

Type I Quasar Host Galaxies



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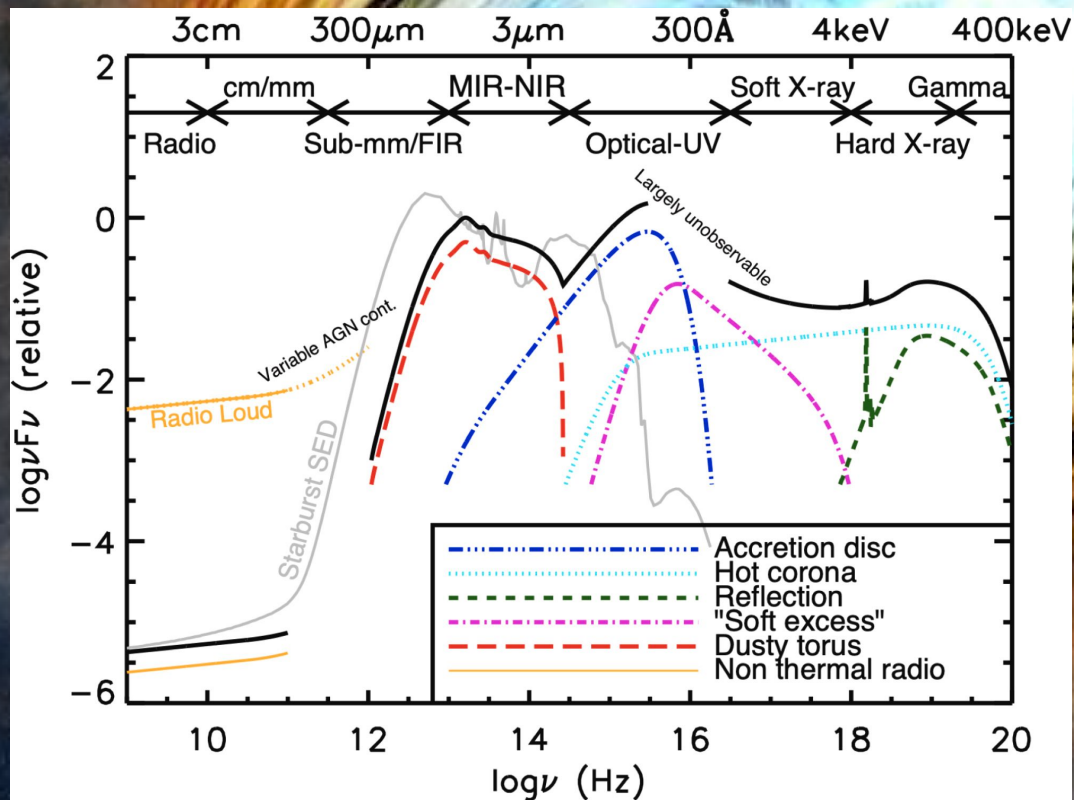
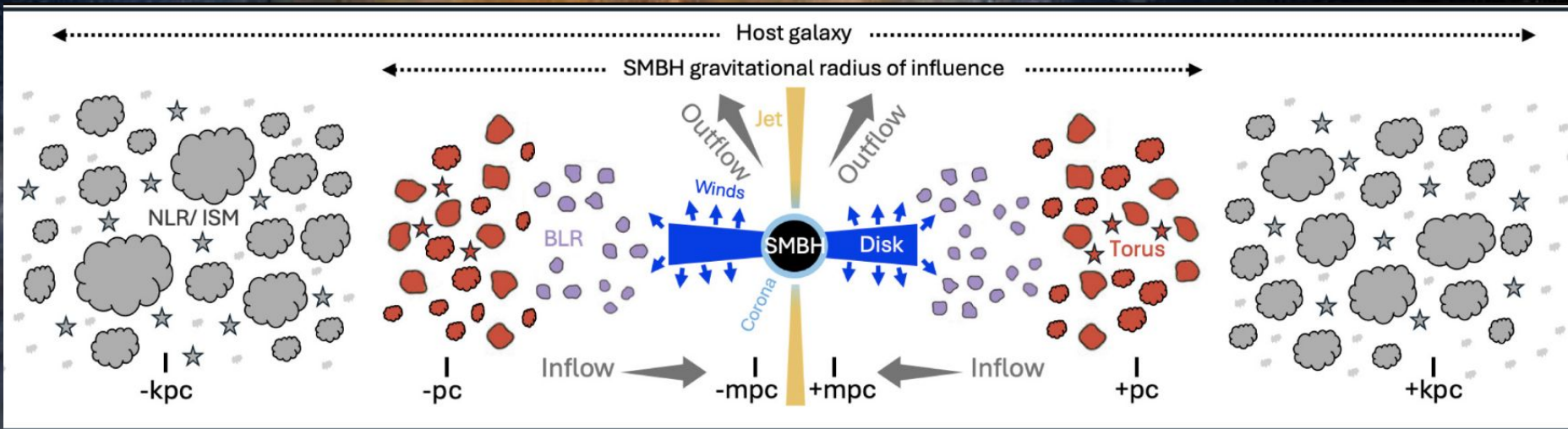
Maria B. Stone

*co-authors Roberto de
Propriis, Clare Wethers,
Nischal Acharya, Jari
Kotilainen, Johanna Hartke,
Kalle Karhunen, Seppo Laine,
and GAMA collaboration*

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Maria Stone,, Nordic-Baltic Astronomy Days 2026



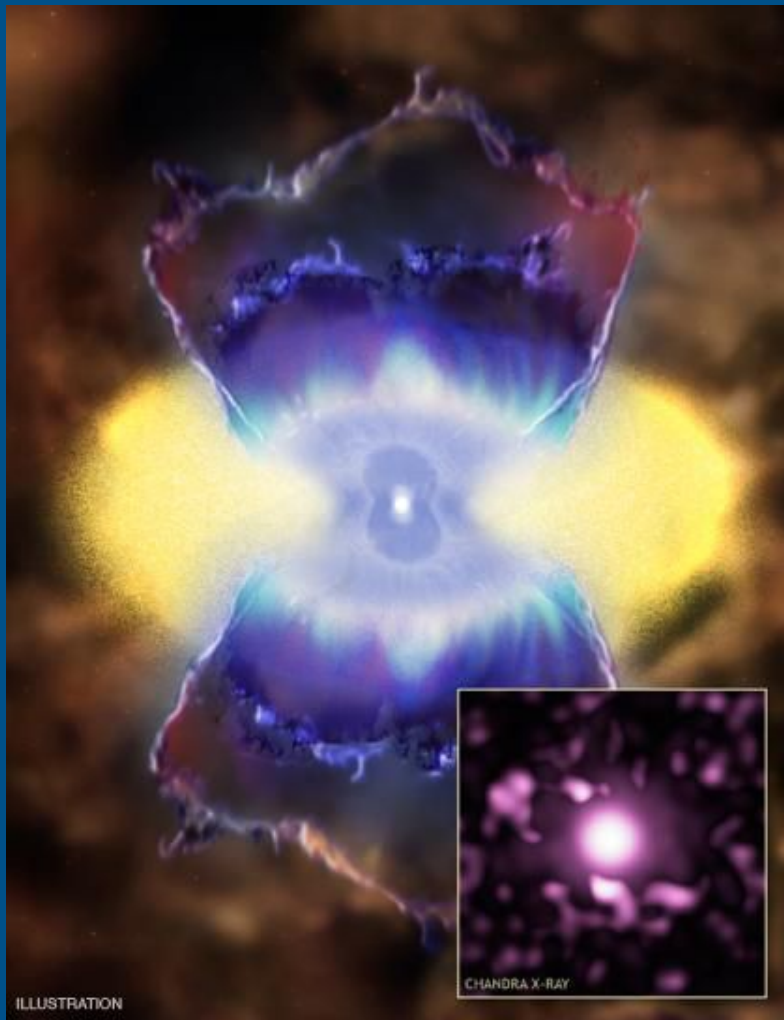


Adapted from Alexander+2025 Review

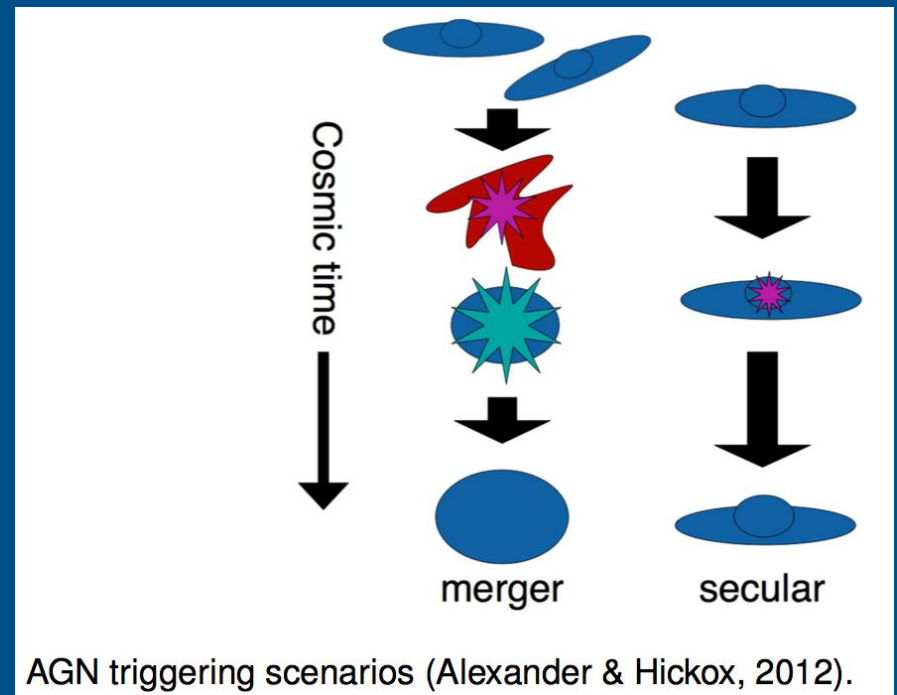
Ignition?

Mergers or Secular

e.g. Di Matteo + 2015, Villforth+2017



4C37.43 hot X-ray producing gas clouds
NASA, *Chandra* Image Archive, Stockton+2006



AGN triggering scenarios (Alexander & Hickox, 2012).

