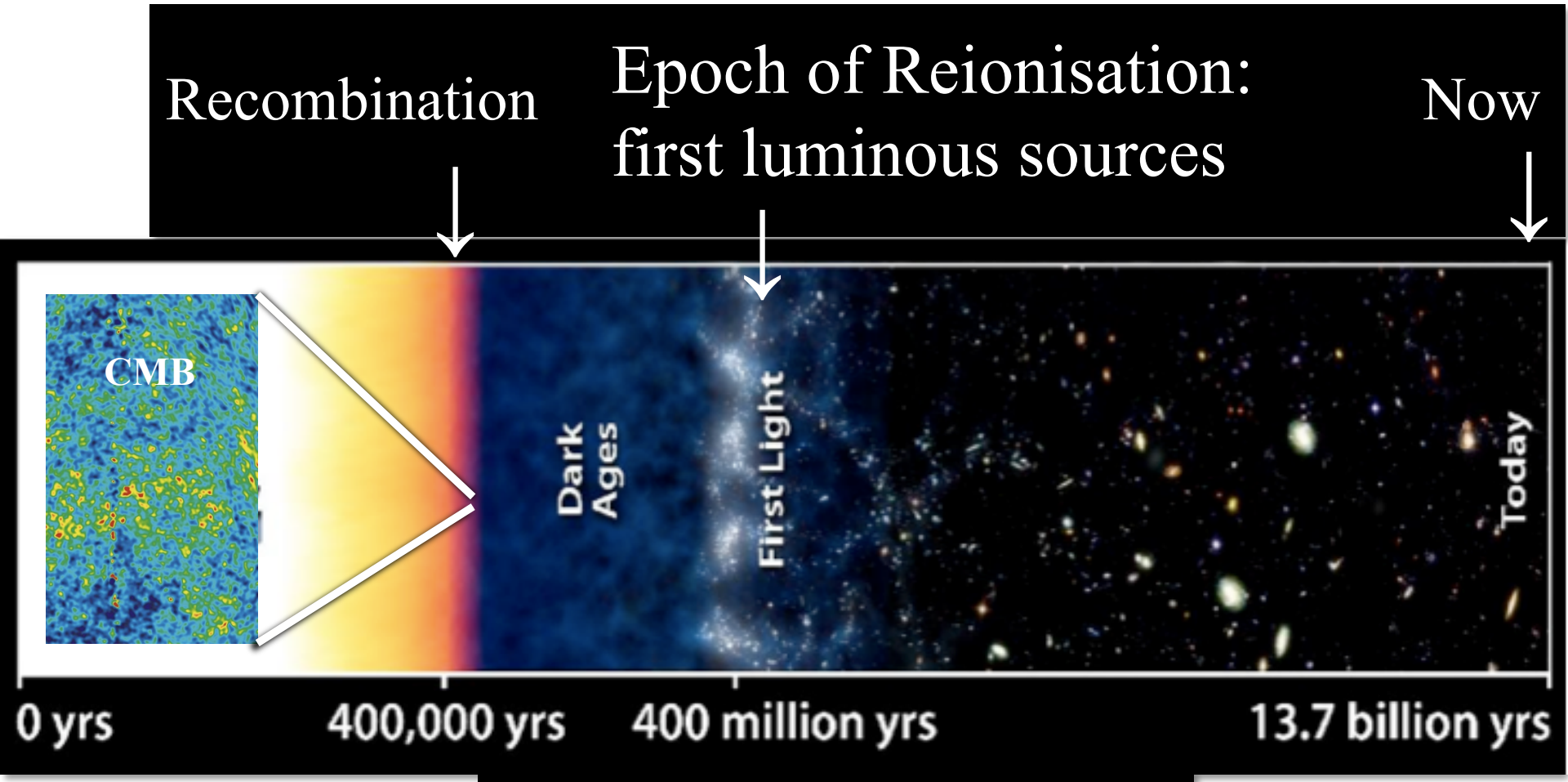
ALMA observations of z>6.5 quasar hosts:

Massive galaxy formation in the epoch of reionisation

Bram Venemans (MPIA)

The Epoch of Reionisation



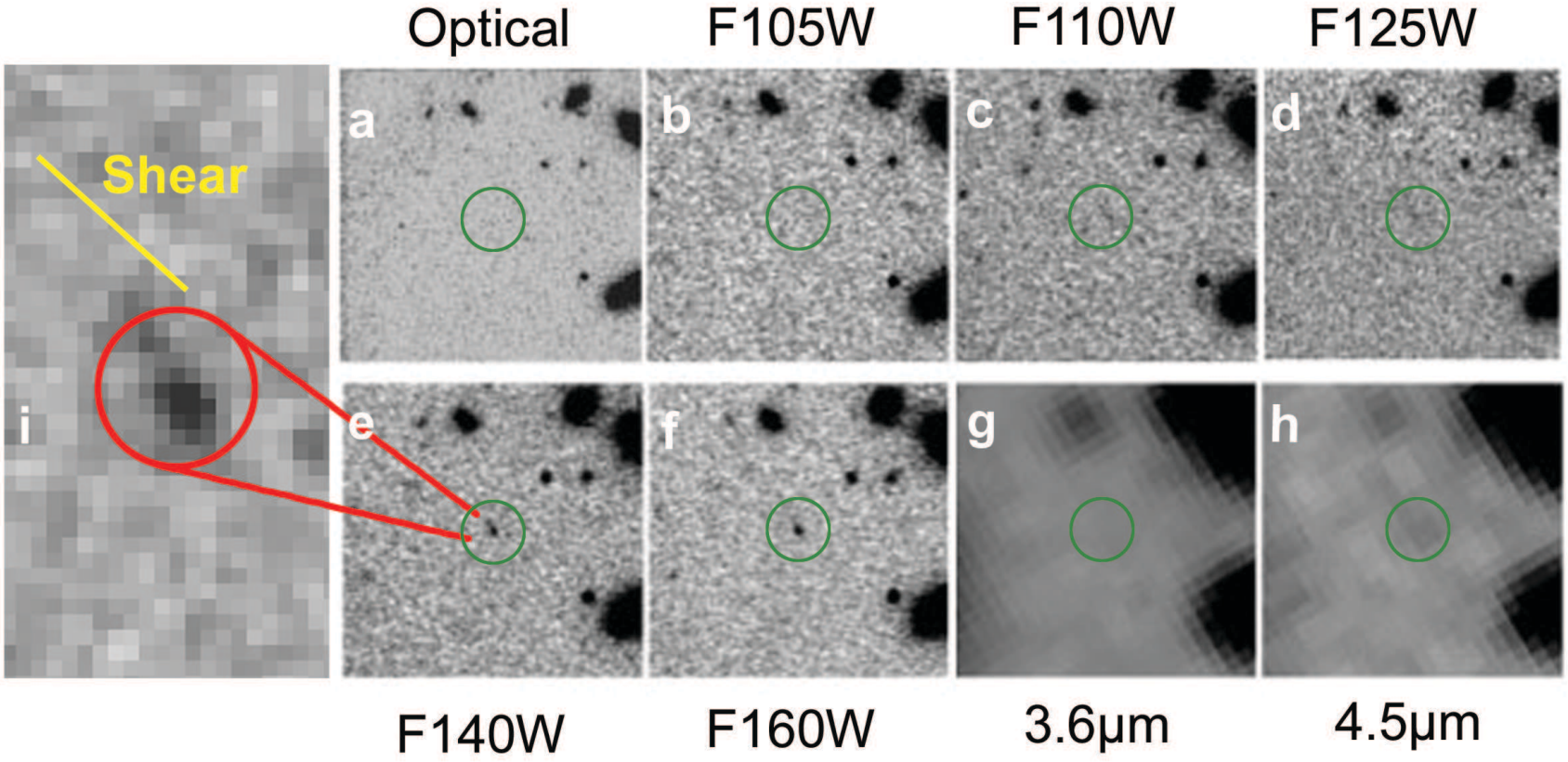
Background

- When did the first galaxies and black holes form and what were their characteristics?

- Tremendous progress in discovering galaxies out to z>10 (e.g. Bouwens+ 11,12,13; Mclure+ 10,11,13; Oesch+ 12,13; Ouchi+ 09,10; Zheng+ 12)

- Hard to study these galaxies in detail with current facilities

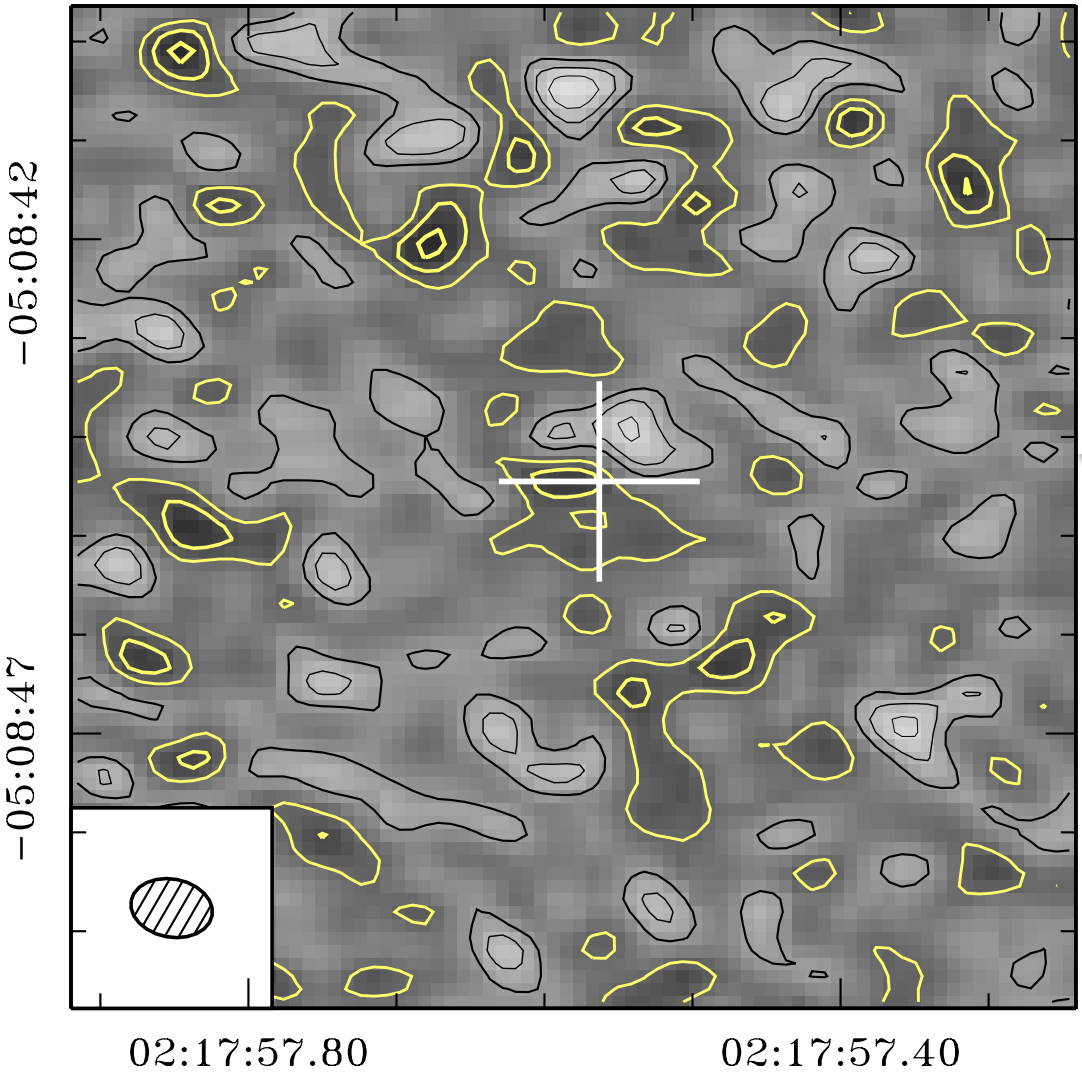
Example: MACS1149-JD at z~9.6 (Zheng+ 12)



Follow-up faint sources difficult

Even getting redshifts is challenging…

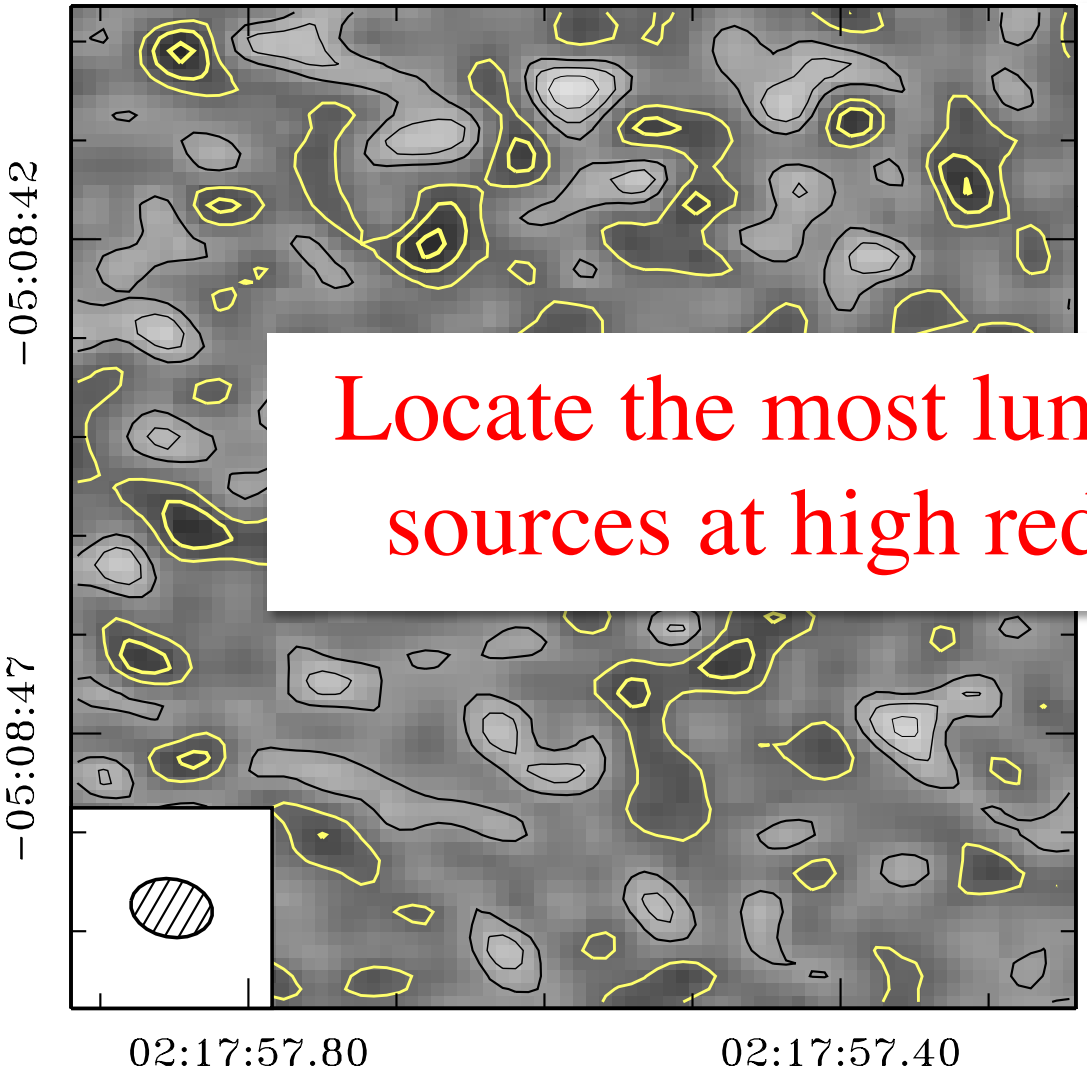
“Himiko” at z=6.595: SFR_{UV}~100 M_{sun}/yr



Undetected in the FIR continuum in 3.2 hrs with ALMA Cycle 0 (16 ant.)

