Testing AGN feedback on cold molecular gas in local luminous Seyfert galaxies

DAVID ROSARIO

CENTRE FOR EXTRAGALACTIC ASTRONOMY
DURHAM UNIVERSITY

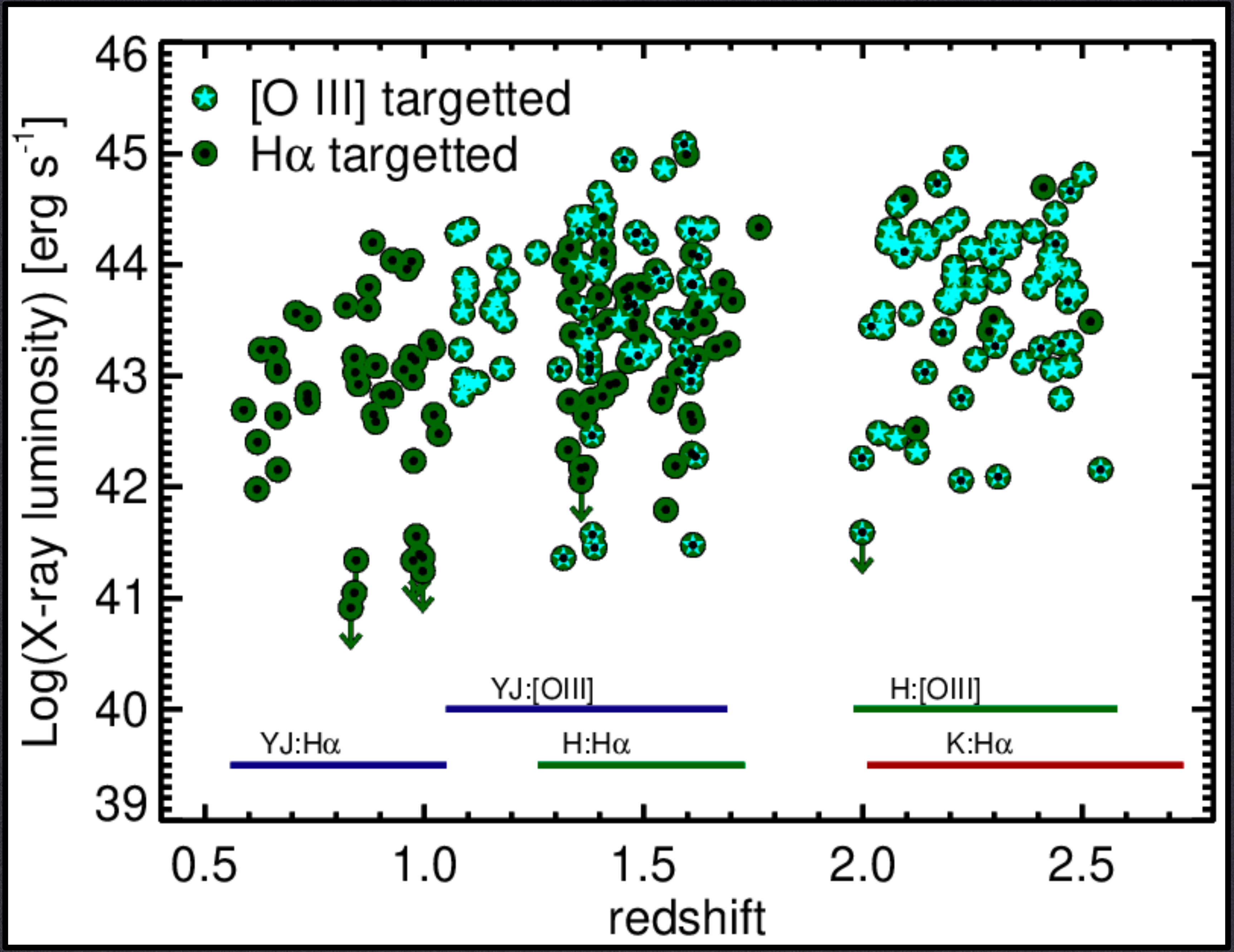
AGN do not destroy star-forming molecular gas

Rosario et al. 2018, MNRAS, 473, 5658

What is the clearest observational evidence that AGN suppress the stellar growth of galaxies?

KASHz:

250 X-ray AGN with NIR IFU spectroscopy and (soon) ALMA imaging



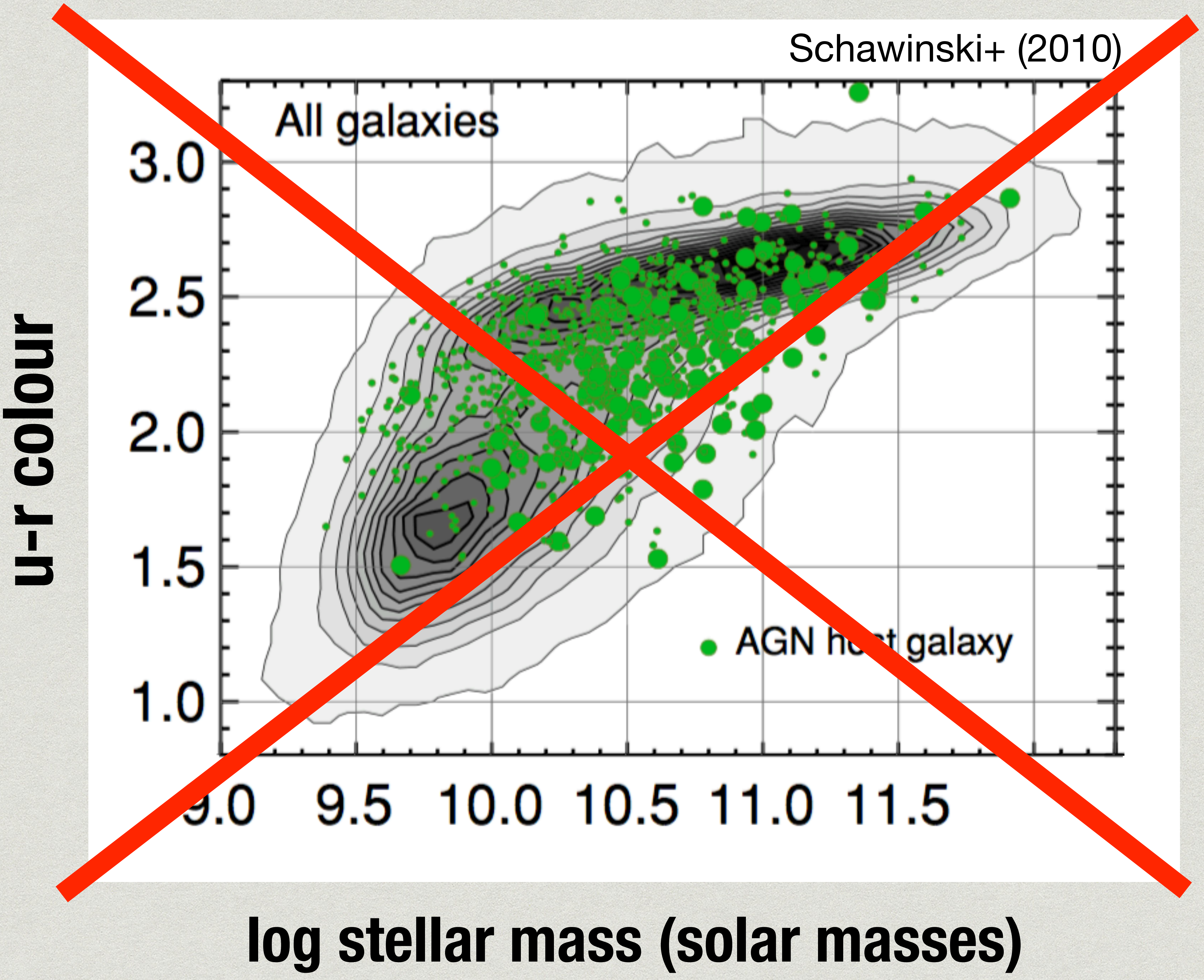
4 orders of magnitude in X-ray luminosity

141 [O III] covered

163 Hα covered

53 with both lines

Harrison+ (2016)
Harrison+ (in prep.)
Rosario+ (in prep.)



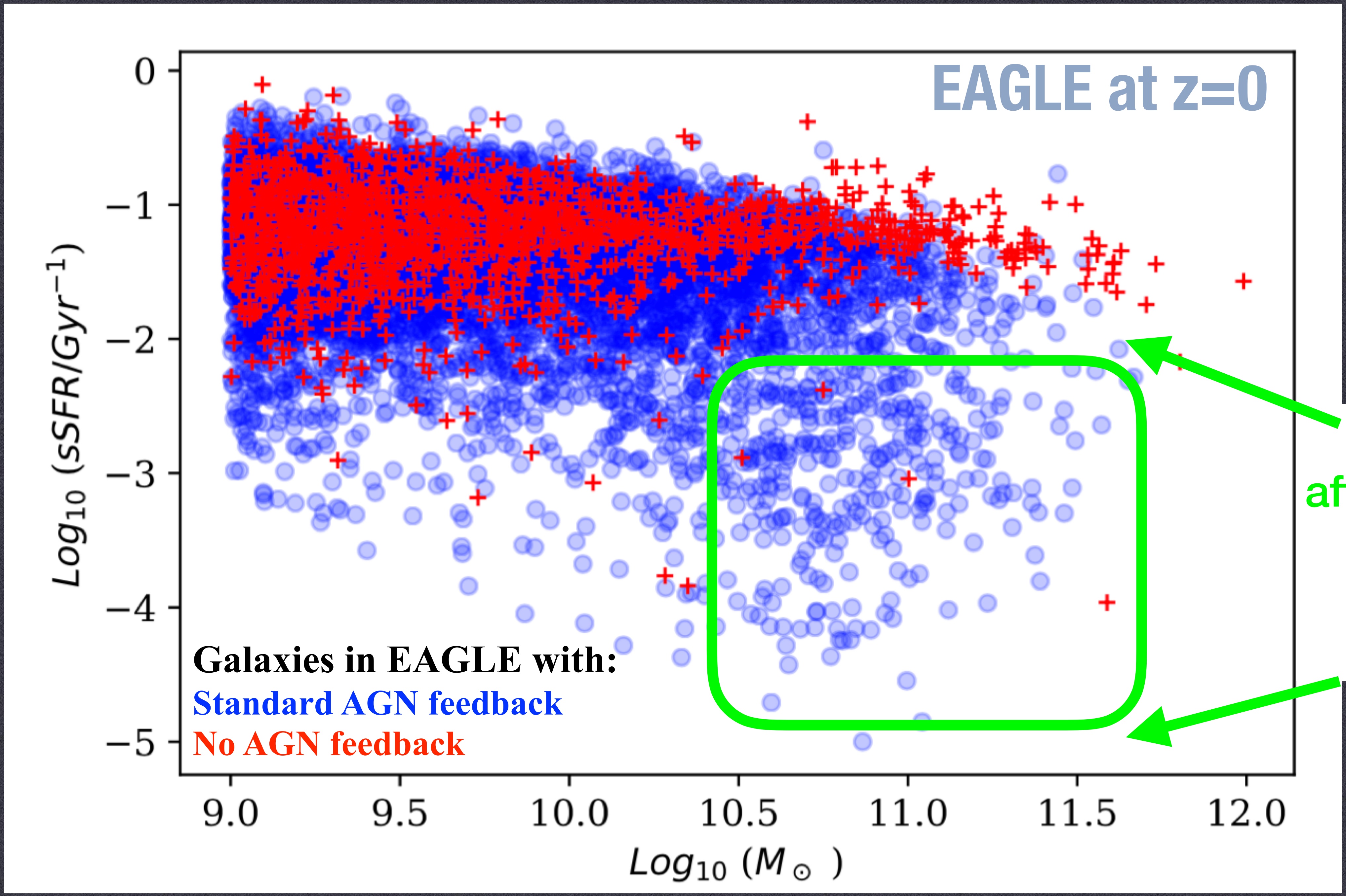
Schawinski+ (2010)

Jan Scholtz (PhD student)

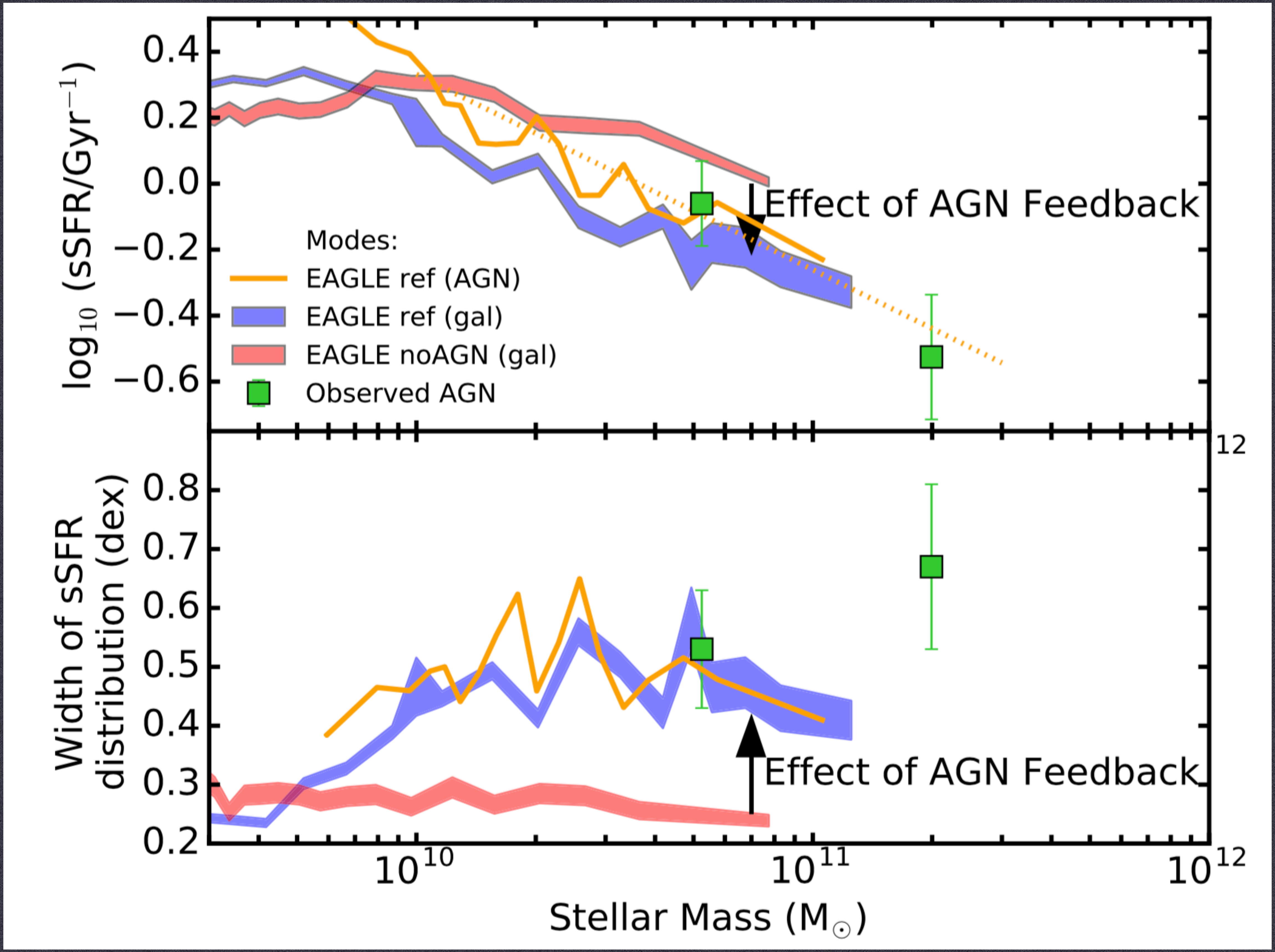
Scholtz+ (2018)

Thomas Jackson (MSc student)

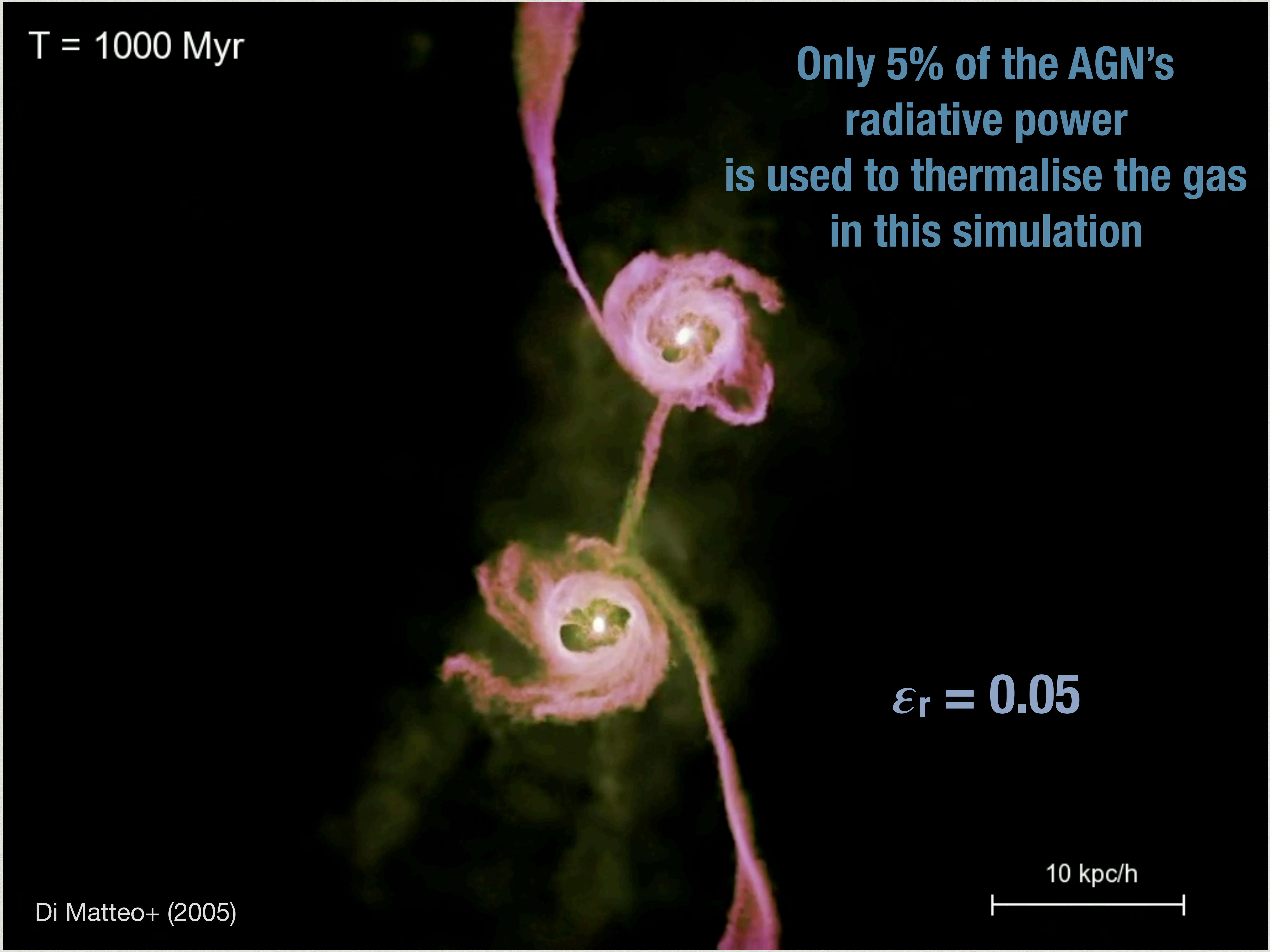
Jackson+ (in prep.)



