2017年6月7日＠大阪大学

第４回銀河進化研究会

SHELLQs-ALMA: submm properties of galaxies hosting less-luminous quasars at z > 6

泉拓磨 (NAOJフェロー)

& SHELLQs-collaboration

Mm/submm Follow-up of HSC-detected z > 6 Quasars

- 初期かつ一般的なクエーサーの発現環境・母銀河の特徴付け
  → SFR, M_{dyn}, M_{gas}, M_{dust}
- 始原的な共進化関係の探査
- 宇宙初期天体の金属量進化
- 母銀河・周辺環境へのAGN feedback

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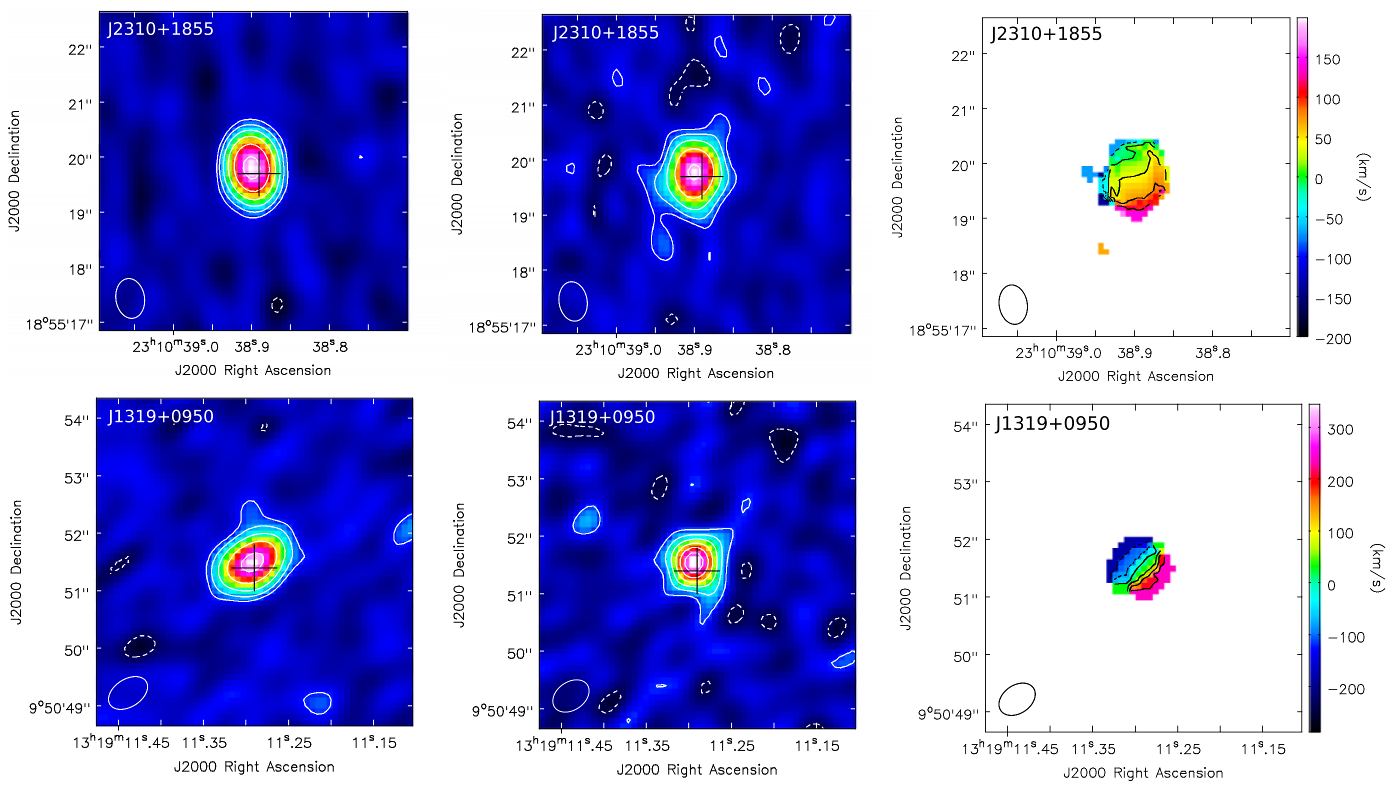
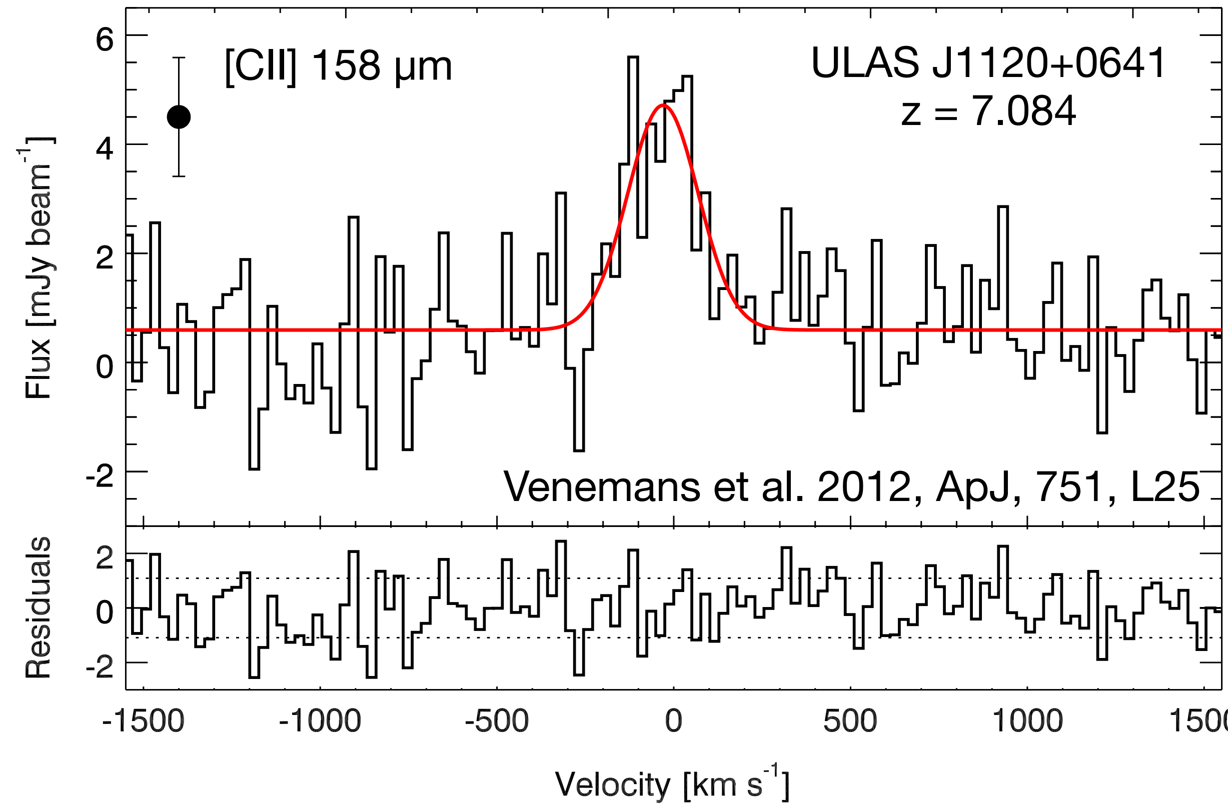
[CII] & FIR properties of z > 6 luminous QSOs

Dust | [CII] | Vel. field



Wang et al. 2013, ApJ, 773, 44 w/ ALMA

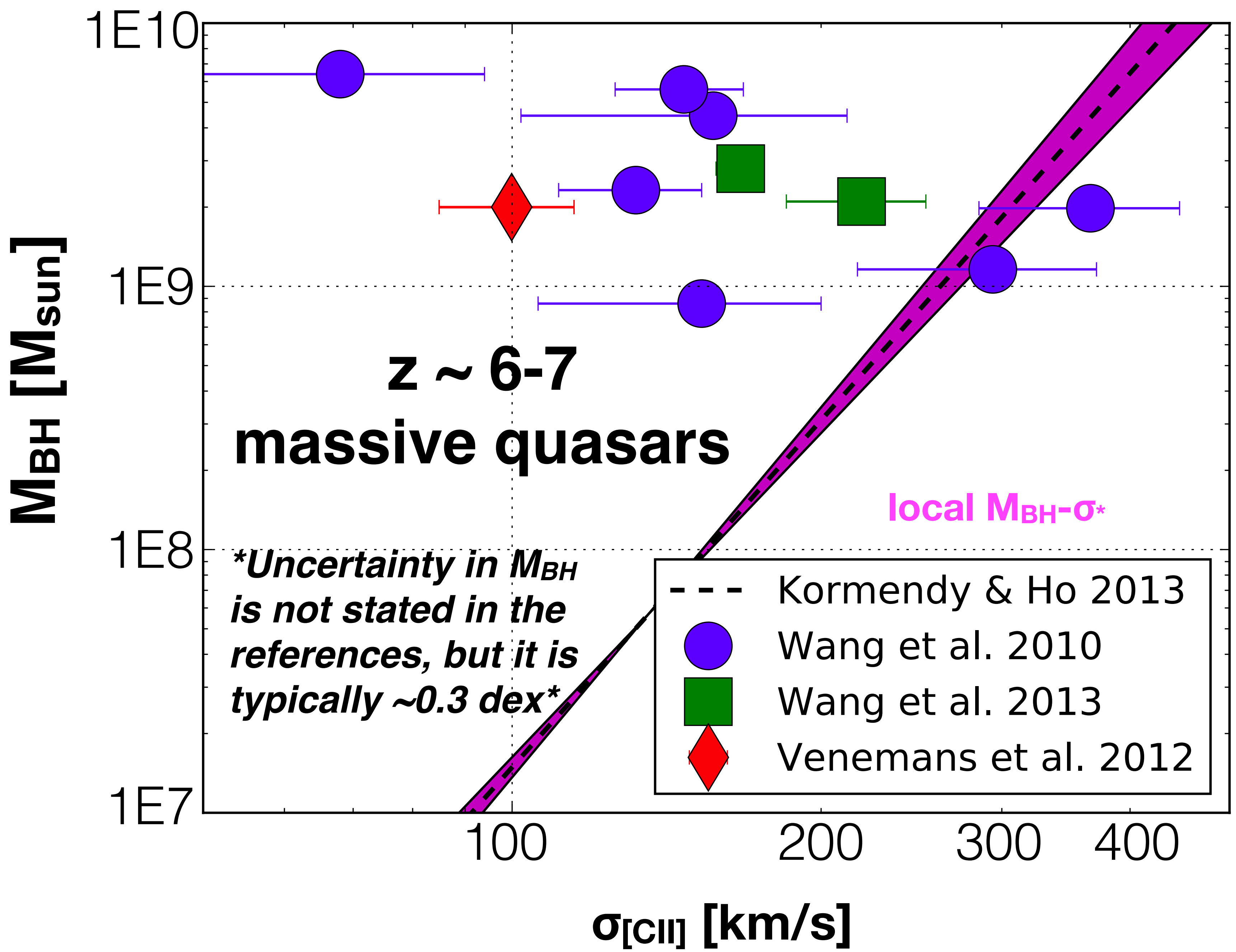


- ULIRG/SMG-class!!
- Question: Do all (z > 6) quasars reside in such vigorously star forming ***monsters***? - characterize their surrounding environ.

