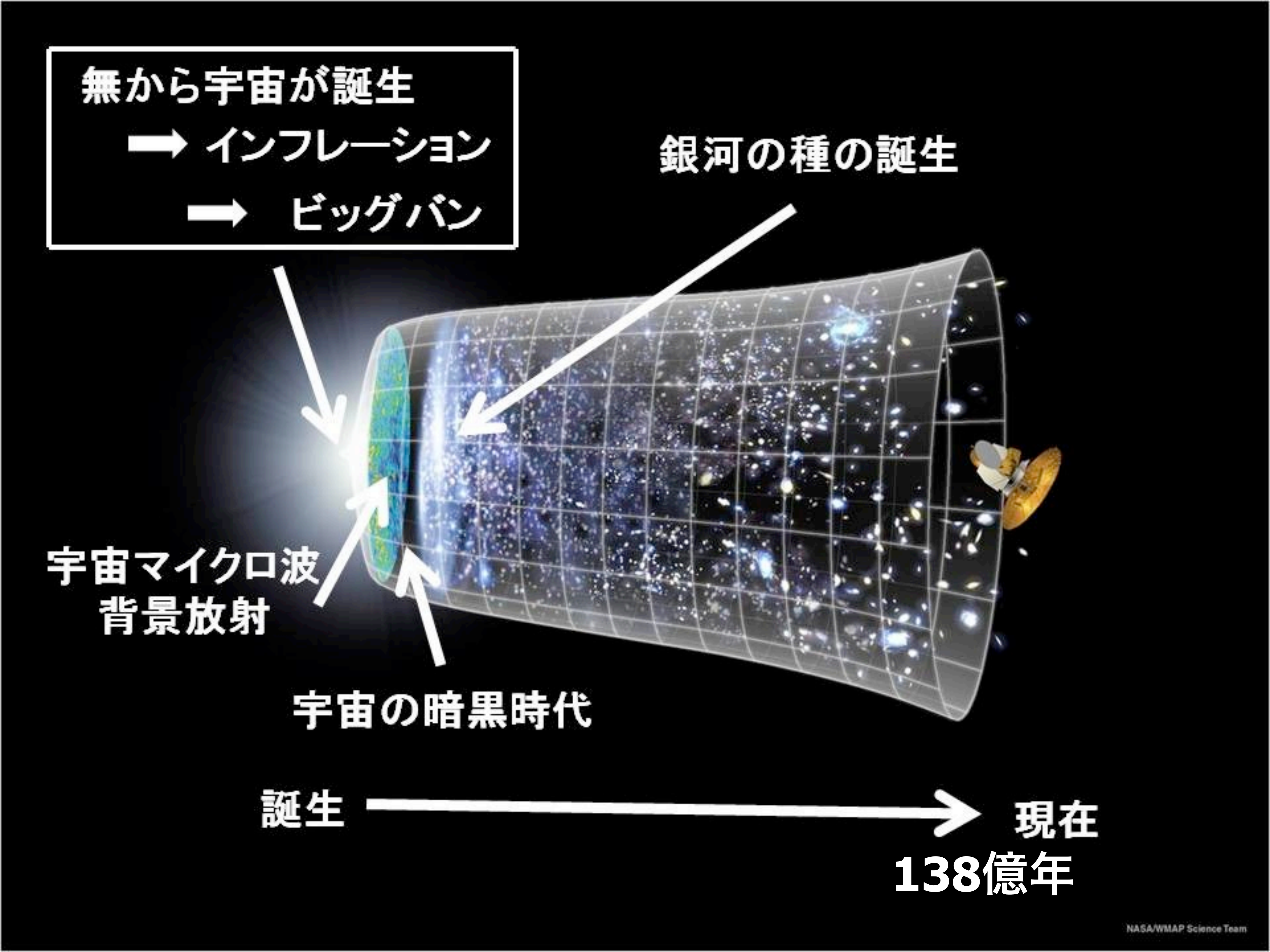
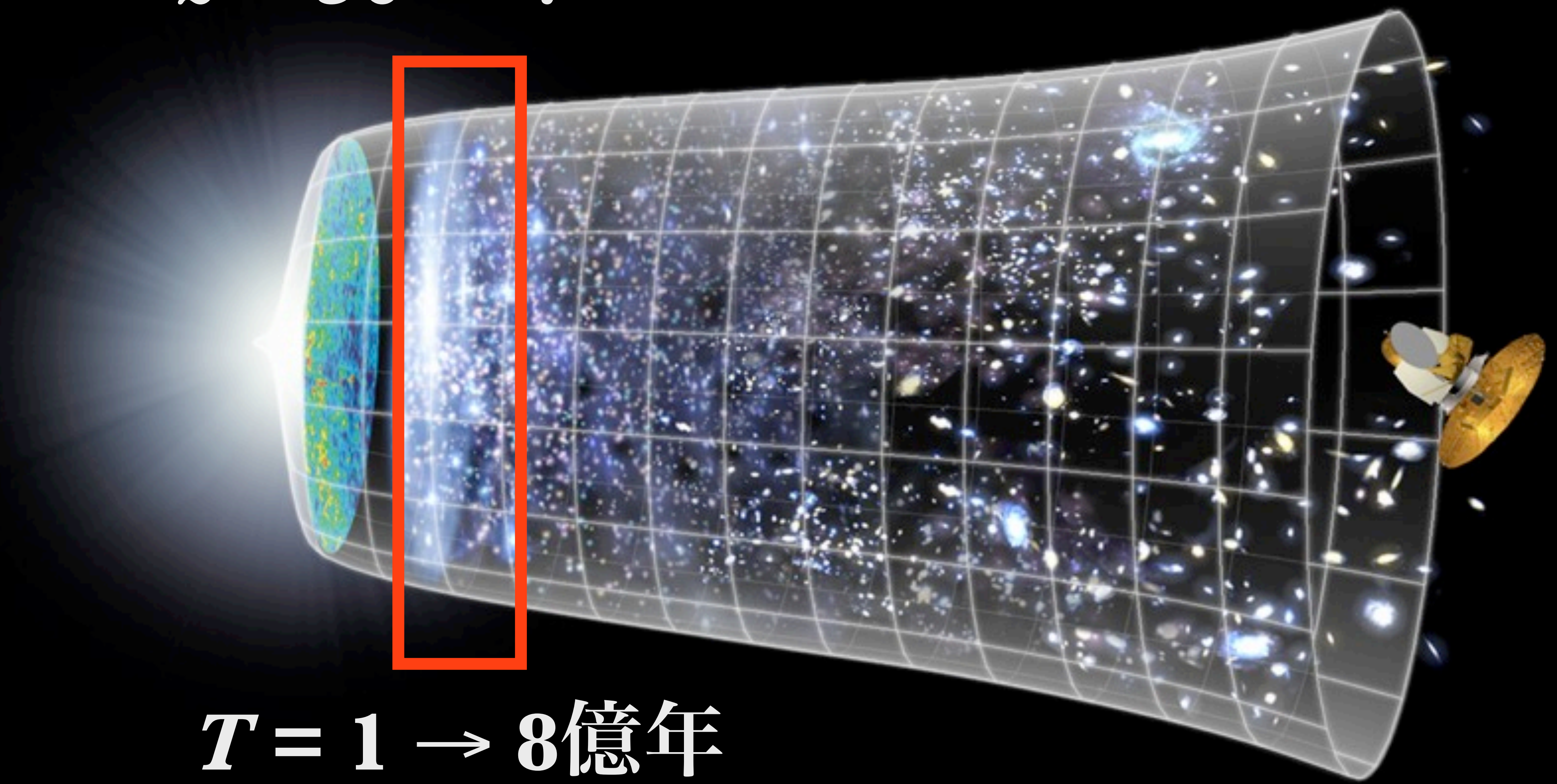
初代ブラックホール形成の観測的研究の現状

谷口義明
愛媛大学宇宙進化研究センター


無から宇宙が誕生
➡ インフレーション
➡ ビッグバン
銀河の種の誕生
宇宙マイクロ波
背景放射
宇宙の暗黒時代
誕生
現在
138億年
NASA/WMAP Science Team

初代ブラックホールの時代

$z = 30 \rightarrow 7$



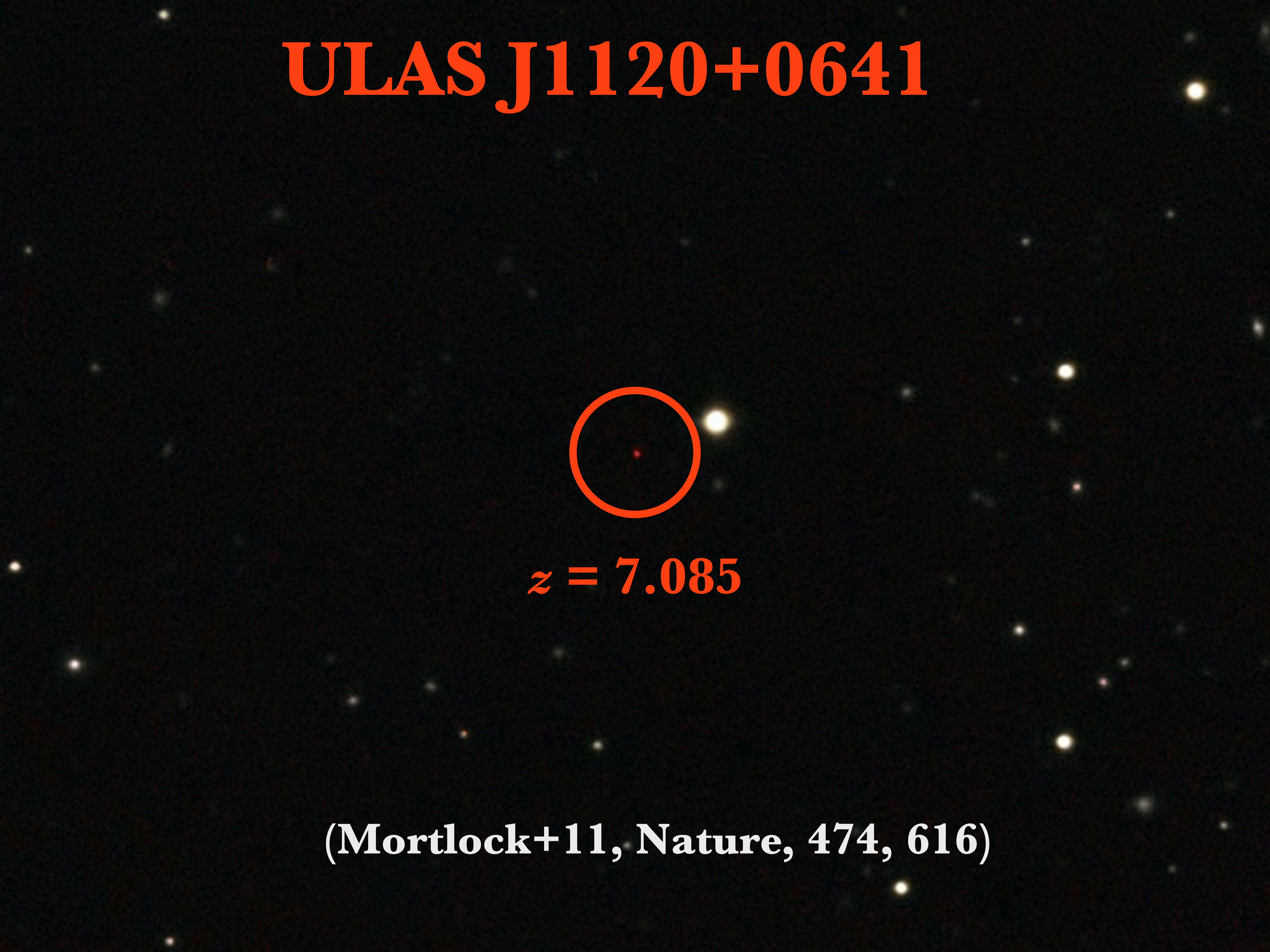
$T = 1 \rightarrow 8$億年

NASA/WMAP Science Team

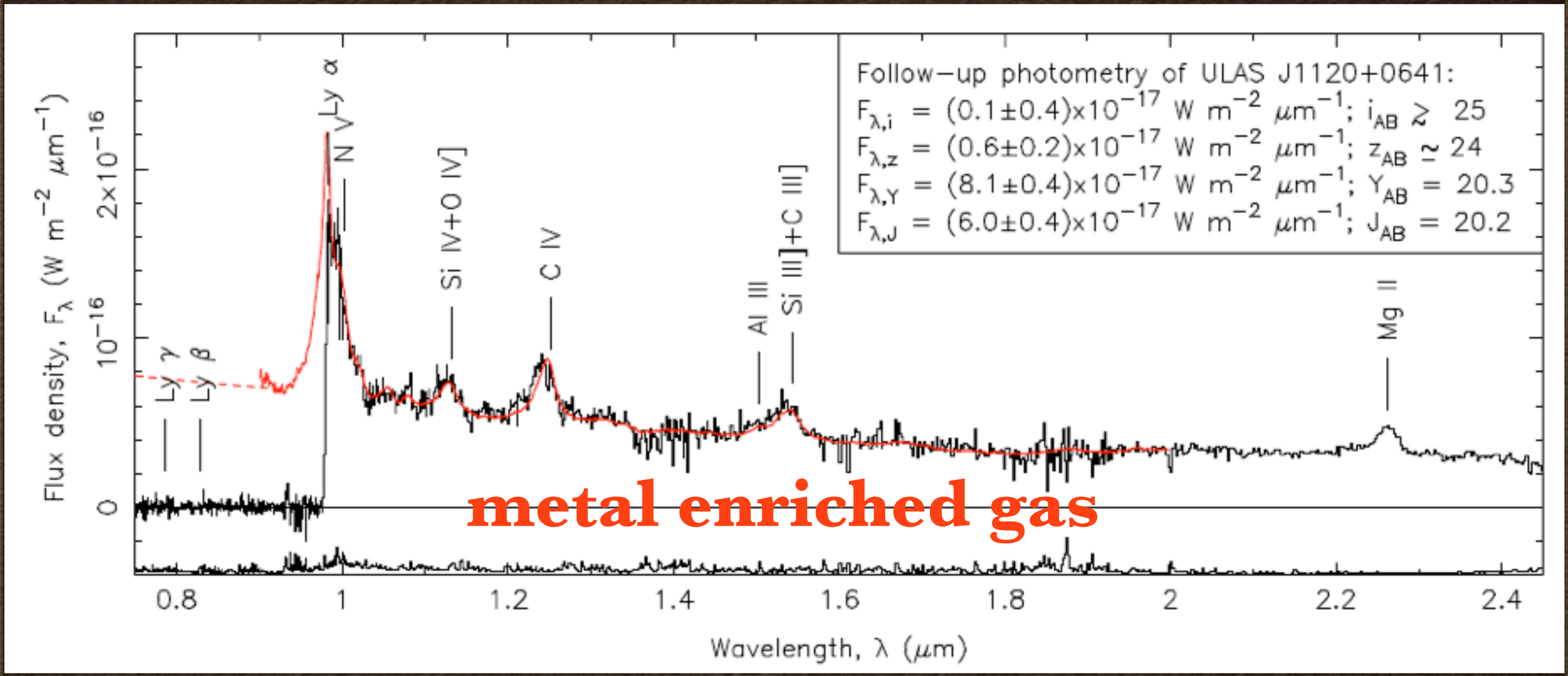
宇宙の一番星は見えるか？

M_u	N	$z=10$	$z=20$	$z=30$
($M_\odot$)		(1.65μm)	(3.15μm)	(4.65μm)
500	1	38.4	39.3	39.9
500	100	33.4	34.3	34.9
500	10000	28.4	29.4	29.9
100	1	40.9	41.8	42.4
100	100	35.9	36.8	37.4
100	10000	30.9	31.8	32.4

Pop III stars の SED = Black Body with T=10^5 K
$L_{bol} = 10^{7.1}\,L_\odot$ for M = 500 $M_\odot$ & $L_{bol} = 10^{6.1}\,L_\odot$ for M = 100 $M_\odot$
(Bahena & Klapp 2010, ApSS, 327, 219)


ULAS J1120+0641
z = 7.085
(Mortlock+11, Nature, 474, 616)

Observed Spectrum of ULAS J1120+0641



$f_\lambda \propto \lambda^{-0.5}$

Composite of
169 SDSS quasars
@ z = 2.3 - 2.6

$M_\bullet$

$FWHM$(MgII)=3800±200 km s^{-1}

↓

$M_\bullet = 2\times10^9\ M_\odot$

$z = 7.085 \rightarrow T = 0.77$ Gyr

$\langle dM_\bullet / dt \rangle \sim 3\ M_\odot$ /yr

SMBH growth rate

1. Nominal average growth rate

   $M_\bullet = 2\times10^9\ M_\odot$

   $z = 7.085 \rightarrow T = 0.77$ Gyr

   $<dM_\bullet / dt> \sim 3\ M_\odot$ /yr

2. $L_{\rm bol}$ -based growth rate

   $L_{\rm bol} = \eta\ dM/dt\ c^2$

   η : radiative efficiency

   dM/dt :gas accretion rate

   $dM_\bullet / dt = (1-\eta)/\eta\ L_{\rm bol}\ c^{-2}$

   $L_{\rm bol} = 2.6\times10^{47}$ erg s^{-1}

   $dM_\bullet / dt = 40\ M_\odot$/yr

SMBH-Spheroid Relation

$SFR([\mathrm{CII}]) = 200\ M_\odot/\mathrm{yr}$

$dM_{\mathrm{spheroid}}/dt = 200\ M_\odot/\mathrm{yr}$

$dM_\bullet/dt = 40\ M_\odot/\mathrm{yr}$

$dM_\bullet/dM_{\mathrm{spheroid}} = 0.2$

$\gg M_\bullet/M_{\mathrm{spheroid}} = 0.0014$

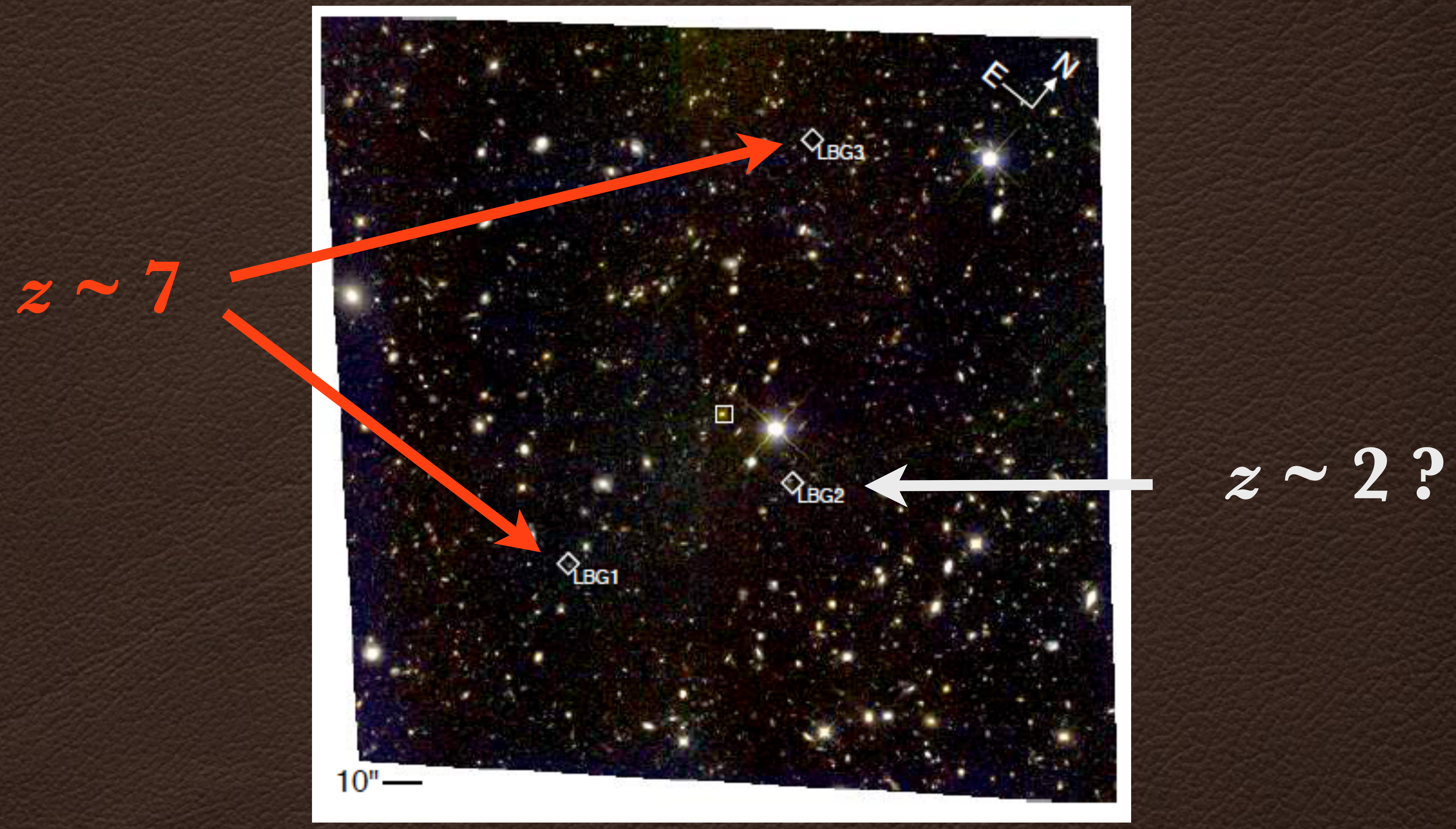
in the local universe

(Barnett+15, AA, in press arXiv:1411.5551)

rapid growth at $z > 7$

Environ

HST iYJ composite



No excess of galaxies with > *L***

(Simpson+14, MN, 442, 3454)

What ULAS J1120+0641 tells us

1. SMBH with $M_\bullet = 2\times10^9\ M_\odot$ @ $z \sim 7$
   SMBH growth time is shorter than 0.8 Gyr
2. rapid growth with $dM_\bullet / dt = 40\ M_\odot / \mathrm{yr}$
   different coevolution in early phase ?
3. metal-enriched gas
   enhanced recent-past star formation
   starburst-AGN connection ?
4. born in an ordinary environ
   SMBHs do not always favor over density ?