AGN feedback affects the width of the SFR-mass relationship in galaxies.



Scholtz+ (2018)



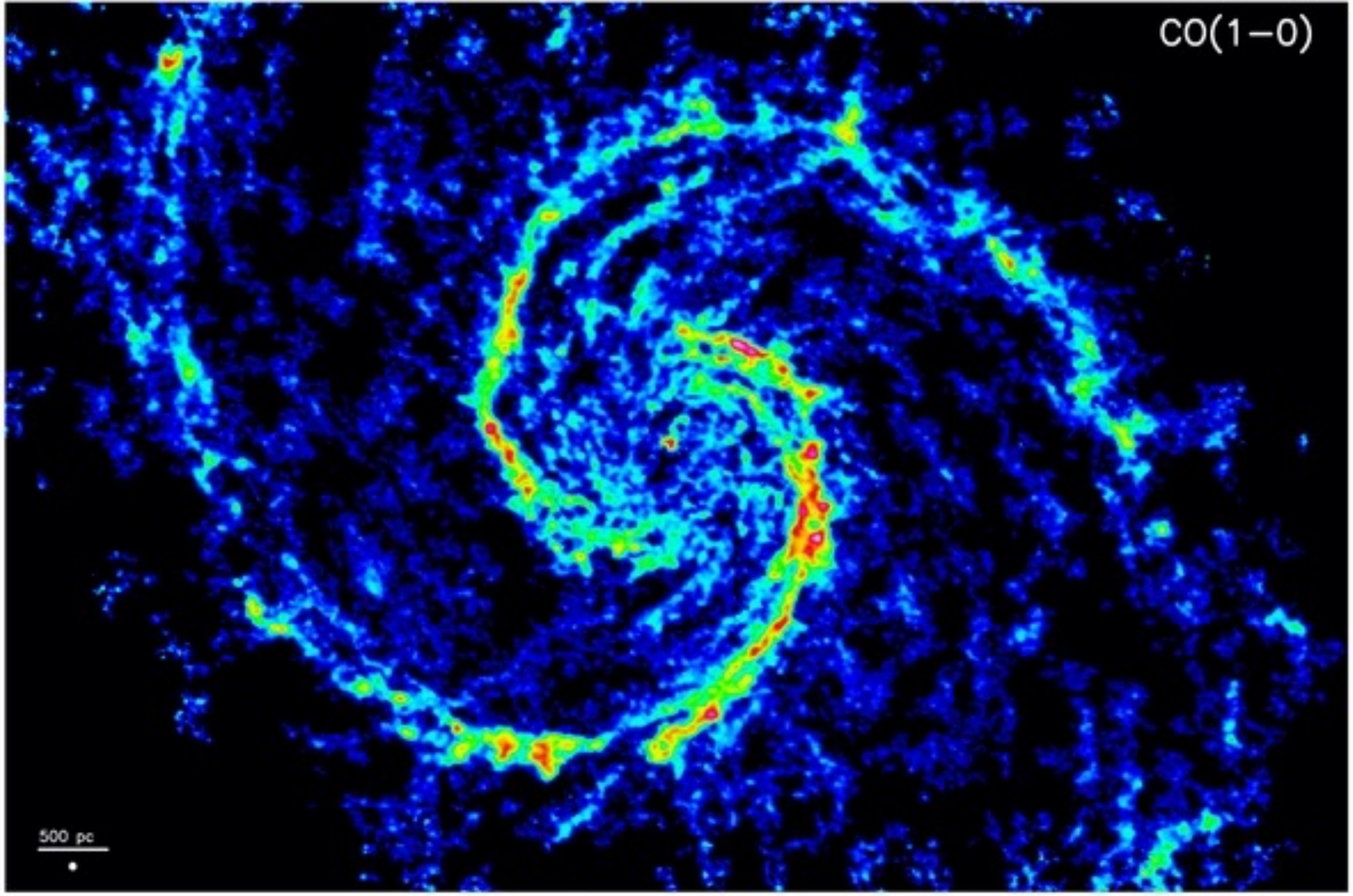
Only 5% of the AGN’s radiative power is used to thermalise the gas in this simulation

$\varepsilon_r = 0.05$

Di Matteo+ (2005)

Consider an AGN with bolometric luminosity L_{bol}

accreting steadily for a time t_{AGN}


CO(1–0)
500 pc

Radiative energy absorbed in the galaxy over the AGN's lifetime

$$E_{\mathrm{rad}} \quad \approx \quad \epsilon_r \, L_{bol} \, t_{\mathrm{AGN}}$$

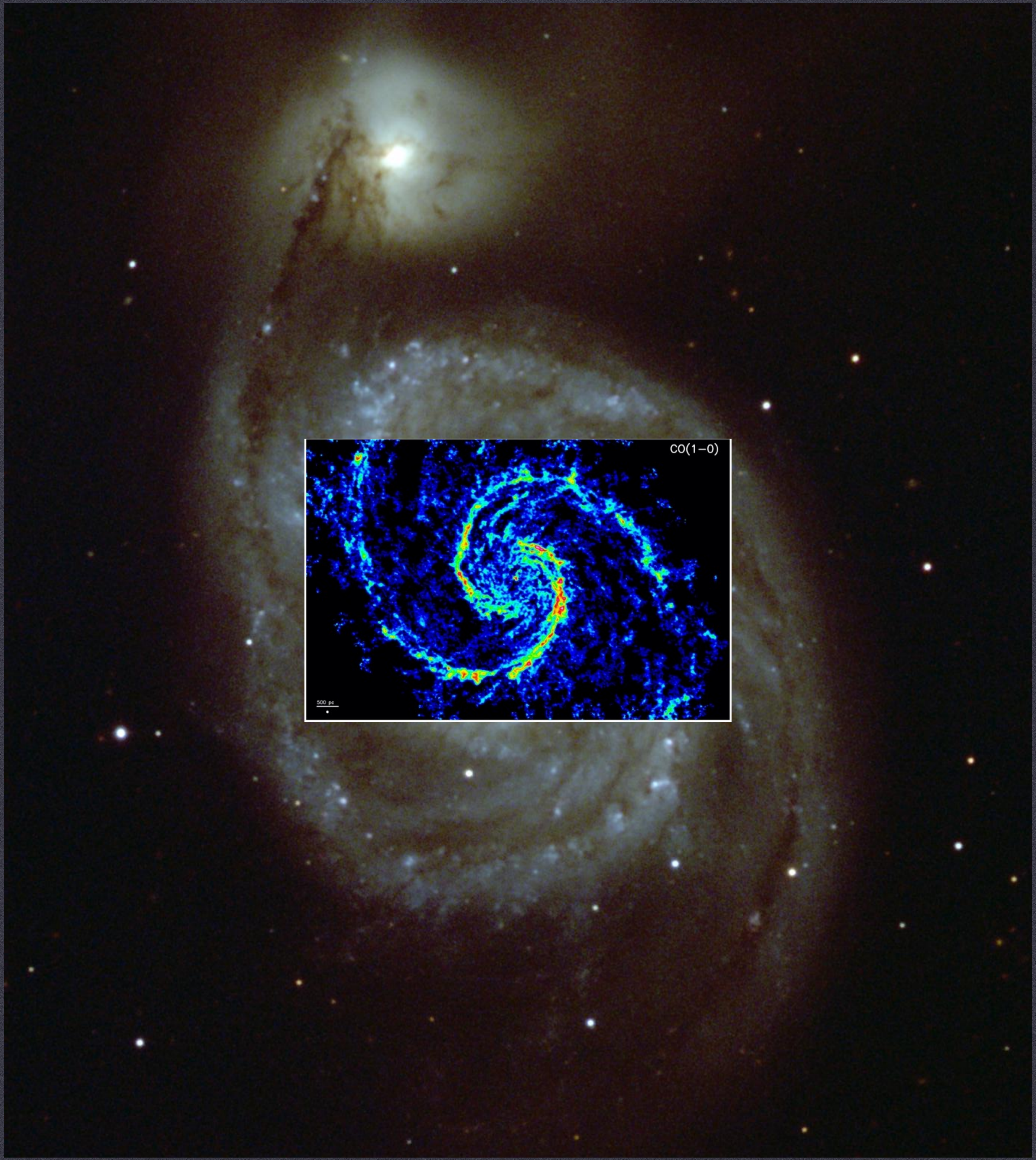
Consider an AGN with bolometric luminosity L_{bol} accreting steadily for a time t_{AGN}

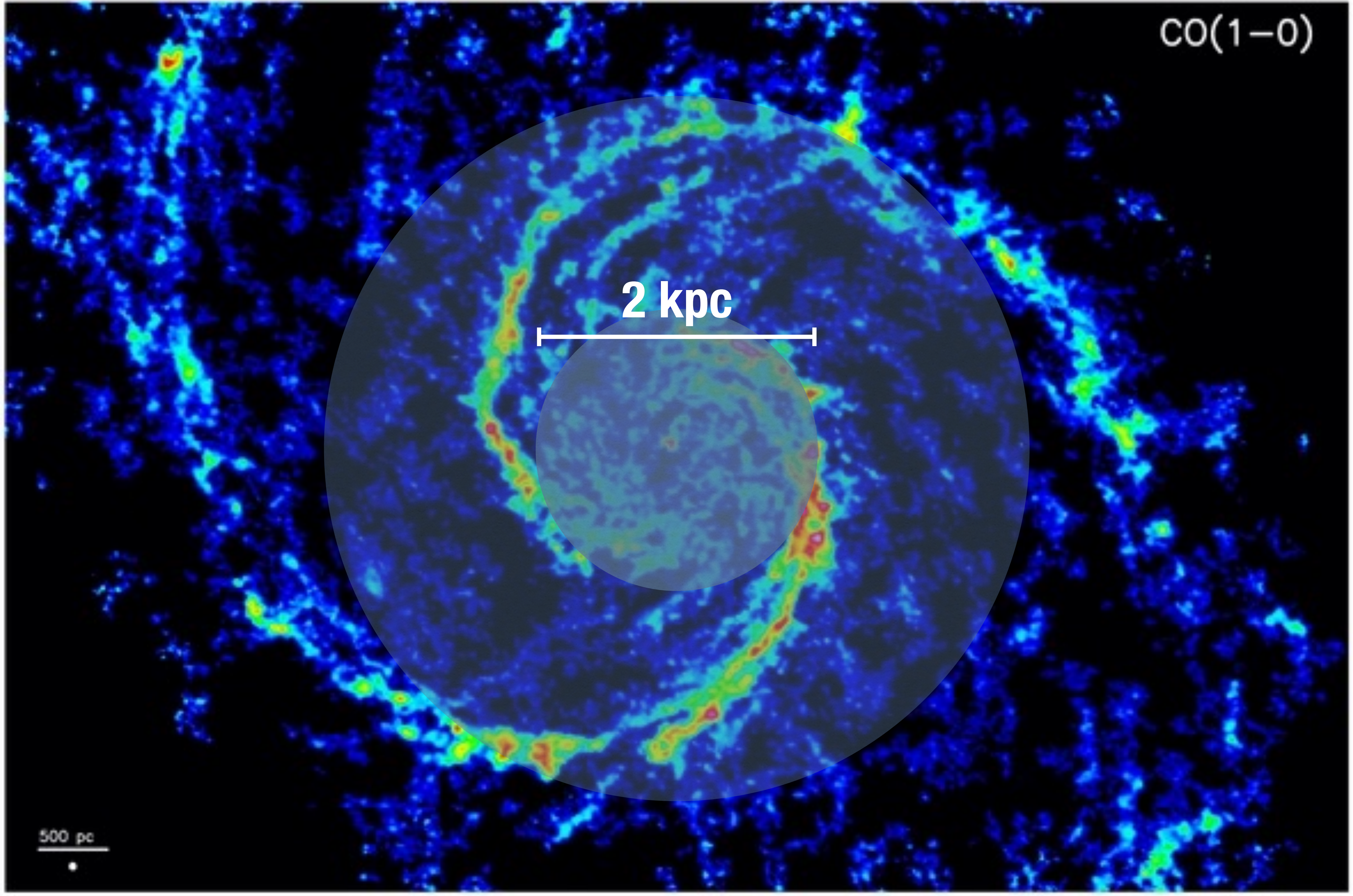
Radiative energy absorbed in the galaxy over the AGN's lifetime

$$E_{\rm rad} \quad \approx \quad \epsilon_r \, L_{bol} \, t_{\rm AGN}$$

A wind with
terminal speed V_w
travels from the nucleus to
Dist = $V_w \times t_{AGN}$
over the AGN's lifetime

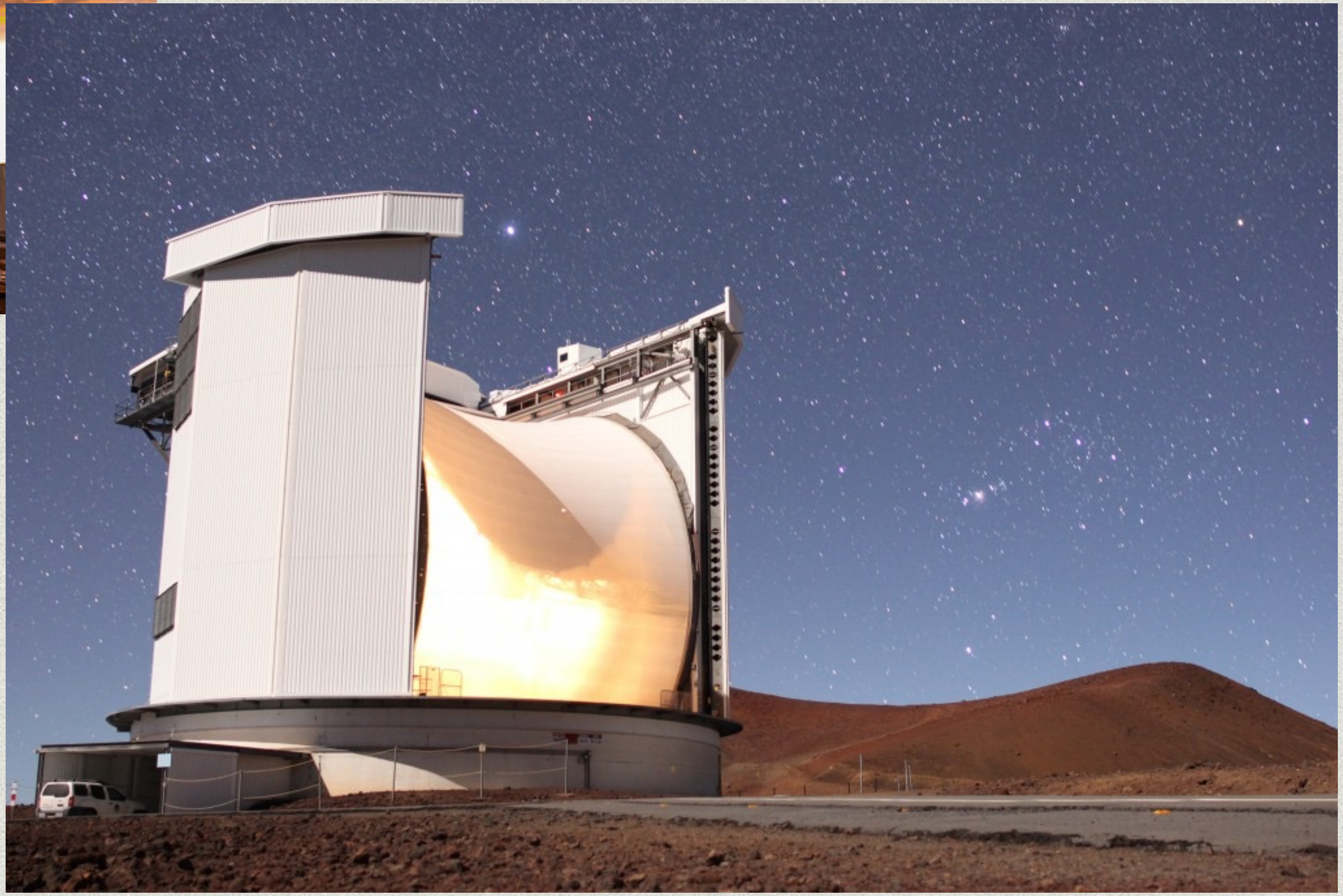
If: V_w = 1000 km/s
and
t_{AGN} = 1 Myr
then
Dist = 1 kpc