Ouchi+ 2013

“Himiko” at z=6.595: SFR_{UV}~100 M_{sun}/yr

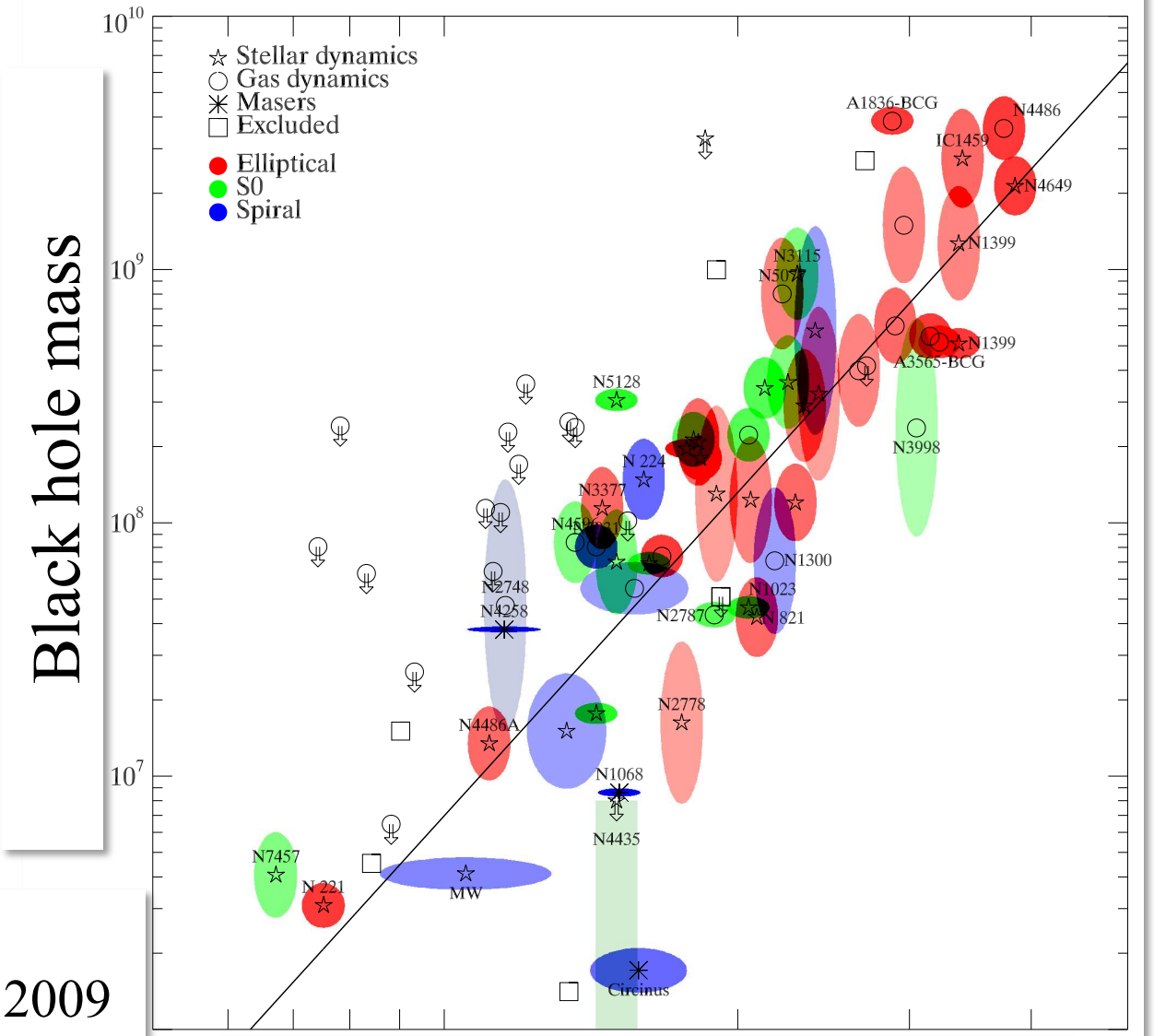


Undetected in the FIR continuum in 3.2 hrs with ALMA (16 ant.)

Locate the most luminous sources at high redshift

Ouchi+ 2013

Massive black hole → massive/ luminous galaxy



see e.g.
Gültekin et al. 2009

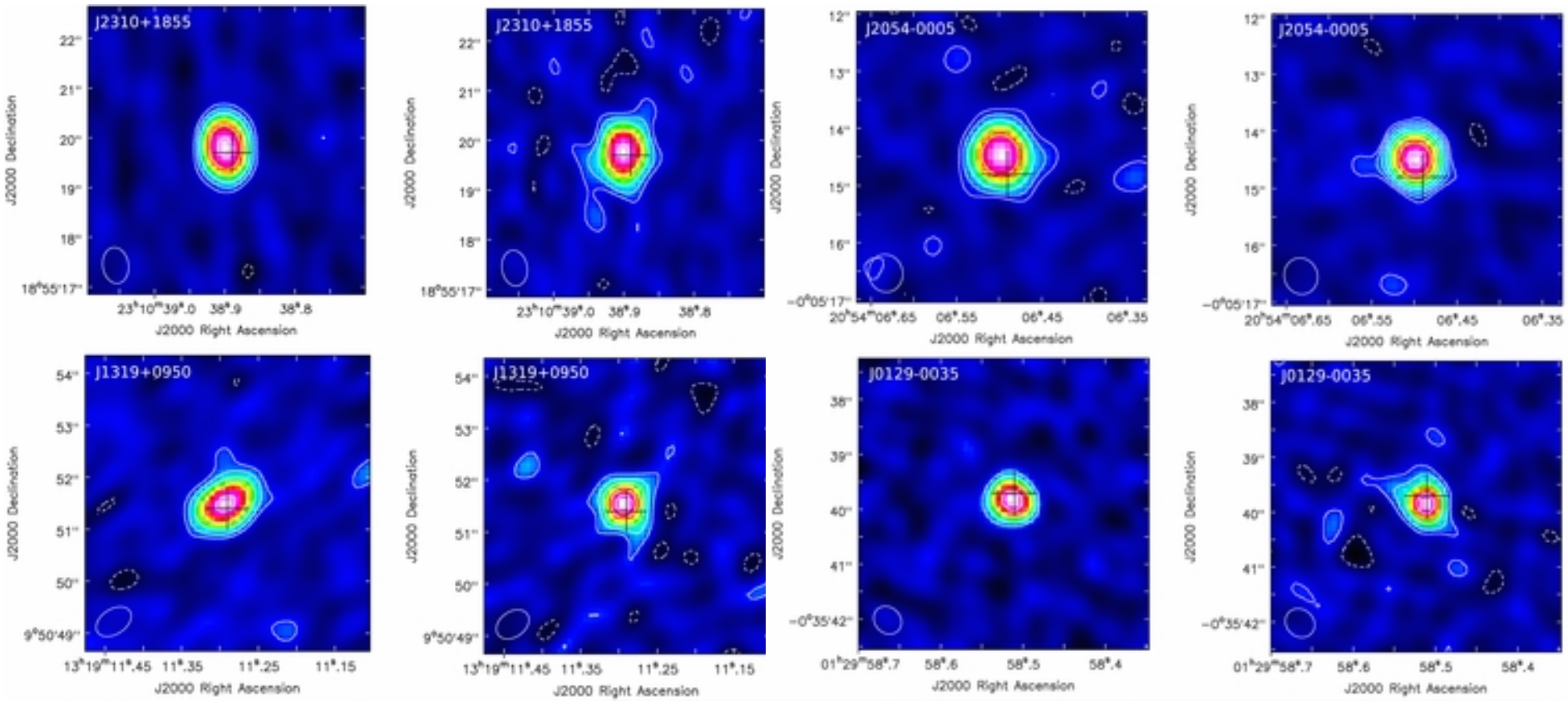
Massive black holes at high redshift

- Find massive black holes: look for quasars
- Problem: quasars are very rare
- Need multicolour surveys over large area

→ SDSS very successful in discovering many luminous quasars up to z=6.4 (J1148 at z=6.4)

Dust and [CII] emission in SDSS quasars

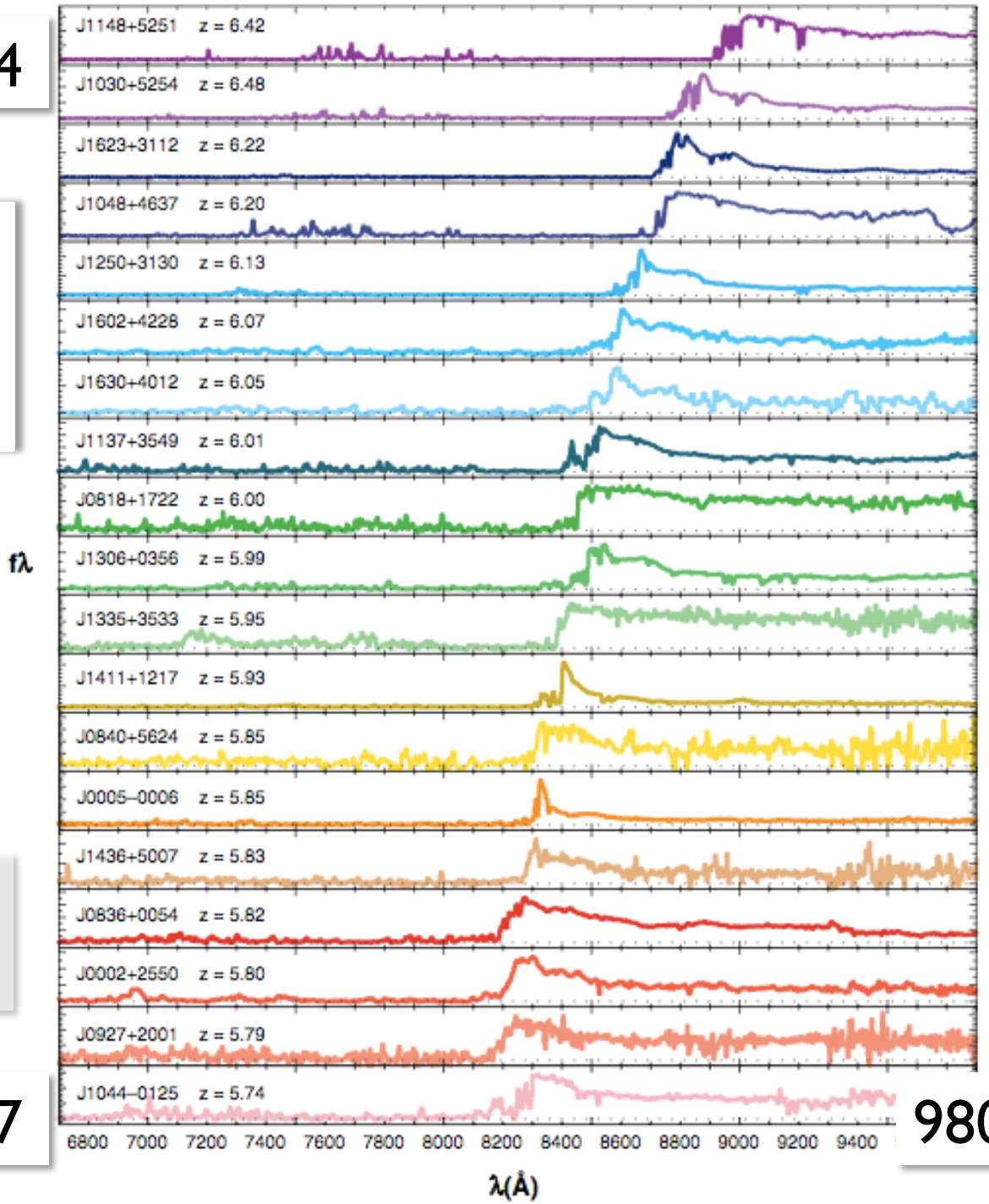
ALMA Cycle 0 data of mm bright quasars at z~6



