Séminaire Lagrange – OCA Nice
April 23rd, 2019

Marie Skłodowska-Curie Actions

Clues on radio AGN feedback at high-redshift from deep radio surveys

2018 MNRAS, 481, 4971

Ivan Delvecchio

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On behalf of:
V. Smolčić, G. Zamorani, D.J. Rosario, M. Bondi, S. Marchesi,
T. Miyaji, M. Novak, M.T. Sargent, D.M. Alexander, J. Delhaize,
E. Daddi & the COSMOS team

Outline

- Why do we care about AGN?

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- Why do we care about AGN?

- The deepest radio view of AGN in the COSMOS field: the *VLA-COSMOS 3 GHz Large Project*

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- Radio AGN since z~4: does AGN feedback "quench" star formation?

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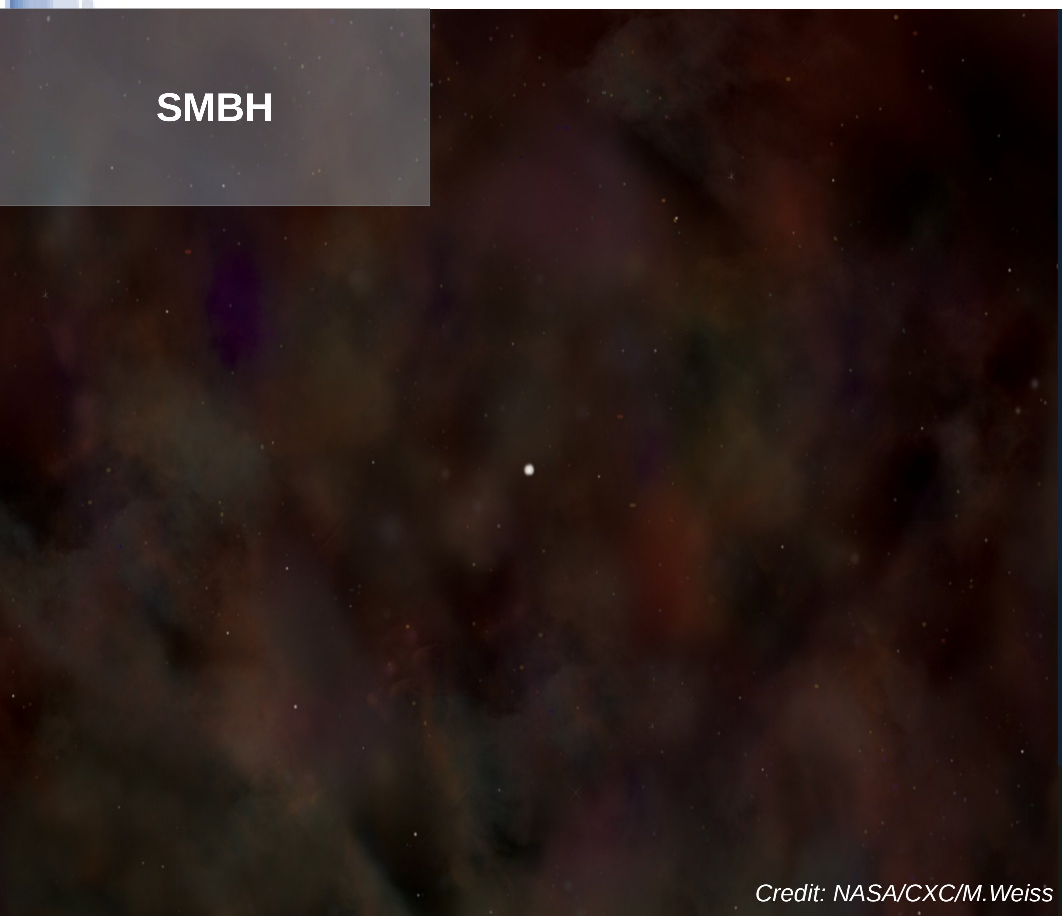
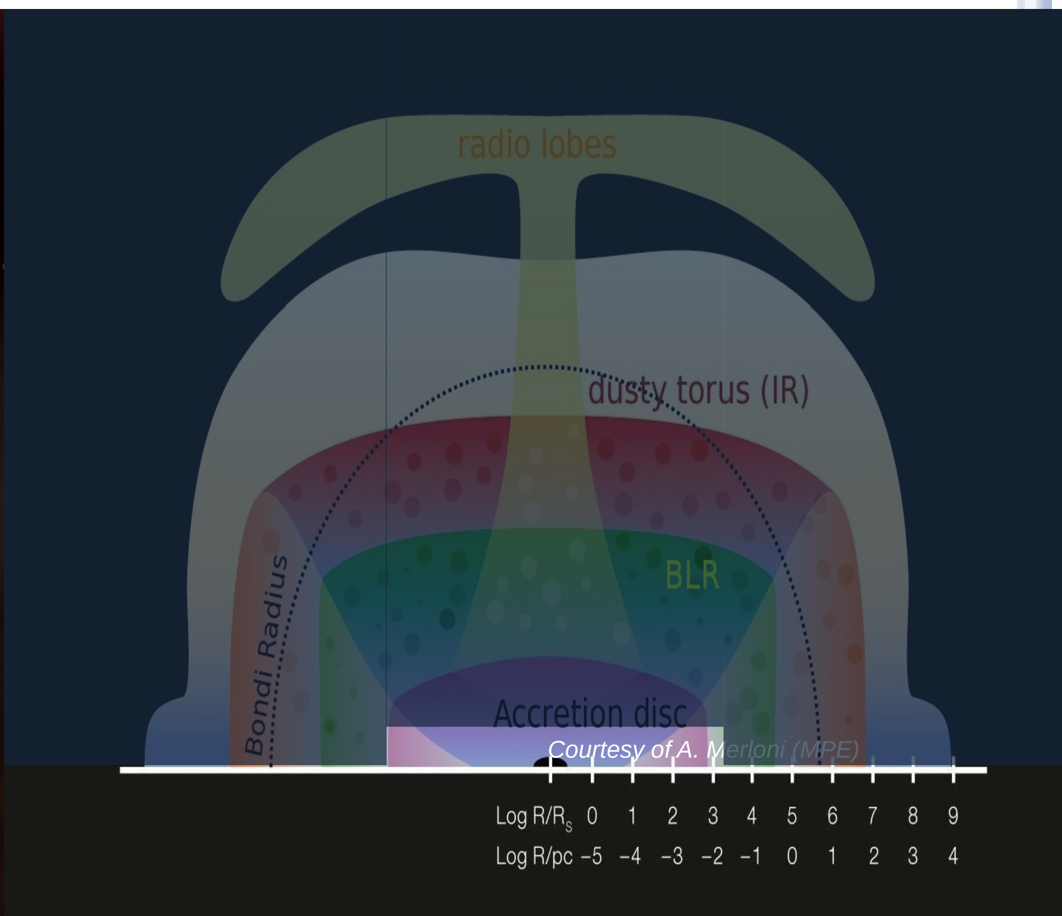
- Implications and summary

Anatomy of an AGN

- Super massive black hole (SMBH): $M_{bh} = 10^6 - 10^{10}\ M_{sun}$





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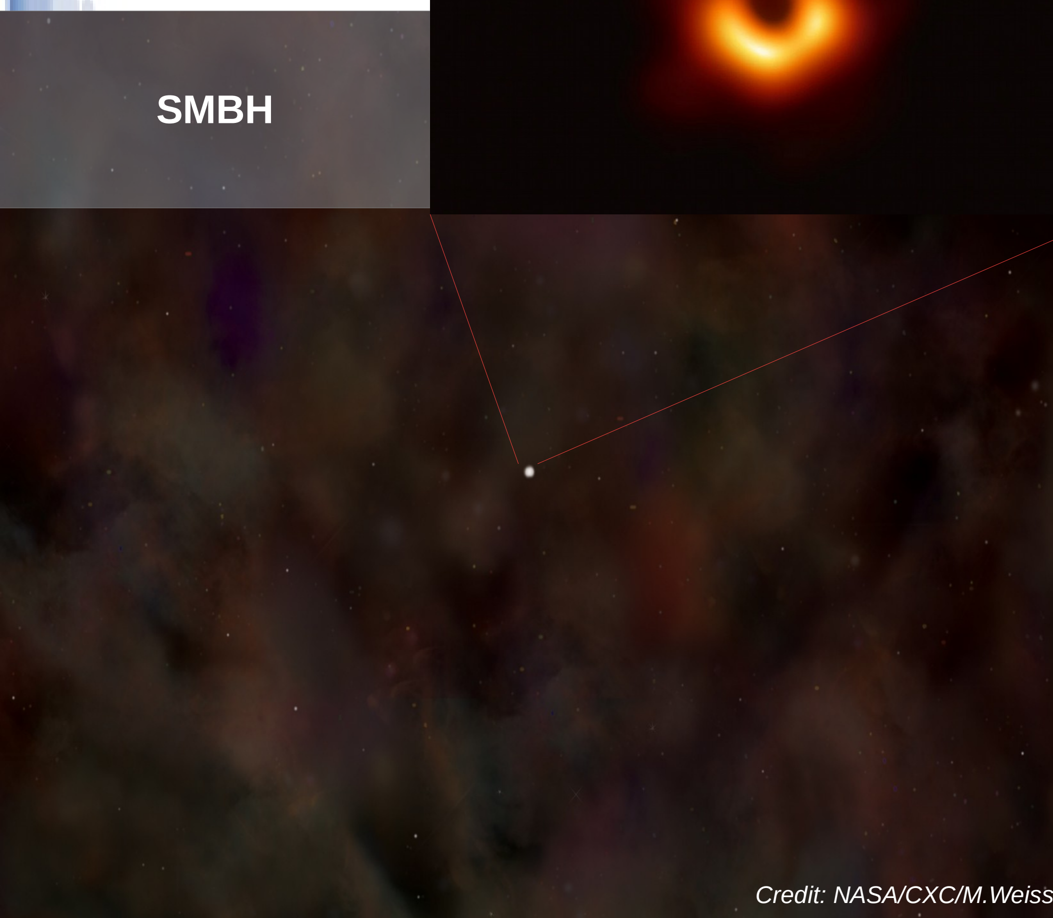
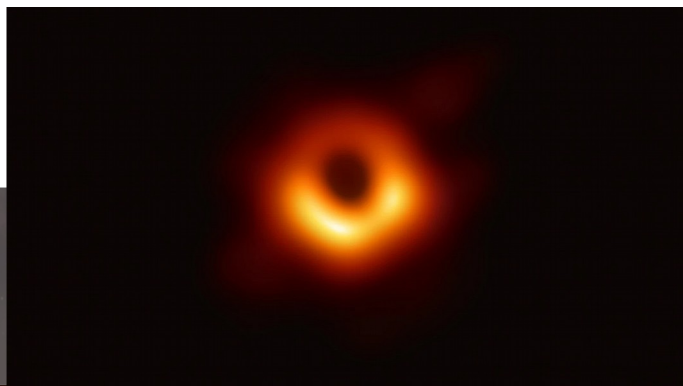
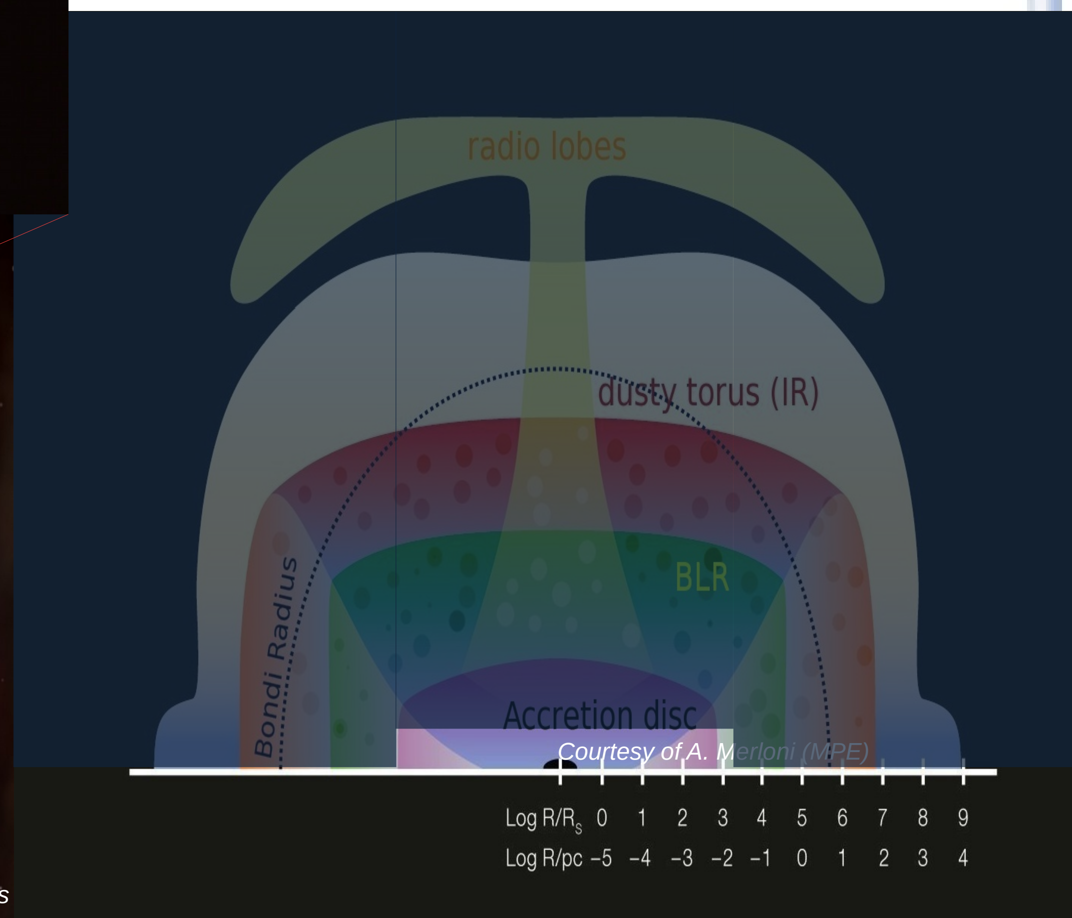
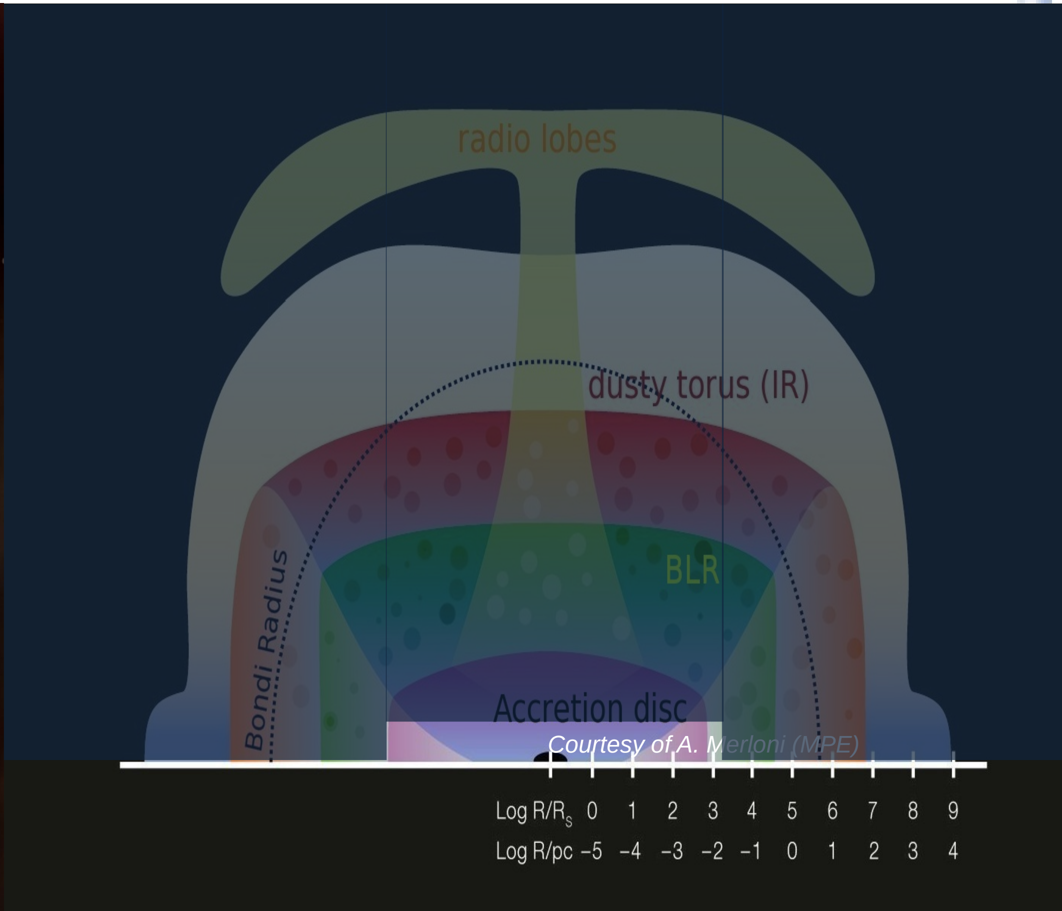






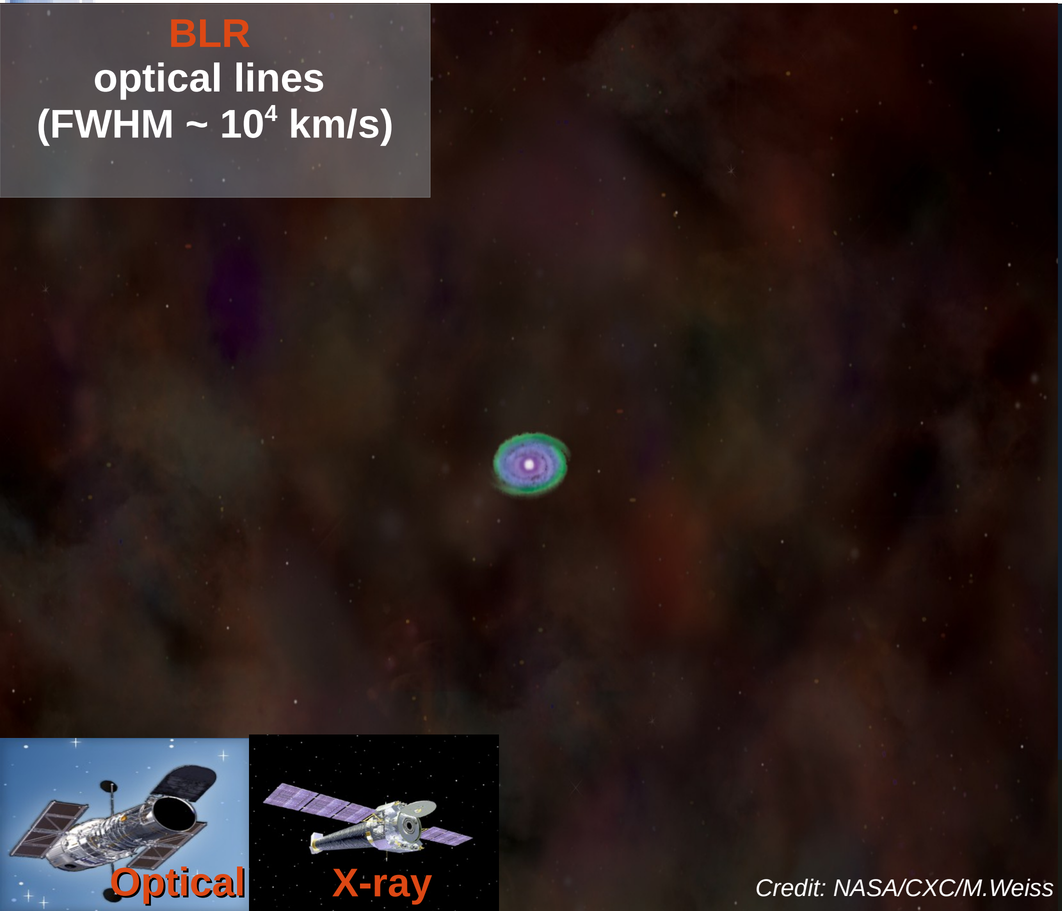
Anatomy of an AGN

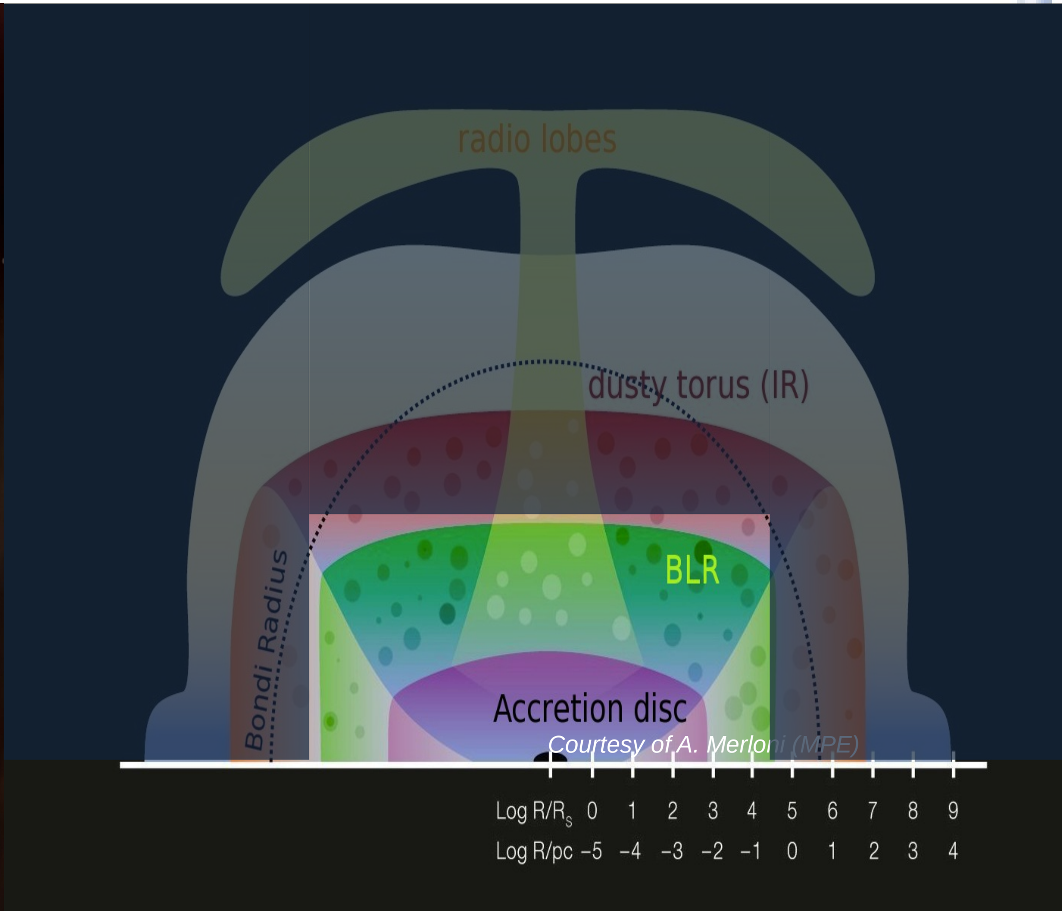
- Super massive black hole (SMBH): $M_{bh} = 10^6 - 10^{10} M_{sun}$
- Accretion disc



