It’s a Zoo Out There: 
Utilizing the Galaxy Zoo System to Supplement the Sloan Digital Sky Survey 
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Abstract

Within the results of the Sloan Digital Sky Survey (SDSS)’s Data Release 7, a group of faint red galaxies has been found to exhibit enhanced clustering on small scales. Recent evidence suggest that these are satellites clustering in the outer, massive halos of galaxy clusters, but photometrically these satellites behave differently from both bright red and faint blue galaxies. These faint red galaxies are especially disky for similarly-colored ellipticals, with their Sersic index and shape suggesting the presence of small structures seen usually in spirals; they consistently display characteristics that fall between the traditional red elliptical and blue spiral galaxies, and we believe them to be a morphological transition phase. Using the quantitative properties observed by SDSS and the additional data provided by the Galaxy Zoo (GZ) program, we have constrained the classification of these galaxies in greater detail and with additional statistical methods than available using either system independently. I also developed a planetarium program for the Cleveland Museum of Natural History, teaching the basics of galaxy morphology classification used in the GZ program.

Introduction

The Sloan Digital Sky Survey is one of the most ambitious undertakings that astronomy as a field has ever undertaken. Over 200 scientists at more than 30 institutions have succeeded in making the largest color image of the sky yet recorded, mapping more than one quarter of the sky in multiple wavelengths. In the first eight years of operation, it
acquired images and spectra of over 930,000 galaxies [1]. Now in its third run (SDSS-III), SDSS has almost 500 million objects within its observing footprint.

Unfortunately, Sloan’s greatest strength is also its greatest weakness: the process of galaxy classification, traditionally done by eye due to undependable computer results, is no longer feasible for such a sample. Algorithms such as the one used automatically in the Sloan pipeline can sort objects into stars, quasars, and galaxies rather reliably, however sorting within the galaxy bin remains problematic. Galaxies are non-static entities, constantly interacting with each other and being pulled closer together by gravity into groups; there is a continuous spectrum ranging from ellipticals (ellipsoidal, old stellar populations, and a smooth surface-brightness profile) to spirals (rotating, flat disk sometimes with a bulge and prominent arms, and usually star forming), with lots of gray area in the middle (“S0” populations, especially) in which classifications are less concrete. Computer algorithms need to be “taught” the techniques to classify the data to be analyzed, so when there is no definition agreed upon by astronomers for any specific classification it leads to biases in the output depending on what the inputting astronomer defined a galaxy class to be. In the case of our work, it could depend on the definition of an S0 galaxy as either a disky elliptical or a bulgy disk – deceptively similar, but the models for formation are drastically different.

To reliably classify the wealth of galaxies present in the SDSS, astronomers needed to enlist the help of more than just graduate students to get through them all in a useful amount of time. GZ was born from this need, utilizing laypeople volunteers with no mandatory scientific background to classify galaxies based on apparent properties – elliptical or spiral, how many arms if spiral and what direction the arms were rotating,
bulge present, etc – described in a series of tutorials. It was expected to take over two years for the public to classify the initial data set of a million SDSS galaxies; within the first year they received 50 million classifications, so each galaxy was classified an average of 50 times. In the second run, over 60 million additional classifications were made of 250,000 galaxies from the initial sample [2]. With so many classifications of the same galaxy, the statistics involved become much more reliable – if all users agree on a classification, it is most likely correct. If a few users makes an incorrect classification, and the others are in agreement, the effect of the incorrect classifications are minimal. The human eye remains the best possible tool for classifying galaxies because of its ability to notice patterns and oddities, and some of those oddities were faint red galaxies that exist somewhere between ellipticals and spirals. These transitional phases are of great interest to astronomers, because they represent evolutionary processes happening over huge time scales in multiple types of intergalactic environments.

We propose to study the nature of the dim red galaxy population seen by Zehavi et al, using the morphological properties observed by SDSS and the additional data provided by the GZ program, in greater detail and with additional statistical methods. If the dim red galaxies are the results of accretion, we should observe them in the outer halos of clusters that contain bright red galaxies in the central regions. Characteristics such as the Sersic index (Sersic 1968, Blanton et al 2005) and the observed disk shape will be quantified to determine if this population is, in fact, predominantly made of S0 galaxies.

