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Role of environment in the jet powering mechanism in radio quasars - insights from LoTSS

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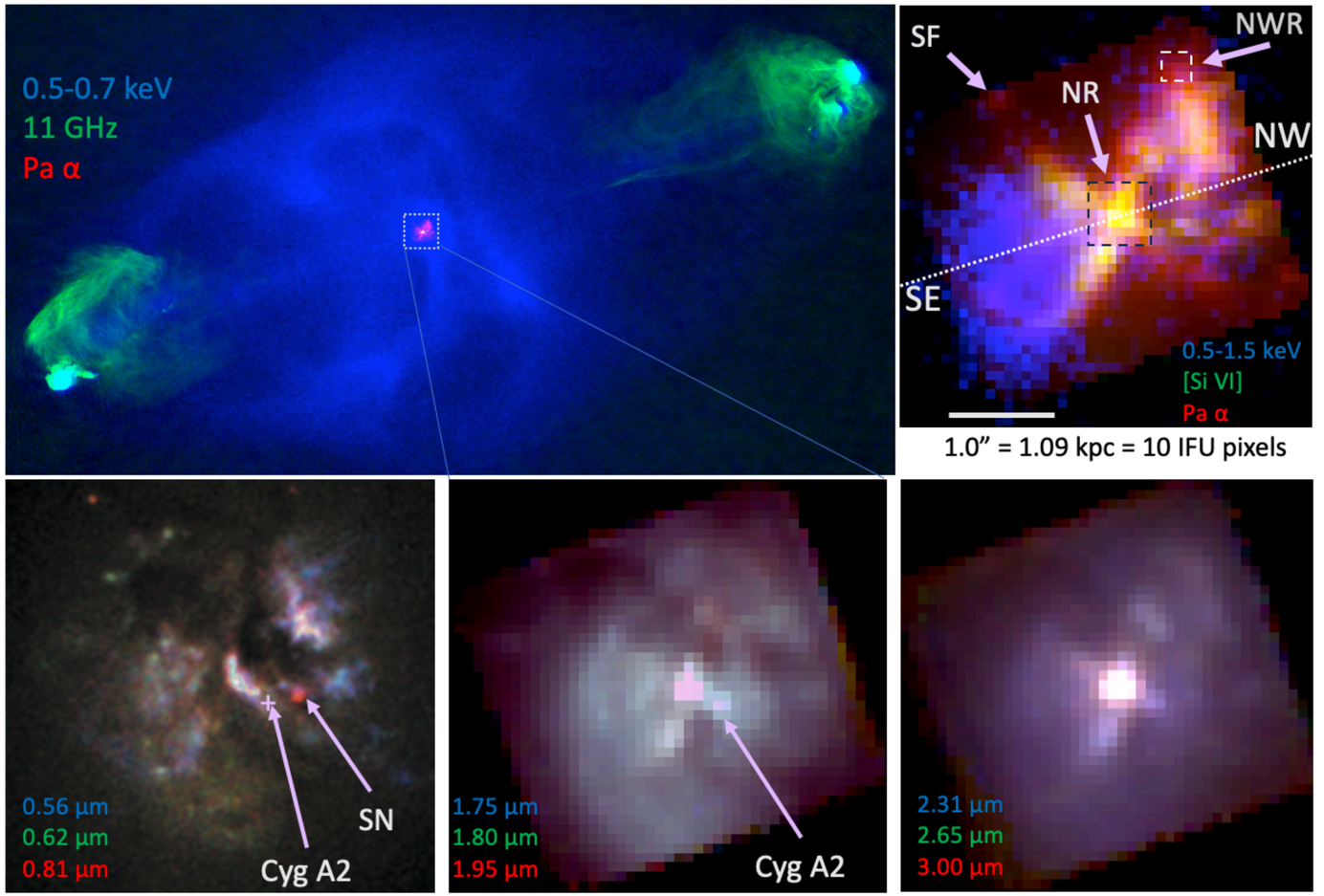
10/07/25, NAM 2025

Link to jet power: large-scale environment

Introduction

- Environment might have more direct influence on the jet formation/powering

  ➡ ***[individual]*** **Nearby studies show dense environment can foster jet production (e.g. Cygnus A; Barthel, Arnaud+96)**



Credit: Ogle+25

Link to jet power: large-s ent

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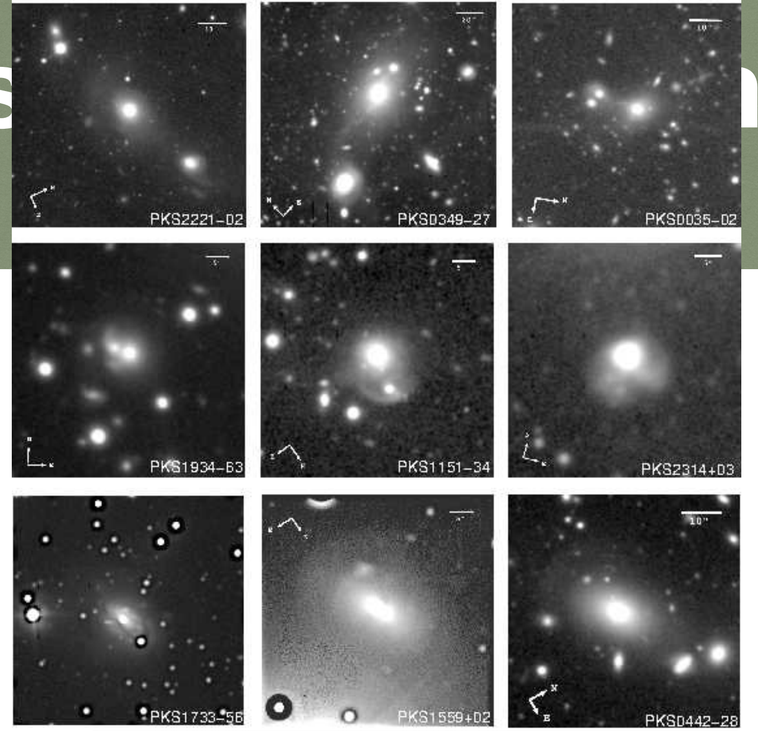
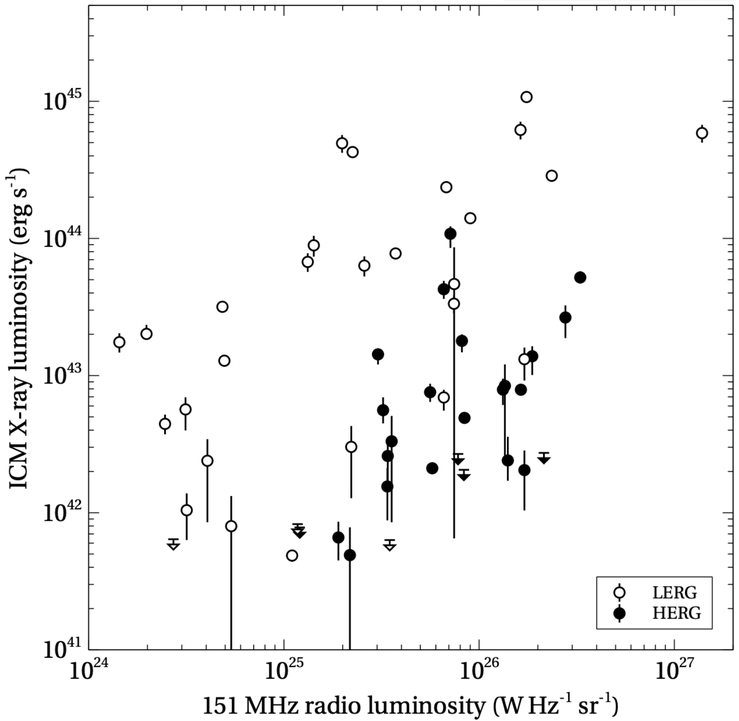
  ➡ Nearby studies show dense environment can foster jet production (e.g. Cygnus A; Barthel, Arnaud+95)

