

Dark Secrets of Baryons: Illuminating Dark Matter–Baryon Interactions with JWST

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The James Webb Space Telescope (JWST) has discovered bright galaxies at high redshifts ($z \approx 10$ – 14) and various galaxy candidates extending to even higher redshifts ($z \approx 15$ – 30). Many astrophysical and beyond the Standard Model physics scenarios have been proposed to explain these observations. We investigate, *for the first time*, the implications of dark matter (DM) scattering with baryons (protons and electrons) in light of the JWST UV luminosity function (UVLF) observations. These interactions suppress structure formation on galactic scales, which may have an observable effect on the UVLF measurements at high redshifts. Using a recent galaxy formation model designed to explain high-redshift observations, we obtain strong upper limits on DM-baryon scattering cross sections and explore new regions of the parameter space. For DM-proton scattering with cross section $\propto v^{-2}$ velocity dependence, we obtain the strongest limit for DM masses of ~ 1 – 500 MeV. For other cases that we study (DM-proton scattering cross section $\propto v^0, v^{-4}$ and DM-electron scattering cross section $\propto v^0, v^{-2}, v^{-4}$), our limits are competitive with those obtained from other cosmological observables. Our Letter highlights the potential of JWST observations as a novel and powerful probe of nongravitational interactions of DM.

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Introduction—In its first few years of operation, JWST has observed some of the earliest galaxies, which formed within ~ 300 million years after the Big Bang [1–31]. Using photometry, astronomers identified numerous galaxy candidates, many of which were later confirmed spectroscopically [8,19,32–41]. While the findings of the JWST are consistent with our current cosmological paradigm, observations have reported a surprisingly high abundance of bright galaxies at very early epochs ($z \gtrsim 10$). These galaxy abundances exceed expectations from pre-JWST models calibrated with Hubble Space Telescope (HST) and Spitzer Space Telescope data [42,43]. Several studies have explored the implications of these observations on galaxy formation models at very high redshifts [25,44–92] and the impact of beyond the Standard Model physics on cosmological structure formation [93–128].

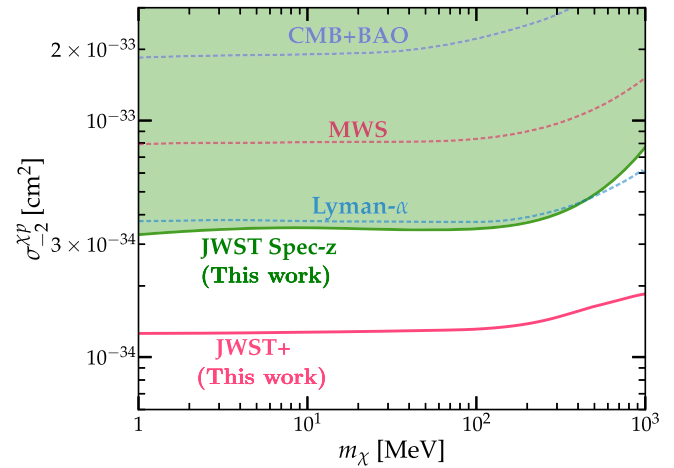


FIG. 1. 95% C.L. upper limits on the normalization of the velocity-dependent electric-dipole-moment-like ($\sigma \propto v^{-2}$) DM-proton elastic scattering cross section as a function of the DM particle mass m_χ . The green shaded region is excluded by the “JWST Spec- z ” setup, while the deep pink line shows the upper limit on the normalization derived from the “JWST+” setup defined in the main text. Other dashed curves represent additional cosmological constraints: Lyman- α forest (cyan), Milky Way satellite count (pink), and CMB + BAO (baryonic acoustic oscillations) (purple) [143,144].

Within the standard cosmological framework, $\sim 26.5\%$ of the current energy density of the Universe is attributed to cold dark matter (CDM), whose existence has been

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established only through its gravitational influence on visible matter and radiation [129–137]. However, the fundamental nature of DM remains unknown, and it may couple nongravitationally to Standard Model particles [137–142]. Over the past few decades, researchers have sought to probe such interactions using a variety of astrophysical and cosmological observations, as well as terrestrial experiments.

