

Galaxy Zoo: Classifications for Galaxies in HST Legacy Imaging

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ABSTRACT

This will be the data release paper for GZ Hubble. We present the classifications, the methodology for data reduction and corrections for redshift dependent biases in the observed morphologies.

1 INTRODUCTION

2 SAMPLE AND DATA

2.1 Summary of HST Legacy Survey Imaging

- AEGIS has 1 orbit each (2200 seconds) in F606W (V band) and F814W filter and has been dithered to 0.03 "/pixel; the imaging covers 710 arcmin².

- GOODS targeted 2 fields, GOODS-N and GOODS-S, imaging in 4 filters – F435W (B), F606W (V), F775W (i), and F850LP (z). The mean exposure times vary, from 1000 - 2100 seconds. The images have been dithered to a pixel scale of 0.03 "/pixel and covers at total area of 320 arcmin² (160 arcmin² per field). The filters that Griffith et al uses for the colored images were F606W and F775W for GOODS-N and F606W and F850LP for GOODS-S.

- COSMOS has 1 orbit (2028 seconds) in the F814W (I band) filter and has been dithered to 0.05 "/pixel; it covers the largest area, 1.8 deg².

- GEMS has 1 orbit (2160 and 2286 seconds) in the F606W and F850LP filters, with a pixel scale of 0.03 "/pixel; it covers 800 arcmin²

2.2 User Weighting

The votes of individual users who classified galaxies in Galaxy Zoo Hubble are combined to make a vote fraction for each question on the classification tree. Users votes are weighted slightly (in a method identical to that described in Willett et al. 2013) such that users who frequently disagree with all other users end up having very low weights. The majority of users have weights very close to 1.0 (**STEVEN: Is this true for GZH - do you have a plot of the distribution of user weights or consistencies we can include here?**).

3 CORRECTING FOR REDSHIFT DEPENDENT CLASSIFICATION BIAS

Previous version of Galaxy Zoo morphology classifications (Lintott et al. 2011, Willett et al. 2013) were based on observations of galaxies in the Sloan Digital Sky Survey (SDSS) which are typically at $z < 0.1$. In these cases it could be assumed that there was no real evolution of the morphologies of galaxies and therefore any observed changes in the distribution of galaxies with different consensus morphologies was assumed to be due to the effects of redshift on the image quality (*i.e.* the reduction in physical resolution, surface brightness dimming etc). So for both previous releases of GZ morphologies, a correction was provided for redshift dependent bias based on matching the classification fractions at the highest redshifts with those at the lowest redshift. See Bamford et al. (2009) and Willett et al. (2013) for the details.

In the GZH samples the redshift range is so large that we expect to find redshift evolution of the types and morphologies of galaxies which are seen. So the previous methods of correcting for redshift dependent bias will not work. In addition the effects of band shifting will change the images even more across these redshift ranges. Figure ?? which illustrates one possible effect of losing features in spiral galaxies at high redshift).

In order to test the effects of redshift we made images of the same galaxy at a variety of redshifts using input images from the SDSS (cite the SDSS) and the FERENGI code (cite Ferengi) to produce images from these typical of those observed in the HST surveys.

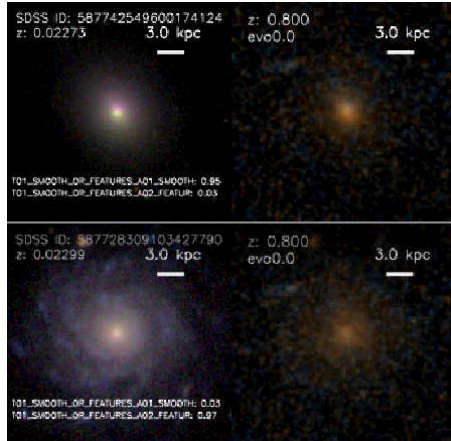
3.1 Selection of FERENGI Input Galaxies

We select 288 different galaxies in SDSS imaging to run through the FERENGI code.

The selection spanned a variety of galaxy morphologies (as indicated by GZ2 classifications), with a range of surface

Table 1. Summary of GZ Hubble Samples

Survey	t_{exp} seconds	Filters	Resolution "/pix	Area sq arcmin	N_{galaxies}
AEGIS	2200	F606W (V) and F814W (I)	0.03	710	
COSMOS	2028	F814W (I)	0.05	6480	
GEMS	2160/2286	F606W (V) and F850LP (z)	0.03	800	
GOODS	1000-2100s	F435W (B), F606W (V), F775W (i), F850LP (z)	0.03	320	

**Figure 1.** Examples of an obvious spiral and obvious elliptical at $z = 0$ which both look similar when redshifted to $z = 0.8$. See below for the description of the method for redshifting.

brightnesses, and also spanned the redshift range of SDSS targets (in $N_z = 4$ bins) in order to be optimised for different target minimum redshifts in HST imaging.

