Low-frequency radio continuum emission in optically selected quasars

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SPARCS, University of Lisbon – Lisbon, May 6, 2019

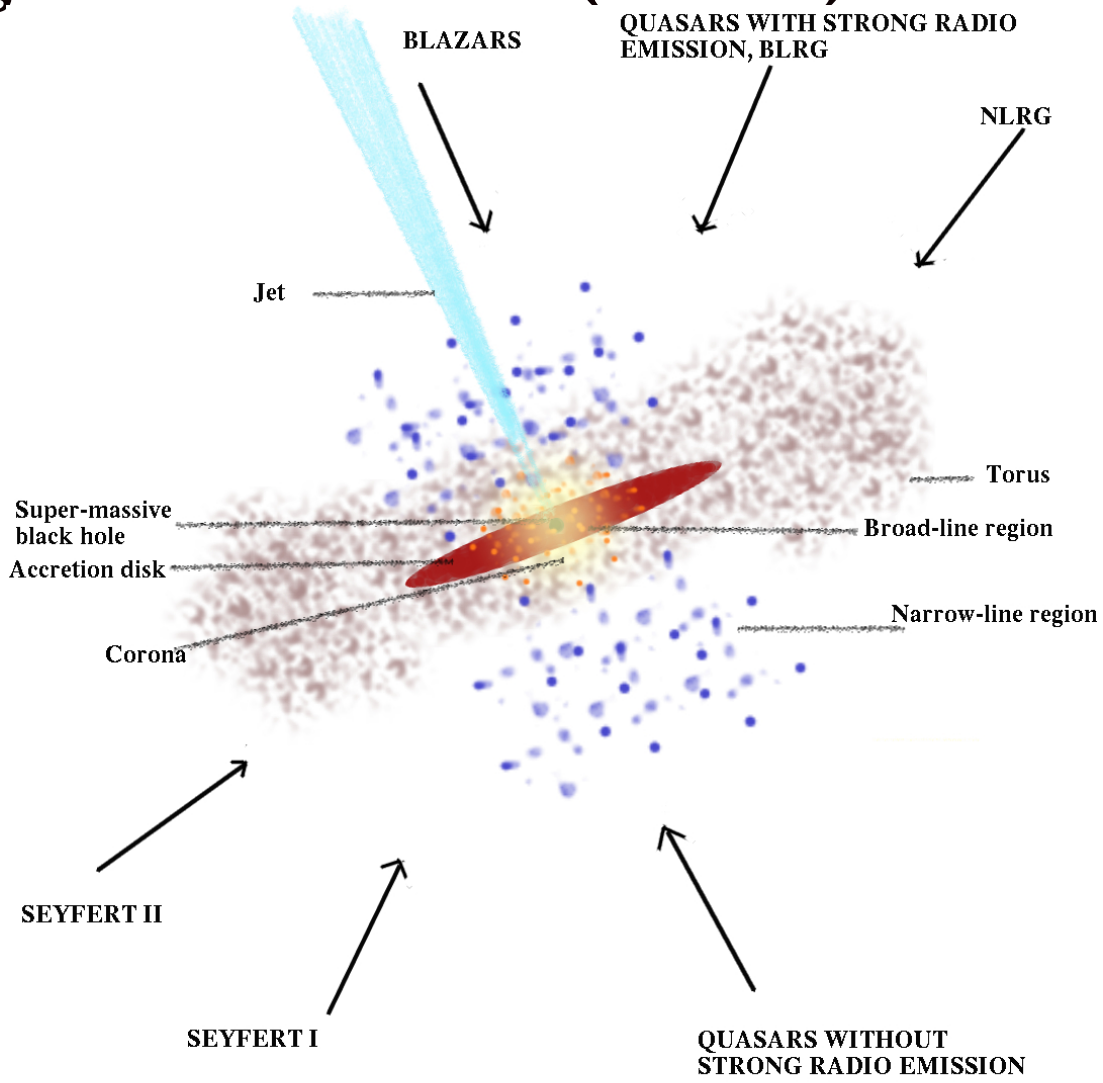
Outline

- Active galactic nuclei (AGN)
- Motivation
- Quasar sample and radio data

  SDSS QSOs

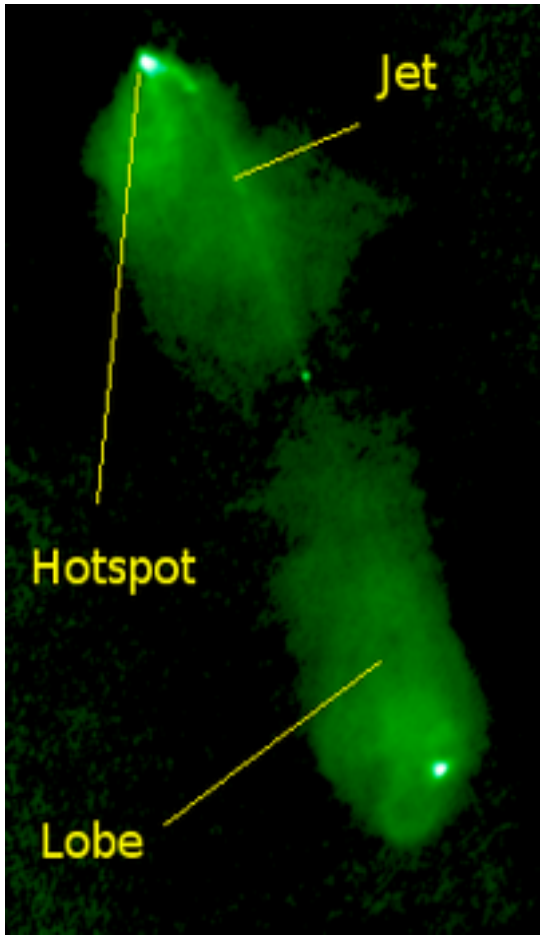
  LOFAR data over the HETDEX and H-ATLAS/NGP regions
- Results
- Conclusions & future works [*Gürkan et al. 2019*]

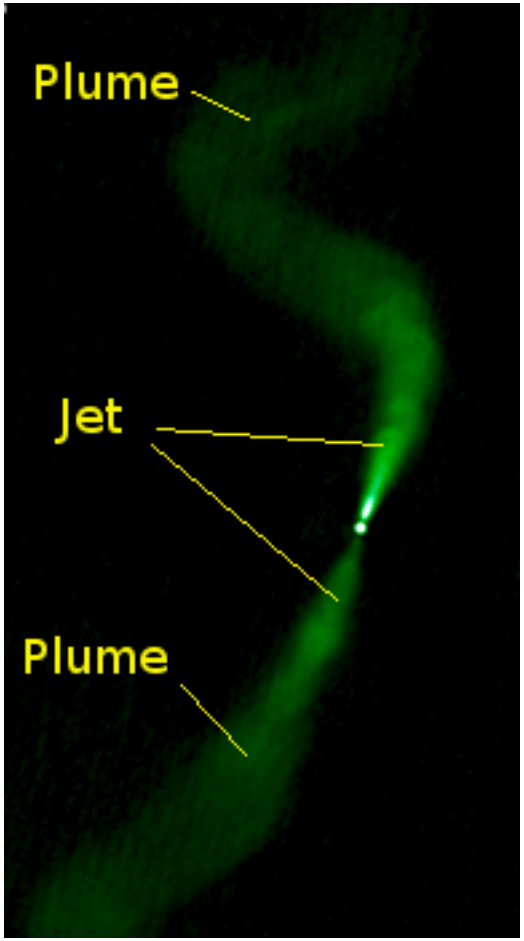
Active galactic nuclei (AGN)



Radio classification

Fanaroff & Riley 1974





FRII: Edge-brightened

FRI: Centre-brightened

Motivation

- *Is there a radio loudness dichotomy in QSOs?*
- *Does $\mathscr{R}$ depend on any galaxy parameters?*
- *What is the source of radio emission in optically selected QSOs?*

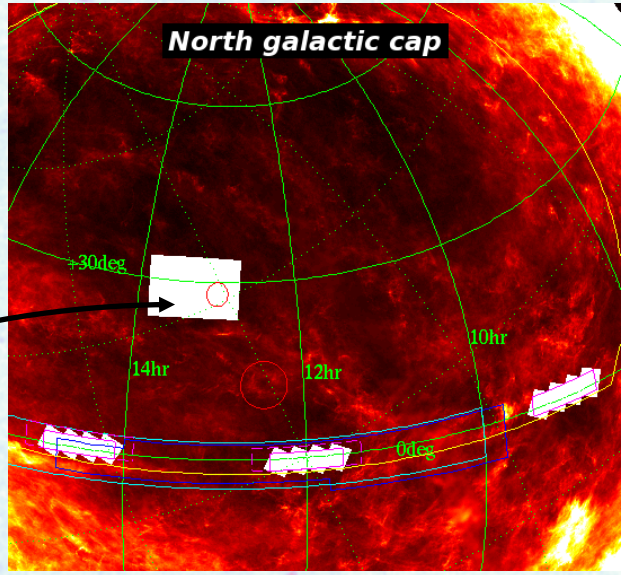
The classification ratios defined to date are not clear,

The definition of radio loudness involved using fluxes (or luminosities) at a various optical and radio bands,

Construction of the radio loudness definitions to date have been based on samples from different surveys and samples with varying properties,

A good fraction of QSOs classified as RL and RQ in the literature might present similar properties.

