The amazing radio nature of active galaxies at 3 GHz VLA-COSMOS

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Astronomy on Tap Jena; Rogue Astrophysics

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BOLOGNA

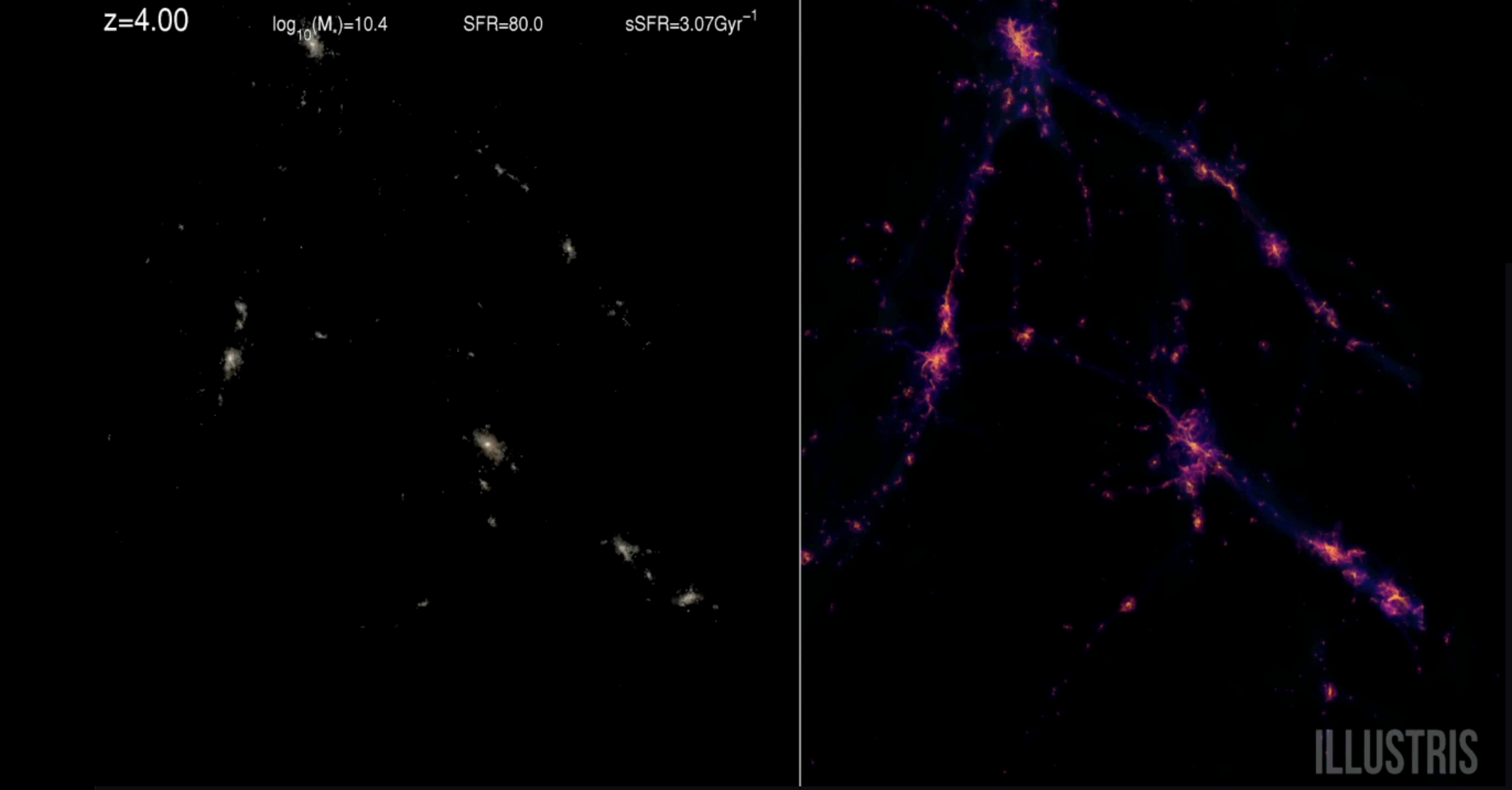
JUNE 2021

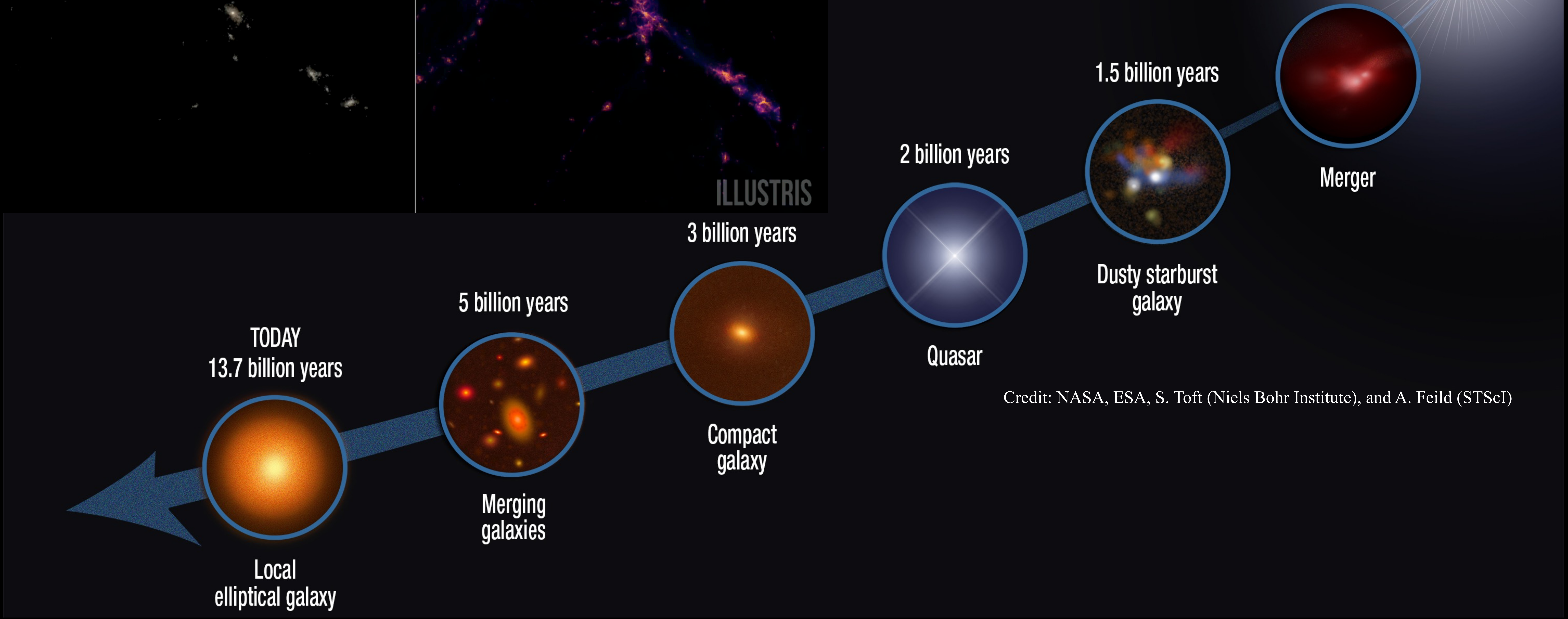
galaxy growth and evolution

Wechsler & Tinker 2018

credit: TNG50

galaxy merging

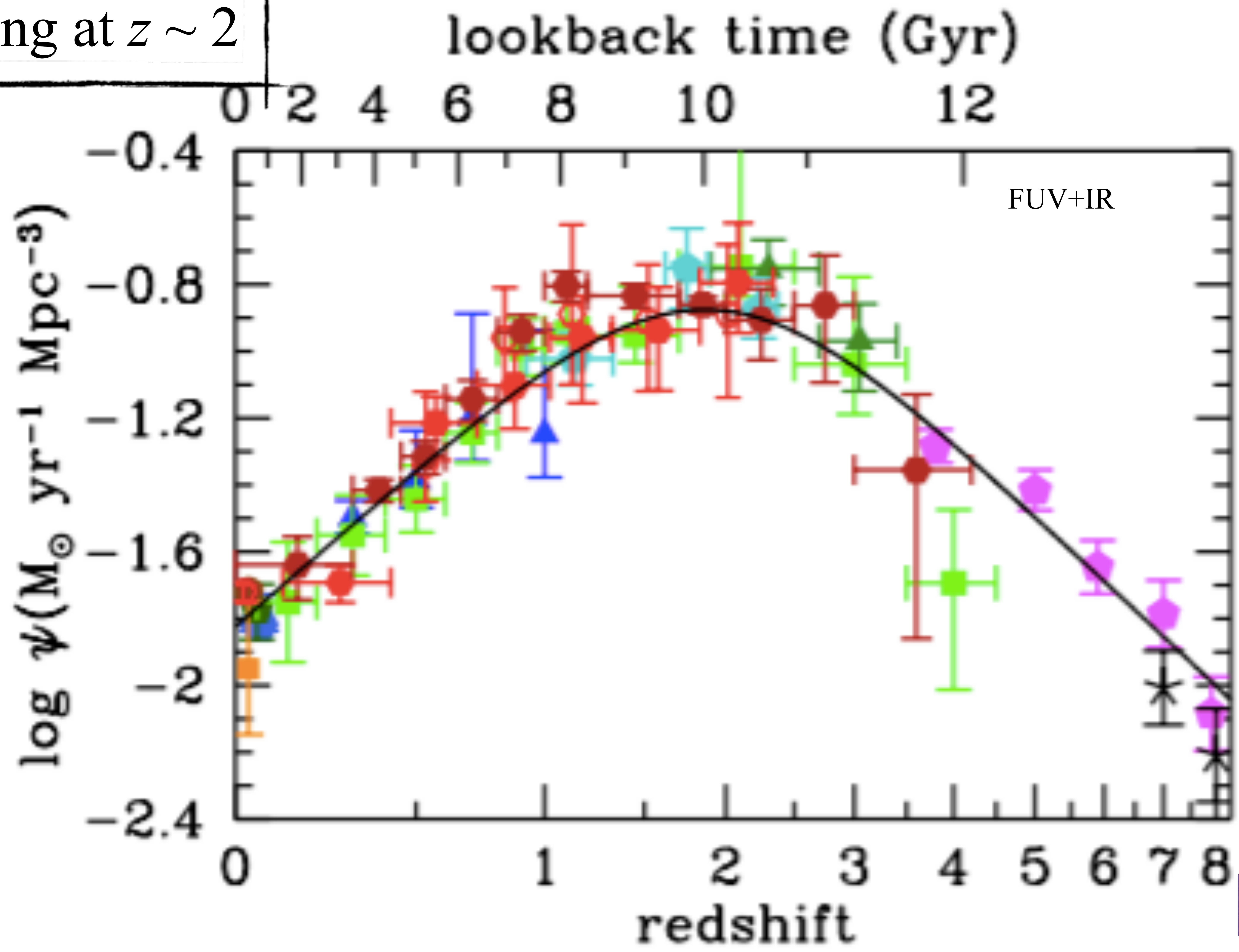




Credit: NASA, ESA, S. Toft (Niels Bohr Institute), and A. Feild (STScI)

cosmic star formation history

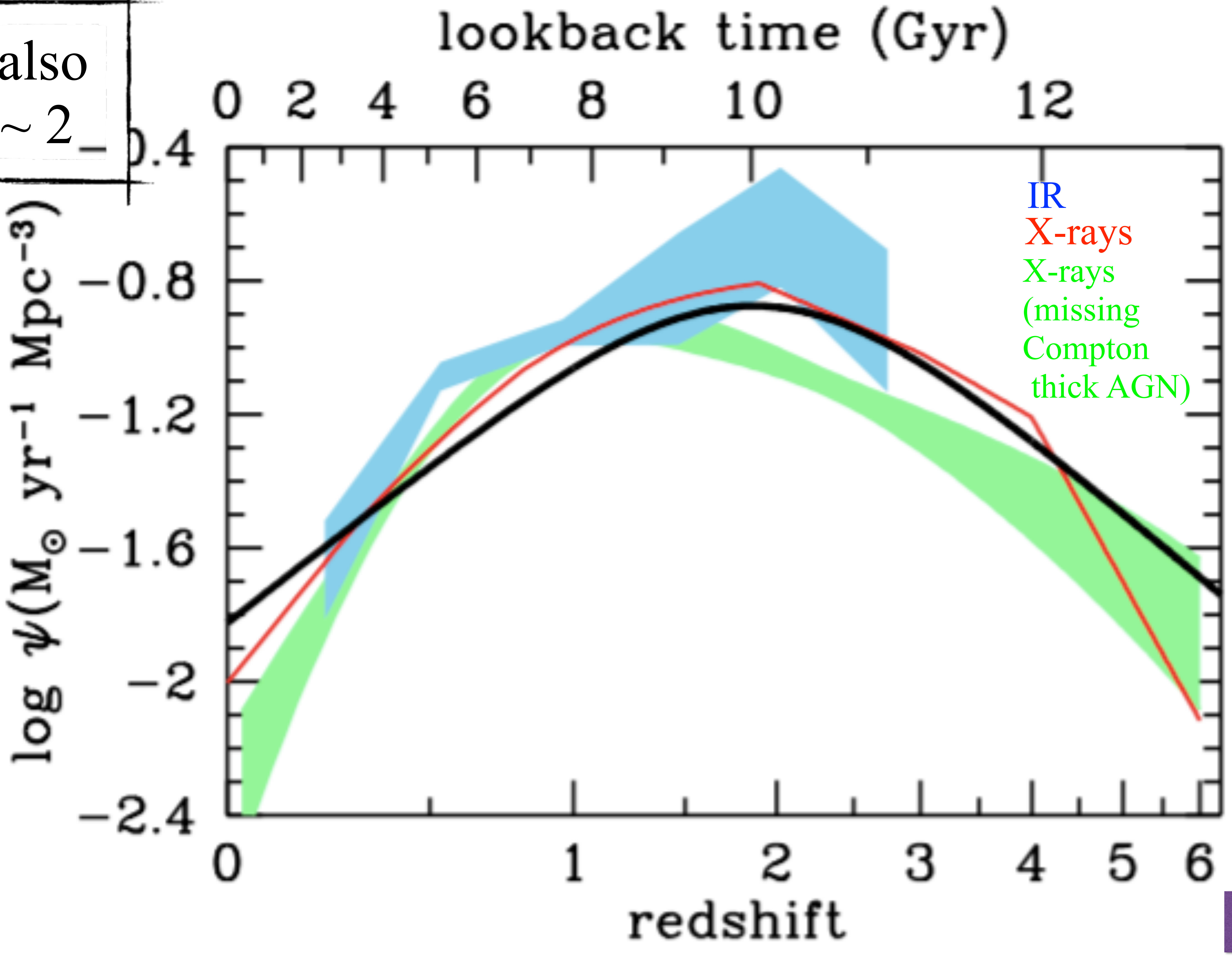
➡SFRD peaking at $z \sim 2$



Madau & Dickinson (2014)

cosmic star formation history

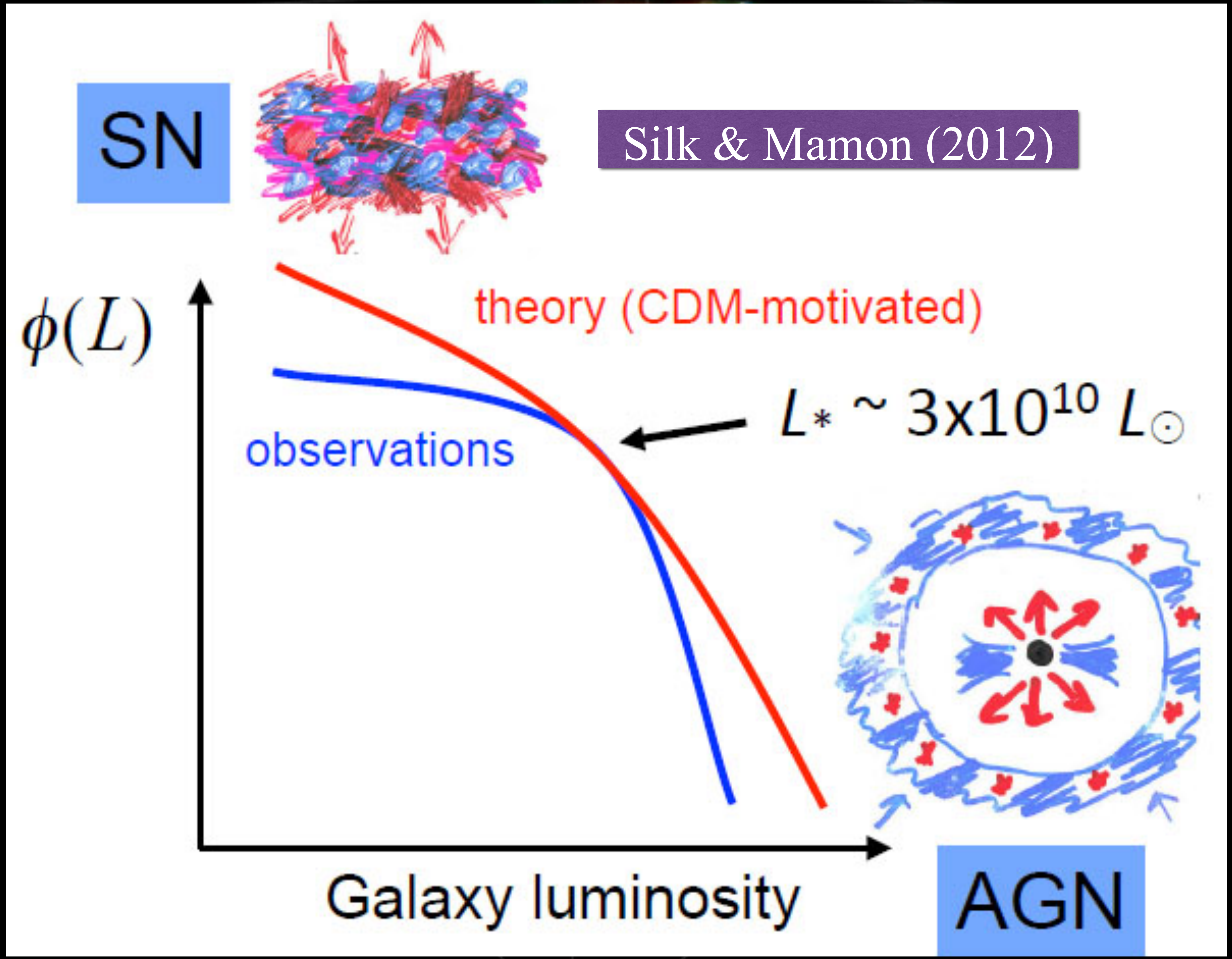
➡ BH growth also peaking at $z \sim 2$

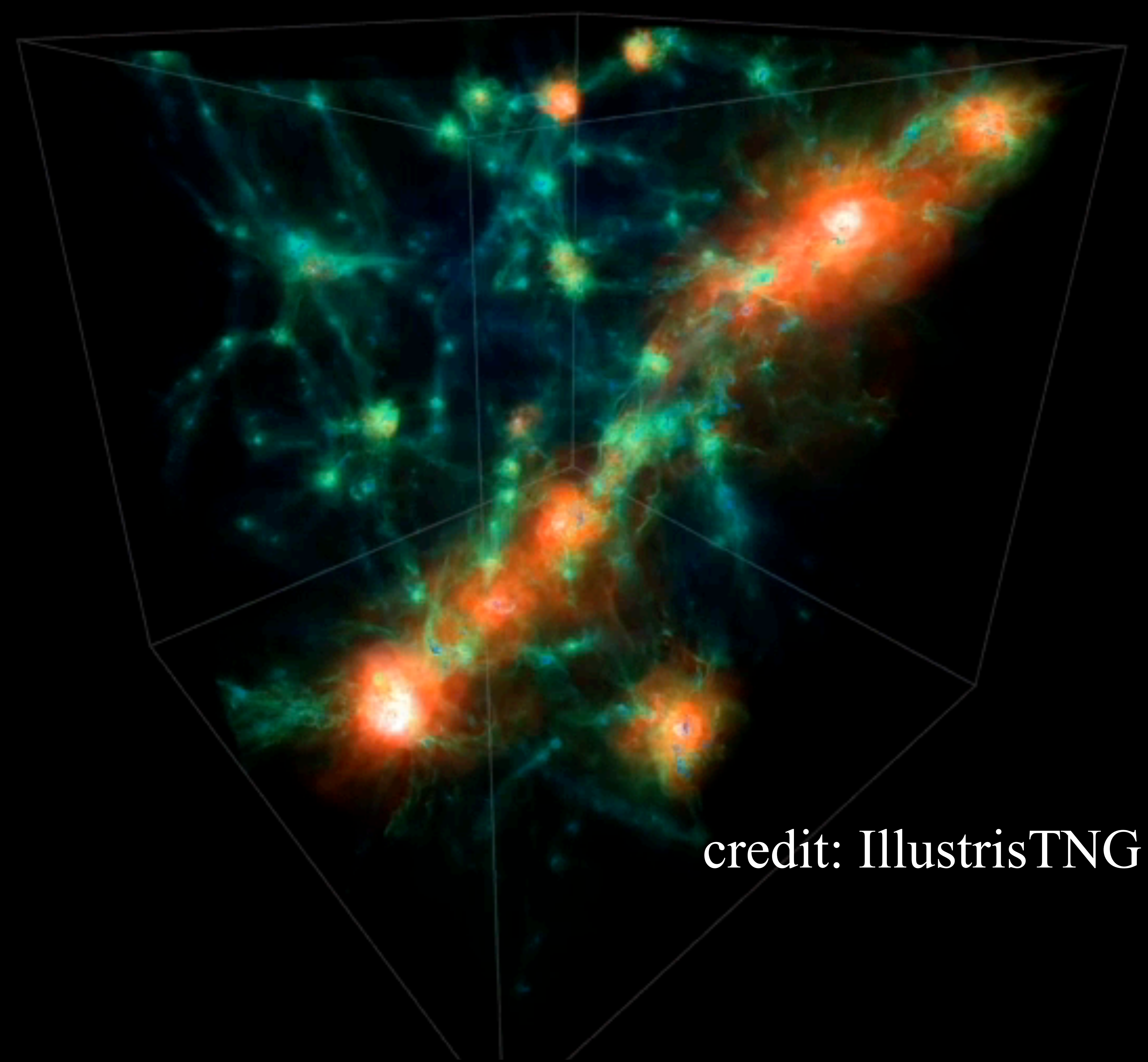


Madau & Dickinson (2014)

feedback

➡need to regulate galaxy growth not to have overly massive galaxies





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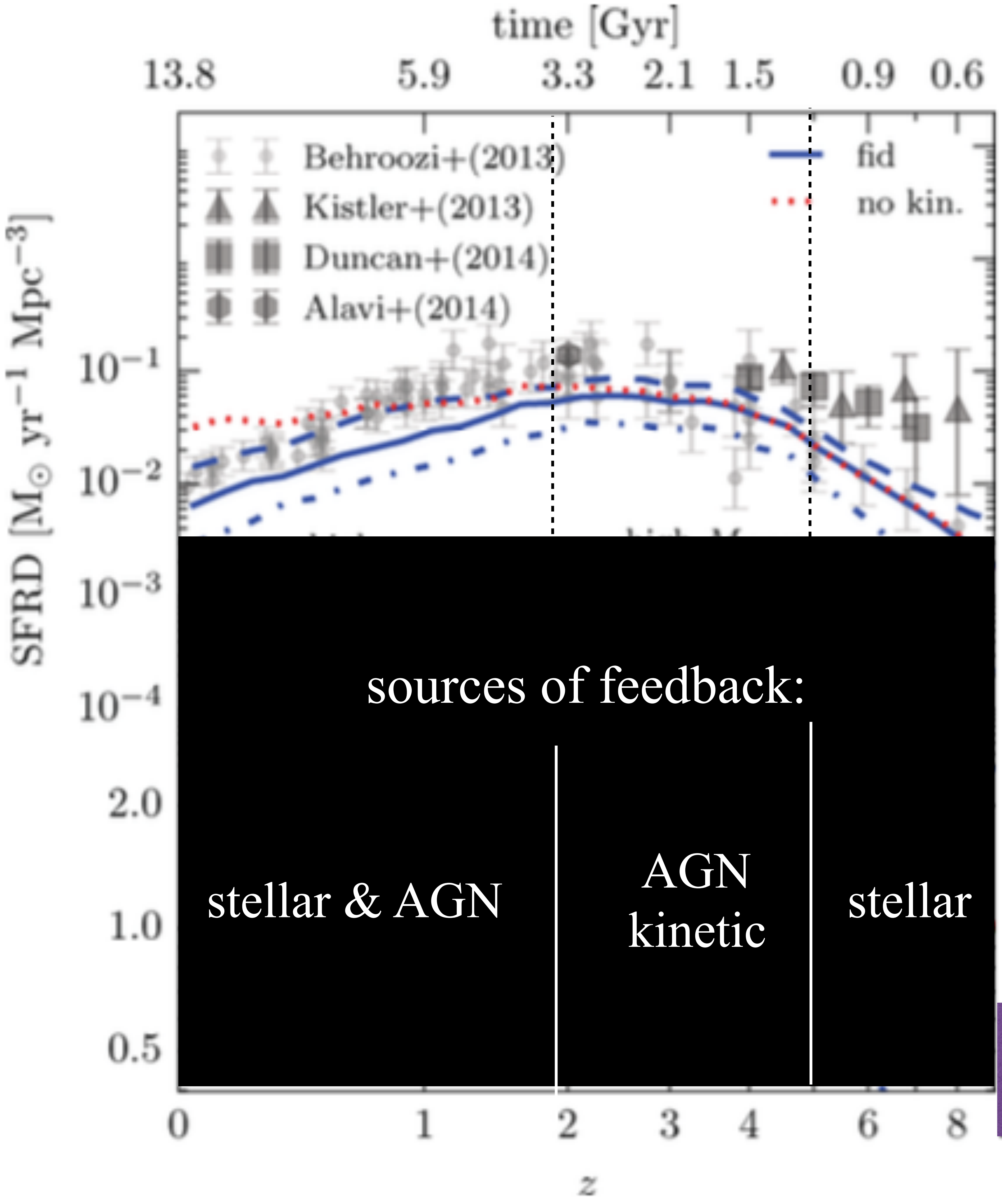
star-formation-rate density vs redshift



