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HOSTS AND ENVIROMENTS OF RADIO-ACTIVE AGN

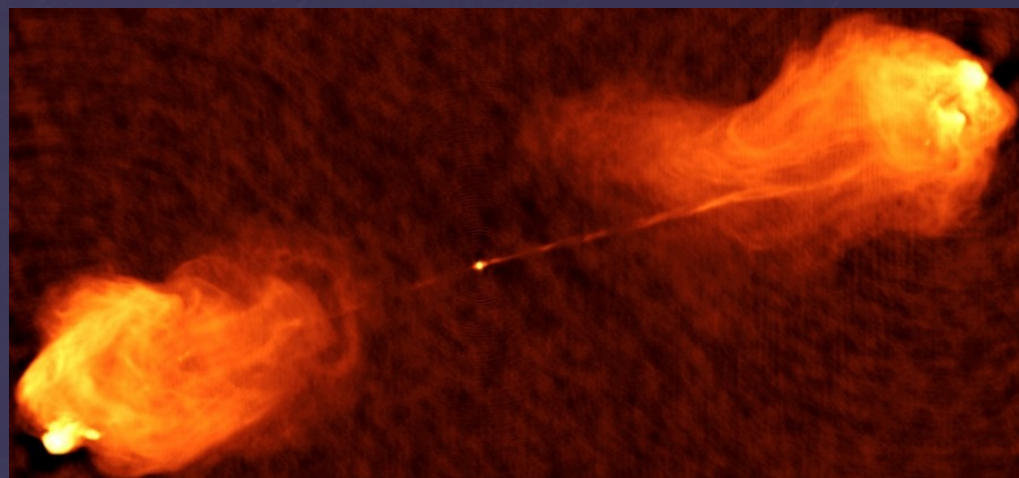
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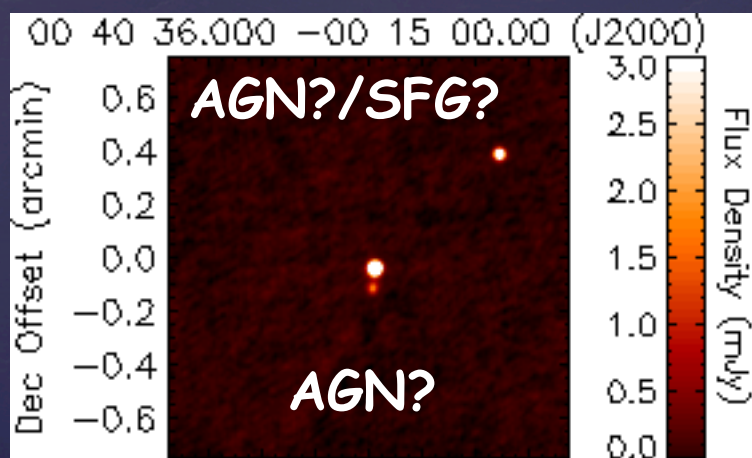
(Magliocchetti+2014;2016,2017,
2018a,2018b)



RADIO-EMITTING AGN OR STAR-FORMING GALAXY?



AGN!!



0.60.40.20.0-0.20.40.6

RA Offset (arcmin)

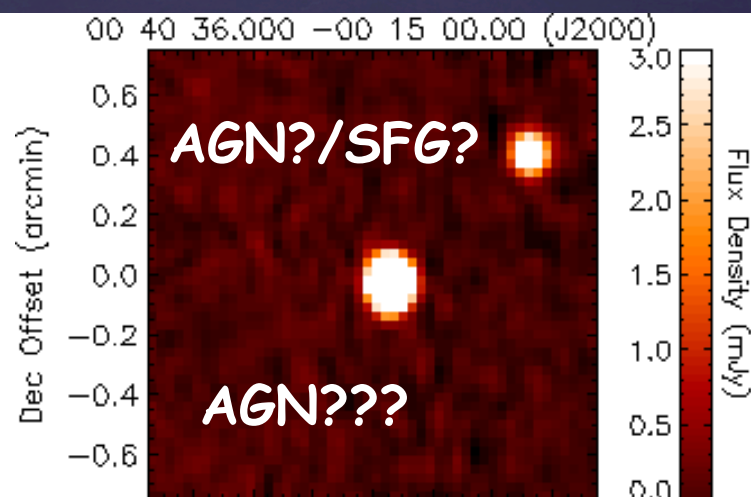
150 x 150 pixels extracted from Stripe 82 image

Brightest pixel is 22.82 mJy/beam at

X, Y = 78, 72 pixels

RA, Dec = 00 40 35.880 -00 15 02.40 (J2000)

RMS noise 0.054 mJy



0.6 0.4 0.2 0.0 -0.2 -0.4 -0.6

RA Offset (arcmin)

