Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

JWST evidence for a sharp ``Cosmic Daybreak'' at z=15

Thomas Broadhurst

tom.j.broadhurst@gmail.com

University of the Basque Country https://orcid.org/0000-0002-8785-8979

Jiashuo (Josh) Zhang

Donostia International Physics Center, DIPC

Tzihong Chiueh

Hsi-Yu Schive

Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Keiich Umetsu

Academia Sinica Institute of Astronomy and Astrophysics https://orcid.org/0000-0002-7196-4822

Jose Diego

Instituto de Física de Cantabria https://orcid.org/0000-0001-9065-3926

Paloma Morilla

Physics Dept. University of the Basque Country https://orcid.org/0009-0008-5791-1012

Alvaro Pozo

Donostia International Physics Center

Chian-Chou Chen

Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) https://orcid.org/0000-0002-3805-0789

Jeremy Lim

University of Hong Kong https://orcid.org/0000-0003-4220-2404

Pablo Pérez-González

Centro de Astrobiología (CAB), CSIC/INTA https://orcid.org/0000-0003-4528-5639

Rogier Windhorst

Arizona State University

Article

Keywords:

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11184287/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: There is **NO** Competing Interest.

JWST evidence for a sharp "Cosmic Daybreak" at $z = 15$

Jiashuo (Josh) Zhang[1], Tom Broadhurst[1,2,3],* Tzihong Chiueh[5,6], Hsi-Yu Schive[5,6], Keiichi Umetsu[7], Jose M. Diego[10], Paloma Morilla[3], Alvaro Pozo[1], Chian-Chou Chen[7], Jeremy Lim[8,9], Pablo G. Pérez-González[11], and Rogier Windhorst[12]

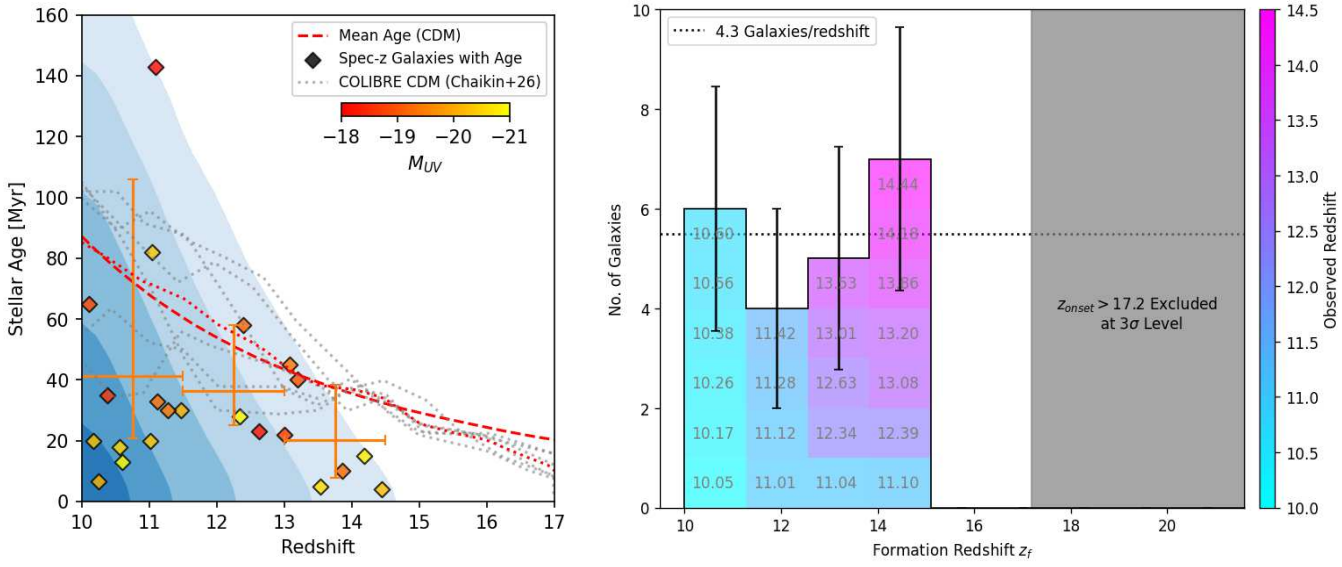
[1]*Donostia International Physics Center, DIPC, Basque Country, San Sebastián, 20018, Spain* [2]*Ikerbasque, Basque Foundation for Science, E-48011 Bilbao, Spain* [3]*Department of Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain* [5]*Department of Physics, National Taiwan University, Taipei 10617, Taiwan* [6]*National Center for Theoretical Sciences, National Taiwan University, Taipei 10617, Taiwan* [7]*Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), No. 1, Section 4, Roosevelt Road, Taipei 106319, Taiwan* [8]*Department of Physics, The University of Hong Kong, Hong Kong S.A.R.* [9]*The Hong Kong Institute for Astronomy and Astrophysics, The University of Hong Kong, Hong Kong S.A.R.* [10]*Instituto de Física de Cantabria (CSIC-UC), Avda. Los Castros s/n., 39005 Santander, Spain* [11]*Centro de Astrobiología (CAB), CSIC-INTA, Ctra. de Ajalvir km 4, Torrejón de Ardoz, E-28850, Madrid, Spain* [12]*School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-1404, USA*

Luminous young galaxies have been uncovered with relative ease by JWST, extending to z=14.5, so it is puzzling that deeper spectroscopy of fainter candidates now finds only interlopers. This redshift 'ìmpasse" is underscored by the measured stellar ages of these high-z galaxies, which we show converge to zero by z=15, with a marked absence of earlier star-formation. Taken literally, such a late transition from the Dark Ages to luminous galaxies is unlike the gradual Cosmic Dawn of standard LCDM, but does confirm a key prediction of Wave Dark Matter, ψDM, as a Bose-Einstein condensate. The de Broglie wave pressure resists gravity until a substantial Jeans mass of $4\times10^9 M_\odot$ is overcome at z=15, corresponding to a light boson $m_\psi = 2.2^{+0.4}_{-0.3}\times10^{-22}$eV, and similar to independent estimates from lensing anomalies and dwarf galaxies. Furthermore, the substantial luminosities of the highest redshift galaxies appear to converge to the initial Jeans scale of ψDM, whereas LCDM predictions extend to lower luminosities and larger ages than observed. These contrasting predictions can be definitively tested as JWST observations accumulate, with diametric implications for Dark Matter as heavy particles beyond the Standard Model or ultra-light bosons motivated by the String Axiverse.

Many high redshift galaxies discovered by JWST at z>10 now have measured ages, spanning $5-150$ Myrs in deep JWST spectroscopy, allowing galaxy formation to be directly charted. High rates of ongoing star formation [1] are derived within compact galaxies, $r \leq 300$pc [2] with steep, metal-poor UV stellar continua [3–5] and large equivalent width ratios of [C III]/Hβ [6–8] indicating young ages $\leq$ 10Myr. Larger stellar ages of up to $\simeq$ 150 Myrs are measured for lower luminosity galaxies, closer to z=10, including post-starburst examples [9, 10]. Here we compare all reported age estimates at z>10 in Figure 1a, revealing the range of ages appears to narrow steadily with increasing redshift, to minimum of $\leq$ 10 Myrs by z=14, indicating that z=15 can be identified empirically as the onset of galaxy formation. We can also use these ages to estimate formation redshifts, z_f, by subtracting the stellar age of each galaxy from its cosmological age given by the measured redshift. This produces a flat trend of z_f up to an abrupt limit of z_f=15.1, above which there is a complete absence of earlier formed, younger galaxies, significant at $> 3\sigma$ level beyond z>17.2, as shown in Figure 1b.

The success of JWST in advancing the redshift frontier has relied mainly on F150W dropout selection, for which the interloper rate has not been significant up to the current maximum of z$\simeq$14.5. However, attempts to push further with F200W dropouts appear to have reached a puzzling "impasse¨, with only $\simeq$ 20 viable photo-z candidates identified in the current multi-survey analyses [14–19], for which spectroscopy of the first seven F200W dropouts [17, 20] finds only interlopers, with z<6.6. These cases have bimodal, high and low redshift photo-z solutions, so it can be predicted that spectroscopy of further such F200W dropouts will yield only interlopers with high probability. Hence, this absence above z=14.5 is stringent, at least for the high luminosities typical of the galaxies discovered near the limit of z=14.44 [21]. Furthermore, the Ly-break at z=14.5 causes only a 30% reduction in F200W flux, so if such luminous galaxies are present at higher redshift they would be easier to recognise by dropping out more strongly in F200W, reaching a maximum depth at z=17.2. Hence, it is despite this deepening that nothing has yet been confirmed beyond z=14.5. For the next filter, F277W, corresponding to

* tom.j.broadhurst@gmail.com



(a) (b)

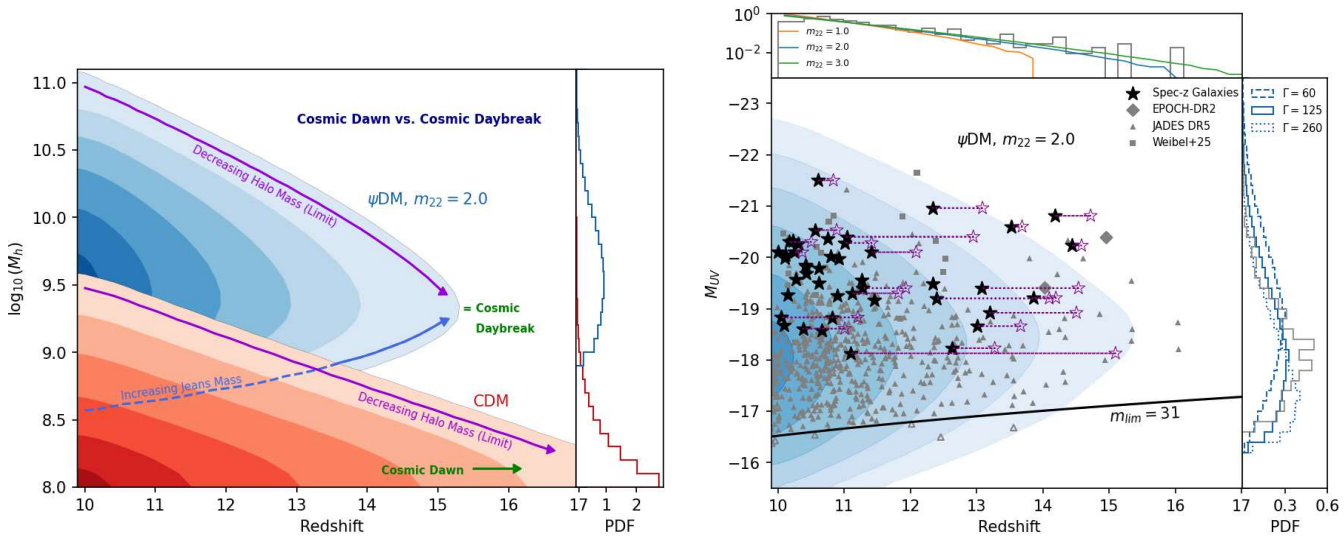
FIG. 1: **Left Panel:** All 22 galaxies with reported stellar ages, compared with their spectroscopic redshifts, indicating by z=15 there is a convergence in age to a minimum of only a few Myrs. The mean observed age and error bars are also indicated. The observations match well the age distribution for ψDM, shaded in blue, for a boson mass of $m_{22} = 2$, for which galaxies first form at z=15. The red dashed line shows the LCDM-based prediction for the evolving halo mass function, which has older mean ages and extends to higher redshift than ψDM. This predicted trend is accurately followed by luminous galaxies highlighted by the latest COLIBRE hydro-simulations[11], shown by the red dotted line, averaged over six individual luminous JWST galaxies (grey dotted lines). and for which star formation extends to $z \simeq 20$. **Right Panel** Individual formation redshifts calculated for all 22 galaxies after subtracting each reported stellar age from the observed cosmological age given by the spectroscopic redshift (shown on the histogram). A marked onset in formation is evident at z=15.1, above which no earlier star formation is inferred empirically, representing a 3σ absence of earlier forming galaxies above z=17.2.

z=18.7-25.5, a complete absence of any dropout candidates is reported by Ref [17], whereas 3 faint candidates have been proposed as high-z possibilities in the currently deepest F277W pointing of the NGDEEP field, reaching $m_{F277W} = 31$, with photo-z´s of z=16-20 [15], for which follow-up spectroscopy is strongly motivated.