Multifaceted study of GAMA Quasars

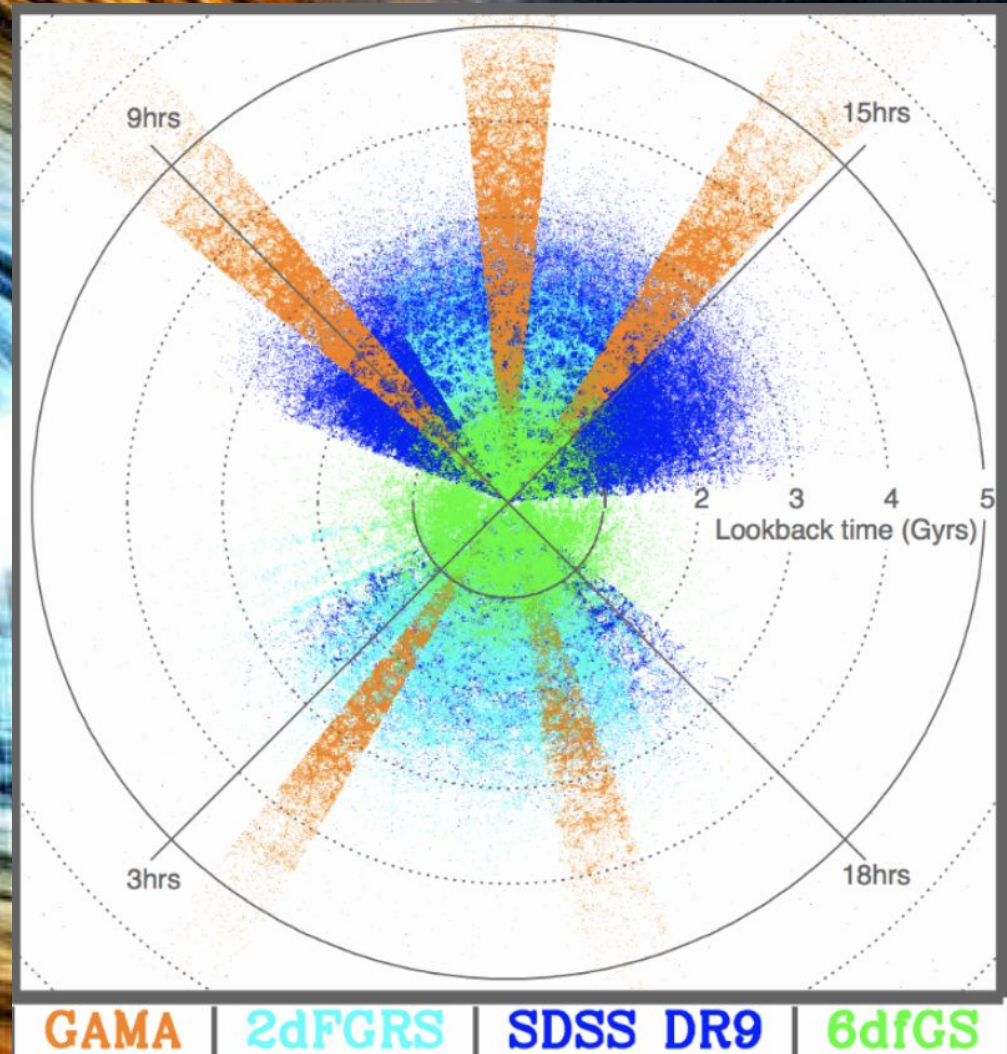


Galaxy And Mass Assembly

<http://www.gama-survey.org/>

spectroscopic survey

- ~300,000 galaxies
- $r < 19.8$ mag
- $z < 0.3$
- ~286 deg²



DATA

$z = 0.1-0.35$

Type I Quasar
sample

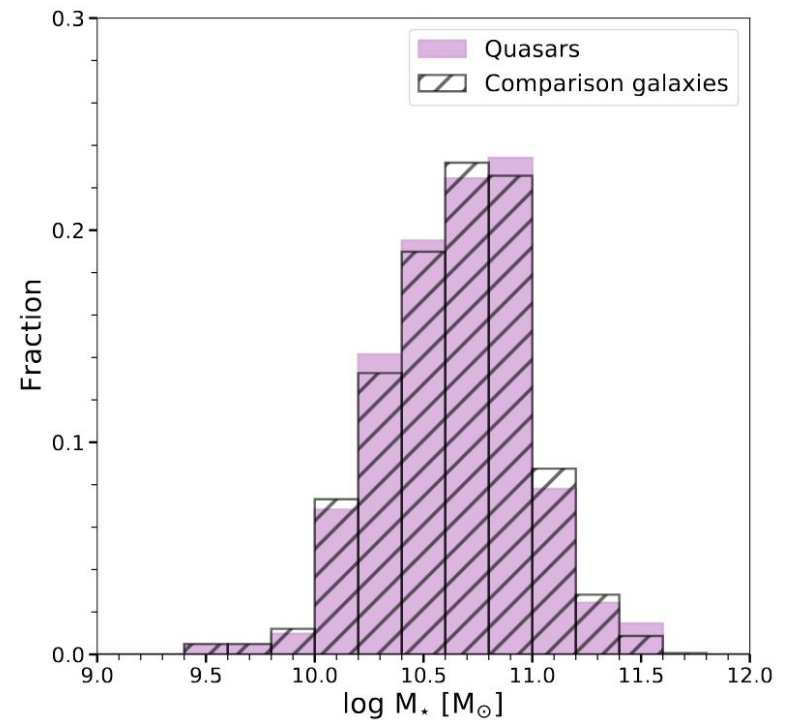
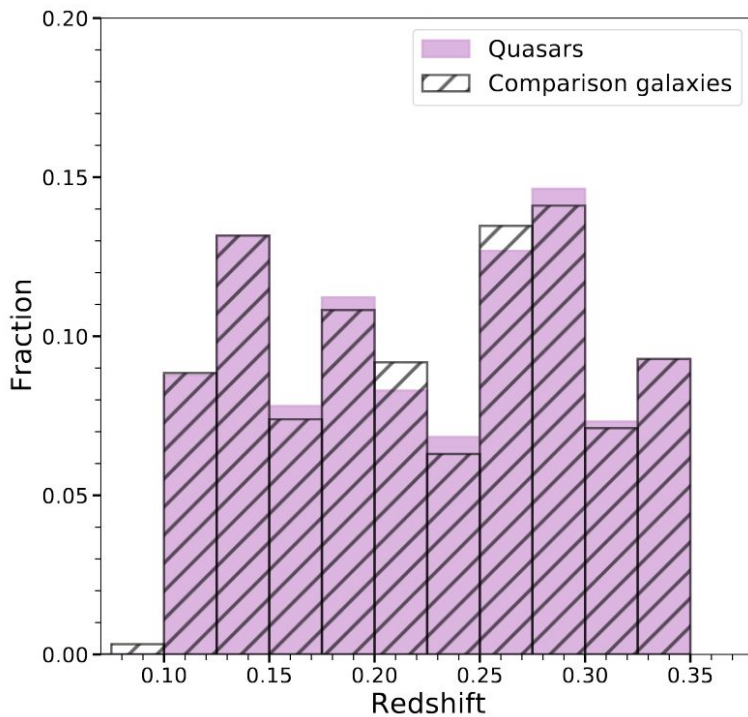
1 set

205 quasars in the set

Comparison galaxy
sample

200 sets

205 galaxies per set



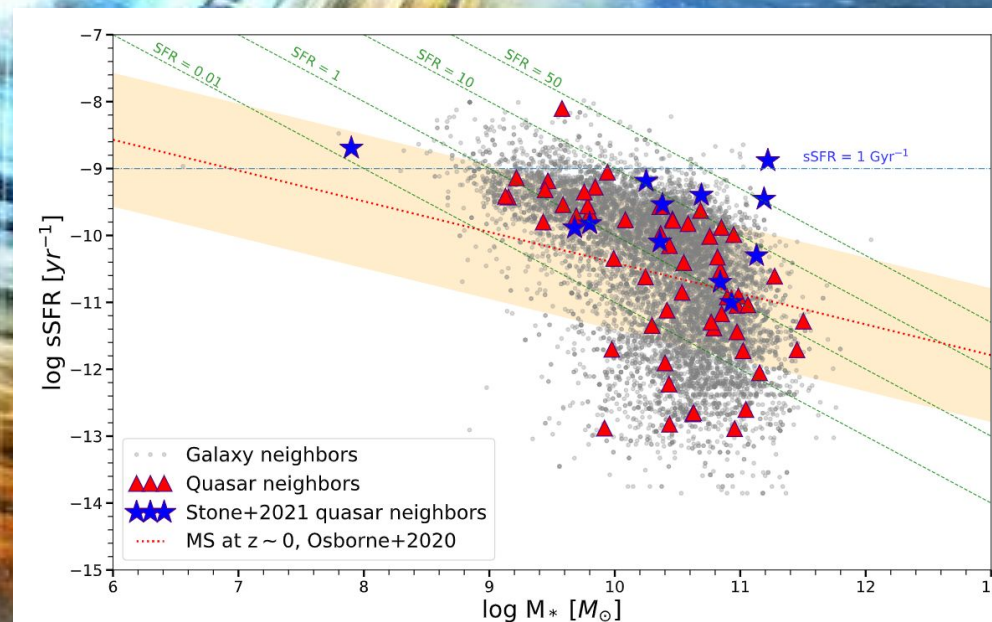
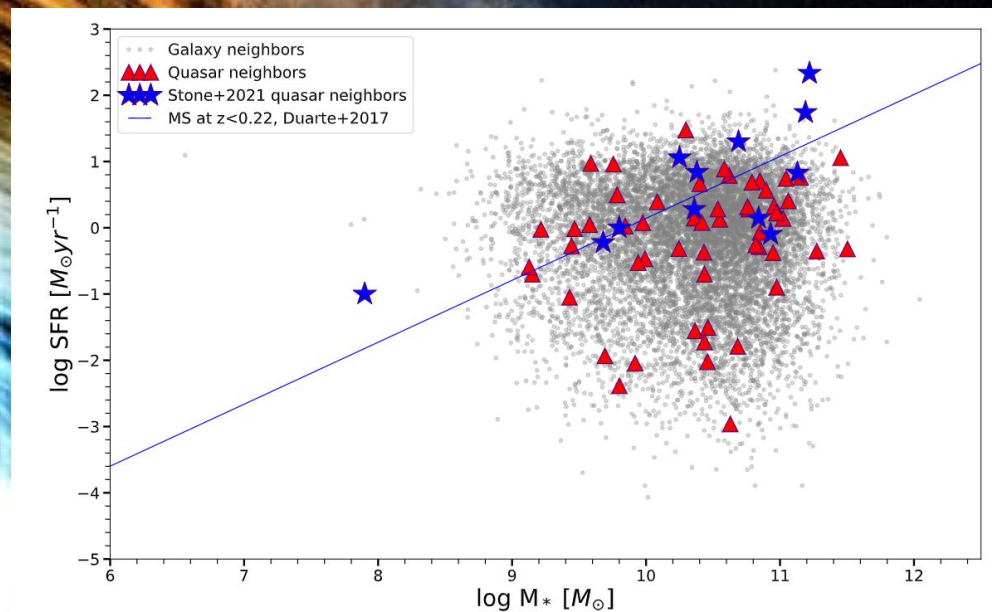
Published Research on GAMA quasars

- Wethers+2022, ApJ

galaxy number counts and group membership similar to those of the matched galaxy sample

- Stone+2023, ApJ

no statistically significant difference between the populations of quasar neighbors and normal galaxy neighbors in our sample across many physical stellar population parameters



Zoom-in closer to the SMBH

Host galaxy environment

*What kind of galaxies are these
active galaxies?*

Galaxy and Mass Assembly (GAMA): The Properties of Quasar Host Galaxies: Star Formation Histories and Stellar Populations.

Authors:

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Roberto de Propriis

Jari Kotilainen

Clare Wethers

Nischal Acharya

GAMA collaboration co-authors

ApJ, 2026

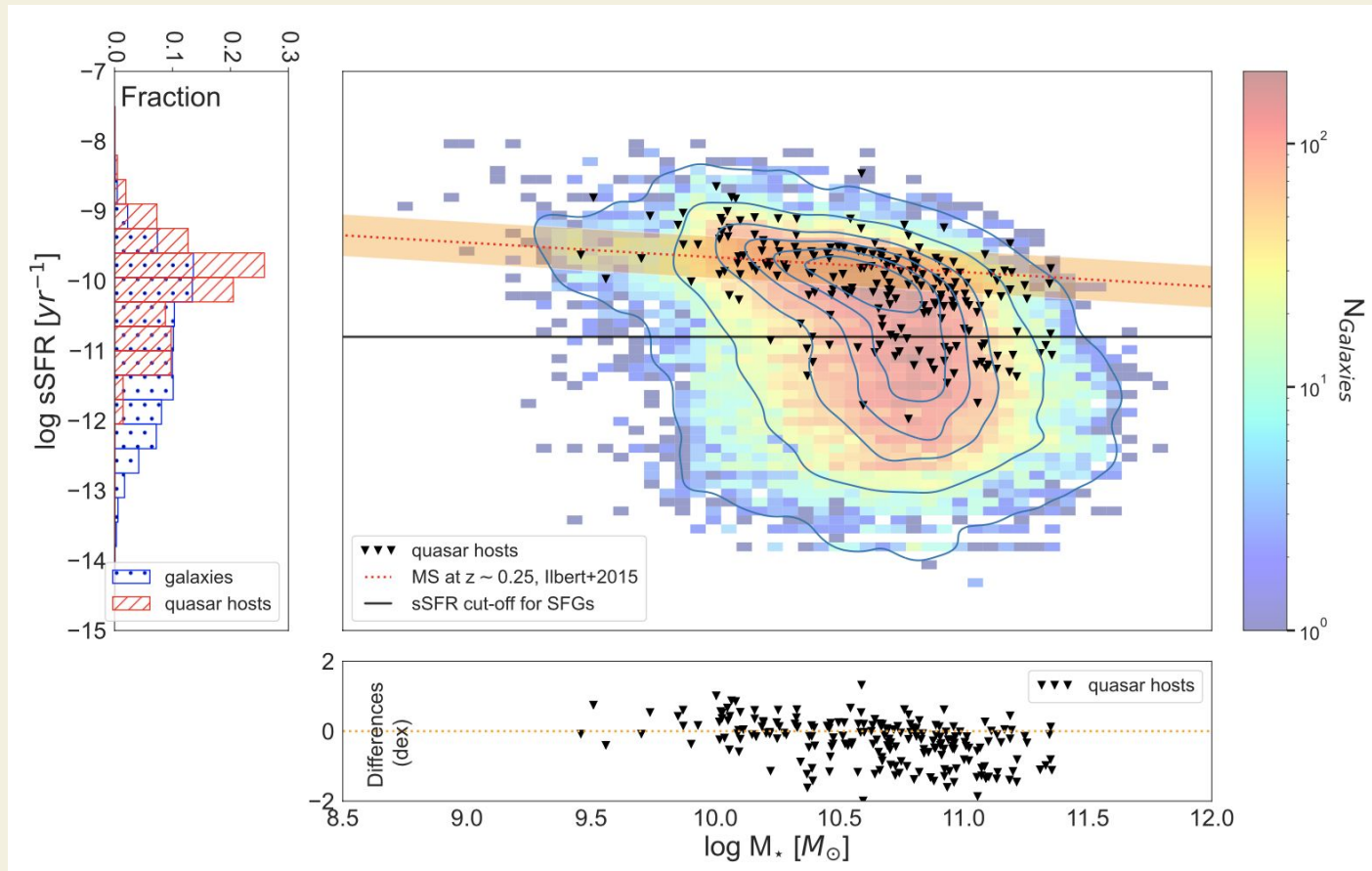


Beatrice Tinsley * (stellar population diagnostics used in SED)

