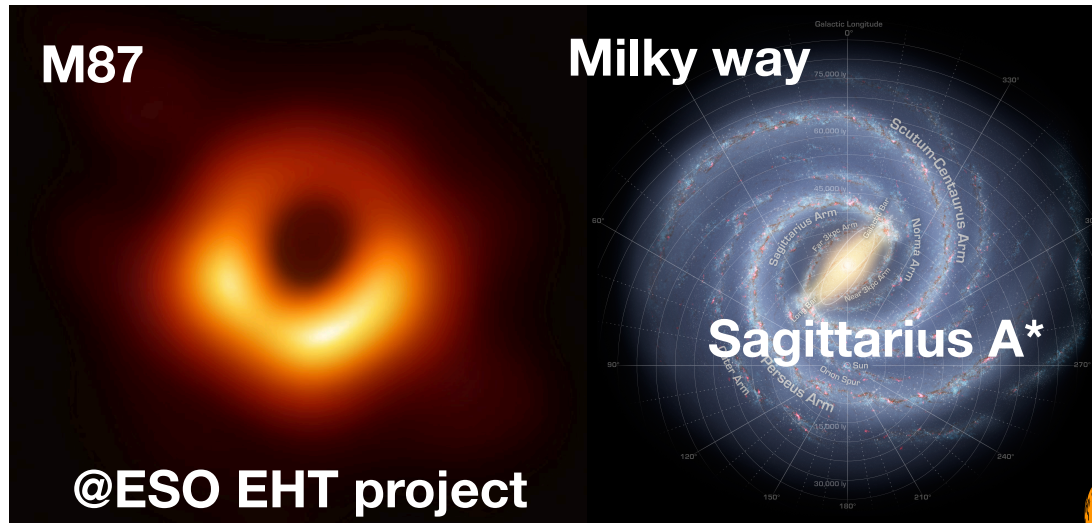


Black hole mass and Eddington ratio distributions of the $z=4$ less-luminous quasars over the HSC Wide field

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Background: How is the formation of massive black holes?



- **Supermassive black holes (SMBH)** are **ubiquitous** at the center of local massive galaxies;
- stellar BH $\sim 10\text{-}100$ solar mass
massive BH $\sim 10^6\text{-}10^{11}$ solar mass

How are those “monsters” formed?

Possible SMBH growth history

direct collapse
 $\sim 10^6$ 太陽質量



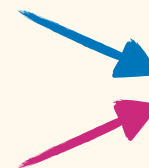
+milder growth

PopIII star
 $\sim 10^3$ 太陽質量

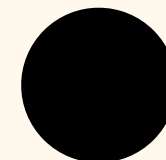


seed
black hole

+fast growth



$\geq 10^6$ 太陽質量



massive
black hole

early universe

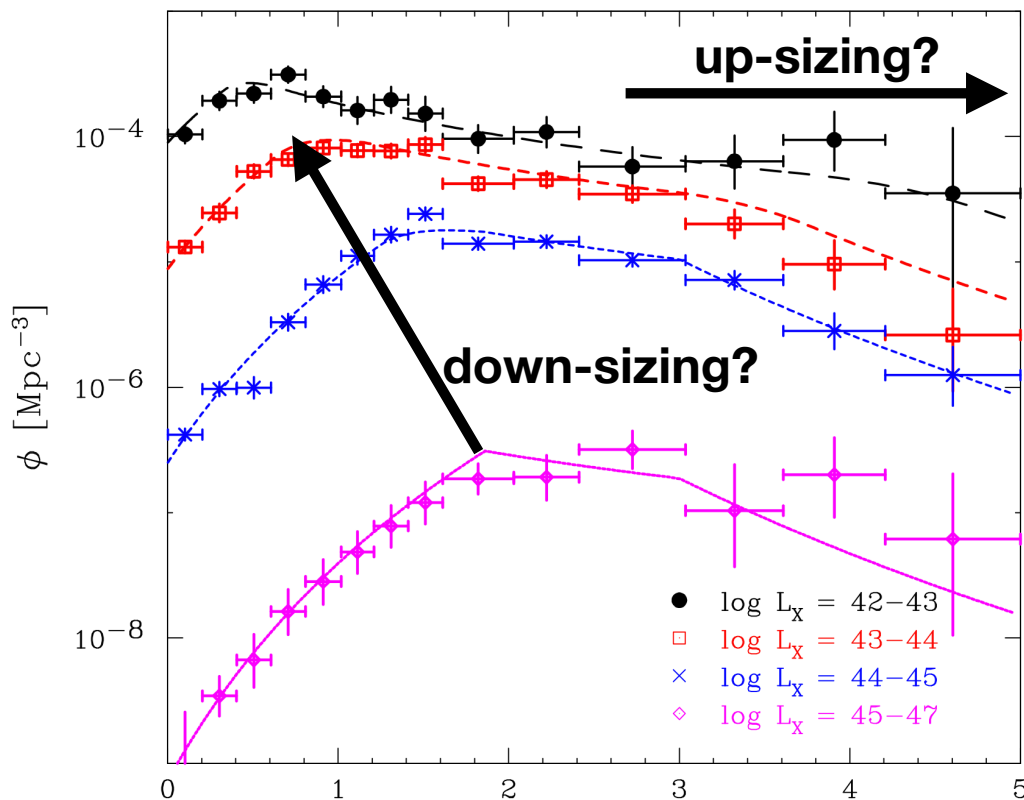
now

Which origin?

