# HIGH-Z QUASARS IN MULTI-WAVELENGTH SURVEYS: CONNECTING THE PC TO KPC SCALES

Manda Banerji

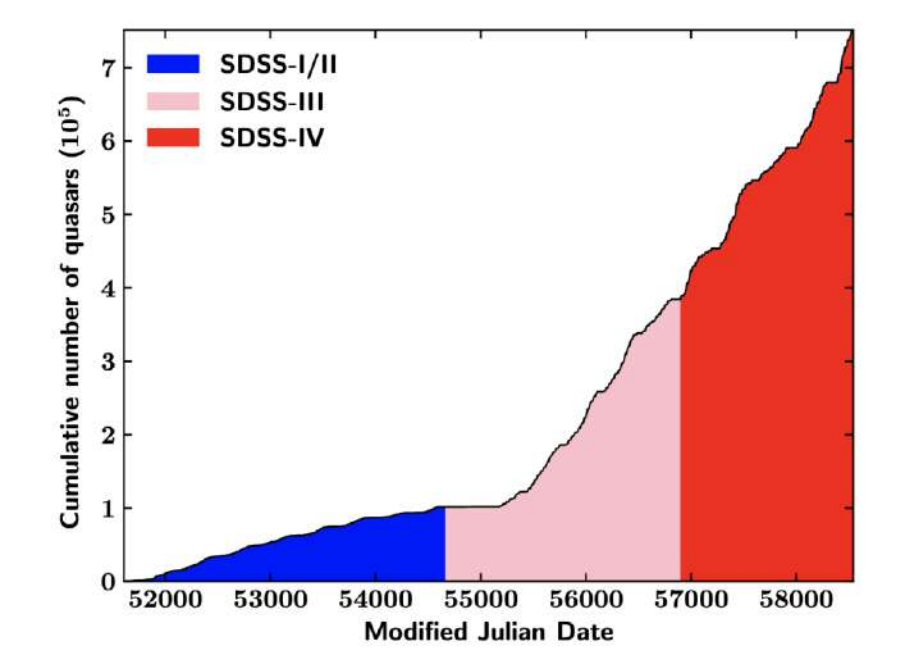
(University of Southampton)

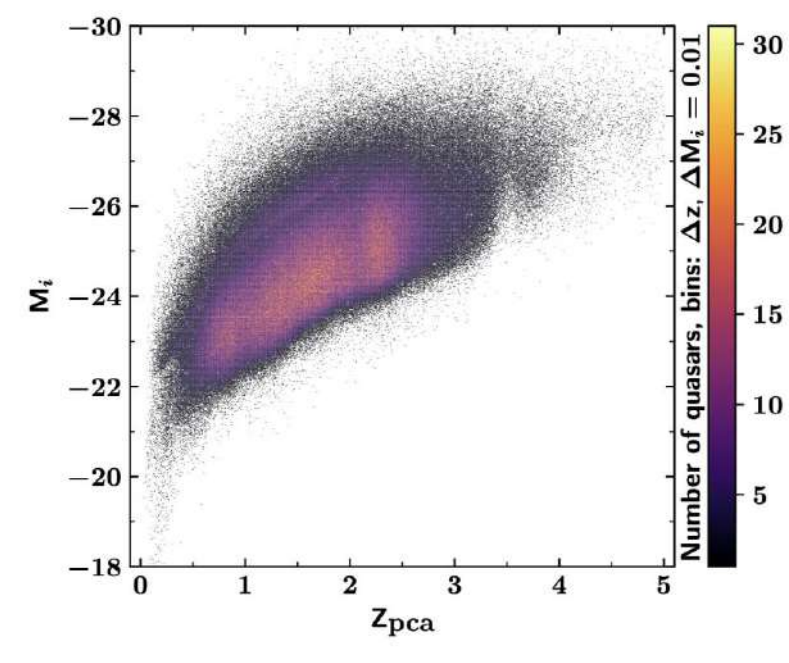
**Matt Stepney (Southampton), Shenli Tang (Southampton), Stephen Molyneux (Southampton),** Matthew Temple (UDP Chile), Amy Rankine (U. Edinburgh), Paul Hewett (IoA, Cambridge), Gordon Richards (Drexel), James Matthews (Oxford)

# OUTLINE

- **High-z quasar demographics from large spectroscopic surveys**
  - Measuring accretion and outflow properties
  - Different tracers of outflows - broad emission lines, broad absorption lines, narrow emission lines
  - Evolution of outflow properties with luminosity, black hole mass, redshift
  - Molecular gas properties
- **Dusty and red quasars**
  - Differences in outflow properties between red and blue quasars?
  - Connecting black-hole and host galaxy properties via imaging, spectroscopy and molecular gas