Wang+ 2013; see also Willott+ 2013

z=6.4

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



Fan, Carilli & Keating 2006

z=5.7

9800 A

Massive black holes at high redshift

- Find massive black holes: look for quasars
- Problem: quasars are very rare
- Need multicolour surveys over large area

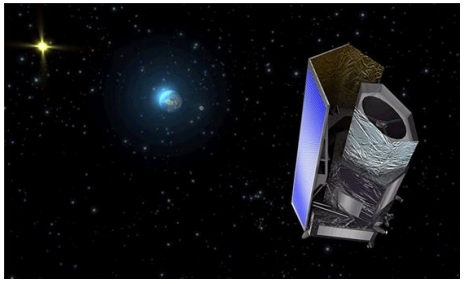
→ SDSS very successful in discovering many luminous quasars up to z=6.4 (J1148 at z=6.4)

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

Near infrared wide field surveys

- UK Infrared Deep Sky Survey (UKIDSS)
- ESO VISTA surveys (VIKING, VHS)
- Pan-STARRS: includes y-band (~1 micron)
- Upcoming: Dark Energy Survey, Euclid, LSST, …

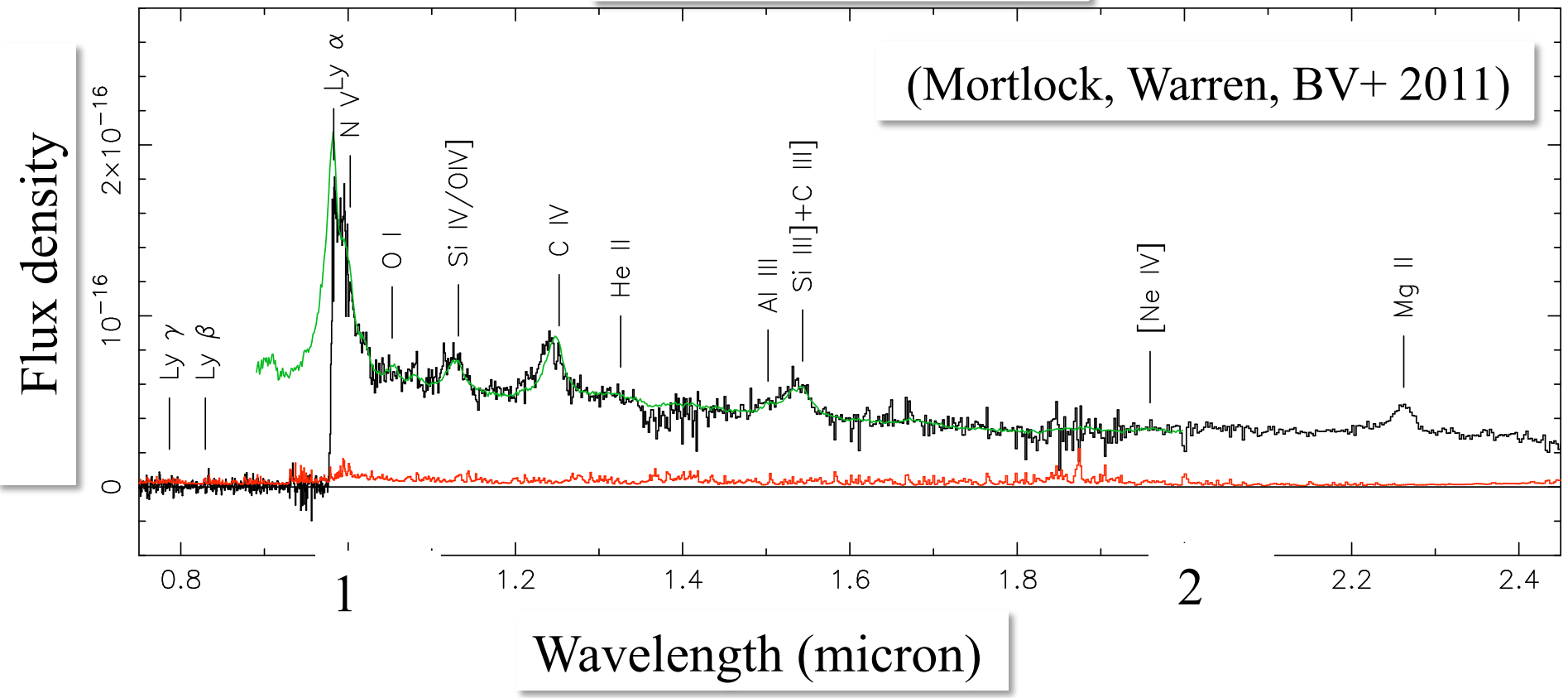
Pan-STARRS



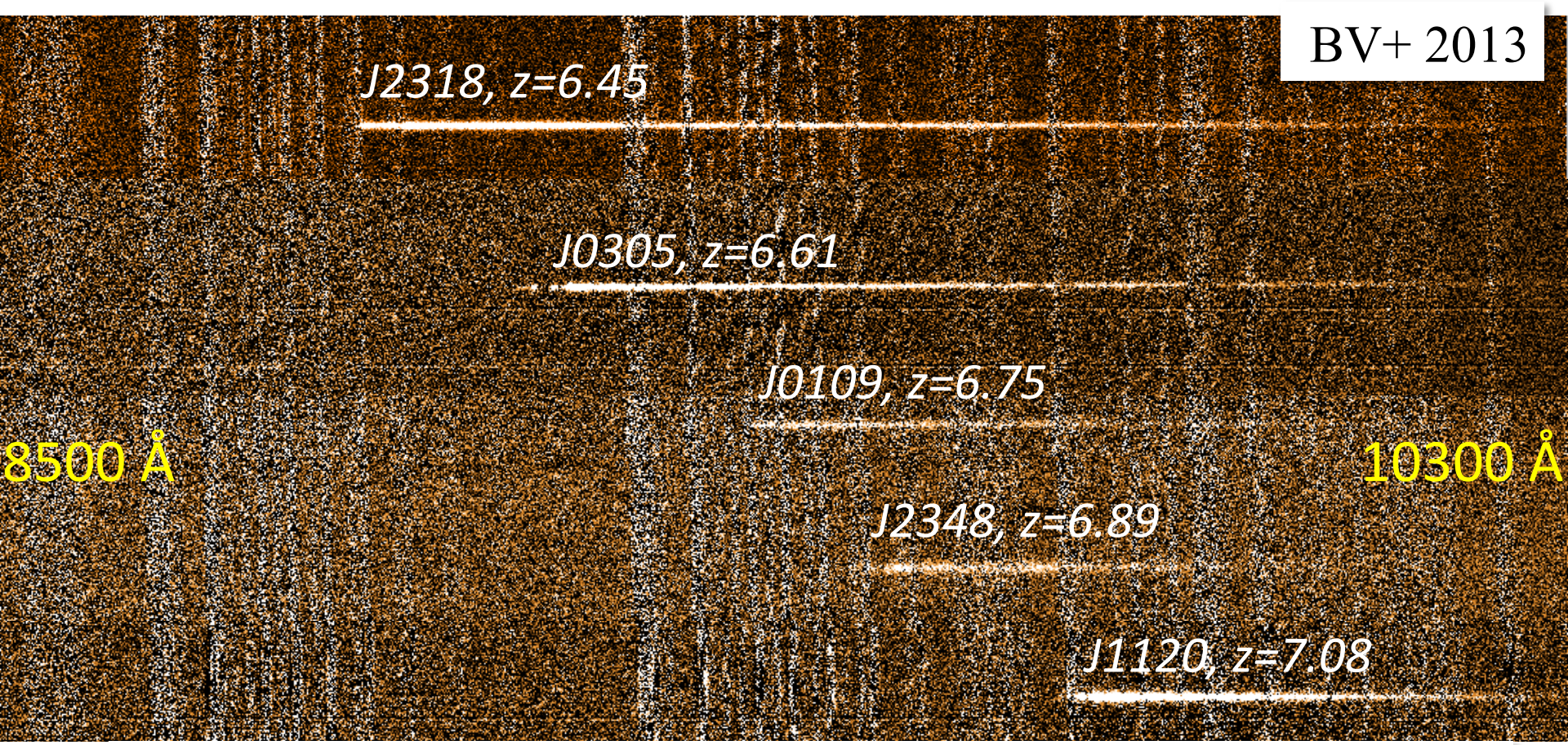
A luminous quasar in UKIDSS at z=7.1

Bright quasar: $M_{1450} = -26.6$, $M_{BH} \approx 3 \times 10^9\ M_\odot$

ULAS J1120+0641

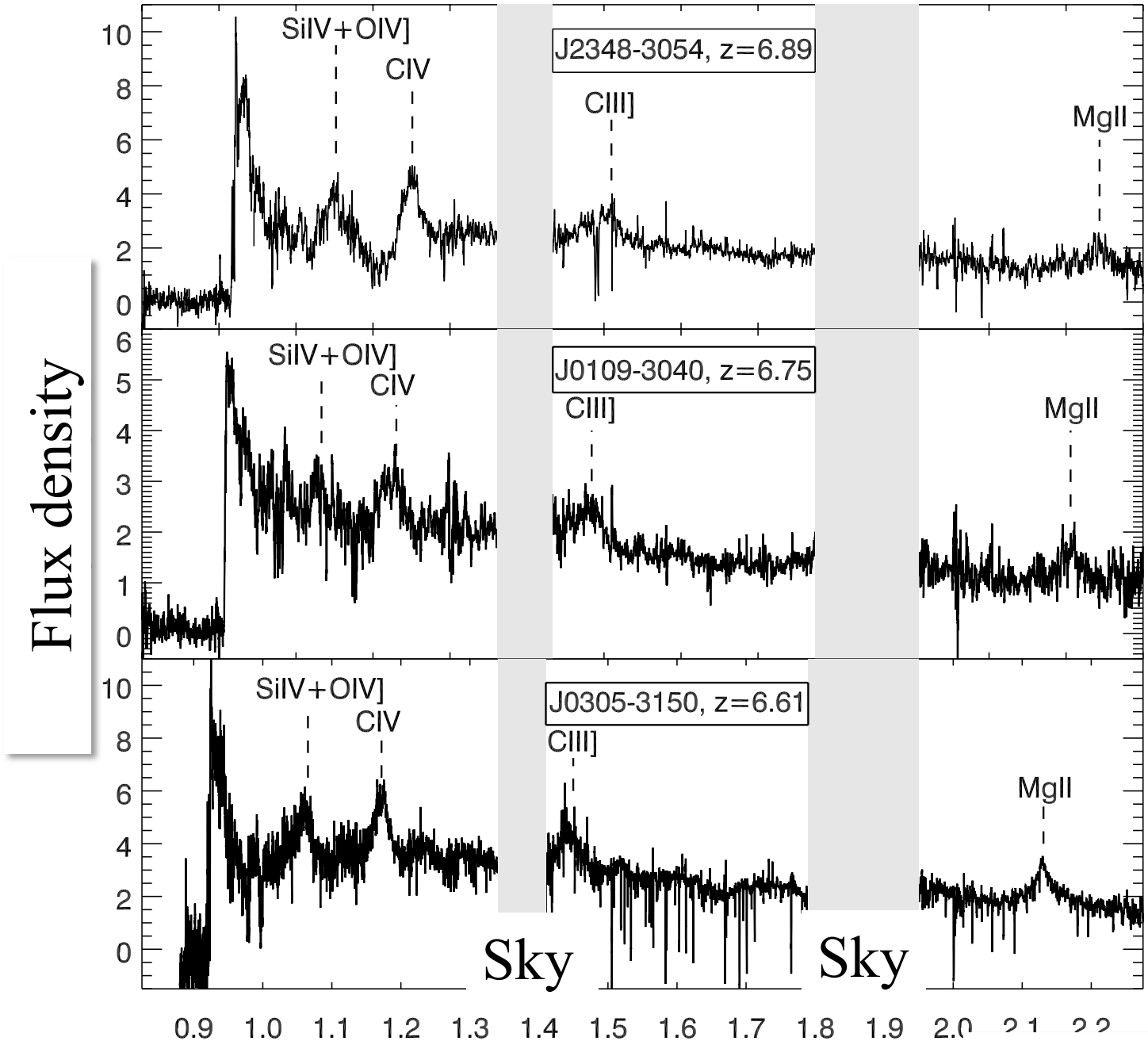


Four $z \gtrsim 6.5$ quasars from VISTA/VIKING



- 4 $z > 6.5$ quasars in VISTA/VIKING survey

  $Y_{AB} \sim 20.8 - 21.3 \rightarrow M_{UV}$: -25.5 to -26.1



Black hole mass:

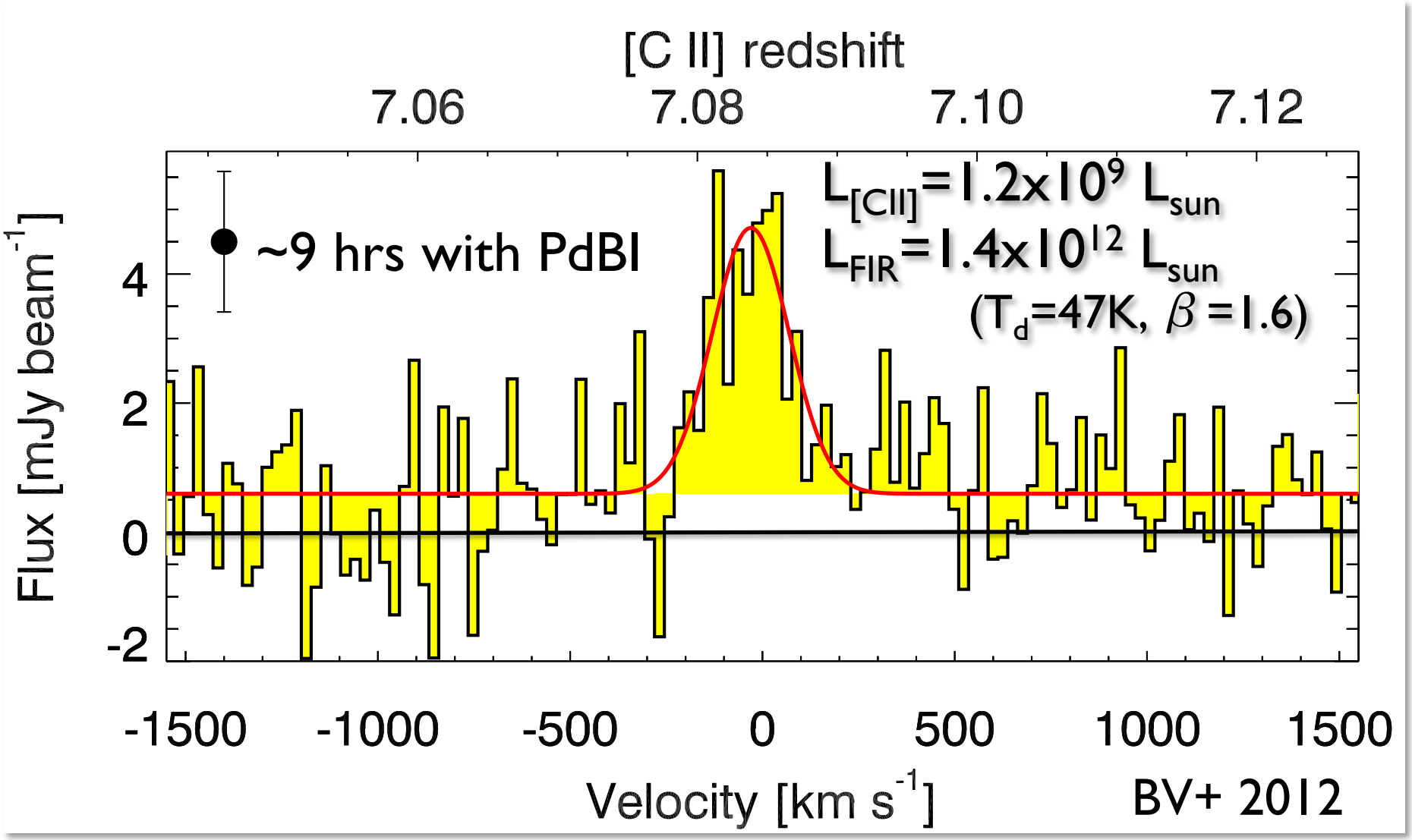
$2.1 \times 10^9 M_\odot$

$1.5 \times 10^9 M_\odot$

$1.0 \times 10^9 M_\odot$

De Rosa, BV+ 2014

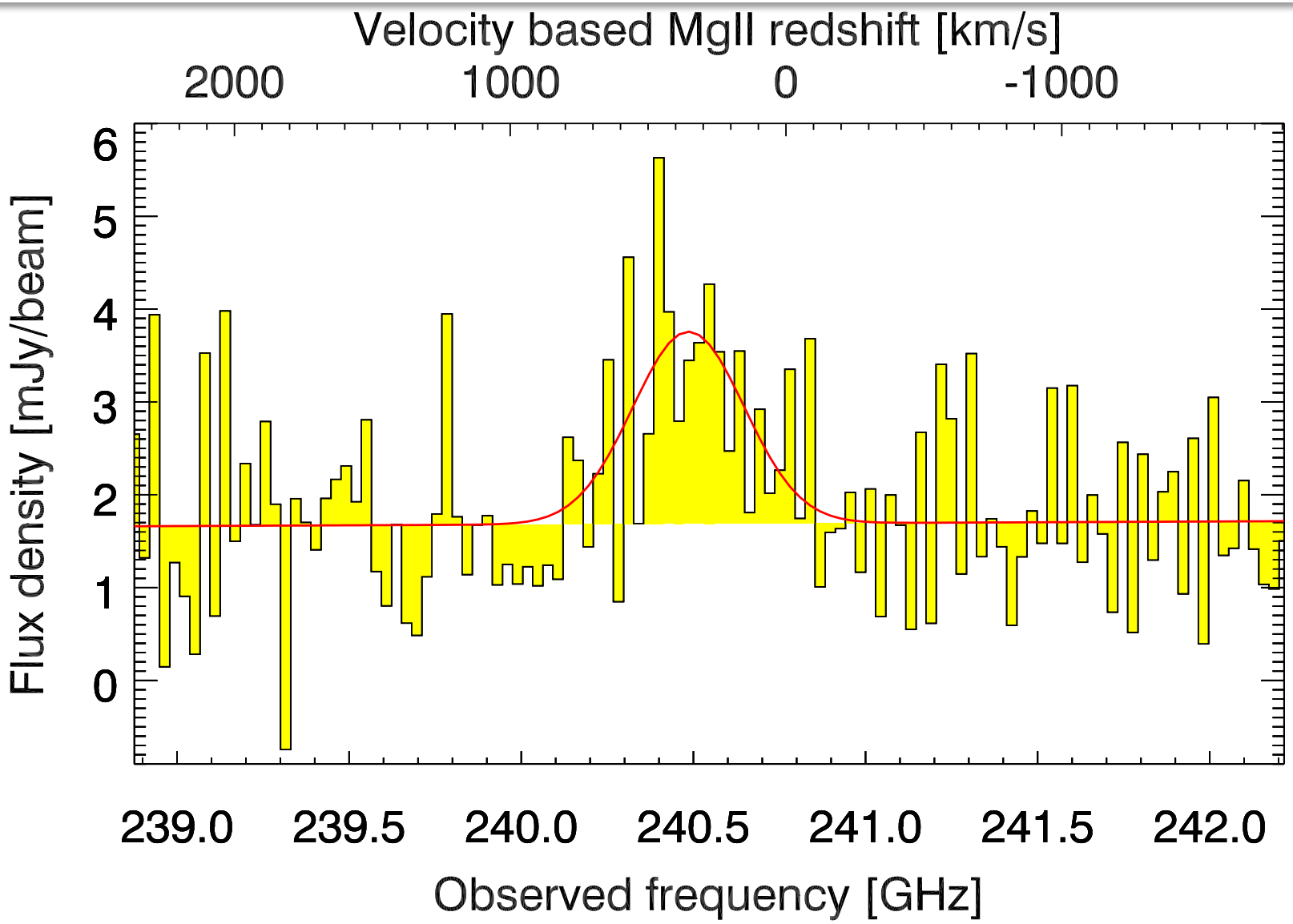
Spectrum of J1120+0641 at z=7.1



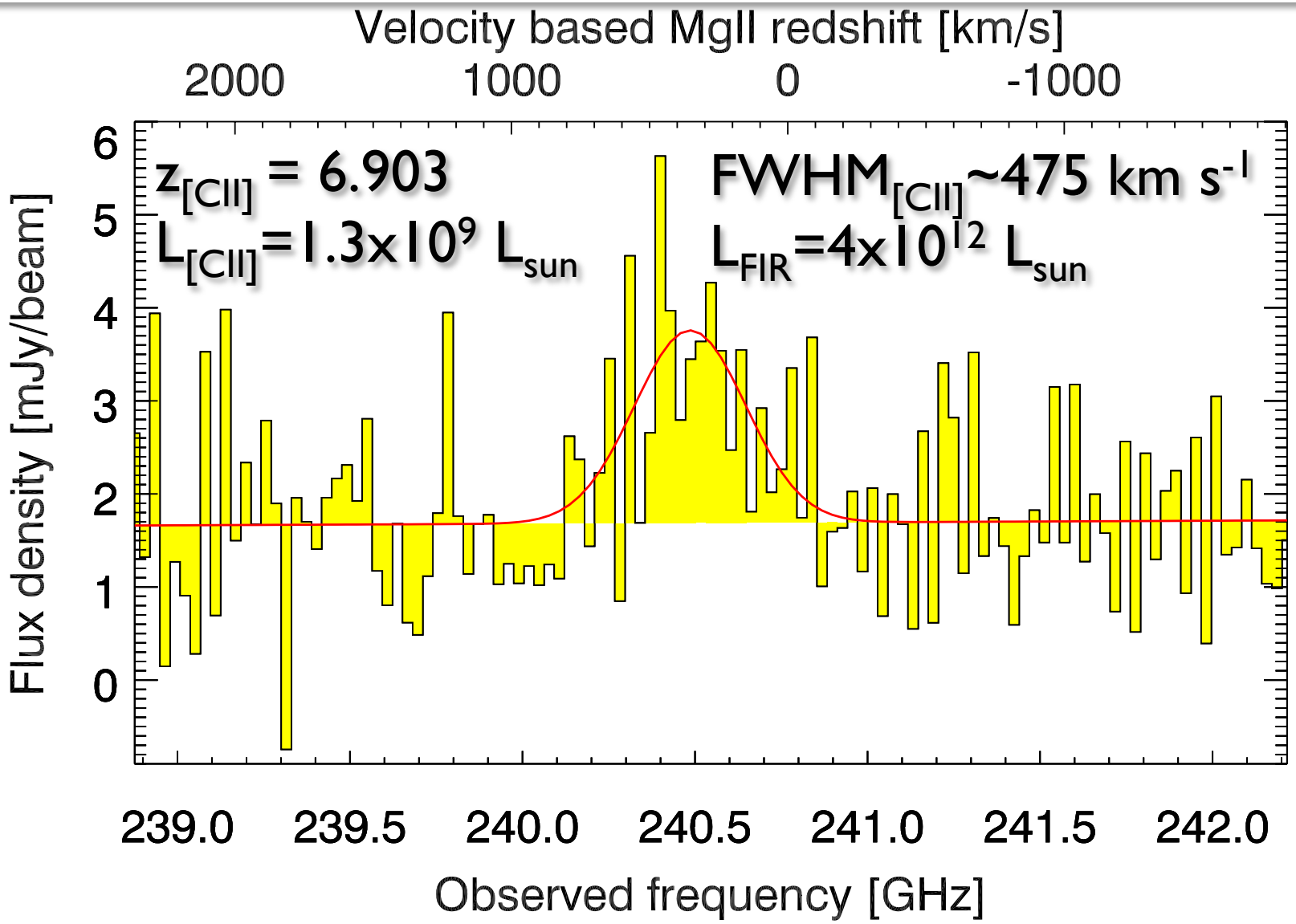
ALMA Cycle 1 snapshot observations

- Observations in Oct-Nov 2013
- 3 z>6.5 quasar hosts from VIKING
- 21-30 min execution time (per source)
- 23-30 antennas used
- 10-16 min on-source (45-60% efficiency)
- reach same sensitivity as 9 hrs PdBI(!)
- Resolution ~0.5” (requested: 1.6”)

