Coevolution of Black Holes and Host Galaxies At High Redshift

Presenter

Jiyun Di

1st-Year MA student

Stony Brook University

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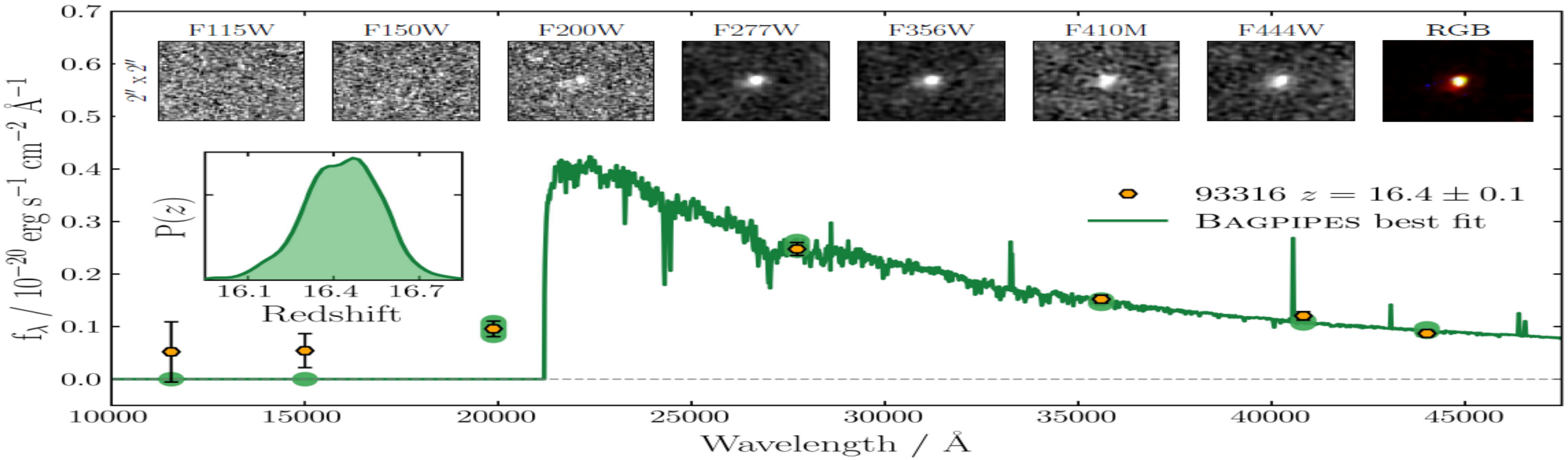
Preview:

1. BHs, AGN, and related objects in host galaxies
2. Co-evolution empirical relations: $M_{\rm BH}/M_{\rm bulge}$ $M_{\rm BH} - M_{\rm halo}$ $M_{\rm BH} - \sigma$
3. Lauer Bias
4. Feedbacks in galaxy evolutions

Introduction – High redshift galaxies

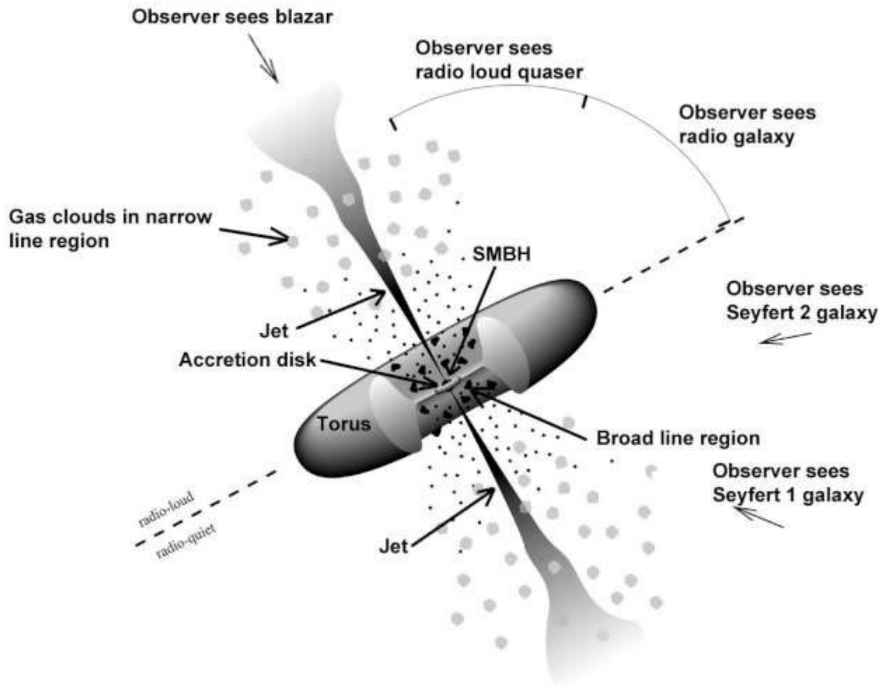
- Much attention has focused on attempting to measure the star-formation histories at high-redshift galaxies using new telescopes such as *JWST*.
- Finding and confirming such dim, dark, early-type and young galaxies is extremely hard.
- The largest redshifts of galaxies observed so far:

  z~8.5 (spec; Carnall et al. 2023), z~16.4 (photo, see below; Donnan et al. 2022)



