Illuminating the dark ages: the most distant quasars in (public) surveys

Bram Venemans (MPIA)

Collaborators

Team Quasars @ MPIA

- Eduardo Bañados
- Roberto Decarli
- Ema Farina
- Chiara Mazzucchelli
- Fabian Walter
- Laura Zschaechner

Pan-STARRS1 KP10

- Ken Chambers (Hawaii)
- Gisella De Rosa (Ohio)
- Xiaohui Fan (Arizona)
- Hans-Walter Rix (MPIA)
- Rob Simcoe (MIT)

KiDS QSO team (Kapteyn)

- Gijs Verdoes-Kleijn
- Johnson Mwebaze
- Edwin Valentijn

\+ KiDS team (PI: Kuijken)

VIKING quasar SWG

- Richard McMahon (IoA)
- Joseph Findlay (Wyoming)
- Will Sutherland (QMUL)

UKIDSS quasar group

- Steve Warren (Imperial)
- Daniel Mortlock (Imperial)

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

  → not found in deep (HST) blank fields

  → need multi-colour **surveys** over large area

The search for distant quasars

- Problem: high redshift quasars are very rare

  → not found in deep HST blank fields

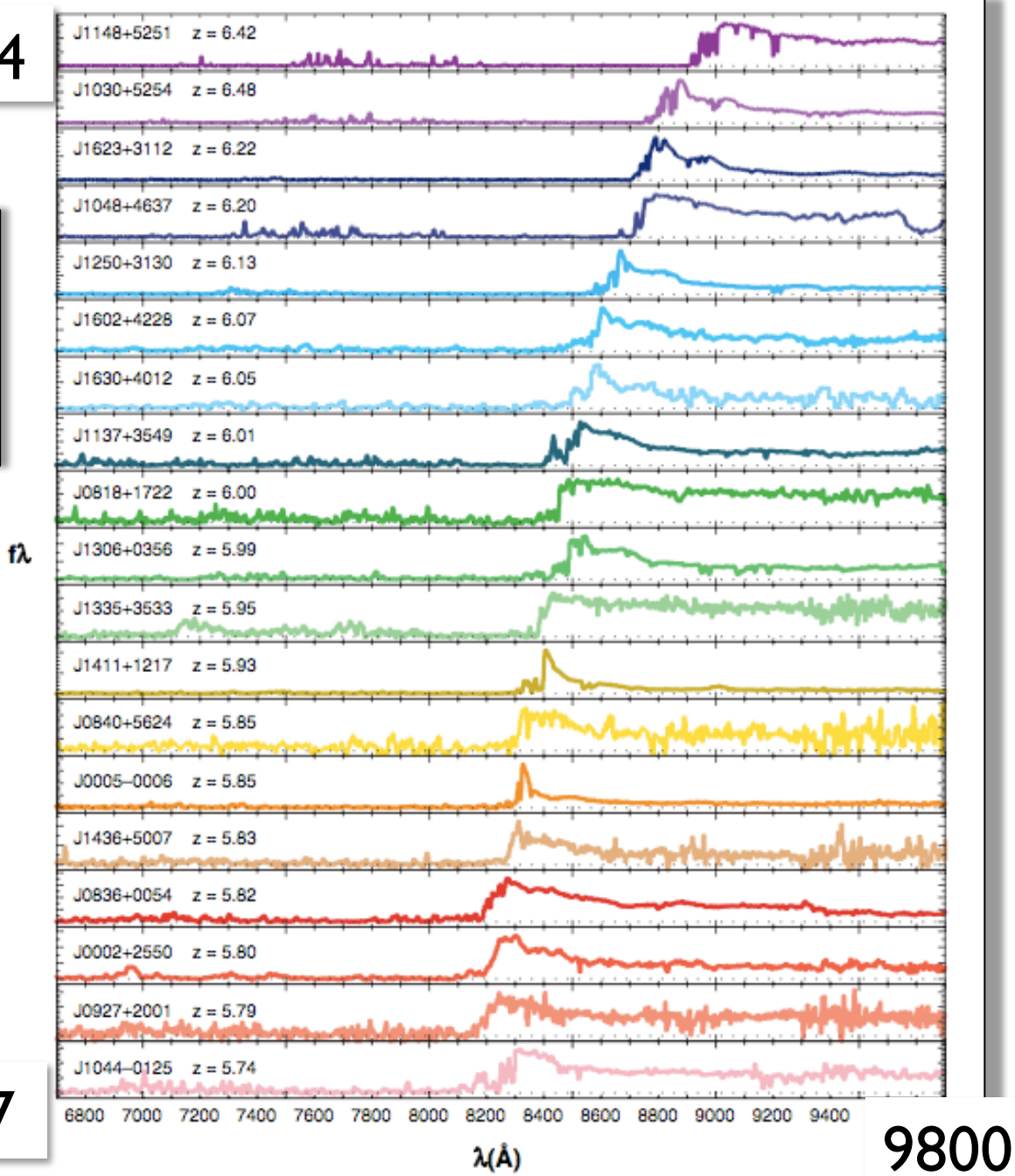
  → need multi-colour **surveys** over large area
- SDSS very successful, discovered many luminous quasars up to $z = 6.4$

z=6.4

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

Fan, Carilli & Keating 2006

z = 5.7



9800 Å

The search for distant quasars

- Problem: high redshift quasars are very rare

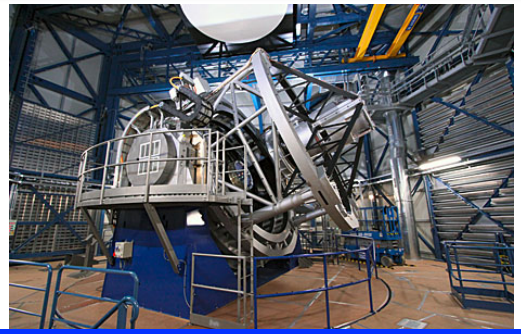
  → not found in deep HST blank fields

  → need multi-colour **surveys** over large area
- SDSS very successful, discovered many luminous quasars up to $z = 6.4$

  → to find quasars at higher redshifts, wide field NIR surveys are needed

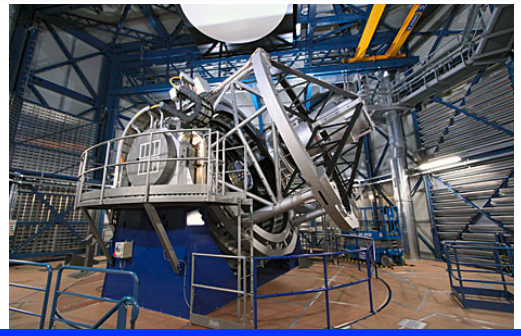
Quasar searches in near IR surveys

- UKIDSS LAS
- VISTA/VIKING
- Pan-STARRS
- Dark Energy Survey, HSC, Euclid, LSST, …



Quasar searches in near IR surveys

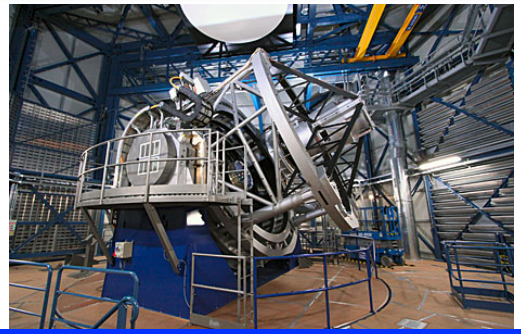
- UKIDSS LAS: 4000 deg^2, J_{AB}~20.5
- VISTA/VIKING
- Pan-STARRS
- Dark Energy Survey, HSC, Euclid, LSST, …



Pan-STARRS

Quasar searches in near IR surveys

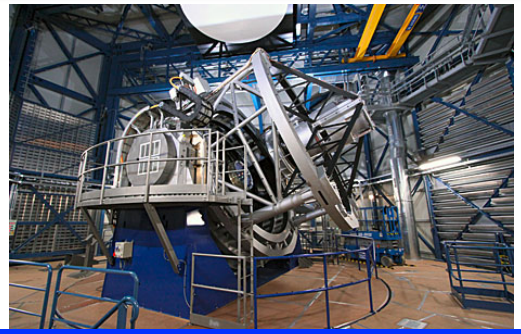
- UKIDSS LAS: 4000 deg^2, J_{AB}~20.5
- VISTA/VIKING: 1500 deg^2, J_{AB}~21.5-22.0
- Pan-STARRS
- Dark Energy Survey, HSC, Euclid, LSST, …



