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Heavy Seeds and the Multi-scale Fueling of Early Supermassive Black Holes and Little Red Dots

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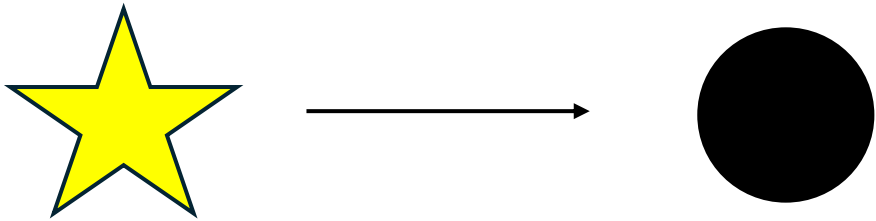
Introduction

- Too massive AGN/SMBHs in the early Universe
- Current mass measurement indicate deviations from local relations
- New class of objects named 'Little Red Dots', suggested to be AGN

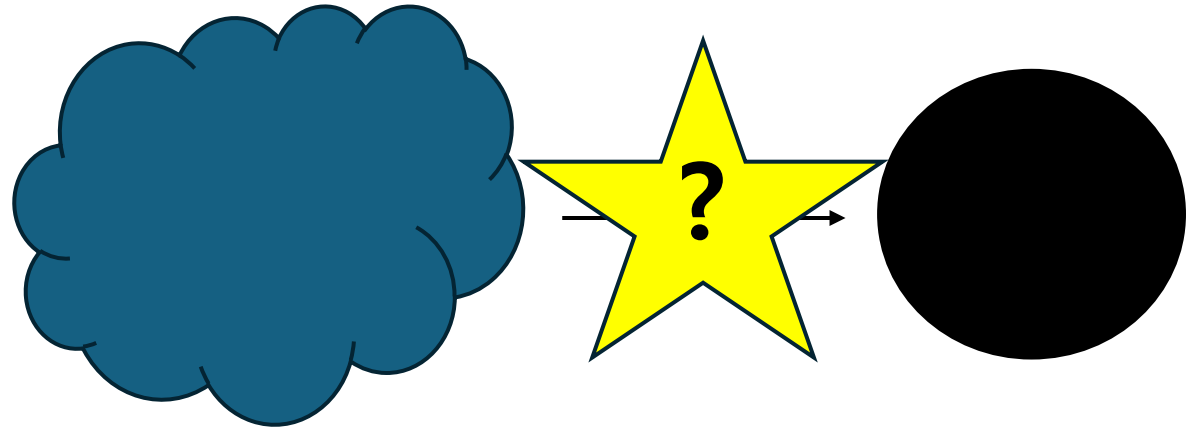


SMBH seeding models

- Light Seeds from Pop III remnants
- Heavy Seeds from Direct Collapse



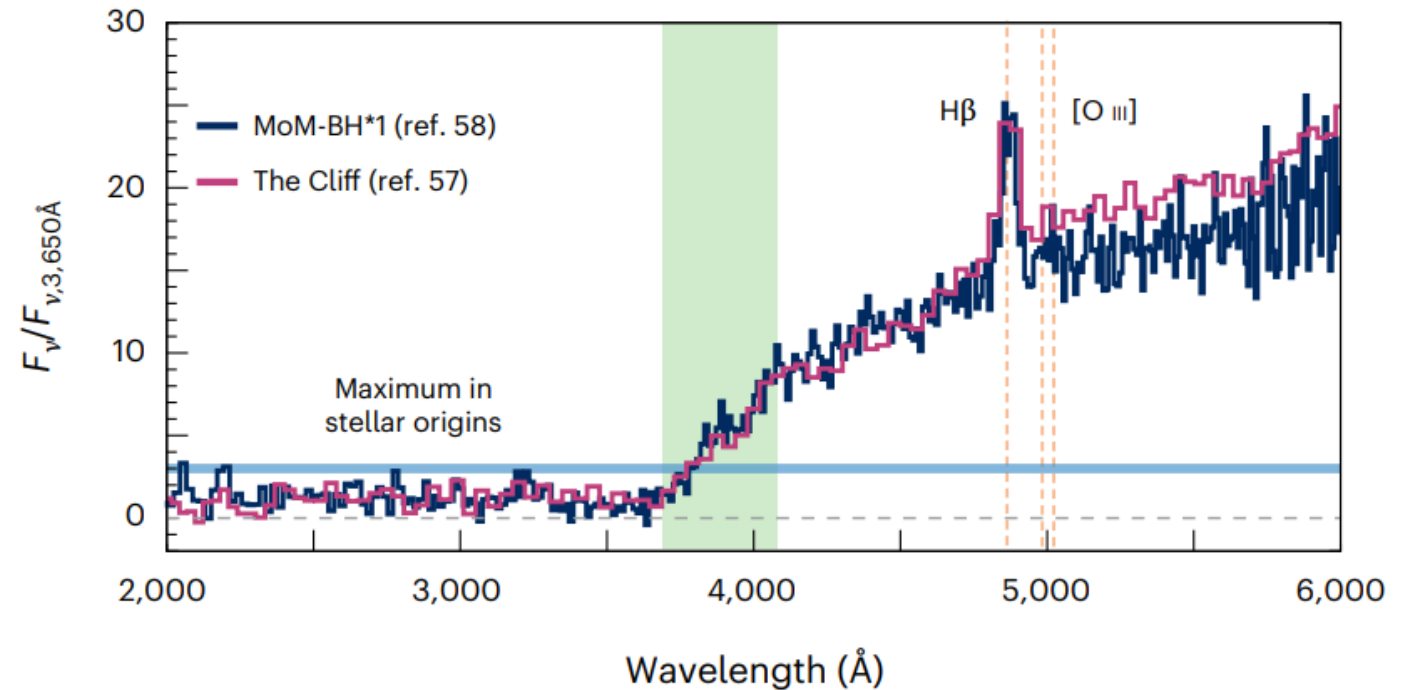
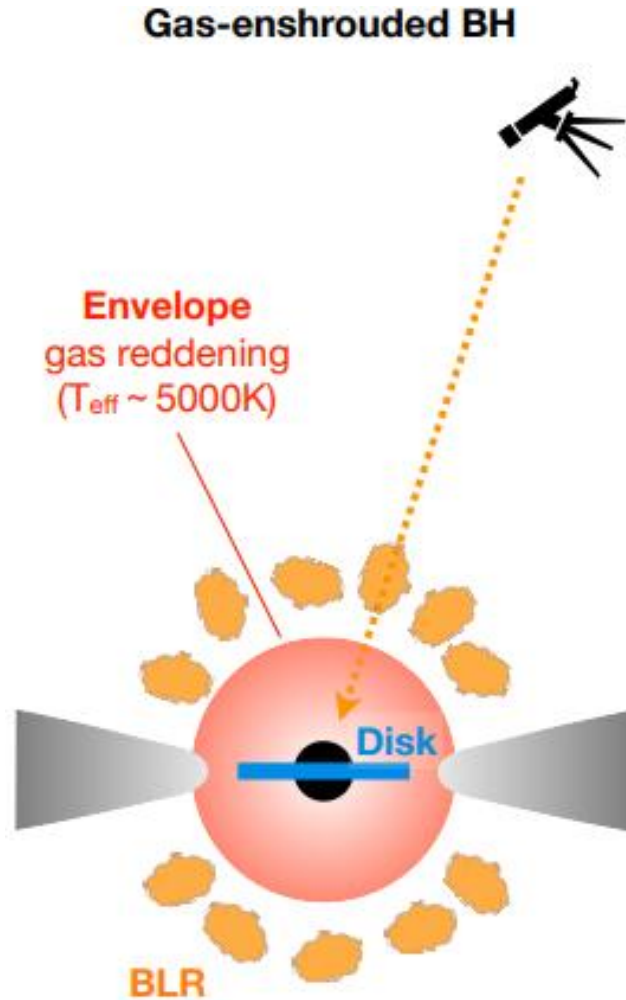
• 40-260 $M_{\odot}$