sources of feedback:

stellar & AGN

AGN kinetic

stellar

Weinberger+17
Illustris TNG

AGN simulation - ESO

https://www.eso.org/public/videos/eso1907h/

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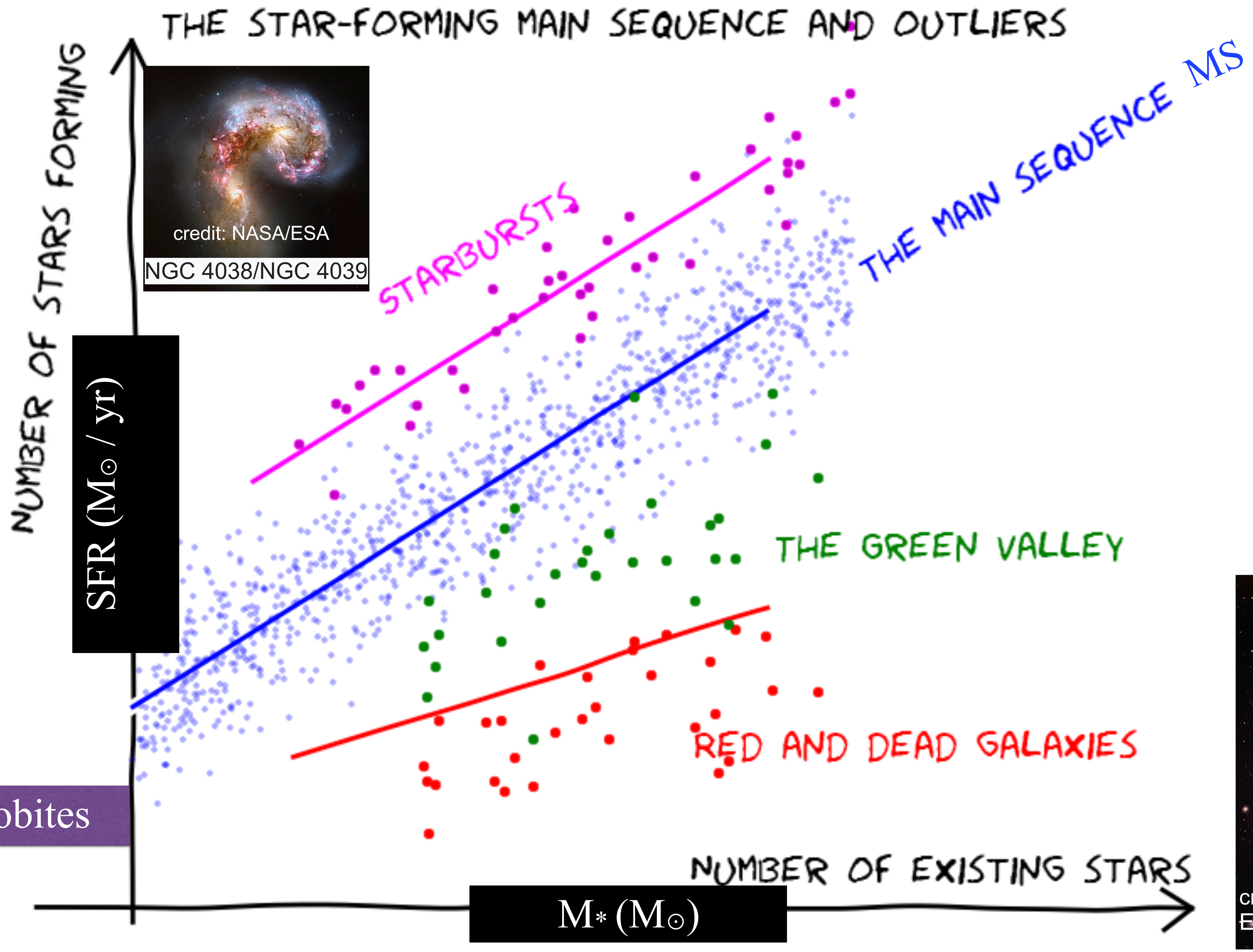
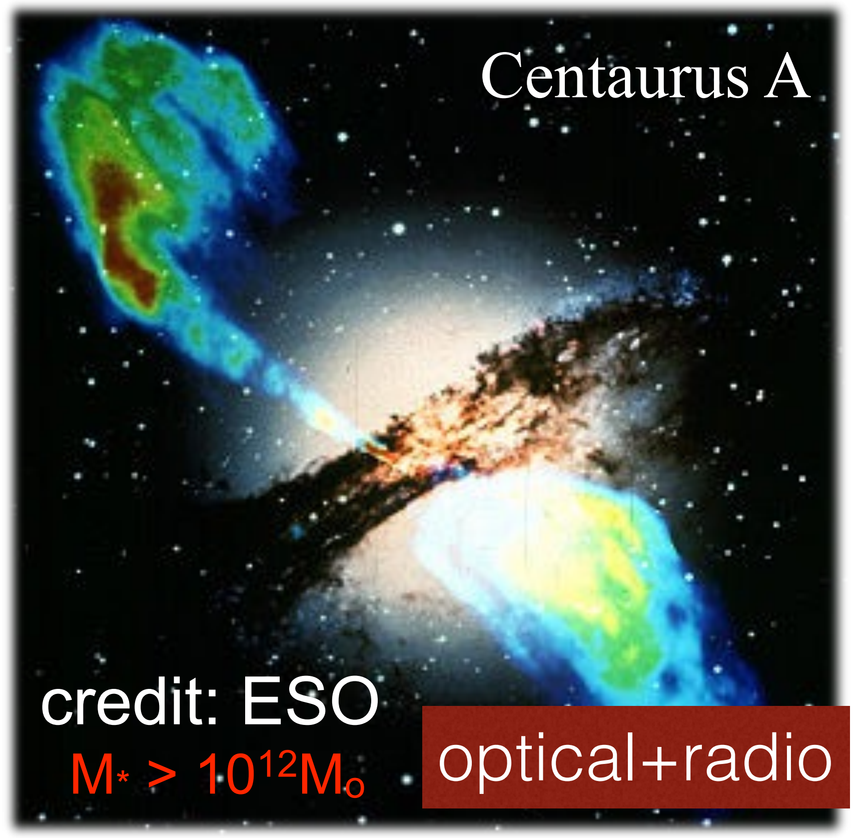
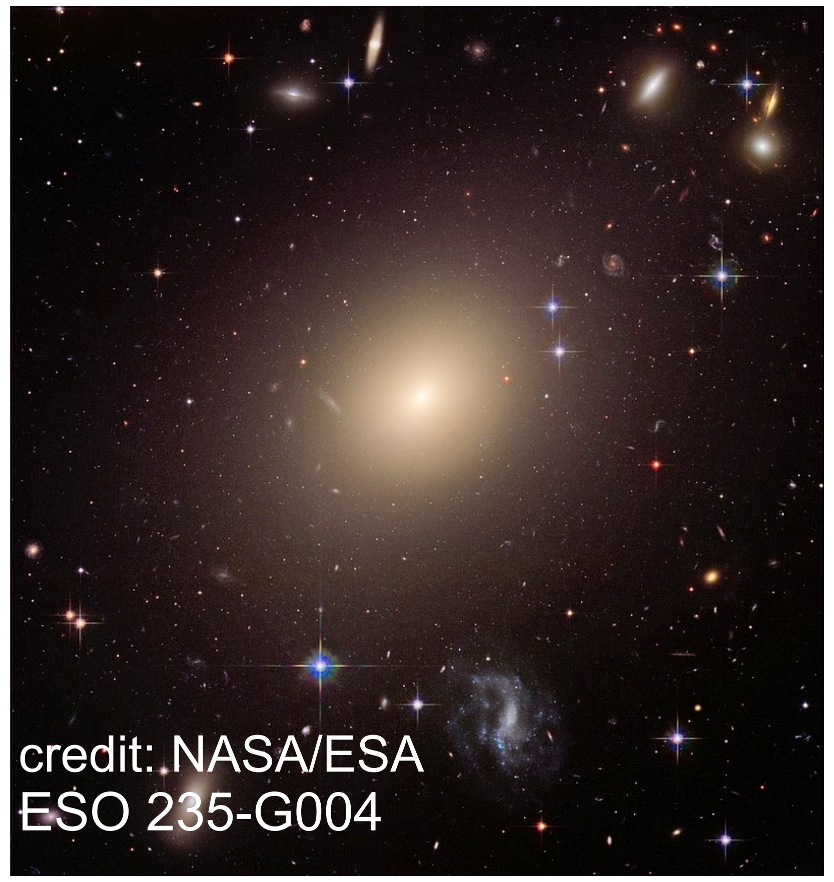
star-formation-rate density vs redshift



credit: astrobites





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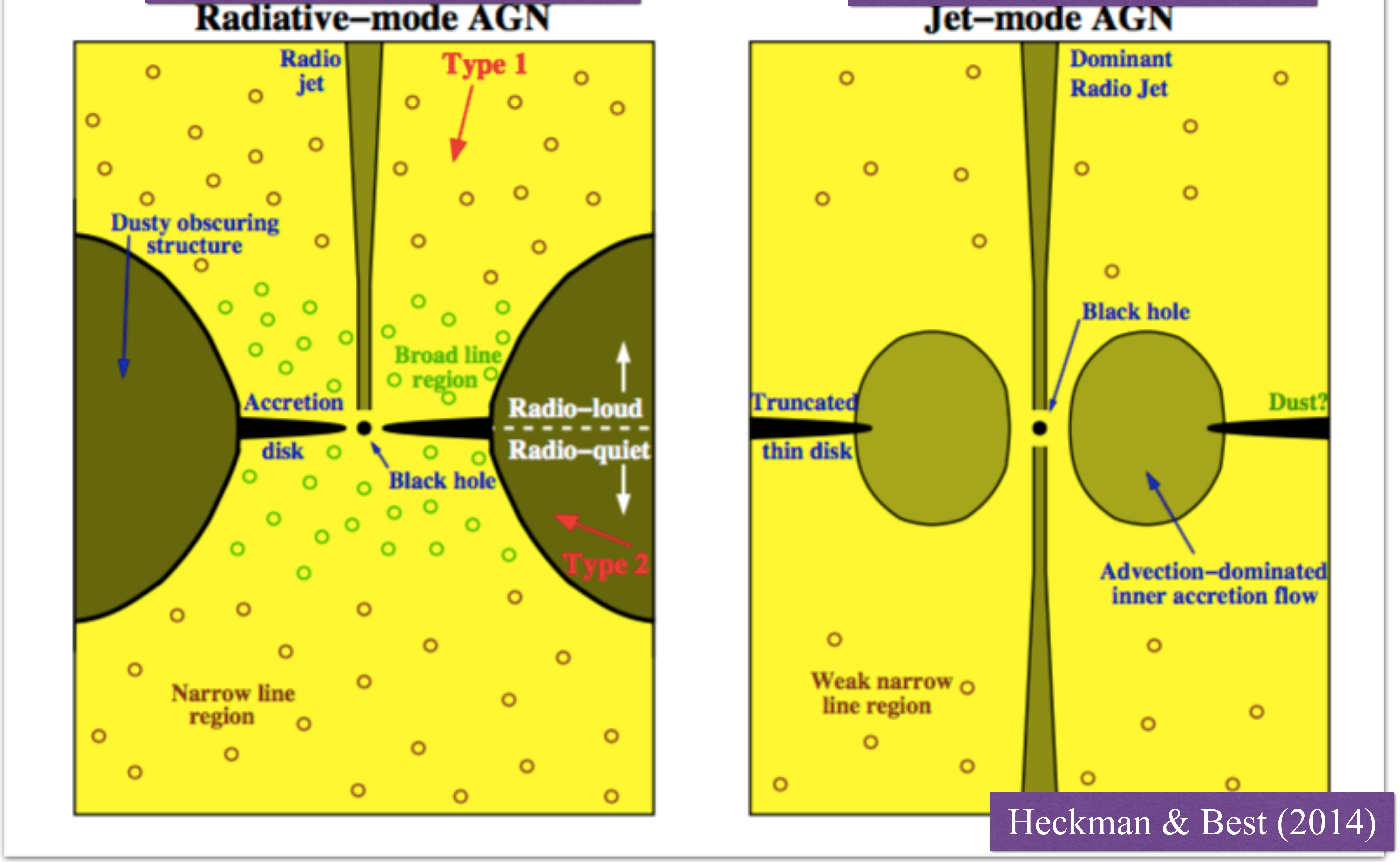
2 modes of accretion

high excitation - cold mode
$L_{20cm} \geq 10^{26}$ W/Hz
~Eddington ratio λ

low excitation - hot mode
$L_{20cm} < 10^{26}$ W/Hz
sub-Eddington ratio λ



Heckman & Best (2014)

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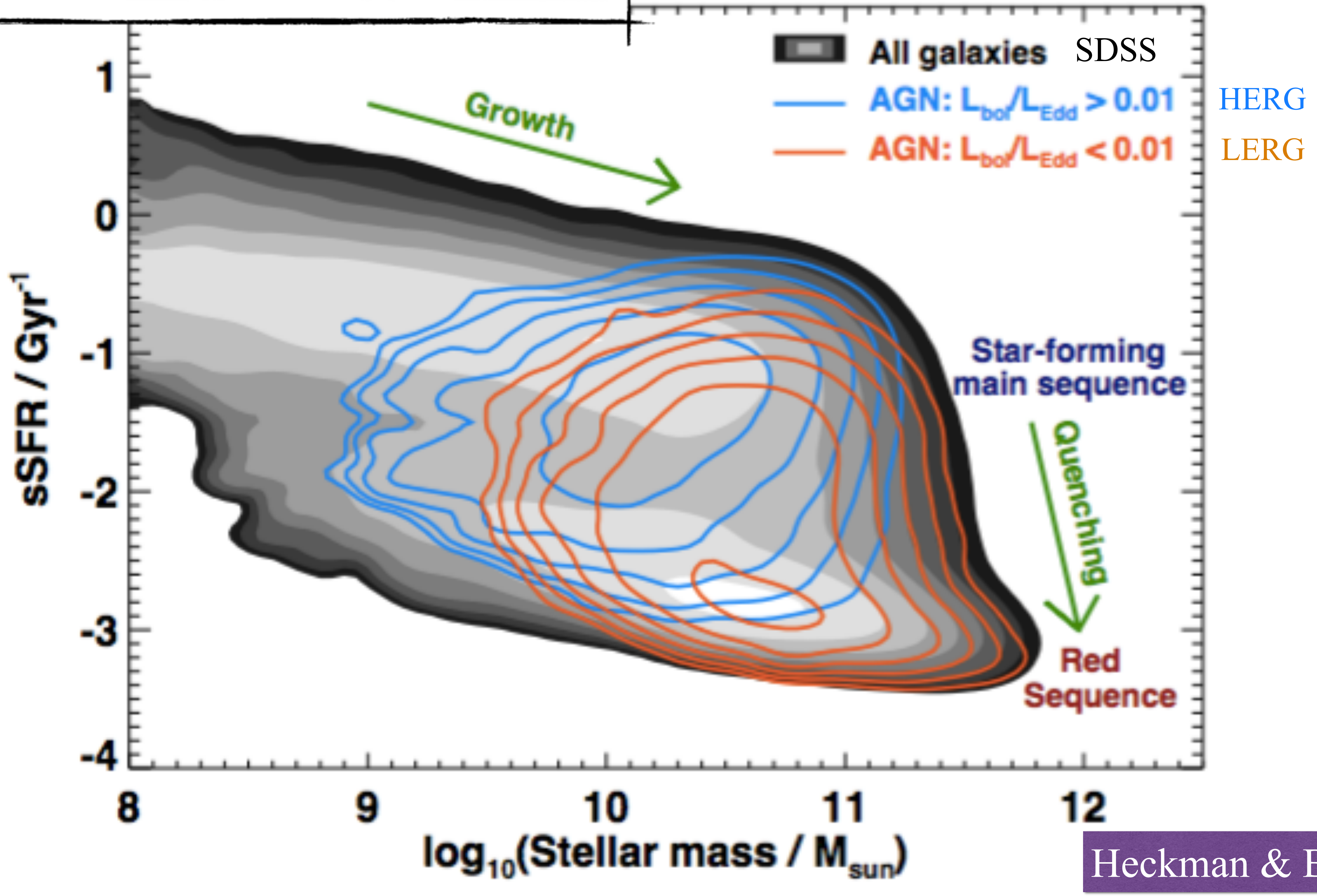
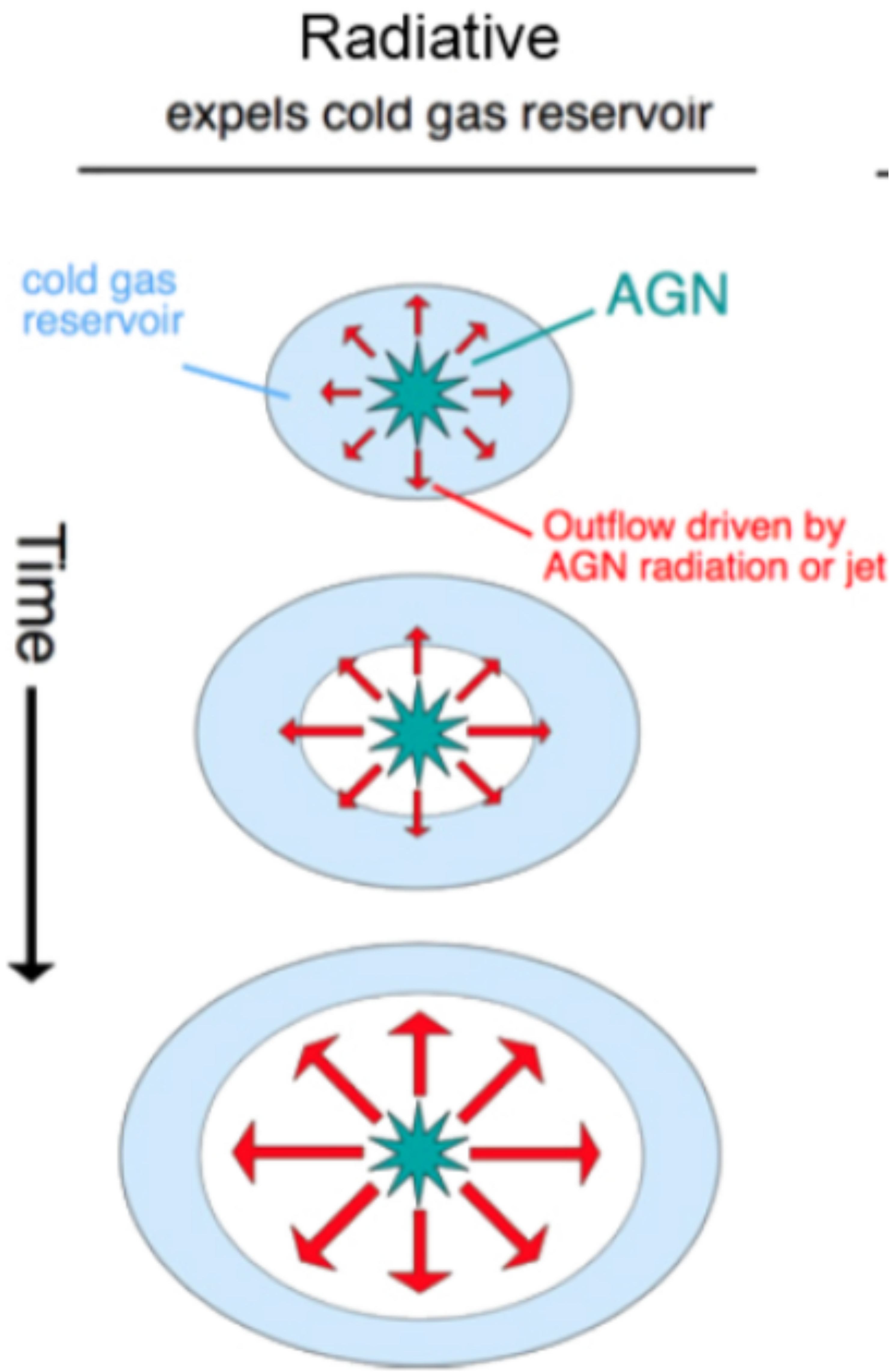
galaxy evolution - quenching of SF

➡ AGN role in quenching of star-formation



Heckman & Best 14

2 modes of feedback from AGN



Fabian (2012)

animation NASA
https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11821

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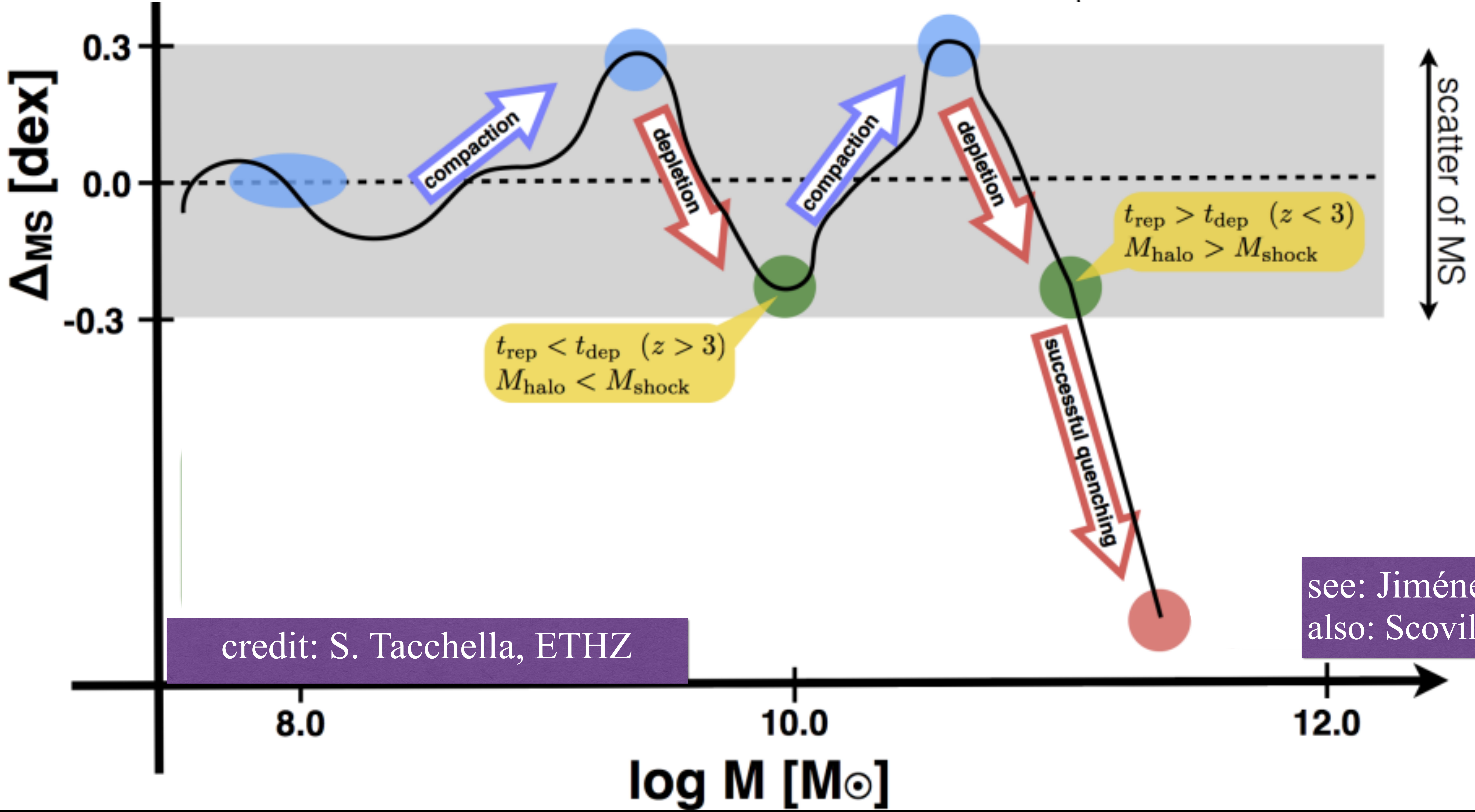
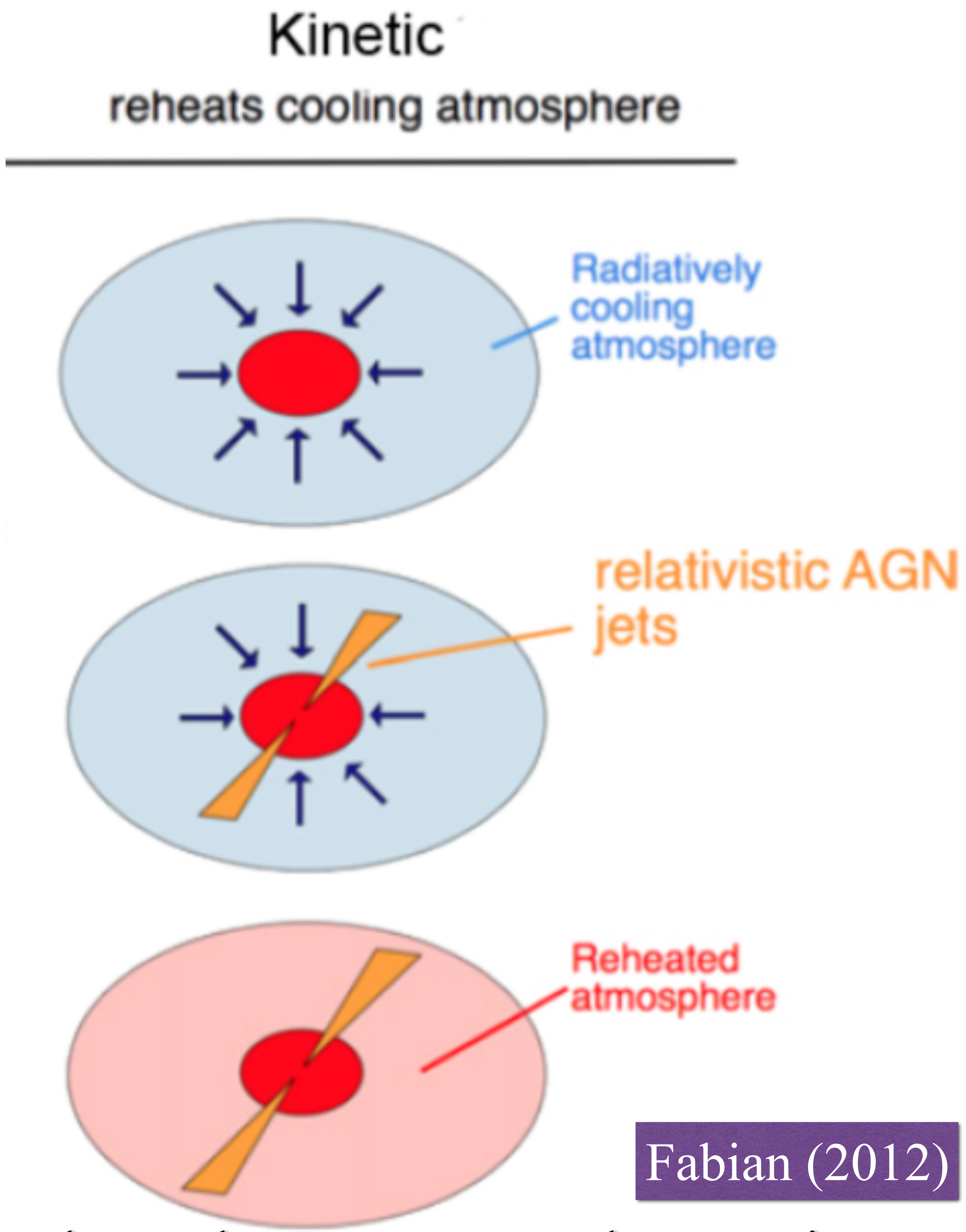
quenching - not so easy

