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Galaxy and Mass Assembly (GAMA) survey: comparing neighborhoods of low-redshift quasars (0.1<z<0.3) and inactive galaxies through Monte Carlo simulation

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I am an Astronomy PhD student with background in Molecular Biology and French and a rich work experience. My doctoral thesis topic is “Galaxy evolution through the lens of active galactic nuclei (their host galaxies, supermassive black holes, and environments)”. My career goal is to continue astronomy research as a postdoc in the field of galaxy formation and evolution, using observational data. My value is to have family/work balance. I enjoy exploring nature and languages.

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and EDUFI fellowship (Finnish National Agency for Education).

Education and degrees awarded

2017-present	Ph.D., Astronomy, University of Turku, Finland
2017	MS Physics, MA French, San José State University (SJSU), California, USA
2010	BS Molecular Biology, BA French, Chemistry Minor, SJSU, California, USA, Cum Laude

Stone, Maria Babakhanyan, "Master's Thesis: Comparative Study of Broadband Photometry Relations for Ultra-Diffuse and Normal Galaxies in the Coma Cluster" (2017). Master's Theses. 4823. San José State University.

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What is the role of SMBH activity in the evolution of galaxies?

- Massive galaxies harbor supermassive black holes (SMBH) in their center. The so called active galactic nuclei (AGN) are a small percentage of galaxies with SMBH which are actively accreting matter.
- *How do AGN get triggered? What role does this activity play in the evolution of galaxies? What impact do SMBH have on their environment at different scales?*
- Through cosmological simulations, AGN feedback is considered to deposit energy and momentum into the interstellar medium (Somerville & Dave 2015; Naab & Ostriker 2017).
- Minor and major merger simulations are proposed to be one method of AGN triggering (King & Pounds 2015). Galaxy collision simulations reveal star formation bursts and strong inflows of material, which could serve as fuel for feeding the AGN (Di Matteo, Springel & Hernquist 2005).
- Secular processes (such as bar instabilities) are an alternative scenario for AGN triggering (Hopkins & Hernquist 2006).
- *How are different properties of neighboring galaxies affected by the AGN activity? Do AGN affect the star formation in the neighboring galaxies? (e.g. via jets Blandford et al. 2019).*
- In my PhD research, I explore the AGN and their environments. For low-redshift quasars from the SDSS Stripe 82, the study by Karhunen et al. 2014 suggests that the local environment of quasars has only weak contribution to the triggering and fuelling the AGN. For the same sample of quasars, Stone et al. 2021 showed that the SFR of the companion galaxies is modest.
- In the project presented here, we exploit the GAMA survey data to have a larger sample (Wethers et al. in preparation). We also have a control group of normal galaxies of the same mass and redshift, to have a sound comparison between the quasar neighborhood and the neighborhood of normal galaxies.

Environment

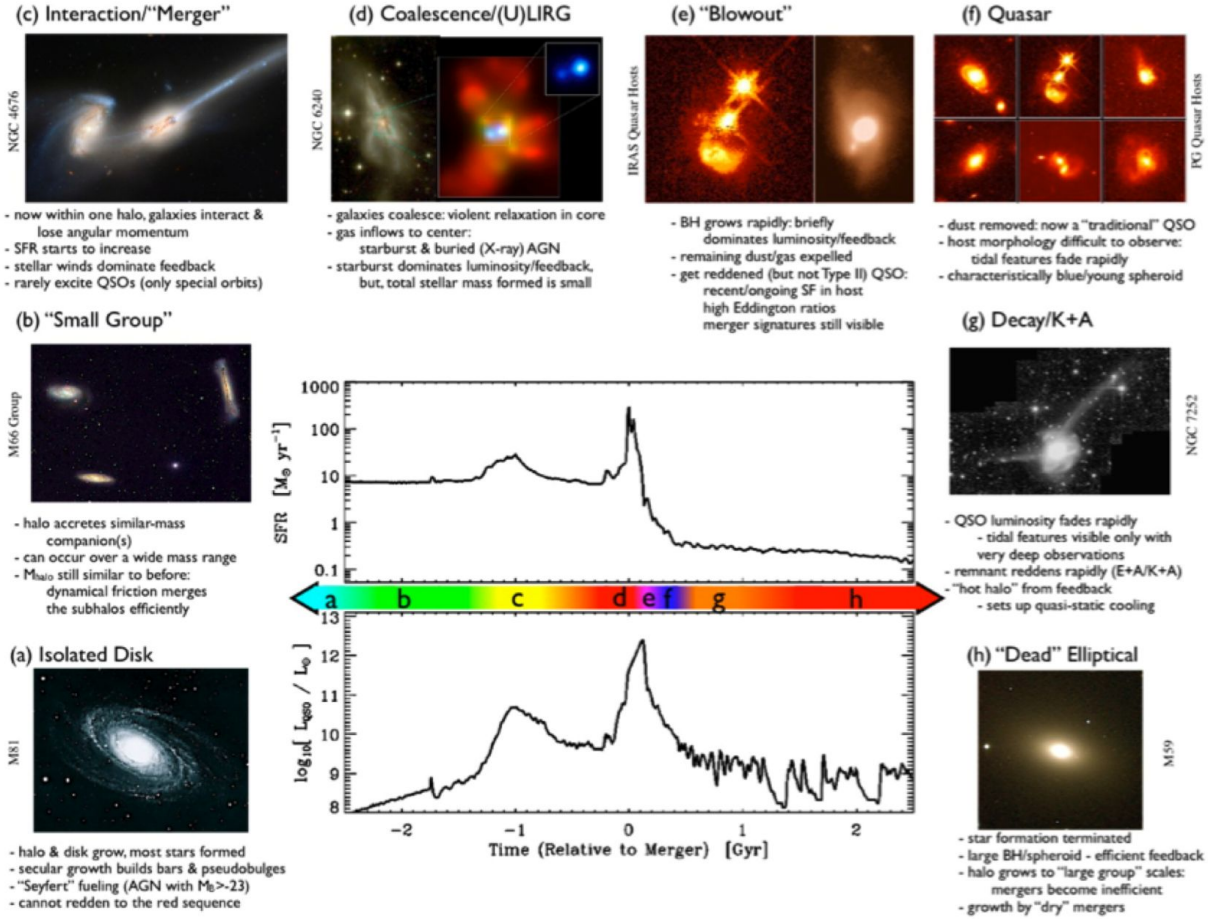
quasar / inactive galaxy?
different scales
number density
Large Scale Structure
...

Ignition?