Among the many possible types of interactions, DM-baryon (electrons or protons) elastic scattering has been extensively studied for a broad class of theoretical models [143–151]. Depending on the underlying particle-physics model, such interactions lead to the exchange of both heat and momentum between DM and baryons, resulting in shallower gravitational potential wells. These weakened potentials delay the gravitational collapse of matter, affecting the accumulation of DM and baryons, thus, suppressing structure formation [144,145,148,149,152]. DM-baryon interactions have been examined through their signatures on the Cosmic Microwave Background (CMB) [144,152,153], the cosmological 21-cm signal [154–157], the Lyman- α forest [143,158], the observed population of Milky Way satellite (MWS) galaxies [143,149,159,160], and galaxy clustering data [161].

We investigate elastic scattering between DM and baryons using the JWST UV luminosity function (UVLF) data. For such interactions, the momentum-transfer cross section between DM and baryons, $\sigma_{T,n}^{XB}$, is parametrized as

$$\sigma_{T,n}^{XB} = \sigma_n^{XB} v^n, \quad (1)$$

where σ_n^{XB} is the normalization for the scattering cross section, $B \in \{p, e^\pm\}$, is the target particle, v is the relative velocity between DM and baryons, and n is an exponent that may be positive or negative, depending on the underlying interaction model. We examine $n = 0$, $n = -2$, and $n = -4$ cases, corresponding respectively to contact, electric-dipole-moment-like, and Coulomb-like interactions.

The UV luminosity of a galaxy and the mass of its host DM halo are correlated [162]; thus, UVLF measurements can serve as sensitive probes of these DM-baryon interactions. We adopt the modeling framework provided by the simulation suite Thesan–Zoom [163] in order to connect the DM halo mass to the galaxy UVLF [164–172].

Figure 1 shows the 95% confidence level (C.L.) upper limits on the normalization of the DM-proton interaction cross section, σ_{-2}^{XP} , for velocity-dependent ($n = -2$) interactions as a function of the interacting DM (IDM) mass, m_χ . We use the JWST spectroscopic UVLF measurements of ~ 40 galaxies from Refs. [19,24,25] and the top-hat window function; this setup is referred to as JWST Spec-z. We find that the upper limits on σ_{-2}^{XP} from this setup (green solid line) provide the strongest constraint among existing cosmological observables. We also use a modified setup called JWST+. Here, we include the JWST spectroscopic UVLF measurements from Refs. [29,30] together with

photometric measurements at median redshifts $z \sim 17$ and $z \sim 25$ from [20–22,26,27], in addition to the previously used spectroscopic datasets, along with the smooth- k window function. This is a more appropriate filter since the top-hat filter function does not sufficiently damp the contributions at small scales and includes residual fluctuations [173], overestimating the number of small halos. As expected, the inclusion of ultra-high-redshift data improves our constraints by a factor of ~ 3 (deep pink solid line), since higher redshift observations probe smaller scales (larger k values), making the data sensitive to smaller DM-baryon scattering cross sections. For both setups, we use the Pantheon likelihood and impose Gaussian priors on ω_b [174], and on A_s and n_s from CMB measurements [130].

The suppression of the matter power spectrum can be quantified by the transfer function $T(k)$, whose square is defined as the ratio of the matter power spectra for IDM and Λ CDM. In Fig. 2, $T^2(k)$ decreases gradually with increasing comoving wave number, k , resulting in a similar level of suppression across the k scales probed by JWST, Lyman- α , and MWS observations. Consequently, the limits from these probes are comparable. However, since JWST reports an overabundance of high-redshift structures, the suppression induced by IDM is more incompatible with the JWST data, leading to the strongest constraints among all probes for sub-GeV IDM masses. Additional constraints for this scenario have been derived from other independent observational probes [161,175].

Since the JWST+ setup includes photometric data as well, these results may be subject to change. For this reason, we derive constraints using this new setup only for values of n where JWST already provides the strongest limits or is expected to do so as more data become available. We show our $n = -4$ constraints from this setup in Supplemental Material [176].