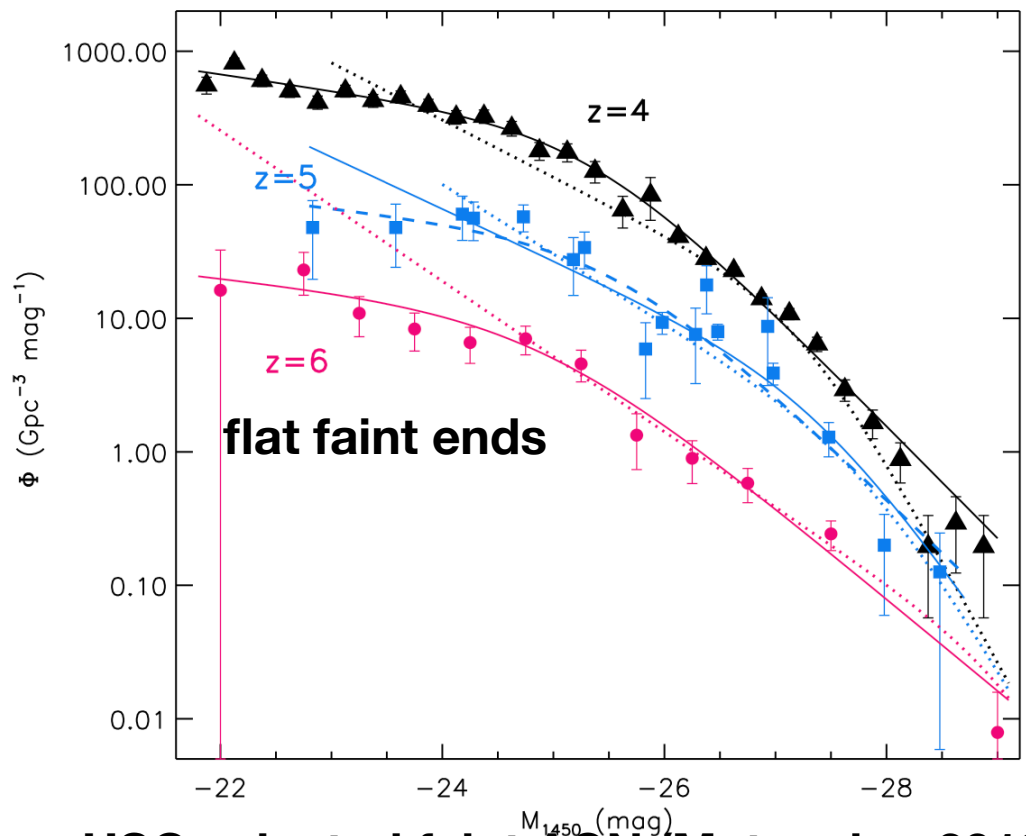
Background: How is the formation of massive black holes?

constraints from the AGN luminosity function

- X-ray selected Compton-thin AGNs
 - **down-sizing trend**: luminous AGNs are formed at earlier epochs
 - vs. **up-sizing trend**: less-luminous AGNs are more abundant at earlier epochs
- Optical selected quasars at $z > 3$:
 - flat faint-end $\rightarrow$ the down-sizing trend



X-ray selected AGN (Ueda+2014)

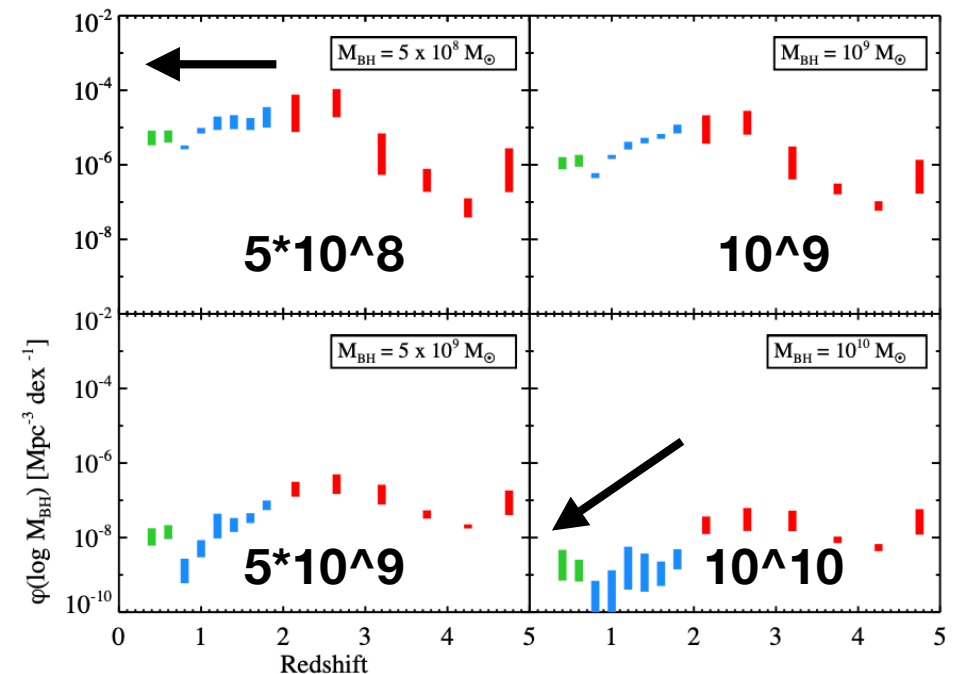
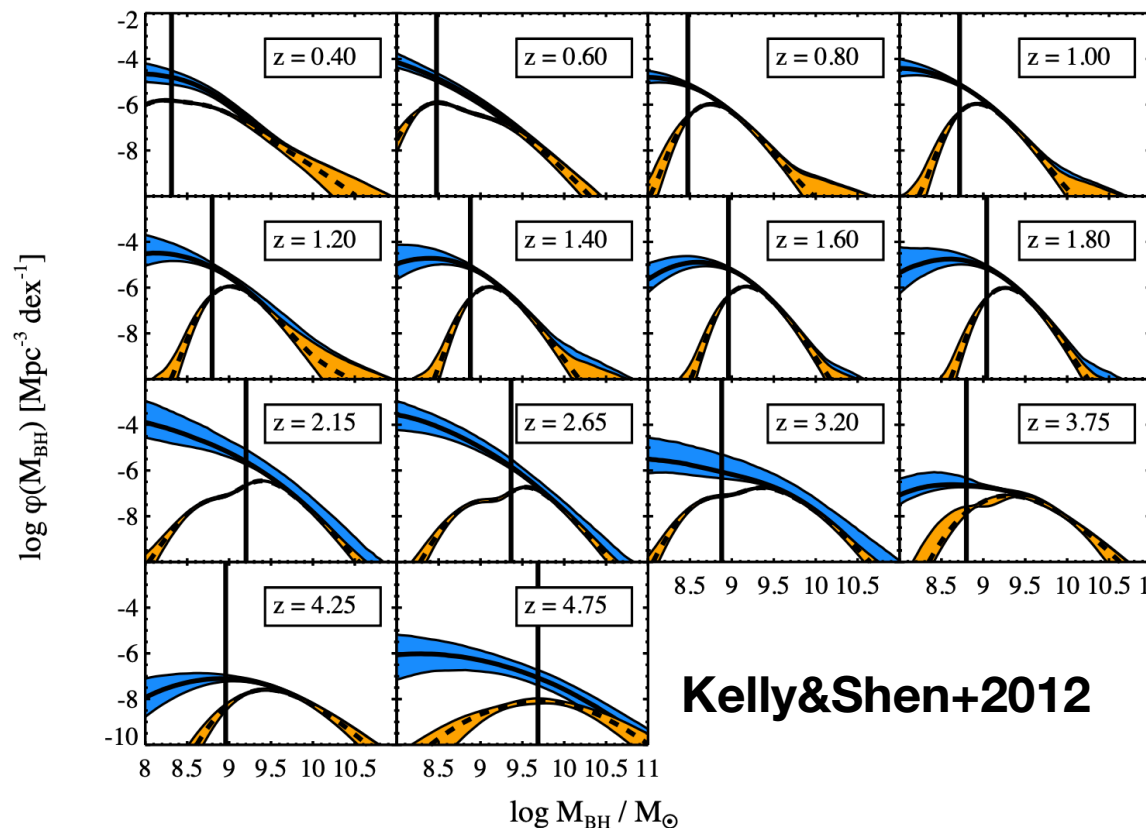