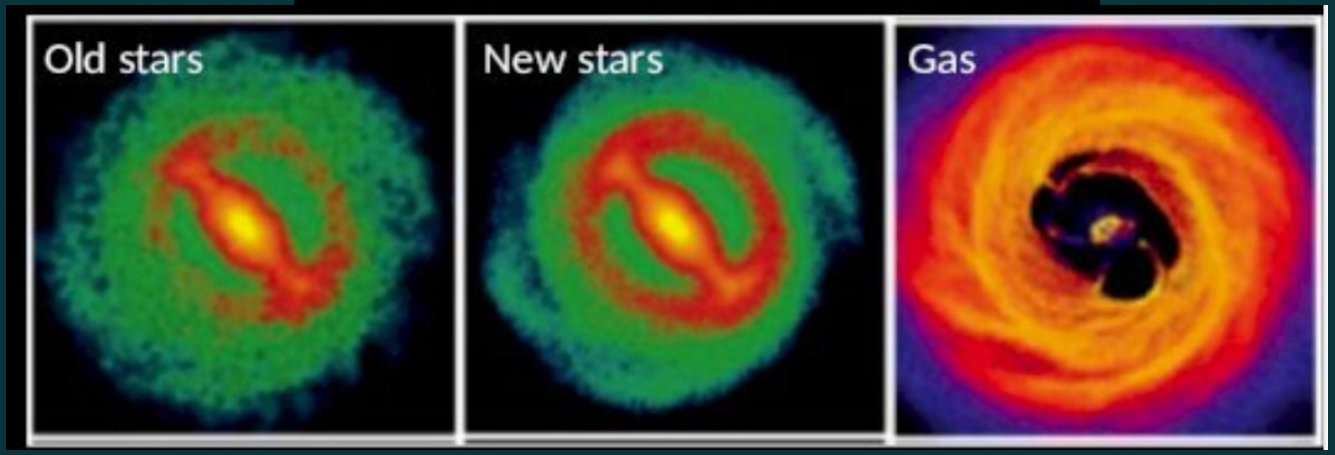
Mergers or Secular

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

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



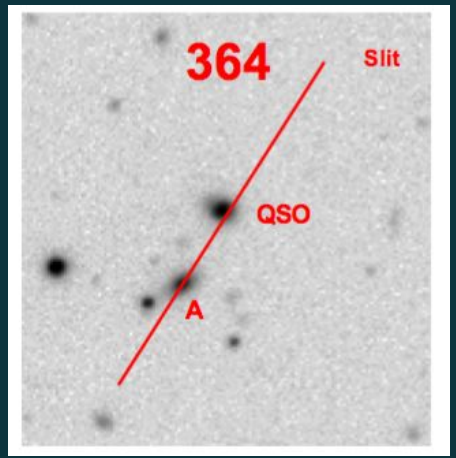
Hopkins+2008, NOAO

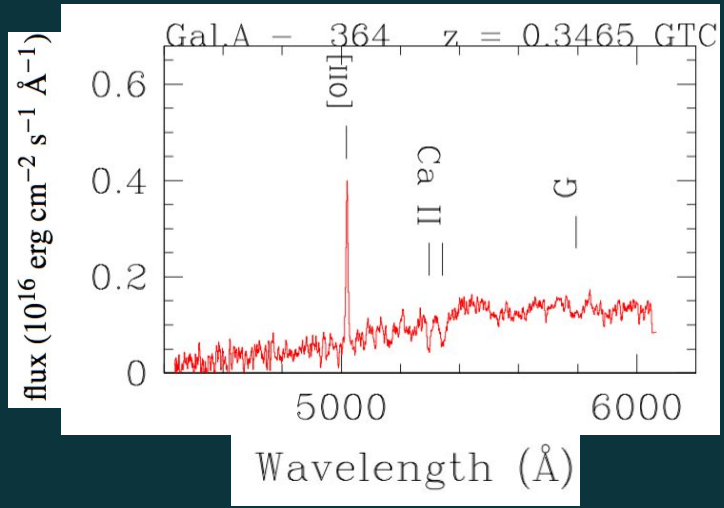


Disc instabilities, bars, spiral arms. Credit: Karen Masters, simulation from Athanassoula+2013

What can we learn from observations of close environments of quasars
~ about the fueling of the nuclear activity?
~ and about the star formation in the neighboring galaxies?
(Stone et al. 2021, MNRAS)

- *Spectroscopic Survey of 34 quasar fields (Bettoni+2017, Stone+2021)*
- *0.2<z<0.5*
- *neighborhoods within about 300 kpc Projected Distance*
- Main Collaborators: Daniela Bettoni, Renato Falomo from INAF Padova





RESULTS

- *redshifts of 56 candidate companion galaxies*
- *15/34 quasars had an associated companion galaxy*

what does this mean?

Stone+2021 MNRAS

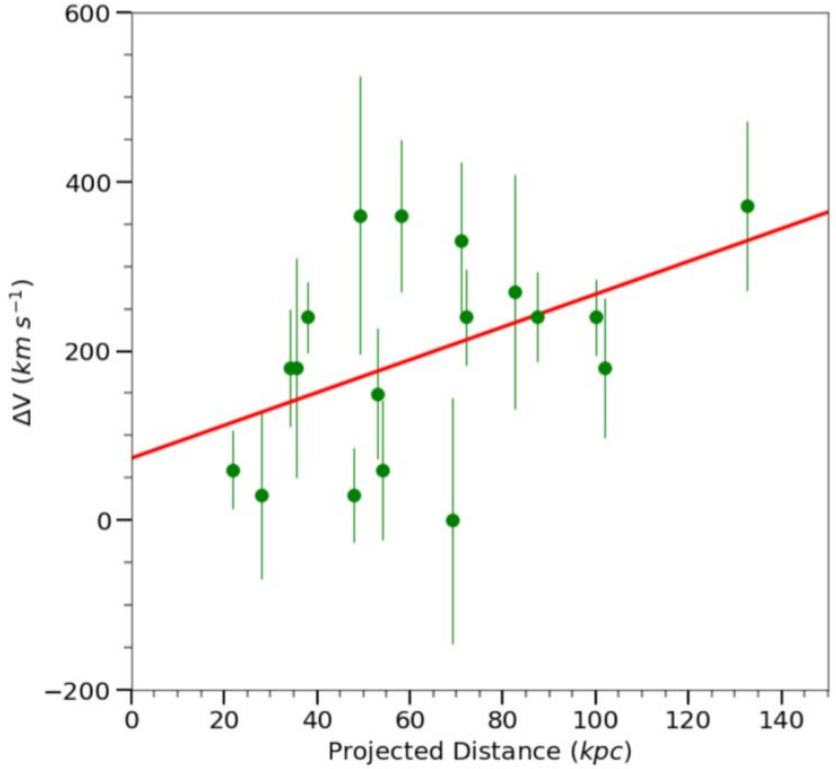
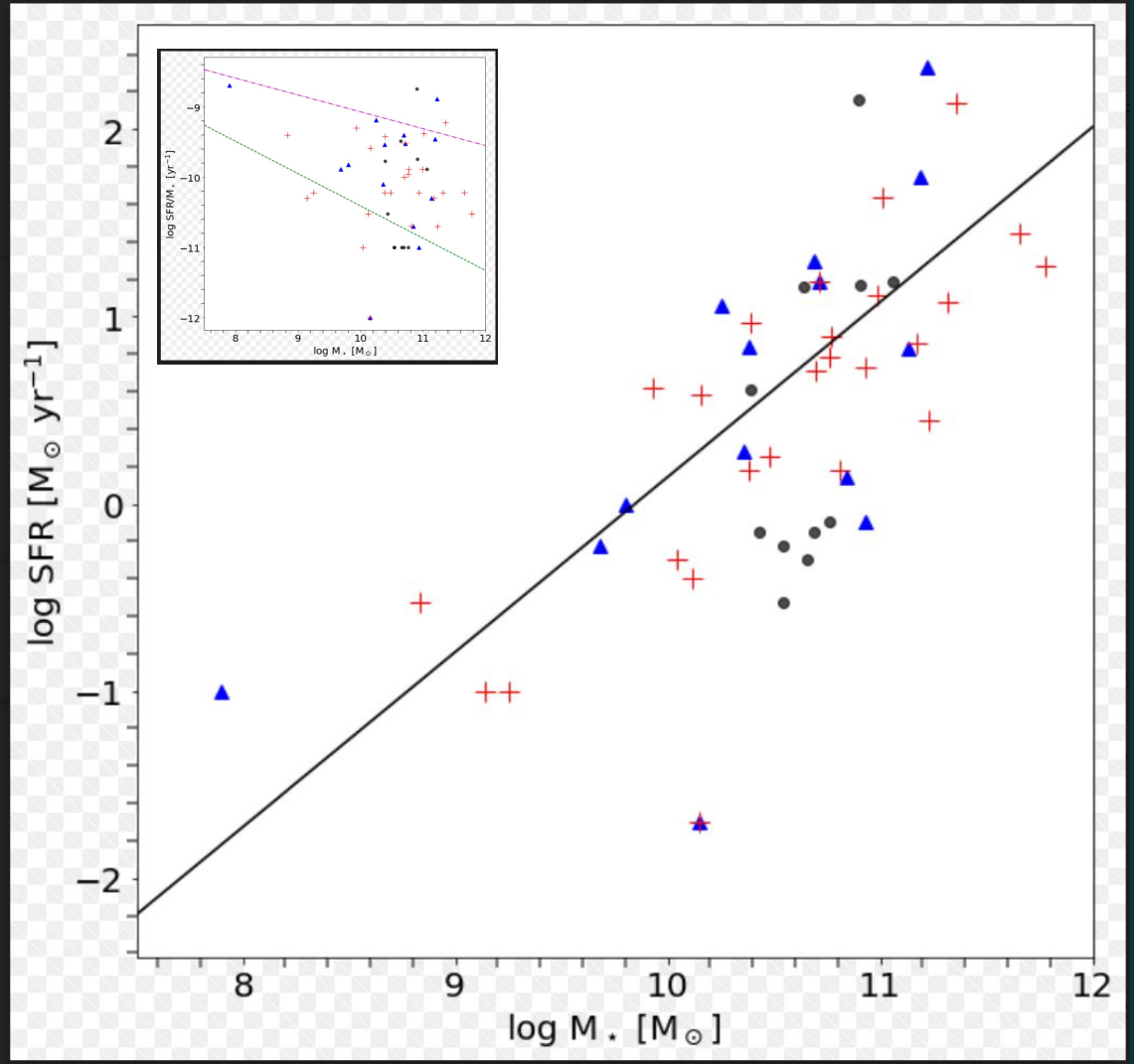


Figure 3. Radial velocity difference between the QSO and the associated companion galaxy as a function of the PD of the companion. The solid red line is the formal best fit; $\Delta V = 1.935 \times \mathrm{PD} + 73.407$, correlation coefficient $r = 0.469$ (Pedregosa et al. 2011).

