A Sample of HII Regions in the Far Outskirts of Host SINGG Galaxies

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Star formation traditionally proceeds within the high density, kinematically active regions of galaxy disks. Here, we find evidence for star formation in the low density halos of galaxies at projected distances up to 50 kpc from the galaxy disk. 68 small, isolated emission-line objects, (Emission Line Dots, ELDots) derived from 98 images (of target galaxies with recessional velocities between 500 and 4000 km/s) in the NOAO Survey for Ionization in Neutral Gas Galaxies (SINGG) compose our sample of candidates for isolated star-forming regions. ELDots are located at least twice the μ_R = 25 mag arcsec^{-2} isophotal radius from the apparent host galaxy and appear as high equivalent width, unresolved objects in continuum-subtracted Hα images. We present the spectroscopic follow-up of one of our ELDots, and confirm that this object represents star formation in the low density environment of the SINGG host galaxy and is not a higher-redshift background object. Moreover, our recent follow-up work suggests that ~1/6 of the ELDots will turn out to be HII regions associated with a host SINGG galaxy, possibly located in the far outskirts of the galaxy's halo, and representing an atypical mode of star-formation. The number of confirmed sources has a direct impact on our understanding of the enrichment and ionization source of the intergalactic medium (IGM), the trigger of star formation for the first stars formed in the universe, and potential contributors to intracluster light (ICL). We expect to nearly complete the spectroscopic confirmation for our sample by May of 2006. Below, we highlight two SINGG systems: a newly discovered and confirmed halo HII region near ESO 481-G017 and three HII regions in the outskirts of NGC 1533 previously presented by Ryan-Weber et al. (2004) and newly resolved with the Hubble Space Telescope.

ESO 481-G017

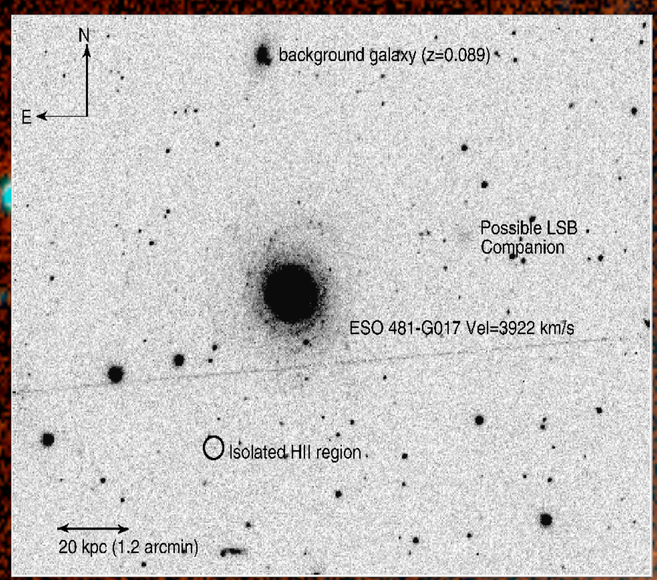

Figure 1 - Continuum (R-band) plus Hα image of the galaxy ESO 481-G017 (SINGG J0317-22). The spiral arms of this galaxy appear to extend to nearly 20 kpc while the circled ELDot (a tiny pocket of newly formed stars) appears 43 kpc from the galaxy. The ELDot was identified via a program that selects small, high Hα equivalent width objects at more than two times the μ_R = 25 mag arsec^{-2} isophotal ellipse. Upcoming Australia Telescope Compact Array (ATCA) observations will reveal if an extended HI envelope or tidal HI features are present.

