Are dusty QSOs in a blow-out phase?

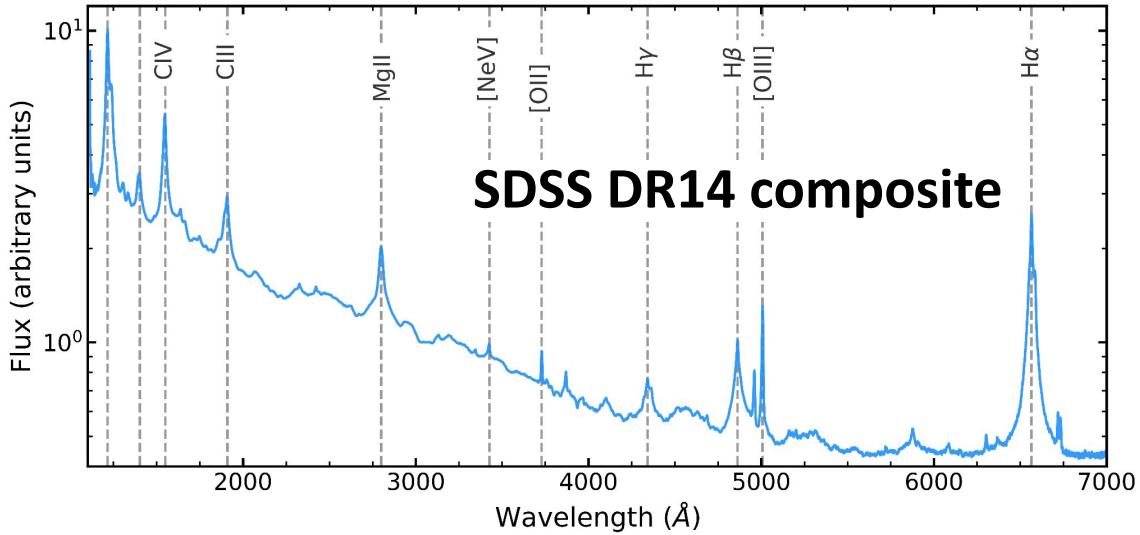
Vicky Fawcett

Chris Harrison, Dave Alexander, David Rosario, Gaby Calistro Rivera, Preeti Kharb, Leah Morabito, & friends

Newcastle University

Quasars

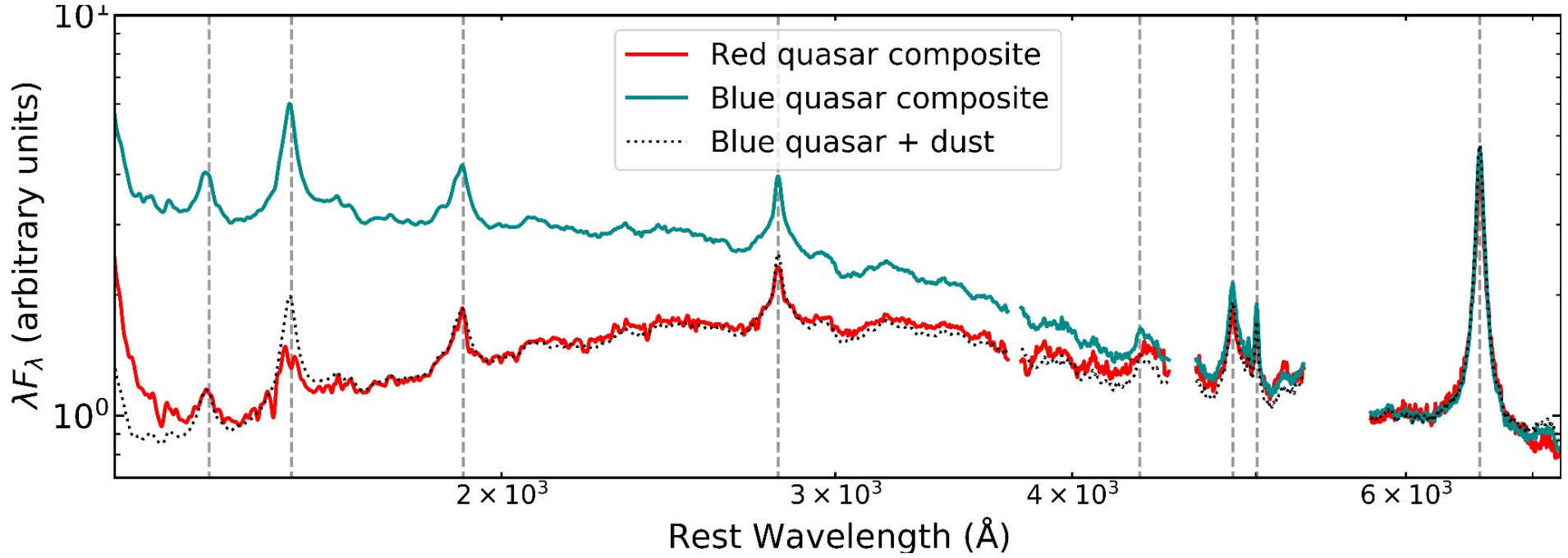
- Quasars, also known as quasi-stellar objects (QSOs), are extremely luminous active galactic nuclei (AGN)
- The majority of the quasar population have blue optical colours, typically due to an unobscured view of the accreting supermassive black hole



Credit: NASA, ESA and J. Olmsted (STScI)

Red Quasars

- However, an important fraction have much redder colours coined “red QSOs”
  (e.g., Webster+1995; Richards+2003; Glikman+2007; Banerji+2015; Klindt+2019)



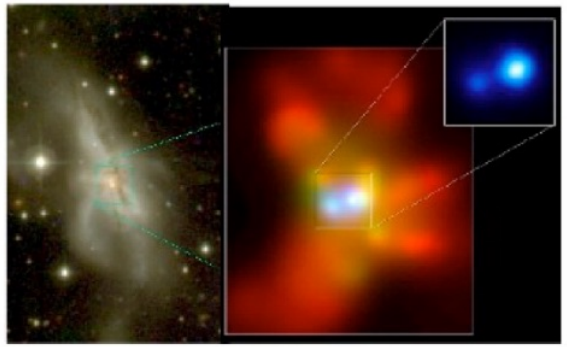
Dusty QSOs as a transitional phase in galaxy evolution

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

(c) Interaction/“Merger”

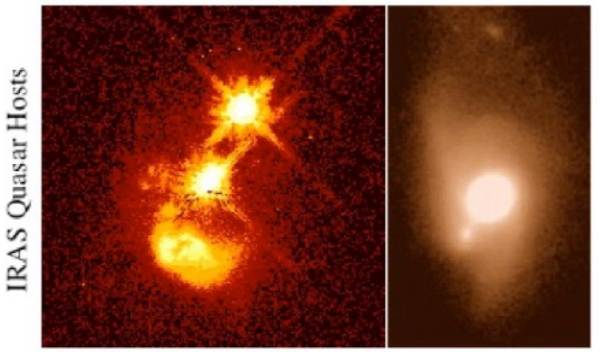
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



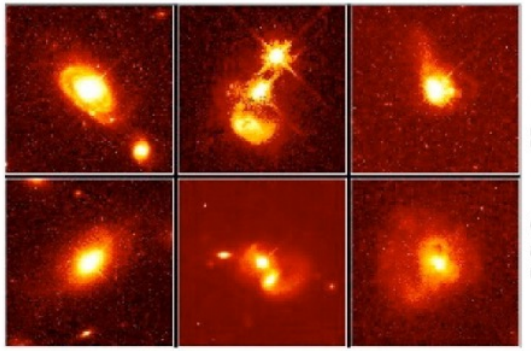
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) “Blowout”



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host, high Eddington ratios, merger signatures still visible

(f) Quasar



- dust removed: now a “traditional” QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

Hopkins+08

Dusty QSOs as a transitional phase in galaxy evolution

- Understanding this blow-out phase is important for models of galaxy evolution and supermassive black hole growth

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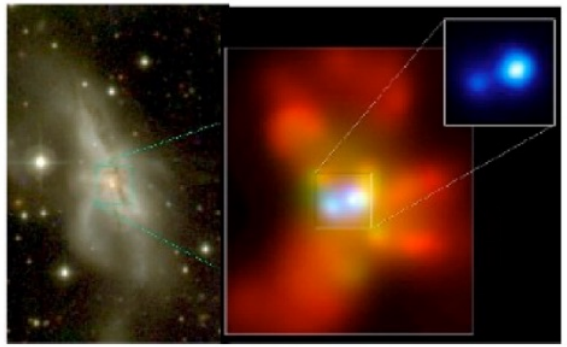

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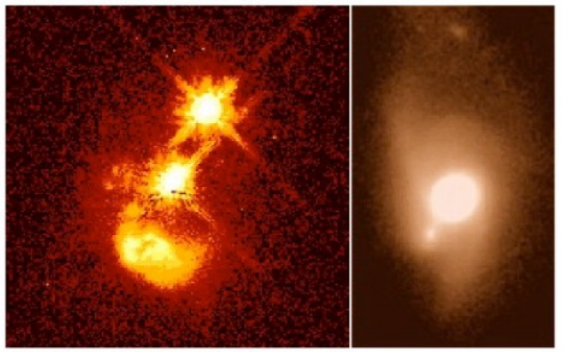

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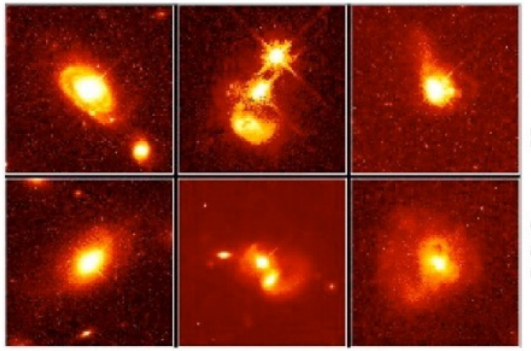

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Hopkins+08

Red QSOs are potentially an important transitional, or “blow-out” phase in the evolution of QSOs

(c) Interaction/“Merger”

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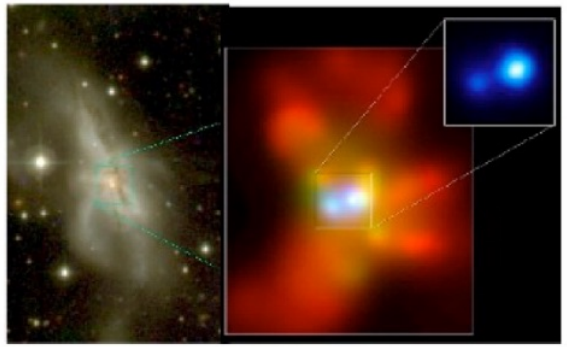

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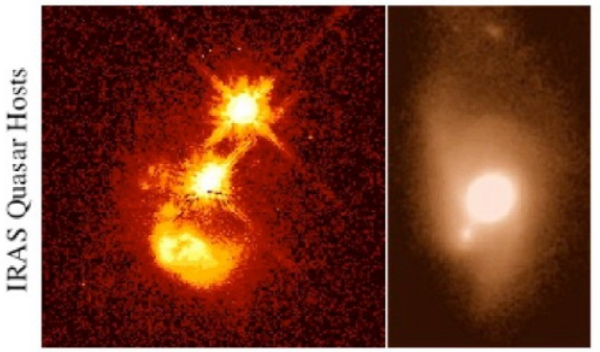

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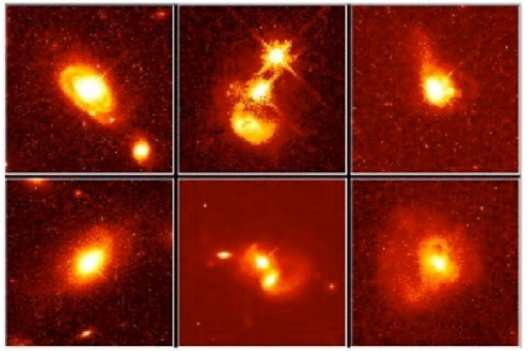

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Hopkins+08

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

The Dark Energy Spectroscopic Instrument (DESI)

- The Dark Energy Spectroscopic Instrument (DESI) will measure the spectra of over ~40 million galaxies and ~3 million quasars covering up to 14,000 square degrees
- The instrument is on the Mayall 4m telescope at Kitt Peak National Observatory
- The main focus of DESI is to constrain possible models of dark energy
- The 5 year main survey began on May 14th 2021

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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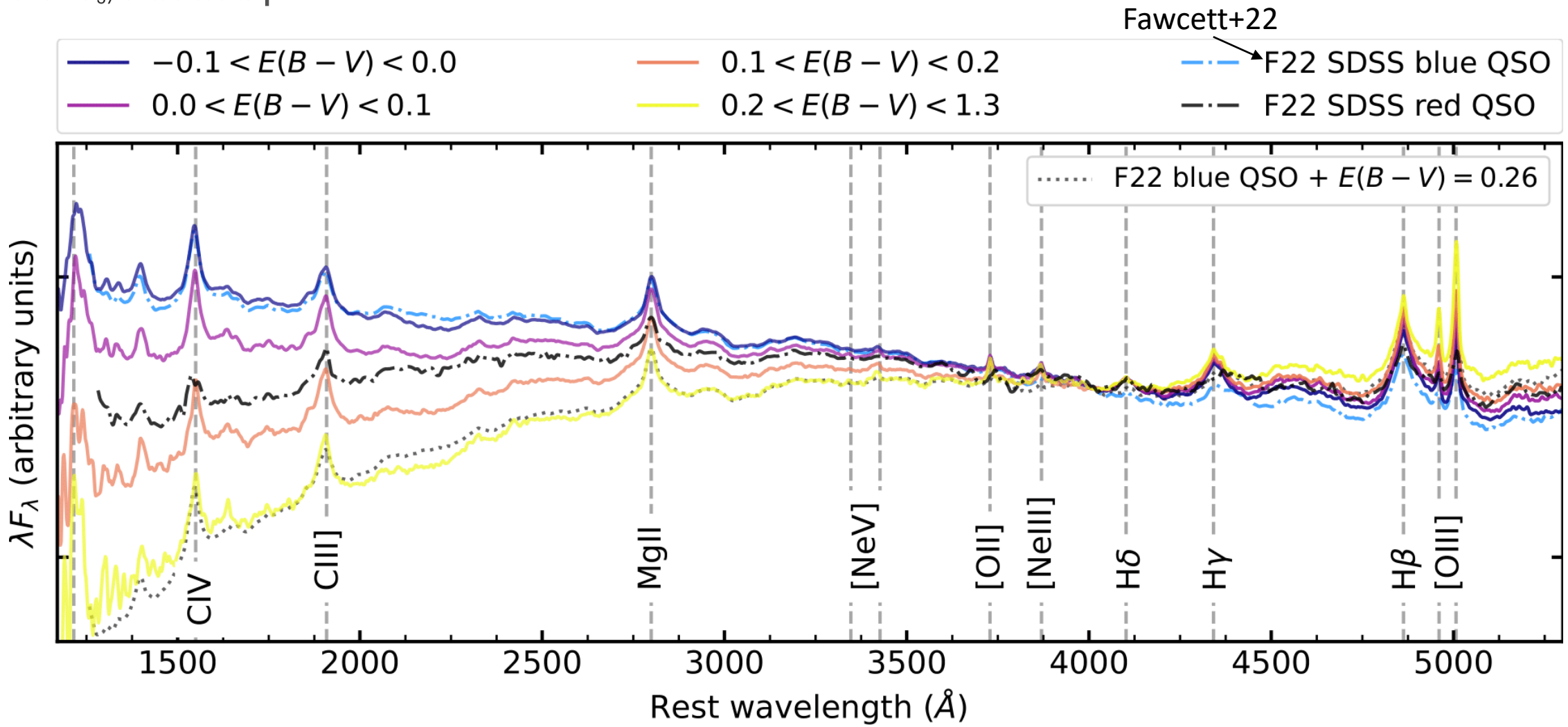
We have a DESI secondary target program that uses a WISE infrared selection to select dust-reddened QSOs that are otherwise missed by the nominal QSO selection

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Pushing to higher dust extinctions with DESI



Newcastle University

NAM - Victoria Fawcett - vicky.fawcett@newcastle.ac.uk

NAM DURHAM UNIVERSITY 2025

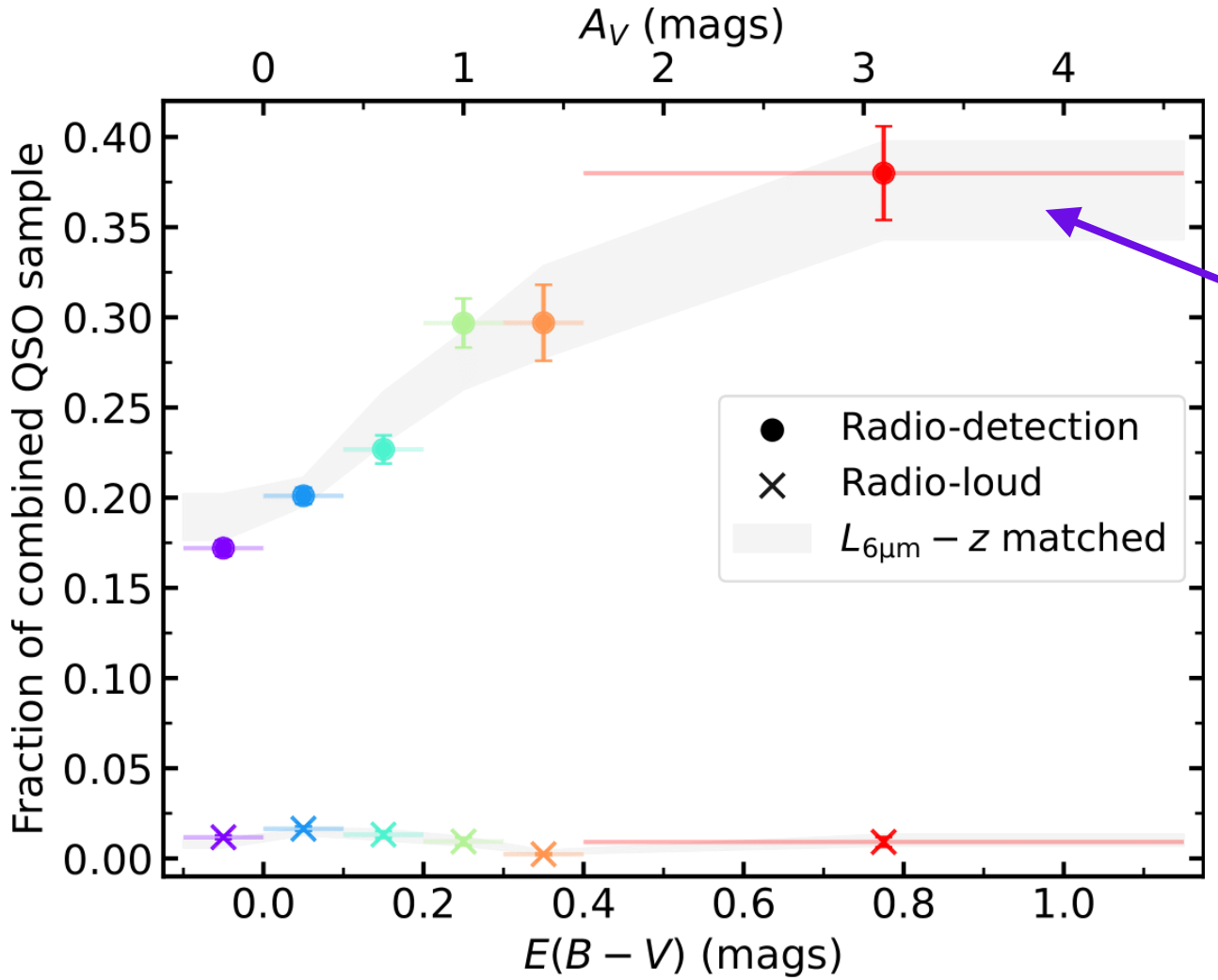
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Pushing to higher dust extinctions with DESI