HSC selected faint AGN (Matsuoka+2018)

Background: How is the formation of massive black holes?

constraints from the black hole mass function

- **luminosity of AGNs may not directly reflect the mass assembly of SMBHs** due to wide distribution of Eddington ratios among AGNs
- **Further constraints on black hole mass function are necessary**
- **BHMF obtained from the SDSS quasars (virial black hole mass):**
 - massive SMBHs tend to be formed at earlier epochs → down-sizing trend?

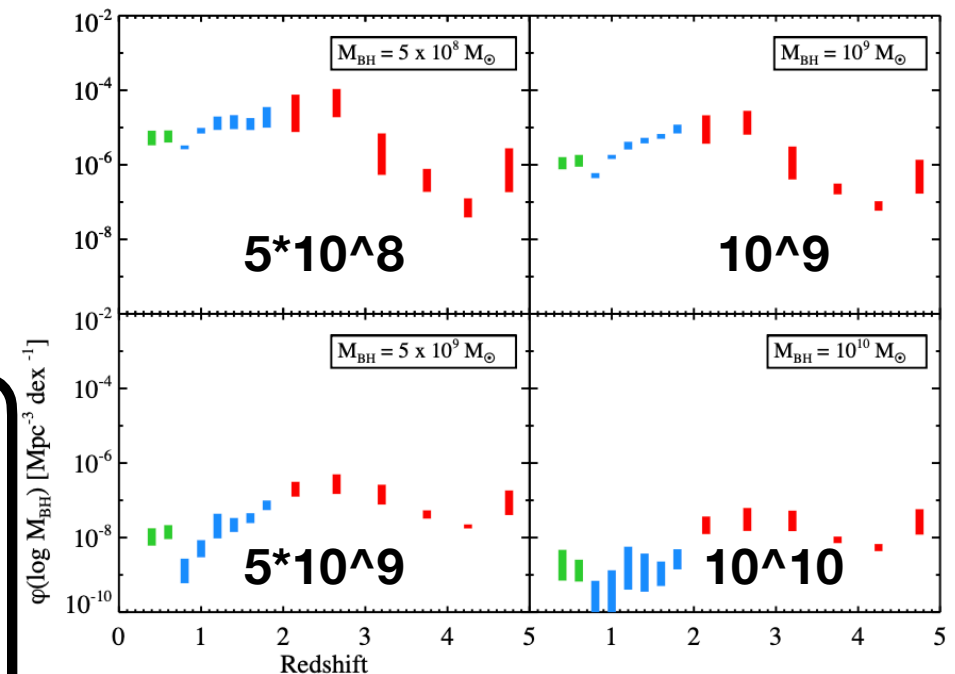
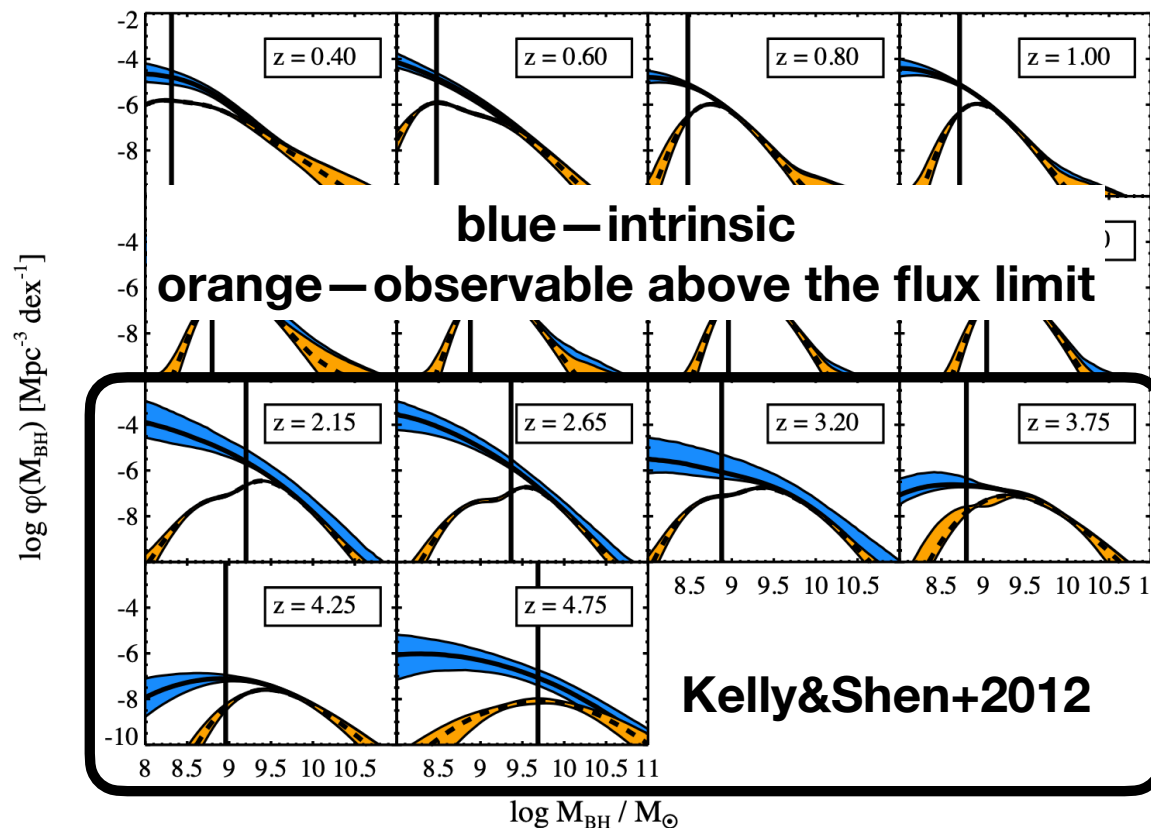


