中国科学院紫金山天文台
Purple Mountain Observatory,Chinese Academy of Sciences

中国科学技术大学
University of Science and Technology of China

JWST high z observation:
探索暗物质和暗能量性质

Reporter: Lei Lei (4-yr PhD Candidate, leilei@pmo.ac.cn)

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2024 Oct 14 @ 苏州 – 紫金山暗物质研讨会

SFR & SFE

Model

The SFR is derived from the accretion rate of baryons and the total SFE,

$$\mathrm{SFR_{UV}} = f_{\mathrm{tot}} \times \dot{M}_b,$$ f_{tot} represents the SFE of stars

The accretion rate of the baryon (M_b) is from the accretion rate of the dark matter halo (M_h)

$$\dot{M}_{\mathrm{b}} = f_{\mathrm{b}} \times \dot{M}_{\mathrm{h}},$$

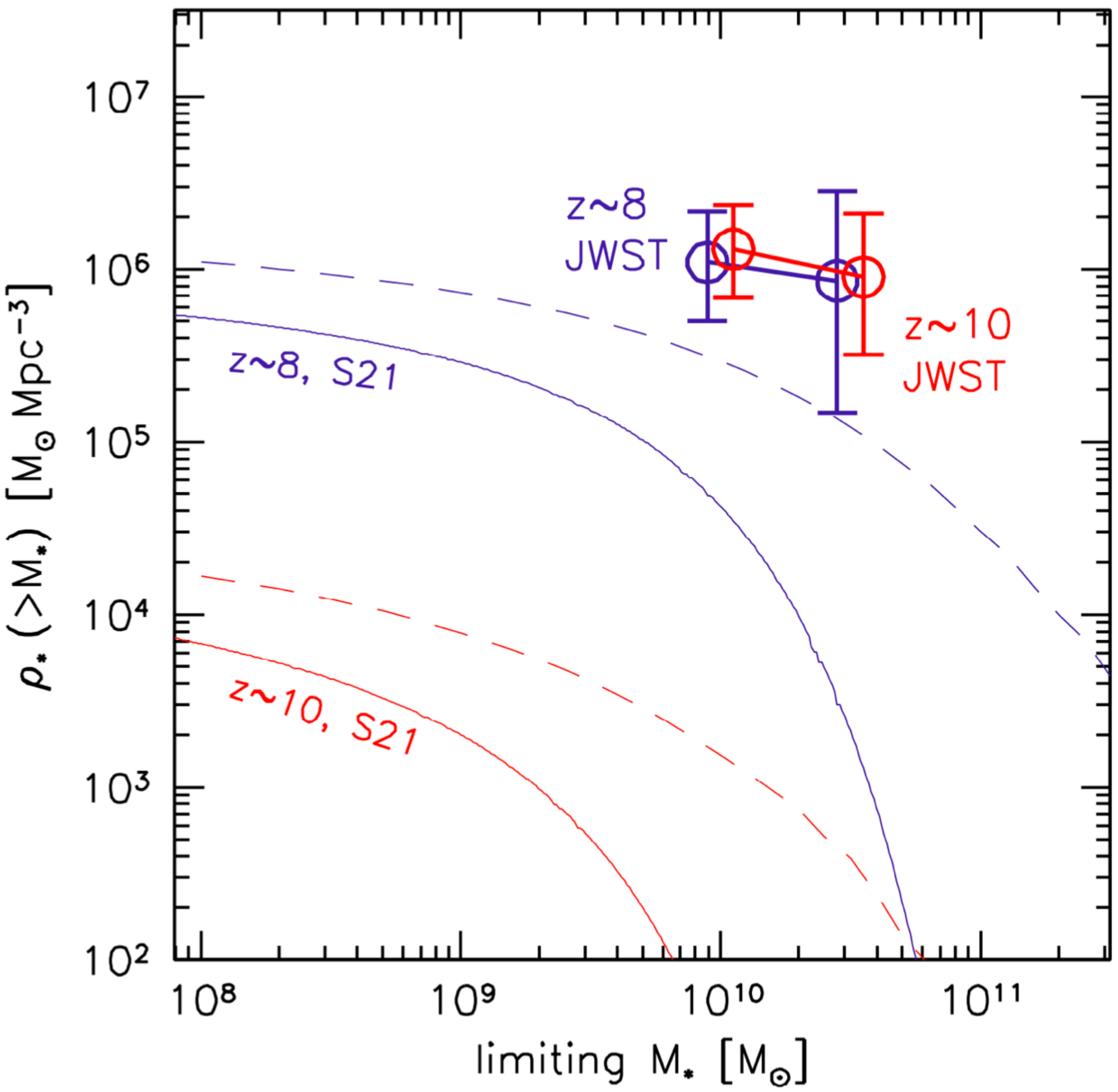
$$f_{\mathrm{b}} \equiv \frac{\Omega_{\mathrm{b}}}{\Omega_{\mathrm{m}}} = 0.156.$$

Data

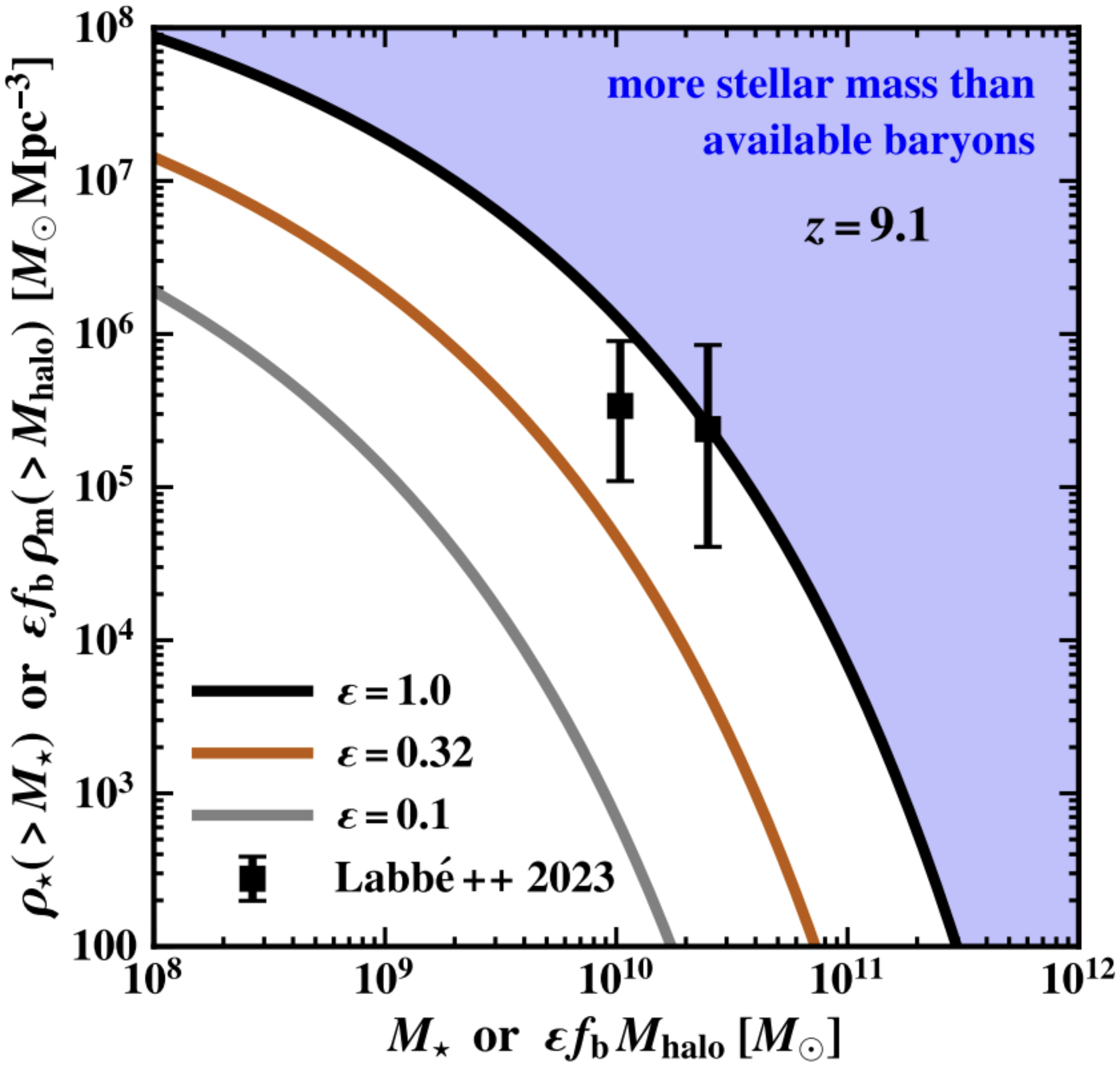
$$\mathrm{SFR_{UV}}(\mathrm{M_\odot\,yr^{-1}}) = \mathcal{K}_{\mathrm{UV}} \times \mathrm{L_{UV}}(\mathrm{erg\,s^{-1}\,Hz^{-1}})$$

Here, $\mathcal{K}_{\mathrm{UV}}$ represents the conversion factor, which depends on the stellar populations of galaxies [33]. In the standard scenario, this conversion factor takes the value $\mathcal{K}_{\mathrm{UV}} = 1.15 \times 10^{-28}\,\mathrm{M_\odot\,yr^{-1}/(erg\,s^{-1}\,Hz^{-1})}$, assuming a Salpeter IMF within the mass range of 0.1 to $100\,\mathrm{M_\odot}$ [34]. For extremely metal-poor ($Z = 0$)

High z Excesses of SFR in JWST

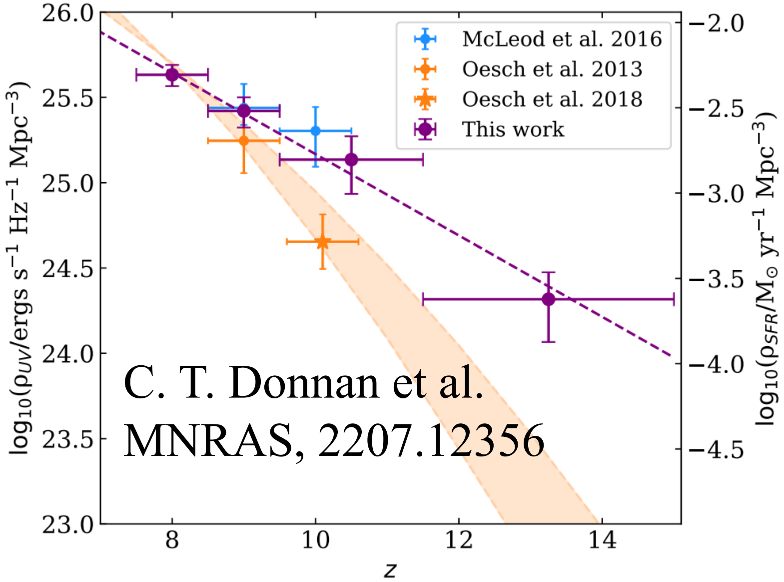


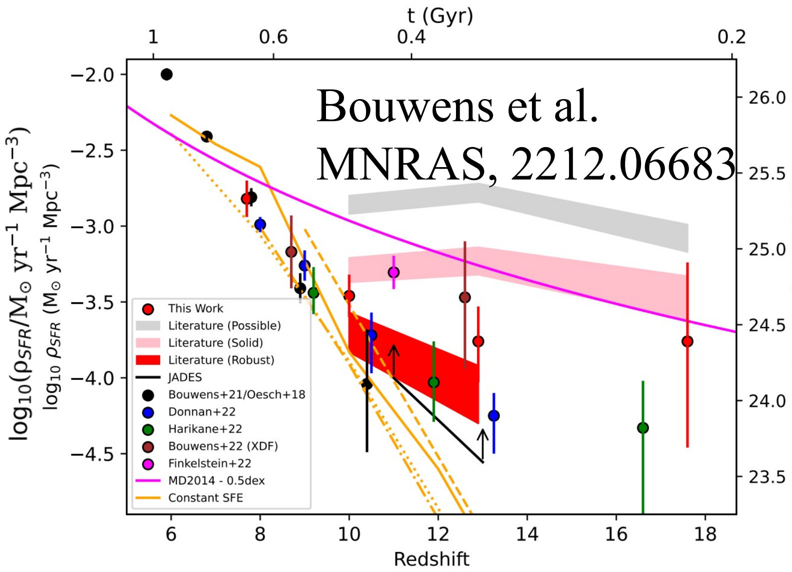
Ivo Labbe´ et al. 2022 nature

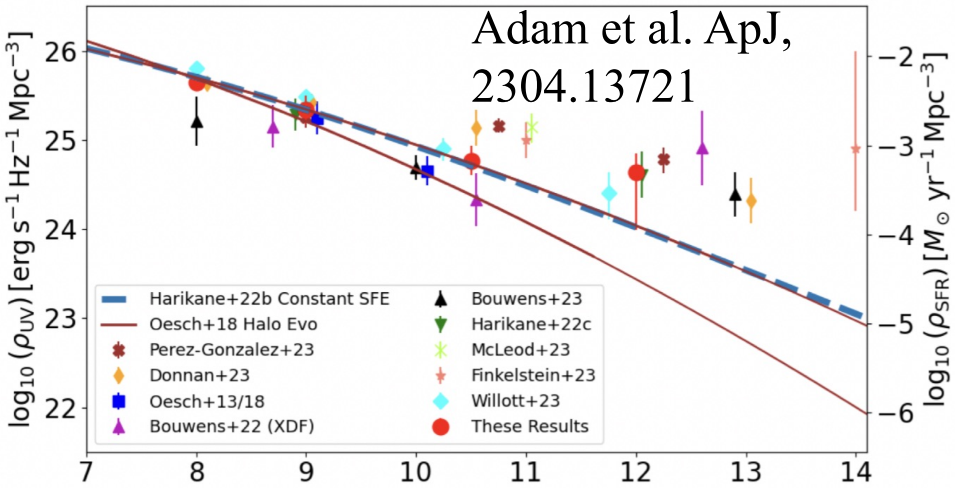


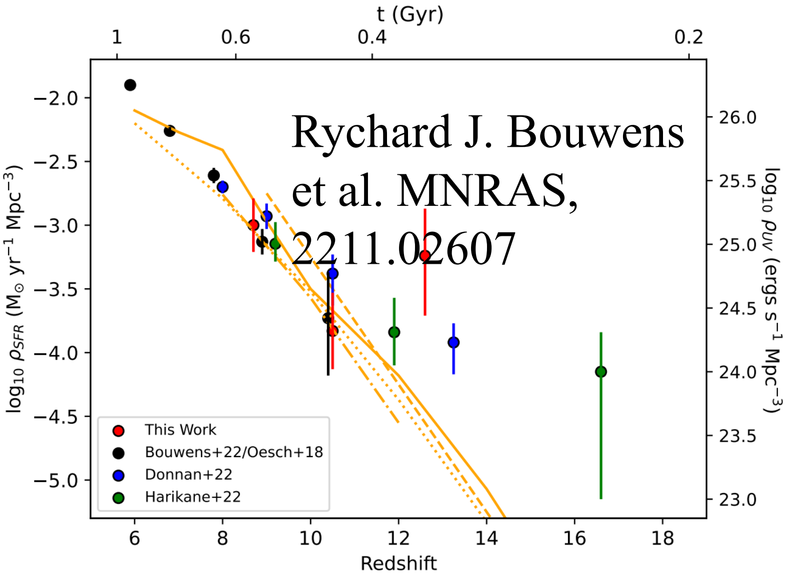
Michael Boylan-Kolchin *Nature Astron.* 7 (2023)