Pan-STARRS

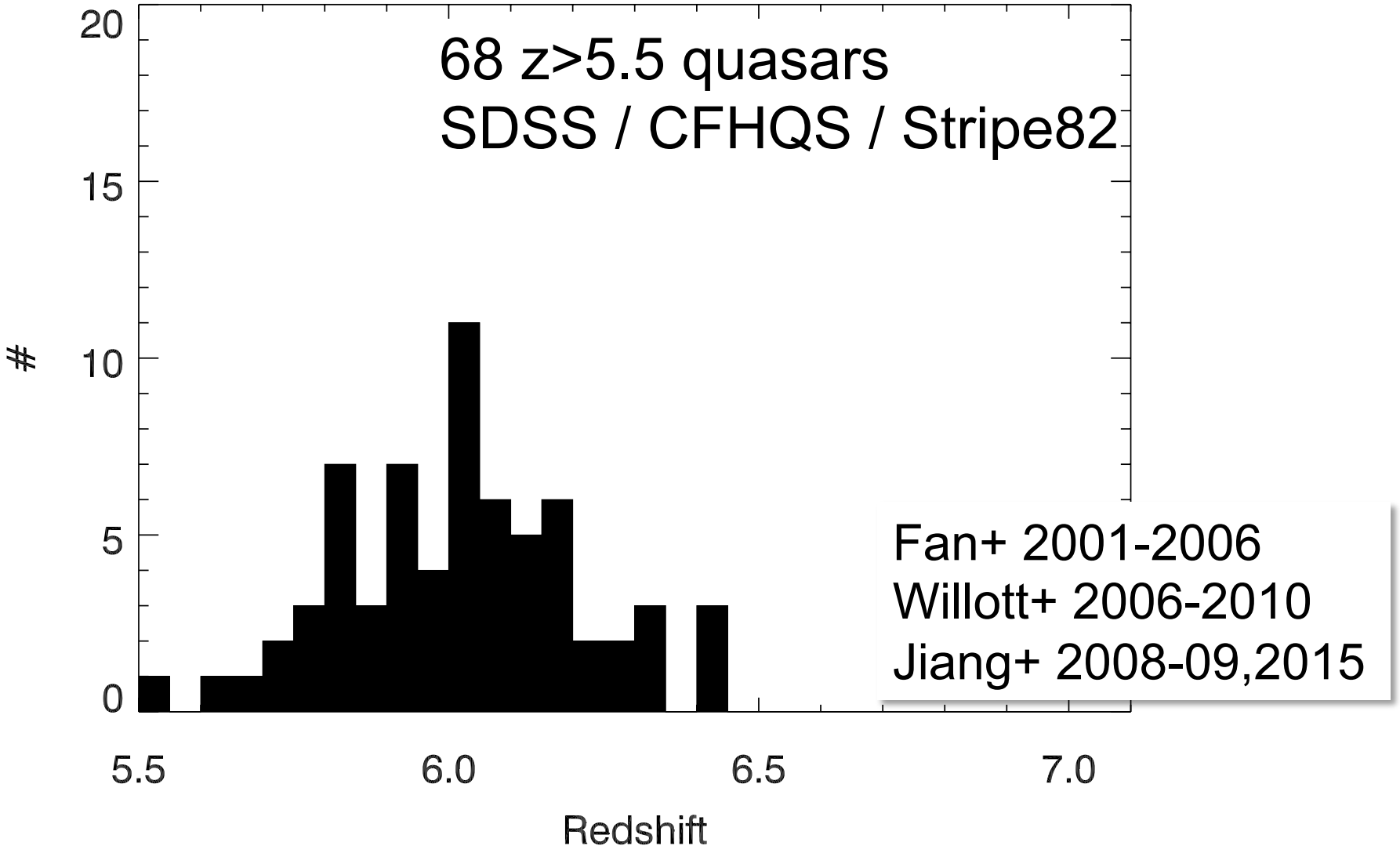
Quasar searches in near IR surveys

- 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, HSC, Euclid, LSST, …

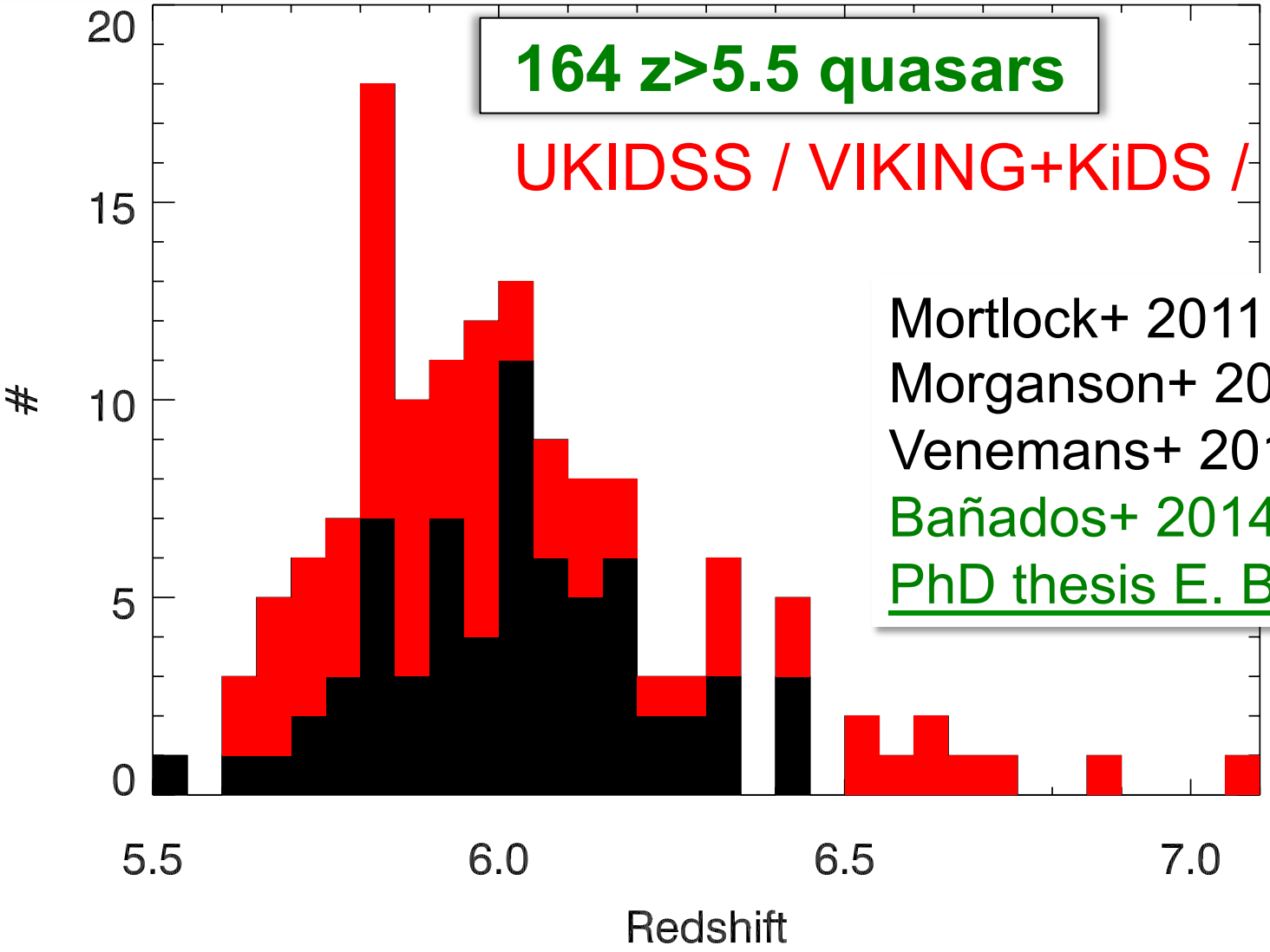


Pan-STARRS

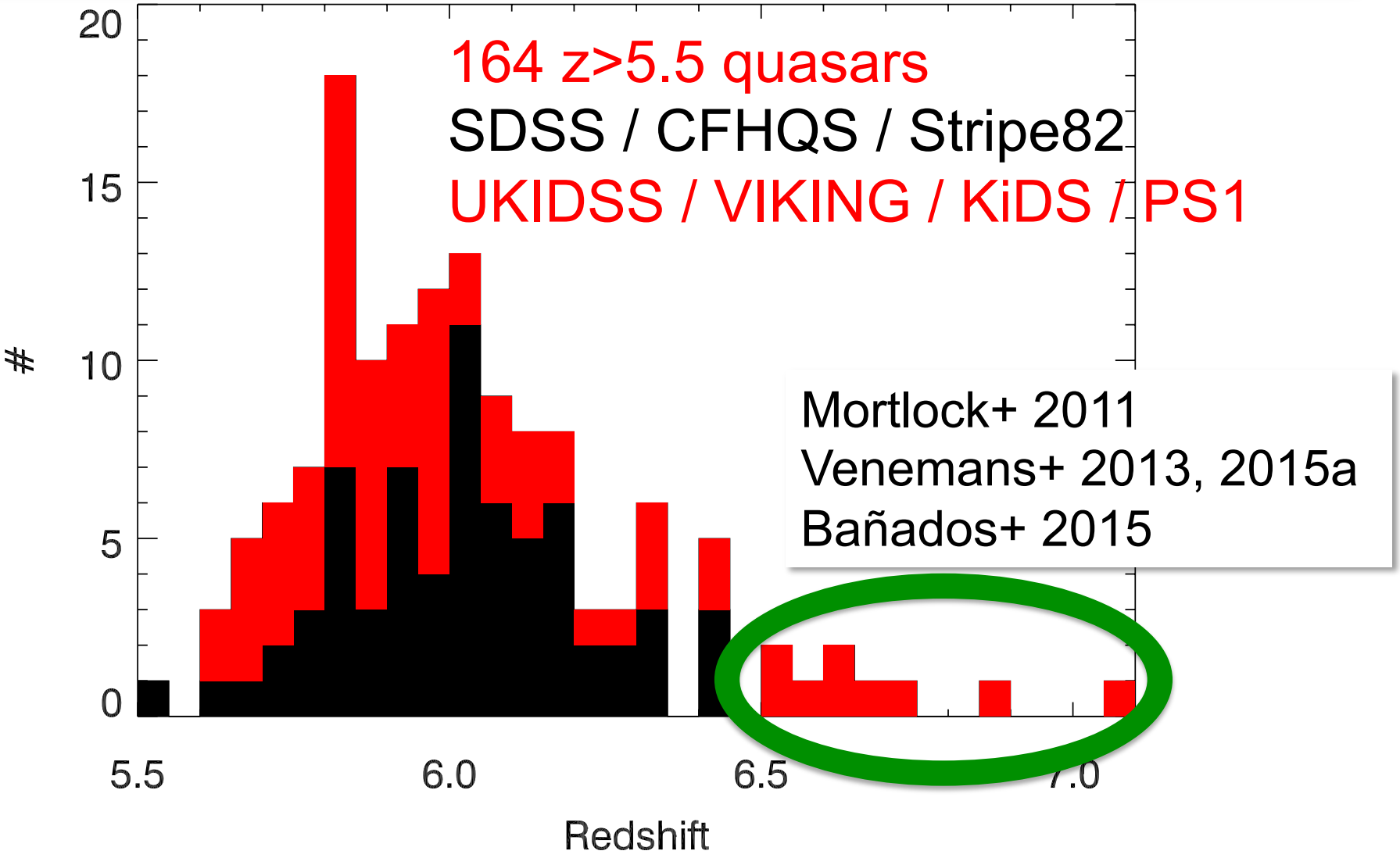
Quasar searches in near IR surveys



