East-Asia AGN Workshop 2017
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SHELLQs-ALMA: submm properties of galaxies hosting less-luminous quasars at z > 6

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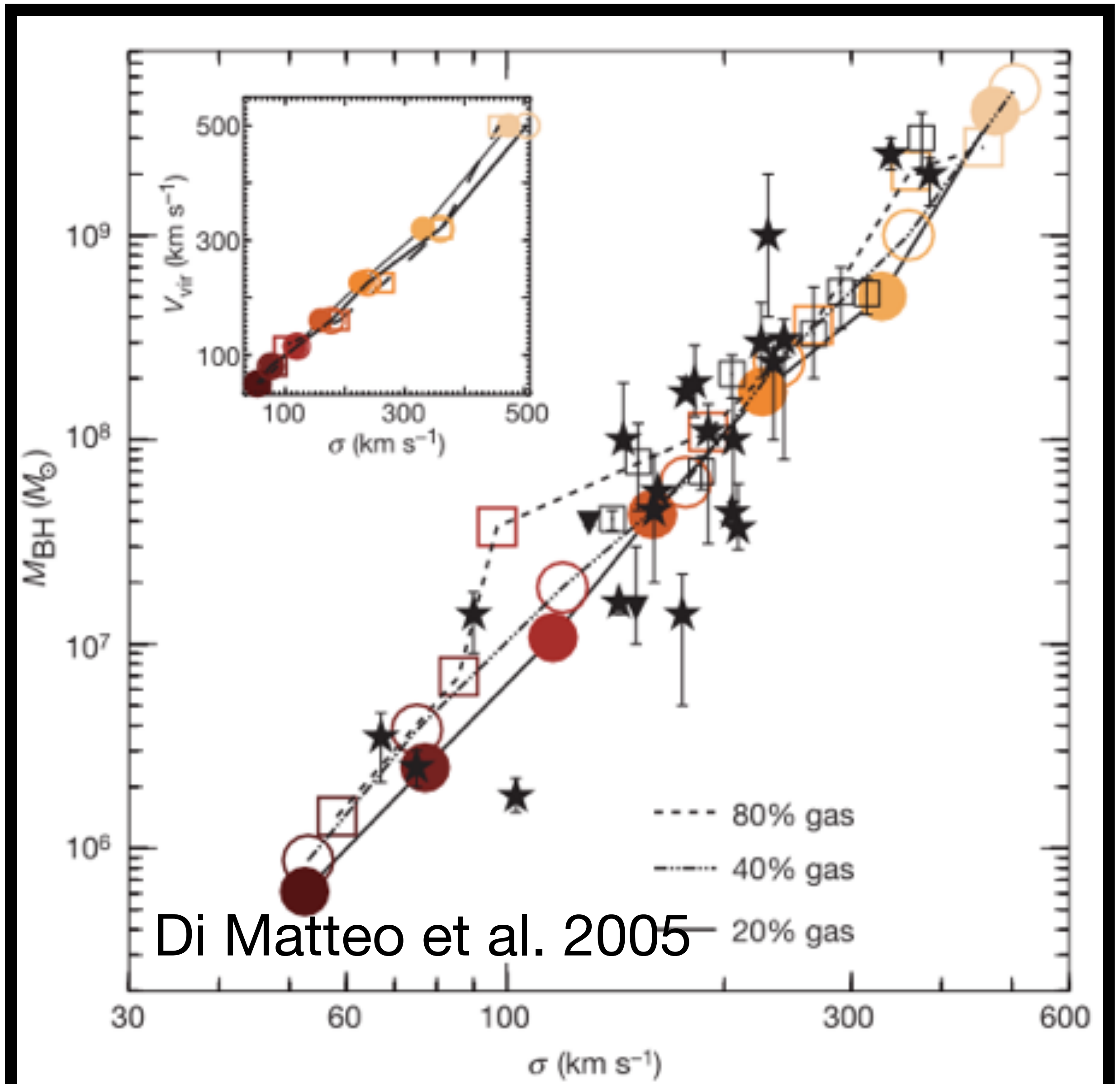
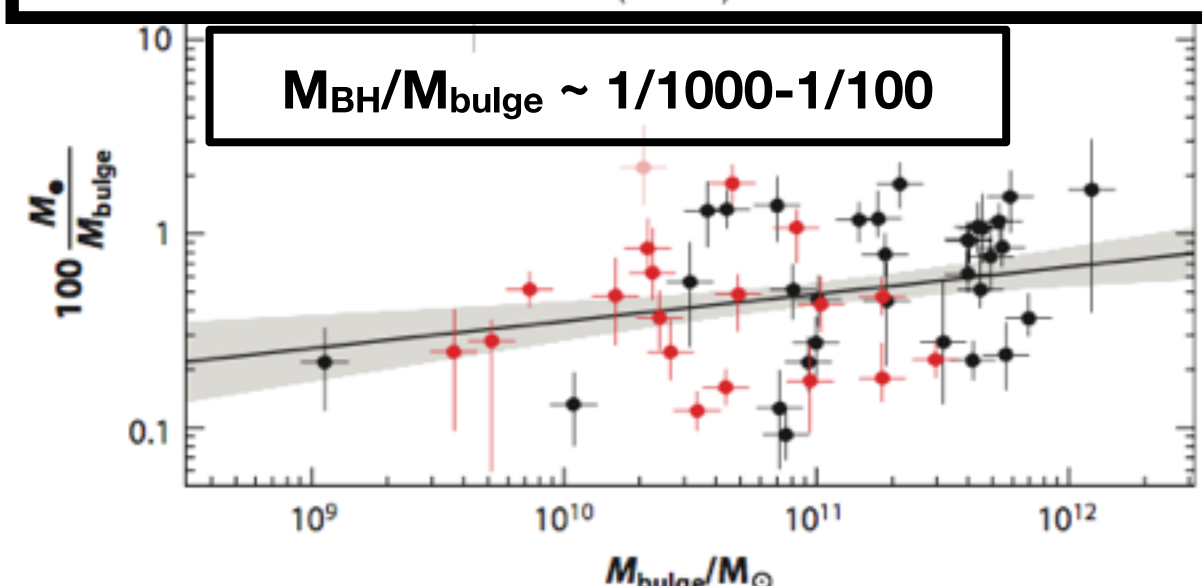
→ *Izumi et al. to be submitted*

Co-evolution of SMBH and galaxy



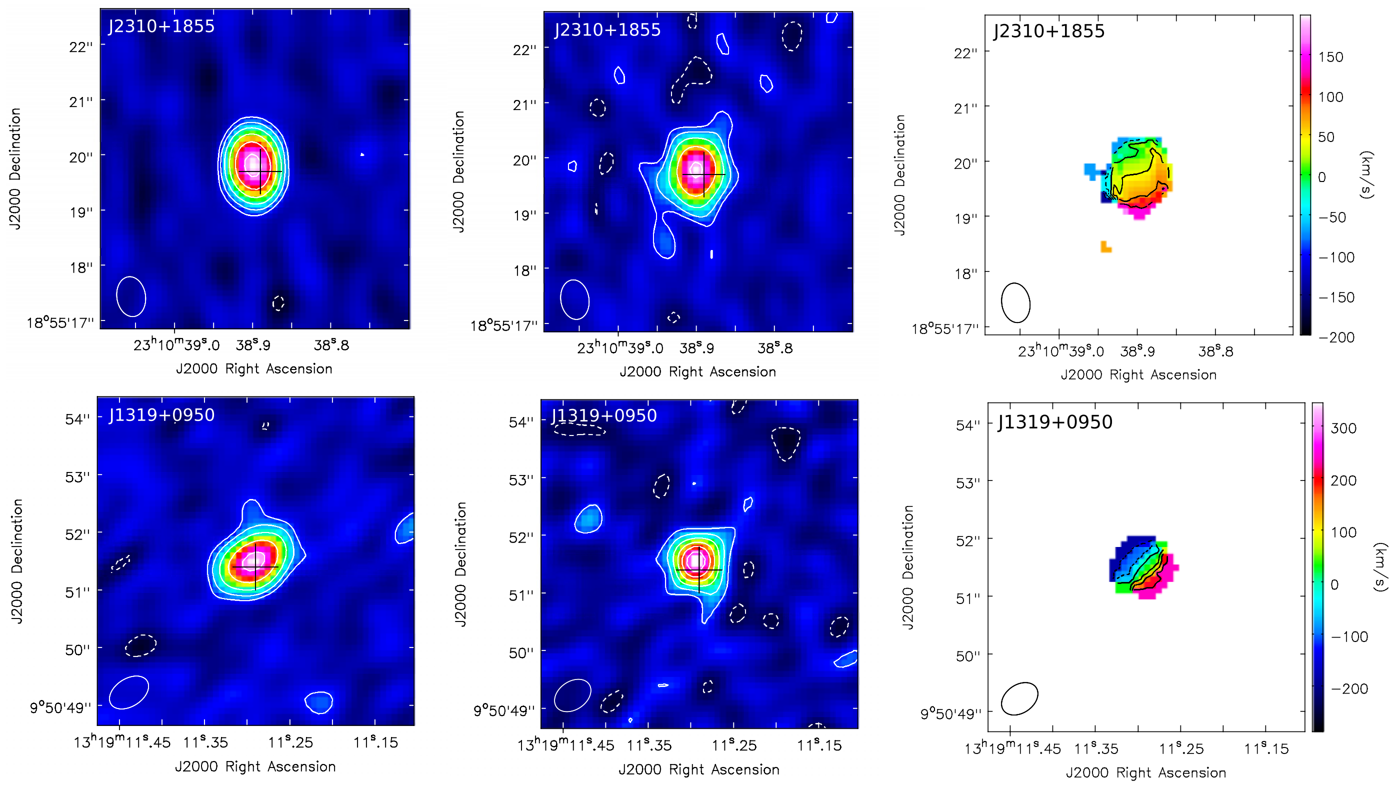


- M_{BH} is tightly correlated with M_{bulge} and σ_* → ***Co-evolution***
- Favoured scenario: Merger-induced starburst & AGN, and subsequent "AGN feedback" to regulate the star formation (e.g., Hopkins et al. 2008; Fabian 2012, ARA&A, 50, 455)
- ***When, how, and where the relation has arisen?***