CO(1−0)
500 pc


CO(1–0)
2 kpc
500 pc

Millimetre telescopes for the South

APEX 12m, Chajnantor, Chile



JCMT 15m, Mauna Kea, Hawaii

Gravitational potential energy of molecular gas in a galactic centre (insignificant dark matter, low HI fraction)

$$E_{\rm PE} \approx -\frac{G M_\star M_{H2}}{\eta \, R_{\rm beam}} \, (1 + f_{\rm gas})$$

Gas fraction $f_{gas} = M_{H2} / M_\star$

geometrical factor $\eta = 1$ for a uniform disk

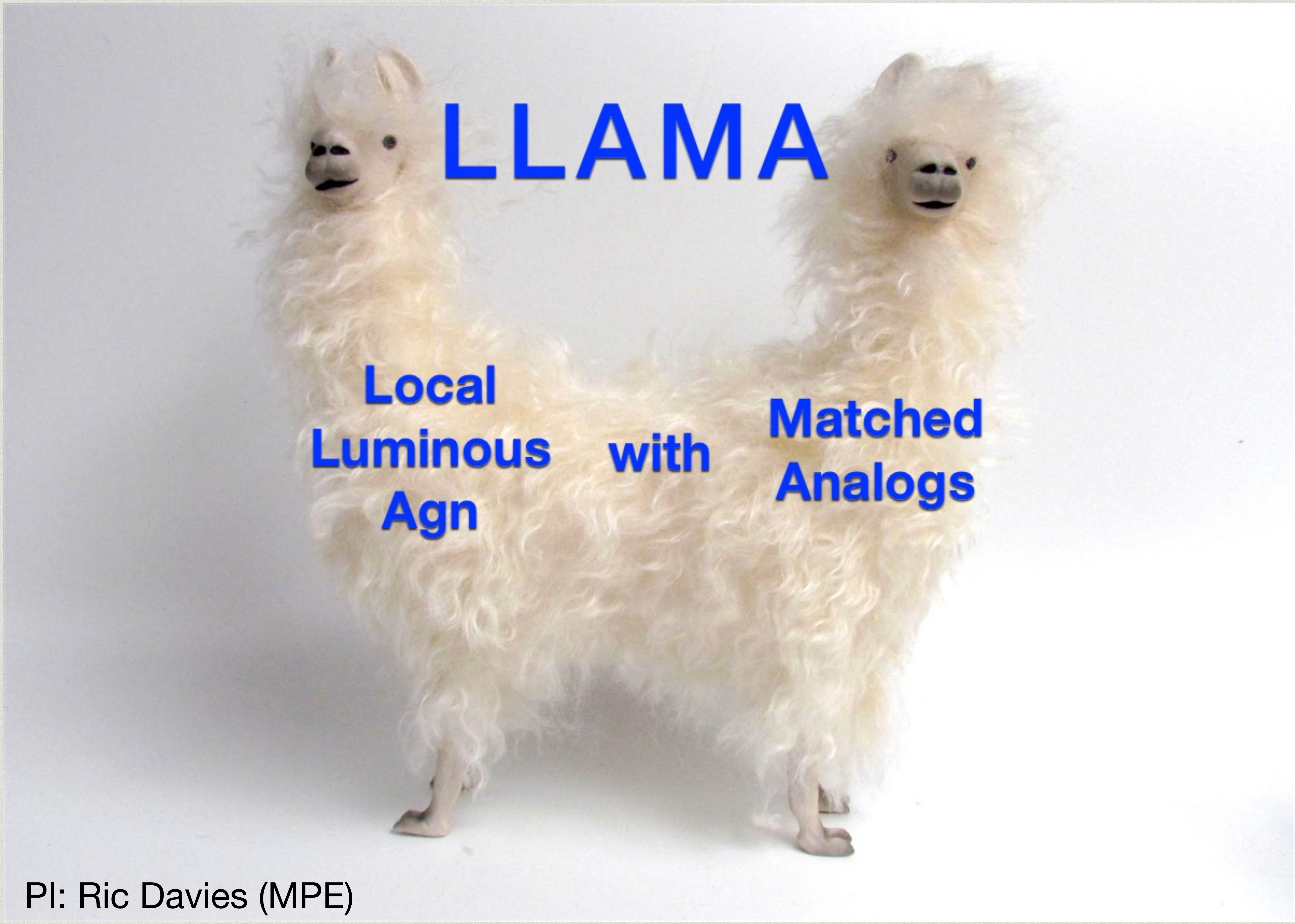
in a singular isothermal spherical potential

If the ratio

$E_{rad} / |E_{PE}| \sim 1$

in a galaxy's central region,

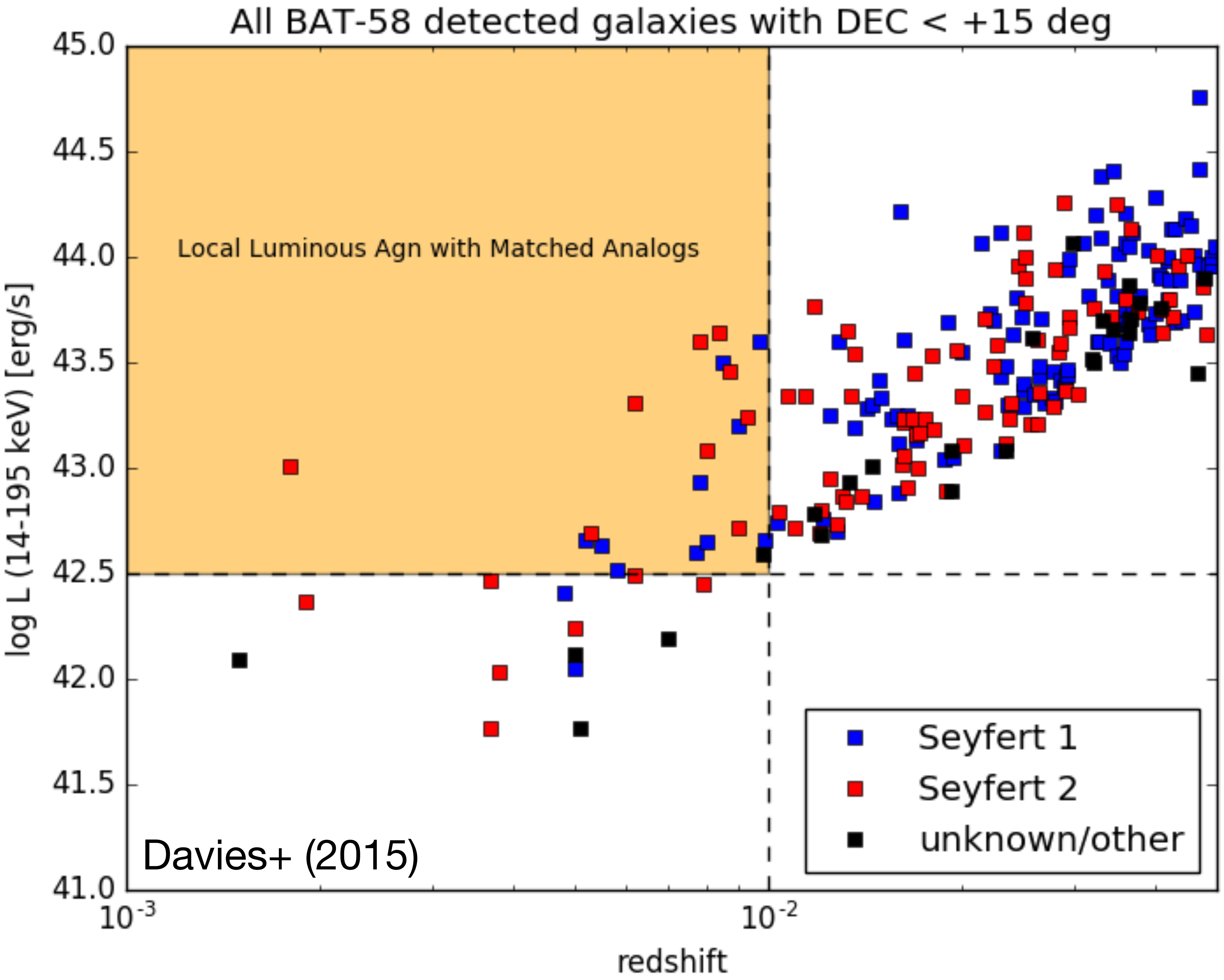
the AGN can displace significant molecular gas.



LLAMA

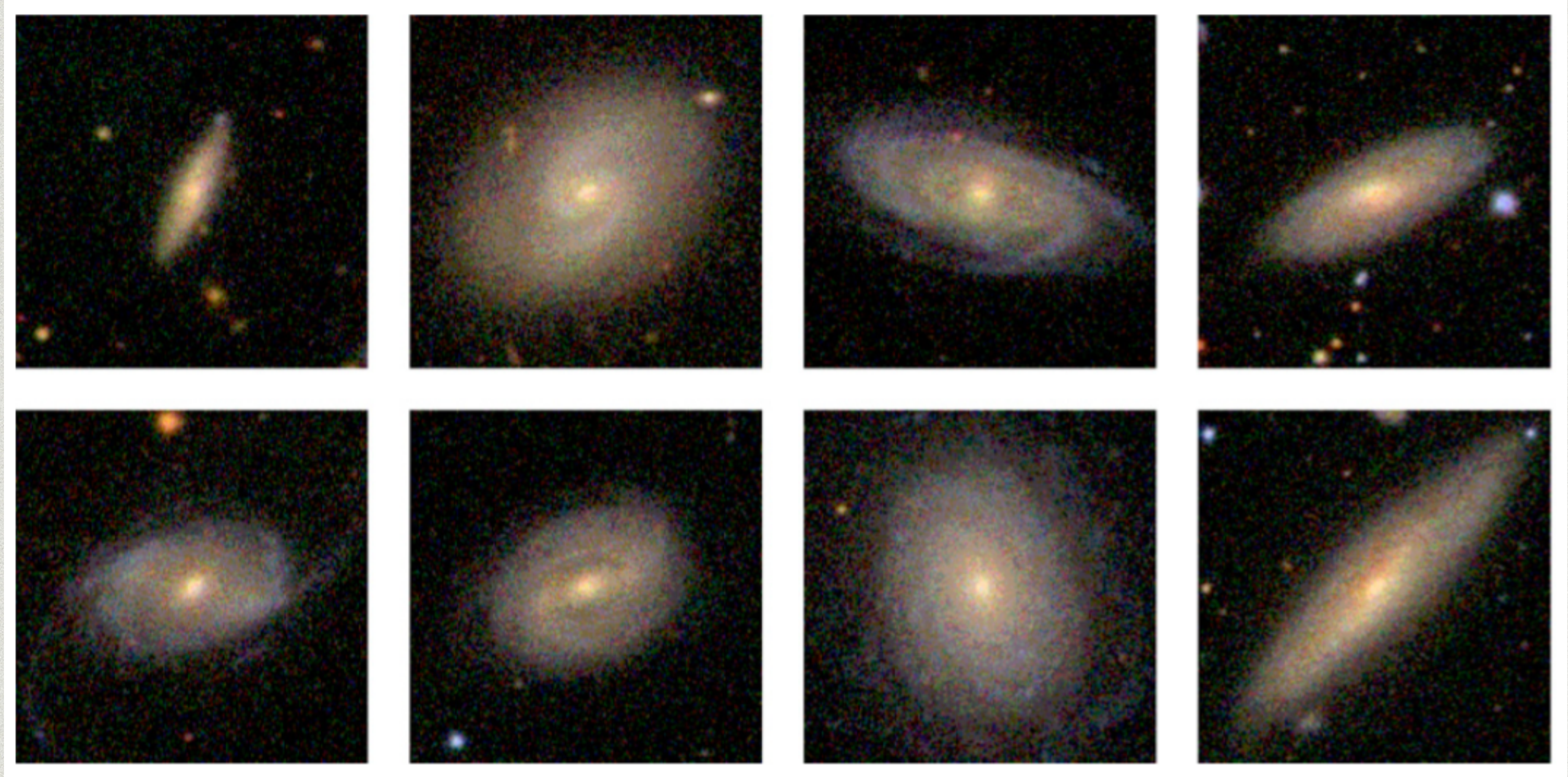
Local Luminous Agn with Matched Analogs

PI: Ric Davies (MPE)


All BAT-58 detected galaxies with DEC < +15 deg
Local Luminous Agn with Matched Analogs
log L (14-195 keV) [erg/s]
45.0
44.5
44.0
43.5
43.0
42.5
42.0
41.5
41.0
10^{-3}
10^{-2}
redshift
Seyfert 1
Seyfert 2
unknown/other

Davies+ (2015)

Local AGN hosts are mostly massive disks with substantial bulges

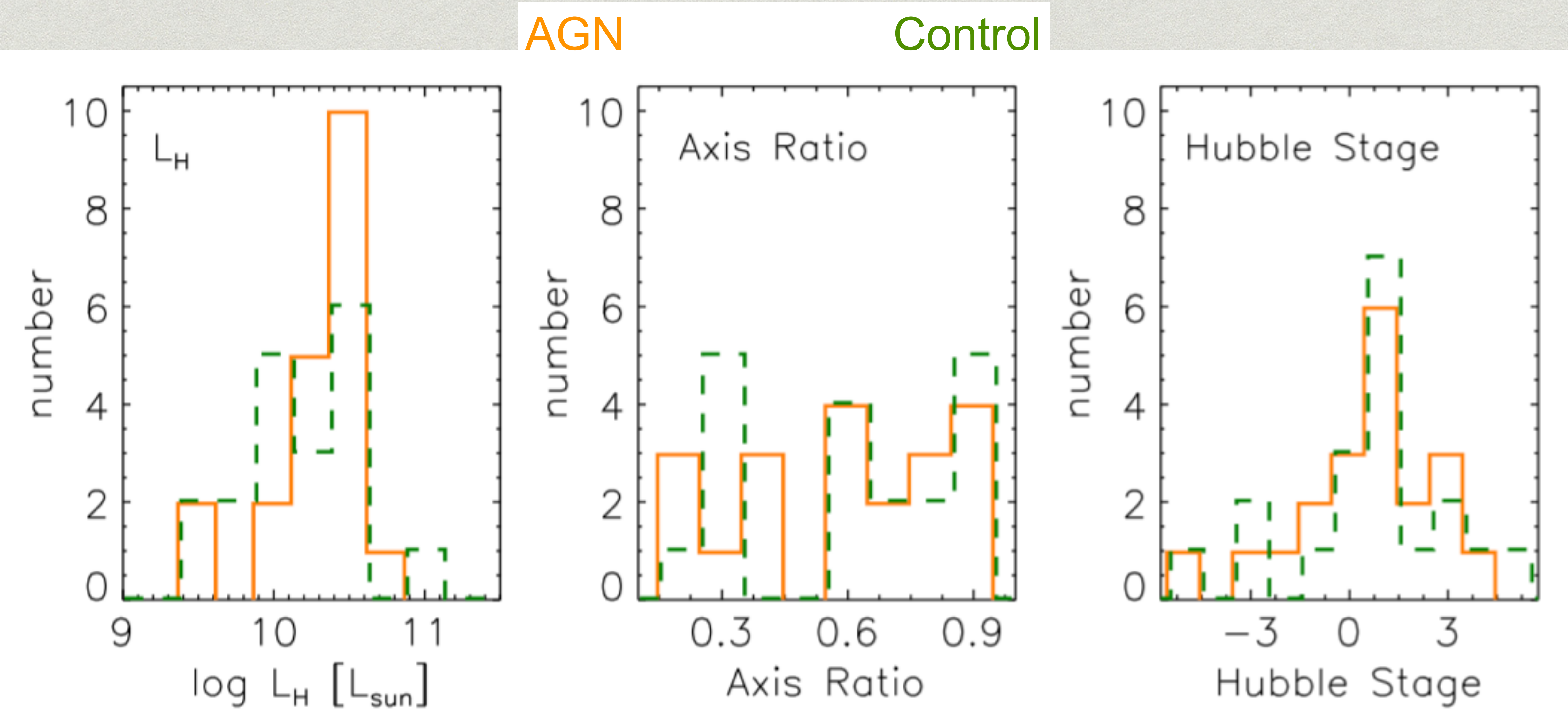


Schawinski+ (2010)