RESULTS

- *12/18 of associated companion galaxies had [OII] emission line*
- *modest SFR, median~4.3 M(sun)/yr*
- *few companions had high SFR*
- *what does this mean?*

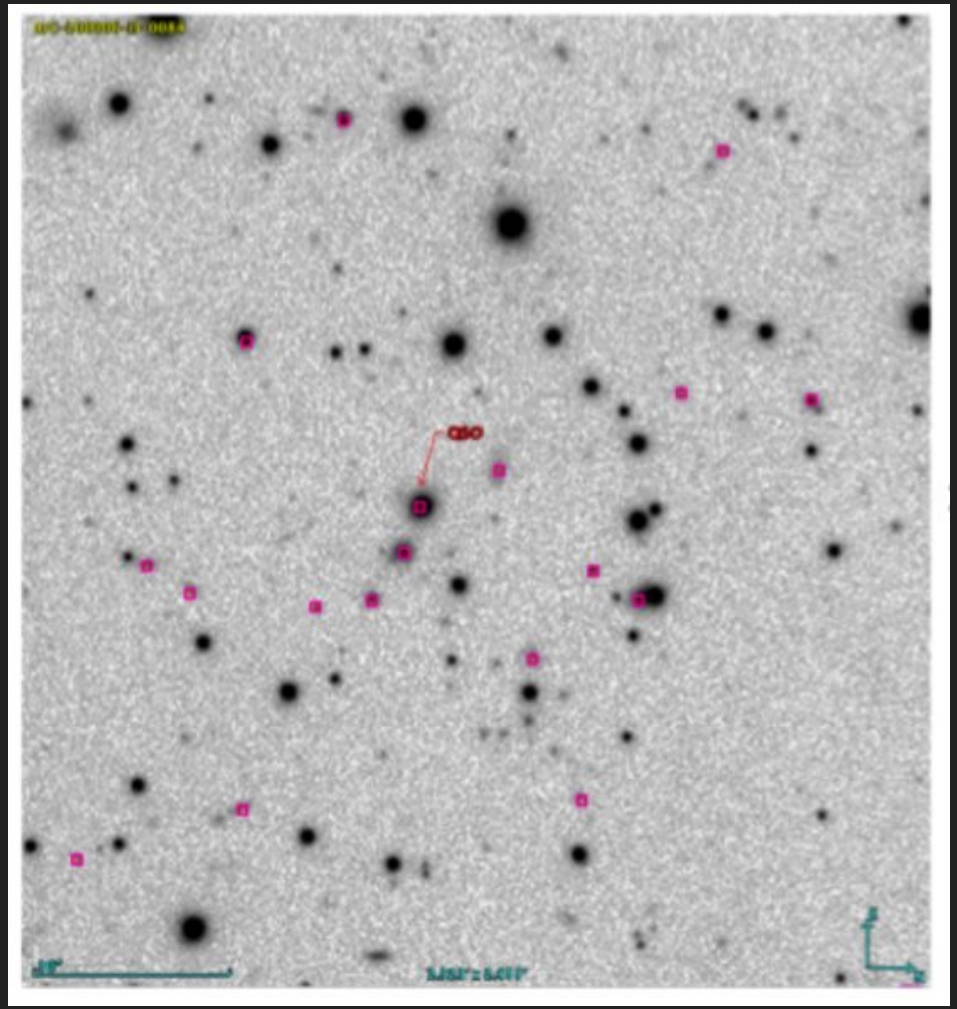
Kennicutt+2012, Duarte Puertas+2017, Osborne+2020 Stone+2021 MNRAS



MOS follow-up study

"Is there a relationship between the nuclear activity of quasars and gas-rich mergers of galaxies?".

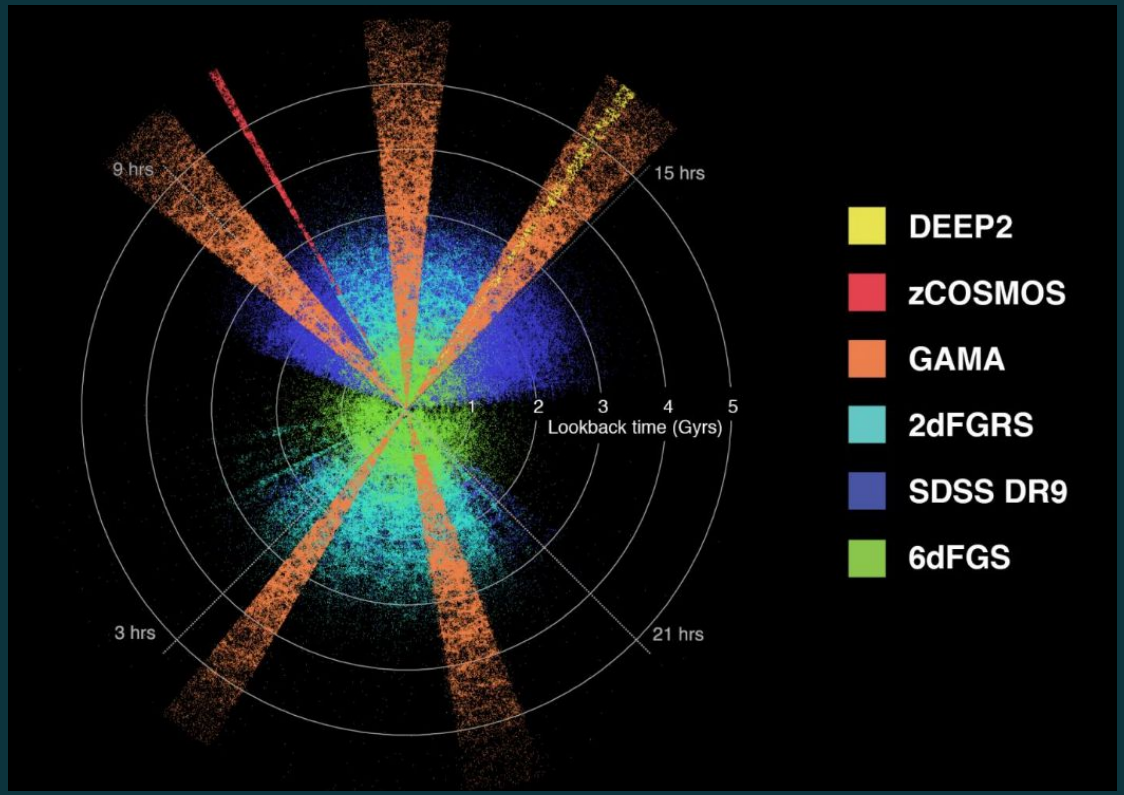
Image credit : *ESO*



Galaxy And Mass Assembly, http://www.gama-survey.org/

spectroscopic survey

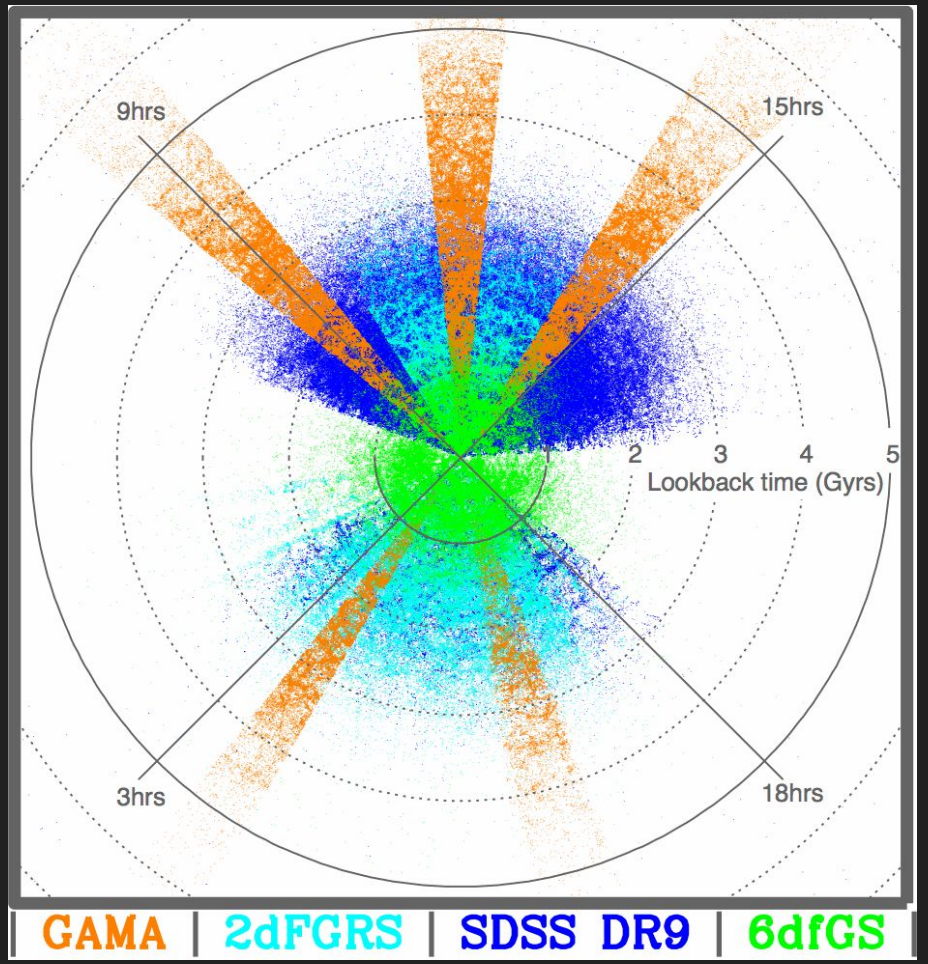
- ~300,000 galaxies
- r < 19.8 mag
- z < 0.3
- ~286 deg^2



Aim of the project

To compare the neighborhoods of quasars to the neighborhoods of inactive galaxies, using GAMA Survey data (Stone et al. in prep.)