• $\sim 10^4 - 10^5 M_{\odot}$

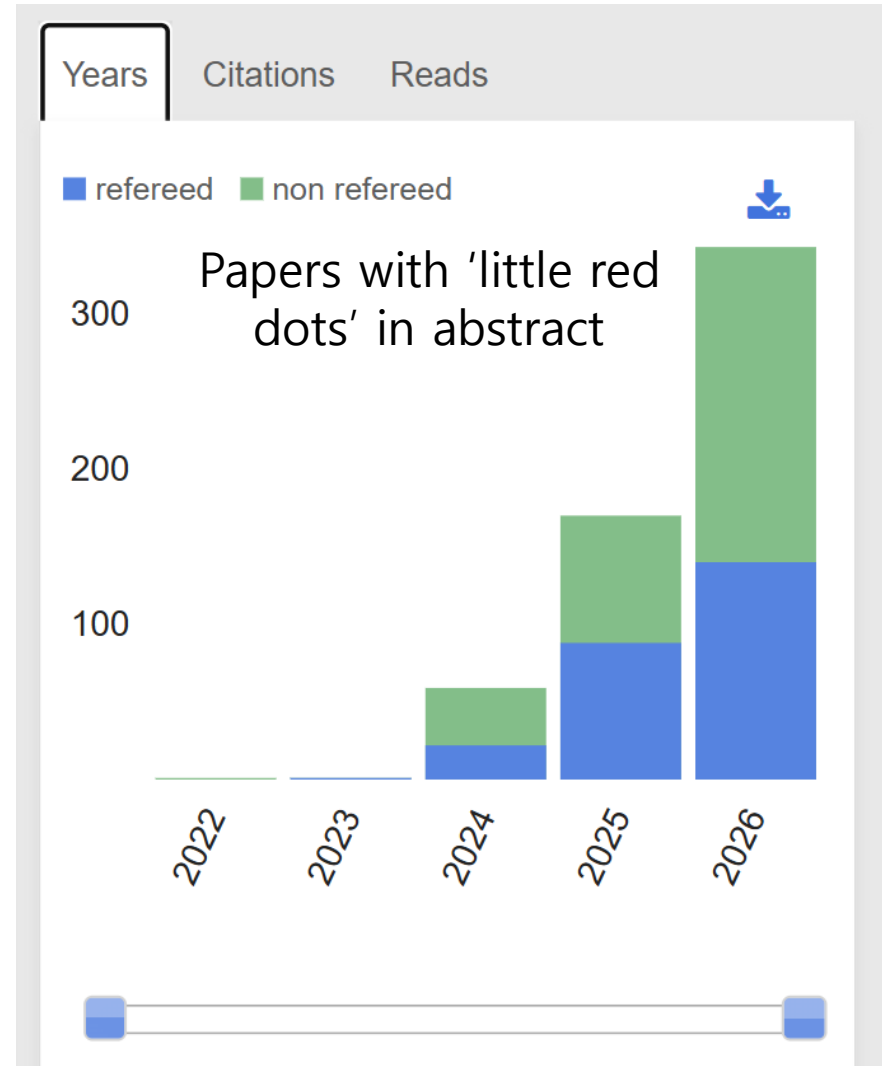
Little Red Dots

- Dense gas envelope around the accreting SMBH may produce LRDs

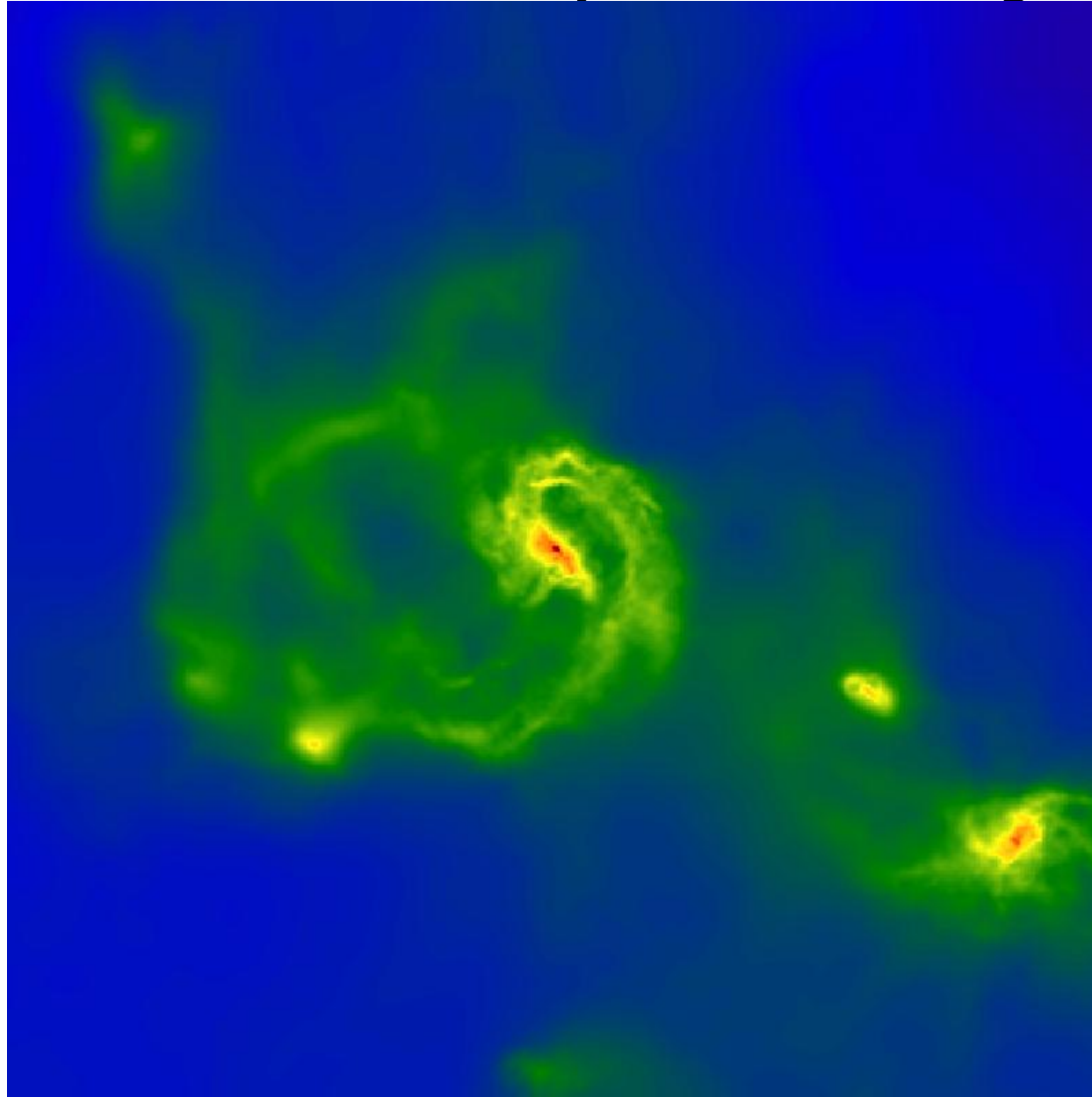


Little Red Dots

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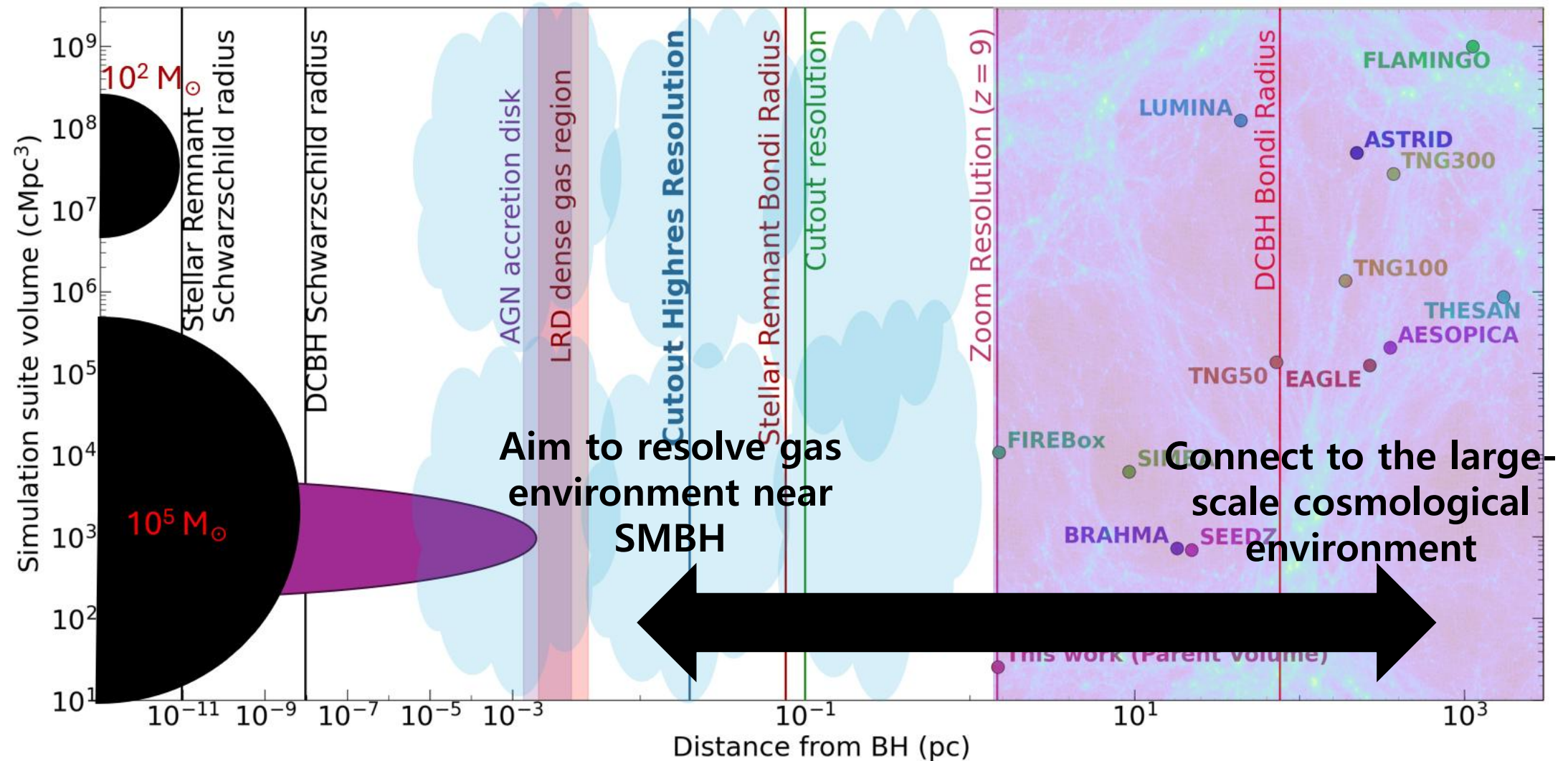
Exploring SMBH Formation Pathways with Cosmological Simulations



