

A Black Hole Mass Threshold Framework for Bimodal Early Galaxy Evolution: Insights from JWST's JADES-GS-z14-0 (Revised Version)

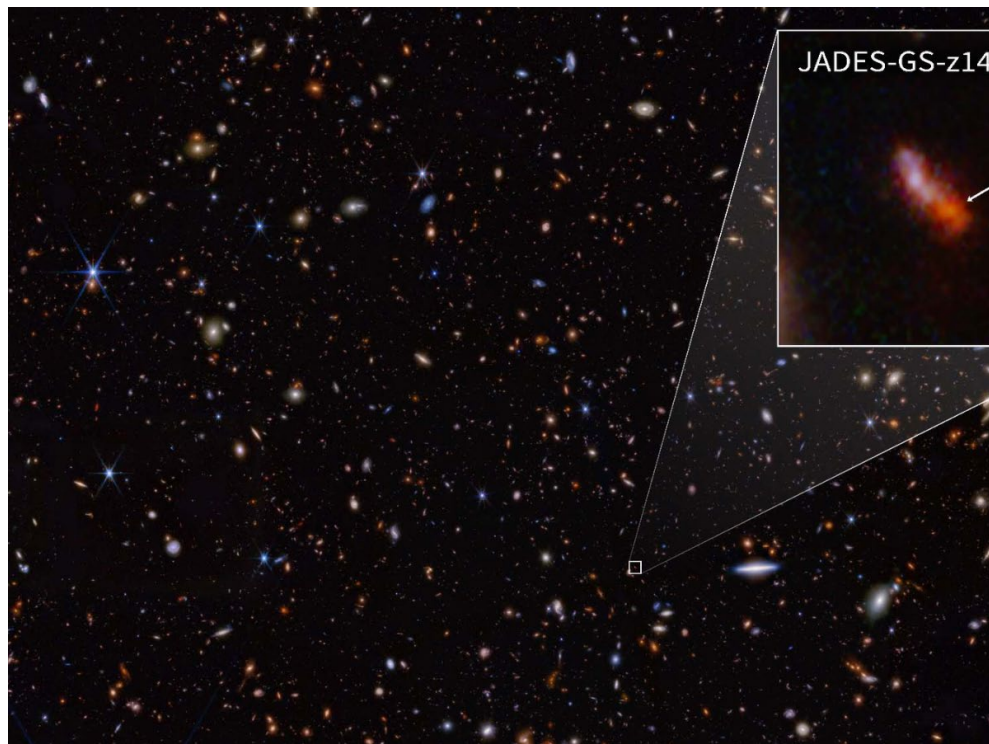
Author: Chien Hung Hsiang, chienhs@ntu.edu.tw Assisted by Grok and ChatGPT

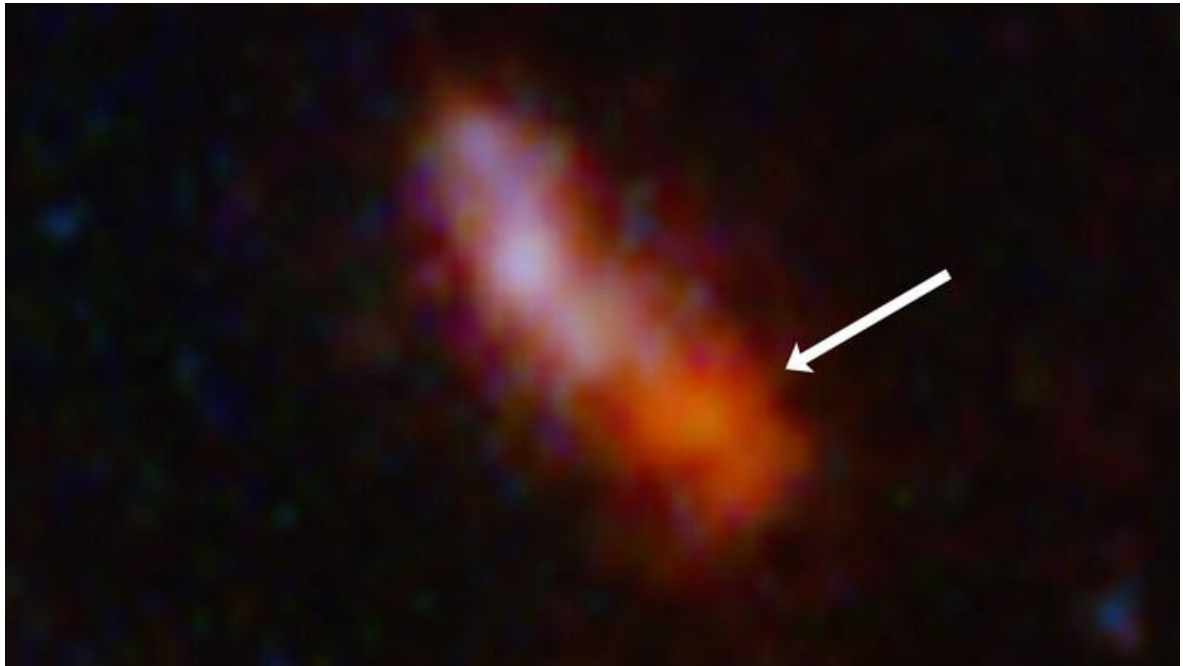
Abstract JWST observations reveal a bimodal high-redshift population: compact starbursts like JADES-GS-z14-0 ($z \approx 14.32$) and early quasars. We refine a framework positing a critical black hole mass threshold $M_{\text{BH,crit}} \sim 10^6\text{--}10^7 M_{\odot}$, where AGN feedback transitions from momentum-driven (localized, sustaining star formation) to energy-driven (global quenching, quasar dominance). Enhanced analytic scaling, links to lower- z analogs, and existing simulations motivate this value. We detail a phased plan with methodologies, resources, risks/mitigations, and a table for feasibility. This revision strengthens theoretical justification, computational details, and risk assessment per reviewer feedback.

