Peer Review File

Manuscript Title: A dusty, compact object bridging galaxies and quasars at cosmic dawn

Reviewer Comments & Author Rebuttals

Reviewer Reports on the Initial Version:

Referee #1 (Remarks to the Author):

This paper is focussed on GNqz7-J1236, a clearly unusual object with an observed redshift of z ~ 7.2, which is hence seen as it was when the Universe was just ~750 Myr old. The paper presents a wide range of data on this object, in particular using comparisons with other known populations (mainly at lower redshifts) to investigate its true nature.

Most of the paper adopts the interpretation that GNqz7-J1236 is a low-luminosity quasar/AGN hosted by a massive star-forming galaxy, an interpretation that is consistent with much of the available data. This would make GNqz7-J1236 particularly interesting, as it would then be the first high-redshift object seen bridging the "gap" between ordinary galaxies and those with active nuclei. The quasar model is not, however, the only reasonable interpretation of the data presented, which are at least as consistent with the less interesting alternative that GNqz7-J1236 is "just" a luminous star-forming dusty galaxy. As most of the subsequent analysis would be rendered moot if this second interpretation were to be confirmed subsequently, the most important thing to assess about this paper is the degree to which this analysis is speculative as opposed to being on a solid footing. Several different observations are relevant here:

1. The authors state that the presence of "broad Ly alpha and CIII] emission line features" indicates GNqz7-J1236 is a quasar; but the spectrum shown in Figure 1 does not justify such a strong statement, with only marginal evidence for these emission lines. It would be useful to see the data "as is", without the comparison spectra which inevitably lead the eye, particularly around CIII]. As the comparison object is presumably more luminous, it would have a more massive black hole and hence broader lines that would be plausible here even adopting the quasar model, so the apparent match around CIII] in particular is potentially misleading. What would be the expected CIII] line shape for the proposed black hole mass for GNqz7-J1236, and how would this compare with the data?

2. Stronger evidence for the quasar interpretation is the high infrared flux, and particularly the F_24/F_8 flux ratio shown in Extended Data Figure 1, which is inconsistent with the presented galaxy models at least. But this is effectively a photometric selection of the type used by previous authors to identify this object as high-redshift, and notoriously vulnerable to over-interpretation of outliers. Moreover, the application of such a technique to redshift ~7 from redshifts of 1-3 is a significant

extrapolation, as flux ratio shown in the vertical axis here is roughly equivalent to that in the horizontal axis for the sample Ivison et al. (2004, ref. 38) use to motivate this classification method.

3. The degree to which the infrared flux argues against a standard galaxy SED appears weaker than the level to which non-detection in X-rays (given the deep Chandra data in this field) is inconsistent with GNqz7-J1236 being a quasar or AGN (as shown in Extended Data Figure 2). The more straightforward interpretation of the lack of X-ray emission is that this object does not have an AGN at its heart.

(4. There is also mention of the fact that no such quasar, even this faint, would be expected in such a small area at these redshifts, which prima facie again argues against this interpretation; although the numbers behind this are an extrapolation from brighter Type I quasars, so if this were a fainter Type II quasar this wouldn't necessarily represent a contradiction. Given the amount of data available on this particular object, such population-level arguments are less important.)

Taken together, the above certainly confirm GNqz7-J1236 as an interesting or unusual object, but do not justify its confident interpretation as a quasar, hence putting much of the subsequent statements in the paper on an overly-conditional basis. This remains a genuinely interesting discovery, and it would be reasonable to expect that this object will be the subject of significant further observational campaigns. As such, I think it would be more appropriate for this paper to appear in a high-profile specialist journal (e.g., ApJ Letters) until its nature can be established with greater certainty.

Minor points:

- Page 1, last line: "infer" should be "imply".

- Figure 1: There s a clear detection in F850LP postage stamp, which is seemingly inconsistent with the spectrum in this wavelength range (although it is a bit hard to tell given that the legend obscures some of the data points in the spectrum). Related to this, it might be helpful to indicate the approximate wavelength range for each filter, rather than just a point, as F850LP is particularly broad. It's also a bit strange to refer to a "Lyman break at z = 7.23 +/- 0.05": the break is at a certain wavelength, not a redshift.

- Extended Data Table 1: Rather than (or in addition to) publishing 3-sigma upper limits for the Herschel and other bands with non-detections, it would be more useful to report the actual measured value, as in the case of the bluer HST bands. That said, Figure 2 suggests that these measurements aren't really meaningful for this source, as the plausible fluxes in these bands are so far below the Herschel detection limit.

- Extended Data Figure 1, caption: "doted" should be "dotted".

Referee #2 (Remarks to the Author):

Firstly I would like to apologise to the editors and authors for the delay in submitting this review.

This is a very interesting result that provides a pathway to better understanding the early stages of galaxy evolution, specifically addressing early black hole growth. However, I do not think it merits publication in Nature. Many of the main results highlighted in the main article are based on approaches that are not necessarily correct and are not clearly motivated and explained by the authors. This brings into question how strong the conclusions of this work can really be. However, if my recommendation is not followed and the editorial office considers the article merits publication in Nature, there are a number of improvements that need to be taken into account before publication. Below I give my responses to the guideline questions for the assessments of the manuscript.

———Key results———

In this article the authors present the discovery of a possible transitional (red) quasar (GNqz7-J1236) at a redshift of ~7.2. Although this is not the highest redshift at which a quasar has been discovered, this is the first detection of a red quasar at these redshifts. The redshift of the quasar is spectroscopically confirmed for the first time in this paper. The quasar is reported to have an under-massive black hole mass of 10^7 M_sol and a super-Eddington accretion rate, based on its X-ray weakness. Multi-band photometry in combination to new deep mm-observations of the continuum and [CII] emission with NOEMA, allow for the definition of the uv—mm spectral energy distribution (SED). The SFR is estimated at 1600 Msol/yr, with dust and gas masses of 1.6x10^8 Msol and 2.0x10^10 Msol respectively. Comparison to a galaxy evolution semi-analytical model suggests that GNqz7-J1236 could be a direct progenitor of luminous unobscured quasars at later epochs.

———Validity———

One major flaw in this paper is the lack of a clear definition of the classification given to the quasar GNqz7-J1236. This quasar is defined/categorised as a red quasar, and although still a type 1 quasar is referred to as obscured in several cases throughout the paper. However, a clear definition of a type 1 red quasar (and blue quasar that is mentioned in the first paragraph) is lacking. Furthermore, there is no clear comparison of the differences between red quasars, typical unobscured (type 1) quasars, and obscured quasars/AGN (type 2), and how these all fit together. Instead, when calculating estimates of BH mass and Eddington ratio the authors use relationships of typical unobscured luminous quasars that are not necessarily comparable to the red quasar of this paper. Later on in their interpretation of their results the authors compare their red quasar properties to those of a highly obscured AGN (ref. 18), which is not a type 1 quasar and again is not necessarily accurate comparison for the aims of this study.

———Originality and significance———

Based on my knowledge of recent publications in this field, this is an original study presenting new data on the source GNqz7-J1236, in combination with older reprocessed data. The source GNqz7-J1236 and the results presented in this study will be of significant interest in the field of extragalactic astronomy, as it presents a new aspect of z>6 quasars and early BH growth. However, I expect some of the results and methodologies to be questioned (at least for the current version of this work).

———Data & Methodology———

>Quality of data:

The authors present new deep observations of GNqz7-J1236 with NOEMA at 1 and 3mm, with both continuum and [CII] and CO(7-6) emission being detected. Additional lines were covered in these observations providing upper limits for CO(6-5) and [CI](2-1). In addition to the NOEMA observations the authors use photometry from X-ray to radio. As GNqz7-J1236 is in the GOOD-N/CDF-N field it benefits from high quality deep surveys across the spectral range covered by this study.

Overall, the data is of a sufficient quality. However, it should be noted that the spatial resolution is significantly different between the different data used. The NOEMA observations have beam sizes of 0.64”x0.44” and 4.7”x4.1” at 1mm and 3mm respectively, while the beam sizes for observation in other instruments such as Spitzer/MIPS and SCUBA2 are significantly larger. This is not clearly addressed by the authors, and some discussion on this is necessary especially when combining such photometry to perform SED analysis.

>Validity of approach:

There are a few main points to this paper that rely heavily on the methodologies used. For some cases the approaches used are either flawed or have not been explained and motivated thoroughly enough. I outline them below:

- Although allot of weight is put on the X-ray faint emission of this source, and some properties are estimated based on it. The actual photometric upper limit is not clearly stated. The authors assume a photon index of 2.0 to calculate the rest-frame 2-8keV luminosity upper limit, but they do not motivate this choice and do not provide the equation used for the estimation.

- The authors use the X-ray luminosity upper limit to estimate the Mbh and Eddington ratio by comparing to the correlation between the optical to x-ray spectral index (a_ox) and Eddington ratio. This correlation is defined based on quasars at local and high-z; however, these sources are not classified as red quasars, GNqz7-J1236 is significantly under luminous in both optical and X-ray in comparison to them, and therefore it is not clear why it is expected that this correlation will be valid for a source like GNqz7-J1236 . The authors say: " we obtain an Eddington ratio greater than unity at a 5sigma level", It is not clear what this means, and how the 5sigma level is defined. No further information on this is provided in the Methods section.

-On the same note, there is no clarification as to how the Mbh was calculated from the optical luminosity. And why the X-ray estimate is preferred over the optical.

-SFR estimates are subject to the IMF assumed. The authors have not clarified which IMF is used in their estimates. Furthermore, when comparing between different populations it is important to make sure that the IMF assumptions are consistent between populations.

-Size estimates of the mm and [CII] emission are presented in the main article. However, the details presented in the Methods section show that not only are these estimates significantly smaller than the observed resolution, begging the question as to how they could be defined, but also the estimate of the radius for the 1.3mm continuum is estimated at 0.07" with an error of 0.44". This highlights that this estimate should not be used, and the upper limits on the effective radii of the emission need to be redefined.