Anatomy of an AGN

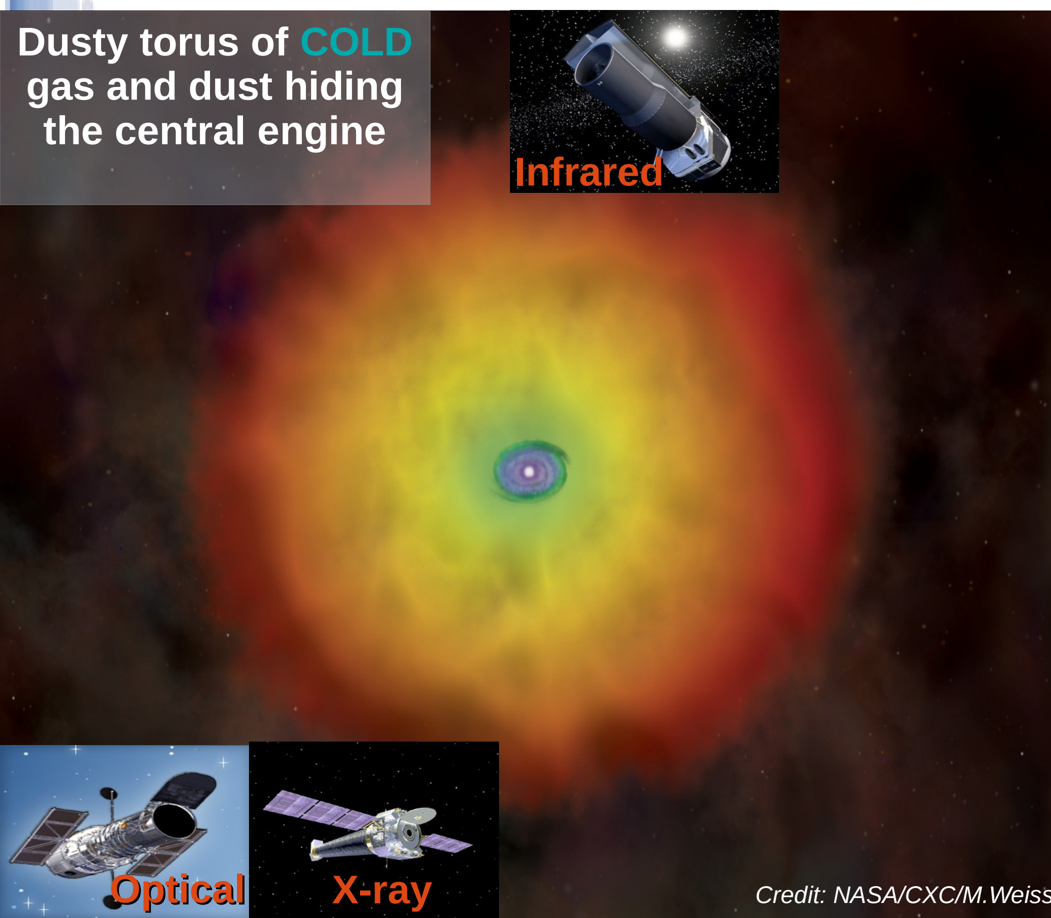
- Super massive black hole (SMBH): $M_{bh} = 10^6 - 10^{10}\ M_{sun}$
- Accretion disc + broad line region (BLR)

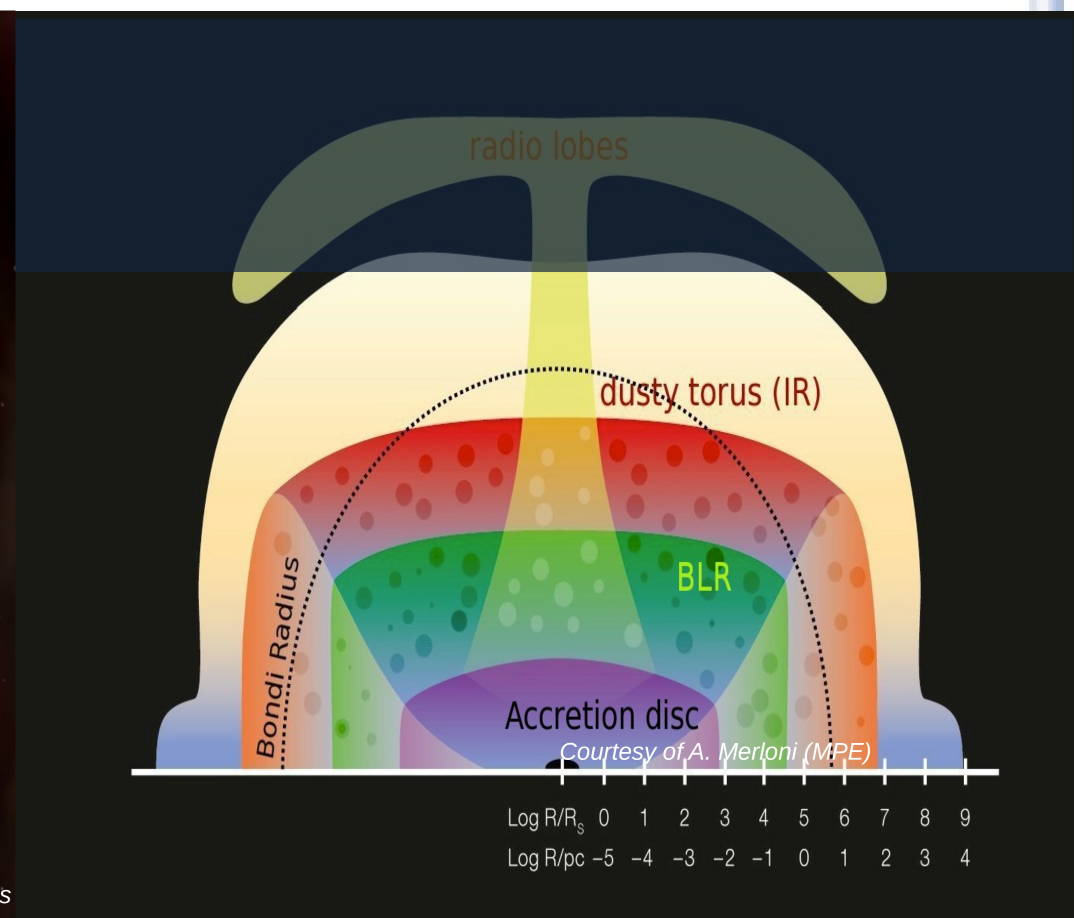




Anatomy of an AGN

- Super massive black hole (SMBH): $M_{bh} = 10^6 - 10^{10}\ M_{sun}$
- Accretion disc + broad line region (BLR) and narrow line region (NLR)
- Dusty torus of gas and dust (= AGN obscuration)





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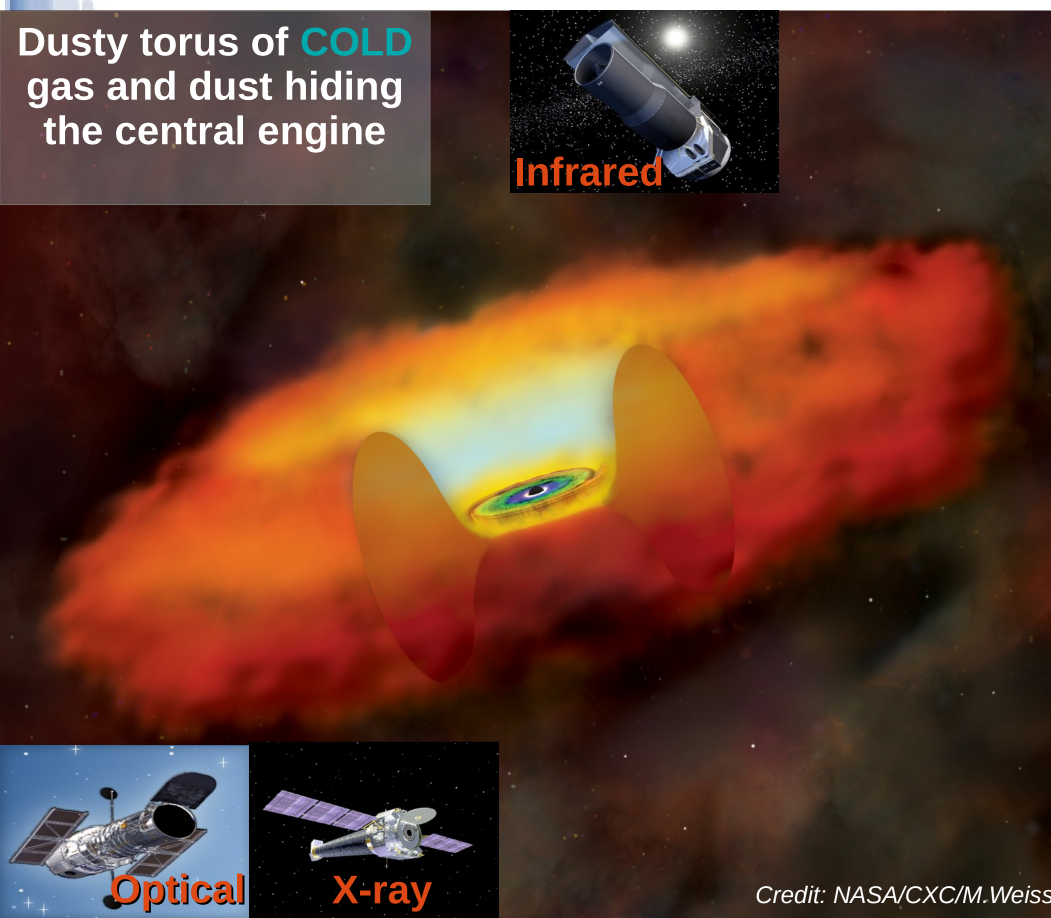

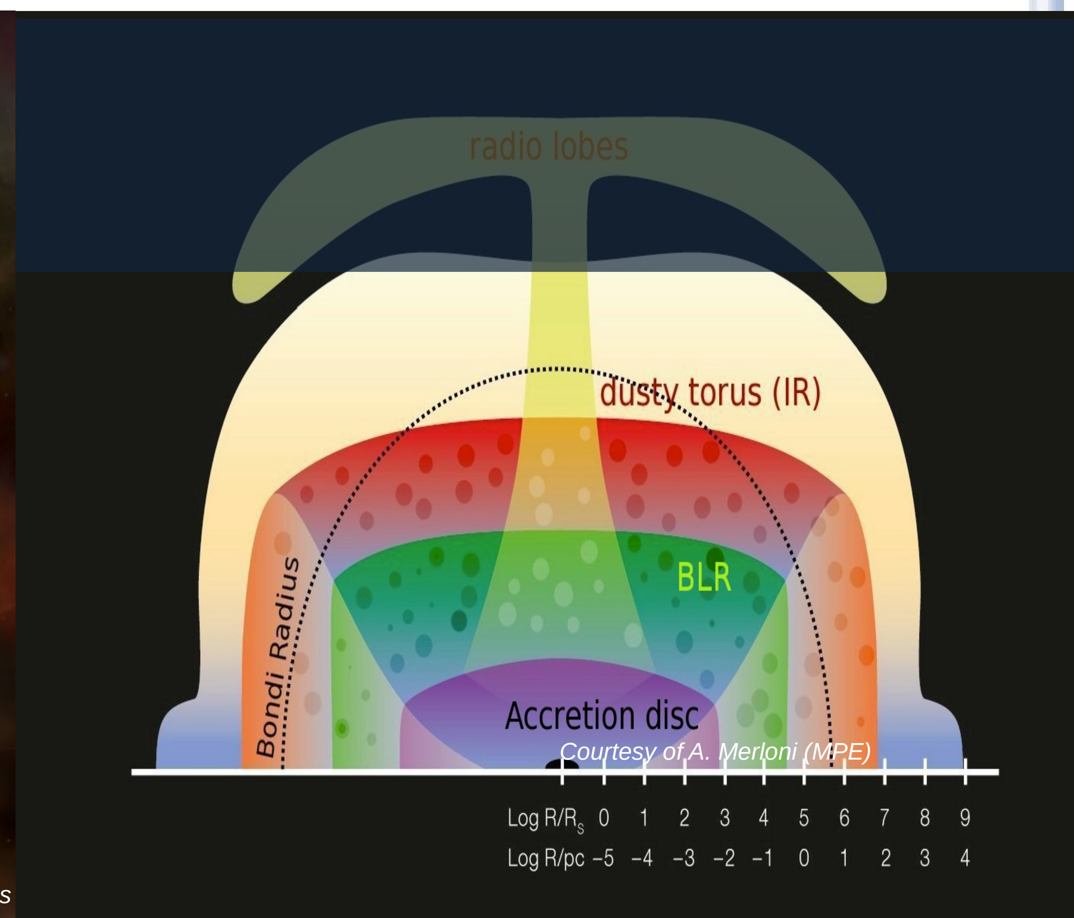

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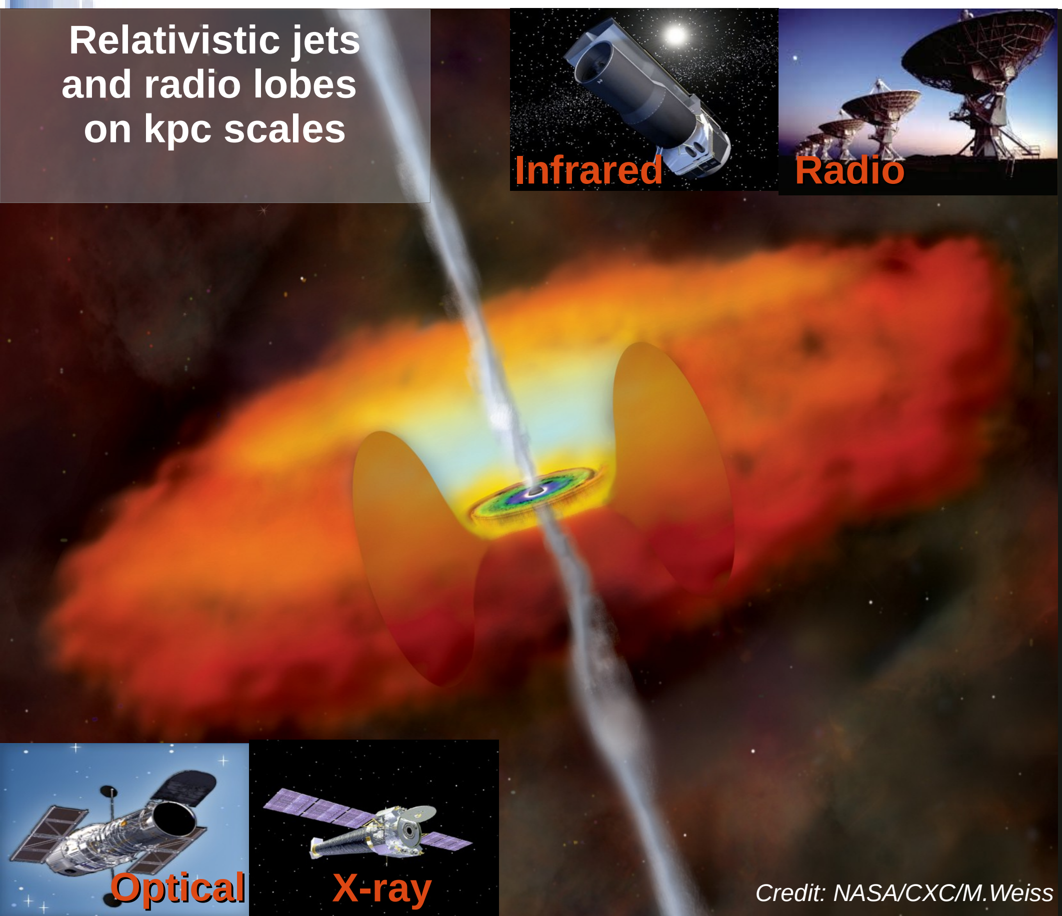
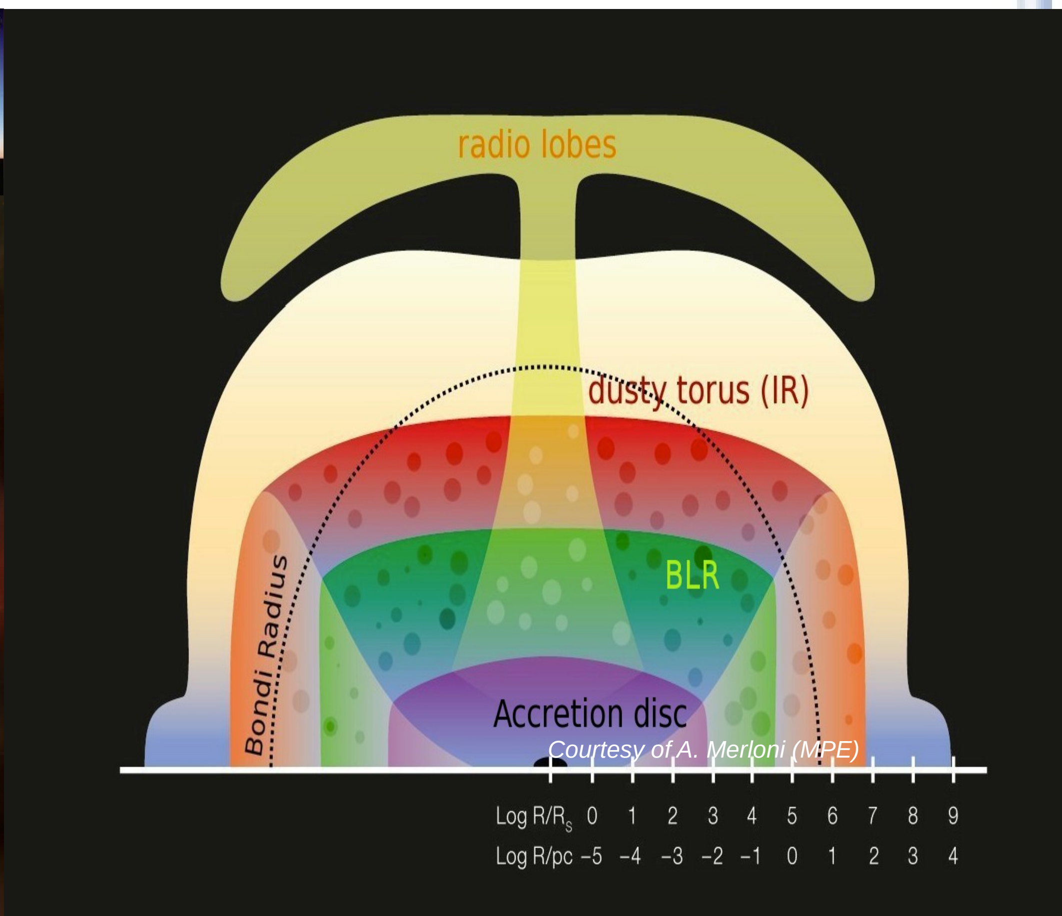
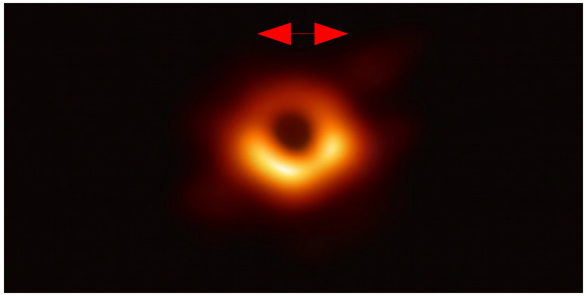
- Dusty torus of gas and dust (= AGN obscuration) + Radio jets and lobes





Active Galactic Nuclei (AGN)

0,001 pc



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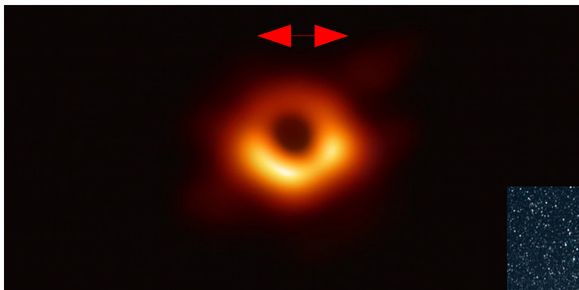
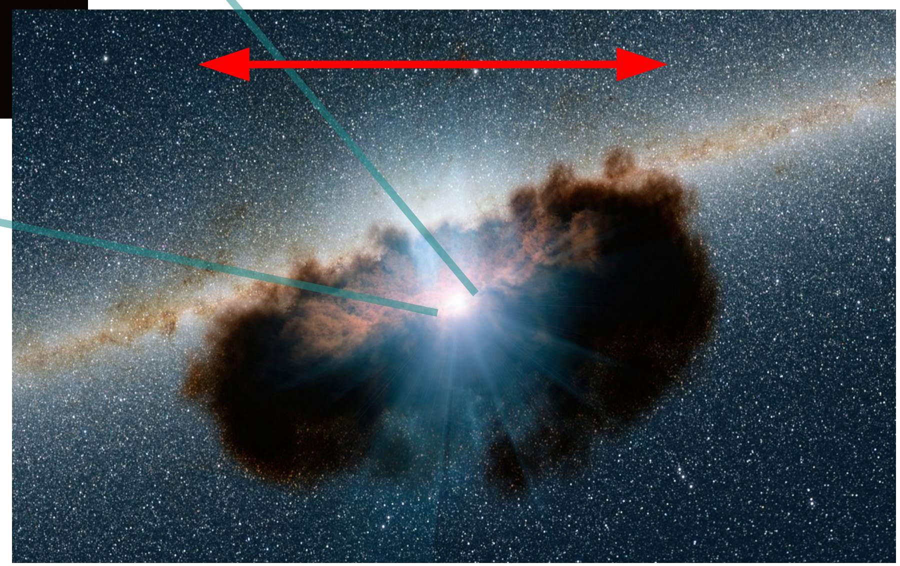


1-10 pc



x 10000

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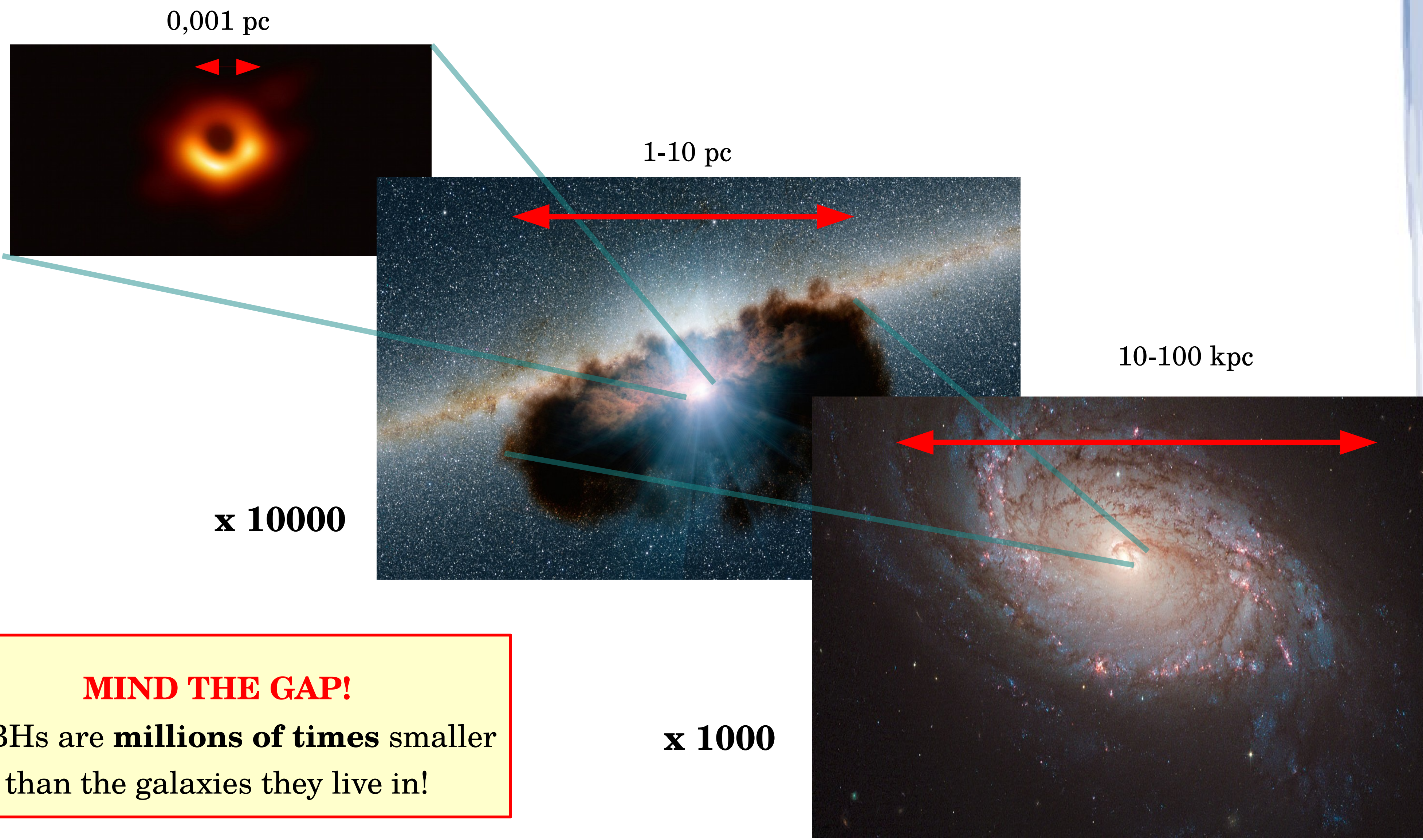
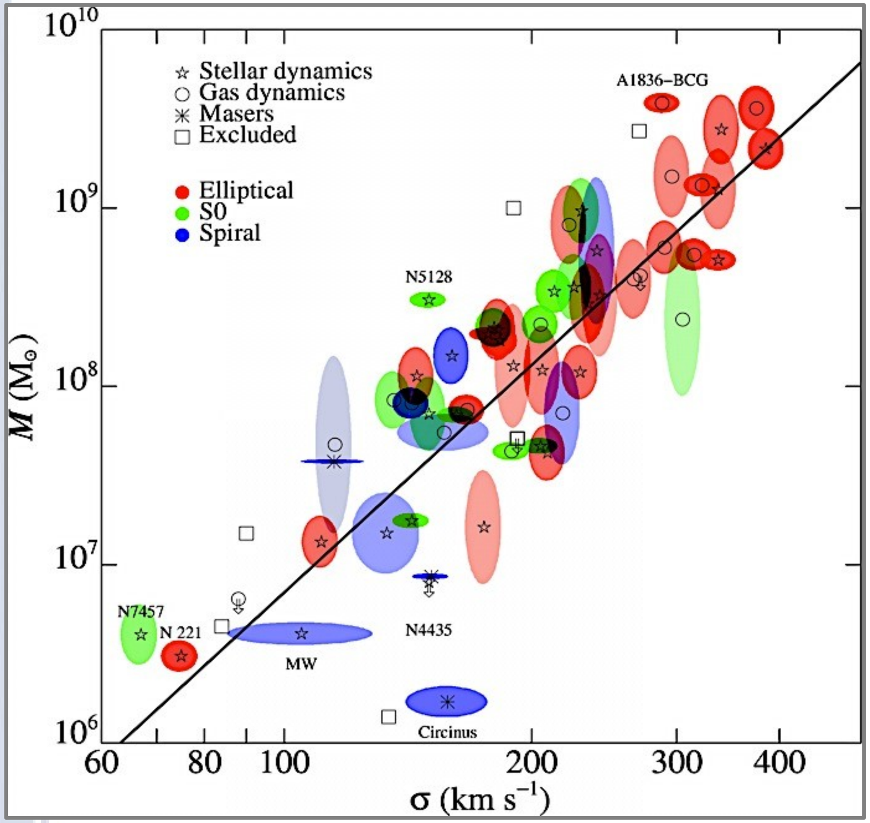


MIND THE GAP!