Param.	Typical value
SFR	~100 - 1000 M_{sun}/yr
M_{gas}	~a few x E10 M_{sun}
M_{dust}	~a few x E8 M_{sun}
M_{BH}	~a few x E9 M_{sun}

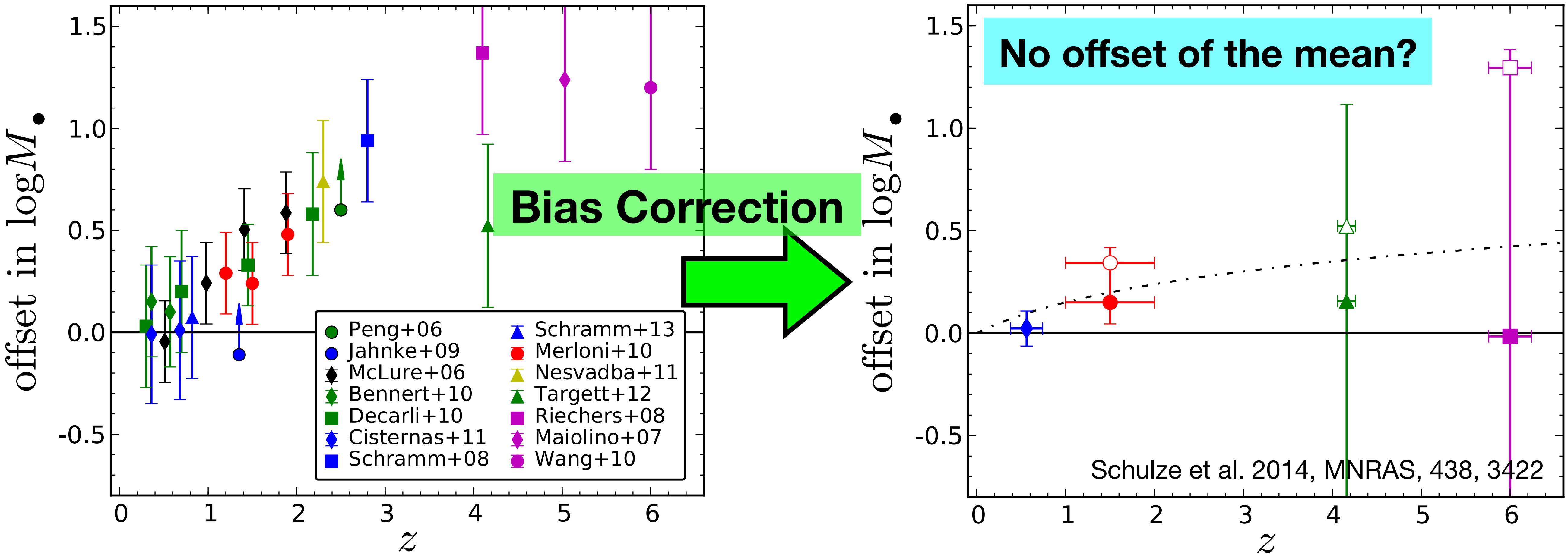
e.g., Wang et al. 2010, ApJ, 714, 699

Primordial co-evolution at z > 6 quasars?



- M_{BH} of luminous z > 6 quasars are overmassive
  → SMBH earlier, galaxies later? No synchronisation with the hosts?

Selection bias to probe high-z objects?



- High-z quasars could be biased to luminous (= massive) objects
- No evolution in co-evolutionary relations once we account for the bias? (e.g., Schulze et al. 2014; Lauer et al. 2007)

We need high-z less-luminous quasars → HSC×ALMA!

Submm follow-up observations toward HSC-detected high-z quasars with ALMA

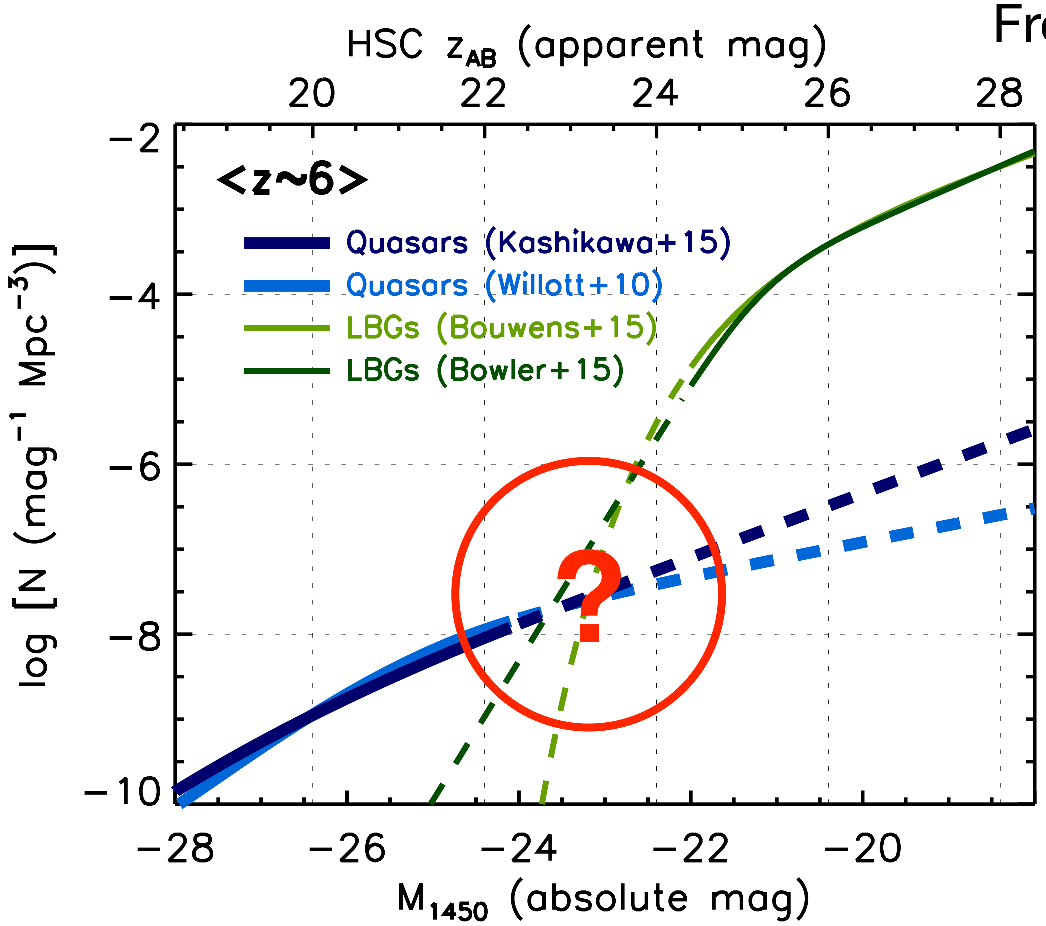
Izumi et al. in prep.

Based on: ALMA Cycle 4 (#2016.1.01423.S; Izumi+)

Targets@Cycle 4

Quasar	z_{opt}	M_{1450}	Deliver (JST)	D_L (Mpc)	Scale (kpc/“)	L_{Bol} (L_{sun})	BAL
J0859+0022	6.39	-23.56	Feb 15	62086.1	5.51	3.9E+12	N
J1152+0055	6.37	-24.91	Feb 14	61860.8	5.52	1.4E+13	N
J2216-0016	6.10	-23.56	Feb 11	58827.4	5.66	3.9E+12	Y
J1202-0057	5.93	-22.44	May 12	56925.2	5.75	1.4E+12	N

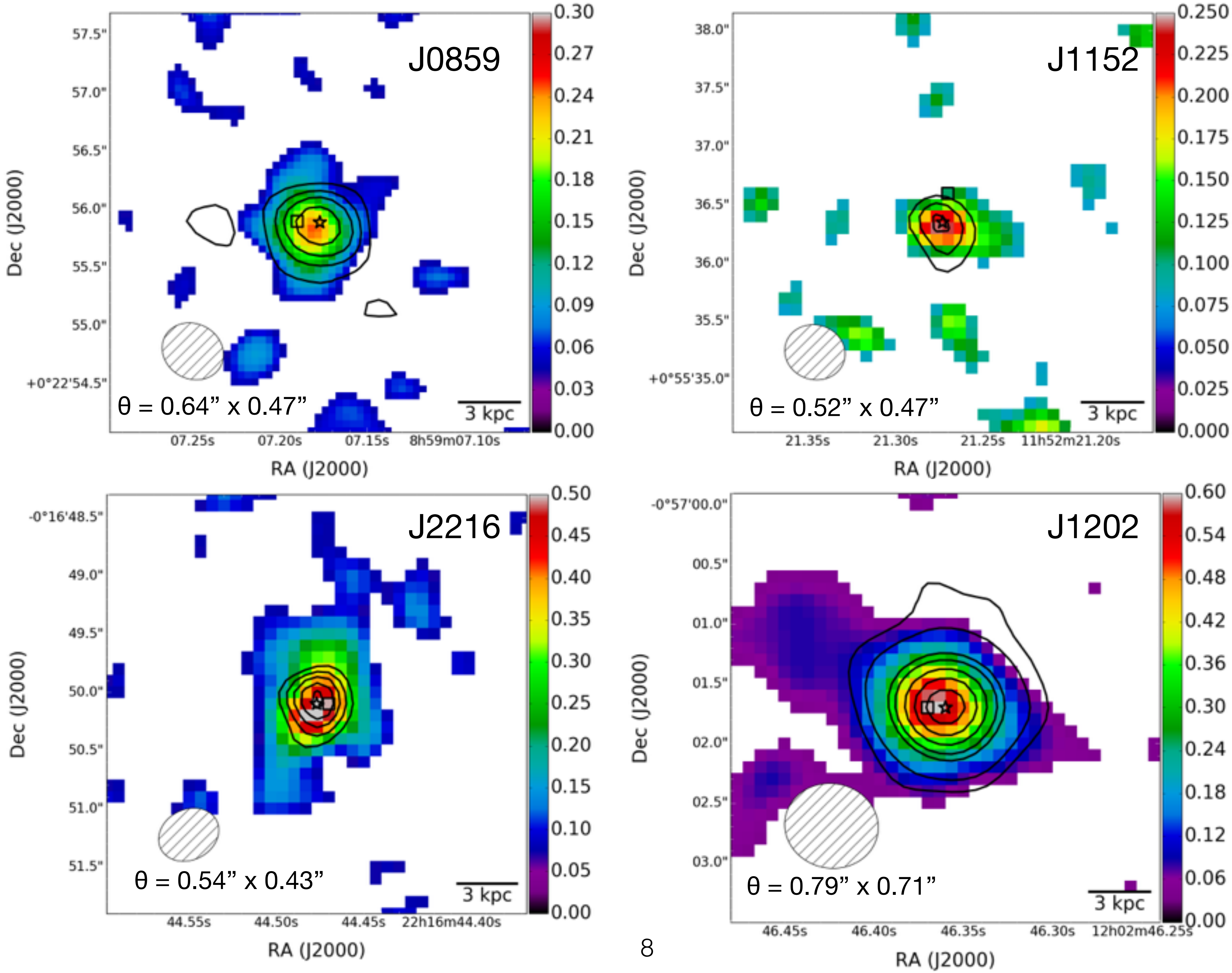
From SHELLQs quasars (Matsuoka et al. 2016, ApJ, 828, 26)



