

East-Asia AGN Workshop 2017
Dec. 4-6, 2017 @Kagoshima University, Japan

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

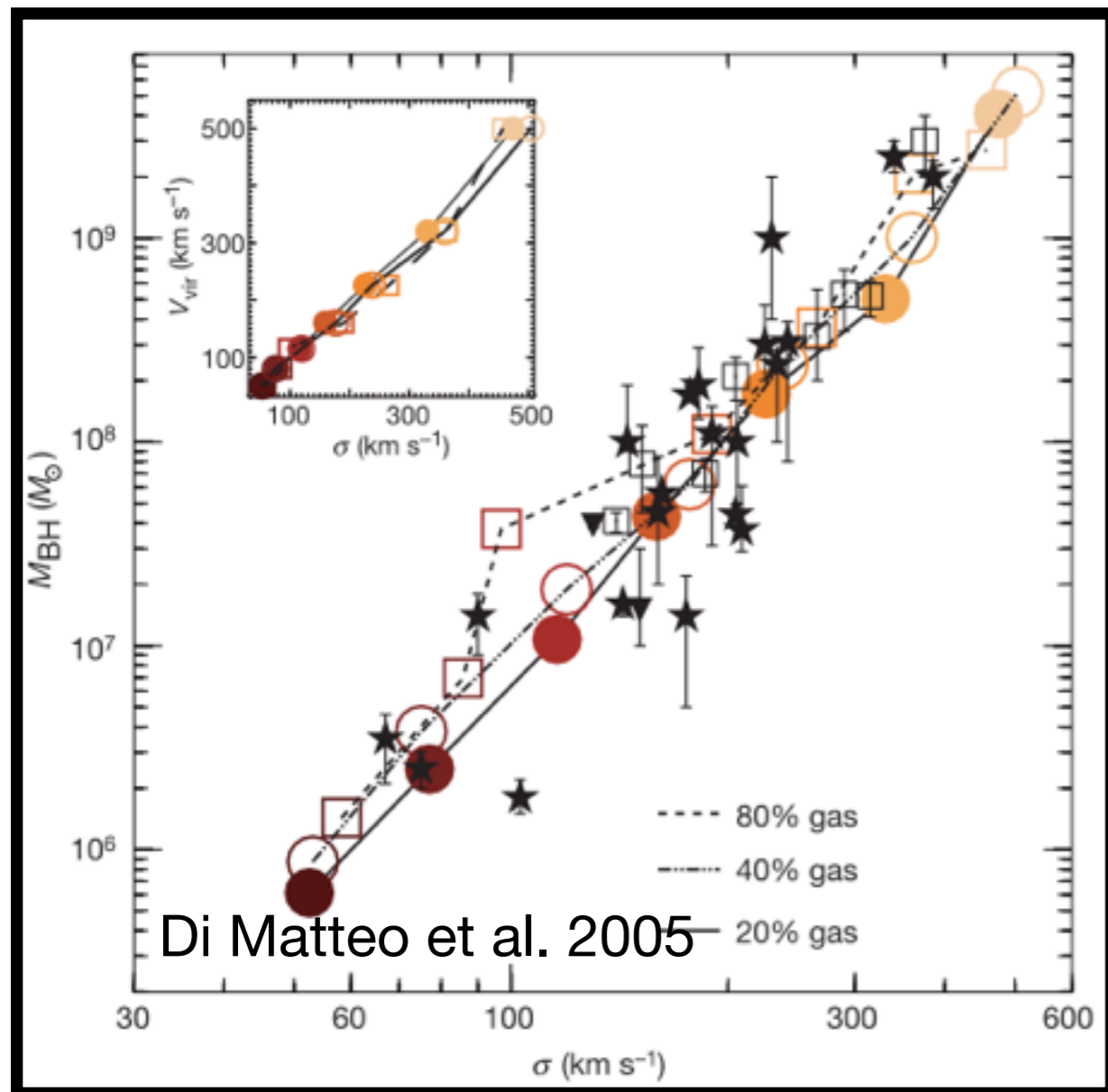
Takuma Izumi
(NAOJ Fellow)

→ *Izumi et al. to be submitted*

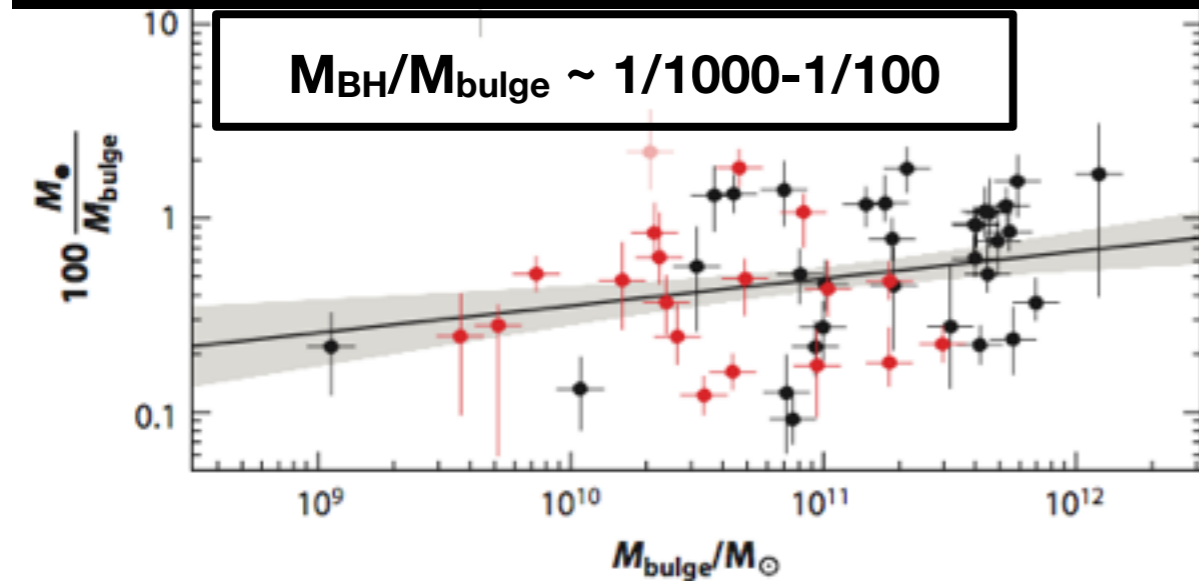


Co-evolution of SMBH and galaxy

2

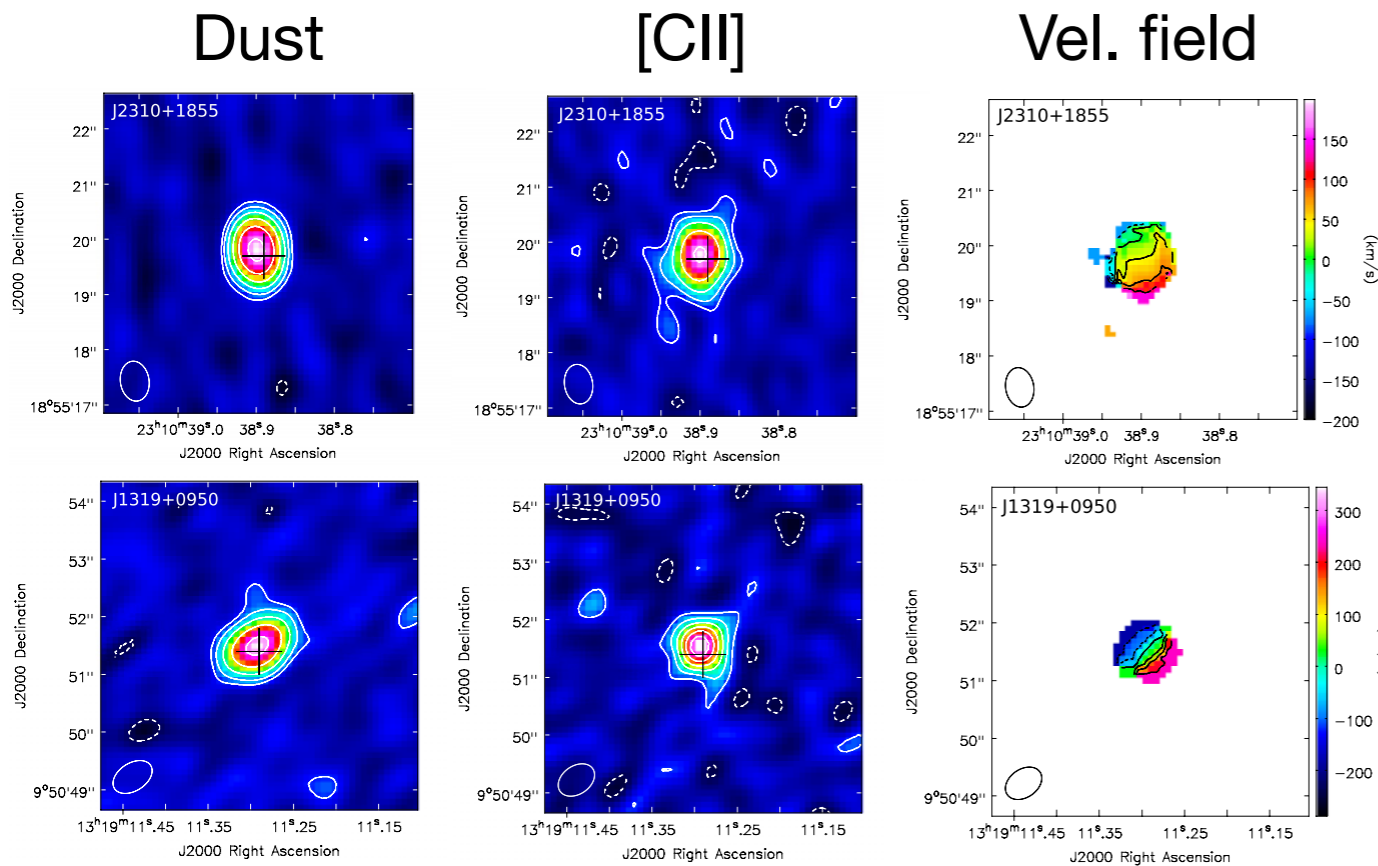


- M_{BH} is tightly correlated with M_{bulge} and σ^* → **Co-evolution**
- Favoured scenario: Merger-induced starburst & AGN, and subsequent “AGN feedback” to regulate the star formation (e.g., Hopkins et al. 2008; Fabian 2012, ARA&A, 50, 455)
- **When, how, and where the relation has arisen?**