Introduction – AGN, SMBH, and Host galaxy

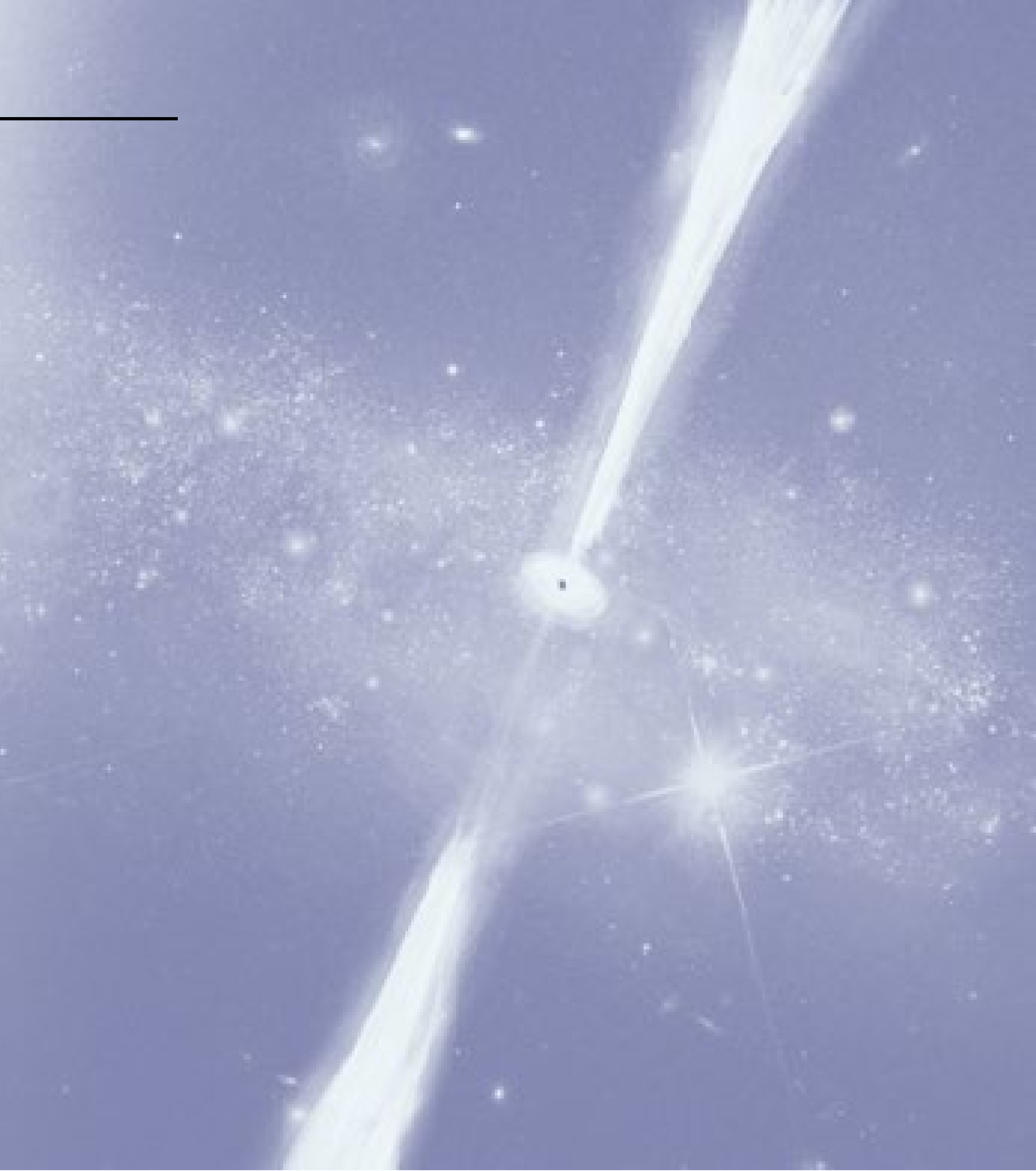
- **A**ctive **G**alactic **N**uclei (AGN) are the dense regions at the galactic center.
- For each bulge-galaxy, AGN has a **s**uper-**m**assive **b**lack **h**ole (SMBH; $> 10^5\ M_{\odot}$)
- Correlations between SMBH's mass and their host galaxy properties (e.g. bulge mass, luminosity, velocity dispersion) have been found over decades.



Credit: *Fermi Gamma-ray Space Telescope*

Introduction – High redshift galaxies

- To study the correlation changes as redshift goes, we explore the black hole and host galaxy’s evolutions.
- Evolution tracers:
  - SMBH mass
  - Bulge/Halo/Stellar masses
  - Velocity dispersion
  - Bulge/host luminosities
  - …

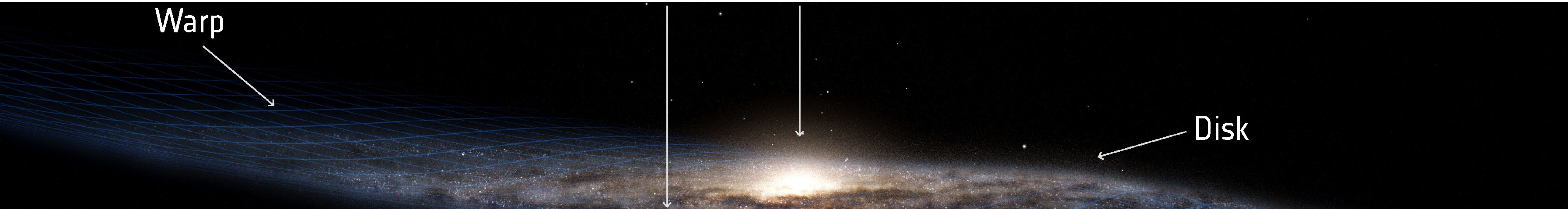


Who forms first?