Sample and data



Radio data:

Low Frequency Array (LOFAR)

– LOTSS *[Shimwell +19, Williams+19, Duncan+19]*

~71 μJy/beam sensitivity and 6 arcsec resolution

– H-ATLAS/North Galactic Pole *[Hardcastle +16]*

~ 100 μJy/beam sensitivity and 6 arcsec resolution (Far-IR measurements from Herschel)

Optical data:

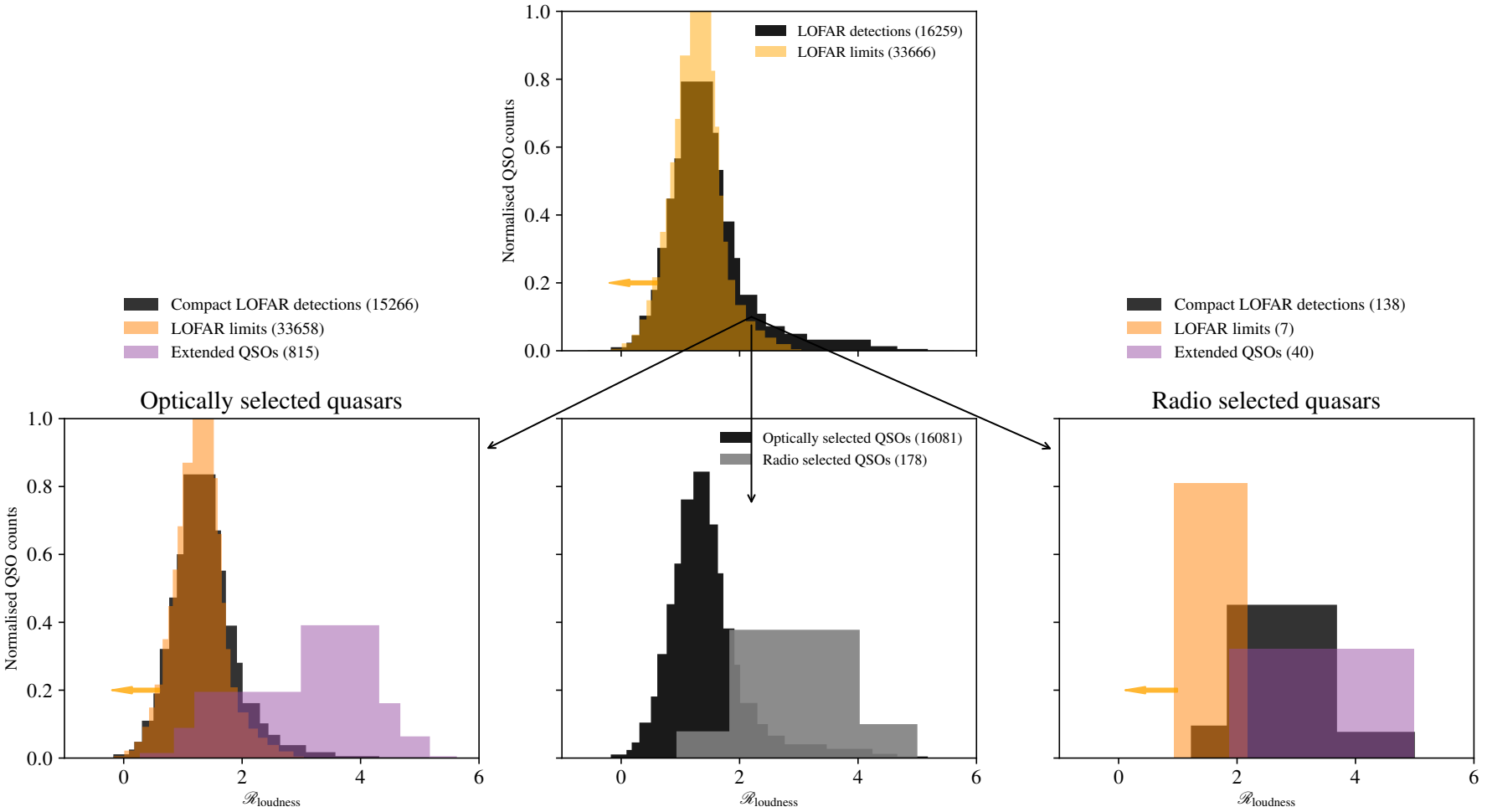
Sample ⟶ SDSS-BOSS DR14 *[Alam et al. 2015, Ross et al. 2012, Paris et al. 2014]*

Redshifts *(0 < z < 6)*, SDSS band magnitudes *(u,g,r,i,z)*

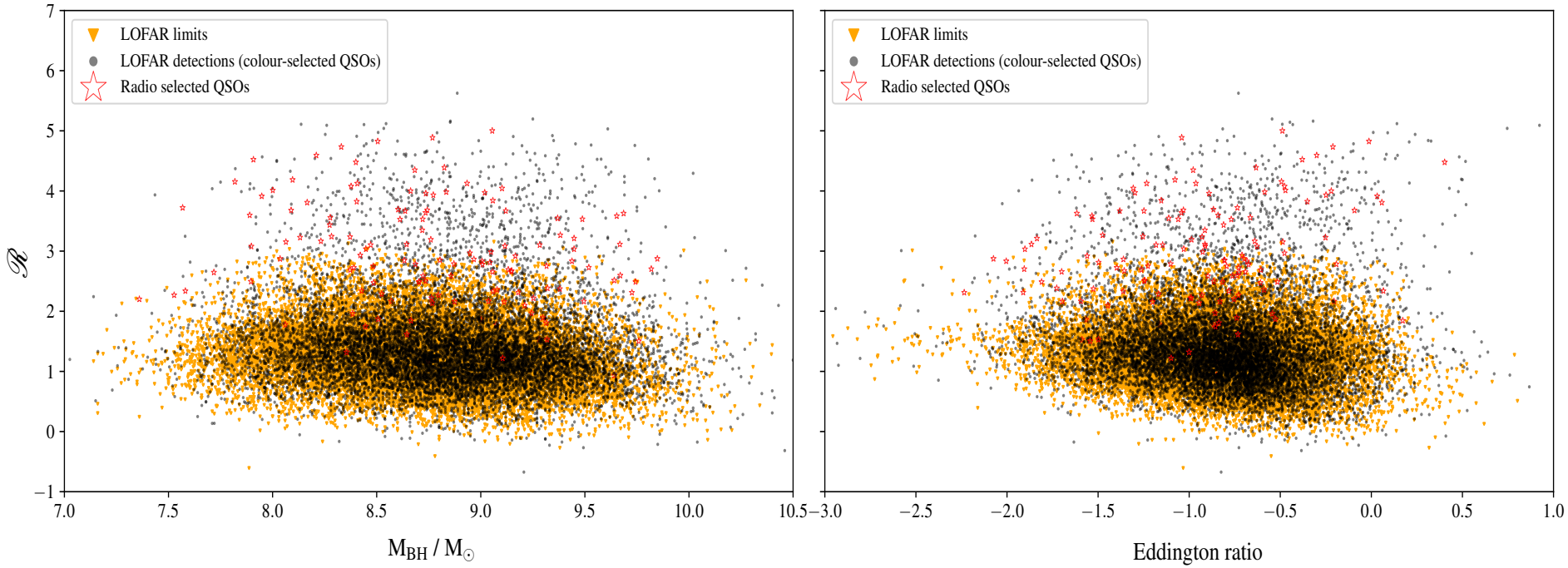
Optical bolometric luminosities, black hole masses and Eddington ratios ⟶ Shen +11 Kozlowski +17

Results – Radio loudness ($\mathscr{R}$)

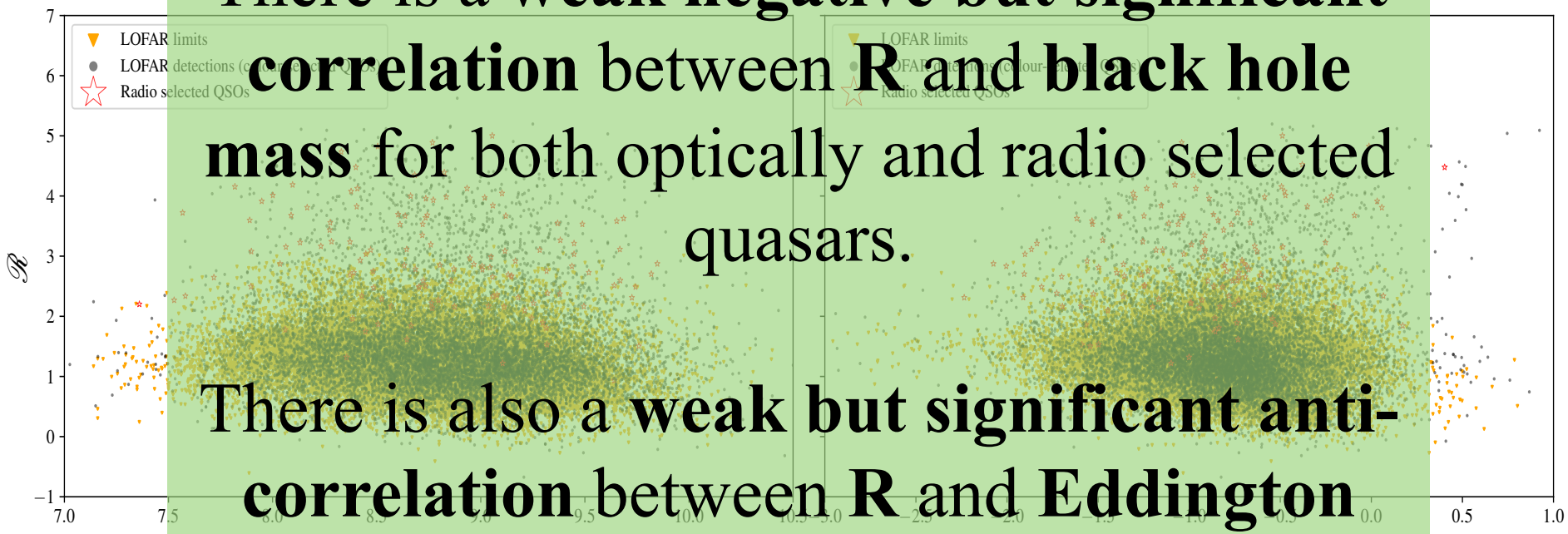
$$\mathscr{R} = \frac{L_{150}(W/Hz)}{L_{i-band}(W/Hz)}$$



