Toward “Complete Census” of Supermassive Black Holes with ULTIMATE

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Considerations: from SMBH/AGN perspective

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- ✶ We may still want to do JH survey over the area overlooked by WFIRST.
  (e.g., HSC/PFS survey fields where abundant targets are available for follow-up.)
- ✶ AGNs are point sources and benefit from the sensitivity improvement with GLAO.
  Do we also gain from the better spatial resolution?
- ✶ Broad-line AGNs are relatively sparse on the sky (~10 per 15’ FoV at $i < 24$ mag).

Questions from the organizers

Q1: What is the key science/observations for ULTIMATE in your research field?
✶ "Complete census" of supermassive black holes (SMBHs) by a HK spectroscopic survey, combined with the HSC and PFS surveys.
(✶ Also, systematic IFS observations of AGN host galaxies.)

Q2: Which instrument is the 1st priority for ULTIMATE?
✶ MOS (M-IFS).

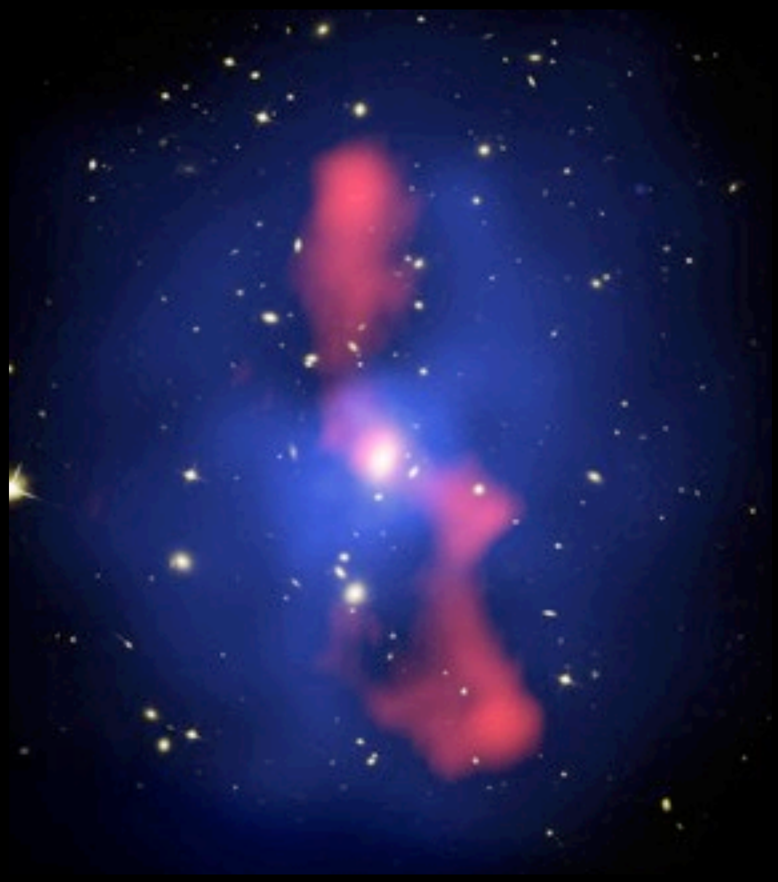
Q3: Do you have good science cases with GLAO + MOIRCS in ~2020-2023?
✶ The HK spectroscopic survey can be started with lower efficiency.

Q4: Which survey design sounds best for you?
✶ (D) MOS survey, with a fraction of slits allocated to HSC-PFS AGNs/galaxies.

SMBHs: why do we care?

<u>They are ubiquitous in the Universe</u>

- ✶ Almost every galactic bulge hosts SMBHs, at least in the local Universe.
- ✶ They date back to z ~ 7 and beyond, only <1 Gyr after the Big Bang.
- ✶ They contain ~1/1000 of the host bulge masses; this is huge!



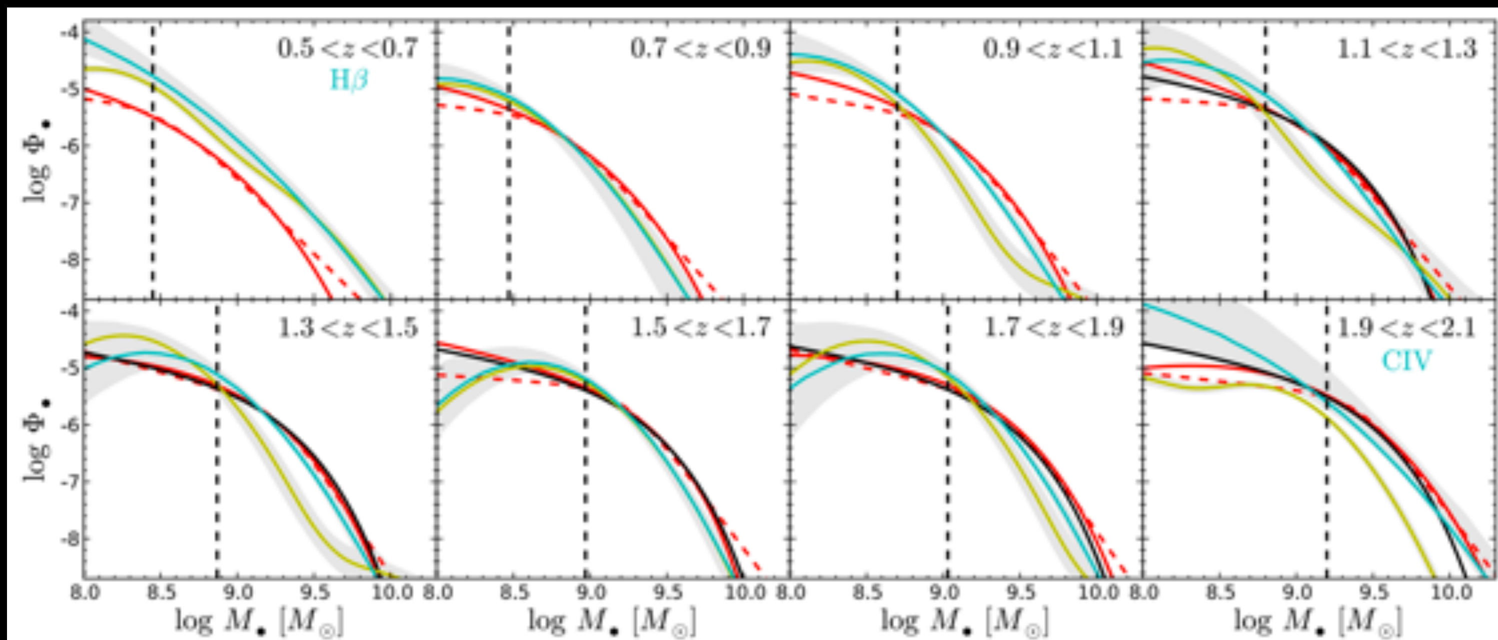
<u>They may have had a critical impact on galaxy evolution</u>

- ✶ Tight correlation between SMBH and host masses.
- ✶ AGN host galaxies are often accompanied by fast gas outflows and very turbulent velocity fields.
- ✶ Models need the “AGN feedback” to reproduce observed galaxies, e.g., their luminosity function.