In 98 narrowband Hα images obtained by the Survey for Ionization in Neutral Gas Galaxies (SINGG, based on HIPASS, the HI Parkes All Sky Survey, see Barnes et al. 2001), ~70 tiny ELDots up to 50 kpc from the nearest galaxy have been discovered (Ryan-Weber et al. 2004, Werk et al. 2006). Unambiguous spectroscopic confirmation (i.e., more than two emission lines detected) has been completed for 13 systems, three of which contain genuine intergalactic star-forming regions, NGC 1533, HCG 16, and now ESO 481-G017. Based on their Hα emission-line strengths, each HII region is powered by the equivalent of 0.1-8 O5 V stars, and these stars are most likely members of small stellar clusters with masses ~10^3 $M_\odot$. A few other recent studies have found similar objects in various environments (e.g., NGC 4388, Gerhard et al., 2002; A1367, Sakai et al., 2002; NGC1490, Oosterloo et al. 2003; NGC 4402, Cortese et al., 2004; Stephan's Quintet, Mendes De Oliveira et al., 2004). In every case, it appears as though star formation is proceeding atypically -- neither in the luminous inner regions of galaxies (see e.g. Martin & Kennicutt 2001) nor in the faint outer arms of spirals (e.g. Ferguson et al. 1998), but rather in a low-density galactic halo, in-between galaxies in a cluster environment, or within gaseous tidal debris surrounding the galaxy.

ESO 481-G017

The ELDot near the early type spiral galaxy ESO 481-G017 (see Figure 1) has a high Hα flux and virtually no continuum emission (Hα equivalent width > 1400 Angstroms), ruling out a significant underlying stellar population and suggesting that new stars have formed where no stars previously existed. The HI surface density near the ELDot is unknown, but considering its distance from the galaxy, is likely to lie below the traditional surface density cutoff for star formation (10^{21} cm^{-2}, Kennicutt et al. 1989) as is the case with the ELDots in NGC 1533. The velocity dispersion of the HI in the vicinity of the ELDot (if any) will help decide if the object should be classified as an outer disk HII region, or if its star formation has been collisionally induced. To these ends, we hope to obtain compact array observations of the galaxy sometime this summer.

NGC 1533

The peculiar horseshoe-like distribution of HI around NGC 1533 as seen in Figure 2 may have resulted from the tidal destruction of a galaxy in the nearby Dorado Group (~1° away), its remnant now wrapped around NGC 1533. The HI has no obvious optical counterpart seen in either the DSS image or the SINGG image. Interestingly, the HI surface density in the vicinity of the ELDots is 1-3 × 10^{20} cm^{-2}, well below the star-formation cutoff mentioned above. Additionally the gas in these regions has unexpectedly high velocity dispersions up to 30 km/s, suggesting that the star formation has resulted from cloud-cloud collisions. The velocities of isolated HII regions 1,2 and 5 coincide well with the HI gas, which is bound to and rotating around NGC 1533 (Ryan-Weber et al. 2003), and it is therefore likely that the newly formed stars will remain bound in the tidal debris. Is it possible then that these small HII regions are the progenitors of tidal dwarf galaxies? The HI gas in their vicinity could certainly provide the fuel from which more stars could form, so a tidal dwarf galaxy could have the chance to emerge over time (Ryan-Weber et al. 2004), however unlike tidal dwarf galaxies, many of these HII regions are not forming in the highest density concentration of gas.

NGC 1533

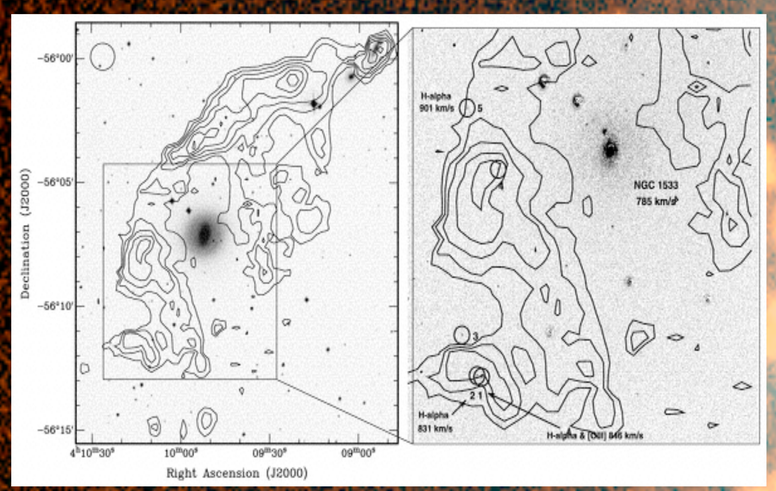

Figure 2 - On the right is the DSS image of NGC 1533 with ATCA HI contours overlaid at 1.6, 2.0, 2.4, 2.8, 3.2, 3.6, and 4.0 X 10^{20} cm^{-2}. The beam is shown in the upper left corner. The enlargement on the left shows the continuum-subtracted Hα image with the isolated HII regions labeled and the Hα velocities noted when available (Figure 2 from Ryan-Weber et al. 2004).

