A striking signature of shocks in compact red quasars?

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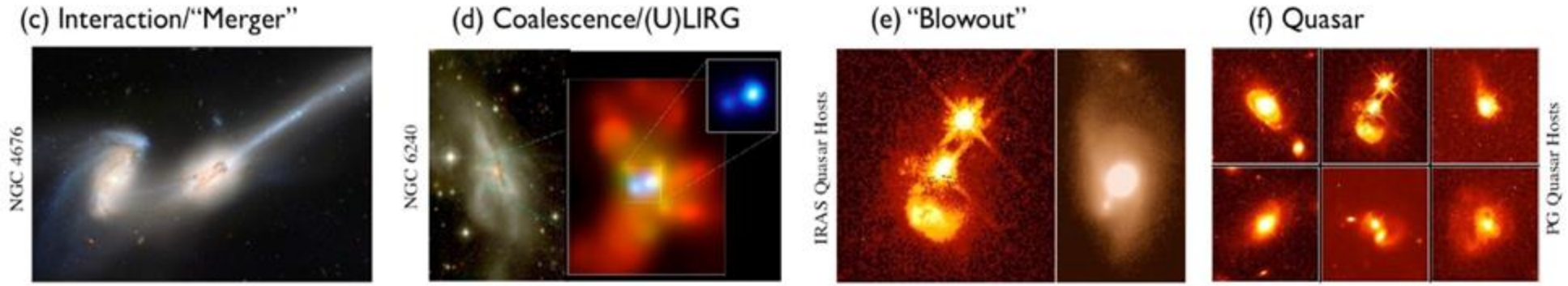
Supervisors: David Alexander & Claire Greenwell

Active Galactic Nuclei – from ISCO to CGM and from cosmic dawn to the present day, NAM, 9 July

Image Credit: ESO/M. Kornmesser

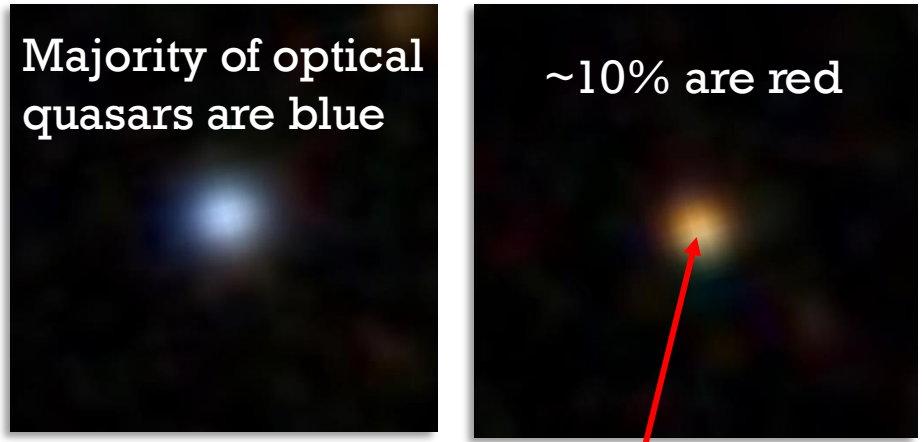
Why care about red quasars?



Hopkins+08

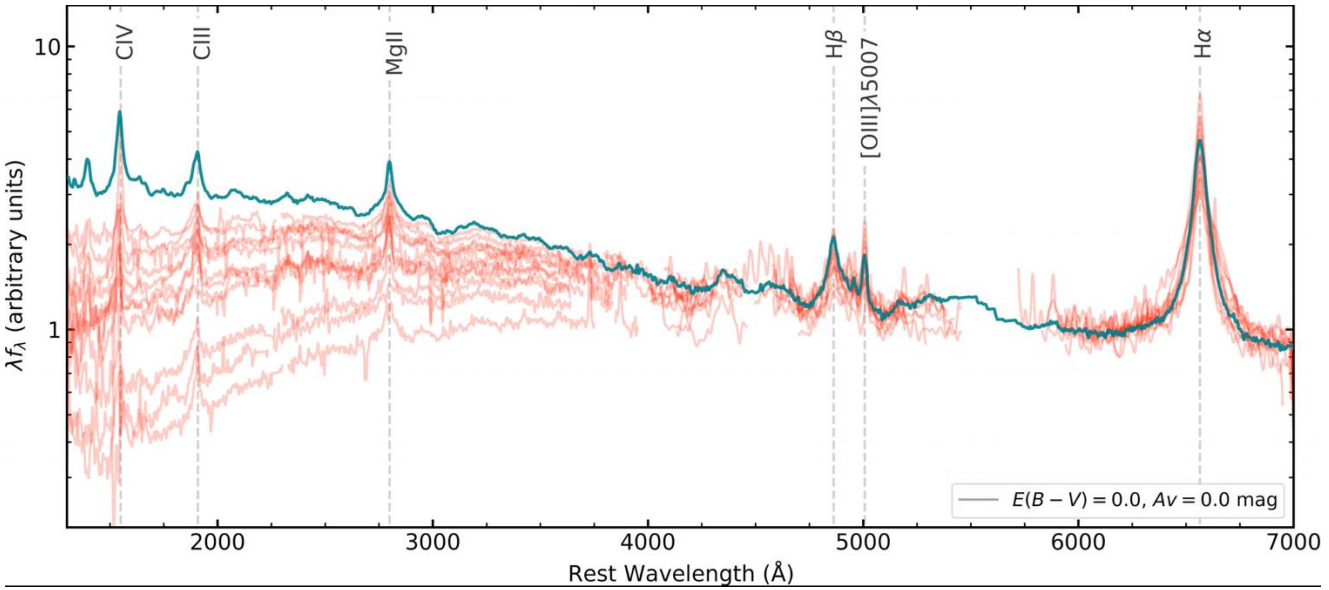
Galaxy simulations predict there is a transitional phase in the evolution of galaxies, also known as a **"blow-out"** phase

Optical images taken from SDSS



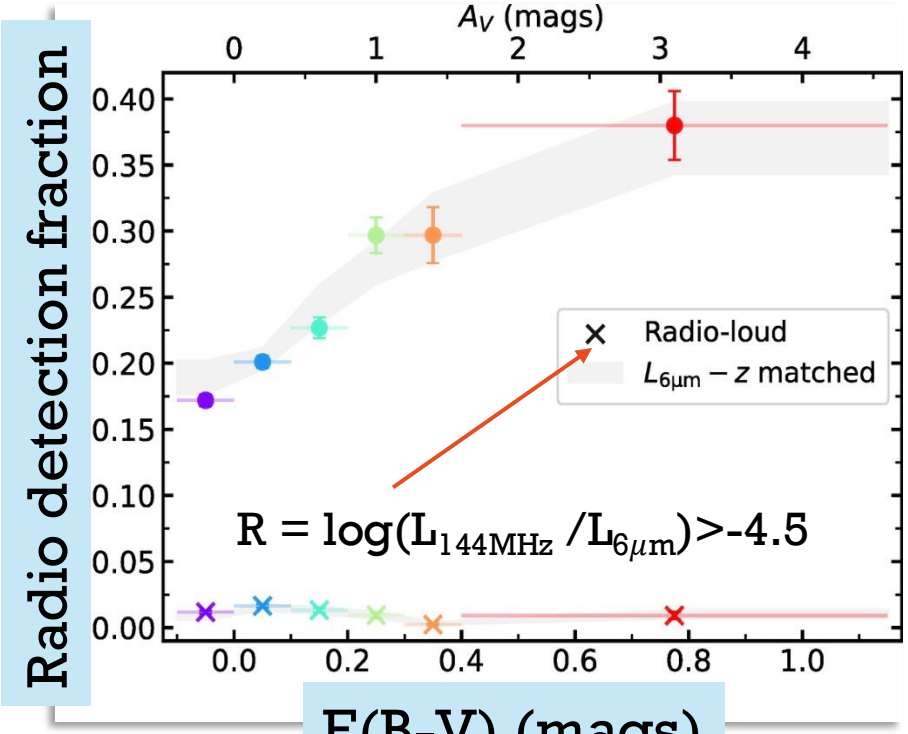
light dust obscuration: E(B-V)<~0.5 & still observe broad lines

Fawcett+ 22



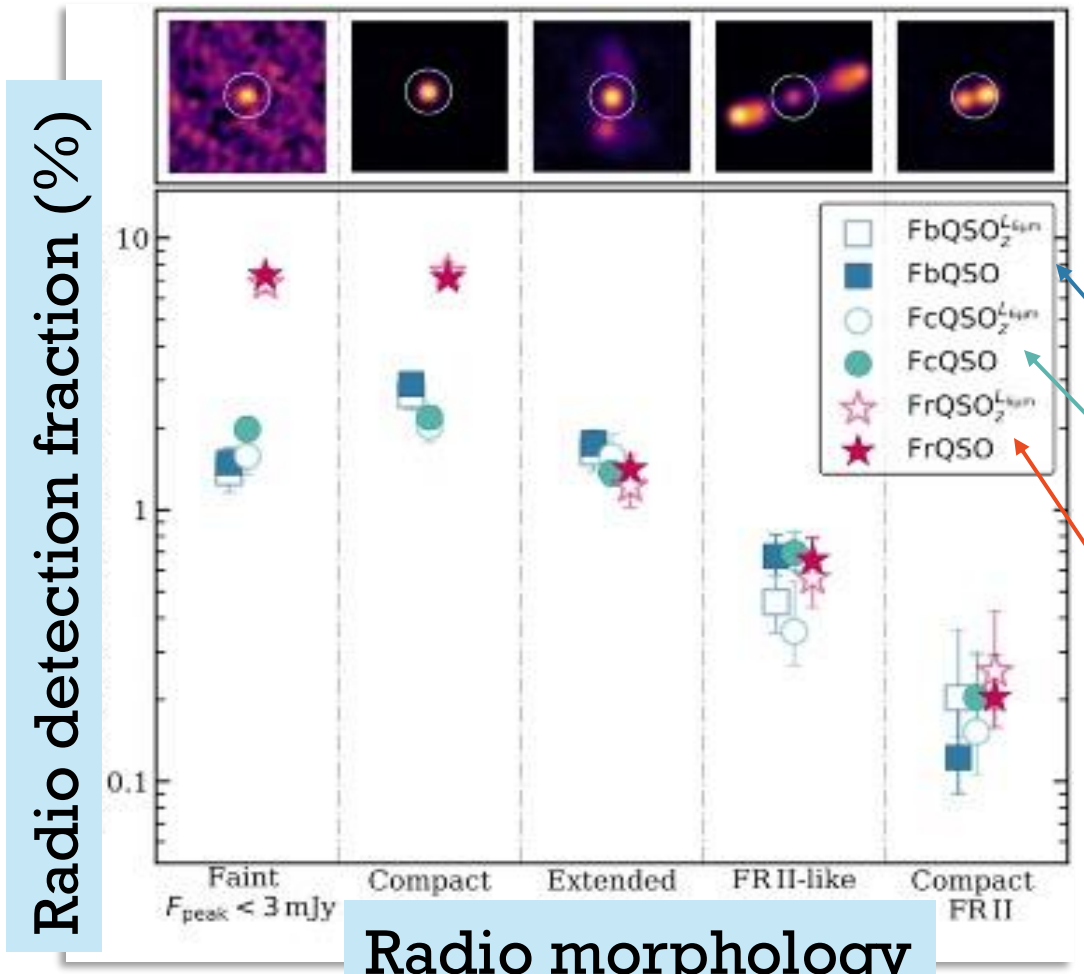
Dust-radio connection

Fawcett +23: Radio detection – opacity connection



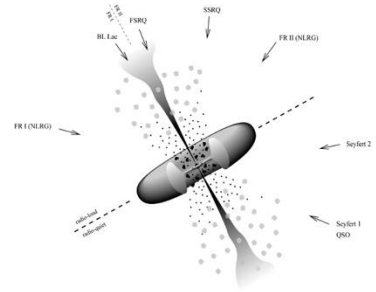
- Dust-reddened quasars ~2-3 x more likely to be detected than typical blue quasars (eg. Klindt+19, Rosario+20, Fawcett+20,21)
- predominantly due to radio-quiet/intermediate sources

Klindt +19



- Excess detection rates driven by compact (<host galaxy scale) radio morphologies (eg. Fawcett+20, Rosario+21)

not explained by orientation!



10% bluest g*-i*

middle 10% g*-i*

10% reddest g*-i*

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Klindt +19

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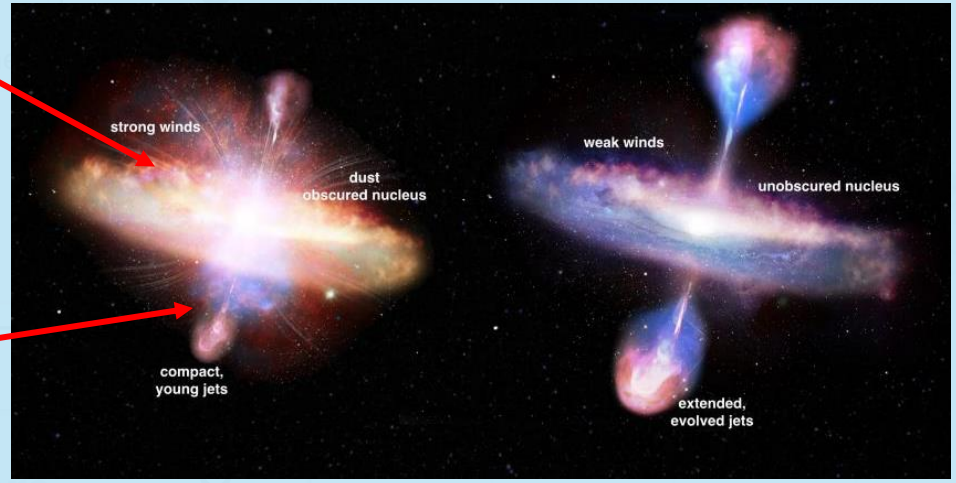
What is causing this excess radio emission?

