

Supermassive black holes, host galaxies and **their** **dark matter** halos at $z > 6$

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Takumi Tanaka (Kavli IPMU; Univ. of Tokyo; FoPM)

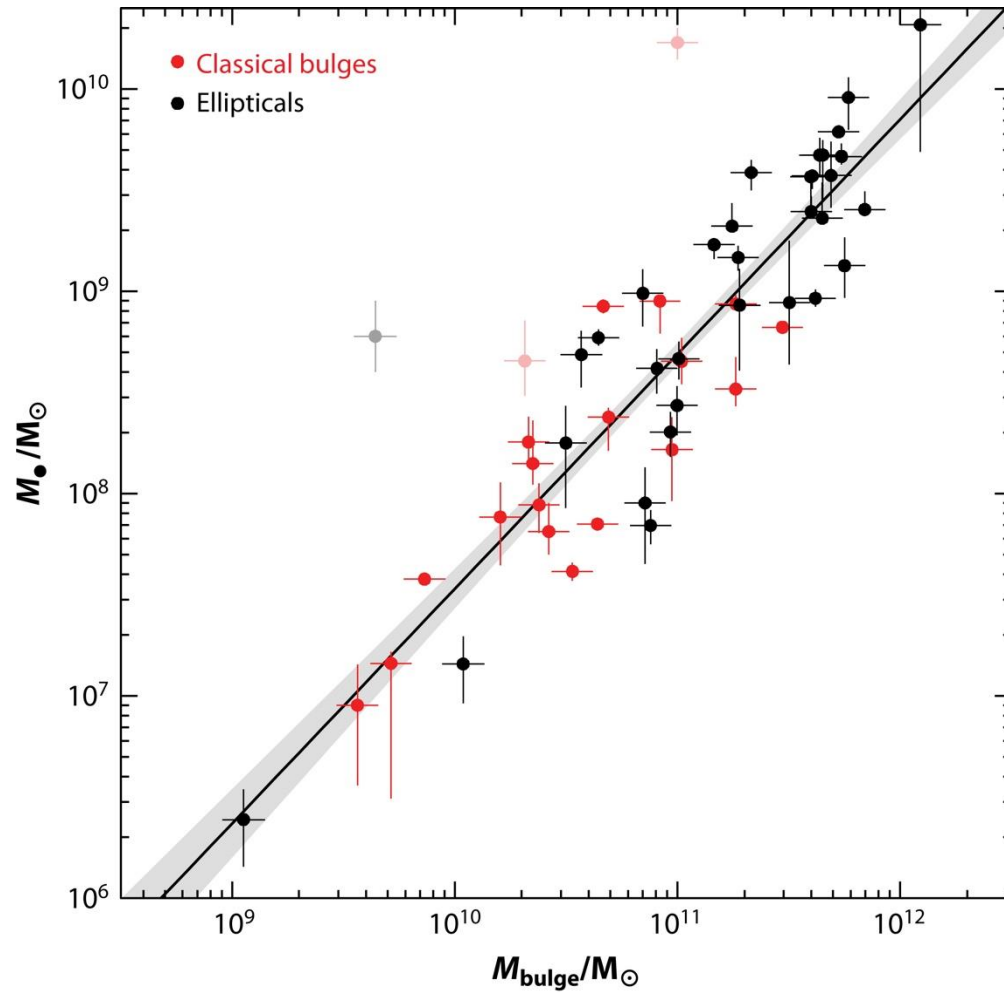
Junyao Li (Univ. of Illinois)

Xuheng Ding (Wuhan Univ.)

What's the fundamental connection?

black hole ↔ bulge ↔ galaxy ↔ dark matter halo

Local black hole – bulge mass relation



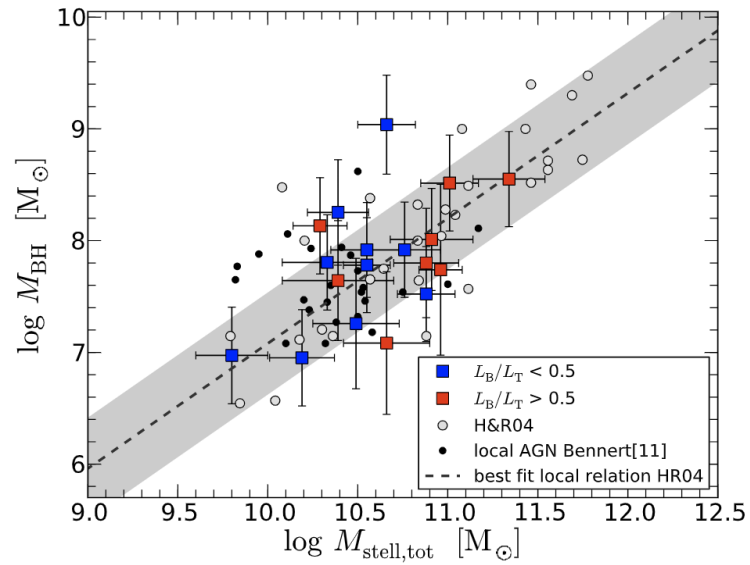
Kormendy & Ho 2013

Host galaxies of quasars with Hubble Space Telescope



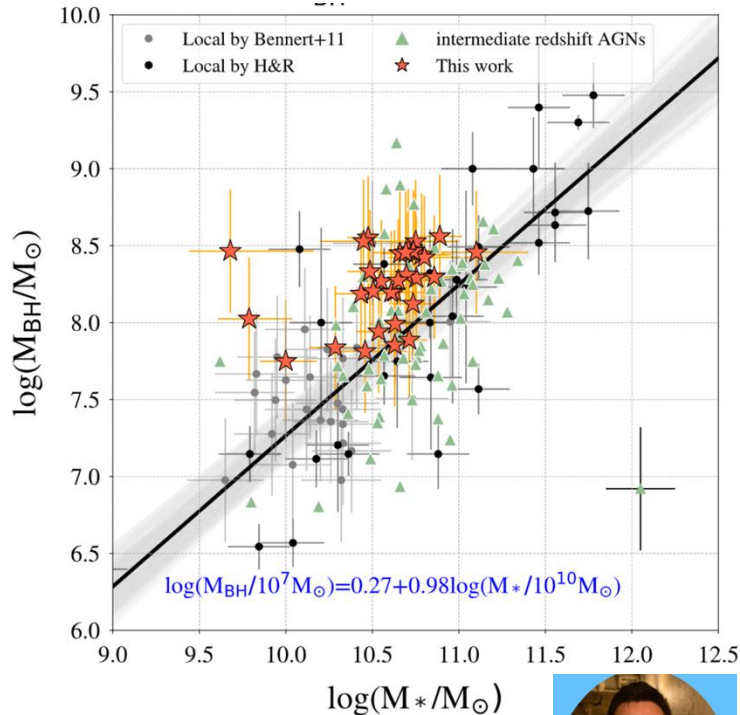
Advanced Camera for Surveys (optical)

18 quasars ($z \sim 0.5$)



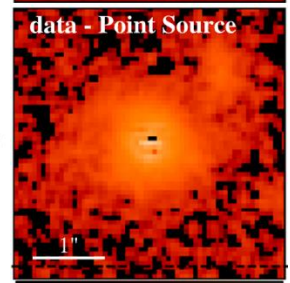
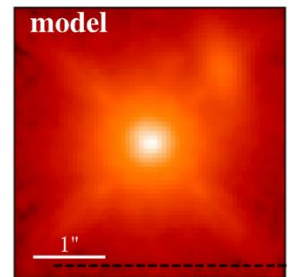
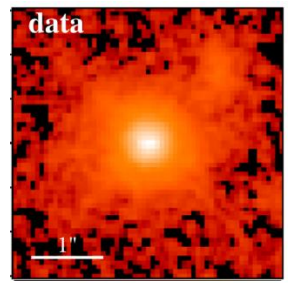
Malte Schramm & JDS 2013

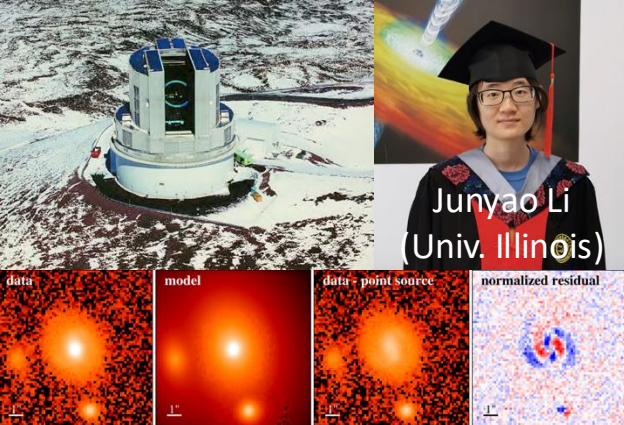
WFC3 (IR)
32 quasars ($z \sim 1.5$)



Ding, JDS, Treu+ 2020

Black hole masses from Subaru/FMOS (Schulze+2018)