-SED fitting: HST data shows multiple nearby objects at a radius of 2". Considering how much of the photometry used in the MIR—mm have a lower resolution than that, how are the authors confident that they are comparing like to like when combining the photometry for the SED analysis and that these nearby objects are not contributing to the observed emission.

>Quality of presentation:

The data and methodology are not sufficiently detailed to allow for

reproducibility of the results. The methods followed and comparisons made are not always clearly motivated and explained. The article itself does not present the results in a concise and easy to follow way, but seems to jump back and forth between topics. For example the redshift is presented early on based on the optical data from HST, but later on in the article the value of the redshift is revised based on the NOEMA. It would be better to have a clear definition of the redshift at the beginning using both the HST and NOEMA data, before moving on to the other aspects of the source. Same applies when presenting the X-ray results etc.

———Appropriate use of statistics and the treatment of uncertainties———

Errors are not always clearly indicated (with error bars) in the figures, and in certain cases the authors have purposefully ignored large uncertainties when referring to estimated values in the main article.

———Conclusions———

Based on the points I have outlined previously, I do not find the conclusions to be robust and reliable.

———Suggested improvements———

To improve this manuscript the authors will need to address the points brought up earlier on the validity of some of the methods used. Significant improvement is further needed in providing the detailed information needed to make the results reproducible. Furthermore the methodologies and comparison samples need to be sufficiently motivated.

Another important point for improvement is the presentation of the red quasar classification, how it fits in to the different types of AGN populations, and making sure comparisons made are to similar types of sources in the literature or otherwise clearly motivated sources for comparison (see point in section “Validity”).

———References———

Considering the source presented here is classified as a red quasar, there is a lack of references to studies on such objects at high-redshifts.

———- Clarity and Context ———

The abstract is not as clear and accessible as it could be, mainly due to the use of specifications such as blue and red quasars that are not clearly defined. When it comes to the rest of the article, again the lack of a clear definition of red quasars set in the context of other AGN populations and galaxy evolution, and the comparisons to different types of sources for different aspects of the conclusions the authors want to reach, makes the article hard to clearly assess and follow.

Author Rebuttals to Initial Comments:

We thank the constructive comments from the expert referees in the review. We are glad to read that both referees acknowledge the importance of the result, while we also understand that some of our arguments were not clearly explained, a communication failure on our part. We have revised our manuscript, following the recommendations and suggestions of the referees. For easy review, our revised texts in the manuscript is shown with blue texts, and we assign numbers of [1.X] and [2.X] for each response to the comment from the referee #1 and #2, respectively. For a few additional revisions, we assign another number of [3.X].

> Referees' comments:

> Referee #1 (Remarks to the Author):

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> 1. The authors state that the presence of "broad Ly alpha and CIII] emission line features" indicates GNqz7-J1236 is a quasar; but the spectrum shown in Figure 1 does not justify such a strong statement, with only marginal evidence for these emission lines. It would be useful to see the data "as is", without the comparison spectra which inevitably lead the eye, particularly around CIII]. As the comparison object is presumably more luminous, it would have a more massive black hole and hence broader lines that would be plausible here even adopting the quasar model, so the apparent match around CIII] in particular is potentially misleading. What would be the expected CIII] line shape for the proposed black hole mass for GNqz7-J1236, and how would this compare with the data?

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> (4. There is also mention of the fact that no such quasar, even this faint, would be expected in such a small area at these redshifts, which prima facie again argues against this interpretation; although the numbers behind this are an extrapolation from brighter Type I quasars, so if this were a fainter Type II quasar this wouldn't necessarily represent a contradiction. Given the amount of data available on this particular object, such population-level arguments are less important.)

> Taken together, the above certainly confirm GNqz7-J1236 as an interesting or unusual object, but do not justify its confident interpretation as a quasar, hence putting much of the subsequent statements in the paper on an overly-conditional basis. This remains a genuinely interesting discovery, and it would be reasonable to expect that this object will be the subject of significant further observational campaigns. As such, I think it would be more appropriate for this paper to appear in a high-profile specialist journal (e.g., ApJ Letters) until its nature can be established with greater certainty.

[1.1]
We think that there is no doubt that this object is a quasar: the UV emission is a bright point source as detected by Hubble and has far too high a surface luminosity to be a star-forming galaxy.

The SNR in the Hubble images are very good (~100 at the peak in F125W, for example), showing a point-source morphology in all bands, and from our fits to the radial profile, we can constrain the effective radius of the UV emission very well (as described in the revised Method Section 3 and Extended Data Figure 1). We find the effective radius is less than 70pc at 3sigma upper limit. At the same time, although the source is much fainter than typical quasars, the source is still quite luminous, ~1.5 mag more luminous than the bright Lyman-break galaxies so far spectroscopically confirmed at z > 7 (e.g. Bowler et al. 2017, MNRAS, 466, 3612) with the apparent F160W magnitude of 23.09+/-0.05 ABmag. The absolute UV magnitude is between -27.4 and -30.0 ABmag after dust correction, depending on whether we use a steep or flat dust law (SMC extinction or Calzetti, respectively). That means that its surface luminosity density reaches 5e14 to 7e15 Lsun/kpc^2, corresponding to a surface SFR density of between 2e5 and 2e6 Msun/yr/kpc^2 (!). This is 2 to 3 orders of magnitude above the Eddington limit for star-forming systems (Andrews & Thompson 2011, ApJ, 727, 97; see also e.g., Simpson et al. 2015, ApJ, 799, 81; Hodge et al. 2019, 876, 130; Pereira-Santaella et al. 2021, A&A in press, arXiv2104.08238). So we believe that there is no doubt that this object is a quasar.

To clarify these properties and the quasar interpretation of GNqz7-J1236, we have revised the 2nd paragraph in the main article and newly added Method Section 3 gDefinition of quasar category and classification of GNqz7-J1236 h and Extended Data Figure 1. We would also answer the four specific points proposed by the referee below.

[1.1.1] broad Lya and CIII] emission lines
It is true that the broad Lya and CIII] lines are tentative. Quantitatively, if we perform the power-law fitting to the rest-frame UV continuum with the G141 grism spectrum, we find that the significance levels of the broad Lya and CIII] line features are 3.7sigma and 3.4sigma levels. Here, the wavelength range where the line is potentially detected is not included in the fitting. To clarify that Lya and CIII] line features are tentative and that the quasar interpretation is mainly based on the bright UV emission with the point-source morphology (see the response of [1.1]), we have revised the 1st and 2nd paragraphs of the main article and the 3rd paragraph of Method Section 2.

Regarding the expected CIII] line shape, the line profile also largely depends on the total line luminosity and the velocity center, where the CIII] line is often blue-shifted from the systemic redshift due to the nuclear outflow (e.g., Meyer et al. 2019, MNRAS, 487, 3305). Besides, there is a possibility that powerful outflows broaden the broad line (e.g., Zou et al. 2020, MNRAS, 499, 2), and actually, this might be taking place in GNqz7-J1236, as it is often reported that such powerful outflows are observed in high-z red quasars (e.g., Finnerty et al. 2020, ApJ, 905, 16). We thus think that it is hard to make predictions on the expected CIII] line profile.

[1.1.2] MIR color
We agree that the previous manuscript was misleading, indicating that the strong evidence for the quasar interpretation was likely established from the bright 24 flux alone. As described in the response of [1.1], the bright and point-source UV properties sufficiently conclude that GNqz7-J1236 is a quasar. In this context, we believe that the MIR color properties would also be helpful to have an independent double-check for the interpretation. To clarify that the quasar interpretation is mainly based on the bright UV and point-source properties and that the MIR color properties are a supportive material for the interpretation, we have added clarifying text in the 2nd and 3rd paragraphs of the new Method Section 3.

Although it is true that the MIR color diagnostic based on 4.5um, 8.0um, and 24um flux densities is originally established for z~1-3 galaxies (e.g., Ivison et al. 2004), we believe that it is reasonable to revisit and redefine the possible color ranges in the diagram for each population at e.g., z =5-8 and make use of it to understand the source properties at z = 7.2, as far as different populations are separated in the diagram beyond the color errors of the target. We find that the color tracks of Type 1 quasar and star-forming populations are sufficiently separated in the diagram at z=5-8 (see Extended Data Fig. 2). To clarify that we have indeed redefined the possible color ranges of the populations at z=5-8, instead of using the same color criteria in the z=1-3 case, we have revised the manuscript in the 3rd paragraph of the new Method Section 3. To increase the completeness of the diagnostic, we have added 12 additional color tracks from star-forming templates, generated by the photometric redshift estimate code, EAZY (Brammer et al. 2008, ApJ, 686, 2) in Extended Data Fig. 2. We confirm that the EAZY templates for galaxies show the possible MIR color ranges similar to the local star-forming galaxy templates.

[1.1.3] X-ray faintness
Please see the response of [1.1].
Please note that similarly X-ray weak quasars are reported to be abundant among weak emission line quasars (rest-frame EW(CIV) < 16 ð; e.g., Luo et al. 2015, ApJ, 805, 2; Pu et al. 2020; ApJ, 900, 2) with more powerful quasar feedback (Gibson et al. 2009, ApJ, 692, 758) in the intermediate redshift of z~1-3, which is consistent with the properties and interpretation of GNqz7-J1236 as a young transitioning-phase quasar (see also the 8th paragraph of the main article).