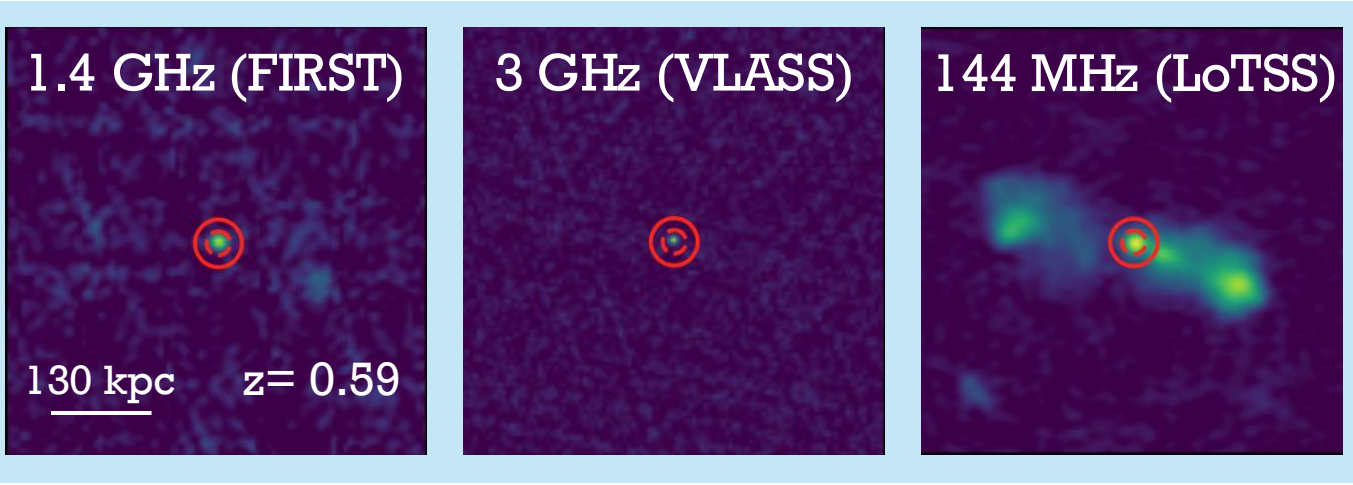
Red quasar ⟶ Blue quasar

Shocks due to AGN driven winds?

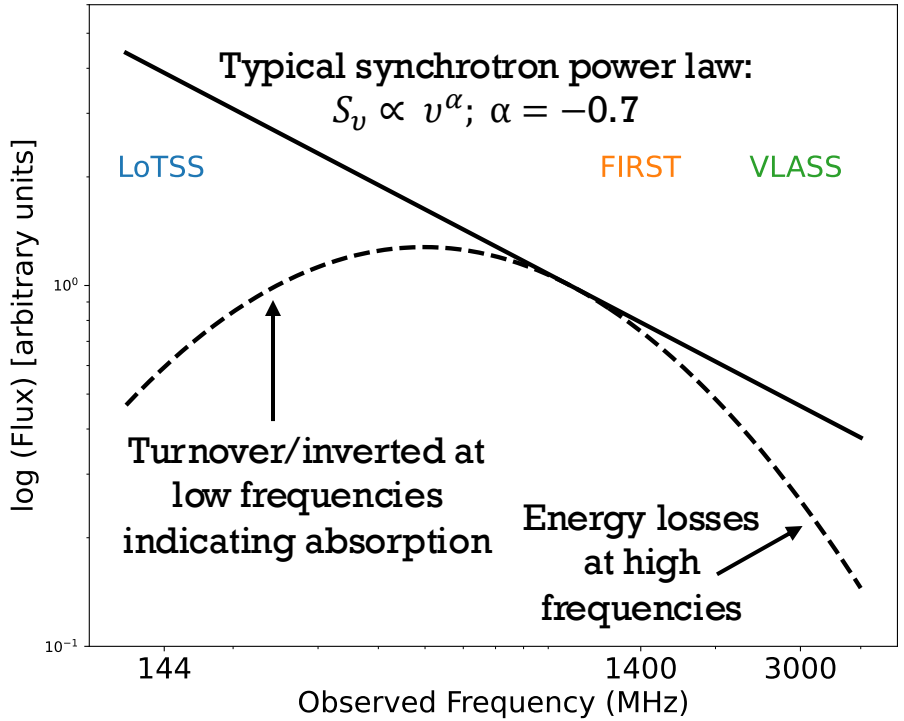
Low power jets interacting with higher opacity ISM?



Radio morphologies at different frequencies



- Previous work: biggest differences among compact & faint radio morphologies
- morphology classification usually in one frequency only (eg. Klindt+19, Rosario+20)
- radio sources can look very different at different frequencies/resolutions/sensitivities

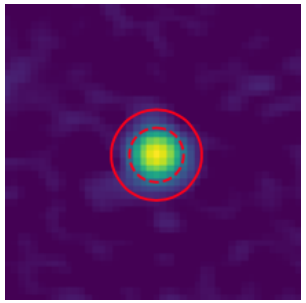


- Extended low frequency emission – previous episode of activity?
- Radio spectral slopes – probe underlying radio emission mechanism

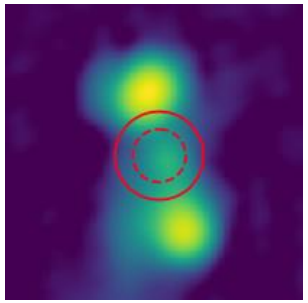
Red quasars more likely to remain compact at all frequencies

- Visually inspected radio images of all sources > 3 mJy (632 red quasars, 1426 blue/control quasars) in **each radio survey**
- Simple classification (each survey):

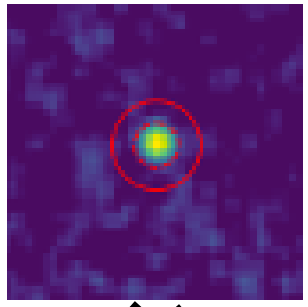
compact



not compact



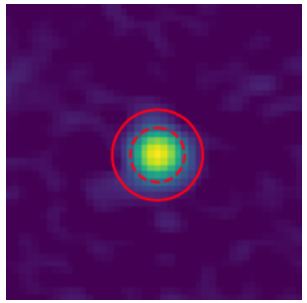
FIRST compact quasars

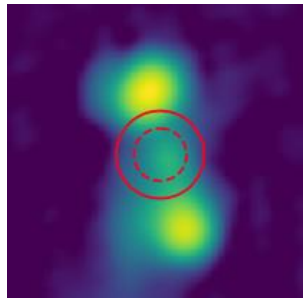


Red quasars detected 2-3x as often as blue

97% remain compact in VLASS (3GHz; < 8-20kpc)

+ LoTSS compact
= **"truly compact"**





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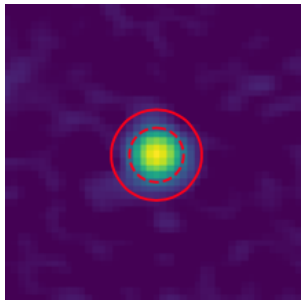

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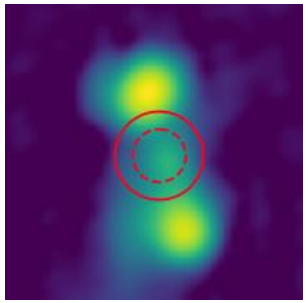

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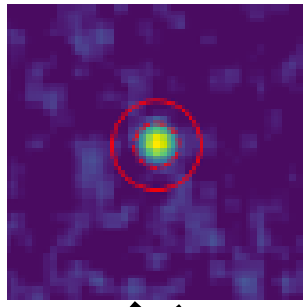

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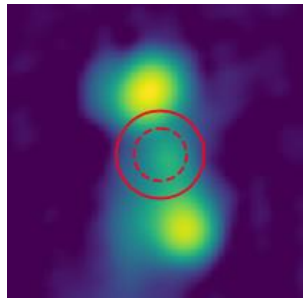
= 83% of FIRST compact red quasars

= 73% of FIRST compact blue quasars



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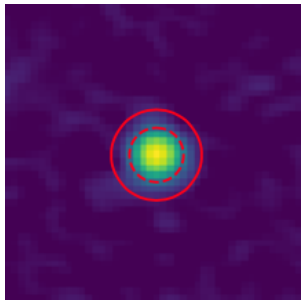

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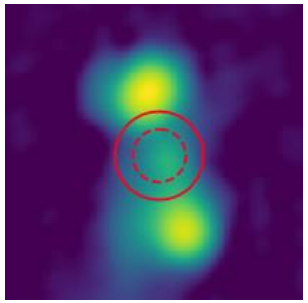

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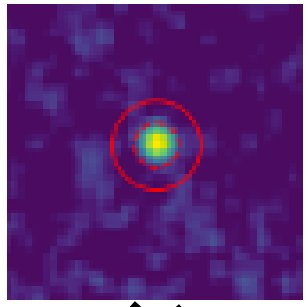

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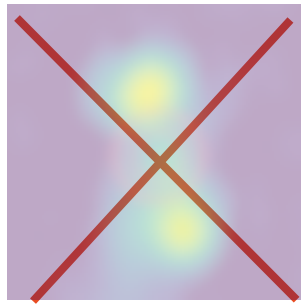

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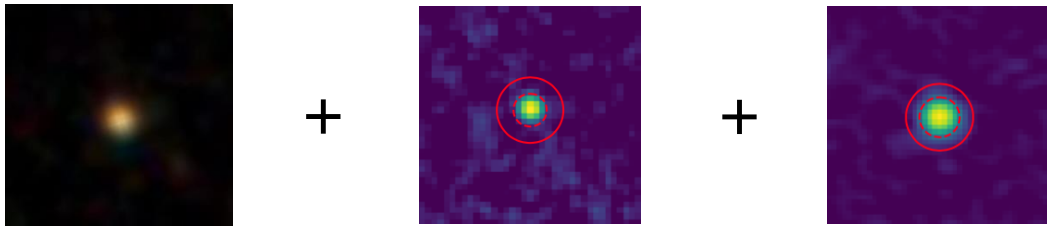
red and blue quasars detected at **similar** rates

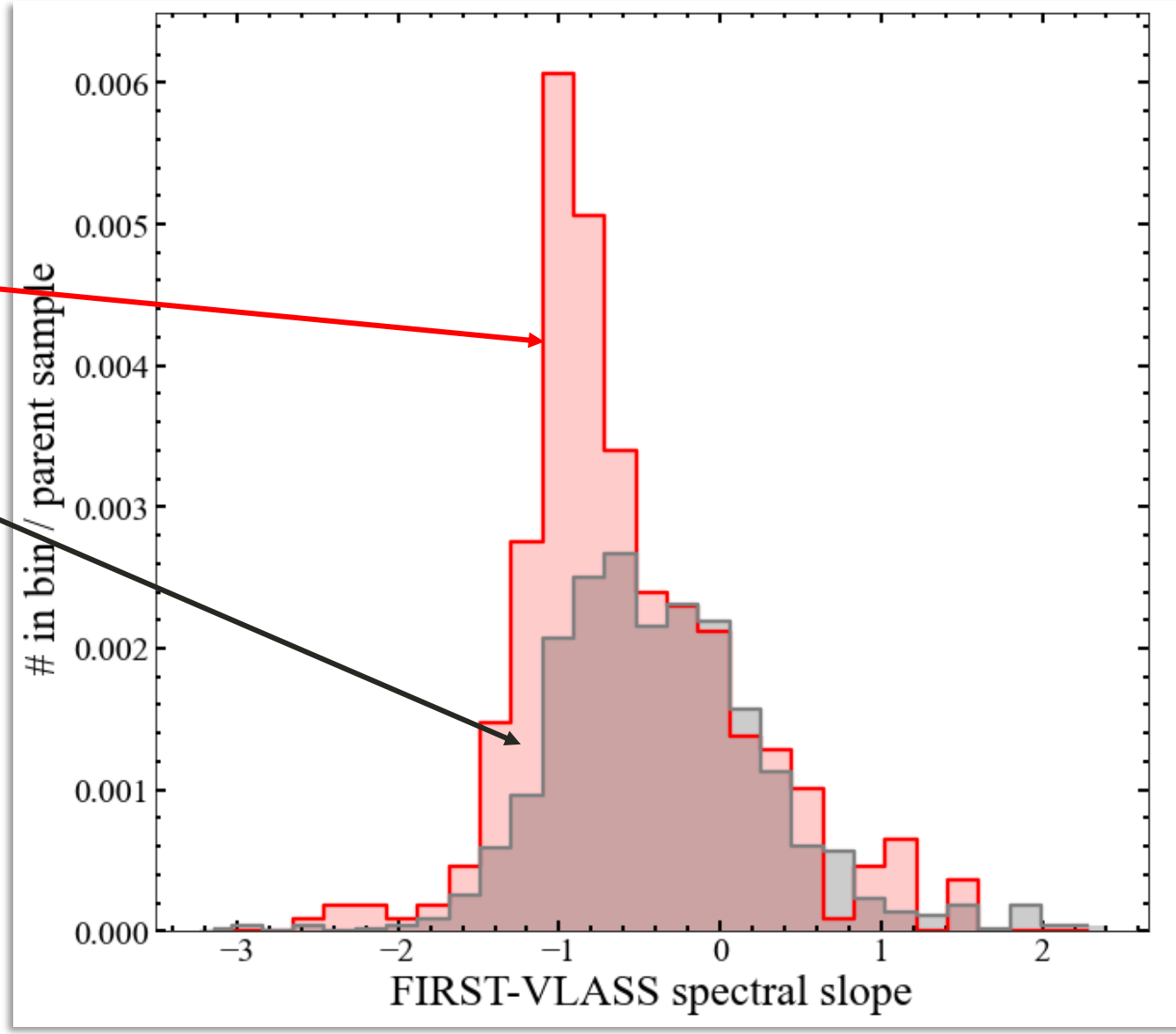
Steep radio spectral slopes in truly compact red quasars

- 1.4 GHz – 3 GHz spectral slope of truly compact vs. fake compact quasars

red quasar + truly compact



all other classifications: consistent distributions



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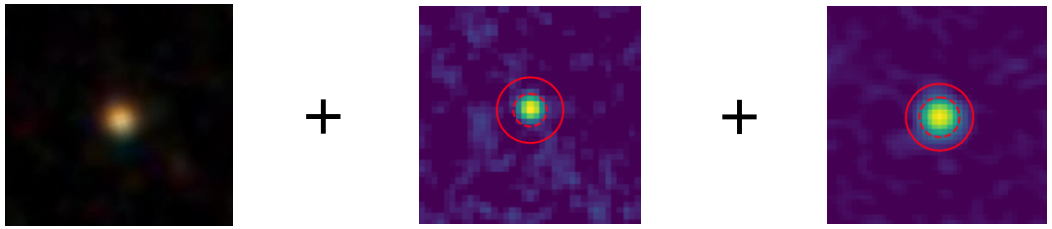