1. SMBH:
    a) Seeds: Population III stars (oldest, very early stars) or direct halo gas.
    b) Relatively, portion of BH's mass M_{BH} decreases to the local value (present value) as it evolves with the host
2. Not SMBH: Halo gas with angular momentum could not fall into the center.

- At low redshift (local), SMBH only counts for about few 0.1% mass of the host (galaxy) bulge.

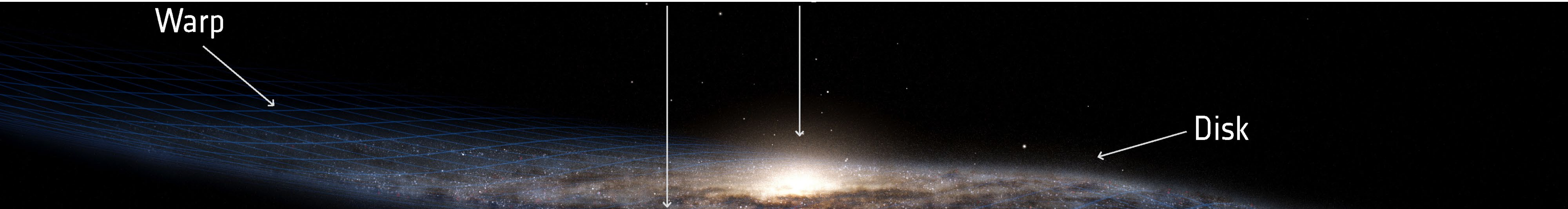
Credit: Stefan Payne-Wardenaar



Possible co-evolution tracer (as a function of z)? $M_{\rm BH}/M_{\rm bulge}$ Relation

- $M_{\rm BH}/M_{\rm bulge}$ Relation:
  - $M_{\rm BH}/M_{\rm bulge} \sim 10^{-2.31}$ for local (Kormendy & Ho 2013)
- $M_{\rm BH} - M_{\rm halo}$ Relation
- $M_{\rm BH} - \sigma$ (velocity dispersion) Relation

Credit: Stefan Payne-Wardenaar



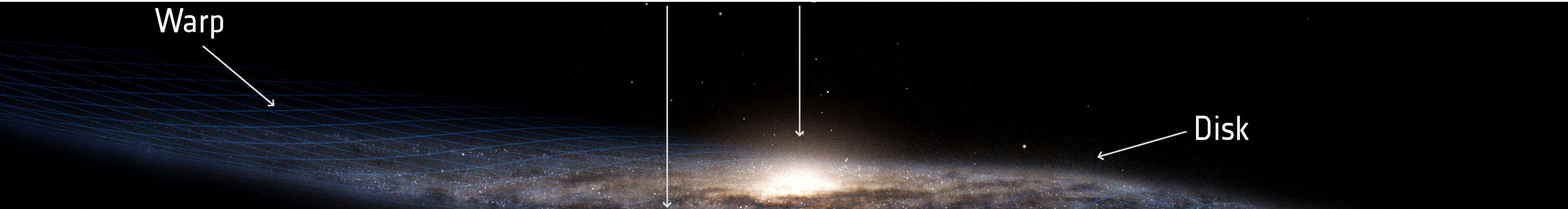
Problem on $M_{\rm BH}/M_{\rm bulge}$ Relation: Lauer Selection Bias

- Expectation: “the high-z galaxy expect a larger $M_{\rm BH}/M_{\rm bulge}$?”
  - Quasars at $z \sim 6$: $> 10^{-1.9}$ to $10^{-1.5}$ (Wang et al. 2013)
  - $z \sim 4-7$: $> 10^{-2}$ (Venemans et al. 2012)
- Lauer et al. (2007) argued there might be due to a selection effect:

Low-mass galaxies with SMBHs (high ratio) are more likely to be found than

high-mass galaxies with typical BHs (low ratio).

Credit: Stefan Payne-Wardenaar



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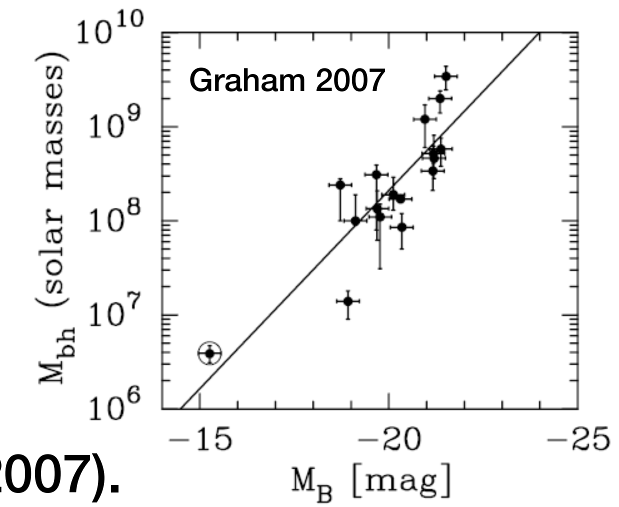


- This could be explained from two perspectives:

1) $M_{\rm BH} - L$ relation's slope uncertainty

- $$\log\left(\frac{M_{\rm BH}}{M_\odot}\right) = -0.42(\pm 0.06)(B+20.0) + 8.32(\pm 0.10)$$ (Graham 2007).
- Luminosity L can be inferred from B-band magnitude B. Larger B, larger error $M_{\rm BH}$.