SF properties of low-z Type I quasar hosts

- data from the GAMA spectroscopic survey
- SED analysis with CIGALE to estimate star formation properties.
- ~80% are star forming galaxies.
- compared to inactive galaxies, quiescent galaxies fraction is lower by a factor of ~2.

- quasar host galaxies are galaxies which have been star forming for all times previously
- triggering the nuclear activity happens in the local Universe mainly by secular processes and by minor mergers

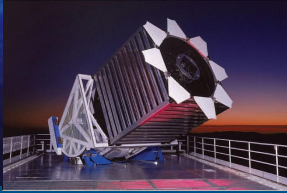


Now, we need the star formation properties data to compare quasar host SF to normal galaxy SF

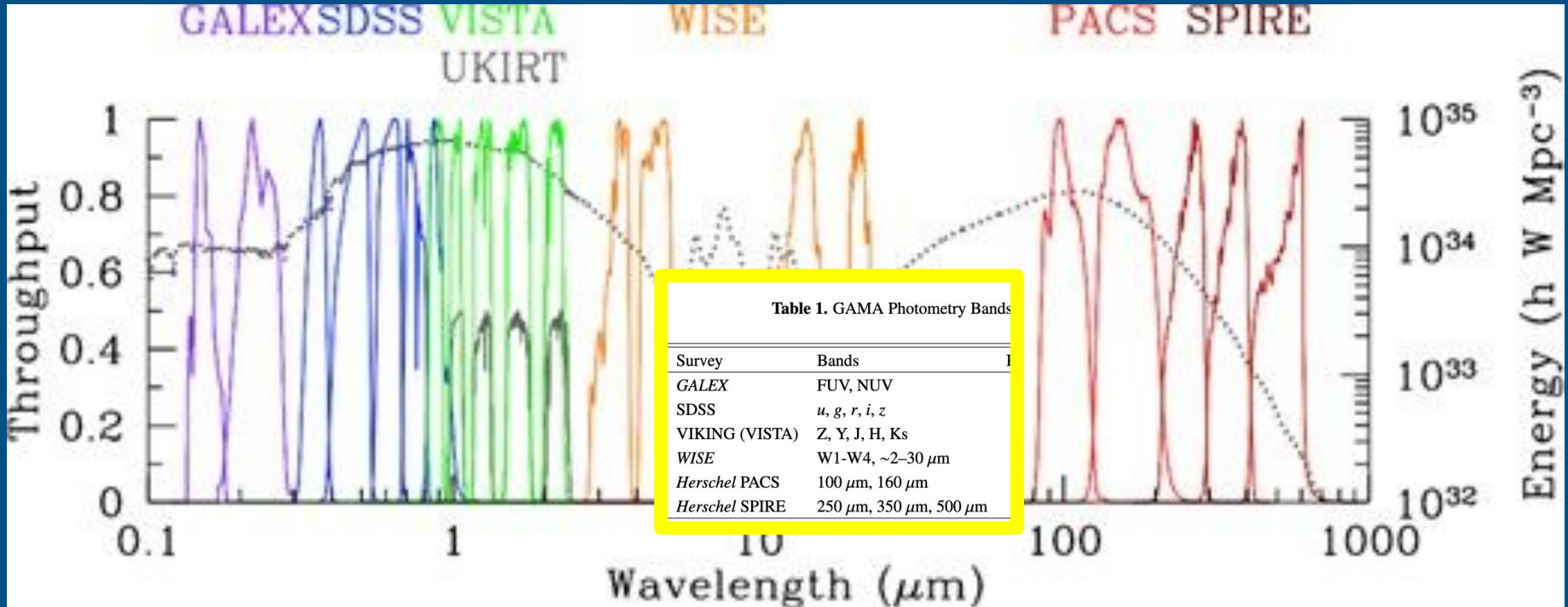
Normal galaxies sample ->

SF estimates are given in GAMA archive, based on SED analysis with MAGPHYS

Quasar hosts -> not reliable MAGPHYS data because AGN component is not taken into account -> use CIGALE



Herschel

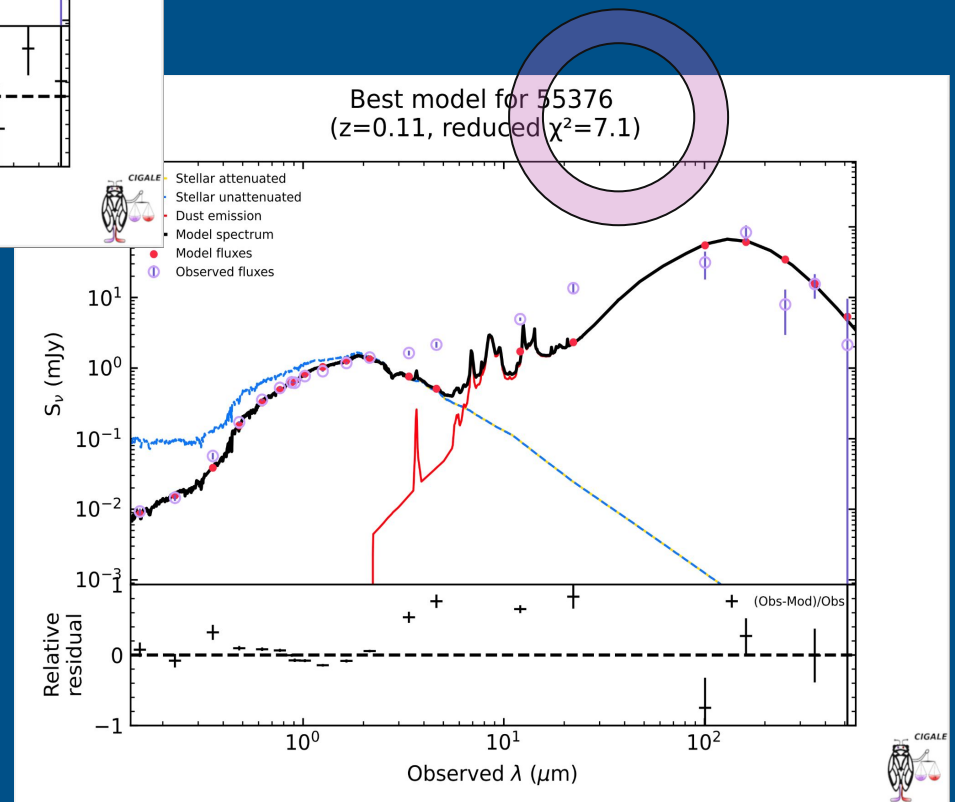
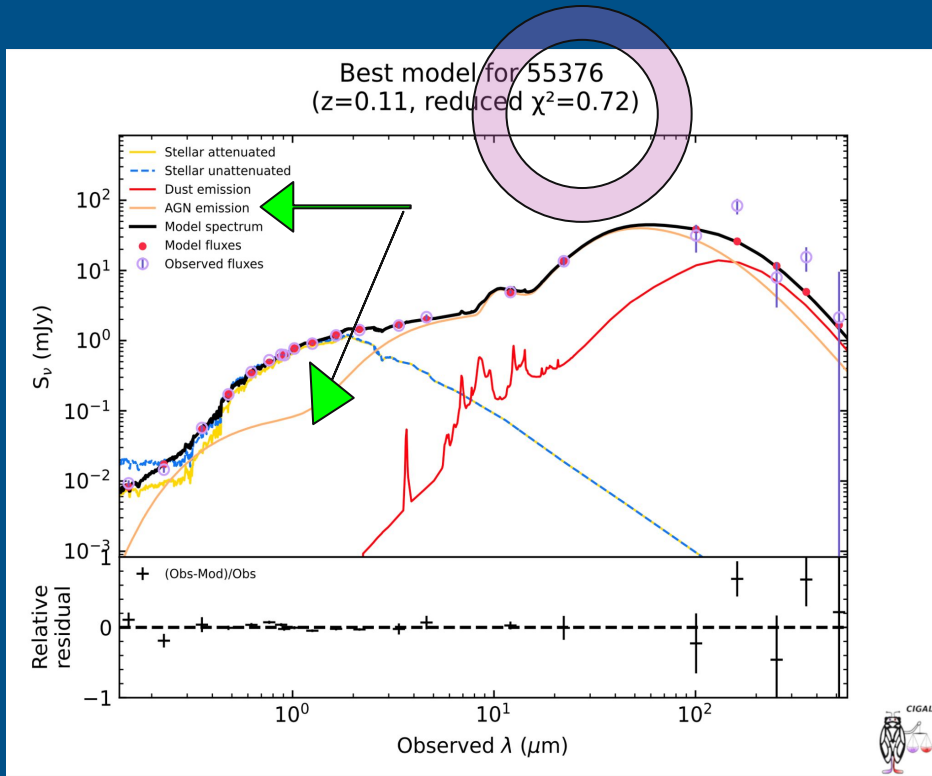