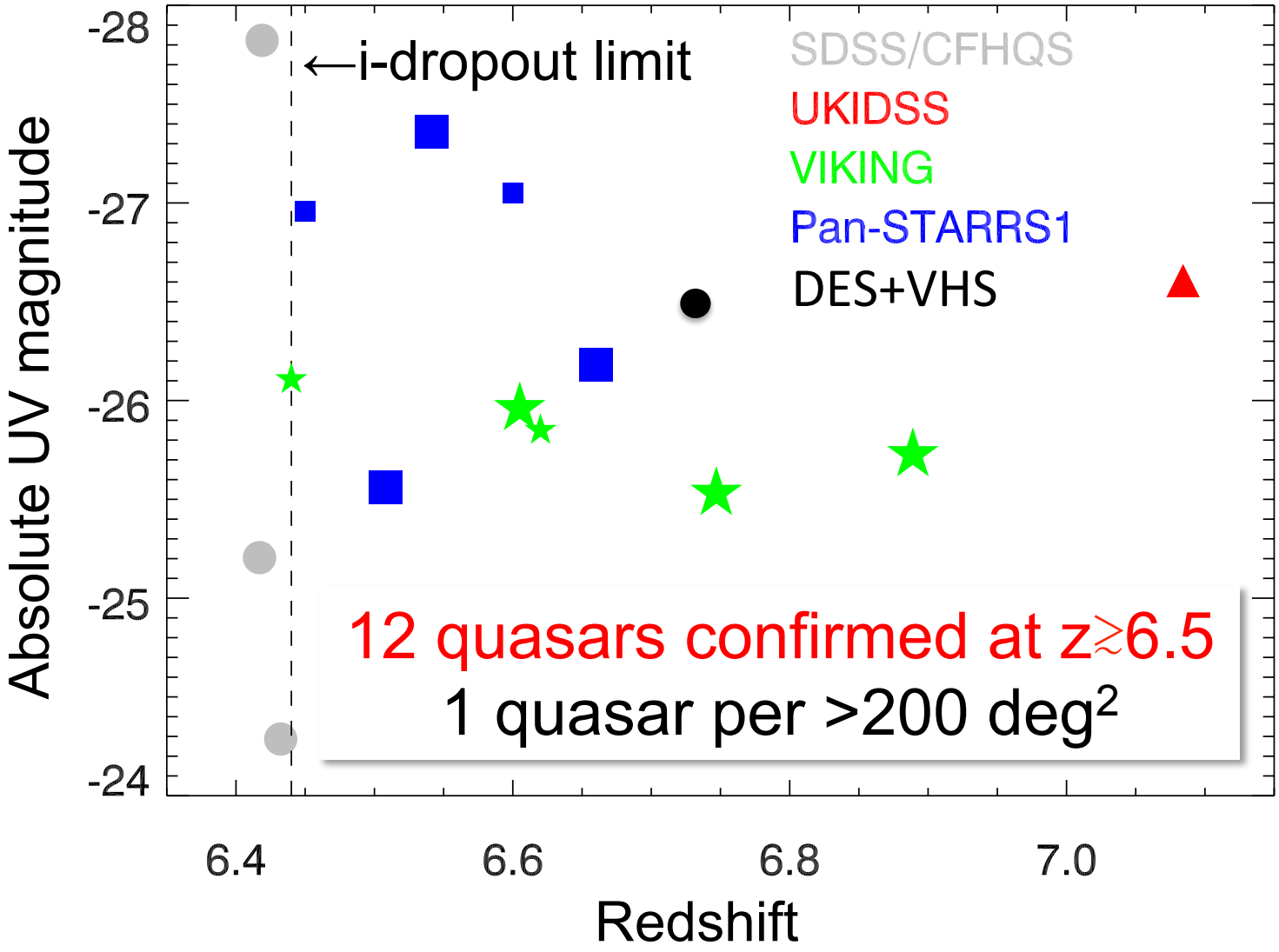
Quasar searches in near IR surveys



Quasar searches in near IR surveys

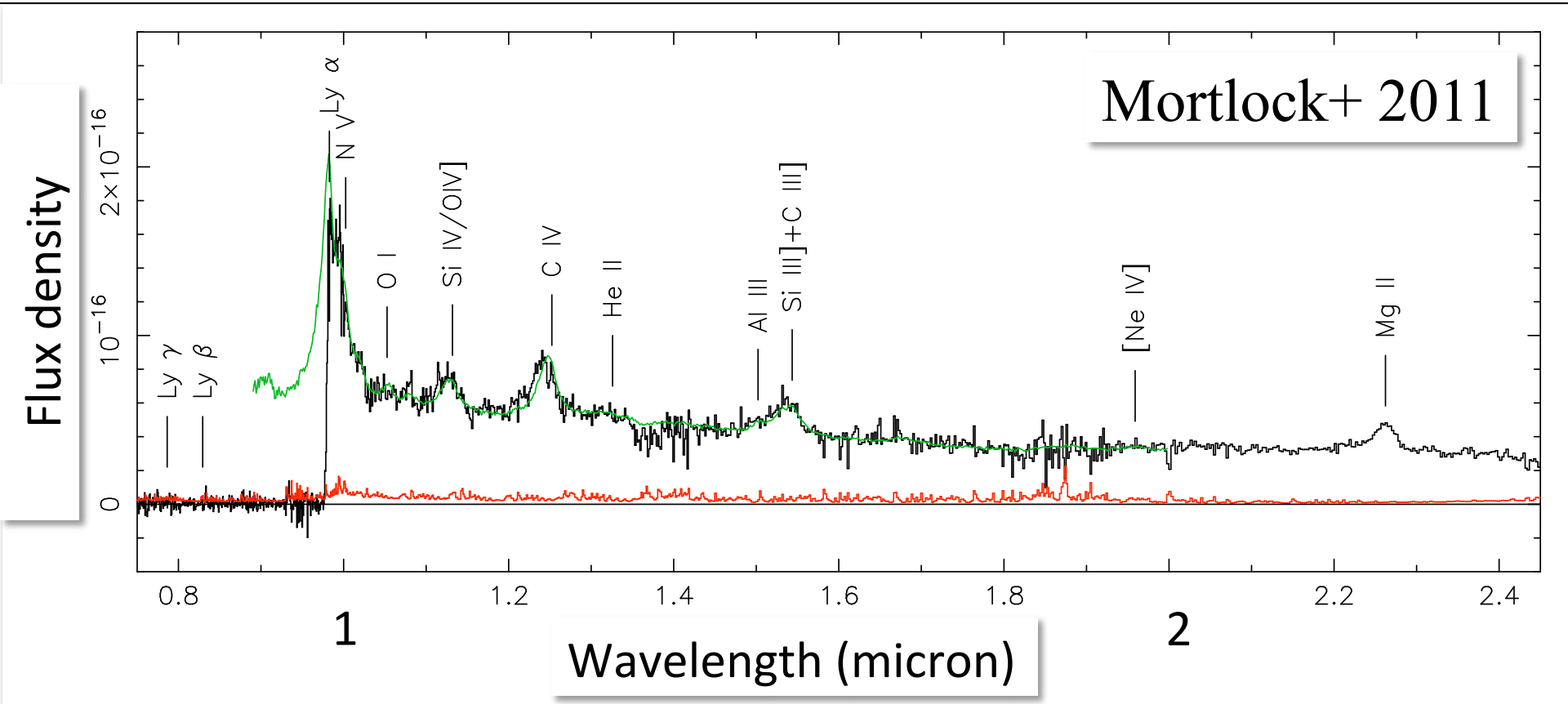


Quasar searches in near IR surveys



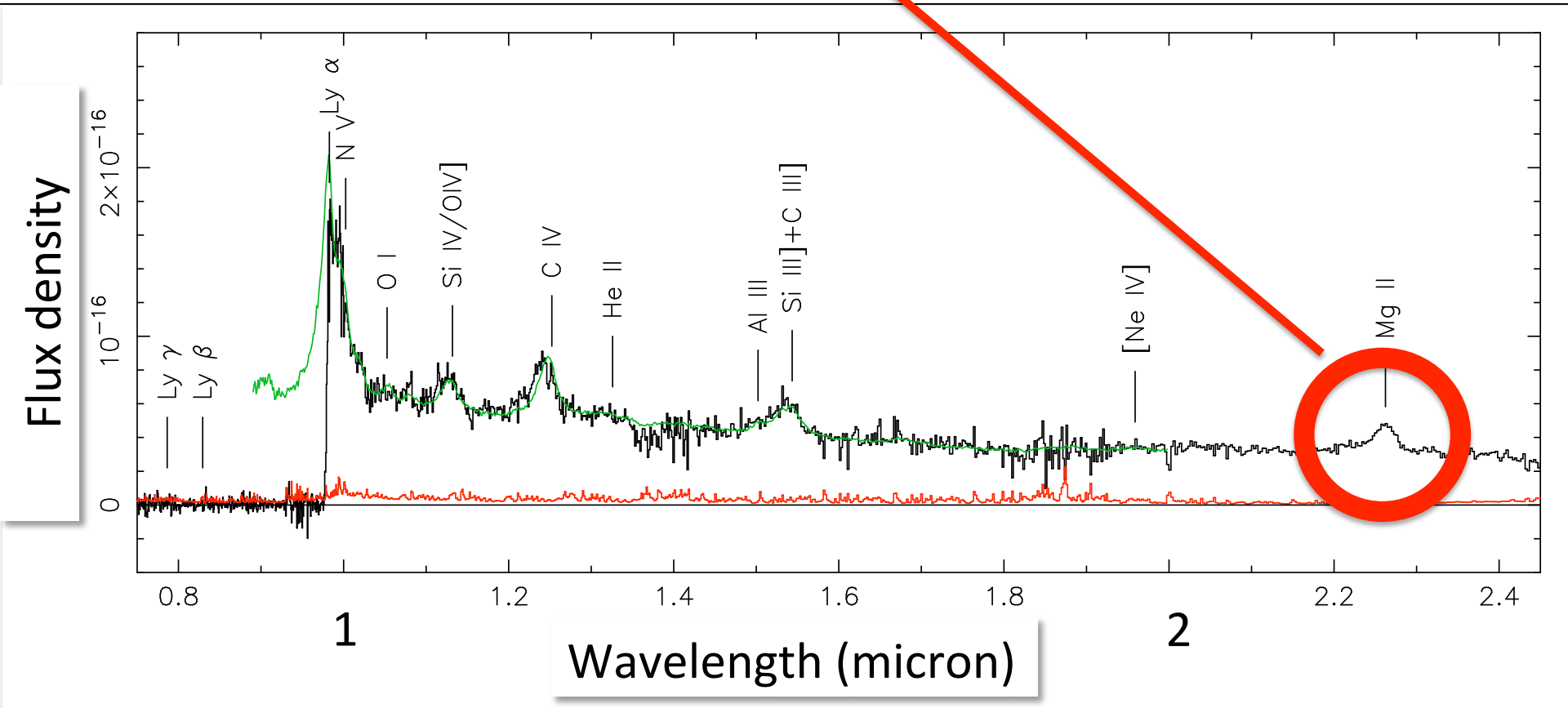
UKIDSS: a luminous quasar at $z = 7.1$

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