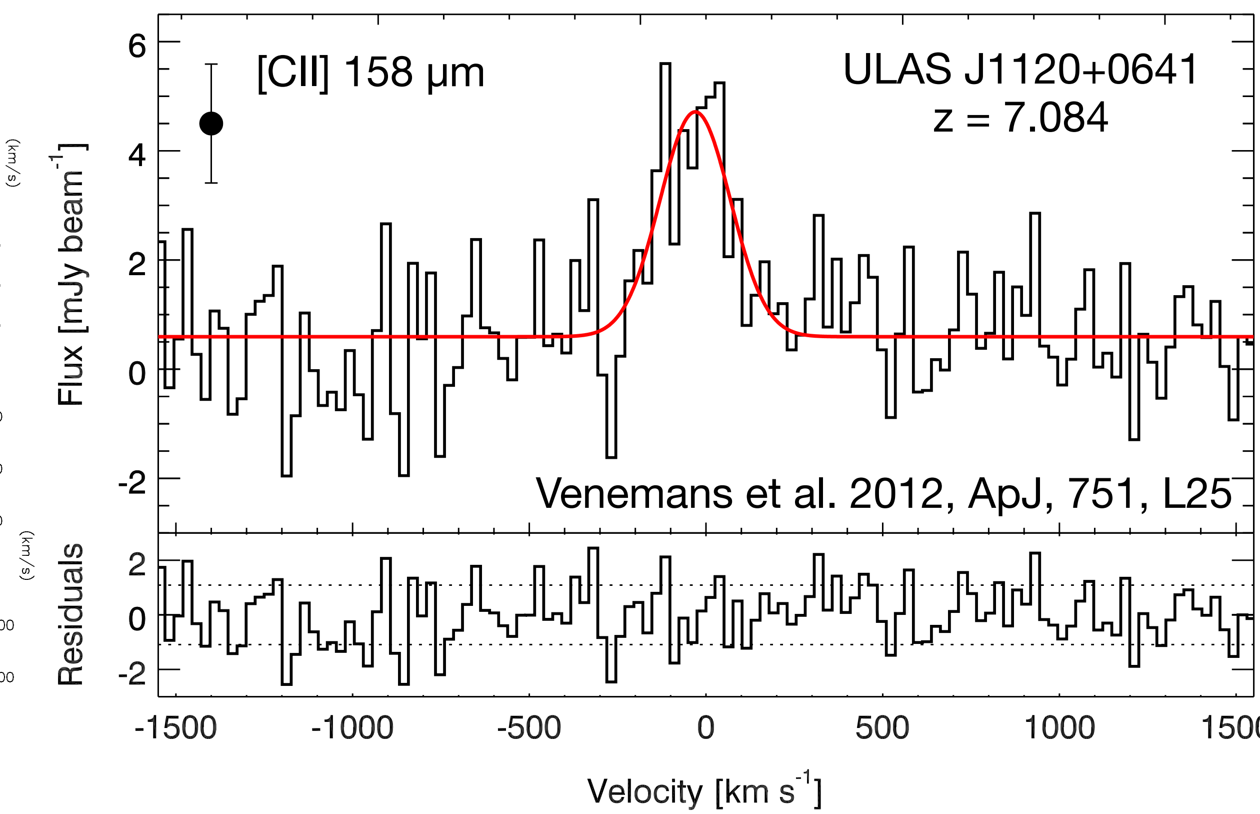
Reveal (i) SMBH feeding/ feedback and (ii) galaxy growth over the cosmic time

Host galaxy properties of high-z quasars

Dust [CII] Vel. field



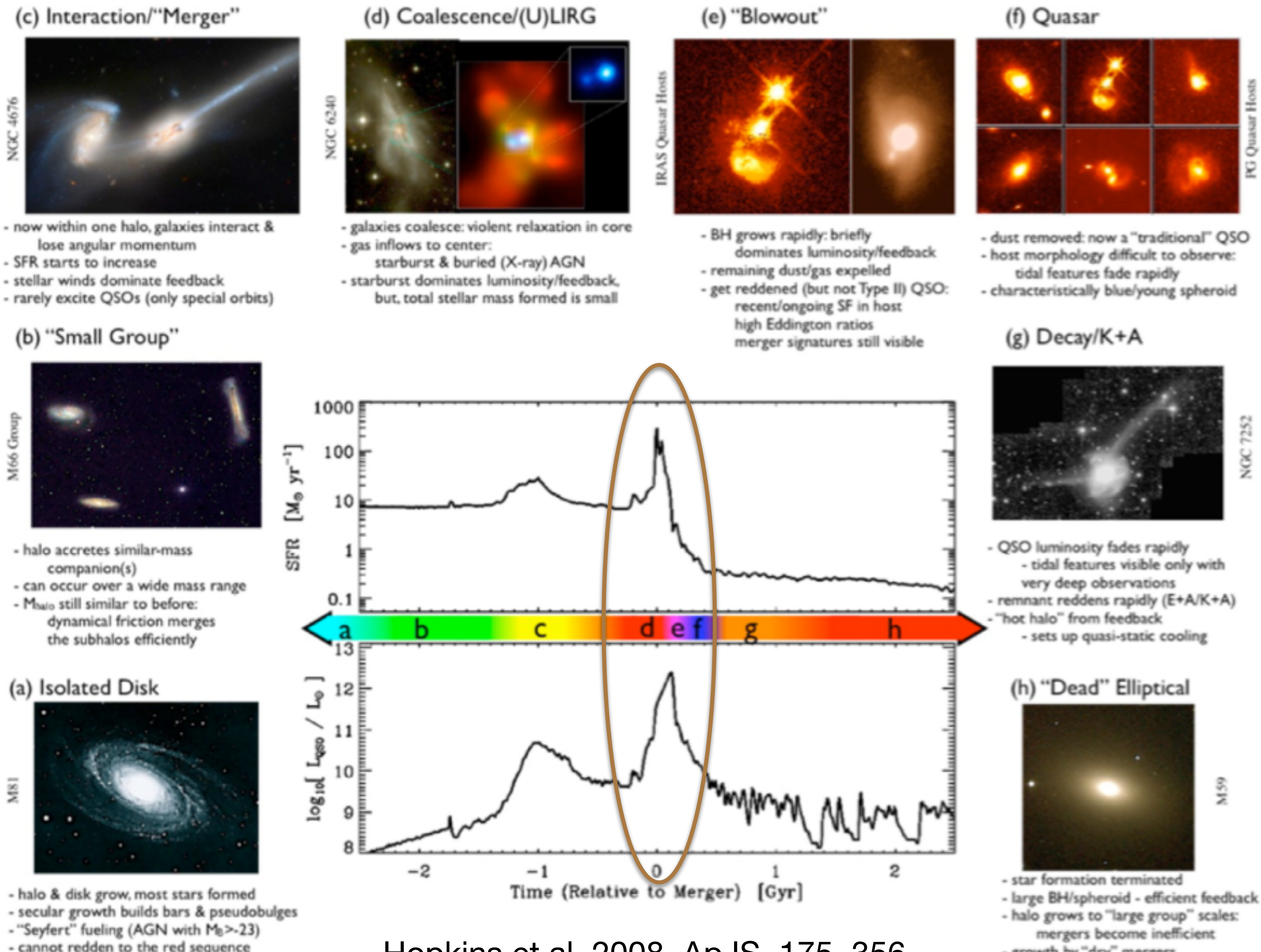
Wang et al. 2013, ApJ, 773, 44 w/ ALMA



- Luminous quasars at z >~ 6 (L_{Bol} > 1e14 L_{sun})
- ULIRG/SMG-class star formation!
- Rapid, vigorous, and coeval SMBH and galaxy growths (SF time scale < 100 Myr)