[1.1.4] Number density
GNqz7-J1236 is most likely to be classified as a Type 1 red quasar (see the response [2.1]), but it is true that comparing the derived number density with that of Type II quasar (although no one currently knows at this redshift) is also important to discuss the true abundance of the quasar population at z>7. But, we would like to evoke that GNqz7-J1236 is discovered despite its uniquely faint properties in optical, X-ray, and emission lines, owing to the exceptionally rich and deep multi-wavelength data of GOODS-N. Such a rich ensemble of the data is a very rare case in high-redshift quasar studies, given the limited number of filters and the shallowness of the data used in those studies generally relying on wide-area surveys. Therefore, regardless of the true quasar classification of GNqz7-J1236, the important point is that the discovery of GNqz7-J1236 suggests that the z>7 quasar population could be more abundant than what we currently know from typical Type 1 quasars alone. Although this unique discovery is a fruit of the uniform reprocessing of all archival HST and Spitzer data, we believe that this will lead to additional discoveries in the near future, enabled by the upcoming next-generation facilities such as the James Webb Space Telescope.

Minor points:

> - Page 1, last line: "infer" should be "imply".

[1.2]
We have corrected it.

> - Figure 1: There s a clear detection in F850LP postage stamp, which is seemingly inconsistent with the spectrum in this wavelength range (although it is a bit hard to tell given that the legend obscures some of the data points in the spectrum). Related to this, it might be helpful to indicate the approximate wavelength range for each filter, rather than just a point, as F850LP is particularly broad. It's also a bit strange to refer to a "Lyman break at z = 7.23 +/- 0.05": the break is at a certain wavelength, not a redshift.

[1.3]
We have revised Figure 1 by adding the filter passbands for F850LP and F105W. We have also revised the 2nd paragraph of the main article and the caption of Fig.1 to clarify that the Lyman break is taking place at the wavelength of ~ 1.0um, instead of z=7.23 +/- 0.05.

> - Extended Data Table 1: Rather than (or in addition to) publishing 3-sigma upper limits for the Herschel and other bands with non-detections, it would be more useful to report the actual measured value, as in the case of the bluer HST bands. That said, Figure 2 suggests that these measurements aren't really meaningful for this source, as the plausible fluxes in these bands are so far below the Herschel detection limit.

[1.4]
As the referee mentions, we placed the 3sigma upper limits from the literature rather than measuring the actual values, especially in the Herschel bands, since the values are likely dominated by the confusion noise in the Herschel bands, which could be misleading. Instead, we have replaced the 3sigma upper limit for the JVLA 3-cm band with an actual value that is not suffered from the confusion limit. We have revised the 1st paragraph of Method Section 5.

> - Extended Data Figure 1, caption: "doted" should be "dotted".

[1.5]
We have corrected it.

> Referee #2 (Remarks to the Author)
> Firstly I would like to apologise to the editors and authors for the delay in submitting this review.

> This is a very interesting result that provides a pathway to better understanding the early stages of galaxy evolution, specifically addressing early black hole growth. However, I do not think it merits publication in Nature. Many of the main results highlighted in the main article are based on approaches that are not necessarily correct and are not clearly motivated and explained by the authors. This brings into question how strong the conclusions of this work can really be. However, if my recommendation is not followed and the editorial office considers the article merits publication in Nature, there are a number of improvements that need to be taken into account before publication. Below I give my responses to the guideline questions for the assessments of the manuscript.

> \ \ \Key results \ \ \
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> \ \ \Validity \ \ \
> One major flaw in this paper is the lack of a clear definition of the classification given to the quasar GNqz7-J1236. This quasar is defined/categorised as a red quasar, and although still a type 1 quasar is referred to as obscured in several cases throughout the paper. However, a clear definition of a type 1 red quasar (and blue quasar that is mentioned in the first paragraph) is lacking. Furthermore, there is no clear comparison of the differences between red quasars, typical unobscured (type 1) quasars, and obscured quasars/AGN (type 2), and how these all fit together. Instead, when calculating estimates of BH mass and Eddington ratio the authors use relationships of typical unobscured luminous quasars that are not necessarily comparable to the red quasar of this paper. Later on in their interpretation of their results the authors compare their red quasar properties to those of a highly obscured AGN (ref. 18), which is not a type 1 quasar and again is not necessarily accurate comparison for the aims of this study.

[2.1]
A Type 1 quasar is defined to have at least one broad emission line (FWHM > 1000-2000 km/s) in the spectrum, while Type 2 quasars are defined by those that do not satisfy it, but has too bright emission lines, X-ray, or radio continuum for a galaxy. In the classical AGN unification models, this difference is generally explained by different viewing angles to the central accretion disks (e.g., Antonucci 1993, ARAA, 31, 473; Urry & Padovani 1995, PASP, 197, 803), where the observer fs lines of sights in Type 2 quasars penetrate through optically thick dusty materials that block the nuclear broad emission lines.

Red quasars are generally defined to have at least one broad emission line in the spectrum and thus be different from Type 2 quasars, but to be significantly reddened by dust. The red color threshold has been evaluated with optical, optical-MIR, NIR-radio, and MIR wavelengths (e.g., Richards et al. 2003, AJ, 126, 3; Urrutia et al. 2008, ApJ, 674, 1; Glikman et al. 2012, ApJ, 757, 51; Ross et al. 2015, MNRAS, 453, 4; Kato et al. 2020, PASJ, 72, 5). For example, Richards+03, Glikman+12, and Kato+20 identify high-redshift red quasars with the optical color excess threshold of E(B-V) >~ 0.1. Compared to Type 2 quasars that are almost completely obscured in the UV/optical due to the nearly edge-on view of the dust torus, the reddening of red quasars is more moderate than that of Type 2 quasars, where the sightlines to red quasars may graze the dust torus or may be obscured by the dust in the host galaxy. In this context, red quasars are thought to represent an early phase of the quasar life-cycle: an obscured phase before the energy output of radiation, winds, and/or jets from the AGN and central star-formation expels the obscuring material and transitions to an unobscured blue quasar. This is consistent with hydrodynamical simulations of galaxy mergers and quasar feeding (e.g., Hopkins+06; Glickman+12) and observational results for red quasars at z~1-3 (e.g., Glikman+2012; Urrutia+12; Bongiorno+14). On the other hand, Type 2 quasars are not reddened as a result of e.g., recent mergers and are not tied into the evolutionary picture of the galaxy and quasar co-formation as a result of the reddening of the nuclear emission (e.g., Sturm et al. 2006, ApJ, 642, 81; Zakamska et al. 2006, ApJ, 132, 1496).

In summary, the difference between Type 1 or Type 2 quasars originates from the viewing angle, and they are distinguished from whether their nuclear emission is visible or not, respectively. Red quasars are categorized as Type 1 quasars showing the nuclear broad-line emission, but also has dust reddening of the nuclear emission (see also e.g., Sec. 1 of Glikman et al. 2012, ApJ, 757, 51; Kato et al. 2020, PASJ, 72, 5).

In addition to the tentative detection of the broad Ly-alpha (3.7sigma) and CIII] lines (3.4sigma) (Fig. 1, see also the response of [1.1.1]), the highly visible nuclear emission evident in the rest-frame UV properties of the point-source morphology and the remarkably bright for a galaxy (still lower luminosity than other known z>7 quasars, though), clearly establish GNqz7-J1236 as a Type 1 quasar (see also the response of [1.1]). The HST data shows that the rest-frame UV SED shape of GNqz7-J1236 is clearly distinct from the SDSS quasar composite, but consistent with a high-redshift red quasar template (Fig. 1). Besides, the E(B-V) value of GNqz7-J1236 meets the general red color criteria for the high-redshift red quasar used in previous studies (e.g., Richards et al. 2003, AJ, 126, 3; Glikman et al. 2012, ApJ, 757, 51; Kato et al. 2020, PASJ, 72, 5). We thus regard GNqz7-J1236 as a (Type 1) red quasar throughout the paper. With these definitions, the super-Eddington quasar W2246-0526 is also classified as a (Type 1) red quasar with the broad MgII and CIV emission lines albeit with a much stronger reddening of E(B-V) = 5 (Tsai et al. 2018, ApJ, 868, 1; Diaz-Santos et al. 2018, Science, 362, 1034).

Following the referee fs suggestion, we have revised the 1st (i.e., abstract), 2nd, and 3rd paragraphs of the main article and newly added Method Section 3 gDefinition of quasar category and classification of GNqz7-J1236 h to clarify the definition of each category of the quasar and classification of our target. We have also newly added a paragraph for how they all fit together at the beginning of Method Section 8 to make the motivation clear for the comparison with other populations, especially with high-redshift dusty starbursts, (Type 1) blue, and (Type 1) red quasars. We have also revised the 2nd and 3rd paragraphs of Section 8 and the captions of Extended Data Figure 7 and 8 to make what is suggested from these comparisons more clear.

Since the physical mechanisms of the Eddington limit and the accretion disk inside of the dust materials should be unchanged between the dust-obscured and unobscured quasars, we calculated the M_BH value in the Eddington-limited accretion case with the dust-corrected bolometric luminosity by utilizing the general Eddington limit equation which has been widely used for both obscured and unobscured quasar studies (e.g., Fan et al. 2001, AJ, 122, 2833; Vestergaard 2004, ApJ, 601, 676; Borys et al. 2005, ApJ, 635, 853; Bongiorno et al. 2014, MNRAS, 443, 2077; Wu et al. 2015, Nature, 518, 512; Decarli et al. 2018, ApJ, 854, 97; Kato et al. 2020, PASJ, 72, 5).

> \ \ \Originality and significance \ \ \
> Based on my knowledge of recent publications in this field, this is an original study presenting new data on the source GNqz7-J1236, in combination with older reprocessed data. The source GNqz7-J1236 and the results presented in this study will be of significant interest in the field of extragalactic astronomy, as it presents a new aspect of z>6 quasars and early BH growth. However, I expect some of the results and methodologies to be questioned (at least for the current version of this work).

[2.2]
Following referee fs specific suggestions below, we have revised manuscript the methodologies for the results (see the responses of [2.3], [2.4], [2.5], [2.6], [2.7], [2.8], [2.9], [2.10], [2.11], and [2.12]).

