Illuminating the Dark Ages: Quasars in the Epoch of Reionisation

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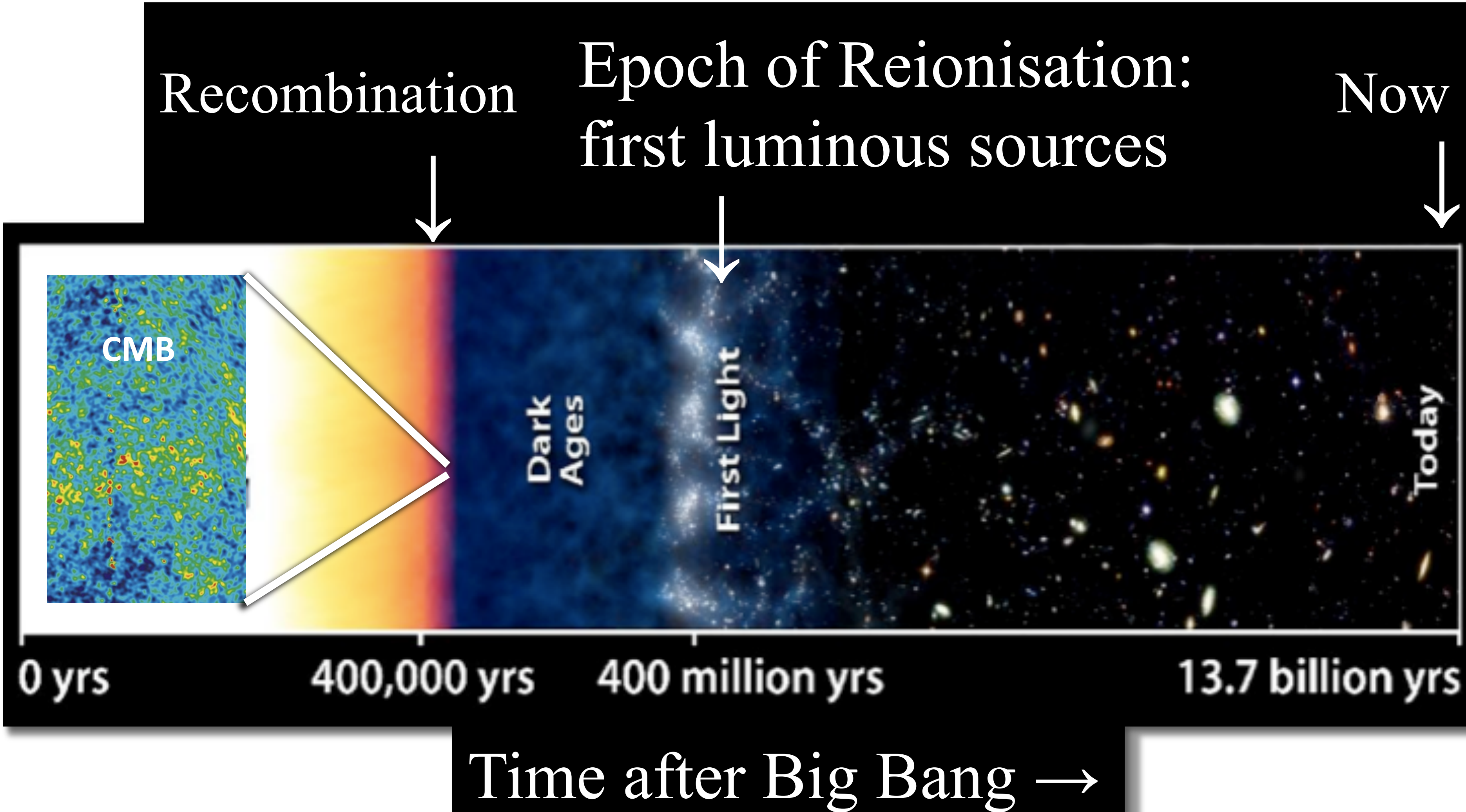
The Epoch of Reionisation



Distant quasars: probes of the early universe

- Quasars at redshifts $z \gtrsim 6$ can be used to:

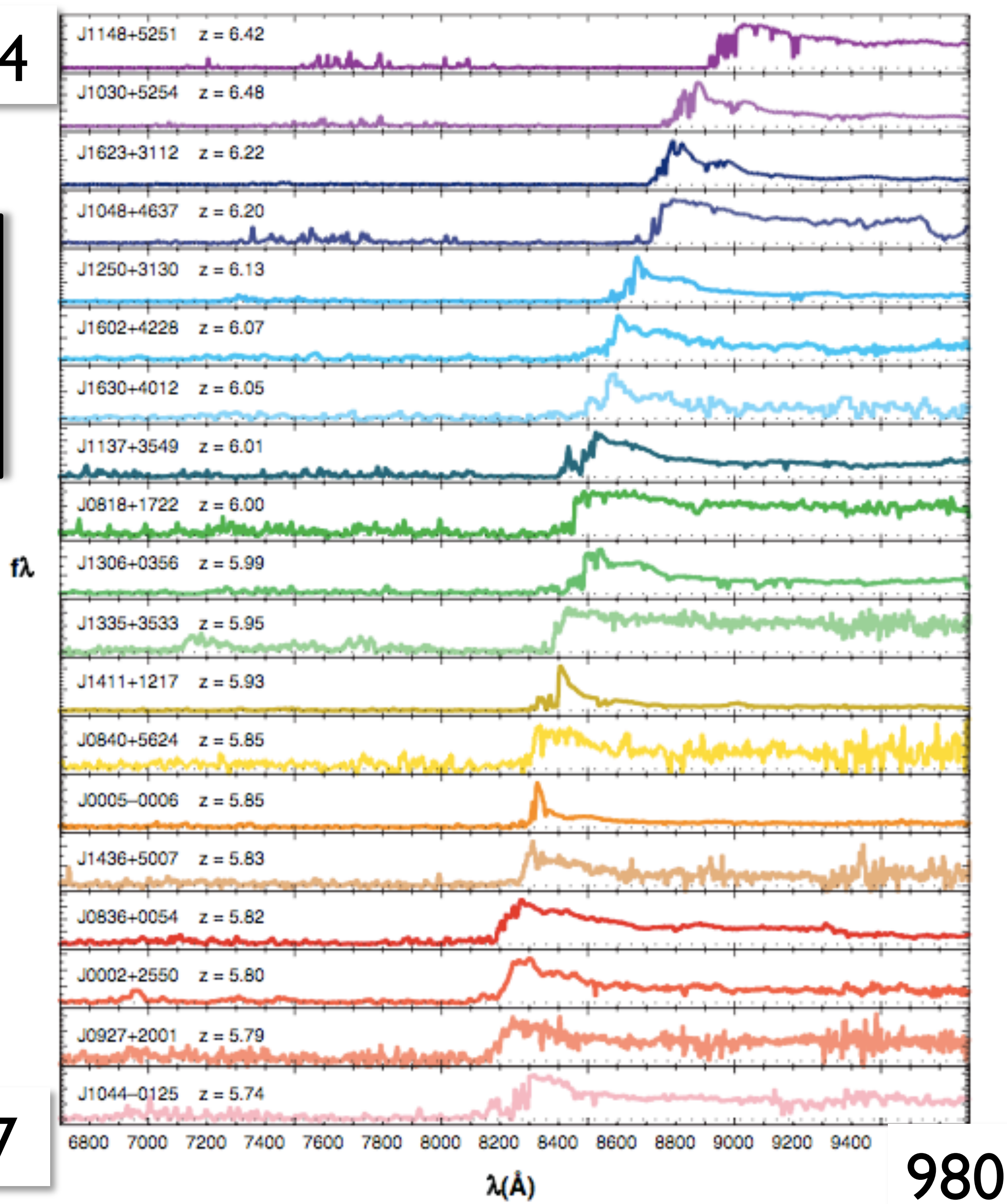
- determine the state of the intergalactic medium
- measure space density of massive black holes
- study the formation of massive host galaxies
- locate galaxy overdensities in the early universe

The search for distant quasars

- Problem: high redshift quasars are very rare
- Need multi-colour surveys over large area

→ SDSS very successful, discovered many luminous quasars up to $z = 6.4$

19 quasars at 5.7 < z < 6.4 from the SDSS survey



Fan, Carilli & Keating 2006

The search for distant quasars

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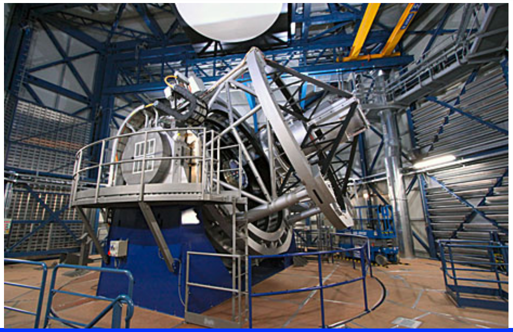
- To find quasars at higher redshifts, wide field NIR surveys are needed

Quasar searches in near IR surveys

- UKIDSS LAS: 4000 deg^2, J_{AB}~20.5
- VISTA/VIKING: 1500 deg^2, J_{AB}~21.5-22.0
- Pan-STARRS: 3π, y_{AB}~20.5-21.0
- Dark Energy Survey, Euclid, LSST, …