Our observations will shed light into the origins of this group, and their role in galaxy and galaxy cluster formation. The presence of a transitional population would be a strong marker for the evolutionary processes that those clusters have undergone in the past.
We also aim to discover if this is an old, complete transition process or if they are part of a larger population that is still occurring in ongoing galactic cluster accretion. If morphological constraints on the sample can accurately cut out a sample of S0 galaxies from the SDSS database, and be applied to future surveys, then this could result in the largest sample of lenticular transition galaxies ever quantified and remove some of the mystery surrounding how – and when – S0 galaxies occur.

**Background and Previous Work**

Following Edwin Hubble’s publication of a classification system for Extra-Galactic Nebulae (1926), astronomers have sorted every galaxy they study into that system based on its observed structures. There are traditionally spiral types, elliptical types, and “irregulars” - spirals tend towards the bright blue of young stellar populations; ellipticals are mostly comprised of red, old populations; and irregulars usually represent mergers, collisions, or odd formations that aren’t easily classifiable. As telescopes improved, however, and the number of galaxies and galaxy clusters observed increased drastically, a small population of galaxies was recognized as belonging to a mediatory phase: S0. These S0 galaxies display the characteristics of both spirals and ellipticals (Figure 1, Figure 6) because they usually possess a strong disk and bulge but contain an aging stellar population – as such they are jokingly referred to as “red and dead” by galactic astronomers (Figure 1) because of their old stars and lack of star formation. S0s represent a transition in which stellar formation was shut down by an outside force, often presumed to be caused by a spiral being disrupted by other galaxies as it enters and moves within a cluster (Gunn and Gott 1972, Dressler 1980, and Dressler et al 1997). While this is
accepted as a plausible explanation, the mechanism behind and evolution of these S0 galaxies is still strongly debated (Boselli and Gavazzi 2006) and no one model has proved effective thus far for characterizing them. There have been several studies into these S0 galaxies, notably those of Barr et al (2007) and Moran et al (2007), but the large scale of the SDSS has provided the first opportunity for study of an extended sample with the possibility of harboring many S0s.

Within the SDSS Data Release 7 results, there was evidence of higher-than-predicted clustering of faint \(-17 > Mr > -19\) red galaxies (Zehavi et al 2005b) located in the bottom quadrant of the color-magnitude diagram (Figure 2). While these are “faint” galaxies, they are not to be confused with dwarf galaxies that have even fainter magnitudes – a galaxy flagged as a dim red galaxy in SDSS data is highly unlikely to be a dwarf elliptical (Figure 3) due to the flux limit on the sample. For a large sample of galaxies containing all classifications, there is normally a strong, monochromatic relation between increased clustering and increased luminosity (Figure 4). Zehavi et al found that when that graph is repeated using only the red galaxies, the dim galaxies are more clustered than their brighter counterparts on small scales (Figure 5). Hogg et al (2003) found that there was a tendency for faint red galaxies to be found in dense clusters, which Zehavi et al (2005) and

Figure 1: Examples of a traditional spiral, a “red and dead” spiral, and a traditional elliptical. Taken by SDSS, and used in Galaxy Zoo tutorial.
Berlind et al (2005) elaborated upon with their conclusions that these SDSS galaxies represent the recent accretion of satellites into massive halos that results in truncated star formation and that they do represent a transitory phase. The gravitational pressure of the accretion might be sufficient to strip the star-forming gases from the incoming spiral galaxy – not necessarily causing disruption of the structure of the spiral, but effectively extinguishing future stellar formation. The exact evolutionary path of these galaxies, and their true classification, however, are still unknown.

![Color vs Magnitude diagram for the three samples used by Zehavi and Janowiecki, where black are the dim blue, red are the dim red, and green are the bright red galaxies.](image)

**Figure 2: Color vs Magnitude diagram for the three samples used by Zehavi and Janowiecki, where black are the dim blue, red are the dim red, and green are the bright red galaxies.**

**Objectives**

Using the newly-released responses from the Galaxy Zoo programs, and the power of the SuperMongo program, I hope to be able to select a high-probability sample of S0s (if that’s what our dim red galaxies turn out to be) from the other hundreds of millions of SDSS objects. The Galaxy Zoo sample is focused on morphology, with the users specifically
instructed not to base their classifications on the color of the galaxy. SDSS contains magnitudes in the $u, g, r, i, z$ bandpasses, which can then be used to get the color ($g - r$, for example) of each galaxy that overlaps between the SDSS and GZ samples.