If the wider and deeper JWST surveys continue to find the redshift limit only creeps slowly towards z=15 this would be firmly at odds with the long predicted scale-free growth for LCDM, where galaxy formation smoothly extends to lower masses and higher redshifts, well beyond z=15, as illustrated in Figures 1a (red dotted line) and Figure 2a (red contours) and by the FIRE-2 and recent COLIBRE hydro-simulations [11, 22]. By contrast, a sudden and late transition to relatively massive galaxy formation is a key prediction of Wave Dark Matter, ψDM, recognized in cosmological simulations [23] prior to JWST, where the earliest galaxy appeared at z=13, with substantial halo mass of $\sim 10^{9.5} M_\odot$. This onset redshift and initial galaxy mass depends only on the boson mass as the only free parameter for ψDM, which was set to a relatively light value of $m_\psi = 0.8 \times 10^{-22}$eV in these first simulations[23]. Here, for the first time we derive a scaling of the onset redshift with boson mass using the inherent Jeans condition for ψDM set by the Uncertainty Principle, when self-gravity first overcomes the effective wave pressure on the de Broglie scale, defining an halo Jeans scale $k_J = (16\pi G_N \rho_h)^{1/4} (\frac{m_\psi}{\hbar})^{1/2}$ with ρ_h being the azimuthal mean halo density, below which galaxy formation is strongly suppressed [24–26]. For virialized halos, ρ_h follows from the virial over-density Δ_v for non-relativistic collapse [27], which is also appropriate for ψDM. The Jeans condition says galaxies lighter than,

$$M_{min} \approx 1.10 \times 10^9 M_\odot (\frac{m_\psi}{2.2 \times 10^{-22}\text{eV}})^{-3/2} (\frac{1+z}{16})^{3/4}$$

cannot collapse to form a virialized halo. An estimate for the redshift of galaxy formation z_{onset} then follows when M_{min} matches the scale above which heavier halos, corresponding to heavy density peaks, are exponentially suppressed (see Appendix A for details). We confirm in Figure 3 that our analytical z_{onset} estimate (blue dashed curve) agrees with the simulation result of Ref [23] within 1σ uncertainty, indicated by the red star in Figure 3. Using the simulation result as an calibration, giving the red curve, we infer a ψDM mass of $m_\psi \approx 2.18^{+0.41}_{-0.34} \times 10^{-22}$eV from the redshift limit of z_f =15.1. We comment that above argument is independent of the specific form of



(a) (b)

FIG. 2: **Left Panel** Comparison of LCDM and ψDM halo mass distributions, showing the convergence to the limiting Jeans mass at z∼15 predicted for ψDM, with a mass of $m_{22} = 2$. **Right Panel** All reported UV Magnitudes vs spectroscopic redshifts (bold points) and also galaxies with photo-z´s reported in the latest deep and wide analyses[12, 13], together with two confident photo-z cases ($\beta < -3.0$) marked as grey diamonds[14]. The observed excess of luminous detections at z>13 resembles well the V-shaped prediction for ψDM based on the halo mass distribution shown on the left. While photo-z sample extends to $z \sim 16$, purple dotted lines tracing back to when spectroscopically confirmed high-z galaxies have formed do not extend beyond $z \sim 15.1$, as emphasized in Figure 1.

ψDM halo mass functions (HMFs), and derives only from physical arguments. We can also estimate z_{onset} by explicitly integrating the ψDM HMFs above halo Jeans limit, as seen by green curve using the same volume as Ref [23], finding good agreement with their simulation result. For the current survey volume of 0.2 sq. degrees FOV achieved by ASTRODEEP [28] and the latest EPOCHS-DR2 [14], a lighter mass of $m_{22} \simeq 1.7$ is inferred from z_f=15.1, and by doubling the survey area to 0.4 sq. degrees, the maximum predicted redshift for this ψDM mass increases somewhat to z_f=15.4. Regardless the method, the inferred boson masses are in agreement with the range spanned by independent estimates, plotted as horizontal dotted lines in Figure 3 [29–32], and will be better constrained as JWST observations accumulate.

We now examine the distribution of luminosities for z>10, as an additional DM discriminant. The HMF for ψDM is predicted to converge to the initial Jeans mass at z=15 marking the onset of galaxy formation, resulting in a distinctive V-shaped distribution in Figure 2a. This contrasts with the scale free decline with redshift for LCDM, illustrating the slow Cosmic Dawn, also shown in Figure 2a. We compare these contrasting predictions with all reported data shown in Figure 2b, including reliable photo-z´s reported to data in major surveys[12, 13] and the full spectroscopic data (Table 1). In making our model comparison we assume a fixed halo-to-stellar mass ratio (Γ) and a constant star formation history for all galaxies, and use `Bagpipes` [34] stellar synthesis code to generate the UV absolute magnitude, M_{UV}, as a function of age. For more details on the simulated sample, see Appendix. The effect of varying Γ is indicated on the right panel of Figure 2b, showing that an increase shifts the prediction of ψDM to higher mean luminosity, with a good fit to the data plotted in Figure 2b achieved with $\Gamma = 125$, corresponding to a modest stellar mass of one percent of the halo mass (and a cosmic baryon-star conversion efficiency of $\sim 5\%$). The characteristic V-shaped distribution of ψDM describes well the data, which appears to narrow with increasing redshift, centred on an absolute magnitude of $M_{UV} \sim -19$ by z∼15, well above a flux limit of $m_{lim} = 31$, and quite different from the generic prediction of LCDM for which galaxies should be crowded down to the flux limit at any redshift, unlike the data, as can be inferred from Figure 2a.

Selection effects modulate the redshift detection in Figure 2, from broadband selection to the differing depths and filter choices of the major JWST surveys. These have been accurately corrected for in recent measurements of the integrated UV luminosity density[18, 33], shown in Figure 4 as black data points, allowing for a quantitative comparison with model predictions. For LCDM, the detailed FIRE-2 hydro simulation designed as a benchmark prediction just prior to JWST [22] is shown in Figure 4, invoking bursty star-formation, matching the lower redshift range but overshoots the latest data at high-z. The relatively steep observed redshift trend is readily matched by our simple ψDM prediction in Figure 4, for the same

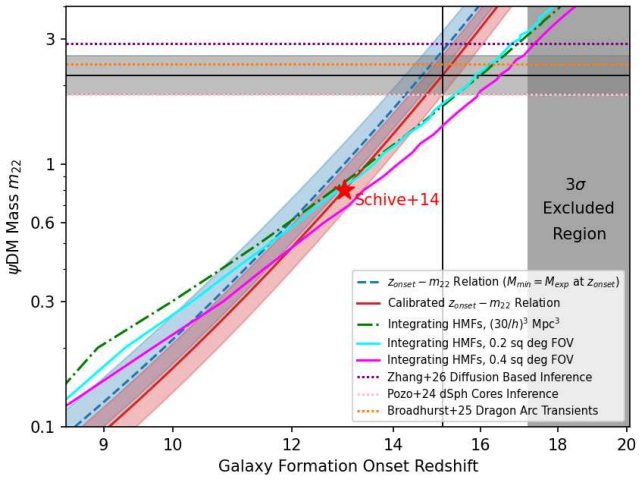


FIG. 3: The locus of formation redshift z_f as a function of boson mass (blue dashed curve) obtained through matching the scale of exponentially suppressed density peaks with minimum gravitational collapse scale. The plotted scaling agrees well with the highest redshift halo seen in the cosmological simulation of ψDM at z=13 [23], indicated by the red star, and implying mass of $m_{22} \simeq 2.2$ for z_f=15.1 after calibration (red curve). The green solid curve shows the alternative HMF based locus that also agrees with simulation and finds a boson mass of $m_{22} \simeq 1.7$ for z_f=15.1. The magenta curve shows the modest increase in maximum redshift we predict for different ψDM masses by doubling the surveyed area. These Jeans and HMF based boson masses are similar to independent estimates from lensing and dynamics shown by horizontal dashed lines [29–32].

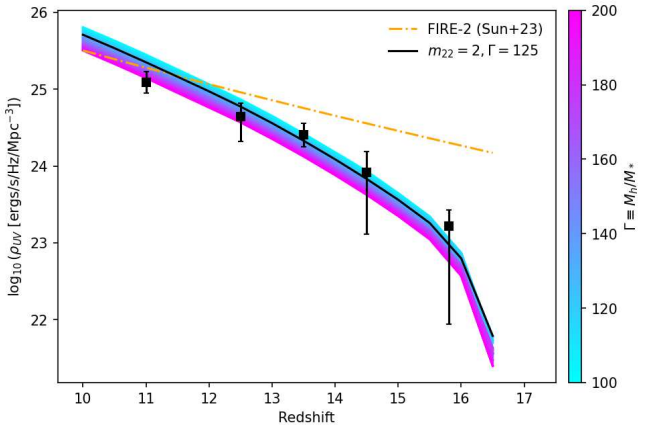


FIG. 4: Integrated UV density from the recent multi-survey analysis [18, 33] compared with ψDM ($m_{22} = 2.0$) predictions for a range of halo to stellar mass ratio (Γ) colour coded. It can be seen that despite the simplicity of our model the integrated UV density is well reproduced with $\Gamma = 125$ (black line), consistent with the V-shaped $M_{UV} - z$ distribution of Figure 2b. The dashed orange line is the benchmark FIRE-2 hydro-LCDM modelling [22]), which is shallower than the data, over predicting the observed decline at high-z.

mean Γ and boson mass used in Figure 2b, assuming only the evolving HMF for ψDM and a simple constant SFH model for galaxies.

