# A $z \simeq 0.4$ Little Red Dot analog: An Extended Starburst with an Overmassive Black hole

Xiaoyang Chen [1,2] Kohei Ichikawa [1] Masayuki Akiyama [3] Kohei Inayoshi [4] Akio K. Inoue [2,5]
Masafusa Onoue [6,7] Yoshiki Toba [8,9] Jorge Zavala [10] Tom Bakx [11] Toshihiro Kawaguchi [12]
Kianhong Lee [13,3,14] Naoki Matsumoto [3] and Bovornpratch Vijarnwannaluk [15,3]

ABSTRACT

One of the most remarkable discoveries of JWST is a population of compact, red sources at $z > 4$, commonly referred to as Little Red Dots (LRDs). Spectroscopic identifications reported that most LRDs are active galactic nuclei (AGNs), which are preferentially found around $z \sim 6$ and could imply a key phase in the formation and growth of black holes (BHs) in the early universe. Photometric surveys at lower redshift have recently been carried out to trace their evolution across cosmic time, and a small number of LRDs have been spectroscopically identified at both Cosmic Noon and in the local universe. Here we report the discovery of one of the lowest-$z$ analogs of LRDs, J204837.26-002437.2 (hereafter J2048) at $z = 0.4332$, using new Gemini-N/GMOS IFU observations combined with archival multi-band photometric SED data. The GMOS data reveal extended blue emission from starburst with a star formation rate of 400 $M_\odot\,\mathrm{yr}^{-1}$, together with an extended, highly fast ionized outflow. This is the first spectroscopic confirmation of extended host emission and outflow in an LRD-like galaxy, providing a unique laboratory for understanding the nature of their high-redshift counterparts. Moreover, J2048 would host an extremely overmassive BH with a BH–to–stellar mass ratio of $\simeq 0.6$, with the BH mass and host stellar mass estimated to be $10^{10.2}$ and $10^{10.4}\,M_\odot$, respectively. We discuss the origin and evolutionary fate of J2048, and the implications that such low-$z$ analogs have for interpreting the properties of high-$z$ LRDs.

- **Little Red Dots (LRDs)**
  - Discovered by JWST at $z > 4$
  - Host AGN (broad line signature)
  - Weak NIR/MIR emission and non-detection by ALMA → no hot/warm dust heated by AGN torus?
  - V-shape SED (blue in UV and red in opt) ← due to star formation? AGN?
  - Detailed study is difficult due to the distance/compactness.
- This study identifies a low-$z$ LRD analog, J2048, at $z \sim 0.4$.
  - Parent sample: AKARI+SDSS ULIRGs
  - Observations: $R$~1000 GMOS IFU (5"x7" with 0.2"/pix ~ 1 kpc/pix)
  - Archival SDSS/2MASS/WISE/IRAC+MIPS photometry
- Similar to high-$z$ LRDs, J2048 shows V-shape SED and has compact, red continuum, and hosts overmassive BH.
- J2048 can be a good target to interpret the properties of high-$z$ LRDs, and to understand the formation and rapid growth of BHs in the early universe.

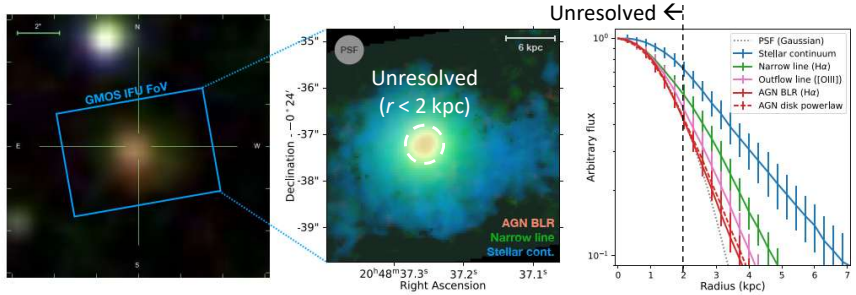



**Figure 1.** **Left:** SDSS *gri*-bands composite image of J2048. The field of view of the GMOS IFU observation is over-plotted as a blue rectangular. **Middle:** Composite image of J2048 from the best spectral fitting results of GMOS IFU data. The red, green, and blue colors denote the AGN BLR Hα line, narrow Hα line, and young stellar continuum (integrated in rest frame 3500–4000 Å), respectively. The grey circle shows the PSF FWHM of 0.65″. **Right:** Average radial profiles of young stellar continuum (blue; 3500–4000 Å), narrow Hα line (green), outflow [OIII] line (purple; the "outflow line 1" component in Figure 2), AGN BLR (red solid) and disk power-law component (red dashed). The profiles are arbitrarily normalized at the center. An approximate PSF using a Gaussian profile with FWHM of 0.65″ is shown in grey dotted line, which can reproduce the bulk of the unresolved AGN BLR and power-law components.