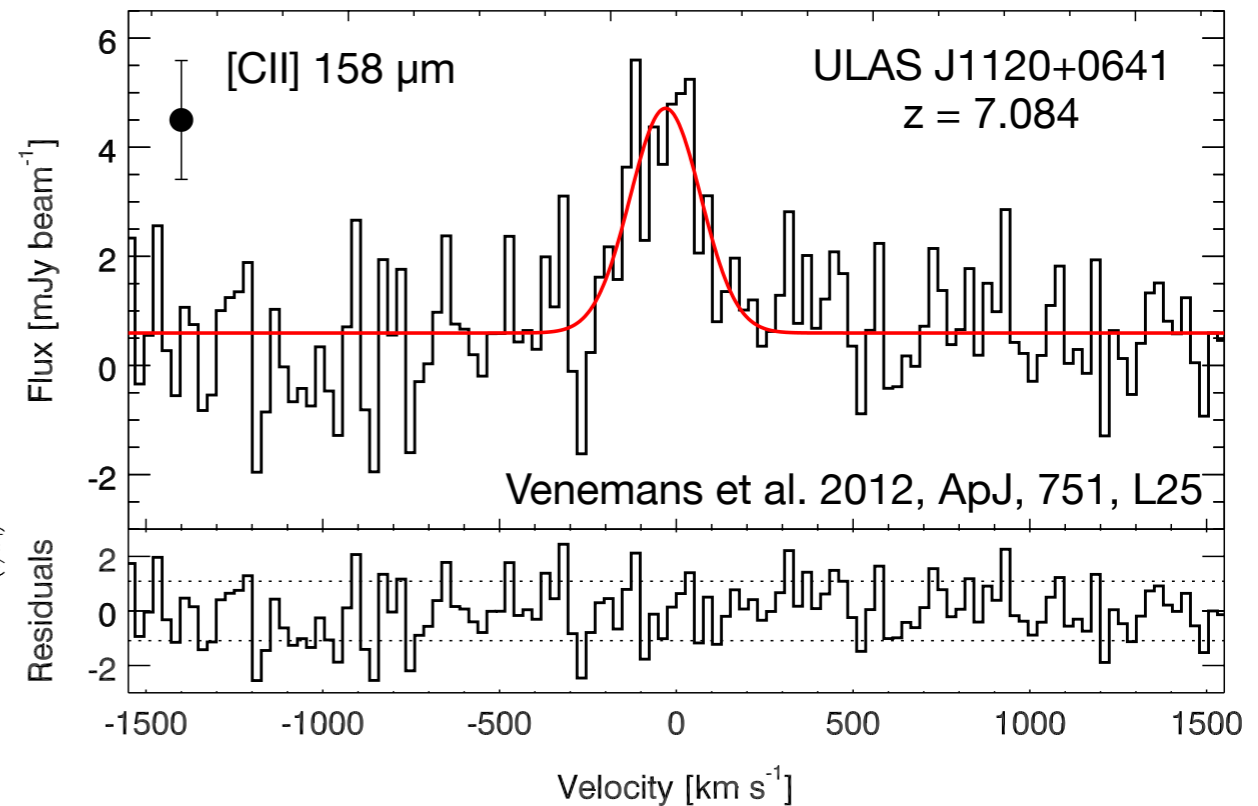
Reveal (i) SMBH feeding/feedback and (ii) galaxy growth over the cosmic time

Host galaxy properties of high-z quasars ³



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

- Luminous quasars at $z > \sim 6$ ($L_{\text{Bol}} > 10^{14} L_{\text{sun}}$)
- ULIRG/SMG-class star formation!
- Rapid, vigorous, and coeval SMBH and galaxy growths (SF time scale < 100 Myr)



Venemans et al. 2012, ApJ, 751, L25

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

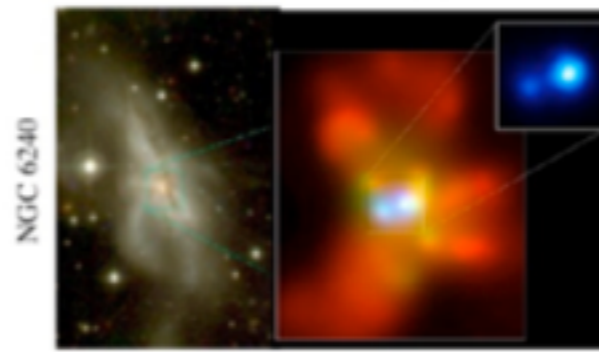
e.g., Wang et al. 2010, ApJ, 714, 699

(c) Interaction/"Merger"



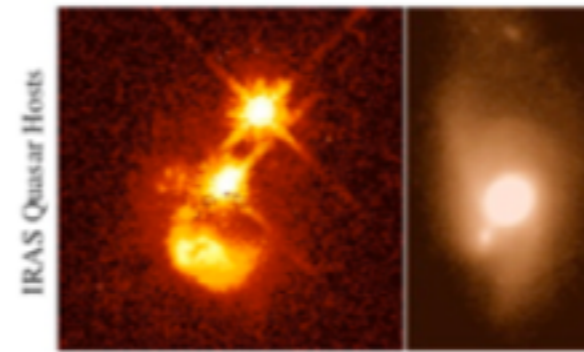
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



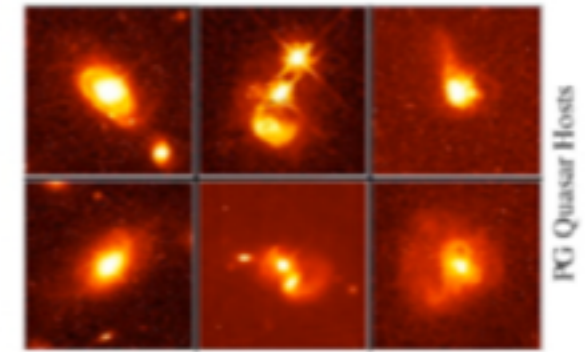
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



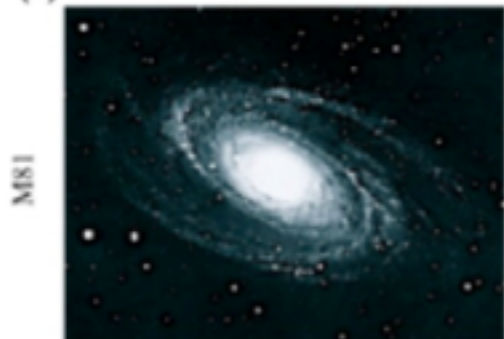
- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

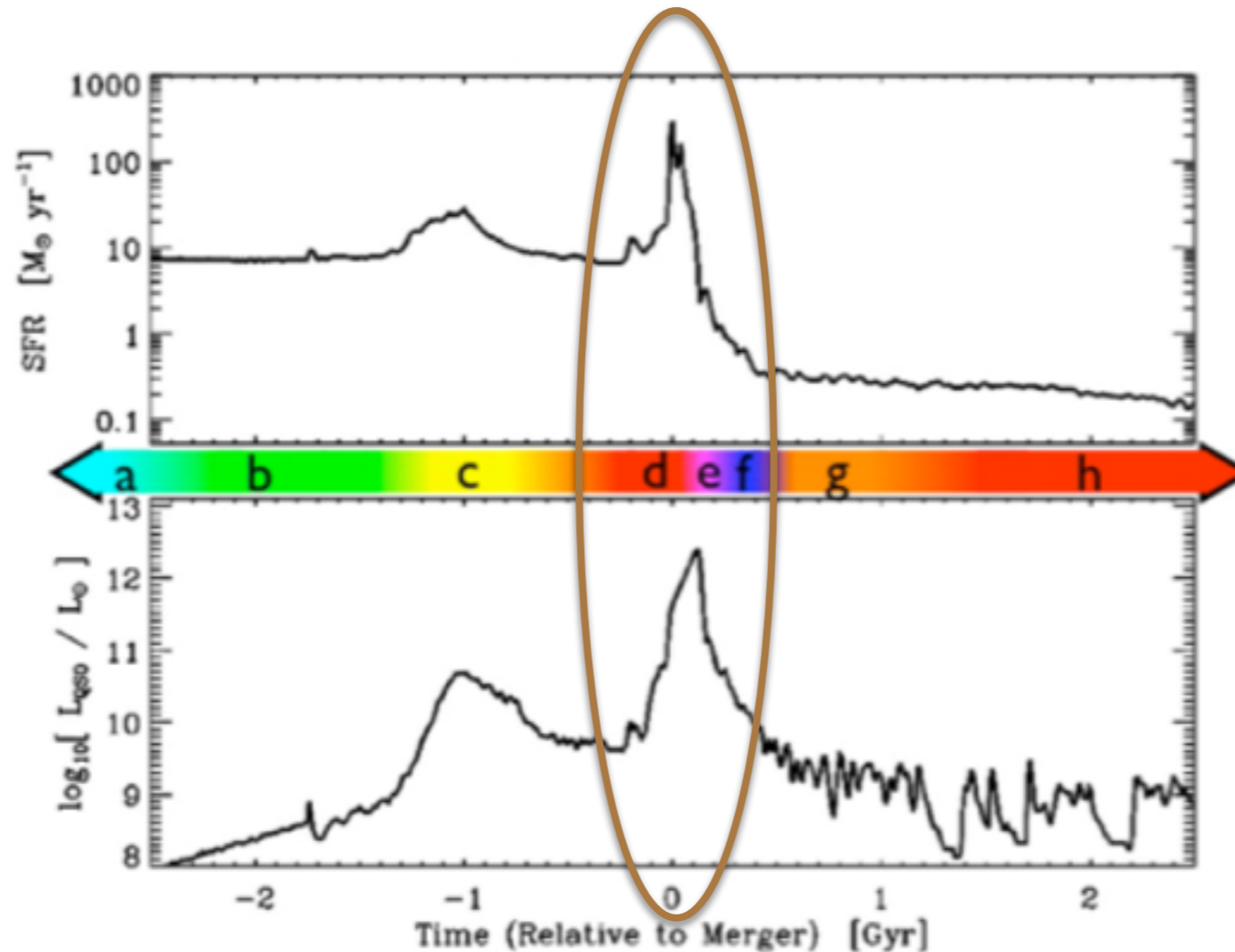


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

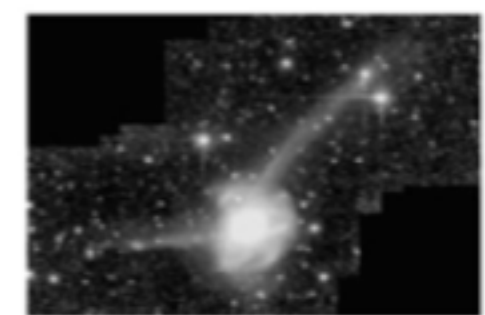
(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_{\text{BH}} > 10^6 M_{\odot}$)
- cannot redden to the red sequence



(g) Decay/K+A



- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

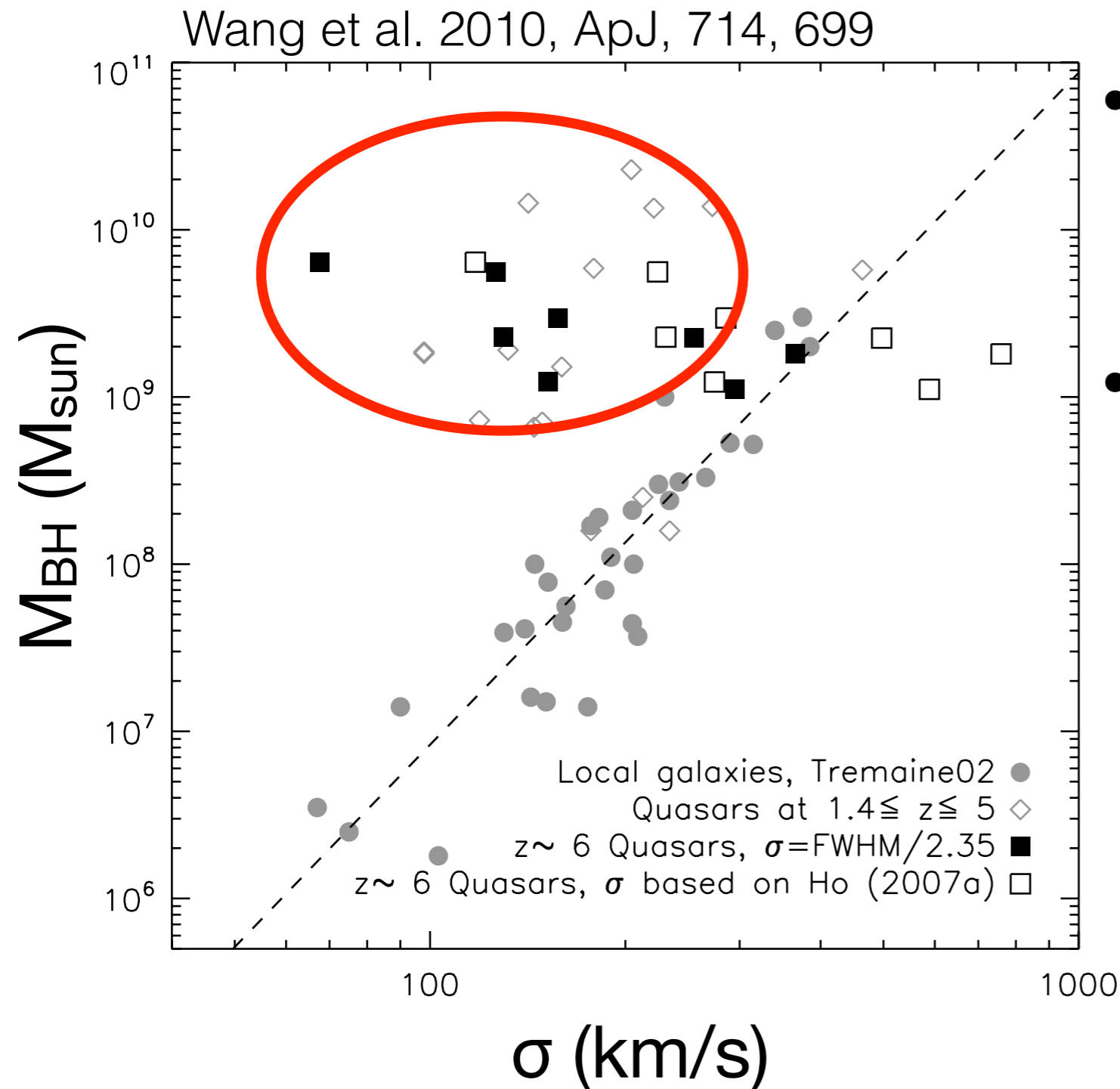
(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