2) Schechter (1976) Luminosity Function (a Prob. Distri.)

- $$\phi(L)\mathrm{d}L = \phi^*\,(L/L^*)^{-\alpha}\,e^{-L/L^*}\,\frac{\mathrm{d}L}{L^*}.$$
- Number density of galaxies is falling off rapidly with L,
- Population of high-L galaxy blackholes were missed (Lauer et al. 2007).

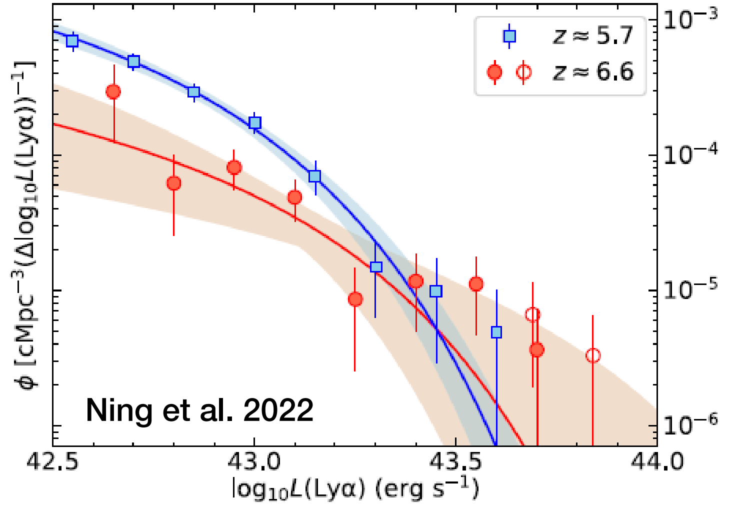
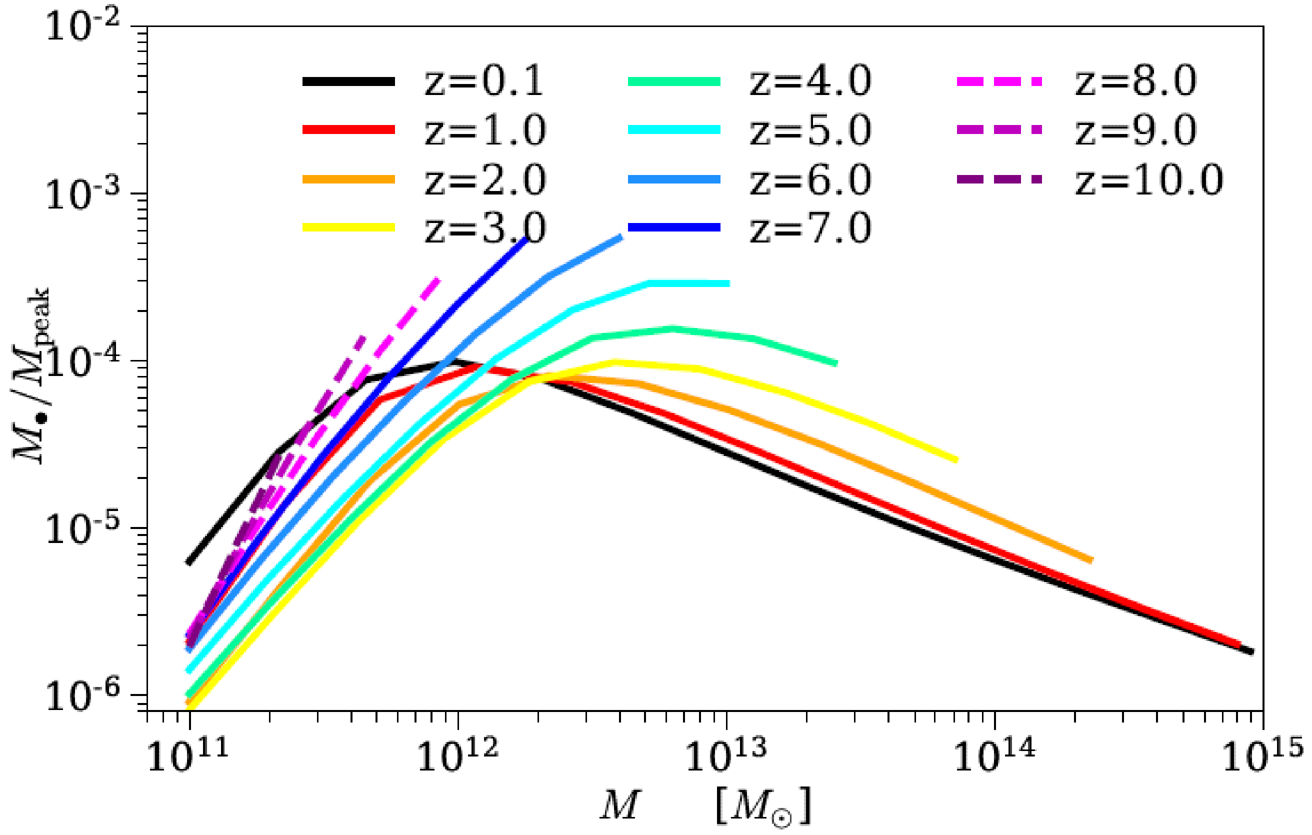


Figure 14. The Lyα LFs at $z \approx 5.7$ (blue, from Z22) and $z \approx 6.6$ (red, this work), which are both obtained by our spectroscopic survey. The lines represent the best-fit Schechter functions, while the corresponding colored shades cover the 1σ regions of the fitting.

