THE HOST GALAXY PROPERTIES OF VARIABILITY SELECTED AGN IN THE PAN-STARRS1 MEDIUM DEEP SURVEY

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ABSTRACT

We study the properties of 975 active galactic nuclei (AGNs) selected by variability in the Pan-STARRS1 Medium deep Survey. Using complementary multi-wavelength data from the ultraviolet to the far-infrared, we use spectral energy distribution fitting to determine the AGN and host properties at $z < 1$ and compare to a well-matched control sample. We confirm the trend previously observed: that the variability amplitude decreases with AGN luminosity, but we also observe that the slope of this relation steepens with wavelength, resulting in a “redder when brighter” trend at low luminosities. Our results show that AGNs are hosted by more massive hosts than control sample galaxies, while the rest frame dust-corrected NUV − $r$ color distribution of AGN hosts is similar to control galaxies. We find a positive correlation between the AGN luminosity and star formation rate (SFR), independent of redshift. AGN hosts populate the entire range of SFRs within and outside of the Main Sequence of star-forming galaxies. Comparing the distribution of AGN hosts and control galaxies, we show that AGN hosts are less likely to be hosted by quiescent galaxies and more likely to be hosted by Main Sequence or starburst galaxies.

Key words: galaxies: nuclei – galaxies: star formation

1. INTRODUCTION

One of the remaining classes of puzzling astronomical objects is active galactic nuclei (AGNs). AGN emission is powered by massive black holes, which are expected to be hosted by most massive galaxies (Magorrian et al. 1998) and virtually all galaxies. Besides the interest in high energy physics and strong gravity involved in the processes shaping their emission, AGNs are also crucial in the context of galaxy formation and evolution. The energy released by AGNs in the interstellar medium has long been invoked by simulation studies to explain the quenching of star formation activity in massive galaxies (e.g., Croton et al. 2006). Evidence for active feedback has also been brought by observations (e.g., Fabian 2012; Tombesi et al. 2015), but remains highly controversial. Indeed, while a number of studies found that AGN activity seems to shut down star formation (e.g., Schawinski et al. 2009; Farrah et al. 2012; Page et al. 2012), a similar number of studies show that it does not (e.g., Netzer 2009; Mullaney et al. 2012b; Rosario et al. 2013), and AGN luminosity is actually positively correlated with the star formation rate (SFR; Mullaney et al. 2012a). However, this relation has also been observed to be flat in redshift intervals at $z < 2.5$ (Stanley et al. 2015).

Over the last decade there has also been considerable work on understanding the triggering mechanisms of AGN activity. The most common scenario is that gas-rich galaxy mergers trigger AGN activity, which in turn quenches star formation (Hopkins et al. 2008). Observations do not fully support this scenario however: while luminous quasar hosts display signatures of current or past merger activity (Stockton 1982; Canalizo & Stockton 2001; Bennett et al. 2008), moderate luminosity AGNs reside preferentially in galaxies displaying undisturbed morphologies (Gabor et al. 2009; Cisternas et al. 2011; Kocevski et al. 2012).

Most of the aforementioned studies focused on AGNs selected from their X-ray emission or ultraviolet/optical emission lines. While successful, these studies are biased against heavily obscured AGNs (which can be detected in the far-infrared, FIR) and low luminosity AGNs, where the contribution of the host galaxy can be of the same order or larger than that of the AGN. With the advent of large time domain surveys, such as Pan-STARRS1 (Kaiser et al. 2010) and the upcoming LSST (Ivezic et al. 2008), a new window is opening for building large samples of AGNs using variability as a complementary selection (e.g., Sarajedini et al. 2006; Sesar et al. 2007; Schmidt et al. 2010; Villforth et al. 2012), albeit with its own set of selection biases including a bias against Type 2 AGNs. Indeed, AGNs display variability over the whole spectrum and over a wide range of timescales, which is thought to be related to accretion disk instabilities; long-term variability for the so-called changing-look quasars is explained by variable obscuration (e.g., Tohline & Osterbrock 1976; Cohen et al. 1986; Denney et al. 2014; Shappee et al. 2014) or a change in the ionizing flux of the central source (LaMassa et al. 2015), which has been observed only in a handful of objects.

Variability selection enables one to probe a large range of AGN luminosities, and is not biased against low luminosity objects because the amplitude of AGN variability actually increases for fainter AGNs (e.g., Hook et al. 1994; Trevese et al. 1994; Vanden Berk et al. 2004; Wilhite et al. 2008; Bauer et al. 2009; Zuo et al. 2012; Gallastegui-Aizpun & Sarajedini 2014). In this paper, we revisit the connection between AGNs and host galaxy properties using a sample of ~1000 AGNs selected by their optical variability in the Pan-STARRS1 Medium Deep Survey and complemented by ancillary data from the ultraviolet (UV) to the FIR. Thanks to this large wavelength coverage, we are able to separate the AGNs and the host contributions to the observed spectral energy distribution (SED), which allows us to investigate the link between host and AGN properties. While large samples of point-like quasars have previously been built through variability selection (e.g.,
MacLeod et al. 2012), only small sets (∼50) have been considered to investigate the AGN host properties connection (Villforth et al. 2012; Klesman & Sarajedini 2014).

This paper is organized as follows: in Section 2 we present our variability selected AGN sample and the ancillary data. Section 3 describes our fitting method to separate the AGN and host contribution to the observed SED. In Section 4 we present our results, which are further discussed in Section 5, before concluding in Section 6. Throughout we use a Λ-flat cosmology (ΩM = 0.3, ΩΛ = 0.7, H0 = 70 km s⁻¹ Mpc⁻¹) and a Chabrier (2003) initial mass function (IMF).

2. DATA

2.1. Variability Selected AGN

We use the sample of candidate AGNs selected by variability from Kumar et al. (2015). We only recall here the main characteristics of the method, and refer the reader to Kumar et al. (2015) for full details. Our sample is based on the classification of extragalactic variable sources detected during the first 2.5 years of PS1 observations. During their ∼5 month window of seasonal variability, each PS1 Medium Deep Field is observed nightly, cycling through four filters (Tonry et al. 2012)—gPS1 (λeff = 481 nm), rPS1 (λeff = 617 nm), iPS1 (λeff = 752 nm), and zPS1 (λeff = 866 nm)—with observations in the same filter every three nights, and observations in the gPS1 (λeff = 962) nm filter near the full moon, with an average number of total epochs per filter for this 2.5 year sample of 36. Nightly images are processed through a frame subtraction analysis pipeline; sources are tagged as a transient and published to an alerts database if they are detected with a signal-to-noise ratio (S/N) > 5 in at least three different images within a time window of 15 days. While this pipeline was designed to detect supernovae (SNe), variability in the nuclei of galaxies also is detected as positive and negative excursions in the difference images. We then match these transient alerts with a catalog created from the stacked PS1 images (described in Section 2.2), and only classify the light curves of transients within the Kron elliptical radius of an extended galaxy with i < 24 mag: the magnitude range for which the star/galaxy classification is reliable.