Pan-STARRS

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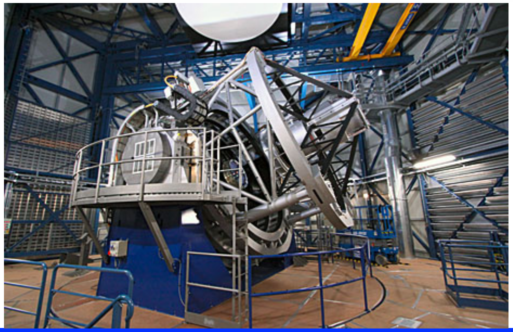

Pan-STARRS

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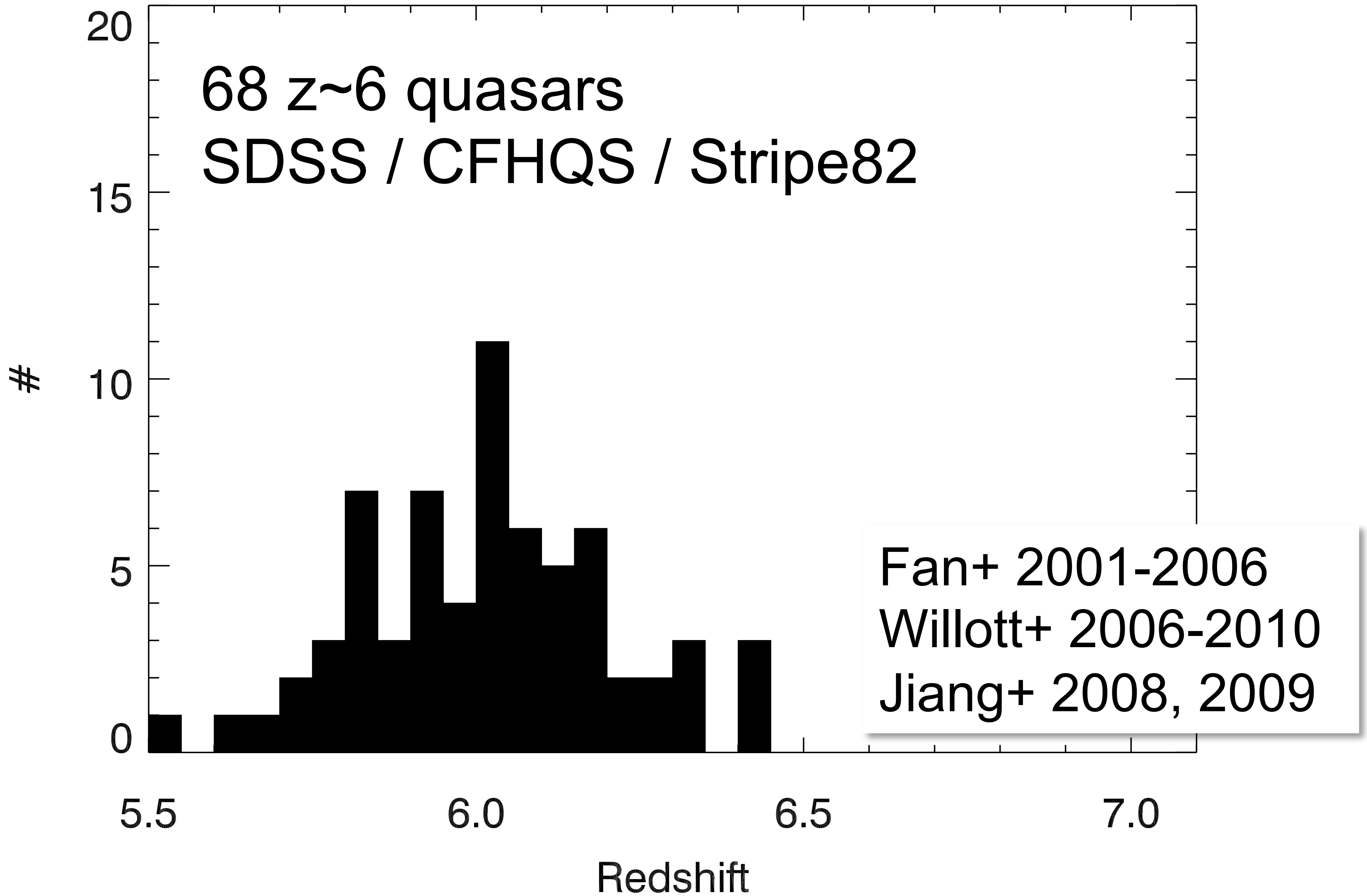

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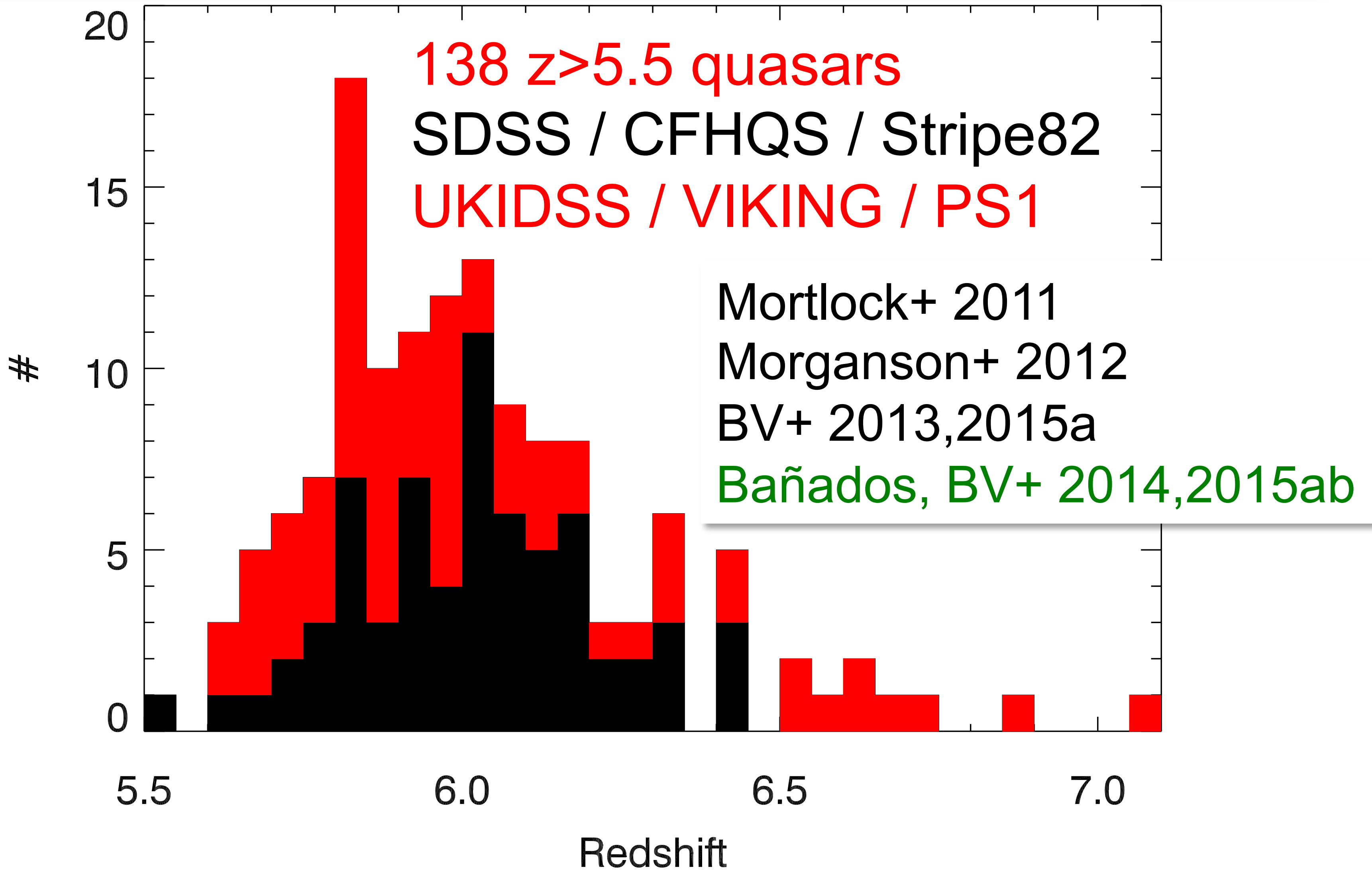
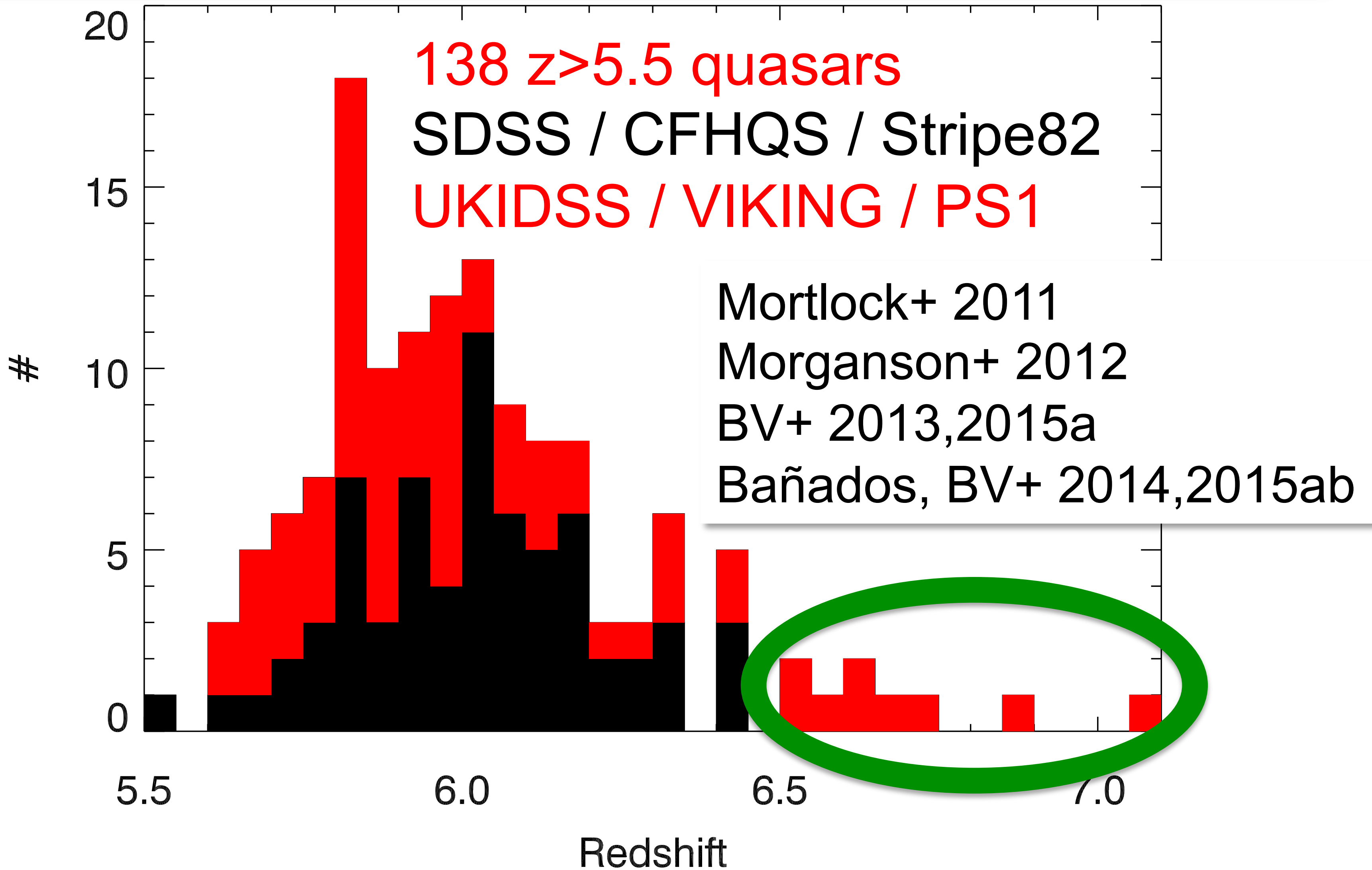