Results – $\mathscr{R}$ and SMBH parameters



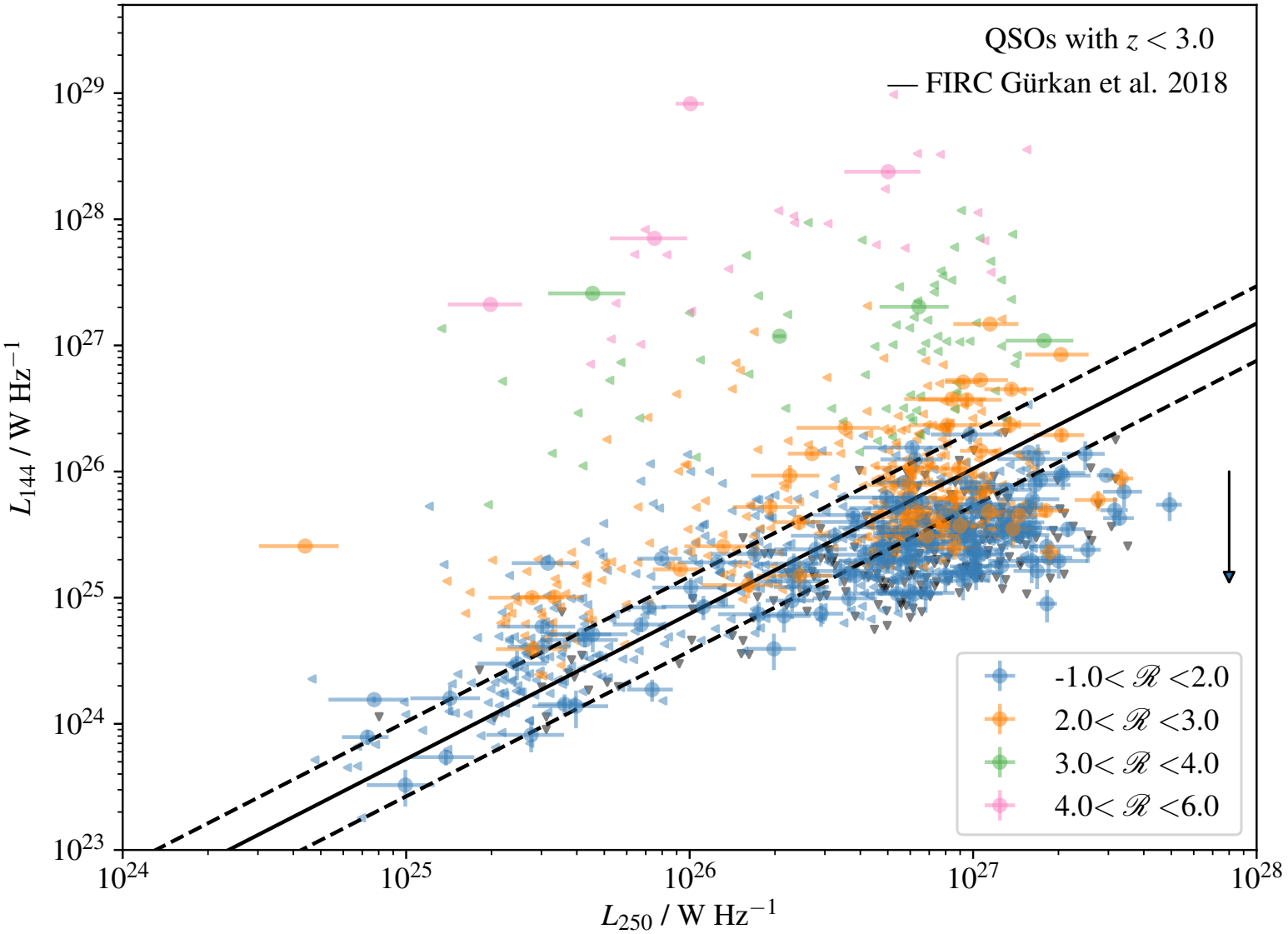
Results – $\mathscr{R}$ and SMBH parameters



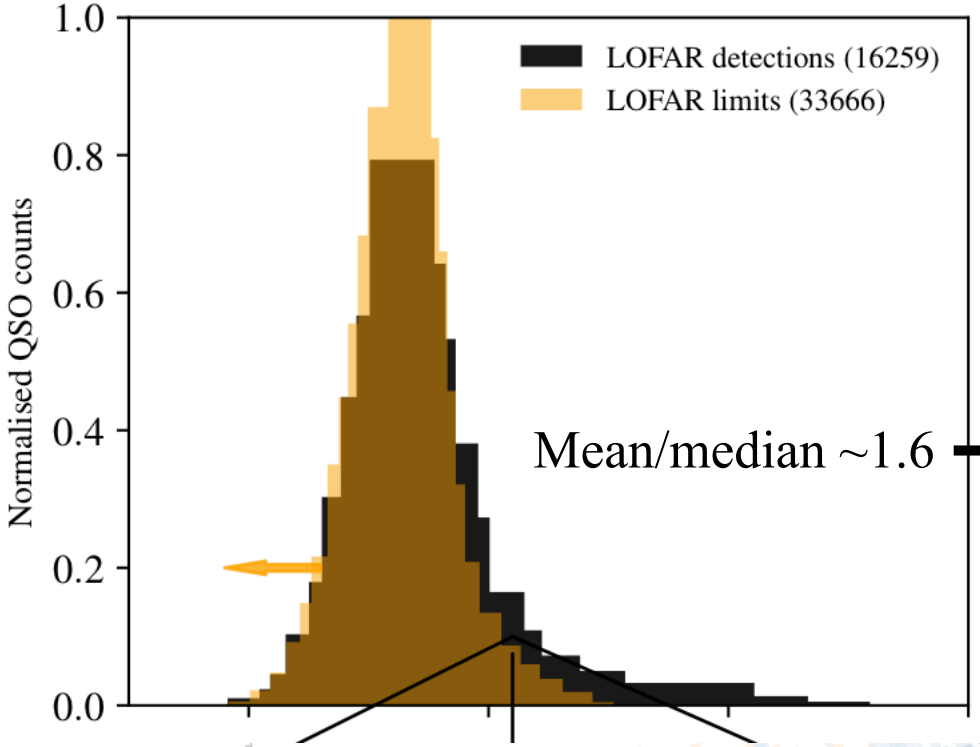
There is a **weak negative but significant correlation** between **R** and **black hole mass** for both optically and radio selected quasars.

There is also a **weak but significant anti-correlation** between **R** and **Eddington ratio** for optically selected quasars.

Results – the source of radio emission in QSOs



Results – the source of radio emission in QSOs



Mean/median ~1.6 → **driven by star-formation?**

AGN power – SFR relation for RQ AGN [*Gürkan* +2015]

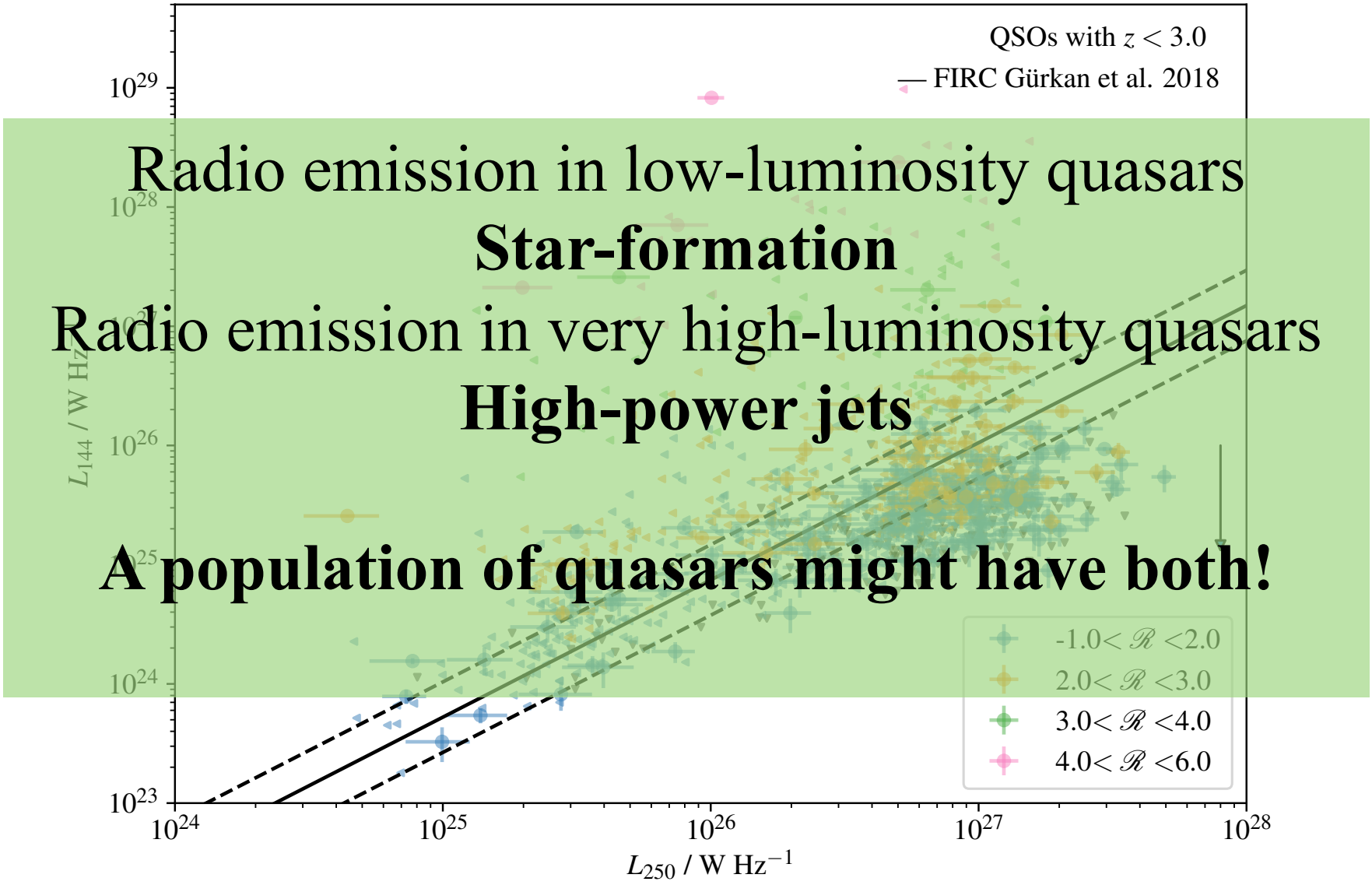
Radio luminosity – SFR relation for star-forming galaxies [*Gürkan* +2018]