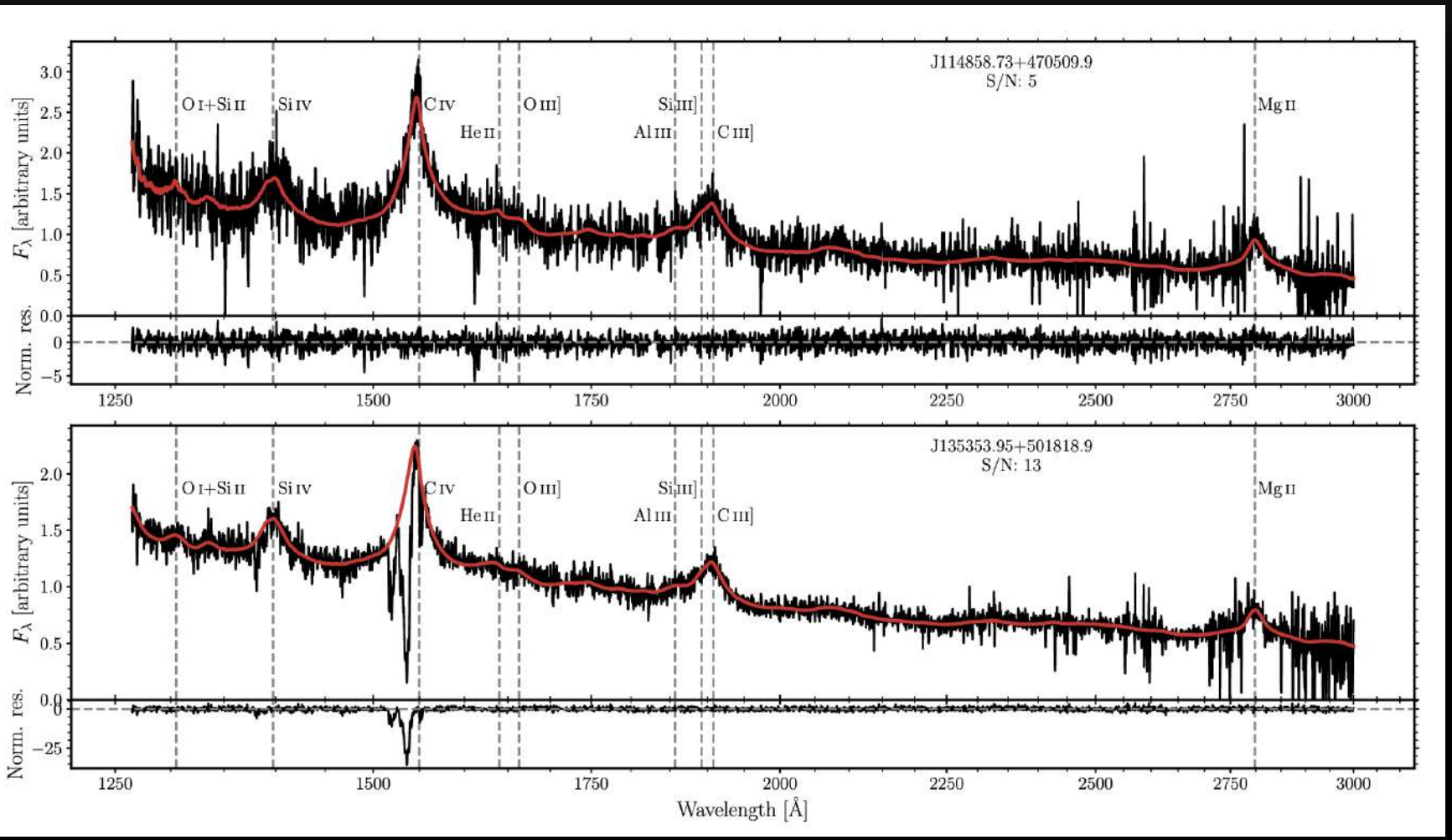
# THE SLOAN DIGITAL SKY SURVEY (SDSS)



