MNRAS 000, 1–2 (2016) Preprint 14 July 2016 Compiled using MNRAS LaTeX style file v3.0

Peas Environments

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Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT
Volunteers from Galaxy Zoo project dubbed a class of young [O III] emission line galaxies,"Green Peas", due to their bright green colour and the fact that they were unresolved in SDSS imaging. Many of these low mass galaxies (M$\sim$ $10^{8.5}$ – 10^{10} $M_\odot$) had high star formation rates($\sim$ 10 $M_\odot yr^{-1}$), slightly sub-solar metallicities (log[O/H] + 12 ~8.7) and low reddening ($E(B - V) \leq 0.25$). In this paper we investigate their local environments.

Key words: galaxies: evolution, galaxies: formation, galaxies: starburst, galaxies: dwarf, galaxies: high-redshift, galaxies: Seyfert

1 INTRODUCTION

The original Galaxy Zoo project (**?**) enlisted the help of over 250,000 members of the public to morphologically classify almost 10^6 galaxies from the Sloan Digital Sky Survey (SDSS; **?**). Galaxy Zoo project contines with more than 2x10e5 classifies today providing multiple independent classificatons to a variety of images (Lintott 2011), have proven relaible and led to numerous sci results land 2008 to Willet 2015).

The Galaxy Zoo website[1] provided a randomly selected *gri* composite colour image from the SDSS main galaxy sample and asks the volunteers to classify the morphology of the displayed object. Galaxy Zoo also provides an online discussion forum[2] where volunteers may ask questions about unusual or challenging objects. This allows us to tap into another advantage of human classifiers: they can easily identify and then investigate odd objects. One such class of highly unusual objects was named "Green Peas" as they appeared to be unresolved round point sources that looked green in the *gri* composite. These objects had galaxy-type spectral features (as opposed to broad-line quasar spectra or stellar spectra), and their green colour was driven by a very powerful [OIII] λ5007 emission line that substantially increased the r-band luminosity relative to the adjacent g and i band (green being the colour represented by the r-band in the SDSS colour composites). As a result of this selection, the Peas are found at redshifts $0.112 \lesssim z \lesssim 0.360$, mostly beyond the main galaxy sample but much nearer than luminous quasars.

After their initial discover - lots of interest in these galaxies:

The Green Peas provide a unique local laboratory in which we can investigate processes key to the formation and evolution of galaxies in the early universe. They are in essence living ?fossils,? undergoing extraordinary, intense starbursts unlike any other galaxies known in the local universe. Their color is due to a large amount of emission in an oxygen line [OIII]/5007A that made their appearance green in the SDSS images. Galaxies, very similar to the Green Peas, have been at a range of redshifts (e.g., Taniguchi et al. 2010, Xia et al. 2012). In the years since the publication of their discovery paper by the Galaxy Zoo Science Team, the peas are beginning to fulfill their promise as a living fossil of galaxy evolution.

Follow-up studies of the Green Peas and other compact, low-redshift, star forming galaxies have found them to be authentically metal-poor galaxies, with lower oxygen abundances than other star forming galaxies of a similar mass (Amorin et al. 2010, 2011). Several studies have looked in great detail at the abundances of various elements in the Green Peas, something that cannot be done in their high redshift analogs. This has resulted in a variety of interesting results, including the importance of Wolf-Rayet stars in the ionization of the gas in the Green Peas (Hawley 2012, Amorin et al. 2012). They have also been shown to have energetic outflows of gas (Amorin et al. 2012) and have been used to understand the astrophysics regulating the production of Lyman-alpha emission lines (Henry et al. 2015). Their morphologies have been confirmed to be clumpy by HST imaging (Overzier et al. 2010) and results have suggested that star formation in the peas occurs in several separate knots throughout the galaxy (Amorin et al. 2012). Additionally, underlying older stellar populations have been revealed through low-luminosity emission (Amorin et al. 2012a). Their radio emission suggests they have strong magnetic fields, larger than that of the Milky Way (Chakraborti et al. 2012).