↓

$\mathscr{R}$~1.5 due to star-formation,

agrees well with the mean/median value we find (assuming these quasars follow the relations…)

Results – the source of radio emission in QSOs



Radio emission in low-luminosity quasars

Star-formation

Radio emission in very high-luminosity quasars

High-power jets

A population of quasars might have both!

Conclusions

- *Is there a radio loudness dichotomy in QSOs?*

Optically selected QSOs show a wide continuum of radio properties.

- *Does $\mathscr{R}$ depend on any BH parameters?*

We observe a weak dependency of $\mathscr{R}$ on black hole mass and Eddington ratio.

- *What is the source of radio emission in optically selected QSOs?*

Star-formation or jets or both!

Gürkan et al. 2019

Future work –I

Radio luminosity function of QSOs & *spectral index*

Using Murchison Widefield Array (MWA) Survey data – GLEAM [Hurley-Walker +17]

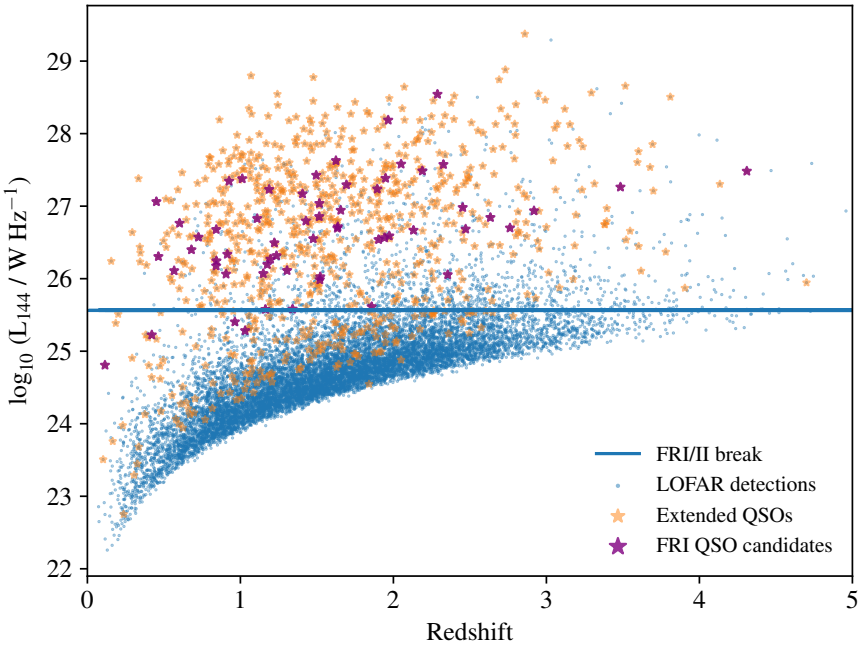
Future work –II

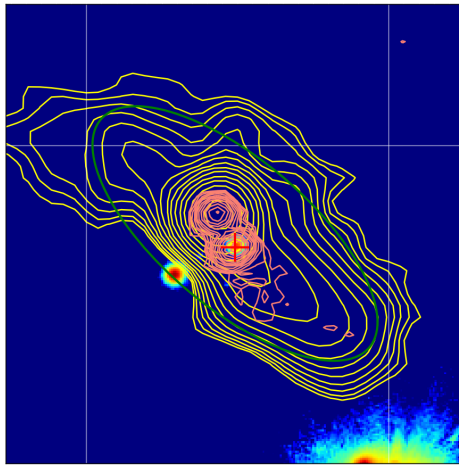
Radio luminosity function of QSOs &

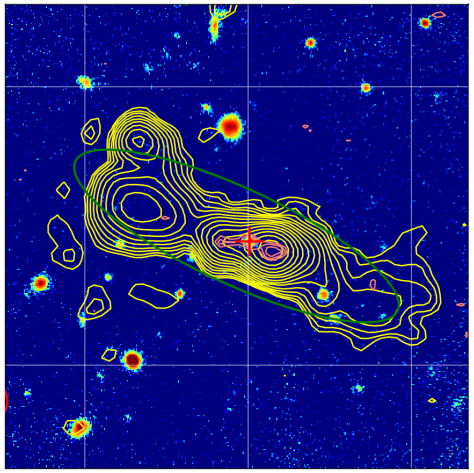
as a function of galaxy/nuclear parameters

Using LoTSS – HETDEX data and deeper LOFAR data

Future work –III: QSOs with centred-brightened radio morphology (i.e. FRI)







JVLA snapshot survey of 60 FRI QSO candidates [granted!]

(i) How does FRI QSO population compare to FRI radio galaxies?,
(ii) What are the differences between FRI and FRII QSOs? and
(iii) How does the prevalence of FRI structures change as a function of accretion properties, estimated jet power, host galaxy and environmental properties?