  ➡ ***[cluster]*** **Further supported by higher X-ray incidence (rich hot gas) + favour rich cluster environment**



Credit: Tadhunter+16



Credit: Ineson+15

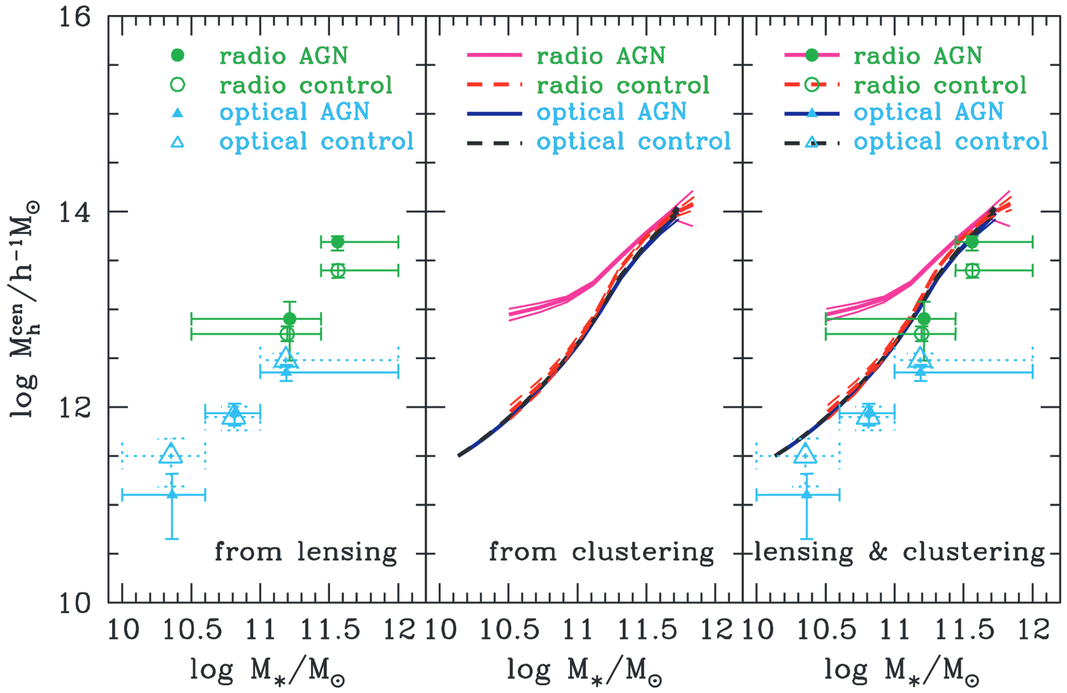
Link to jet power: large-scale environment

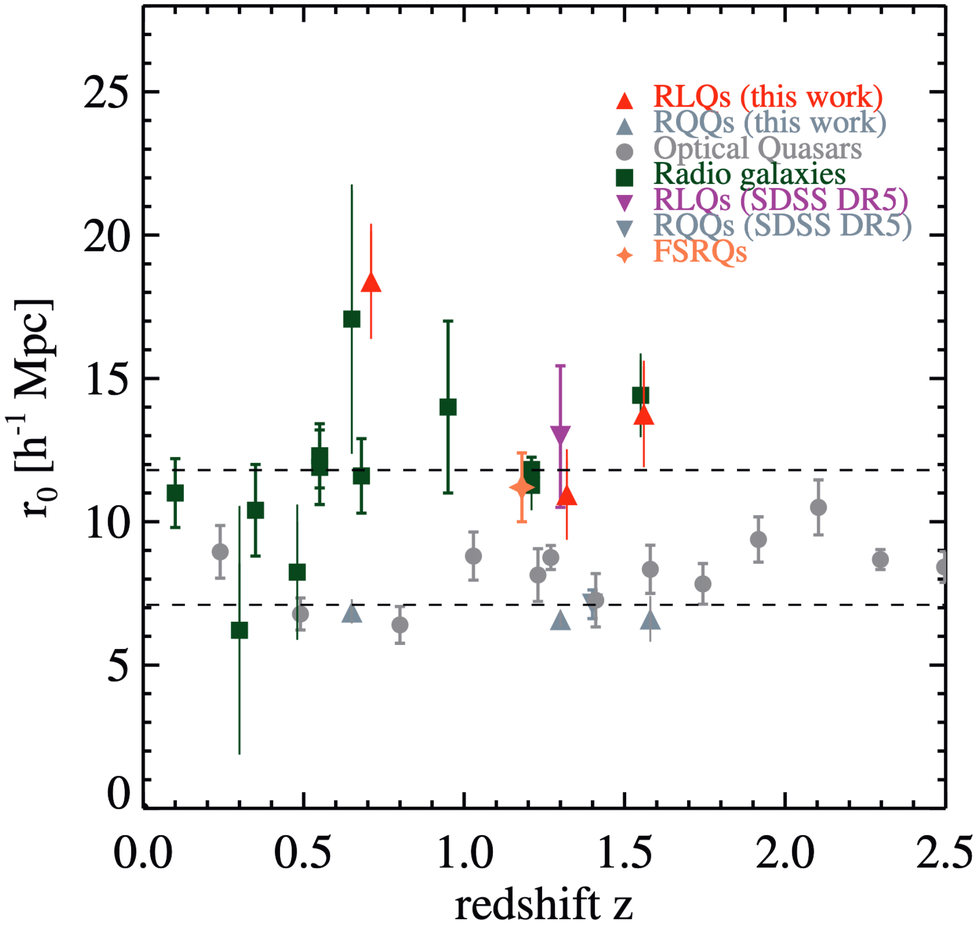
Introduction

- Environment might have more direct influence on the jet formation/power

FIRST-detected quasars

➡ ***[halo]*** RL QSOs seem to be **more clustered** than RQ QSOs (Mandelbaum+08, Shen+09, Retana-Montenegro+17) -> ***more massive haloes (BHs?)***