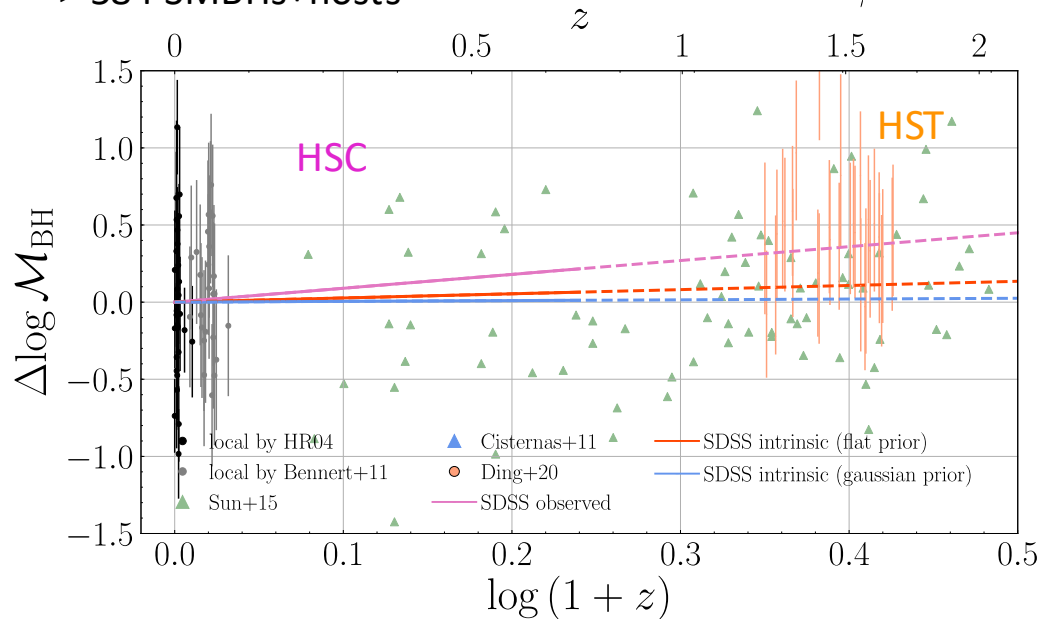




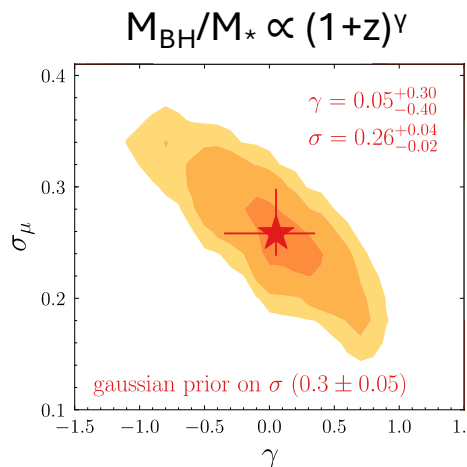
Junyao Li
(Univ. Illinois)

Li, JDS et al. 2021

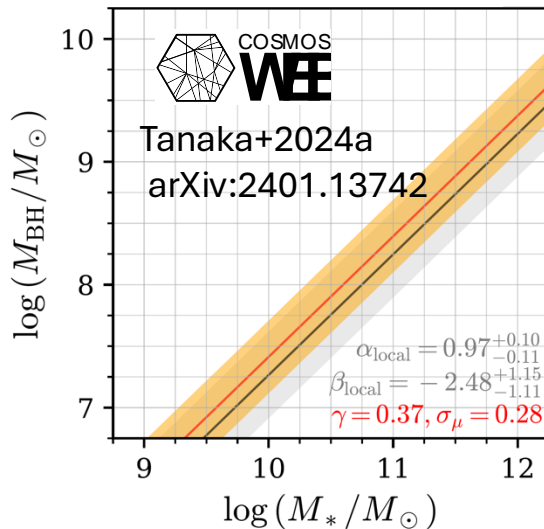
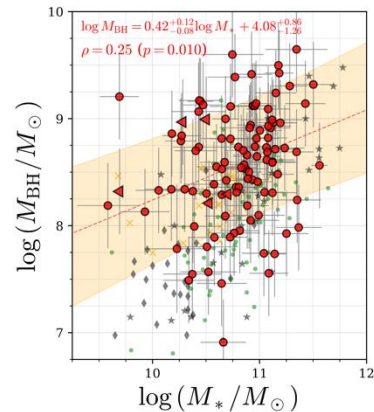
> 584 SMBHs+hosts



Evolution of the $M_{\text{BH}} - M_*$ relation



JWST
($0.8 < z < 2.5$)



CID-668
($z=0.97$)

CID-211
($z=1.17$)

CID-203
($z=1.36$)

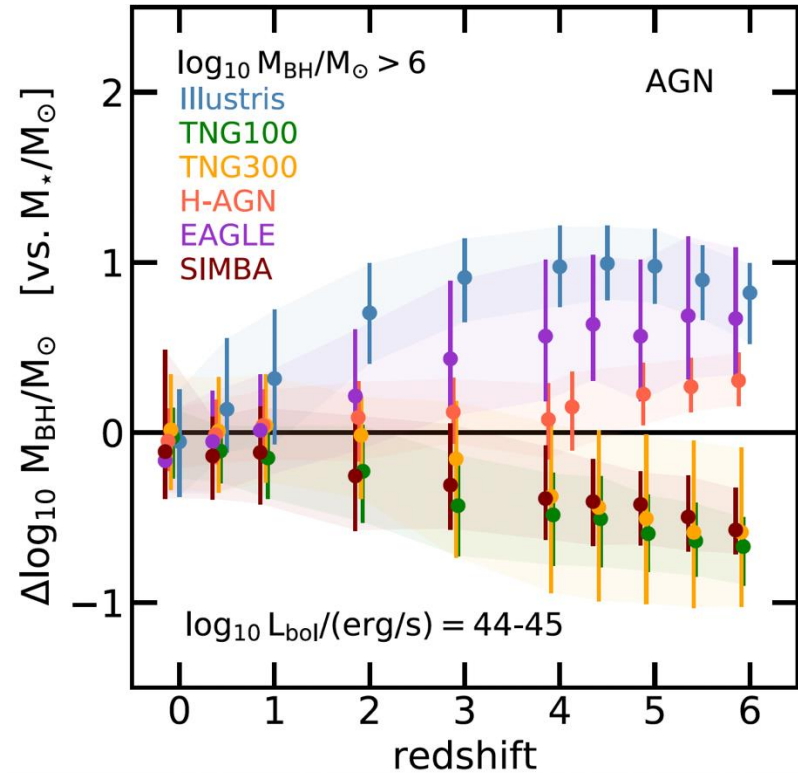
CID-1174
($z=1.55$)

CID-273
($z=1.85$)

Evolution of supermassive black holes and galaxies

- $M_{BH} / M_*(z)$

$$\Delta \log M_{BH} = \log \left(\frac{M_{BH}}{M_*} \right) - \log \left(\frac{M_{BH}}{M_*} \right)_{z=0}$$

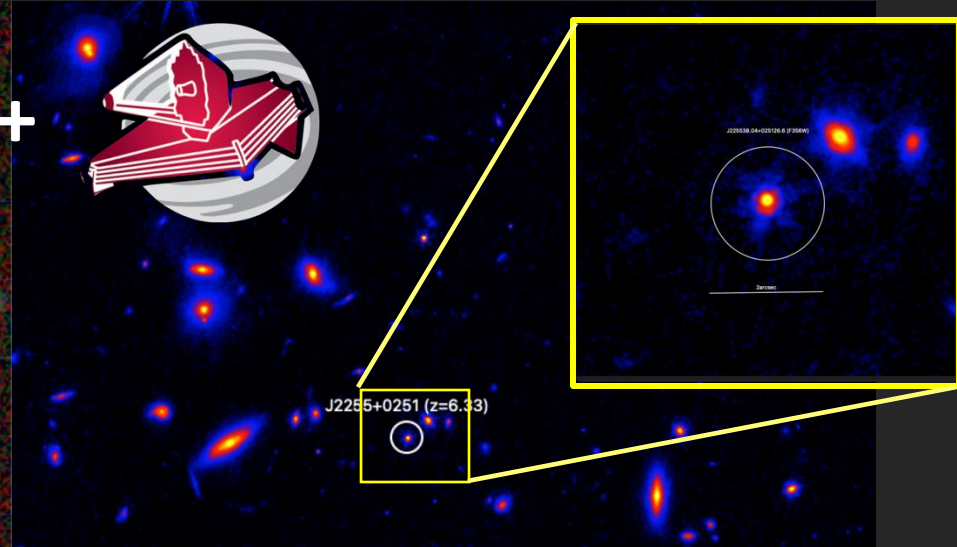
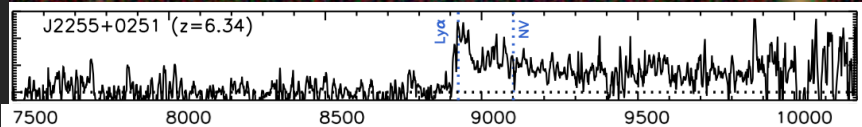
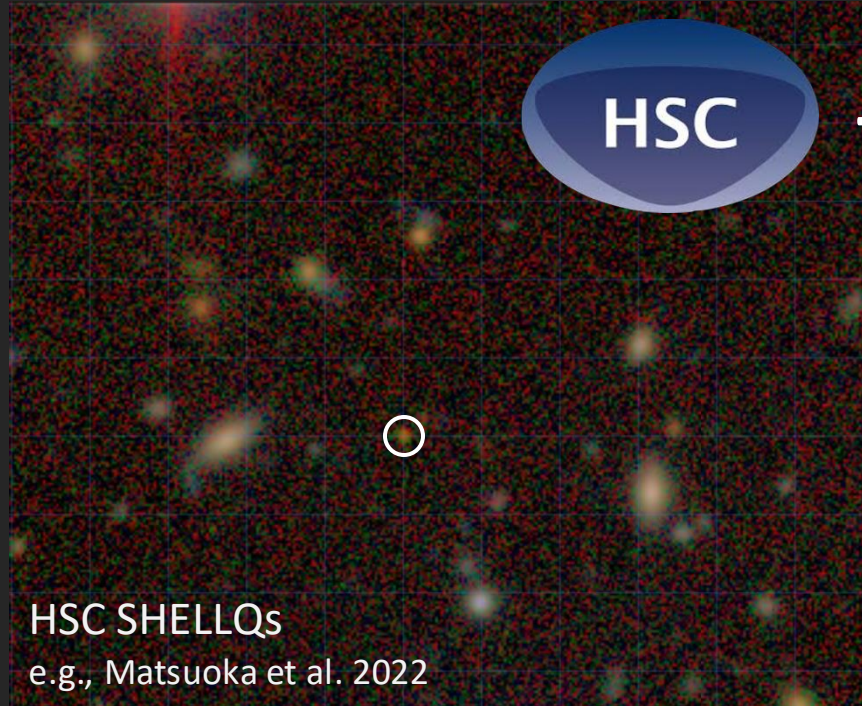
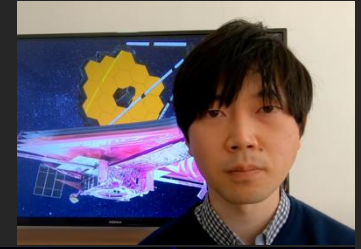