The light curves of variable sources in gPS1, rPS1, iPS1, and zPS1 image differencing are fitted with five models: a Gamma distribution, a Gaussian distribution, an analytic SN model (all three modeling SN-like light curves), an Omstein–Uhlenbeck process (modeling AGN-like light curves, Kelly et al. 2009), and a constant flux model (modeling noise). The quality of the fits is then used to classify the variable sources using a K-means clustering algorithm with three centers (SN, AGN, or noise model). Out of 4361 extragalactic transient alerts, the light curves of 2262 are classified as similar to those of AGNs and considered “nuclear.” We further restrict the sample to objects with iPS1 > 18 to avoid bright galaxies, where the difference imaging is more likely to introduce image differencing artifacts that can cause centroid errors and a false nuclear positive. This cut minimizes the contamination by non-AGNs to 16%, according to a verification set of objects with spectroscopic redshifts, while maximizing the number of AGNs in the sample. We are then left with 1768 objects.

2.2. Pan-STARRS1 Data

We perform our custom reduction of the Pan-STARRS1 Medium Deep data survey. We use the stacks generated by the Pan-STARRS1 image processing pipeline (Magnier 2006), as well as the CFHT u-band data obtained by E. Magnier as follow up of the Medium Deep fields, which covers 65% of the survey. We have at hand six bands: uCFHT, gPS1, rPS1, iPS1, zPS1, and yPS1. We perform photometry using the following steps and consider the Pan-STARRS1 skyell as the smallest entity: (i) resample the u-band images to the Pan-STARRS1 resolution (0.′′25 pixel⁻¹) and register all images; (ii) for each band fit the PSF to a Moffat function and match that PSF to the worst PSF in each skyell; (iii) using these PSF matched images, we derive a χ² image (Szalay et al. 1999); (iv) we perform photometry using the dual mode of SExtractor (Bertin & Arnouts 1996), detecting objects in the χ² image and measuring the fluxes in the PSF matched images: the Kron-like apertures are defined from the χ² image and hence are the same over all bands. The detection threshold, defined by the χ² distribution, is equivalent to a S/N of 1.9σ.

2.3. Other Data Sets

We cross match our AGN sample to a number of other data sets to constrain their SEDs. Table 1 shows statistics of the available photometry for the final sample.

2.3.1. GALEX

We first cross match our sample with the public GALEX (Martin et al. 2005) data using a 5″ radius by decreasing order of priority: data from the Deep Imaging Survey (DIS), the Medium Imaging Survey (MIS), and the All-sky Imaging Survey (AIS). For the DIS, we use the standard pipeline data, while for the MIS and the AIS we use the GCAT Unique Source Catalogs, which contain the standard pipeline photometry and optimized photometry for extended objects (<1″). 83% of sources have a GALEX cross match. Budavári et al. (2009) and Seibert et al. (2005) show that 5″ is the optimal search radius for GALEX-SDSS matches, and estimate an upper limit of 2% for the number of false matches.

We also make use of the University of Maryland Time Domain Survey data (Gezari et al. 2013, 2015). We remeasure the GALEX photometry for objects that are in images where the exposure time (in FUV or NUV) is greater than the archive images. We also derive an upper limit at 1σ for nondetected sources. This process adds photometry for 7% of our sources. Finally, we also attempt to measure the photometry for all objects without a cross match with GALEX archive data, or derive an upper limit if no detection is found.

2.3.2. Spitzer

We cross match our sample with the Spitzer Enhanced Imaging Products (SEIP) using a 2″ search radius; 95% of our sources have a match within 1″. According to the SWIRE release 2, we expect only a few percent of false positive matches in that range.

The SEIP contains high-quality photometry in IRAC (3.6, 4.5, 5.8, and 8. μm) and MIPS (24 μm) bands; 54% of objects in our sample have a cross match with SEIP sources.

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http://galex.stsci.edu/casjobs/
http://archive.stsci.edu/prepds/gcat/
http://irsa.ipac.caltech.edu/data/SPITZER/Enhanced/SEIPOverview.html
http://irsa.ipac.caltech.edu/data/SPITZER/SWIRE/docs/delivery_doc_r2_v2.pdf
2.3.3. WISE

We cross match our sample with the custom reduction of the WISE data from Lang et al. (2014, unWISE) using a cross match search radius of 1", Lang et al. (2014) performed prior photometry based on SDSS sources in their own version of the WISE coadds (Lang 2014). This version of the WISE catalog has the advantage of providing a WISE flux for all SDSS sources at the SDSS angular resolution. We find a cross match for 93% of objects; given that unWISE is based on SDSS prior positions, we expect a few percent of false positive matches.

2.3.4. Spectroscopic Redshifts

We cross match our sample with a number of spectroscopic catalogs using a search radius of 1". We expect only a few percent of false matches because these data sets are all based on optical data. We cross match with SDSS DR12 (Alam et al. 2015), which provides most of the spectroscopic counterparts. We also cross match with the following surveys: the COSMOS bright spectroscopic sample (Lilly et al. 2007), the PRIMUS survey ( Coil et al. 2011; Cool et al. 2013), the VIPERS survey (Guzzo et al. 2014), the VVDS survey (Le Fevre et al. 2004, 2005; Garilli et al. 2008), the DEEP2 survey (Newman et al. 2013), and the Veroncat catalog (Véron-Cetty & Véron 2010). Among our 1768 objects, 585 (33%) have a spectroscopic redshift, 493 (85%) of the spectroscopic objects) have been classified as AGN, and 87 (15%) have been classified as galaxies.

