The Fate of the Interstellar Medium in Early-type Galaxies. II. Observational Evidence for Morphological Quenching*

Leniewska, Aleksandra; Michaowski, M. J.; Gall, C.; Hjorth, J.; Nadolny, J.; Ryzhov, O.; Solar, M.

Published in:
Astrophysical Journal

DOI:
10.3847/1538-4357/acdcfc

Publication date:
2023

Document version
Publisher's PDF, also known as Version of record

Document license:
CC BY

Citation for published version (APA):
The Fate of the Interstellar Medium in Early-type Galaxies. II. Observational Evidence for Morphological Quenching*

Aleksandra Leśniewska1,2 ©, M. J. Michałowski1 ©, C. Gall2 ©, J. Hjorth2 ©, J. Nadolny1 ©, O. Ryzhov1 ©, and M. Solar1 ©
1 Astronomical Observatory Institute, Faculty of Physics, Adam Mickiewicz University, ul. Słoneczna 36, Poznań, Poland; aleksandra.lesniewska@amu.edu.pl
2 DARK, Niels Bohr Institute, University of Copenhagen, Jagtvej 128, DK-2200 Copenhagen N, Denmark

Received 2023 April 28; revised 2023 June 5; accepted 2023 June 7; published 2023 July 31

Abstract

The mechanism by which galaxies stop forming stars and get rid of their interstellar medium (ISM) remains elusive. Here, we study a sample of more than 2000 elliptical galaxies in which dust emission has been detected. This is the largest sample of such galaxies ever analyzed. We infer the timescale for removal of dust in these galaxies and investigate its dependence on physical and environmental properties. We obtain a dust-removal timescale in elliptical galaxies of $\tau = 2.26 \pm 0.18$ Gyr, corresponding to a half-life time of $1.57 \pm 0.12$ Gyr. This timescale does not depend on environment, stellar mass, or redshift. We observe a departure of dusty elliptical galaxies from the relation between star formation rate and dust mass. This is caused by the star formation rates declining faster than the dust masses and indicates that there exists an internal mechanism that affects star formation but leaves the ISM intact. Morphological quenching together with ionization or outflows caused by older stellar populations (Type Ia supernovae or planetary nebulae) is consistent with these observations.

Unified Astronomy Thesaurus concepts: Early-type galaxies (429); Elliptical galaxies (456); Galaxy ages (576); Galaxy evolution (594); Galaxy quenching (2040); Interstellar medium (847); Dust destruction (2268)

1. Introduction

Dust influences the evolution of galaxies by acting as a catalyst for molecule formation and providing shielding from interstellar radiation. Its emission can also be used as a diagnostic for properties of the interstellar medium (ISM; Scoville et al. 2016). There are several processes that can contribute to dust removal from galaxies. Dust can be incorporated in newly formed stars (astration; Gall & Hjorth 2018) or destroyed by active galactic nucleus (AGN) feedback (Fabian 2012). Supernovae (SNe) may destroy newly formed and preexisting dust by forward and reverse shock waves (Bianchi & Schneider 2007; Cherchneff & Dwek 2010; Gall et al. 2011; Lakićević et al. 2015; Temim et al. 2015). Dust can also be destroyed by planetary nebulae. This is due to heating of gas by shocks from colliding planetary nebulae (Conroy et al. 2015). Galactic outflows contribute to dust removal and can be very effective due to radiation pressure-driven dusty flows (Bianchi & Ferrara 2005). Hot gas ($\sim 10^5$ K) present in some regions of ISM can also cause erosion of dust particles. The smallest grains are the most vulnerable to this mechanism (Bocchio et al. 2012).

