Intrinsic dust and star-formation scaling relations in nearby galaxies

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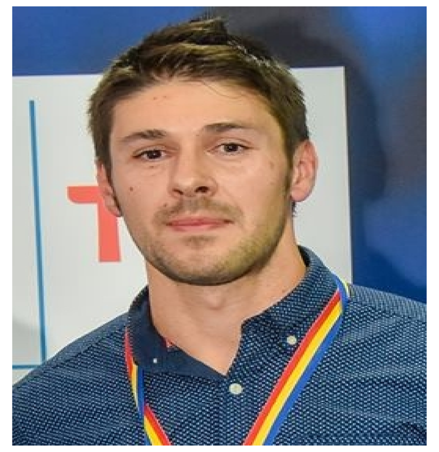

Motivation

Accurate, unbiased dust and star-formation scaling relations are essential in studies of ISM evolution, star-formation and galaxy evolution studies, or related to the duty cycle of dust and gas in galaxies. It is known that dust introduces the most significant effects and degeneracies in the observed (measured) photometric and structural parameters of galaxies and their main constituents – discs and bulges, with inclination (projection) and decomposition effects having a non-negligible contribution. These effects are stronger at shorter wavelengths and higher disc inclinations (Tuffs et al. 2004, Gadotti et al. 2010, Pastrav et al. 2013a,b). Obtaining thus intrinsic (corrected) scaling relations and show the extent of biases introduced, is thus very important for the previously mentioned studies.

Sample

Our sample is formed by all the unbarred spiral and lenticular galaxies from the SINGS/KINGFISH survey (Kennicutt et al. 2003, 2011): NGC0024, NGC0628, NGC1377, NGC1482, NGC1705, NGC2841, NGC2976, NGC3031, NGC3190, NGC3621, NGC3773, NGC3938, NGC4254, NGC4450, NGC4594, NGC4736, NGC4826, NGC5033, NGC5055, NGC5474, NGC5866, NGC7331 and NGC7793.

Method

1) surface photometry for the B band and Hα line images, to derive the total integrated fluxes using curve-of-growth (CoG) method;

2) structural analysis of the whole sample through a multi-component 2D bulge-disk decomposition, using parametric functions (exponential disk+Sérsic profile+sky), with GALFIT (Peng et al. 2002,2010) data analysis algorithm and in-house star masking routines;

3) derive central dust opacities in B band and Hα line using the correlation (Eq. 1) found by Grootes et al. (2013), between face-on dust opacity and the stellar mass surface density (Eq. 2);

4) Calculation of dust masses (Eq. 3/ Eq. 2 in Grootes et al. 2013) considering Popescu et al. (2011 model) for dust geometry (diffuse dust→ exponential disks), which considers Draine et al. (2003) dust model; subsequently, calculation of dust-to-stellar mass ratios and dust-to-gas ratios (observed and corrected), using stellar and gas masses found in the literature (e.g. Remy-Ruyer et al. 2014 & Grossi et al. 2015 – stellar masses, Kennicutt et al. 2008 & Moustakas et al. 2010 – HI gas masses, etc.);

5) Apply the numerical corrections for projection, dust & decomposition effects to the measured parameters to derive intrinsic (corrected) parameters involved in the analysed dust/ISM and star-formation scaling relations.

(A detailed description of the method and procedure can be found in **Pastrav 2020** and **Pastrav 2021**).

$$\log(\tau_B^f) = 1.12(\pm 0.11)\cdot\log\left(\frac{\mu_*}{M_\odot\,\mathrm{kpc}^{-2}}\right) - 8.6(\pm 0.8) \qquad (1)$$

$$\mu_* = \frac{M_*}{2\pi r^2_{e,ss,r}} \qquad (2)$$

$$\tau_B^f = K\frac{M^{\mathrm{diff}}_{\mathrm{dust}}}{r^2_{s,d,B}} \approx K\frac{M_{\mathrm{dust}}}{r^2_{s,d,B}} \qquad (3)$$

Scaling Relations

Results

- a) the slope of the B band Mdust-M* relation (Fig. a) is **1.05±0.23** for the observed relation and 0.90±0.13 for the intrinsic one; average B band dust opacity (see plot) is consistent with studies done on larger samples (e.g Driver et al. 2007 found 3.8±0.7; van der Giessen et al. derived ~4.1); σ(rms)=0.07 and r(Pearson coefficient)=0.99 for the obs. relation; Mdust values for the galaxies in our sample are consistent with the values derived in Remy-Ruyer et al. (2014) and Aniano et al. (2020);

- b) an increase in dust opacity (B band) with both M* and μ* is observed (Figs. b,c), as also recently found by van der Giessen et al. (2022) analysing a much larger sample of galaxies from SDSS & GAMA surveys;

- c) the expected decreasing trends with stellar mass or μ* for the Mdust/M* ratio (Figs. d, e) are only recovered after applying the corrections; the average value for the Mdust/M* ratio (**-2.88** in log scale, for the observed rel.) is in very good agreement with values found of -2.85 by Skibba et al. (2011) or -3.03 by Calura et al. (2017), using other methods;

- d) σ=0.34 and r=-0.86 for intrinsic Mdust/M*-μ* relation, consistent with values of σ=0.45 and r=-0.79 derived by Cortese et al. (2012) for galaxies including the KINGFISH spirals; a weaker increasing trend and correlation is found for the μ*-M* relation, with r=0.53 (obs.)/0.57(intrin.) and σ=0.04 dex (obs. & intrin. relations);

- e) another scaling relation is shown in Fig. g), the ratio of **Hα flux (or luminosity)/Mdust vs. M*** → a consequence of SFR-M* and Mdust-M* relations, with a derived slope of **α=-1.09±0.16 (obs.) /α=-0.95±0.20** ;

- f) the increasing trends in the MHI/Mdust vs M* and Mdust/M* vs MHI/M* (Figs. h, j) is recovered, with the average value for dust-to-gas ratios (-2.19 or 0.66%) consistent with the one found by Cortese et al. (2012) of -2.1 for HI normal galaxies; the rms is low (0.15 & 0.03) while the correlation coefficient r=0.55 (obs)/0.36 (intrin) is consistent with r=0.31 found in Cortese et al. (2012); practically no correlation is observed for the corrected MHI/Mdust vs μ* (Fig. i), in line with what was found by Cortese et al. (2012) → r=0.07 vs r=0.05; a weaker correlation is found for the Mdust/M* vs MHI/M* relation with r<0.5;

- g) the ratio of the **intrinsic** disc scale-lengths seen in optical B band and in **Hα** line, as a function of M* or stellar mass surface density is **lower than 1.0**, mildly increasing / decreasing, and shows **the extent of optical emission in the disc vs the extent to which star-formation is distributed in the young stellar discs of galaxies**.

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