DM-baryon interaction—We study DM-baryon elastic scattering for two distinct baryon targets: protons and electrons, allowing energy and momentum exchange. The resulting effect of these interactions is qualitatively similar in both cases: a suppression of $P(k)$ on scales that depend on the interaction type and strength.

To quantitatively incorporate the effects of DM-baryon interactions, collisional terms must be added to the cosmological perturbation equations to compute the evolution of linear perturbations in the DM and baryon fluids. The formalism is well described in [143,144,147–149,152,160,161,207–216] and detailed in Supplemental Material [176].

We solve the modified cosmological perturbation equations for IDM scenarios using CLASS_DMB[143], a modified version of CLASS [217], to obtain $P(k)$. We reproduce both the suppression of power at relevant scales and acoustic features attributed to dark acoustic oscillations [151,218,219].

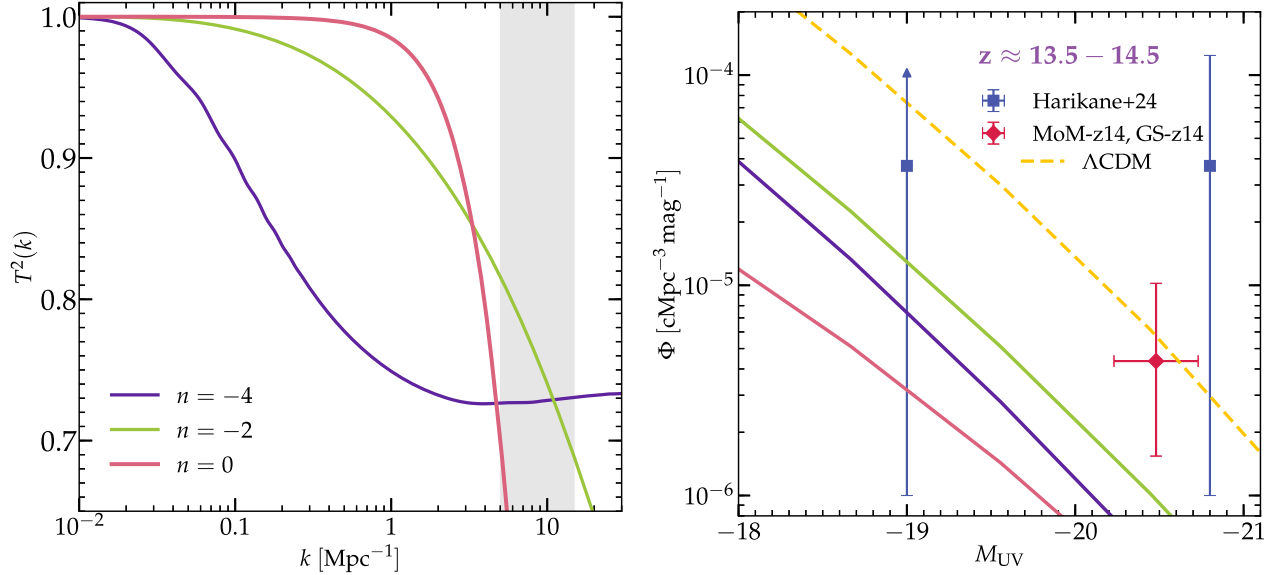


FIG. 2. Left: Comparison of the ratio $T^2(k) = P_{\text{IDM}}(k)/P_{\Lambda\text{CDM}}(k)$ of power spectrum of IDM to that of ΛCDM . We consider IDM cases with different values of n : $n = 0$ (pink), $n = -2$ (green), and $n = -4$ (purple), for DM of mass $m_\chi = 1$ MeV, interacting with protons. The cross section for each case corresponds to the 95% C.L. upper limits obtained in this Letter: $\log_{10}(\sigma_{\text{p}}^{\text{p}}/\text{cm}^2)$ for $n = 0, -2, -4$ cases are $-27.49, -33.48$, and -40.33 , respectively, using JWST Spec-z analysis. The suppression of power spectrum at the characteristic scales (gray shaded region) is visible. Right: Comparison of the UVLFs at $z \approx 14$ for ΛCDM (dashed yellow curve) and for IDM (same color code as in the left panel) for the same IDM scenarios. Data points represent UVLF measurements at $z \approx 14$ from Harikane *et al.* [25] (blue squares) and from the MoM-z14 + GS-z14 galaxy observations [19] (red diamond). The choice of astrophysical parameters for ΛCDM corresponds to the best-fit values from [166] with $\log_{10}(M_c/M_\odot) = 10.5$, while those for the interacting scenarios are fixed at the best-fit values from our MCMC analysis.

Model for the UV luminosity function—We describe the semianalytical model for calculating the UVLF, a key observable of early galaxies, starting from $P(k)$. Two major steps are involved: (i) calculating the halo mass function (HMF) and (ii) prescribing the galaxy-halo connection. We further assume that each DM halo hosts one galaxy.