Over the past decades, many theoretical works have been developed to model the formation, evolution, and destruction of dust in galaxies. Among the first research dealing with dust evolution is by Dwek & Scalo (1980), who emphasized the importance of SNe. Barlow (1978) studied sputtering of dust grains in H II regions, intercloud medium, cloud–cloud collisions, shock waves, and SN remnants, concluding that the last of these dominates this process. Gall et al. (2011) developed a numerical model of galactic chemical evolution and studied the effect of galaxy properties on the evolution of dust. Dust destruction was described in the model as being caused by SN shocks. The tested properties of dust evolution depend very strongly on the initial mass function. Slavin et al. (2015) focused on dust destruction by SNe, which resulted in a dust-removal timescale of 2–3 Gyr.

Recent studies of high-redshift ($z \sim 1.6–3.3$) lensed quiescent galaxies have shown that their dust-to-stellar mass ratios are of order $10^{-4}$ (Whitaker et al. 2021). Similarly, Blánquez-Sesé et al. (2023) showed that high-redshift galaxies are characterized by gas fractions an order of magnitude higher than those detected in the local universe.

In order to separate the processes of dust formation and removal, it is an advantage to study galaxies with little dust formation, but with detectable ISM. Therefore, dusty early-type galaxies (ETGs; ellipticals and lenticulars) form a suitable sample for such an endeavour. The dust emission of only several dozen such galaxies has been analyzed (Rowlands et al. 2012; Smith et al. 2012; Agius et al. 2013, 2015; di Serego Alighieri et al. 2013; Hjorth et al. 2014; Danish et al. 2016; Michałowski et al. 2019; Magdis et al. 2021). Hjorth et al. (2014) showed that dusty early-type galaxies do not follow the relation between the star formation rates (SFRs) and dust masses (da Cunha et al. 2010) and they discussed formation or quenching scenarios. Michałowski et al. (2019, 2023) revealed an exponential decline of the dust-to-stellar mass and gas-to-stellar mass ratios with galaxy age and measured the timescale of this process to be $2.5 \pm 0.4$ Gyr. To date, this is the only measurement of the dust-removal timescale in dusty early-type galaxies and is based on a sample of 61 galaxies.

Dusty elliptical galaxies are quite rare. Hence, far-infrared/submillimeter surveys need to cover a large area to detect a high number of galaxies to build a significant sample. The ESA Herschel Space Observatory (henceforth Herschel, Pilbratt et al. 2010) has provided deep infrared observations of...
hundreds of square degrees of the sky. Its large field of view, $4' \times 8'$, and sensitivity have led to the detection of dust in millions of galaxies.

One of the major observation projects regarding cosmological and galaxy evolution, Galaxy and Mass Assembly (GAMA); Driver et al. 2011, 2016; Smith et al. 2011; Baldry et al. 2018), brings together the latest generation of instruments and surveys, such as the Anglo-Australian Telescope (AAT), Sloan Digital Sky Survey (SDSS), and Herschel. These data sets were combined in a database of several hundred thousand galaxies, with a magnitude limit in the $r$ band of 19.8 mag. Such an extensive catalog not only allows the examination of the relationships between individual quantities, but also gives the possibility of additional sampling into bins of various parameters.

In this paper we study a large sample of more than 2000 elliptical galaxies in which dust was detected. The sample size allows us to investigate dust evolution as a function of various galaxy properties. We focus on relationships between their physical and environmental parameters. The objective of this paper is to distinguish the mechanisms contributing to the removal of dust in elliptical galaxies and investigate its dependence on physical and environmental properties.

We use a cosmological model with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_L = 0.7$, and $\Omega_m = 0.3$. We assume the Chabrier (2003) initial mass function.

