Dwarf Galaxies: From the Deep Universe to the Present
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Star formation in dwarf galaxies in the ELAIS N1 field

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Abstract. We estimated several parameters of dwarf galaxies, including their star formation rate and dust mass, and compared them with galaxies with larger stellar masses.

We have chosen dwarf galaxies in the ELAIS N1 field, and fitted their Spectral Energy Distributions (SED). We used data from the new Herschel SPIRE and PACS Point Source catalogues to constrain the infrared radiation. Data available in VIZIER from multiple surveys have also been used.

We determined that the star formation rate (SFR), M_* and $M_{\rm dust}$ is one order of magnitude lower in dwarf galaxies compared to galaxies with larger stellar masses. However, the starburtiness was higher in the dwarf galaxies. They also had lower redshifts than normal galaxies, so we compared them to a subsample of normal galaxies with lower redshifts. The dust masses and SFRs of the dwarf galaxies were slightly lower, but their starburtiness was higher.

Keywords. galaxies: star formation, galaxies: dwarf, infrared: galaxies

1. Introduction

The European Large Area ISO Survey (ELAIS, Rowan-Robinson *et al.* 1999), which was one of the biggest open-time projects of the Infrared Space Observatory (ISO), has covered a total of 12 square degrees on the sky, and measurements were taken in four different bands (in a wavelength range of 6.7-175 μm). The survey consisted of multiple smaller regions, and one of these regions was the ELAIS N1 field. ELAIS N1 became one of the most known regions on the sky thanks to multiple follow up surveys, providing photometric measurements of the region from the optical to the radio.

There are thousands of extragalactic objects in the region, so we collected photometric data and the redshifts of galaxies in this field. We fitted their spectral energy distribution (SED), and derived their physical properties like stellar mass, star formation rate, and dust mass. We divided our sources depending on their stellar mass, and compared the dwarf galaxies to the larger galaxies.

We also compared our sources to the star forming main sequence (MS) of galaxies, to see the mode of star formation in the different samples. The actively star forming galaxies follow a relation between the stellar mass and SFR, with increasing SFR at higher stellar mass. The galaxies below this line are passive objects, with little or no ongoing star formation. The galaxies over the MS are starbursts (Schreiber *et al.* 2015). Another way of examining the activity of star formation is calculating the starburtiness: $R_{\rm SB} = sSFR/sSFR_{\rm MS}$, where $sSFR$ is the specific star formation rate. An $R_{\rm SB}$ below 1/4 signals a quiescent galaxy, and values above 4 indicate starbursts (Rodighiero *et al.* 2011; Sargent *et al.* 2012).

Table 1. The parameters of the examined dwarf galaxies (redshift, stellar and dust mass, starburstiness and the χ^2 of the SED fitting). Redshifts are taken from SDSS (a: photometric, b: spectroscopic). Their SDSS classification is listed in the last column: SF - starforming, SB - starburst. The means of the estimated parameters of dwarf and normal galaxies are also given.

	z	SFR ($M_\odot$/yr)	log M_* ($M_\odot$)	log M_{dust} ($M_\odot$)	log L_{IR}	R_{SB}	χ^2	SDSS
[RLP2006] EN1-J160844+545846	0.04^a	0.11	8.63	6.47	8.88	2.91	1.3	–
[TRG2010] 9	0.13^b	3.69	9.54	8.58	10.54	9.89	1.36	SB
[RLP2006] EN1-J160918+545351	0.11^a	0.46	9.56	8.23	9.54	1.22	1.2	–
2MASS J16124108+5439566	0.03^b	0.32	9.21	6.01	9.56	2.22	2.36	SB
SDSS J160310.63+550115.3	0.05^b	0.31	9.44	7.56	9.48	1.22	2.81	SF
2MASS J16065766+5403231	0.07^b	2.38	9.58	7.21	10.28	6.55	3.28	SB
[VV2003c] J161103.6+535136	0.08^b	1.28	9.28	6.85	10.04	6.92	1.98	SB
Dwarf	0.07	1.24	9.32	7.27	9.67	4.41		
Normal (All)	0.36	14.45	10.65	8.5	10.87	1.25		
Normal (local: z<0.14)	0.09	1.23	10.47	7.68	10.19	0.59		