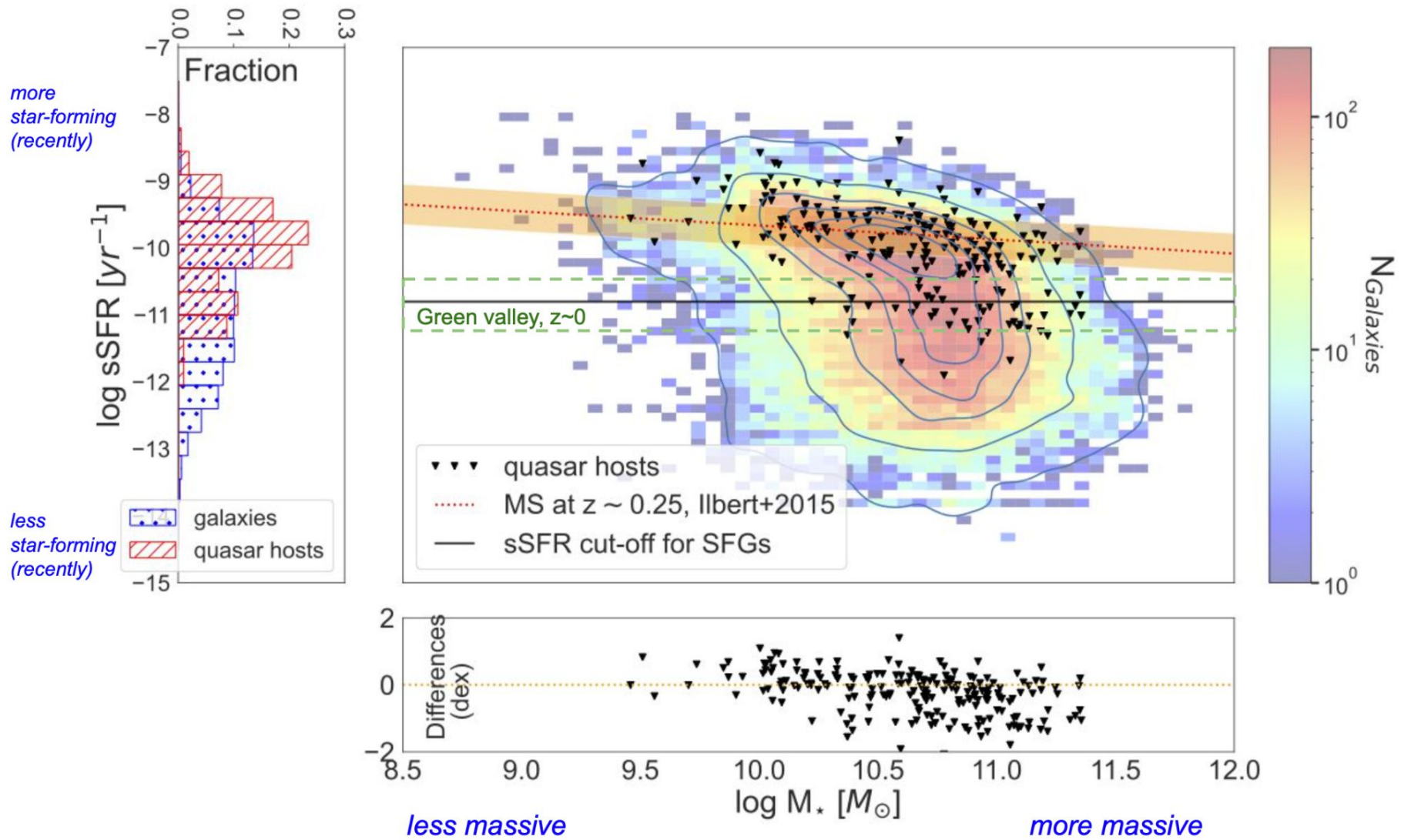
FUV-FIR regime is well-sampled as there is data for 21 photometry bands for all objects

Driver+2016

SED with CIGALE

Quasar example
+/- AGN component





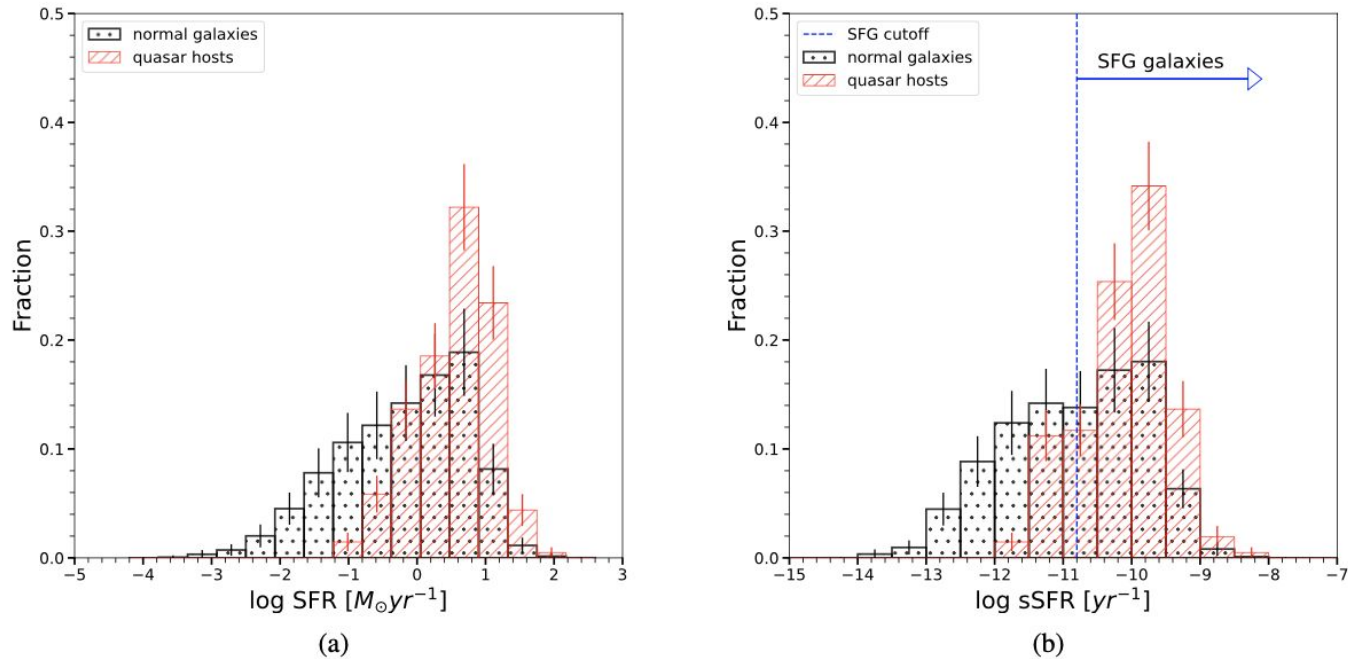


Figure 7. Histograms of SF properties with Poisson error bars: (a) SFR, (b) sSFR. Data for comparison galaxies are from GAMA archive, for quasar hosts from CIGALE SED fits. For quasar hosts, the error bar represents the Poisson error. For comparison galaxies, the plotted fraction in each bin is the average fraction from all 200 realizations, and the error bar represents the standard deviation. In each case, the distribution of values for quasar sample lies in the peak of the normal galaxy distribution. However, there are few quenched AGN hosts.

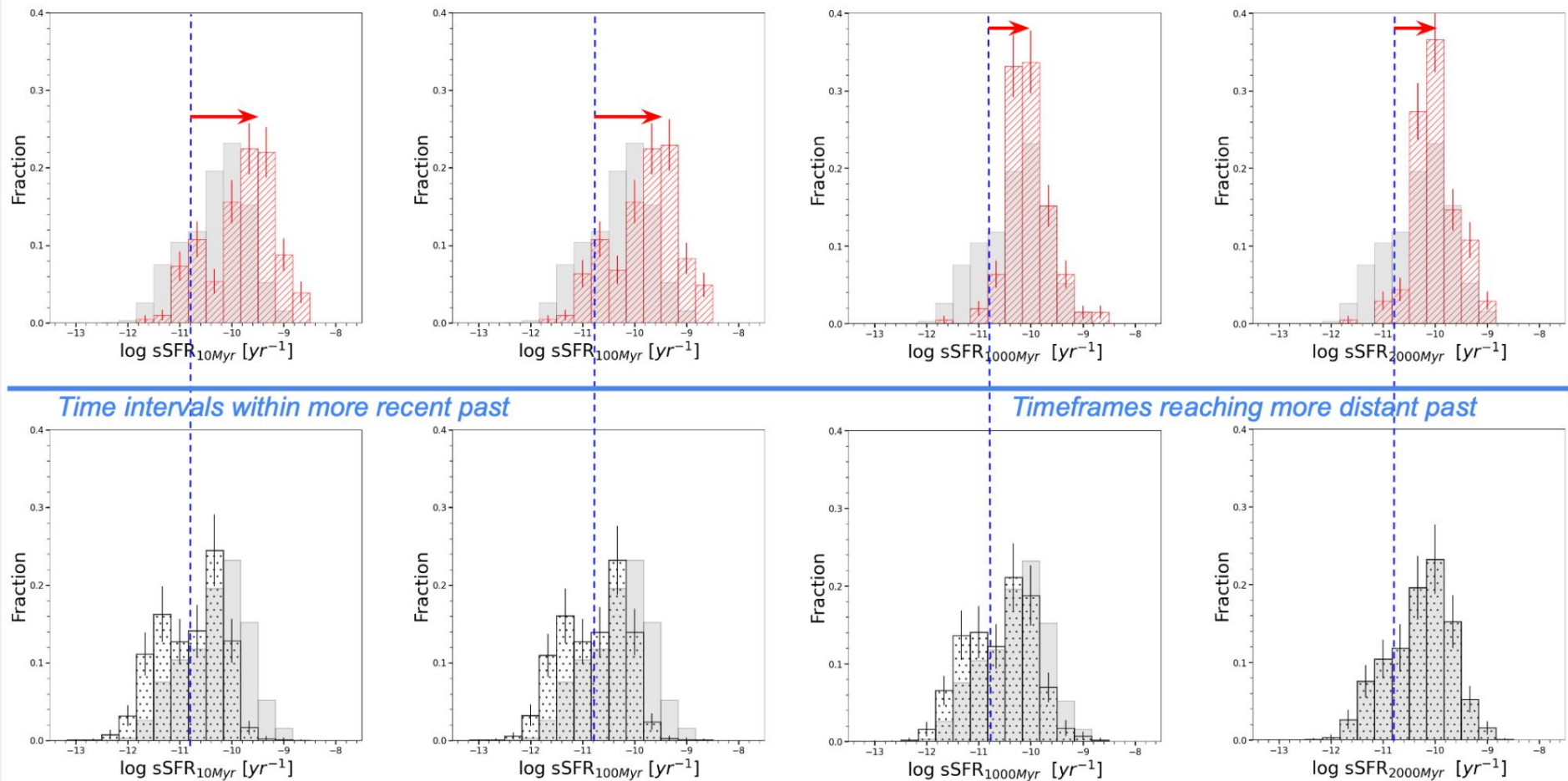


Figure 8. Histograms of sSFR averaged over 10, 100, 1000, and 2000 Myr. For quasars, the error bar represents the Poisson error. For comparison galaxies, the plotted fraction in each bin is the average fraction from all 200 realizations, and the error bar is the standard deviation.

- quasar host galaxies are galaxies which have been star forming for all times previously

Host Galaxy Morphology - METHOD

Apply a simple Hubble classification scheme, similar to Galaxy Zoo (Lintott et al. 2008).

We assess

- whether quasar activity has any preference to be associated with spiral galaxies or elliptical galaxies, and
- how this compares to a control sample of inactive galaxies.

Stone et al., in prep.

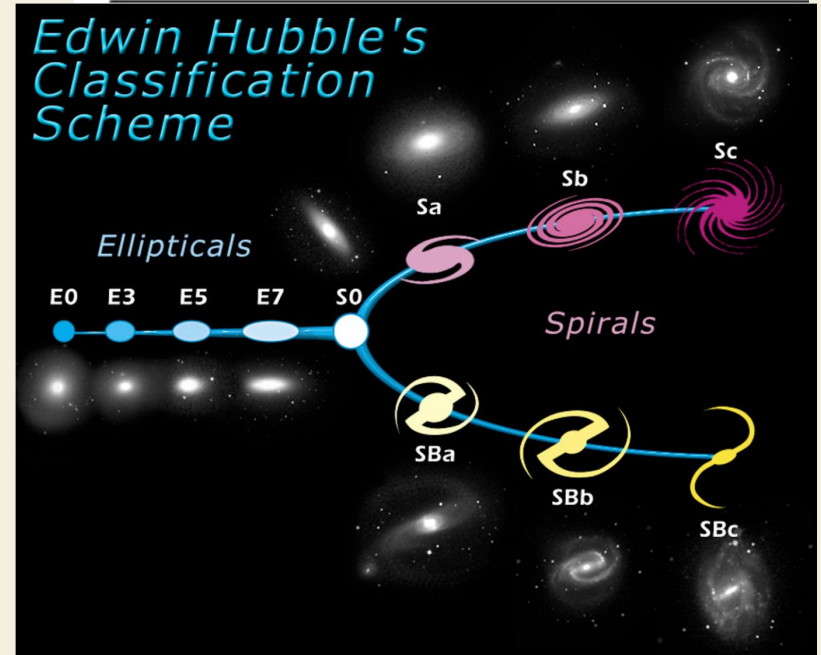
Morphology Class

Early-type (E or S0)

Middle-type (Sa or Sb)

Late-type (Sc or later)

Unknown (Possible merger)



Host Galaxy Morphology – Imaging DATA

We use archival imaging data from the Hyper Suprime Cam archive (*Stone et al., in prep.*)

HSC–SSP photometry in g, r, i bands



Figure 1. Quasar images from SDSS DR16, PANSTARRS DR2, and HSC PDR3 archives (from left to right respectively). The PANSTARRS and HSC image cutouts have 30 arcsec sides. GAMA CATAID 30887.

