

Little Red Dots: The Assembly of Early Supermassive Black Holes in the JWST Era

David D Vaida ^{1,*} and Ryan Jeffrey Farber ²

¹ Independent Researcher

²Department of Physics, Purdue University Fort Wayne, Fort Wayne, IN, USA

Correspondence*:

David D Vaida

ddvaida28@gmail.com

ABSTRACT

Since the launch of James Webb Space Telescope (JWST) in late 2021, our understanding of high-redshift objects has faced several upheavals. JWST has discovered much more massive galaxies and supermassive black holes (SMBH) than cosmological models had expected. Furthermore, JWST observations have revealed an entirely novel population of high-redshift objects. Characterized by a dominant red rest-frame component and point-like morphology, these “little red dots” (LRD) have set off a flurry of observational and theoretical follow-up. The current identity of LRD is highly debated, yet falling into two main scenarios: active galactic nuclei (i.e., SMBH) or compact star-forming regions. If star-forming, LRD would represent the highest stellar densities ever observed. If SMBH, their high Eddington fractions, and already high masses, help elucidate the growth of the most massive SMBH found by JWST in the early Universe ($z \gtrsim 4$). In this mini-review, we present the observational evidence accumulated to date, including sub-millimeter probes of LRD dust masses, constraints on radio and X-ray emission from stacking, and rest-frame ultraviolet & optical measurements provided by JWST. Furthermore, we highlight how identifying additional LRD that are truly primarily SMBH-driven may help to shed light on the formation of ‘overly massive’ SMBH discovered by JWST within the first billion years since the Big Bang.

Keywords: Little Red Dots, Supermassive Black Holes, JWST, AGN, Super-Eddington Accretion, Supermassive Stars, Direct Collapse Black Holes, Primordial Black Holes

1 INTRODUCTION

Since the launch of James Webb Space Telescope (JWST; Gardner et al. 2023; McElwain et al. 2023) ~four years ago, JWST has discovered an increasing population of supermassive black holes (SMBH) that challenge the current paradigm of black hole formation and growth (Jacak 2025 and see the recent review Harikane 2025). Specifically, JWST-discovered SMBH are far more massive than expected to be present at such high redshifts (~billion solar mass black holes are present within the first billion years after the Big Bang), suggesting much more rapid formation than would be possible for Pop III stars accreting at the Eddington limit (Kiyuna 2025 and see the ~recent reviews Inayoshi et al. 2020; Volonteri et al. 2021; Jeon et al. 2025a).

Instead, these ‘overly’ massive SMBH may have formed through Eddington-limited accretion from heavy seeds, such as direct collapse black holes from atomic cooling halos and supermassive stars (Kiyuna et al., 2024; Lu et al., 2024; Jeon et al., 2025b), or primordial black holes (Delos et al., 2024;

Riotto and Silk, 2025; Carr and Green, 2025). Alternatively, these SMBH may have formed through hierarchical merging of light seed black holes in active galactic nucleus (AGN) disks (Vaccaro et al., 2024), in dense nuclear or globular star clusters (Kritos et al., 2025; Lahén et al., 2025) or had their growth rates boosted beyond the Bondi rate (and Eddington limit) via fuzzy dark matter soliton cores (Chiu et al., 2025).

Clearly, much uncertainty exists regarding precisely how SMBH grew so rapidly in the early universe. Perhaps the best way to uncover the physical mechanism by which these black holes formed is to find the extension of such a population at high-redshifts that are growing at lower luminosities. Such an intermediate mass population will help to illuminate the seed masses (Akins et al., 2025b); moreover, constraints on the accretion rates of such intermediate objects will help understand what seed masses are required for the requisite rapid growth to the observed SMBH masses.

Possibly constituting such intermediate mass SMBH in an active state, little red dots (LRD) describe a typically high-redshift population with compact morphology, broad ~ 1000 s km/s H α line widths (Kocevski et al., 2024; Zhang et al., 2025), and simultaneously blue ultraviolet (UV) continua yet red optical colors (Setton et al., 2024; Hviding et al., 2025). Originally, LRD were detected for redshifts $4.2 < z < 5.5$ (Matthee et al., 2024); however, additional JWST observations have uncovered a larger population of LRD extending from redshifts $3 < z < 10$ (Labbe et al., 2024; Graham et al., 2025). In addition to a growing population of LRD characterized by JWST, LRD have been investigated by increasingly deep multiwavelength campaigns stretching from radio to X-ray bands.

In this mini-review, we highlight the findings of the most recent LRD observations across the electromagnetic spectrum with a focus on identifying the physical origins of LRD. In section 2 we contextualize the discovery of LRD with respect to the first few JWST surveys performed. Subsequently, in section 3, we discuss additional multi-wavelength studies that round out the characterization of LRD. Synthesizing the observations detailed in prior sections, in section 4, we discuss theoretical interpretations of LRD that claim to explain the observed properties of LRD. Finally, we zoom-out and discuss the state of the field of LRD origins more broadly, along with the future directions that can more conclusively end the controversy in section 5. Understanding these mechanisms is crucial for accurately interpreting high-redshift observations and for uncovering how the first SMBHs originated.

2 LRD DISCOVERY THROUGH THE LENS OF JWST SURVEYS

Some of the first images from JWST, utilizing the Near Infrared Camera (NIRCam; Rieke et al., 2023), through the Cosmic Evolution Early Release Science program (CEERS; Finkelstein et al., 2023), were found to contain very red galaxies (e.g., Endsley et al. 2023; Labbé et al. 2023; Onoue et al. 2023) implying high-redshift galaxies much more massive than expected from the current cosmological paradigm Λ Cold Dark Matter (CDM; Boylan-Kolchin 2023; Ferrara et al. 2023; Lovell et al. 2023).

