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DETECTING VARIABILITY IN JWST'S 'LITTLE RED DOTS' WITH GRAVITATIONAL LENSING

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Abstract. The new category of extremely red high-redshift sources, discovered by JWST, known as "Little Red Dots" have raised much interest in the community over the past few years and sparked many debates as to their nature, if they are powered by active galactic nuclei (AGN), or rather by star-formation. We here use the time-delay information induced by strong gravitational lensing in the multiply-imaged LRD at $z = 7.04$ known as A2744-QSO1 to probe its emission for variability, a tell-tale sign for AGN activity. We find both broad Balmer lines detected with JWST (Hα and Hβ) to display significant variability, consistently by 20 %, over a time of 875 d (2.4 yr in the rest-frame). This clearly shows this LRD, and thus probably others as well, to indeed be AGN and is consistent with the latest LRD AGN models.

Keywords: gravitational lensing: strong, galaxies: high-redshift, quasars: emission lines, quasars: supermassive black holes, quasars: individual: A2744-QSO1

1 Introduction

Ever since their first detection, JWST's (Gardner et al. 2023; McElwain et al. 2023) "Little Red Dots" (LRDs; e.g. Kocevski et al. 2023; Furtak et al. 2023a; Matthee et al. 2024; Labbé et al. 2025; Greene et al. 2024), a new category of extremely red point-sources at $z \gtrsim 4$, have sparked much attention and debate in the high-redshift community. With several hundreds of LRDs known to date (e.g. Kokorev et al. 2024; Kocevski et al. 2024), ranging from the local Universe (e.g. Lin et al. 2025) to the highest redshifts (e.g. $z = 9.3$; Taylor et al. 2025), there has been a heated debate whether LRDs are powered by an accreting supermassive black hole (e.g. Furtak et al. 2024; Greene et al. 2024; Rusakov et al. 2025) or rather over-dense star-formation (e.g. Pérez-González et al. 2024; Baggen et al. 2024). Since typical type 1 active galactic nuclei (AGN) are know to vary (e.g. Matthews & Sandage 1963; Kelly et al. 2009), the detection of variability in LRDs could represent one way to shed more light onto their nature. So-far, several studies have been conducted and found no evidence of significant photometric variability in LRDs (Kokubo & Harikane 2024; Zhang et al. 2024; Tee et al. 2025).

In this work, which was published in Furtak et al. (2025), we leverage the relative time delay induced by strong gravitational lensing (SL) between the three images of the only multiply-lensed LRD detected to date, A2744-QSO1 (Furtak et al. 2023a, 2024) at $z = 7.04$, to search for variability. According to the latest SL model of the SL galaxy cluster Abell 2744 (Furtak et al. 2023b; Price et al. 2025), the time-delays between the three images span 22 yr (2.7 yr in the rest-frame). This gives us a much longer base-line to study LRD variability than the $2 - 4$ yr probed by multi-epoch observations of blank fields.

2 Detection of significant variability in A2744-QSO1

We use the *Ultra-deep NIRSpec and NIRCam ObserVations before the Epoch of Reionization* (UNCOVER; Bezanson et al. 2024) JWST spectroscopy of A2744-QSO1, taken with the *Near Infrared Spectrograph* (NIRSpec; Jakobsen et al. 2022; Böker et al. 2023) and published in Price et al. (2025), to search for variability in the broad Hα and Hβ lines. We find the equivalent width (EW) of both lines to consistently drop by 18 ± 3 % and 22 ± 8 % respectively between images C and A, i.e. over a time of 2.4 yr in the rest-frame. A similar result

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was independently found by Ji et al. (2025), which confirms our findings. Together, these measurements clearly show that LRDs, and this object in particular, are indeed AGN.

We also investigate the LRD in question for broad-band photometric variability, but do not find any significant detection, similar to previous works. According to AGN variability simulations that we run especially for this source (Secunda et al. 2025), this is however to be expected given the relatively low rate of sampling the light-curve employed both here and in other LRD variability studies. This means that the absence of photometric variability so-far does not rule-out an AGN nature for LRDs (Secunda et al. 2025).

Our findings are consistent with the latest models for LRDs, the so-called black-hole star (BH*; Naidu et al. 2025; de Graaff et al. 2025) model, of a super-massive black hole enshrouded in a dense cocoon of turbulent hydrogen gas. Deeper investigation of LRD variability will require large numbers of epochs of observation to frequently probe the light-curve. Ultimately, we might be able to perform reverberation-mapping for multiply-imaged AGN and LRDs thanks to the SL time-delays as explored in theory in Golubchik et al. (2024).

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