2. Data and SED fitting

We collected photometric data from VIZIER, SDSS (Sloan Digital Sky Survey, Blanton *et al.* 2017), WISE (Wide-field Infrared Survey Explorer, Cutri *et al.* 2014), the ELAIS N1 combined catalogue (Rowan-Robinson *et al.* 2013) and the new Herschel Point Source Catalogues (Marton *et al.* 2017, Schulz *et al.* 2017). We only considered sources which have Herschel detections. Including the Herschel far-infrared (FIR) data is important for the estimation of the star formation rate and dust mass. The UV and optical radiation of young stars are absorbed by the dust around them, and then it is re-emitted in FIR by the dust. We also used the AKARI/IRC source catalogues for the ELAIS North field (Davidge *et al.* 2017), but it covers only a small region of the ELAIS N1.

We used CIGALE for the SED fitting (Noll *et al.* 2009, Burgarella *et al.* 2005, Boquien *et al.* 2018). Different modules can be chosen for the different mediums and processes in galaxies: stellar emission, nebular emission, dust emission and attenuation, and synchrotron emission. We selected a delayed τ model for star formation history, and the Bruzual & Charlot (2003) stellar emission model with Chabrier (2003) Initial Mass Function. Nebular continuum and line emission were also included. We chose a double power law attenuation curve (combining the attenuation caused by the warmer birth clouds and the cold interstellar medium), with the updated Draine & Li (2007) infrared emission model.

We divided our sources based on the results of the SED fitting (we considered our sources as dwarf galaxies if log $M_* < 9.7$). Two dwarf galaxy candidates ([RLP2006] EN1-J160844+545846, EN1-J160918+545351), and 45 normal galaxies have AKARI detection. There are additional 5 dwarf galaxy candidates, and 81 normal galaxies without AKARI data. So we have 7 dwarf galaxy candidates, and 126 with larger stellar masses in total. The results of the SED fittings are summarized in Table 1. One of the SEDs is shown in Fig. 1.: [RLP2006] EN1-J160844+545846, and the others are shown in Fig. 2.

3. Results and discussion

Our dwarf galaxy candidates have low redshifts (z < 0.14), while the galaxies with higher log M_* have higher redshifts. The star formation rate, M_* and M_{dust} are one order of magnitude lower in dwarf galaxies. We calculated the starburstiness (R_{SB}), and the dwarf galaxies are above the main sequence of star formation on average (Table 1.). Three dwarf galaxy candidates in our sample could even be classified as a starburst (R_{SB} > 4). However, the R_{SB} is smaller in the normal galaxies on average.

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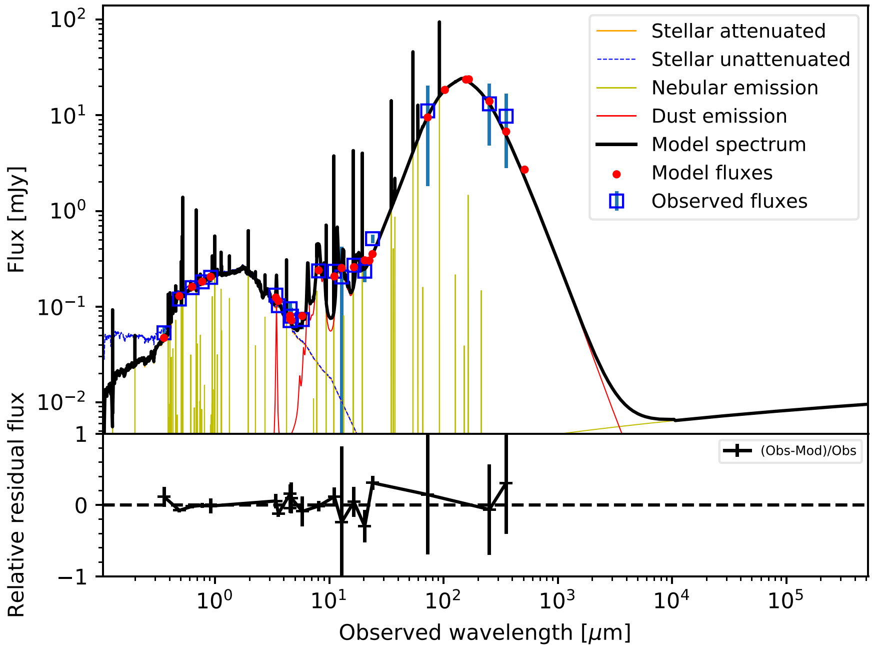

