The Fourth National Workshop on the SKA Project

Sharpening the Italian science case for the SKAO

Dept. Physics, Univ. Catania (Italy)

28/11/2023

Tracing the cosmic assembly of supermassive black holes and galaxies in the SKA era

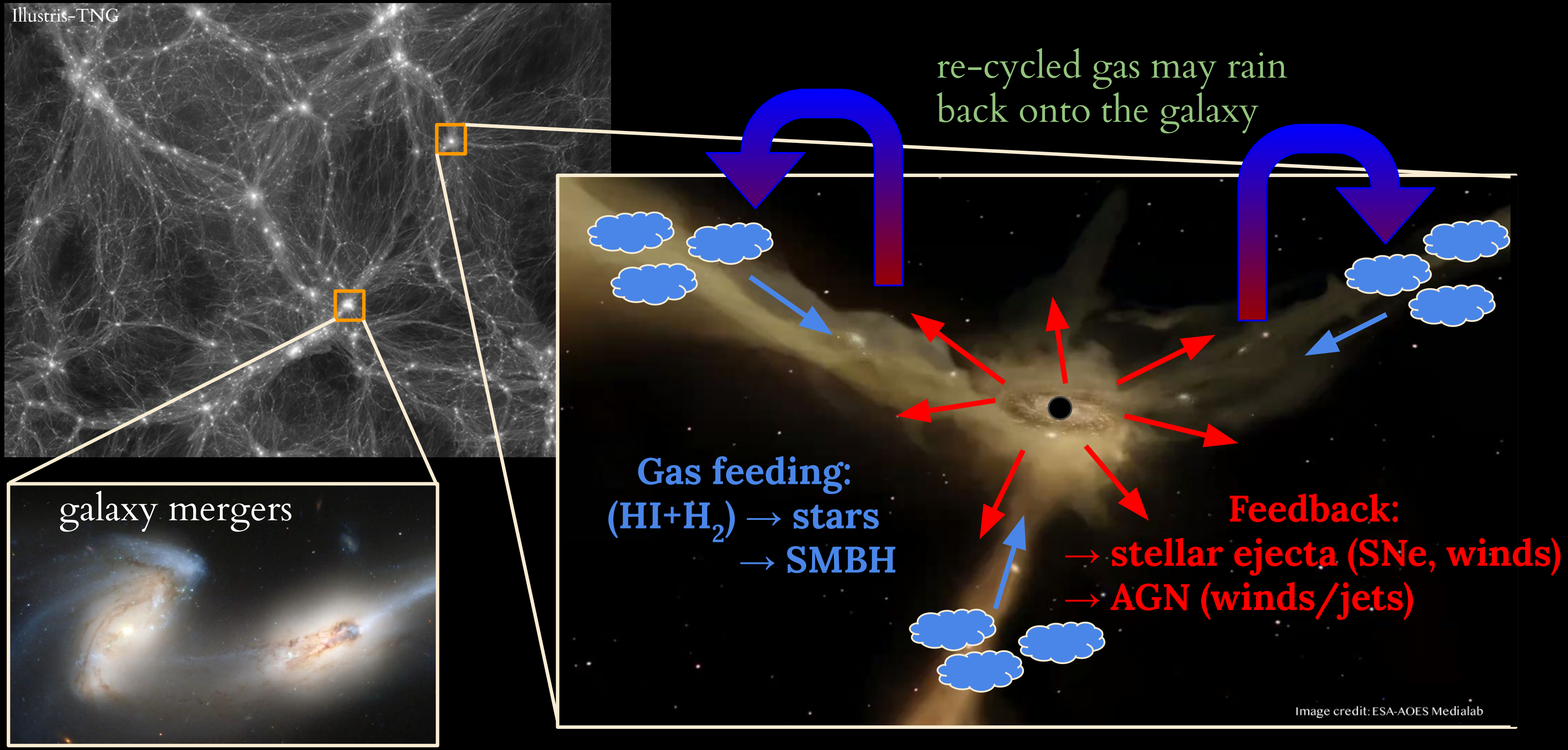
Ivan Delvecchio (INAF-OAB)

ivan.delvecchio@inaf.it

Outline

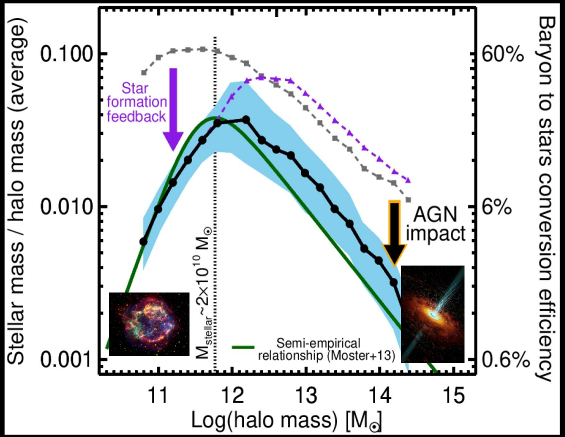
- Open questions in galaxy/AGN evolution
- Why looking at radio-continuum emission?
- Highlights from radio-continuum surveys on galaxy/AGN evolution
- Prospects and synergies with the SKA

The baryon cycle



Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

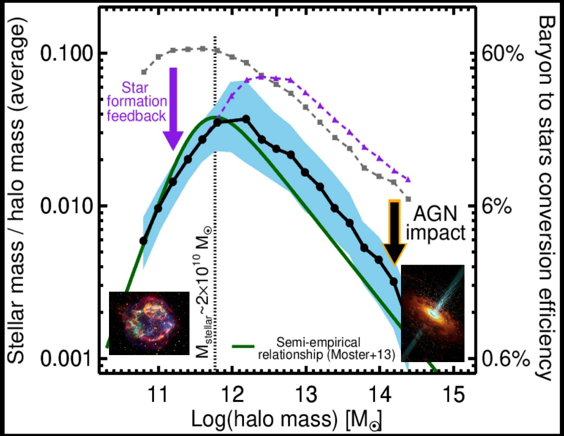
See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others



Harrison 2017

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others

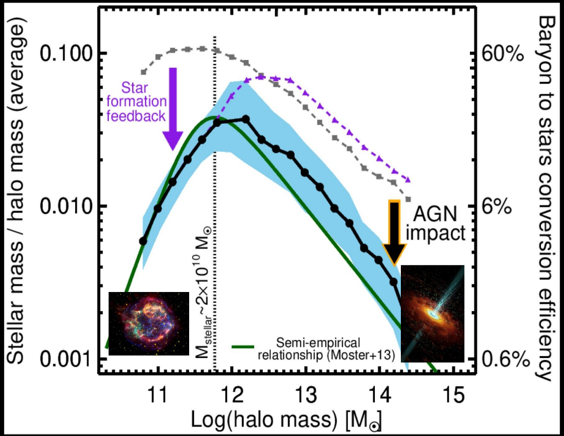


Harrison 2017

What is the role of internal (stellar+AGN feedback, morphology) vs external (environmental) mechanisms in shaping the galaxy assembly?

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others

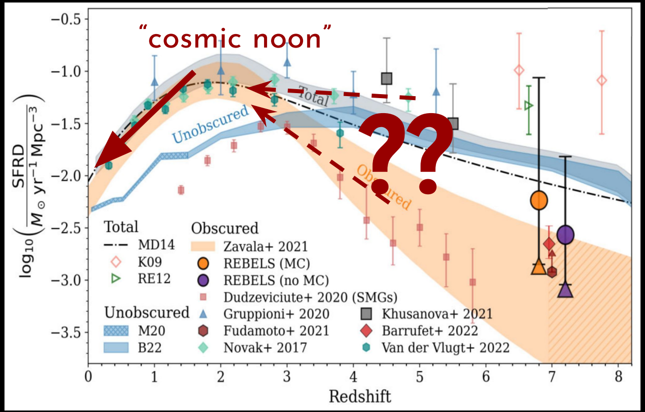


Harrison 2017

What is the role of internal (stellar+AGN feedback, morphology) vs external (environmental) mechanisms in shaping the galaxy assembly?

A full census of stellar assembly: the cosmic star-formation rate density (SFRD)

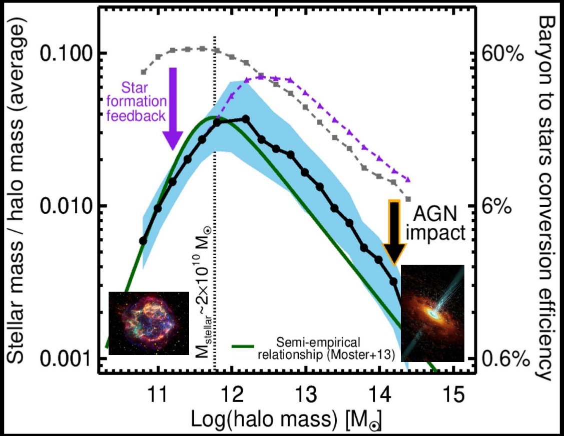
Madau & Dickinson 2014 (MD14); Bouwens+2015; Sijacki+2015; Volonteri+2016; Ranalli+2016; Novak+2017; Oesch+2018; Loiacono+2020; Gruppioni+2020; Khusanova+2021; Zavala+2021; Fudamoto+2021; Kono+2022; Enia+2022; Barrufet+2022; van der Vlugt+2022, Algera+2023, Traina+2023; and many others



Algera+2023

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others

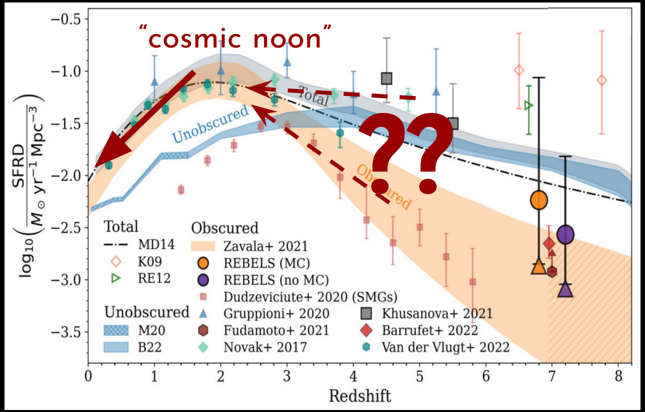


Harrison 2017

What is the role of internal (stellar+AGN feedback, morphology) vs external (environmental) mechanisms in shaping the galaxy assembly?

A full census of stellar assembly: the cosmic star-formation rate density (SFRD)

Madau & Dickinson 2014 (MD14); Bouwens+2015; Sijacki+2015; Volonteri+2016; Ranalli+2016; Novak+2017; Oesch+2018; Loiacono+2020; Gruppioni+2020; Khusanova+2021; Zavala+2021; Fudamoto+2021; Kono+2022; Enia+2022; Barrufet+2022; van der Vlugt+2022, Algera+2023, Traina+2023; and many others

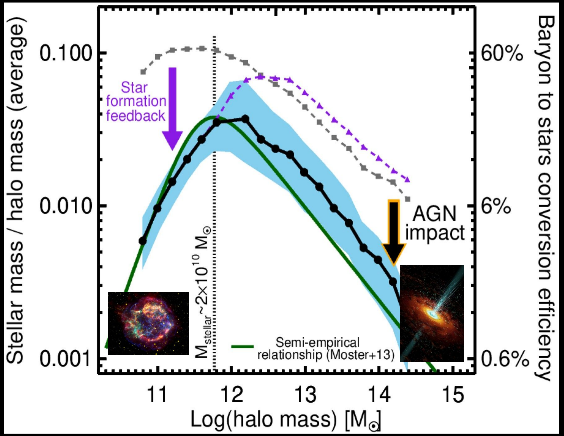


Algera+2023

What is the total star formation history of the Universe? Need for independent dust-free SFR tracer not affected by confusion

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others

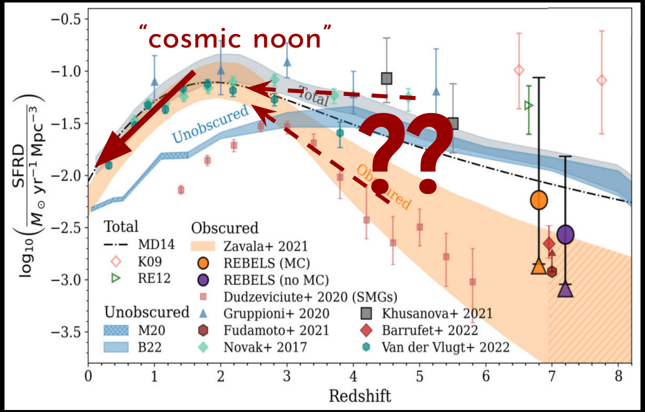


Harrison 2017

What is the role of internal (stellar+AGN feedback, morphology) vs external (environmental) mechanisms in shaping the galaxy assembly?

A full census of stellar assembly: the cosmic star-formation rate density (SFRD)

Madau & Dickinson 2014 (MD14); Bouwens+2015; Sijacki+2015; Volonteri+2016; Ranalli+2016; Novak+2017; Oesch+2018; Loiacono+2020; Gruppioni+2020; Khusanova+2021; Zavala+2021; Fudamoto+2021; Kono+2022; Enia+2022; Barrufet+2022; van der Vlugt+2022, Algera+2023, Traina+2023; and many others

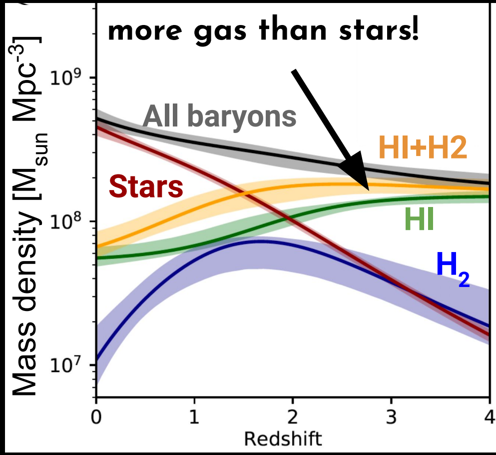


Algera+2023

What is the total star formation history of the Universe? Need for independent dust-free SFR tracer not affected by confusion

Tracing the internal growth of structures within galaxies from ($HI+H_2$) gas reservoir

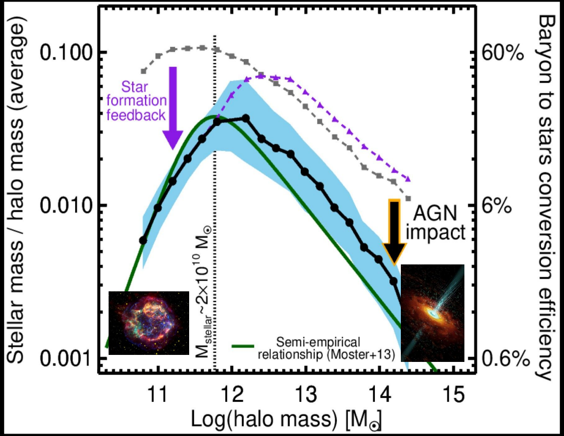
Leroy+2008; Daddi+2010; Genzel+2010; Tacconi+2010; Geach+2011; Saintonge+2013, Magdis+2013; Tacconi+2018, 2020; Liu+2019; Walter+2020; Decarli+2020; Boogaard+2020. **JWST**: Cheng+2022; Guo+2022; Ferreira+2022; Kartaltepe+2023; etc



Walter+2020, ASPECS

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the halo mass

See e.g. Croton+2006; Bower+2006; Silk 2011; Gaspari+2011; Moster+2013; Dubois+2013; Hirschmann+2014; Khandair+2014; Vogelsberger+2014; Somerville & Dave 2015; Crain+2015; Choi+2018; Cattaneo+2019; Moster+2019; Veilleux+2020; Péroux & Howk 2020, and many others

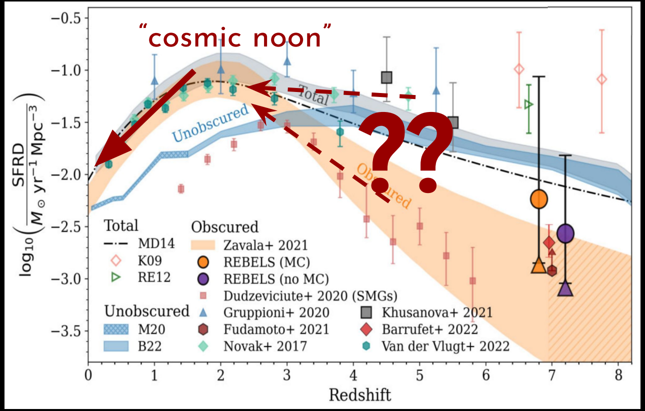


Harrison 2017

What is the role of internal (stellar+AGN feedback, morphology) vs external (environmental) mechanisms in shaping the galaxy assembly?