Full Census of SMBHs and Host Galaxies at $z = 6$

PI: Masafusa Onoue (KIAA, Kavli IPMU)

Co-PIs: Xuheng Ding, J. Silverman (Kavli IPMU), T. Izumi (NAOJ), Y. Matsuoka (Ehime)

Co-Is: Michael Strauss (Princeton), Knud Jahnke (MPIA) + 38 additional collaborators



Article

Detection of stellar light from quasar host galaxies at redshifts above 6

<https://doi.org/10.1038/s41586-023-06345-5>

Xuheng Ding^{1,2}, Masafusa Onoue^{3,4,5}, John D. Silverman^{2,6}, Yoshiki Matsuoka⁷, Takuma Izumi⁸, Michael A. Strauss⁹, Knud Jahnke¹⁰, Camryn L. Phillips¹¹, Junyao Li¹², Received: 25 November 2023

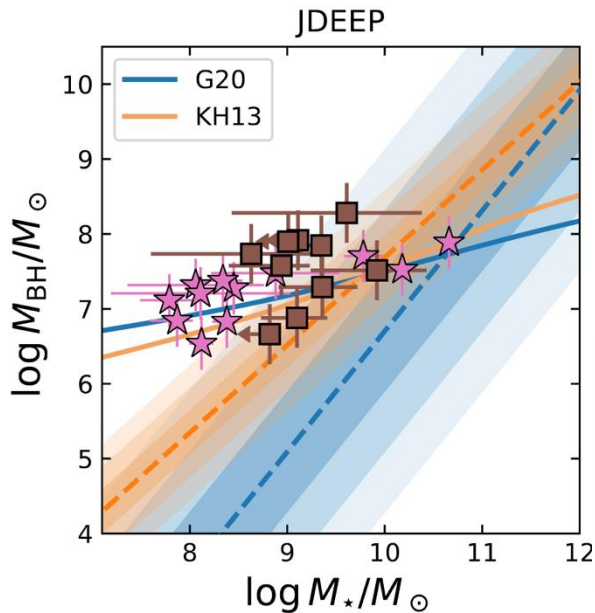
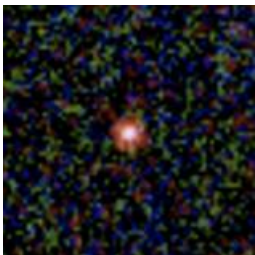
Cycle 1 Go
50 hrs

Ding, Onoue, JDS et al. Nature 2023

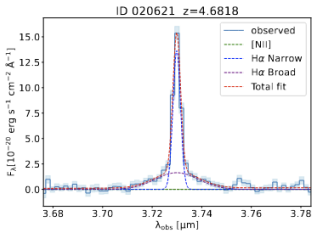
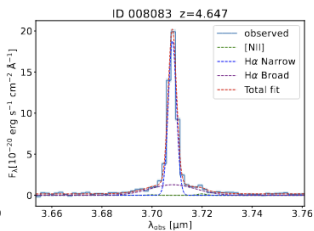
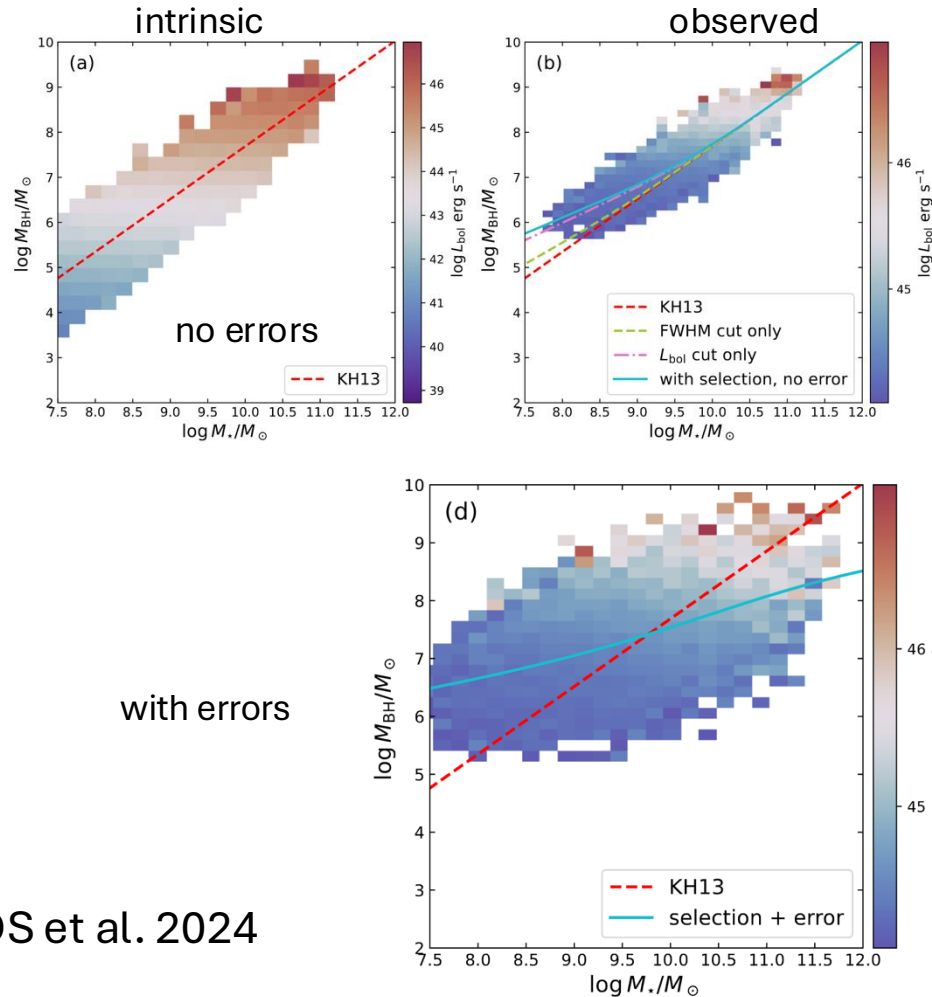
Onoue et al. in prep

JWST studies at $4 < z < 6$

Little red dots



Simulated distributions



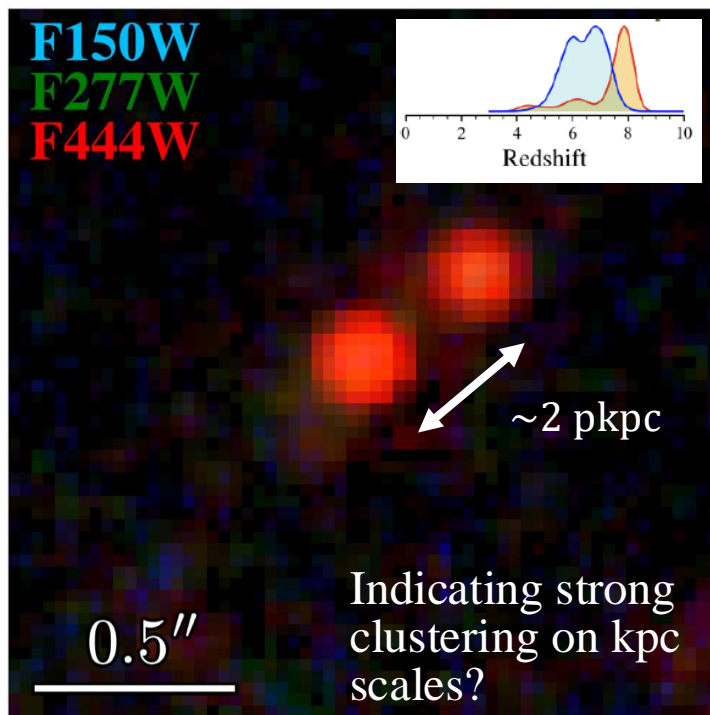
Li, JDS et al. 2024

Merger makes monster SMBHs?

