DIRECTLY DETECTING THE IRREDUCIBLE MILLICHARGED BACKGROUND

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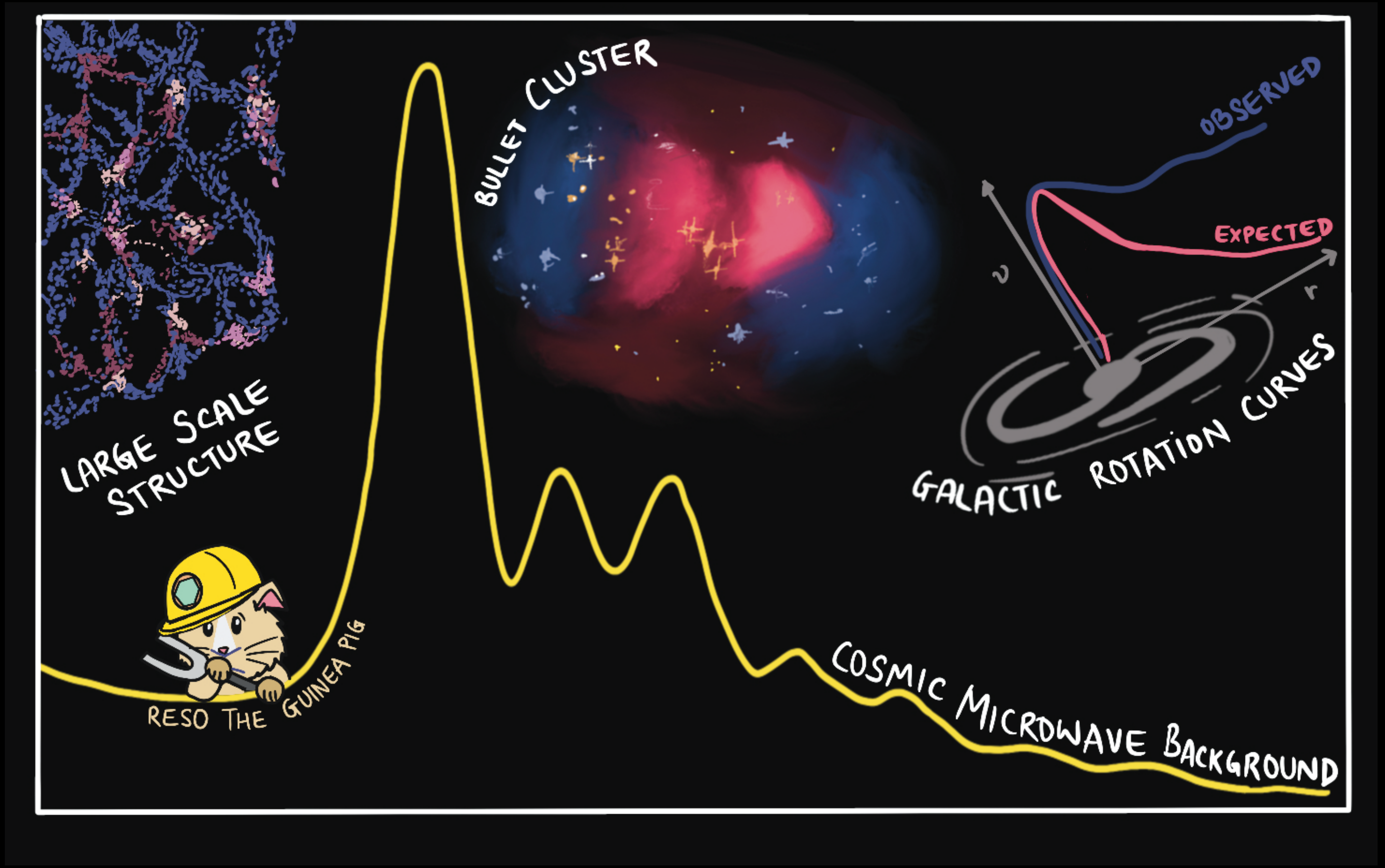
MCGILL U.

BASED ON 2407.21096
W/ ELLA ILES AND KATELIN SCHUTZ

WHERE IS THE NEW PHYSICS?

WHERE IS THE NEW PHYSICS?