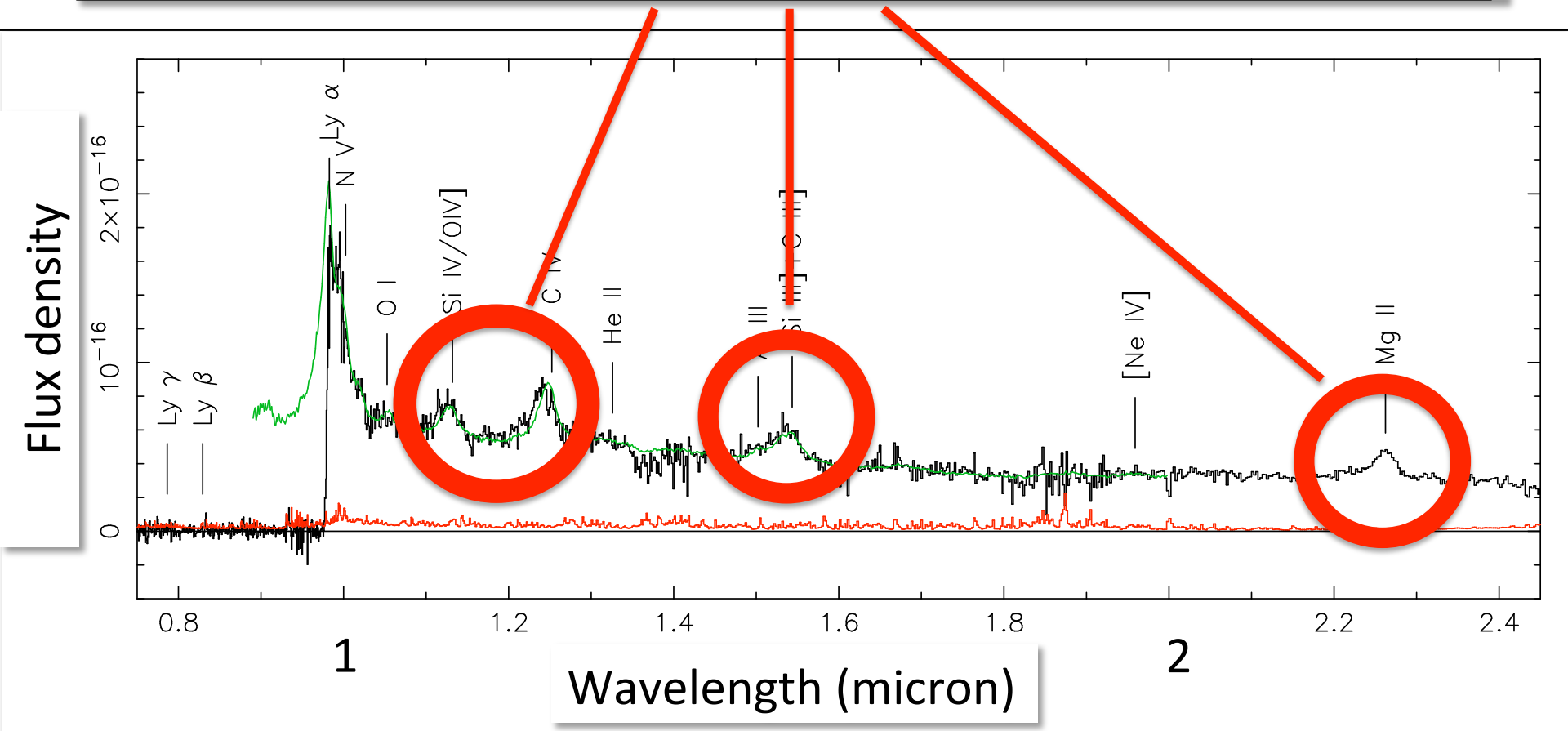
UKIDSS: a luminous quasar at $z = 7.1$

MgII line width + quasar luminosity: black hole mass



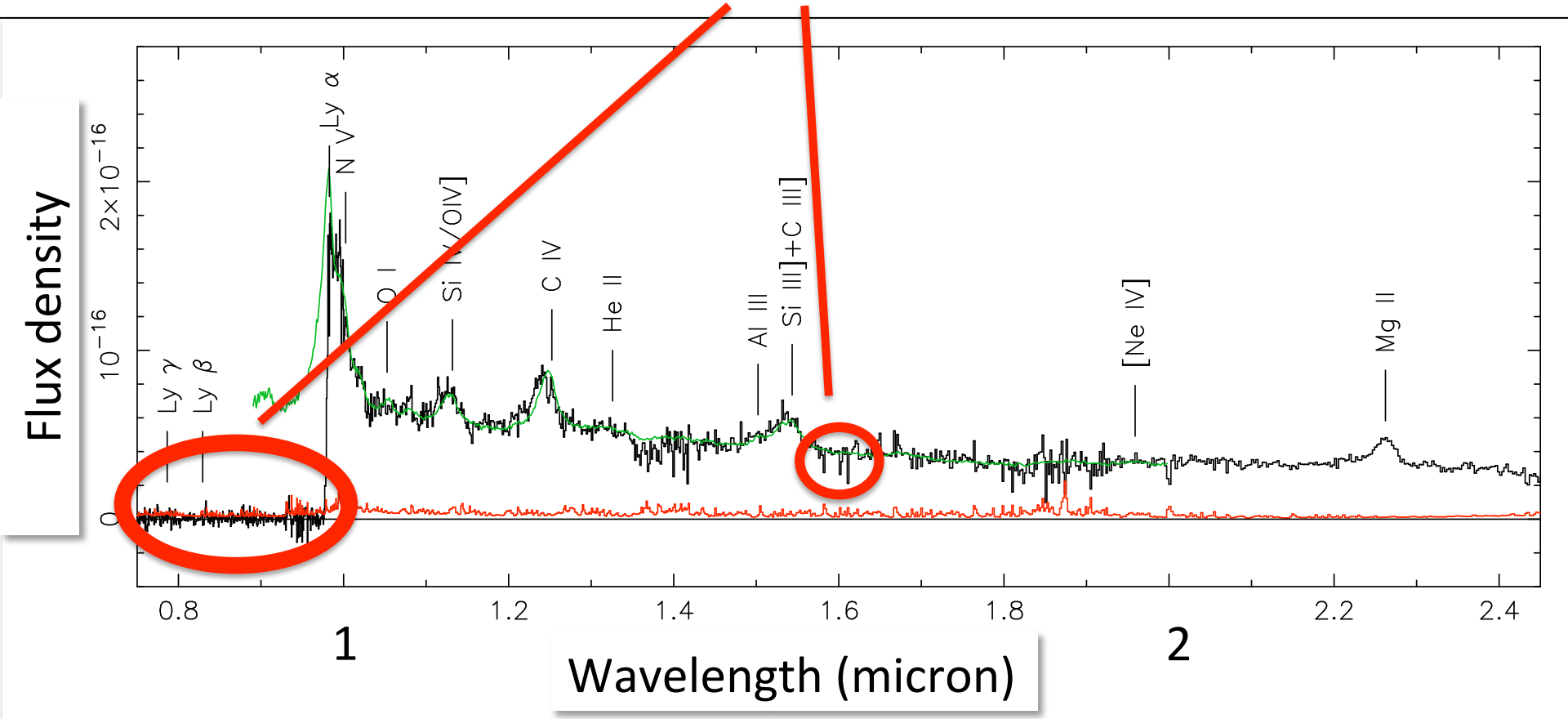
UKIDSS: a luminous quasar at $z = 7.1$

Emission lines: enrichment of broad line region



UKIDSS: a luminous quasar at $z = 7.1$

