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Lord of LRDs: Insights into a "Little Red Dot" with a low-ionization spectrum at $z = 0.1$

Xihan Ji,[1,2★] Francesco D'Eugenio,[1,2] Ignas Juodžbalis,[1,2] Dominic J. Walton,[3] Andrew C. Fabian,[4] Roberto Maiolino,[1,2,5] Cristina Ramos Almeida,[6,7] Jose A. Acosta Pulido,[6,7] Vasily A. Belokurov,[4] Yuki Isobe,[1,2,8] Gareth Jones,[1,2] Claudia Maraston,[9] Jan Scholtz,[1,2] Charlotte Simmonds,[1,2] Sandro Tacchella,[1,2] Elena Terlevich,[10,11,12] Roberto Terlevich[10,4,11]

1. Introduction

Little Red Dots (LRDs)

- Found at z>5 (rapid decline at z<4)
- V-shaped spectral turnover near Balmer limit (~3600A)
  => local early-type galaxy/SMBH cannot reproduce
- Compact size ~100-300pc

Possible explanations :

(1) massive/compact stellar populations
=> resulting in 1e9-10Msun, too massive and cannot explained by lambda-CDM framework / stellar mass density too high (1e5-6Msun/pc^2)
=> Continuum may be dominated by AGN accretion disc?
(2) gas-obscured accretion disc of AGN
(3) accretion disc of AGN obscured by special dust
(4) emission from extended, gravitationally unstable accretion disc of AGN
…

- High-column density and dense gas is ubiquitous in early z>2 gAGNs (Maiolino+24b)
- LRD makes up ~30% of AGN (Hainline+25)
- Many of LRDs show broad Balmer emissions (>1000km/s)
- Weak X-ray emission, without no high-ionization emission lines
- Weak/no variability
- ~20% show non-stellar strong Balmer absorption

⇒ High column density gas (N_H>1e24/cm^2) ?
⇒ Super-Eddington accretion?

Observationally difficult due to their high-redshift

⇒ low-z : three z~2 LRDs spectroscopically confirmed
⇒ Lin+25b : z<0.4 GPs with broad-line AGNs
  - 6/19 have V-shaped UV-optical continua
  - However they show
    * turnover point not close to Balmer limit
    * strong [NII]
    * No Balmer absorption
    * strong HeII 4686 which is not detected in LRDs

2. Spectroscopic and Photometric Data

Lin+25a : two z=0.1-0.2 local BL LRDs
=> SDSSJ1025+1402 :

- Identified in Izotov+07 broad-line dwarf galaxy catalog
- V-shaped turnover near Balmer limit
- Halpha absorption
- Point source like morphology
- Metal poor (<0.1Zsun)
- high ionization lines are weaker than typical Seyferts
- Stable lightcurve, small variability in Halpha

Data

- Archival : SDSS and Gemini-N optical spec. data
- GTC OSIRIS Spec.
- Chandra archive, NuSTAR DDT : no-detection
- Photometric points from GALEX FUV to WISE W4

3. Spectral Measurements

- Hbeta absorption is redshifted/Halpha blueshifted => they have independent kinematics
- Absorption pattern cannot reproduced by stellar population
- Weak FeII lines are identified, like high-z LRDs
- Three Halpha emission components (92, 727(NB), 2050 (BB) km/s)