Since UVLF quantifies the number density of galaxies per unit UV magnitude, the relevant quantity is the HMF, defined as the number density of DM halos per unit mass at a given redshift z . Calculation of the HMF using the extended Press-Schechter formalism requires two functions calibrated using N -body simulations. We adopt the top-hat (for JWST+ setup, smooth- k) filter function and use the ellipsoidal model of halo collapse, with the Sheth-Tormen fitting function to compute the halo abundance. The effects of DM-baryon interactions are encoded in the mass variance $\sigma^2(M_h, z)$, where M_h is the DM halo mass.

We use the galaxy-halo connection prescription from Thesan-Zoom simulations [164–172], a suite of zoom-in simulations tracing the evolution of galaxies during the first two billion years of the Universe, making them suitable for JWST observations. We model the halo-scale star-formation efficiency (SFE), $\epsilon_\star(M_h)$, by [166]

$$\epsilon_\star(M_h) = \frac{\epsilon_0}{(M_h/M_0)^{-\alpha_\star} + (M_h/M_0)^{-\beta_\star}}, \quad (2)$$

where ϵ_0 , $\alpha_\star$, $\beta_\star$, and M_0 are the SFE model parameters. This broken power-law model, introduced in [166], is motivated by distinct physical mechanisms that regulate gas outflows at such high redshifts. This model does not capture the turnover in the SFE at higher halo masses ($\sim 10^{12} M_\odot$) expected to arise from active galactic nuclei (AGN) or other feedback processes [220,221]; instead, we cap $\epsilon_\star(M_h)$ at a constant value $\epsilon_\star(M_c)$ beyond a critical halo mass M_c . This reflects the fact that the dynamical range probed by the Thesan-Zoom simulations extends only up to $M_h \leq M_c \simeq 10^{10} M_\odot$ [166]. Throughout our analysis, we fix this capping mass to $\log_{10}(M_c/M_\odot) = 10.5$. We estimate the star formation rate (SFR) using the halo mass accretion model adopted in [166,222], based on the GUREFT simulations [51]. However, cosmologies with suppressed halo formation can modify the accretion history, making it sensitive to the underlying DM physics. We discuss this point in Supplemental Material [176]. Empirical relations between the SFR and specific UV luminosity of galaxies [94,166] allow us to calculate the median UV magnitude, M_{UV} , as a function of M_h .

Stochasticity is expected in various galaxy formation scenarios [223–229]. We model this effect by assuming a scatter of $\sim \mathcal{O}(1)$ mag (termed the UV variability) about the median $M_{\text{UV}}-M_h$ relation. We adopt the empirical model of variability in Ref. [166] which matches the predictions

from various simulations [55,230–235]. Finally, we compute the binned UVLF $\bar{\Phi}_{\text{UV}}^i$ by integrating the galaxy number counts over UV magnitude bins of width ΔM_{UV}^i [236]

$$\bar{\Phi}_{\text{UV}}^i(z) = \frac{1}{\Delta M_{\text{UV}}^i} \int dM_{\text{UV}} \int dM_h \frac{dn_h(z)}{dM_h} p(M_{\text{UV}}|M_h), \quad (3)$$