Quasar searches in near IR surveys



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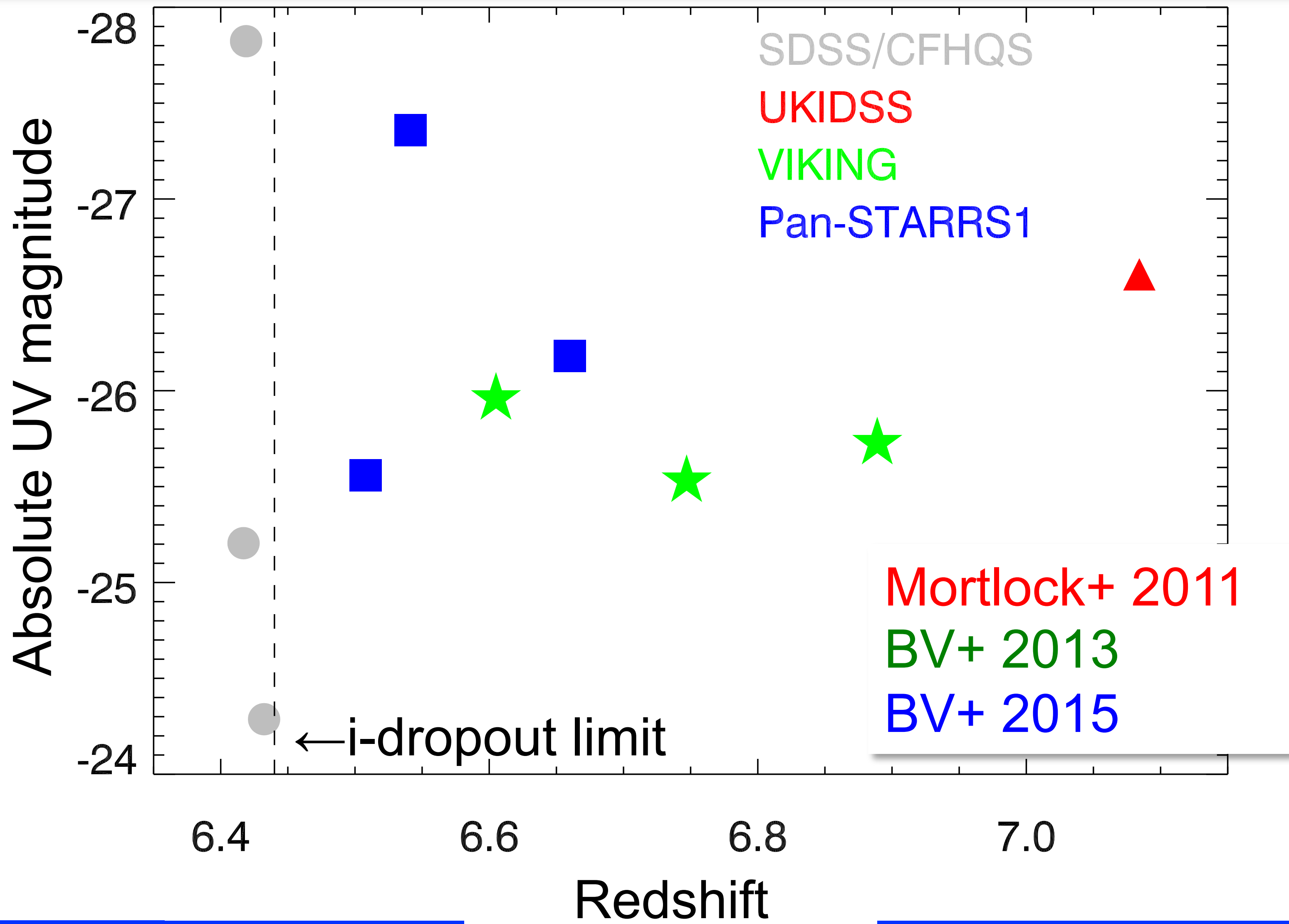