$z=2 \rightarrow z=0$:
massive SMBHs decrease
less-massive ones keep flat

Background: How is the formation of massive black holes?

Motivation & goal

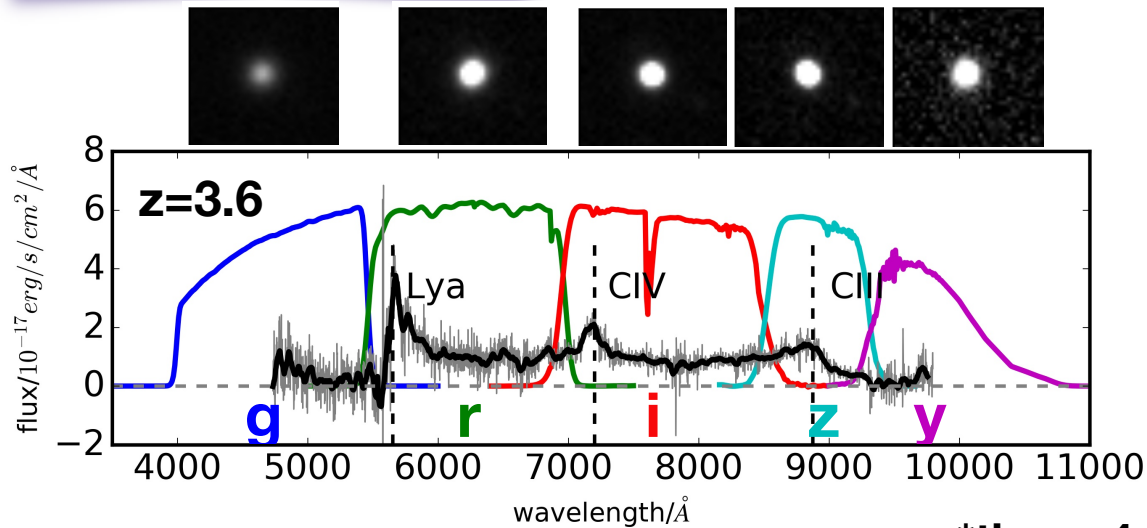
- Problem: BHMFs constrained by the SDSS quasars are **highly biased to the luminous ones**
- Motivation: **constrain the less-massive end of BHMF at $z=4$** with a large sample of **less-luminous** quasars $\rightarrow$ wide and deep imaging of the **HSC-SSP**