SMBHs are **millions of times** smaller than the galaxies they live in!

Galaxies and SMBHs know each other

Gultekin et al. (2009)



- Black hole masses correlate in nearby spheroidals with galaxy bulge properties:

  M_{BH} – σ relation (rms ~ 0.3 dex)

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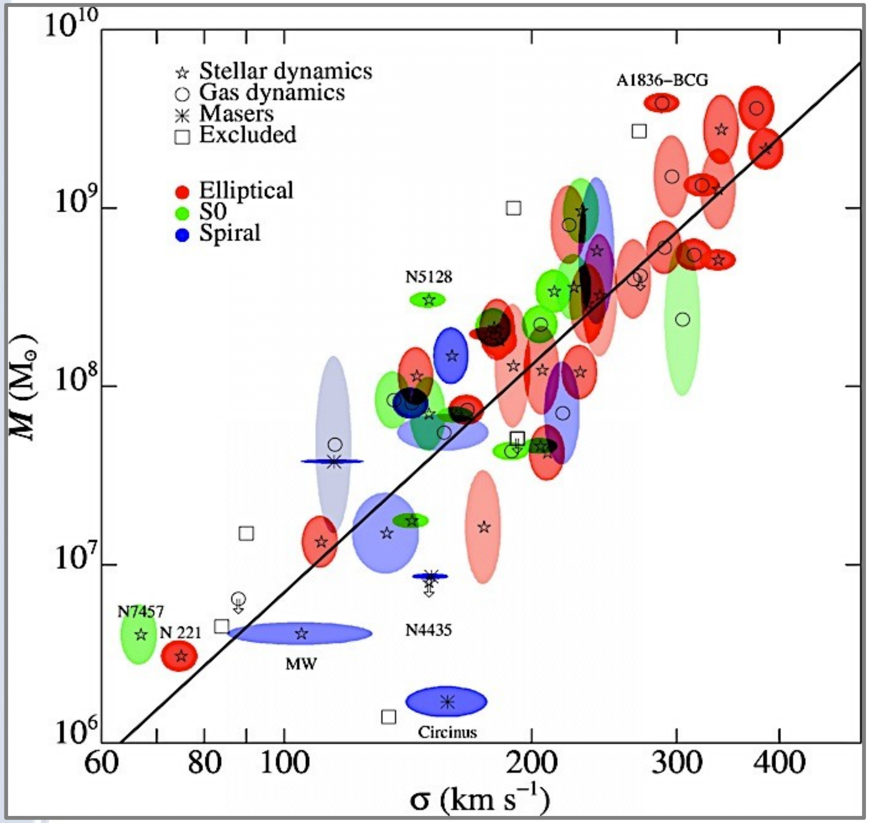
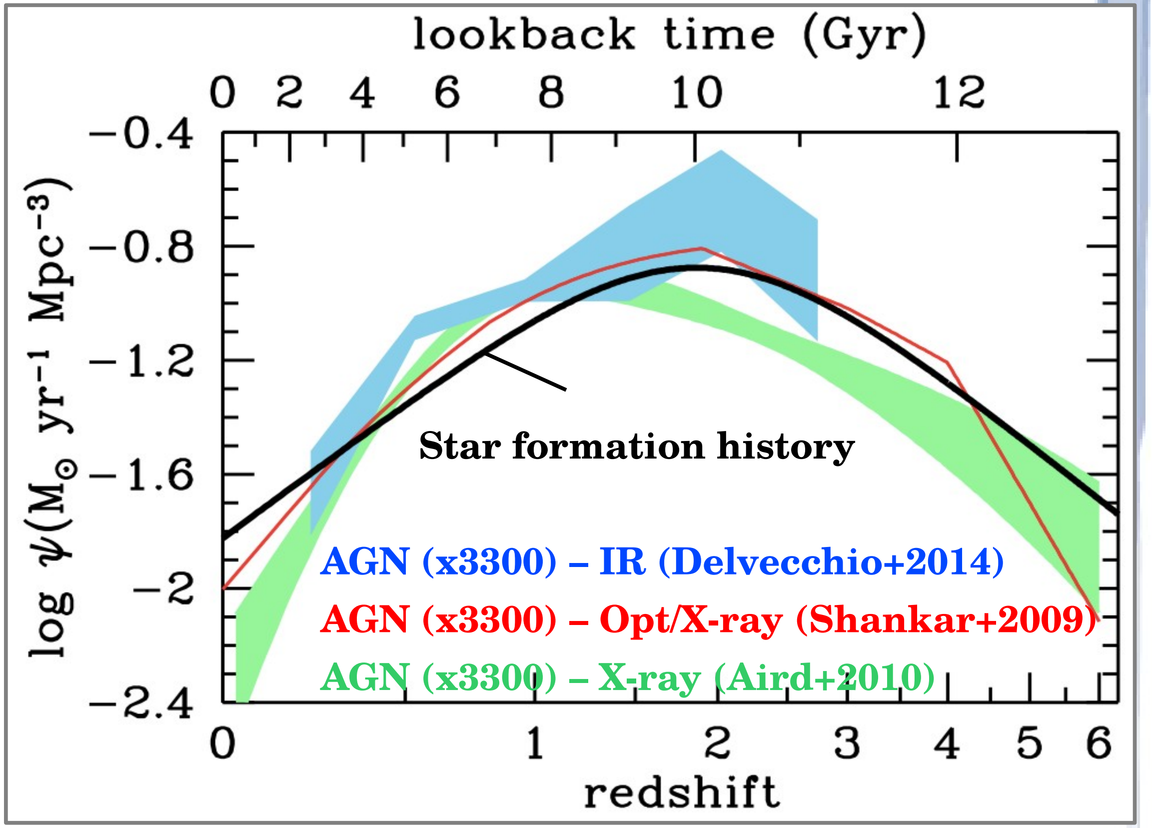


Madau & Dickinson (2014)



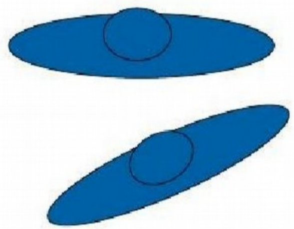
- Black hole masses correlate in nearby spheroidals with galaxy bulge properties:
  M_{bh} – σ relation (rms ~ 0.3 dex)

- Cosmic star formation history and black hole accretion history closely trace each other.

Sanders et al. (1988); Alexander & Hickox (2012)

The need for AGN feedback

- Early phase



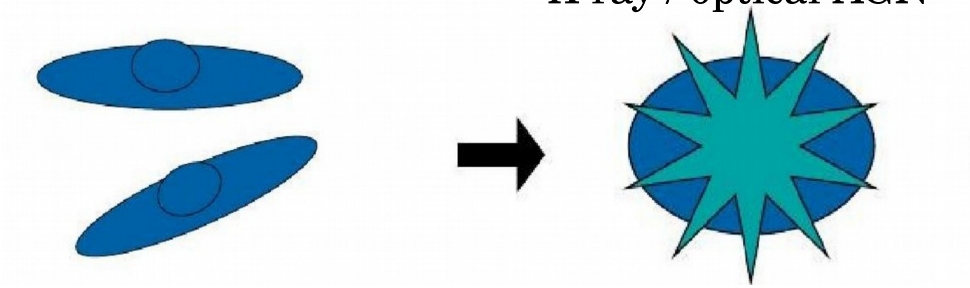
Galaxy mergers /
Stochastic processes

Sanders et al. (1988); Alexander & Hickox (2012)

The need for AGN feedback

- Early phase

- **Star forming** galaxy
- X-ray / optical AGN



Galaxy mergers / Stochastic processes

Gas inflow: SMBH becomes an AGN

"Radiative mode"

t

Sanders et al. (1988); Alexander & Hickox (2012)

The need for AGN feedback

- Early phase

- **Star forming** galaxy
- X-ray / optical AGN

- **Red** and passive galaxy
- Radio AGN

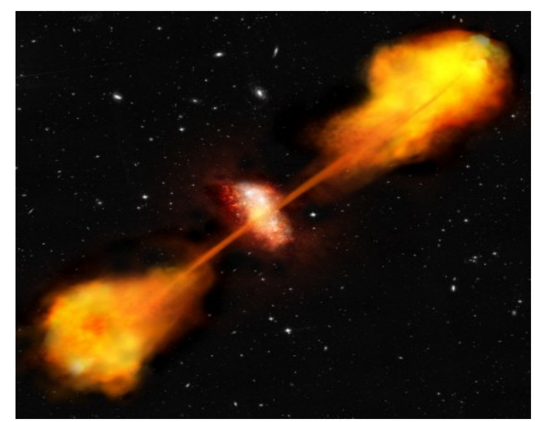
Galaxy mergers / Stochastic processes

Gas inflow: SMBH becomes an AGN

AGN feedback hampers galaxy star formation

"Radiative mode"

"Jet mode"



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Sanders et al. (1988); Alexander & Hickox (2012)

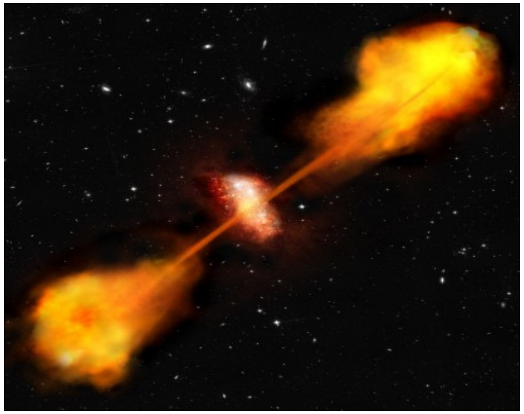
The need for AGN feedback

Open questions:

- How are radio jets formed?
- Why are jets only seen in a small fraction of galaxies?
- How does AGN feedback change across cosmic time?

"Radiative mode"

"Jet mode"



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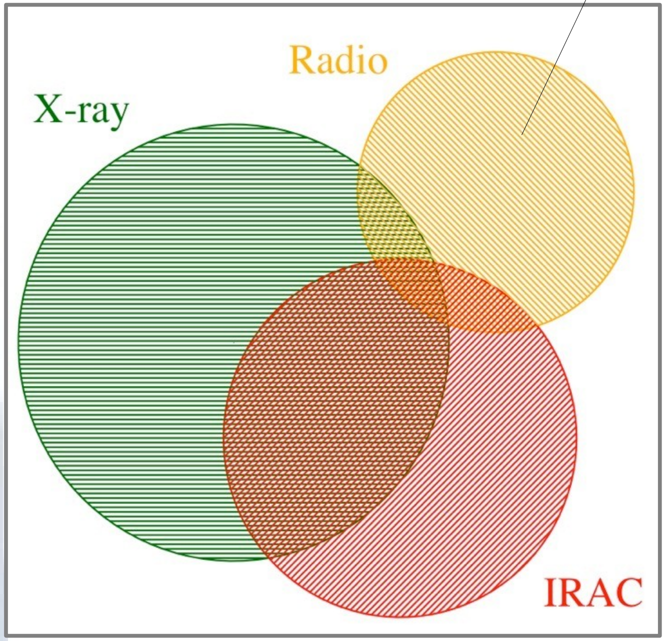
Radio (<u>bright</u>) AGN at z<1 are special

$L_{1.4} > 10^{24.8}$ W/Hz



Hickox et al. (2009)

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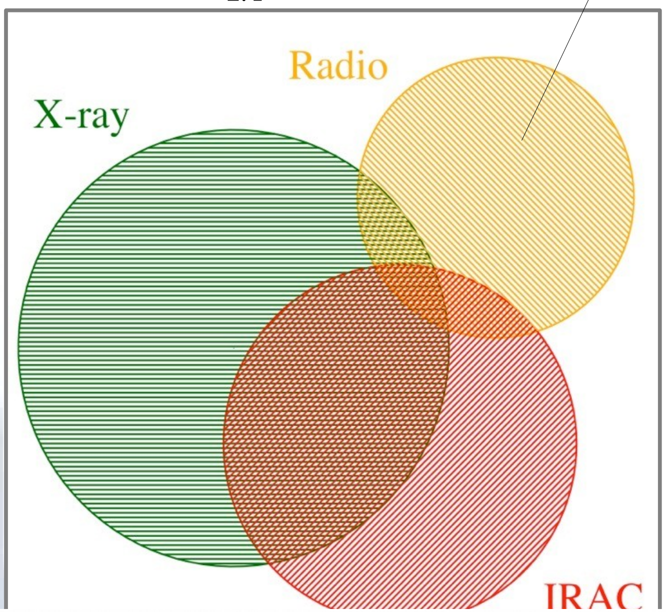

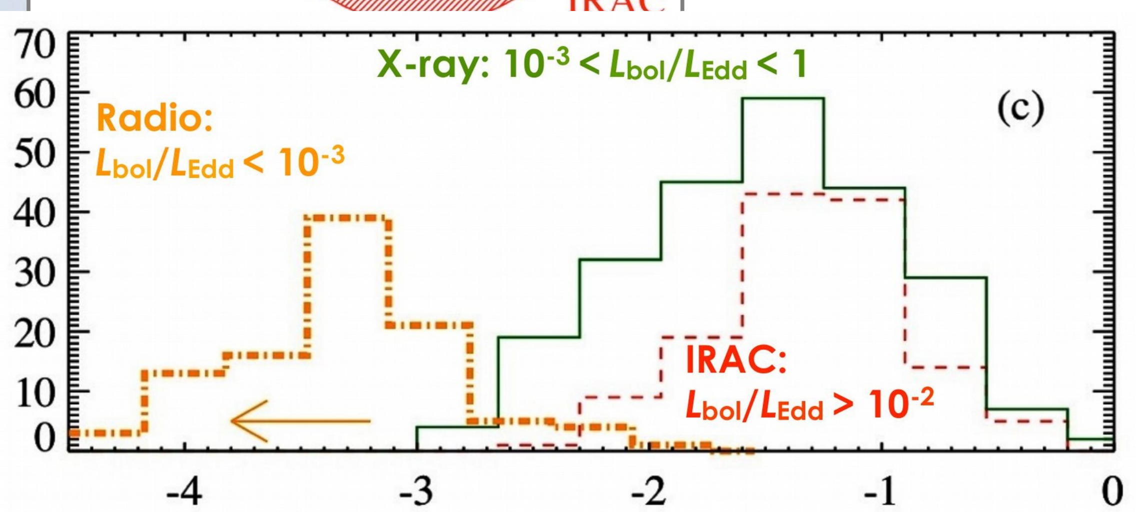

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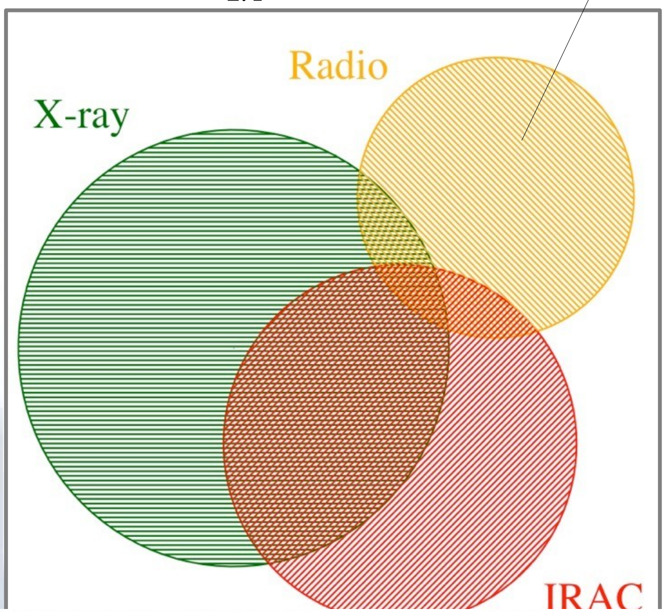

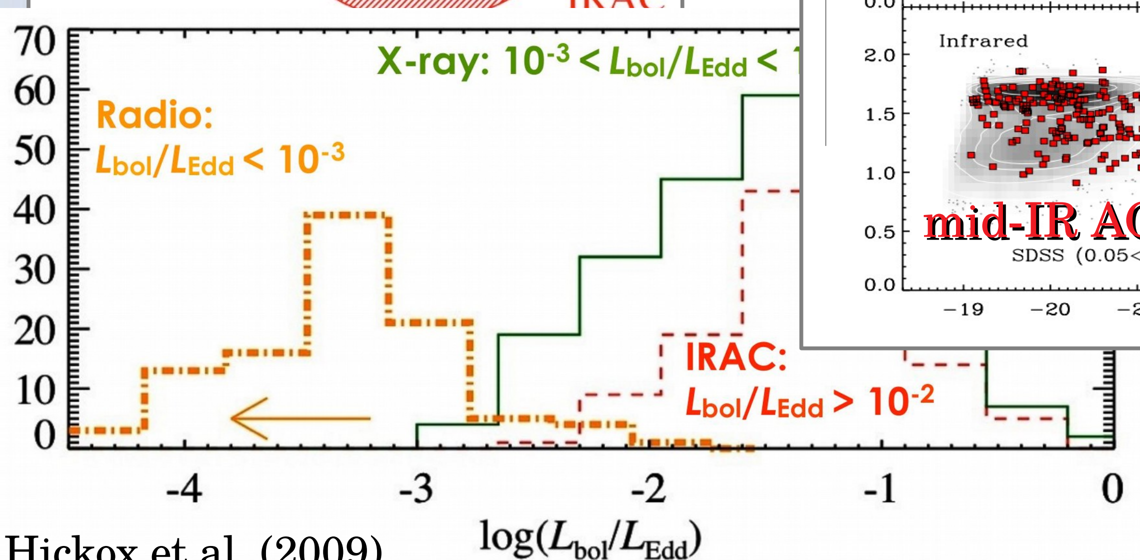

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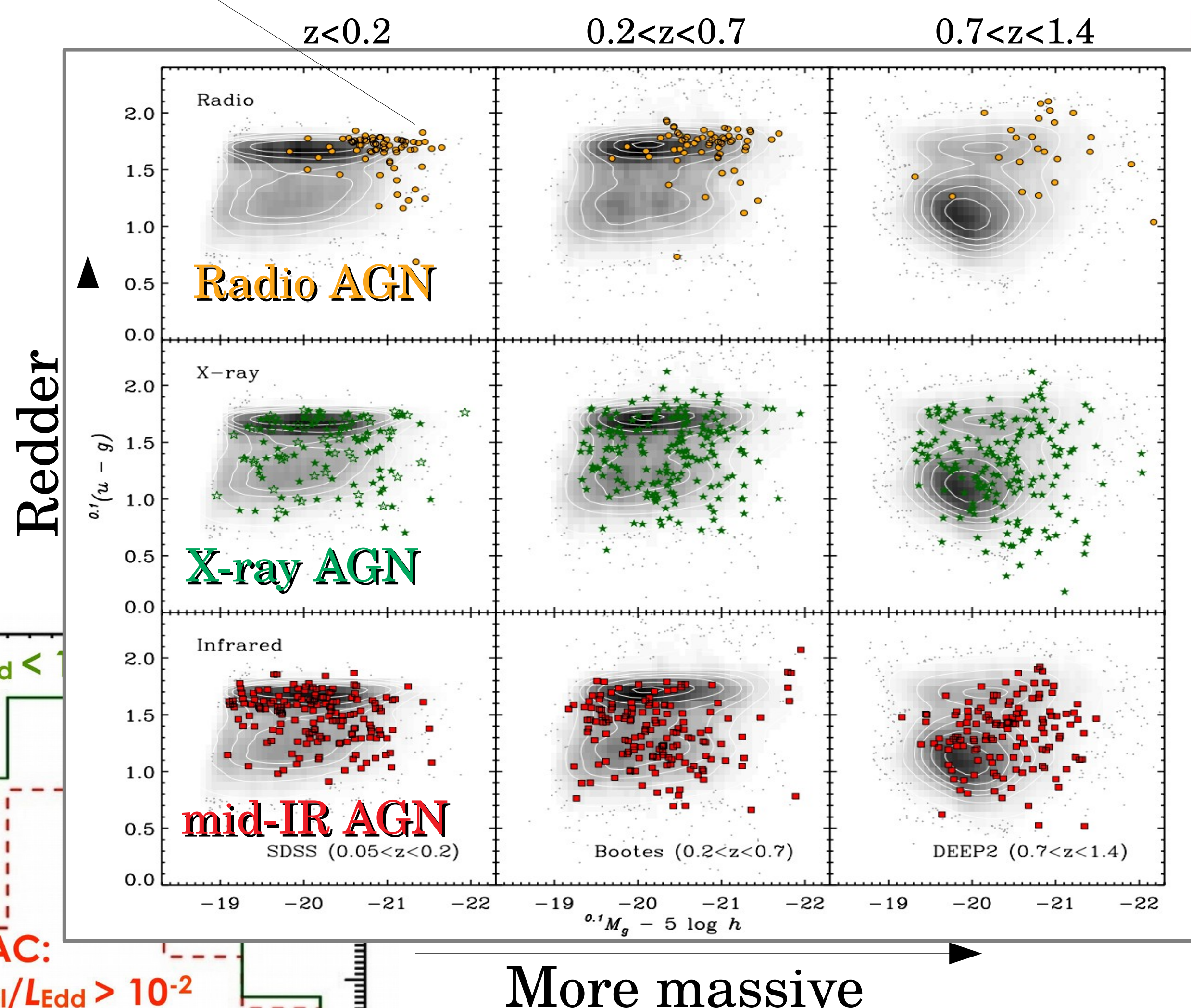

Goulding et al. (2014)

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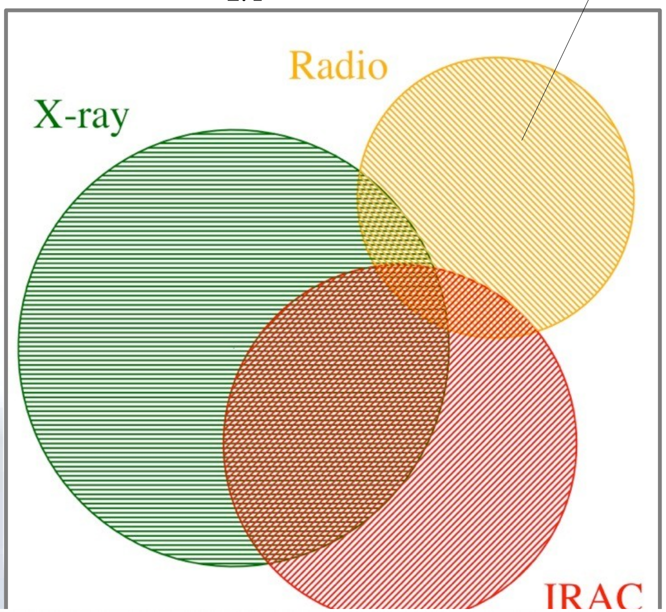

