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Discovering dark matter: using JWST observations and bilayer graphene

Ranjan Laha

Centre for High Energy Physics

Indian Institute of Science, Bengaluru, India

arXiv: 2511.02906 (accepted in Physical Review Letters) + arXiv: 2604.21969

Thanks to my collaborators: Souradeep Das, Ranjini Mondol, Abhijeet Singh, Rinchen Sherpa, Anuvab Sarkar, Tarak Nath Maity, Paramita Dutta, and Anirban Das

INDIAN INSTITUTE OF SCIENCE

CHEP Centre for High Energy Physics Indian Institute of Science

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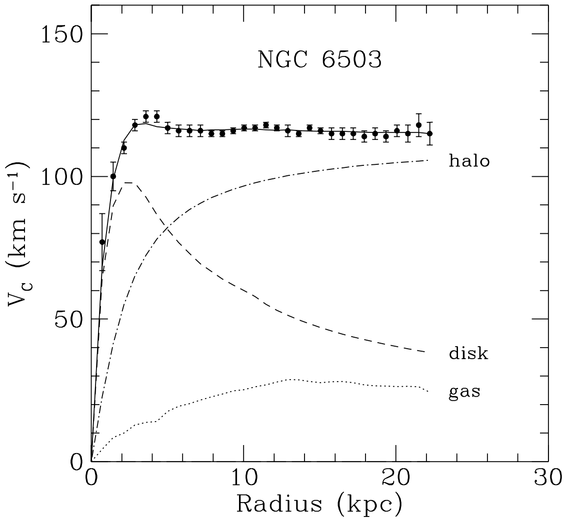
- Conclusion

Introduction to Dark Matter

Gravitational detection of dark matter



Begeman, Broeils & Sanders MNRAS 249 (1991) 523

Dark matter accounts for approximately a quarter of the total energy density of the Universe

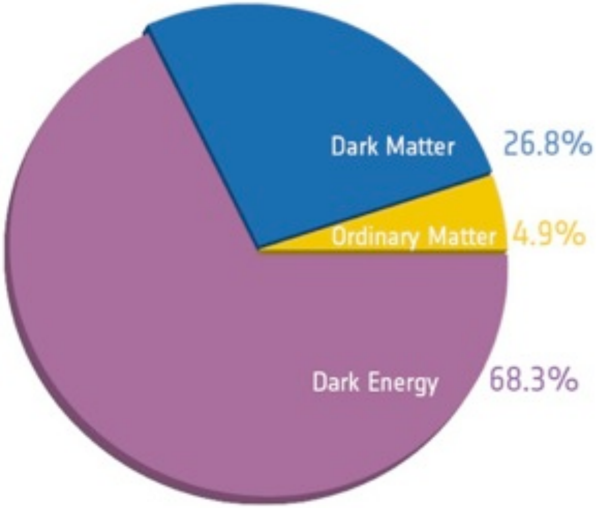
Gravitational detection of dark matter at various astrophysical scales

Bullet cluster

https://en.wikipedia.org/wiki/File:1e0657_scale.jpg

ESA website

http://sci.esa.int/planck/51557-planck-new-cosmic-recipe/



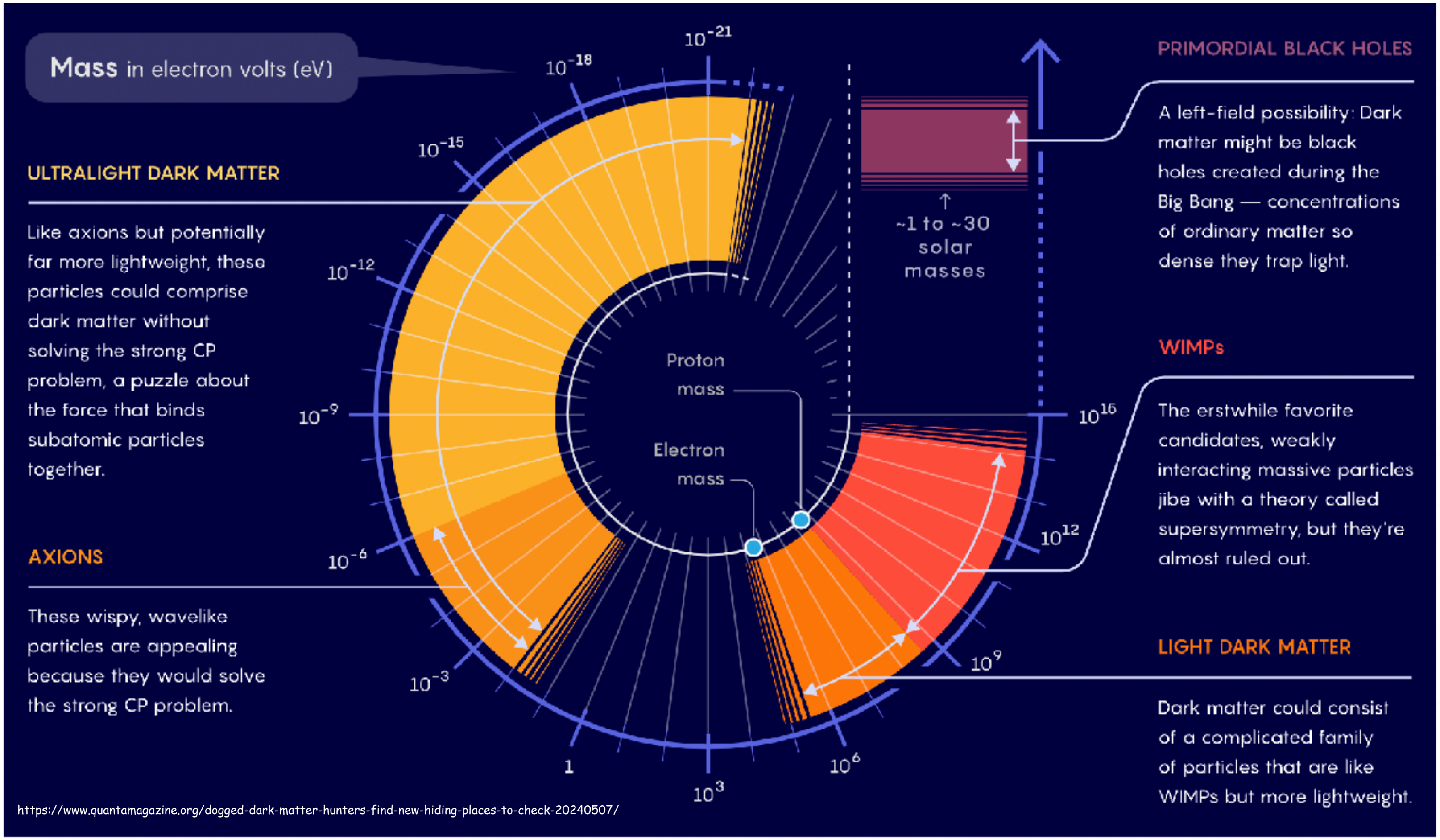
The interaction rate of dark matter with light is much weaker than electromagnetic rate

Dark matter is responsible for the large scale structure of the Universe

Density of water = 1 g cm^{-3}

Density of dark matter in this room = 5.35×10^{-25} g cm^{-3}

Dark matter candidates

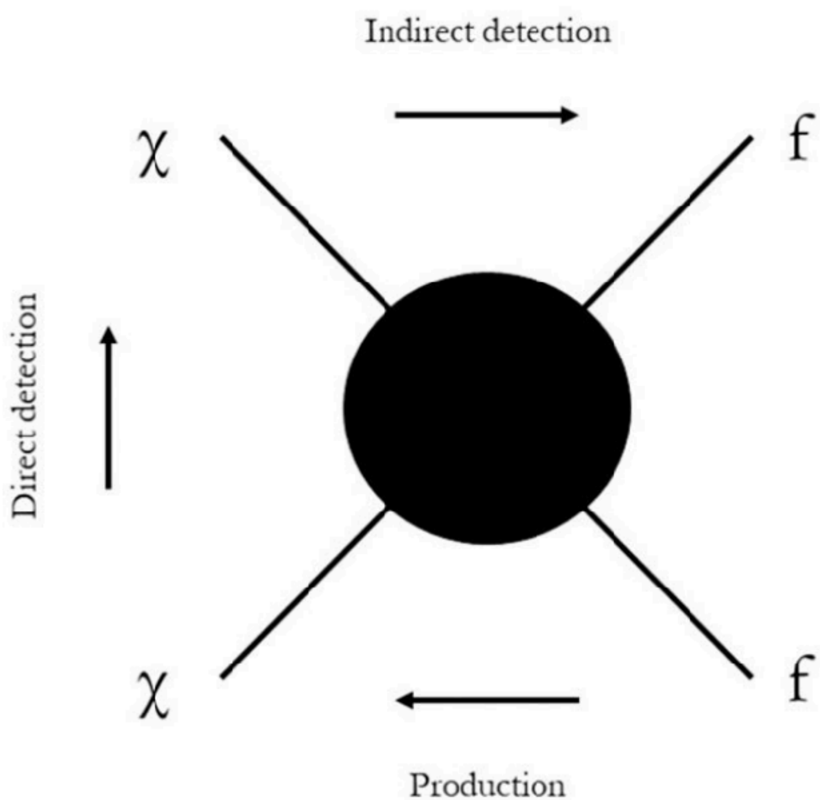


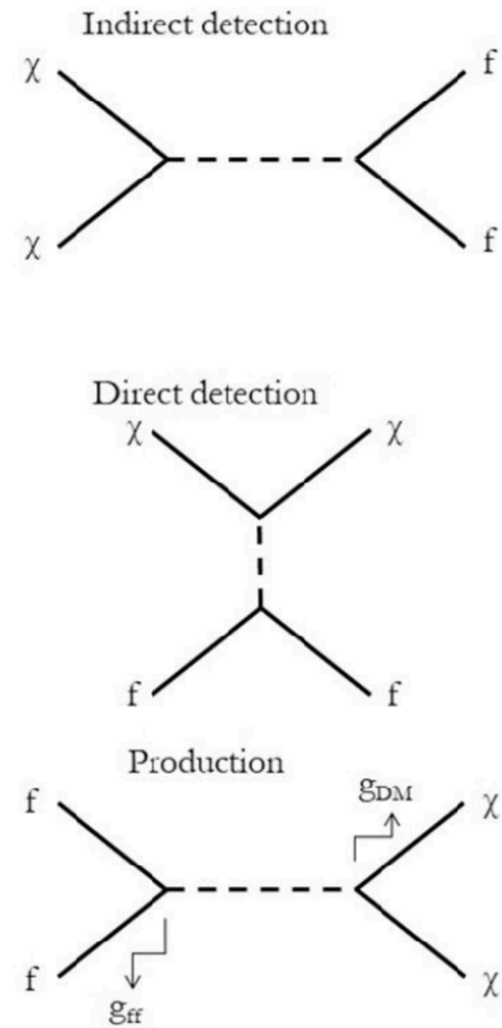
Wide range in dark matter candidate masses

We need to thoroughly test all well-motivated candidates

It is important to test all regions of the dark matter mass parameter space and all different couplings of dark matter - Standard Model particles

Does dark matter interact with Standard Model particles via non-gravitational interactions?

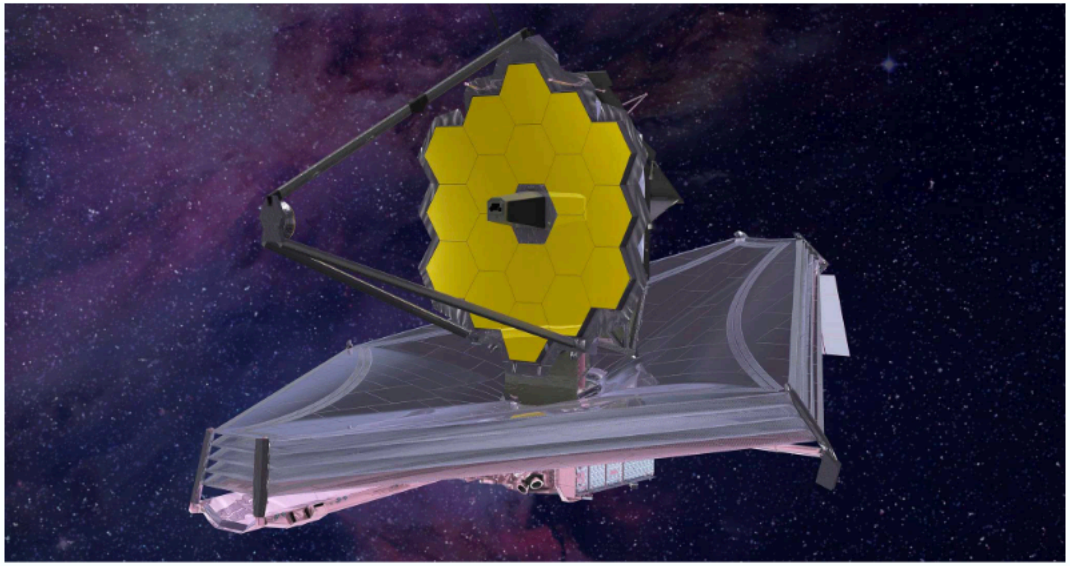




Slide idea: Ranjini Mondol

https://www.cambridge.org/core/journals/philosophy-of-science/article/methoddriven-experiments-and-the-search-for-dark-matter/98E0DBCF79C8B3503C8BB28DBC95689C

Part 1: Dark Secrets of Baryons: Illuminating Dark Matter-Baryon Interactions with JWST



Credit: Northrop Grumman

arXiv: 2511.02906 (accepted in Physical Review Letters)

Souradeep Das, Ranjini Mondol, Abhijeet Singh, and Ranjan Laha

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

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

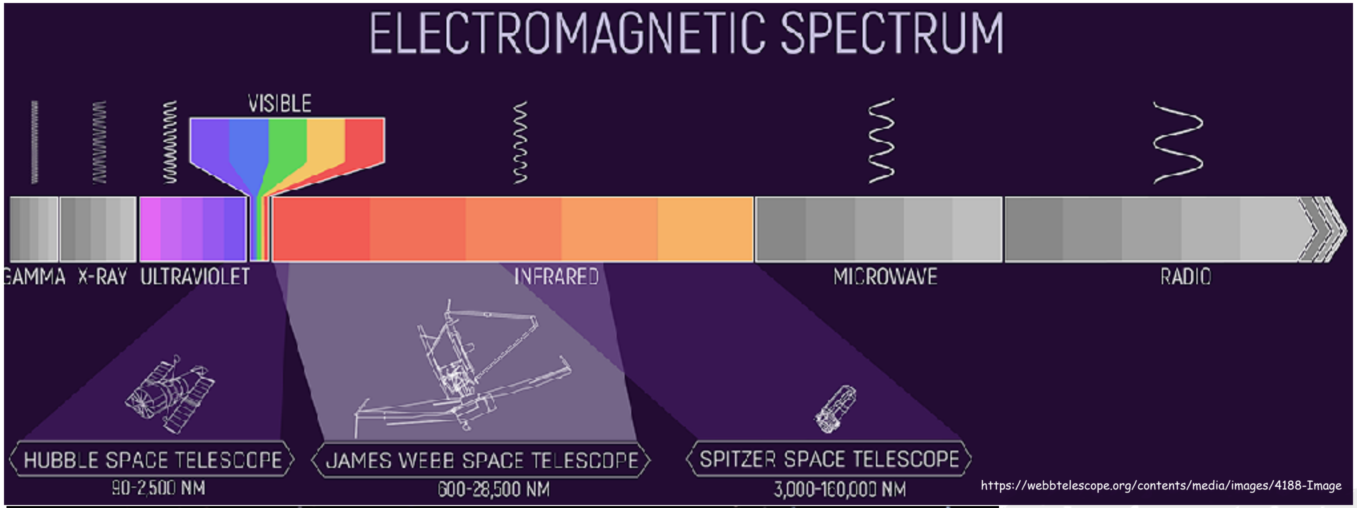
Souradeep Das [1,2,*] Ranjini Mondol [1,†] Abhijeet Singh [1,‡] and Ranjan Laha [1,§]
[1] *Centre for High Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru 560012, India*
[2] *Department of Physics, Ohio State University, 191 West Woodruff Avenue, Columbus, OH 43210*
(Dated: November 6, 2025)

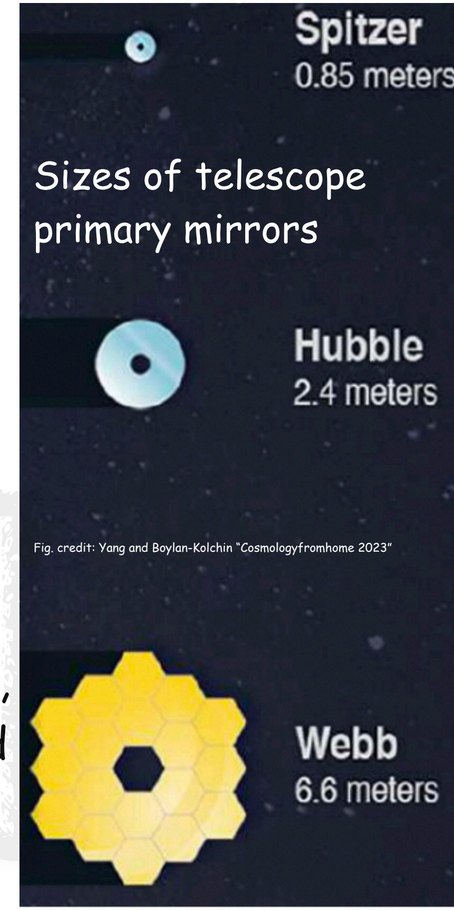
The James Webb Space Telescope (JWST) has discovered numerous bright galaxies at high redshifts ($z \approx 10 - 14$). Many astrophysical models and beyond the Standard Model physics scenarios have been proposed to explain these observations. We investigate, for the first time, the implications of dark 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 $\sim 1 - 500$ 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 study highlights the potential of JWST observations as a novel and powerful probe of non-gravitational interactions of DM.