![Figure 3: From Zehavi and Janowieki et al., a random selection of examples from each category of the sample. Note that each box is 0.5' on a side. The dim red galaxies show...](image)

The galaxies classified by the GZ users can then be analyzed using their color, chance of being a spiral, apparent bulge size, calculated bulge to disk ratio, Sersic index, and assorted other properties to pull out the part of the sample most likely to be S0s. This initial sample would be larger than that used by Zehavi et al., but still small enough that the eye test can be implemented to check the classifications and look for other trends. SDSS also contains clustering information which describes the proximity to other galaxies, an estimate on the size of the dark matter halo it is within based on cluster gravity interactions, any
interactions it is currently undergoing, etc. that will allow me to check the results of Zehavi et al.’s smaller sample – that these dim red galaxies are more clustered than the bright red galaxies inhabiting the centers of these huge galaxy clusters.

If the first part of the project is successful and the dim reds do turn out to be morphological S0s, and a statistically significant number of S0s can be pulled from the Galaxy Zoo sample, then a future project can begin to construct models for formation and evolution that would lead to the present conditions. The main location of S0s will be particularly interesting, because it could lead to finally singling out a method for evolution or at least assigning a method to how the variations of S0 are created. Finding the ratio of disky bulges to bulgy disks will also be a priority, because that will also show which method of creating S0s is more common. If a pattern in the location of these S0s exists, then I could provide a system for specifically searching out S0 galaxies within clusters – a great improvement over pouring through images of every cluster, looking for possible S0s. However, that would need to be in the future after much further analysis.

Figure 4: From Zehavi and Janowiecki, showing the observed clustering correlation function vs the scale of separation for the entire sample of galaxies separated by magnitude.

Figure 5: From Zehavi and Janowiecki, showing the observed clustering correlation function vs the scale of separation for only the red galaxies of the sample. The overly-clustered faint red galaxies are the ones we will be attempting to better quantify.
**Methods**

Rather than using raw SDSS data from the pipeline, I decided to use the Large Scale Structure Survey (LSS) data for the ~550,000 galaxies that Idit had been using with her initial clustering analysis. Not only did that ensure we were using the same initial number of galaxies, but their group already corrected the magnitudes and properties for reddening, seeing, etc that would be very time-consuming to redo on my own. This dataset included all

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**Figure 6:** Histograms of distribution of Zehavi et al properties for each of their galaxy populations. Top: The radius enclosing 90% of the light divided by the radius enclosing 50% of the light. Middle: The Sersic index of each galaxy. Bottom: $\mu_{50}$ surface brightness of each galaxy. Exact values are not as important to note, as is the fact that the dim red galaxies (red line) consistently display intermediate properties that are obviously
between those of the dim blues (blue line) and the bright reds (magenta line).

of the quantitative properties I needed (Figure 6), but unfortunately they assigned each
galaxy an ID for their survey and did not include the overarching SDSS ObjectID – to
match between the LSS data and GZ data, I was forced to use their positions on the sky to
assign each galaxy the proper ID number.

There were some mismatches due to the elapsed time between observations, so
approximately 5% of galaxies were removed to prevent double-assigning IDs; if there was
not a 1:1 match, the galaxy was not used. The useful GZ information included only the
weighted fraction responses to each question, which is the final stage of GZ-provided
analysis. Since users must register to begin classifying galaxies, GZ can track their
responses and down-rate users who are unreliable (meaning they consistently choose the
“wrong” classification, based on all of the other responses). This final weighted fraction
represents the fraction of users who answered the question with that specific answer, and is
essentially the probability that the answer is correct because of the number of
classifications of each object. In the end, ~225,000 galaxies were in common between the
two groups and were used in my project. I used the astronomy plotting program
SuperMongo (Appendix 1) to analyze and present the results, which can be seen below.