More dust = more likely to be detected in the radio

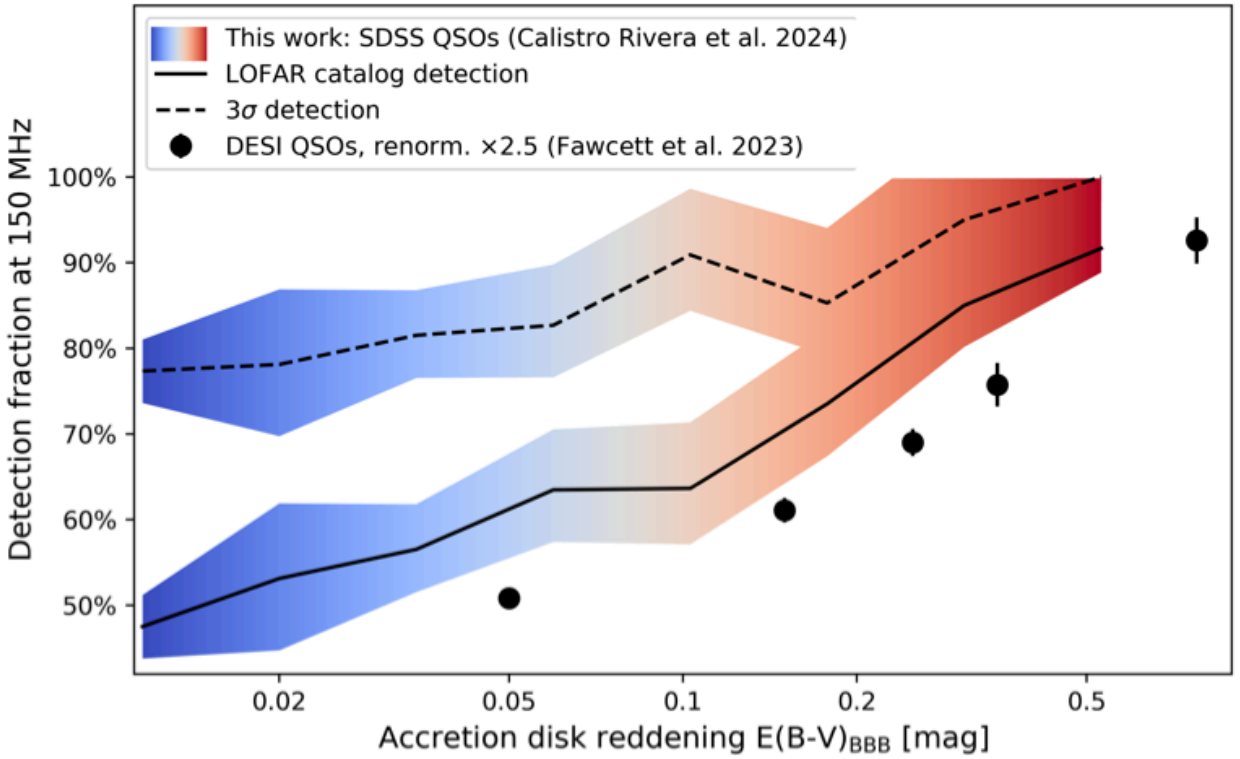
—> connection between amount of dust and outflows? Jets?

$$\mathcal{R} = \log_{10} \frac{L_{144\,\mathrm{MHz}}}{L_{6\,\mu\mathrm{m}}}$$



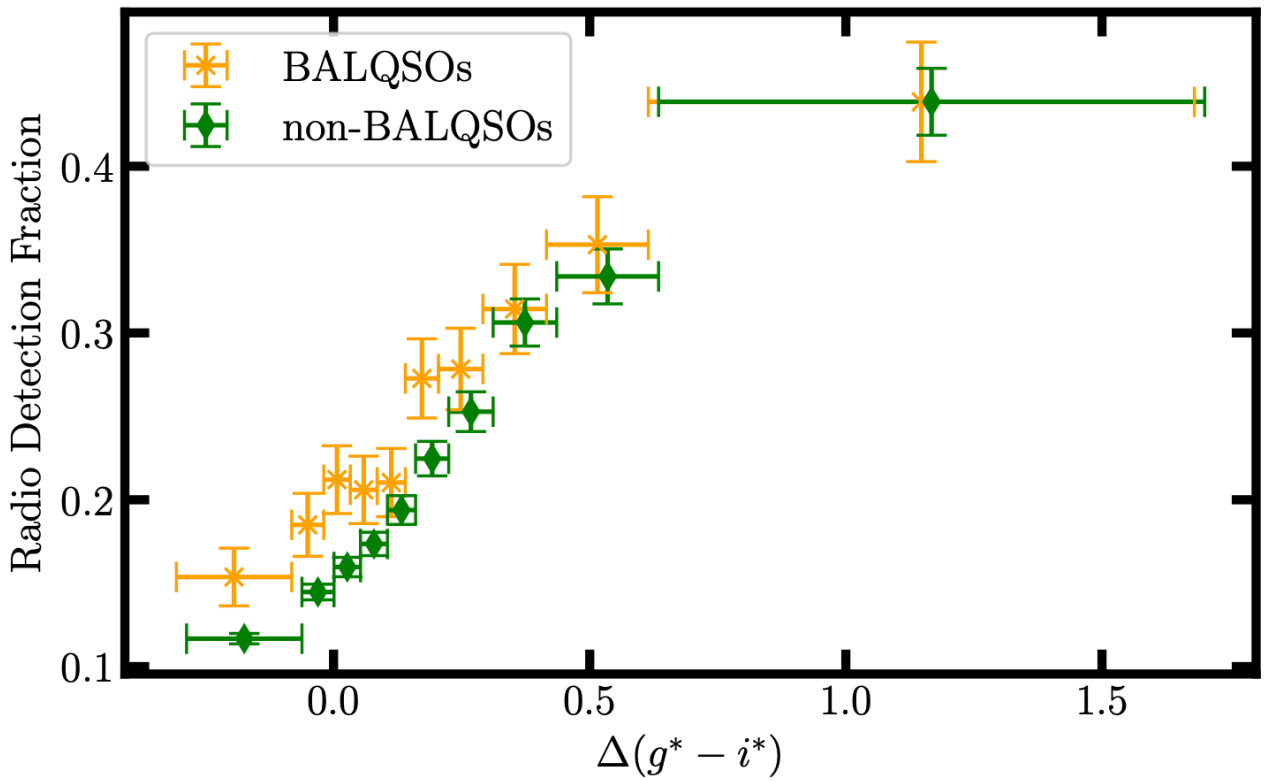
Luminosity-redshift matched

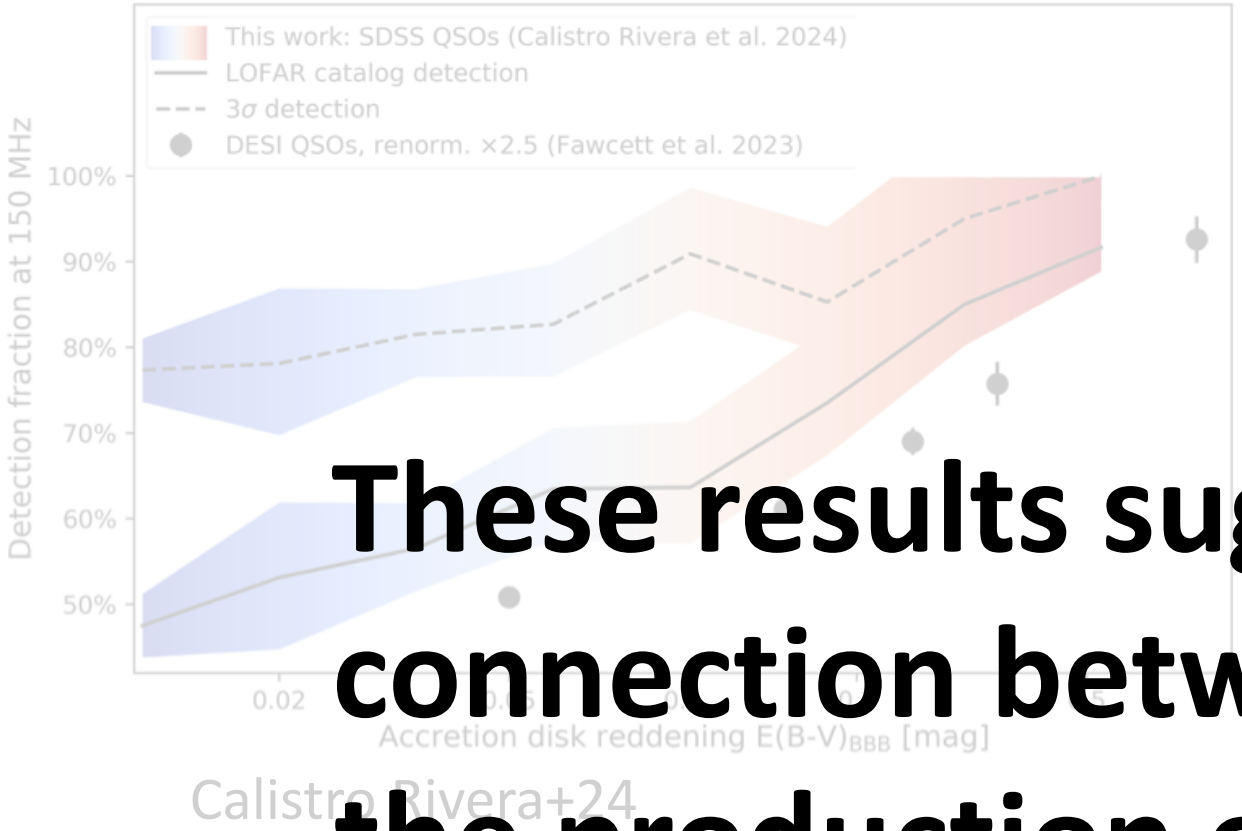
Using LOFAR LoTSS DR2 (144 MHz) Shimwell+22



Calistro Rivera+24

Petley+24





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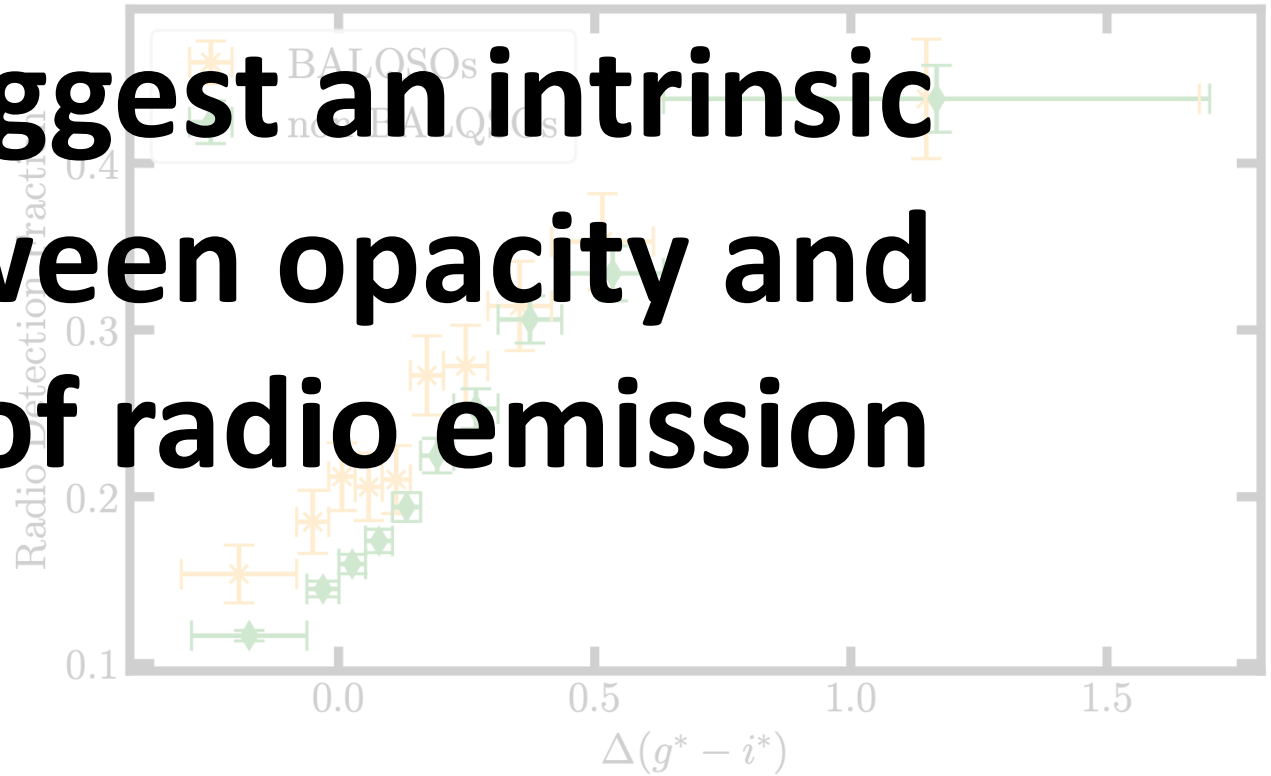
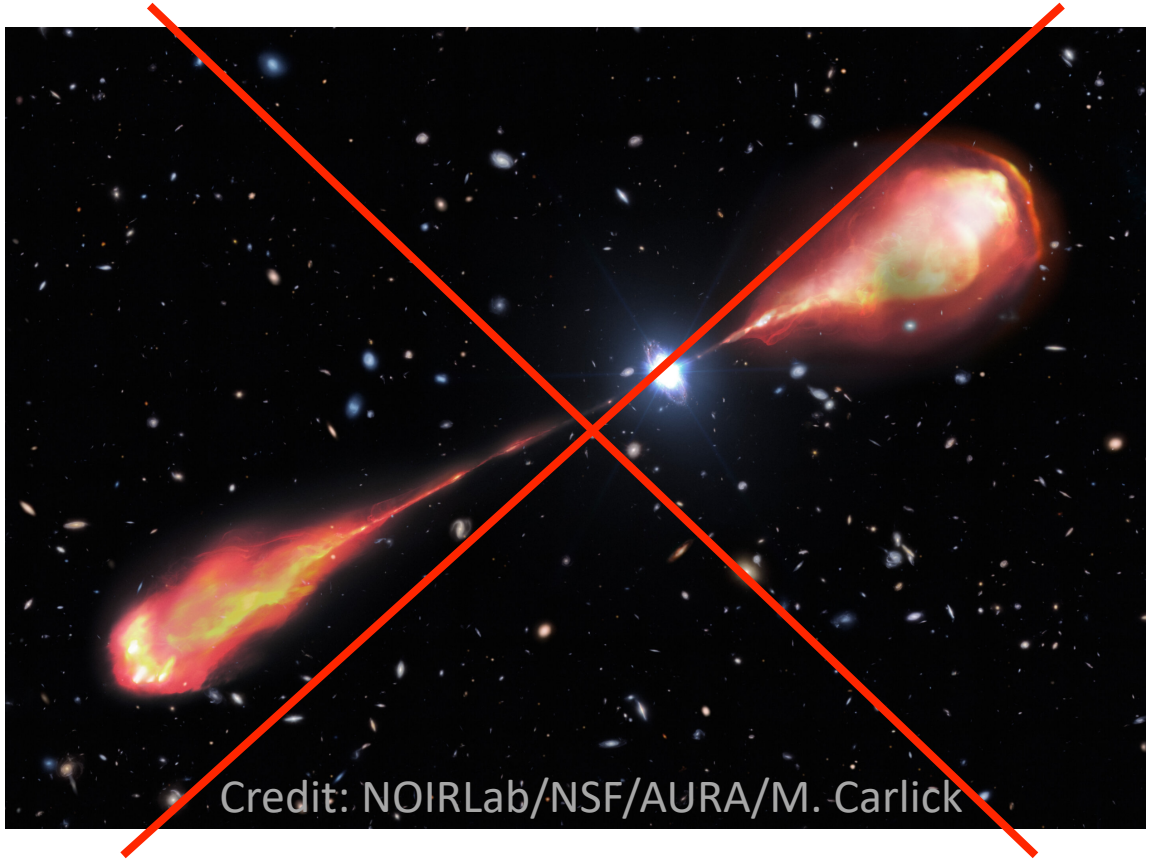


These results suggest an intrinsic connection between opacity and the production of radio emission

The enhanced radio emission in dusty QSOs is not due to powerful radio jets

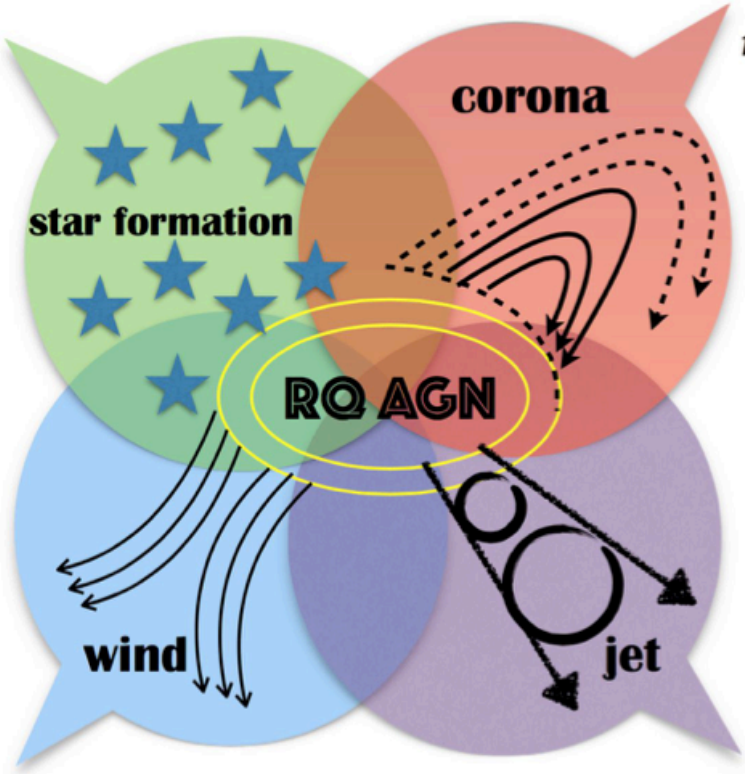


See e.g.,
Klindt+19;
Fawcett+20,21;
Rosario+20

What drives the radio-dust connection?

diffuse, low brightness,
FIR-radio relation

Neupert effect,
$L_r/L_X \sim 10^{-5}$
mm-band compact core

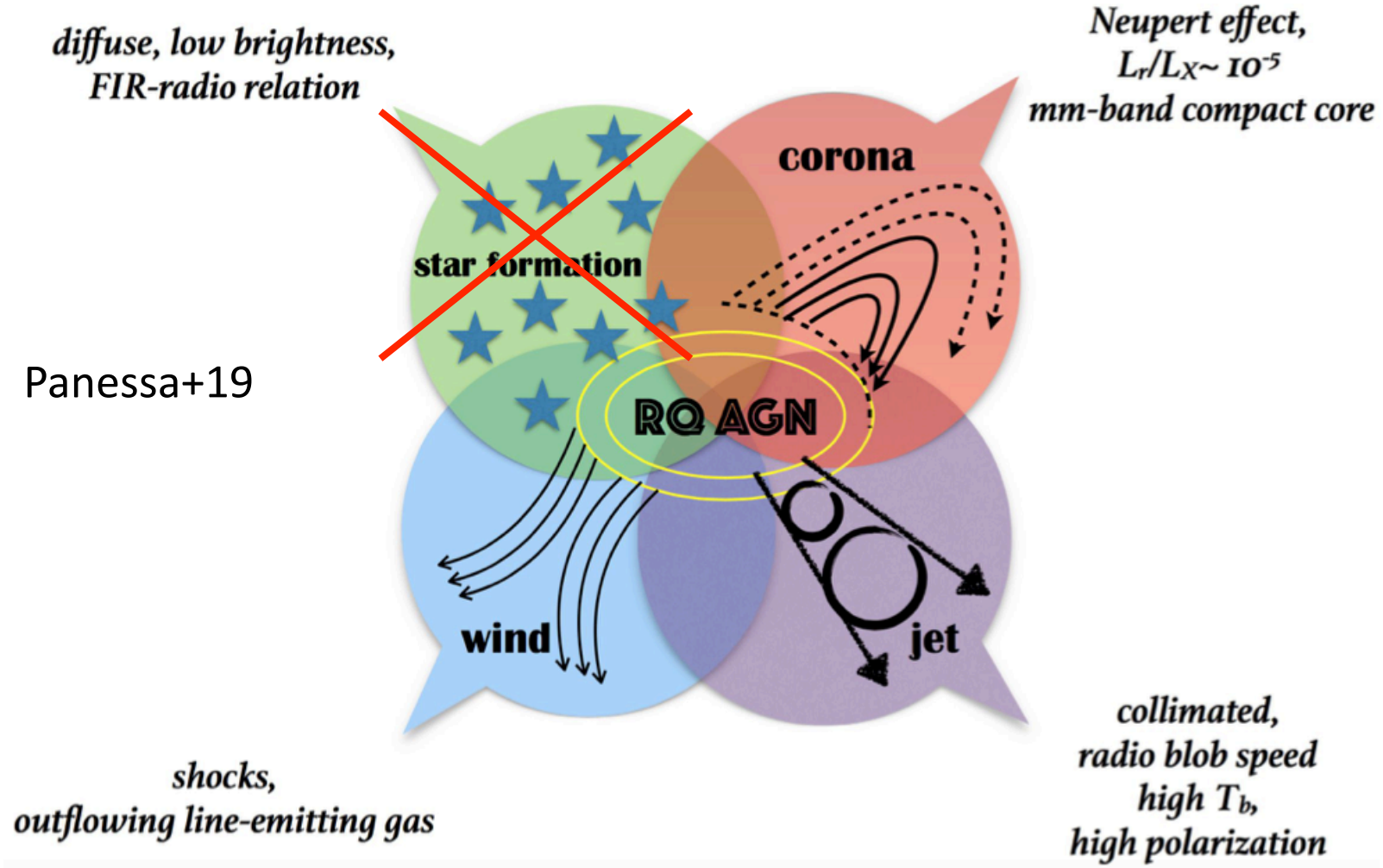


Panessa+19

shocks,
outflowing line-emitting gas

collimated,
radio blob speed
high T_b,
high polarization

What drives the radio-dust connection?