2. Data and Sample

2.1. GAMA Catalog

Herschel covered an area of 161.6 deg$^2$ of the GAMA fields and provided information on dust emission at 250, 350, and 500 $\mu$m. The GAMA catalog for these fields contains properties of 120,114 galaxies based on modeling of spectral energy distributions with the Multi-wavelength Analysis of Galaxy Physical Properties (MAGPHYS; da Cunha et al. 2008). This includes dust masses, stellar masses, star formation rates, and luminosity-weighted stellar ages. The values of these parameters were obtained by the GAMA project and are presented in their MagPhys catalog. We also obtained a wide range of parameters related to photometry, a single-Sérsic fit to the SDSS 2D surface brightness distribution (Kelvin et al. 2012), and the local environment of galaxies, such as galaxy surface density ($\Sigma$) calculated based on the distance to the fifth nearest neighbor within a velocity difference of $\pm 1000$ km s$^{-1}$ (Brough et al. 2013).

2.2. Sample

We used the $r$-band Sérsic index (Sérsic 1963), $n$, to select elliptical galaxies by requiring that $n > 4$. This resulted in 22,571 galaxies. From this set of galaxies we selected dusty ellipticals with a minimum signal-to-noise ratio at the Herschel SPIRE (Griffin et al. 2010) 250 $\mu$m filter of 3. This step resulted in 2956 galaxies, so 13% of elliptical galaxies are detected by Herschel. This is higher than the detection rate of 5.5% obtained for similar galaxies by Rowlands et al. (2012), who required a higher significance of 5$\sigma$ at 250 $\mu$m.

Rowlands et al. (2012) visually classified galaxies to the early-type category at redshifts 0.01 < $z$ < 0.32. We selected galaxies in the same redshift range. At higher redshifts the morphological classification is uncertain (de Albernaz Ferreira & Ferrari 2018) and the sample could contain compact, highly star-forming (not elliptical) galaxies. Our final selection, including the redshift cut, resulted in 2050 galaxies. Our selection roughly corresponds to a flux-limited sample above 20.7 mJy at the SPIRE 250 $\mu$m, although adopting that limit would result in 17% of galaxies having a signal-to-noise ratio ($S/N$) less than 3. Selection of galaxies based on SPIRE 250 $\mu$m flux $> 20.7$ mJy does not affect our results

The uncertainties of the physical properties are the following, measured separately for main sequence (MS) and below-MS subsamples: 0.12-0.14 dex for stellar age, 0.1-0.3 dex for SFR, 0.15-0.22 dex for $M_{dust}$ and 0.1 dex for $M_{stellar}$ where the higher values correspond to the galaxies below the MS.

Rowlands et al. (2012) estimated that 2% of dusty early-type galaxies in their sample are likely chance projections of a dust-free galaxy and a background dusty galaxy. Our selection criteria are similar: we used the updated GAMA archive (DR3), Sérsic index $> 4$ instead of visual classification, and the same redshift range, so we expect a similar fraction, which does not affect our analysis. The main difference is the area over which the galaxies were selected, resulting in a much larger sample of 2050 objects than the 44 galaxies studied in Rowlands et al. (2012).

3. Results

3.1. Main Sequence

We divided the selected galaxies into two groups: galaxies within and below the MS of star-forming galaxies. Figure 1 (top) presents a comparison of our galaxies with a redshift-dependent MS as measured by Speagle et al. (2014, Equation (28)). We adopted a measured MS width of 0.2 dex (Speagle et al. 2014), independent of redshift. Any galaxy below the MS by more than 0.2 dex is assigned to the “below-MS” group in this paper. Our sample covers the redshift range uniformly with a sensitivity $< 100$ times below the MS at all redshifts. This resulted in 722 MS dusty elliptical galaxies and 1328 below-MS galaxies.

We tested the validity of the Speagle MS for our data using late-type galaxies from GAMA, which have been selected based on Sérsic index $< 2.5$, 0.1 < $z$ < 0.15, and $S/N > 3$ at SPIRE 250 $\mu$m. We find an agreement between the Speagle MS and the MS estimated using the selected late-type galaxies, in particular in the stellar mass range covered by our ETG sample.