➡MS galaxies go through a compaction and depletion phase
➡then they quench



see: Jiménez-Andrade…EV+19
also: Scoville+17

2 modes of feedback from AGN

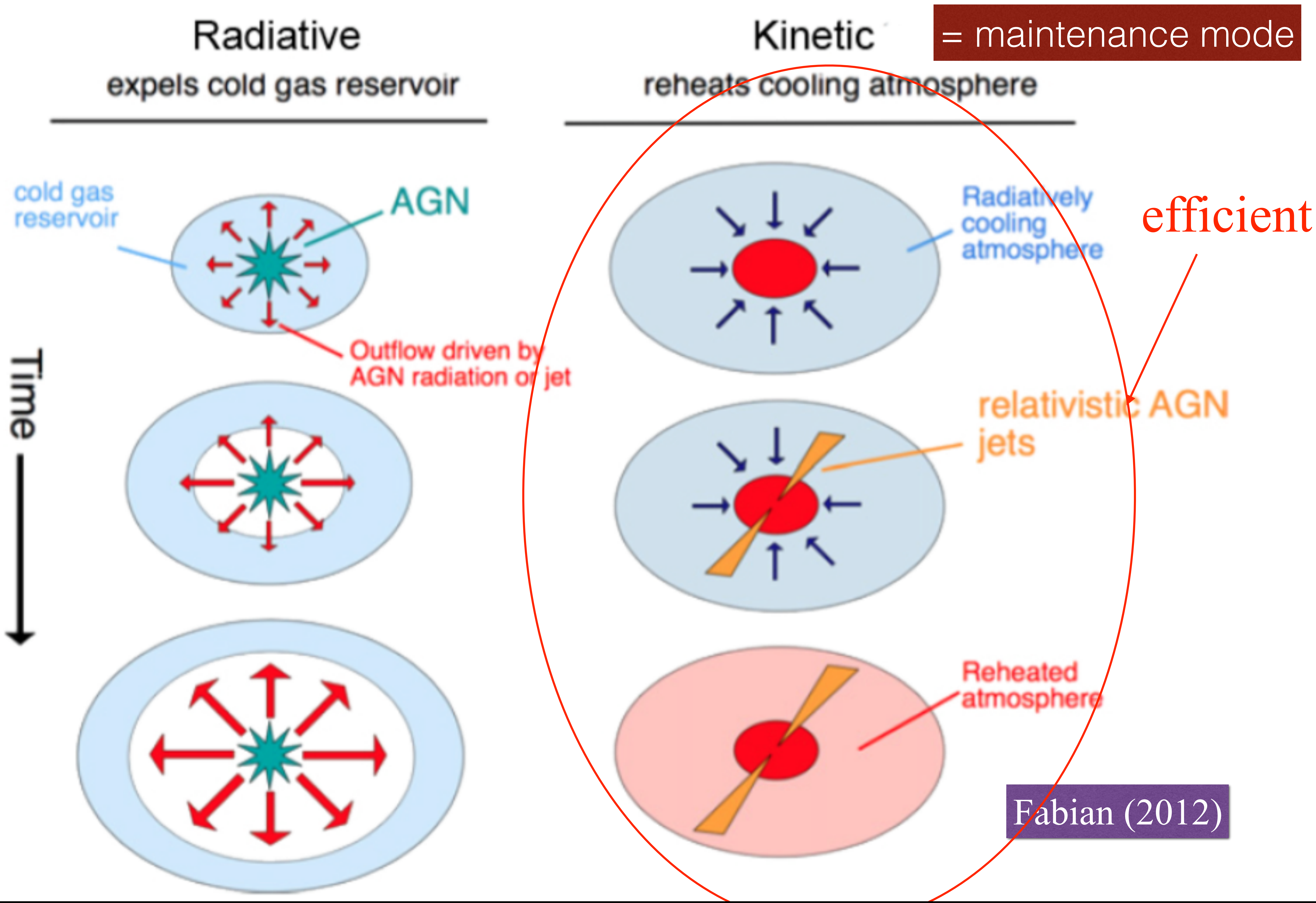


Fabian (2012)

animation NASA

https://www.nasa.gov/feature/goddard/2021/peering-into-a-galaxys-dusty-core-to-study-an-active-supermassive-black-hole

take home



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classic FR-type radio sources

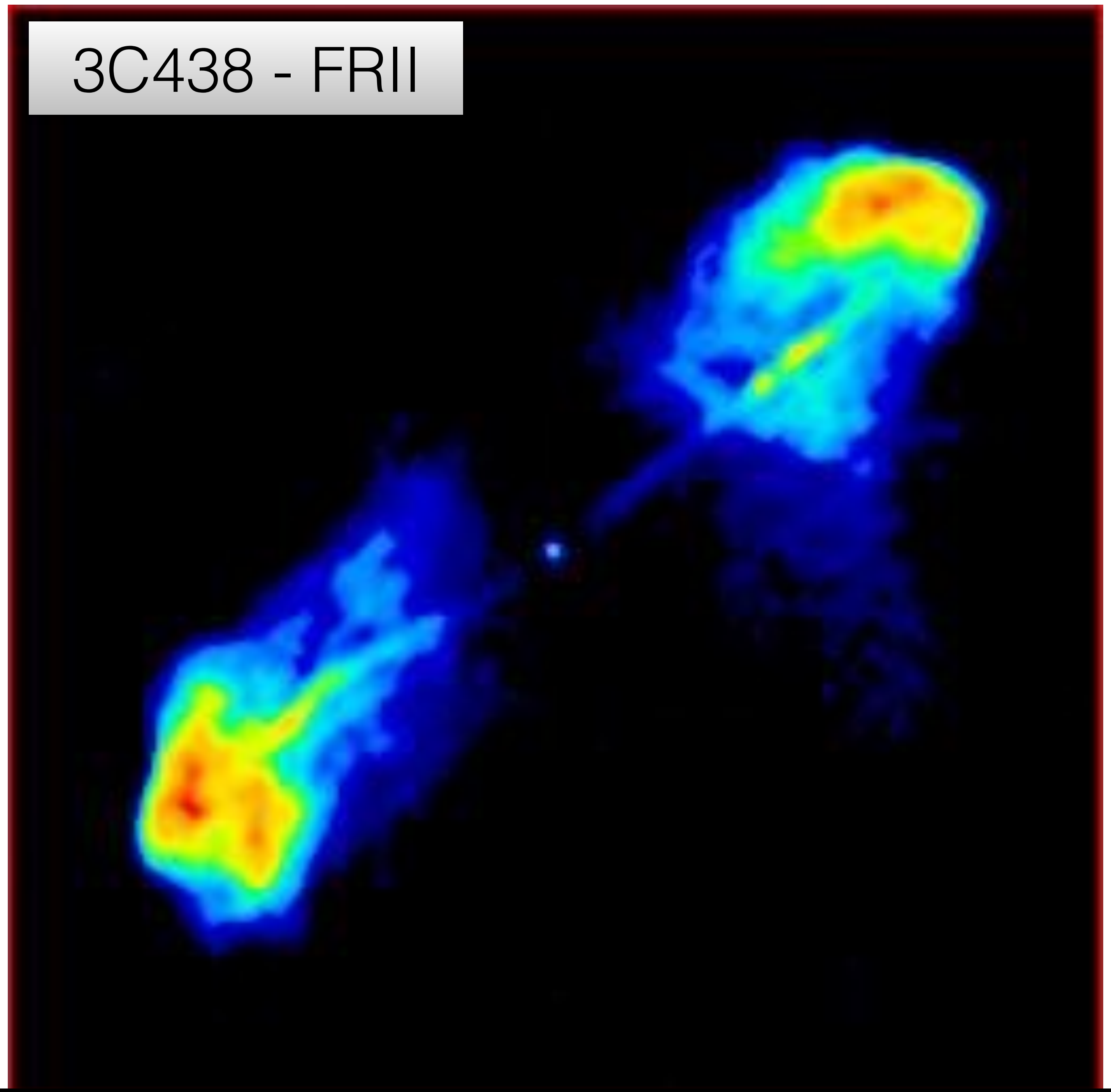
- correlation between position of energy deposited and total luminosity (Fanaroff & Riley 1974)

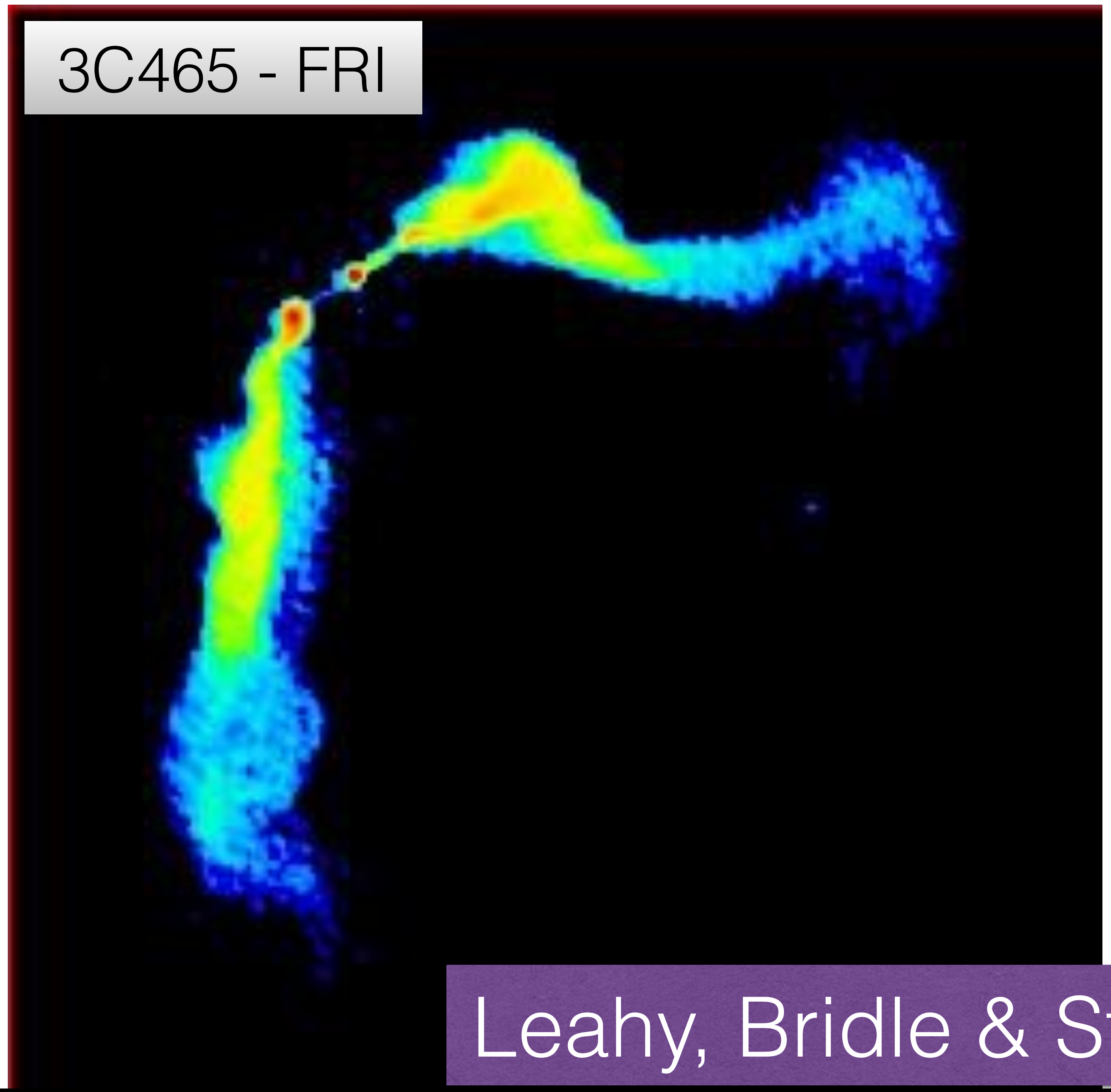
FRII or edge brightened

$r_{hotspots} / r_{total} > 0.5$

FRI or edge darkened

$r_{hotspots} / r_{total} < 0.5$





Leahy, Bridle & Strom

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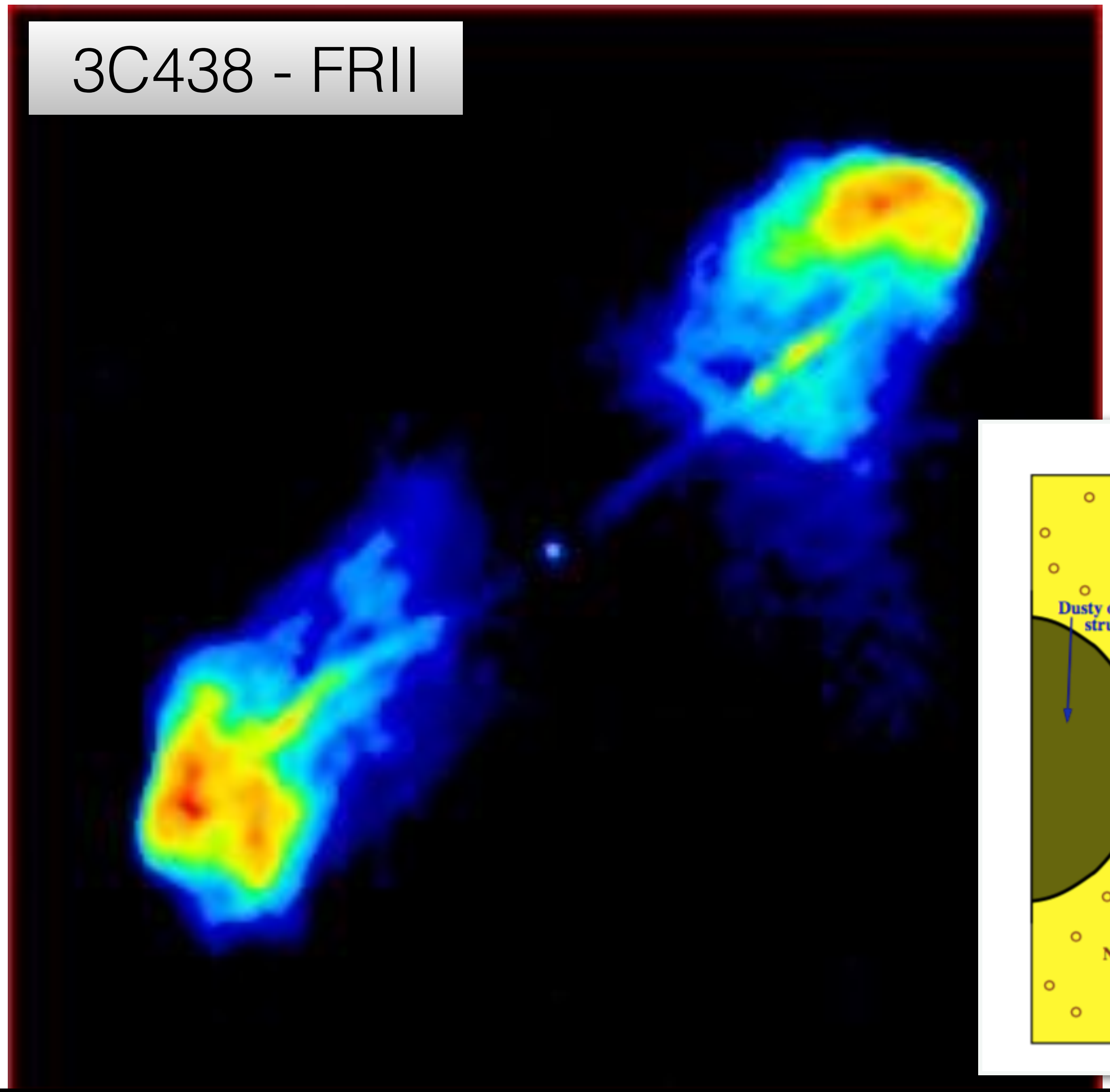

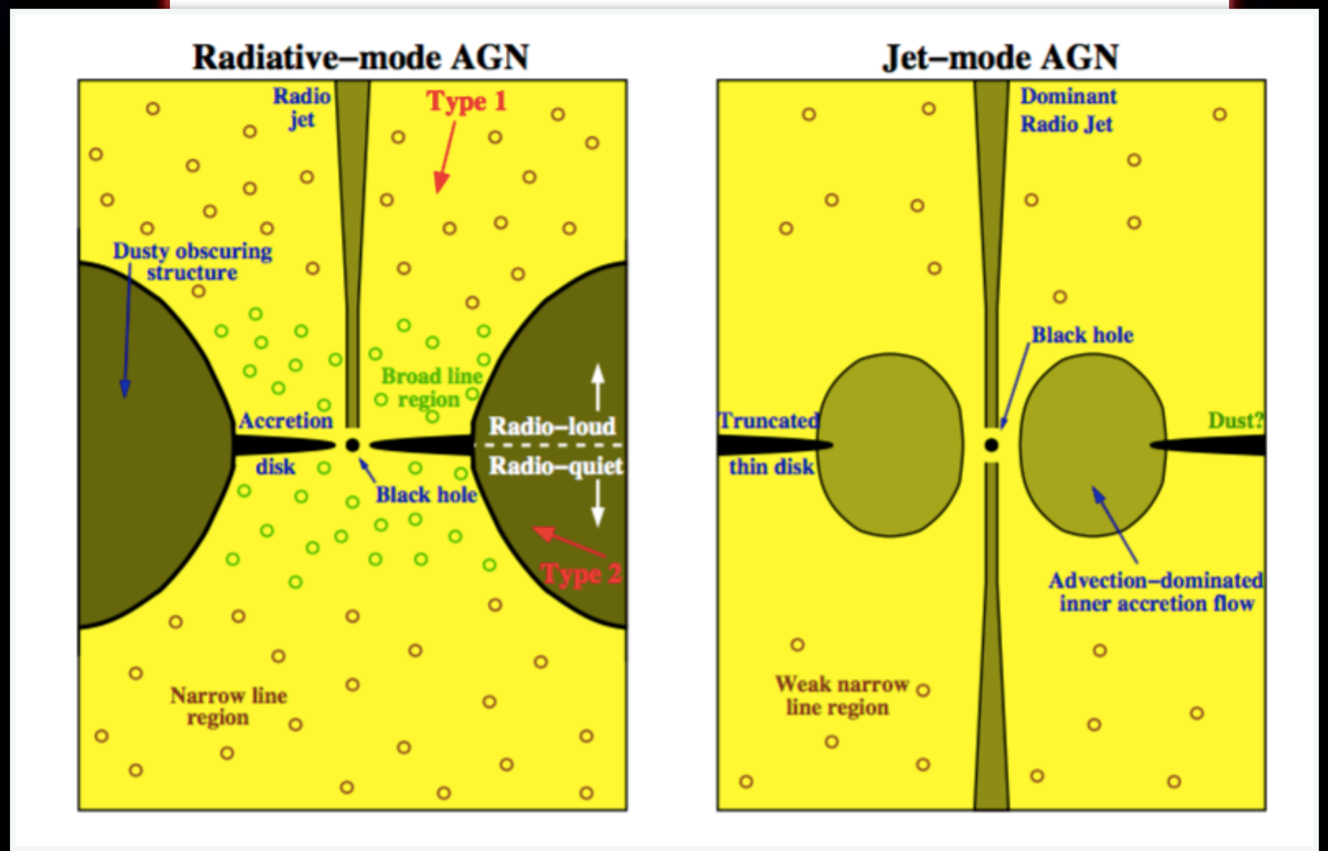

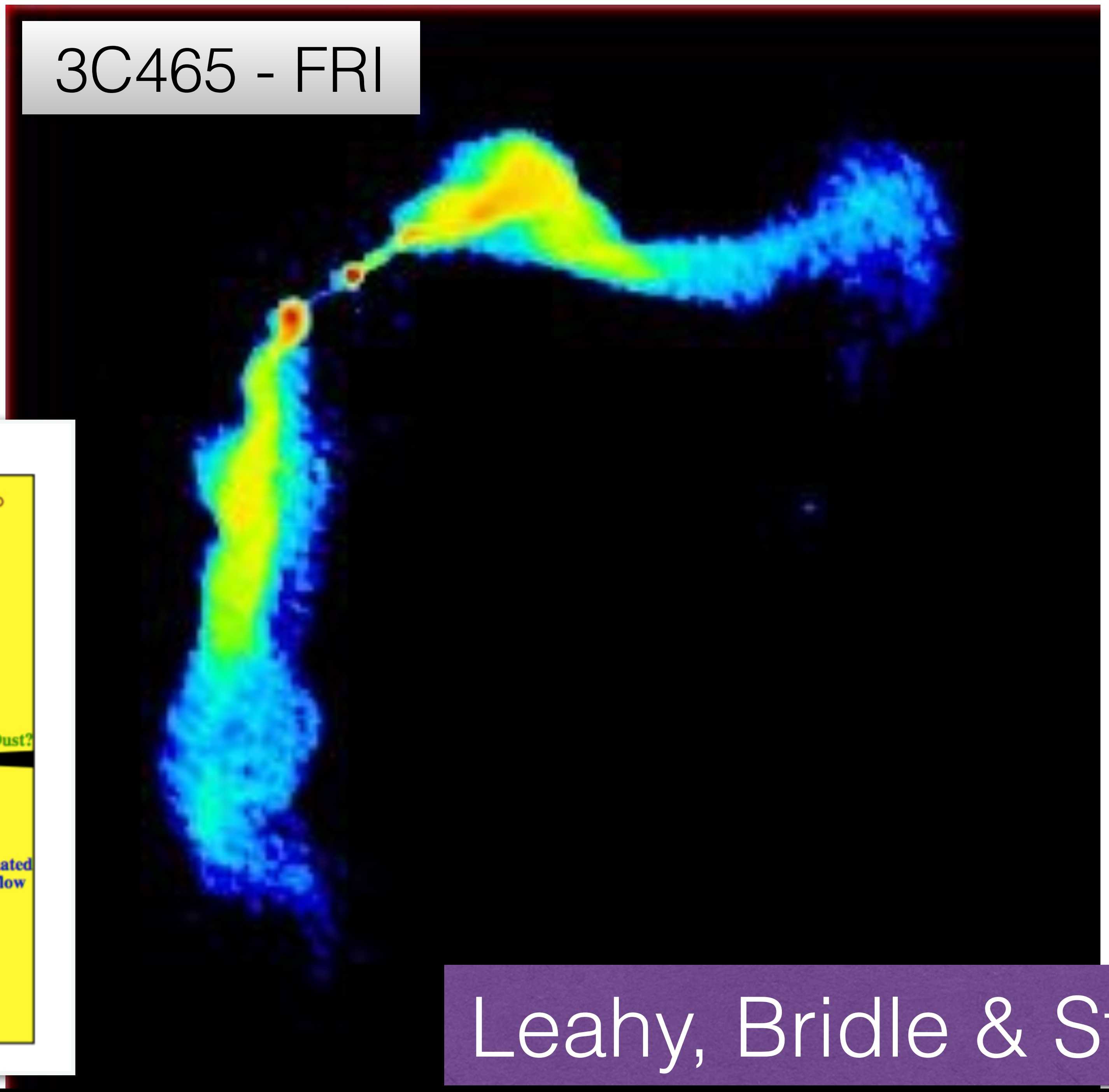

Leahy, Bridle & Strom

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the radio AGN zoo

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Cosmic Evolution Survey COSMOS

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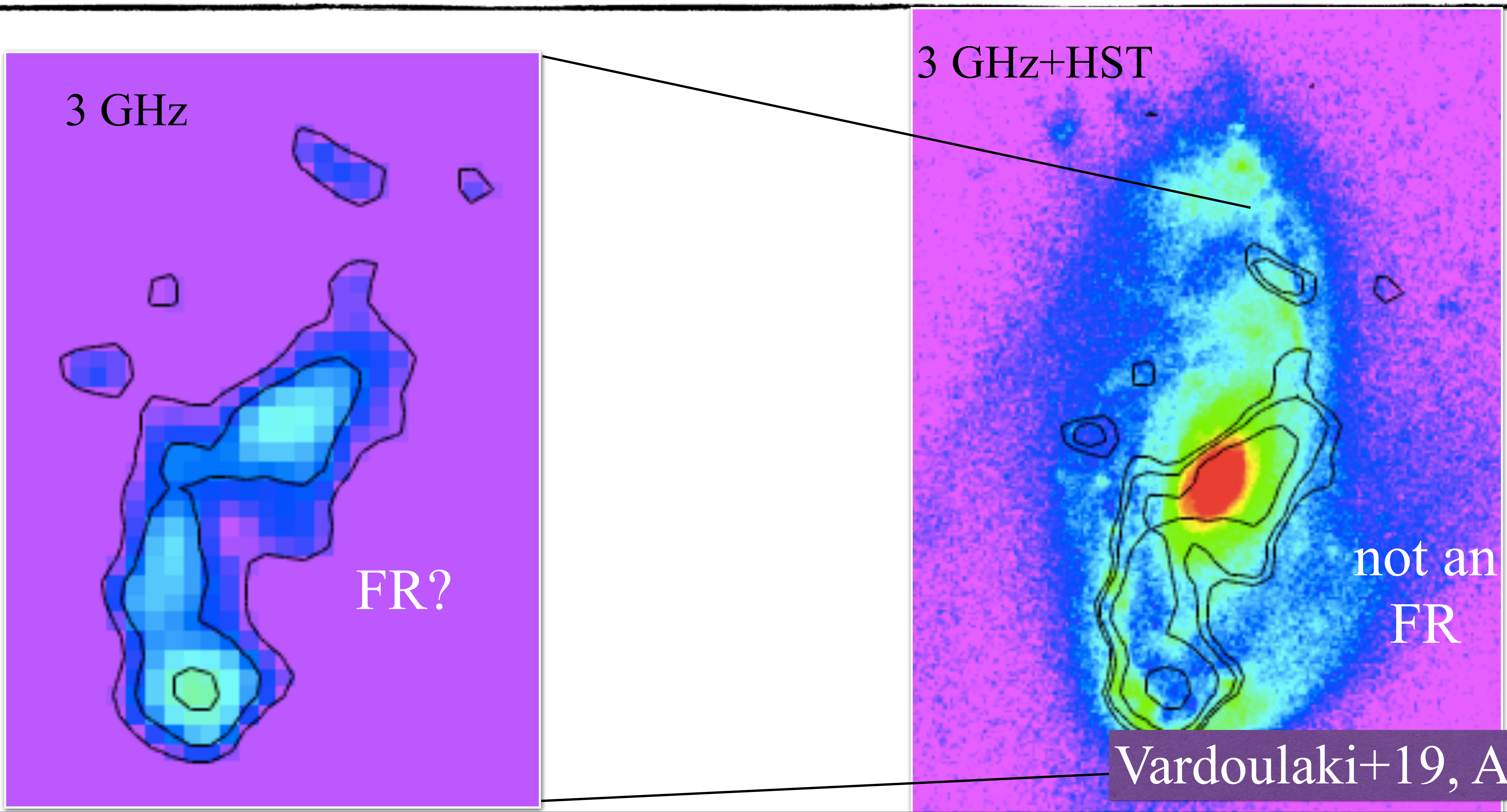
what are you?

