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Detecting H II Regions in "Pure" Starburst Galaxies with SDSS Data

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Abstract. The relationship between active galactic nuclei (AGN) and starburst galaxies is poorly understood, partially due to galaxies exhibiting both AGN and starburst activity. To better understand the connection, we analyze a sample of "pure" AGN or starburst at redshift $z = 0.1$ selected using mean field independent component analysis (MFICA). Simulations of starburst galaxy emission suggests that the locally optimally-emitting cloud (LOC) model can fit observations and improve our ability to distinguish the impact of differences in metallicity, ionization parameter, and ionizing flux. To test for the existence of such clouds in our galaxy sample, we examine the Sloan Digital Sky Survey (SDSS) images of our pure galaxies. At this distance, even large star-forming H II regions (e.g. 30 Doradus) only fill part of an SDSS pixel. However, we compare the morphology of the distant galaxies to more nearby ones (i.e. NGC 4713, NGC 4038/4039) to estimate the number of larger H II regions. While the clumpiness parameter of a galaxy in theory might indicate the existence of these regions, a straightforward calculation of the clumpiness parameter is ineffective for galaxies at $z = 0.1$. Typically, one subtracts a smoothed version of a galaxy image from the same image. We instead test a different approach to establish a smooth image and thus better identify the clumps. We subtract the smoother infrared z-band from the sharper ultraviolet u-band. We test this procedure using NGC 4713, a nearby starburst galaxy, artificially degraded to match images of our "pure" starburst galaxies.

Keywords. galaxies: starburst, techniques: image processing, H II regions

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1. H II Regions and Clumpiness of "Pure" Starburst Galaxies

The Baldwin, Phillips, & Terlevich (BPT; 1981) diagram has been used for decades to delineate emission-line galaxies into those dominated by active galactic nuclei (AGN) versus starbursts. Using mean field independent component analysis (MFICA), Allen *et al.*(2013) extracted "pure" AGN and "pure" starburst galaxies. Richardson *et al.*(2015) has shown that the emission lines from pure starburst galaxies are best explained by variations in the ionizing flux, assuming an locally-optimally emitting cloud (LOC) model, rather than with changes in the metallicity (Levesque, Kewley, & Larson 2010).

We have tested wheter the "clumpiness" of the $z = 0.1$ galaxies could be used to estimate the contributions of H II regions to the overall flux. Several metrics are used to quantify the morphologies of galaxies, including concentration C, asymmetry A, and smoothness/clumpiness S. The average concentration C for our pure star-forming galaxies is ~ 2.6. The smoothness S has a median value of 0.02 (using the Lotz, Primack, Madau definition) or 0.2 (using the Conselice definition). The asymmetries show some dependence on the ionization. However, none of these parameters shows a strong correlation with the clearly different morphologies evident in the Sloan Digital Sky Survey (SDSS) images. The clumpiness, which might indicate the presence of H II regions, shows no strong relationship with the ionization. By degrading the resolution and signal-to-noise of an SDSS image of a nearby sprial galaxy, NGC 4713 ($d = 14$ Mpc) to progressively further distances, we found that the calculated clumpiness S is greatly affected by distance. The "background clumpiness" quickly dominates the "signal clumpiness."

We next explored if multiple bands might provide a more reliable clumpiness (S). Given that u-band images of NGC 4713 show much sharper features than the z-band images, we can calculate a two-image S using them. However, we found that this leads to unreliable measures of S when applied to our simulated images of NGC 4713 at varying distances (d = 14 to 60 Mpc).

2. The Morphology of "Pure" Starburst Galaxies

Overlaying the morphologies of the pure starburst galaxies as classified by Galaxy Zoo amateurs (Lintott *et al.*2008) onto a BPT diagram, we found the most highly-ionized ones are irregular while the lower ionization pure starburst galaxies are voted to be either spiral or elliptical. Are these Galaxy Zoo morphologies correct? While the galaxies tagged as irregular by amateurs almost certainly are irregular and galaxies tagged as spirals are clearly spiral galaxies, it is possible that the galaxies voted to be elliptical may in fact be spiral galaxies with very faint spiral arms. To test this, we constructed a color-magnitude diagram for a random sample of 10,000 Galaxy Zoo SDSS galaxies. Both a "blue cloud" (where spirals and irregulars are expected) and a "red sequence" (where ellipticals are found) are clearly evident. Examining a color-magnitude diagram of our distant "pure" starburst galaxies, we found that all of them fall outside of the red sequence. Thus, we assume that these are not ellipticals. Many of them may be spirals with arms too faint to be identified by the Galaxy Zoo volunteers, as was found by analysis of galaxies in SDSS Stripe 82 (Schawinski *et al.*2010).

Inspecting the SDSS images Allen *et al.*(2014) starburst galaxiy subsets (s41=high ionization, s01=low ionization), we found that many of the s31 galaxies are in the process of merging whereas many of the the s01 galaxies have spiral structure. We assume the nearby NGC 4038/4039 (the Antennae Galaxies) is one example of what we expect our pure irregular starburst galaxies might look like. It has several large H II regions comparable to 30 Doradus, the largest H II region just outside of the Milky Way Galaxy. Another useful example spiral galaxy is M33, the Triangulum Galaxy. Within M33 is NGC 604, an H II region similar in size to 30 Doradus. However, at a distance of $z = 1$, even a very large H II region (such as 30 Doradus, a.k.a. the Tarantula Nebula) would be sub-pixel in size. We anticipate the finding nearby analogues to our $z = 1$ may allow us to estimate H II distributions in the more distant galaxies.

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