Region	RA range	Dec range	Main survey limit
G02	30.2 - 38.8	–10.25 - –3.72	r < 19.8
G09	129.0 - 141.0	–2 - +3	r < 19.8
G12	174.0 - 186.0	–3 - +2	r < 19.8
G15	211.5 - 223.5	–2 - +3	r < 19.8
G23	339.0 - 351.0	–35 - –30	i < 19.2



Data
proprietary from GAMA

Region	N (Quasars)
G09	56
G12	71
G15	78

1. **Quasars (0.1<z<0.3)**
   205 quasars
   (Nischal's Master's thesis, Wethers+2021 submitted ApJ, Stone et al. in prep)
   a. Large Quasar Astrometric Catalogue 224 (LQAC-4), which identifies a near-complete sample of 225 >400,000 Type-I quasars (Gattano et al. 2018)
2. **Inactive galaxies**
   200 sets of 205 comparison galaxies, selected from **GAMA survey**
   DMU **SpecCat** -> Table **SpecObj**
   It contains redshifts from GAMA survey observations and from other sources

Comoving distances

- Background: Comoving distance (line-of-sight) remains constant with epoch if the two objects are moving with the Hubble flow.
- Get comoving distances (Mpc) from Redshift (z) values.
  - assume Flat Lambda-CDM cosmology
  - H0=70 km/s/Mpc, Omega_m = 0.3
  - use python/numpy/astropy (checked with NED)
- For quasars (56) from G09 region.
- And for GAMA survey galaxies.
- Ref: Liske+2000 (general), Hogg+2000 (distances in cosmology), Peebles 1993

$$D_{\rm C} = D_{\rm H} \int_0^z \frac{dz'}{E(z')}$$

Hubble constant

$$E(z) \equiv \sqrt{\Omega_{\rm M}\,(1+z)^3 + \Omega_k\,(1+z)^2 + \Omega_\Lambda}$$

$$D_{\rm H} \equiv \frac{c}{H_0} = 3000\,h^{-1}\ {\rm Mpc} = 9.26 \times 10^{25}\,h^{-1}\ {\rm m}$$

Comoving separation

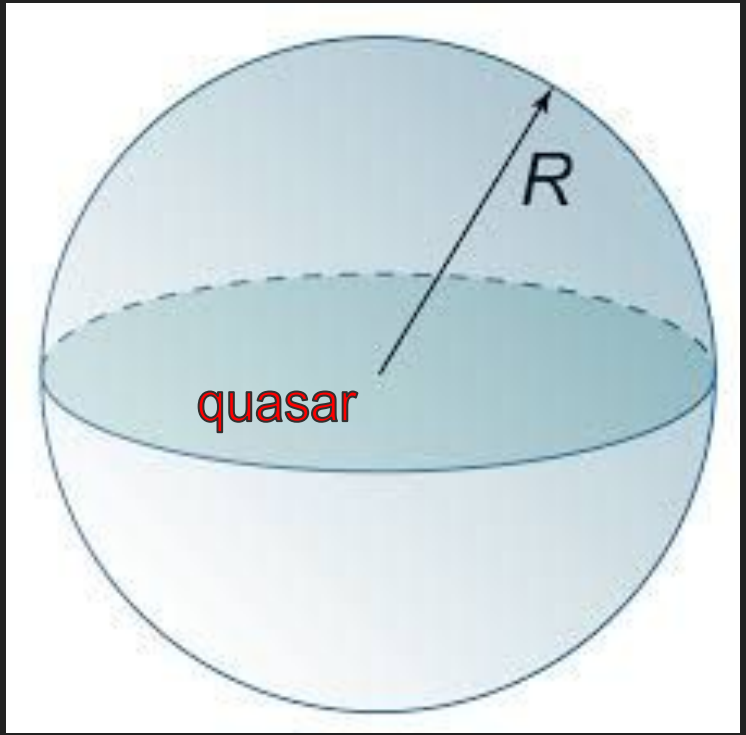
- Comoving separation in flat universe (k=0) reduces to cosine rule
- theta = angular separation between two objects, calculated based on RA and dec coordinates. (J2000 for GAMA database).
- Ref: Peacock “Cosmological Physics”, Liske+2000 (general), Lindsay+2014 (cosine rule formula), examples in Truebenbach+2018, Carvalho+2018

$$r = \left(\chi_1{}^2 + \chi_2{}^2 - 2\chi_1\chi_2\cos\theta\right)^{\frac{1}{2}},$$

- from GAMA survey, out of 344905 objects, 73 (0.02%) had a problem (NaN), e.g. due to z=-9 (CATAID 5276327). All 73 NaN objects are ignored, as their redshift z~-9.0

Methods

- For each quasar, select galaxies from GAMA survey within a set volume (sigma8)
- Get properties from GAMA database, e.g. sersic index, stellar mass, star formation, etc.
- Do the same for each of the comparison galaxies



Identify neighboring galaxies within a fixed volume

- RESULTS
- within the sigma8 volume, most quasars did NOT have a neighbor
- * Some quasars have more than 1 neighbor!

Region	N (Quasars)	N (quasars with neighbors)	f (quasars with neighbors)	N (neighbors)
G09	56	18	33.8%	24
G12	71	24	32.1%	28
G15	78	28	35.8%	44
All	205	70	34.1%	96

Properties pulled from GAMA survey- SFR

- Use MagPhys, “This DMU provides physical stellar population and ISM parameters for galaxies in the GAMA II equatorial survey regions”. http://www.gama-survey.org/dr3/schema/dmu.php?id=15
- SFR
  - Column #93, SFR_0_1_Gyr_best_fit, Msun/yr (Best fit stellar formation rate)
- I removed data points which are the same as the seed quasar itself
- Some neighbors lack SFR values!

Properties pulled from GAMA survey - SFR

- Some neighbors lack SFR values!
- * Some quasars have more than 1 neighbor!

Region	N (Quasars)	N (quasars with neighbors)	f (quasars with neighbors)	N (neighbors)	N (neighbors with SFR)	
G09	56	18	33.8%	24	12	
G12	71	24	32.1%	28	14	
G15	78	28	35.8%	44	29 *	
All	205	70	34.1%	95	55	

Identify neighboring galaxies within a fixed volume for galaxies

- RESULTS -> preliminary -> for N=200 sets
- for one set

Set	N (galaxies)	N (galaxies with neighbors)	f (galaxies with neighbors)
1	205	64	31.2%
2	205	58	28.2%
3	205	72	35.1%
4	205	66	32.1%

Identify neighboring galaxies within a fixed volume for galaxies

- RESULTS -> preliminary -> for N=200 sets

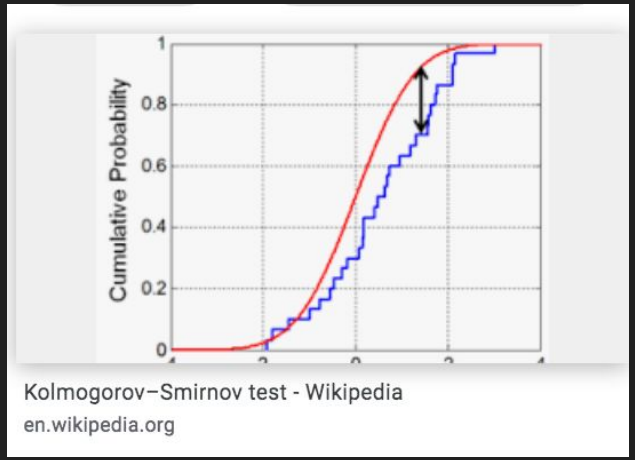
N sets	N galaxies in all sets	N (galaxies with neighbors)	N (neighbors)	N (neighbors with SFR)
200	41000 (205 per set)	12998 (31.7%)	16644	10802 (64.9%)

Preliminary Results

- The Kolmogorov-Smirnov Two Sample Test (KS2) allowed us to compare statistically the two samples (using scipy and statsmodels python packages).
- The null hypothesis in this case is that the two samples are from the same distribution.
- There is no statistically significant difference between the populations of quasar neighbors and normal galaxy neighbors in our sample across many physical stellar population parameters.