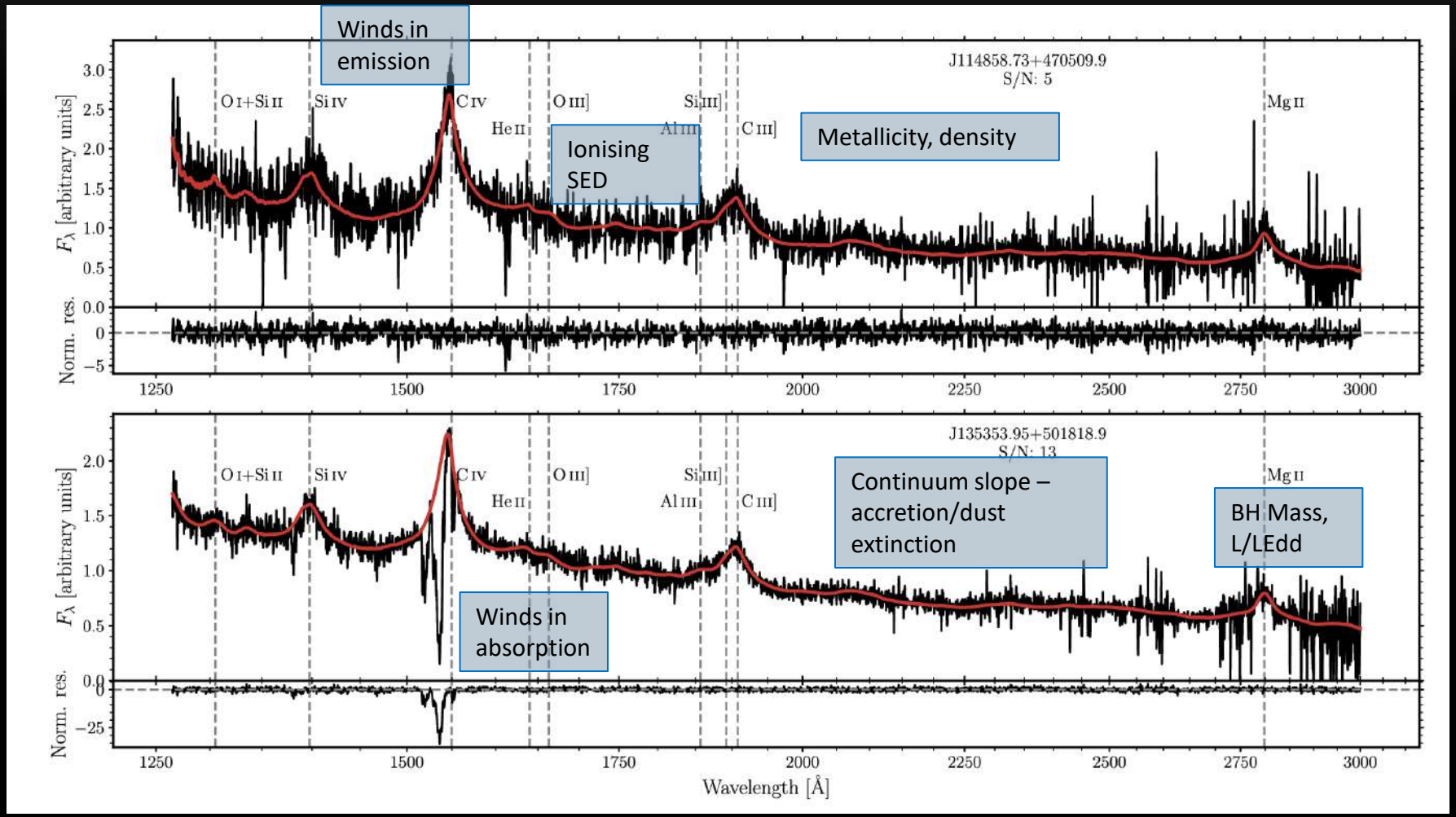

Data Release 16 contains spectra for 750k quasars covering an unprecedented range in luminosity and redshift (Lyke+20) – statistical studies of the high-redshift quasar population now possible

# REST-UV SPECTRA OF HIGH-Z QUASARS



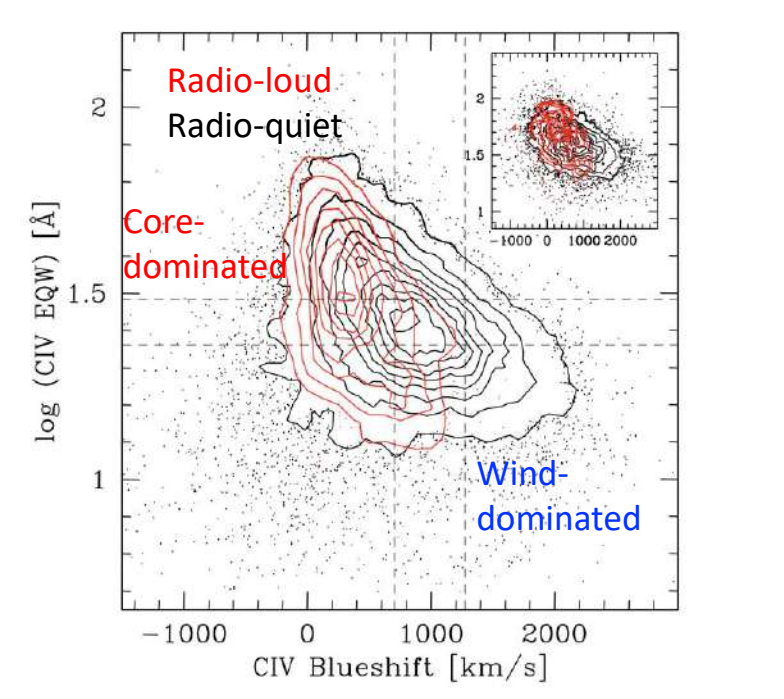

Richards+11; Shen+11; Coatman, Hewett, MB+16,17; Rankine (incl. MB)+20,21; Rakshit+20; Rivera+21,22; Temple, MB+21; Wu&Shen 22; Temple (incl. MB)+23; Stepney, MB+23;

# REST-UV SPECTRA OF HIGH-Z QUASARS

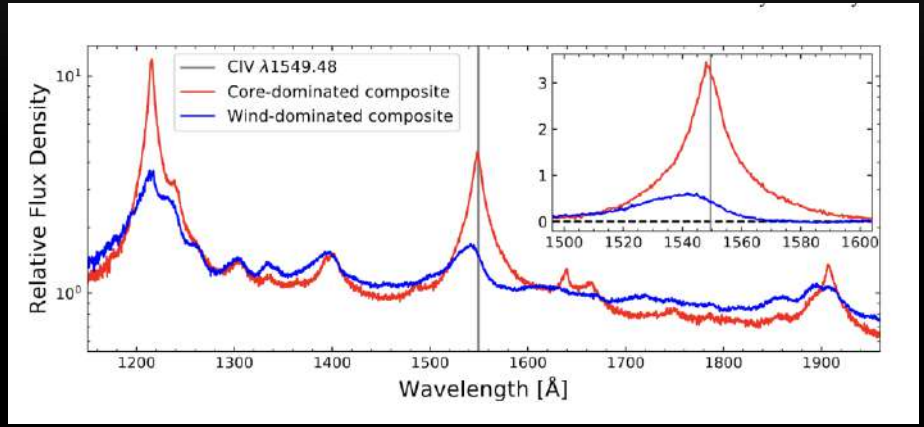



Richards+11; Shen+11; Coatman, Hewett, MB+16,17; Rankine (incl. MB)+20,21; Rakshit+20; Rivera+21,22; Temple, MB+21; Wu&Shen 22; Temple (incl. MB)+23; Stepney, MB+23;