- The first discovery of **dual LRDs**

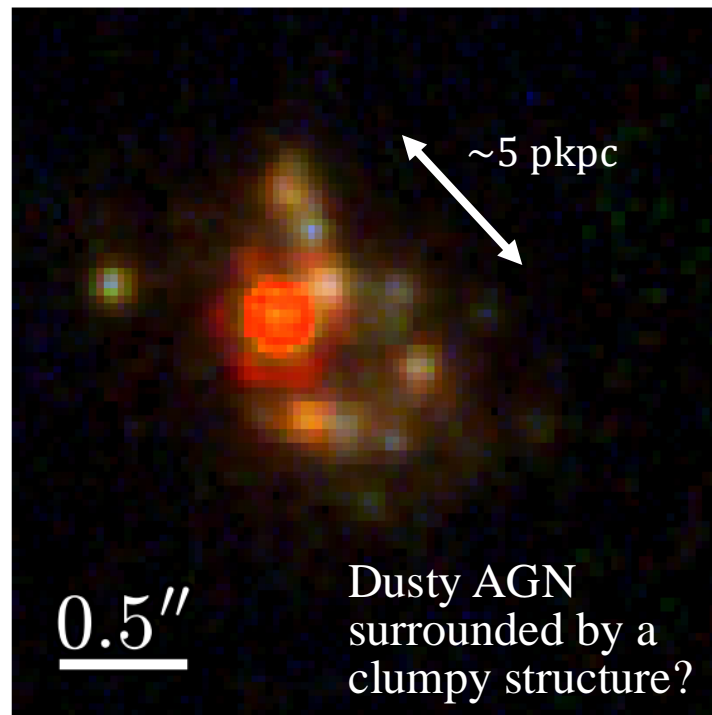
Tanaka+2024c

The redshift record for dual AGNs?



- **Crimson Behemoth (Tanaka+2024b)**

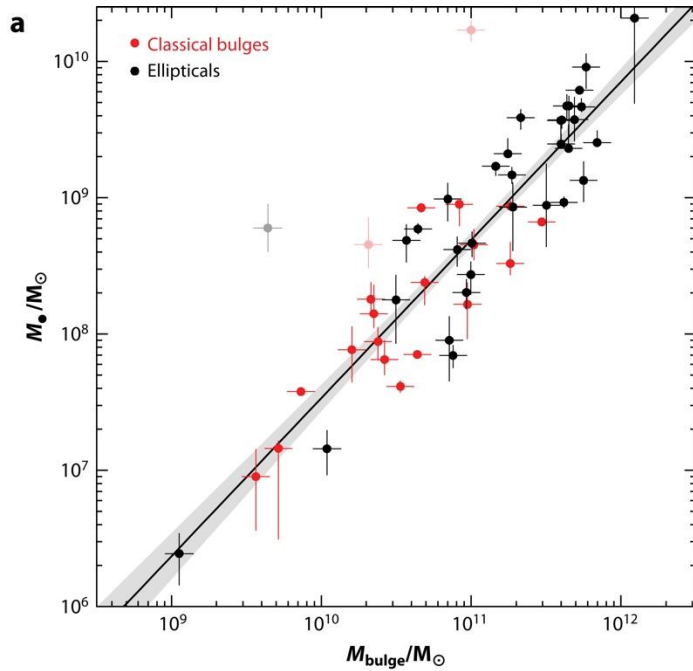
Complex merger system with dusty AGN @z=4.91



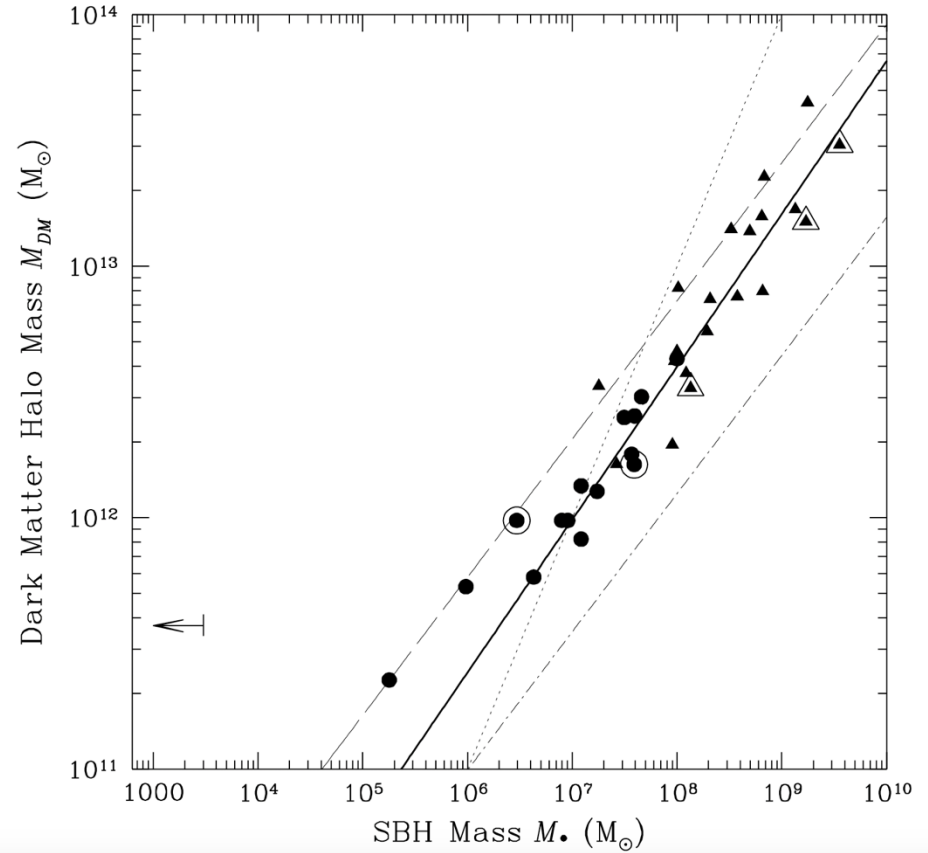
We need follow-up spectroscopic observations!!

supermassive black hole - dark matter connection

A black hole – dark matter connection?

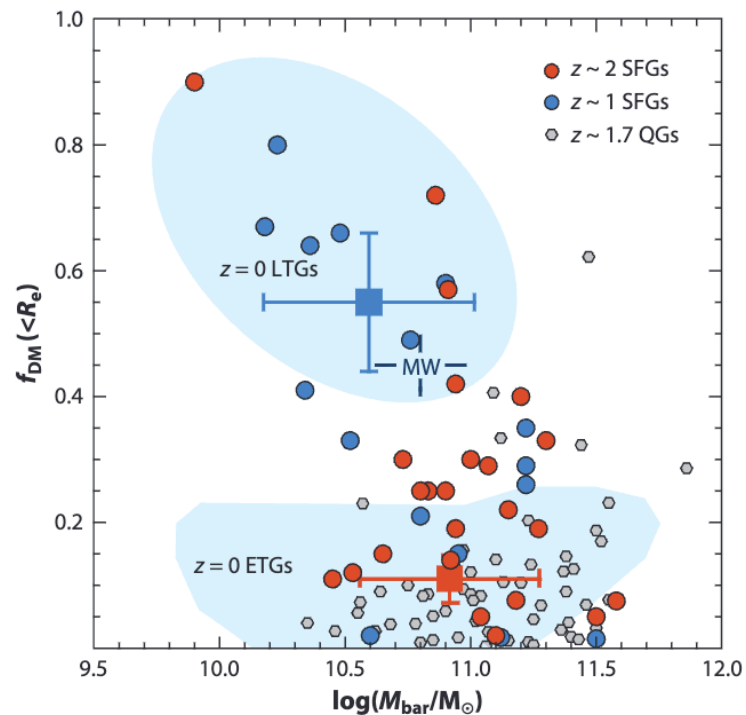
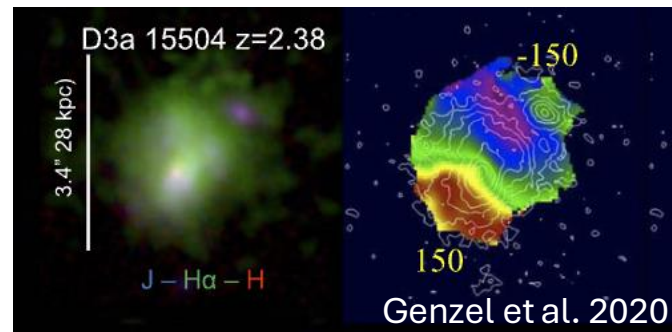
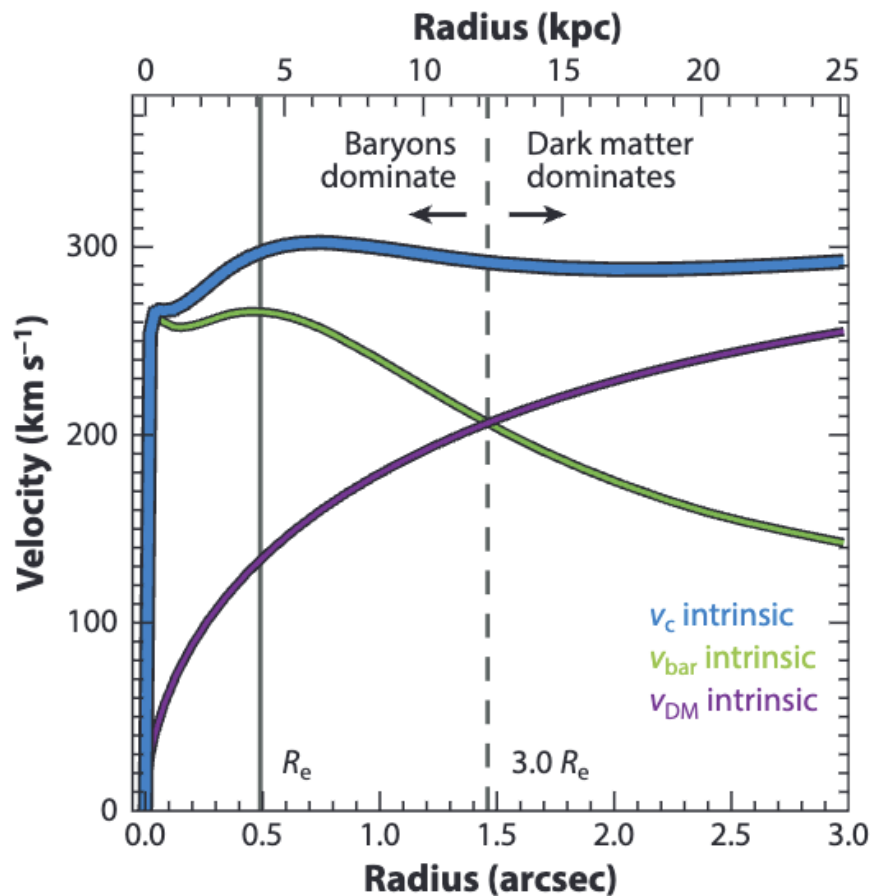