A further distinguishing test can be made with spectroscopy of the lower luminosity photo-z candidates at z>13, seen in Figure 2b, which if found to have substantial stellar ages of 40Myrs, would support LCDM [11], as shown in Figure 1a, whereas ages of <10Myrs are required by ψDM. This UV spectral slope of the stellar population may also help, as all galaxies close to z=15 need to be very young for ψDM as is indeed seen for the highest redshift galaxies, very steep in the UV [2, 5, 21, 35], including two very blue proposed photo-z candidates $\beta < -3.0$ near z=14.5 [14]. But for LCDM, UV slopes would be reddened by comparably older stellar ages, or by substantial dust extinction that is predicted in hydro-simulations [11], providing a further testable prediction motivating deep JWST spectroscopy of lower luminosity candidates at z>13.5.

It has been over a year since the z=14.44 record redshift was established, despite the high luminosities of the highest redshift galaxies. This also appears to be the case for the large lensing programs underway with JWST, where over 100 massive lensing clusters reach highly magnified sources, but nothing has been found beyond z=15 despite the positive magnification biassed faint-end luminosity function for LCDM (see Appendix). Hence, a continued absence of higher redshift galaxies may soon falsify LCDM and by the same token may bolster ψDM. Galaxy formation is also delayed by Warm Dark Matter (WDM), as free streaming smooths away substructure but may be distinguished by lensing from the ubiquitous granular substructure of ψDM[30, 36]. Other distinguishing measurements include filament induced elongation of young galaxies [37, 38] and stellar dynamics heated by internal de Broglie wave action[29, 39]. Currently for ψDM the boson mass favoured here of $\simeq 2 \times 10^{-22}$eV is consistent with the lensing and dynamical estimates, but substantial improvements in observational precision of these estimates are feasible thanks to JWST, providing stringent tests of these leading DM contenders.

ACKNOWLEDGMENTS

TJB thanks Richard Ellis and Guido Roberts-Borsani for inspiring discussions. J.Z. and TJB. acknowledge the CEX2024-001491-S grant, funded by MICIU/AEI/10.13039/501100011033. TJB. is supported by the Spanish Grant PID2023-149016NB-I00 (MINECO/AEI/FEDER, UE). J.L. acknowledges the RGC/GRF 17304425 grant. K.U. acknowledges support from the National Science and Technology Council of Taiwan (grants NSTC 112-2112-M-001-027-MY3 and NSTC

115-2112-M-001-027-) and the Academia Sinica Investigator Award (grant AS-IA-112-M04). H.Y.S. is supported by the National Science and Technology Council (NSTC) of Taiwan under Grant No NSTC 115-2628-M-002-019-MY4. Also PGP-G acknowledges support from grants PID2022-139567NB-I00 and PID2025-169195NB-I00 funded by Spanish Ministerio de Ciencia, Innovación y Universidades MICIU/AEI/10.13039/501100011033, and the European Union FEDER program *Una manera de hacer Europa*.

Appendix A: ψDM $z_{onset} - m_{22}$ scaling

The lowest mass galaxies formed in ψDM at a given redshift correspond to the minimum mass whose self-gravity can over-come the effective wave pressure on the de Broglie scale, within which the Uncertainty Principle prevents confinement of material. A corresponding Jeans scale can be defined, setting the lower halo mass limit, such that [24]:

$$k_J = (16\pi G_N \rho_h)^{1/4} \left(\frac{m_\psi}{\hbar}\right)^{1/2},$$

where ρ_h is mean halo density. For virialized halos, ρ_h is simply given by $\Delta_v \overline{\rho_m}$ with Δ_v the virial over-density constant obtainable from fitting to ΛCDM simulation [27]:

$$\Delta_v = \frac{18\pi^2 + 82(\Omega_m - 1) - 39(\Omega_m - 1)^2}{\Omega_m(z)},$$

$$\Omega_m(z) = \Omega_{m0}(1+z)^3 \left(\frac{H_0}{H(z)}\right)^2,$$

The above Jean scale k_J corresponds to a minimum halo mass scale of:

$$M_{min} = \frac{4\pi}{3}\Delta_v \overline{\rho_m}\left(\frac{2\pi}{k_J}\right)^3 = (1+z)^{3/4}\Delta_v(z)^{1/4} m_{22}^{-3/2}\left(\frac{\Omega_{m,0}h^2}{0.143}\right)^{1/4} 1.23\times 10^8 M_\odot,$$

where $m_{22} \equiv m_\psi/10^{-22}$, and we adopt $\Omega_{m,0} = 0.315$, $H_0 = 67.37$ km/s/Mpc as measured by Planck Collaboration *et al.* [40]. Note this Jeans cut-off is lower than $M_{1/2}$ characterizing where ψDM linear matter power spectrum (and HMF) is halved compared to that of LCDM[41], because $M_{1/2}$ encodes earlier suppression from radiation-dominated epoch, whereas M_{min} prohibits the collapse of small over-densities in matter-dominated epoch. In Figure 5, we plot M_{min} at different redshifts for $m_{22} = 1, 3, 9, 27$ as coloured dashed curves, where it can be seen the lighter the boson mass, the heavier the minimum halo mass.

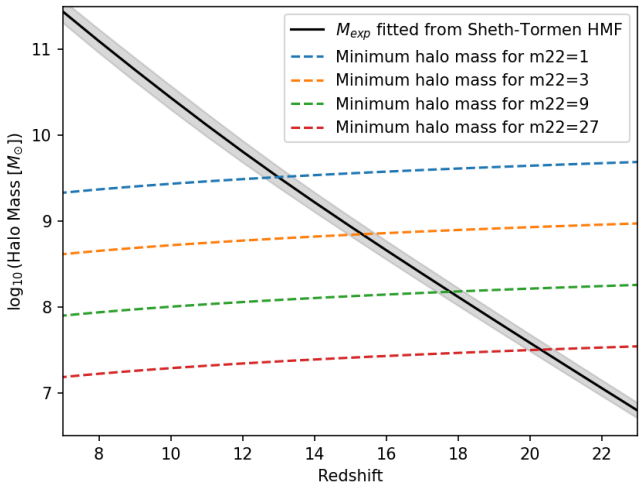


FIG. 5: Lower cut-off (i.e. Jeans limit) mass M_{min} for four choices of boson masses of $m_\psi = 1, 3, 9, 27 \times 10^{-22}$eV, dashed curves, compared with the exponential cut-off mass scale M_* (solid black curve) estimated for the Sheth-Tormen HMFs. Shaded region indicates the numerical fitting uncertainty. An onset redshift can be defined as where M_{min} and M_{exp} meet, as shown in Figure 3.

Very massive galaxies at high redshifts are also suppressed, owing to exponentially suppressed abundance of large over-densities. Hence, we can arrive at the corresponding maximum, or onset, redshift of galaxy formation for each m_{22} by equating M_{min} with the turnover scale of the HMFs. For this purpose we adopt python package `hmfmake` [42] to construct the Sheth-Tormen HMFs as a function of redshift, and measure the corresponding exponential cut-off mass scales M_{exp} through fitting Sheth-Tormen HMFs with a Press-Schechter form $\frac{dn}{d\ln M} = AM^\alpha e^{-(\frac{M}{M_{exp}})^\beta}$. In Figure 5, this fitted M_{exp} at different redshift is plotted as a black solid line, with the numerical uncertainty in fitting shown as gray shaded region. This figure then provides pictorial representation for z_{onset} as a function of ψDM mass, corresponding to where intersection of curves occurs as shown. $z_{onset}-m_{22}$ scaling thus obtained, along with uncertainty, is shown in Figure 3 as the blue dashed line.

Appendix B: simulated sample

In Figure 2b, we compare all reported spec-z galaxies at $z > 10$ from multiple JWST field surveys and the lensed examples, with our ψDM based predictions for the distribution of luminosity with redshift. The corresponding simulated sample was obtained through numerical sampling of HMFs, where we started from an initial redshift of 30, and 'track' the formation of galaxies in small redshift increments of 0.05, with the number of sampled galaxies obtained through integrating Sheth-

Tormen HMFs with simulation-based ψDM low-mass end suppression[41] included. As quantum pressure forbids over-densities on a mass scale below M_{min} to collapse, our HMF integration limits are from $M_{min}(z, m_{22})$ to $10^{17} M_\odot$ for ψDM model. For LCDM model without low-mass end suppression on HMF, for comparison done in Figure 2a, we adopt integration limits from $10^8 M_\odot$ to $10^{17} M_\odot$ instead. We assume a fiducial area of 0.2 square degree matching the large area achieved by ASTRODEEP catalog[28] and latest EPOCHS-DR2 [14].

At each redshift, halo masses are randomly drawn from the underlying HMF and ages are randomly assigned from the cumulative age distribution, measured from all previously injected galaxies with ages evolved to the current working redshift. Figure 1 presents the stellar age distribution thus obtained for ψDM, showing an increased upper limits at lower redshift and convergence to zero age near $z_{onset} \sim 15$, while the red dotted line showing mean stellar age at different redshifts for LCDM extends to higher redshifts. The stellar masses of sampled galaxies are assigned with a fixed halo-to-stellar mass ratio, $\Gamma \equiv M_h/M_* \simeq 125$. Then the stellar masses, along with respective assigned ages, are converted into M_{UV} assuming a constant SFH for galaxies. More specifically, we used public-available python library `bagpipes` with default BC03 stellar grids[43] to obtain Age-M_{UV} curve, fixing to $M_* = 10^9 M_\odot$ and assuming observationally motivated metallicity $Z = 0.1 Z_\odot$ and ionization parameter $\log U = -2$ for high spec-z galaxies [6, 7]. The final luminosity-redshift distribution of simulated galaxies is presented by blue contours in Figure 2b.