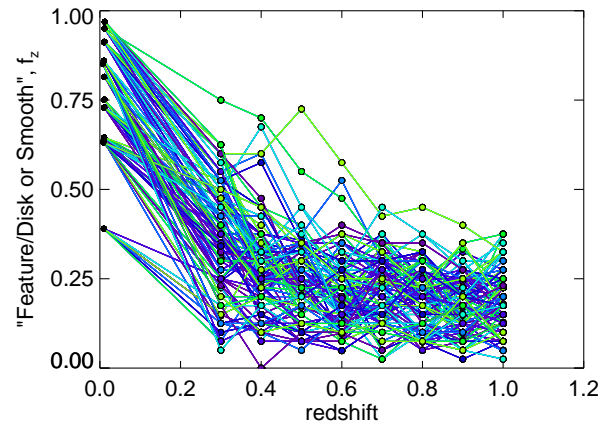
The selection criteria for the different morphological categories is summarised in Table 2. The surface brightness selection ($N_\mu = 3$) was (1) low: $\mu > 21.5\text{magarcsec}^2$; (2) mid: $20.5 < \mu < 21.5\text{magarcsec}^2$; and (3) high: $\mu < 20.5\text{magarcsec}^2$.

For each of the four “target redshifts” ($z = 0.3, 0.5, 0.8$ and 1.0), the images were redshifted in $\Delta z = 0.1$ bins up to $z = 1.0$. In addition different evolution models were assumed in FERENGI. This evolution is a crude mechanism that is suppose to mimic the brightness increase of galaxies with increasing redshift. The evolution mechanism allows us to make galaxies brighter as linear function of redshift, and that is it. It is an empirical addition to the magnitude of a galaxy of the form $M' = ez + M$, where M' is the corrected magnitude, e is the evolutionary correction in magnitudes. (i.e. $e = -1$ essentially brightens the galaxy by 1 magnitude by $z = 1$). We ran FERENGI for values of e starting from $e = 0$ and decreasing to $e = -3.5$ in $\Delta e = 0.5$ steps. Depending on the target, or starting redshift we ran FERENGI for several final redshifts and different evolution models as summarized in Table 3.

Two series of example redshifted images are shown in Figure 2, both for runs with no evolution ($e = 0$).

Table 3. Summary of FERENGI runs

z_{target}	$N_{z\text{bins}}$	$N_{\text{evolution}}$	e_{max}	N_{runs}	N_{total}
0.3	8	7	-3.0	56	4031
0.5	6	4	-1.5	24	1728
0.8	3	3	-1.0	9	648
1.0	1	3	-1.0	3	216

**Figure 3.** Preliminary results of the FERENGI redshifting exercise. WARNING NO USER WEIGHTING.... For a range of vote fraction levels with three surface-brightness levels and 7 evolutionary corrections each (the colours indicate evolutionary correction value with green being $e = 0$, we show the range of evolution of the vote fractions for featured vs. smooth with redshift.

3.2 Results of FERENGI Analysis

We show here the **preliminary** results of citizen scientist classifications of images of galaxies placed at artificial redshifts. Figure ?? shows the **preliminary** range of change of vote fractions for the change of p_{features} with redshift, for galaxies with different vote fraction levels, three ranges of surface-brightness levels and 7 evolutionary corrections (this last bit is indicated by the colour).