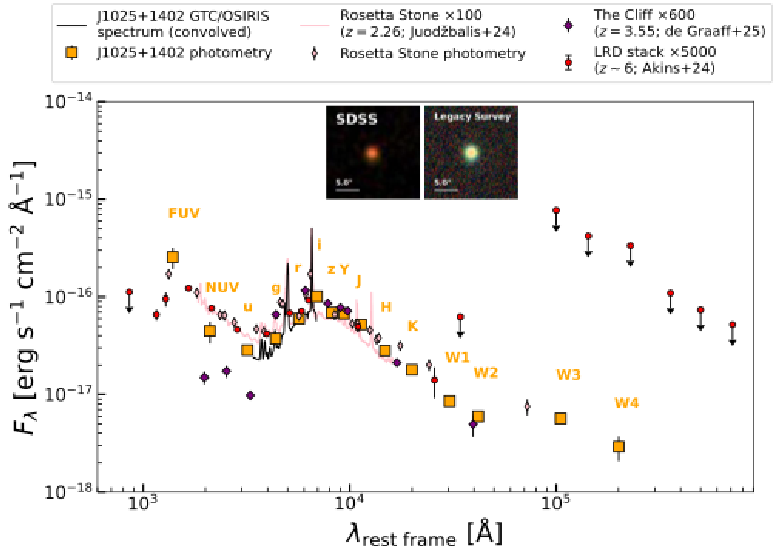

Figure 1. Comparison between the spectrophotometric SEDs of J1025+1402, the Rosetta Stone (one of the lowest-z LRDs discovered by *JWST* at $z = 2.26$, Juodžbalis et al. 2024a), the Cliff (one of the LRDs showing the strongest Balmer break at $z = 3.55$, de Graaff et al. 2025), and the median stack of the

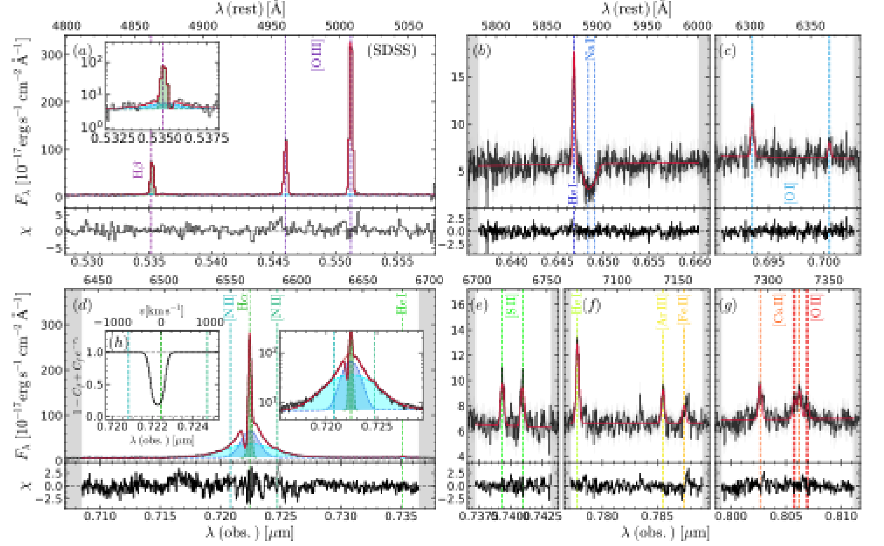

Figure 2. Best-fit spectral models for part of the observed spectra of J1025+1402. *Panel (a)* SDSS spectrum around Hβ and [O III], where Hβ has a narrow component, a broad component, and a redshifted absorption (modelled with Equation 1) shown in the zoomed-in panel. Panels (b) and (c) Gemini/GMOS spectrum around He I, NaD, and [O I], where NaD is modelled as an absorber with kinematics independent of narrow emission lines. *Panel (d)* Gemini/GMOS spectrum around Hα, [N II], and He I, where Hα has a narrow component, a broad component (modelled as a double-Gaussian function), and a blueshifted absorption shown in the zoomed-in panel. *Panels (e), (f), and (g)* Gemini/GMOS spectrum around [S II], He I, [Ar III], [Fe II], [Ca II], and [O II]. [Fe II] and [Ca II] show different line profiles compared to other narrow lines, suggesting that they come from a different region.

4. Comparison with high-z LRDs

Photometry

- Stronger MIR constraint than high-z LRDs
- Re<620pc
- M*=1e10Msun => >1e3.5Msun/pc^2, high density : stellar mass overestimated?