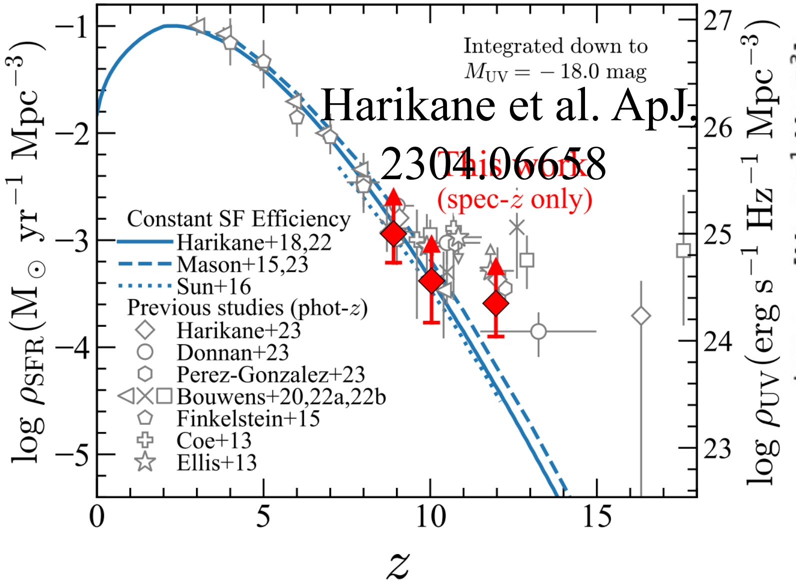
High z Excesses of SFR in JWST

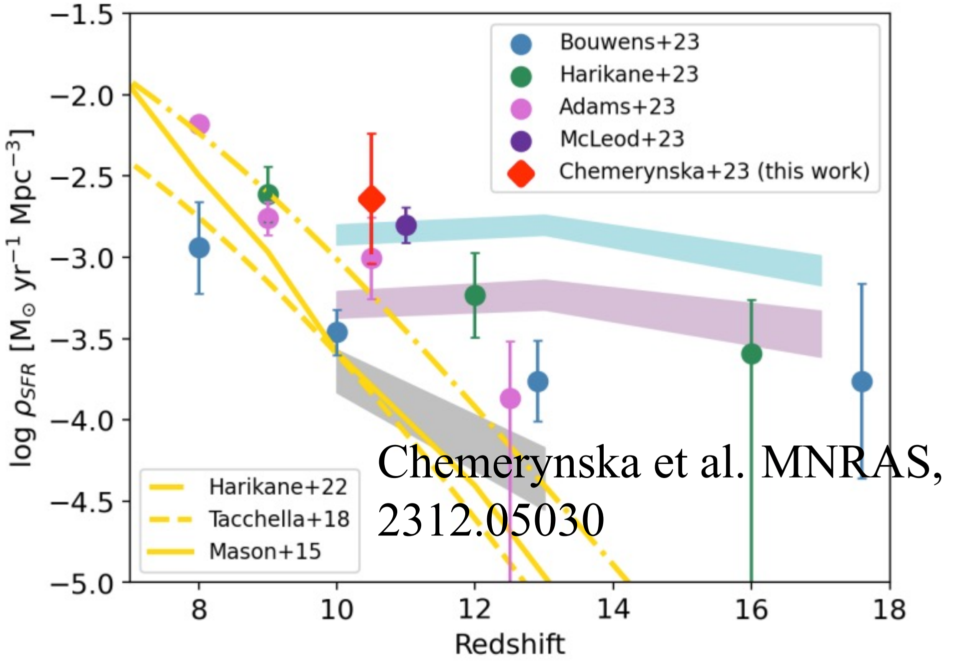












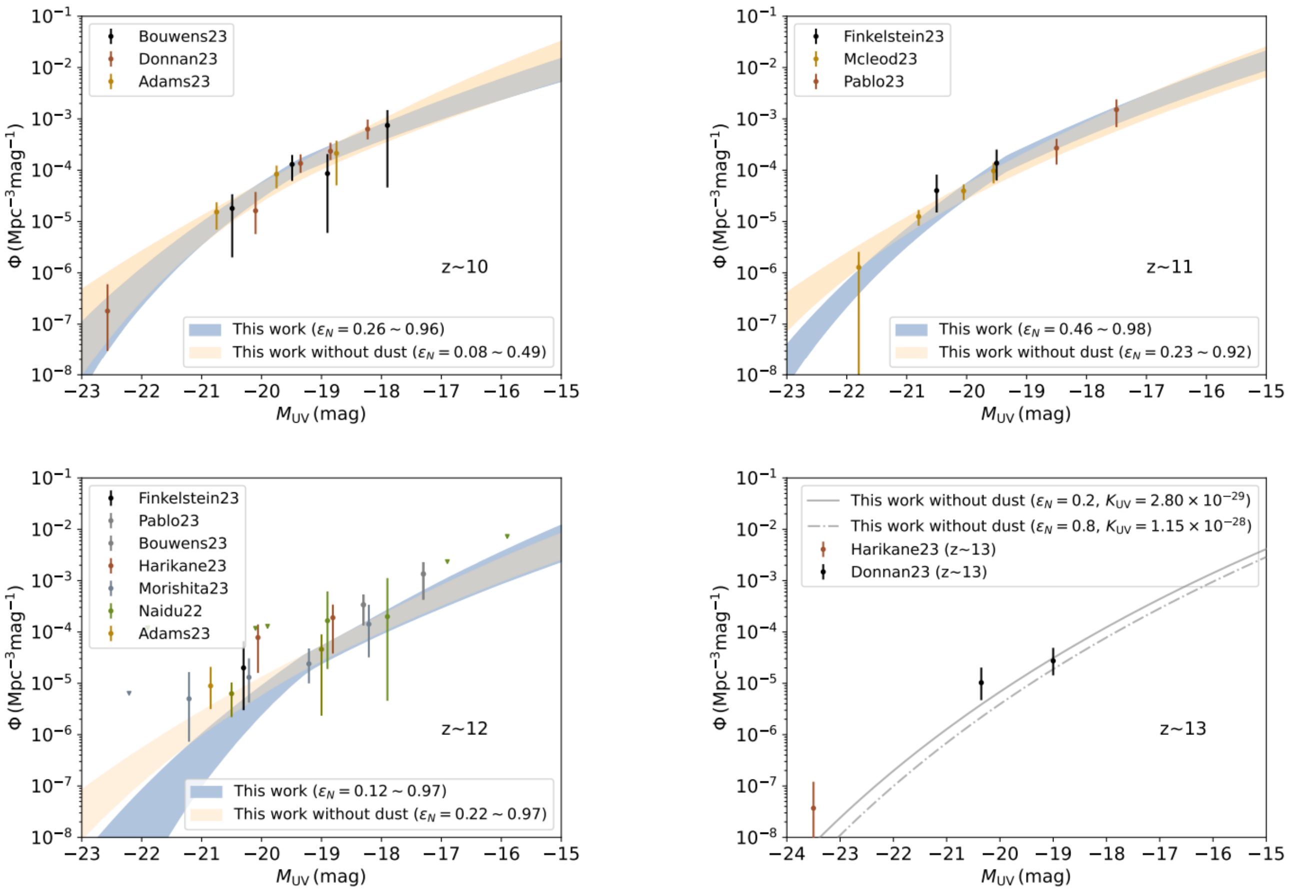
High z Excesses of SFR in JWST

12 papers

Naidu et al.	ApJL,	2207.09434
Morishita et al.	ApJL,	2207.11671
Donnan et al.	MNRAS,	2207.12356
Bouwens et al.	MNRAS,	2211.02607
Finkelstein et al.	ApJL,	2211.05792
Bouwens et al.	MNRAS,	2212.06683
Perez-Gonzalez et al.	ApJL,	2302.02429
Harikane et al.	ApJ,	2304.06658
Adam et al.	ApJ,	2304.13721
McLeod et al.	MNRAS,	2304.14469
Chemerynska et al.	MNRAS,	2312.05030
Yung et al.	MNRAS,	2304.04348

Pop III stars ?

2307.12487, ApJ Letter, Wang Yi-Ying, Lei Lei, et al. (2023)



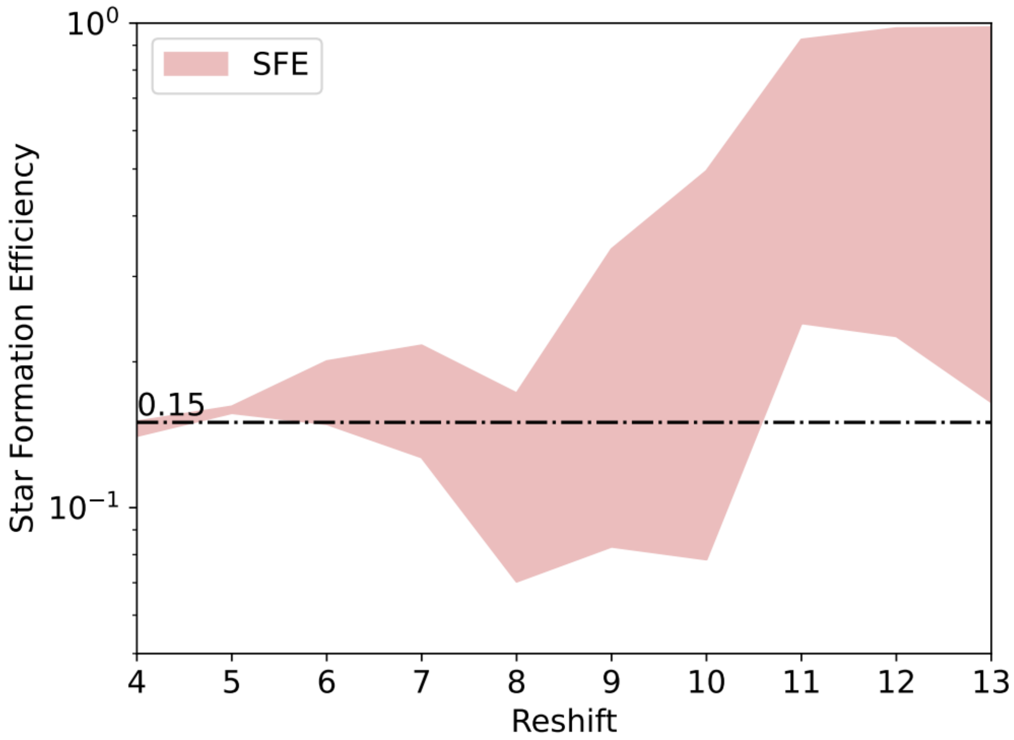
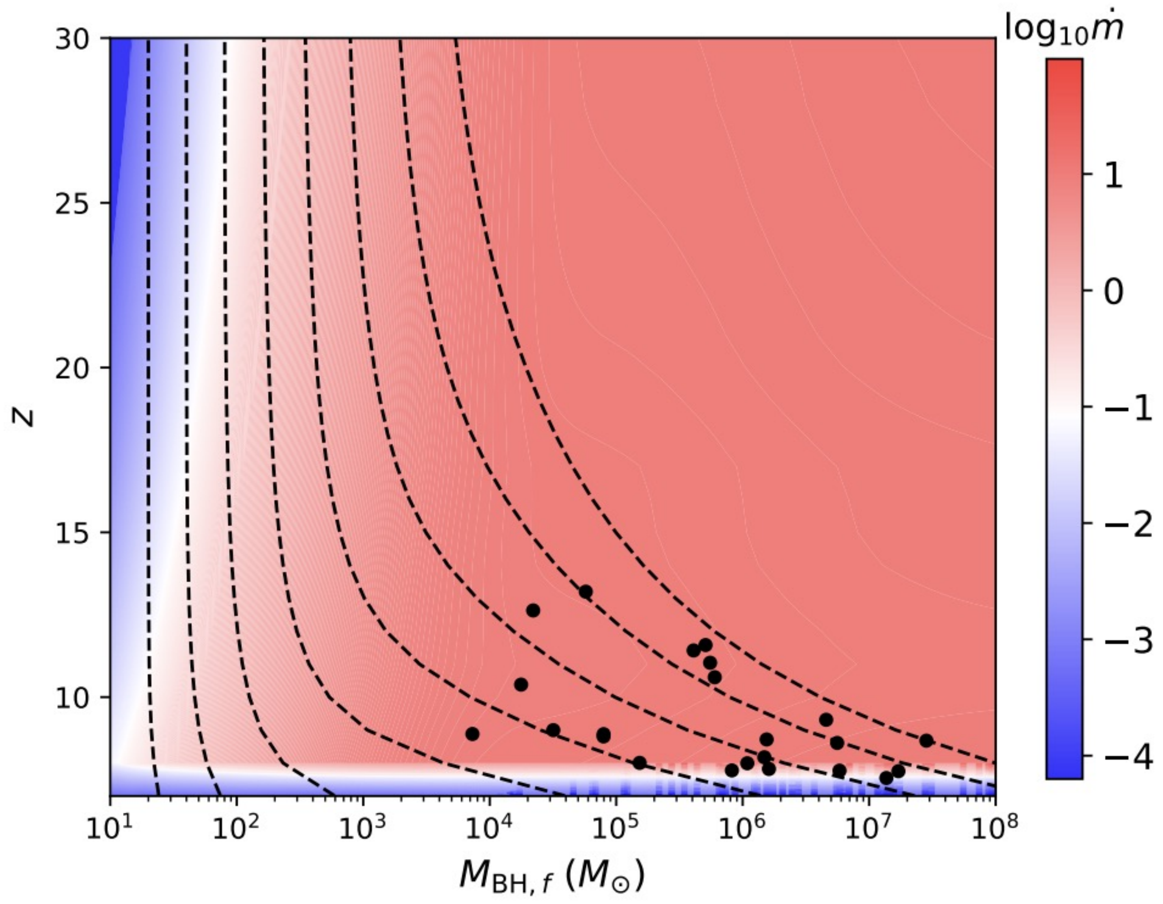
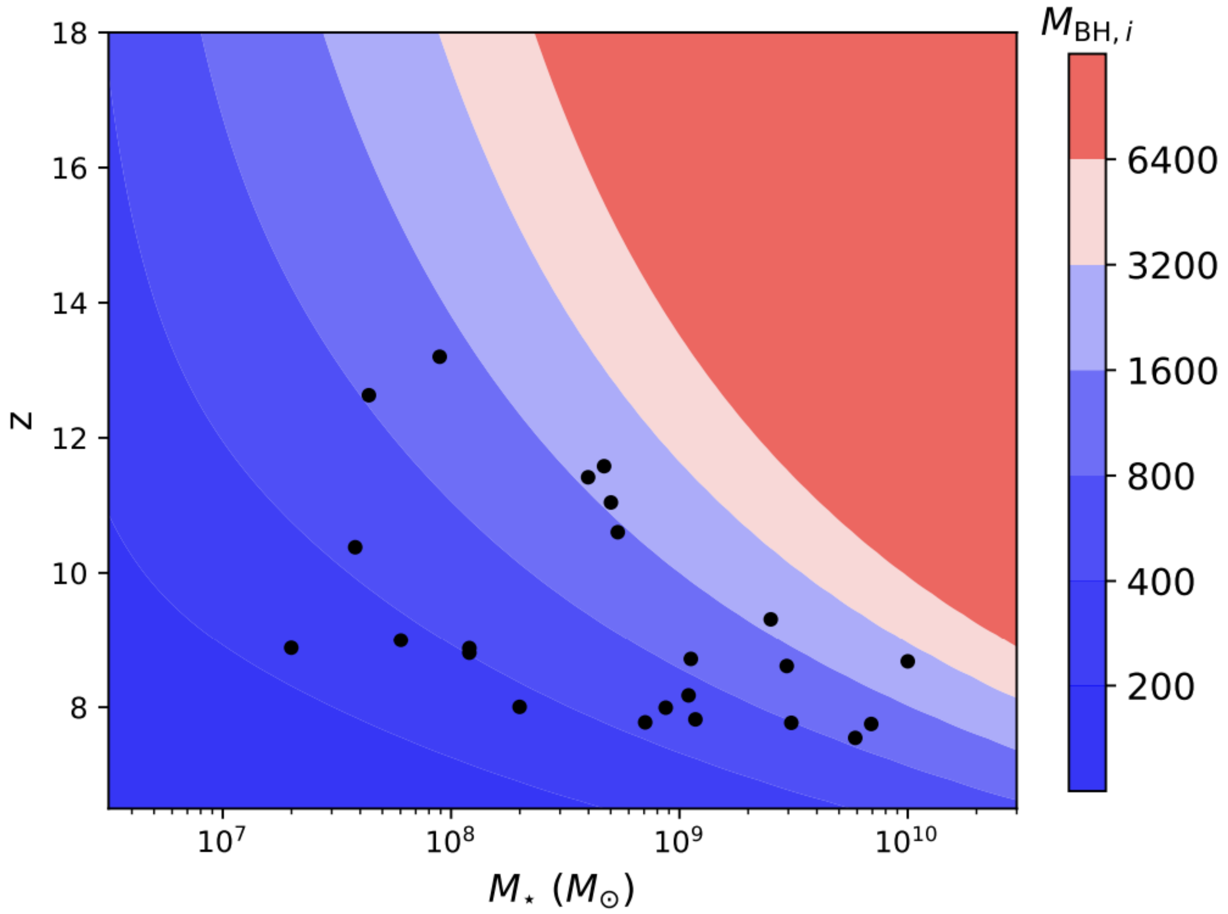


Figure 4. The evolution of peak SFE with redshift. The shaded pink region represents the range of maximum SFE values with a 68% credible uncertainty at each redshift. At $z \geq 10$, the estimation of SFE is performed without considering the impact of dust attenuation.

JWST high z : PBH ?

2303.09391, SCPMA, Guan-Wen Yuan, Lei Lei, et al. (2024)