Panessa+19

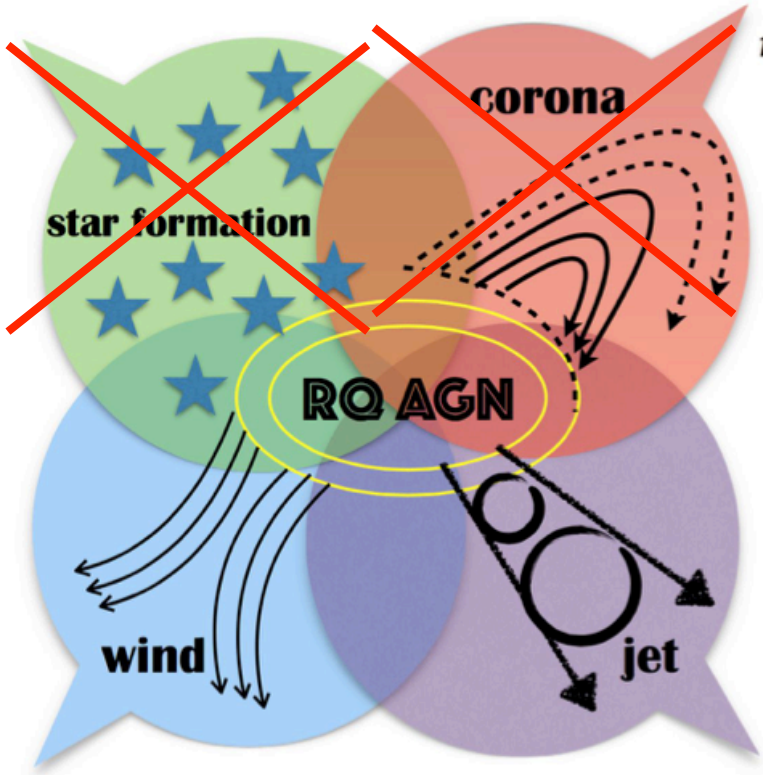
Fawcett+20
Calistro Rivera+21
Yue+24

Note: Andonie+22 found a difference between the star formation properties of unobscured and fully obscured QSOs

What drives the radio-dust connection?

diffuse, low brightness, FIR-radio relation

Neupert effect, $L_r/L_X \sim 10^{-5}$ mm-band compact core



Panessa+19

Assume to be negligible

Fawcett+20
Calistro Rivera+21
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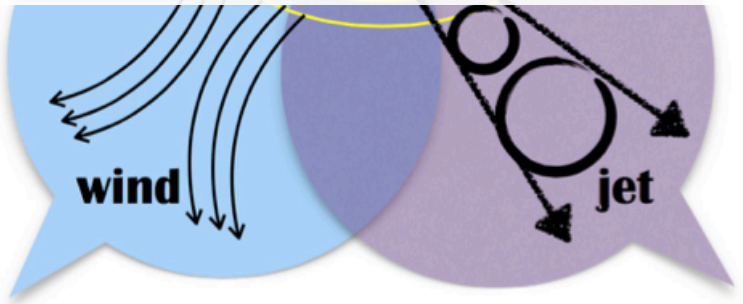
shocks, outflowing line-emitting gas

collimated, radio blob speed high T_b, high polarization

What drives the radio-dust connection?

The enhanced radio emission in dusty QSOs is likely due to either low-powered jets or wind/jet-driven shocks = blow-out phase?



shocks, outflowing line-emitting gas

collimated, radio blob speed high T_b, high polarization

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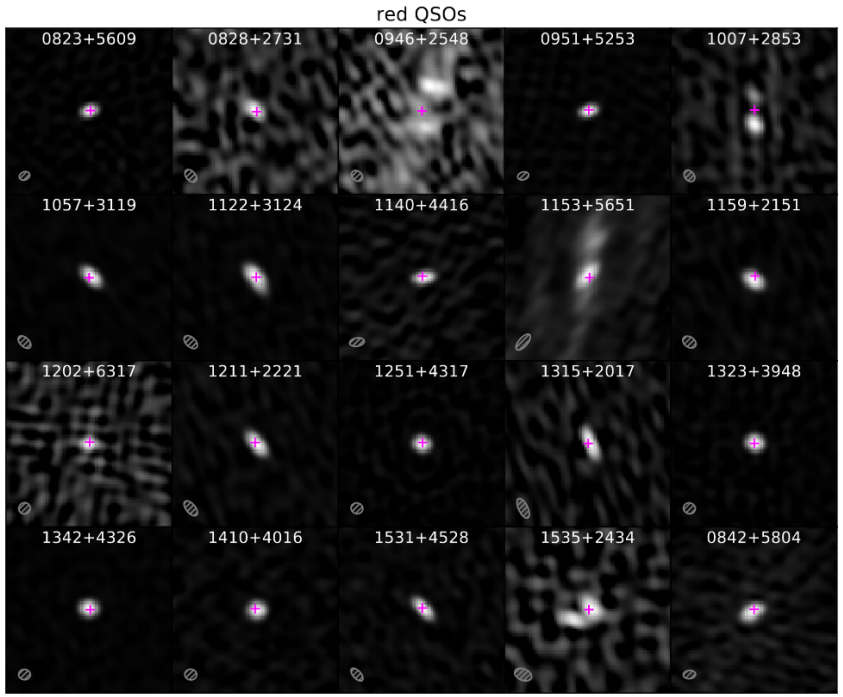
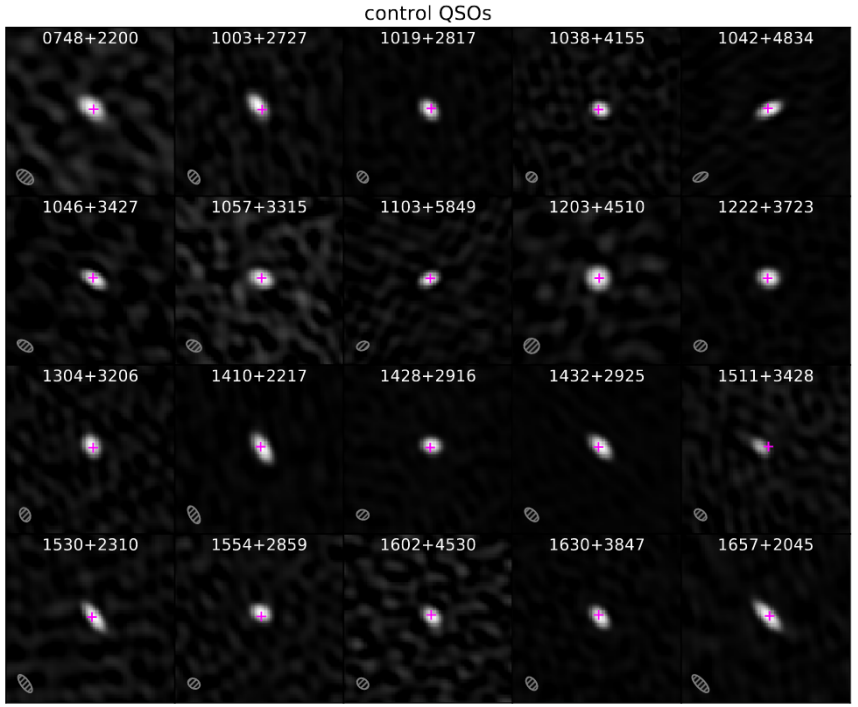
Radio SEDs with uGMRT

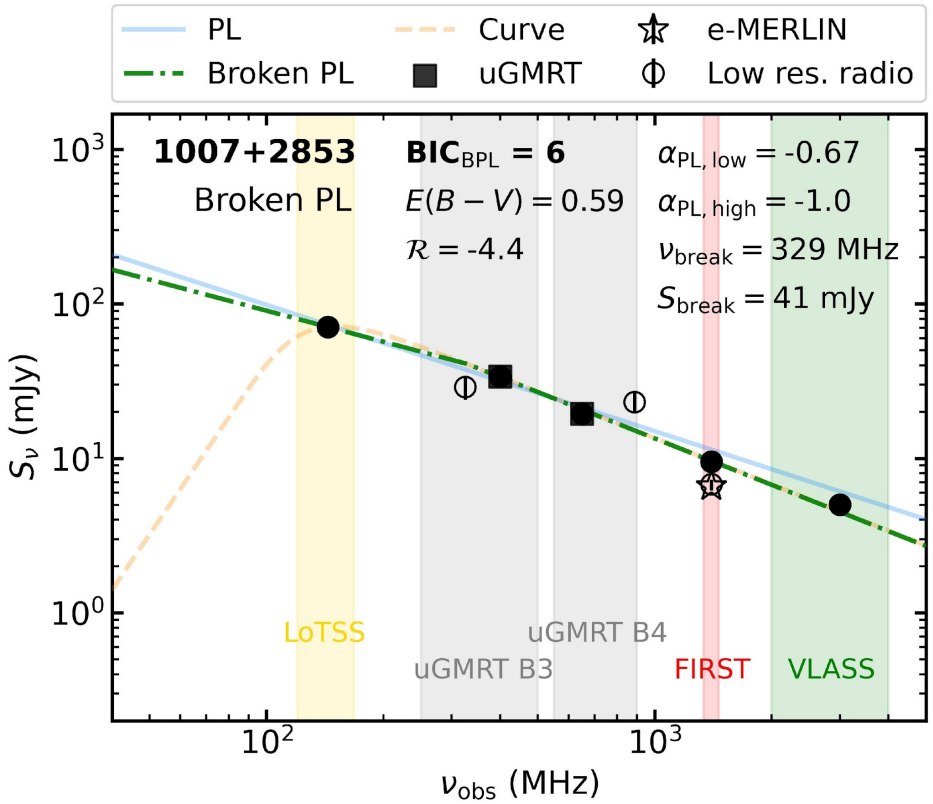
- Using band-3 (400 MHz) and band-4 (650 MHz) uGMRT data for 40 e-MERLIN targets studied in Rosario+21, we constructed sensitive 0.144-3 GHz radio SEDs (with the addition of LoTSS, FIRST, and VLASS)





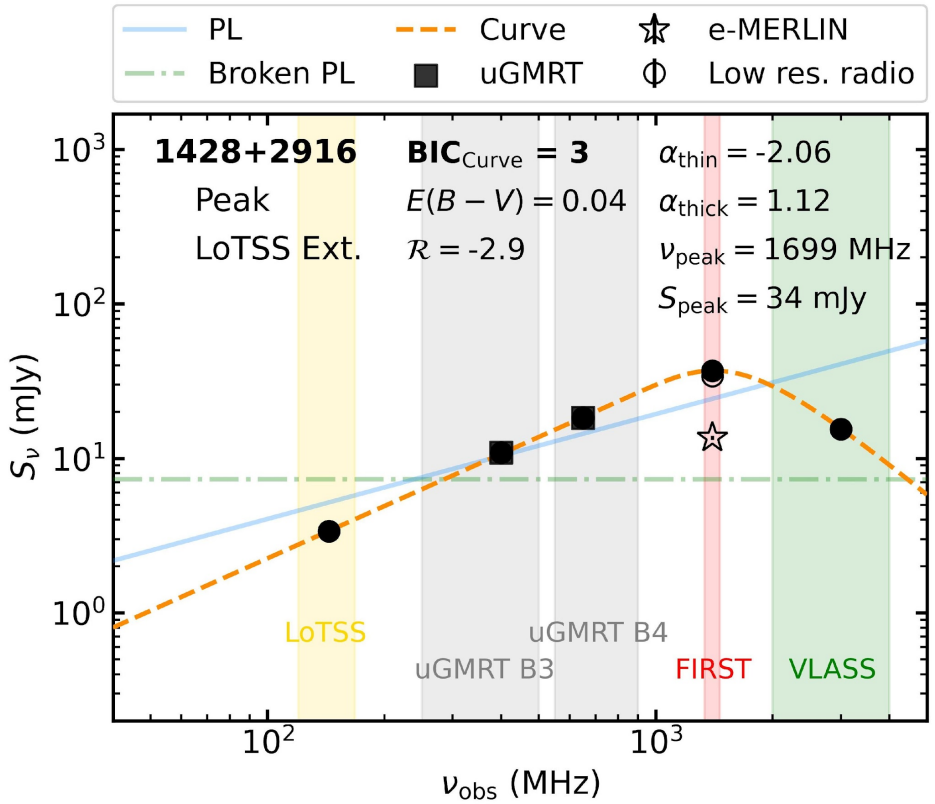
What is the origin of the enhanced radio emission in red QSOs?

Common for red QSOs



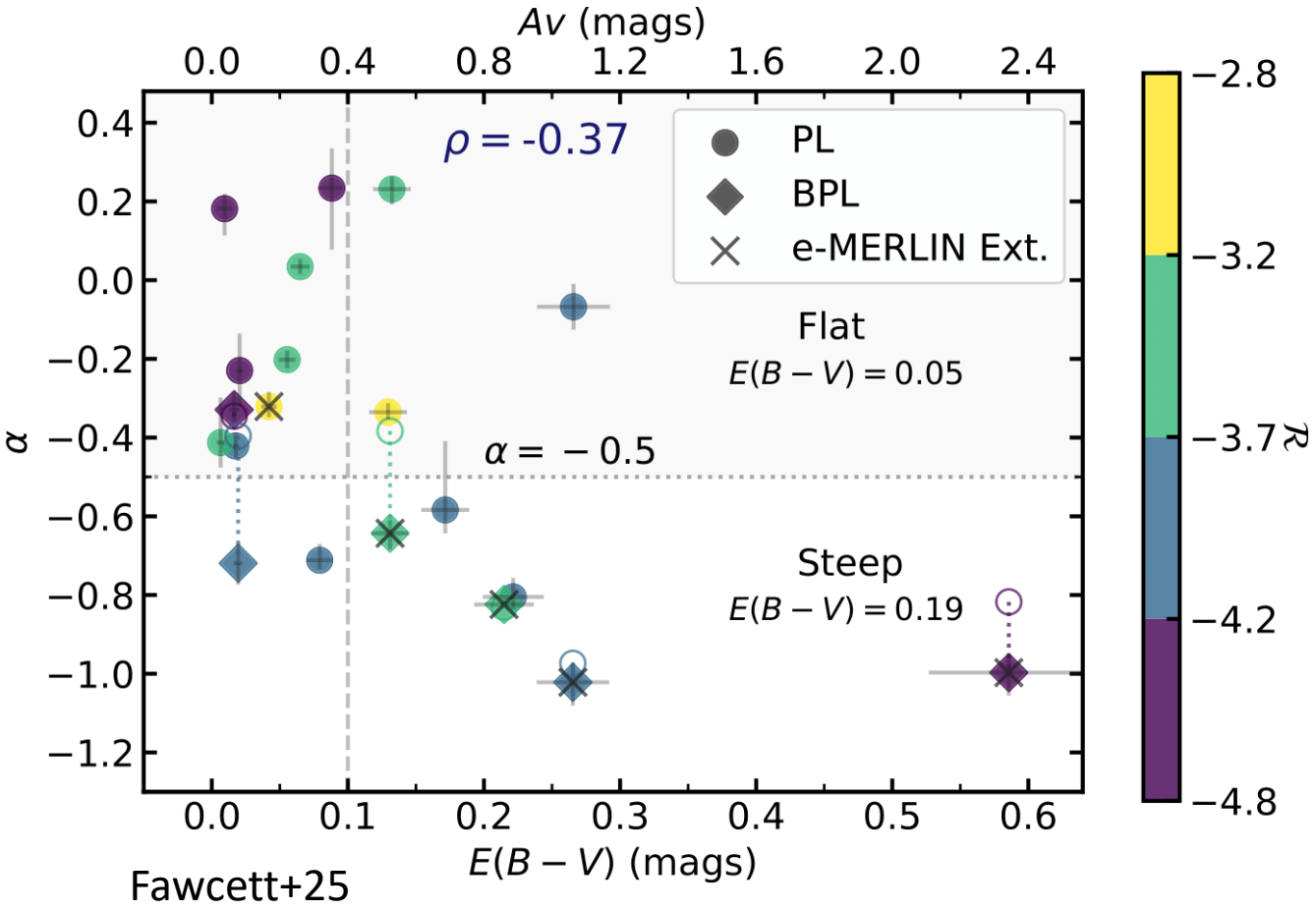
Outflow-driven shocks

Common for blue QSOs



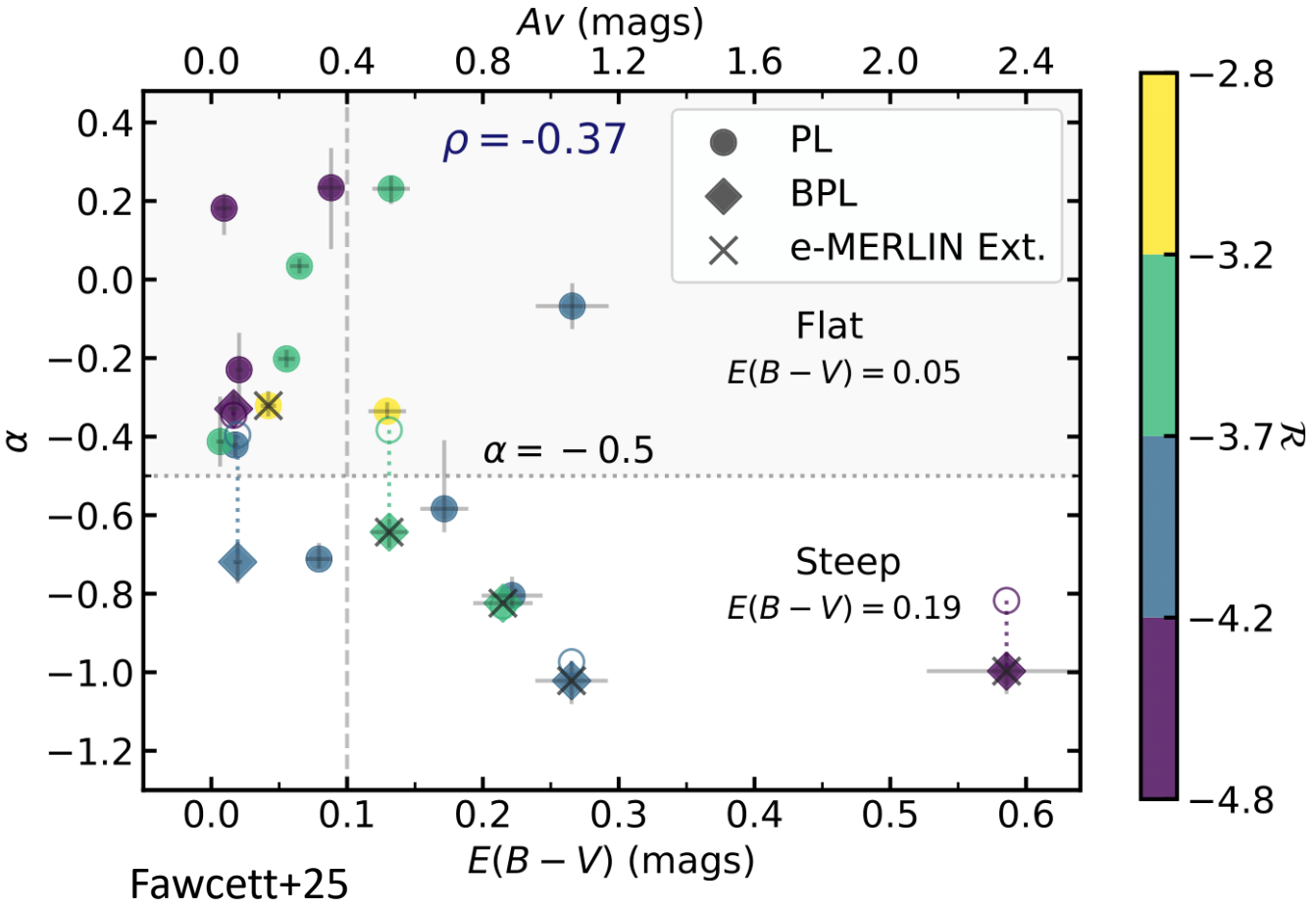
Compact radio jets

Tentative evidence for correlation between reddening and steepness of the radio spectral slope