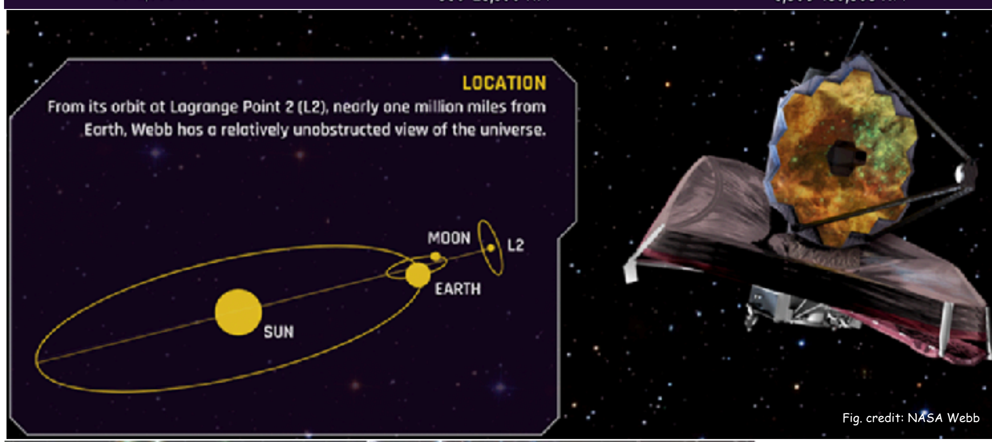
arXiv: 2511.02906

accepted in Physical Review Letters

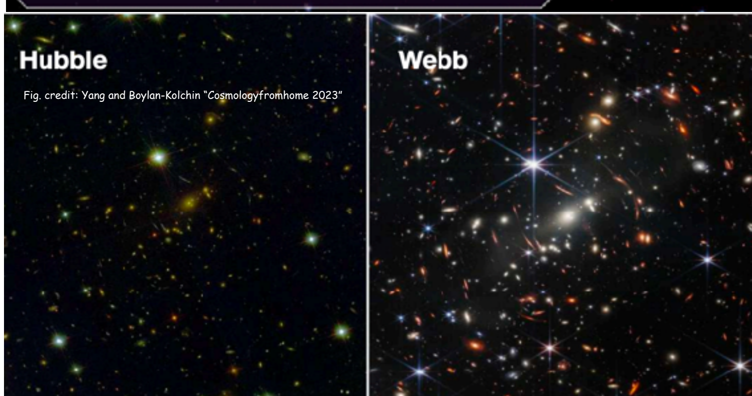
JWST (James Webb Space Telescope)

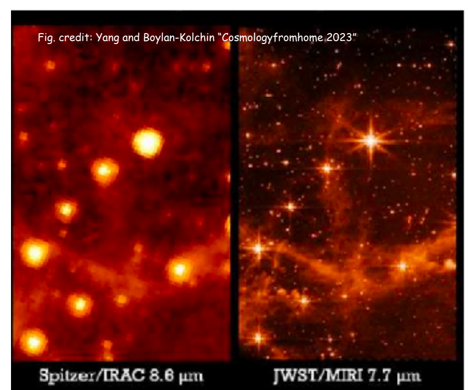






Four different instruments on-board: NIRSpec, NIRCam, MIRI, and NIRISS





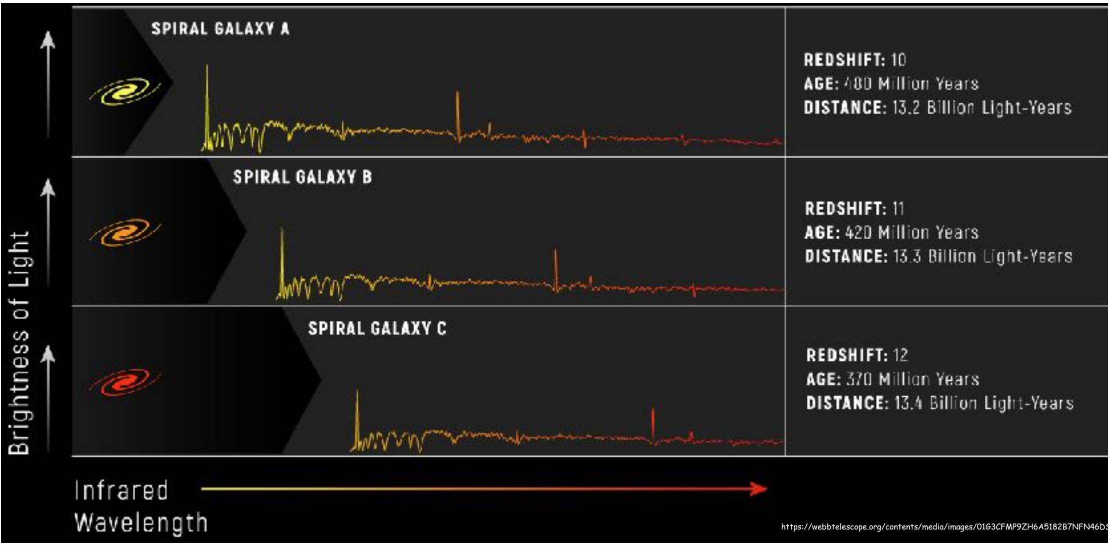
NIRSpec: Near InfraRed Spectrograph

NIRCam: Near InfraRed Camera

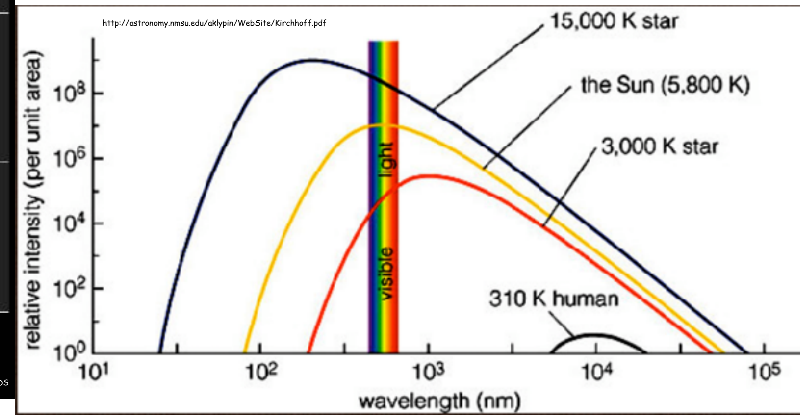
MIRI: Mid InfraRed Instrument

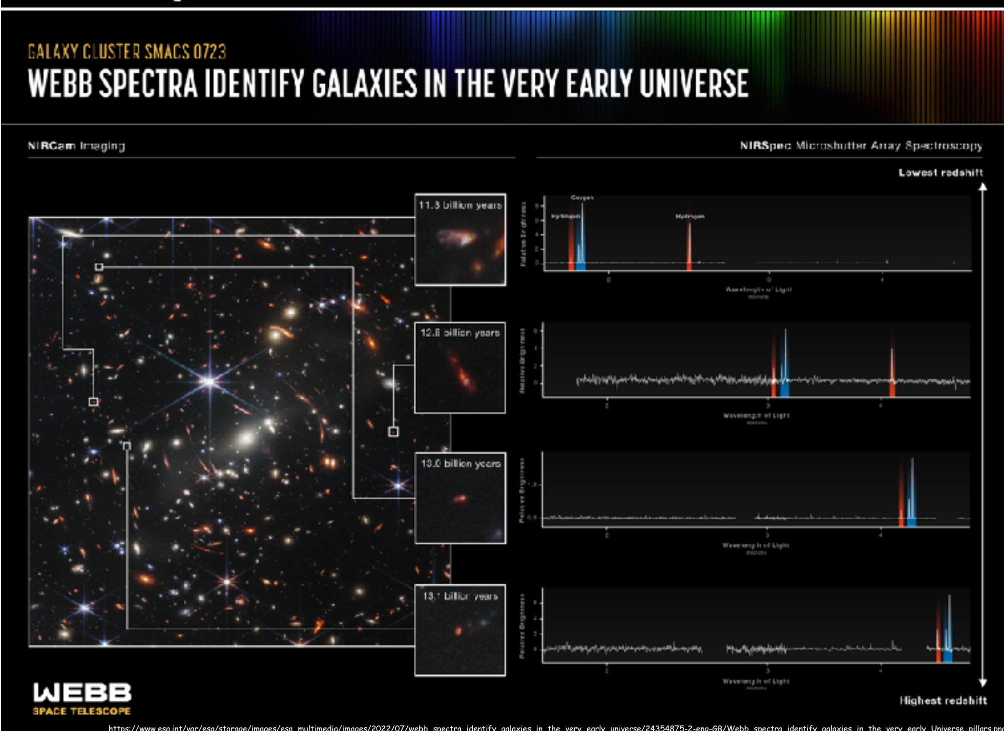
NIRISS: Near InfraRed Imager and Slitless Spectrograph

Earliest galaxies observed



Young (and thus hotter) stars emit mostly in the UV wavelengths



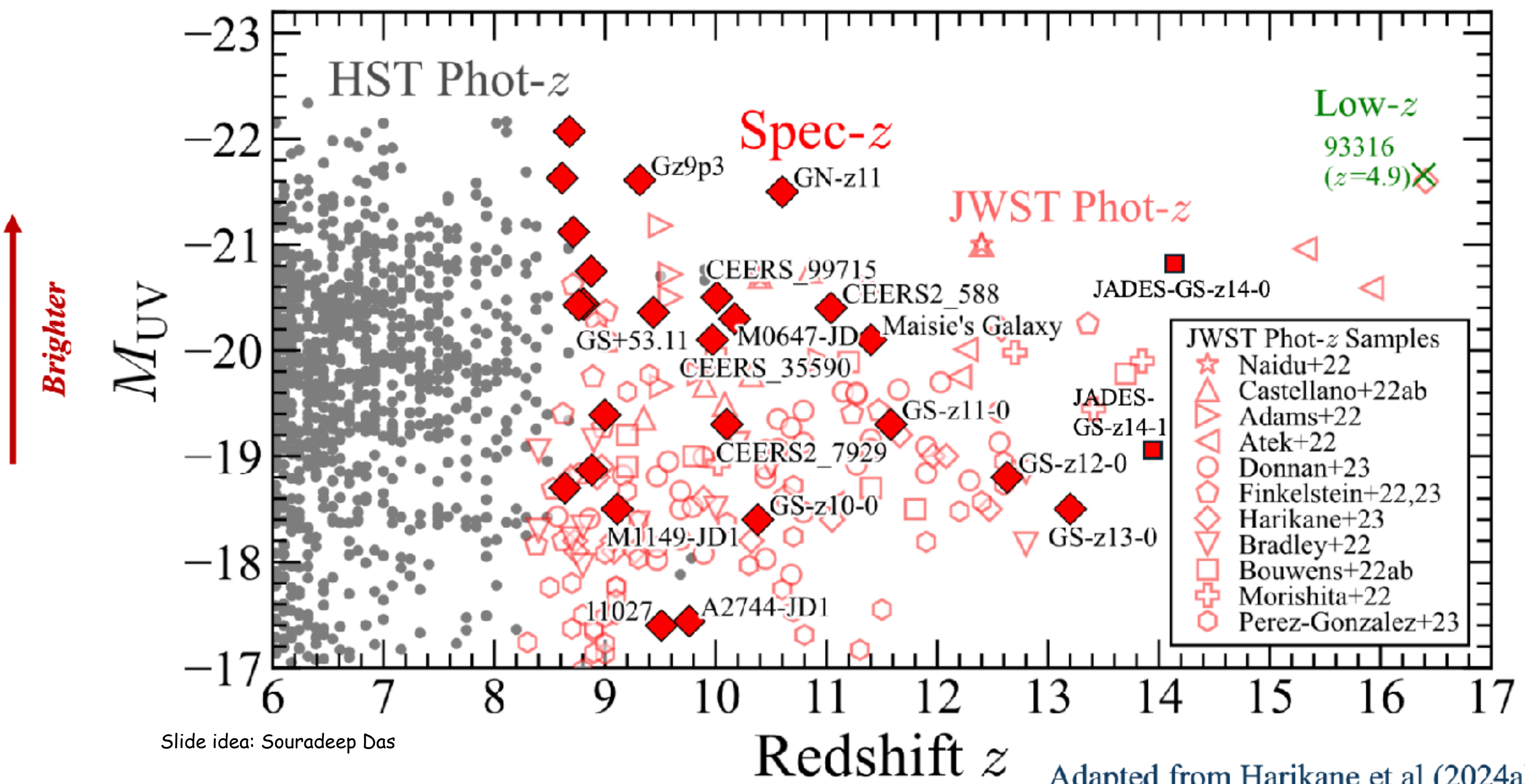


These UV emissions get redshifted to longer wavelengths (i.e., optical and IR)

$$\lambda_{\rm obs} = (1+z)\lambda_{\rm emit}$$

We need IR telescopes to observe the earliest galaxies

A sample of the earliest galaxies

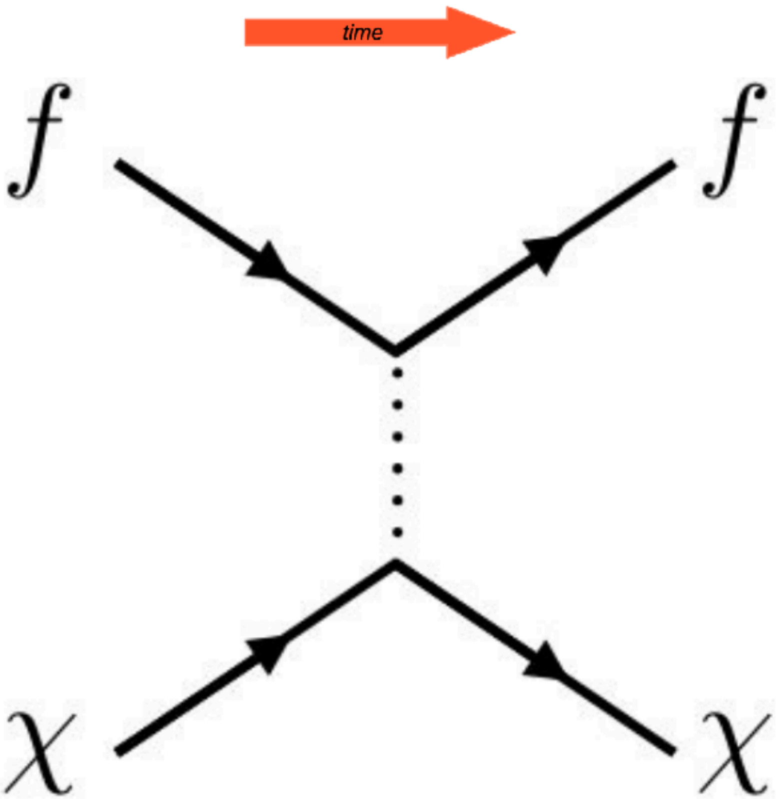


Slide idea: Souradeep Das

Adapted from Harikane et al (2024a), Carniani et al (2024)

A large number of galaxies at redshifts $z \gtrsim 10$ have been discovered by JWST

Dark Matter-Baryon elastic scattering



$$f = e^{\pm}, p \qquad \chi = \text{DM particle}$$

https://indico.cern.ch/event/1166693/contributions/5281043/attachments/2641770/4571955/Boddy-Avignon.pdf

We consider dark matter particles elastically scattering with protons and electrons (cosmologically, both protons and electrons are referred to as baryons)

Transfer cross-section

$$\sigma_\chi^T = \int (1 - \cos\theta) \frac{d\sigma}{d\Omega} d\Omega$$

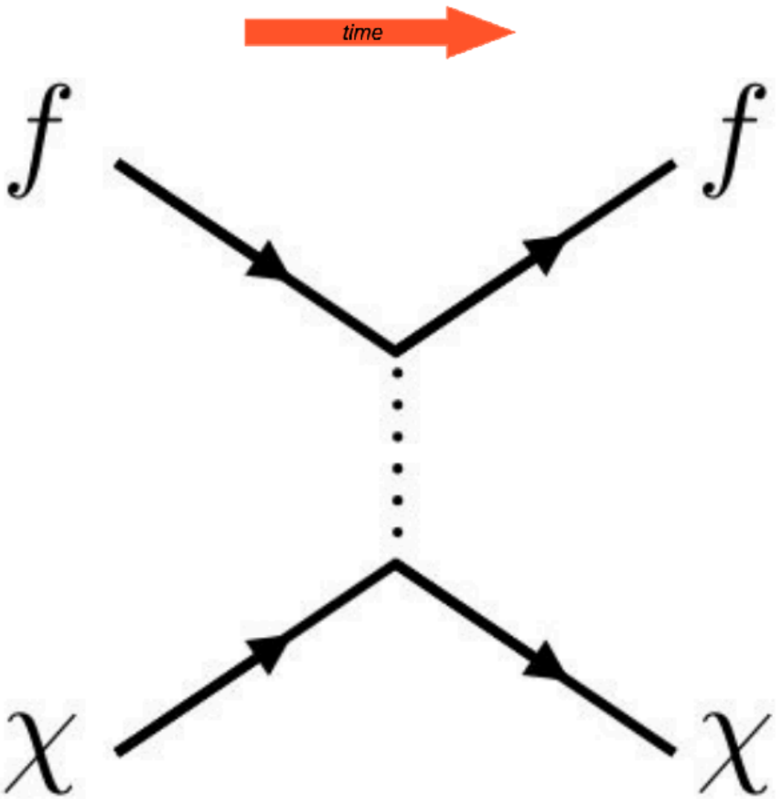
We parametrize the transfer cross-section as

$$\sigma_\chi^T = \sigma_0 v^n$$

v = relative velocity between dark matter and baryons

Slide idea: Ranjini Mondol, Souradeep Das, and Abhijeet Singh

Dark Matter-Baryon elastic scattering



$f = e^{\pm}, p \qquad \chi = \text{DM particle}$

We consider

$\sigma_\chi^T \propto v^0$: contact interactions; interactions mediated by a heavy particle

$\sigma_\chi^T \propto v^{-2}$: electric-dipole-like interactions

$\sigma_\chi^T \propto v^{-4}$: Coulomb-like interactions

https://indico.cern.ch/event/1166693/contributions/5281043/attachments/2641770/4571955/Boddy-Avignon.pdf

Slide idea: Ranjini Mondol, Souradeep Das, and Abhijeet Singh

How does this affect structure formation?