50 x 50 pixels extracted from FIRST image 00405-00130Z

Brightest pixel is 23.65 mJy/beam at

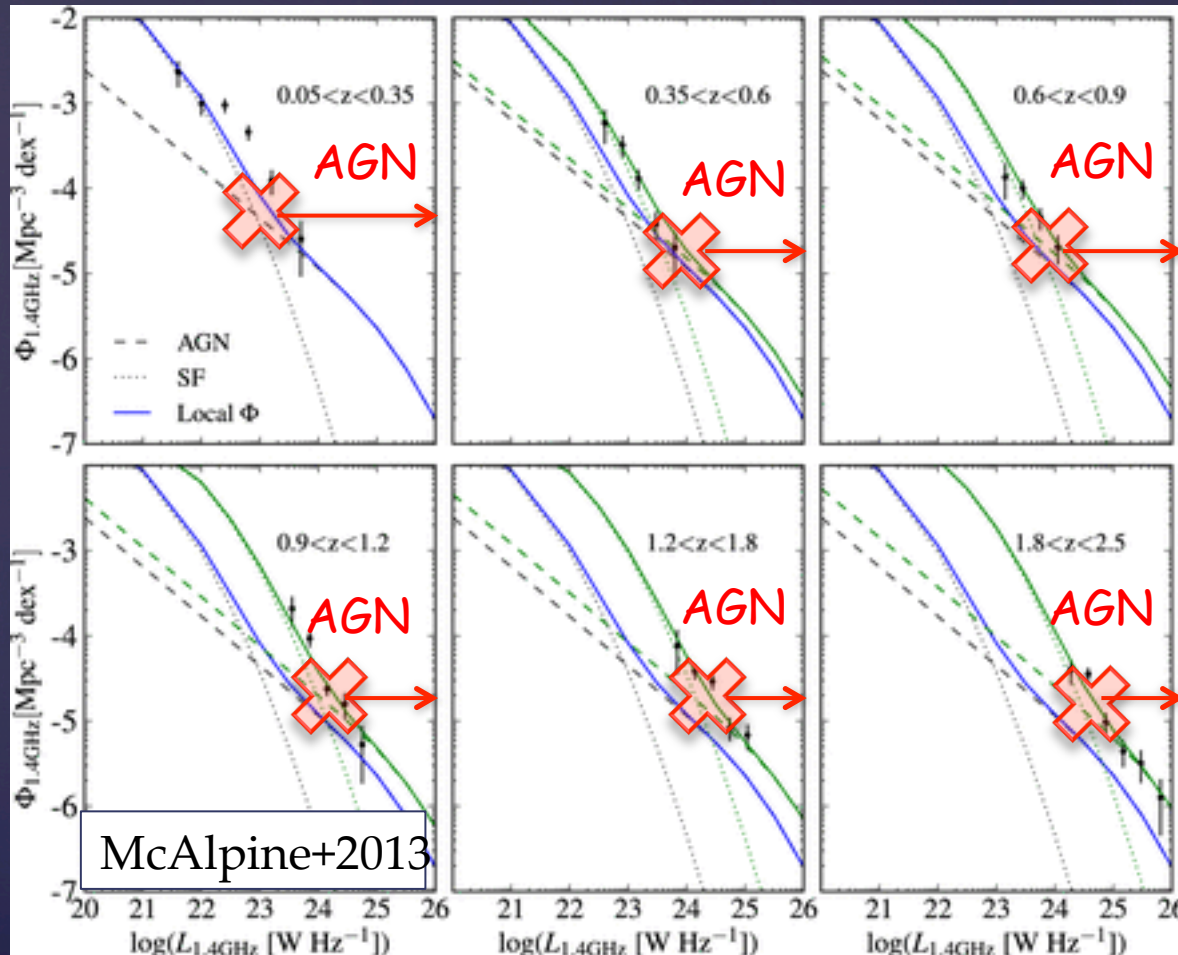
X, Y = 28, 25 pixels

RA, Dec = 00 40 35.813 -00 15 02.40 (J2000)

RMS noise 0.108 mJy

CRITERIA FOR AGN/SF DIVISION IN RADIO SURVEYS

(Magliocchetti+2014;2016,2017,2018a,2018b)



Radio data from VLA-VIRMOS (Bondi+ 2003). 1 deg² complete to 100mJy: 1054 sources

From McAlpine+13 RLF
 z evolution of cross-point
 from SF-dominated to
 AGN-dominated sources:
 $\text{Log}_{10} P_{\text{cross}}(z) = \text{Log}_{10} P_{0,\text{cross}} + z$
 @ $z < 1.8$
 $\text{Log}_{10} P_{\text{cross}} = 23.5$ [W/Hz/sr]
 @ $z > 1.8$

$P_{0,\text{cross}}$ break of local SF RLF
 (Magliocchetti+2002;
 Mauch & Sadler 2007)

AGN all sources with $P(z) > P_{\text{cross}}(z)$

SF all sources with $P(z) < P_{\text{cross}}(z)$ [N.B. also includes RQQ]

FIELD AND DATA SELECTION

A) COSMOS-VLA Survey (Bondi+2008)

$N_{\text{tot}} (F_{1.4\text{GHz}} > 60 \mu\text{Jy})$: 2382

$N_z (F_{1.4\text{GHz}} > 60 \mu\text{Jy}) = 2123$ (90%)