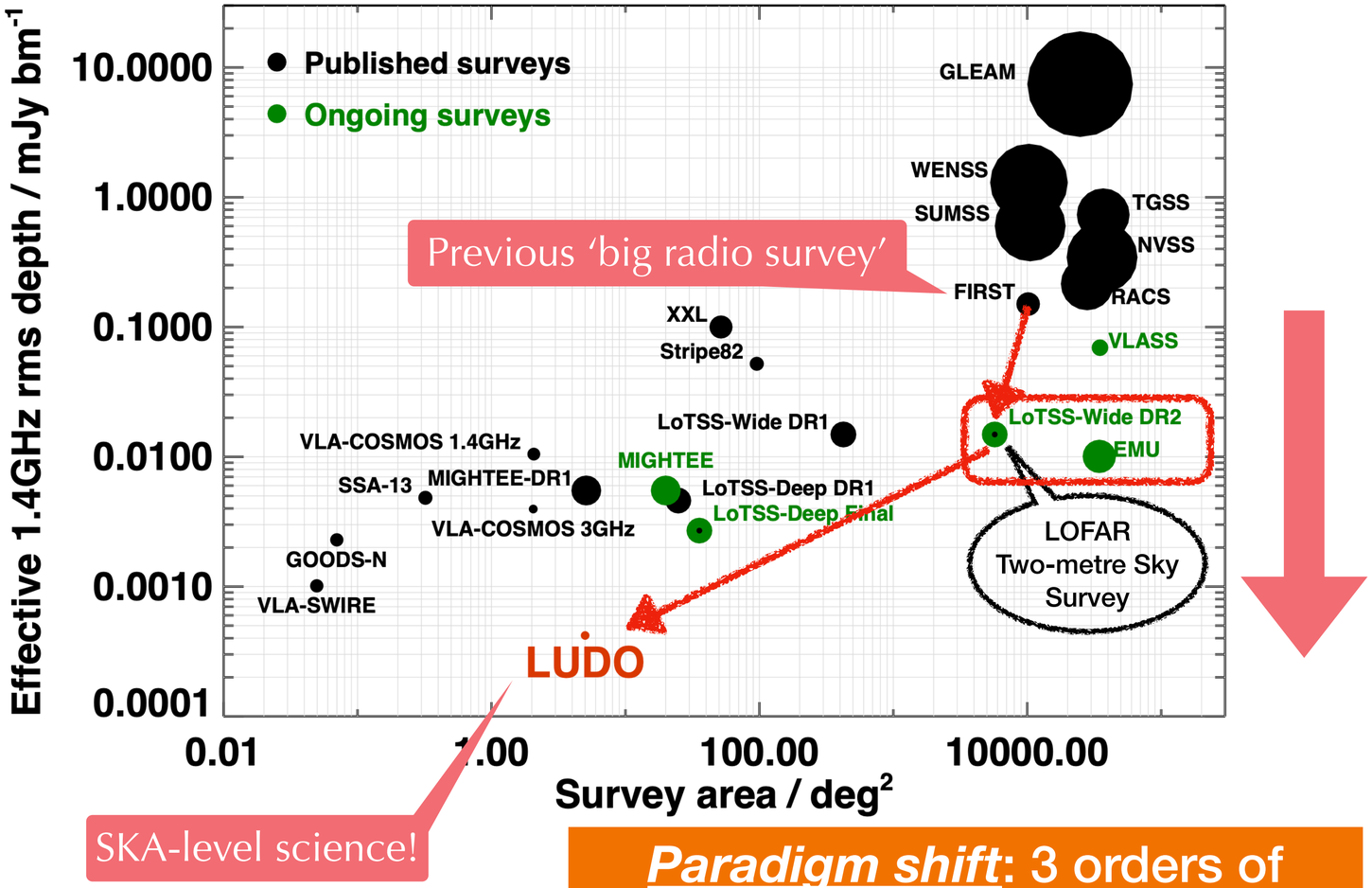


Left: Mandelbaum+08; Upper: Retana-Montenegro+17

Link to jet power: large-scale environment

Radio quasars in the era of deep radio surveys

- Next-gen radio surveys probes well into the ‘radio-quiet’ regime:



Paradigm shift: 3 orders of magnitude deeper into radio sky

Link to jet power: large-scale environment

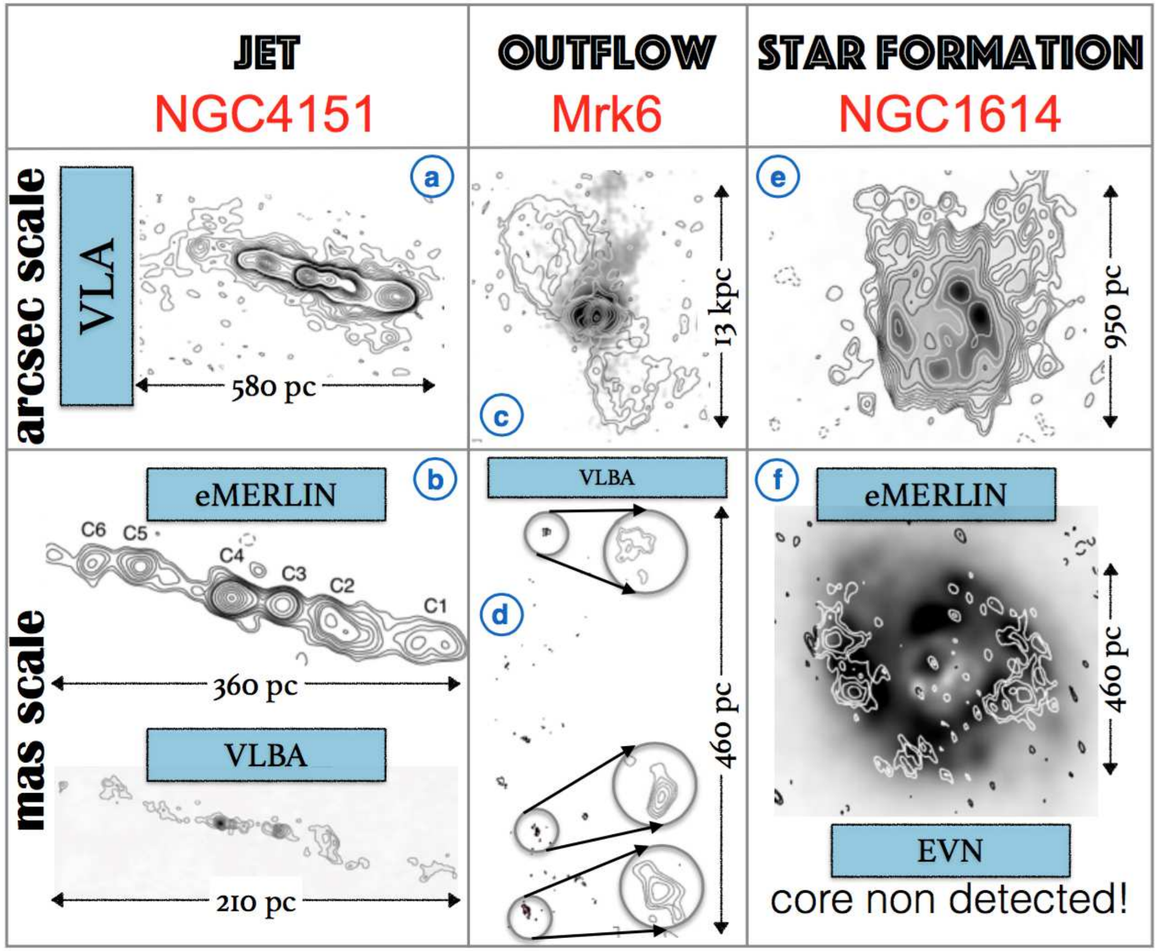
Radio quasars in the era of deep radio surveys