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

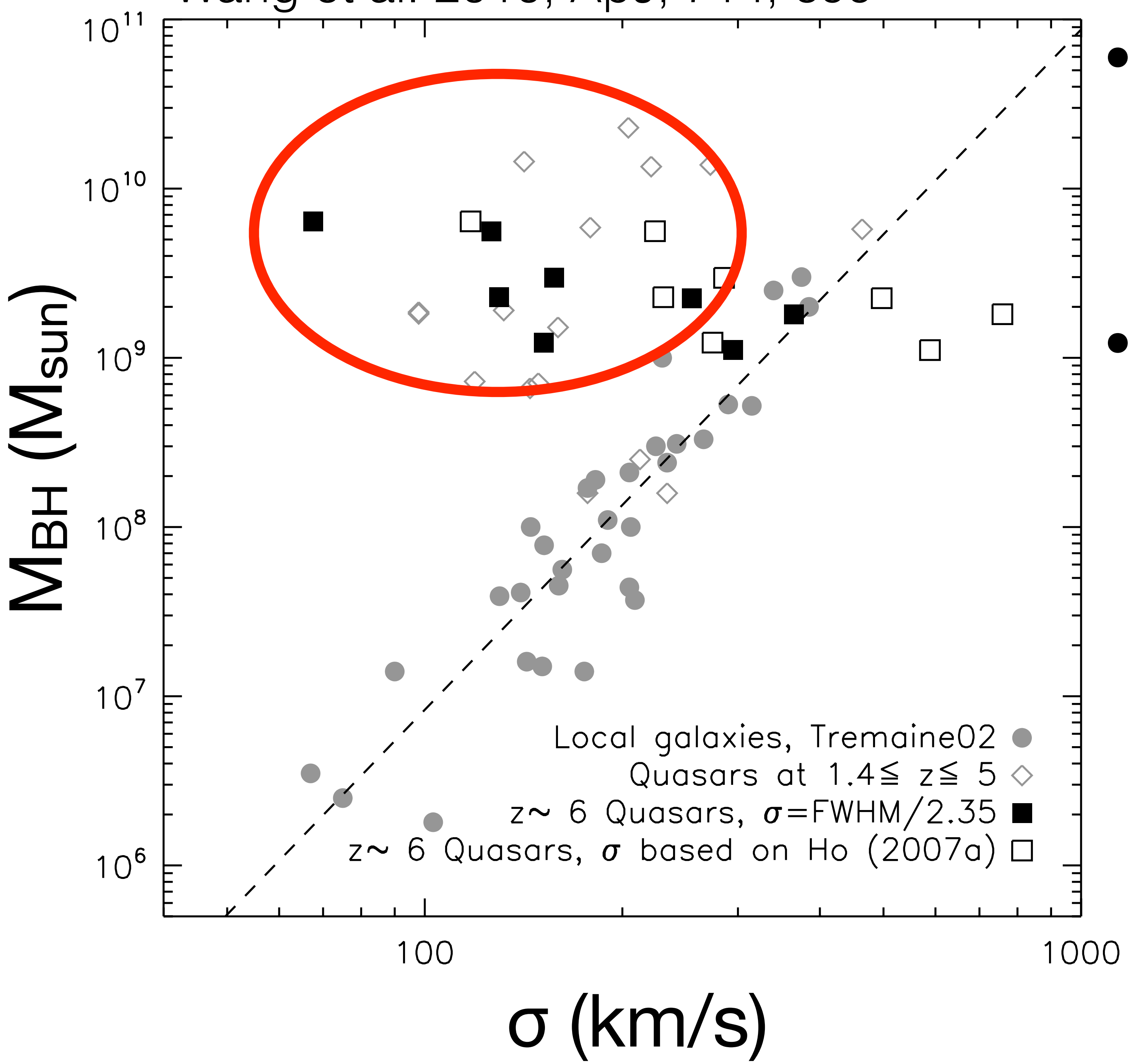
e.g., Wang et al. 2010, ApJ, 714, 699



Hopkins et al. 2008, ApJS, 175, 356

Early co-evolution: likely a biased one

Wang et al. 2010, ApJ, 714, 699

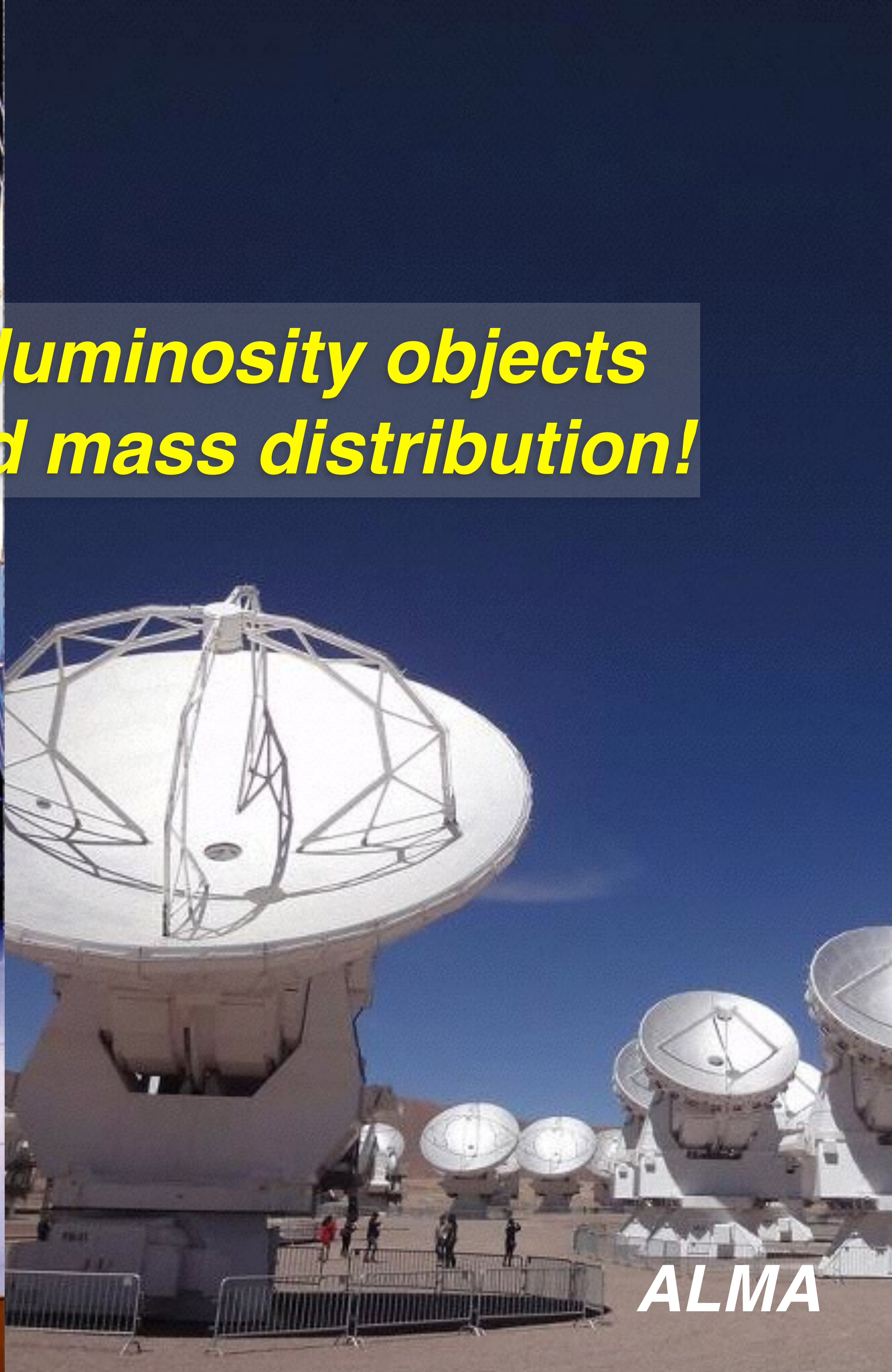


- M_{BH} of some optically-luminous z > 6 quasars are over-massive → SMBH earlier, galaxies later?
- But we should care about a selection bias to prefer luminous (~ massive) objects

※ Gas-σ is used instead of stellar σ in quasars

Probing-down low luminosity objects
→ Depict less-biased mass distribution!