Jeon et al. (2023) MNRAS, 524, 176, Jeon et al. (2025a), ApJ, 979, 127

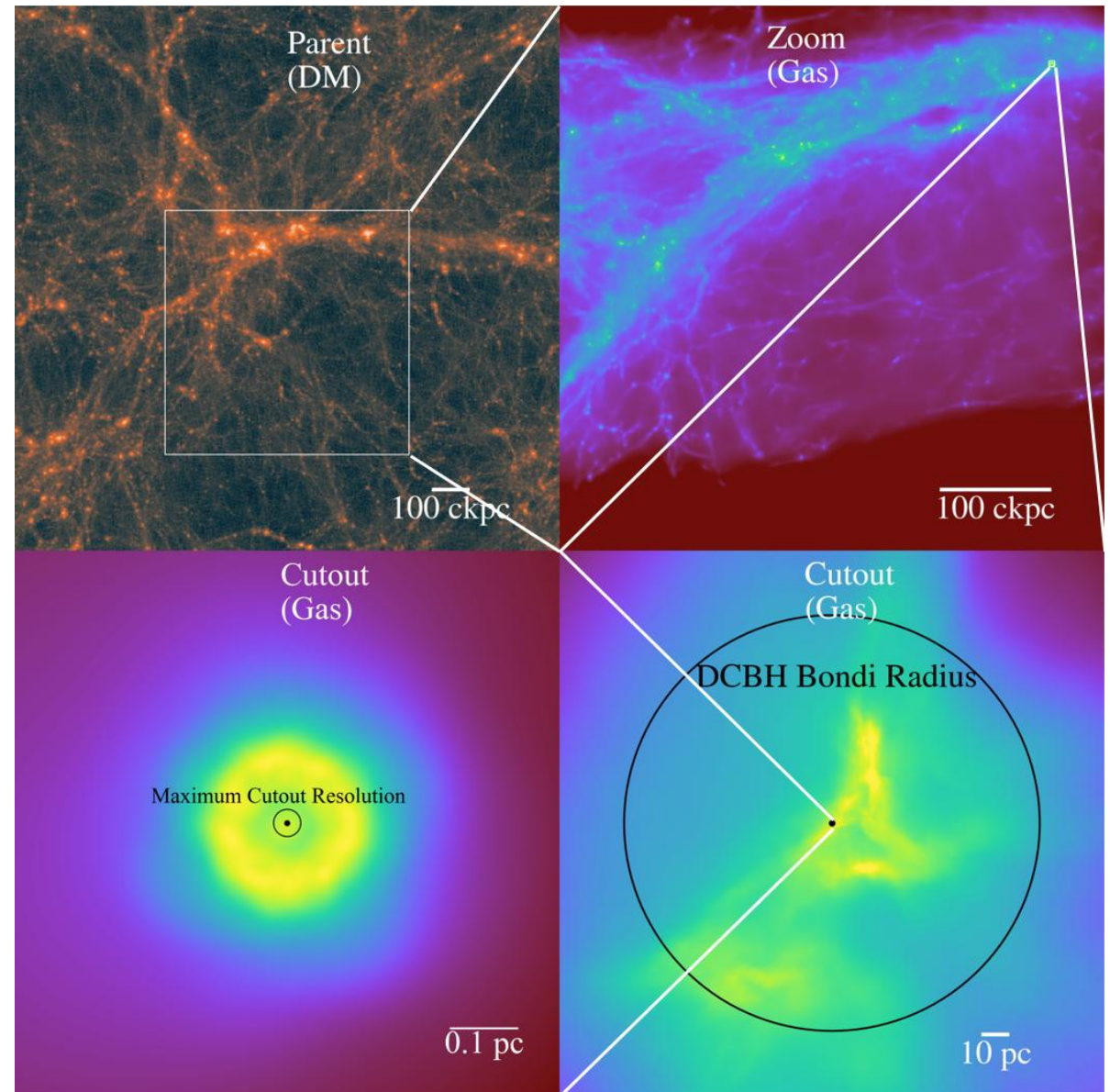
Challenge in Simulating SMBHs

- The scales SMBH evolution covers is too large



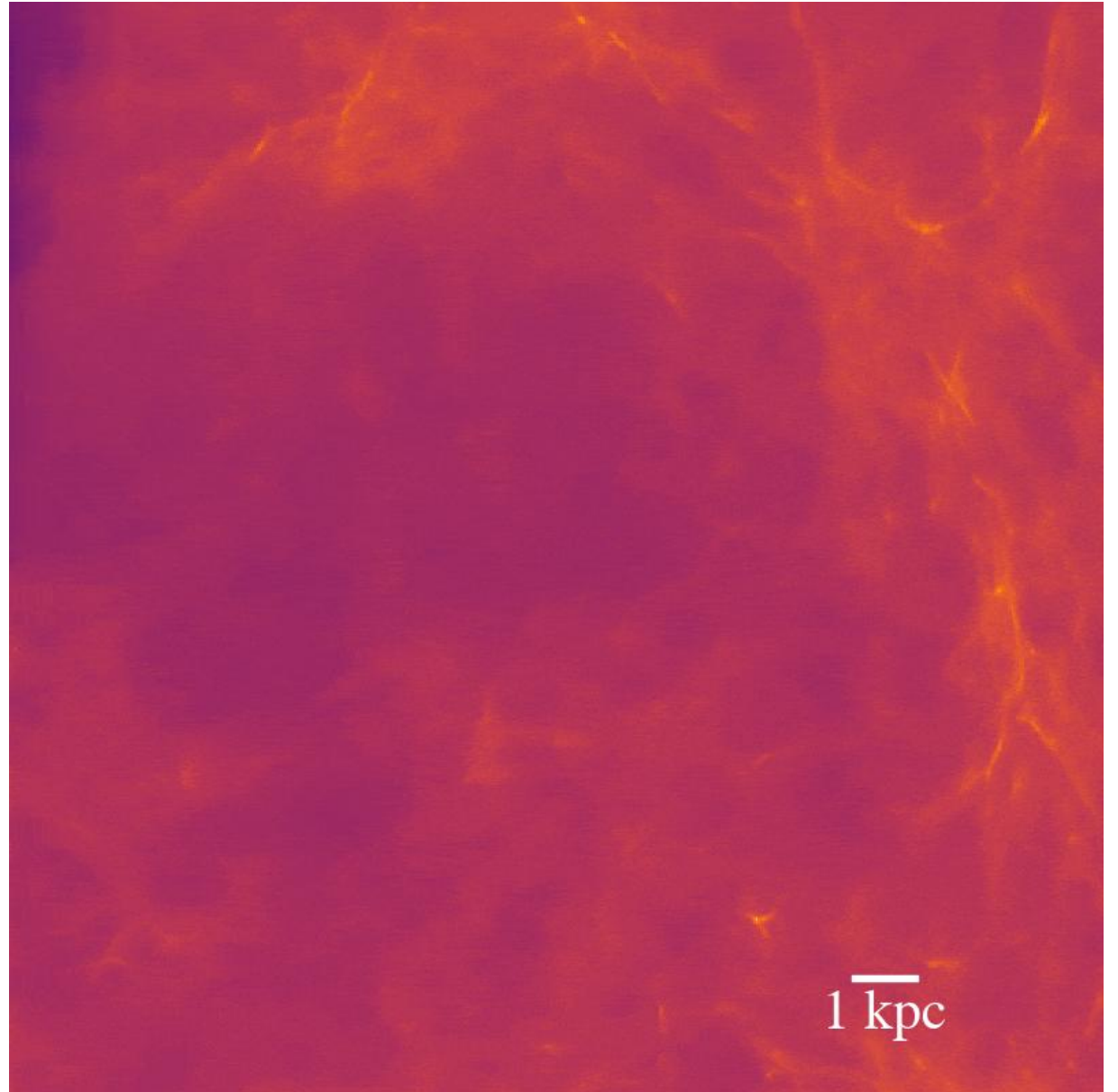
Cutout Technique to Resolve BH Evolution

- Excise a small region around a BH and rerun at higher resolution
- As large-scale information is removed, run for only short periods