Keywords: Galaxy formation, JWST, black holes, AGN feedback, cosmic dawn

1. Introduction and Observational Motivation

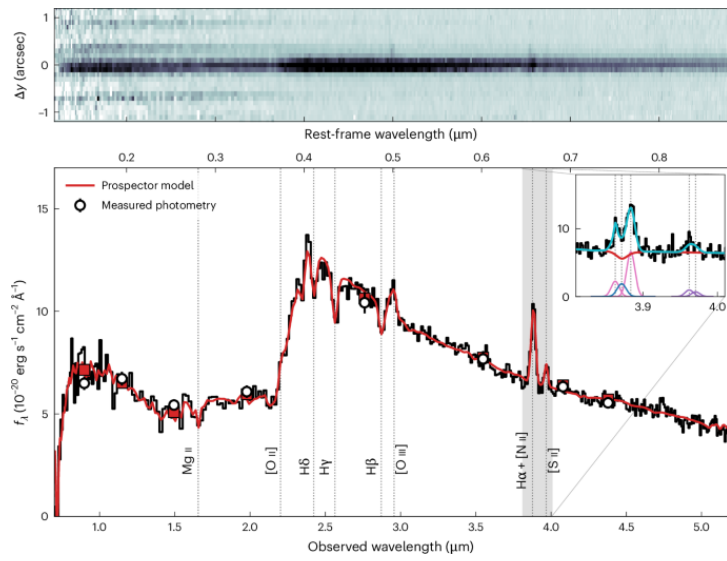
JWST challenges Λ CDM by detecting mature systems early. JADES-GS-z14-0 stands out with compact size, high stellar mass, and no AGN signs (Maiolino et al. 2024).