A full census of stellar assembly: the cosmic star-formation rate density (SFRD)

Madau & Dickinson 2014 (MD14); Bouwens+2015; Sijacki+2015; Volonteri+2016; Ranalli+2016; Novak+2017; Oesch+2018; Loiacono+2020; Gruppioni+2020; Khusanova+2021; Zavala+2021; Fudamoto+2021; Kono+2022; Enia+2022; Barrufet+2022; van der Vlugt+2022, Algera+2023, Traina+2023; and many others

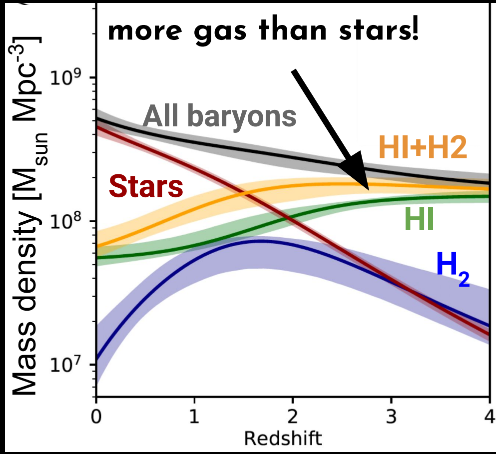


Algera+2023

What is the total star formation history of the Universe? Need for independent dust-free SFR tracer not affected by confusion

Tracing the internal growth of structures within galaxies from (HI+H_2) gas reservoir

Leroy+2008; Daddi+2010; Genzel+2010; Tacconi+2010; Geach+2011; Saintonge+2013, Magdis+2013; Tacconi+2018, 2020; Liu+2019; Walter+2020; Decarli+2020; Boogaard+2020. **JWST**: Cheng+2022; Guo+2022; Ferreira+2022; Kartaltepe+2023; etc



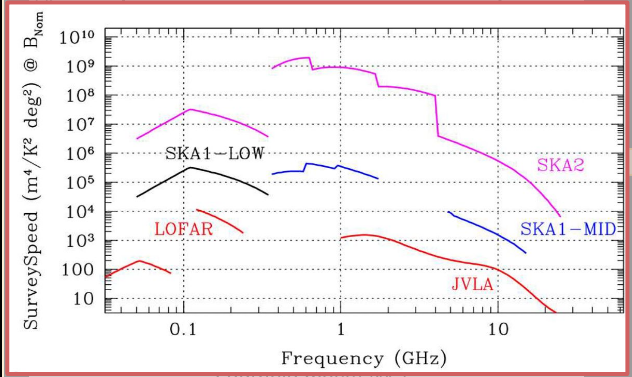
Walter+2020, ASPECS

How and when are different galaxy components (e.g. disk vs. bulge) formed?

Galaxy (baryon) assembly is not efficient (<20%) and strongly depends on the h... mass

Large statistics (fov, survey speed)

See e.g. Croton+2006; ...w+2006; Sil... Gaspari+2011; Moster+20...; ...2013; Hi... 2014; Khandair+2014; Vogelsberger+2014; Som... & Davé 2015; Crain+2015; Choi+2018; ...2019; Moster+2019; Veilleux+2020; Péroux & ... 2020, and many others



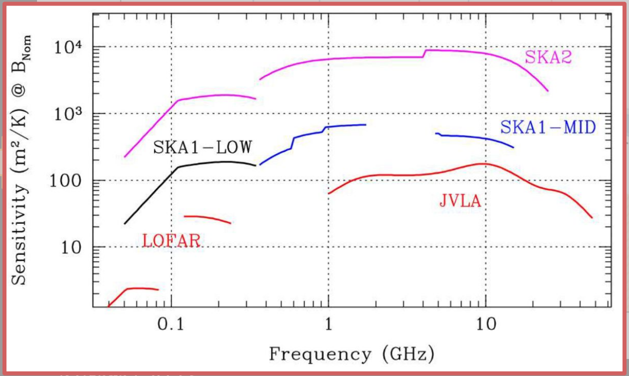
Harrison 2017

A full census of mass assembly: the cosmic star-formation rate density (SFRD)

Sensitivity

Madau & Dickinson 2014 (MD14); ...+2015; Sijacki+2015; Volonteri+2016; Ranalli+2016; ...+2017; Oesch+2018; Loiacono+2020; Gr... 2020; Khusanova+2021; Zavala+2021; Fudamoto+2021; Kono+2022; ...+2022; Barrufet+2022; van der Vlugt+2022, Algera+2023; Traina+2023; and many others

“cosmic noon”



Algera+2023

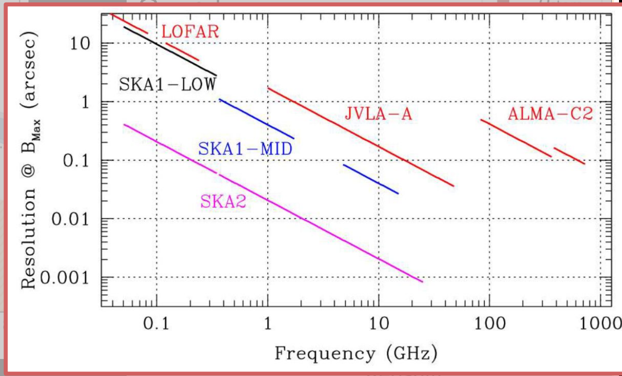
Tracing the internal growth of structures within galaxies from (HI+H_2) gas reservoir

sub-arcsec angular resolution

Leroy+2008; Dadd... Genzel+20...; Geach+2011; ...+2013; Tacconi+2018, 202...; Walter+2020; Decarli+2020; ...+2020; JWST: Cheng+2022; Guo+20...+2022; Kartaltepe+2023; etc

much more gas

In galaxies



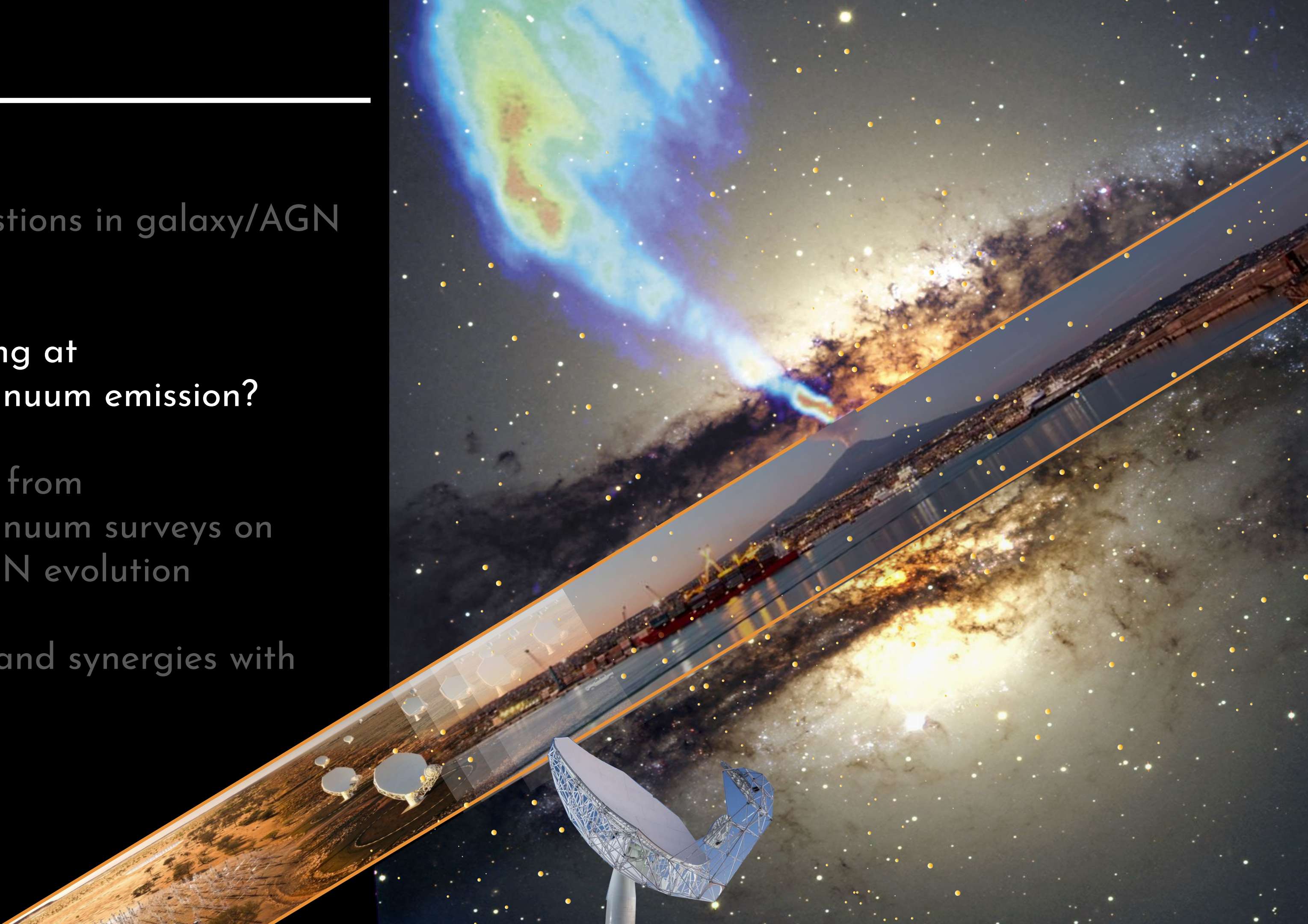
...2020, ASPECS

What is the role of i... (stellar+AGN feedback, m... vs external (environ... mechanisms in shaping ... assembly?

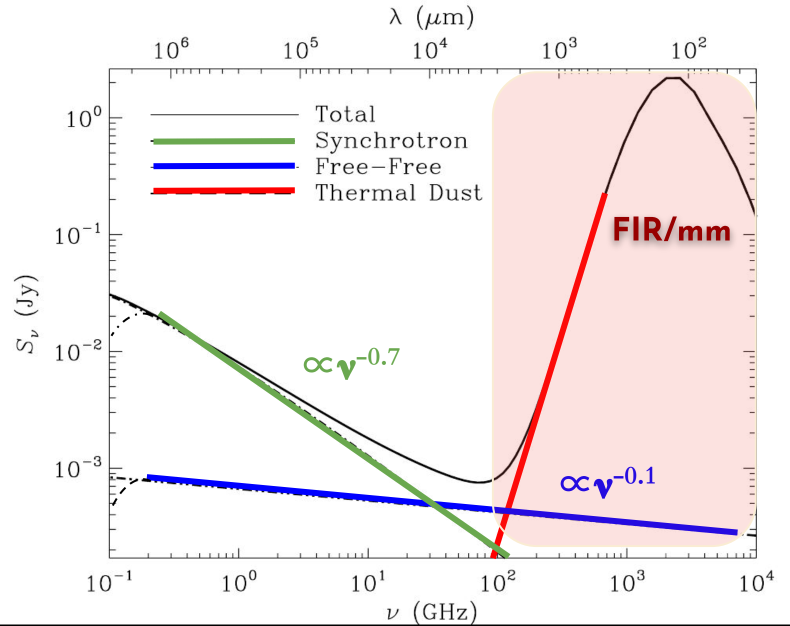
...and when are different ...components (e.g. disk vs. ...formed? What triggers ...mpact starbursts?

Outline

- Open questions in galaxy/AGN evolution
- Why looking at radio-continuum emission?
- Highlights from radio-continuum surveys on galaxy/AGN evolution
- Prospects and synergies with the SKA



What do we see in radio-continuum? A brief recap



Murphy 2009

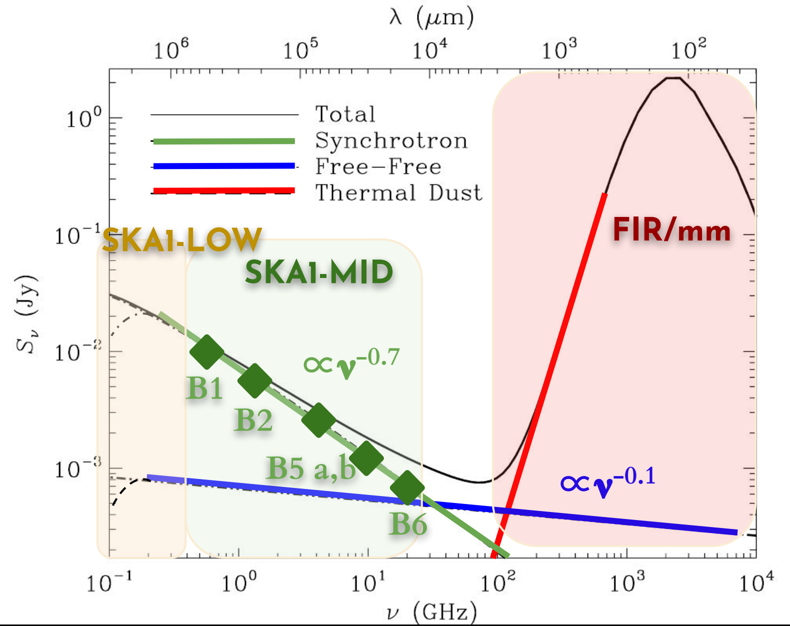
Grey body (thermal): dust grains heated by young and fairly massive (>5 M_{sun}) stars → SFR [10-100 Myr]

Free-free (thermal): HII regions, recent star formation episodes → SFR [3-10 Myr]

Synchrotron (non-thermal): cosmic ray electrons accelerated by shock waves when massive (>8 M_{sun}) stars explode as SNe → SFR [10-100 Myr]

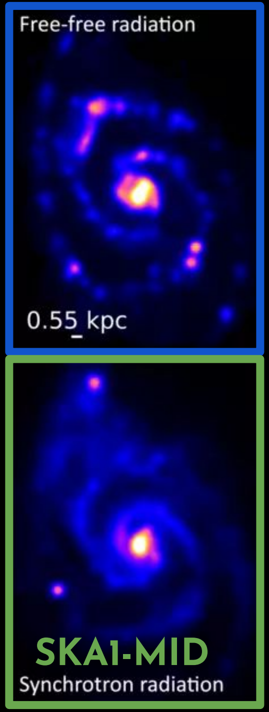
(Condon 1992; see review by Kennicutt & Evans 2012)

What will the SKA1-MID see in radio-continuum?



Murphy 2009

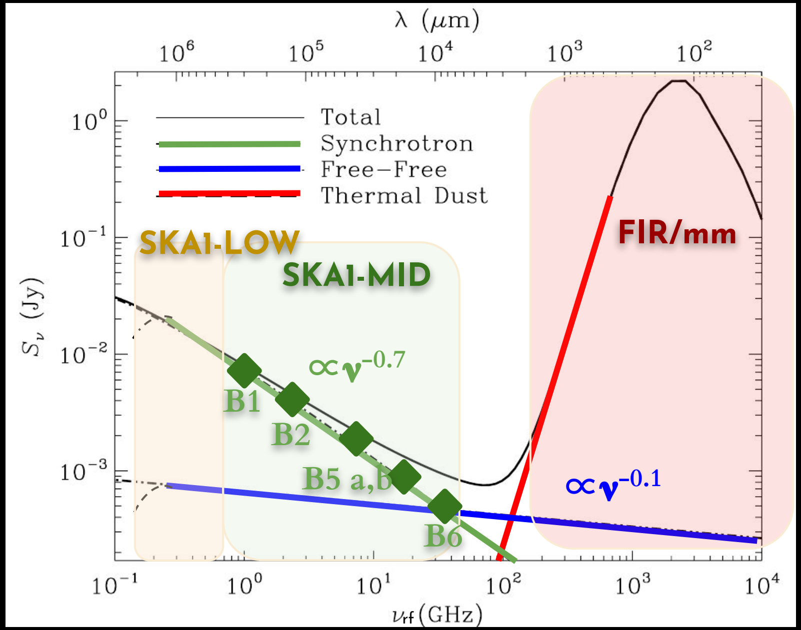
z~0
(observed)



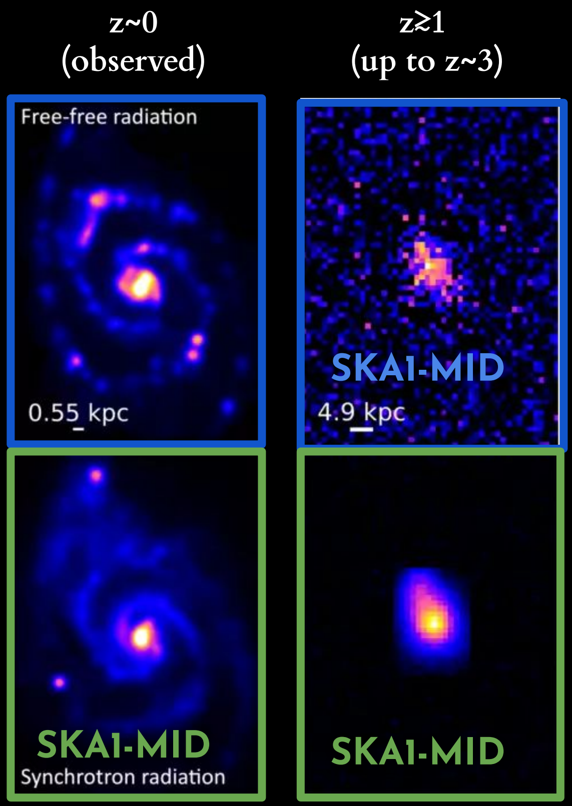
© Ghasemi-Nodehi et al. / MPIA

What will the SKA1-MID see in radio-continuum?