- Next-gen radio surveys probes well into the ‘radio-quiet’ regime:

  ➡ Jets in RQ AGNs: VLBI observation challenges RL/RQ dichotomy

  - ***How to distinguish between the host galaxy star formation (SF) and weak AGN activities (jet/ outflow)?***

★ **What causes the powering efficiency of jets to vary across a wide range?**



Credit: Panessa+19

Two-component Bayesian model

Separating SF and AGN in radio flux density distribution

Well-defined random + weight for optical selection

ensure similar accretion rate/ redshift for input quasar

SDSS catalogue

Redshift

***i*-band magnitude ($\mathscr{M}_i$) / $L_{\rm bol}$**

$\mathscr{M}_i - z$ **grids**

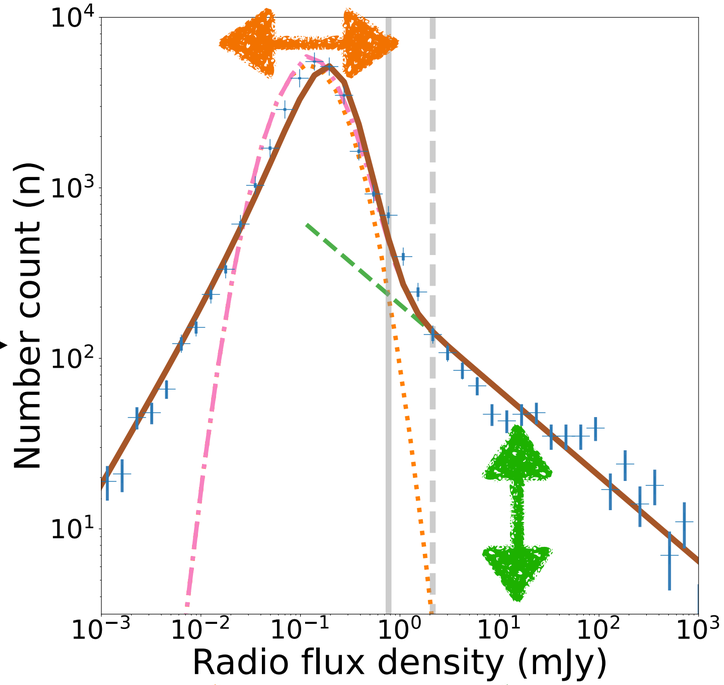
Target: optically identified quasar from eBOSS

Radio flux density

LoTSS DR2 catalogue

LoTSS DR2 mosaic

Model best-fit



Host SF dist.

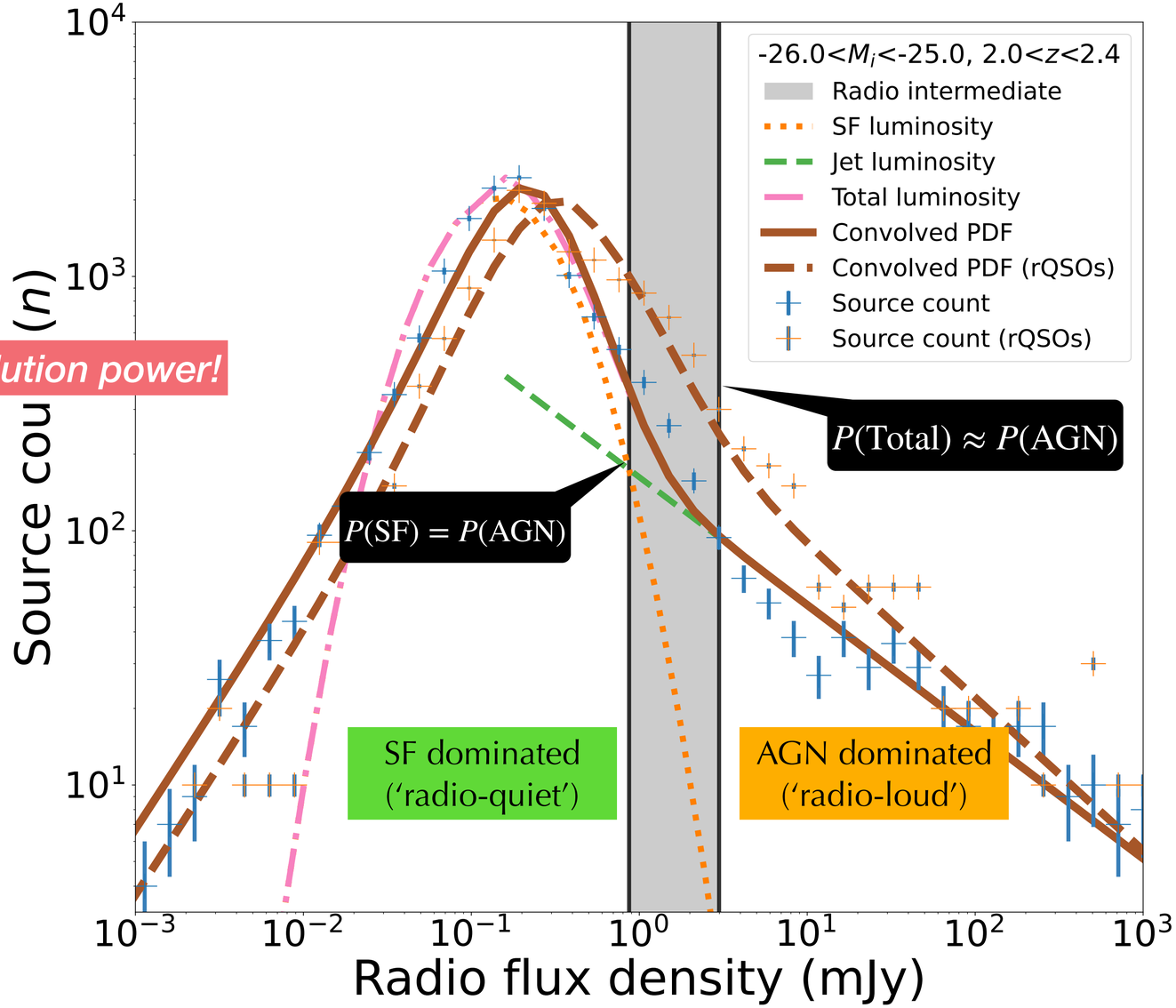
AGN jet/ wind dist.

Before we start…

Is ‘radio-loudness’ a good definition?

- Traditionally use single value thresholds (e.g. $R = f_{5\mathrm{GHz}}/f_{4400\text{Å}}$)
- The two-component model enables classification by **physical processes** on survey datasets

Available with less depth / resolution power!