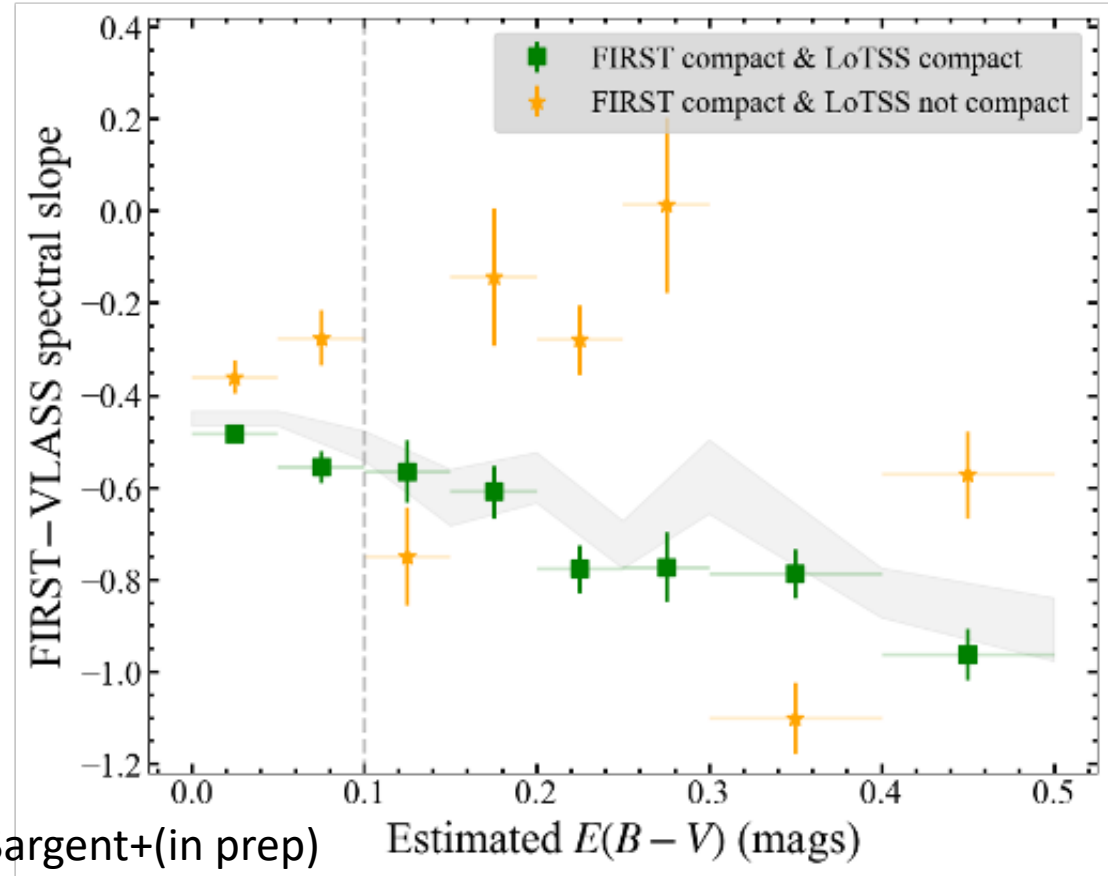


Tentative evidence for correlation between reddening and steepness of the radio spectral slope

See talk by Ciera Sargent!



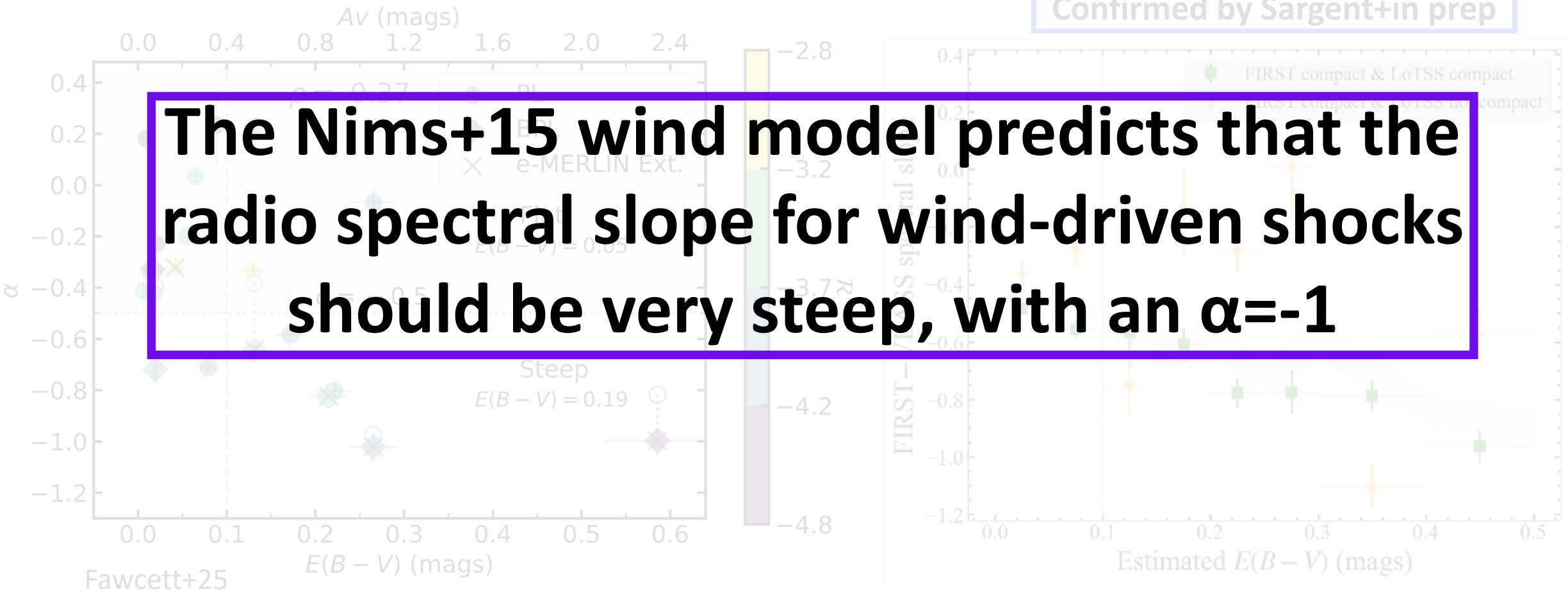
Fawcett+25



Sargent+(in prep)

Tentative evidence for correlation between reddening and steepness of the radio spectral slope

Confirmed by Sargent+in prep

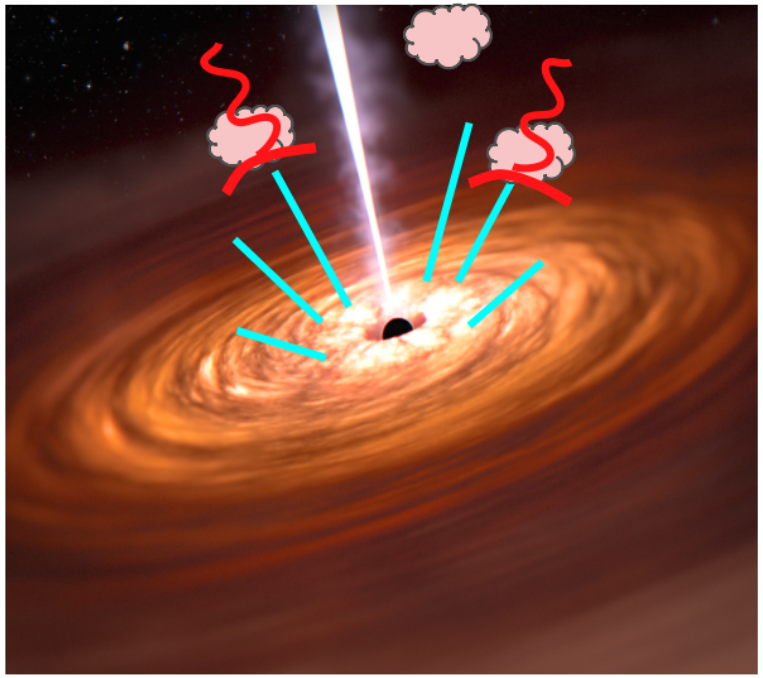


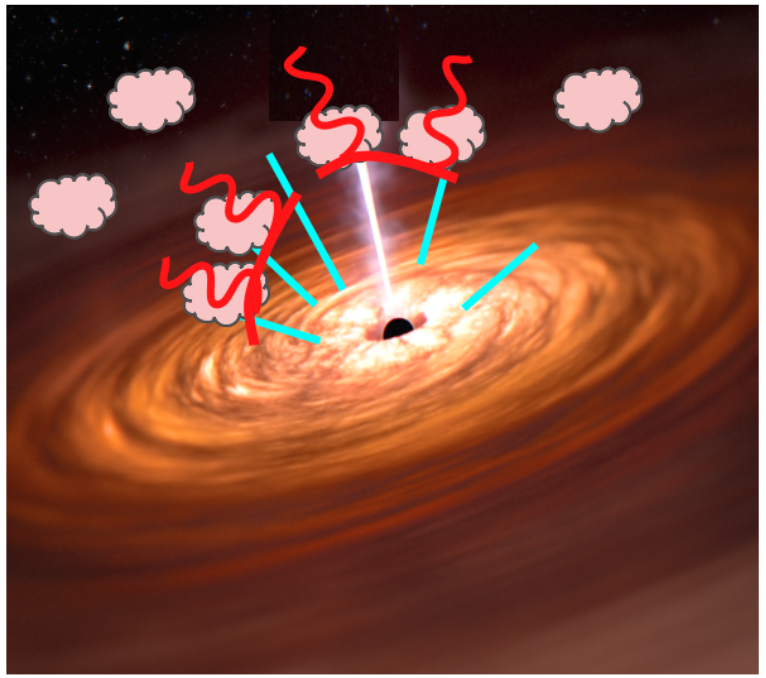
The Nims+15 wind model predicts that the radio spectral slope for wind-driven shocks should be very steep, with an α=-1

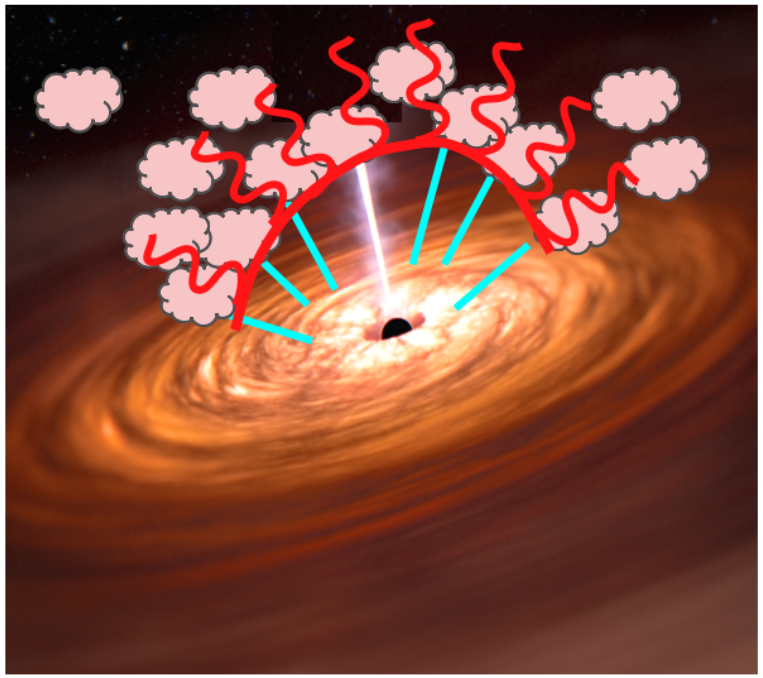
= shocks

= radio waves

= winds/outflows







Conclusions

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- With DESI, we find a strong link between the presence of dust and the radio emission
- We rule out star-formation and large-scale radio-loud jets as the origin of the radio-dust connection
- We find a tentative connection between the amount of dust obscuration and the steepness of the radio spectral slope
  - This could be evidence for shocks in red QSOs = blow-out phase

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We have X-shooter & e-MERLIN data to further test the outflow-driven shock scenario + DESI [OIII] outflows

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Dusty QSOs are prime candidates for a blow-out phase in the evolution of galaxies

Don’t forget to check out the North East exhibition in TLC 39 !

SPACE INVESTIGATORS
ASTRONOMY IN THE NORTH EAST

Conclusions

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Future work

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- We have obtained e-MERLIN C-band data to image the sub-kpc scale radio emission in this sample of red and blue QSOs

- We have obtain VLT/X-shooter data to explore the shock, dust, and outflow properties of a sample of red and blue QSOs

- Utilising VLT/MOONS NIR spectra we will explore the outflow- radio-reddening connection in heavily reddened and obscured AGN

Small-scale radio

Obscured AGN

Star Formation

Dust Extinction

Eddington Ratio

MOONS

Shocks?

DESI [OIII]

DESI selection

Steep spectrum

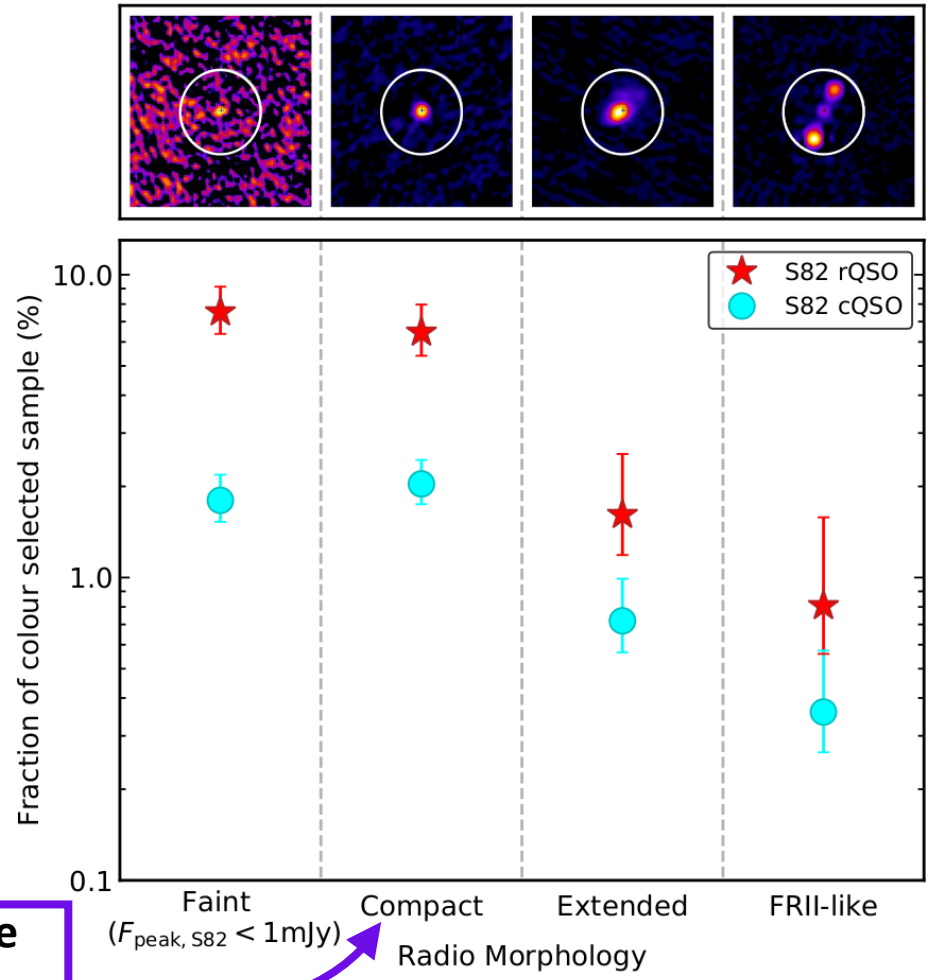
MgII absorbers

uGMRT

What drives the radio-dust connection?