## ☐ Properties obtained from the entire galaxy

arXiv:2510.02801

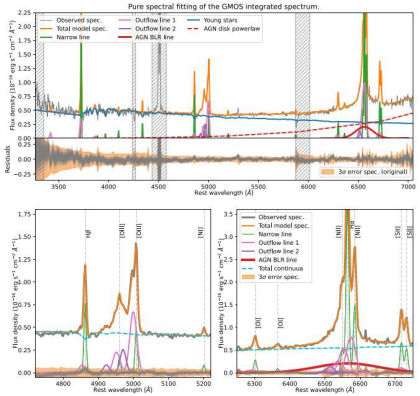



**Figure 2.** Best-fit results of the pure spectral fitting (Section 3.1) for the GMOS spectrum of the entire galaxy with fitting residuals (top and middle panels), as well as two zoomed-in regions around Hβ-[OIII] (bottom-left) and Hα-[NII] (bottom-right), respectively. The observed spectrum is shown in grey. The total model is shown in orange, with the young stellar continuum in blue and the AGN power-law component in red dashed lines. Emission lines include the narrow component (green), two broad blueshifted outflows (purple and violet), and the BLR Hα line (thick red). Grey hatched areas are excluded due to poor data quality. Note that in the top panel, the outflow profiles of the sum of Hα-[NII] complex are shown for the sake of illustration.

← Fig2: Fitting to the GMOS optical spectrum.

- Outflow (primary): $v$ ~ -500 km/s
  - Ionized by AGN (from [OIII]/Hβ ratio)
  - Marginally extended (~1.8kpc)
- Outflow (secondary): $v$ ~ -2250 km/s
  - Ionized by AGN (from [OIII]/Hβ upper limit)
  - Spatially unresolved → compact than the primary
- BLR (Hα): FWHM ~ 10,000 km/s
  - Combined with $L_{5100}$ → $M_{BH} \sim 10^{10.2} M_\odot$
- Spatially extended (~2.5kpc) narrow lines
  - Ionized by young stars (from BPT)
  - $SFR \sim 140\ M_\odot/yr$, $A_V \sim 2.5$ mag (from Balmer decr.)

Fig3: Fitting to the GMOS spectrum + archived photometry. →

- Young Stellar Population (YSP)
  - $M_{YSP} \sim 10^{9.9} M_\odot$, $SFR \sim 400\ M_\odot/yr$ ($SFR_{IR} \sim 450$)
- Old Stellar Population (OSP)
  - $M_{OSP} < 10^{11}\ M_\odot$

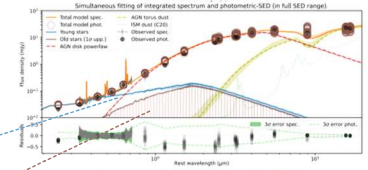



**Figure 3.** Best-fit results of the simultaneous spectrum+SED fitting (Section 3.2) for observations of the entire galaxy in the wavelength range of the spectrum (top) and all used SED data (lower-middle; rest-frame 0.2–20 μm) with their fitting residuals, respectively (upper-middle and bottom panels). Black dots and brown open circles denote the photometric data and the best-fit models, respectively. The legends of models are the same as those used in Figure 2. The AGN torus model is denoted in yellowgreen dashed curve. Shaded areas show the 25%–75% uncertainty ranges from Monte Carlo simulation for each component. The unconstrained old stellar population is shown as a 1$\sigma$ upper limit (brown hatched; Section 4.2). The best-fit ISM dust model of J2048 from Chen et al. (2020) is shown in green dotted line as a reference. Note that all the residuals in the upper-middle and bottom panels are shown in unit of $F_\lambda$ ($10^{-16}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$) for the sake of illustration. The scatters reflect the fitting residuals of the original and mock data of the spectra (grey curves) and photometric points (black dots). Modified errors (to reflect the calibration errors) are shown in green shadow region and dashed lines.