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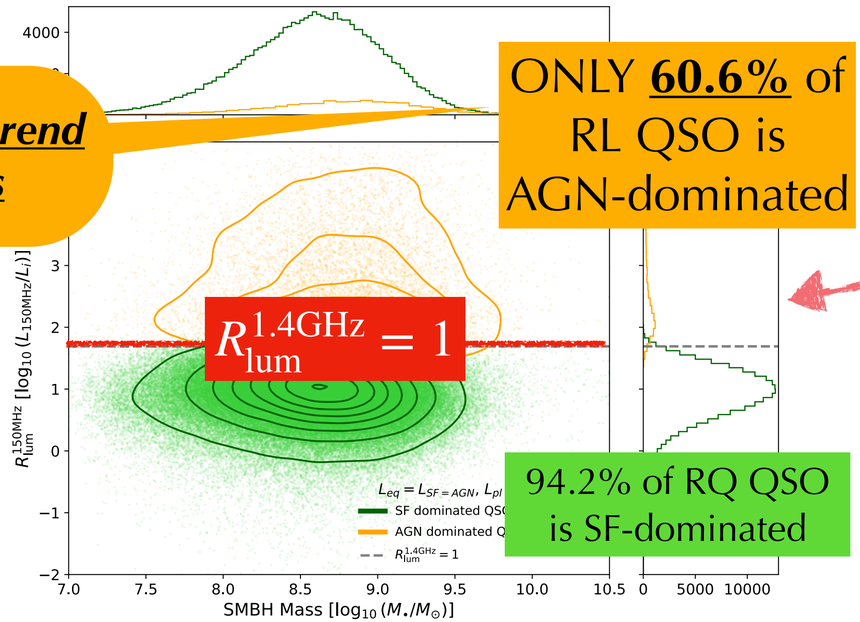
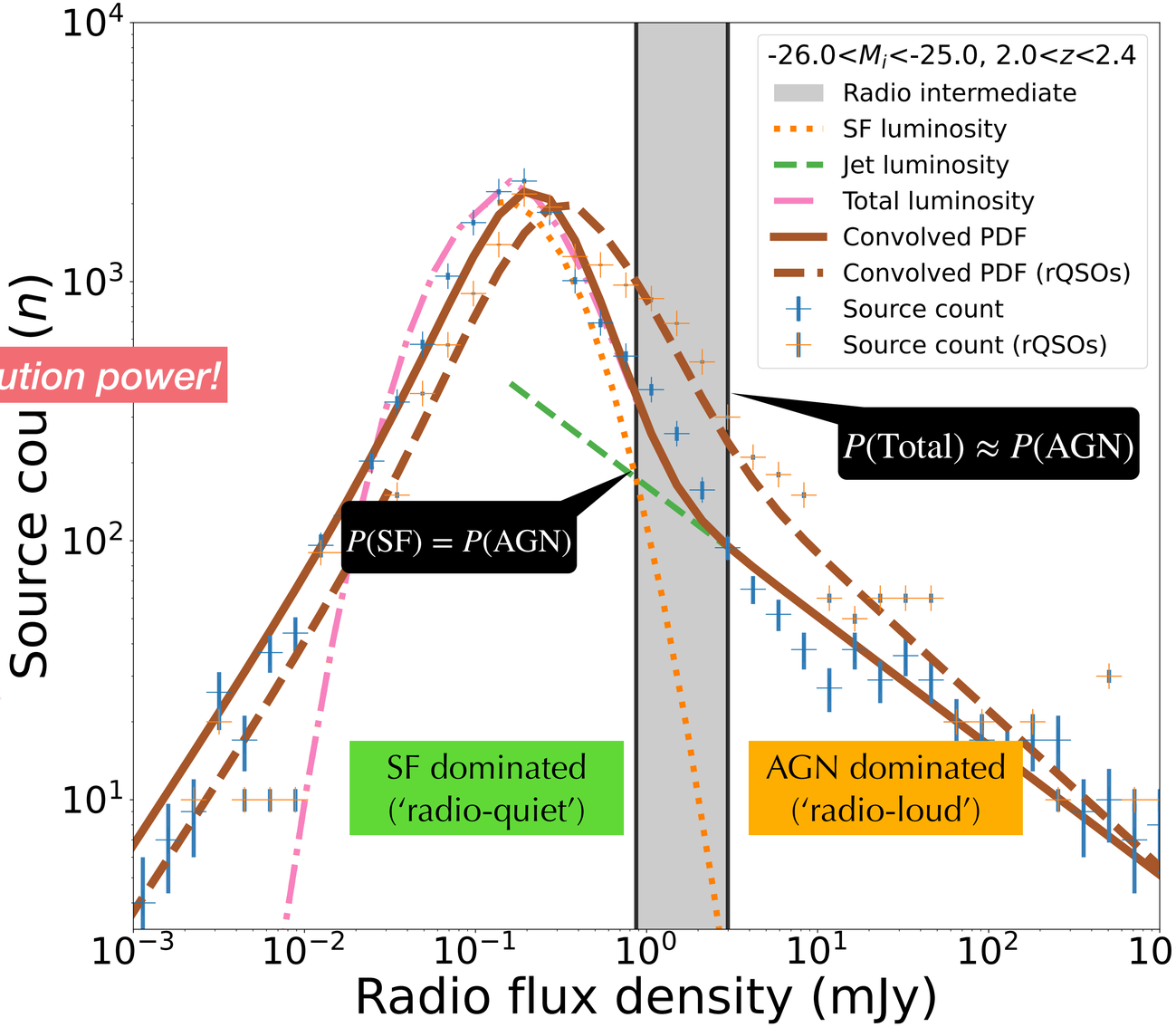


Wiped out the trend in RL QSOs

ONLY **60.6%** of RL QSO is AGN-dominated

94.2% of RQ QSO is SF-dominated



The ‘radio loudness’ problem

Current caveats

- This affects (almost) **all works** related to radio AGN population, especially in the SKA era!
- Naïve assumptions are made:
  - Assuming radio power has no evolution with optical luminosity/redshift
  - Assuming same radio spectral slope
  - Assuming single-band photometry = bolometric luminosity

The ‘radio loudness’ problem

Ways to improve - some thoughts for discussion!

- **<u>Bottom line</u>**: calibrate for RL thresholds across different radio/optical/X-ray frequencies (e.g. 5GHz vs. 1.4GHz/144MHz, B-band vs. i-band vs. $L_{3000\text{Å}}$ photometry, luminosity vs. flux)

Are we tracing the same population?

The ‘radio loudness’ problem

Ways to improve - some thoughts for discussion!

- **Bottom line**: calibrate for RL thresholds across different radio/optical/X-ray frequencies (e.g. 5GHz vs. 1.4GHz/144MHz, B-band vs. i-band vs. $L_{3000\text{Å}}$ photometry, luminosity vs. flux)

- Better ways: test for different RL thresholds; include additional populations (e.g. radio intermediate, high-power radio loud)

What exact population are we tracing?

The ‘radio loudness’ problem

Ways to improve - some thoughts for discussion!