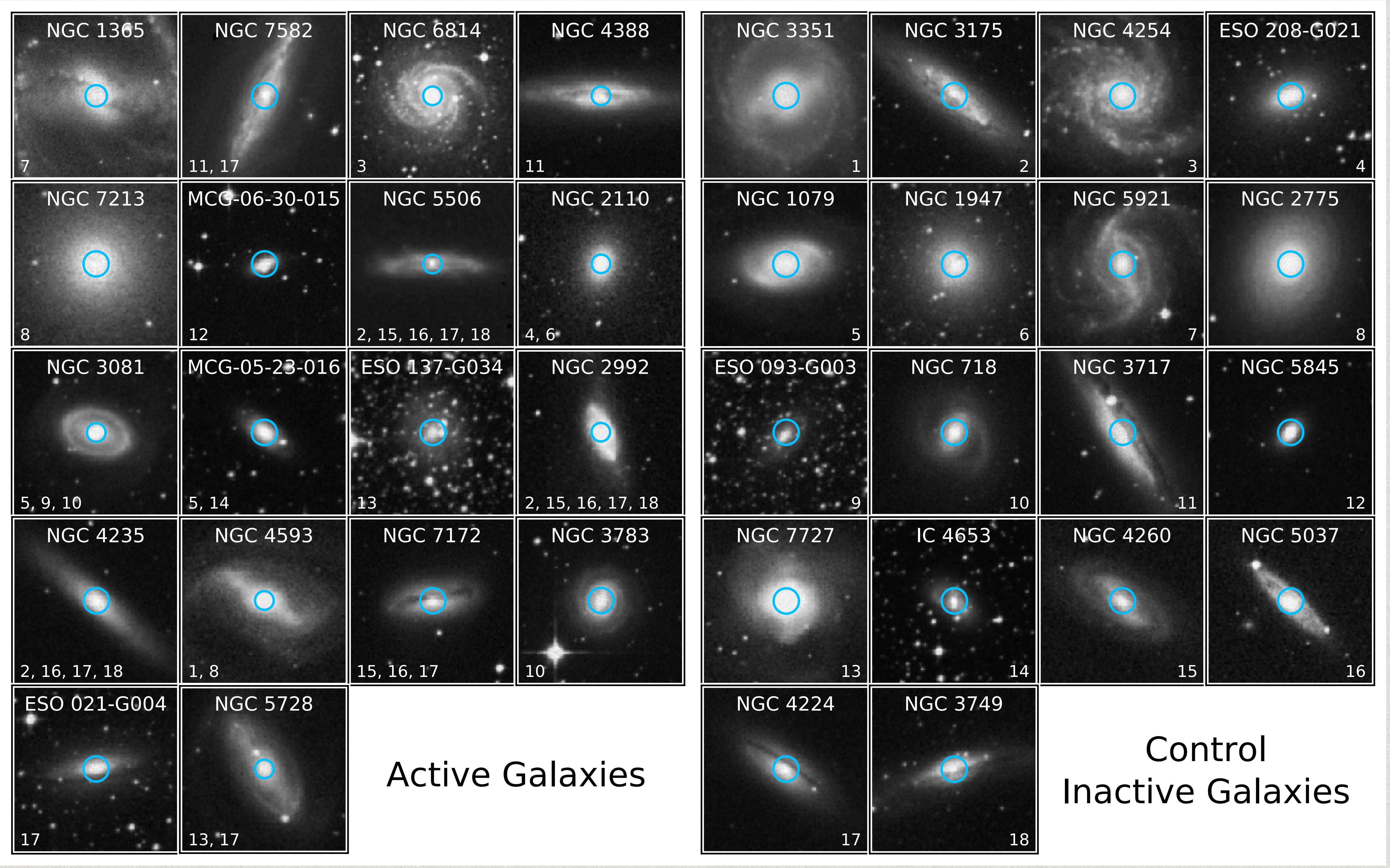
AGN are matched to a set of **completely inactive** galaxies

(No: X-rays, AGN lines, MIR excess, Gamma Rays)

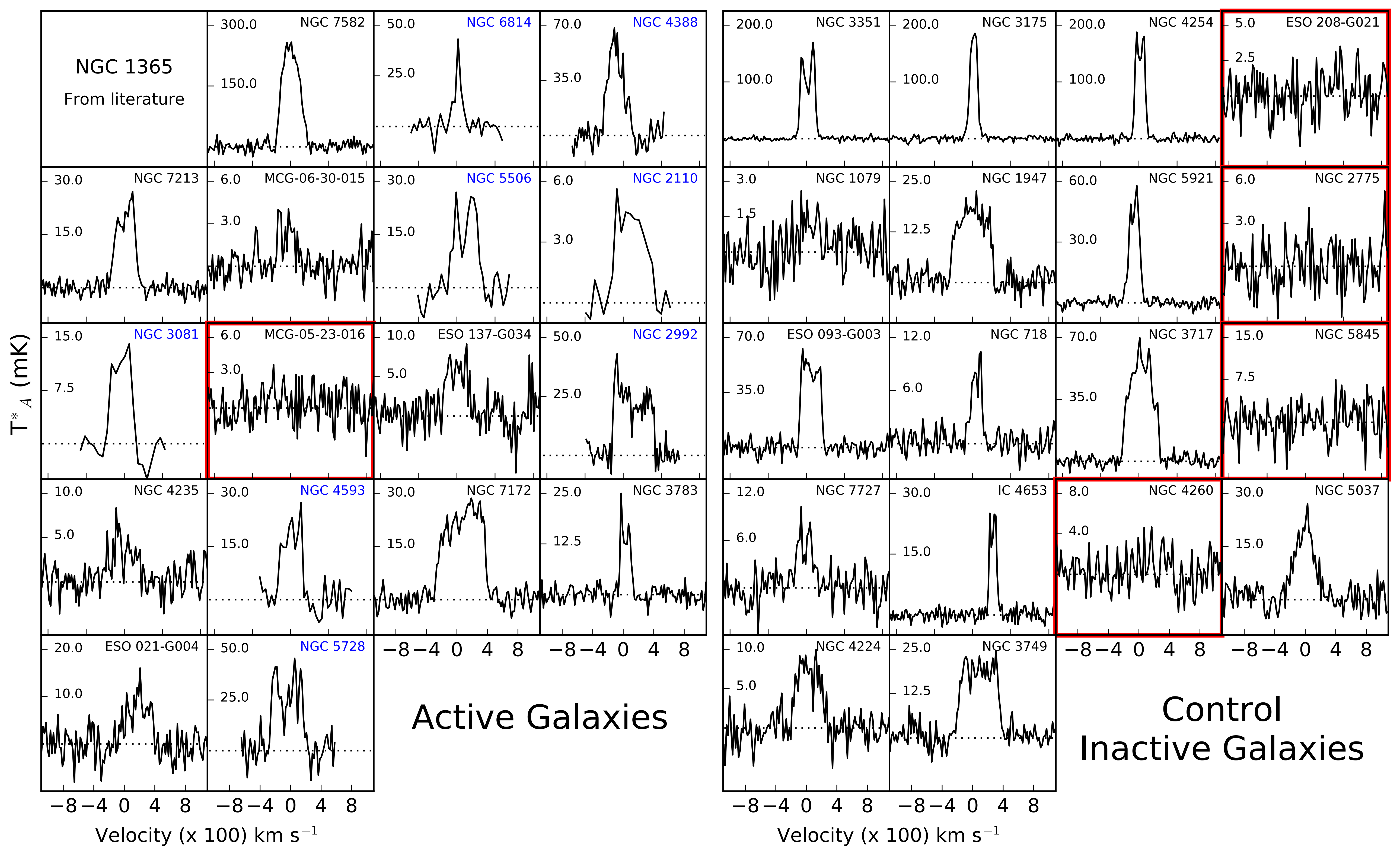
by NIR luminosity, galaxy morphology and inclination



Davies+ (2015)



DSS R-band images, 3’ on a side



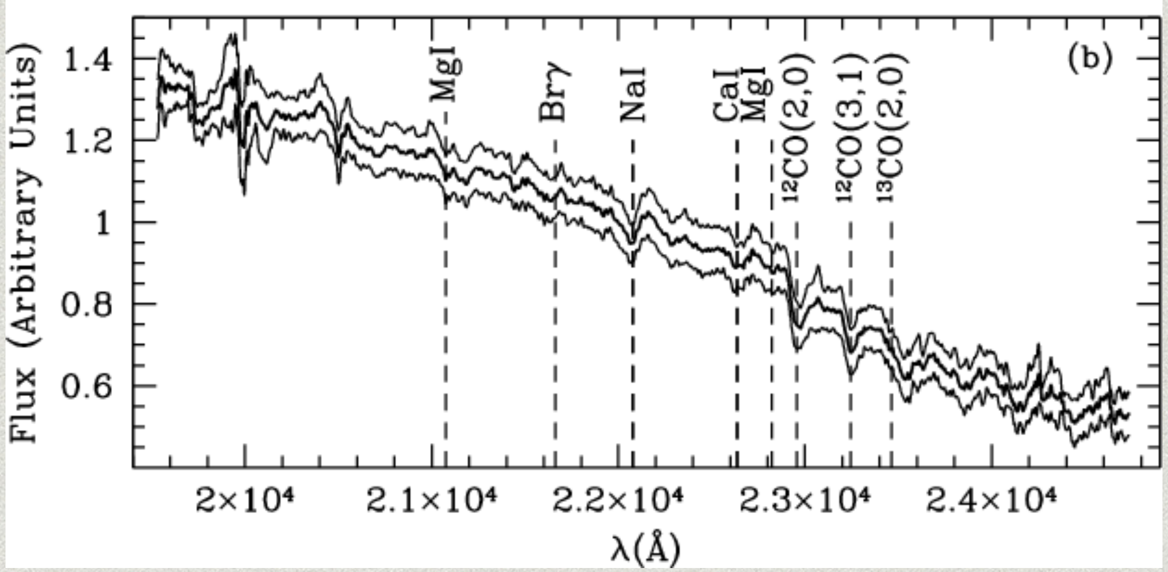
CO 2→1 spectra of 36 galaxies (18 active/18 inactive)

~90% detected with S/N > 3 detections

Central Stellar Masses

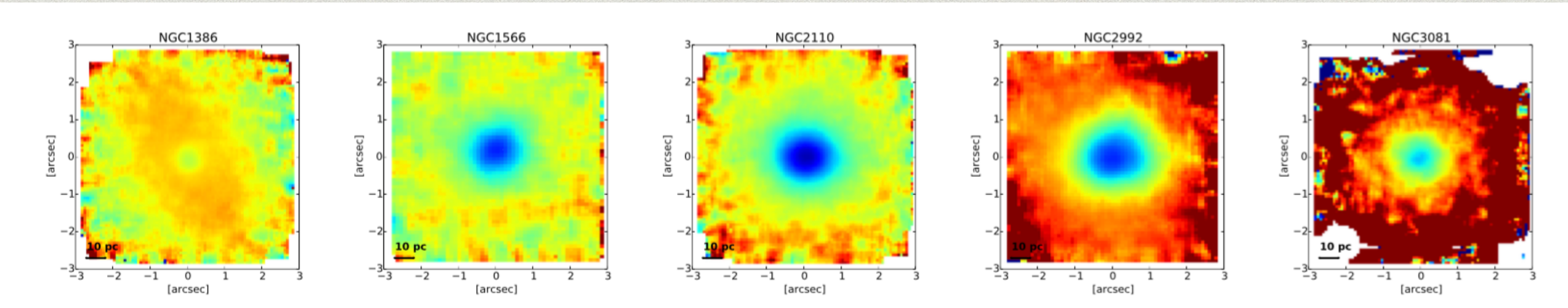
The stellar mass over the CO beam

This is not trivial for AGN. But IFU data exists for all our galaxies, so we use the dilution of the CO bandhead



Examples of LLAMA AGN with central CO bandhead dilution due to nuclear emission

Burtscher+ (2015)



a) $L_X \rightarrow L_{bol}$

b) NIR flux → $M_\star$

c) CO luminosity → M_{H2}

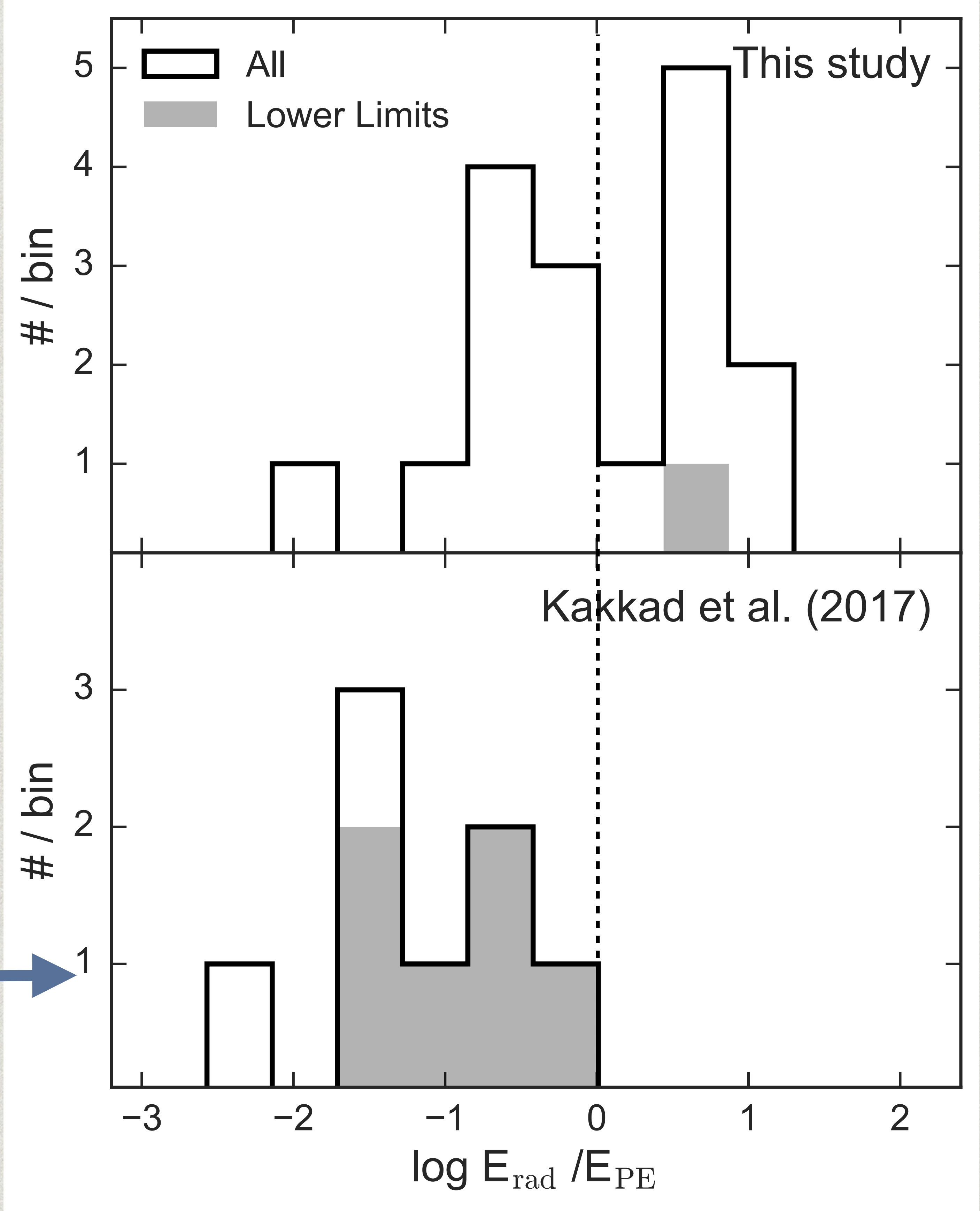
d) R_{beam} = CO beamsize

e) ϵ_r = 5%

$$E_{\rm rad} \approx \epsilon_r \, L_{bol} \, t_{\rm AGN}$$

$$E_{\rm PE} \approx -\frac{G M_\star M_{H2}}{\eta \, R_{\rm beam}} (1 + f_{\rm gas})$$

Similar analysis for AGN at z~1.5 with ALMA CO observations



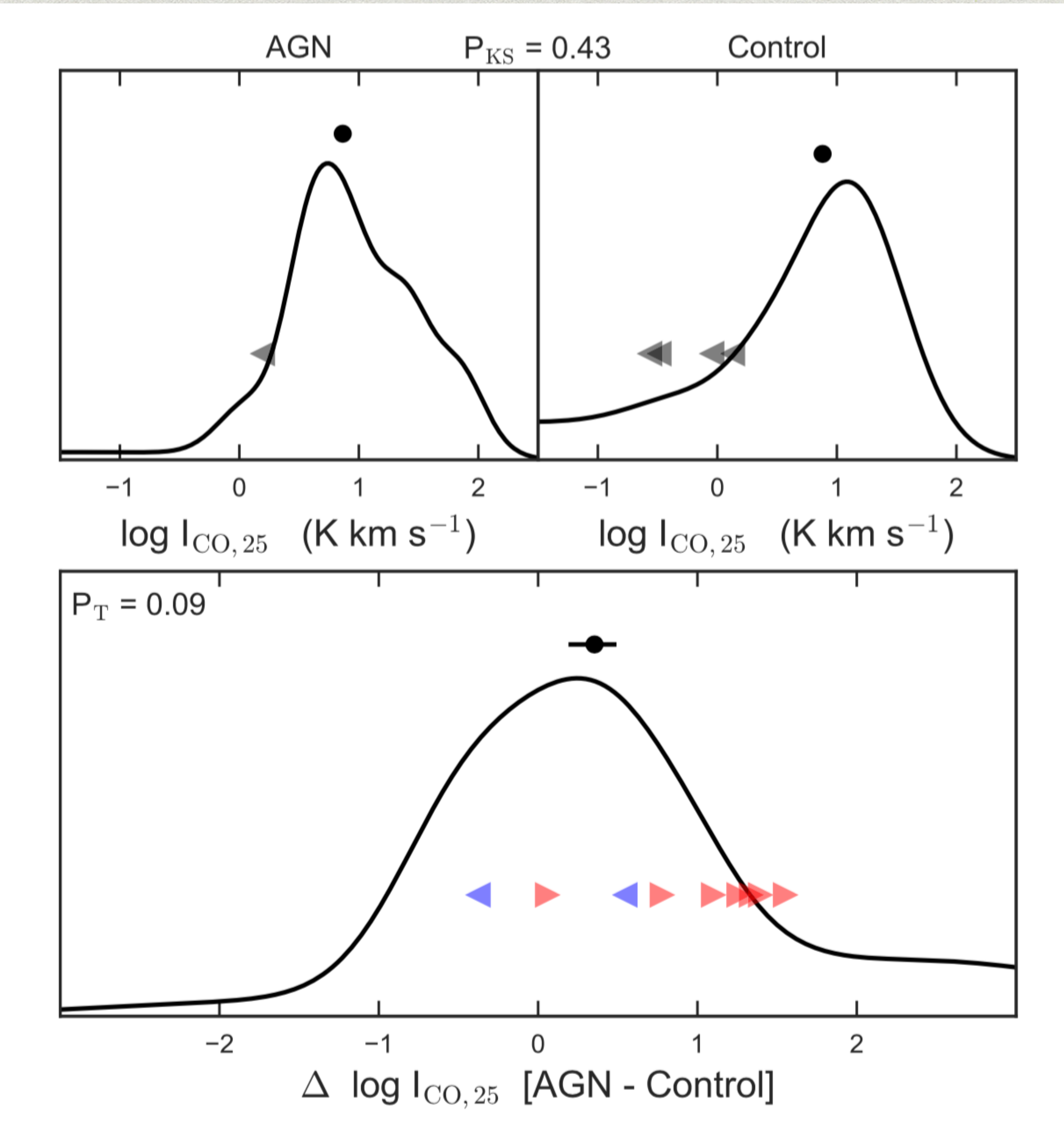
Among half of the LLAMA AGN, there is enough nuclear power to potentially destroy molecular gas on kpc scales.