3.2. Dust-removal Timescale

Figure 1 presents dust-to-stellar mass ratio as a function of luminosity-weighted stellar age (middle panel). There is an evident decline in the mass ratio as galaxies evolve over time. Fitting an exponential function to this plane, as in Michalowski et al. (2019), allows us to evaluate the timescale of the dust mass removal for different galaxy properties:

$$\frac{M_{dust}}{M_*} = A \times e^{-\text{age}/\tau},$$

where $A$ is the normalization constant and $\tau$ is the dust-removal timescale. We obtained a dust-removal timescale for all elliptical galaxies of $\tau = 2.26 \pm 0.18$ Gyr with the
corresponding half-life time of $1.57 \pm 0.12$ Gyr. The values of the dust-removal timescale, the half-life time, and the normalization constant are presented in Table 1. To our knowledge, this is the first determination of the dust-removal timescale for such a large sample and for different galaxy properties.

We also fit the exponential function separately to galaxies on and below the MS. The elliptical galaxies below the MS (red line) follow the fit obtained by Michalowski et al. (2019, lime green line), whereas the elliptical galaxies on the MS (blue line) are characterized by a faster decline in dust mass. The results of our fitting are given in Table 1.
One of the basic parameters that is useful for subdivision into smaller bins is stellar mass, because galaxies of different masses may evolve differently. The three top panels in Figure 2 show the dust-to-stellar mass ratio as a function of age for three stellar mass bins in the range \( m_{\text{stellar}} \sim 10 \log M_{\odot} \) and with a 0.5 dex width. The fits for these stellar mass bins are consistent with each other within the error bars (Table 1). Therefore, we conclude that the decline in dust mass with time does not depend on stellar mass in the analyzed range.

The most massive group with \( m_{\text{stellar}} \geq 11.5 \log M_{\odot} \) contains no MS galaxies, and includes only galaxies with great ages and low dust-to-stellar mass ratios. It is not possible to fit an exponential function to these galaxies because the dynamical range of both properties is too small. However, these galaxies are still consistent with the fitted dust-removal function obtained for galaxies at lower masses.

Other galaxies in the close proximity of elliptical galaxies can affect their ISM. Therefore, we studied the role of the galaxy environment. The GAMA catalog provides galaxy surface density, \( \Sigma \), in the G15 field for galaxies at \( z < 0.18 \) (Brough et al. 2013). There are 384 of our dusty ETGs satisfying these criteria, and for 373 of them (97%) \( \Sigma \) has been measured. The dust decline as a function of age in bins of \( \Sigma \) is presented in Figure 2 (middle row). It is evident that the decline in dust mass is independent of the galaxy environment. We reached the same conclusion when we analyzed the effect of environment in narrower ranges of stellar mass.

Our sample spans the redshift range 0.01–0.32, corresponding to 3.6 Gyr of the evolution of the universe. Figure 2 (bottom) shows that the dust removal does not depend on redshift, as galaxies follow the same trend in dust removal at each redshift bin.

3.3. Dust Masses versus Star Formation Rates

Figure 1 (bottom) presents the SFR–\( M_{\text{dust}} \) relation for our 2050 dusty elliptical galaxies. It is evident that our MS elliptical galaxies follow the da Cunha et al. (2010) relation (black line). Hence for MS elliptical galaxies the decrease in SFR is accompanied by a similar decrease in the dust mass, so they stay on the relation. However, as first shown by Hjorth et al. (2014), elliptical galaxies below the MS are found above the da Cunha et al. (2010) relation with higher dust masses than what their SFRs imply.

3.4. Central Surface Luminosity

From the GAMA catalog of light profiles we used the values of the central surface brightness and converted them to central surface luminosities (luminosity per kpc\(^2\)). We find that the decrease in dust mass with the age of the elliptical galaxies does not depend on the central surface luminosity.