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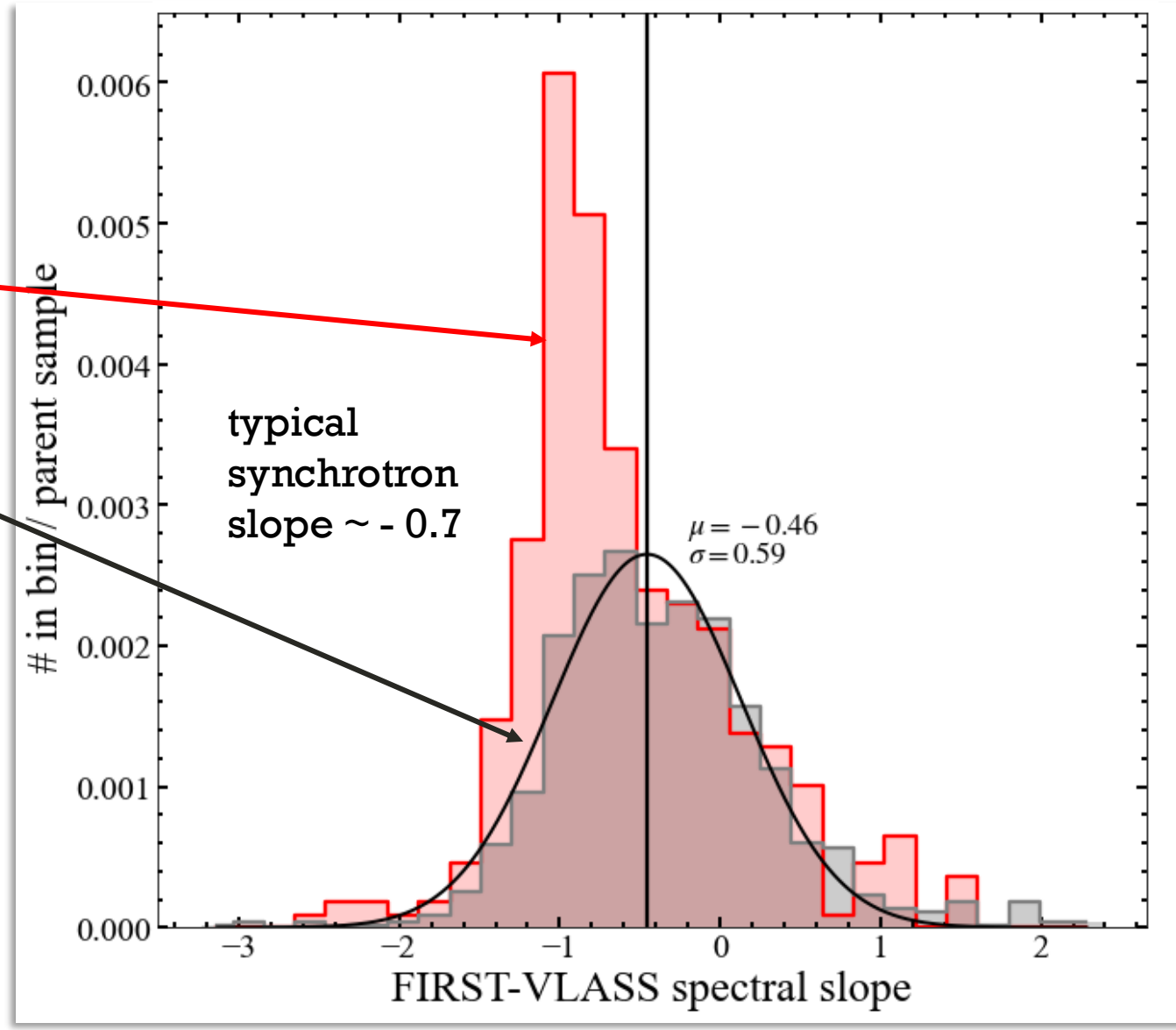

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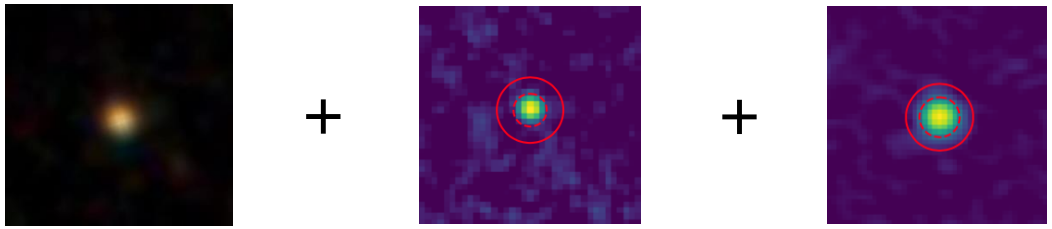

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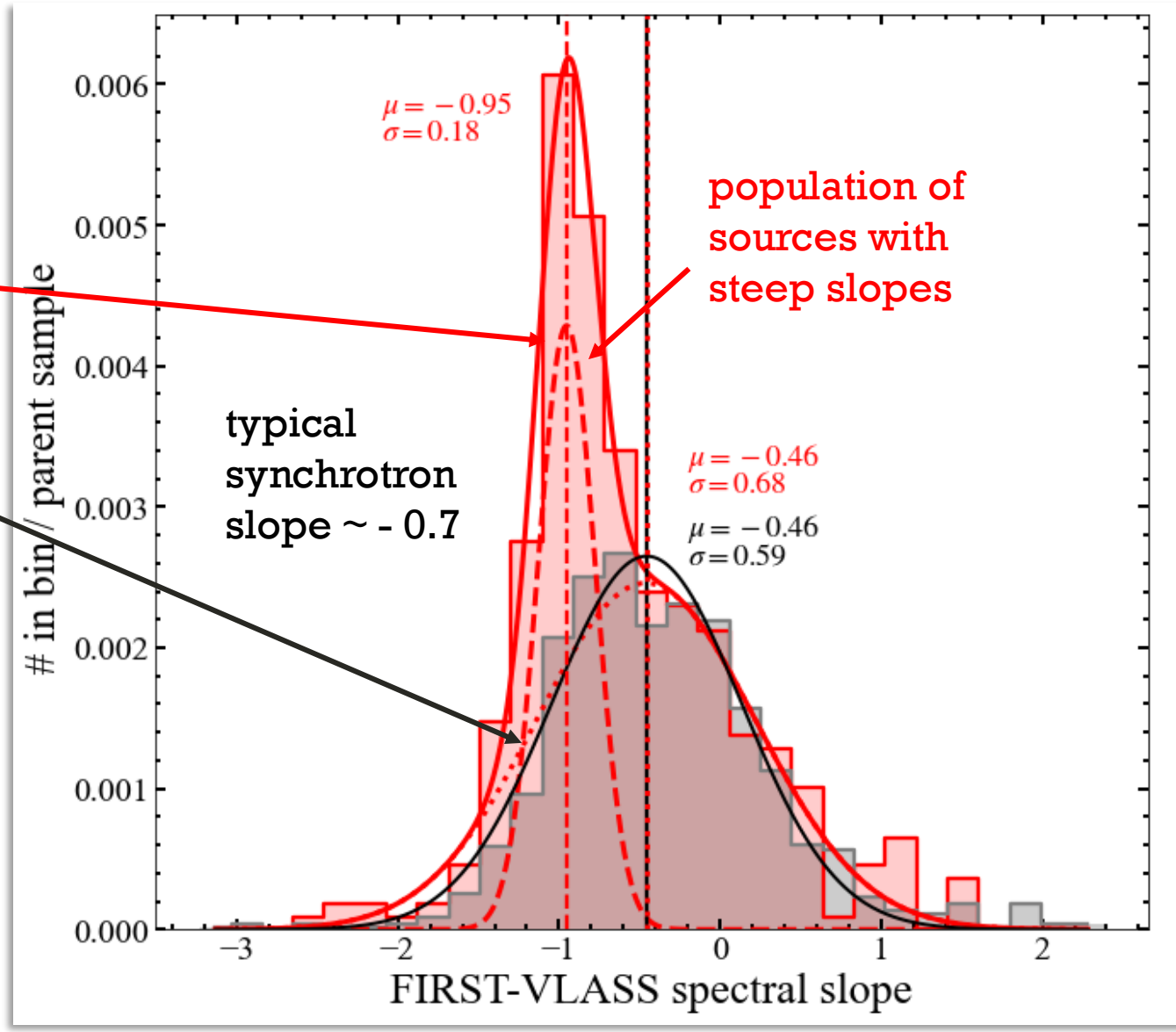
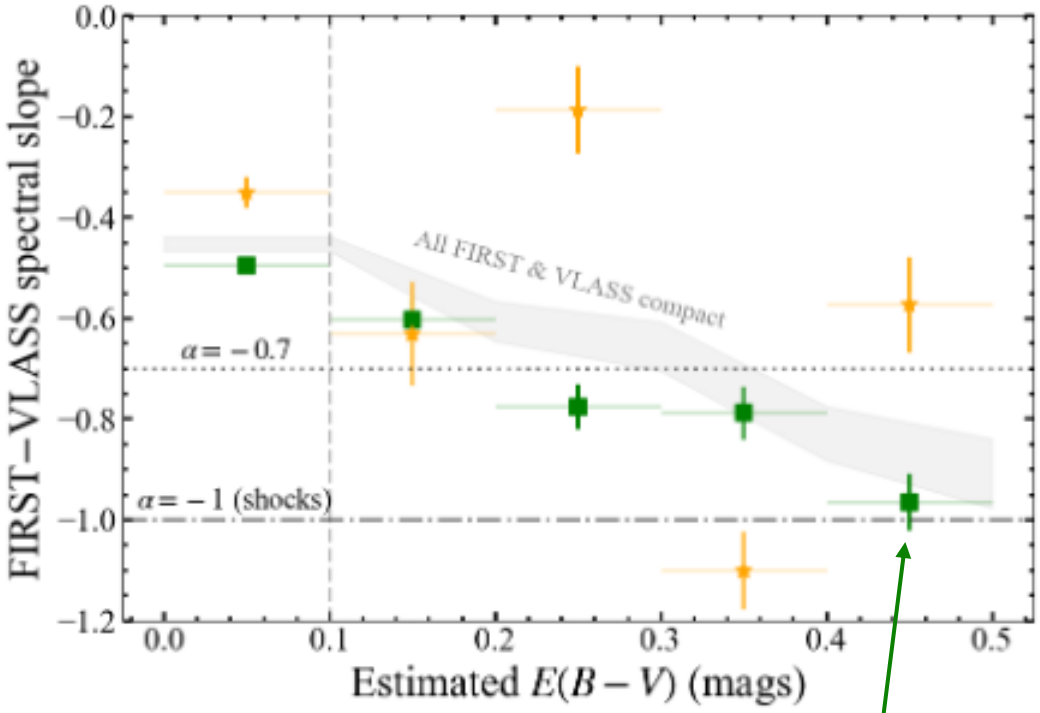
Truly compact red quasars contain a population of steep slope sources that drive the excess radio detection rates

- makes up ~ 30% of all truly compact red quasars
- are preferentially radio quiet/radio intermediate



Radio-dust connection for truly compact quasars only

- Fawcett+25: weak but significant trend of steepening radio spectral slope with E(B-V)
- We can now split this into truly vs fake compact quasars:



Spectral slope steepens with E(B-V) for truly compact quasars only

Radio-detection rate also connected to E(B-V) for truly compact quasars only

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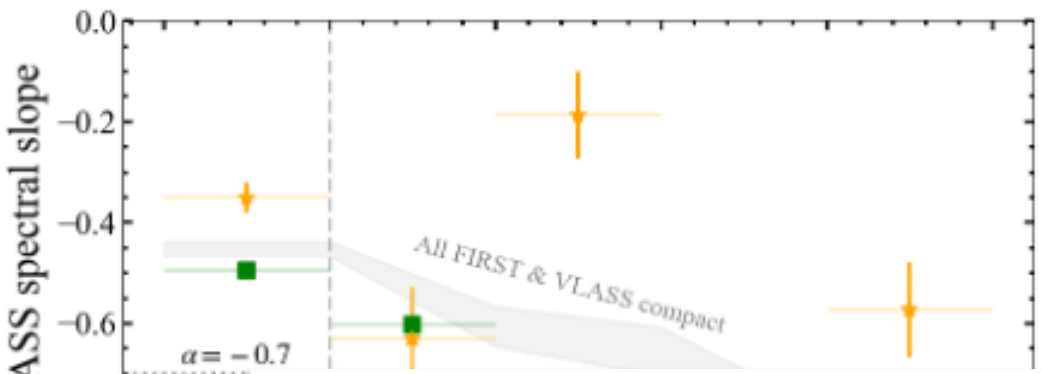


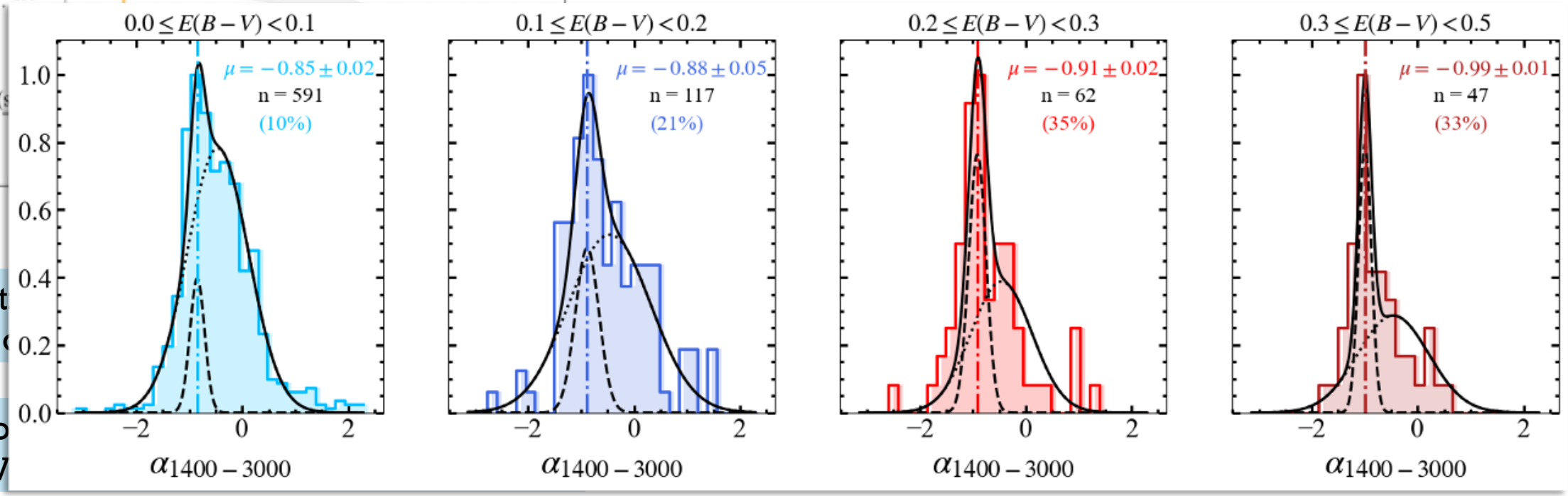
Non-thermal emission from electrons accelerated by an AGN wind shock (Nims+15):

$$\nu L_\nu \approx 10^{-5}\,\xi_{-2}\,L_{\rm AGN}\left(\frac{L_{\rm kin}}{0.05\,L_{\rm AGN}}\right) \quad (\nu \gtrsim \nu_{\rm cool}).$$