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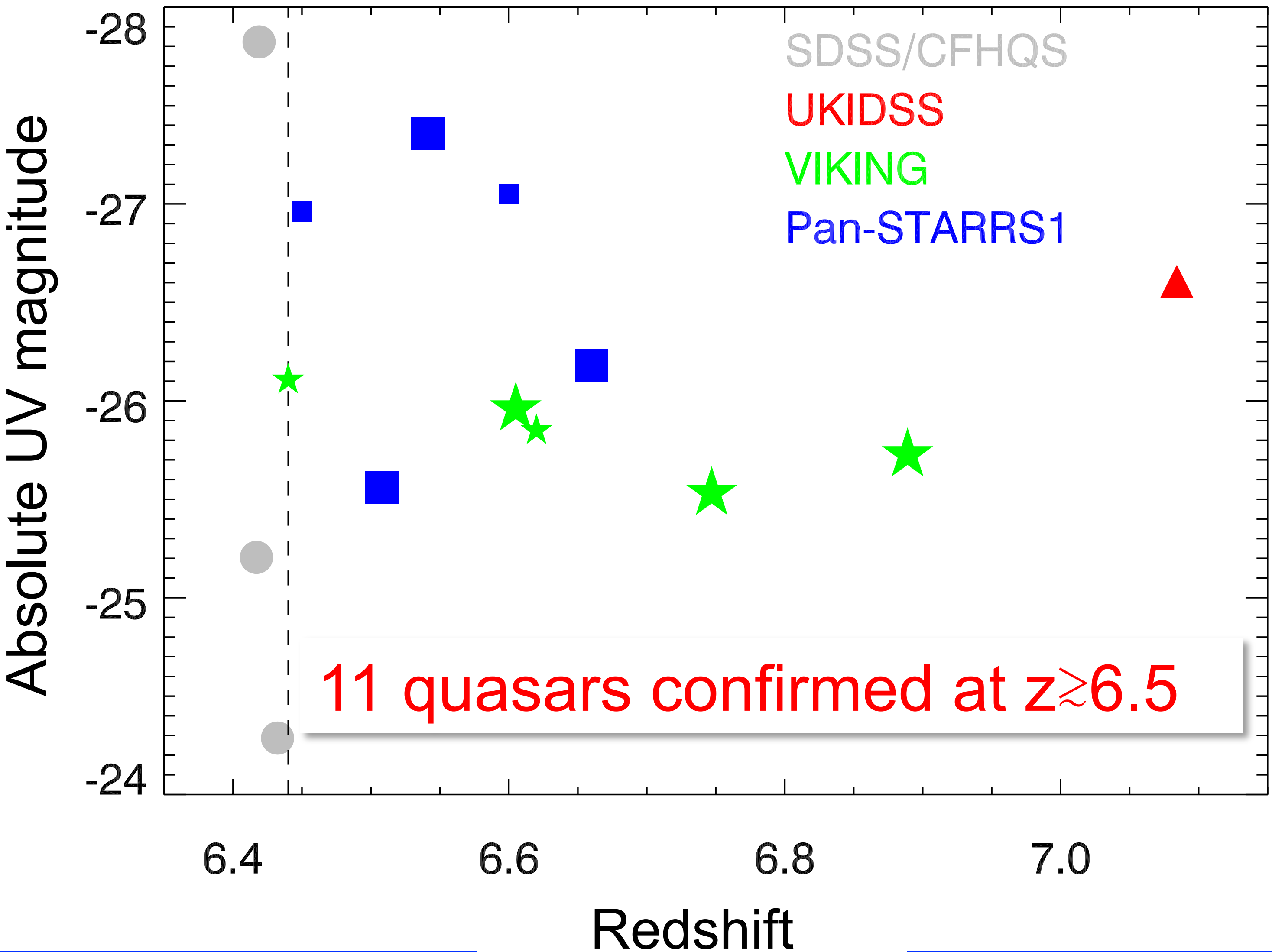
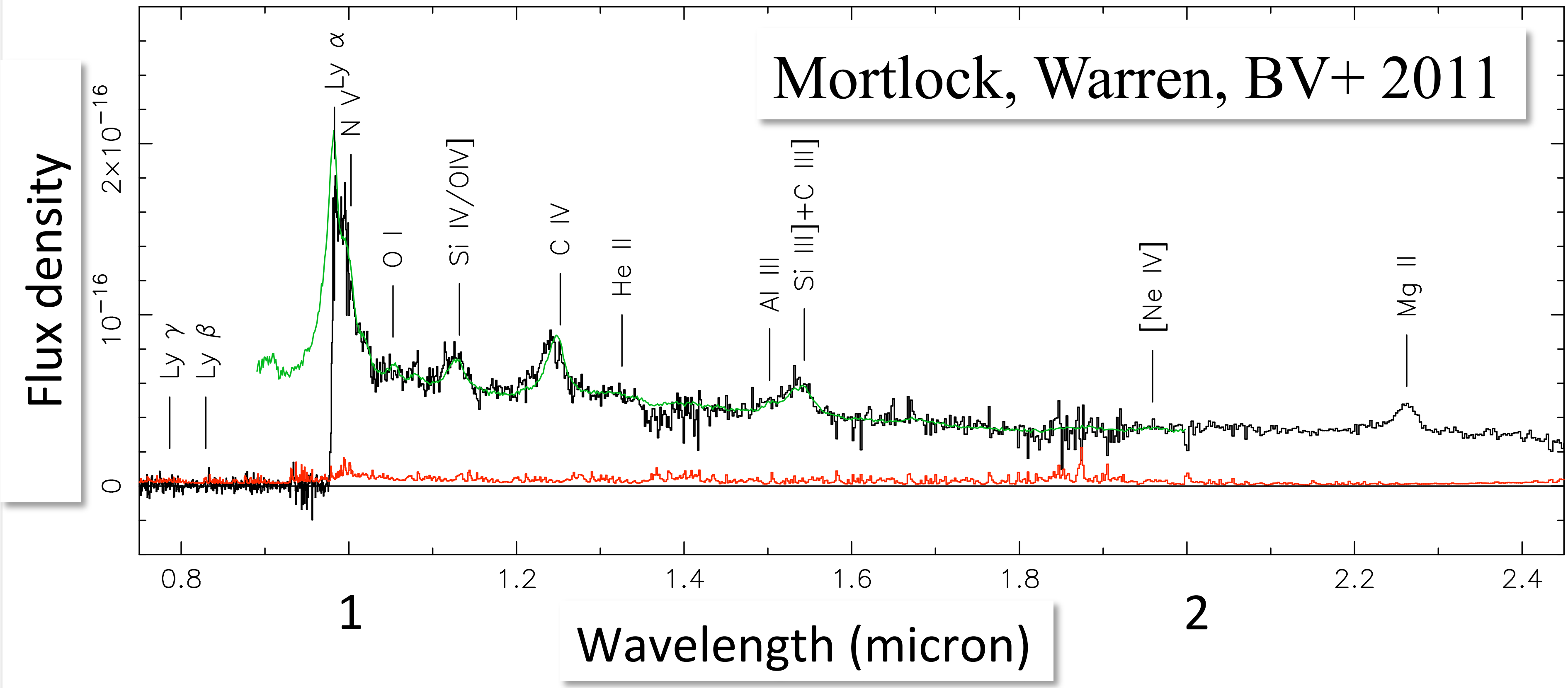


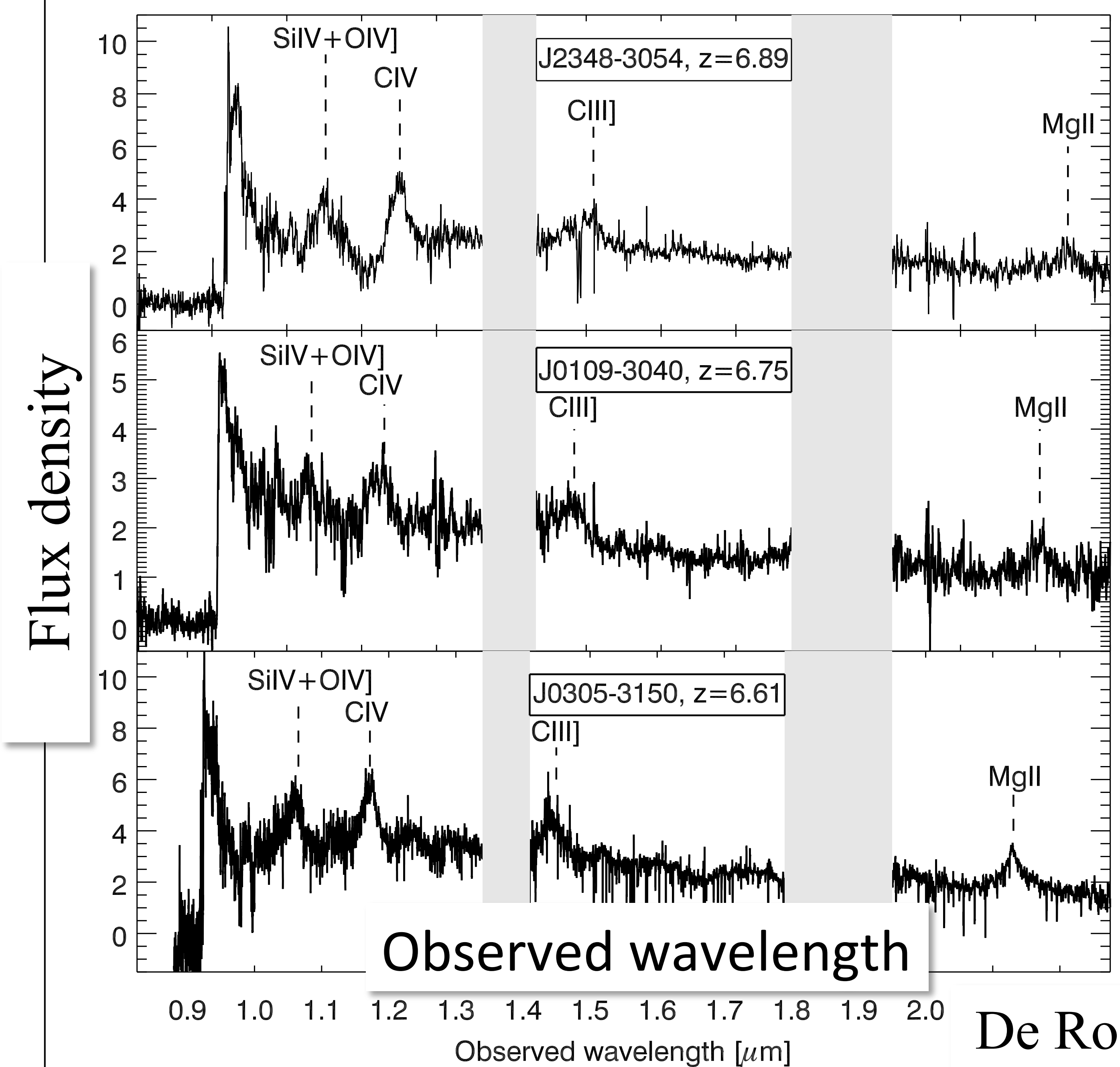
UKIDSS: a luminous quasar at $z = 7.1$

Bright source: $M_{1450} = -26.6$ ($K_{AB} = 19.6$!)