- single frequency classification: highly subjective
- need for multi-wavelength data



Vardoulaki+19, A&A, 627A, 142

identification/classification

- how do we separate/classify the populations in samples of tens of thousands of radio sources?

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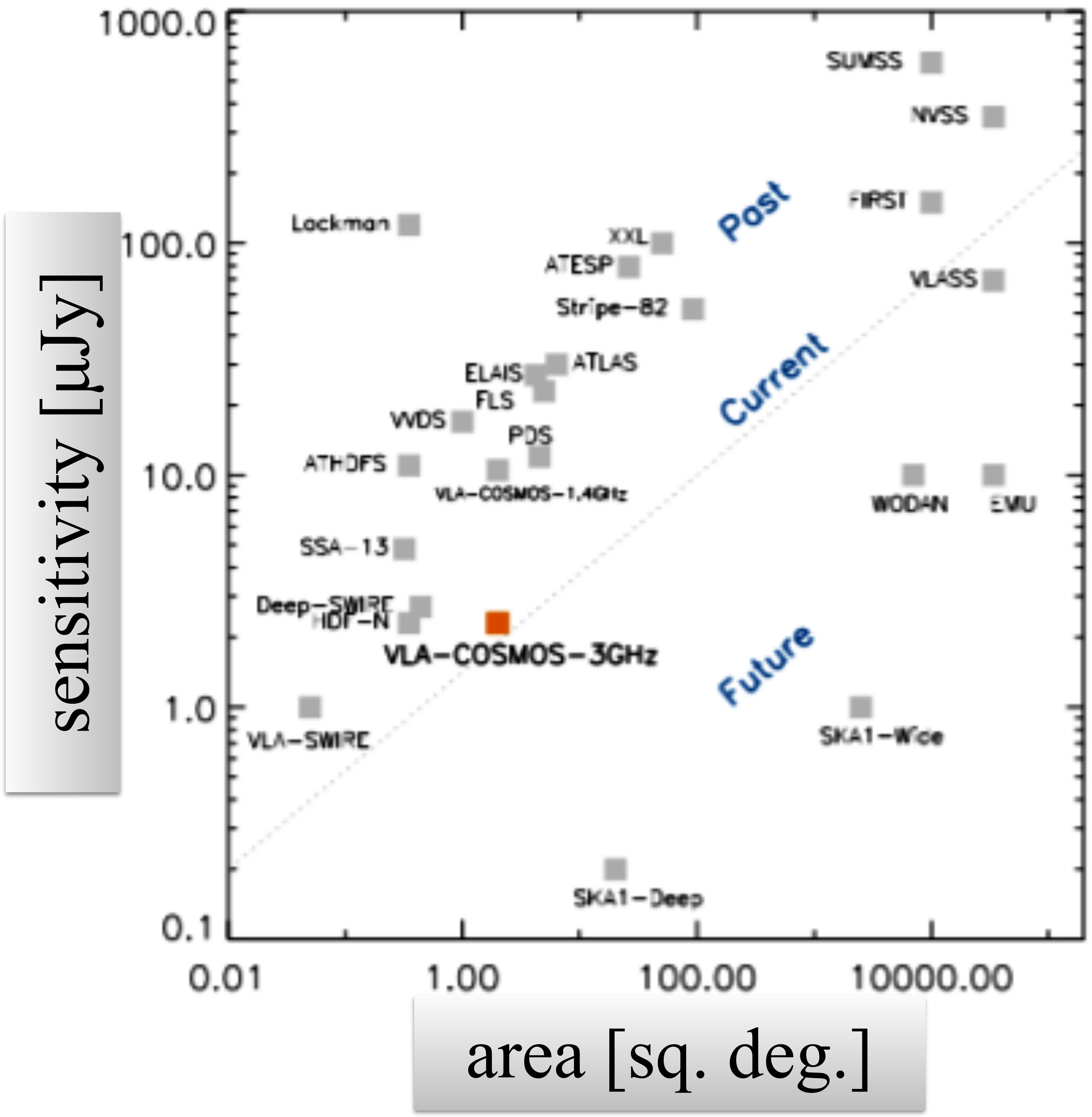
3 GHz VLA-COSMOS

- VLA-COSMOS Large Survey @ 3 GHz (Smolčić…EV+17a)
- ~2.6 deg^2
- median *rms* ~ 2.3 μJy/beam
- 0.75 arcsec resolution
- **multi-λ** coverage (Laigle+16)
- **hosts** (Smolčić+17b)

Smolčić…EV+17a



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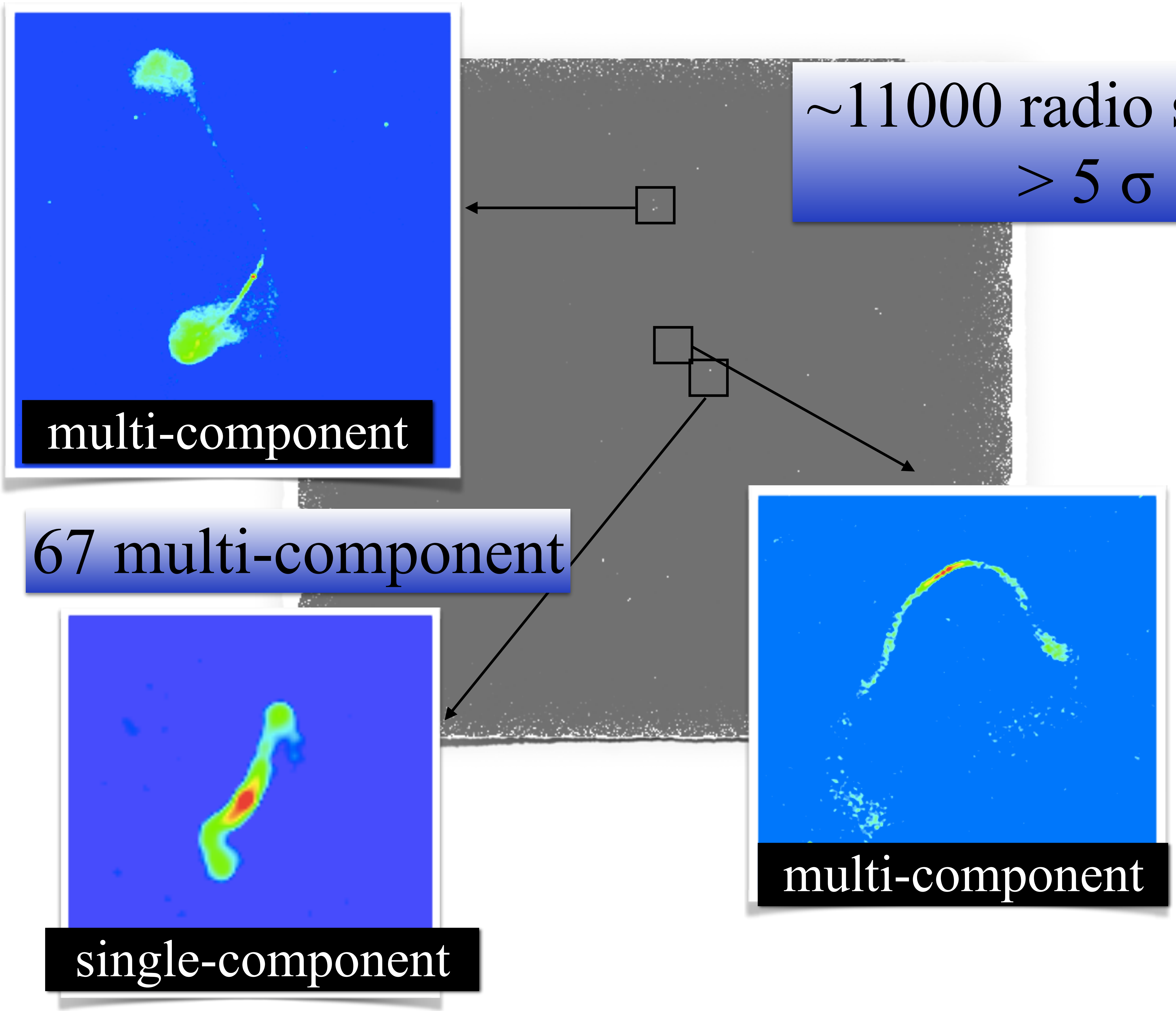
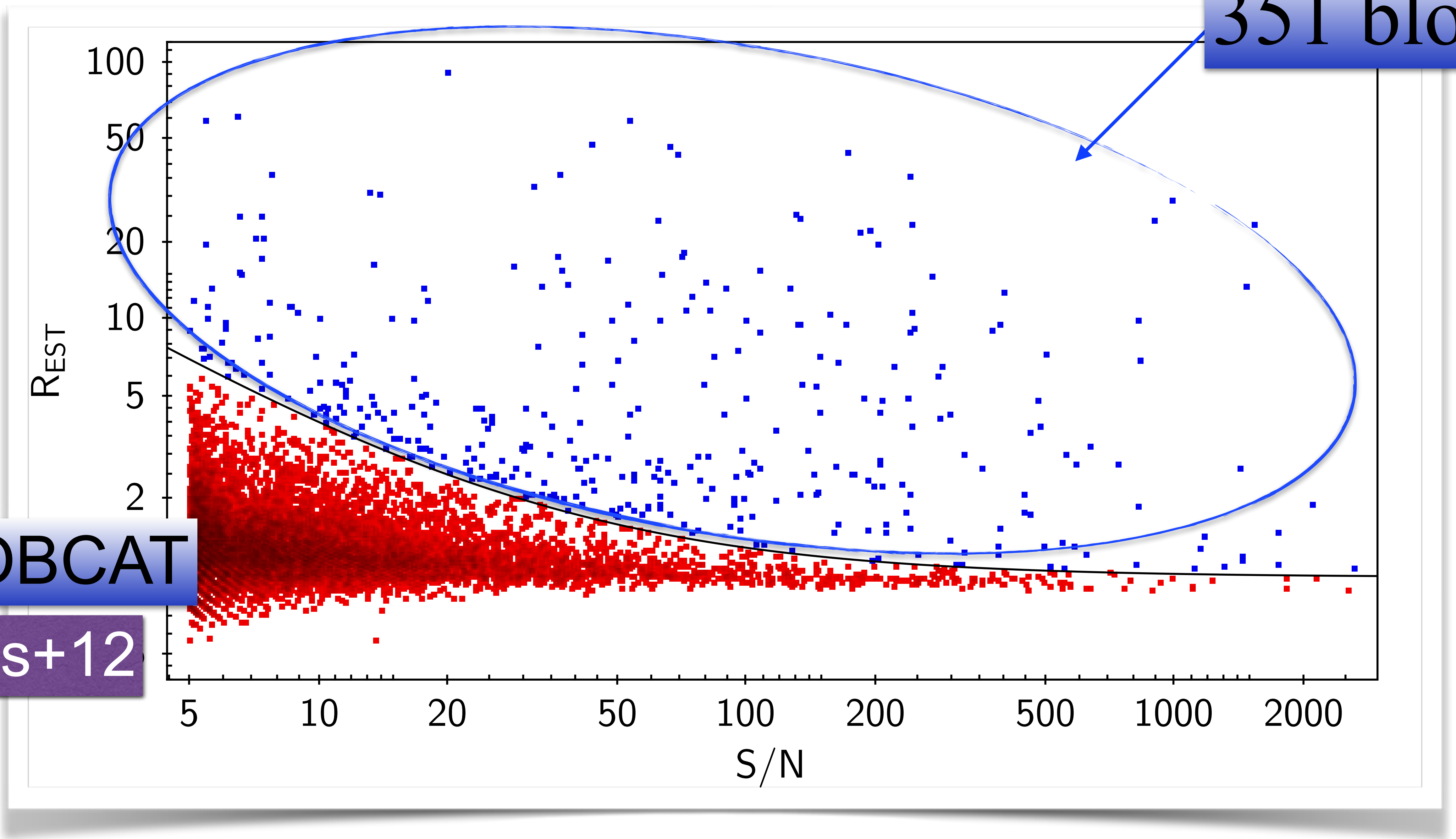
3 GHz VLA-COSMOS

~11000 radio sources
> 5 σ



visually inspected sample
351 blobs



Vardoulaki+21, A&A, 648A, 102
Vardoulaki+19, A&A, 627A, 142

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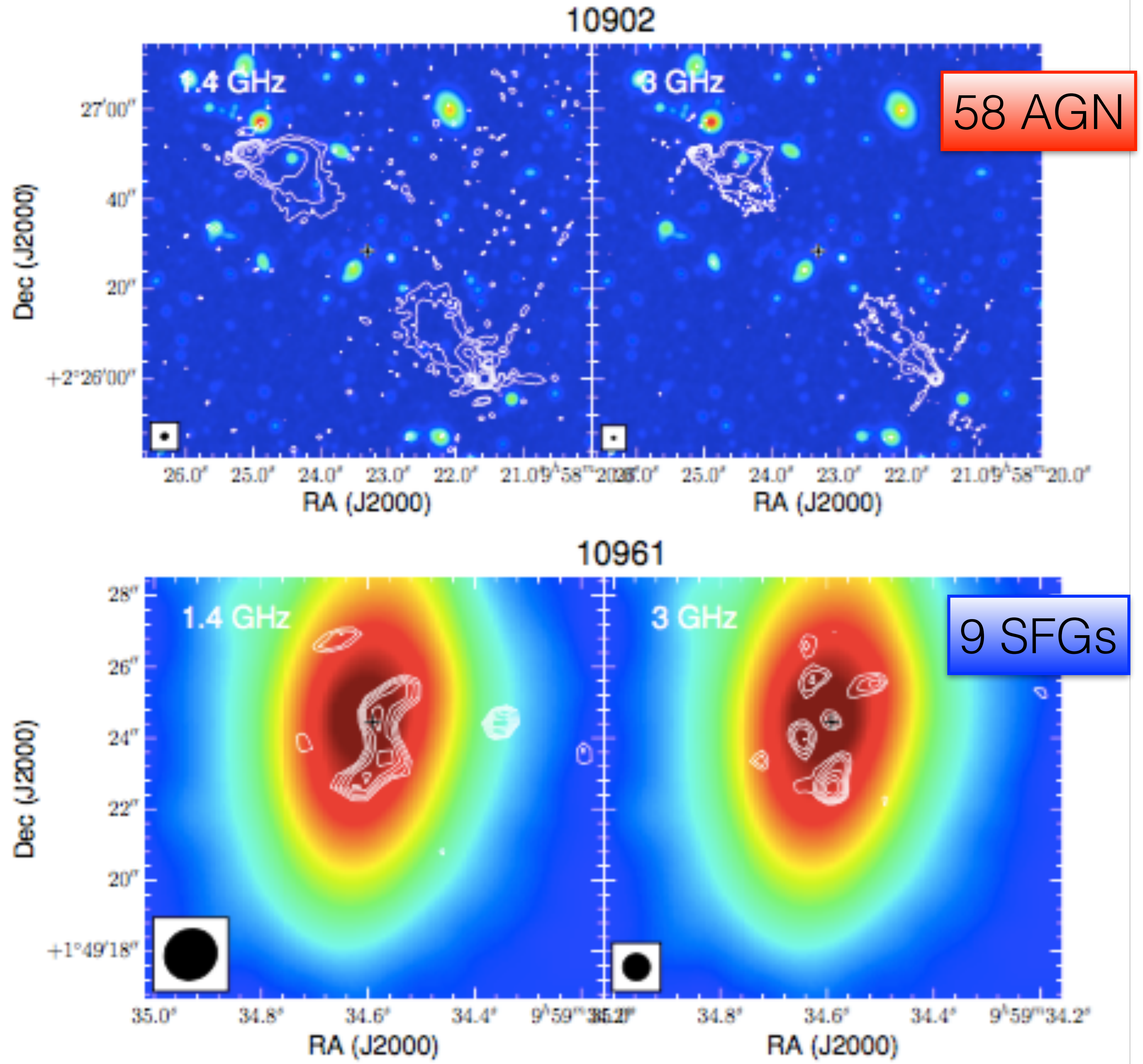
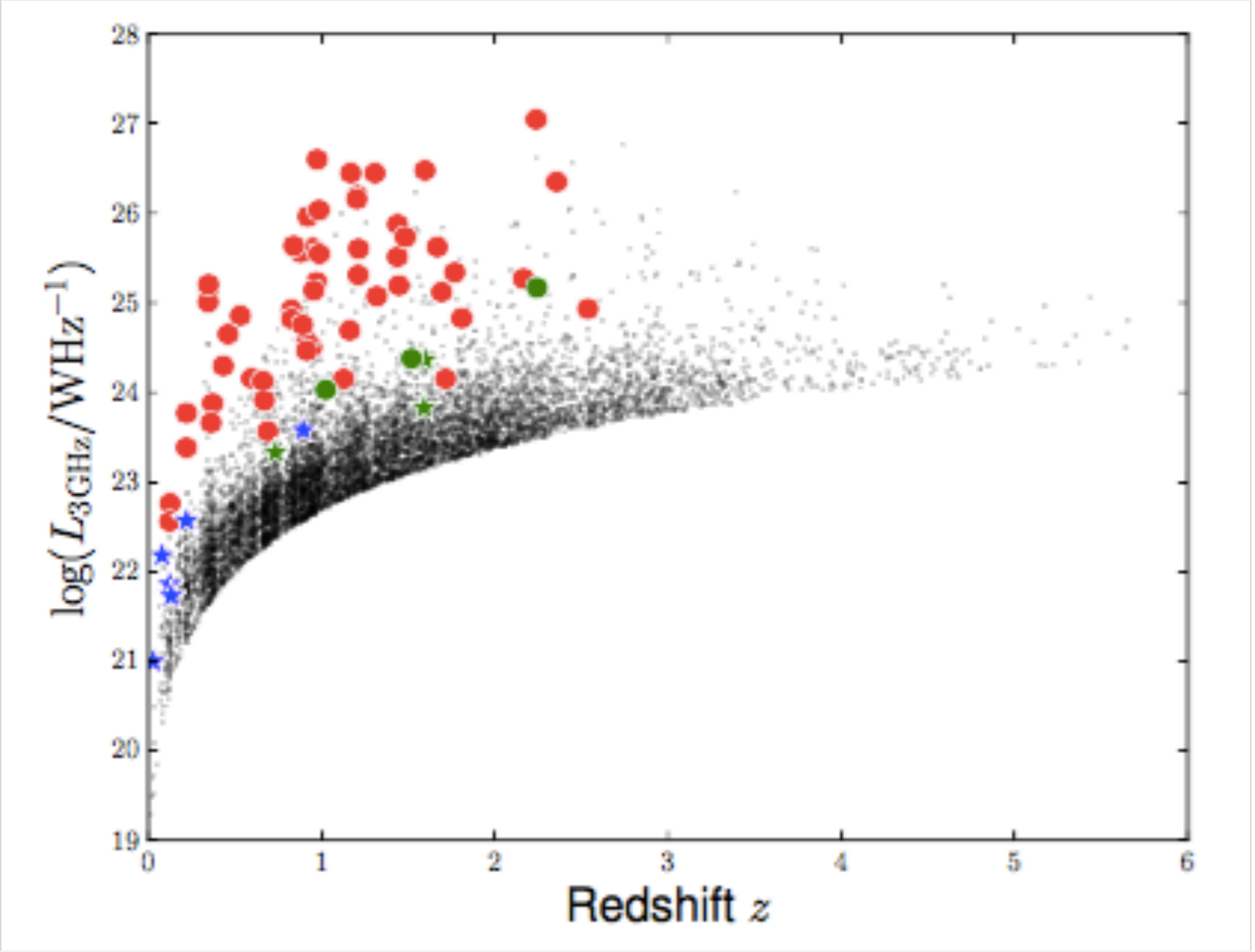
multi-components at 3-GHz

- **3 GHz VLA-COSMOS Large Project (Smolčić+, incl. EV, 17α):**
  - ➡ 0".75 resolution, 2.3μJy/beam down to 10μJy



multicomponent
58 AGN 9 SFGs



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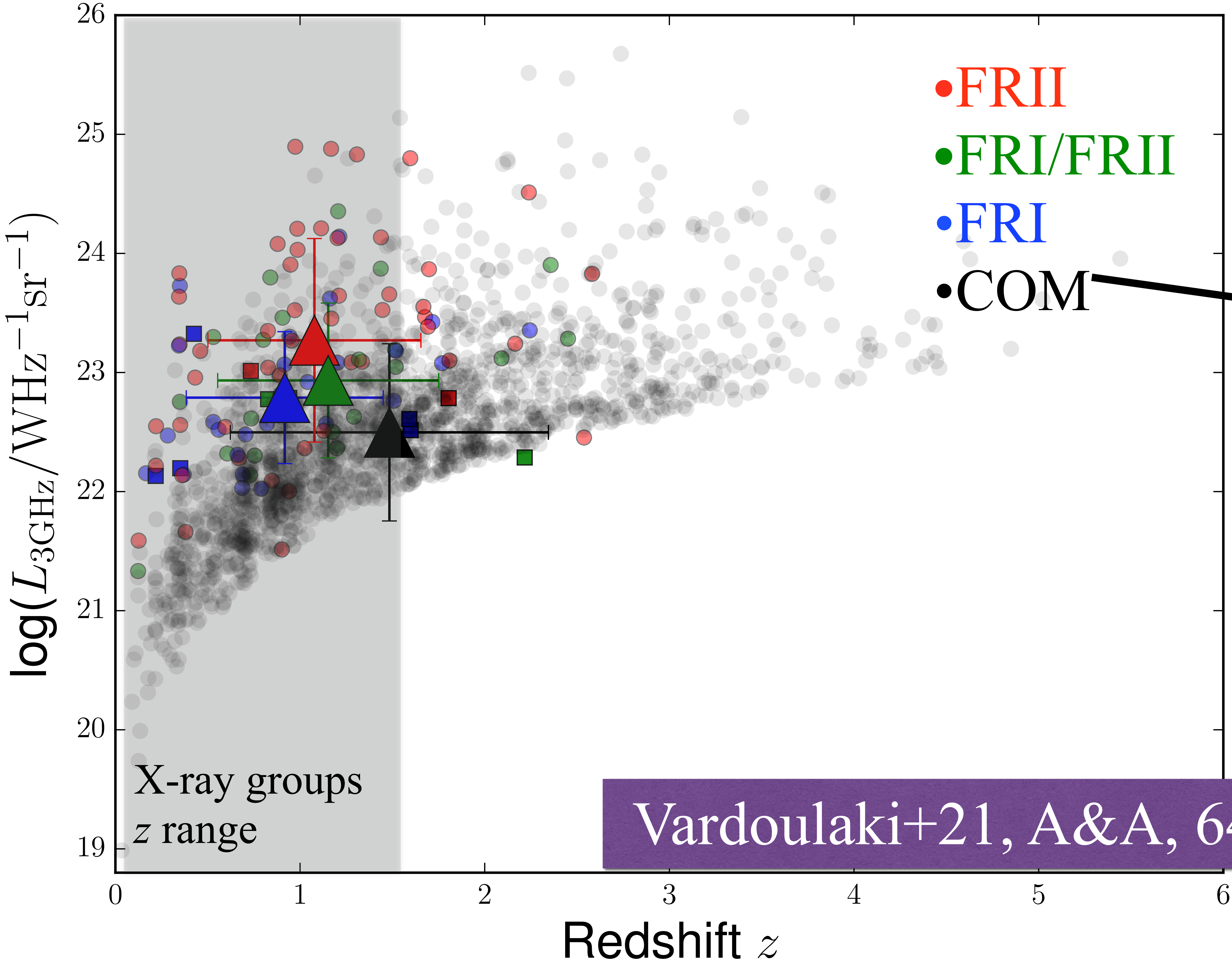
radio AGN @ 3 GHz VLA-COSMOS