Consideration of the longer wavelength properties of these red objects with the Mid-Infrared Instrument (MIRI; Argyriou et al., 2023) and spectra collected with the Near-Infrared Spectrograph (NIRSpec; Bagnasco et al., 2007) resulted in lower mass estimates, while identifying very broad

Balmer line emission and a V-shaped spectral energy distribution (SED): simultaneous blue rest-frame UV and red rest-frame optical colors (Carnall et al., 2023; Kocevski et al., 2023; Barro et al., 2024). However, extremely large equivalent widths of the Balmer emission lines suggested a stellar component may contribute a significant fraction to the otherwise clear signature of AGN activity (Carnall et al., 2023).

Although a small fraction of these red objects were later found to be foreground brown dwarfs, a larger sample of low-luminosity red objects at high-redshift with a characteristic v-shaped SED, point-like morphology, and broad Balmer lines (Furtak et al., 2023; Greene et al., 2024; Labbe et al., 2024) were discovered through the Ultradeep NIRSpec and NIRCам Observations before the Epoch of Reionization (UNCOVER; Bezanson et al., 2024)) program. Combining deep NIRCам photometric and wide-field slitless spectroscopy (WFSS; grism) observations from the EIGER (Kashino et al., 2023) and FRESCO (Oesch et al., 2023) surveys, Matthee et al. (2024) coined the term ‘little red dots’ (LRD) to explain the surprisingly abundant population: about 1% of galaxies at redshift $z > 5$ were found to host LRD, while the number density 10^{-5} per cMpc^{-3} (co-moving cubic Mega-parsec) is 10-100 times larger than expected by extrapolating the UV luminosity function.

Following up on the primarily photometric surveys that incidentally contained little red dots, the Red Unknowns: Bright Infrared Extragalactic Survey (RUBIES; De Graaff et al. 2025), was designed to specifically investigate LRD through a homogeneous spectroscopic survey. Utilizing NIRSpec and covering cosmic noon ($z \sim 2$) and earlier, RUBIES has revealed that LRD show a spectroscopic link between three defining characteristics: broad Balmer lines, a rest-optical point source, and a v-shaped continuum, across 1500 galaxies studied (Hviding et al., 2025).

The characteristic bimodal spectral energy distribution was confirmed spectroscopically as one of the defining characteristics of LRD (Hviding et al., 2025). In Figure 1, we present three complementary RUBIES diagnostics. First, the $\beta_{\text{UV}}-\beta_{\text{opt}}$ plane shows compact red sources in a tight locus distinct from the parent sample. Second, an Euler diagram quantifies the strong overlap among the three LRD criteria—broad Balmer lines, a dominant rest-optical point source, and a V-shaped continuum. Third, demographics linking redshift to JWST photometric filter flux ratio $F_{356\text{W}}/F_{444\text{W}}$ and UV absolute magnitude M_{UV} to $L_{\text{H}\alpha}$ indicate that LRD are UV-faint at fixed $L_{\text{H}\alpha}$ yet dominate among the most extreme $\text{H}\alpha$ emitters. Taken together, these diagnostics tie the characteristic blue-UV/red-optical SED to an unresolved structure and broad Balmer emission, consistent with compact, partly obscured accretion.

3 OBSERVATIONAL CONSTRAINTS ON LRD

Studying the rest-frame UV of LRD, detections of the high-ionization coronal line [FeX] strongly suggest an AGN nature (Kocevski et al., 2023; Furtak et al., 2024). On the other hand, non-detections of HeII emission lines in the far UV (FUV) and MgII are more consistent with photoionization by massive stars (Akins et al., 2024). Additionally, a Balmer break, observed for many LRD, typically suggests an aged stellar population, though it is not universal (Akins et al., 2024). On the other hand, detections of strong C iv, marginal He ii and [Fe x], together with broad $\text{H}\alpha$ all combined strongly support an AGN interpretation (Inayoshi and Maiolino, 2025).

As early as 2024, it was reasoned that (most) LRD dust masses must be quite limited $< 10^{4-5} M_{\odot}$ due to their compact sizes yet relatively low mass available for attenuation (Casey et al., 2024). Indeed,

deep NOEMA observations of $z > 7$ LRD (Xiao et al., 2025) as well as multi-band Atacama Large Millimeter/Submillimeter Array (ALMA; Wootten and Thompson, 2009) observations of a couple of the brightest LRD known resulted in stringent non-detections (Setton et al., 2025). Observations of a larger sample (~ 60) LRD with ALMA in the 1.3 mm continuum band similarly resulted in no detections, even with stacking, suggesting LRD either have modest dust reservoirs ($A_v \sim 2 - 4$) or otherwise very dense gas 10^9 cm^{-3} causes the obscuration. The paucity of dust in LRD extends to a broader range of wavelengths in the far-IR and sub-mm: LRD observations in the rest-frame IR in Spitzer/MIPS $24 \mu\text{m}$, JCMT/SCUBA-2 $850 \mu\text{m}$, ALMA 1.2 & 2.0 mm, and MeerKAT/VLA 1.3 & 3.0 GHz all resulted in non-detections (Bao et al., 2025).

Consistent with non-detections at redder wavelengths, Brooks et al. (2025) investigated the dust attenuation of Balmer narrow-line emission and broad-line signatures in 29 $z > 3.5$ AGN selected from JWST surveys (CEERS, JADES, and RUBIES). The narrow-line emission is consistent with no dust attenuation, which Brooks et al. (2025) consider to be consistent with star formation at larger scales in the galaxy. They place a lower limit on the dust attenuation $A_v > 3.6$ due to non-detection ($< 3\sigma$) of the broad $\text{H}\beta$ line even after stacking 25 of their sources, which they say is consistent with a dust-obscured AGN.

Multi-wavelength observations resulting in non-detections have extended to an increasingly larger sample of LRD. Studying 434 LRD in the JWST COSMOS-Web survey, Akins et al. (2025b) find no detections, even when stacking, in X-ray, mid-IR, far-IR/submillimeter, and radio bands. Their non-detections are consistent with prior work of smaller samples that found LRD are not detected, or quite weakly emitting, in X-ray (Ananna et al., 2024; Yue et al., 2024; Maiolino et al., 2025) and in radio (Mazzolari et al., 2024; Perger et al., 2025; Gloude-mans et al., 2025).