2.4. Photometric Redshifts

We estimate photometric redshifts using the code lephare (Arnouts et al. 1999; Ilbert et al. 2006), which determines photometric redshifts by fitting the observed photometry to libraries of galaxies, quasars, and stars template SEDs. We use our training set built from objects with spectroscopic redshifts to assess the quality of the photometric redshifts. We do not include Spitzer 24 μm or the W3 and W4 WISE bands because they probe ranges of the SED not dominated by stellar emission in the redshift range we are interested in. Determining photometric redshifts with small errors for AGN/quasar dominated objects is notoriously difficult because the SEDs of these objects are close to featureless (see e.g., Richards et al. 2009), and narrow-band photometry is required to improve significantly the quality of the estimates (Salvato et al. 2011).

We performed extensive tests to obtain the best photometric redshifts for our AGN sample. We first determined the zero-point offsets for the bands, and then compared the flux from the best-fitting galaxy SED models for spectroscopic galaxies in our sample to the actual photometry (Ilbert et al. 2009). In a second step, we tested a number of combinations for the AGN-dominated SED templates. We obtained the best results by using a subset of 22 templates out of the 30 templates used by Salvato et al. (2009). We trimmed the list of 30 templates by excluding the templates that are never retained as a best model when the fitting is performed with the redshift fixed at its spectroscopic value.

We show a comparison of the photometric and spectroscopic redshifts on Figure 1. Using $\Delta z = z_{\text{spec}} - z_{\text{phot}}$, we quantify the error on the photometric redshifts as $\text{err}(z) = \Delta z / (1 + z_{\text{spec}})$, and use the normalized median absolute deviation $\sigma_{\Delta z/(1+z_{\text{spec}})} = 1.4826 \times \text{median}(|\text{err}(z) - \text{median}(\text{err}(z))|)$ as a global measure. We consider objects with $|\text{err}(z)| > 0.15$ as outliers, and note the percentage of these objects as $\eta$. For our full spectroscopic sample, the overall error is $\sigma_{\Delta z/(1+z_{\text{spec}})} = 0.08$, and $\eta = 28.1\%$. These numbers are in agreement with those usually obtained using broadband photometry (e.g., Salvato et al. 2011).

For this study, we chose hereafter to restrict the sample to objects with $0.1 < z_{\text{phot}} < 1$; these limits are shown as dotted lines on Figure 1. We set the upper limit because the quality of the photometric redshifts decreases significantly for $z > 1$, and set the lower limit to avoid outliers a low redshifts. In this range, the error is $\sigma_{\Delta z/(1+z_{\text{spec}})} = 0.06$, and $\eta = 17.5\%$. Our final cuts leave us with 1160 objects. We further use spectroscopic redshifts whenever available. Doing so lowers the actual errors on photometric redshifts in our sample. To derive the resulting errors, we assume that the redshift errors for objects with spectroscopic redshifts are negligible compared with the photometric redshift errors. Assuming that objects without spectroscopic redshifts (757 objects) have the same photometric redshift errors as those with spectroscopic redshifts (403 objects), the actual error for our final AGN sample is $\sigma_{\Delta z/(1+z_{\text{spec}})} = 0.03$, and the percentage of outliers $\eta = 11.5\%$.

2.5. Control Sample

We build a control sample using the full catalog from one of the Medium Deep fields, MD04. We follow the same procedure as for the AGN sample described above to obtain photometry in other wavelengths (see Section 2.3). We use only extended objects following our custom star/galaxy separation, based on machine learning techniques (Heinis et al., submitted), and determine photometric redshifts using the code lephare. The error on photometric redshifts is $\sigma_{\Delta z}/1 + z_{\text{spec}} = 0.05$ and the
outliers percentage is \( \eta = 11\% \). We keep objects with the same 
distribution in \( \nu_{PS1} \) like the AGN sample. We also limit the 
sample to \( 0.1 < z_{\text{phot}} < 1.1 \), which is the same as for the AGN 
sample. We are left with 16,401 objects.

### 3. SED FITTING

#### 3.1. pCIGALE

We use the code pCIGALE\(^7\) to perform SED fitting and 
estimate physical parameters. pCIGALE is the python 
version of the former CIGALE code (Noll et al. 2009), which 
provides new features in addition to having a different coding 
language. While pCIGALE preserves the same features of 
CIGALE, this new version has been designed for a broader set 
of scientific applications and improved performance. We provide 
here a short description of the latest version of 
pCIGALE to date.

pCIGALE (see also Ciesla et al. 2015) has two different 
and independent functions: SED modeling (M. Boquien et al. 2016, 
in preparation) and SED fitting (D. Burgarella et al. 2016, 
in preparation). The SED modeling function allows one to build 
a galaxy SED from the UV to the sub-mm based on single stellar 
population synthesis models, chosen star formation histories 
(SFHs), and energy balance. The full SED is built by re-

emitting in the IR the energy absorbed by dust in the UV-

optical. Here we use delayed SFHs, which have been shown to 
reproduce accurately the SEDs of galaxies over a wide redshift 
range:

\[
\text{SFR}(t) = (t - t_{\text{age}}) \exp \left( \frac{t - t_{\text{age}}}{t_{\text{main}}} \right)
\]

We consider the stellar population models of Bruzual & 
Charlot (2003), which are convolved by the SFH and then 
attenuated by dust. We use the law of Calzetti et al. (2000) to 
estimate the extinction by dust, and the libraries of Dale et al. 
(2014) to model the re-emission in the IR of this energy. Using 
pCIGALE, Buat et al. (2014) showed that the constraint from 
the IR rest frame range is essential to derive accurate SFR 
estimates. In particular, they found that SFR estimated by SED 
fitting without IR data are on average overestimated by 20%. In 
details, low SFR are overestimated and large SED are 
underestimated by factors up to 2.5. They also showed that the 
intrinsinc dispersion in SFR increases by a factor 2 when no 
IR data is used.

Finally, pCIGALE also allows us to include AGN emission, 
to be added to the stellar one, using the templates from Fritz 
et al. (2006), which consist of two components: the central 
source and dust. The emission of the central source is assumed 
to follow power laws with a different index in three wavelength 
ranges (spanning \( 0.001 < \lambda < 20 \mu m \)). The dust component 
consists of scattering and the thermal emission from the

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\(^7\) http://cigale.lam.fr/

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changes in the UV/optical. The dust torus itself is modeled 
using a flared disc geometry (Efstathiou & Rowan-Robinson 
1995). The models of Fritz et al. (2006) have been 
extensively tested in previous works e.g., Hatziminaoglou 
et al. 2008, 2010; Feltre et al. 2012). We list in Table 2 the 
parameters we use for the SED fitting.

pCIGALE creates a library of models combining all 
parameters; a number of properties are derived for each model, 
such as the stellar mass \( (M_\star) \) and the SFR averaged over the 
last 100 Myr. For the AGN component, we compute for each 
model the luminosity at 5100 Å \( (L_{5100}) \) and the absolute 
magnitude in the \( g_{PS1} \) band. pCIGALE computes the \( \chi^2 \) 
statistics for each model, and builds the probability distribution 
function (PDF) for each parameter and derived property using 
these \( \chi^2 \) values. The parameter or property value we use is the 
average value weighted over this PDF, and the error is the 
standard deviation that thus encodes the width of this PDF. In 
the following, we use only objects with \( \chi^2_{\text{reduced}} < 5 \) (975 
objects).