3.5. Quenching

To study the evolution of dusty elliptical galaxies, we divided our sample into eight bins of stellar age. Figure 3 (top)
presents SFR versus stellar mass with the addition of the median values in age bins, separately for the MS and below-MS elliptical galaxies. These medians are presented in Table 2 in the Appendix. The medians of SFRs and stellar masses of MS elliptical galaxies are as expected close to the MS. For elliptical galaxies below the MS, with increasing age the medians move away from the MS toward lower SFRs. The youngest below-MS elliptical galaxies are \( \sim 0.6 \text{ dex} \) below the MS and the oldest have SFRs more than 10 times lower than the youngest.

Figure 3 (bottom) presents dust mass versus SFR with the medians in age bins for the MS and below-MS elliptical galaxies (Table 2). The medians for MS ellipticals are located close to each other and to the da Cunha et al. (2010) relation (black line), with no clear evolution. Elliptical galaxies below the MS have higher dust masses for their SFRs than what the da Cunha et al. (2010) relation implies. We fitted a power-law function to the medians of the galaxies below the MS in the form \( \log(M_{\text{dust}}) = (0.55^{+0.10}_{-0.11}) \times \log(\text{SFR}) + (7.89^{+0.03}_{-0.01}) \).

Leśniewska et al.

Figure 3. SFR as a function of stellar mass (top) and dust mass as a function of SFR (bottom). Color coding distinguishes MS galaxies (blue stars) and galaxies below the MS (red circles). The star-forming main sequence at \( z = 0.18 \) based on Speagle et al. (2014) and the da Cunha et al. (2010) relation are shown (black lines). The median values of SFR, stellar age, and dust mass for eight galaxy age ranges are marked as filled crosses for the MS galaxies, and as filled circles for galaxies below the MS. In addition to the color coding, the size of the symbol increases with age. The red line shows a power-law fit to the median values of the galaxies below the MS in the form \( \log(M_{\text{dust}}) = (0.55^{+0.10}_{-0.11}) \times \log(\text{SFR}) + (7.89^{+0.03}_{-0.01}) \).

3.6. Sample Evaluation

To ensure that our selection is robust, we studied a subsample of galaxies with at least two detections among five Herschel bands (S/N \( > 3 \)). This resulted in 1430 galaxies. The exponential curve fitting gives the same results as the original sample within the error limits of these parameters. This shows that increasing the number of required band detections does not change our results and conclusions.

In order to check the correctness of the stellar ages calculated by the GAMA project, we analyzed the average spectral energy distribution (SED) for eight stellar age bins defined in the previous section. There is a clear correlation between the bin age and the relative normalized (in the near-infrared) flux. The oldest bin shows lower flux at the blue part of the SED, while the youngest bin shows the most prominent blue part of the SED that corresponds to the young stellar population of massive and hot OB stars. Normalization in the near-infrared (equivalent to a stellar mass normalization, as considered around \( 10^{7.9} M_\odot \) (0.8 dex above the relation). With increasing age, their SFRs decrease faster than their dust masses. This results in the oldest galaxies having SFR around \( 0.1 M_\odot \text{ yr}^{-1} \) (a factor of 10 decrease) and dust mass of \( 10^{7.3} M_\odot \) (a factor of 4 decrease), placing them 1.3 dex above the relation.
above), gives a clear decrease in luminosity in the far-infrared with increasing age, equivalent to the decrease in dust-to-stellar mass ratio.

The GAMA project database also contains information about the D4000 break (Cardiel et al. 1998; Balogh et al. 1999). The strength of this break as a function of luminosity-weighted age for the below-MS galaxies from our sample shows that older galaxies have higher D4000, consistent with their determined age. The Spearman’s rank correlation is 0.47 and the probability of the null hypothesis of no correlation is $10^{-70}$.