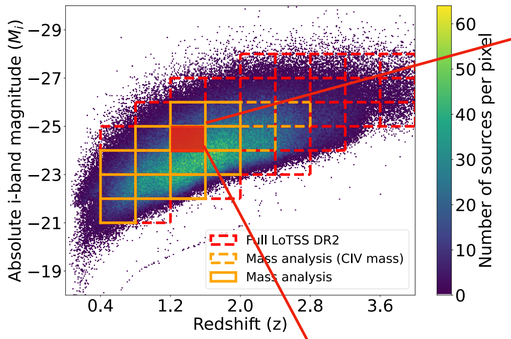
- **Bottom line**: calibrate for RL thresholds across different radio/optical/X-ray frequencies (e.g. 5GHz vs. 1.4GHz/144MHz, B-band vs. i-band vs. $L_{3000\text{Å}}$ photometry, luminosity vs. flux)
- Better ways: test for different RL thresholds; include additional populations (e.g. radio intermediate, high-power radio loud)
- Best way: apply the model -> only things needed are redshift + luminosity + radio flux density + non-radio-selected sample
  - Or refer to the table values in Yue+24… (if SDSS quasars)
  - Or use brightness temperature approach (if high-res radio image available; Morabito+22,25)

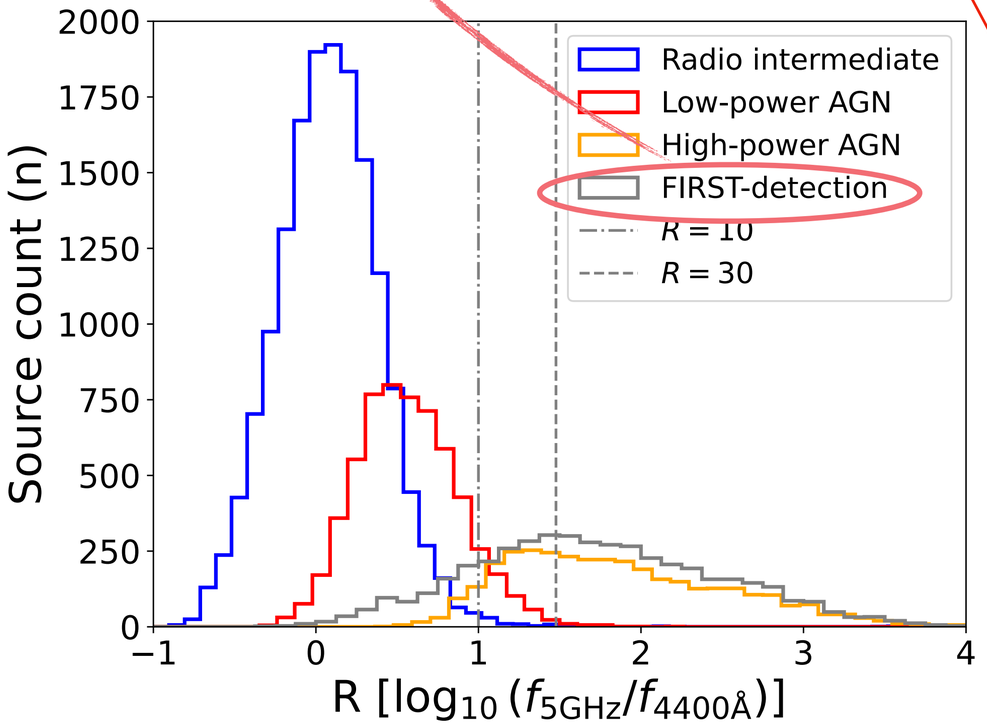
What is actually going on in these populations?

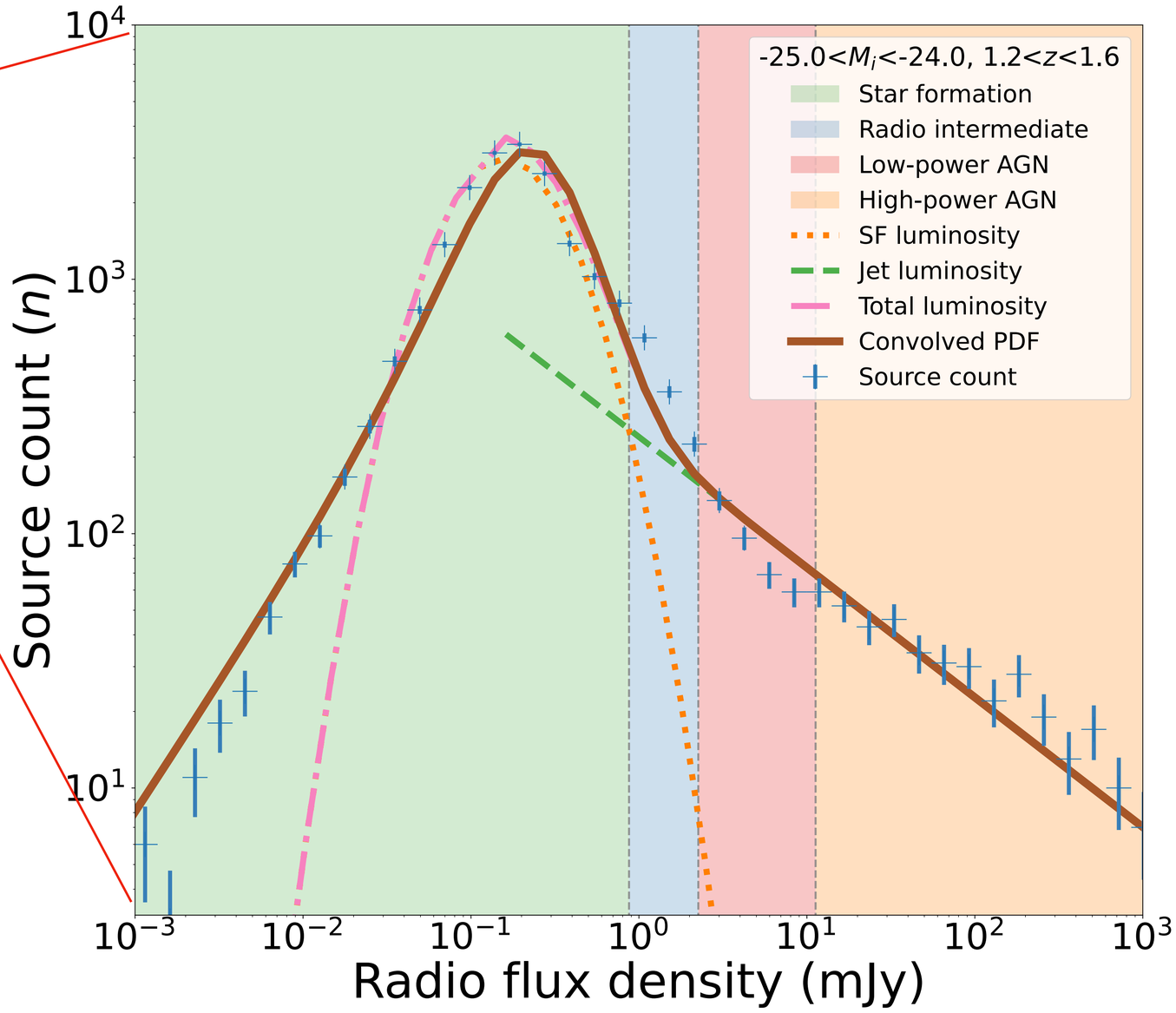
Link to jet power: large-scale environment

(Re)-defining radio quasar population

Used in previous radio quasar clustering studies (e.g. Shen+09; Retana-Montenegro+17)