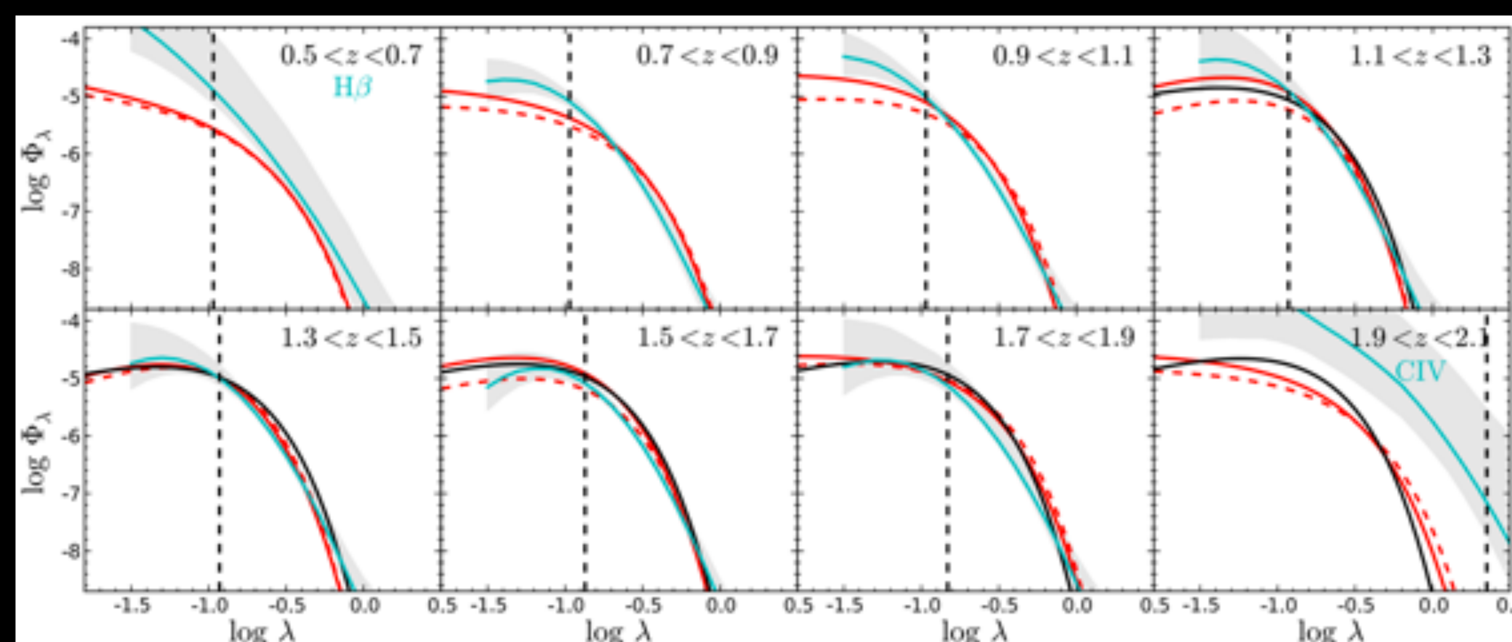
and many more reasons...

M and $\dot{M}$: two fundamental quantities

M: SMBH mass, $\dot{M}$: mass accretion rate, often expressed as the Eddington ratio $\lambda \propto \dot{M}/M$



COSMOS + VVDS + SDSS
(Schulze+15)



- ✶ We need to know the mass and accretion-rate functions to “understand” SMBHs as a population.
- ✶ In order to do so, we have to collect a larger and more homogeneous sample across redshifts.

→ Subaru HSC + PFS + ULTIMATE!

M and $\dot{M}$: two fundamental quantities

SMBHs come in three(+) flavors, in optical-NIR observations.

- ✶ Broad-line (BL) AGNs, identified with broad (> 1000 km/s) emission lines
- ✶ Narrow-line (NL) AGNs, identified with narrow emission lines with BPT-like diagrams
- ✶ Quiescent or optically-dim SMBHs (e.g., heavily-obscured AGNs)

(NL AGNs and Quiescent/optically-dim SMBHs: galaxies)

HSC finds candidates of
- BL

HSC finds galaxies, which may contain
- NL
- Q/OD

X-ray and MIR missions find obscured
- BL
- NL
- Q/OD

PFS confirms and measures $\dot{M}$ in
- BL
- NL @ z < 1.5 (BPT, MEx)
- Q/OD @ z < 1.5 (BPT, MEx)

ULTIMATE confirms and measures $\dot{M}$ in
- NL @ 2 < z < 4 (BPT, MEx)
- Q/OD @ 2 < z < 4 (BPT, MEx)

PFS measures M in
- BL @ z < 3.5 (Hβ, MgII)
- NL @ z < 1.5 (σ_{star})
- Q/OD @ z < 1.5 (σ_{star})

ULTIMATE measures M in
- BL @ 4 < z < 7 (Hβ, MgII)
- NL @ 2 < z < 4 ([O III], σ_{star})
- Q/OD @ 2 < z < 4 (σ_{star})

M and $\dot{M}$ functions across redshifts

HSC searches for broad-line AGNs (and galaxies)

HSC-SSP survey

300 nights over 2014 - 2019(?)