Problem on $M_{\rm BH}/M_{\rm bulge}$ Relation: Lauer Selection Bias

Zhang et al. 2022



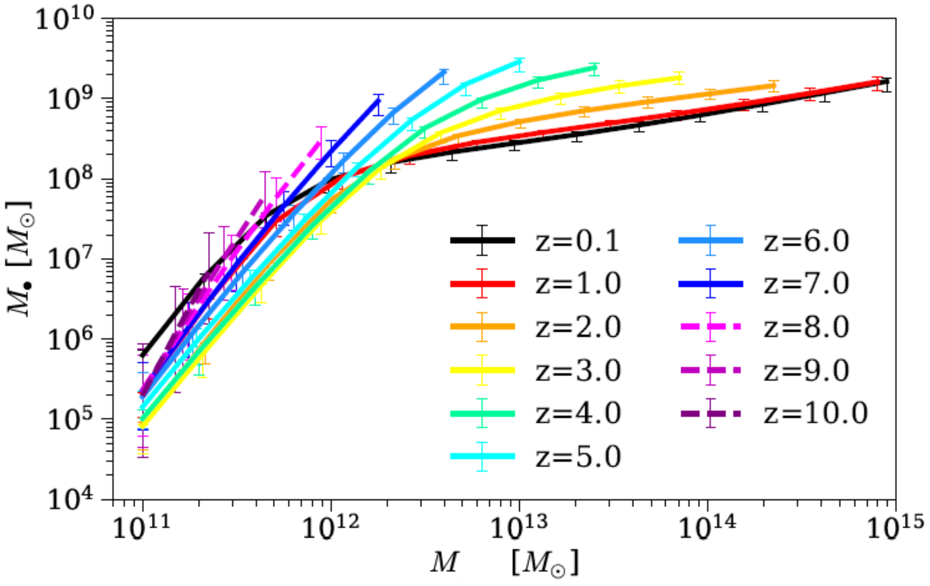


Figure 14. Top Panel: the best-fitting median $M_\bullet$–$M_{\rm peak}$ (peak halo mass) relation from $z = 0$– 10 (see §4.2). **Bottom Panel:** the best-fitting $M_\bullet/M_{\rm peak}$ ratios as a function of $M_{\rm peak}$ and z. The error bars show the 68% confidence intervals inferred from the model posterior distribution. The scaling relations at $z \geqslant 8$ are shown in dashed lines, which remain to be verified by future observations (by, e.g., *JWST*). All the data used to make this plot can be found here.

- When selecting sample with large $M_{\rm BH}$, we are more likely to observe low-mass galaxies.

Problem on $M_{\rm BH}/M_{\rm bulge}$ Relation: No redshift dependence!

- No significant redshift dependence in $M_{\rm BH}/M_{\rm bulge}$. Not a tracer! (e.g. Zhang et al. 2022)