NIR spectroscopy of $z > 6.5$ quasars

Characterising the central region



Black hole mass:

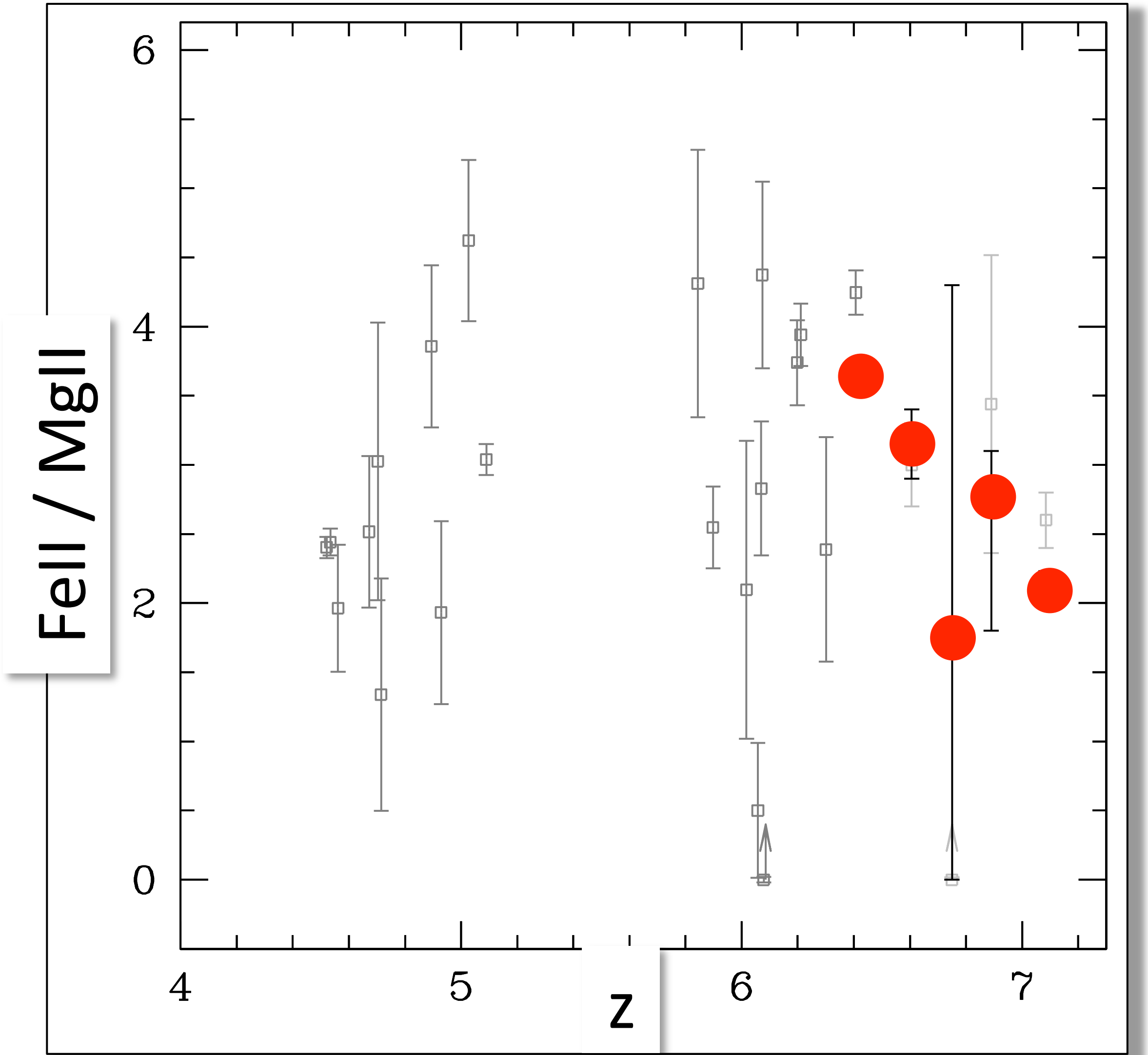
$2.1 \times 10^9 M_\odot$

$1.5 \times 10^9 M_\odot$

$1.0 \times 10^9 M_\odot$

De Rosa, BV+ 2014

Enrichment of broad line region



No evolution of the enrichment close to the BH up to $z \sim 7$

De Rosa, BV+ 2014
BV+ 2015a

NIR spectroscopy of $z > 6.5$ quasars

Characteristics of the central region:

- No evolution in metal line ratios
- Black hole masses ~(0.5-3.7)x10^9 $M_\odot$
- Eddington ratio: 13% - 100%

→ requires >10^4 $M_\odot$ black hole seeds or prolonged Eddington accretion at $z > 7$

Mortlock+ 2011; De Rosa, BV+ 2014; BV+ 2015a

Quasar ionisation regions

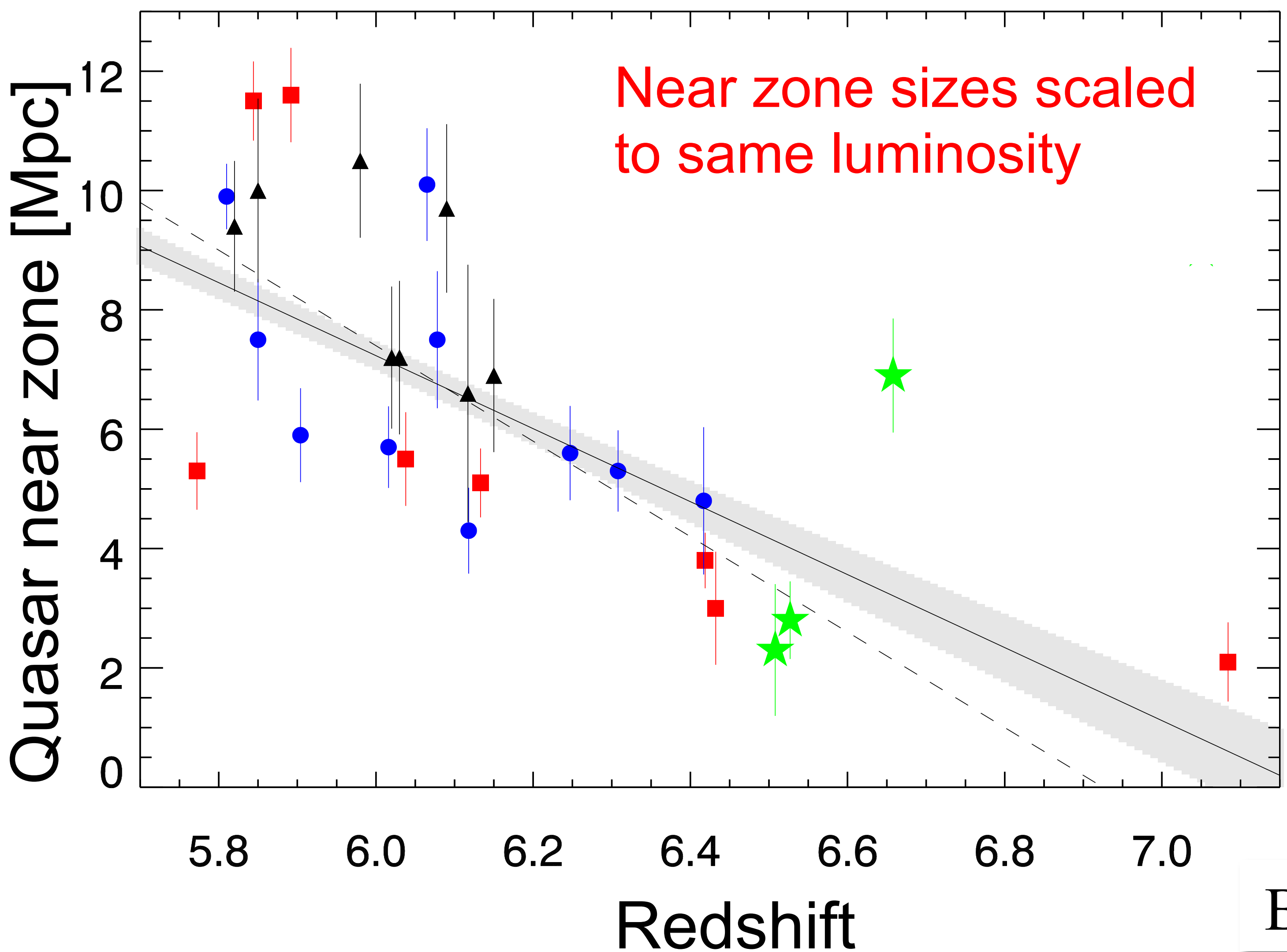
Quasar near zone:

- HII region around quasar
- Size of near zone:

$R \propto (1+z)^{-1} f_{HI}^{-1/3} (t_Q \times L)^{1/3}$ (e.g. Fan+ 2006)

