Challenges in Panchromatic Modelling with
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High-resolution radiation transfer modelling of barred galaxies

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Abstract. Dust radiative transfer simulations provide us with the unique opportunity to study the heating mechanisms of dust by the stellar radiation field. From 2D observational images we derive the 3D distributions of stars and dust. Our aim is to analyze the contribution of the different stellar populations to the radiative dust heating processes in the nearby face-on barred galaxies NGC 1365, M 83 and M 95. We wish to decompose the FIR-submm SED and quantify the fraction directly related to star formation. To model the complex geometries mentioned above, we used SKIRT, a state-of-the-art, 3D Monte Carlo radiative transfer code designed to simulate the absorption, scattering and thermal re-emission of dust in a variety of environments. We find that the contribution of the evolved stars (8 Gyr) to the dust heating is non-negligible ($\sim 35\%$) and can reach as high as 70%. We also find a tight correlation between the heating fraction by the unevolved stars ($\leqslant 100$ Myr) and the specific star formation rate.

Keywords. radiative transfer - ISM: dust, extinction - galaxies: individual: NGC 1365, M83, M95 - galaxies: ISM - infrared: ISM

1. Introduction

Dust grains are responsible for the attenuation and reddening effects at ultraviolet (UV) and optical wavelengths. Dust absorbs roughly 30% of the light emitted by stars and redistributes this light back in the infrared wavelengths (Popescu *et al.* 2002; Skibba *et al.* 2011; Viaene *et al.* 2016; Bianchi *et al.* 2018). The dust emission in this regime is often used to trace star formation activity (Calzetti *et al.* 2007, 2010; Kennicutt *et al.* 2009), however the contribution of the old stars to the dust heating can be non-negligible (e.g., Bendo *et al.* 2012, 2015) and needs to be considered while estimating the star formation rate (SFR) of a galaxy. We use radiation transfer (RT) modelling to create a realistic model of the radiation field and its interaction with dust, by quantifying the relative contribution of each stellar population to the dust heating. The advantage of using RT modelling in relation to other methods, such as pixel-by-pixel SED (spectral energy distribution) fitting, is that it takes into account the effect of non-local heating.

2. Modelling approach

We construct a self-consistent 3D model for a galaxy, with the Monte-Carlo RT code SKIRT (Baes *et al.* 2011; Camps & Baes 2015), taking into account all relevant physical

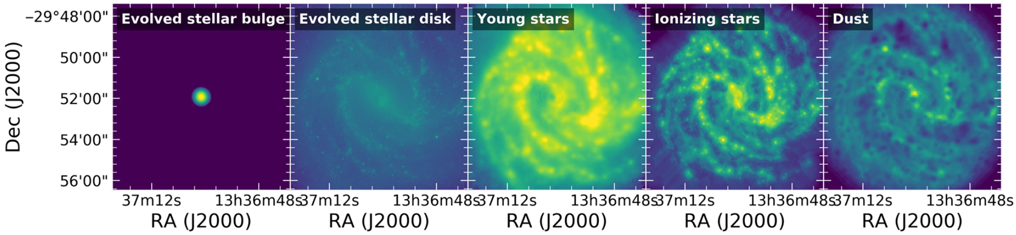

Figure 1. Input component maps of M 83. The colour coding is in log scale and reflects a normalised flux density.

processes such as scattering, absorption and thermal re-emission by dust. In this work we focus on three nearby face-on barred galaxies, NGC 1365, M 83 and M 95. The model for each galaxy consists of four stellar components and a dust component. We consider a central stellar bulge, and a disk populated by evolved and unevolved (young and ionizing) stars. We model the evolved and young stars using the Bruzual & Charlot (2003) single stellar populations (SSP) of ages 8 Gyr and 100 Myr respectively, while for the ionizing stars we adopt the SED templates from MAPPINGS III (Groves *et al.* 2008) assuming an age of 10 Myr.

Here we describe briefly the steps we followed to retrieve the stellar and dust geometries, for each galaxy. First we perform a bulge-disk decomposition using an IRAC 3.6 μm image, tracing the emission of evolved stars. We model the bulge with a flattened Sérsic profile and assume that the contamination from the unevolved stars and from dust emission in the central region are negligible. By subtracting the bulge from the disk we were able to obtain a map of the evolved stars in the disk. To get the distribution of the young and the ionizing stars in the disk we use the GALEX far-ultraviolet (FUV) image, and the MIPS 24 μm image combined with an Hα map respectively. We constrain the dust component in the disk through a FUV attenuation map, while for the dust composition we used the dust model THEMIS (Jones *et al.* 2017). The different components can be seen in Fig. 1.

