A striking signature of shocks in compact red quasars?

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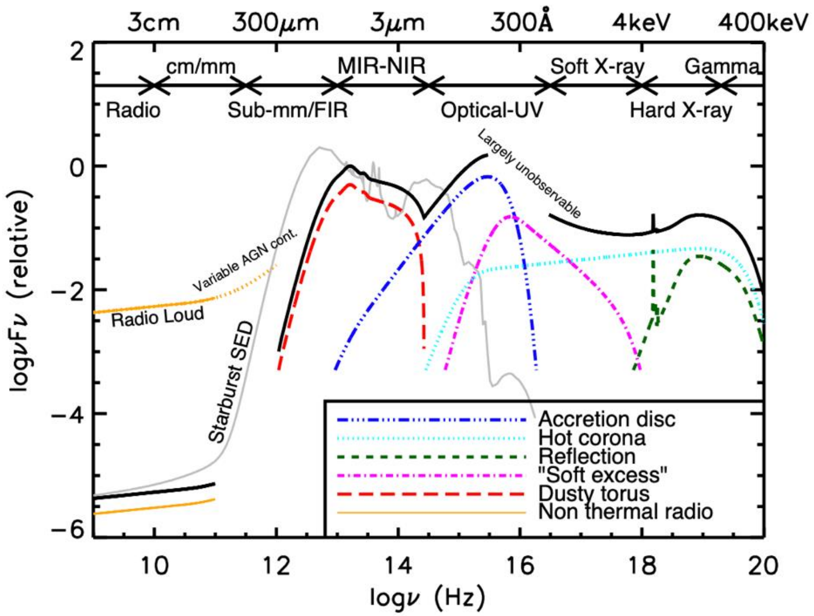
Supervisors: David Alexander & Claire Greenwell

Radio Astronomy in the build up to the SKAO
NAM, 9 July

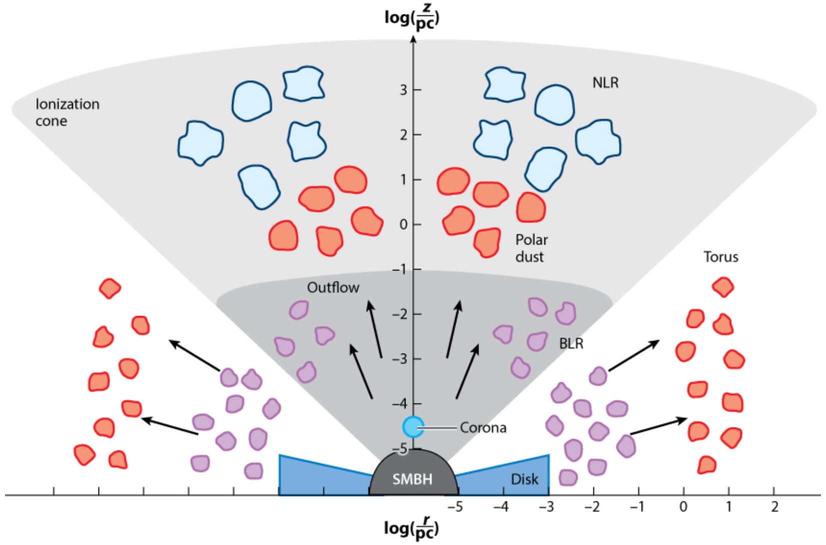
Image Credit: ESO/M. Kornmesser

Background

Image credit: ESO/M. Kornmesser

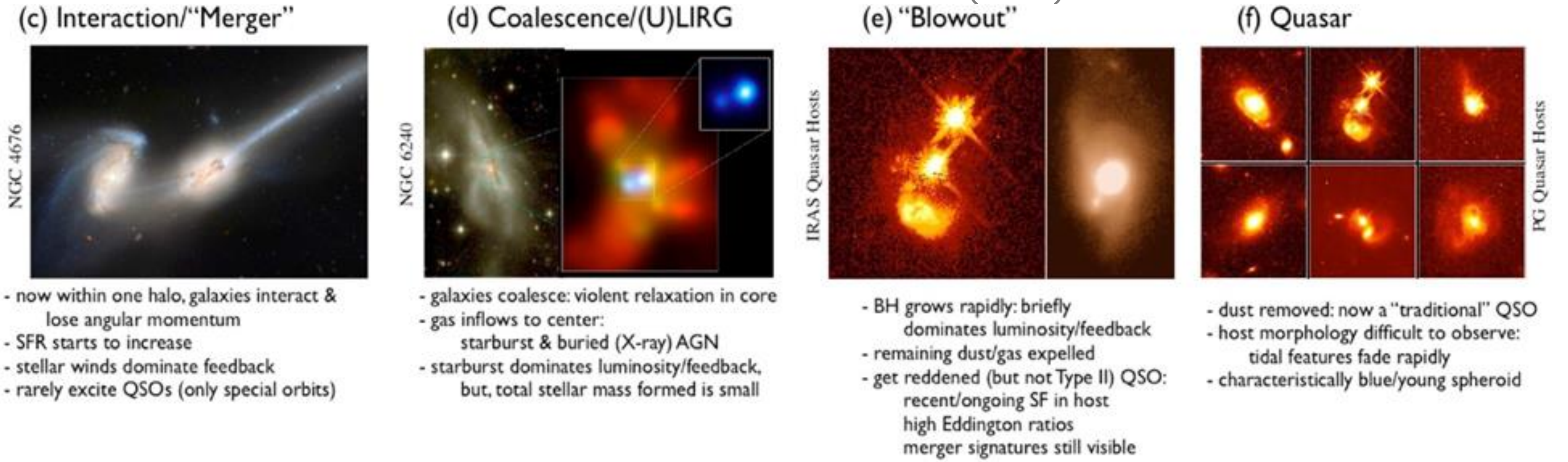


Harrison (2014)



Hickox & Alexander (2018)

Hopkins+08



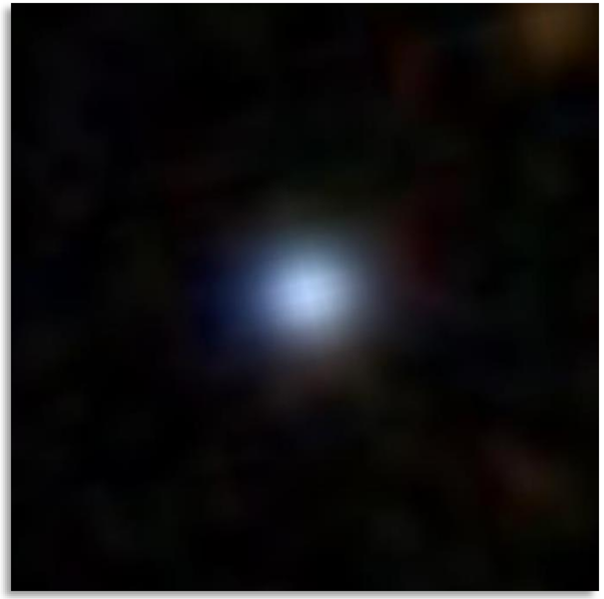
Galaxy simulations predict a dusty **"blow-out"** phase

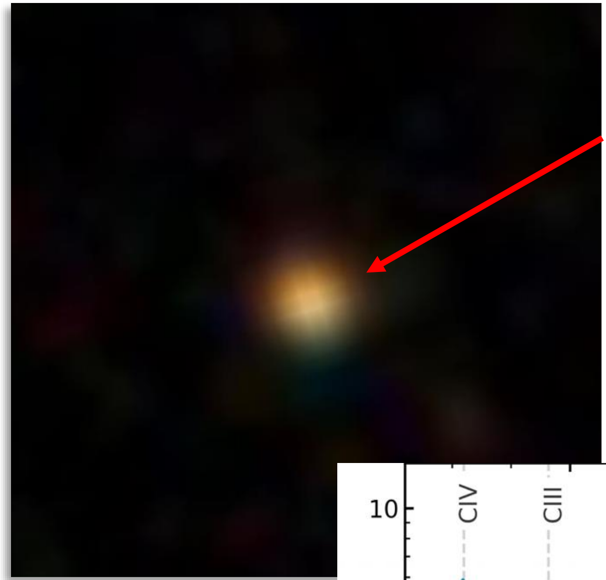
I'll be focussing on **red quasars**

What is a red quasar?

Majority of optical quasars are blue

~10% are red

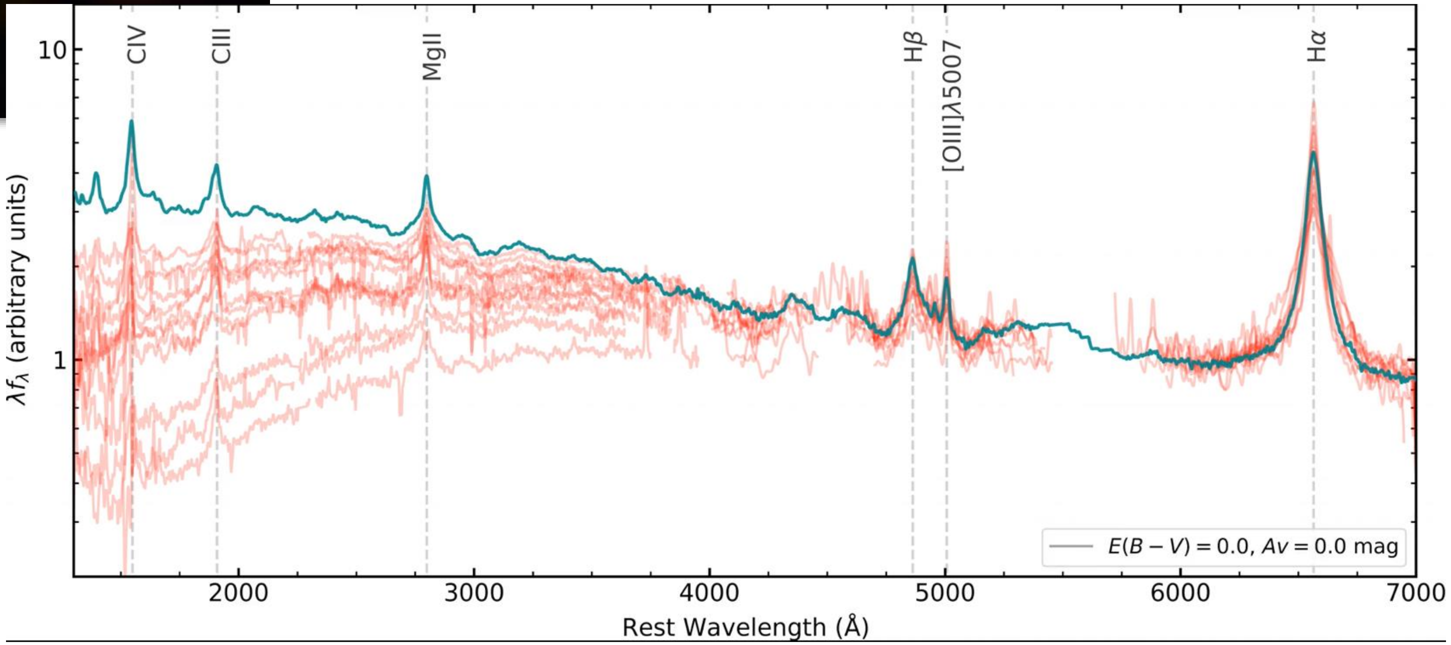




Optical images taken from the Sloan Digital Sky Survey (SDSS)

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

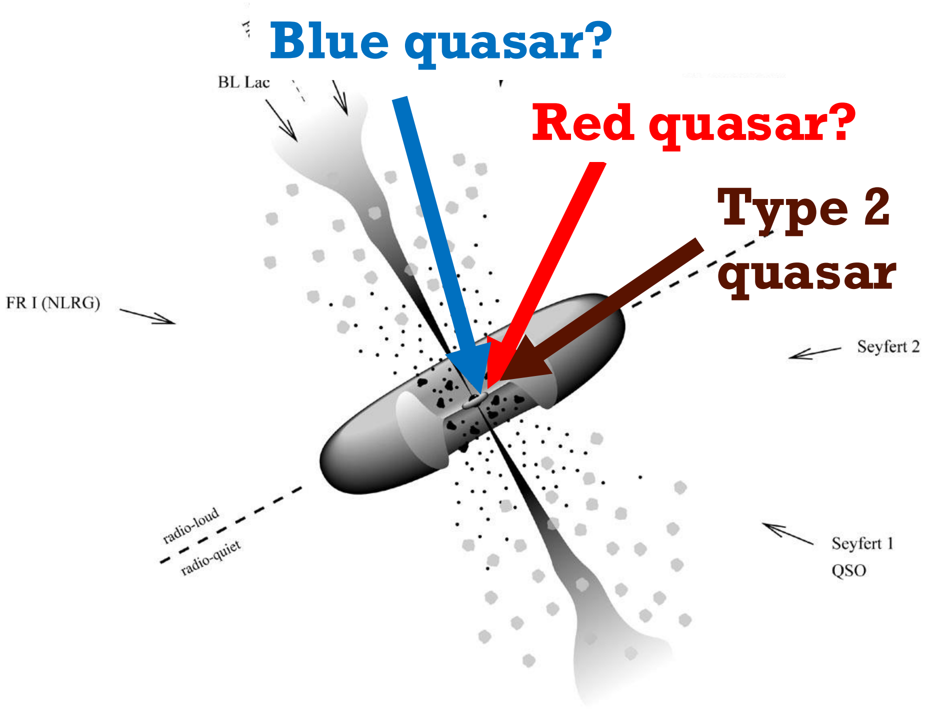
Fawcett+ 22



Where is the dust coming from?

Red/dusty quasars as a transitional phase

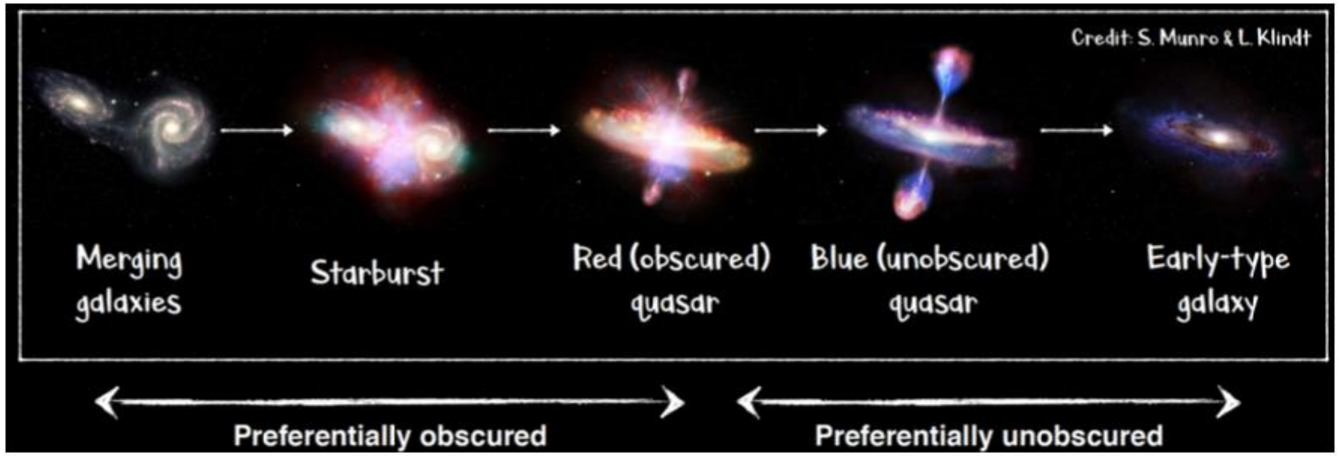
Orientation model: differences in observed properties due only to observers' line of sight



Torres & Anchordoqui (2004)

…and/or…?

Transition/evolution model: Red quasar represents a brief obscured—unobscured transition phase?

