AGN-host connection in radio AGN

“How to (hopefully)
not get lost in the jungle
of radio AGN:
clues from their hosts”

BOLOGNA & FRIENDS
RADIO GALAXIES

1-2 March 2023

Ivan Delvecchio
(INAF-OAB) & friends

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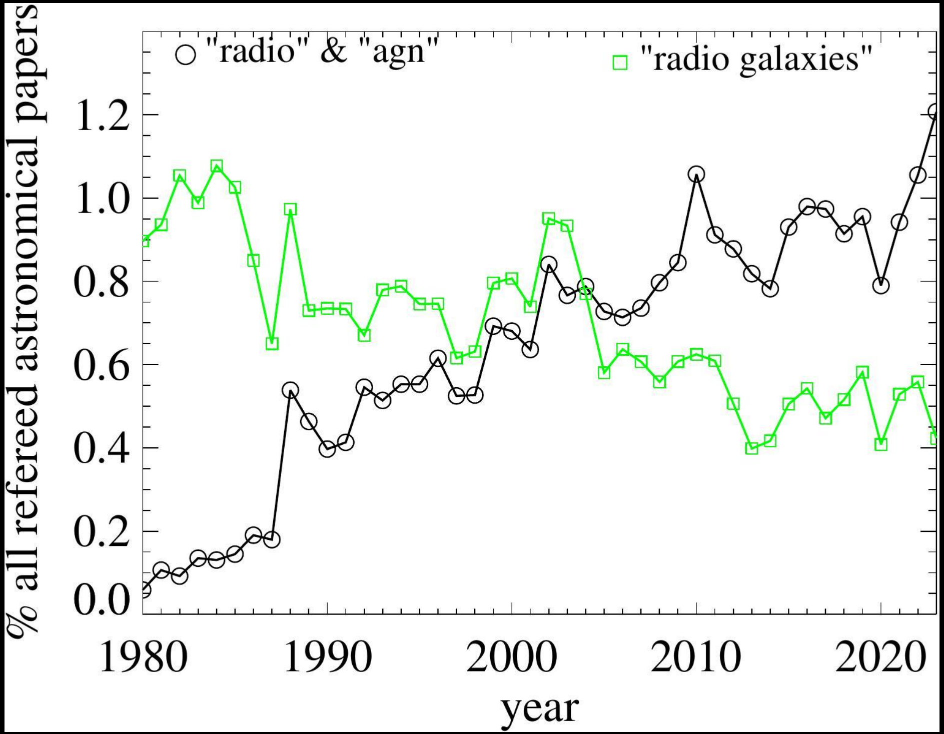
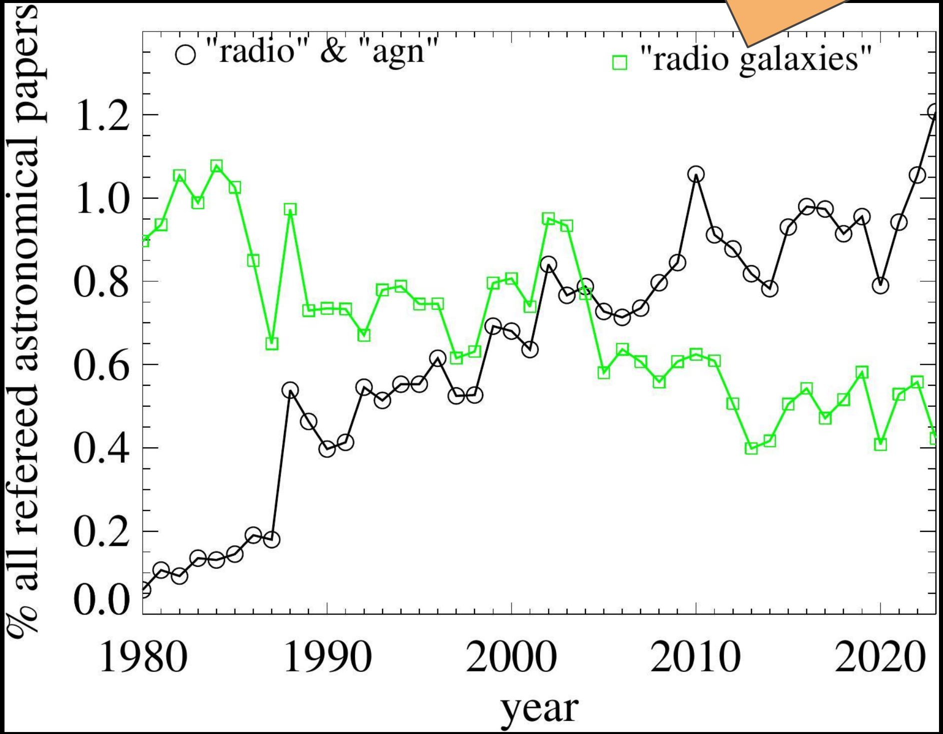
An evolving nomenclature

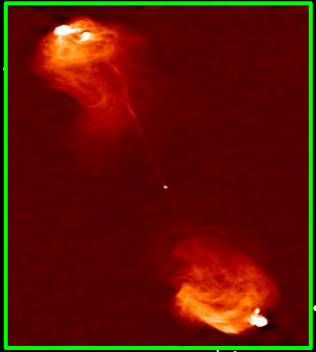


An evolving nomenclature

feedback in action!



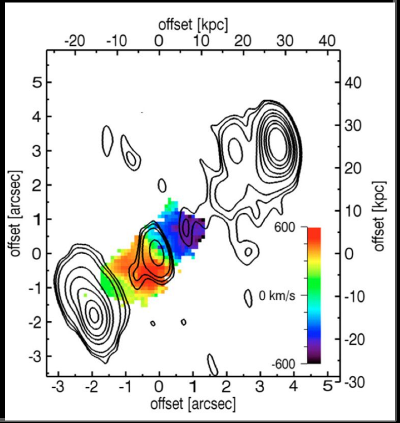
Centaurus A
$L_{1.4}$~ 2x10^{24} W/Hz
(Cooper 1965)



Cygnus A
$L_{1.4}$~ 5x10^{27} W/Hz
(Hey, Phillips & Parsons 1946)

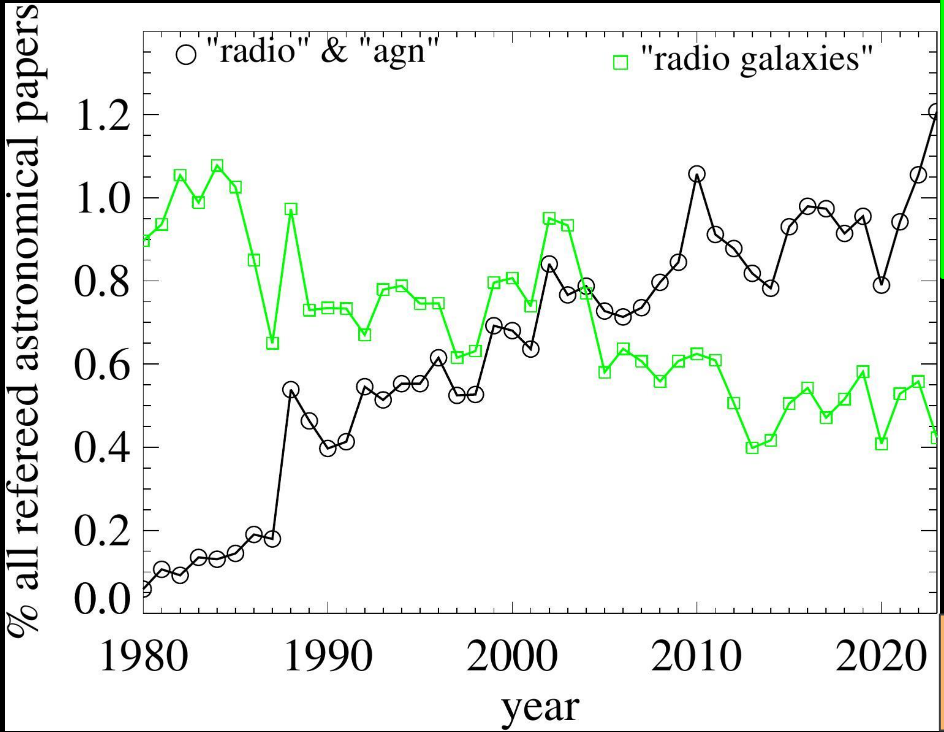
Jets capable of launching powerful outflows

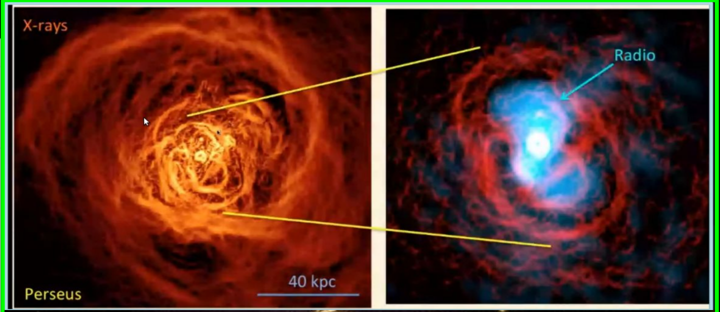
(e.g.Boehringer+1993, Carilli+1994, Rizza+2000, McNamara+2000, Bîrzan+2004,2012, Balmaverde+2018; Nesvadba+2021, …)

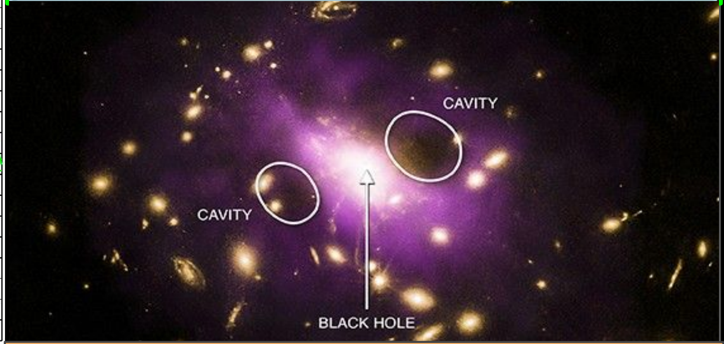


Ejective & preventive feedback

Jets inject energy isotropically in the ISM/ICM through shock waves, sound waves, and buoyantly rising bubbles (see Blanton+2010; Fabian 2012).