- The radio emission tends to be on small scales (~<2 kpc; Fawcett+20; Rosario+21)

Fawcett+20



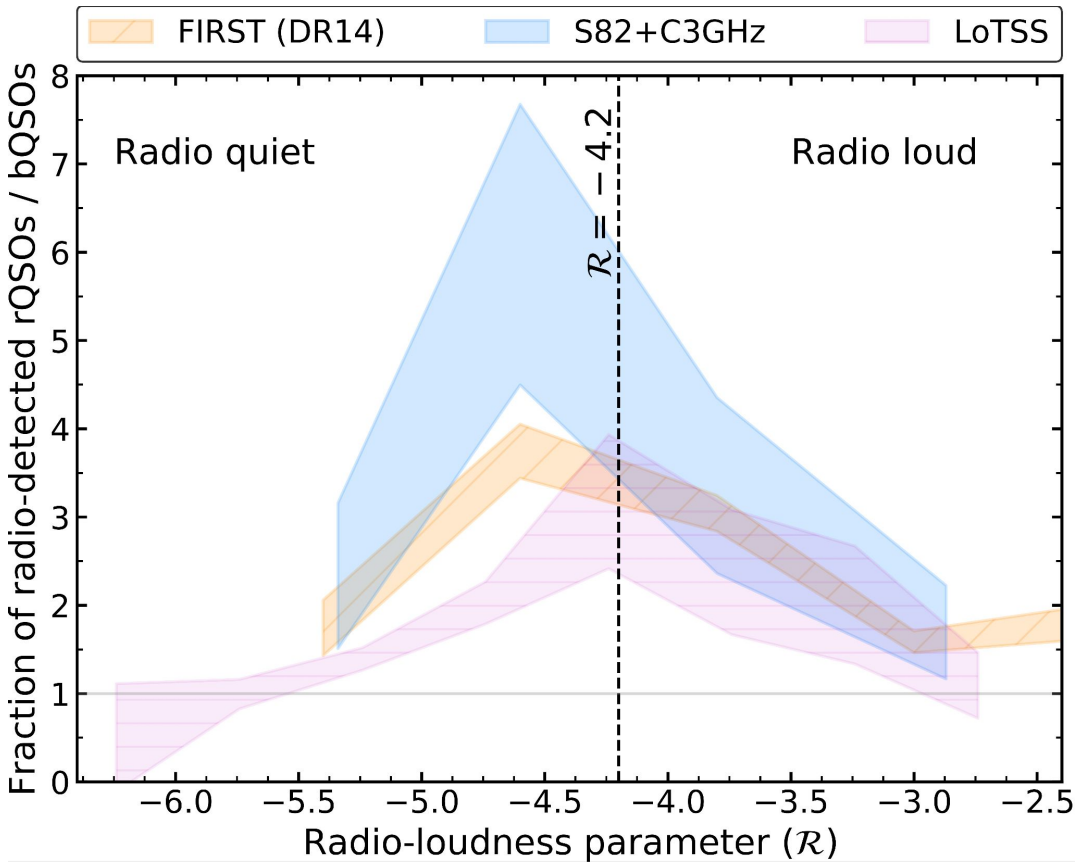
Compact = unresolved at the resolution of the radio survey

What drives the radio-dust connection?

- The radio emission tends to be on small scales (~<2 kpc; Fawcett+20; Rosario+21)

- The enhanced radio emission peaks around the radio-loud/radio-quiet threshold (i.e., moderate radio luminosities; Klindt+19; Fawcett+20; Fawcett+21)

Fawcett+21



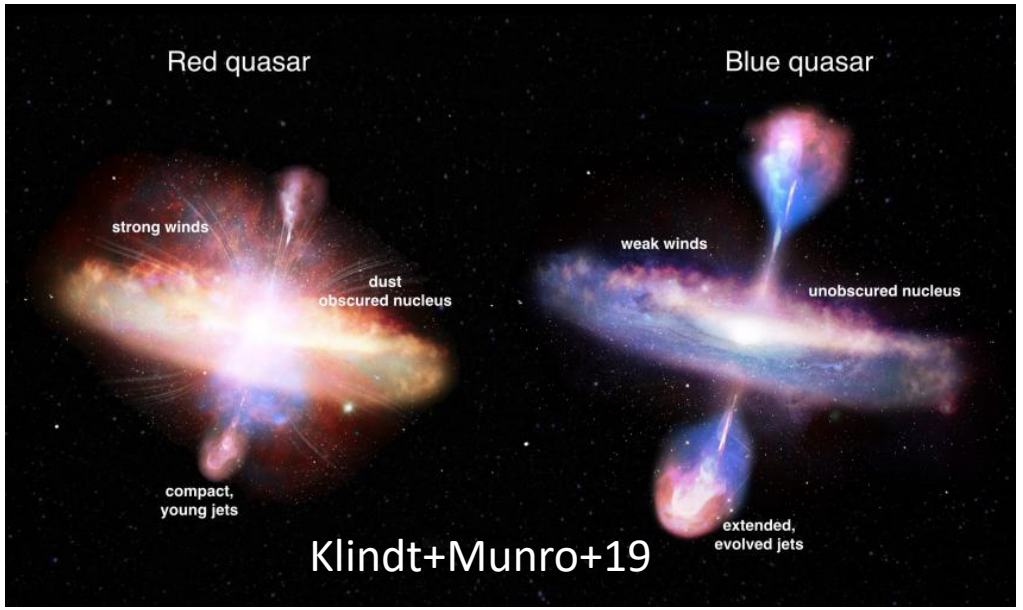
The enhanced radio emission in dusty QSOs is not due to powerful radio jets

Credit: NOIRLab/NSF/AURA/M. Carlick

Observational signatures of a blow-out phase

If this blow-out phase exists, we would maybe expect to find dusty/obscured QSOs with:

- Disturbed host galaxies/ a higher incidence of mergers
- Higher star formation rates
- More powerful outflows
- Higher accretion rates
- Under-massive black holes



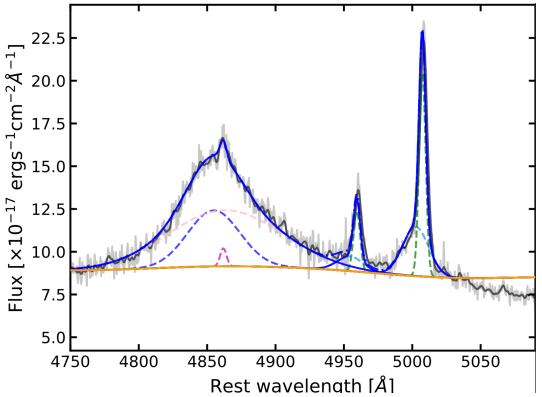
Evidence for shocks in dusty QSOs?

- Connection between dust and radio in QSOs
  - More dust obscuration = higher radio detection fraction
  - More dust obscuration = steeper spectral slopes
- Steep spectral slopes consistent with the prediction from shocks in the Nims+15 wind model
- Calistro Rivera+21 found a hot dust excess and stronger [OIII] outflows in red QSOs
- Haidar+24 found that the radio emission in nearby AGN is co-spatial with the extended MIR emission ***See Houda Haidar's talk!***

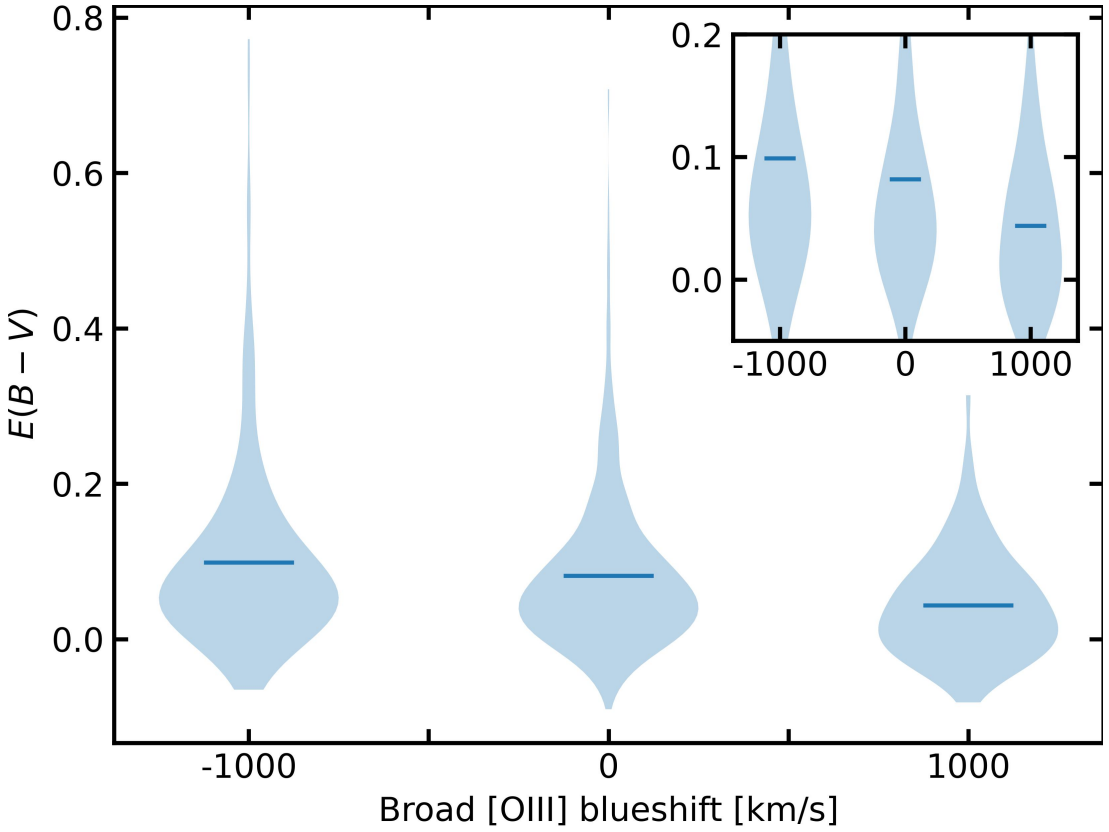
!Preliminary!

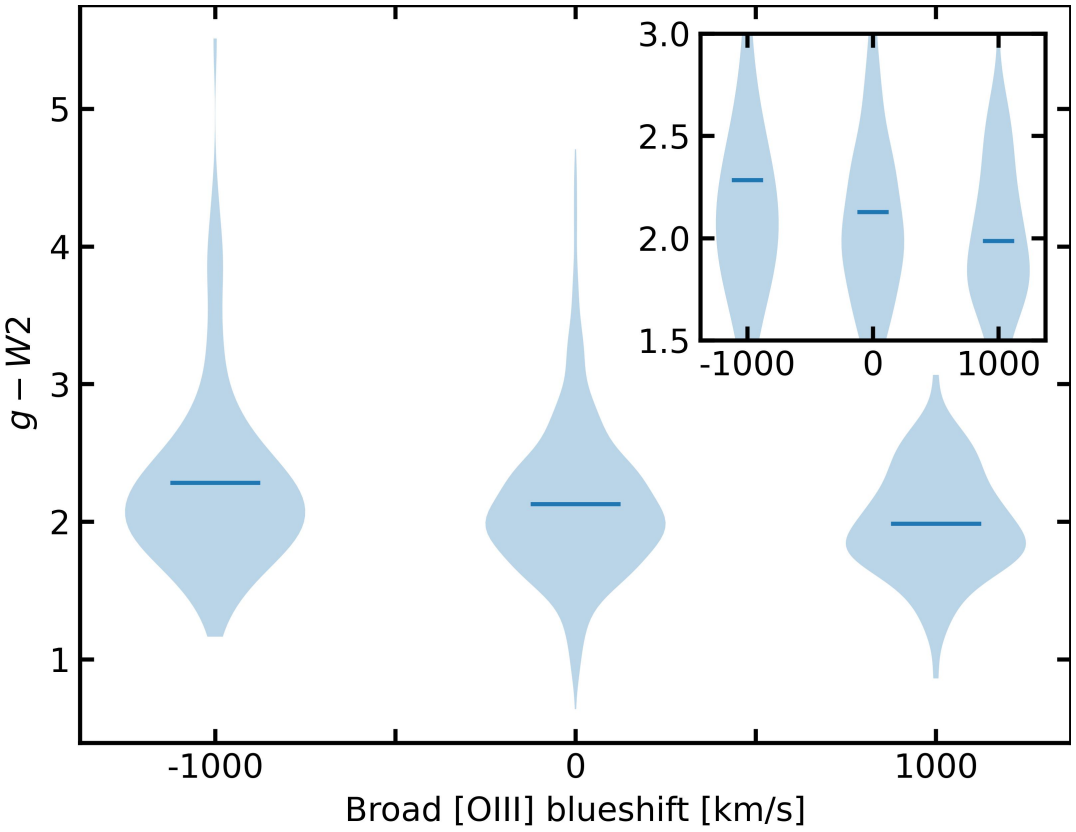
[OIII] outflows in DESI QSOs

See also Emmy Escott's talk!



Fawcett+(in prep)





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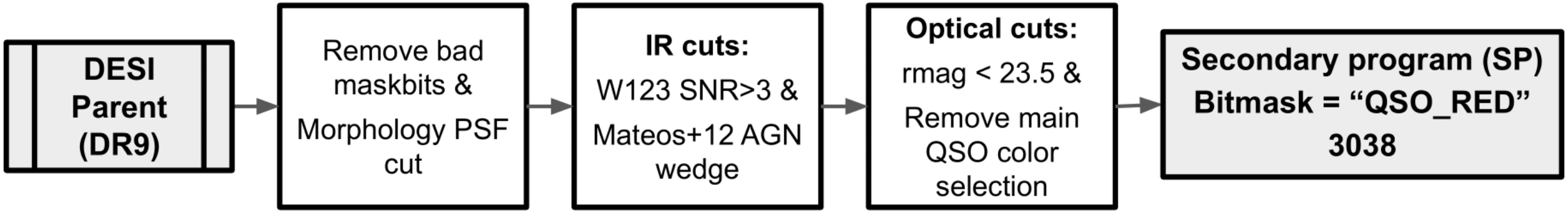
DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

Target selection

Dec 2020 - June 2021



~32,000 by 2026!

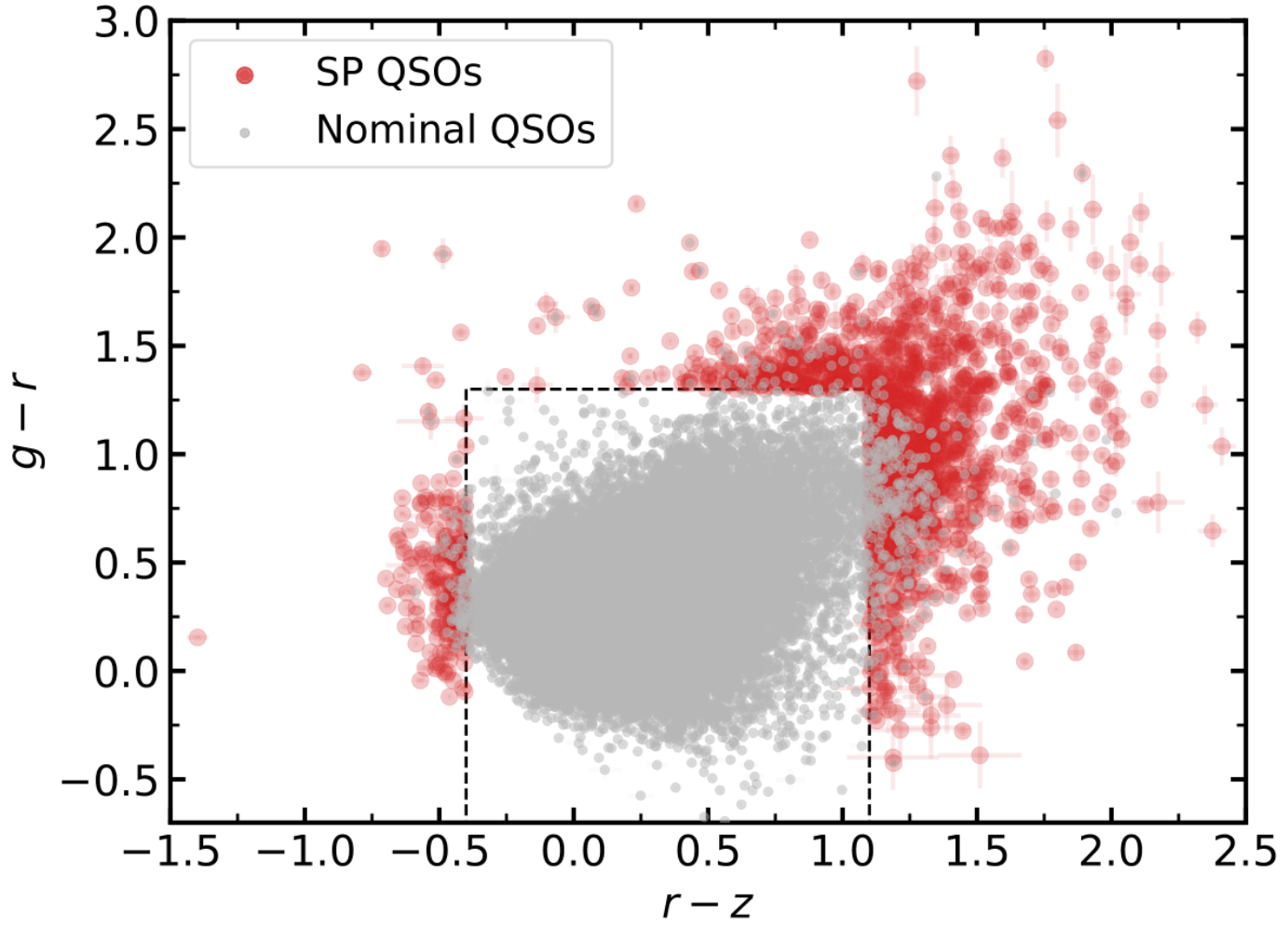
74% of the high quality objects are QSOs (from VI)

DARK ENERGY SPECTROSCOPIC INSTRUMENT
U.S. Department of Energy Office of Science

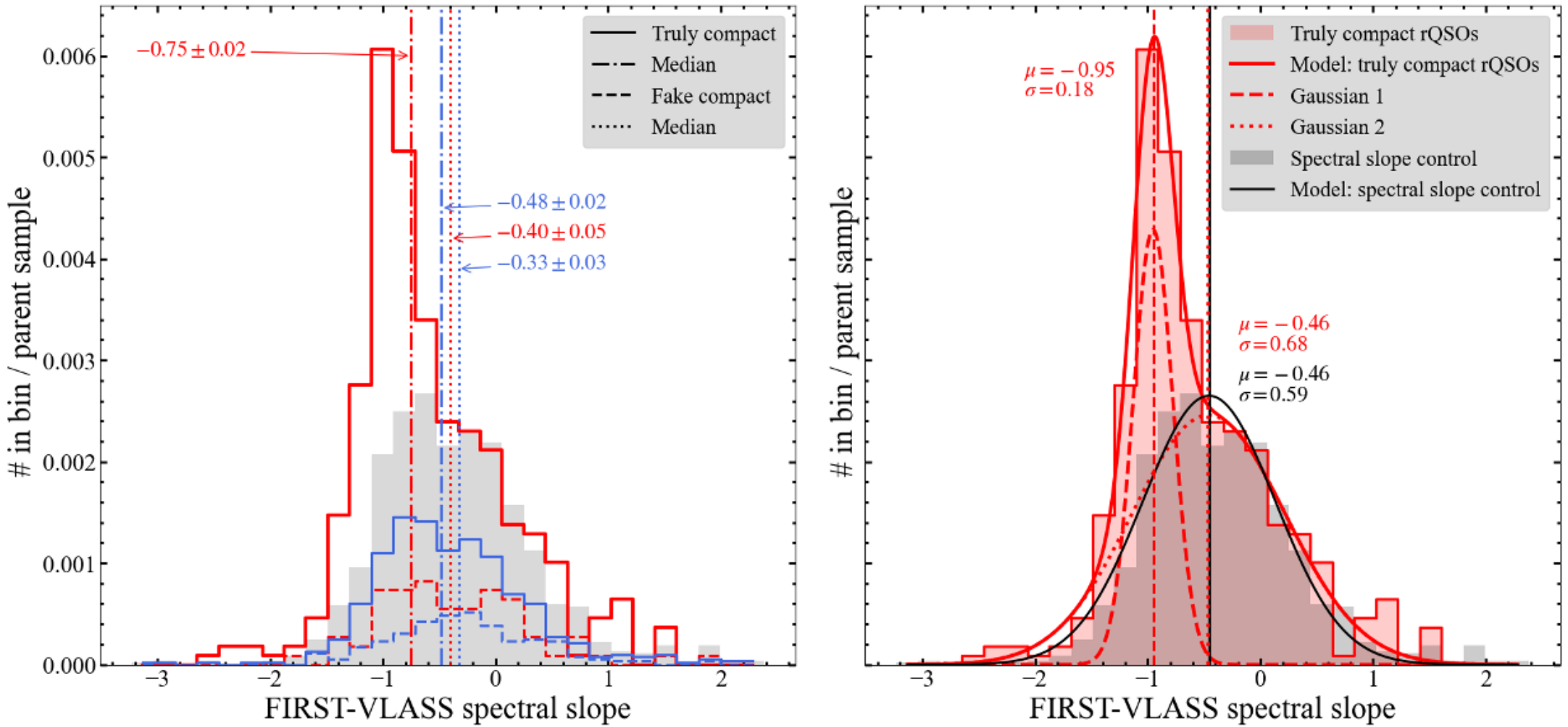
Constructing the final QSO sample

To explore the radio properties of DESI QSOs, we combined our secondary program (SP) QSOs with a larger sample of QSOs selected by the nominal DESI QSO program