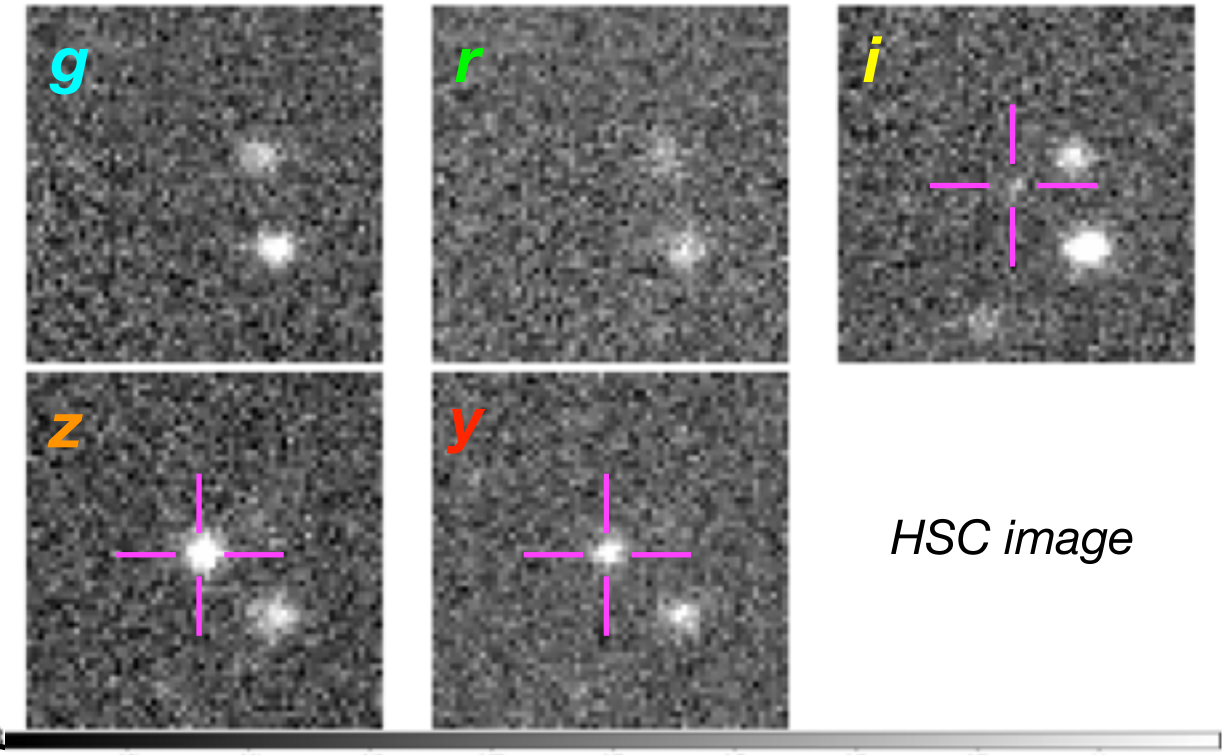
To detect [CII] and FIR continuum

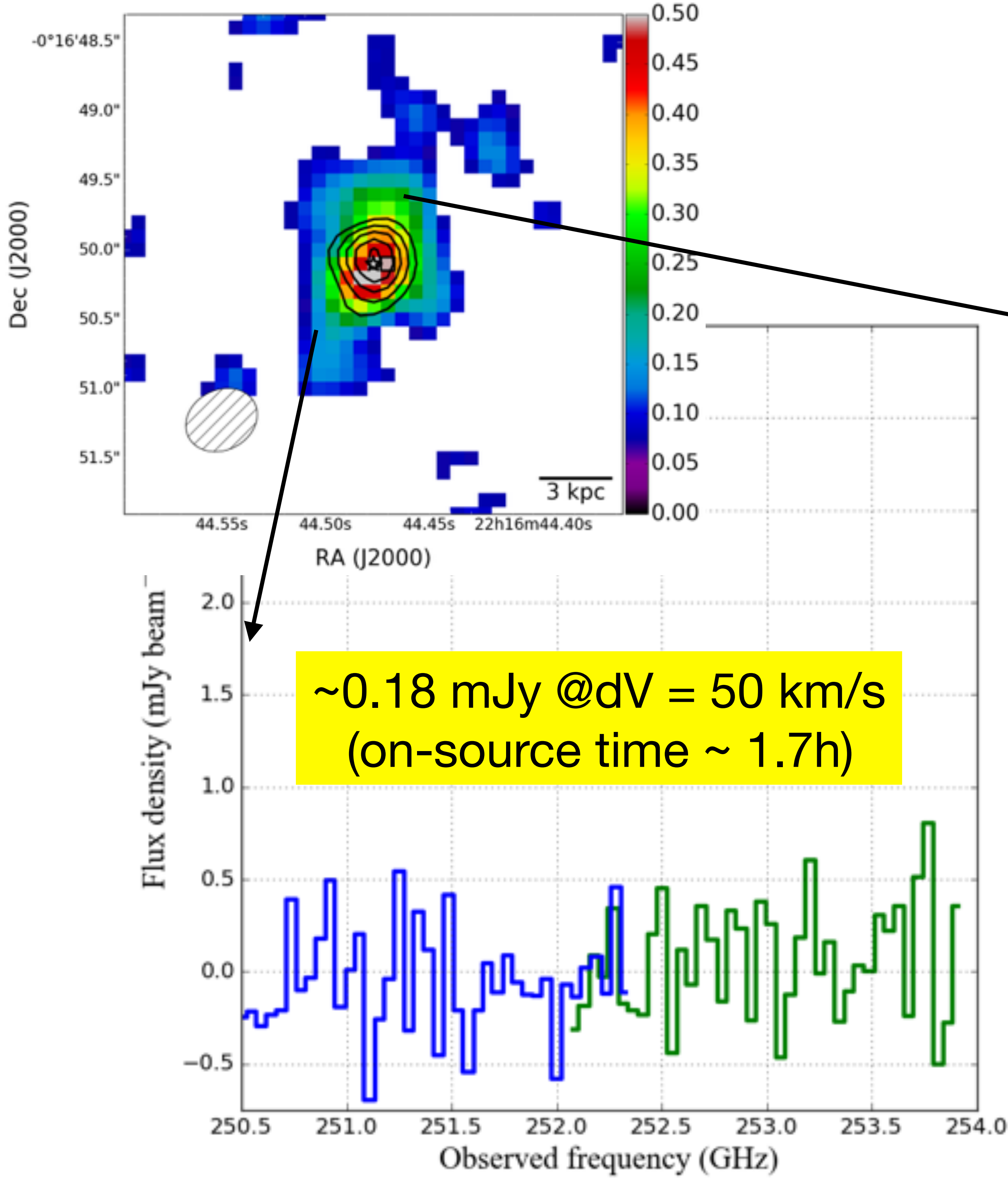
→ higher resolution, other lines@future ALMA cycles

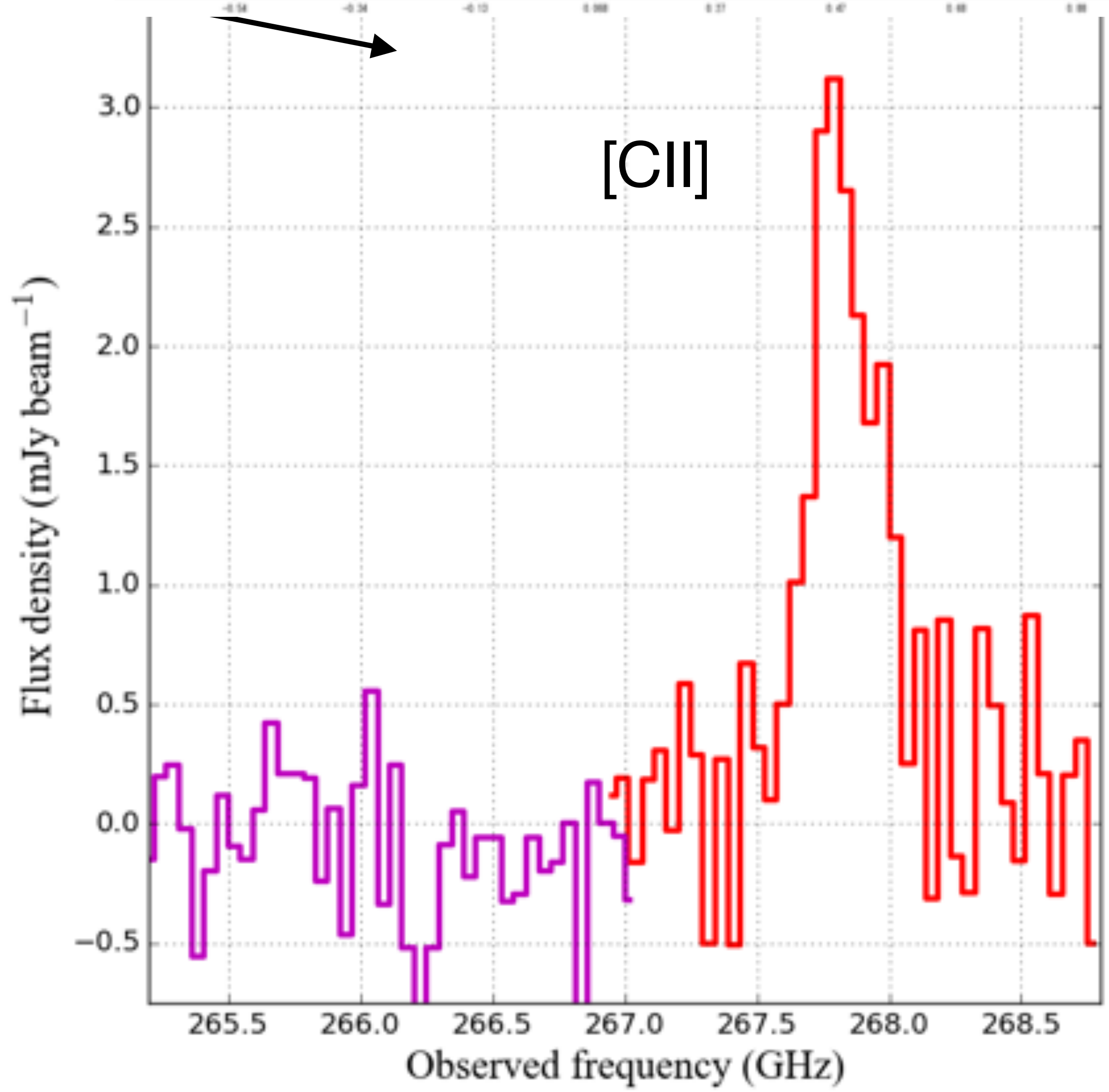
Spatial distribution (color: [CII], contour: FIR Cont.)



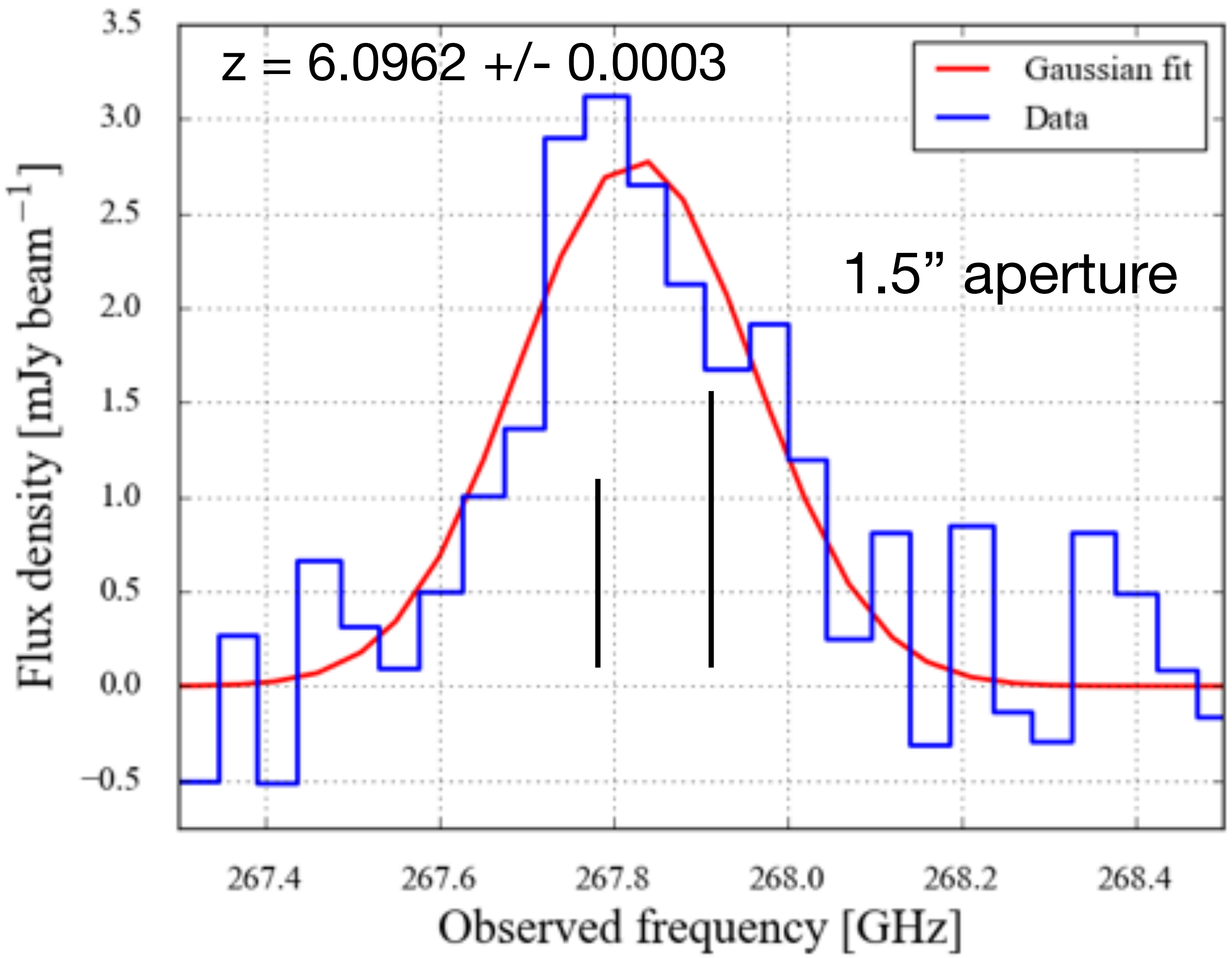
Band 6 spectrum (J2216)