WHAT'S HAPPENING
ON THE DARK SIDE?



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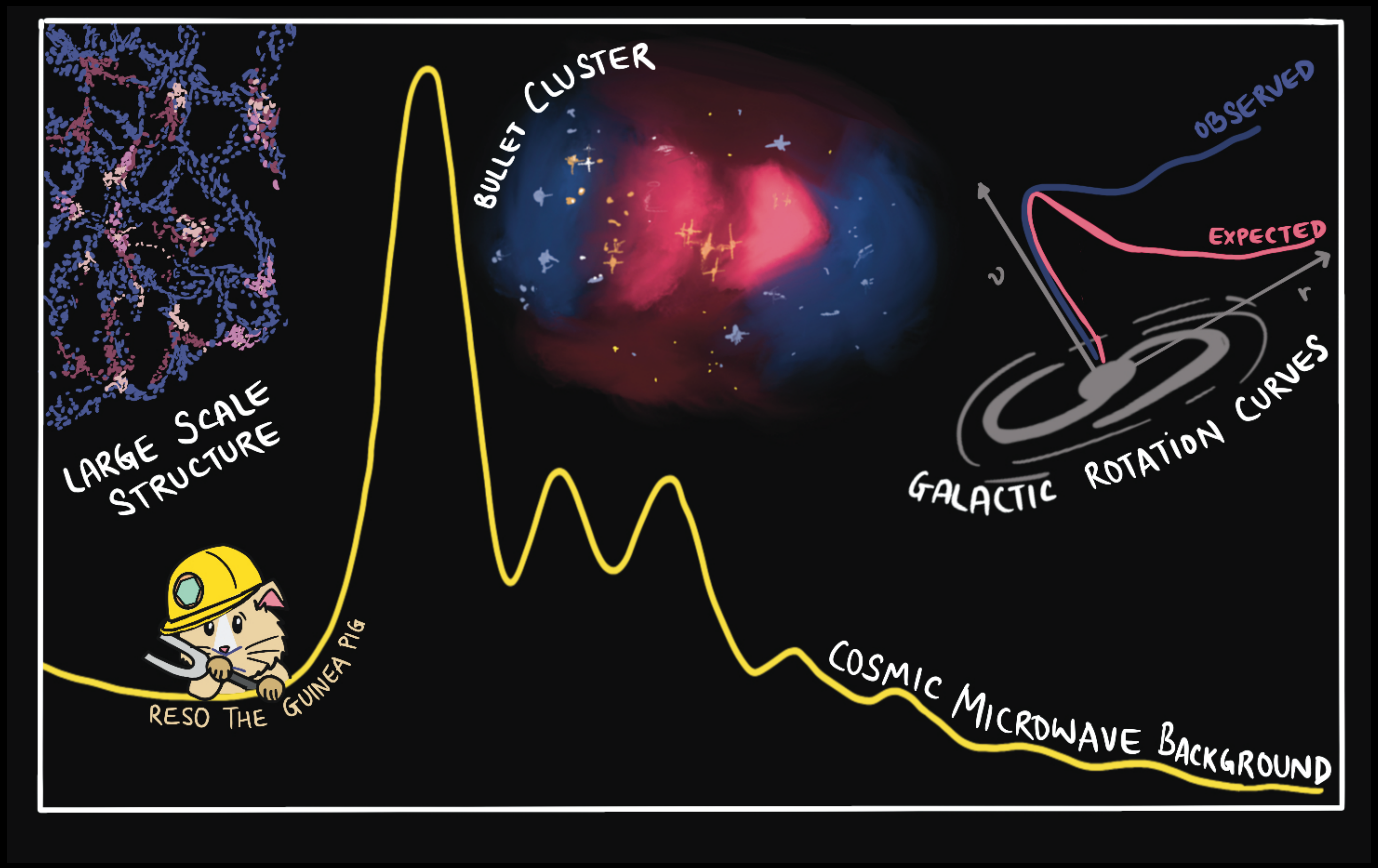

WHAT'S THE DEAL WITH THE STANDARD MODEL?

Neutrino masses?
Strong CP problem?
Hierarchy problem?

Experimental anomalies?

NECESSITATE UV COMPLETION!

