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Dust in dwarf galaxies: The case of NGC 4214

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Abstract. We have carried out a detailed modelling of the dust heating and emission in the nearby, starbursting dwarf galaxy NGC 4214. Due to its proximity and the great wealth of data from the UV to the millimeter range (from GALEX, HST, *Spitzer*, Herschel, Planck and IRAM) it is possible to separately model the emission from HII regions and their associated photodissociation regions (PDRs) and the emission from diffuse dust. Furthermore, most model parameters can be directly determined from the data leaving very few free parameters. We can fit both the emission from HII+PDR regions and the diffuse emission in NGC 4214 with these models with "normal" dust properties and realistic parameters.

Keywords. dust, extinction, galaxies: irregular, galaxies: individual (NGC 4214), galaxies: ISM

1. Introduction

The dust spectral energy distributions (SEDs) of dwarf galaxies frequently show differences to those of spiral galaxies. The two main differences are: (i) a relatively low emission at 8 μm, most likely due to a lower PAH content at low metallicities (e.g. Draine *et al.* 2007, Engelbracht *et al.* 2008), and (ii) a submillimeter (submm) "excess" which has been found in the SED of many starbursting, low-metallicity galaxies (Lisenfeld *et al.* 2002, Galliano *et al.* 2003, 2005, Bendo *et al.* 2006, Galametz *et al.* 2009, 2011, Israel *et al.* 2010, Bot *et al.* 2010). Different reasons have been suggested to explain this excess:

(1) A large amount of cold (< 10 K) dust (Galliano *et al.* 2003, 2005, Galametz 2009, 2011). However, extraordinarily large dust masses are needed for this explanation and it is unclear, how these large amounts of cold dust can be shielded efficiently from the interstellar radiation field (ISRF).

(2) A low dust emissivity spectral index of $\beta = 1$ in the submm. Different dust grains have been suggested to be responsible for this, from very small grains (Lisenfeld *et al.* 2002), fractal grains (Reach *et al.* 1995) to amorphous grains (Meny *et al.* 2007).

(3) Spinning grains (Ferrara & Dettmar 1994; Draine & Lazarian 1998). Bot *et al.* (2010) showed that this grain type could explain the submm and mm excess in the Large and Small Magellanic Cloud.

In order to interpret the dust SED of a galaxy a physical model is needed, based on realistic dust properties and taking into account the heating and emission of dust immersed in the wide range of ISRFs. Ideally, radiation transport in a realistic geometry should be done, but it is often difficult due to the complex geometry and large number of parameters. Models can generally be classified into three broad groups: (1) modified blackbody fits, which are too simple to describe reality correctly but give a first idea of the range of dust temperatures, (2) semiempirical models that try, in a simplified way, to describe dust immersed in a range of different radiation fields (e.g. Dale *et al.* 2001, Draine *et al.* 2007, Galametz *et al.* 2009, 2011, da Cunha *et al.* 2008) and (3) models that include full radiation transfer (e.g. Popescu *et al.* 2000, 2011 for spiral galaxies, Siebenmorgen & Krügel 2007 for starburst galaxies) which are the most precise description of a galaxies if all parameters, including the geometry, is known.

We model the dust emission of the nearby ($D = 2.9$ Mpc) starbursting dwarf galaxy NGC 4214. Due to its proximity and the large amount of ancillary data it is possible to apply physical models that take into account the full radiation transfer and constrain their input parameters. Here, we describe the general outline of our work and the results. A more detailed description of the available data, the data reduction and the determination of the model input parameters is presented in Hermelo *et al.* in this volume.

2. The observed SED of NGC 4214

NGC 4214 is an irregular galaxy, dominated by two bright, young star-forming (SF) regions in its center (called NW and SE in this work). A great wealth of data is available for this object, ranging from GALEX ultraviolet (UV), Hubble Space Telescope (HST) UV to infrared (IR) images, Spitzer IRAC and MIPS, Herschel SPIRE, IRAM MAMBO at 1.2mm, as well as Planck detections at 350, 550 and 850 μm. Furthermore the galaxy has been mapped in HI as part of the THINGS project (Walter *et al.* 2008) and has been observed with OVRO in CO(1-0) (Walter *et al.* 2001).

The large amount of data, most of them at a high spatial resolution, allows to determine the dust SED separately for the emission from the SF regions SE and NW, where the dust is heated by nearby massive stars, and the diffuse dust heated by the general interstellar radiation field. Figure 1 shows the observed dust SED of the individual SF regions (top) and of the diffuse medium (bottom), determined by subtracting the emission of both SF regions from the total dust emission.

3. The models

We separately modelled the emission from the massive SF regions and the diffuse dust emission. We use the model of Groves *et al.* (2008) that describes the emission from an HII region together with its surrounding PDR. For the diffuse emission we used the library of model SEDs from Popescu *et al.* (2011).

The model by Groves *et al.* describes the luminosity evolution of a star cluster of mass $M_{\rm cl}$ from stellar population synthesis, and incorporates the expansion of the HII region and PDR due to the mechanical energy input of stars and SNe. The dust emission from the HII region and surrounding PDRs is calculated from radiation transfer. The main parameters in this model are: (1) metallicity, (2) age of the cluster, (4) external pressure, (3) compactness parameter, C, which parametrizes the heating capacity of the stellar cluster and depends on $M_{\rm cl}$ and the external pressure of the ambient medium, (5) column density of the PDR, $N_{\rm H}$, and (6) covering factor, $f_{\rm cov}$, defining which fraction of the HII region is surrounded by the PDR. The large amount of data and results from previous studies allow us to constrain most parameters (all except $N_{\rm H}$) very tightly from observations (see Hermelo *et al.* in this volume).