## ☐ Properties of the central region of the galaxy, and Comparison with $z$>4 LRDs

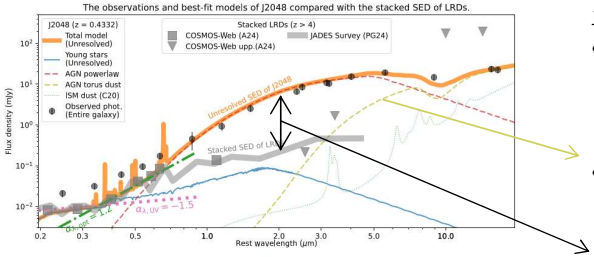
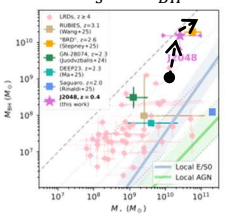



**Figure 4.** Best-fit models of the simultaneous spectrum+SED fitting for J2048 in the unresolved ($r < 2$ kpc) region of J2048. The unresolved SED (orange thick line) is obtained by subtracting the best-fit models of the extended outskirt region (Figure 5 and A3) from the best-fit SED of the entire galaxy (Figure 3). The best-fit power-law models for the unresolved SED are shown in purple dotted (UV, < 3500 Å) and green dash-dotted lines (optical, 4000–6500 Å), respectively. The stacked SED of LRDs in JADES (Pérez-González et al. 2024) and COSMOS-Web surveys (Akins et al. 2024) are shown in grey thick curves and squares, respectively; the upper limits of LRDs in COSMOS-Web survey are shown in grey triangles. All stacked SED are normalized to 0.01 mJy at rest 3000 Å for a direct comparison of the unresolved SED of J2048 and high-$z$ LRDs.

← Fig4: SED of the central (unresolved) region.

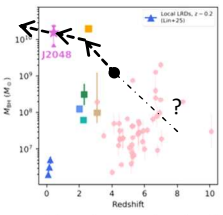
- Rest UV-optical SED
  - is dominated by young stars.
  - shows V-shape continuum.
  - → blue UV is formed by star formation, not AGN.
- Rest MIR (AGN dust torus) is detected.
  - Too faint to be detected at $z$>4.
  - Consistent with non-detection for high-$z$ LRDs.
- Redder than $z$>4 LRDs.
  - Due to higher extinction ($A_{V,PL} \sim 6.3$).
  - → JWST may miss such highly obscured AGNs at $z$>4.

$M_s$ vs. $M_{BH}$



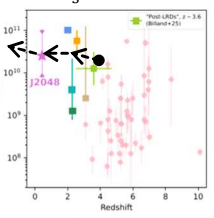

- J2048's BH is 100x massive than the local E/S0 relation.

$M_{BH}$ evolution




- Already massive ($z$>4)
- Further growth (via mergers?) ($z$~2)
- Still grows (super Eddington) ($z$~0.4) →

$M_s$ evolution




- Slow growth ($z$>4)
- Quenched ($z$~2)
- Starburst ($z$~0.4)

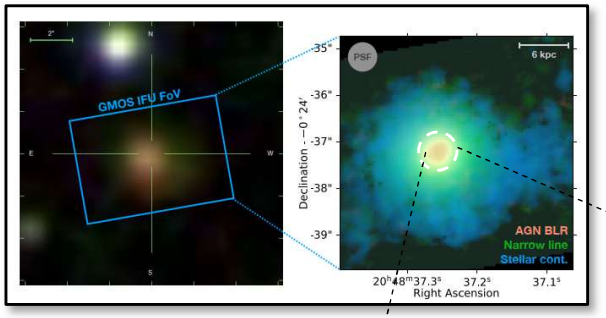
↓

Terminated soon due to the strong outflow.

← Fig6: Mass growth.

- Evolution scenario: "early and rapid BH growth" and "suppressed stellar buildup via outflow feedback" result in an overmassive BH.
  - J2048 is likely a descendant of massive $z$>4 LRDs.
  - The growth of $M_s$ was probably suppressed by AGN feedback and mergers at $z$~2, resulting in very high $M_s/M_{BH}$ ratio at $z$~0.4.
- The host cannot increase $M_s$ sufficiently (100x) from z=0.4 to 0.
  - → J2048 will not reach the local relation.

J2048 provides insight into early galaxy/BH evolution.




## Narrow emission lines

- [OII], [OIII], Hβ, Hα, [NII], [SII]
- $A_V \sim 2.5$

## Outflow #1

- [OII], [OIII], Hβ, Hα, [NII], [SII]
- $A_V \sim 3.9$

## Broad emission line

- Hα
- $A_V > 6$

## Power-law continuum from disk

- $A_{V,PL} \sim 6.3$
- Attenuated by dust outside the torus.

## NIR/MIR emission from torus

- J2048 (or LRDs) may have a thinner torus than typical?
- → MIR emission becomes weak?