Inferring a difference in the star-forming properties of lower versus higher X-ray luminosity AGNs

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ABSTRACT
We explore the distribution of $R_{\text{MS}} \equiv \text{SFR}/\text{SFR}_{\text{MS}}$ (where SFR$_{\text{MS}}$ is the star formation rate of ‘main-sequence’ star-forming galaxies) for AGN hosts at $z = 1$. We split our sample into two bins of X-ray luminosity divided at $L_X = 2 \times 10^{43}$ erg s$^{-1}$ to investigate whether the $R_{\text{MS}}$ distribution changes as a function of AGN power. Our main results suggest that, when the $R_{\text{MS}}$ distribution of AGN hosts is modelled as a log-normal distribution (i.e. the same shape as that of MS galaxies), galaxies hosting more powerful X-ray AGNs (i.e. $L_X > 2 \times 10^{43}$ erg s$^{-1}$) display a narrower $R_{\text{MS}}$ distribution that is shifted to higher values compared to their lower $L_X$ counterparts. In addition, we find that more powerful X-ray AGNs have SFRs that are more consistent with that of MS galaxies compared to lower $L_X$ AGNs. Despite this, the mean SFRs (as opposed to $R_{\text{MS}}$) measured from these distributions are consistent with the previously observed flat relationship between SFR and $L_X$. Our results suggest that the typical star-forming properties of AGN hosts change with $L_X$, and that more powerful AGNs typically reside in more MS-like star-forming galaxies compared to lower $L_X$ AGNs.

Key words: galaxies: active – galaxies: evolution – galaxies: statistics – X-rays: galaxies.

1 INTRODUCTION
It is now recognised that the activity caused by the growth of supermassive black holes (SMBHs) at the centre of galaxies [observed as active galactic nuclei (AGNs)] has played a major role in shaping today’s galaxies (e.g. Gebhardt et al. 2000; King 2003). However, although there are multiple lines of empirical evidence showing that SMBH growth is on average related to the growth of their host galaxy via star formation (see Harrison 2017, for a review), there is no clear consensus on the physical mechanisms (should it be, e.g. feedback or common fuel-triggering mechanism) that generate these trends between average SMBH and galaxy growth.

To better understand the impact of SMBH growth in galaxy evolution, one can measure the star formation rate (SFR) of a large sample of AGN hosts at multiple epochs. Using HERSCHEL, which provides an unprecedented view of the galaxy star formation at far-infrared (FIR) wavelengths, recent studies have found that (1) there is no relationship between mean SFR and X-ray luminosity ($L_X$, a proxy for AGN power, e.g. Stanley et al. 2015; Lanzuisi et al. 2017; Stanley et al. 2017) and (2) that the mean AGN host SFR is broadly consistent with that of normal star-forming galaxies (e.g. Mullaney et al. 2012; Stanley et al. 2015) for which the SFR is correlated to the stellar mass via the main sequence (MS; e.g. Schreiber et al. 2015, hereafter S15). However, although HERSCHEL provides the deepest view of SFRs at FIR wavelengths, a large fraction of AGN hosts (typically more than 50 per cent) are not individually detected, meaning most studies rely on methods such as stacking to obtain averages. As these averages can potentially be dominated by bright outliers, the empirical mean SFR of AGNs might not be representative of the ‘typical’ SFRs of the full AGN sample, increasing the complexity of investigating the AGN–galaxy connection (e.g. Mullaney et al. 2015; Scholtz et al. 2018).

Instead of relying on mean SFRs, Mullaney et al. (2015; hereafter M15) have measured the full distribution of SFRs relative to that of the MS ($R_{\text{MS}} \equiv \text{SFR}/\text{SFR}_{\text{MS}}$) for AGN hosts out to $z \sim 4$ using a combination of HERSCHEL and ALMA observations. They found that the mean average of the $R_{\text{MS}}$ distribution is consistent with that of the MS, yet the mode (i.e. the most common value) lies below that of the MS. This is a consequence of the mean being enhanced by bright outliers, leading to a biased picture. Furthermore, they report an $R_{\text{MS}}$ distribution for AGN hosts twice as broad as that of MS star-forming galaxies, demonstrating that the star-
forming properties of AGN hosts are more diverse than that of MS galaxies. However, interestingly, they do not find any evidence of a significant evolution of the \( R_{\text{MS}} \) distribution with redshift. More recently, Scholtz et al. (2018) have measured the distribution of specific SFRs (SFRs relative to stellar masses; sSFRs) for massive (i.e. \( M_\star > 2\times 10^{10} M_\odot \)) galaxies hosting bright (i.e. \( L_X > 10^{43} \text{erg s}^{-1} \)) AGNs in a large range of redshifts (i.e. \( 1.5 < z < 3.2 \)), and find good agreement with that of simulated galaxies taken from the EAGLE simulation (see Scholtz et al., 2018, and references therein). They report no differences in the distribution of sSFR with \( L_X \) for AGNs with \( L_X > 10^{43} \text{erg s}^{-1} \). As demonstrated in Scholtz et al. (2018), while the sSFR distribution hints important information regarding the connection between AGN and their host galaxies, it lacks of context in terms of the MS of star-forming galaxies. Instead, the \( R_{\text{MS}} \) distribution and how it changes with \( L_X \) provide a better insight of the star-forming properties of AGN hosts within this context of the MS of star-forming galaxies.