NAGN=704 (272 FIR) -- shallower in radio/FIR but wider area

B) GOODS-N + GOODS-S (Morrison+2010; Miller+2013)

$N_{\text{tot}} (F_{1.4\text{GHz}} > 20 \mu\text{Jy})$: 401 + 142

$N_z (F_{1.4\text{GHz}} > 20 \mu\text{Jy})$: 267 + 114 ($\approx 75\%$)

NAGN=32+15 (23+8 FIR) -- deeper in radio/FIR but smaller area

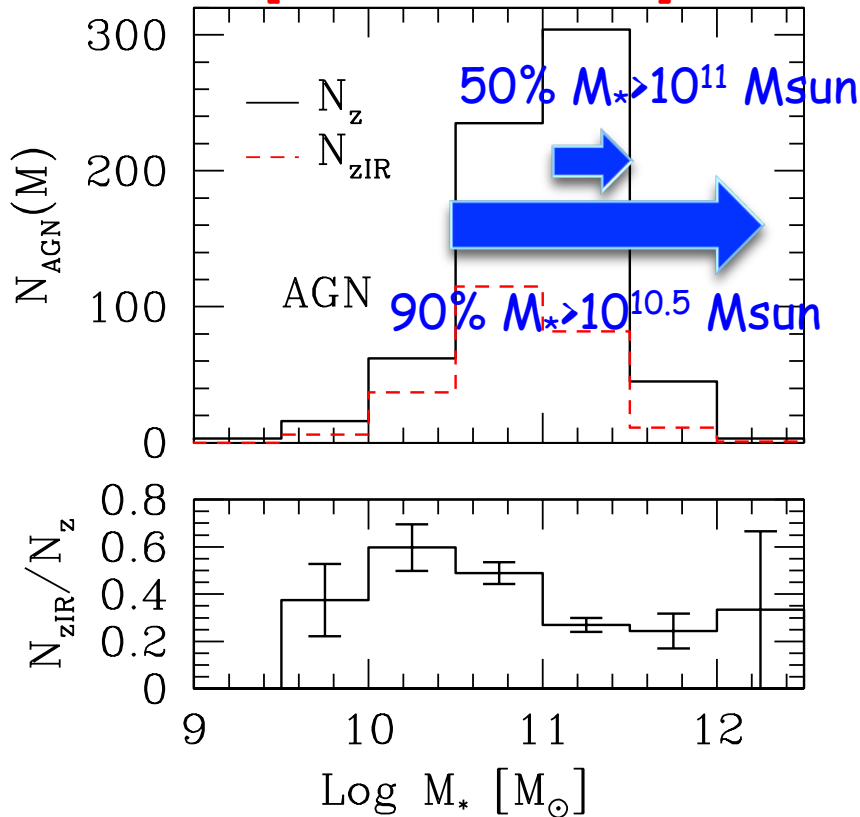
N.B. All samples complete up to $z \sim 3.5$

Success-rate independent of radio flux (up to ~ 3 mJy) and redshift

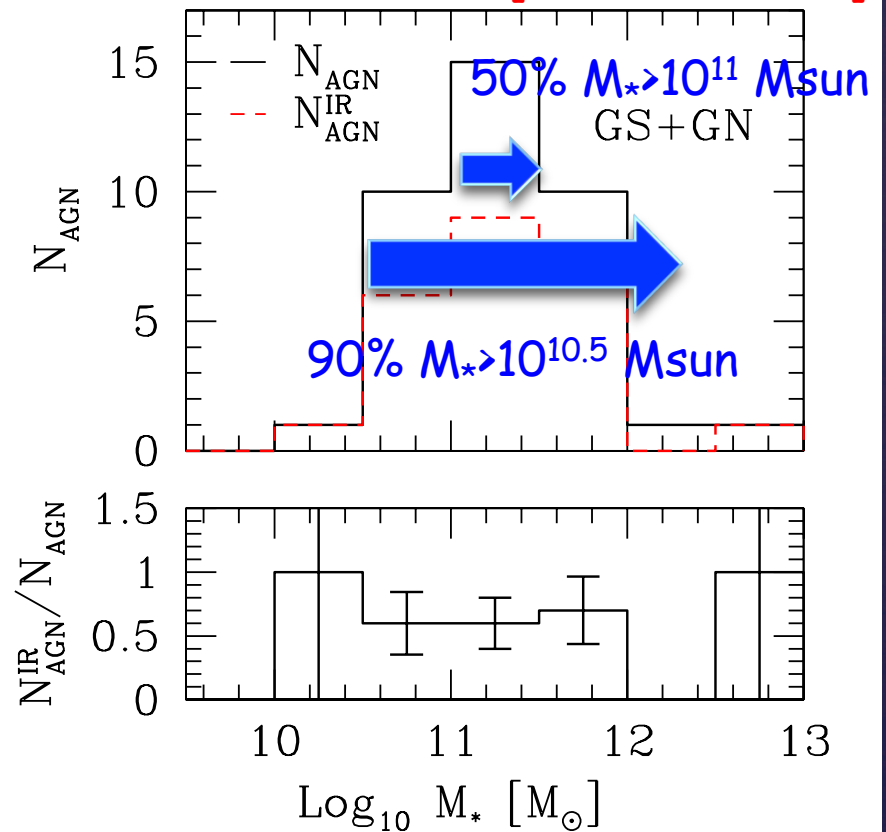
STELLAR MASSES OF RADIO-AGN HOSTS

90% have $M_* > 10^{10}$ Msun. 50% $M_* > 10^{11}$ Msun

COSMOS [N=704 - 272 FIR]