- (at z>1) B5-B6: mostly free-free emission → SFR_{th}
- B1-B2: mostly synchrotron emission → $SFR_{non\text{-}th}$



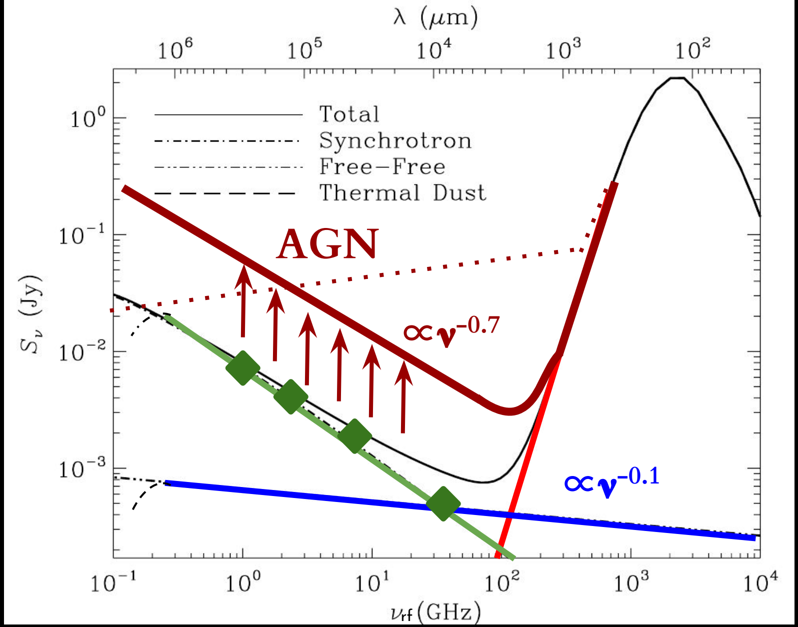
Murphy 2009



© Ghasemi-Nodehi et al. / MPIA

Radio (loud) AGN in radio-continuum

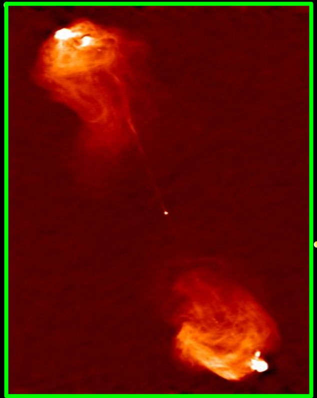
- Radio "loud", or radio-excess, or "jetted" AGN
- Hard to distinguish from SF based on spectral index, if not flat/inverted (e.g. Padovani 2016; Hardcastle+2019; Magliocchetti+2014; 2022)



Murphy 2009

feedback in action!

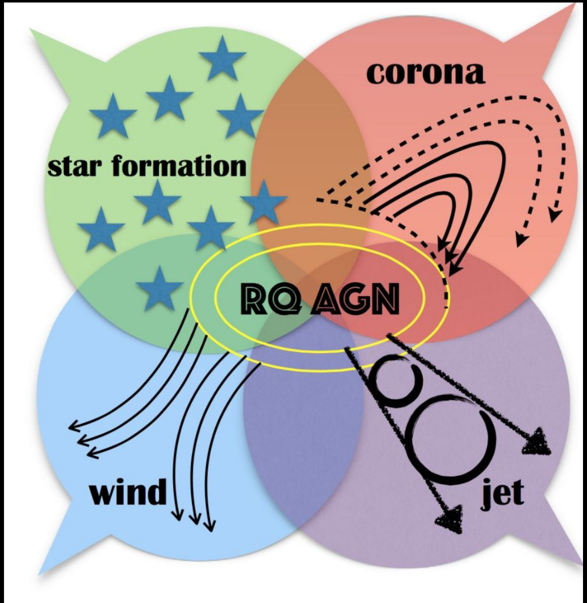
Centaurus A
$L_{1.4}$~ 2×10^{24} W/Hz
(Cooper 1965)



Cygnus A
$L_{1.4}$~ 5×10^{27} W/Hz
(Hey, Phillips & Parsons 1946)

Radio (quiet) AGN in radio-continuum

- The (composite) nature of RQ-AGN is still debated



review by Panessa+2019

see F. Panessa's talk

[Radio morphology, T_B, sp. index, radio loudness, opt spectra, …]

→ There is no "ultimate selection" of RQ-AGN (Magliocchetti+2022)

COMPILATION OF "RQ" DEFINITIONS:

Faint 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]

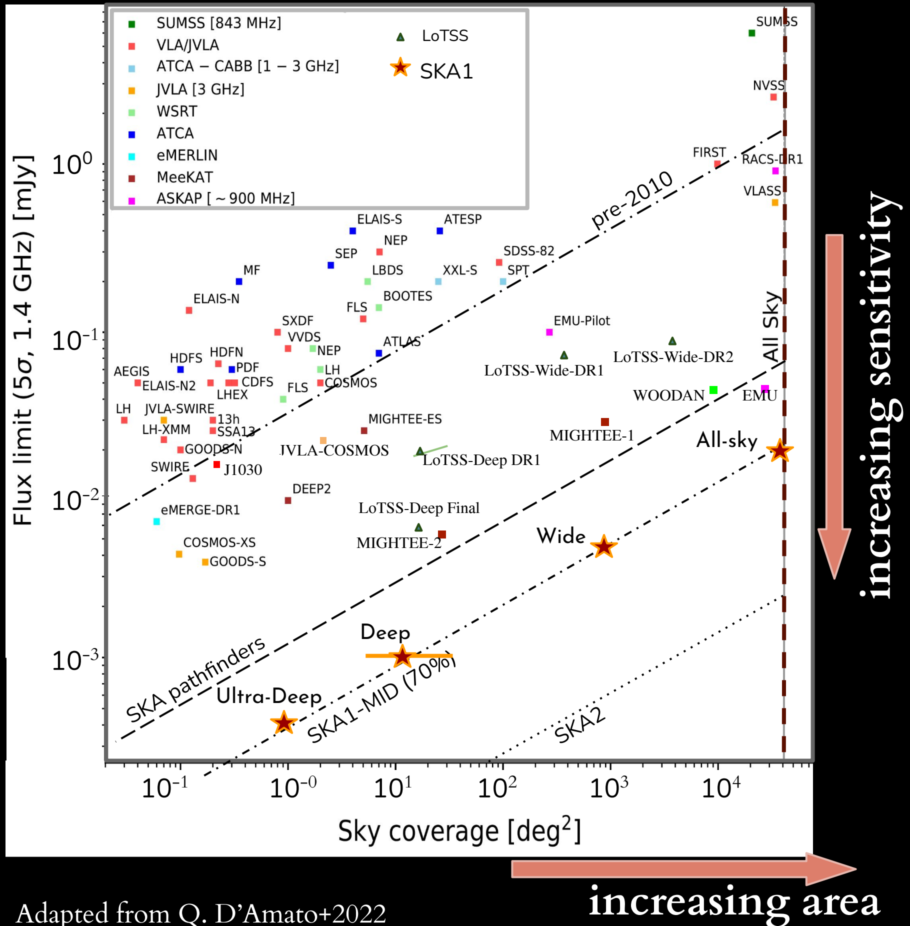
Faint wrt SF in the host

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

Outline

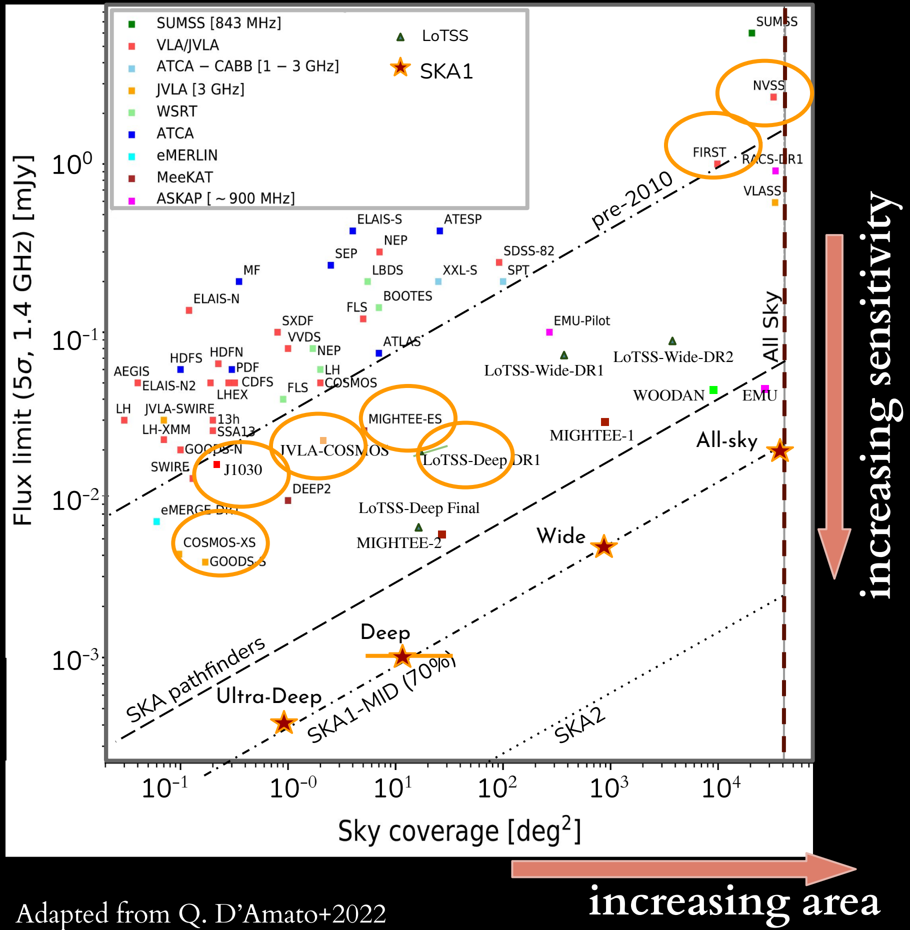
- Open questions in galaxy/AGN evolution
- Why looking at radio-continuum emission?
- Highlights from radio-continuum surveys on galaxy/AGN evolution
- Prospects and synergies with the SKA

What is the nature of the radio source population?



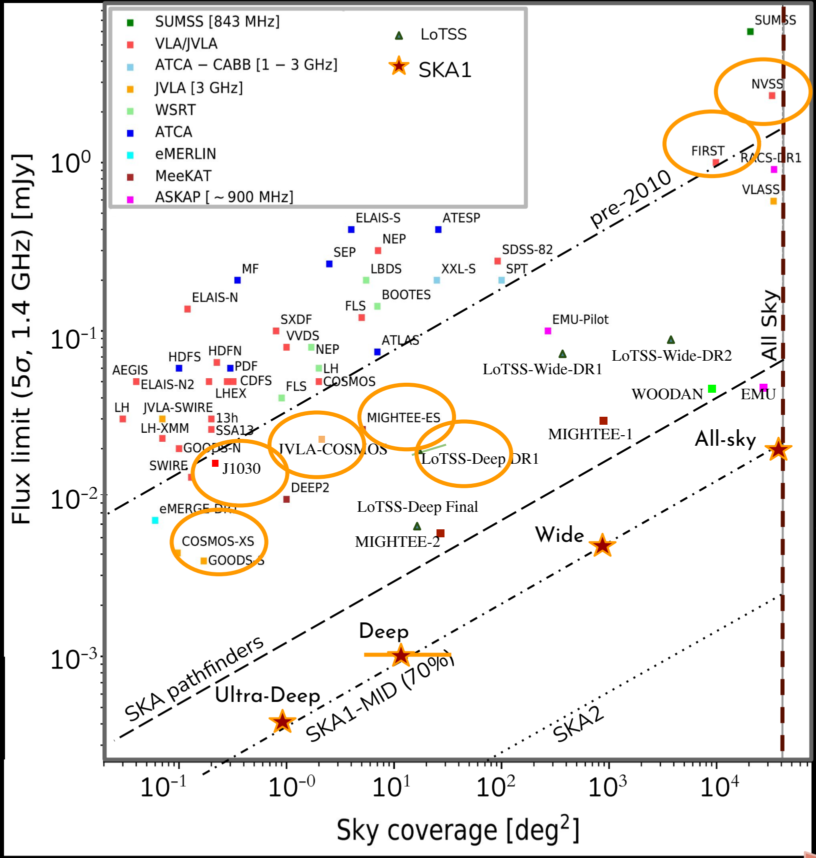
Adapted from Q. D'Amato+2022

What is the nature of the radio source population?



Adapted from Q. D'Amato+2022

What is the nature of the radio source population?

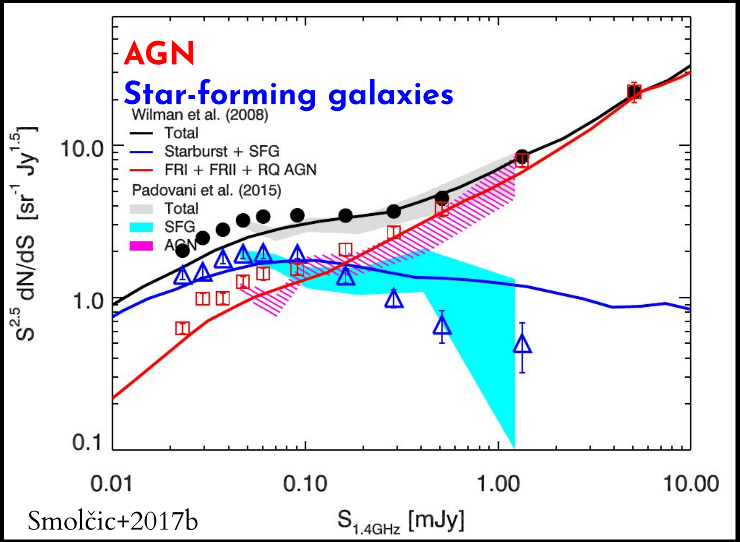


increasing sensitivity

increasing area

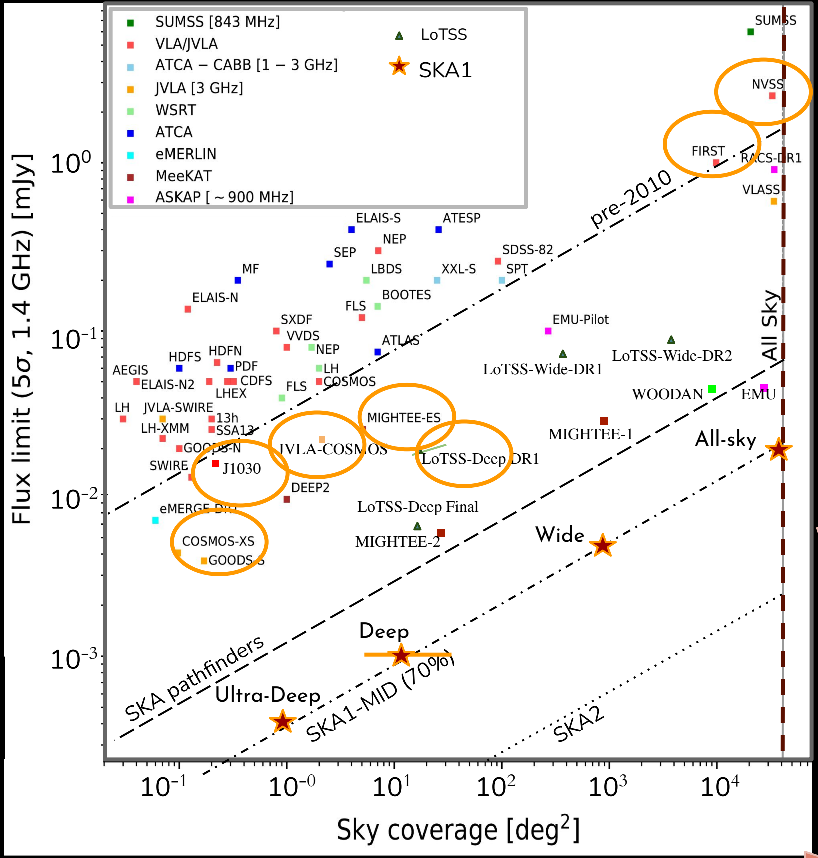
Adapted from Q. D'Amato+2022

AGN vs star-forming galaxies



Condon 1992; Bonzini+2013; Vernstrom+2014; Mancuso+2015,2017; Prandoni & Seymour 2015; Smolčic+2017b; Prandoni 2018; Heywood+2020; Algera+2020; Matthews+2021; Kono+2022; Hale+2023, …

What is the nature of the radio source population?