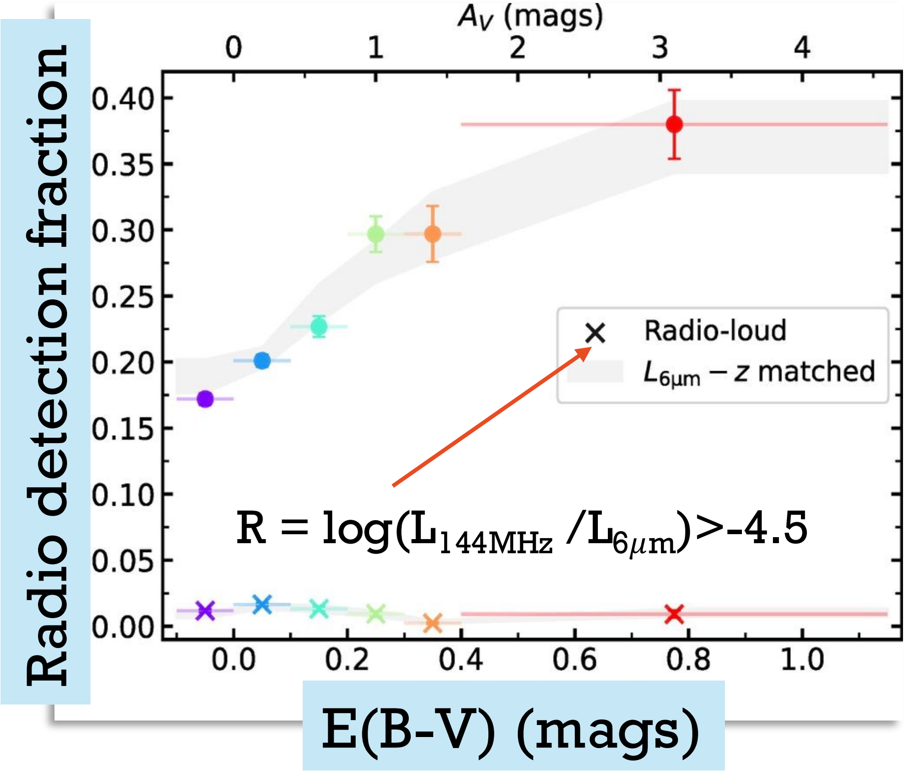


e.g., Sanders +88, Hopkins+08, Alexander & Hickox (2012)

How can we distinguish between these models?

- in a transition model we would expect fundamental differences in properties not due to selection/orientation effects

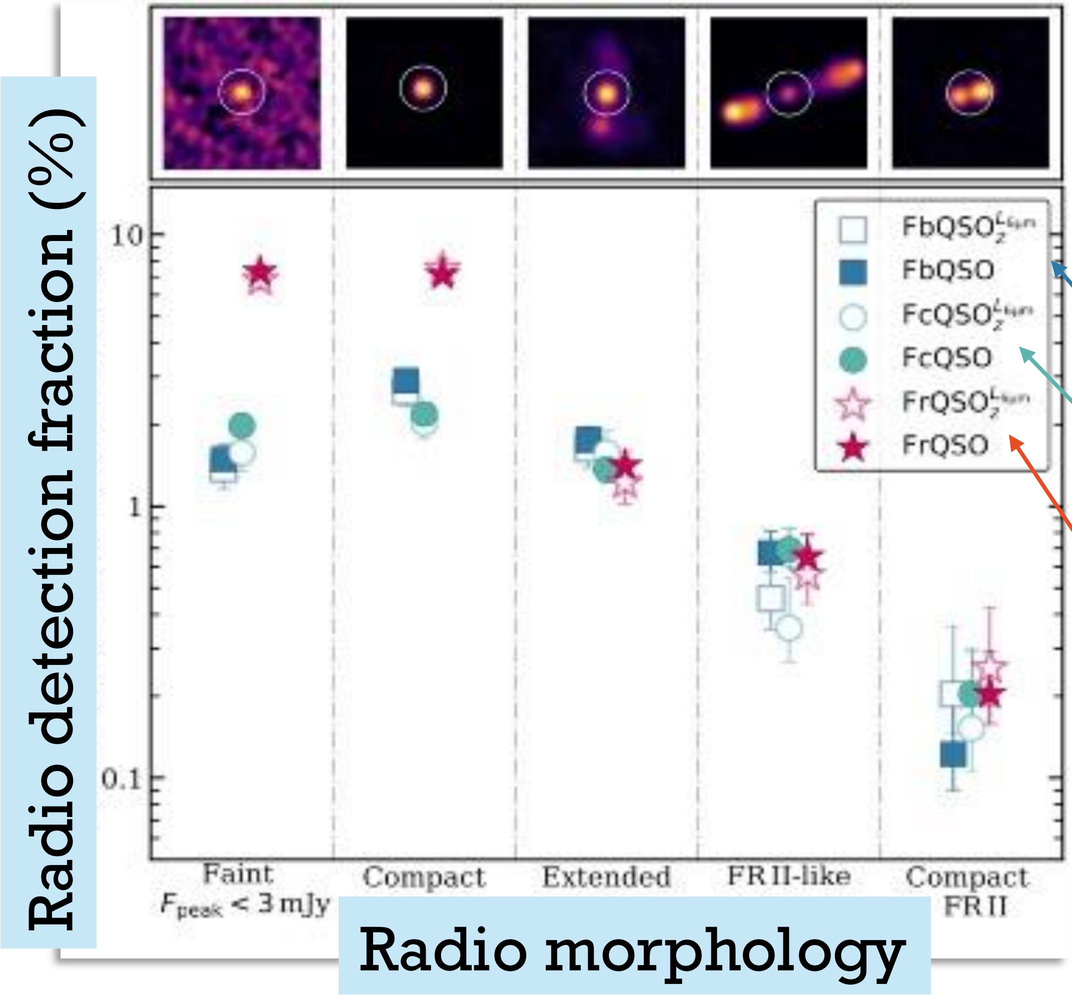
Fawcett +23: Radio detection – opacity connection



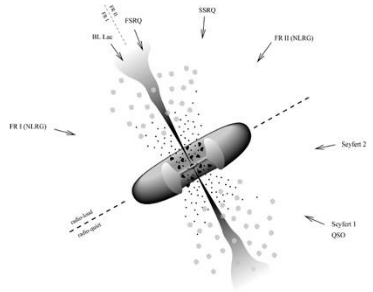
$R = \log(L_{144MHz} / L_{6\mu m}) > -4.5$

- 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



not explained by orientation!



10% bluest g*-i*

middle 10% g*-i*

10% reddest g*-i*

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

Dust-radio connection

Fawcett +23: Radio detection – opacity connection

Klindt +19

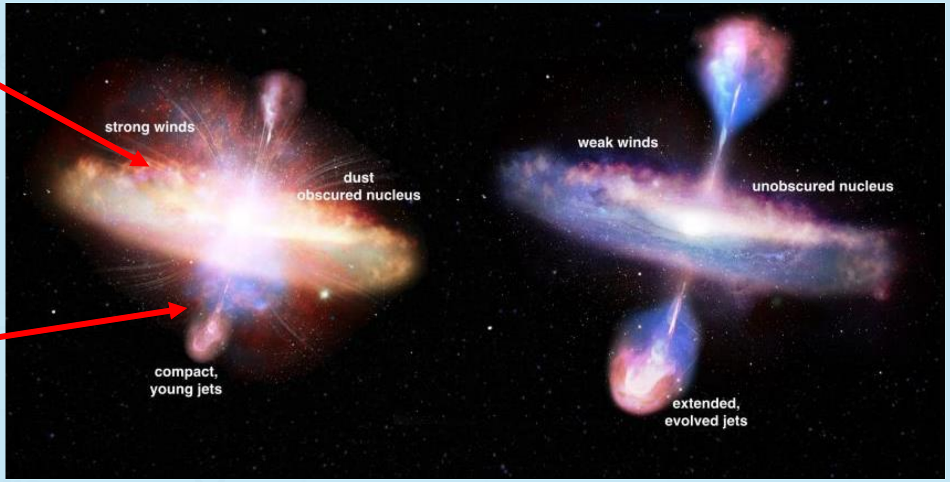
not explained by orientation!

What is causing this excess radio emission?

Shocks due to AGN driven winds?

Low power jets interacting with higher opacity ISM?

Red quasar → Blue quasar

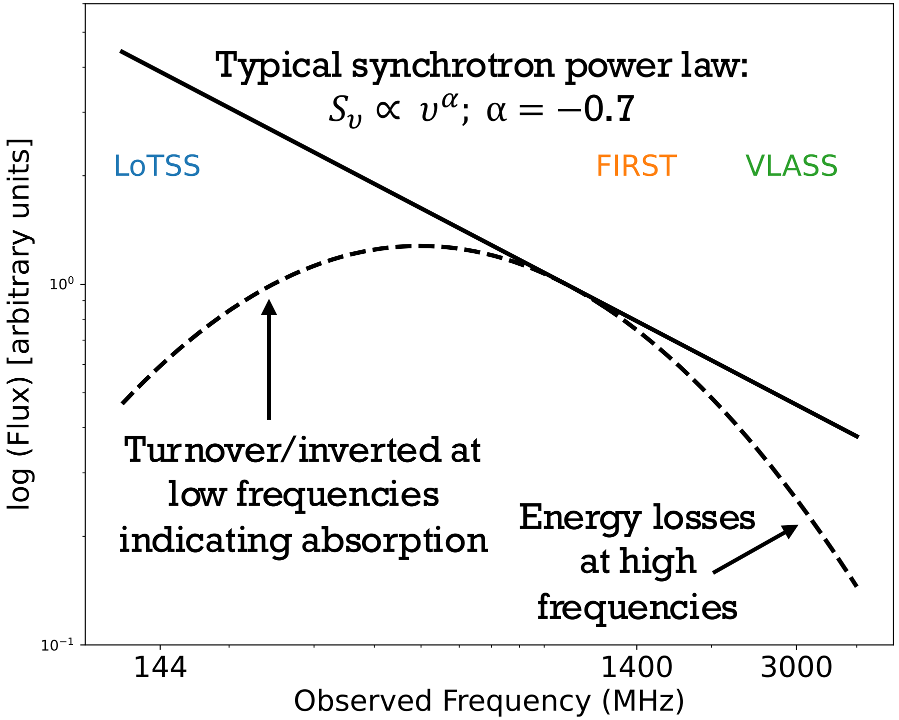


- predominantly due to radio-quiet/intermediate sources

galaxy scale) radio morphologies (eg. Fawcett+20, Rosario+21)

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

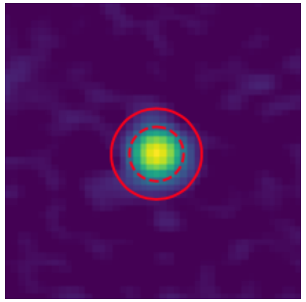


- **Extended low frequency emission – previous episode of activity?**
- **Radio spectral slopes – probe underlying radio emission mechanism**

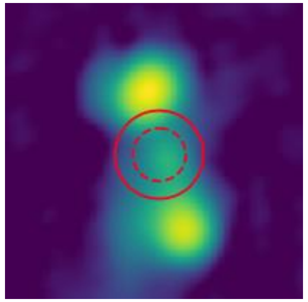
Red quasars more likely to remain compact at all frequencies

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

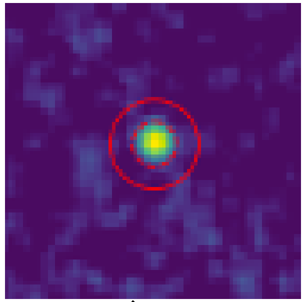
compact



not compact



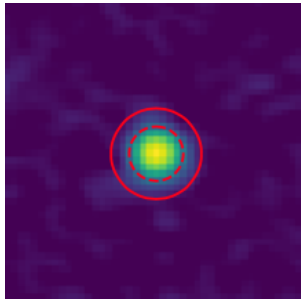
FIRST compact quasars

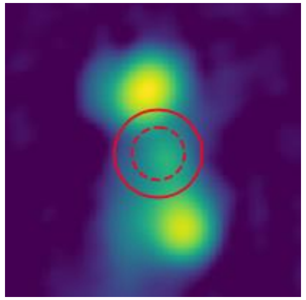


Red quasars detected 2-3x as often as blue

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

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





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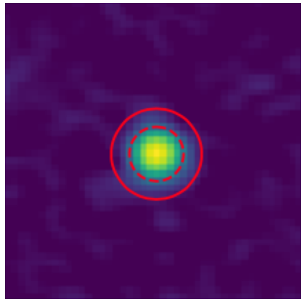

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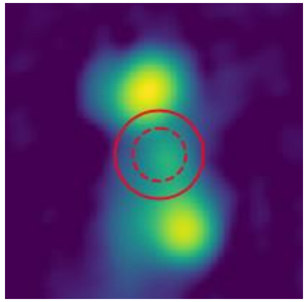

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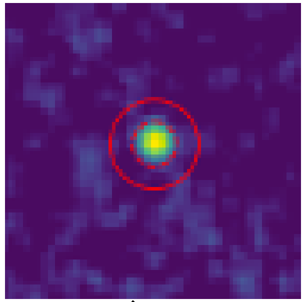

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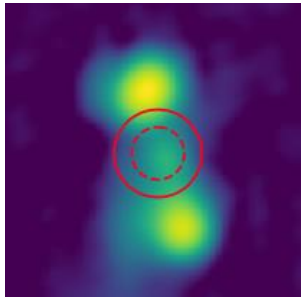
= 83% of FIRST compact red quasars

= 73% of FIRST compact blue quasars



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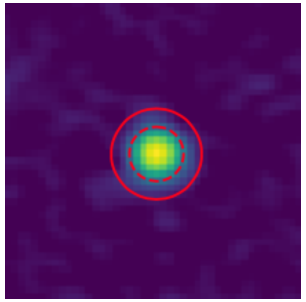
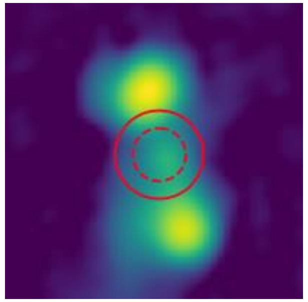


not compact



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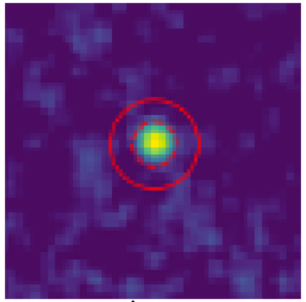

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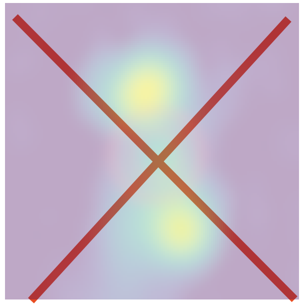


+ LoTSS not compact
= **“fake compact”**

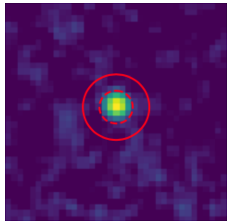
red and blue quasars detected at **similar** rates