where $n_h(z)$ is the comoving number density of halos, $dn_h(z)/dM_h$ is the HMF at redshift z , and $p(M_{\text{UV}}|M_h)$ is the probability density that a halo of mass M_h hosts a galaxy with UV magnitude M_{UV} . The outer integral is over the i th M_{UV} bin. Following Ref. [166], we model $p(M_{\text{UV}}|M_h)$ as a Gaussian with a median value $M_{\text{UV}}^{\text{Med}}$ and width $\sigma_{\text{UV}}(M_h)$, termed UV variability

$$\sigma_{\text{UV}}(M_h) = \max[\sigma_{\text{UV},10^{10.5}M_\odot} - 0.34\log_{10}(M_{h,10.5}), 0.4], \quad (4)$$

where $\sigma_{\text{UV},10^{10.5}M_\odot}$ is the UV variability at a DM halo mass of $10^{10.5}M_\odot$ and $M_{h,10.5}$ is the halo mass scaled by $10^{10.5}M_\odot$. Our astrophysical model is independent of z , so the entire z dependence in UVLF arises from the HMF.

In the next section, we discuss how we use this model to constrain the DM-baryon scattering cross section.

Results—We sample the model parameters using the Markov chain Monte Carlo (MCMC) code MontePython [237–239] with the GALLUMI [162] (modified according to [166]) and Pantheon likelihood pipelines. We discuss our choice of priors in the End Matter.

The constraining power of a particular observable on IDM is determined by some key factors, such as the scales probed by the observable, the statistical and systematic uncertainties in the data, as well as possible discrepancies between the Λ CDM model and the data. For example, suppression effects caused by IDM may be compensated by unaccounted-for systematics in astrophysical model, making it difficult to isolate the impact of the interaction.

The highest-redshift galaxy spectroscopically confirmed by JWST lies at $z = 14.44 \pm 0.02$ [19]. In Fig. 2 (right panel), we present UVLFs for Λ CDM and IDM cosmologies at $z \approx 14$. As expected, the UVLFs calculated for IDM cosmologies are suppressed relative to Λ CDM. The UVLF for the Λ CDM cosmology, with astrophysical parameters [ϵ_0 , α_* , β_* , M_0 , and $\sigma_{\text{UV}}(10^{10.5}M_\odot)$] set to the best-fit values given in [166], fits the data better than IDM scenarios.

The ordering of UVLFs for different values of n in Fig. 2 (right panel) recovers the corresponding ordering of $P(k)$ (left panel) at $k \approx 10 \text{ Mpc}^{-1}$ (shown by the gray shaded region) corresponding to the smallest scales probed by the JWST UVLF [240]. Because the suppression due to IDM shifts to larger k for smaller σ_n^B , the maximum k values probed by an observation are important in determining the