[CII] spectrum of J2348-3054 at z~6.9

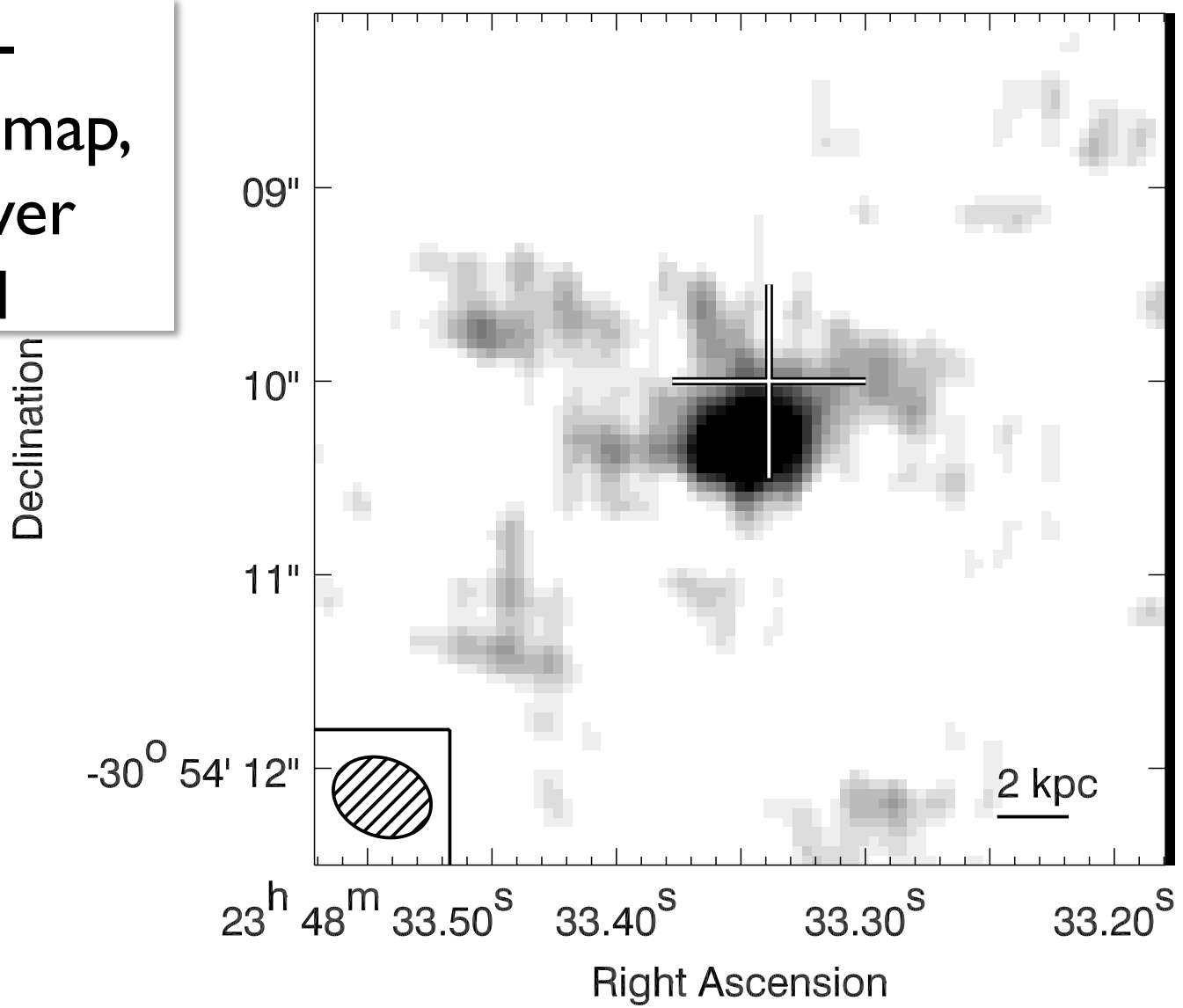


[CII] spectrum of J2348-3054 at z~6.9



Map of [CII] emission of J2348-3054

Continuum-subtracted map, averaged over line FWHM



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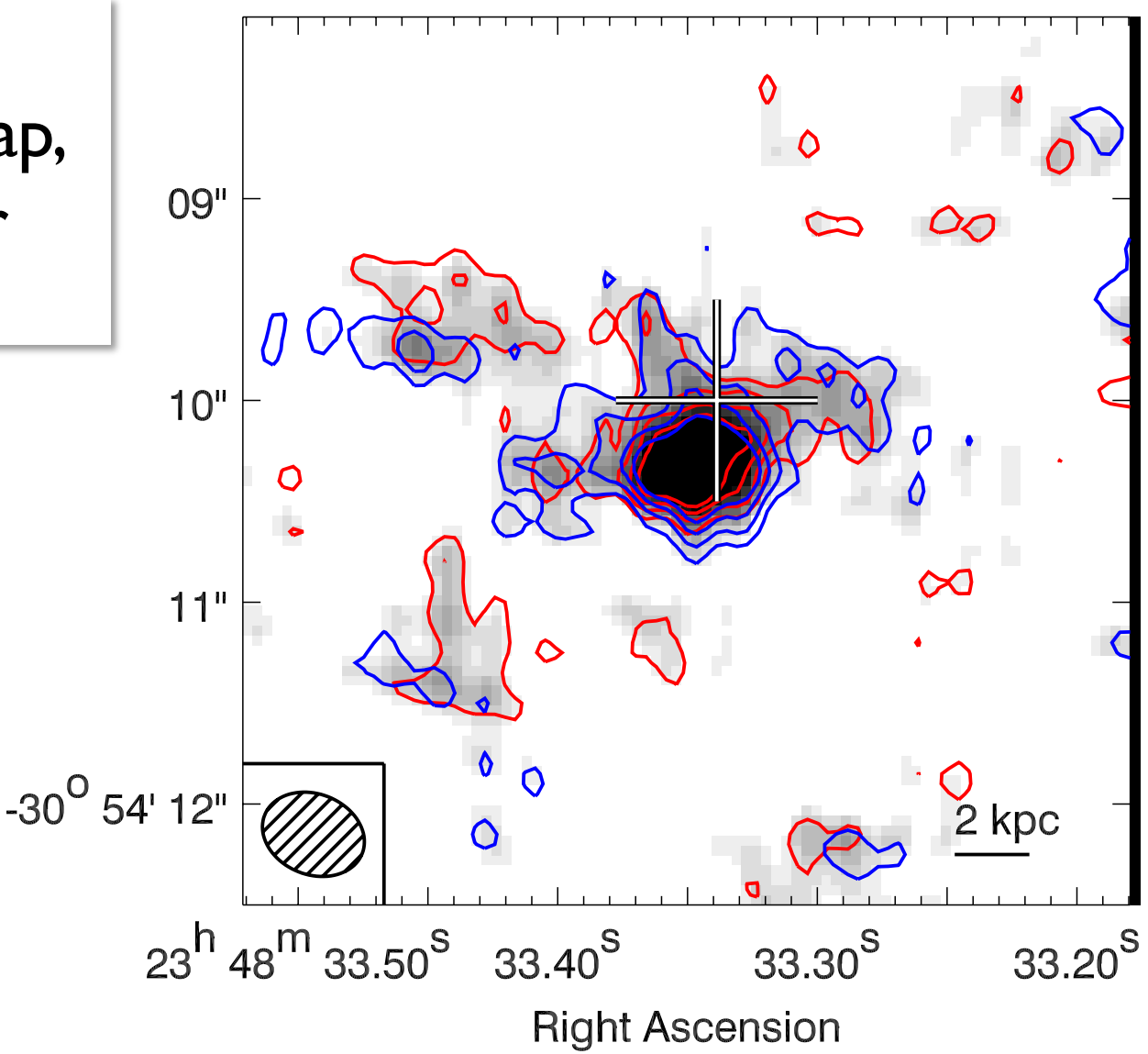
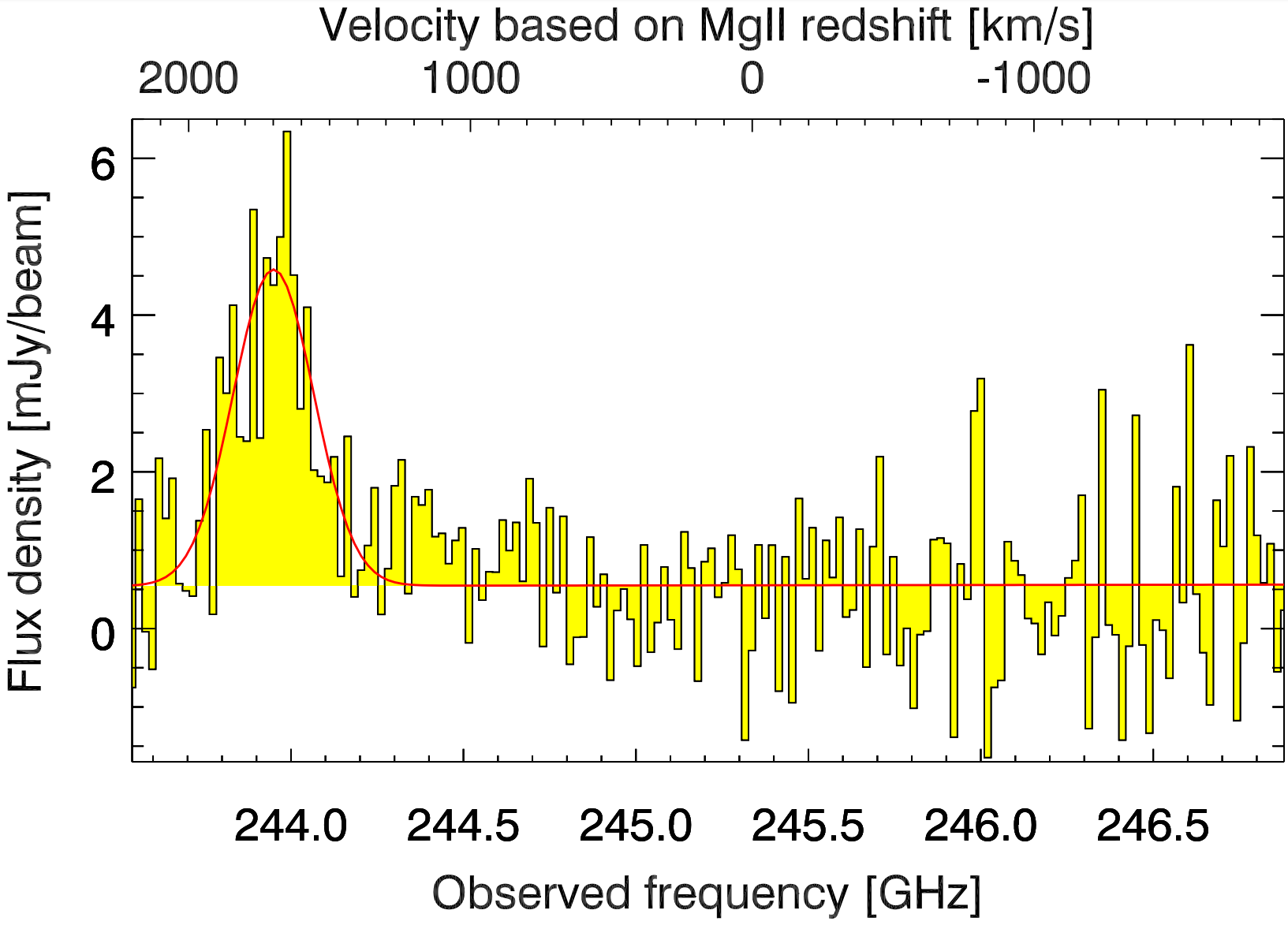