Host Morphology - Preliminary Results

Our findings are that quasar host galaxies are mostly middle or late type spirals, as compared to the inactive galaxies, where most galaxies fall into the early type category.

Spiral galaxies usually have some level of star formation, so these morphological results echo similar observation that the nuclear activity is turned on in galaxies which also have an on-going star formation processes.

In both quasar and inactive galaxy samples, merging galaxies or galaxies with peculiar features were observed at various degrees.

On-going validation of the method, by estimating the Sersic index with a rough GALFIT decomposition.

Table 5. The number (and fraction) of objects in each morphology type.

Sample	E/S0	Sa/Sb	Sc/late	Unknown
Quasars				
SAMPLE A	80 (39.0±0.2%)	85 (41.5±0.2%)	28 (13.7±0.1%)	12 (5.9±0.0%)
Galaxies				
Average of all samples	125.7 (61.63±0.3%)	43.3 (21.1±0.1%)	27.3 (13.3±0.1%)	9 (4.2±0.0%)

CONCLUSIONS

- For AGN host SF properties, our main conclusion is that most (80%) quasars lie on the star forming main sequence for normal galaxies and 20% are hosted in quenching or quenched systems.
- The SFHs of these galaxies show that they have generally been SFGs over the past 2~Gyr but have experienced a modest star formation increase (by a factor of 2–3) over the past 100~Myr.
- **This finding suggests that AGN activity is more likely to be triggered by internal or secular processes, with major mergers playing only a minor role.**
- *On-going work on host morphology: Compared to the inactive galaxies, quasar hosts have more disk-type morphologies than early-type. More than twice the number of quasar hosts are in the Unknown category.*

Future extensions

- Low surface brightness domain, to observationally address the minor merger scenario



(c) Interaction/"Merger"



- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(b) "Small Group"



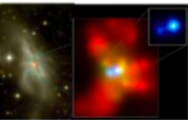
- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{sub} still similar to before: dynamical friction merges the subhalos efficiently

(a) Isolated Disk



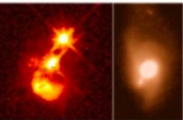
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_{\text{BH}} > 23$)
- cannot redden to the red sequence

(d) Coalescence/(U)LIRG



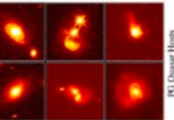
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



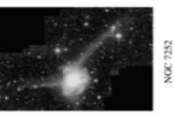
- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(g) Decay/K+A

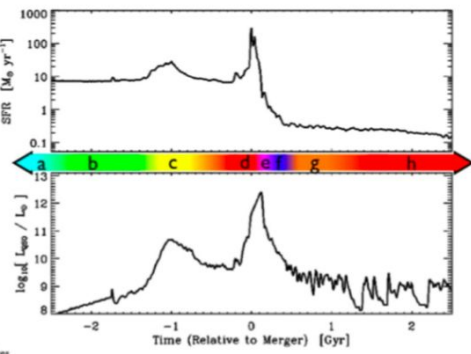


- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

(h) "Dead" Elliptical

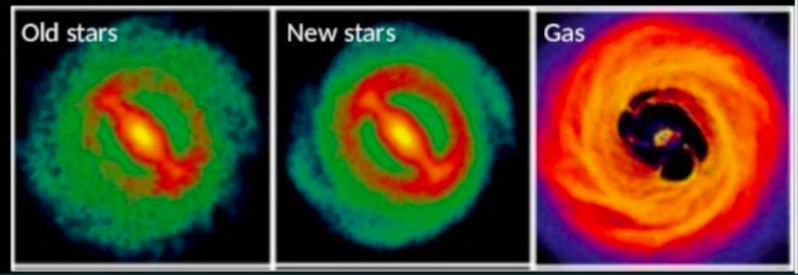


- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers



Hopkins+2008, NOAO

Disc instabilities, bars, spiral arms. Credit: Karen Masters, simulation from Athanassoula+2013



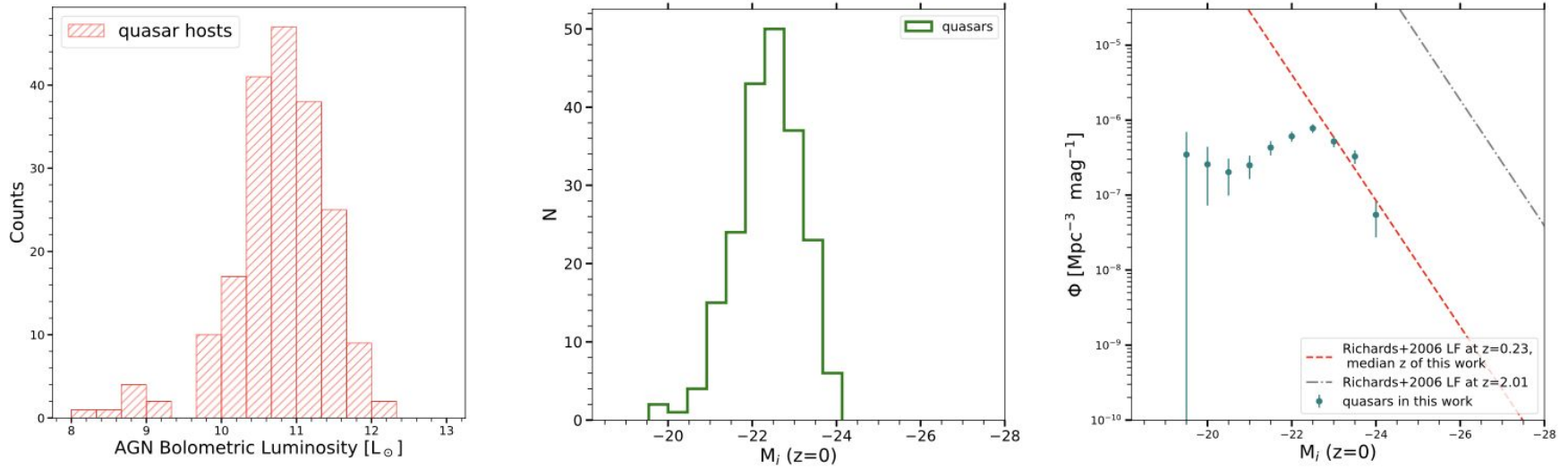


Figure 5. *Left* The distribution of bolometric luminosities for quasars derived from CIGALE fits. This excludes 8 quasars (3.9 % of quasar sample) where CIGALE did not return a quasar luminosity. *Middle* The distribution of absolute SDSS i band magnitude (k -corrected and extinction corrected based on GAMA survey data). *Right* Optical luminosity function of quasars. Bin width of 0.5 mag. The errors are based on Poisson statistics.

Table 2. Model parameters for SED fitting with CIGALE in this work. The AGN component (SKIRTOR) was included only for quasar fits. For further details on the parameters, see the CIGALE manual and Boquien et al. 2019; Yang et al. 2022.

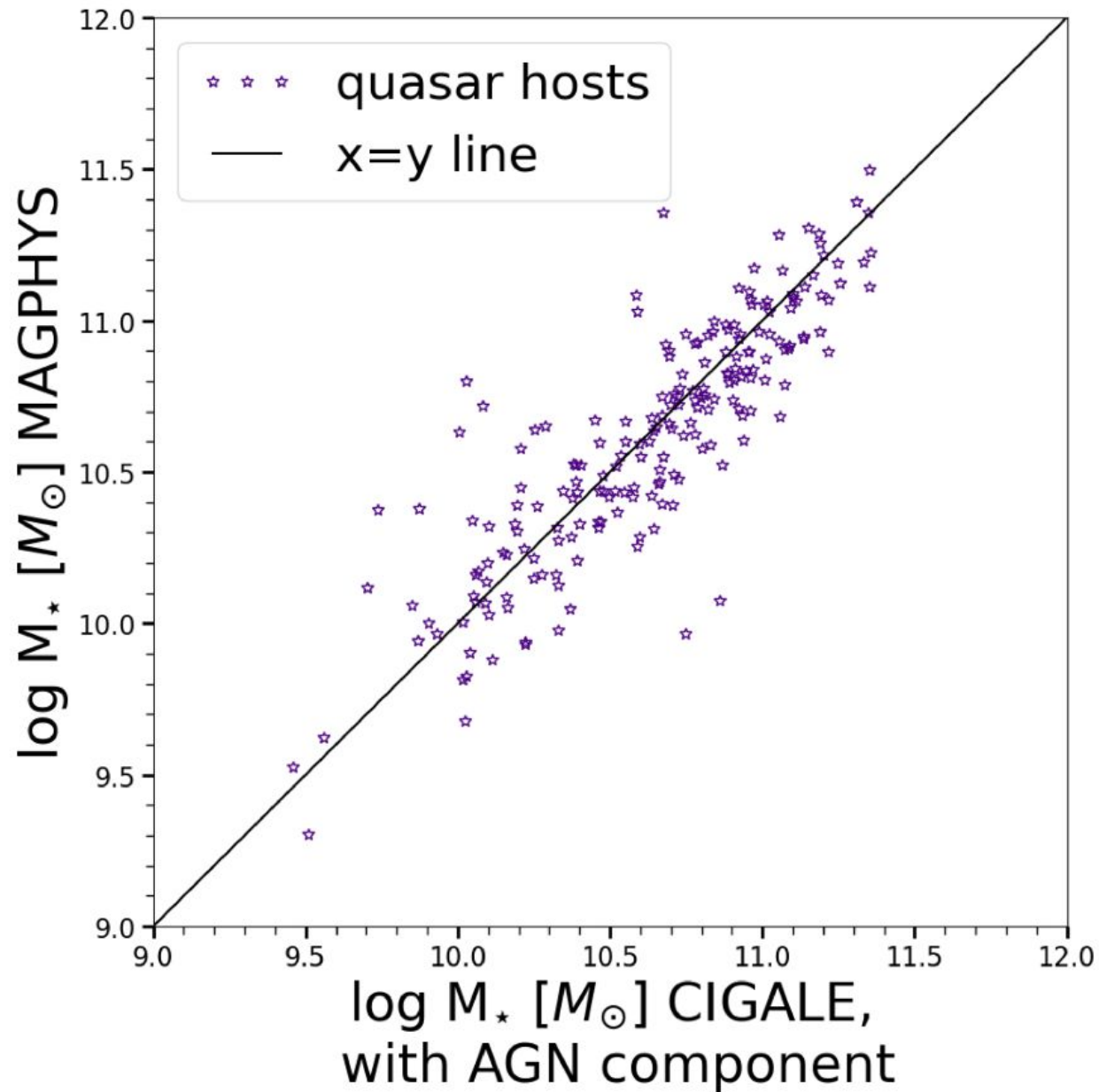
Module and Parameter (Symbol)	References and Values
SFH	<i>Delayed SFH with an optional recent burst</i>
Age of the main population (Myr)	3000, 5000, 7000, 8000, 9000, 10000
e-folding time of the main population (Myr), τ_{main}	1000, 3000, 5000, 8000, 10000
Age of the recent burst (Myr)	50, 20000 (continuous SFH)
e-folding time of the burst (Myr)	50, 500
Burst mass fraction	0.0, 0.1
SSP	<i>Bruzual & Charlot (2003)</i>
Initial mass function (IMF)	Chabrier (2003)
Metallicity (Z)	0.02 (Solar)
Galactic dust attenuation	<i>Modified Calzetti (2000) attenuation law</i>
Color excess of nebular lines	0.1, 0.2, 0.3, 0.4, 0.5, 0.6
Reduction factor	0.44
Slope of the power law	-0.2, 0.0
Galactic dust emission	<i>Dale et al. (2014)</i>
Alpha slope	2.0
AGN (UV-to-IR)	<i>SKIRTOR (Stalevski et al. 2012, 2016)</i>
Viewing Angle	30° (Type I)
Delta	-1,-0.9,-0.8,-0.7,-0.6,-0.5,-0.4,-0.3,-0.2,-0.1,0.1,0.6
AGN fraction	0.0,0.01,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,0.99
$E(B - V)$ (magnitudes)	0., 0.05, 0.1, 0.2, 0.4, 0.6
Extinction law of polar dust	Small Magellanic Cloud