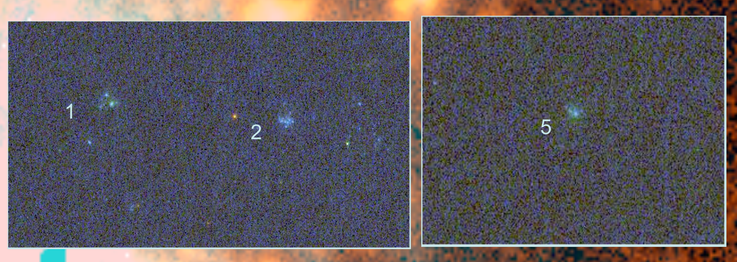

Figure 4 -Hubble Space Telescope images of ELDots 1, 2 and 5 (labeled in Figures 2 and 4) taken with the High Resolution Camera (HRC) are able to resolve the small star clusters ionizing the HII regions. On these three-color images, red represents F814W (I Band), green represents F555W (V Band), and blue represents F250W (UV).

For the first time, we have resolved images of these isolated HII regions, showing them to be small clumps of young stars (see Figure 4). ELDots 1 and 5 appear fuzzy, with most of their emission in V-band (F555W), while ELDot 2 is quite blue, with most of its emission in the UV (F250W). The fuzziness of ELDots 1 and 5 may be due to nebular emission. The sources are composed of two to four clumps and are about 0.5" x 0.25", or 24pc x 12pc (for D=10 Mpc,double for D = 21 Mpc -- the distance of NGC 1533 is between 10 and 21 Mpc). This size is consistent with the size of a loose stellar cluster or association. Given that ELDot 5 has an AB magnitude of 24.35 in the UV (F250W), and that we expect a single O9V star at 10 Mpc to have a magnitude of 24.7, and at 21 Mpc to have a magnitude of 26.3, this region contains anywhere from 1.3 to 6.9 O9V stars. Hence each lump visible in this region may represent a single ionizing O star. Additionally, ELDot 5 appears not to have a nearby stellar stream, and looks completely isolated. This ELDot may represent the first stellar seeds of galaxies in the universe.

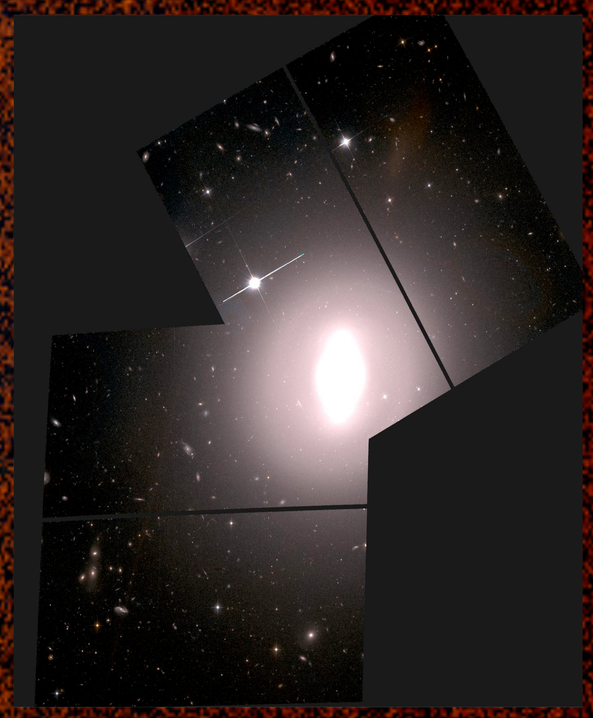

Figure 6- Hubble Space Telescope image of NGC 1533 taken in parallel with the Wide Field Camera (WFC). Red=I (F814W), Green=Avg(V+I), Blue=V (F606W)