Results

Remaking the color-magnitude diagram (excerpt in Figure 2) to map the
distribution of galaxies based on the responses of GZ users yields Figure 7. It is broken up
by the galaxies for which over 75% of users say the galaxy is a featureless elliptical, 75%
say a disk, or for which no consensus was reached. The black line represents the division between “blue” and “red” galaxies as defined by Zehavi et al to separate the red sequence (vertical stripe on the right) from the blue cloud (leftward-branching cloud). As expected the majority of the disk galaxies lie in the blue cloud, but the smooth ellipticals and inconclusive galaxies are spread across all magnitudes and both colors. The majority of the dim red galaxies obviously fall mostly into the elliptical category, followed by unclassified and even some as disks. However, just seeing them as ellipticals is not particularly helpful – we need to look at them in more detail, to start to quantify any intermediate properties.

![Figure 7](image)

*Figure 7: Morphology distribution for the galaxies in common between GZ and the LSS survey within the SDSS data. Each x-axis has the same scale for the g-band – r-band color, and each y-axis for the r-band absolute magnitude. P_ellip indicates that at least 75% of users classified that galaxy as a smooth elliptical; likewise P_disk means at least 75% agreement that the galaxy is a disk and P_other means that there was no agreement.*

The flux limit on the GZ sample means that the faintest objects will drop off really quickly, even if they are relatively nearby. Since we are now looking at only the brightest of the dim red galaxies, I needed to ensure that they still display the same intermediate
characteristics that the entire group as a whole did. I remade Figure 6 with my sample (Figure 8 and Figure 9), and while Figure 8 has a different scalar factor involved in the x-axis they do both show the same intermediate properties seen in Figure 6. The dim red galaxies do have properties that lie between the other morphology groups as far as quantitative observations are conserved, regardless of whether or not morphological qualitative observations agree with that.

Figure 8: Histogram of the distribution of \(\mu_{50}\) values for each of the galaxy populations. Compare to Figure 6. Used as a check that we are still looking at the same dim red galaxies, and as expected the dim reds fall between the other groups.

After confirming these galaxies are the intermediate ones we want to study, I wanted to expand further and express exactly how users classified the galaxies they were given. First up was the distribution of ellipticals since that is how most of the galaxies in the sample were classified. Figure 10 is a histogram showing the final weighted fraction given to each of the galaxies from each population. The bright and dim reds are almost all
classified as smooth and featureless ellipticals, with most of them over 70% certainty. This fraction can be interpreted as a percentage: 0% of the group classified it as elliptical, up to 100% of the group agreeing that it was featureless. The dim blues have more of the population being flagged as having features, but still most of them end up being called ellipticals. We were not expecting the dim reds to all be tossed in so casually; rather, we hoped to see a distribution more like the dim blues insinuating the users were more uncertain in classifying them. However, that seems to not be the case. It is important to note that there is an order of magnitude difference for each ±1 value of astronomical magnitude – the dim reds are on the order of 100x to 10,000x fainter than the bright reds. When imaging such faint objects, even when they are relatively nearby, things tend to get missed or simply averaged out depending on the resolution of the image.

Figure 9: Histogram of the distribution of the galaxies’ radii. Compare to Figure 6, but realize the scale on the x-axis is different (inverse, and Figure 6 involves a concentration parameter described in Zehavi et al). Also a check on our galaxies, but they again fall between the bright reds and the dim blues.
Since there would not be much we could do in the case of the images being too poor of quality for adequate morphological classification, I moved on to one of the next questions asked users: is there anything odd about the galaxy you are classifying, or anything to make you unsure of how to respond to a question? If an S0 galaxy were put through the system, we would expect there to be some expressed uncertainty in how to classify it; if astronomers cannot agree, how could the general public? Figure 11 is a histogram of the responses to the question, again represented for each galaxy as a weighted fraction of the responses. In this case, “0” refers to the entire survey group agreeing that there was nothing odd or unusual about the galaxy, and “1” meaning that all respondents were in agreement that there was something odd about the galaxy.