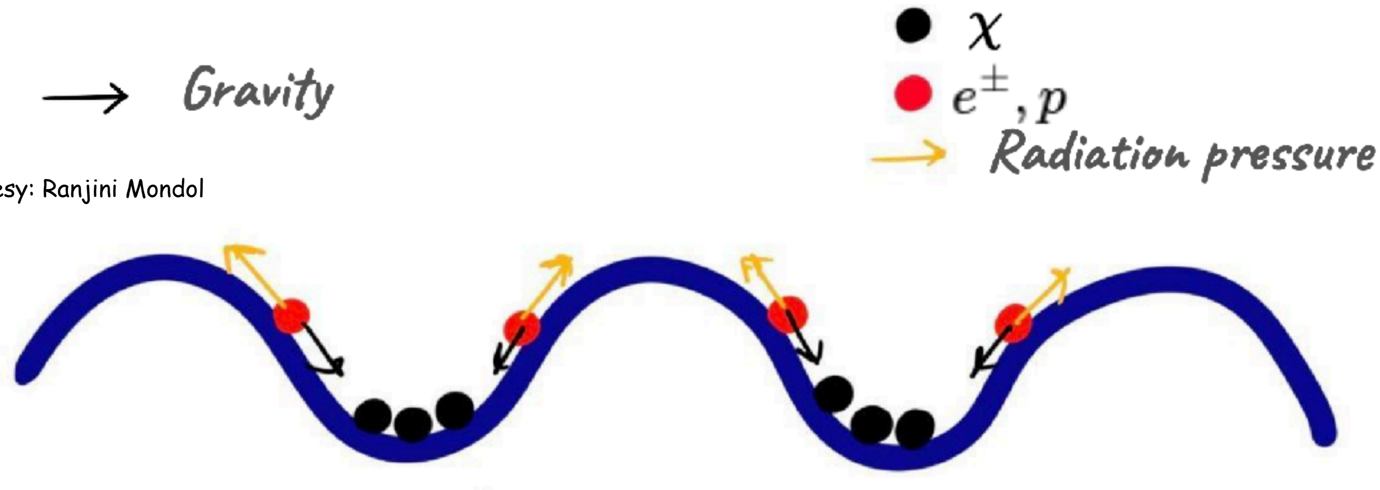


Image courtesy: Ranjini Mondol

How does this affect structure formation?

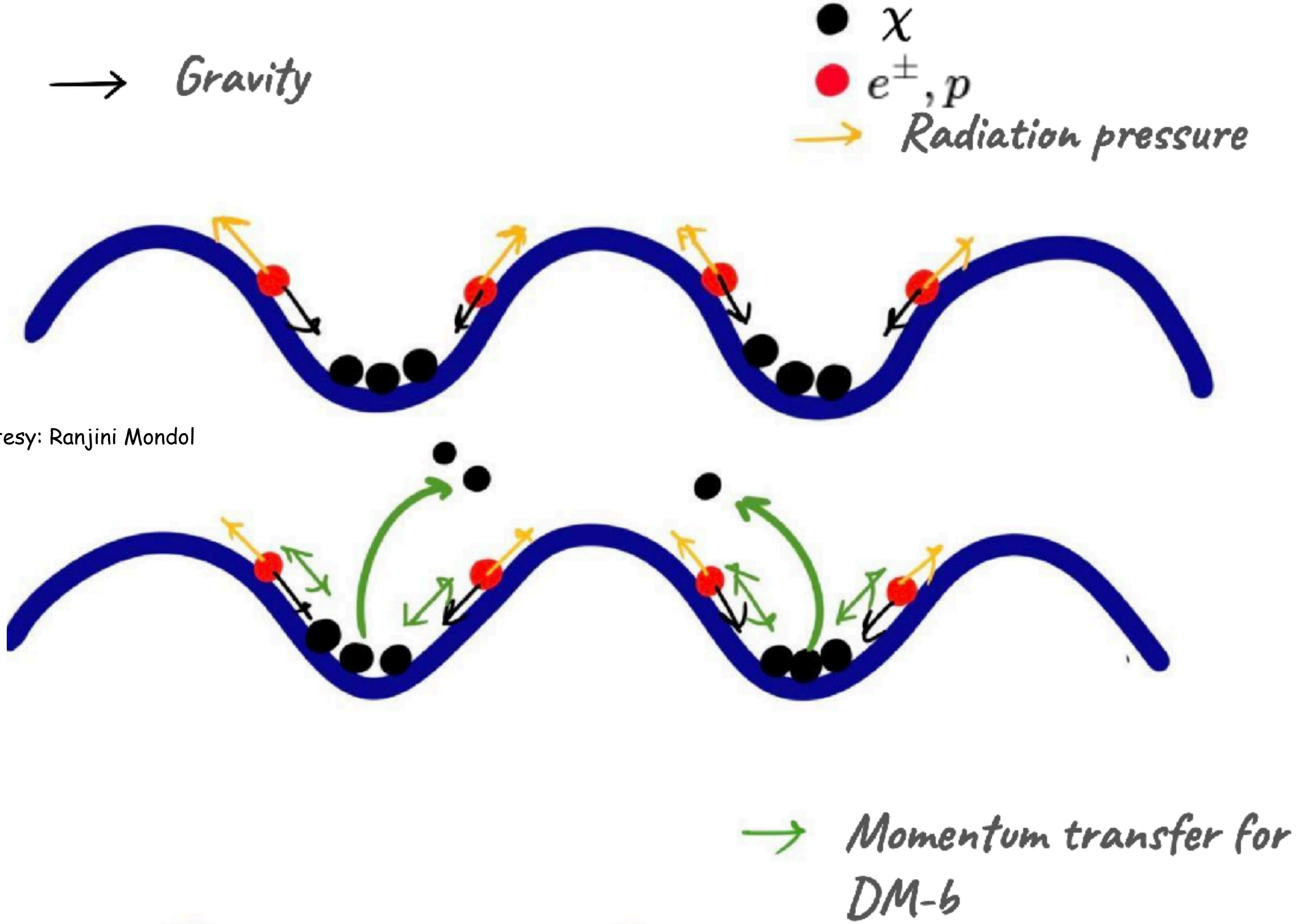


Image courtesy: Ranjini Mondol

How does this affect structure formation?

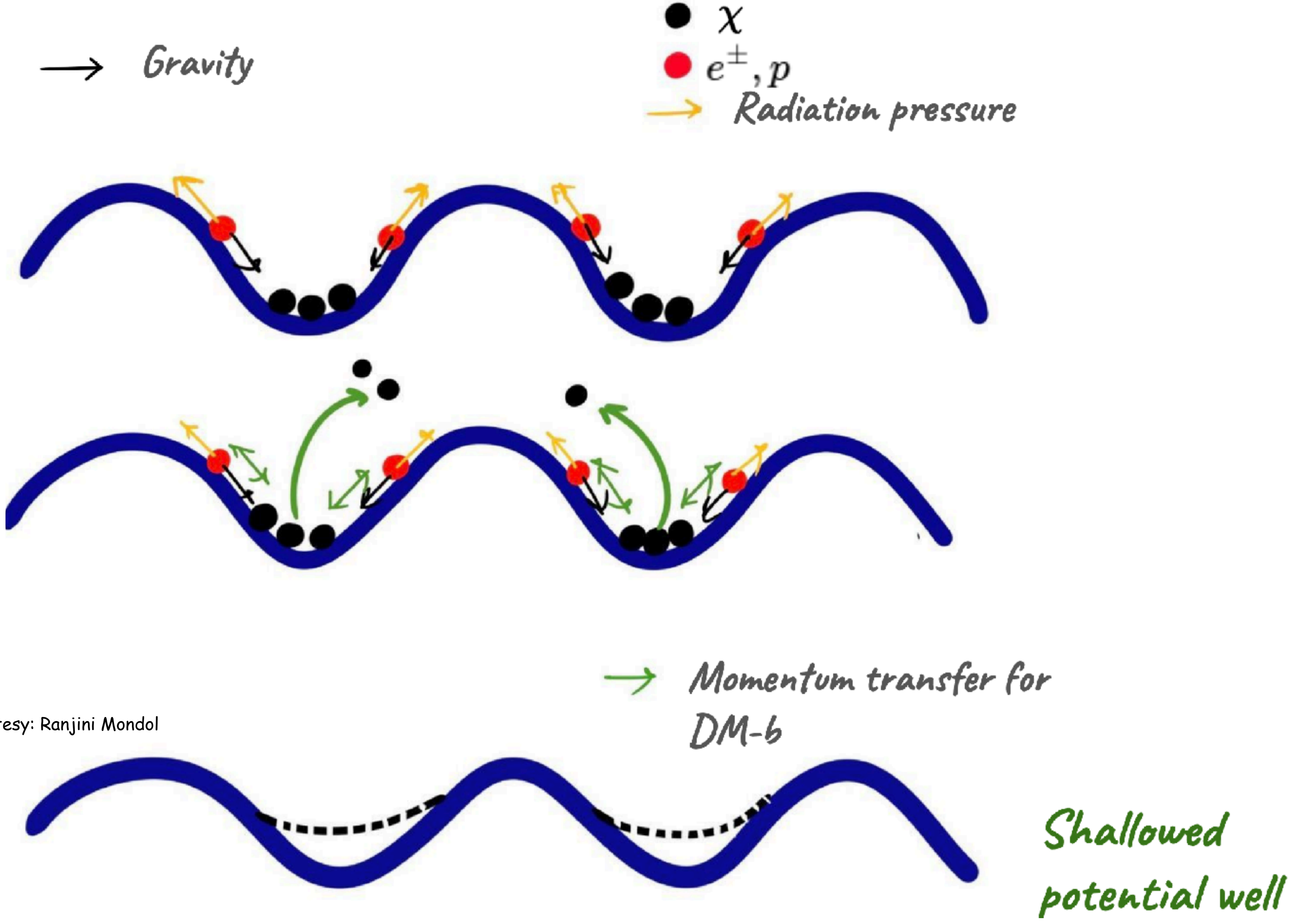
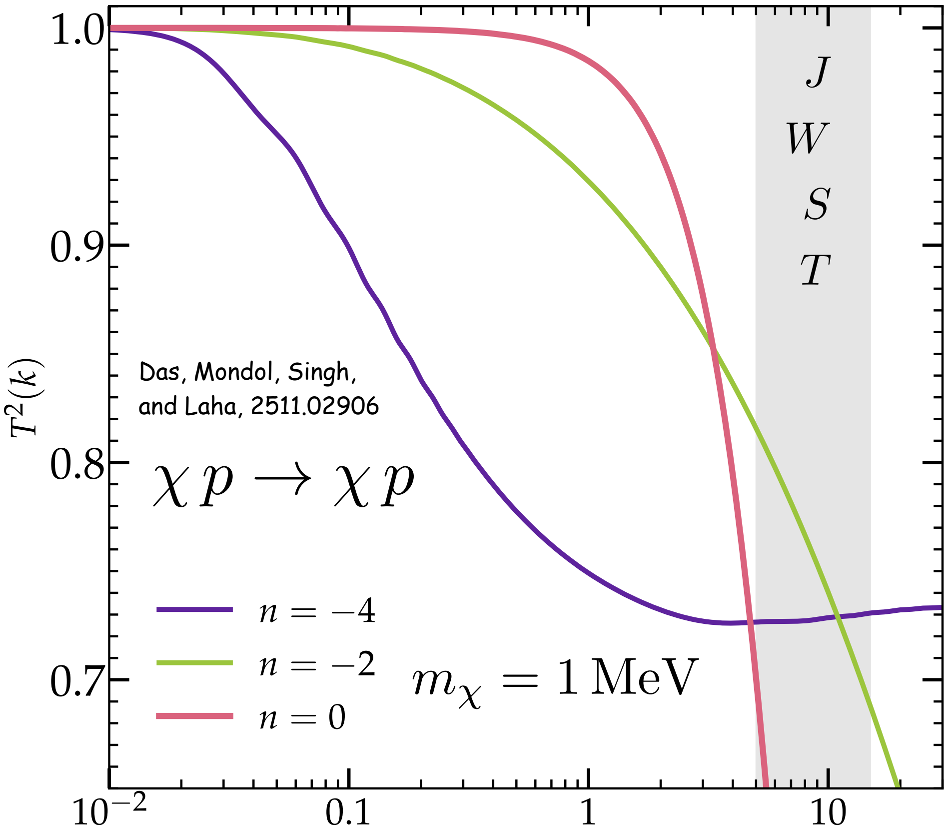
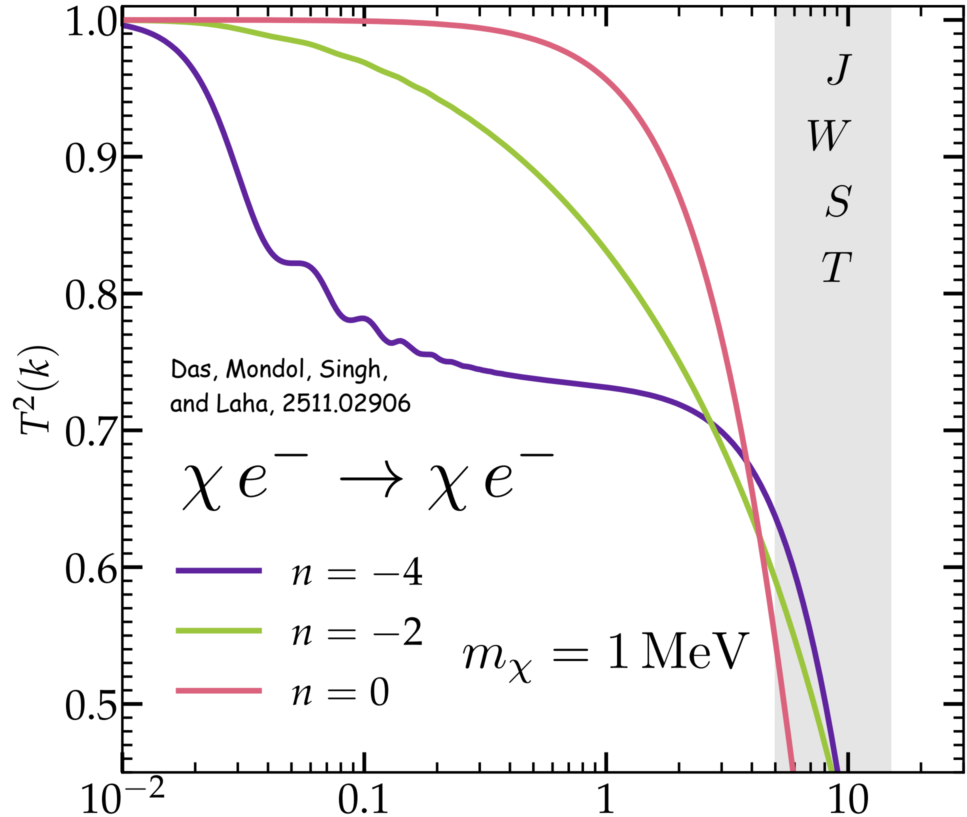