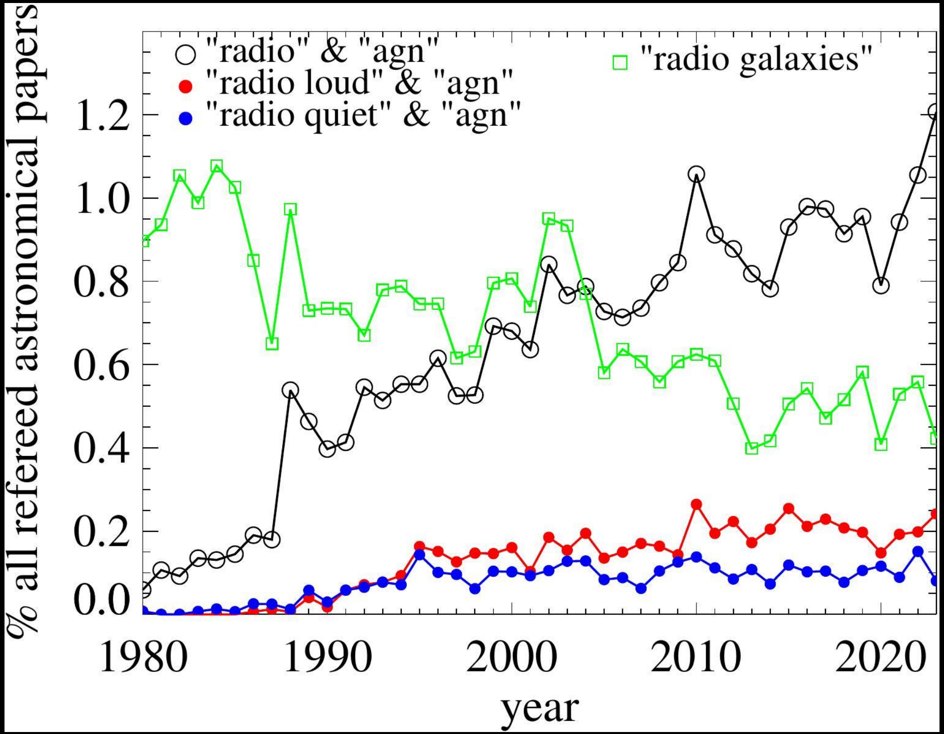




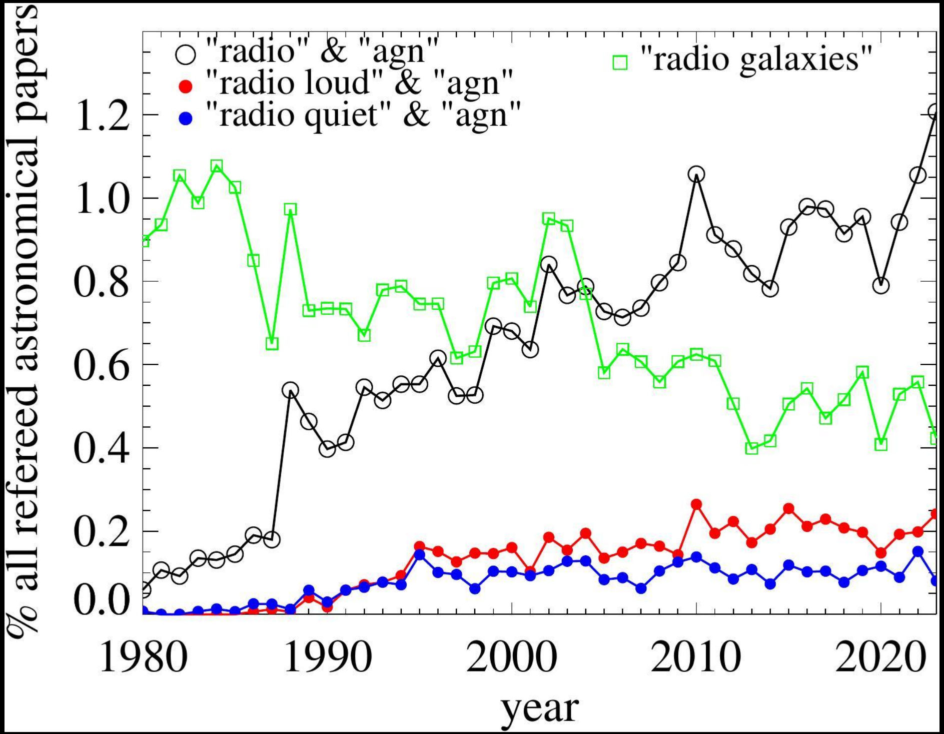
jet-mode feedback prevents overcooling at the center of galaxy clusters

(McNamara & Nulsen 2007; Gaspari+2011; Gitti+2012; McDonald+2013; Hlavacek-Larrondo+2015; Li+2017; Yang+2019).

“Radio loud” vs “radio quiet”



“Radio loud” vs “radio quiet”



“Radio loud” if:

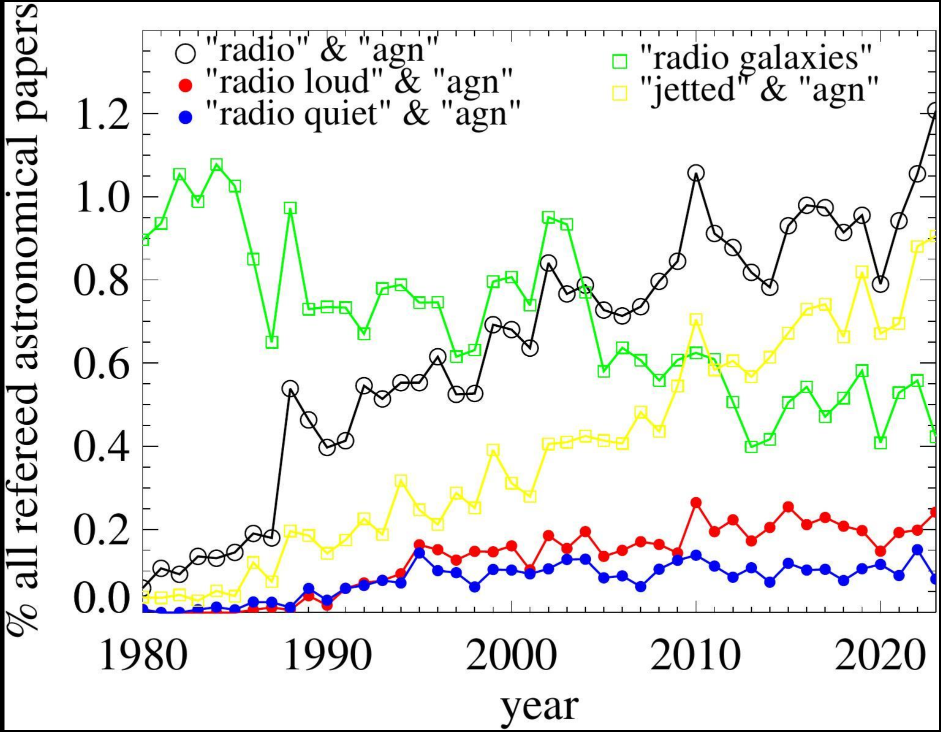
Excess wrt AGN at other λ

- $R_B = \log(L_{5GHz} / L_B) > 1$
  [Kellerman+1989]
- $R_X = \log(\nu L_{5GHz} / L_{2\text{-}10\,keV}) > -3.5$
  [Tarashima & Wilson 2003; Lambrides+2020]
- $R_K = \log(\nu L_{5GHz} / L_{6um}) > -4.2$
  [Klindt+2019; Rosario+2020]

Excess wrt SF in the host

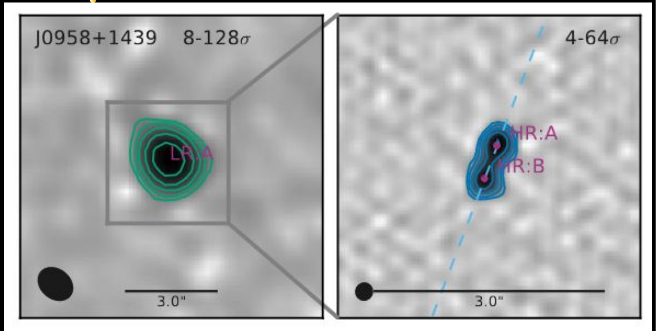
- $q_{24} = \log(S_{24um} / S_{1.4GHz}) < f(z)$
  [Appleton+2004; see Bonzini +2015]
- $q_{FIR} = \log(S_{FIR} / S_{1.4GHz}) < 1.68$
  [Del Moro+2013]
- $q_{TIR} = \log(L_{TIR} / L_{1.4GHz}) < f(z,M_\star)$
  [ID+2017,2021]