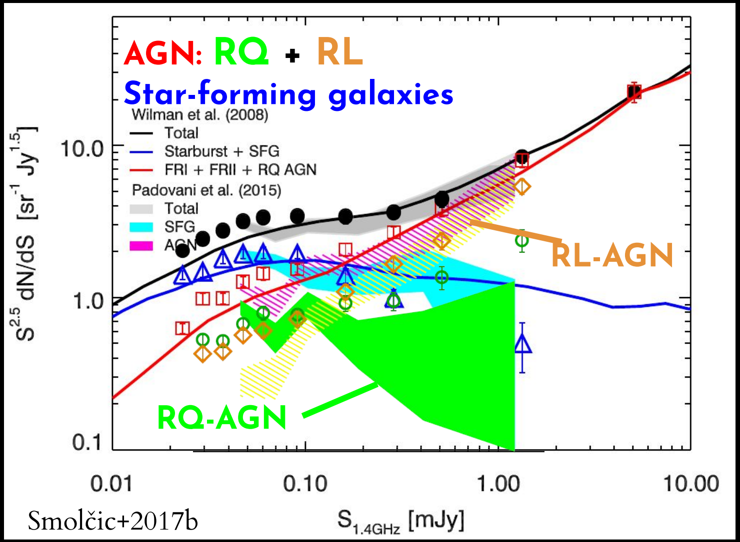


increasing sensitivity

increasing area

Adapted from Q. D'Amato+2022

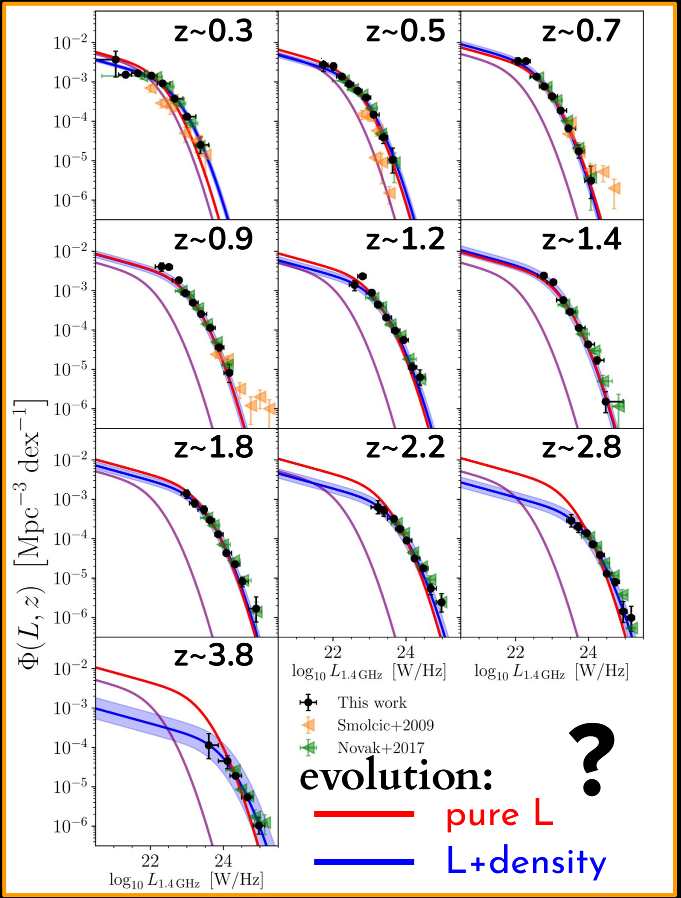
AGN vs star-forming galaxies



Composite nature (RQ-AGN & SFGs) at <0.1 mJy

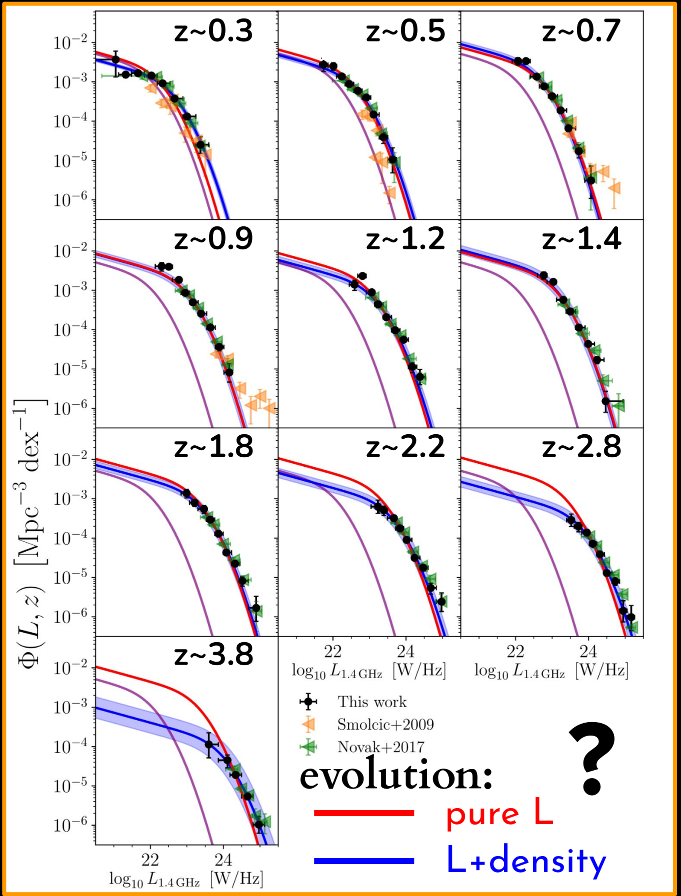
Condon 1992; Bonzini+2013; Vernstrom+2014; Mancuso+2015,2017; Prandoni & Seymour 2015; Smolčic+2017b; Prandoni 2018; Heywood+2020; Algera+2020; Matthews+2021; Kono+2022; Hale+2023, …

The radio view of cosmic star formation history

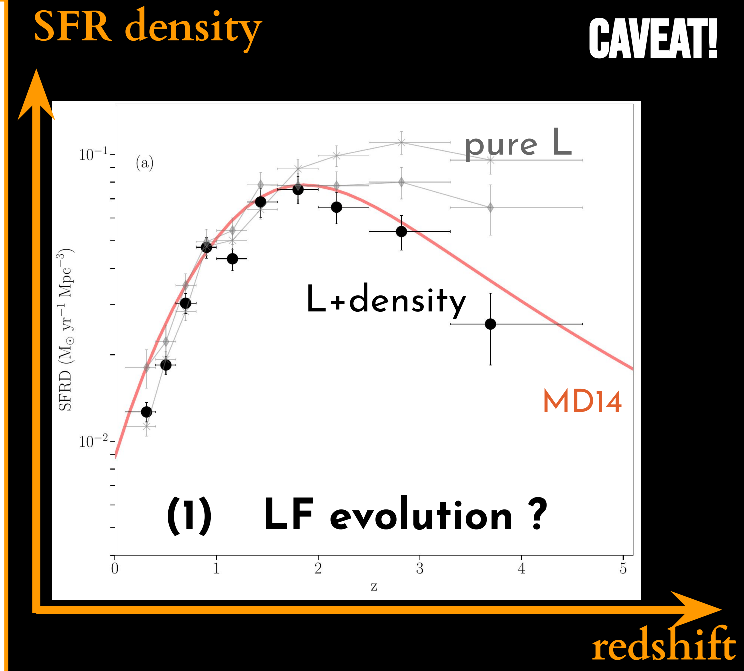


Van der Vlugt+2022 - COSMOS XS (JVLA 3+10 GHz)

The radio view of cosmic star formation history

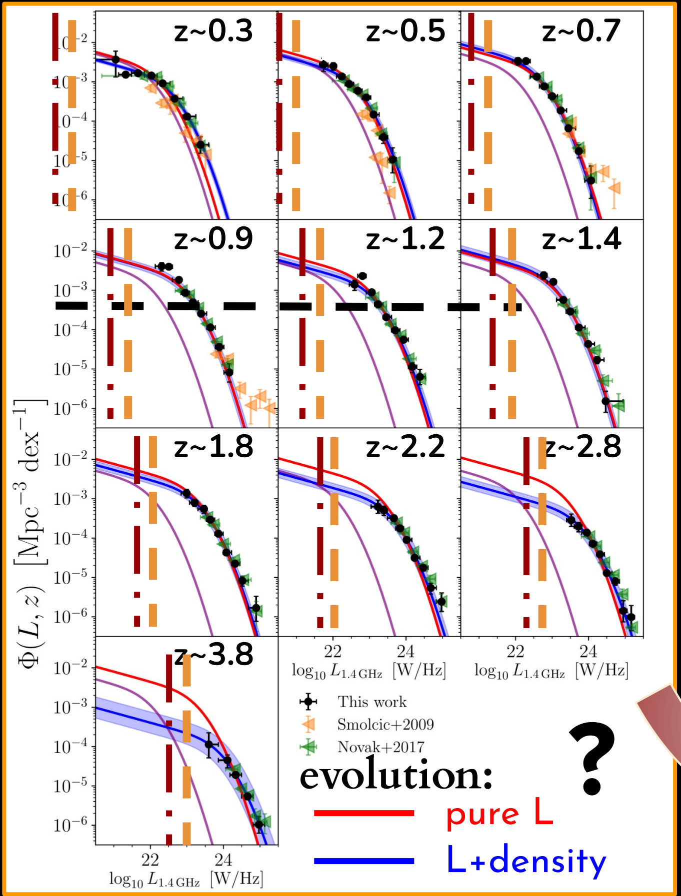


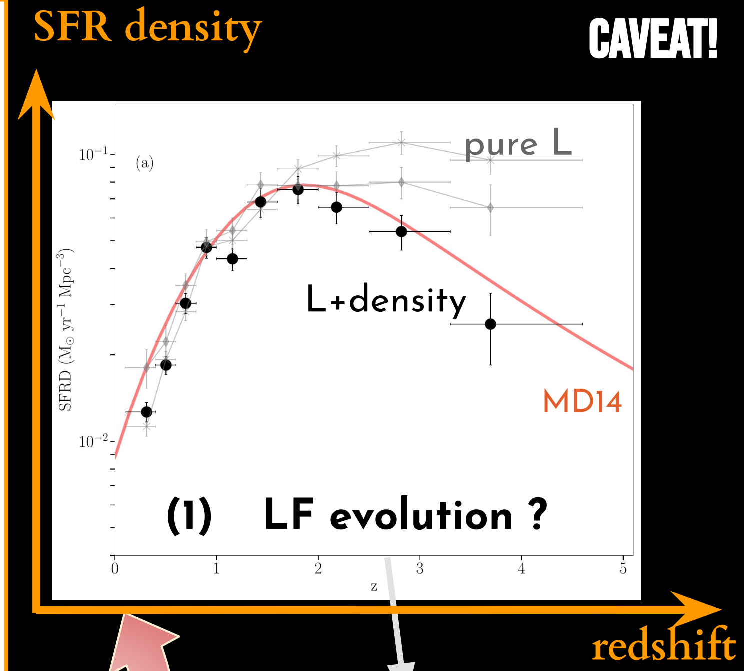
CAVEAT!



Van der Vlugt+2022 - COSMOS XS (JVLA 3+10 GHz)

The radio view of cosmic star formation history

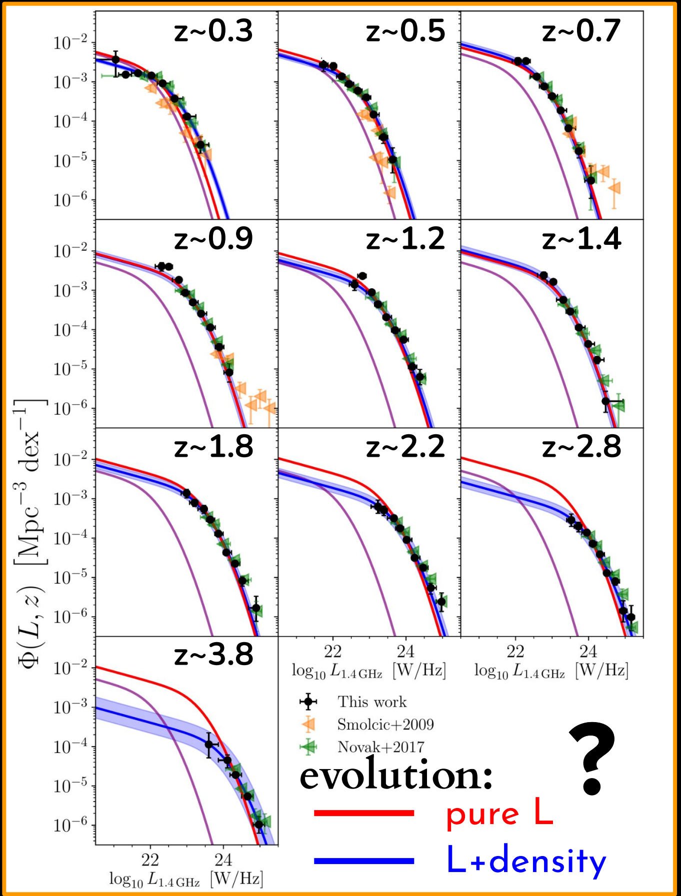


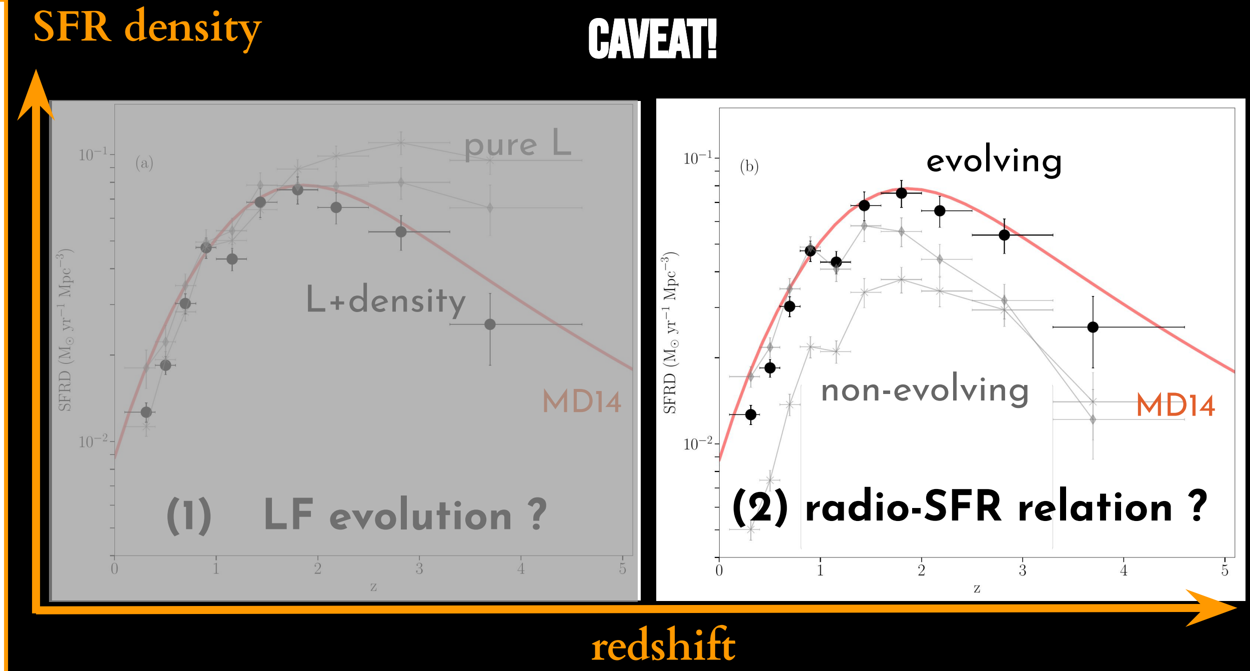


SKA1-MID (Deep & Ultra-Deep) surveys will allow us to discriminate among different evolutionary paths!