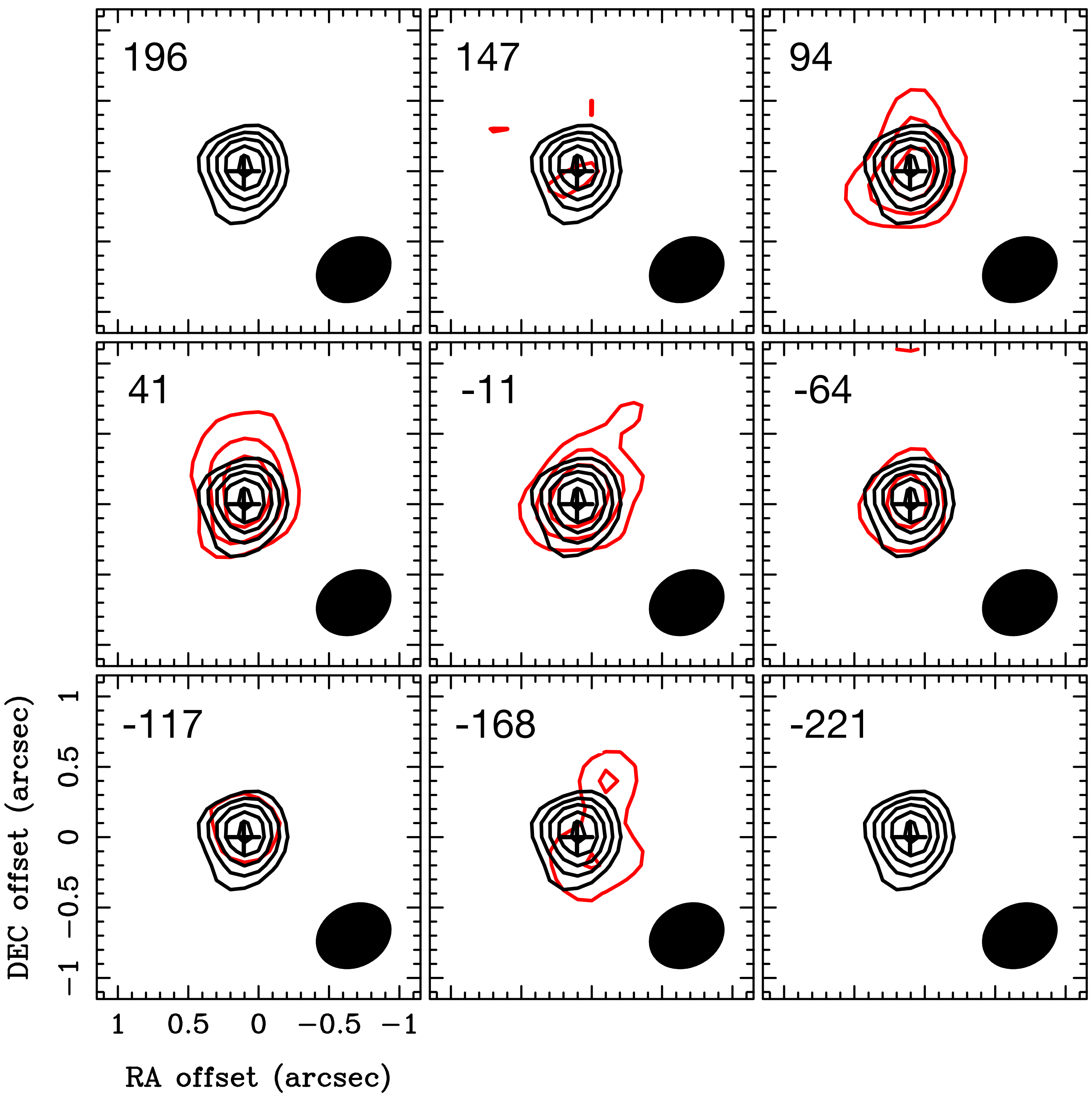


[CII] spectrum (J2216)



Peak = 2.79 +/- 0.22 mJy/beam
Centroid: 267.8259 +/- 0.0124 GHz
FWHM: 355.57 +/- 32.72 km/s

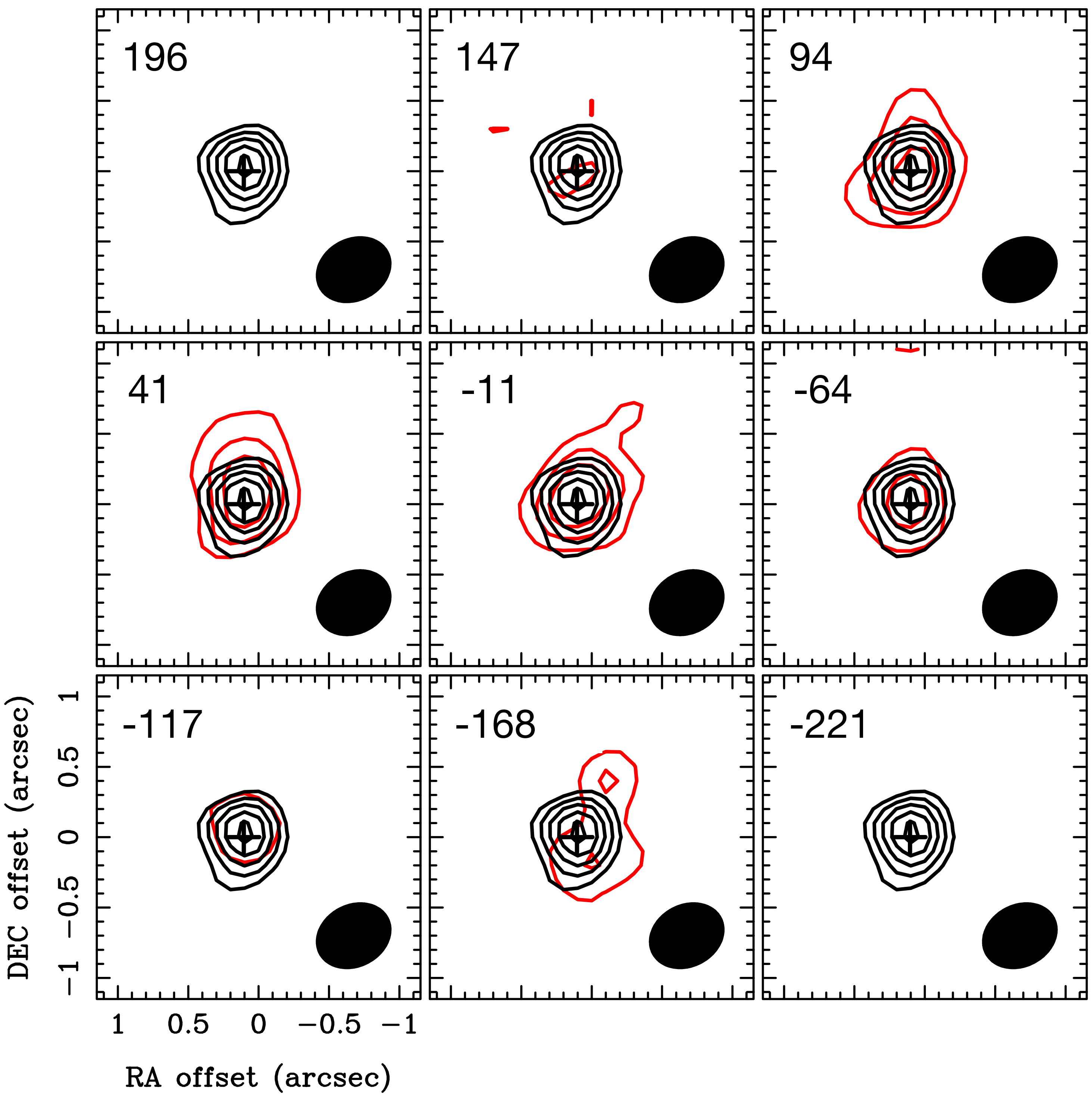
[CII] spectrum (J2216)



[CII]: Red contour = 3,5,7σ; 1σ = 0.183 mJy/beam@dV~50 km/s

Band 6 continuum: Black contour = 3,4,5,6,7σ; 1σ = 13.2μJy/beam

[CII] spectrum (J2216)



- Spatially more extended than the continuum emission.

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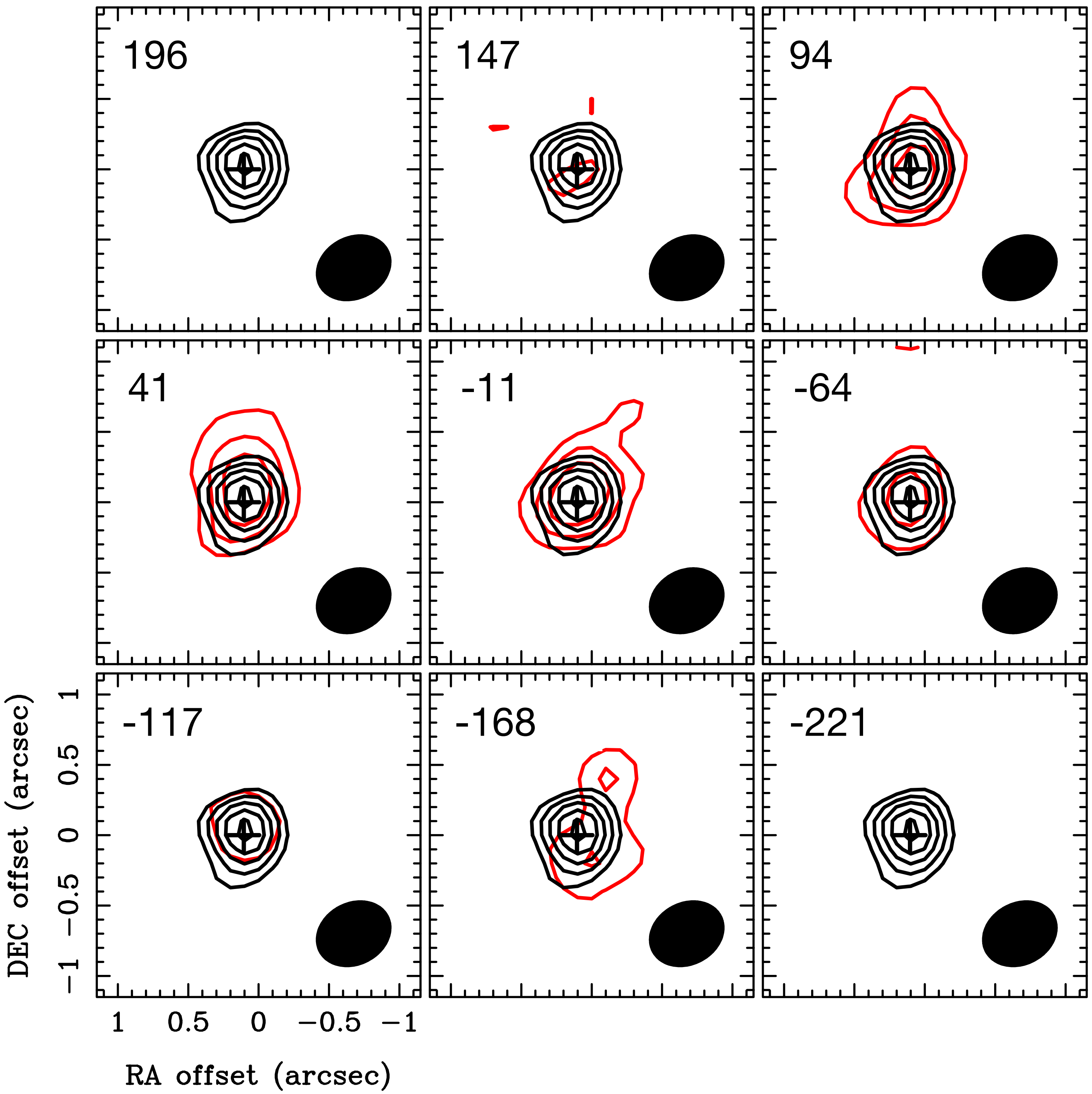

- Spatially more extended than the continuum emission.
- Every channel has the same centroid at the AGN position
  → indication of **outflows**??
  → recall this is a **BAL** quasar
- Or a signature of a past merger?