In this work, we propose to expand upon M15 and measure whether the \( R_{\text{MS}} \) distribution changes with \( L_X \). As there is no apparent evidence of the \( R_{\text{MS}} \) distribution evolving with redshift (M15), we focus on AGNs at \( z = 1 \) (i.e. close to the peak of activity for both SMBH accretion and SFR; Aird et al. 2015). We describe our sample selection and sample properties in Section 2. We present our analysis in Section 3, the results of which are shown in Section 4. The implications of our results are discussed in Section 5, and we conclude in Section 6. Throughout, we adopt a WMAP–7 year cosmology (Larson et al. 2011) and a Chabrier (2003) initial mass function (IMF) when calculating stellar masses and SFRs.

2 SAMPLE SELECTION AND PROPERTIES

Our sample of X-ray sources is from the catalogue of Marchesi et al. (2016) that provides absorption-corrected 2–10 keV \( L_X \) for AGNs in the COSMOS field. We only retain sources that have \( 0.8 < z < 1.2 \) to probe AGNs around \( z = 1 \) and minimize the effect of the SFR evolution with redshift (S15). We find that 776 AGNs in Marchesi et al. (2016) satisfy this requirement (\( \sim 75 \% \) of which have spectroscopic redshifts), among which 664 are also covered by HERSCHEL observations. We further remove 123 X-ray sources out of the 664 that have upper limits on their intrinsic X-ray luminosities as they mostly affect the lower luminosity range (i.e. \( L_X \sim 10^{42–43} \text{erg s}^{-1} \)) and could be associated with star formation activity. We show in the top panel of Fig. 1 the distribution of \( L_X \) for our full sample of 541 AGNs. We match these X-ray AGNs to the catalogue of Jin et al. (2018) that contains ‘superdeblended’ IR photometry (i.e. at 24, 100, 160, 250, 350, and 500 \( \mu \)m) for the COSMOS field measured using a method outlined in Liu et al. (2018). Of these, we find that 100 (i.e. \( \sim 18 \% \)) show no detection in any of these IR wavelengths. For each of these, we derive 3\( \sigma \) upper limits\(^2\) at 100 and 160 \( \mu \)m using the COSMOS maps provided by the PACS Evolutionary Probe team (Lutz et al. 2011). Our final sample of X-ray selected AGNs contains 541 sources with IR detections in at least one of the following bands: 24 \( \mu \)m (81 per cent), 100 \( \mu \)m (21 per cent), 160 \( \mu \)m (15 per cent), 250 \( \mu \)m (35 per cent), 350 \( \mu \)m (22 per cent), and 500 \( \mu \)m (7 per cent), or upper limits at 100 and 160 \( \mu \)m.

To measure SFRs, we use a similar approach than that of Bernstein et al. (2016) which employs multicomponent IR spectral energy distribution (SED) fitting using DECOMPIR\(^3\) (Mullaney et al. 2011). Briefly, DECOMPIR performs chi-square minimization to select the best combination of one out of five templates for the host galaxy emission\(^4\) and an empirically derived AGN template (see Bernstein et al. 2016 and references therein for details on the fitting approach). The IR luminosities arising from star formation are then derived from the fits (after removing the AGN contamination), and converted to SFRs using equation (4) in Kennicutt (1998) adapted for a Chabrier (2003) IMF. This fitting approach is applied to the 30 per cent of our sources that have IR SEDs with at least three photometric points. For the remaining 70 per cent of the sources, we derive SFR upper limits by only fitting the host galaxy templates (i.e. ignoring AGN contamination) using DECOMPIR when the AGN is only detected in two photometric bands, or by using the most common of DECOMPIR templates (i.e. ‘SB2’) found for our sample with multiple detections, and for which we choose the

\(^2\)The \( 1\sigma \) upper limits are estimated using the standard deviation of a flux distribution built by performing 100 times aperture photometry on randomly selected positions located within the full width at half maximum of the point spread function. The aperture corrections are publicly available at http://www.mpe.mpg.de/resources/PEP/DR1_jarballs/readme_PEP_global.pdf.