THERE ARE **PROBABLY** NEW PARTICLES BEYOND THE STANDARD MODEL AND THESE NEW PARTICLES **MAY** BE DARK MATTER

PARAMETERIZING NEW PHYSICS

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Determine particle type

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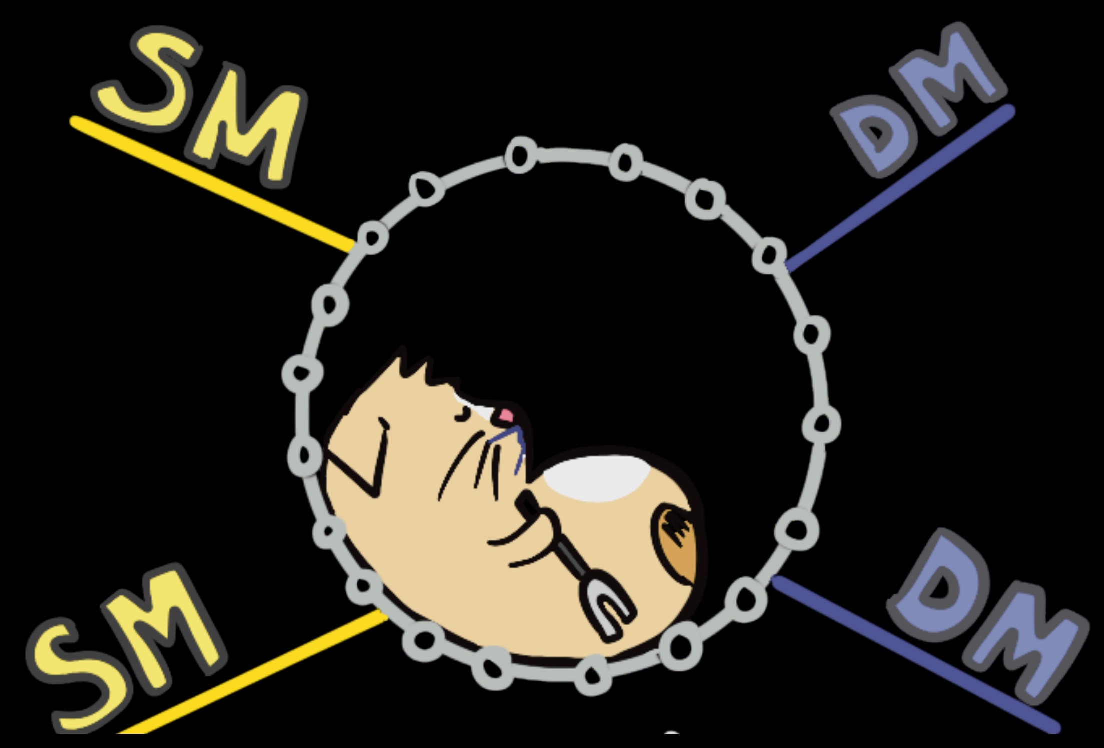