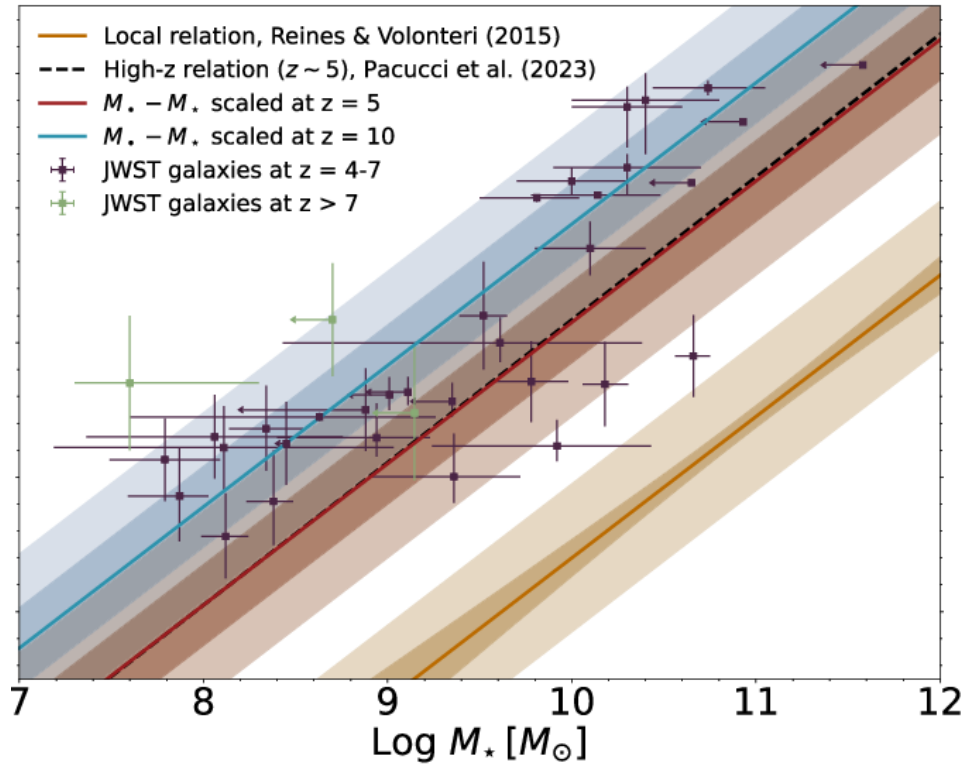


[sci.news](https://www.sci.news)

This bimodality suggests black hole growth regulates paths.



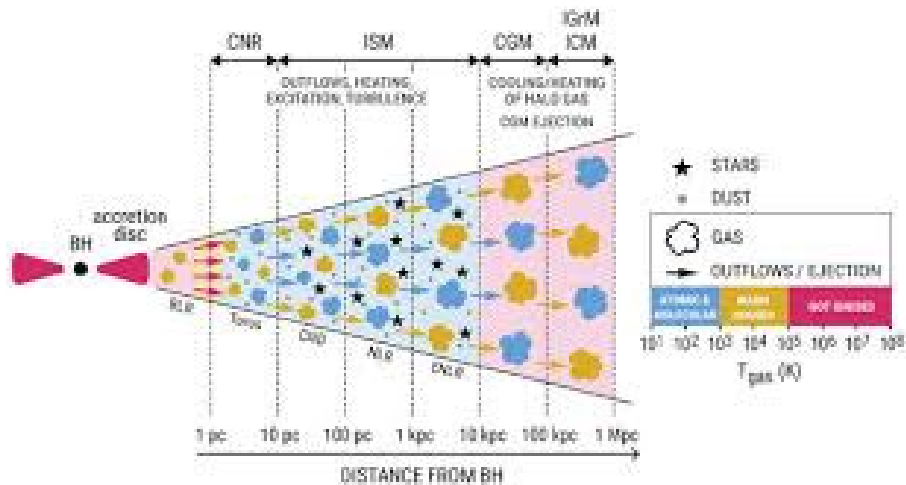
[nature.com](https://www.nature.com)



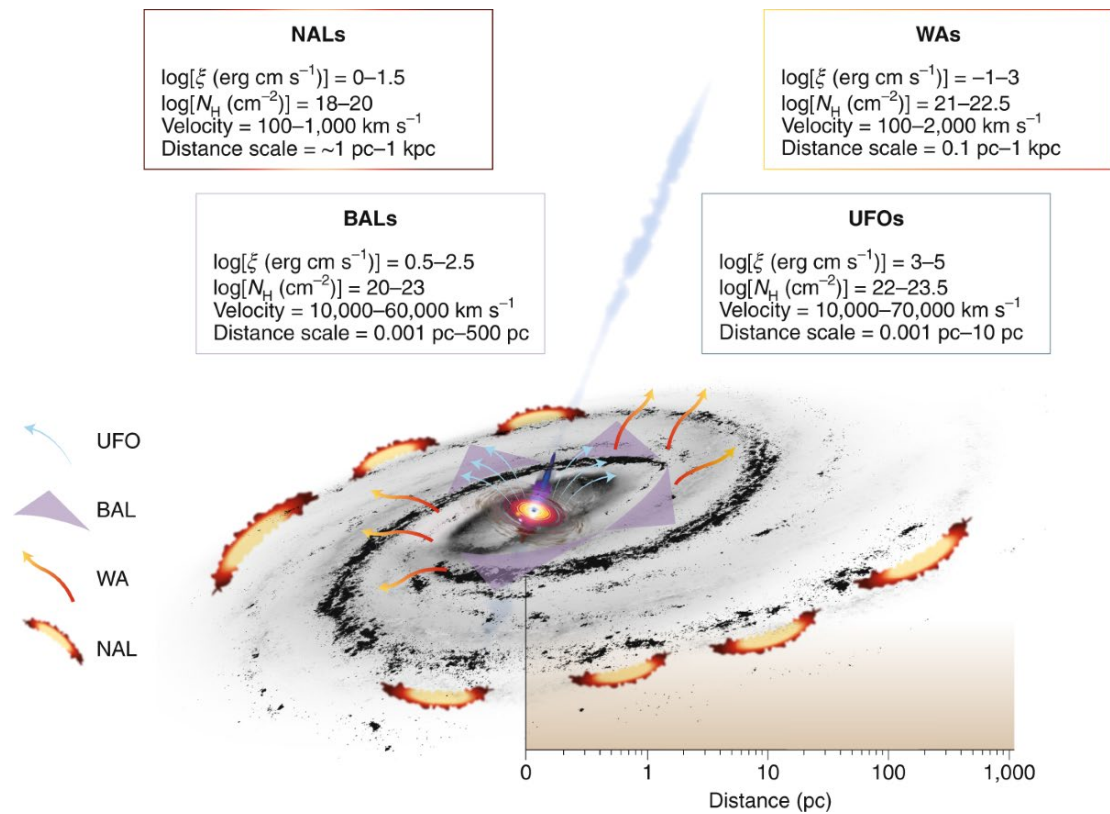
[researchgate.net](https://www.researchgate.net)