\(^3\)DECOMPIR is publicly available at https://sites.google.com/site/decompir.

\(^4\)See Mullaney et al. (2011) for a full description of the galaxy templates that are available in DECOMPIR.
highest normalization that does not overpredict any detected photometric points or upper limits at 100 and 160 μm. These are SFR upper limits since, should the IR be contaminated by AGN emission, it would decrease the contribution of the host to the IR luminosities, hence SFRs. As our aim is to measure the distribution of SFRs for AGNs relative to that of the MS, we also require host stellar masses. These are derived using CIGALE that performs a multicomponent ultraviolet-to-IR SED fits accounting for AGN contamination (Noll et al. 2009; Ciesla et al. 2015), and shown in the bottom panel of Fig. 1. Our stellar mass estimation is fully presented in Grimmett et al. (submitted). However, as the stellar masses in CIGALE can be affected by contamination from unobscured AGNs (Ciesla et al. 2015), we also performed our analysis using only obscured AGNs (representing roughly 60 per cent of our full sample). In doing so, we find consistent results compared to using the full sample, suggesting that our results are robust to any biases in our mass estimation. The SFR of the MS is derived using equation (9) of S15 adapted for a Chabrier (2003) IMF.

To explore how the distribution of the star-forming properties of AGN hosts changes with $L_X$, we split our sample of X-ray selected AGNs in two bins of $L_X$ separated at $L_X = 2 \times 10^{43}$ erg s$^{-1}$, which we refer to as the low and high $L_X$ samples. This cut was chosen to return similar numbers of AGNs between the low and high $L_X$ samples. Overall, our low $L_X$ sample contains 271 sources (50 per cent of the full sample), of which 206 (76 per cent of the low $L_X$ sample) have SFR upper limits and 189 (70 per cent of the low $L_X$ sample) have spectroscopic redshifts, while our high $L_X$ sample contains 270 sources (50 per cent of the full sample) of which 187 (69 per cent of the high $L_X$ sample) have SFR upper limits and 219 (81 per cent of the high $L_X$ sample) have spectroscopic redshifts.

3 MEASURING THE $R_{\text{MS}}$ DISTRIBUTION

We now have a sample of 541 X-ray selected AGNs at $z = 1$ separated into bins of low and high $L_X$ and for which we have constraints (in terms of detections or upper limits) of SFRs and stellar masses. However, the presence of a large number of SFR upper limits (~70 per cent) prevents us from directly deriving the distribution of SFRs. Instead, following M15, we assume that the distribution of SFRs relative to that of the MS ($\text{SFR}/\text{SFR}_{\text{MS}} \equiv R_{\text{MS}}$) follows a log-normal distribution as observed for star-forming galaxies (e.g. Sargent et al. 2012; S15), and for which the probability density function (PDF) is defined as

$$\text{PDF} = \frac{1}{\sqrt{2\pi} \sigma} \times \exp \left( -\frac{(\log_{10} (\text{SFR}) - \mu)^2}{2\sigma^2} \right),$$

where $\mu$ and $\sigma$ are the mean and the standard deviation of the logarithm of $R_{\text{MS}}$, respectively. As suggested by M15, this assumption is to ease comparison between the $R_{\text{MS}}$ distribution of AGN hosts and MS star-forming galaxies. We perform maximum likelihood estimation (MLE) to find the parameters $\mu$ and $\sigma$ that best fit the observed $R_{\text{MS}}$ distributions for both the low and high $L_X$ samples (see Fig. 3 top panel). We use an MLE framework as it allows us to incorporate SFR upper limits (see Grimmett et al. submitted). Due to the complexity of our likelihood function, it cannot be maximized analytically. As a consequence, we maximize it by randomly sampling the posterior distributions of $\mu$ and $\sigma$ employing the affine invariant ensemble sampler of Goodman & Weare (2010) fully implemented to EMCEE (Foreman-Mackey et al. 2013). The benefit of this is that we obtain best-fitting values with meaningful uncertainties that fully account for the presence of a large number of upper limits. We use flat (bounded) prior distributions and check the posterior distributions to verify that they are not constrained in any way by the choice of our prior distributions. The median value of the posterior distribution is taken as the best-fitting parameter, and the standard deviation as its 1σ uncertainty.