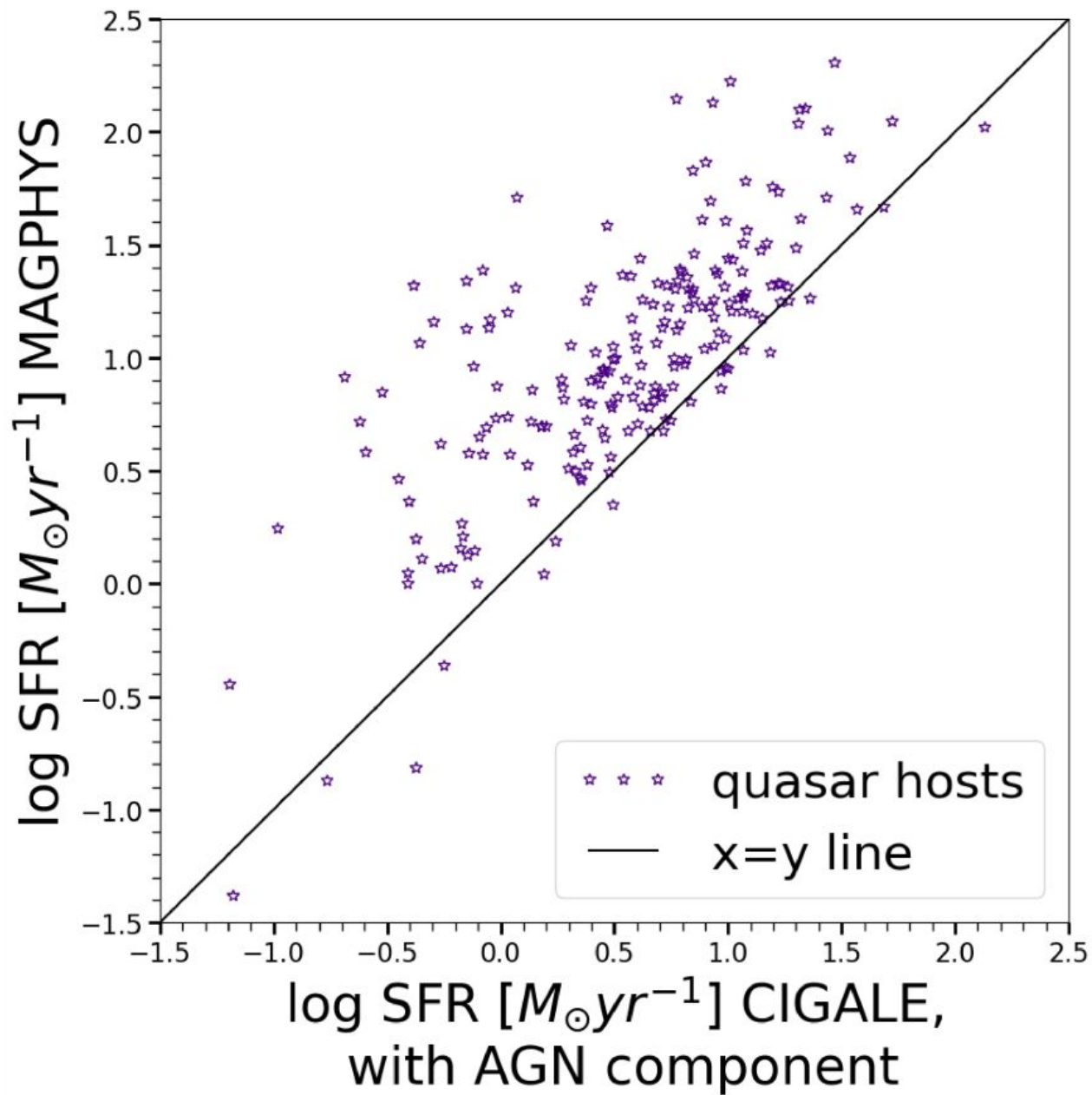
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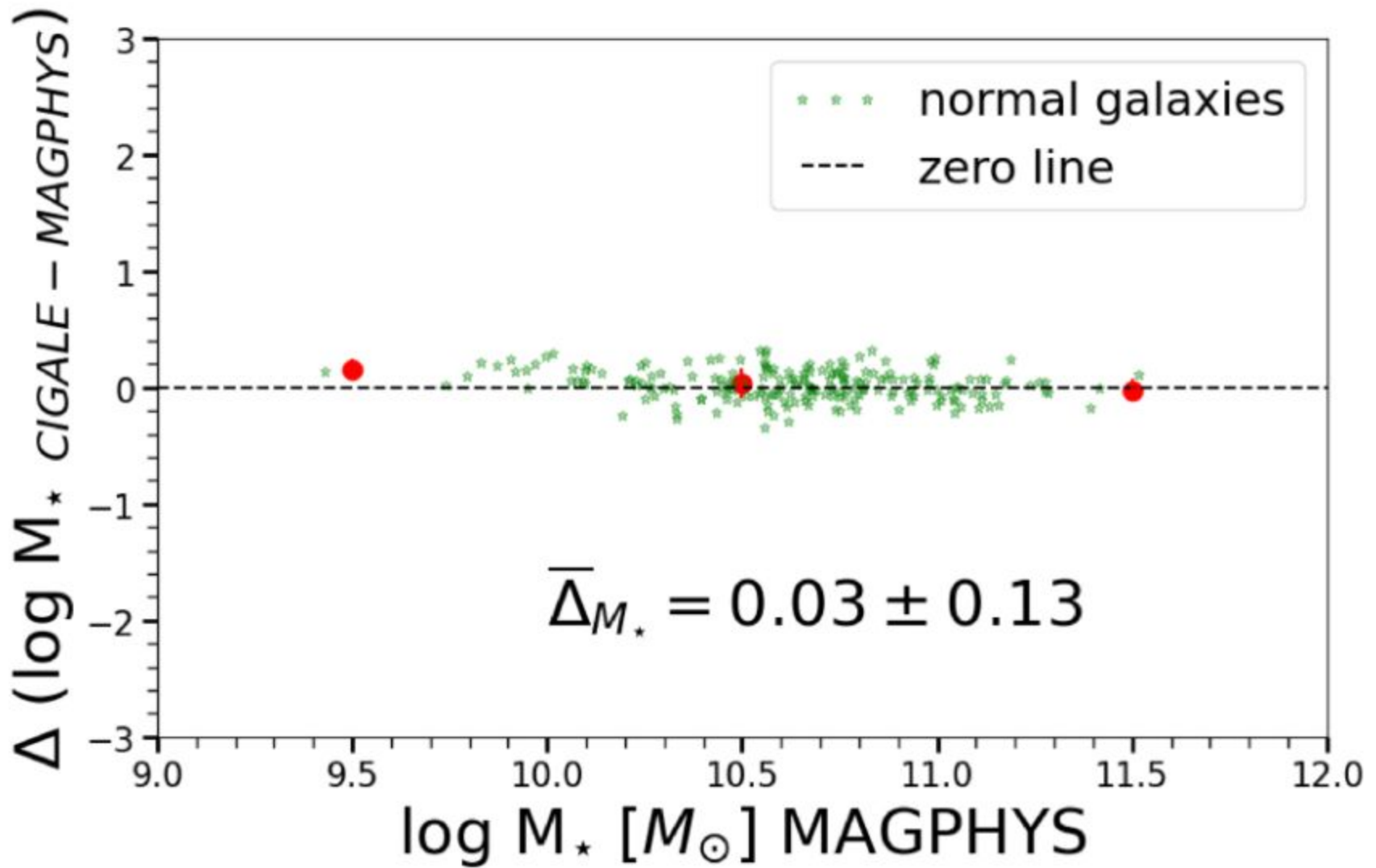
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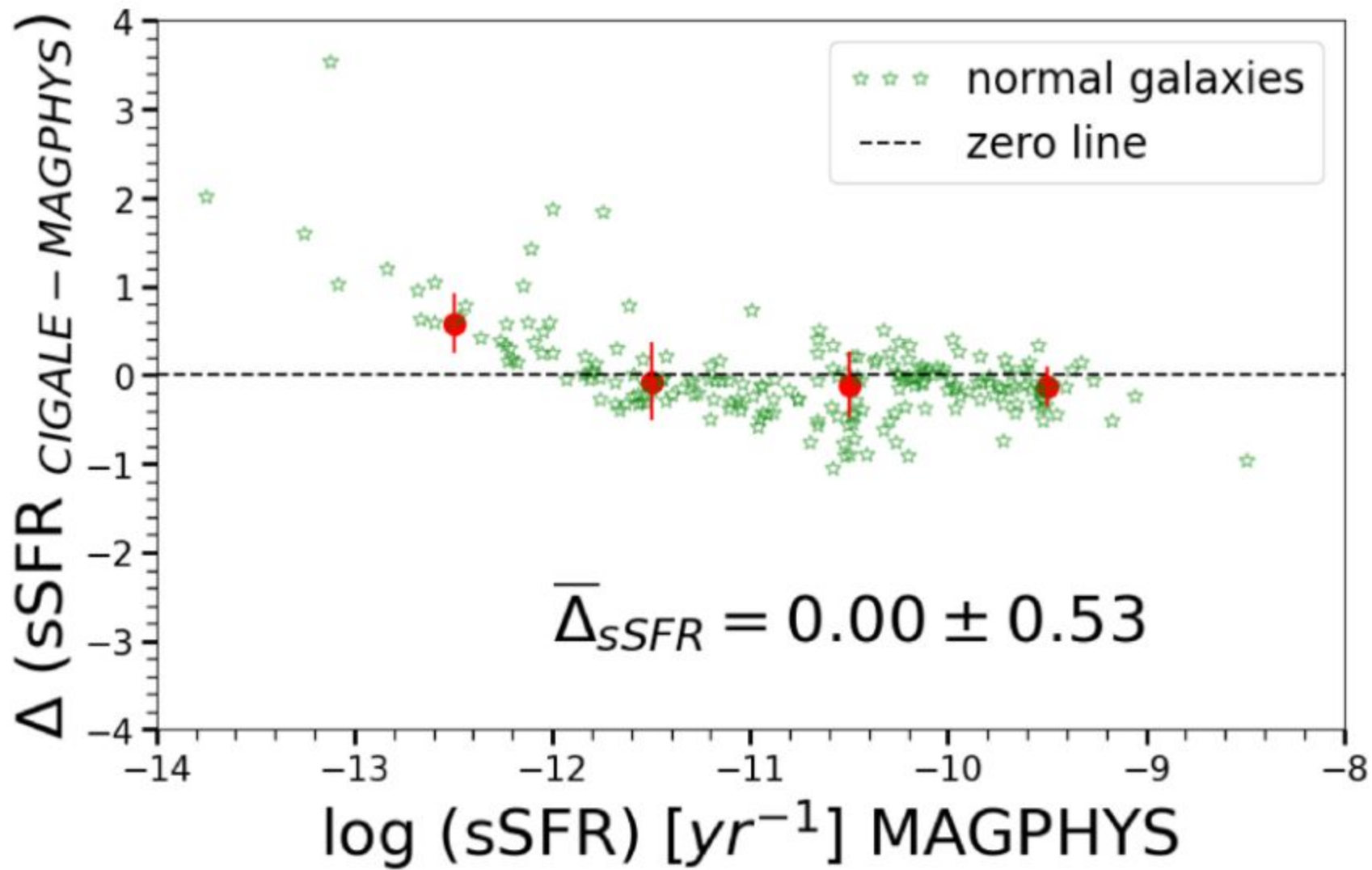
Parameter	MAGPHYS fits in GAMA (Driver et al. 2018)	Contrast with CIGALE fits in this study
IMF	Chabrier (2003)	same
SFH	Single (exponentially decaying) SFH	different
SSP	BC03 models (Bruzual & Charlot 2003)	same
Dust Attenuation Law	Charlot & Fall (2000)	different
Metallicity	a wide range of values	a single value

Table 4. Comparison of the main ingoing assumptions between CIGALE and MAGPHYS SED codes. The full set of parameters in our CIGALE runs are given in § 2, Table 2. The MAGPHYS fitting process for GAMA survey are described in more detail in (Driver et al. 2018).