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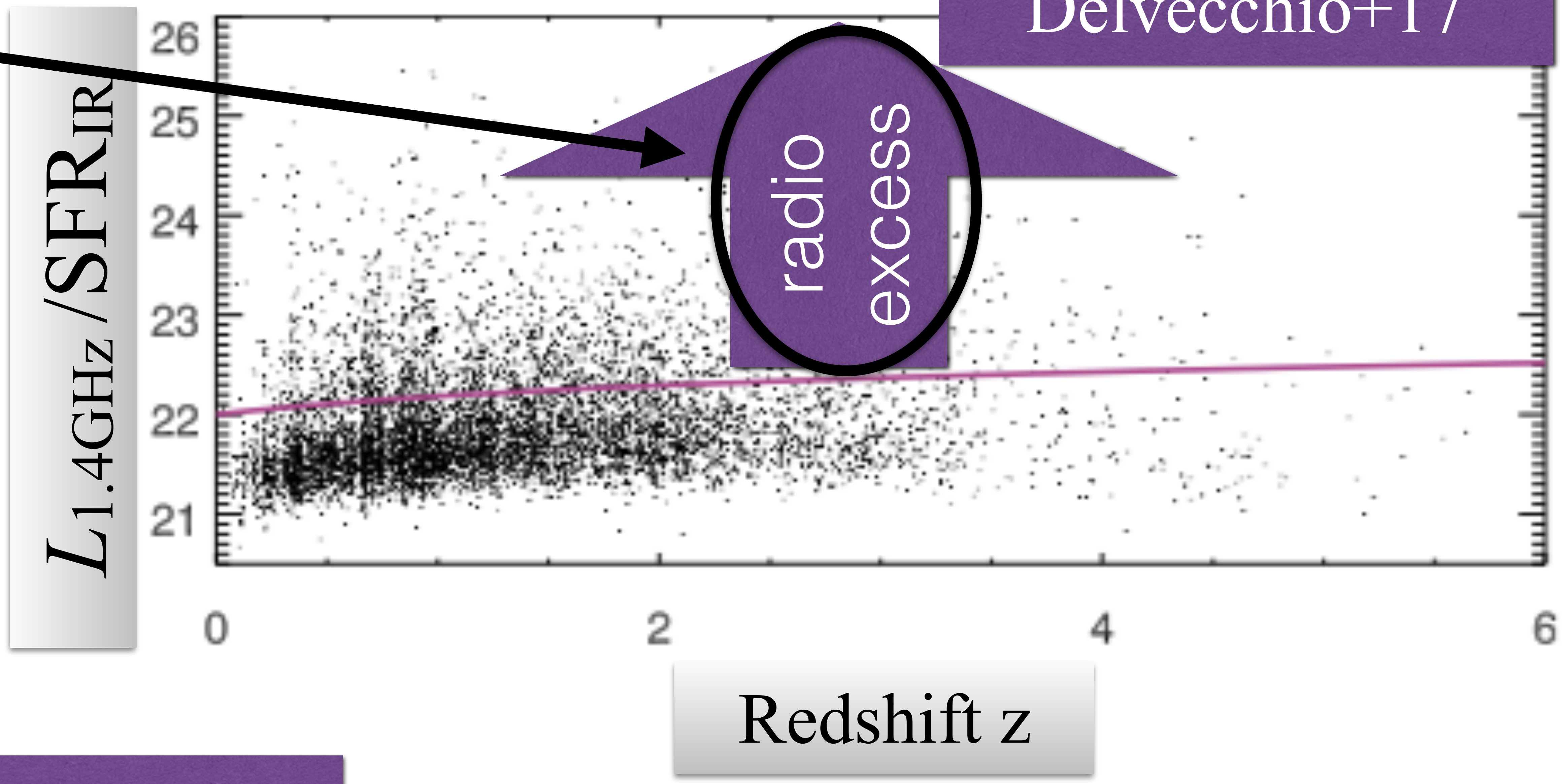

Smolčić…EV+17b
Delvecchio+17

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3 GHz VLA-COSMOS

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FR v physical properties & environment

Vardoulaki+21, A&A, 648A, 102

FR radio sources at 3-GHz VLA-COSMOS:

overlap of distributions

1. <u>sizes & radio power:</u>

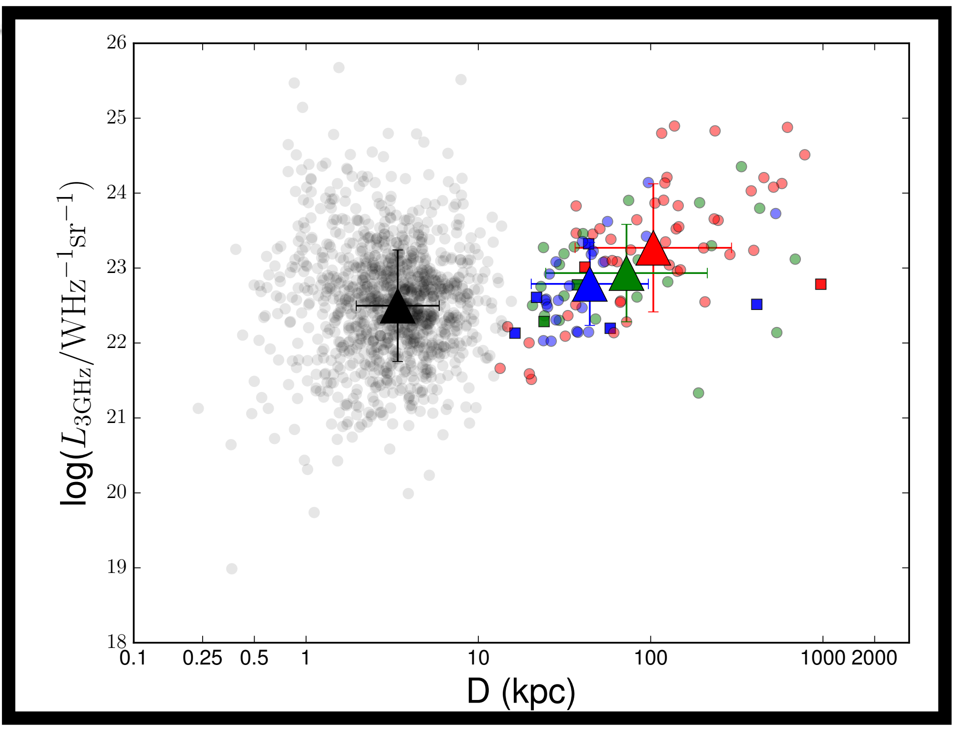
- *L-D*: FRIIs (slightly) brighter & larger than FRI/FRIIs & FRIs

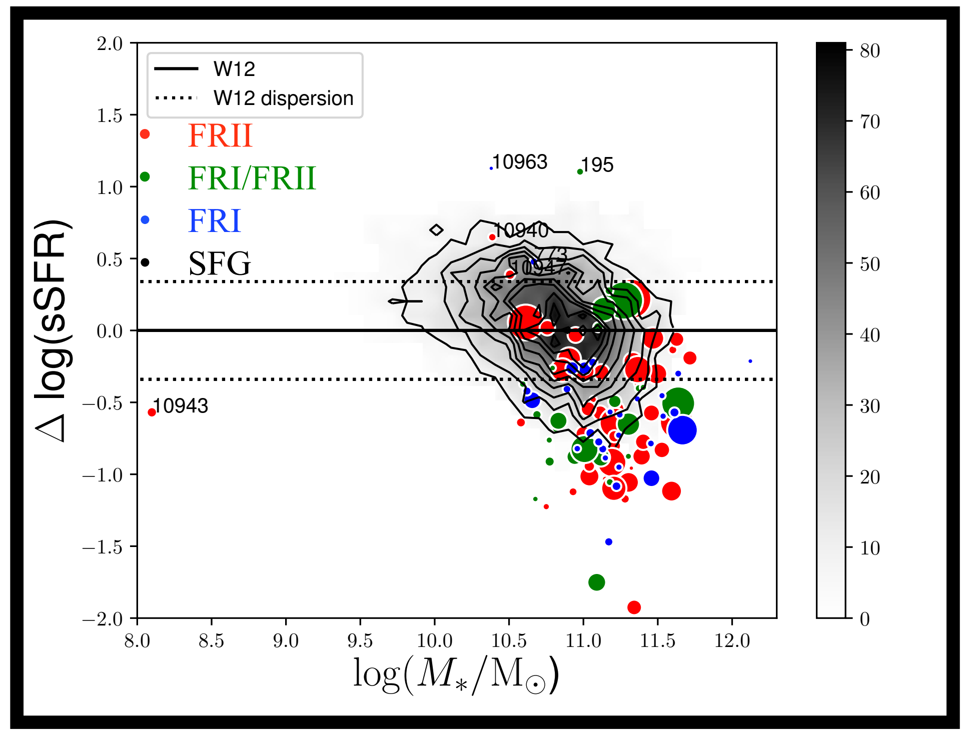
2. <u>Eddington ratio (X-rays):</u>

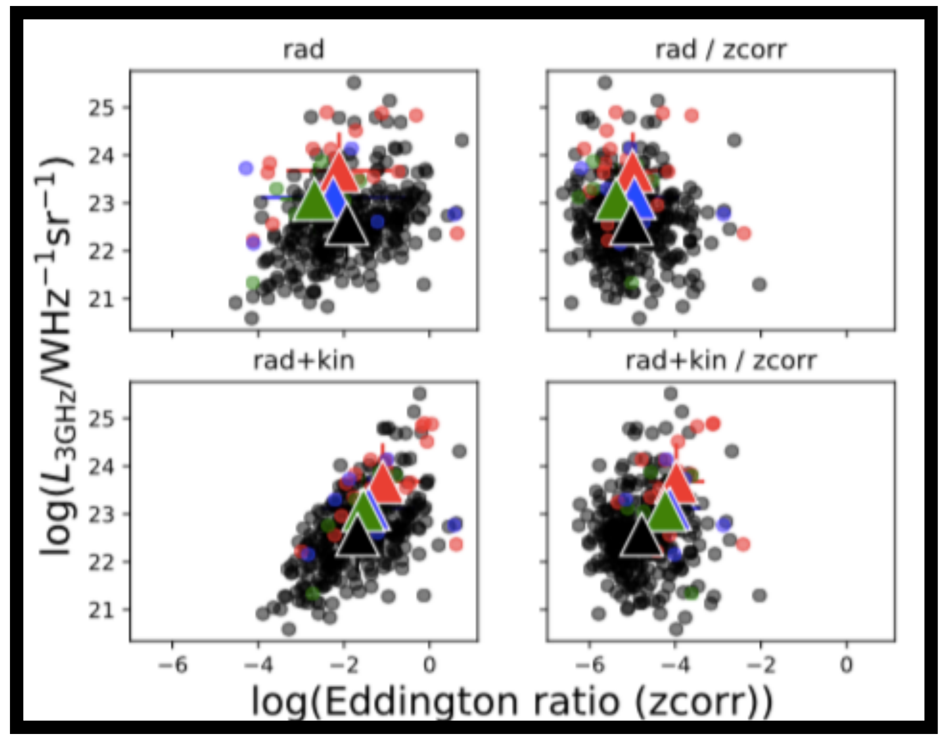
- FRIIs > FRIs with Q_{jet} added - but sub-Eddington

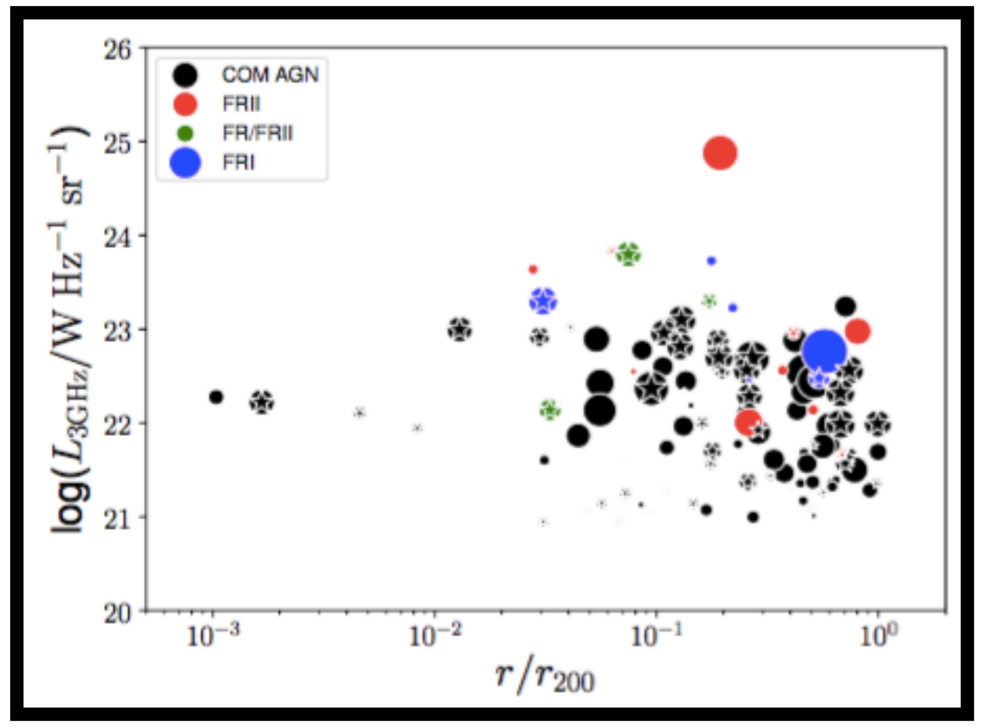
3. <u>environment (hosts, X-ray groups, density fields):</u>

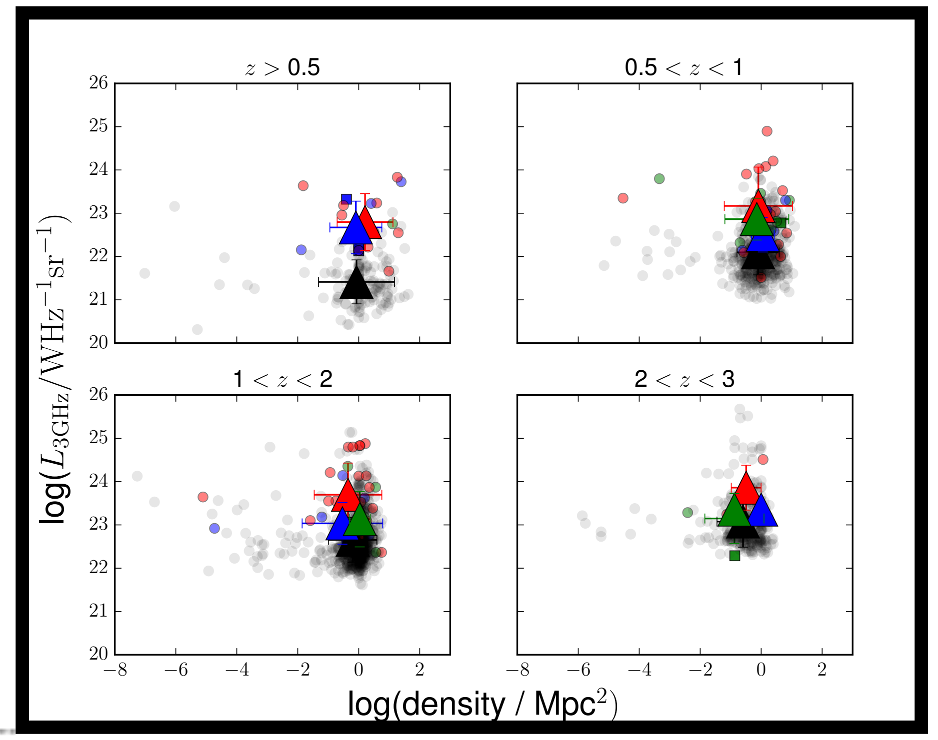
- quenched hosts > 10^{10} M_{sun} ; no preferred location within X group
- FRIs & FRIIs & FRI/FRII ~ density environments $z < 2$; ≠ literature

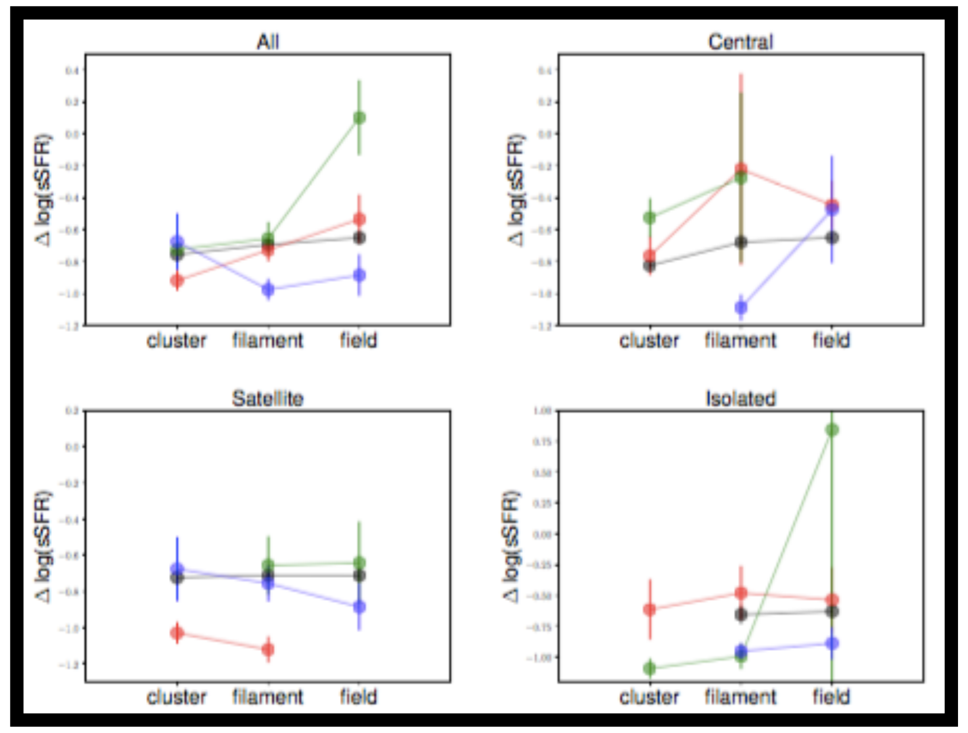






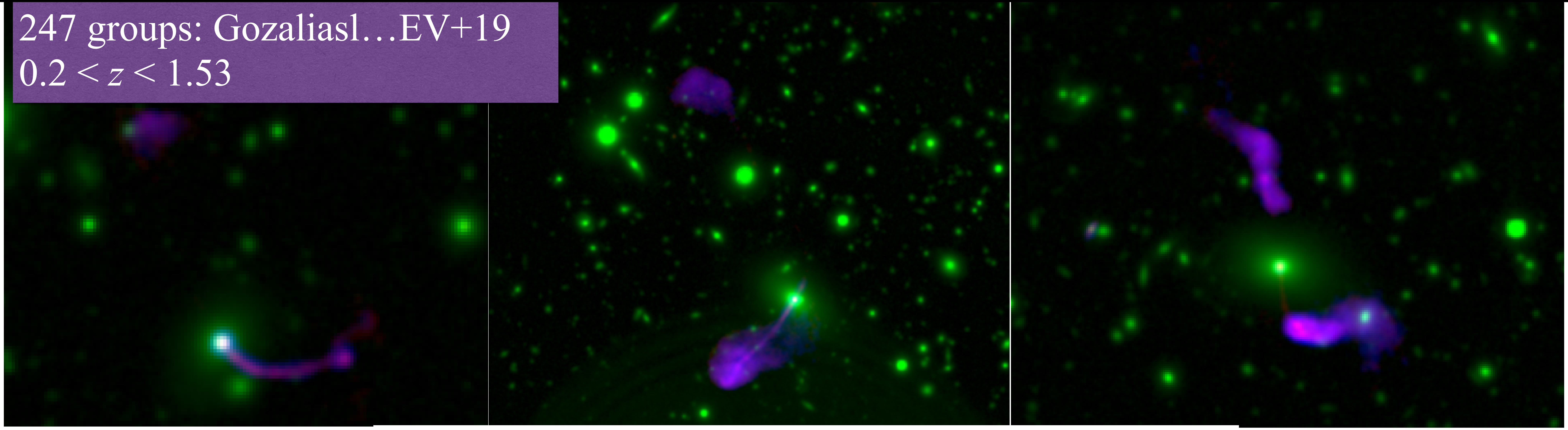




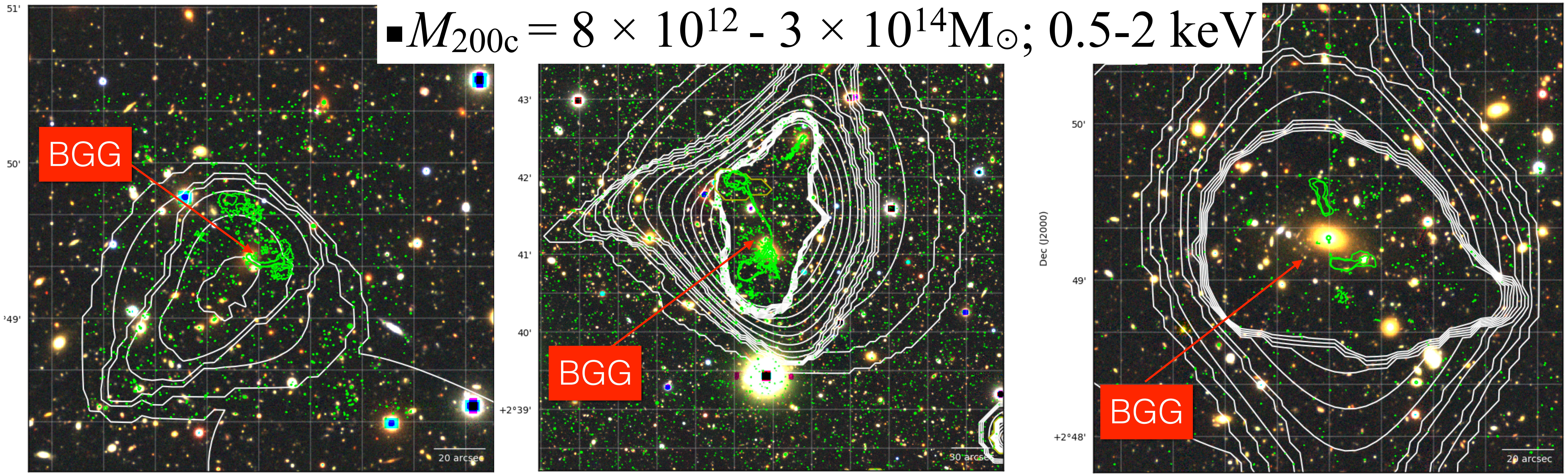


AGN feedback - FRs in COSMOS X-ray groups

247 groups: Gozaliasl…EV+19
$0.2 < z < 1.53$



- $M_{200c} = 8 \times 10^{12} - 3 \times 10^{14} M_{\odot}$; 0.5-2 keV



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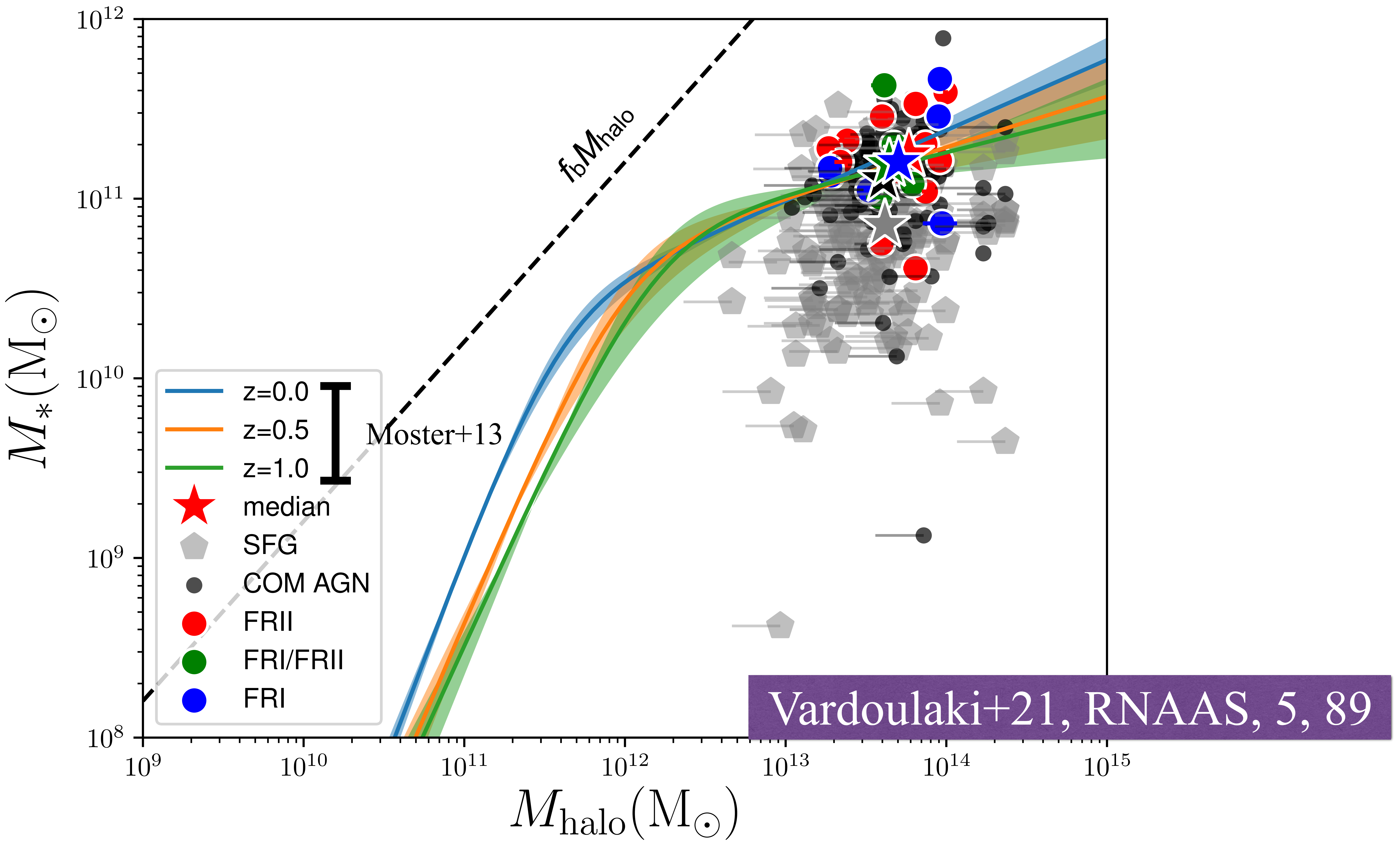
M_* - $M_{\rm halo}$ relation