# THE CIV EMISSION LINE SPACE



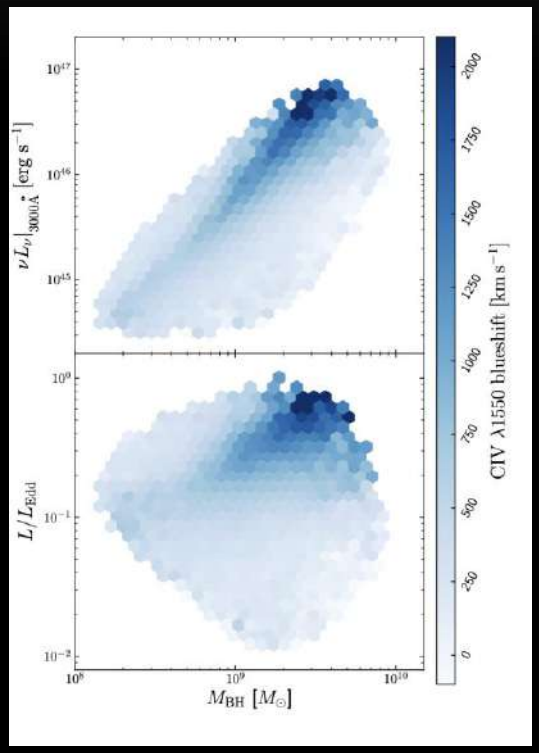

Richards+11, Rankine+20,21, Temple+21a,b, Temple+23

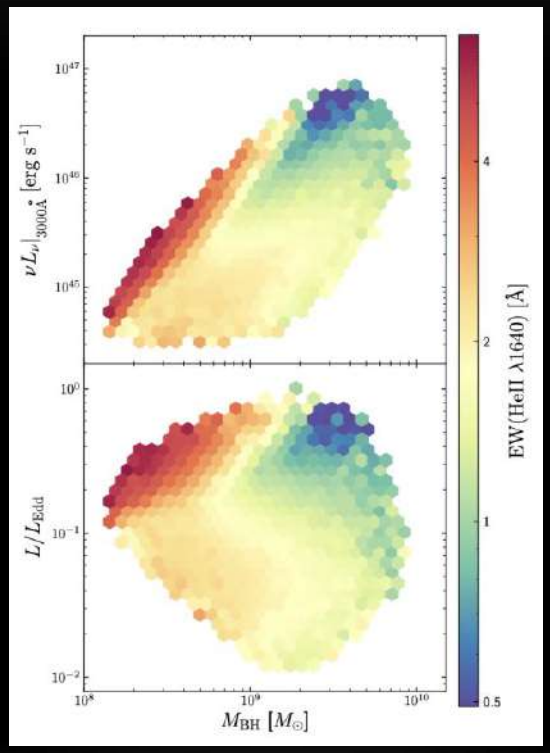



Quasars show systematic trends in the CIV emission line space of blueshift versus EW suggesting this space is tracing fundamental differences in quasar SED and black-hole/accretion properties

# SUB-PC SCALE WINDS DEPEND ON ACCRETION PROPERTIES

Temple, Matthews..MB..+23



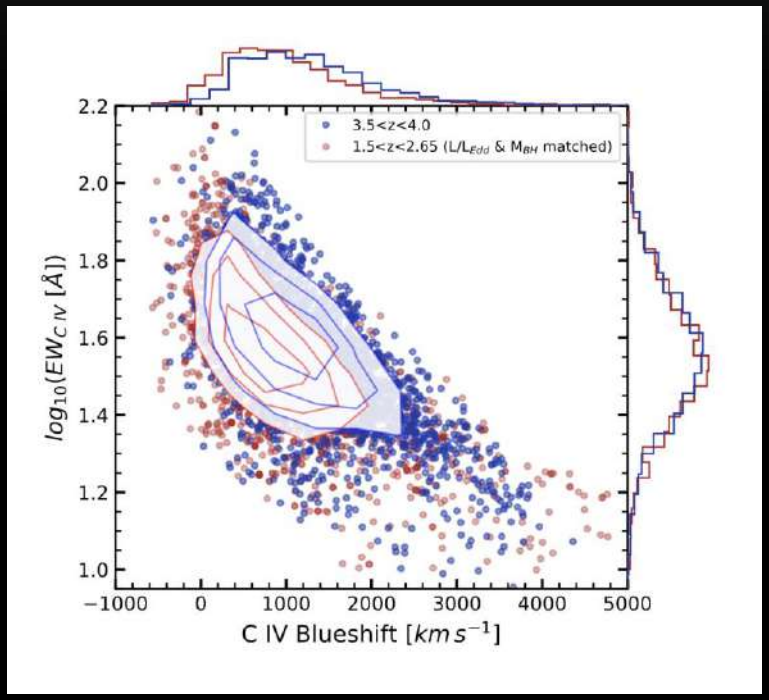



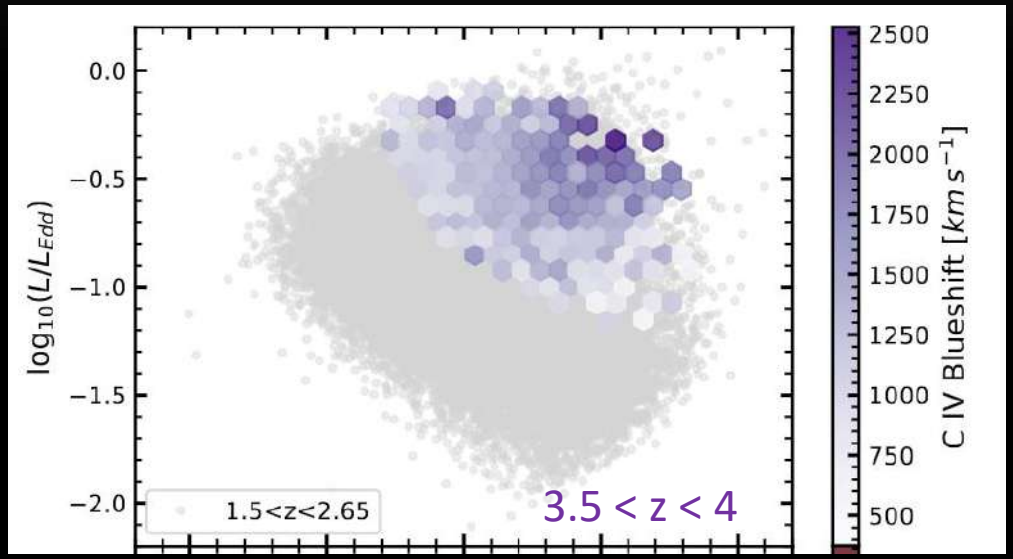

High blueshifts (strong radiatively-driven winds) observed at high black-hole masses and above a critical Eddington ratio of >0.25 consistent with theoretical predictions (e.g. Guistini & Proga 19)

For low MBH and high accretion rates we see increased HeII emission – harder ionizing SED and more line emission due to a failed wind?