Image courtesy: Ranjini Mondol

Linear matter power spectrum in the presence of dark matter - baryon interactions





$$T^2(k) = P_{\mathrm{IDM}}(k)/P_{\Lambda\mathrm{CDM}}(k)$$

$$\log_{10}(\sigma_n^{\chi p}/\mathrm{cm}^2)$$

$n = 0: \; -27.49$

$n = -2: \; -33.48$

$n = -4: \; -40.33$

$$\log_{10}(\sigma_n^{\chi e}/\mathrm{cm}^2)$$

$n = 0: \; -27.84$

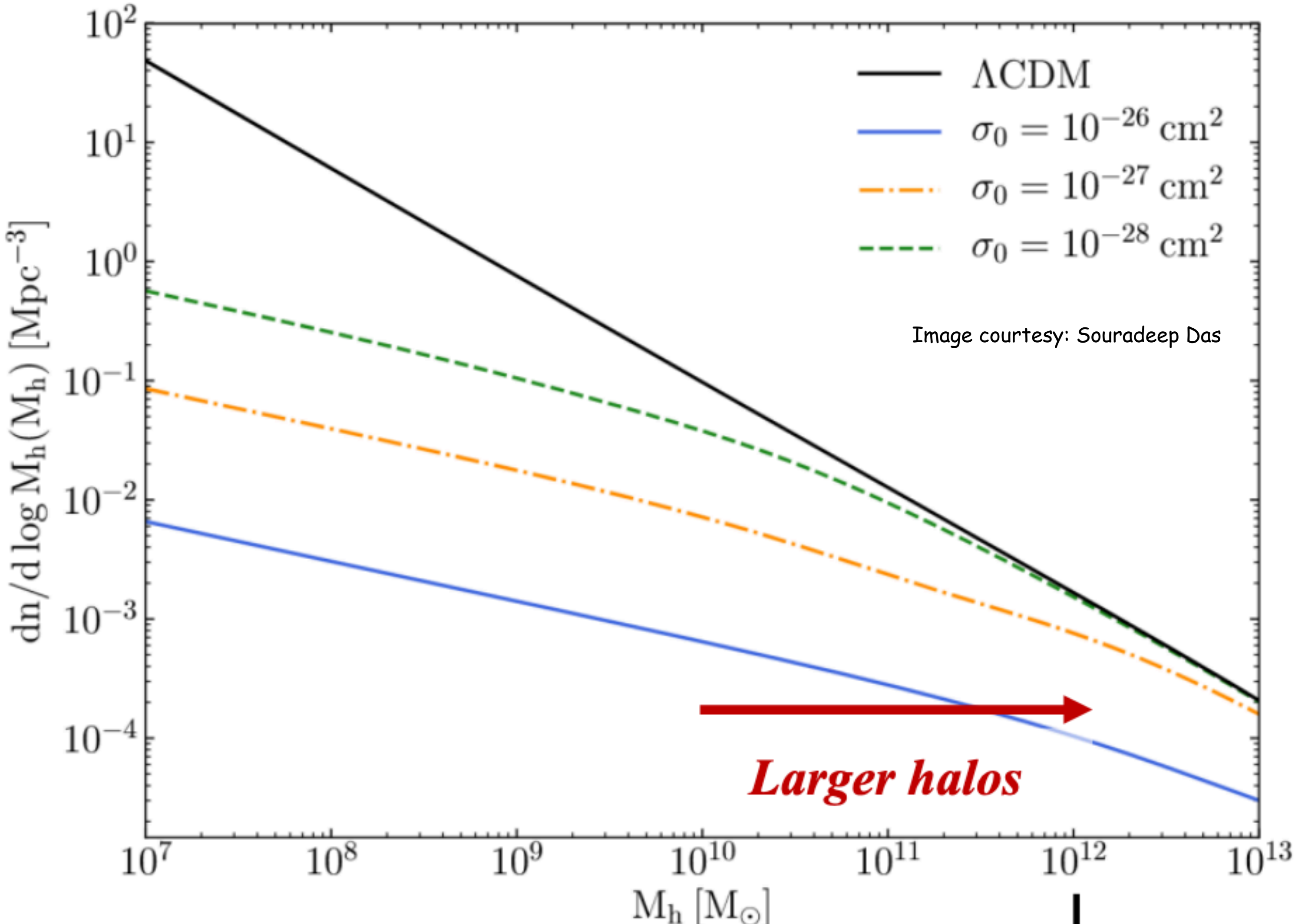
$n = -2: \; -31.14$

$n = -4: \; -35.42$

Halo mass function

Dark matter - baryon interactions mainly suppresses low-mass halos

Larger cross-sections imply a higher suppression



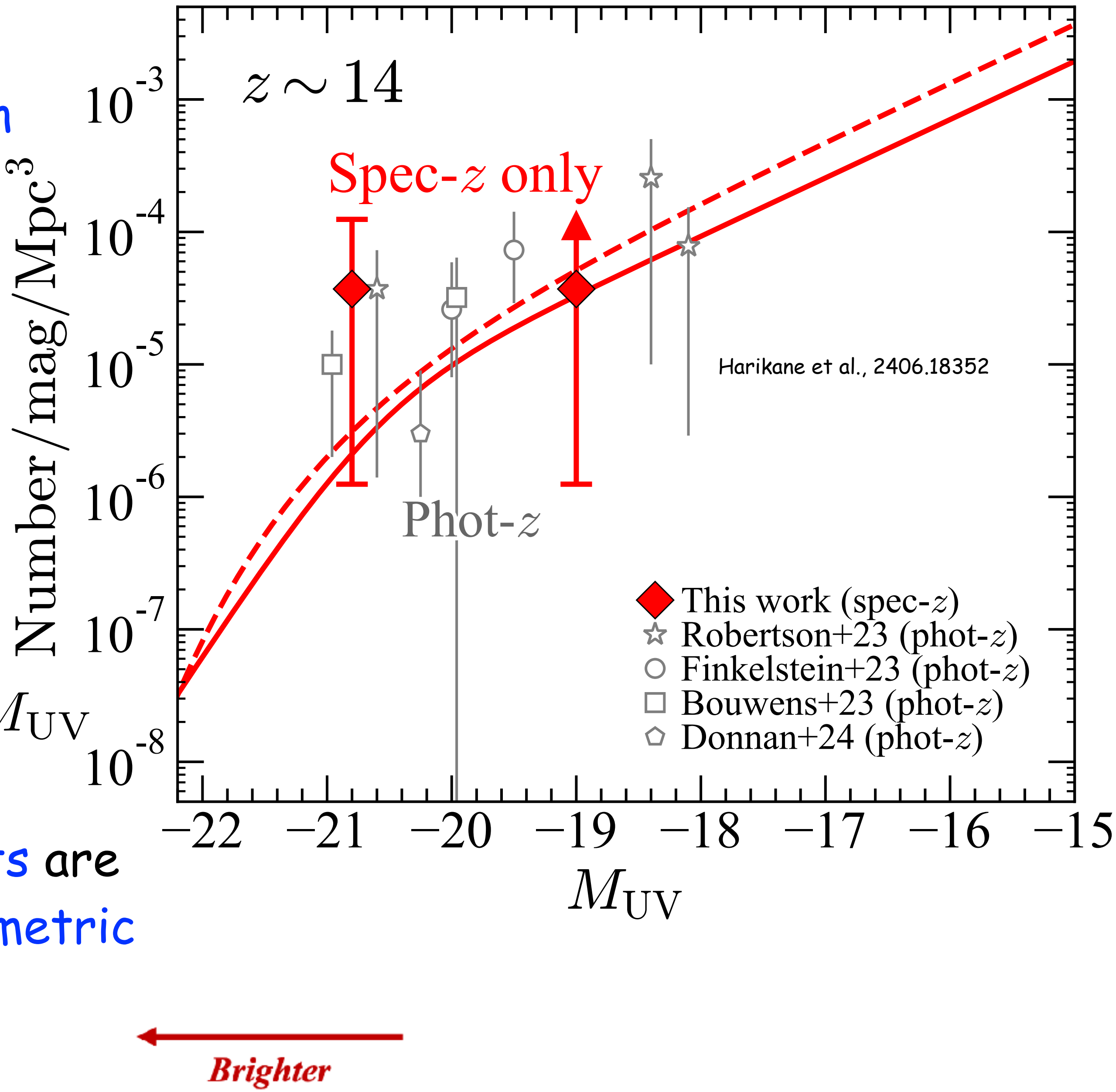
~Milky Way halo mass

Do we have a new probe of this suppression and consequently probe dark matter - baryon scattering cross-section?

UV Luminosity Function

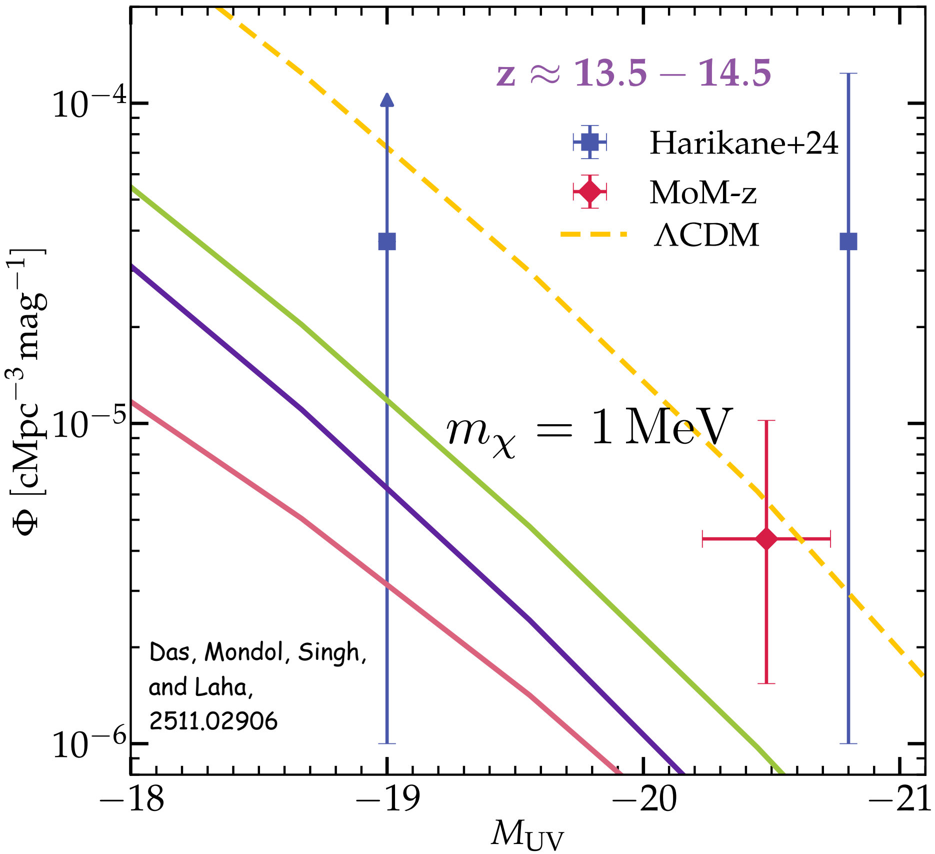
UV Luminosity Function (UVLF) quantifies the number of galaxies per unit volume per unit interval of $M_{\rm UV}$ at various redshifts

$$dn = \phi_{\rm UV}(M_{\rm UV}, z)\, dM_{\rm UV}$$



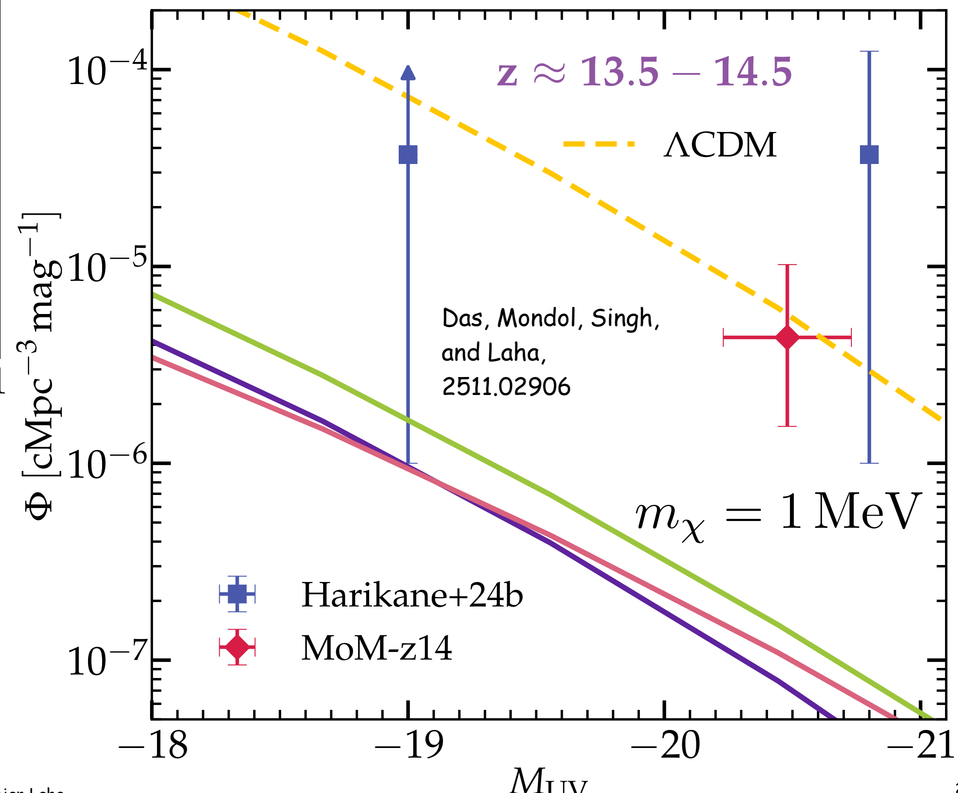
Spectroscopic redshifts are very well known; photometric redshifts have larger uncertainties

Comparing UV Luminosity Function due to dark matter - baryon interactions with data

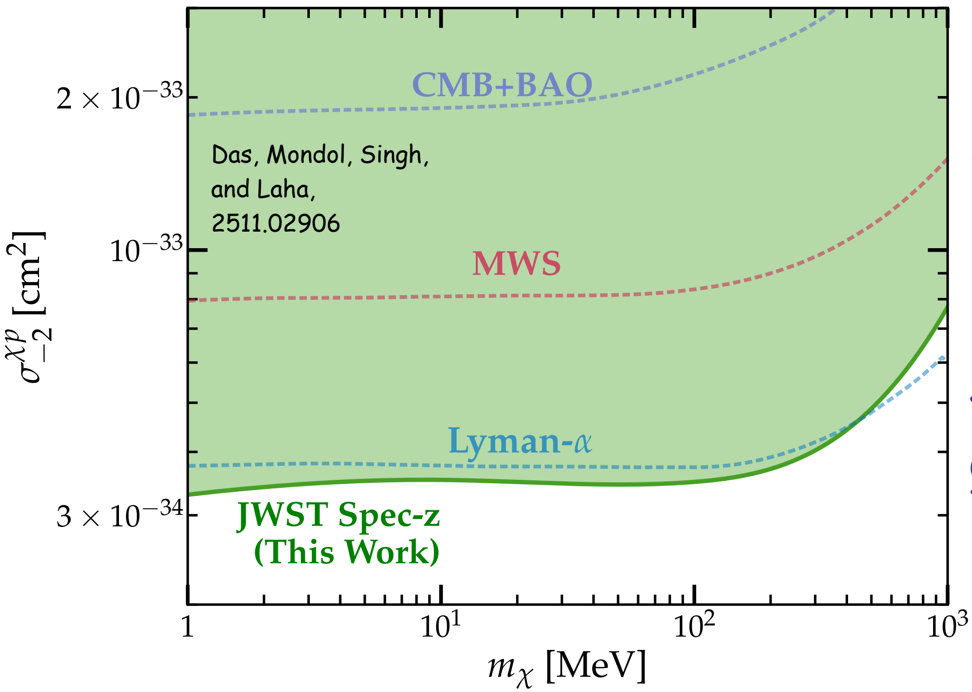


UVLF measurements disagree with theoretically calculated predictions due to dark matter - baryon interactions

$\log_{10}(\sigma_n^{\chi p}/\mathrm{cm}^2)$	$\log_{10}(\sigma_n^{\chi e}/\mathrm{cm}^2)$
$n=0: \ -27.49$	$n=0: \ -27.84$
$n=-2: \ -33.48$	$n=-2: \ -31.14$
$n=-4: \ -40.33$	$n=-4: \ -35.42$

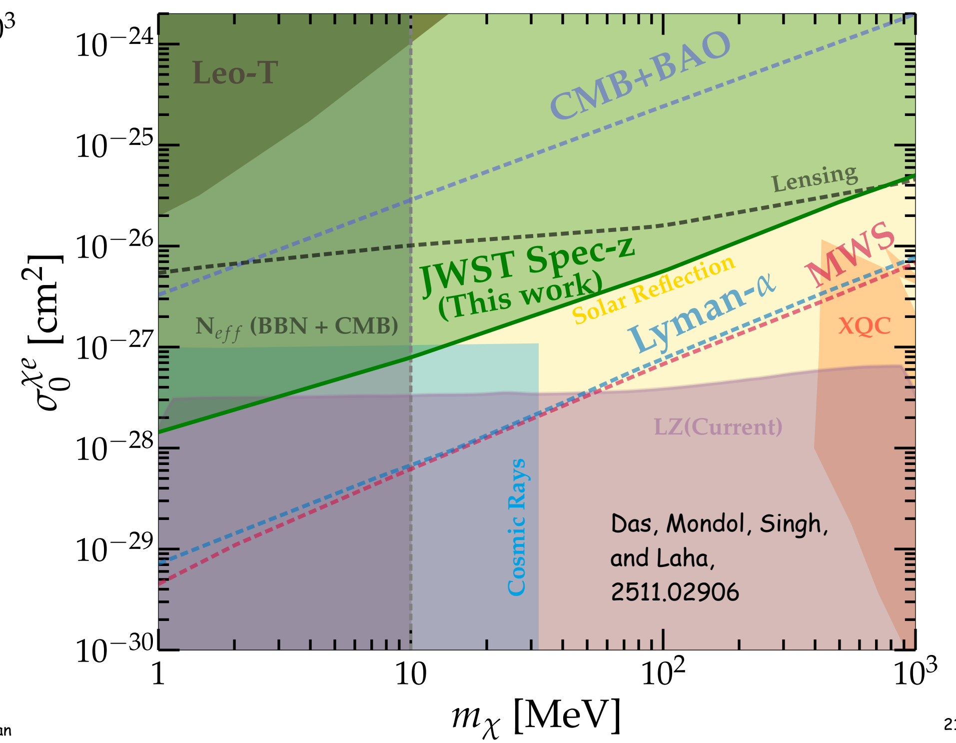


Results

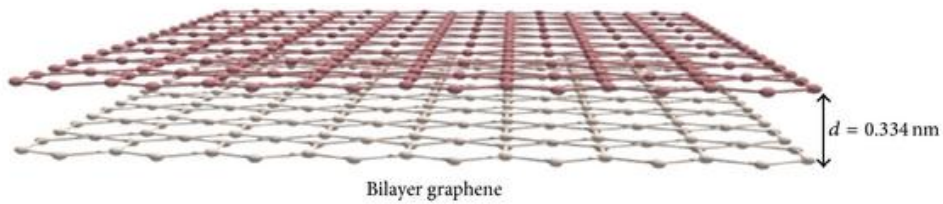


We derive the strongest constraints on dark matter - proton scattering for $\sigma_\chi^T = \sigma_0 v^{-2}$ using the data from 40 spectroscopically confirmed galaxies

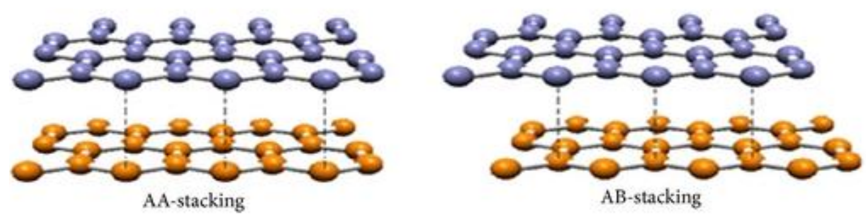
Our results for the dark matter - electron scattering for $\sigma_\chi^T = \sigma_0 v^0$ is better than that obtained from CMB + BAO, and it will improve with discovery of more galaxies at these high redshifts