Thank you

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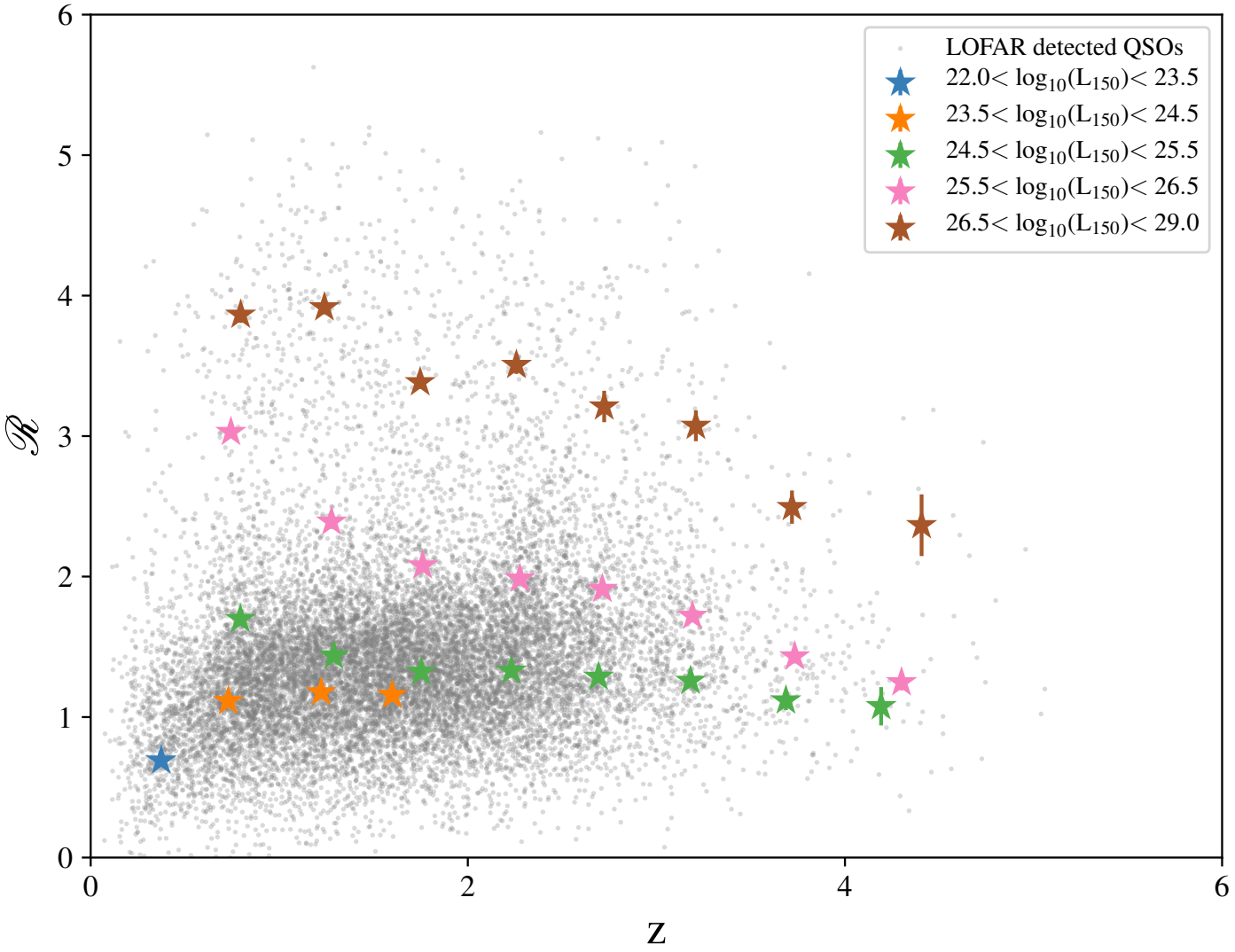
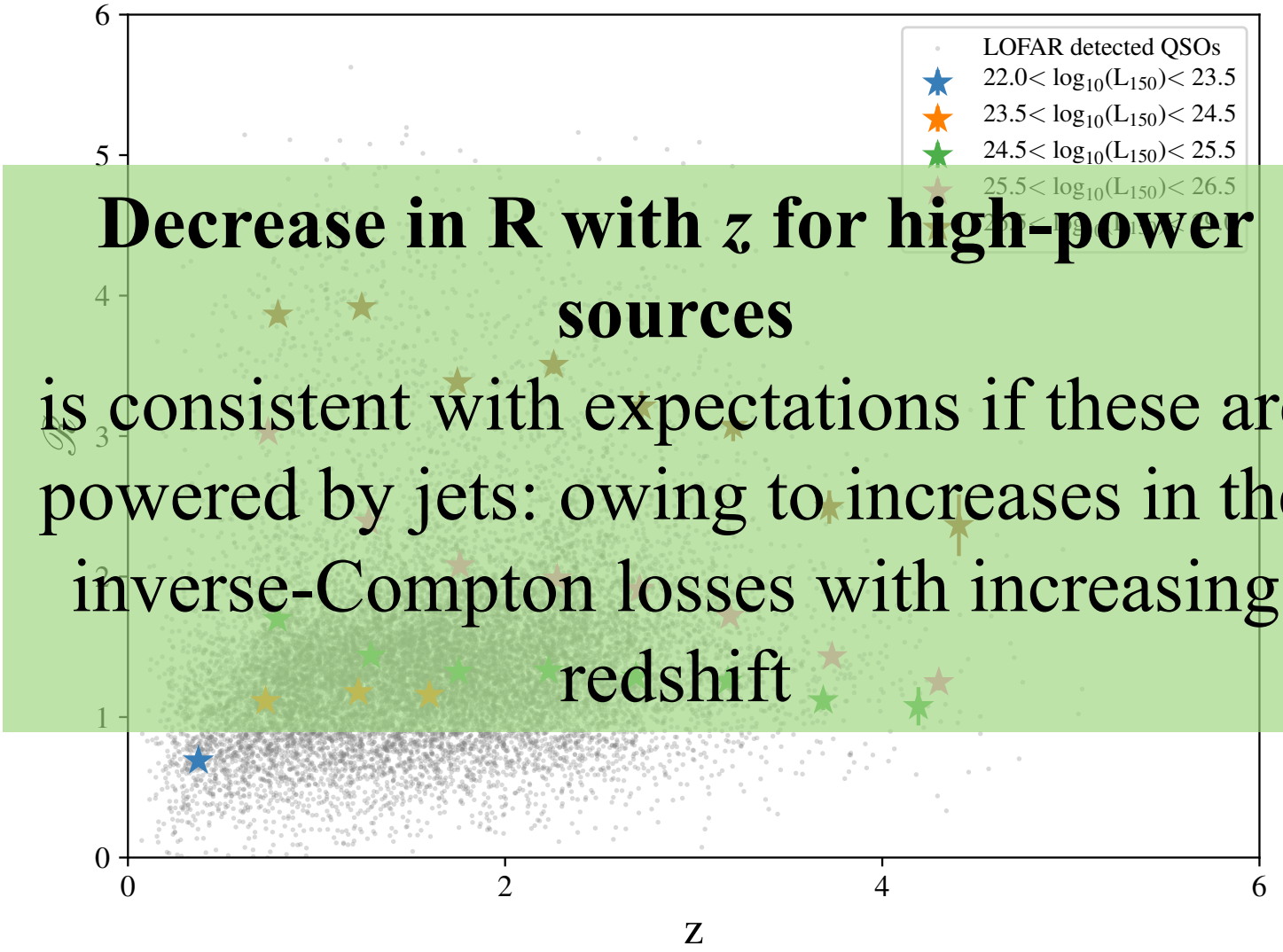
Results – $\mathscr{R}$, z and low-freq. radio luminosity



Results – $\mathscr{R}$ and SMBH parameters



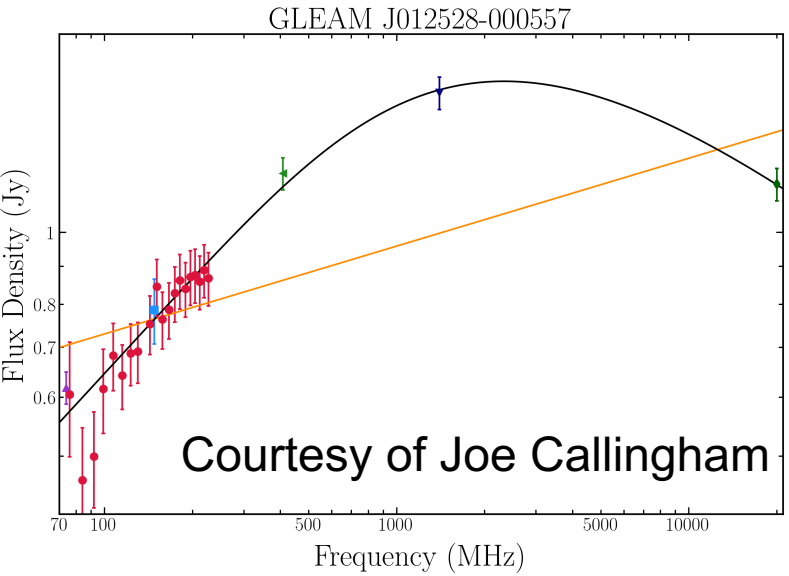
Decrease in R with z for high-power sources

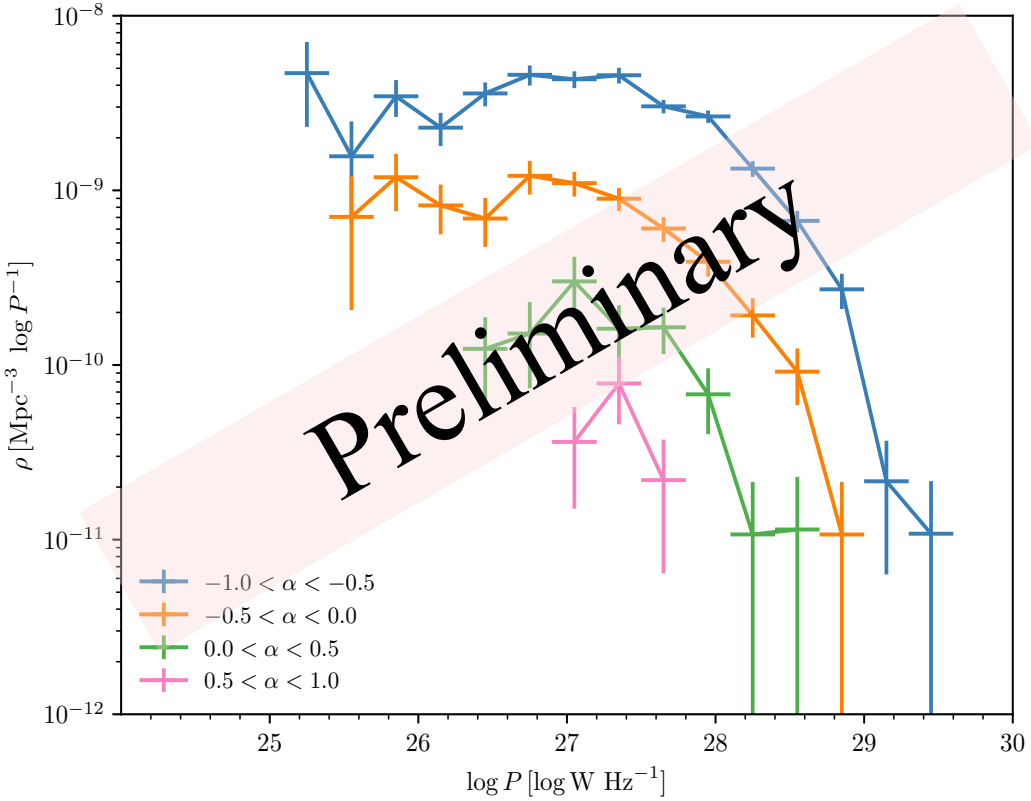
is consistent with expectations if these are powered by jets: owing to increases in the inverse-Compton losses with increasing redshift