4 RESULTS

4.1 The distributions of $R_{\text{MS}} = \text{SFR}/\text{SFR}_{\text{MS}}$

In this work, we explore how the distribution of AGN host SFRs relative to that of the MS for galaxies of $z = 1$ changes with $L_X$. To do this, we define $R_{\text{MS}} \equiv \text{SFR}/\text{SFR}_{\text{MS}}$ as the relative distance from the MS and derive its distribution assuming a log-normal shape with parameters $\mu$ and $\sigma$ (i.e. similar to that of MS galaxies) split between low- and high-$L_X$ AGNs (separated at $L_X = 2 \times 10^{43}$ erg s$^{-1}$). Within this assumption, we find that the parameters $\mu$ and $\sigma$ for the low and high $L_X$ samples show differences (see Table 1) and that their likelihood distributions peak at different locations in the $\mu-\sigma$ parameter space (see Fig. 2). In particular, our results suggest that the $R_{\text{MS}}$ distribution of higher $L_X$ AGNs is narrower (i.e. smaller $\sigma$ by a factor of 1.4) than that of lower $L_X$ AGNs (see Fig. 2), indicating less diversity in the star-forming properties of higher $L_X$ AGN hosts. We also find that the $R_{\text{MS}}$ distribution of higher $L_X$ AGN hosts peaks at a higher value of $R_{\text{MS}}$ (i.e. higher $\mu$ by a factor of 3) than that of lower $L_X$ AGNs (see Fig. 2). These can also be seen in the bottom panel of Fig. 3 where we show the $R_{\text{MS}}$ distributions for low- and high-$L_X$ AGN hosts.

In the context of the MS for star-forming galaxies of $z = 1$, we find that, while assuming that the $R_{\text{MS}}$ distribution of AGN hosts follows a log-normal distribution, the parameters $\mu$ and $\sigma$ of higher $L_X$ AGNs are more consistent with those reported for the MS when compared to lower $L_X$ AGNs at $z \sim 1$ (see Fig. 2). This suggests

5CIGALE is publicly available at https://cigale.lam.fr.

6EMCEE is publicly available at http://dfm.io/emcee/current/.
The observed $R_{\text{MS}}$ distributions split between low- and high-$L_X$ AGNs (see keys). The arrows indicate the presence of upper limits. Bottom: The optimized PDFs of $R_{\text{MS}}$ split between low (red dotted line) and high (blue dashed line) $L_X$ AGNs. The uncertainties on the PDFs are shown with 500 black thin lines generated by randomly varying $\mu$ and $\sigma$ around their $1\sigma$ uncertainties. We also show the $R_{\text{MS}}$ distribution of the MS for star-forming galaxies as reported in S15. We find that the $R_{\text{MS}}$ distribution of higher $L_X$ AGNs is narrower and closer to that of the MS of galaxies than that of the lower $L_X$ AGNs.

Table 1. The results of the MLE performed to find $\mu$ and $\sigma$ that best fit the observed $R_{\text{MS}}$ distributions for our low and high $L_X$ sample of AGNs. Associated errors on each parameter are the $1\sigma$ uncertainties measured from the posterior distributions (see Section 3). We also show results for the AGN sample at $z < 1.5$ of Mullaney et al. (2015) and for the MS of star-forming galaxies of Schreiber et al. (2015).

| Sample                  | $\mu$          | $\sigma$       |
|-------------------------|-----------------|----------------|
|                         | mean of ln($R_{\text{MS}}$) | std. dev. of ln($R_{\text{MS}}$) |
| This work               | $-0.30^{+0.06}_{-0.04}$ | $0.55^{+0.05}_{-0.03}$ |
| Low-$L_X$ AGNs          | $-0.10^{+0.04}_{-0.02}$ | $0.40^{+0.03}_{-0.01}$ |
| High-$L_X$ AGNs         | $-0.38^{+0.07}_{-0.08}$ | $0.6^{+0.1}_{-0.1}$ |
| All AGNs ($z < 1.5$)    | $-0.38^{+0.07}_{-0.08}$ | $0.6^{+0.1}_{-0.1}$ |
| (Mullaney et al. 2015)  | $-0.06^{+0.02}_{-0.01}$ | $0.31^{+0.02}_{-0.01}$ |
| (Schreiber et al. 2015) |                 |                |