Van der Vlugt+2022 - COSMOS XS (JVLA 3+10 GHz)

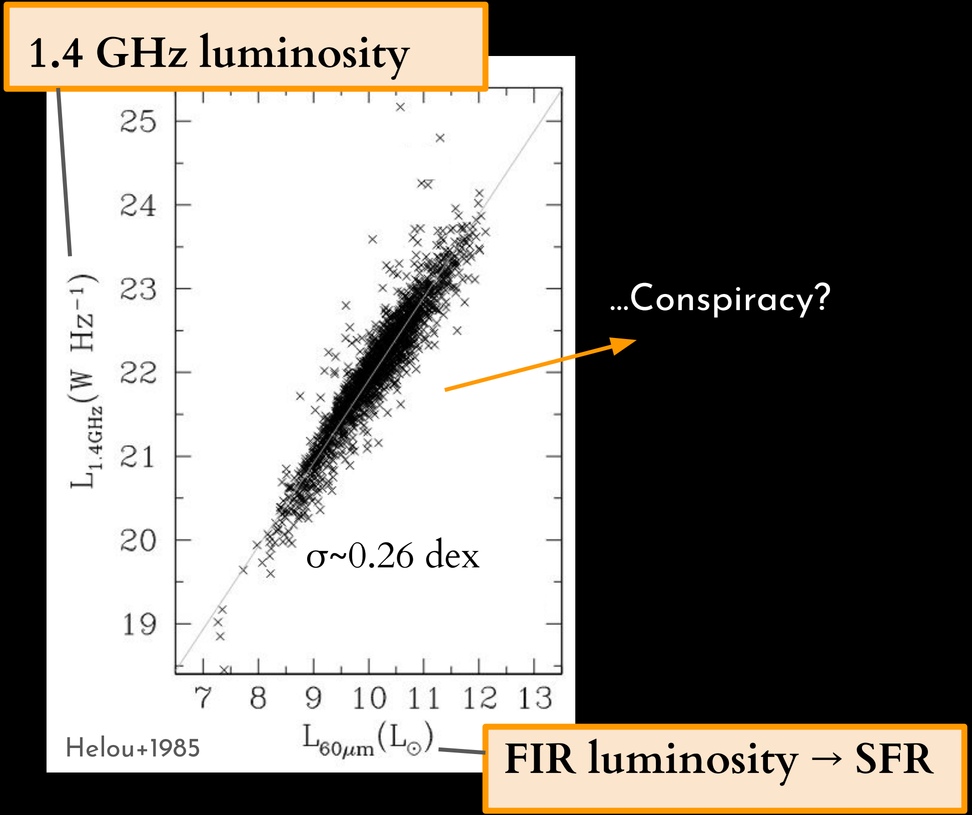
The radio view of cosmic star formation history





Van der Vlugt+2022 - COSMOS XS (JVLA 3+10 GHz)

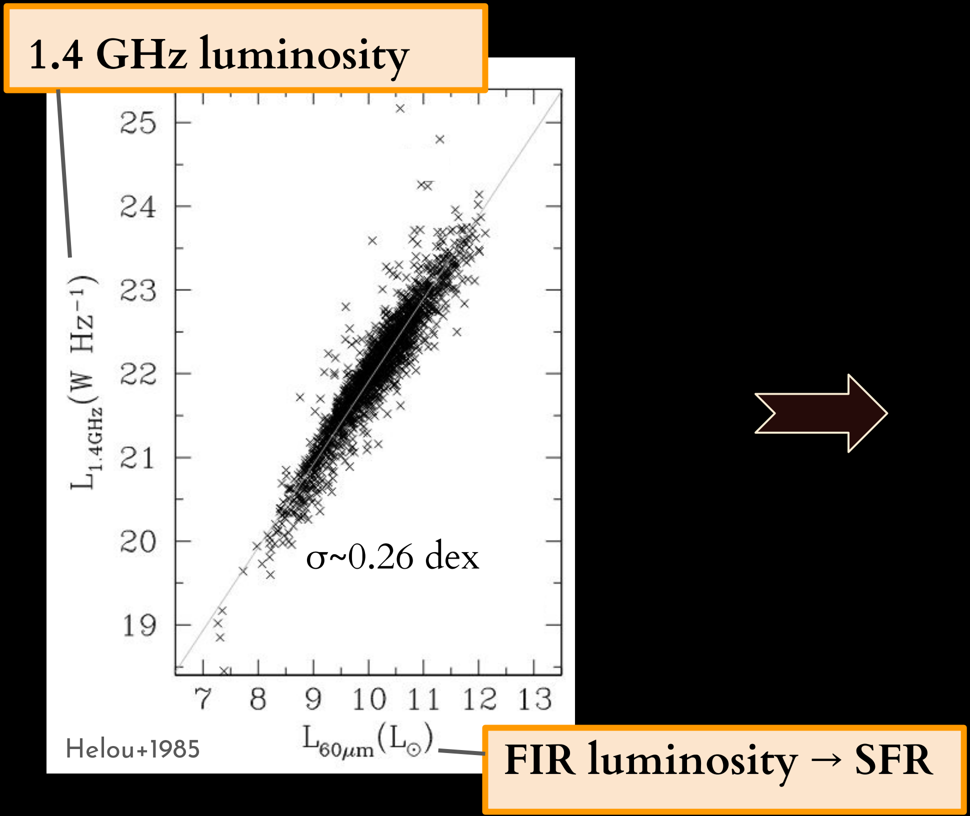
A universal radio-SFR relation?



…Conspiracy?

(e.g. Harwit & Pacini 1975; Rickard & Harvey 1984; de Jong+1985; Helou+1985; Hummel+1988; Condon 1992; Garrett 2002; Bell 2003; Appleton+2004; Murphy+2008; Jarvis+2010; Sargent+2010; Ivison+2010a,b; Bourne+2011; Smith+2014; Magnelli+2015; Calistro Rivera+2017; Delhaize+2017; Gürkan+2018; Read+2018; Molnár+2018; Algera+2020b; Smith+2021; **ID+2021**; Molnár+2021; Matthews+2021; Bonato+2021, Giulietti+2022, Akriti+2023; Schober+2023, Hansen+2023, …)

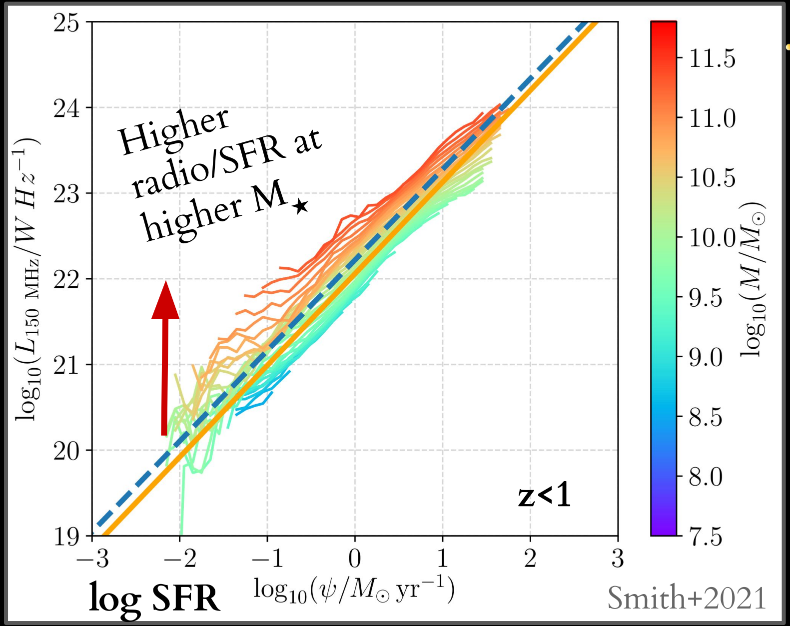
A universal radio-SFR relation? Maybe not



Smith+2021 (**LoTSS**: LOFAR@144MHz):

L_{144}-SFR relation is mainly driven by $M_\star$

(see also Gurkan+2018; Read+2018, **ID+2021**)



(e.g. Harwit & Pacini 1975; Rickard & Harvey 1984; de Jong+1985; Helou+1985; Hummel+1988; Condon 1992; Garrett 2002; Bell 2003; Appleton+2004; Murphy+2008; Jarvis+2010; Sargent+2010; Ivison+2010a,b; Bourne+2011; Smith+2014; Magnelli+2015; Calistro Rivera+2017; Delhaize+2017; Gürkan+2018; Read+2018; Molnár+2018; Algera+2020b; Smith+2021; **ID+2021**; Molnár+2021; Matthews+2021; Bonato+2021, Giulietti+2022, Akriti+2023; Schober+2023, Hansen+2023, …)

A universal radio-SFR relation? Maybe not

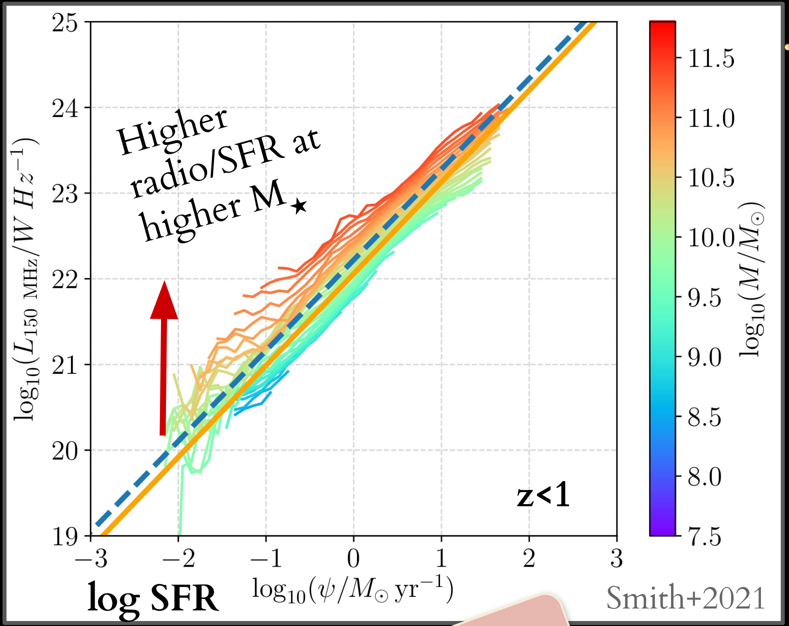
Using radio-continuum as a SFR tracer requires $M_\star$-dependent recipes, <u>but</u>:

- ❑ Debated theoretical framework (Schober+2023; but see Hansen+2023; Lacki & Thompson 2010; Schleicher & Beck 2013; Tabatabei+2017, …)
- ❑ Redshift evolution not fully understood (Magnelli+2015; Delhaize+2017; Bonato+2021)
- ❑ Other proxies for $M_\star$: dust temperature (Smith+2014); radio power (Molnár+2021); SFR (Gurkan+2018)
- ❑ $M_\star$ incompleteness at $<10^{10}$ M_{sun}
- ❑ Do SMGs and starbursts follow this relation? (e.g. Jimenez-Andrade+2019; Algera+2021)
- ❑ radio AGN contamination? (VLBI follow-up)

Smith+2021 (**LoTSS**: LOFAR@144MHz):

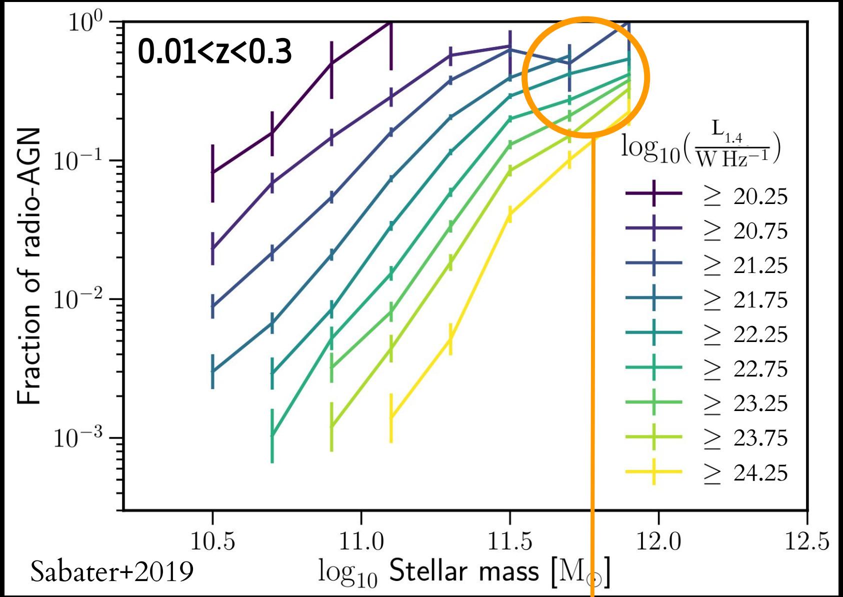
L_{144}-SFR relation is mainly driven by $M_\star$

(see also Gurkan+2018; Read+2018, **ID+2021**)



see M. Giulietti's talk

How frequent is (radio) AGN triggering?

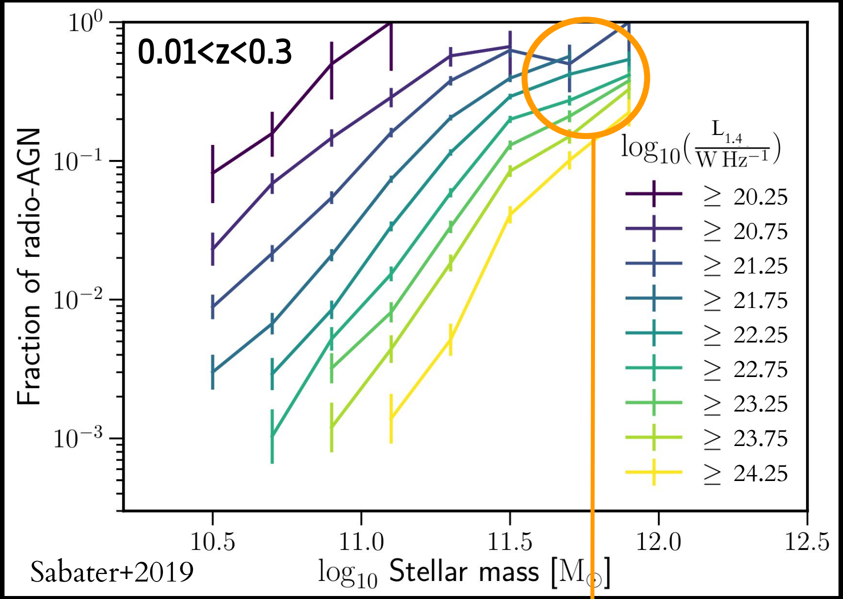


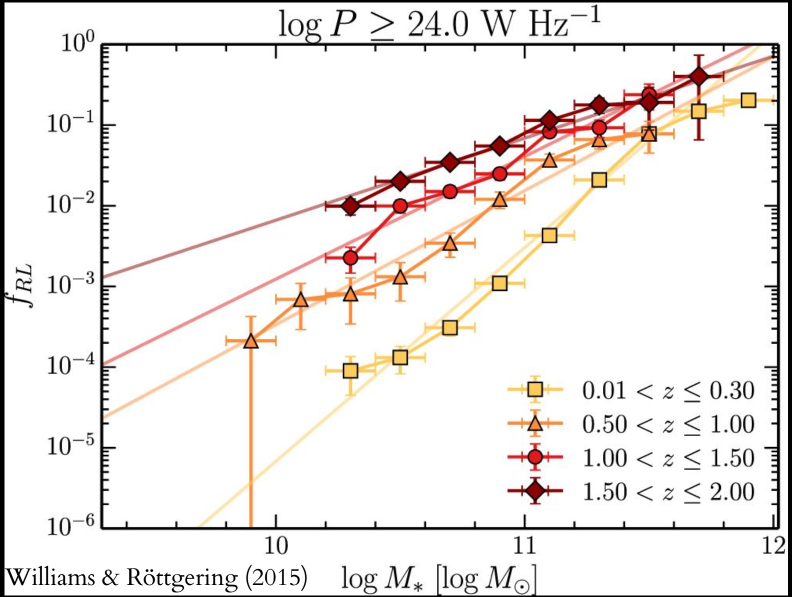
- LoTSS: LOFAR 144MHz data —> scaled to 1.4GHz

The most massive galaxies are always switched on!

See also, e.g. Ito+2022; Kondapally+2022; ID+2022

How frequent is (radio) AGN triggering?





- LoTSS: LOFAR 144MHz data —> scaled to 1.4GHz
- SDSS+NVSS+VLA

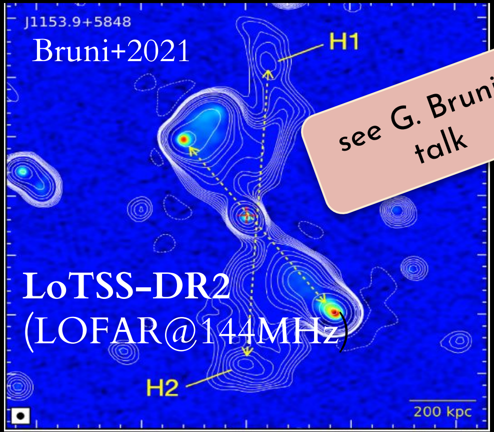
The most massive galaxies are always switched on!

Higher duty cycle in more massive galaxies at higher redshift !