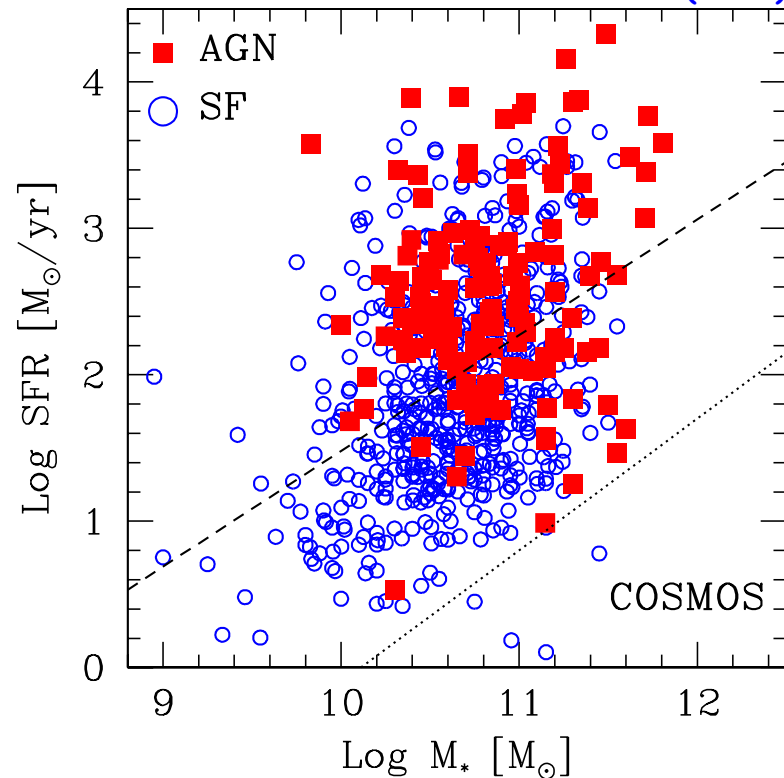
GOODSN+GOODSS [N=47 - 31 FIR]



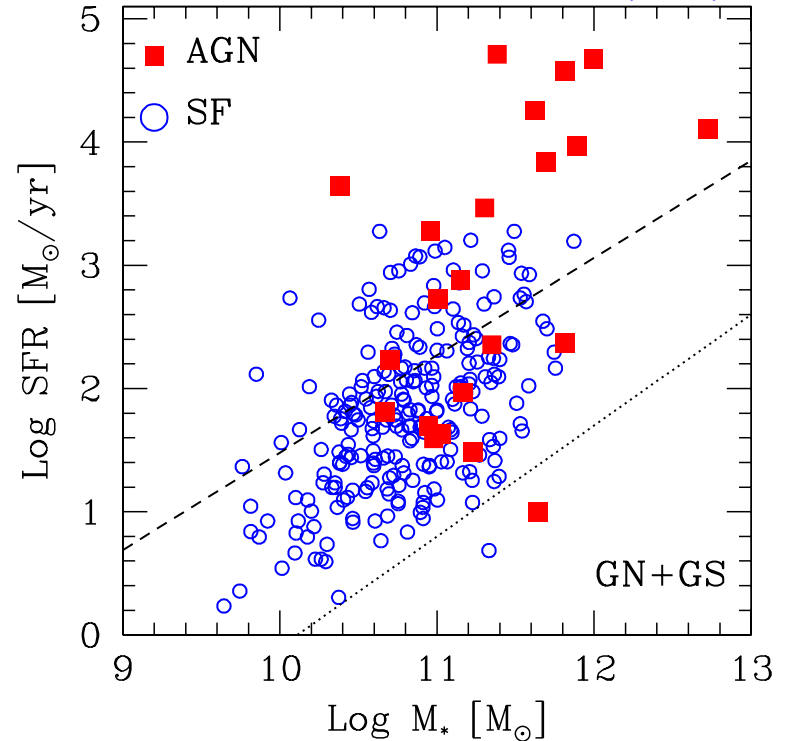
HOSTS OF RADIO AGN EXTREMELY MASSIVE GALAXIES AT ALL REDSHIFTS

STAR-FORMING ACTIVITY WITHIN RADIO-AGN HOSTS

COSMOS AGN WITH FIR ACTIVITY (38%)