Kormendy & Ho 2013



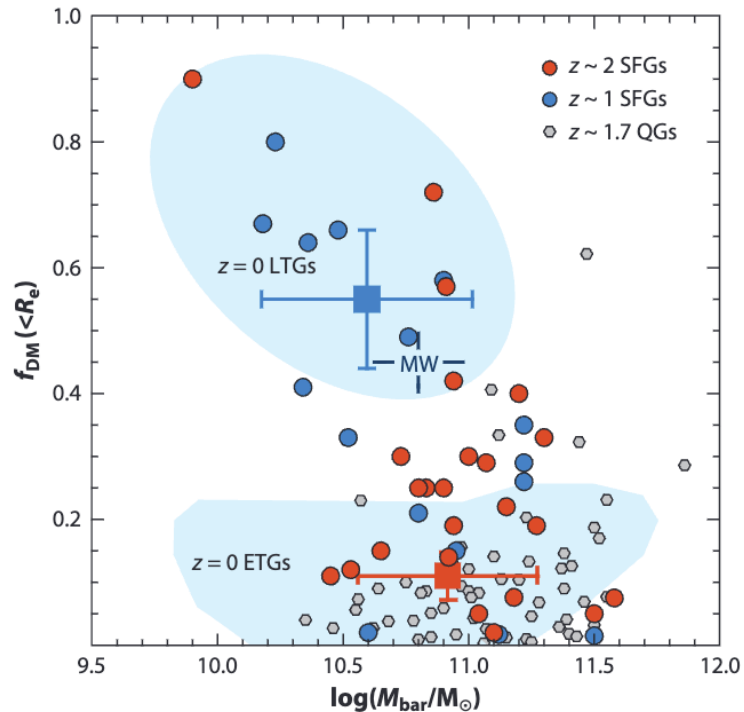
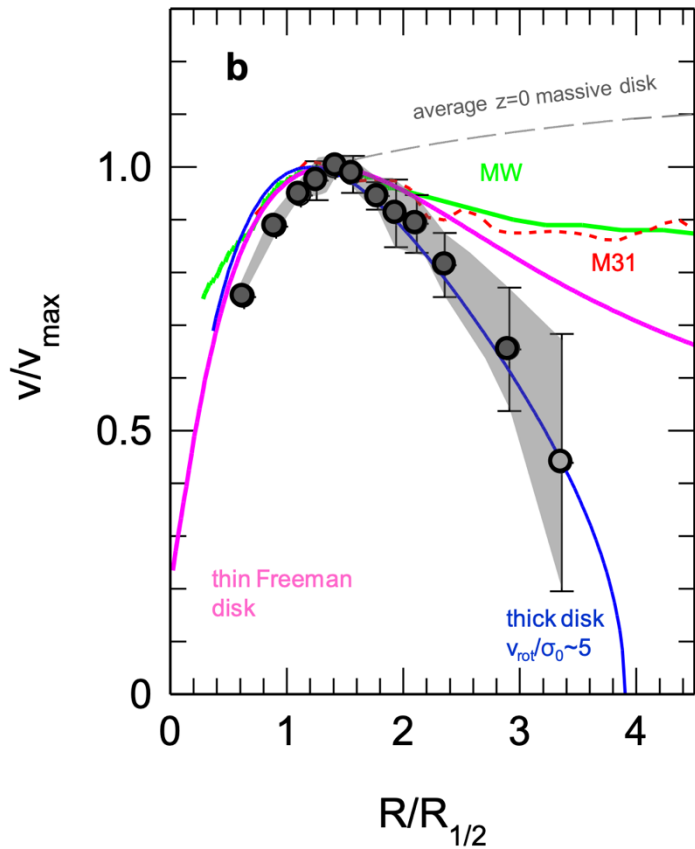
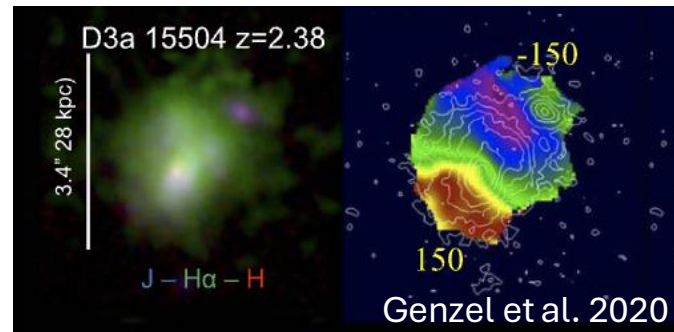
Ferrarese 2022

Rotation curves of high-z galaxies



Strongly baryon-dominated disk galaxies at the peak of galaxy formation ten billion years ago[†]

Genzel et al. 2017



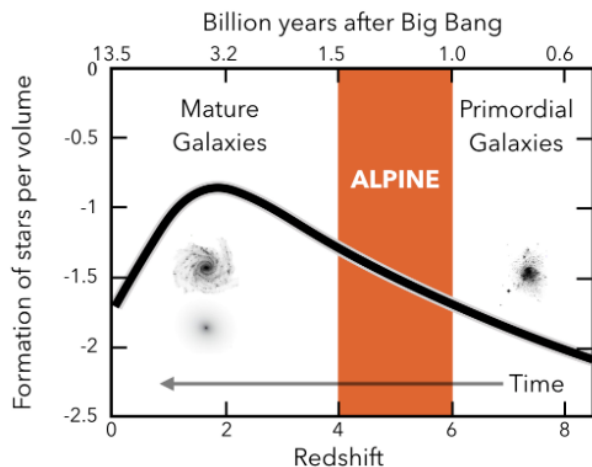
ALPINE



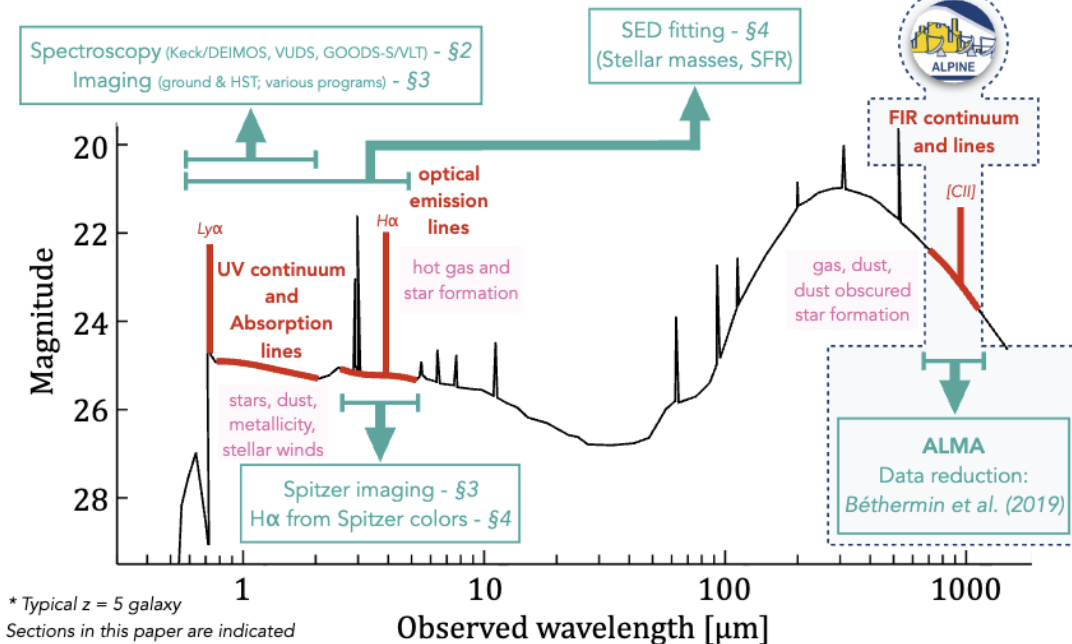
ALPINE : A large ALMA program to study the gas and dust in 118 galaxies in the early universe