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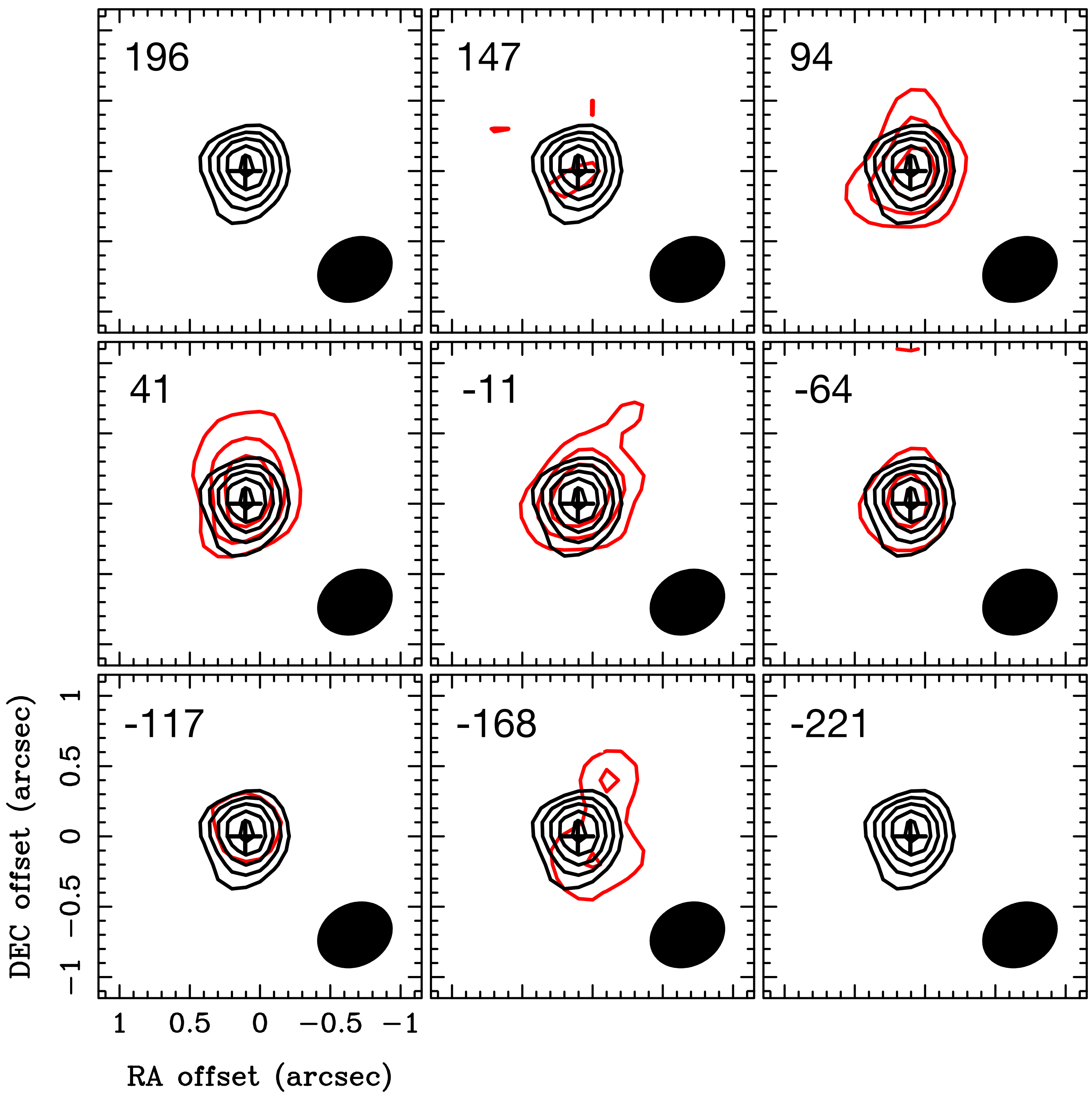

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FIR properties of the HSC-quasars

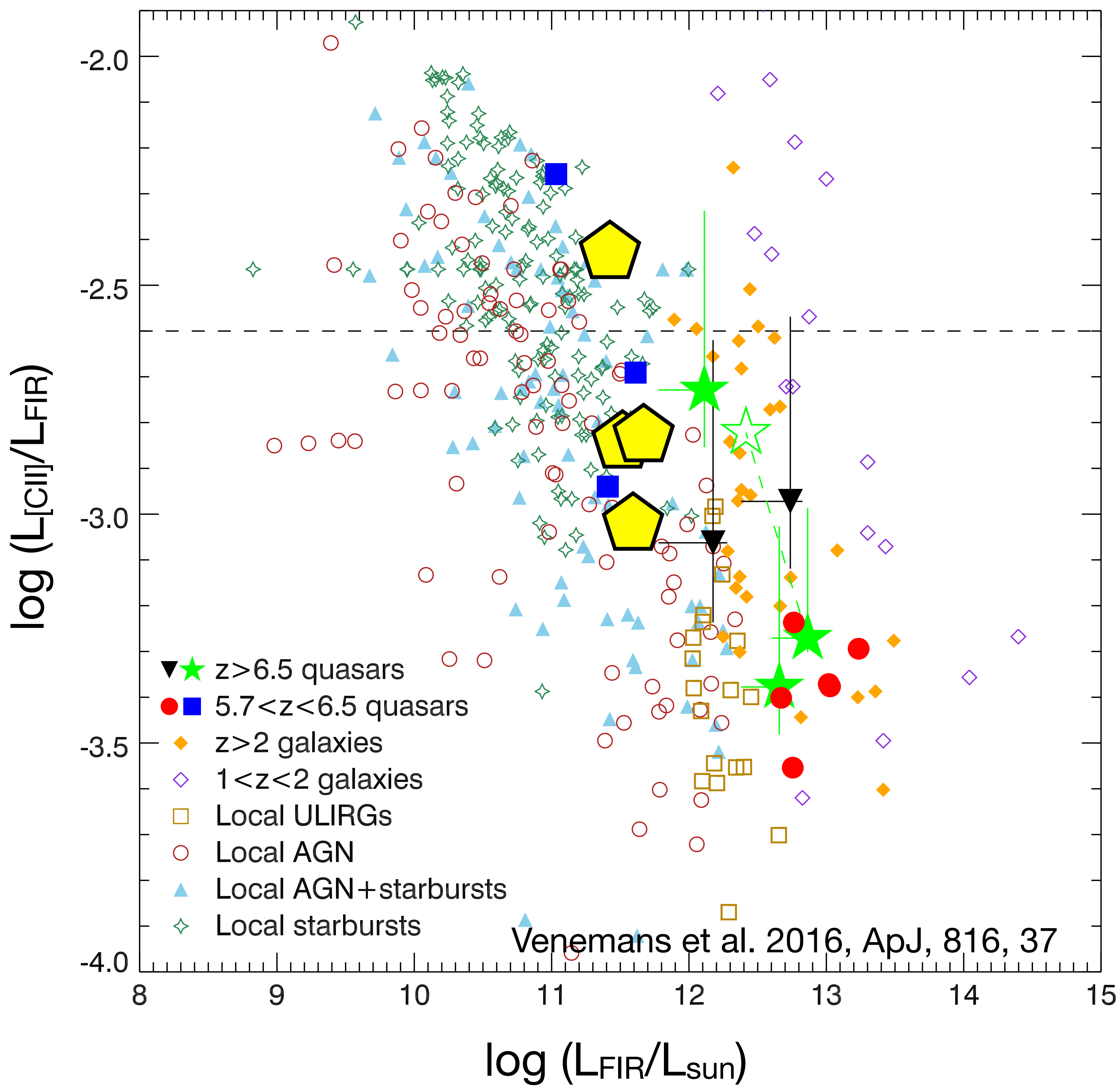
	$S_{[CII]}$ (Jy km/s)	$L_{[CII]}$ (1E8 L_{sun})	B6 continuum (μJy)	L_{FIR} (1E11 L_{sun})	M_{dust} (1E7 M_{sun})	$SFR_{[CII]}$ (M_{sun}/yr)
J0859	0.45 +/- 0.09	4.6 +/- 0.9	157 +/- 23	3.4 +/- 0.5	2.4 +/- 0.4	31
J1152	0.37 +/- 0.12	3.8 +/- 1.2	189 +/- 32	4.1 +/- 0.7	2.9 +/- 0.5	26
J2216	1.06 +/- 0.13	10.2 +/- 1.3	136 +/- 27	2.7 +/- 0.6	2.0 +/- 0.4	68
J1202	0.67 +/- 0.06	7.3 +/- 0.6	246 +/- 12	4.8 +/- 0.2	3.4 +/- 0.2	49

T_d = 47 K, β = 1.6; integrated over FIR = 42.5 - 122.5 μm
SFR (M_{sun}/yr) = 1.0E-7 * ($L_{[CII]}/L_{sun})^{0.98}$; De Looze et al. (2011) for L_{FIR} < 1E12 L_{sun} (Kroupa IMF)

- **LIRG to weak ULIRG-class objects even @ z > 6 !**
  - c.f., SFR = 100-1000 M_{sun}/yr for luminous SDSS quasars @ z > 6
- These FIR values could be still upper limits (recall these are low-luminosity quasars)

What kind of galaxies are they? (1/2)

[CII]-deficit?



Similar to local LIRG-class objects
→ They would have similar gas density, radiation field, etc.as well?