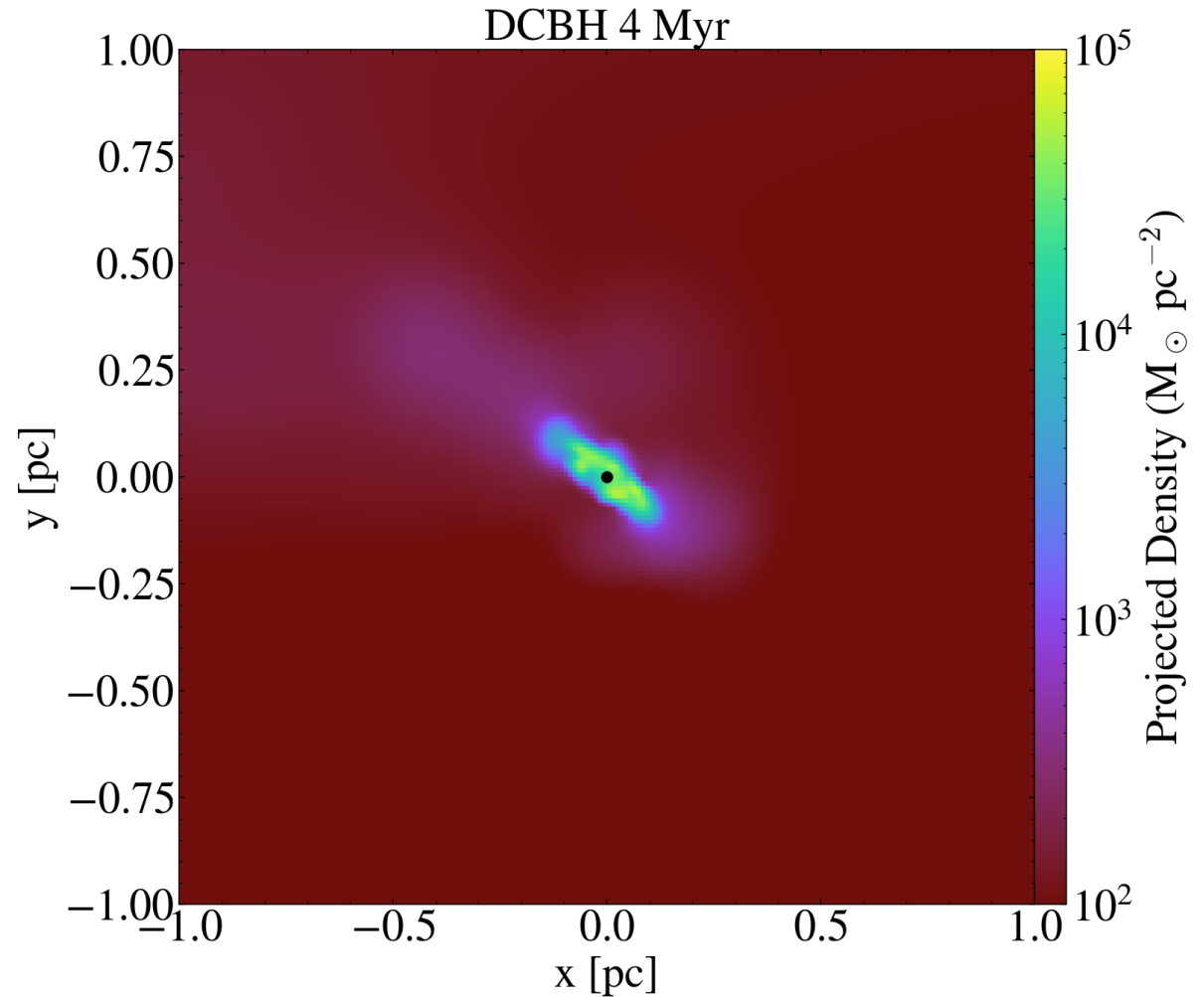
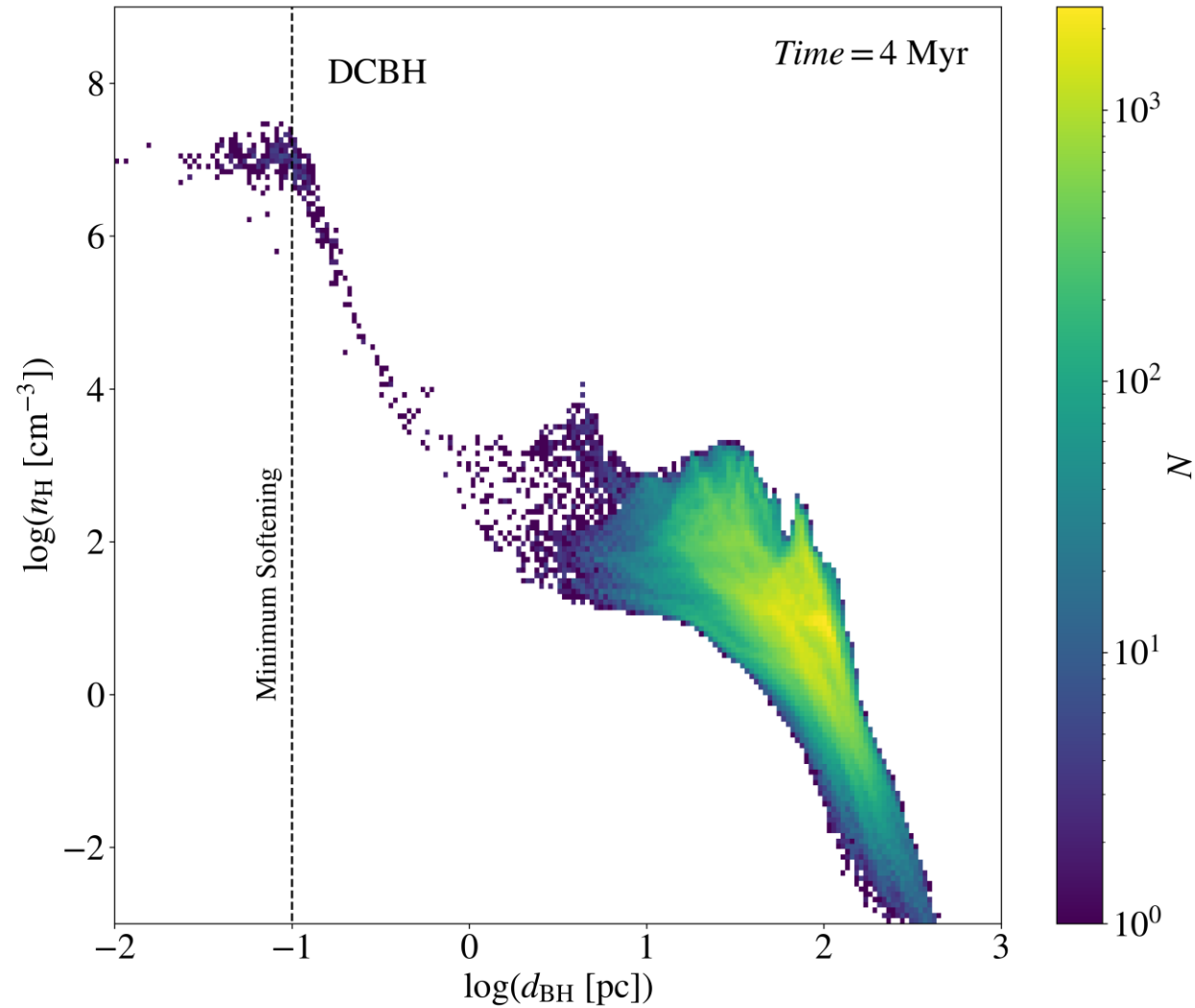
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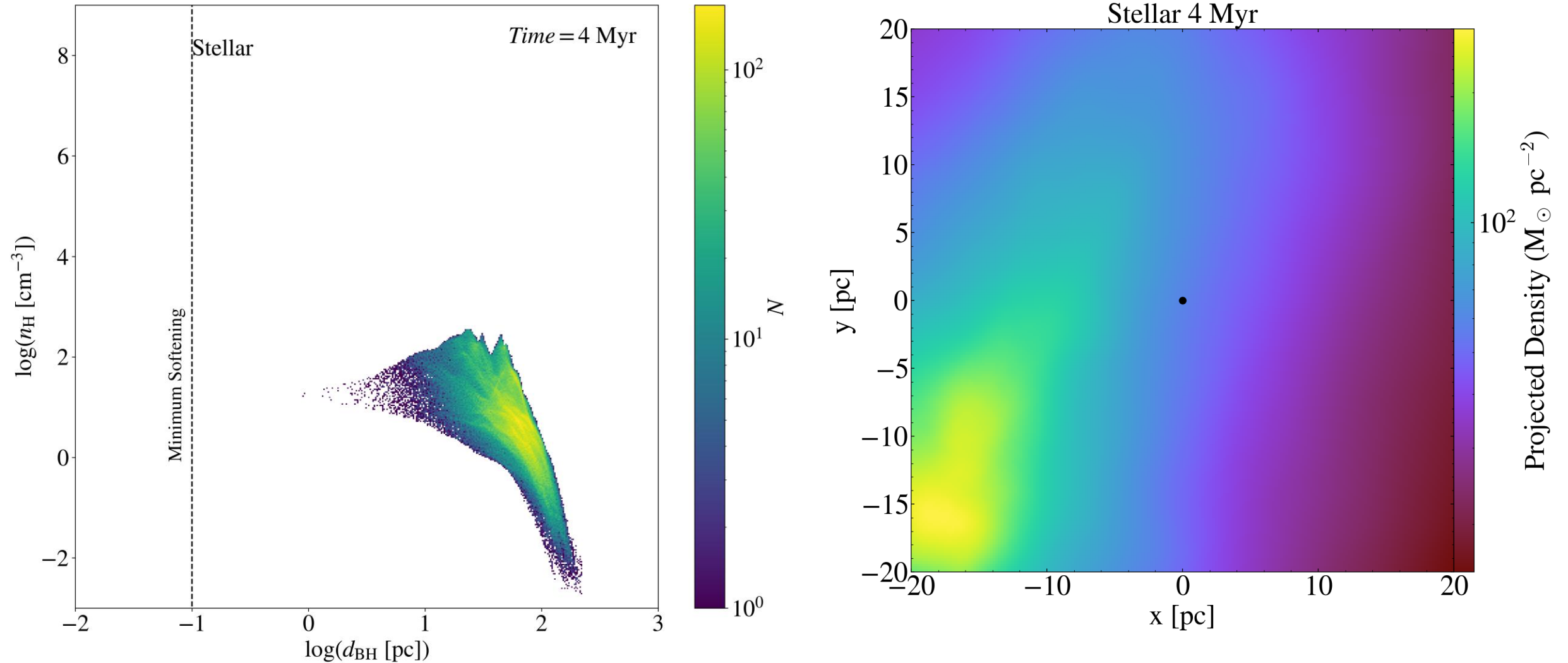
DCBH Case