PI: Olivier Le Fevre

coPIs: JDS, M. Bethermin, A. Faisst, P. Capak, P. Cassata, D. Schaerer, L. Yan



29+ papers

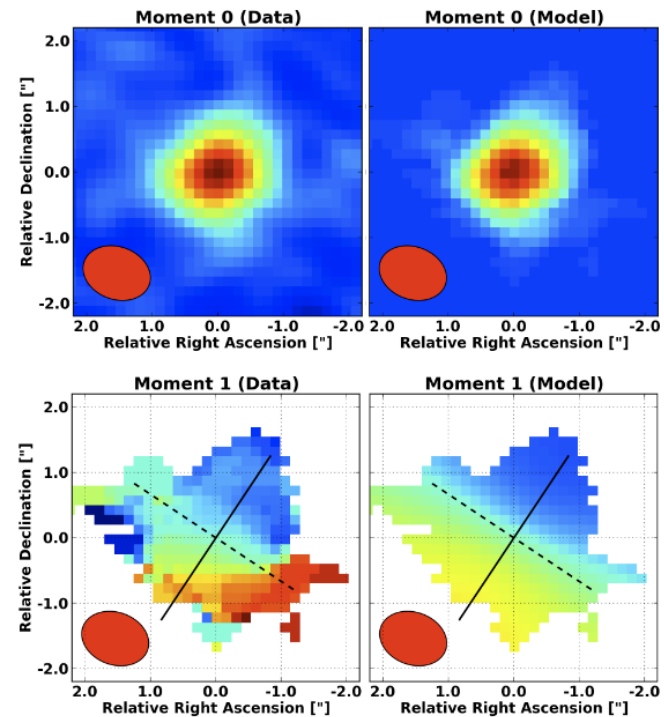
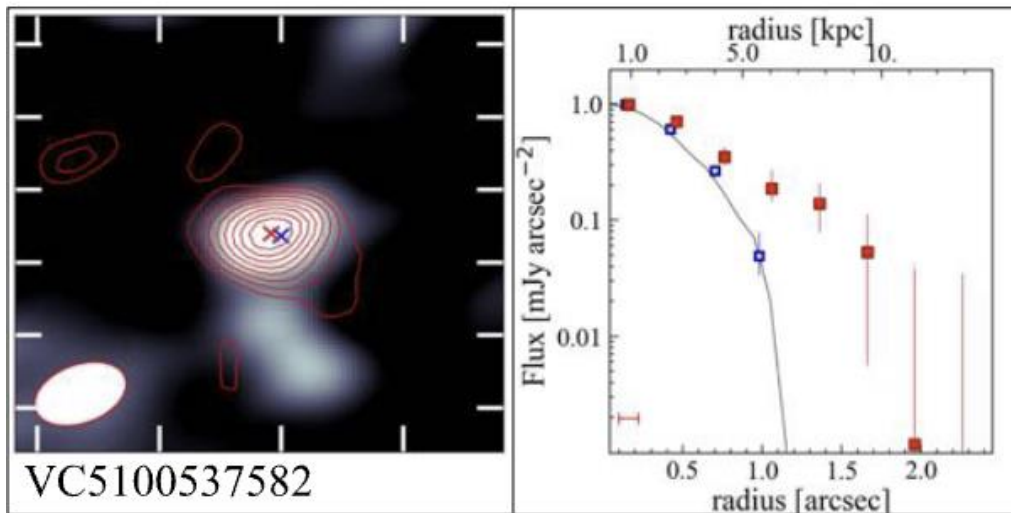


* Typical $z = 5$ galaxy
Sections in this paper are indicated

ALPINE

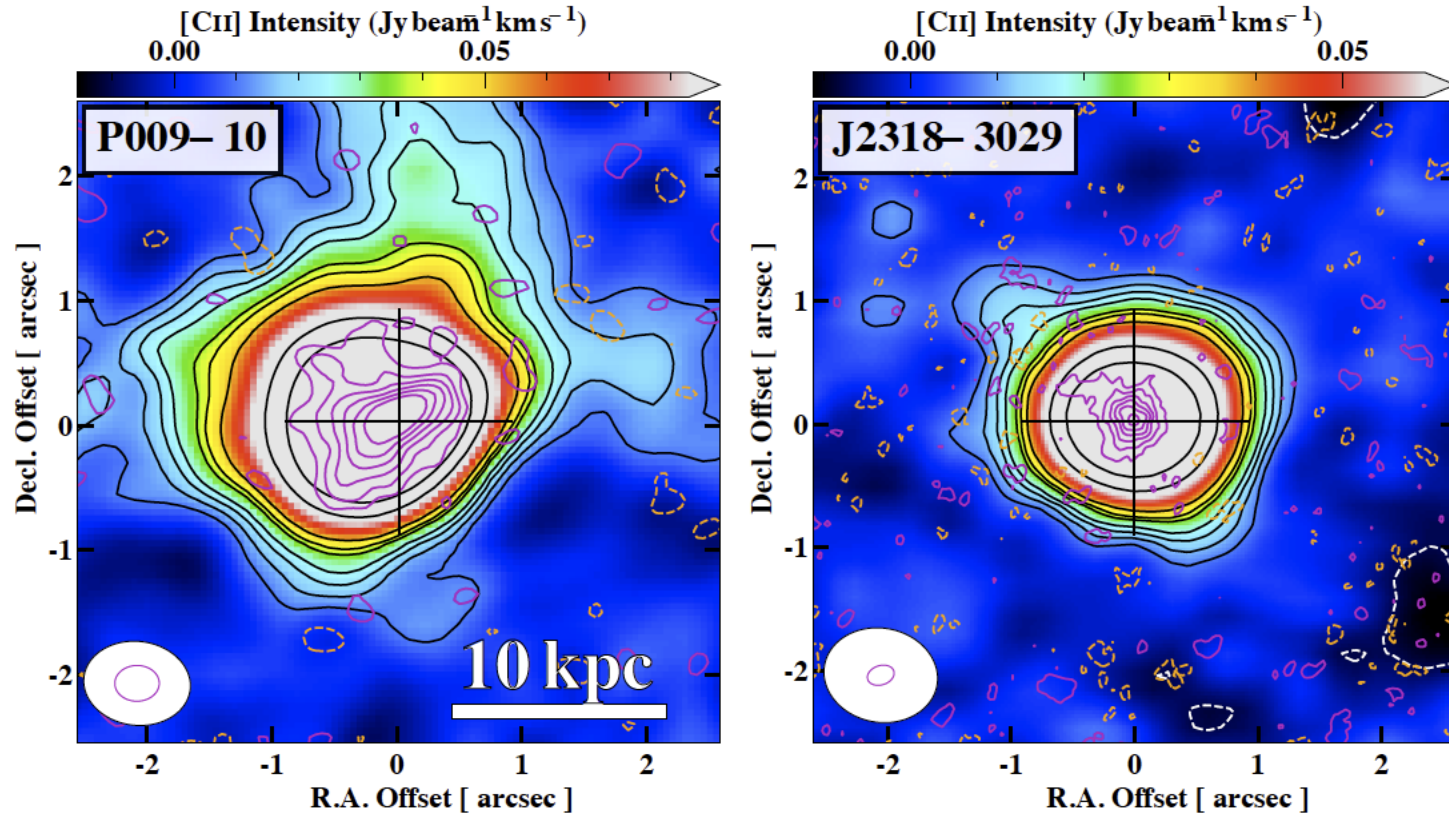


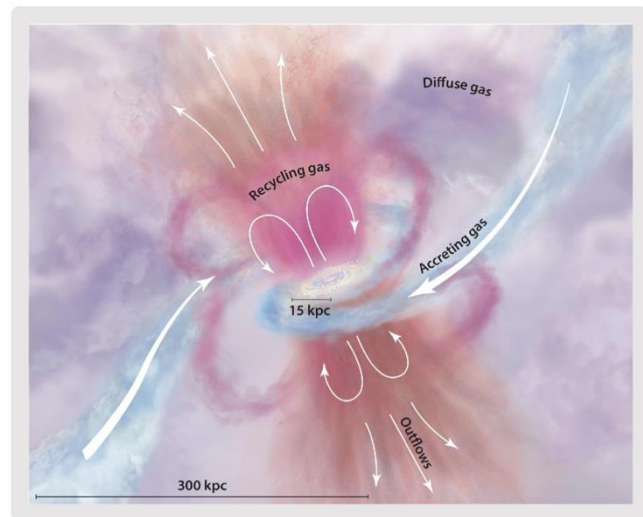
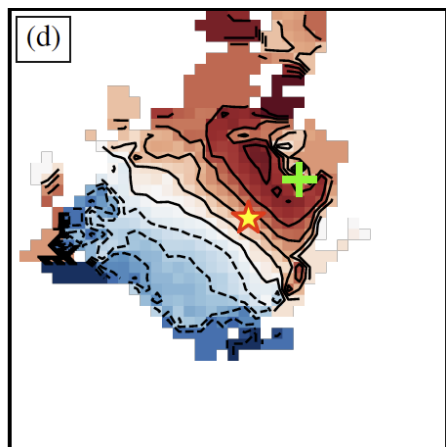
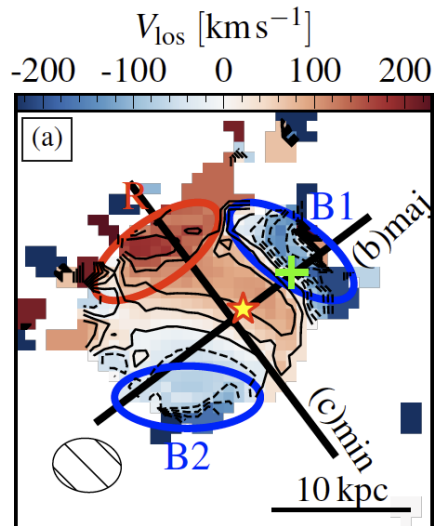
[CII] halos of distant galaxies ($4 < z < 6$)