Spectrum

- shows similar shape around Balmer limit with a z~2 LRD

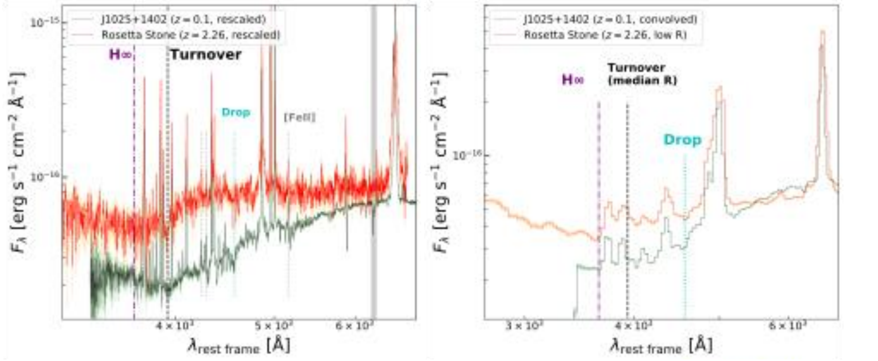

Figure 5. Comparison between the UV-optical spectra of J1025+1402 and the high-z LRD, the Rosetta Stone, at $z = 2.26$ (Juodžbalis et al. 2024a). *Left:* the

5. Emission Line and Absorption Line Diagnostics

5.1 Blackhole parameters

- No NB, BB components in [OIII] => n_e>1e7 cm^-3 for BB and NB => NB, BB are BLRs
- Av_BLR=5.2
- MBH=1e6.47Msun => 1e7.22Msun (dust corr)
- lambda_Edd=0.25 => 1.40 (dust corr)

5.2 Gaseous environment

- Low N2/Ha, S2/Ha => low metallicity SFR, no NLRs
  => soft EUV spectrum
- 0.11Zsun : Below MZR
- Should be Fe poor, but rich [FeII] emission observed (Fig 9)
- Fe2 4245/5159 => nH~1e7.5cm^-3 (Fig10) => stratified NLR?
- Ha abs : -62km/s, Hb abs : +100km/s, NaD abs : -50km/s
  => Ha, NaD in outflow?

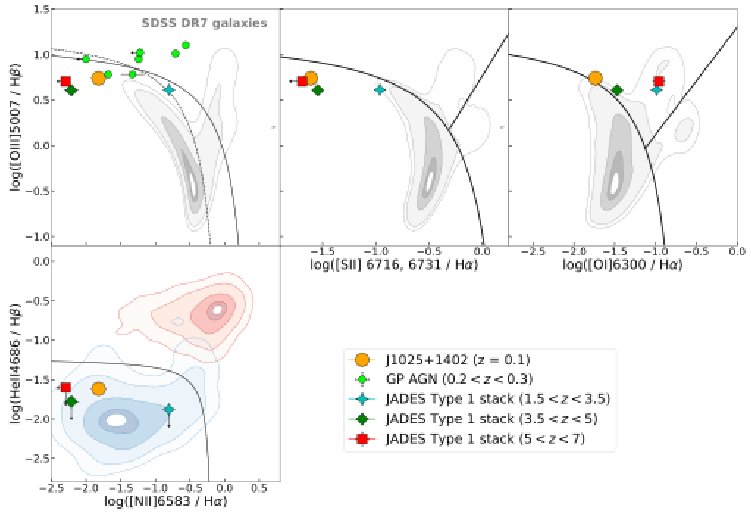

Figure 7. Locations of J1025+1402 in four optical diagnostic diagrams. In comparison, we show SDSS DR7 galaxies with S/N > 5 for all lines involved as

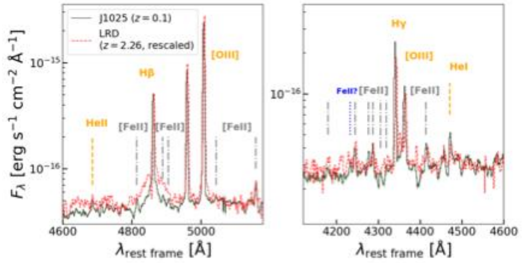

Figure 9. Comparison between the GTC/OSIRIS spectrum of J1025+1402 and the rescaled JWST/NIRSpec G235M spectrum (R ~ 1000) of the Rosetta Stone.