Quasars at $z > 6.5$

1. ULAS J1120+641 @ $z = 7.1$

   Mortlock+11, Nature, 474, 616

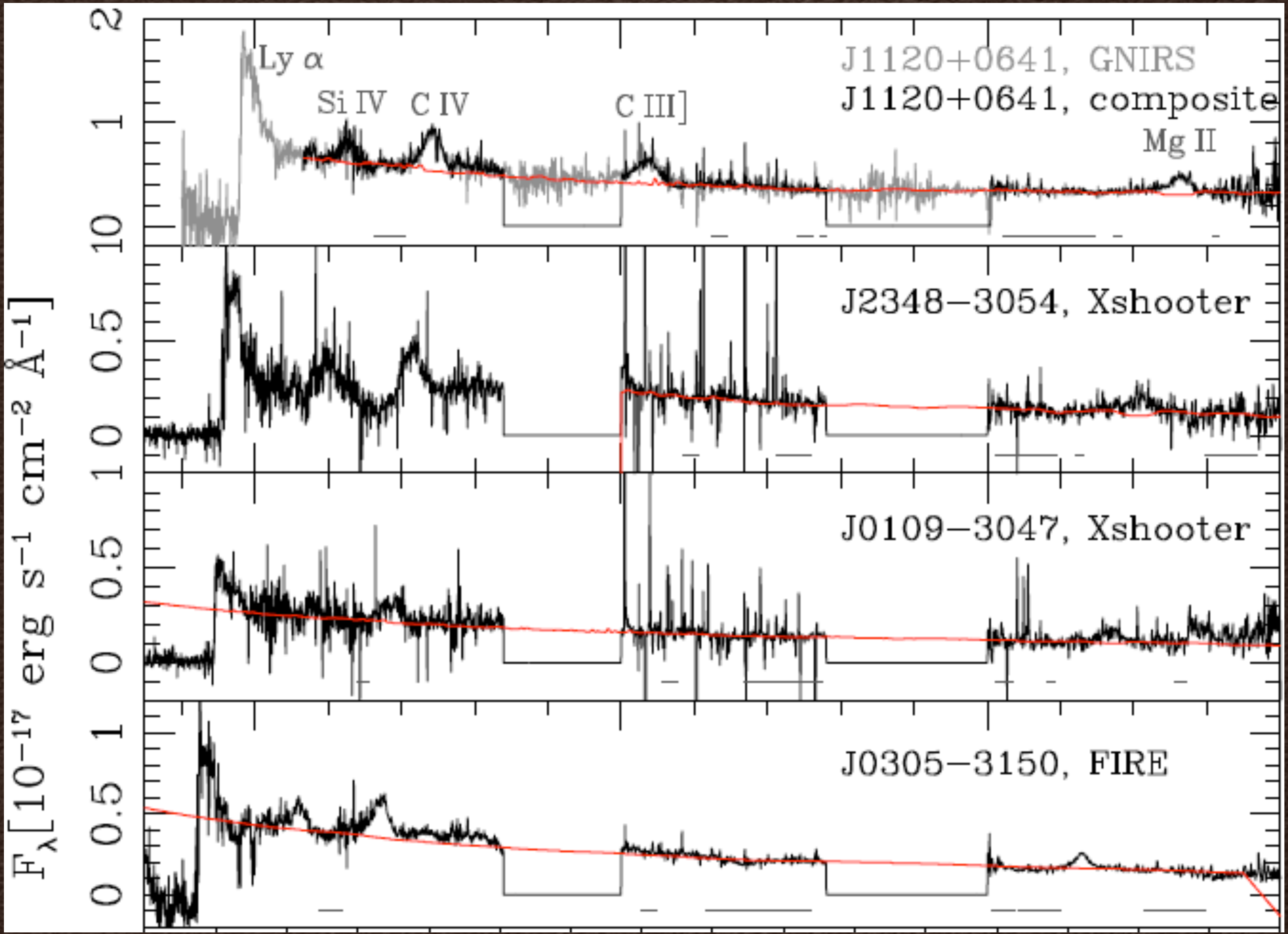
2. VIKING J2348-3054 @ $z = 6.9$
3. VIKING J0109-3040 @ $z = 6.7$
4. VIKING J0305-3150 @ $z = 6.6$

   Venemans+13, ApJ, 779, 24

Quasar Name	R.A. (J2000)	Decl. (J2000)	z	$M_{1450,AB}$	A_V
J1120+0641	$11^h20^m01\overset{s}{.}48$	$+06°41'24\overset{''}{.}3$	7.1	-26.6 ± 0.1	0.1601
J2348–3054	$23^h48^m33\overset{s}{.}34$	$-30°54'10\overset{''}{.}0$	6.9	-25.72 ± 0.14	0.0408
J0109–3047	$01^h09^m53\overset{s}{.}13$	$-30°47'26\overset{''}{.}3$	6.7	-25.52 ± 0.15	0.0669
J0305–3150	$03^h05^m16\overset{s}{.}92$	$-31°50'56\overset{''}{.}0$	6.6	-25.96 ± 0.06	0.0381

(De Rosa+14, ApJ, 790, 145)

Quasars at $z > 6.5$



(De Rosa+14, ApJ, 790, 145)

Quasars at $z > 6.5$

	J1120+0641	J2348–3054	J0109–3047	J0305–3150
M_{BH} (Mg II) (10^9 $M_\odot$)	$2.4^{+0.2}_{-0.2}$	$2.1^{+0.5}_{-0.5}$	$1.5^{+0.4}_{-0.4}$	$0.95^{+0.08}_{-0.07}$
M_{BH} (C IV) (10^9 $M_\odot$)	$1.09^{+0.02}_{-0.04}$	...	$0.77^{+0.05}_{-0.1}$	$1.20^{+0.06}_{-0.05}$
L_{Bol}/L_{Edd}	0.48	0.18	0.24	0.68
$L_{Bol}/L_{Edd2011}$	0.52	0.19	0.26	0.74
Si IV/C IV	0.35 ± 0.01	...	0.39 ± 0.19	0.52 ± 0.02
C III]/C IV	0.73 ± 0.01	...	...	...
Fe II/Mg II	$2.10^{+0.13}_{-0.02}$	$2.8^{+0.3}_{-1.0}$	$1.8^{+2.5}_{-1.8}$	$3.2^{+0.7}_{-0.7}$
$EW_{C IV}$ (Å)	26.3 ± 0.3	...	$20.6 \pm +4.7$	27.0 ± 0.8

(De Rosa+14, ApJ, 790, 145)

Quasars at z > 6.5

$$t = 0.45\ \mathrm{Gyr} \left(\frac{\epsilon}{1-\epsilon} \right) \frac{L_{\mathrm{Edd}}}{L_{\mathrm{Bol}}} \ln \left(\frac{M_t}{M_0} \right)$$

(Shapiro 05, ApJ, 620, 59)

$L_{\mathrm{bol}}/L_{\mathrm{Edd}} = 0.4$

$\varepsilon = 0.07$

(radiative efficiency; Voronteri & Rees 05, ApJ, 633, 624)

Need t_{growth} = 1.2 - 1.4 Gyr to build up SMBH with $10^9\ M_\odot$ in quasars at $z > 6.5$

(De Rosa+14, ApJ, 790, 145)

Quasars at $z > 6.5$

How massive could be seed BHs ?

seed formation	accretion time	seed mass ($M_\odot$)
$z = 10$	0.3 Gyr	3×10^7
$z = 15$	0.5 Gyr	3×10^6
$z = \infty$	0.8 Gyr	8×10^4

(De Rosa+14, ApJ, 790, 145)

Black Holes in the Universe

1. Stellar Black Hole
   $M_\bullet \sim 5 - 15\, M_\odot$
   in all galaxies

2. Intermediate-Mass Black Hole (IMBH)
   $M_\bullet \sim 10^2 - 10^4 M_\odot$ (Taniguchi+00, PASJ, 52,533)
   $z = 0 - 30$ (?)

3. Supermassive Black Hole (SMBH)
   $M_\bullet > 10^6\, M_\odot$
   $z = 0 - 7.1$ (?)

What are seeds @ $z \sim 7 - 30$?
- Baryonic version -

1. IMBHs as remnants of either Pop III or VMS (very massive stars) or both

   $M_\bullet \sim 10^2 M_\odot$

   e.g., Madau & Rees 01, ApJ, 551, L27
   Tanaka & Haiman 09, ApJ, 696, 1798

2. Direct collapse of proto galaxies or that driven by a merger between pristine HI clouds

   $M_\bullet \sim 10^{4-6} M_\odot$

   e.g., Begelman+06, MN, 370, 289
   Volonteri+08, MN, 383, 1079
   Mayer+09, Nature, 466, 1082
   Bonoli+14, MN, 437, 1576

What are seeds @ $z \sim 7$ - 30 ?
- Dark matter version -

3. **Dark star** powered by neutralino DM annihilation in DM haloes with $M_{\rm halo} \sim 10^{5\text{-}6} M_\odot$ @ $z \sim 10$ - 50

(e.g., Spolyar+08, PhRvL, 100, 051101)

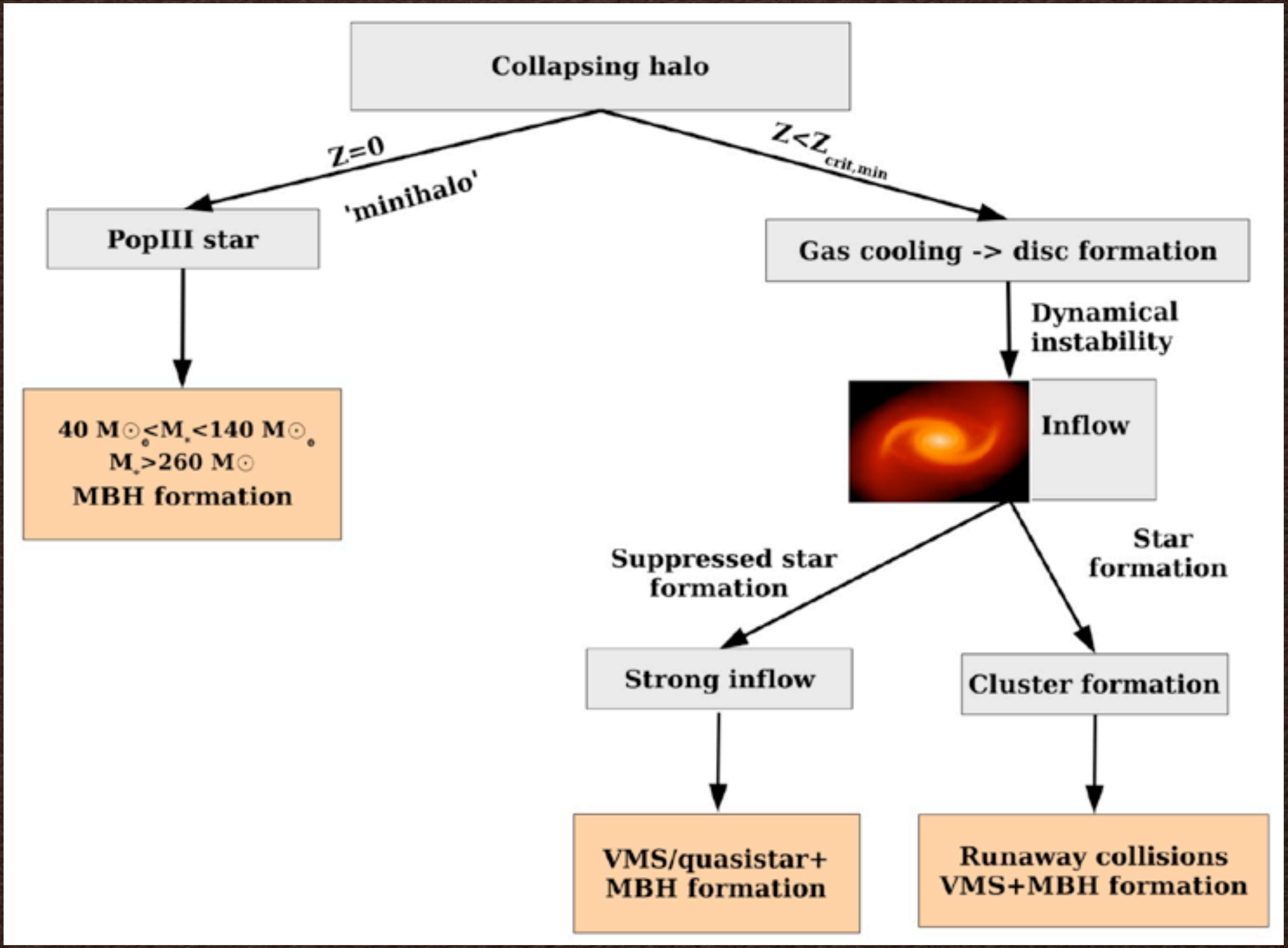
4. Formation from **ultra-strongly self-interacting DM**

suppose a small fraction of DM ($f < 0.1$)
is ultra-strongly self-interacting

if $f = 1.12\times10^{-5}$, $M_\bullet \sim 2\times10^5\ M_\odot$ @ $z = 13$
→ explains ULAS J1120+0641 @ $z = 7.1$

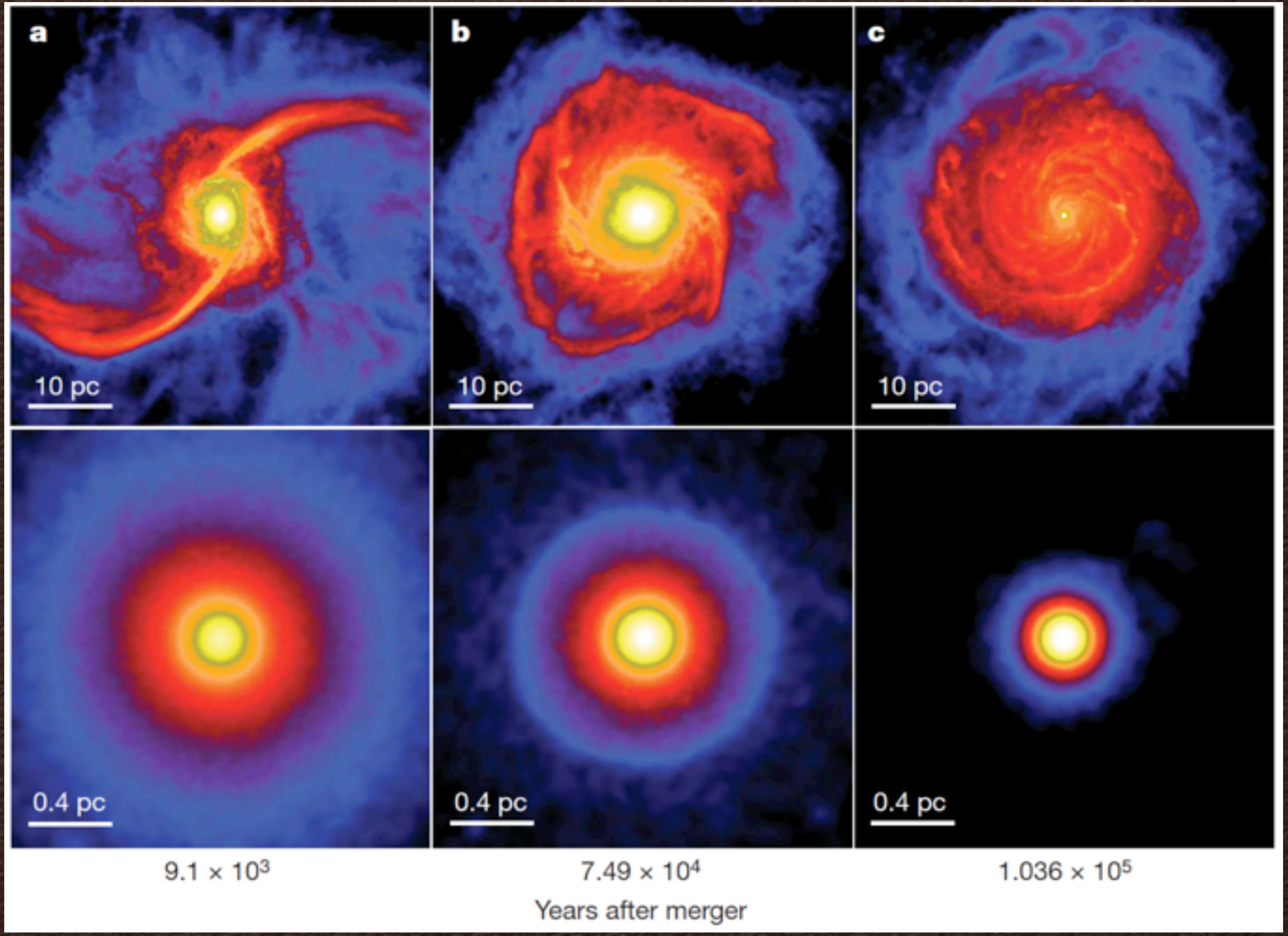
(Pollack+15, arXiv:1501.0001)

IMBH Formation @ $z > 7$



(Volonteri 10, A&ARv, 18, 279)

Direct collapse driven by a merger between pristine HI clouds



(Mayer+10, Nature, 466, 1082)

What drives mass growth @ $z \sim 7$ - 30 ?

1. Super Eddington accretion ?
   e.g., Super-critical accretion via a slim disk
   Madau+14, ApJ, 784, L38
2. Eddington accretion + successive mergers
   Taniguchi 04, PTPS, 155, 205
3. Runaway merger in a star cluster with gas inflow
   Alexander & Natarajan 14, Sci, 345, 133
4. Successive mergers of hosts
   Tanaka 14, arXiv:1405.3023
5. Accretion of radiatively-cooled gas
   Park & Ricotti 12, ApJ, 747, 9

Kyoto Model for Formation of SMBH

(Taniguchi 2004, PTPS, 155, 205)

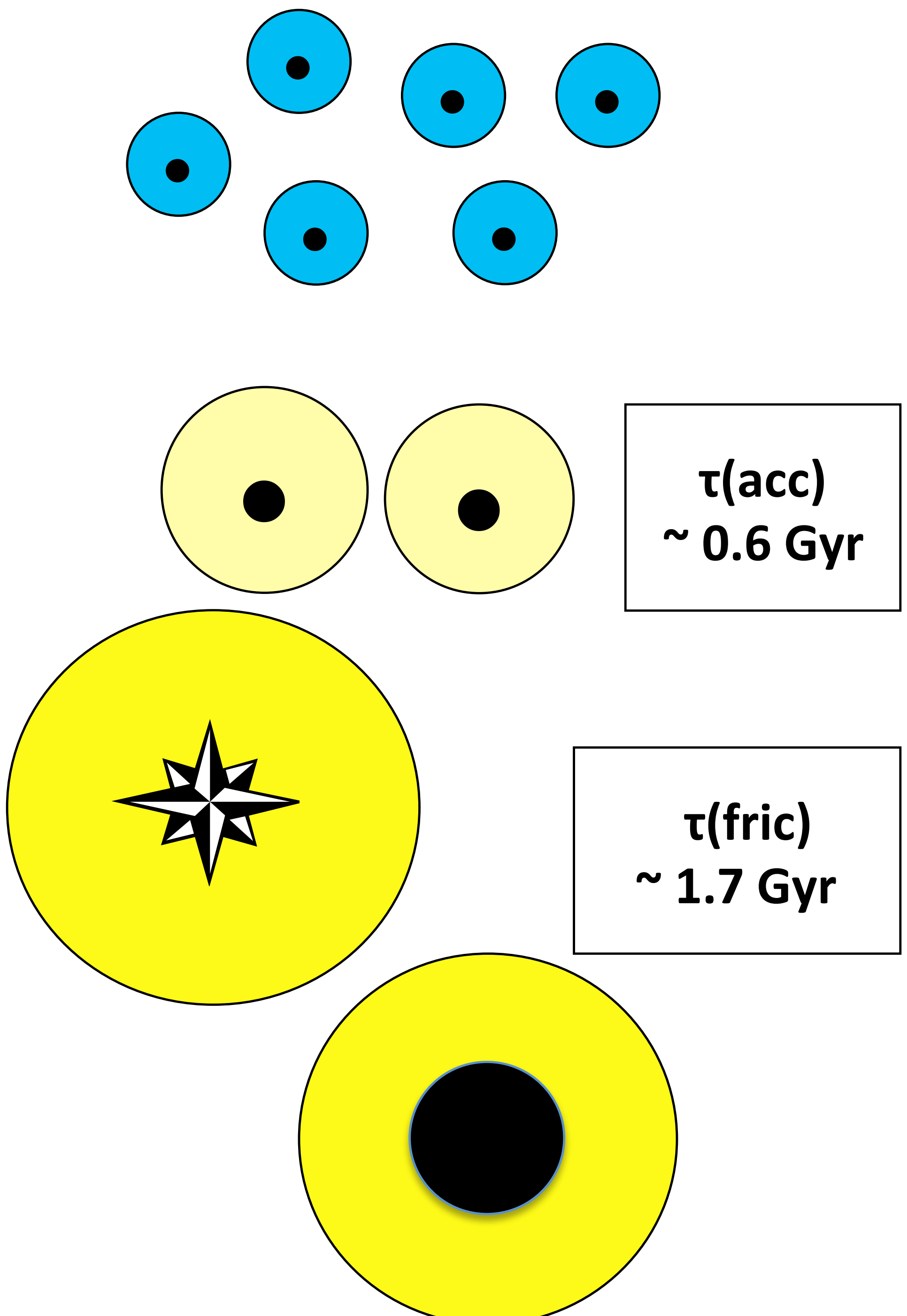
Pop III-driven IMBH
$M_\bullet$ ~ 100 M_{sun} @ z ~ 30