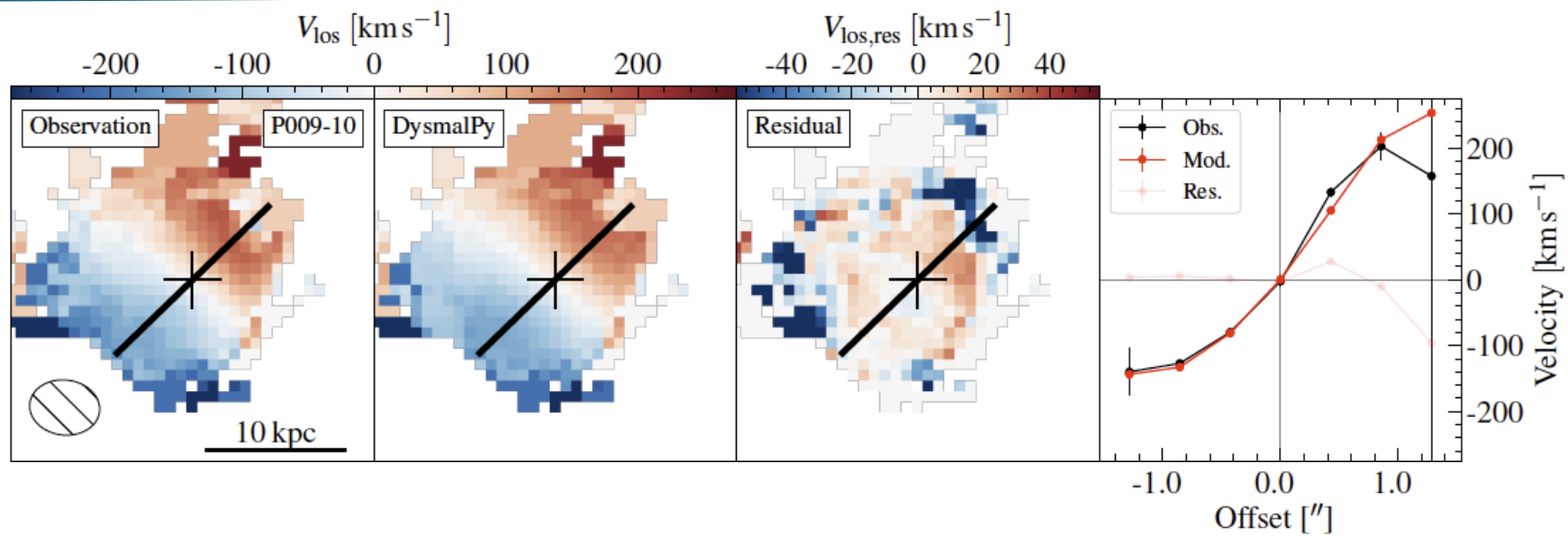
Fujimoto, JDS et al. 2020

[CII] halos of $z > 6$ quasars (Cycle 8, PI JDS)

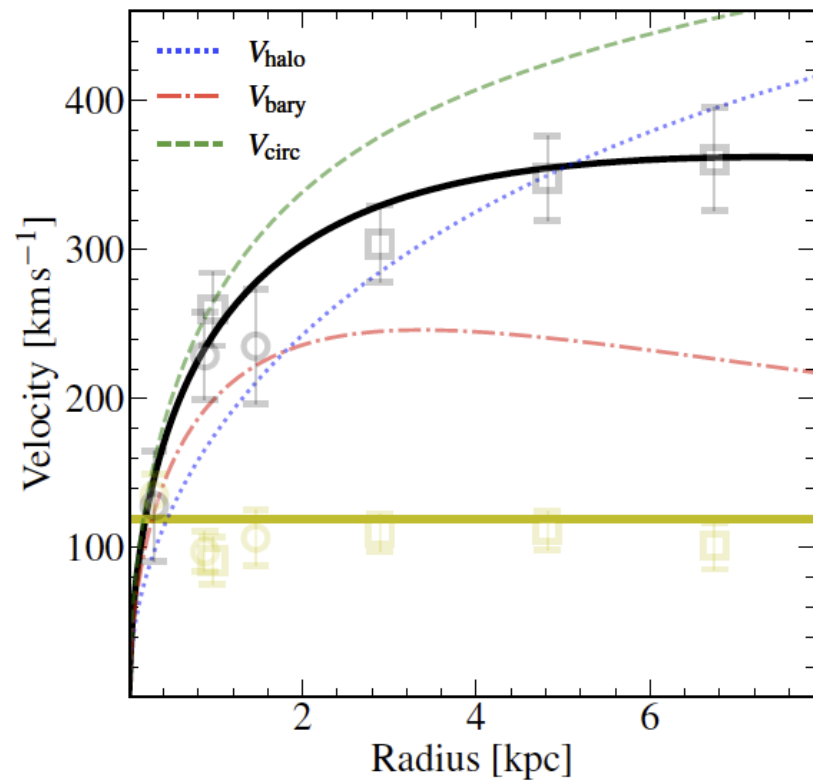
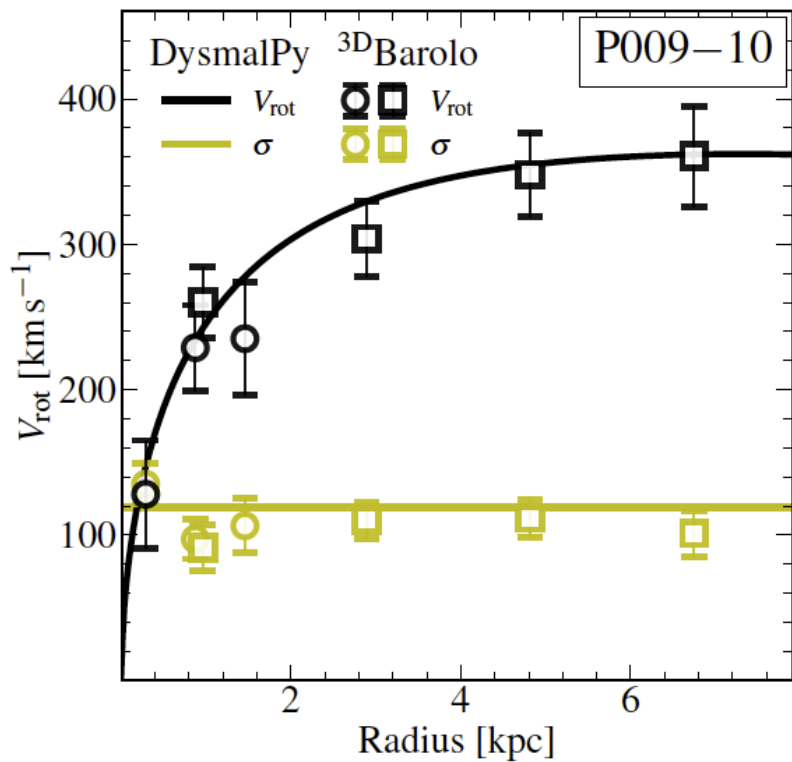


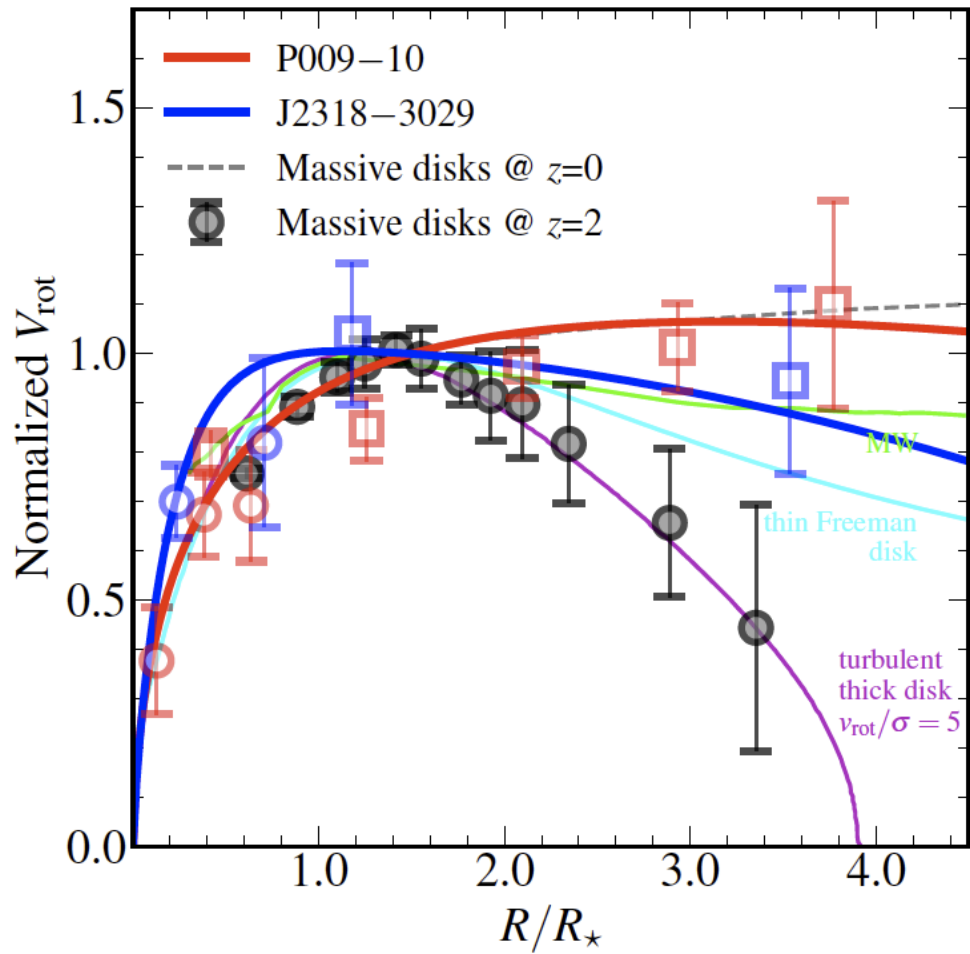


Tumlinson+ (2017)

