Galaxy Evolution and Feedback across Different Environments
Proceedings IAU Symposium No. 359, 2020
T. Storchi-Bergmann, W. Forman, R. Overzier & R. Riffel, eds.
doi:10.1017/S1743921320002367

Characterizing circumnuclear starbursts in the local universe with the VLA

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Abstract. Nuclear rings are excellent laboratories to study star formation (SF) under extreme conditions. We compiled a sample of 9 galaxies that exhibit bright nuclear rings at 3-33 GHz radio continuum observed with the Jansky Very Large Array, of which 5 are normal star-forming galaxies and 4 are Luminous Infrared Galaxies (LIRGs). Using high frequency radio continuum as an extinction-free tracer of SF, we estimated the size and star formation rate of each nuclear ring and a total of 37 individual circumnuclear star-forming regions. Our results show that majority of the SF in the sample LIRGs take place in their nuclear rings, and circumnuclear SF in local LIRGs are much more spatially concentrated compared to those in the local normal galaxies and previously studied nuclear and extra-nuclear SF in normal galaxies at both low and high redshifts.

Keywords. radio continuum: galaxies, galaxies: starburst

1. Introduction

Nuclear star-forming rings occur in about 20% of nearby spiral galaxies (Knapen *et al.* 2004). Studies on nuclear rings in mostly local low-luminosity galaxies have shown that they are locations of active star formation (SF) (e.g. Buta & Combes 1996). In this work, we use extinction-free 3-33 GHz radio continuum observations from the Jansky Very Large Array (VLA) to study the physical properties of circumnuclear star formation (CNSF) along the nuclear rings of 4 local Luminous Infrared Galaxies (LIRGs; $L_{\rm IR}[8{-}1000\mu m] \geqslant 10^{11} L_\odot$), which are mostly gas-rich mergers (Sanders & Mirabel 1996). To provide context, we also performed the same analyses on 5 lower-luminosity normal star-forming galaxies with nuclear rings. We selected the sample LIRGs (NGC 1614, NGC 1797, NGC 7469, NGC 7591) from a subset of 68 LIRGs in the Great Observatories All-sky LIRG Survey (GOALS; Armus *et al.* 2009) that were observed with the VLA, and the low-luminosity galaxies (NGC 1097, NGC 3351, NGC 4321, NGC 4826, IC342) from the Star Formation in Radio Survey (SFRS; Murphy *et al.* 2012) of 56 nearby normal star-forming galaxies. The selected 9 galaxies are the only ones that exhibit distinct bright nuclear ring features, out of a combined total of 124 galaxies observed with the two surveys. VLA observations for all 9 sample galaxies share the same spectral setup as well as similar physical resolution (~100pc), which allows us to consistently measure and compare the radio properties of their nuclear rings and CNSF regions.

2. Circumnuclear Starbursts in different host environments

Through fitting the azimuthally averaged light profiles of the highest resolution observation, we estimated the radius of each ring and derived its star formation rate (SFR) based on recipes given by Murphy *et al.* (2012). We found that the nuclear rings in the sample LIRGs (median SFR $\sim 17 M_{\odot}/\mathrm{yr}$) produce stars at more than an order of magnitude higher rates than the ones in the sample normal galaxies (median SFR $\sim 0.3 M_{\odot}/\mathrm{yr}$). However, the overall sizes of the nuclear rings in the LIRGs (median $R \sim 250$pc) are smaller than the ones in the normal galaxies (median $R \sim 360$pc).

To better picture the roles played by CNSF in our sample galaxies, we compare our radio-derived SFR of each nuclear ring to the total SFR of each host galaxy derived from a combination of $L_{\mathrm{IR}}[8{-}1000\mu m]$ and L_{FUV} from the literature, accounting for significant AGN contribution to the bolometric luminosities of the LIRGs estimated by Díaz-Santos *et al.* (2017). The result shows that nuclear rings account for over 50% of the total SFRs in all 4 sample LIRGs. In the sample normal galaxies, the contribution from the nuclear rings is much lower (all below 50%), indicating that most of their SF takes place in the extra-nuclear regions. The high SFR contribution of the nuclear rings in the LIRGs demonstrates the crucial role of CNSF in the galaxy transformation process.

Taking advantage of our high resolution data, we performed structural analysis of our data with the *Astrodendro* Python package and further extracted a combined total of 37 individual CNSF regions in the nuclear rings of our sample galaxies. This was done to estimate sizes, SFRs and SFR surface densities (Σ_{SFR}) of individual star-forming knots. Our results show that CNSF in the sample of LIRGs (median $\Sigma_{\mathrm{SFR}} \sim 170 M_{\odot}\mathrm{kpc}^{-2}\mathrm{yr}^{-1}$) are around 100 times more spatially concentrated than for the sample of normal galaxies (median $\Sigma_{\mathrm{SFR}} \sim 2 M_{\odot}\mathrm{kpc}^{-2}\mathrm{yr}^{-1}$).

3. Circumnuclear Starbursts vs. Extra-nuclear star formation

To investigate the behaviour of our CNSF regions in contrast to general SF behaviours in systems represented by our sample, we gathered size and SFR measurements of SF regions in 48 local LIRGs from GOALS (Larson *et al.* 2020), 41 local normal galaxies from SINGS (Kennicutt *et al.* 2003) and 25 normal galaxies at $z \sim 1-4$ from Livermore *et al.* (2012) and Livermore *et al.* (2015). We found that CNSF measured for LIRGs in our present study is more spatially concentrated than SF previously probed in mostly extra-nuclear regions in both normal and IR-luminous galaxies. Furthermore, our comparison shows that CNSF regions in the sample LIRGs have higher Σ_{SFR} than SF regions in normal galaxies at $z > 1$, which means that the extreme environment of the central regions of LIRGs may be unique at both low and high redshifts.

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https://doi.org/10.1017/S1743921320002367 Published online by Cambridge University Press