highly incomplete at
 $z > 2$

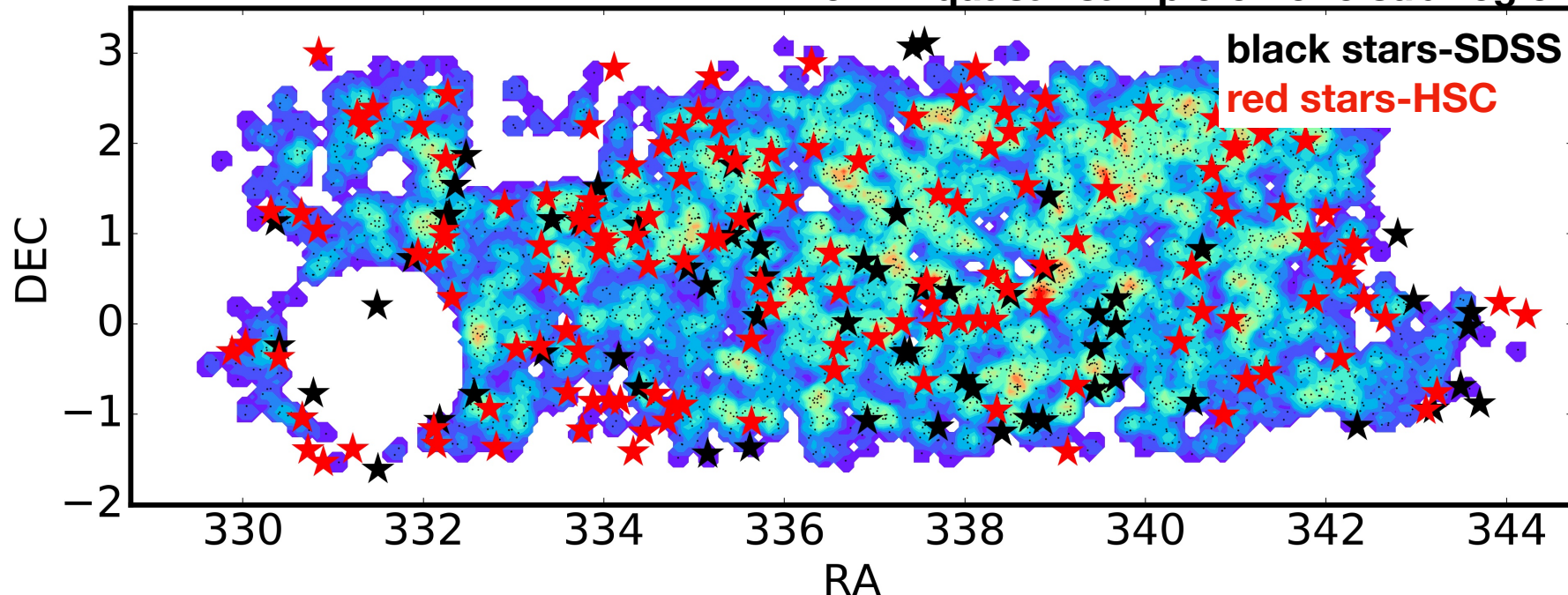
Selection of the $z \sim 4$ less-luminous quasar sample

the color selection

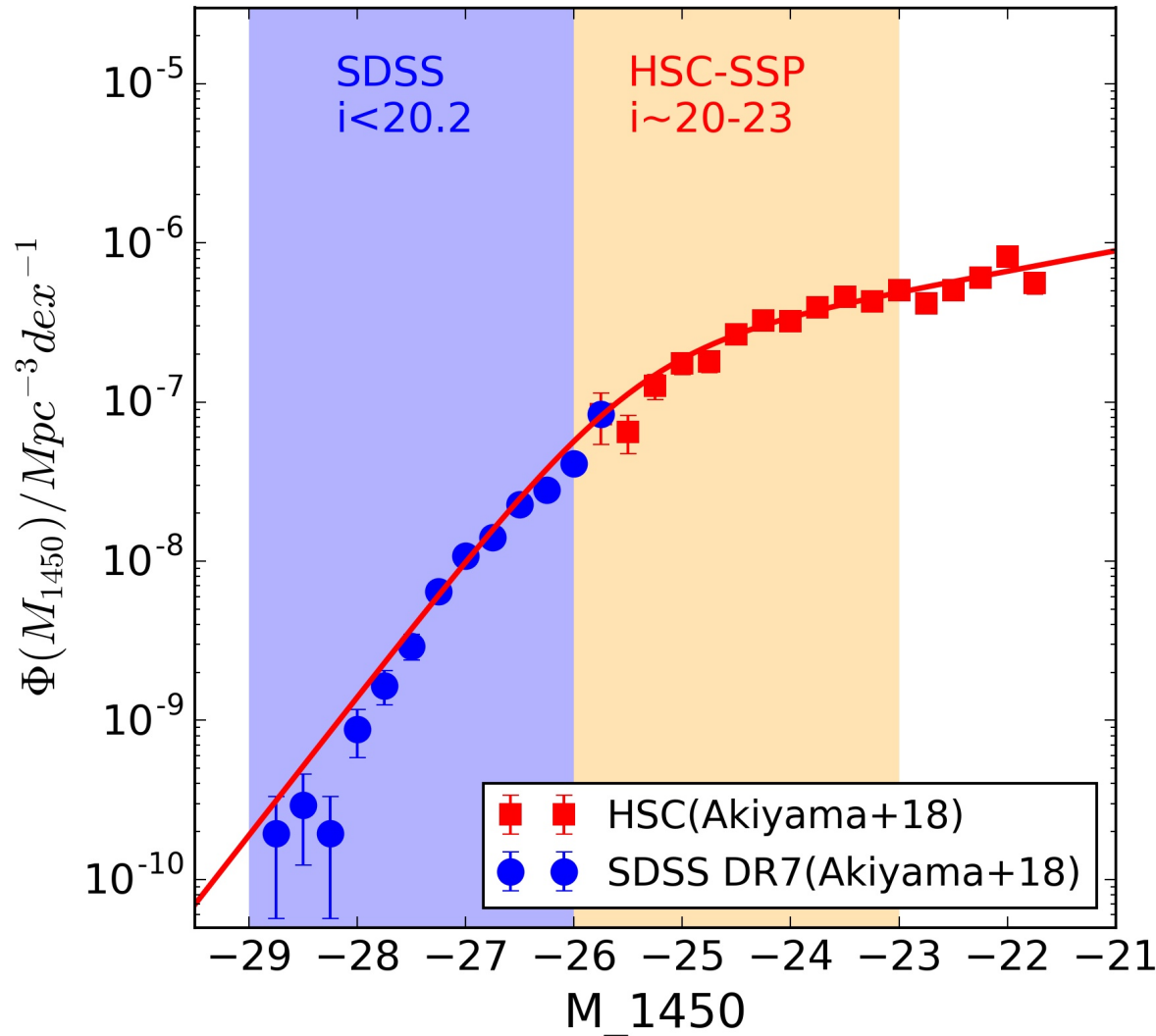


- HSC-SSP Wide imagings:
 - the g-drop colors + stellar morphology
- wide area $\rightarrow$ large sample
- deep detection $\rightarrow$ wide luminosity range