Ciesla et al. (2015), in particular, tested the performance of 
pCIGALE to recover the properties of AGNs in the case of 
realistic SFHs drawn from a semianalytic simulation. Ciesla 
et al. (2015) show that pCIGALE is able to recover accurately 
the properties of the AGNs and the host galaxy, provided that 
the observed SED is constrained from the UV to the FIR rest 
frame, and that the fraction of the AGN emission in the IR, 
\( f_{\text{AGN}} \) is larger than 0.1.

#### 3.2. AGN Luminosity: SEDs Versus Spectra

One of the main AGN properties we use hereafter is the 
luminosity at 5100 Å, \( L_{5100} \). Using a spectroscopic sample, we 
check how well we can recover \( L_{5100} \). We use every object in 
our sample with a counterpart in SDSS DR12 with a spectrum 
classified as a quasar. We correct the spectra for Galactic 
extinction using the Schlegel et al. (1998) map, and the 
extinction curve from Cardelli et al. (1989), with \( R_V = 3.1 \); we 
also shift the spectra to rest frame using the listed redshift. We 
are only interested here in the continuum luminosity, so we fit 
the continuum with a power law \( \left( L_\lambda = A\lambda^n \right) \) for 
\( 2500 < \lambda < 5500 \) and exclude the regions of the spectra around the 
\( \text{Mg} \, II, \text{H} \beta, \) and \( \text{O} \, III \) lines. We then obtain the luminosity at 
5100 Å as \( \lambda L_{5100} \). This measure can be contaminated by the host 
luminosity, so we use Equation (1) from Shen et al. (2011) 
to correct our estimate from host contribution. On the other hand, 
we fit the broadband photometry SED of the same objects with 
pCIGALE. We compare the luminosities at 5100 Å that we 
derive from the SED and the spectra in Figure 2.

In Figure 2, we show the results of the SED fitting using 
AGNs of Type 1, because among our objects with spectro-
scopic redshifts and classifications only 5% are Type 2. As can 
be seen in Figure 2, there is excellent agreement between the 
two methods.
Table 2
pCIGALE Fitting Parameters

| Parameter                          | Value                          | Description                  |
|------------------------------------|--------------------------------|------------------------------|
|                                    |                                | Delayed Star Formation History|
| \( \tau_{\text{max}} \) (Myr)     | [100, 500, 1000, 5000, 100000] | Star formation timescale     |
| Age (Myr)                          | [100000, 13536]                | Age of the oldest stars in the galaxy |
|                                    |                                | Extinction Law (Calzetti et al. 2000) |
| \( E(B-V) \)                       | 0.01, 0.05, 0.1, 0.2, 0.3, 0.5 | Color excess of the stellar continuum |
|                                    |                                | Dust Templates (Dale et al. 2014) |
| \( \alpha_{\text{SF}} \)          | 1, 2, 3, 4                    | Exponent of the intensity of the radiation field |
|                                    |                                | AGN Models (Fritz et al. 2006) |
| \( \frac{R_{\text{max}}}{R_{\text{min}}} \) | 60                             | Ratio of the external to internal radius of the dust torus |
| \( \gamma_{\text{dust}} \)        | 0.1, 0.6, 2, 0.6, 2, 0.6, 0.10 | Optical depth at 9.7 \( \mu \)m of the dust torus |
| \( \beta \)                        | 0.5                           | Parameter describing the torus density profile |
| \( \gamma \)                       | 4.                            | Parameter describing the torus density profile |
| \( \Theta (\text{deg}) \)         | 40.                           | Opening angle of the dust torus |
| \( \psi (\text{deg}) \)           | 89.99 (Type 1)               | Angle between the AGN axis and the line of sight |
| \( f_{\text{AGN}} \)              | 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7 | AGN fraction in the IR |

Note. Parameters used for the SED fitting with pCIGALE. For the templates of Dale et al. (2014), we fix the AGN fraction to zero.

4. RESULTS

4.1. Stellar Mass Distribution

In Figure 3 we show the stellar mass distribution of the AGNs derived by pCIGALE (blue shaded histogram). We compare it with that of the control sample (gray shaded histogram). Figure 3 suggests that the stellar mass distribution of AGNs is different from inactive galaxies, because it is skewed toward large masses (~\( 10^{10.6} M_\odot \)). We checked whether the variability selection can explain this trend by simulating the level of variability for galaxies in our control sample. We assume that each galaxy in the control sample hosts an AGN, and assign a black hole mass \( M_{\text{BH}} \) using the total stellar mass—black hole mass relation from Bennert et al. (2011). We then convert \( M_{\text{BH}} \) to Eddington luminosity, and further to a bolometric luminosity using the Eddington ratio distribution from Kelly et al. (2010). Using the bolometric correction of Krawczyk et al. (2013), we obtain an estimate of \( L_{5100} \). We assume that the AGNs have a power law SED \( f_\lambda \propto \lambda^{-1.5} \), and use this luminosity as a normalization. We derive the AGN flux in the PS1 g filter, and finally use the relation we observe between the fractional variability \( \Delta f/f \) and \( L_{5100} \) (see Section 4.3). We compute what the brightest magnitude \( m_{\text{g}} \) is for this simulated variable source, and keep only objects with \( m_{\text{g}} < 23 \) mag (the sensitivity limit for the detection of sources in the PS1 difference imaging). The resulting stellar mass distribution is shown in shaded black in Figure 3. It is clear that the variability cut has little impact on the control sample stellar mass distribution. This is expected because the AGN luminosity is correlated with the host stellar mass (given the black hole mass-stellar mass correlation, e.g., Häring & Rix 2004; Kormendy & Ho 2013; McConnell & Ma 2013; Reines & Volonteri 2015), but anti-correlated with the amplitude of variability.