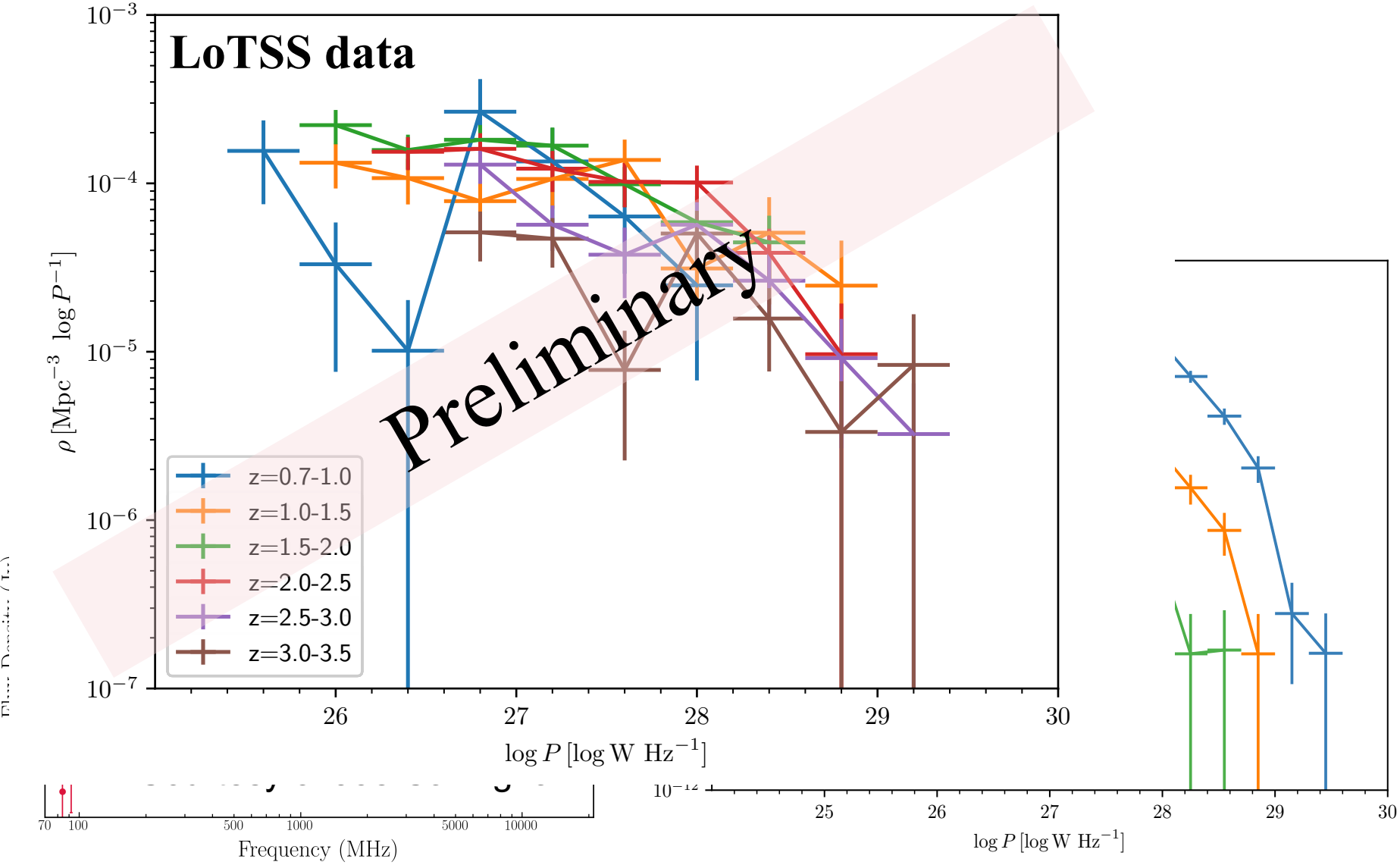
Future work –I

[Gürkan, Williams, Callingham et al. 2019 – in prep]

- Covers entire sky south of Dec 30° at **72-231 MHz**
- RMS ~5 - 10mJy, resolution ~2 arcmin
- 1st year GLEAM extragalactic catalogue has 307 455 components