- The massive BH can induce a buildup of dense gas nearby



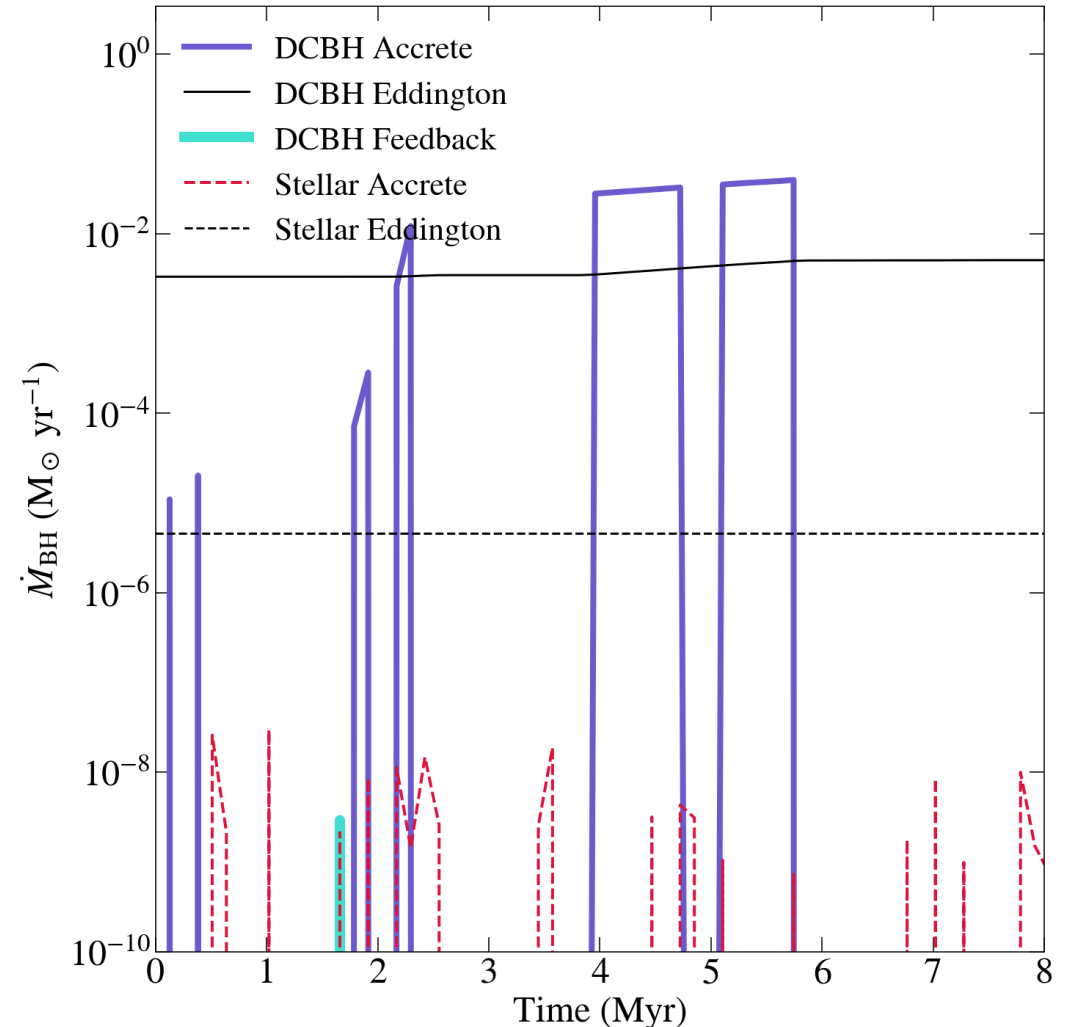
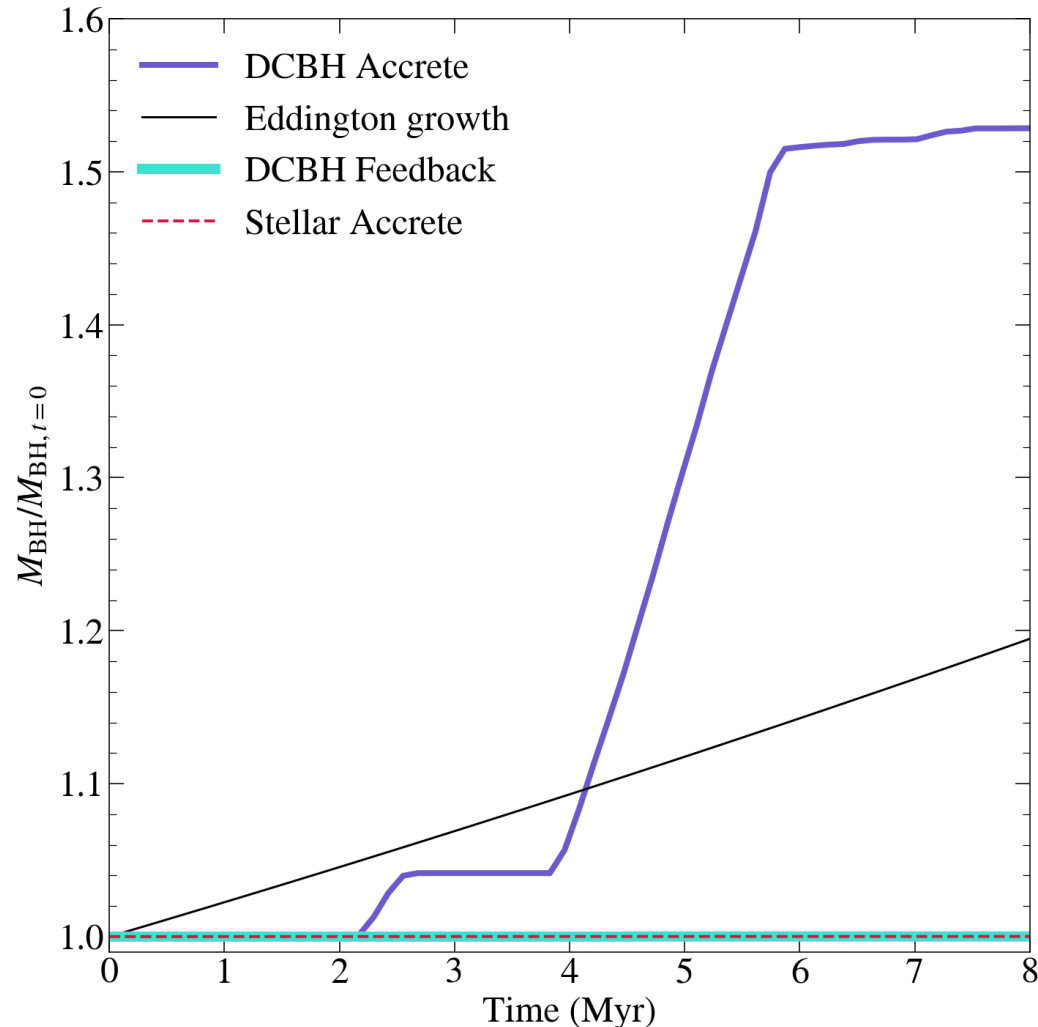
Stellar Remnant Case

- The low-mass BH remains dormant without affecting the gas



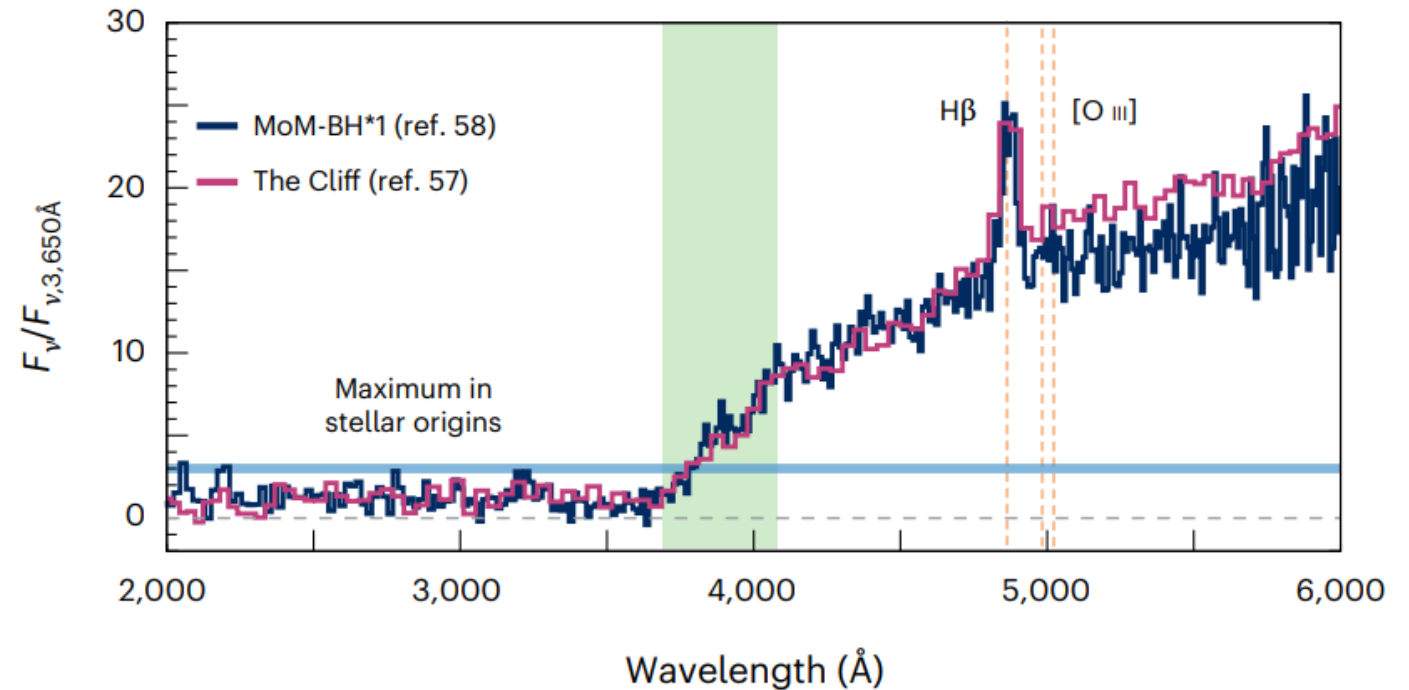
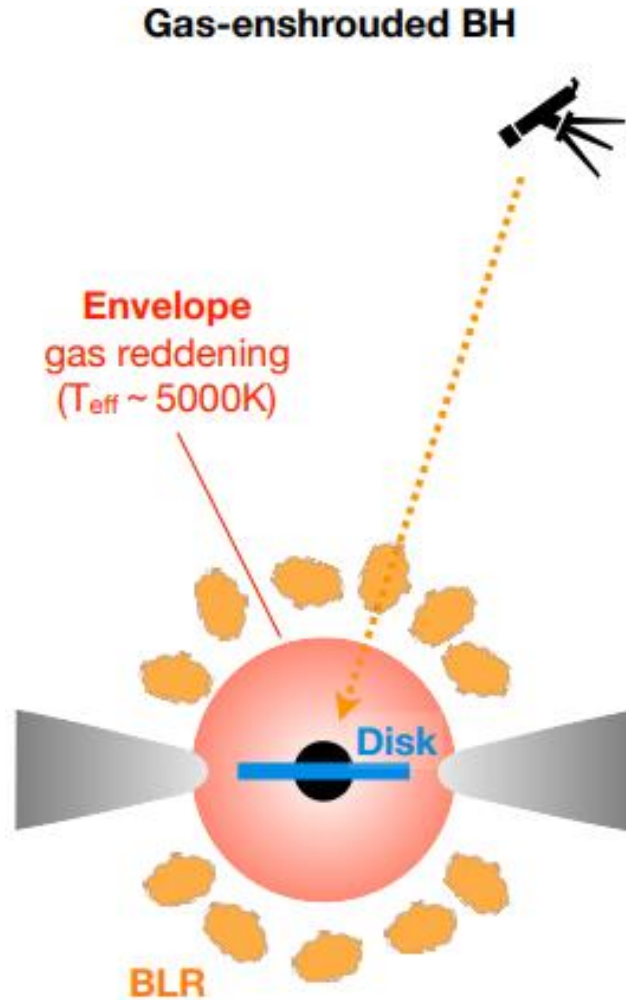
BH Mass Evolution

- BH only evolves in mass in the heavy seed case
- Feedback shuts off growth, but not well modeled yet