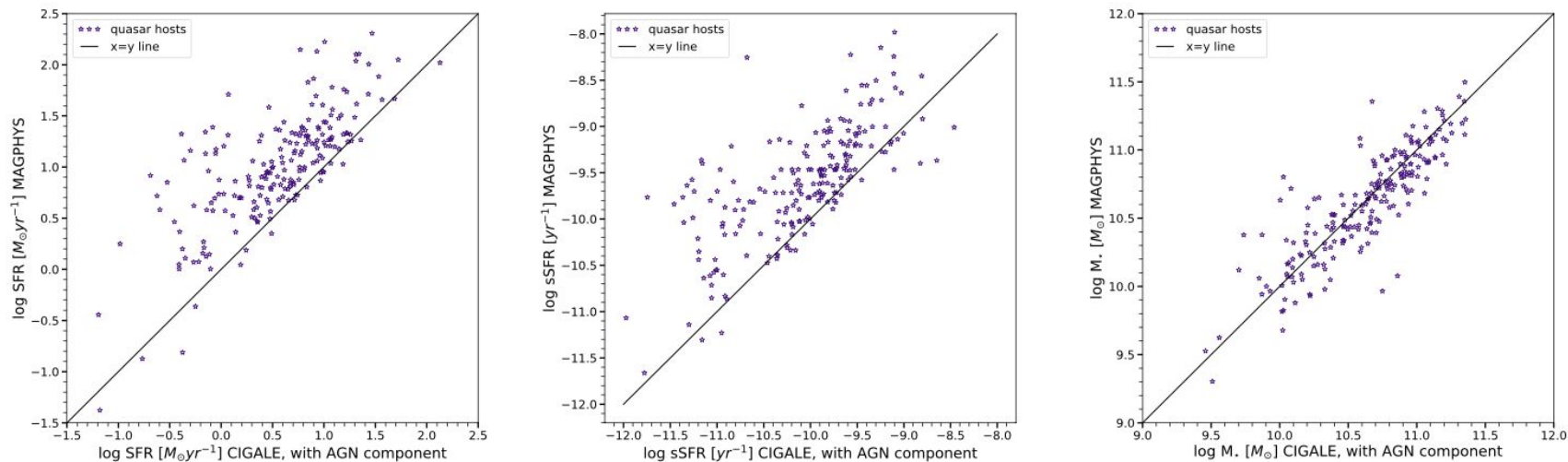


Figure 2. Comparison between the MAGPHYS SED fitting results (no AGN component) and CIGALE SED fitting results (including an AGN component) for SFR, sSFR, and stellar mass for the sample of quasar host galaxies (Wethers et al. 2022; Stone et al. 2023).

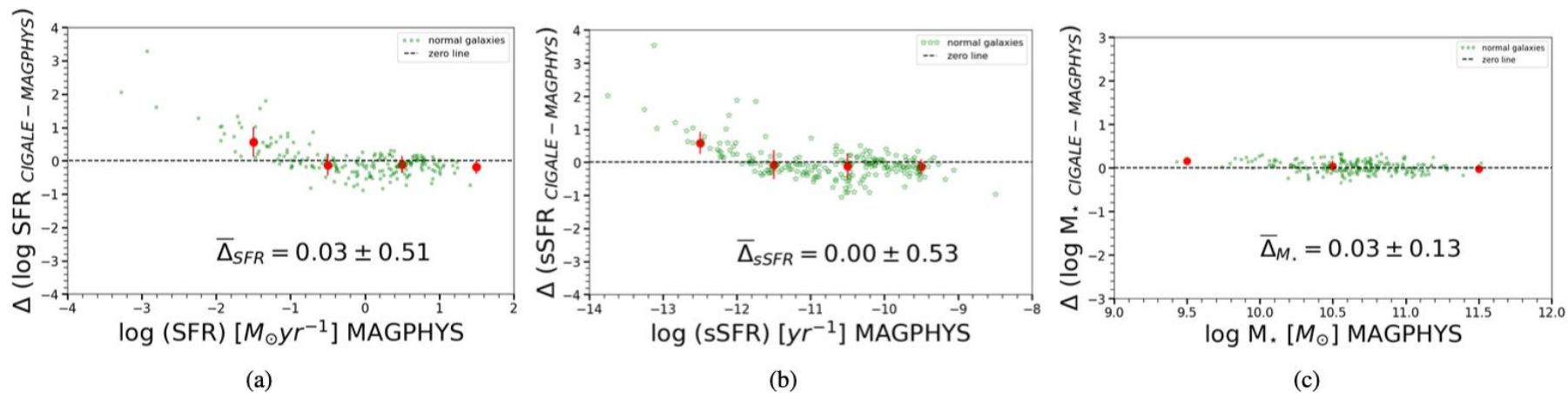


Figure 3. Differences (Δ) comparing the MAGPHYS and CIGALE SED fitting results (without AGN component) for (a) SFR, (b) sSFR, and (c) stellar mass for inactive galaxies. The red filled circles represent the median difference in each 1 dex bin of SFR, excluding the bins with small number statistics. Error bars reflect the standard deviation in that bin.

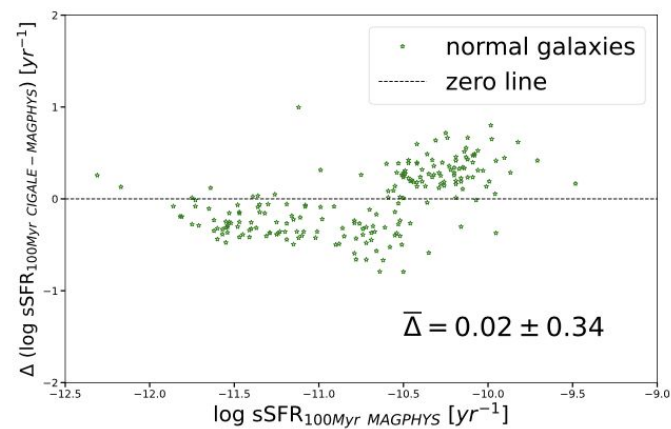
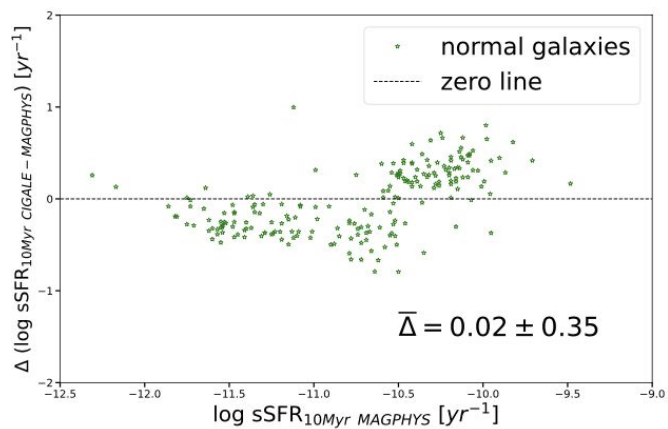
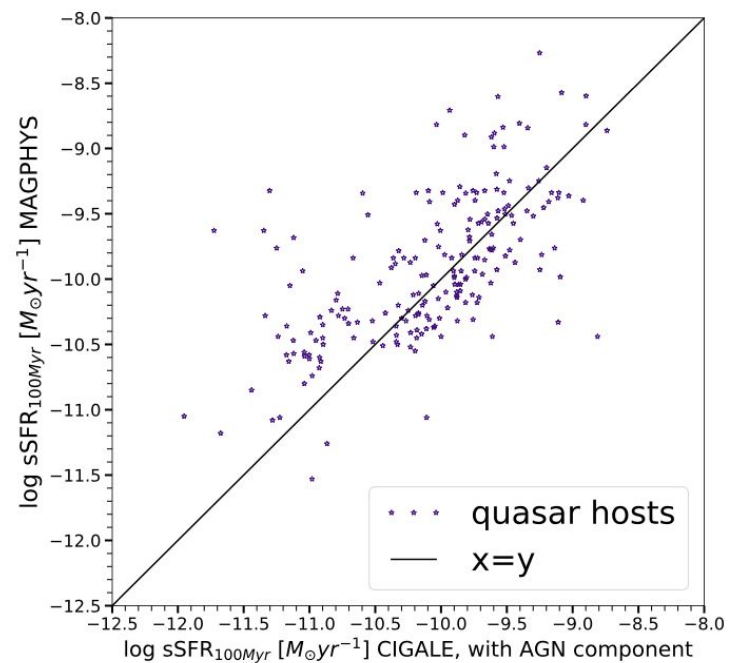
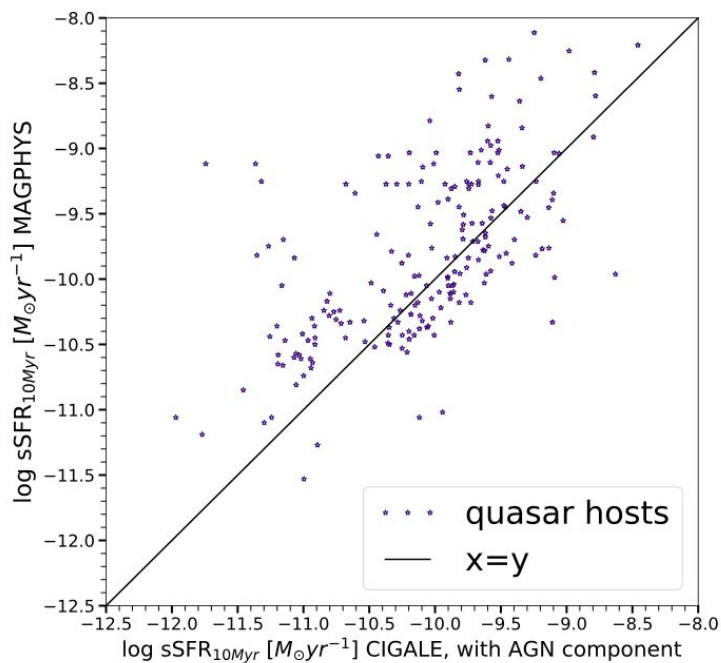
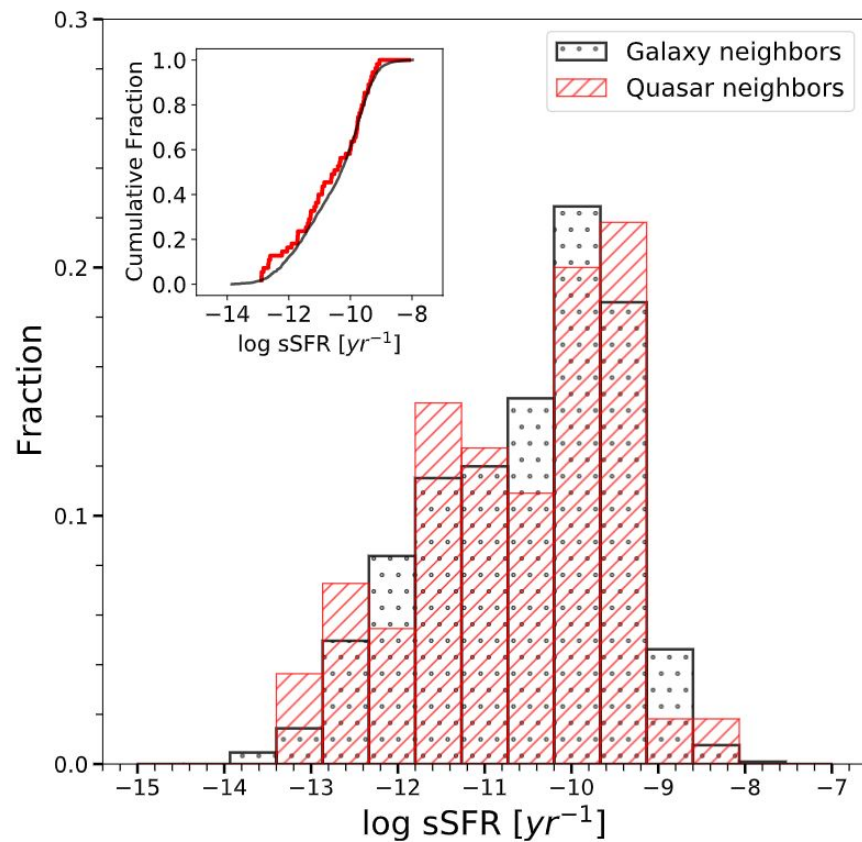
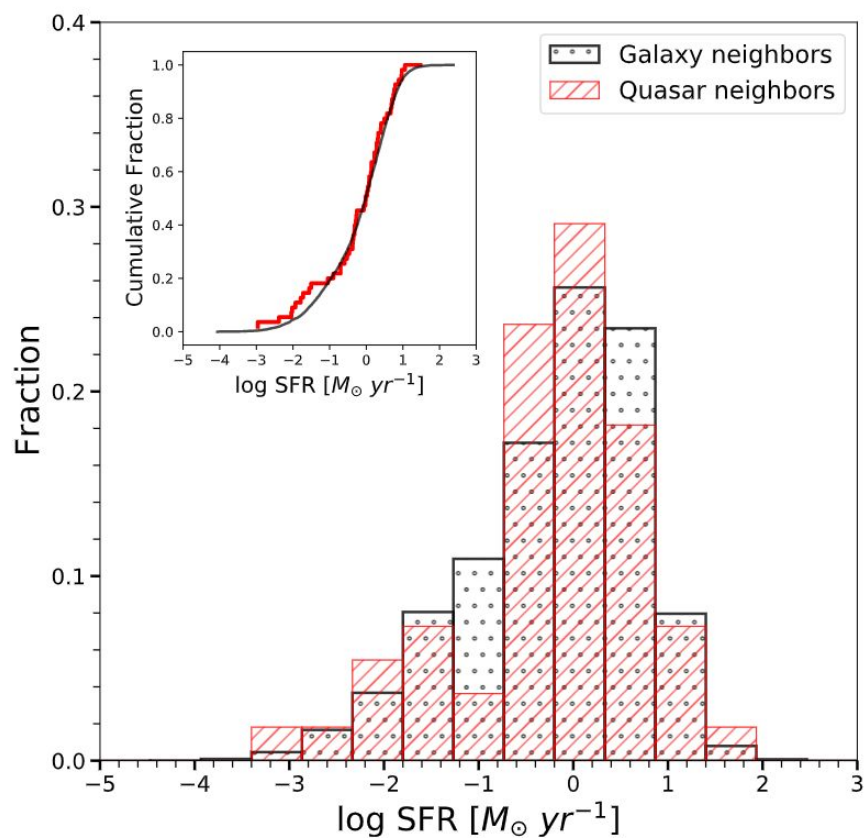
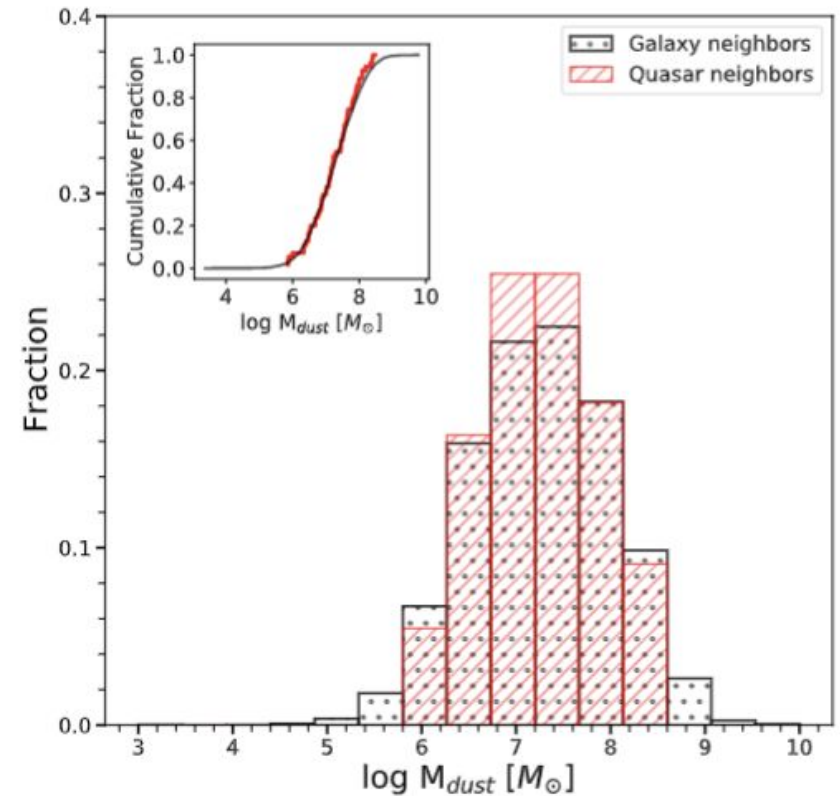
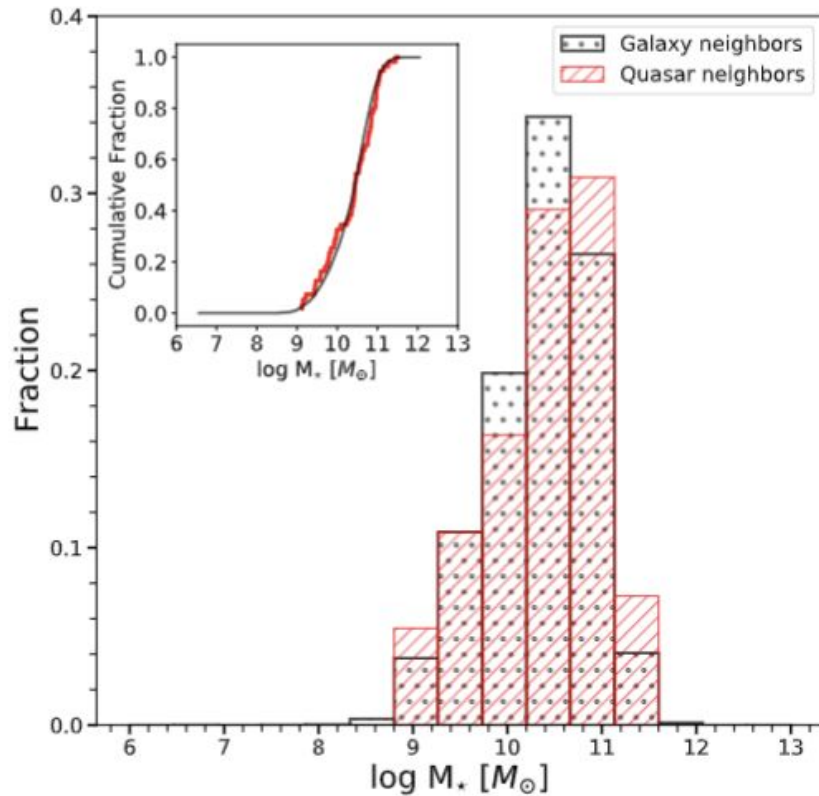