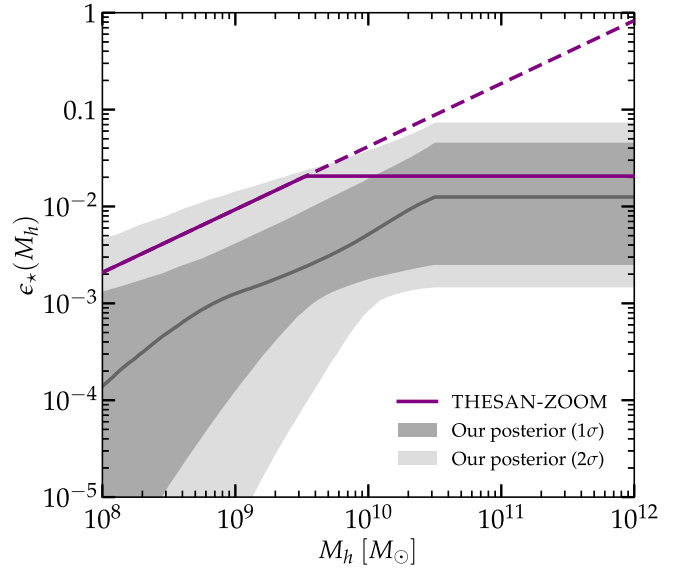


FIG. 3. The magenta solid line shows the SFE as a function of halo mass for the Λ CDM cosmology, using the best-fit SFE model parameters from [166] at $z \approx 14$. The gray line, the dark gray, and light gray shaded regions show the median, 1σ , and 2σ intervals, respectively, for SFE [Eq. (2)] sampled from our posterior distributions for $m_\chi = 1 \text{ MeV}$, $n = -2$, $B = p$, and with JWST Spec-z setup, as a function of M_h . The dashed line represents $\epsilon_*(M_h)$ from the best-fit Thesan-Zoom model, extended beyond the cutoff $M_c = 10^{10.5}M_\odot$.

stringency of the corresponding upper limits. The one-to-one correspondence between transfer functions and UVLFs across different n values may not hold, as each case involves distinct astrophysical parameters. We show similar plots for DM-electron interactions in Supplemental Material [176].

In Fig. 3, we present the best-fit SFE, along with the 1σ and 2σ bands (shown in gray) as a function of halo mass M_h , derived from MCMC samples of the model parameters, for the DM-proton interaction case with $n = -2$, with $m_\chi = 1 \text{ MeV}$ with the JWST Spec-z setup. The magenta line, representing the best-fit SFE model parameters from [166], lies within the 2σ confidence interval, and within the 1σ interval at higher halo masses. This concordance suggests that the Thesan-Zoom simulation-based model reliably captures the star formation physics relevant for JWST observations.

We show our limits for the mass range $1 \text{ MeV} - 1 \text{ GeV}$. Cosmological probes like the Lyman- α forest measurements [241], CMB lensing [242], MWS [160], and JWST (this Letter) give strong constraints on sub-GeV DM masses. In contrast, direct detection experiments are more sensitive to heavier DM masses [243–256].

We do not consider DM particle masses below 1 MeV since Big Bang nucleosynthesis (BBN) and CMB place the strongest constraints on this mass range by measuring the cosmological relativistic degrees of freedom [257–259]. In IDM cosmologies, during very early epochs, DM interacts

with baryons, thermally coupling to the baryonic plasma [260]. For strong σ_n^B , the interaction can increase the number of relativistic degrees of freedom, N_{eff} , during the BBN and CMB epochs, which is disallowed, given that there are three neutrino species.

Discussion and conclusions—We investigate DM-baryon interactions using JWST high-redshift UVLF data. For a broad class of models, the momentum-transfer interaction cross section between DM and baryons can be expressed as $\sigma_{T,n}^B = \sigma_n^B v^n$. We constrain σ_n^B for $n = 0, -2$, and -4 , with $B \in \{p, e\}$. From Fig. 1, we see that JWST provides the strongest constraint across a wide range of sub-GeV DM masses for the $n = -2$ case. This is attributed to the nature of suppression in this case, where the transfer function diminishes gradually, making the suppression at JWST scales comparable to those probed by Lyman- α and MWS observations. This is a new observable in addition to existing probes of DM-baryon scattering [137,147,149,151,152,159–161,175,212,216,261–281].

The largest comoving wave numbers k probed by cosmological observations follow $k_{\text{CMB}} \lesssim k_{\text{Ly-}\alpha} \lesssim k_{\text{JWST}} \lesssim k_{\text{MWS}}$, corresponding to the CMB, Lyman- α forest, JWST, and MWS observations, respectively. However, the constraining power of a cosmological observation depends on both the dataset and the nature of the suppression at the largest k scales it accesses. Consequently, for $n = 0$, the resulting limits are weaker than those from the Lyman- α and MWS observations. We show the corresponding constraint plots in Supplemental Material [176].