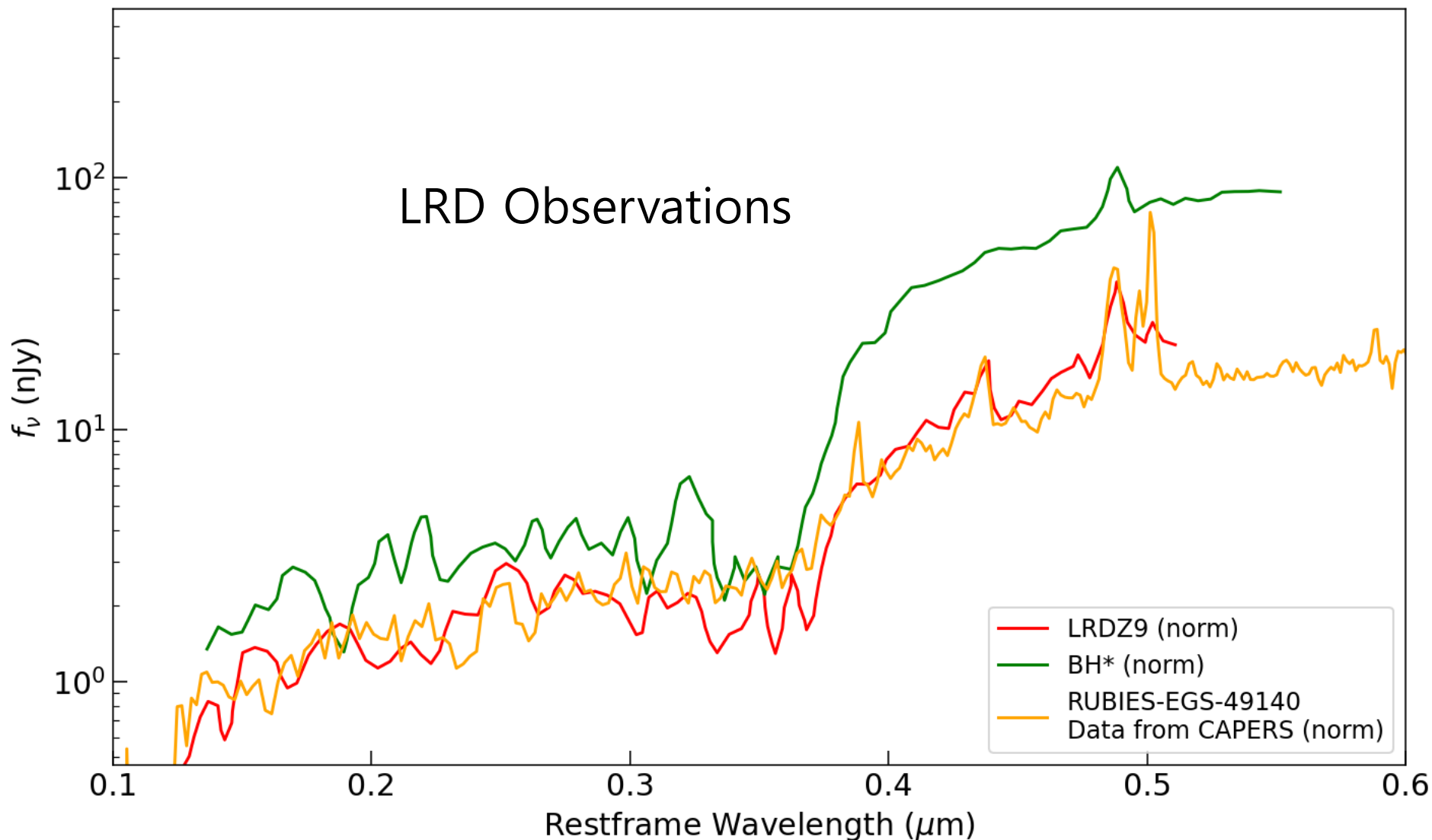
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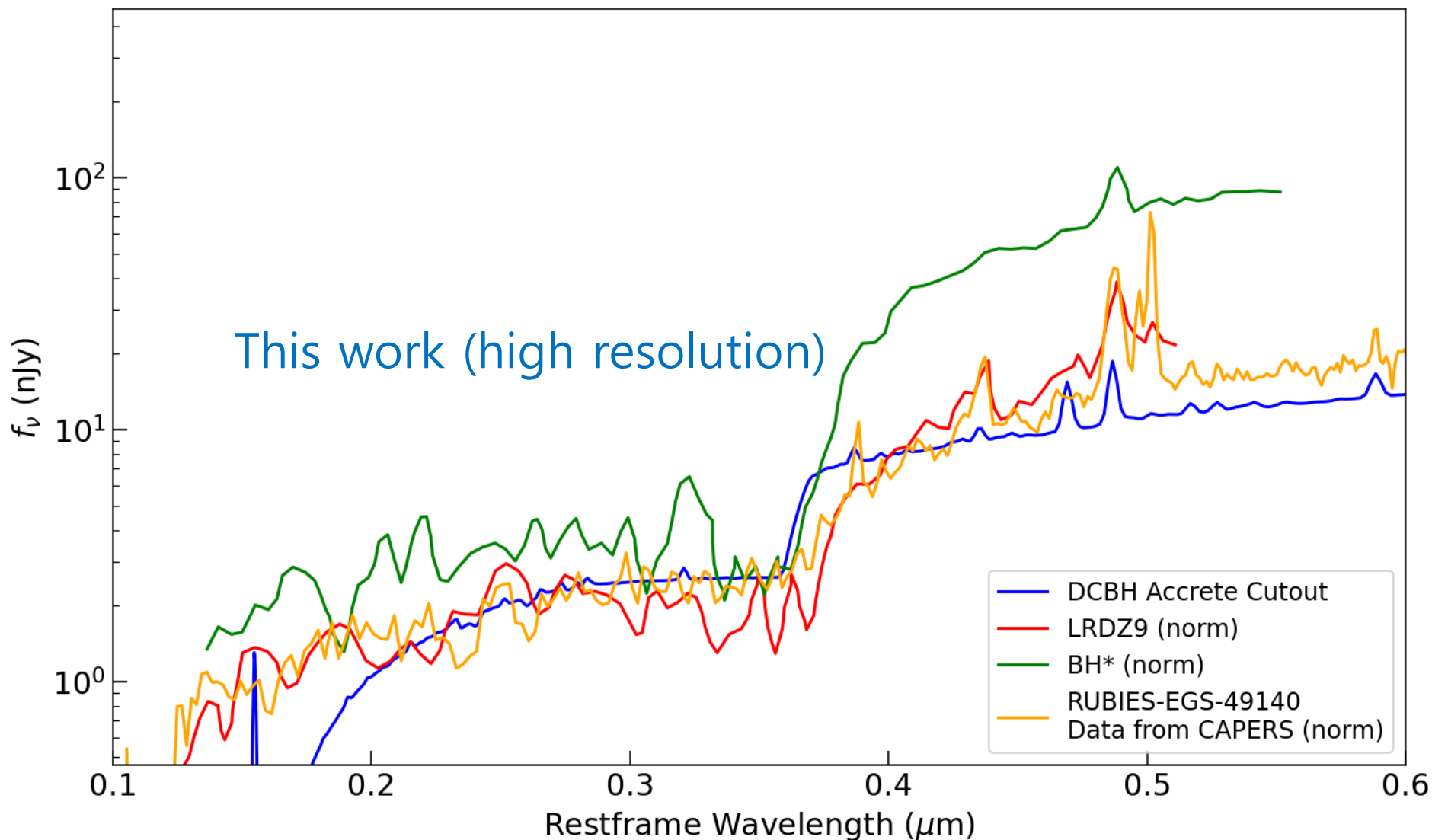
Little Red Dots

- Heavy seeds can induce dense gas for LRD-like spectra
- Unresolvable in regular cosmological simulations