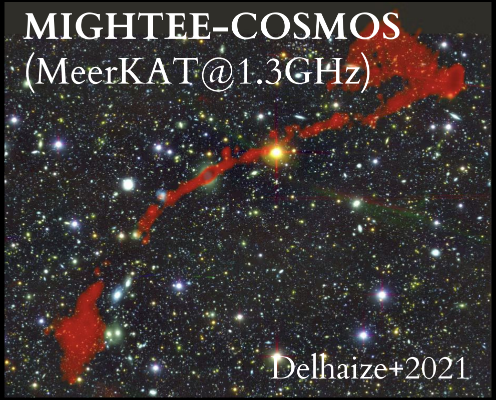
See also, e.g. Ito+2022; Kondapally+2022; ID+2022

AGN duty cycle in radio galaxies

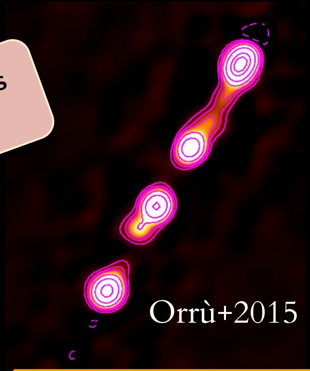
Giant radio galaxies



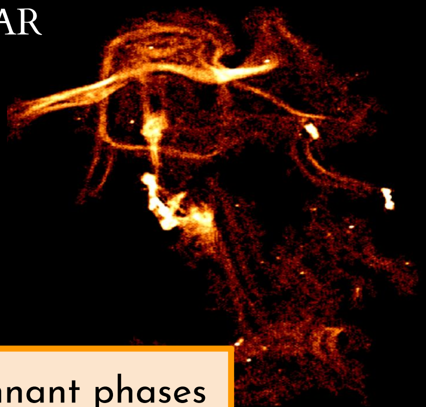
see G. Bruni's talk



Remnants & Restarted radio galaxies



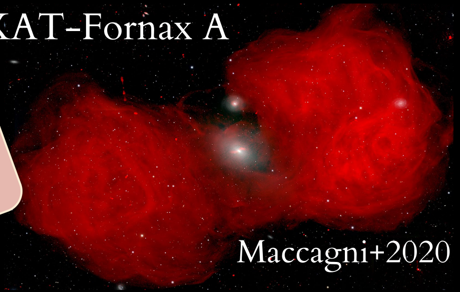
LOFAR



Brienza+2021

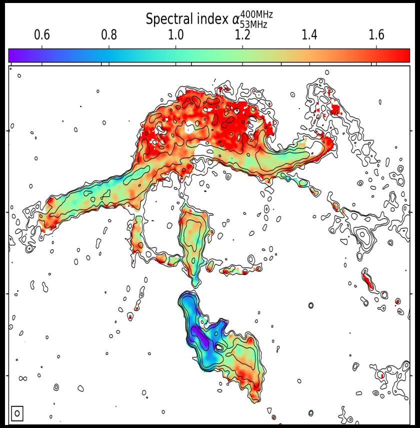
- ❑ Extended emission: remnant phases
- ❑ Multi-frequency ⟶ duty cycle
- ❑ Spectral index map ⟶ e⁻ ageing

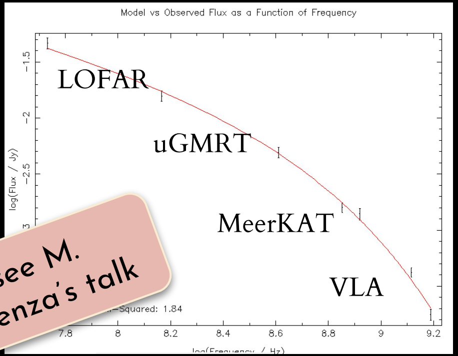
MeerKAT-Fornax A



see F. Maccagni's talk

Spectral index maps

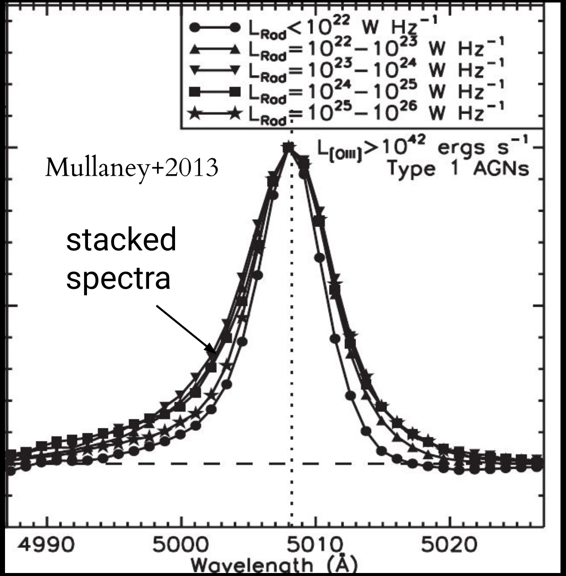




see M. Brienza's talk

Compact (~kpc) radio AGN & outflows

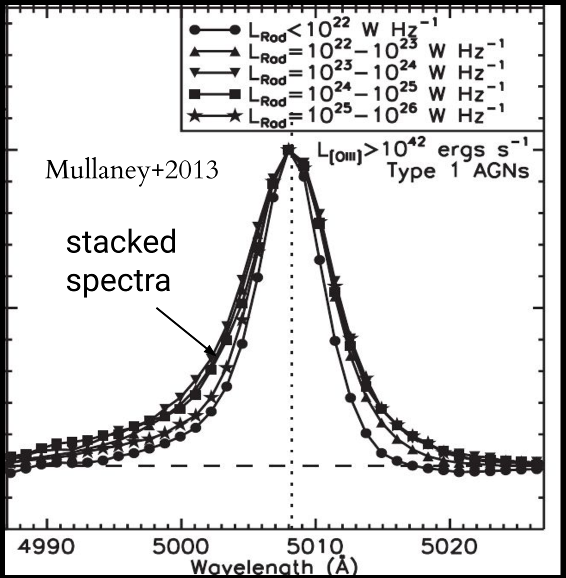
SDSS: >24000 [OIII]-selected



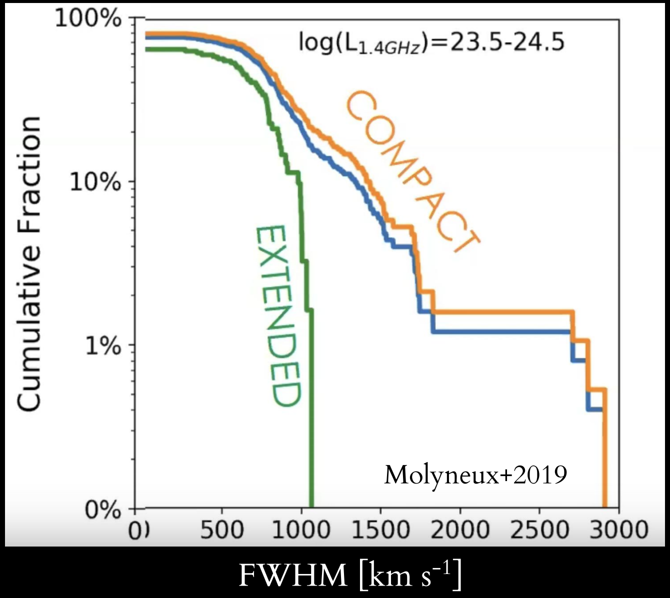
Brighter radio AGN ($L_{1.4}$~ 10^{23-25} W/Hz) show stronger (500-1000 km/s) ionized outflows than at lower $L_{1.4}$

Compact (~kpc) radio AGN & outflows

SDSS: >24000 [OIII]-selected



z<0.2 SDSS + FIRST/NVSS



Brighter radio AGN ($L_{1.4}$~ 10^{23-25} W/Hz) show stronger (500-1000 km/s) ionized outflows than at lower $L_{1.4}$

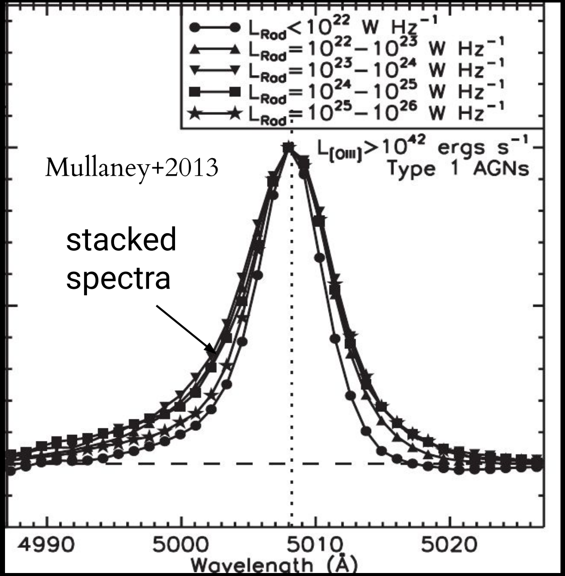
[OIII] outflows are faster in more compact radio sources (<kpc): **causal jet-outflow connection?**

Compact (~kpc) radio AGN & outflows

FR0

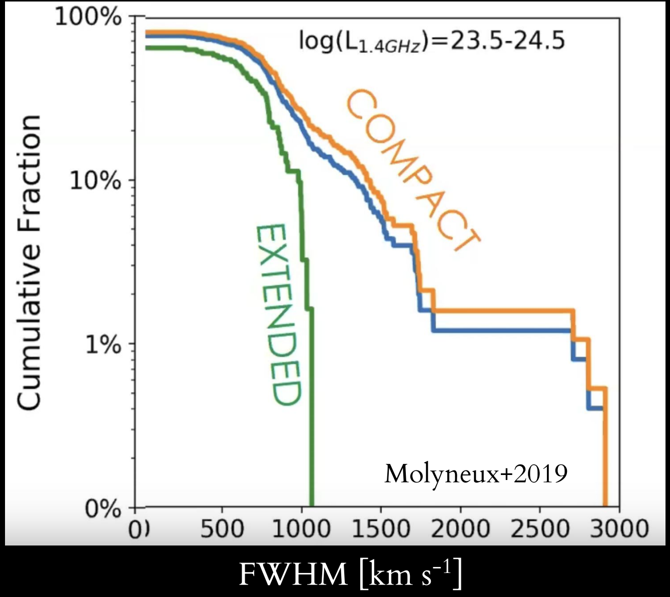
e.g. Giovannini+2023; Baldi+2023 A&A review

SDSS: >24000 [OIII]-selected



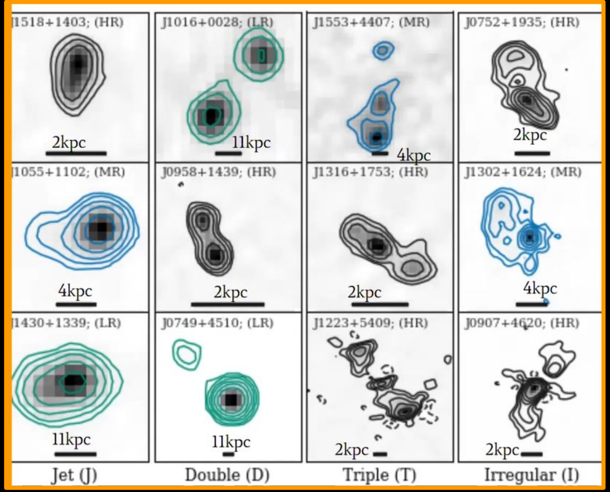
Brighter radio AGN ($L_{1.4}\sim10^{23\text{-}25}$ W/Hz) show stronger (500-1000 km/s) ionized outflows than at lower $L_{1.4}$

z<0.2 SDSS + FIRST/NVSS



[OIII] outflows are faster in more compact radio sources (<kpc): **causal jet-outflow connection?**

QFeedS survey: z<0.2 SDSS with $L_{[OIII]}>10^{42}$ erg/s, + VLA+ e-MERLIN

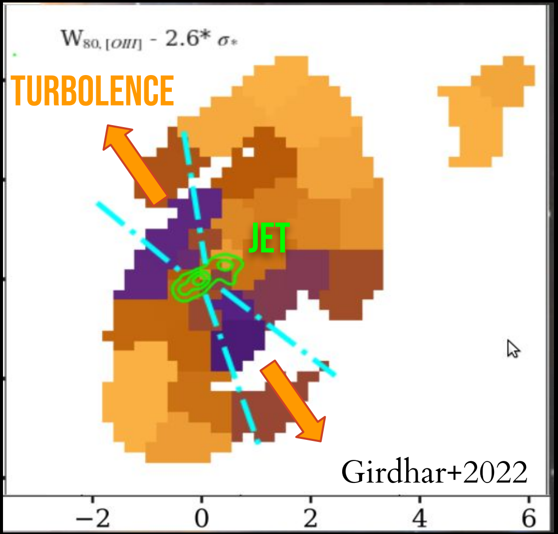


Jarvis+2019,2021

>60% feature 1-60 kpc-scale radio AGN structures: **Radio AGN are common also in the RQ regime!**

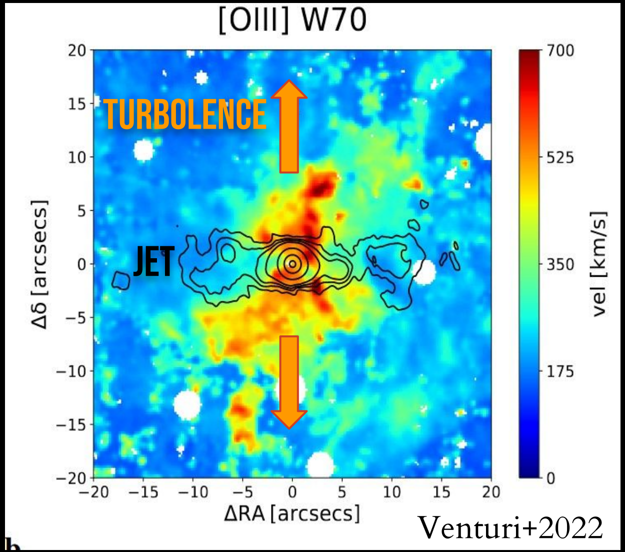
Compact (~kpc) jets may induce turbulence in the ISM

RQ-Quasar



- Low inclination (<40°) wrt galaxy disk
- RQ AGN with low-power jets (< 10^{44} erg/s)
- Multi-phase kpc-scale gas outflows: ionized (MUSE) and molecular (ALMA)

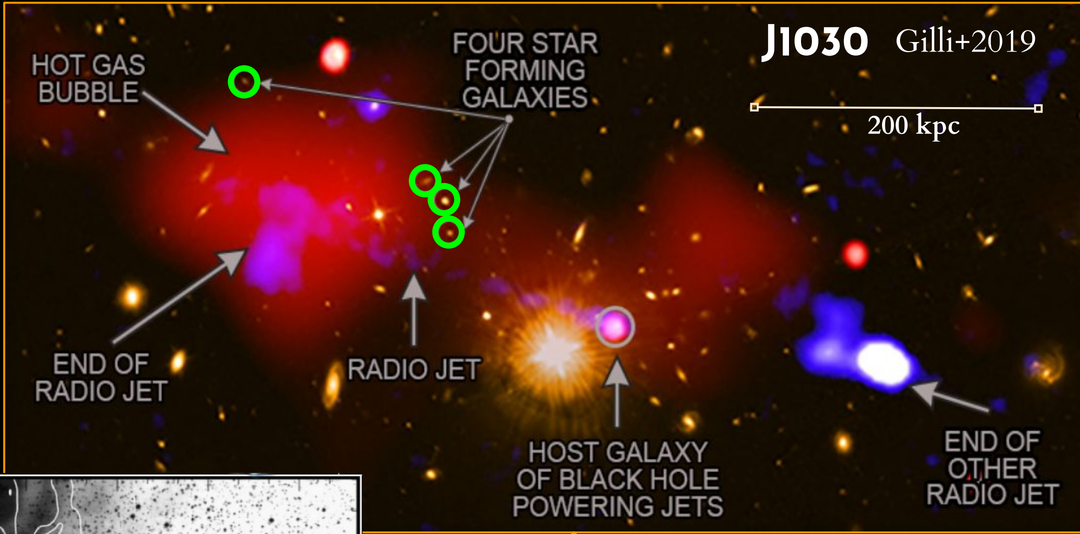
RQ-Seyfert



Jet-galaxy disc interaction → shock-heating ISM and driving turbulence perpendicular to jet propagation!

Couto+13, Riffel+14,15, Schnorr-Müller+14, Lena+15, Diniz+15, Freitas+18, Finlez+18, Schönell+2019, García-Burillo+19, Shimizu+19, Durré&Mould19, Shin+19, López-Cobá+20, Feruglio+20, Comerón+2021, Ruschel-Dutra+2021, Girdhar+2022; Venturi+2022

Jet-induced star formation?