Even though we used the smooth- k filter function in our JWST+ setup, applying it only to the spectroscopic data used in the JWST Spec- z setup does not significantly change our results compared to using the top-hat filter function. This is attributed to the sparsity of the data, which is expected to change as we observe more galaxies at these redshifts. However, the suppression of smaller structures can change the merger rate in the early Universe, as the number of smaller halos decreases. This can lead to reduced halo accretion rates, which become relevant for warm dark matter or IDM scenarios. We study the effect of suppression on the accretion rate for $n = -2$ case for the JWST+ setup and present our results in Supplemental Material [176].

The UVLF data carry information not only about the cosmological model, but also about the astrophysics at such high redshifts. Pre-JWST astrophysical models within the Λ CDM cosmology have difficulty in explaining the JWST data on galaxy abundances [42,100,236]. To ensure robustness, we marginalize over the astrophysical parameters so that the limits become insensitive to the astrophysical modeling choice.

Our Letter presents, for the first time, new regions of DM-baryon scattering cross section probed by JWST observations. Although the currently available dataset provides the strongest constraints on dipole-moment-like ($n = -2$) DM-proton interactions only, the discovery of

more galaxies at high redshifts is expected to make the limits for other values of n competitive with, or even surpassing, existing bounds. In addition, understanding the astrophysics at the cosmic dawn through simulations adapted for high redshifts will lead to insightful conclusions, including the possibility of new discoveries. Through observations of the first galaxies, we hope to explore novel ways to probe the fundamental nature of DM.

Note added—Recently, Ref. [282] appeared on arXiv, exploring a similar scenario using the HST UVLF dataset. We use the JWST UVLF measurements, which contain more high-redshift data compared to HST. At higher redshifts, structures become smaller and probe larger values of k and, thus, become sensitive to lower values of the DM-baryon scattering cross sections. JWST is, therefore, capable of providing the strongest constraint on one class of DM-proton interaction models using only ~ 40 galaxies. As new data arrives, it is expected to place the best constraints on a broader class of models. Their paper studied the DM-proton interactions only, while we present constraints on both DM-proton and DM-electron interactions. While they studied $n = 0, +2, +4$ models, we study $n = 0, -2, -4$ models.

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Data availability—The data that support the findings of this article are not publicly available upon publication because it is not technically feasible and/or the cost of preparing, depositing, and hosting the data would be prohibitive within the terms of this research project. The data are available from the authors upon reasonable request.

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End Matter

UVLF data—The UVLF data used in this Letter are taken from a set of 25 galaxies presented in [24], ten galaxies from Ref. [25] (and references therein), ten galaxies from [29], seven galaxies from [30], two galaxies from Ref. [19], two galaxies from [20], five galaxies from [21], nine sources from [27], and upper limits on UVLFs from [21,22,26]. We only consider UVLF measurements at redshifts $z \gtrsim 8$. All data with redshift $z \sim 16$ are obtained from spectroscopically confirmed galaxies, while for our “JWST+” analyses, we also include photometric ultra-high-redshift UVLF data and upper or lower limits for $z \gtrsim 17$. At each redshift, we convert the set of discrete M_{UV} values to bins either using the bin widths quoted in the respective paper or conservatively by choosing the larger of the differences to adjacent M_{UV} values as the bin width.

Likelihood analysis—We modified part of the GALLUMI pipeline, adopting the formalism of Ref. [166] as described in the text. We incorporate dust using the prescription of Ref. [283], extrapolated to $z \approx 10$, which closely matches the Thesan-Zoom simulations [165]. We use the following likelihood function for the binned- $\bar{\Phi}_{\text{UV}}$:

$$\log \mathcal{L} = -\frac{1}{2} \sum_z \sum_i \left\{ \begin{array}{l} \left(\frac{\bar{\Phi}_{\text{UV}}^i - \Phi_{\text{UV}}^{\text{up},i}}{\delta \Phi_{\text{UV}}^{\text{up},i}} \right)^2, \quad \bar{\Phi}_{\text{UV}}^i > \Phi_{\text{UV}}^i \\ \left(\frac{\bar{\Phi}_{\text{UV}}^i - \Phi_{\text{UV}}^{\text{lo},i}}{\delta \Phi_{\text{UV}}^{\text{lo},i}} \right)^2, \quad \bar{\Phi}_{\text{UV}}^i < \Phi_{\text{UV}}^i \end{array} \right. \quad (\text{B1})$$