The results presented in Figure 3 suggest that AGNs are mostly hosted by larger stellar mass galaxies than the underlying galaxy population.

\[ \log(L_{5100, \text{SEDfitting}}[\text{ergs}^{-1}]) \]

\[ \log(L_{5100, \text{spectra}}[\text{ergs}^{-1}]) \]

Figure 2. Comparison of the SED fitting measurement of \( L_{5100} \) with the measurement from the spectra. We compare the estimate of \( L_{5100} \) obtained from pCIGALE (y-axis) with the one obtained directly from the spectrum (x-axis).

4.2. Color Distribution

We show in Figure 4 (left panel) the distribution of the total rest frame NUV – r color (i.e., the combination of the host and AGN). Note that this color is corrected for dust attenuation. Given the different mass distributions of the control sample and the AGN, we use here a mass-matched version of the control sample. We show the limits of the Green Valley as dashed lines on Figure 4 (e.g., Wyder et al. 2007). As expected, compared with the control sample, the distribution of AGN host total colors peaks in the blue sequence, because the AGN emission contributes significantly to the SED and can dominate over the...
stellar populations. In the right panel, we show the distribution of the host galaxy only rest frame NUV − r color, given by our SED fitting decomposition. Here the distribution of the host colors is strikingly similar to that of the control sample. In other words, our results show that hosts of AGNs have the same color distribution as regular, non-AGN galaxies. There is no obvious link between harboring an AGN and the rest frame NUV − r color of its host galaxy stellar population.

4.3. Amplitude of Variability

We investigate the relation between the amplitude of the AGN variability and the AGN luminosity. We use the measure from the image differencing of the minimum magnitude in the g, r, i, and z bands (i.e., the maximum flux of the variable component of the AGN measured over the course of the survey). We convert this magnitude to an absolute magnitude (e.g., $M_{g,\text{min}}$) and derive the relative amplitude of the variability as

$$\log \left( \frac{\Delta f}{f} \right) = -0.4(M_{g,\text{min}} - M_g)$$

where $M_g$ is the g-band absolute magnitude of the AGN component derived from the SED fitting. We then use a similar process for the other bands. We derive the AGN bolometric luminosity, $L_{\text{AGN}}$, using the relation from Netzer & Trakhtenbrot (2014) for the bolometric correction at 5100 Å: $b_{5100} = 53 - \log L_{5100}$.

We show in Figure 5 the relation between this measure of variability in the g, r, i, z bands and $L_{\text{AGN}}$. We use here only objects (831) that have a measure of the minimum apparent magnitude in the g, r, i, z bands. We adjust the relations between $\Delta f/f$ and $L_{\text{AGN}}$ by:

$$\log \left( \frac{\Delta f}{f} \right) = \beta \left[ \log(L_{\text{AGN}}) - 44.5 \right] + \log \left( \frac{\Delta f}{f} \right)_{0}$$

We use Orthogonal Distance Regression to perform these fits. This method allows us to take into account errors both on $\Delta f/f$ and $L_{\text{AGN}}$. The errors on the parameters for these fits are the standard errors on the estimated parameters, which are derived from the covariance matrix estimated during the fit. We list in Table 3 the best-fit parameters in the g, r, i, and z bands.

We note that our sensitivity to AGN variability is set by our magnitude limit in the difference images of $m_{\text{lim}} \sim 23$ mag. Thus, for a variable AGN, a bright AGN will be detected at $\gtrsim -0.45$ in the g band and to $\sim -0.53$ in the z band. This steepening of the relation is mostly due to the objects that are fainter than $L_{\text{AGN}} < 10^{43.3}$ erg s$^{-1}$. We also perform the fit excluding these objects, and find that while the decrease in $\beta$ is less pronounced ($-0.34$ in g to $-0.43$ in z), it is still significant.

The trends we observe—that variability amplitude decreases with AGN luminosity—has been noted by a number of studies (e.g., Hook et al. 1994; Trevese et al. 1994; Vanden Berk et al. 2004; Wilhite et al. 2008; Bauer et al. 2009; Zuo et al. 2012; Gallastegui-Aizpun & Sarajedini 2014). This trend suggests that AGN variability can be interpreted by Poissonian models. In that case, the slope of the variability-luminosity relation $\delta L/L_{\text{AGN}}$ is expected to be $\beta = -0.5$. When we consider all objects in the fit, we find slopes that are consistent with Poissonian models in the r, i, and z bands, whereas the
slope is shallower in \( g \). When we consider only objects with \( \log(L_{\text{AGN}}) > 43.5 \) as a dotted line. On the panels representing the results for the \( r, i, \) and \( z \) bands, we show in blue the fits obtained in the \( g \) band as reference.

Figure 5. Relative variability amplitude in the \( g, r, i, \) and \( z \) bands as a function of AGN bolometric luminosity. The upper x-axis shows the corresponding AGN absolute magnitude. In each panel, we show the best fit to Equation (3) as a black dashed line, and the dashed area around it represents the errors on the fit. Similarly, we also show the fit to Equation (3) using only objects with \( L_{\text{AGN}} > 10^{43.5} \) as a dotted line. On the panels representing the results for the \( r, i, \) and \( z \) bands, we show in blue the fits obtained in the \( g \) band as reference.

Table 3

Best-Fit Parameter Values for Equation (3) in the \( g, r, i, \) and \( z \) bands

| Band | \( \beta \) (All Objects) | \( \log \left( \frac{\Delta V}{\gamma} \right)_0 \) (All Objects) | \( \beta \) (\( L_{\text{AGN}} > 10^{43.5} \) \) | \( \log \left( \frac{\Delta V}{\gamma} \right)_0 \) (\( L_{\text{AGN}} > 10^{43.5} \) \) |
|------|----------------|-------------------|----------------|----------------|
| \( g \) | \(-0.45 \pm 0.02\) | \(-0.08 \pm 0.01\) | \(-0.34 \pm 0.02\) | \(-0.11 \pm 0.01\) |
| \( r \) | \(-0.48 \pm 0.02\) | \(-0.10 \pm 0.01\) | \(-0.32 \pm 0.02\) | \(-0.15 \pm 0.01\) |
| \( i \) | \(-0.53 \pm 0.02\) | \(-0.14 \pm 0.01\) | \(-0.45 \pm 0.02\) | \(-0.17 \pm 0.01\) |
| \( z \) | \(-0.53 \pm 0.02\) | \(-0.11 \pm 0.01\) | \(-0.43 \pm 0.02\) | \(-0.15 \pm 0.01\) |