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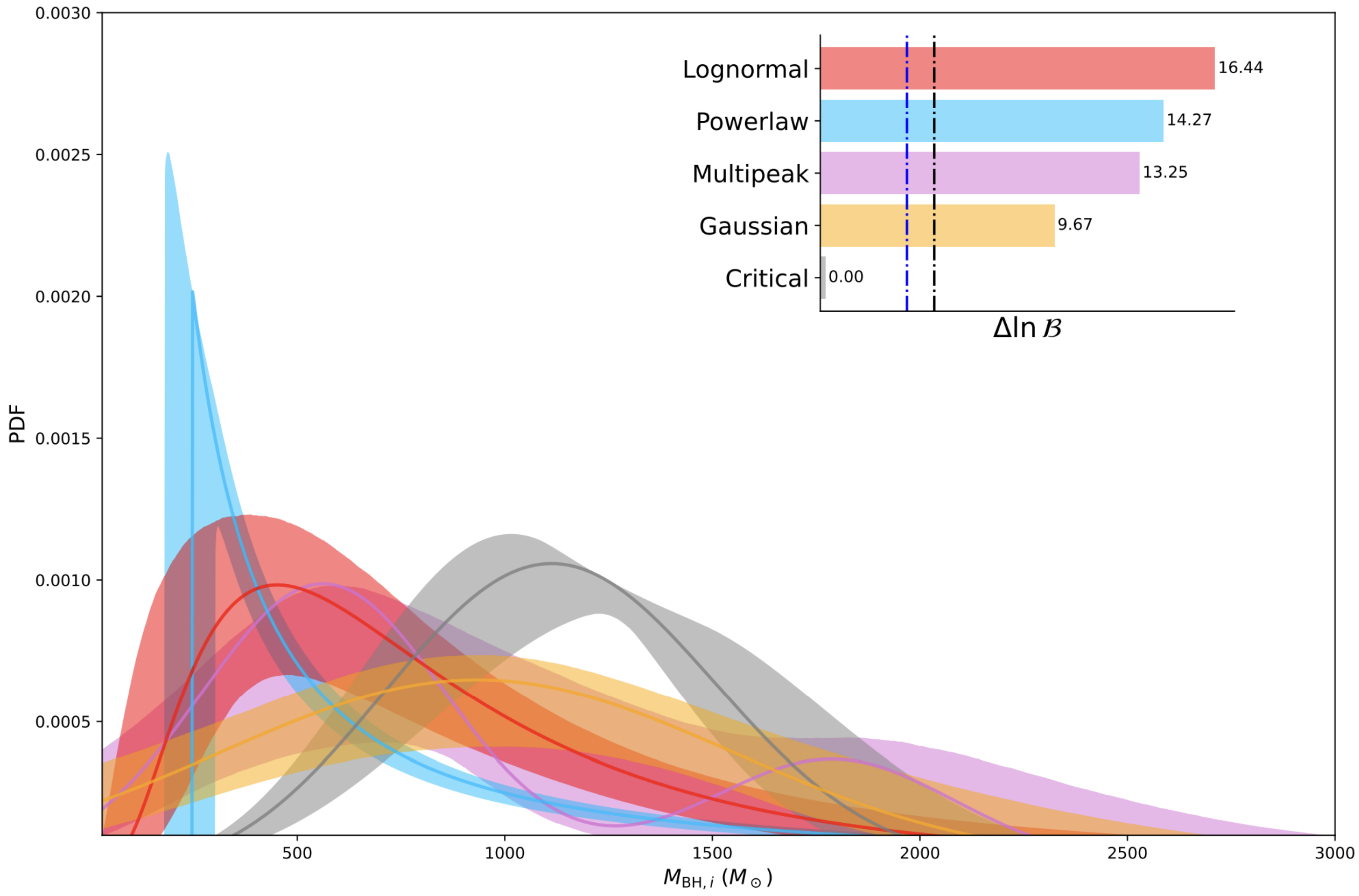
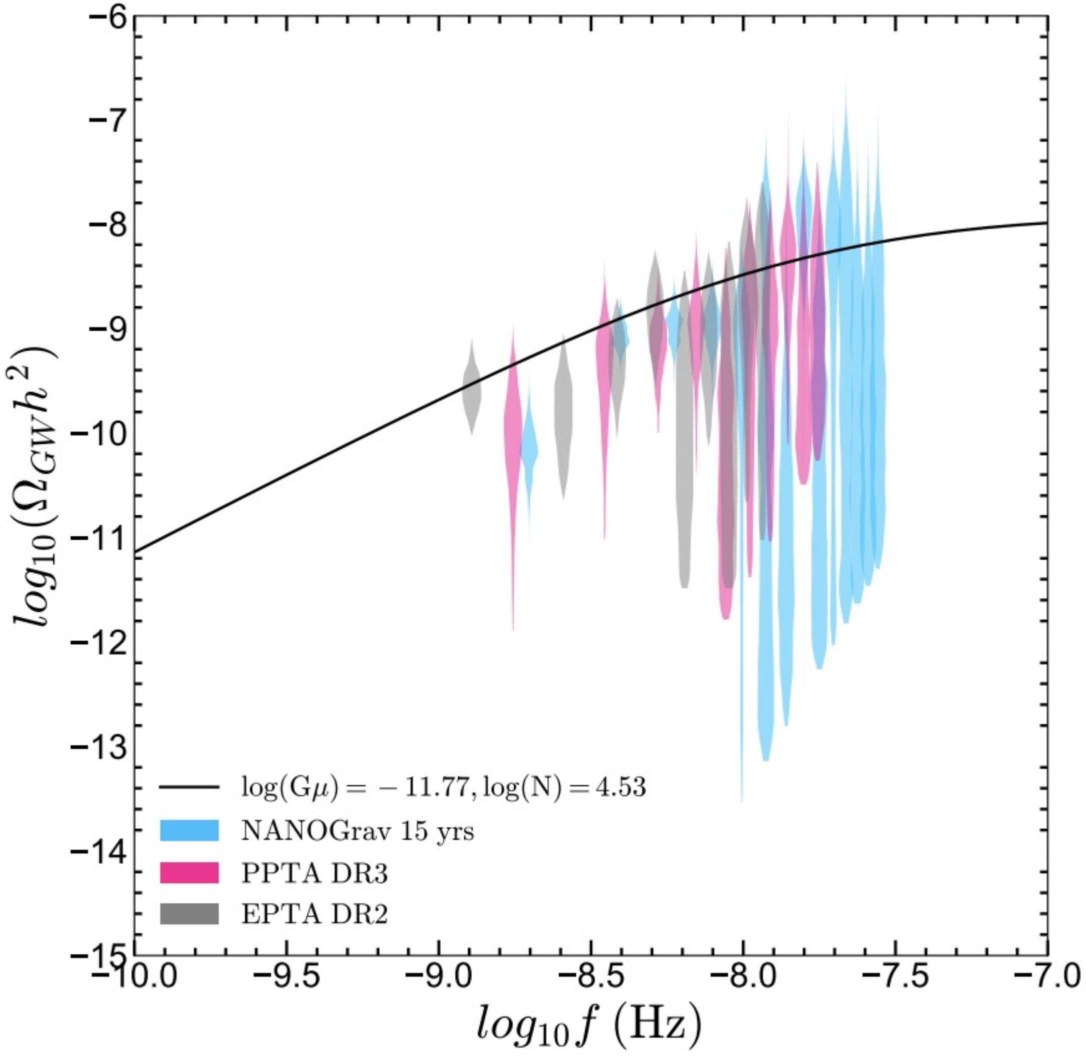
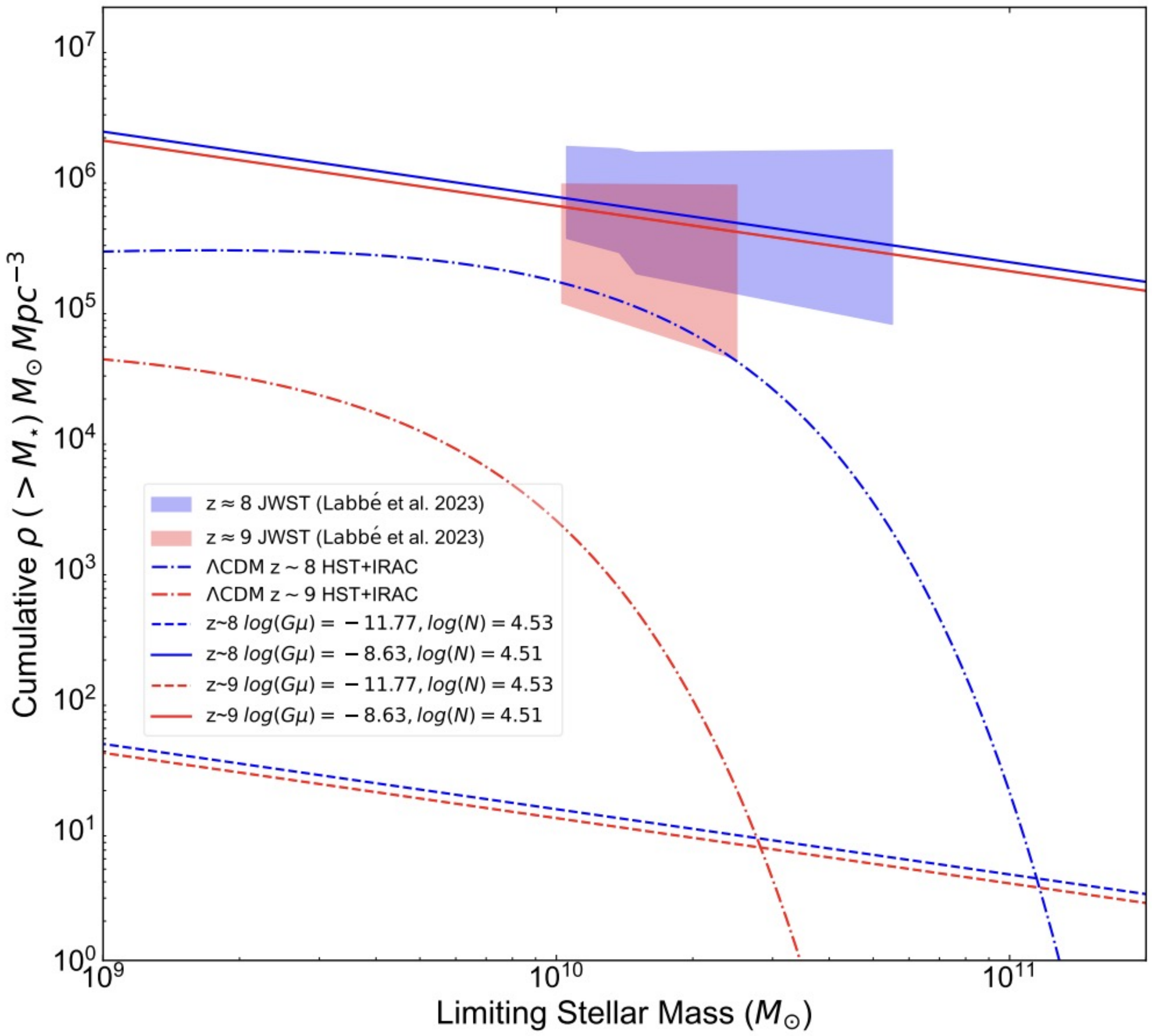


JWST high z : Cosmic String ?

2306.17150 , SCPMA, Zi-Wei Wang, Lei Lei, et al. (2024)





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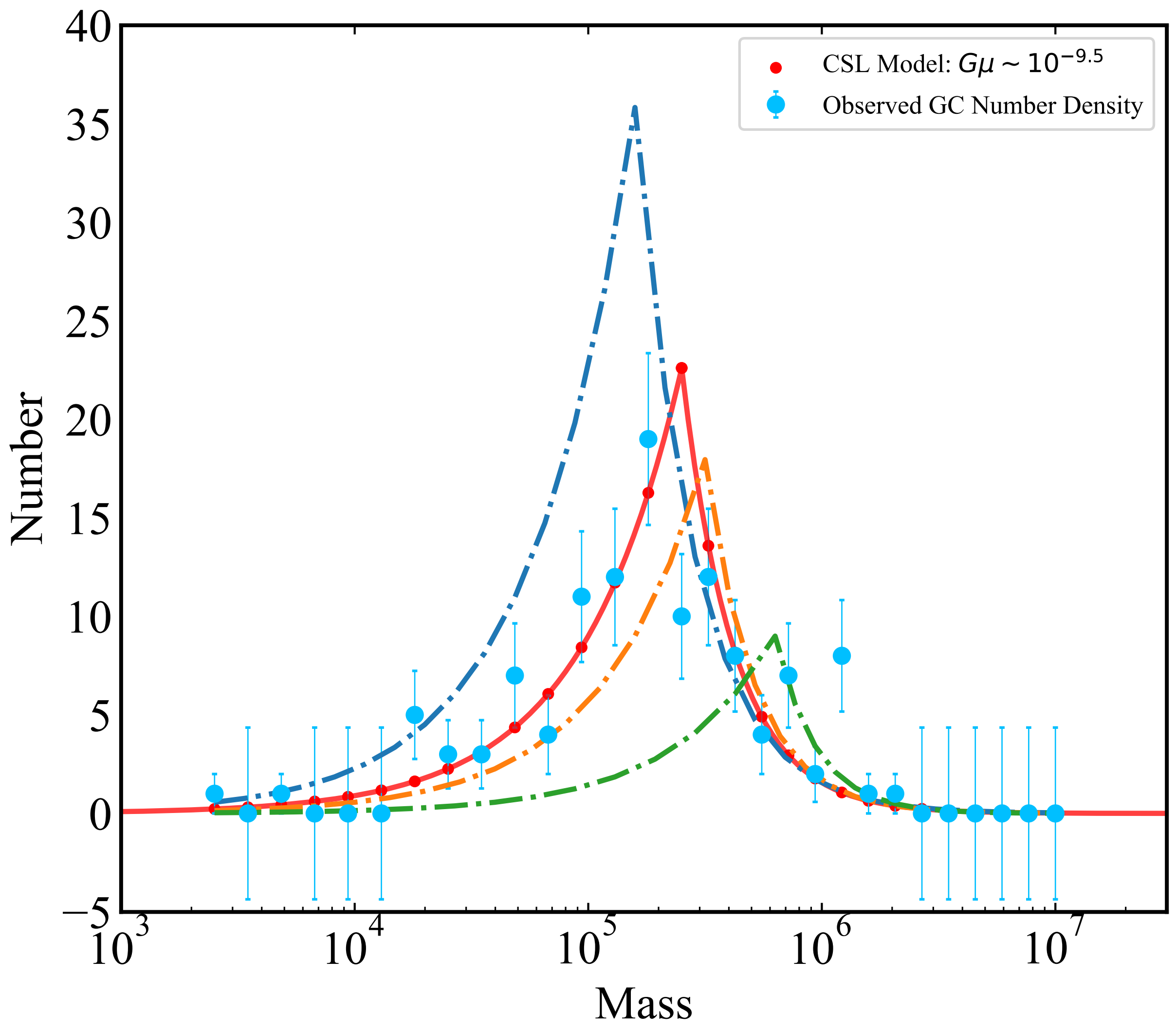
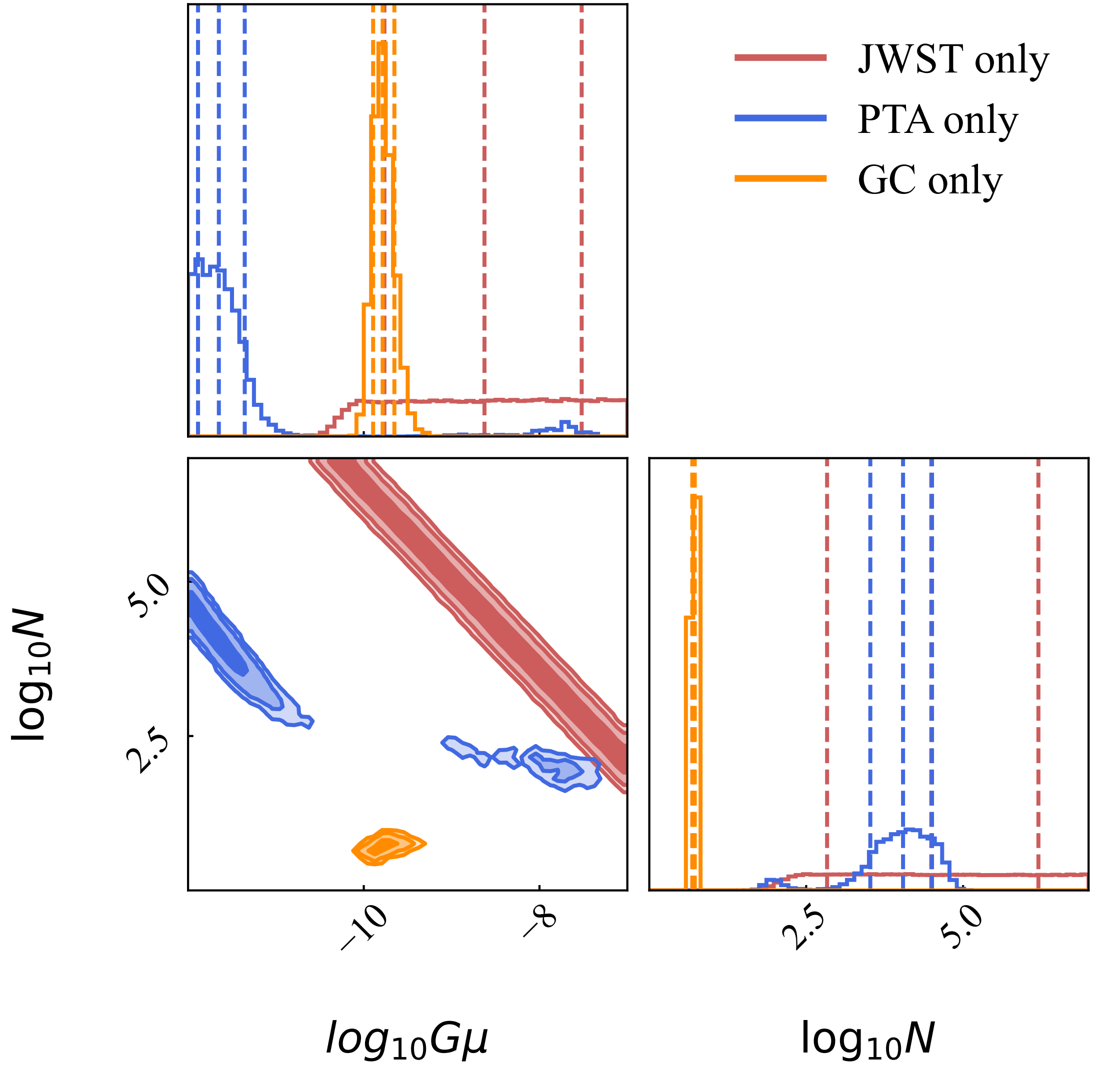




Dark Matter： Current State

arxiv: 2406.01705

DARK MATTER

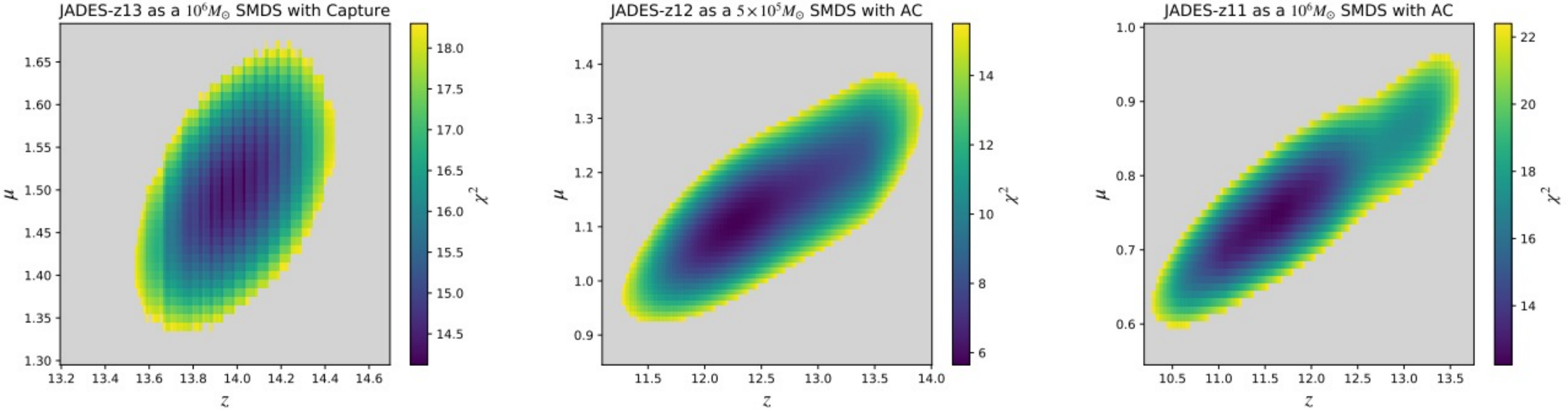
• • • Needs confirmation • • •

PROPERTIES

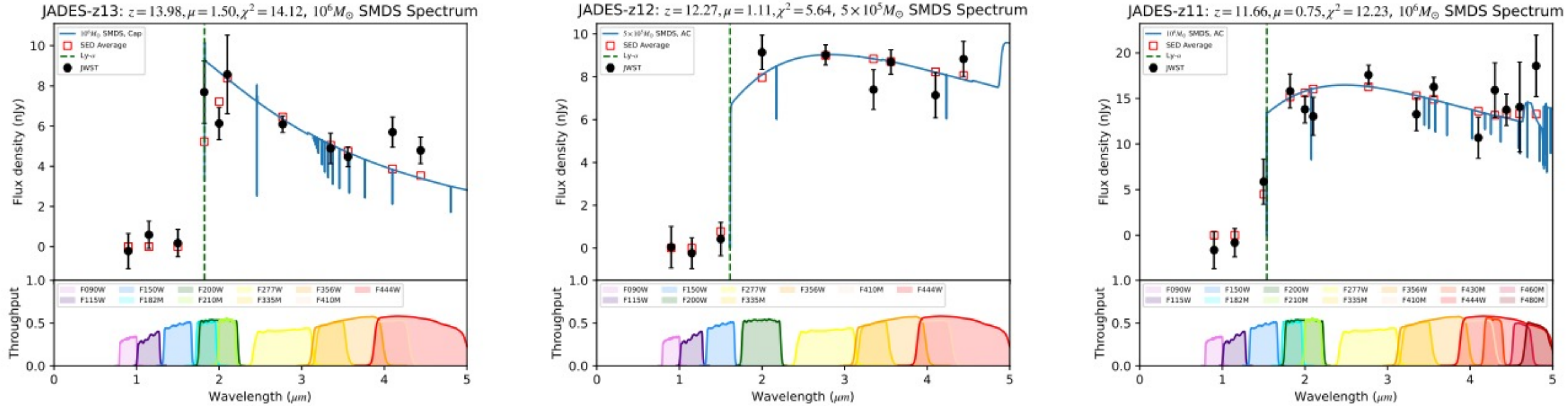
$I(J^{PC})$	MASS	WIDTH	DECAY MODES	PRODUCTION
$?(?^{??})$	$?\pm ?$	$?\pm ?$	STABLE ?	$\sigma(?? \to ??) = ?$

JWST high z: Dark Star?