where $\bar{\Phi}_{\text{UV}}^i$ is the binned UVLF calculated in Eq. (3), and is, thus, a function of the cosmological model and astrophysical parameters. Moreover, it implicitly depends on z through its dependence on the HMF. The JWST measurement (with 1σ uncertainties) of the UVLF in the i th bin at redshift z is given by

$$\left(\Phi_{\text{UV}}^i \right)_{-\delta \Phi_{\text{UV}}^{\text{lo},i}}^{+\delta \Phi_{\text{UV}}^{\text{up},i}}.$$

Our likelihood function enables accommodation of asymmetric error bars on the measured UVLFs. We sum over each M_{UV} bin across redshifts, relevant to different analyses.

We run the likelihood analysis for different choices of DM mass m_χ , baryon component B , and velocity dependence n . The free parameters of our model

TABLE I. Priors on cosmological and astrophysical parameters. Ranges for the astrophysical parameters are motivated by the Thesan-Zoom simulations [166].

Parameter	Prior
$\log_{10} \sigma_n^{\chi B}$	Uniform ^a
Ω_χ	$\mathcal{U}[0.0, 0.3]$
$\omega_b \times 10^2$	$\mathcal{N}(2.233, 0.036)$
n_s	$\mathcal{N}(0.9649, 0.0042)$
$A_s \times 10^9$	$\mathcal{N}(2.1, 0.03)$
$\alpha_\star$	$\mathcal{U}[0.0, 3.0]$
$\beta_\star$	$\mathcal{U}[0.0, 3.0]$
$\log_{10} \epsilon_0$	$\mathcal{U}[-3.0, 0.0]$
$\log_{10} M_0$	$\mathcal{U}[7.0, 11.0]$
$\sigma_{\text{UV}}(10^{10.5} M_\odot)$	$\mathcal{U}[0.001, 3.0]$
M	$\mathcal{U}[-21, -18]$

^aThe range of the uniform prior is selected according to the choice of (m_χ, B, n) .

include cosmological parameters $\{n_s, A_s, \omega_b, \Omega_\chi, \sigma_n^{\chi B}\}$, and astrophysical (nuisance) parameters $\{\alpha_\star, \beta_\star, \epsilon_0, M_0, \sigma_{\text{UV}}(10^{10.5} M_\odot), M\}$. Here, n_s , A_s , and ω_b are standard Λ CDM parameters while Ω_χ replaces the CDM abundance Ω_c in our analysis (we assume 100% IDM). We impose Gaussian priors on ω_b from BBN [174], and on A_s , n_s from CMB measurements [130], as JWST UVLF data do not constrain them stringently [240]. Further, we fix θ_s and τ to their Planck measurements [130]. We assume uniform priors on the DM abundance Ω_χ , logarithm of the cross section $\log_{10} \sigma_n^{\chi B}$, parameters $\{\alpha_\star, \beta_\star, \log_{10} \epsilon_0, \log_{10} M_0\}$ characterizing the SFE, the UV variability $\sigma_{\text{UV}}(10^{10.5} M_\odot)$, and the intrinsic SNIa magnitude M . These priors are summarized in Table I. Note that the prior on $\log_{10} \sigma_n^{\chi-B}$ is always uniform, but the range is chosen according to the specific choice of (m_χ, B, n) .

As highlighted in the main text, we use MontePython to perform Markov chain Monte Carlo runs with the likelihood and prior discussed above. We run 40 parallel MCMC chains until the Gelman-Rubin criterion satisfies $R < 1.05$ for each parameter. We marginalize over the posterior samples to obtain 95% C.L. upper limits on $\log_{10}(\sigma_n^{\chi B})$. This procedure is repeated for each individual choice of m_χ , B , and n . We vary $n \in \{0, -2, -4\}$, $B \in \{e, p\}$, and consider five values of m_χ in the range $1 \text{ MeV} \leq m_\chi \leq 1 \text{ GeV}$.