Appendix C: Anticipated Number of Highly Magnified Galaxies/Arcs

The fact that there has been no detection of strongly lensed high-z galaxies beyond redshift 15 is startling for LCDM given the large number (~ 150 through a rough estimate) of clusters surveyed, as we show below with a quick estimate on the number of highly magnified $15 \leq z \leq 16$ galaxies anticipated. Magnification bias [44–46] finds the density of lensed galaxies to be

$$n_{len}(z, \mu_z, m_{lim}) = \frac{\int_{-\infty}^{m_{lim}+2.5\log_{10}\mu_z} \phi(m', z) dm'}{\mu_z},$$

where $\phi(m)$ is the underlying LF, m_{lim} is the magnitude limit, and μ_z the lensing magnification factor whose appearance in the bottom reflects that the cosmic volume is simultaneously reduced as the detection limit is lowered (by $2.5 \log_{10} \mu$). Above expression converts to an estimate of the total number of lensed $15 \leq z \leq 16$ galaxies through explicit integration over redshift, given the knowledge of underlying LF and also covered areas by differently magnified regions. For highly magnified regions with $\mu > 15$, Ref [47] (Figure 3) demonstrates that different lensing clusters share the same scaling law for the covered areas above a given magnified factor, with an median relation of $A(> \mu) \approx 10[\text{sq. arcmin}]/\mu$ that we shall adopt. We may further differentiate above scaling to give $S(\mu) \approx 10/\mu^2$, such that $A(> \mu) = \int_\mu^\infty S(\mu) d\mu = 0 - (-10/\mu) = 10/\mu$, with which, we calculate the total number of lensed arc (or strongly lensed galaxies with $\mu > \mu_0$) above detection threshold m_{lim} as:

$$N = N_{cluster} \int dz \int_{\mu_0} d\mu_z \; n_{len}(z, \mu_z, m_{lim}) S(\mu_z) \frac{dV}{d\Omega dz}\bigg|_z$$

where $N_{cluster}$ is number of clusters currently imaged by JWST ≈ 150, and $\frac{dV}{d\Omega dz}$ is incremental cosmic volume per square arcmin. Using FIRE-2 LFs and $m_{lim} = 31$, we anticipate ~ 19 $15 \leq z \leq 16$ galaxies should have been imaged already given the large sample of lensing clusters that have been imaged today.

While above calculation is based on a specific (FIRE-2) UV LFs model, we emphasize that the detection of high-z galaxies are made easier with gravitational lensing for LCDM in general, as the scale free structure formation suggests an ever increasing abundance of fainter galaxies, which compensates for the $1/\mu$ reduction in cosmic volume and leads to $n_{len} > n_{unlensed}$, i.e. positive magnification bias. Those fainter $z > 15$ galaxies are non-existent in ψDM, hence gravitational lensing would only be magnifying total emptiness, as is hinted by the current no detections of highly magnified galaxies.

[1] V. Kokorev, Ó. A. Chávez Ortiz, A. J. Taylor, S. L. Finkelstein, P. Arrabal Haro, M. Dickinson, J. Chisholm, S. Fujimoto, J. B. M. noz, R. Endsley, W. Hu, L. Napolitano, S. M. Wilkins, H. B. Akins, R. Amoriín, C. M. Casey, Y. Cheng, N. J. Cleri, J. Cole, F. Cullen, E. Daddi, K. Davis, C. T. Donnan, J. S. Dunlop, V. Fernández, M. Giavalisco, N. A. Grogin, N. Hathi, M. Hirschmann, J. S. Kartaltepe, A. M. Koekemoer, H.-H. Leung, R. A. Lucas, D. McLeod, C. Papovich, L. Pentericci, P. G. Pérez-González, R. S. Somerville, X. Wang, L. Y. A. Yung, and J. A. Zavala, CAPERS Observations of Two UV-bright Galaxies at z ¿ 10. More Evidence for Bursting Star Formation in the Early Universe, ApJ **988**, L10 (2025), arXiv:2504.12504 [astro-ph.GA].

[2] J. M. Helton, J. E. Morrison, K. N. Hainline, F. D'Eugenio, G. H. Rieke, S. Alberts, S. Carni-

ani, J. Leja, Y. Li, P. Rinaldi, J. Scholtz, M. Stone, C. N. A. Willmer, Z. Wu, W. M. Baker, A. J. Bunker, S. Charlot, J. Chevallard, N. J. Cleri, M. Curti, E. Curtis-Lake, E. Egami, D. J. Eisenstein, P. Jakobsen, Z. Ji, B. D. Johnson, N. Kumari, X. Lin, J. Lyu, R. Maiolino, M. Maseda, P. G. Pérez-González, M. J. Rieke, B. Robertson, A. Saxena, F. Sun, S. Tacchella, H. Übler, G. Venturi, C. C. Williams, C. Willott, J. Witstok, and Y. Zhu, Ionizing Photon Production Efficiencies and Chemical Abundances at Cosmic Dawn Revealed by Ultra-Deep Rest-Frame Optical Spectroscopy of JADES-GS-z14-0, arXiv e-prints , arXiv:2512.19695 (2025), arXiv:2512.19695 [astro-ph.GA].

[3] A. J. Bunker, A. Saxena, A. J. Cameron, C. J. Willott, E. Curtis-Lake, P. Jakobsen, S. Carniani, R. Smit, R. Maiolino, J. Witstok, M. Curti, F. D'Eugenio, G. C. Jones, P. Ferruit, S. Arribas, S. Charlot, J. Chevallard, G. Giardino, A. de Graaff, T. J. Looser, N. Lützgendorf, M. V. Maseda, T. Rawle, H.-W. Rix, B. R. Del Pino, S. Alberts, E. Egami, D. J. Eisenstein, R. Endsley, K. Hainline, R. Hausen, B. D. Johnson, G. Rieke, M. Rieke, B. E. Robertson, I. Shivaei, D. P. Stark, F. Sun, S. Tacchella, M. Tang, C. C. Williams, C. N. A. Willmer, W. M. Baker, S. Baum, R. Bhatawdekar, R. Bowler, K. Boyett, Z. Chen, C. Circosta, J. M. Helton, Z. Ji, N. Kumari, J. Lyu, E. Nelson, E. Parlanti, M. Perna, L. Sandles, J. Scholtz, K. A. Suess, M. W. Topping, H. Übler, I. E. B. Wallace, and L. Whitler, JADES NIRSpec Spectroscopy of GN-z11: Lyman-α emission and possible enhanced nitrogen abundance in a z = 10.60 luminous galaxy, A&A **677**, A88 (2023), arXiv:2302.07256 [astro-ph.GA].

[4] S. Carniani, K. Hainline, F. D'Eugenio, D. J. Eisenstein, P. Jakobsen, J. Witstok, B. D. Johnson, J. Chevallard, R. Maiolino, J. M. Helton, C. Willott, B. Robertson, S. Alberts, S. Arribas, W. M. Baker, R. Bhatawdekar, K. Boyett, A. J. Bunker, A. J. Cameron, P. A. Cargile, S. Charlot, M. Curti, E. Curtis-Lake, E. Egami, G. Giardino, K. Isaak, Z. Ji, G. C. Jones, N. Kumari, M. V. Maseda, E. Parlanti, P. G. Pérez-González, T. Rawle, G. Rieke, M. Rieke, B. R. Del Pino, A. Saxena, J. Scholtz, R. Smit, F. Sun, S. Tacchella, H. Übler, G. Venturi, C. C. Williams, and C. N. A. Willmer, Spectroscopic confirmation of two luminous galaxies at a redshift of 14, Nature **633**, 318 (2024), arXiv:2405.18485 [astro-ph.GA].

[5] C. T. Donnan, D. J. McLeod, R. J. McLure, J. S. Dunlop, F. Cullen, M. Dickinson, P. Arrabal Haro, A. J. Taylor, C. Bondestam, F.-Y. Liu, K. Z. Arellano-Córdova, L. Barrufet, R. Begley, A. C. Carnall, H. Golawska, H.-H. Leung, D. Scholte, and T. M. Stanton, Spectroscopic confirmation of a large and luminous galaxy with weak emission lines at $\mathbf{z = 13.53}$, arXiv e-prints , arXiv:2601.11515 (2026), arXiv:2601.11515 [astro-ph.GA].

[6] G. Roberts-Borsani, P. A. Oesch, R. Ellis, A. Weibel, E. Giovinazzo, R. Bouwens, P. Dayal, A. Fontana, K. E. Heintz, J. Matthee, R. A. Meyer, L. Pentericci, A. Shapley, S. Tacchella, T. Treu, F. Walter, H. Atek, S. Bose, M. Castellano, Y. Fudamoto, T. Morishita, R. P. Naidu, R. L. Sanders, and A. van der Wel, JWST Spectroscopic Insights Into the Diversity of Galaxies in the First 500 Myr: Short-Lived Snapshots Along a Common Evolutionary Pathway, MNRAS 10.1093/mnras/stag701 (2026), arXiv:2508.21708 [astro-ph.GA].

[7] M. Tang, D. P. Stark, C. A. Mason, V. Gelli, Z. Chen, and M. W. Topping, The JWST Spectroscopic Properties of Galaxies at $z = 9 - 14$, arXiv e-prints , arXiv:2507.08245 (2025), arXiv:2507.08245 [astro-ph.GA].

[8] J. Scholtz, M. S. Silcock, E. Curtis-Lake, R. Maiolino, S. Carniani, F. D'Eugenio, X. Ji, P. Jakobsen, K. Hainline, S. Arribas, W. M. Baker, R. Bhatawdekar, A. J. Bunker, S. Charlot, J. Chevallard, M. Curti, D. J. Eisenstein, Y. Isobe, G. C. Jones, E. Parlanti, P. G. Pérez-González, P. Rinaldi, B. Robertson, S. Tacchella, H. Übler, C. C. Williams, C. Willott, and J. Witstok, JADES: carbon-enhanced, nitrogen-normal compact galaxy at z = 11.2, MNRAS **545**, staf2107 (2026), arXiv:2507.17809 [astro-ph.GA].

[9] M. Bradač, J. Judež, C. Willott, G. Rihtaršic, N. S. Martis, A. Harshan, G. Felicioni, Y. Asada, G. Desprez, D. Clowe, A. H. Gonzalez, C. Jones, B. C. Lemaux, M. Markevitch, V. Markov, L. Mowla, G. Noirot, A. H. G. Peter, A. Robertson, G. T. E. Sarrouh, M. Sawicki, T. Schrabback, and R. Tripodi, Star Formation under a Cosmic Microscope: Highly Magnified z = 11 Galaxy behind the Bullet Cluster, ApJ **995**, L74 (2025), arXiv:2509.20446 [astro-ph.GA].

[10] Y. Harikane, P. G. Perez-Gonzalez, J. Alvarez-Marquez, M. Ouchi, Y. Nakazato, Y. Ono, K. Nakajima, H. Umeda, Y. Isobe, Y. Xu, and Y. Zhang, A UV-Luminous Galaxy at z=11 with Surprisingly Weak Star Formation Activity, arXiv e-prints , arXiv:2601.21833 (2026), arXiv:2601.21833 [astro-ph.GA].

[11] E. Chaikin, A. Pontzen, C. S. Frenk, J. Schaye, S. Lu, R. A. Crain, and A. Durrant, The progenitors of $zrsim10$ JWST galaxies in the COLIBRE simulations, arXiv e-prints , arXiv:2608.19007 (2026), arXiv:2608.19007 [astro-ph.GA].