Early co-evolution: likely a biased one

4



- 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 (\sim massive) objects



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

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

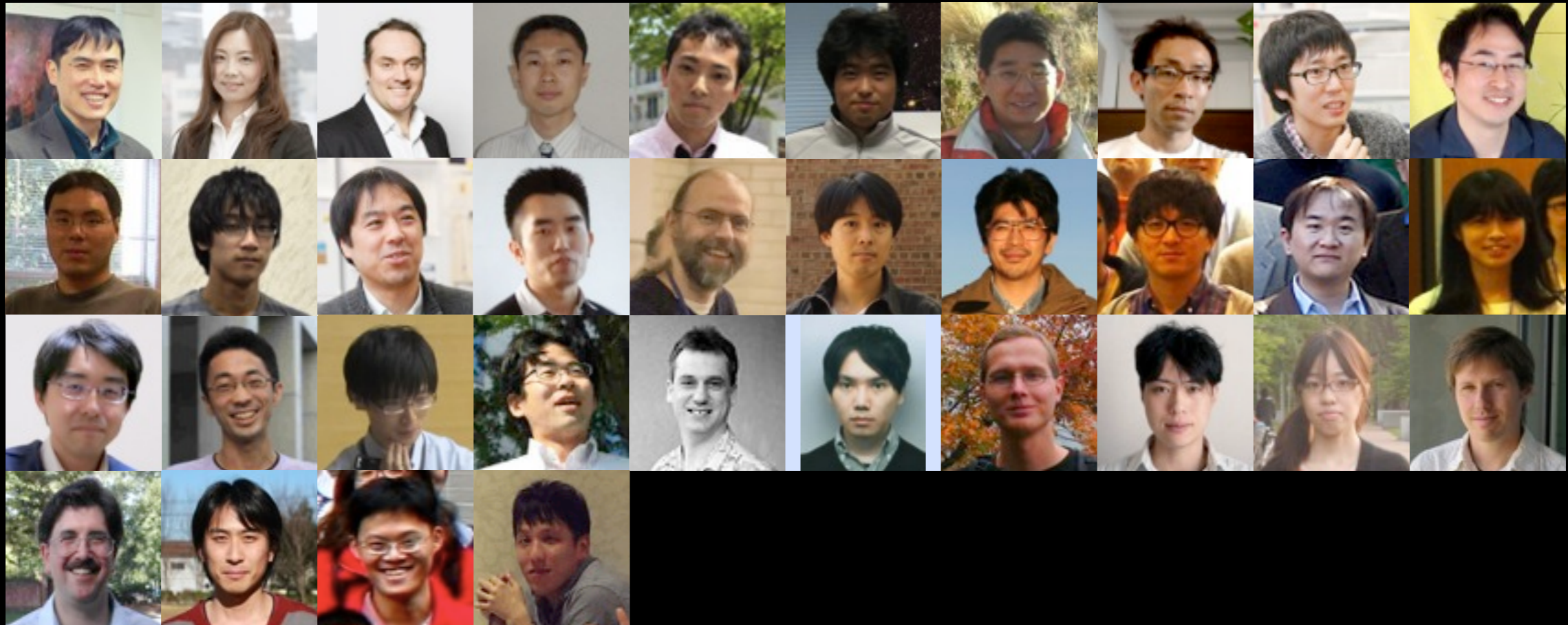
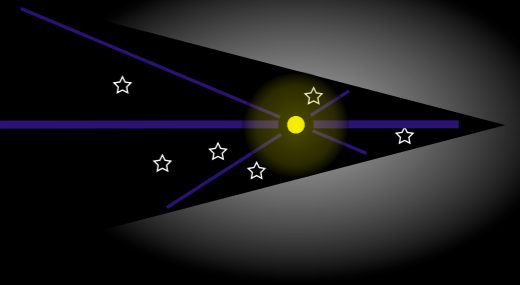
Subaru/Hyper Suprime-Cam



ALMA

SHELLQs

Subaru High-z Exploration of Low-Luminosity Quasars



Members

Y. Matsuoka¹ (PI)

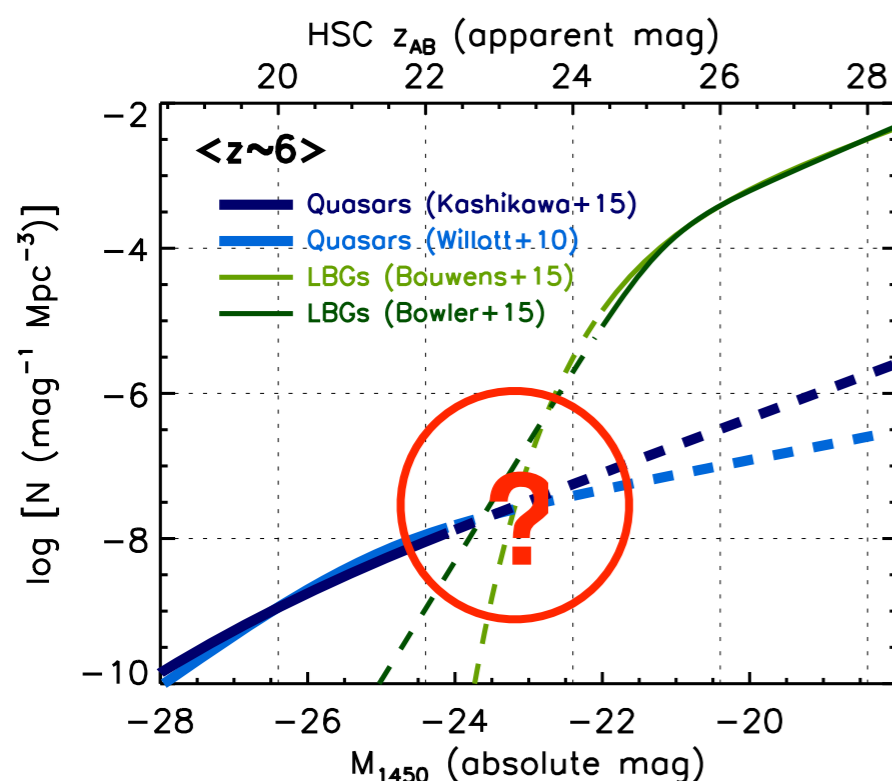
M. Akiyama², N. Asami³, S. Foucaud, T. Goto⁴, Y. Harikane⁵, H. Ikeda¹, M. Imanishi¹, K. Iwasawa⁶, T. Izumi⁵, N. Kashikawa¹, T. Kawaguchi⁷, S. Kikuta¹, K. Kohno⁵, C.-H. Lee¹, R. H. Lupton⁹, T. Minezaki⁵, T. Morokuma⁵, T. Nagao⁸, M. Niida⁸, M. Oguri⁵, Y. Ono⁵, M. Onoue¹, M. Ouchi⁵, P. Price⁹, H. Sameshima¹⁰, A. Schulze⁵, T. Shibuya⁵, H. Shirakata¹¹, J. D. Silverman⁵, M. A. Strauss⁹, M. Tanaka¹, J. Tang¹², Y. Toba⁸

¹NAOJ, ²Tohoku, ³JPSE, ⁴Tsinghua, ⁵Tokyo, ⁶Barcelona, ⁷Sapporo Medical, ⁸Ehime, ⁹Princeton, ¹⁰Kyoto Sangyo, ¹¹Hokkaido, ¹²ASIAA

ALMA Cycle 4 observations

7

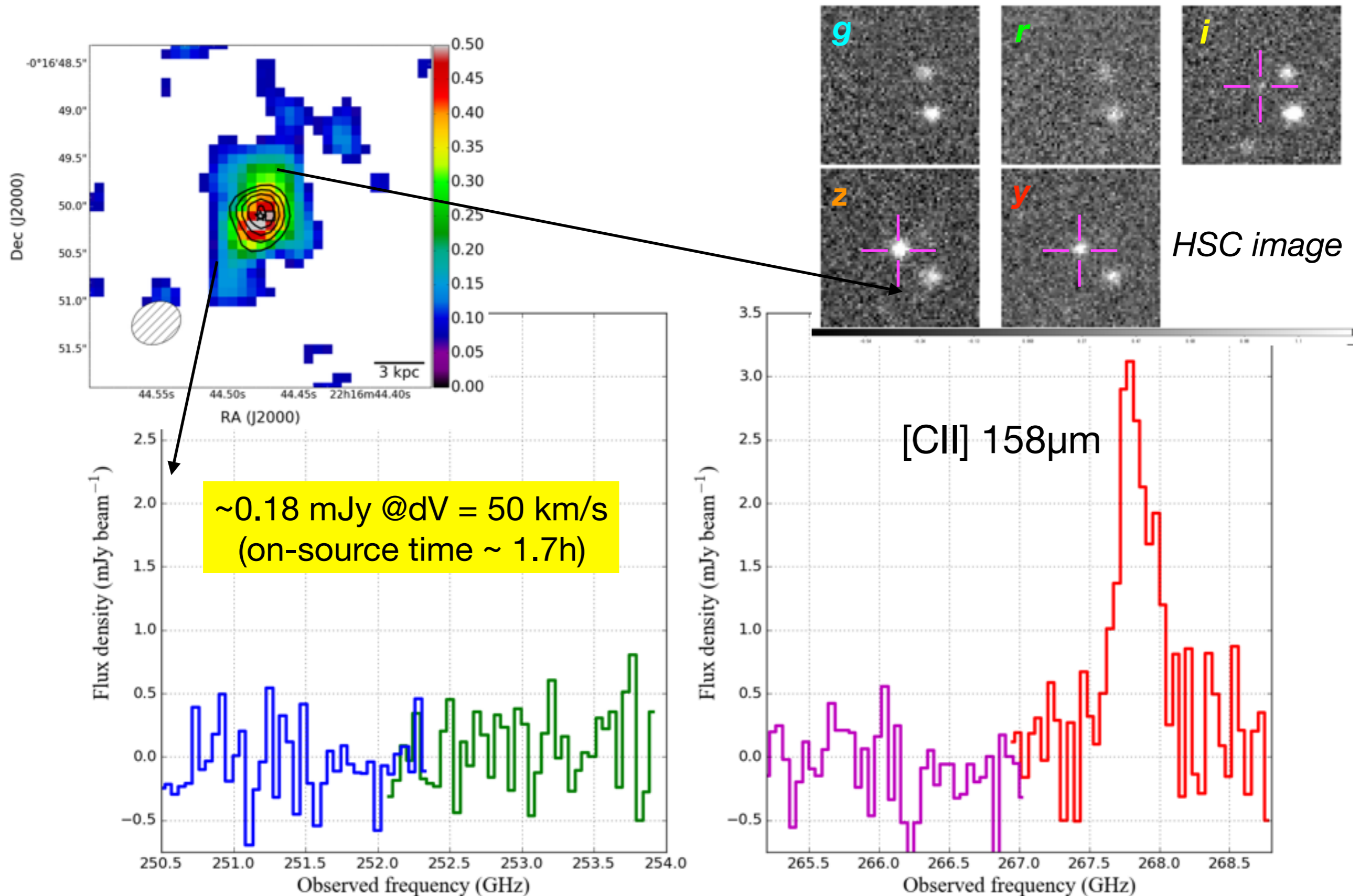
Quasar	z_{opt}	M_{1450}	L_{Bol} (L_{sun})	BAL	θ ([CII])	1σ (mJy/b), $dV=50$ km/s	1σ (μ Jy/b): cont.
J0859+0022	6.39	-23.56	$3.9E+12$	N	$0.64'' \times 0.47''$	0.12	9.5
J1152+0055	6.37	-24.91	$1.4E+13$	N	$0.52'' \times 0.47''$	0.24	20.7
J2216-0016	6.10	-23.56	$3.9E+12$	Y	$0.54'' \times 0.43''$	0.18	13.2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