*the $z \sim 4$ quasar sample on one sub-region



Constraints on the luminosity function at z=4



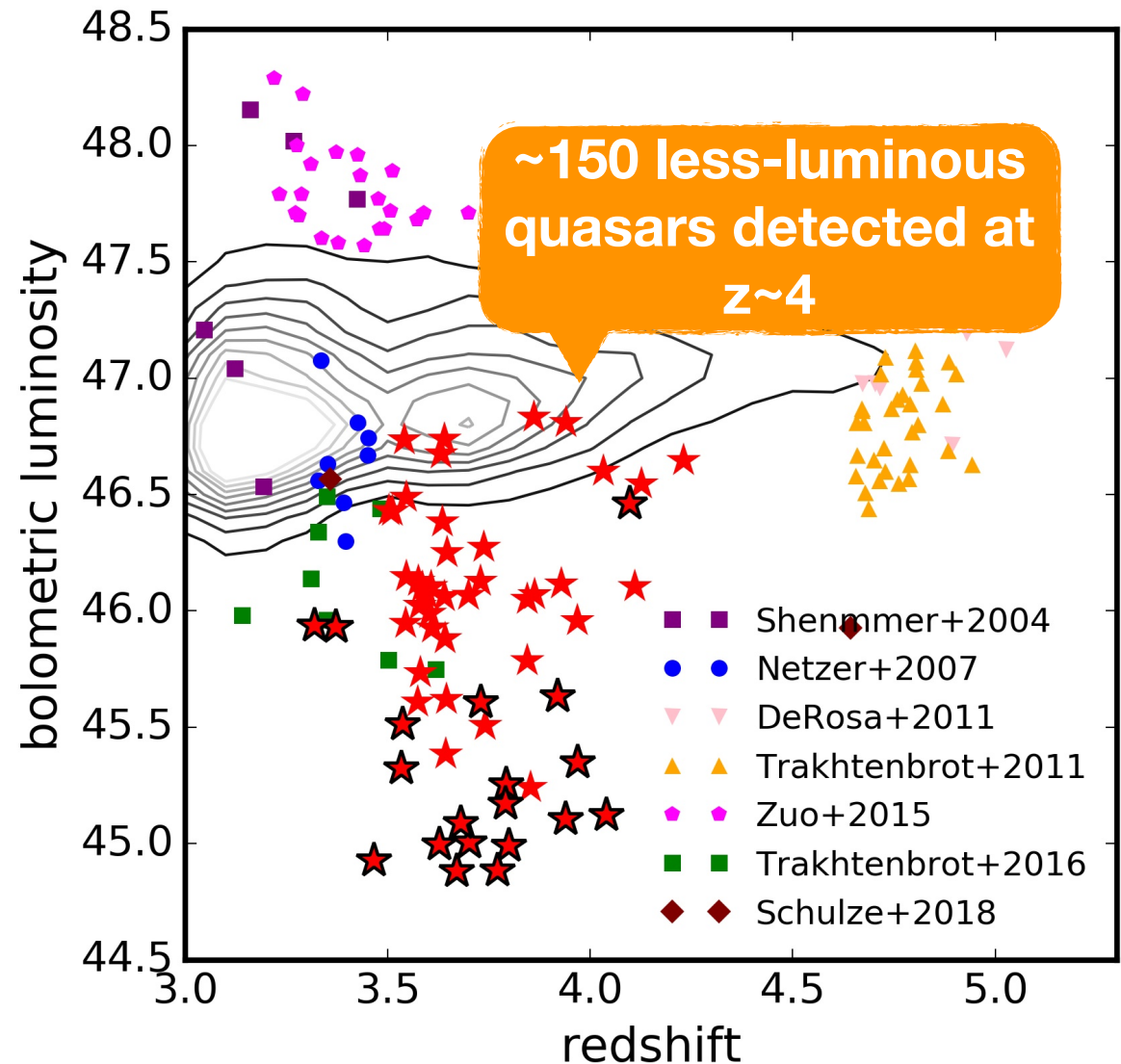
the new constrained QLF shows a **clear break** at $M_{1450} \sim -25$, and a **flat faint end**:

→ the HSC quasar sample are abundant, dominating the quasar population at the epoch

we are targeting the “typical” accreting SMBHs at z=4

Spectroscopic follow-ups of the $z \sim 4$ less-luminous quasars

- **AAT/2dF+AAOmega:**
 - 3.5n/5n on 2017. Jul + 2h/2n on 2018. Jun;
 - ~3h exposure time for each target field;
 - data reduction — OzDES pipeline
- **Keck/DEIMOS:**
 - 2n on 2019. Apr;
 - ~1h exposure for each target field;
- **DEEP2 pipeline**