$\nu L_\nu \sim$ constant $\rightarrow L_\nu \propto \nu^{-1}$ ie. $\alpha \approx -1$

Spect
truly

Radio
E(B-V



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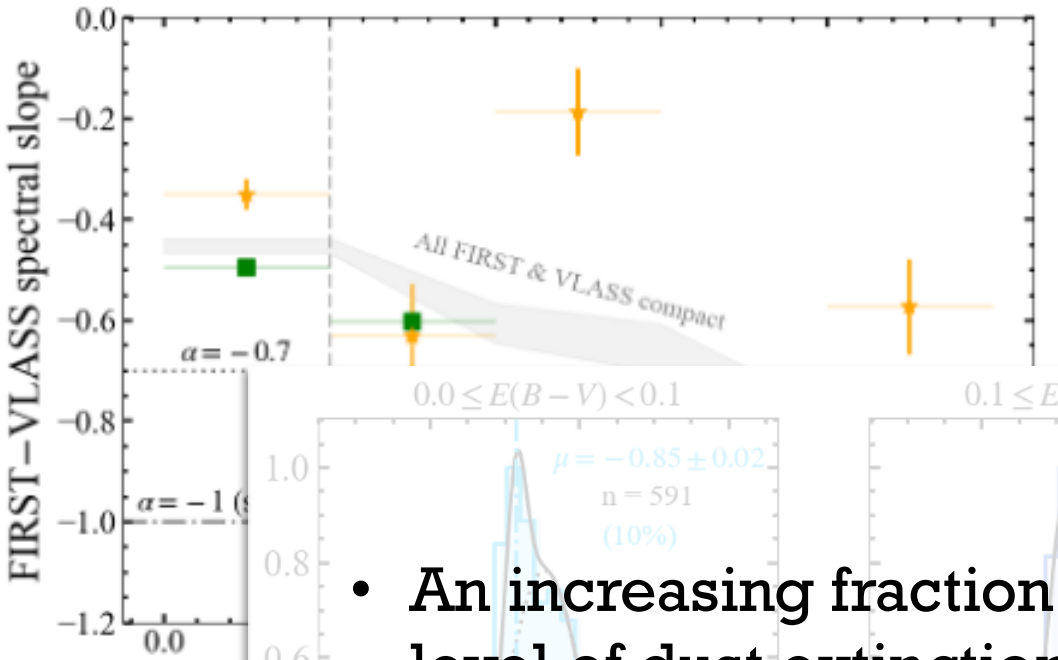

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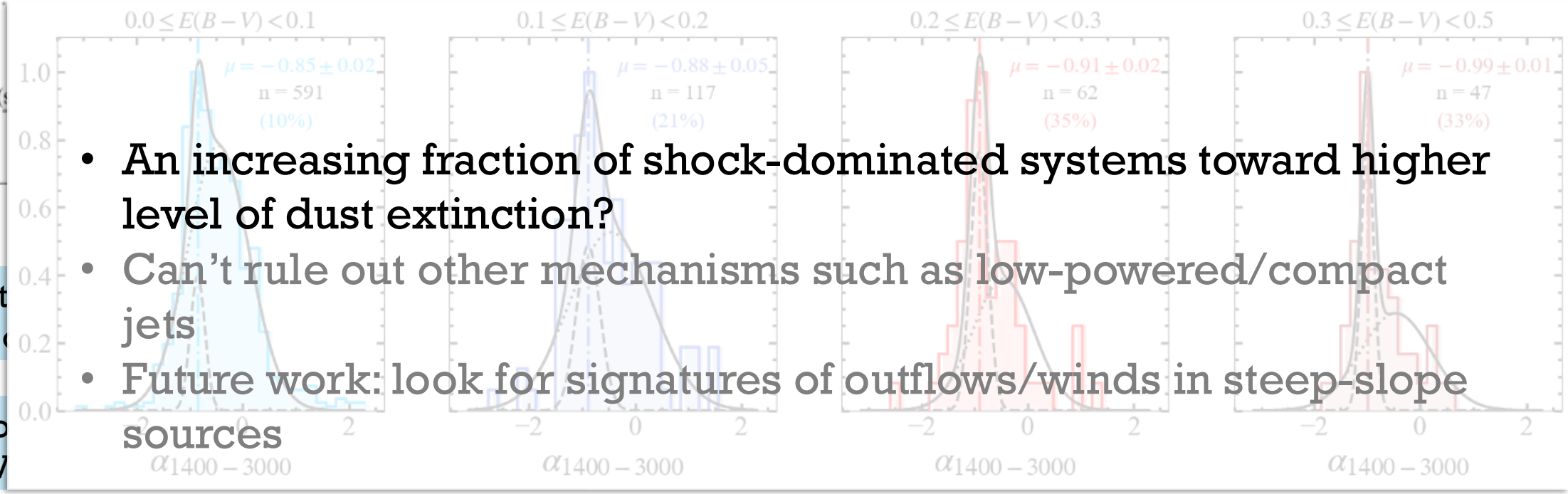
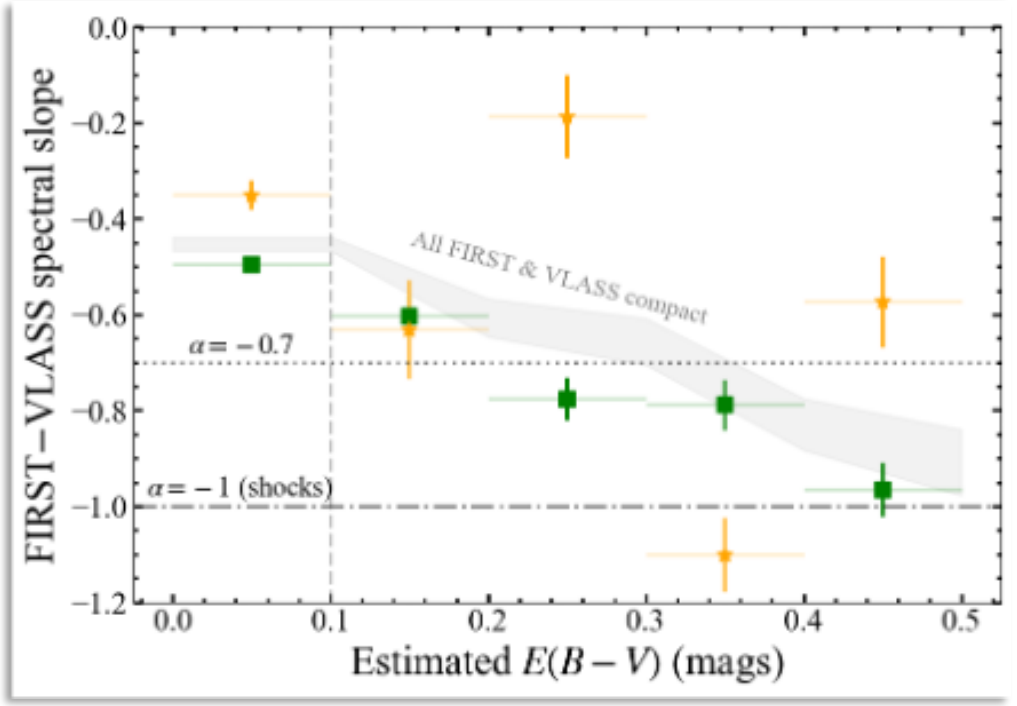
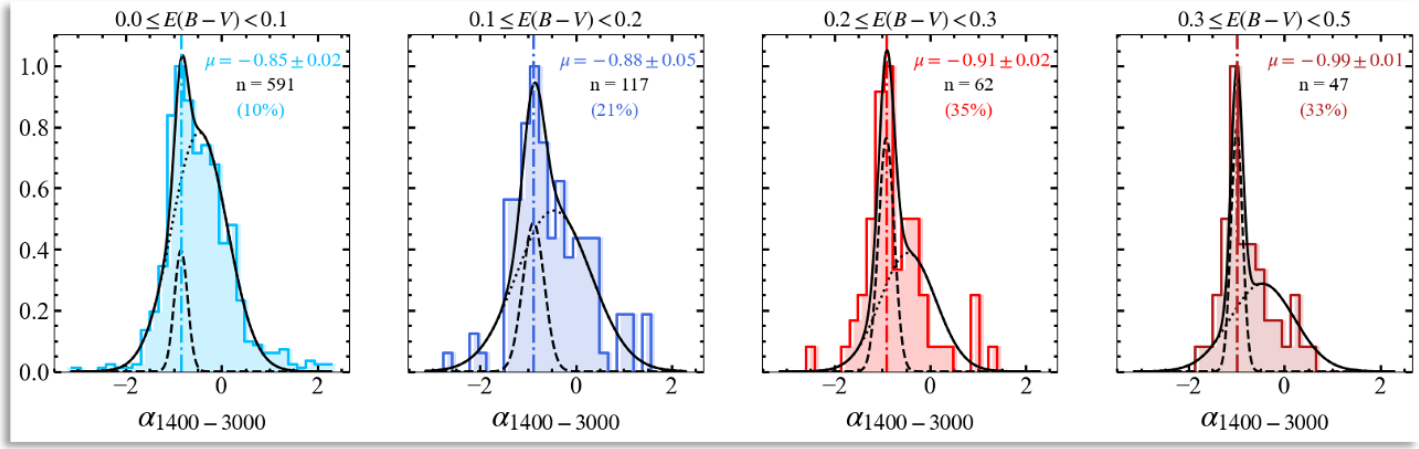


- An increasing fraction of shock-dominated systems toward higher level of dust extinction?
- Can't rule out other mechanisms such as low-powered/compact jets
- Future work: look for signatures of outflows/winds in steep-slope sources

Summary

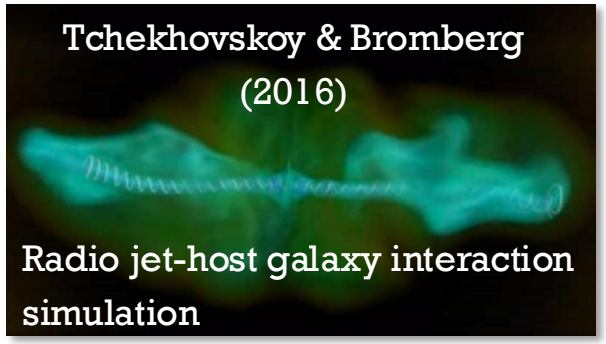
- There is a connection between dust and radio spectral slopes/detection rates in quasars
- The radio-dust connection in red quasars is mostly driven by systems with unresolved radio emission in both FIRST (1.4 GHz) and LoTSS (144 MHz)
- These "truly compact" red quasars contain a population of sources with steep radio spectral slopes of $\alpha \sim -1$
- This is consistent with the prediction from AGN-wind shocks in the Nims+15 model
- Consistent with a "dusty blow-out" phase?





Backup slides

Red quasars as a dusty blow-out phase?



gas infall – obscuration increasing

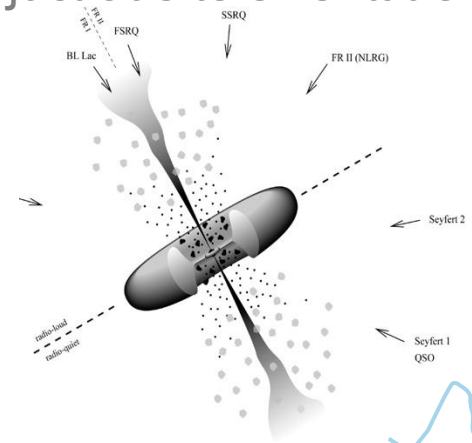
dusty blow-out phase

eg. Nims+ 2015

steep radio spectral slopes

unobscured/ blue quasar

some quasars likely red just due to orientation



extended radio emission fades

= shocks

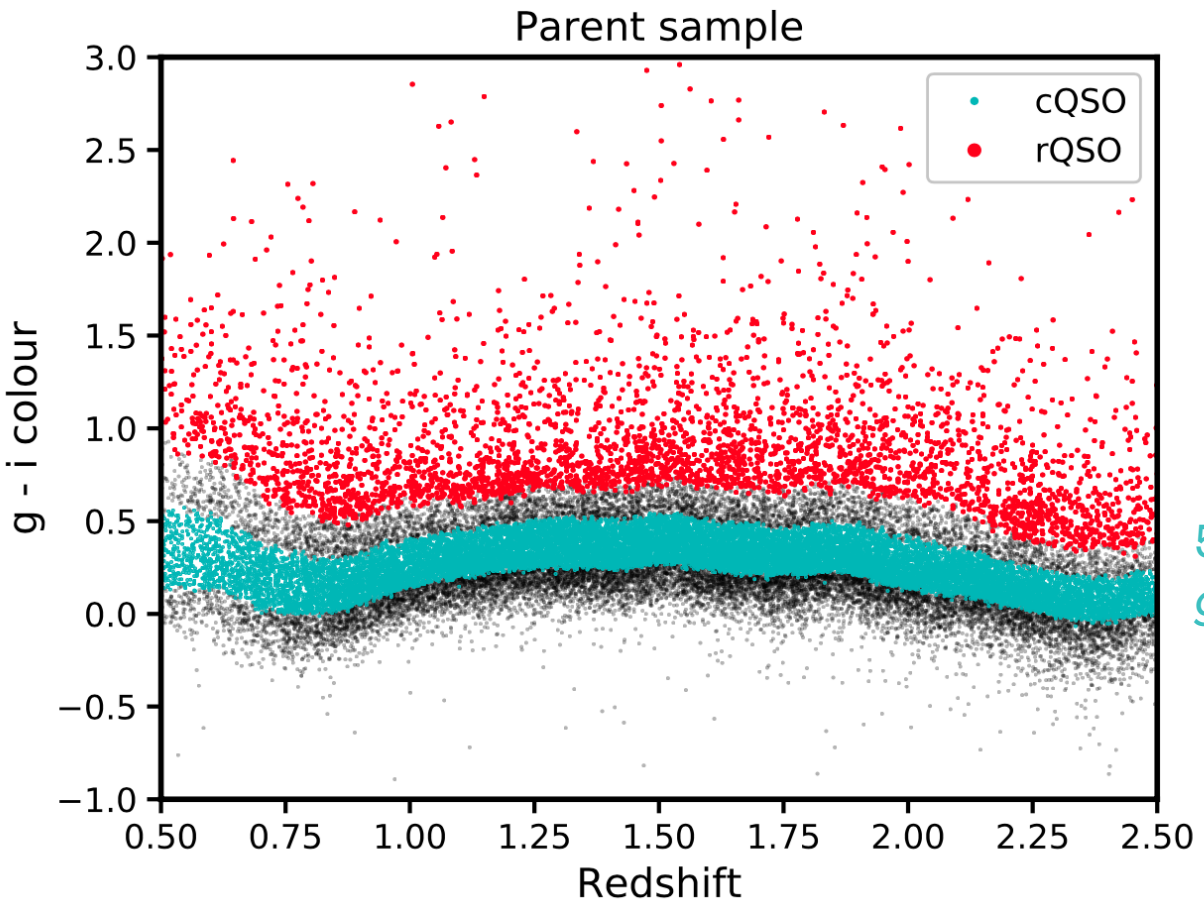
= radio emission

extended radio emission fades (high frequency faster)