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

Band 6 full spectrum: J2216 (example)

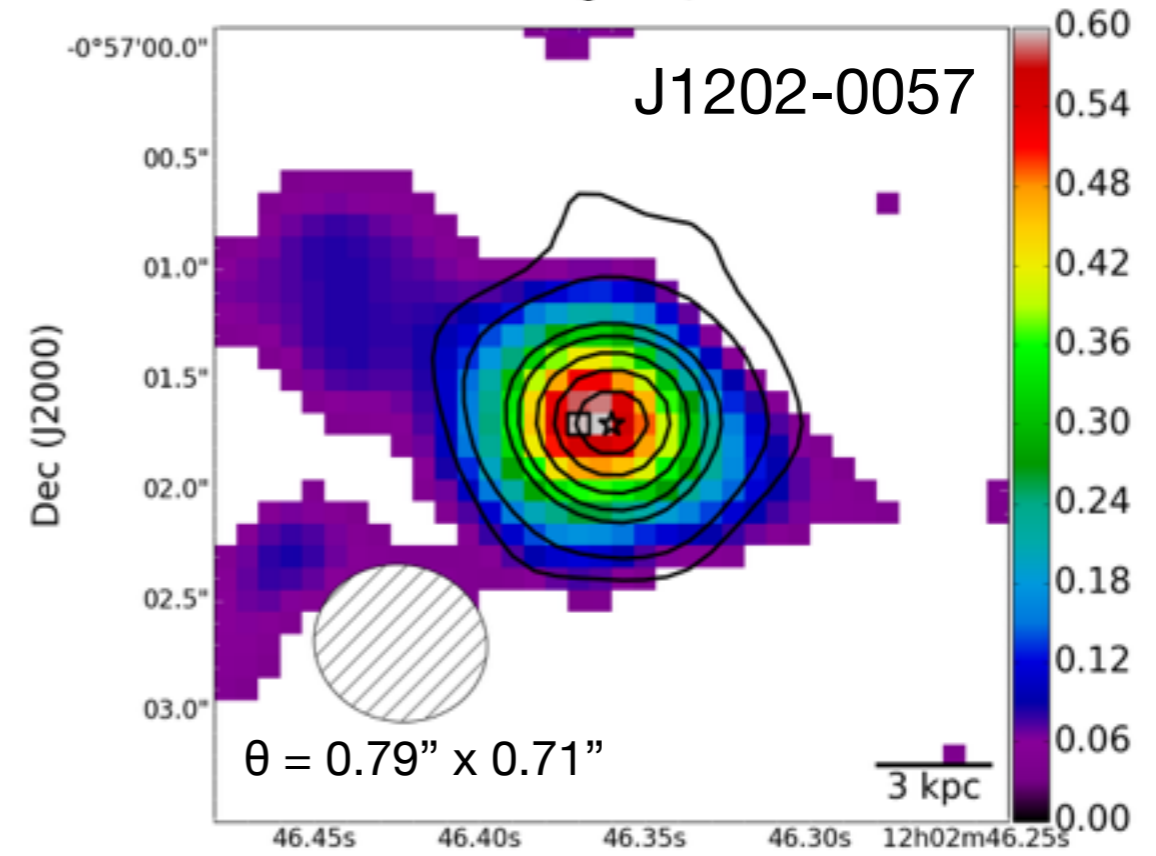
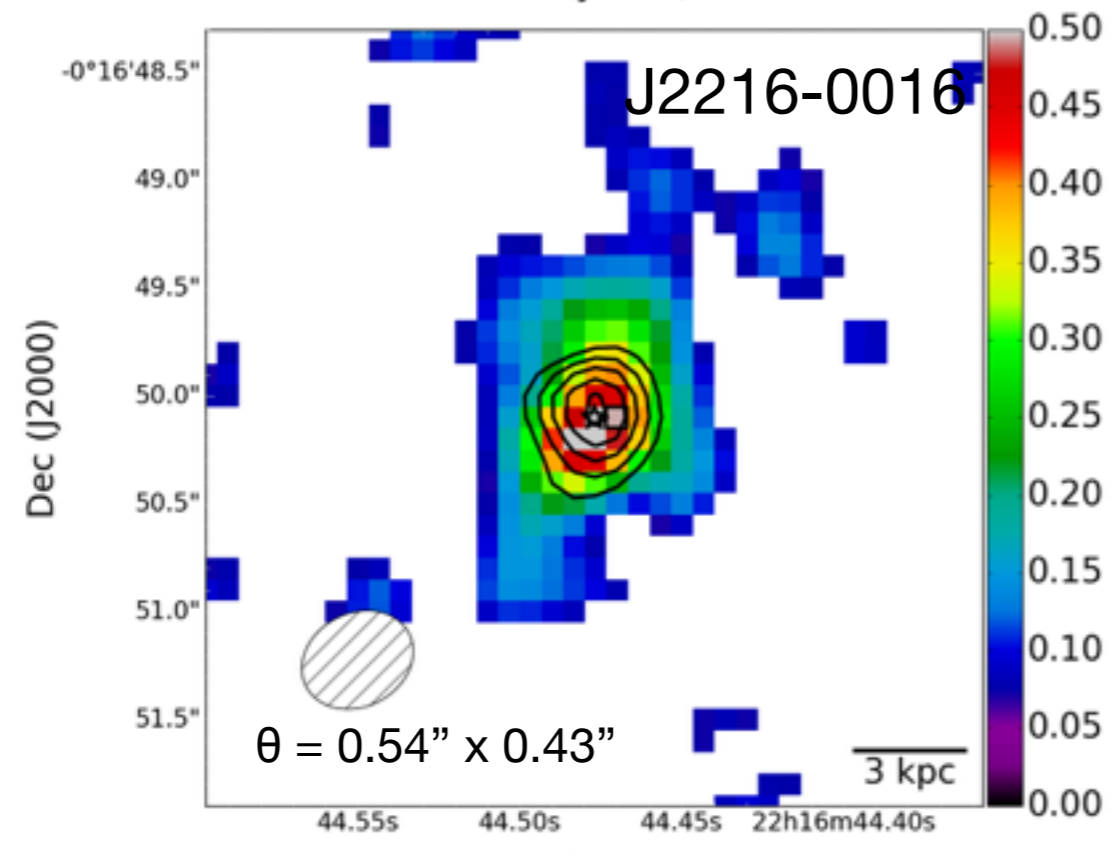
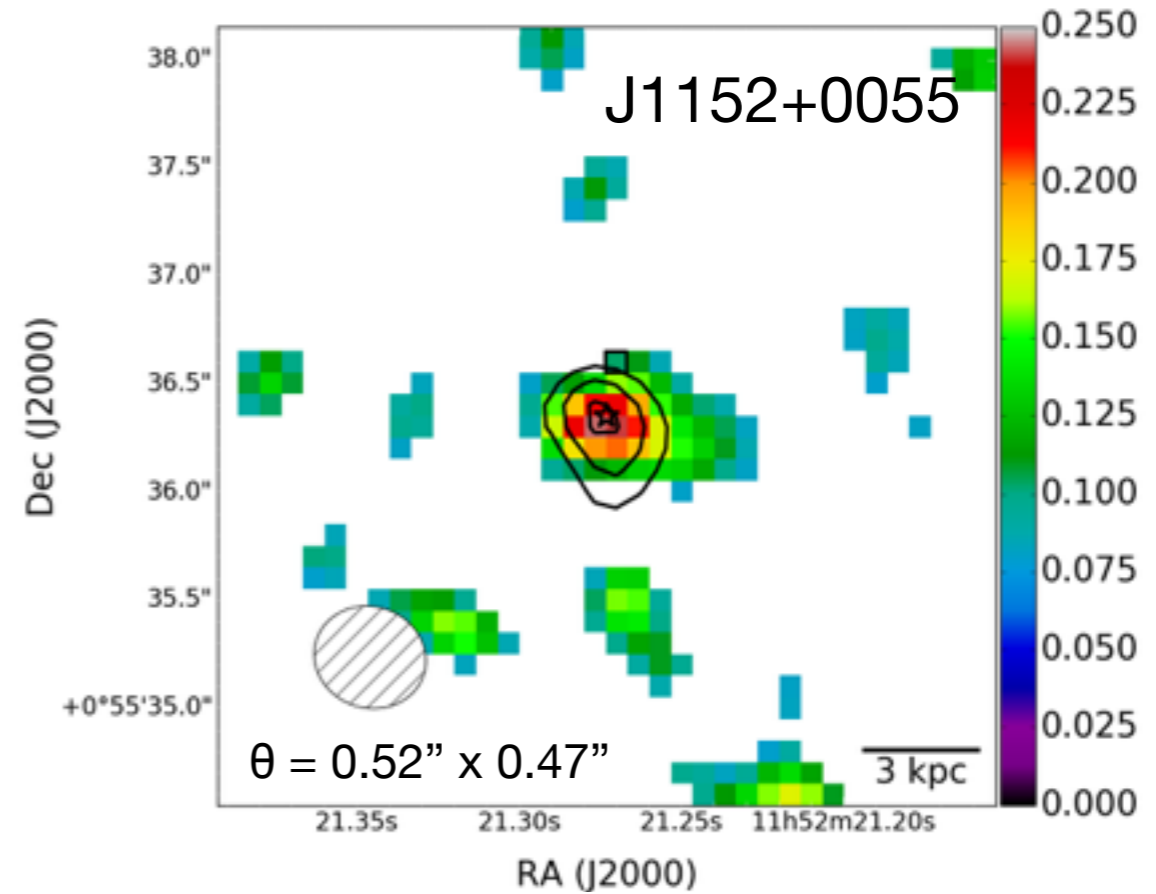
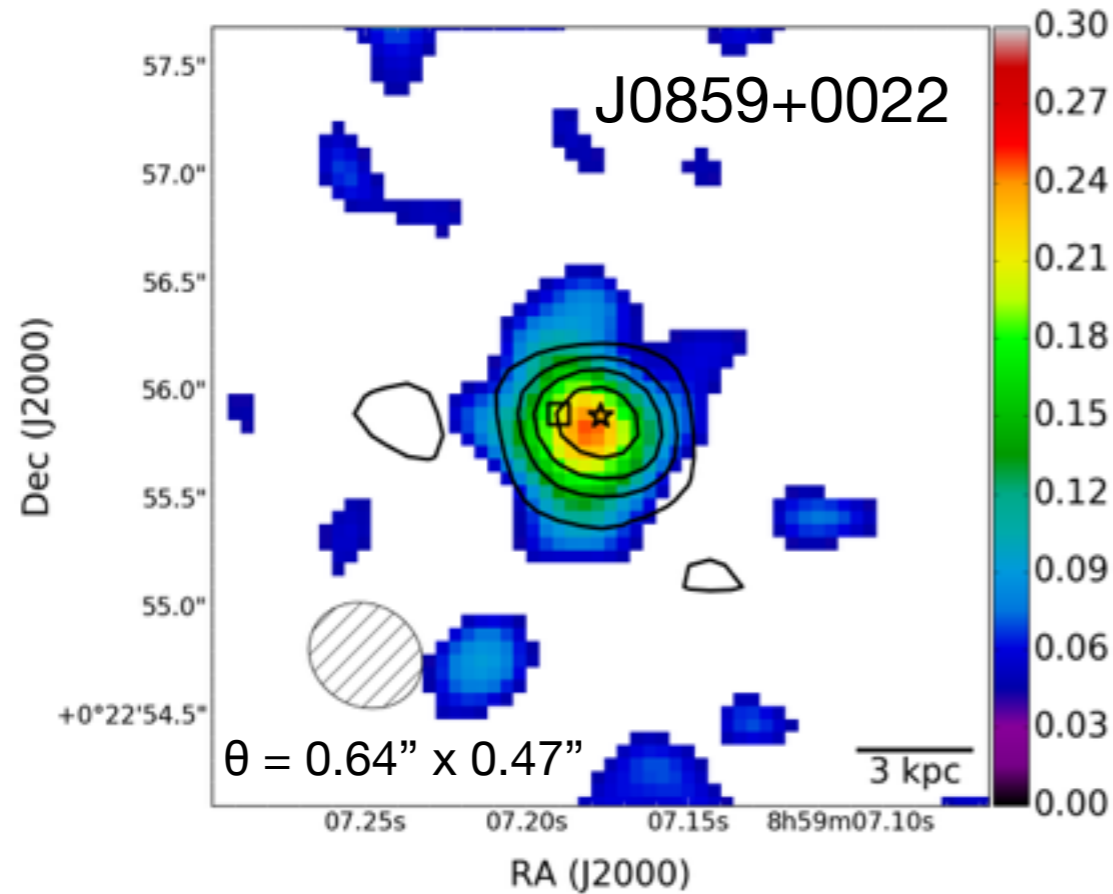
8