The physics uncovered in nearby Seyferts is relevant for AGN feedback on molecular gas at high redshift.

CO intensity $\propto$ molecular gas mass

Individual distributions for both types of galaxy

Distributions of the difference with all control pairs considered together



If we can measure
the molecular gas mass in the central kiloparsecs,
we can examine:

The molecular gas fraction (f_{gas})

If AGN destroy or drive away molecular gas,
f_{gas} will drop.

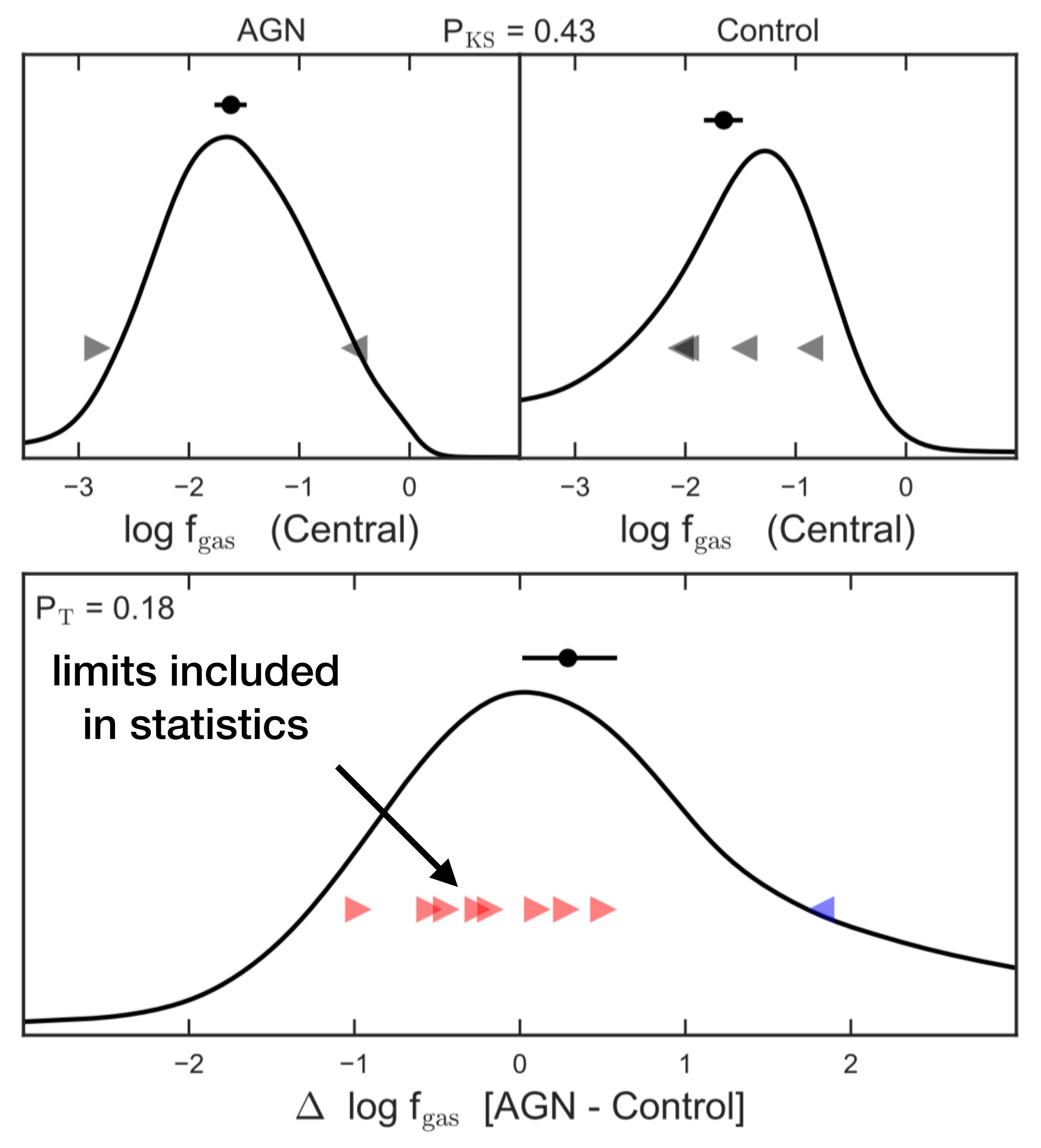
Molecular gas fractions

We adopt

$\alpha_{CO} = 1.5$

lower than the Milky Way, but consistent with the centres of nearby galaxies

(Sandstrom+ 2013)



limits included in statistics

If we can measure
the molecular gas mass in the central kiloparsecs,
we can examine:

The star formation efficiency (SFR / M_{H2})

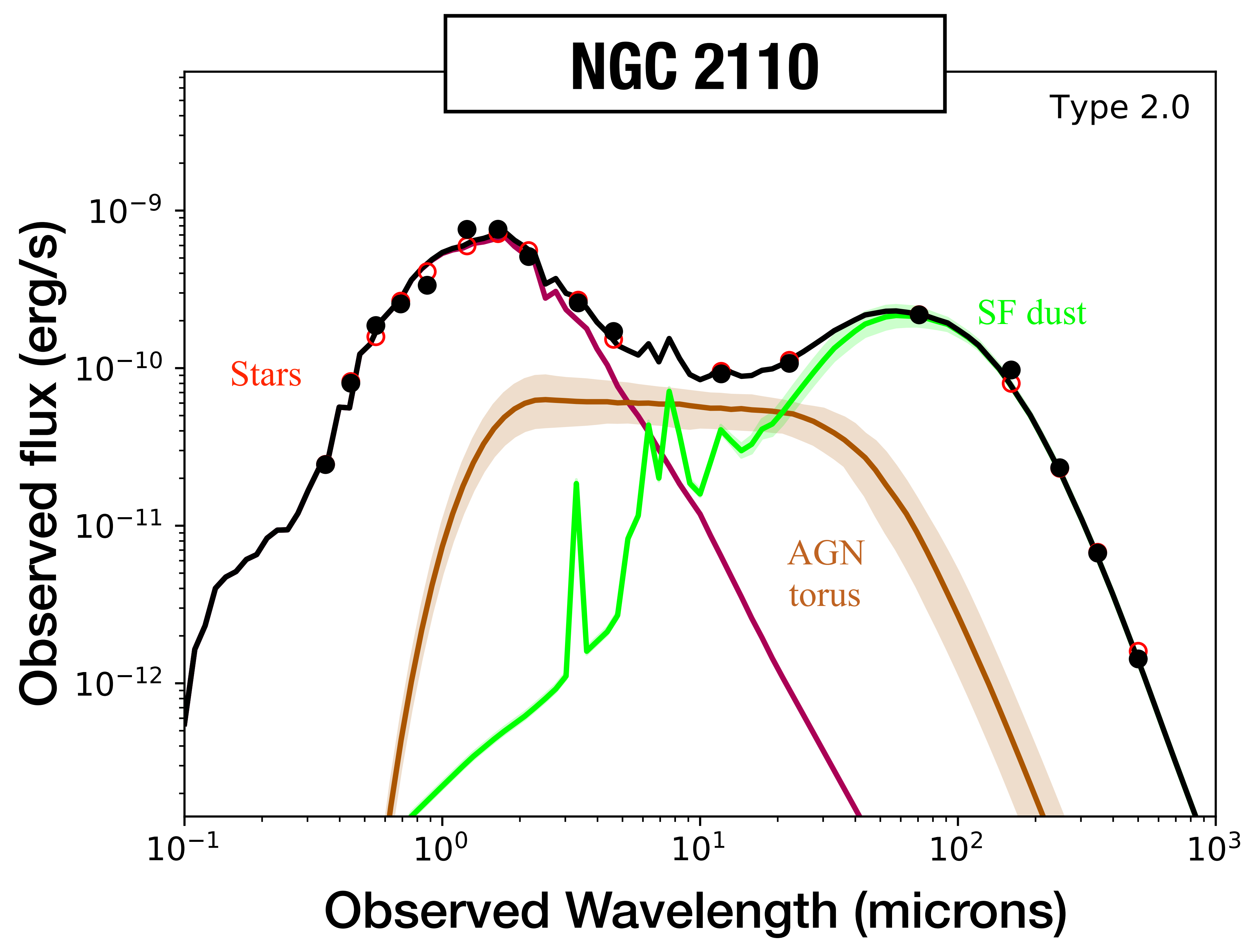
If AGN destabilise molecular clouds, this
efficiency will drop (negative feedback)
or rise (positive feedback).

But we need the SFR over the CO beam.

FortesFit

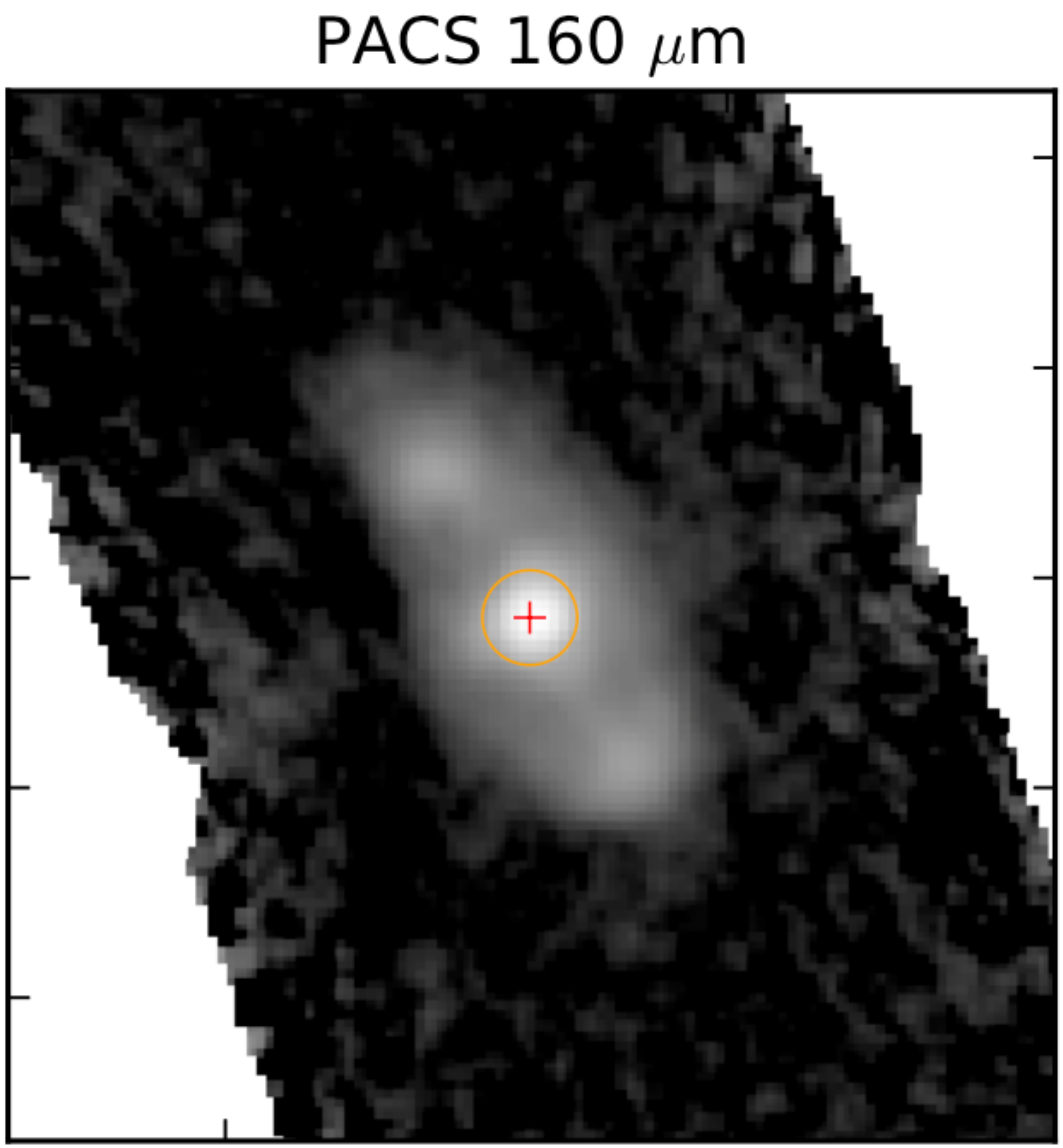
github.com/vikalibrate/FortesFit

Rosario+ (in prep.)