**Figure 10:** Histogram distribution of the fraction of users classifying each galaxy as smooth and featureless (an elliptical). While the bright reds do consist almost entirely of cluster ellipticals, it is of note that both the dim reds and dim blues are also classified mostly as ellipticals.
Figure 11: Histogram distribution of the fraction of users classifying each galaxy as “odd.” This was one of the last questions asked, and was a chance for users to flag that galaxy if they were having trouble answering a question or were just unsure of how to properly classify it.

The dim reds, based on this diagram, are classified with the highest certainty of any of the three groups – the majority of users saw nothing odd about the galaxy, but did notice some “odd” features in the faint blues of similar brightness. This is once again a surprising disappointment, and raises interesting questions regarding the way the galaxies were classified. Users are instructed to ignore the color of the galaxy and make selections based solely on observed features, but there might still be a tendency to put all red-appearing things into the elliptical category.

The redshift distribution of my sample (Figure 12) demonstrates the effect of our flux-limited sample – the bright red galaxies are typically found in clusters very far away from our Local Group, and while the dim reds and the dim blues are expected to appear at
a similar volume density at all redshifts we are only able to see them when relatively nearby.

Figure 12: Redshift distribution of the galaxies. Note the bright reds are much further out, since they are found mostly in large clusters very far away from our own Local Group.

Conclusion and Future Work

This could put permanent limitations on situations the Galaxy Zoo data can be used in, if the redshift and brightness of the objects being studied lead to large portions of the galaxies being incorrectly classified. It may be that the intrinsically fainter objects, regardless of distance, will not yield good results with the current setup. The images of these faint, fuzzy objects are scaled down to a website image only a few square inches in size, which might completely erase all traces of already-hard-to-see features. The untrained eyes of the “citizen scientists” might also just fail to notice any small traces that
remain. To find if there are actually features there, future work would need to include a “re-do” of these dim galaxies in which both general people and scientists were presented with higher-quality images of the same galaxies and asked to answer the same questions. If the results are the same, it means these galaxies are just too small and faint to be classified by eye reliably. If the results are different, however, then the options described in the objectives section could be continued with in future work.

However, I am not quite done with this project – over the next week (past the deadline for this paper, unfortunately), my adviser and I will be finishing up the analysis portion of the project. We can still say something about the general properties of these galaxies (e.g. 60% of them have medium-sized, boxy bulges) after defining 75% agreement as being a confirmed property for each of the questions, so there will be further results – be them positive, negative, or inconclusive – not included in this paper.

**Planetarium Program**

I created a show for the CMNH, which ran as the public program in October and November, inspired by the Galaxy Zoo program. Entitled “Extragalactic Road-trip,” it flew viewers through the SDSS universe to visit galaxies representative of each of the main classifications. It served as an introduction to the galaxy morphological classification system used by astronomers, the same process used by Galaxy Zoo to allow the public to be involved in classifying SDSS galaxies. It also delved into the physical characteristics that lead to the observed properties, what actually differs between types of galaxies, and how astronomers think different types of galaxies formed. Several thousand guests came
to see the show during its initial run, and it received positive-enough reviews that they will run it again in the future.

Figure 13: Steinmetz et al simulation of spiral galaxy formation, showing the slow accretion of smaller objects over time.

Figure 14: “Grand Design” spiral Andromeda in different wavelengths, showing regions of star formation within the arms.

Figure 15: Mihos and Maxwell simulation of the formation of the Cartwheel Galaxy, one of many examples seen of a merger.
Acknowledgements

I would like to thank Idit Zehavi and Steven Janowiecki for the initial work that inspired this project, as well as Jason Davis (Astronomy Programs Coordinator at the Cleveland Museum of Natural History) for his help and support. Chris Mihos was also helpful and generous in supplying some of the simulations used in the planetarium program.