ΔT ~ 0.6 Gyr (z: 30 → 10)

Gas accretion-driven SMBH
$M_\bullet$ ~ 10^7 M_{sun} @ z ~10

ΔT ~ 1.7 Gyr (z: 10 → 3)

Major merger-driven SMBH
$M_\bullet$ ~ 10^9 M_{sun} @ z ~3-6



Super-exponential accretion

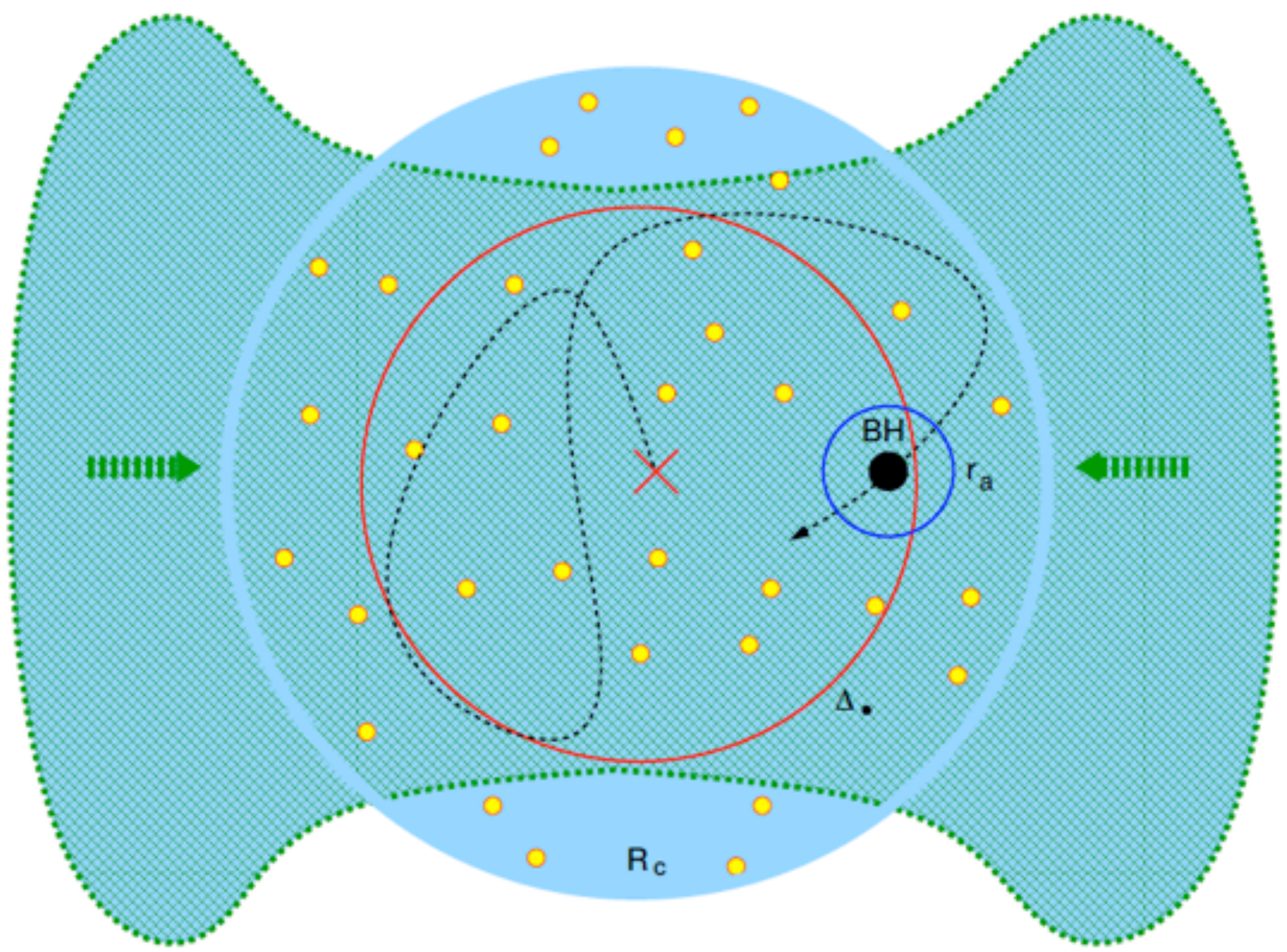


Figure 1: A schematic depiction of accretion by a low-mass BH in a dense gas-rich cluster. Dense cold gas (green) flows to the center (red cross) of a stellar cluster (light blue region) of total mass $M_c = N_\star M_\star + M_g$ and radius R_c, which contains $N_\star$ stars (yellow circles) of mass $M_\star$ each with velocity dispersion $\sigma_\star$, and gas of mass M_g. The gas is nearly pressure-supported and close to the virial temperature. A stellar BH (black circle) of mass $M_\star < M_\bullet \ll M_c$, which is accreting from its capture radius r_a (dark blue circle), is initially in fluctuation-dissipation equilibrium with the stars and is scattered by them (black dashed line) with velocity dispersion $\sigma_\bullet \sim \sqrt{M_\star/M_\bullet}\sigma_\star$ over a distance scale $\Delta_\bullet \sim \sqrt{M_\star/M_\bullet}R_c$ (red circle).

(Alexander & Natarajan 14, Sci, 345, 133)

Coevolution or not ?
- Local Universe -

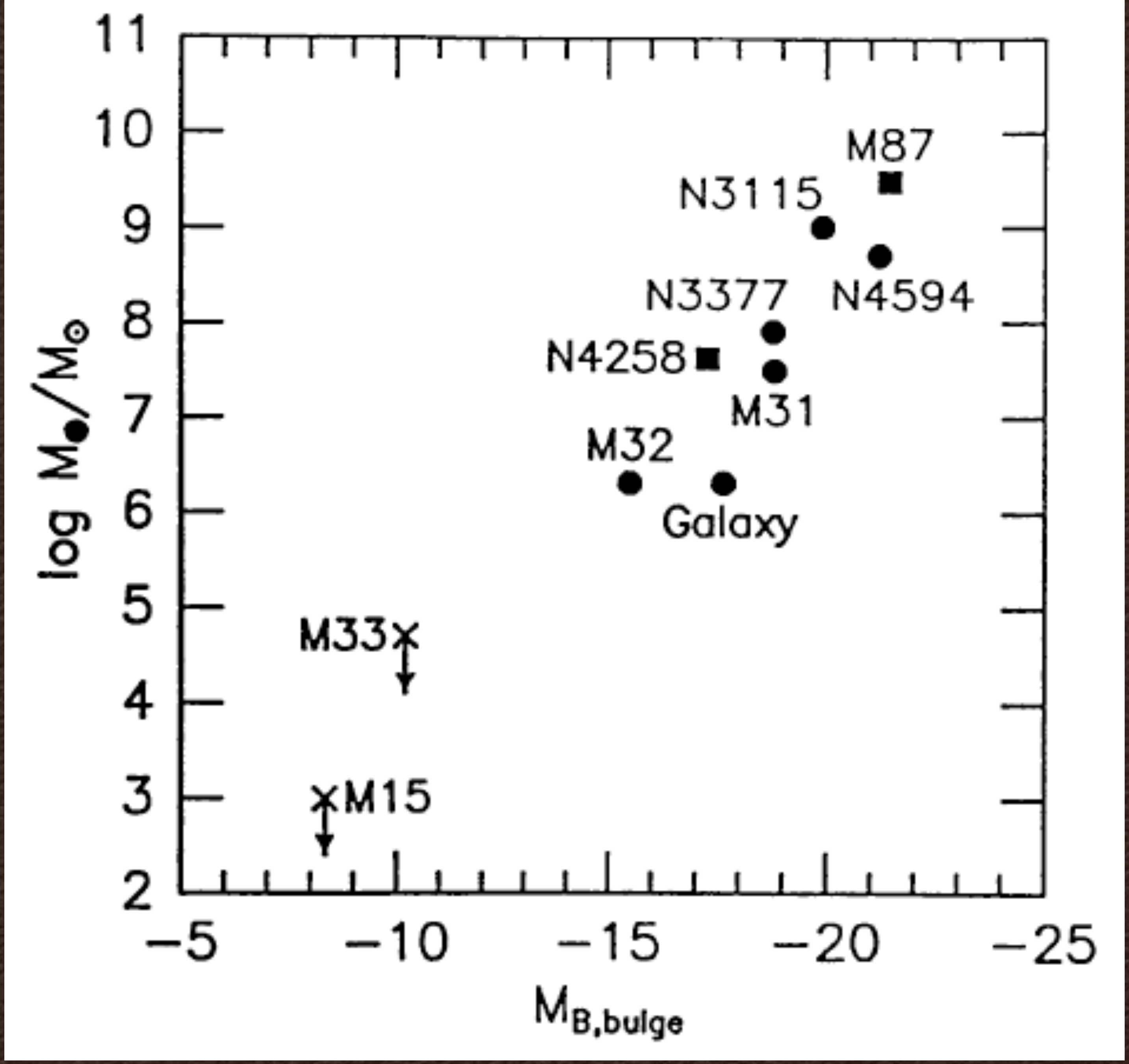
Coevolution

Kormendy & Richstone 95, ARAA, 33, 581
Magorrian+98, AJ, 115, 2285
Markoni & Hunt 03, ApJ, 589, L21
Gultekin+09, ApJ, 698, 198
Kormendy & Ho 13, ARAA, 51, 511 §8

No coevolution ?

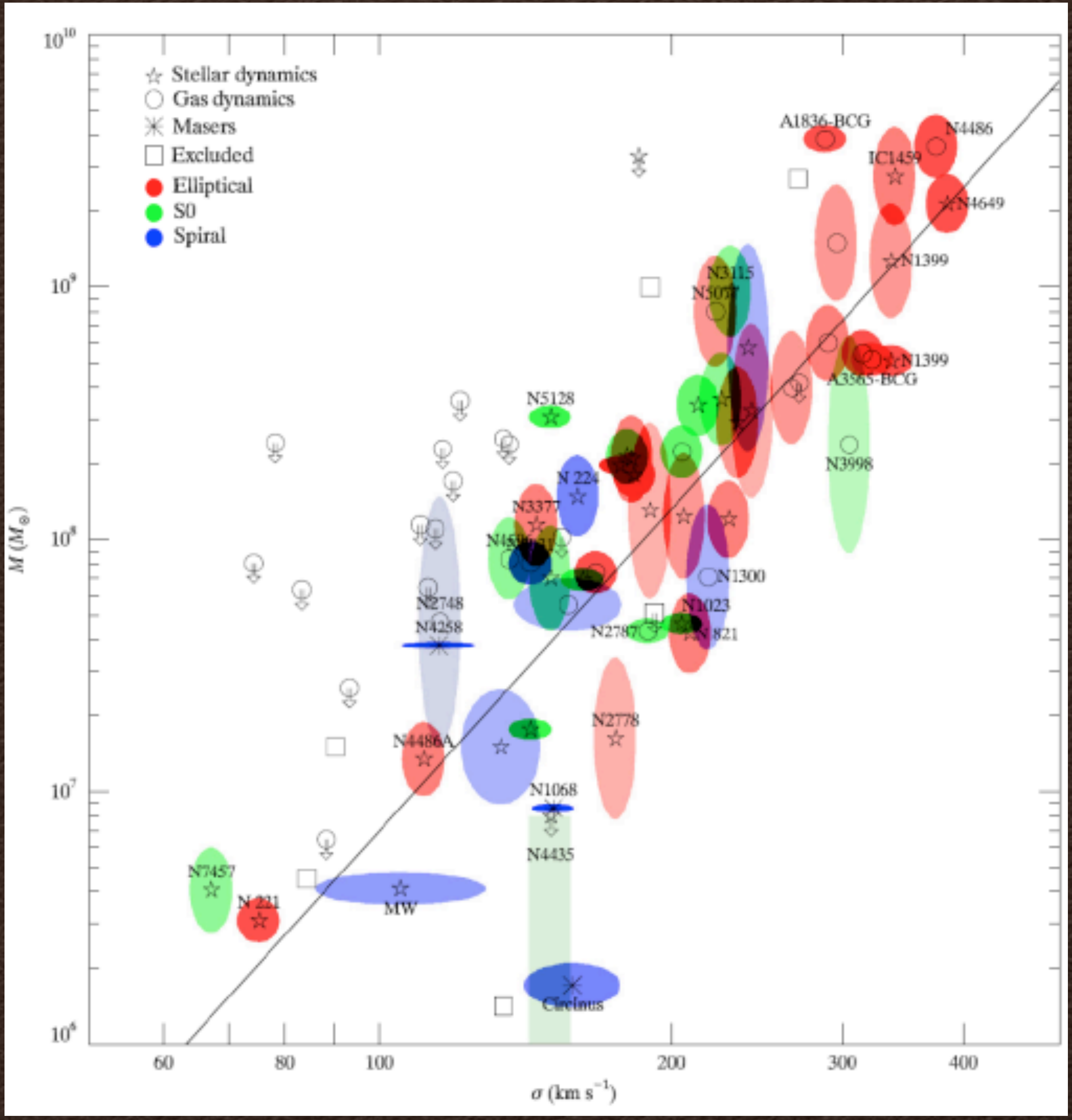
Kormendy+11, Nature, 469, 374
Kormendy & Bender 11, Nature, 469, 377
Kormendy & Ho 13, ARAA, 51, 511 §8

$M_\bullet$ - $M_{B,bulge}$ Relation in 1995
$M_\bullet / M_{bulge} = 0.0022$



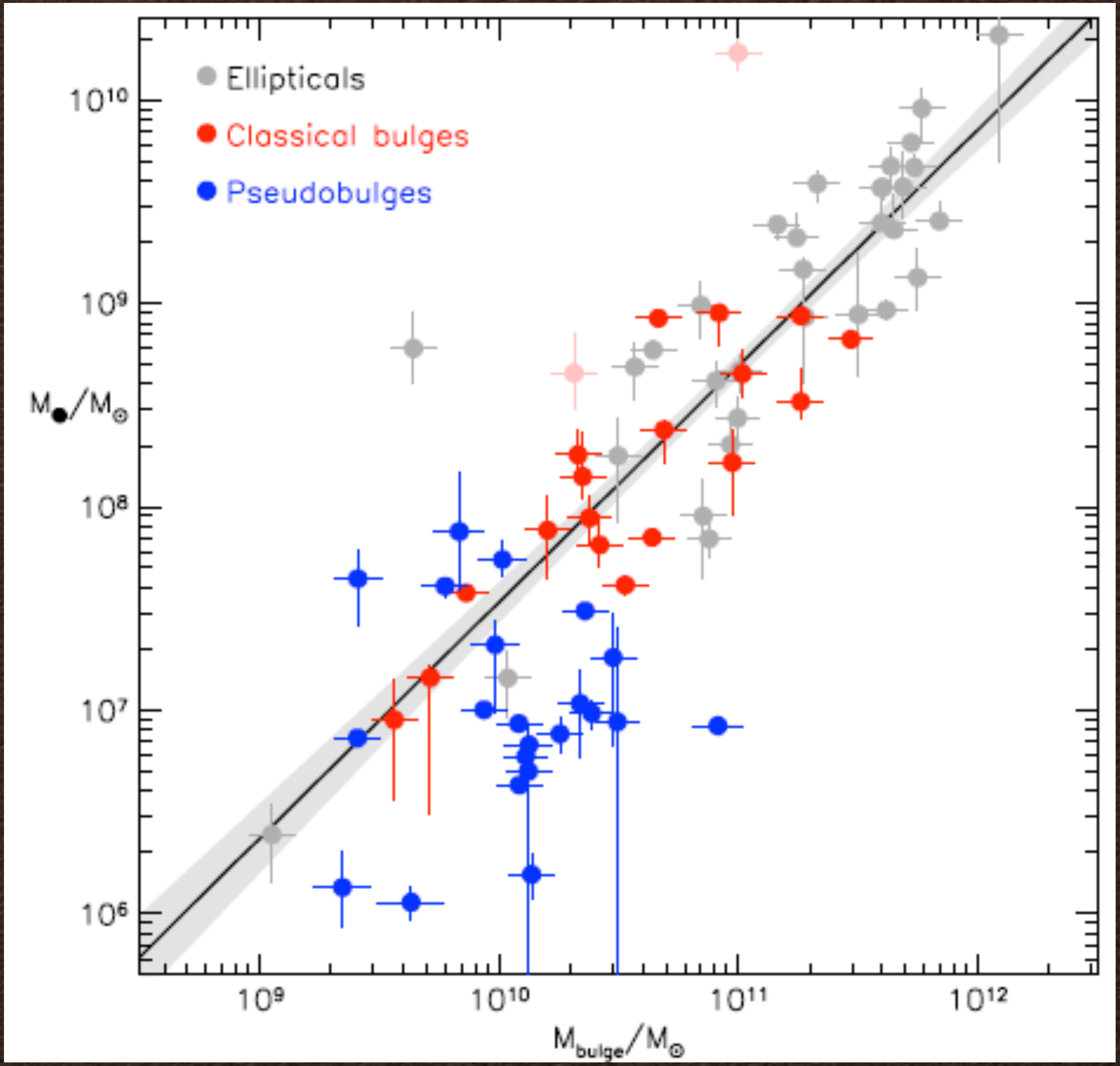
(Kormendy & Richstone 95, ARAA, 33, 581)

$M_{\bullet} \sim \sigma$ relation



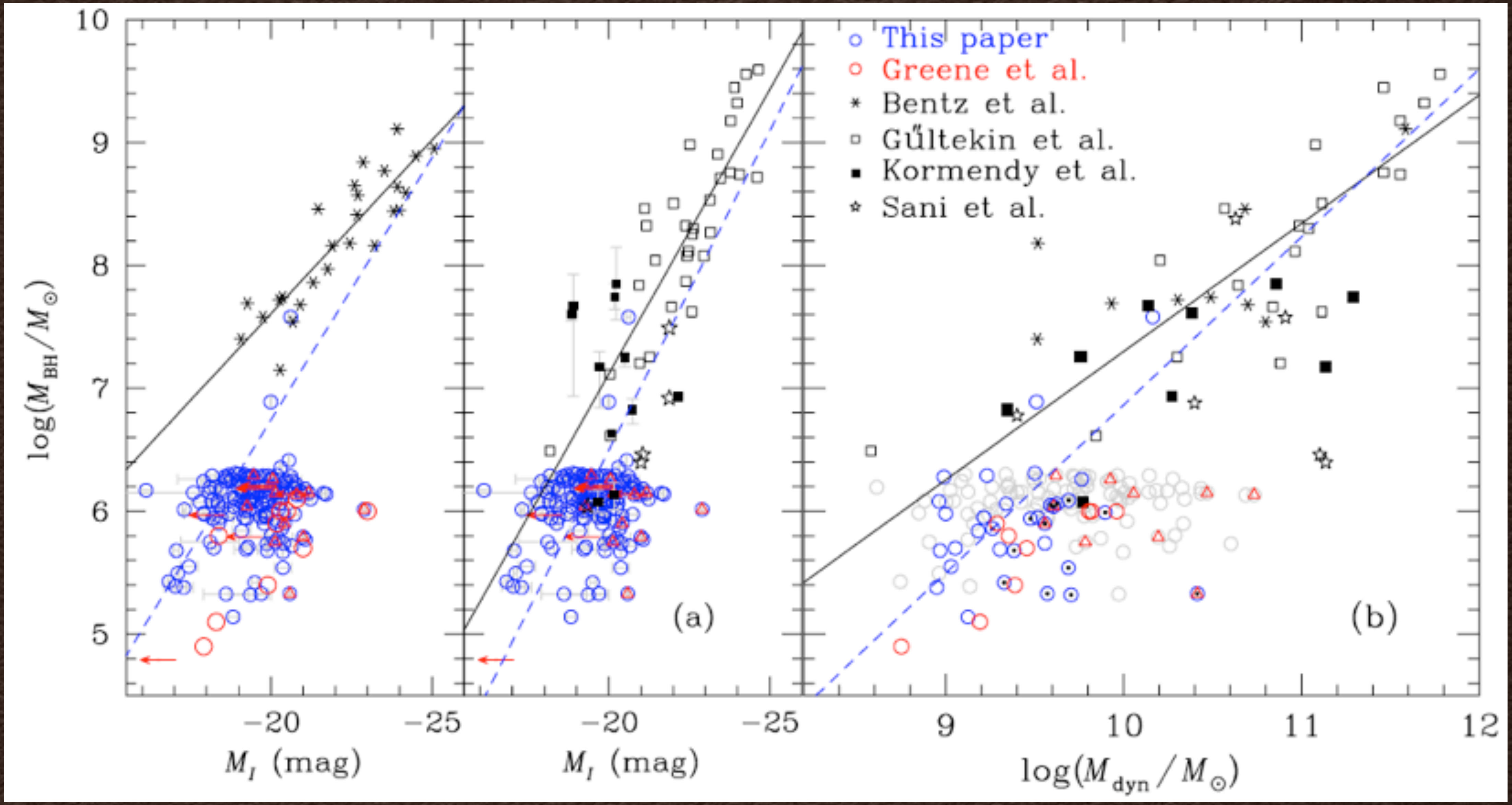
(Gultekin+09, ApJ, 698, 198)