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

+



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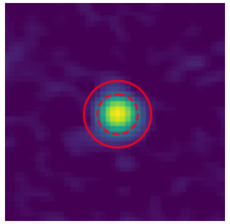
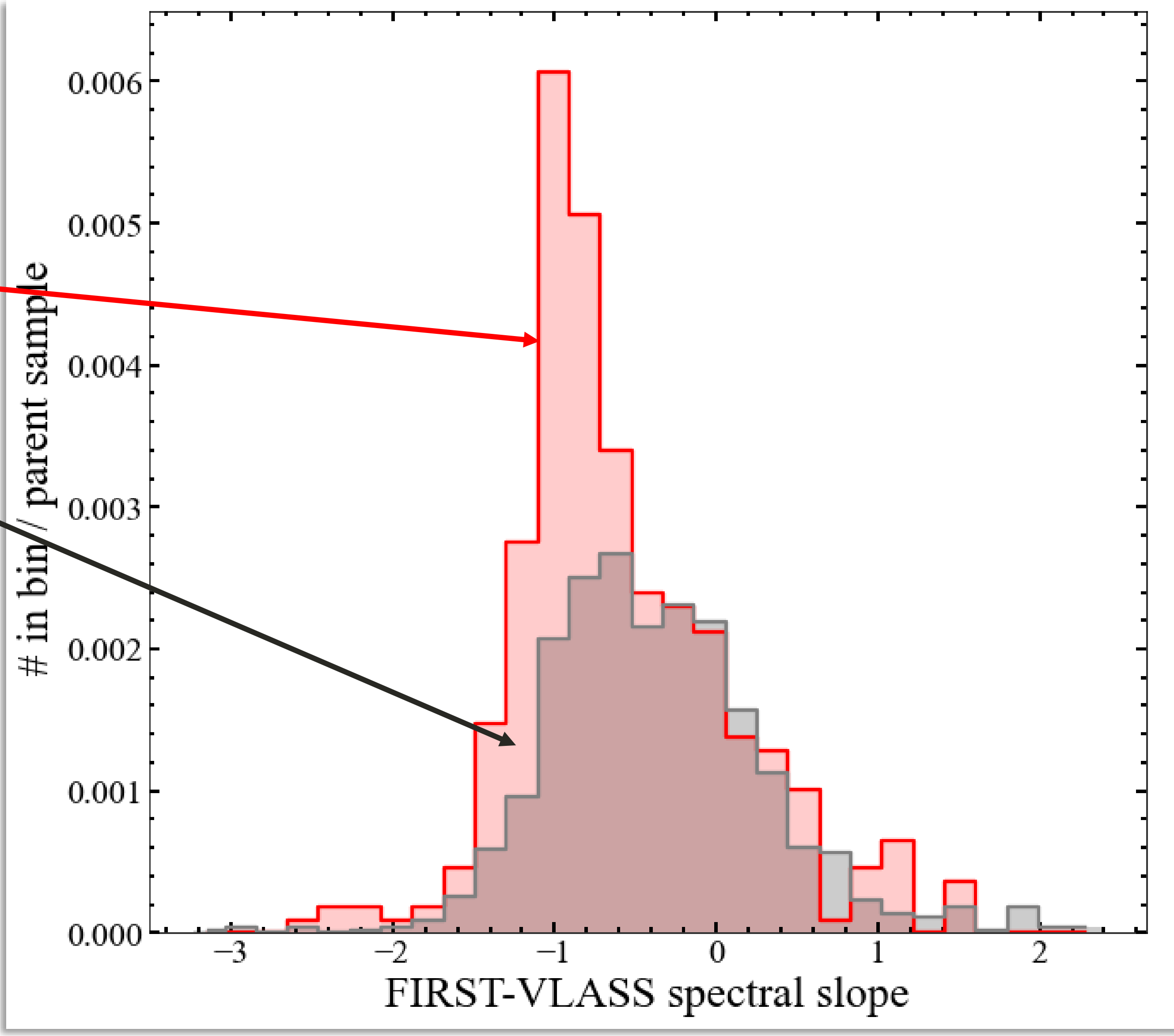


all other classifications: consistent distributions



Steep radio spectral slopes in truly compact red quasars

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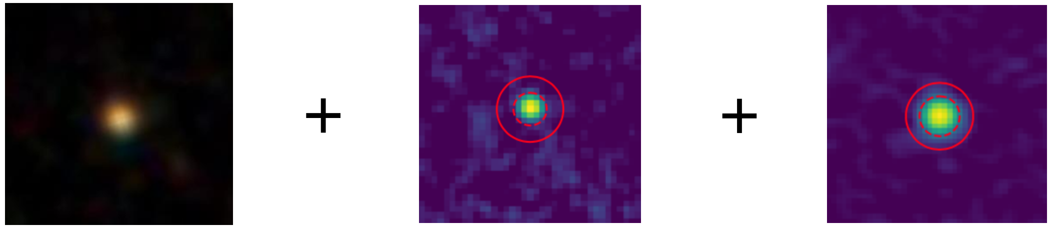

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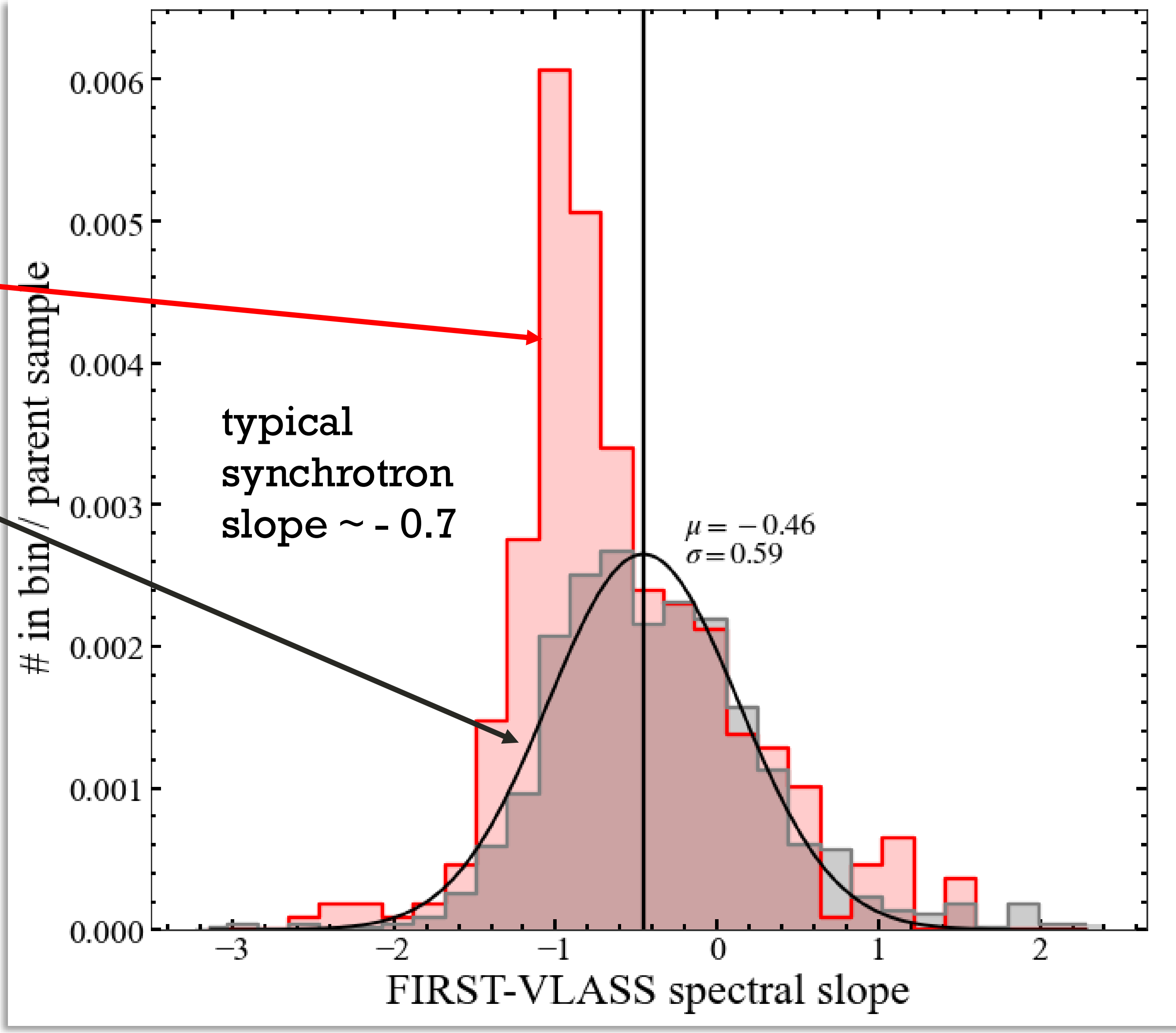
- fake compact red quasars have similar spectral slopes to typical (FIRST compact) blue quasars



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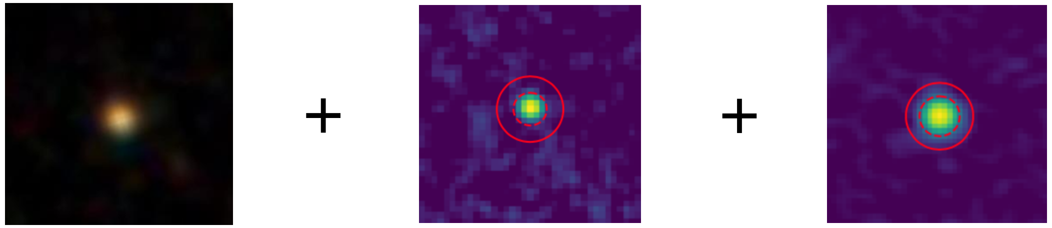

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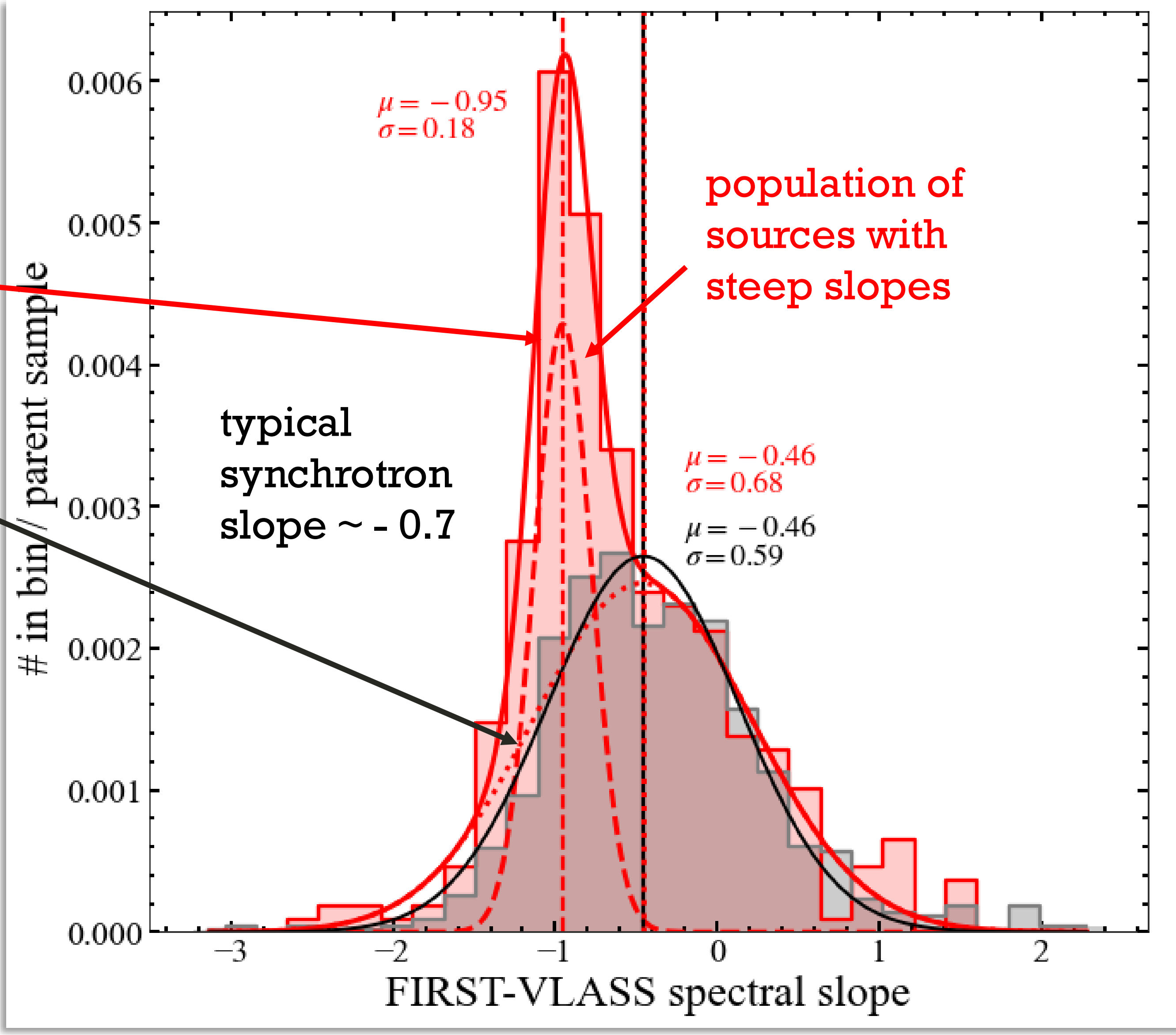


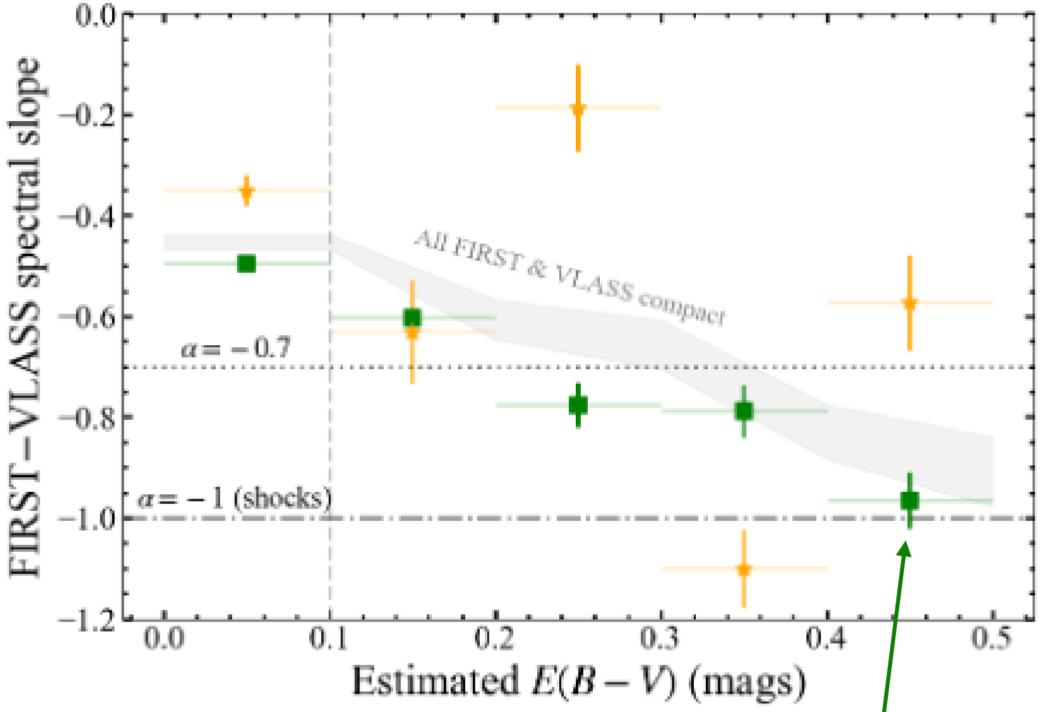
- fake compact red quasars have similar spectral slopes to typical (FIRST compact) blue quasars