The library of models from Popescu *et al.* (2011) is calculated including the full radiation transfer for a disk galaxy. The model galaxy consists of two exponential stellar disks, describing old and young stars, respectively, together with their associated dust disks. Two additional components of the model can be neglected in our case: a bulge which is absent in NGC 4214 and individual dusty SF regions, which we subtracted from the SED and modelled separately with the model of Groves *et al.* (2010). The main parameters of the diffuse model are: (1) the total central face-on opacity in the B-band, τ_B^f, (2) the star formation rate, SFR, (3) the clumpiness factor F which is the same as $f_{\rm cov}$ of Groves *et al.*, (3) the normalized luminosity of the old stellar population, old, and (4) the exponential scale-length of the stellar emission in the blue band, h_s. From the primary parameters SFR and F, Popescu *et al.* define the star formation rate powering the diffuse dust emission, $SFR' = SFR \times (1 - F)$. We observationally determined $h_s = 873^{+172}_{-123}$ pc and $F = 0.55$, the average of the values of NW and SE. We left SFR', τ_B^f and old as free parameters.

4. Results and conclusions

In Fig. 1 we show the fits of the models to the data, separately for both SF regions and for the diffuse emission. The parameters were chosen within the tight constraints given by the observations. Note that for the diffuse component the flux level of the dust emission is not free but is fixed by the observationally measured SFR.

The Groves *et al.* (2008) model fits all data points of the region NW longwords of 10 μm within the errors. The fit for the SE region is good for the dust SED but overestimates the thermal radio emission. Here, a better fit could be achieved for ages higher than those estimated for the central clusters (4.5 instead of 3.5 Myr). This could indicate that the

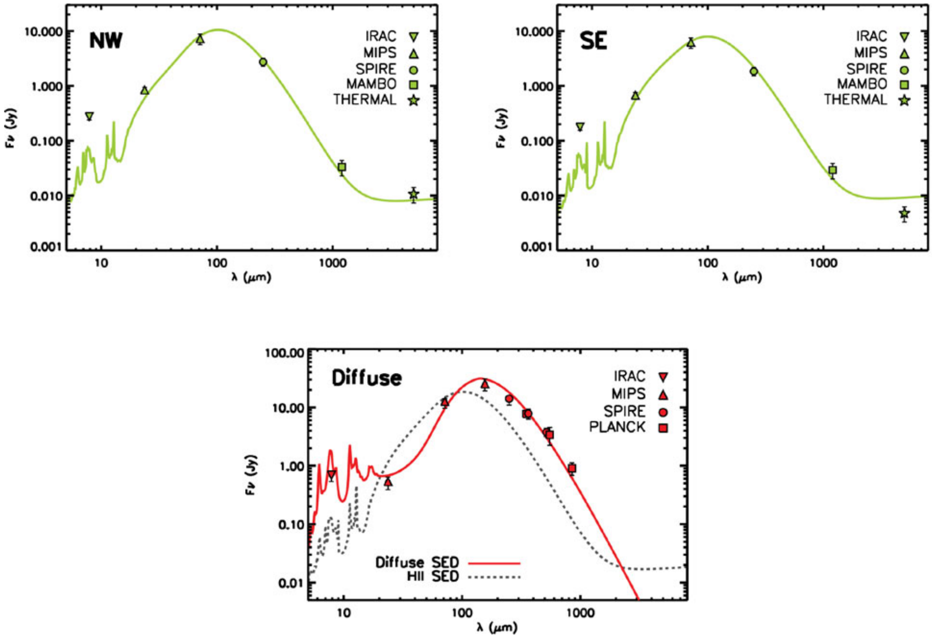

Figure 1. *Top:* The dust emission of the HII regions NW (left), SE (right) and the best-fit model for the parameter range determined by the observations. *Bottom:* The same for the diffuse emission. For illustration, the sum of the fit to NW+SE is also included (dashed line).

dust within our apertures is not only heated by the central clusters but also by an older stellar population. The model underestimates the emission at 8 μm, the reasons for this still need to be investigated. We achieve an excellent fit for the diffuse dust emission for the best-fit values of $\tau_B^f = 2$, $SFR' = 0.0071\,M_\odot\ \mathrm{yr}^{-1}$ and $old = 0$. However, the best-fit SFR derived from SFR' and F is a factor of about 1.7 below the corresponding value derived from the observed, attenuation corrected integrated UV-to-optical luminosity of NGC 4214. A possible reason for this discrepancy is that part of the stellar UV emission leaves the galaxy before contributing to the diffuse dust heating. This is not an unlikely scenario for a starbursting dwarf galaxy where massive stars can create holes in the ISM around them. Alternatively, differences in the geometry of the model galaxy and NGC 4214 (e.g. a higher ratio of the vertical scale-height to the radial scale-length in NGC 4214) could also have an effect.

In conclusion, we obtain an in general good agreement between model predictions, based on standard dust properties, and the data. There are no indications for a submm excess in this galaxy. The fact that we achieve a good agreement between models and data shows that this approach is a fruitful way to better understand the SED of nearby dwarf galaxies.

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