4 THEORETICAL INTERPRETATIONS

We next consider how LRD spectral properties arise and why AGN and stellar interpretations can both appear. Forward modeling shows that an AGN continuum filtered by dense nearly dust free gas can generate a strong Balmer break and broad Balmer lines while leaving the UV relatively blue, a combination that matches several spectroscopic LRD with tentative variability present (2.6σ ; D'Eugenio et al., 2025). In particular, the inclusion of mid-IR and redder data (from MIRI & ALMA) has led to mixed results. While the red optical and near-IR data can be fit by an obscured accretion disk with scattered AGN light (Lambrides et al., 2024; Pacucci and Narayan, 2024; Madau, 2025), stellar-dominated (even starburst) models provide improved fits (Pérez-González et al., 2024; Carranza-Escudero et al., 2025). Moreover, the concerns that a stellar nature of LRD is inconsistent with the maximal brightness surface density in the local universe (Hopkins et al., 2010), is alleviated due to MIRI and ALMA observations decreasing the requisite stellar mass (Williams et al., 2024). On the other hand, recent analysis of LRD from the JWST Advanced Deep Extragalactic Survey (JADES; Eisenstein et al., 2023) with NIRCcam and MIRI photometry suggest one LRD with a 2% AGN contribution to the luminosity, one completely star-forming, and the rest with 20-70% contributions from AGN (Durodola et al., 2025). Similarly, recent analysis of MIRI data increases the fit for stellar components, reducing the number of AGN-only solutions without eliminating AGN altogether (Furtak et al., 2025).

To explain the paucity of radio, X-ray, and far-IR/sub-mm emission, modeling work has extended beyond the standard models of AGN. Quasi star or black hole envelope models predict compact very red sources with strong Balmer features during specific evolutionary phases that overlap LRD selections, suggesting some LRD may represent heavy seeds in formation (Begelman and Dexter, 2025; Durodola et al., 2025). Black hole envelopes embedded in dense gas can also reproduce red continua and strong lines in a way

that mimics faint AGN (Kido et al., 2025; Naidu et al., 2025). On the other hand, simulations of collapsing clusters predict enhanced tidal disruption activity and luminous transients that can generate broad lines and variable continua in compact systems, offering another channel that suggests a non-standard AGN origin of LRD with rapid black hole growth in cluster cores (Bellovary, 2025). Dusty inflow models explain very red rest-optical colors and broad absorption and predict that mid-IR observations should be constraining (Li et al., 2025). Simulations of high redshift environments indicate that compact AGN can arise in gas rich protoclusters where repeated fueling and multiphase outflows sculpt line profiles and continuum shape (Kannan et al., 2025). Observations of multiphase outflows around $z \sim 5$ quasars show that such winds can be common and energetic, which supports the idea that some LRD reflect wind-bearing accretion states rather than aged stellar populations (Brazzini et al., 2025). These models collectively predict that modest changes in geometry, column density, and recent fueling history can toggle an object between apparently AGN-like and stellar-like diagnostics, which explains why LRD form a mixed class.

Considering a multiply imaged LRD at redshift 7 from UNCOVER, Furtak et al. (2025) investigated time variability, leveraging lensing time delays of 22 years (rest-frame ~ 3 yr). Finding significant variability in $H\alpha$ and $H\beta$ lines, Furtak et al. (2023) confirmed the AGN nature of this LRD. We show Furtak et al. (2025) their figure 1 in Figure 2. Clearly, the $H\alpha$ and $H\beta$ line fluxes have evolved significantly from epoch 7 (marked in blue) to epoch 8 (marked in green). This constitutes strong AGN evidence for several reasons. First, the Balmer lines are very broad (FWHM a few 10^3 km s^{-1}), which requires the high velocities of gas near a black hole and cannot be produced by normal star-forming H II regions. The line fluxes and profiles vary on rest-frame \sim year timescales, the expected behavior of a compact broad-line region responding to a changing ionizing source. Since the spectra are normalized and the multiple images are separated by known lensing delays, the differences cannot be due to calibration or lensing and must be intrinsic. Photometric non-variability does not contradict this result, since AGN continuum variability is stochastic and can be modest over the sampled interval.

5 DISCUSSION AND CONCLUSION

Despite recent progress, many caveats surround the work performed to-date attempting to identify the nature of individual LRD. Many LRD are X-ray and radio quiet even in stacks, which could be consistent with heavy obscuration and low coronal efficiency (as expected from super-Eddington accretion models; Secunda et al. 2025) or purely stellar solutions; stellar templates fit a large fraction of LRD with mid-IR data included (Hainline et al., 2025). Radio and X-ray constraints specific to compact high redshift sources show that non-detections do not rule out accretion for the luminosities expected from thick trapping dominated flows, which raises the need for sensitive follow up tuned to low efficiency spectra rather than relying on shallow stacks (Latif et al., 2025). Deeper observations in radio bands may uncover a tail of detections if even a minority of LRD host jets or compact cores, which provides a near-term observational test of the mixed population picture (Latif and Whalen, 2025).

Completeness studies for obscured narrow line AGN show that color cuts and emission line thresholds can miss faint or partially obscured accretors, which implies that some LRD-like systems may be absent from current AGN catalogs and that selection bias can skew interpretations (Bouwens et al., 2025; Scholtz et al., 2025).

Ultimately, LRD likely comprise both genuine rapidly growing black holes and compact star-forming systems, and resolving their roles in early black hole demographics will require deeper mid-IR coverage, higher signal to noise spectroscopy that targets both Balmer and high ionization UV lines, and radio and

X-ray follow up that is matched to the efficiencies expected for thick discs rather than thin ones (Akins et al., 2025a).

In particular, measuring time variability would provide ‘smoking-gun’ evidence for an AGN nature of individual LRD. As most LRD are not multiply imaged as in the target of Furtak et al. (2025), collecting additional epochs of LRD photometric and spectroscopic measurements extending several years will be necessary. The upcoming TWINKLE campaign (JWST Proposal Cycle 4, ID 7404PI, PI: Naidu) will be the next possibility to find variability in the Balmer emission line fluxes. While expensive, deeper observations of truly AGN-generating LRD will be crucial to better understand the assembly of supermassive black holes within the first billion years from the Big Bang.

CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

DDV: Writing – original draft, review and editing. RJF: Writing – review and editing.

ACKNOWLEDGMENTS

We thank Lukas Furtak and Adi Zitrin for their permission to re-use their figure as shown in our Figure 2. We thank Raphael Hviding for their permission to re-use their figure as shown in our Figure 1. DDV thanks his family for their belief and support throughout the writing process.

REFERENCES

- Akins, H. B., Casey, C. M., Berg, D. A., Chisholm, J., Franco, M., Finkelstein, S. L., et al. (2024). Strong rest-uv emission lines in a “little red dot” agn at $z = 7$: Early smbh growth alongside compact massive star formation? arXiv preprint arXiv:2410.00949
- Akins, H. B., Casey, C. M., Chisholm, J., Berg, D. A., Cooper, O., Franco, M., et al. (2025a). Tentative detection of neutral gas in a little red dot at $z = 4.46$. arXiv preprint arXiv:2503.00998
- Akins, H. B., Casey, C. M., Lambrides, E., Allen, N., Andika, I. T., Brinch, M., et al. (2025b). Cosmosweb: The overabundance and physical nature of “little red dots”—implications for early galaxy and smbh assembly. *The Astrophysical Journal* 991, 37
- Ananna, T. T., Bogdán, Á., Kovács, O. E., Natarajan, P., and Hickox, R. C. (2024). X-ray view of little red dots: Do they host supermassive black holes? *The Astrophysical Journal Letters* 969, L18
- Argyriou, I., Glasse, A., Law, D. R., Labiano, A., Álvarez-Márquez, J., Patapis, P., et al. (2023). Jwst miri flight performance: the medium-resolution spectrometer. *Astronomy & Astrophysics* 675, A111
- Bagnasco, G., Kolm, M., Ferruit, P., Honnen, K., Koehler, J., Lemke, R., et al. (2007). Overview of the near-infrared spectrograph (nirspec) instrument on-board the james webb space telescope (jwst). In *Cryogenic optical systems and instruments XII (SPIE)*, vol. 6692, 174–187
- Bao, L., Tsai, C.-W., Wu, J., Wang, T., Li, G., Assef, R. J., et al. (2025). Investigating little red dots with uv excess: Are they the high-redshift siblings of blue hot dust-obscured galaxies? *The Astrophysical Journal* 992, 117

- Barro, G., Pérez-González, P. G., Kocevski, D. D., McGrath, E. J., Trump, J. R., Simons, R. C., et al. (2024). Extremely red galaxies at $z = 5-9$ with miri and nirspec: dusty galaxies or obscured active galactic nuclei? *The Astrophysical Journal* 963, 128
- Begelman, M. C. and Dexter, J. (2025). Little red dots as late-stage quasi-stars. arXiv preprint arXiv:2507.09085
- Bellovary, J. (2025). Little red dots are tidal disruption events in runaway-collapsing clusters. *The Astrophysical Journal Letters* 984, L55
- Bezanson, R., Labbe, I., Whitaker, K. E., Leja, J., Price, S. H., Franx, M., et al. (2024). The jwst uncover treasury survey: ultradeep nirspec and nircam observations before the epoch of reionization. *The Astrophysical Journal* 974, 92
- Bouwens, R. J., Banados, E., Decarli, R., Hennawi, J., Yang, D., Algera, H., et al. (2025). Beneath the surface: $> 85\%$ of $z > 5.9$ qsos in massive host galaxies are uv-faint. arXiv preprint arXiv:2506.24128
- Boylan-Kolchin, M. (2023). Stress testing λ cdm with high-redshift galaxy candidates. *Nature Astronomy* 7, 731–735
- Brazzini, M., D’Odorico, V., Bischetti, M., Feruglio, C., Cupani, G., Becker, G., et al. (2025). Multi-phase investigation of outflows in the circumgalactic and interstellar media of luminous quasars at $z \sim 5$. *Astronomy & Astrophysics* 698, A145
- Brooks, M., Simons, R. C., Trump, J. R., Taylor, A. J., Bagley, M. B., Backhaus, B., et al. (2025). Here there be (dusty) monsters: High-redshift active galactic nuclei are dustier than their hosts. *The Astrophysical Journal* 986, 177
- Carnall, A. C., McLure, R. J., Dunlop, J. S., McLeod, D. J., Wild, V., Cullen, F., et al. (2023). A massive quiescent galaxy at redshift 4.658. *Nature* 619, 716–719
- Carr, B. J. and Green, A. M. (2025). The history of primordial black holes. In *Primordial Black Holes* (Springer). 3–33
- Carranza-Escudero, M., Conselice, C. J., Adams, N., Harvey, T., Austin, D., Behroozi, P., et al. (2025). Lonely little red dots: Challenges to the agn-nature of little red dots through their clustering and spectral energy distributions. arXiv e-prints, arXiv:2506
- Casey, C. M., Akins, H. B., Kokorev, V., McKinney, J., Cooper, O. R., Long, A. S., et al. (2024). Dust in little red dots. *The Astrophysical Journal Letters* 975, L4
- Chiu, H.-H. S., Schive, H.-Y., Yang, H.-Y. K., Huang, H., and Gaspari, M. (2025). Boosting supermassive black hole growth in the early universe by fuzzy dark matter solitons. *Physical Review Letters* 134, 051402
- De Graaff, A., Brammer, G., Weibel, A., Lewis, Z., Maseda, M. V., Oesch, P. A., et al. (2025). Rubies: a complete census of the bright and red distant universe with jwst/nirspec. *Astronomy & Astrophysics* 697, A189
- Delos, M. S., Rantala, A., Young, S., and Schmidt, F. (2024). Structure formation with primordial black holes: collisional dynamics, binaries, and gravitational waves. *Journal of Cosmology and Astroparticle Physics* 2024, 005
- D’Eugenio, F., Maiolino, R., Perna, M., Uebler, H., Ji, X., McClymont, W., et al. (2025). Blackthunder strikes twice: rest-frame balmer-line absorption and high eddington accretion rate in a little red dot at $z = 7.04$. arXiv preprint arXiv:2503.11752
- Durodola, E., Pacucci, F., and Hickox, R. C. (2025). Exploring the active galactic nucleus fraction of a sample of jwst’s little red dots at $4 < z < 8$: Overmassive black holes are strongly favored. *The Astrophysical Journal* 985, 169