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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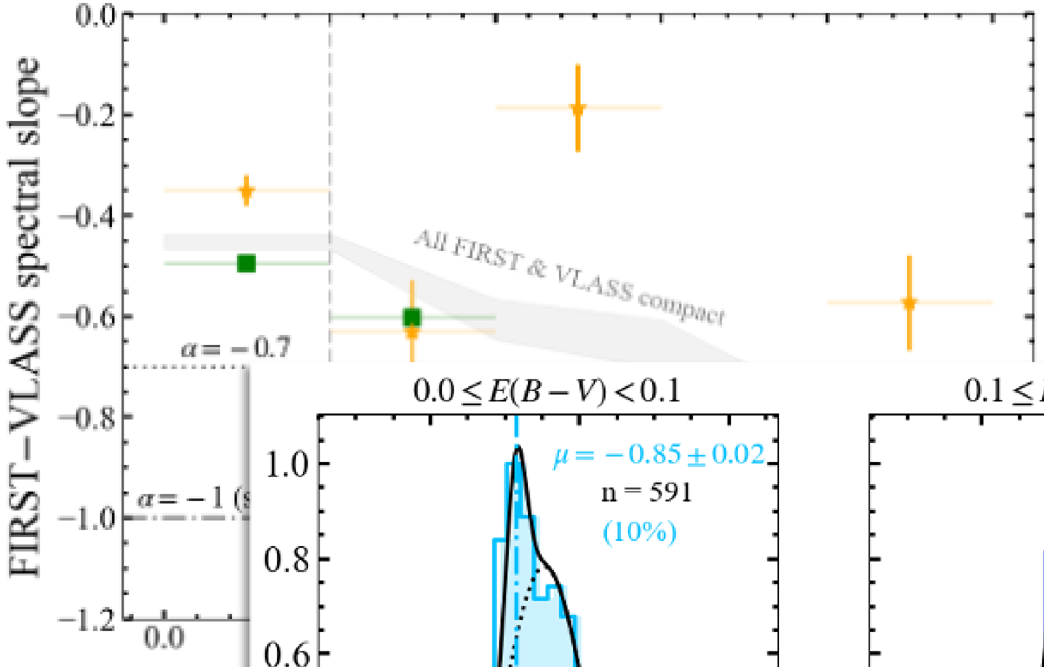


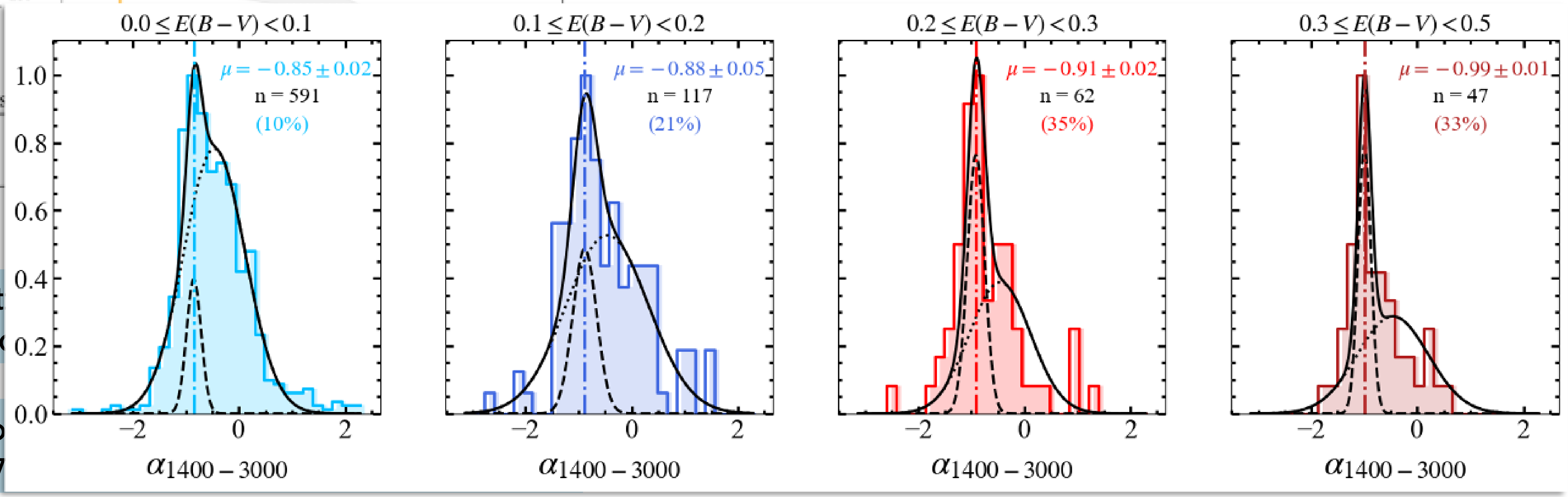
Spect
truly

Radio
E(B-V

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. $\alpha \approx -1$



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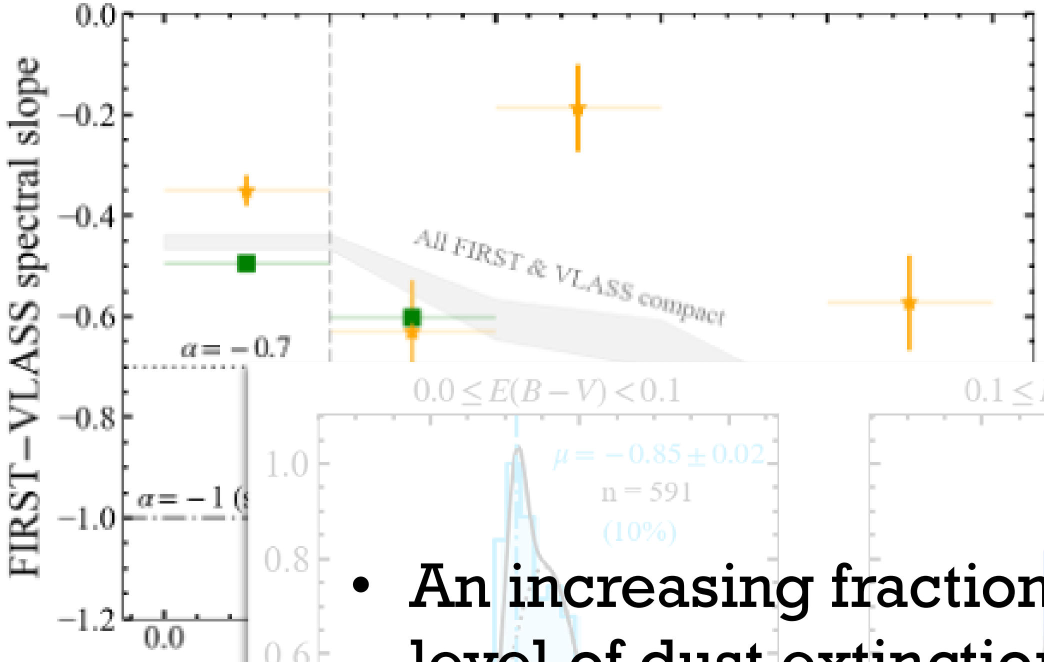


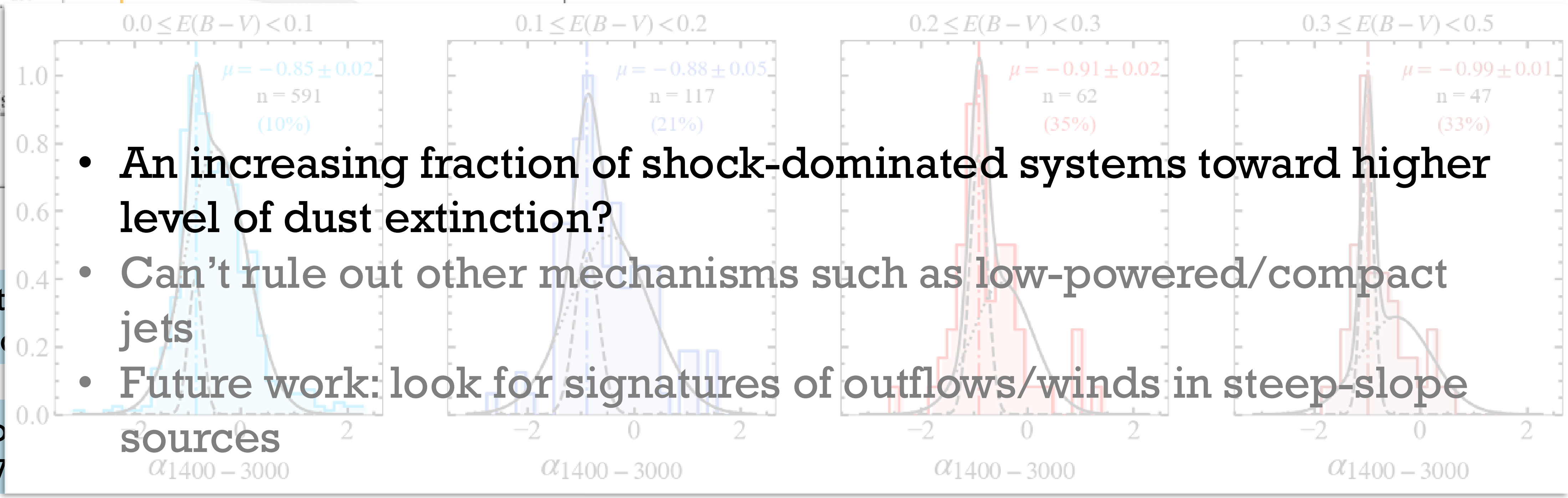
Non-thermal emission from electrons accelerated by an AGN wind shock (Nims+15):

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

νL_ν ~ constant → $L_\nu \propto \nu^{-1}$ ie. $\alpha \approx -1$

Spect...
truly ...

Radio...
E(B-V...



- **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

The future with SKAO

- SKA – southern sky:
  - will overlap 4MOST IR AGN survey – extend work to more obscured systems
- ultimately (with SKA1-mid) will cover greater range of frequency- fill gaps in radio SED
- further constrain origin of the compact radio emission

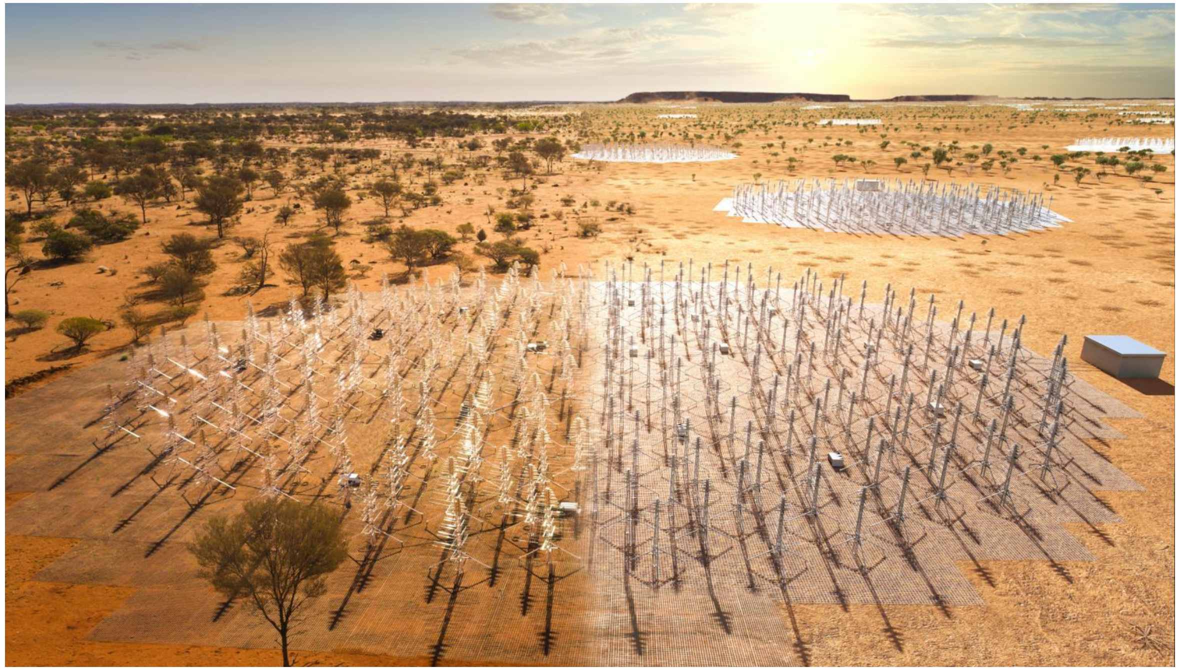
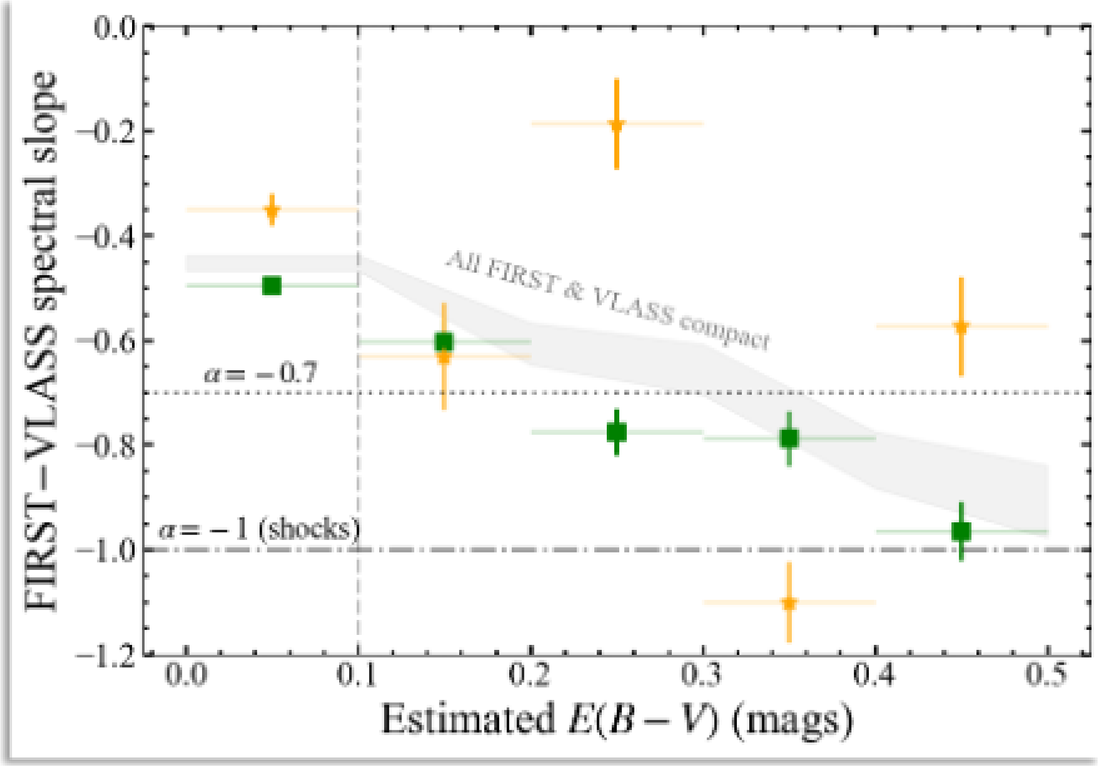
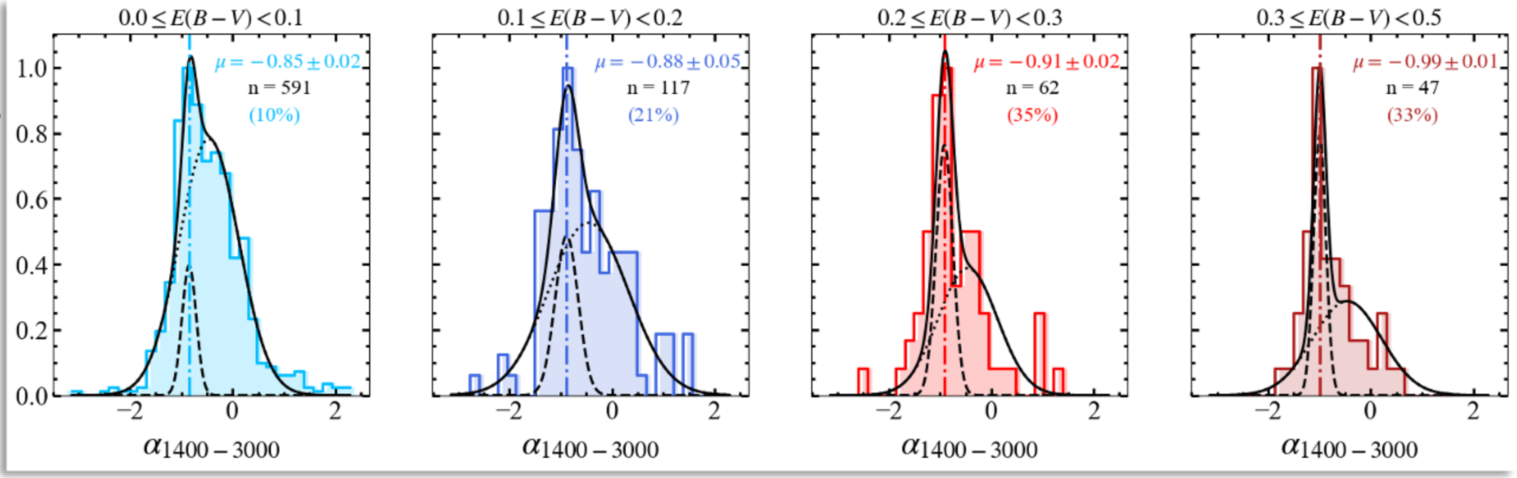