✶ Wide 1400 deg^2, r_{AB} < 26.1 mag
✶ Deep 27 deg^2, r_{AB} < 27.1 mag
✶ UDeep 3.5 deg^2, r_{AB} < 27.7 mag

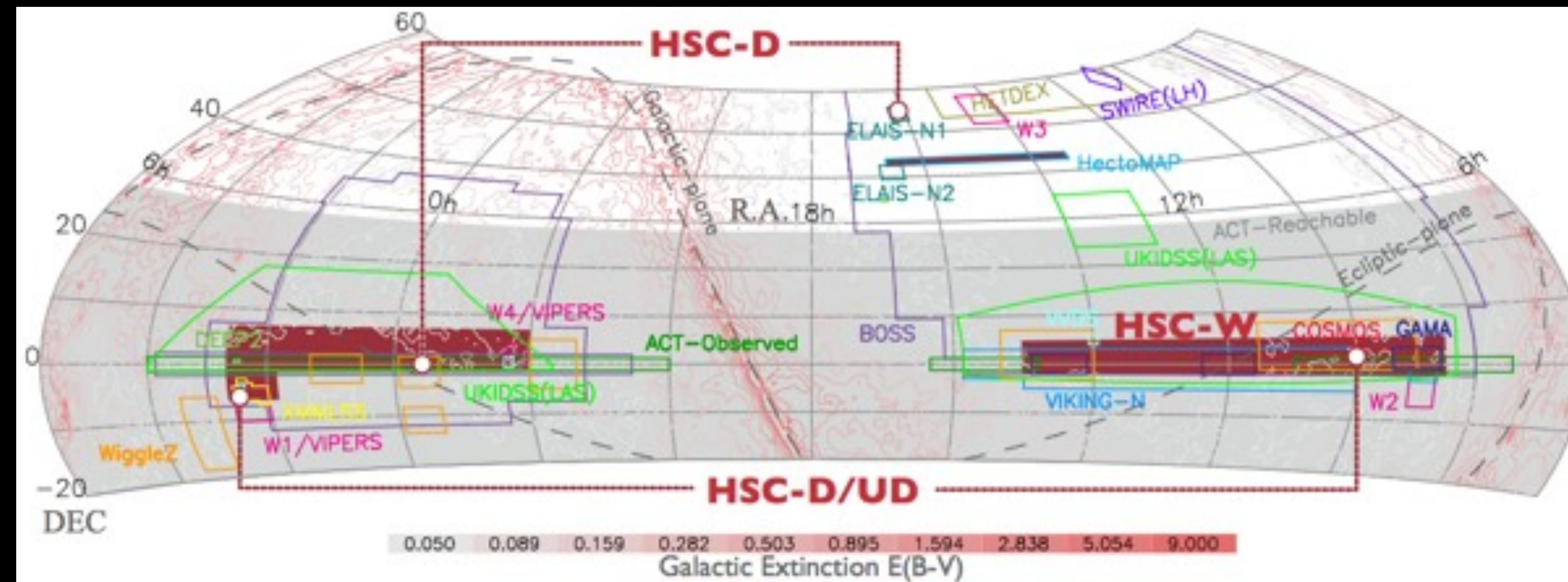
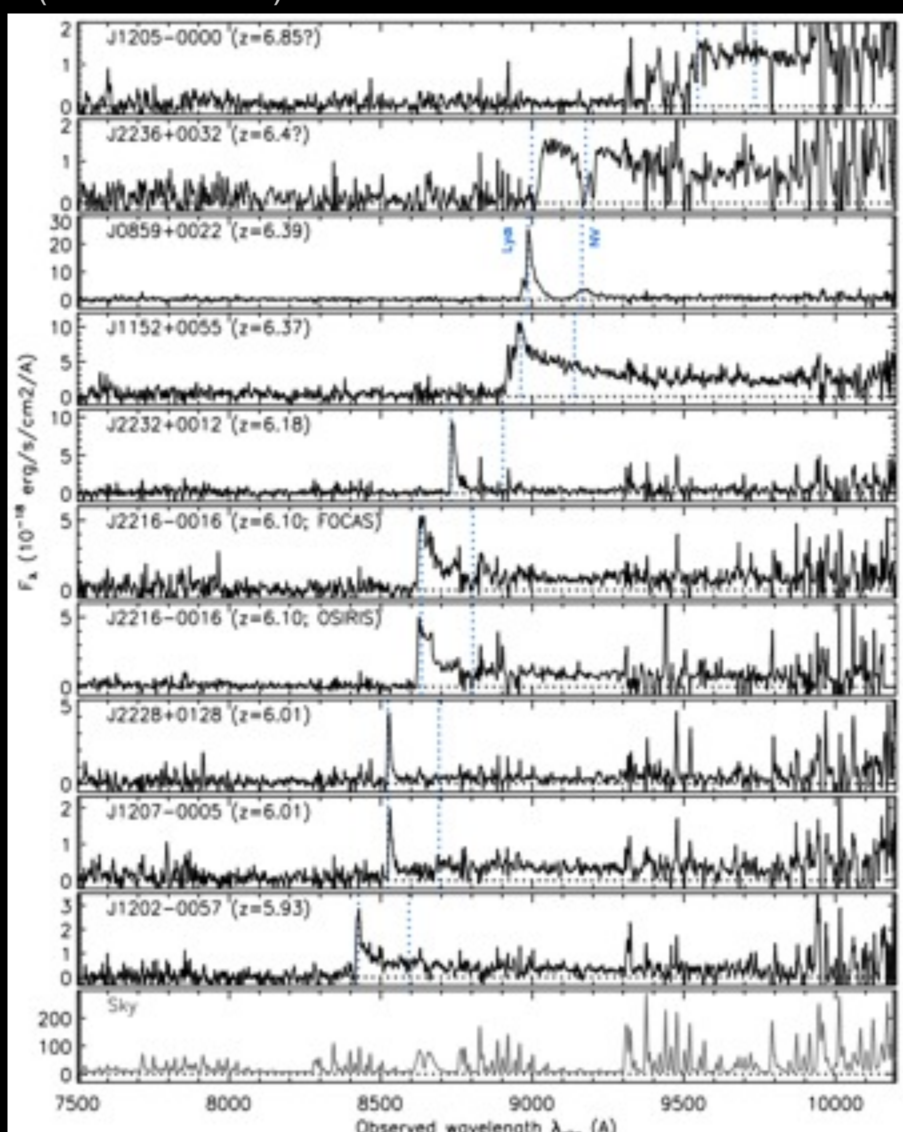


Table 7: Quasar Samples

	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

(Matsuoka+16)