[12] K. N. Hainline, D. J. Eisenstein, L. Whitler, B. Robertson, B. D. Johnson, P. Jakobsen, D. Puskás, S. Tacchella, J. M. Helton, Z. Wu, S. Arribas, W. M. Baker, A. J. Bunker, A. J. Cameron, S. Carniani, C. Carreira, S. Charlot, J. Chevallard, E. Curtis-Lake, F. D'Eugenio, Q. Duan, E. Egami, R. Hausen, Z. Ji, T. J. Looser, R. Maiolino, P. Mengistu, P. G. Pérez-González, M. Rieke, P. Rinaldi, F. Sun, J. A. A. Trussler, H. Übler, C. C. Williams, C. N. A. Willmer, C. Willott, and J. Witstok, JWST Advanced Deep Extragalactic Survey Data Release 5: Photometrically Selected Galaxy Candidates at z ¿ 8, ApJ **1004**, 161 (2026), arXiv:2601.15959 [astro-ph.GA].

[13] A. Weibel, P. A. Oesch, C. C. Williams, C. K. Jespersen, M. Shuntov, K. E. Whitaker, H. Atek, R. Bezanson, G. Brammer, I. Chemerynska, A. P. Cloonan, P. Dayal, L. J. Furtak, A. Hutter, Z. Ji, M. V. Maseda, and M. Xiao, Exploring Cosmic Dawn with PANORAMIC I: The Bright End of the UVLF at $z \sim 9 - 17$, arXiv e-prints , arXiv:2507.06292 (2025), arXiv:2507.06292 [astro-ph.GA].

[14] D. Austin, C. J. Conselice, T. Harvey, N. J. Adams, L. Quilley, J. C. J. D'Silva, V. Rusakov, Q. Li, L. Westcott, C. Goolsby, J. Arcidiacono, K. Madgwick, W. J. Roper, B. Frye, N. A. Grogin, R. O. III, and R. Windhorst, Epochs-dr2 i: Expanded data release and properties of $6.5 < z < 16.5$ photometrically selected galaxies across nircam deep fields covering $\sim 700\,\mathrm{arcmin}^2$ with the galfind software (2026), arXiv:2609.24987 [astro-ph.GA].

[15] P. G. Pérez-González, G. Östlin, L. Costantin, J. Melin-

der, S. L. Finkelstein, R. S. Somerville, M. Annunziatella, J. Álvarez-Márquez, L. Colina, A. Dekel, H. C. Ferguson, Z. Li, L. Y. A. Yung, M. B. Bagley, L. A. Boogaard, D. Burgarella, A. Calabrò, K. I. Caputi, Y. Cheng, M. Dickinson, A. Eckart, M. Giavalisco, S. Gillman, T. R. Greve, M. Hamed, N. P. Hathi, J. Hjorth, M. Huertas-Company, J. S. Kartaltepe, A. M. Koekemoer, V. Kokorev, Á. Labiano, D. Langeroodi, G. C. K. Leung, P. Natarajan, C. Papovich, F. Peissker, L. Pentericci, N. Pirzkal, P. Rinaldi, P. van der Werf, and F. Walter, The Rise of the Galactic Empire: Ultraviolet Luminosity Functions at z $\sim$ 17 and z $\sim$ 25 Estimated with the MIDIS+NGDEEP Ultra-deep JWST/NIRCam Data Set, ApJ **991**, 179 (2025), arXiv:2503.15594 [astro-ph.GA].

[16] R. A. Meyer, L. Barrufet, L. A. Boogaard, R. P. Naidu, P. A. Oesch, and F. Walter, NOEMA reveals the true nature of luminous red JWST z ¿ 10 galaxy candidates, A&A **681**, L3 (2024), arXiv:2310.20675 [astro-ph.GA].

[17] M. Castellano, A. Fontana, E. Merlin, P. Santini, L. Napolitano, N. Menci, P. G. Pérez-González, A. Calabrò, D. Paris, L. Pentericci, J. A. Zavala, M. Dickinson, S. L. Finkelstein, T. Treu, R. O. Amorin, P. Arrabal Haro, P. Bergamini, L. Bisigello, M. Catone, E. Daddi, P. Dayal, A. Dekel, A. Ferrara, F. Fortuni, G. Gandolfi, M. Giavalisco, C. Grillo, S. T. Guida, N. P. Hathi, B. W. Holwerda, A. M. Koekemoer, V. Kokorev, Z. Li, M. Llerena, R. A. Lucas, S. Mascia, B. Metha, T. Morishita, T. Nanayakkara, F. Pacucci, G. Roberts-Borsani, G. Rodighiero, P. Rosati, V. Salazar, R. Schneider, R. S. Somerville, A. Taylor, M. Trenti, A. Trinca, X. Wang, P. J. Watson, L. Yang, and L. Y. A. Yung, Pushing JWST to the extremes: Search and scrutiny of bright galaxy candidates at z $\simeq$ 15-30, A&A **704**, A158 (2025), arXiv:2504.05893 [astro-ph.GA].

[18] D. J. McLeod, J. S. Dunlop, R. J. McLure, C. T. Donnan, R. Begley, S. Antonogiannaki, D. Magee, G. D. Illingworth, P. Arrabal Haro, C. Bondestam, A. C. Carnall, F. Cullen, M. Dickinson, R. S. Ellis, B. L. Frye, H. Golawska, N. A. Grogin, I. J. B. Holst, P. S. Kamieneski, H.-H. Leung, F.-Y. Liu, T. M. Stanton, and E. R. Tittley, A search for the first galaxies across $>$ 0.6 deg^2 of JWST imaging: new evidence for a rapid decline in star-formation activity at $z > 12$, arXiv e-prints , arXiv:2604.16666 (2026), arXiv:2604.16666 [astro-ph.GA].

[19] G. Gandolfi, G. Rodighiero, L. Bisigello, A. Grazian, S. L. Finkelstein, M. Dickinson, M. Castellano, E. Merlin, A. Calabrò, C. Papovich, A. Bianchetti, E. Bañados, P. Benotto, M. Catone, F. Buitrago, E. Daddi, G. Girardi, M. Giulietti, M. Hirschmann, B. W. Holwerda, P. Arrabal Haro, A. Lapi, R. A. Lucas, Y. Lyu, M. Massardi, F. Pacucci, P. G. Pérez-González, T. Ronconi, M. Tarrasse, S. Wilkins, B. Vulcani, L. Y. A. Yung, J. A. Zavala, B. Backhaus, M. Bagley, V. Buat, D. Burgarella, J. Kartaltepe, Y. Khusanova, A. Kirkpatrick, D. Kocevski, A. M. Koekemoer, E. Lambrides, N. Pirzkal, and G. Yang, Ultrahigh-redshift or closer-by, dust-obscured galaxies?: Deciphering the nature of faint, previously missed F200W dropouts in CEERS, A&A **708**, A195 (2026), arXiv:2502.02637 [astro-ph.GA].

[20] P. Arrabal Haro, M. Dickinson, S. L. Finkelstein, J. S. Kartaltepe, C. T. Donnan, D. Burgarella, A. C. Carnall, F. Cullen, J. S. Dunlop, V. Fernández, S. Fujimoto, I. Jung, M. Krips, R. L. Larson, C. Papovich, P. G. Pérez-González, R. O. Amorín, M. B. Bagley, V. Buat, C. M. Casey, K. Chworowsky, S. H. Cohen, H. C. Ferguson, M. Giavalisco, M. Huertas-Company, T. A. Hutchison, D. D. Kocevski, A. M. Koekemoer, R. A. Lucas, D. J. McLeod, R. J. McLure, N. Pirzkal, L.-M. Seillé, J. R. Trump, B. J. Weiner, S. M. Wilkins, and J. A. Zavala, Confirmation and refutation of very luminous galaxies in the early Universe, Nature **622**, 707 (2023), arXiv:2303.15431 [astro-ph.GA].

[21] R. P. Naidu, P. A. Oesch, G. Brammer, A. Weibel, Y. Li, J. Matthee, J. Chisolm, C. L. Pollock, K. E. Heintz, B. D. Johnson, X. Shen, R. E. Hviding, J. Leja, S. Tacchella, A. Ganguly, C. Witten, H. Atek, S. Belli, S. Bose, R. Bouwens, P. Dayal, R. Decarli, A. de Graaff, Y. Fudamoto, E. Giovinazzo, J. E. Greene, G. Illingworth, A. K. Inoue, S. G. Kane, I. Labbe, E. Leonova, R. Marques-Chaves, R. A. Meyer, E. J. Nelson, G. Roberts-Borsani, D. Schaerer, R. A. Simcoe, M. Stefanon, Y. Sugahara, S. Toft, A. van der Wel, P. van Dokkum, F. Walter, D. Watson, J. R. Weaver, and K. E. Whitaker, A Cosmic Miracle: A Remarkably Luminous Galaxy at zspec = 14.44 Confirmed with JWST, The Open Journal of Astrophysics **9**, 56033 (2026), arXiv:2505.11263 [astro-ph.GA].

[22] G. Sun, C.-A. Faucher-Giguère, C. C. Hayward, X. Shen, A. Wetzel, and R. K. Cochrane, Bursty Star Formation Naturally Explains the Abundance of Bright Galaxies at Cosmic Dawn, ApJ **955**, L35 (2023), arXiv:2307.15305 [astro-ph.GA].

[23] H.-Y. Schive, T. Chiueh, and T. Broadhurst, Cosmic structure as the quantum interference of a coherent dark wave, Nature Physics **10**, 496 (2014), arXiv:1406.6586 [astro-ph.GA].

[24] W. Hu, R. Barkana, and A. Gruzinov, Fuzzy Cold Dark Matter: The Wave Properties of Ultralight Particles, Phys. Rev. Lett. **85**, 1158 (2000), arXiv:astro-ph/0003365 [astro-ph].

[25] P. J. E. Peebles, Fluid Dark Matter, ApJ **534**, L127 (2000), arXiv:astro-ph/0002495 [astro-ph].

[26] D. J. E. Marsh and J. Silk, A model for halo formation with axion mixed dark matter, MNRAS **437**, 2652 (2014), arXiv:1307.1705 [astro-ph.CO].

[27] G. L. Bryan and M. L. Norman, Statistical Properties of X-Ray Clusters: Analytic and Numerical Comparisons, ApJ **495**, 80 (1998), arXiv:astro-ph/9710107 [astro-ph].