- extended radio emission
- observed with typical distribution of radio spectral slopes

"fake compact" quasars

Red & control colour selection

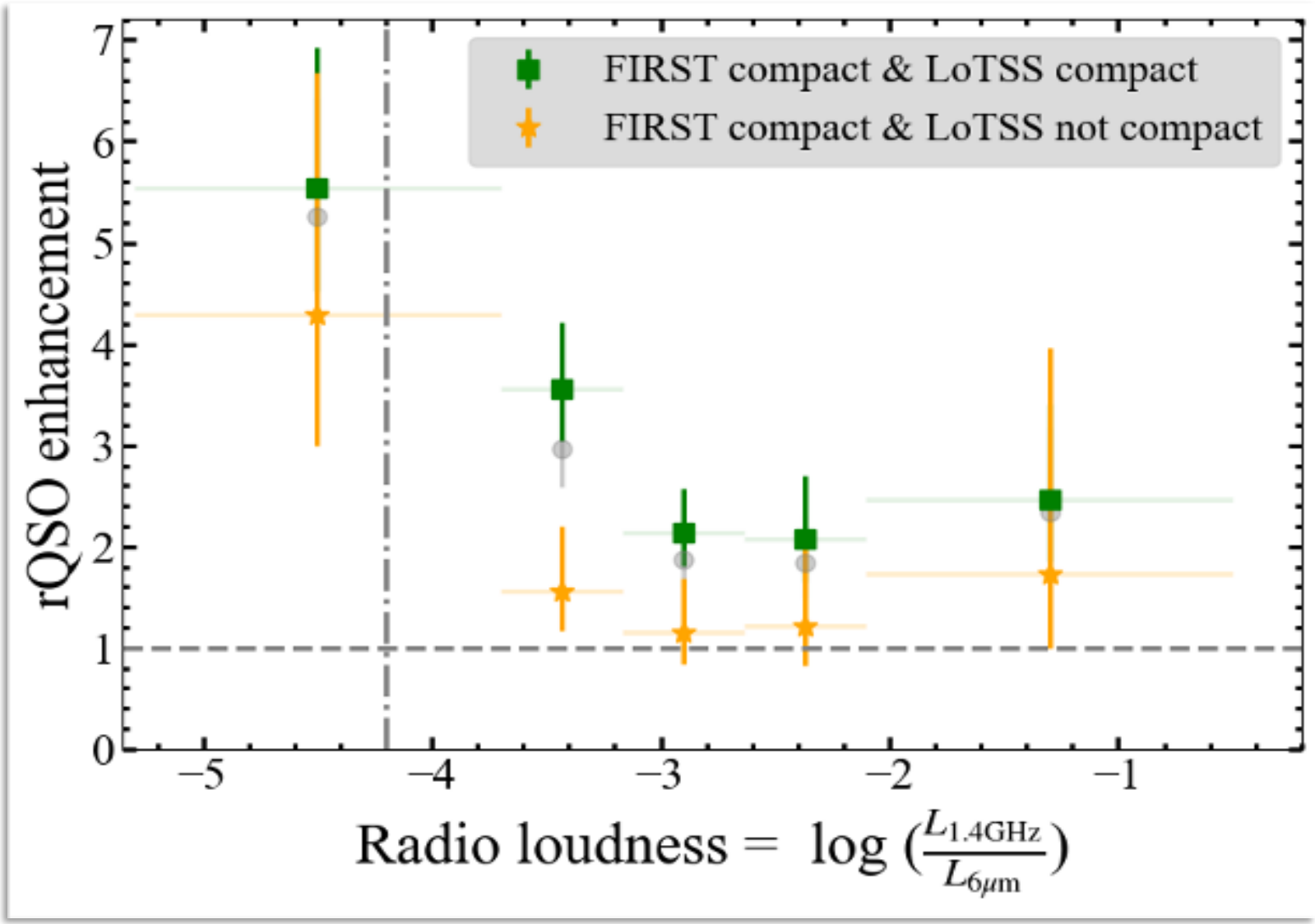


SDSS optically selected red and blue/control quasars (0.2 < z < 2.4) from Fawcett+2022:

top 10% *g*-i**

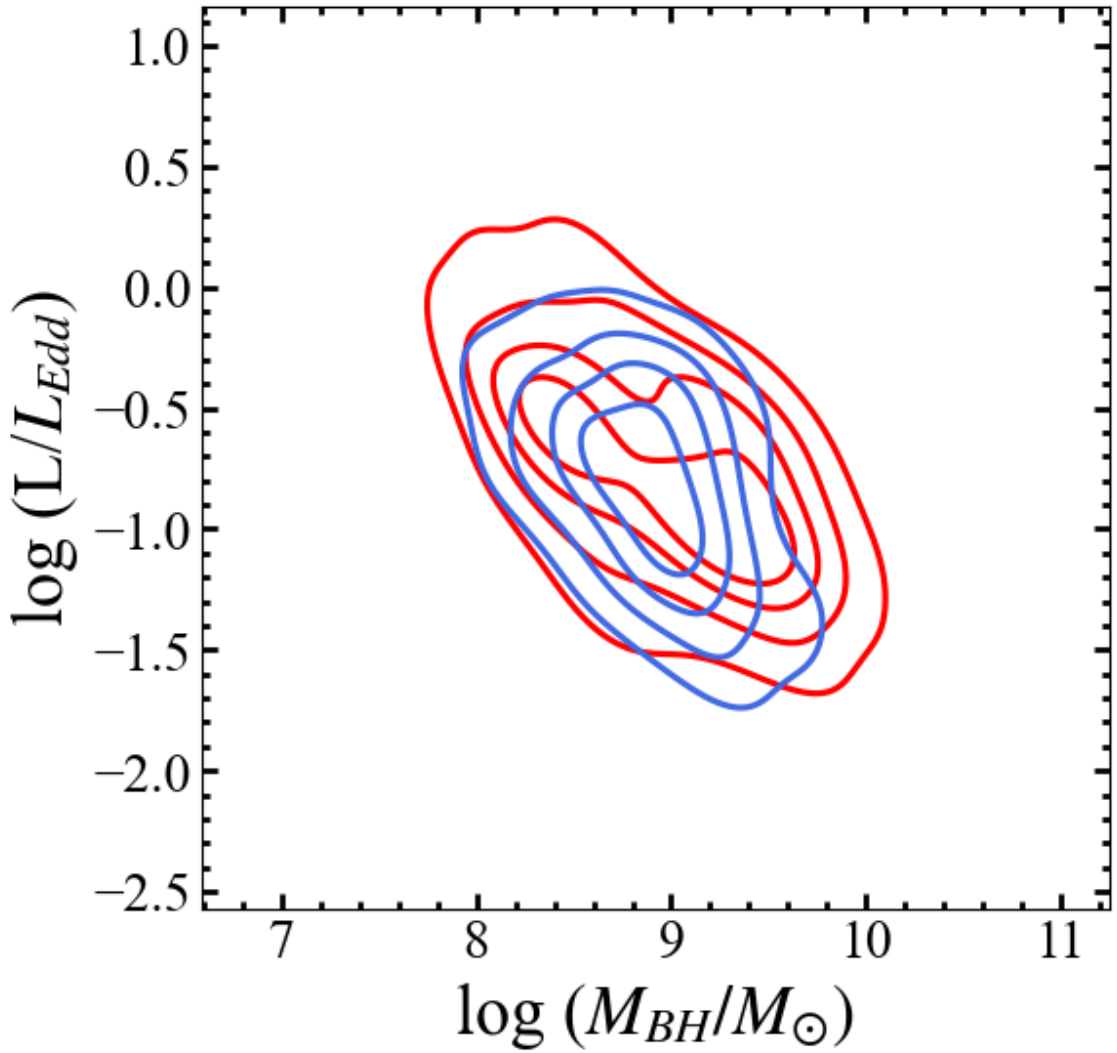
50% around median *g*-i**

Radio loudness



Differences in the central engines? Preliminary

- Eddington ratios - previous work finds mixed results for red quasars:
  - no difference in L/Ledd (Calistro Rivera+2021),
  - red quasars slightly lower L/Ledd (Fawcett+2022),
  - higher L/Ledd (Urrutia+2012)
- Rakshit+2020 BH mass and luminosity values – corrected for E(B-V)
- no strong difference in L/Ledd
- BH mass distributions different