- Eisenstein, D. J., Willott, C., Alberts, S., Arribas, S., Bonaventura, N., Bunker, A. J., et al. (2023). Overview of the jwst advanced deep extragalactic survey (jades). *arXiv preprint arXiv:2306.02465*
- Endsley, R., Stark, D. P., Whitler, L., Topping, M. W., Chen, Z., Plat, A., et al. (2023). A jwst/nircam study of key contributors to reionization: the star-forming and ionizing properties of uv-faint $z \sim 7-8$ galaxies. *Monthly Notices of the Royal Astronomical Society* 524, 2312–2330
- Ferrara, A., Pallottini, A., and Dayal, P. (2023). On the stunning abundance of super-early, luminous galaxies revealed by jwst. *Monthly Notices of the Royal Astronomical Society* 522, 3986–3991
- Finkelstein, S. L., Bagley, M. B., Ferguson, H. C., Wilkins, S. M., Kartaltepe, J. S., Papovich, C., et al. (2023). Ceers key paper. i. an early look into the first 500 myr of galaxy formation with jwst. *The Astrophysical Journal Letters* 946, L13
- Furtak, L. J., Labbé, I., Zitrin, A., Greene, J. E., Dayal, P., Chemerynska, I., et al. (2024). A high black-hole-to-host mass ratio in a lensed agn in the early universe. *Nature* 628, 57–61
- Furtak, L. J., Secunda, A. R., Greene, J. E., Zitrin, A., Labbé, I., Golubchik, M., et al. (2025). Investigating photometric and spectroscopic variability in the multiply imaged little red dot a2744-qso1. *Astronomy & Astrophysics* 698, A227
- Furtak, L. J., Zitrin, A., Plat, A., Fujimoto, S., Wang, B., Nelson, E. J., et al. (2023). Jwst uncover: extremely red and compact object at $z_{\text{phot}} \sim 7.6$ triply imaged by a2744. *The Astrophysical Journal* 952, 142
- Gardner, J. P., Mather, J. C., Abbott, R., Abell, J. S., Abernathy, M., Abney, F. E., et al. (2023). The James Webb Space Telescope Mission. *Publications of the Astronomical Society of the Pacific* 135, 068001. doi:10.1088/1538-3873/acd1b5
- Gludemans, A. J., Duncan, K. J., Eilers, A.-C., Farina, E. P., Harikane, Y., Inayoshi, K., et al. (2025). Another piece to the puzzle: Radio detection of a jwst-detected active galactic nucleus candidate. *The Astrophysical Journal* 986, 130
- Graham, A. W., Chilingarian, I., Nguyen, D. D., Soria, R., Durré, M., and Forbes, D. A. (2025). Dot to dot: High- z little red dots in diagrams with galaxy-morphology-specific scaling relations. *Publications of the Astronomical Society of Australia* 42, e068
- Greene, J. E., Labbe, I., Goulding, A. D., Furtak, L. J., Chemerynska, I., Kokorev, V., et al. (2024). Uncover spectroscopy confirms the surprising ubiquity of active galactic nuclei in red sources at $z > 5$. *The Astrophysical Journal* 964, 39
- Hainline, K. N., Maiolino, R., Juodžbalis, I., Scholtz, J., Übler, H., d'Eugenio, F., et al. (2025). An investigation into the selection and colors of little red dots and active galactic nuclei. *The Astrophysical Journal* 979, 138
- Harikane, Y. (2025). Early galaxies and supermassive black holes discovered by the james webb space telescope. *Astrophysics and Space Science* 370, 85
- Hopkins, P. F., Murray, N., Quataert, E., and Thompson, T. A. (2010). A maximum stellar surface density in dense stellar systems. *Monthly Notices of the Royal Astronomical Society: Letters* 401, L19–L23
- Hviding, R. E., de Graaff, A., Miller, T. B., Setton, D. J., Greene, J. E., Labbé, I., et al. (2025). Rubies: A spectroscopic census of little red dots; all v-shaped point sources have broad lines. *arXiv preprint arXiv:2506.05459*
- Inayoshi, K. and Maiolino, R. (2025). Extremely dense gas around little red dots and high-redshift active galactic nuclei: A nonstellar origin of the balmer break and absorption features. *The Astrophysical Journal Letters* 980, L27
- Inayoshi, K., Visbal, E., and Haiman, Z. (2020). The assembly of the first massive black holes. *Annual Review of Astronomy and Astrophysics* 58, 27–97