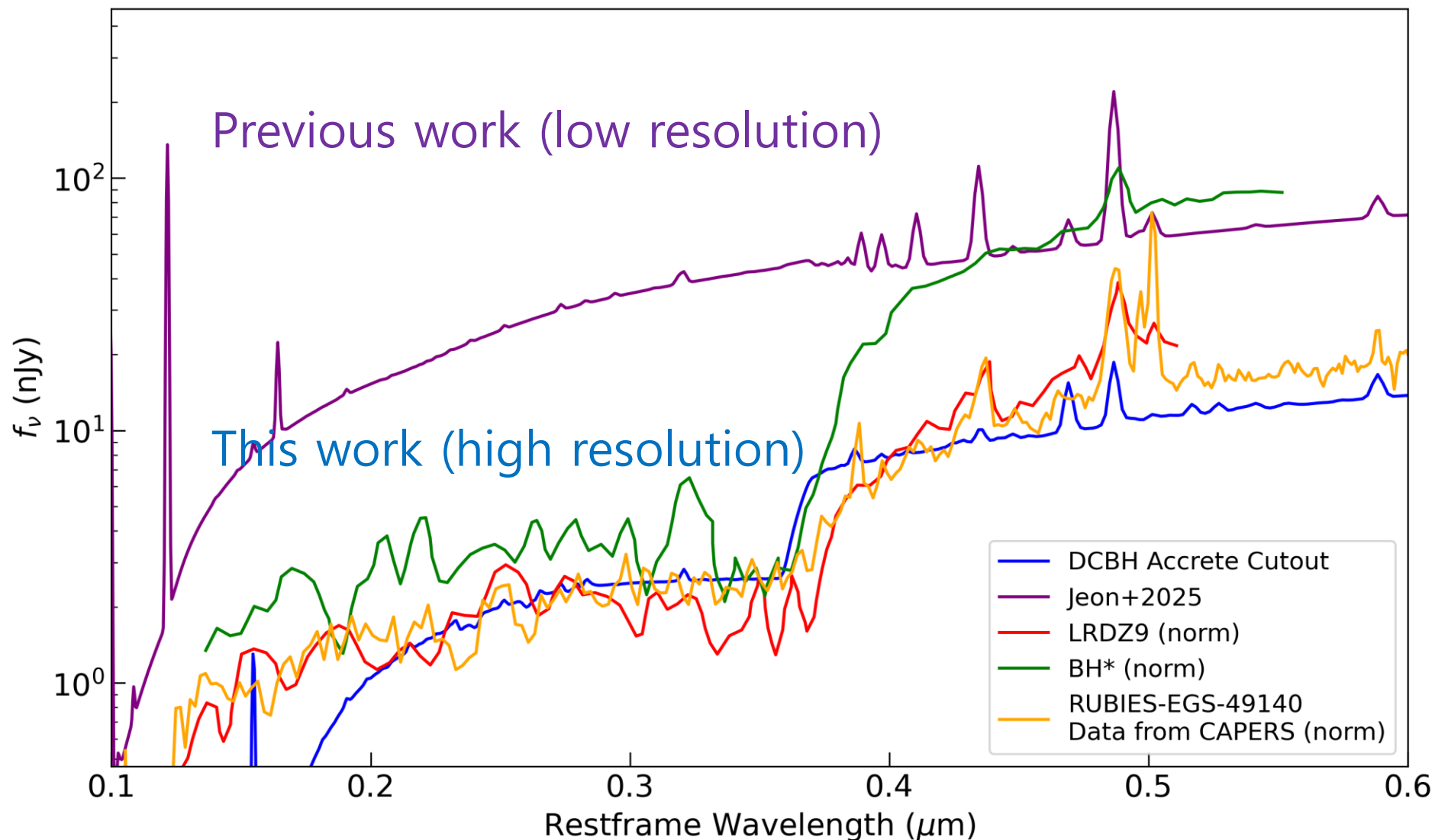
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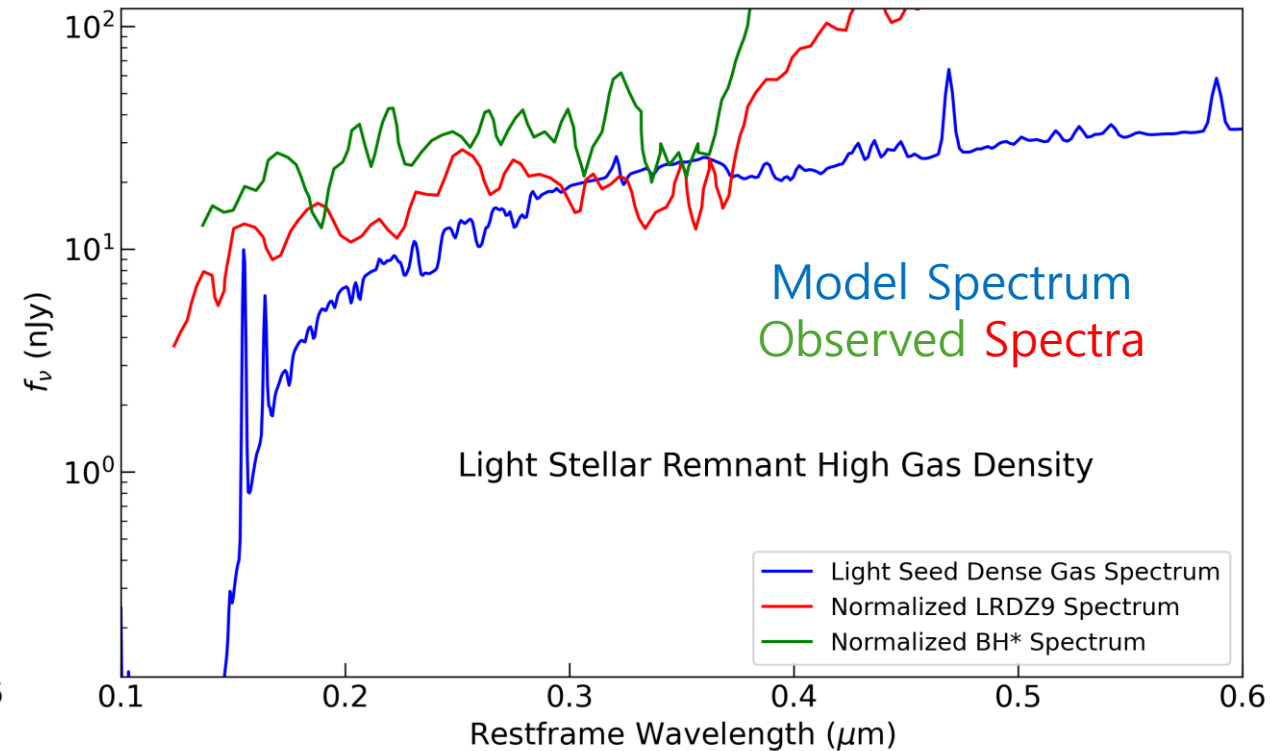
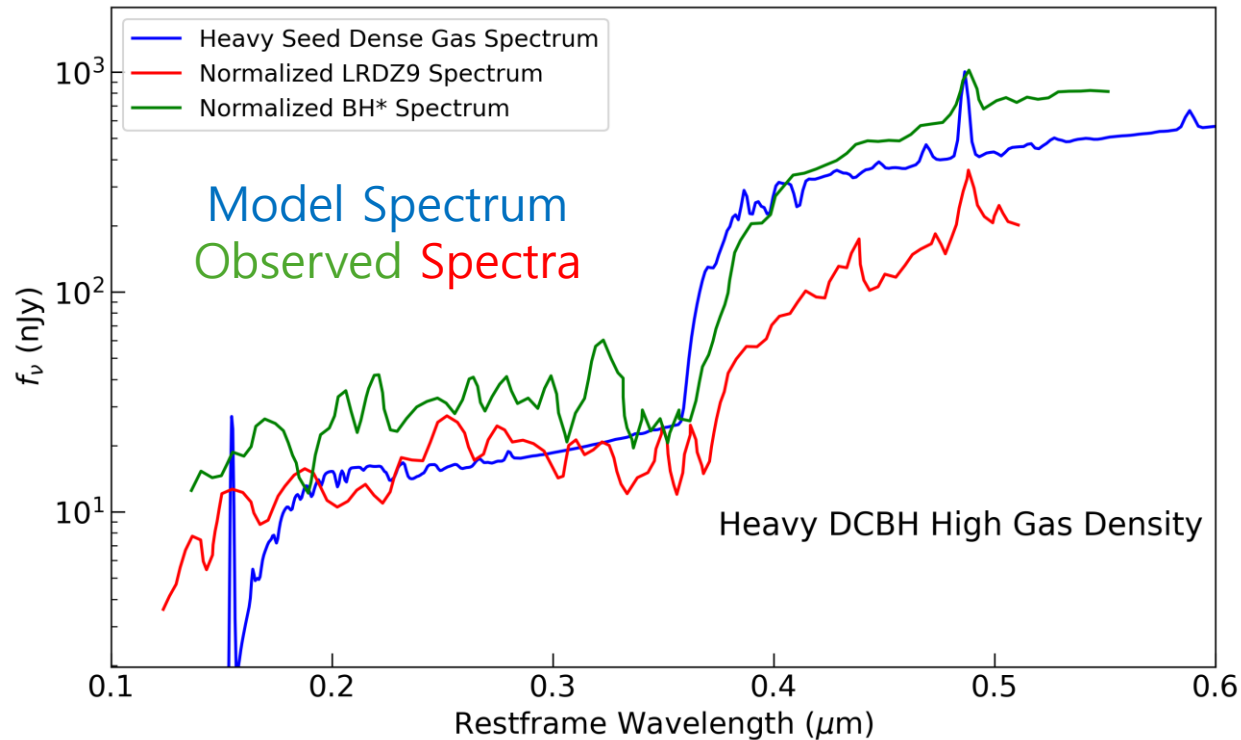
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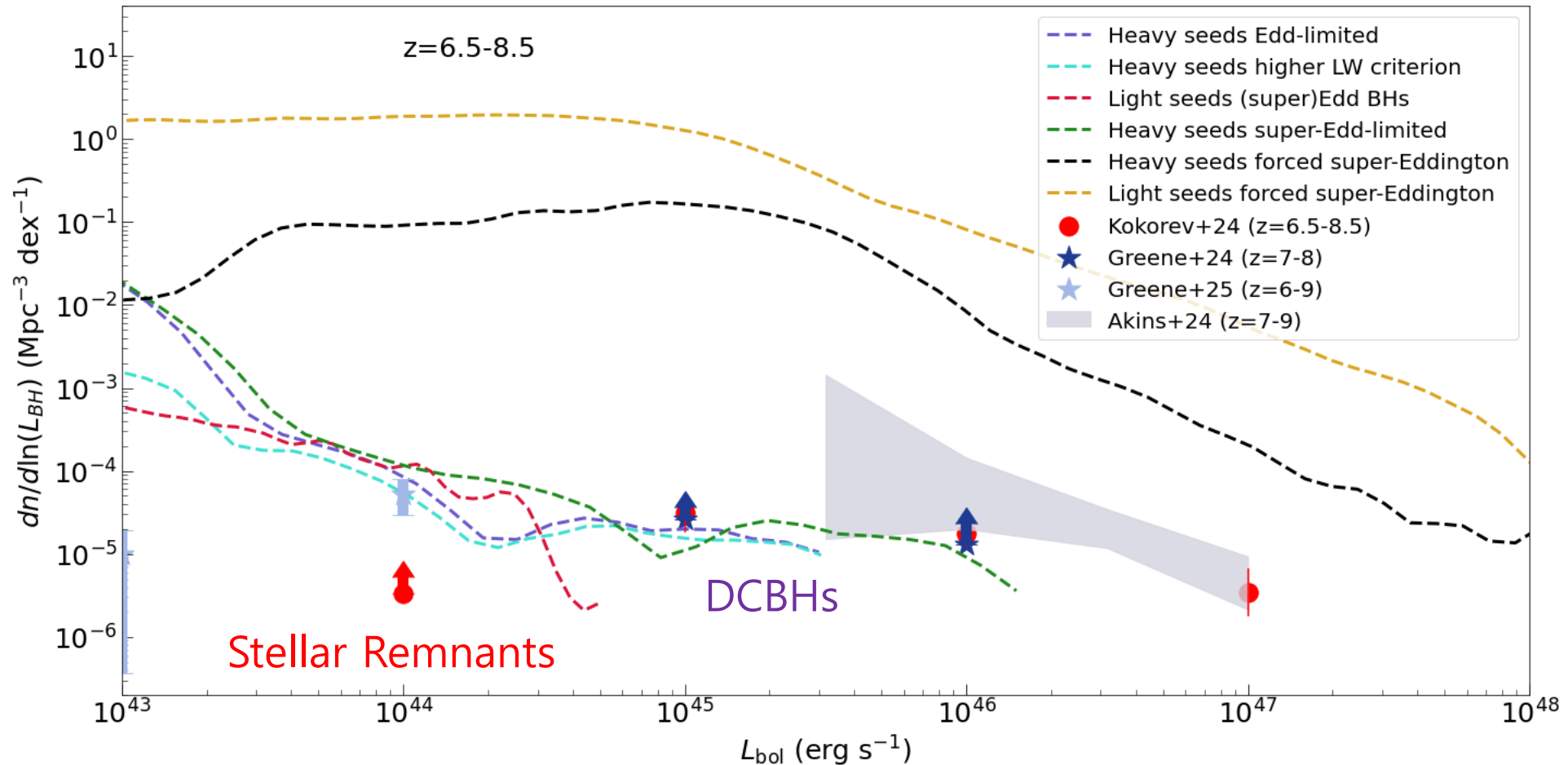
Little Red Dots