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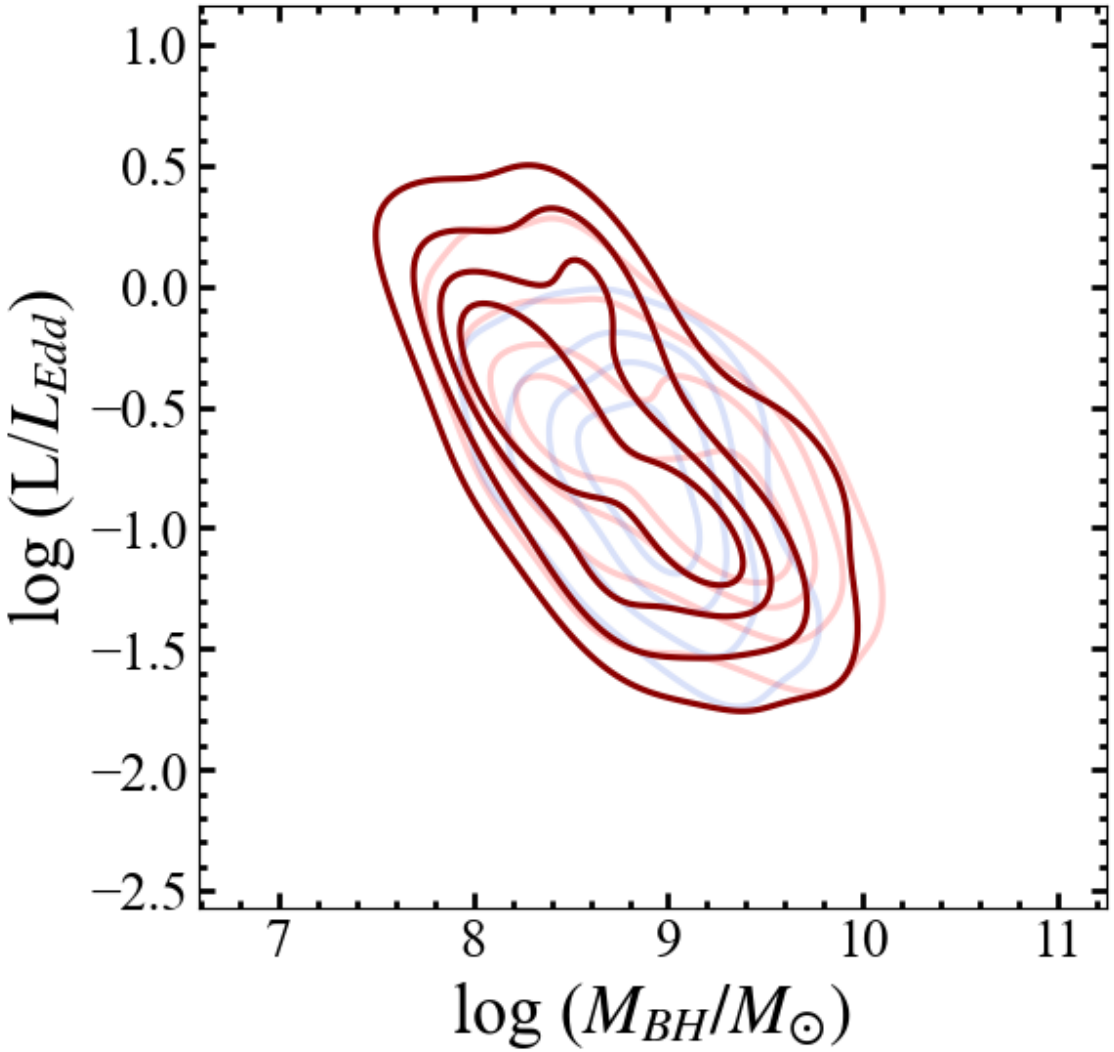
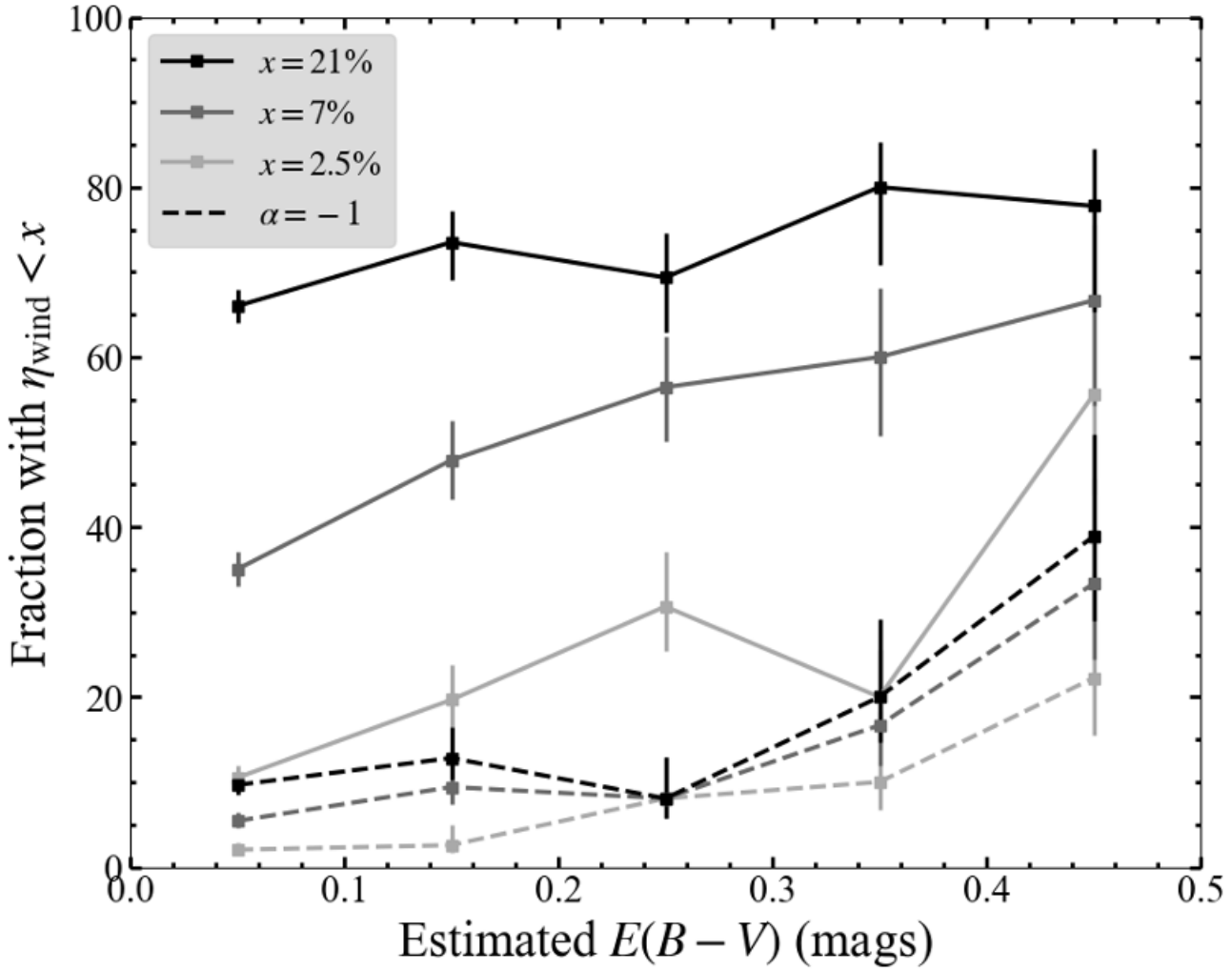
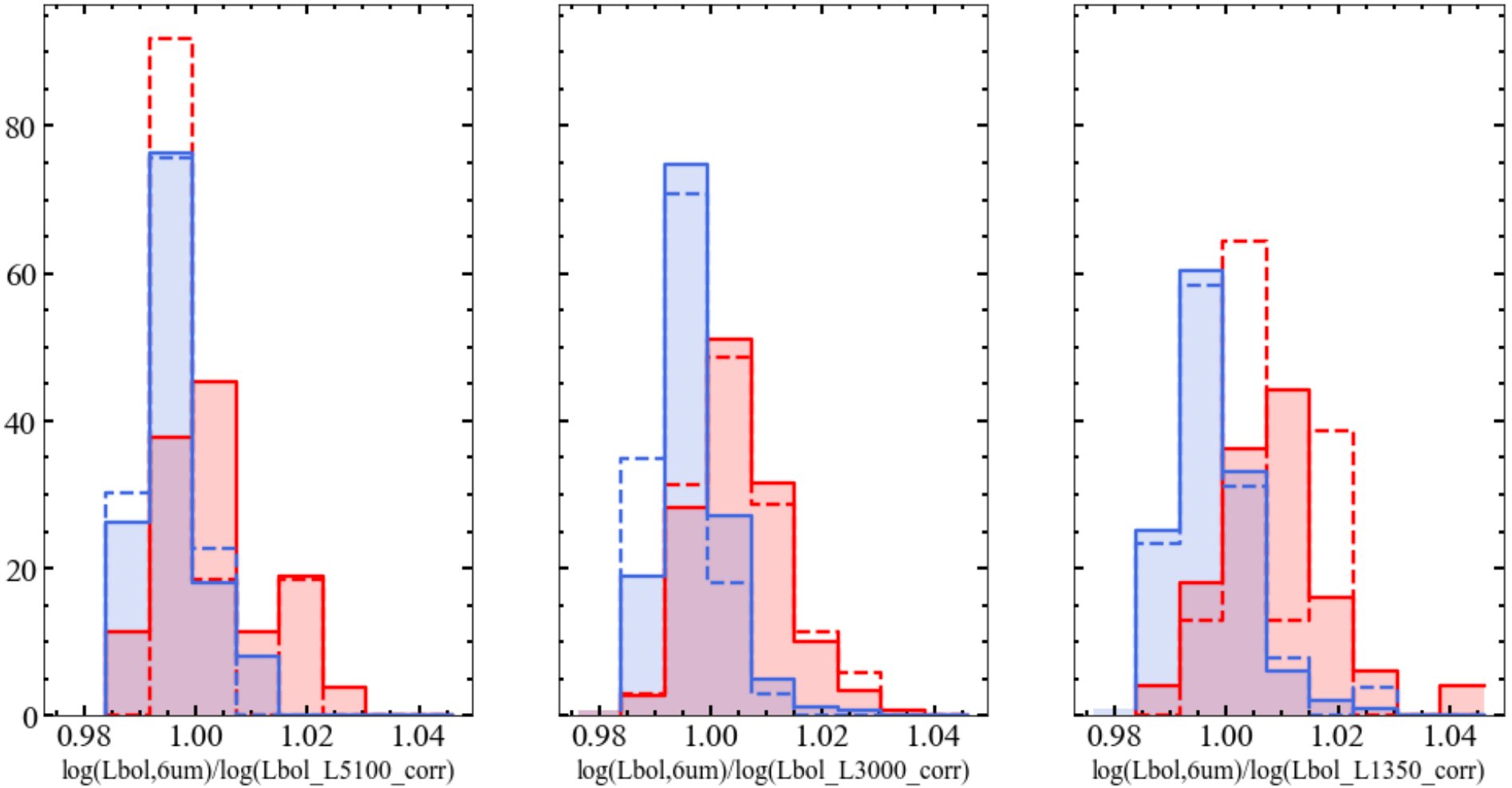
- Steep truly compact red quasars: less massive BHs and higher Eddington ratios?



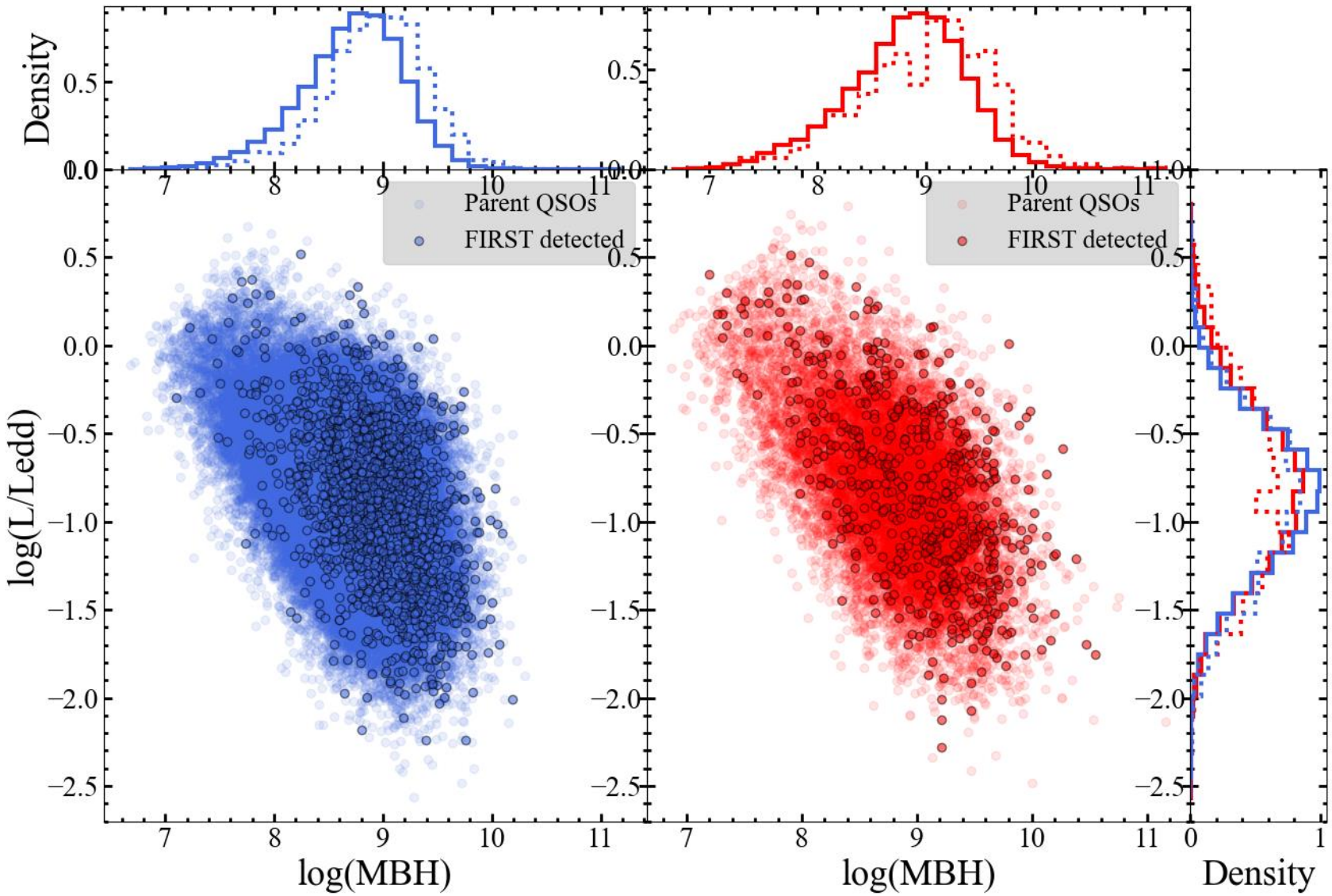
Wind efficiency parameter



MIR excess

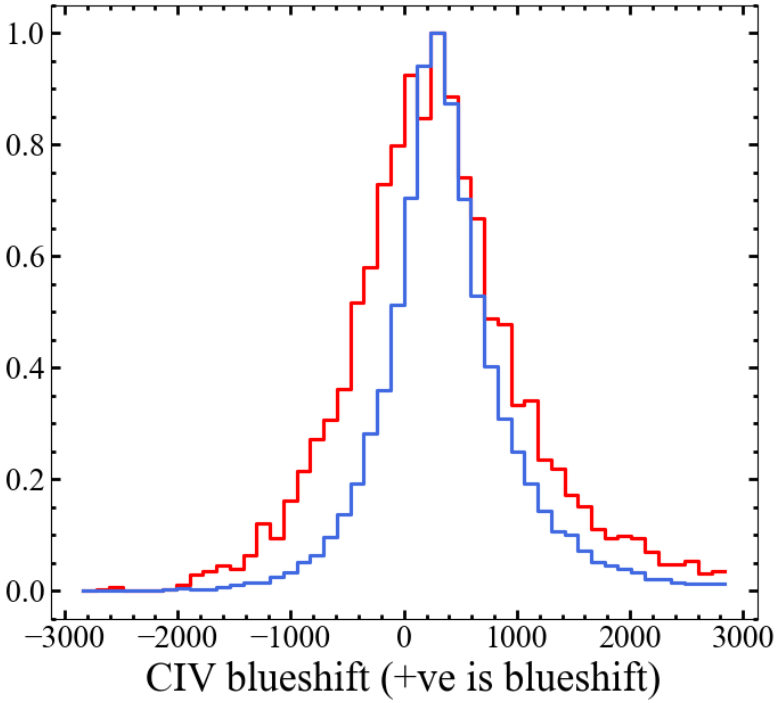

80
60
40
20
0
0.98
1.00
1.02
1.04
log(Lbol,6um)/log(Lbol_L5100_corr)
0.98
1.00
1.02
1.04
log(Lbol,6um)/log(Lbol_L3000_corr)
0.98
1.00
1.02
1.04
log(Lbol,6um)/log(Lbol_L1350_corr)

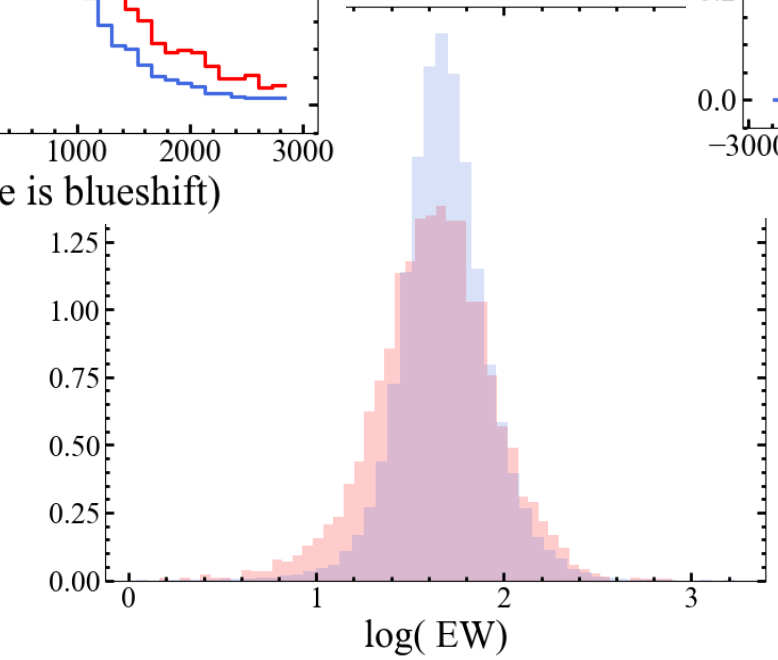
L/Ledd - MBH plane



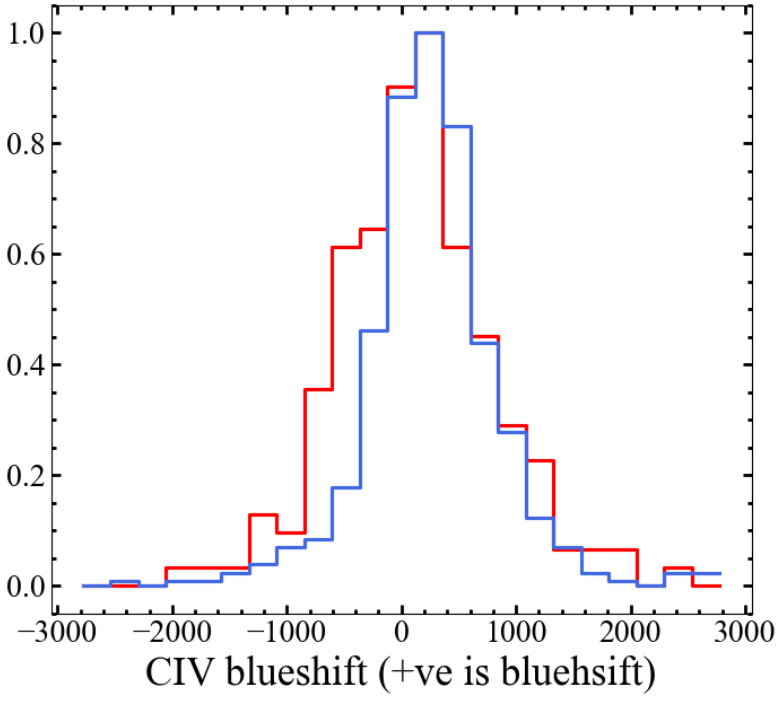
CIV blueshifts and EW (v. preliminary)