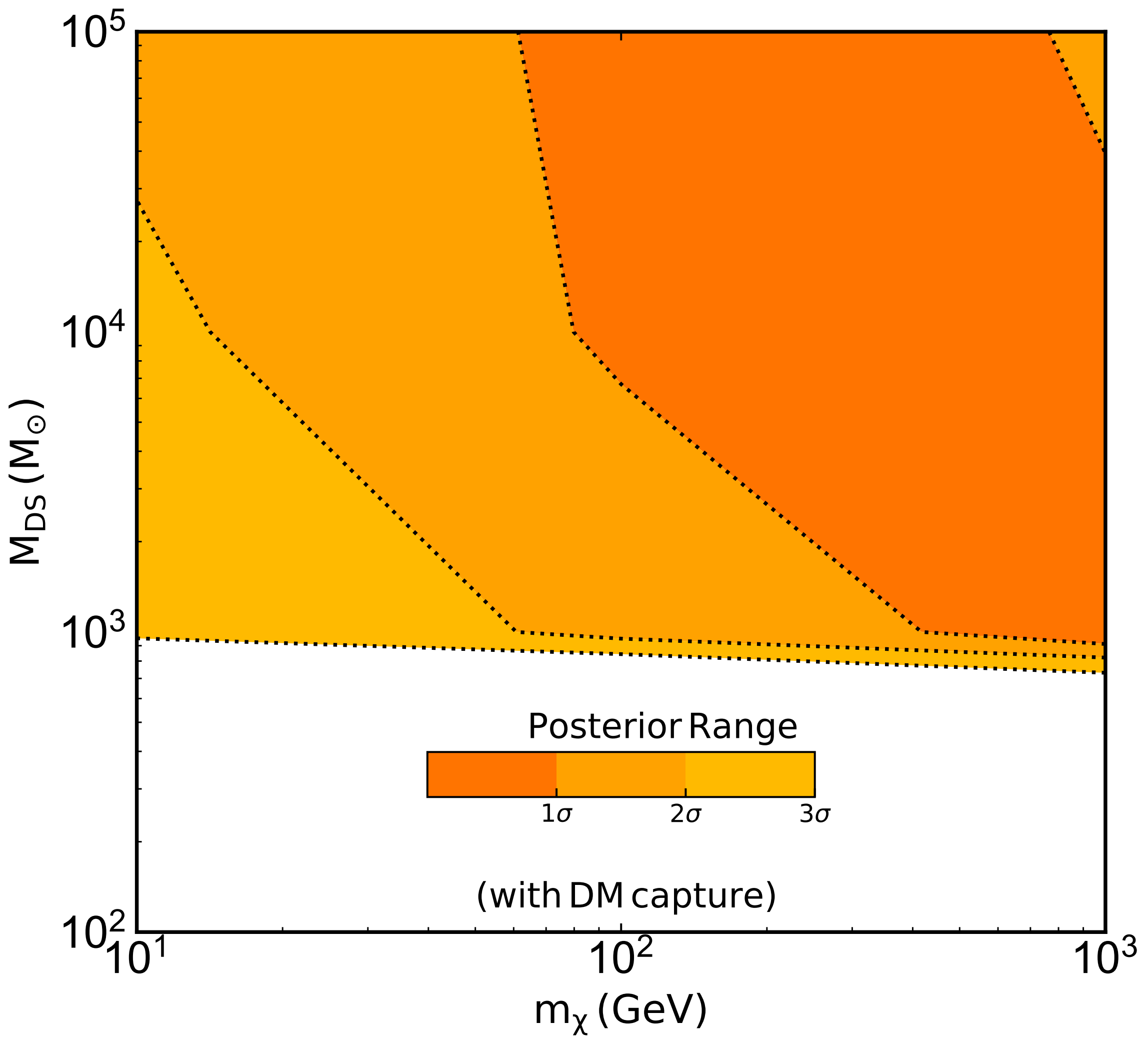
Cosmin Ilie, PNAS, 2023, arxiv:2304.01173

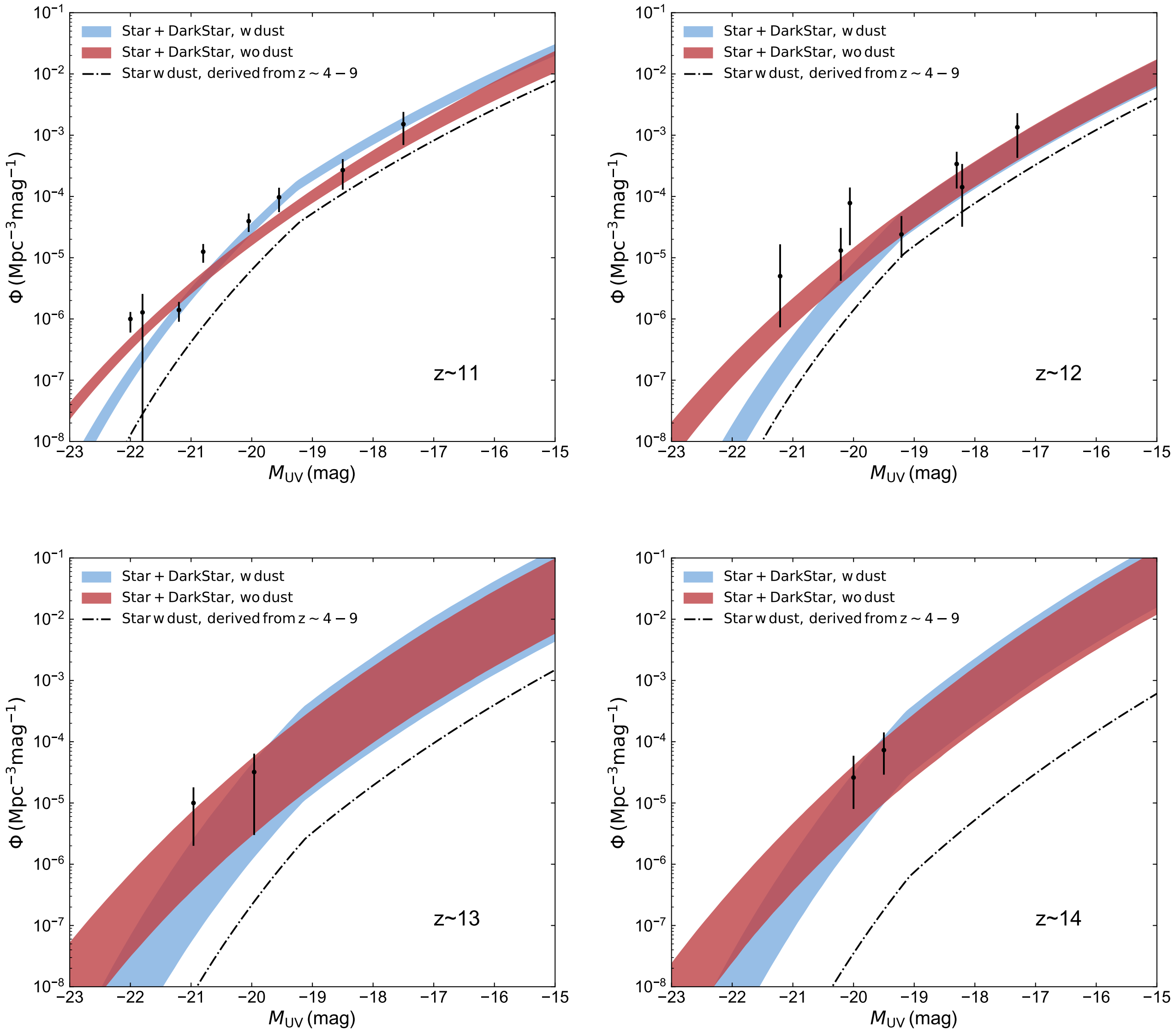


SED is not so good for parameter estimation of dark matter model



JWST high z: Dark Star?



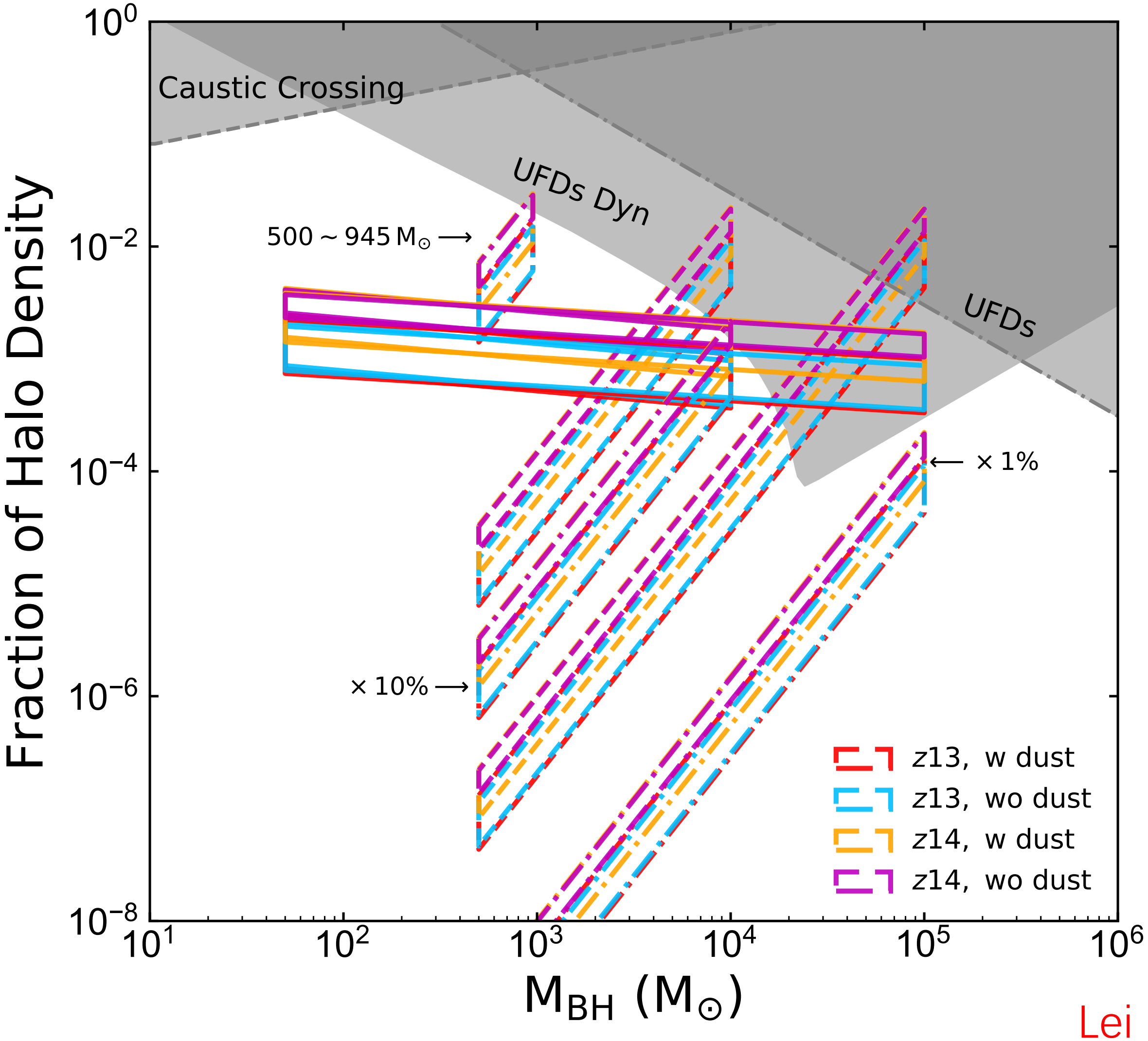


Lei et al, 2024 submitted to ApJ

Can Dark Stars account for the star formation efficiency excess at very high redshifts?

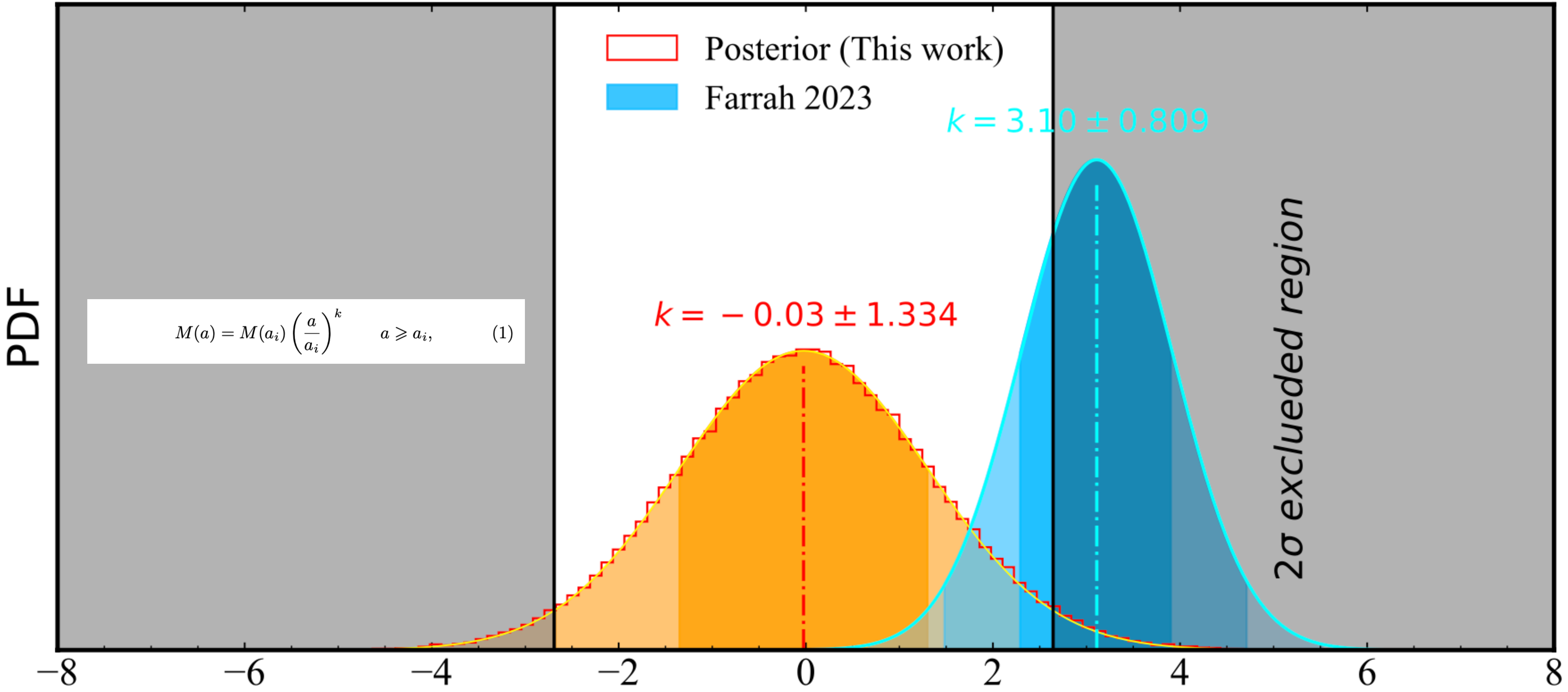
DS is strongly constrained by MACHOs —— too much dark star BH

$$\psi(m) = \epsilon_{\rm DS,eff} f_{\rm b} \left(\frac{\xi_0 \phi(m) m^2}{M_{\rm tot}} \right)$$



Lei et al, 2024 submitted to ApJ

JWST high z: Dark Energy-BH coupling?