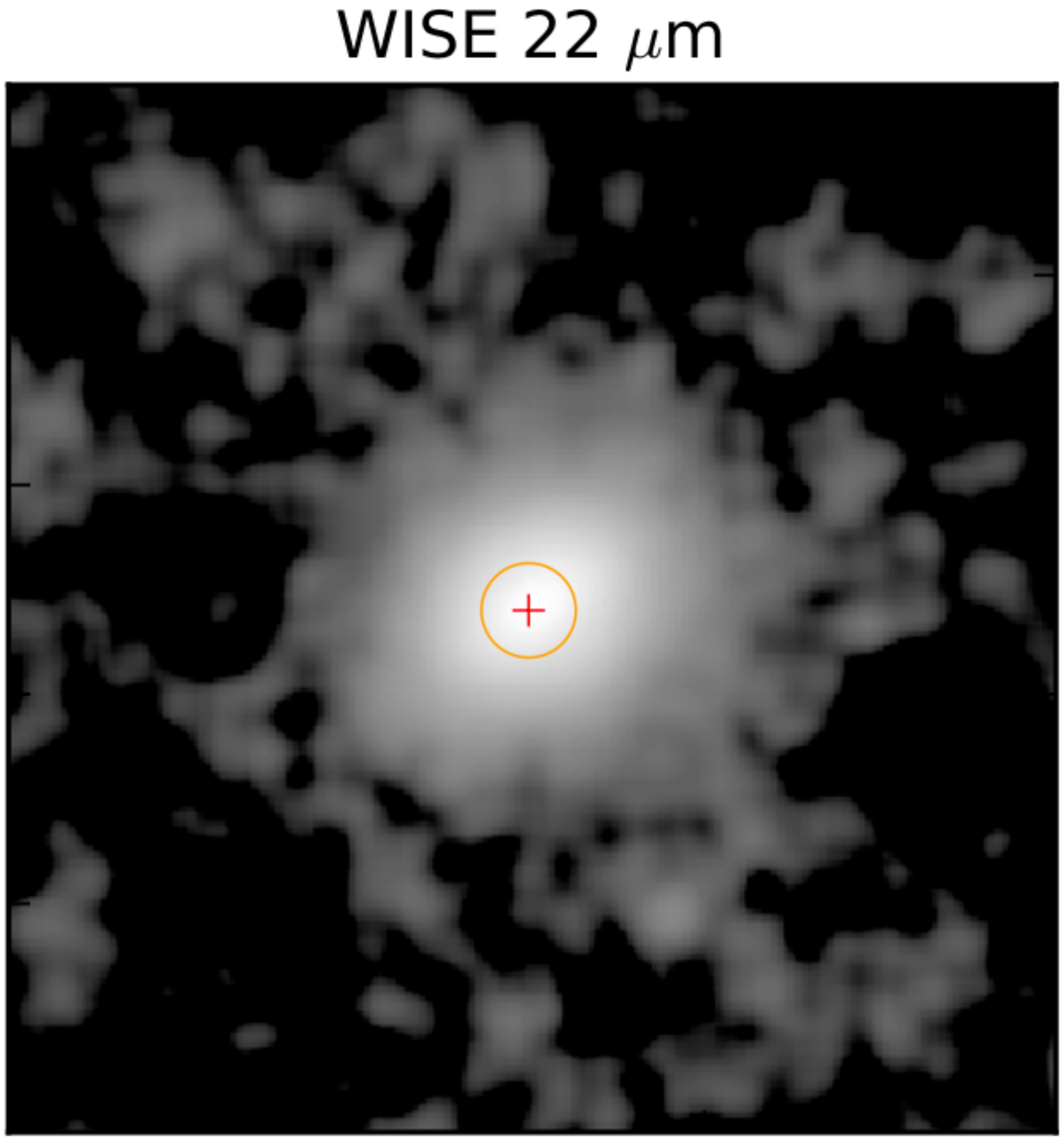


Central Star Formation Rates

NGC 5728

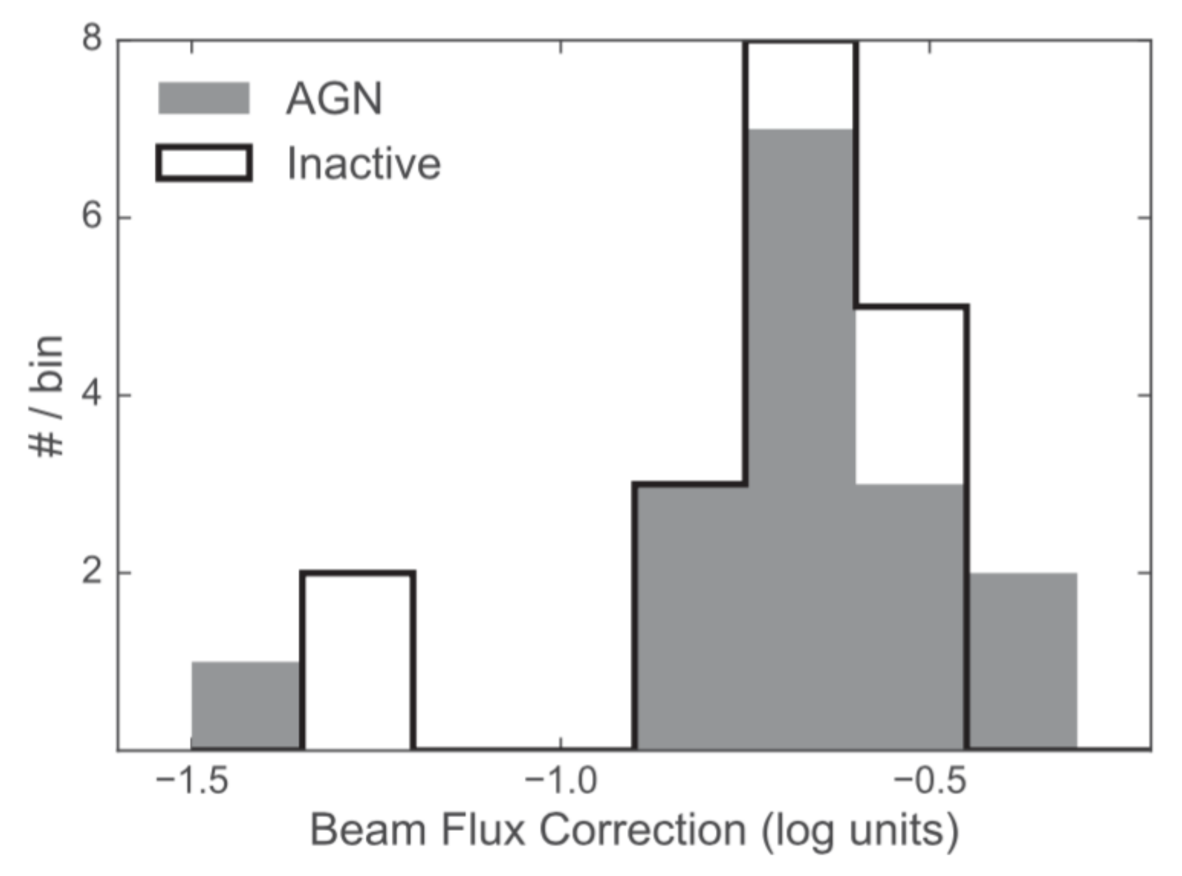


NGC 1947



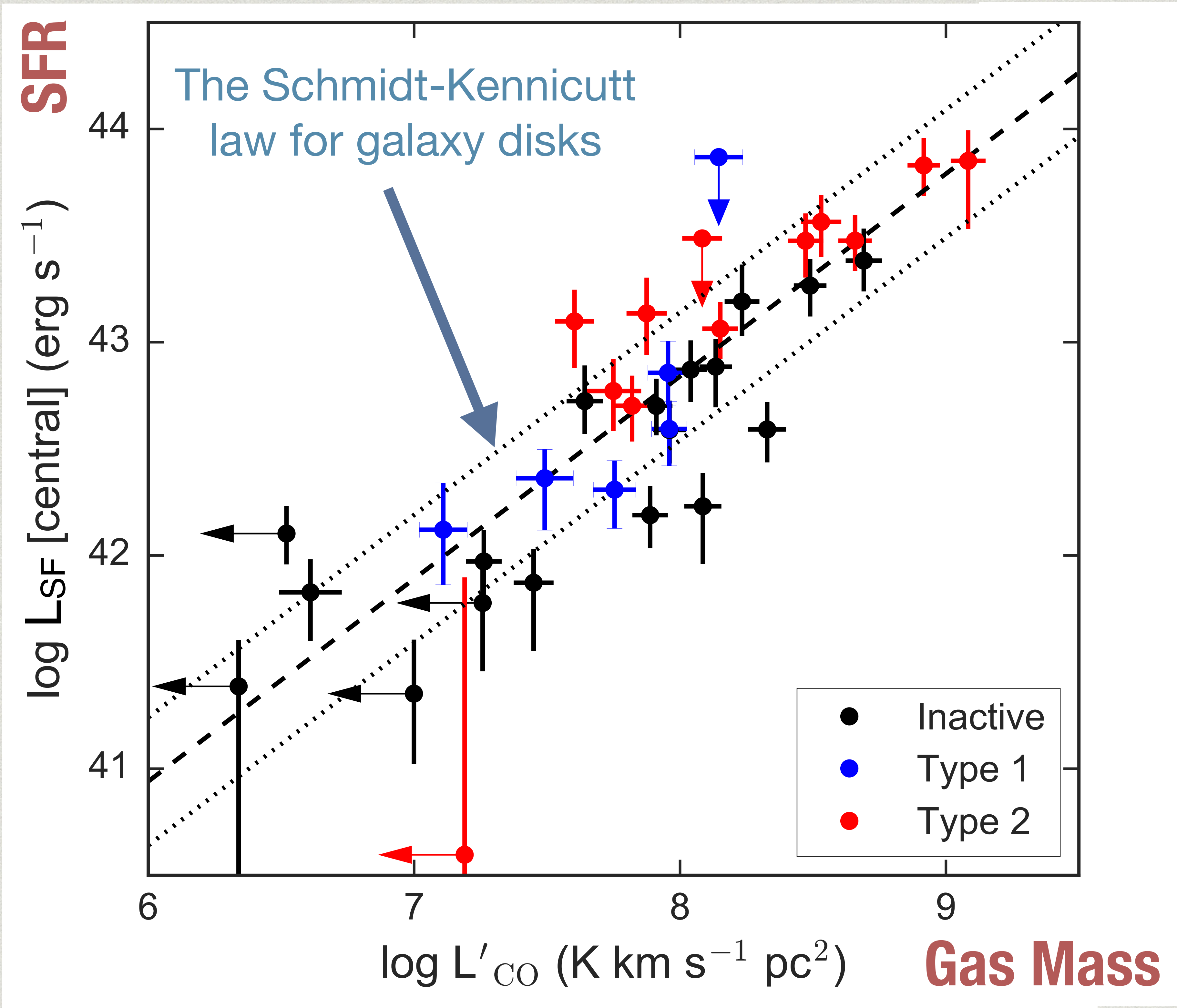
Central Star Formation Rates

FIR-based SFRs scaled to match the CO telescope beam.



A robust treatment of all uncertainties, including systematics of SFR calibrations, CO conversion factors, AGN contamination.

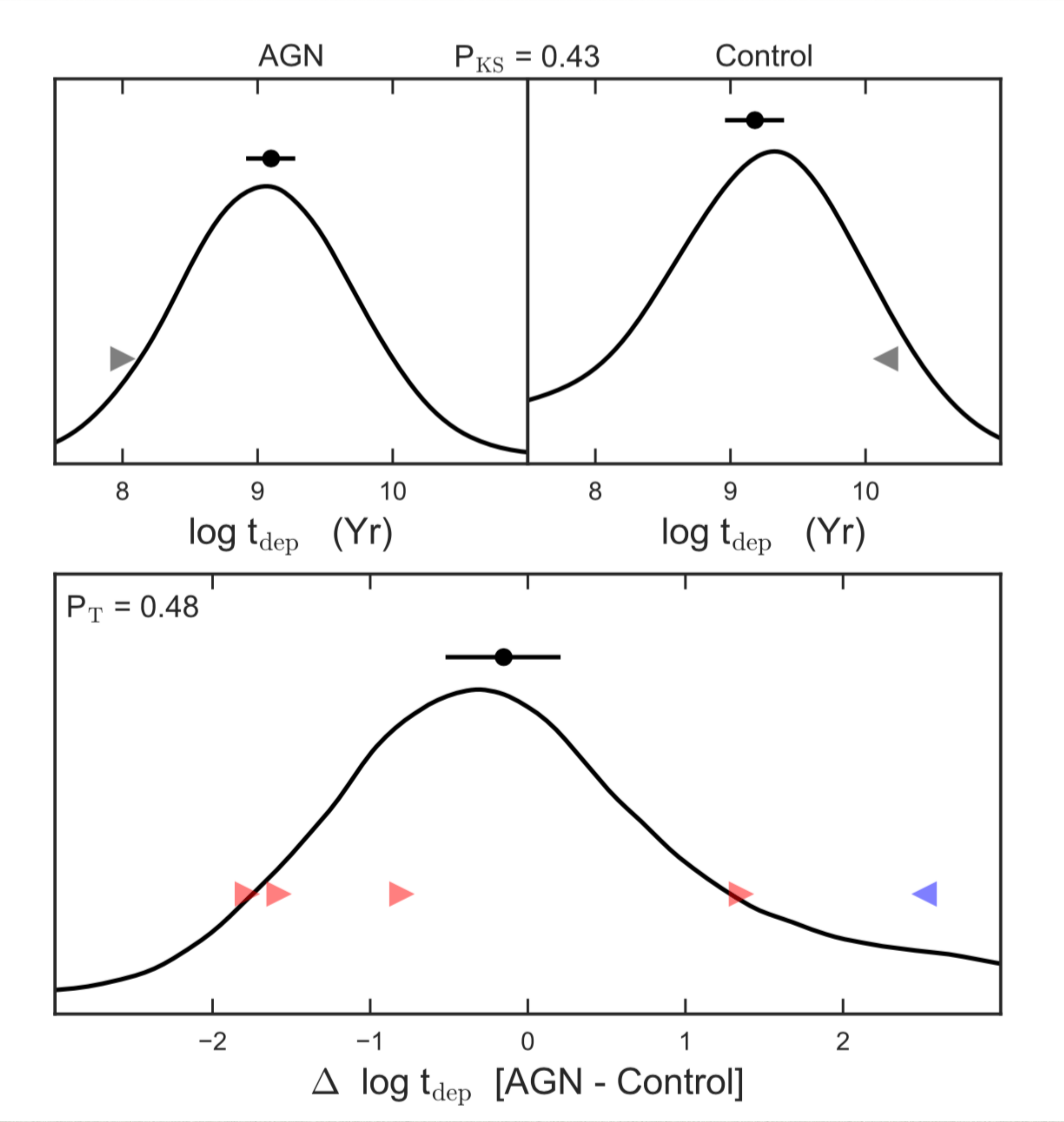
The star-formation efficiency of the central molecular gas



Molecular gas "depletion times"

The inverse of the star formation efficiency.

No statistical difference between AGN and control galaxies.



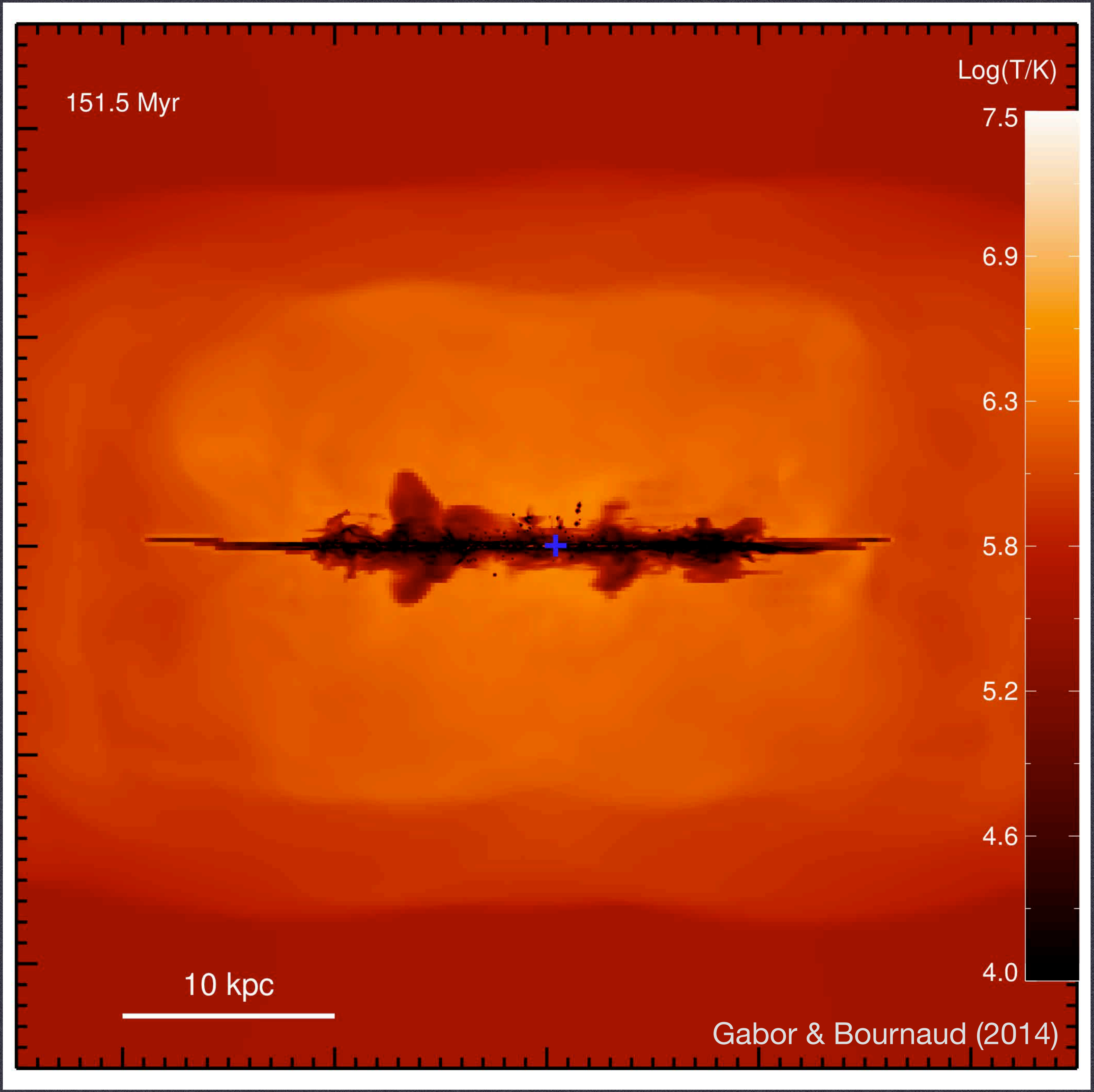
SUMMARY

The central molecular gas fractions and central star-formation efficiencies of local bright Seyferts are statistically indistinguishable from similar inactive galaxies.

But these Seyferts are energetic enough to destroy a substantial part of this molecular gas.

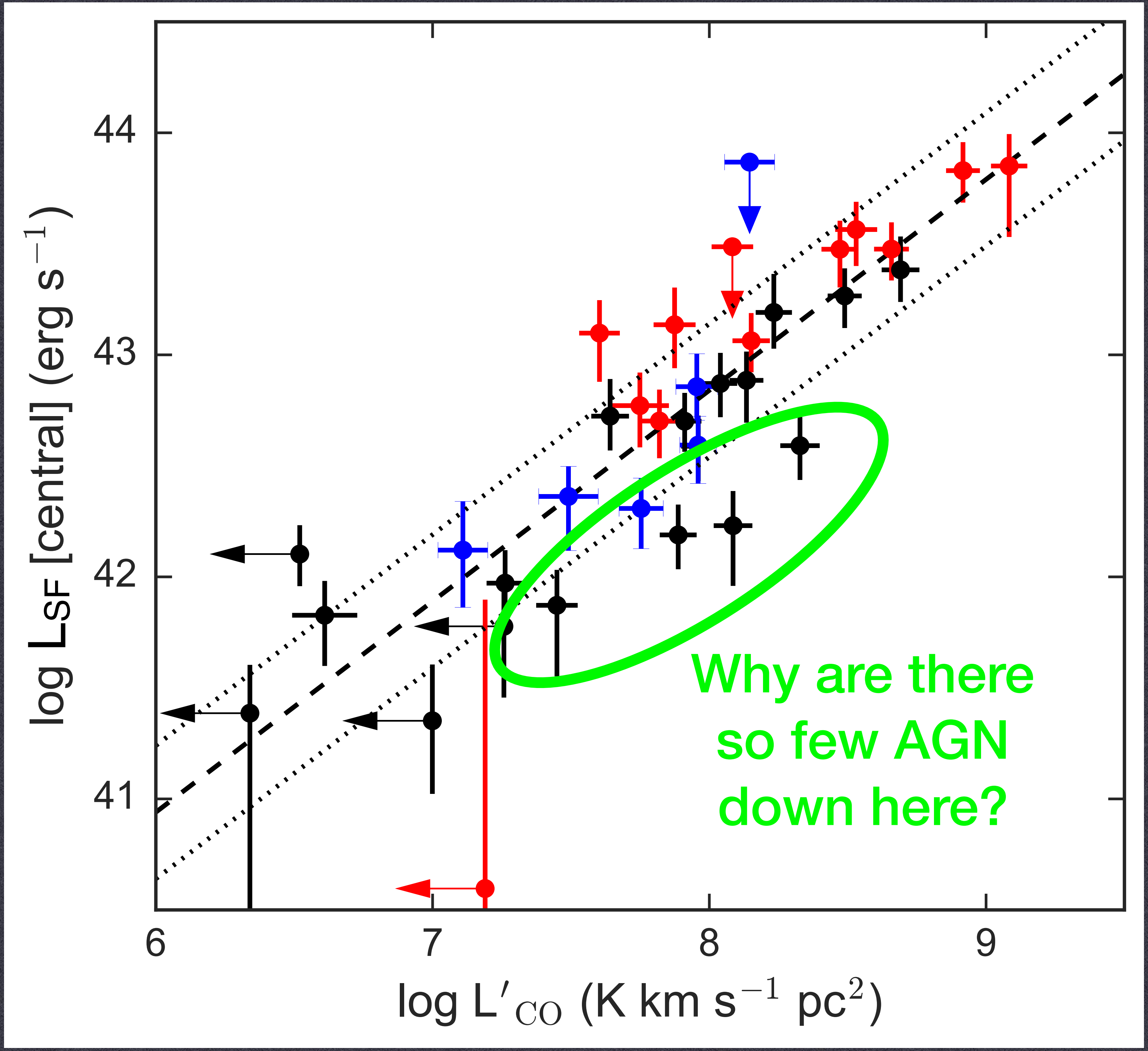
We conclude: the coupling of an AGN’s luminosity to the star-forming material in its vicinity is not as strong as models demand.