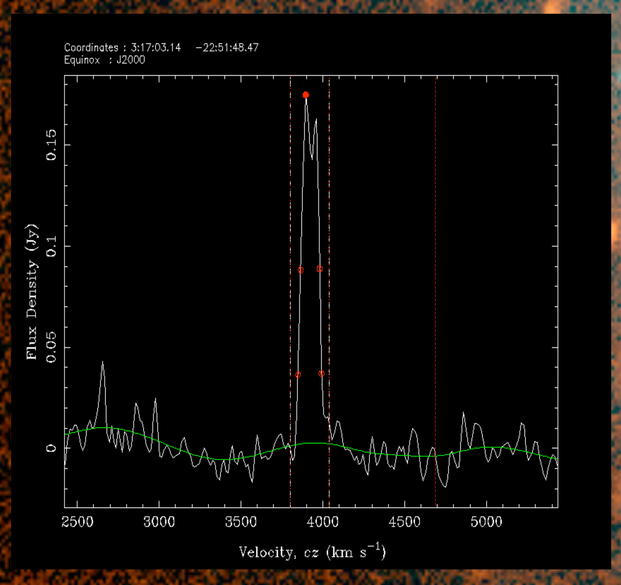

Figure 5 - HI spectrum of ESO 481-G017 with the velocity of the detected HII region marked by the red dashed line. Also marked are w_{20} and w_{50} . At 4701 ± 82 km/s the HII region lies far beyond the escape velocity of the galaxy. This indicates the HII region is forming outside of an extended disk of ESO 481-G017.

ESO 481-G017 has a velocity of 3922 km/s, and therefore the velocity of the ELDot, measured from 5 lines in its spectrum (see Figure 3), at 4701± 82 km/s is quite discrepant. This near 800 km/s deviation could indicate that this region is not in the disk of the galaxy, and thus quite isolated. Given a w_{20} of 143 km/s, and taking the inclination to be 35° (Braatz, Wilson & Henkel 1996) for ESO 481-G017, the ELDot is at least 600 km/s above the escape velocity of the SINGG galaxy. Moreover,The HI spectrum in Figure 5 shows neither a large velocity gradient nor anomalous velocity gas. While this ELDot may represent a burst of star formation in an unseen LSB companion to ESO 481-G017, it may also represent the formation of a new companion galaxy. If indeed isolated, this ELDot will produce metals and photons that will enter the IGM unhindered by dense gas.

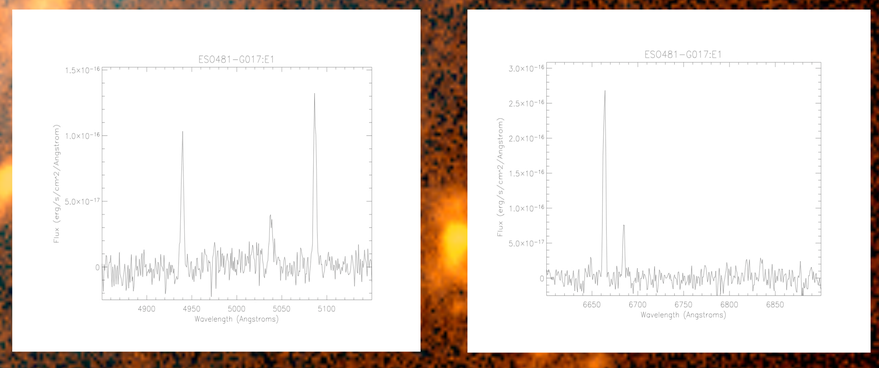

Figure 3 -Emission lines for the isolated HII region near ESO 481-G017 show that the object is not a background galaxy but rather a small star-forming region just outside the SINGG host galaxy. The lines detected for this system are: Hα, [NII], [OIII], Hβ, and [SII]. The spectrum was obtained under clear conditions on the 6.5m Baade Telescope (with the Inamori Magellan Areal Camera and Spectrograph -- IMACS) at Las Campanas Observatory on Novemeber 28, 2005.

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Background image is a two-color image of SINGG J1105-00
Where red is Hα and blue is continuum emission (R-band).