[28] E. Merlin, P. Santini, D. Paris, M. Castellano, A. Fontana, T. Treu, S. L. Finkelstein, J. S. Dunlop, P. Arrabal Haro, M. Bagley, K. Boyett, A. Calabrò, M. Correnti, K. Davis, M. Dickinson, C. T. Donnan, H. C. Ferguson, F. Fortuni, M. Giavalisco, K. Glazebrook, A. Grazian, N. A. Grogin, N. Hathi, M. Hirschmann, J. S. Kartaltepe, L. J. Kewley, A. Kirkpatrick, D. D. Kocevski, A. M. Koekemoer, G. Leung, J. M. Lotz, R. A. Lucas, D. K. Magee, D. Marchesini, S. Mascia, D. J. McLeod, R. J. McLure, T. Nanayakkara, L. Napolitano, M. Nonino, C. Papovich, L. Pentericci, P. G. Pérez-González, N. Pirzkal, S. Ravindranath, G. Roberts-Borsani, R. S. Somerville, M. Trenti, J. R. Trump, B. Vulcani, X. Wang, P. J. Watson, S. M. Wilkins, G. Yang, and L. Y. A. Yung, ASTRODEEP-JWST: NIRCam-HST multi-band photometry and redshifts for half a million sources in six extragalactic deep fields, A&A **691**, A240 (2024), arXiv:2409.00169 [astro-

ph.GA].
[29] A. Pozo, T. Broadhurst, G. F. Smoot, T. Chiueh, H. N. Luu, M. Vogelsberger, and P. Mocz, Dwarf galaxies united by dark bosons, Phys. Rev. D **109**, 083532 (2024), arXiv:2302.00181 [astro-ph.CO].
[30] T. Broadhurst, S. K. Li, A. Alfred, J. M. Diego, P. Morilla, P. L. Kelly, F. Sun, M. Oguri, H. Williams, R. Windhorst, A. Zitrin, K. T. Abe, W. Chen, L. Dai, Y. Fudamoto, H. Kawai, J. Lim, T. Liu, A. K. Meena, J. M. Palencia, G. F. Smoot, and L. L. R. Williams, Dark Matter Distinguished by Skewed Microlensing in the "Dragon Arc", ApJ **978**, L5 (2025), arXiv:2405.19422 [astro-ph.CO].
[31] J. Zhang, T. Broadhurst, J. Lim, P. Morilla, and S. K. Li, Multi-copy axion transfer function and observational implications of effective de Broglie scales, A&A **713**, A100 (2026).
[32] J. Zhang, T. Broadhurst, A. Pozo, T. Chiueh, J. Schive, J. Lim, F. Marleau, T. Sunayama, K. Umetsu, M. Bouhmadi-Lopez, and M. Oguri, Generating the wide sequence of Diffuse Galaxies with de Broglie waves of Dark Matter, arXiv e-prints , arXiv:2609.11510 (2026), arXiv:2609.11510 [astro-ph.GA].
[33] C. T. Donnan, J. S. Dunlop, R. J. McLure, D. J. McLeod, and F. Cullen, No evidence (yet) for increased star-formation efficiency at early times, MNRAS **539**, 2409 (2025), arXiv:2501.03217 [astro-ph.GA].
[34] A. C. Carnall, R. J. McLure, J. S. Dunlop, and R. Davé, Inferring the star formation histories of massive quiescent galaxies with BAGPIPES: evidence for multiple quenching mechanisms, MNRAS **480**, 4379 (2018), arXiv:1712.04452 [astro-ph.GA].
[35] Z. Wu, D. J. Eisenstein, B. D. Johnson, P. Jakobsen, S. Alberts, S. Arribas, W. M. Baker, A. J. Bunker, S. Carniani, S. Charlot, J. Chevallard, M. Curti, E. Curtis-Lake, F. D'Eugenio, K. Hainline, J. M. Helton, T. Y.-Y. Hsiao, X. Ji, Z. Ji, T. J. Looser, G. Rieke, P. Rinaldi, B. Robertson, J. Scholtz, F. Sun, S. Tacchella, J. A. A. Trussler, C. C. Williams, C. N. A. Willmer, C. Willott, J. Witstok, and Y. Zhu, JADES-GS-z14-1: A Compact, Faint Galaxy at $z \approx 14$ with Weak Metal Lines from Extremely Deep JWST MIRI, NIRCam, and NIRSpec Observations, ApJ **992**, 212 (2025), arXiv:2507.22858 [astro-ph.GA].
[36] A. Amruth, T. Broadhurst, J. Lim, M. Oguri, G. F. Smoot, J. M. Diego, E. Leung, R. Emami, J. Li, T. Chiueh, H.-Y. Schive, M. C. H. Yeung, and S. K. Li, Einstein rings modulated by wavelike dark matter from anomalies in gravitationally lensed images, Nature Astronomy **7**, 736 (2023), arXiv:2304.09895 [astro-ph.CO].
[37] V. Pandya, H. Zhang, M. Huertas-Company, K. G. Iyer, E. McGrath, G. Barro, S. L. Finkelstein, M. Kümmel, W. G. Hartley, H. C. Ferguson, J. S. Kartaltepe, J. Primack, A. Dekel, S. M. Faber, D. C. Koo, G. L. Bryan, R. S. Somerville, R. O. Amorín, P. Arrabal Haro, M. B. Bagley, E. F. Bell, E. Bertin, L. Costantin, R. Davé, M. Dickinson, R. Feldmann, A. Fontana, R. Gavazzi, M. Giavalisco, A. Grazian, N. A. Grogin, Y. Guo, C. Hahn, B. W. Holwerda, L. J. Kewley, A. Kirkpatrick, D. D. Kocevski, A. M. Koekemoer, J. M. Lotz, R. A. Lucas, C. Papovich, L. Pentericci, P. G. Pérez-González, N. Pirzkal, S. Ravindranath, C. Rose, M. Schefer, R. C. Simons, A. N. Straughn, S. Tacchella, J. R. Trump, A. de la Vega, S. M. Wilkins, S. Wuyts, G. Yang, and L. Y. A. Yung, Galaxies Going Bananas: Inferring the 3D Geometry of High-redshift Galaxies with JWST-CEERS, ApJ **963**, 54 (2024), arXiv:2310.15232 [astro-ph.GA].
[38] A. Pozo, T. Broadhurst, R. Emami, P. Mocz, M. Vogelsberger, L. Hernquist, C. J. Conselice, H. N. Luu, G. F. Smoot, and R. Windhorst, A smooth filament origin for distant prolate galaxies seen by JWST and HST, Nature Astronomy **10**, 306 (2026), arXiv:2407.16339 [astro-ph.GA].
[39] S.-R. Chen, H.-Y. Schive, and T. Chiueh, Jeans analysis for dwarf spheroidal galaxies in wave dark matter, MNRAS **468**, 1338 (2017), arXiv:1606.09030 [astro-ph.GA].
[40] Planck Collaboration, N. Aghanim, Y. Akrami, M. Ashdown, J. Aumont, C. Baccigalupi, M. Ballardini, A. J. Banday, R. B. Barreiro, N. Bartolo, S. Basak, R. Battye, K. Benabed, J.-P. Bernard, M. Bersanelli, P. Bielewicz, J. J. Bock, J. R. Bond, J. Borrill, F. R. Bouchet, F. Boulanger, M. Bucher, C. Burigana, R. C. Butler, E. Calabrese, J.-F. Cardoso, J. Carron, A. Challinor, H. C. Chiang, J. Chluba, L. P. L. Colombo, C. Combet, D. Contreras, B. P. Crill, F. Cuttaia, P. de Bernardis, G. de Zotti, J. Delabrouille, J.-M. Delouis, E. Di Valentino, J. M. Diego, O. Doré, M. Douspis, A. Ducout, X. Dupac, S. Dusini, G. Efstathiou, F. Elsner, T. A. Enßlin, H. K. Eriksen, Y. Fantaye, M. Farhang, J. Fergusson, R. Fernandez-Cobos, F. Finelli, F. Forastieri, M. Frailis, A. A. Fraisse, E. Franceschi, A. Frolov, S. Galeotta, S. Galli, K. Ganga, R. T. Génova-Santos, M. Gerbino, T. Ghosh, J. González-Nuevo, K. M. Górski, S. Gratton, A. Gruppuso, J. E. Gudmundsson, J. Hamann, W. Handley, F. K. Hansen, D. Herranz, S. R. Hildebrandt, E. Hivon, Z. Huang, A. H. Jaffe, W. C. Jones, A. Karakci, E. Keihänen, R. Keskitalo, K. Kiiveri, J. Kim, T. S. Kisner, L. Knox, N. Krachmalnicoff, M. Kunz, H. Kurki-Suonio, G. Lagache, J.-M. Lamarre, A. Lasenby, M. Lattanzi, C. R. Lawrence, M. Le Jeune, P. Lemos, J. Lesgourgues, F. Levrier, A. Lewis, M. Liguori, P. B. Lilje, M. Lilley, V. Lindholm, M. López-Caniego, P. M. Lubin, Y.-Z. Ma, J. F. Macías-Pérez, G. Maggio, D. Maino, N. Mandolesi, A. Mangilli, A. Marcos-Caballero, M. Maris, P. G. Martin, M. Martinelli, E. Martínez-González, S. Matarrese, N. Mauri, J. D. McEwen, P. R. Meinhold, A. Melchiorri, A. Mennella, M. Migliaccio, M. Millea, S. Mitra, M.-A. Miville-Deschênes, D. Molinari, L. Montier, G. Morgante, A. Moss, P. Natoli, H. U. Nørgaard-Nielsen, L. Pagano, D. Paoletti, B. Partridge, G. Patanchon, H. V. Peiris, F. Perrotta, V. Pettorino, F. Piacentini, L. Polastri, G. Polenta, J.-L. Puget, J. P. Rachen, M. Reinecke, M. Remazeilles, A. Renzi, G. Rocha, C. Rosset, G. Roudier, J. A. Rubiño-Martín, B. Ruiz-Granados, L. Salvati, M. Sandri, M. Savelainen, D. Scott, E. P. S. Shellard, C. Sirignano, G. Sirri, L. D. Spencer, R. Sunyaev, A.-S. Suur-Uski, J. A. Tauber, D. Tavagnacco, M. Tenti, L. Toffolatti, M. Tomasi, T. Trombetti, L. Valenziano, J. Valiviita, B. Van Tent, L. Vibert, P. Vielva, F. Villa, N. Vittorio, B. D. Wandelt, I. K. Wehus, M. White, S. D. M. White, A. Zacchei, and A. Zonca, Planck 2018 results. VI. Cosmological parameters, A&A **641**, A6 (2020), arXiv:1807.06209 [astro-ph.CO].
[41] H.-Y. Schive, T. Chiueh, T. Broadhurst, and K.-W. Huang, Contrasting Galaxy Formation from Quantum Wave Dark Matter, ψDM, with ΛCDM, using Planck and Hubble Data, ApJ **818**, 89 (2016), arXiv:1508.04621