\ \ \Data & Methodology \ \ \
>Quality of data:
>The authors present new deep observations of GNqz7-J1236 with NOEMA at 1 and 3mm, with both continuum and [CII] and CO(7-6) emission being detected. Additional lines were covered in these observations providing upper limits for CO(6-5) and [CI](2-1). In addition to the NOEMA observations the authors use photometry from X-ray to radio. As GNqz7-J1236 is in the GOOD-N/CDF-N field it benefits from high quality deep surveys across the spectral range covered by this study.
> Overall, the data is of a sufficient quality. However, it should be noted that the spatial resolution is significantly different between the different data used. The NOEMA observations have beam sizes of 0.64 hx0.44 h and 4.7 hx4.1 h at 1mm and 3mm respectively, while the beam sizes for observation in other instruments such as Spitzer/MIPS and SCUBA2 are significantly larger. This is not clearly addressed by the authors, and some discussion on this is necessary especially when combining such photometry to perform SED analysis.

[2.3]
It is true that there are several objects near GNqz7-J1236 that are seen in HST maps. Three faint sources visible in Fig. 1 each offset by ~1.8" from GNqz7-J1236 are resolved in the IRAC images with deblended [4.5um] flux densities of 0.08 }0.03, 0.08 }0.02 and 0.19 }0.02 uJy, clockwise from the lower left. They are bluer than GNqz7-J1236 and have photometric redshifts z < 2, where galaxy templates that include re-emitted dust emission in the mid-IR have 24um / 4.5um ratios between 0.5 and 10. Thus, we expect that the faint neighboring sources together could contribute a maximum of 10%, likely much less, of the unresolved 24um source at the position of GNqz7-J1236. Since these three faint HST sources are not detected in the deep NOEMA 1-mm map, the contributions to the FIR bands are also negligible.

Although we report the 1-mm continuum detection from a nearby dusty object, ND1, with a ~3.5 h offset from GNqz7-J1236, we discussed the potential contribution of this object to the SCUBA2 850um photometry in the manuscript, and its potential contribution was already subtracted from the 850um photometry (see the 2nd paragraph of Method Section 5). By adopting the Briggs weighting (robust = 0.0), we have produced a higher-resolution 3-mm map whose beam size is smaller than the offset of ND1, but no 3-mm emission from ND1 fs position is confirmed. Thus, ND1 fs contribution to the 3-mm band photometry is also negligible.

To clarify that we have verified the potential contributions to the photometry from the nearby objects and subtract them when necessary, we have revised the 1st and 2nd paragraphs of Method Section 5 and Extended Data Table 1 note.

>Validity of approach:
>There are a few main points to this paper that rely heavily on the methodologies used. For some cases the approaches used are either flawed or have not been explained and motivated thoroughly enough. I outline them below:
> - Although allot of weight is put on the X-ray faint emission of this source, and some properties are estimated based on it. The actual photometric upper limit is not clearly stated. The authors assume a photon index of 2.0 to calculate the rest-frame 2-8keV luminosity upper limit, but they do not motivate this choice and do not provide the equation used for the estimation.

[2.4]
We estimate the upper limit for the X-ray as follows. The Chandra 2-Ms data (Xue et al. 2016, 224, 2) mean background counts in the full band is 0.171. Based on the continuous Poisson distribution with a mean value of 0.171, we compute an upper limit on the net counts of < 1.1 at the 99% confidence level (i.e. the upper cumulative probability distribution at 99%). Assuming the average photon index

Gamma=2.0 obtained among high-redshift quasars up to z=7.5 (Nanni et al. 2017, A&A, 603, 128; Banados et al. 2018, ApJL, 856, 2; Pons et al. 2020, MNRAS, 491, 3; Vito et al. 2021, A&A, 649, 133), we use the online Portable Interactive Multi-Mission Simulator (https://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3pimms/w3pimms.pl) and estimate upper limits for the X-ray luminosity, including a correction for the Galactic absorption in this direction N_H = 9.64e19cm^-2 (HI4PI collaboration 2016). The upper limit estimate depends on the choice of the photon spectral index, Gamma. The typical range of spectral indices for X-ray AGN at this redshift is Gamma=1.7-2.3 (Wang et al. 2021, ApJ, 908, 53). Assuming even an extremely soft spectrum of Gamma=2.3 increases the luminosity upper limit by ~30%, still well below the expected value. We have added further details for the derivation of the X-ray luminosity and its motivation in the 3rd paragraph of Method Section 5.

> - The authors use the X-ray luminosity upper limit to estimate the Mbh and Eddington ratio by comparing to the correlation between the optical to x-ray spectral index (a_ox) and Eddington ratio. This correlation is defined based on quasars at local and high-z; however, these sources are not classified as red quasars, GNqz7-J1236 is significantly under luminous in both optical and X-ray in comparison to them, and therefore it is not clear why it is expected that this correlation will be valid for a source like GNqz7-J1236 . The authors say: g we obtain an Eddington ratio greater than unity at a 5sigma level h, It is not clear what this means, and how the 5sigma level is defined. No further information on this is provided in the Methods section.

In Figure 3 and Extended Data Fig. 3, the upper limits of GNqz7-J1236 are drawn after the dust correction. The correlation between alpha_ox and the Eddington ratio reported in previous studies includes the dust reddened quasars, where the authors applied the dust correction for those quasars (e.g., Lusso et al. 2010). In order to clarify that we compare GNqz7-J1236 in those figures based on the dust-corrected values, we have added an explanation of it in captions of Fig. 3 and Extended Data Fig. 2.

[2.5]
We calculate the 5sigma level by evaluating on a log scale how much the Eddington ratio of 1 deviates from the Eddington ratio of 12.2 that is expected from the alpha_ox vs. Eddington ratio relation (Lusso et al. 2010; see also e.g., Lusso et al. 2016; Nanni et al. 2017; Vito et al. 2019; Chiaraluce et al. 2018; Zou et al. 2020) at alpha_ox = -2.23 (our upper limit estimate for GNqz7-J1236). The 1sigma uncertainty of the best-fit relation (the gray shaded area in Fig. 3) at alpha_ox = -2.23 is ~0.2 dex. We thus estimate the deviation of the Eddington ratio of 1 with alpha_ox = -2.23 to be 5.5 (= (log(12.2) - log(1)) / 0.2) sigma level. To clarify how we define the confidence level, we have revised the 4th paragraph of Method Section 5. We have also corrected the value from 5sigma to 5.5sigma.

> -On the same note, there is no clarification as to how the Mbh was calculated from the optical luminosity. And why the X-ray estimate is preferred over the optical.

[2.6]
We used the following equation for the Eddington-limited M_BH estimate from the bolometric luminosity of the quasar, which has been widely used in high-redshift quasar studies (see the last paragraph in the response of [2.1]):
L_Edd = 1.3e38 * (M_BH / M_sun) erg/s
(e.g., Wu et al. 2015, Nature, 518, 512).
We have added the above equation in the 2nd paragraph of Method Section 6.

We do not intend to have a preference in the choice of the methods for the MBH estimate. In the 2nd paragraph of the main article, we show the above bolometric luminosity based MBH estimate, following the general approach. Then, the independent estimate from the X-ray faint property provides a consistent but even lower M_BH value. Our argument is that both of these independent estimates are consistent with our interpretation that GNqz7-J1236 is a unique young quasar at z=7.2 with M_BH <~10^8 Msun.

> -SFR estimates are subject to the IMF assumed. The authors have not clarified which IMF is used in their estimates. Furthermore, when comparing between different populations it is important to make sure that the IMF assumptions are consistent between populations.

[2.7]
We derive the SFR value from our LIR estimate with the calibration of Murphy et al. (2011) that is widely used in high-z quasar host studies (e.g, Venemans et al. 2020, ApJ, 904, 2). In Murphy et al. (2011), the authors assume the Kroupa IMF. We have revised the 3rd paragraph of Method Section 6 to clarify our IMF assumption. We agree that it is important to make the IMF assumptions consistent with different objects when comparing the physical properties related to the IMF. We have checked the IMF assumption in each literature and applied the correction factor, when necessary, and revised Extended Data Figure 7. Note that a certain number of the literature uses the Chabrier IMF, while the correction factor for the SFR estimate is 1.06 between Kroupa and Chabrier IMFs (see e.g., Schaerer et al. 2020, A&A, 643, A3). We confirm that the IMF correction does not change our argument for the comparison of the SFR estimates among different populations.

> -Size estimates of the mm and [CII] emission are presented in the main article. However, the details presented in the Methods section show that not only are these estimates significantly smaller than the observed resolution, begging the question as to how they could be defined, but also the estimate of the radius for the 1.3mm continuum is estimated at 0.07 h with an error of 0.44 h. This highlights that this estimate should not be used, and the upper limits on the effective radii of the emission need to be redefined.

[2.8]
We show the best-fit estimate and its error based on the visibility-based fitting CASA task UVMODELFIT. However, a large error emerges when the source is not spatially resolved and the fitting is not converged, rather than the actual lower/upper limits in this task. In fact, an image-based fitting CASA package IMFIT returns the un-resolved solution for the 1.3-mm dust continuum. Not to make the reader confused for the definition of the upper limit, we alternatively evaluate the upper limit based on an approximate formula for the smallest resolvable size (theta_min) estimated for the interferometric data:
theta_min = beta * (lambda_c / 2 / S/N^2)^0.25 * theta_beam
(eq. 7, Marti-Vidal et al. 2012, A&A, 541, A135), where theta_beam is the synthesized beam size (FWHM), beta is a coefficient which takes a range of 0.5-1.0, and lambda_c is a probability cutoff. With lambda_c = 3.84 in the same manner as previous studies (Fujimoto et al. 2017, ApJ, 850, 83; Franco et al. 2018, A&A, 620, A152; Franco et al. 2020a, A&A, 643, A53; Gomez-Guijarro et al. 2021, arXiv:2106.13246) and a conservative beta value of 1.0, we obtain the upper limit in FWHM of 0. h18 (0. h09 in effective radius r_e) for the 1.3-mm continuum. We thus place the upper limit of r_e = 0. h09 (480 pc).