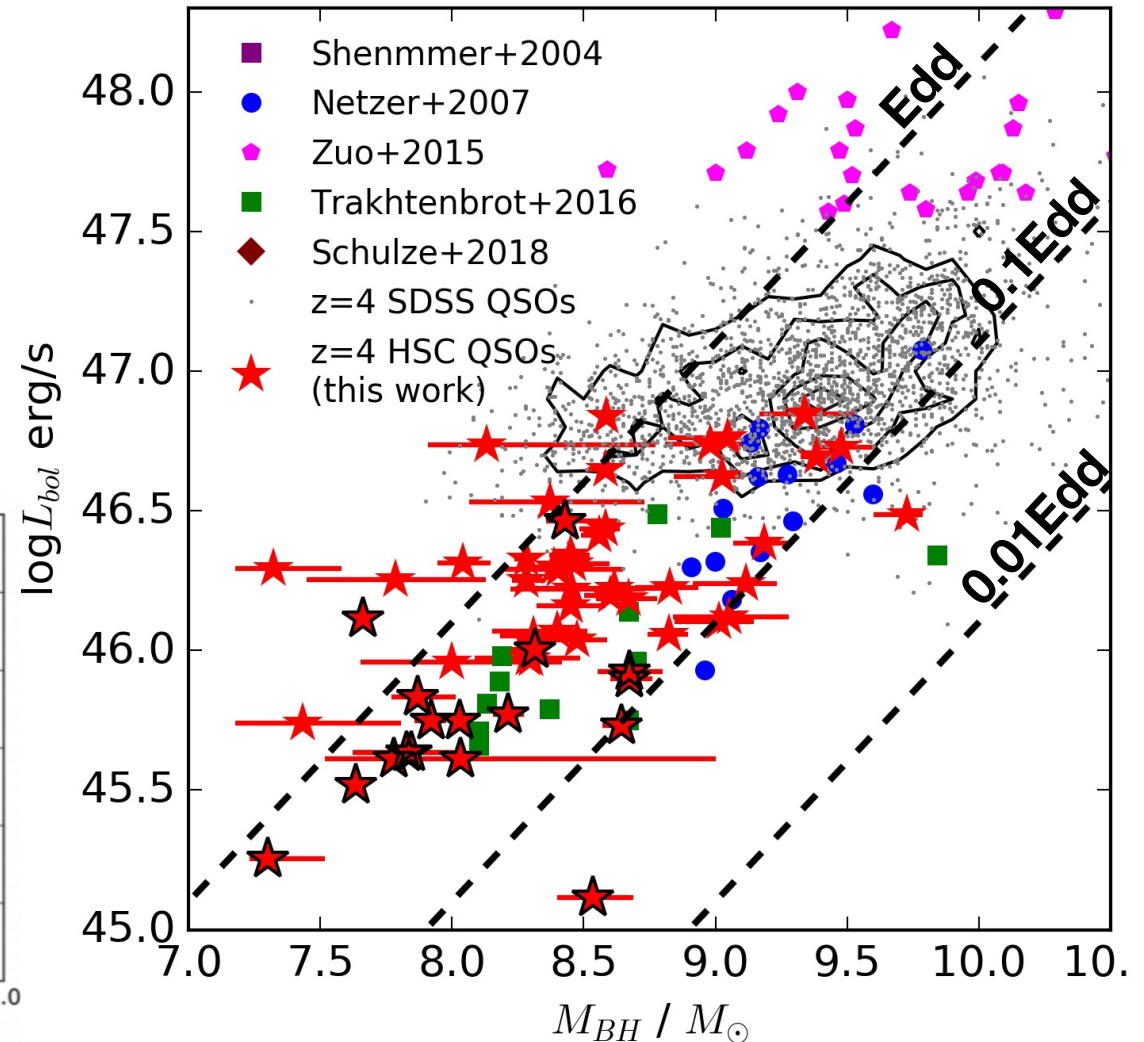
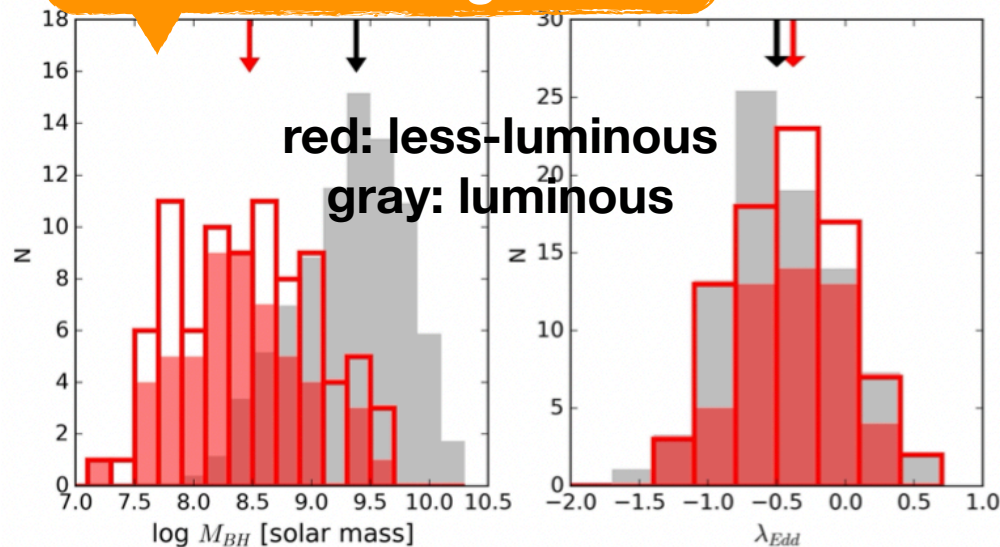
The black hole mass and Eddington ratios

The CIV-based virial black hole mass estimator

● Calibrated by
Vestergaard&Peterson+2006:

$$\log\left(\frac{M_{\text{BH,vir}}}{M_{\odot}}\right) = 6.66 + 0.53\log\left(\frac{\lambda L_{1350}}{10^{44} \text{ erg s}^{-1}}\right) + 2\log\left(\frac{\text{FWHM}_{\text{CIV}}}{\text{km s}^{-1}}\right)$$