Structure dependent relation



(Kormendy & Ho 13, ARAA, 51, 511)

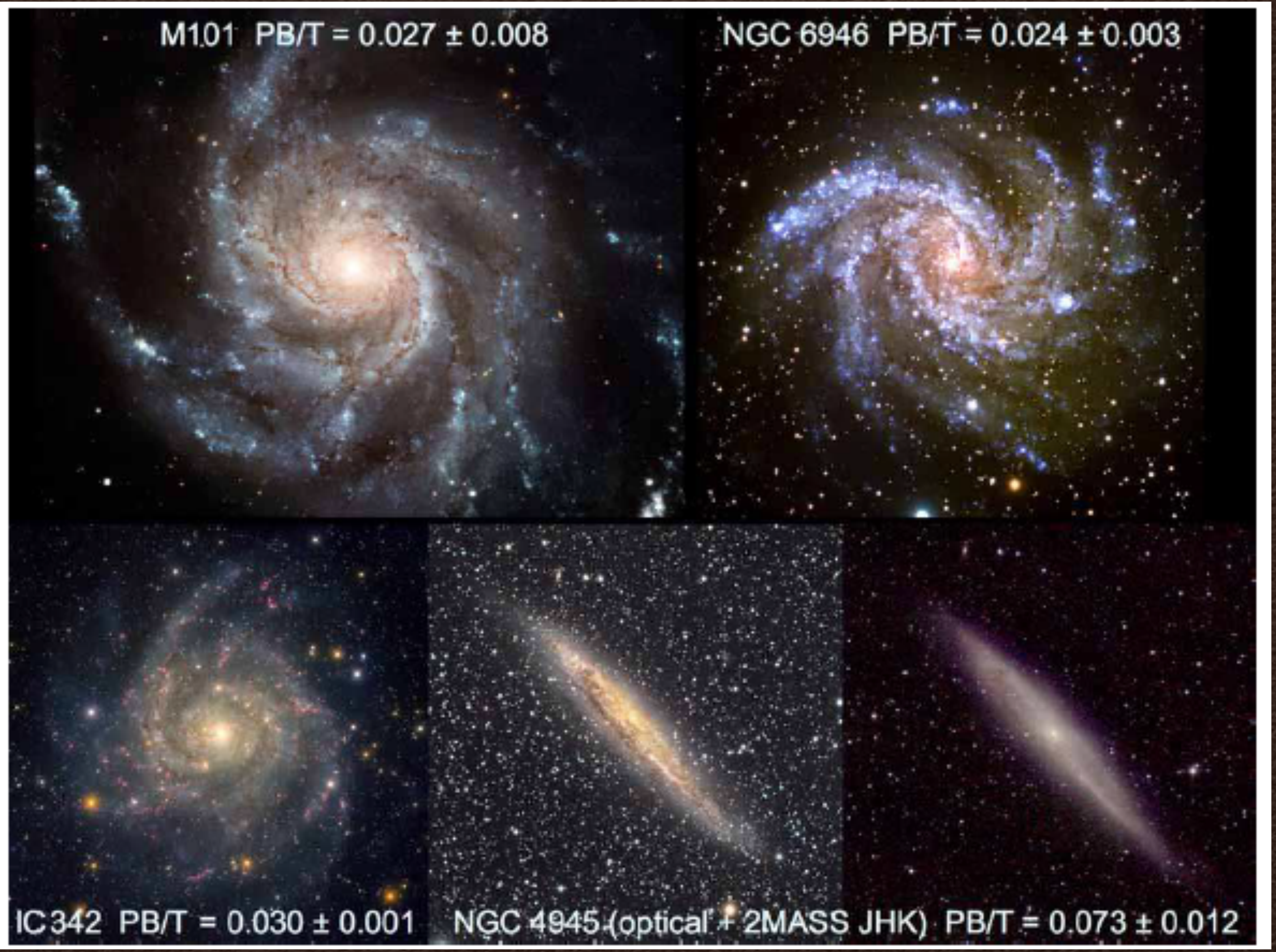
Less massive galaxies do not follow ?



174 galaxies with $M_\bullet < 2\times10^6\ M_\odot$ from SDSS DR4; see for detail, Green & Ho 07, ApJ, 670, 92

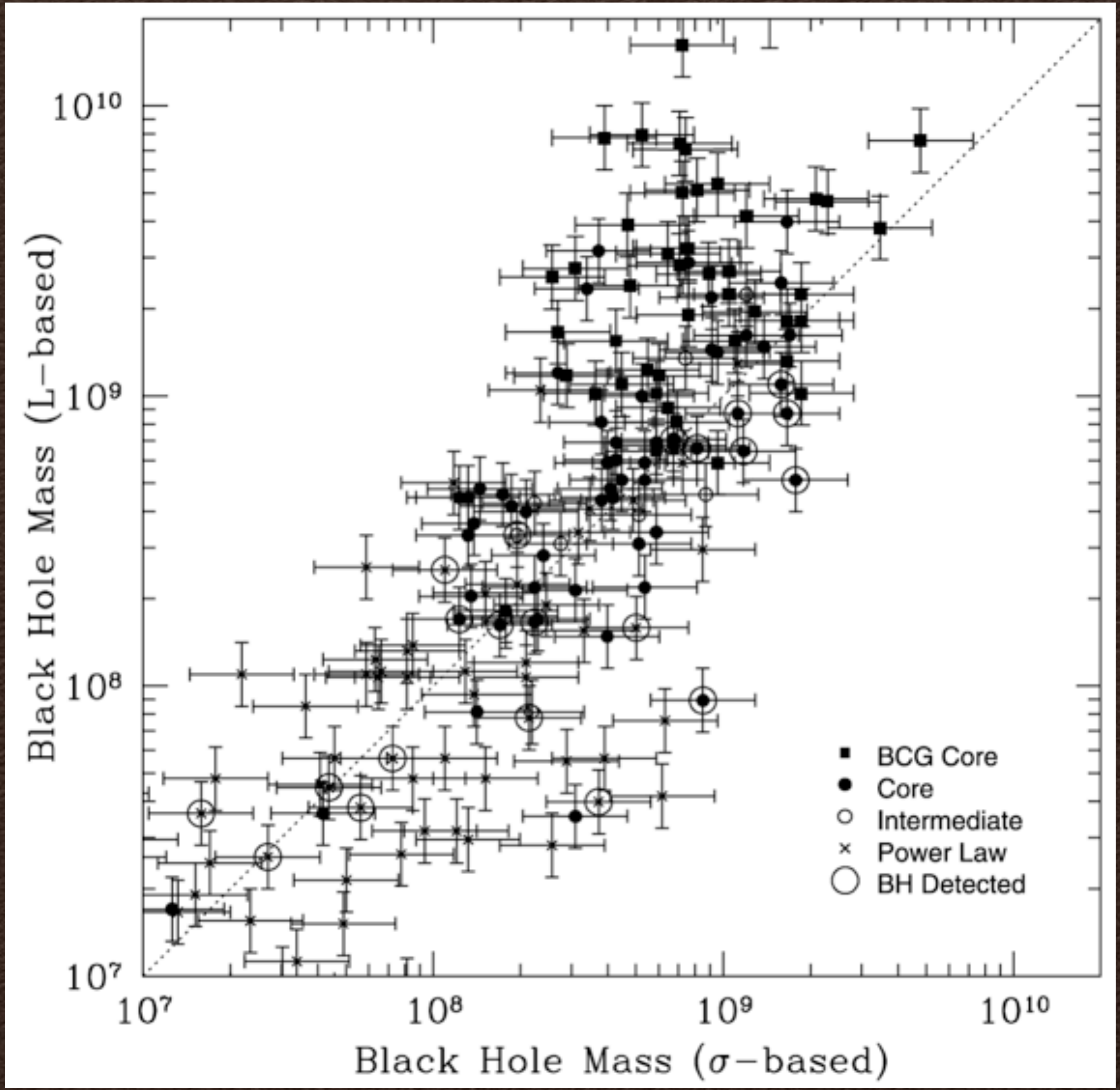
(Jiang+11, ApJ, 737, L45)

Pseudo Bulge in disk galaxies



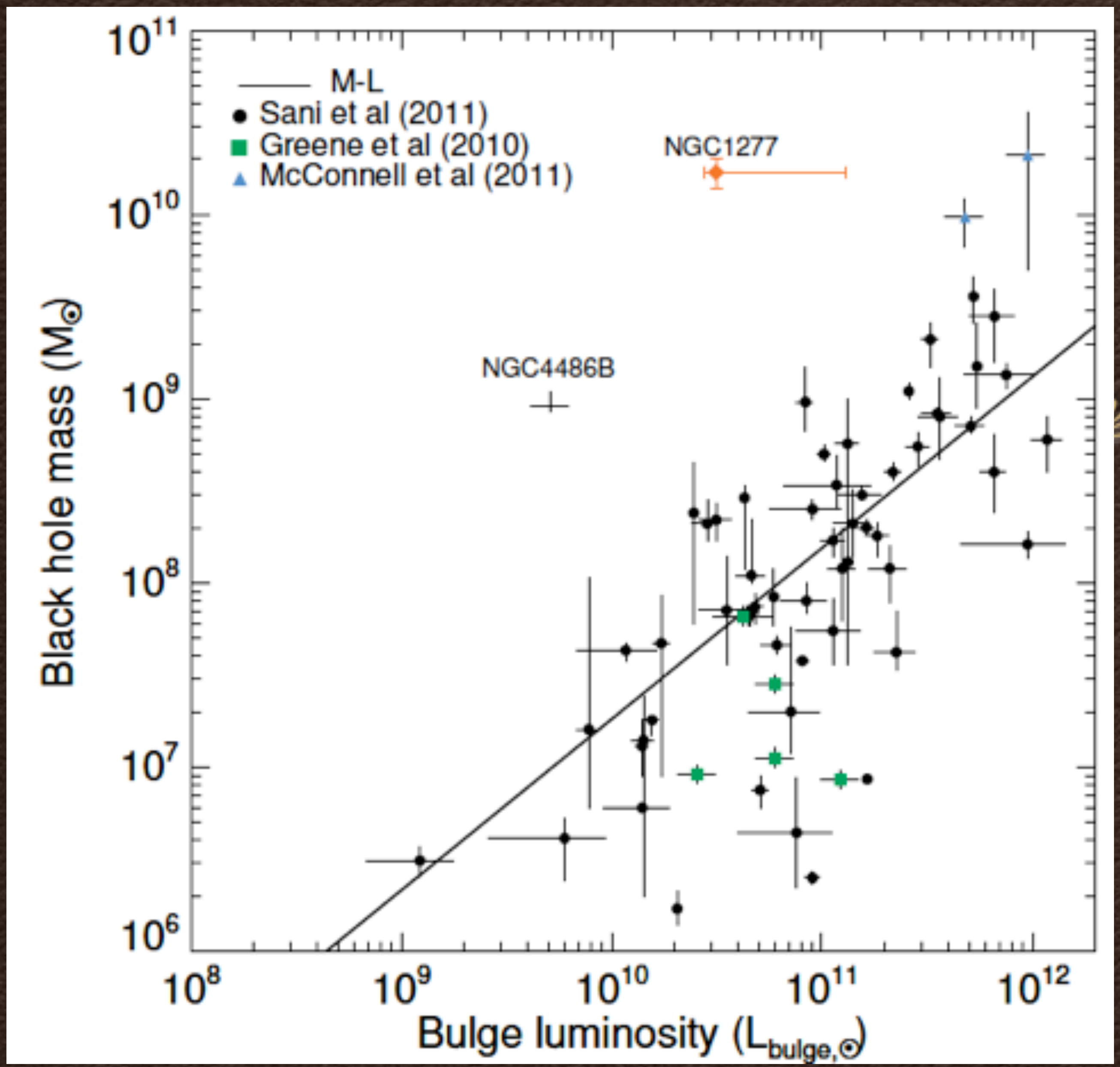
(Kormendy 13, arXiv:1311.2609)

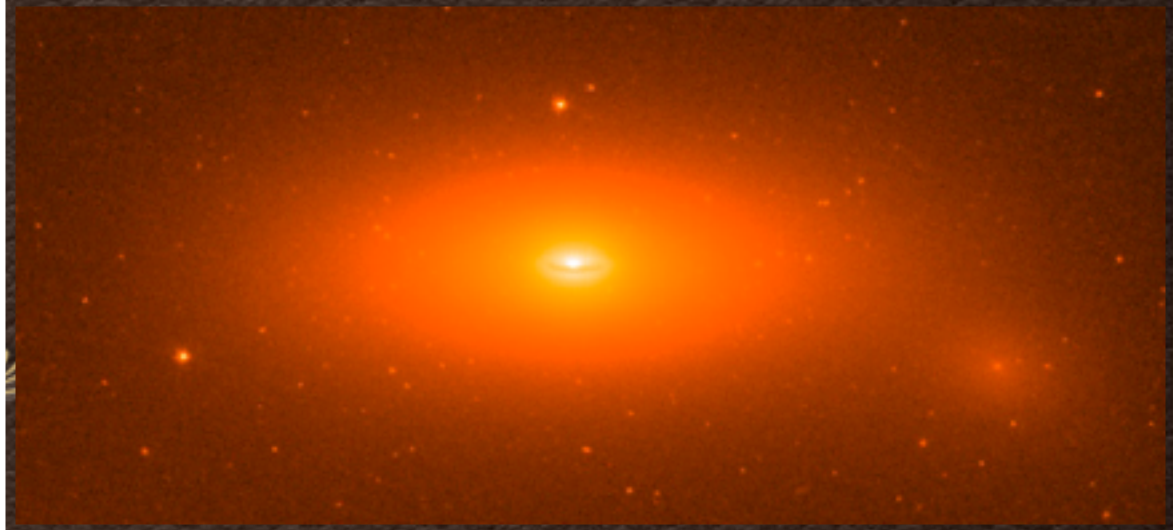
L-based vs. σ-based $M_\bullet$



(Lauer+07, ApJ, 662, 808)

Outlier
- The case of NGC 1277 -





$M_\bullet \sim 1.7\times10^{10}\ M_\odot$

$\sim 0.59\ M_{\mathrm{bulge}}$

(van den Bosch+12, Nature, 491, 729)

Coevolution or not ?
- Theoretical predictions -

Quasar feedback shuts off both Bulge & BH growth

Energy conservation

$$M_{\rm crit} < \frac{1}{2\pi} \frac{\sigma_T}{G^2 m_p c} \frac{f_{\rm gas}}{f_w} \sigma^5$$

(Silk & Rees 98, AA, 331, L1)

Momentum conservation

$$M_{\rm crit} < \frac{1}{2\pi} \frac{\sigma_T}{G^2 m_p} \frac{v_w}{c} \frac{f_{\rm gas}}{f_w} \sigma^4$$

(Fabian 99, MN, 308, L39)

Coevolution or not ?
- Theoretical predictions -

No help of Quasar feedback ?

1. Due to common merger history
   on the evolution of both bulge and SMBH

e.g., Peng 07, ApJ, 671, 1098
Jahnke & Maccio 11, ApJ, 734, 92

2. Gravitational torque limited accretion of SMBHs
   Mass accretion rate $\propto$ Large-scale inflow rate

Angles-Alcazar+13, ApJ, 770, 5

Coevolution or not ?
- Cosmological -

Redshift independent coevolution

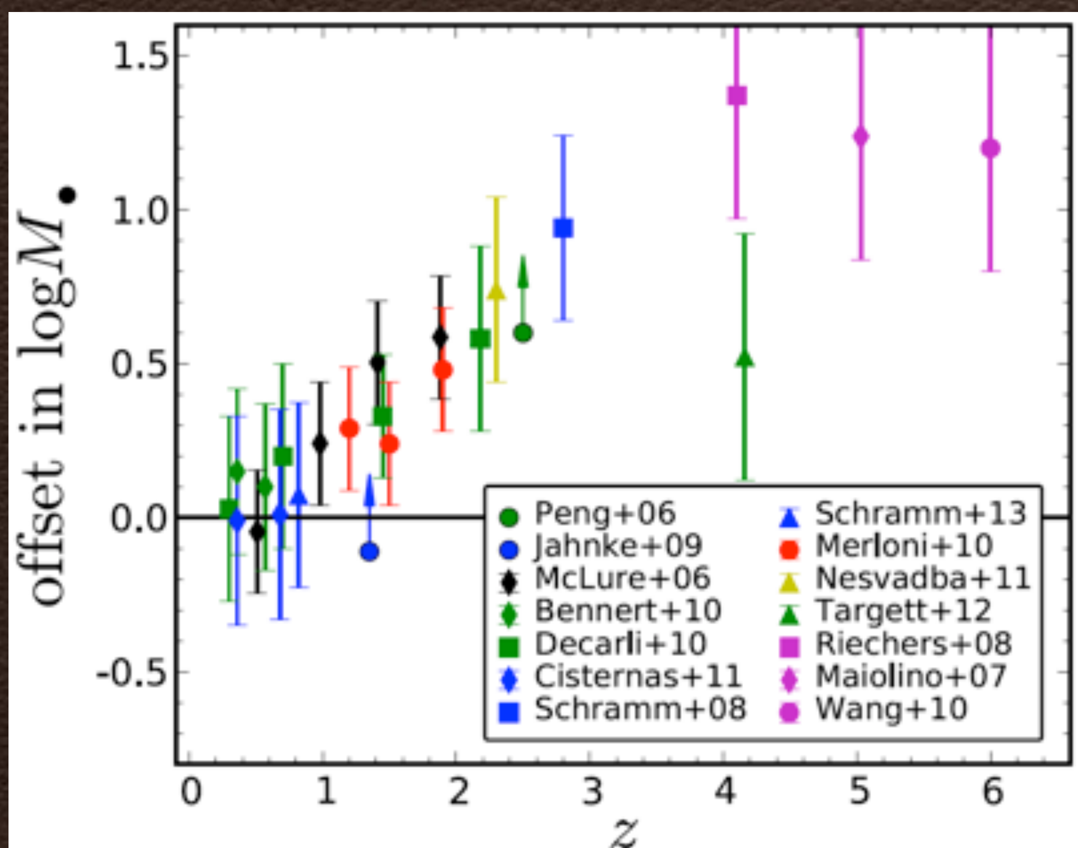
Jahnke+09, ApJ, 706, L215
Lapi+14, ApJ, 782, 69
Sheman+14, arXiv:1410.8514
Schulze & Wisotzki 14, MN, 438, 3422

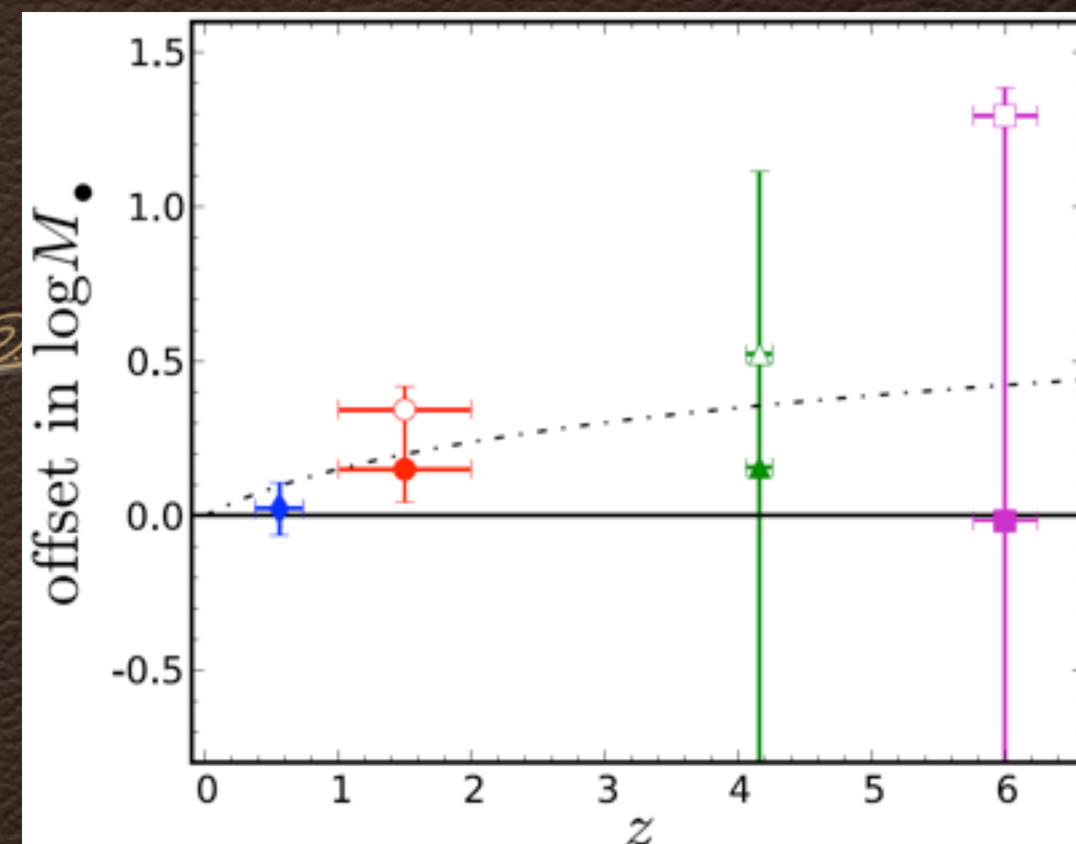
Redshift dependent coevolution

Croton 06, MN, 369, 1808
Robertson+06, ApJ, 641, 90
Lamastra+10, MN, 405, 29
Dubois+11, MN, 420, 2662

Coevolution or not ?
- Cosmological -

observed **selection-effect corrected**





see FILLED symbols

(Schulze & Wisotzki 14, MN, 438, 3422)

(see also, § 8.6.7 & Fig. 38 in KH13)

First IMBH in DM halo @ $z = 30$

$M_{\rm DM\ halo} \sim 10^6\, M_\odot$

$M_{\rm baryon} \sim 10^5\, M_\odot$

$M_\bullet \sim 10^2\, M_\odot$

$M_\bullet / M_{\rm baryon} \sim 0.001$

$\sim$ local value

Coevolution or not ?