Gallastegui-Aizpun & Sarajedini (2014) also observed that the slope of the variability function steepens between the \( g, r, \) and \( i \) SDSS bands for Type 1 AGN. We note that Gallastegui-Aizpun & Sarajedini (2014) constrained the variability function down to \( M_i \sim -18.5 \), while here we extend the range of measurements down to \( M_i \sim -14 \). Numerous studies (e.g.,
Vanden Berk et al. 2004; Zuo et al. 2012; Gallastegui-Aizpun & Sarajedini 2014) have reported that the amplitude of variability is larger at bluer wavelengths. Thanks to our sample spanning a larger range of bolometric luminosities, we can revisit this claim. At $L_{\text{AGN}} \geq 10^{43.5}$ erg s$^{-1}$, we observe that on average the amplitude of variability is larger in $g$ than in the other bands, which is consistent with previous results. At fainter luminosities, however, which were not sampled by previous studies, AGNs display larger variability amplitudes in redder bands. We examine in Figure 6 the wavelength and luminosity dependence of the relative variability amplitude. We show in four bins of $\log(L_{\text{AGN}})$ the average relative variability amplitude as a function of rest frame wavelength. The errors bars are derived by propagating the errors in the mean. These measures show that for $43 < \log(L_{\text{AGN}}[^{\text{erg}} s^{-1}]) < 45$, there is no significant wavelength dependence of the AGN variability (i.e., the relation is consistent with a flat one at the 1 $\sigma$ level). For bright AGNs, at $45 < \log(L_{\text{AGN}}[^{\text{erg}} s^{-1}]) < 46.5$, we observe that the variability decreases at redder wavelengths (2.5 $\sigma$ level); for faint AGNs, at $42 < \log(L_{\text{AGN}}[^{\text{erg}} s^{-1}]) < 43$, the trend reverses, as the variability increases at redder wavelengths (2.7 $\sigma$ level).

### 4.4. AGN and Host SFR

We investigate in Figure 7 the relation between the host SFR and the AGN bolometric luminosity. Our results show that for variability selected AGNs, there is an overall good correlation between SFR and the bolometric AGN luminosity. We also color code the symbols by the redshifts of the objects in Figure 7. This shows that higher redshift objects display higher SFRs and bolometric AGN luminosity. The observation that the commonly observed SFR–$L_{\text{AGN}}$ relation is built from the contribution of galaxies at various redshifts is consistent with the results from Stanley et al. (2015) based on the X-ray selected sample. Stanley et al. (2015) furthermore found that, at a given redshift, there is no correlation between SFR and $L_{\text{AGN}}$; at a given redshift (0.2 < z < 2.5), the relation between SFR and $L_{\text{AGN}}$ is mostly flat, while the amplitude of this relation increases with redshift. The superposition of these relations yields the impression of an overall correlation between SFR and $L_{\text{AGN}}$. Contrary to Stanley et al. (2015), we observe an overall relation between SFR and $L_{\text{AGN}}$ that is preserved at all redshifts sampled here. We note that Stanley et al. (2015) use a different technique to determine the SFR, which is likely to yield overestimates in the case of Type 2 AGNs (Ciesla et al. 2015). We compare our results with the average SFR–$L_{\text{AGN}}$ relation observed by Netzer (2009; dashed line on Figure 7) from a sample at low redshift (z ~ 0.1) of Type-I and Type-II AGN. Netzer (2009) further shows that higher redshift (z ~ 2–3) QSOs from Lutz et al. (2008) also fall on this relation at higher SFRs and $L_{\text{AGN}}$. Our results are in excellent agreement with the relation from Netzer (2009). We note that the object selection used by Netzer (2009) is different from the one we use because it combines Types I and II selected from spectral features in the rest frame optical; moreover the methods Netzer (2009) used to derive SFR and $L_{\text{AGN}}$ are completely different from ours.

We also checked whether our SED fitting technique makes it possible to probe the whole range of SFR and $L_{\text{AGN}}$. The models we use do probe the whole range; moreover the actual values of the parameters (SFR and $L_{\text{AGN}}$) we use are derived from the PDF built during the SED fitting, which also allows a larger spread around the models.

In a recent work, Rosario et al. (2012) studied the properties of X-ray selected AGNs at z < 2.5 using constraints in the FIR from Herschel/PACS data. They found that at high $L_{\text{AGN}}$ luminosities, the SFR–$L_{\text{AGN}}$ relation follows a trend similar to the one we observe, but at lower luminosities the average SFR is constant. Their findings are in line with earlier results from Lutz et al. (2010), who performed stacking at 870 $\mu$m using similar AGN samples. These two regimes in the SFR–$L_{\text{AGN}}$ relation are expected to reflect the two regimes of black hole growth, starburst-like at high $L_{\text{AGN}}$, and “hot halo” at low $L_{\text{AGN}}$.
(e.g., Gutcke et al. 2015). Our results do not support these observations. We note that the results from Rosario et al. (2012) are based on the luminosities at 60 μm, while here we derive an SFR from a full SED modeling. Rosario et al. (2012) argue that their 60 μm luminosity estimates are not contaminated by AGN emission. As mentioned by Rosario et al. (2012), AGN contribution to theSED at 60 μm would require large dust torii (Fritz et al. 2006), which are thought to be rare.

A potential reason for the difference between our results and those from Rosario et al. (2012) is that our selection does not bias against quiescent galaxies or galaxies with very low SFRs. Note that Salvato et al. (2009) showed that the fraction of quiescent galaxies in the XMM-Newton COSMOS sample (the catalog used by Rosario et al. 2012 in the COSMOS field) is small. Another possible reason for the discrepancy is that we do not probe well AGNs fainter than \( L_{\text{AGN}} \lesssim 10^{42.5} \) erg s\(^{-1}\), a range where Rosario et al. (2012) observe the flattening of the SFR–\( L_{\text{AGN}} \) relation. Our variability selection is also biased against fainter sources. Due to photometric errors, faint AGNs require a larger fractional variability to be detected than bright AGNs (we explain this more clearly in Section 4.3). Thus, this will translate to a luminosity threshold at a given redshift range below which we are unable to detect variability.

4.5. AGNs and The Main Sequence of Star Formation

In Figure 8 we show the location of AGNs in theSFR–\( M_\star \) plane, color coded by the AGN bolometric luminosity, along with the distribution of galaxies in the control sample, shown as contours. We also show the fit to the locus of star-forming galaxies obtained by Schreiber et al. (2015), at the median redshifts of the control sample (\( \tau_{\text{median}} = 0.39 \)), after converting their results to a Chabrier IMF.