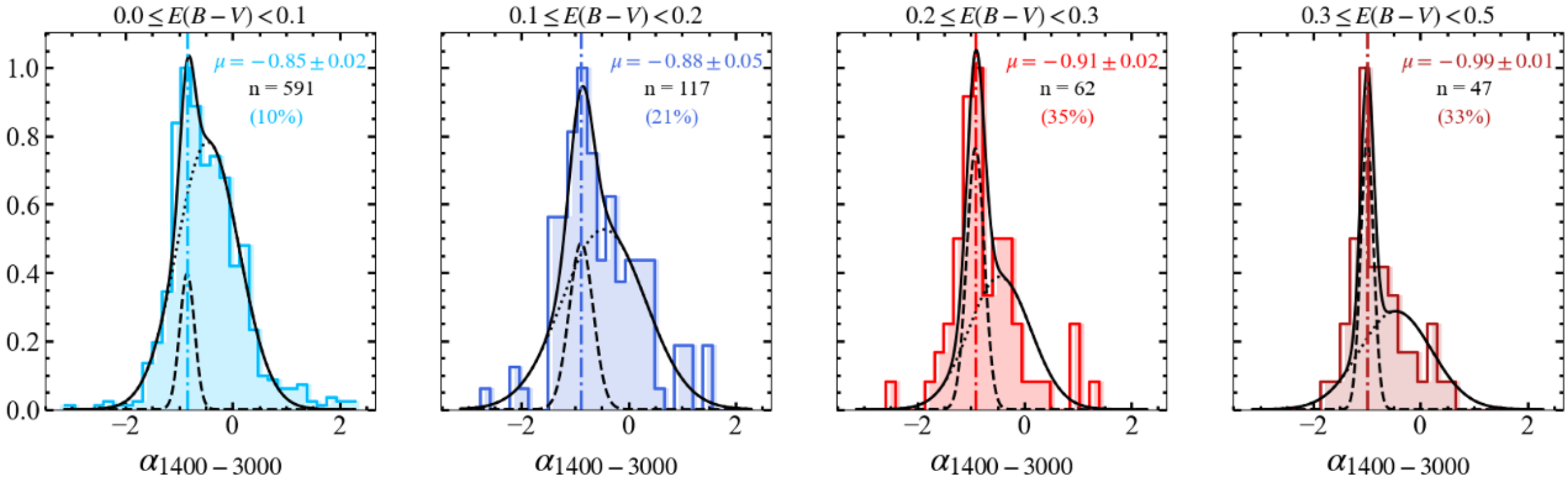
Fawcett+23



Sargent+in prep



Sargent+in prep



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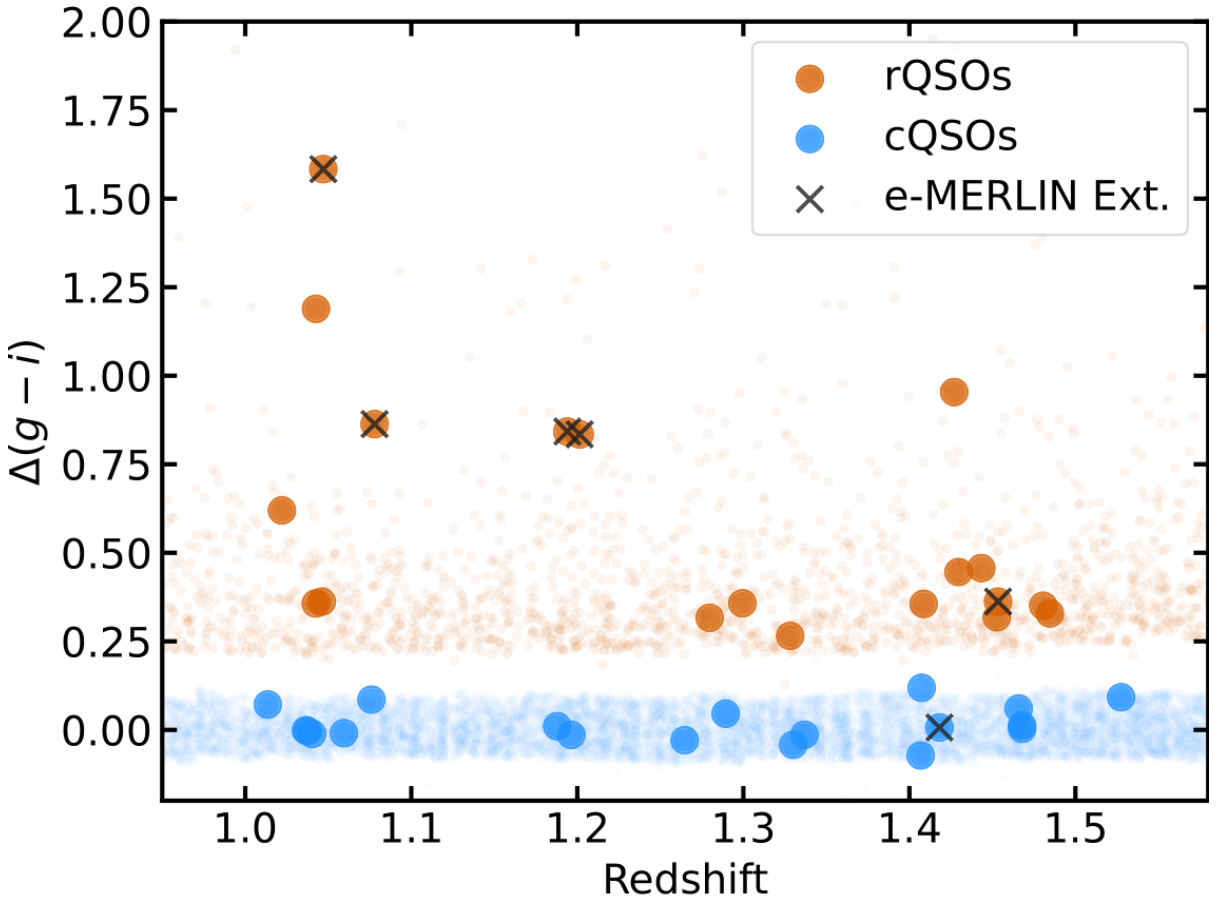
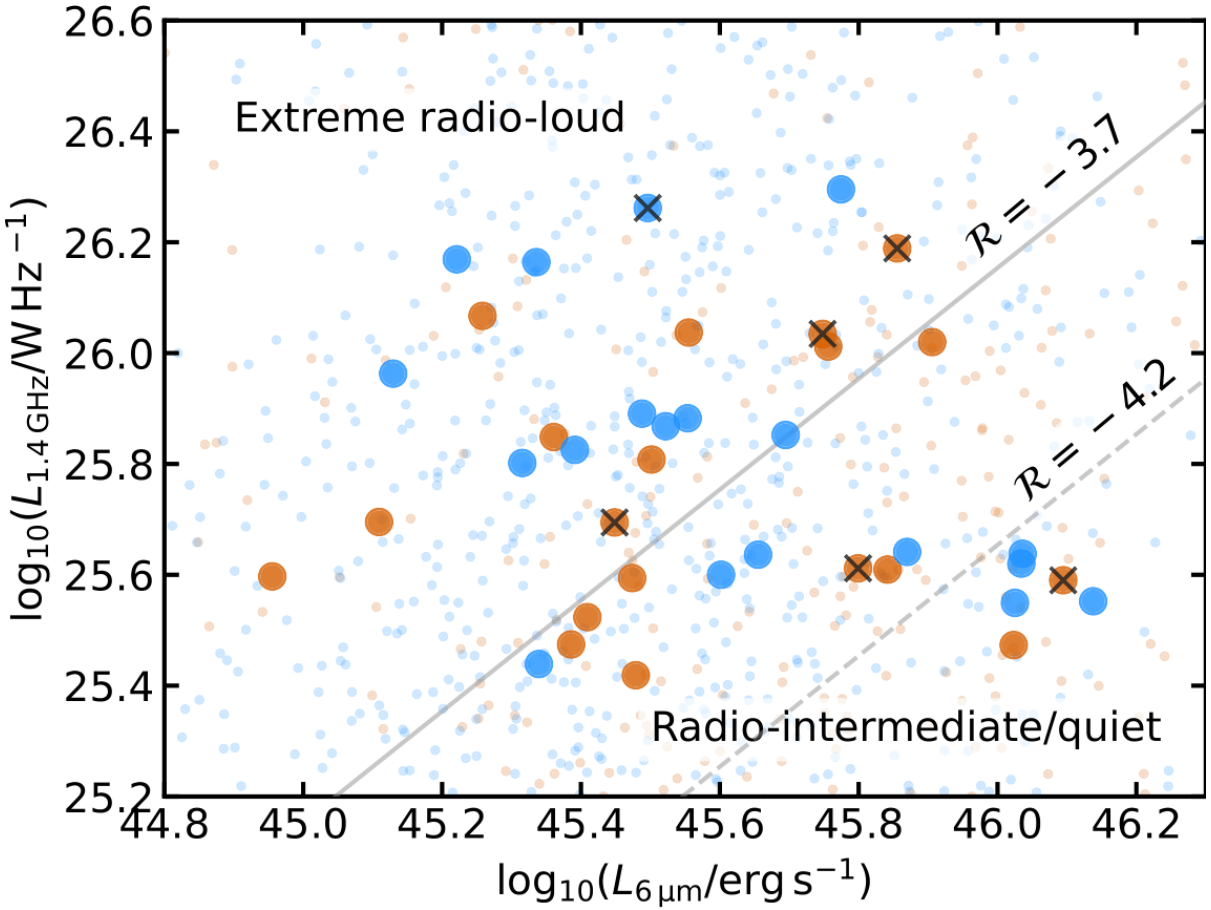
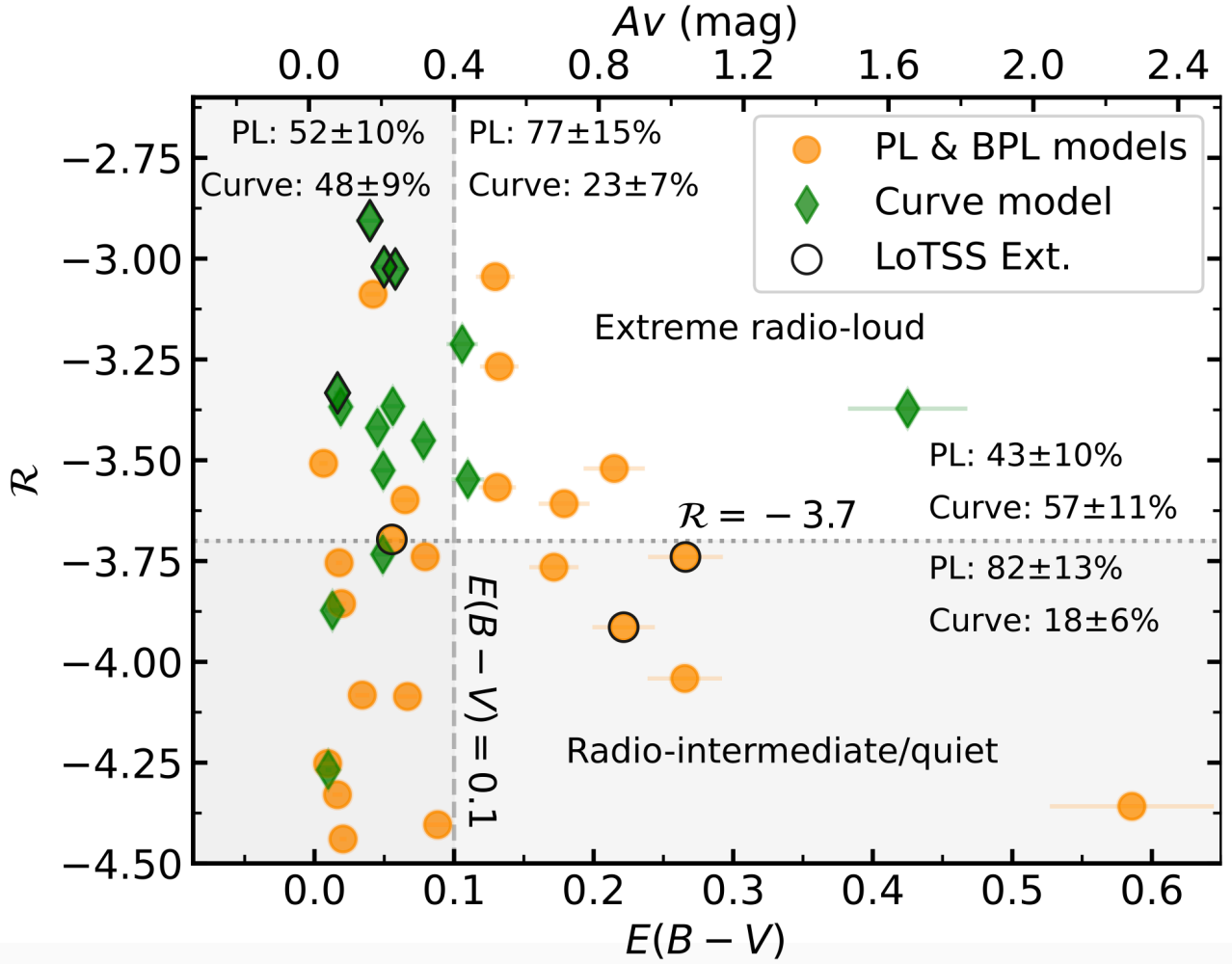
Radio SEDs with uGMRT





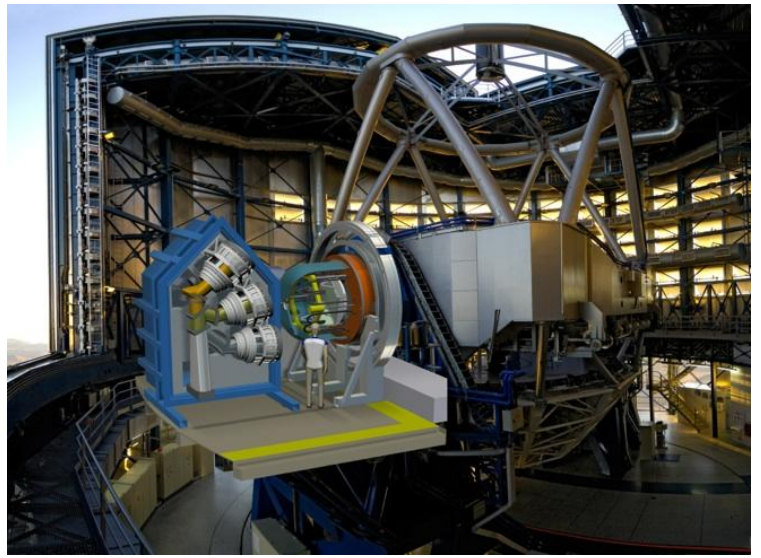
QSOs fit with a curved model are more likely to be very radio-loud

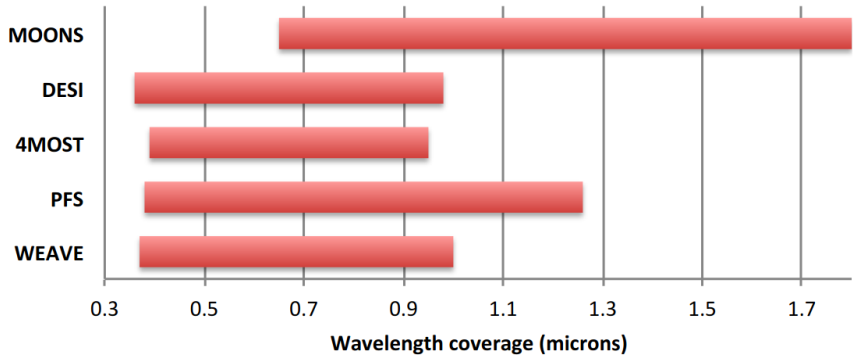


Fawcett et al. (2025)

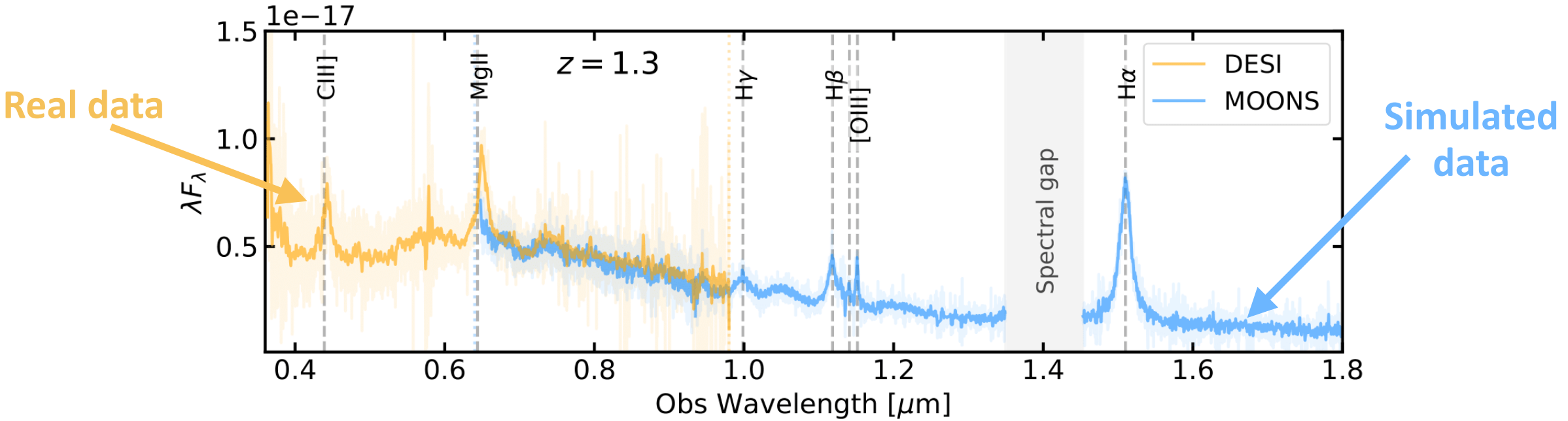
Future work with the Multi-Object Optical and Near-IR Spectrograph (MOONS)

- MOONRISE GTO (first light ~end of 2025) will observe thousands of type 1 and type 2 AGN
- With MOONS we can bridge the gap between the modestly reddened QSOs in DESI and fully obscured QSOs
- The wavelength coverage will enable [OIII] outflow studies beyond z>1 (the current limitation of optical spectroscopy)