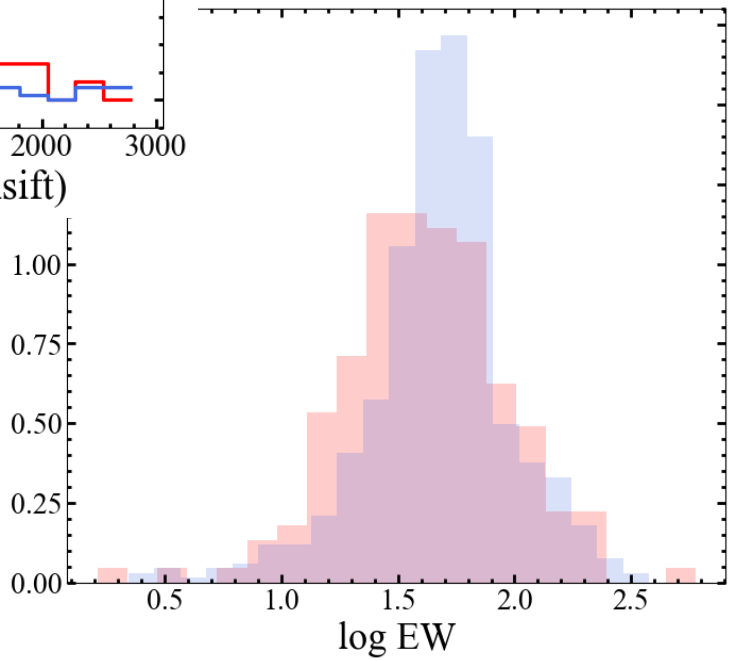
parent:



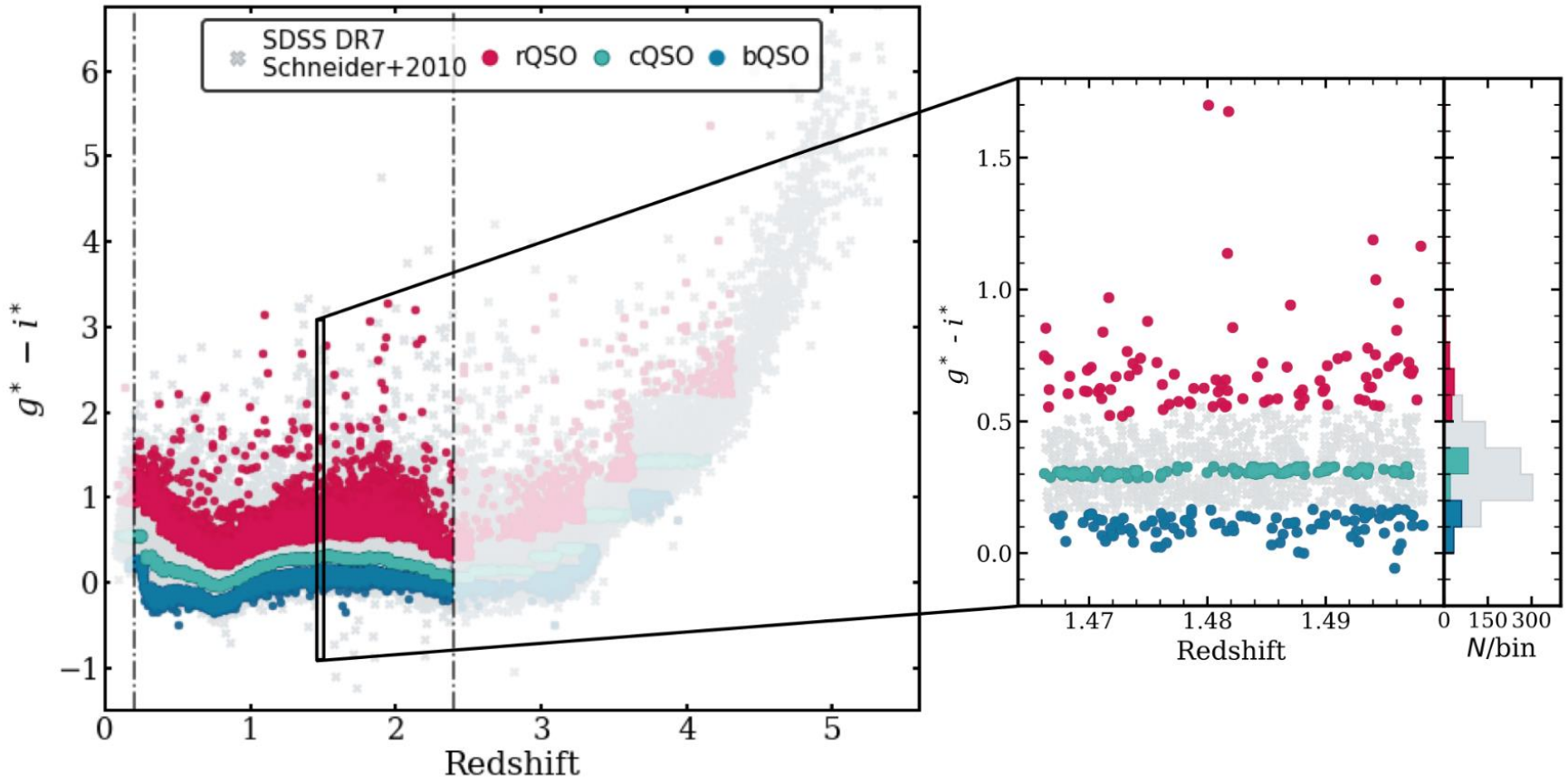


radio detected:

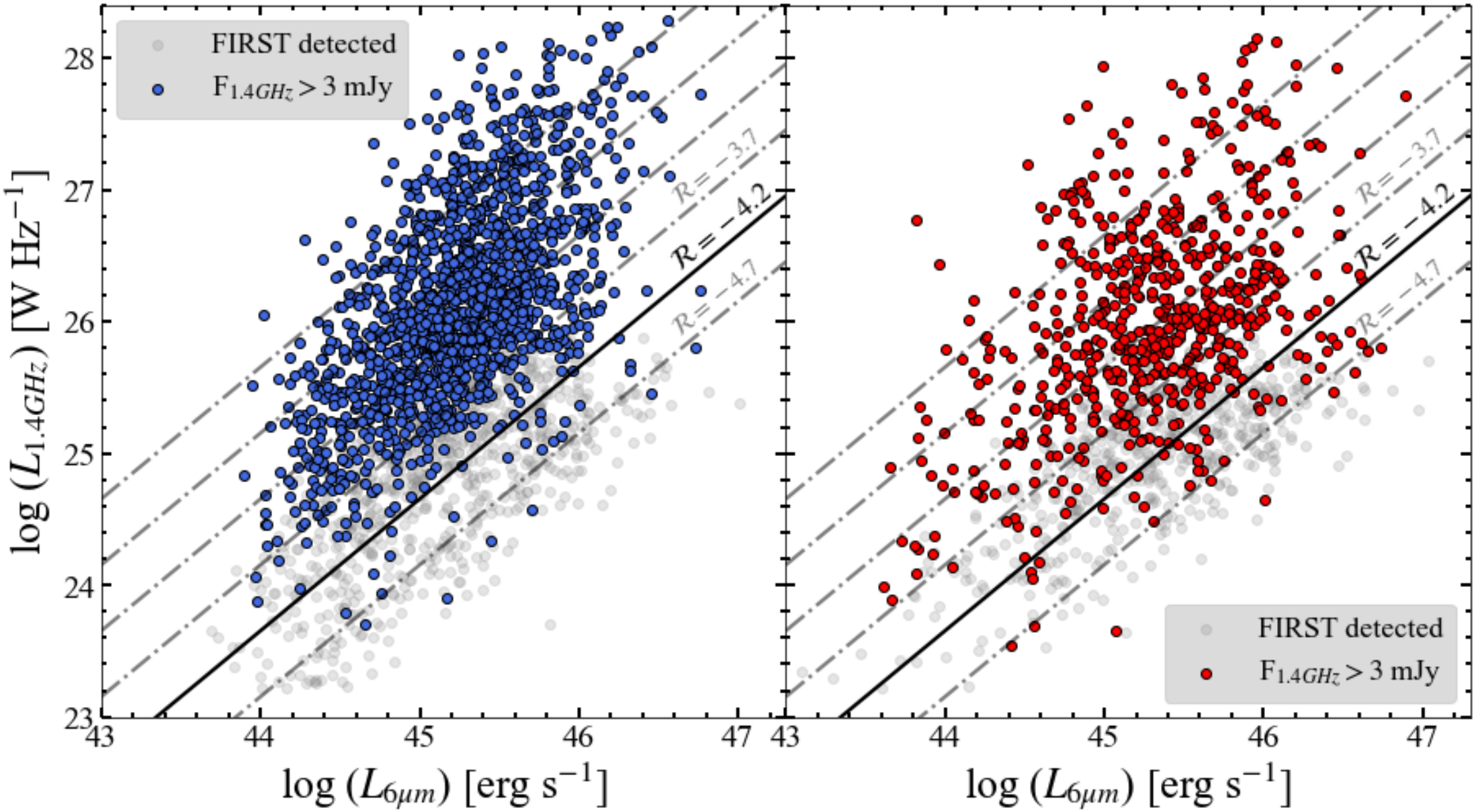




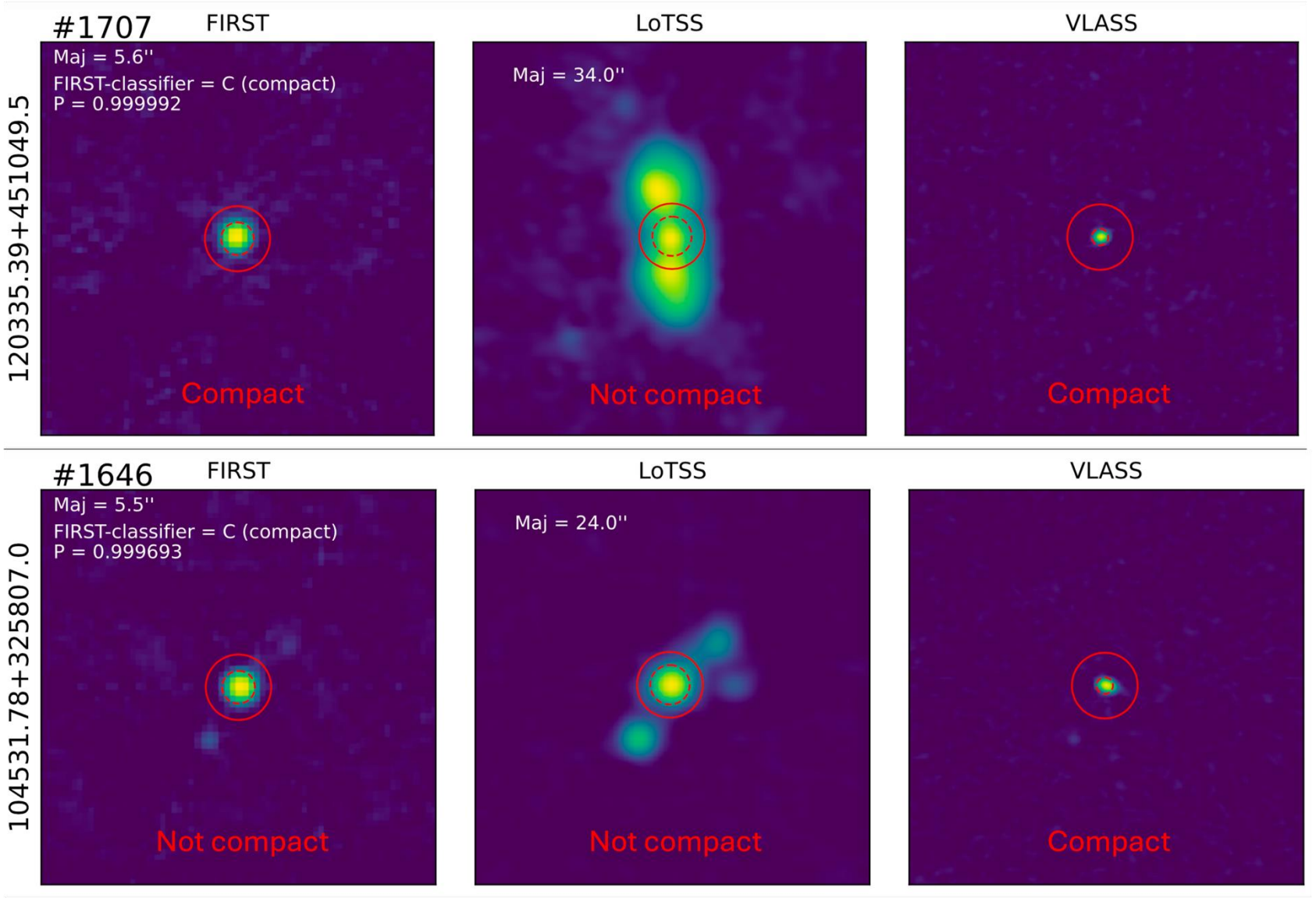
g*-i* selection



Klindt et. al (2019)