Comparing statistics

- Kolmogorov-Smirnov Two Sample Test (KS2)
  - based on the distance between the empirical distribution function of the two samples.
- ***python*** packages
  - ***scipy*** for calculating the test statistic and
  - ***statsmodels*** for visualization of eCDF.



- null hypothesis
  - two samples are from the same distribution
- alternative hypothesis
  - two samples come from different distributions

Rejecting the null hypothesis means that we reject the possibility that the two samples are coming from the exact same distribution.

Comparing statistics

quasars
total number of neighbors with SFR

55

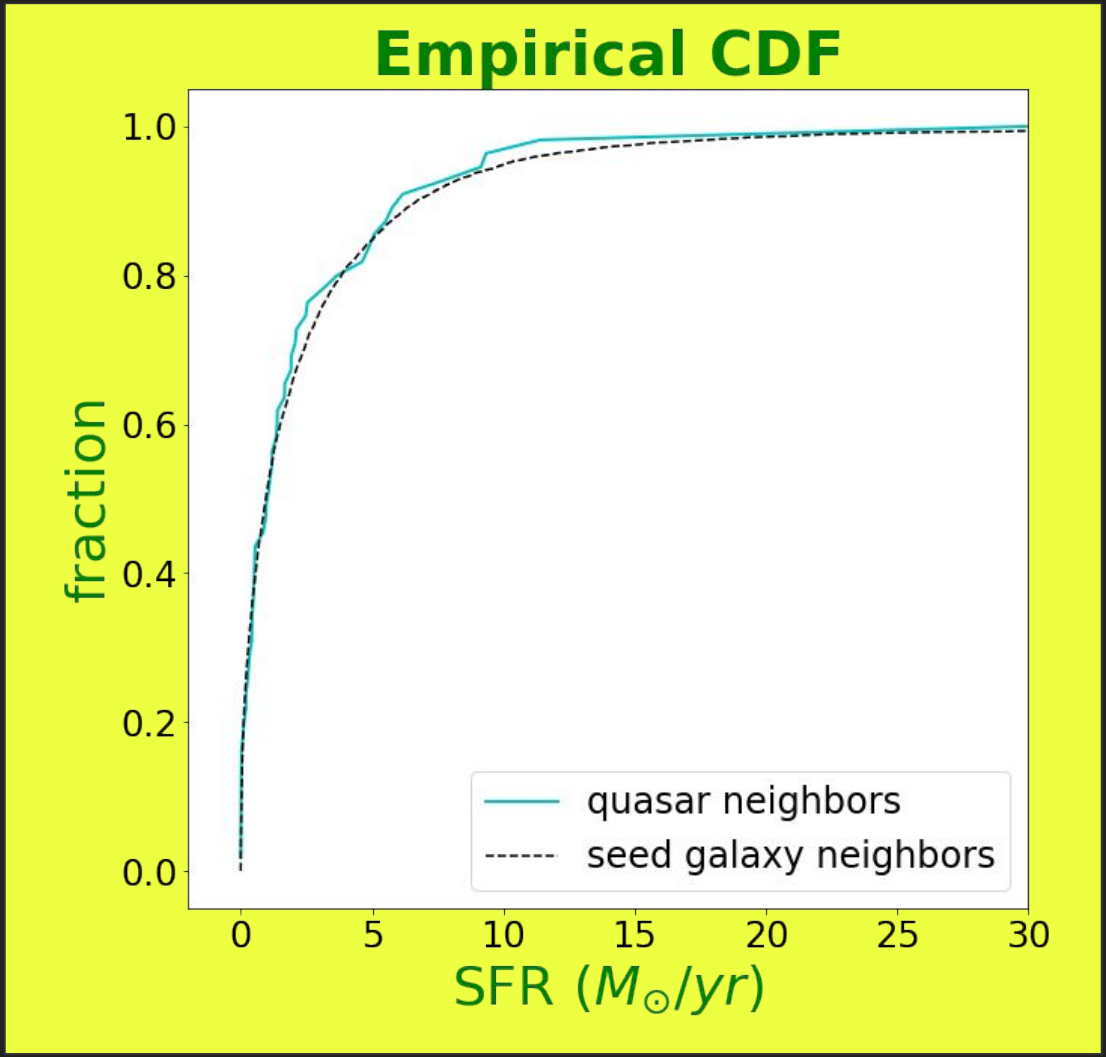
seed-galaxies
total number of neighbors with SFR

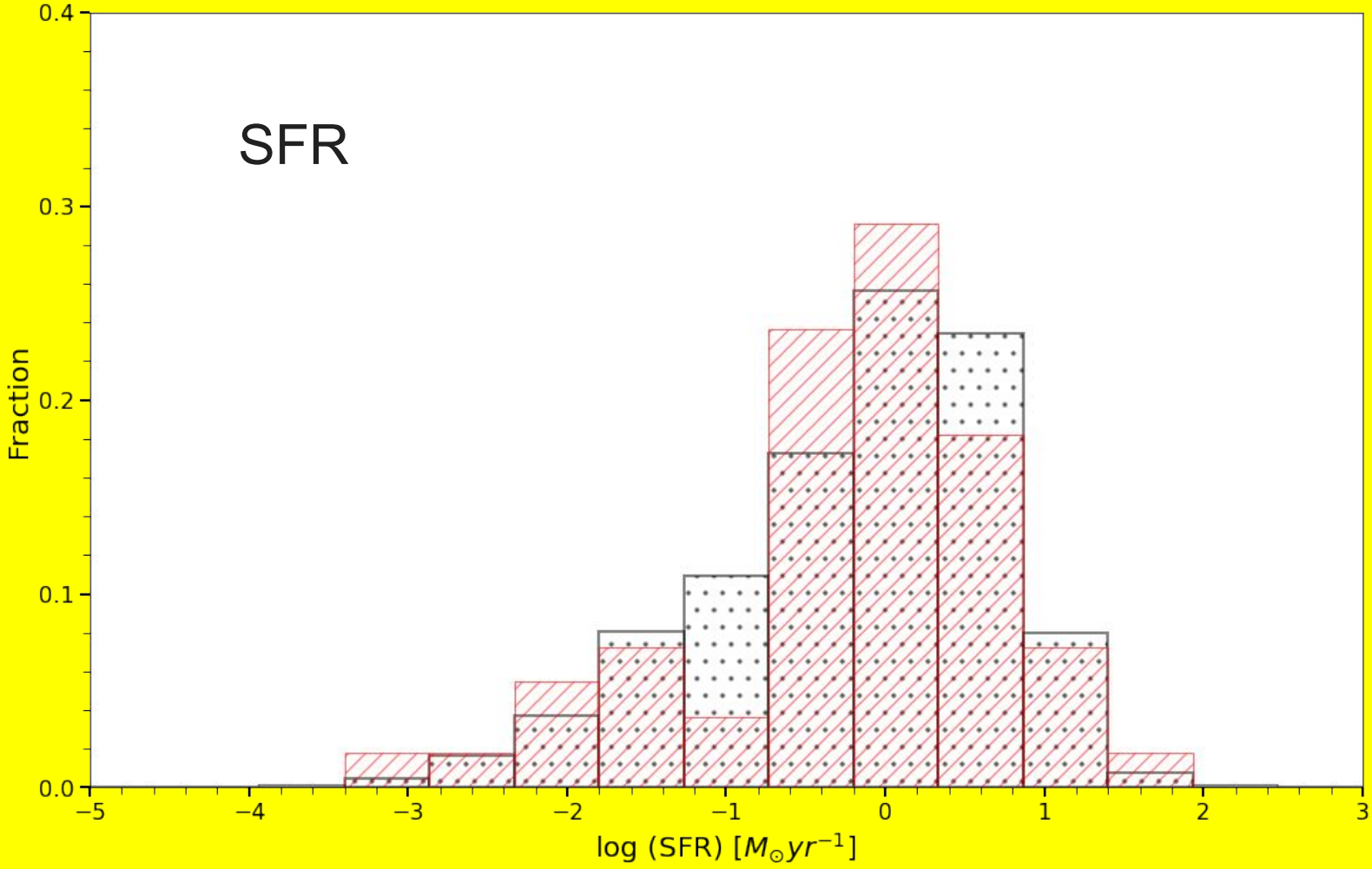
10802

Comparing statistics

- SFR
  - KS test statistic = 0.06
  - p-value = 0.96
  - > 0.05/0.01 (critical)
  - cannot reject H_0