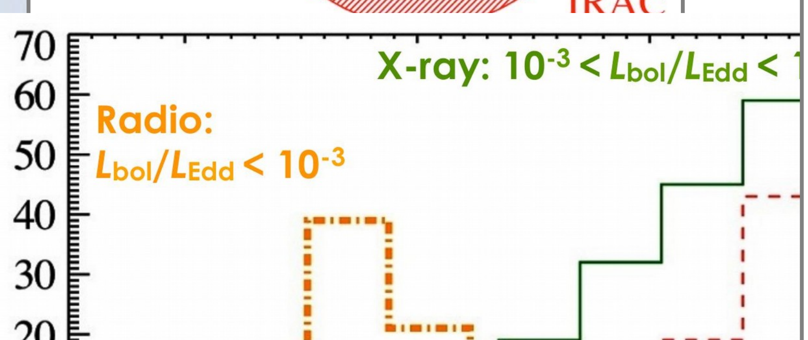

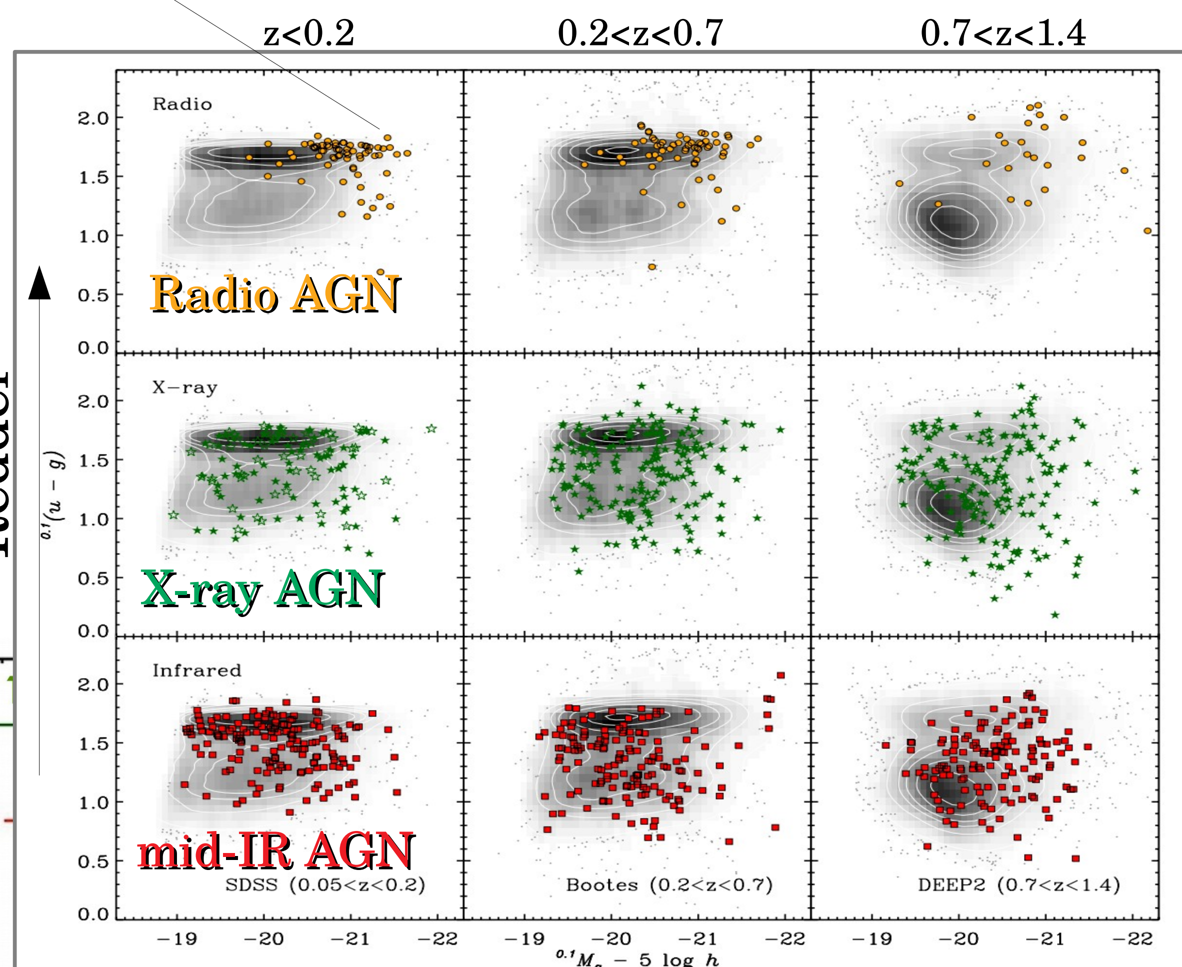

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Radio AGN at z<1 are weakly accreting SMBHs hosted within massive and passive galaxies

Hickox et al. (2009)

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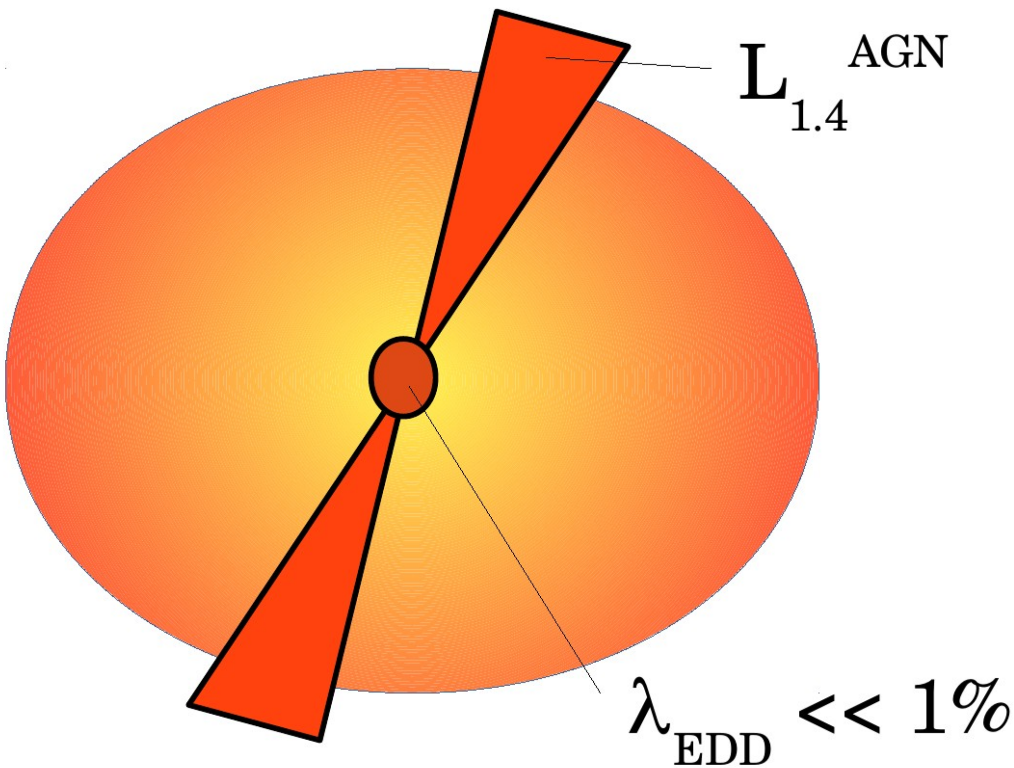

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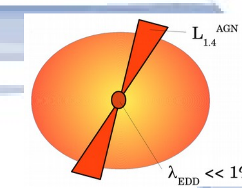
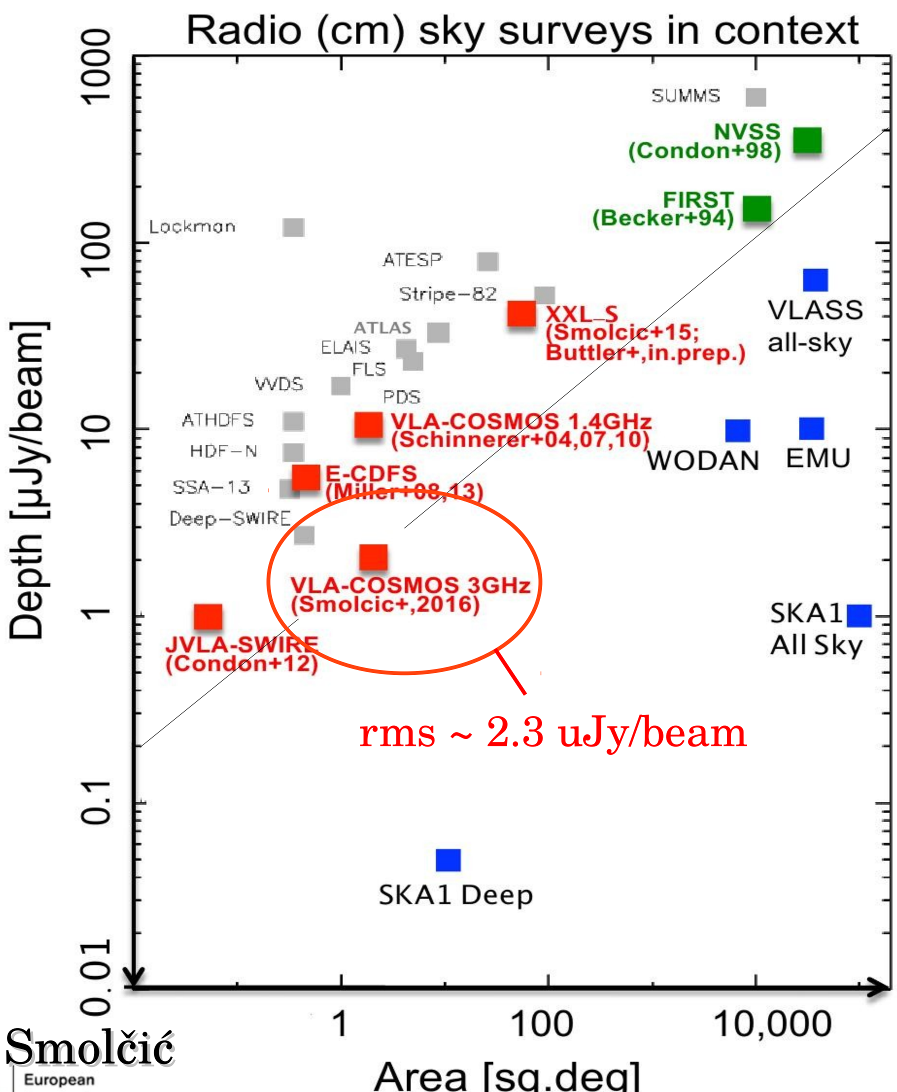


Going deeper and further back in time: The VLA-COSMOS 3 GHz Large Project



PI: V. Smolčić

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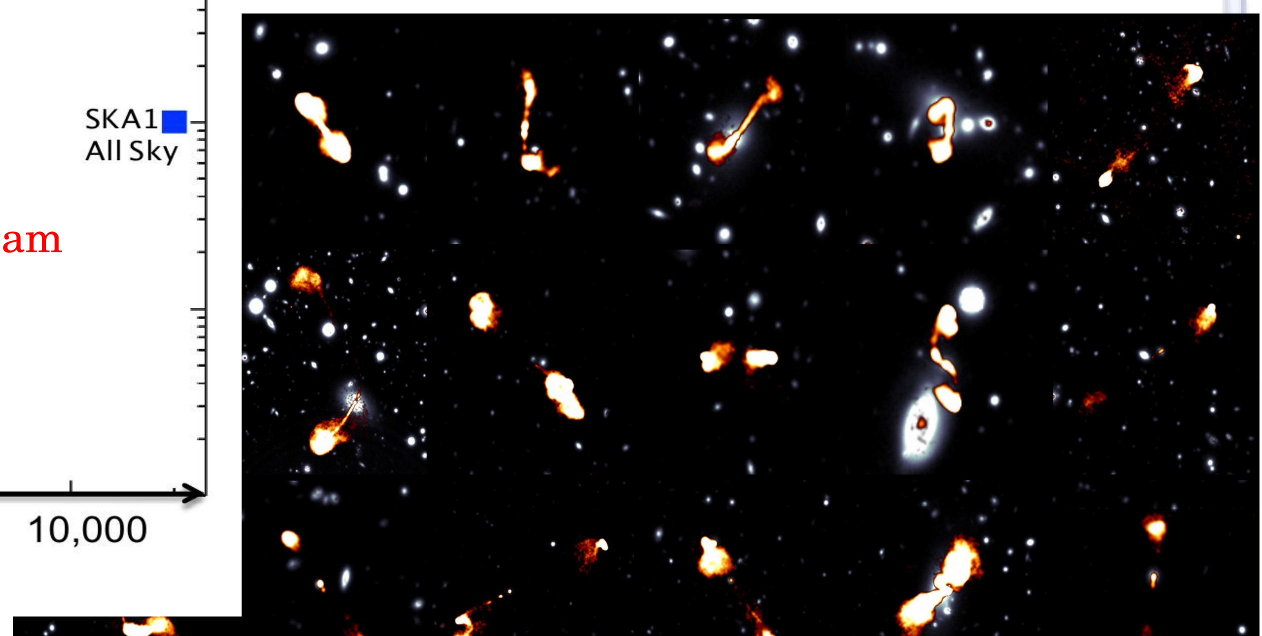

Credit: M. Novak

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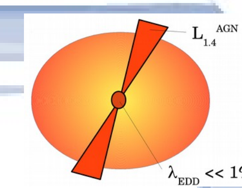
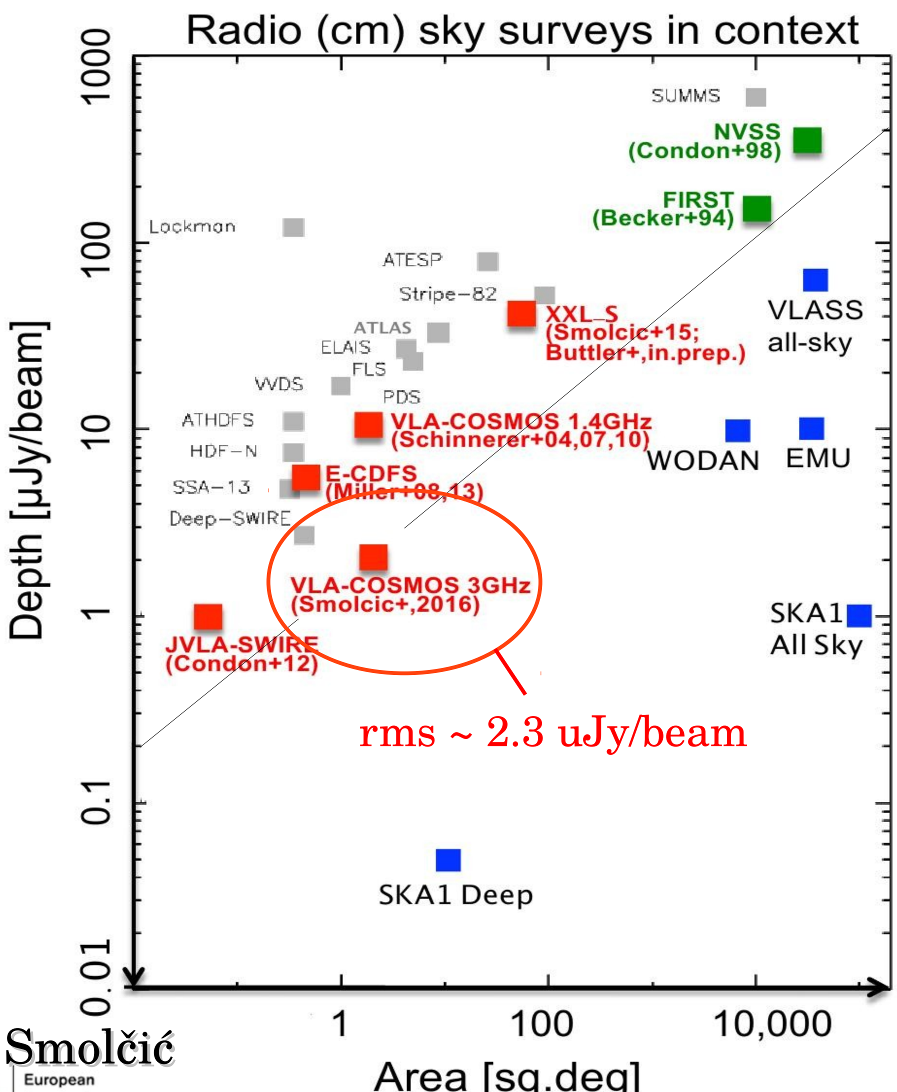
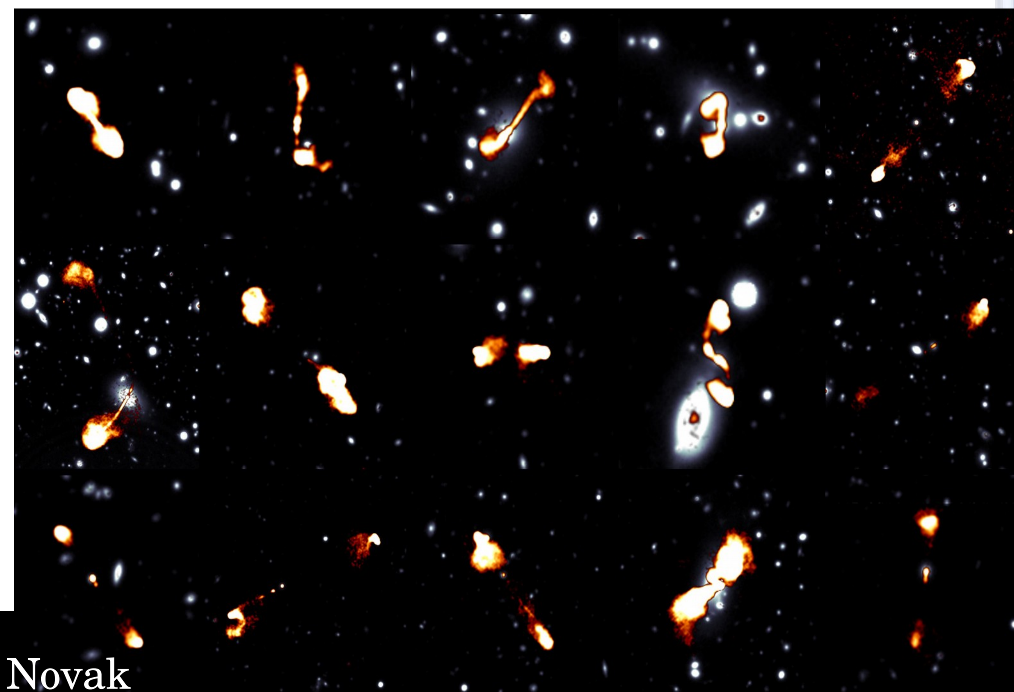




- 7729 radio sources selected at 3 GHz (10 cm) at 0.75" resolution, with optical/NIR counterpart in the COSMOS2015 catalogue (Smolčić, ID et al. 2017b).
- Press release on A&A special issue: http://cosmos.astro.caltech.edu/news/52



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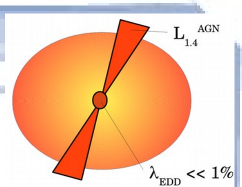

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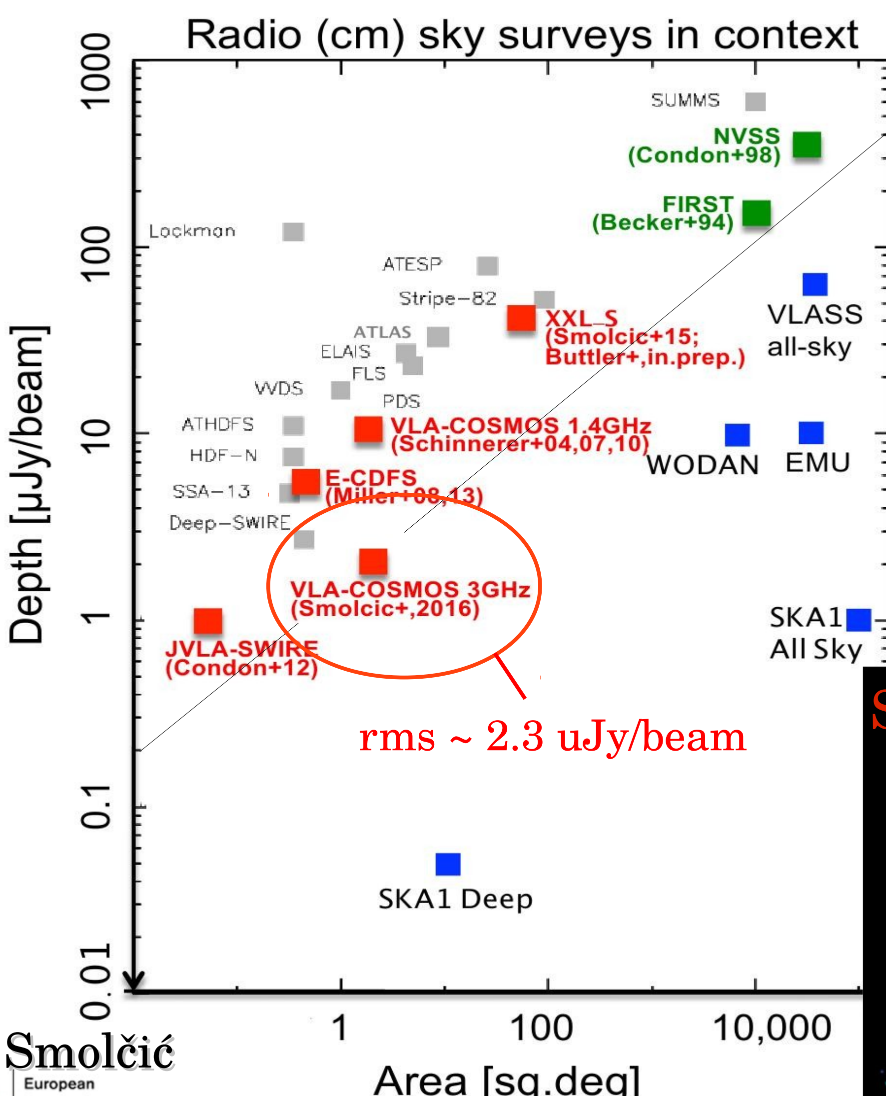

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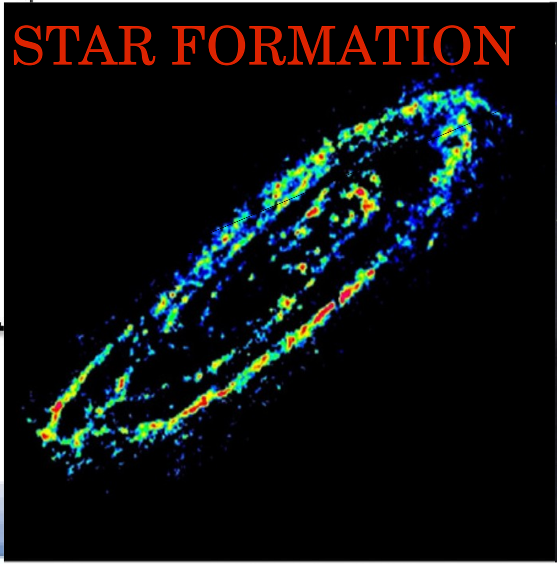
Radio emission:



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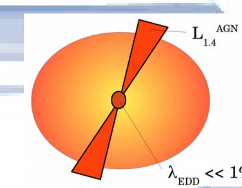