1. Uncertainty in low-mass end
2. Large scatter (more than 1 dex)
3. Structure dependent relation
4. Presence of outliers

Not single mechanism ?
Not simple evolution ?

Coevolution or not ?

Not single mechanism ?
Not simple evolution ?

Why do we see rough correlation ?

Starburst-AGN connection may explain ?

Implication
for co-evolution like properties
from starburst-AGN connection

Starburst-AGN Connection

Active SMBHs in metal-enriched gas even at z ~ 7

Starburst comes first, then AGN comes later

Suggesting an evolutionary connection from starburst to AGN

If so, the same driving mechanism works for both starburst & AGN

Evidence for Starburst → AGN connection

AGN tend to show concurrent or post starburst nature

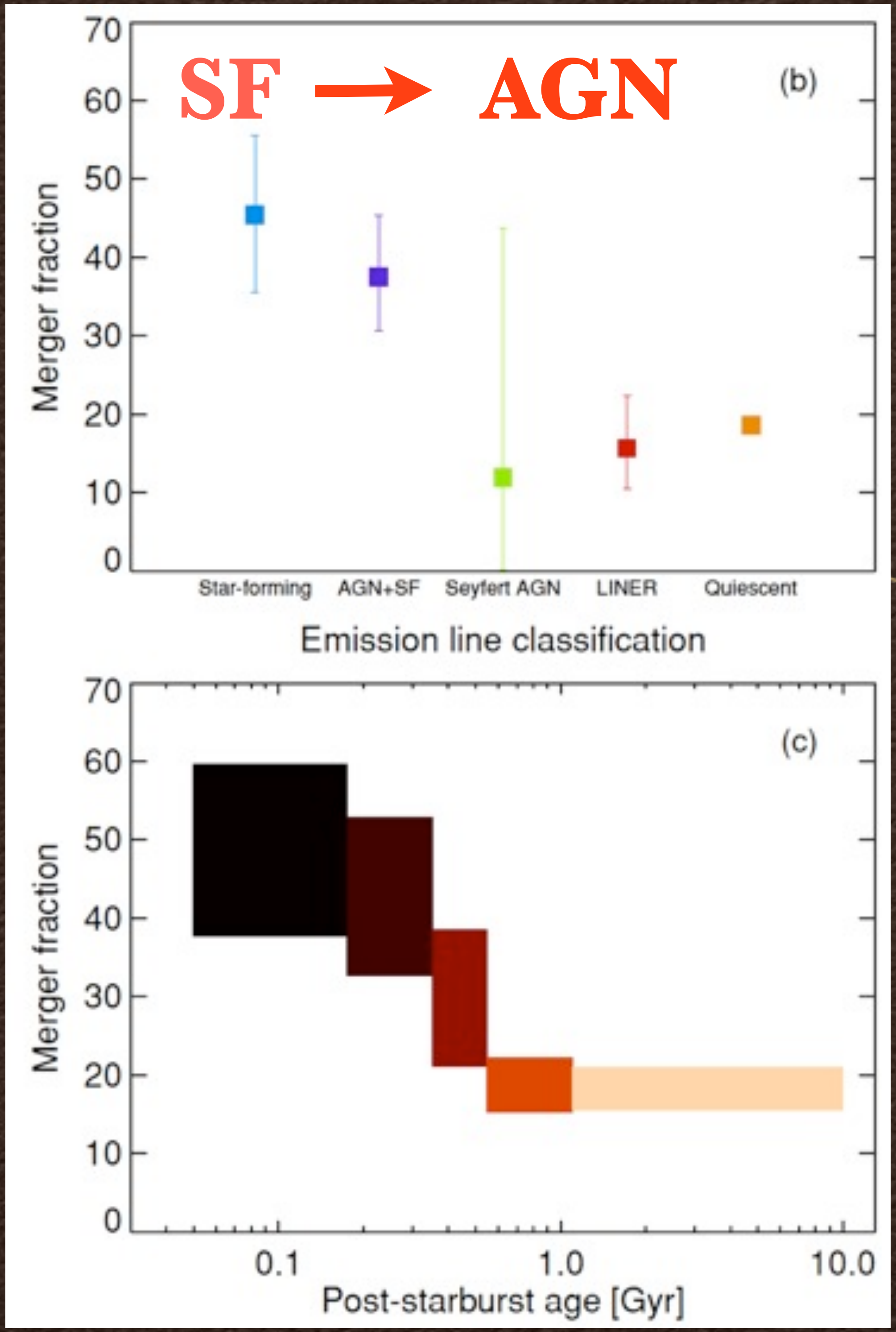
1. Seyferts

   Cid-Fernandes+01, ApJ, 558, 81

2. Quasars

   Kauffmann+03, MN, 311, 576
   Wild+07, MN, 668, 543
   Wild+10, MN, 405, 933
   Matsuoka, Y.+14, ApJ, 780, 165

Evolutionary connection
from starburst to AGN ?



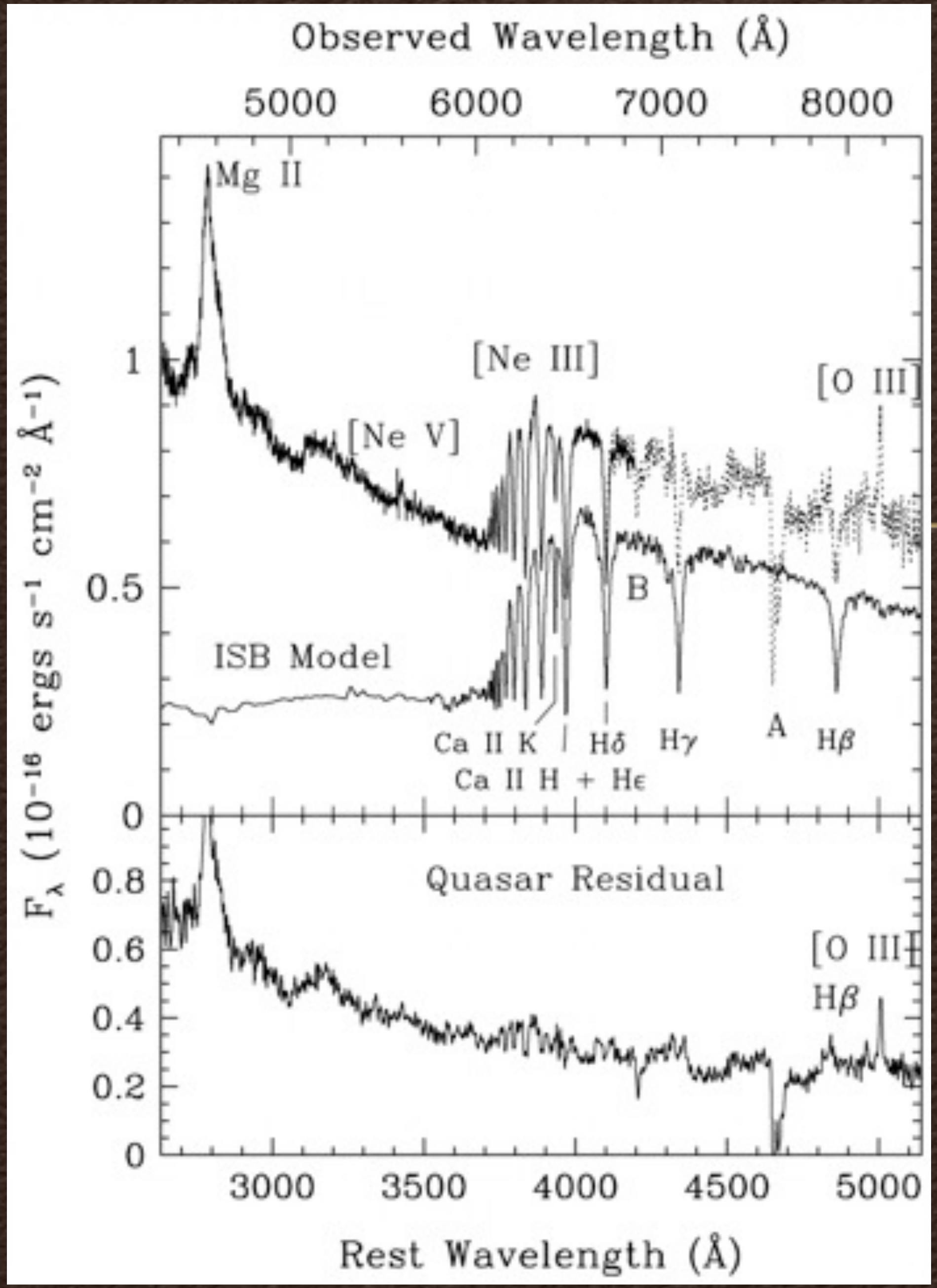
Starbursts:
more disturbed
early phase

Seyferts:
little disturbed
late phase

(Schawinski+10, ApJ, 714, L108)

Post-starburst Quasar

UN J1025-0040 @ z = 0.634



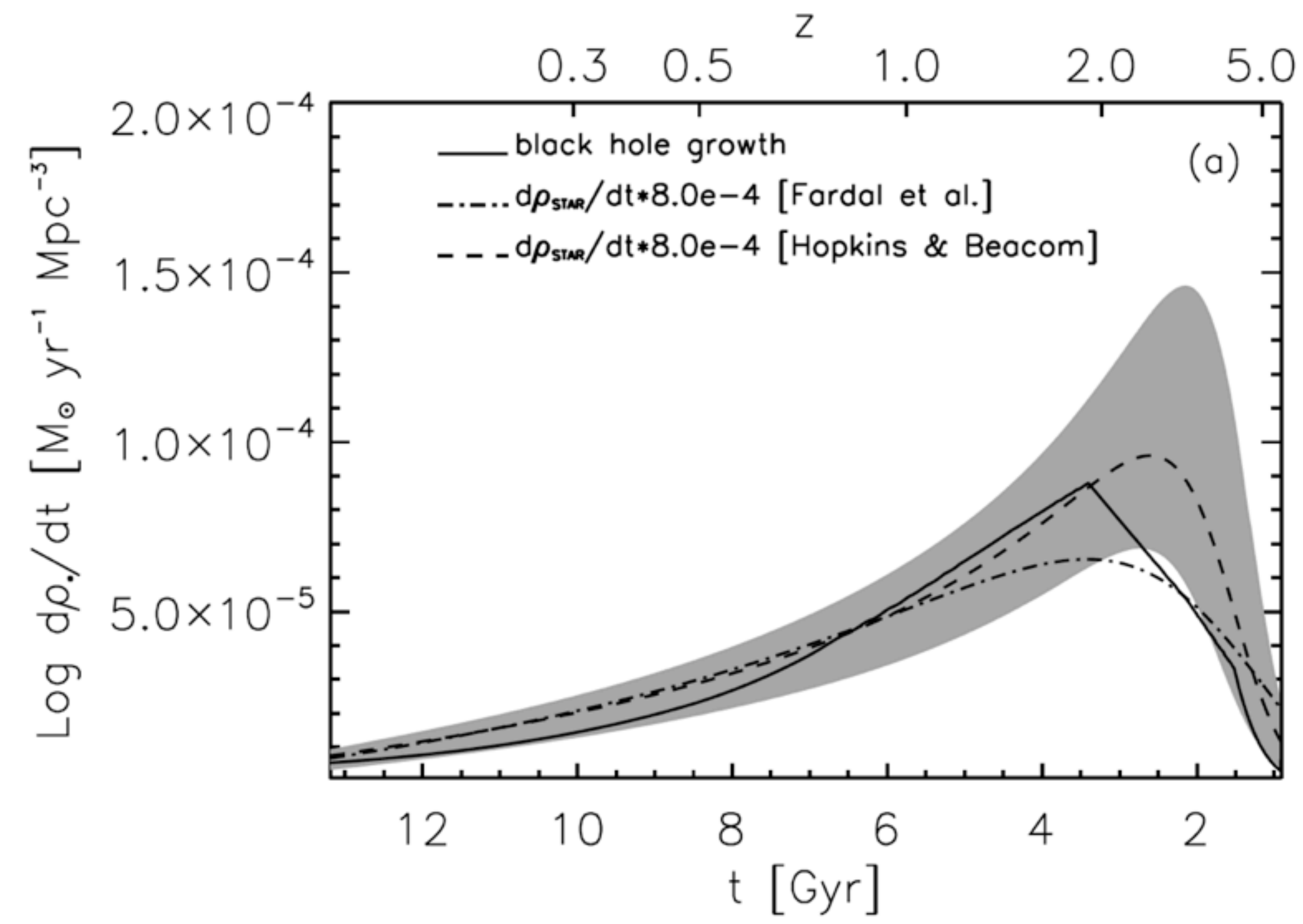
see also,
Cales+13, ApJ, 762, 90

38 PSB quasars

- **$\langle z \rangle \sim 0.3$**
- **major mergers**
- **$M_\bullet \sim 10^8\, M_\odot$**
- **$M_{host} \sim 10^{10.5}\, M_\odot$**
- **$\tau_{SF} \sim 5\times10^8$ - a few Gyr**

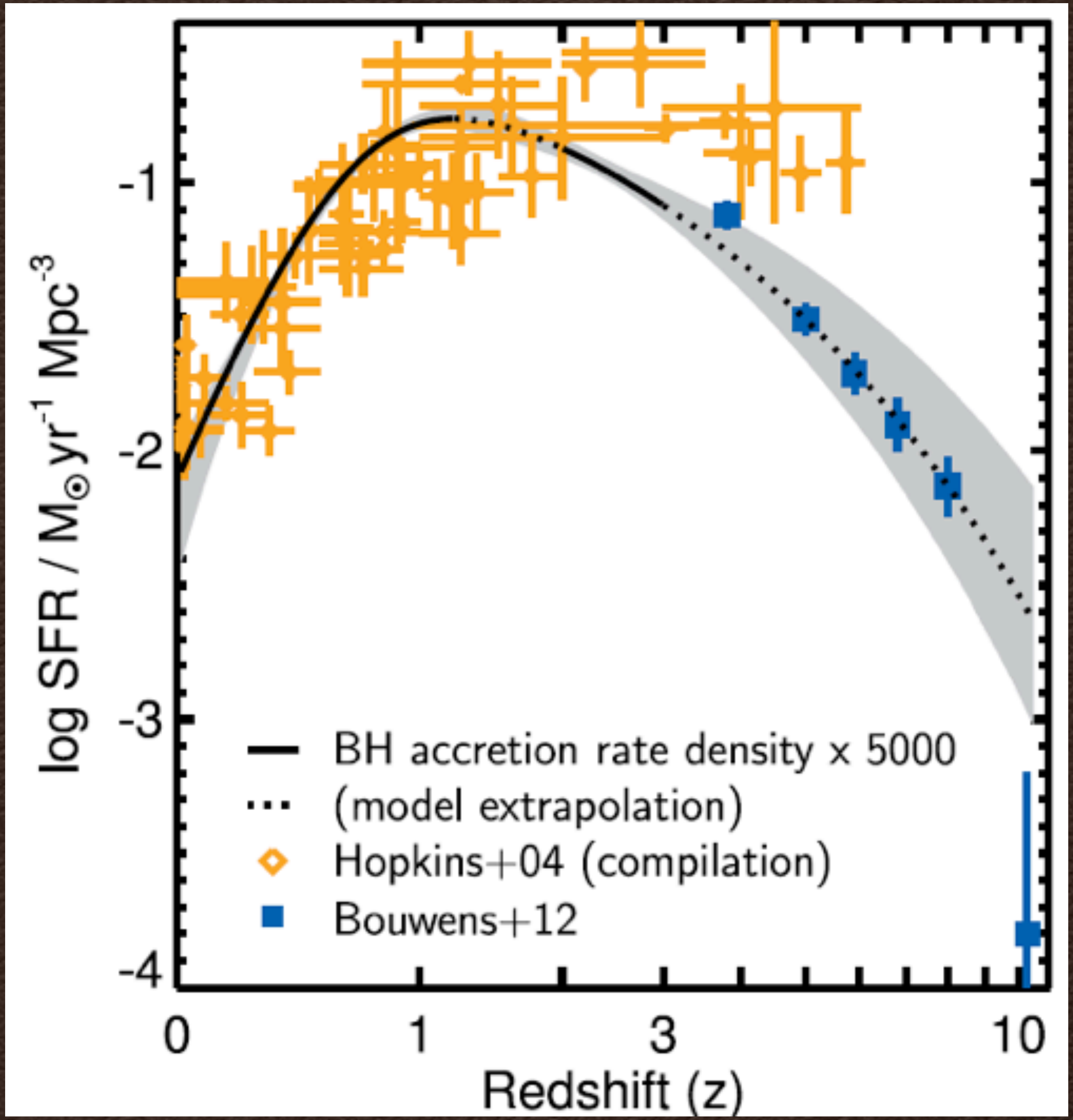
(Brotherton+99, ApJ, 520, L87)

Evolution of BH Growth



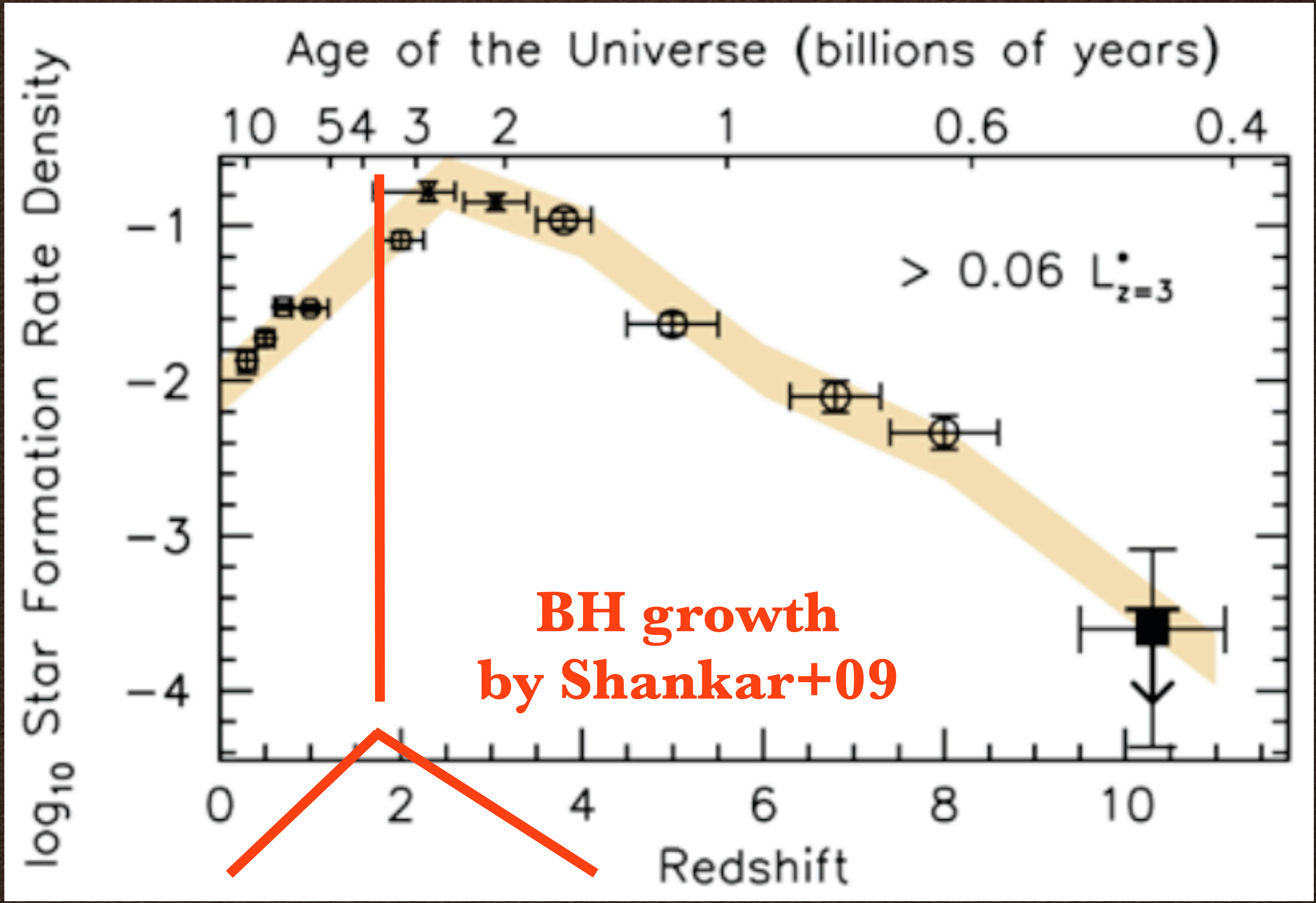
(Schankar+09, ApJ, 690, 20)

Evolution of BH Growth



Kormendy & Ho 13, ARAA, 51, 511

BH growth slower than SF ?



http://www.firstgalaxies.org/the-latest-results

Two types of activity in galaxies

AGN (Seyfert)