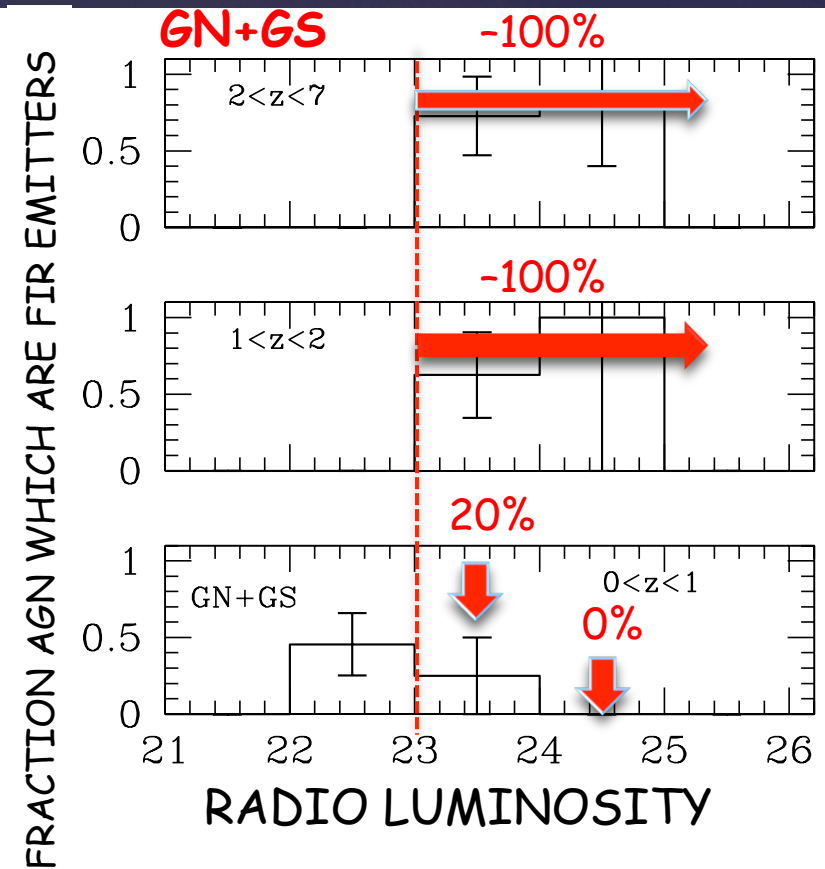
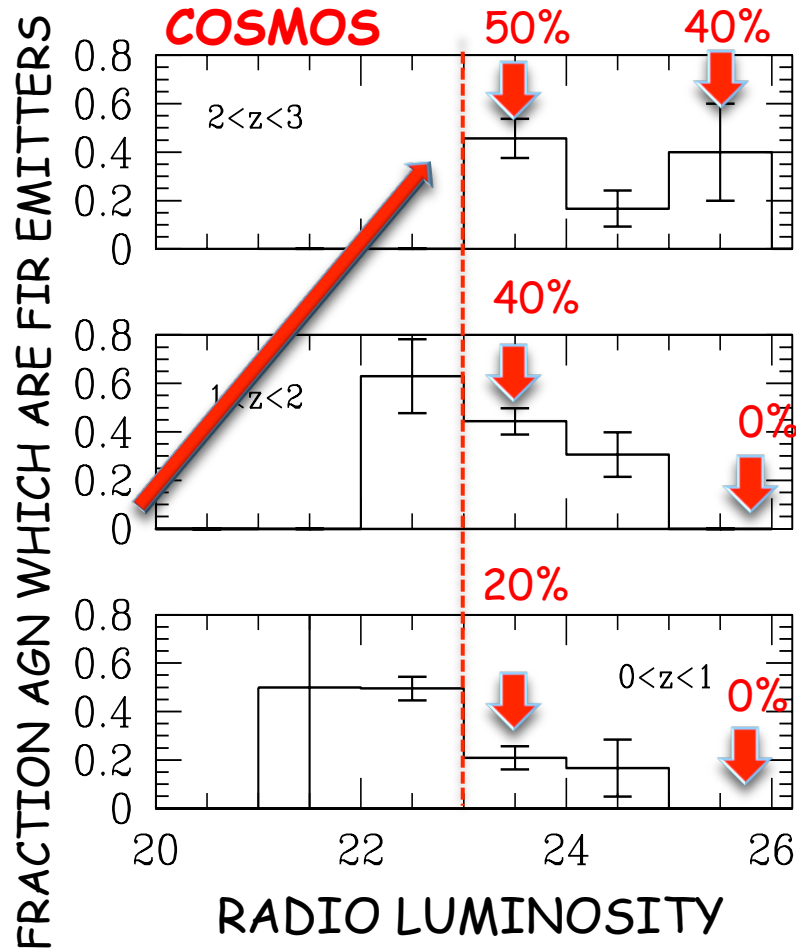


GN+GS AGN WITH FIR ACTIVITY (66%)



HOSTS OF RADIO EMITTING AGN NOT ONLY VERY MASSIVE BUT SITES OF INTENSE STAR FORMATION ACTIVITY, PARTICULARLY AT $z > 1$

Fraction of FIR emitters amongst radio-selected AGN as a function of radio luminosity at different cosmological epochs