that the $R_{\text{MS}}$ distribution for higher $L_X$ AGNs is in better agreement with that of MS star-forming galaxies when compared to lower $L_X$ AGNs (see Fig. 3 bottom panel), and that therefore higher $L_X$ AGNs at $z \sim 1$ are more likely to reside in MS star-forming galaxies than lower $L_X$ AGNs. However, interestingly, this does not prevent a large fraction of galaxies hosting lower $L_X$ AGNs from experiencing star formation at a level consistent with MS galaxies (e.g. with $R_{\text{MS}} > 0.4$; see Fig. 3 bottom panel). This is a consequence of the broader $R_{\text{MS}}$ distribution for lower $L_X$ AGNs. Finally, we also find that our results are broadly consistent with those of M15, who performed a similar analysis but for AGNs with $z < 1.5$, complemented with ALMA data, and not split between low- and high-$L_X$ AGNs (see Fig. 2).

4.2 The relationship between SFR and $L_X$

We have explored the star-forming properties of AGNs at $z \sim 1$ by measuring the $R_{\text{MS}}$ distribution for low- and high-$L_X$ AGN hosts, assuming that it has the shape of that of MS galaxies (see Section 3). Our results indicate that galaxies hosting higher $L_X$ AGNs have typical SFRs consistent with MS star-forming galaxies, in contrast to galaxies hosting lower $L_X$ AGNs.

That the distribution of $R_{\text{MS}}$ differs between lower and higher $L_X$ AGNs apparently contradicts recent findings of a flat relationship between SFR and $L_X$ (e.g. Stanley et al. 2015; Lanzuisi et al. 2017). We investigate this apparent contradiction by measuring both the mean of $R_{\text{MS}}^{\text{mean}}$ and the mode of $R_{\text{MS}}^{\text{mode}}$ of the $R_{\text{MS}}$ distributions for low- and high-$L_X$ AGNs using our best fit of $\mu$ and $\sigma$ (see Table 1). Knowing $R_{\text{MS}}$ for each host, we are able to derive the mean and the mode SFR for low- and high-$L_X$ AGNs. We show in Fig. 4 that our average SFRs are in agreement with recent studies that find a flat relationship between SFR and $L_X$ (e.g. Stanley et al. 2015; Lanzuisi et al. 2017). However, as expected, our mode SFRs systematically lie below our mean SFRs, since the means are affected by bright outliers. The reason why our mean SFRs are in better agreement with the flat relationship reported by, e.g. Stanley et al. (2015), is that they use stacking analysis to account for undetected sources which is, in essence, on-image mean-averaging. We further find that the difference between our mode and mean SFRs changes with $L_X$. This is a consequence of the broader $R_{\text{MS}}$ distribution of galaxies hosting lower $L_X$ AGNs. We stress that the differences between the mean and the mode SFR of our $L_X$ bins are consistent within the $1\sigma$ error bars derived from propagating the uncertainties found in the parameters $\mu$ and $\sigma$ that define our $R_{\text{MS}}$ distribution (see Table 1).

\footnote{The mean is defined as $R_{\text{MS}}^{\text{mean}} = \exp (\mu + \sigma^2/2)$.}

\footnote{The mode is defined as $R_{\text{MS}}^{\text{mode}} = \exp (\mu - \sigma^2)$.}
5 DISCUSSION

In this work, we investigate the $R_{\text{MS}} \equiv \text{SFR/SFR}_{\text{MS}}$ distribution at $z = 1$ of AGNs split in two bins of $L_X$ separated at $L_X = 2 \times 10^{43}$ erg s$^{-1}$, and assuming that it follows a log-normal distribution, as found for that of MS star-forming galaxies (e.g. S15). Our results hint that the $R_{\text{MS}}$ distributions for low- and high-$L_X$ AGNs are different. In particular, we suggest that the $R_{\text{MS}}$ distribution of higher $L_X$ AGN hosts is narrower than that of lower $L_X$ AGNs, which is equivalent to there being less diversity in the host star-forming properties of higher $L_X$ AGNs (see Section 4.1). We propose that the diversity of SFRs in lower $L_X$ AGNs is a consequence of the relative ease for a galaxy to trigger a lower luminosity AGN, as suggested by the large relative number of low-$L_X$ AGNs as opposed to high-$L_X$ AGNs in the X-ray luminosity functions (e.g. Aird, Coil & Georgakakis 2017). In addition, within our assumptions, the $R_{\text{MS}}$ distribution of higher $L_X$ AGNs is in better agreement with that of MS galaxies. This could indicate the necessity of a significant amount of gas (i.e. enough to sustain MS host SFRs) to trigger luminous X-ray AGNs.