2. Theoretical Foundation and Justification for $M_{\text{BH,crit}}$

We base the threshold on momentum- vs. energy-driven feedback (King 2003, 2005).



[mdpi.com](https://www.mdpi.com)

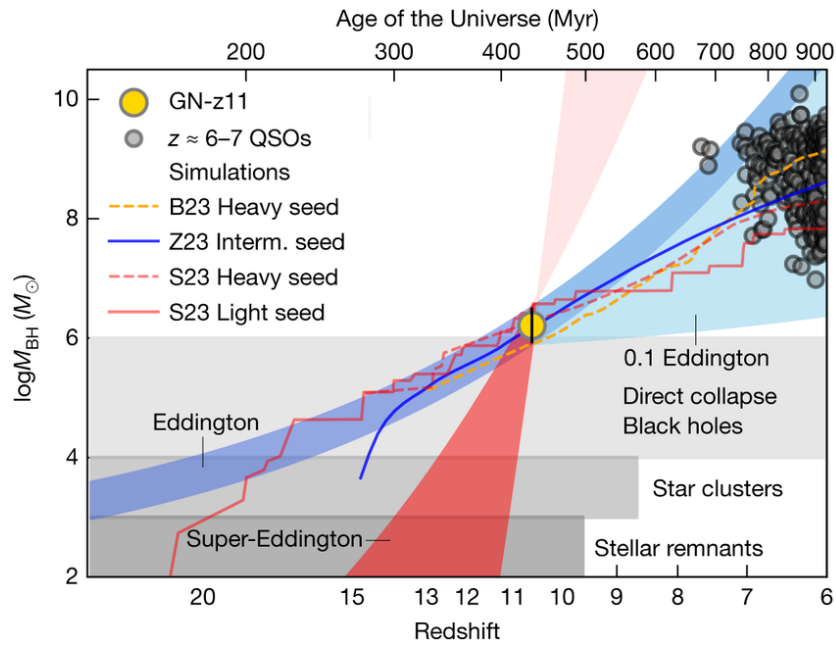


nature.com

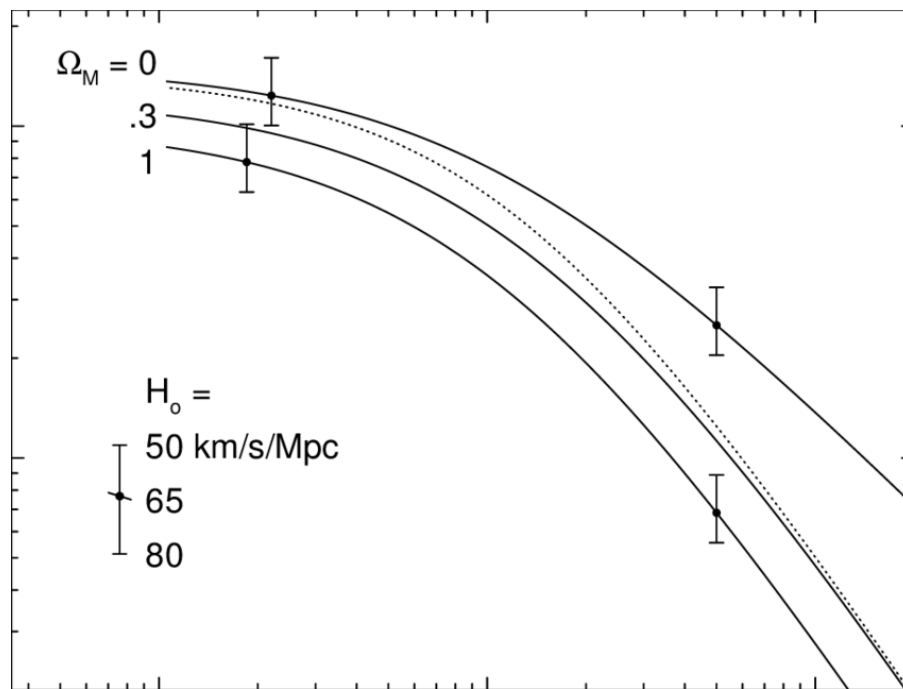
Lower- z analogs ($z \sim 6 - 8$ quasars/starbursts) and simulations (e.g., heavy seeds reaching $\sim 10^7 M_{\odot}$) support $10^6 - 10^7 M_{\odot}$.

Enhanced calculation: Feedback energy $\varepsilon M_{\text{BH}} c^2$ ($\varepsilon \sim 0.05 - 0.1$) over τ_{Edd} matches $E_{\text{bind}} \sim 0.1 M_{\text{halo}} \sigma^2$. For $M_{\text{halo}} \sim 10^{10} M_{\odot}$, $\sigma \sim 70$ km/s, $M_{\text{BH,crit}} \sim 10^6 - 10^7 M_{\odot}$.

Growth tracks show divergence.



[researchgate.net](https://www.researchgate.net)



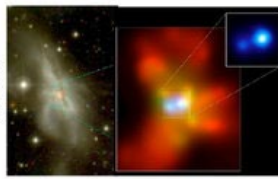
[researchgate.net](https://www.researchgate.net)