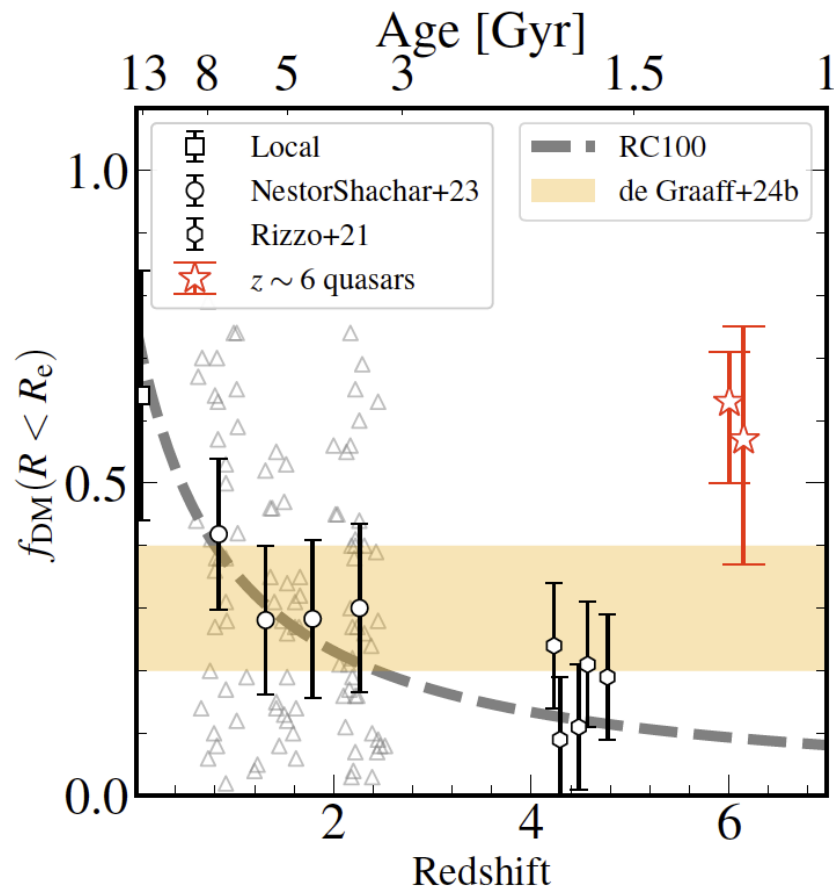


Rotation curves of $z > 6$ quasars

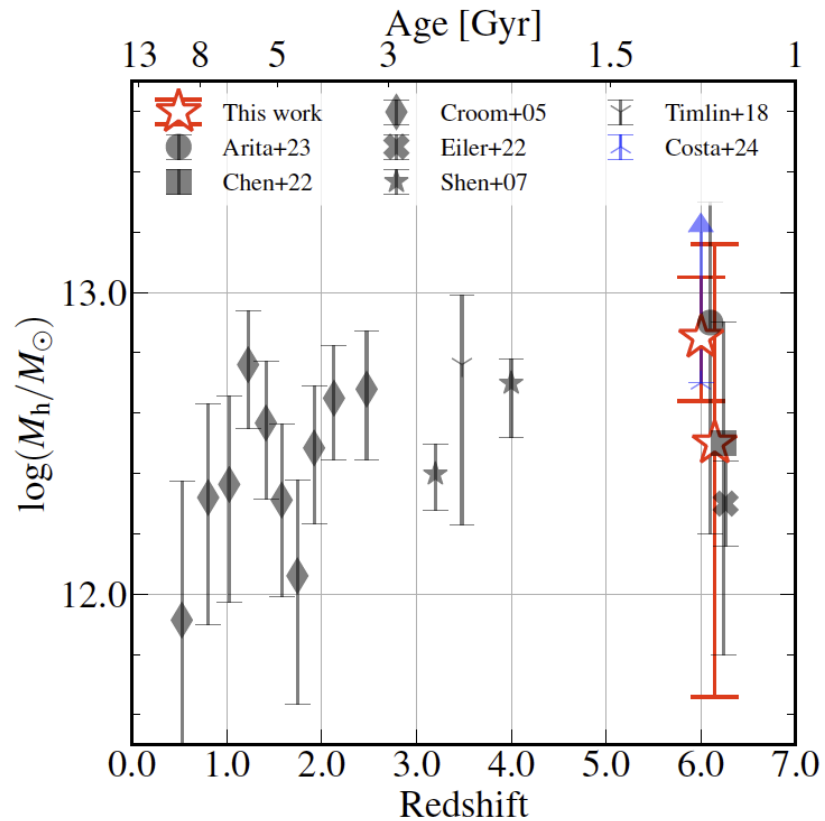




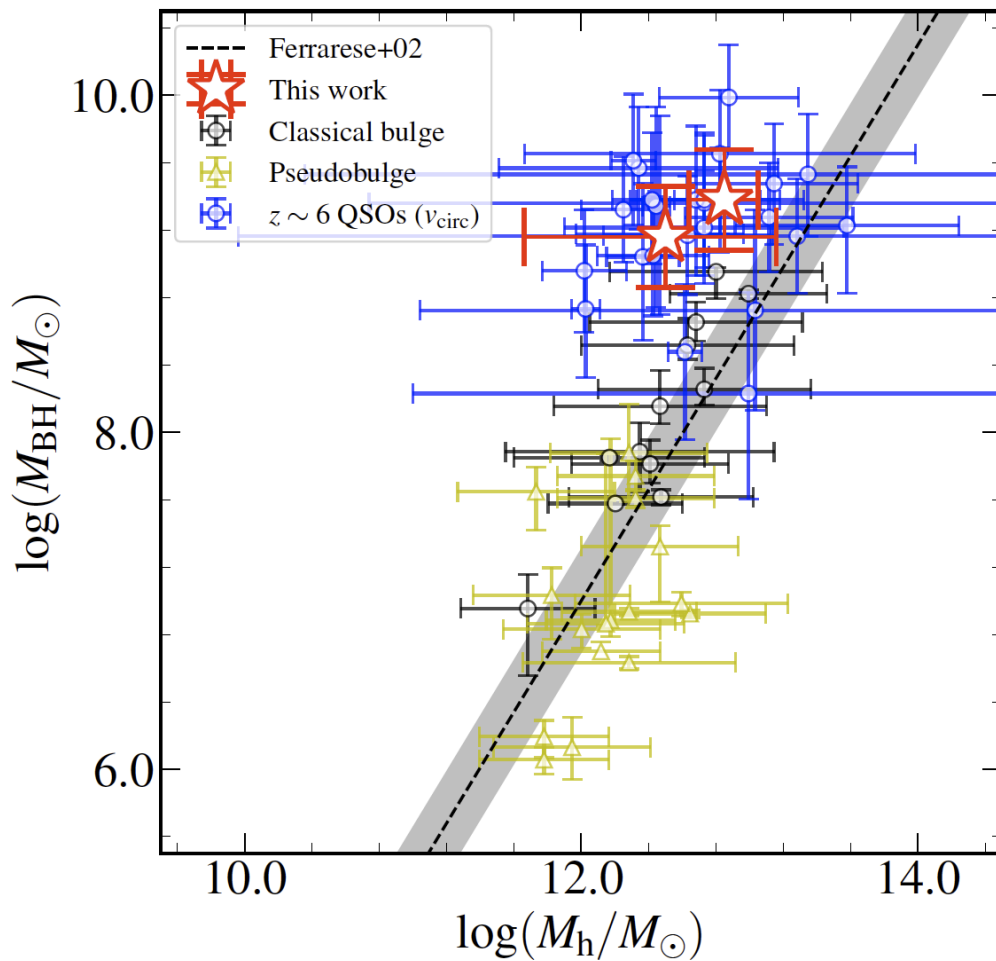
Dark matter fraction



Halo masses



Black hole – halo mass relation



Conclusions

- co-evolution of galaxies and their SMBHs up to $z \sim 6$
- dark matter is playing an important role in the early universe
- more to come: BH – host galaxy – (halo) relations with JWST, PFS, Euclid, Roman
- thank you Hitoshi for the early support (happy birthday)