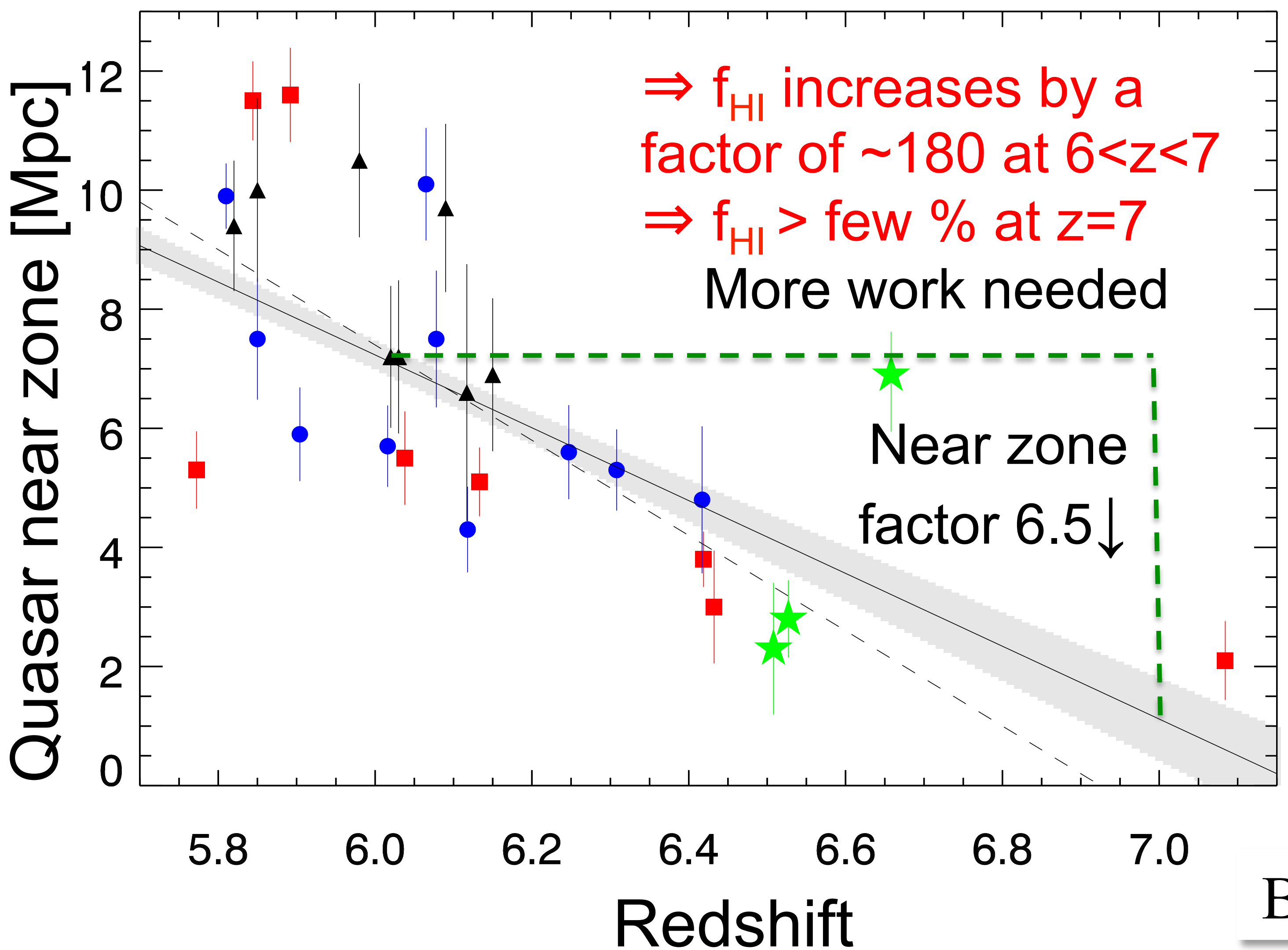
- f_{HI} neutral H fraction
- t_Q quasar age
- L quasar luminosity

Quasar ionisation regions



BV+ 2015a

Quasar ionisation regions

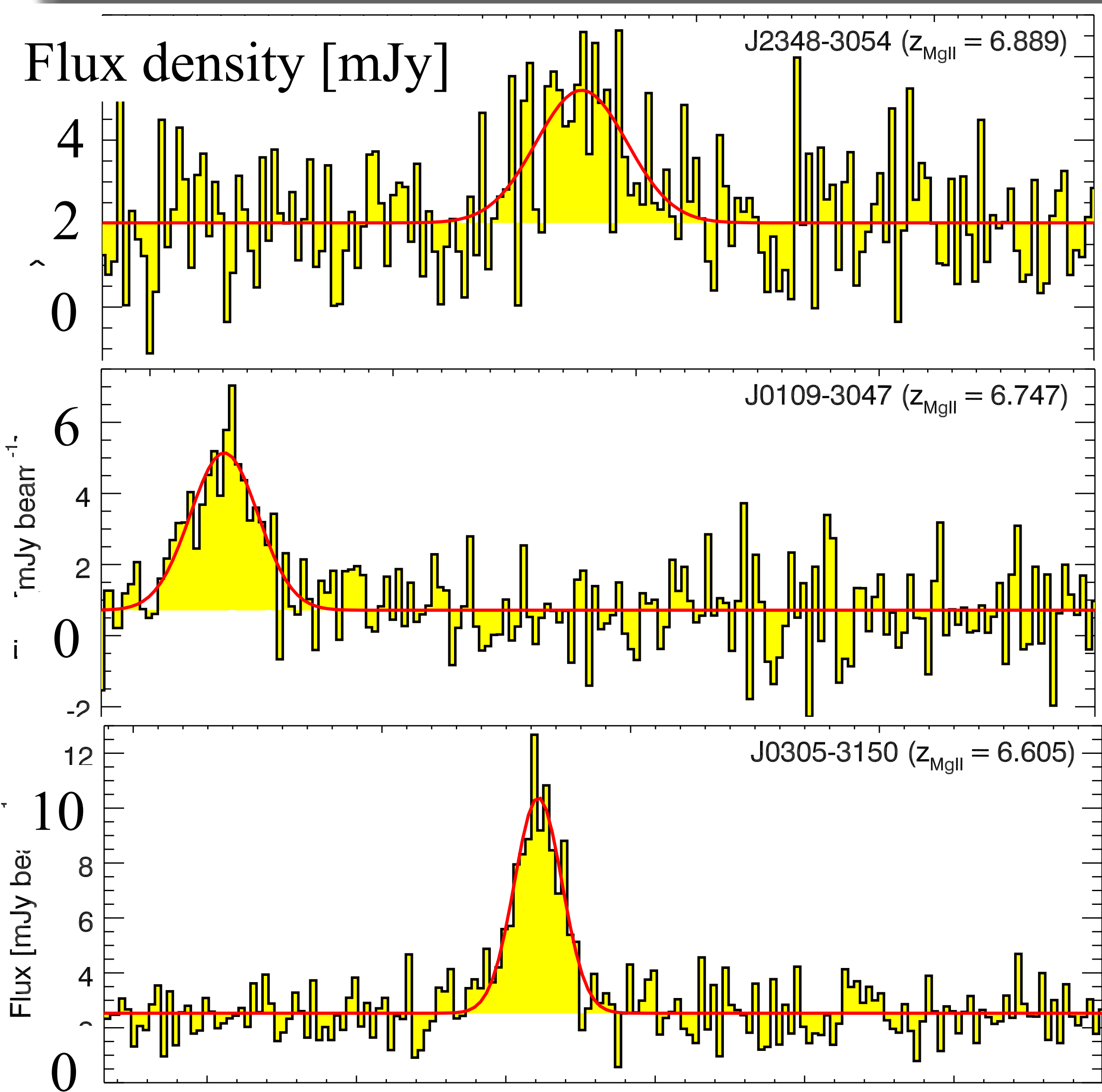


BV+ 2015a

mm observations of quasar host

- Due to bright central source, need to go to far-infrared to detect host galaxy
- ALMA Cycle 1 observations of 3 z>6.6 quasars
- Snapshot: 10-15 minutes on-source

ALMA imaging of 6.6<z<6.9 quasars



[CII] cooling line & FIR dust continuum detected:

- $L_{[CII]} = 2\text{-}4 \times 10^{9} L_{\odot}$
- $L_{FIR} = 1\text{-}13 \times 10^{12} L_{\odot}$