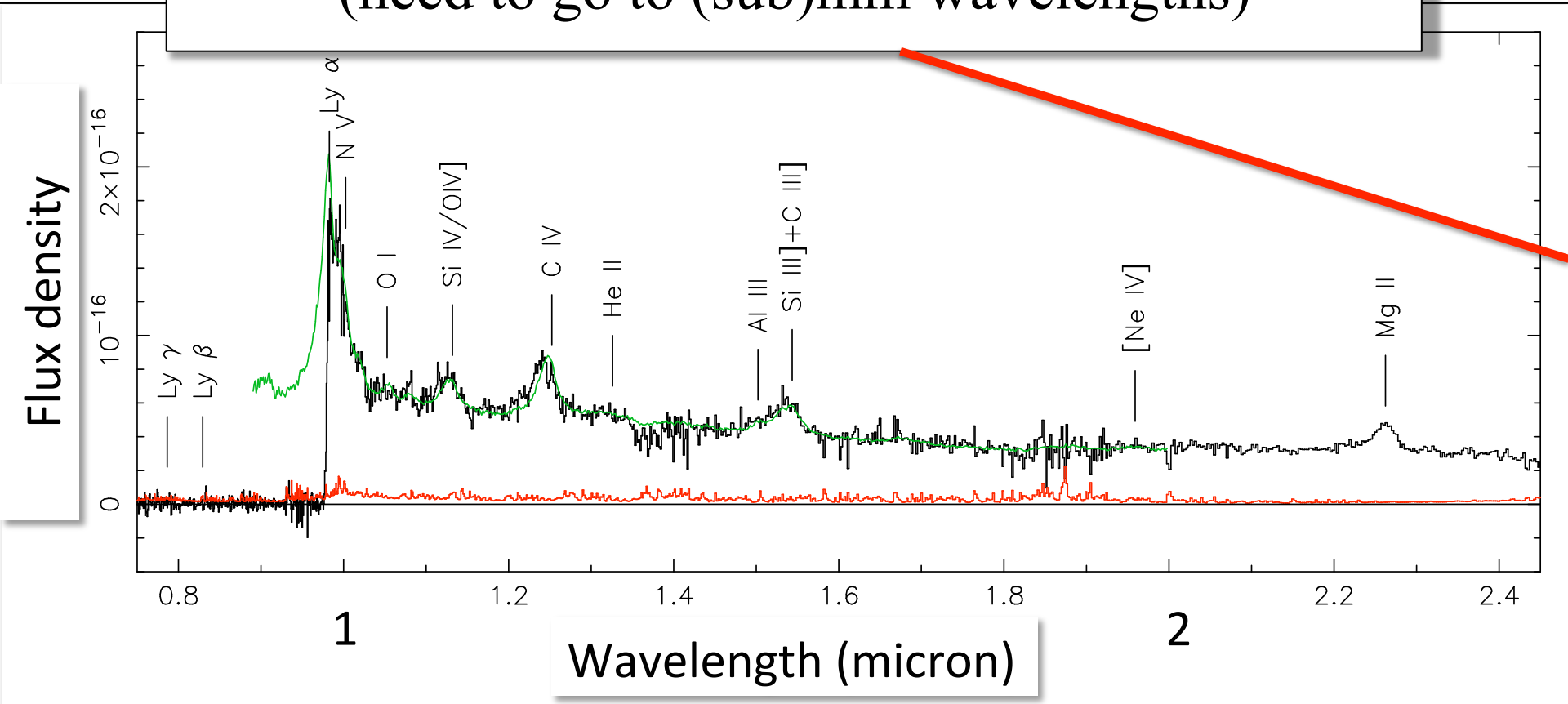
Absorption lines: reionisation, metals in IGM

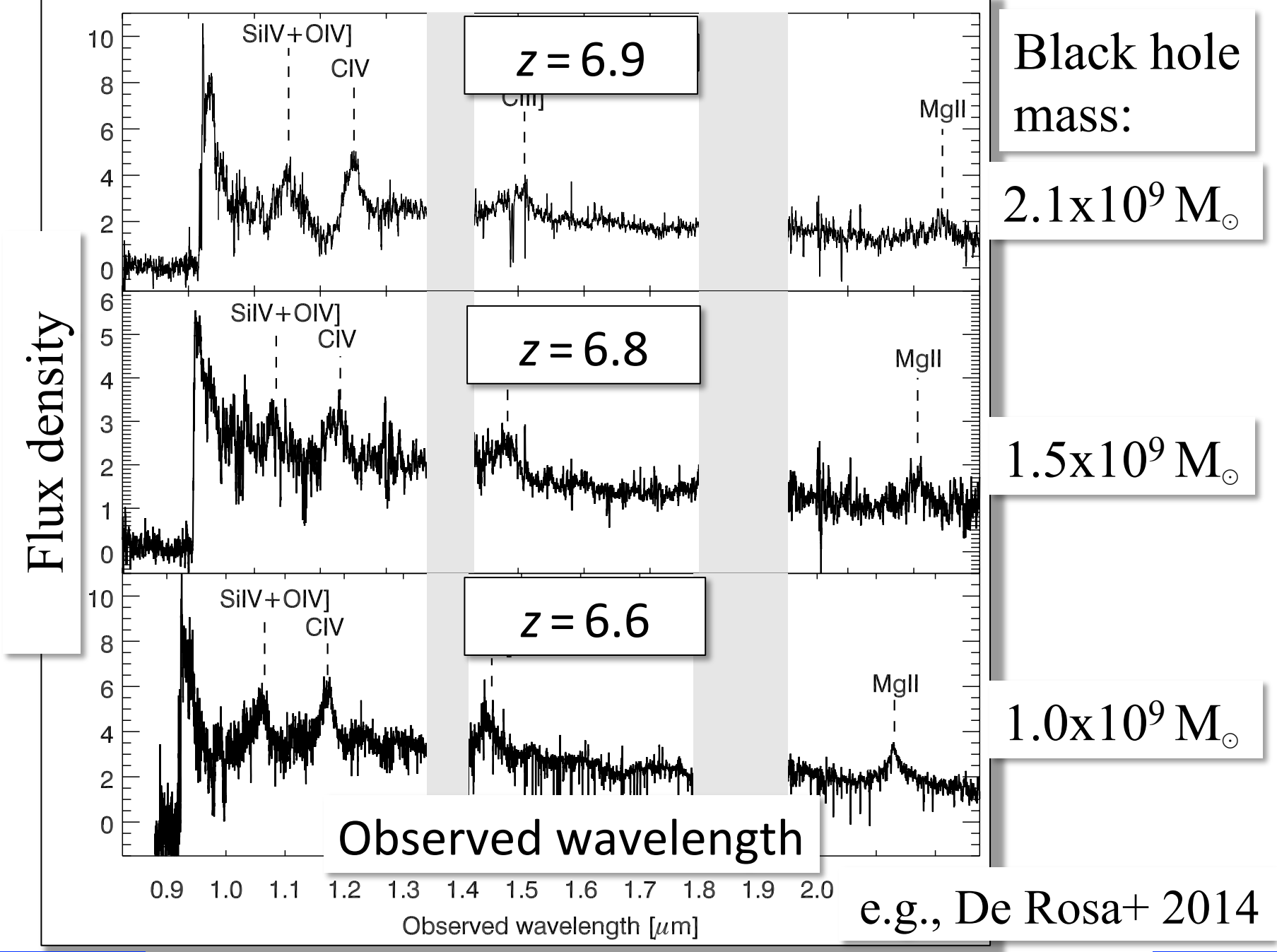


UKIDSS: a luminous quasar at $z = 7.1$

Host galaxy: massive galaxy in formation

(need to go to (sub)mm wavelengths)





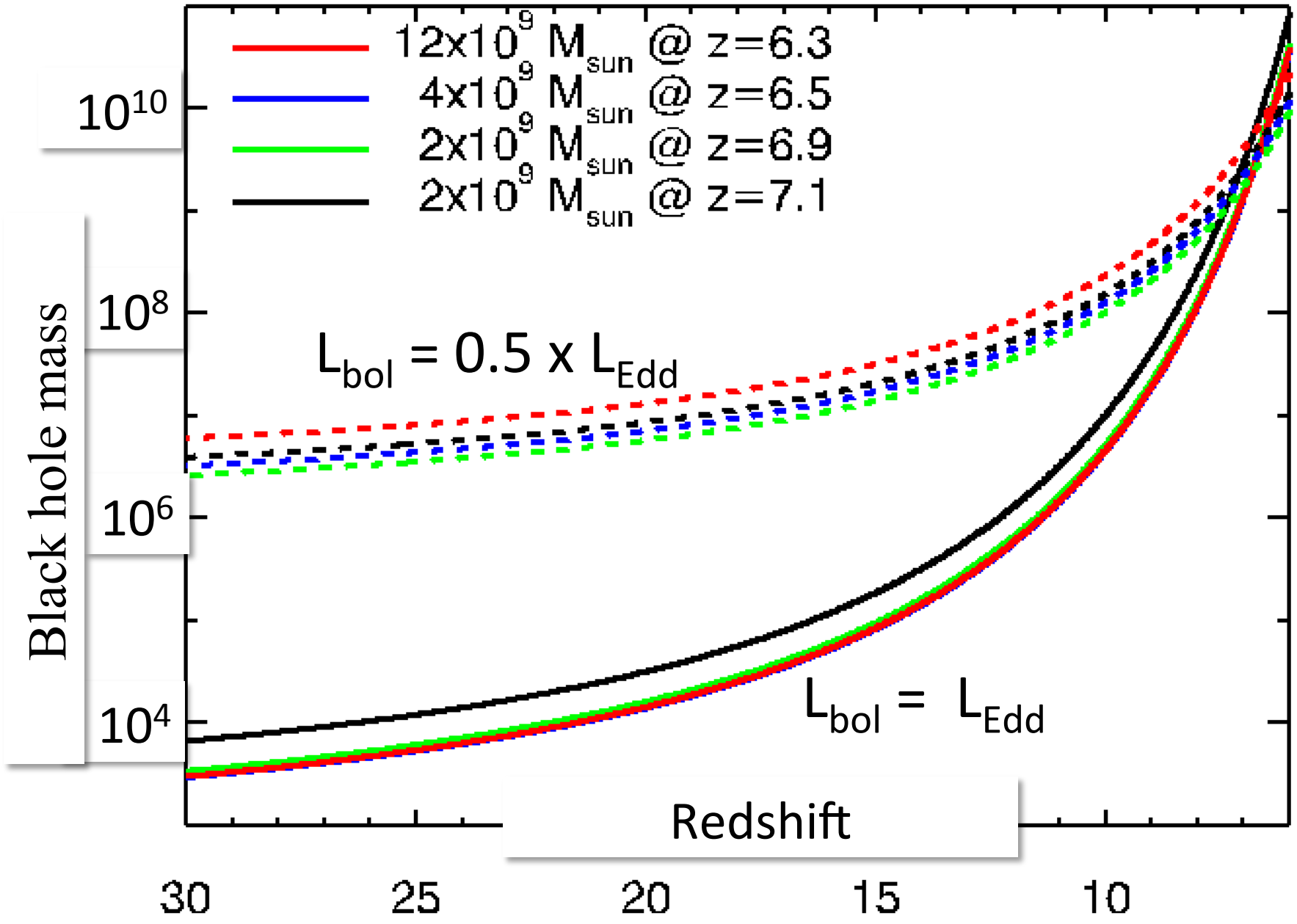
Black hole mass:

$2.1 \times 10^9\ M_\odot$

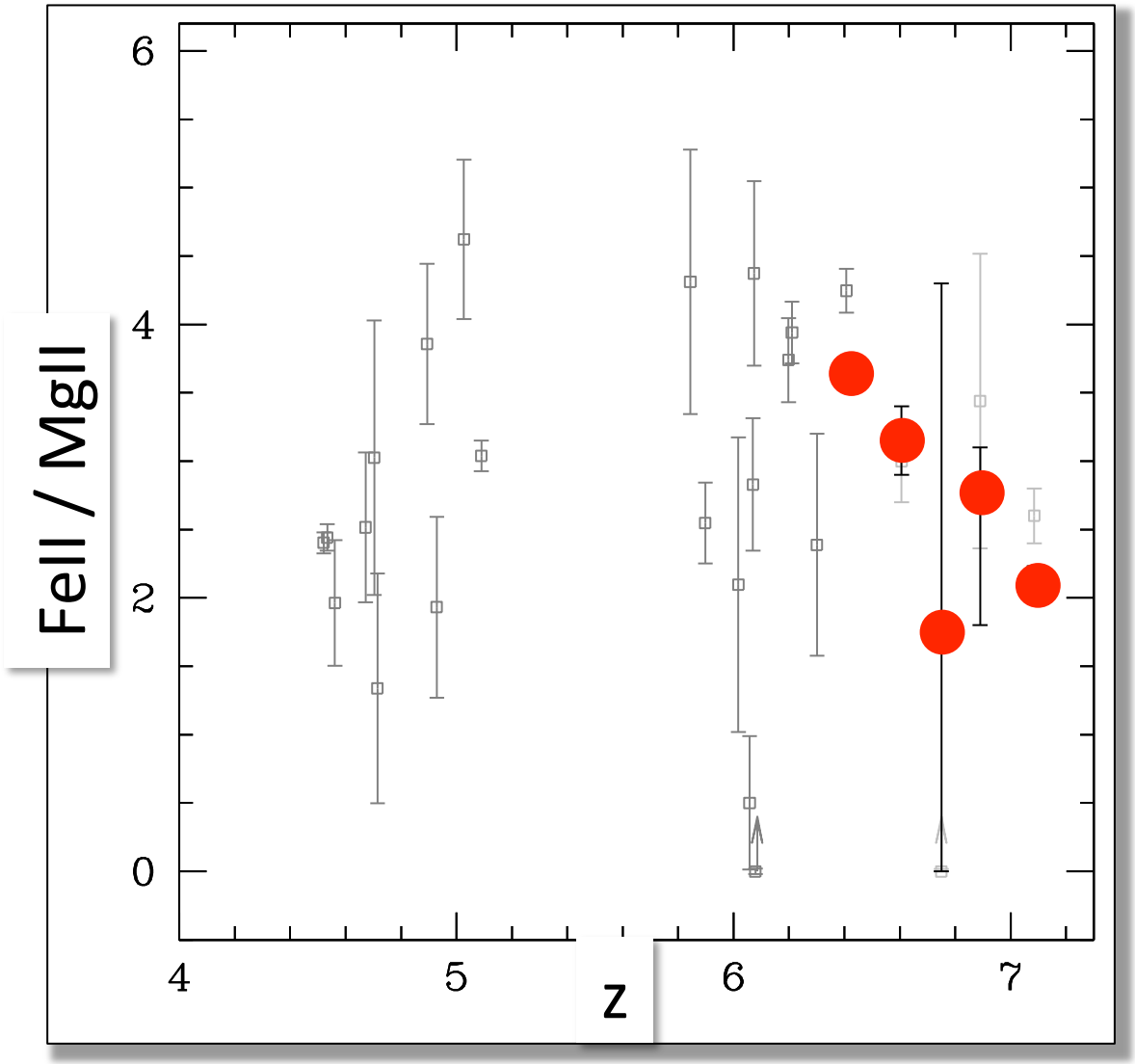
$1.5 \times 10^9\ M_\odot$

$1.0 \times 10^9\ M_\odot$

e.g., De Rosa+ 2014


12x10^9 M_sun @ z=6.3
4x10^9 M_sun @ z=6.5
2x10^9 M_sun @ z=6.9
2x10^9 M_sun @ z=7.1
L_bol = 0.5 x L_Edd
L_bol = L_Edd
Black hole mass
10^10
10^8
10^6
10^4
Redshift
30
25
20
15
10