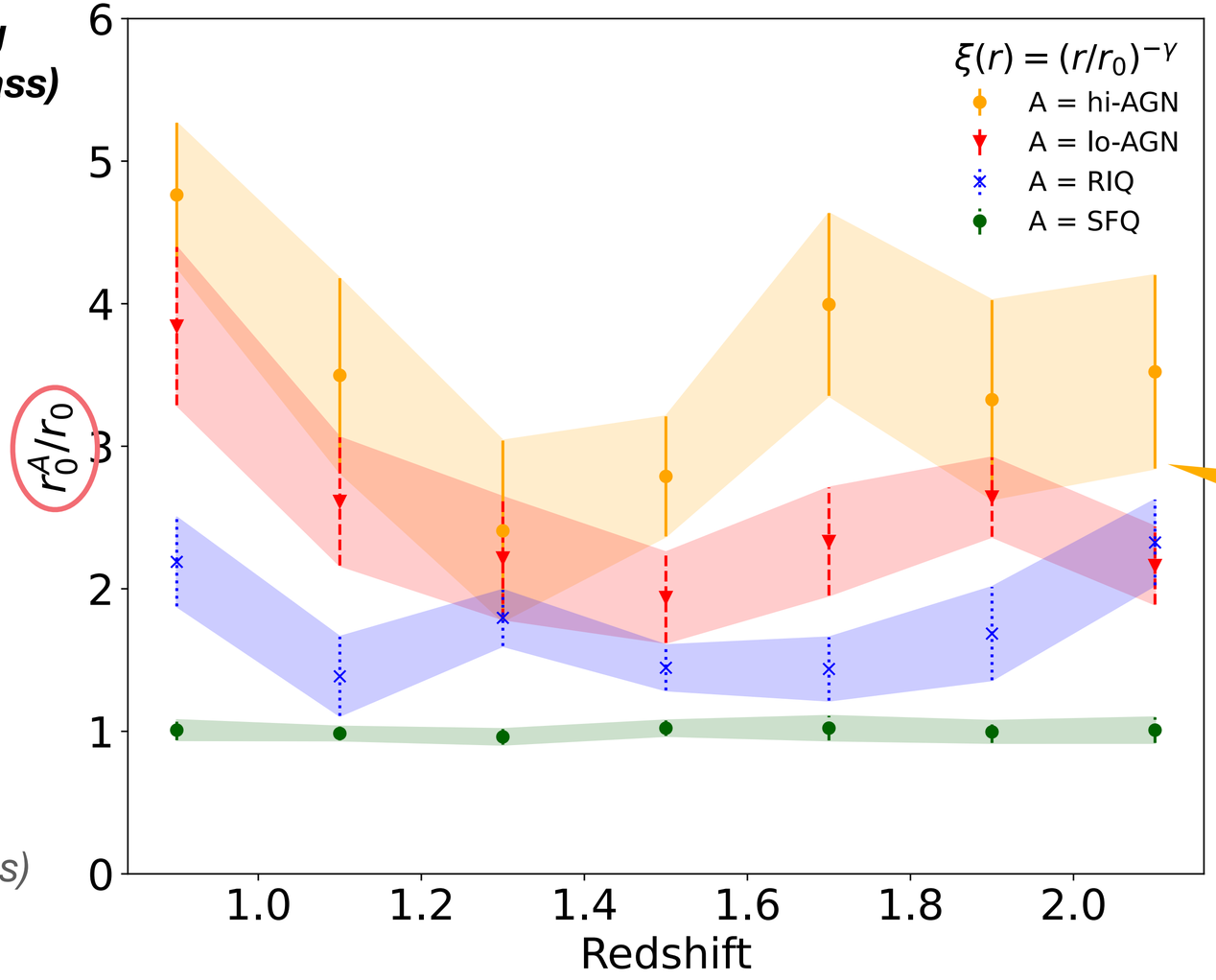


Link to jet power: large-scale environment

Clustering signal from two-point correlation function (TPCF)

More clustering (higher halo mass)

r_0 = *correlation length of entire quasar sample fitted from TPCF*



Less clustering (Lower halo mass)

Fraction of AGN jet component in the quasar radio emission

Halo mass is **positively correlated** with jet fraction in quasar radio emission

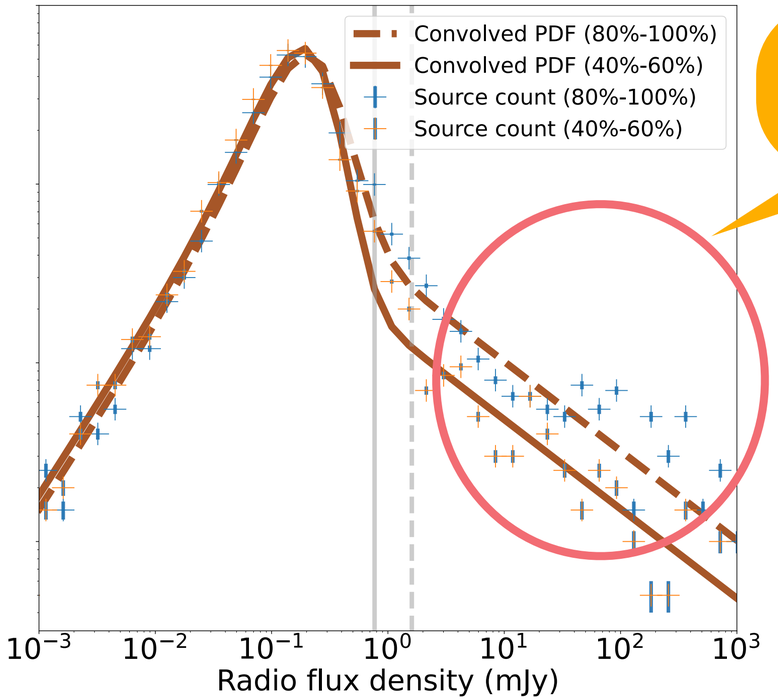
Jet power is **strongly linked** to the *halo gas reservoir*

Link to jet power: large-scale environment

Halo mass vs. BH mass

- Are jet-dominated quasars more clustered because of massive haloes or massive BHs residing in massive haloes?

Most massive BHs have a higher jet incidence, possibly due to domination of kinetic accretion mode (e.g. Yue+25)