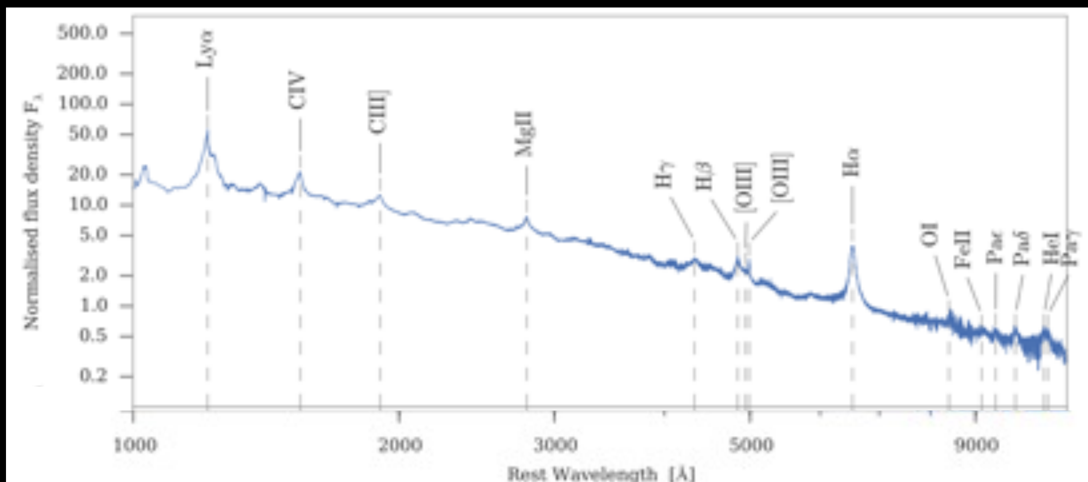
✶ BL-AGN candidates are now routinely selected with HSC colors.
✶ Individual efforts of spectroscopic follow-up are underway. (e.g., SHELLQs, our Subaru intensive program to identify z > 6 quasars)

✶ Numerous galaxies are being detected, with photo-z estimates, which may contain NL-AGNs or quiescent/optically-dim SMBHs.

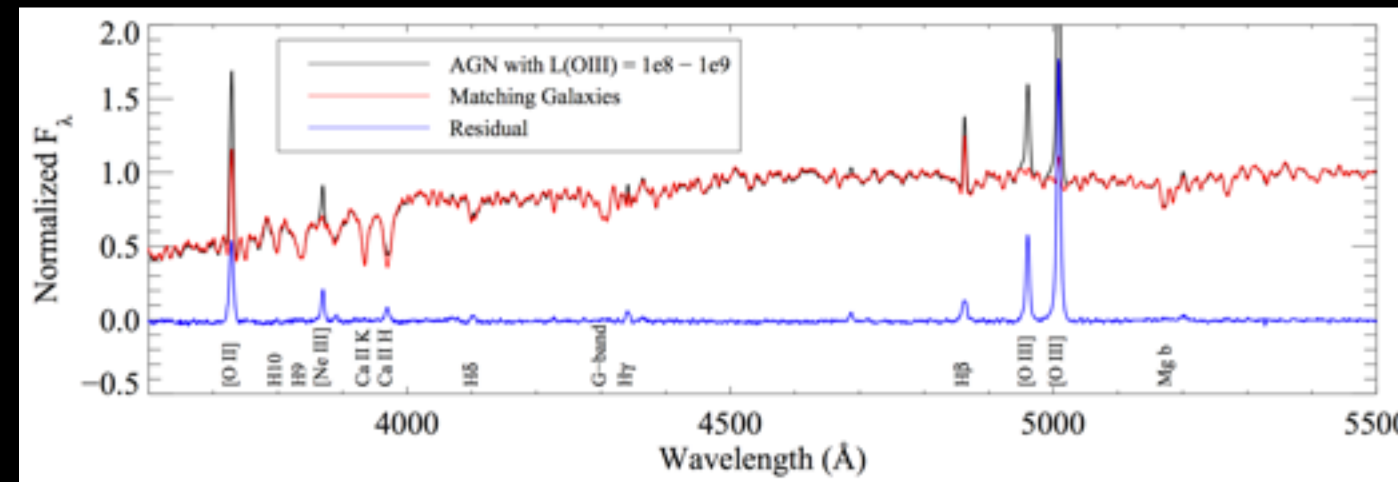
✔ Obscured population? (X-ray, MIR, ... → Ueda-san's talk)

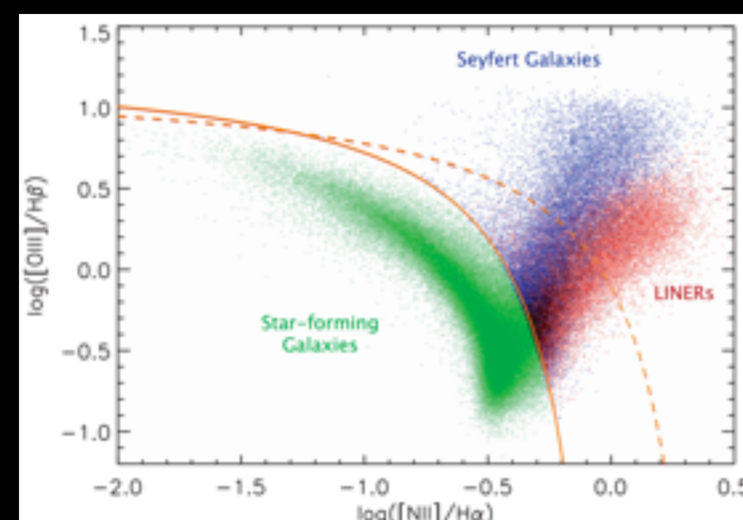
PFS/ULTIMATE confirms AGNs/SMBHs, and measures $\dot{M}$

BL AGNs (Selsing+16)