✦247 groups: Gozaliasl…EV+19 $0.08 < z < 1.53$

✦$M_{\rm halo}$ is M_{200} (L_X-M_{200c} scaling relation Leauthaud+10)

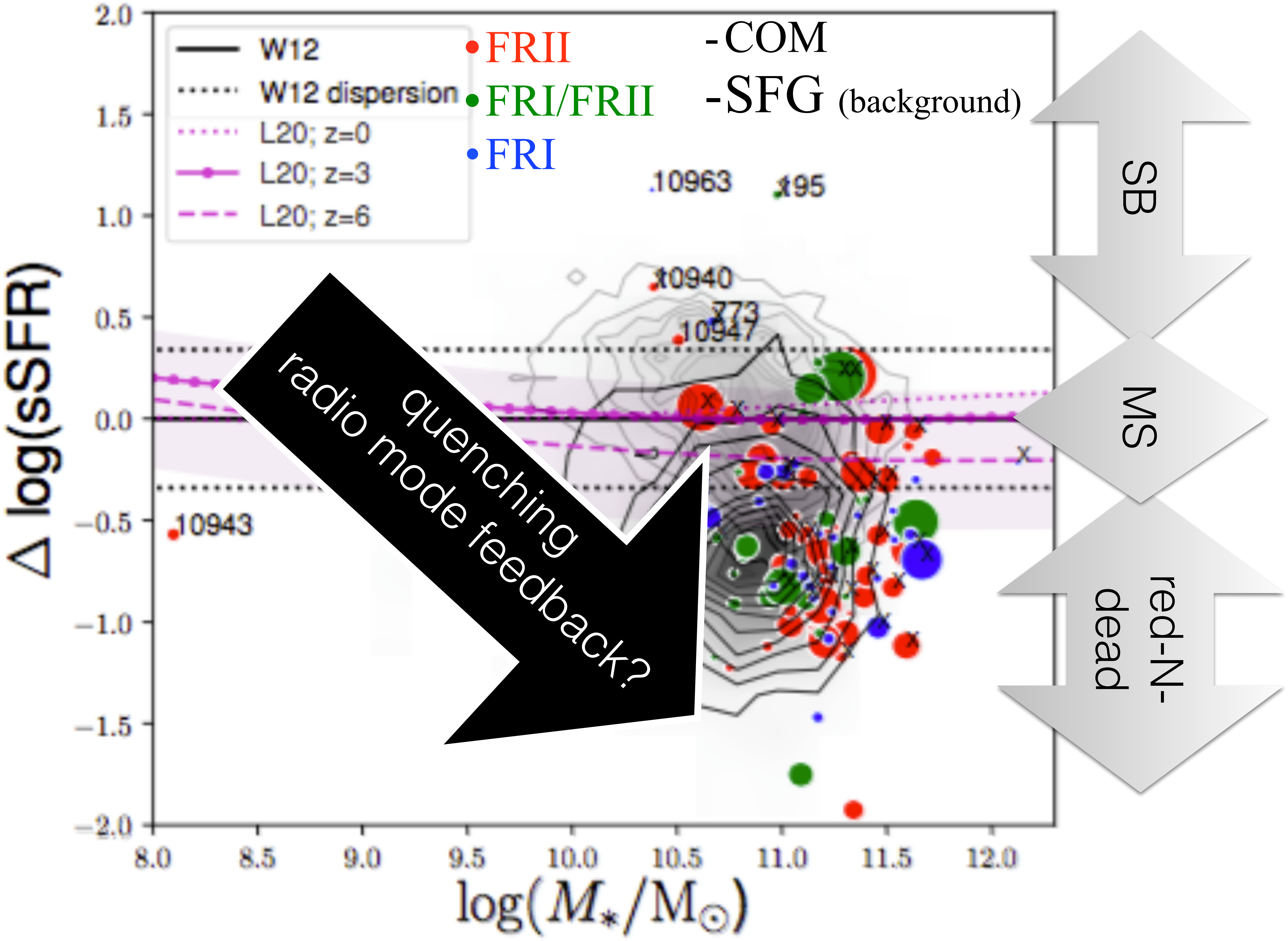
✦ in X-ray groups:

- 24/75 FRs
- 87/963 COM AGN
- 171/6452 SFGs



Vardoulaki+21, RNAAS, 5, 89

AGN radio-mode feedback



Vardoulaki+21, A&A, 648A, 102

AGN radio-mode feedback

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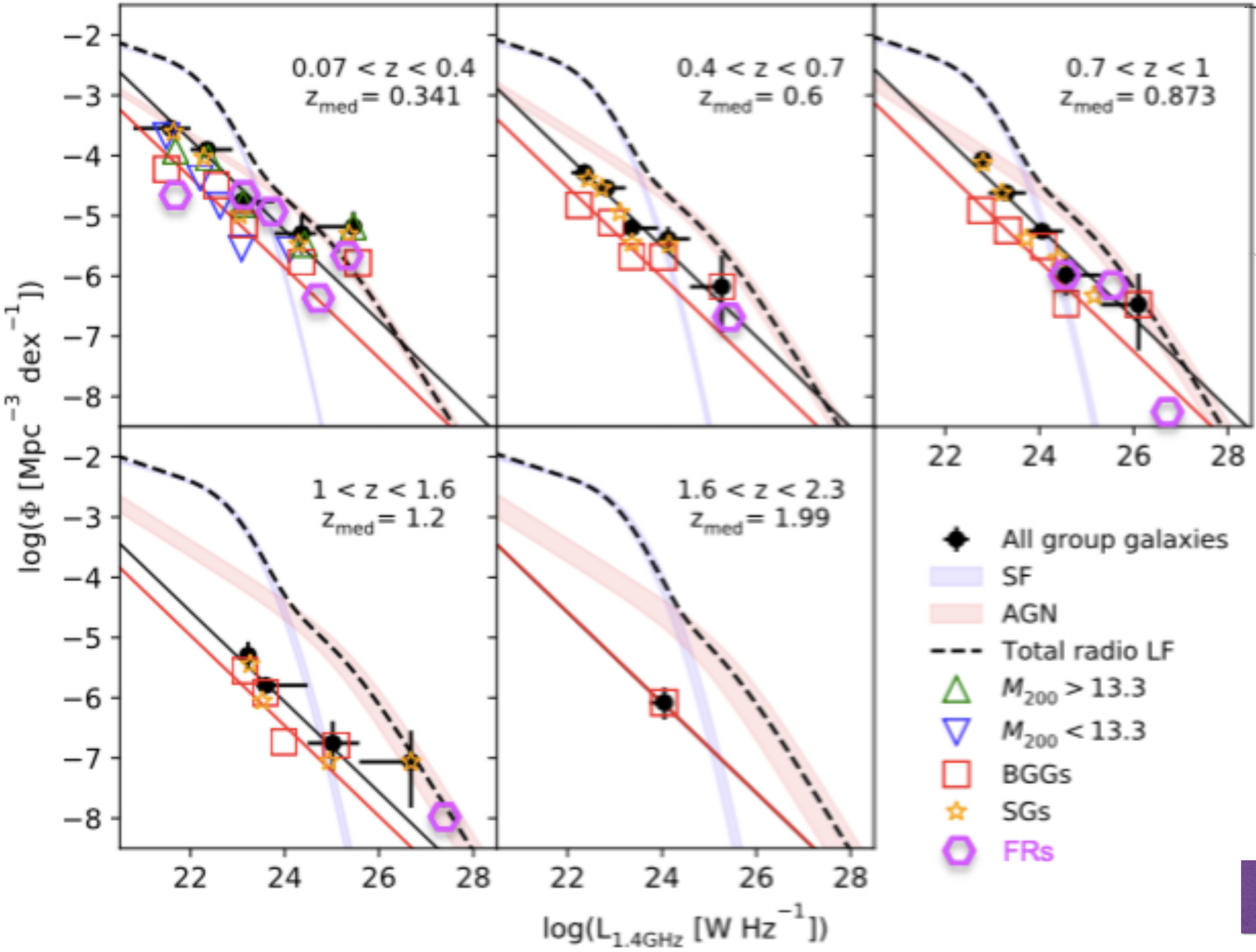
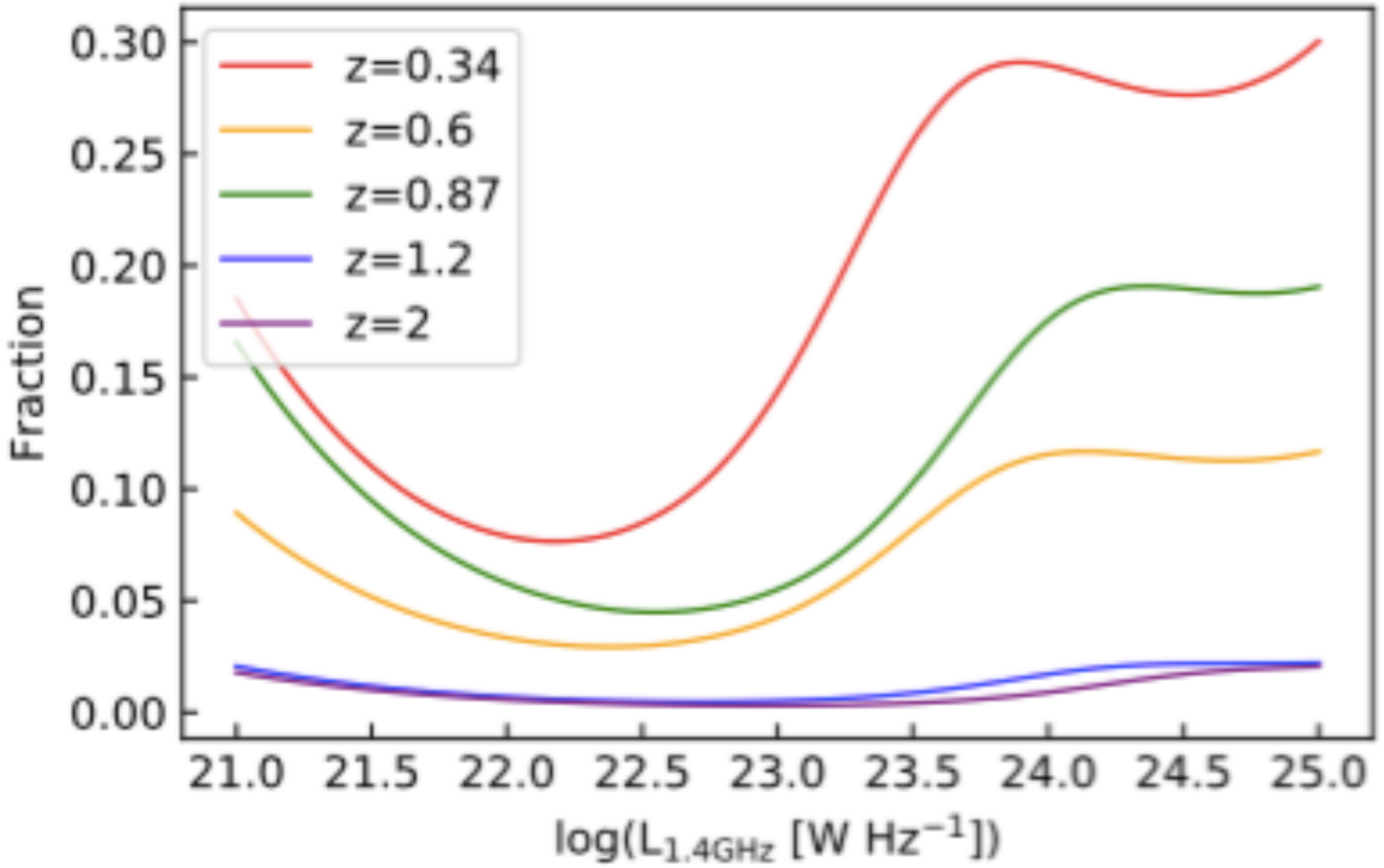
the evolution of the radio luminosity function of group galaxies in COSMOS

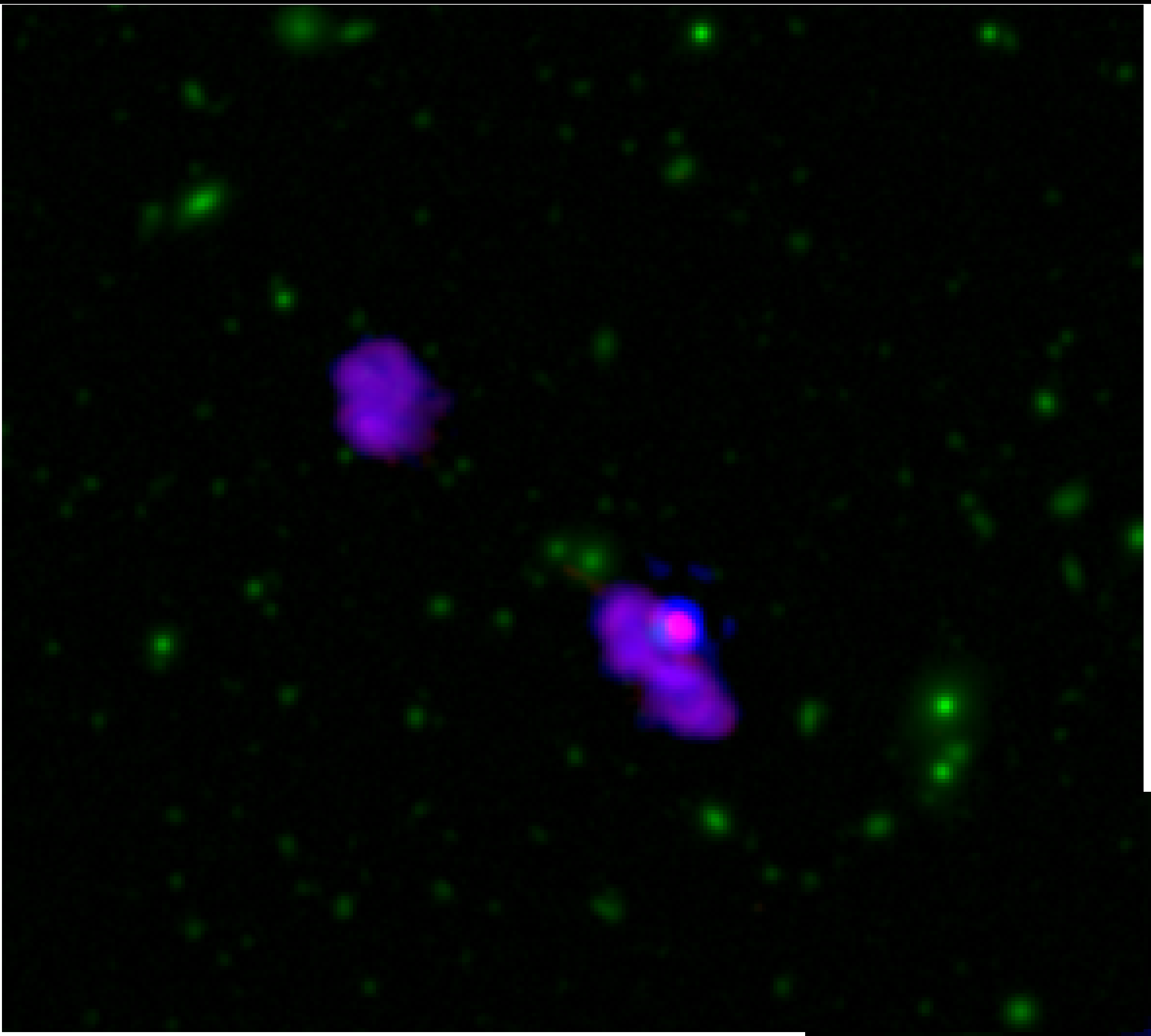


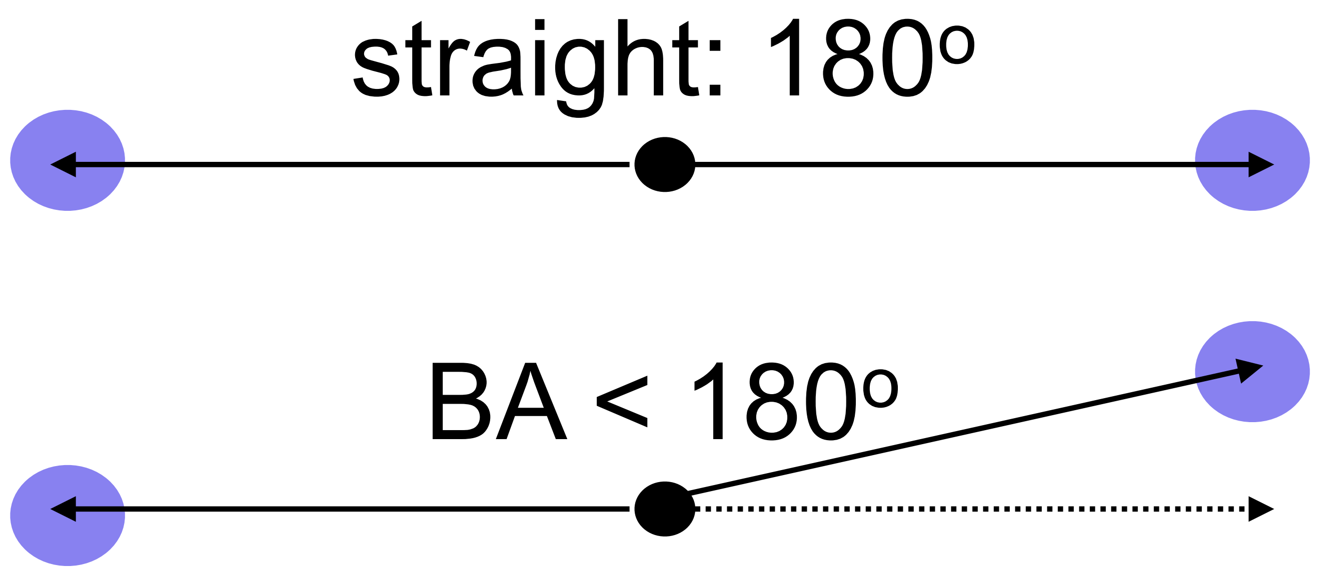
➡ contribution of galaxy groups & FRs higher above 10^{23} W/Hz and for $z < 1$

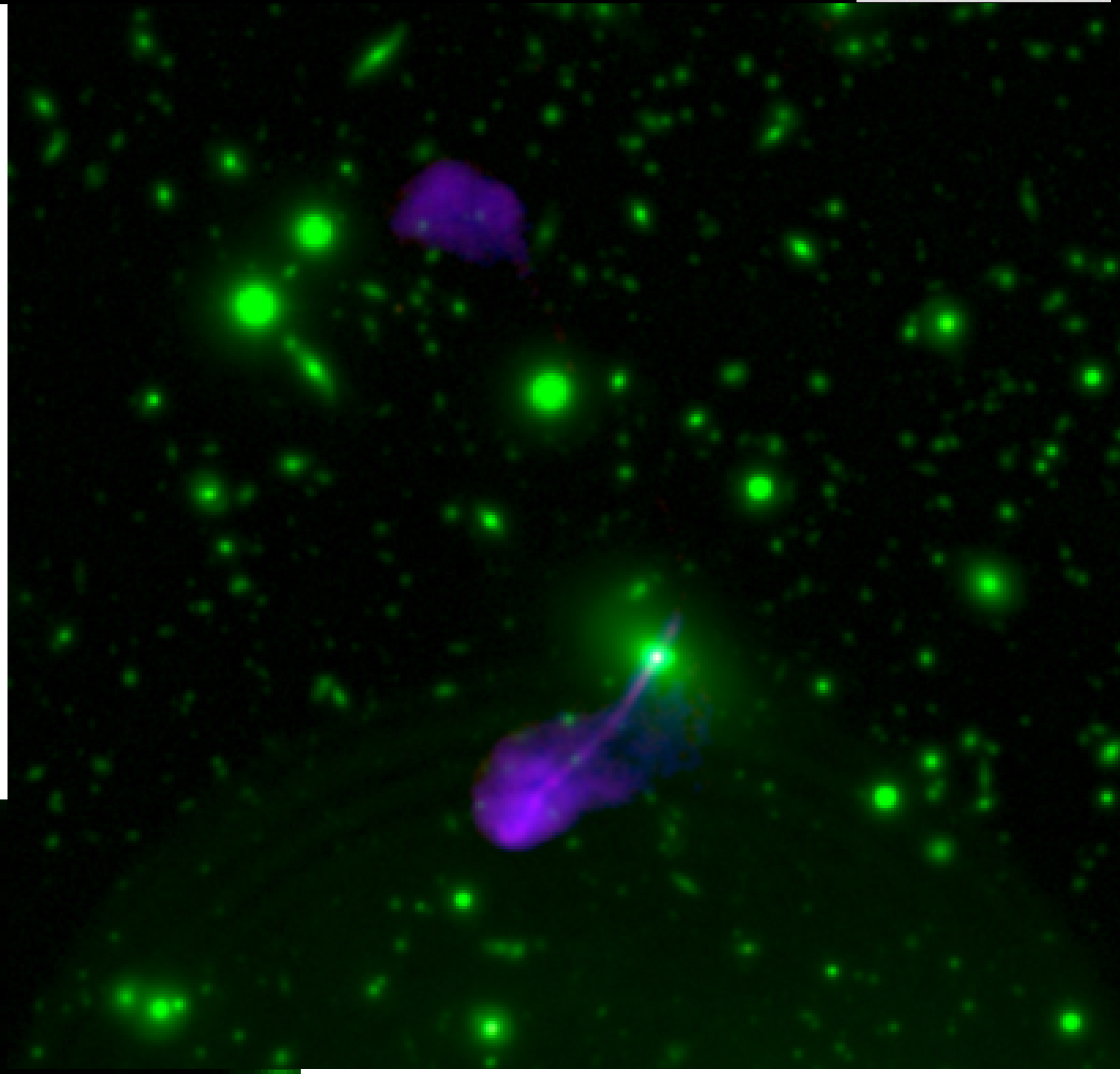


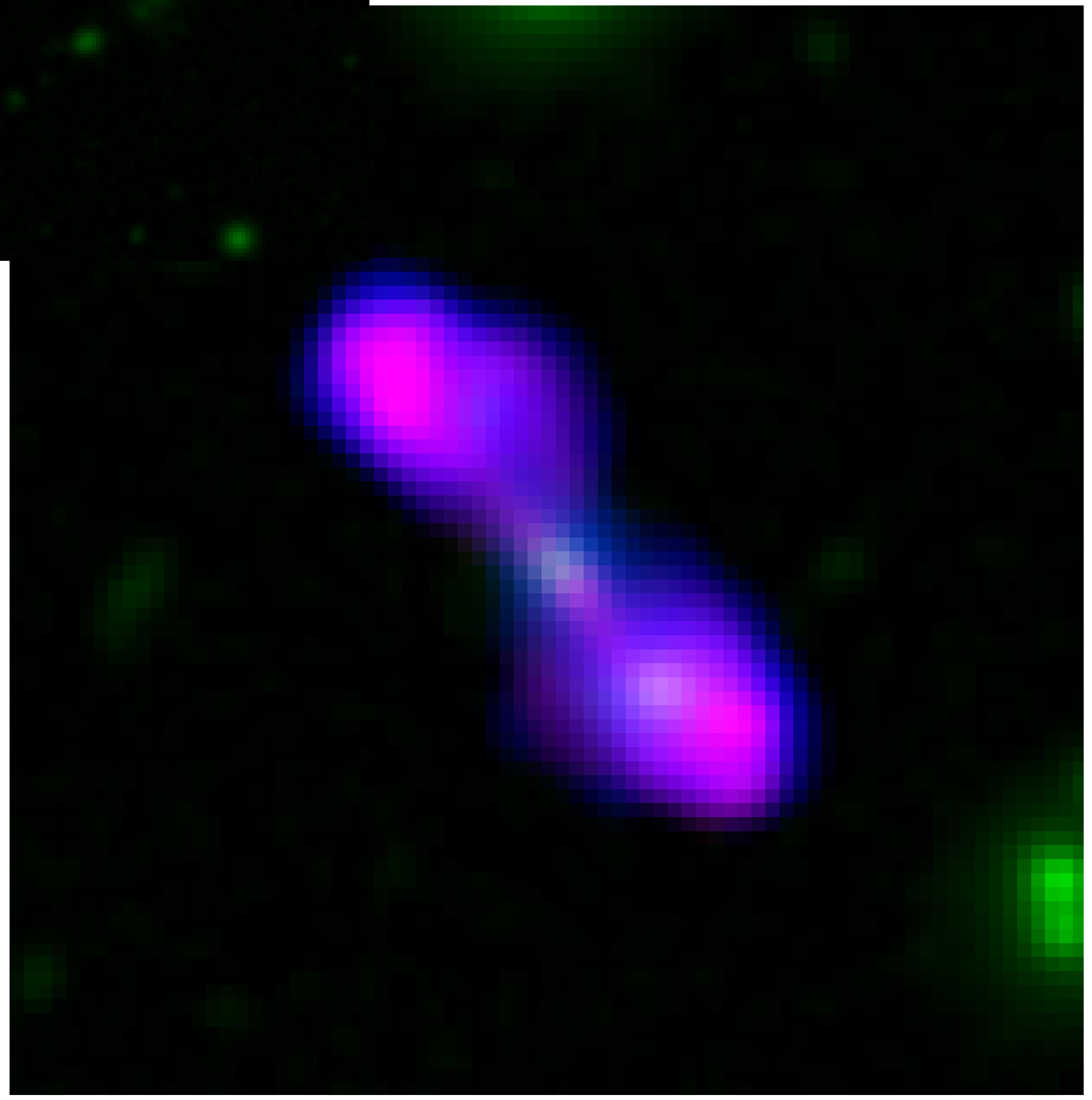
Vardoulaki, Gozaliasl, Novak, et al. in prep.

