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Galaxy Zoo: Classifications for Galaxies in HST Legacy Imaging

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* *This publication has been made possible by the participation of more than 200,000 volunteers in the Galaxy Zoo project. Their contributions are individually acknowledged at* `http://www.galaxyzoo.org/volunteers`.

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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 arcmin^2.
- 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 arcmin^2 (160 arcmin^2 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 deg^2.
- 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 arcmin^2

3 CORRECTING FOR REDSHIFT DEPENDENT CLASSIFICATION BIAS

We can't do what we did in Bamford et al. (2009) for the original GZ or Willett et al. (2013) for GZ2 because these both depended on the assumption of no redshift bias. 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.

We also expect to see changes in the apparent morphology of galaxies due to band shifting and surface brightness effects (e.g. see Figure **??** which illustrates one possible effect of losing features in spiral galaxies at high redshift). So we need to measure this.

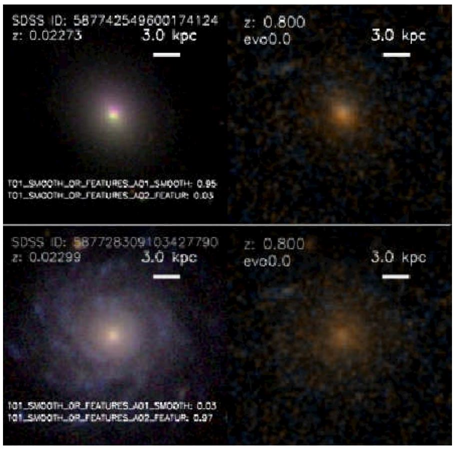

Figure 1. Examples of an obvious spiral and obvious elliptical at $z = 0$ which both look similar when redshifted to $z = 0.8$. See below for the description of the method for redshirting.

So 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 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: $\mu > 21.5$magarsec^2;

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Table 1. Summary of GZ Hubble Samples

Survey	$t_{\rm exp}$ seconds	Filters	Resolution $''$/pix	Area sq arcmin	$N_{\rm galaxies}$
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	

Table 2. Summary of morphological categories selected for FERENGI sample

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

(2) mid: $20.5 < \mu < 21.5$magarsec^2; and (3) high: $\mu < 20.5$magarsec^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 ($e = 0$).

3.2 Results of FERENGI Analysis

We show here the **currently fake** results of citizen scientist classifications of images of galaxies placed at artificial redshifts. Figure **??** shows the **currently fake** change of vote fractions for the change of $p_{\rm features}$ with redshift, for three galaxies with different vote fraction levels, three surface-brightness levels and 7 evolutionary corrections.

Table 3. Summary of FERENGI runs

$z_{\rm target}$	$N_{z\rm bins}$	$N_{\rm evolution}$	$e_{\rm max}$	$N_{\rm runs}$	$N_{\rm total}$
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

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 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

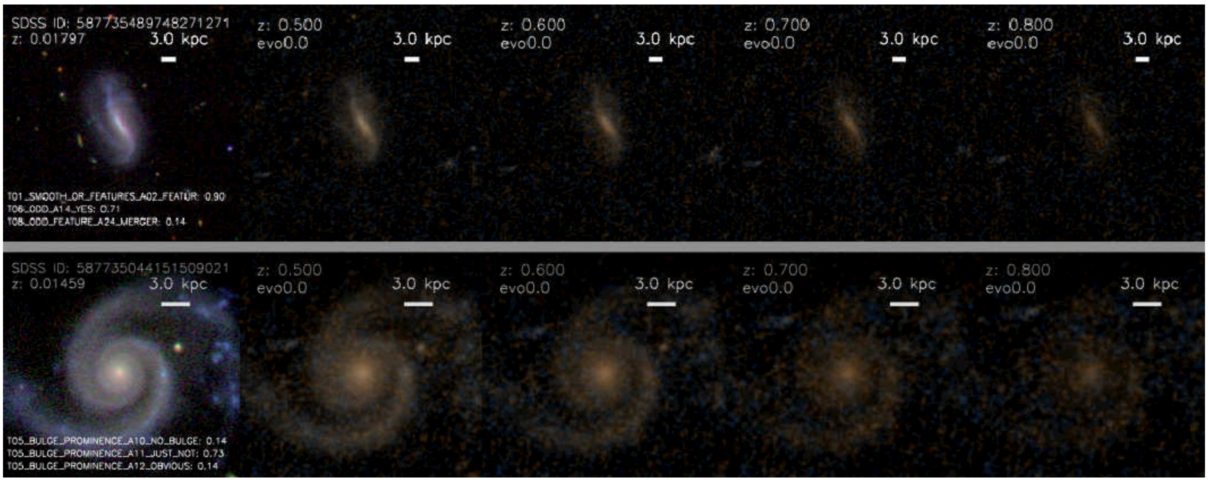

Figure 2. Examples of two galaxies which have been run through the FERENGI code to produce simulated HST images.

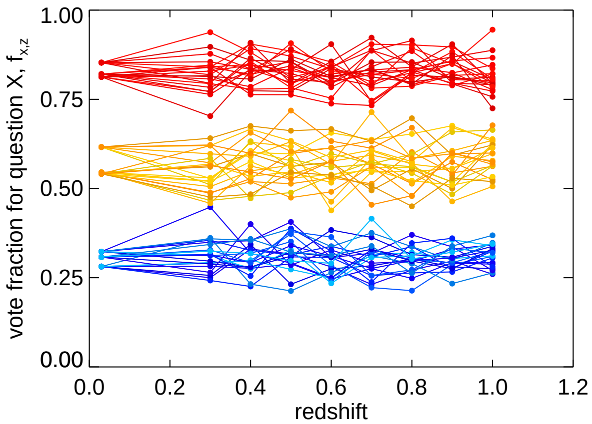

Figure 3. Fake results of the FERENGI redshifting exercise. For three vote fraction levels with three surface-brightness levels and 7 evolutionary corrections each, we show the evolution of the vote fractions for feature X with redshift.

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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