Results from studies of these galaxies can provide challenges to commonly accepted models. For example the strong magnetic fields, challenge models that suggest magnetic fields grow slowly over time (amplification of seed magnetic field models) and observations of the variation in Lyman alpha emission line profiles and strengths challenge models of the dependence of the emission line shape on gas properties in the galaxy. The peas have held up their promise of lending new insights into galaxy evolution by characterizing an active mode of star formation, which contrasts with the

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[1] http://www.galaxyzoo.org
[2] http://www.galaxyzooforum.org

typical more passive evolution dominating the local galaxy population. Studies of the Peas have suggested that a galaxy?s evolutionary pathway may depend on stochastic initial conditions (Hunt et al. 2012, Magrini et al. 2012), leading insights into our understandings of how galaxies throughout the Universe form.

Environment backgrounds: COSMOS sample out to $z \lesssim 3$ found median galaxy SFR and sSFR similar across environment at $z \gtrsim 1$, but depend on environment below. Environmental quenching only relevant at lower z, mass quenching may dominate at higher z. (Darvish et al. 2016, http://arxiv.org/abs/1605.03182)

Should now use WMAP 9 cosmological parametners (0.282,0.718,0.697 - Hinshaw et al. 2013, omega m, lambda, h)

2 DATA

2.1 Sample Selection

The original sample of Peas (**?**) was taken from the SDSS DR7 spectroscopic sample and contained 251 objects of which 81 were classified as Star Forming by our reductions of the spectra using Gandalf. To DR7's release of the original SDSS survey in 2008, with 1.6 million spectra over 9380 $degs^2$ and 357 million unique imaging objects over 45,000 $degs^2$(**?**), DR12 adds all data from SDSS-III, expanding ugriz imaging by 5200 $degs^2$, and 2.5 million spectra from the the Baryon Oscillation Spectroscopic Survey (**?**). For the present study, we have updated the sample to include the SDSS DR12 data release.

Using the CasJobs[3] application provided by SDSS, the original search of the DR7 spectroscopic sample for Peas (originally noticed by eye in Galaxy Zoo) in the redshift range $0.112 < z < 0.360$,which puts the [O III] λ5007 line in the r-band filter.

uniformly searched t To define a colour selection criteria, we compared the sample of ~100 Peas identified by the Galaxy Zoo volunteers to a comparison sample of 10,000 galaxies and 9,500 QSOs at the same redshifts over the colour space defined by the 5 SDSS bands. The 10,000 galaxies were selected to match the redshift and g-band magnitude distributions of the Peas. The QSO sample contains all spectroscopically confirmed QSOs in the Peas redshift range, because the sample is overall too luminous to match the Peas magnitude distribution. Figure **??** displays two colour-colour plots with Peas (green crosses), comparison galaxies (red points) and comparison QSOs (purple stars). The chosen green Pea colour selection is shown by the darkened black lines. The precise colour cuts were selected to avoid both the QSO and overall galaxy sequences and to highlight the unusual objects selected by eye in the Galaxy Zoo forum. The colour limits are:

$$u - r \leq 2.5 \tag{1}$$

$$r - i \leq -0.2 \tag{2}$$

$$r - z \leq 0.5 \tag{3}$$

$$g - r \geq r - i + 0.5 \tag{4}$$

$$u - r \geq 2.5(r - z) \tag{5}$$

[3] http://casjobs.sdss.org/CasJobs/

We illustrate the effectiveness of this colour selection in Figure **??**. It divides the Peas from the loci of both the galaxy and the quasar population. This colour selection technique effectively uses the narrow-band survey technique common in high redshift galaxy searches, only here applying it to the broader SDSS filters. Because we are using broad filters, we are only sensitive to galaxies with extreme [O III] equivalent widths. Further, because we have selected the r-band filter for colour selection, we are not sensitive to Pea-like objects at lower and higher redshifts.

Although most of the Peas were identified by the SDSS spectroscopic pipeline as having galaxy spectra (4 were classified as unknown), only 7 were targeted by the SDSS spectral fibre allocation as galaxies. This means most were targeted as serendipitous objects, the majority flagged as `SERENDIP_BLUE`, `SERENDIP_DISTANT` and `TARGET_QSO_FAINT`. These target flags are for objects lying outside the stellar locus in color space and "`DISTANT`" here refers to distance from the stellar locus, `QSO_FAINT` is also used for objects flagged as stellar that are both fainter than i=20 mag and outside the stellar locus in colour space (**?**). These objects were targeted by fibers as they became available in a given field, so their selection function is not well determined. Without a uniform selection for the Peas across the sky, their absolute space density cannot be accurately assessed.