[astro-ph.GA].
[42] S. G. Murray, C. Power, and A. S. G. Robotham, HMFcalc: An online tool for calculating dark matter halo mass functions, Astronomy and Computing **3**, 23 (2013), arXiv:1306.6721 [astro-ph.CO].
[43] Changing to BPASS v2.2.1 grids with same SFH model would make young galaxies $\lesssim 20$ Myr brighter by maximally $\lesssim 0.45$ mag, and hence extends the brighter end of M_{UV} distribution. The overall distribution is same for both ψDM and LCDM models and does not alter our discussion.
[44] T. J. Broadhurst, A. N. Taylor, and J. A. Peacock, Mapping Cluster Mass Distributions via Gravitational Lensing of Background Galaxies, ApJ **438**, 49 (1995), arXiv:astro-ph/9406052 [astro-ph].
[45] E. Leung, T. Broadhurst, J. Lim, J. M. Diego, T. Chiueh, H.-Y. Schive, and R. Windhorst, Magnification Bias of Distant Galaxies in the Hubble Frontier Fields: Testing Wave Versus Particle Dark Matter Predictions, ApJ **862**, 156 (2018), arXiv:1806.07905 [astro-ph.GA].
[46] J. Zhang, J. Lim, T. Broadhurst, S. K. Li, M. C. Li, G. Manzoni, and R. Windhorst, Magnification Bias Reveals Severe Contamination in Hubble Frontier Field Photo-z Catalogs, ApJ **988**, 279 (2025), arXiv:2507.09142 [astro-ph.CO].
[47] A. Acebron, A. Zitrin, D. Coe, G. Mahler, K. Sharon, M. Oguri, M. Bradač, L. D. Bradley, B. Frye, C. J. Forman, V. Strait, Y. Su, K. Umetsu, F. Andrade-Santos, R. J. Avila, D. Carrasco, C. Cerny, N. G. Czakon, W. A. Dawson, C. Fox, A. T. Hoag, K.-H. Huang, T. L. Johnson, S. Kikuchihara, D. Lam, L. Lovisari, R. Mainali, M. Nonino, P. A. Oesch, S. Ogaz, M. Ouchi, M. Past, R. Paterno-Mahler, A. Peterson, R. E. Ryan, B. Salmon, D. P. Stark, S. Toft, M. Trenti, B. Vulcani, and B. Welch, RELICS: A Very Large ($\theta_E \sim 40$") Cluster Lens—RXC J0032.1+1808, ApJ **898**, 6 (2020), arXiv:1912.02702 [astro-ph.CO].
[48] J. M. Helton, G. H. Rieke, S. Alberts, Z. Wu, D. J. Eisenstein, K. N. Hainline, S. Carniani, Z. Ji, W. M. Baker, R. Bhatawdekar, A. J. Bunker, P. A. Cargile, S. Charlot, J. Chevallard, F. D'Eugenio, E. Egami, B. D. Johnson, G. C. Jones, J. Lyu, R. Maiolino, P. G. Pérez-González, M. J. Rieke, B. Robertson, A. Saxena, J. Scholtz, I. Shivaei, F. Sun, S. Tacchella, L. Whitler, C. C. Williams, C. N. A. Willmer, C. Willott, J. Witstok, and Y. Zhu, Photometric detection at 7.7 μm of a galaxy beyond redshift 14 with JWST/MIRI, Nature Astronomy **9**, 729 (2025), arXiv:2405.18462 [astro-ph.GA].
[49] K. N. Hainline, F. D'Eugenio, P. Jakobsen, J. Chevallard, S. Carniani, J. Witstok, Z. Ji, E. Curtis-Lake, B. D. Johnson, B. Robertson, S. Tacchella, M. Curti, S. Charlot, J. M. Helton, S. Arribas, R. Bhatawdekar, A. J. Bunker, A. J. Cameron, E. Egami, D. J. Eisenstein, R. Hausen, N. Kumari, R. Maiolino, P. G. Pérez-González, M. Rieke, A. Saxena, J. Scholtz, R. Smit, F. Sun, C. C. Williams, C. N. A. Willmer, and C. Willott, Searching for Emission Lines at z ¿ 11: The Role of Damped Lyα and Hints About the Escape of Ionizing Photons, ApJ **976**, 160 (2024), arXiv:2404.04325 [astro-ph.GA].
[50] B. Wang, S. Fujimoto, I. Labbé, L. J. Furtak, T. B. Miller, D. J. Setton, A. Zitrin, H. Atek, R. Bezanson, G. Brammer, J. Leja, P. A. Oesch, S. H. Price, I. Chemerynska, S. E. Cutler, P. Dayal, P. van Dokkum, A. D. Goulding, J. E. Greene, Y. Fudamoto, G. Khullar, V. Kokorev, D. Marchesini, R. Pan, J. R. Weaver, K. E. Whitaker, and C. C. Williams, UNCOVER: Illuminating the Early Universe-JWST/NIRSpec Confirmation of z ¿ 12 Galaxies, ApJ **957**, L34 (2023), arXiv:2308.03745 [astro-ph.GA].
[51] J. Witstok, P. Jakobsen, R. Maiolino, J. M. Helton, B. D. Johnson, B. E. Robertson, S. Tacchella, A. J. Cameron, R. Smit, A. J. Bunker, A. Saxena, F. Sun, S. Alberts, S. Arribas, W. M. Baker, R. Bhatawdekar, K. Boyett, P. A. Cargile, S. Carniani, S. Charlot, J. Chevallard, M. Curti, E. Curtis-Lake, F. D'Eugenio, D. J. Eisenstein, K. N. Hainline, G. C. Jones, N. Kumari, M. V. Maseda, P. G. Pérez-González, P. Rinaldi, J. Scholtz, H. Übler, C. C. Williams, C. N. A. Willmer, C. Willott, and Y. Zhu, Witnessing the onset of reionization through Lyman-α emission at redshift 13, Nature **639**, 897 (2025), arXiv:2408.16608 [astro-ph.GA].
[52] E. Curtis-Lake, S. Carniani, A. Cameron, S. Charlot, P. Jakobsen, R. Maiolino, A. Bunker, J. Witstok, R. Smit, J. Chevallard, C. Willott, P. Ferruit, S. Arribas, N. Bonaventura, M. Curti, F. D'Eugenio, M. Franx, G. Giardino, T. J. Looser, N. Lützgendorf, M. V. Maseda, T. Rawle, H.-W. Rix, B. Rodríguez del Pino, H. Übler, M. Sirianni, A. Dressler, E. Egami, D. J. Eisenstein, R. Endsley, K. Hainline, R. Hausen, B. D. Johnson, M. Rieke, B. Robertson, I. Shivaei, D. P. Stark, S. Tacchella, C. C. Williams, C. N. A. Willmer, R. Bhatawdekar, R. Bowler, K. Boyett, Z. Chen, A. de Graaff, J. M. Helton, R. E. Hviding, G. C. Jones, N. Kumari, J. Lyu, E. Nelson, M. Perna, L. Sandles, A. Saxena, K. A. Suess, F. Sun, M. W. Topping, I. E. B. Wallace, and L. Whitler, Spectroscopic confirmation of four metal-poor galaxies at z = 10.3-13.2, Nature Astronomy **7**, 622 (2023), arXiv:2212.04568 [astro-ph.GA].
[53] J. A. Zavala, M. Castellano, H. B. Akins, T. J. L. C. Bakx, D. Burgarella, C. M. Casey, Ã. s. A. Chávez Ortiz, M. Dickinson, S. L. Finkelstein, I. Mitsuhashi, K. Nakajima, P. G. Pérez-González, P. Arrabal Haro, P. Bergamini, V. Buat, B. Backhaus, A. Calabrò, N. J. Cleri, D. Fernández-Arenas, A. Fontana, M. Franco, C. Grillo, M. Giavalisco, N. A. Grogin, N. Hathi, M. Hirschmann, R. Ikeda, I. Jung, J. S. Kartaltepe, A. M. Koekemoer, R. L. Larson, J. McKinney, C. Papovich, P. Rosati, T. Saito, P. Santini, R. Terlevich, E. Terlevich, T. Treu, and L. Y. A. Yung, A luminous and young galaxy at z = 12.33 revealed by a JWST/MIRI detection of Hα and [O III], Nature Astronomy **9**, 155 (2025), arXiv:2403.10491 [astro-ph.GA].
[54] G. Rodighiero, A. Ferrara, M. Catone, L. Napolitano, P. Cassata, G. Gandolfi, E. Merlin, A. Grazian, A. Renzini, L. Bisigello, M. Castellano, P. G. Pérez-González, B. Pérez-Díaz, E. Iani, C. Gruppioni, S. L. Finkelstein, A. M. Koekemoer, A. Bianchetti, and F. Sinigaglia, EGS-z11-R0: a red, dust-rich galaxy at Cosmic Dawn, arXiv e-prints , arXiv:2603.15841 (2026), arXiv:2603.15841 [astro-ph.GA].
[55] K. C. Kreilgaard, C. A. Mason, T. Morishita, Y. Zhang, V. Gelli, N. Leethochawalit, T. Treu, M. Trenti, Abdurro'uf, H. Atek, M. Bradač, L. D. Bradley, A. J. Bunker, N. Saputra Haryana, M. J. Hayes, Z. Liu, V. Mehta, M. Rafelski, G. Roberts-Borsani, C. Scarlata, M. Stiavelli, R. A. Sutanto, K. Takahashi, and B. Vulcani, BEACON: JWST NIRCam Pure-parallel Imaging

Survey. III. Constraints on the UV LF and the Clustering of z˜7-14 Galaxies, arXiv e-prints , arXiv:2604.17963 (2026), arXiv:2604.17963 [astro-ph.GA].

[56] J. Witstok, R. Smit, W. M. Baker, P. Rinaldi, K. N. Hainline, H. S. B. Algera, S. Arribas, T. J. L. C. Bakx, A. J. Bunker, S. Carniani, S. Charlot, J. Chevallard, M. Curti, E. Curtis-Lake, D. J. Eisenstein, K. E. Heintz, J. M. Helton, G. C. Jones, R. Maiolino, M. V. Maseda, P. G. Pérez-González, C. L. Pollock, B. E. Robertson, A. Saxena, J. Scholtz, I. Shivaei, F. Sun, S. Tacchella, H. Übler, D. Watson, C. J. Willott, and Z. Wu, On the origins of oxygen: ALMA and JWST characterise the multi-phase, metal-enriched, star-bursting medium within a 'normal' z ¿ 11 galaxy, The Open Journal of Astrophysics **9**, 55261 (2026), arXiv:2507.22888 [astro-ph.GA].

[57] C. L. Pollock, K. E. Heintz, J. Witstok, R. Gottumukkala, G. Brammer, S. Bose, A. J. Cameron, P. Dayal, P. van Dokkum, J. Fynbo, V. Gelli, M. J. Hayes, A. K. Inoue, C. d. P. Lagos, P. Laursen, R. A. Meyer, R. Naidu, P. Oesch, L. E. Rowland, N. R. Tanvir, S. Tacchella, C. Terp, F. Valentino, F. Walter, J. Weaver, and C. Witten, Characterising Lyα damping wings at the onset of reionisation: Evidence for highly efficient star formation driven by dense, neutral gas in UV-bright galaxies at $z > 9$, arXiv e-prints , arXiv:2602.11783 (2026), arXiv:2602.11783 [astro-ph.GA].