Our sample contains a large number of SFR upper limits. Yet, our MLE approach fully accounts for this effect by providing sensible uncertainties, and shows that, with the current level of SFR detections at $z \sim 1$ using FIR wavelength, it is likely that lower and higher $L_X$ AGNs have different $R_{\text{MS}}$ distributions (i.e. see Fig. 2). If confirmed, the larger agreement between the $R_{\text{MS}}$ distribution for higher $L_X$ AGNs with that of the MS of star-forming galaxies suggests a stronger link between SMBH and galaxy growth for powerful AGNs. That is, the concurrence of a higher $L_X$ AGN – indicating ongoing SMBH growth – with a less diverse, more MS-like star-forming host galaxy – suggesting host galaxy growth. The similar galaxy mass distributions between our low and high $L_X$ samples (see the bottom panel of Fig. 1) allow us to make such a direct link between average $L_X$ and average SMBH accretion rate by using the specific $L_X$ (i.e. $L_X/M_*$) as a proxy for Eddington ratio (see Bernhard et al. 2018, and references therein). In this context, our results are consistent with recent studies that find that the SMBH accretion rate changes with the host galaxy properties (e.g. Kauffmann & Heckman 2009; Georgakakis et al. 2014; Wang et al. 2017; Aird, Coil & Georgakakis 2018ba; Bernhard et al. 2018; Grimm et al. submitted). Furthermore, the finding of an $R_{\text{MS}}$ distribution for higher $L_X$ AGNs in better agreement with MS galaxies is also consistent with results showing that quasar-like AGN activity is often found in star-forming galaxies (e.g. Rosario et al. 2013; Kalfountzou et al. 2014; Stanek et al. 2017).

Finally, we note that our results hold (i.e. narrower distribution for higher $L_X$ AGNs) when only considering galaxies with stellar masses $M_*>10^{10} M_\odot$ as is often used to avoid incompleteness (e.g. Scholtz et al. 2018).

6 CONCLUSION

We measure the $R_{\text{MS}}$ distribution of $z = 1$ AGN hosts split between low- and high-$L_X$ AGNs separated at $L_X = 2 \times 10^{43}$ erg s$^{-1}$. We use a sample of 541 X-ray selected AGNs from the COSMOS field for which we derive SFRs or upper limits and measure stellar masses (see Section 2). We perform MLE to infer the $R_{\text{MS}}$ distribution of the two samples of AGN hosts incorporating upper limits and under the assumption that the $R_{\text{MS}}$ distribution is parametrized as a log-normal distribution, identical to that of the MS of star-forming galaxies (see Section 3). Our main results show that, with this assumption, the $R_{\text{MS}}$ distribution of higher $L_X$ AGNs is narrower (i.e. smaller $\sigma$ by a factor of 1.4) and peaks at a higher value of $R_{\text{MS}}$ (i.e. higher $\mu$ by a factor of 3) than that of lower $L_X$ AGNs (see Fig. 2). This suggests less diversity in the star-forming properties of higher $L_X$ AGNs when compared to their lower $L_X$ counterpart. We speculate that the larger diversity in the star-forming properties of lower $L_X$ AGNs may arise from the relative ease of an SMBH to trigger a low-$L_X$ AGN in comparison to triggering a higher $L_X$ AGN. Furthermore, higher $L_X$ AGNs have hosts with star-forming properties in better agreement with that of MS star-forming galaxies, indicating that higher $L_X$ AGNs are more likely to reside in MS star-forming galaxies. We also investigate the relationship between SFR and $L_X$ for our two distributions by measuring the change in the mean and the mode of SFR with $L_X$ (see Section 4.2). We find that our mean and mode SFRs are consistent with the flat relationship found between SFR and $L_X$, and that the mode SFRs lie below that of the mean, with a larger difference between the mean and the mode at lower $L_X$ (see Fig. 4). This is a consequence of the differences in the widths of the distributions at low and high $L_X$ with the mean SFR being affected at different levels by bright outliers in the low and high $L_X$ samples.

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