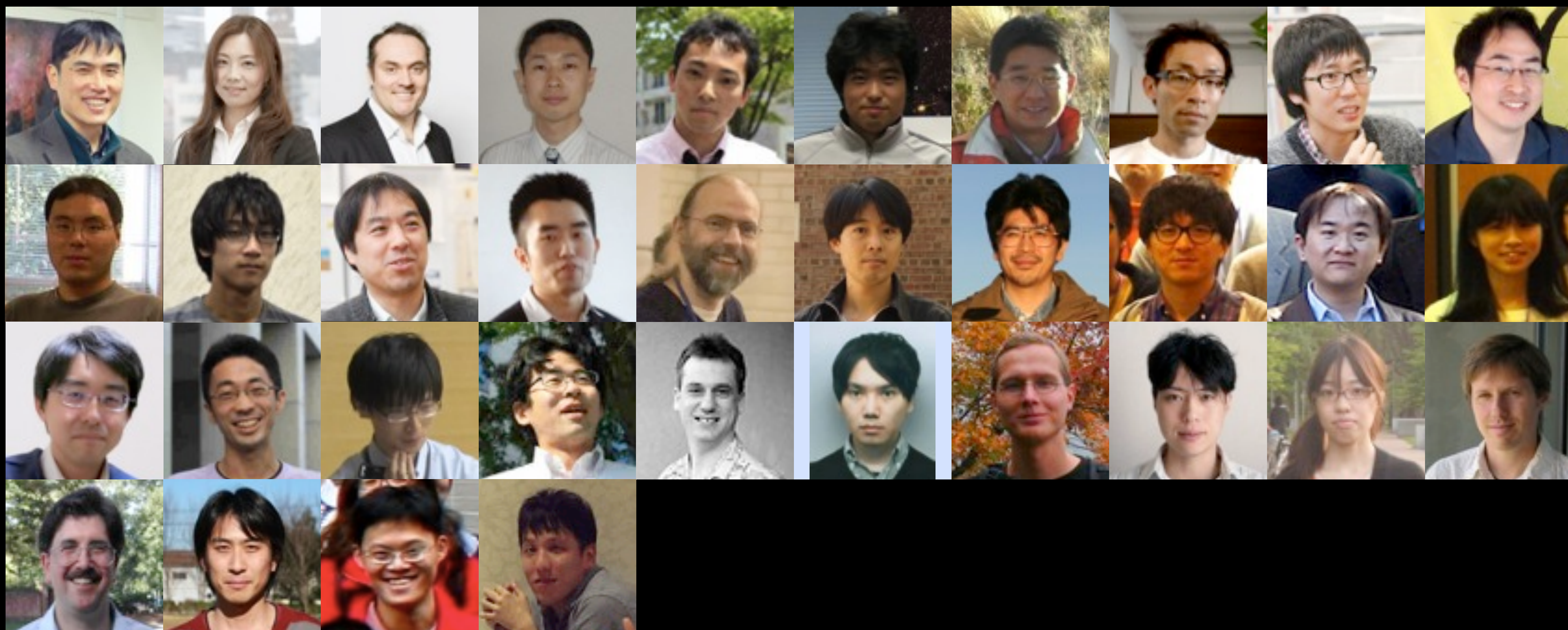
Subaru/Hyper Suprime-Cam



ALMA

SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars



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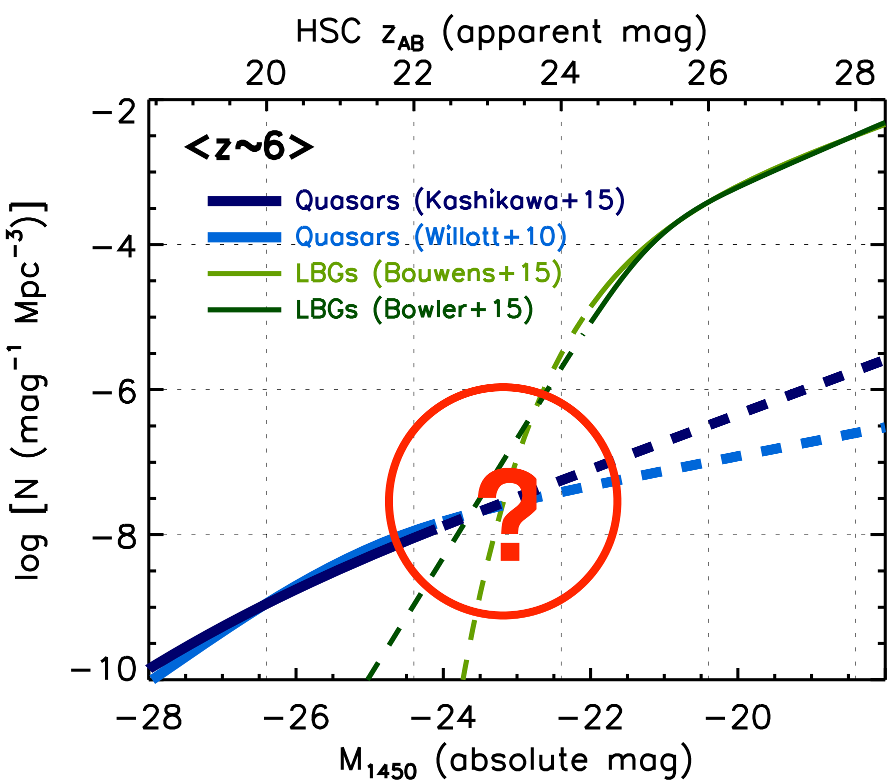
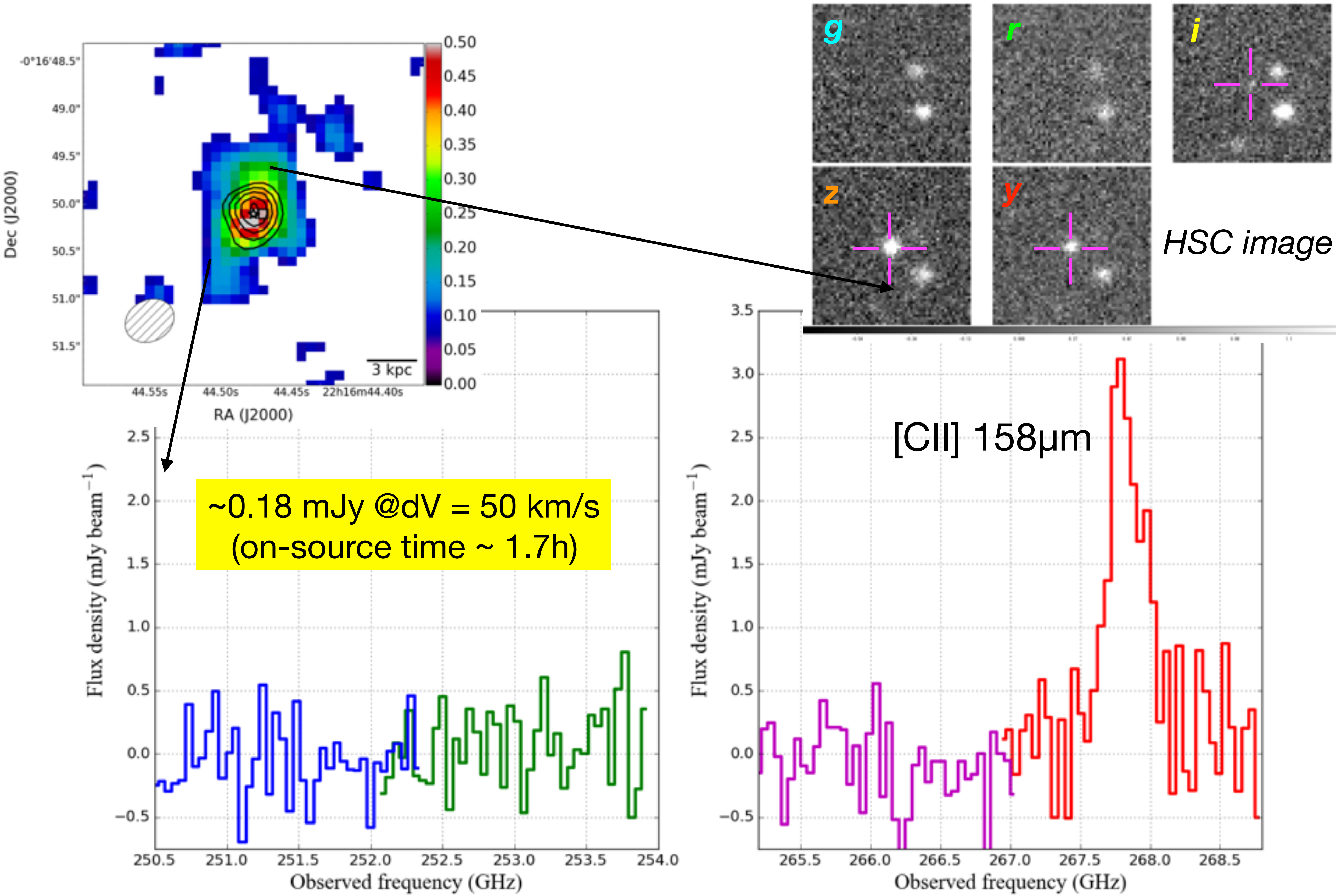
ALMA Cycle 4 observations

Quasar	z_{opt}	M_{1450}	L_{Bol} (L_{sun})	BAL	θ ([CII])	1σ (mJy/b), dV=50 km/s	1σ (μJy/b): cont.
J0859+0022	6.39	-23.56	3.9E+12	N	0.64” x 0.47”	0.12	9.5
J1152+0055	6.37	-24.91	1.4E+13	N	0.52” x 0.47”	0.24	20.7
J2216-0016	6.10	-23.56	3.9E+12	Y	0.54” x 0.43”	0.18	13.2
J1202-0057	5.93	-22.44	1.4E+12	N	0.79” x 0.71”	0.12	8.8



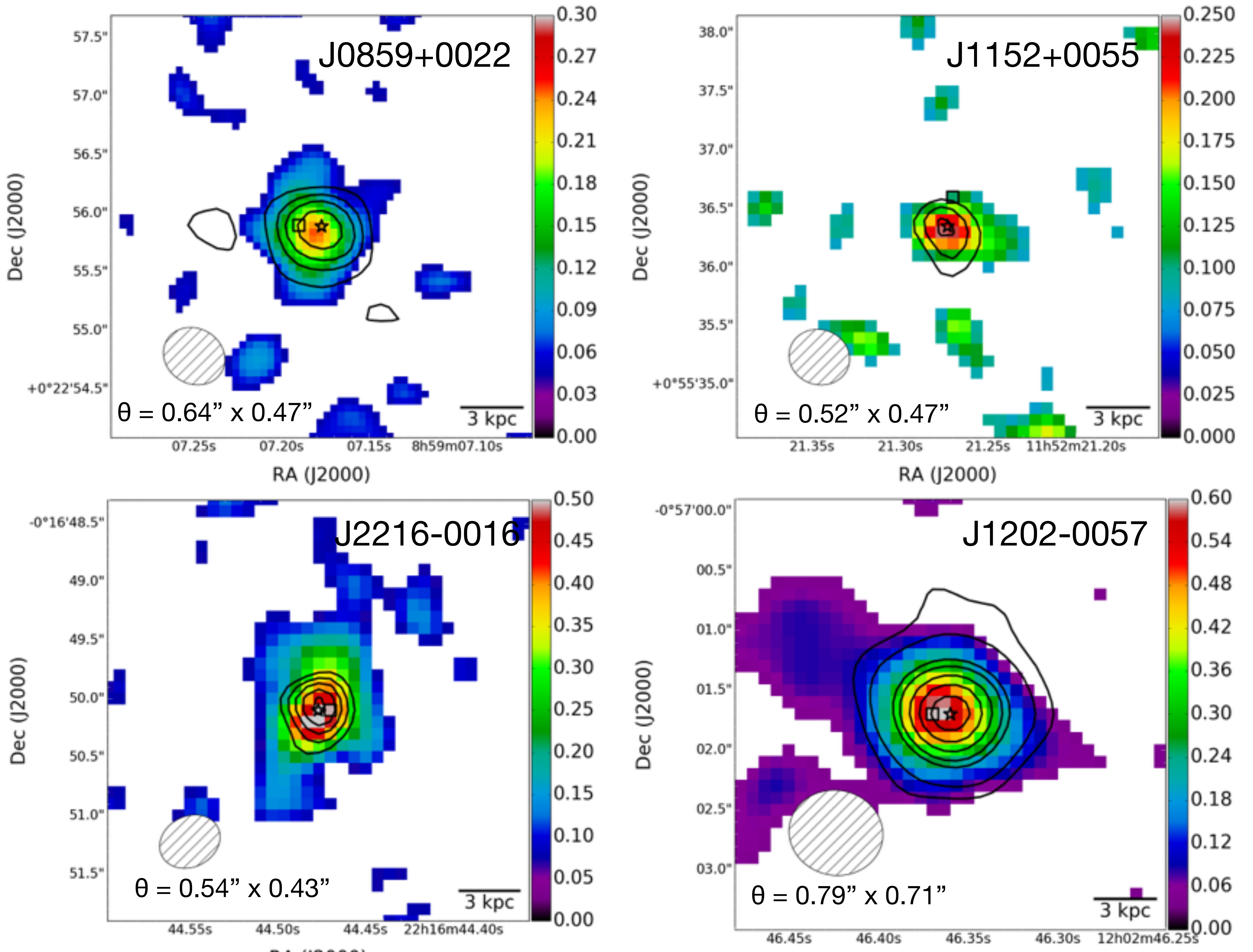
- Four HSC quasars at z~6 (from Matsuoka+16)
- Aimed at detecting the [CII] and underlying rest-FIR continuum emission

Band 6 full spectrum: J2216 (example)