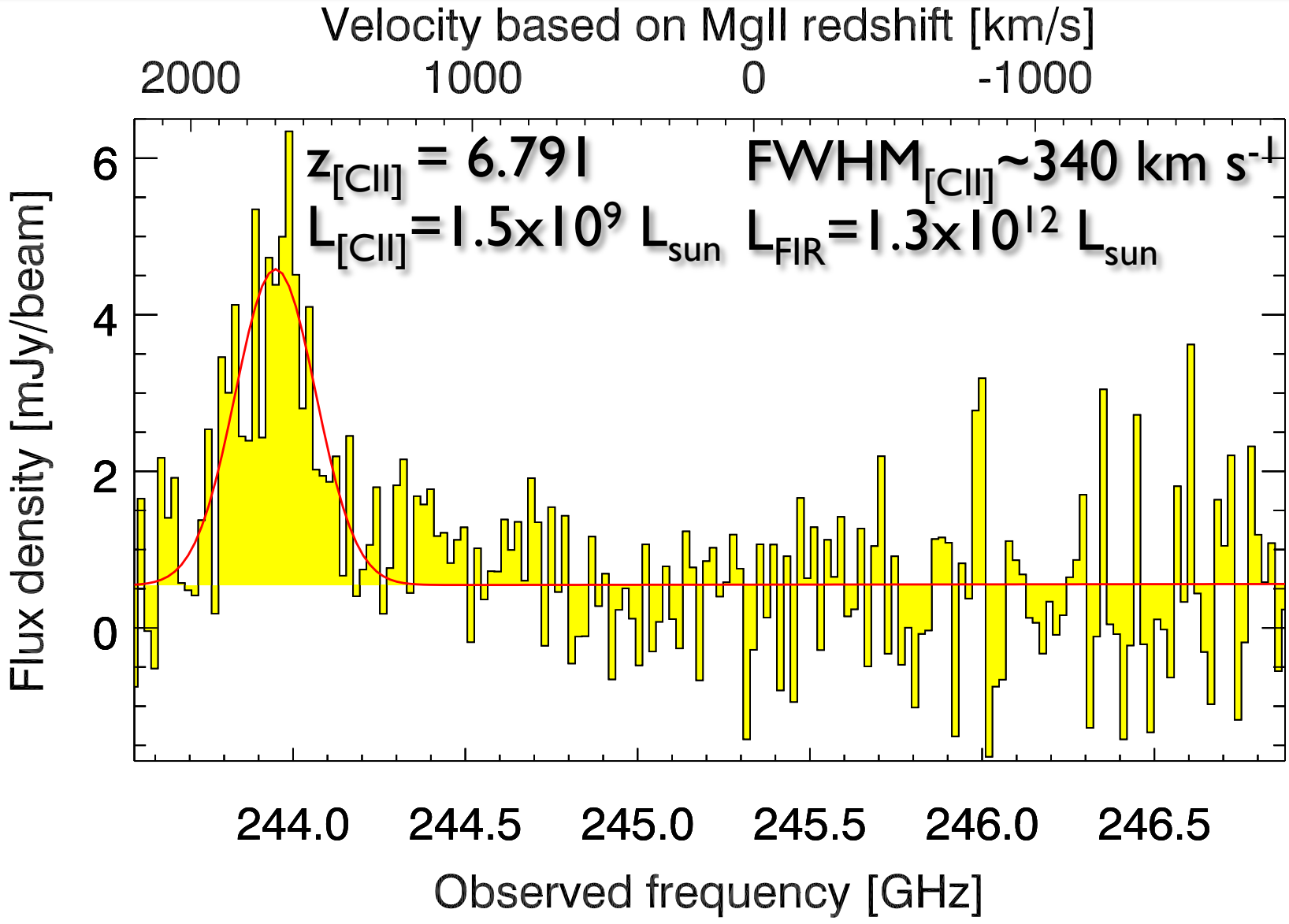
Blue: blue side of line peak

Red: red side of line peak

[CII] spectrum of J0109-3047 at z~6.75

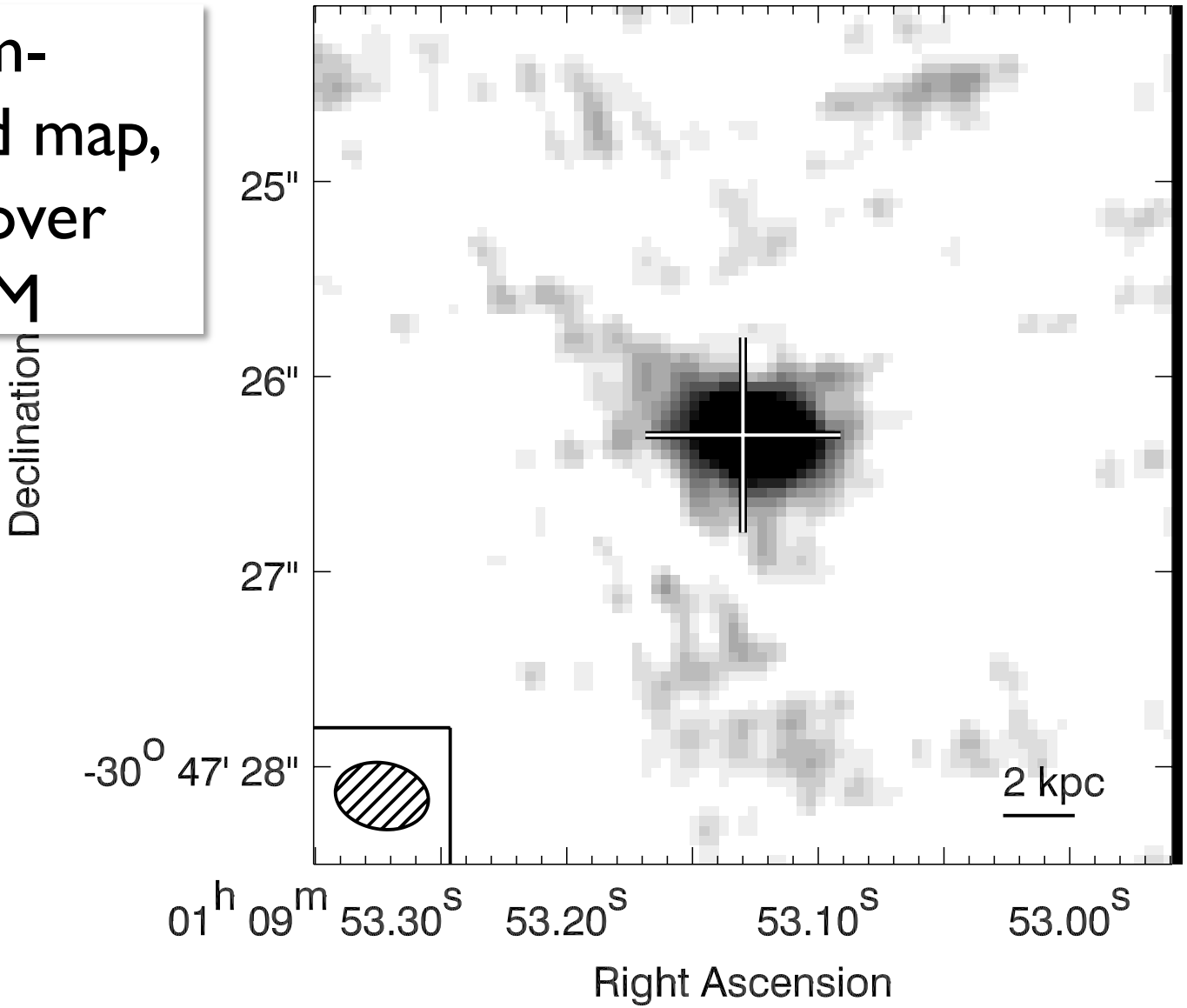


[CII] spectrum of J0109-3047 at z~6.75



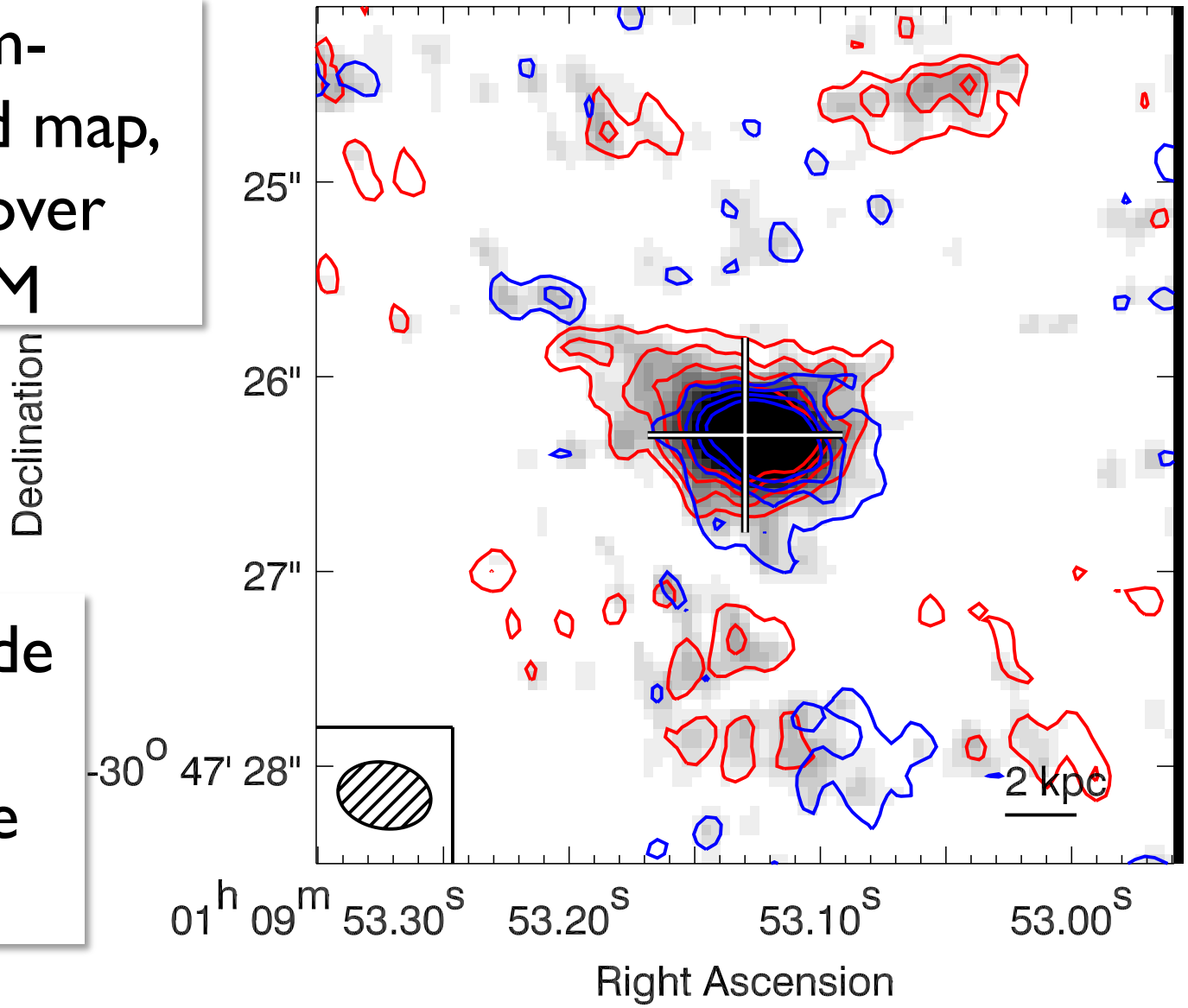
Map of [CII] emission of J0109-3047

Continuum-subtracted map, averaged over line FWHM



Map of [CII] emission of J0109-3047

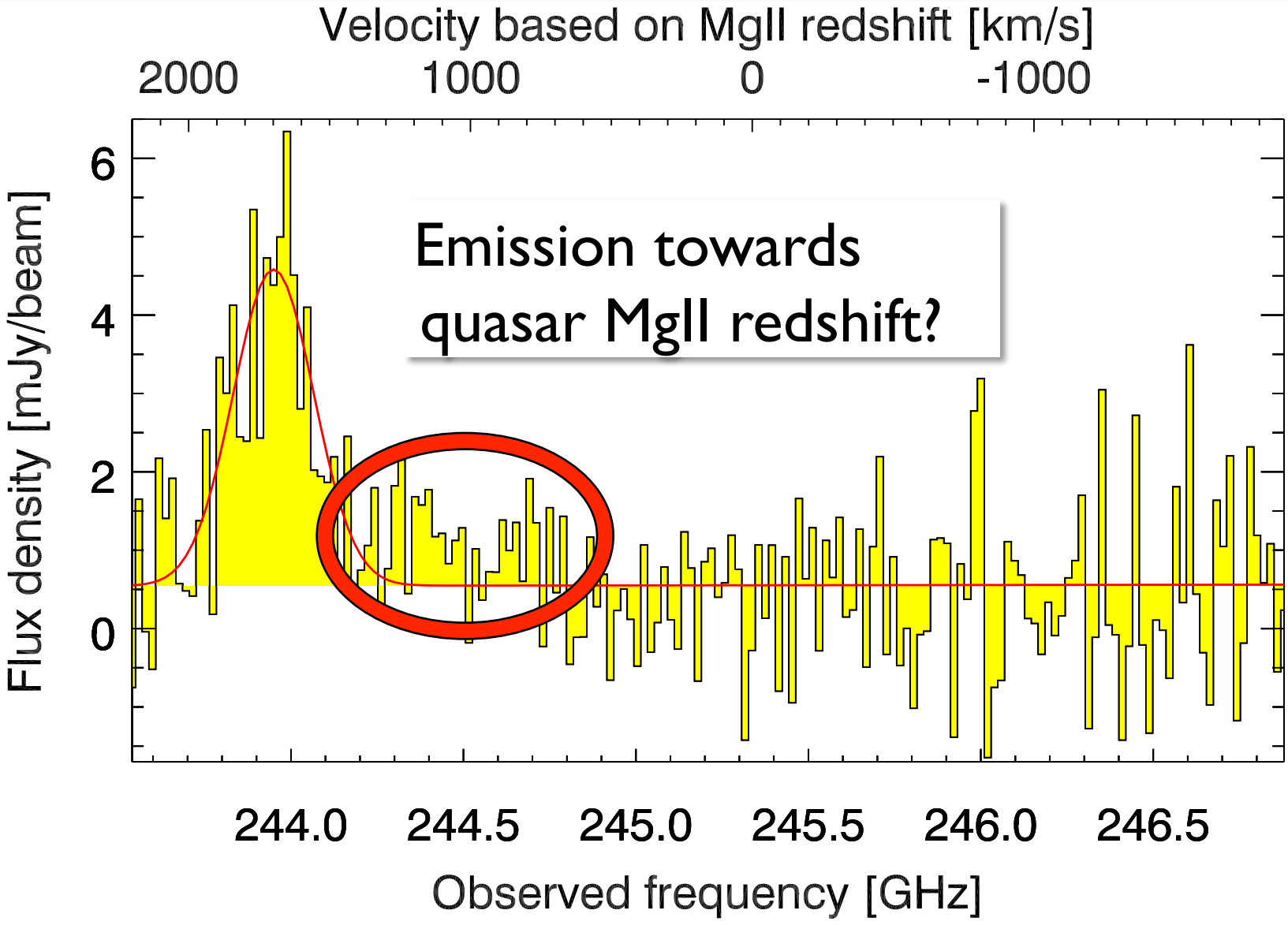
Continuum-subtracted map, averaged over line FWHM