# EVOLUTION IN EMISSION LINE PROPERTIES WITH REDSHIFT

Stepney, MB+23



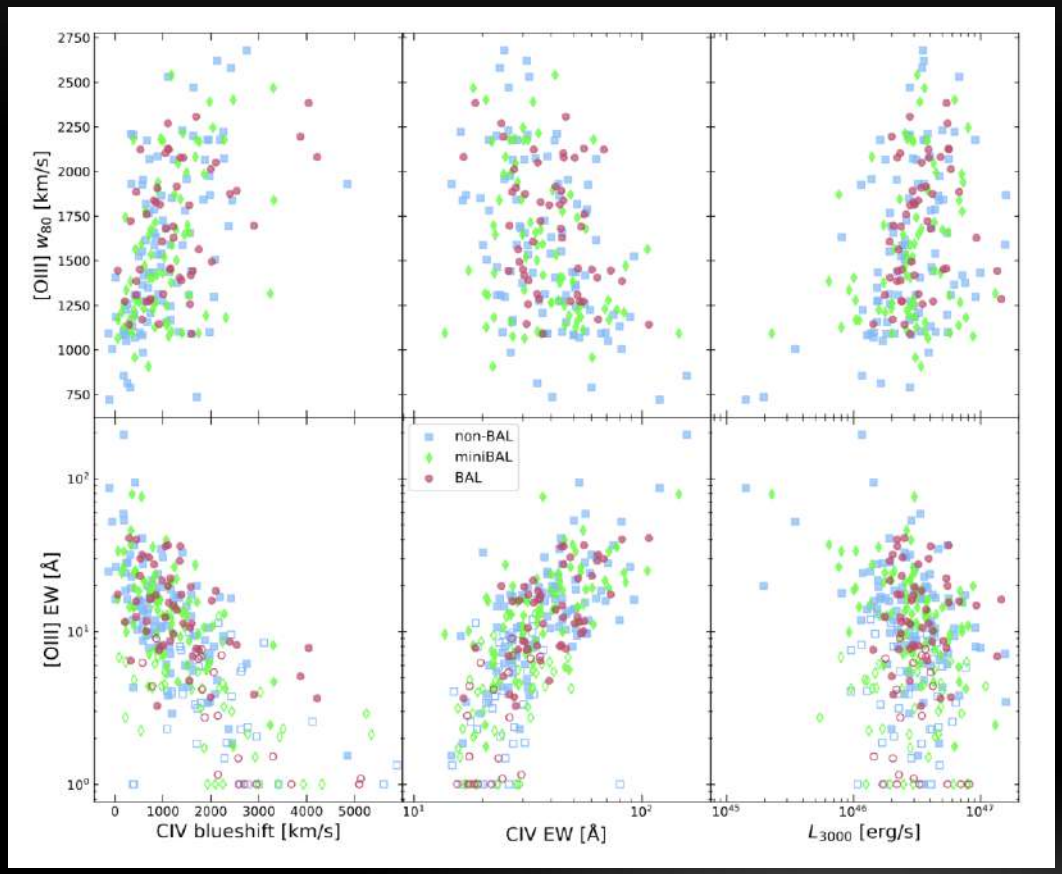




At z~4 (where statistical studies are possible) – no evidence for any redshift evolution in the UV line properties of quasars when we match in fundamental properties like black-hole mass and accretion rate.

4MOST AGN Survey (GTO) will obtain spectra for tens of thousands of z > 4 quasars starting in 2025 – also DESI, WEAVE

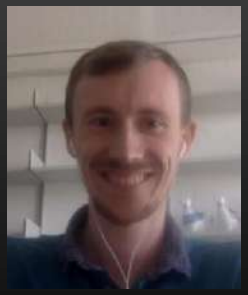
# KILOPARSEC SCALE OUTFLOWS VIA [OIII]

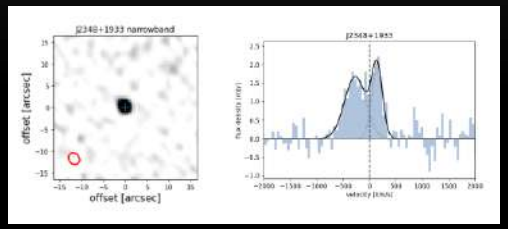
Temple, Rankine, MB+24, Submitted

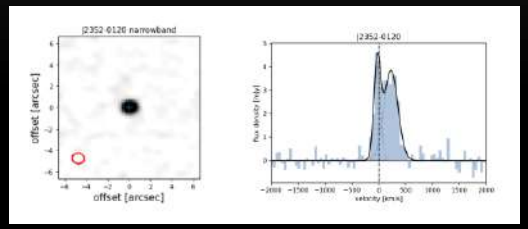


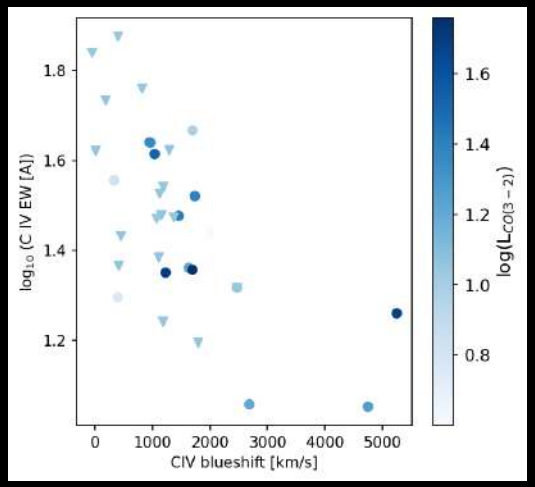

- NLR properties mapped in a large sample of ~330 luminous quasars from SDSS DR16 including 73 BALs and 120 mini-BALs
- Broad line region (CIV) and narrow-line region ([OIII]) outflow velocities are correlated (albeit with significant scatter). Correlation not purely driven by luminosity, which suggests BLR winds are able to propagate and influence properties on up to kpc scales
- No difference in the NLR properties between BALs and non-BALs