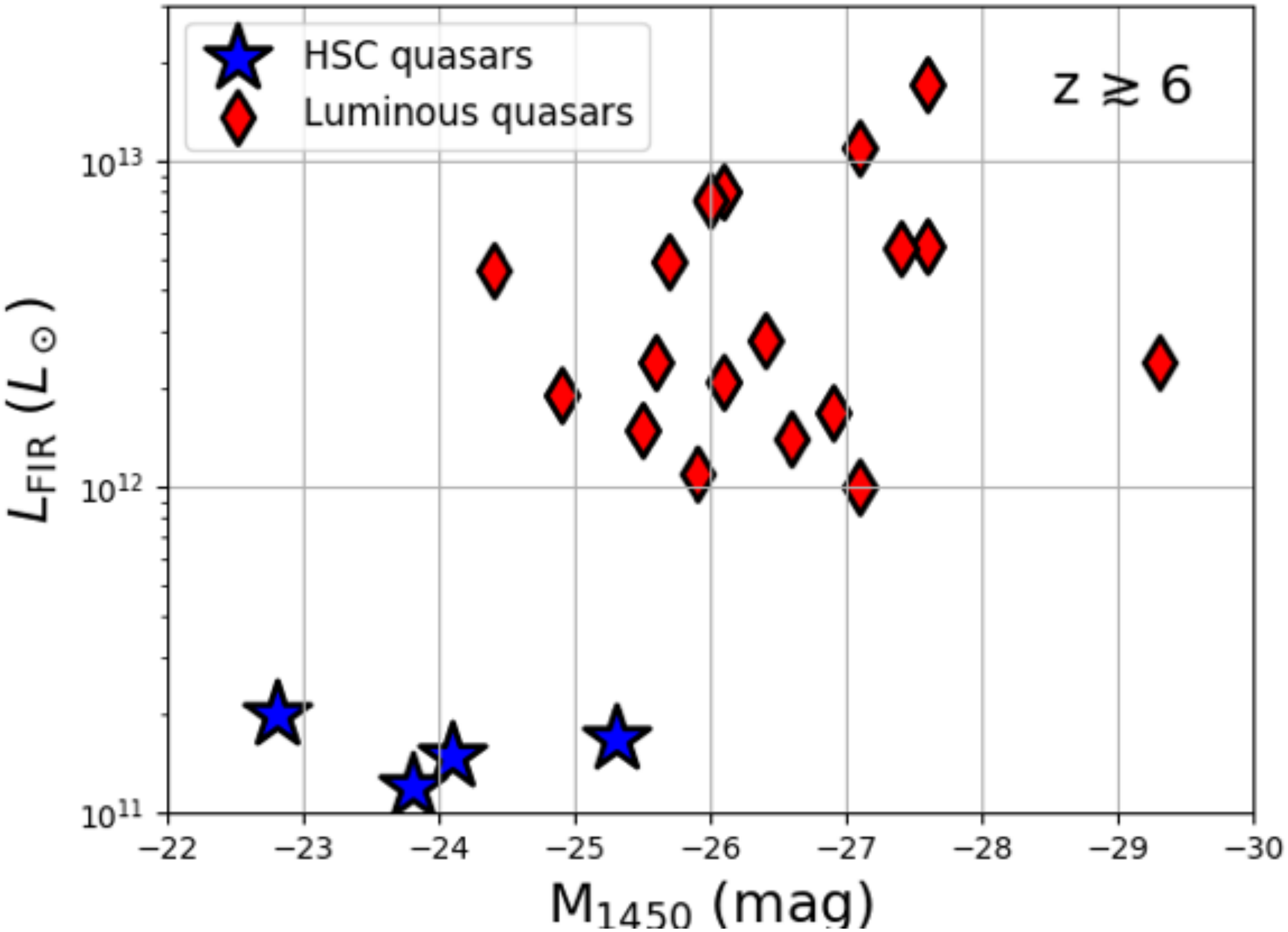


Results: Spatial distribution

Color = [CII]
Contour = FIR continuum



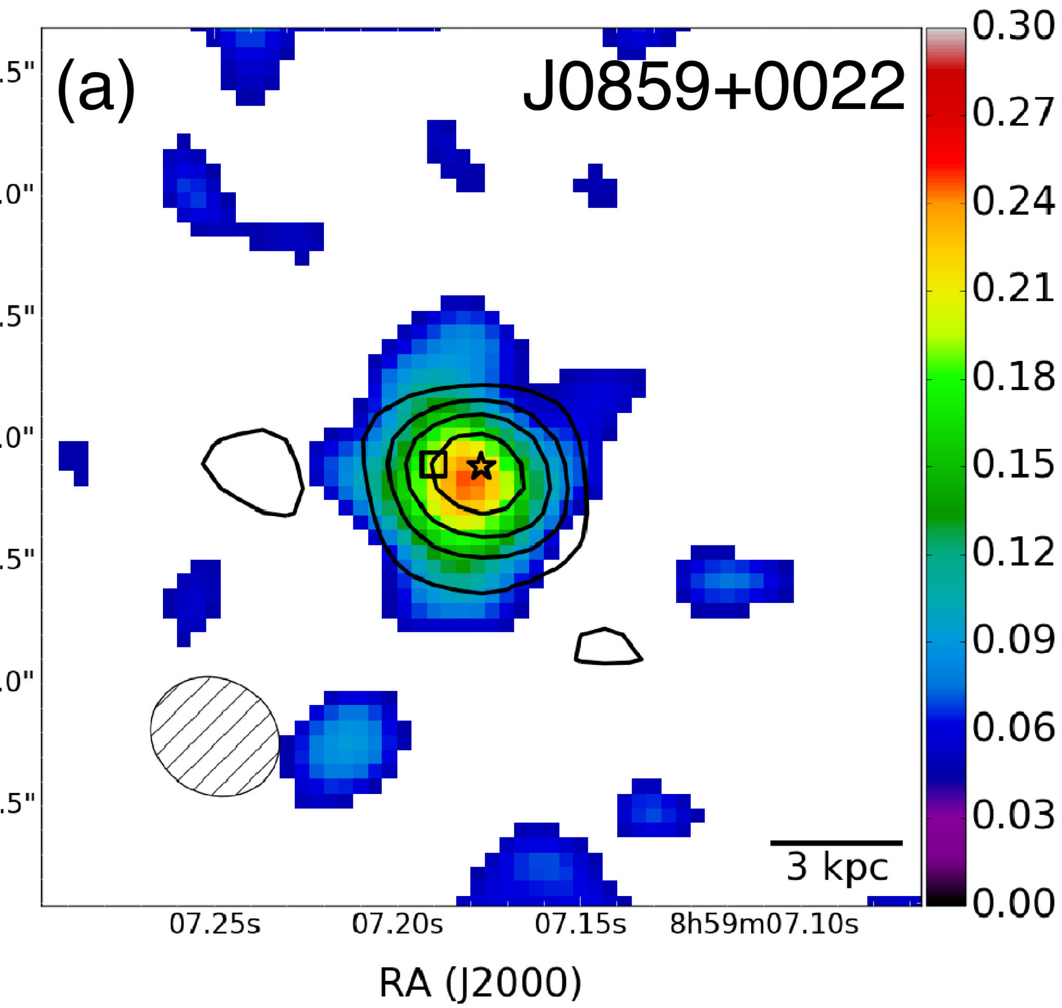
FIR properties of the HSC-quasars



	M_{dust} (1E7 M_{sun})	SFR_{IR} (M_{sun}/yr)
J0859	5.0 ± 0.7	28 ± 4
J1152	6.0 ± 1.0	34 ± 6
J2216	4.1 ± 0.8	23 ± 5
J1202	7.1 ± 0.3	40 ± 2

- **LIRG-class objects @ z > 6 !**
- Moderate SFR (23-40 M_{sun}/yr; L_{IR}-based)
  - c.f., SFR ~ 100-1000 M_{sun}/yr for optically luminous quasars @ z > 6

Size of the emitting region



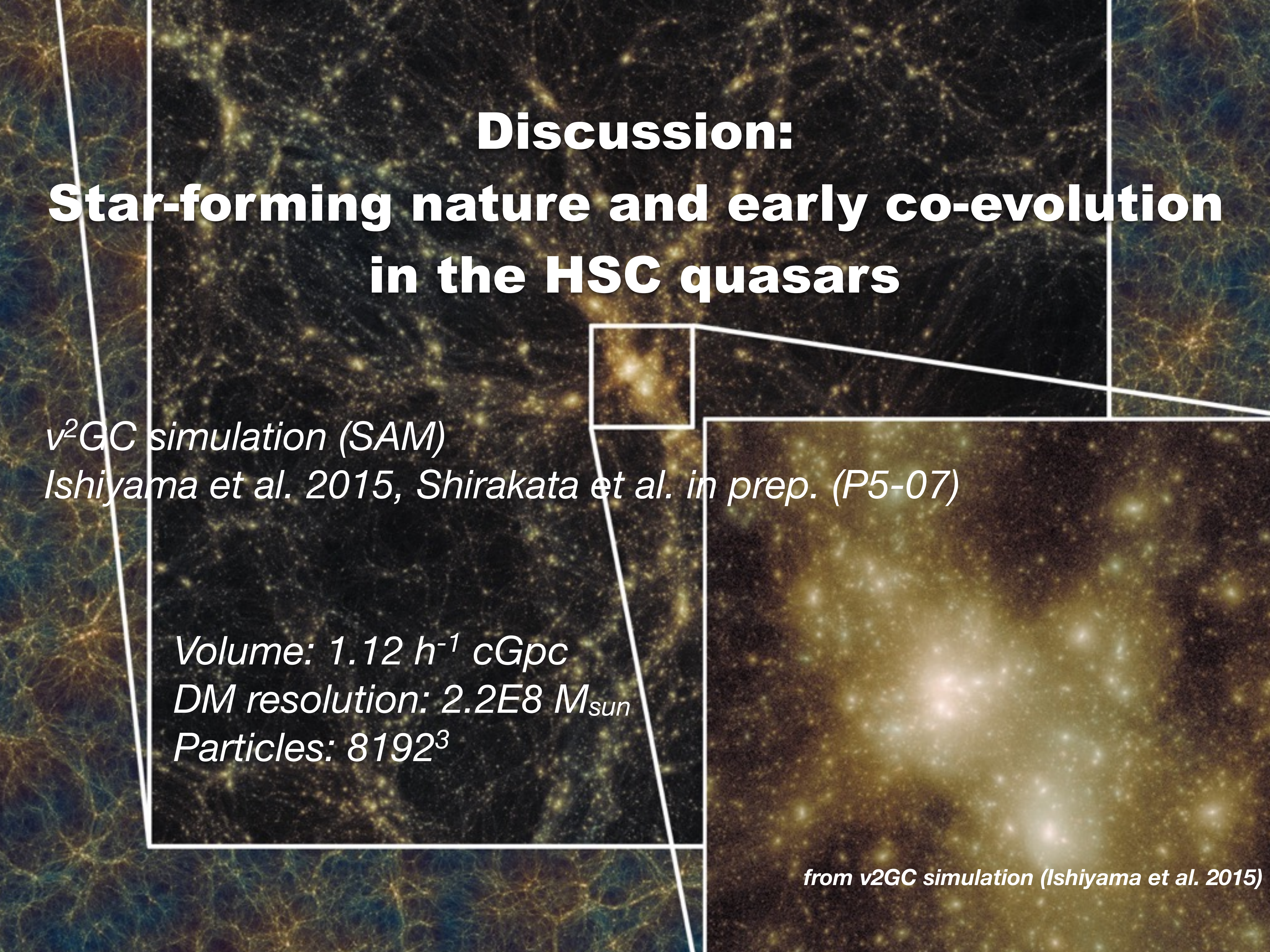
Quasar	Size ([CII] FWHM)
J0859+0022	(2.8±0.8) kpc x (1.8±1.0) kpc
J1152+0055	(3.0±1.1) kpc x (1.4±0.7) kpc
J2216-0016	(5.2±0.8) kpc x (2.5±0.7) kpc
J1202-0057	(2.6±0.7) kpc x (1.5±1.1) kpc