Zhang et al. 2022

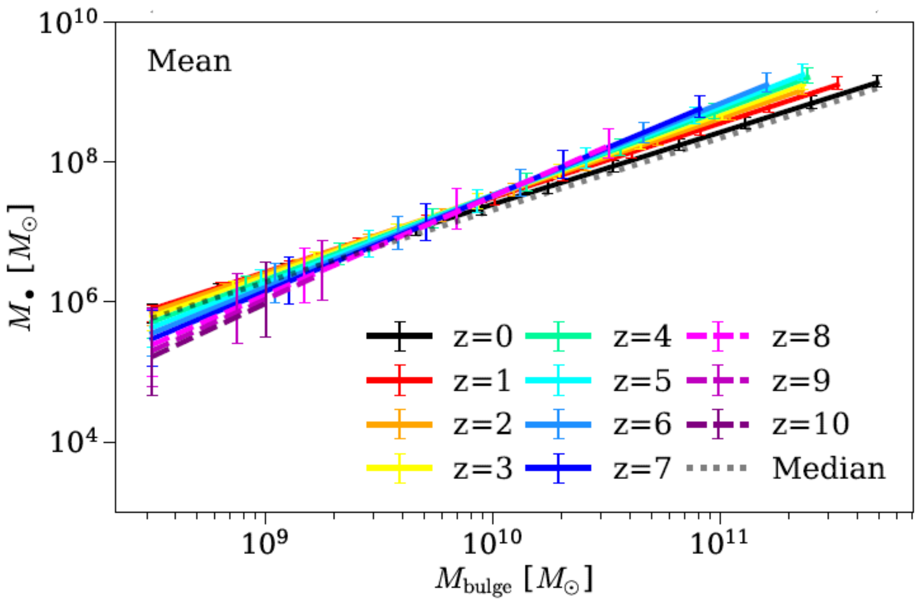


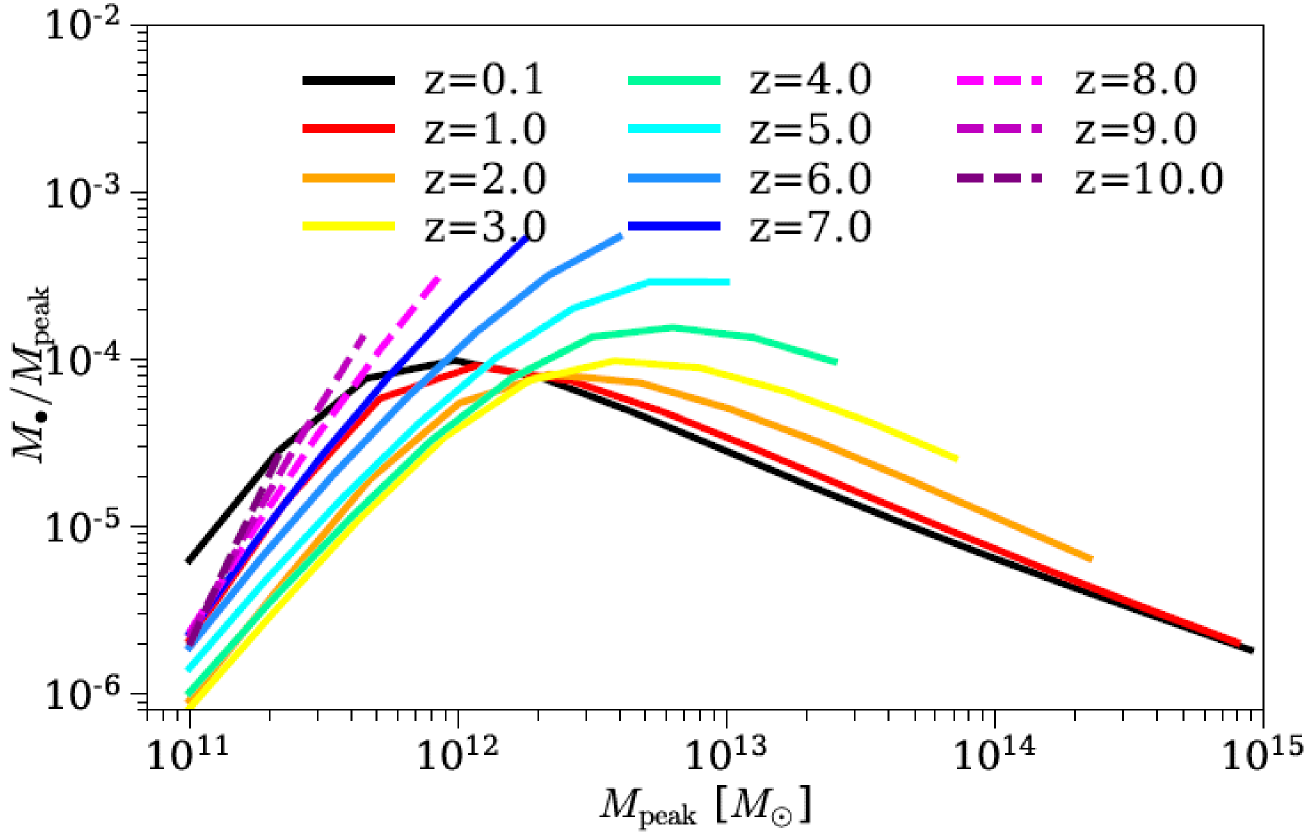
Figure 12. The evolution of the mean $M_\bullet$–$M_{\rm bulge}$ relation from $z = 0-10$ (see §4.2). The grey dotted line shows the median relation at $z = 0$ for comparison. The error bars show the 68% confidence intervals inferred from the model posterior distribution. The scaling relations at $z \geqslant 8$ are shown in dashed lines, which remain to be verified by future observations (by, e.g., *JWST*). All the data used to make this plot can be found here.

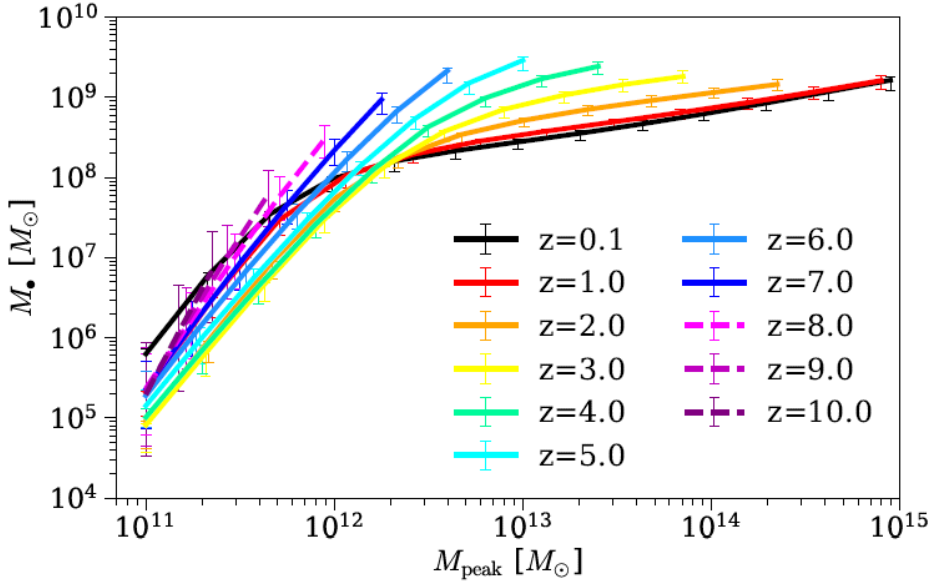
- Local SMBHs are also unlikely to grow with their host galaxies' masses but correlate with halo mass. (Powell et al. 2022)

Other co-evolution tracers

- $M_{\rm BH} - M_{\rm halo}$: BH to peak halo mass (as a function of z).
- $M_{\rm BH} - \sigma$: BH to velocity dispersion (as a function of z).