Two samples are from the same distribution

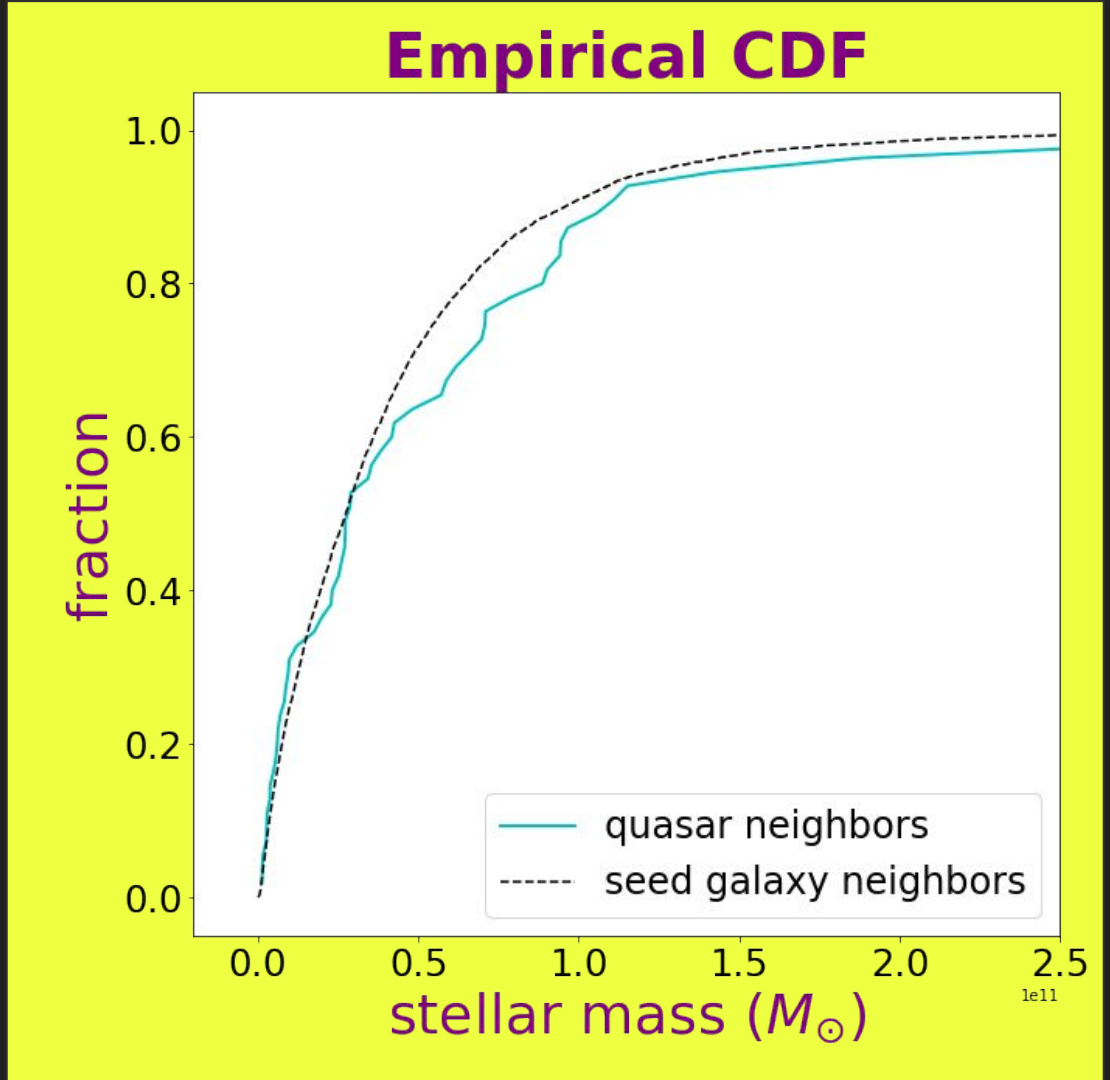


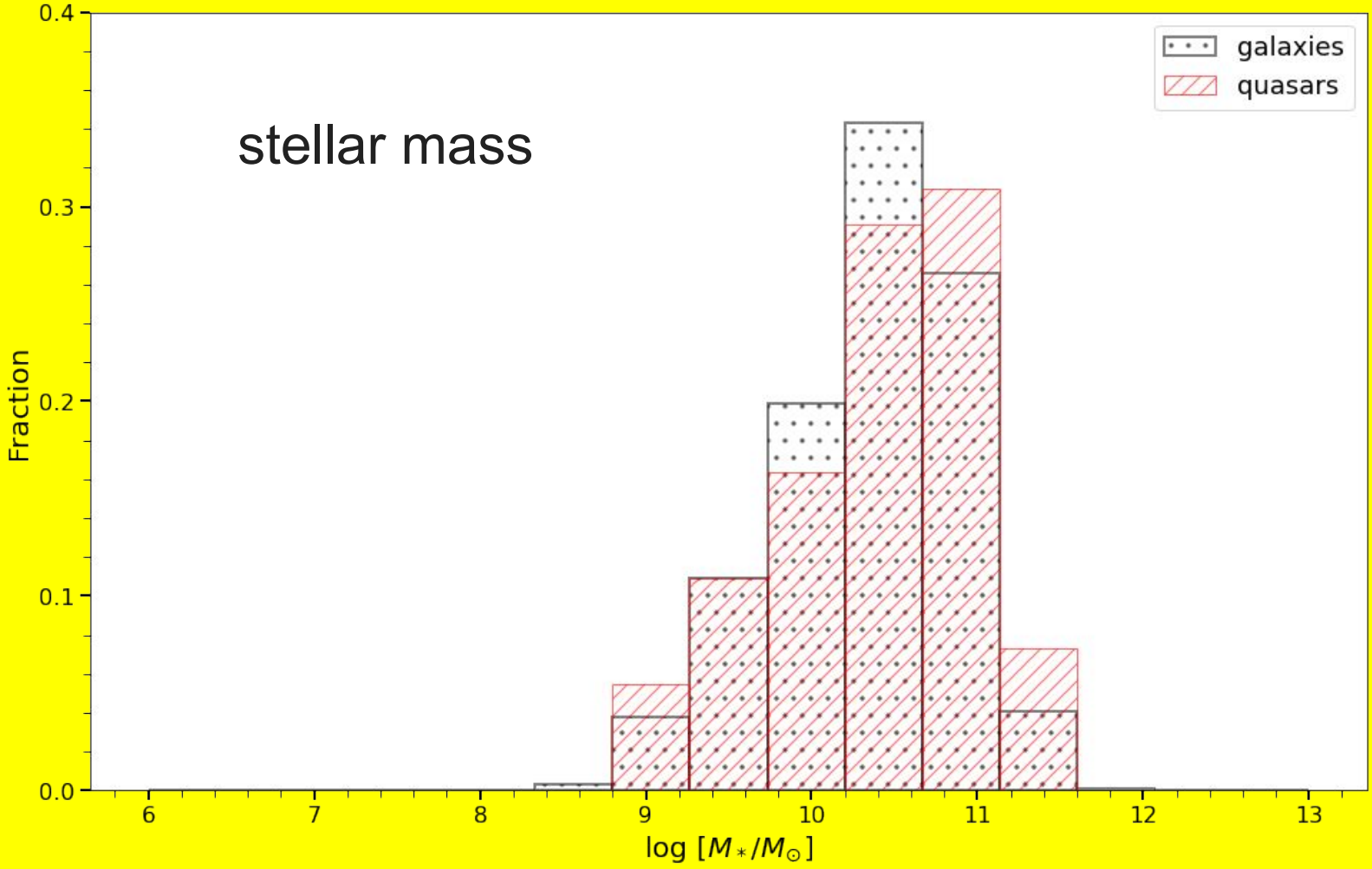

SFR
Fraction
0.0
0.1
0.2
0.3
0.4
−5
−4
−3
−2
−1
0
1
2
3
log (SFR) [$M_\odot yr^{-1}$]

Comparing statistics

- stellar mass
  - KS test statistic = 0.12
  - p-value = 0.32
  - > 0.05/0.01 (critical)
  - cannot reject H_0

Two samples are from the same distribution




stellar mass
galaxies
quasars
Fraction
0.0
0.1
0.2
0.3
0.4
6
7
8
9
10
11
12
13
log [$M_*/M_\odot$]