- FWHM ~ a few kpc
- Comparable to the sizes of optically-luminous quasars (SFR ~ 100-1000 M_{sun}/yr; M_{dust} > 1e8 M_{sun})
  → An order of mag. difference in Σ_{ISM}
  → Key parameter of *SMBH accretion* (e.g., Hopkins & Quataert 2010)

Discussion:
Star-forming nature and early co-evolution in the HSC quasars

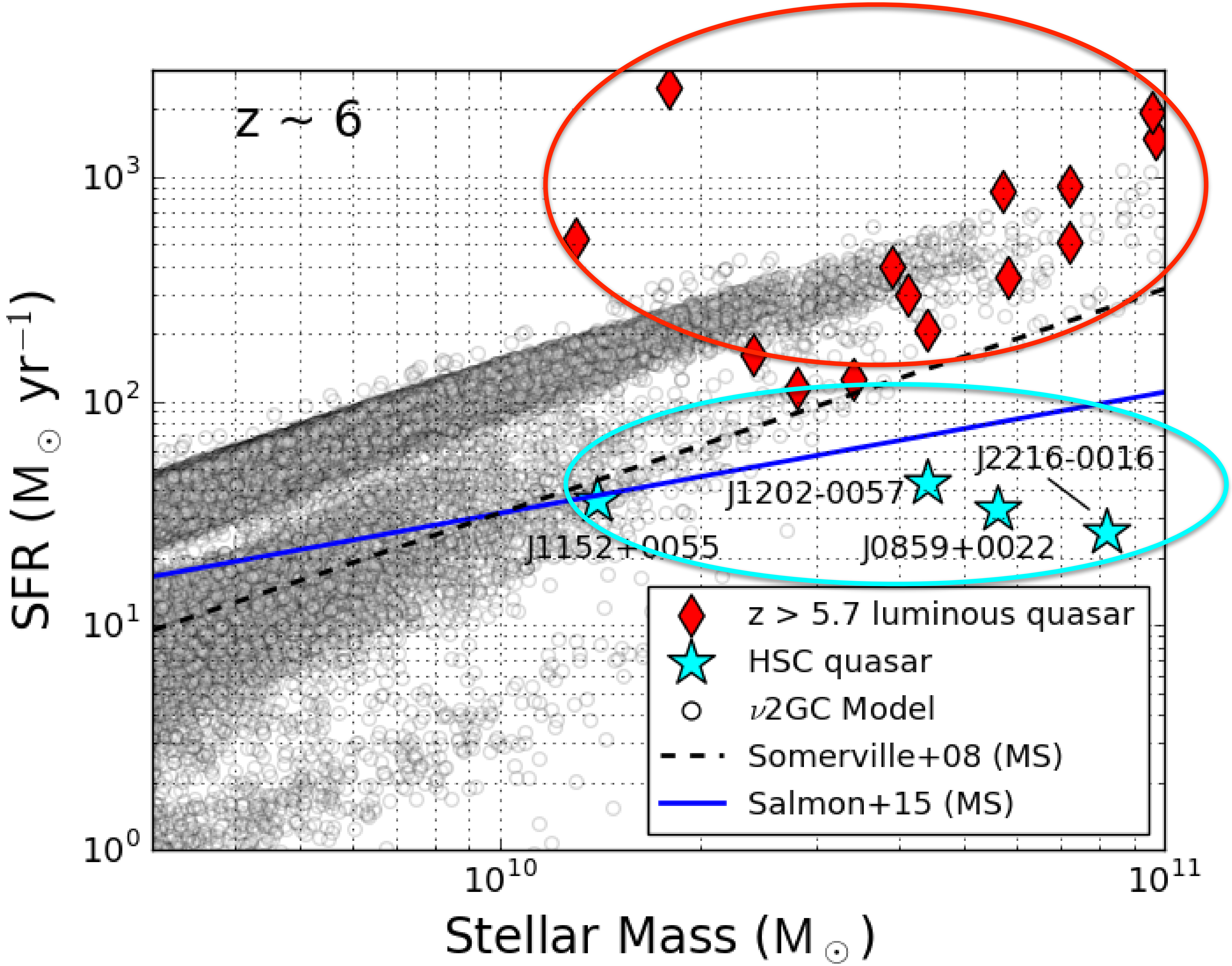
v^2GC simulation (SAM)
Ishiyama et al. 2015, Shirakata et al. in prep. (P5-07)

Volume: 1.12 h^{-1} cGpc
DM resolution: 2.2E8 M_{sun}
Particles: 8192^3

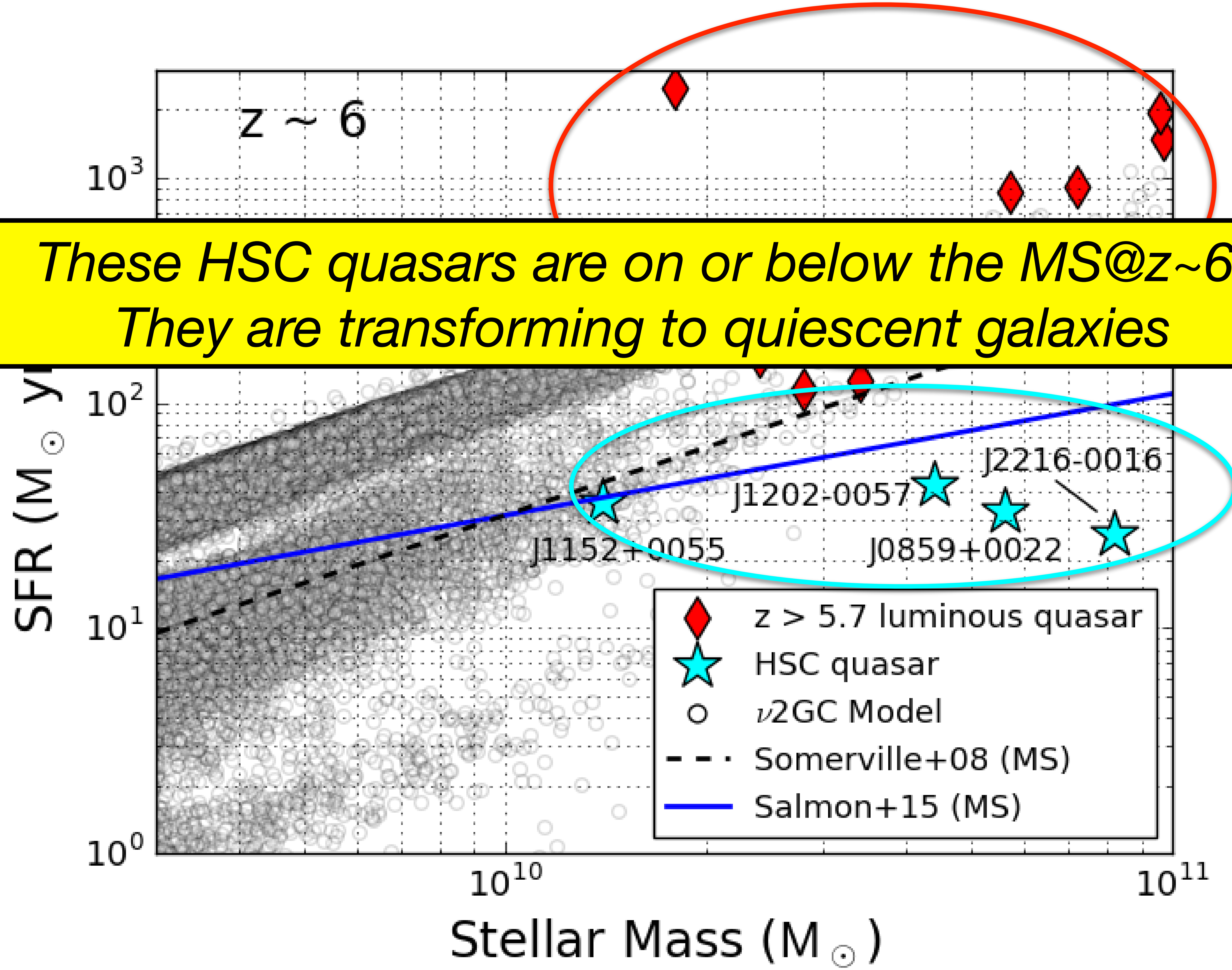


from v2GC simulation (Ishiyama et al. 2015)