4. Discussion

Our key result is the confirmation of the exponential decrease in the dust mass with age using an unprecedentedly large sample. We also found that SFRs of dusty ellipticals below the MS decline faster with age than their dust masses, and the decline in dust mass is independent of stellar mass, environment, redshift, and central surface luminosity. As suggested by Hjorth et al. (2014) and Michalowski et al. (2019, 2023), morphological quenching is a potential mechanism for departing from the da Cunha et al. (2010) relation. This is consistent with our findings. The process may be responsible for the gravitational stability that stops the collapse of gas clouds, resulting in a slower rate of star formation. At the same time, the process does not change the amount of gas, which means that the dust mass observed in these galaxies does not decrease proportionally with the SFR. Other processes must be responsible for the decline in the dust masses, e.g., the destruction of dust by feedback from older stellar populations (see Michalowski et al. 2023). This includes Type Ia SNe (Li et al. 2020) or planetary nebulae (Conroy et al. 2015).

AGN feedback is also a potential mechanism for ISM removal (Fabian 2012). Recent studies suggest that quenching is connected with integrated AGN feedback over the lifetime of a galaxy, which is correlated with the mass of its supermassive black hole, not the instantaneous AGN luminosity (Bluck et al. 2020a, 2020b, 2022, 2023; Piotrowska et al. 2022). This mass is correlated with the bulge mass (Magerorion et al. 1998; Häring & Rix 2004), which can be approximated by the galaxy central surface luminosity. We did not detect any dependence of the decline in dust on this parameter (Section 3.4), which suggests that integrated AGN feedback is not a dominant mechanism of dust removal. This is because if the integrated feedback were responsible for the dust removal in our galaxies then galaxies with higher central surface luminosities (more massive black holes and therefore stronger feedback) would exhibit a faster decline in the ISM. This finding is consistent with our study of the Baldwin–Phillips–Terlevich (Baldwin et al. 1981) diagram, which shows that only up to 15% of galaxies in our sample host AGNs, which means that they cannot have any significant effect on reducing the amount of dust in these galaxies (O. Ryzhov et al. 2023, in preparation).

We did not find any redshift dependence or environmental influence on dust removal, which is inconsistent with external mechanisms of dust removal. The dust removal also does not depend on the stellar mass (in the explored range of $\log(M_{\text{stellar}}/M_\odot) = 10–11.5$), so the process scales linearly with mass (a bigger galaxy has proportionally more dust and proportionally more efficient dust removal).

We note that the lack of below-MS elliptical galaxies at or even below the SFR–$M_{\text{dust}}$ relation is not due to a detection limit at $M_{\text{dust}}$. The limit is $10^{5.2} M_\odot$ at $z = 0.05$ and $10^{6.7} M_\odot$ at $z = 0.3$ (Michalowski et al. 2019), so if such galaxies existed, they would be detected.

5. Conclusions

We analyzed ISM and stellar properties of 2050 dusty elliptical galaxies, which has never been done before on such a large sample. Our findings support the morphological quenching as a mechanism behind their decline in SFR, as proposed by Hjorth et al. (2014). This is because the galaxies below the MS do not follow the da Cunha et al. (2010) SFR–$M_{\text{dust}}$ relation, having higher dust masses for a given SFR. We also found that they evolve away from this relation as they age, with SFRs decreasing faster than dust masses.

We obtained a dust-removal timescale for dusty elliptical galaxies of $2.26 \pm 0.18$ Gyr, which is consistent with the value of $2.5 \pm 0.4$ Gyr found by Michalowski et al. (2019). The decline in dust mass does not depend on stellar mass, implying a linear scaling of this effect with galaxy mass. Moreover there is no dependence of the decrease in dust mass on the galaxy environment or redshift, so the decline in dust mass is of an internal nature. The independence of this decline from the central surface luminosity (a proxy for integrated black hole activity) suggests that AGN feedback is not responsible for the decline in ISM.