We are in the “jetted AGN” era



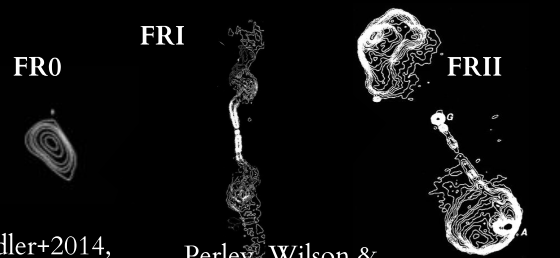
“**jetted**” AGN if we see
strong **relativistic jets**
[e.g. Padovani 2016]

Bear in mind:
angular resolution matters



Maini+2016; Jarvis+2019,2021;
Girdhar+2022, …

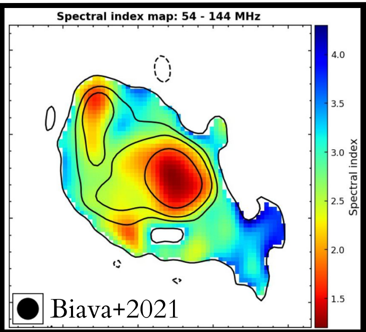
Jetted beasts and how to find them…

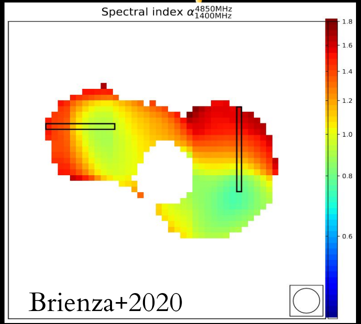


Sadler+2014, Baldi+2015

Perley, Wilson & Scott 1979

Bridle+1994





jet morphology

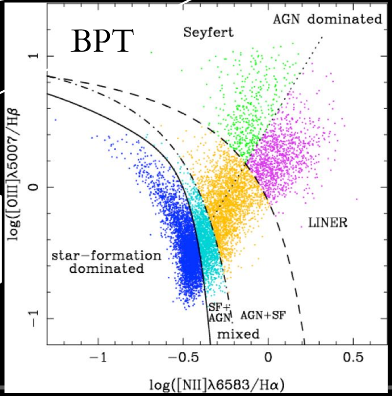
Radio AGN?

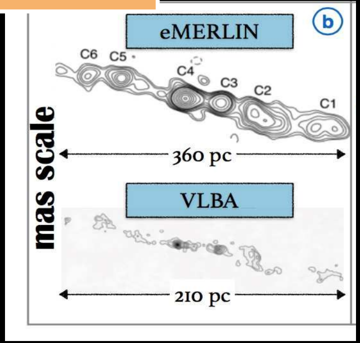
spectral index (map)

radio power/loudness

brightness temperature

Panessa+2019



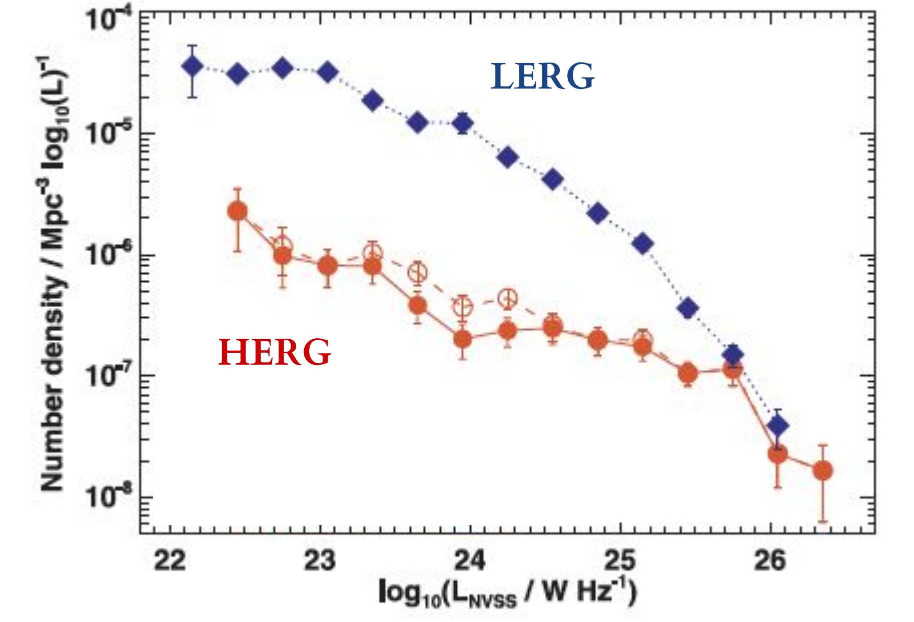


optical spectroscopy

Baldwin 1981; Best+2005,2012; Heckman & Best 2014; Baldi+2021, …

A two-fold radio AGN population in the local Universe

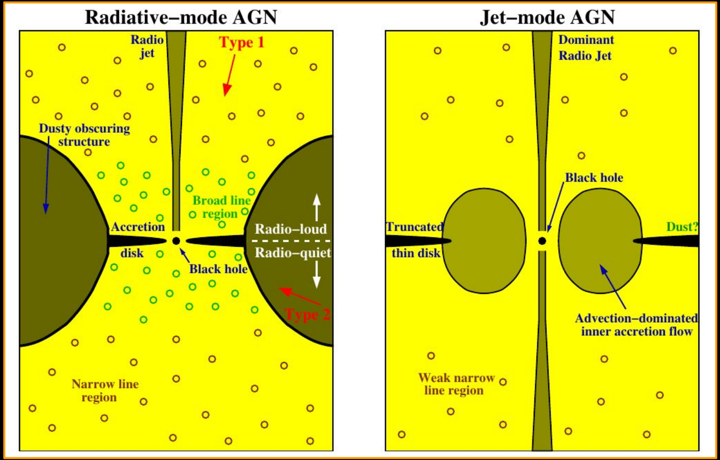
Best & Heckman (2012)



- AGN diagnostics:
  - *D4000* vs $L_{150MHz}/M_\star$
  - BPT
  - $L_{H\alpha}$ vs L_{150MHz}
  - WISE (W2-W3)

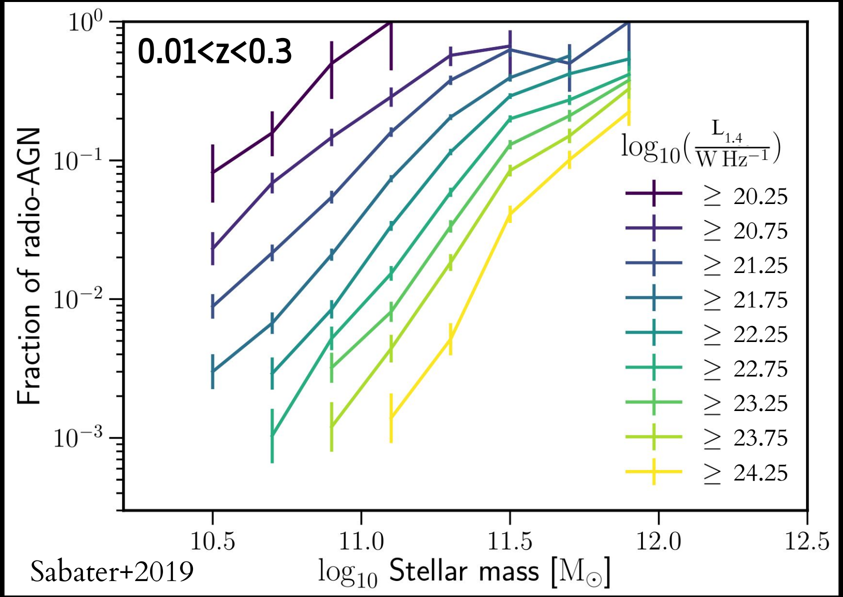
HERG (5% of all radio AGN at $L<10^{25}$W/Hz)

LERG (95% of all radio AGN at $L<10^{25}$W/Hz)



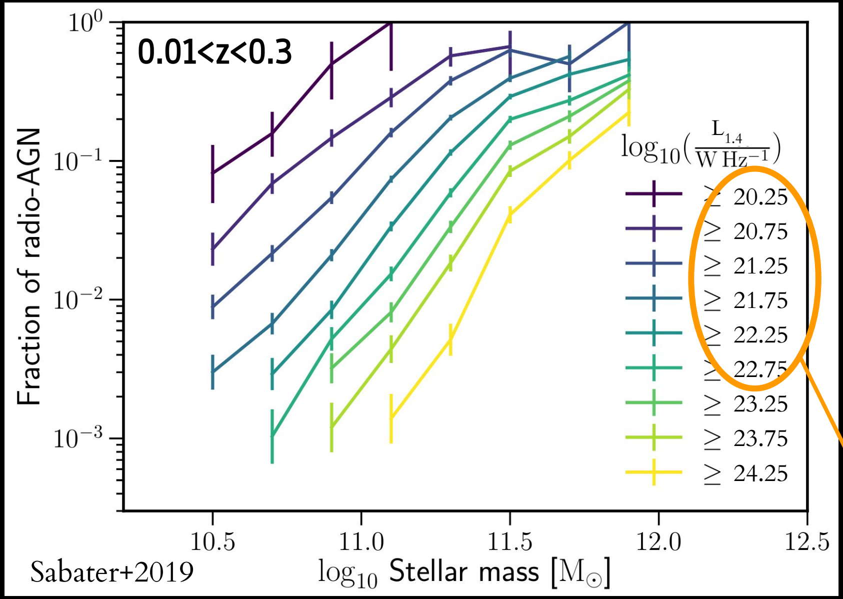
Heckman & Best (2014)