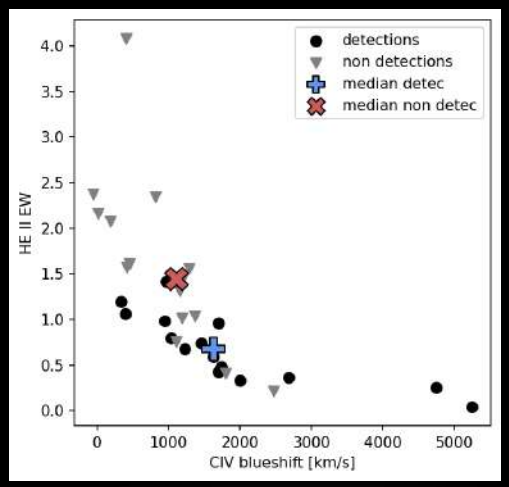
# MOLECULAR GAS IN LUMINOUS Z=2 QUASARS





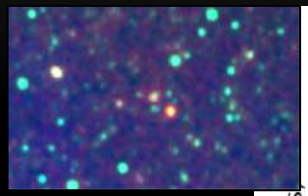



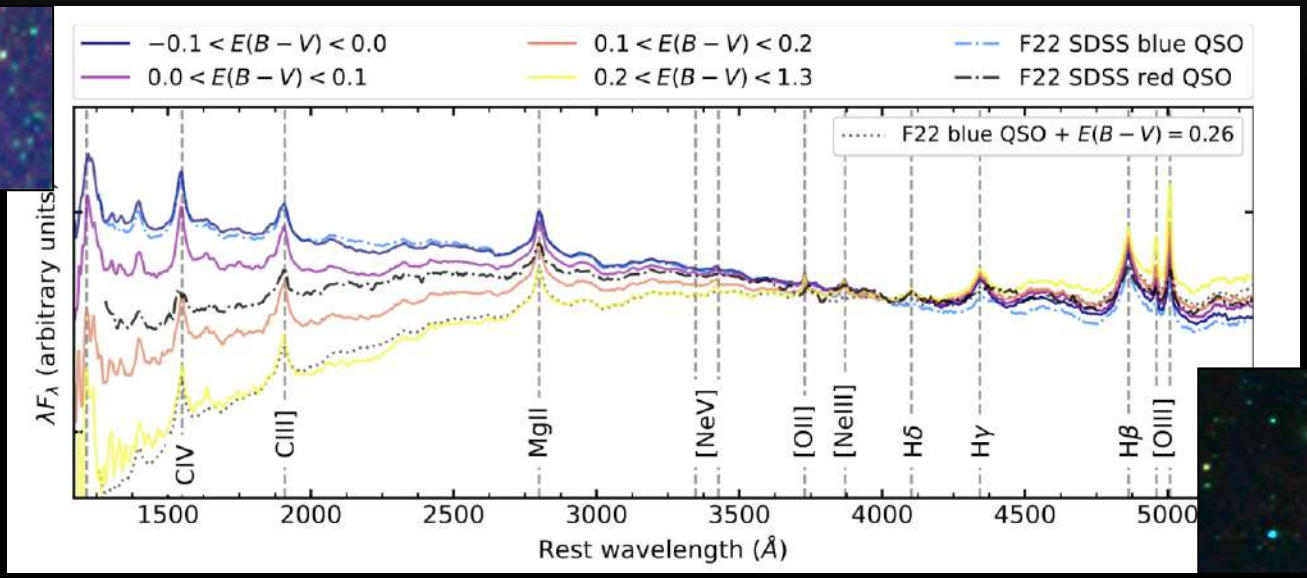

Molyneux, MB, Temple+ in prep

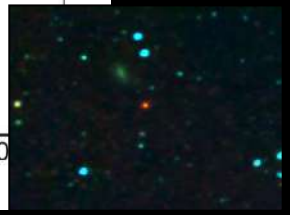
- ALMA Large Program to observe CO(3-2) in quasars across the CIV space – around 30 new quasars observed + archival data = 40 quasars at z=2
- No strong correlation in gas properties and UV line properties. Maybe tentative evidence that high ionizing SEDs are associated with gas-poor host galaxies while strong BLR outflows associated with gas-rich hosts.
- Detailed analysis ongoing