6. Interpretation of the SED

6.1 Cool optical

- Red continuum, peas around Ha
- Various absorption => cannot reproduce with stellar (G-K type)
  Balmer, NaD, CaK, G-band, Mgb
- Low ionization potential for absorption lines => cool temperature
- Recent model of hi-z LRD : AGN accretion discs and BLRs obscured by dense neutral gas (n_H~1e10-11 cm^-3)

6.2 Missing X-ray (Fig 14)

- L_2-10keV < 7e41erg/s (3-sigma)
- L_10-30keV < 1e42 erg/s (3-sigma)

⇒ Extremely x-ray weak

⇒ Compton thick, N_H>1e24cm^-2

6.3 Extreme FUV

- Only available in 3 phot. Points
- beta_NUV-u=-1.1
- Beta_FUX-NUV=-4.2 !
  => cannot reproduced by emission-line contamination
  => dust-free thick neutral gas can reproduce, but unwanted Balmer break occurs (Fig 17)
- No preferrable model exists at the moment

6.4 Low MIR emission

- CIGALE SED fif (Fig 18)
- Blue AGN model fits the best, but unwanted Baler break occurs
- M*=1e10Msun, 2Gyr stellar population (assuming the continuum is dominated by stellar component)

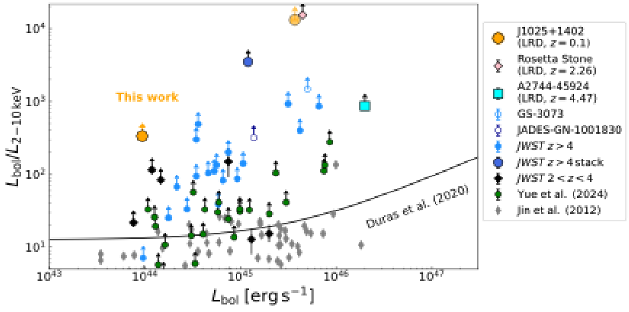

Figure 14. Comparison between the nominal bolometric luminosities and the bolometric-to-X-ray luminosity ratios for different samples of broad-line AGN.

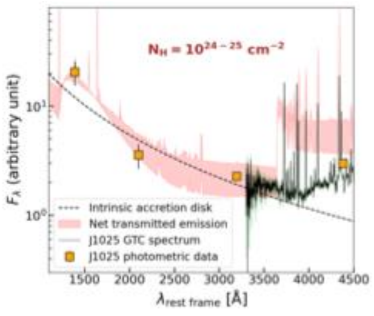

Figure 17. Photoionization model of a gas-enshrouded accreting black hole.

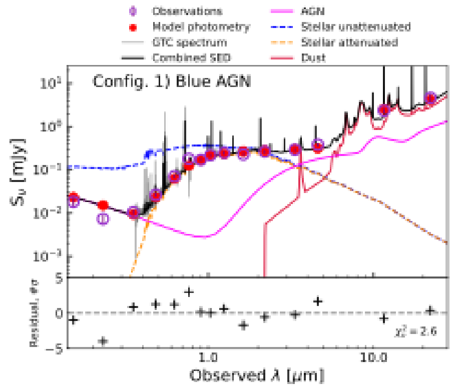

Figure 18. Best-fit CIGALE SED models for J1025+1402 from FUV to MIR,

7. Discussion

7.1 Stellar mass of the host galaxy

- Chemically richer than hi-z weak-line LRD.
- Overmassive on MZR
- Dynamical mass from emission line width : <8e9Msun
  <= smaller than M* from SED fit, same trend observed in hi-z LRDs

7.2 Total energy budget

- From Balmer line Inferred Lbol~1e45 erg/s (Av=5.2) or 9e43 (Av=0)
- L_FUV-MIR~6e43 erg/s favors no-extinction

=> Ha/Hb>20 may be caused by collisional excitation

=> Consistent with observed Paschen decrement which is smaller