Figure 4. *Top*—Comparison between the MAGPHYS (no AGN component) and CIGALE (with AGN component) SED fitting results for sSFR averaged over the past 10 and 100 Myr, for quasar hosts. *Bottom*—Differences (Δ) between CIGALE and MAGPHYS estimates for inactive galaxies (without AGN component).

Results



Results



KS Test Results

Table 1
KS and AD Test Results

Property	Units	Statistic $D_{KS} (A_k)$	p -value $p_{KS} (p_{AD})$	Figure	Ref.
MORPHOLOGY from Sérsic photometry DMU					1,4,5
Sérsic index (n)	...	0.15 (-0.4)	0.12 (0.25)	Fig. 3	
COLORS from LambdaPhotometry DMU					2,6
SDSS $u - r$	...	0.08 (-0.6)	0.80 (0.25)	Fig. A.1	
SDSS $g - r$	...	0.10 (-0.5)	0.54 (0.25)	Fig. A.2	
<i>GALEX</i> $NUV - SDSS r$	...	0.09 (-0.7)	0.77 (0.25)	Fig. A.3	
SFH & PHYSICAL PARAMETERS from MagPhys DMU					1,3
SFR	$M_{\odot} \text{ yr}^{-1}$	0.06 (-0.9)	0.96 (0.25)	Fig. A.4a	
Specific SFR (sSFR)	yr^{-1}	0.07 (-0.7)	0.89 (0.25)	Fig. A.4b	
SFR _{ave} over the last 10^7 yr	$M_{\odot} \text{ yr}^{-1}$	0.07 (-0.2)	0.88 (0.25)	Fig. A.5a	
SFR _{ave} over the last 10^8 yr	$M_{\odot} \text{ yr}^{-1}$	0.07 (-0.7)	0.86 (0.25)	Fig. A.5b	
SFR _{ave} over the last 10^9 yr	$M_{\odot} \text{ yr}^{-1}$	0.09 (-0.5)	0.67 (0.25)	Fig. A.5c	
SFR _{ave} over the last 2×10^9 yr	$M_{\odot} \text{ yr}^{-1}$	0.11 (-0.1)	0.37 (0.25)	Fig. A.5d	
SF timescale	Gyr^{-1}	0.08 (-0.8)	0.73 (0.25)	Fig. A.6a	
Time since the last burst of SF ended	dex(yr)	0.09 (-0.6)	0.64 (0.25)	Fig. A.6b	
Total M_{\star} ever formed (integral of the SFR)	M_{\odot}	0.12 (0.1)	0.32 (0.25)	Fig. A.7a	
Total mass of dust	M_{\odot}	0.05 (-0.9)	0.99 (0.25)	Fig. A.7b	
Fraction of mass formed in bursts over the last 10^7 yr	...	0.04 (18.9)	0.99 (0.001)	Fig. A.8a	
Fraction of mass formed in bursts over the last 10^8 yr	...	0.04 (6.0)	0.99 (0.001)	Fig. A.8b	
Fraction of mass formed in bursts over the last 10^9 yr	...	0.08 (-0.3)	0.84 (0.25)	Fig. A.8c	
Fraction of mass formed in bursts over the last 2×10^9 yr	...	0.15 (0.4)	0.12 (0.22)	Fig. A.8d	
Age of the oldest stars in the galaxy	dex(yr)	0.07 (-0.9)	0.88 (0.25)	Fig. A.9a	
Metallicity	Z_{\odot}	0.12 (-0.2)	0.33 (0.25)	Fig. A.9b	

Table 3
Model Parameters for SED Fitting with CIGALE

Module and Parameter (Symbol)	References and Values
SFH	<i>Delayed SFH with an optional recent burst</i>
Age of the main population (Myr)	3000, 5000, 7000, 8000, 9000, 10,000
e-folding time of the main population (Myr), τ_{main}	1000, 3000, 5000, 8000, 10,000
Age of the recent burst (Myr)	50, 20,000 (continuous SFH)
e-folding time of the burst (Myr)	50, 500
Burst mass fraction	0.0, 0.1
SSP	G. Bruzual & S. Charlot (2003)
IMF	G. Chabrier (2003)
Metallicity (Z)	0.02 (Solar)
Galactic dust attenuation	<i>D. Calzetti (2000) attenuation law</i>
Color excess of nebular lines	0.1, 0.2, 0.3, 0.4, 0.5, 0.6
Reduction factor	0.44
Slope of the power law	-0.2, 0.0
Galactic dust emission	D. A. Dale et al. (2014)
Alpha slope	2.0
AGN (UV to IR)	<i>SKIRTOR</i> (M. Stalevski et al. 2012, 2016)
Viewing Angle	30° (Type I)
Delta	-1, -0.9, -0.8, -0.7, -0.6, -0.5, -0.4, -0.3, -0.2, -0.1, 0.1, 0.6
AGN fraction	0.0, 0.01, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.99
$E(B - V)$ (magnitudes)	0., 0.05, 0.1, 0.2, 0.4, 0.6
Extinction law of polar dust	Small Magellanic Cloud

Note. Column (1): list of parameters in each module of the CIGALE SED tool used in this work. Column (2): parameter values adopted in our SED analysis with the CIGALE tool. The AGN component (SKIRTOR) was included only for quasar fits. For further details on the parameters, see the CIGALE manual and M. Boquien et al. (2019), G. Yang et al. (2022).