# DUSTY AND RED QUASARS

Fawcett+22





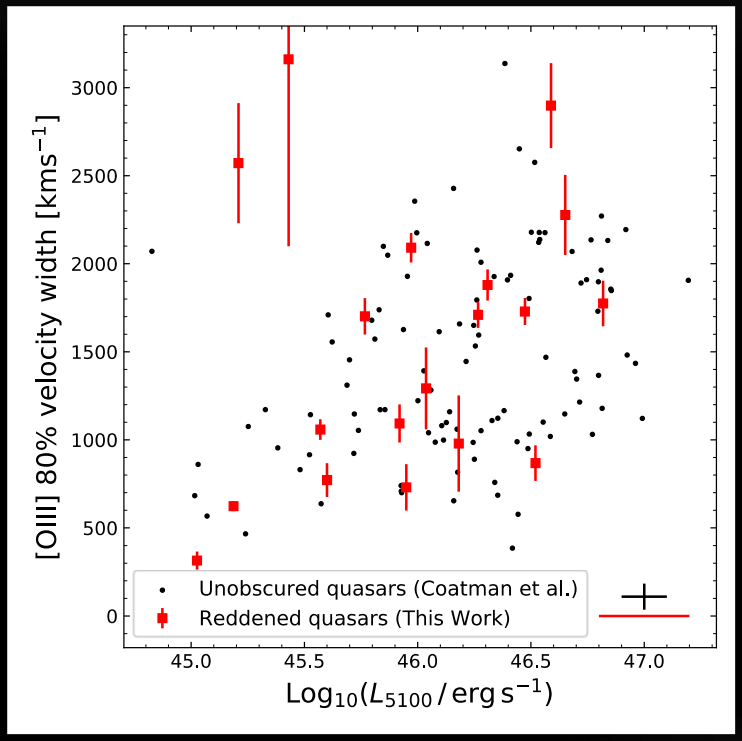



Sizeable populations of red/dusty broad-line (Type 1) quasars discovered using ground-based optical and infrared imaging and spectroscopic surveys (e.g. MB+12,13,15, Glikman+12,22; Fawcett+22, 23; Assef+15, LaMassa+17, Hamann+17, Temple+19…)

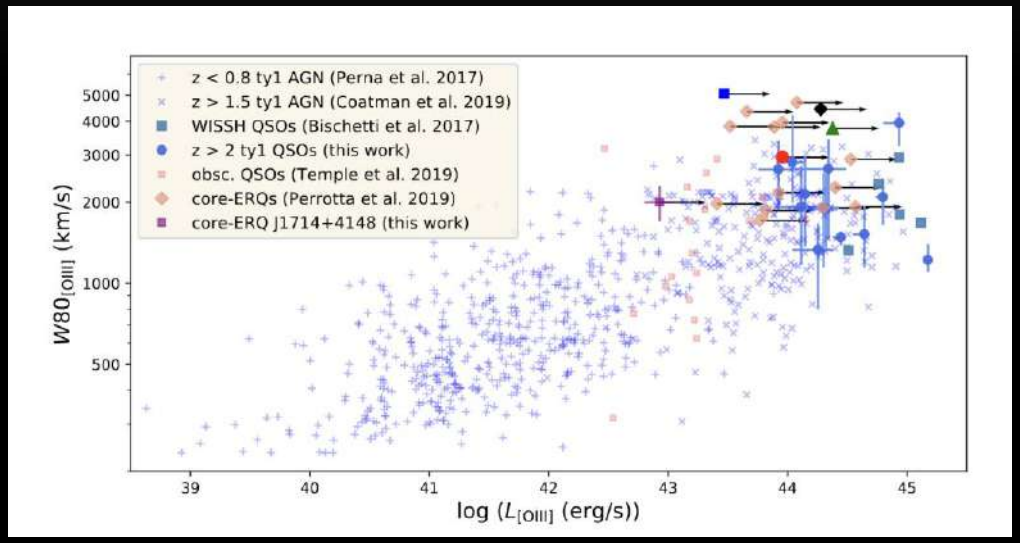
JWST now uncovering a very significant population of red AGN in the early Universe (e.g. Labbe+23, Greene+23) – 33% AGN among zphot > 5 selected galaxies!

# [OIII] OUTFLOWS IN DUSTY QUASARS

Temple, MB+19



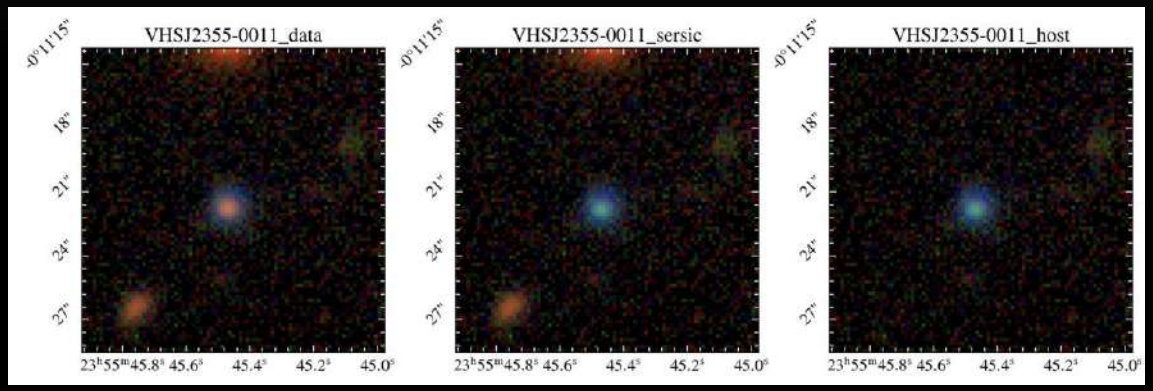

Villar-Martin+18

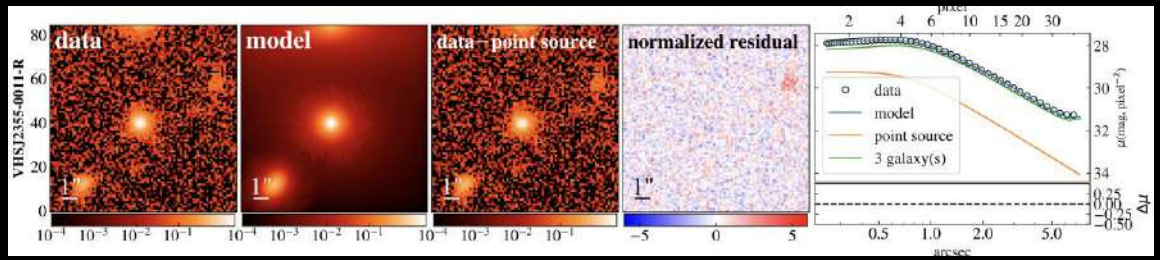



No evidence to suggest red/dusty quasars have stronger outflows compared to luminosity-matched blue quasars at similar redshifts

# HOST GALAXIES OF RED QUASARS WITH HSC

Tang, MB+ in prep




HSC imaging (~0.5” seeing) now allows us to resolve host galaxy emission in z=2 red quasars