Powerful radio AGN are more likely associated to ongoing star-formation at earlier epochs. ~100% at $z > 1$ for deep enough FIR surveys. NO SIGN OF NEGATIVE FEEDBACK only present for $z < 1$ and only for radio-bright sources

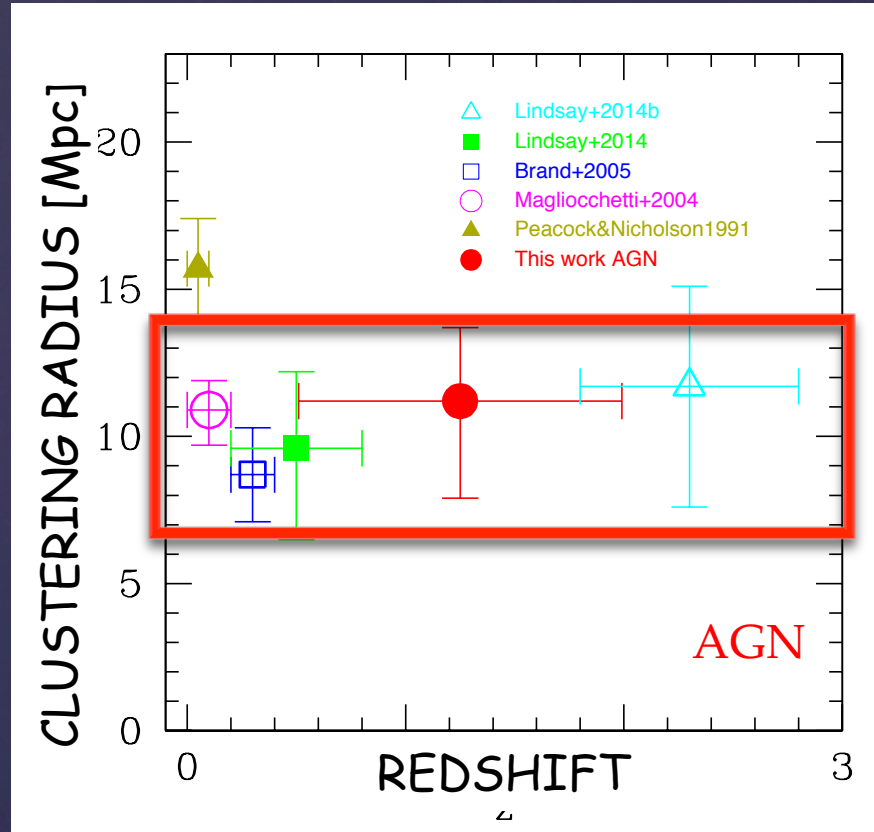
WHAT HAVE WE LEARNED SO FAR?

- 1) Radio-emitting AGN are hosted by very massive galaxies at all z
- 2) Most of them are in the process of forming stars at very high rates
- 3) Such star-forming activity much more intense in the past.
Deepest FIR surveys show that $\sim 100\%$ of high ($z > \sim 1$) redshift radio-active AGN are associated to SF events
→ NO (negative) AGN-to-SF FEEDBACK at those z
- 4) Feedback only present in the $z > 1$ universe and for mainly for sources which are radio-powerful

AND WHAT ABOUT AGN LARGE-SCALE ENVIRONMENT?

Investigate spatial distribution via 2ptCF and direct pinpoint on known structures (COSMOS)