FIRST detected
$F_{1.4GHz} > 3$ mJy
$\mathcal{R} = -3.7$
$\mathcal{R} = -4.2$
$\mathcal{R} = -4.7$
$\log (L_{1.4GHz})$ [W Hz^{-1}]
$\log (L_{6\mu m})$ [erg s^{-1}]
23
24
25
26
27
28
43
44
45
46
47

visual inspection

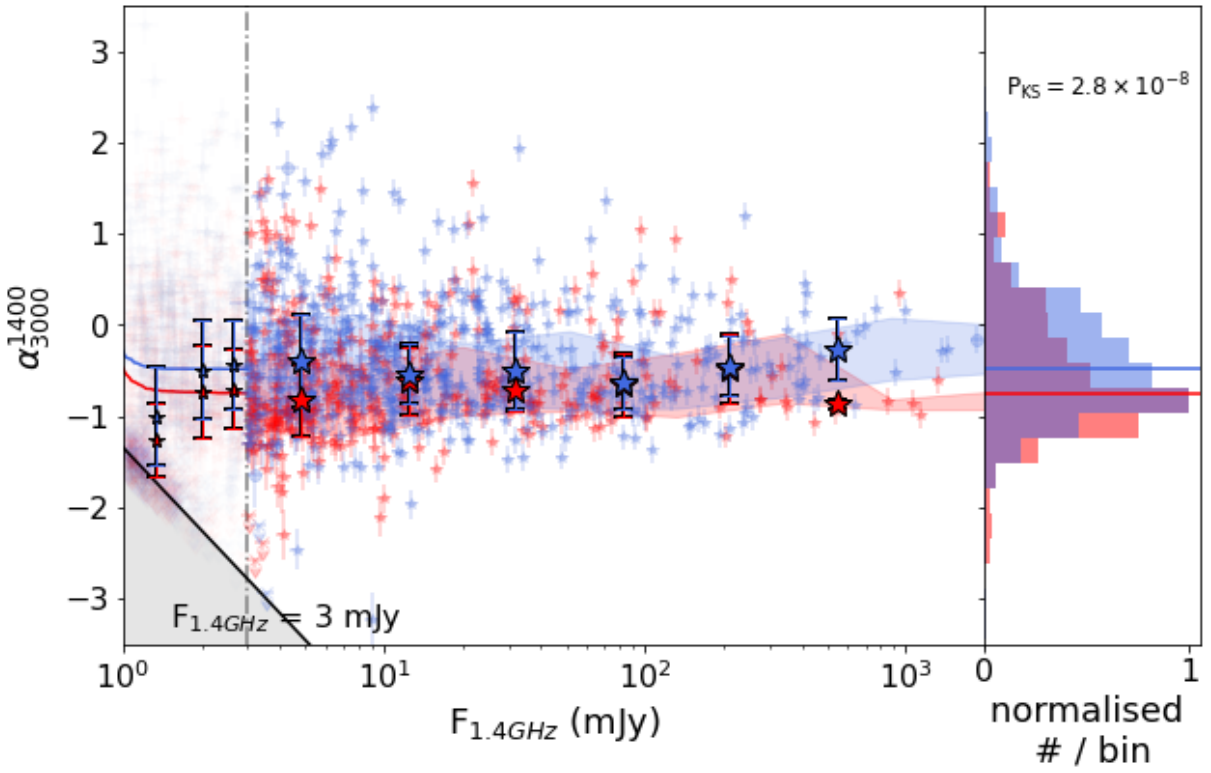


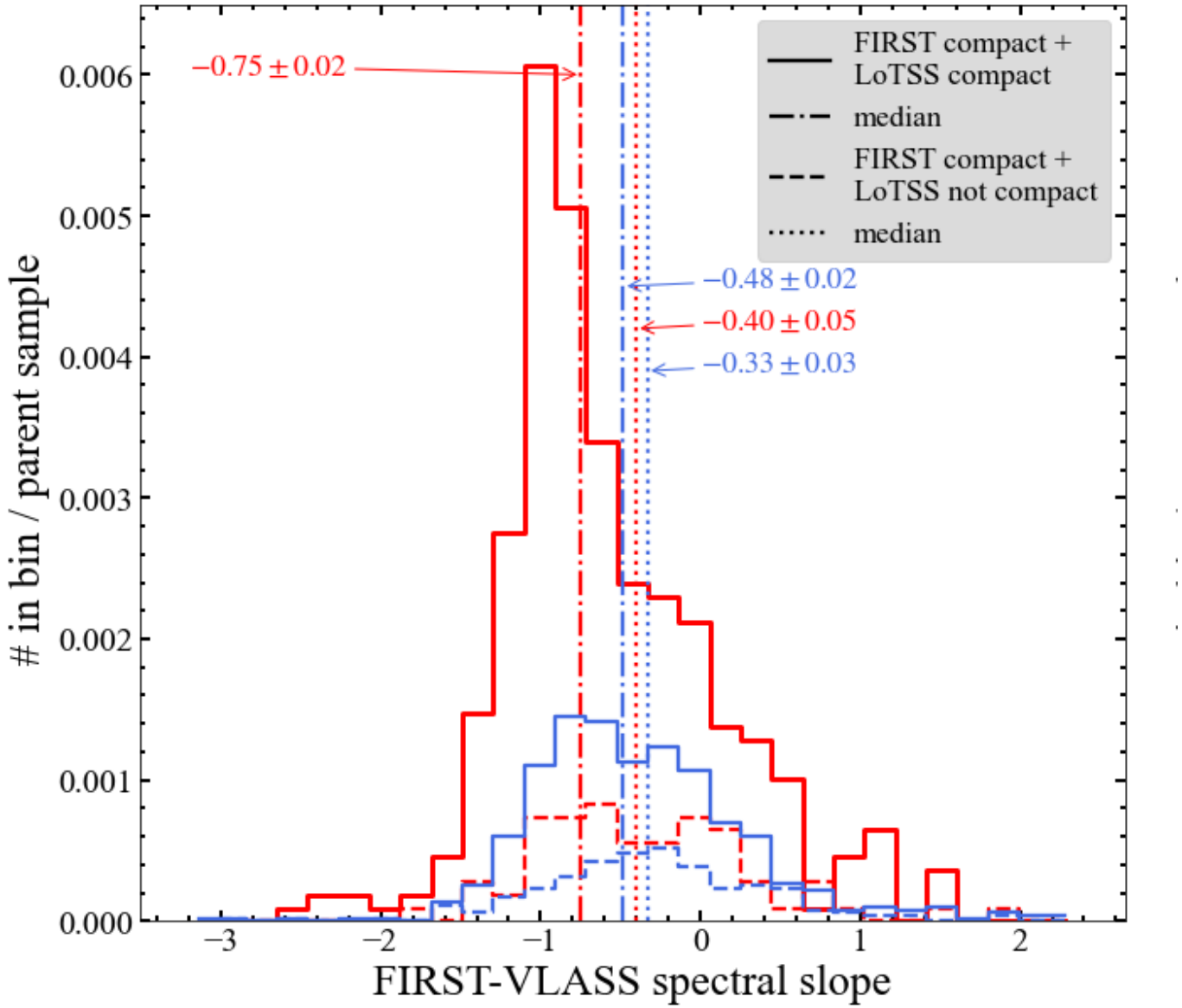
alpha vs flux

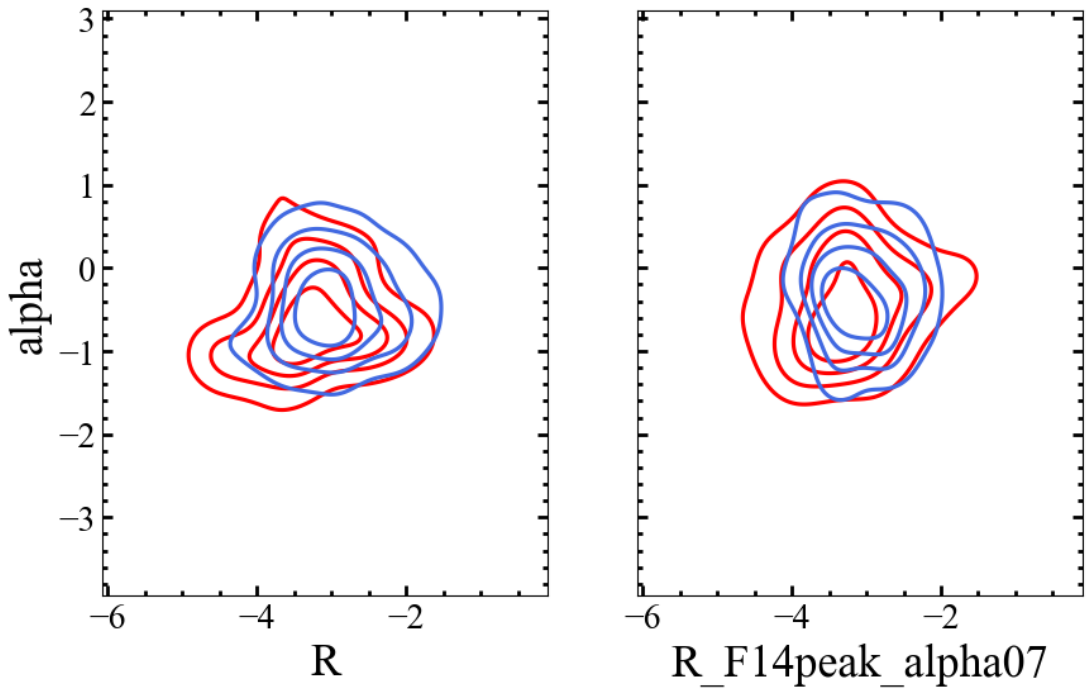
FIRST-VLASS:

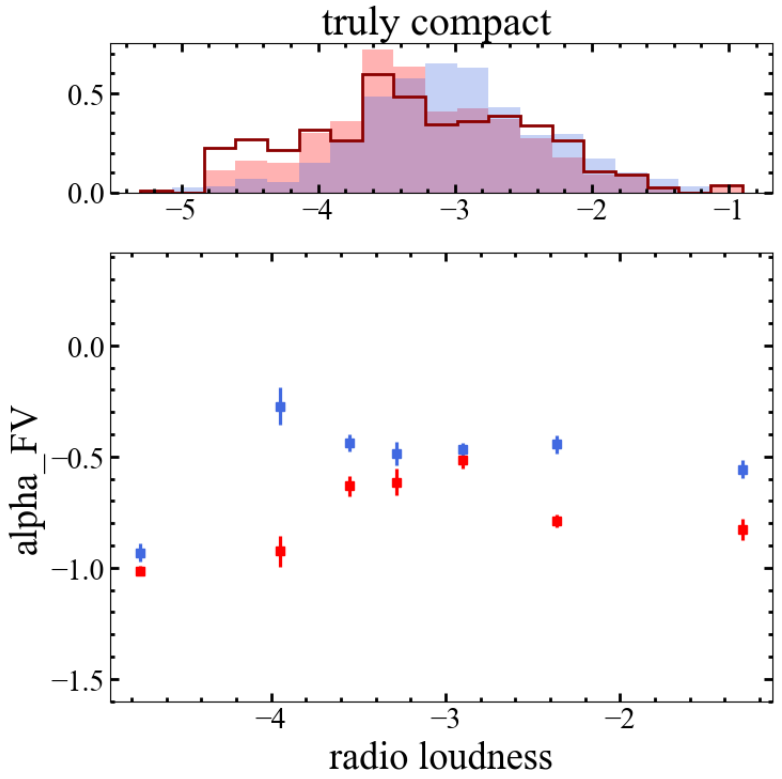
Red quasars median slope = -0.75 ± 0.02

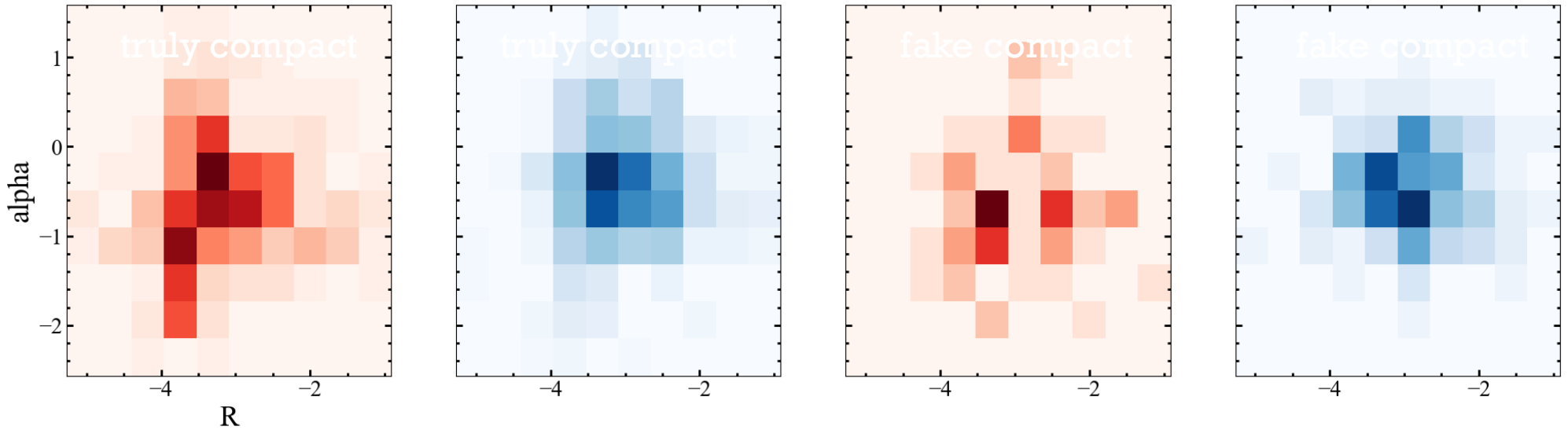
Blue quasars median slope = -0.48 ± 0.02




FIRST compact + LoTSS compact
median
FIRST compact + LoTSS not compact
median
−0.75 ± 0.02
−0.48 ± 0.02
−0.40 ± 0.05
−0.33 ± 0.03
in bin / parent sample
FIRST-VLASS spectral slope
0.000
0.001
0.002
0.003
0.004
0.005
0.006
−3
−2
−1
0
1
2


alpha
R
R_F14peak_alpha07


truly compact
alpha_FV
radio loudness


truly compact
truly compact
fake compact
fake compact
alpha
R