Results: Spatial distribution

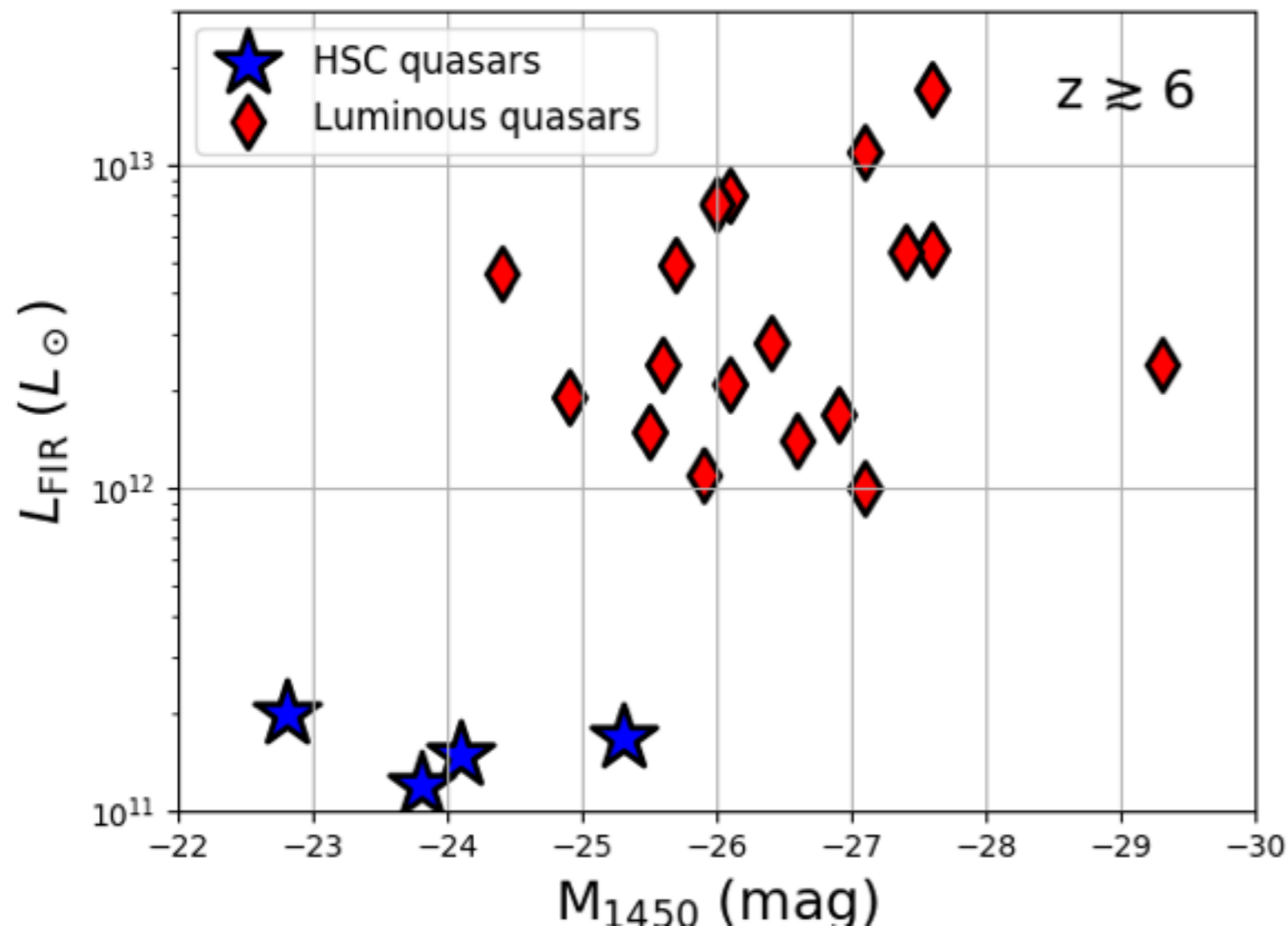
Color = [CII]
Contour = FIR continuum

9



FIR properties of the HSC-quasars

10

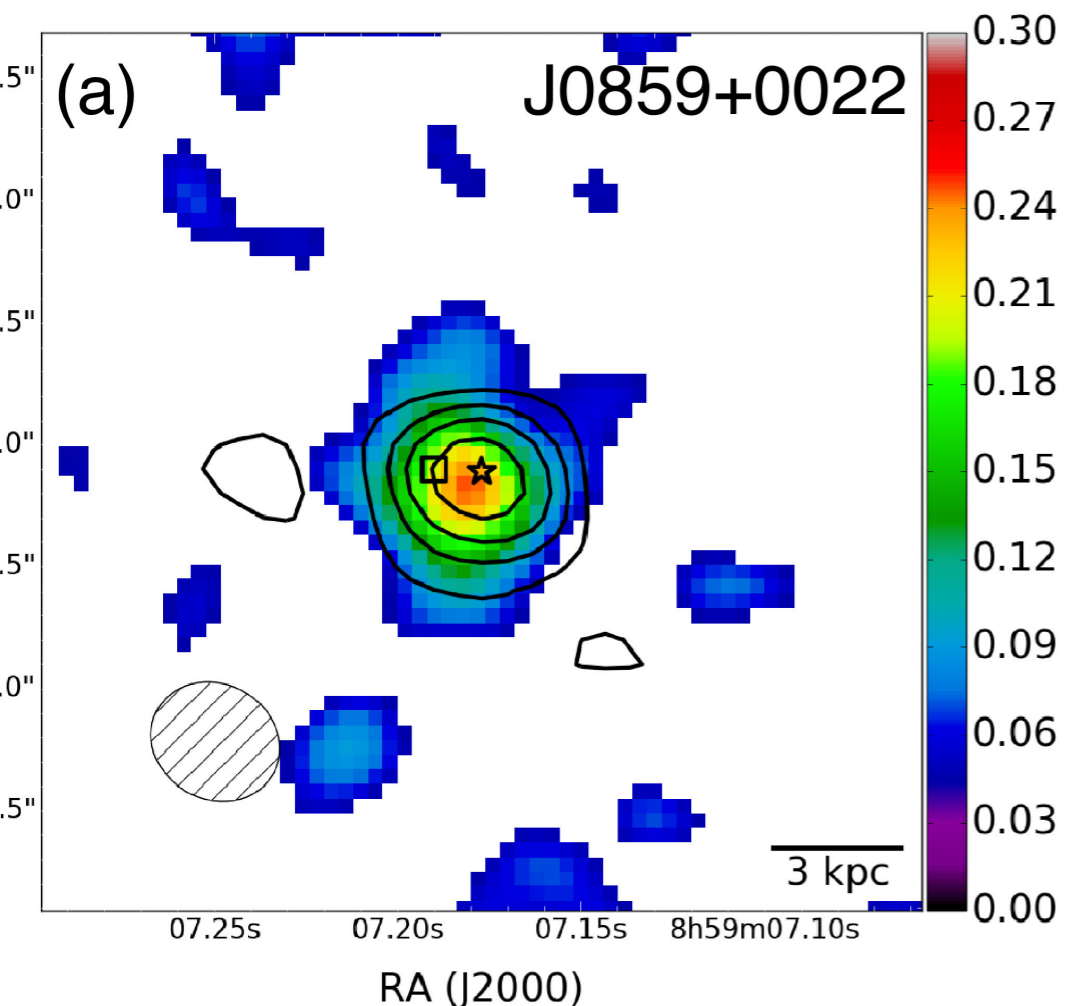


	M_{dust} ($10^7 M_{\text{sun}}$)	SFR_{IR} (M_{sun}/yr)
J0859	5.0 ± 0.7	28 ± 4
J1152	6.0 ± 1.0	34 ± 6
J2216	4.1 ± 0.8	23 ± 5
J1202	7.1 ± 0.3	40 ± 2