CLUSTERING ANALYSIS: COMPARISON OF AGN RESULTS WITH LITERATURE



Peacock& Nicholson 1991

$F > 500$ mJy - $z < 0.1$

Magliocchetti+2004 -- 2dF+FIRST

$F > 1$ mJy (AGN) -- $\langle z \rangle = 0.1$

Brand+2005 -- Texas-Oxford+NVSS

$F > 3$ mJy -- $\langle z \rangle = 0.3$

Lindsay+2014 - GAMA+FIRST

$F > 1$ mJy -- $\langle z \rangle = 0.5$

Lindsay+2014b - VLA-VIRMOS

$F > 0.09$ mJy -- $\langle z \rangle = 2.2$

Magliocchetti+2016 - VLA-COSMOS

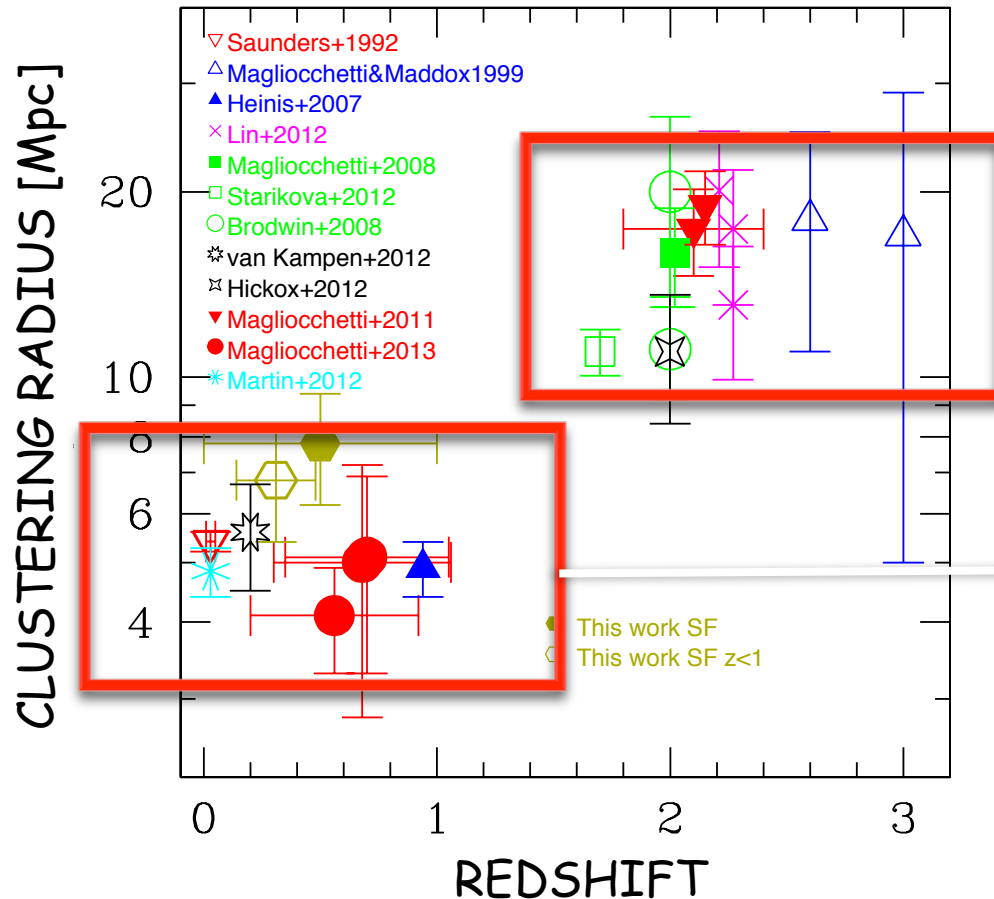
$F > 0.15$ mJy -- $\langle z \rangle = 1.3$

$M^{\text{HALO}}_{\text{MIN}} \approx 10^{13.5} M_{\text{sun}}$
 (groups-to-clusters of galaxies)

Except for P&N excellent agreement amongst different results →
 → INDEPENDENCE OF AGN CLUSTERING PROPERTIES ON
 1) REDSHIFT and 2) RADIO LUMINOSITY ($P < \sim 10^{24.5-25}$ W/Hz)

RADIO-ACTIVE AGN RESIDE WITHIN THE SAME STRUCTURES AT ALL
 RADIO LUMINOSITIES $< \sim 10^{24.5-25}$ W/Hz. NO EVOLUTION IN PROPERTIES
 DURING COSMIC EPOCHS AT LEAST SINCE $z \sim 3$! **NO DOWNSIZING**

CLUSTERING ANALYSIS: COMPARISONS OF SF RESULTS WITH LITERATURE



Adapted from Magliocchetti+2014

Red: 60mm RF selection
Blue: UV selection
Magenta: BzK selection
Green: 24mm selection
Black: 250mm (RF) selection
Cyan: HI selection
Gold: radio-SF selection (this work)

$$M_{\text{HALO MIN}} \approx 10^{13.5} M_{\text{sun}}$$

$$M_{\text{HALO MIN}} \approx 10^{11.5} M_{\text{sun}}$$

**Peculiar trend of SF clustering.
Jump in the clustering properties
beyond $z > 1.5$.**

**At variance with AGN
SF hosted by very massive
structures only $z > 1.5$**

DOWNSIZING

RELATIONSHIP BETWEEN DARK AND LUMINOUS MATTER IN AGN

$M_{\min}$ from clustering ----- M_* from Laigle+2016 catalogue

$\langle M_* \rangle / M_{\min} < 10^{-2.7}$ relatively small stellar content (large uncertainties)

DURATION OF RADIO-ACTIVE AGN PHASE

Comparison of observed space density of AGN with that expected for dark matter haloes more massive than $M_{\min}$ (from clustering results)

Fraction of haloes with $M_{\min} > 10^{13.6} M_{\text{sun}}$ host of a radio-active AGN = 0.4
→ about one in two haloes observed to host radio-AGN (a lot!!)