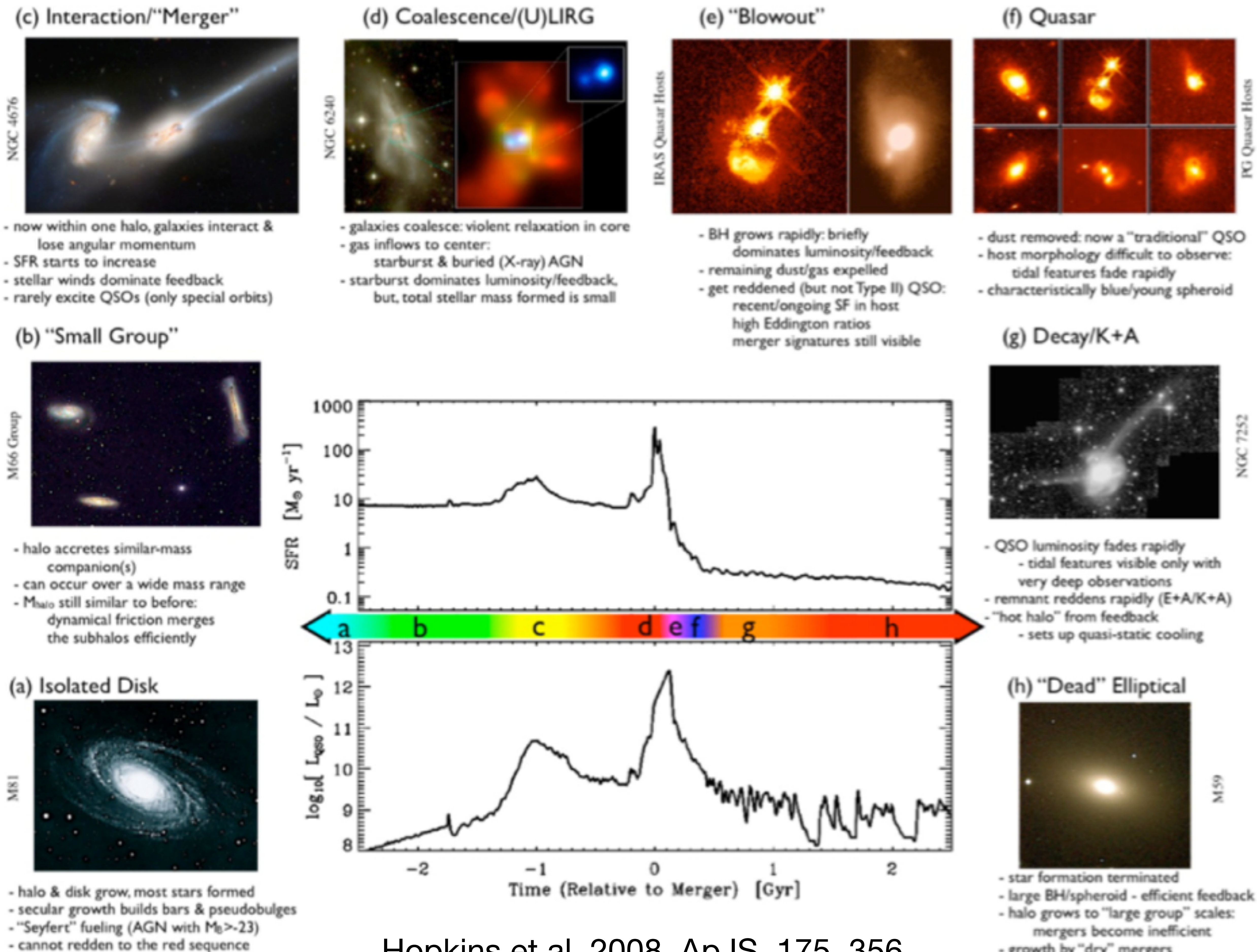
Star formation levels



Star formation levels

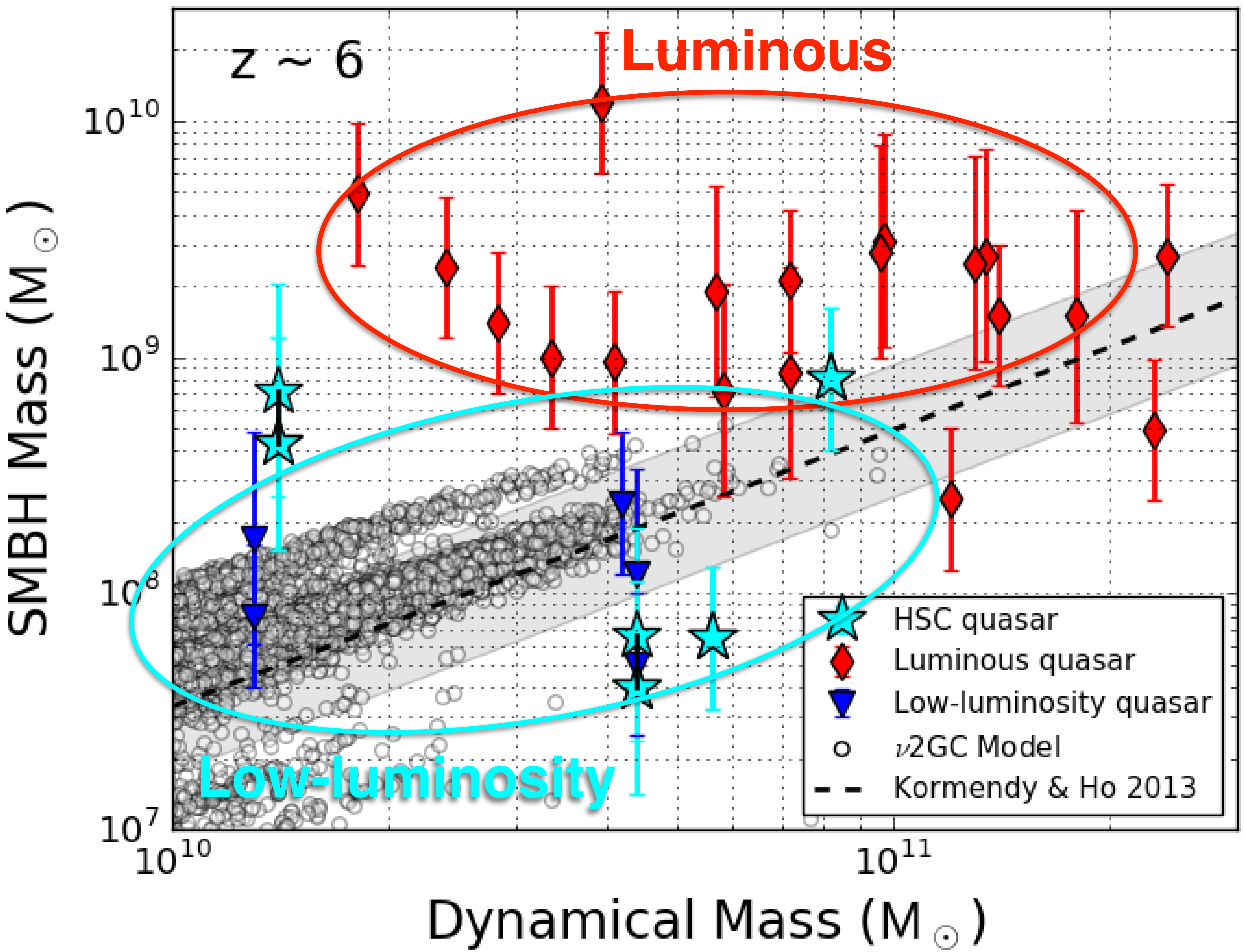


These HSC quasars are on or below the MS@z~6: They are transforming to quiescent galaxies