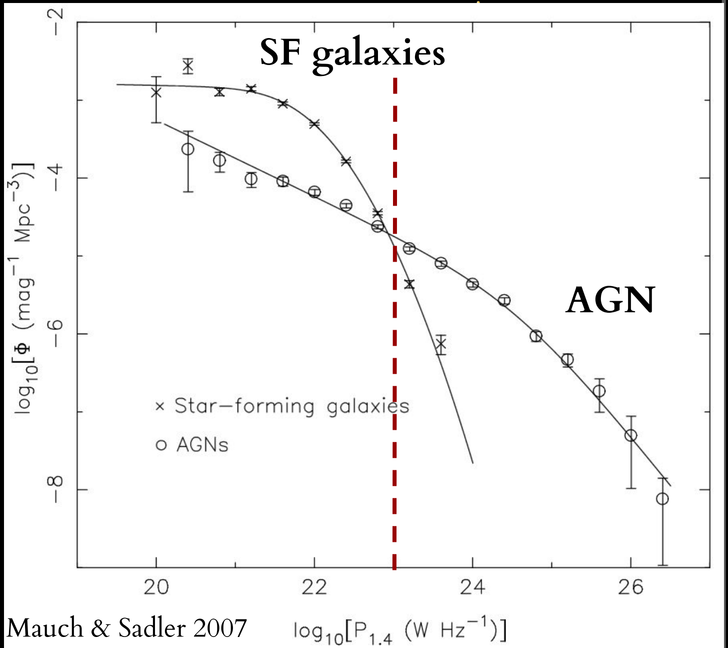
The most massive galaxies are always switched on



- LOFAR 150MHz data —> scaled to 1.4GHz
- AGN diagnostics:
  - *D4000* vs $L_{150MHz}/M_\star$
  - BPT
  - $L_{H\alpha}$ vs L_{150MHz}
  - WISE (W2–W3)

Can we access radio-faint AGN in *all* galaxies?





- ❏ LOFAR 150MHz data —> scaled to 1.4GHz
- ❏ AGN diagnostics:
  - *D4000* vs $L_{150MHz}/M_\star$
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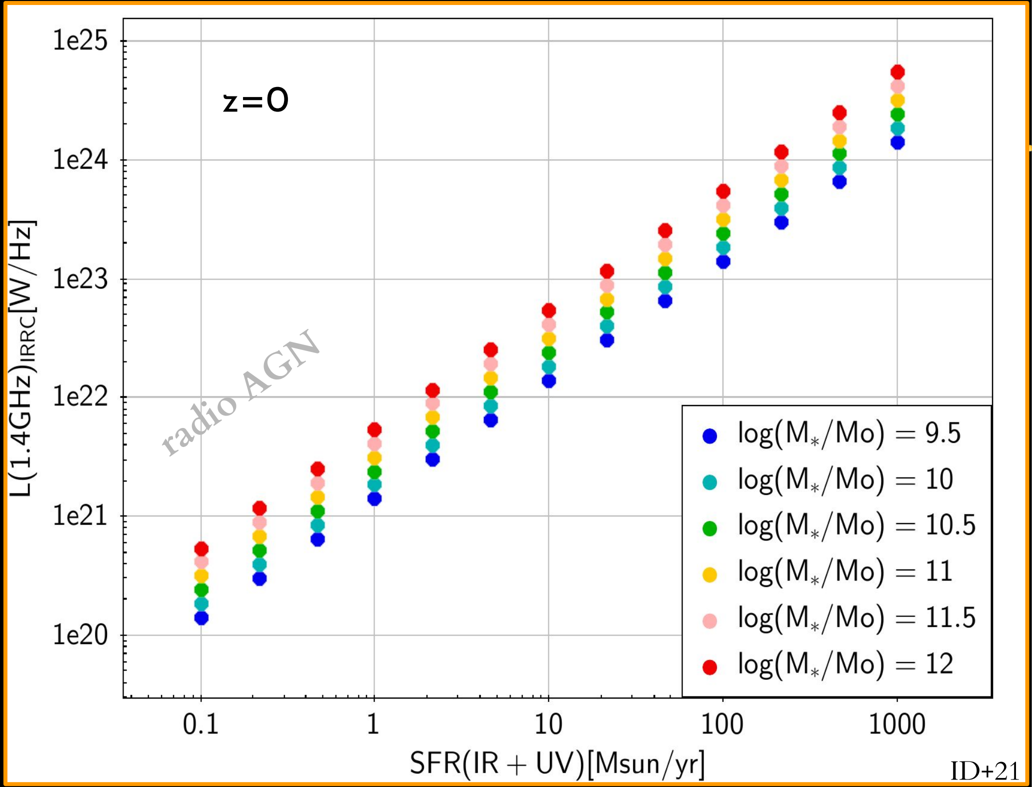
  - $L_{H\alpha}$ vs L_{150MHz}
  - WISE (W2–W3)

Moderately luminous radio AGN ($L_{1.4}<10^{23}$ W/Hz) are "*loud*" only in weakly star-forming galaxies

$L_{1.4}$ - SFR conversions across the galaxy population

$L_{1.4}$–SFR relation is strongly dependent on $M_\star$ (Gurkan+2018; Read+2018; ID+2021; Smith+2021)

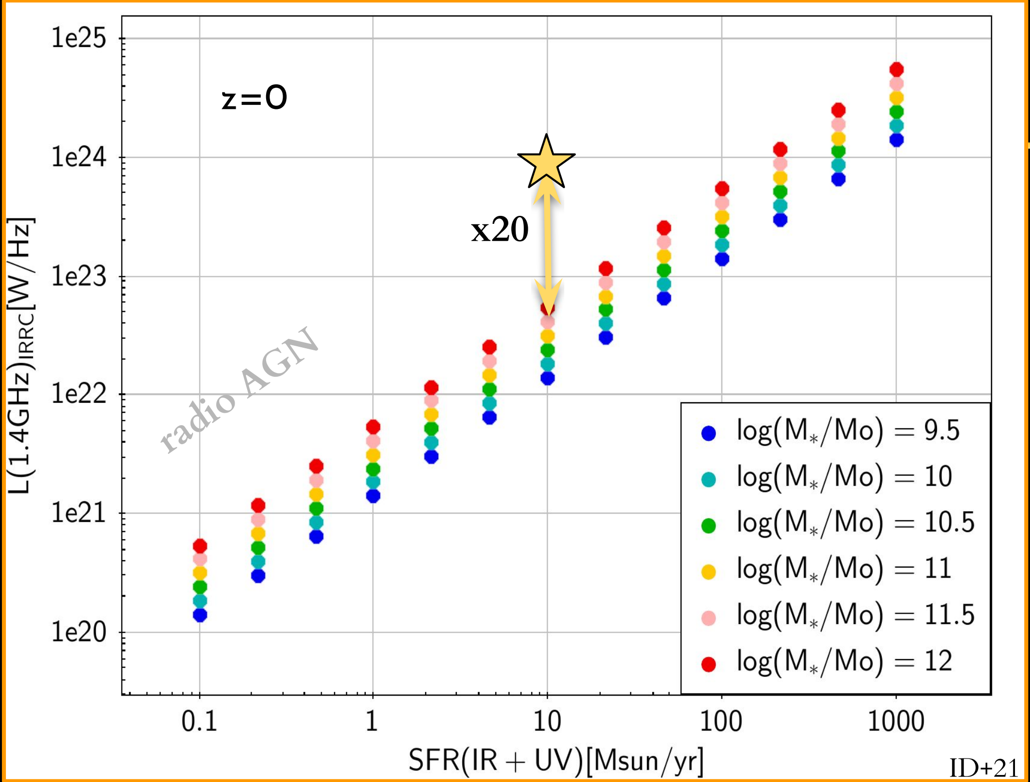


$L_{1.4}$ - SFR conversions across the galaxy population

A few examples:

$L_{1.4}$ = 10^{24} W/Hz
$\log(M_\star/M_{sun})$ = 11
SFR = 10 M_{sun}/yr (MS)

→ radio-excess = AGN



ID+21

$L_{1.4}$ - SFR conversions across the galaxy population

A few examples:

$L_{1.4} = 10^{24}$ W/Hz
$\log(M_\star/M_{sun}) = 11$
SFR = 10 M_{sun}/yr (MS)

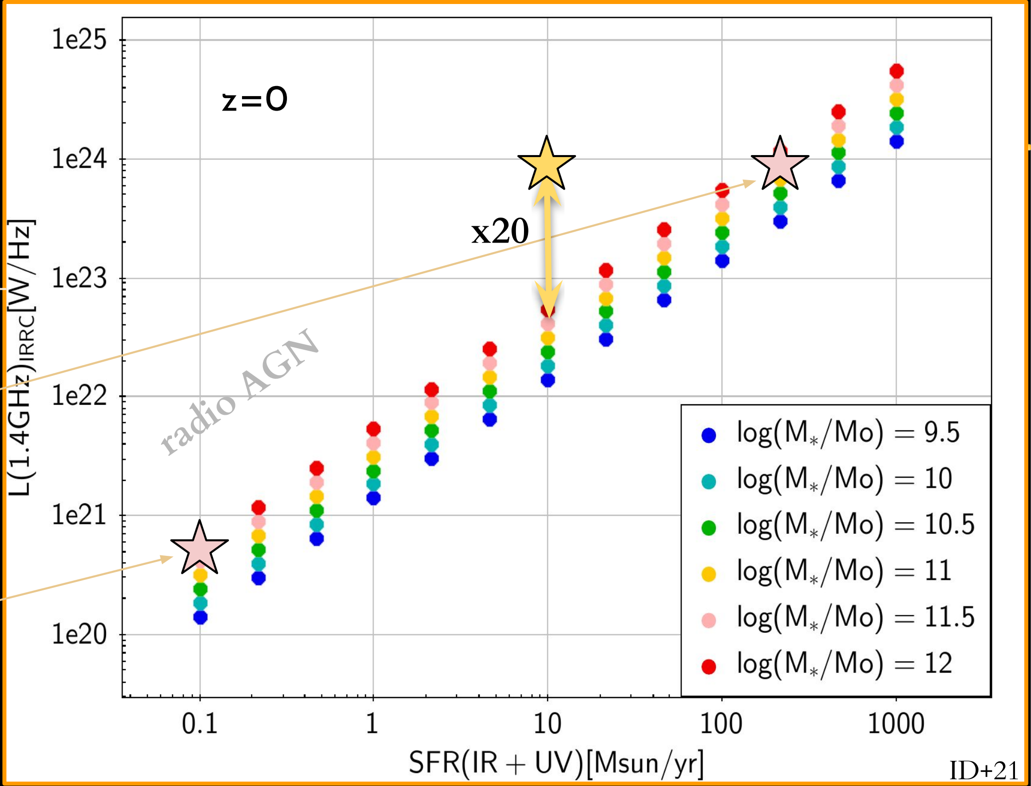
→ radio-excess = AGN

$L_{1.4} = 10^{24}$ W/Hz
$\log(M_\star/M_{sun}) = 11.5$
SFR = 200 M_{sun}/yr (ULIRG)