To create the 3D distribution of the disk components we assign to each one of them an exponential profile of different scale heights based on previous estimates of the vertical extent of edge-on galaxies (De Geyter *et al.* 2014). We create a dust grid based on the dust component, through which the photons propagate in our simulations. We use a binary tree dust grid (Saftly *et al.* 2014) with approximately 3 million dust cells for each galaxy. Finally, three free parameters in our model are determined via a χ^2 optimisation procedure. These parameters are: the FUV luminosities of the young and ionizing stars and the dust mass. Initial guesses for these parameters are based on global SED fitting performed with CIGALE (Boquien *et al.* 2018) by (Nersesian *et al.* 2019) for 814 DustPedia galaxies (Davies *et al.* 2017).

3. Results

From our simulations it is possible to retrieve the absorbed energy in each dust cell originating from the different stellar populations in the model and thus to quantify the dust heating fraction from the unevolved stellar populations. An example of the dust heating map of M 83 is given in Fig. 2. The left panel shows the heating fraction map of a face-on view of M 83. The histogram in the right panel displays the heating fraction distribution within the dust cells, weighed by dust mass. For M 83 we find that 63% of the heating originates from the unevolved stars with the lowest values in the most central regions. Similarly, in NGC 1365, 66% of the heating originates from the unevolved stars, while for M 95 we find that the dust is mainly heated by the evolved stars with the

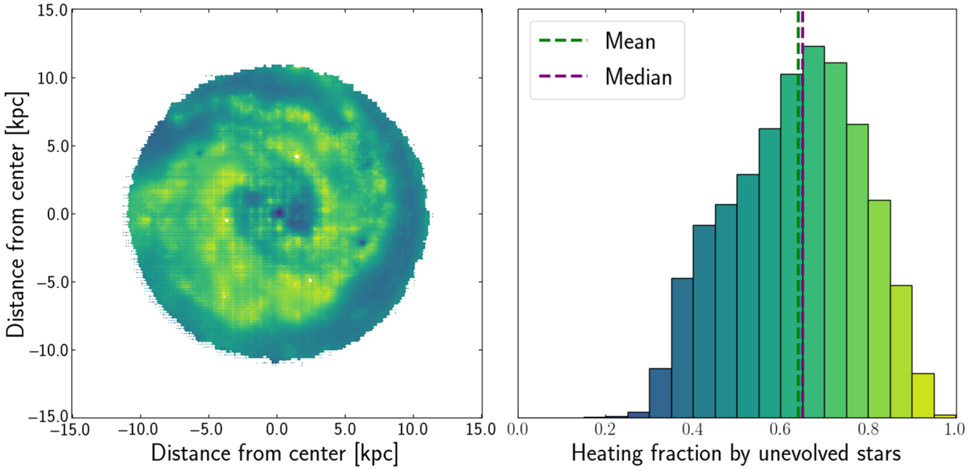

Figure 2. Left panel: Face-on view of the heating fraction by unevolved stars, as obtained from the 3D dust cell distribution, for M 83. Right panel: Distribution of the dust cell heating fractions, weighed by dust mass. The green dashed line is the mean value, while the purple dashed line is the median.