Hopkins et al. 2008, ApJS, 175, 356

Early co-evolution in z ~6 quasars



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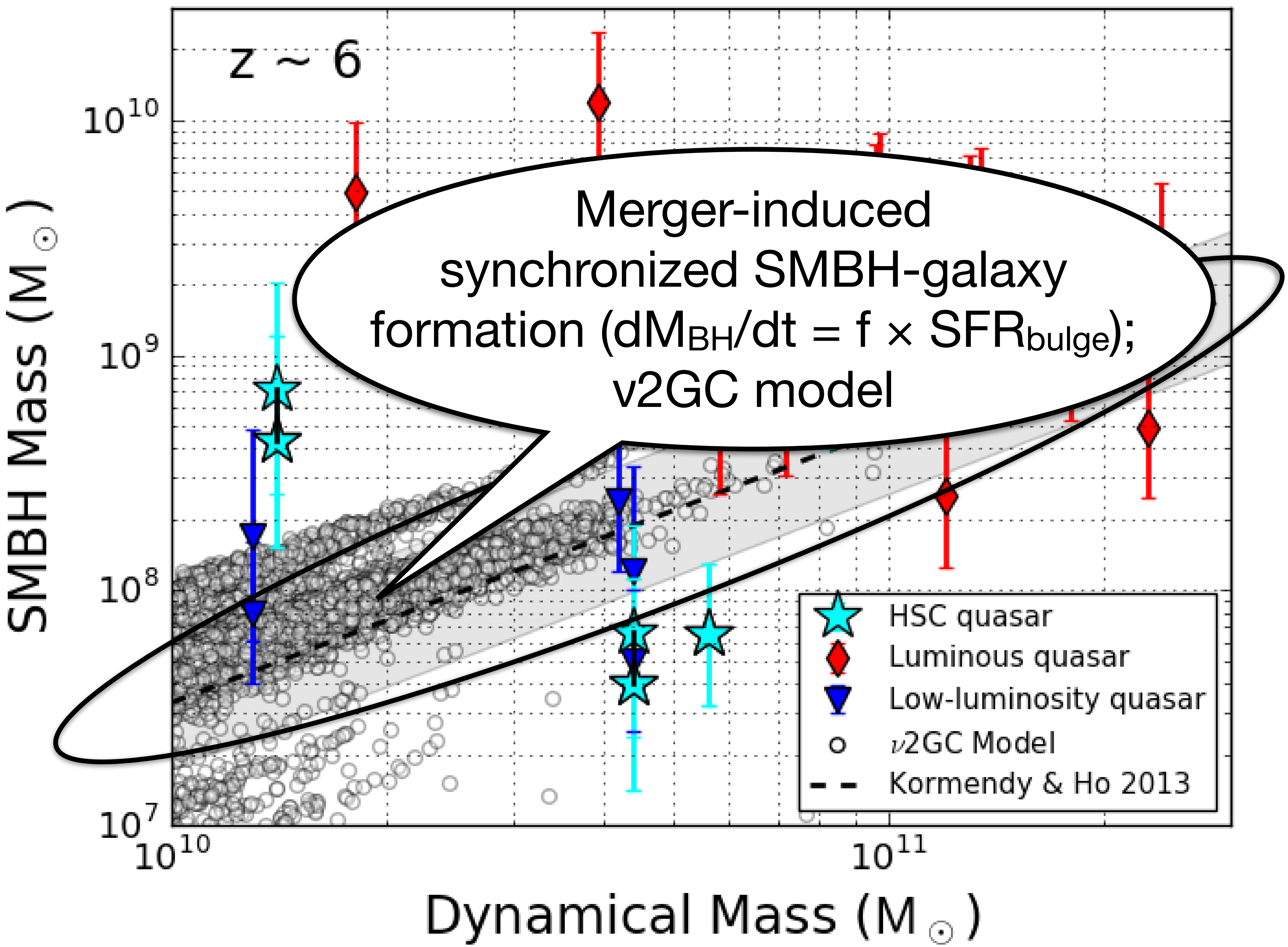
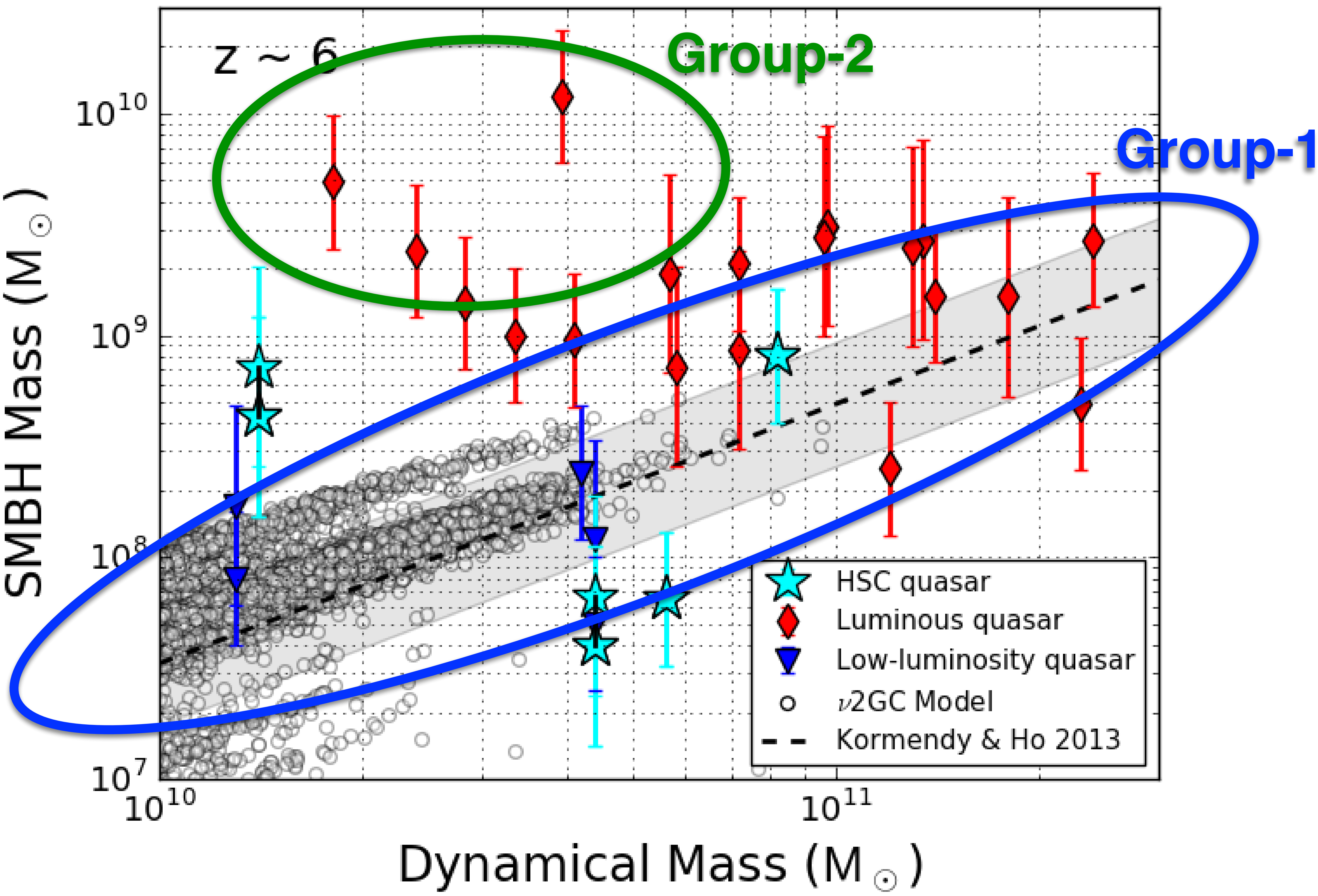
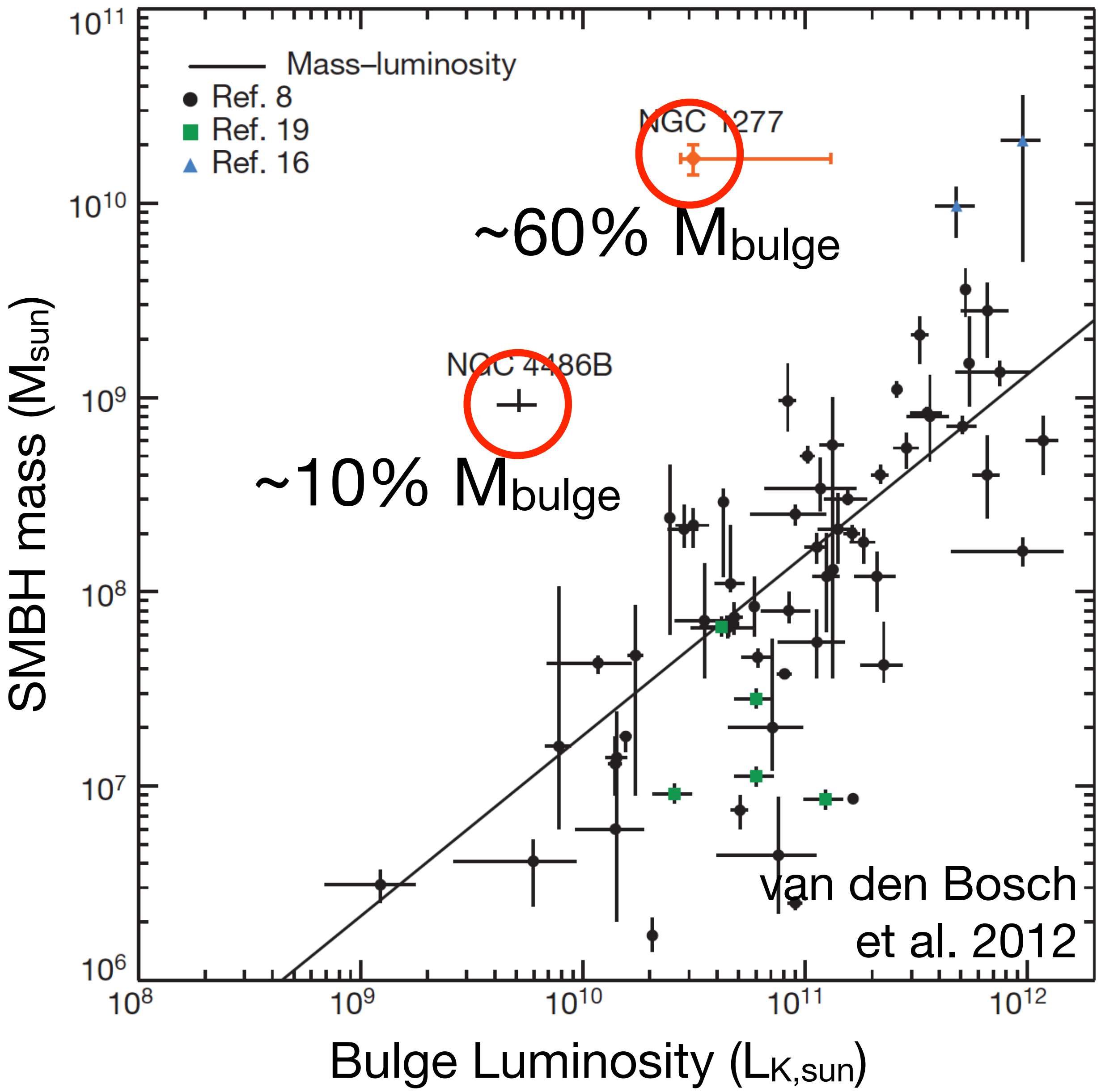


Early co-evolution in z ~6 quasars



Early co-evolution in z ~6 quasars



Group-1

- Roughly follow the local relation → merger-induced, synchronised SMBH-galaxy evolution model may explain (although many of them must live in quite massive halos)

Group-2

- Quite hard to reproduce with the ν2GC scheme; another scheme
- Appear as over-massive M_{BH} at z ~ 0 as well?

Summary

- ALMA follow-up of four low-luminosity HSC quasars at $z > 6$.
- LIRG-like FIR properties (L_{FIR}, $L_{[CII]}$, M_{dust}) in their hosts.
  - SFR ~ 20-40 M_{sun}/yr
  → Clear contrasts to those of the previously discovered quasar-hosts (~ULIRG/SMG-class star formation)
- The HSC quasars are on or below the MS at $z \sim 6$
  → Rapid transition phase to quiescent galaxies?
- Low-luminosity quasars follow the local co-evolutionary relations
- Adding lower-luminosity (lower-mass) quasars enhances the likely existence of two quasar populations,
  (i) those roughly following the local relation ← standard model :)
  (ii) those showing clear enhancement in M_{BH} ← another scheme?