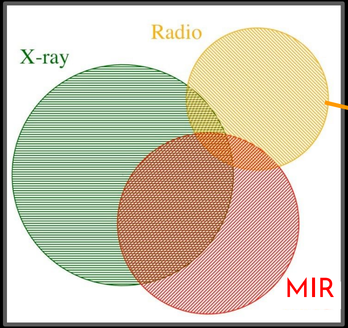
or

$L_{1.4} = 10^{20.5}$ W/Hz
$\log(M_\star/M_{sun}) = 11.5$
SFR = 0.1 M_{sun}/yr (quiescent)

→ consistent with SF



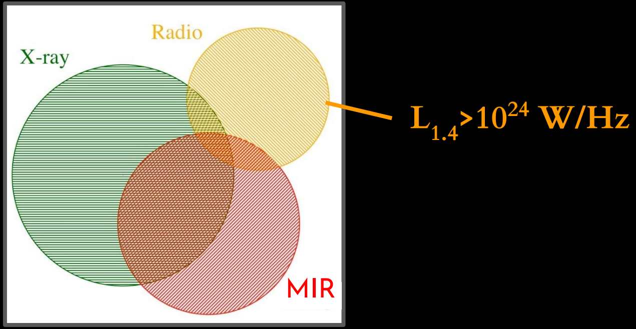
What are the host galaxies of radio AGN at z≲1?



$L_{1.4} > 10^{24}$ W/Hz

Hickox+2009

What are the host galaxies of radio AGN at $z \lesssim 1$?



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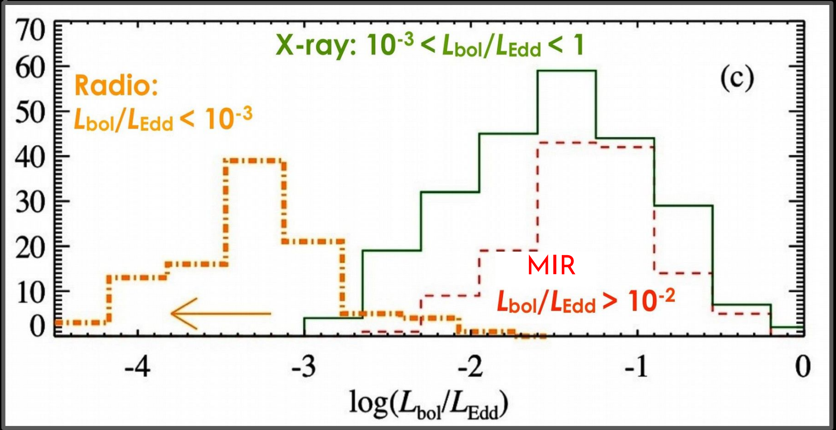

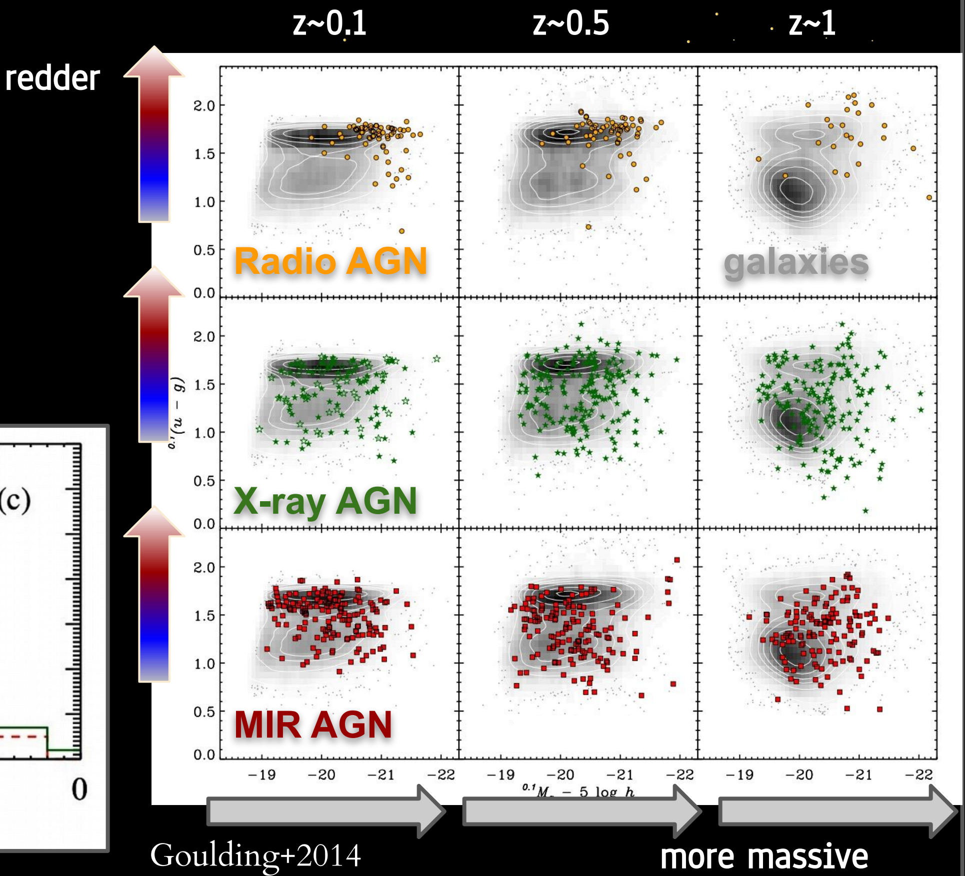

Goulding+2014

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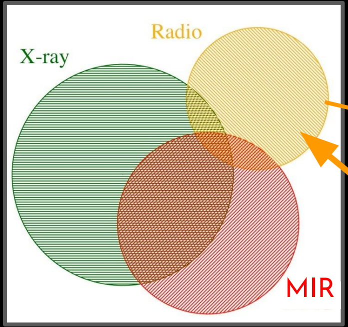