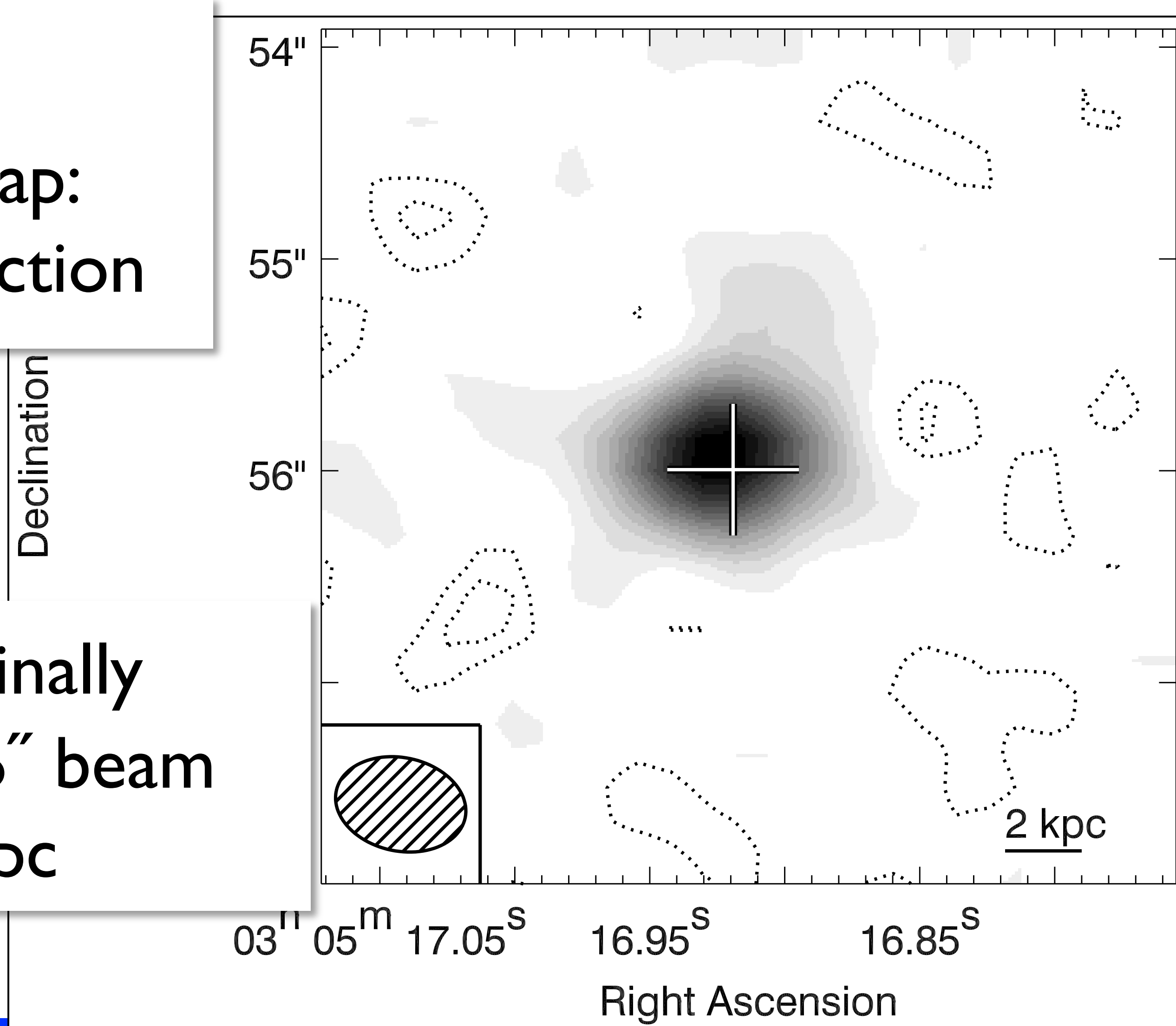
→ SFR~100-1000 $M_{\odot}$/yr

BV+ 2015b

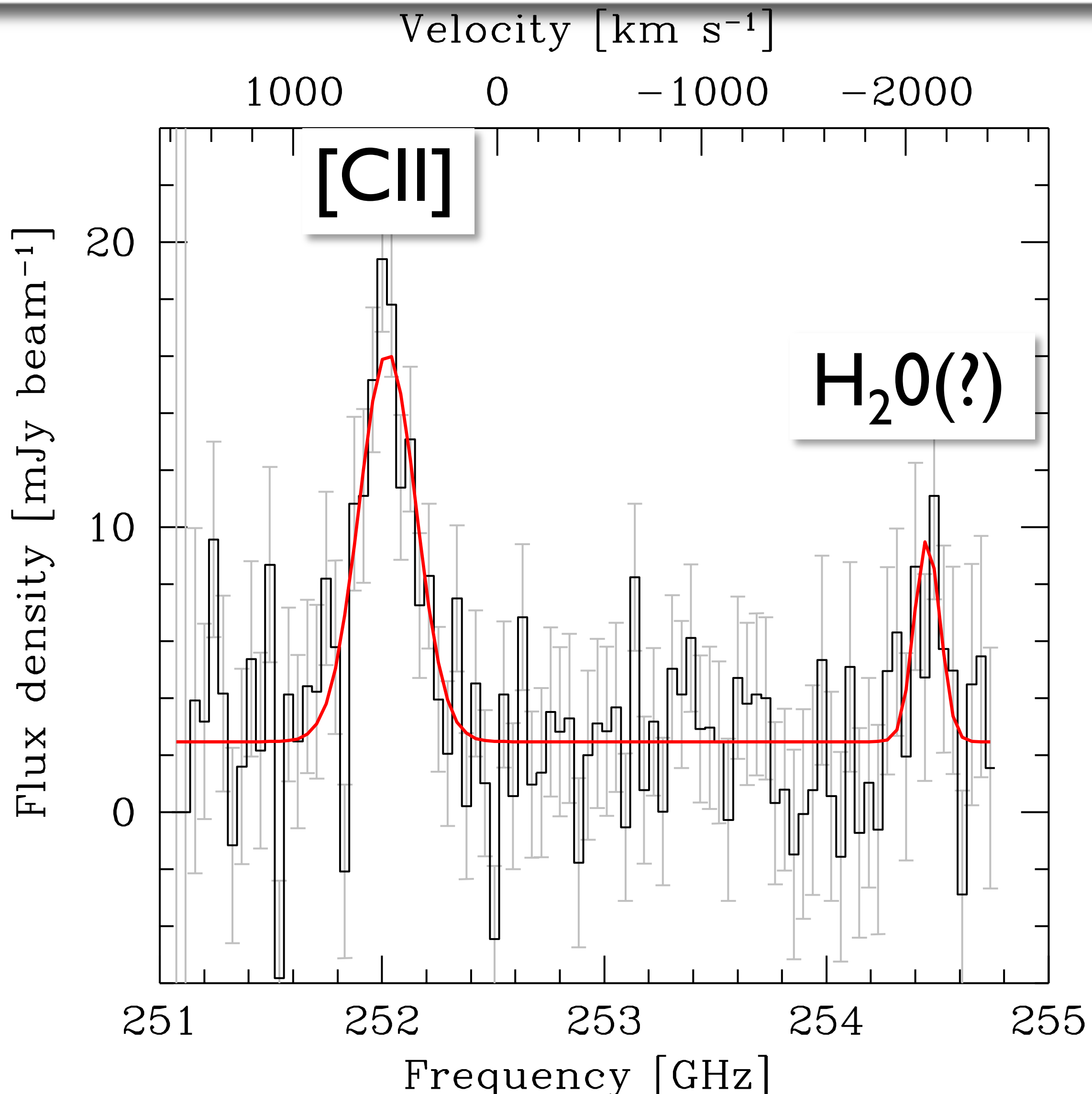
Map of [CII] emission of z=6.6 host

Continuum-subtracted map: 25sigma detection

Emission marginally resolved in 0.6″ beam
Size: 3.4x2.2 kpc



2hr PdBI on M_{UV}=-27.2 quasar at z=6.5



Brightest [CII] emitter at z>6.4

Tentative detection of H_2O

Ideal to study ISM with ALMA

Bañados+ 2015c

Summary of mm observations

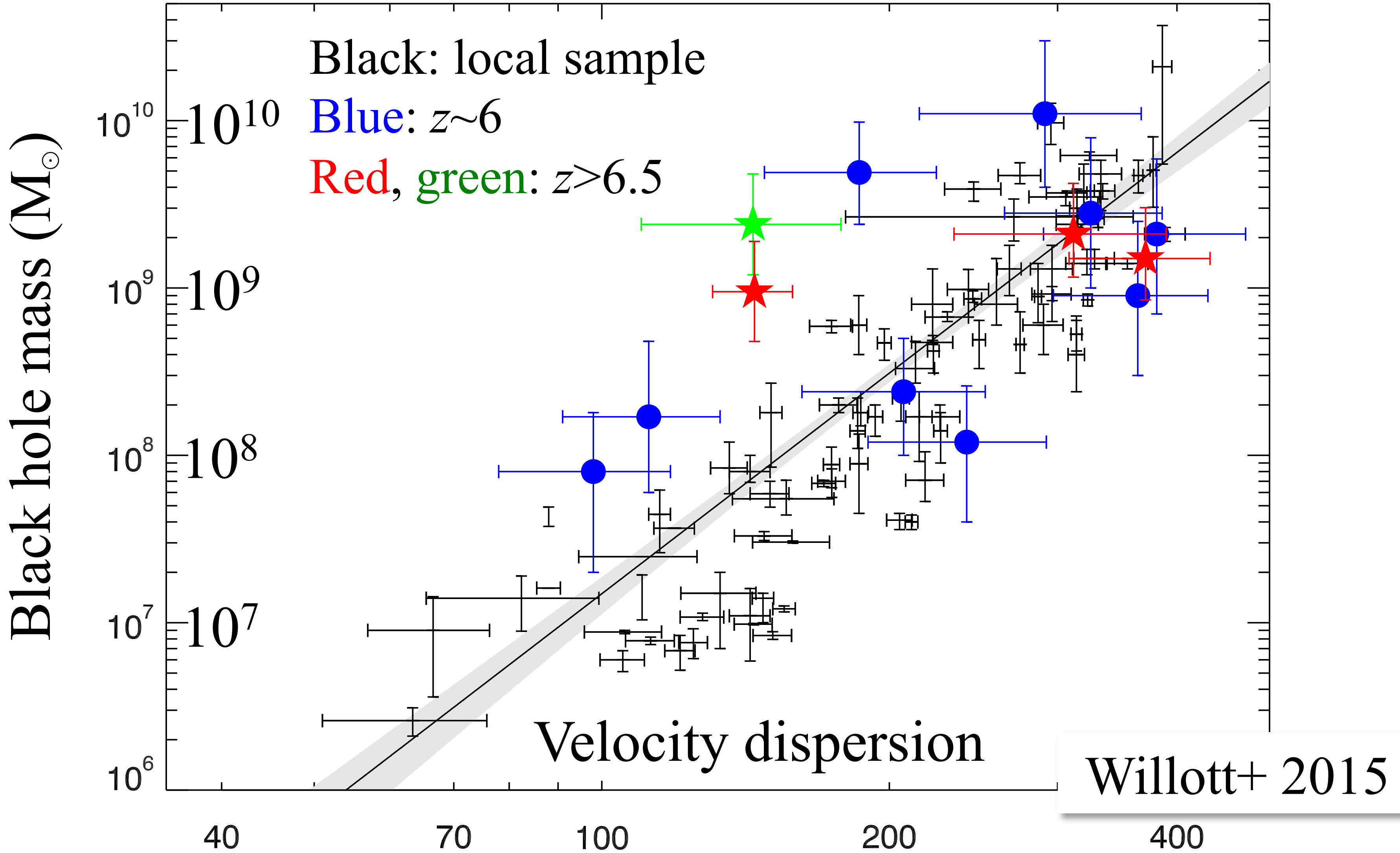
- ALMA/PdBI observations of 5 $z > 6.5$ quasars:
  - [CII] luminosities of (1.2-5.2) x 10^9 $L_\odot$
  - FIR luminosities ~(1-13) x 10^{12} $L_\odot$
    → SFRs: 60-1200 $M_\odot$ yr^{-1}
  - Sizes of line emitting region ~2-3 kpc
  - Signs of more components (outflow?)