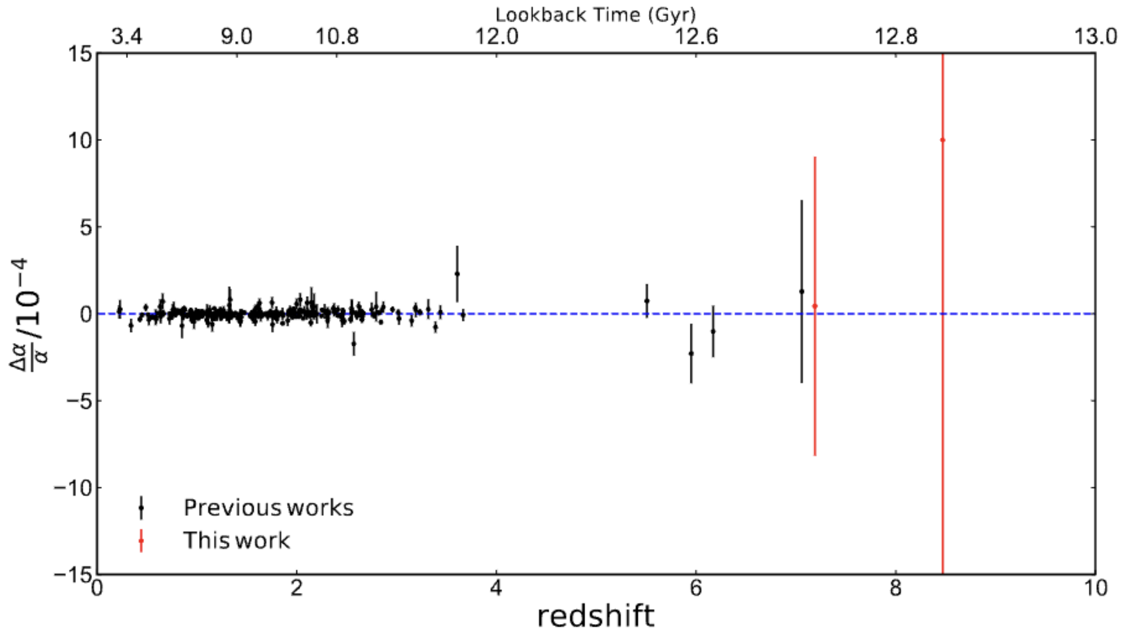
$$M(a) = M(a_i)\left(\frac{a}{a_i}\right)^k \qquad a \geqslant a_i, \qquad (1)$$

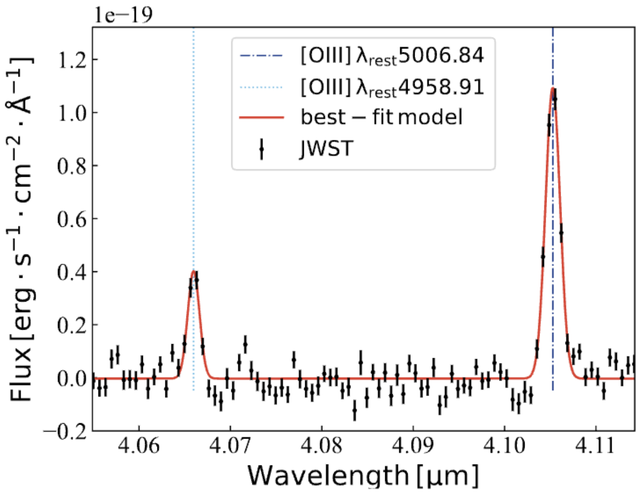
2305.03408 Lei et al, 2024 SCPMA

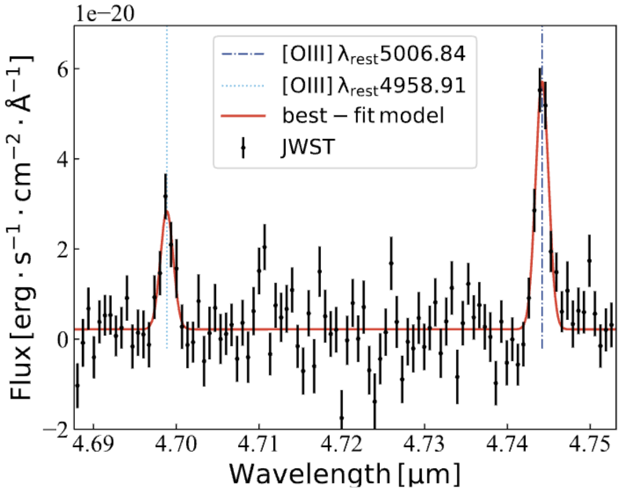
JWST high z: Dark Energy-EM coupling?

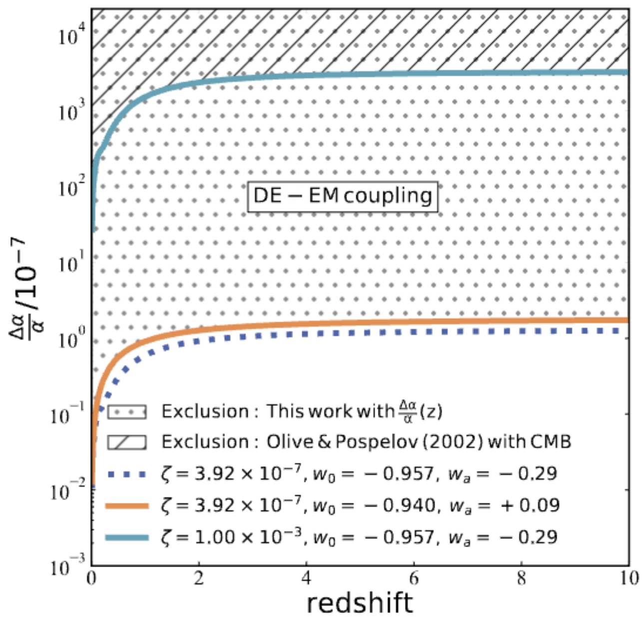
$\zeta \leq 3.92 \times 10^{-7}$ (at 95% Confidence Level).

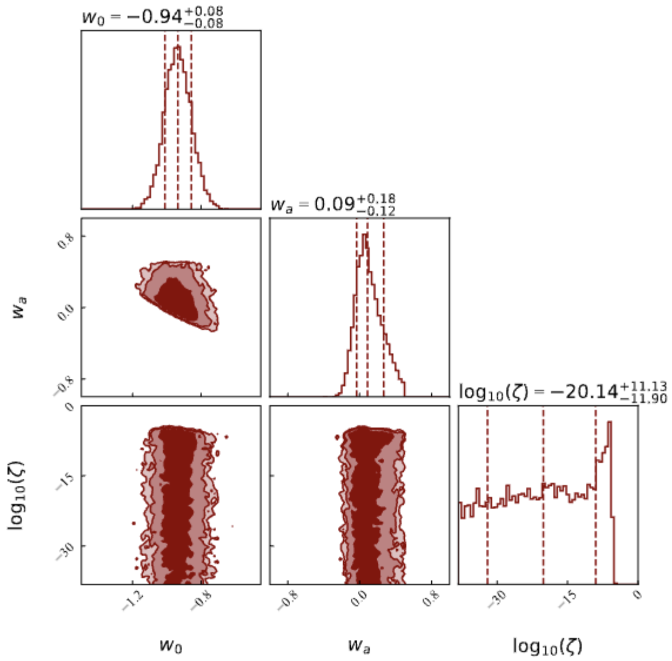
$$\frac{1}{\alpha}\frac{d\alpha}{dt} = 0.30^{+4.5}_{-4.5} \times 10^{-17}\ \mathrm{yr}^{-1}$$











Ze-Fan Wang, Lei Lei, et al. 2024 submitted to RAA

JWST high z: DM & DE

Summary

暗物质：

Lei et al, 2024 submitted to ApJ (sorry no arxiv, please wait):	DarkStar不行
2306.17150 , Zi-Wei Wang, Lei Lei, et al. (2024) , SCPMA:	Cosmic String不太行
2307.12487, Wang Yi-Ying, Lei Lei, et al. (2023) , ApJ Letter：	Pop III可能性
2303.09391, Guan-Wen Yuan, Lei Lei, et al. (2024) , SCPMA：	PBH可能行吧

暗能量：

2305.03408 Lei et al, 2024 SCPMA:	BH不太行
Ze-Fan Wang, Lei Lei et al, 2024 submitted to RAA:	EM不明显

Dark Star

Dark Star Engine Power

the standard annihilation cross section[1]

$$\langle \sigma v \rangle = 3 \times 10^{-26} \mathrm{cm}^3/\mathrm{s},$$

WIMP annihilation produces energy at a rate per unit volume

$$\hat{Q}_{DM} = n_\chi^2 \langle \sigma v \rangle m_\chi = \langle \sigma v \rangle \rho_\chi^2 / m_\chi,$$

The luminosity from the DM heating is

$$L_{DM} \sim f_Q \int \hat{Q}_{DM} dV$$

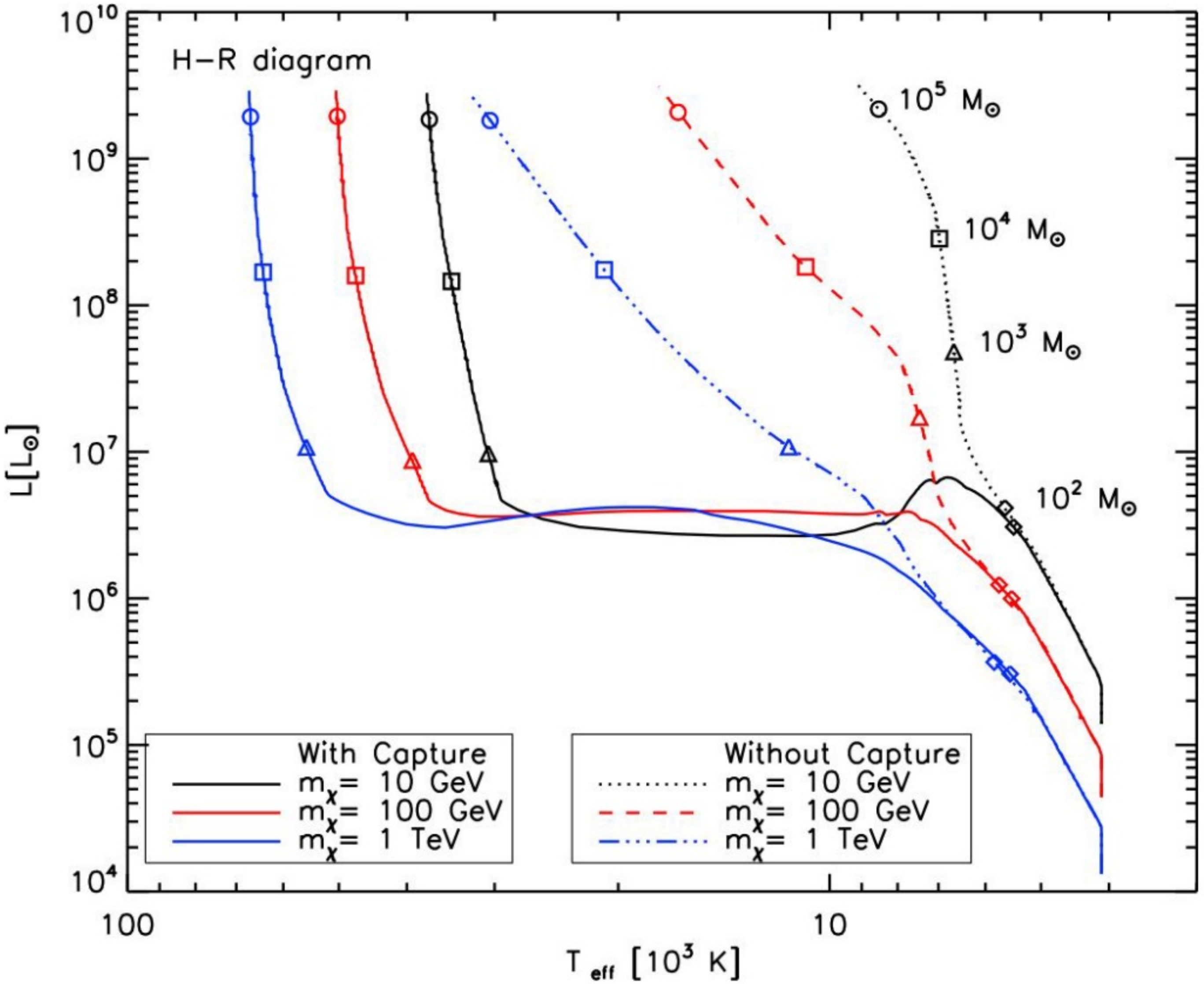
There are four possible contributions to the DS luminosity:

$$L_{tot} = L_{DM} + L_{grav} + L_{nuc} + L_{cap}$$

$f_Q = 2/3$

$$L_{cap} = 2 m_\chi \Gamma_{cap} = 2 m_\chi f_Q \int dV \rho_{cap}^2 \langle \sigma v \rangle / m_\chi$$

arxiv: 1002.2233



Dark Star

Dark Star DM Capture

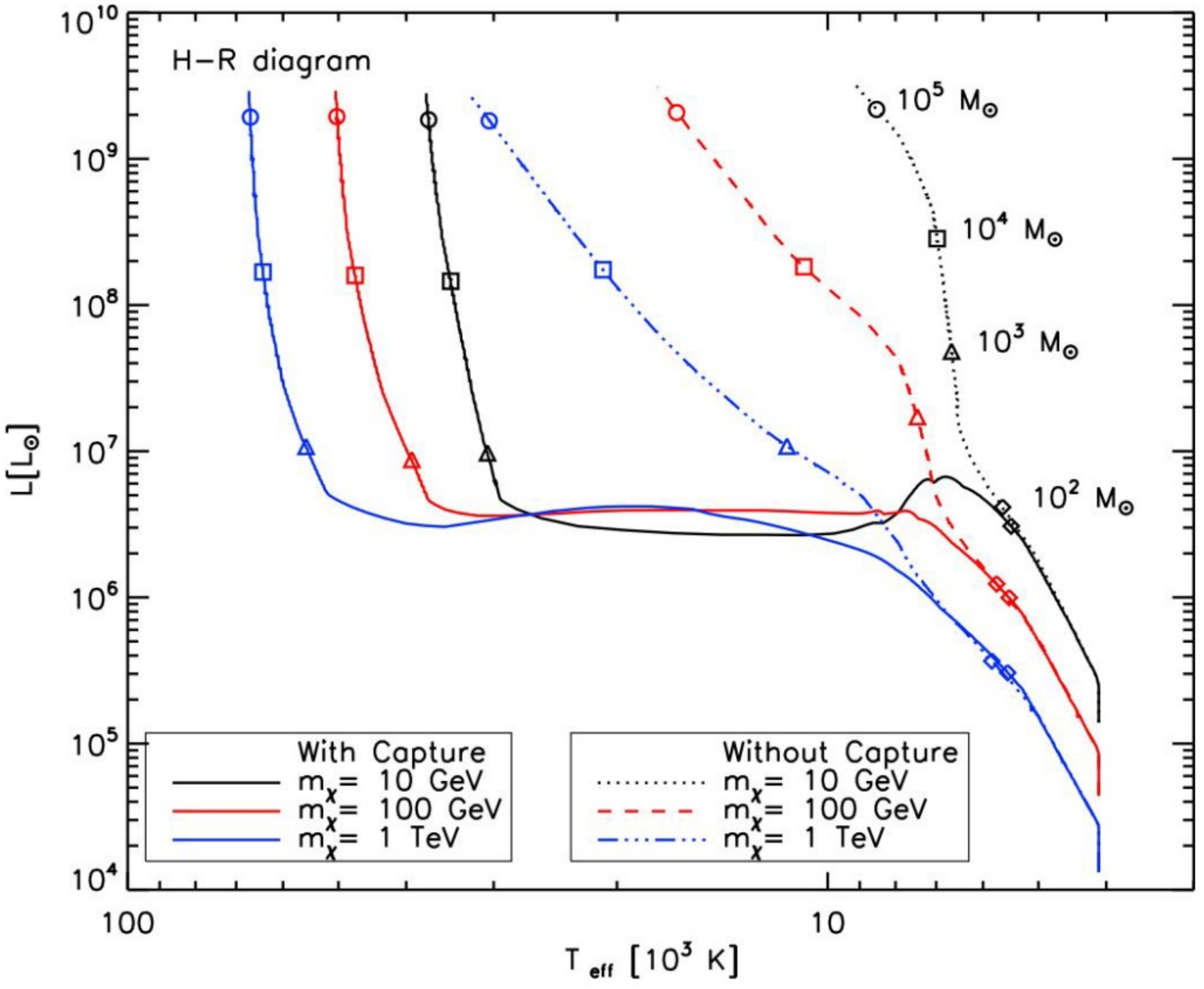
$$L_{cap} = 2m_\chi \Gamma_{cap} = 2m_\chi f_Q \int dV \rho_{cap}^2 \langle \sigma v \rangle / m_\chi$$

$$\sigma_c = 10^{-39} \text{ cm}^2$$

$$\bar{\rho}_\chi = (10^{10} - 10^{14}) \text{GeV cm}^{-3}$$

"minimal capture" value considered in all our previous papers. Our fiducial cross section is just below the experimental bound for spin-dependent (SD) scattering; the bound on spin-independent (SI) scattering is much tighter: $\sigma_{c,SI} < 3.8 \times 10^{-44}$ cm^2 for $m_\chi = 100$GeV (Ahmed et al. 2009). We will show that capture can produce sufficient DM in the star to keep DM heating alive for a long time. The details of our procedure for including capture have previously been presented in Spolyar et al. (2009) and will not be repeated here.

arxiv: 1002.2233



WIMPs Annihilation Powered Very Massive Dark Stars
-- Dark star is not dark! --

$$\mathrm{SFR_{UV}}(\mathrm{M_\odot\,yr^{-1}}) = \mathcal{K}_{\mathrm{UV}} \times L_{\mathrm{UV}}(\mathrm{erg\,s^{-1}\,Hz^{-1}}), \quad (1)$$

where $\mathcal{K}_{\mathrm{UV}} = 1.15\times10^{-28}\,\mathrm{M_\odot\,yr^{-1}/(erg\,s^{-1}\,Hz^{-1})}$ is the conversion factor with the Salpeter IMF at 1500 Å.

$$\frac{\mathcal{K}_{\mathrm{UV,DS}}}{\mathcal{K}_{\mathrm{UV,Pop\,III}}} = \frac{(M/L)_{\mathrm{DS}}}{(M/L)_{\mathrm{Pop\,III}}},$$

$$\mathrm{M/L} = \frac{M_{\mathrm{tot}}}{L_{\mathrm{tot}}}, \quad (2)$$

$$M_{\mathrm{tot}} = \int_{m_{\mathrm{low}}}^{m_{\mathrm{up}}} \xi_0 m\phi(m)\,dm, \quad (3)$$