(c) Interaction/"Merger"



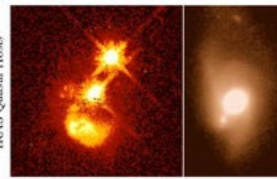
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(d) Coalescence/(U)LIRG



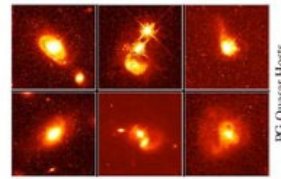
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



- BH grows rapidly: briefly dominates luminosity/feedback
- remaining dust/gas expelled
- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(b) "Small Group"

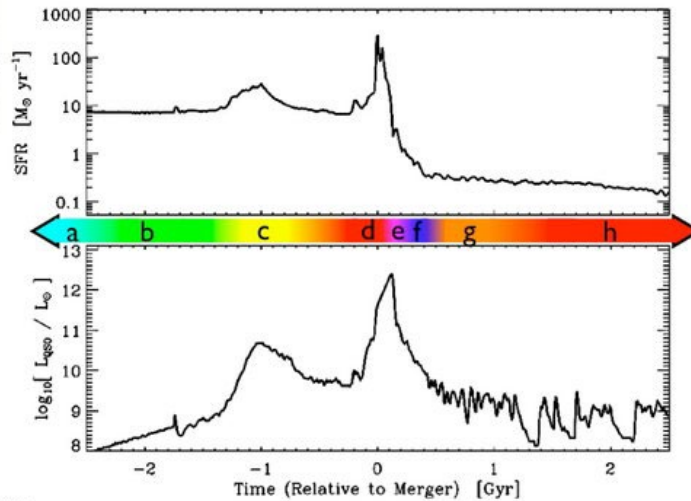


- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- M_{halo} still similar to before: dynamical friction merges the subhalos efficiently

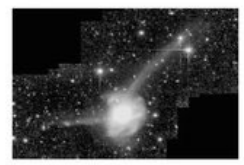
(a) Isolated Disk



- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with $M_B > -23$)
- cannot redden to the red sequence



(g) Decay/K+A



- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers

[researchgate.net](https://www.researchgate.net)