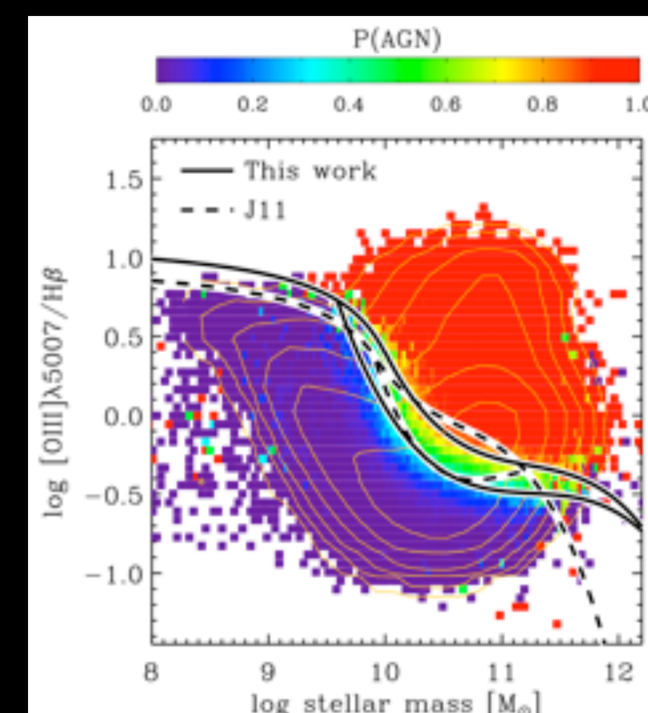
NL AGNs or Q/OD SMBHs (Kauffmann+03)





BPT diagram (Fosbury+07)

MEx diagram (Juneau+11)



$\dot{M}$ (or its upper limit) is derived from the AGN continuum or line luminosity

✔ Bolometric correction? (X-ray, MIR)

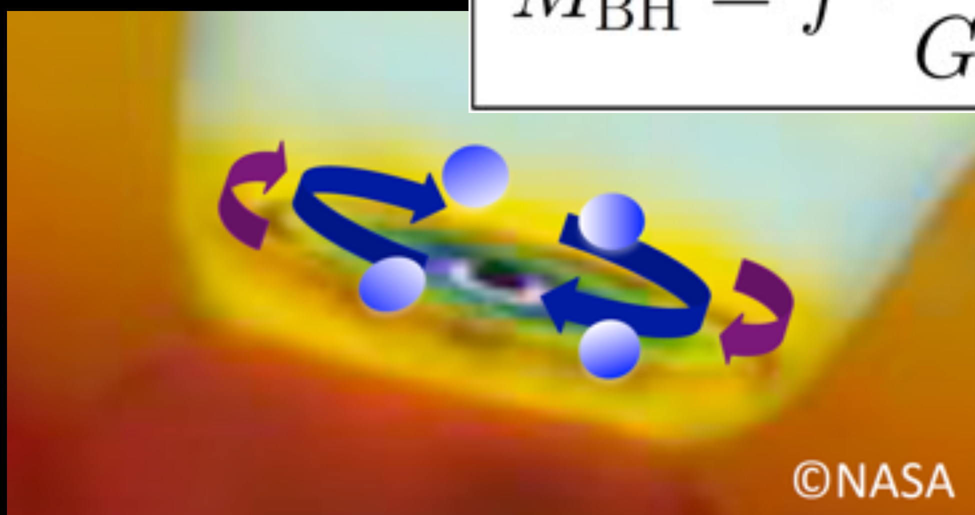
✔ Radiation efficiency? (models, "continuity-condition" measurements)

✔ How robust are these diagrams (PFS)?

PFS/ULTIMATE measures M

BL AGNs: Hβ and/or MgII λ2800 measurements

$$M_{\rm BH} = f\,\frac{r\sigma^2}{G}$$



(c) Minezaki-san

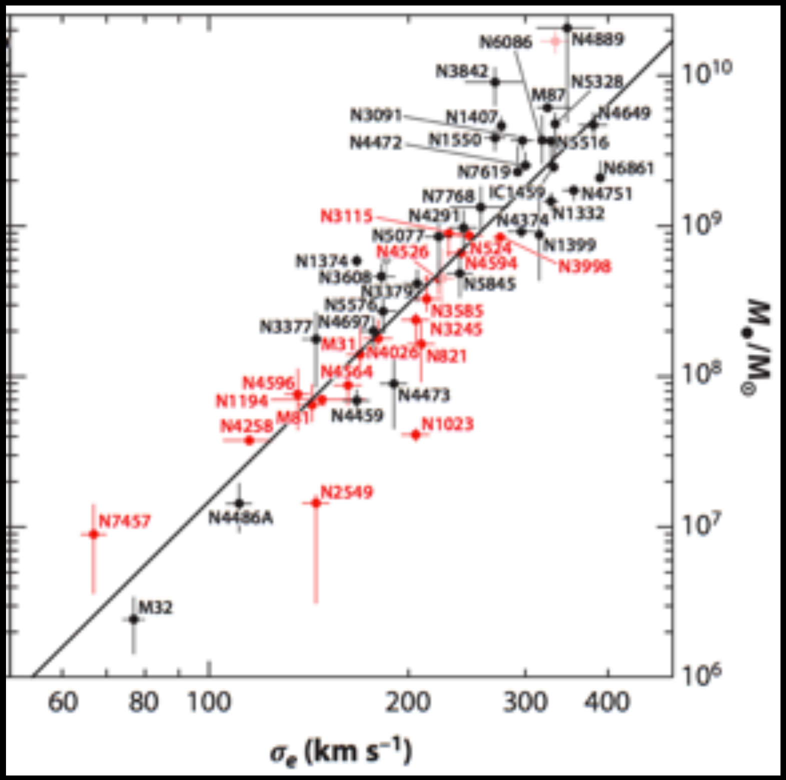
✔ Calibration? (PFS-RM)

McLure+02

$$\frac{M_{\rm bh}}{M_\odot} = 3.37\left(\frac{\lambda L_{3000}}{10^{37}\,{\rm W}}\right)^{0.47}\left[\frac{{\rm FWHM(Mg\,II)}}{\rm km\,s^{-1}}\right]^2$$

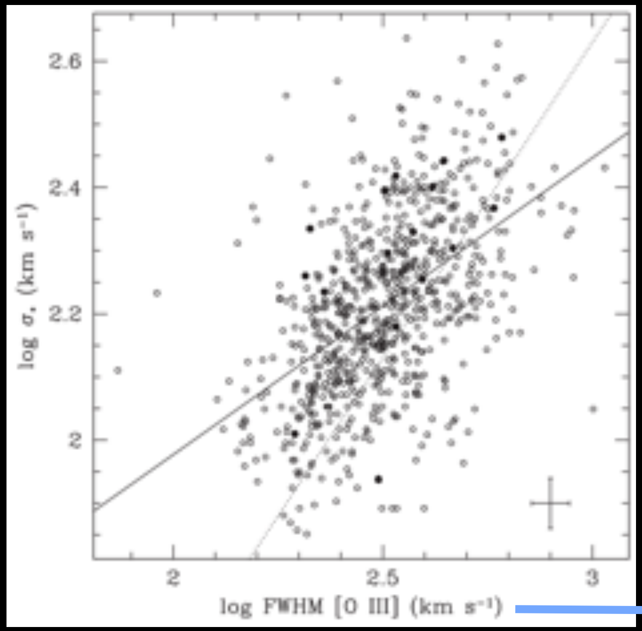
NL AGNs or Q/OD SMBHs: σ_{star} and/or [O III] measurements