Acknowledgments

A.L., M.J.M., J.N., and M.S. acknowledge the support of the National Science Centre, Poland through the SONATA BIS grant No. 2018/30/E/ST9/00208. This research was funded in whole or in part by National Science Centre, Poland (grant number: 2021/41/N/ST9/02662). For the purpose of Open Access, the author has applied a CC-BY public copyright licence to any Author Accepted Manuscript (AAM) version arising from this submission. A.L. and C.G. acknowledge the support of the Leon Rosenfeld Foundation. A.L. acknowledges the support of Adam Mickiewicz University in Poznań, Poland via program Uniwersytet Jutra II (PWr.03.05.00-00-Z303/18). O.R. acknowledges the support of the National Science Centre, Poland through the grant 2022/01/4/ST9/00037. This work is supported by a VILLUM FONDEN Investigator grant (project number 16599) and a Young Investigator Grant (project number 25501). GAMA is a joint European-Australasian project based around a spectroscopic campaign using the Anglo-Australian Telescope. The GAMA input catalog is based on data taken from the Sloan Digital Sky Survey and the UKIRT Infrared Deep Sky Survey. Complementary imaging of the GAMA regions is being obtained by a number of independent survey programmes including GALEX MIS, VST KiDS, VISTA VIKING, WISE, Herschel-ATLAS, GMRT, and ASKAP, providing UV to radio coverage. GAMA is funded by the STFC (UK), the ARC (Australia), the AAO, and the participating institutions. The GAMA website is http://www.gama-survey.org/.

Appendix

Numerical Values from Figures

Below, we present the median values in eight age bins, separately for the MS and below-MS elliptical galaxies.
Table 1
Dust-removal Timescale $\tau$, Half-life Times, and Normalizations from Fitting Exponential Functions to the Middle Panel of Figure 1 and All Panels from Figure 2

<table>
<thead>
<tr>
<th></th>
<th>$\tau$ (Gyr)</th>
<th>$\tau_{1/2}$ (Gyr)</th>
<th>$A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS galaxies</td>
<td>1.53 ± 0.22</td>
<td>1.06 ± 0.15</td>
<td>−2.16 ± 0.04</td>
</tr>
<tr>
<td>Below MS</td>
<td>2.36 ± 0.22</td>
<td>1.64 ± 0.15</td>
<td>−2.33 ± 0.03</td>
</tr>
<tr>
<td>All galaxies</td>
<td>2.26 ± 0.18</td>
<td>1.57 ± 0.12</td>
<td>−2.31 ± 0.02</td>
</tr>
<tr>
<td>log($M_{\text{stellar}}/M_\odot$)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0−10.5</td>
<td>2.71 ± 0.72</td>
<td>1.88 ± 0.50</td>
<td>−2.34 ± 0.05</td>
</tr>
<tr>
<td>10.5−11.0</td>
<td>3.03 ± 0.40</td>
<td>2.10 ± 0.27</td>
<td>−2.51 ± 0.03</td>
</tr>
<tr>
<td>11.0−11.5</td>
<td>2.98 ± 0.59</td>
<td>2.07 ± 0.41</td>
<td>−2.56 ± 0.05</td>
</tr>
<tr>
<td>$\Sigma$/$\text{Mpc}^{-2}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;0.3</td>
<td>2.40 ± 0.81</td>
<td>1.66 ± 0.56</td>
<td>−2.45 ± 0.08</td>
</tr>
<tr>
<td>0.3−0.8</td>
<td>2.36 ± 0.87</td>
<td>1.63 ± 0.60</td>
<td>−2.48 ± 0.10</td>
</tr>
<tr>
<td>&gt;0.8</td>
<td>1.97 ± 0.57</td>
<td>1.36 ± 0.40</td>
<td>−2.33 ± 0.11</td>
</tr>
</tbody>
</table>

Note. Median and standard deviation calculated based on logarithmic values of SFR, $M_{\text{stellar}}$, and $M_{\text{dust}}$ parameters in each bin.