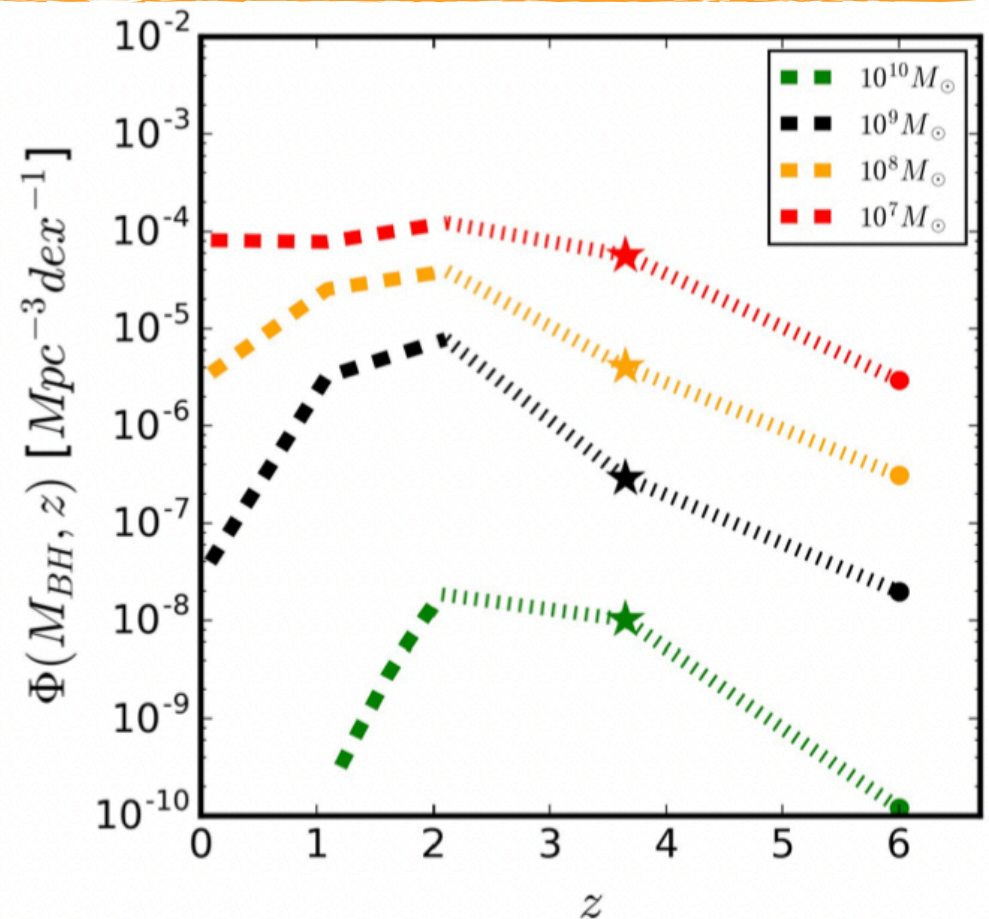
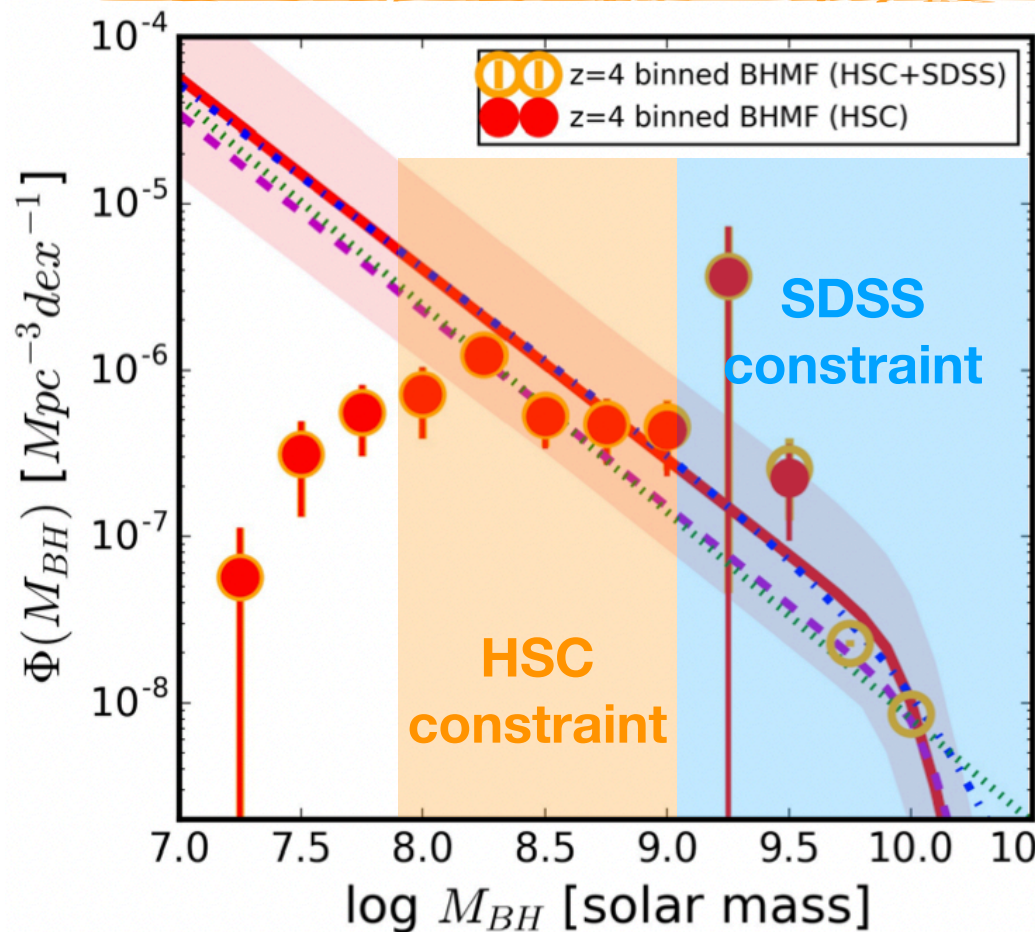
less-luminous quasars
● smaller BH mass
● similar Eddington ratio



The black hole mass function at $z=4$

results & discussion

- the newly constrained BHMf at $z=4$:
 - no clear turn-over
 - enhance the constraints down to 10^8 solar mass
- overall shape of BHMf's does not change much during $z=2-6 \rightarrow$ down-sizing



Summary

Take home message

- we select a unique **z=4 low-luminosity quasar** sample → the “**typical**” accreting SMBHs;
- spec follow-up: **~150** quasars covering a wide L_{bol} range identified
- compared to high-L quasars: **less massive & similar Edd ratio**
- new constraints on the low mass end of the z=4 BHMF
 - no clear turn-over
 - enhance the constraints down to 10^8 solar mass
 - consistent with the down-sizing evolution trend

Thank you!

What is this monster??
-still not clear...