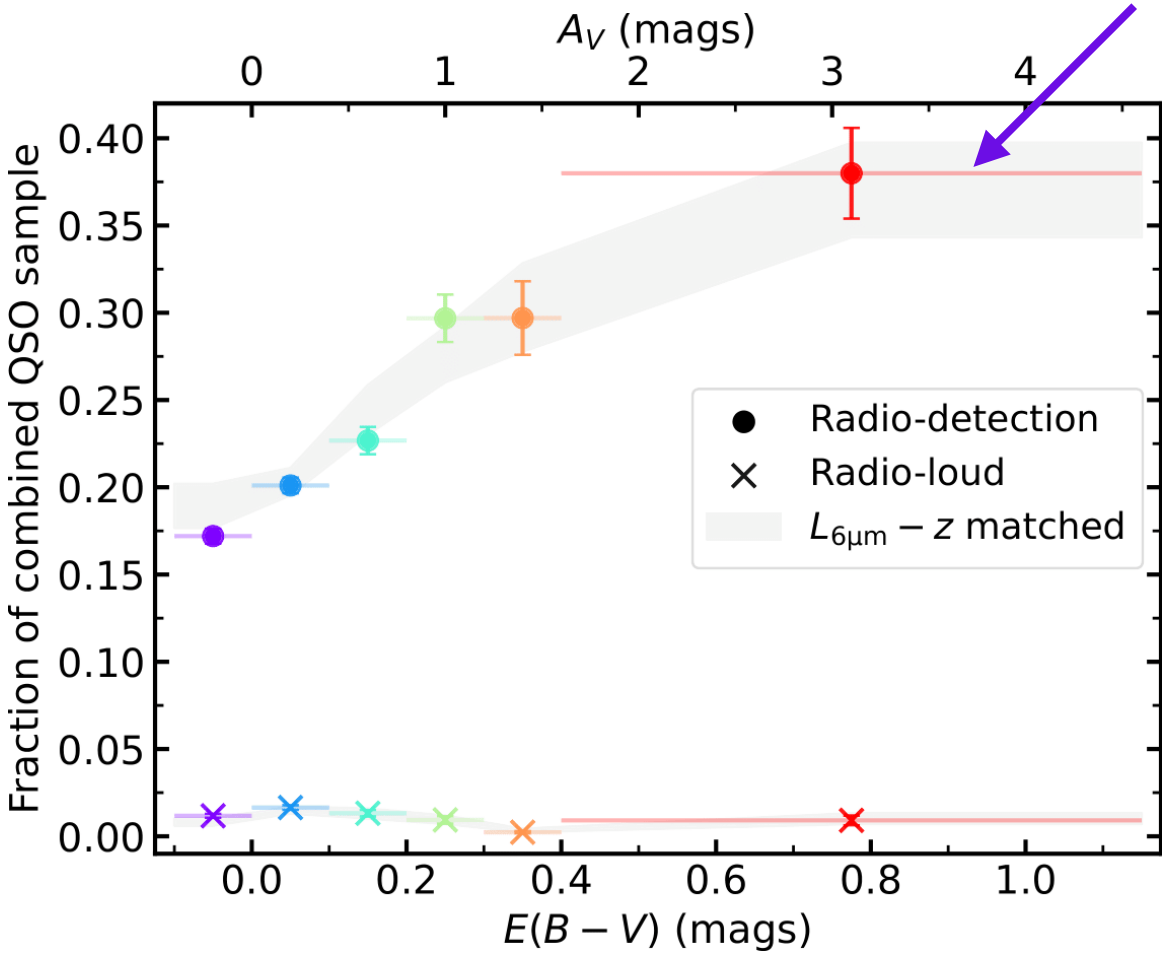


Future work with the Multi-Object Optical and Near-IR Spectrograph (MOONS)

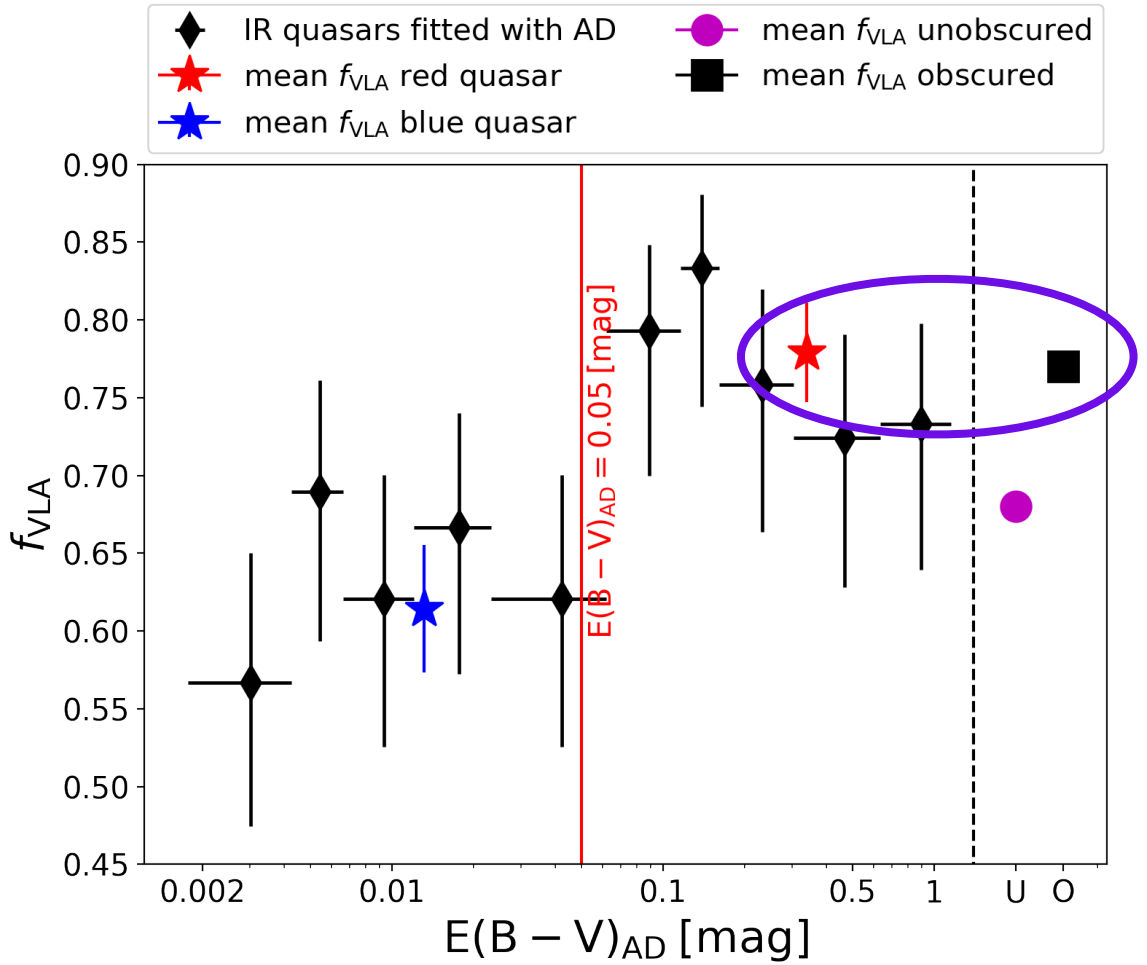


- Better constraint of the continuum and underlying dust extinction curve
- For QSOs with 1.5<z<2.5, both [OIII] and CIV will be present which can be used to simultaneously probe outflows at kpc and sub-pc scales

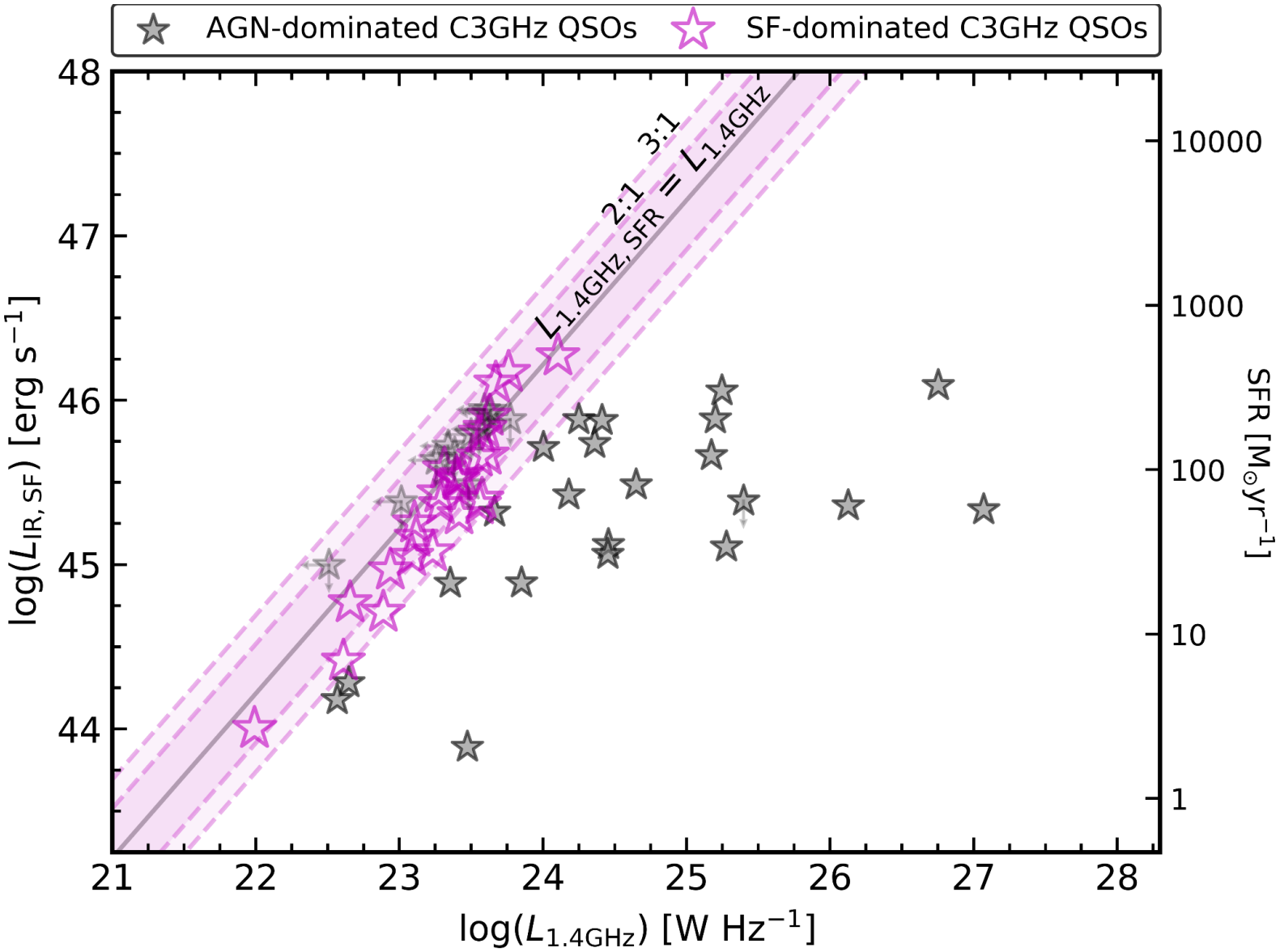
“Saturation” point?



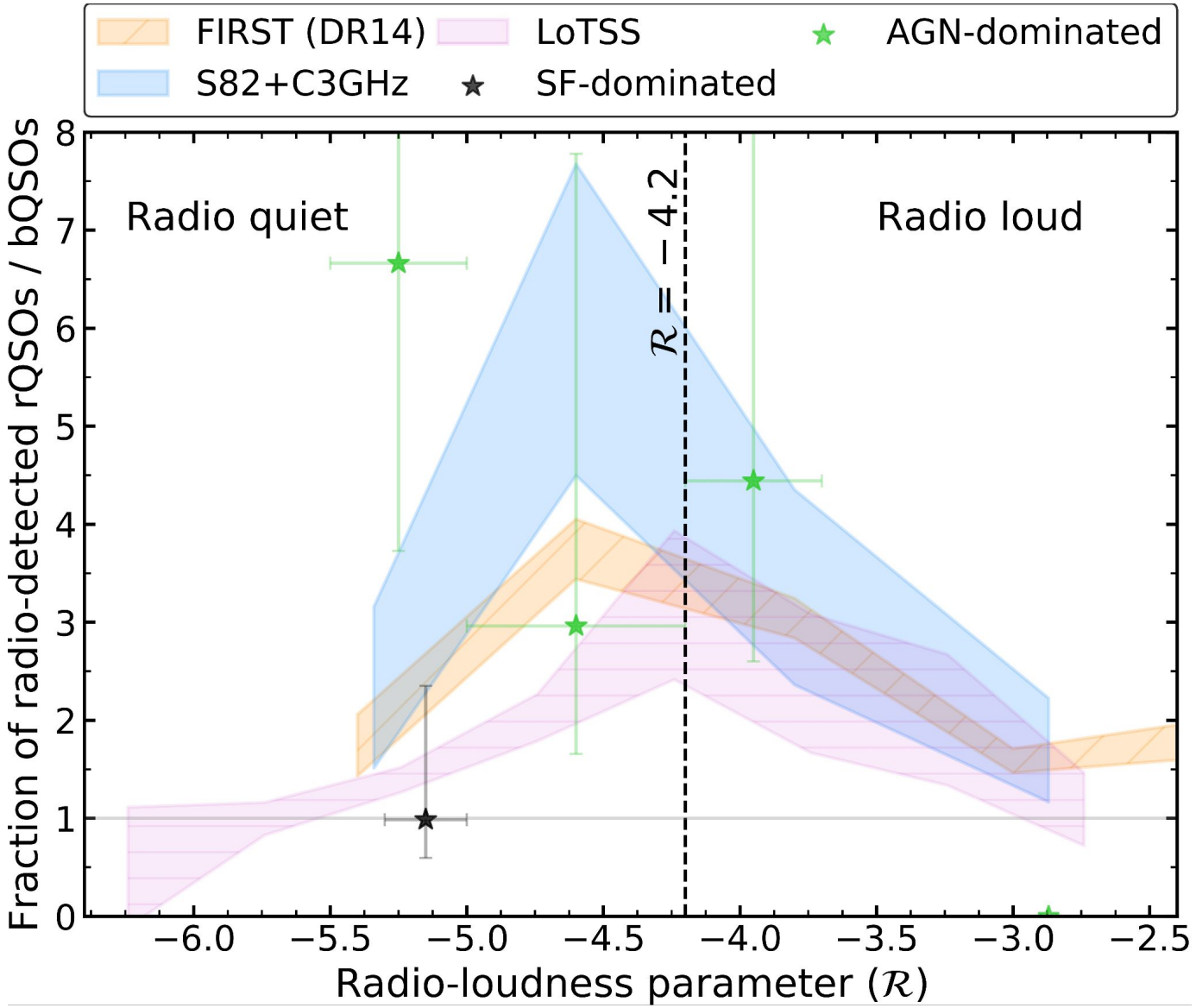
Fawcett+23



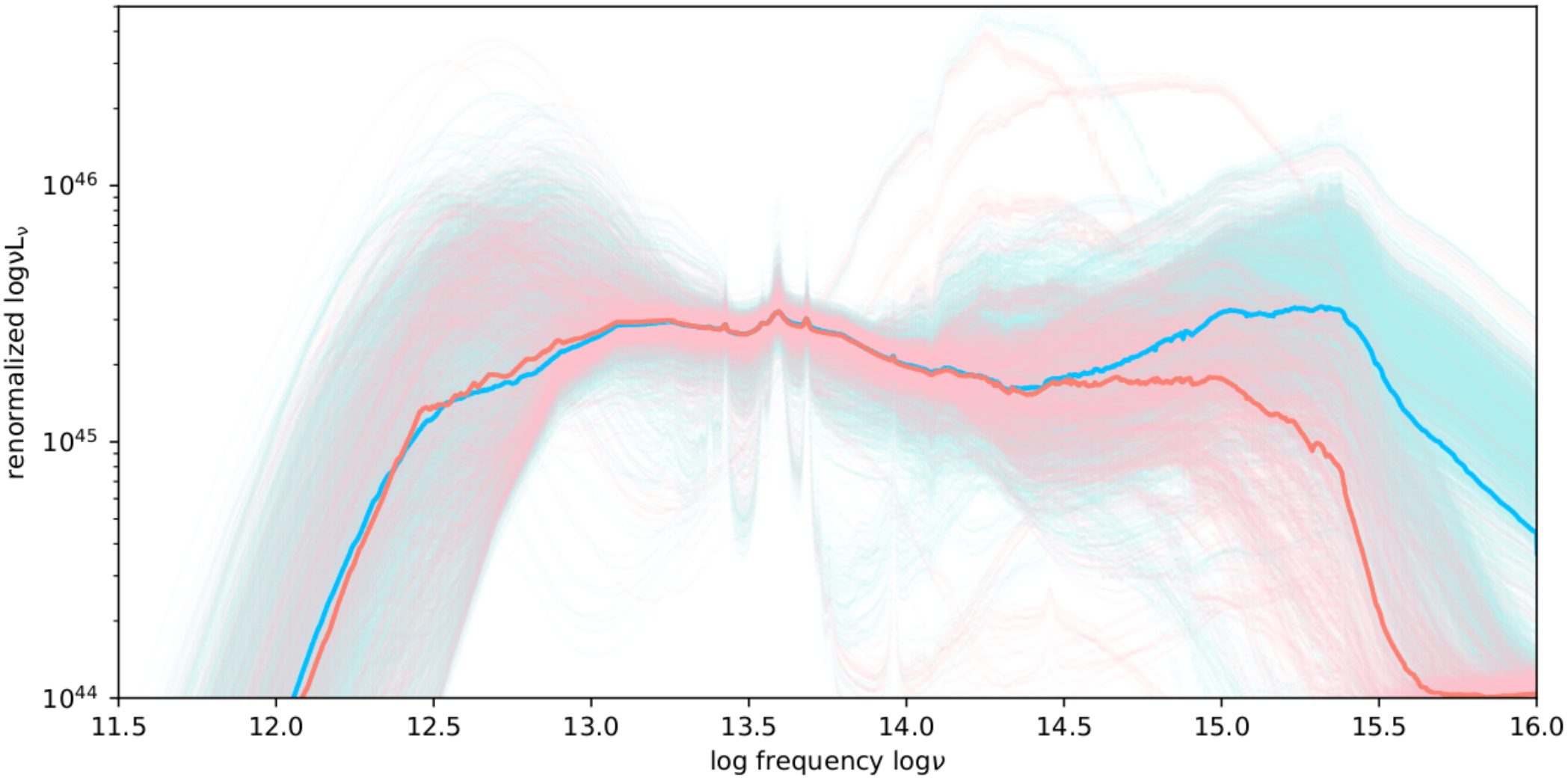
Andonie+22

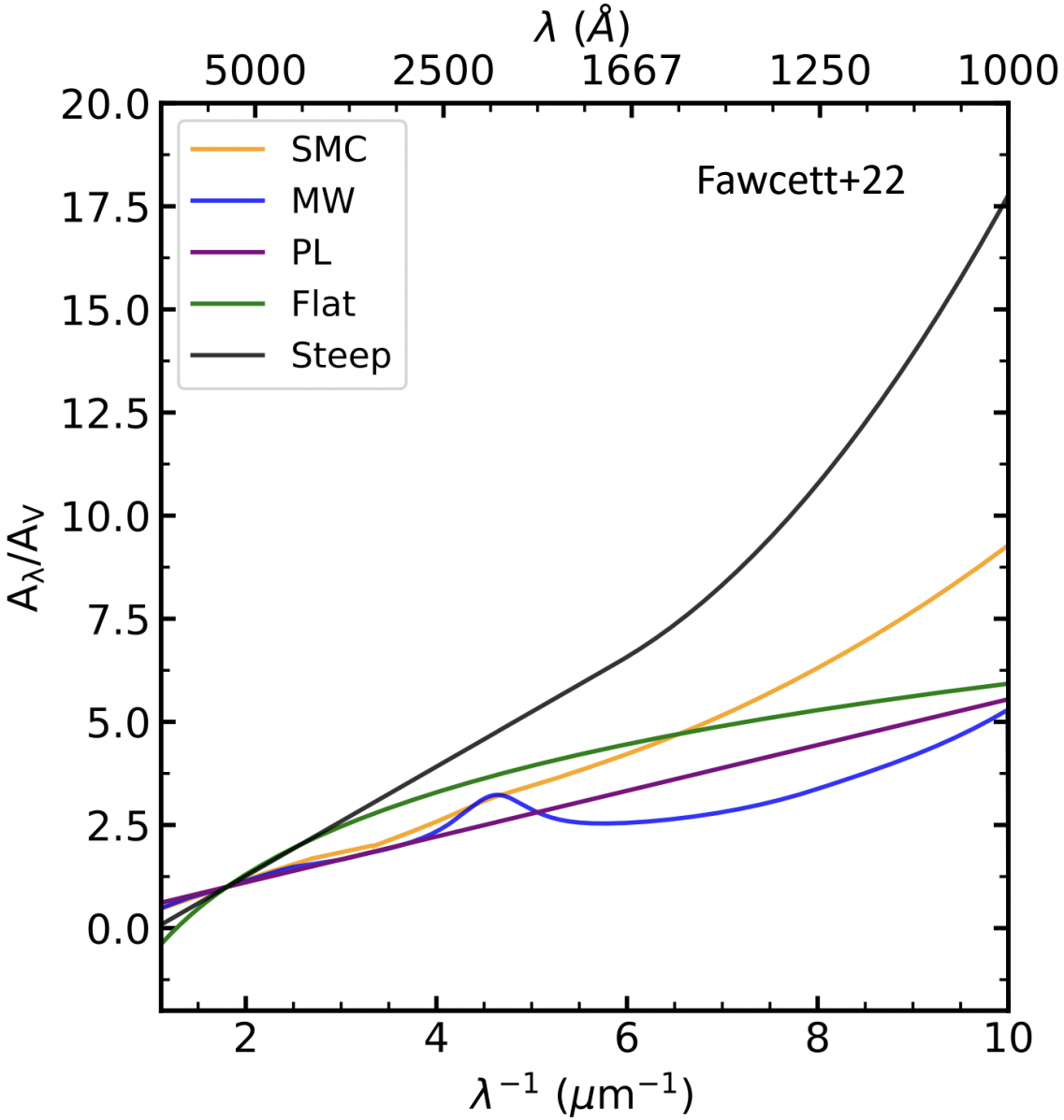

AGN-dominated C3GHz QSOs
SF-dominated C3GHz QSOs
3:1
2:1
$L_{1.4GHz, SFR} = L_{1.4GHz}$
$\log(L_{IR, SF})$ [erg s^{-1}]
SFR [$M_\odot yr^{-1}$]
$\log(L_{1.4GHz})$ [W Hz^{-1}]
48
47
46
45
44
21
22
23
24
25
26
27
28
10000
1000
100
10
1