Note that the synthesized beam size in interferometric data gives an idea of the mean resolution of the multiple baselines in the data, and thus a better constrain can be obtained than the mean resolution, if the object is detected in a good S/N. This also explains that theta_min in the above approximate formula is given as a function of theta_beam and S/N. For this reason, the [CII] and 1.3-mm continuum sizes have been well constrained even below the beam size.

We have revised the 1st paragraph of the main article, the 6th paragraph of Method Section 4, Extended Data Table 2, and Extended Data Figures 6 and 8 based on this updated upper limit for the 1.3-mm dust continuum size.

>-SED fitting: HST data shows multiple nearby objects at a radius of 2 h. Considering how much of the photometry used in the MIR \mm have a lower resolution than that, how are the authors confident that they are comparing like to like when combining the photometry for the SED analysis and that these nearby objects are not contributing to the observed emission.

[2.9]
Please see the response of [2.3].

[2.10]
> Quality of presentation:
> The data and methodology are not sufficiently detailed to allow for reproducibility of the results. The methods followed and comparisons made are not always clearly motivated and explained. The article itself does not present the results in a concise and easy to follow way, but seems to jump back and forth between topics. For example the redshift is presented early on based on the optical data from HST, but later on in the article the value of the redshift is revised based on the NOEMA. It would be better to have a clear definition of the redshift at the beginning using both the HST and NOEMA data, before moving on to the other aspects of the source. Same applies when presenting the X-ray results etc.

Following the referee fs suggestion, we have removed several redshift descriptions of z=7.190 and z=7.23 from the manuscript and make it clear that the source redshift is accurately determined with NOEMA at z=7.1899+/-0.0005. We have also corrected Figure 1 by shifting the lower-z blue and red quasar templates according to the NOEMA redshift of z=7.1899, instead of the HST grism redshift of z=7.23. However, we note that the HST and NOEMA redshifts are consistent within the errors, supporting their results each other. Besides, the HST-based redshift features the Lya line and the Lyman- break, where the potential difference from the [CII]-based systemic redshift may include physical implications such as the expanding shell of HI (e.g., Verhamme et al. 2006, A&A, 460, 2). Therefore, we believe that showing the HST-based redshift estimate could be also useful for the community. To clarify the derivation and that HST-grism redshift is consistent with the NOEMA redshift, we have added the description in the 3rd paragraph of Method Section 2.
For the estimate of the X-ray luminosity, please see the response of [2.4].

> \ \ \Appropriate use of statistics and the treatment of uncertainties \ \ \
> Errors are not always clearly indicated (with error bars) in the figures, and in certain cases the authors have purposefully ignored large uncertainties when referring to estimated values in the main article. As we described at the beginning of the Method Section, the error values/bars generally represent the 1sigma uncertainty, where the sigma value denotes the root-mean-square or standard deviation, unless otherwise specified. However, we realized that we missed the description of how we estimate and define the error in some of the figures. To clarify the definition of each error bar in each figure, we have revised the 2nd paragraph of Method Section 8 and captions of Figure 1, 2, 3, Extended Data Figure 2, 3, 6, 7, 8, and 9.

[2.11]
We show the uncertainties for all estimates in Method and Extended Data Table 2, while we did not show some of the uncertainties in the main article in order not to confuse readers with too many values. Because the source redshift, the less luminous and red-color properties of the quasar emission, and the dusty starburst host are the key characteristics of GNqz7-J1236, the uncertainties

are explicitly stated for the estimates of redshift, bolometric luminosity, UV continuum slope alpha_lambda (and E(B-V)), and SFR in the main article. The uncertainty of the bolometric luminosity was mistakenly missed in the previous manuscript even in Extended Data Table 2, which we have added in the 3rd paragraph of the main article, the 2nd paragraph of Method Section 6, and Extended Data Table 2. Given the large systematic uncertainty for the M_BH estimate even with spectroscopic measurements in general (+/-~0.5 dex, see e.g., Shen 2013, Bull. AStr. Soc. India, 41, 61), we show the M_BH estimate in one significant digit without the uncertainty. Note that recent high-z quasar studies published from Nature do not always show the uncertainties for e.g., bolometric luminosity and M_BH estimates in the main article (e.g., Wu et al. 2015, Nature, 518, 512; Banados et al. 2018, Nature, 553, 473). We thus believe that our current format does meet the general Nature format.

> \ \ \Conclusions \ \ \
> Based on the points I have outlined previously, I do not find the conclusions to be robust and reliable.

> \ \ \Suggested improvements \ \ \
> To improve this manuscript the authors will need to address the points brought up earlier on the validity of some of the methods used. Significant improvement is further needed in providing the detailed information needed to make the results reproducible. Furthermore the methodologies and comparison samples need to be sufficiently motivated.

[2.12]
Following the referee fs suggestions, we have revised the manuscript related to the method, the reproducibility of results, and the motivation of the method (see the responses of [2.3], [2.4], [2.5], [2.6], [2.7], [2.8], and [2.11]).

Regarding the choice of comparison samples in Figure 3, Extended Data Figure 7, 8, and 9, the main scope is the evolutionary sequence from dusty starbursts, red quasars, and blue quasars (see also the response of [2.1]), where GNqz7-J1236 is the first example of the red quasar at z>7. It is thus important to compare the properties of GNqz7-J1236, especially with those of dusty starbursts and blue quasars at similar redshifts and discuss whether the transitioning properties can be obtained or not. In this context, we notice that it is also important to compare GNqz7-J1236 with lower-z red quasars. We have thus revised Figure 3, Extended Data Figure 3, 7, 8, and 9 by adding plots of the high-redshift red quasars from the literature. To make our scope clear, we have also revised a part of the color assignment and the label of the plots in these figures. To describe the update of the comparison samples, we have revised the 4th paragraph of Method Section 5 and the 2-4th paragraphs of Method Section 8. Note that it is difficult to achieve preparing the same comparison samples in all figures due to the limited amount of the observations and different scopes of the previous studies, and thus the comparison samples are not always the same among the figures.

> Another important point for improvement is the presentation of the red quasar classification, how it fits in to the different types of AGN populations, and making sure comparisons made are to similar types of sources in the literature or otherwise clearly motivated sources for comparison (see point in section gValidity h).

[2.13]
Regarding the red quasar classification, please see the response of [2.1].
Regarding the comparison, please see the response of [2.12].

> \ \ \References \ \ \
> Considering the source presented here is classified as a red quasar, there is a lack of references to studies on such objects at high-redshifts.

[2.14]
In the new Method Section 3 where we have added the detail classification (see the response of [2.1]), we have further added the references of the red quasar studies (e.g., Richards et al. 2003, AJ, 126, 3; Ross et al. 2015, MNRAS, 453, 4; Glikman et al. 2004, ApJ, 607, 60; Glikman et al. 2013, ApJ, 778, 127; Urrutia et al. 2009, ApJ, 698, 1095; Lacy et al .2007, AJ, 133, 186). If we miss any important references for the high-redshift red quasar studies, we would appreciate it if the referee explicitly let us know the references.

> \ \ \- Clarity and Context \ \ \
> The abstract is not as clear and accessible as it could be, mainly due to the use of specifications such as blue and red quasars that are not clearly defined. When it comes to the rest of the article, again the lack of a clear definition of red quasars set in the context of other AGN populations and galaxy evolution, and the comparisons to different types of sources for different aspects of the conclusions the authors want to reach, makes the article hard to clearly assess and follow.

[2.15]
Following the referee fs suggestion, we have revised the abstract to make the category of the quasars and the evolutionary sequence from the dusty starburst, the red quasar, and the blue quasars more clear. Note that, because the Nature formatting guide requires the readability for any scientists in title and abstract (https://www.nature.com/nature/for-authors/formatting-guide), we have not added the quantitative definition and classification for the red and blue quasars in the abstract, but added them in the 3rd paragraph of the main article and Section 3 in Method (please see also the response of [2.1]).

(Further revisions)
[3.1]
To avoid the potential contribution from CIII] line in the UV continuum slope measurement, we have updated the measurement by using the HST G141 grism spectrum, instead of F125W, F140W, and F160W photometry. We obtain alpha_lambda = 0.1 +/- 0.3, which is consistent with the previous measurement of -0.1+/-0.4 within the errors, and thus our arguments are unchanged by this update. We have revised the 3rd paragraph of Method Section 2 to describe this updated measurement.

[3.2]
Related to the response of [2.7], we notice that we need to correct the different assumptions for the dust mass absorption coefficient among the literature when comparing the dust mass. Because we couldn ft find the reference of the assumption of kappa in some cases in the literature, we systematically recalculate the dust mass with an equation (2) of Venemans et al. (2018), 866, 159. For the re-calculation, we adopt the dust mass absorption coefficient kappa = kappa0 * pow(nu/nu_250um, beta), where nu is frequency and kappa0 = 5.1 cm^2/g at 250um which is used in our FIR SED model of Draine & Li (2007), ApJ, 657, 2. To describe this procedure, we have revised the 2nd paragraph of Method Section 8 and Extended Data Fig. 7.

[3.3]
Related to the response of [2.1], we notice that the short depletion time scale of ~10 Myr is also an important characteristic of GNqz7-J1236, compared to other populations. To clarify that GNqz7-

J1236 has a uniquely short depletion time scale, we have newly added a panel (d) in Extended Data Fig. 7 and revised the 2nd paragraph of Method Section 8.

[3.4]
Related to the response [2.1], we have corrected the wording from gluminous quasar h to gblue quasar h where that is appropriate throughout the paper. We have also clarified the definition of the blue quasar in the 1st paragraph of Method Section 2.

[3.5]
We have switched the order of Extended Data Fig. 7 and Extended Data Fig. 8 to match the order they are mentioned in the main article.