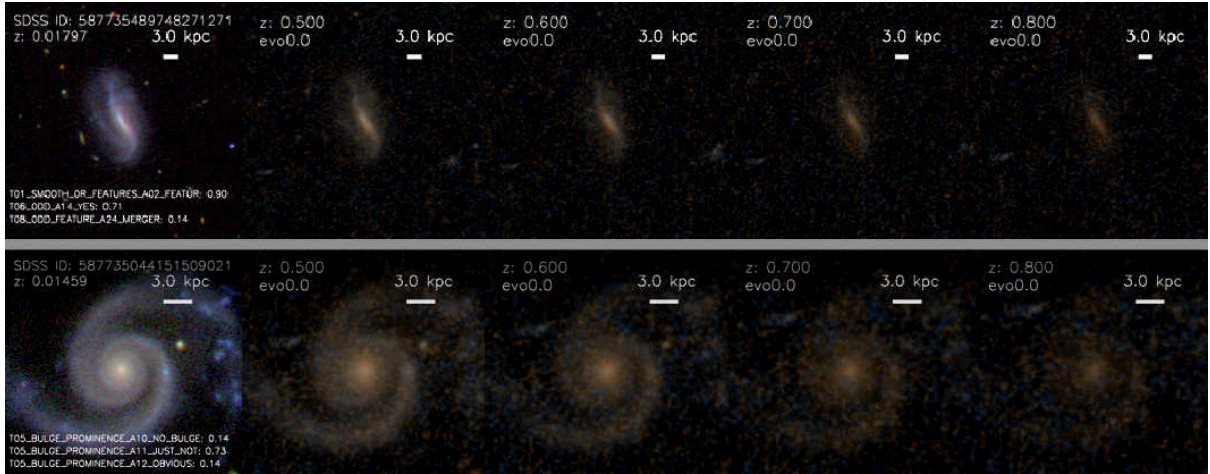
3.2.1 TODO LIST

We need to do:

- Calculate the magnitudes, surface brightnesses and sizes of the galaxies in the FERENGI images....
- Plot of magnitude distribution of galaxies in each of

Table 2. Summary of morphological categories selected for FERENGI sample

Morphology	Label	Selection	N_{objects} ($N_z \times N_\mu$)
Features	Yes	$p_{\text{features}} > 0.8, p_{\text{odd}} < 0.1$	12
	Int	$0.3 < p_{\text{smooth}} < 0.6, p_{\text{odd}} < 0.1$	12
	No	$p_{\text{smooth}} > 0.8, p_{\text{odd}} < 0.1$	12
Merger	No	$p_{\text{features}} > 0.8, p_{\text{odd}} < 0.1, p_{\text{merger}} < 0.1$	12
	Int	$p_{\text{odd}} > 0.5, 0.1 < p_{\text{merger}} < 0.4$	12
	Yes	$p_{\text{odd}} > 0.5, p_{\text{merger}} > 0.4$	12
Edge-on	Yes	$p_{\text{edgeon}} > 0.8, p_{\text{features}} > 0.5$	12
	Int	$0.4 < p_{\text{edgeon}} < 0.8, p_{\text{features}} > 0.5$	12
	No	$p_{\text{edgeon}} < 0.2, p_{\text{features}} > 0.5$	12
Bar	No	$p_{\text{bar}} < 0.1, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2$	24
	Int	$0.2 < p_{\text{bar}} < 0.4, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2$	24
	Yes	$p_{\text{bar}} > 0.8, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2$	24
Visible spiral	No	$p_{\text{spiral}} < 0.2, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2, p_{\text{bar}} < 0.1$	12
	Int	$0.2 < p_{\text{spiral}} < 0.8, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2, p_{\text{bar}} < 0.1$	12
	Yes	$p_{\text{spiral}} > 0.8, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.2, p_{\text{bar}} < 0.1$	12
Oblique Bulge Size	No	$p_{\text{nobulge}} > 0.6, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.5, p_{\text{bar}} < 0.2$	12
	Int	$p_{\text{justnoticeable}} > 0.6, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.5, p_{\text{bar}} < 0.2$	12
	Yes	$p_{\text{obvious/dominant}} > 0.5^1, p_{\text{features}} > 0.5, p_{\text{edgeon}} < 0.5, p_{\text{bar}} < 0.2$	12
Edge-on bulge shape	Round	$p_{\text{rounded}} > 0.5, p_{\text{features}} > 0.5, p_{\text{edgeon}} > 0.5$	12
	Boxy	$p_{\text{boxy}} > 0.4, p_{\text{features}} > 0.5, p_{\text{edgeon}} > 0.2$	12
	Non	$p_{\text{nobulge}} > 0.5, p_{\text{features}} > 0.5, p_{\text{edgeon}} > 0.5$	12

**Figure 2.** Examples of two galaxies which have been run through the FERENGI code to produce simulated HST images. The value of p_{features} for each panel is (1) Top row: $p_{\text{features}} = 0.9, 0.625, 0.35, 0.35, 0.225$ and (2) Bottom row: $p_{\text{features}} = 1.00, 0.875, 0.875, 0.625, 0.375$.

the four GZH subsamples with the magnitudes of our fake galaxies over plotted.

- Instructions of how to link the $z = 0$ p_X values for galaxies with a given size, magnitude (surface brightness) in the GZH images.

4 SUMMARY

Now people go and do science with these awesome Galaxy Zoo Hubble classifications.

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REFERENCES