Image credit: SKAO

Summary

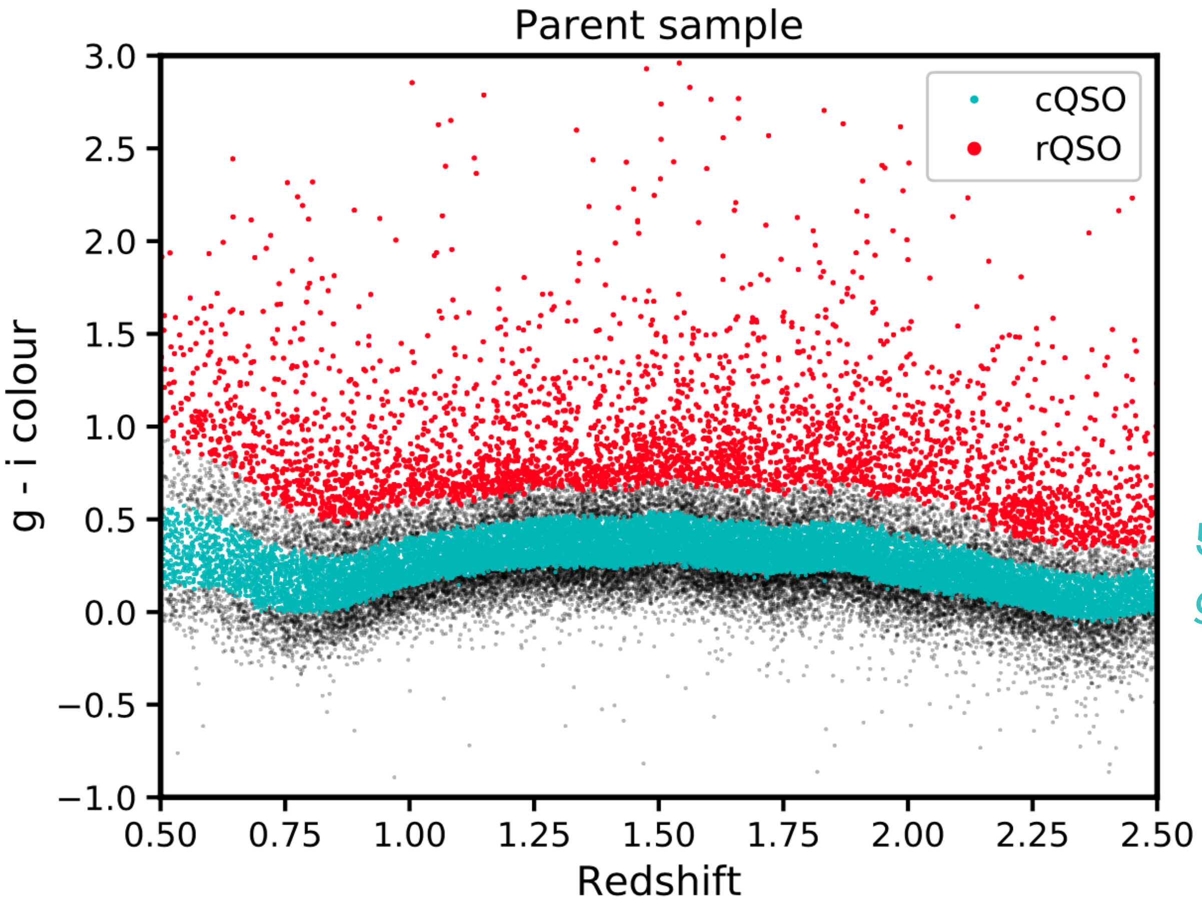
- There is a connection between dust and radio spectral slopes/detection rates in quasars
- The radio-dust connection in red quasars is mostly driven by systems with unresolved radio emission in both FIRST (1.4 GHz) and LoTSS (144 MHz)
- These "truly compact" red quasars contain a population of sources with steep radio spectral slopes of α~-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 & control colour selection

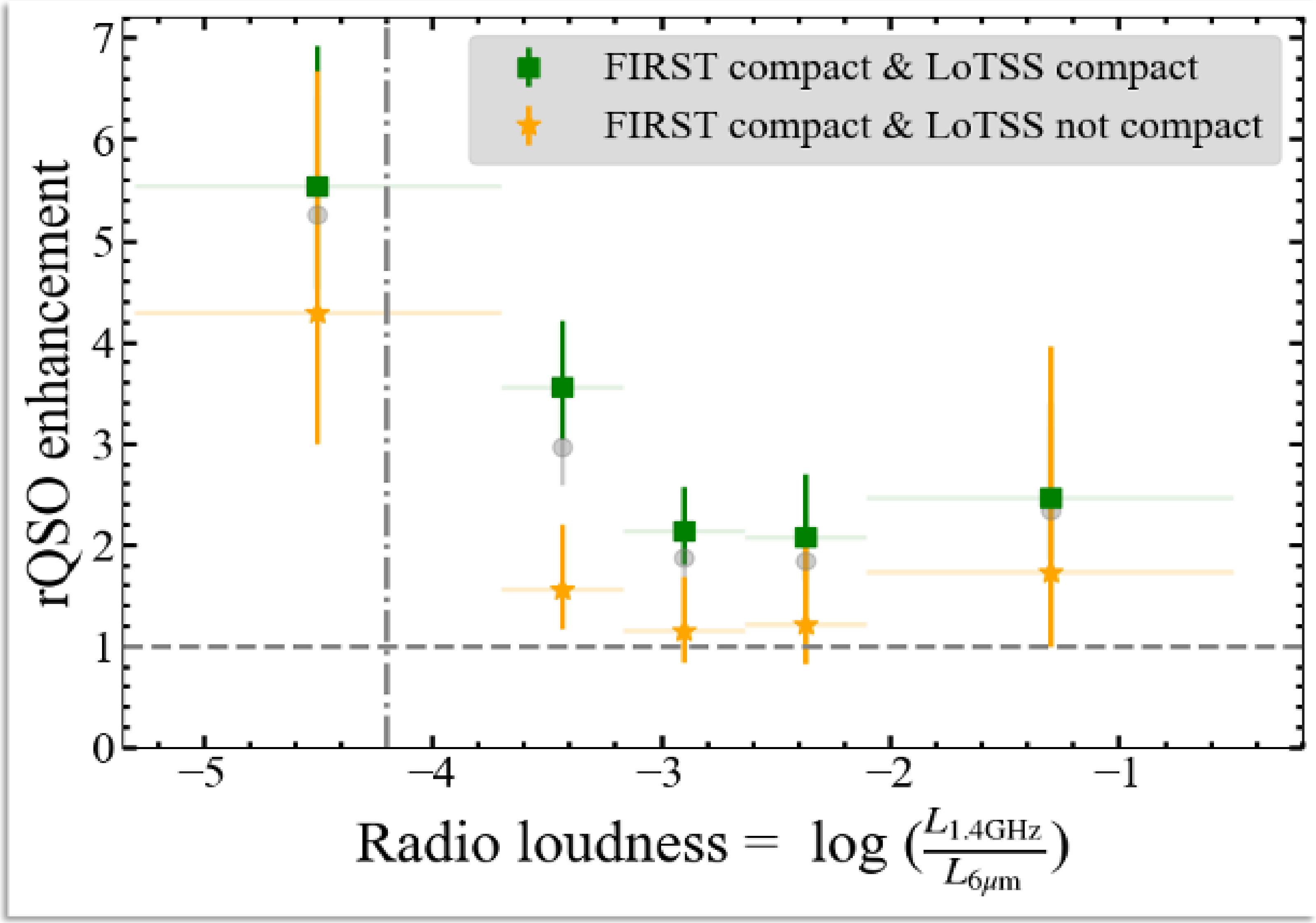


SDSS optically selected red and blue/control quasars (0.2 < z < 2.4) from Fawcett+2022:

top 10% *g*-i**

50% around median *g*-i**

Radio loudness



Ciera Sargent (ciera.l.sargent@durham.ac.uk)

Radio-dust connection for truly compact quasars only

- Fawcett+23: radio-detection fraction increases with E(B-V)
- Fawcett+25: weak but significant trend of steepening radio spectral slope with E(B-V)
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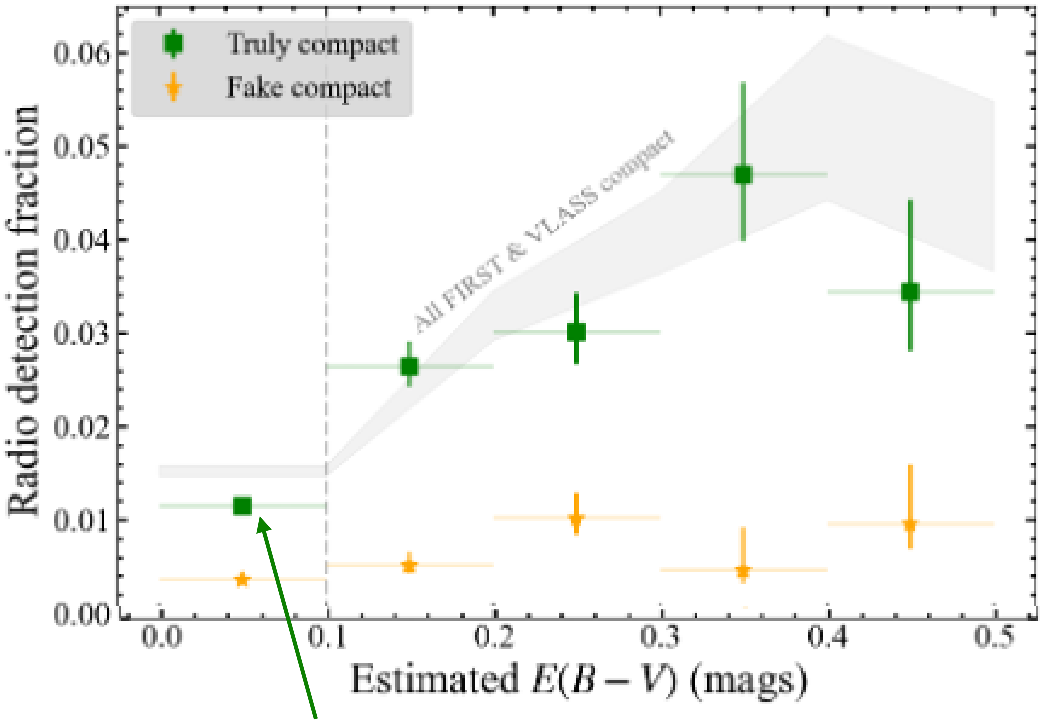
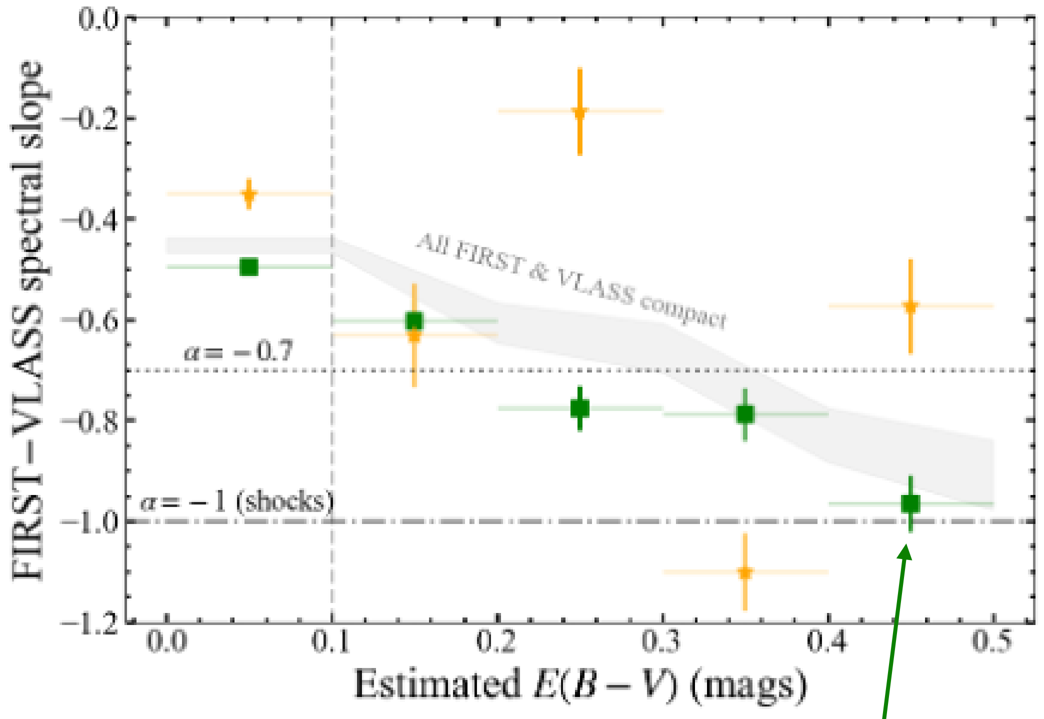


Radio-detection rate connected to E(B-V) for truly compact quasars only

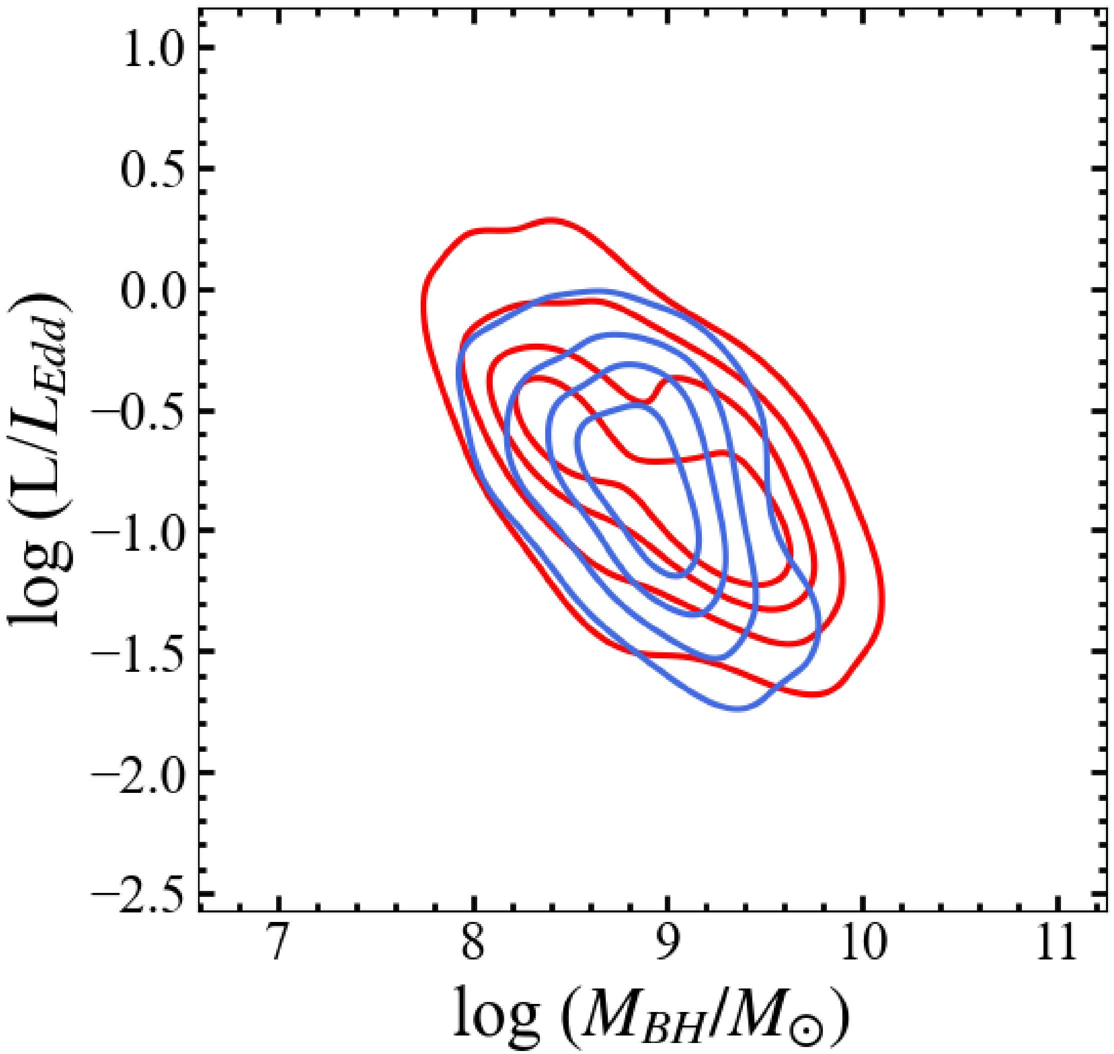


Spectral slope steepens with E(B-V) for truly compact quasars only

What is the physical meaning for this correlation?