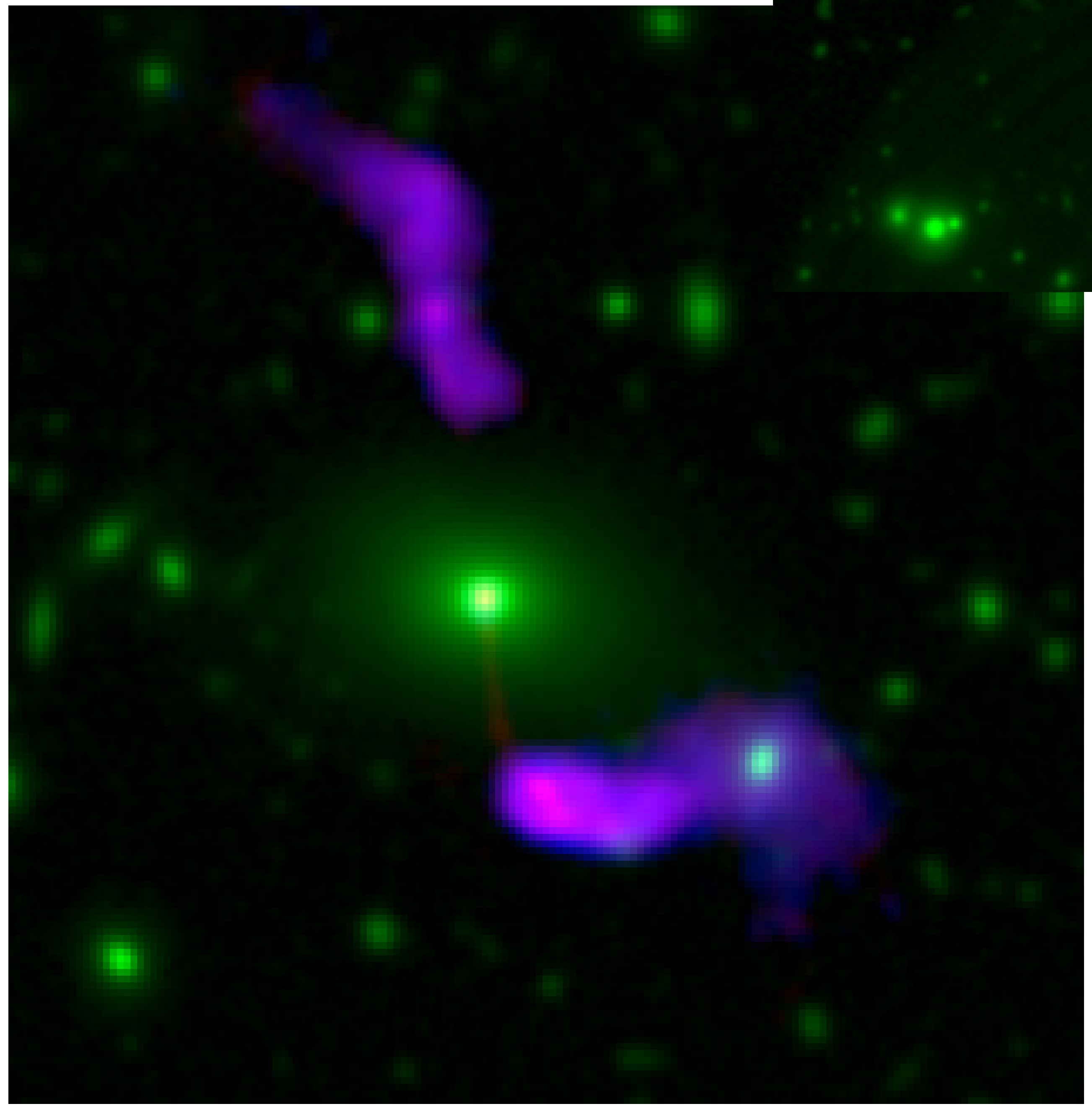
FR bent angle











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take away

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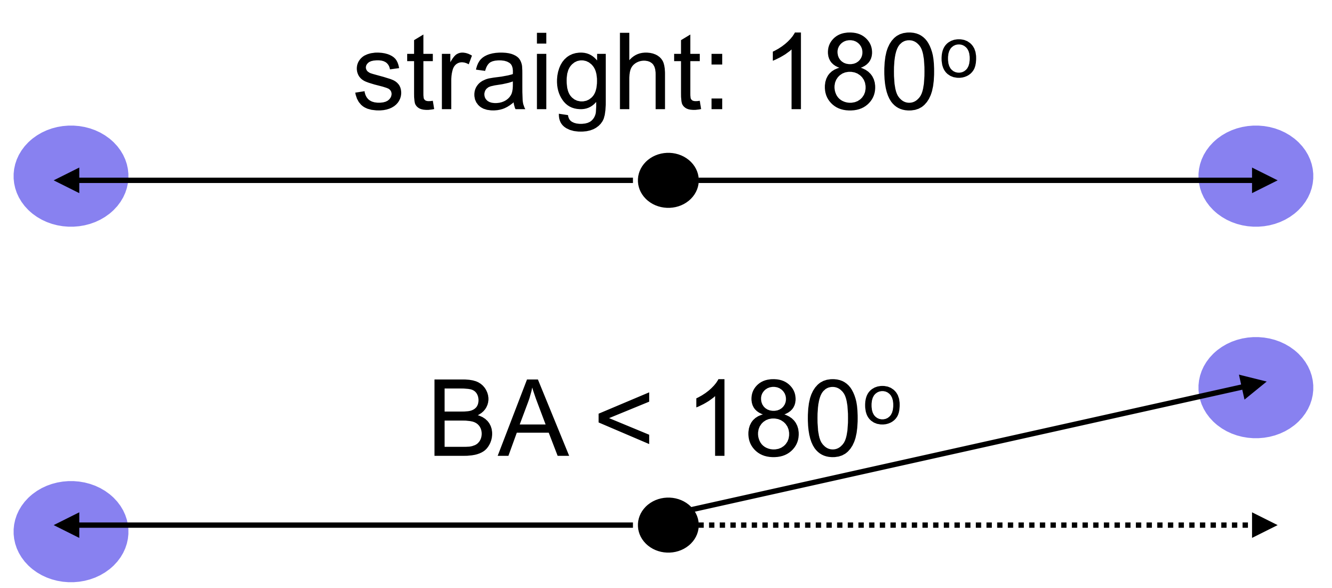
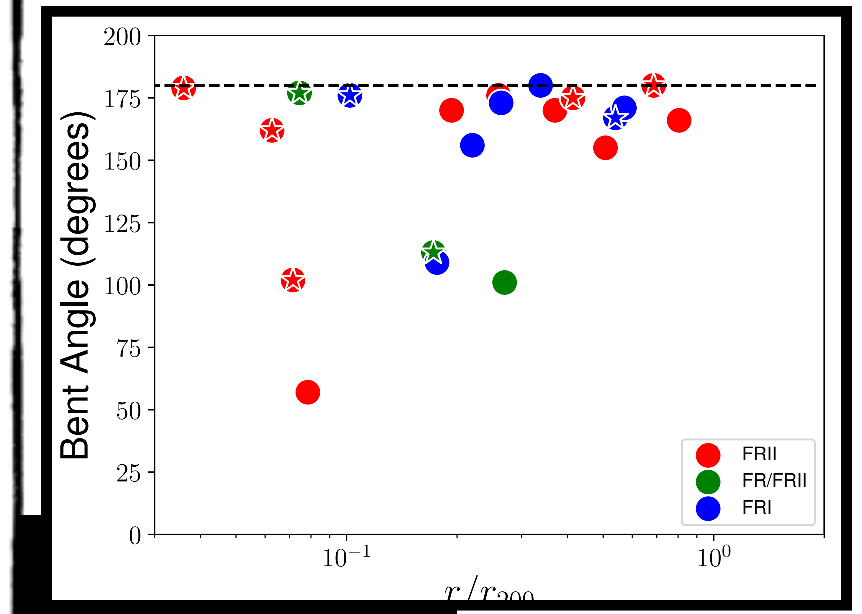
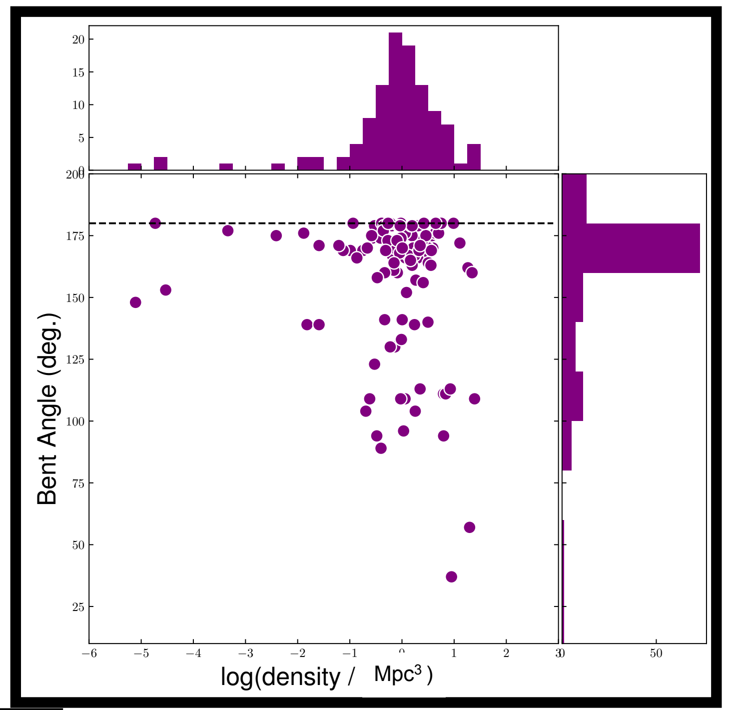
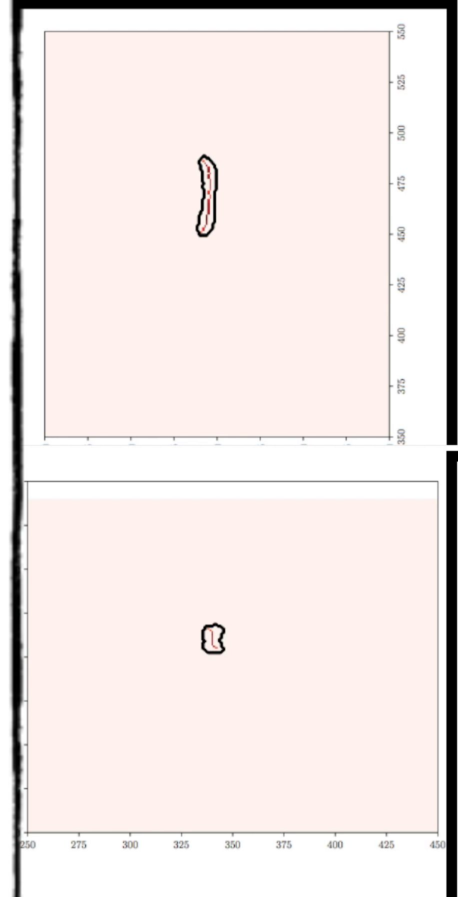
- 3GHz VLA-COSMOS; 2.6 deg^2, 0''.75, 2.3μJy/beam (Smolčić…EV+17a; Vardoulaki+21, A&A, 648A, 102)
- distortion of FR structure traced by angle between lobes/jets: bent angle
- **$\langle BA_{FRs} \rangle = 167.0^o$ +/- $55^o.1$, $\langle z_{FRs} \rangle = 0.90$; $\langle BA_{FRs\_z<0.5} \rangle = 155.5^o$ +/- $85^o.1$**
- no clear relation of BA to:
  - distance from X-ray group centre, group temperature
  - density fields, Darvish environments (cluster, filament, field)
  - **indications for low BA (<75^o) in dense environments & filaments**
- **comparison to simulations (Vazza+21):**
  - z = 1: BA evolution within the dispersion of COSMOS data
  - z = 0.5: COSMOS data agree (large dispersion)

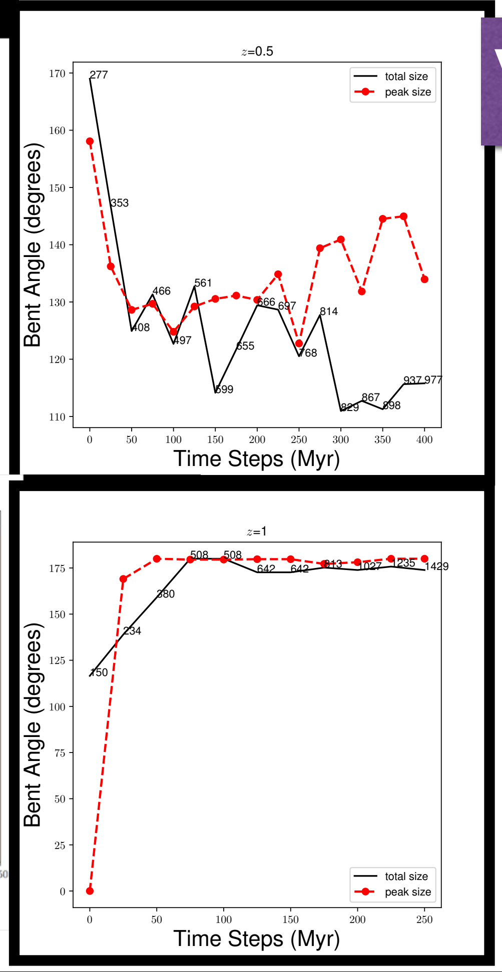


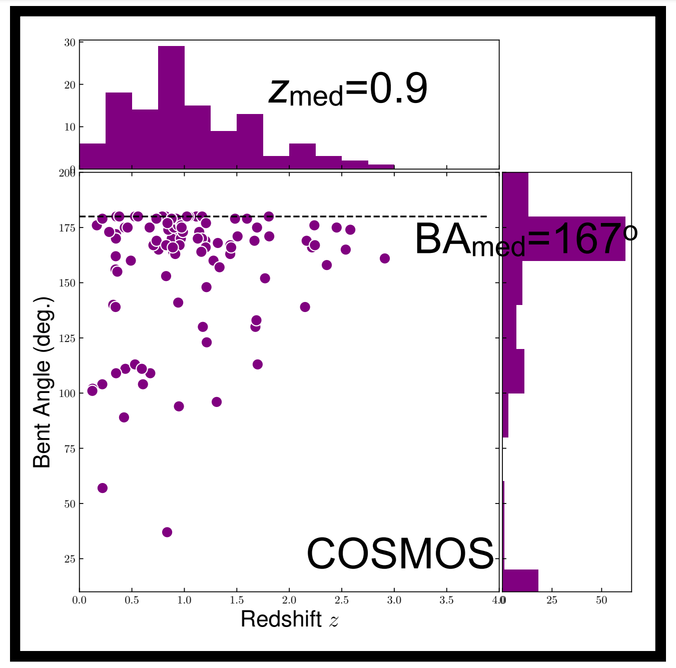




Vardoulaki+in prep.







semi-auto code: size + FR class

1. Skeletonise
2. Clustering
3. Maximising d
4. FR classification

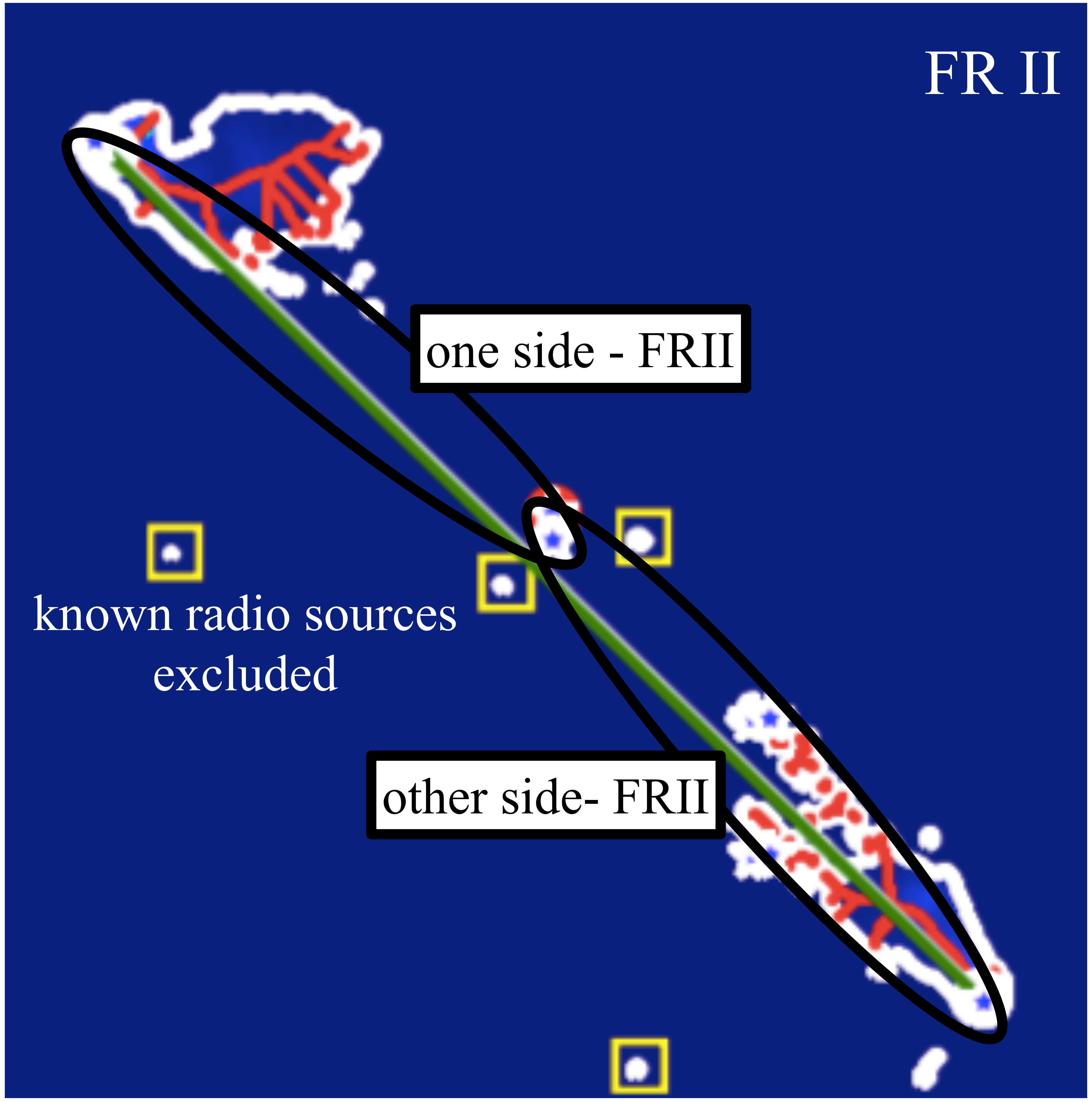
developed by Eric Jimenez Andrade

developed by EV

good LAS estimation for ~93% of sources

Vardoulaki+21, A&A, 648A, 102
Vardoulaki, Jimenez Andrade+in prep.

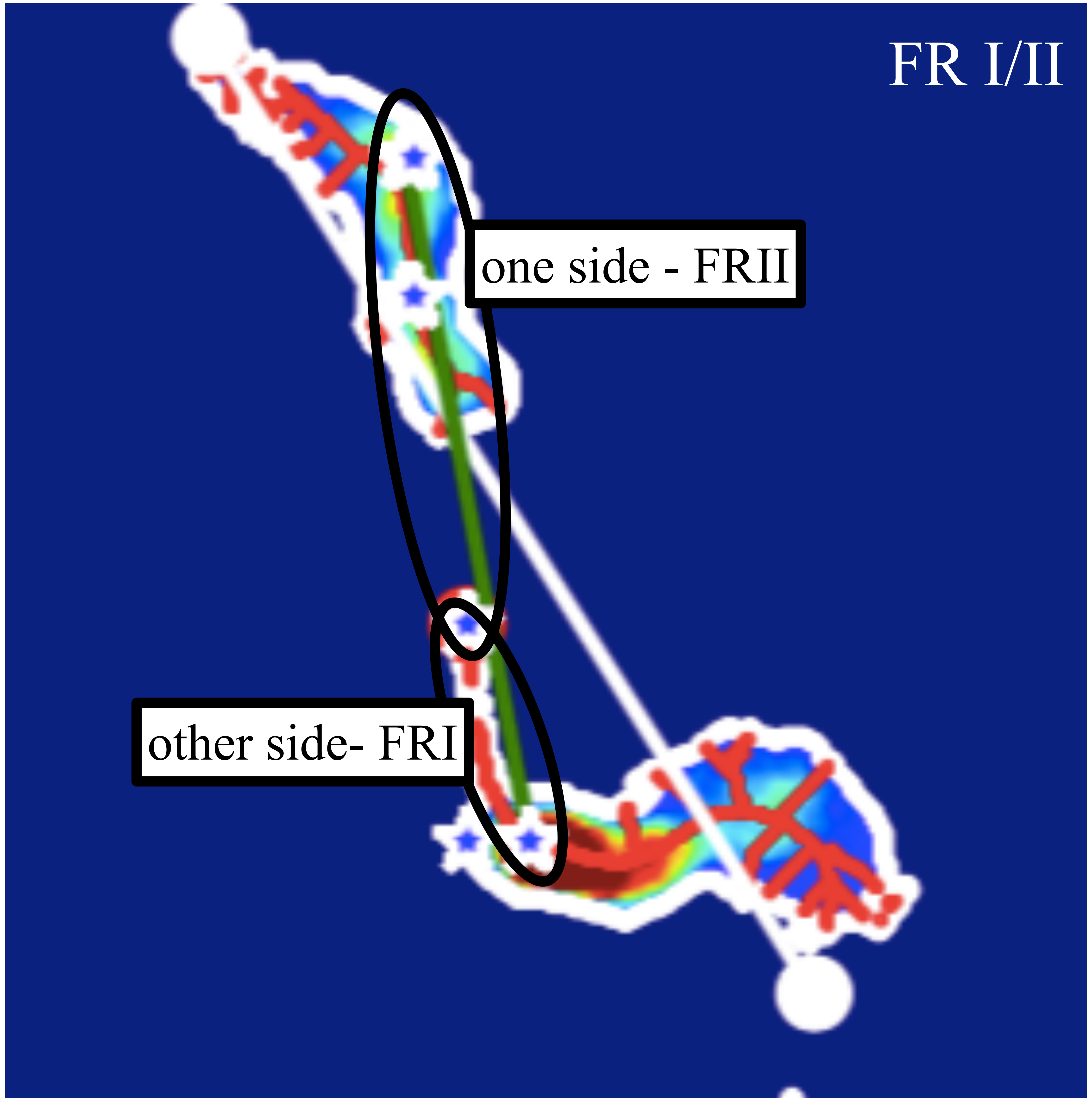
semi-auto code: FR class

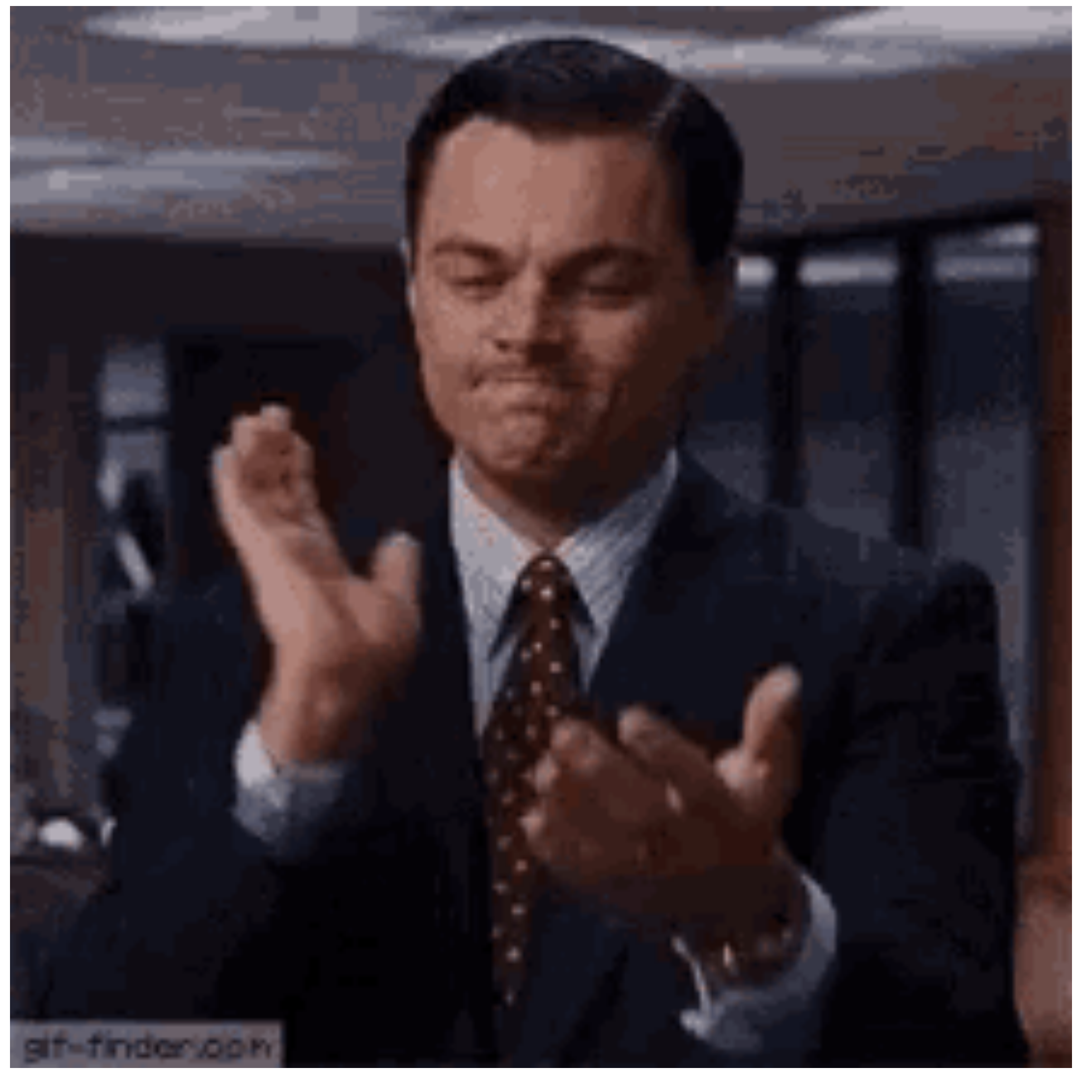


- finds flux maxima ★
- measures the max difference between LAS and flux peaks on each side of the skeleton centre
- uses classic FR classification scheme to give FR class
- good FR estimate for 44% of sources - compared to visual

Vardoulaki+21, A&A, arXiv200910721V
Vardoulaki, Jimenez Andrade+in prep.

semi-auto code: FR class





Vardoulaki+21, A&A, arXiv200910721V
Vardoulaki, Jimenez Andrade+in prep.