3. Application and Alternatives

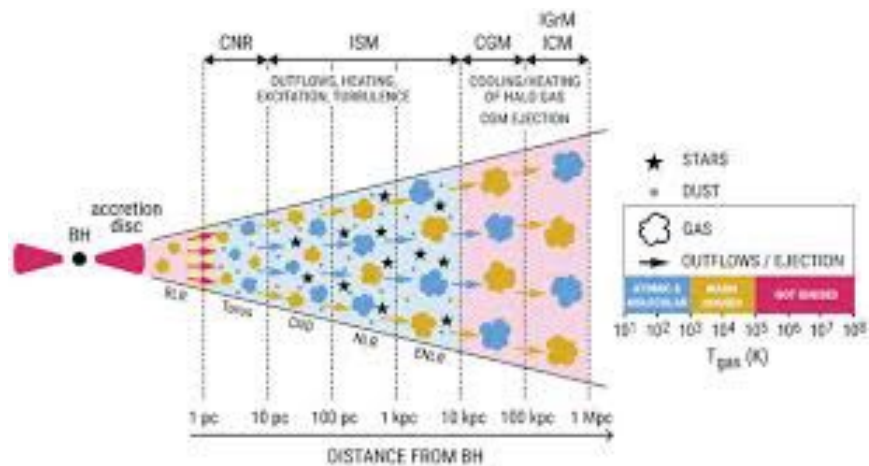
JADES-GS-z14-0 fits sub-threshold. Alternatives (high SFE, top-heavy IMF) fail to explain sharp bimodality; threshold predicts mass-dependent signatures.

4. Detailed Phased Research Plan

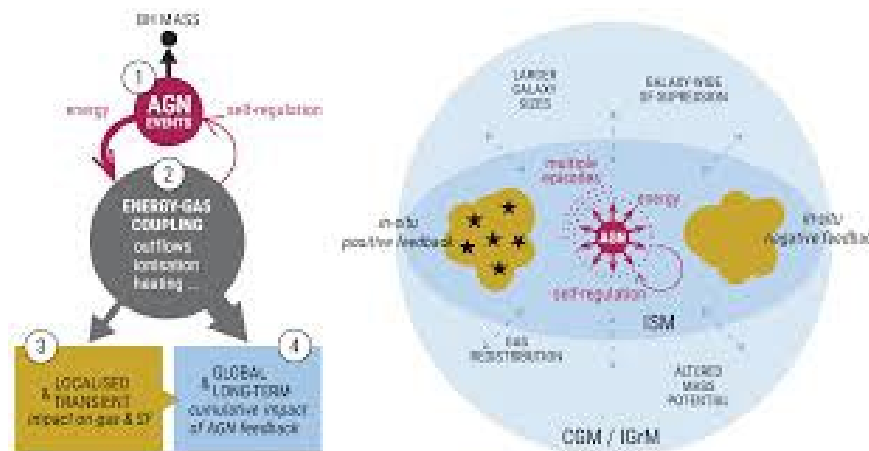
Phase 1 (0 – 6 months: Theoretical): One-zone models (Python/SymPy) vary seeds/accretion; predict sSFR vs. M_{BH} .

Phase 2 (6 – 12 months: Observational): Archival NIRSPEC; virial limits from $[O III]/H\beta$ widths (single-epoch, calibrated on lower-z).

Phase 3 (12 – 18 months: Simulations): Modify IllustrisTNG-like semi-analytic (e.g., Santa Cruz SAM) or GADGET subgrid: switch momentum (low M_{BH}) to energy loading (high); box 10 – 20 Mpc/h, 10 – 20 realizations.



[mdpi.com](https://www.mdpi.com)



[mdpi.com](https://www.mdpi.com)

Resource Table

Phase	Personnel (months)	Compute (core-hours)	Data/Resources
1	3 – 4	Minimal (laptop)	Open papers
2	4 – 5	Minimal	Public MAST
3	6 – 8	$10^4 - 10^5$	Open codes

Risks and Mitigations

- Weak M_{BH} constraints at high- z → Use lower- z ($z \sim 6 - 10$) calibration.
- Simulations inconclusive → Fallback to pure semi-analytic.
- Oversimplification → Iterate with stochastic seeds.

5. Conclusion

This refined framework explains early bimodality via a physically motivated threshold. The plan is feasible and testable.

Acknowledgments Revised v2 responding to aiXiv reviewer (2025/12/18). Assisted by Grok/ChatGPT.

References (expanded)

- Maiolino et al. 2024, Nature
- King 2003/2005, ApJL
- Inayoshi et al. 2020, ARA&A
- Harikane et al. 2024, ApJ
- Additional: Recent reviews on high-z feedback analogs.