$f_{Seyfert}$ ~ 10 % (Ho+97, ApJ, 487, 568)
τ ~ 1 Gyr

Starburst

$f_{Starburst}$ ~ 3 % (Balzano 83, ApJ, 268, 602)
τ ~ 0.5 Gyr

HII nuclei

f_{HII} ~ 20 % (Ho+97, ApJ, 487, 568)

Seyfertization

(Taniguchi 1987, ApJ, 317, L57)

$N_{OB} > 10^4$ stars in a nuclear region

Working Hypothesis

Activity never occurs in isolated galaxies

Activity inevitably occurs in mergers between nucleated systems

M32 =
nucleated satellite

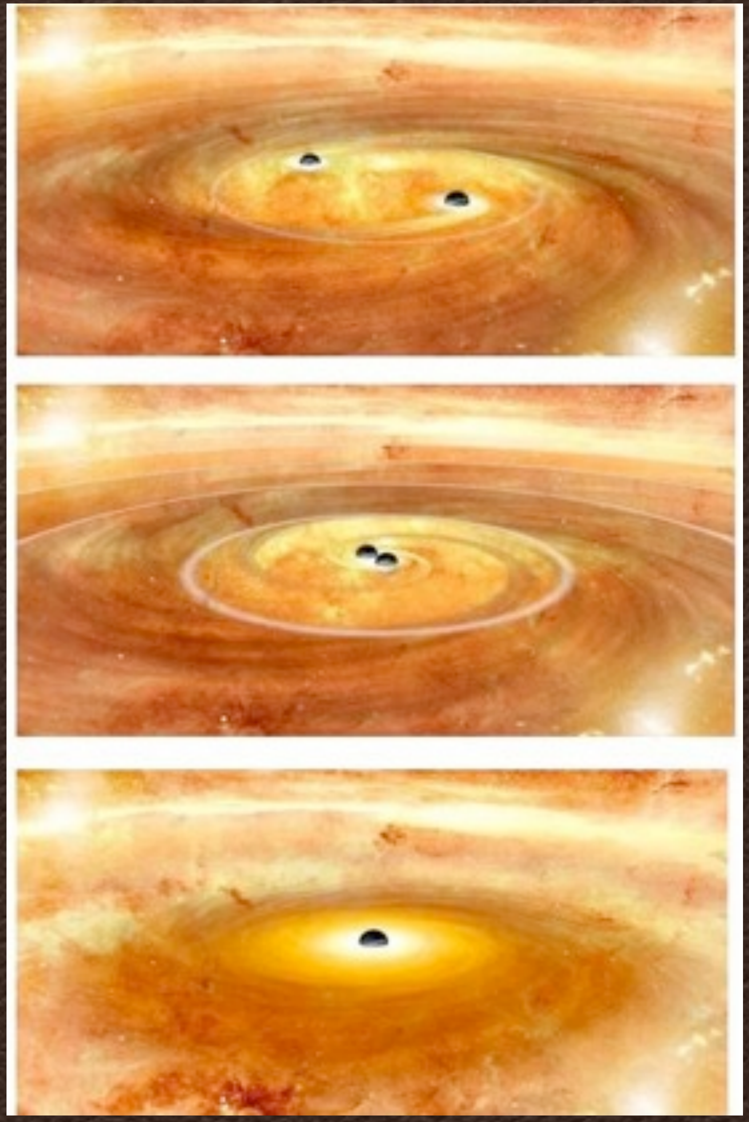
M31 will be Seyfertized

LMC =
non-nucleated satellite

MW will NOT be
Seyfertized

If the partner is nucleated, two SMBHs can inspiral and then merge into one

~ 1 Gyr journey



(Satoru Iguchi)

(see also Khan+12 ApJ, 756, 30)

Nucleated-Merger-Driven Evolutionary Unified Model

Seyfert

r < 1 pc

Taniguchi 99
ApJ, 524, 65

Starburst

r ~ 10 - 100 pc

Taniguchi & Wada
96, ApJ, 469, 581

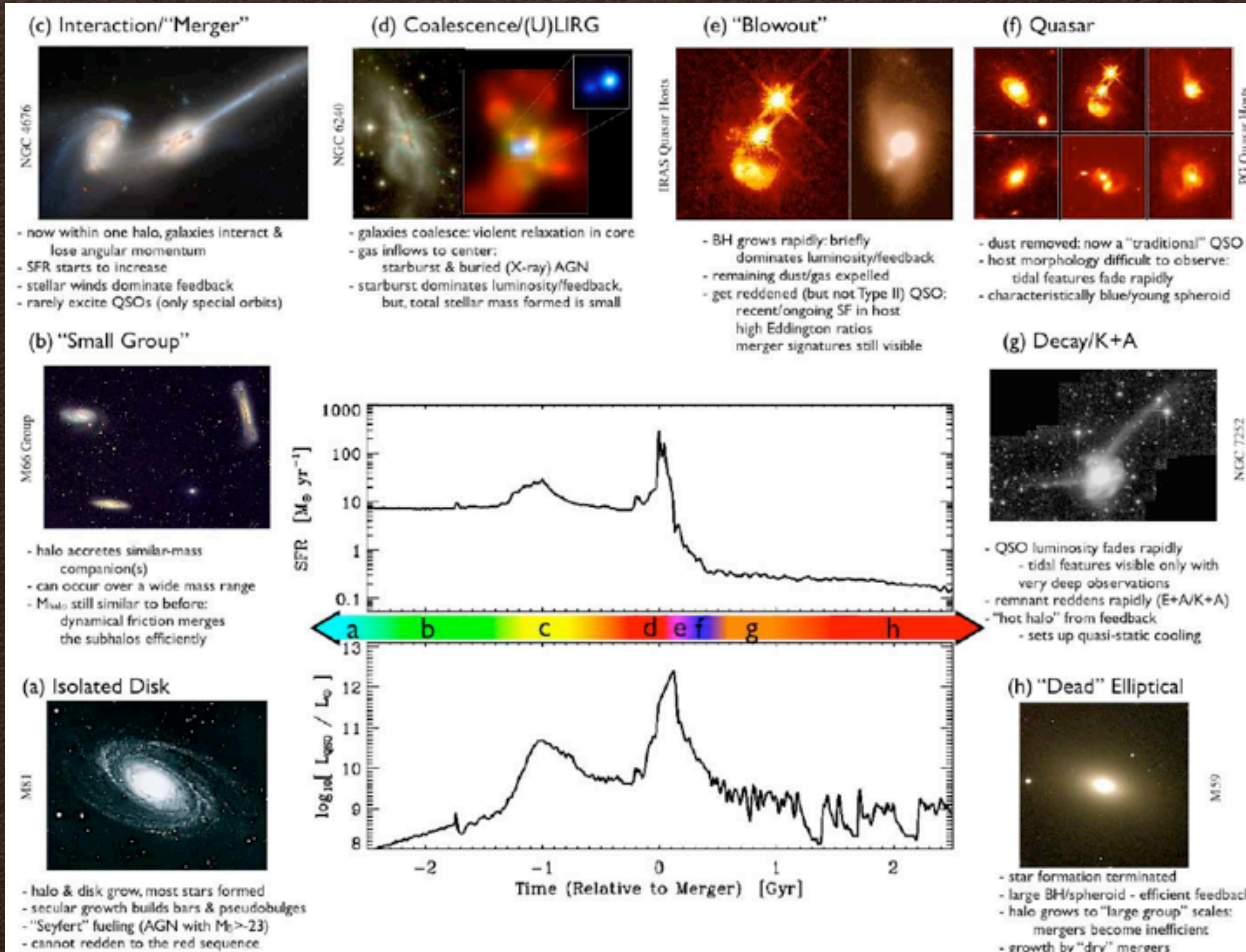
Normal

Starburst-AGN Connection High-L version

major merger between/among gas-rich galaxies ⟶ ULIRG ⟶ Quasar

1. Major merger between galaxies
   Sanders+88, ApJ, 325, 74
   Hopkins+08, ApJS, 175, 356

2. Multiple merger among galaxies
   Taniguchi & Shioya 98, ApJ, 501, L167
   Borne+00, ApJ, 529, L77
   Bekki 01, ApJ, 546, 189
   Taniguchi+12, ApJ, 753, 78



(Hopkins+08, ApJS, 175, 356)

Starburst-AGN Connection
Low-L version

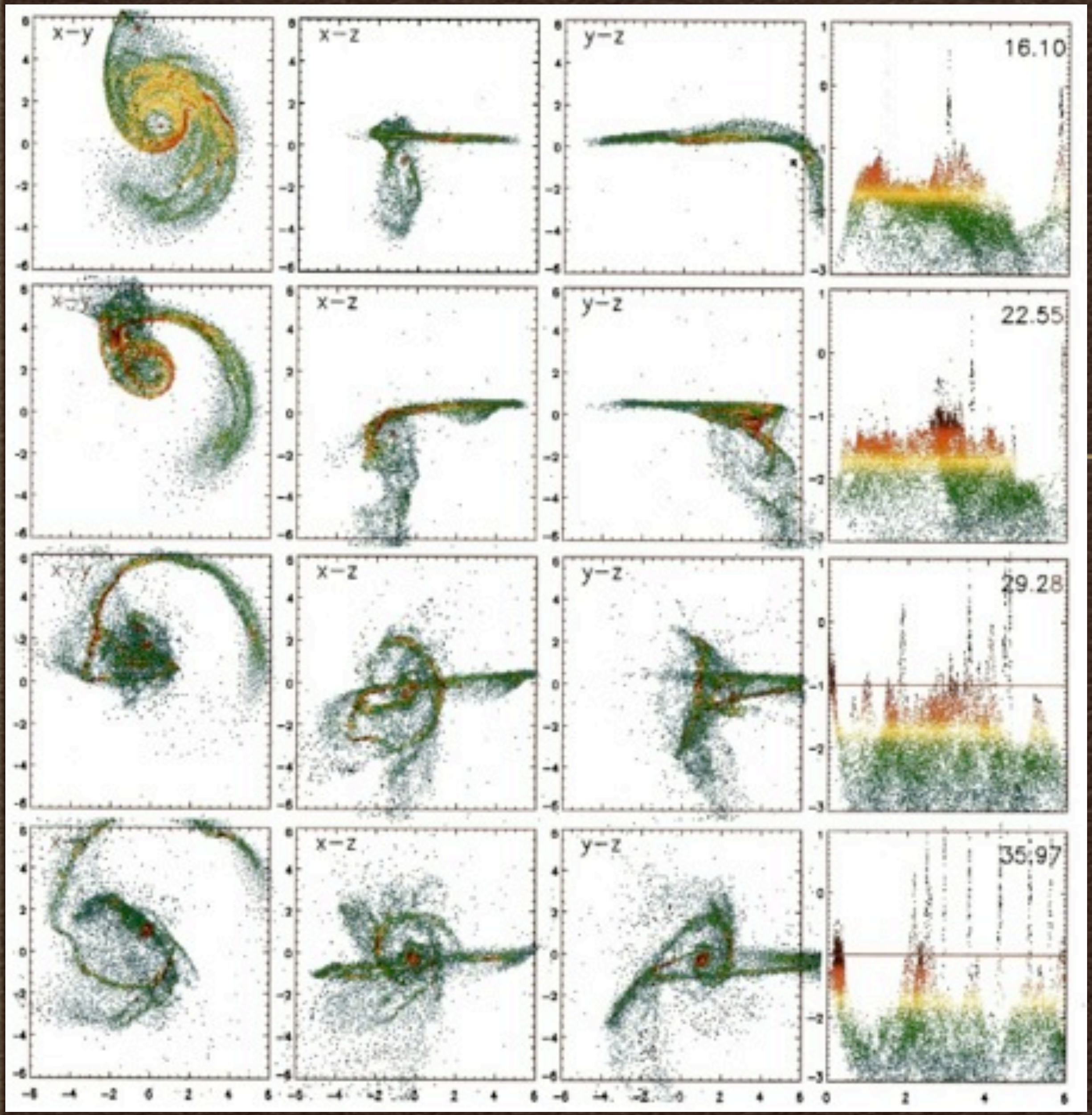
minor merger
with
a nucleated satellite → Nuclear Starburst → Seyfert

1. Nuclear Starburst
   Taniguchi & Wada 1996, ApJ, 469, 581

2. Seyfertization
   Taniguchi 99, ApJ, 524, 65

Minor Merger Drives Nuclear Starburst

Minor merger with a nucleated satellite



SMBH binary makes strong shocks, driving nuclear starburst

(Taniguchi & Wada 1996, ApJ, 469, 581)

Nucleated MERGER-Driven MODEL for Triggering AGNs

ONLY Major Merger → *Quasar*

(Sanders+88, ApJ, 325, 74)

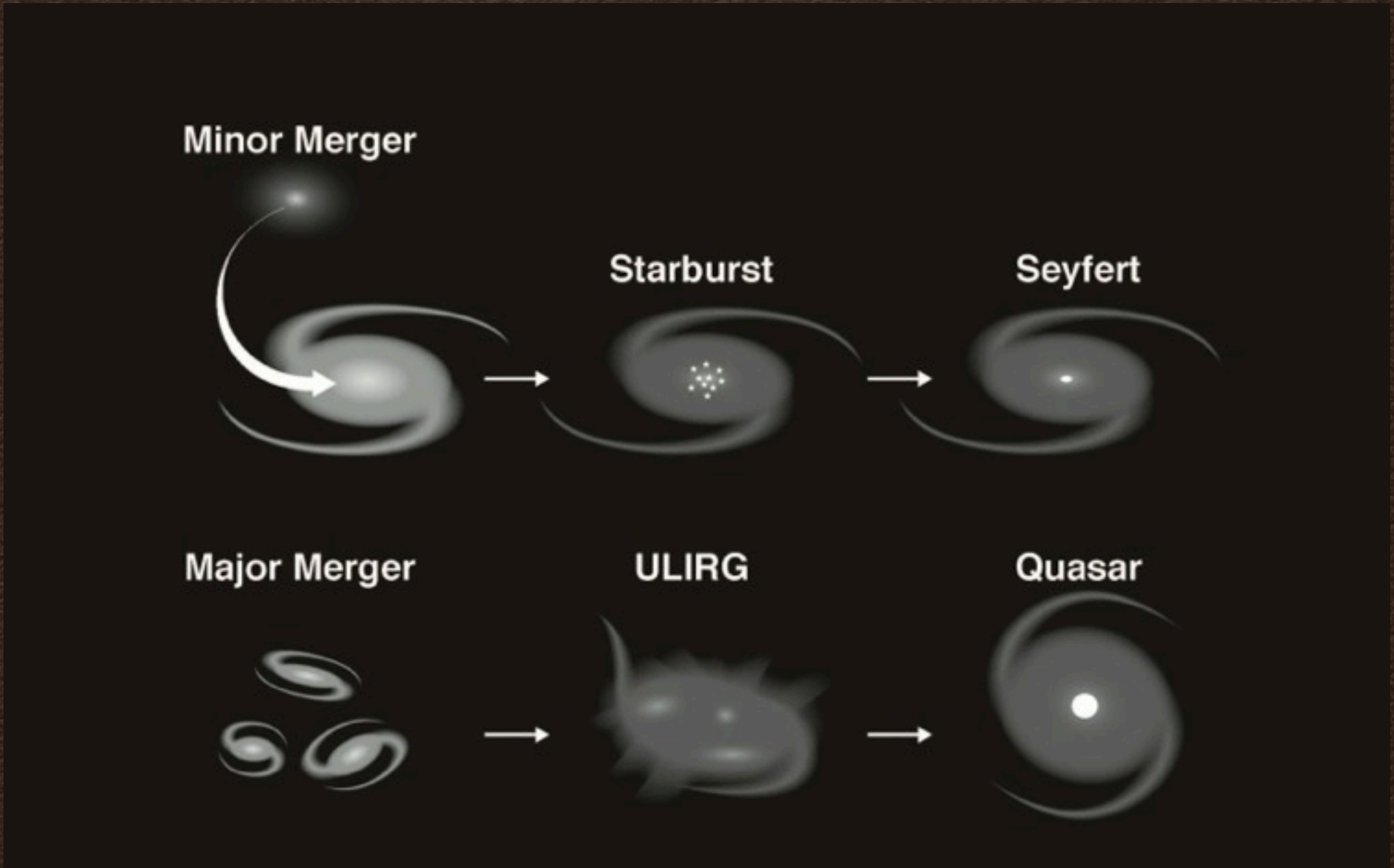
(see also Hopkins+08, ApJS, 175,356)

(see also Taniguchi+12, ApJ, 753, 78)

ONLY Minor Merger → *Seyfert*

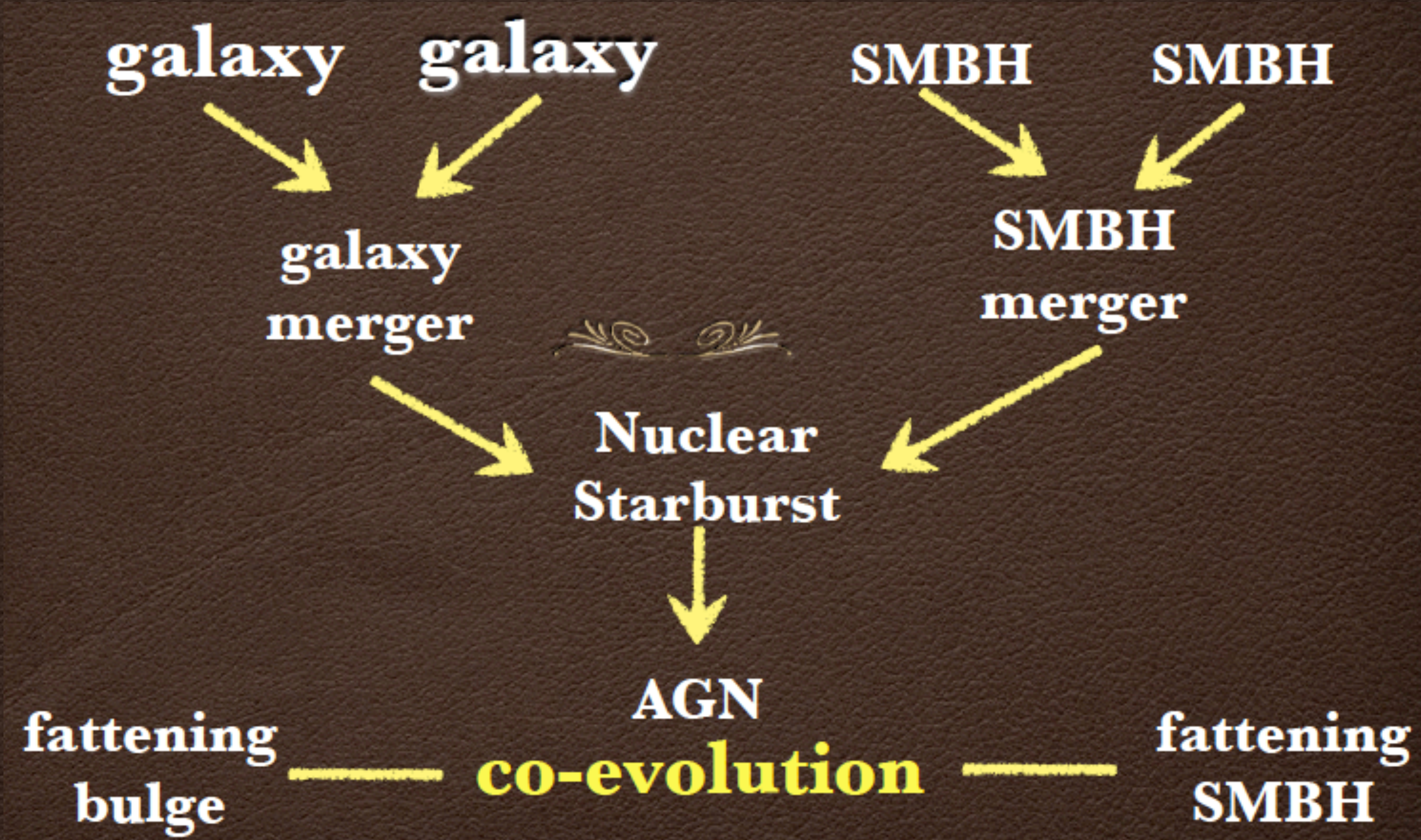
(Taniguchi 99, ApJ, 524, 65)

Nucleated Merger-Driven EVOLUTIONARY Unified Model for Triggering Nuclear SB & AGNs



(Taniguchi 13, ASPC, 477, 265)

Implication for Quasi-coevolution



(Taniguchi 13, EWASS2013)

AGN stops here

No star formation for a while

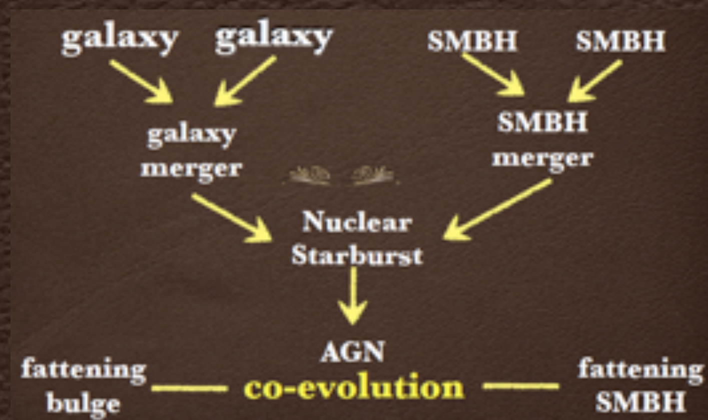
because

Circumnuclear gas swept up !