Part 2: Dive deeper with SUBMARINE: SUB-MeV dArk matter diRect detectIon using bilayer grapheNE



credit— arXiv: 1412.1359



arXiv: 2604.21969

Rinchen Sherpa, Anuvab Sarkar, Tarak Nath Maity, Paramita Dutta, Ranjan Laha, and Anirban Das

Dive deeper with SUBMARINE: SUB-MeV dArk matter diRect detectIon using bilayer grapheNE

Dive deeper with SUBMARINE: SUB-Mev dArk matter diRect detectIon using bilayer grapheNE

Rinchen Sherpa ,[1,*] Anuvab Sarkar ,[1,2,†] Tarak Nath Maity ,[3,‡] Paramita Dutta ,[4,§] Ranjan Laha ,[1,¶] and Anirban Das [5,6,**]

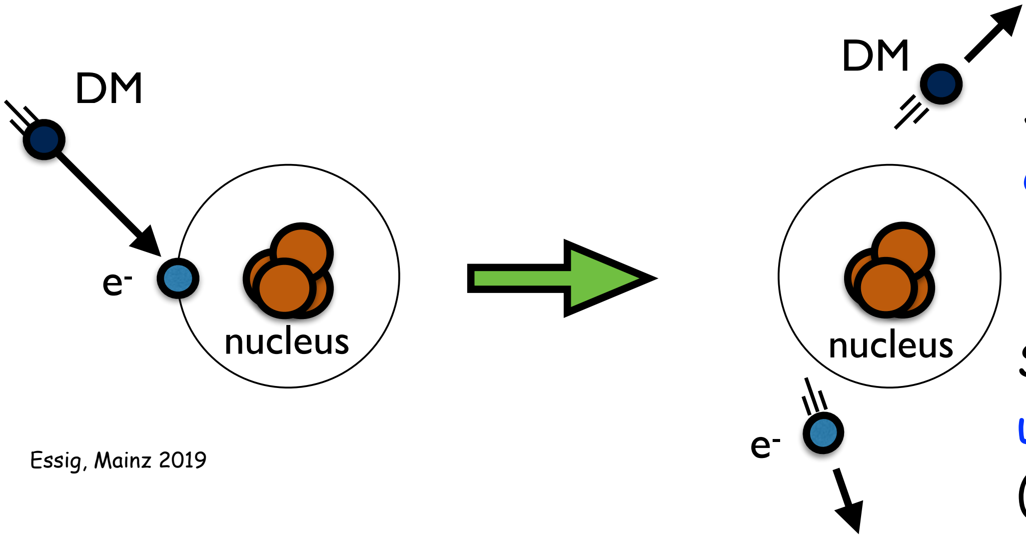
[1]*Centre for High Energy Physics, Indian Institute of Science, C. V. Raman Avenue, Bengaluru-560012, India*
[2]*Department of Physics, Ohio State University, 191 West Woodruff Avenue, Columbus, OH 43210, USA*
[3]*School of Physics, The University of Sydney and ARC Centre of Excellence for Dark Matter Particle Physics, NSW 2006, Australia*
[4]*Theoretical Physics Division, Physical Research Laboratory, Navrangpura, Ahmedabad-380009, India*
[5]*Theory Division, Saha Institute of Nuclear Physics, 1/AF, Bidhannagar, Kolkata-700064, India*
[6]*Homi Bhabha National Institute, Training School Complex, Anushaktinagar, Mumbai-400094, India*

(Dated: April 27, 2026)

Novel target materials with anisotropic response will play a key role in detecting low-mass dark matter in upcoming experiments. Bilayer graphene is one such material that has been proposed for the detection of sub-MeV mass dark matter particles via electronic excitations. In this work, we calculate scattering rate via a massive mediator in bilayer graphene. With an exposure as small as ~ 0.5 mg-year, bilayer graphene can probe new regions of the parameter space. The anisotropic response function of bilayer graphene leads to a sidereal-day modulation in the scattering rate, depending on its orientation with respect to the Galactic dark matter wind. We find significant modulation in the scattering rate for sub-MeV mass dark matter, demonstrating bilayer graphene's promise for a future experiment. We hope that our work will motivate the community to investigate bilayer graphene as a novel target material, and that it may lead us to discover the particle nature of dark matter.

arXiv: 2604.21969

Dark matter - electron scattering



Essig, Mainz 2019

Sensitive to dark matter - electron coupling

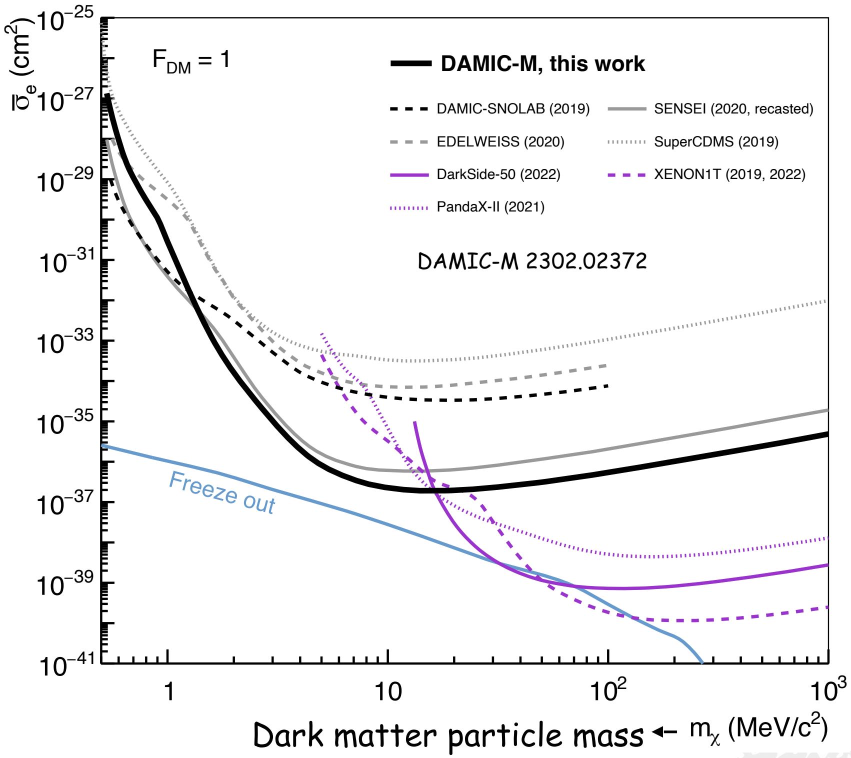
Search for the electron recoil in underground experiments (experiments are situated underground to suppress various backgrounds)

Generally sensitive to lower dark matter masses as compared to nuclear scattering

Many on-going and near future laboratory experiments are pursuing this search strategy, e.g., SENSEI, XENON (various versions), DarkSide-50, CDMS, EDELWEISS, and DAMIC

Tremendous progress during the last few years

Dark matter - electron scattering



Target materials: silicon
⇩
(Smallest target mass, however lowest DM mass threshold)
⇩
most sensitive to DM masses ~ 10 MeV

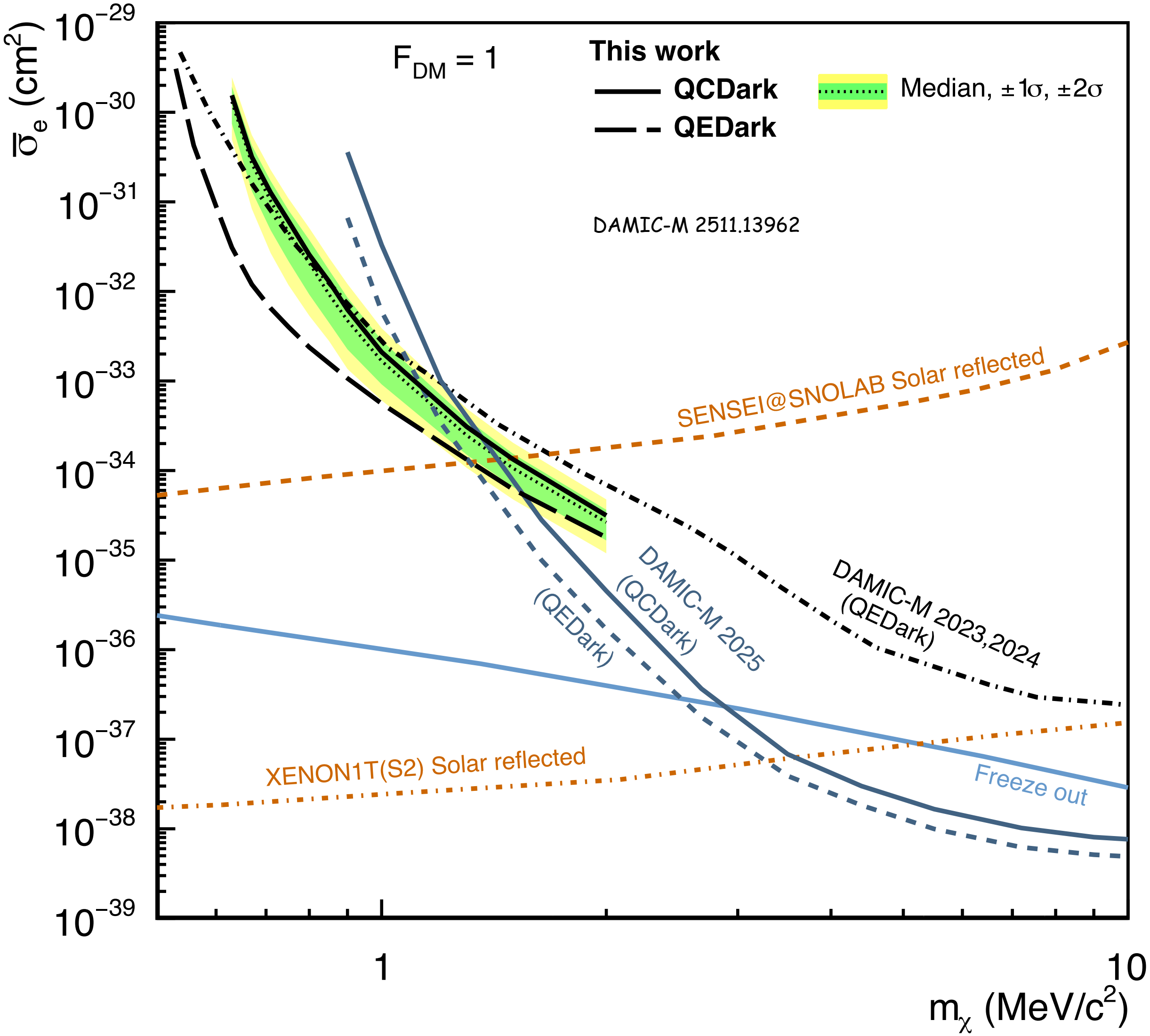
These upper limits assume the Standard Halo Model of dark matter velocity distribution

Target materials: xenon
⇩
(Largest target mass and heaviest DM mass threshold)
⇩
most sensitive to DM masses ~ 200 MeV

argon ⇨ (Mid-range target mass mid-range DM mass threshold)
⇩
most sensitive to DM masses ~ 50 MeV

See Maity and Laha 2208.14471 for effects of dark matter substructures for xenon-based detectors; Maity et al 2011.12896 for effects due to modifications in halo velocity distributions; and many others

Dark matter - electron scattering



- How do we probe lighter dark matter particle masses?

Energy deposition from dark matter scattering

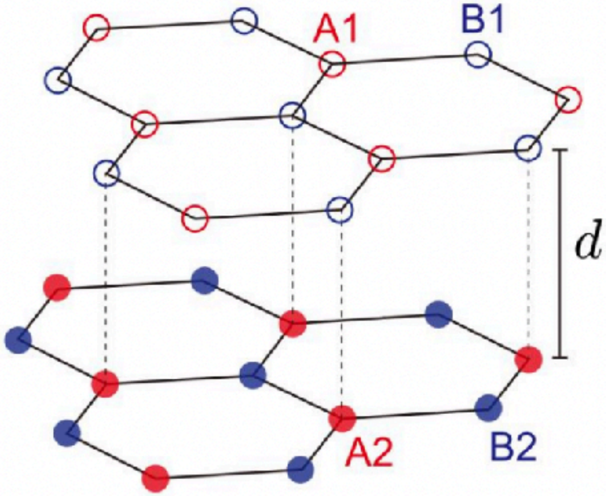
$$v_{DM} \simeq 10^{-3}c \qquad p_{DM} \simeq 10^{-3}m_{DM} \qquad E_{DM} \simeq 10^{-6}m_{DM}$$

Dark matter mass	Dark matter energy	Condensed Matter scale
20 MeV	~ 10 eV	Atomic ionization energy
2 MeV	~ 1 eV	Semiconductor band gap
100 keV	~ 50 meV	Optical phonon energy, superconductor band gap

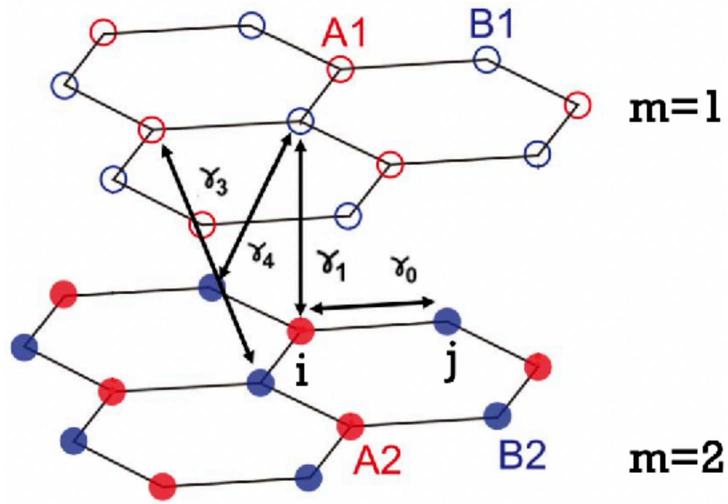
- In order to probe dark matter particles with masses $\lesssim \text{MeV}$, we need to use materials which are potentially sensitive to $\mathcal{O}(50\,\text{meV})$ energy deposition

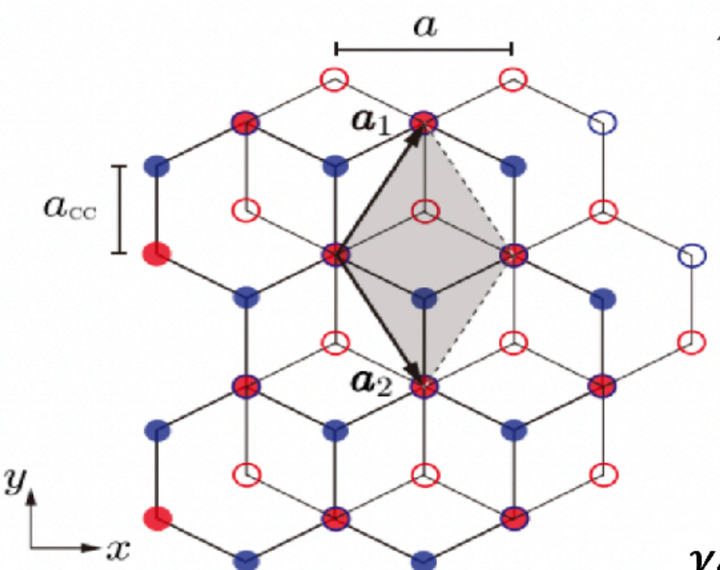
Slide idea: Rinchen Sherpa and Anuvab Sarkar

Our choice of material: bilayer graphene



Side view



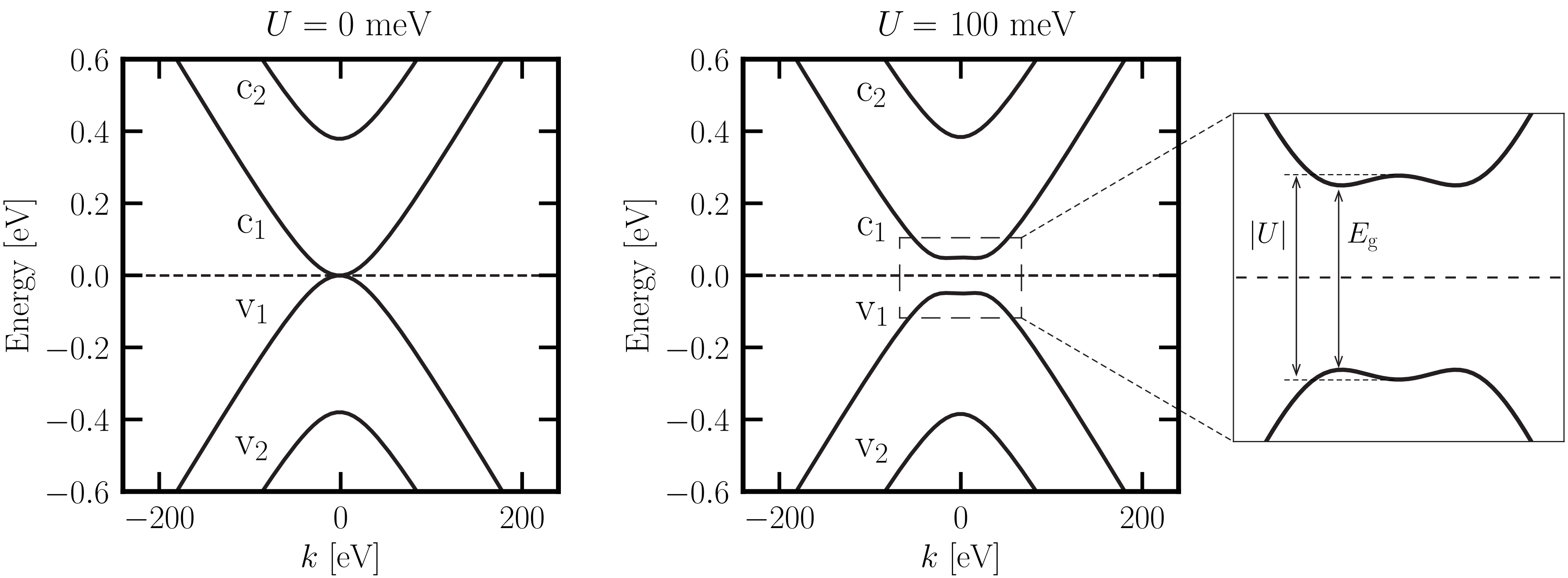


Top View

$$\mathcal{H}_{\mathrm{t.b}} = -\gamma_0 \sum_{\substack{\langle i,j \rangle \\ m,\sigma}} \left(a^{\dagger}_{m,i,\sigma} b_{m,j,\sigma} + H.c. \right) - \gamma_1 \sum_{j,\sigma} \left(b^{\dagger}_{1,j,\sigma} a_{2,j,\sigma} + H.c. \right) - \gamma_4 \sum_{j,\sigma} \left(b^{\dagger}_{1,j,\sigma} b_{2,j,\sigma} + a^{\dagger}_{2,j,\sigma} a_{1,j,\sigma} + H.c. \right) - \gamma_3 \sum_{j,\sigma} \left(a^{\dagger}_{1,j,\sigma} b_{2,j,\sigma} + H.c. \right)$$