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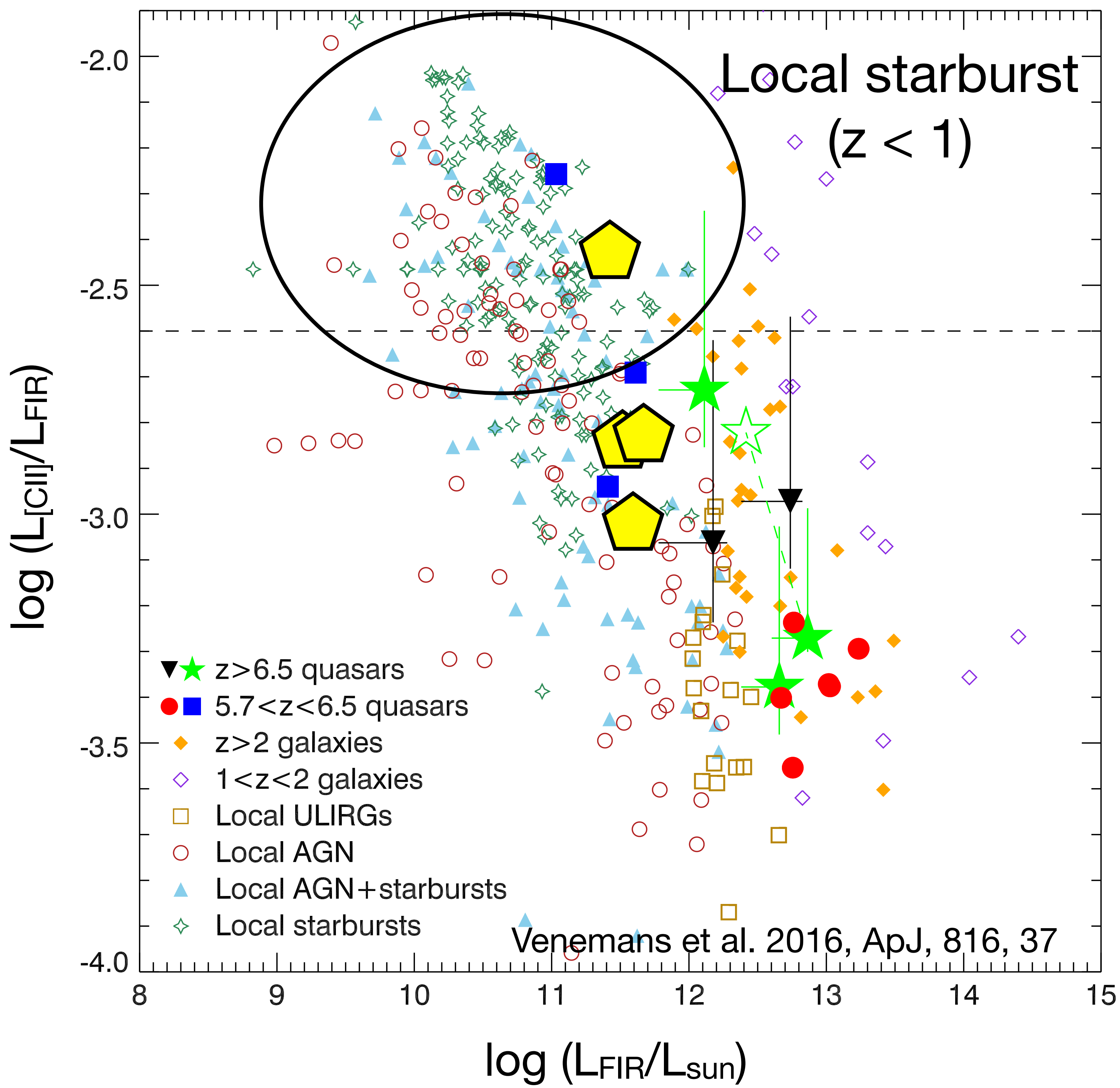

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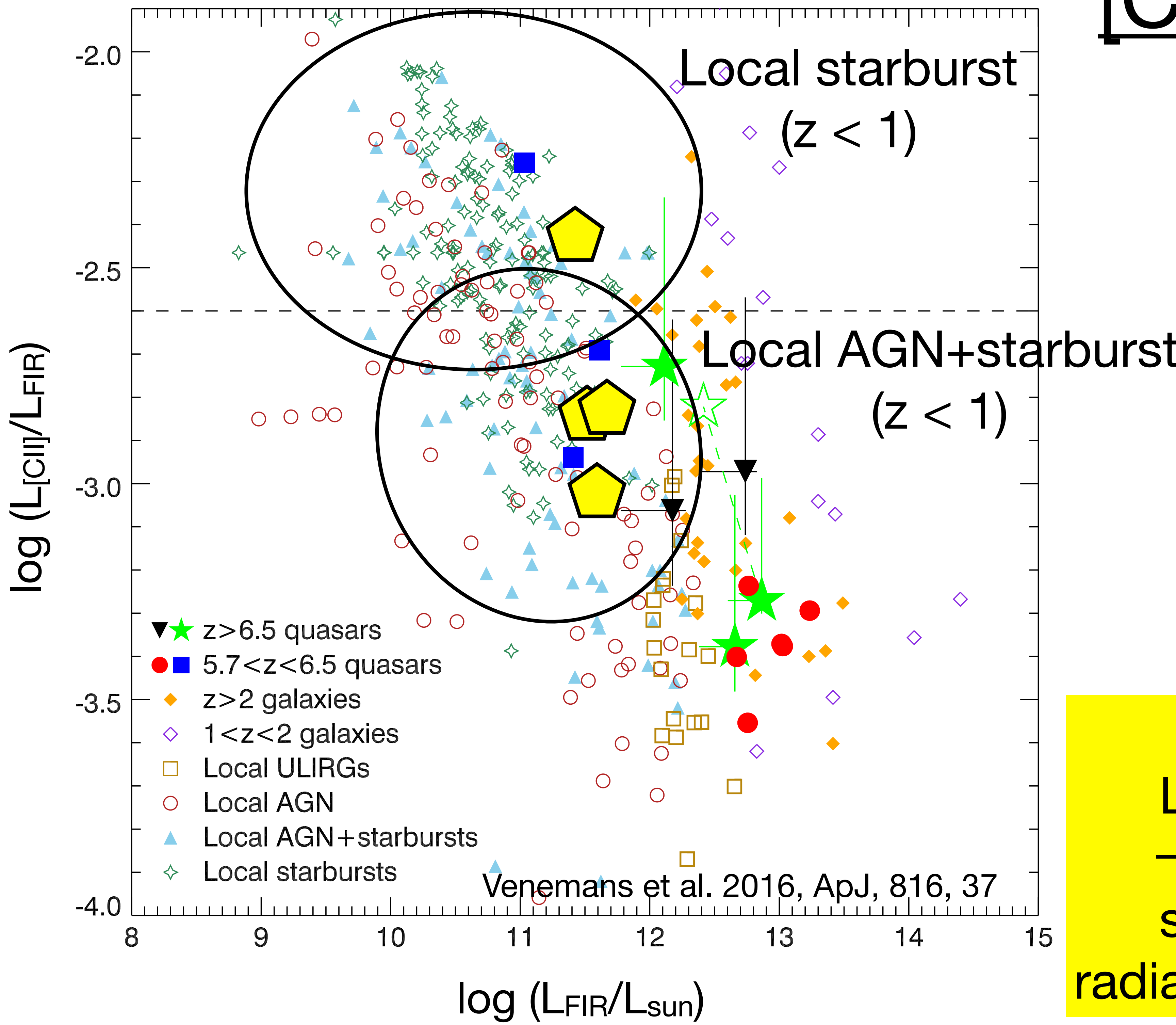

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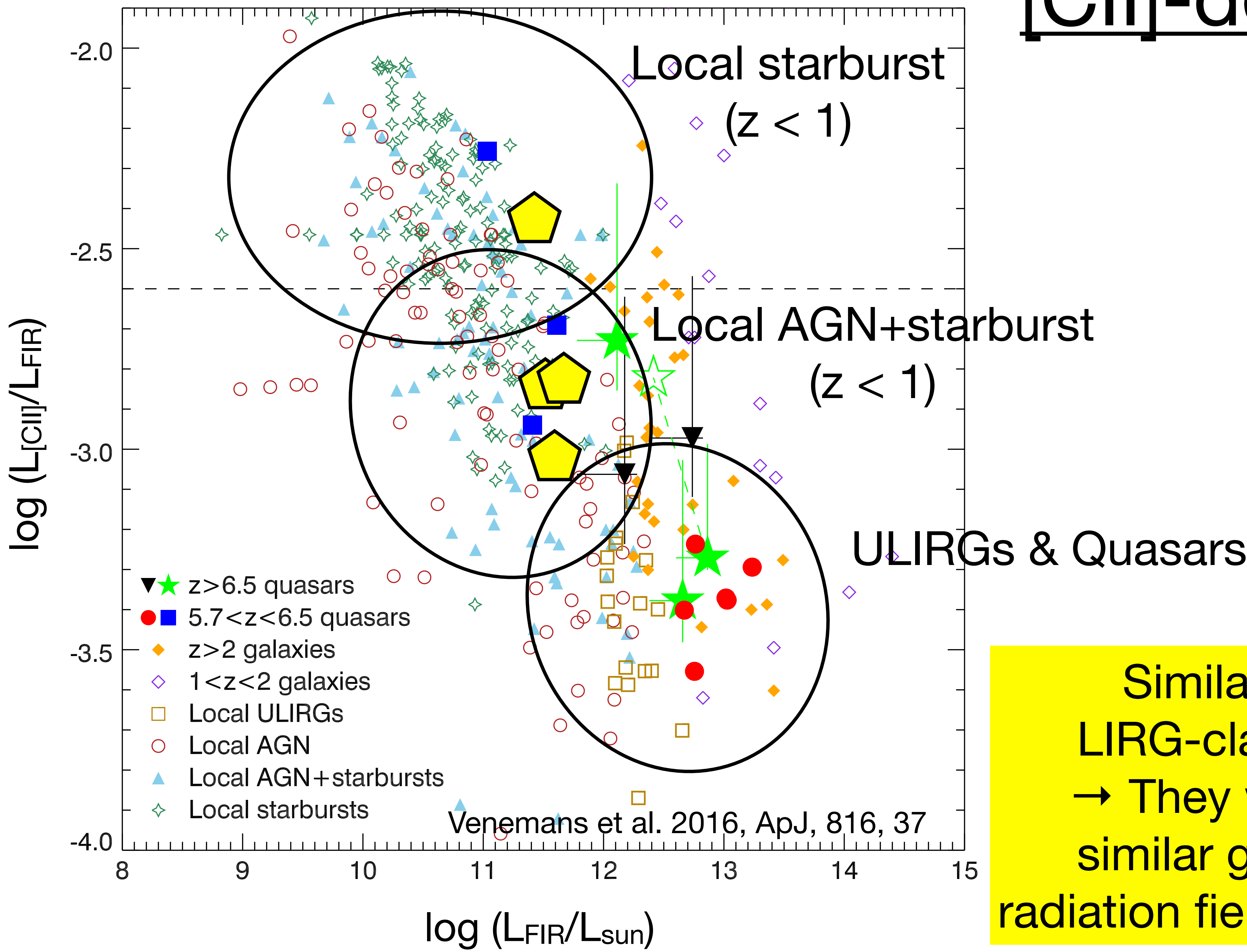
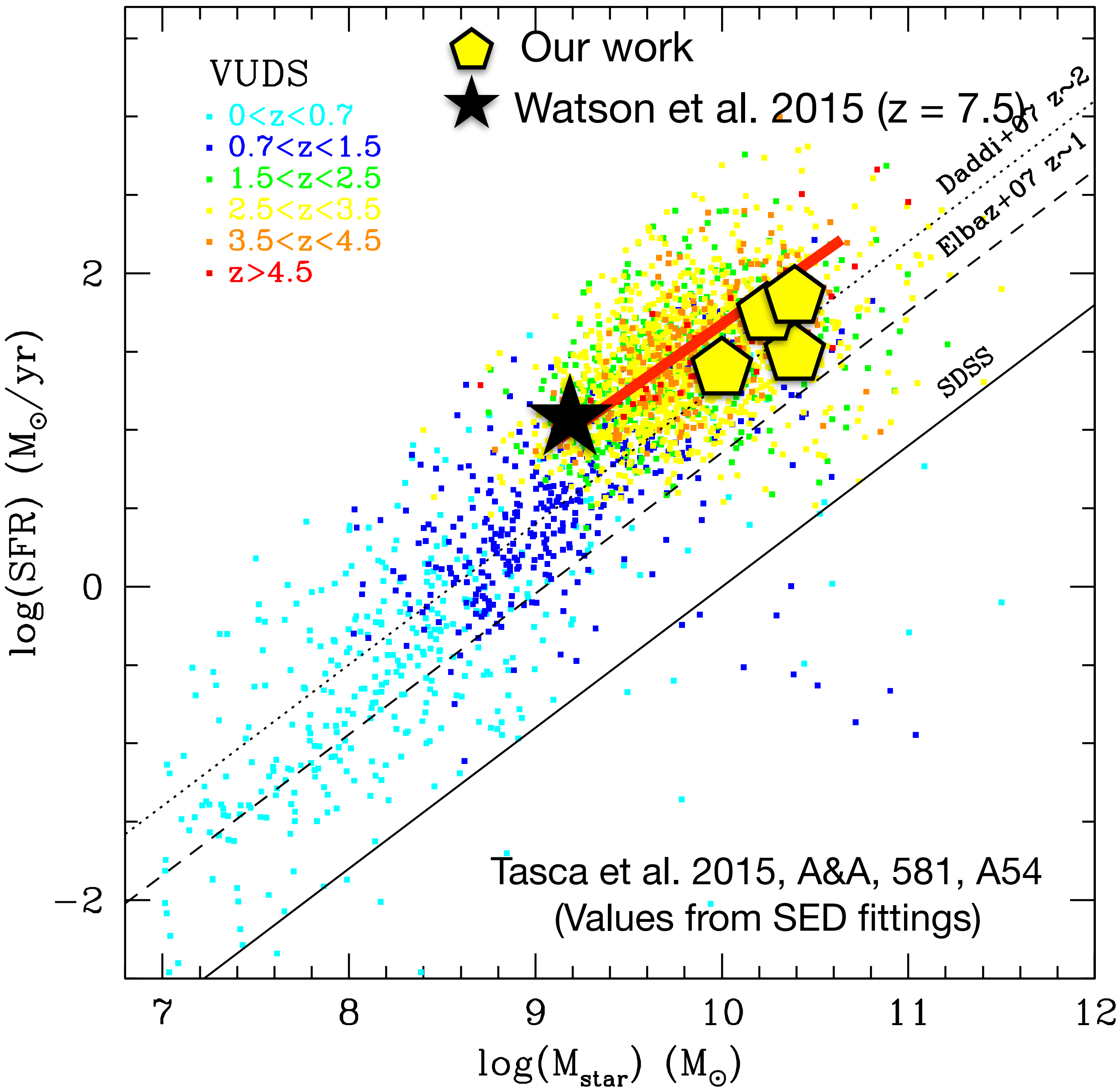
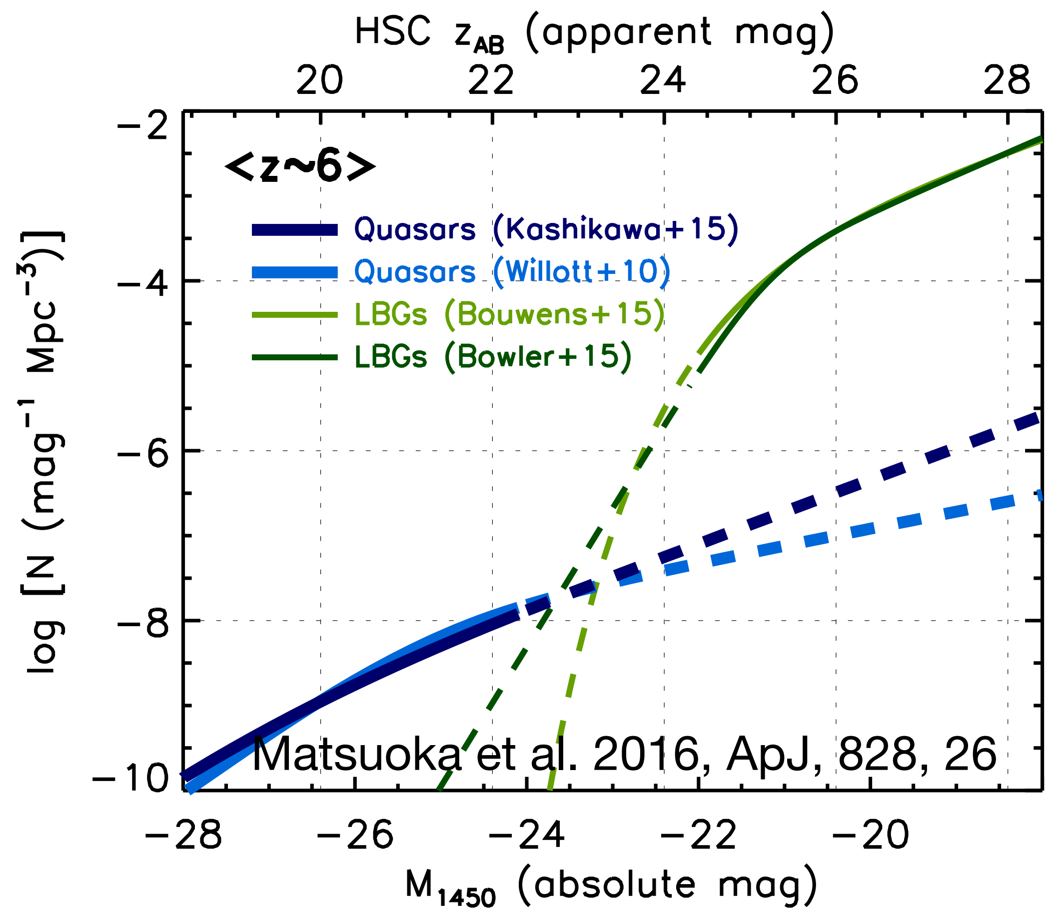