Enrichment of broad line region

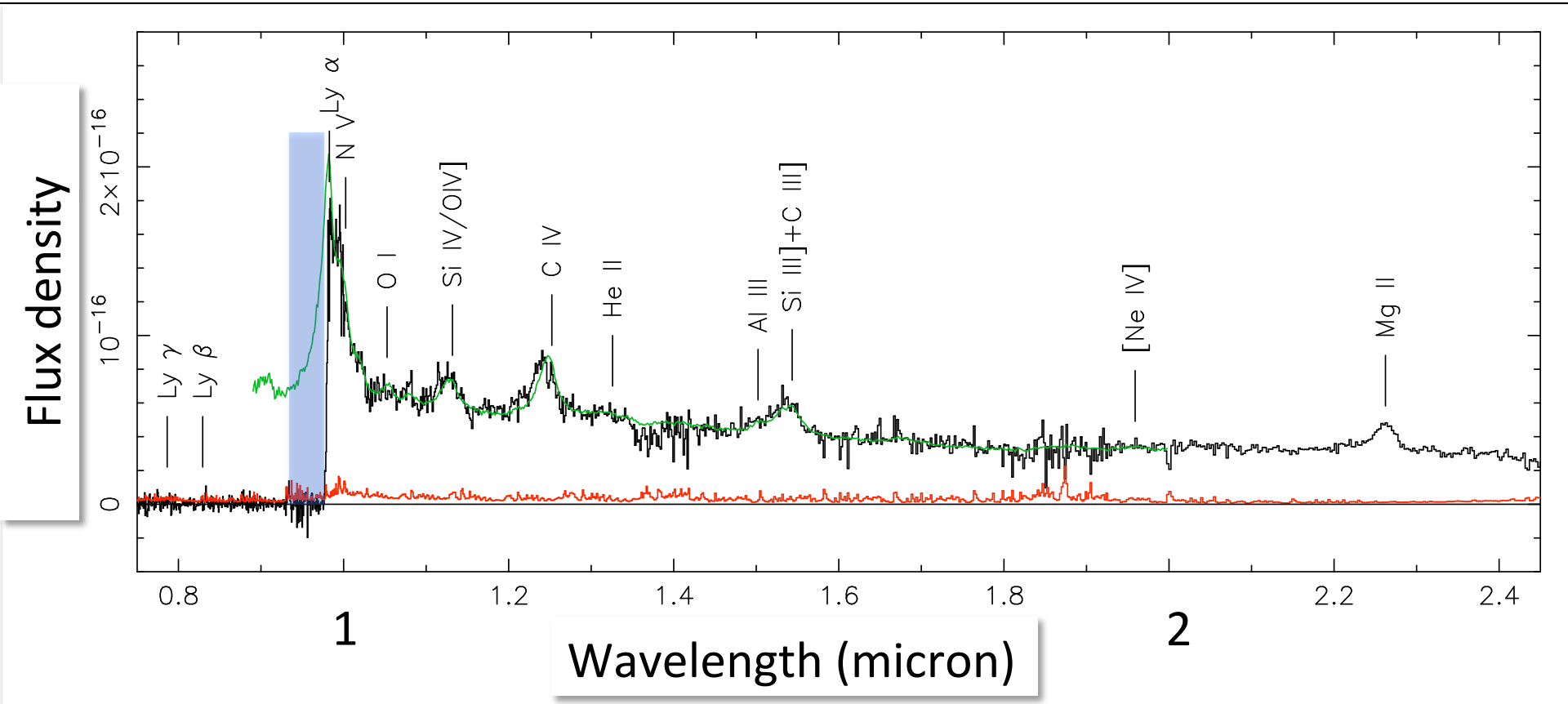


No evolution of the enrichment close to the BH up to $z \sim 7$

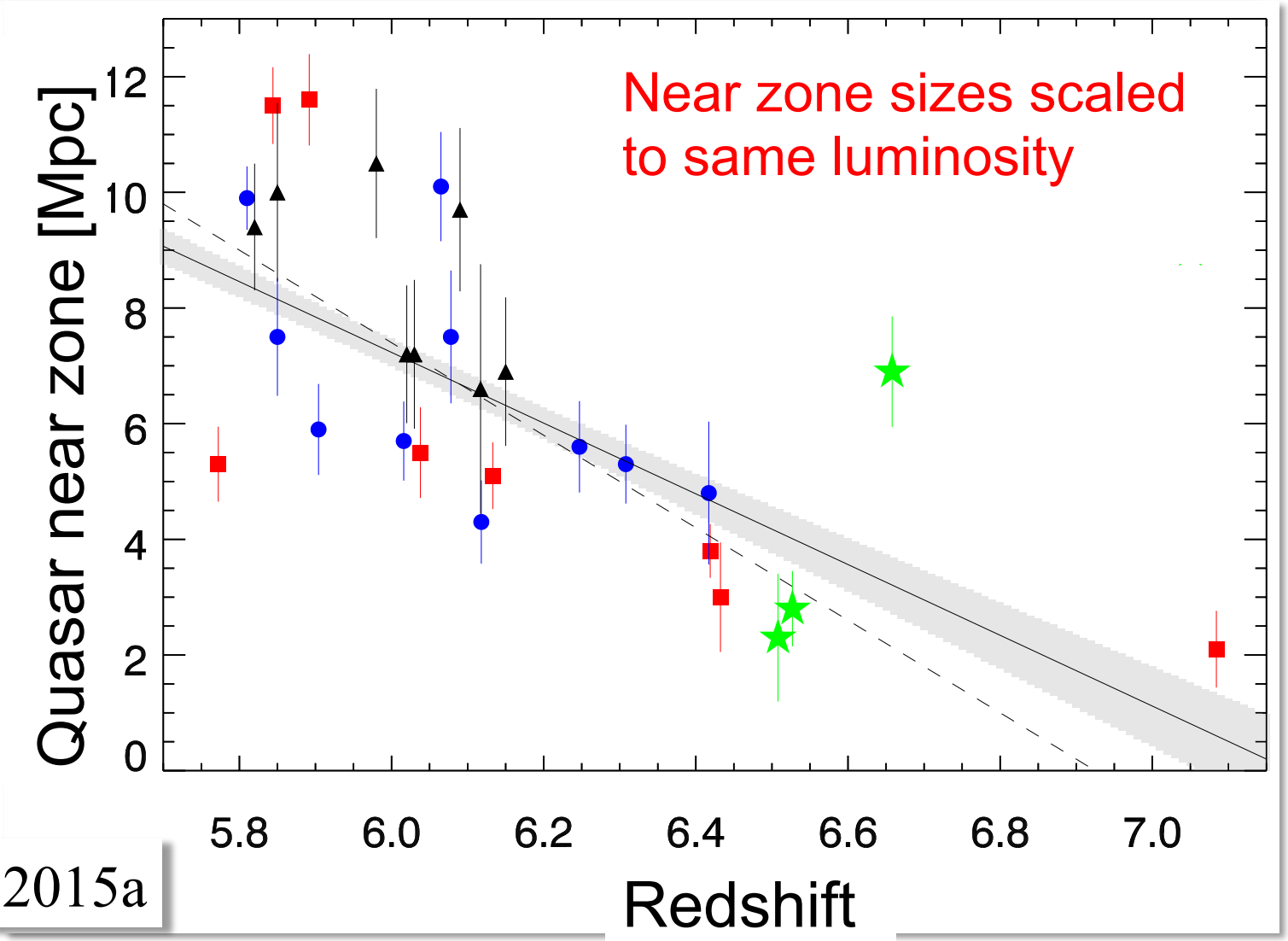
e.g., De Rosa+ 2014

Quasar ionisation region

Near zone size: $R \sim f_{HI}^{-1/3}$ (e.g. Fan+ 2006)



Quasar ionisation regions



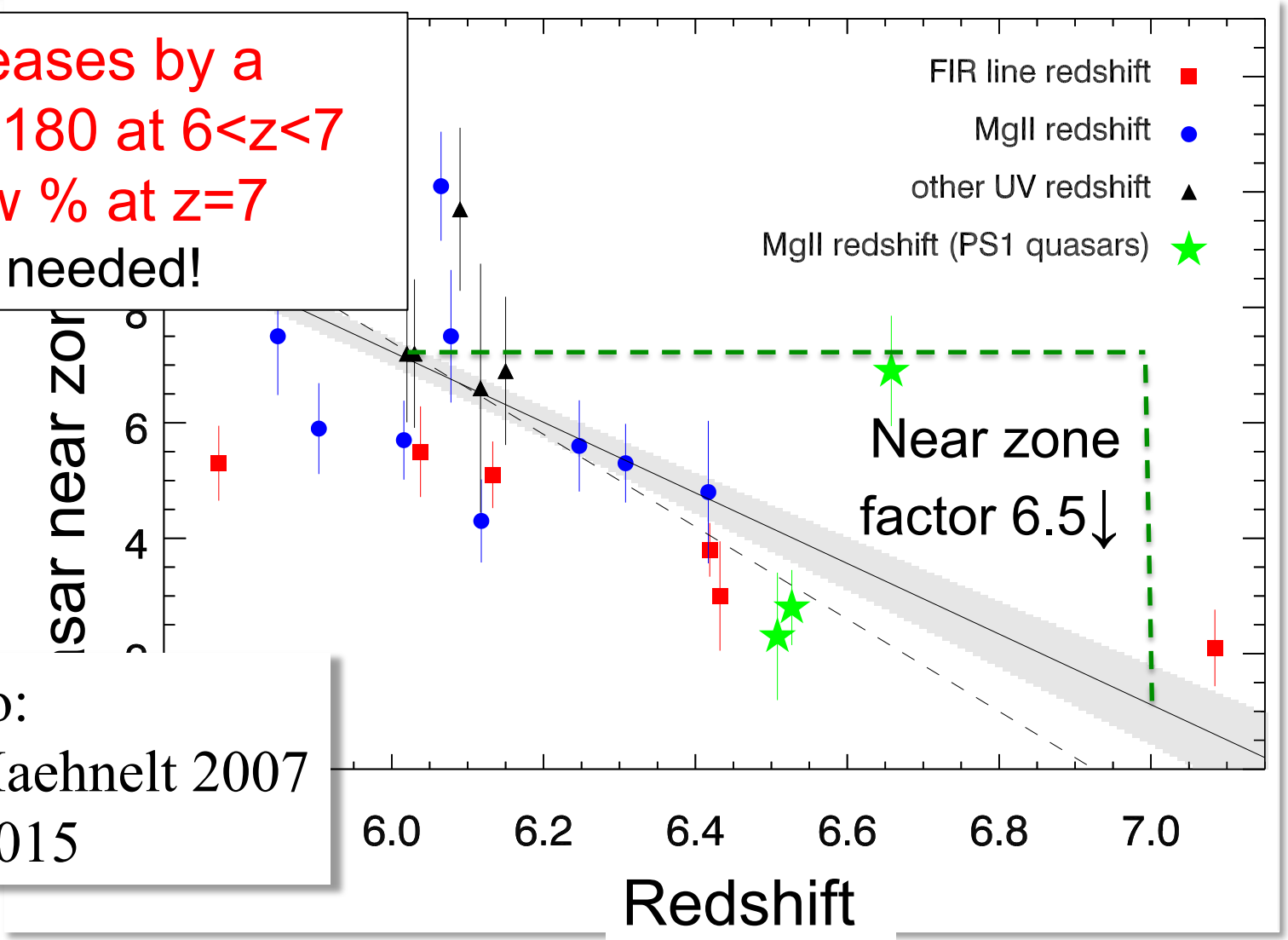
Venemans+ 2015a

Quasar ionisation regions

⇒ f_{HI} increases by a factor of ~180 at 6<z<7

⇒ f_{HI} > few % at z=7

More work needed!



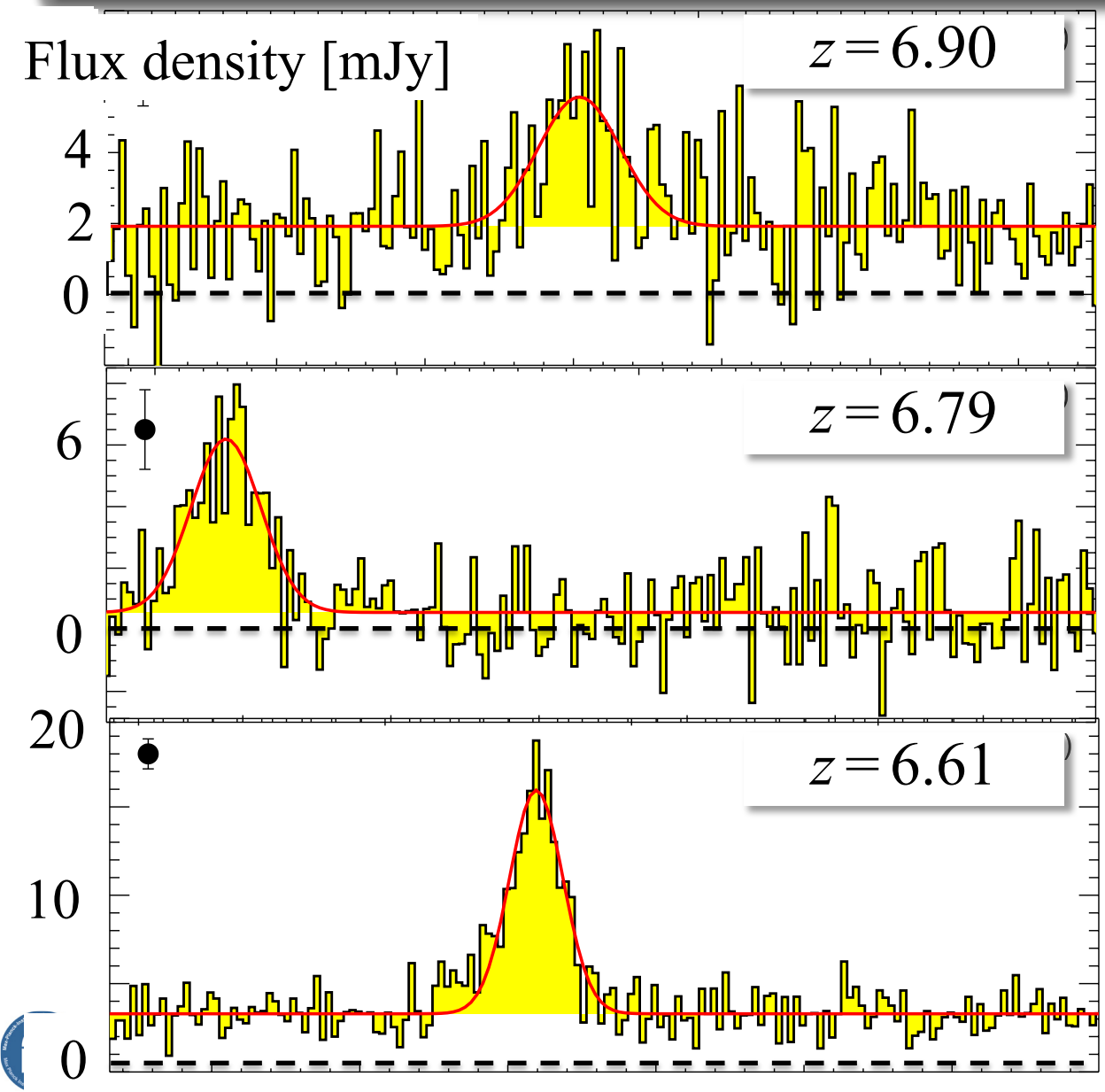
But see also:
Bolton & Haehnelt 2007
Keating+ 2015