γ_0, γ_1, γ_3, γ_4 are hopping parameters

Our choice of material: bilayer graphene



- Applying a voltage, U, between the two layers opens up a band gap, E_g, between the valence band and the conduction band

$$E_g \approx |U|$$

Sherpa, Sarkar, Maity, Dutta, Laha, and Das
arXiv: 2604.21969

- By varying the potential, one can change the band gap and this can be used to differentiate the signal from background

Dark matter scattering in bilayer graphene

Dark matter density — Dark matter velocity Distribution — Target volume — Interaction Hamiltonian

$$R_\chi = \frac{1}{\rho_T}\frac{\rho_\chi}{m_\chi}\int d^3\mathbf{v} f_\chi(\mathbf{v}) \frac{V\, d^3\mathbf{p}'_\chi}{(2\pi)^3} \sum_f |\langle f, \mathbf{p}'_\chi | \Delta H_{\chi T} | i, \mathbf{p}_\chi \rangle|^2 2\pi \delta(E_f - E_i + E'_\chi - E_\chi)$$

Target density — Dark matter mass

$$R_\chi = \frac{1}{\rho_T}\frac{\rho_\chi}{m_\chi}\int d^3\mathbf{v} f_\chi(\mathbf{v}) \int \frac{d^3\mathbf{q}}{(2\pi)^3} d\omega \frac{\pi \bar{\sigma}(q)}{\mu_\chi^2} \delta(\omega + E'_\chi - E_\chi) \times \underbrace{\frac{2\pi}{V}\sum_f |\langle f | \mathcal{O}_T(\mathbf{q}) | i \rangle|^2 \delta(E_f - E_i - \omega)}_{S(\mathbf{q},\omega)}$$

Sherpa, Sarkar, Maity, Dutta, Laha, and Das
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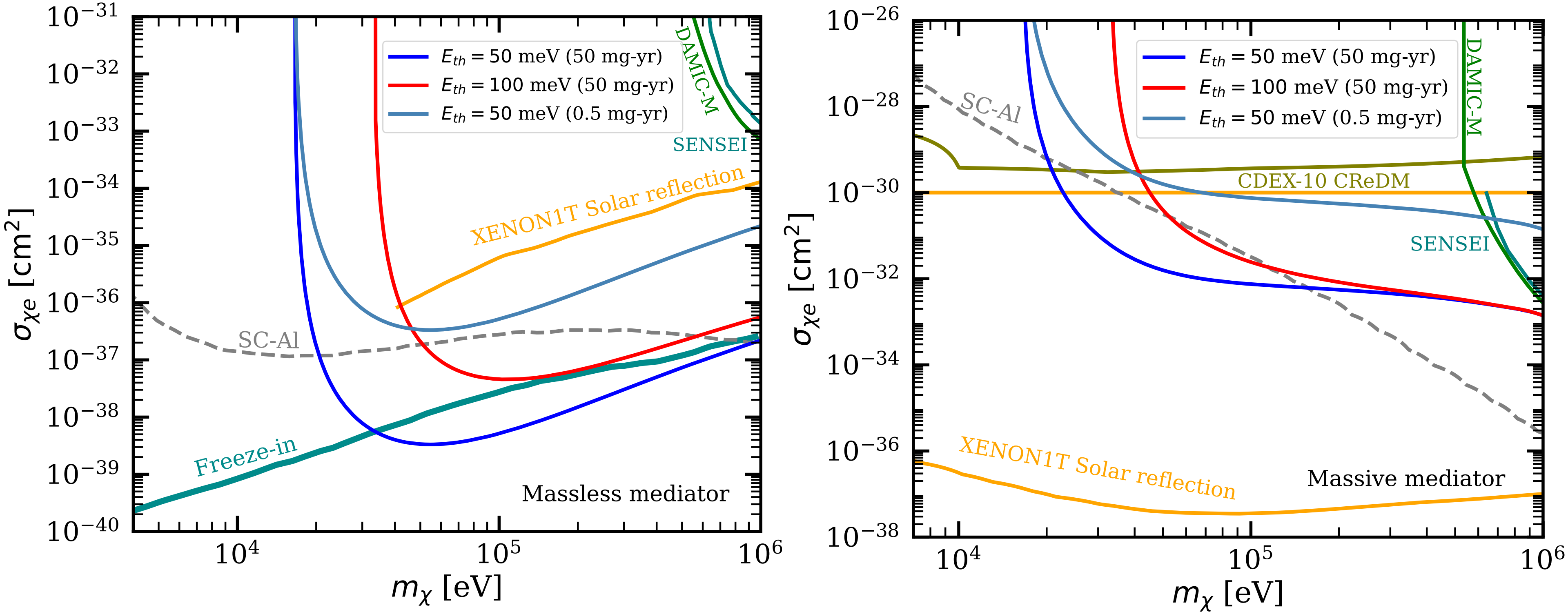
$S(\mathbf{q},\omega)$= dynamic structure factor, informs us about how the material responds to a momentum $\mathbf{q}$ and energy ω. It depends on the electron density in the material

Dark matter scattering in bilayer graphene



Sherpa, Sarkar, Maity, Dutta, Laha, and Das
arXiv: 2604.21969

Projected sensitivity of DM-electron scattering cross section in bilayer graphene for two applied voltages U = 50 meV (blue) and U = 100 meV (red) assuming an exposure of 3 events in 50 mg-yr and 0.5 mg-yr

One can probe new parts of the parameter space with an exposure of 0.5 mg-yr

My connection with CCAPP

I was a Ph.D. student in the Ohio State University from 2009 to 2014, working with Prof. John F. Beacom

I work on various topics in theoretical astroparticle physics, astrophysics, cosmology, and particle physics. Majority of the time, I think about dark matter, neutrinos, gamma-rays, cosmic-rays, beyond the Standard Model physics, gravitational waves, etc.

Other CCAPP folks with whom I collaborated: Basudeb Dasgupta, Kenny C. Y. Ng, Shunsaku Horiuchi, Kohta Murase, Sheldon Campbell, Eric G. Speckhard, Matthew D. Kistler, and Bei Zhou

During my Ph.D., we worked on a number of topics in dark matter, high-energy astrophysical neutrinos, and supernova neutrinos

My connection with CCAPP

The wide variety of science topics pursued in CCAPP helped me to work in these topics and learn even more research areas

Both theoretical and experimental efforts in various topics helped me

I made life-long friends and collaborators

Not only did my science improve, I improved as a human being during my time in CCAPP

Last two decades have been great for CCAPP, here's wishing for even more success in the upcoming decades

Currently, I am an Assistant Professor at the Centre for High Energy Physics (CHEP), Indian Institute of Science (IISc), Bengaluru, India; please visit us.

Conclusions

Searching for beyond the Standard Model in cosmology and particle physics is one of the major avenues of research

I discussed two different ideas to explore this research area:

(i) We demonstrated that JWST observations can set the most stringent and competitive constraints on a variety of particle physics models of dark matter - baryon interactions

(ii) We demonstrated that bilayer graphene will be an excellent probe of sub-MeV dark matter particles scattering with electrons

Best wishes to CCAPP

Questions & comments: ranjanlaha@iisc.ac.in

JWST (James Webb Space Telescope)

Fig. credit: NASA Webb

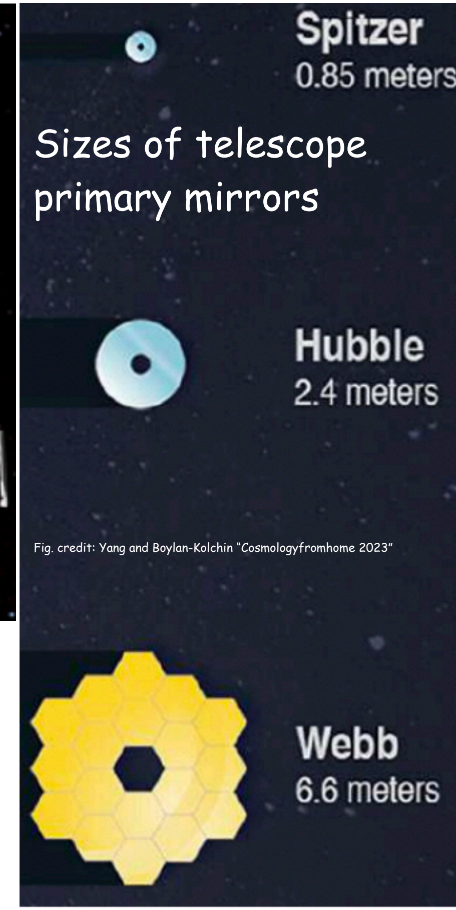


Fig. credit: Yang and Boylan-Kolchin "Cosmologyfromhome 2023"

Four different instruments on-board: NIRSpec, NIRCam, MIRI, and NIRISS

NIRSpec: Near InfraRed Spectrograph

NIRCam: Near InfraRed Camera

MIRI: Mid InfraRed Instrument

NIRISS: Near InfraRed Imager and Slitless Spectrograph

How does this affect structure formation?

We assume that dark matter consists of a single particle and 100% of it is interacting with baryons

χ = dark matter

We model the dark matter and baryons as a fluid

$R_{\chi-b} \propto \sigma_\chi^T$

= conformal momentum-exchange rate due to dark matter - baryon interactions

aH = conformal Hubble parameter

c_χ = sound speed in dark matter fluid

$$\delta := \frac{\delta\rho}{\bar{\rho}},$$

Density contrast

$$\theta := \nabla . \mathbf{v}$$

Divergence of velocity

Continuity $\dot{\delta}_\chi = -\theta_\chi + 3\dot{\phi}$

Pressure term: DM is no longer cold

Momentum transfer

Euler $\dot{\theta}_\chi = -aH\theta_\chi + \boxed{k^2 c_\chi^2 \delta_\chi} + \boxed{R_{\chi-b}(\theta_b - \theta_\chi)} + k^2\psi$

Heat Flow $\dot{T}_\chi = -2aHT_\chi + \boxed{2R'_{\chi-b}(T_\gamma - T_\chi)}$

Heat transfer

k = wavenumber of perturbations

Image courtesy: Souradeep Das

dot represents derivative w.r.t. conformal time

$\phi,\ \psi$ = metric perturbations in the conformal Newtonian gauge

How does this affect structure formation?

We model the dark matter and baryons as a fluid

$$\dot{\delta}_b = -\theta_b + 3\dot{\phi}$$

$$\dot{\theta}_b = -aH\theta_b + k^2 c_b^2 \delta_b + R_{b-\chi}(\theta_\chi - \theta_b) + R_{b-\gamma}(\theta_\gamma - \theta_b) + k^2\psi$$

$$\dot{T}_b = -2aHT_b + 2R'_{b-\chi}(T_\chi - T_b) + 2R'_{b-\gamma}(T_\gamma - T_b)$$

$$R_{b-\gamma} \propto \sigma_{\rm Thomson} \qquad R'_{\chi-b} \propto R_{\chi-b} \qquad R'_{\chi-b} \propto R_{\chi-b}$$

Momentum and heat is exchanged between dark matter and baryons

These modified cosmological perturbation equations are solved using the class_dmb code, which is a modified version of CLASS (Cosmic Linear Anisotropy Solving System), and one obtains the linear matter power spectrum $P(k)$

Halo mass function

$$\frac{dn}{d\log M_h}(z) = M_h \frac{\rho_{m,0}}{M_h^2} f(\sigma(M_h)) \left| \frac{d\ln\sigma}{d\ln M_h} \right|$$

n = number density of halos with mass M_h at redshift z

$\rho_{m,0}$ = co-moving matter density

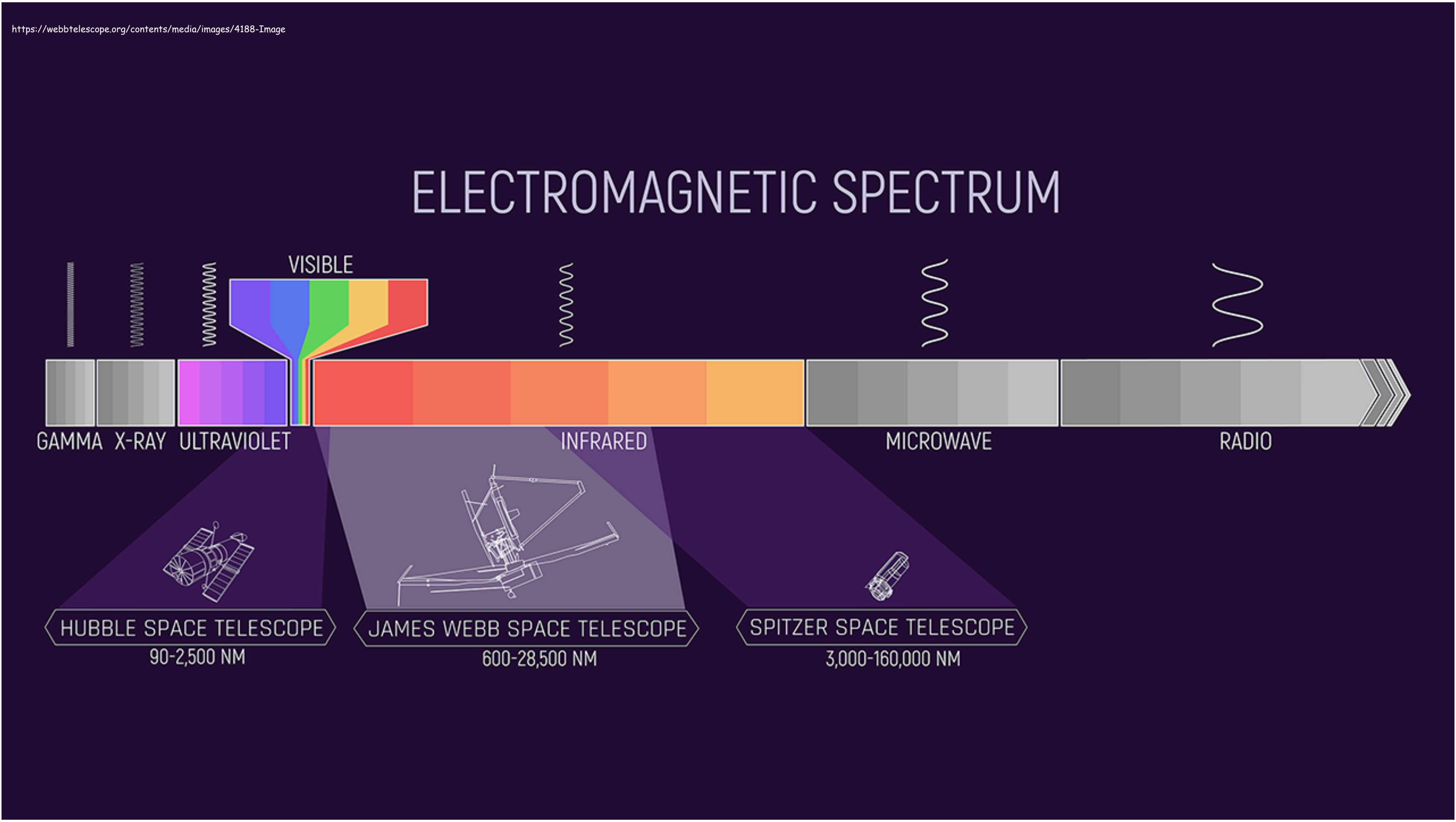
$\sigma^2(R) = \frac{1}{2\pi^2} \int_0^\infty dk\, k^2\, W^2(kR)\, P(k)$ = variance of the smoothed density contrast within a sphere of radius R

$W(kR)$ = Fourier transform of a window function, called kernel or filter function