- 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 @ $z > 6$

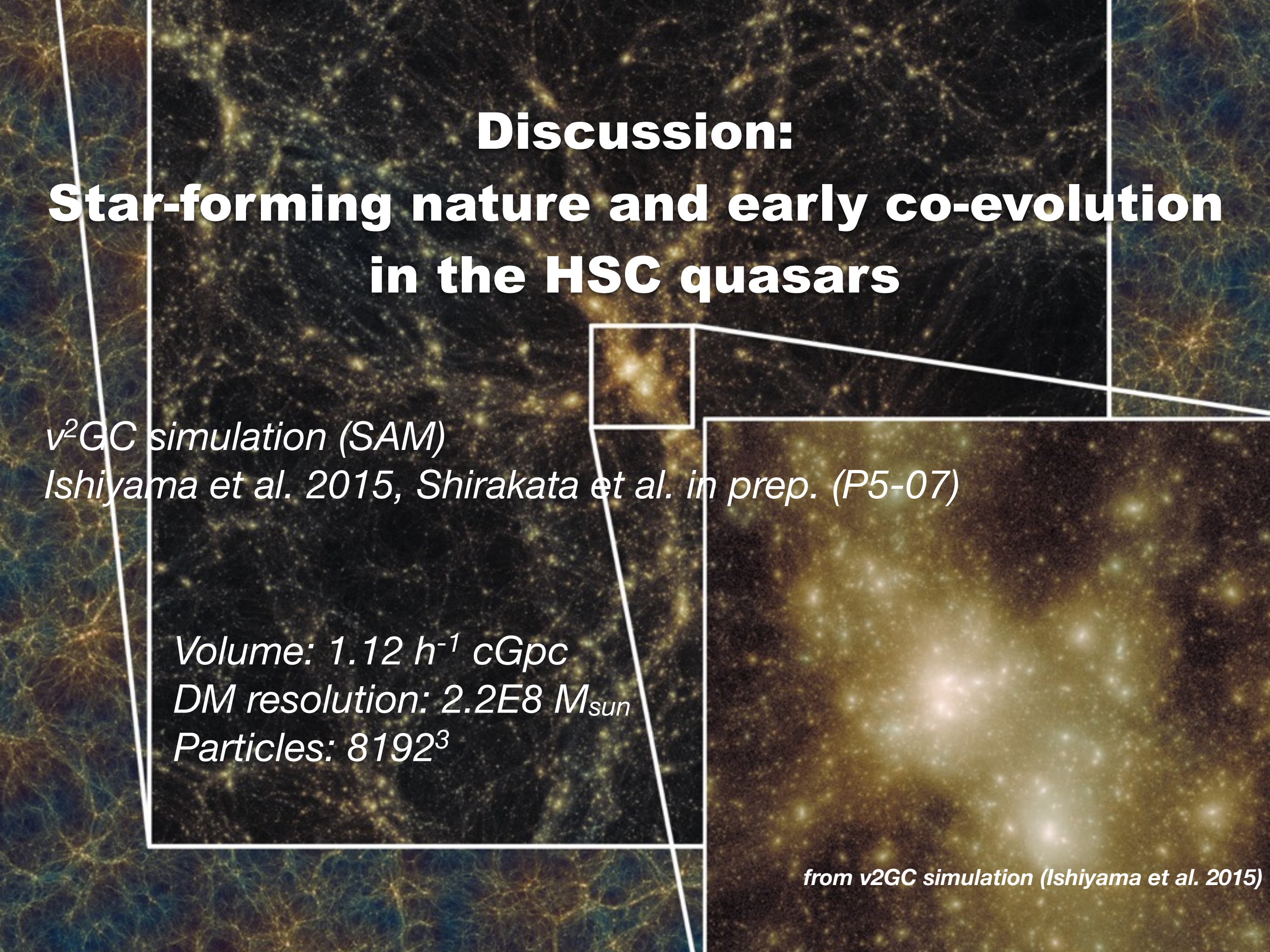
Size of the emitting region

11



Quasar	Size ([CII] FWHM)
J0859+0022	$(2.8 \pm 0.8) \text{ kpc} \times (1.8 \pm 1.0) \text{ kpc}$
J1152+0055	$(3.0 \pm 1.1) \text{ kpc} \times (1.4 \pm 0.7) \text{ kpc}$
J2216-0016	$(5.2 \pm 0.8) \text{ kpc} \times (2.5 \pm 0.7) \text{ kpc}$
J1202-0057	$(2.6 \pm 0.7) \text{ kpc} \times (1.5 \pm 1.1) \text{ kpc}$

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

A visualization of the cosmic web from a v2GC simulation. It shows a dense network of yellow and orange filaments and nodes against a dark blue background. A white rectangular box highlights a specific region, and a white line points from this box to a larger, zoomed-in view of a galaxy cluster on the right side of the image.

Discussion:

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

v²GC simulation (SAM)

Ishiyama et al. 2015, Shirakata et al. in prep. (P5-07)

Volume: $1.12 h^{-1} \text{ cGpc}$

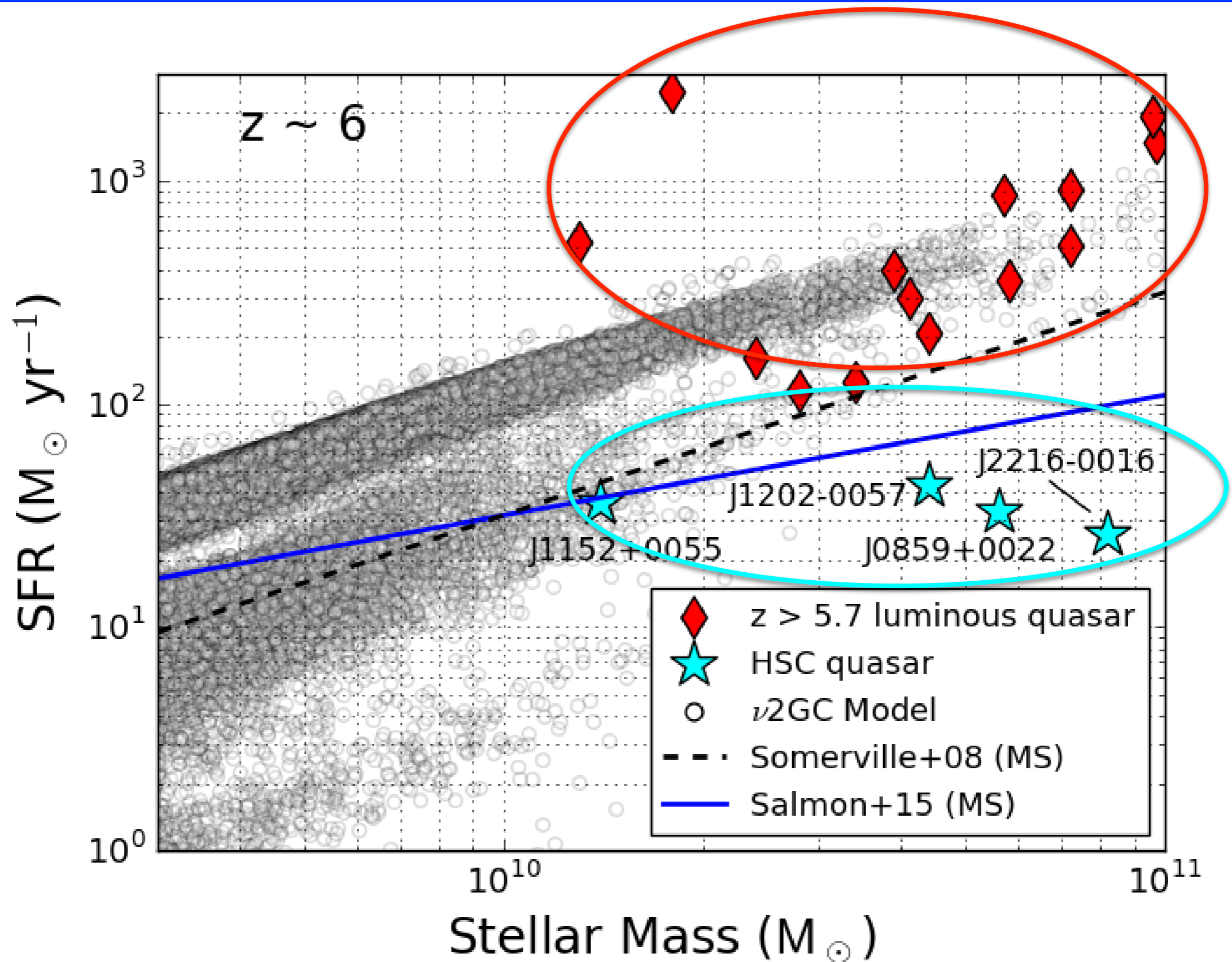
DM resolution: $2.2E8 M_{\text{sun}}$

Particles: 8192^3

from v2GC simulation (Ishiyama et al. 2015)