Zhang et al. 2022





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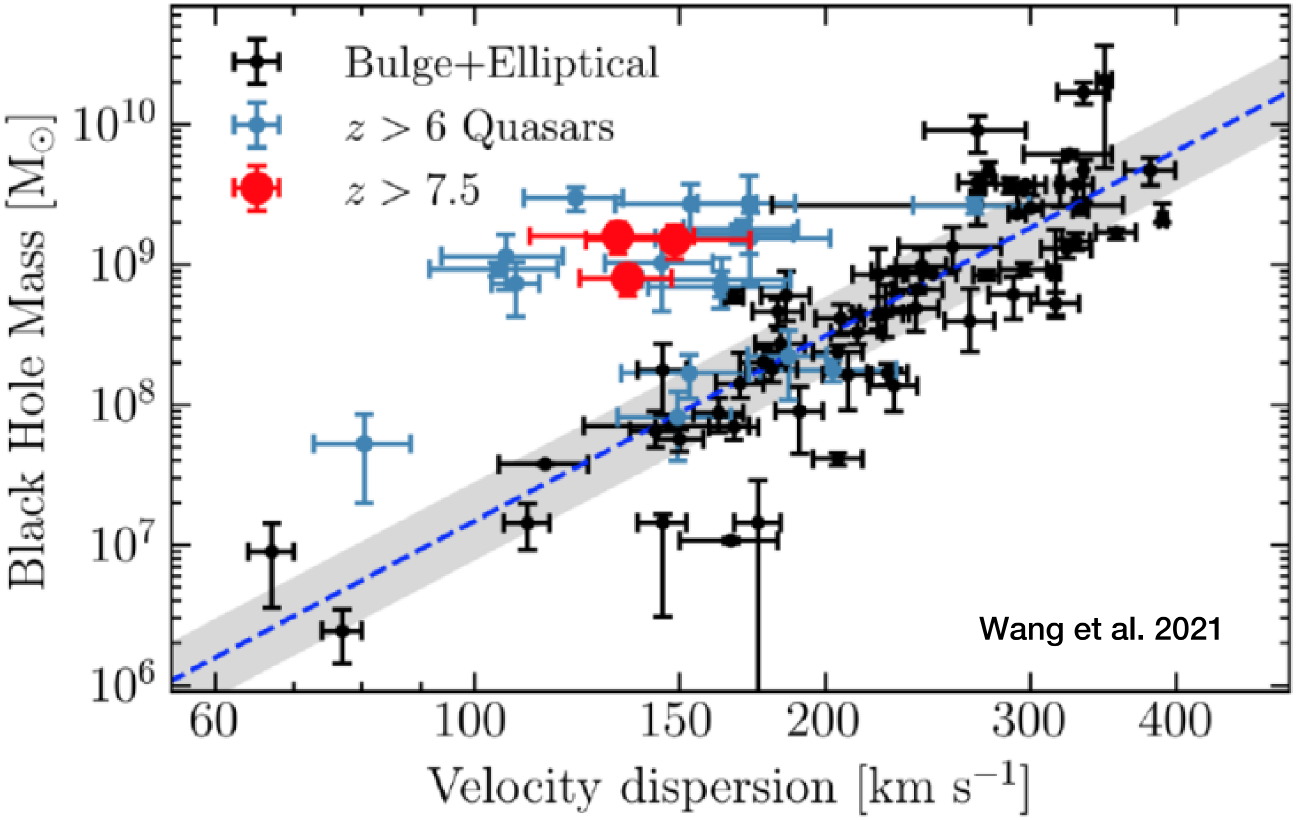
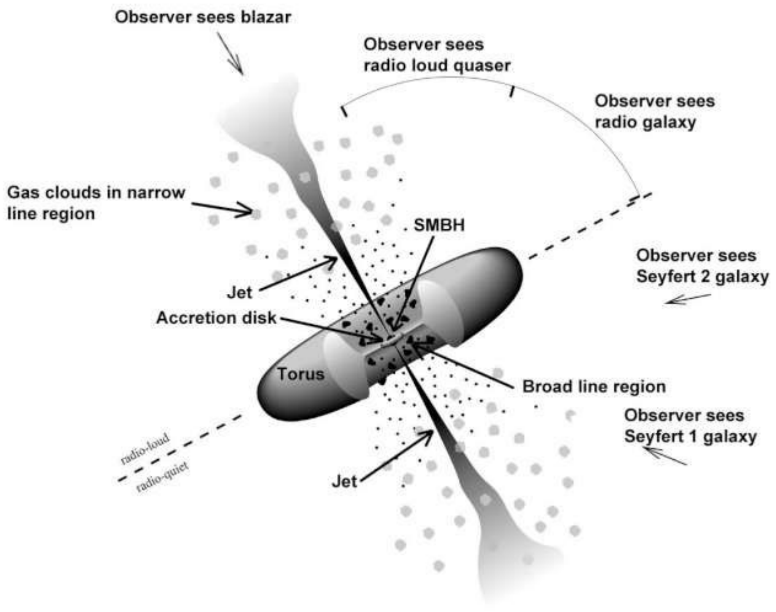