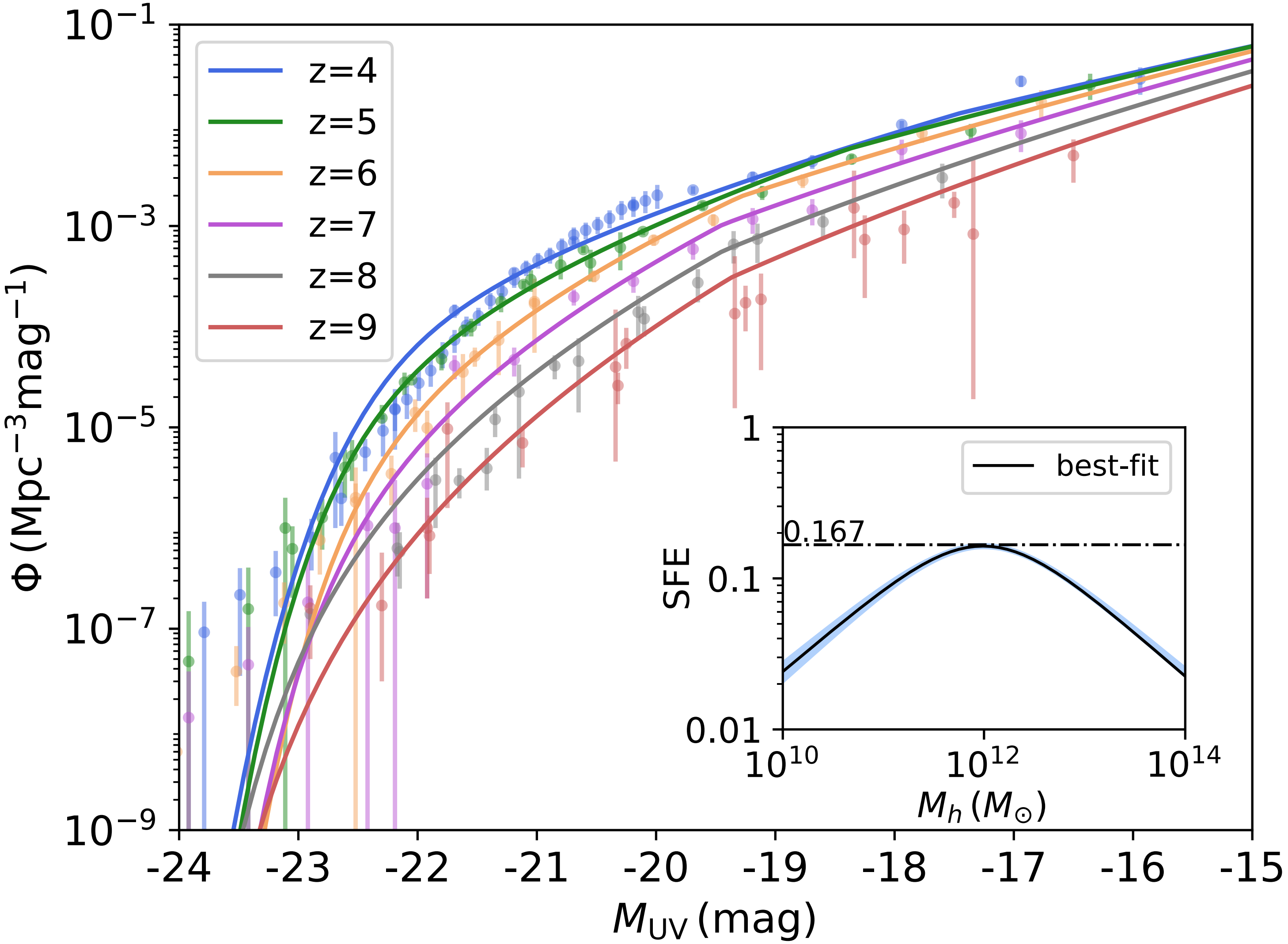
$$L_{\mathrm{tot}} = \int_{m_{\mathrm{low}}}^{m_{\mathrm{up}}} \xi_0 L(m)\phi(m)\,dm, \quad (4)$$

TABLE I. UV luminosity-to-SFR conversion factor of stars, Pop III stars and dark stars.

Population Type	IMF Type	m_{low} $\mathrm{M_\odot}$	m_{up} $\mathrm{M_\odot}$	α	Z $\mathrm{Z_\odot}$	$\mathcal{K}_{\mathrm{UV}}$ $\frac{\mathrm{M_\odot\,yr^{-1}}}{(\mathrm{erg\,s^{-1}Hz^{-1}})}$	η_{UV} [a] $\frac{\mathrm{erg\,s^{-1}Hz^{-1}}}{(\mathrm{M_\odot\,yr^{-1}})}$	$\epsilon_{\star,\mathrm{rad}}$ [b]
Stars* [c]	Salpeter	1×10^{-1}	1×10^{2}	2.35	0.02	1.26×10^{-28}	7.94×10^{27}	2.79×10^{-4}
Stars*	Salpeter	1×10^{-1}	1×10^{2}	2.35	0.0004	1.07×10^{-28}	9.32×10^{27}	3.28×10^{-4}
Pop III*	Salpeter	5×10^{1}	5×10^{2}	2.35	0	2.80×10^{-29}	3.57×10^{28}	1.26×10^{-3}
DS, w Cap m_χ = 10 Gev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.79×10^{-29}	3.59×10^{28}	1.27×10^{-3}
DS, w Cap m_χ = 100 Gev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.59×10^{-29}	3.86×10^{28}	1.36×10^{-3}
DS, w Cap m_χ = 1 Tev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.70×10^{-29}	3.70×10^{28}	1.31×10^{-3}
DS, w Cap m_χ = 10 Gev	power-law	5×10^{2}	1×10^{4}	-0.17	0	3.88×10^{-29}	2.58×10^{28}	9.10×10^{-4}
DS, w Cap m_χ = 100 Gev	power-law	5×10^{2}	1×10^{4}	-0.17	0	3.59×10^{-29}	2.78×10^{28}	9.82×10^{-4}
DS, w Cap m_χ = 1 Tev	power-law	5×10^{2}	1×10^{4}	-0.17	0	3.30×10^{-29}	3.03×10^{28}	1.70×10^{-3}
DS, wo Cap m_χ = 10 Gev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.28×10^{-29}	4.38×10^{28}	1.55×10^{-3}
DS, wo Cap m_χ = 100 Gev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.58×10^{-29}	3.88×10^{28}	1.37×10^{-3}
DS, wo Cap m_χ = 1 Tev	power-law	5×10^{2}	1×10^{5}	-0.17	0	2.76×10^{-29}	3.62×10^{28}	1.28×10^{-3}
DS, wo Cap m_χ = 10 Gev	power-law	5×10^{2}	1×10^{4}	-0.17	0	1.63×10^{-29}	6.14×10^{28}	2.17×10^{-3}
DS, wo Cap m_χ = 100 Gev	power-law	5×10^{2}	1×10^{4}	-0.17	0	2.87×10^{-29}	3.48×10^{28}	1.23×10^{-3}
DS, wo Cap m_χ = 1 Tev	power-law	5×10^{2}	1×10^{4}	-0.17	0	3.12×10^{-29}	3.21×10^{28}	1.13×10^{-3}

Lei et al. 2024 ApJ, submitted

WIMP Dark Matter Annihilation Powered Very Massive Dark Stars
-- Low z case: SFE < 20% --



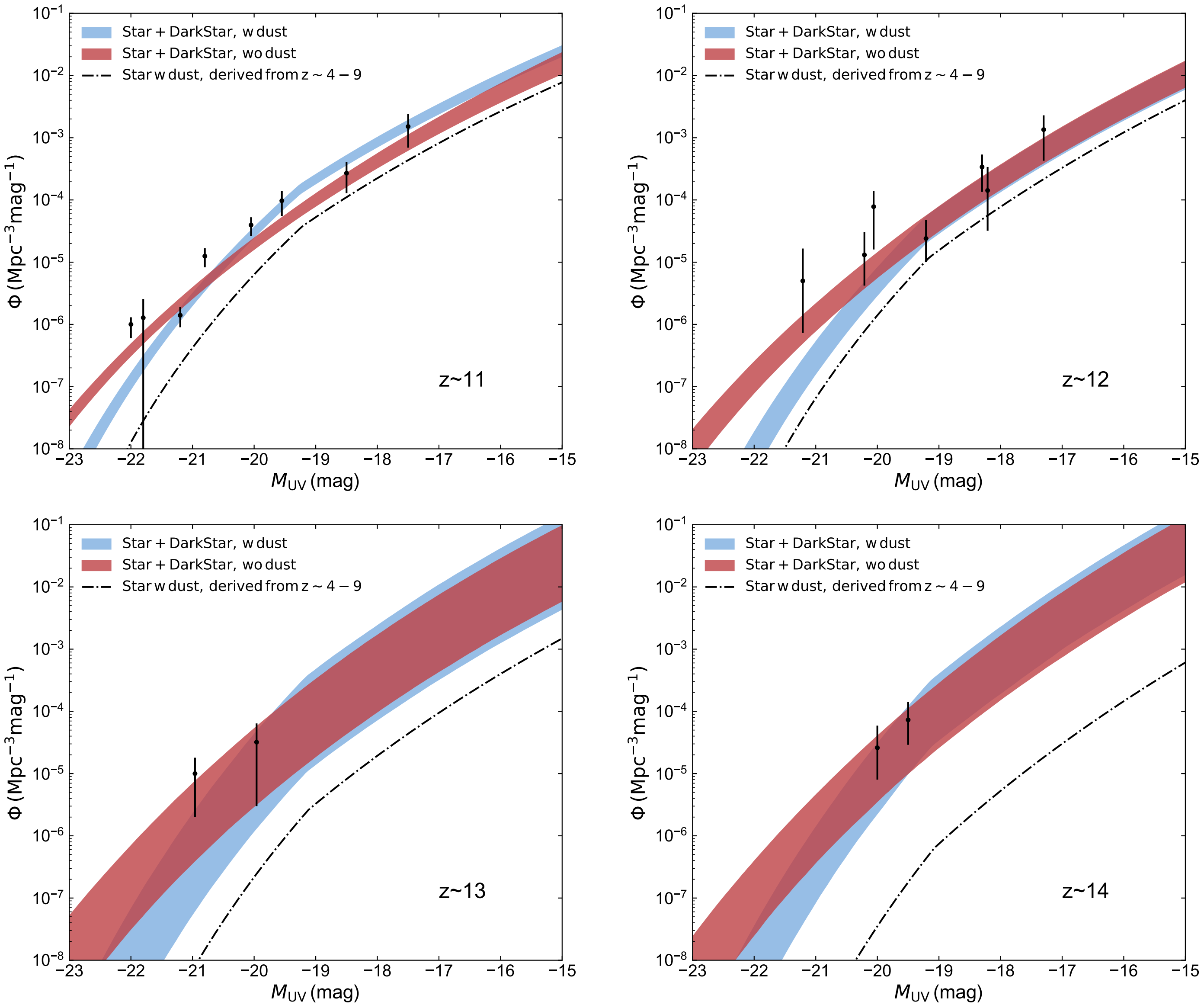
$$\mathrm{SFR_{UV}} = f_{\mathrm{tot}} \times \dot{M}_b, \quad f_{\mathrm{tot}} = f_{\mathrm{S}} + f_{\mathrm{DS}}, \tag{8}$$

$$f_{\mathrm{S}} = \frac{2\epsilon_{\mathrm{N}}}{\left(\frac{M_{\mathrm{h}}}{M_1}\right)^{-\beta} + \left(\frac{M_{\mathrm{h}}}{M_1}\right)^{\gamma}}, \tag{9}$$

$$f_{\mathrm{DS}} = \epsilon_{\mathrm{DS}}\left(\frac{M_{\mathrm{h}}}{M_1}\right)^{\gamma_{\mathrm{DS}}}, \tag{10}$$

Lei et al. 2024 ApJ, submitted

WIMP Dark Matter Annihilation Powered Very Massive Dark Stars
-- Dark star is not dark! --



$$\mathrm{SFR_{UV}} = f_{\mathrm{tot}} \times \dot{M}_b, \qquad f_{\mathrm{tot}} = f_{\mathrm{S}} + f_{\mathrm{DS}}, \tag{8}$$

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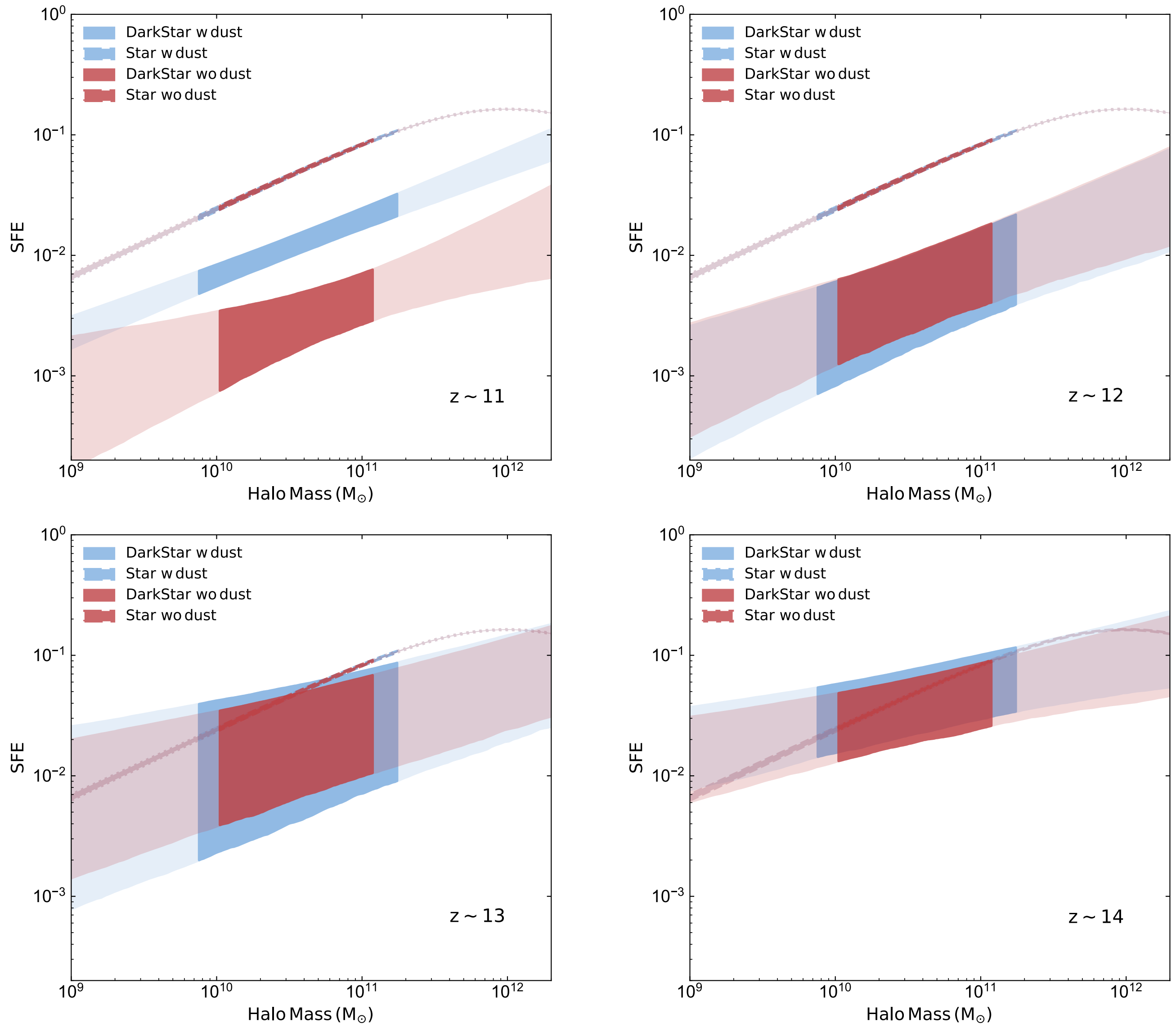
$$f_{\mathrm{DS}} = \epsilon_{\mathrm{DS}}\left(\frac{M_{\mathrm{h}}}{M_1}\right)^{\gamma_{\mathrm{DS}}}, \tag{10}$$

Lei et al. 2024 ApJ, submitted

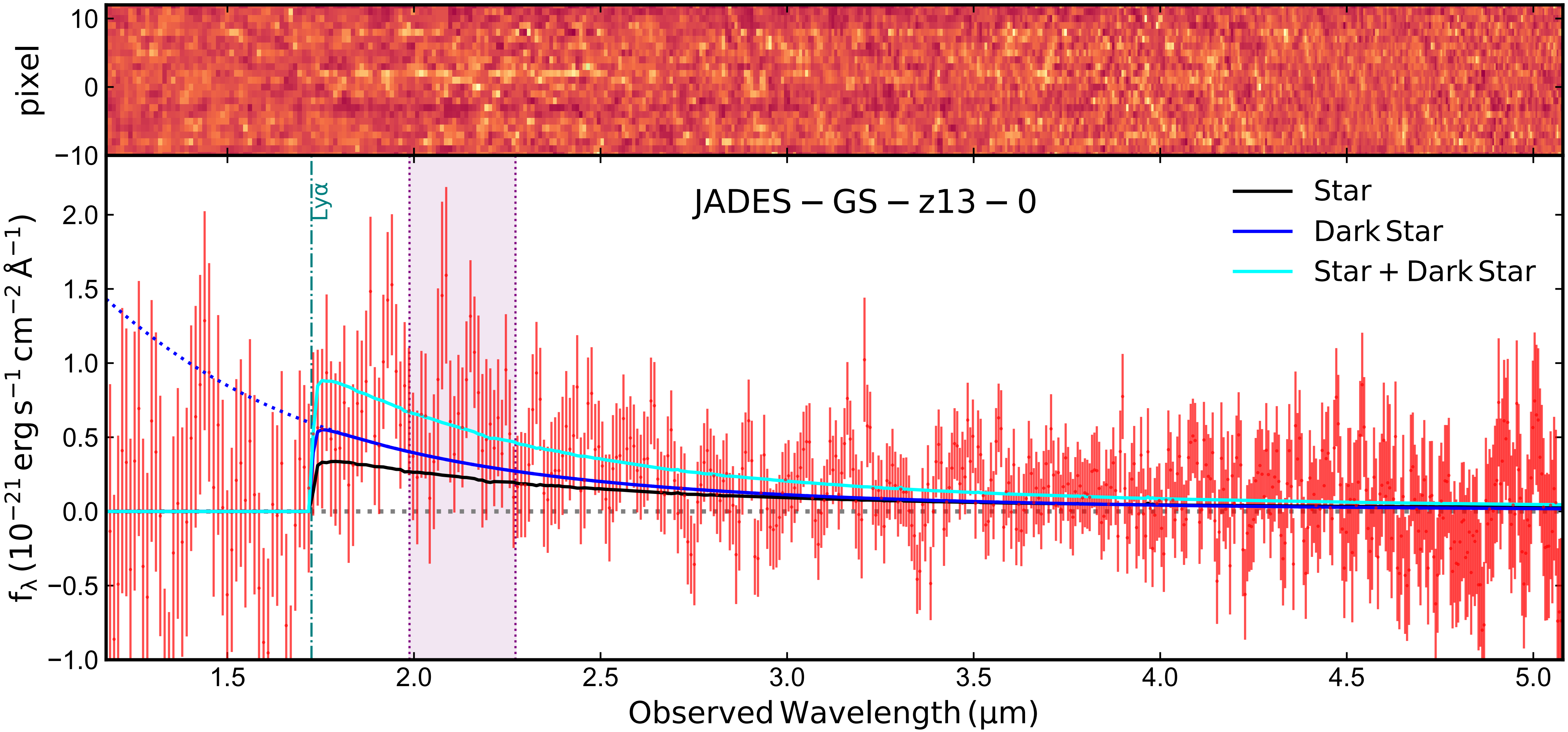
WIMP Dark Matter Annihilation Powered Very Massive Dark Stars in JWST High Redshift Galaxies