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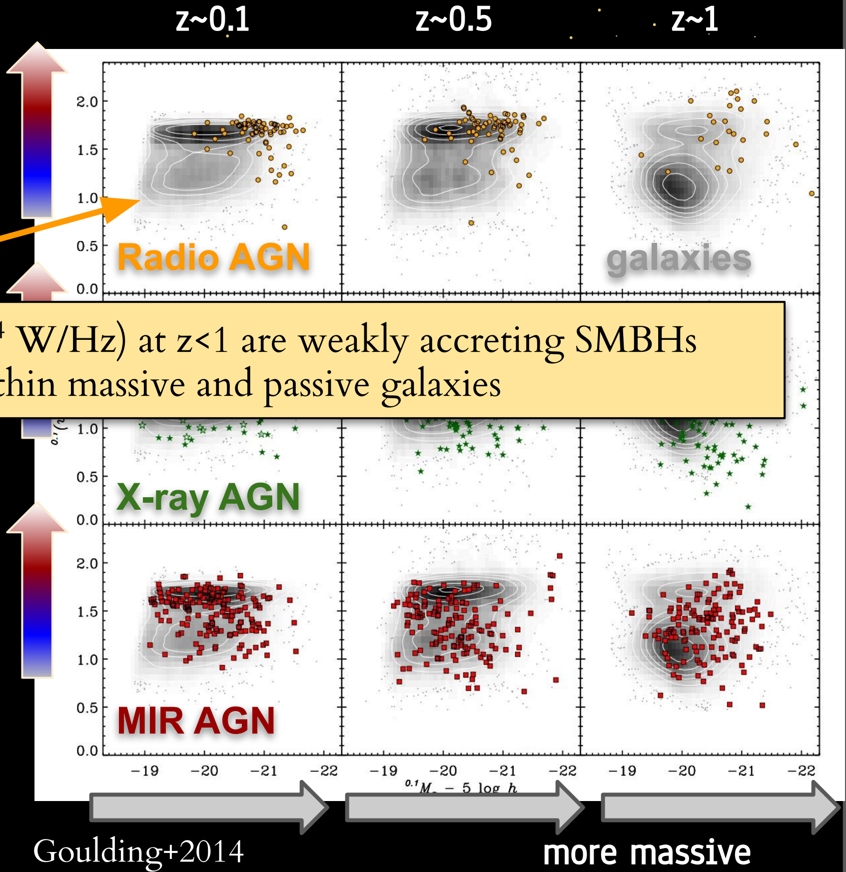
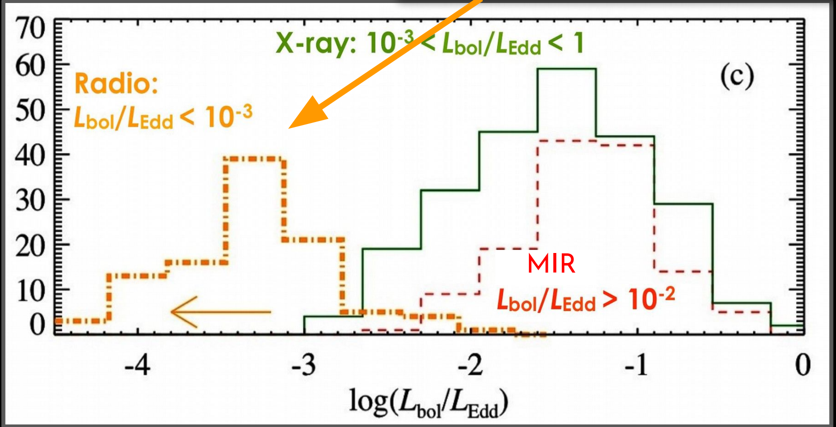
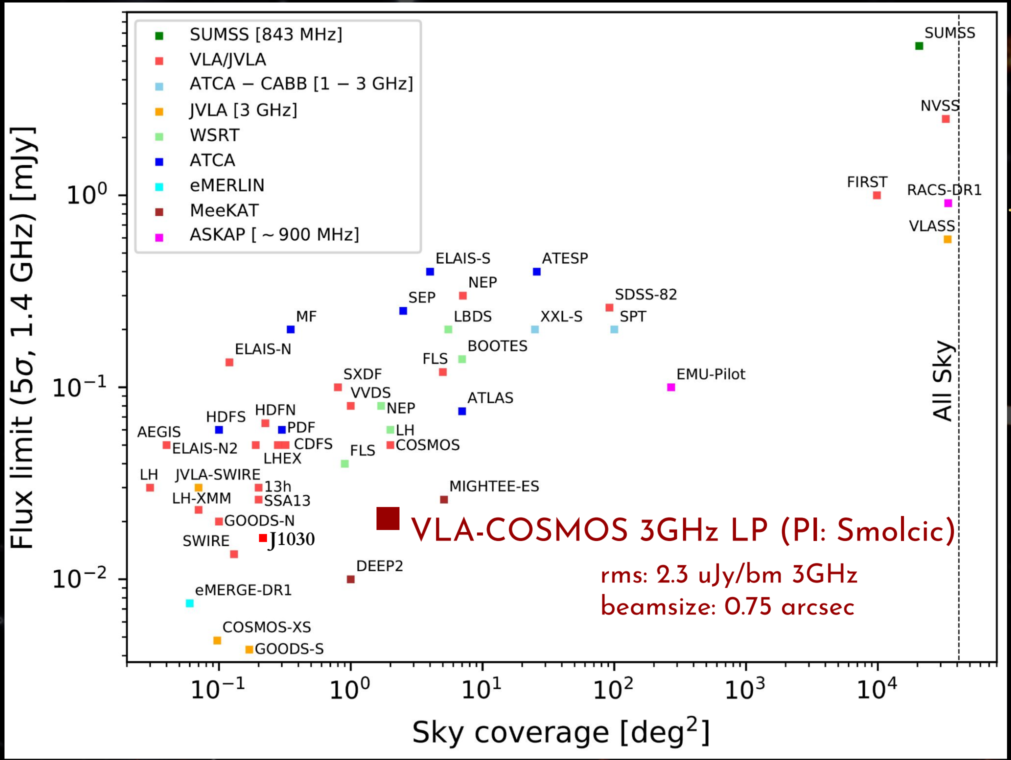


Goulding+2014

Radio AGN ($L_{1.4}>10^{24}$ W/Hz) at z<1 are weakly accreting SMBHs hosted within massive and passive galaxies



High-z radio AGN with deep radio surveys

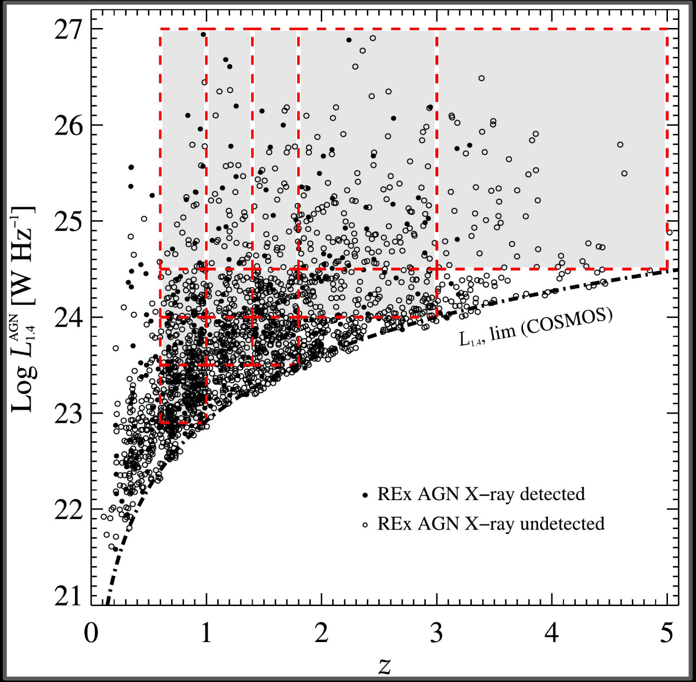


Adapted from Q. D'Amato+2019

Credit: M. Novak

Accretion and ejection in radio AGN at z≳1

ID+2018



- Selecting a $L_{1.4}$ -complete subset of >1200 radio-excess AGN (binned in $L_{1.4}$-z)
- ~15% are detected with deep *Chandra* imaging (Civano et al. 2016; Marchesi et al. 2016)
- X-ray stacking of radio AGN (CSTACK)*

* http://lambic.astrosen.unam.mx/cstack/

Accretion and ejection in radio AGN at z≳1

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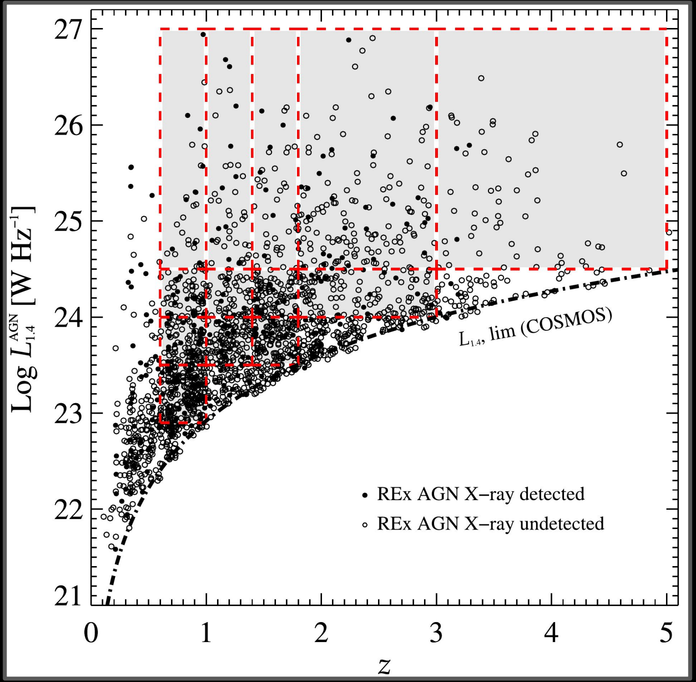

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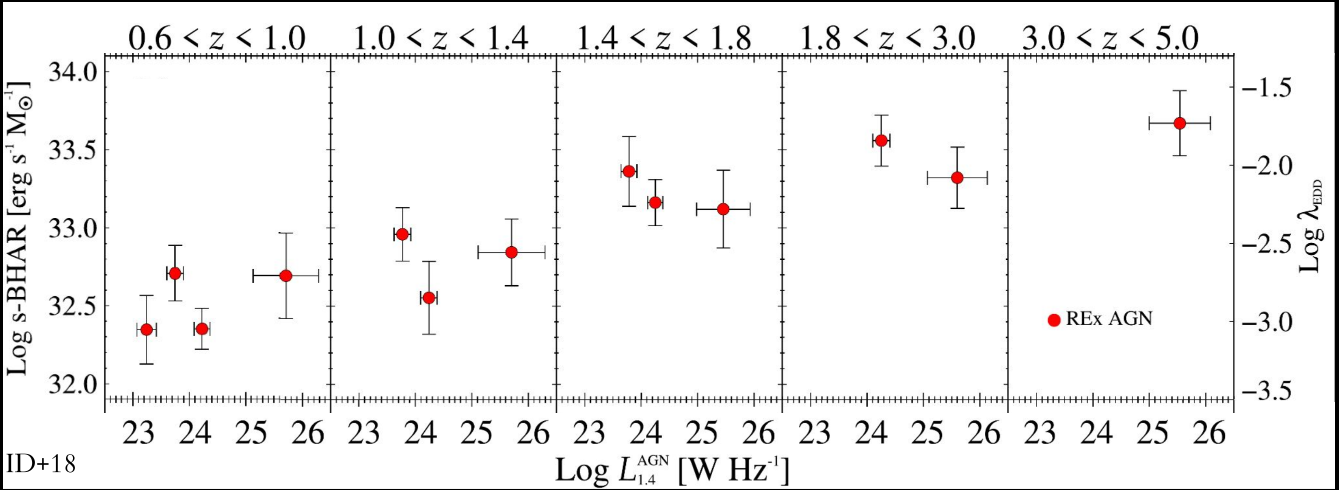
<L_X> → <s-BHAR> → <λ_{EDD}>