References

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Dressler 1997, AIPC, 393, 535D

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Preparation
Appendix 1: Reference SuperMongo Code

up    macro read dimred.sm
x11   device x11 -bg white -fg black
esps  define fname ? {enter output .ps filename?}
      device postencap $fname
      define script ? {enter macro name?}
      $script
      hardcopy
      x11

colormag
      data fdata.txt
      read{z 5 Mg 6 Mr 7 pellip 10 pdisk 11}
      set eMr= Mr+2*(1-1*(z-0.1))*(z-0.1)
      set color = Mg - Mr
      set mr = -23,-15,0.5
      set cline= 0.21 - 0.03*mr
      ctype black
      expand 1.25
      define x_gutter 0.7
      window 3 1 1 1
      box
      limits -0.25 1.6 -17 -23
      ylabel Mr
      ctype red
      ptype 1 1
      points color eMr IF (pellip >= 0.75)
      ctype black
      ltype 0
      lweight 2
      connect cline mr
      relocate -0.25 -19
      draw 1.6 -19
      relocate -0.25 -21
draw 1.6 -21
c relocate 0 -23.1
c expand 1.001
c label P_ellip >= 0.75
c
c type black
c define x_gutter 0.5
c window 3 1 2 1
c box
c limits -0.25 1.6 -17 -23
c expand 1.25
c xlabel Mg-Mr
c c type blue
c ptype 1 1
c points color eMr IF (pdisk >= 0.75)
c c type black
c ltype 0
c lweight 2

c connect cline mr
c relocate -0.25 -19
c draw 1.6 -19
c relocate -0.25 -21
c draw 1.6 -21
c relocate 0 -23.1
c expand 1.001
c label P_disk >= 0.75
c c type black
c define x_gutter 0.5
c expand 1.25
c window 3 1 3 1
c box
c limits -0.25 1.6 -17 -23
c c type green
c ptype 1 1
c points color eMr IF (pellip < 0.75 && pdisk < 0.75)
loadhists

data fdata.txt

read{
z 5 Mg 6 Mr 7 mu 8 r5090 9 pellip 10 pdisk 11 pedge 12 pbar 14 pspiral 16 pnonbulge 18 psmbulge 19 povbulge 20 pdombulge 21 podd 22 pround 24 pibround 25 pcigar 26 pring 27 plens 28 pdisturbed 29 pirregular 30 pothodd 31 pmerger 32 pdust 33 proundbulge 34 pboxbulge 35 ptigarms 37 pmedarms 38 plooarms 39 punkarms 45}

set eMr= Mr+2*(1-1*(z-0.1))*(z-0.1)
set color = Mg - Mr
set mr = -23,-15.0.5
set cline= 0.21 - 0.03*mr

zhist

#redshift

set brz = z IF(eMr < -21 && color >=(0.21 - 0.03*eMr))
set drz = z IF(eMr >= -19 && color >=(0.21 - 0.03*eMr))
set dbz = z IF(eMr >= -19 && color <(0.21 - 0.03*eMr))
set drbins = 0,0.5,0.005
set brbins = 0.0.5.0.005
set brsbins = histogram(brz:brbins)
vecminmax brsbins min max
set fbrsbins = brsbins / $max

set dbbins = 0.0.5.0.005
set drsbins = histogram(drz:drbins)
vecminmax drsbins min max
set fdrsbins = drsbins / $max

set dbbins = 0,0.5,0.005
set dbsbins = histogram(dbz:dbbins)
vecminmax dbsbins min max
set fdbsbins = dbsbins / $max

window 1 1 1 1
expand 1.25
cetype black
limits 0 0.3 0 1.1
box
cetype red
lweight 3
ltype 0
histogram brbins fbrsbins

cetype green
histogram drbins fdrsbins
ltype 0
cetype blue
histogram dbbins fdbsbins
lweight 1
cetype black
xlabel "Redshift"
ylabel "Number of galaxies per bin / Nmax"
relocate 0.16 1
ltype 0
cetype red
draw 0.2 1
label Bright Reds
relocate 0.16 0.9
cetype green
draw 0.2 0.9
label Dim Reds
relocate 0.16 0.8
ltype 0
ctype blue
draw 0.2 0.8
label Dim Blues
ctype black

rhist

#r50/r90

set brr = r5090 IF(eMr < -21 && color >=(0.21 - 0.03*eMr))

set drr = r5090 IF(eMr >= -19 && color >=(0.21 - 0.03*eMr))

set dbrr = r5090 IF(eMr >= -19 && color <(0.21 - 0.03*eMr))

set brbins = 0,0.8,0.01
set brsbins = histogram(brr:brbins)
vecminmax brsbins min max
set fbrsbins = brsbins / $max