EMPIRICAL M - σ_{star} relation (Kormendy+13)



✔ How global is this relation? (TMT)

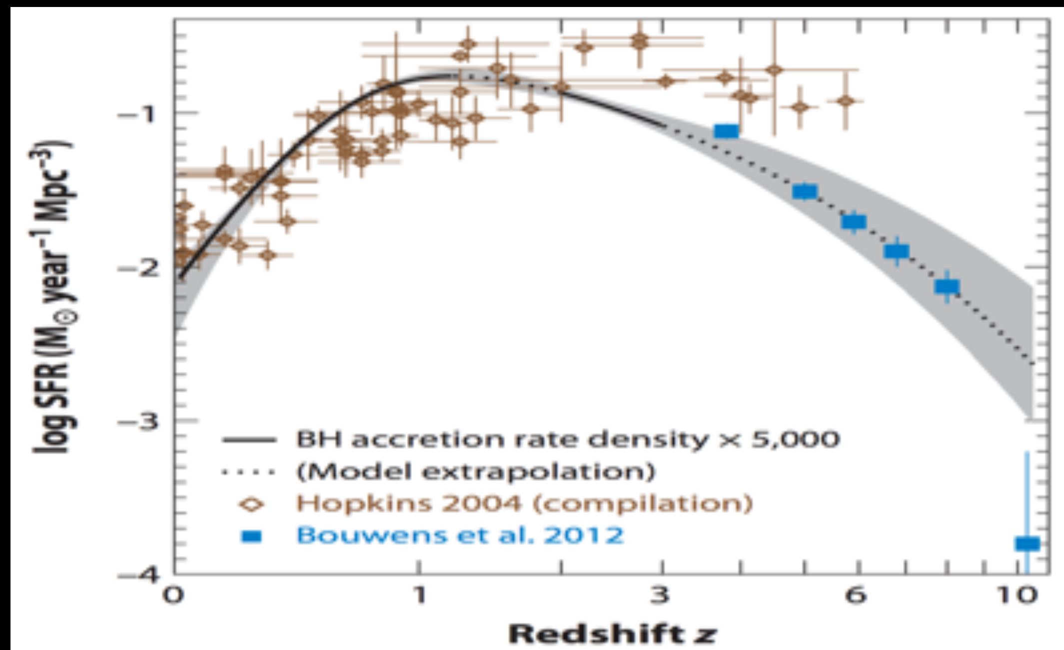
✔ What is the physical origin? (TMT)



✔ Calibration? (PFS)

[O III] width as a surrogate for σ_{star} (e.g., Brotherton+15)

ULTIMATE/MOS probes more distant Universe



✶ Evolution of SFR density and BH mass-accretion density (x5,000) across redshifts

(Aird+12, Kormendy+13)

	z	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
BL	Mg II (λ2800)		PFS	PFS	PFS	PFS	PFS	PFS	PFS							
BL	Hβ (λ4861)	PFS	PFS	PFS	PFS											
NL Q/OD	σ_{star} (≲ 5000 Å)	PFS	PFS	PFS	PFS											
NL	[O III] (λ5007)	PFS	PFS	PFS	PFS											

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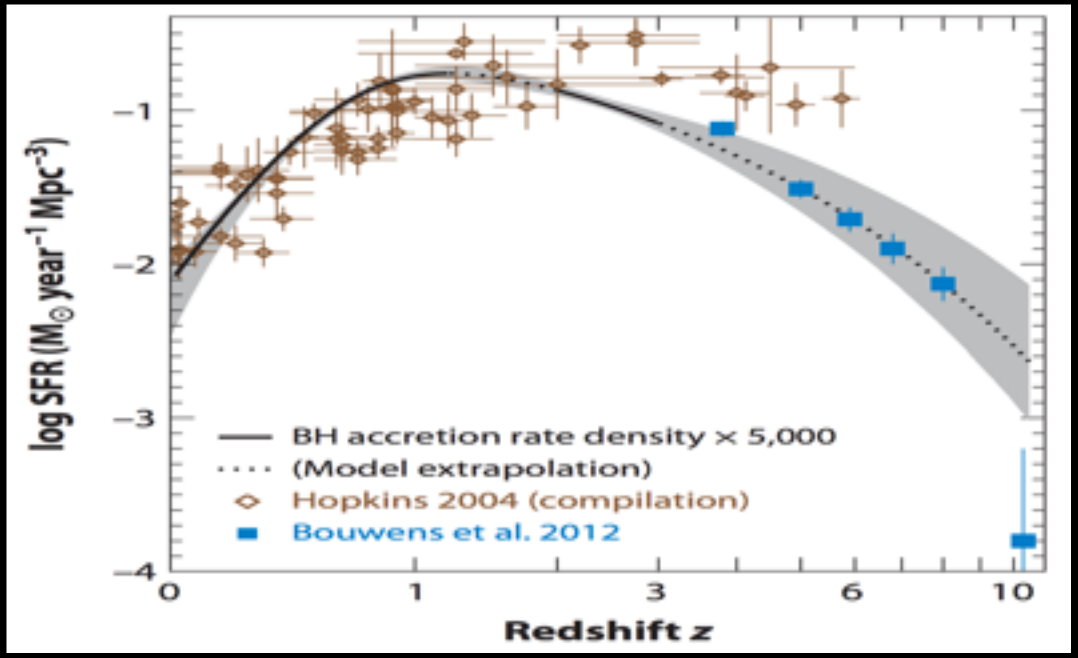

