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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

Data release paper for GZ Hubble

1 INTRODUCTION

2 SAMPLE AND DATA

2.1 Summary of HST Legacy Survey Imaging

- AEGIS has1 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

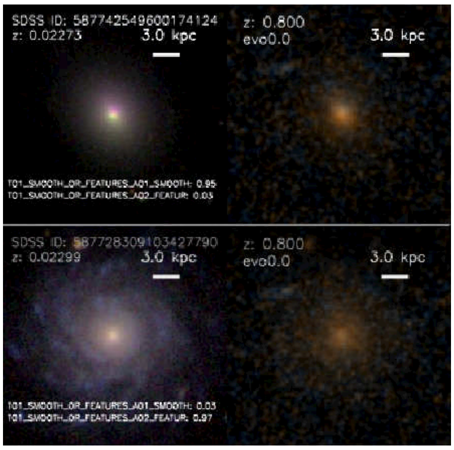

Figure 1. Examples of an obvious spiral and obvious elliptical at $z = 0$ which both look similar when redshifted to $z = 0.8$. See below for the description of the method for redshirting.

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.

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 redshifts in HST imaging.

The selection criteria for the different morphological categories is summarised in Table 1. The surface brightness selection ($N_\mu = 3$) was (1) low: $\mu > 21.5$magarsec^2; (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

Table 1. Summary of morphological categories

Morphology	Label	Selection	$N_{\rm objects}$ ($N_z \times N_\mu$)
Features	Yes	$p_{\rm features} > 0.8$, $p_{rmodd} < 0.1$	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

Table 2. Summary of FERENGI runs

Starting redshift	$N_{z\rm bins}$	$N_{\rm evolution}$	$e_{\rm max}$	$N_{\rm runs}$	$N_{\rm total}$
0.3	8	7	3.5	56	4031
0.5	6	4	2.0	24	1728
0.8	3	3	1.5	9	648
1.0	1	3	1.5	3	216

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 increasing up 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 2.

Two series of example redshifted images are shown in Figure 2.

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.

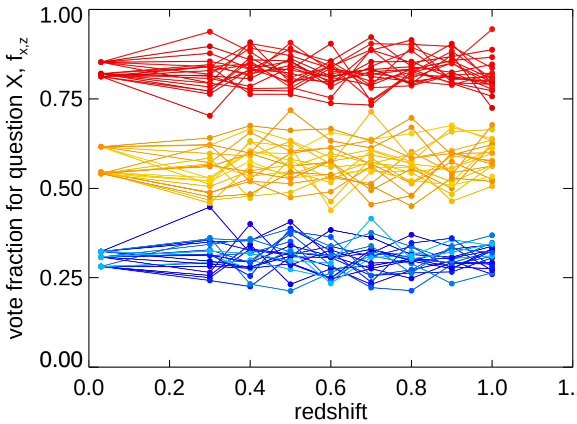

Figure 3. Fake results of the FERENGI redshifting exercise. For three vote fraction levels with three surface-brightness levels and 7 evolutionary corrections each, we show the evolution of the vote fractions for feature X with redshift.

4 SUMMARY

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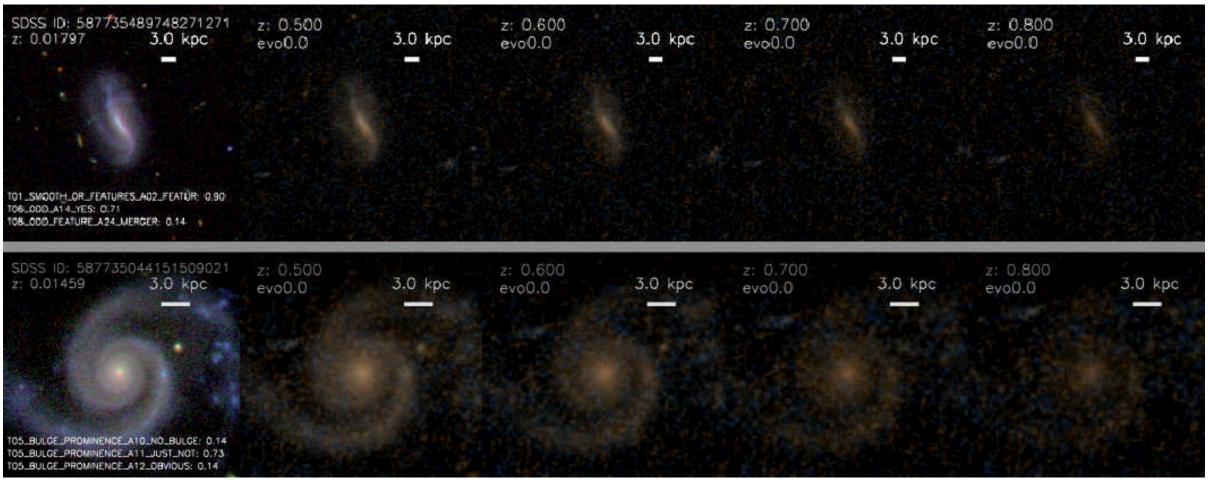

Figure 2. Examples of two galaxies which have been run through the FERENGI code to produce simulated HST images.

stitutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/.

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REFERENCES