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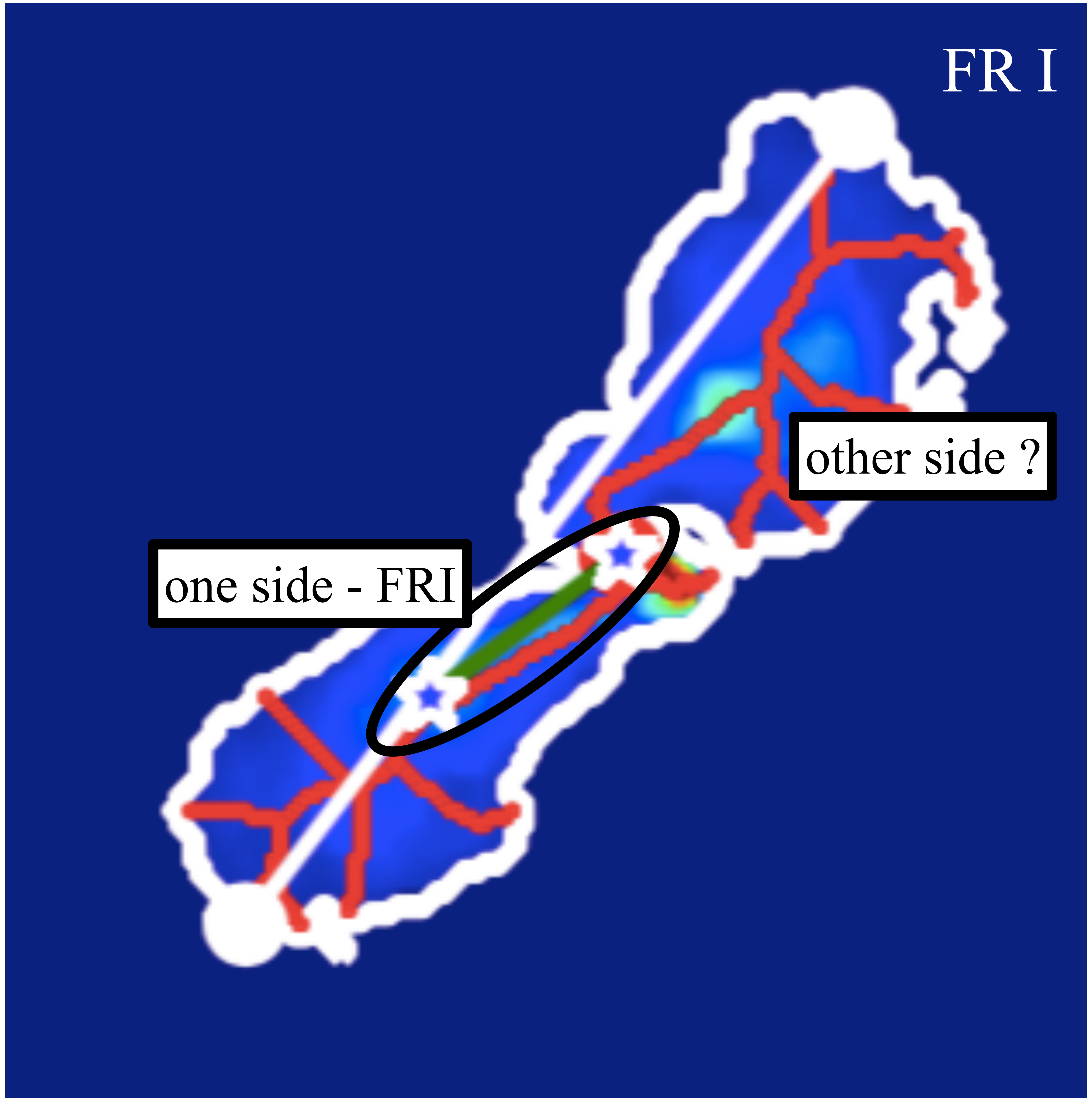
semi-auto code: FR class



Vardoulaki+21, A&A, arXiv200910721V
Vardoulaki, Jimenez Andrade+in prep.

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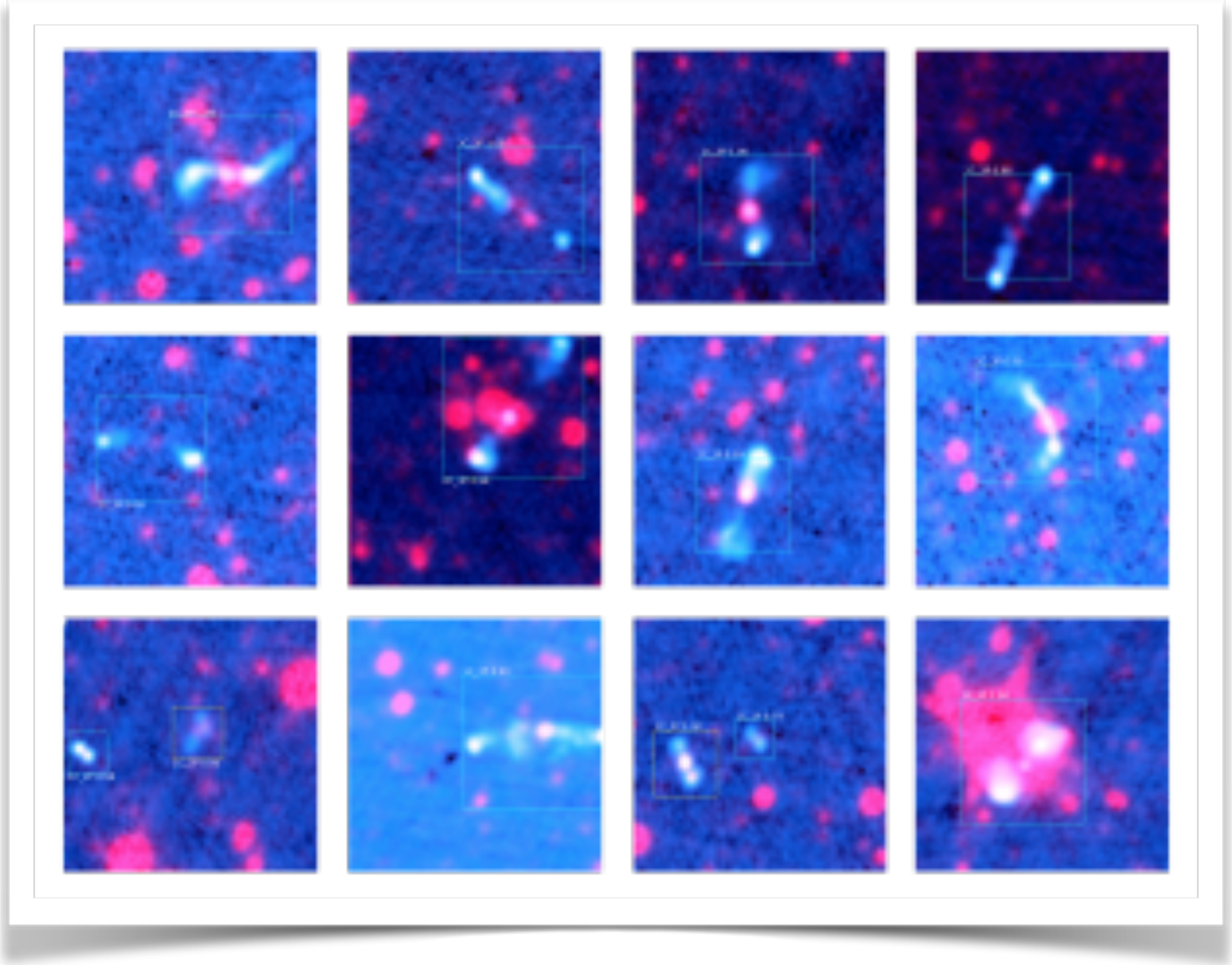
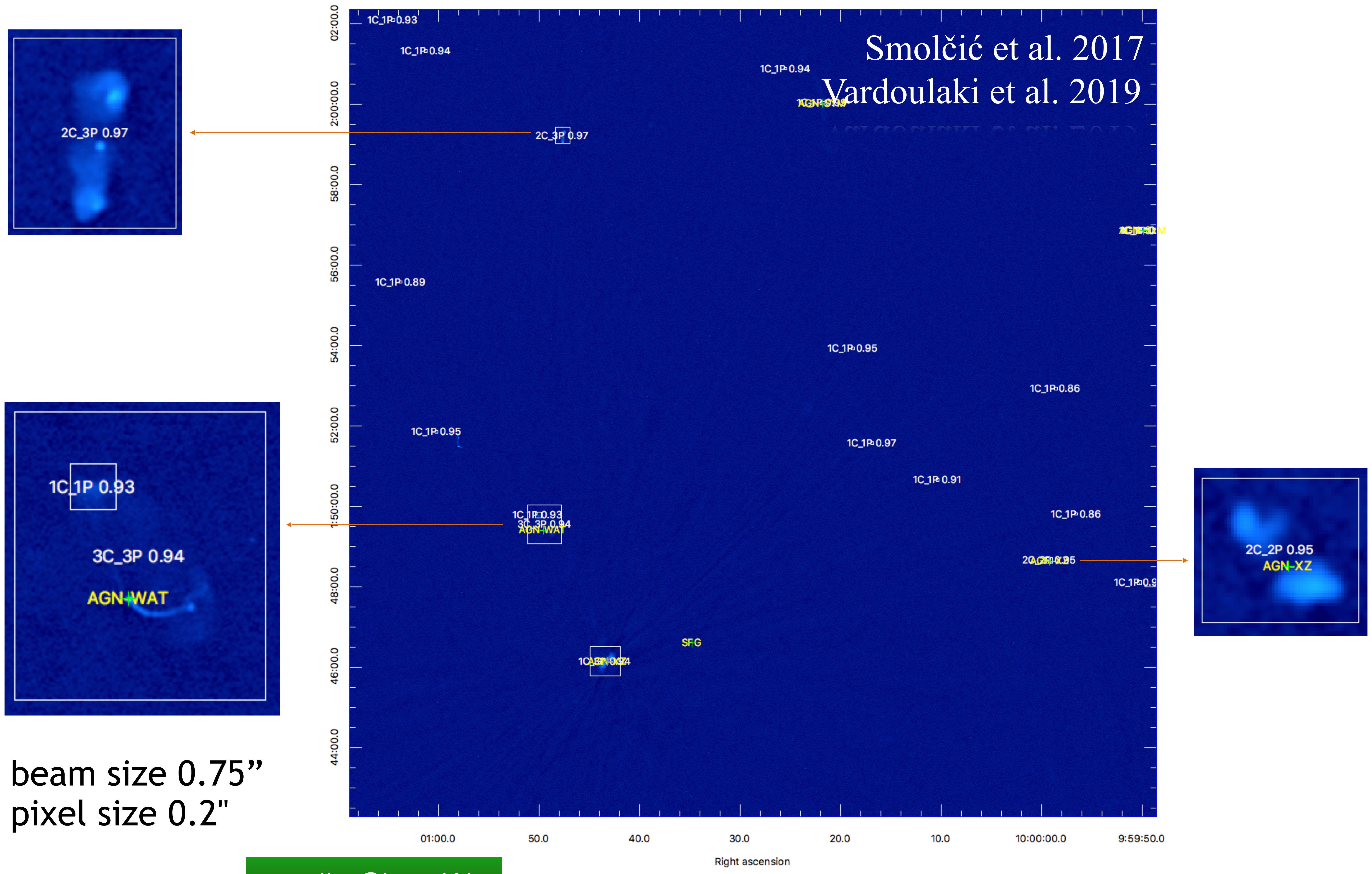


Based on Wu+18 & Vardoulaki+19

ClaRAN tested on VLA-COSMOS at 3 GHz

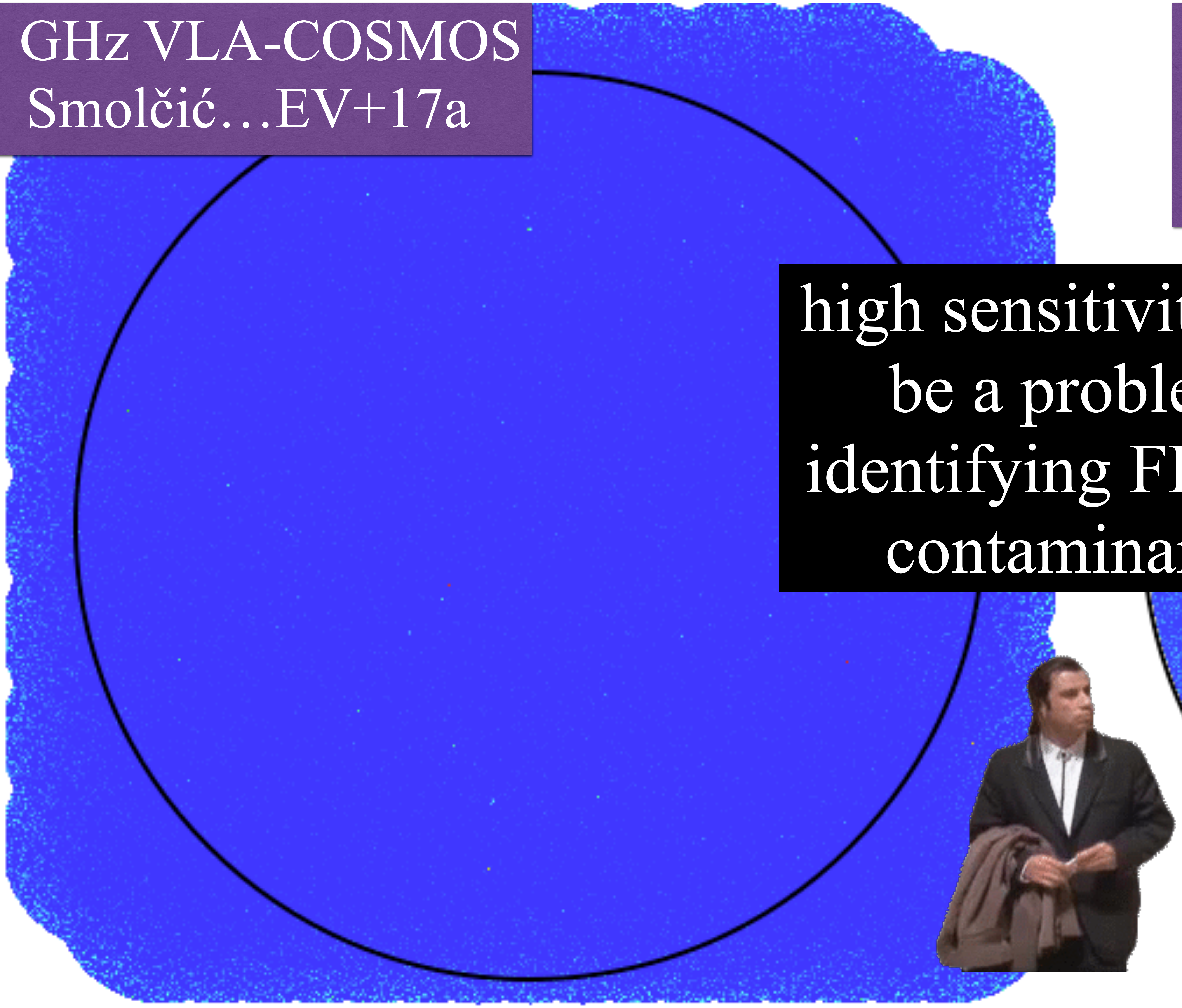


beam size 0.75”
pixel size 0.2"

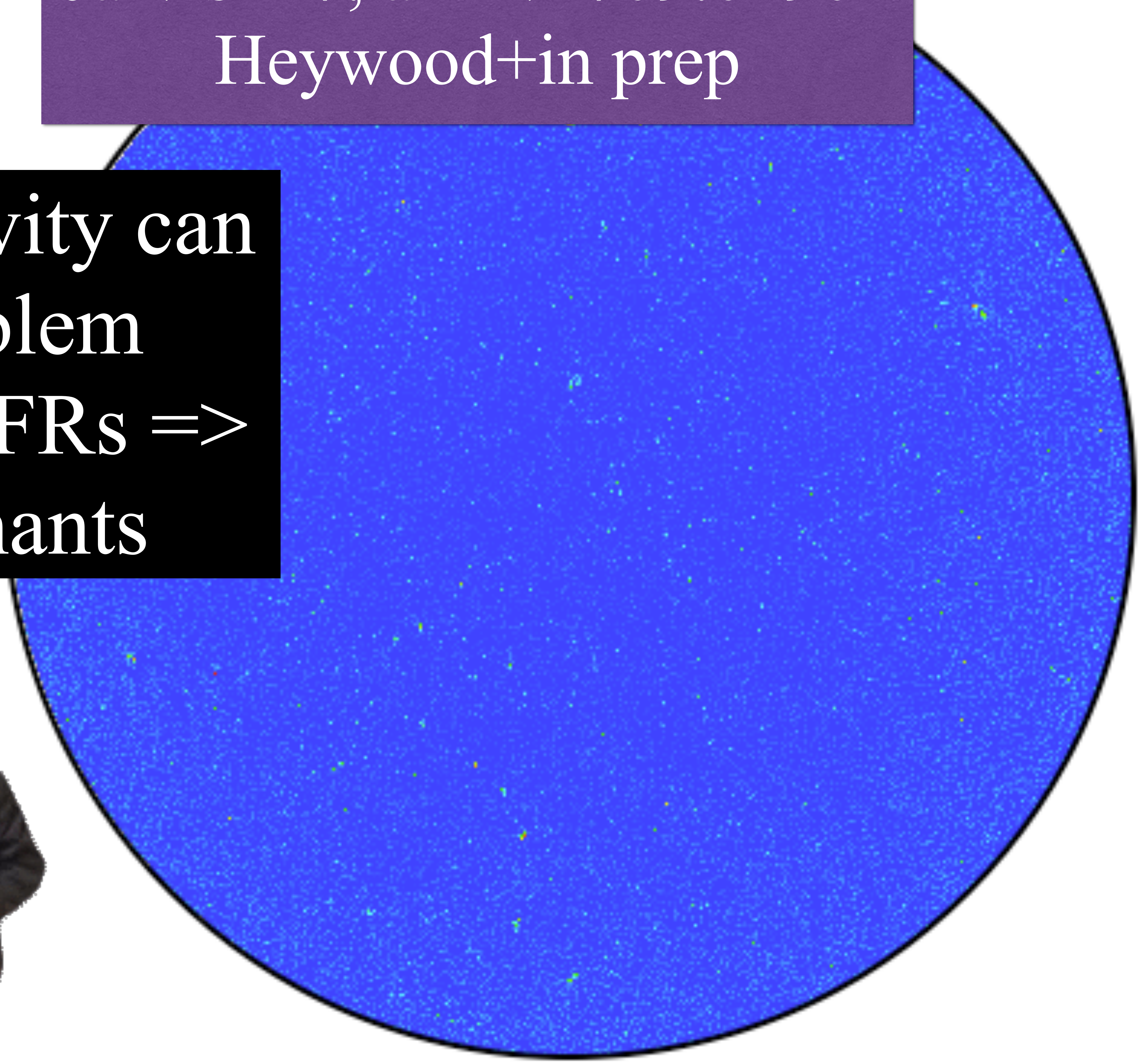
credit: Chen Wu

3GHz VLA-COSMOS vs MIGHTEE COSMOS

3 GHz VLA-COSMOS
Smolčić…EV+17a



MIGHTEE
Jarvis+17, arXiv1709.01901
Heywood+in prep



high sensitivity can be a problem identifying FRs => contaminants

3GHz VLA-COSMOS vs MIGHTEE COSMOS

Vardoulaki+21, A&A, arXiv:2009.10721

based on Vardoulaki+21	3 GHz VLA-COSMOS 2.6 deg^2	MIGHTEE COSMOS (1.3 GHz) ~1 deg^2
rms/resolution	2.3 μJy/beam 0".75	4 μJy/beam (confusion limit) 4".5
FRs	130	99*
not in coverage		31
resolved/ unresolved* jets		81 / 18

3GHz VLA-COSMOS vs MIGHTEE COSMOS

Vardoulaki+21, A&A, arXiv:2009.10721

Vardoulaki+in prep.

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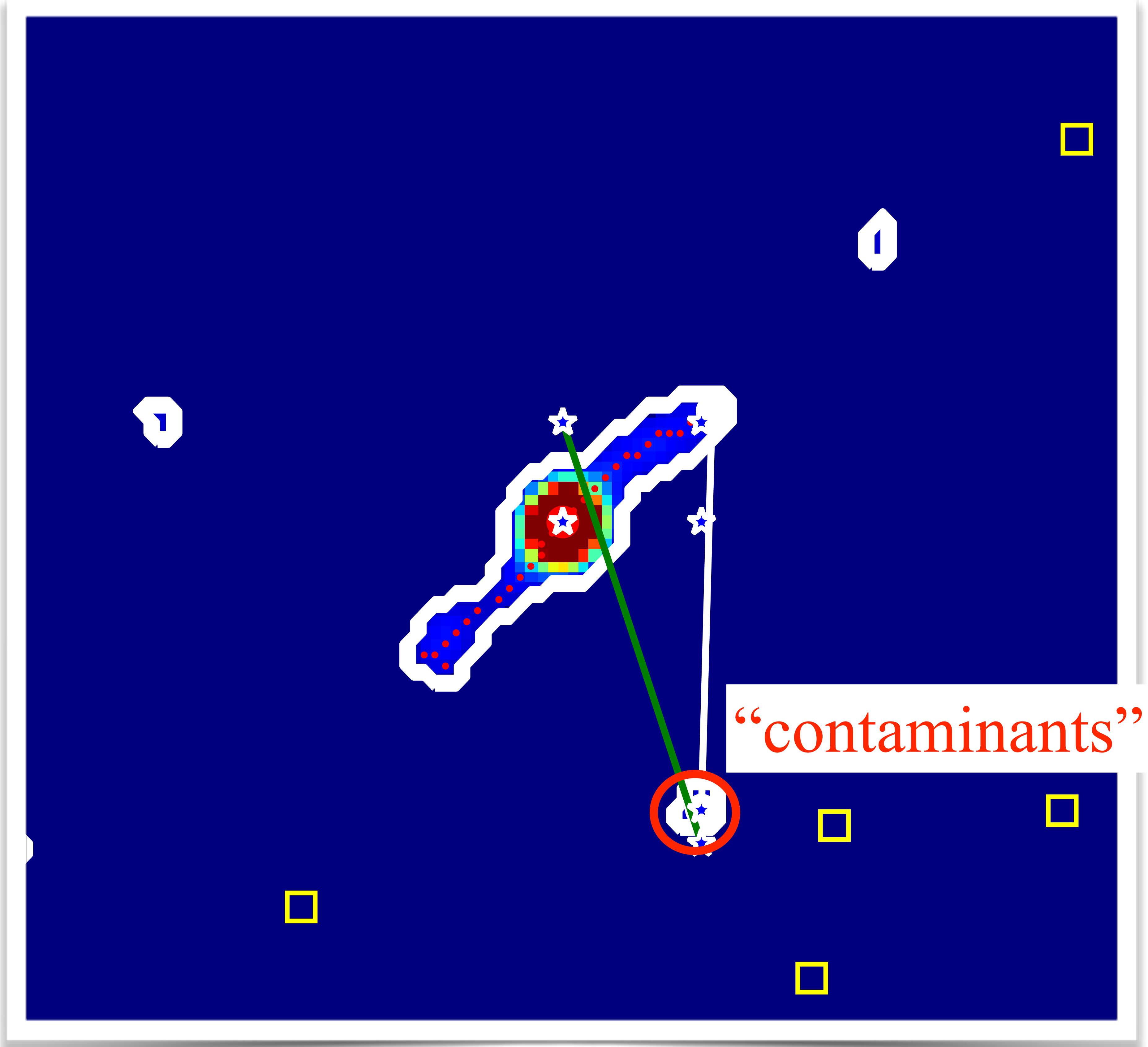
current solution

• remove “contaminants”, i.e. objects not related to FR structure



Vardoulaki+in prep.

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take away

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- The COSMOS field ideal for multi-wavelength studies
- 3 GHz VLA-COSMOS; 2.6 deg^2, 0".75, 2.3μJy/beam (Smolčić…EV+17a; Vardoulaki+19, A&A, 627A, 142; Vardoulaki+21, A&A, 648A, 102)
- compared radio structure to physical properties (size, radio luminosity, Eddington ratio, host SFR, M_*, SFH) and environment (location within X-ray groups, T, $M_{\rm halo}$, density fields, cosmic web)
- multi-comp sources: e.g. VLASS ~$10^{4\text{-}5}$, EMU ~10^3 (Vardoulaki+19)
- big data is here…

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