Blue: blue side of line peak

Red: red side of line peak

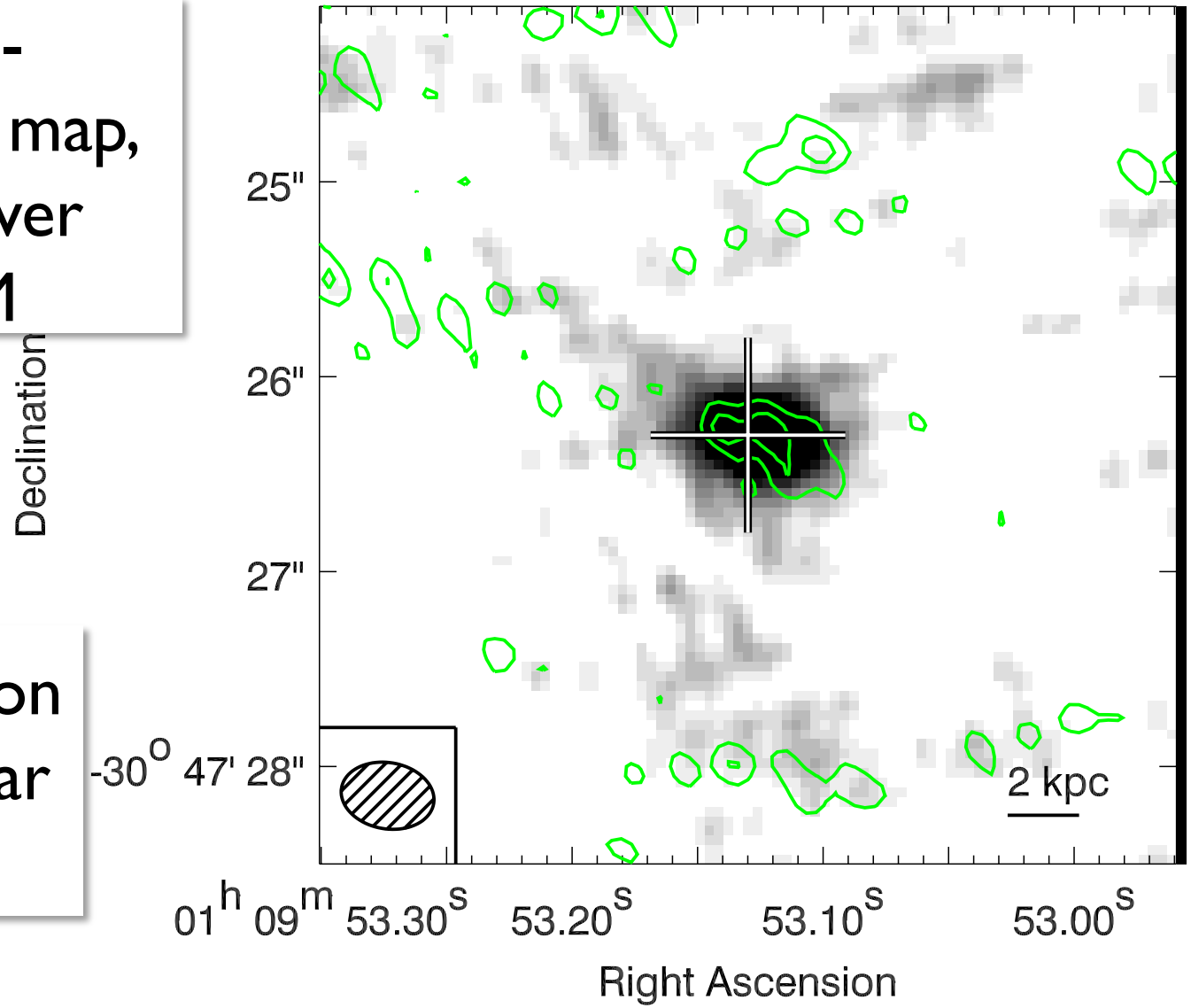
[CII] spectrum of J0109-3047 at z~6.75



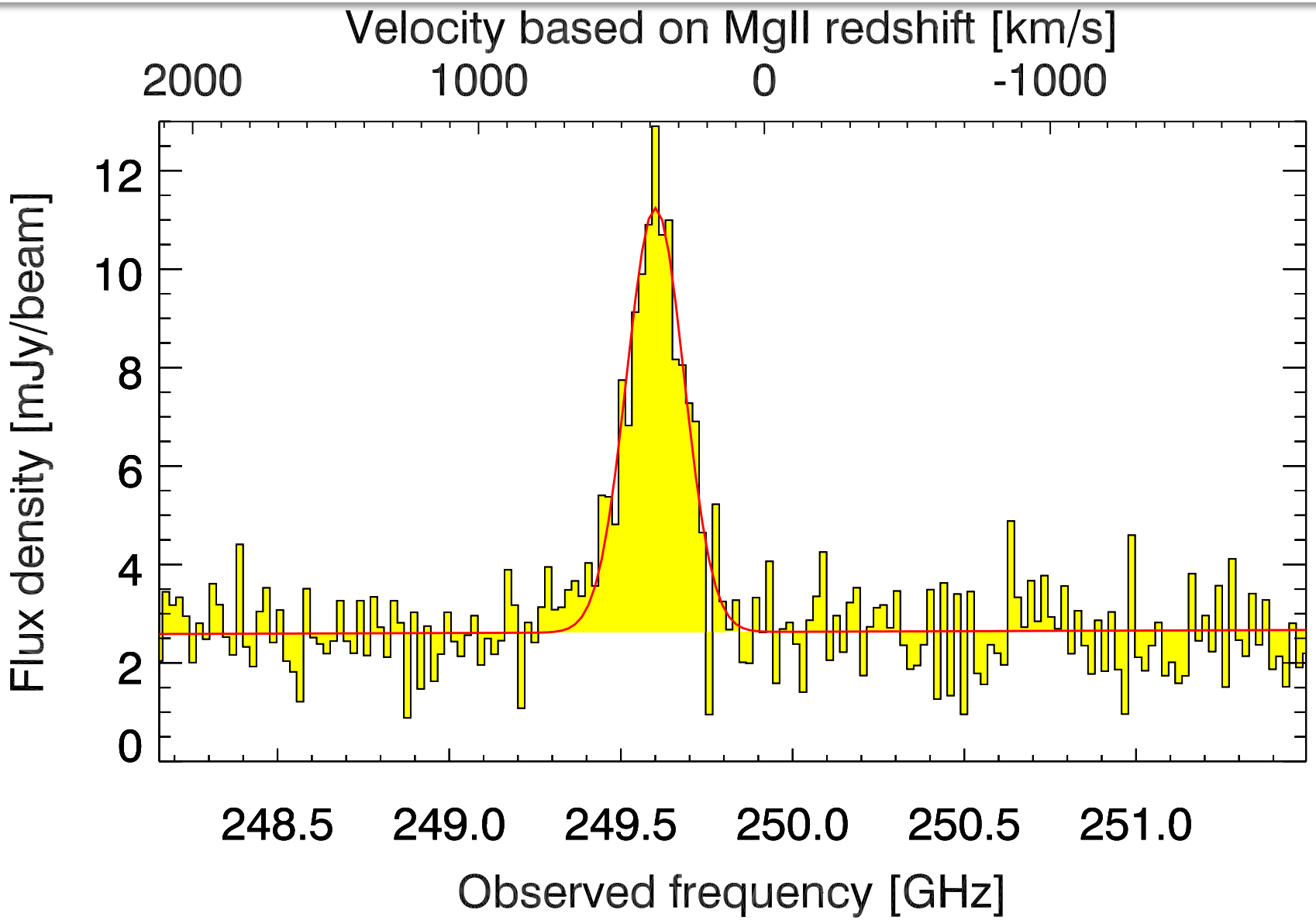
Map of [CII] emission of J0109-3047

Continuum-subtracted map, averaged over line FWHM

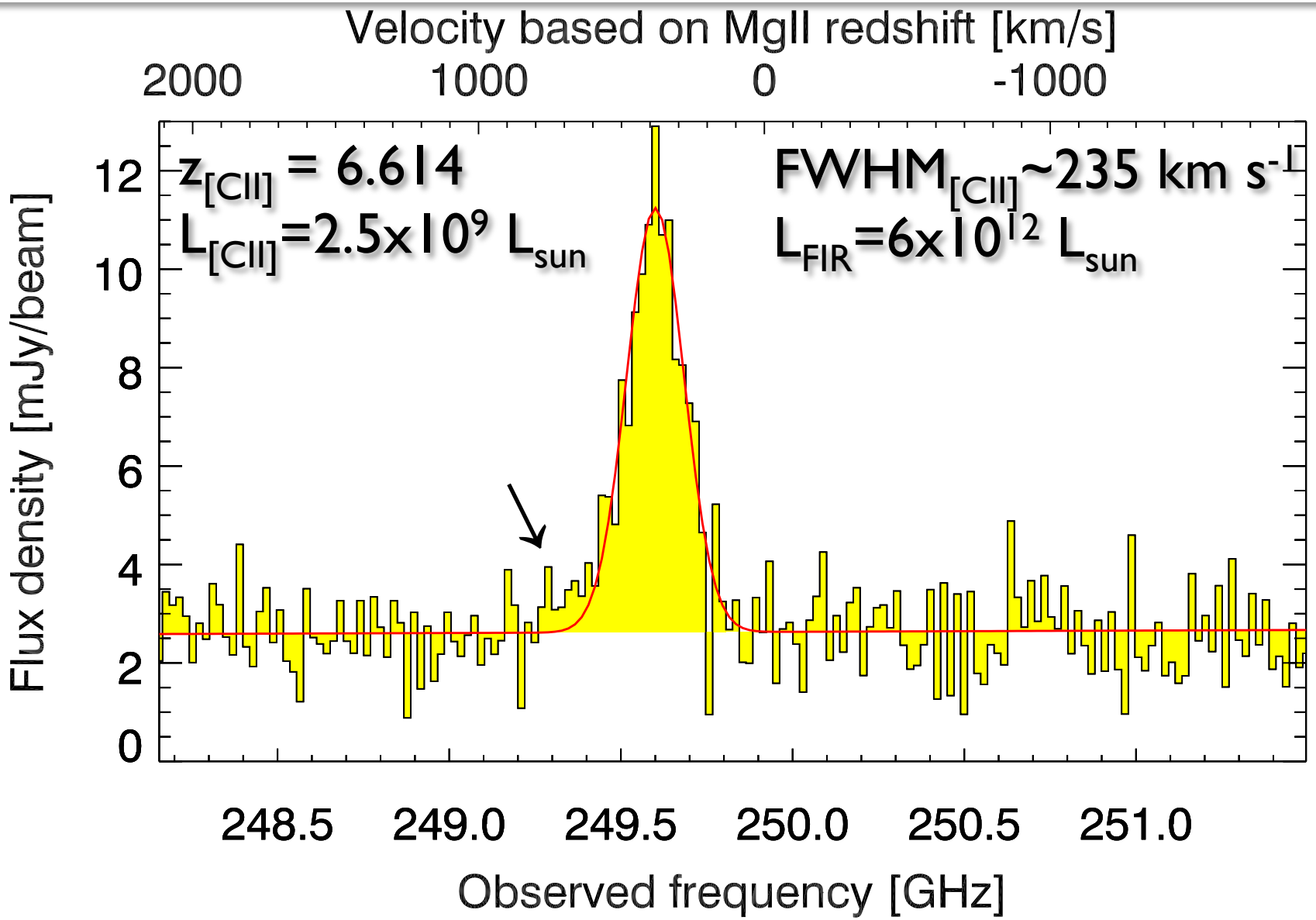
Green: emission towards quasar MgII redshift



[CII] spectrum of J0305-3150 at z~6.6

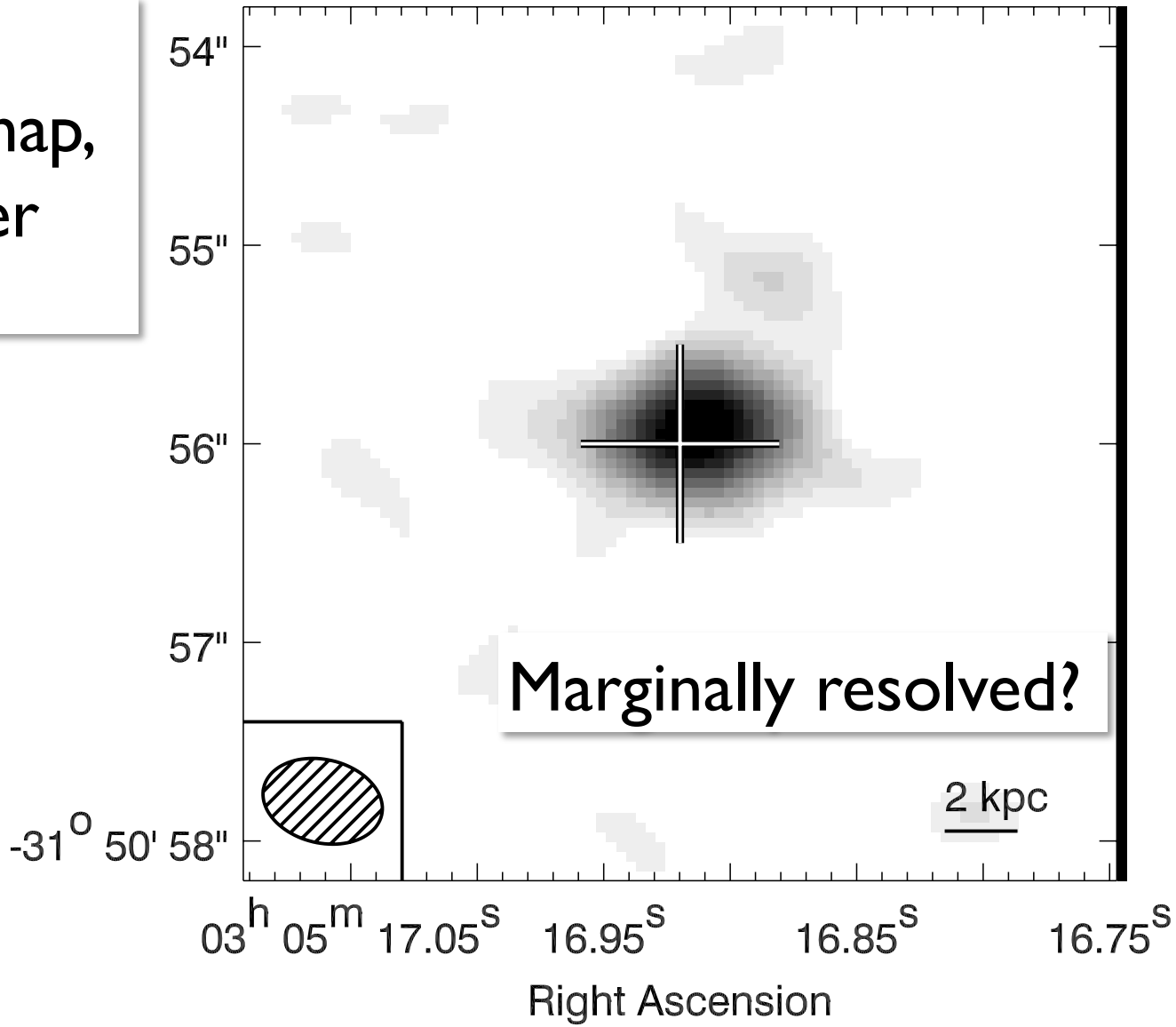


[CII] spectrum of J0305-3150 at z~6.6



Map of [CII] emission of J0305-3150

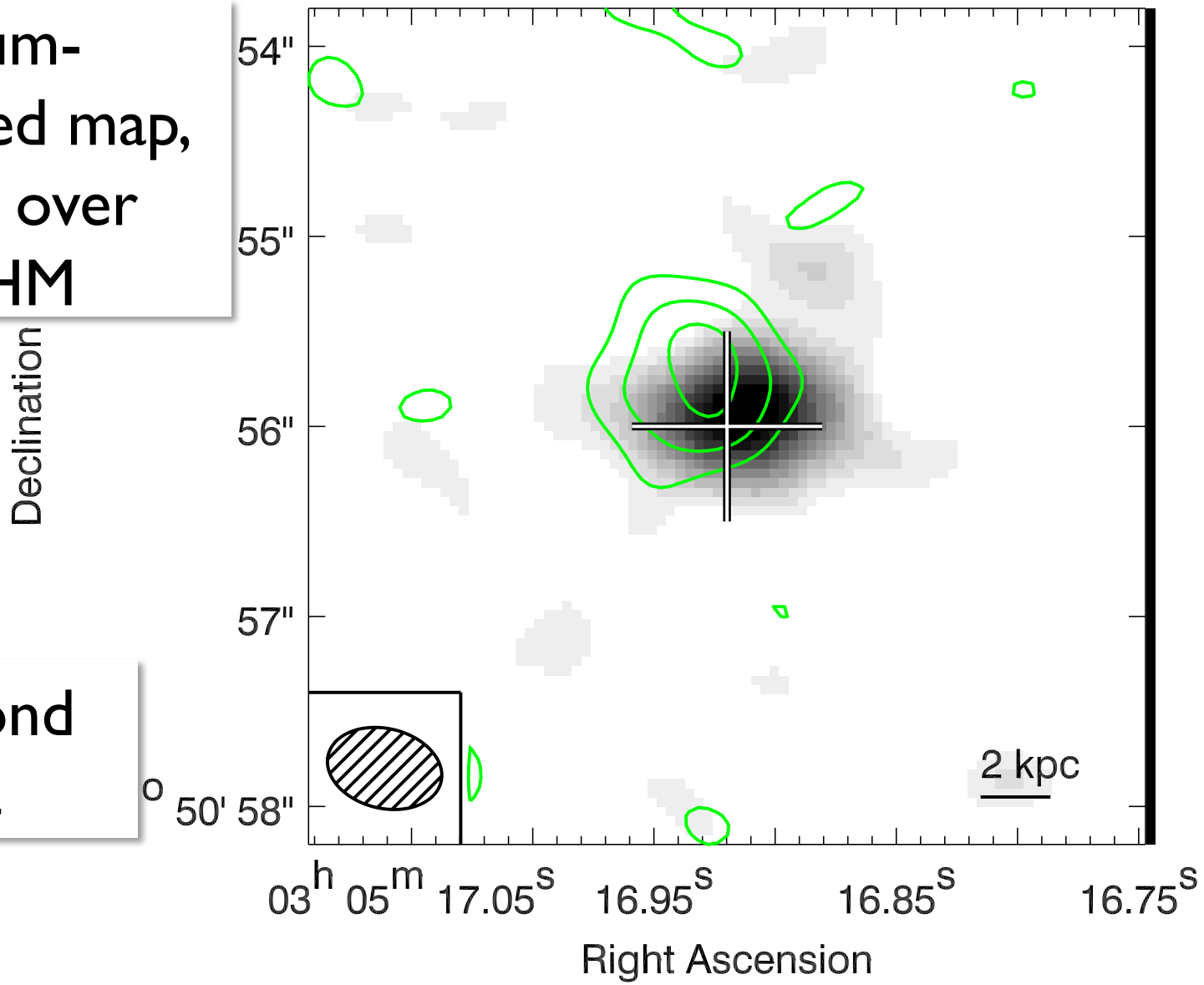
Continuum-subtracted map, averaged over line FWHM