- Under the same choice of environment, stellar remnant system cannot reproduce LRD spectra



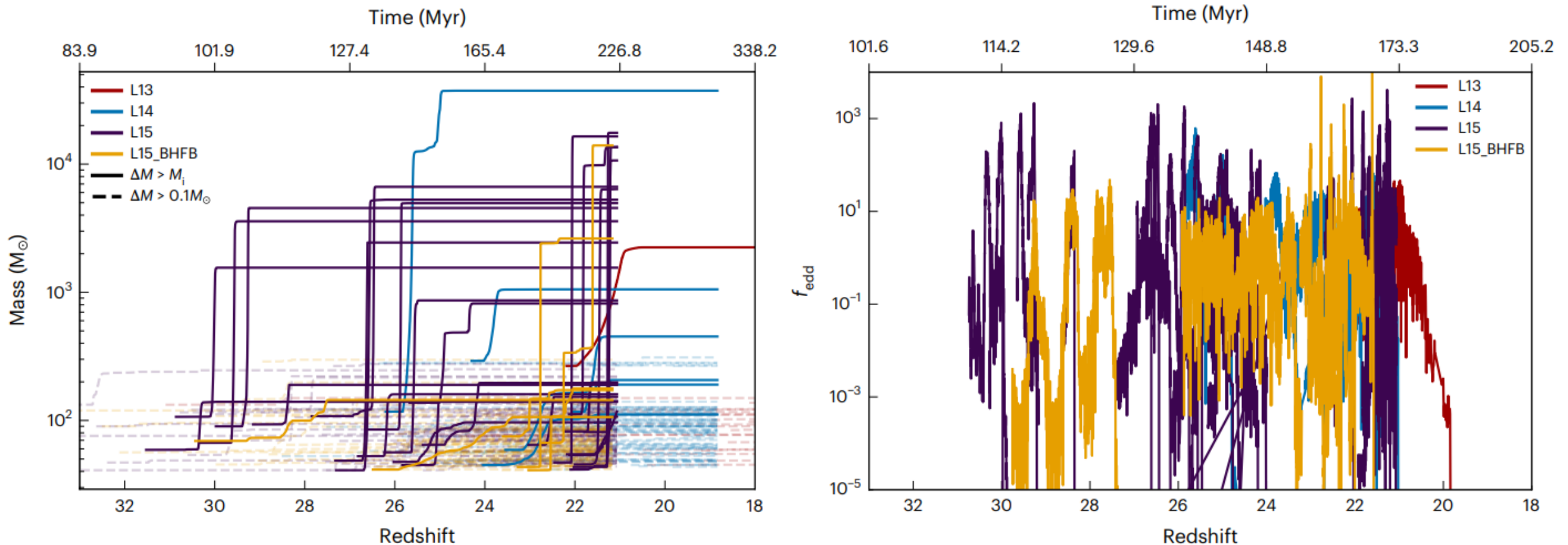
Little Red Dots?

- DCBH Population agrees with LRD population statistics



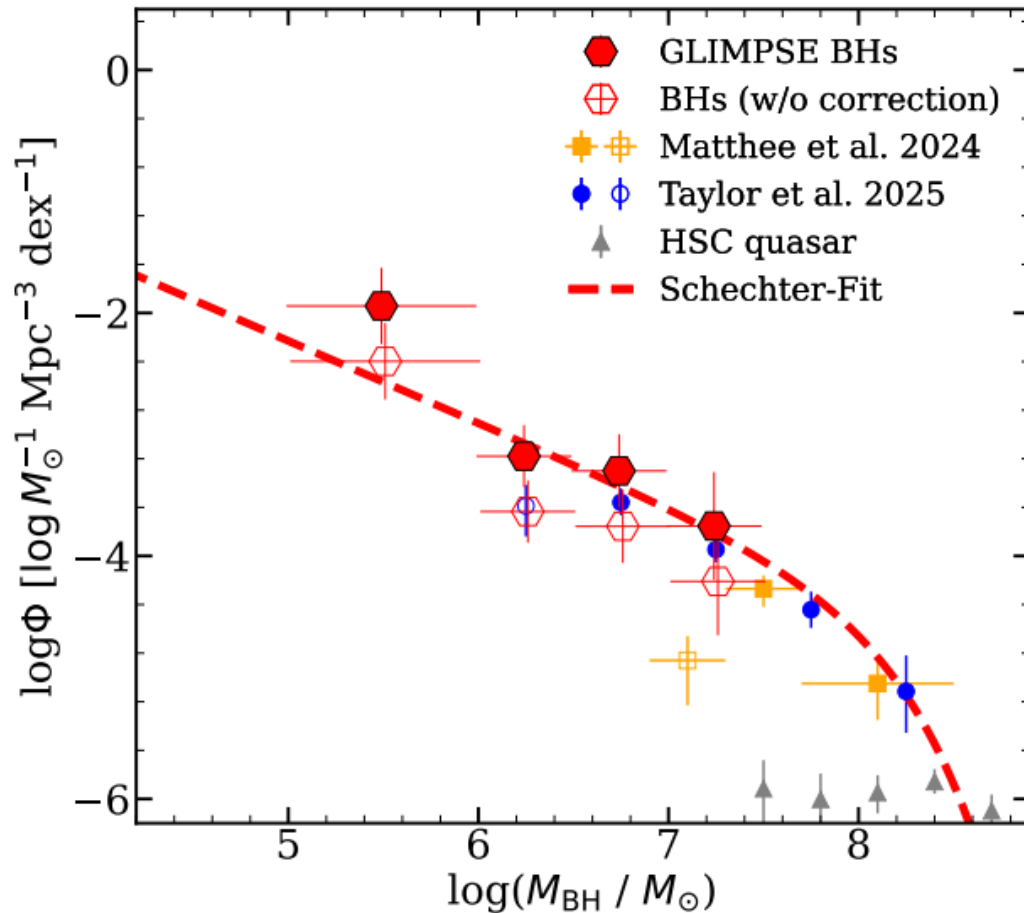
Are Stellar Remnant BHs Irrelevant?

- Other works show stellar remnants still may be able to grow
- Future investigations will be needed

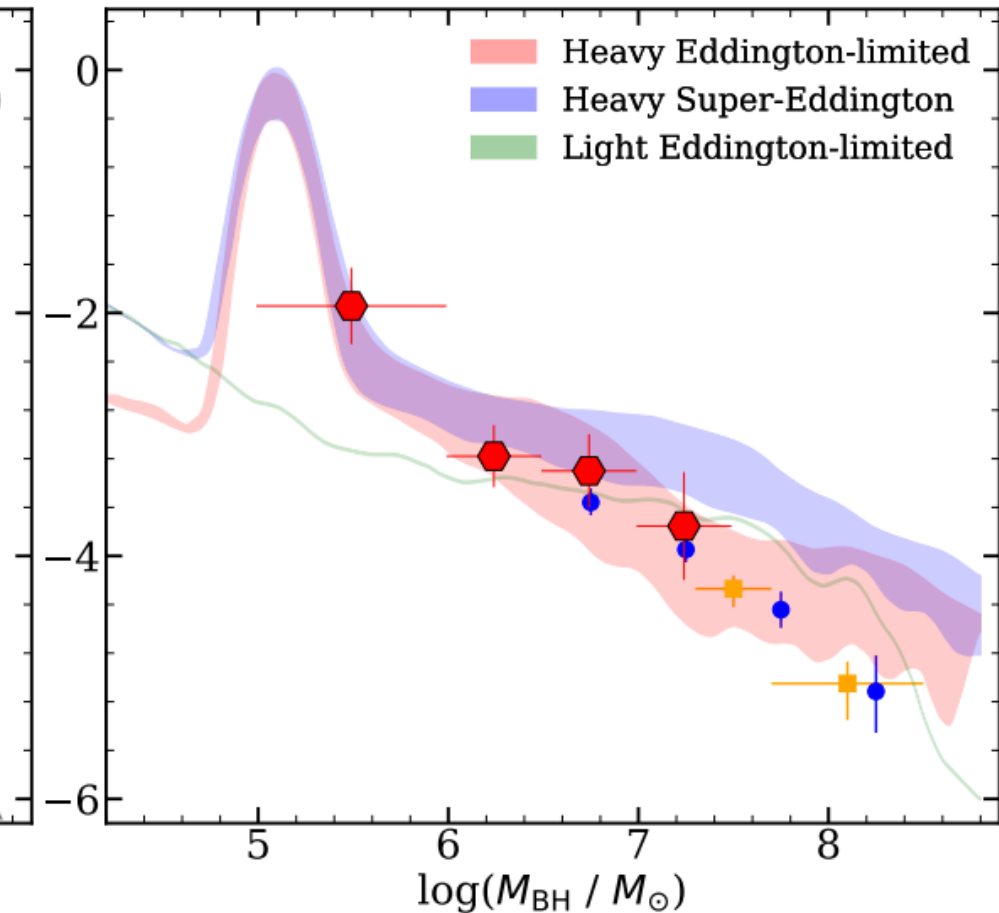


Are DCBHs Real?

- No direct observations yet
- Possible indications from gravitational lensing observations



Fei et al. (incl. Jeon) (2026b), ApJ, 1003, 2



Jeon et al. (2025b), ApJ, 988, 110

Conclusions

- Heavy seeds are more likely to be the origins of early SMBHs and LRDs
- Additional observations and theoretical work will be needed to follow up the viability of lower mass BH seeds, existence of heavy seeds, and environmental effects