$f(\sigma)$ = fitting function

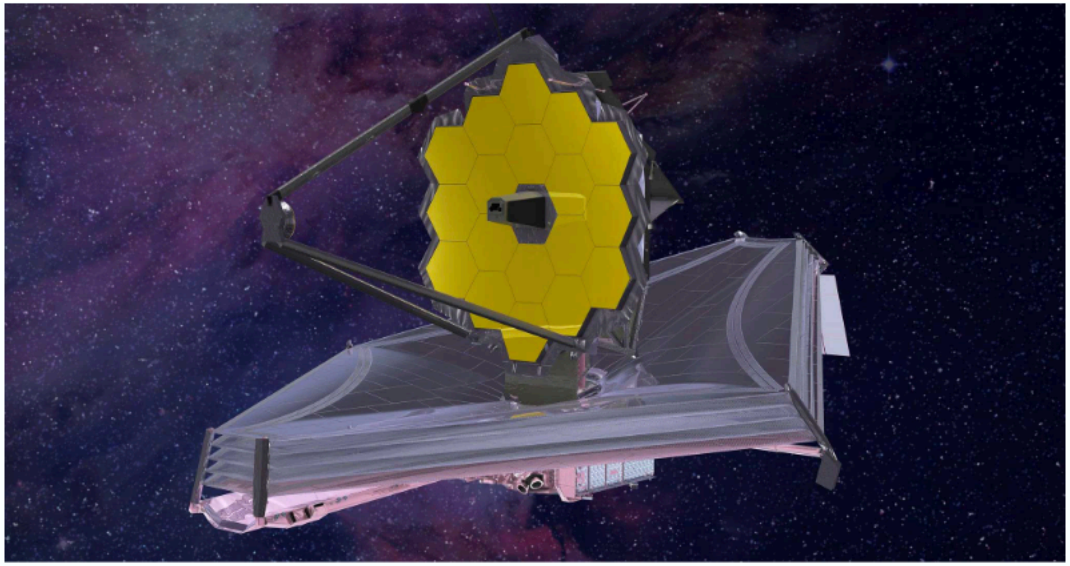
Extended Press-Schechter formalism in order to have a statistical measure of the halo mass distribution

JWST (James Webb Space Telescope)



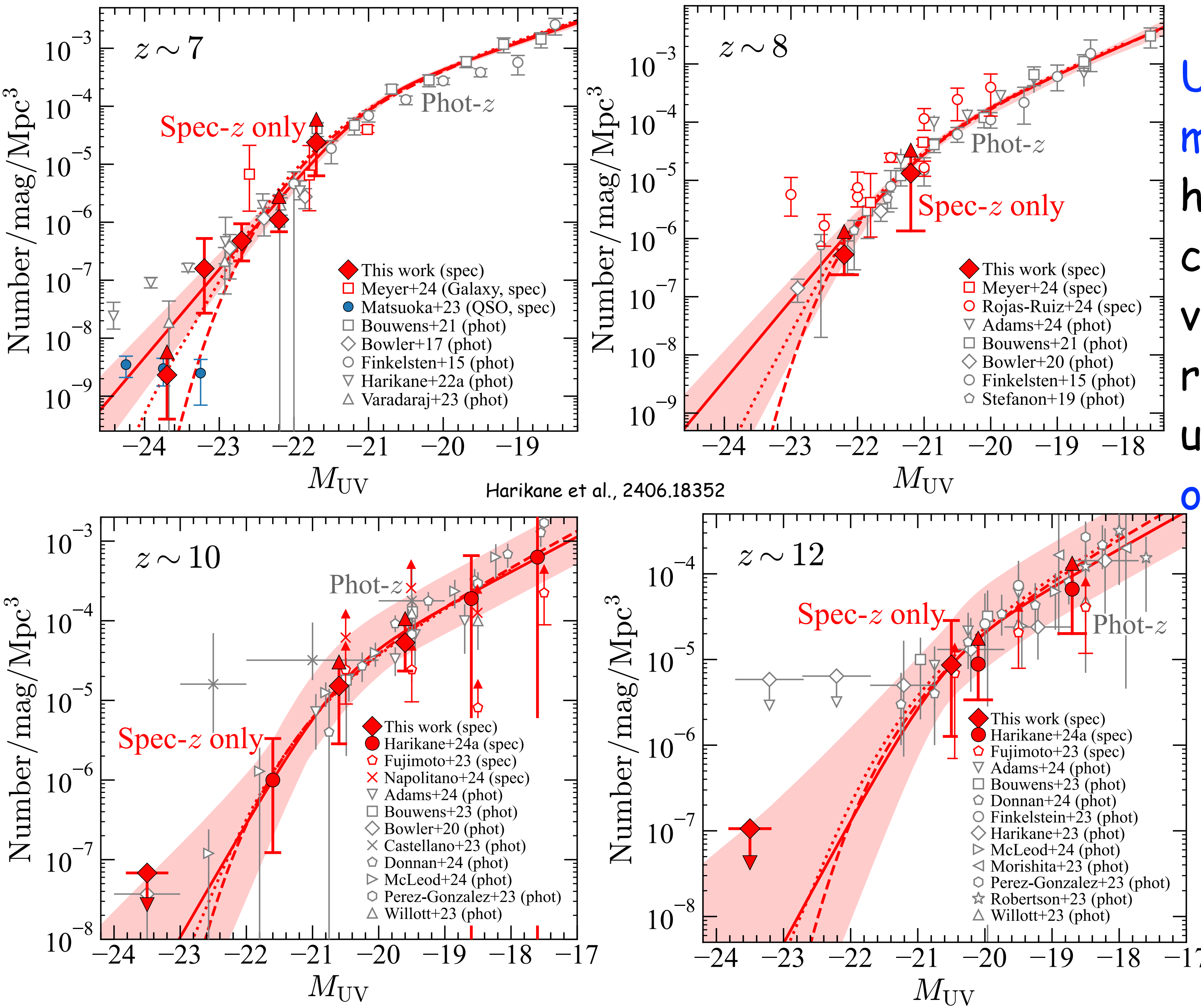
JWST is an infra-red telescope covering wavelengths 600 nm to 28500 nm

James Webb Space Telescope



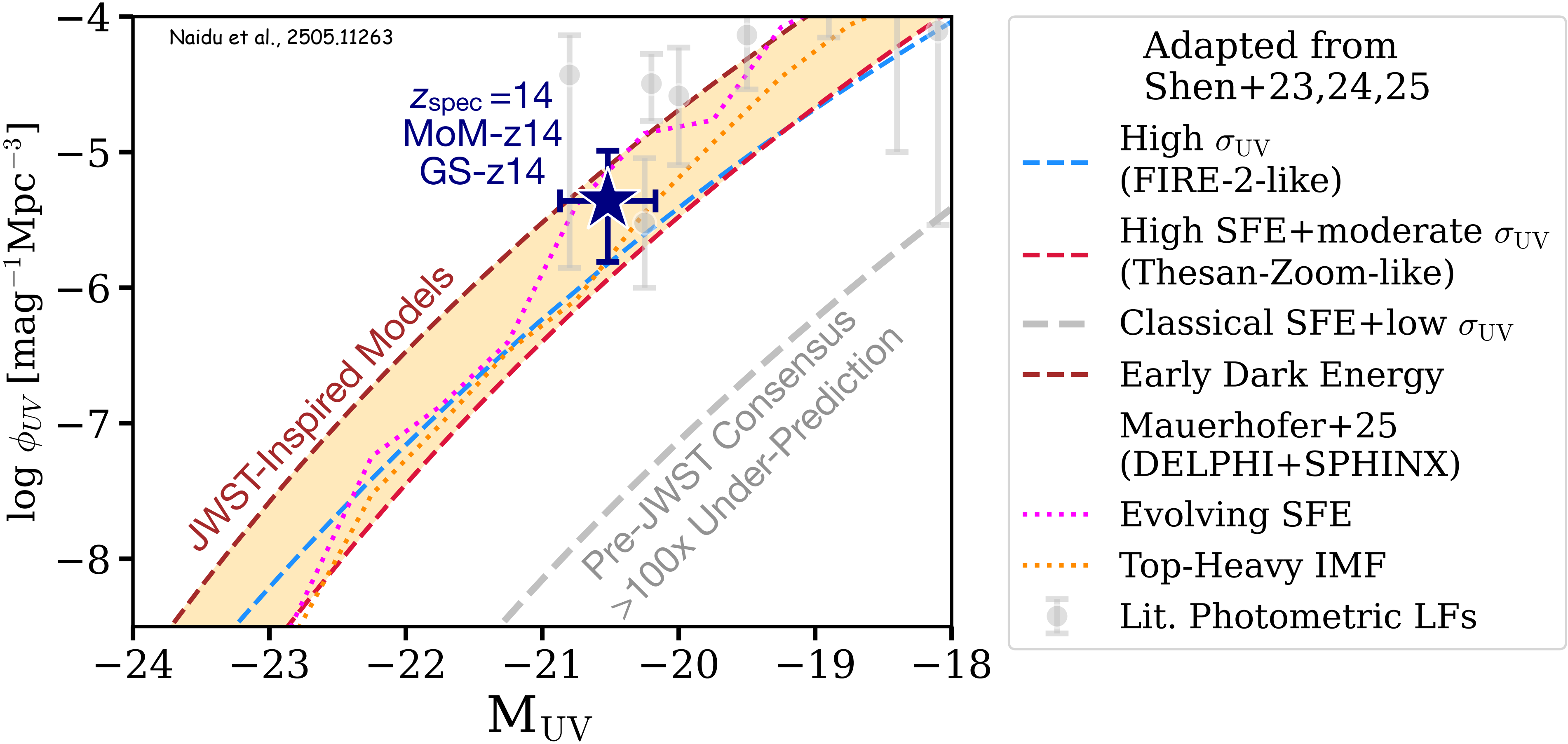
Credit: Northrop Grumman

UV Luminosity Function



UVLF measurements have been conducted in various redshifts using JWST observations

UV Luminosity Function



Highest redshift galaxy MoM-z14 $z_{\rm spec} = 14.44 \pm 0.02$

Second highest redshift galaxy JADES-GS-z14-0

Carniani et al., 2409.20533

$z_{\rm spec} = 14.1796 \pm 0.0007$

Conclusions for part 1

- JWST has opened up a new infra-red view of our Universe
- Given its leading sensitivity, one can try to conduct searches for dark matter using its observations
- A major result from various JWST observations is the discovery of numerous bright galaxies at high redshifts
- A significant dark matter - baryon interactions will suppress the production of galaxies at high redshifts
- Using UV luminosity function derived from JWST data-set, we derive the leading/ competitive constraints on dark matter - baryons interactions for a variety of particle physics models

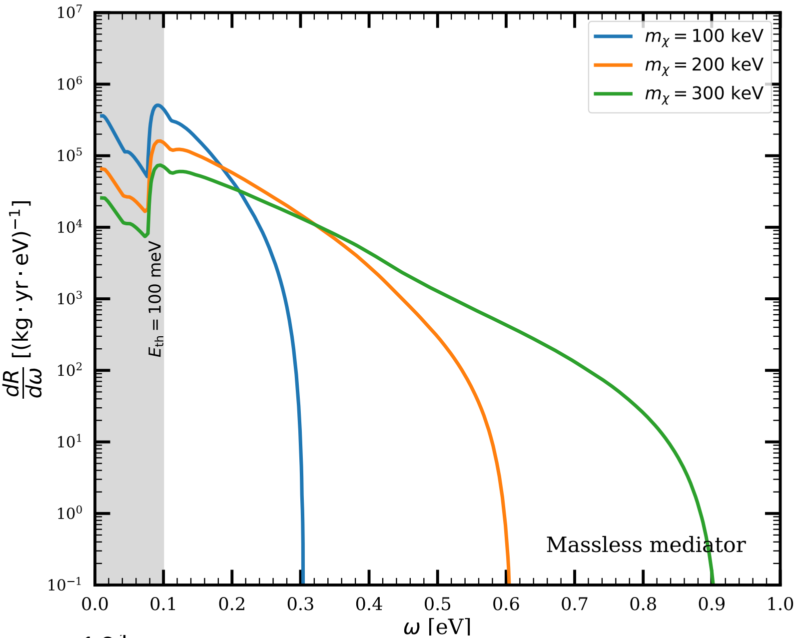
Das, Mondol, Singh, and Laha,
arXiv: 2511.02906

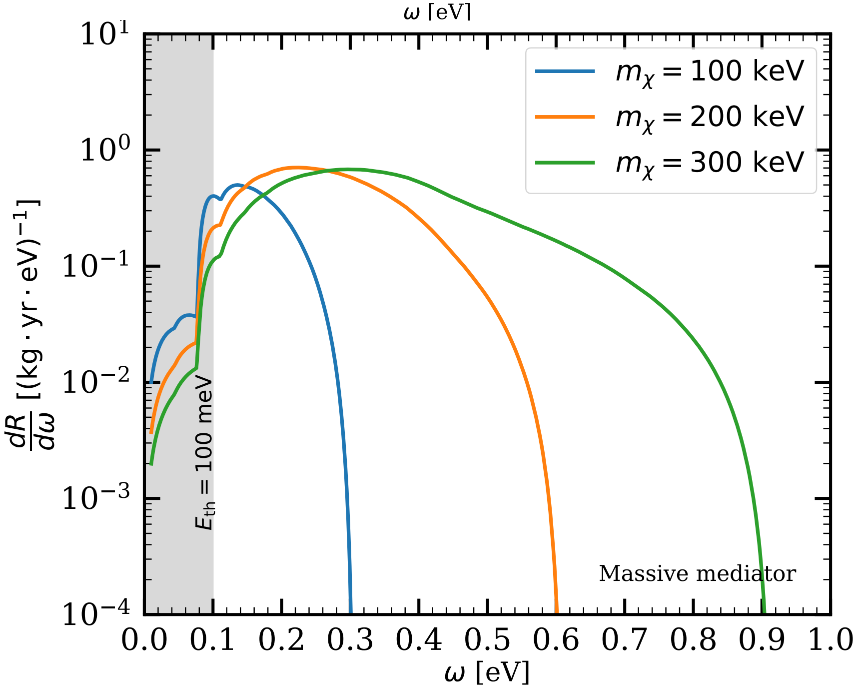
Dark matter - electron scattering

Dark matter - electron scattering in bi-layer graphene

Results

Dark matter scattering in bi-layer graphene





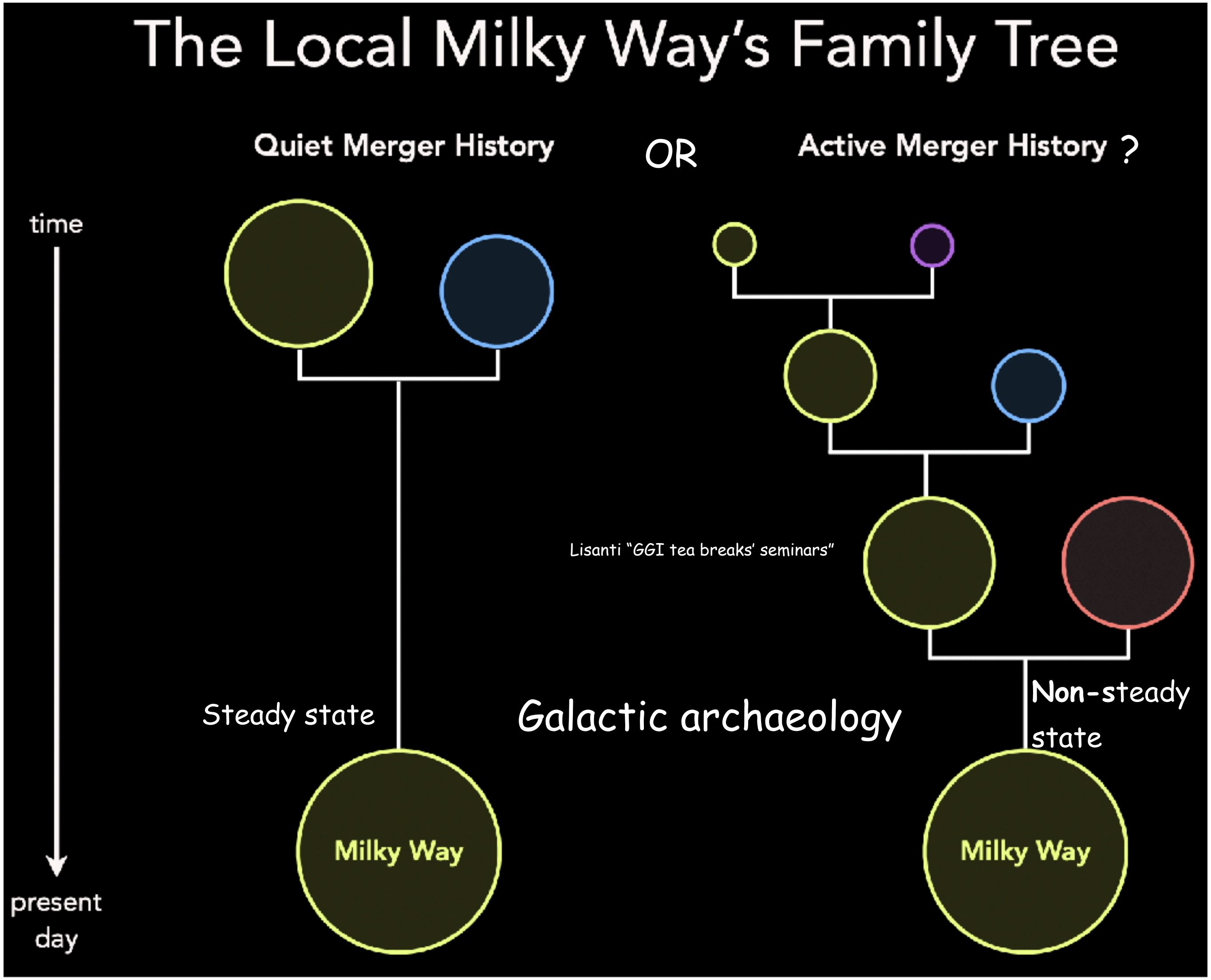
Recoil spectrum of electrons in bi-layer graphene due to dark matter scattering. The three lines represent various dark matter masses. The energy threshold in these two plots is 100 meV. These plots assume a mass-less mediator and a massive mediator.

The dark matter - electron scattering cross-section is $\sigma_{\chi e} = 10^{-38}\,\mathrm{cm}^2$

Sherpa, Sarkar, Maity, Dutta, Laha, and Das (in preparation)

How does the Milky Way form?