- Enhanced radio emission in rQSOs at R = -5 to -4
- Decrease in enhancement at radio-loud and radio-quiet ends



Calistro Rivera+21



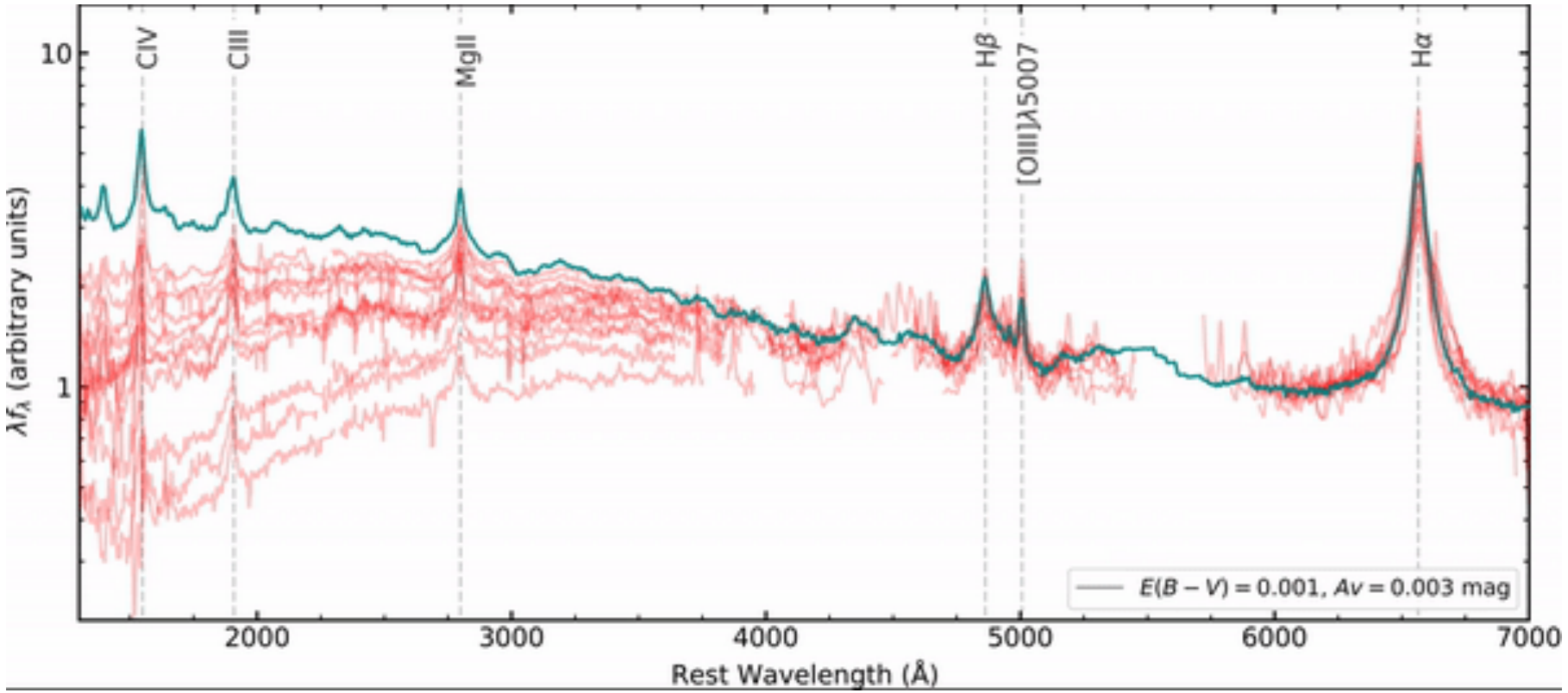


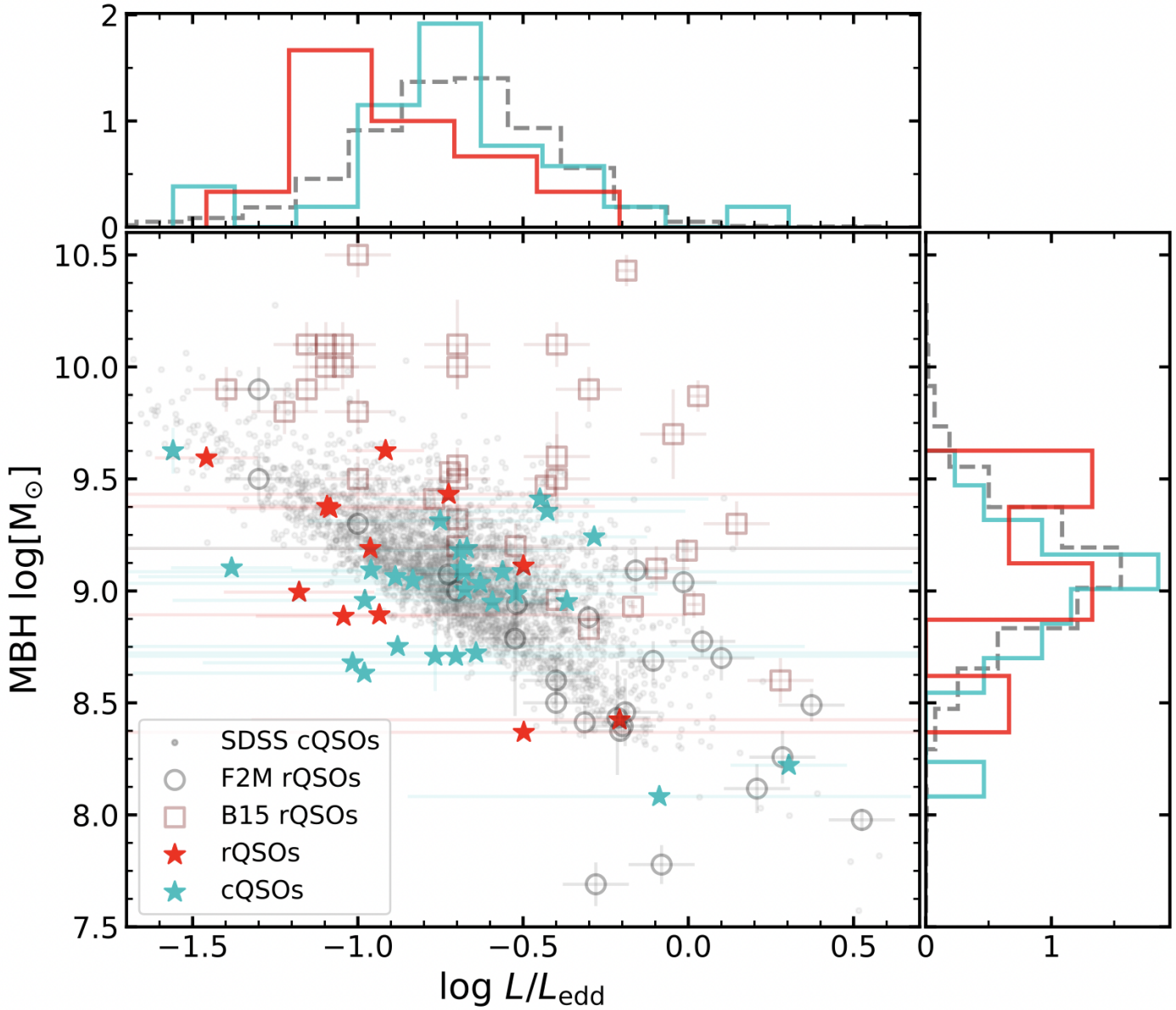
Red QSOs prefer a steep or SMC-like dust extinction curve

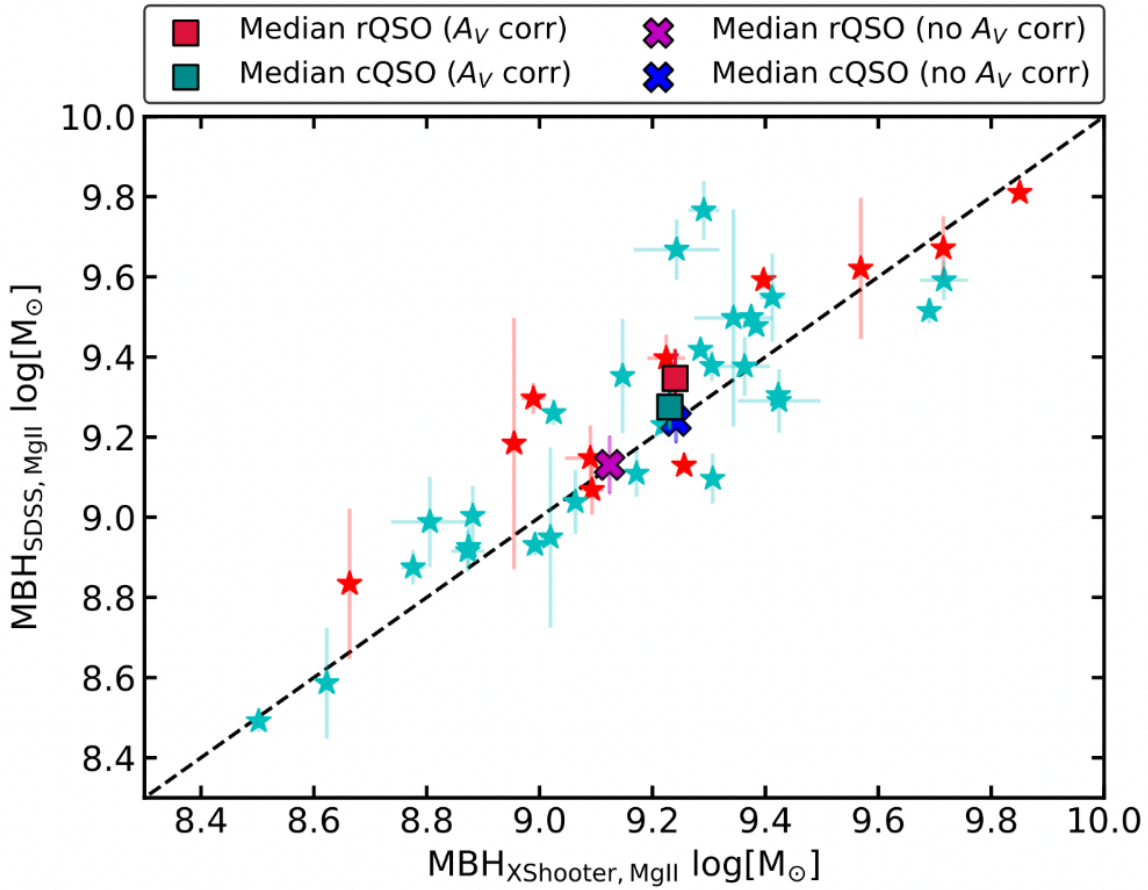
-> implies the dust is predominantly composed of smaller silicate grains

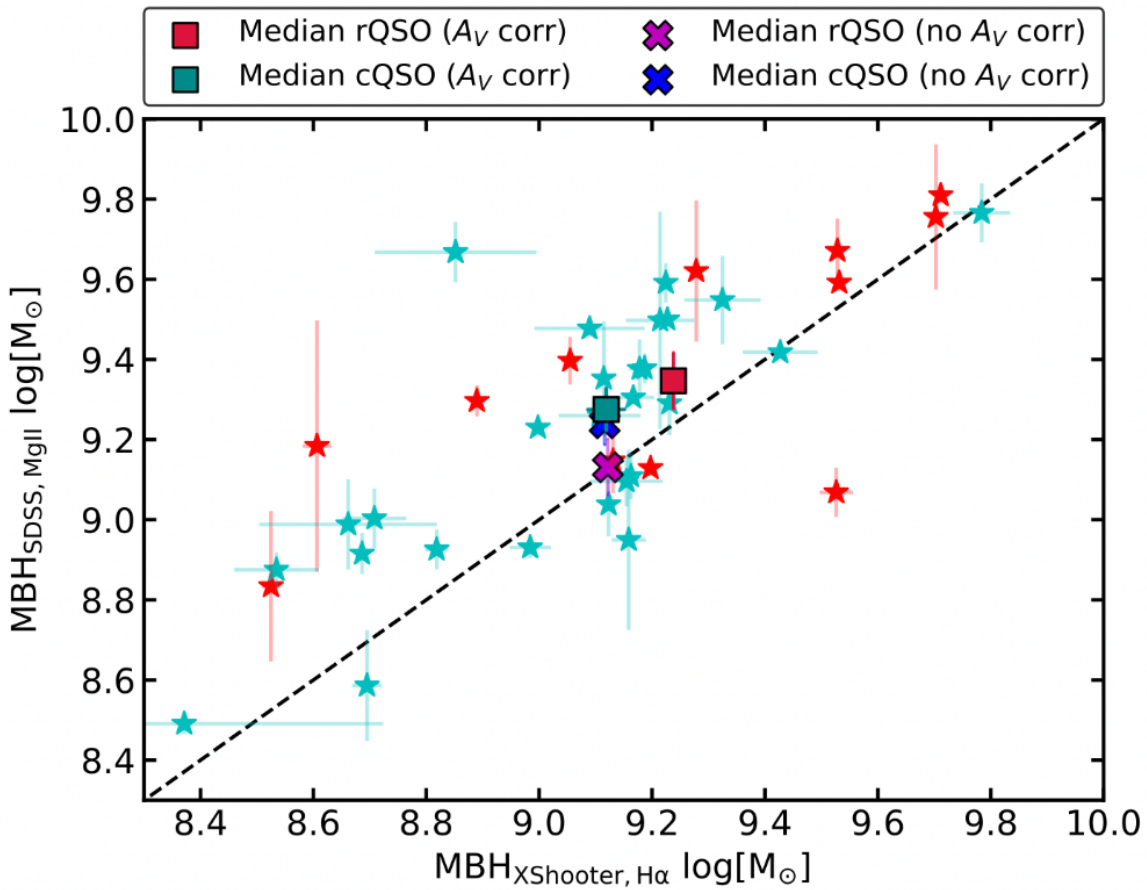
Red QSOs are consistent with dust reddened blue QSOs (Av~0.1-0.6 mag)

Fawcett+22




MBH log[M$_\odot$]
log L/L_{edd}
SDSS cQSOs
F2M rQSOs
B15 rQSOs
rQSOs
cQSOs





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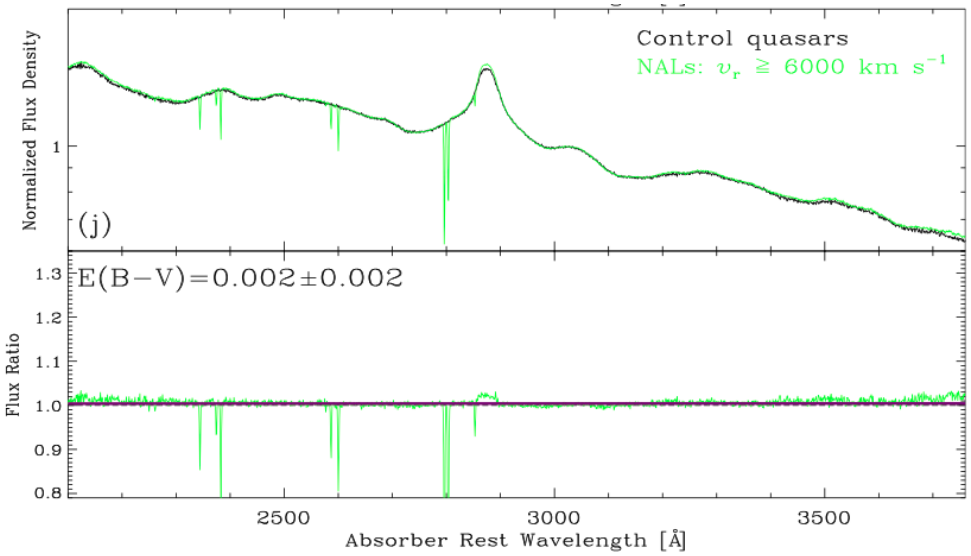
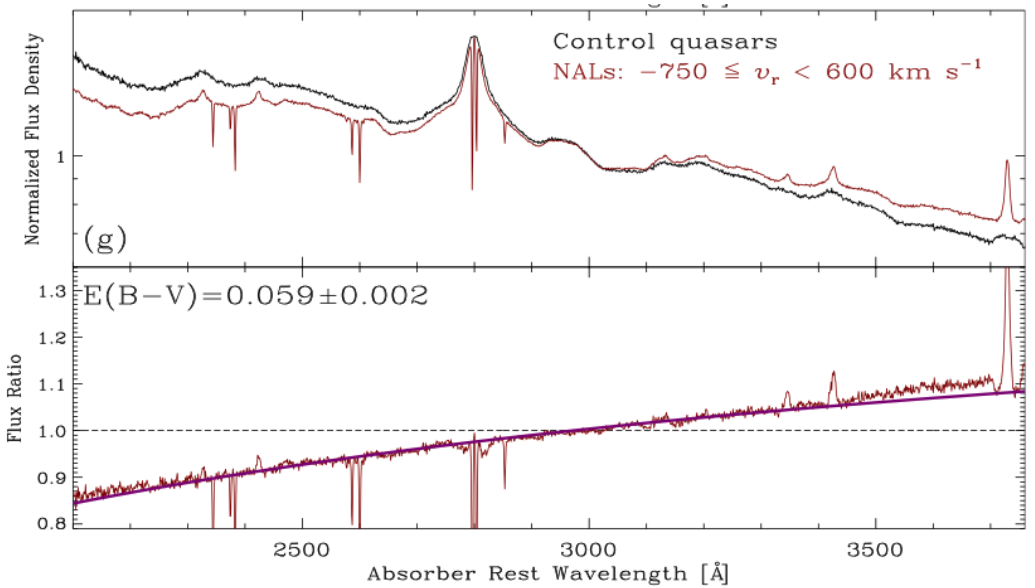


Intervening

Chen et al. (2020)



Associated