"specific BH accretion rate" (s-BHAR ~ $L_X/M_\star$) [Aird+2012]

Eddington ratio (if fixed $M_\star/M_{BH}$)

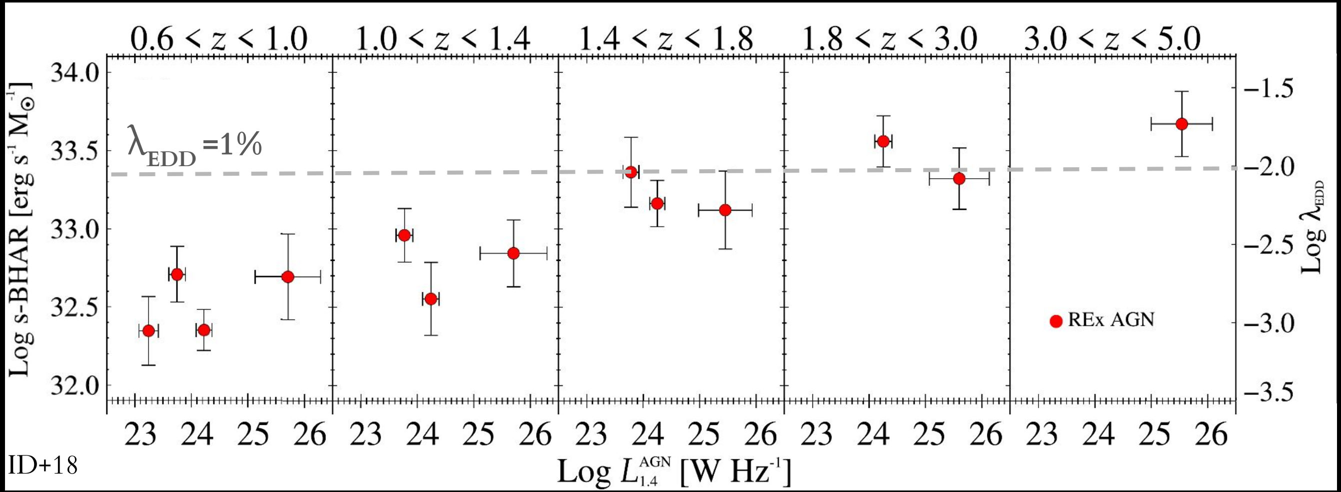
* http://lambic.astrosen.unam.mx/cstack/

Accretion and ejection in radio AGN at z≳1



❑ The average s-BHAR increases by **x10** from z~0.7 to z~3.5

Accretion and ejection in radio AGN at z≳1



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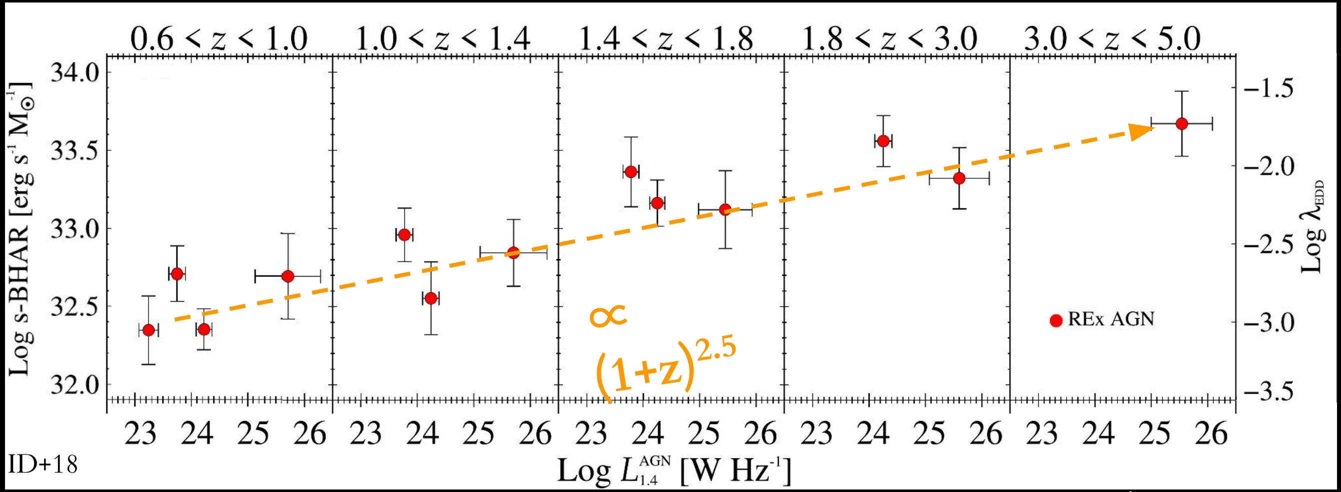
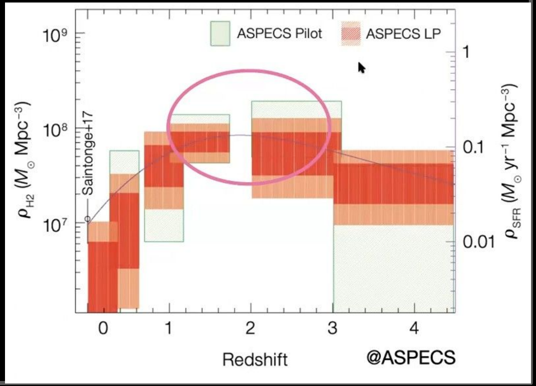
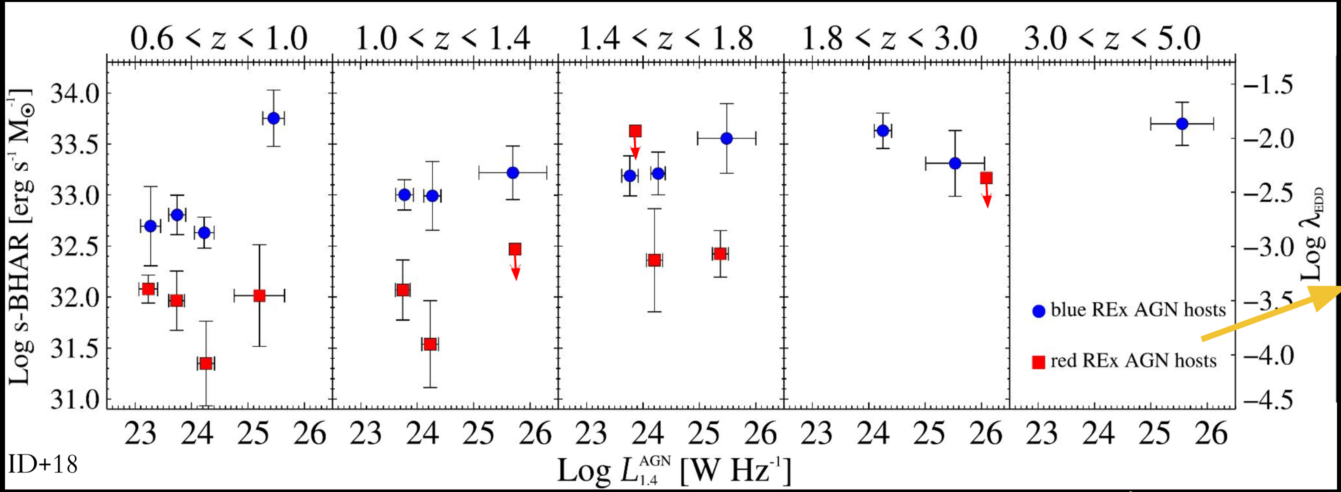
Accretion and ejection in radio AGN at z≳1



- The average s-BHAR increases by **x10** from z~0.7 to z~3.5
- λ_{EDD} ≳ 1% (=radiatively efficient BH accretion) at z>1.5
- The *z*-trend mimics the **evolving f_{H2} in SFGs** (e.g. Saintonge+2012; 2017; Liu+2019; Tacconi+2020; Decarli+2020; Walter+2020, Wang+2022)



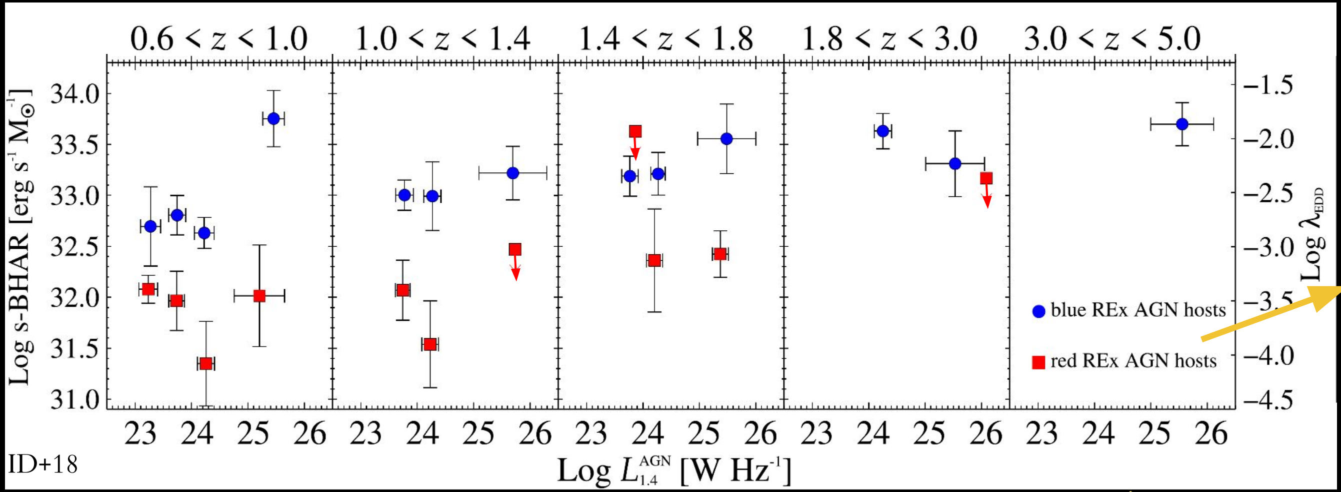
Difference in s-BHAR between blue vs red hosts