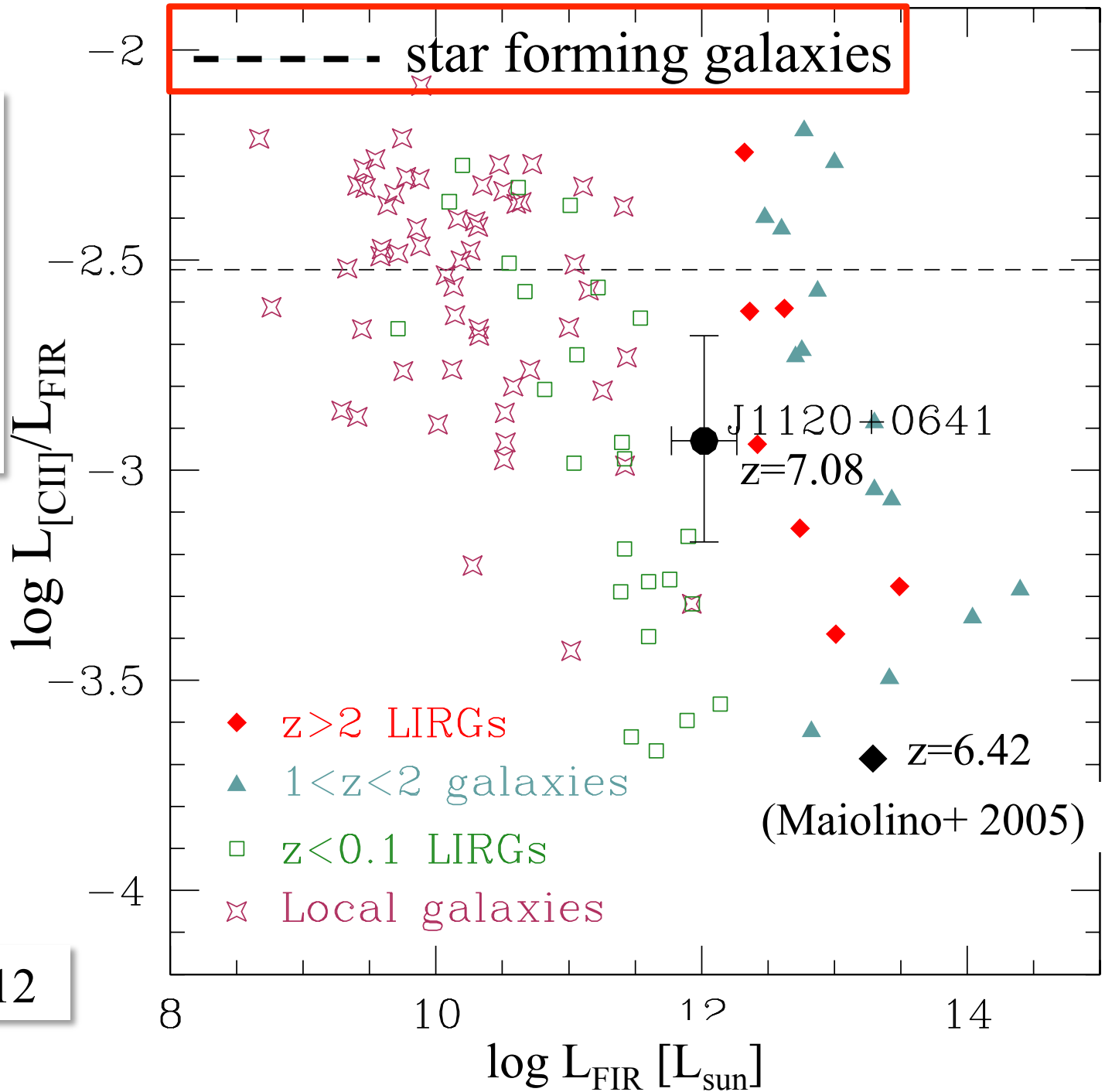
Map of [CII] emission of J0305-3150

Continuum-subtracted map, averaged over line FWHM

Green: second component

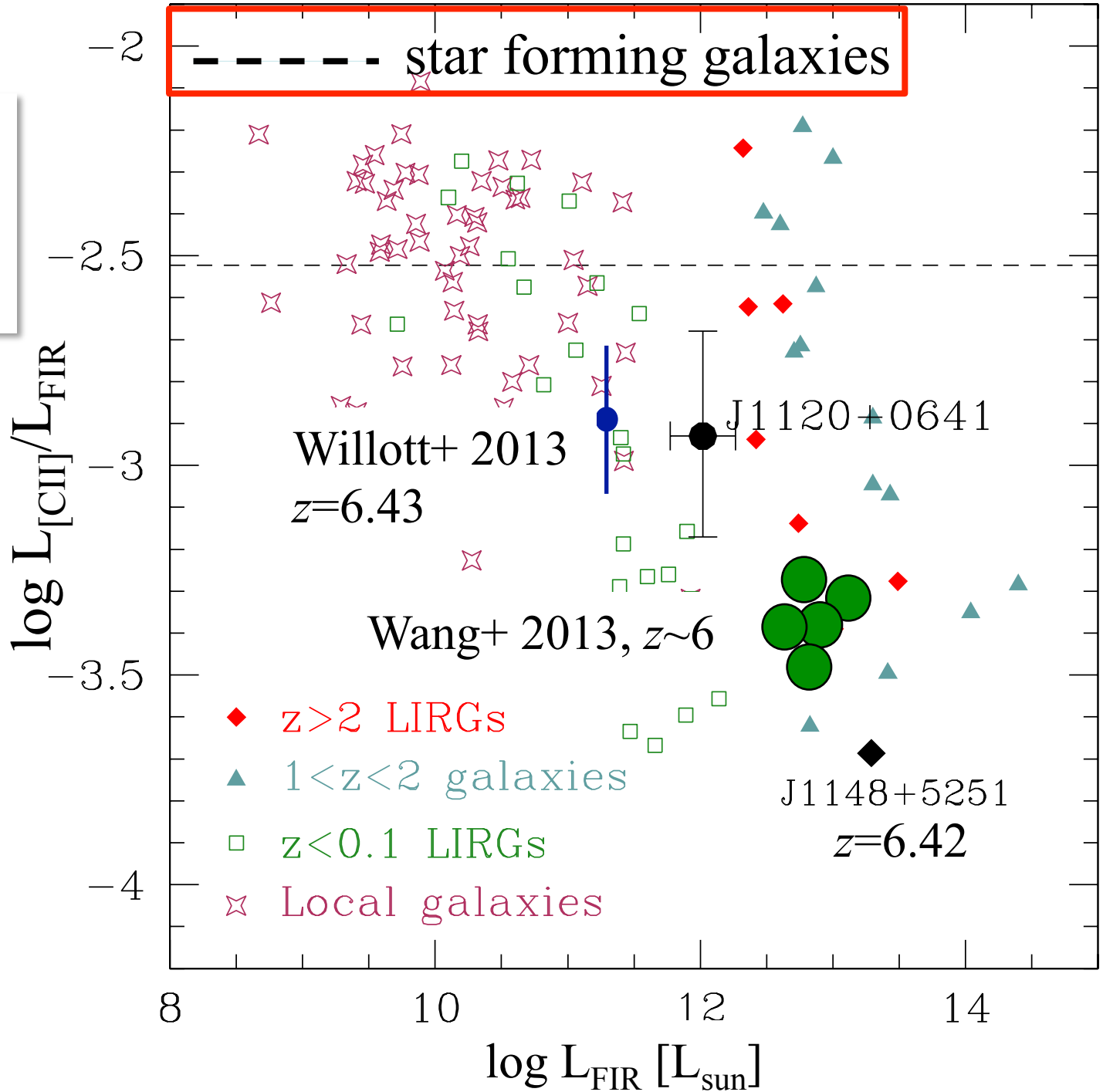


[CII] and FIR luminosity of z>6.5 quasars compared to literature

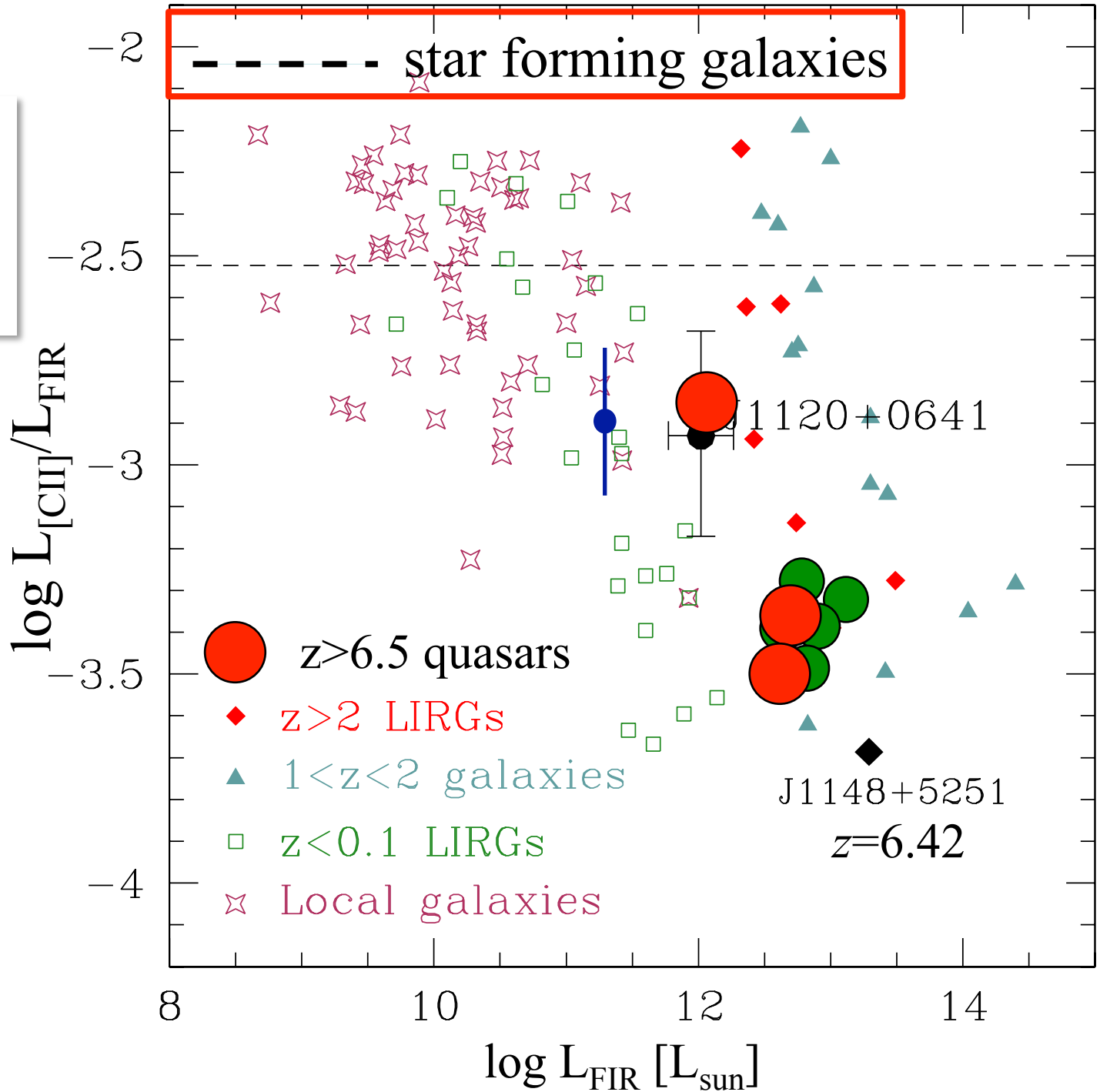


BV+ 2012

Comparison to lower redshift objects



Comparison to lower redshift objects



Summary

- Quasars ideal for early science observations
- ALMA observations of 3 z>6.5 quasars:
  - [CII] luminosities of (1.3-2.5) x 10^9 L_{sun}
  - FIR luminosities ~(1-6) x 10^{12} L_{sun}
  - Velocity shifts between MgII and [CII]
  - Additional components (spatially / in velocity)
  - Range in $L_{[CII]}/L_{FIR}$

Outlook

- More ALMA Cycle 1 observations:

  - high resolution [CII] in z=7.1 quasar host

- Proposed ALMA Cycle 2 observations:

  - [CII] in z>6.5 quasar hosts in higher resolution

  - CO(7-6) and CI transitions

- Study more z>6.5 quasars from VIKING, PS1…