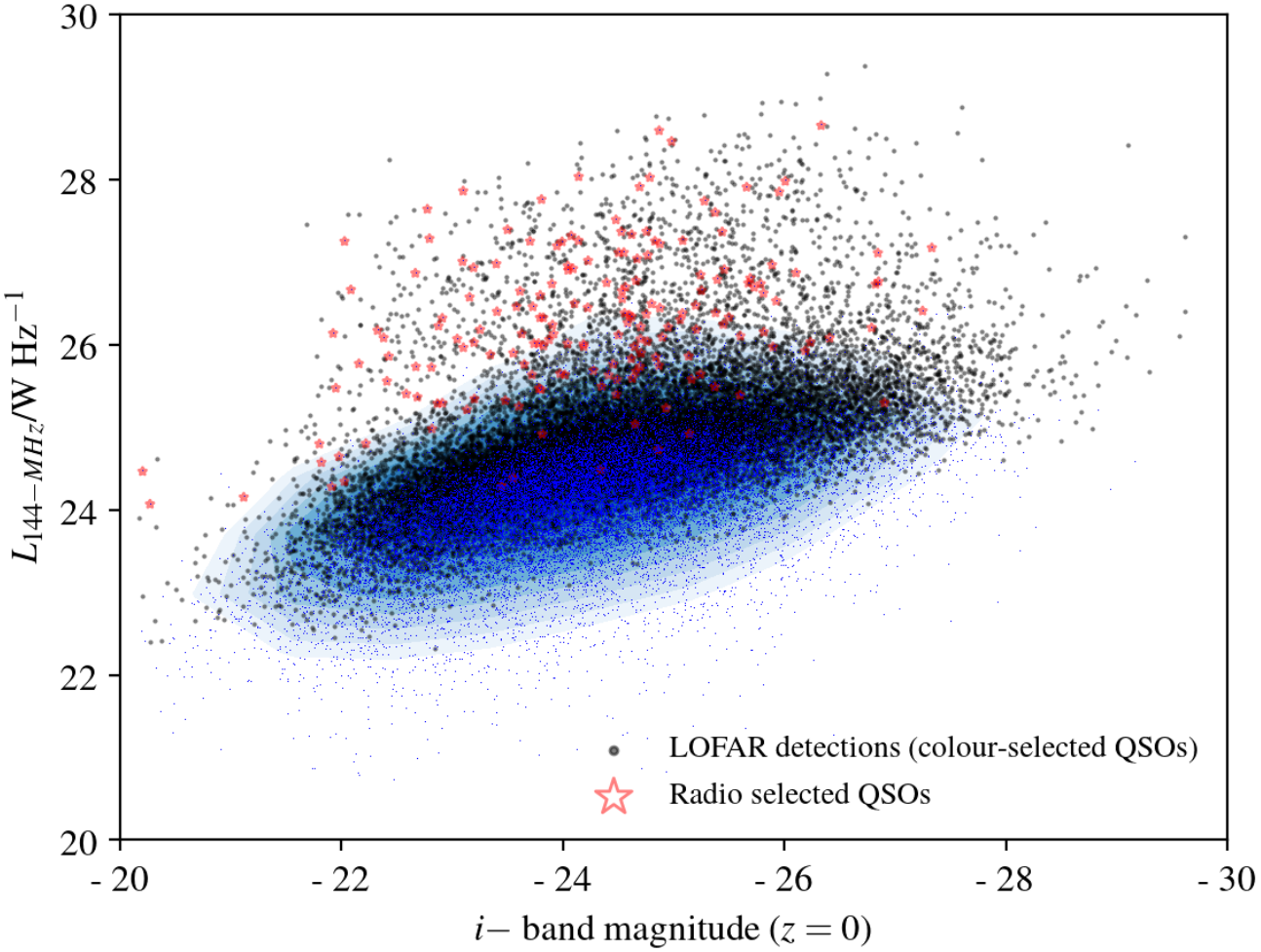


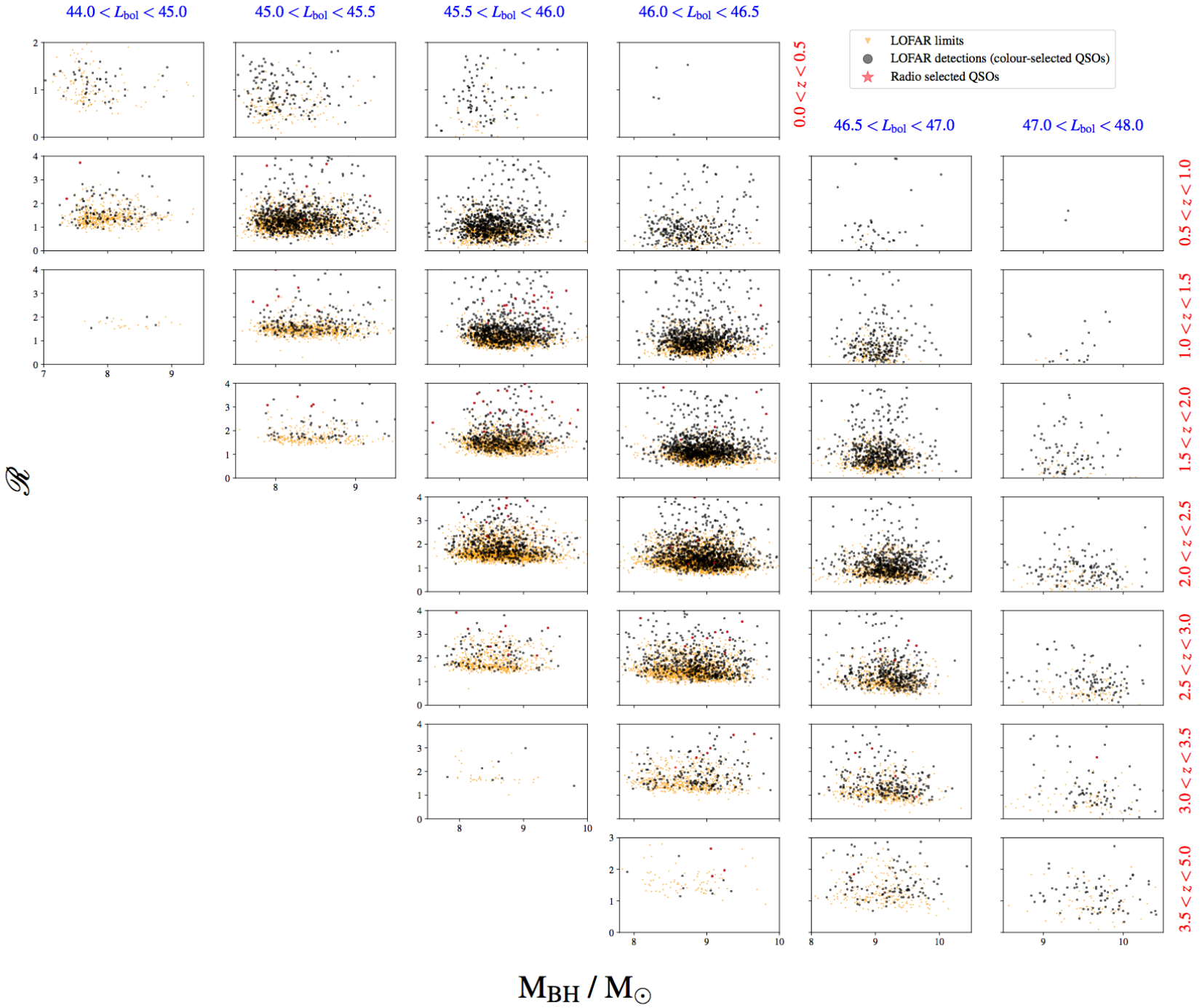


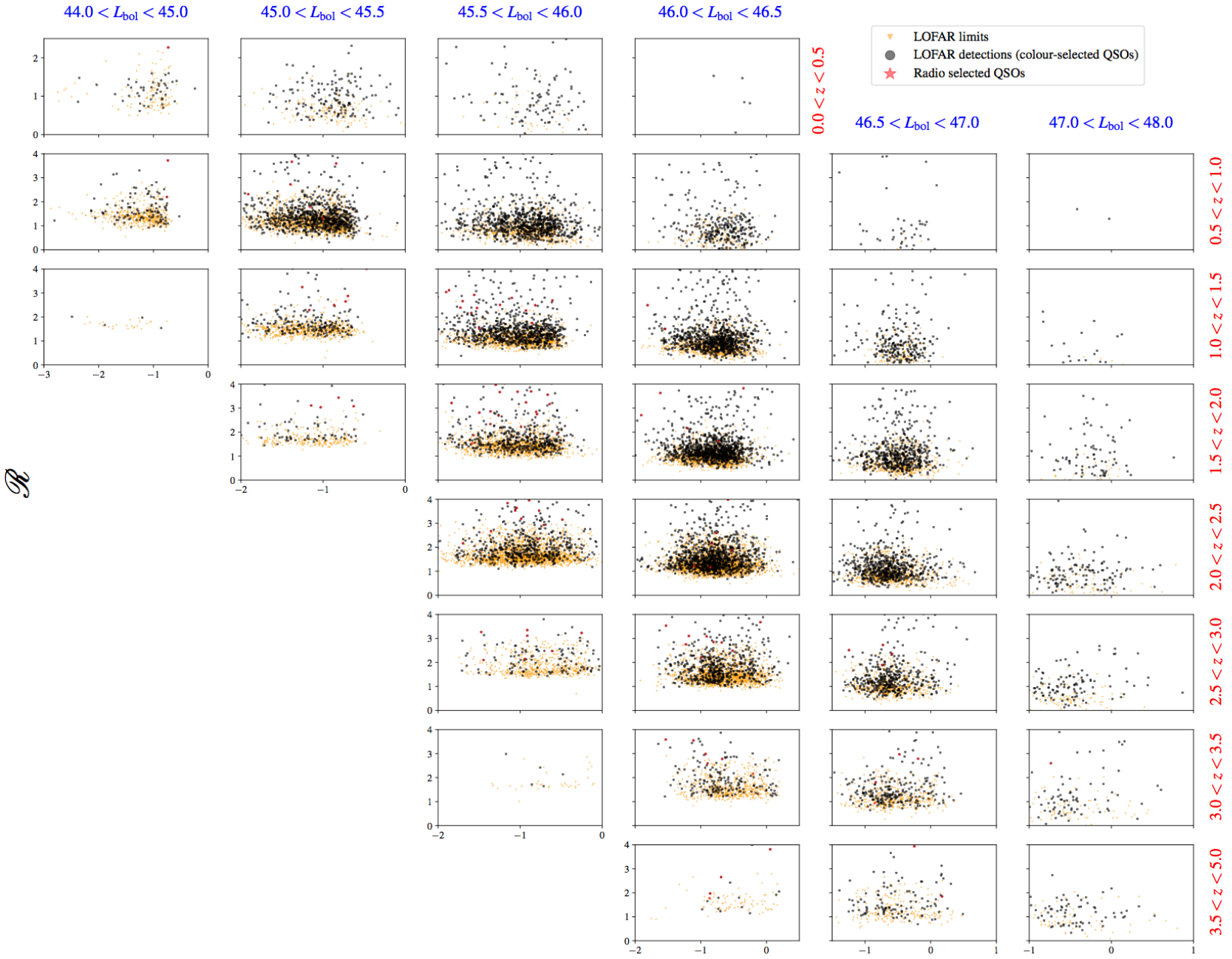

LoTSS data
Preliminary
z=0.7-1.0
z=1.0-1.5
z=1.5-2.0
z=2.0-2.5
z=2.5-3.0
z=3.0-3.5
$\rho\,[\mathrm{Mpc}^{-3}\ \log P^{-1}]$
$\log P\,[\log \mathrm{W\ Hz}^{-1}]$
Frequency (MHz)

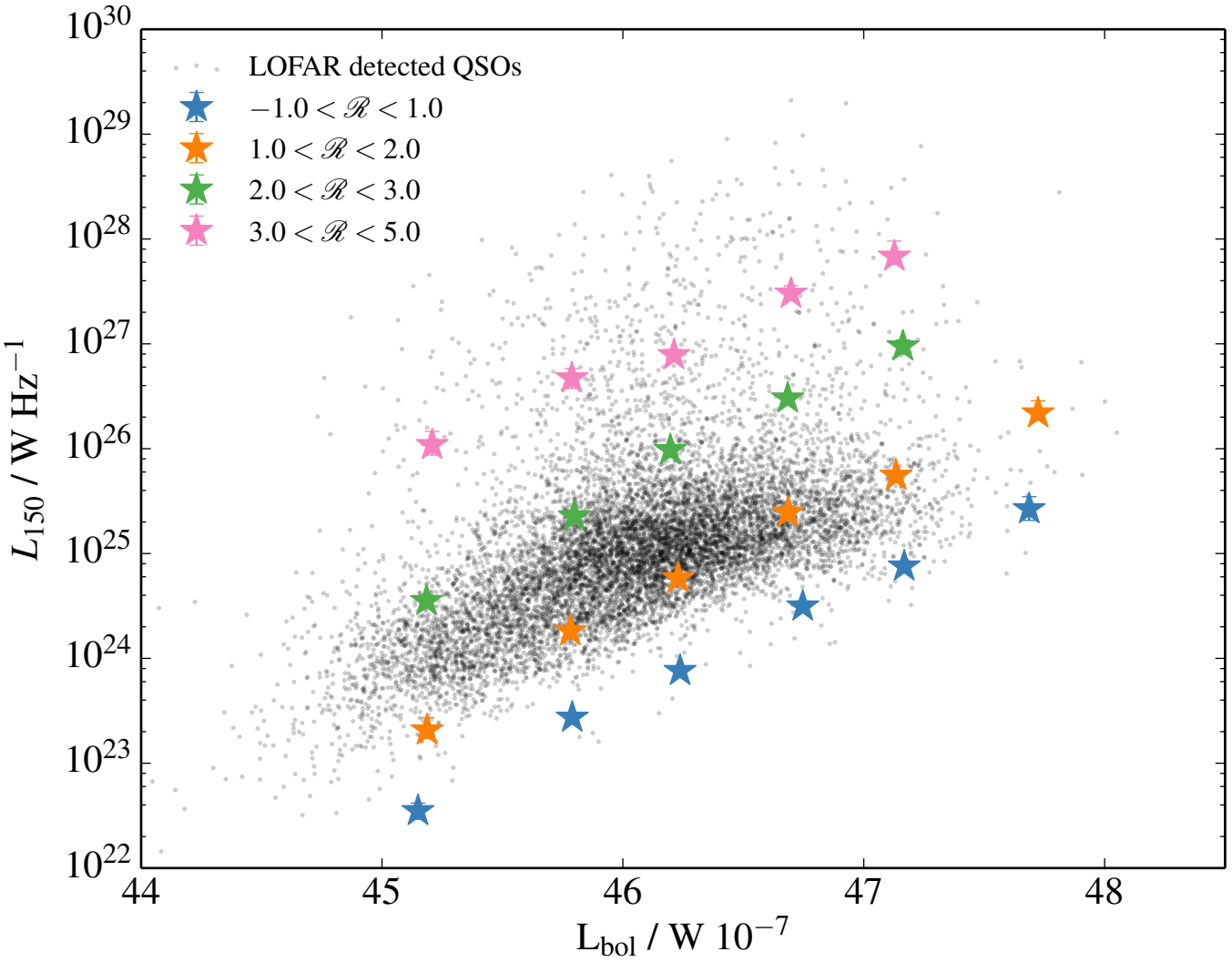
Results – Radio loudness ($\mathscr{R}$)