Co-evolution stops here

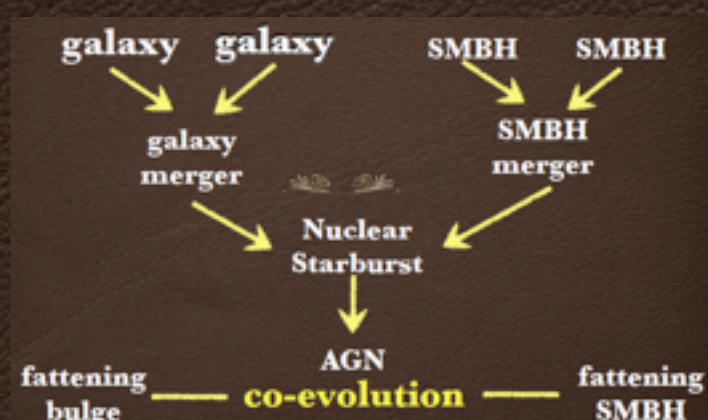
Intermittent co-evolution

no evolution



co-evolution

no evolution



co-evolution

no evolution

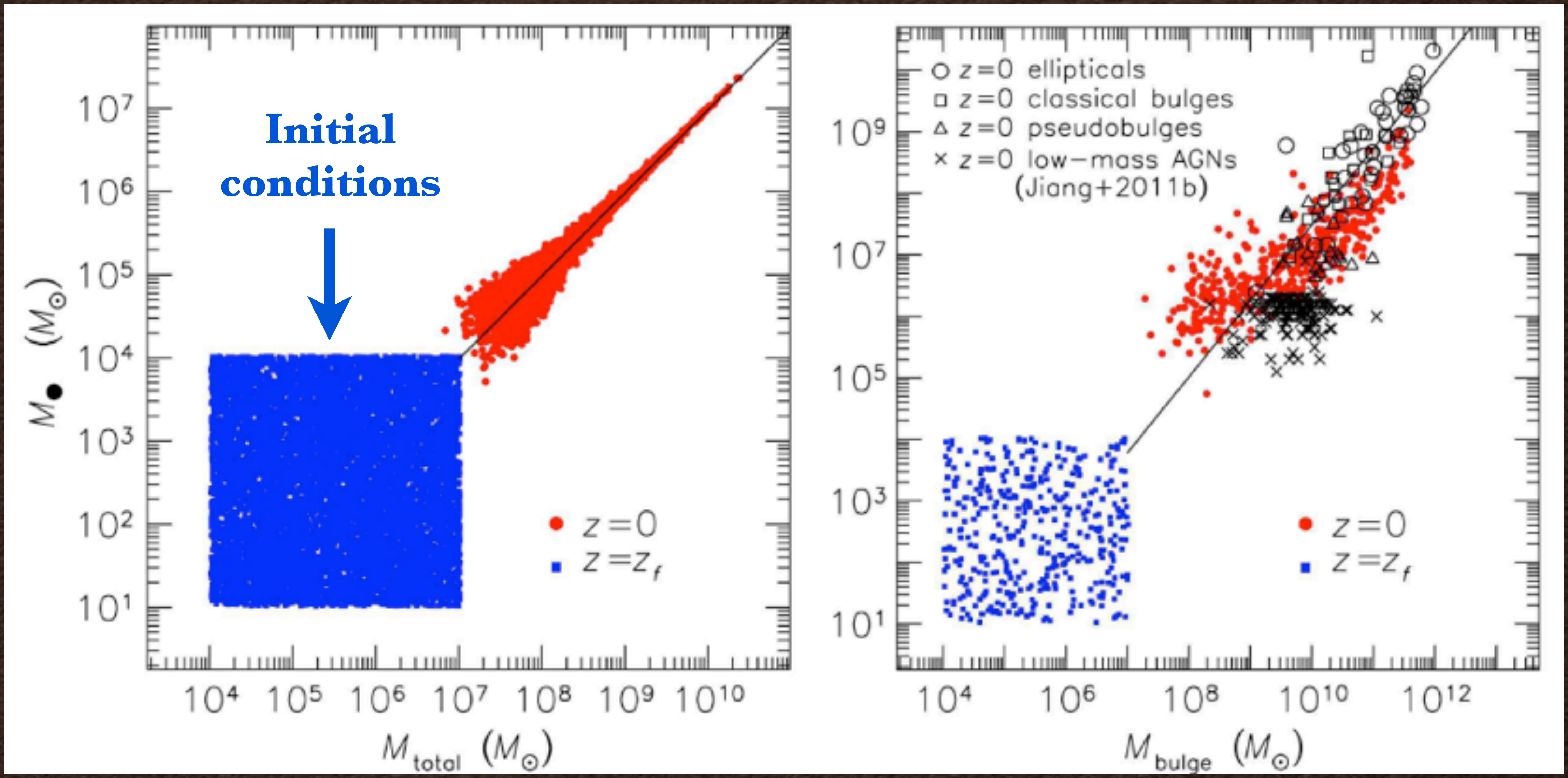
Intermittent model may explain the observed $M_{\bullet}$–$M_{\rm bulge}$ relation

Relation depends on

1. How many merger events ?
2. How intense in each event ?
3. How long in each event ?
4. In which phase we observe ?

Merger-Driven Coevolution

originally proposed by Peng 07, ApJ, 671, 1098
see also, Hirschmann+10, MN, 407, 1016
Jahnke & Maccio 11, ApJ, 734, 92



(Jahnke & Maccio 11, ApJ, 734, 92)
(Kormendy & Ho 13, ARAA, 51, 511: Fig. 37)

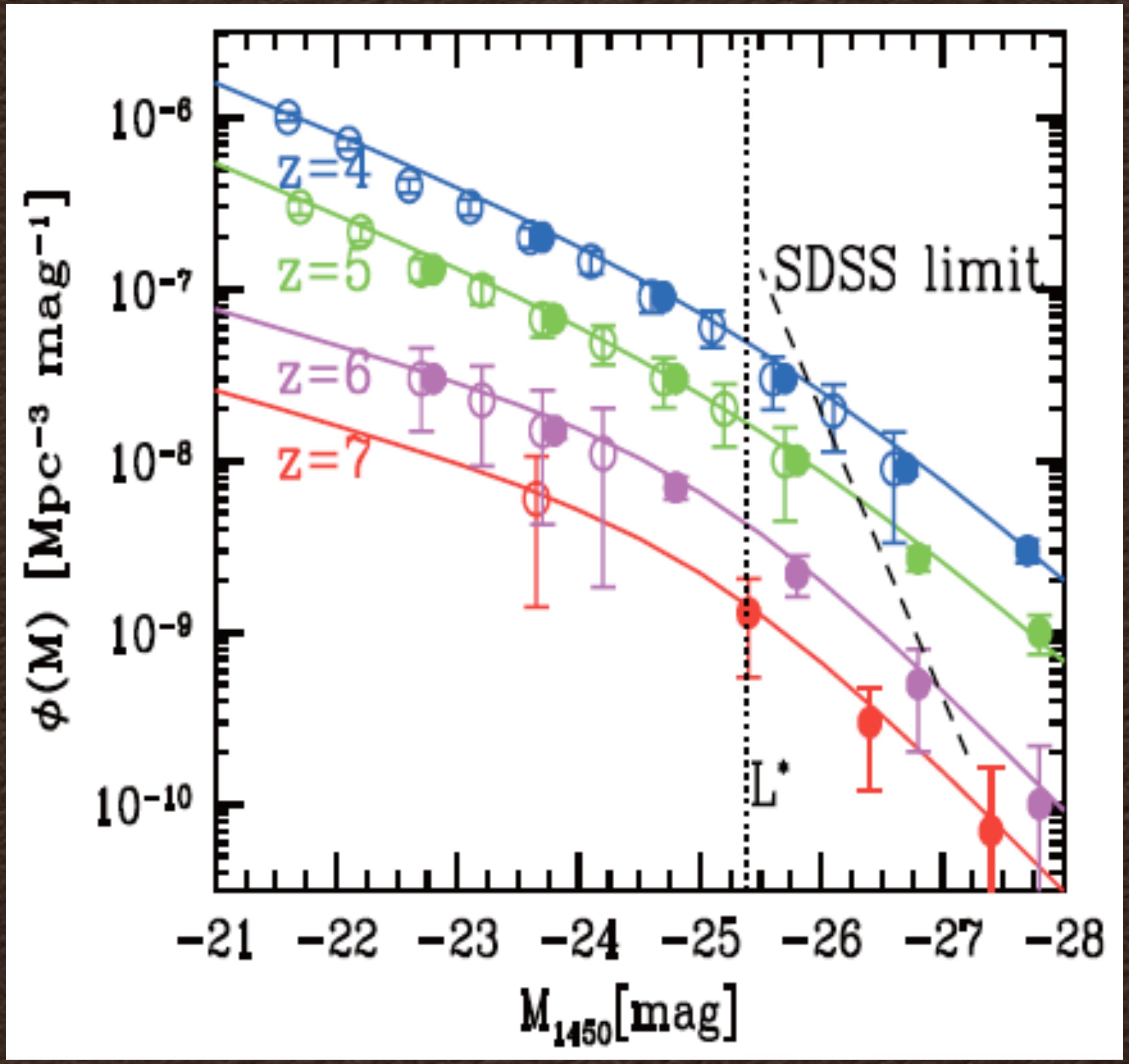
What drives mass growth @ $z \sim 7$ - 30 ?

1. Super Eddington accretion ?
   e.g., Super-critical accretion via a slim disk
   Madau+14, ApJ, 784, L38
2. Eddington accretion + successive mergers
   Taniguchi 04, PTPS, 155, 205
3. Runaway merger in a star cluster with gas inflow
   Alexander & Natarajan 14, Sci, 345, 133
4. Successive mergers of hosts
   Tanaka 14, arXiv:1405.3023
5. Accretion of radiatively-cooled gas
   Park & Ricotti 12, ApJ, 747, 9

Which environ SMBHs favor ?

Need more studies

Quasar Survey by HSC/SSP (Miyazaki+ on going !)

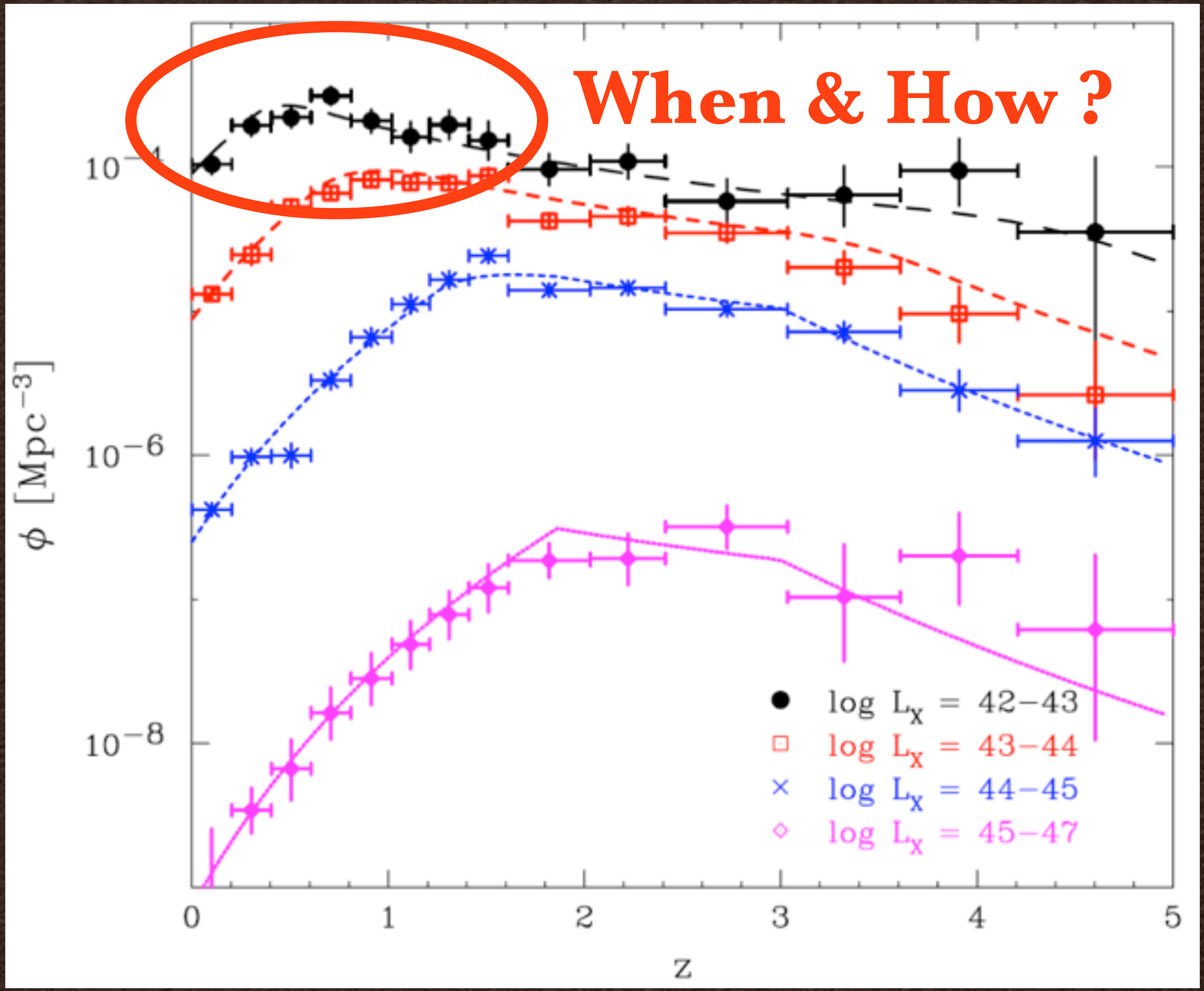


○ Deep
● Wide

Table 7: Quasar Samples

	Wide (1400 deg^2)				Deep (27 deg^2)			
redshift	3.7–4.6	4.6–5.7	5.9–6.4	6.6–7.2	< 1	3.7–4.6	4.6–5.7	6.6–7.2
mag. range	$r < 23.0$	$i < 24.0$	$z < 24.0$	$y < 23.4$	$i < 25.0$	$i < 25.0$	$i < 25.0$	$y < 25.3$
number	6000	3500	280	50	2000	200	50	3

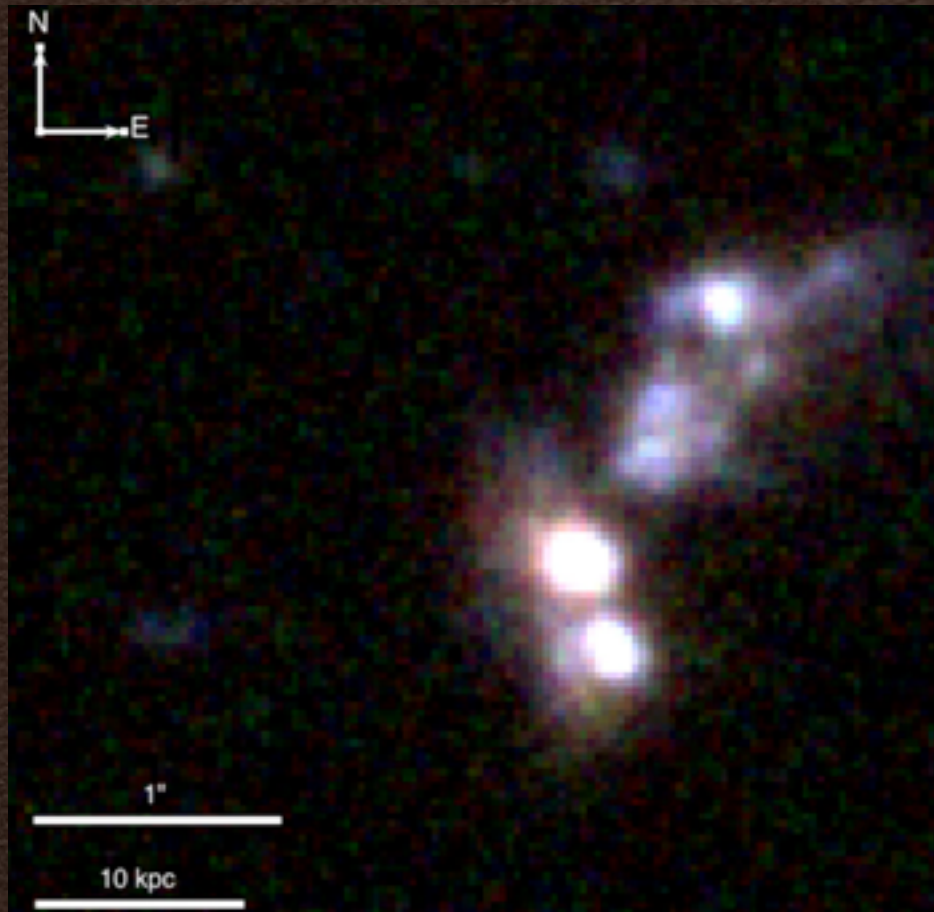
Down sizing in AGNs

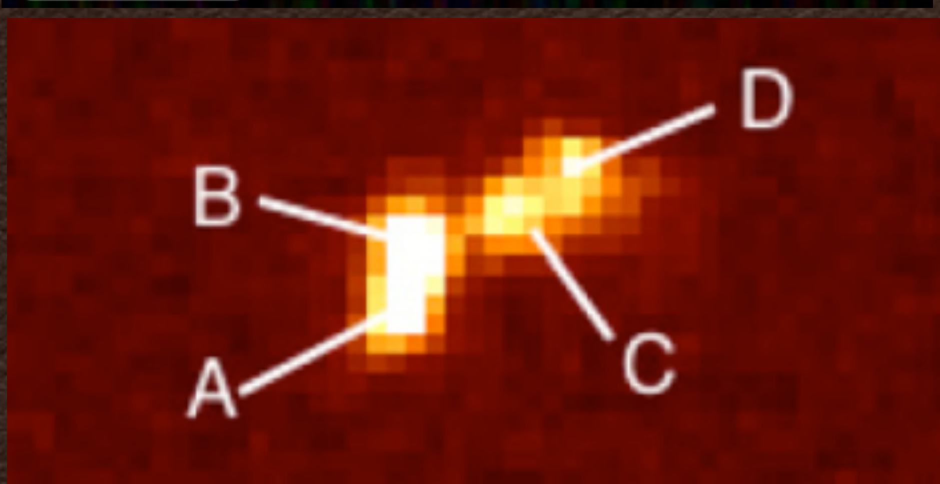


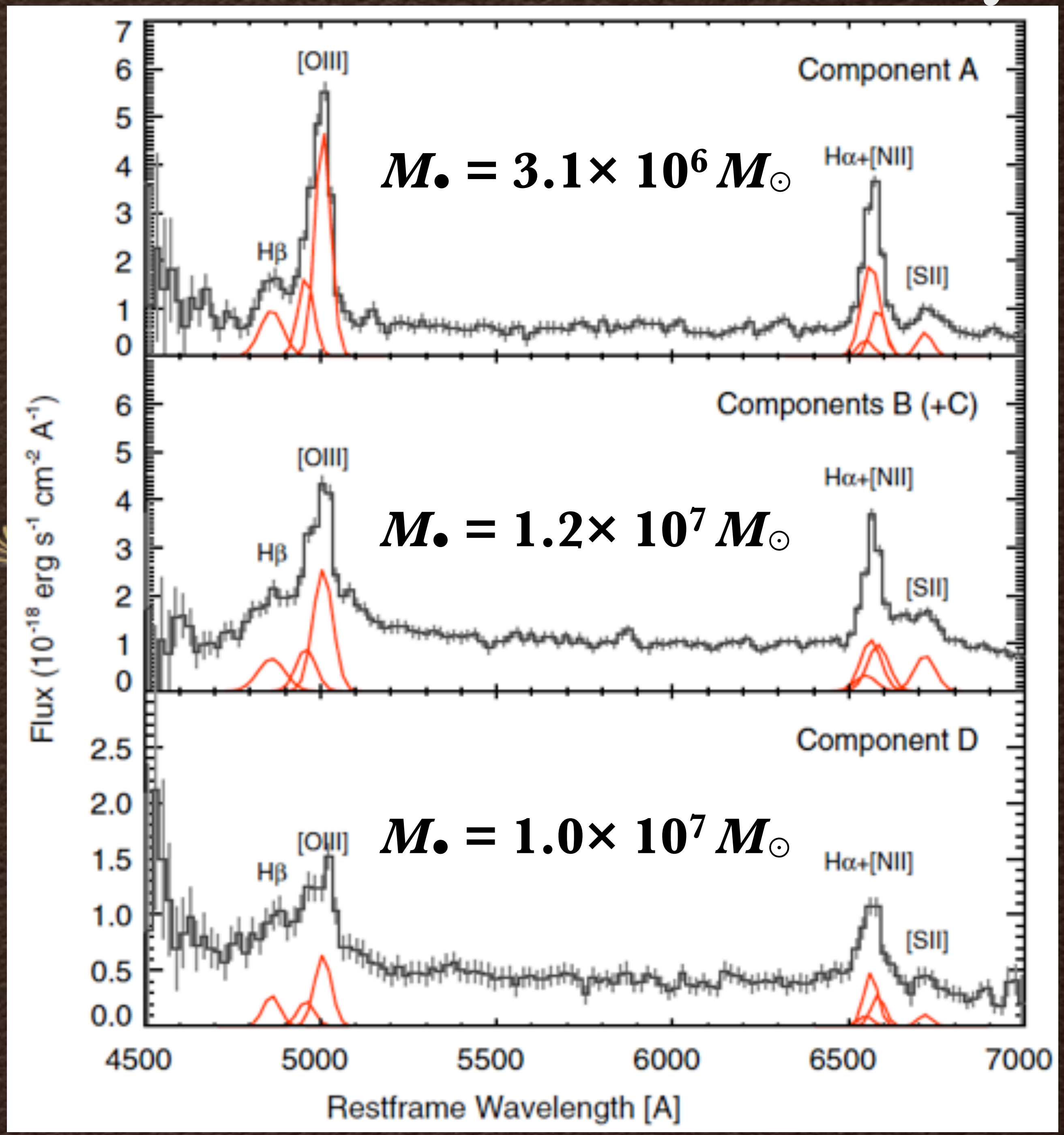
(Ueda+14, ApJ, 786, 104)