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BL	Mg II (λ2800)		PFS	PFS	PFS	PFS	PFS	PFS	PFS	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE
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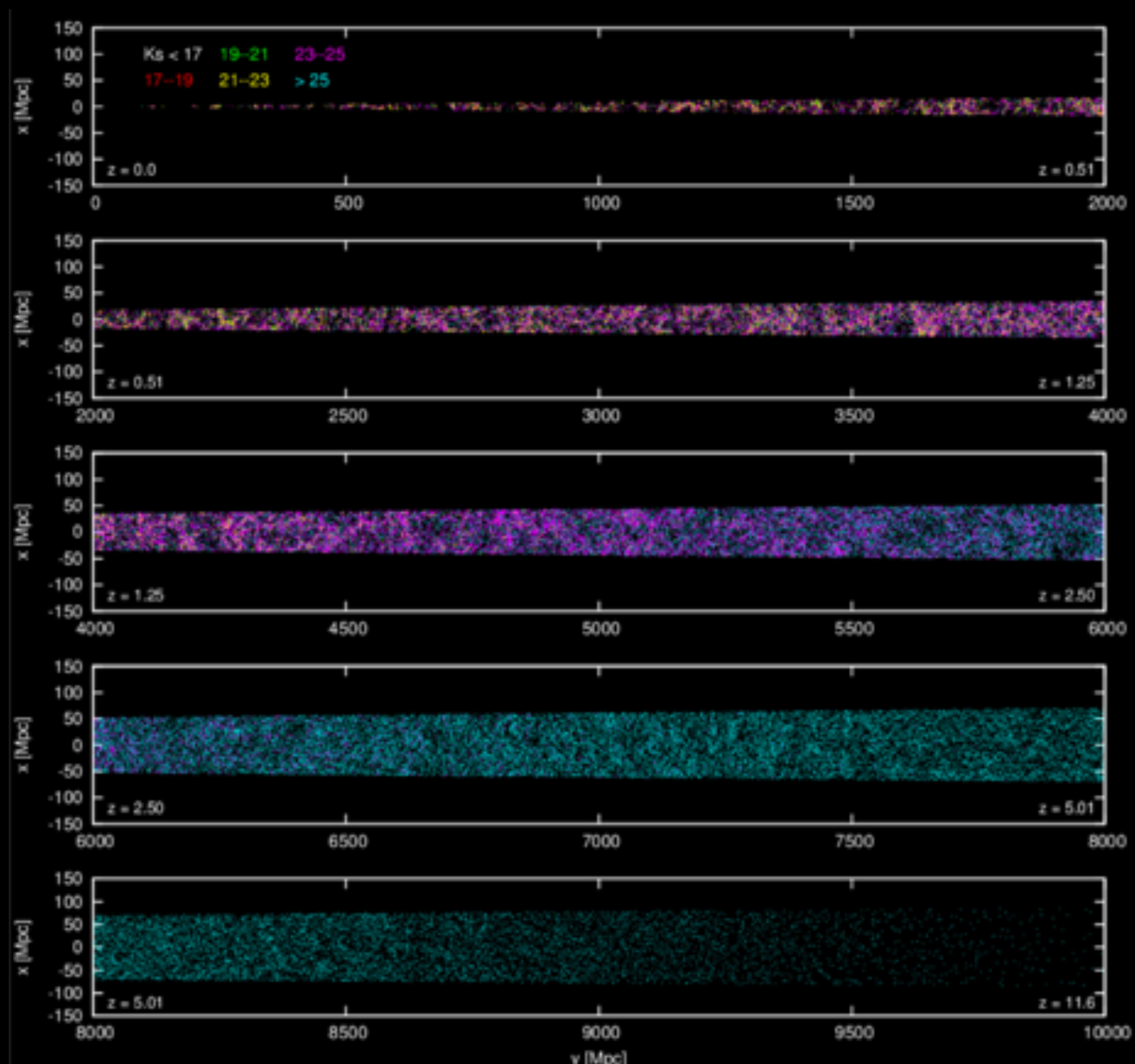
NL Q/OD	σ_{star} (≲ 5000 Å)	PFS	PFS	PFS	PFS	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE							
NL	[O III] (λ5007)	PFS	PFS	PFS	PFS	ULTIMATE	ULTIMATE	ULTIMATE	ULTIMATE							

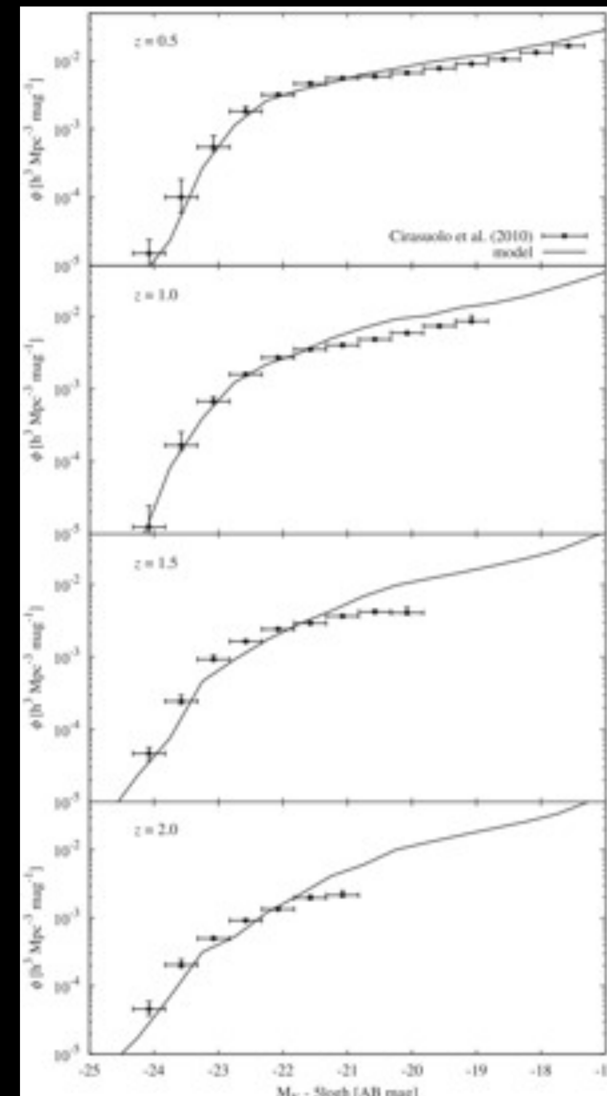
Note: ULTIMATE HK spectroscopy would be limited to luminous part of the HSC-PFS sample, e.g., BOSS-class quasars (~a few per 15’ FoV).