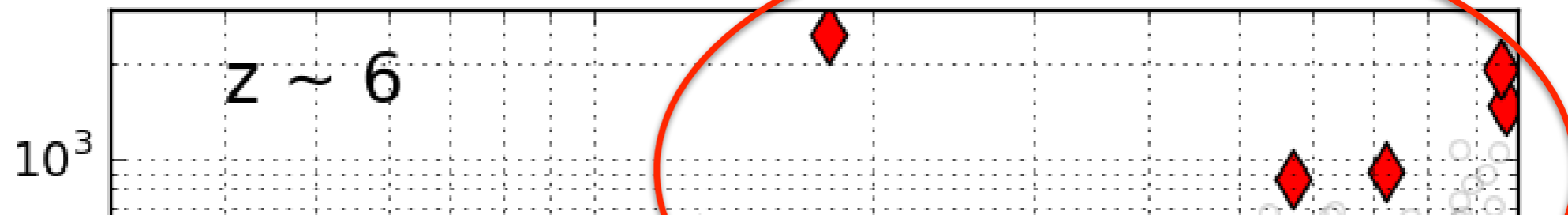
Star formation levels

13

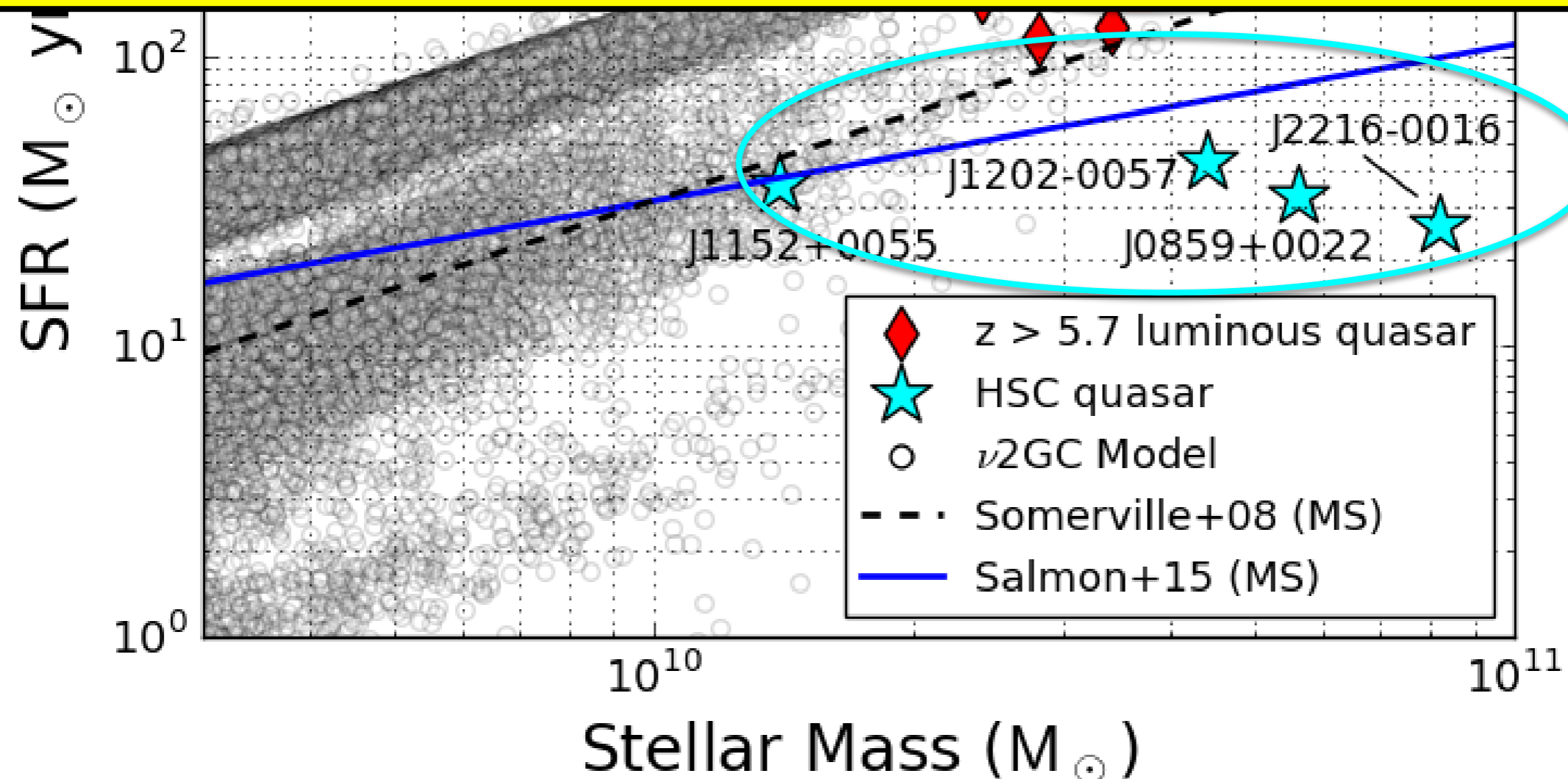


Star formation levels

13



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

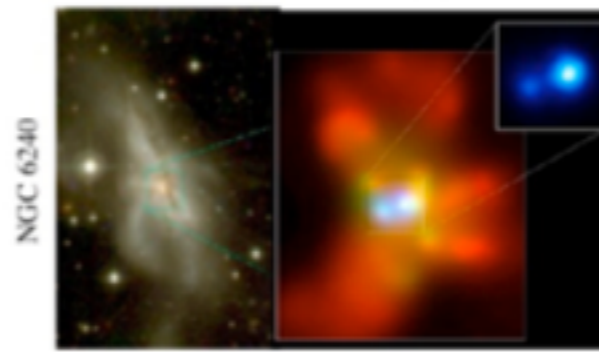


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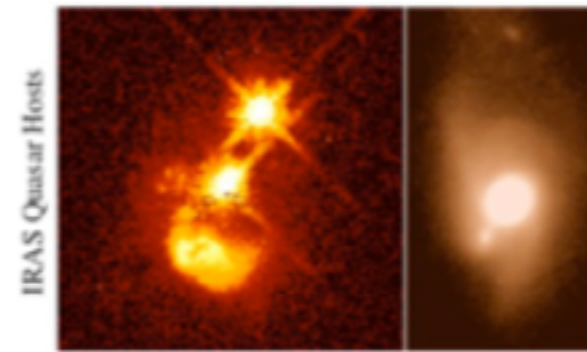
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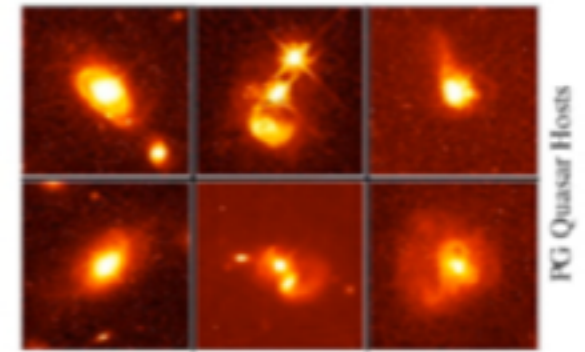
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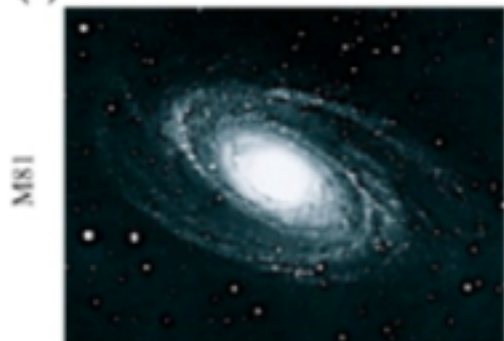
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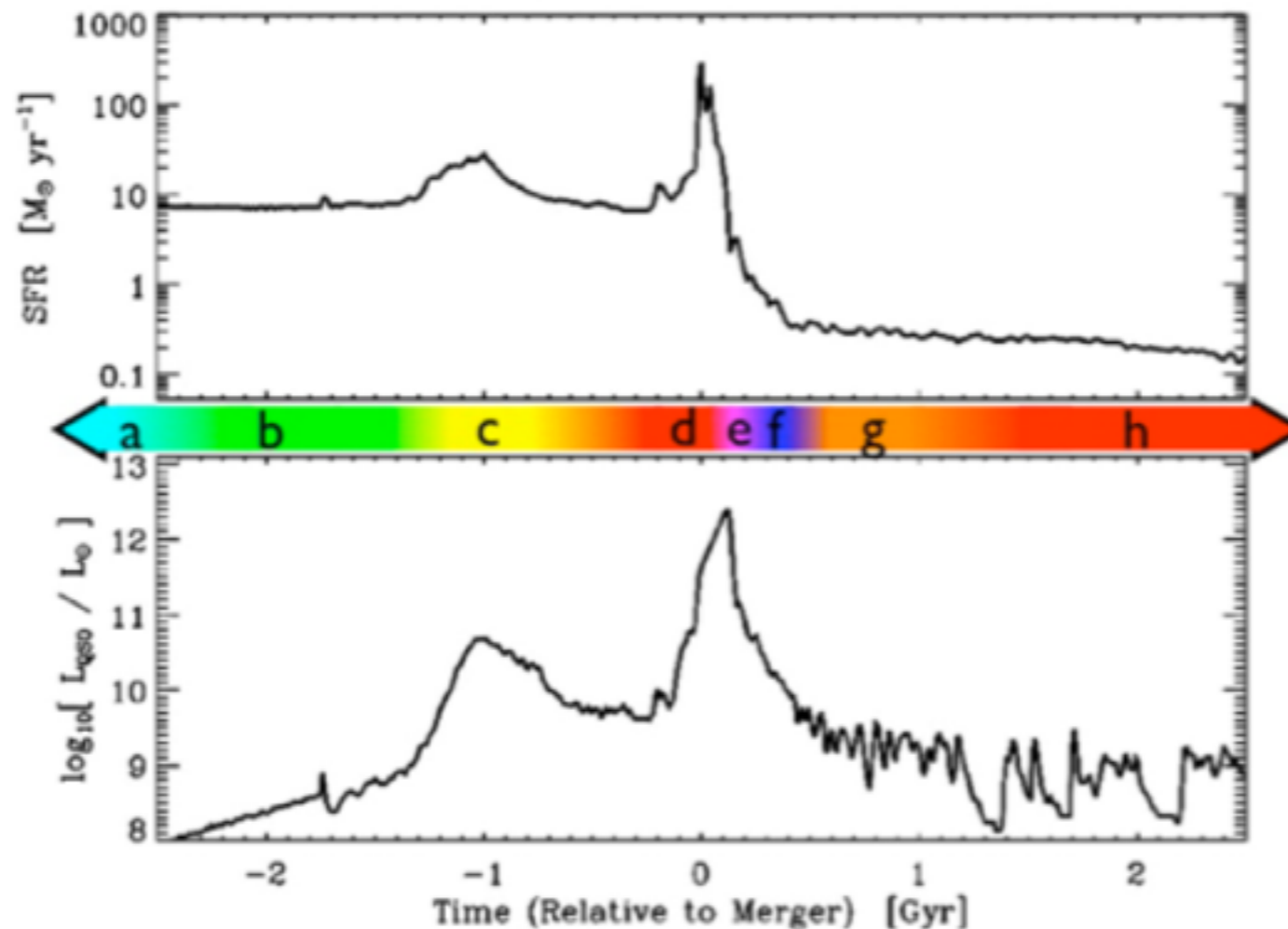


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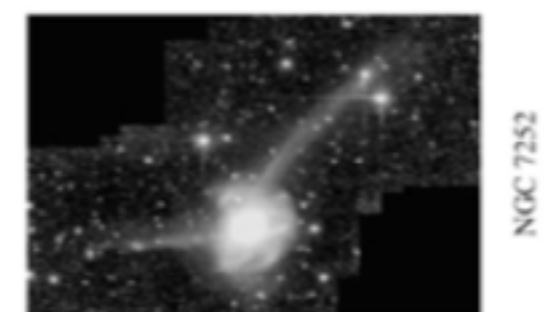
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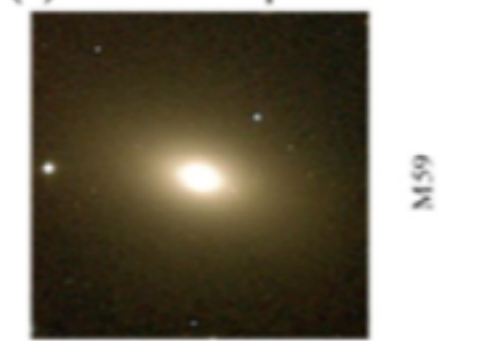


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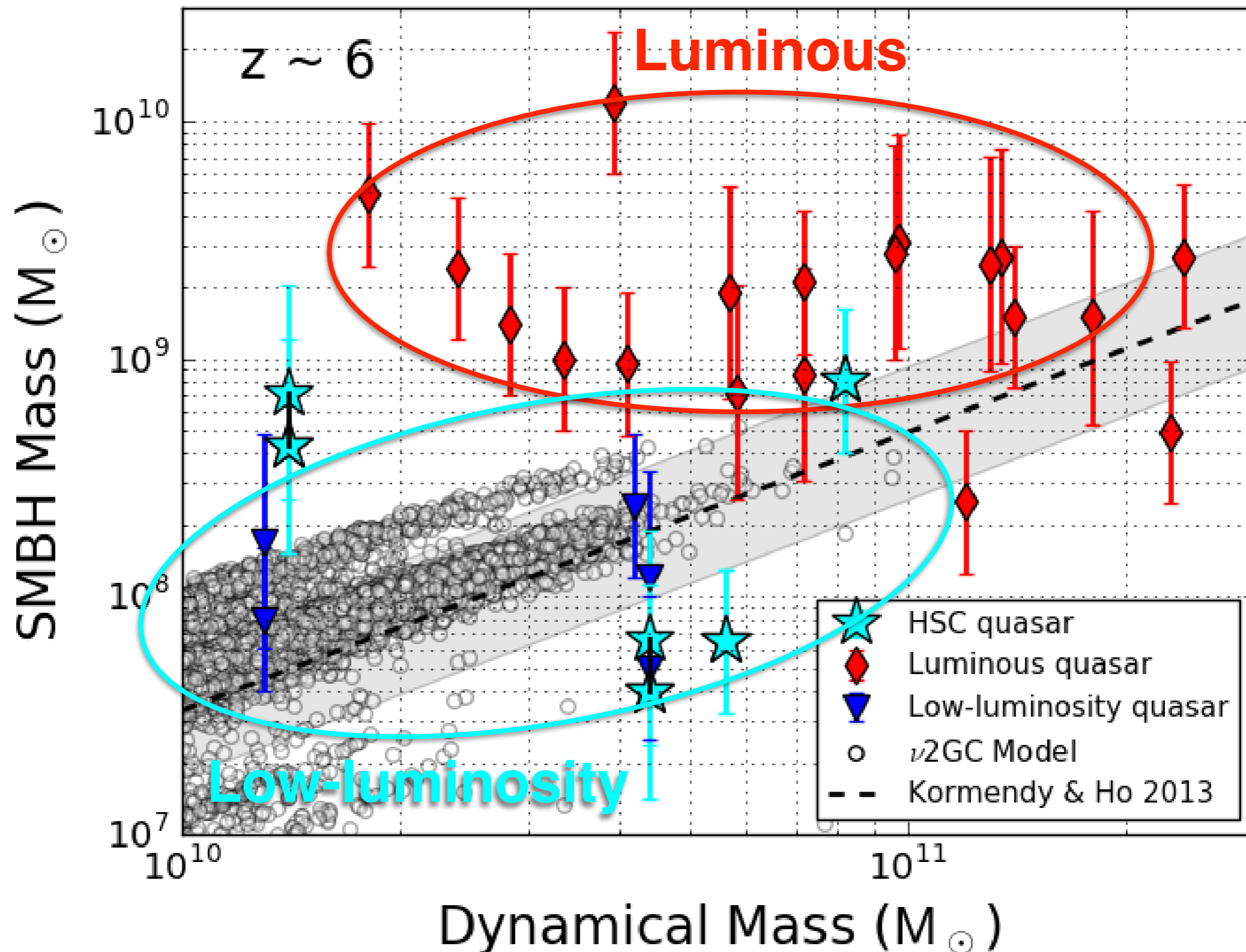
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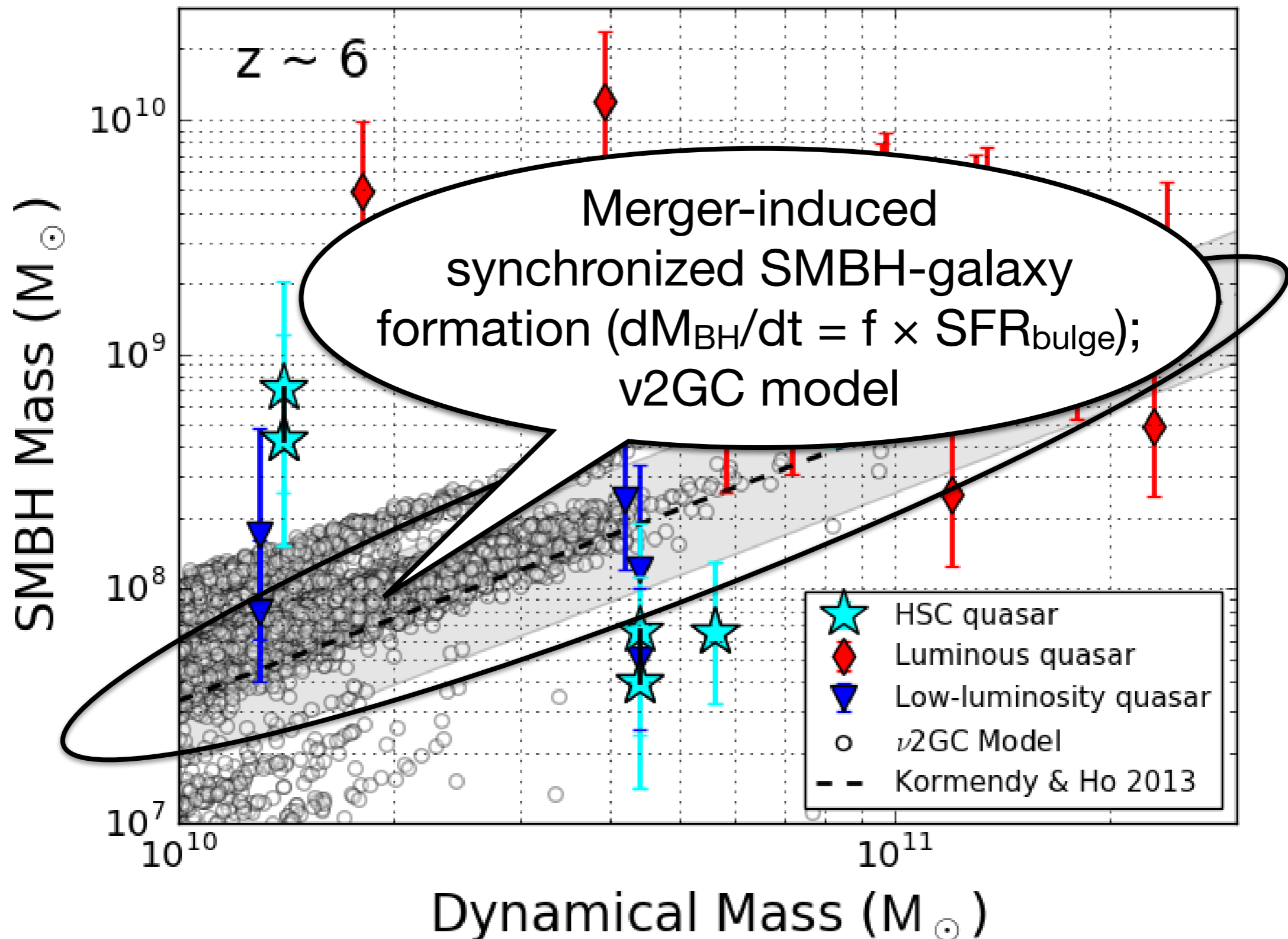
Early co-evolution in $z \sim 6$ quasars