[58] L. Napolitano, M. Castellano, L. Pentericci, P. Arrabal Haro, A. Fontana, T. Treu, P. Bergamini, A. Calabrò, S. Mascia, T. Morishita, G. Roberts-Borsani, P. Santini, E. Vanzella, B. Vulcani, D. Zakharova, T. Bakx, M. Dickinson, C. Grillo, N. Leethochawalit, M. Llerena, E. Merlin, D. Paris, S. Rojas-Ruiz, P. Rosati, X. Wang, I. Yoon, and J. Zavala, Seven wonders of Cosmic Dawn: JWST confirms a high abundance of galaxies and AGN at z $\simeq$ 9-11 in the GLASS field, A&A **693**, A50 (2025), arXiv:2410.10967 [astro-ph.GA].

[59] R. Marques-Chaves, J. Álvarez-Márquez, L. Colina, S. Kendrew, Abdurro'uf, C. Blanco-Prieto, L. A. Boogaard, M. Castellano, K. I. Caputi, A. Crespo-Gomez, A. Fontana, Y. Fudamoto, S. Fujimoto, M. García-Marín, Y. Harikane, S. Harish, T. Hashimoto, T. Hsiao, E. Iani, A. K. Inoue, D. Langeroodi, R. Lin, J. Melinder, L. Napolitano, G. Ostlin, P. G. Pérez-González, C. Prieto-Jiménez, P. Rinaldi, B. Rodríguez Del Pino, P. Santini, Y. Sugahara, A. Varo-O'ferral, G. Wright, and J. Zavala, PRISMS. U37126, a very blue, ISM-naked starburst at z=10.255 with nearly 100% Lyman continuum escape fraction, arXiv e-prints , arXiv:2602.02322 (2026), arXiv:2602.02322 [astro-ph.GA].

[60] T. Y.-Y. Hsiao, Abdurro'uf, D. Coe, R. L. Larson, I. Jung, M. Mingozzi, P. Dayal, N. Kumari, V. Kokorev, A. Vikaeus, G. Brammer, L. J. Furtak, A. Adamo, F. Andrade-Santos, J. Antwi-Danso, M. Bradač, L. D. Bradley, T. Broadhurst, A. C. Carnall, C. J. Conselice, J. M. Diego, M. Donahue, J. J. Eldridge, S. Fujimoto, A. Henry, S. Hernandez, T. A. Hutchison, B. L. James, C. Norman, H. Park, N. Pirzkal, M. Postman, M. Ricotti, J. R. Rigby, E. Vanzella, B. Welch, S. M. Wilkins, R. A. Windhorst, X. Xu, E. Zackrisson, and A. Zitrin, JWST NIRSpec Spectroscopy of the Triply Lensed z = 10.17 Galaxy MACS0647-JD, ApJ **973**, 8 (2024), arXiv:2305.03042 [astro-ph.GA].

[61] L. Napolitano, M. Castellano, L. Pentericci, C. Vignali, R. Gilli, A. Fontana, P. Santini, T. Treu, A. Calabrò, M. Llerena, E. Piconcelli, L. Zappacosta, S. Mascia, R. Tripodi, P. Arrabal Haro, P. Bergamini, T. J. L. C. Bakx, M. Dickinson, K. Glazebrook, A. Henry, N. Leethochawalit, G. Mazzolari, E. Merlin, T. Morishita, T. Nanayakkara, D. Paris, S. Puccetti, G. Roberts-Borsani, S. Rojas Ruiz, P. Rosati, E. Vanzella, F. Vito, B. Vulcani, X. Wang, I. Yoon, and J. A. Zavala, The Dual Nature of GHZ9: Coexisting Active Galactic Nuclei and Star Formation Activity in a Remote X-Ray Source at z = 10.145, ApJ **989**, 75 (2025), arXiv:2410.18763 [astro-ph.GA].

[62] J. Álvarez-Márquez, L. Colina, A. Crespo-Gomez, S. Kendrew, J. Zavala, R. Marques-Chaves, C. Prieto-Jiménez, Abdurro'uf, C. Blanco-Prieto, L. A. Boogaard, M. Castellano, A. Fontana, Y. Fudamoto, S. Fujimoto, M. García-Marín, Y. Harikane, S. Harish, T. Hashimoto, T. Hsiao, E. Iani, A. K. Inoue, D. Langeroodi, R. Lin, J. Melinder, L. Napolitano, G. Ostlin, P. G. Pérez-González, P. Rinaldi, B. Rodríguez Del Pino, P. Santini, Y. Sugahara, T. Treu, A. Varo-O'ferral, and G. Wright, PRISMS. UNCOVER-26185, a metal-poor SFG at z=10.05 with no evidence for a X-ray-luminous AGN, arXiv e-prints , arXiv:2602.02323 (2026), arXiv:2602.02323 [astro-ph.GA].

[63] P. Arrabal Haro, M. Dickinson, S. L. Finkelstein, S. Fujimoto, V. Fernández, J. S. Kartaltepe, I. Jung, J. W. Cole, D. Burgarella, K. Chworowsky, T. A. Hutchison, A. M. Morales, C. Papovich, R. C. Simons, R. O. Amorín, B. E. Backhaus, M. B. Bagley, L. Bisigello, A. Calabrò, M. Castellano, N. J. Cleri, R. Davé, A. Dekel, H. C. Ferguson, A. Fontana, E. Gawiser, M. Giavalisco, S. Harish, N. P. Hathi, M. Hirschmann, B. W. Holwerda, M. Huertas-Company, A. M. Koekemoer, R. L. Larson, R. A. Lucas, B. Mobasher, P. G. Pérez-González, N. Pirzkal, C. Rose, P. Santini, J. R. Trump, A. de la Vega, X. Wang, B. J. Weiner, S. M. Wilkins, G. Yang, L. Y. A. Yung, and J. A. Zavala, Spectroscopic Confirmation of CEERS NIRCam-selected Galaxies at z $\simeq$ 8-10, ApJ **951**, L22 (2023), arXiv:2304.05378 [astro-ph.GA].

Galaxy	z_{spec}	μ	M_{UV}	Age [Myr]	z_{form}	$\log_{10}(M_*[M_\odot])$	References
MoM-z14	14.44	-	-20.23 ± 0.06	4^a	14.59	8.1	[21]
GS-z14-0	14.18	-	-20.81 ± 0.16	15	14.72	8.72	[48]
GS-z14-1	13.86	-	-19.21 ± 0.15	10^b	14.20	7.57	[35]
PAN-z14-1	13.53	-	-20.6 ± 0.2	5	13.69	8.23	[5]
GS-z13-0	13.20	-	-18.92 ± 0.05	40	14.51	7.7	[49]
UNCOVER-13077	13.079	2.3	-19.4 ± 1.8	45	14.54	7.92	[50]
JADES-GS-z13-1-LA	13.006	-	-18.66 ± 0.04	22	13.67	7.74	[51]
GS-z12-0	12.63	-	-18.23 ± 0.16	23	13.27	7.64	[52]
UNCOVER-38766	12.393	1.5	-19.2 ± 0.5	58	14.10	8.63	[50]
CAPERS-EGS-65480	12.344	-	-19.48 ± 0.26	-	-	-	[6]
GHZ2/GLASS-z12	12.338	1.3	-20.96 ± 0.05	28	13.09	9.03	[53]
EGS-z11-R0	11.452	-	-19.16 ± 0.17	-	-	9.64	[54, 55]
CEERS-1	11.416	-	-20.1 ± 0.1	30	12.09	8.3	[20]
GS-z11-1	11.280	-	-19.4 $\pm$ 0.05	< 30	< 11.96	8.03	[8]
JADES-GS-20015720	11.267	-	-19.56 ± 0.17	-	-	-	[6, 7]
GS-z11-0-A	11.122	-	-19.30 ± 0.05	33	11.82	8.43	[56]
BulletArc-z11	11.100	14.0	-18.13 ± 0.28	143	15.10	8.2	[9]
CEERS2-588	11.040	-	-20.4 ± 0.10	82	12.95	9.05	[10]
CAPERS-UDS-z11	11.013	-	-20.28 ± 0.08	< 20	< 11.45	8.7	[1]
MoM-z11-1	10.921	-	-19.98 ± 0.24	-	-	-	[6]
JADES-GS-20177294	10.893	-	-19.25 ± 0.09	-	-	-	[6, 7]
CAPERS-EGS-43539	10.816	-	-18.82 ± 0.36	-	-	-	[6]
MoM-z11-2	10.803	-	-20.02 ± 0.22	-	-	-	[6]
EGS-22637	10.750	-	-20.36 ± 0.09	-	-	-	[6, 57]
GHZ4	10.660	1.64	-18.58 ± 0.11	-	-	-	[58]
JADES-GS-20176151	10.619	-	-19.50 ± 0.14	-	-	-	[6, 7]
EGS-69	10.619	-	-19.78 ± 0.21	-	-	-	[6]
GN-z11	10.603	-	-21.50 ± 0.02	13	10.84	8.73	[3]
CAPERS-UDS-z10	10.562	-	-20.53 ± 0.09	< 18	< 10.89	8.3	[1]
GHZ7	10.430	1.2	-19.82 ± 0.05	-	-	-	[58]
GS-20030902	10.425	-	-19.68 ± 0.09	-	-	-	[6]
GS-72355	10.422	-	-19.85 ± 0.07	-	-	-	[6, 13]
GS-z10-0	10.380	-	-18.61 ± 0.1	35	11.01	7.58	[52]
UDS-52799	10.302	-	-20.26 ± 0.08	-	-	-	[6, 13]
CAPERS-COS-109917	10.272	-	-19.57 ± 0.11	-	-	-	[6, 7]
UNCOVER-37126	10.255	2.19	-20.10 ± 0.05	6.8	10.13	7.77	[59]
GHZ8	10.231	1.2	-20.32 ± 0.07	-	-	-	[58]
JD	10.170	-	-20.3 ± 0.2	20	10.50	8.1	[60]
GHZ9	10.145	1.4	-19.27 ± 0.04	-	-	8.69	[58, 61]
MoM-z10-1	10.116	-	-20.05 ± 0.12	-	-	-	[6]
CEERS-64	10.100	-	-19.99 ± 0.09	-	-	-	[6, 20]
GLASS-z11-17225	10.090	1.55	-18.68 ± 0.13	-	-	-	[58]
UNCOVER-26185	10.054	3.9	-18.83 ± 0.07	65	11.22	8.23	[62]
CEERS-80041	10.010	-	-20.1 ± 0.10	-	-	9.1	[63]

TABLE I: All reported galaxies at $z > 10$ from JWST surveys to date, including reported stellar age estimates and magnification, μ, for lensed sources. The formation redshift is inferred from the spectroscopic redshift minus the stellar age.
[a]: this is the age by which MoM-z14 have formed 50% of its stellar mass.
[b]: this is the age by which GS-z14-1 have formed 67% of its stellar mass.