>50 red quasars where we can already see resolved host galaxy emission in current imaging surveys (HSC, DECam)

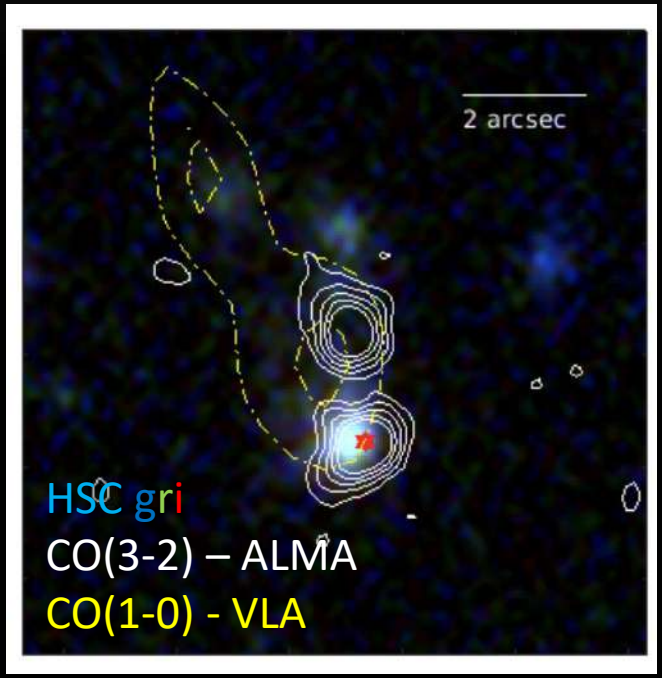
In some cases we even see evidence for mergers

See also Urrutia+08, Glikman+15, Zakamska+19 for results from space-based imaging

LSST+Euclid will provide exquisite imaging for many high-z quasar systems allowing host galaxies to be studied in detail in statistical samples

# HOST GALAXIES OF RED QUASARS FROM ALMA

MB+17, 18, 21




Detailed observations of a red (Av~5 mag) quasar at z=2.566

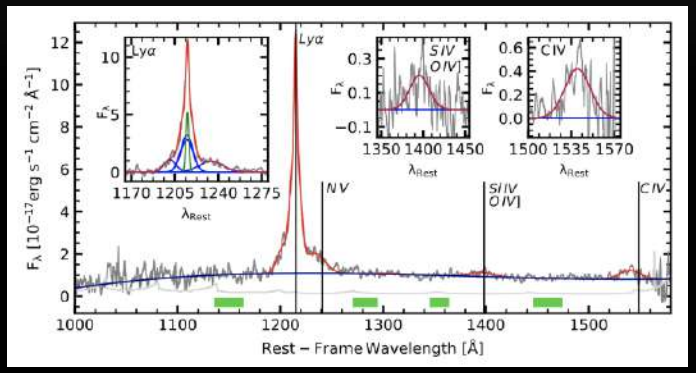
Multiple CO/CI transitions detected with ALMA and VLA

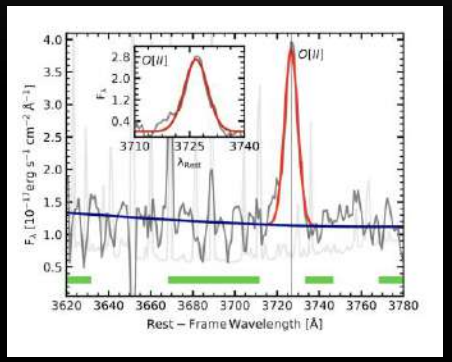
Major merger – 1:3 mass ratio, physical separation of ~15 kpc, velocity separation ~170 km/s

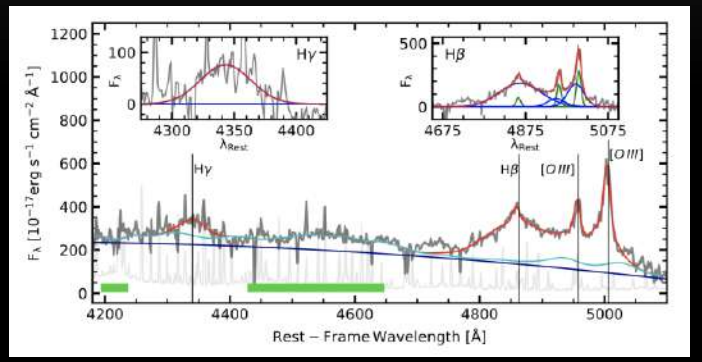
Extended rest-UV emission seen in HSC

# XSHOOTER VIEW OF A DUSTY RED QUASAR

Stepney, MB, Tang+ in prep




10 hr Xshooter spectrum of a dusty red quasar, ULASJ2315 at z=2.56 covering rest-frame UV to rest-frame optical

- Broad Balmer emission lines -> massive black hole
- Broad blueshifted CIV emission -> strong outflows in quasar broad-line region
- Blue wings in [OIII] emission -> strong outflows affecting the narrow-line region gas
- [OII] emission – star formation in host galaxy
- Faint UV continuum inconsistent with dust-reddened quasar – scattered/leaked quasar light + star formation?
- Very strong, high EW Lya emission – star formation?

MOONS AGN Survey (GTO) will obtain spectra for thousands of dusty/red quasars starting 2024/25

# SUMMARY

- Current and future wide-field imaging and spectroscopic surveys provide rich datasets within which to explore correlations between accretion and multi-phase, multi-tracer outflow properties in luminous, high-z quasars

- Dusty and red quasars offer a unique opportunity to simultaneously study black-hole and host galaxy properties in luminous quasars at cosmic noon

- Current and forthcoming surveys and facilities e.g. DESI, WEAVE, 4MOST, VLT-MOONS, JWST, ALMA etc. will allow lots of progress in this area