15



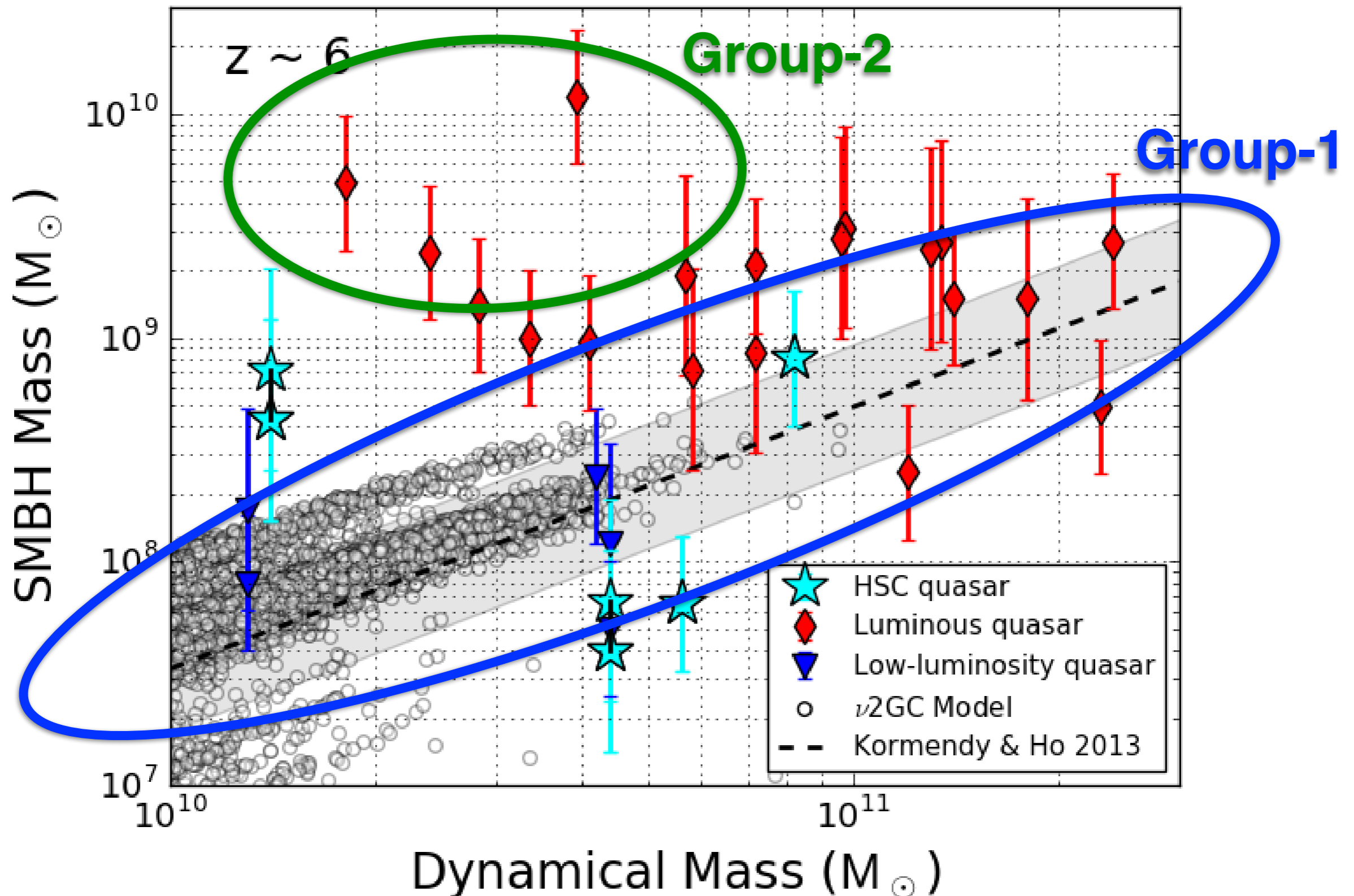
Early co-evolution in $z \sim 6$ quasars

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Early co-evolution in $z \sim 6$ quasars

17



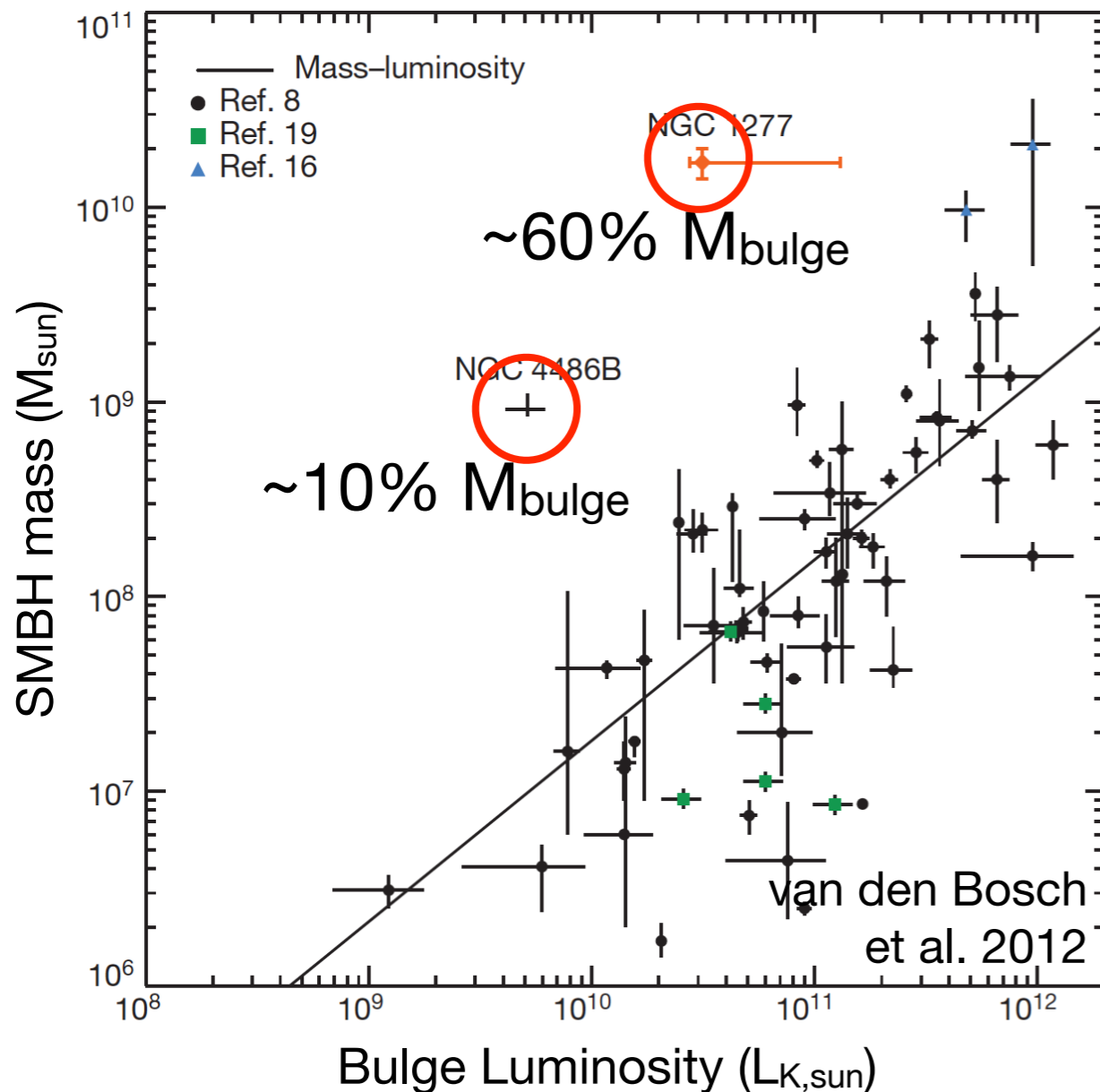
Early co-evolution in $z \sim 6$ quasars

18



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 v2GC scheme; another scheme
- Appear as over-massive M_{BH} at $z \sim 0$ as well?

- ◆ ALMA follow-up of four low-luminosity HSC quasars at $z > 6$.
- ◆ LIRG-like FIR properties (L_{FIR} , $L_{\text{[CII]}}$, M_{dust}) in their hosts.
 - SFR $\sim 20\text{-}40 M_{\text{sun}}/\text{yr}$
 - Clear contrasts to those of the previously discovered quasar-hosts (\sim 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 \leftarrow standard model :)
 - (ii) those showing clear enhancement in M_{BH} \leftarrow another scheme?