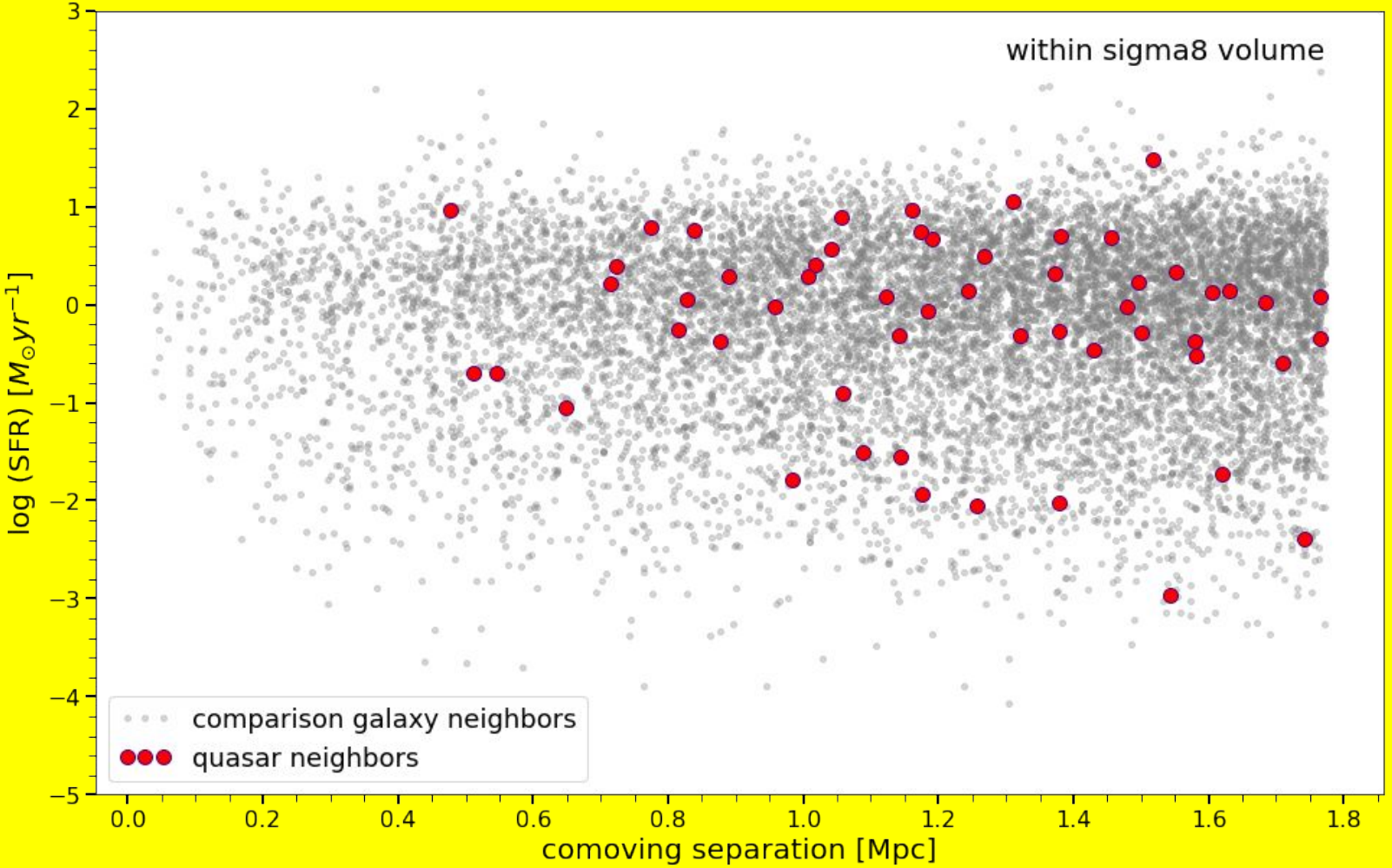
Property	Units	D_{KS}	p_{KS}-value
SFR	$M_\odot/yr^{-1}$	0.06	0.96
Stellar Mass	$M_\odot$	0.12	0.32
Age	dex(yr)	0.07	0.88
Metallicity	$Z_\odot$	0.12	0.33
sSFR	yr^{-1}	0.07	0.89
median SF timescale	Gyr^{-1}	0.08	0.73
fb17		0.04	0.99
fb18		0.04	0.99
fb19		0.08	0.84
fb29		0.15	0.12
sfr17	$M_\odot/yr^{-1}$	0.07	0.88
sfr18	$M_\odot/yr^{-1}$	0.07	0.86
sfr19	$M_\odot/yr^{-1}$	0.09	0.67
sfr29	$M_\odot/yr^{-1}$	0.11	0.37

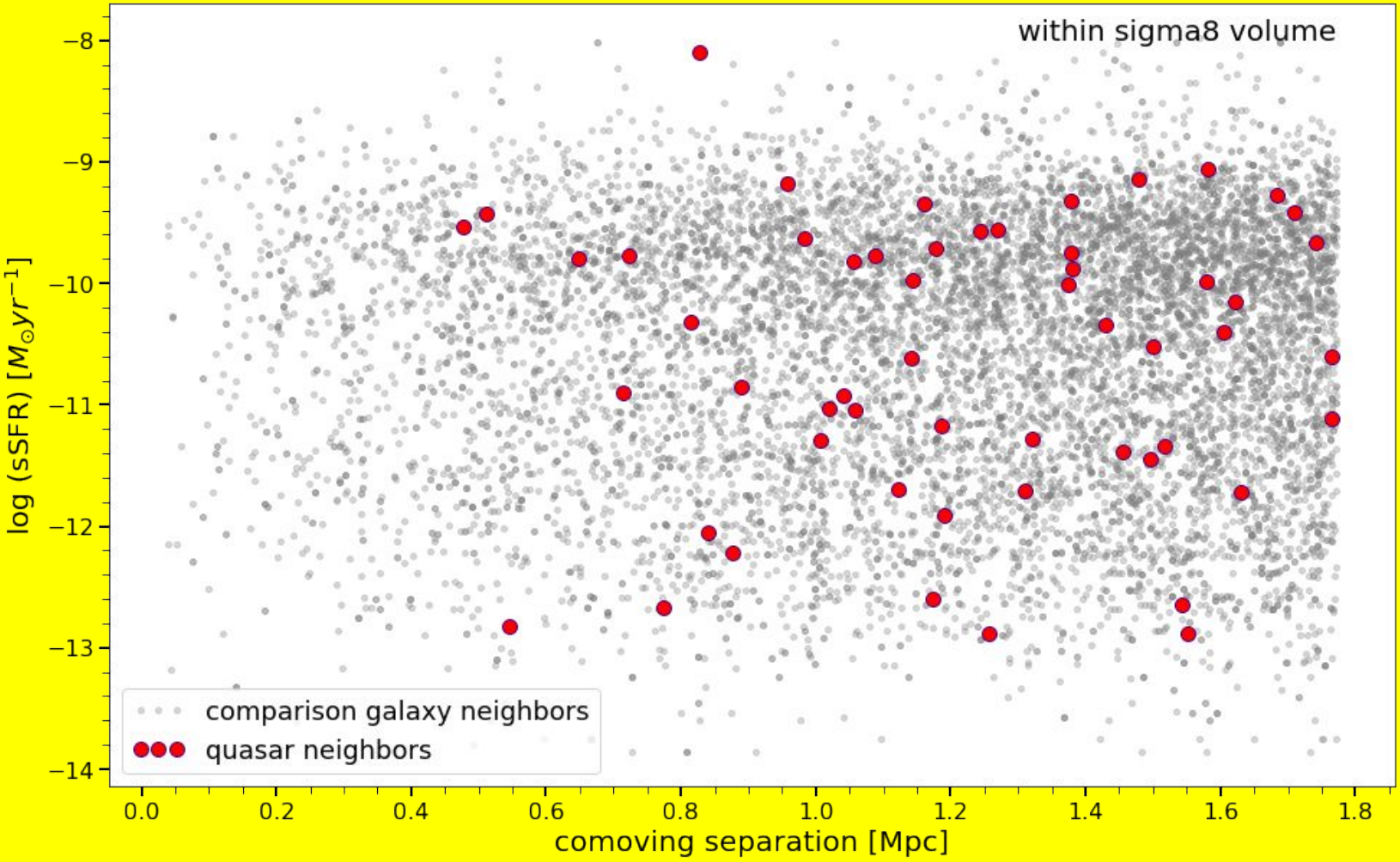
fb17….