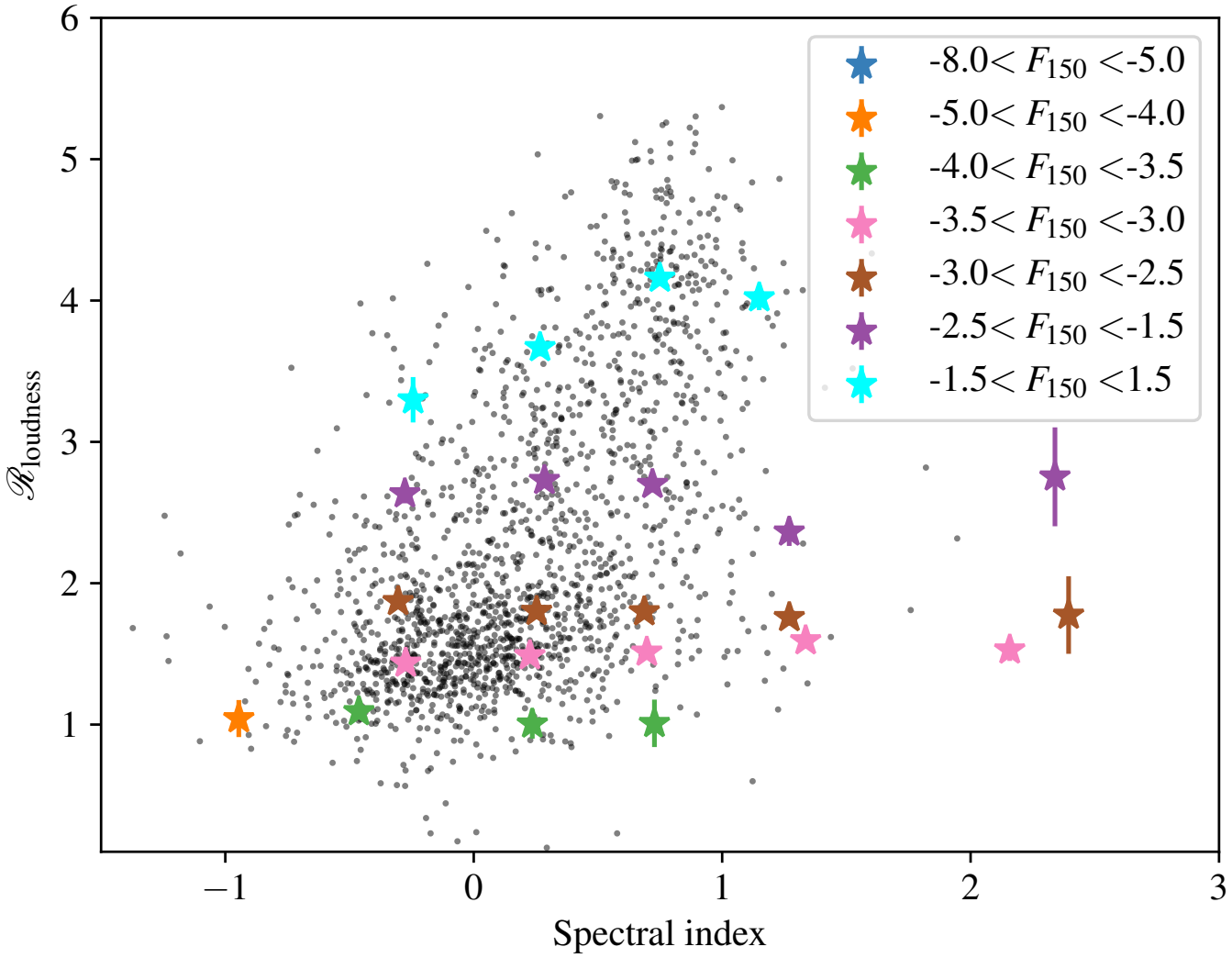
$$\mathscr{R} = \frac{L_{150}(W/Hz)}{\imath d(W/Hz)}$$

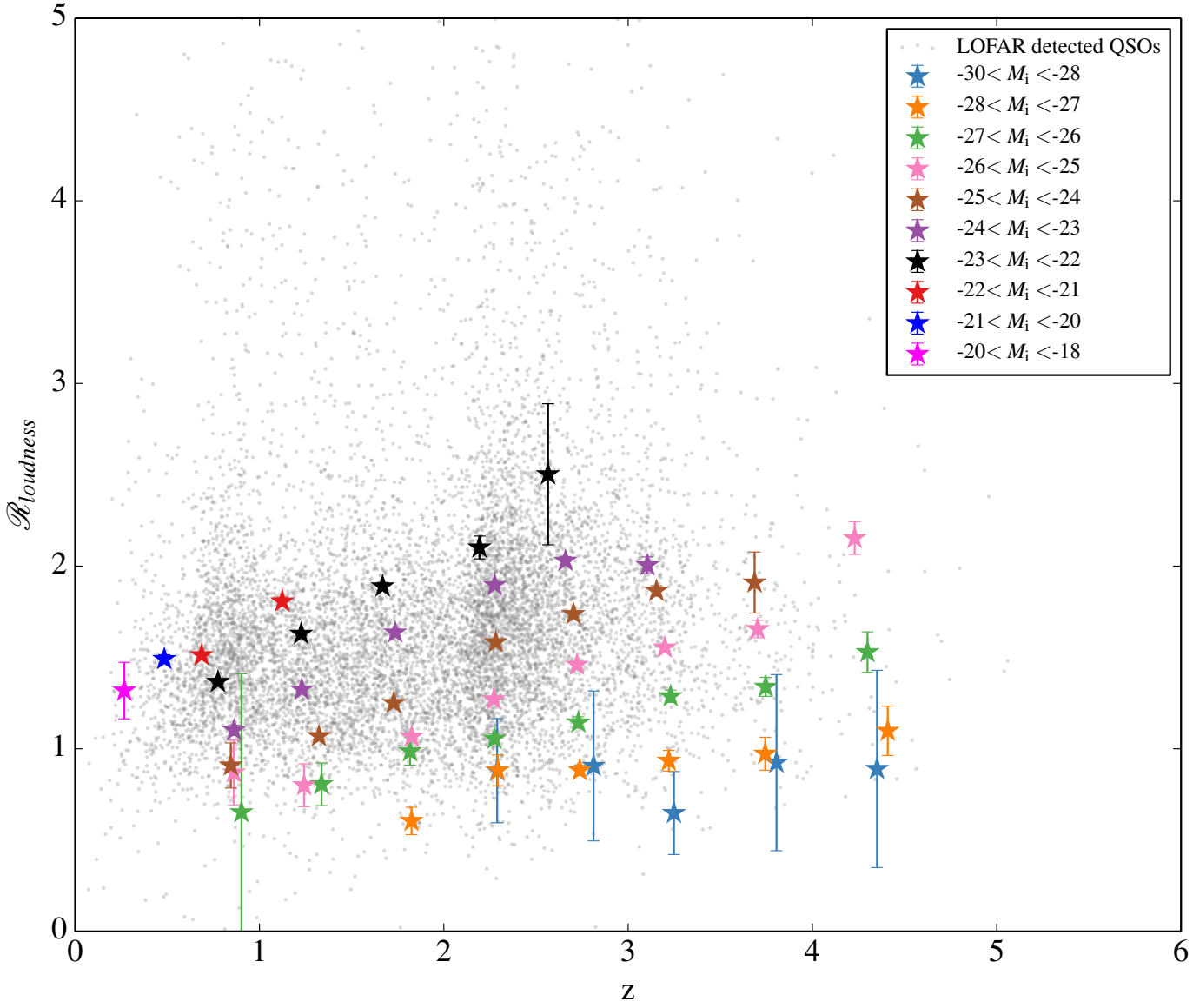



44.0 < L_{bol} < 45.0
45.0 < L_{bol} < 45.5
45.5 < L_{bol} < 46.0
46.0 < L_{bol} < 46.5
46.5 < L_{bol} < 47.0
47.0 < L_{bol} < 48.0
0.0 < z < 0.5
0.5 < z < 1.0
1.0 < z < 1.5
1.5 < z < 2.0
2.0 < z < 2.5
2.5 < z < 3.0
3.0 < z < 3.5
3.5 < z < 5.0
LOFAR limits
LOFAR detections (colour-selected QSOs)
Radio selected QSOs
$\mathscr{R}$
M_{BH} / $M_{\odot}$


$44.0 < L_{\rm bol} < 45.0$
$45.0 < L_{\rm bol} < 45.5$
$45.5 < L_{\rm bol} < 46.0$
$46.0 < L_{\rm bol} < 46.5$
$46.5 < L_{\rm bol} < 47.0$
$47.0 < L_{\rm bol} < 48.0$
$0.0 < z < 0.5$
$0.5 < z < 1.0$
$1.0 < z < 1.5$
$1.5 < z < 2.0$
$2.0 < z < 2.5$
$2.5 < z < 3.0$
$3.0 < z < 3.5$
$3.5 < z < 5.0$
LOFAR limits
LOFAR detections (colour-selected QSOs)
Radio selected QSOs
$\mathscr{R}$
Eddington ratio


LOFAR detected QSOs
$-1.0 < \mathscr{R} < 1.0$
$1.0 < \mathscr{R} < 2.0$
$2.0 < \mathscr{R} < 3.0$
$3.0 < \mathscr{R} < 5.0$
10^{30}
10^{29}
10^{28}
10^{27}
10^{26}
10^{25}
10^{24}
10^{23}
10^{22}
L_{150} / W Hz^{-1}
44
45
46
47
48
L_{bol} / W 10^{-7}


6
5
4
3
2
1
$\mathscr{R}_{\text{loudness}}$
−1
0
1
2
3
Spectral index
-8.0< F_{150} <-5.0
-5.0< F_{150} <-4.0
-4.0< F_{150} <-3.5
-3.5< F_{150} <-3.0
-3.0< F_{150} <-2.5
-2.5< F_{150} <-1.5
-1.5< F_{150} <1.5


LOFAR detected QSOs
-30< M_i <-28
-28< M_i <-27
-27< M_i <-26
-26< M_i <-25
-25< M_i <-24
-24< M_i <-23
-23< M_i <-22
-22< M_i <-21
-21< M_i <-20
-20< M_i <-18
$\mathscr{R}_{loudness}$
z
0
1
2
3
4
5
6