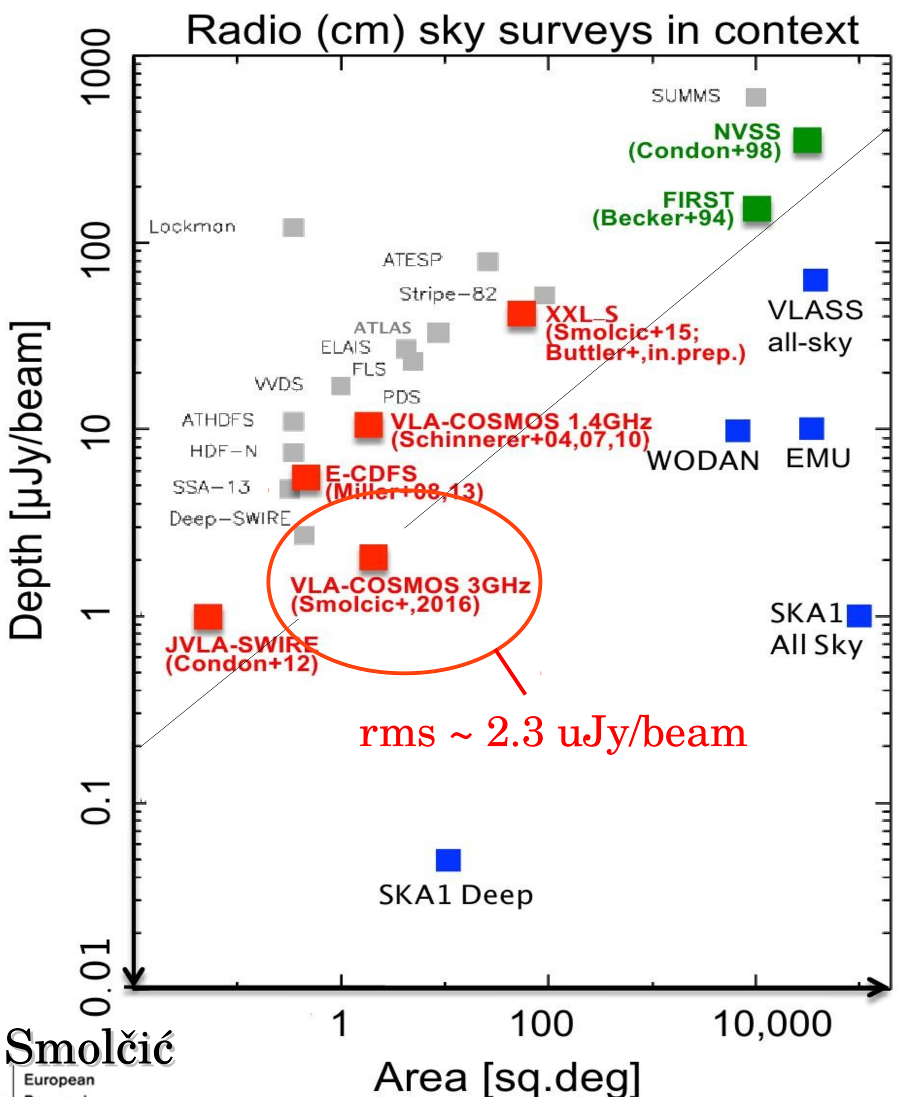

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> 1800 radio AGN: identified via a (>2σ) 4x excess in radio emission, relative to their IR-based star formation rate (Delhaize et al. 2017)

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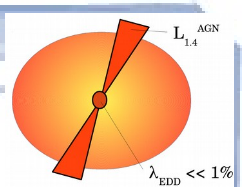
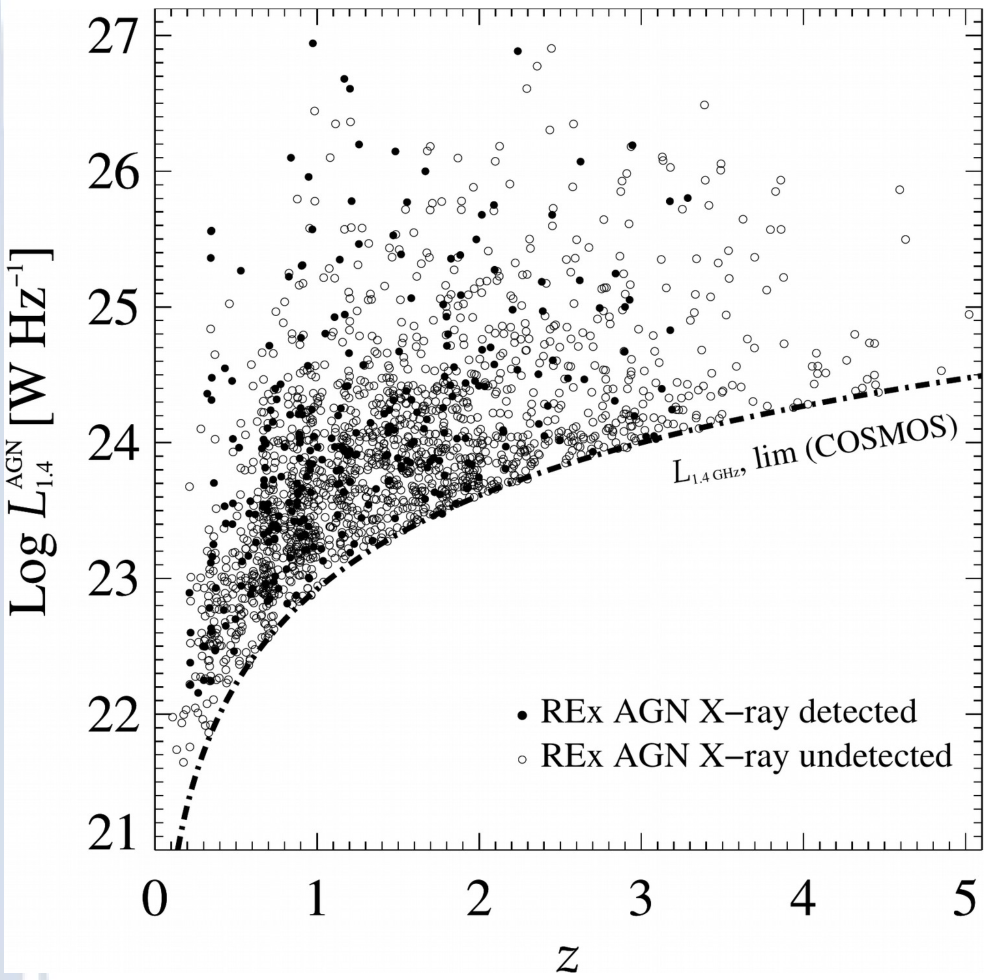
Radio AGN in the COSMOS field





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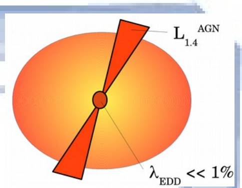
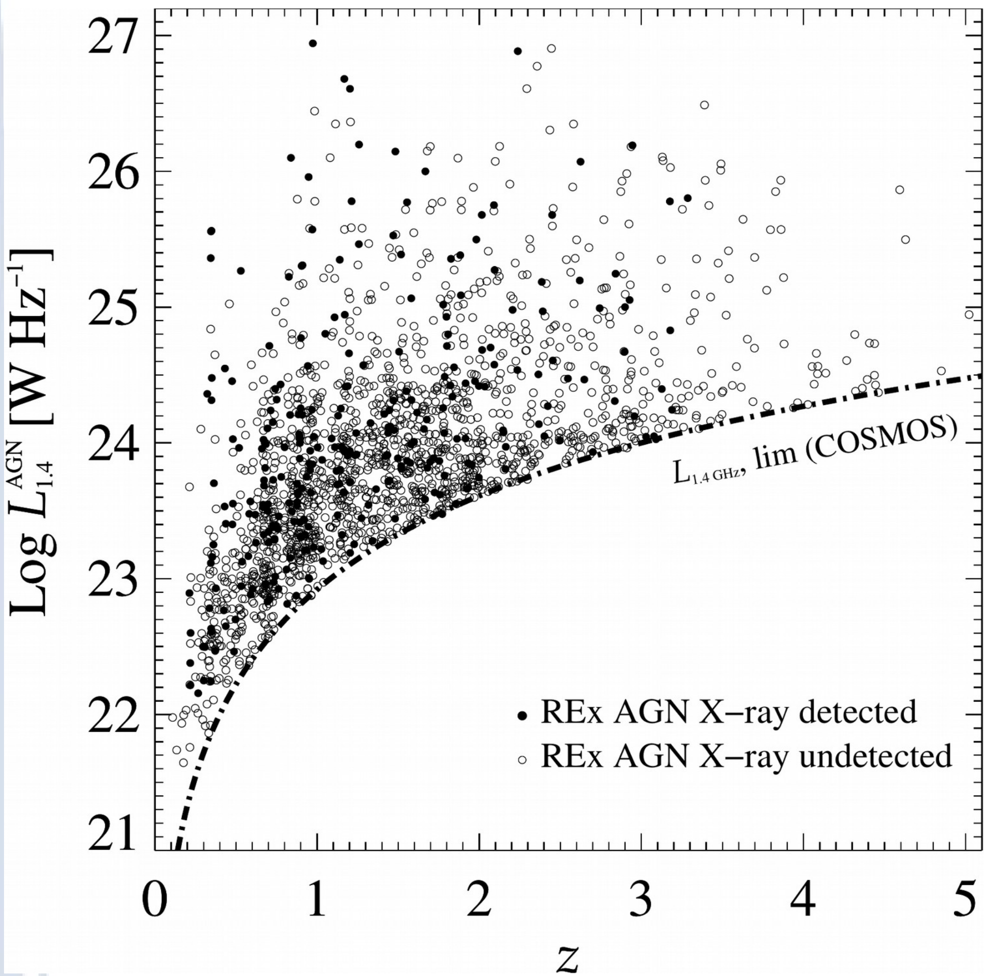
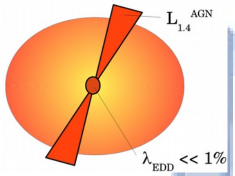


Are Radio AGN radiatively inefficient SMBHs? Does it vary with $L_{1.4}$ and z?





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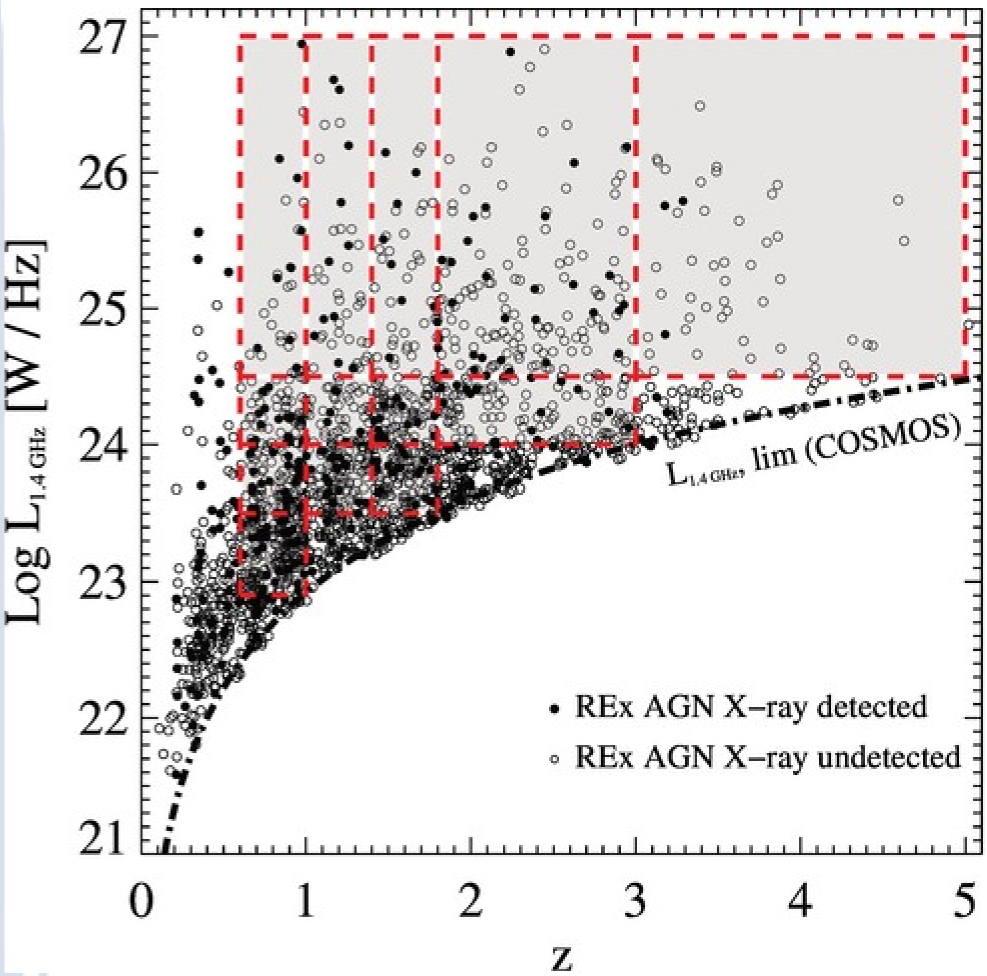
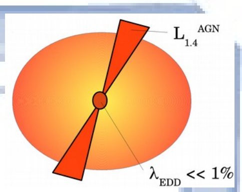


- Selecting a $L_{1.4}$-complete subset of **>1200 radio-excess AGN** out to z~4

Radio AGN in the COSMOS field



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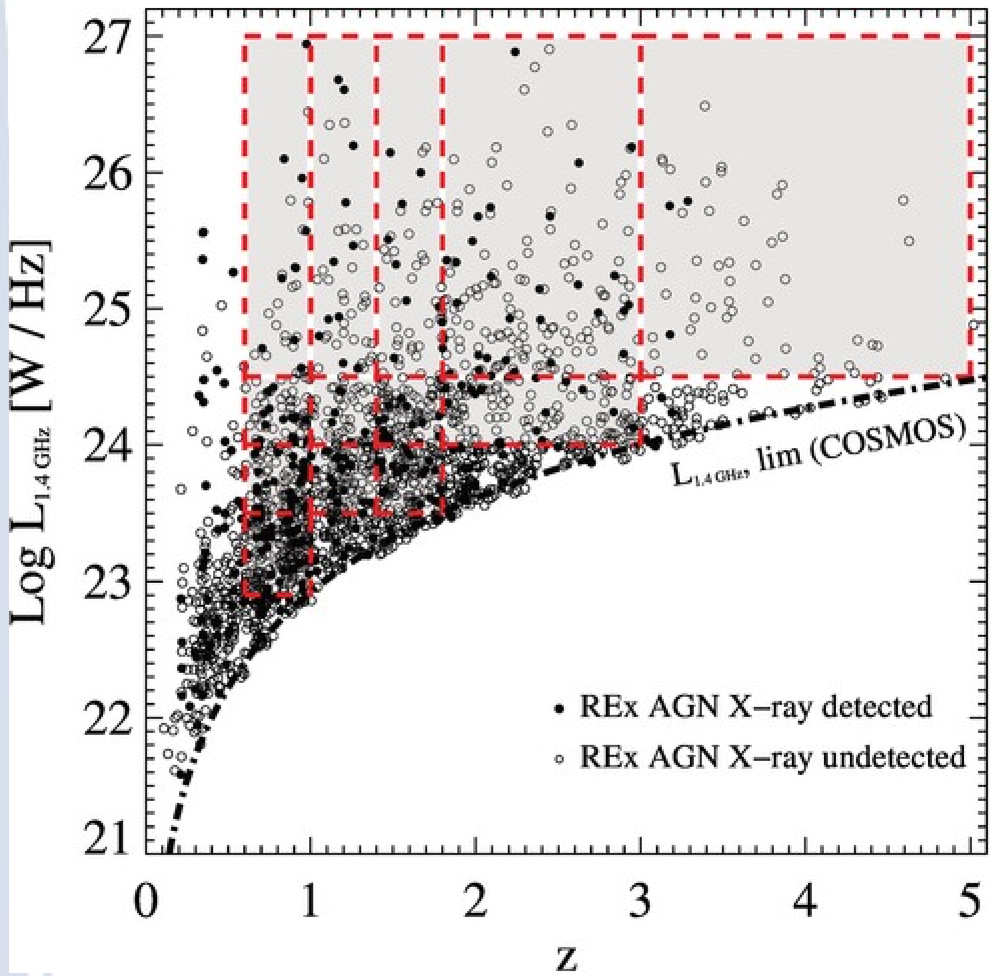
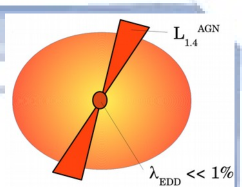


- Selecting a $L_{1.4}$-complete subset of **>1200 radio-excess AGN** out to z~4
- About 12% (906/7729) of them is detected with deep *Chandra* imaging (Civano et al. 2016; Marchesi et al. 2016)



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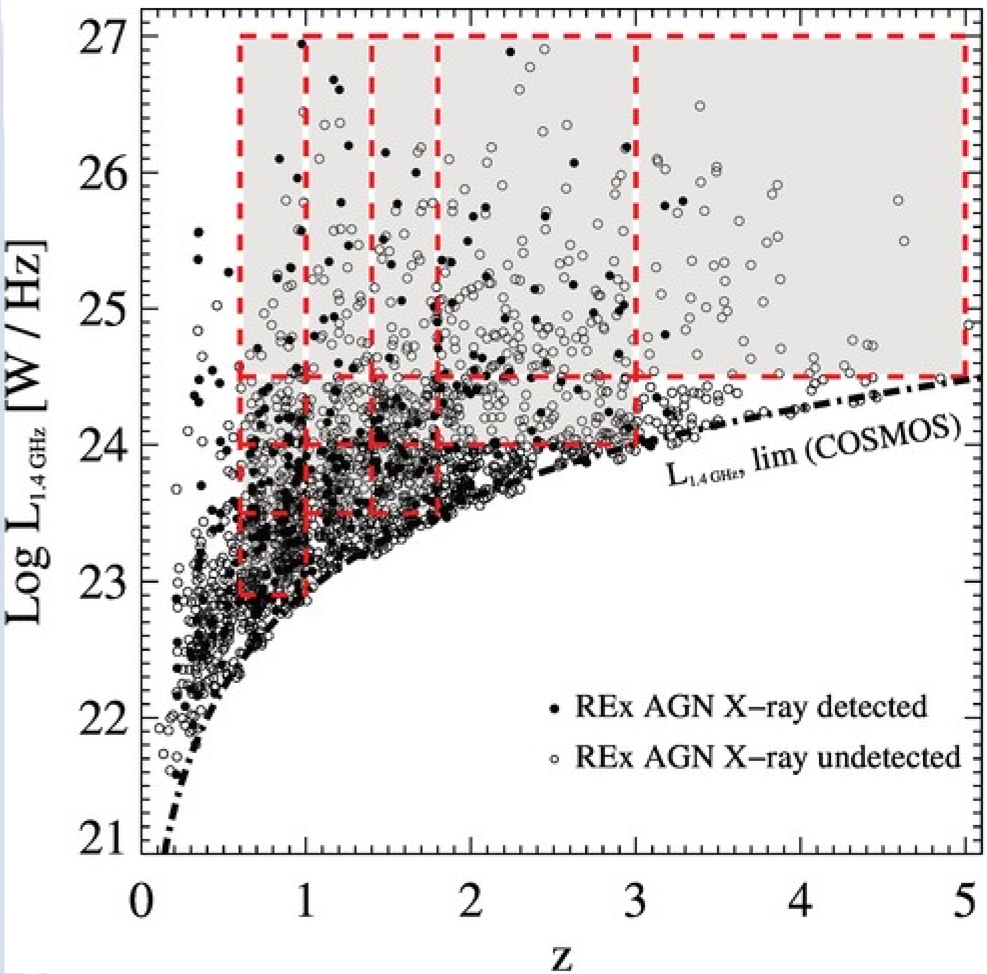

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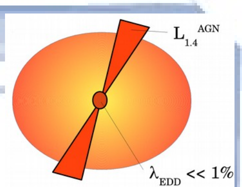
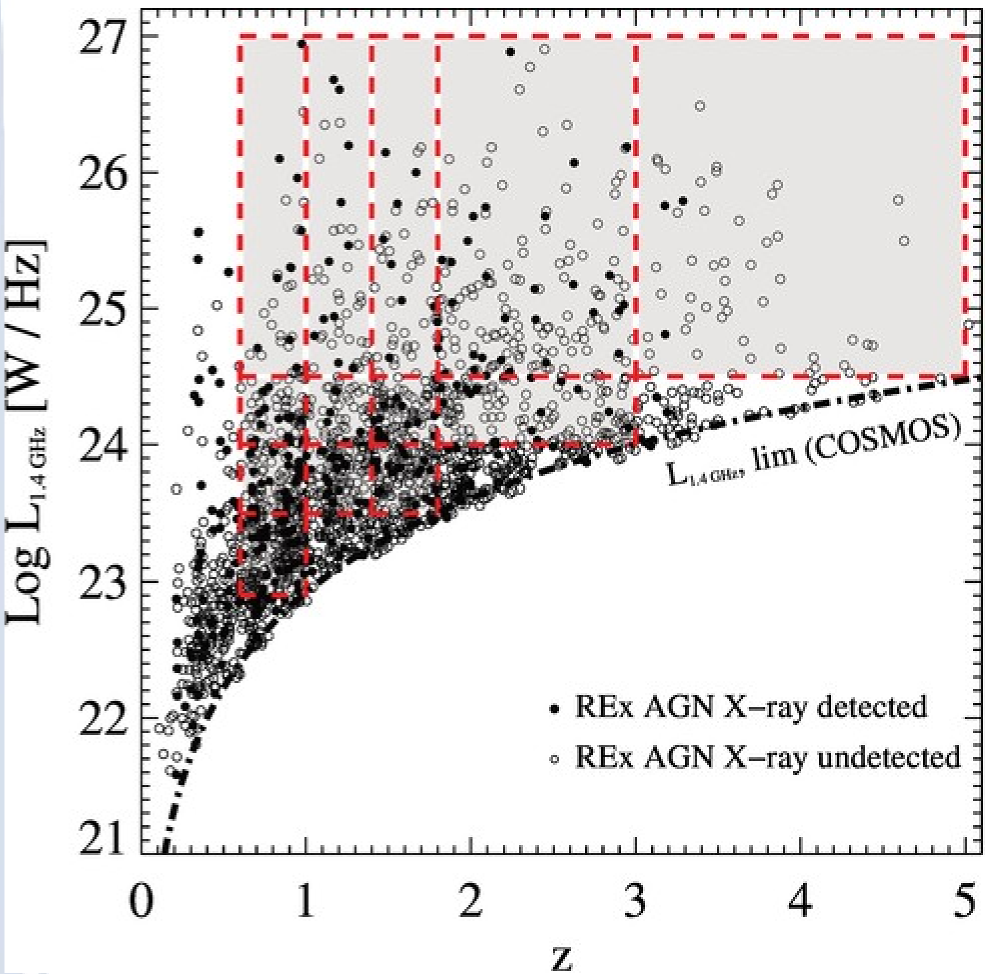
- X-ray stacking of radio AGN (*CSTACK*)*

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



Radio AGN in the COSMOS field

Are Radio AGN radiatively inefficient SMBHs? Does it vary with $L_{1.4}$ and z?