- Jacak, J. E. (2025). Possible nonstellar explanation for the unexpected brightness of the earliest galaxies observed by the James Webb Space Telescope. *Scientific Reports* 15, 19204
- Jeon, J., Bromm, V., Liu, B., and Finkelstein, S. L. (2025a). Physical pathways for JWST-observed supermassive black holes in the early universe. *The Astrophysical Journal* 979, 127
- Jeon, J., Liu, B., Bromm, V., Fujimoto, S., Taylor, A. J., Kokorev, V., et al. (2025b). Little red dots and their progenitors from direct collapse black holes. arXiv preprint arXiv:2508.14155
- Kannan, R., Puchwein, E., Smith, A., Borrow, J., Garaldi, E., Keating, L., et al. (2025). Introducing the thesan-zoom project: radiation-hydrodynamic simulations of high-redshift galaxies with a multi-phase interstellar medium. arXiv preprint arXiv:2502.20437
- Kashino, D., Lilly, S. J., Matthee, J., Eilers, A.-C., Mackenzie, R., Bordoloi, R., et al. (2023). Eiger. I. a large sample of [O III]-emitting galaxies at $5.3 < z < 6.9$ and direct evidence for local reionization by galaxies. *The Astrophysical Journal* 950, 66
- Kido, D., Ioka, K., Hotokezaka, K., Inayoshi, K., and Irwin, C. M. (2025). Black hole envelopes in little red dots. arXiv preprint arXiv:2505.06965
- Kiyuna, M. (2025). Super-Eddington growth ceiling: Analytic constraints on the rapid growth of light-seed black holes in massive clumps. arXiv preprint arXiv:2506.15781
- Kiyuna, M., Hosokawa, T., and Chon, S. (2024). Sequential formation of supermassive stars and heavy seed BHs through the interplay of cosmological cold accretion and stellar radiative feedback. *Monthly Notices of the Royal Astronomical Society* 534, 3916–3935
- Kocevski, D. D., Finkelstein, S. L., Barro, G., Taylor, A. J., Calabrò, A., Laloux, B., et al. (2024). The rise of faint, red AGN at $z > 4$: A sample of little red dots in the JWST extragalactic legacy fields. arXiv preprint arXiv:2404.03576
- Kocevski, D. D., Onoue, M., Inayoshi, K., Trump, J. R., Haro, P. A., Grazian, A., et al. (2023). Hidden little monsters: spectroscopic identification of low-mass, broad-line AGNs at $z > 5$ with CEERS. *The Astrophysical Journal Letters* 954, L4
- Kritos, K., Beckmann, R. S., Silk, J., Berti, E., Yi, S., Volonteri, M., et al. (2025). Supermassive black hole growth in hierarchically merging nuclear star clusters. *The Astrophysical Journal* 991, 58
- Labbe, I., Greene, J. E., Bezanson, R., Fujimoto, S., Furtak, L. J., Goulding, A. D., et al. (2024). Uncover: candidate red active galactic nuclei at $3 < z < 7$ with JWST and ALMA. *The Astrophysical Journal* 978, 92
- Labbé, I., van Dokkum, P., Nelson, E., Bezanson, R., Suess, K. A., Leja, J., et al. (2023). A population of red candidate massive galaxies ~ 600 Myr after the Big Bang. *Nature* 616, 266–269
- Lahén, N., Naab, T., Rantala, A., and Partmann, C. (2025). Mergers all the way down: stellar collisions and kinematics of a dense hierarchically forming massive star cluster in a dwarf starburst. *Monthly Notices of the Royal Astronomical Society* 543, 1023–1038
- Lambrides, E., Garofali, K., Larson, R., Ptak, A., Chiaberge, M., Long, A. S., et al. (2024). The case for super-Eddington accretion: Connecting weak X-ray and UV line emission in JWST broad-line AGN during the first Gyr of cosmic time. arXiv preprint arXiv:2409.13047
- Latif, M. A., Aftab, A., Whalen, D. J., and Mezcua, M. (2025). Radio emission from little red dots may reveal their true nature. *Astronomy & Astrophysics* 694, L14
- Latif, M. A. and Whalen, D. J. (2025). Synergies between Euclid, Roman and JWST could reveal quasars at up to $z \sim 15$. arXiv preprint arXiv:2506.21658
- Li, Z., Inayoshi, K., Chen, K., Ichikawa, K., and Ho, L. C. (2025). Little red dots: Rapidly growing black holes reddened by extended dusty flows. *The Astrophysical Journal* 980, 36

- Lovell, C. C., Harrison, I., Harikane, Y., Tacchella, S., and Wilkins, S. M. (2023). Extreme value statistics of the halo and stellar mass distributions at high redshift: are jwst results in tension with λ cdm? *Monthly Notices of the Royal Astronomical Society* 518, 2511–2520
- Lu, Y., Picker, Z. S., and Kusenko, A. (2024). Direct collapse supermassive black holes from relic particle decay. *Physical Review Letters* 133, 091001
- Madau, P. (2025). Chasing the light: Shadowing, collimation, and the super-eddington growth of infant black holes in jwst-discovered agns. *arXiv preprint arXiv:2501.09854*
- Maiolino, R., Risaliti, G., Signorini, M., Trefoloni, B., Juodžbalis, I., Scholtz, J., et al. (2025). Jwst meets chandra: a large population of compton thick, feedback-free, and intrinsically x-ray weak agn, with a sprinkle of sne. *Monthly Notices of the Royal Astronomical Society* 538, 1921–1943
- Matthee, J., Naidu, R. P., Brammer, G., Chisholm, J., Eilers, A.-C., Goulding, A., et al. (2024). Little red dots: an abundant population of faint active galactic nuclei at $z \sim 5$ revealed by the eiger and fresco jwst surveys. *The Astrophysical Journal* 963, 129
- Mazzolari, G., Gilli, R., Maiolino, R., Prandoni, I., Delvecchio, I., Norman, C., et al. (2024). The radio properties of the jwst-discovered agn. *arXiv preprint arXiv:2412.04224*
- McElwain, M. W., Feinberg, L. D., Perrin, M. D., Clampin, M., Mountain, C. M., Lallo, M. D., et al. (2023). The james webb space telescope mission: optical telescope element design, development, and performance. *Publications of the Astronomical Society of the Pacific* 135, 058001
- Naidu, R. P., Matthee, J., Katz, H., de Graaff, A., Oesch, P., Smith, A., et al. (2025). A “black hole star” reveals the remarkable gas-enshrouded hearts of the little red dots. *arXiv preprint arXiv:2503.16596*
- Oesch, P. A., Brammer, G., Naidu, R., Bouwens, R., Chisholm, J., Illingworth, G., et al. (2023). The jwst fresco survey: legacy nircam/grism spectroscopy and imaging in the two goods fields. *Monthly Notices of the Royal Astronomical Society* 525, 2864–2874
- Onoue, M., Inayoshi, K., Ding, X., Li, W., Li, Z., Molina, J., et al. (2023). A candidate for the least-massive black hole in the first 1.1 billion years of the universe. *The Astrophysical Journal Letters* 942, L17
- Pacucci, F. and Narayan, R. (2024). Mildly super-eddington accretion onto slowly spinning black holes explains the x-ray weakness of the little red dots. *The Astrophysical Journal* 976, 96
- Pérez-González, P. G., Barro, G., Rieke, G. H., Lyu, J., Rieke, M., Alberts, S., et al. (2024). What is the nature of little red dots and what is not. *The Astrophysical Journal* 968, 4
- Perger, K., Fogasy, J., Frey, S., and Gabányi, K. (2025). Deep silence: Radio properties of little red dots. *Astronomy & Astrophysics* 693, L2
- Rieke, M. J., Kelly, D. M., Misselt, K., Stansberry, J., Boyer, M., Beatty, T., et al. (2023). Performance of nircam on jwst in flight. *Publications of the Astronomical Society of the Pacific* 135, 028001
- Riotto, A. and Silk, J. (2025). The future of primordial black holes: open questions and roadmap. *Primordial Black Holes*, 691–706
- Scholtz, J., Maiolino, R., D’Eugenio, F., Curtis-Lake, E., Carniani, S., Charlot, S., et al. (2025). Jades: A large population of obscured, narrow-line active galactic nuclei at high redshift. *Astronomy & Astrophysics* 697, A175
- Secunda, A., Somerville, R. S., Jiang, Y.-F., Greene, J. E., Furtak, L. J., and Zitrin, A. (2025). Do little red dots vary? *The Astrophysical Journal* 996, 6
- Setton, D. J., Greene, J. E., de Graaff, A., Ma, Y., Leja, J., Matthee, J., et al. (2024). Little red dots at an inflection point: Ubiquitous “v-shaped” turnover consistently occurs at the balmer limit. *arXiv preprint arXiv:2411.03424*
- Setton, D. J., Greene, J. E., Spilker, J. S., Williams, C. C., Labbe, I., Ma, Y., et al. (2025). A confirmed deficit of hot and cold dust emission in the most luminous little red dots. *arXiv preprint arXiv:2503.02059*