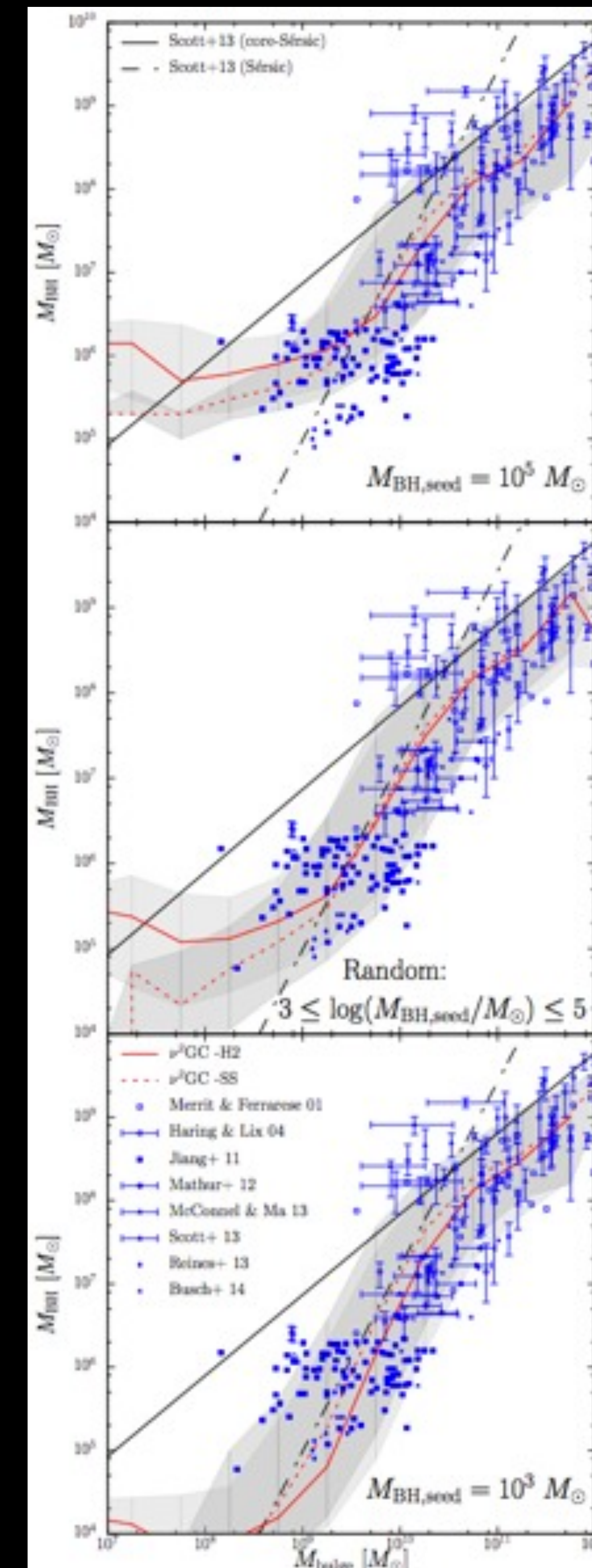
Comparison with theoretical models

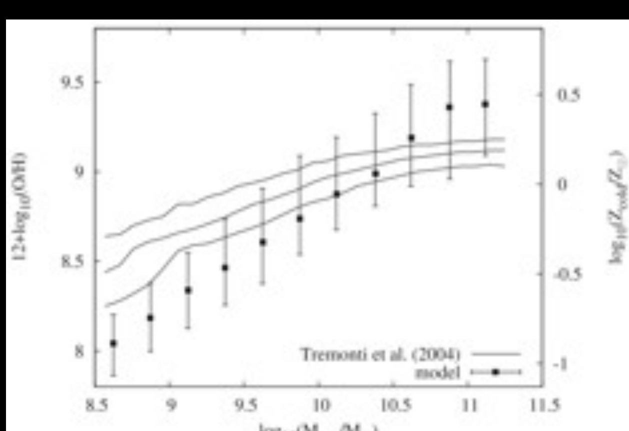
(Makiya+15)



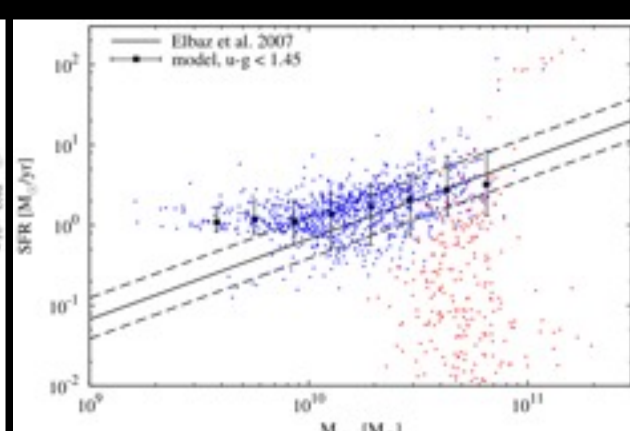
LF evolution



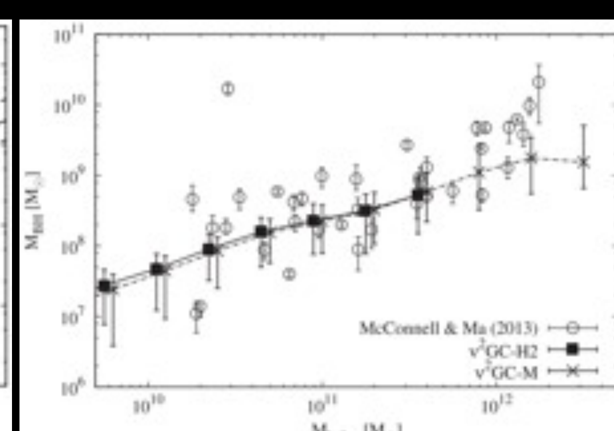




Fundamental relation



SF main sequence



M_{BH} - M_{bulge} relation →

Dependence on $M_{BH\ seed}$ (Shirakata+16)

Summary

- ✶ SMBHs are important; they are ubiquitous in the Universe, and may have had a significant impact on galaxy evolution.
- ✶ We need to constrain the mass and accretion-rate functions, the two fundamental quantities, to “understand” this population.
- ✶ Subaru HSC + PFS + ULTIMATE are a perfect combination, which will provide a critical step toward the “complete census” of SMBHs across the Universe.

Questions from the organizers

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