A number of studies have extensively investigated the relation between SFR and \( M_\star \) for inactive galaxies, from low to high redshifts (e.g., Elbaz et al. 2007; Noeske et al. 2007; Karim et al. 2011; Heinis et al. 2014; Schreiber et al. 2015). Our control sample clearly displays the star-forming sequence with a relation between SFR and \( M_\star \) that is similar to the results obtained by Schreiber et al. (2015), while the bulk of quiescent galaxies are located at lower SFRs and relatively high \( M_\star \) (∼\( 10^{10.75} M_\odot \)). Above a stellar mass of ∼\( 10^{9.5} M_\odot \), AGNs occupy the full range of SFRs. The bolometric AGN luminosity is mostly correlated with SFR, with a weaker additional correlation with \( M_\star \).

Running a principal component analysis on SFR, \( L_{\text{AGN}} \), and \( M_\star \) shows that in this space \( M_\star \) encodes only 5% of the available information. While the distributions of AGN hosts and inactive galaxies look similar above ∼\( 10^{9.5} M_\odot \), they are not necessarily drawn from the same parent distribution, according to Kolmogorov–Smirnov and Mann–Whitney statistics. For instance, there are virtually no AGNs at \( M_\star > 10^{11.25} M_\odot \) and SFR < 1 \( M_\odot \) yr\(^{-1}\).

However, we do observe a significant fraction of AGN hosts within the main sequence of star-forming galaxies. Assuming that the dispersion around the main sequence is 0.3 dex, we determine the percentages of AGN hosts that are above the main sequence, within the main sequence, or below the main sequence. We also perform the same for our control sample, mass matched this time. We derive errors on these fractions using the errors on the stellar mass and SFRs; the results are shown in Figure 9. The percentages of AGN hosts and control sample galaxies show the same trend: they decrease from quiescent to starburst. However, the percentage of AGNs in quiescent hosts is significantly lower than for the control sample. On the other hand, the occurrence of AGNs in MS or starburst hosts is larger than for the control sample.
results suggest that AGN activity is, at least moderately, linked to star formation activity.

5. DISCUSSION

5.1. AGN Variability

We first note that our variable AGN sample has been selected from the PS1 transient alerts—which are by definition variable at the 5\(\sigma\) level in at least three epochs in a time window of 15 days—properly measuring signal-to-noise in the individual difference images (see Section 2.1). This selection criteria means that fainter sources must have a larger fractional variability than brighter sources (see Section 4.3) to be detected at the 5\(\sigma\) level. However, we find in our simulations that regardless of this bias, we are still able to detect AGNs across the full range of host galaxy masses (see Figure 3). Similarly, the trends shown in Figures 5 and 6 cannot be attributed to this selection bias, because our sensitivity to variability at the low luminosity end is well below the observed relations.

Our results on AGN variability are consistent with previous studies showing that the variability amplitude decreases with AGN luminosity (Hook et al. 1994; Trevese et al. 1994; Vanden Berk et al. 2004; Willhide et al. 2008; Bauer et al. 2009; Zuo et al. 2012; Gallastegui-Aizpun & Sarajedini 2014). This trend has been interpreted in the context of Poissonian models, where variations are due to the stochastic superposition of independent flares (e.g., Cid Fernandes et al. 2000). These models predict that the relation between variability amplitude and luminosity have a slope of \(-0.5\). We do observe slopes consistent with this value when we consider all objects in our sample in the r, i, and z bands. The fact that we do not observe relations consistent with the Poissonian case does not actually rule it out. Indeed, selection effects might yield a not well-defined variability relation, and moreover, a slope of \(-0.5\) is only expected in the case of the simplest Poissonian models, where all the components of the models are universal constants among all objects (Cid Fernandes et al. 1996).

As previously noticed by Gallastegui-Aizpun & Sarajedini (2014), we observe that the relation between the variability and \(L_{\text{AGN}}\) steepens at redder wavelengths. A potential interpretation for this effect in a Poissonian context is that there is an underlying nonvariable background component that is redder than the SED of the flares (Cid Fernandes et al. 2000). We find however that this trend is luminosity dependent: for AGNs with \(L_{\text{AGN}} \gtrsim 10^{43.5}\) erg s\(^{-1}\) our results show that the variability is larger in g, but the trend is reversed for fainter AGN. In the context of accretion disk models (Shakura & Sunyaev 1976) where the variability is caused by a change in the accretion rate, one expects the variability to decrease monotonically with wavelength (e.g., Li & Cao 2008), which is inconsistent with our results at the faint end. While the “bluer when brighter” AGNs are the most commonly observed, some “redder when brighter” AGNs have also been noticed. In particular, Gu et al. (2006) used data spanning three months and noticed two flat spectrum radio quasars that become redder when brighter, which was confirmed by Rani et al. (2010). Gu et al. (2006) interpreted this observation as the non-thermal component dominating the UV-optical region of the spectrum when the source brightens.

5.2. AGN and Host Properties

The link between AGNs and their host properties has been widely studied over the last decades, using various techniques and selections. We revisit this topic thanks to our variability selected AGNs.

5.2.1. Color Distribution

Our first result is that, after removing the contribution of the AGNs to the observed color, we find that the color distribution of AGN hosts is similar to that of inactive galaxies. We note that the color distribution of our control sample is not bimodal because we are matching the mass and the i-band apparent magnitude distributions of the control galaxies to that of the AGNs. Our result that the color distribution of AGN hosts is similar to that of inactive galaxies is in contrast with a number of studies, which observed that AGNs are particularly common in green valley galaxies, suggesting that they are responsible for the quenching of star formation in this population. Martin et al. (2007) were one the first to make this observation; we however note that their NUV \(- r\) was not corrected from AGN contamination. Schawinski et al. (2009) studied the host properties of a sample of X-ray selected AGNs, and subtracted a central point source in optical imaging to derive the host optical colors. They claimed that AGNs are mostly found in green valley galaxies. We argue here that our results are actually consistent with theirs, once selection effects are taken into account. First of all, we note that Schawinski et al. (2009) observed few AGNs in hosts fainter than \(M_r = -20.5\). This is in line with the fact that we observe very few AGNs in hosts with stellar masses smaller than \(M_* \sim 10^{10.5}\) M\(_\odot\). Within the range of \(M_*\), their sample probes hosts that are bluer than the red sequence, the color distribution of AGN hosts is rather similar to what we observe. Moreover, the sample of Schawinski et al. (2009) is limited at \(L_{0.1-2.4keV} > 10^{42}\) erg s\(^{-1}\), which corresponds to a bolometric luminosity of \(L_{\text{AGN}} \sim 10^{43}\) erg s\(^{-1}\), assuming a bolometric correction of 10. Given the good correlation we observe between \(L_{\text{AGN}}\) and SFR (Figure 7), this luminosity cut explains why Schawinski et al. (2009) do not observe any AGNs within the red sequence. In this context, Xue et al. (2010) showed that it is essential to properly account for selection effects to discuss the relation between the AGN and host properties. They note in particular that it is critical to use mass-matched samples to compare the color distributions of AGN hosts and non-AGN galaxies. Once this is taken into account, they also found that these color distributions are similar, from \(z = 3\) to \(z = 0\). Aird et al. (2012) also found that the AGN fraction is only moderately enhanced in galaxies with blue or green colors.