Similar to local LIRG-class objects
→ They would have similar gas density, radiation field, etc.as well?

What kind of galaxies are they? (2/2)



Main sequence?



Not above the MS at z ~ 5: clear contrast to luminous quasars

→ Almost "*on*" or "*slightly below*" the MS@z=5

→ Interesting targets to study primordial co-evolution?

Early co-evolution for low-luminosity QSOs

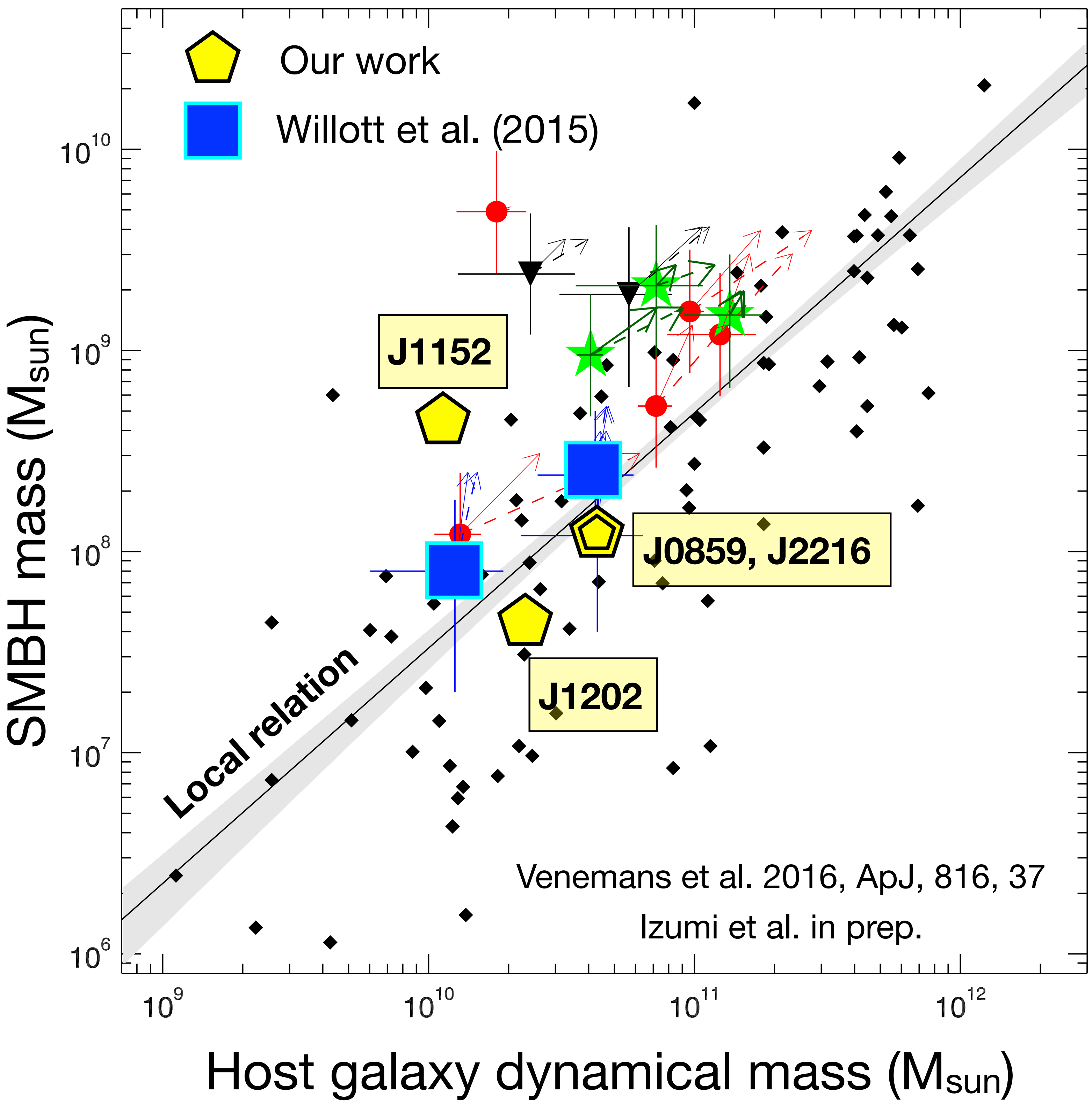
	FWHM (km/s)	V_{circ} (km/s)	Size (“, PA), (kpc)	inclination (°)	M_{dyn} (10^{10} M_{sun})	M_{BH} (10^{8} M_{sun})
J0859	345.9 +/- 45.1	354.7 +/- 46.2	(0.66 x 0.45, -6.0), (3.64 x 2.48)	47	4.3 +/- 0.8	1.2
J1152	192.1 +/- 45.4	173.8 +/- 41.1	(0.75 x 0.42, 66.8), (4.14 x 2.32)	56	1.1 +/- 0.3	4.3
J2216	355.6 +/- 32.8	302.1 +/- 27.9	(1.05 x 0.50, -14.7), (5.94 x 2.83)	62	4.3 +/- 0.6	1.2
J1202	335.1 +/- 24.0	296.4 +/- 21.1	(0.57 x 0.30, 64.4), (3.27 x 1.71)	58	2.4 +/- 0.2	0.43

To keep a consistency with previous works (e.g., Wang et al. 2013; Venemans et al. 2016)

- V_{circ} = 0.75 * FWHM / sin(i) (Ho 2007, ApJ, 669, 821)
- Disk diameter = 1.5 * deconvolved diameter
- $i = \cos^{-1}(a_{min}/a_{maj})$
- M_{BH}: Eddington limit (assumption for the lower limit → Onoue et al. in prep.)
- M_{dyn}/M_{sun} = 230 * (r/pc) * $(V_{circ}/\mathrm{km/s})^2$

