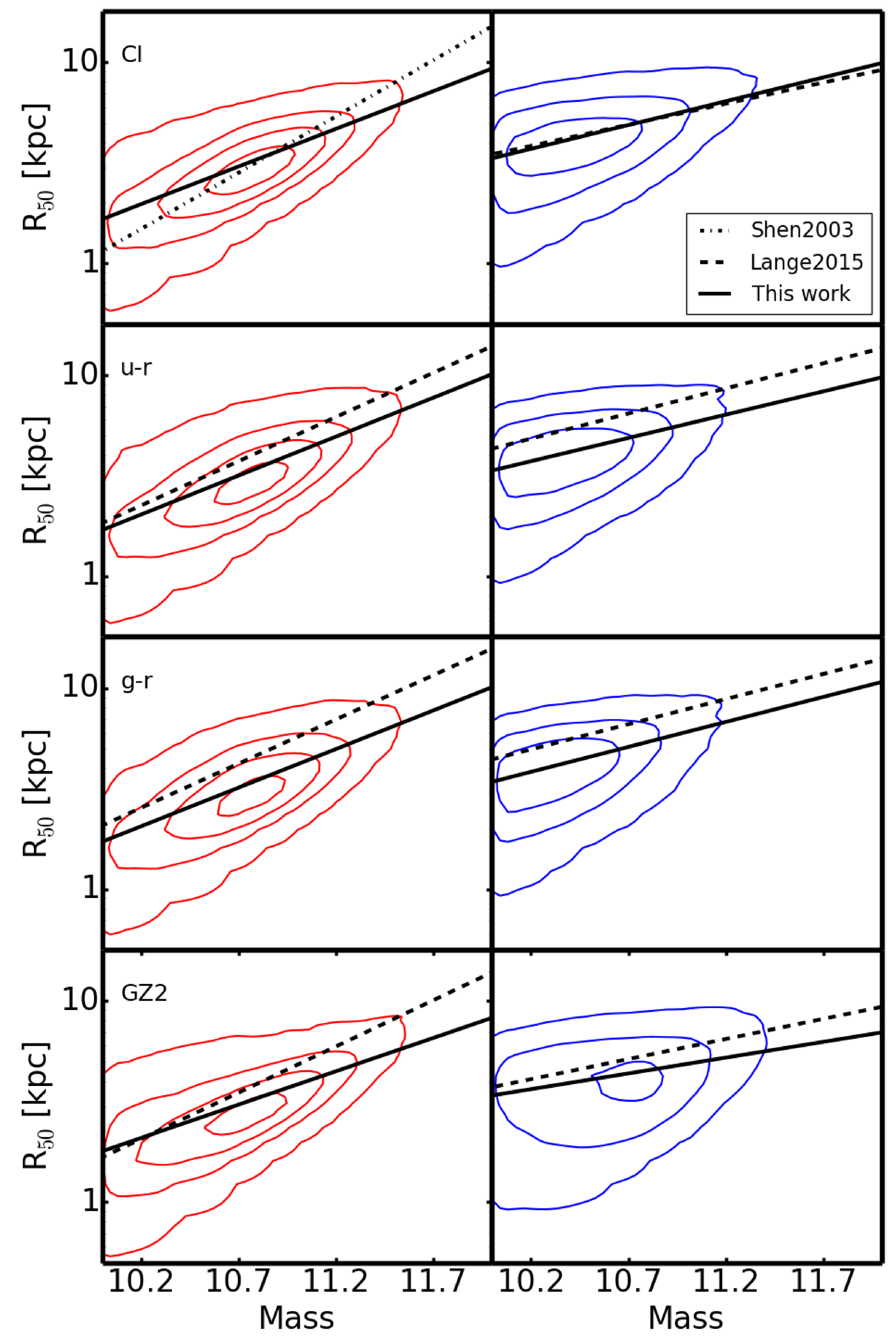

Figure 8. Comparison of mass-size relation to the literature. Red and blue contours show density of our early and late type subdivisions respectively while black lines show mass-size relations. Consdering surveys, sample selection, and morphological indicators are different between our sample and others, the consistency of our preliminary results is encouraging.

Galaxy Zoo 2 is made possible by the efforts of thousands of volunteers. Their contributions are individually acknowledged at authors.galaxyzoo.org

References: Huang et al. 2013, Lange et al. 2015, Mehta et al. 2015, Shen et al. 2003, Willett et al. 2013, van der Wel et al. 2013

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