set drbins = 0,0.8,0.01
set drrsbins = histogram(drr:drbins)
vecminmax drrsbins min max
set fdrsbins = drrsbins / $max

set dbbins = 0,0.8,0.01
set dbrsbins = histogram(dbrr:dbbins)
vecminmax dbrsbins min max
set fdbrsbins = dbrsbins / $max

window 1 1 1 1
expand 1.25
ctype black
limits 0.25 0.8 0 1.1
box
ctype red
lweight 3
ltype 0
histogram brbins fbrsbins
ctype green
histogram drbins fdrsbins
ltype 0
ctype blue
histogram dbbins fdbsbins
lweight 1
ctype black
xlabel "r50/r90"
ylabel "Number of galaxies per bin / Nmax"
relocate 0.5 1
ltype 0
ctype red
draw 0.65 1
label Bright Reds
relocate 0.5 0.9
ctype green
draw 0.65 0.9
label Dim Reds
relocate 0.5 0.8
ctype blue
draw 0.65 0.8
label Dim Blues
ctype black

muhist
#mu50
set brmu = mu IF(eMr < -21 && color >=(0.21 - 0.03*eMr))
set drmu = mu IF(eMr >= -19 && color >=(0.21 - 0.03*eMr))
set dbmu = mu IF(eMr >= -19 && color <(0.21 - 0.03*eMr))
set brbins = 0,30,0.1
set brsbins = histogram(brmu:brbins)
vecminmax brsbins min max
c
set fbrsbins = brsbins / $max
c
set drbins = 0,30,0.1
c
set drsbins = histogram(drmu:drbins)
c
vecminmax drsbins min max
c
set fdrsbins = drsbins / $max
c
c
set dbbins = 0,30,0.1
c
set dbbins = histogram(dbmu:dbbins)
c
vecminmax dbbins min max
c
set fdbsbins = dbbins / $max
c

c
window 1 1 1 1
c
expand 1.25
c
c
c
c
limits 24 16 0 1.1
c
box
c

c
c
c
ctype red
lweight 3
ltype 0
histogram brbins fbrsbins
c
c
c
c
c
c
ctype green
histogram drbins fdrsbins
c
c
c
c
c
c
ctype blue
histogram dbbins fdbsbins
c
lweight 1
ctype black
xlabel "mu"
ylabel "Number of galaxies per bin / Nmax"
c
relocate 19 1
ltype 0
c
c
c
c
c
c
ctype red
c
draw 18 1
c
c
label Bright Reds
relocate 19 0.9
ctype green
draw 18 0.9
label Dim Reds
relocate 19 0.8
ltype 0
ctype blue
draw 18 0.8
label Dim Blues
ctype black

elliphist

#ellipticals

set brpellip = pellip IF(eMr < -21 && color >=(0.21 - 0.03*eMr))
set drpellip = pellip IF(eMr >= -19 && color >=(0.21 - 0.03*eMr))
set dbpellip = pellip IF(eMr >= -19 && color <(0.21 - 0.03*eMr))

set brbins = 0,1,0.03
set brsbins = histogram(brpellip:brbins)
vecminmax brsbins min max
set fbrsbins = brsbins / $max

set dbbins = 0,1,0.03
set dbsbins = histogram(dbpellip:dbbins)
vecminmax dbsbins min max
set fdbsbins = dbsbins / $max

set dbbins = 0,1,0.03
set ddbbins = histogram(dbpellip:dbbins)
vecminmax ddbbins min max
set fddbsbins = ddbbins / $max

window 1 1 1 1
expand 1.25
xticklabels (brbins, fbrsbins)

ctypes blue

ctypes black

xaxis ("Fraction of users classifying galaxy as smooth and featureless")

yaxis ("Number of galaxies per bin / Nmax")

plot (brbins, fbrsbins)

plot (drbins, fdrsbins)

plot (dbbins, fdbsbins)

xlabel "Fraction of users classifying galaxy as smooth and featureless"

ylabel "Number of galaxies per bin / Nmax"

relocate 0.1 0.9

relocate 0.1 0.7

relocate 0.1 0.8

lweight 3

lweight 1