Summary & outlook

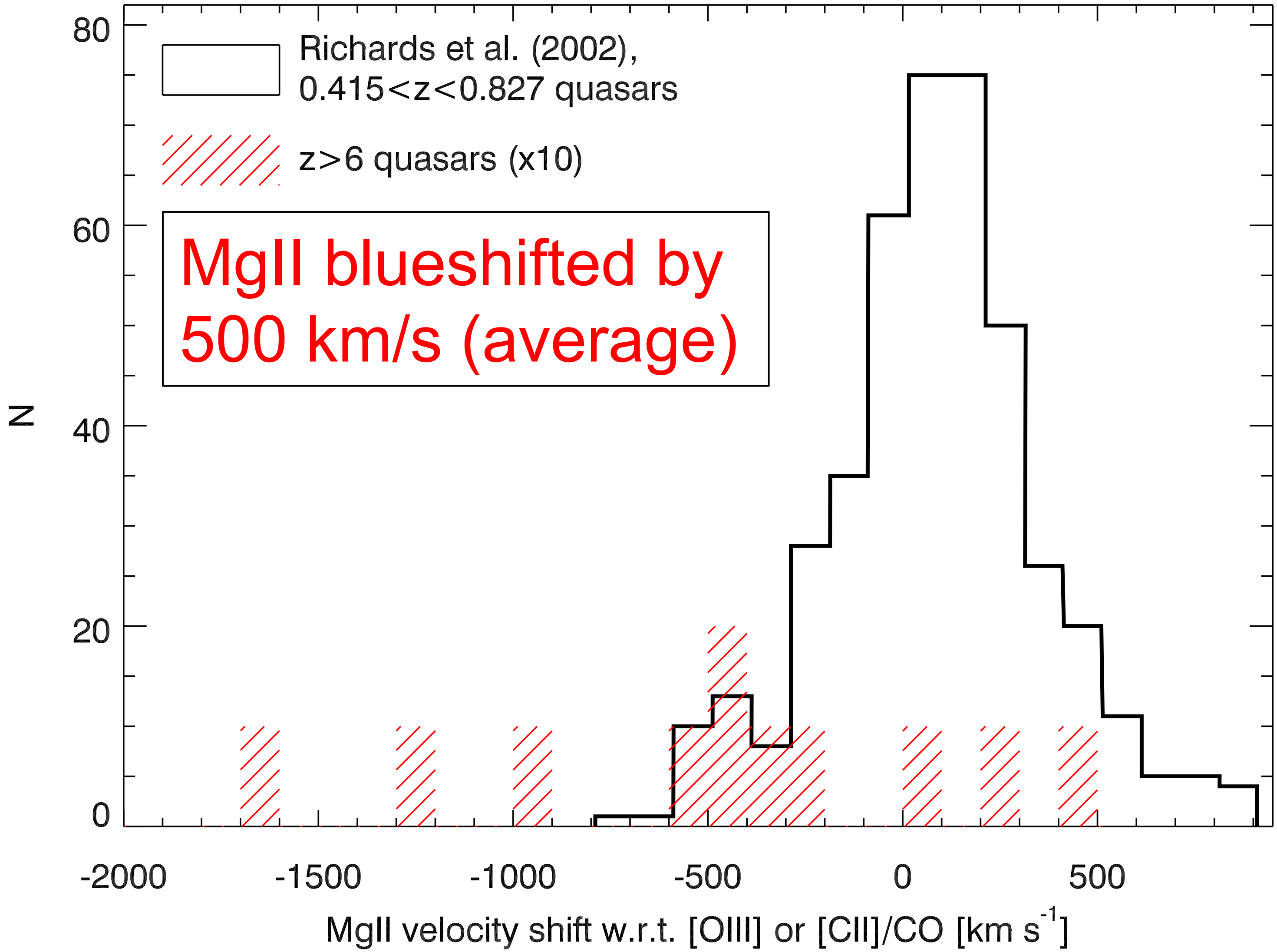
- Quasars ideal targets to study the early universe
- Supermassive ($>10^9\ M_\odot$) hosted by 2-3 kpc dusty galaxies forming stars at $>100\ M_\odot$/yr
- Measure IGM properties in deep quasar spectra
- Study the ISM and constrain dust temperature

  (ALMA CO detections in hand for $z>6.6$ hosts)
- Galaxy environment: so far no (clear) signs of overdensities (e.g. Bañados, BV+ 2013)

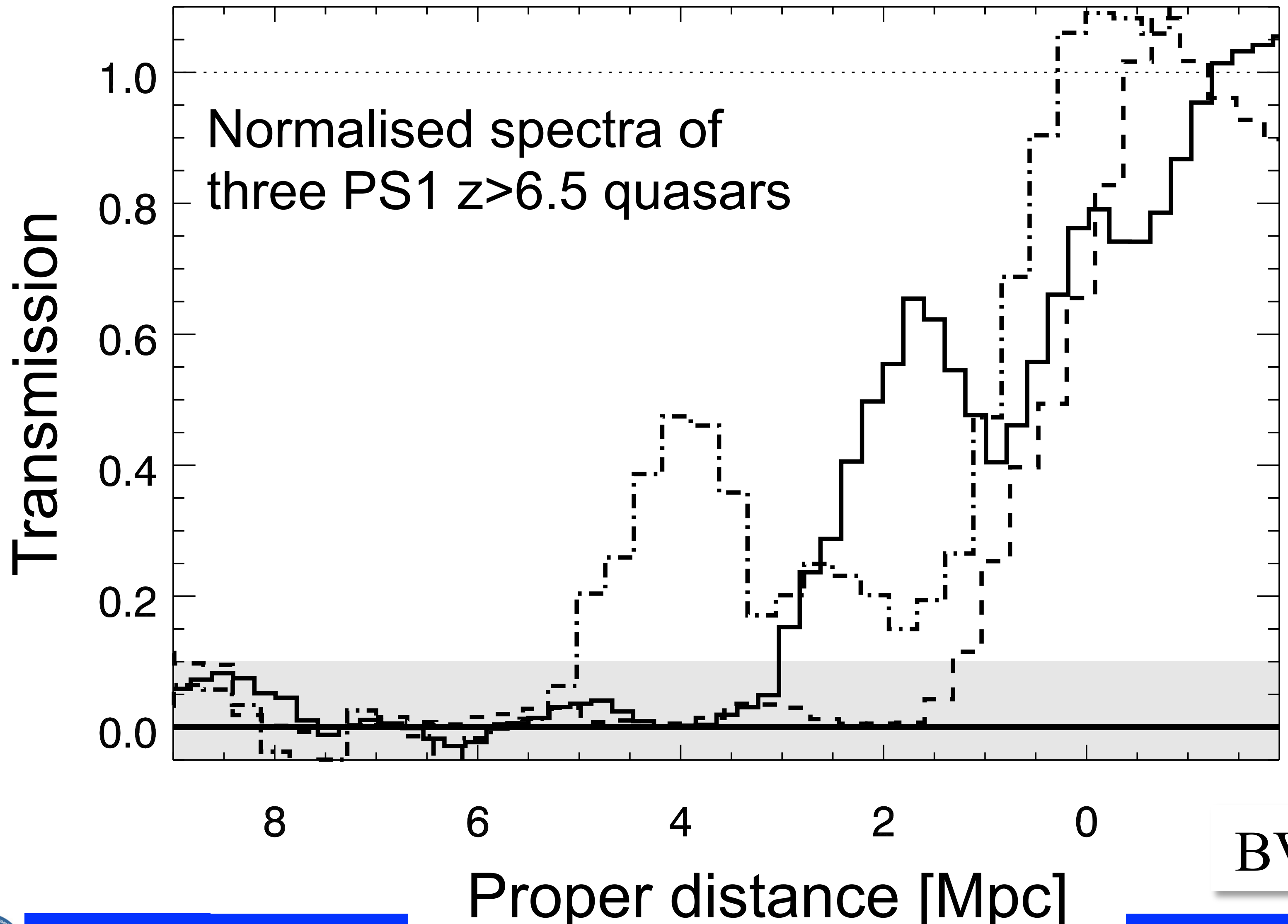
M-sigma relation



FIR line redshift vs MgII



Quasar ionisation regions



BV+ 2015a