- Vaccaro, M. P., Mapelli, M., Périgois, C., Barone, D., Artale, M. C., Dall’Amico, M., et al. (2024). Impact of gas hardening on the population properties of hierarchical black hole mergers in active galactic nucleus disks. *Astronomy & Astrophysics* 685, A51
- Volonteri, M., Habouzit, M., and Colpi, M. (2021). The origins of massive black holes. *Nature Reviews Physics* 3, 732–743
- Williams, C. C., Alberts, S., Ji, Z., Hainline, K. N., Lyu, J., Rieke, G., et al. (2024). The galaxies missed by hubble and alma: the contribution of extremely red galaxies to the cosmic census at $3 < z < 8$. *The Astrophysical Journal* 968, 34
- Wooten, A. and Thompson, A. R. (2009). The atacama large millimeter/submillimeter array. *Proceedings of the IEEE* 97, 1463–1471
- Xiao, M., Oesch, P. A., Bing, L., Elbaz, D., Matthee, J., Fudamoto, Y., et al. (2025). No [cii] or dust detection in two little red dots at $z > 7$. arXiv preprint arXiv:2503.01945
- Yue, M., Eilers, A.-C., Ananna, T. T., Panagiotou, C., Kara, E., and Miyaji, T. (2024). Stacking x-ray observations of “little red dots”: Implications for their active galactic nucleus properties. *The Astrophysical Journal Letters* 974, L26
- Zhang, Z., Jiang, L., Liu, W., and Ho, L. C. (2025). Analysis of multi-epoch jwst images of 300 little red dots: Tentative detection of variability in a minority of sources. *The Astrophysical Journal* 985, 119