[3.6]
Throughout the manuscript, we have also corrected other typos and grammatical errors.
The reference list and the acknowledgement have been updated.

Reviewer Reports on the First Revision:

Referee #3 (Remarks to the Author):

I was asked to review the paper, "A young quasar forming in a dust-enshrouded starburst in the early universe" by Fujimoto et al for Nature. The paper was previously reviewed, and the principal concerns were that the authors did not adequately make the case that the object they are studying is indeed a quasar, as opposed to a galaxy. The reviewers also raised a number of concerns about presentation and definition.

I read the paper (both the original version and the revised version) carefully before reading the previous reviewers' comments. Here I give my own comments. In brief, the object described in this paper is quite intriguing no matter what interpretation one makes of it. This is a very luminous z~7.2 galaxy with comprehensive data ranging from X-rays to radio. It shows an extraordinarily high star formation rate in a quite small volume. The key question, which the previous referees emphasize strongly, is whether the authors have convincingly shown that it is powered by accretion onto a supermassive black hole. The data are confusing, which is part of what makes this object so intriguing. The paper comes to the conclusion that it is indeed a quasar, and assumes that this is the case in all the discussion, but I (like the previous reviewers) would have liked to see more discussion given to the possibility that this is an unusually compact starburst galaxy, rather than a quasar. Here is the evidence given for the quasar nature of the object, and comments I have to explore these questions in more detail:

-The object is unresolved at rest-frame ultraviolet wavelengths with HST resolution, as one would expect for a Type I quasar. I would have liked to see somewhat more discussion of this: in particular, are there any compact starbursts known (at any redshift) that are unresolved with HST? The answer may well be no, but it would be appropriate to state this clearly.

I will also point out that Extended Figure 1 shows results at F125W. It is implied, but never clearly stated, that the images at F105W, F140W, and F160W are also unresolved to the same degree. Is this indeed the case?

-The object is detected strongly at 24 microns (rest-frame 3 microns), with an F24/F8 ratio suggesting an unobscured quasar. First, are there other z>6 objects known with detections at 24 microns? If so, it would be very interesting to see where they lie on Extended Data Figure 1.

The 24 micron flux comes from Magnelli et al, which indicates that there are two sources of flux error: from photon counting statistics (which I believe is the error bar given in Extended Table 1) and from confusion; I think the two are comparable for this source. As far as I could tell, this paper ignores the confusion noise for the 24 micron flux, suggesting that the error bar in Extended Figure 1 is a factor of sqrt(2) too small. I am therefore not yet convinced that the 24 micron detection tells us unambiguously that it is a Type I quasar.

-The SED of the object (Figure 2) is fit to a model of a reddened

Type I quasar plus a starburst. I was not convinced that this model is unique, and I would have liked to see more attempt to try to fit the data with pure galaxy models. Lyman-break galaxies, by definition, emit strongly in the ultraviolet, and so will have a rather different SED than either the dusty starburst or the host galaxy component shown in Figure 2. Perhaps an unobscured starburst model which fits the UV part of the SED, plus a dusty starburst to fit the longer wavelengths, could do a decent job? Perhaps even such a model couldn't fit the rest-frame 3-micron point (see above). But it would be appropriate to more rigorously demonstrate that an AGN component is required to fit the SED.

-It is stated (Page 14, line 306) that the UV luminosity is 1.5 mags more luminous than Lyman-break galaxies at z>7. At slightly lower redshift, there is a class of tremendously luminous LBGs that have been found in the SHELLQs survey (e.g., https://ui.adsabs.harvard.edu/abs/2019ApJ...883..183M/abstract); it would be very interesting indeed to compare your results with those.

-There are ~3.5 sigma detections of broad Ly alpha and CIII]. The current draft backs off somewhat from presenting this as iron-clad proof that this is a Type I quasar; Figure 1 is not convincing in this regard.

-Finally, the object is undetected in very deep X-ray observations. While it is true that AGN with low-luminosity X-ray emission exist, they are unusual and rare, and the simpler explanation is that this object does not host an AGN. (In this context, I was somewhat puzzled by the right-hand panel of Figure 3, which shows dusty starbursts with non-zero black hole masses and X-ray luminosities much larger than the upper limit for this object; are these dusty starbursts in fact AGN?)

I guess I am suggesting that the authors present the results using two parallel tracks: one accepting the Type I AGN hypothesis (as they do in the current draft) and pushing it to its logical extreme (which leads them to conclude a very low-mass black hole with very high accretion rate), and the other asking what sort of object this would be if there is no AGN in at all. In both scenarios, the object is tremendously interesting, but with rather different conclusions in the two limits. It would be very interesting to include some discussion of what further observations could be made to convincingly demonstrate to even a skeptic like me that there is indeed an embedded Type I quasar: e.g., JWST spectroscopy of a broad MgII or Hbeta line.

Let me make some other comments, reading sequentially through the paper.

-The paper never gives the coordinates of the object itself. This makes it difficult to cross-correlate with results from other papers, or to tabulate it in, e.g., the NASA/IPAC Extragalactic Database. The paper must include the full coordinates.

-Page 1, the reference (#10) given for "high-redshift red quasars identified in SDSS" is to a recent SDSS data release paper, which has no information about red quasars per se. This same reference is given in the caption of Figure 1.

-Figure 2: perhaps add a note to the caption that the 21 cm detection is consistent with the enormous star formation rate assumed for this object; that is, it is not due to the AGN. Incidentally, it was a bit unclear whether the inferred reddening for the quasar (E(B-V)=0.11 pm 0.03) was just from the fit to the UV spectrum, or a joint fit to the full SED.

-In the discussion of the NIR-dark galaxy ND1 on Page 17, it might be worth comparing with the intriguing companion galaxies that DeCarli et al. (https://ui.adsabs.harvard.edu/abs/2017Natur.545..457D/abstract) have found adjacent to z~6 quasars.

-Note that Extended Figure 3 is references in the text only after Extended Figure 6.

-Page 24, Section 11 (discussion of color selection): You say that you "assume" that F850,F105, and F125 correspond to z, y, and J bands. You can do better than that; given your SED model fit, you can synthesize the fluxes in the z, y, and J bands. I suspect it won't change the results much, but it is the right thing to do.

Author Rebuttals to First Revision:

We thank the expert referee for their constructive comments. We are glad to see that also the new referee appreciates the implications of the results, while we also understand that some of our arguments were still not clearly explained. We have revised our manuscript again, following the recommendations and suggestions from the editor and the new referee. For easy review, our response to the comments and our revised text in the manuscript are shown using a blue font, and we assign numbers of [R2.X] for each response to the comments by the new referee.

> I was asked to review the paper, "A young quasar forming in a dust-enshrouded starburst in the early universe" by Fujimoto et al for Nature. The paper was previously reviewed, and the principal concerns were that the authors did not adequately make the case that the object they are studying is indeed a quasar, as opposed to a galaxy. The reviewers also raised a number of concerns about presentation and definition.

> I read the paper (both the original version and the revised version) carefully before reading the previous reviewers' comments. Here I give my own comments. In brief, the object described in this paper is quite intriguing no matter what interpretation one makes of it. This is a very luminous z~7.2 galaxy with comprehensive data ranging from X-rays to radio. It shows an extraordinarily high star formation rate in a quite small volume. The key question, which the previous referees emphasize strongly, is whether the authors have convincingly shown that it is powered by accretion onto a supermassive black hole. The data are confusing, which is part of what makes this object so intriguing. The paper comes to the conclusion that it is indeed a quasar, and assumes that this is the case in all the discussion, but I (like the previous reviewers) would have liked to see more discussion given to the possibility that this is an unusually compact starburst galaxy, rather than a quasar. Here is the evidence given for the quasar nature of the object, and comments I have to explore these questions
in more detail:

> -The object is unresolved at rest-frame ultraviolet wavelengths with HST resolution, as one would expect for a Type I quasar. I would have liked to see somewhat more discussion of this: in particular, are there any compact starbursts known (at any redshift) that are unresolved with HST? The answer may well be no, but it would be appropriate to state this clearly. I will also point out that Extended Figure 1 shows results at F125W. It is implied, but never clearly stated, that the images at F105W, F140W, and F160W are also unresolved to the same degree. Is this indeed the case?

[R2.1]
We thank the referee for raising this point. Previous HST studies have reported a positive correlation between size and luminosity in the rest-frame UV wavelength (e.g., van der Wel et al. 2014, ApJ, 788, 28; Shibuya et al. 2015, ApJS, 219, 15) among high-z star-forming galaxies, where the UV luminous galaxies at z~7 show large effective radii of 0.5-3 kpc (e.g., Bowler et al. 2017, MNRAS, 466, 3635). Although several UV compact galaxies are reported at z~2-3 (Barro et al. 2014, ApJ, 791, 52; Marques-Chaves et al. 2020, MNRAS, 499, 105), their sizes are still down to 0.3-1 kpc scales that are 5-20 times larger than the upper limit of 60 pc in our object (GNz7q). In this regard, the surface density of the UV luminosity in GNz7q is ~ 2dex higher than any other objects so far reported even without the dust correction. To clearly convey this uniquely compact and luminous aspect of the source, we have added a new Extended Data Figure 4.

To further address the question by the referee, the object shows a point source morphology in all HST bands. We have revised the left panel of Extended Data Fig. 2 to include the PSF subtraction results in all HST bands. We have also confirmed that similar Sersic profile results are obtained for all other HST bands.

> -The object is detected strongly at 24 microns (rest-frame 3 microns), with an F24/F8 ratio suggesting an unobscured quasar. First, are there other z>6 objects known with detections at 24 microns? If so, it would be very interesting to see where they lie on Extended Data Figure 1. The 24 micron flux comes from Magnelli et al, which indicates that there are two sources of flux error: from photon counting statistics (which I believe is the error bar given in Extended Table 1) and from confusion; I think the two are comparable for this source. As far as I could tell, this paper ignores the confusion noise for the 24 micron flux, suggesting that the error bar in Extended Figure 1 is a factor of sqrt(2) too small. I am therefore not yet convinced that the 24 micron detection tells us unambiguously that it is a Type I quasar.