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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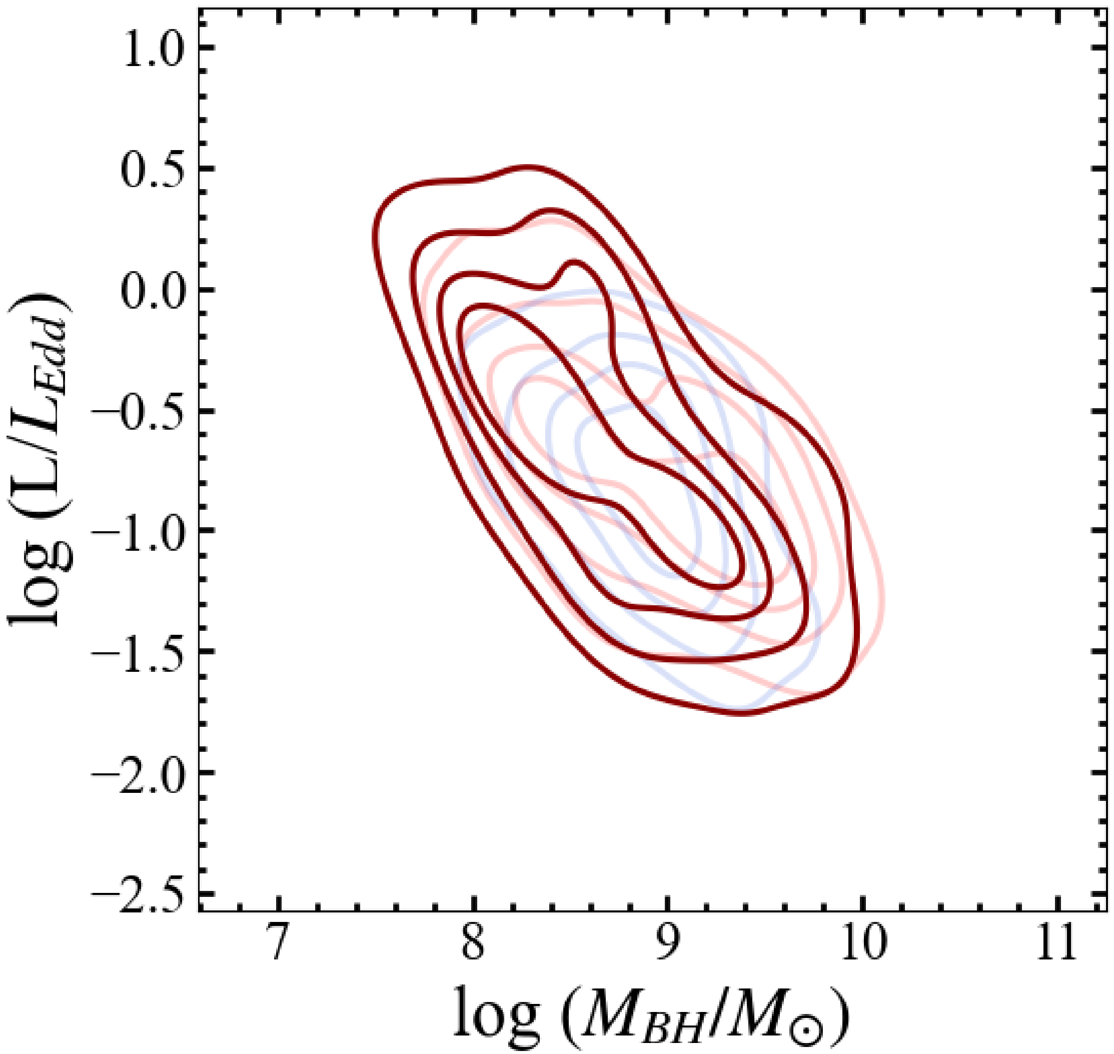
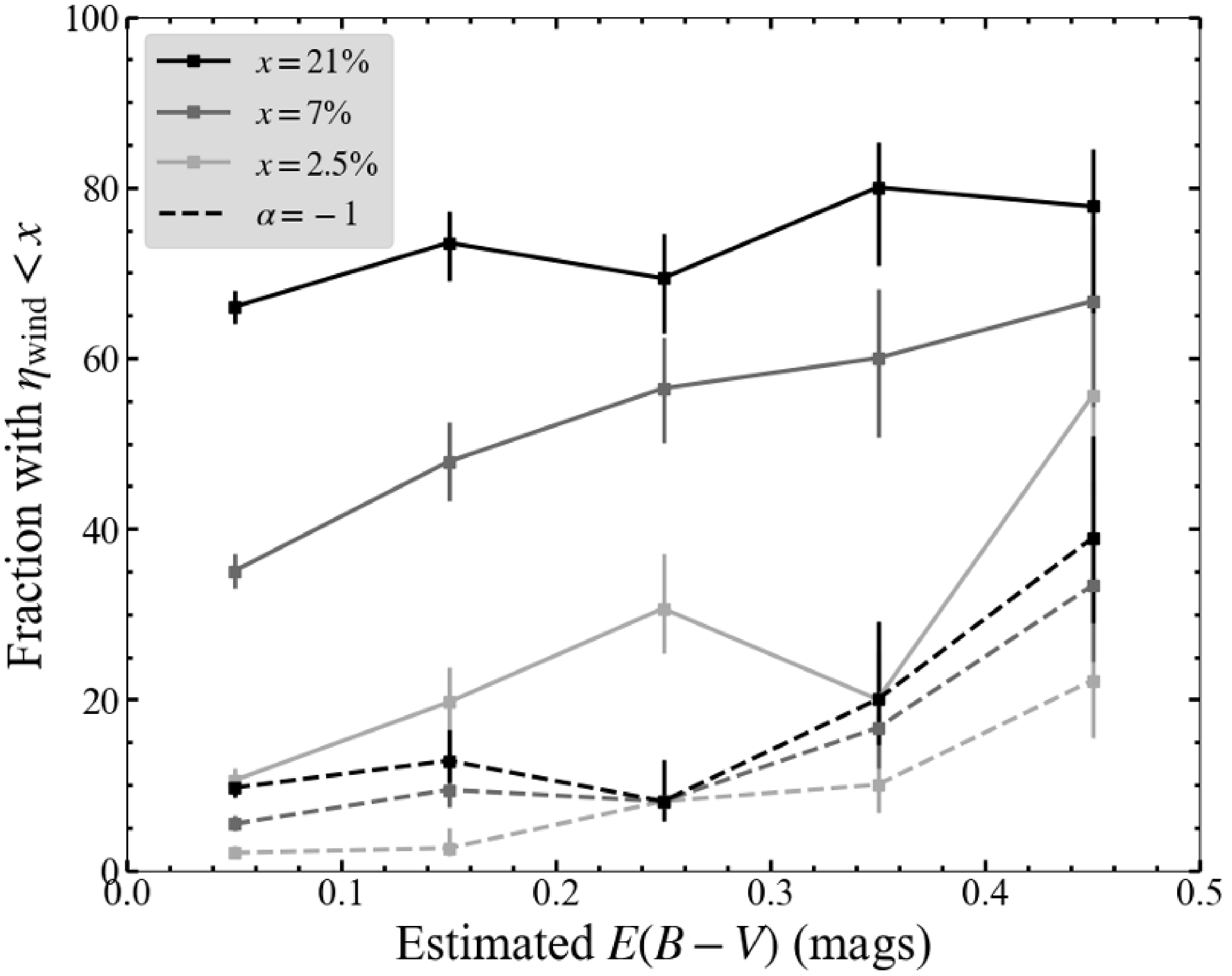
- Rakshit+2020 BH mass and luminosity values – corrected for E(B-V)
- no strong difference in L/Ledd
- BH mass distributions different
- Steep truly compact red quasars: less massive BHs and higher Eddington ratios?



Wind efficiencies



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

Evidence for shocks?

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

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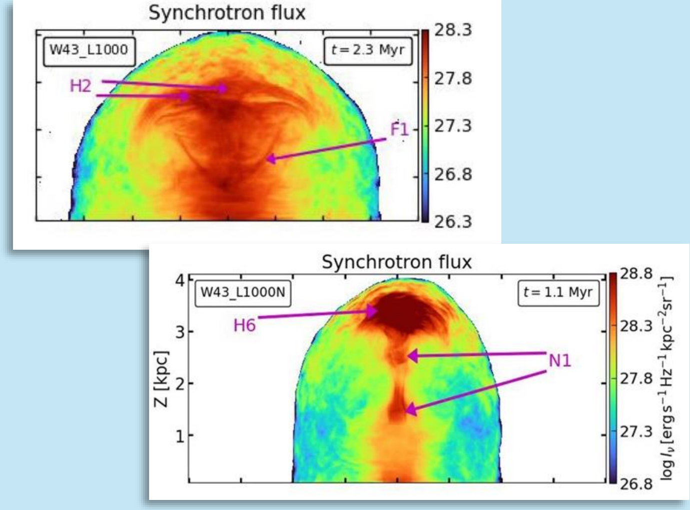
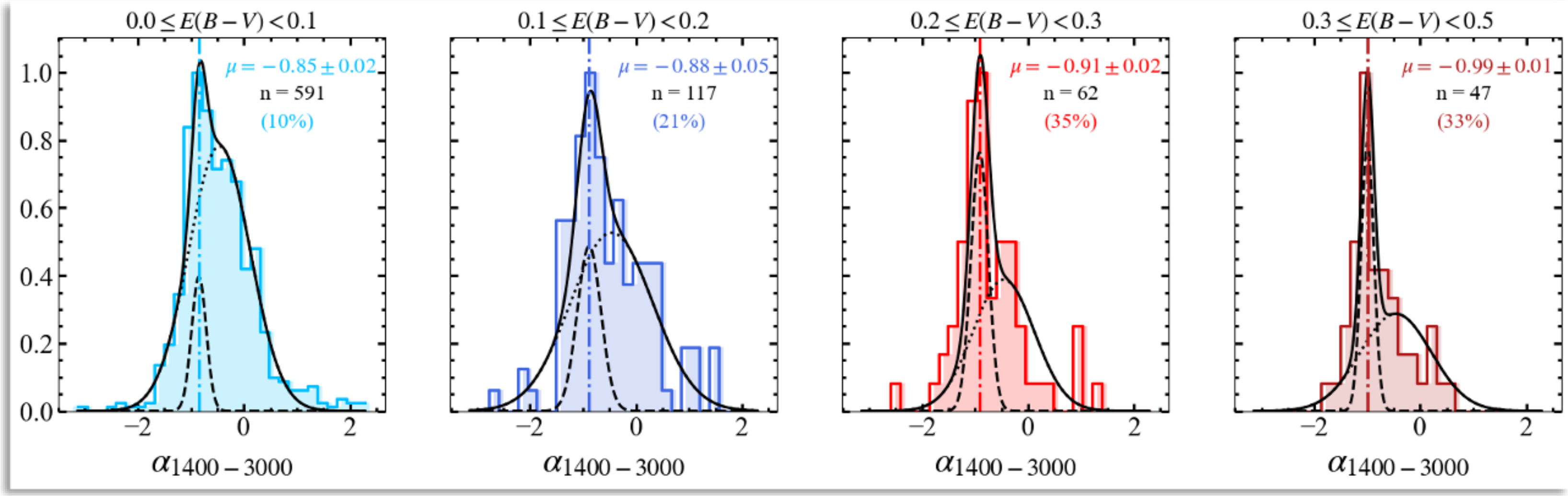
$\nu L_\nu \sim$ constant $\rightarrow L_\nu \propto \nu^{-1}$ ie. $\alpha \approx -1$

- An increasing fraction of shock-dominated systems toward higher E(B-V)?
- A wind driven shock can't explain all cases (mostly the radio-loud)

Jet vs. wind simulations (Meenakshi+24):



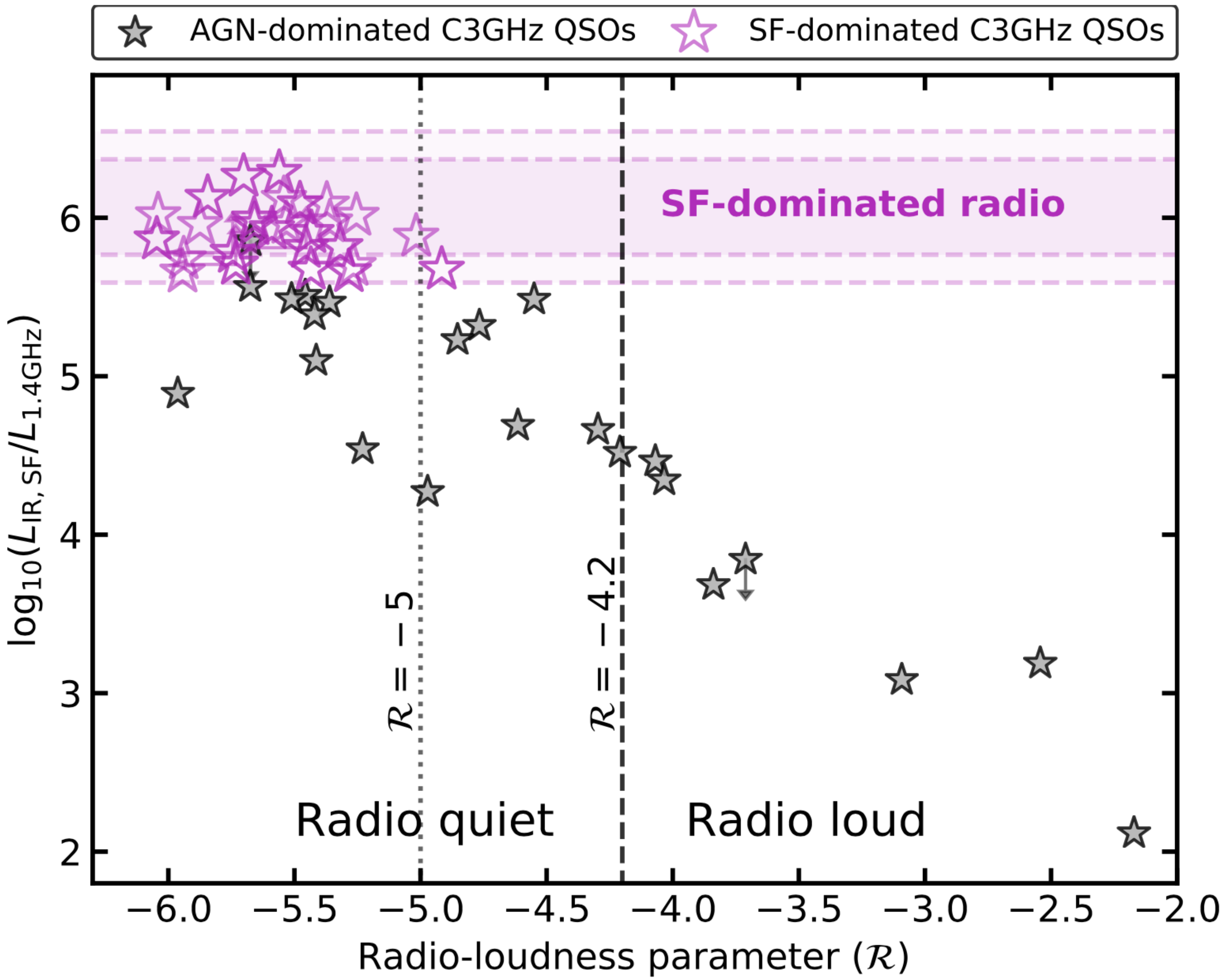
Meenakshi+ (in prep.):
- integrated spectral slope (1.4-3 GHz) steep ($\alpha \approx$ - 0.9 to -1) for low-density winds
- jets produce expected $\alpha \approx$ - 0.7



An intrinsically different injection index?