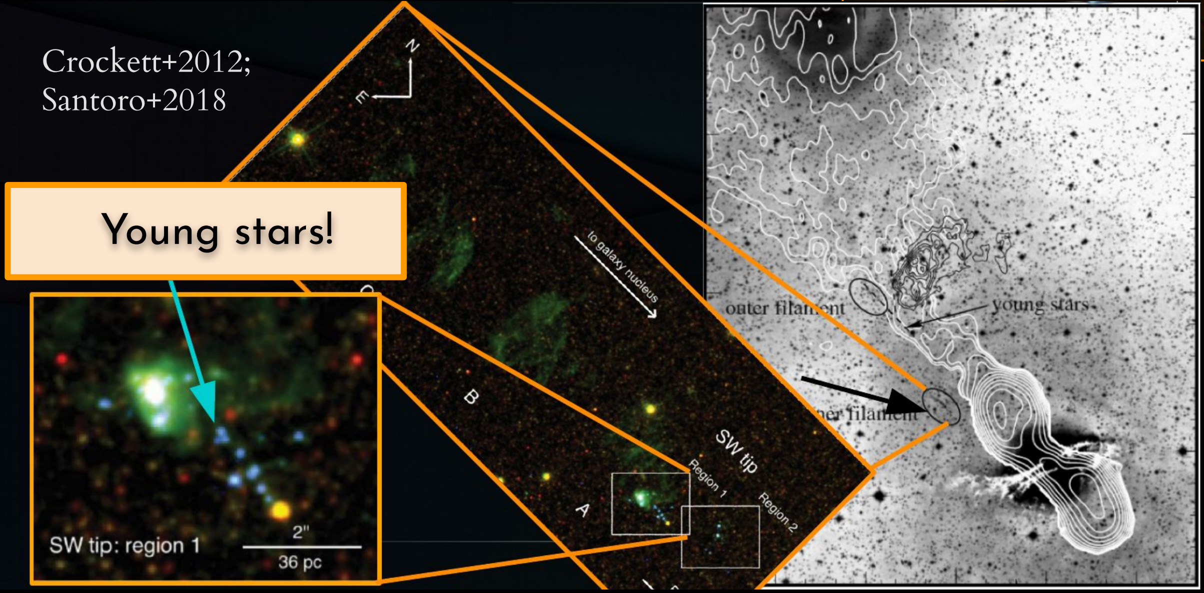


Protocluster at z=1.7
Discovery of **4 highly SFGs** at the edge of FRII-driven bubble

Follow-ups: Chandra, ALMA, VLA, LOFAR, GMRT, NOEMA, VLT, LBT,…

Gilli+2019; Marchesi+2021; Peca+2021; Brienza+2022;2023; D’Amato+2021; 2022

Crockett+2012; Santoro+2018

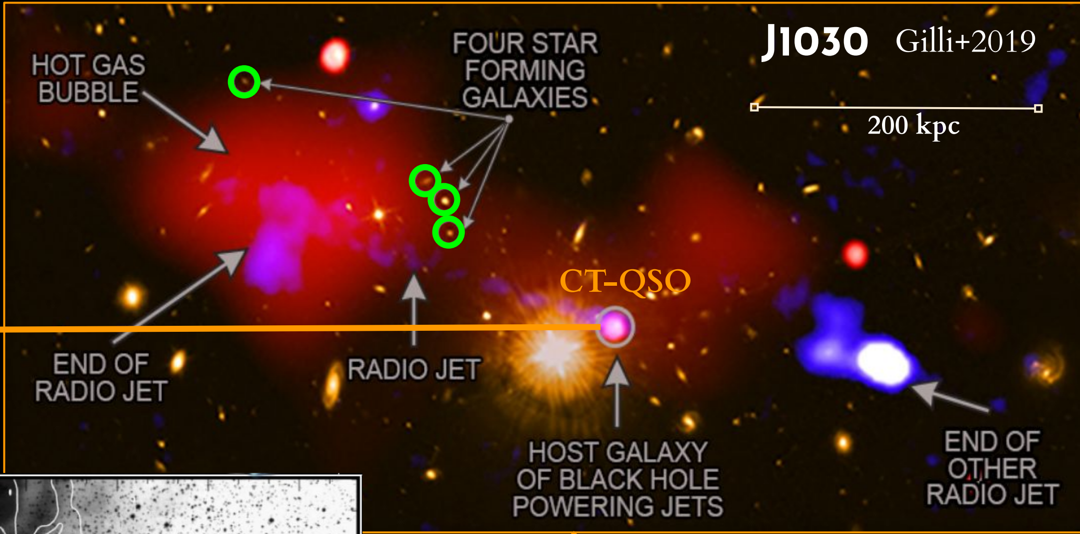


Young stars!

Jet-induced star formation?

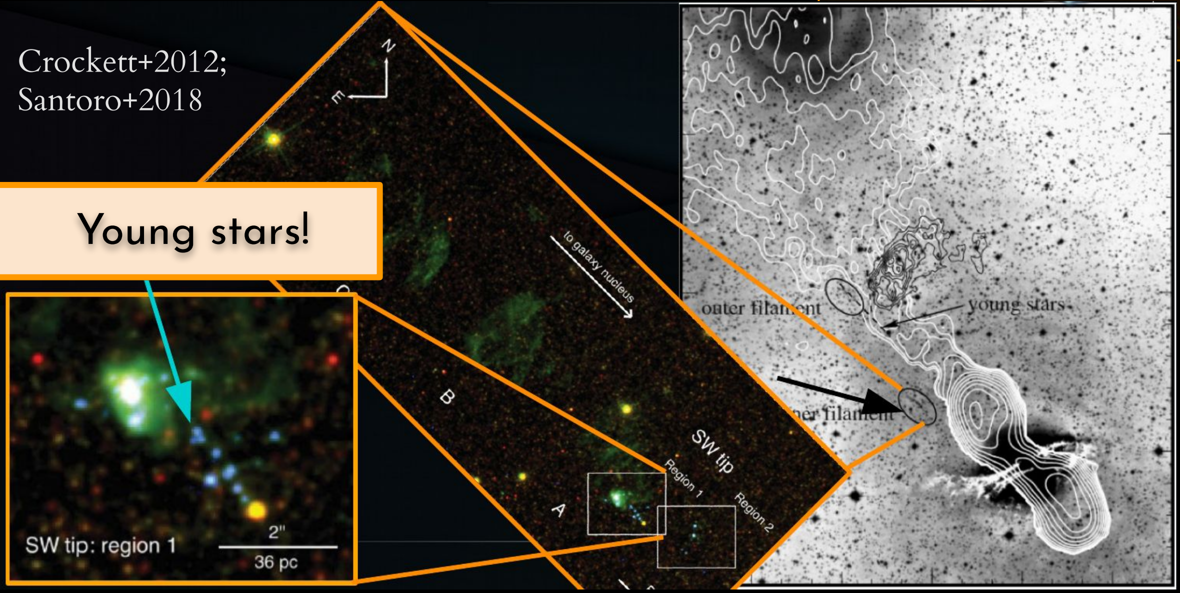
see R. Gilli's talk

Radio AGN as signposts for obscured BH growth?
(see also Klindt+2019; Rosario+2021, …)



Crockett+2012;
Santoro+2018

Young stars!



Protocluster at z=1.7
Discovery of **4 highly SFGs** at the edge of FRII-driven bubble

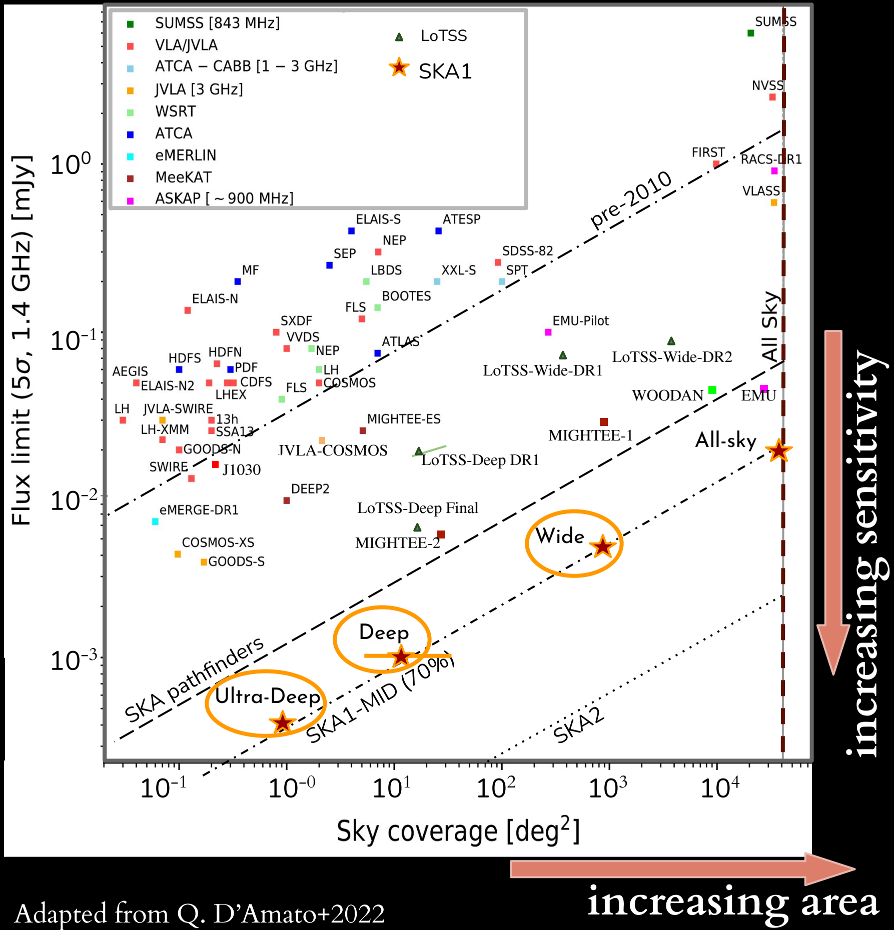
Follow-ups: Chandra, ALMA, VLA, LOFAR, GMRT, NOEMA, VLT, LBT,...

Gilli+2019; Marchesi+2021; Peca+2021; Brienza+2022;2023; D'Amato+2021; 2022

Outline

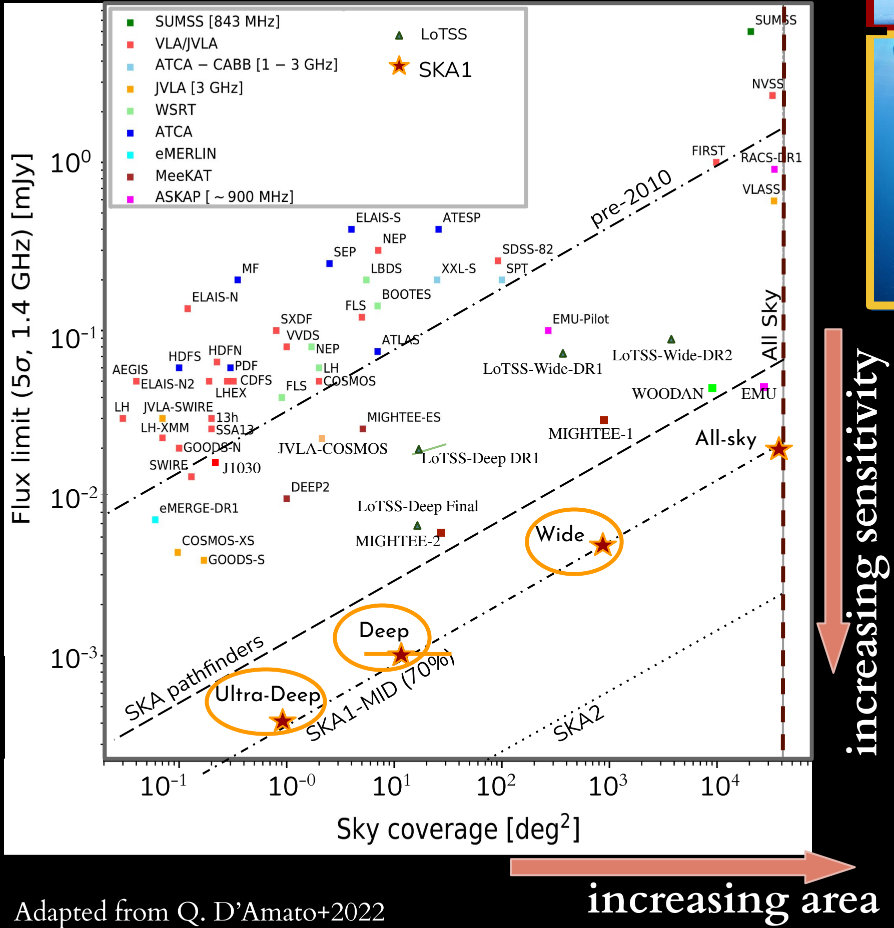
- Open questions in galaxy/AGN evolution
- Why looking at radio-continuum emission?
- Highlights from radio-continuum surveys on galaxy/AGN evolution
- Prospects and synergies with the SKA

What will the SKA see?



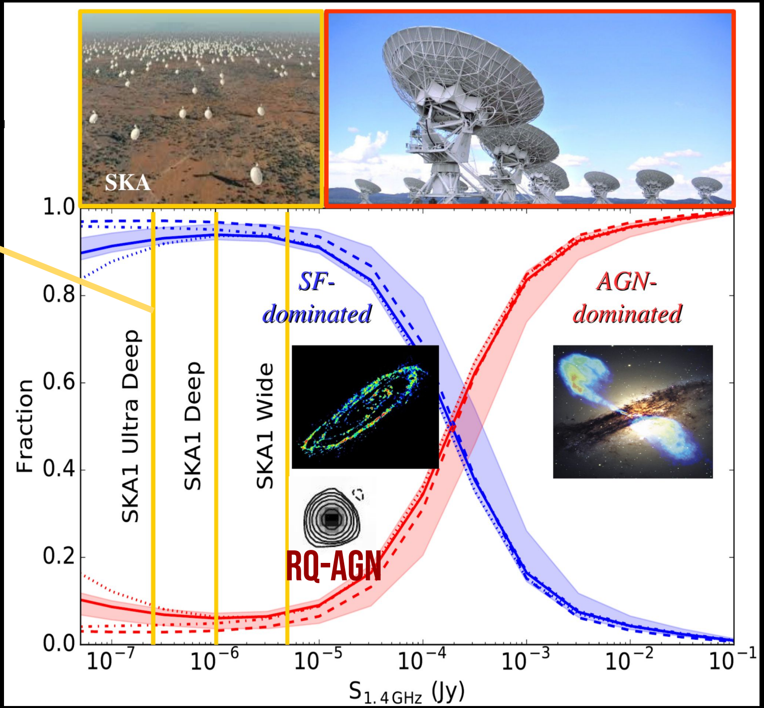
Adapted from Q. D'Amato+2022

What will the SKA see?

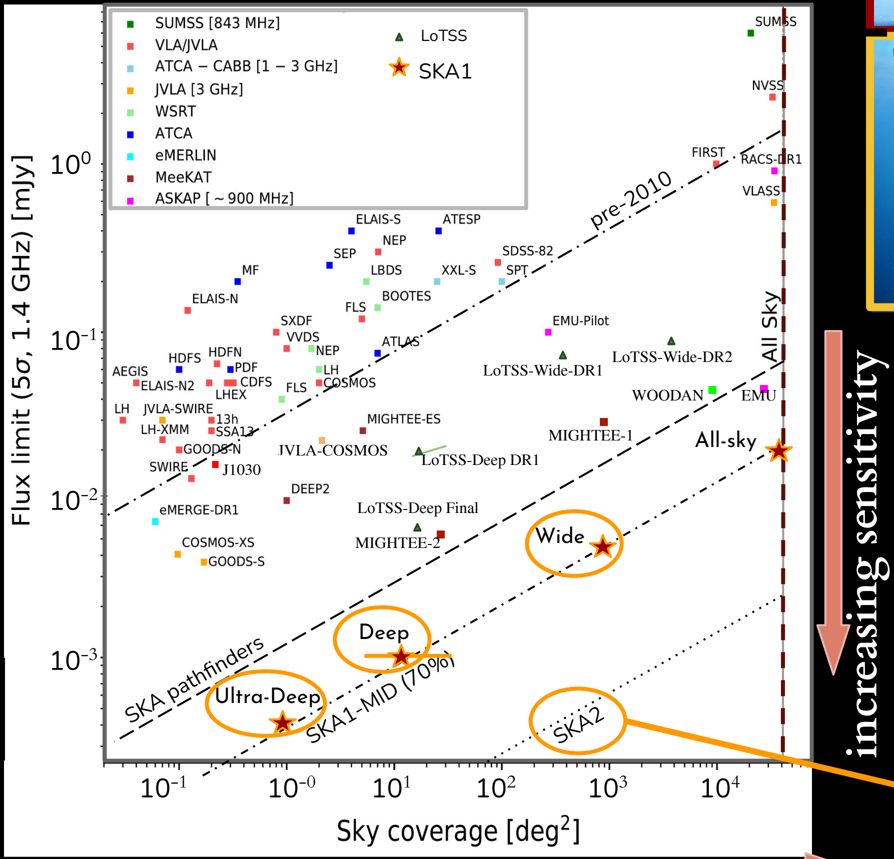


Adapted from Q. D'Amato+2022

Adapted from Novak+2018

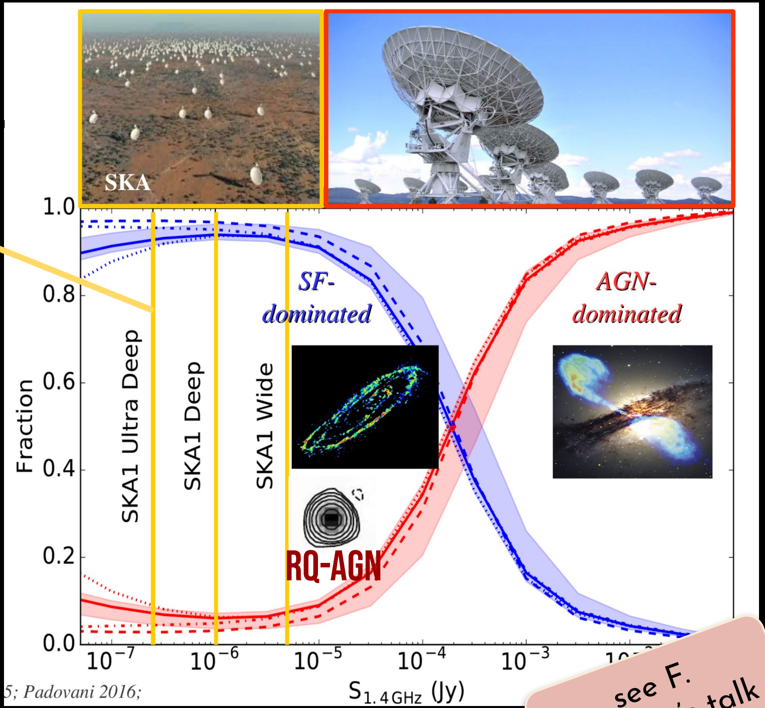


What will the SKA see?