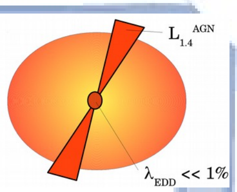
- Selecting a $L_{1.4}$-complete subset of **>1200 radio-excess AGN** out to z~4
- About 12% (906/7729) of them is detected with deep *Chandra* imaging (Civano et al. 2016; Marchesi et al. 2016)
- X-ray stacking of radio AGN (*CSTACK*)*

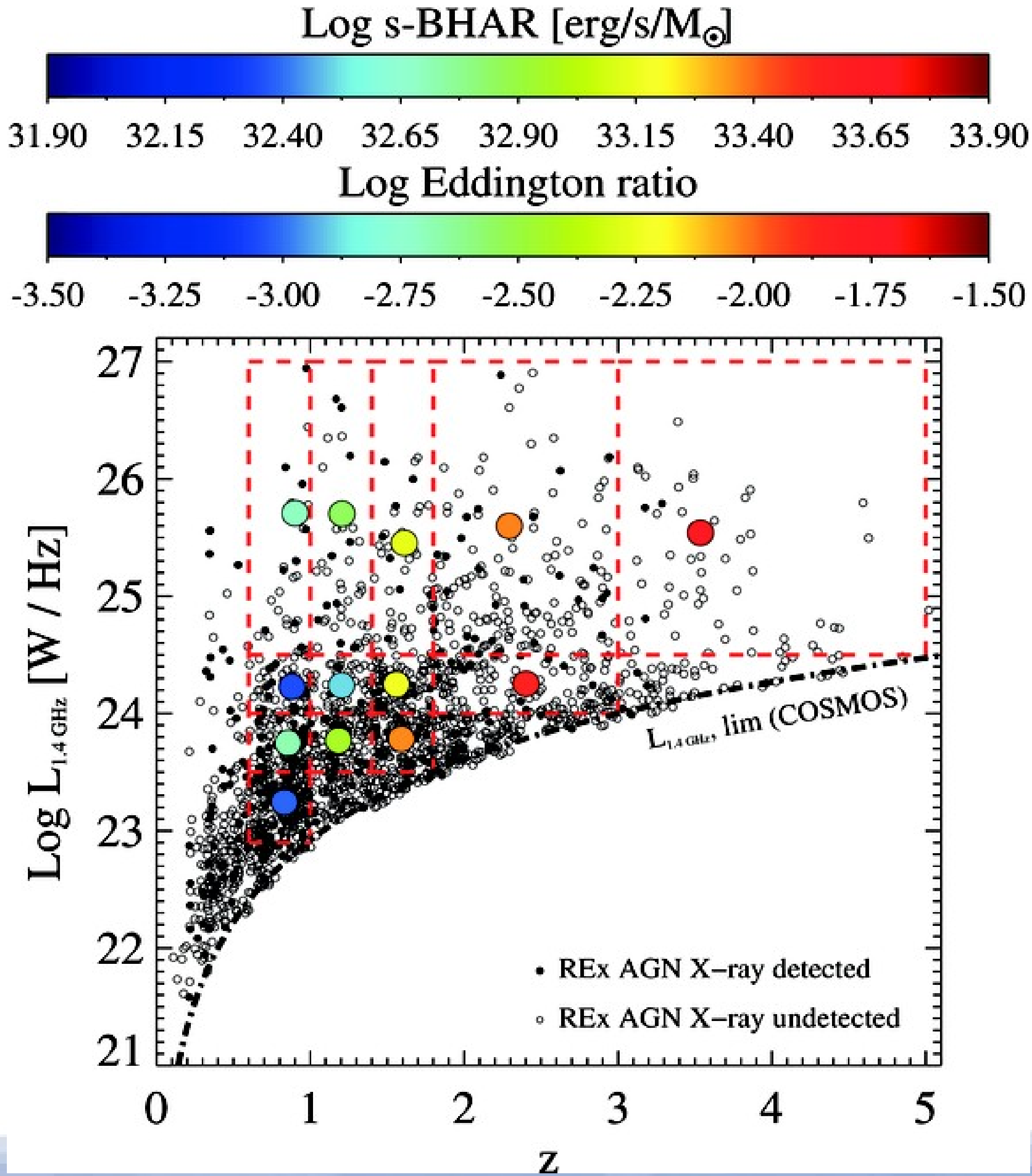
<Lx> ⟶ specific BH accretion rate (**s-BHAR** ~ Lx/M*)

<s-BHAR> ⟷ **<Edd. Ratio>** (if fixed M*/MBH)

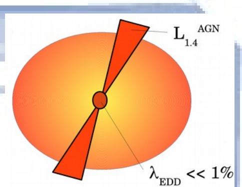
* http://lambic.astrosen.unam.mx/cstack/

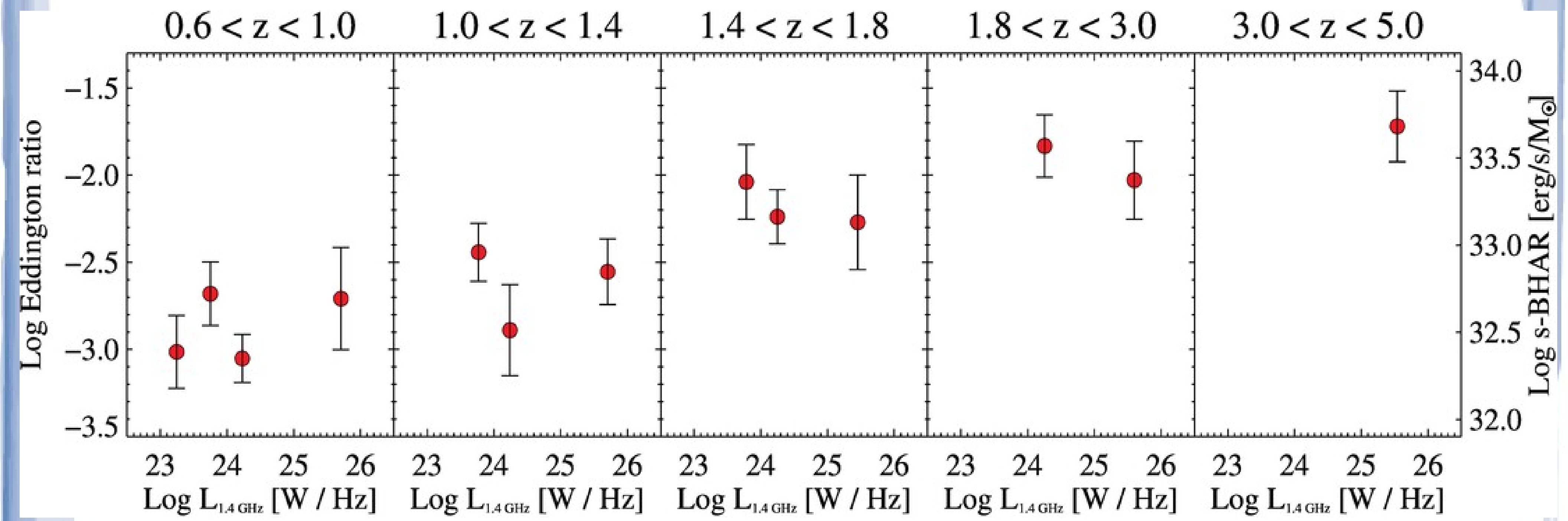
Average s-BHAR as a f($L_{1.4}$, z)



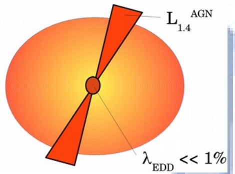


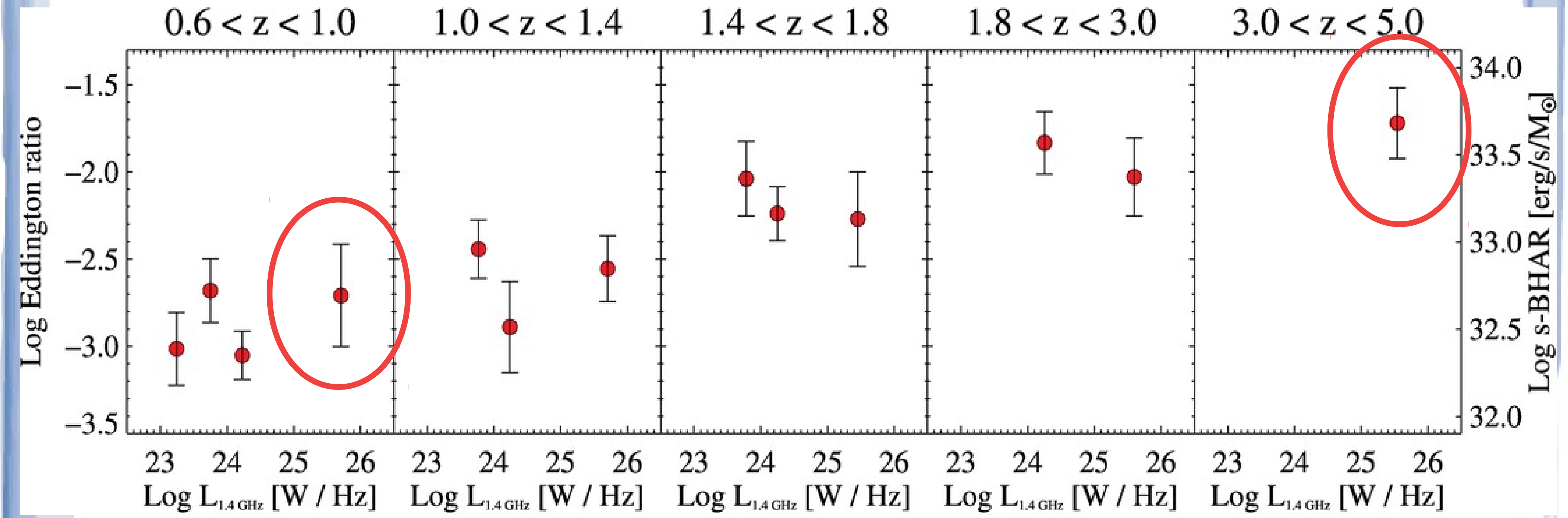
Average s-BHAR as a f($L_{1.4}$, z)



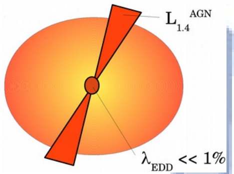


Average s-BHAR as a f($L_{1.4}$, z)

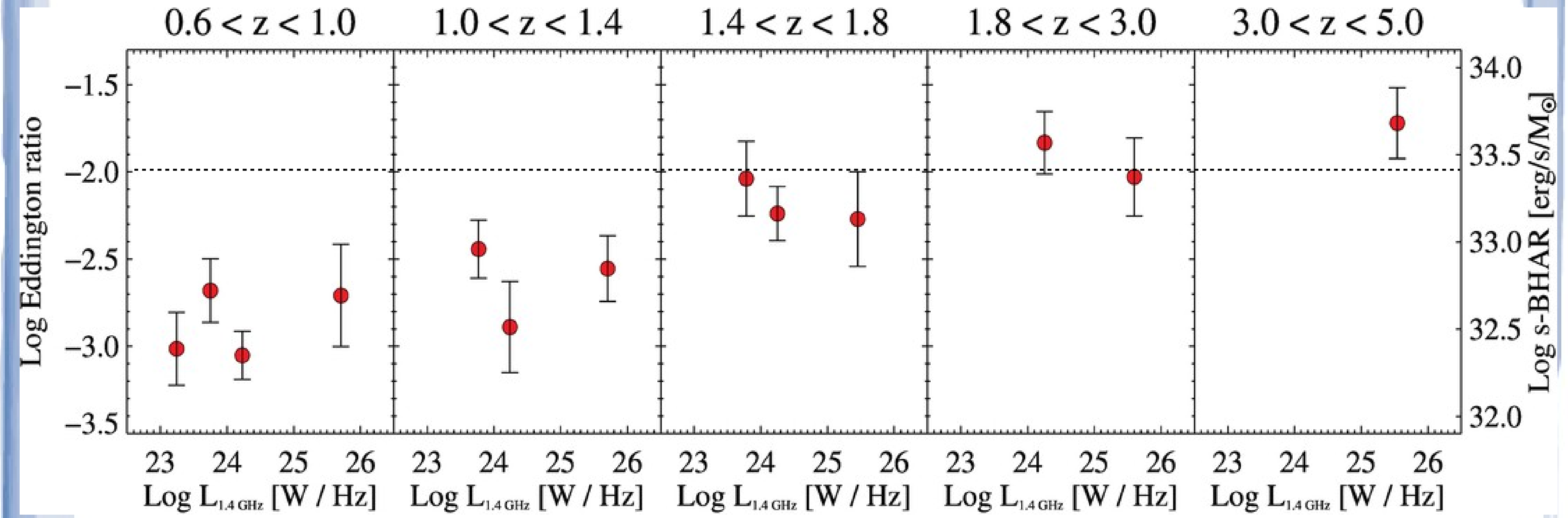




- The average s-BHAR increases by a factor of **10** from z~0.7 to z~3.5

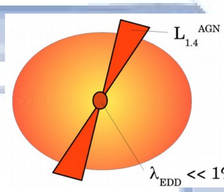


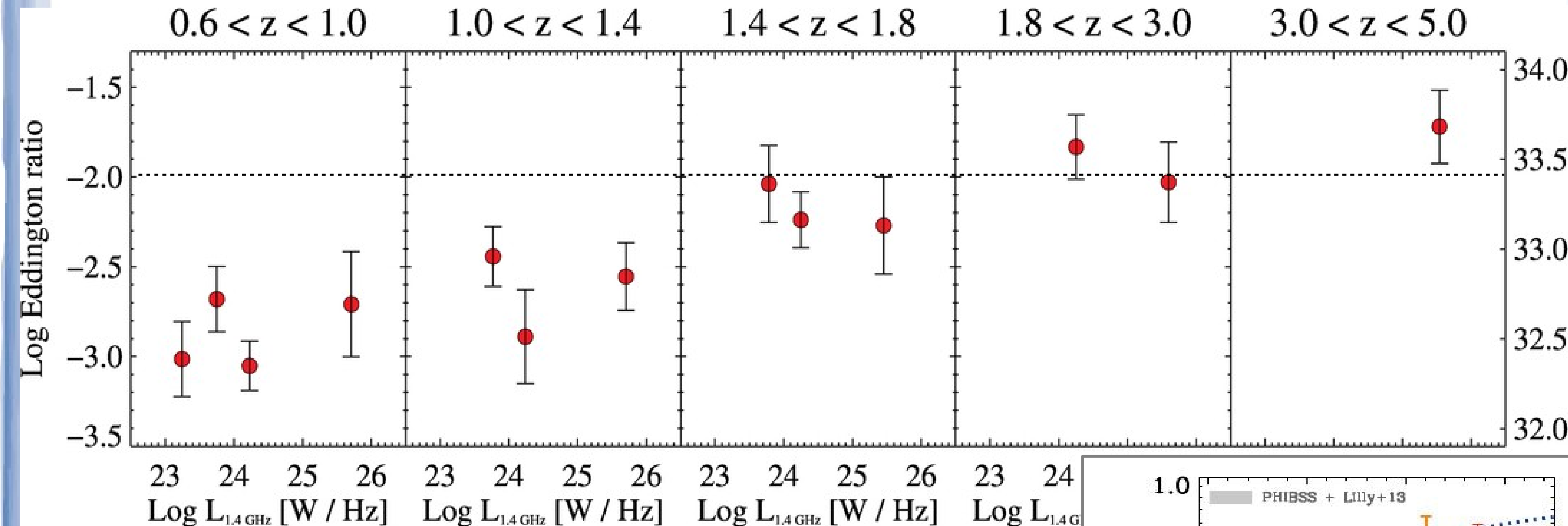
Average s-BHAR as a f($L_{1.4}$, z)



- The average s-BHAR increases by a factor of **10** from z~0.7 to z~3.5
- The Edd ratio exceeds 1% (=**radiatively efficient** BH accretion) at z>1.5 (Aird et al. 2018)

Average s-BHAR as a f($L_{1.4}$, z)

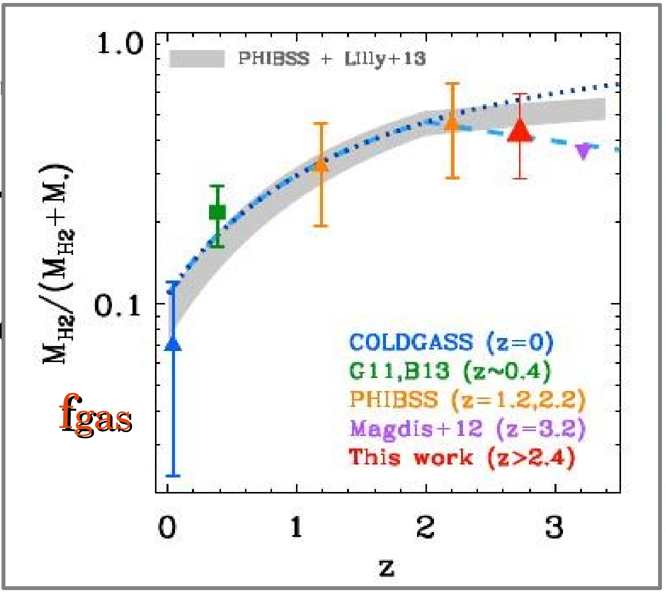




- The average s-BHAR increases by a factor of **10** from z~0.

- The Edd ratio exceeds 1% (=**radiatively efficient** BH ac

SMBH accretion ⟷ **cold gas supply (star forming content)**



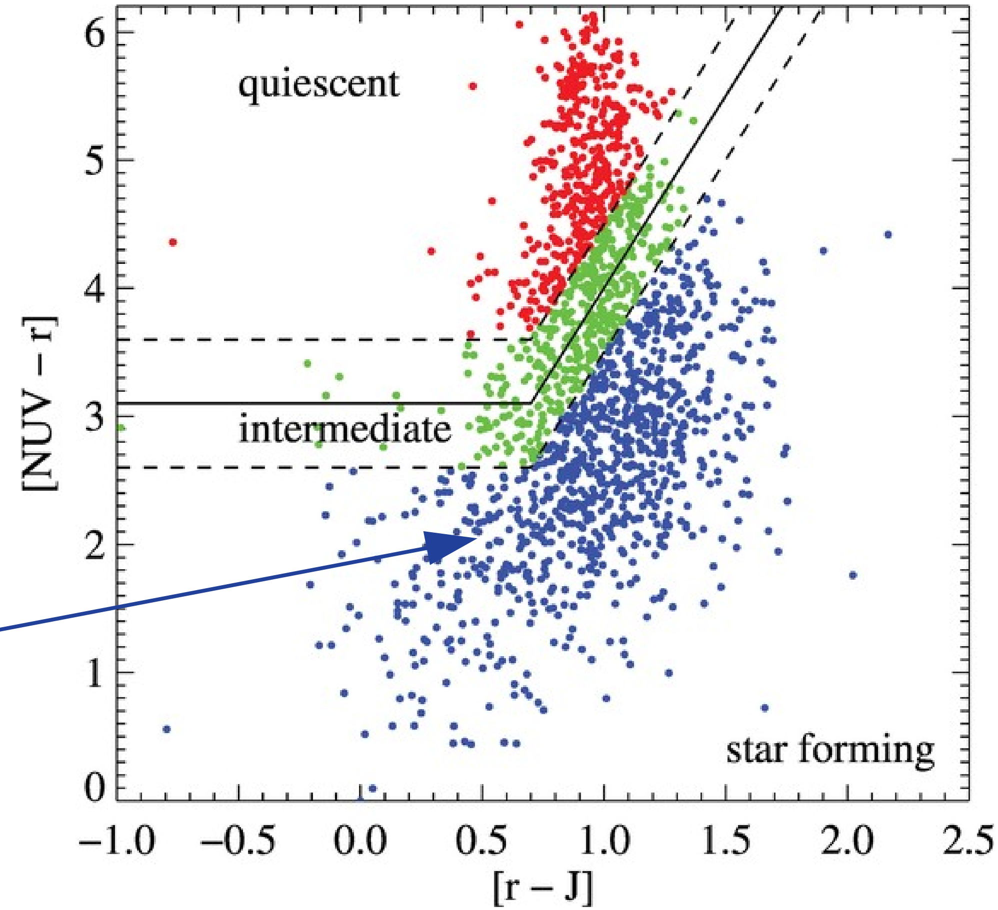
Saintonge et al. (2012)

Star formation in radio AGN hosts

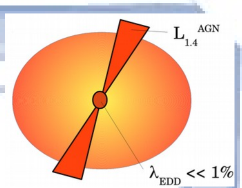
- *(NUV-r)* / *(r-J)* locus to identify **blue** (=star forming) radio AGN hosts (Ilbert et al. 2013; Davidzon et al. 2017)

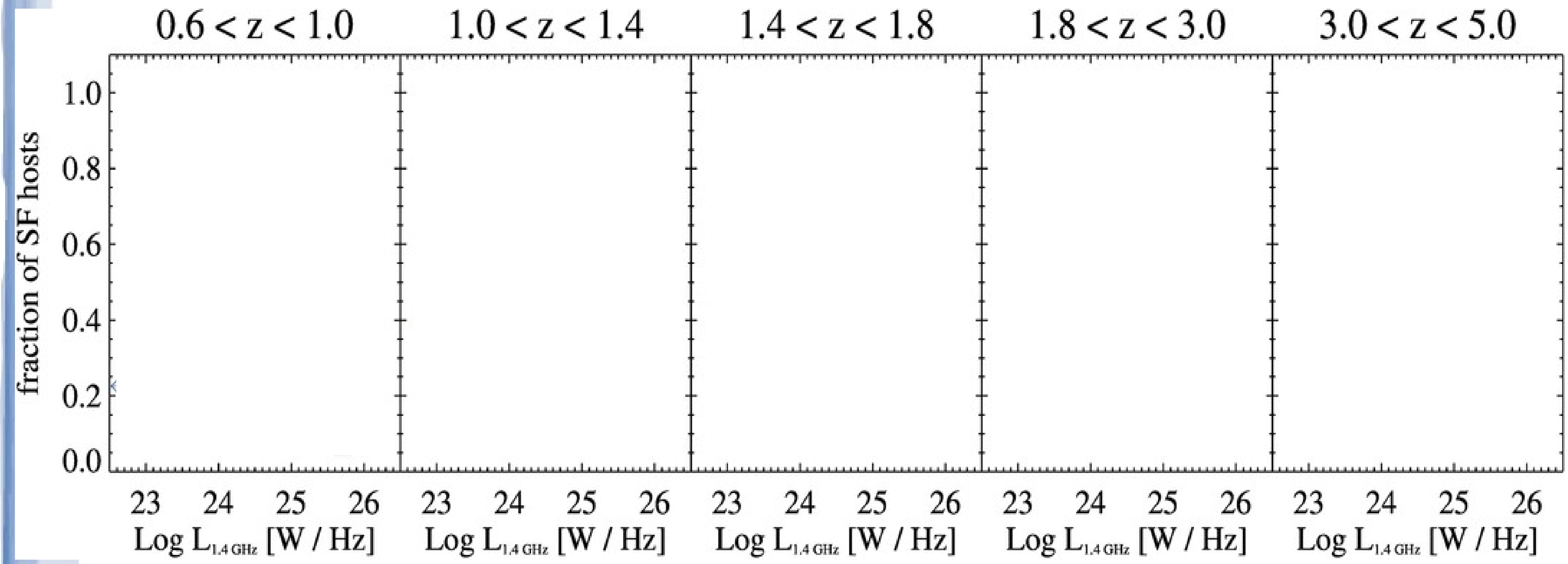
$$f_{SF} = \frac{\text{\# SF Radio AGN hosts}}{\text{\# Radio AGN hosts}}$$

(proxy for star-forming content)