How do AGN quench star-formation?



Gabor & Bournaud (2014)

SPECULATION: IS SELF-GRAVITATION A PRE-REQUISITE FOR AGN FUELLING?

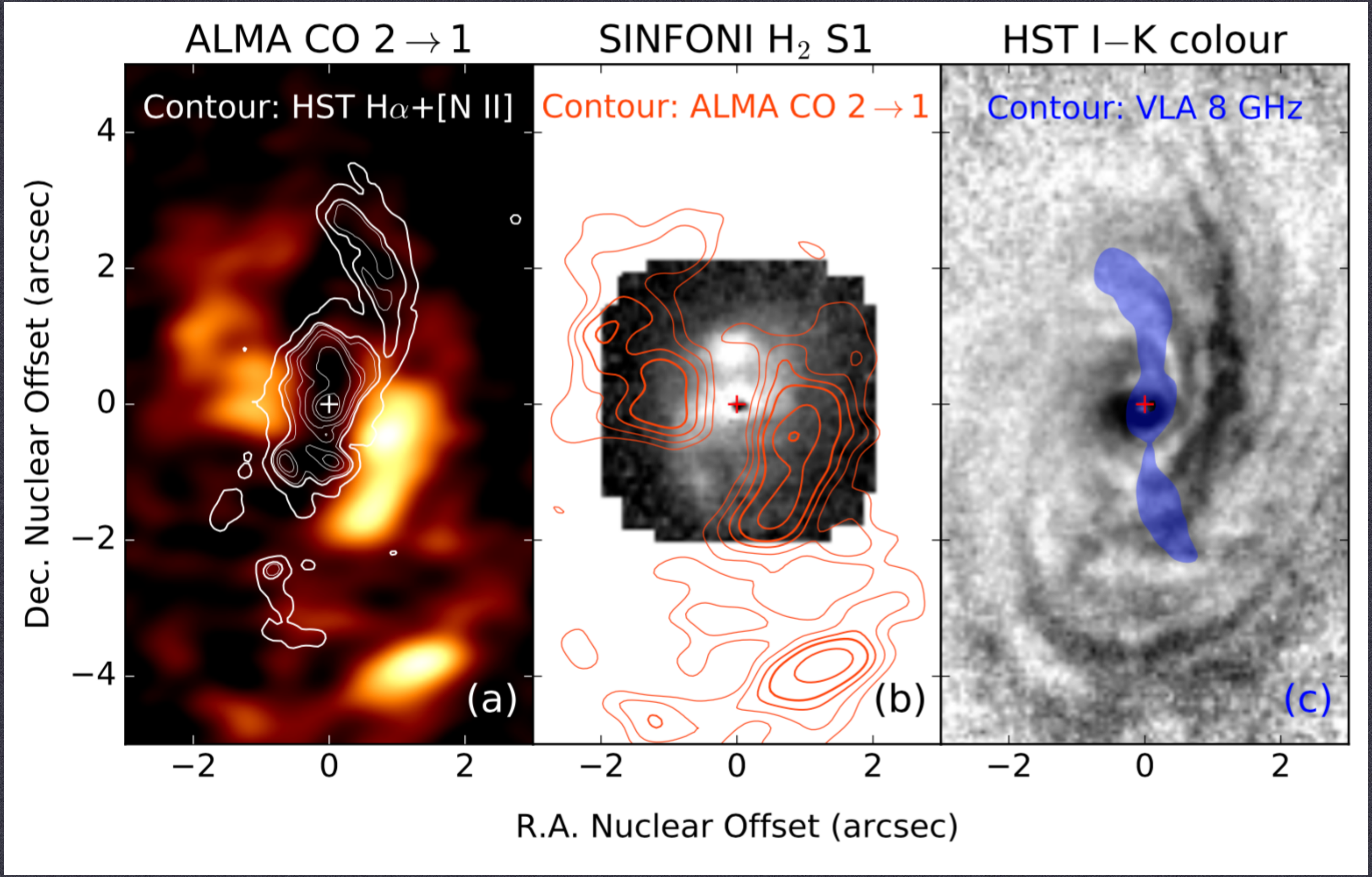


NGC 2110: A CASE STUDY

Cold molecular gas

Hot molecular gas

Dusty gas



Rosario+ 2018 (submitted)

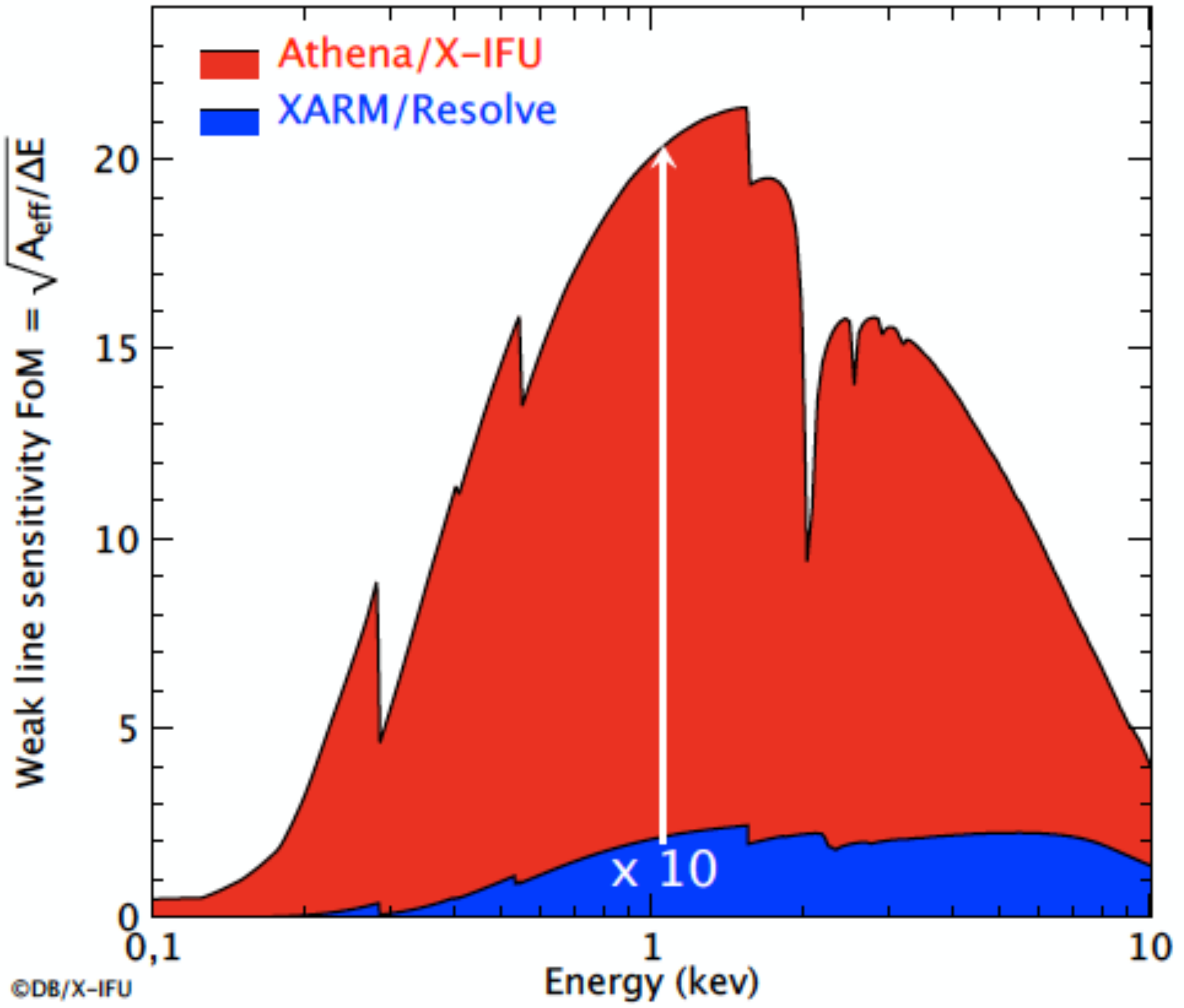
CONCLUSIONS / THOUGHTS

AGN do not summarily destroy dense, star-forming gas. Most of their feedback energy is probably carried away by a hot and ionised phase, with low coupling to molecular gas.

AGN can heat molecular gas, temporarily changing its properties, but the gas remains intact.

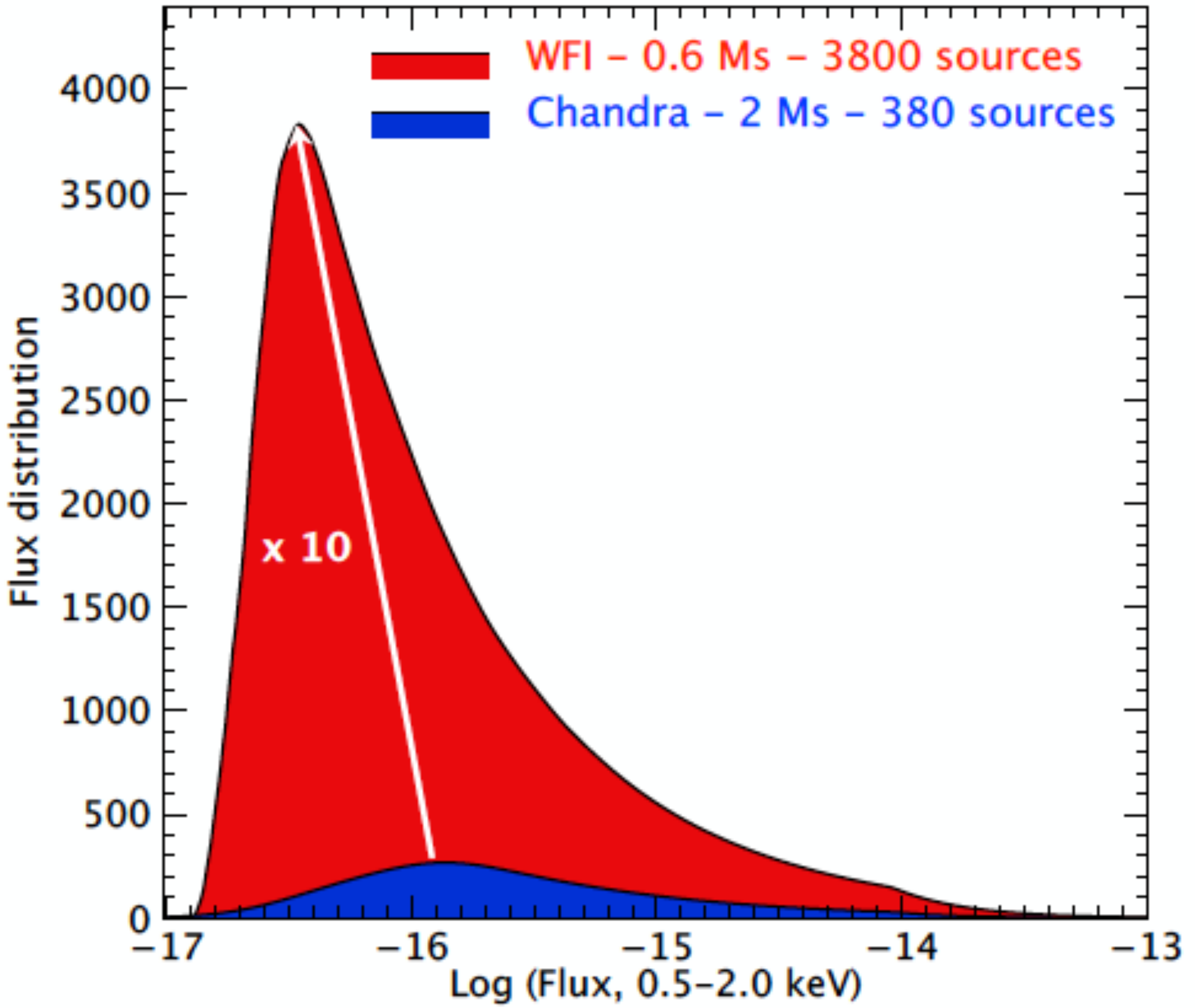
This is still enough to cut-off long term accretion of cold gas into galaxies. The role of AGN feedback in galaxy evolution is mostly to restrict supply.

Athena: a transformational observatory



©DB/X-IFU

Weak line sensitivity comparison between X-IFU and XRISM



Flux distribution comparison between WFI and Chandra deep pointing

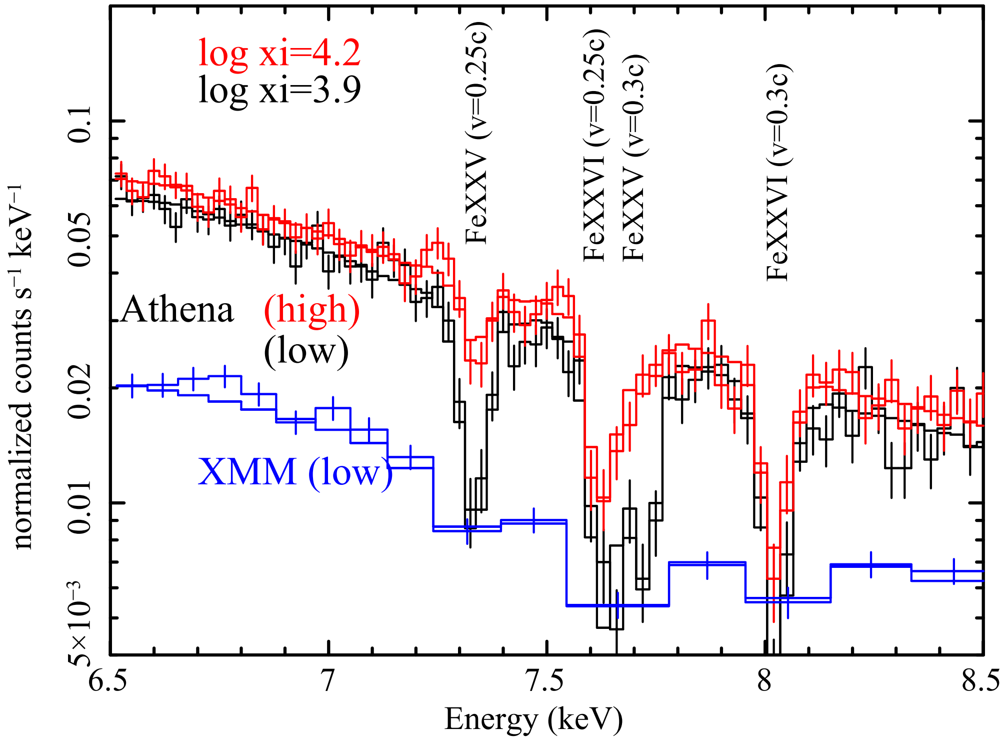
Credits: X-IFU team & J. Aird/A. Rau (WFI team)

AGN winds and outflows

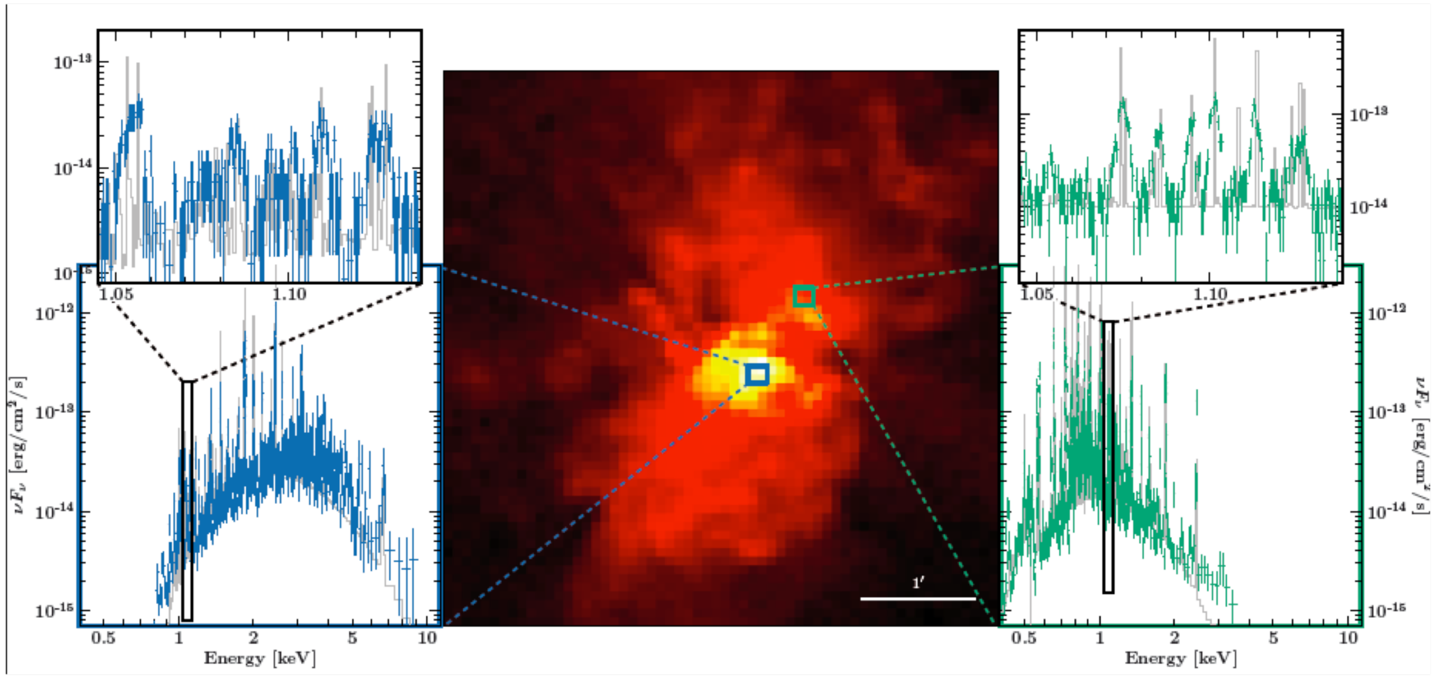
Mechanical feedback effective if $L_{mech} > 1\% \, L_{bol}$