(NUV–r) / (r–J)
(Ilbert+2013; Davidzon +2017)

- The average s-BHAR of blue radio AGN hosts is systematically (>3x) higher than that of red radio AGN hosts, at fixed $L_{1.4}$ and z

Difference in s-BHAR between blue vs red hosts



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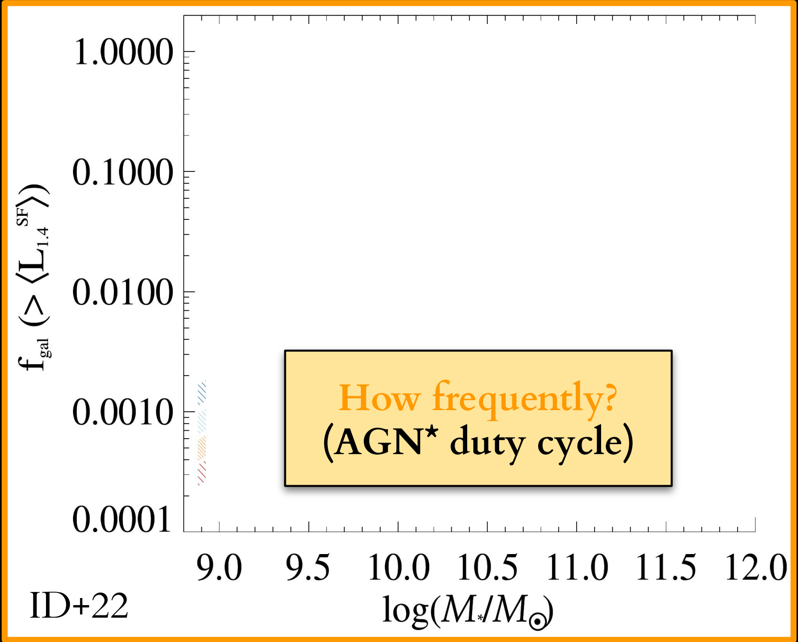
- The average s-BHAR of blue radio AGN hosts is systematically (>3x) higher than that of red radio AGN hosts, at fixed $L_{1.4}$ and z

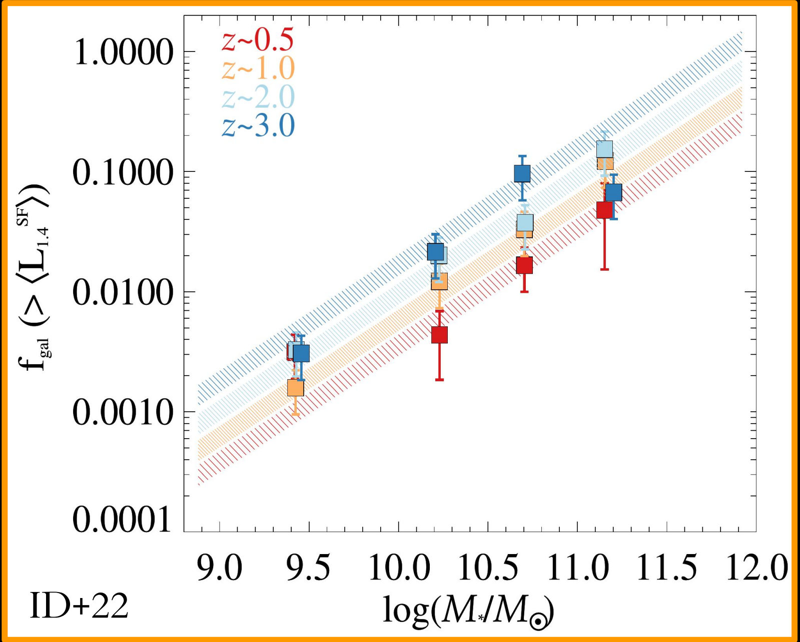
A possible interpretation is that **radio AGN activity is driven by cold gas accretion from the host**

Radio AGN triggering in SFGs: a strong $M_\star$ dependence



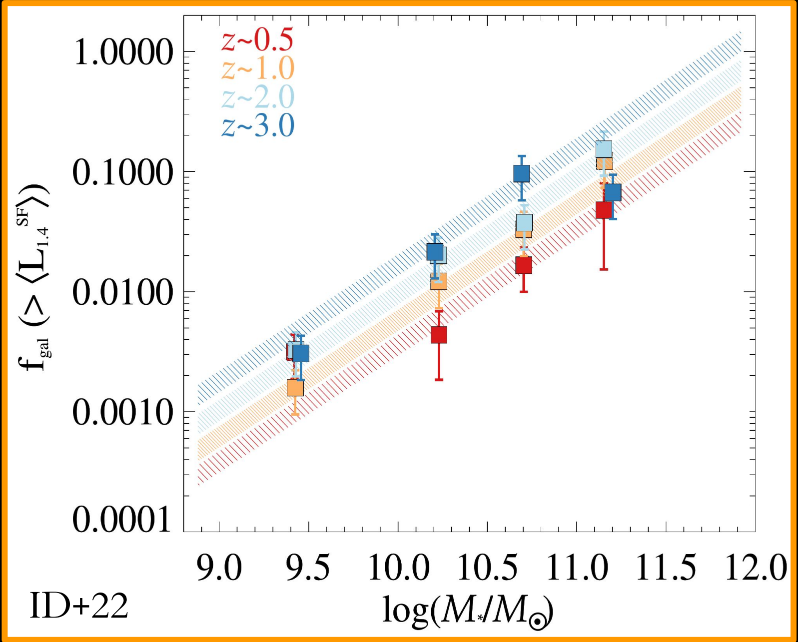
AGN if:
L>$L_{SF}(M_\star, z)$

Radio AGN triggering in SFGs: a strong $M_\star$ dependence



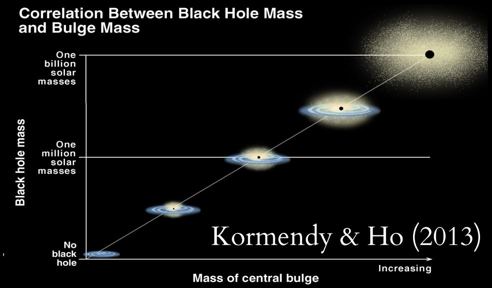
Higher radio AGN duty cycle in more massive galaxies: ≈10% at $M_\star = 10^{11}$ M_{sun}

Radio AGN triggering in SFGs: other proxies



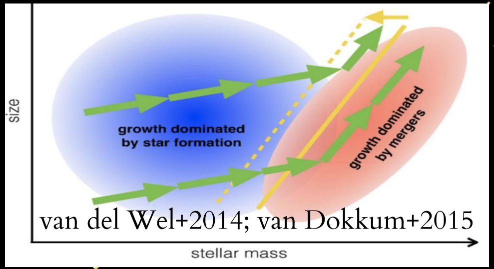
Higher radio AGN duty cycle in more massive galaxies: ≈10% at $M_\star = 10^{11}\ M_{sun}$

BH mass

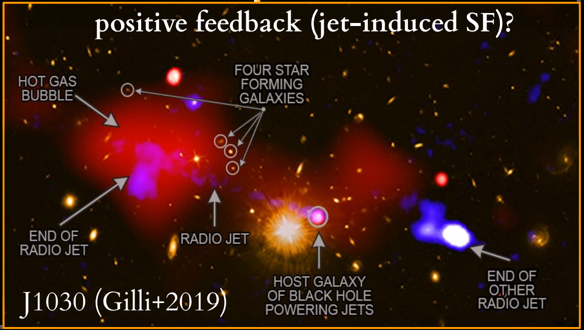


Bulge fraction

Size, compactness

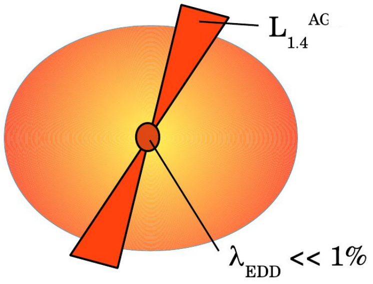


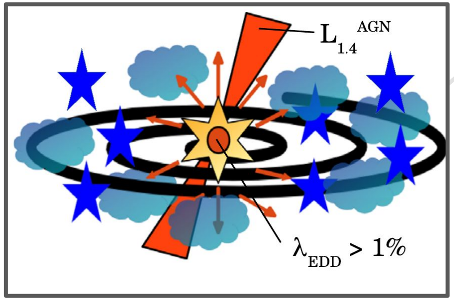
DM halo mass, environment



Accretion and ejection in radio AGN: summary

$z << 1$ ← $z > 1.5$





Red and passive galaxy	RADIO (AND NON) AGN HOST	Blue and highly star-forming galaxy
Weakly accreting SMBH (λ_{EDD} << 1%)	RADIO AGN	Highly accreting SMBH (λ_{EDD} > 1%)

CAVEATS (at high-z):

- galaxies are more compact
- jets are capped to <<kpc scales (unresolved from arcsec imaging)
- not valid for the brightest tip (e.g. Blazars) but at population level
- Beware your host galaxy!

Host galaxies properties ($M_\star$, SFR, f_{H2}) and environment give us clues on the **average accretion rate** (radio or not)

The assembly of DM halo, host-galaxy and the central BH mass are **unsynchronised but mutually intertwined**