SMBHs with $M_\bullet \sim 10^{6\text{-}7} M_\odot$ @ $z = 1.3$

T = 4.8 Gyr



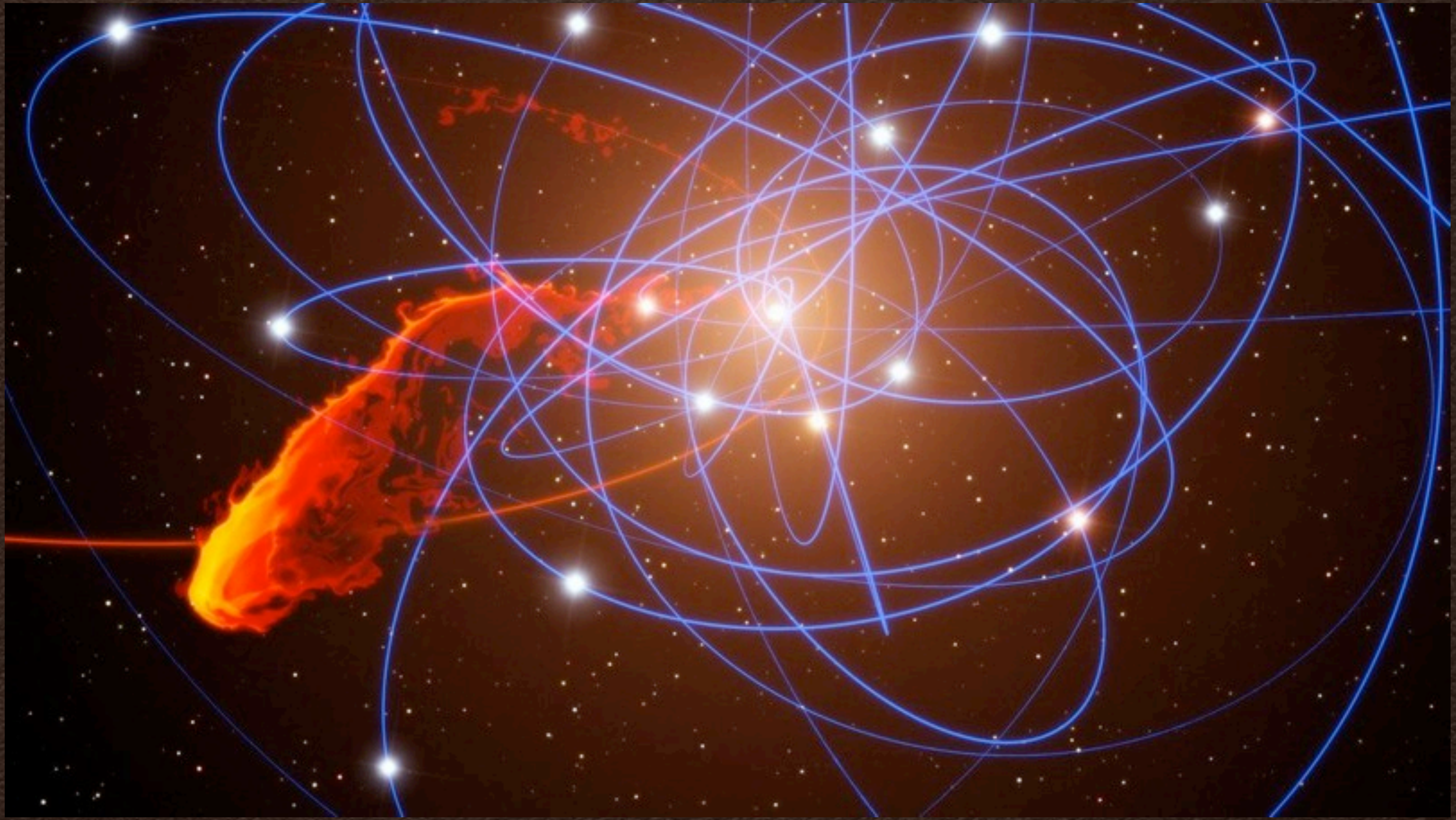




(Schawinski+11, ApJ, 743, L37)

When & how formed ?

$M_\bullet \sim 4 \times 10^6 M_\odot$ in MW

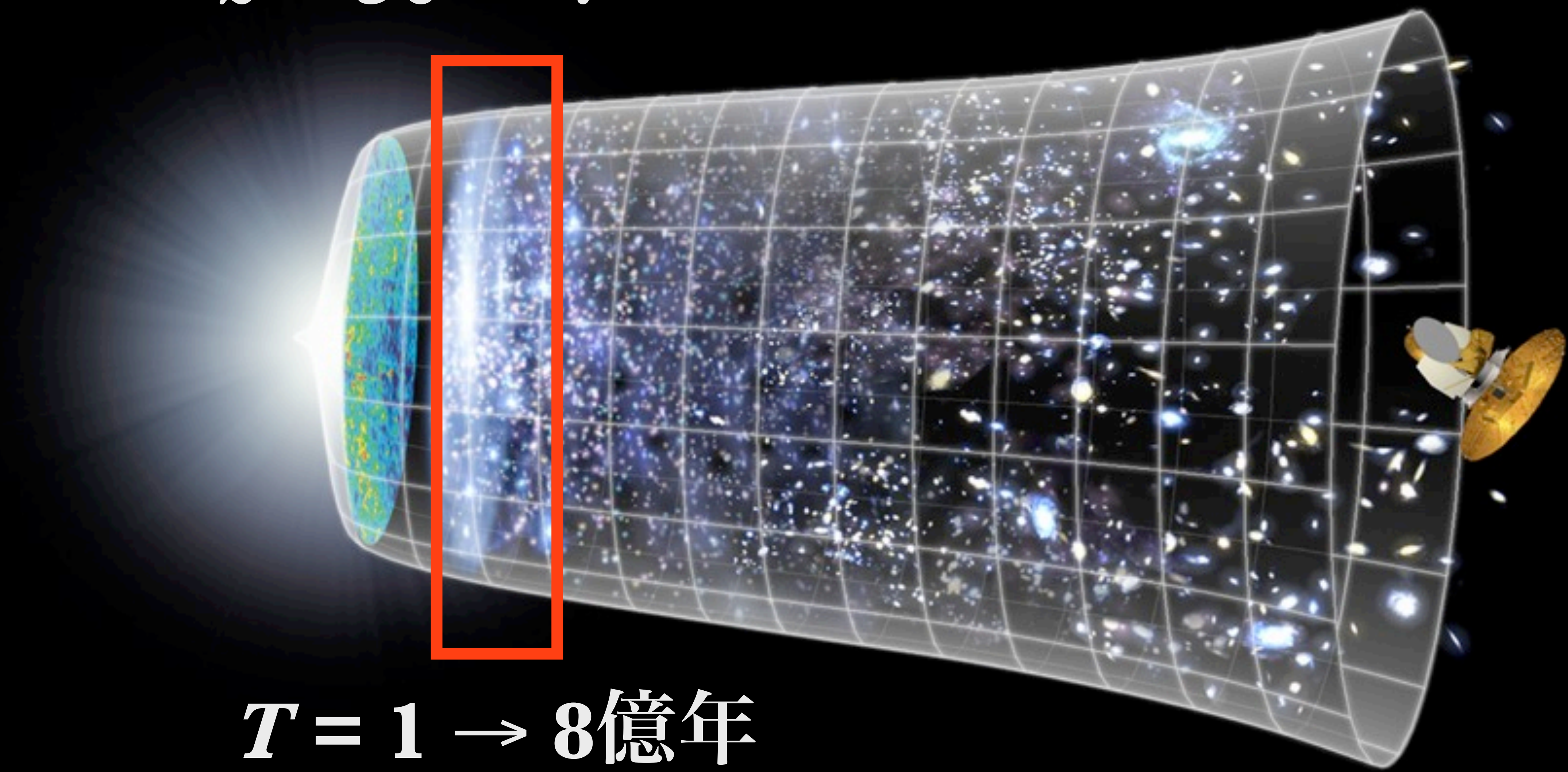


http://en.wikipedia.org/wiki/Sagittarius_A*#mediaviewer/File:G2Cloud_eso1151a.jpeg

Need FULL Understanding on Formation of SMBHs from $z \sim 30$ (?) to 0

Probing AGNs in Early Universe beyond $z \sim 7$

$z = 30 \rightarrow 7$



$T = 1 \rightarrow 8$億年

NASA/WMAP Science Team

The Era of IR Space Telescope

	Euclid	WFIRST	WISH
Mirror	1.2m	1.3m	1.5m
FoV	0.5 deg^2	0.3deg^2	0.23deg^2
Visual Imager	RIz	↓	--
NIR Imager	YJH	0.6-2.0μm	0.9-5.0μm
Lim. Mag.	24AB	25.9AB	28AB
Survey Area	20,000 deg^2	>11,000 deg^2	100 deg^2
Primary Science	Dark Energy	DE, Exoplanet, QSO	First Galaxies

(from presentation by Iwata 12, WISH SW)

WISH Survey for High-z Quasars

	Filter set 3 f1バンド検出 (f0-f1 > 1により選択)				Filter set 3 f2バンド検出 (f1-f2 > 1により選択)			
redshift	UWS Case 1	UWS Case 2	UWS Case 3	UDS	UWS Case 1	UWS Case 2	UWS Case 3	UDS
6 – 7	0	0	0	0	0	0	0	0
7 – 8	7	13	35	8	0	0	0	0
8 – 9	10	18	47	11	0	0	0	0
9 – 10	2	4	9	3	0	0	0	0
10 – 11	< 1	1	1	1	< 1	1	1	< 1
11 – 12	< 1	< 1	< 1	< 1	< 1	< 1	1	< 1

UWS

Case 1 … < 25.5 mag, 400 deg^2

Case 2 … < 25.0 mag, 1000 deg^2

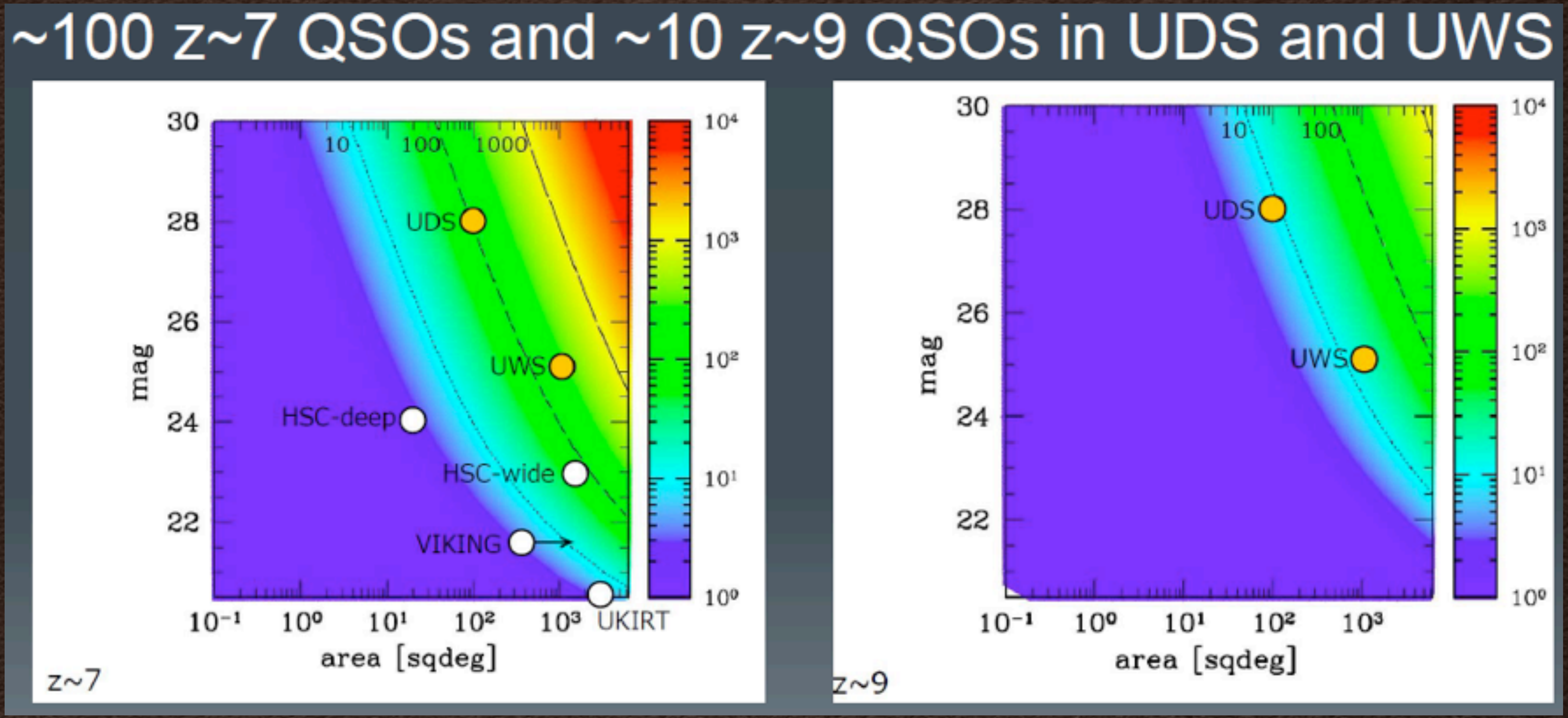
Case 3 … < 24.0 mag, 6300 deg^2

UDS

< 28.0 mag, 100 deg^2

(from presentation by Matsuoka 12 WISH SW)

WISH Survey for High-z Quasars



(from presentation by Kashikawa 12, WISH SW)

宇宙の一番星は見えるか？

M_u	N	$z=10$	$z=20$	$z=30$
($M_\odot$)		(1.65 μm)	(3.15 μm)	(4.65 μm)
500	1	38.4	39.3	39.9
500	100	33.4	34.3	34.9
500	10000	28.4	29.4	29.9
100	1	40.9	41.8	42.4
100	100	35.9	36.8	37.4
100	10000	30.9	31.8	32.4

まず、見えない・・・

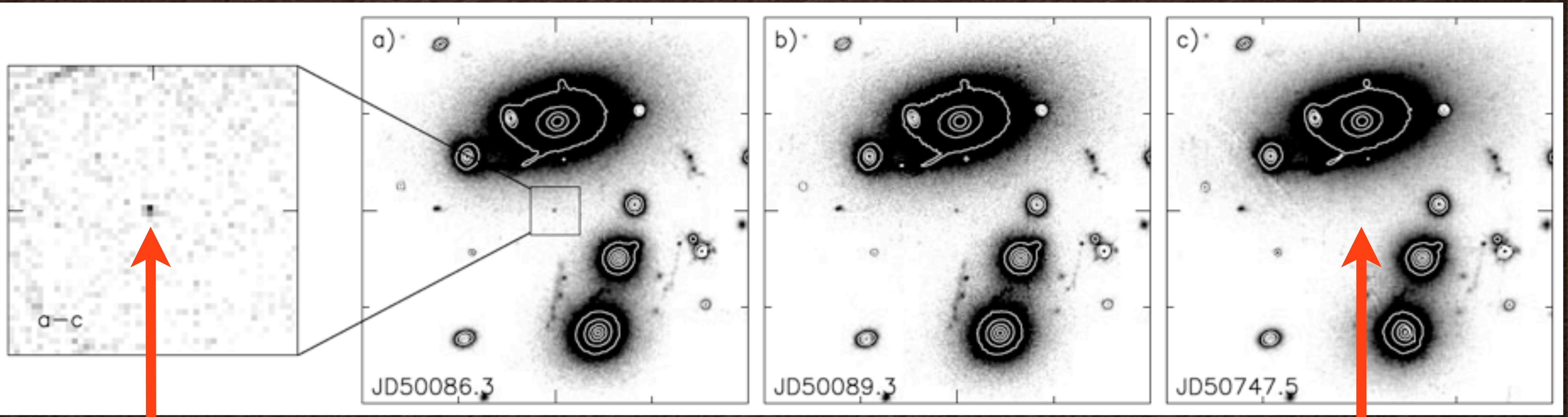
JWST Ultra Deep Field

	Ultra Deep		Shallow Wide		
Filter	AB S/N=5	Exposure Time (hrs)	AB S/N=3	Number of fields	Exposure Time (hrs)
F070W	30.3	23.4	28.5	7	8.8
F090W	30.6	35.8	28.5	7	7.7
F115W	30.9	54.2	28.5	7	6.8
F150W	31.3	97.6	28.6	7	5.8
F200W	31.3	83.2	28.7	27	5.0
F270W	31.3	83.2	28.7	27	15.2
F336W	31.3	83.2	28.7	27	124
F444W	30.9	99.8	28.2	27	77.7
Total		294.2			223.4

http://www.stsci.edu/jwst/doc-archive/white-papers/first_light_study_V.pdf

Thanks to Lensing ?

ACS 114 @ z = 0.31



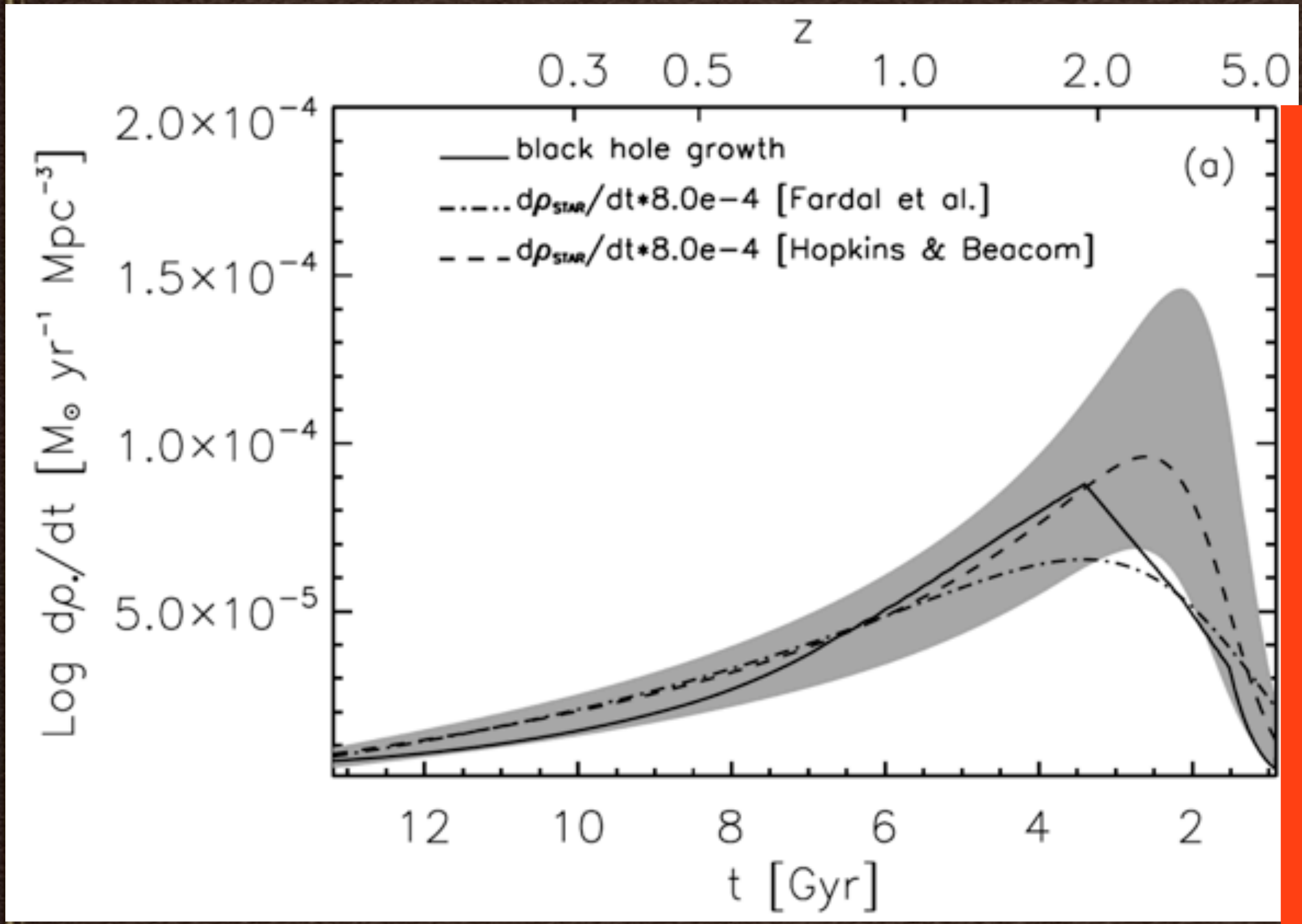
Possible SN Ia with R_{702} = 26.3

Disappeared 21 moth later

Need JWST Frontier Field !

(Sullivan+00, MN, 319, 549)

Evolution of BH Growth



model prediction

now !

observation

>10 yrs later

(Schankar+09, ApJ, 690, 20)

Final Remark

Why are any SMBHs resided in the center of galaxies ?

Open Issues
not discussed in KH13

1. *Why rapid SMBH growth at high redshift ?*

2. *Why not many SMBH binaries ?*

3. *Why in the center of galaxies ?*

宇宙では

起こりうることしか

起こっていない