SFE with DS: little things, large radiation



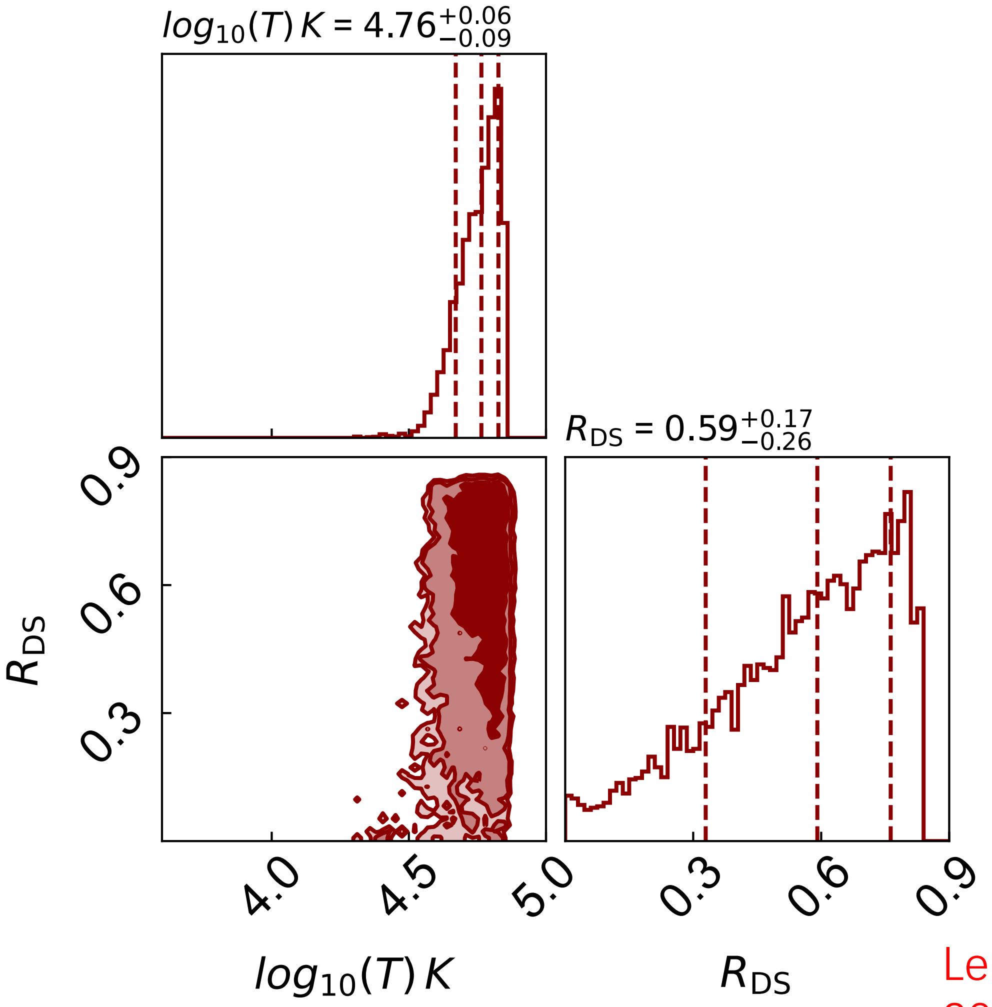
Lei et al. 2024 ApJ, submitted

WIMP Dark Matter Annihilation Powered Very Massive Dark Stars in JWST High Redshift Galaxies

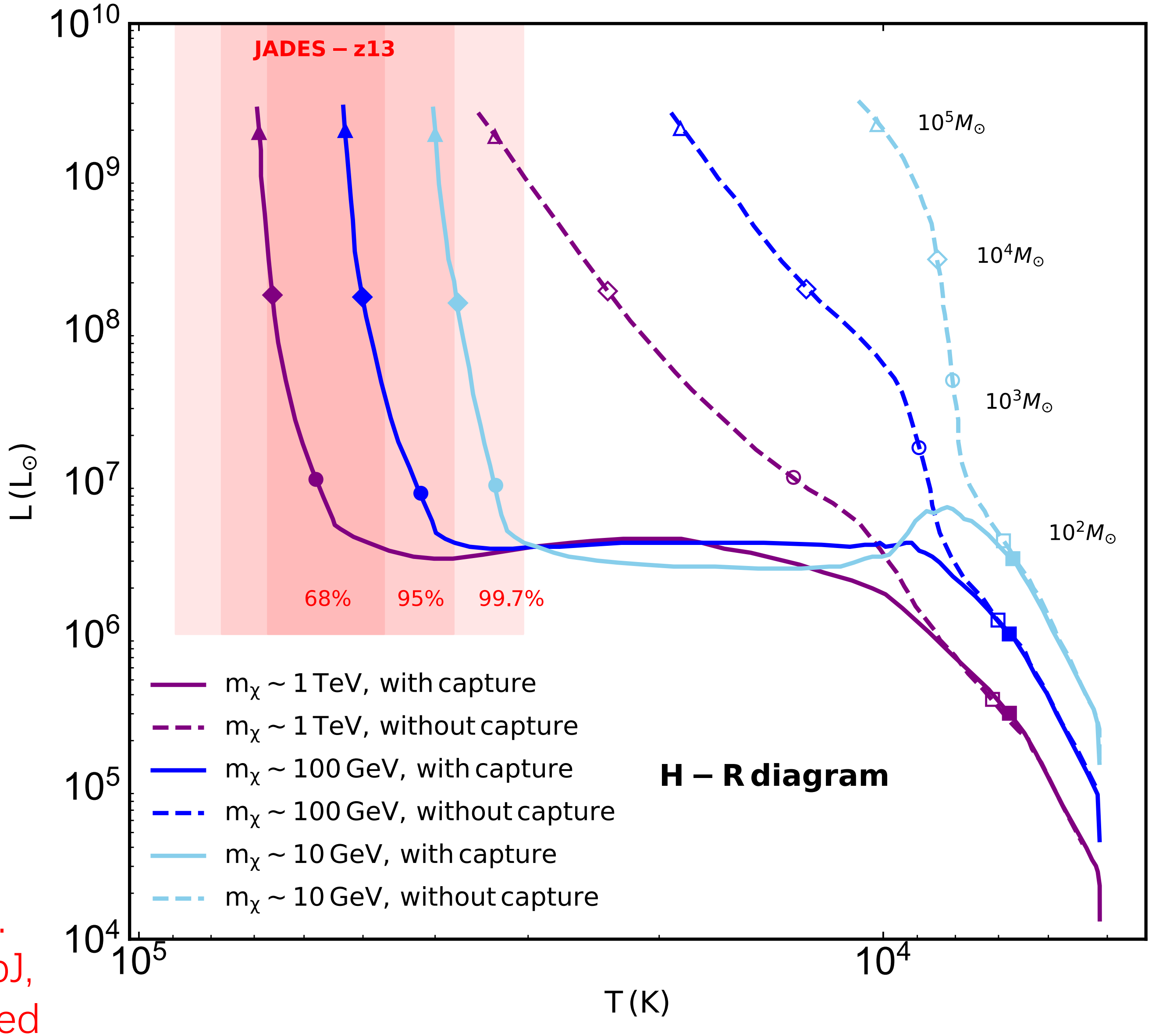


Lei et al. 2024 ApJ, submitted

WIMP Dark Matter Annihilation Powered Very Massive Dark Stars in JWST High Redshift Galaxies

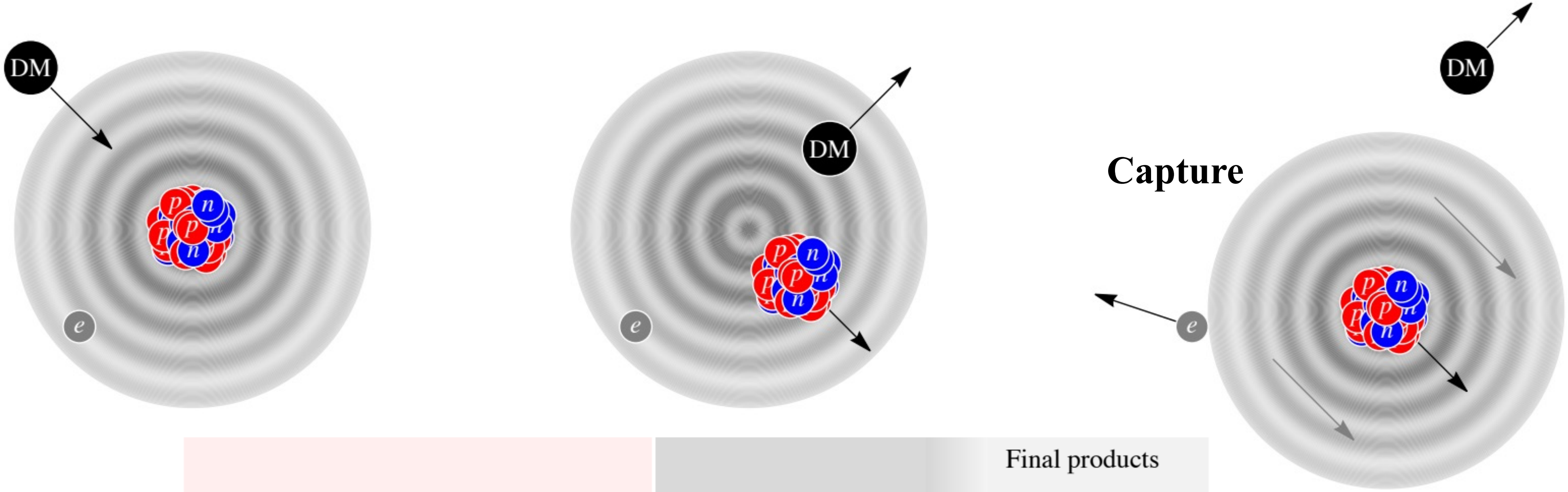


Lei et al. 2024 ApJ, submitted

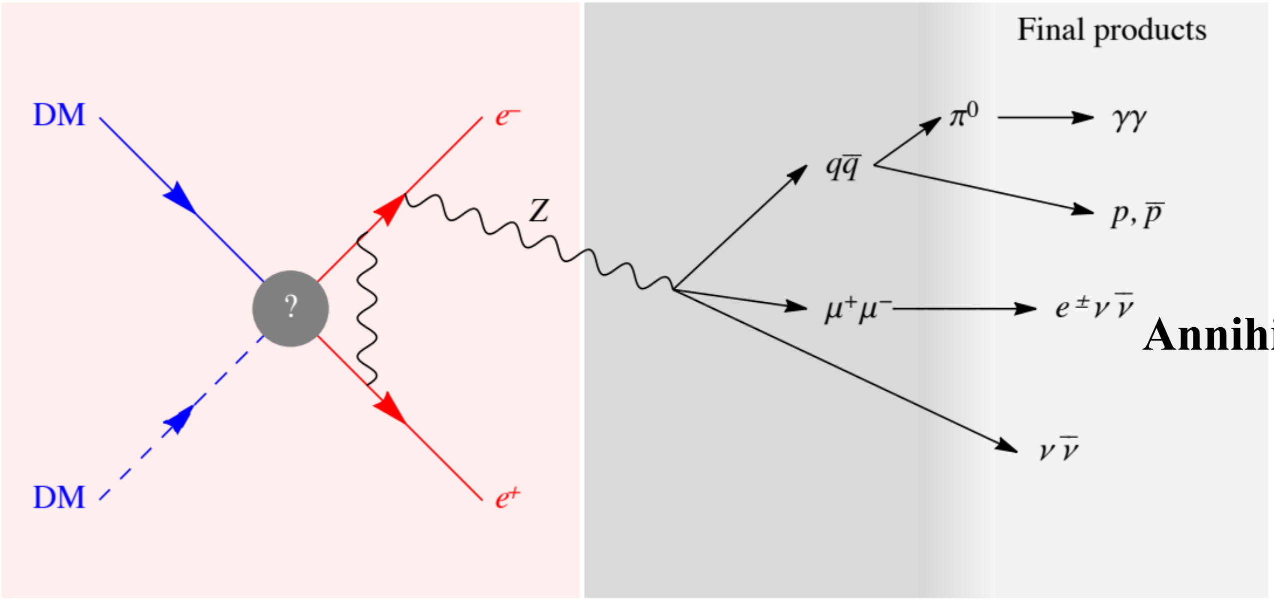


Dark Matter： Capture & Annihilation

arxiv: 2406.01705



Capture



Annihilation

Dark Star

Dark Star DM Capture

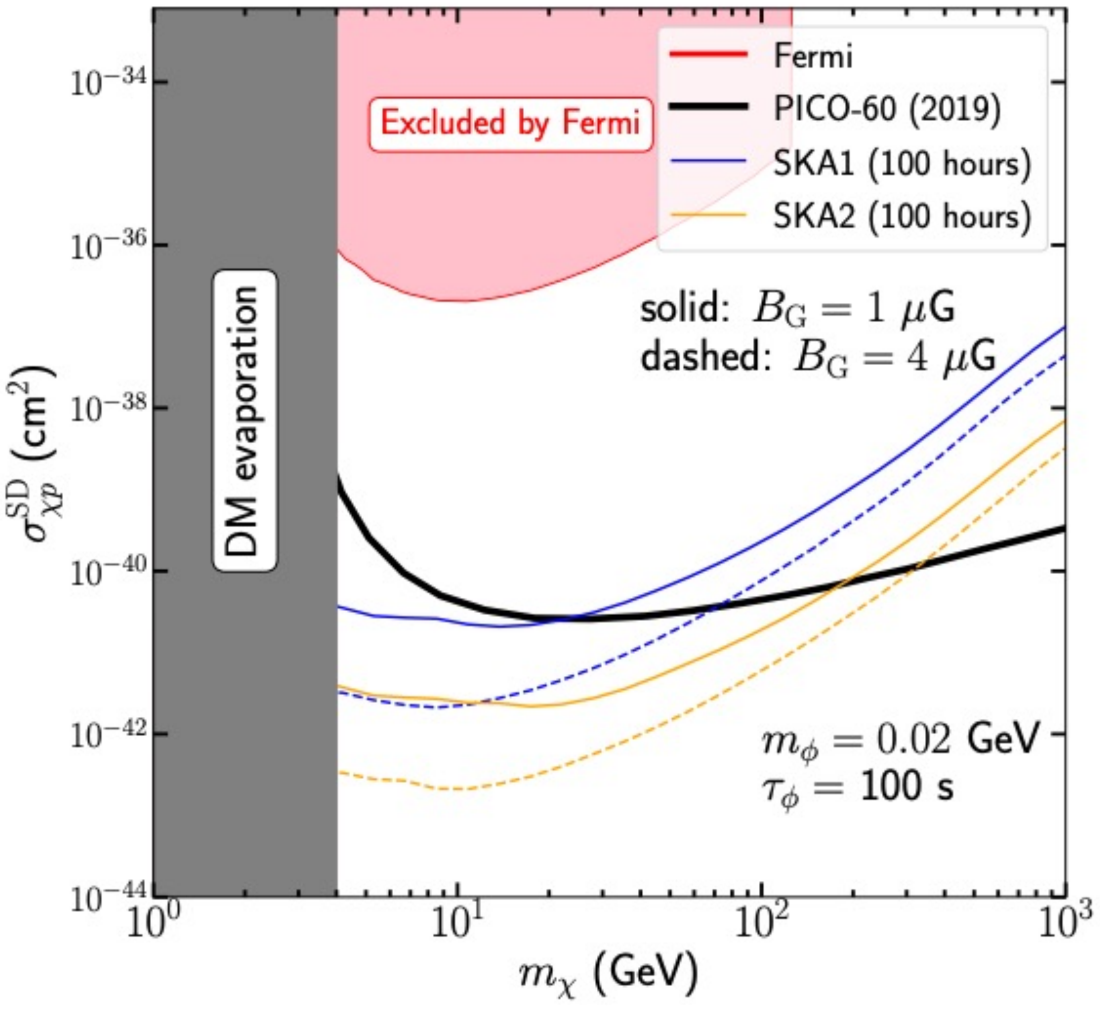
$$L_{cap} = 2m_\chi \Gamma_{cap} = 2m_\chi f_Q \int dV \rho_{cap}^2 \langle \sigma v \rangle / m_\chi$$