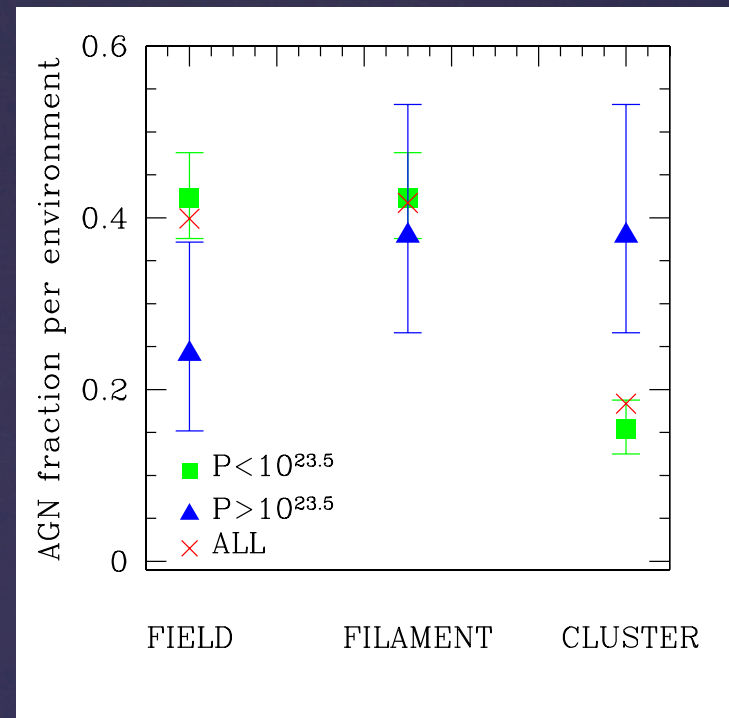
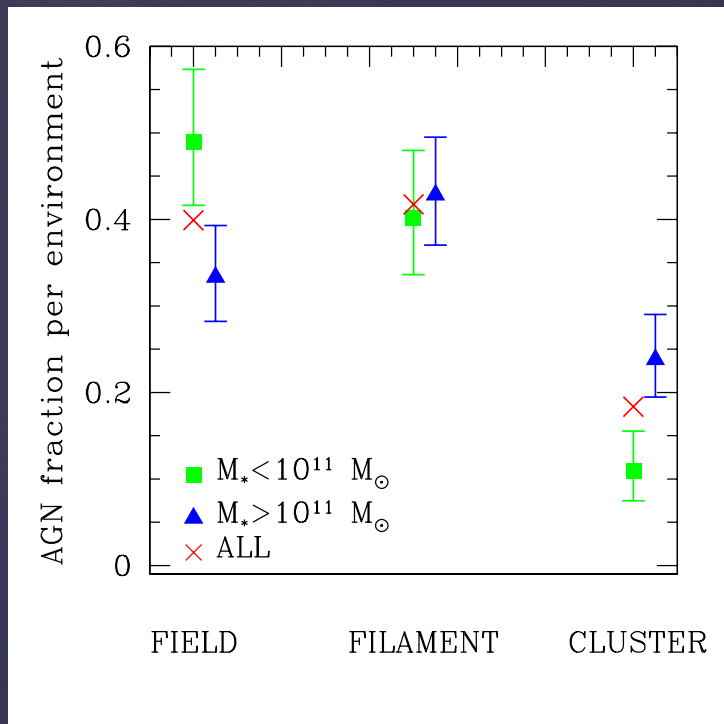
If we assume every halo with $M_{\text{halo}} > M_{\min}$ hosts a black hole that at some point becomes radio-active we derive life-time of radio phase $t = 1 \text{ Gyr}$

$t \gg$ a few $\times 10 \text{ Myr}$ for radio-bright phase (Blundell & Rawlings 1999) →

Radio active phase is recurrent phenomenon

DEPENDENCE OF ENVIRONMENTAL PROPERTIES ON AGN-GALAXY PHYSICS

(218 radio-AGN $z < 1.2$ on COSMOS field. Environments from Darvish+2017)



More massive radio-AGN prefer denser environments
(not only mass-segregation effect. Ask me!)

Most radio-powerful - $P > \sim 10^{24.6}$ W/Hz - AGN prefer denser environments

(cf Peacock & Nicholson clustering results)

CONCLUSIONS

- 1) Radio-emitting AGN are hosted by very massive galaxies at all z
- 2) Most of them are in the process of forming stars at very high rates especially in the past.
Deepest FIR surveys show that $\sim 100\%$ of $z > \sim 1$ radio-AGN are associated to SF events $\rightarrow$ **NO (negative) AGN-to-SF FEEDBACK at those z**
Feedback only present in the $z < 1$ universe and mainly for sources which are radio-powerful
- 3) Hosted by DM halos of masses $> 10^{13.5} M_{\text{sun}}$ (groups-to-clusters of galaxies)
Radio-AGN environmental properties do not depend on radio luminosity (at least up to $P \sim 10^{24.5-25}$ W/Hz) and do not evolve with cosmic epoch
- 4) Stellar content relatively small $\langle M_{\star} \rangle / M^{\text{HALO}} < 10^{-2.7}$
- 5) From comparison of densities **1 out of 2 massive halos host of radio-AGN**
 $\rightarrow \tau \sim 1\text{Gyr} \rightarrow$ **Radio-active phase recurrent phenomenon**
- 6) Dependence of environmental properties on stellar content/AGN emission at different λ /radio luminosity (only for very bright sources)
Connection between sub-pc up to Mpc behaviours?