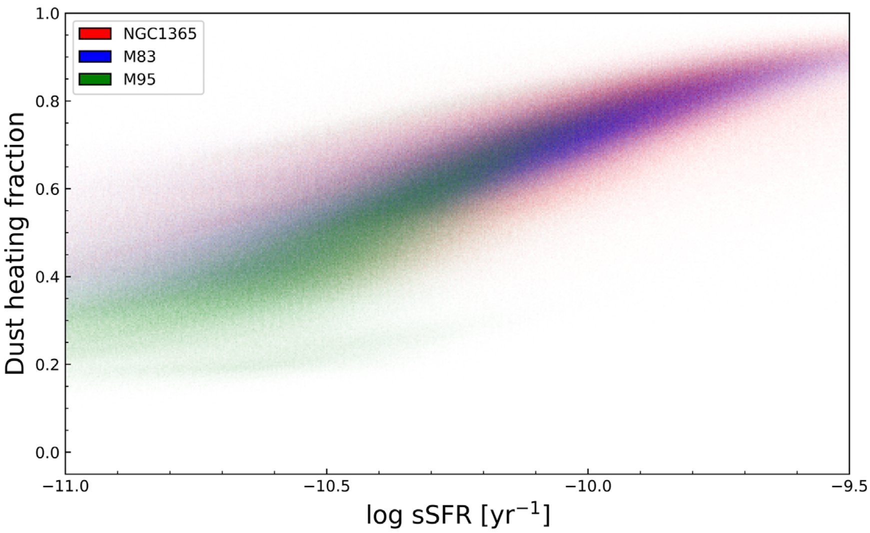

Figure 3. Relation between the sSFR and the relative contribution from the unevolved stars to the dust heating responsible for the total-infrared emission in the RT model of NGC 1365 (red data points), M 83 (blue data points) and M 95 (green data points).

contribution of the unevolved being only 32%. These are the fractions by which a typical far-infrared (FIR) SFR indicator should be corrected in these galaxies.

We also report a strong correlation between the dust heating fraction and the specific star formation rate (sSFR) calculated for each cell. We have used the IRAC 3.6 μm luminosities to estimate the stellar masses (Oliver *et al.* 2010) and the intrinsic FUV luminosities of the unevolved stars to estimate the star formation rates (Kennicutt & Evans 2012). In Fig. 3 we plot the heating fraction as was calculated for each cell and for all three galaxies, as a function of the sSFR. It is immediately evident that there is an increasing trend between the heating fraction and the sSFR. That, in principle, enables us to quantify the heating fraction based on sSFR measurements in other galaxies.

4. Conclusions

We have constructed highly detailed 3D RT models for 3 barred galaxies to investigate the dust heating processes. We find that the contribution from the more evolved stars to the dust emission at the infrared bands is more significant than previously thought. This result questions the use of infrared luminosity as a proxy for the star formation activity in star-forming galaxies. The dust heating fraction by the unevolved stars for NGC 1365, M 83 and M 95 respectively is: 66%, 63% and 32%. Furthermore, we confirm a tight correlation between the dust heating fraction and the sSFR which was previously reported for RT models of M 51 (De Looze *et al.* 2014) and M 31 (Viaene *et al.* 2017). The full description of our method and the results of the modelling of M 81 will be presented in Verstocken *et al.* (2020, submitted), while the detailed results of this study will be presented in Nersesian *et al.* (2020). Finally, the modelling of a galaxy with an additional AGN component, NGC 1068 (M 77) will be presented in Viaene *et al.* (in preparation).

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Discussion

V. Buat: You underlined an attenuation by dust from evolved stars for NIR data (M83 plot), what is the impact of this dust attenuation on the measure of stellar masses?

A. Nersesian: In the figure was depicted the relative contribution of the evolved and unevolved stars to the heating of dust across the wavelength range UV-optical, as determined from the RT model of M 83, and not the fraction of stellar luminosity that is absorbed or attenuated. Of course NIR data are affected by dust attenuation, but in the case of M 83 the effect to the stellar mass measurement is not significant.

F. Egusa: Residual maps look like to have some spiral-like structures? What would be the reason?

A. Nersesian: The spiral-like structures arise because the model has to some extent smoothed out the sharper features of the galaxy. But also has to do to the fact that multiple images, of different bands, were combined to create the input maps of the model.

F. Egusa: NGC 1365 and M 83 have ALMA data, which can be a tracer of molecular gas. Would this gas information help to improve the models?

A. Nersesian: Definitely, using gas maps to trace the SFR regions would help create a more accurate representation of those galaxies in our modelling.

T. Goto: Dust heating fraction has more values in NGC 1365. Why? Maybe AGN, inclination?

A. Nersesian: NGC 1365 has a very strong AGN emission in the center which eventually affects the heating fraction in the central regions of the galaxy.

S. Shen: Does your model include dust destruction? The evolved stars may have UV photons destructing dust grains.

A. Nersesian: No our model does not include dust destruction. However, we use observed images in the FIR to model the dust in the galaxies, which means that dust destruction is already accounted for.