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Dust in dwarf galaxies: The case of NGC 4214

U. Lisenfeld[1], I. Hermelo[1], M. Relaño[1], R. Tuffs[2], J. Fischera[3], B. Groves[4], and C. Popescu[5]

[1]Universidad Granada, Granada, Spain, email: ute@ugr.es, mrelano@ugr.es,israelhermelo@ugr.es

[2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany, email: Richard.Tuffs@mpi-hd.mpg.de

[3]Canadian Institute for Theoretical Astrophysics (CITA), University of Toronto, email: fischera@cita.utoronto.ca

[4]Max-Planck-Institut für Astronomie, Heidelberg, Germany, email: brent@mpia.de

[5]Jeremiah Horrocks Institute for Astrophysics and Supercomputing, University of Central Lancashire, Prestion, U.K., email: cpopescu@uclan.ac.uk

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 distribution (SED) of dwarf galaxies frequently show differences to those of spiral galaxies. The two main differences are: (i) a relatively low emission at 8μm, 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, extraordinarly 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 value of the dust emissivity spectral index of $\beta = 1$ in the submm. Different dust grains have been suggested that could 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 and understand the differences of the

SED of dwarf galaxies, 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 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. 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.

In the present work 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. In the present contribution we describe the general outline of our work and the results, whereas a more detailed description of the available data, the data reduction and the determination of the model input parameters is presented in the contribution of 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 SF regions. It 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. Due to the great wealth of data and previous studies carried out, we can constrain most parameters (all except N_{H}) very tightly from observations (see Hermelo et al.).

In order to fit the diffuse emission, we applied the templates from Popescu et al. (2011), calculated including the full radiation transfer for a disk galaxy. The model 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 young 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 central face-on opacity τ_B, (2) the SF rate (SFR) of the young stellar population, (3) the SFR of the old stellar population and (4) the exponential scale-length, h_s, of the stellar emission. All these parameters can be tightly constrained by the observations (see Hermelo et al.).

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 emission the flux level of the dust emission is not free but is fixed by the observationally measured SFR.

The model by Groves et al. (2008) for the region NW fits all data points longwards of 10 μm within the errors. The fit for the SE region is good, but underestimates slightly the long wavelength data at 1.2mm and 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 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 8μm, the reasons for this still need to be investigated.

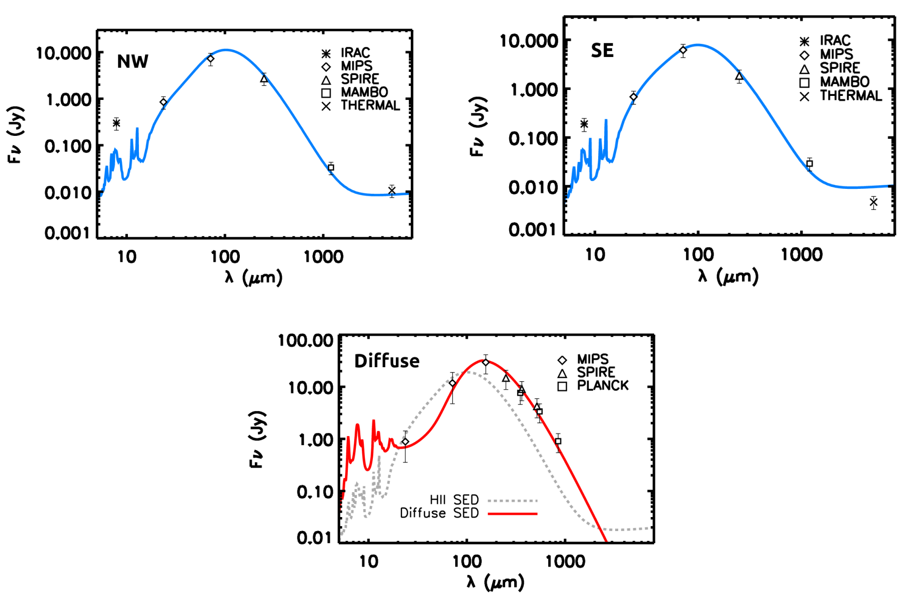

Figure 1. *Top:* The dust emission of the HII regions NW (left), SE (right) and the best-fit model for the parameter range determined by the observations. *Bottom:* The same for the diffuse emission. For illustration, the sum of the fit to NW+SE is also included.

We achieve an excellent fit for the diffuse dust emission. However, we had to assume a larger horizontal scale-length (980-1265 kpc instead of the observed 800 kpc) in order to produce the correct dust temperature. A possible reason for this discrepancy is that the vertical scale height of the stellar light in this irregular galaxy is higher than the model value for normal spiral galaxies adopted in Popescu et al. (2011).

We can calculate the dust mass from eq. (44) of Popescu et al. (2011) ($M_{dust} = \tau_B \times h_s^2 \times 0.99212\ \mathrm{pc}^{-2} M_{\odot}$). With our values of $h_\mathrm{s} = 980$ kpc and $\tau_B = 1$ we derive a dust mass of $9.7 \times 10^5\ M_{\odot}$. Together with $M_{\mathrm{HI}} = 4.1 \times 10^8\ M_{\odot}$ (Walter et al. 2008) and $M_{\mathrm{H2}} = 5.1 \times 10^6\ M_{\odot}$ (Walter et al. 2001, obtained with a Galactic conversion factor) we derived a gas-to-dust mass ratio of 470. This is about three times the Galactic value which is realistic for a galaxy with a $\sim$ three times lower metallicity.

In conclusion, we find that we obtain a generally good agreement between model predictions, based on standard dust properties, and the data. There are no indications for a submm excess. NGC 4214 is a special case because the wealth of ancillary data and its proximity allowed to (i) determine the SED of the dust emission separately for the dust in SF regions (HII region + PDR) and the diffuse dust and (ii) constrain most model input parameters independently from observations. The fact that we achieved a good agreement between models and data shows that this approach is a fruitful way to try to understand the SED of nearby dwarf galaxies and to find the origin of peculiar features as e.g. the submm excess.

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