Table 2
Medians of SFRs, Stellar Masses, Dust Masses (Standard Deviation in Brackets) Plotted in Figure 3, and Number of Galaxies for Each Age Bin

<table>
<thead>
<tr>
<th>log(age) (yr)</th>
<th>log(SFR) ($M_{\odot}$ yr$^{-1}$)</th>
<th>log($M_{\text{stellar}}$) ($M_{\odot}$)</th>
<th>log($M_{\text{dust}}$) ($M_{\odot}$)</th>
<th>Number of Galaxies</th>
<th>log(SFR) ($M_{\odot}$ yr$^{-1}$)</th>
<th>log($M_{\text{stellar}}$) ($M_{\odot}$)</th>
<th>log($M_{\text{dust}}$) ($M_{\odot}$)</th>
<th>Number of Galaxies</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;9.0</td>
<td>0.50 (0.68)</td>
<td>10.15 (0.61)</td>
<td>7.76 (0.54)</td>
<td>133</td>
<td>−0.64 (0.91)</td>
<td>9.95 (1.02)</td>
<td>7.63 (0.84)</td>
<td>15</td>
</tr>
<tr>
<td>9.0−9.2</td>
<td>0.72 (0.44)</td>
<td>10.48 (0.45)</td>
<td>7.78 (0.50)</td>
<td>151</td>
<td>−0.04 (0.43)</td>
<td>10.57 (0.51)</td>
<td>7.88 (0.56)</td>
<td>37</td>
</tr>
<tr>
<td>9.2−9.4</td>
<td>0.69 (0.39)</td>
<td>10.65 (0.39)</td>
<td>7.87 (0.46)</td>
<td>150</td>
<td>−0.04 (0.48)</td>
<td>10.71 (0.46)</td>
<td>7.87 (0.48)</td>
<td>171</td>
</tr>
<tr>
<td>9.4−9.5</td>
<td>0.53 (0.30)</td>
<td>10.72 (0.35)</td>
<td>7.77 (0.43)</td>
<td>119</td>
<td>0.04 (0.47)</td>
<td>10.78 (0.34)</td>
<td>7.93 (0.50)</td>
<td>207</td>
</tr>
<tr>
<td>9.5−9.6</td>
<td>0.47 (0.22)</td>
<td>10.81 (0.20)</td>
<td>7.67 (0.37)</td>
<td>117</td>
<td>−0.07 (0.48)</td>
<td>10.84 (0.33)</td>
<td>7.81 (0.47)</td>
<td>301</td>
</tr>
<tr>
<td>9.6−9.7</td>
<td>0.63 (0.47)</td>
<td>10.92 (0.31)</td>
<td>7.57 (0.37)</td>
<td>17</td>
<td>−0.27 (0.48)</td>
<td>10.93 (0.29)</td>
<td>7.77 (0.45)</td>
<td>328</td>
</tr>
<tr>
<td>9.7−9.8</td>
<td>0.52 (0.21)</td>
<td>10.66 (0.11)</td>
<td>7.94 (0.58)</td>
<td>3</td>
<td>−0.58 (0.54)</td>
<td>10.98 (0.31)</td>
<td>7.56 (0.52)</td>
<td>198</td>
</tr>
<tr>
<td>9.8−10.0</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>−0.97 (0.49)</td>
<td>10.96 (0.28)</td>
<td>7.32 (0.57)</td>
<td>71</td>
</tr>
</tbody>
</table>

References

\[ \text{ORCID iDs} \]
Aleksandra Leśniewska @ https://orcid.org/0000-0001-8723-3533
M. J. Michałowski @ https://orcid.org/0000-0001-9033-4140
C. Gall @ https://orcid.org/0000-0002-8526-3963
J. Hjorth @ https://orcid.org/0000-0002-4571-2306
J. Nadolny @ https://orcid.org/0000-0003-1440-9061
O. Ryzhov @ https://orcid.org/0000-0004-4932-2956
M. Solar @ https://orcid.org/0000-0002-3148-1359
Michałowski, M. J., Gall, C., Hjorth, J., et al. 2023, submitted
Sérsic, J. L. 1963, BAAA, 6, 41