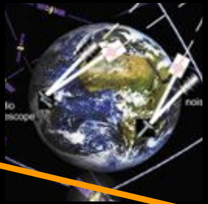


Adapted from Q. D'Amato+2022

Adapted from Novak+2018



see F. Panessa's talk



SKA-VLBI

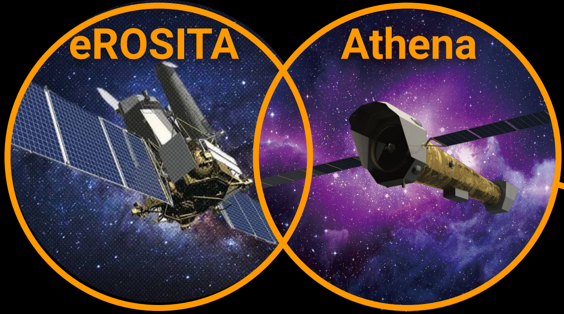
radio morphological information to separate galaxy-vs-AGN emission on a source-by-source basis

Multi-scale	Multi-phase	Multi-frequency

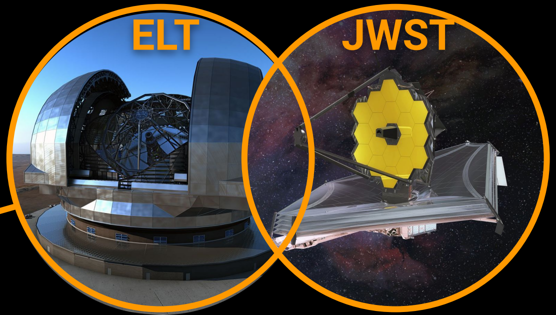
- Star formation history of the Universe
- AGN triggering, feedback, duty cycle
- Int. vs ext. effects in BH/galaxy growth

The SKA legacy

(biased to: galaxy/AGN evolution)



- ❑ Properties of the first galaxies and SMBHs
- ❑ Radiative AGN power



- ❑ Stellar & ionized gas kinematics
- ❑ Disk vs bulge buildup
- ❑ Link jet-outflows at high-z
- ❑ Highly obscured AGN at z>3
- ❑ BH masses

Multi-scale	Multi-phase	Multi-frequency

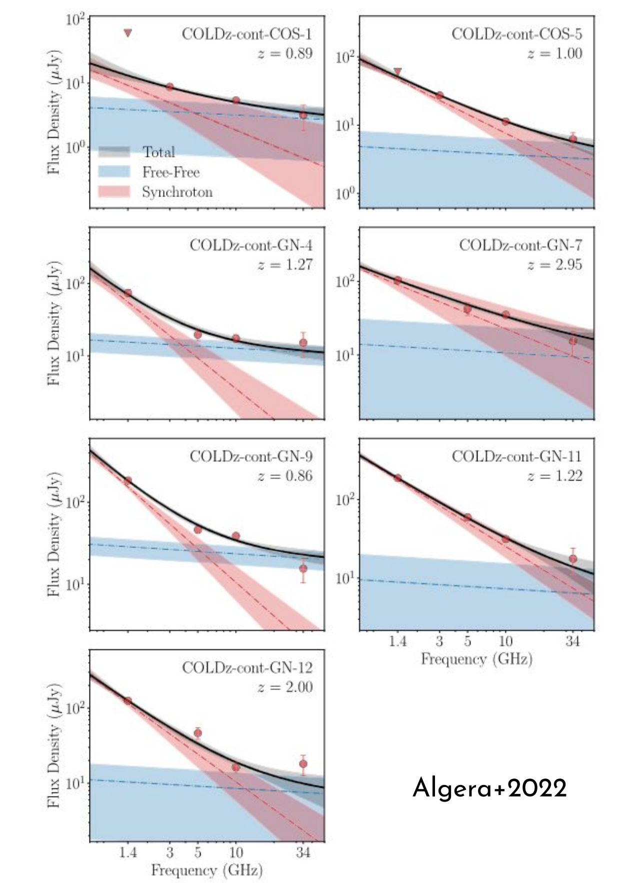
- ❑ Star formation history of the Universe
- ❑ AGN triggering, feedback, duty cycle
- ❑ Int. vs ext. effects in BH/galaxy growth

- ❑ CO emission for spatially-resolved KS law
- ❑ Dust mass/temperature
- ❑ radio-SFR_{IR} relation at high-z

- ❑ Photometry of a billion galaxies and spectra at $z \gtrsim 2$
- ❑ AGN vs SF in groups and (proto)clusters

Supplementary slides

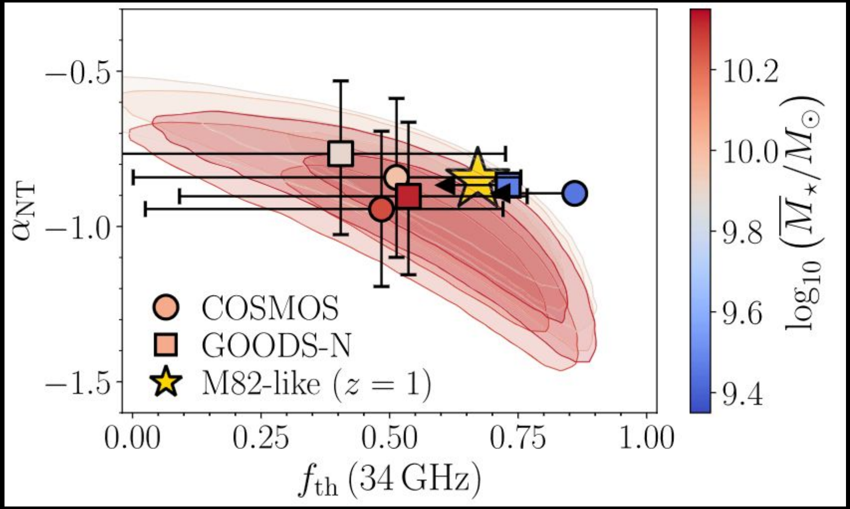
(radio) free free vs SFR relation



Algera+2022

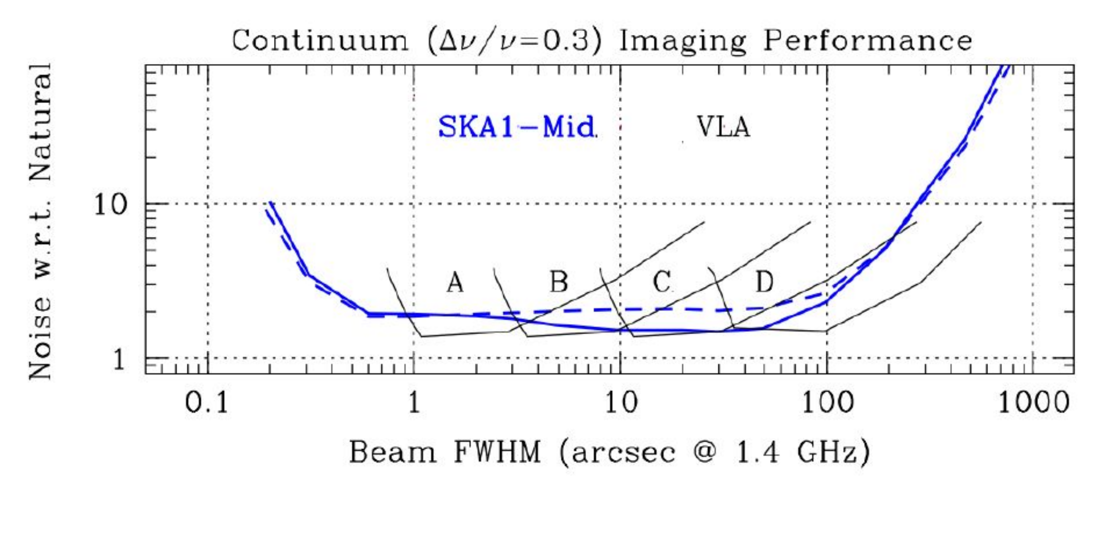
COLD-z survey (COSMOS+GOODS-N): 7 galaxies followed-up at: 1.4, 3, 5, 10 and 34 GHz

- Agreement with M82-like spectrum
- Free-free emission dominant at 34 GHz, but around 5–10% at 1.4 GHz
- Deficit of synchrotron emission (electron ageing?)



SKA1-MID: resolution wrt sensitivity

- 0.5" resolution at 1.4GHz is a sweet spot: best angular resolution at full sensitivity
- we can go to higher resolution at the detriment of decreasing sensitivity
- confusion limit will not be an issue (unlike the SKA-low)

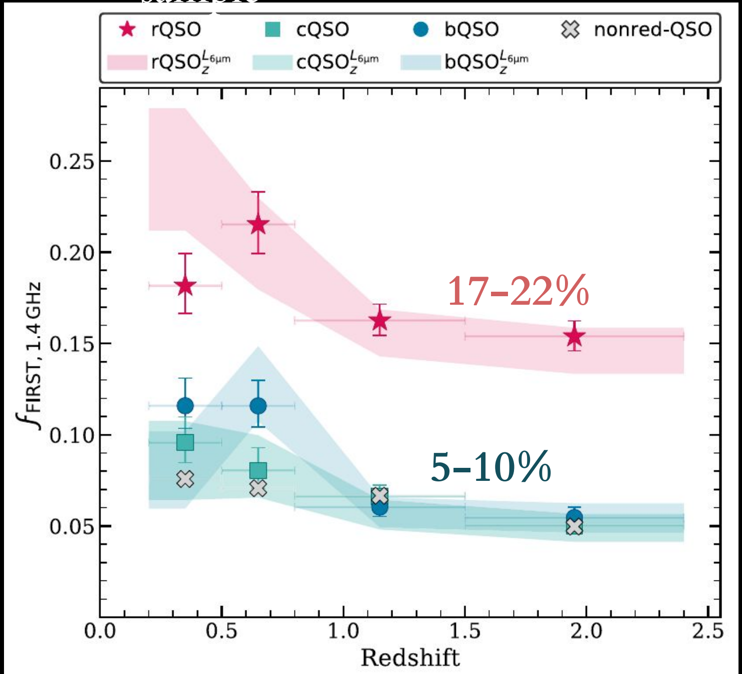


Braun et al. (2019)

Are radio AGN signposts for obscured BH growth?

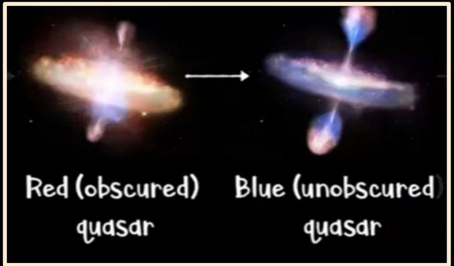
SDSS QSOs + FIRST (0.2<z<2.4)

- Red QSO from (g-i) colours
- Matched (L_{6um}, z) with blue-QSO control sample



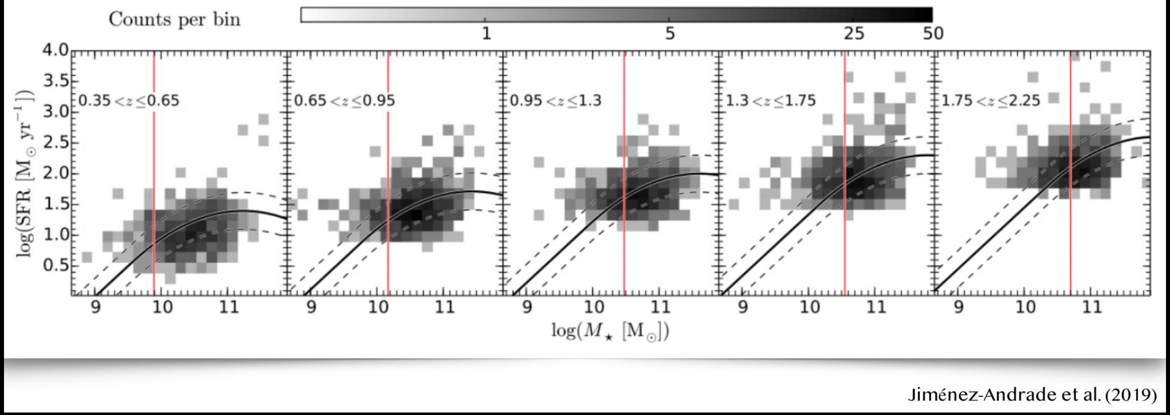
Red QSOs have higher radio detection fraction

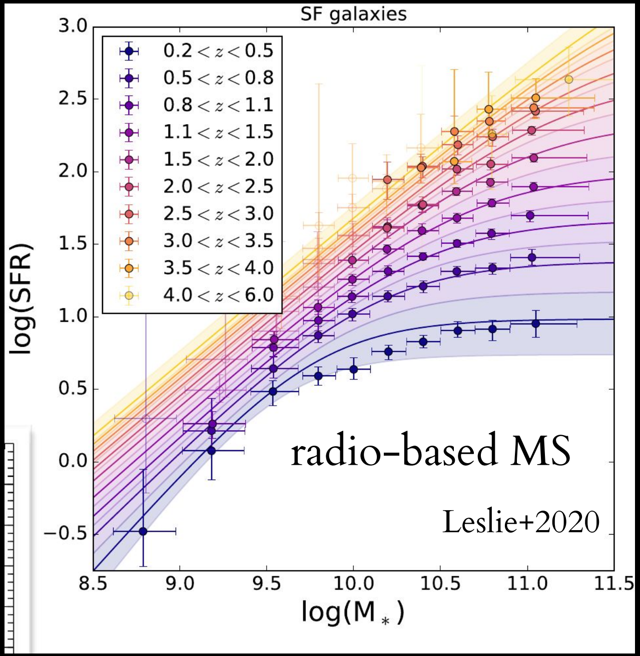
Excess in %detection due to compact (few kpc) jets



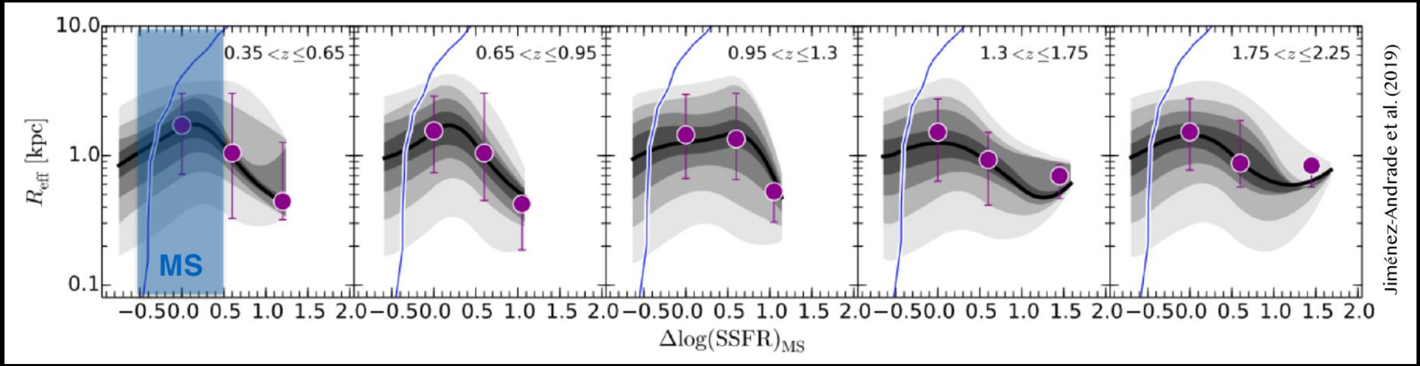
Typical (radio) sizes of SF galaxies

SFR-M* plane of of 3-GHz selected galaxies in VLA-COSMOS





SB galaxies are systematically more compact than MS galaxies: merger-driven star formation above MS?



SKA 1 predictions: SFR and stellar mass over cosmic time