Highest mass quintile
QSOs shows difference in flux density distribution

Link to jet power: large-scale environment

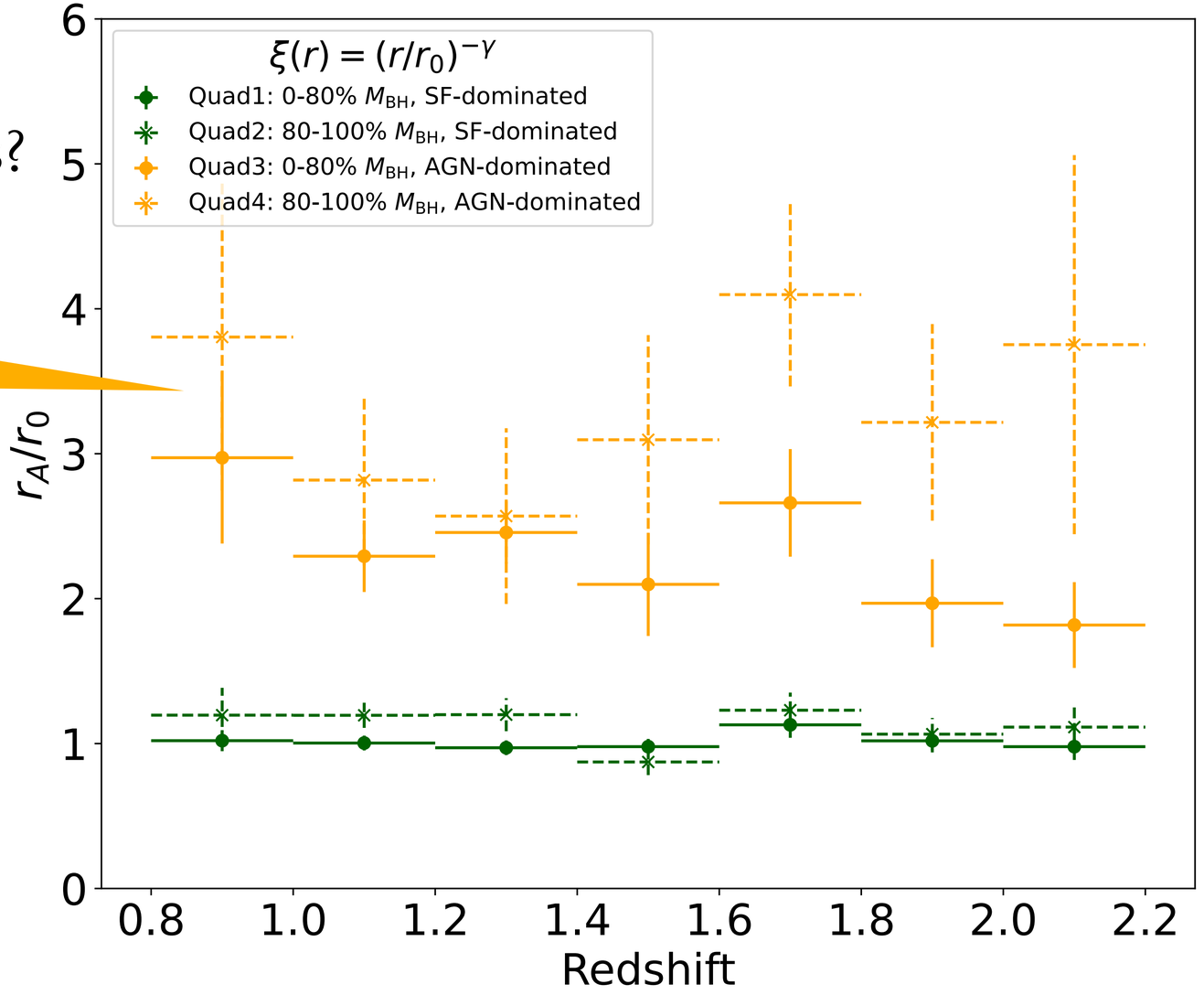
Halo mass vs. BH mass

- Are jet-dominated quasars more clustered because of massive haloes or massive BHs residing in massive haloes?

BH mass / accretion mode alone is not enough to explain the overdensity in jet-dominated quasars

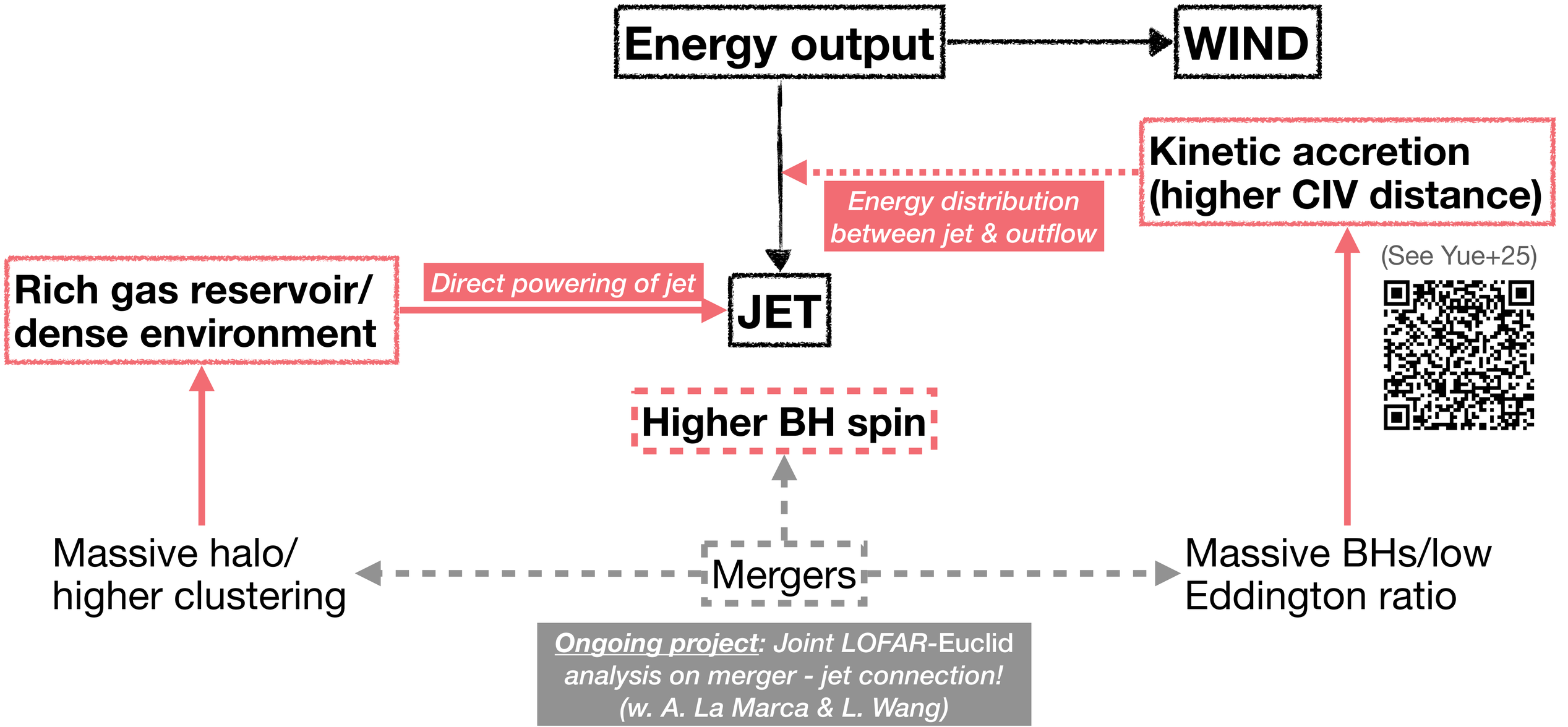
<u>Halo mass > BH mass</u> in determining jet power

<u>More direct powering mechanism?</u>



Towards a census of jet powering mechanism

Possible scenarios



Take-home messages

…and thanks for listening

For my personal website ->

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- Two-component model can disentangle *star-forming component* from host galaxies and *jet component* from AGNs in faint quasar radio emission
- *Radio loudness cannot trace the physical origin of quasar radio emission*; extra attention is needed in deep radio surveys!
- Halo mass is strongly tied to the jet fraction in quasar radio emission - *more powerful the jet, more massive haloes they reside in*
- Large scale environment is more important than BH mass/ accretion mode in determining AGN jet power