AGN Feedbacks in galaxy evolution



Credit: *Fermi Gamma-ray Space Telescope*

- AGN Feedbacks between SMBHs and hosts provide opportunities to build correlations.
- Two modes of AGN feedback modes:
  1. Quasar mode
     - Gas flows in, high accreting rate
  2. Radio mode
     - Slow accreting rate
     - Heat intra-cluster gas surrounding AGN to a high that shutdown halo cooling processes (LF at bright end) and star-formation, i.e. quenching.
     - Result a negative feedback.
- Other negative feedbacks: surrounding starburst winds (quenching)
- Any positive feedback? Yes!
  - Molecular outflow compress dense gas clouds into cocoons (shell-like regions) reaching Jeans and enough clumps that satisfies collapse.

Takeaway

Co-evolution between SMBHs and their hosts are still under discussions while measurements on BH-halo or BH-σ relations at high redshifts are more available.

Mechanisms such as AGN negative wind-like and positive outflow feedbacks are self-regulating processes for star-formation and galaxy evolution.

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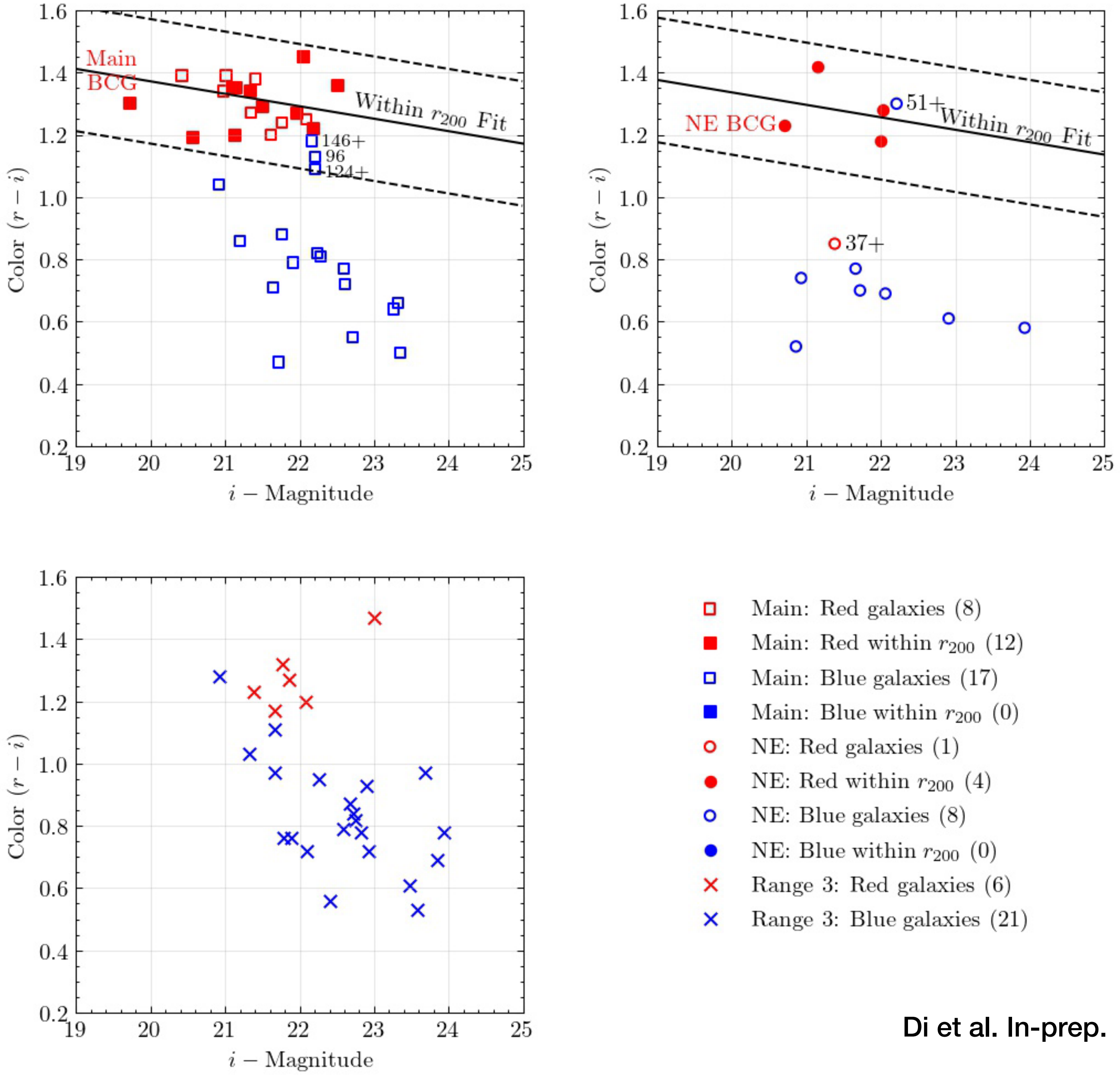
Appendix 1: Quenching and Color-Magnitude Diagram

ISM molecular powerful outflows may be the long-sought “smoking-gun” of quasar mechanical feedback that clears out the molecular disk formed from dissipative collapse during the merger. (Veilleux et al. 2013)

This turns out that the blue star-forming galaxies suddenly jump from blue cloud across green valley into red sequence, as shown in Color-Magnitude Diagram.



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