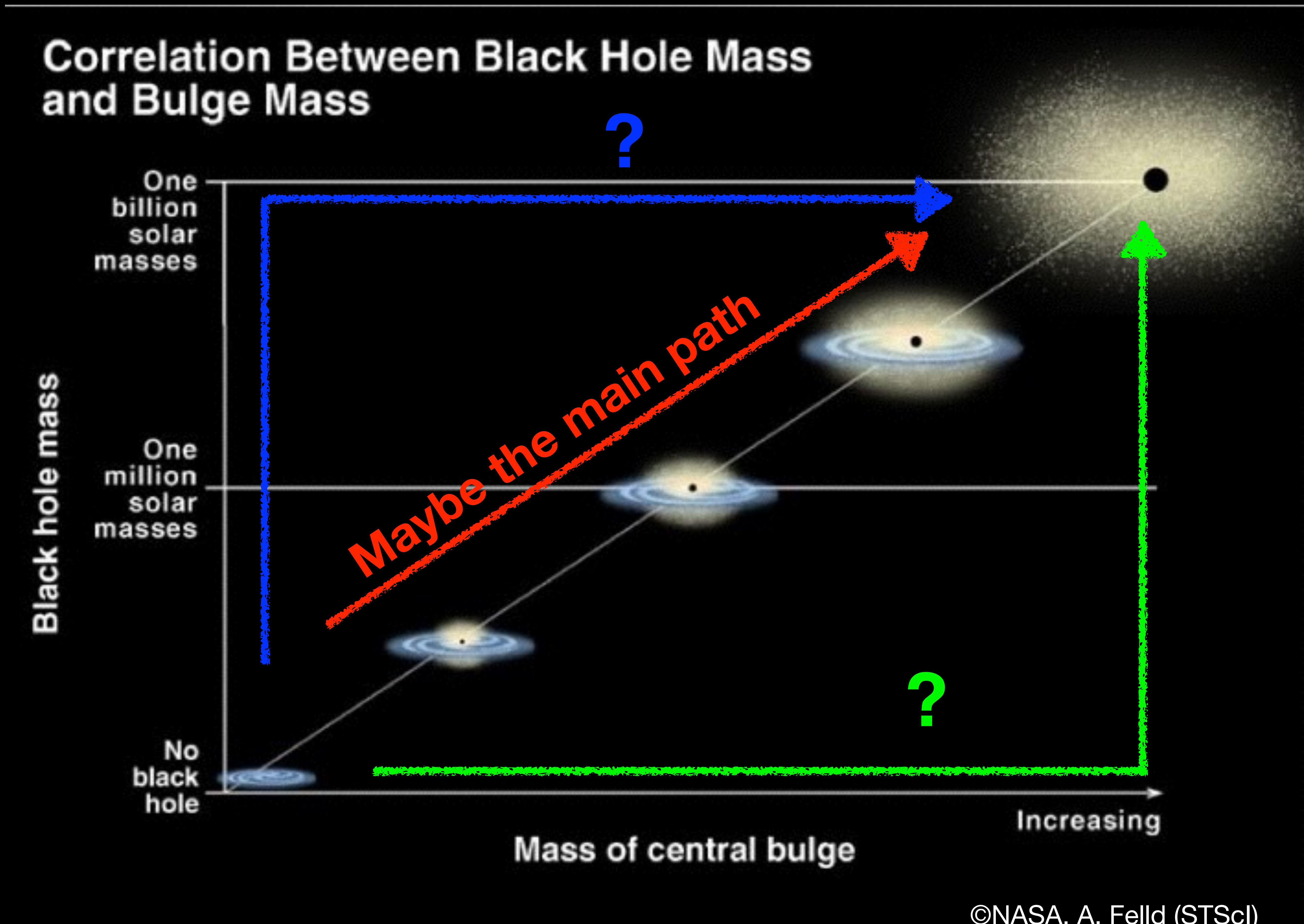
M_{BH} is unknown! (and really hard to meaure; Onoue-san’s talk)
→ JWST!!!

Early co-evolution for low-luminosity QSOs

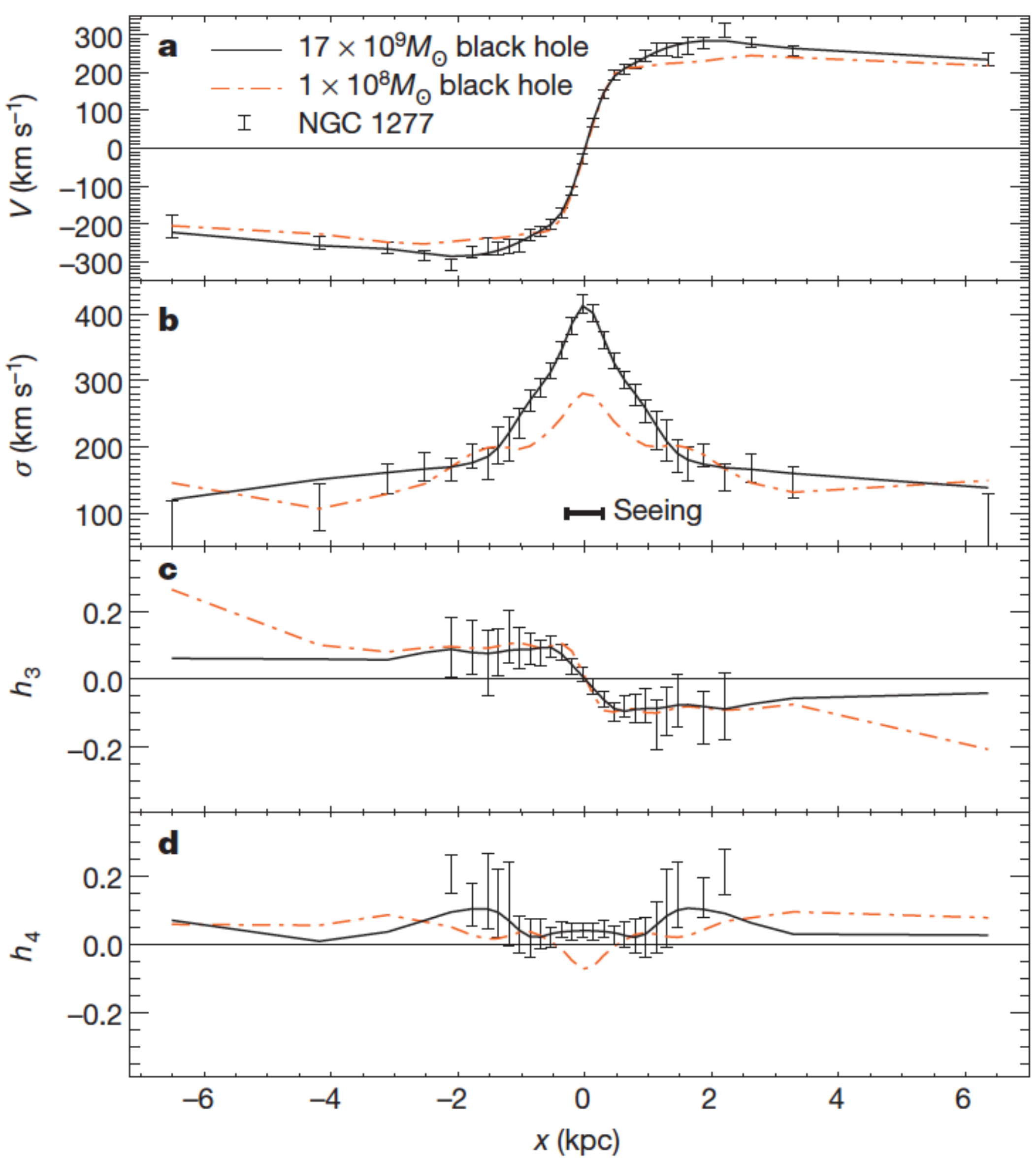


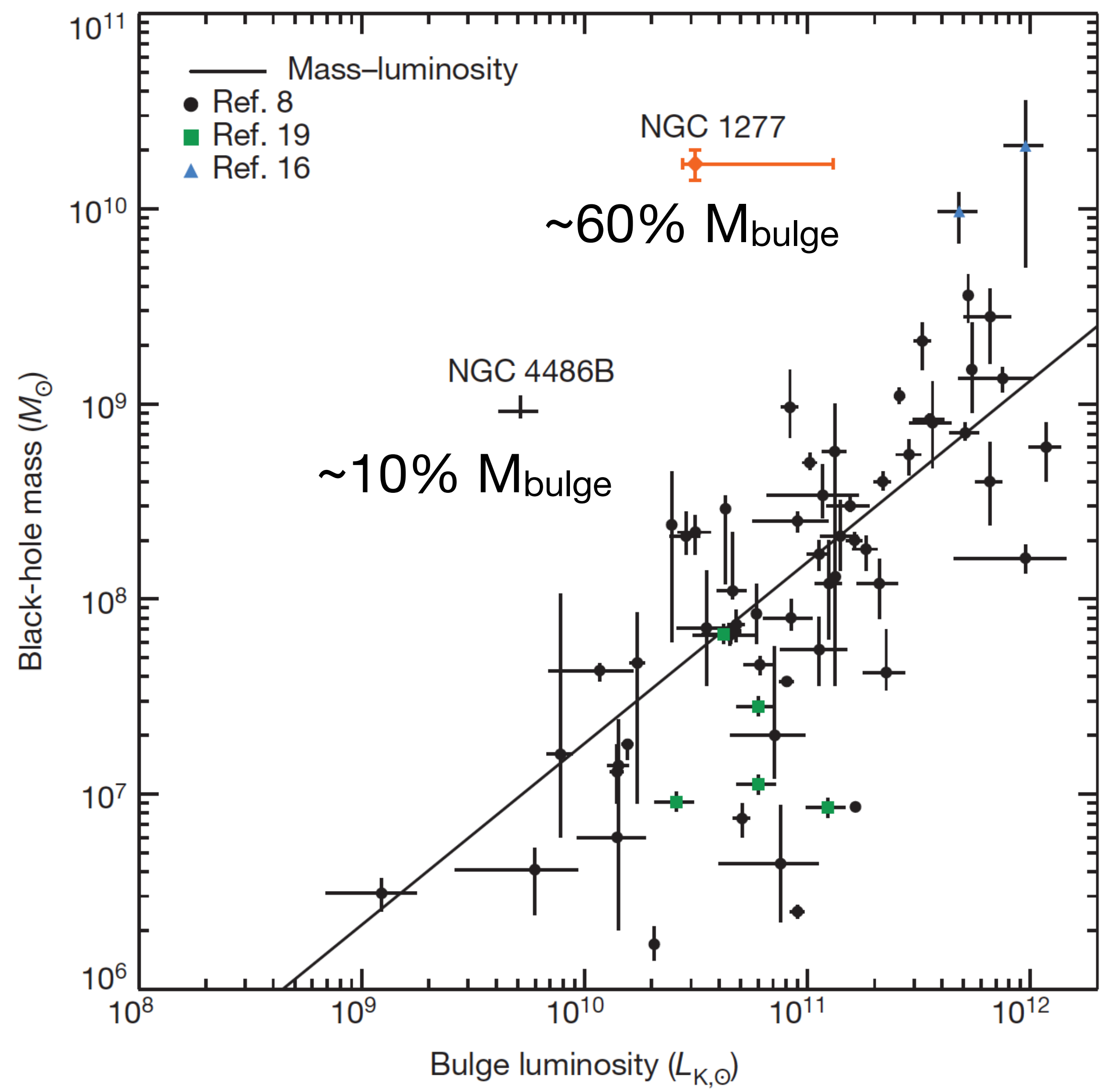
(believe your M_{BH})

- In stark contrast to the most massive/luminous quasars (e.g., SDSS), **low-luminosity quasars lie close to the local relation!**
  → (quasi-)synchronized evolution?
- Demonstrate the importance of probing low-luminosity quasars to reduce the selection bias (e.g., Lauer et al. 2007)
- I support an idea that previously-detected quasars are indeed biased to massive-end


Correlation Between Black Hole Mass
and Bulge Mass
?
One
billion
solar
masses
Maybe the main path
One
million
solar
masses
Black hole mass
?
No
black
hole
Increasing
Mass of central bulge
©NASA, A. Felld (STScI)

Note: Nearby Overmassive SMBH...?





- Do we really need to believe that, ALL galaxies finally converge to the co-evolutionary relations...??

Summary

- ALMA follow-up of HSC-detected low-luminosity quasars at z > 6.
- FIR properties of the hosts are being studied.
  - Cold dust mass, dynamical mass, (and will gas mass?)
- SHELLQs quasars basically have LIRG-like FIR properties in their hosts.
  - L_{FIR}, $L_{[CII]}$, M_{dust}
  - Level of [CII] deficit
  - Likely to be on/below a MS at z ~ 6
  - No companion within R_{proj} < 75 kpc…?
- These are clear contrasts to those of the previously discovered quasar-hosts (~ULIRG/SMG)
- Low-luminosity quasars lie roughly on the local M_{BH}-M_{dyn} (M_{bulge}) relation!
  - Less-biased, low-mass SMBHs will synchronically evolve with their hosts?
  - This would be the *reference* for galaxy evolution