$$\sigma_c = 10^{-39} \text{ cm}^2$$

$$\bar{\rho}_\chi = (10^{10} - 10^{14})\text{GeV cm}^{-3}$$

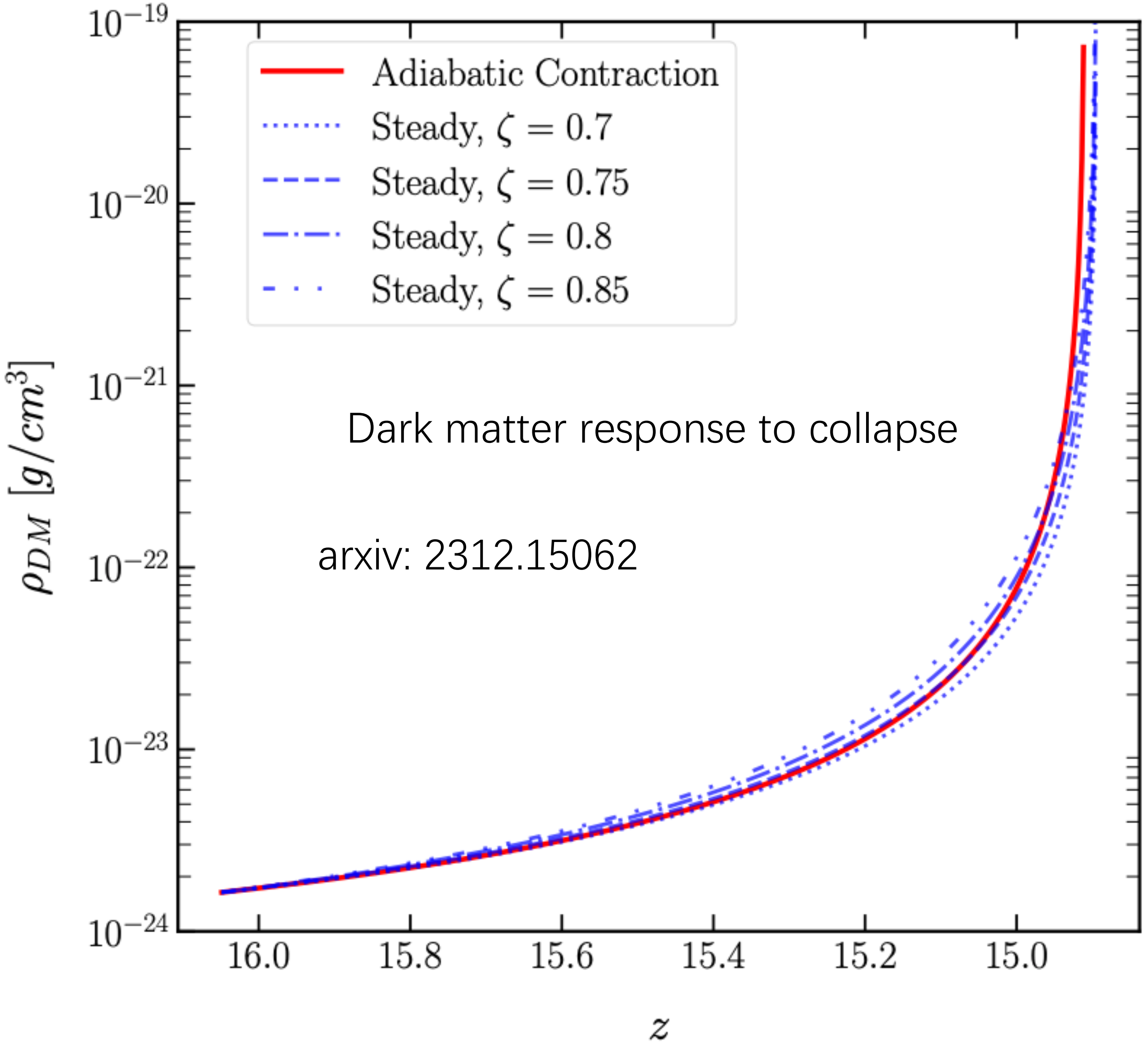
"minimal capture" value considered in all our previous papers. Our fiducial cross section is just below the experimental bound for spin-dependent (SD) scattering; the bound on spin-independent (SI) scattering is much tighter: $\sigma_{c,SI} < 3.8 \times 10^{-44}$ cm^2 for $m_\chi = 100$GeV (Ahmed et al. 2009). We will show that capture can produce sufficient DM in the star to keep DM heating alive for a long time. The details of our procedure for including capture have previously been presented in Spolyar et al. (2009) and will not be repeated here.

arxiv: 1002.2233

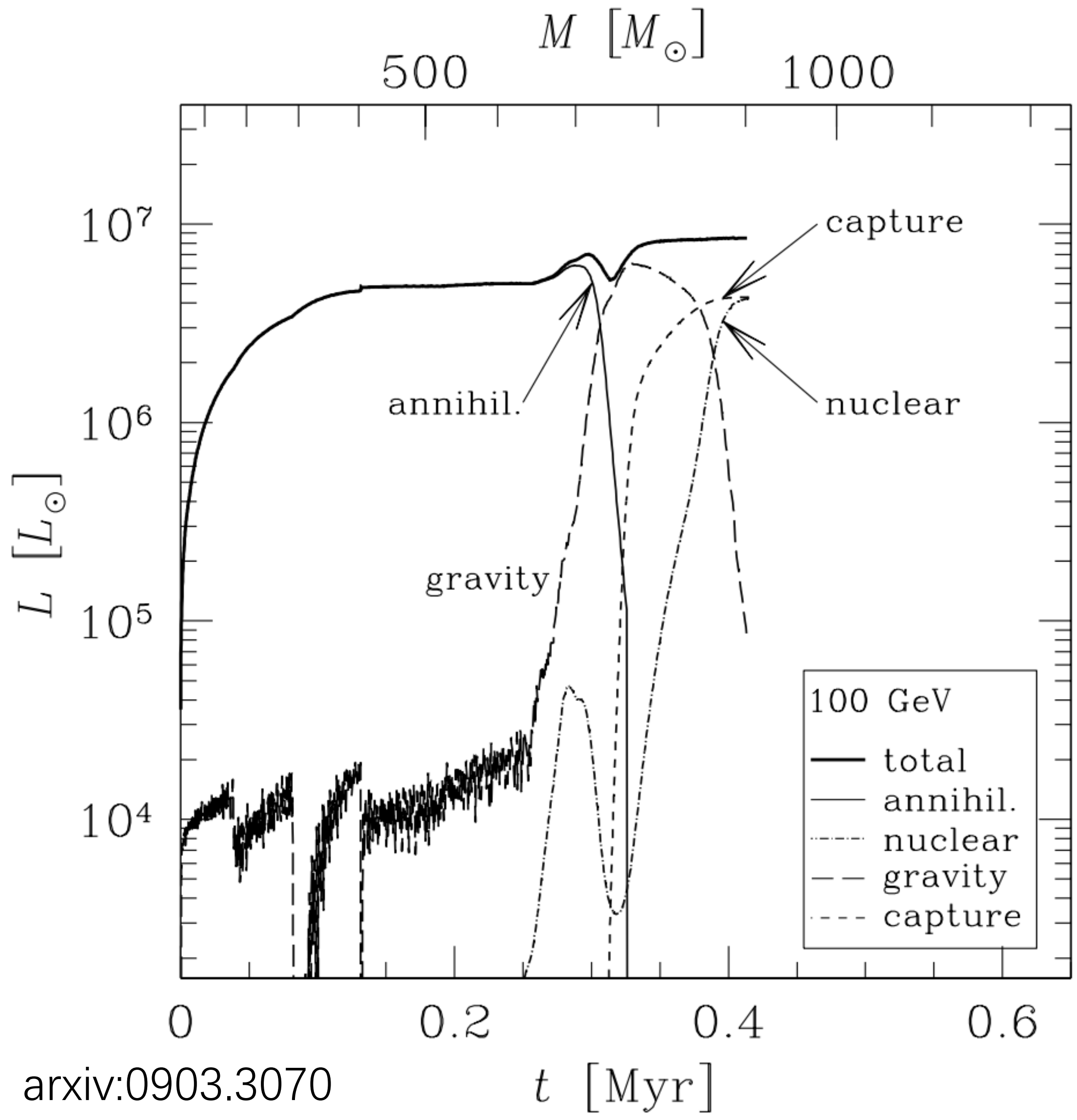


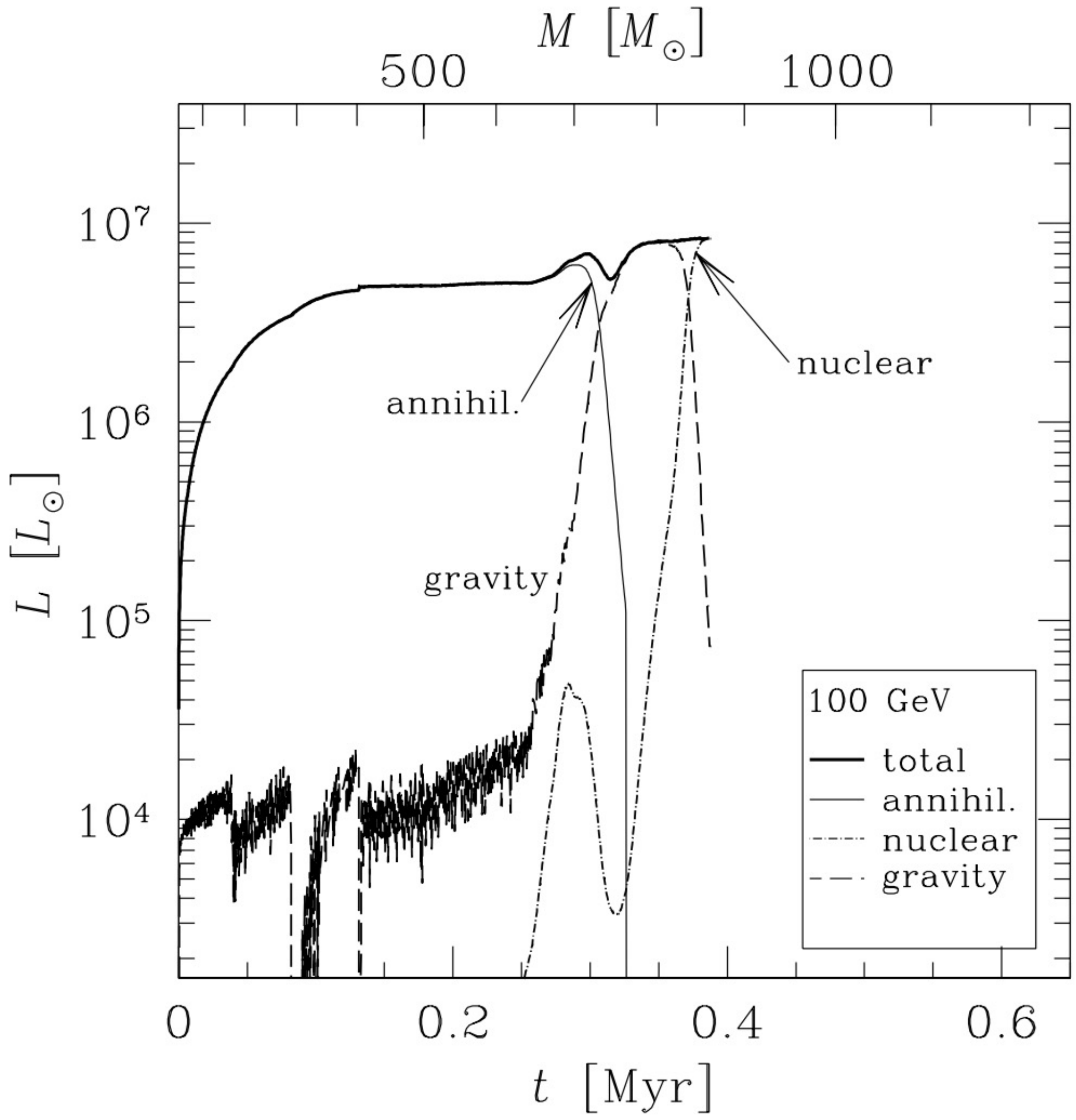
2302.09951, Yu-Xuan Chen et al. JCAP

Dark Matter Collapse



Dark Star

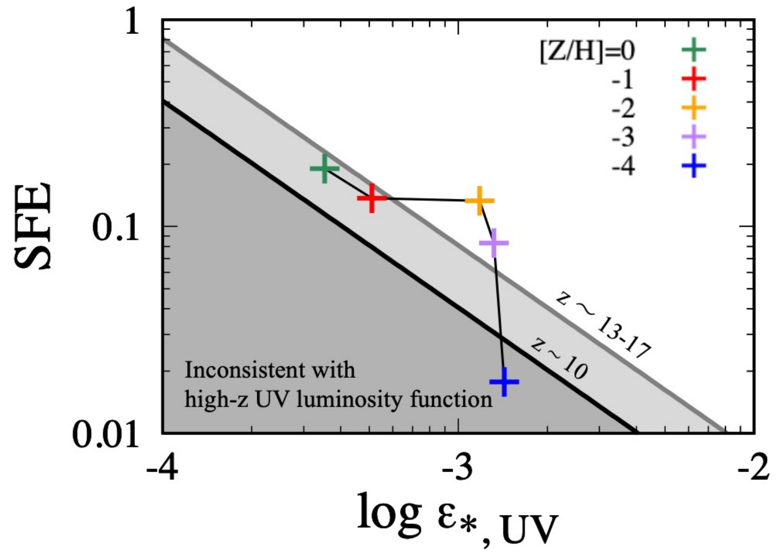


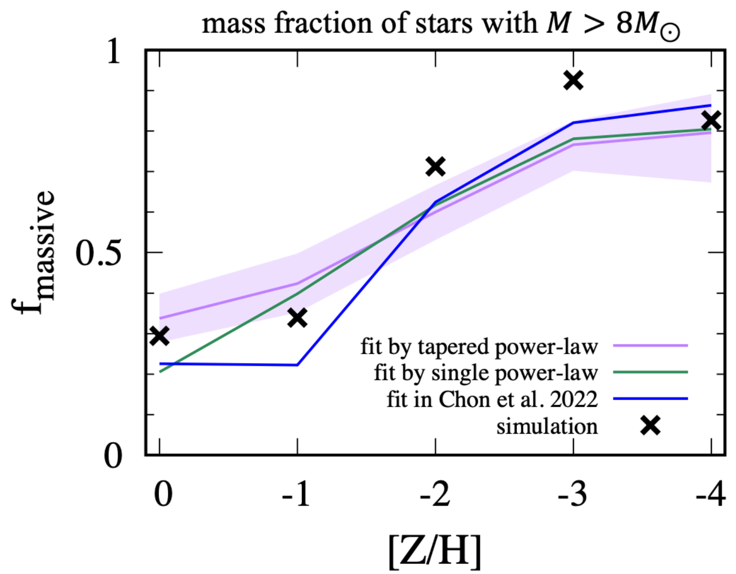


arxiv:0903.3070

JWST high z: Top-Heavy IMF?

2312.13339





fective only in completely terminating star formation. This results in a top-heavy, log-flat IMF similar to those proposed for primordial star formation (e.g. Chon et al. 2021b).

Our findings provide an explanation for the discrepancy between JWST observations and standard galaxy formation models: a higher number of UV luminous galaxies at $z \gtrsim 10$ than expected by theoretical models (e.g. Harikane et al. 2023b). We suggest that a top-heavy IMF may provide a solution for resolving this tension, as it leads to a higher UV emissivity. Our results show that UV emissivities and SFEs in the range of $-3 \lesssim [Z/H] \lesssim -2$ are sufficient to match the number of luminous galaxies observed by JWST. Interestingly, these metallicities are consistent with those observed for the most distant JWST galaxies.

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3. GR singularity

$$ds^2 = \left(1 - \frac{2GM}{r}\right) dt^2 - \frac{dr^2}{1 - 2GM/r} - r^2 d\theta^2 - r^2 \sin^2\theta d\varphi^2 \quad (7.2.1)$$

根据观察，我们看到当 $r \to 2GM$ 时，这一时空间隔出现一个“奇点”。在这一半径处，

$$g_{00} = 1 - \frac{2GM}{r} \to 0 \quad (7.2.2)$$

且

$$g_{11} = -\frac{1}{1 - 2GM/r} \to \infty \quad (7.2.3)$$

Discussion about some New Physics

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2306.11588

3. GR nonsingular BHs

Cosmological coupling of nonsingular black holes

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We show that – in the framework of general relativity (GR) – if black holes (BHs) are singularity-free objects, they couple to the large-scale cosmological dynamics. We find that the leading contribution to the resulting growth of the BH mass ($M_{\rm BH}$) as a function of the scale factor a stems from the curvature term, yielding $M_{\rm BH} \propto a^k$, with $k = 1$. We demonstrate that such a linear scaling is universal for spherically-symmetric objects, and it is the only contribution in the case of regular BHs. For nonsingular horizonless compact objects we instead obtain an additional subleading model-dependent term. We conclude that GR nonsingular BHs/horizonless compact objects, although cosmologically coupled, are unlikely to be the source of dark energy. We test our prediction with astrophysical data by analysing the redshift dependence of the mass growth of supermassive BHs in a sample of elliptical galaxies at redshift $z = 0.8 - 0.9$. We also compare our theoretical prediction with higher redshift BH mass measurements obtained with the James Webb Space Telescope (JWST). We find that, while $k = 1$ is compatible within 2σ with JWST results, the data from elliptical galaxies at $z = 0.8 - 0.9$ favour values of $k > 1$. New samples of BHs covering larger mass and redshift ranges and more precise BH mass measurements are required to settle the issue.

$$ds^2 = \left(1 - \frac{2GM}{r}\right) dt^2 - \frac{dr^2}{1 - 2GM/r} - r^2 d\theta^2 - r^2 \sin^2\theta d\varphi^2$$

GR singularity

$$T_{\mu\nu} = (\rho + p_\perp)\, u_\mu u_\nu + p_\perp\, g_{\mu\nu} - (p_\perp - p_\parallel)\, w_\mu w_\nu\,, \quad (2)$$

$$ds^2 = a^2(\eta)\left[-e^{\alpha(\eta,r)}dt^2 + e^{\beta(\eta,r)}dr^2 + r^2 d\Omega^2\right]. \quad (3)$$

$$e^{-\beta(r,\eta)} = g(r) a^{r\alpha'}\,; \quad (4a)$$

$$\frac{\dot a^2}{a^2}(3 - r\alpha')\, e^{-\alpha} + \frac{1 - e^{-\beta} + r\beta' e^{-\beta}}{r^2} = 8\pi G a^2 \rho\,; \quad (4b)$$

$$\frac{e^{-\beta} + r e^{-\beta}\alpha' - 1}{r^2} + e^{-\alpha}\left(-2\frac{\ddot a}{a} + \frac{\dot a^2}{a^2}\right) = 8\pi G a^2 p_\parallel\,; \quad (4c)$$

Cosmological Coupling → GR nonsingular Solution

$$\dot\rho + \frac{\dot a}{a}(3\rho + 3p_\parallel + r p_\parallel') = 0\,, \quad (4d)$$