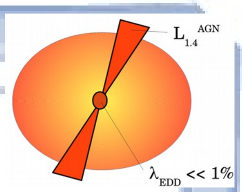


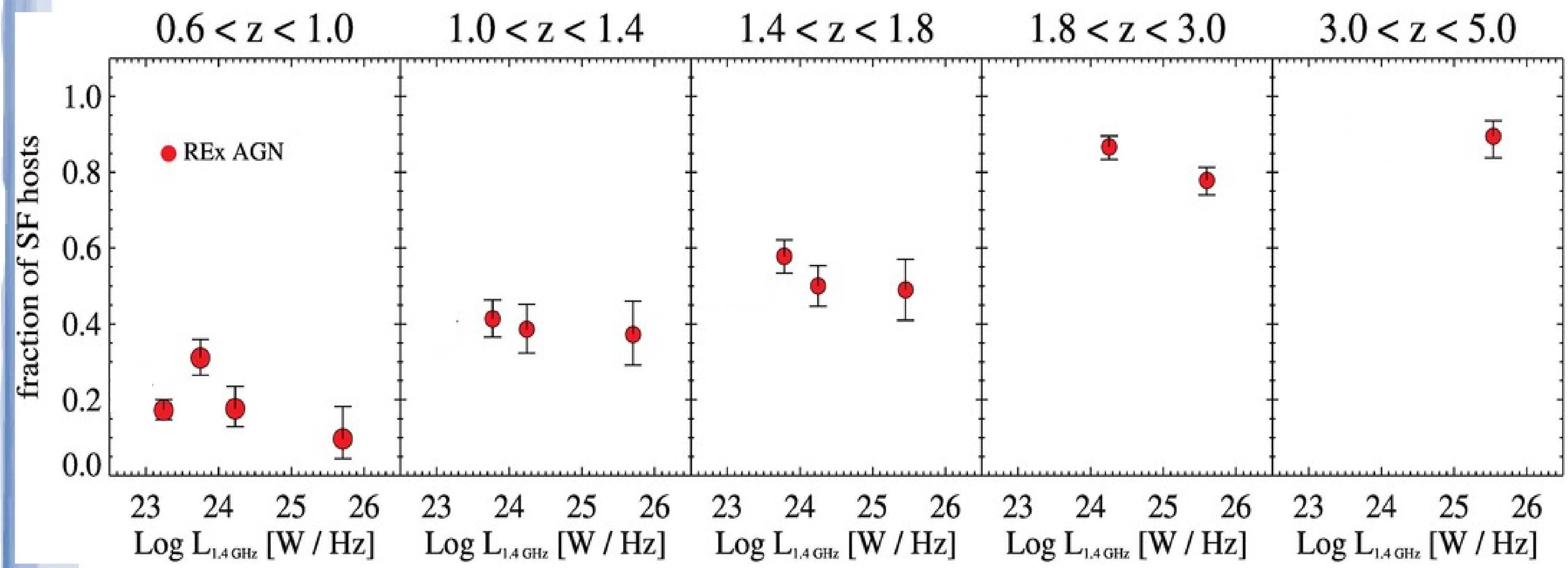
Star formation in radio AGN hosts



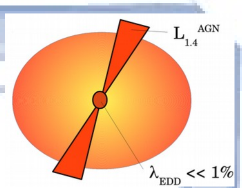


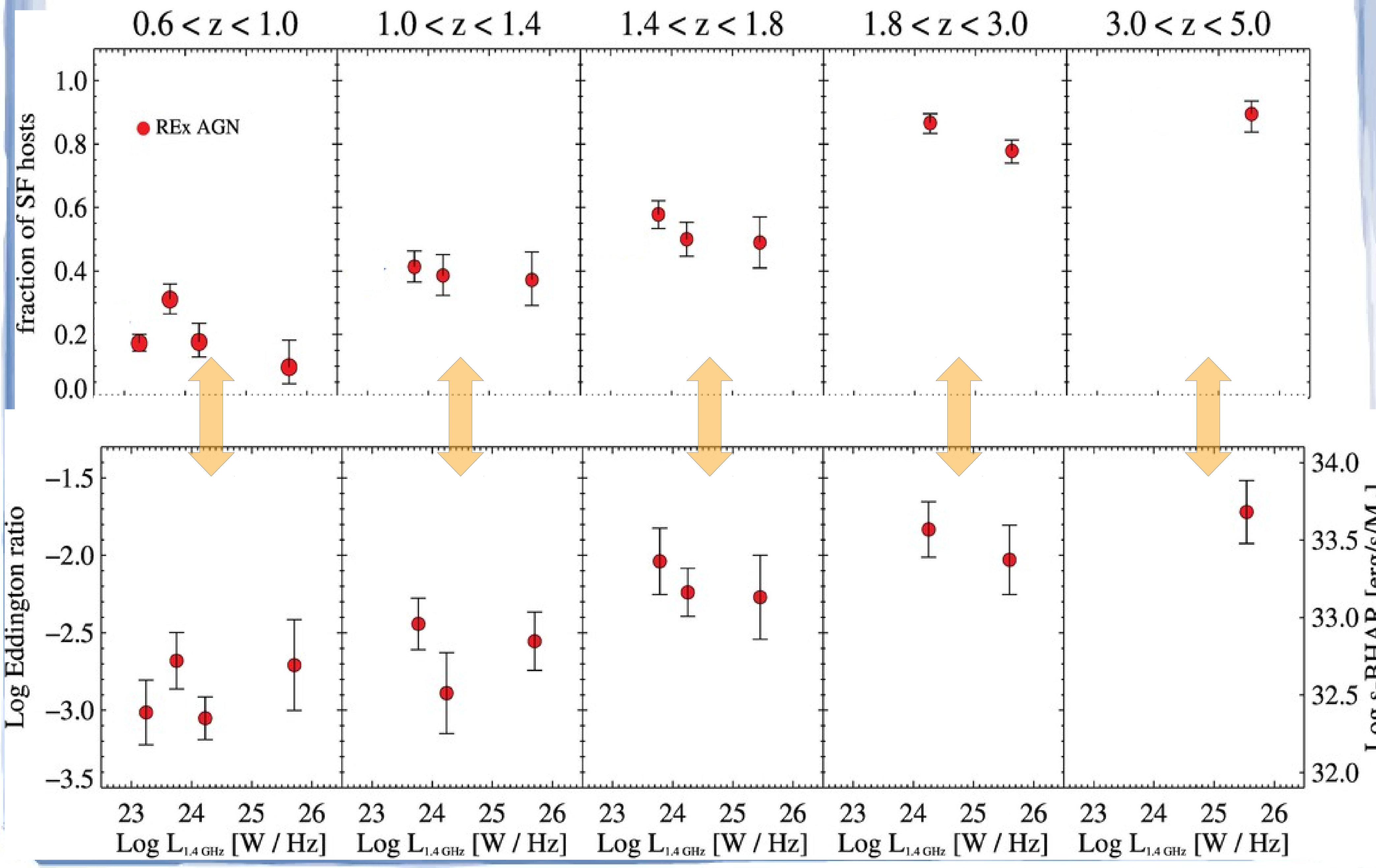
Star formation in radio AGN hosts

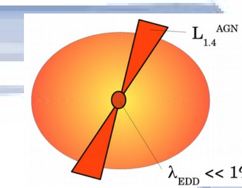




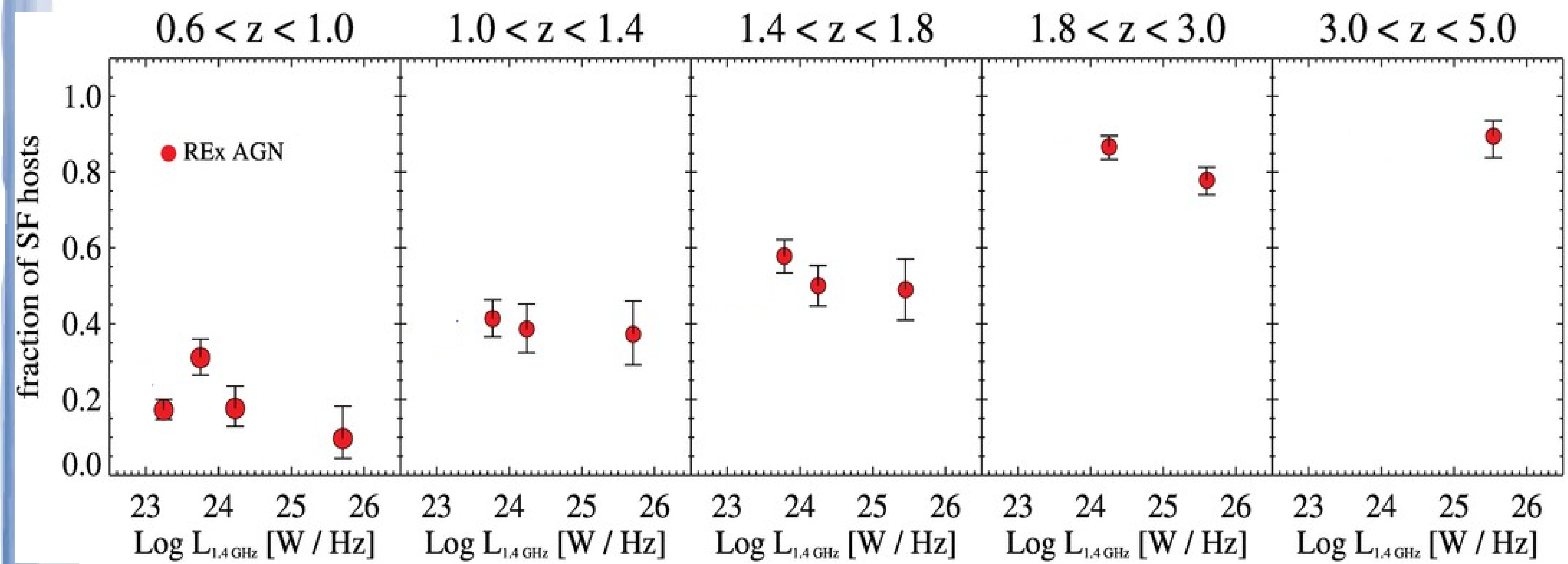
Star formation in radio AGN hosts





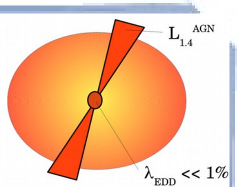


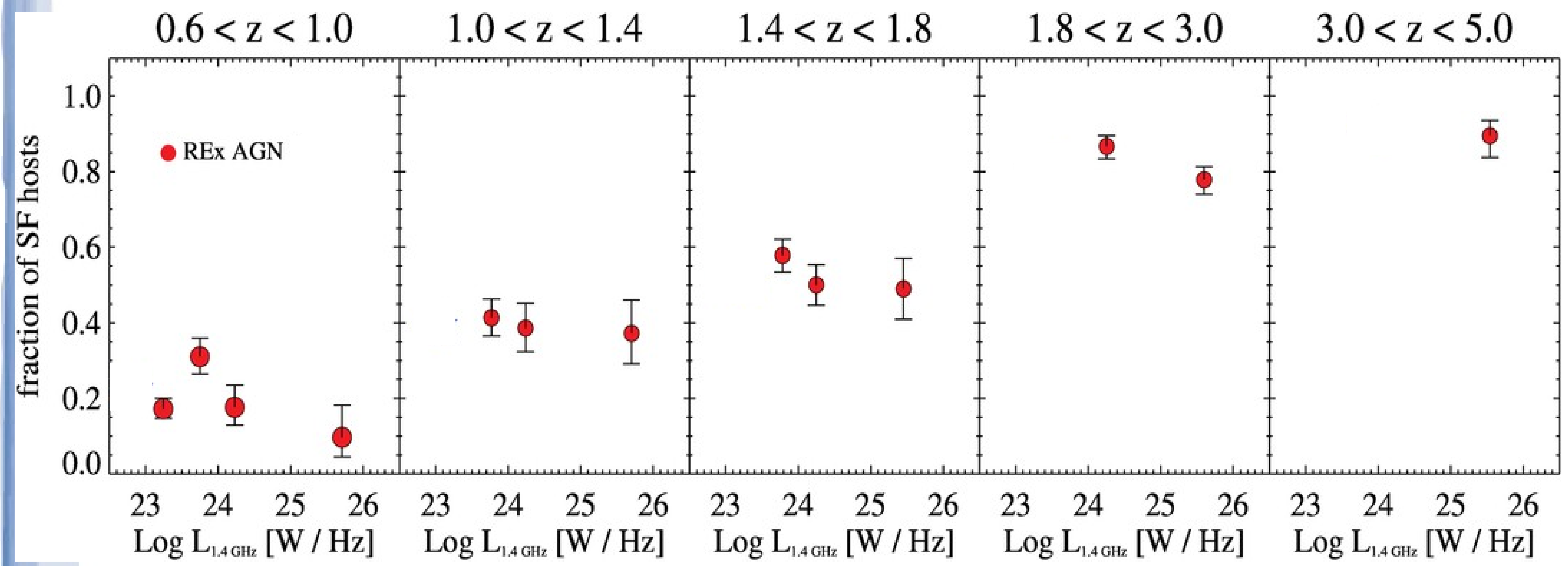
Star formation in radio AGN hosts



- **Radio AGN hosts** were predominantly **star forming** at z>1.5

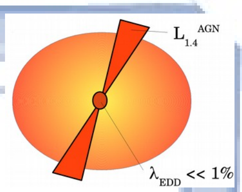
Star formation in radio AGN hosts

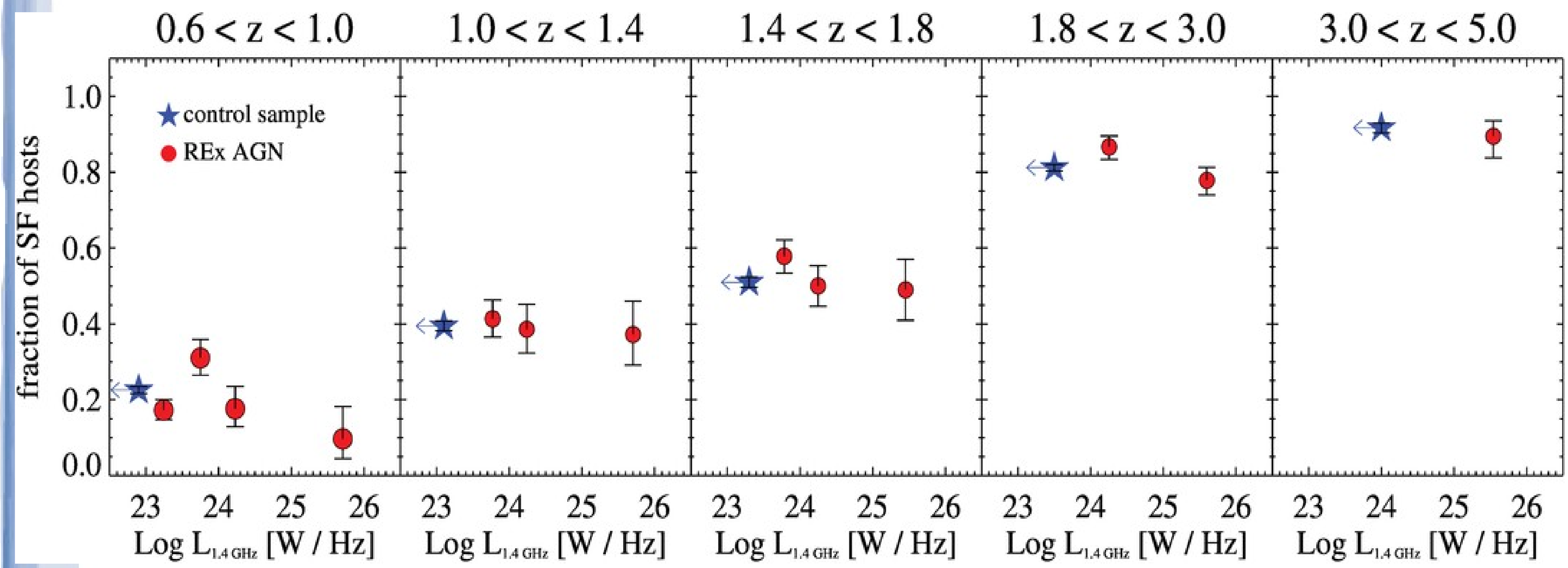




- **Radio AGN hosts** were predominantly **star forming** at z>1.5
- Does it imply that "jet-mode" feedback is less efficient at higher redshift?

Star formation in radio AGN hosts





- **Radio AGN hosts** were predominantly **star forming** at z>1.5
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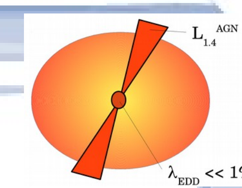
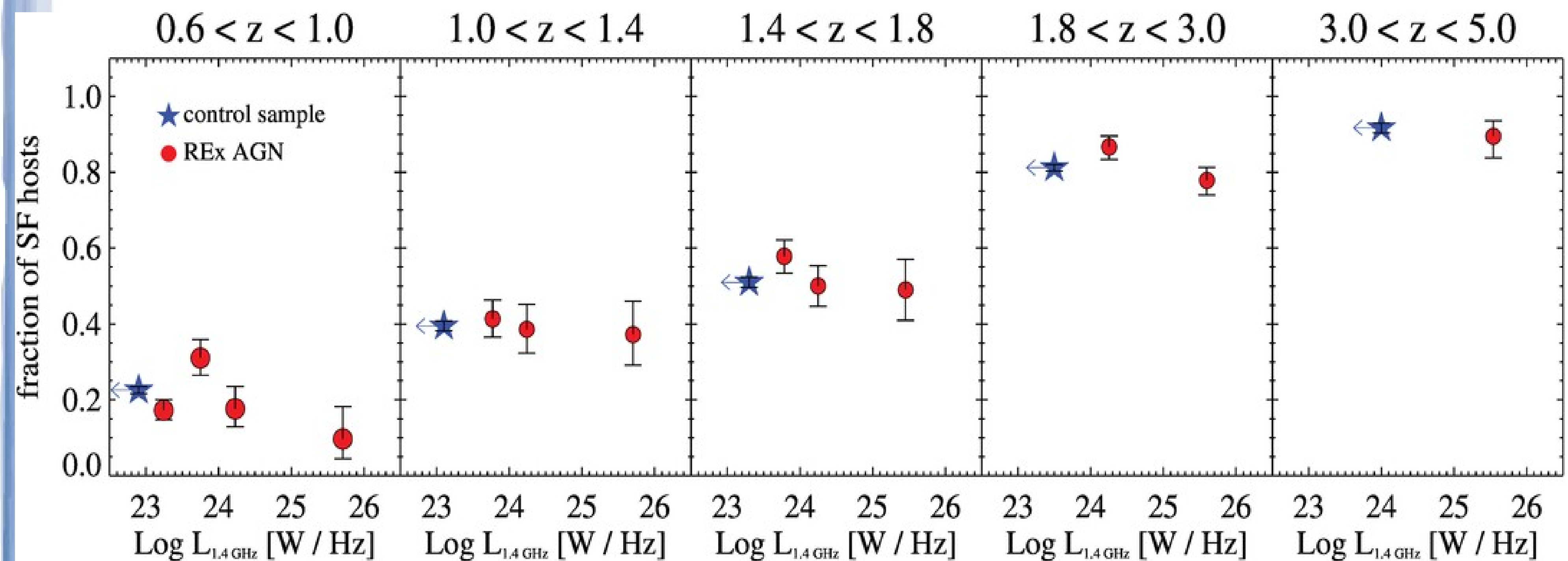
- A **control sample of non-AGN galaxies** (matched in M*-z) shows similar %SF hosts and similar redshift evolution



Star formation in radio AGN hosts



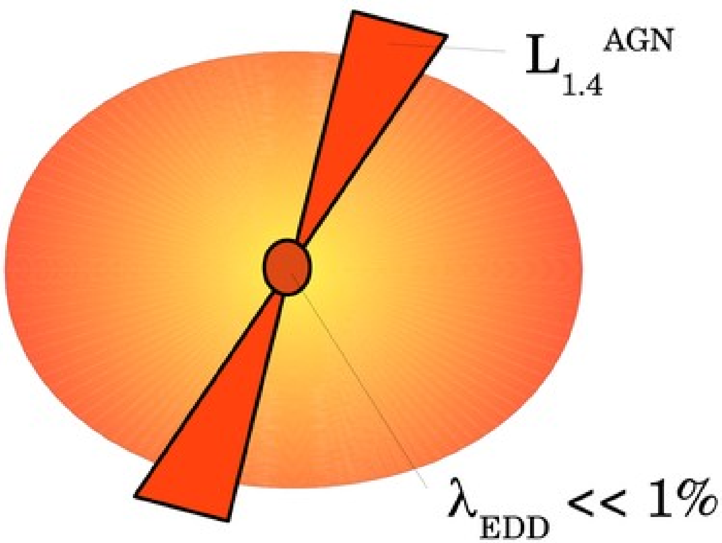
- **Radio AGN hosts** were predominantly **star forming** at z>1.5
- Does it imply that "jet-mode" feedback is less efficient at higher redshift?
- A **control sample of non-AGN galaxies** (matched in M*-z) shows similar %SF hosts and similar redshift evolution

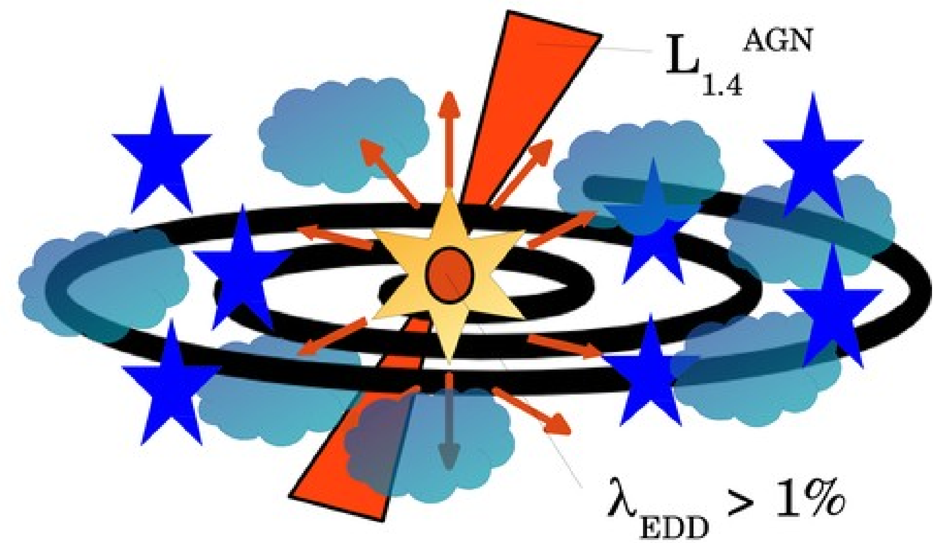
The overall galaxy population becomes more SF with z, while the possible presence of a *radio AGN does not seem to influence its evolution.*

Take-away message

$z << 1$ ← - - - - - - - - - - $z > 1.5$

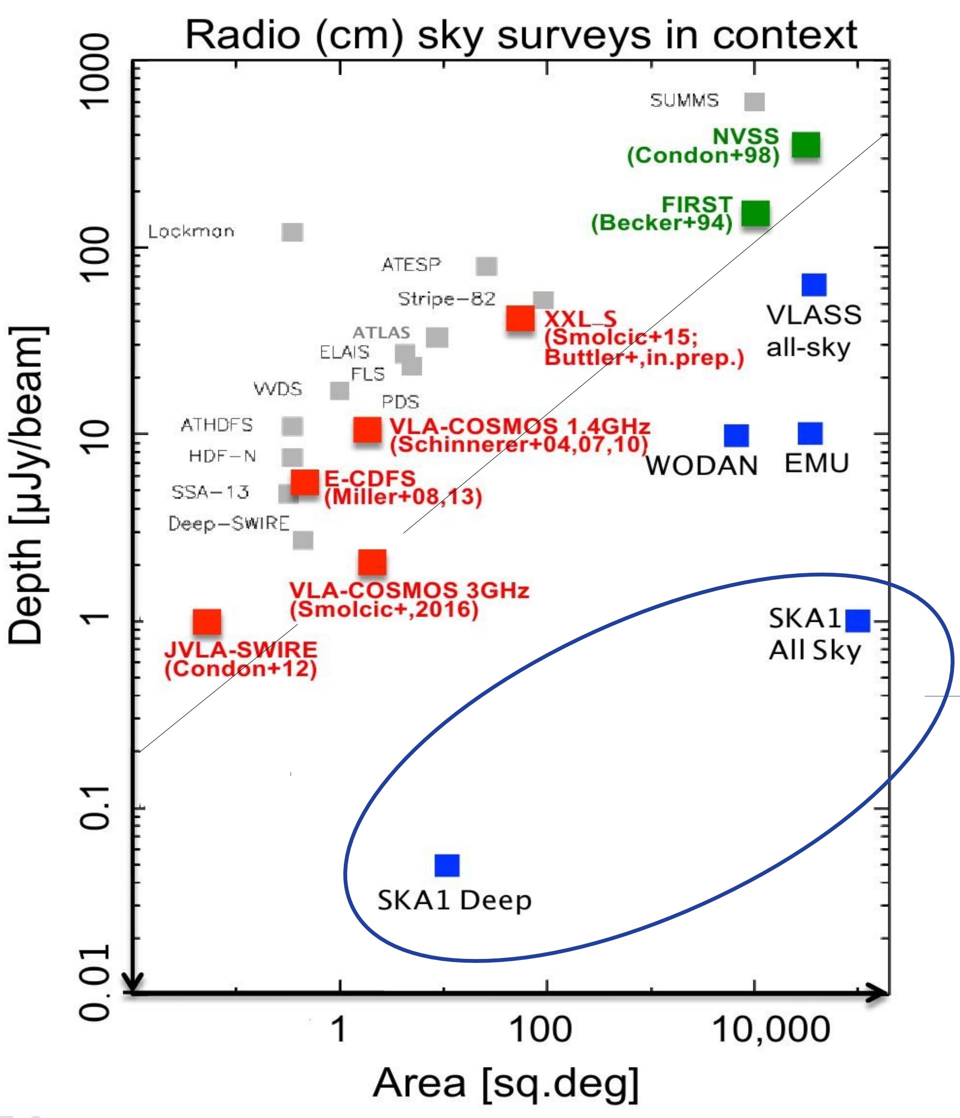
(independently of $L_{1.4}^{AGN}$)

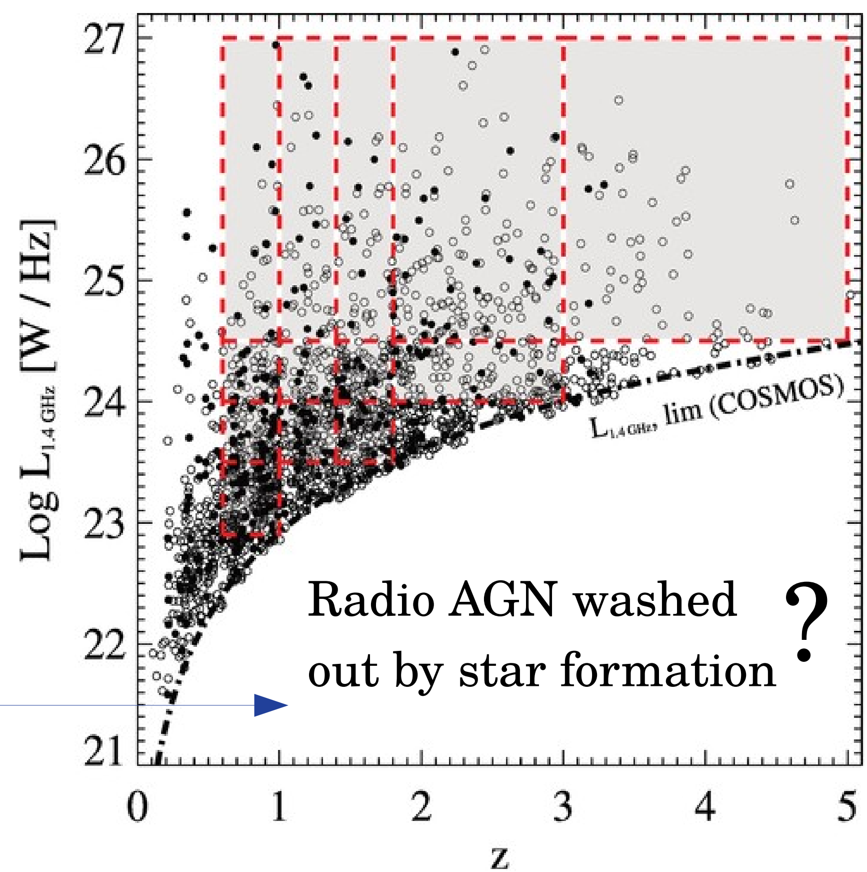




Red and passive galaxy	RADIO (AND NON) AGN HOST	Blue and highly star-forming galaxy
Weakly accreting SMBH ($\lambda_{EDD} << 1\%$)	RADIO AGN	Highly accreting SMBH ($\lambda_{EDD} > 1\%$)