Characteristics of distant quasars

- Due to bright central source, need to go to far-infrared to detect host galaxy
- PdBI DDT of two quasars at $z = 6.5$ and $z = 7.1$
- ALMA Cycle 1 observations of 3 z>6.6 quasars

→ Snapshot: ~15 minutes on-source

ALMA imaging of 6.6<z<6.9 quasars



15 min on-source (Cycle 1)

[CII] emission line & FIR dust continuum detected:

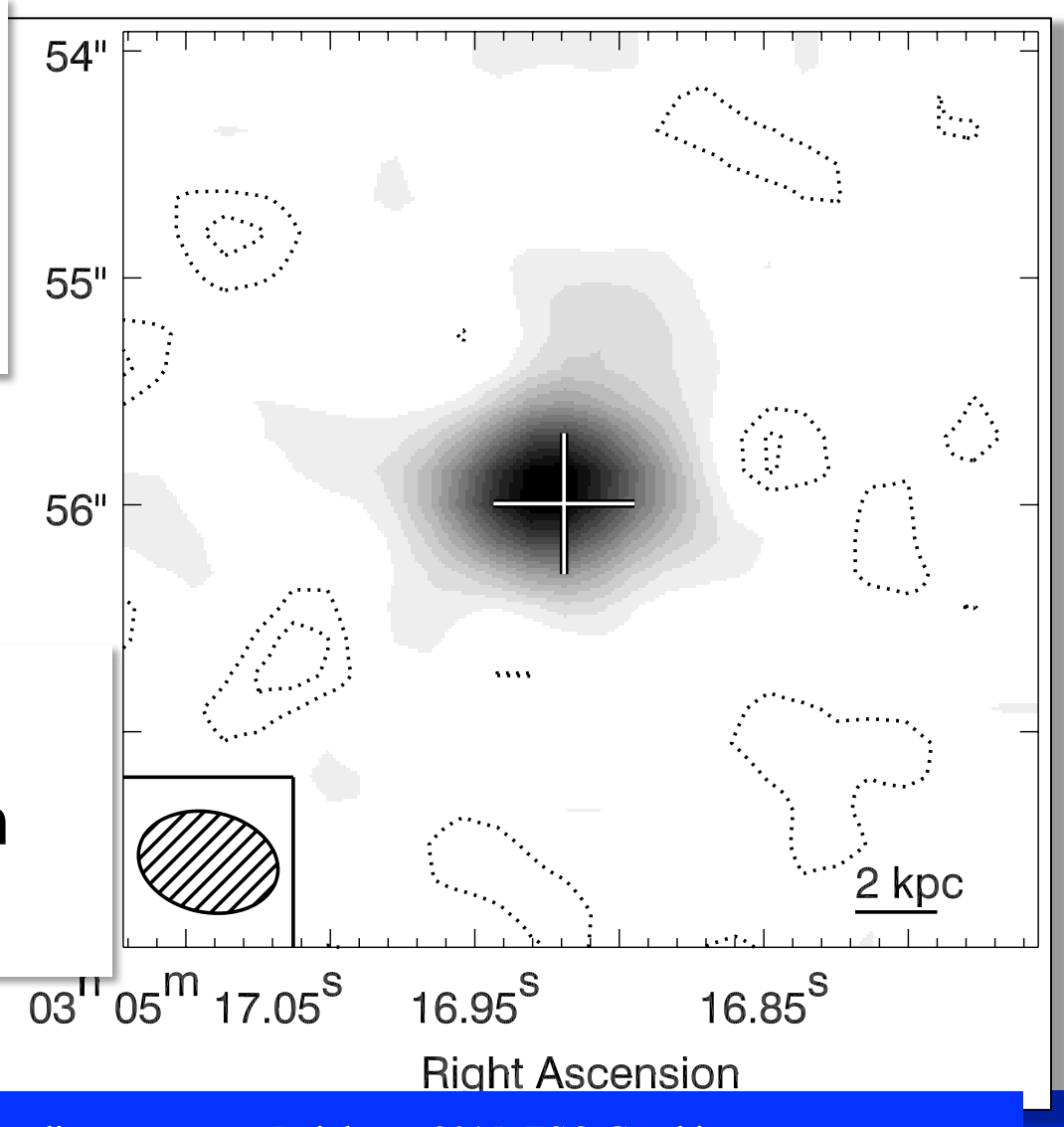
- $L_{[CII]}$ = 2-4 x10^9 $L_\odot$
- L_{FIR} = 1-8x10^{12} $L_\odot$

→ SFR~100-1500 $M_\odot$/yr

Line widths: 250 – 400 km/s

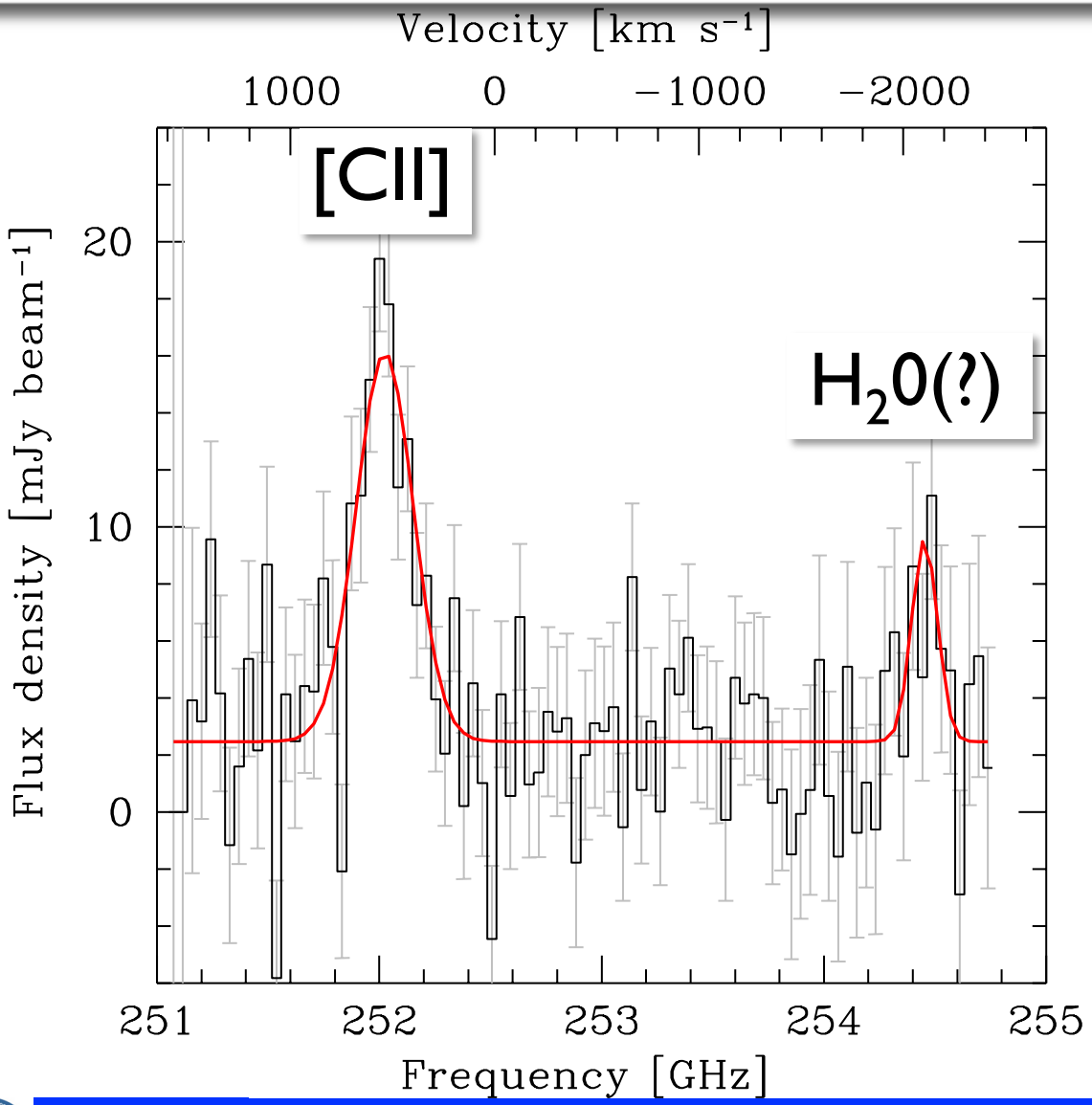
Map of [CII] emission of z=6.6 host

Continuum-subtracted map: 25sigma detection



Emission marginally resolved in 0.6″ beam
Size: 3.3x2.3 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+ 2015b

Summary & outlook

- Quasars ideal targets to study the early universe
- Need large surveys to discover them
- Supermassive (>10^9 M_{sun}) BHs in 2-3 kpc dusty galaxies forming stars at >100 M_{sun}/yr
- Constrain neutral HI fraction and metal enrichment in IGM
- Study the ISM in massive galaxies up to z>7

(ALMA C3 project to study 35 quasars at z>5.9)