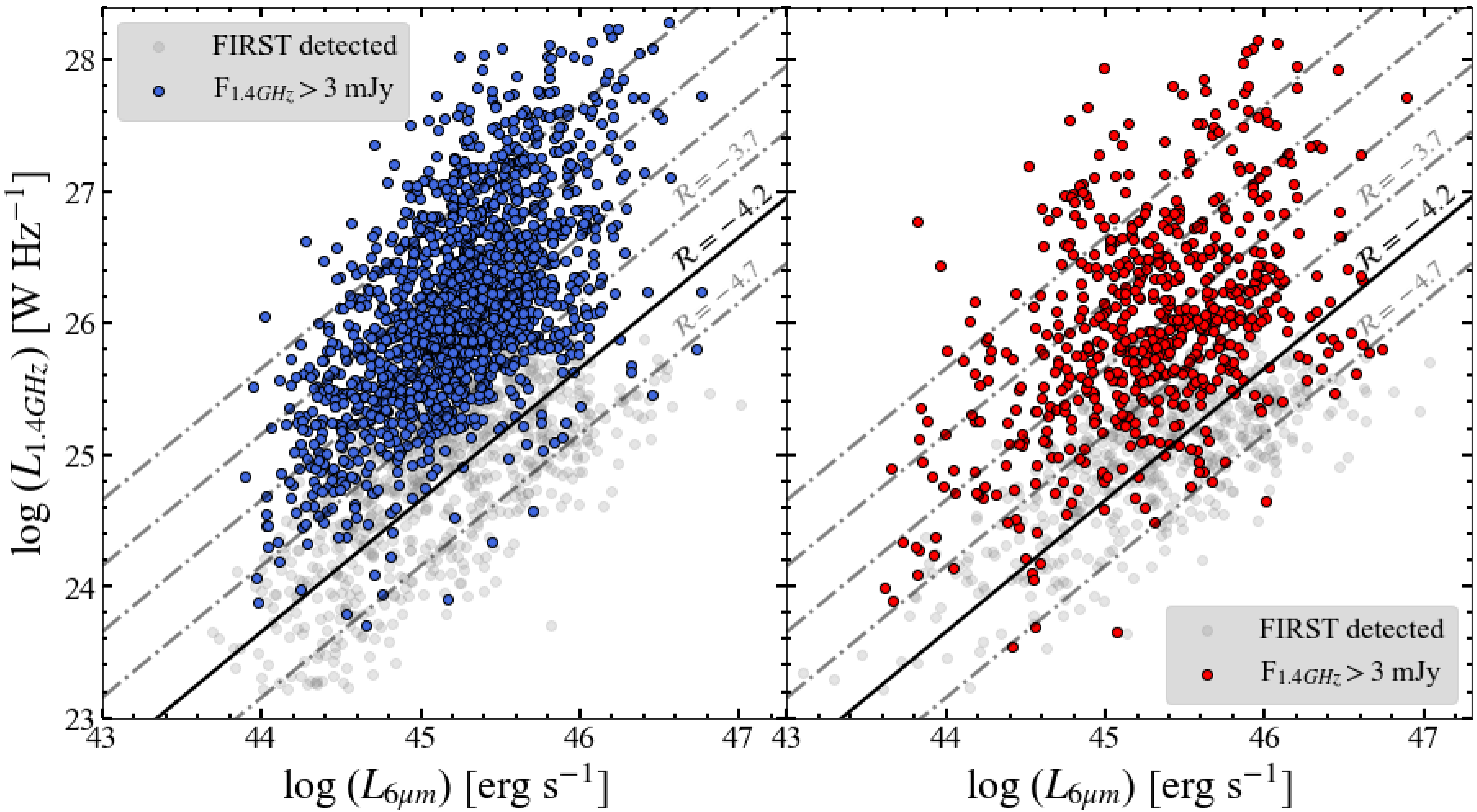
Analogous to USS sources?
- denser ambient medium at higher z alters electron injection index at shock to be steeper (eg. Athreya & Kapahi 1998)

What about star-formation?



- Fawcett+20
- no differences in SF properties of red and blue quasars (Calistro Rivera+21)
- Yue+24: radio excess in red quasars due to AGN-processes

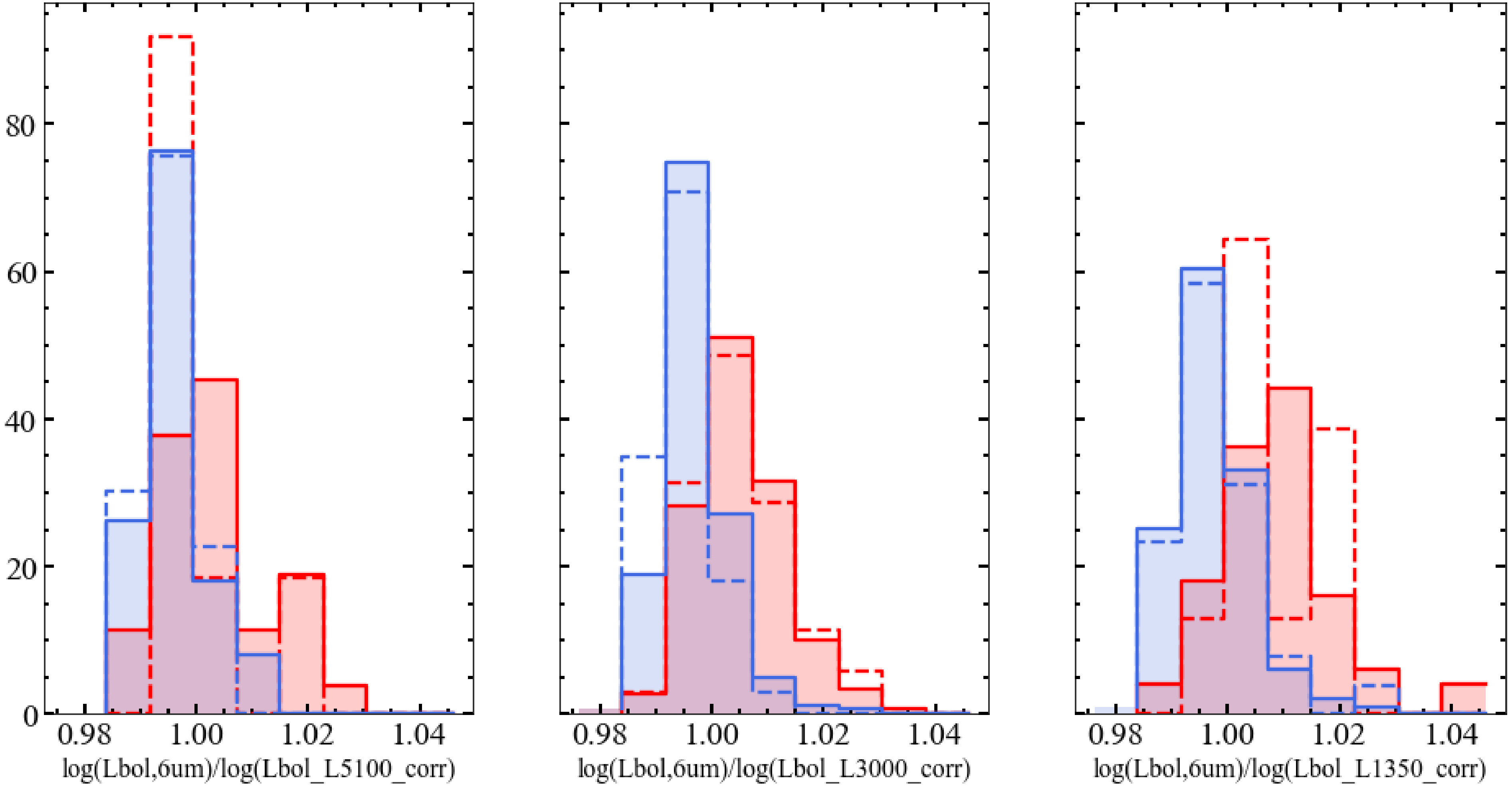
Radio-loudness

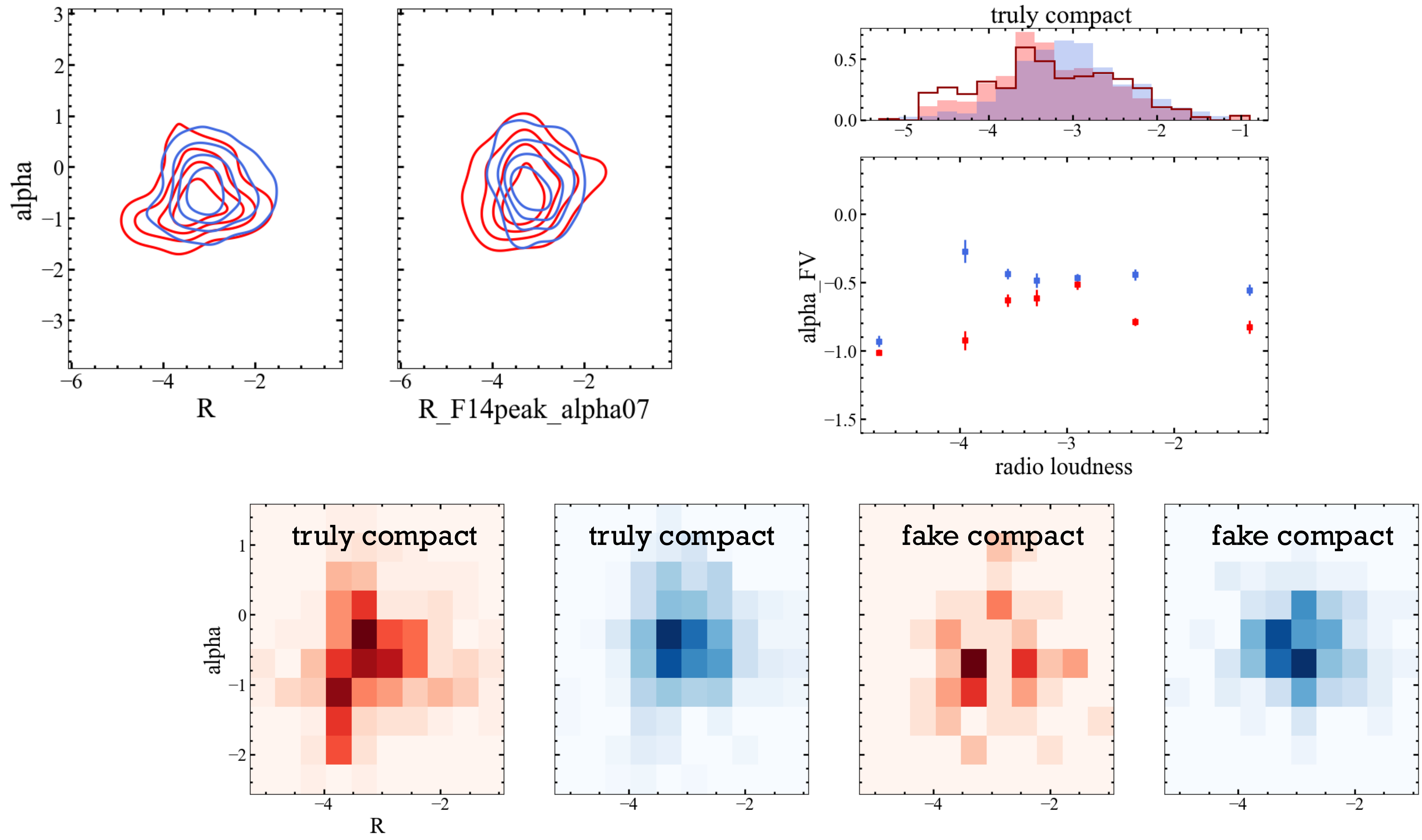


defined here as
R = log(L1.4GHz/L6)

MIR excess

Preliminary



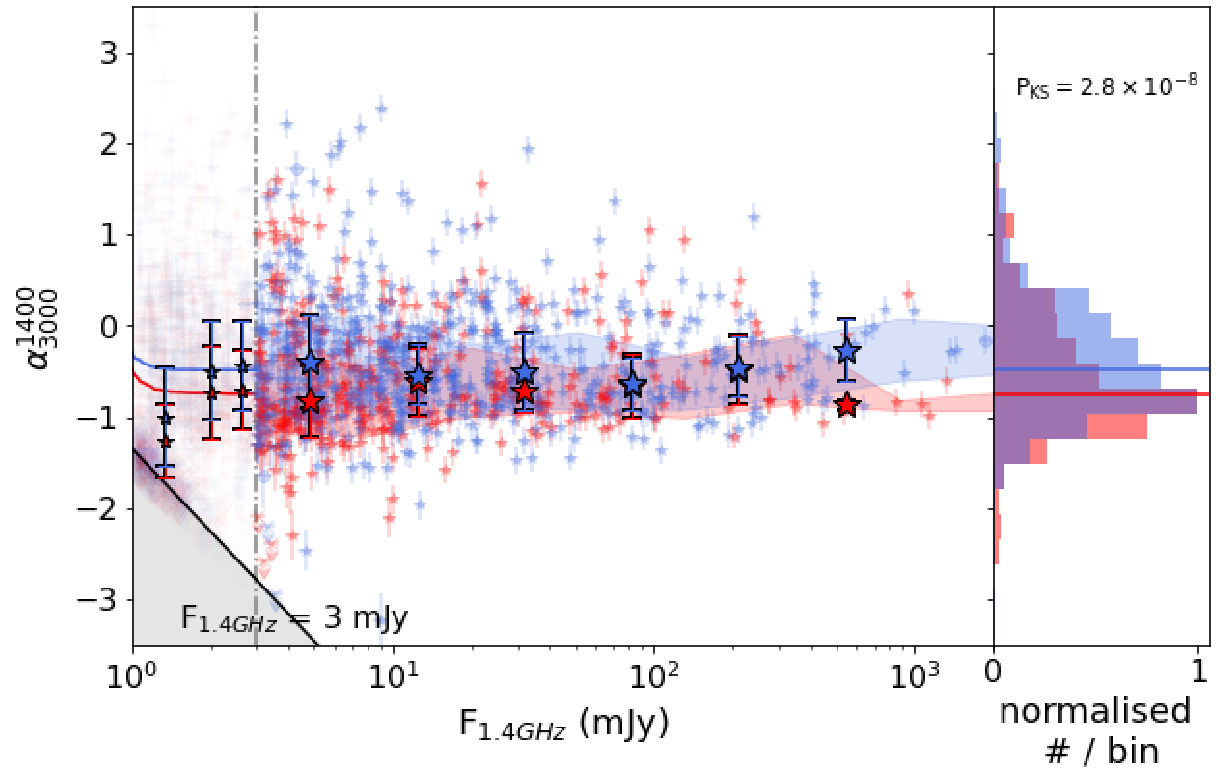

alpha
R
R_F14peak_alpha07
truly compact
radio loudness
alpha_FV
truly compact
truly compact
fake compact
fake compact
alpha
R

alpha vs flux

FIRST-VLASS:

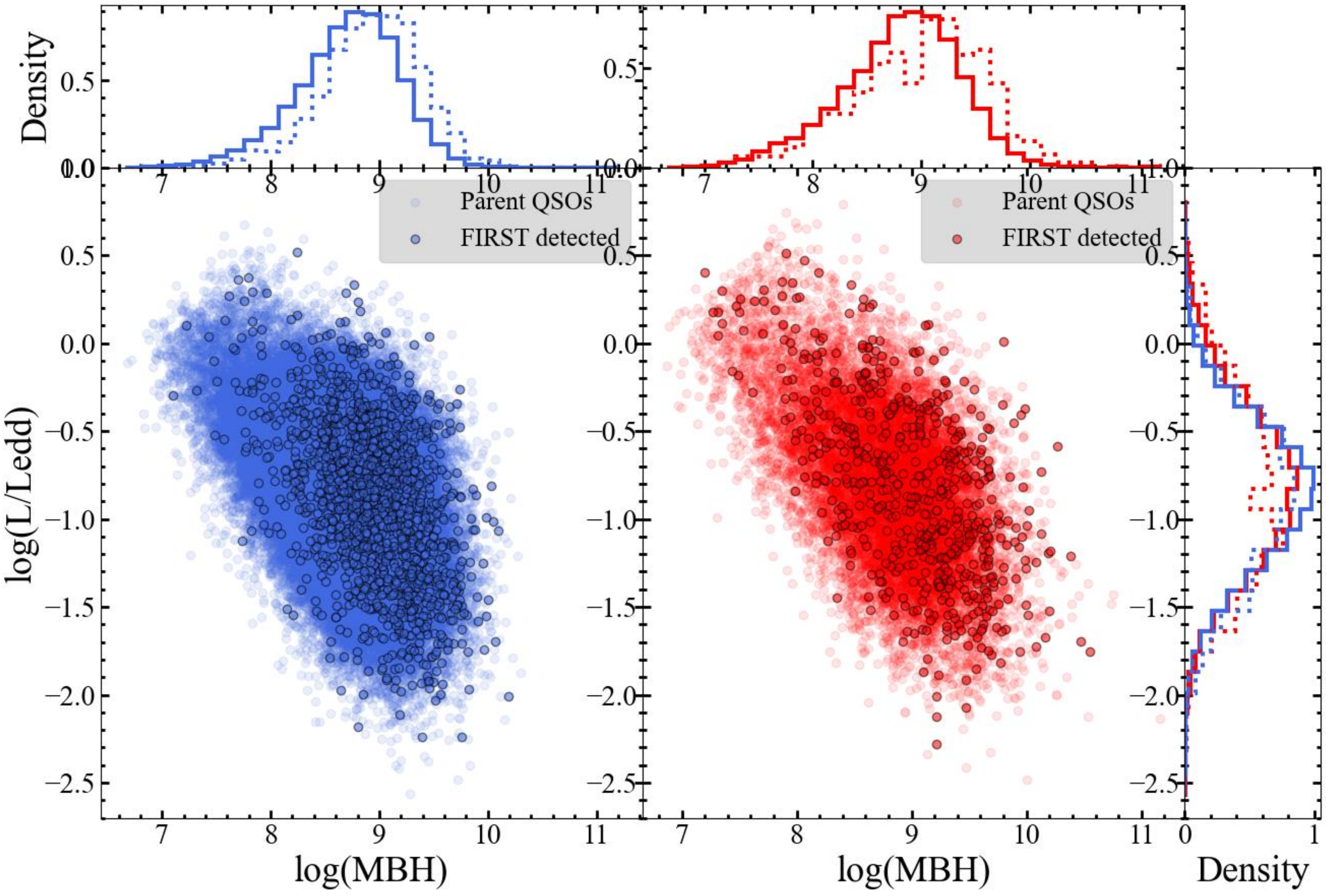
Red quasars median slope = -0.75 ± 0.02

Blue quasars median slope = -0.48 ± 0.02



Preliminary

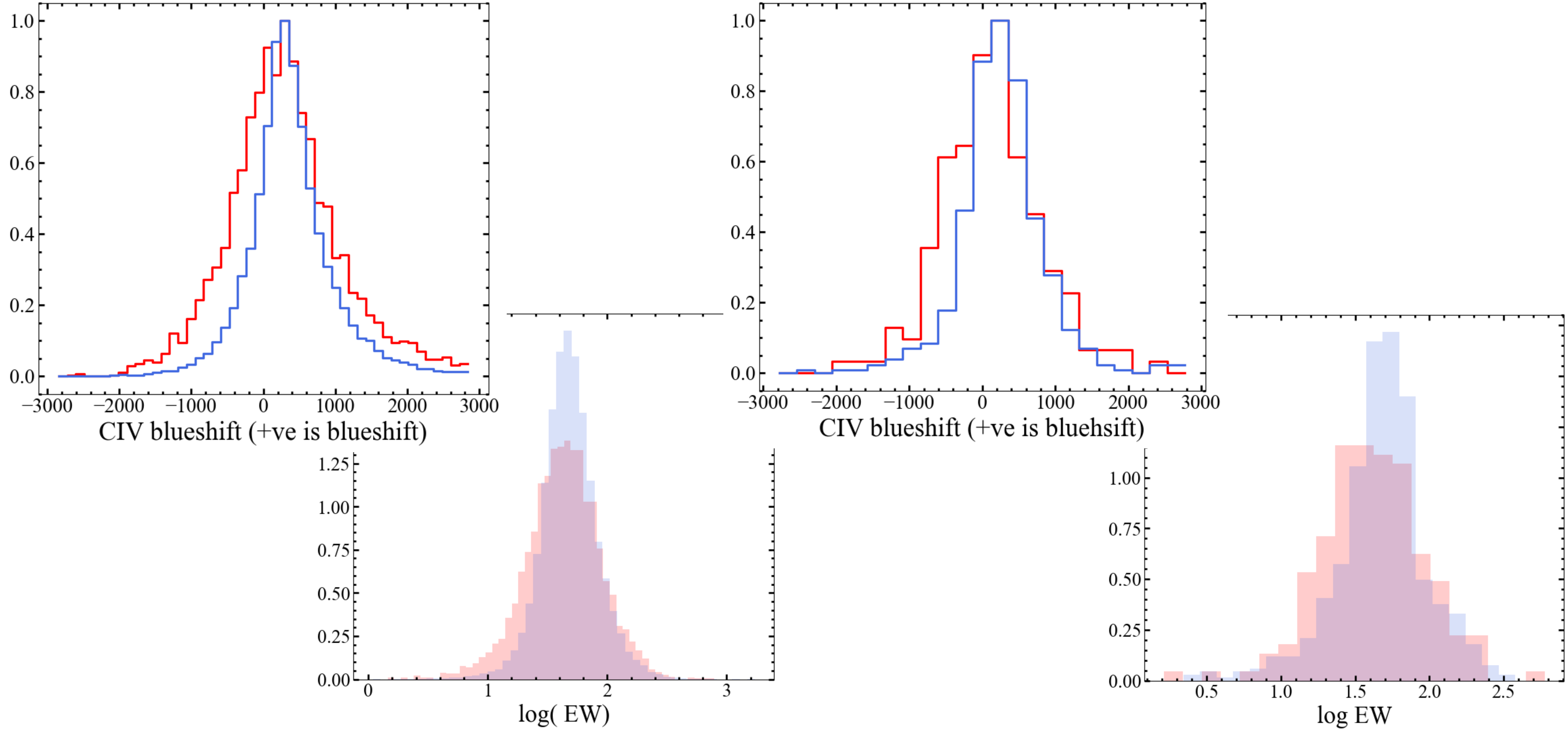
L/Ledd - MBH plane



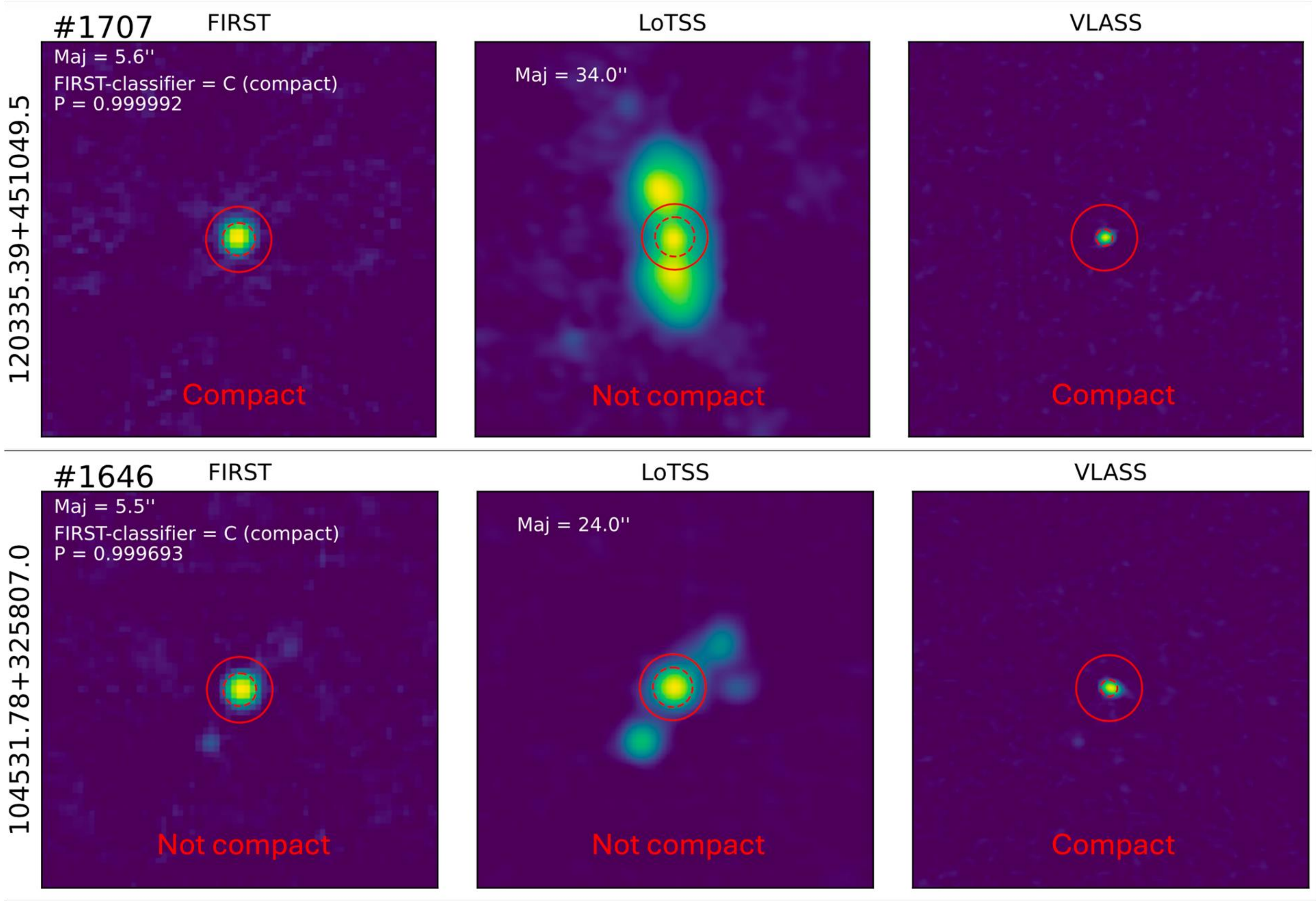
CIV blueshifts and EW (v. preliminary)

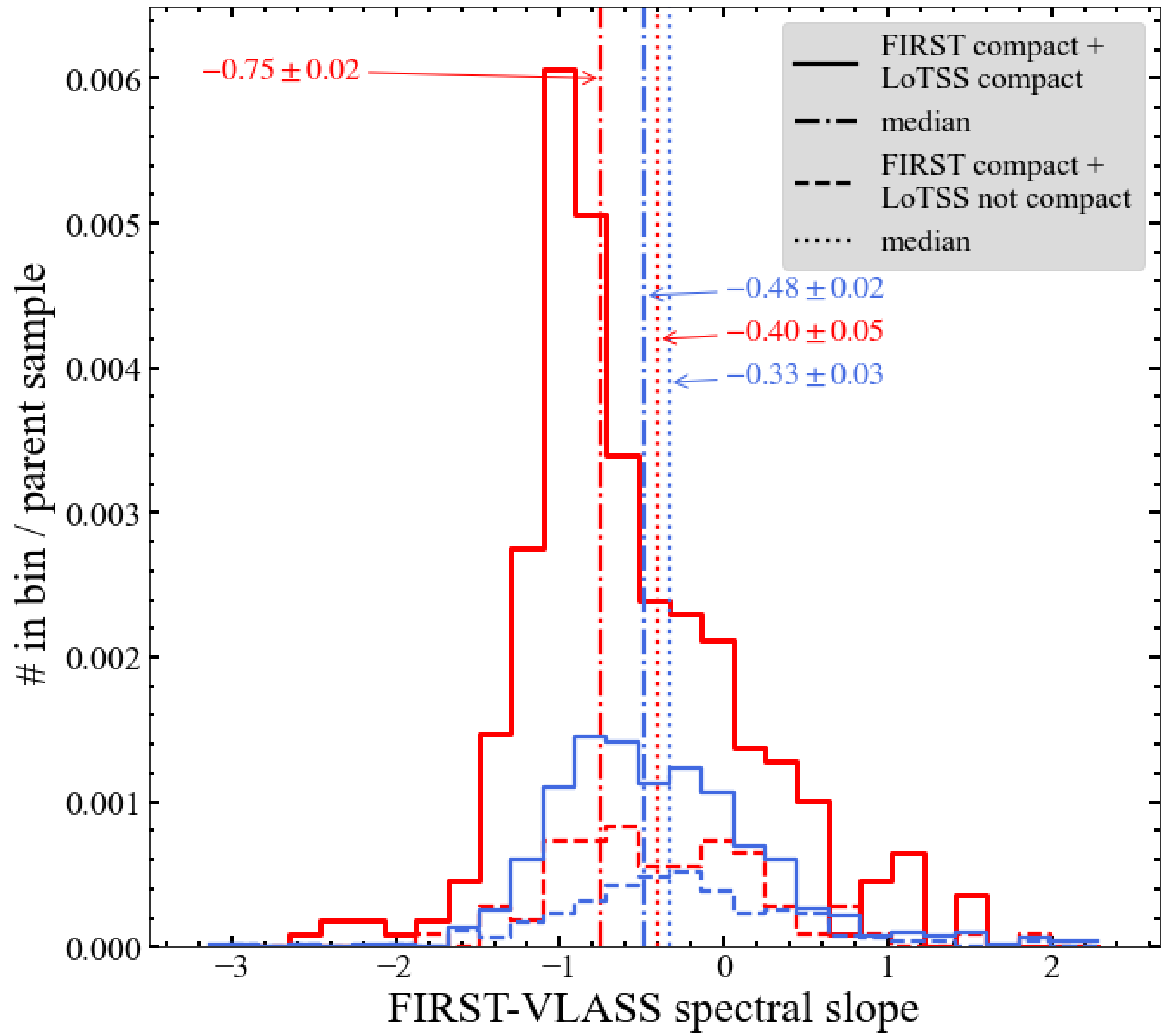
parent:

radio detected:



visual inspection





−0.75 ± 0.02
−0.48 ± 0.02
−0.40 ± 0.05
−0.33 ± 0.03
FIRST compact +
LoTSS compact
median
FIRST compact +
LoTSS not compact
median
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