FIGURE CAPTIONS

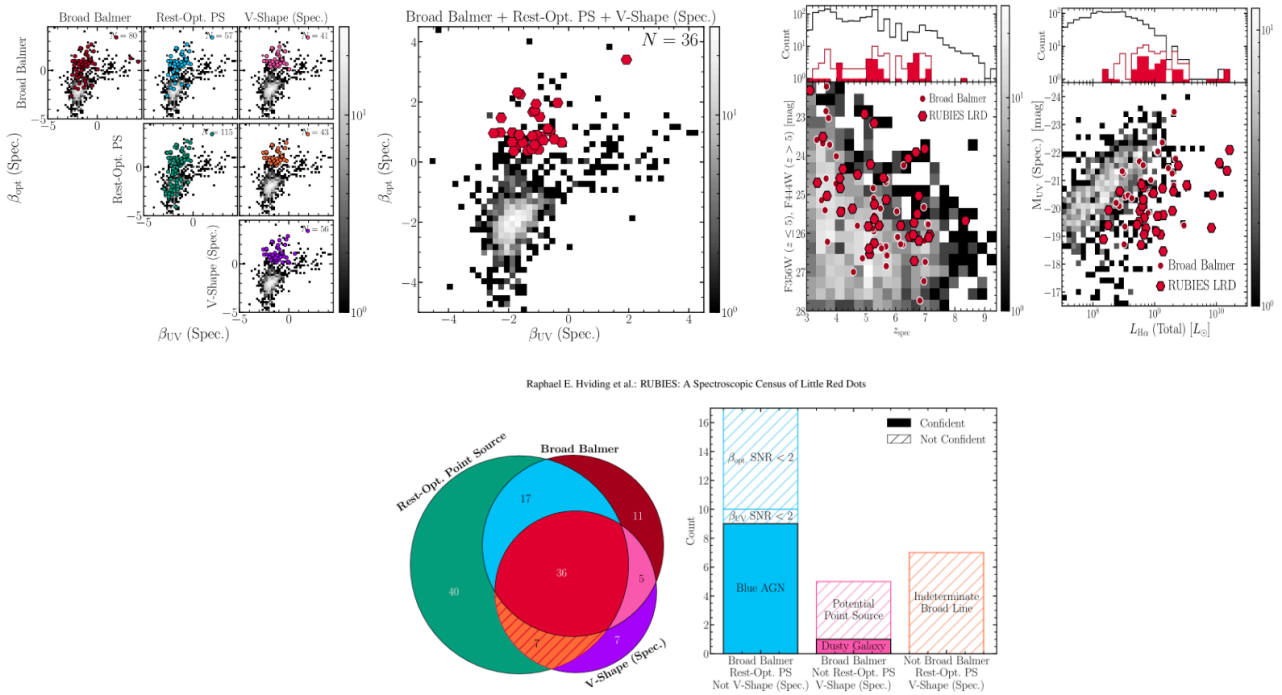


Figure 1. Adapted from Hviding et al. (2025), their Figures 6, 7, and 8 to composite the RUBIES diagnostics for Little Red Dots. In the upper left ‘corner’ plot and upper-middle plot, the β_{UV} – β_{opt} maps show where sources with broad Balmer lines, unresolved rest-optical point sources, and V-shaped continua sit relative to all $z_{spec} > 3.1$ objects. In the upper right, the two heatmaps respectively show the photometric flux in two filters for high vs. low redshift sources (threshold $z = 5$) as a function of spectroscopic redshift, and the spectroscopically derived UV absolute magnitude versus the $H\alpha$ luminosity. Those two heatmaps show LRD are UV-faint at fixed $L_{H\alpha}$ and dominate the most $H\alpha$ -luminous objects at fixed M_{UV} ($F356W$ for $z_{spec} \leq 5$; $F444W$ for $z_{spec} > 5$). Below, the Euler diagram and bar plot show that having a point source and a V-shape implies ~ 80 percent odds of a broad line. Together, the RUBIES survey demonstrate that combining color-slope, compact-morphology, and spectroscopic-shape cuts can define LRD as a population (Hviding et al., 2025).

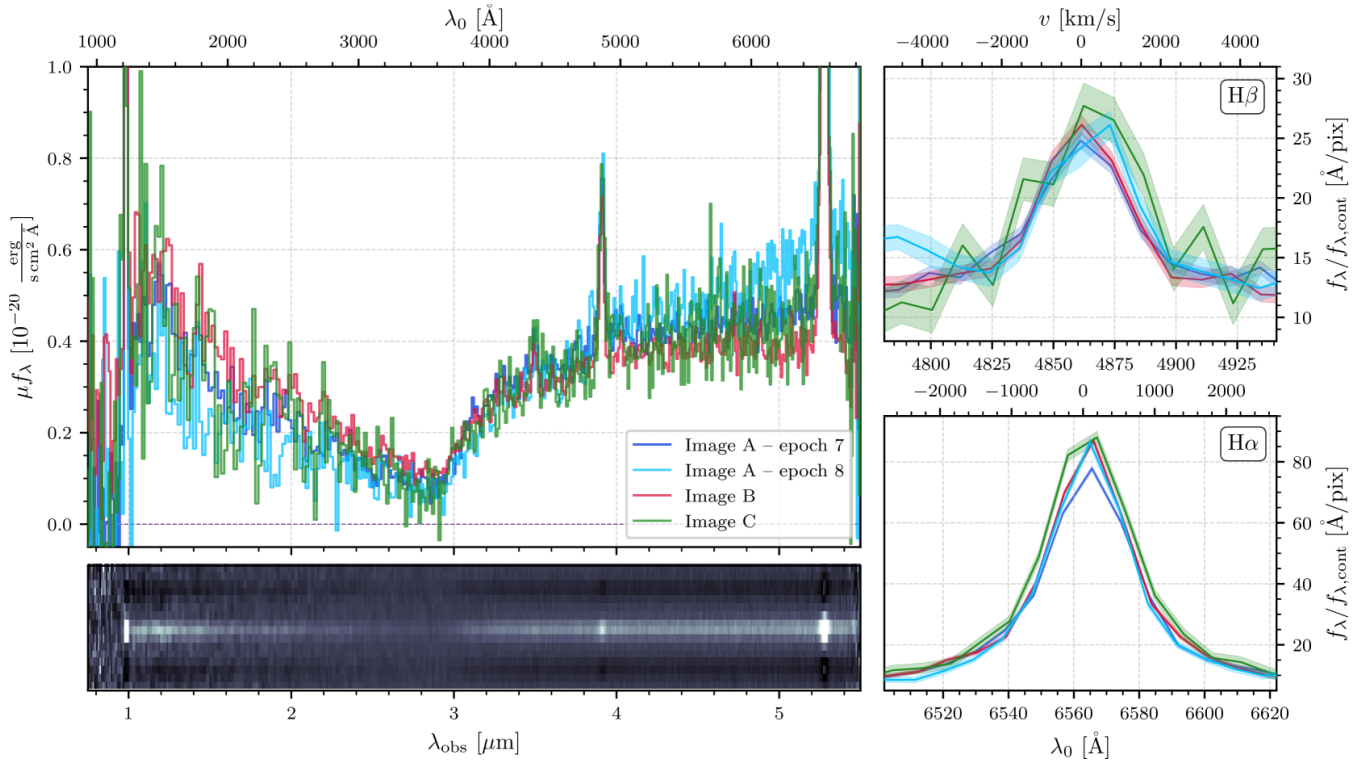


Figure 2. Figure credit: Lukas Furtak and Adi Zitrin, as adapted from Furtak et al. (2025), their Figure 1. This figure provides direct spectroscopic evidence for accretion in the little red dot A2744-QSO1. JWST/NIRSpec-prism observations of the multiply imaged source A2744-QSO1 at multiple epochs capture the full Balmer region and reveal broad H α and H β and their variability. After placing the spectra on a common reference and scaling line profiles by the local continua, the broad shapes persist while only modest equivalent-width changes remain, which is consistent with AGN variability. These measurements show that some LRD host broad-line regions even when continuum variability is weak, supporting an interpretation in which at least part of the LRD population traces active black hole growth (Furtak et al., 2025).