5.2.2. AGN–SFR Connection

A large number of studies have focused on the link between AGN and SFR activity, because AGN feedback has been shown in simulations to be a promising mechanism to quench star formation in galaxies, and explain the global trends in galaxy evolution since \(z = 2\). Our point is not to contradict the fact that AGNs do quench star formation in some galaxies—it is clear that AGNs can inject significant amounts of energy in the intergalactic medium that can prevent further gas from cooling (Croton et al. 2006; Fabian 2012; Tombesi et al. 2015). However, the question is whether AGN feedback is statistically the main process that drives the building of the red sequence of
galaxies observed since \( z = 2 \). Our results show that there is a good correlation between AGNs and SFRs over the whole range of redshift and bolometric luminosity probed here, and hence it is not obvious that AGN feedback is the dominant process. Our results for the SFR–\( L_{\text{AGN}} \) correlation are in contrast with the results from Lutz et al. (2008) and Rosario et al. (2012) who, based on X-ray-AGN selected samples and stacking in the FIR, observe a plateau in the SFR–\( L_{\text{AGN}} \) relation for faint AGNs. This can be interpreted (e.g., Gutcke et al. 2015) by two modes of AGN accretion. The mode corresponding to the SFR–\( L_{\text{AGN}} \) correlation is the “starburst” regime, where galaxies experience starburst and AGN activity with high SFR and black hole accretion rates. The other mode, corresponding to the plateau observed by Lutz et al. (2008) and Rosario et al. (2012), is the “hot-halo” regime, where the growth of the black holes is linked to the AGN feedback mechanism.

The discrepancy between the results of Lutz et al. (2008), Rosario et al. (2012), and ours is mitigated by the fact that we do not probe well the range of luminosities where Lutz et al. (2008) and Rosario et al. (2012) observe the plateau (\( L_{\text{AGN}} \lesssim 10^{43} \text{ erg s}^{-1} \)). However, the SFR values for the few objects we do observe in that range are not consistent with a plateau. One possibility is that our SED fitting procedure would erroneously mistake moderate levels of star formation for moderate levels of AGN activity. However, this seems unlikely according to the work of Ciesla et al. (2015), who showed that at low levels of AGN activity the SED procedure we use properly recovers the SFR. According to the simulations of Gutcke et al. (2015), the plateau in the SFR–\( L_{\text{AGN}} \) correlation is created by a mix of galaxies on and out of the main sequence. We note however that there are some discrepancies between these simulations and the observations. For instance, the \( z \sim 0 \) results from Rosario et al. (2012) are based on the Swift BAT AGN sample of Cusumano et al. (2010). According to Koss et al. (2011), the minimum stellar mass for the hosts of this sample is around \( M_\star \sim 10^{9.8} M_\odot \). In this case it is unlikely, according to the simulations of Gutcke et al. (2015), that faint AGNs with hosts more massive than this limit would have an average SFR larger than one (see their Figure 5).

In summary, our results suggest that for \( 0 < z < 1 \) there is a good correlation between AGN host SFR and \( L_{\text{AGN}} \). This implies that the black hole accretion rates are also well correlated with SFR. These results are consistent with the picture that AGN hosts experience secular evolution, and that black holes are mostly fueled by the same mechanisms that fuel star formation events. We visually inspected the objects in our sample with higher SFRs, and did not find any merger or interaction signatures. This does not mean that mergers or interactions do not trigger AGN activity, but rather it suggests that these events are not the main channels for AGN accretion. These results are in line with the results from Mullaney et al. (2012a), who found that the accretion rates of supermassive black holes are well correlated with SFR from \( z = 2 \) to \( z = 1 \). We note however that while our results are in line with previous ones, suggesting that there is a good correlation between SFR and black hole activity, we cannot get more insight from these results about the physical mechanisms at play in this correlation. Moreover, our sample is biased against Type 2 AGNs. Assuming the scenario of Hopkins et al. (2008), this means that we would be missing a fraction of the AGN population at stages where the star formation and AGN activity are still coexisting. This population of AGNs is hosted by ULIRGs type objects, which we would miss with our UV/optical rest frame selections.

6. CONCLUSIONS

We studied the properties of \( \sim 1000 \) AGN hosts at \( z < 1 \) selected by variability in optical bands in the Pan-STARRS1 survey. Thanks to extensive wavelength coverage from the UV to the FIR, we performed reliable AGN/host decomposition through SED fitting. Our results can be summarized as follows:

1. We usually observe AGNs in massive hosts: \( M_\star \gtrsim 10^{9.5} M_\odot \).
2. The relative amplitude of AGN variability decreases with AGN bolometric luminosity. This relation steepens with wavelength (between \( g \) and \( z \) band), and the steepening is driven by faint AGN \( \log L_{\text{AGN}} < 10^{43.5} \text{ erg s}^{-1} \).
3. The \( NUV - r_{\text{restframe}} \) color distribution of AGN hosts is similar to a mass–matched control sample of non-AGN galaxies.
4. We observe a well defined correlation between \( L_{\text{AGN}} \) and SFR, valid over the whole redshift range we probe, as well as for \( 10^{42.5} < L_{\text{AGN}} < 10^{45.5} \text{ erg s}^{-1} \).
5. Above \( M_\star \gtrsim 10^{9.5} M_\odot \), AGNs are most likely to be hosted by Main Sequence or starburst galaxies than by quiescent ones.
6. These results suggest that there is no obvious correlation between AGN activity and SFR quenching at \( z < 1 \). This is in line with the results of a number of previous studies; however this study does not enable us to point toward a specific fueling mechanism.

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