Mechanical energy released in ultra-fast outflows

Gas, metals and mechanical energy ejected into the circum-galactic medium by AGN and Starbursts



Athena white paper on feedback: Cappi+ (2013)

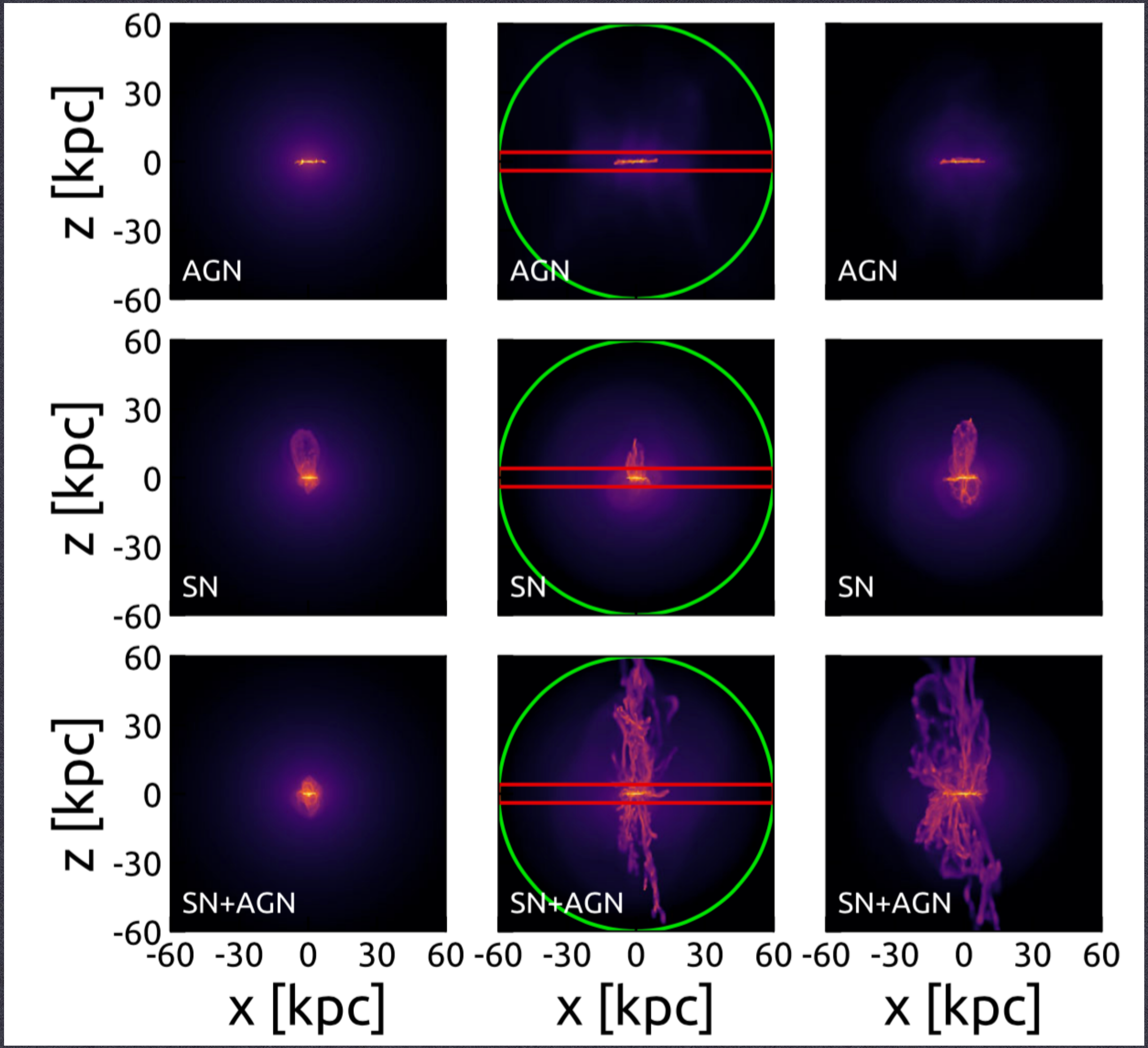


A. Ptak and the *Athena* simulation team (in progress)

Athena Project development: Current status

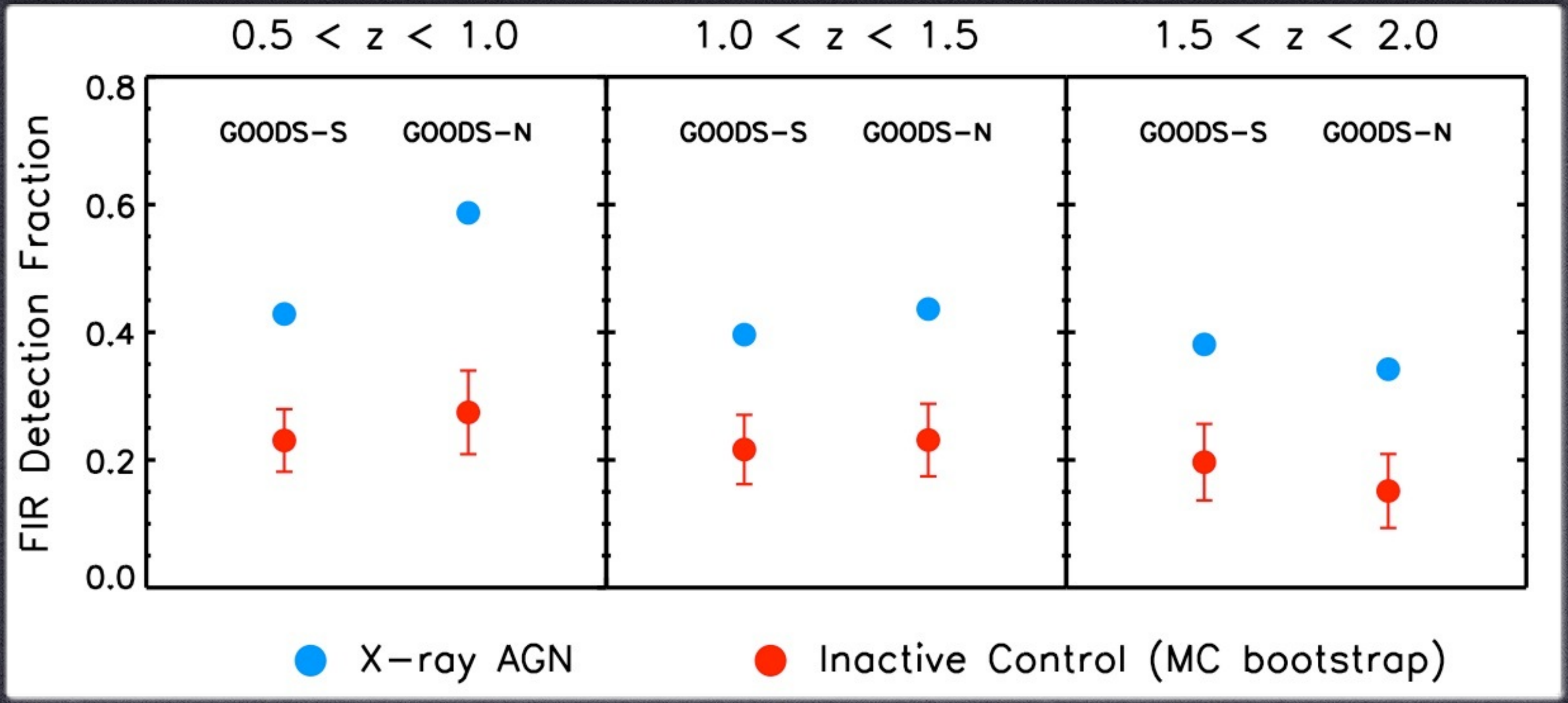
- Phase A ongoing, last milestone Status Review #1 (January 2018):
    - Comprehensively reviewed the Phase A work performed so far at the system level, including technical, cost and schedule aspects
    - Confirmed the good status of the spacecraft design and identified no showstopper to progressing towards adoption
- A modification of the mission baseline was needed to match mass- and cost-constraints:
    - A 15-row mirror baseline (limited science impact, preserving all major science requirements):
    - Reduction of the effective area at 1 keV from 2m^2 to 1.4m^2
    - Reduction of the nominal life from 5 years to 4 years
- The first major reviews of the instruments, the Instrument Preliminary Requirements Reviews (I-PRRs) are scheduled for the second half of 2018

Does star-formation promote AGN feedback?

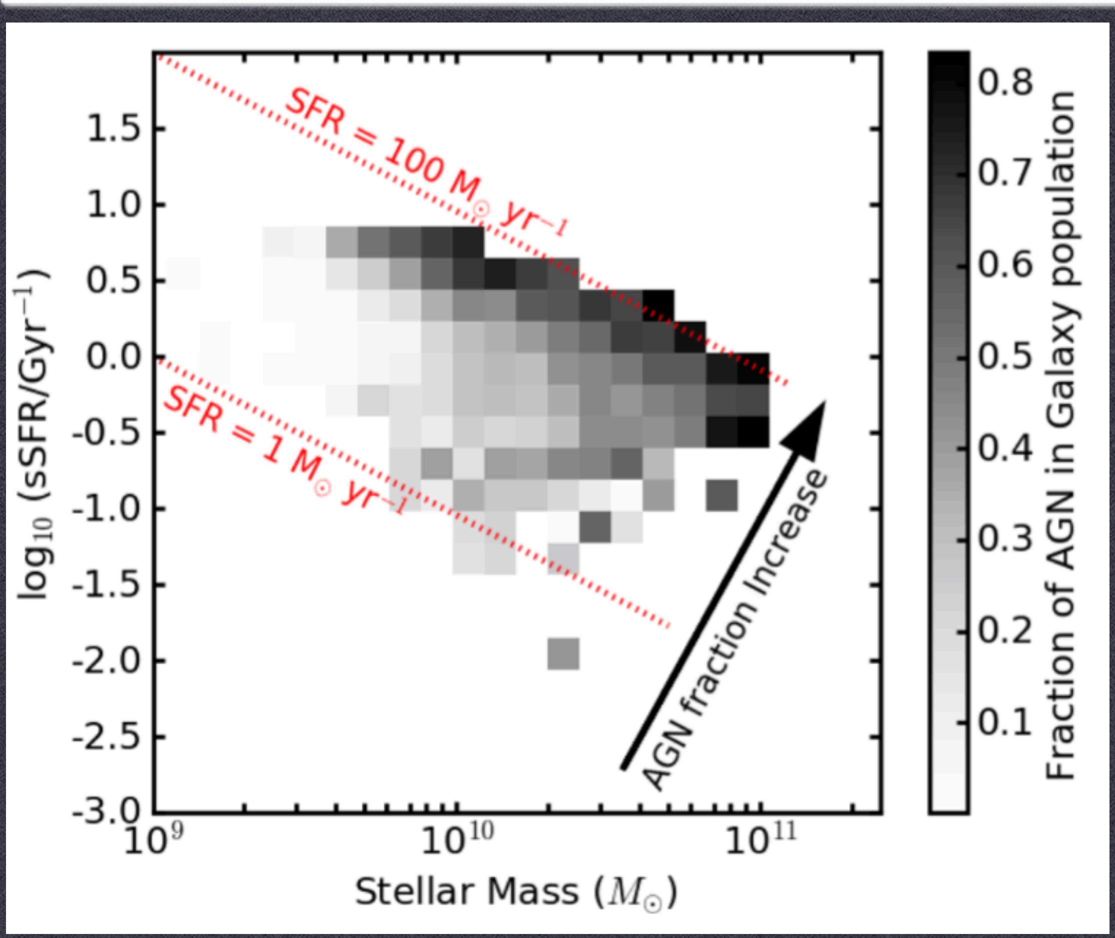


Biernacki & Teyssier (2018)

SF properties of AGN: are they quenching?



Rosario+ (2013)



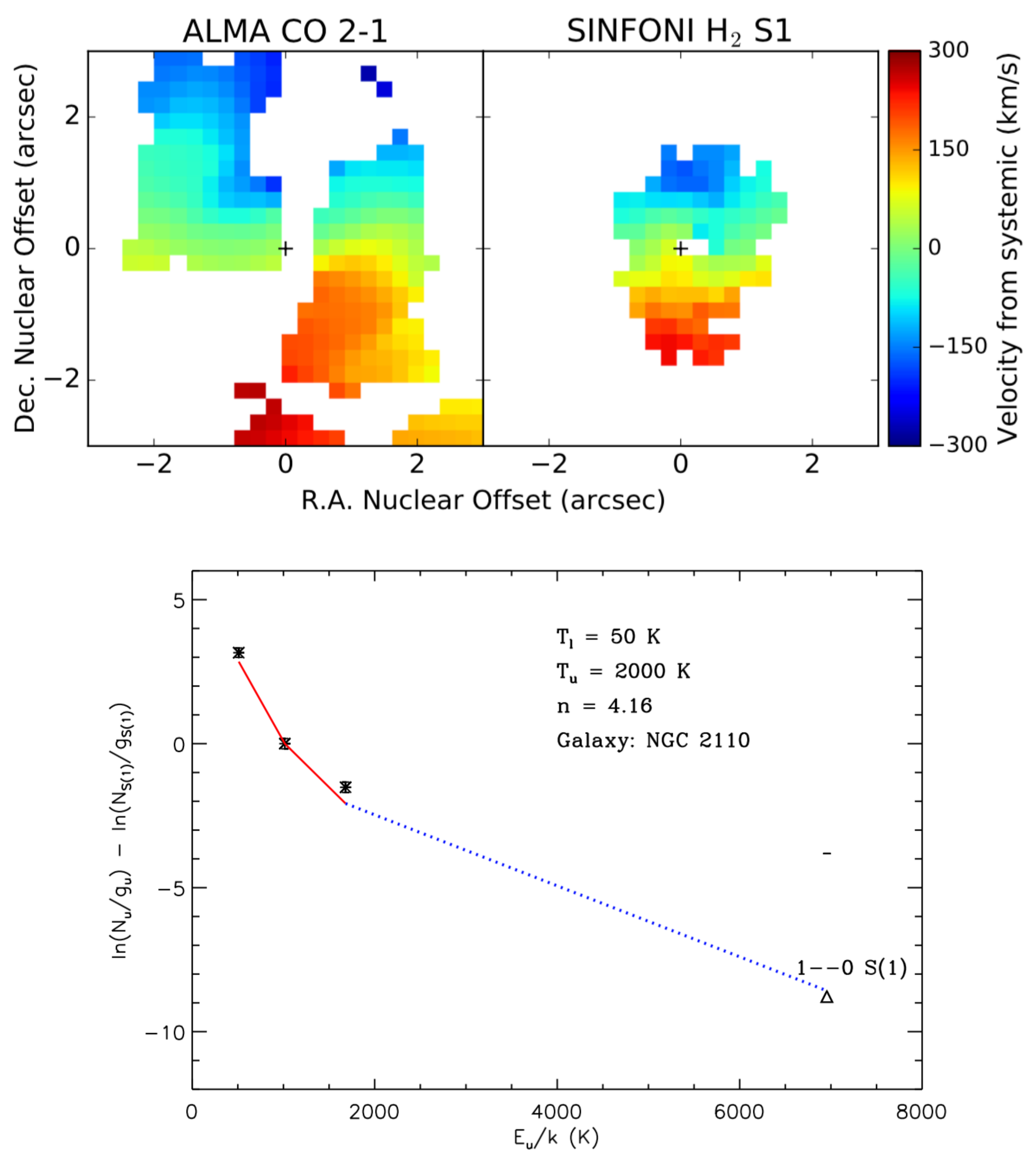
Scholtz+ (2018)

NGC 2110: A CASE STUDY

Using MIR H2 lines, we find that the molecular gas surface density in the CO hole is similar to the CO-emitting gas outside.

It shares the same rotation as the CO.

The AGN heats and excites the molecular gas, but it does not seem to accelerate or destroy it.



Rosario+ 2018, in prep.

FortesFit

github.com/vikalibrate/FortesFit; Rosario+ (in prep.)

FortesFit addresses these issues with:

✓ A general approach to painlessly add any parameterised SED model, and combine them in the fit.

✓ A full treatment of continuous, informative priors, including SciPy stats distributions.

✓ Functionality for hyperpriors (“dependencies”).

✓ Out of the box MCMC and the capability to add other fitting engines with minor development.

Code has been put into public domain, has been used in a published paper, and is in development for used with the KASHz and BASS programs.

Looking for co-developers, testers, users.