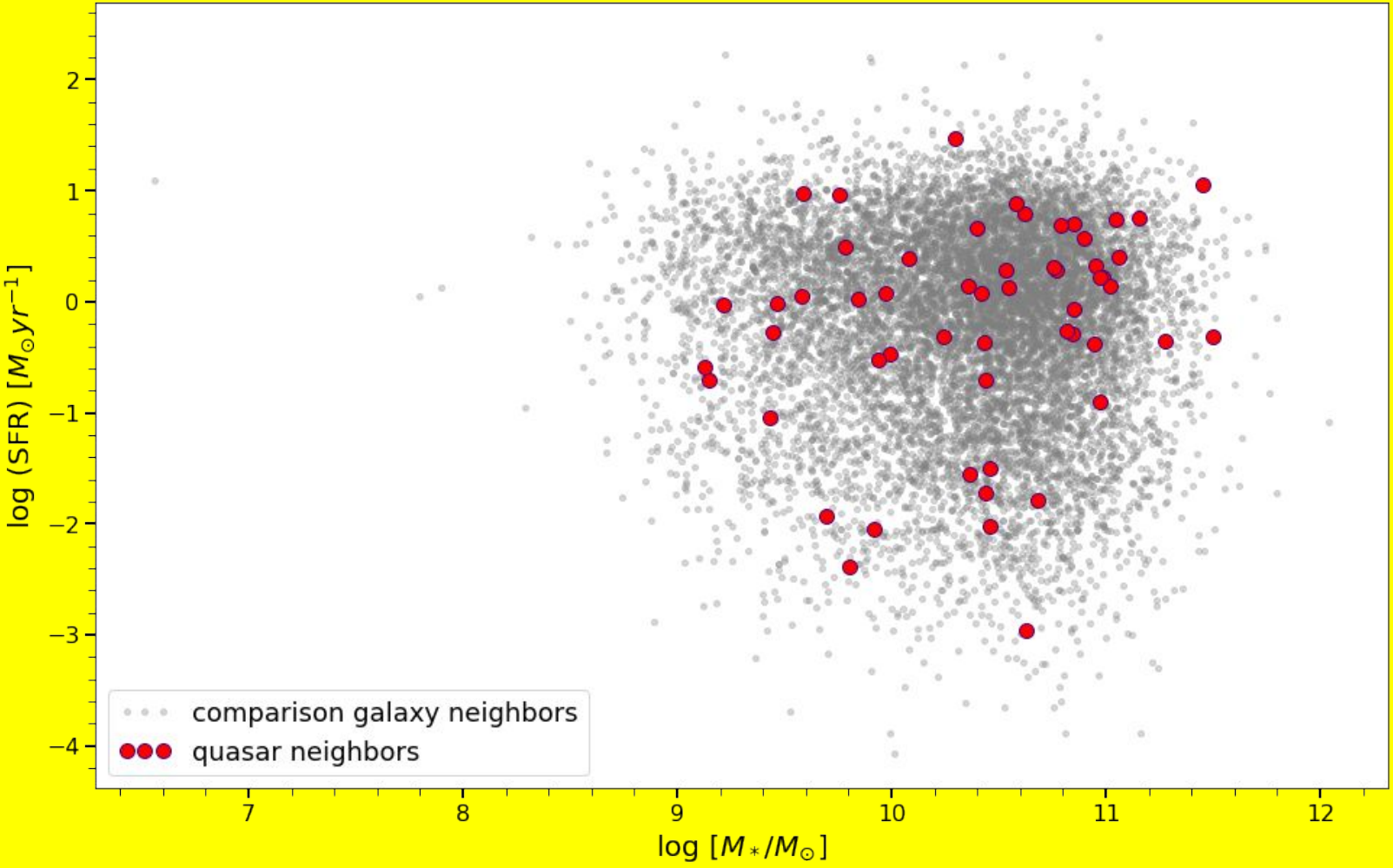
Median fraction of stellar mass formed in bursts
over 10, 100, 1000, 2000 mln yrs

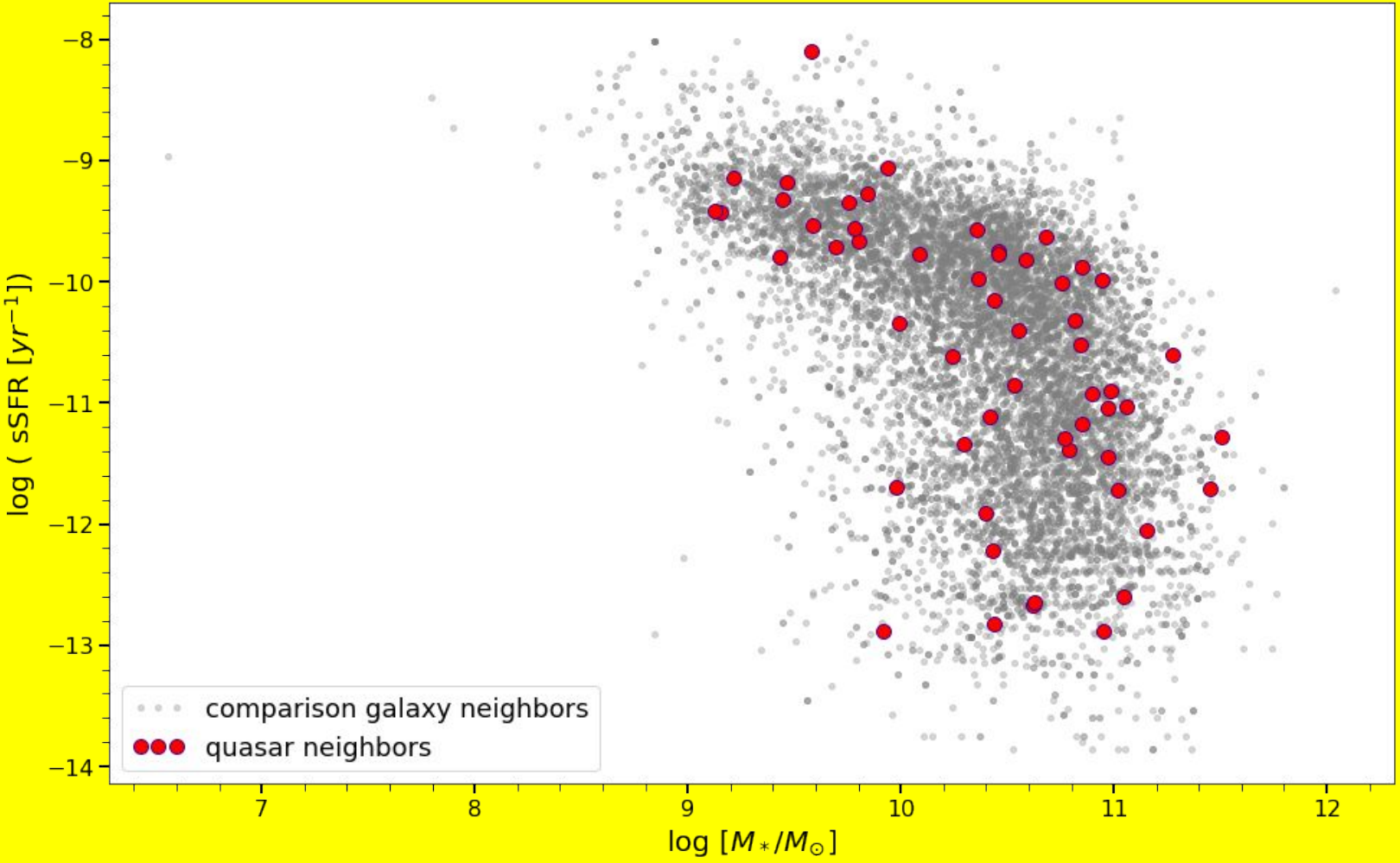
sfr17….

Median SFR averaged over the past 10, 100, 1000, 2000 mln yrs


within sigma8 volume
comparison galaxy neighbors
quasar neighbors
log (SFR) [$M_\odot yr^{-1}$]
comoving separation [Mpc]
3
2
1
0
−1
−2
−3
−4
−5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8


within sigma8 volume
log (sSFR) [$M_\odot yr^{-1}$]
−8
−9
−10
−11
−12
−13
−14
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
comoving separation [Mpc]
comparison galaxy neighbors
quasar neighbors


log (SFR) [$M_\odot yr^{-1}$]
log [$M_*/M_\odot$]
comparison galaxy neighbors
quasar neighbors
2
1
0
−1
−2
−3
−4
7
8
9
10
11
12


log (sSFR [yr^{-1}])
−8
−9
−10
−11
−12
−13
−14
7
8
9
10
11
12
log [$M_*/M_\odot$]
comparison galaxy neighbors
quasar neighbors

CONCLUSIONS

- We are comparing neighborhoods of low-redshift quasars and inactive galaxies with the Galaxy and Mass Assembly (GAMA) survey through Monte Carlo simulation
- The GAMA survey project collected observations using the latest facilities for about 300,000 galaxies and provides a multi-wavelength photometric and spectroscopic data.
- Our preliminary results show that overall there is no statistically significant difference in any of the morphological or star formation properties between the neighbors of quasars and neighbors of inactive galaxies.
- Some properties could be slightly different...
- This finding suggests that quasar activity is a phase in the life of a galaxy and is not dependent on its environment.

~ Thank you~