[R2.2]
We thank the referee for bringing this up. High-z quasars are usually identified in very wide shallow surveys, where sufficiently deep mid-infrared data has been missed (cf. Ross et al. 2020, MNRAS, 494, 1; most of z>6 quasars are not detected in the shallow WISE/W4 band at ~24um), while Leipski et al. (2014) have analyzed MIR SEDs for 69

quasars based on Spitzer and Herschel at z=5-6.4. We have further analyzed the MIR colour properties of GNz7q (see the response [R2.3]) and revised the corresponding figure. The updated results are presented in the new Extended Data Fig. 5, and we have included these 69 quasars taken from Leipski+14 in the new Extended Data Fig. 5. We have confirmed that these 69 quasars have MIR colours similar to GNqz7 with a high 24um/8um ratio. In the right panel of the new Extended Data Fig. 5, we have replaced the colour track (from z=5 to 9) with the single data point fixed at the same redshift as GNz7q of z=7.2 because the redshift of GNz7q is spectroscopically confirmed.

We have corrected the uncertainty of the 24um flux estimate by using the realistic estimate obtained from Monte-Carlo simulations in Magnelli et al. (2011) that include the confusion uncertainty. The error bar of our GNz7q is indeed increased (as the referee rightly pointed out), but it is still sufficiently separated from the distribution of the star-forming galaxies in the MIR colour diagram (right panel of the new Extended Data Fig. 5).

> -The SED of the object (Figure 2) is fit to a model of a reddened Type I quasar plus a starburst. I was not convinced that this model is unique, and I would have liked to see more attempt to try to fit the data with pure galaxy models. Lyman-break galaxies, by definition, emit strongly in the ultraviolet, and so will have a rather different SED than either the dusty starburst or the host galaxy component shown in Figure 2. Perhaps an unobscured starburst model which fits the UV part of the SED, plus a dusty starburst to fit the longer wavelengths, could do a decent job? Perhaps even such a model couldn't fit the rest-frame 3-micron point (see above). But it would be appropriate to more rigorously demonstrate that an AGN component is required to fit the SED.

[R2.3]
We have further analyzed the SED by focusing on the NIR to MIR bands, which we have added in the left panel of the new Extended Data Fig. 5. The red points show the photometry of GNz7q and the coloured lines represent the galaxy and quasar templates normalized at the Spitzer/ch4 band (~8um). We find that the shape of the NIR-MIR SED of GNz7q, especially an excess at MIPS 24 um (rest-frame ~3um), cannot be easily explained by emission from stars and ionized gas associated with star formation activity alone. On the other hand, it is exactly consistent with the typical SEDs of quasars and active nuclei, where the rest-frame ~3um emission is thought to arise from hot dust associated with the nucleus.

Note that explaining the 24 um flux excess by an independent dusty starburst would not be compatible with the submm and mm data points (i.e., L_IR becomes too high). This is seen in Fig.2, where the dusty starburst SPT0311-58W at z=6.9 (the orange curve) matches the 24um flux of our object, but its submm/mm data points exceed those of GNz7q by ~ 1dex. Thus, the high 24um flux of GNz7q is unlikely to be explained even by "an unobscured starburst model which fits the UV part of the SED, plus a dusty starburst to fit the longer wavelengths".

The details of this SED analysis is now described in the 3rd paragraph of the new Method Section 5, and we have revised the 7th paragraph of the main text to briefly clarify these statements.

> -It is stated (Page 14, line 306) that the UV luminosity is 1.5 mags more luminous than Lyman-break galaxies at z>7. At slightly lower redshift, there is a class of tremendously luminous LBGs that have been found in the SHELLQs survey (e.g., https://ui.adsabs.harvard.edu/abs/2019ApJ...883..183M/abstract); it would be very interesting indeed to compare your results with those.

[R2.4]
This is a good suggestion. We have added a new Extended Data Fig. 1, where we compare Muv vs. redshift among the SHELLQs objects and other luminous quasars and galaxies in the literature. The observed UV luminosity of GNz7q falls between the typical quasars and galaxies, where there are several "faint quasars" and "luminous galaxies" that have been reported in previous surveys, including SHELLQs. To understand how much GNz7q is unique from other similar objects so far reported, we also show a comparison of Muv vs. UV continuum slope in the right panel of the new Extended Data Fig.1. We find that GNz7q explores the UV parameter space towards the reddest colour among z>~6 objects, in addition to the unique luminosity range. To clarify these aspects, we have revised the 3rd paragraph of the main text.

Because we have found a similarly UV bright galaxy spectroscopically confirmed at z>7 in the literature (Schouws et al. 2021, submitted to ApJ, arXiv: 2105.12133), we have removed the previous statement that GNz7q is 1.5 mag more luminous than Lyman-break galaxies so far spectroscopically confirmed at z>7.

> -There are ~3.5 sigma detections of broad Ly alpha and CIII]. The current draft backs off somewhat from presenting this as iron-clad proof that this is a Type I quasar; Figure 1 is not convincing in this regard.

[R2.5]
To address this, we have added another possibility that this object is a star-forming galaxy (see the response of [R2.6]) and removed the description of the tentative detections of the broad Lya and CIII] lines in the 2nd paragraph of the main text. We have also removed the description that these tentative detections are supportive for the Type I quasar interpretation from the manuscript.

> - Finally, the object is undetected in very deep X-ray observations. While it is true that AGN with low-luminosity X-ray emission exist, they are unusual and rare, and the simpler explanation is that this object does not host an AGN. (In this context, I was somewhat puzzled by the right-hand panel of Figure 3, which shows dusty starbursts with non-zero black hole masses and X-ray luminosities much larger than the upper limit for this object; are these dusty starbursts in fact AGN?) I guess I am suggesting that the authors present the results using two parallel tracks: one accepting the Type I AGN hypothesis (as they do in the current draft) and pushing it to its logical extreme (which leads them to conclude a very low-mass black hole with very high accretion rate), and the other asking what sort of object this would be if there is no AGN in at all. In both scenarios, the object is tremendously interesting, but with rather different conclusions in the two limits. It would be very interesting to include some discussion of what further observations could be made to convincingly demonstrate to even a skeptic like me that there is indeed an embedded Type I quasar: e.g., JWST spectroscopy of a broad MgII or Hbeta line.

[R2.6]
Following this excellent suggestion, we have revised the manuscript to describe the two possible scenarios in the 1st, 3rd and 4th paragraphs of the main text. Given the MIR colour property (see the response [2.3]) and the extraordinary high surface density of the UV luminosity compared with general galaxies so far known (see the response [2.1]), we have briefly described in the 7th paragraph of the main text that overall the interpretation of the red quasar appears to fit the observations better.

We have added a comprehensive discussion for the interpretation based on the multi-wavelength properties in the new Method Section 5 “Interpretations for GNz7q”. Although the broad UV emission lines are not clearly detected (Fig. 1), a notable group of quasars with exceptionally weak UV broad emission lines have been identified at lower redshifts (e.g., Diamond-Stanic et al. 2009). Moreover, the X-ray observations show that these weak emission line quasars actually have weak X-ray emission with harder X-ray spectra and extremely blue-shifted high-ionization lines compare to normal quasars (Wu et al. 2011, ApJ, 736, 28; 2012, ApJ, 747, 10), indicative of X-ray absorption and a significant nuclear outflow. These trends are explained by a scenario where the inner region of the accretion disk is strongly inflated to a significant height due to unusually high accretion, which blocks the nuclear ionizing continuum and the X-rays from reaching the broad-line region and observers so-called “slim disk” scenario (Luo et al. 2015, ApJ, 805, 2; Ni et al. 2018, MNRAS, 480, 4), which we described in the 8th paragraph of the main text and the Method Section 4. Therefore, the extremely faint X-ray and the lack of the broad UV emission lines of GNz7q exactly match the properties predicted in the rapidly growing young quasar phase. Based on these multiple aspects, we describe the statement that the red quasar interpretation is more likely in Method Section 5. At the same time, we also describe that, alternatively, we might be witnessing an emergence of an unprecedented extremely compact and luminous star-forming region.

We have also revised the last paragraph of the main text to clarify that JWST has the power to give ultimate proof for the quasar classification via the broad Balmer line detection. However, an important caveat is that no one knows what the first quasars look like. E.g., a broad-line region might not form in the first quasars. Therefore, we have also added a brief sentence to state that a future non-detection of the broad Balmer lines may indicate further exciting possibilities, such as the existence of an extraordinary UV luminous and compact star-forming region and stark differences between the first quasars and their descendants.

To reduce the weight of the discussions based on the quasar interpretation throughout the manuscript, we have removed the M_BH estimate based on the Eddington-limited accretion assumption and the AGN bolometric luminosity measurement. In addition, we have moved the previous 10th paragraph of the main text to the 4th paragraph of Method Section 8 that is a discussion of the under-massive BH nature of GNz7q (via the black hole and dynamical mass relation).

As for the right panel of Figure 3, because the local sample is presented to represent the low M_BH regime and confirm that these low M_BH galaxies also follow the sequence, rather than the accurate classification between AGN or dusty starburst, we have replaced the label of “dusty starburst” with “local galaxies”.

> Let me make some other comments, reading sequentially through the paper.

> -The paper never gives the coordinates of the object itself. This makes it difficult to cross-correlate with results from other papers, or to tabulate it in, e.g., the NASA/IPAC Extragalactic Database. The paper must include the full coordinates.

[R2.7]
Thank you for pointing it out. This has now been fixed, and the coordinates are now given in Extended Data Table 2.