SKA: towards a full census of radio AGN



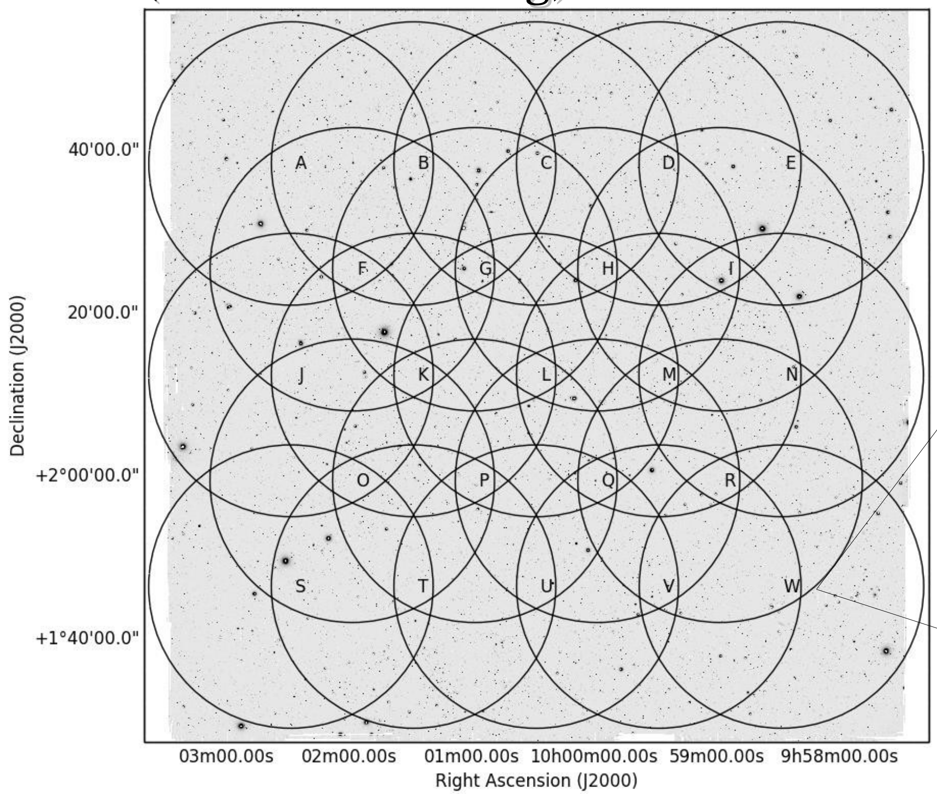


- Overcoming the host-galaxy dilution
- Pin down the AGN jet position at mas resolution (few pc)

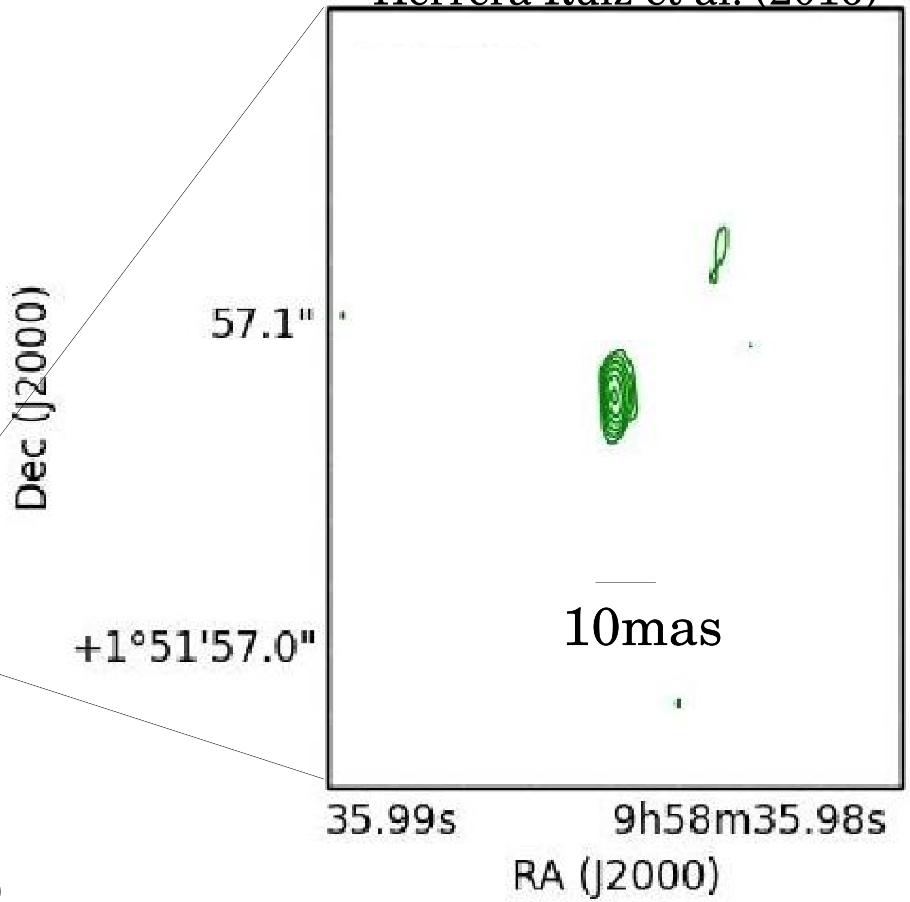
Supplementary slides

Overcoming host-galaxy dilution: VLBI interferometry

(PI: E. Middleberg)

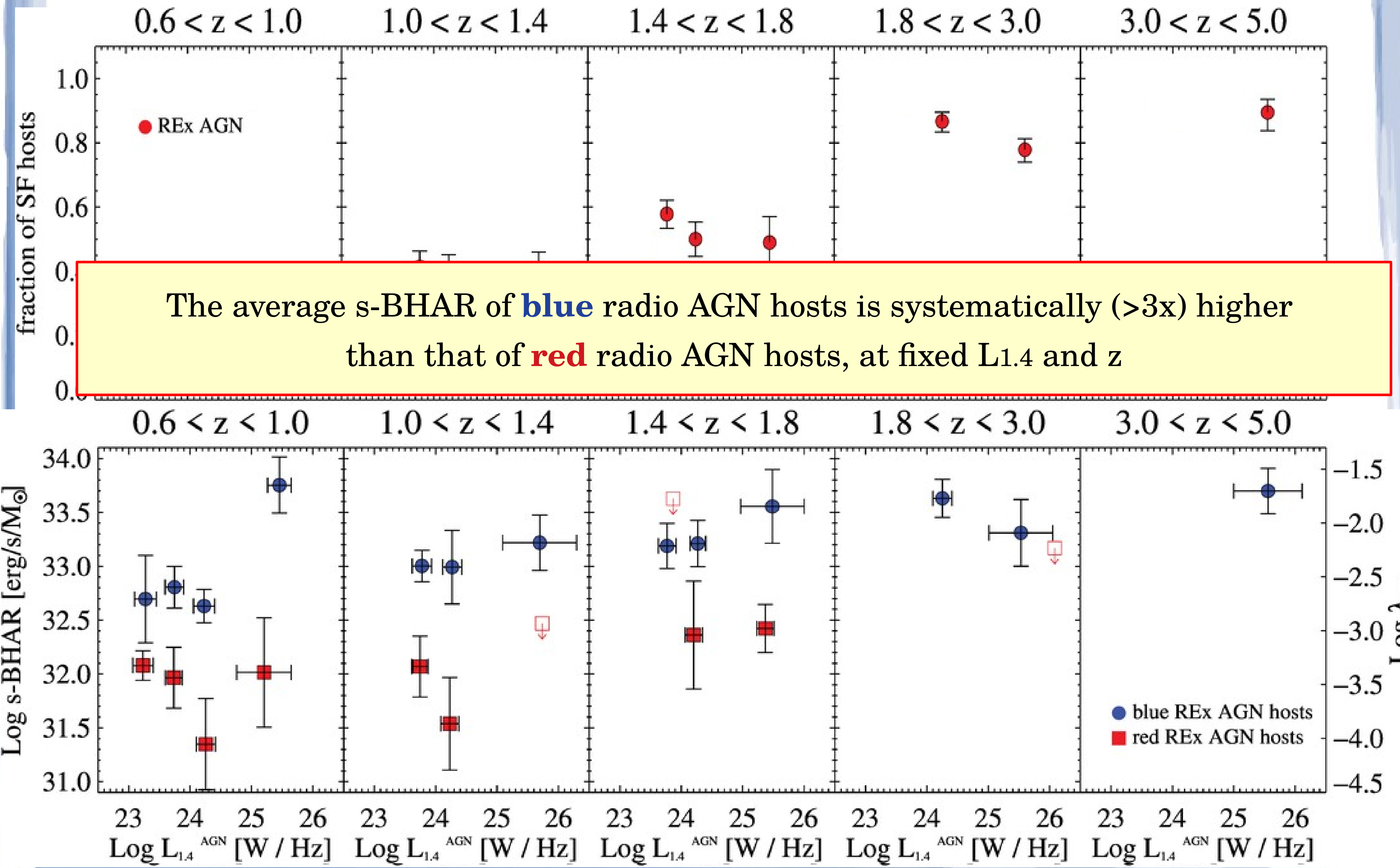


Herrera Ruiz et al. (2016)



(Courtesy of E. Middleberg and N. Herrera Ruiz)

How do *radio AGN* hosts evolve?

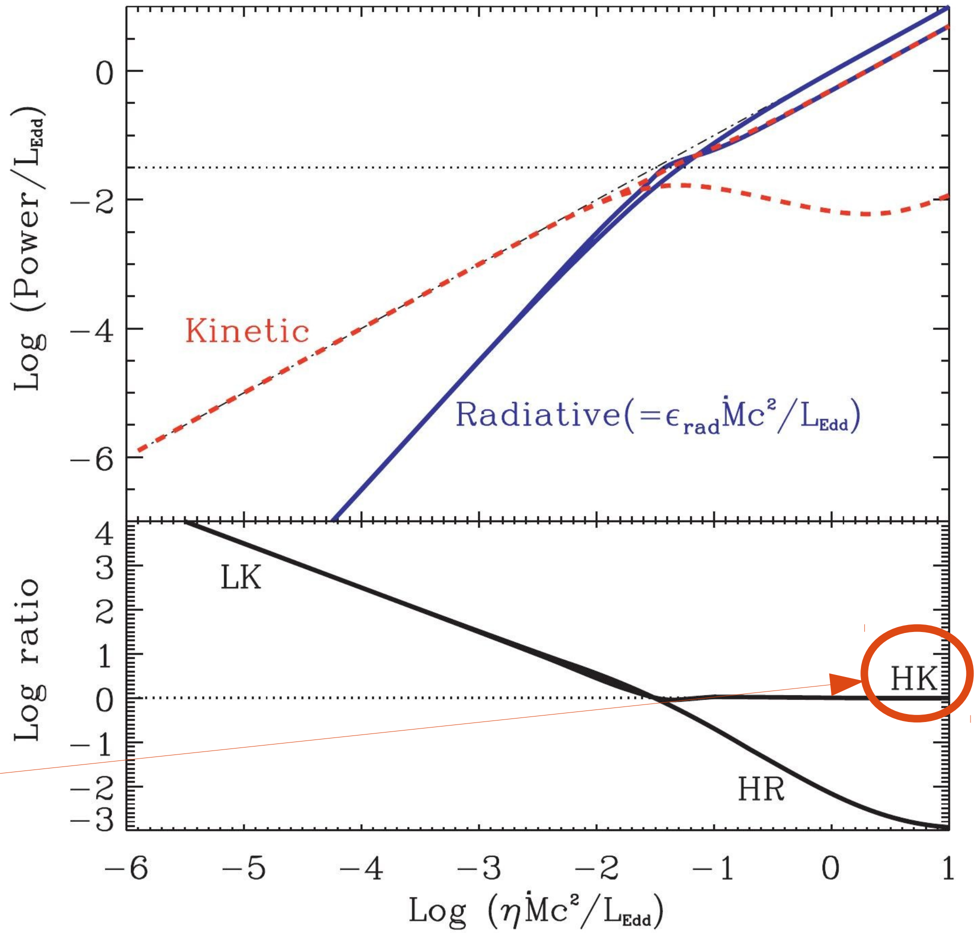


The average s-BHAR of **blue** radio AGN hosts is systematically (>3x) higher than that of **red** radio AGN hosts, at fixed L1.4 and z

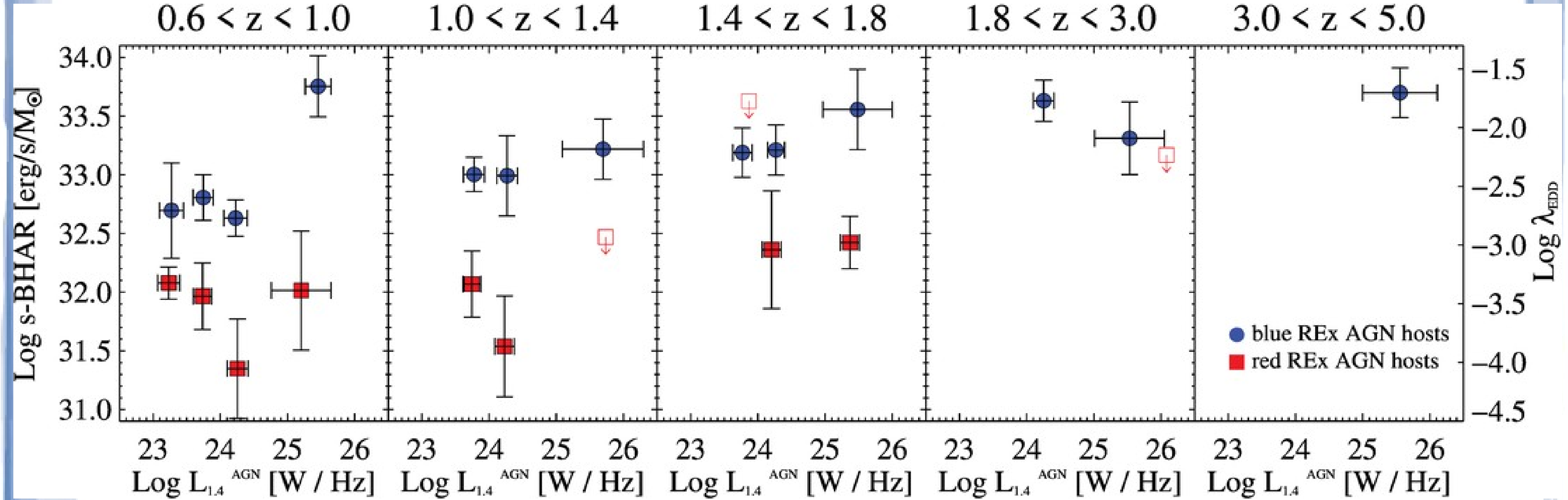
Take-home messages

- All galaxies become typically bluer with redshift, incuding radio AGN hosts
- The qualitatively similar trends between s-BHAR and % SF hosts are plausible if cold gas drives radio AGN activity
- No correlation between X-ray and radio emission processes might explain the non-trend between s-BHAR and L1.4
- Radio jet emission at z>1.5 traces also radiative AGN activity (**High-Kinetic mode**?)

Merloni & Heinz (2008)



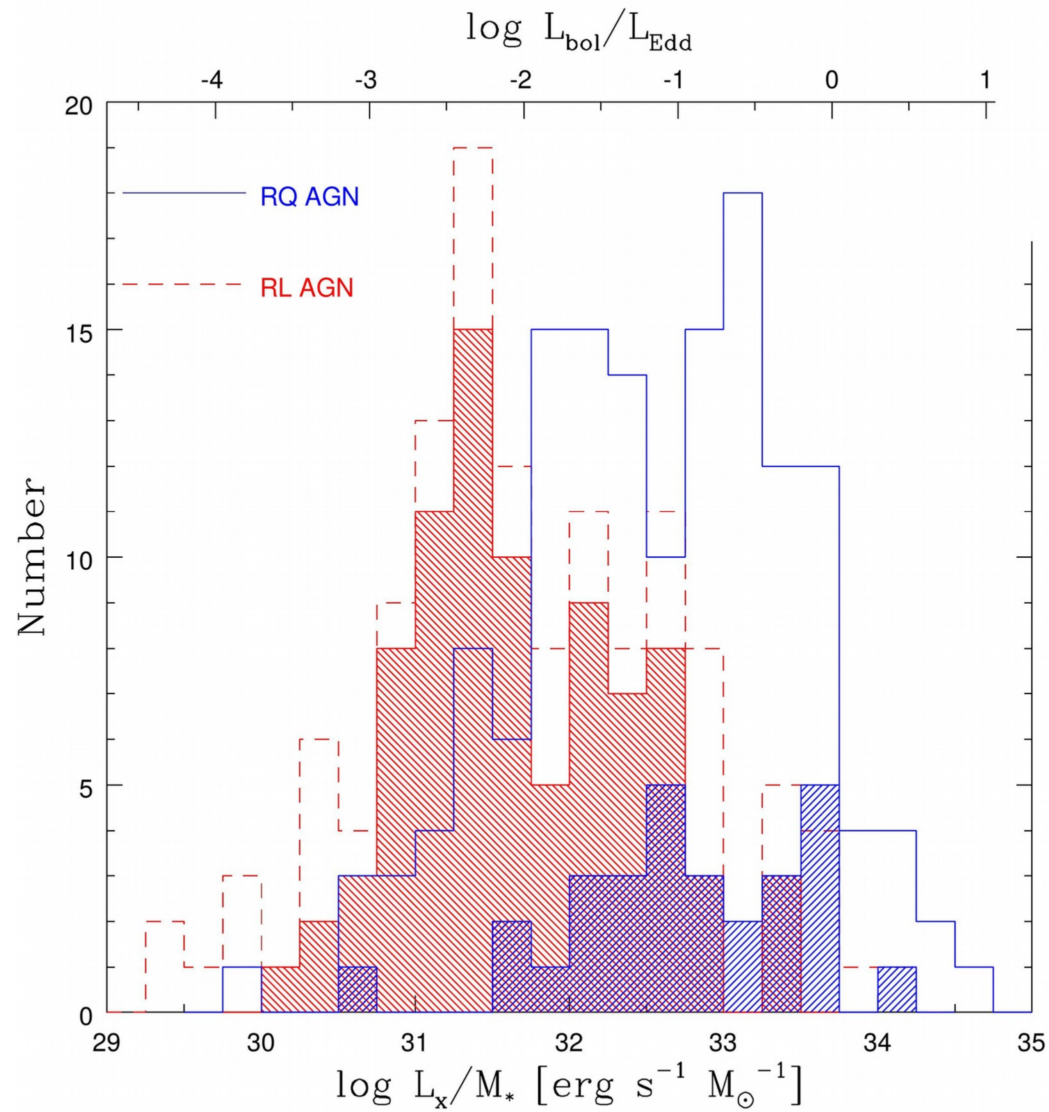
sBHAR of red vs blue radio AGN



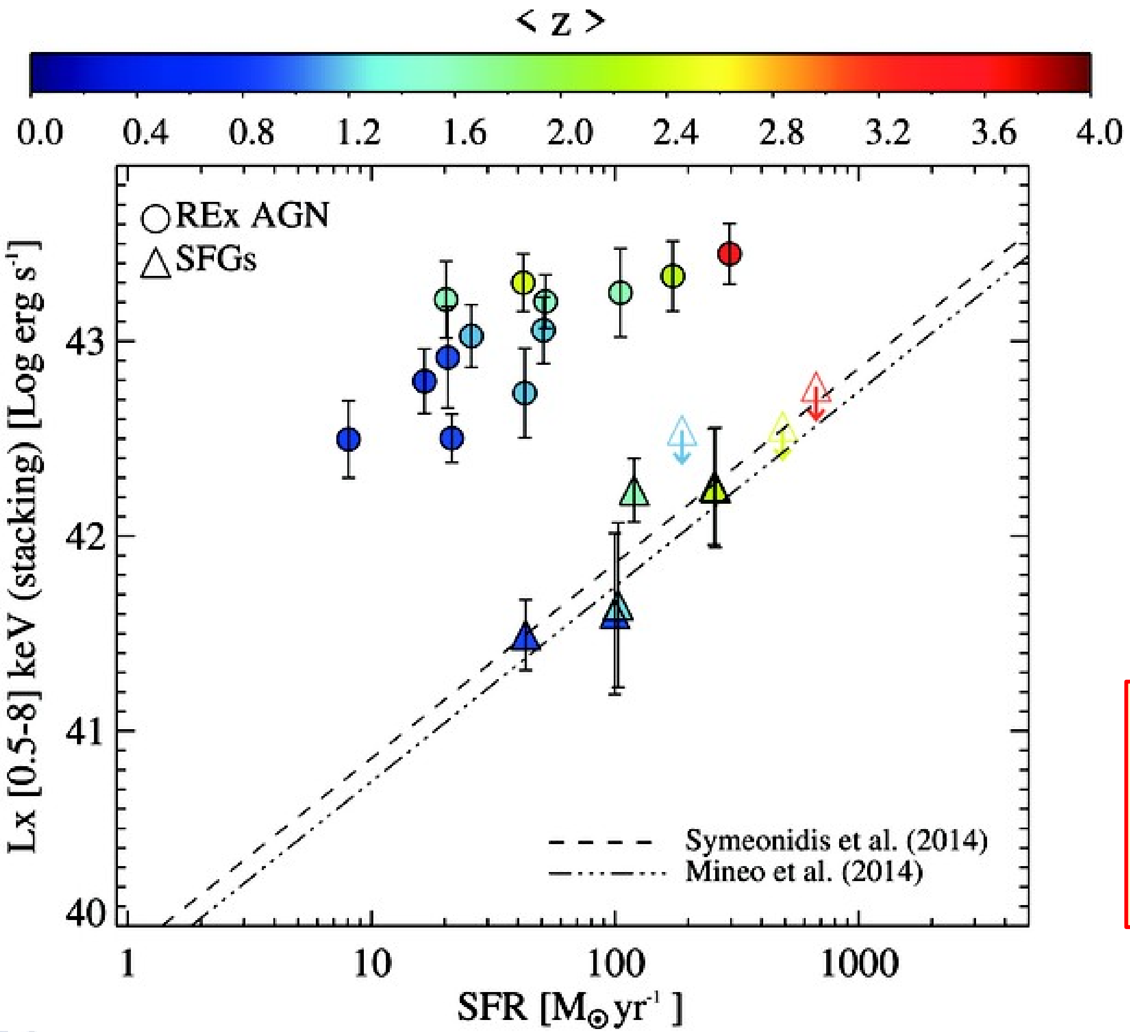
- The average s-BHAR is significantly higher in **blue** radio AGN hosts, at fixed L1.4 and z

Literature: s-BHAR of radio AGN

- Best & Heckman (2012) used multi-wavelength information to distinguish radio loud AGN between HERGs & LERGs
- Padovani et al. (2015) used deep VLA 1.4 GHz data in the E-CDFS to identify radio AGN down to the "radio quiet" regime
- SMBHs accretion rates are mostly limits (shaded areas) due to the large fraction of non-detections.



Average Lx of radio-excess AGN



- X-ray stacking of radio-excess AGN within each L1.4-z bin (*CSTACK*, T.Miyaji)
- Comparison with X-ray emission expected from star formation (Symeonidis et al. 2014; Mineo et al. 2014)

The stacked <Lx> is mostly arising from AGN activity