- Structure formation in ΛCDM (cold dark matter) cosmology is bottom up



Slide idea: Tarak Nath Maity

Dark matter - electron scattering

- We know that dark matter moves inside the Milky Way with a typical velocity $\sim 220\,\mathrm{km\,s^{-1}}$
- But, what is the velocity distribution of dark matter? It depends on the Milky Way formation history
- Typically, we assume that the velocity distribution of dark matter follows the Maxwell-Boltzmann distribution (also called Standard Halo Model)

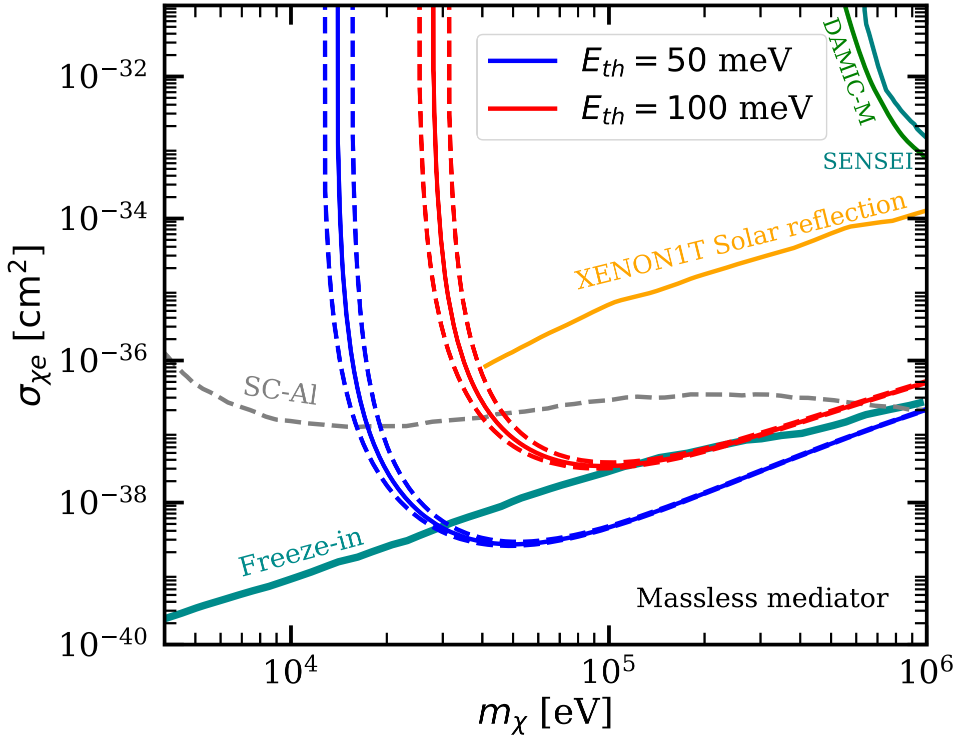
$$f_{\mathrm{gal}}^{\mathrm{MB}}(\mathbf{v}) \propto \exp\left(-\frac{|\mathbf{v}|^2}{2\sigma_v^2}\right)\Theta(v_{\mathrm{esc}} - |\mathbf{v}|)$$

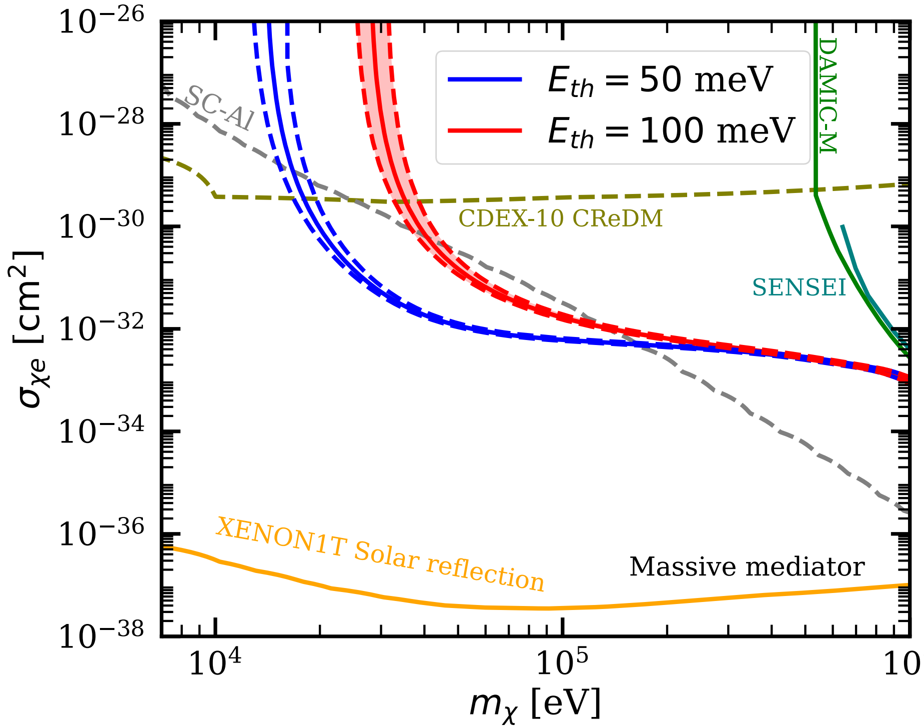
where $\sigma_v \approx 156\,\mathrm{km\,s^{-1}}$

- How does different velocity distributions affect dark matter - electron scattering in bi-layer graphene?
- How do we probe dark matter velocity distribution using dark matter - electron scattering in bi-layer graphene?

See Bloch et al., 2006.14521 JHEP
Maity and Laha 2208.14471 JHEP

Dark matter scattering in bi-layer graphene





Sherpa, Sarkar, Maity, Dutta, Laha, and Das
(in preparation)

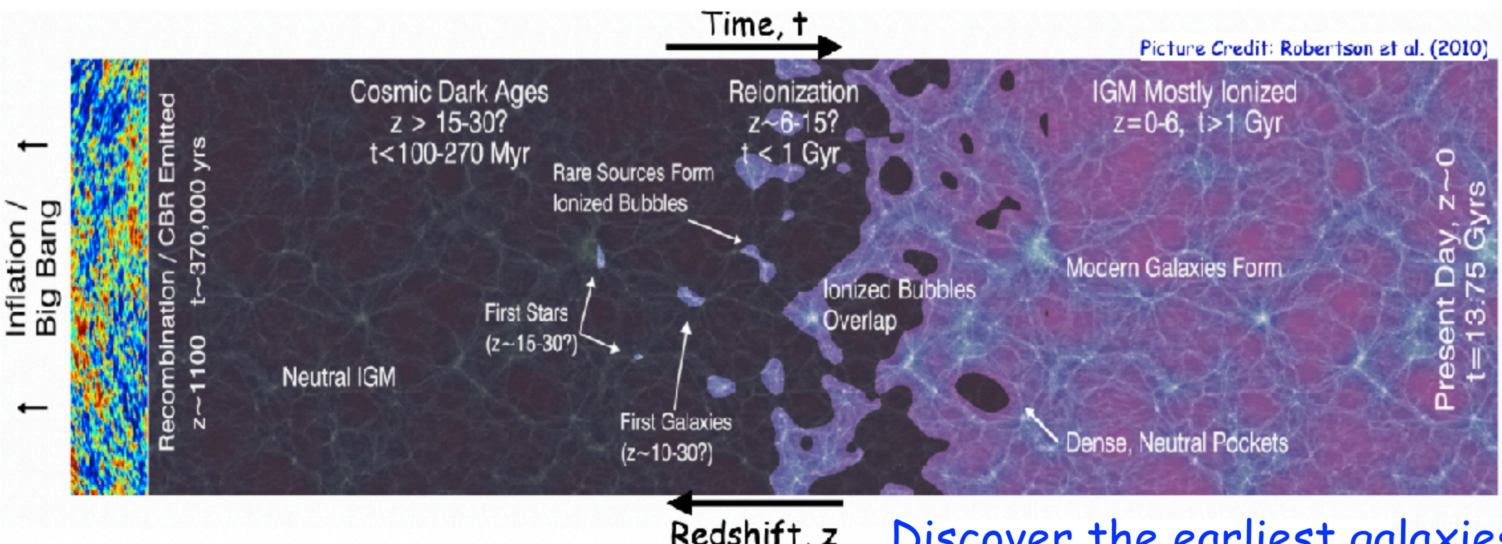
Using results from the DREAMS simulation suite, we study the effect of the uncertainty in the dark matter velocity on the projected sensitivity of DM-electron scattering cross section in bi-layer graphene for two applied voltages U = 50 meV (blue) and U = 100 meV (red) assuming an exposure of 3 events in 50 mg-yr

Cosmology

- - - *Planck* 2018 6-parameter fit to flat ΛCDM cosmology - - -		
baryon density of the Universe	$\Omega_b = \rho_b/\rho_{crit}$	$^{\ddagger}0.02237(15)\,h^{-2} = {}^{\dagger}0.0493(6)$
cold dark matter density of the Universe	$\Omega_c = \rho_c/\rho_{crit}$	$^{\ddagger}0.1200(12)\,h^{-2} = {}^{\dagger}0.265(7)$
100 × approximation to r_*/D_A	$100 \times \theta_{MC}$	$^{\ddagger}1.04092(31)$
reionization optical depth	τ	$^{\ddagger}0.054(7)$
ln(power prim. curv. pert.) $(k_0 = 0.05\,\mathrm{Mpc}^{-1})$	$\ln(10^{10}\Delta^2_{\mathcal{R}})$	$^{\ddagger}3.044(14)$
scalar spectral index	n_s	$^{\ddagger}0.965(4)$

PDG 2024

How do we probe $\Lambda\mathrm{CDM}$ more precisely or in newer regimes or answer outstanding questions about it?



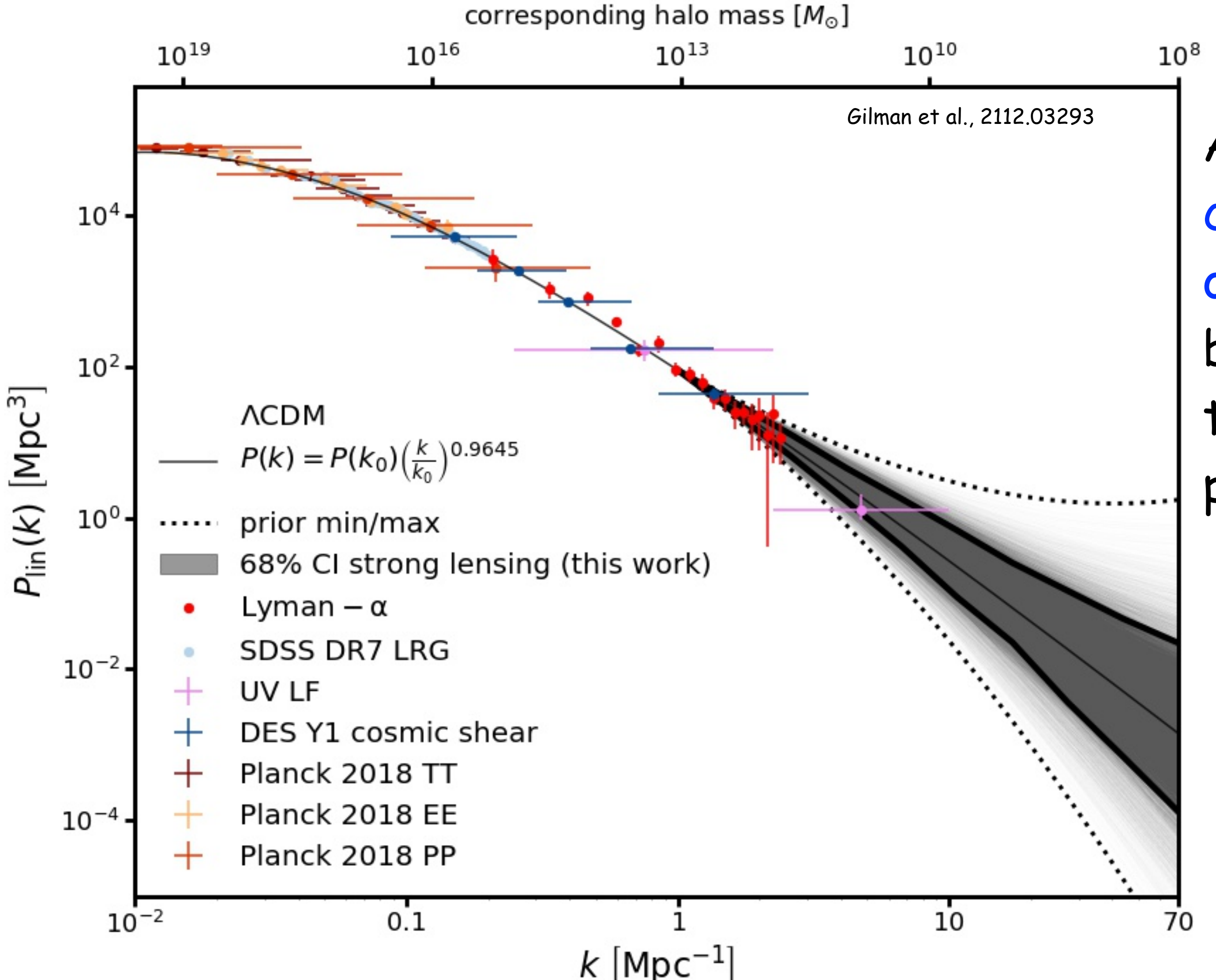
This region is not probed at all (before 2022)
Do we have new data regarding this region?

Discover the earliest galaxies observable and answer fundamental questions about particle physics and astrophysics/ cosmology

Linear matter power spectrum

$$\langle \delta(\mathbf{k})\delta^*(\mathbf{k}')\rangle \equiv (2\pi)^3 \delta(\mathbf{k}-\mathbf{k}')P(k) \qquad k \approx 1/(\text{length scale})$$

Quantifies the strength of density fluctuations at a given scale



A large number of cosmological observables have been used to probe the linear matter power spectrum

Some details taken from Souradeep Das' and Abhijeet Singh's slides

From Halo mass to UV Luminosity Function

Halo mass

↓

Mass accretion rate

$$\dot{M}_{\rm halo} = C\left(\frac{M_{\rm halo}}{10^{12} M_\odot h^{-1}}\right)^{\gamma} \frac{H(z)}{H_0}$$

$$\gamma = 1.000 + 0.329a - 0.206a^2$$

$$\log_{10} C = 2.730 - 1.828a + 0.654a^2$$

↓

Star Formation Rate (SFR)

$$\mathrm{SFR} = \mathrm{SFE}.f_b.\dot{M}_h$$

$$\mathrm{SFE} = \frac{\epsilon}{\left(\frac{M_h}{M_c}\right)^{\alpha_*} + \left(\frac{M_h}{M_c}\right)^{\beta_*}}$$

↓

UV Luminosity

$$L_\nu^{\rm UV} = \frac{1}{\kappa_{\rm UV}} \mathrm{SFR}$$

$$\kappa_{\rm UV} = 1.15 \times 10^{-28}\ \mathrm{M_\odot\ s\ erg^{-1}\ yr^{-1}}$$

↓

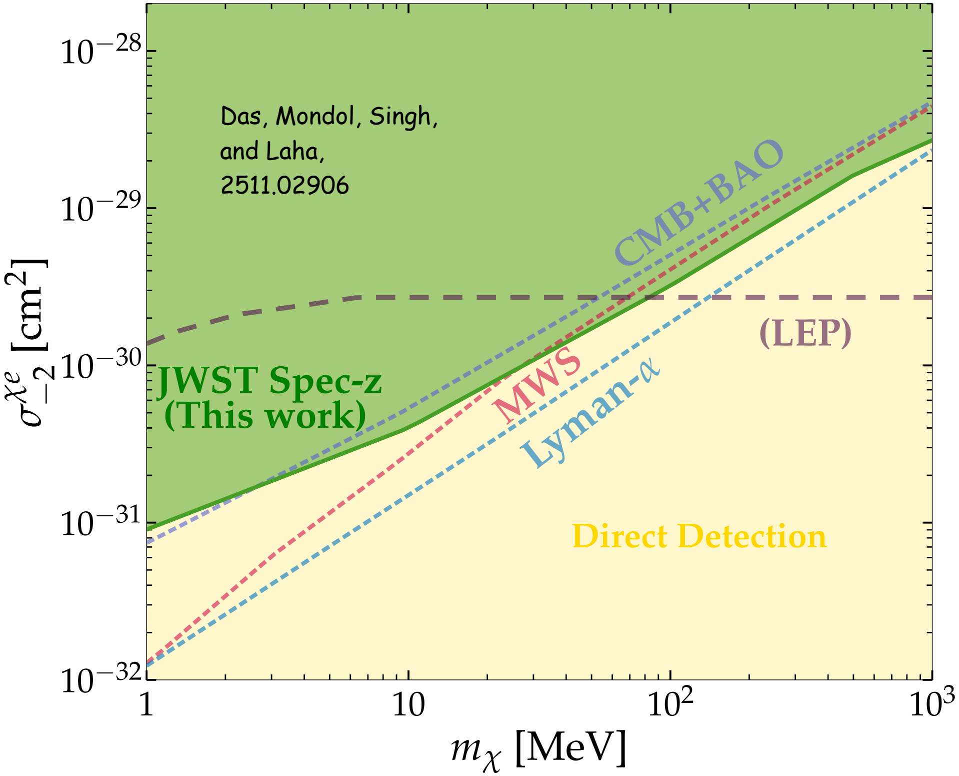
Dust-corrected UV luminosity

$$M_{\rm UV}^{\rm obs} = M_{\rm UV} + A_{\rm UV}$$

$$A_{\rm UV} = -0.34(21 + M_{\rm UV}^{\rm obs}) + 0.79$$

Slide courtesy: Souradeep Das

Results



We derive the competitive constraints on dark matter - electron scattering cross-sections for a variety of velocity-dependencies using the data from 40 spectroscopically confirmed galaxies

Upcoming observations will discover more galaxies at higher redshifts, thus it will significantly strengthen our results