> -Page 1, the reference (#10) given for "high-redshift red quasars identified in SDSS" is to a recent SDSS data release paper, which has no information about red quasars per se. This same reference is given in the caption of Figure 1.

[R2.8]
We have added the reference ID (#6839) of the SDSS red quasar. To avoid duplicated information, we only add the ID in the caption of Figure 1.

> -Figure 2: perhaps add a note to the caption that the 21 cm detection is consistent with the enormous star formation rate assumed for this object; that is, it is not due to the AGN. Incidentally, it was a bit unclear whether the inferred reddening for the quasar (E(B-V)=0.11 pm 0.03) was just from the fit to the UV spectrum, or a joint fit to the full SED.

[R2.9]
We have added the note for the 21cm detection and clarified that E(B-V) is obtained from the joint fit to the full SED in Method Section 5.

> -In the discussion of the NIR-dark galaxy ND1 on Page 17, it might be worth comparing with the intriguing companion galaxies that DeCarli et al.
(https://ui.adsabs.harvard.edu/abs/2017Natur.545..457D/abstract)

have found adjacent to z~6 quasars.

[R2.10]
Based on the results of Decarli et al. (2017), we have revised the 5th and 6th paragraphs and stated that the presence of ND1 is suggestive that this system at z=7.2 would reside in a massive dark matter halo. In Method Section 3, we have also added a sentence to mention the recent ALMA study identifies similar NIR-dark galaxies even at z~7 (Fudamoto et al. 2021, Nature, 597, 7877).

> -Note that Extended Figure 3 is references in the text only after Extended Figure 6.

[R2.11]
We have corrected the order of the Extended Figures.

> -Page 24, Section 11 (discussion of color selection): You say that you "assume" that F850,F105, and F125 correspond to z, y, and J bands. You can do better than that; given your SED model fit, you can synthesize the fluxes in the z, y, and J bands. I suspect it won't change the results much, but it is the right thing to do.

[R2.12]
We have revised Method Section 11 by correcting these values in the suggested manner. We have confirmed that the colours do not change much and do not affect the conclusions.

---------- Additional Revisions----------
[R2.13] Non-detection of X-ray from the SF activity of the host galaxy

We appreciated that given the uniquely deep X-ray data and general X-ray luminosity (L_X) and SFR relations (e.g., Lehmer et al. 2016, ApJ, 825, 1) one would expect an X-ray detection from such an enormous SFR, while the non-detection of X-rays could be explained by the metallicity-dependence of the L_X and SFR relation: L_ X at a given SFR decreases in the high metallicity systems (e.g., Fonasini et al. 2019, ApJ, 885, 1). Based on the latest calibration (Fornasini et al. 2020, MNRAS, 495, 1), we find that at least the solar value is required for the gas-phase metallicity of the host galaxy to meet the X-ray upper limit (Section 4). Since the SFR estimate for the host galaxy of GNz7q is not much changed regardless of its interpretation (or even increased in the star-forming interpretation), the non-detection of X-rays thus indicates that the host galaxy has been experiencing a rapid metal enrichment and reached solar metallicity even at z=7.19. This is consistent with recent ALMA results for a distant quasar at z=7.54 that the ISM gas-phase metallicity of the host galaxy is comparable to the solar value via the FIR line diagnostic (Novak et al. 2019, ApJ, 881, 1).

We have added this statement in the 4th paragraph of Method Section 6, but this does not affect our results and discussions.

[R2.14] Comparison with the cosmological simulation.
Related to the discussion for the interpretation of GNz7q, we realize that it is important to check if there are any progenitors of luminous quasars whose multi-wavelength properties are close to GNz7q at z=7.2, especially for the X-ray faintness relative to the UV-optical luminosity. We have thus checked the multi-wavelength properties of each progenitor and revised Figure 4 by marking the progenitors whose multi-wavelength properties are close to GNz7q (L_X < 10^44.5 erg/s, alpha_OX < -1.9, and SFR > 100 Msun/yr). We also change the colour coding from M_gas to M_dark matter of the system to verify the possibility that GNz7q resides in the massive halo (see the response [R2. 10]). We find four progenitors meet the criteria and draw the M_BH evolution track in the right panel for these four progenitors. Among the four progenitors, one progenitor evolves into a luminous quasar harbouring a SMBH with M_BH > 10^8 Msun at a later epoch. This is the same progenitor we confirmed in the previous manuscript, and thus our discussion is not changed. We also confirm that this progenitor resides in one of the most massive dark matter halos at z=7.2 with M_dark matter ~ 10^12.2 Msun.

Based on these updates, we have revised the 9th paragraph of the main text, Method Section 10, and Figure 4 and its caption.

[R2.15] Name of the object
For easier reading, we have changed the object name from GNqz7-J1236 to GNz7q.

[R2.16] Title and 1st paragraph
We have revised the title and the 1st paragraph, following the formatting rule of Nature and the suggestion from the editor, in addition to the update of the manuscript for the two parallel tracks.

[R2.17] co-author

Given the large contributions of Pascal Oesch regarding the interpretation of ND1 and discussions in this revision process, in addition to sharing his Lyman-break galaxy catalog in this field, he has now been included in the co-author list and removed from the acknowledgements.

[R2.18] Updates of figures

All figures have been reproduced with the same font.

In this process, we have also revised Extended Data Figure 9 by enriching the data points taken from the literature for comparison. For the explanation of the newly added data points, we have also revised its caption, Method Section 2, and the 2nd paragraph of Method Section 8.

[R2.19]

The reference list, the author list, the author's contributions, the acknowledgements have been updated. Typos have been corrected.

Reviewer Reports on the Second Revision:

Referee #3 (Remarks to the Author):

I was pleased that the authors found my suggestions for improving the paper useful, The revised paper is much better, and I recommend that the paper be accepted for publication after the authors have responded to a few final suggestions that I have.

Reading sequentially through:

Page 3, line 90 (end of the paragraph), it is stated that the existence of ND1 implies that GNz7q resides in a dark matter overdensity. I would suggest removing this statement, or at least the conclusion that there is a large overdensity of dark matter. In general, galaxies reside in dark matter halos, and there is no reason to believe that GNz7q is no different. I think this statement is true even without the presence of ND1, and it would be quite a leap to jump from its existence to concluding that GNz7q is the center of a massive overdensity of galaxies. Drawing the analogy with the objects in Ref. 14 is appropriate, but the connection to dark matter halos is just speculation.

Page 4, line 118, "several progenitors... have less massive BHs". Less massive than what?

Page 9, Figure 1 caption, you identify the red quasar as SDSS ID 6839. I simply don't know what this id number refers to.

Page 14, last full paragraph: clarify that the measurement of r_e is done from the 125W filter (or is it the result of a joint fit to all the data?).

Author Rebuttals to Second Revision:

We are glad to see that the expert referee thinks our manuscript deserves publication after addressing further constructive comments raised by the referee. We have revised our manuscript following those comments. For easy review, our response to the comments and our revised text in the manuscript are shown using a blue font. We assign numbers of [R3.X] for each response to the comments by the referee.

> Referee #3 (Remarks to the Author):
> I was pleased that the authors found my suggestions for improving the paper useful, The revised paper is much better, and I recommend that the paper be accepted for publication after the authors have responded to a few final suggestions that I have.

[3.1]
> Reading sequentially through:
> Page 3, line 90 (end of the paragraph), it is stated that the existence of ND1 implies that GNz7q resides in a dark matter overdensity. I would suggest removing this statement, or at least the conclusion that there is a large overdensity of dark matter. In general, galaxies reside in dark matter halos, and there is no reason to believe that GNz7q is no different. I think this statement is true even without the presence of ND1, and it would be quite a leap to jump from its existence to concluding that GNz7q is the center of a massive overdensity of galaxies. Drawing the analogy with the objects in Ref. 14 is appropriate, but the connection to dark matter halos is just speculation.

We agree that it was just speculation. Following the suggestion, we have revised the description with
"The presence of the proximate ND1 galaxy is consistent with the high abundance of companion galaxies reported around luminous quasars at z>6 (Decarli+18)."

[3.2]
> Page 4, line 118, "several progenitors... have less massive BHs".
> Less massive than what?

We intended to state that the BHs of these progenitors are less massive than the most massive regime of 10^8~10^9 Msun. We have revised the description with
"Among the simulated merger histories, several progenitors with multi-wavelength properties similar to GNz7q indeed have relatively low mass SMBHs (M_BH~10^{6.5-7.5} Msun), …"

[3.3]
> Page 9, Figure 1 caption, you identify the red quasar as SDSS ID
> 6839. I simply don't know what this id number refers to.

We use the source reference in SDSS DR12, which corresponds to the following webpage: https://dr12.sdss.org/spectrumDetail?plateid=6839&mjd=56425&fiber=146

We have realized that ID6839 is just a part of the source reference. We have replaced it with a full reference of ID 6839-56425-146 (plate-mjd-fiber). We also add the above link in the data availability section so that any readers can easily access this SDSS source. We have also added the explanation and reference of how this SDSS source has been classified as a red quasar in Method Section 2.

[3.4]
> Page 14, last full paragraph: clarify that the measurement of r_e is done from the 125W filter (or is it the result of a joint fit to all the data?).

Yes, the best-fit value provided in the manuscript is derived with the F125W filter. We have revised the sentence to clarify it.

Other revisions:
[3.5] Nature format
Following the suggestion by the editor, we have revised figure legends of Figs 1 and 2 to satisfy the guideline for figure legends. We have made thousands separated by commas, following the Nature formatting guide.

[3.6] Extended Data Figure order
We correct the order of Extended Data Figs. 3–8 so that references to them in the text of the Method Section can be in numerical order.

[3.7] English
Corrections of English have been carefully done by three native English speakers in our co-authors (Gabe Brammer, Darach Watson, Charles Steinhardt). Not to bother your review, minor English corrections are not highlighted with blue font.

[3.8] Updates
Affiliation, acknowledgement, and author contribution have been updated.