Figure 1. The SED of [RLP2006] EN1-J160844+545846, with a reduced χ^2 of 1.3. The model spectral energy distribution of the whole galaxy is marked by the solid black line. The unattenuated stellar emission is marked by a dashed blue line and the attenuated by an orange solid line. The nebular emission is marked by a yellow, and the dust emission by a red line. The observed fluxes are marked by blue squares, and the fluxes from the model SED by red points.

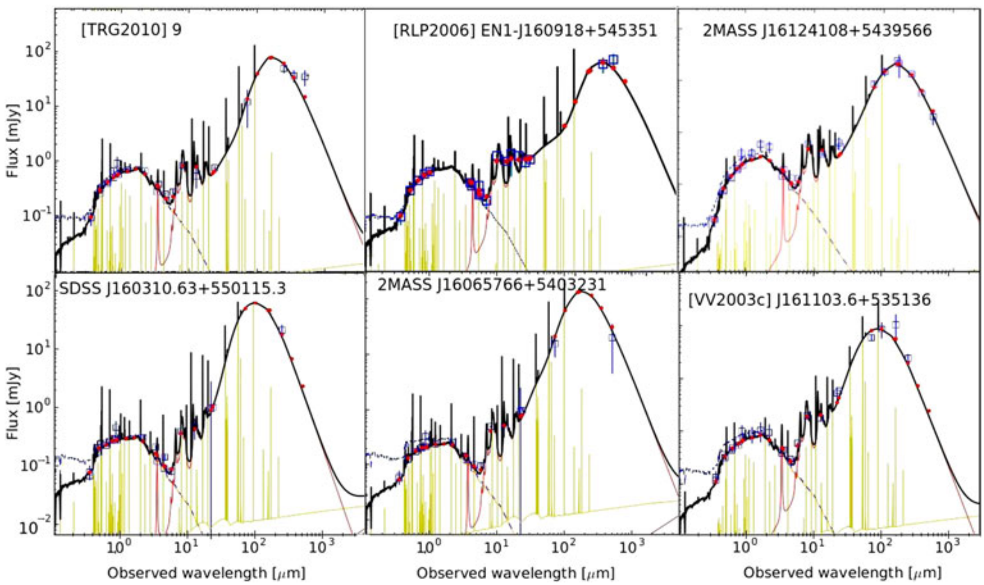

Figure 2. The SEDs of the other dwarf galaxy candidates, the notation is the same as in Fig. 1.

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We also compared our dwarf galaxy sample with normal galaxies at lower redshifts ($z < 0.14$, 36 galaxies in total). The properties of these two samples are more similar: while M_* is one order of magnitude lower in dwarf galaxies, $M_{\rm dust}$ is 1/3 of the $M_{\rm dust}$ in galaxies with larger masses. The star formation rates are similar, but the $R_{\rm SB}$ is higher on average.

Compared to Rowan-Robinson *et al.* (2013), we got significantly smaller total stellar masses. The optical spectra of 2MASS J16065766+5403231 and [TRG2010] 9 were examined in Toba *et al.* (2014) and Trichas *et al.* (2010), and both of them were identified as starforming galaxies, which is consistent with our SED fittings. Five sources have a spectrum in the SDSS database, and all of them are classified as starbursts or starforming galaxies (Table 1.), which is also in agreement with our estimated starburstinesses.

Magdis *et al.* (2013) estimated some properties of 2MASS J16124108+5439566: log $L_{\rm IR} = 9.54$ and log $M_{\rm dust} = 6.44$. We got the same luminosity, but our dust mass is smaller. Wu *et al.* (2010) also got a similar luminosity: log $L_{\rm IR} = 9.51$.

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