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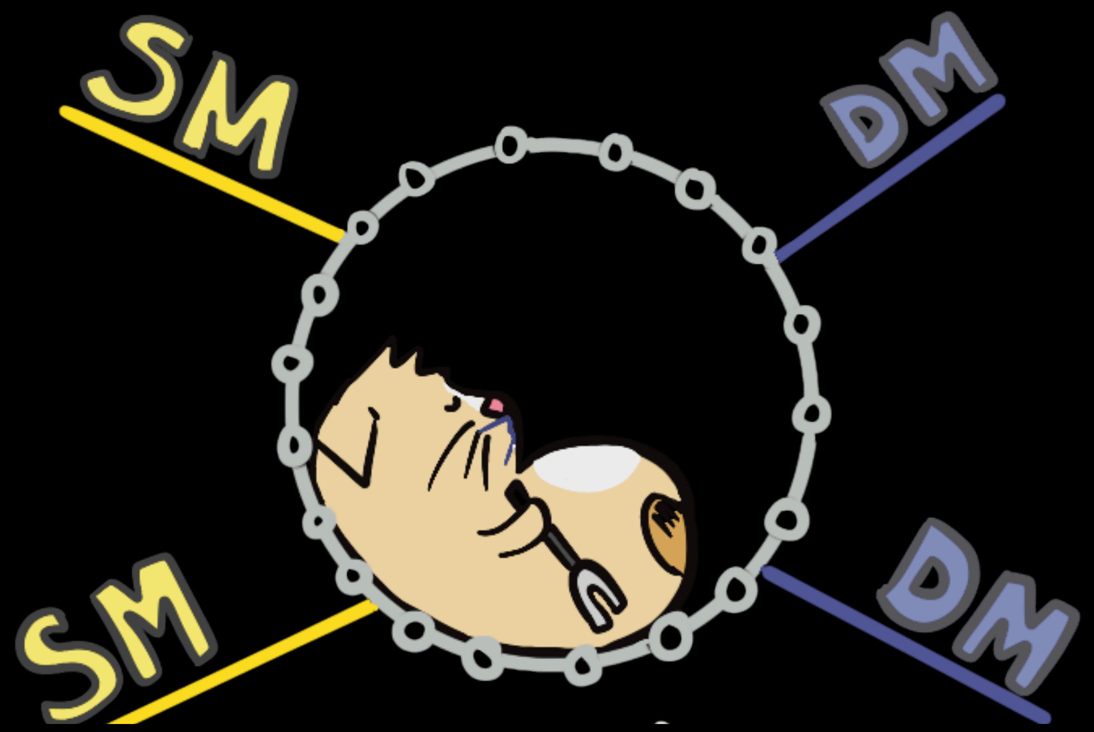
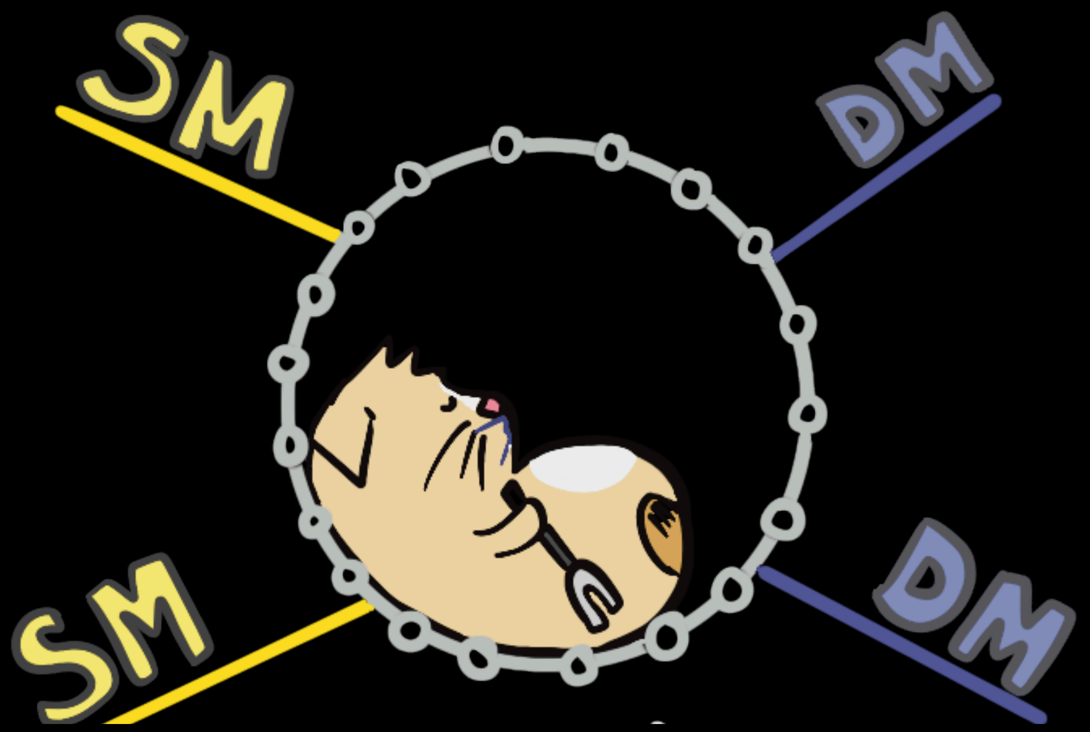


Only a limited number of renormalizable operators!

PARAMETERIZING NEW PHYSICS

DETERMINE PARTICLE TYPE

DETERMINE INTERACTION TYPE



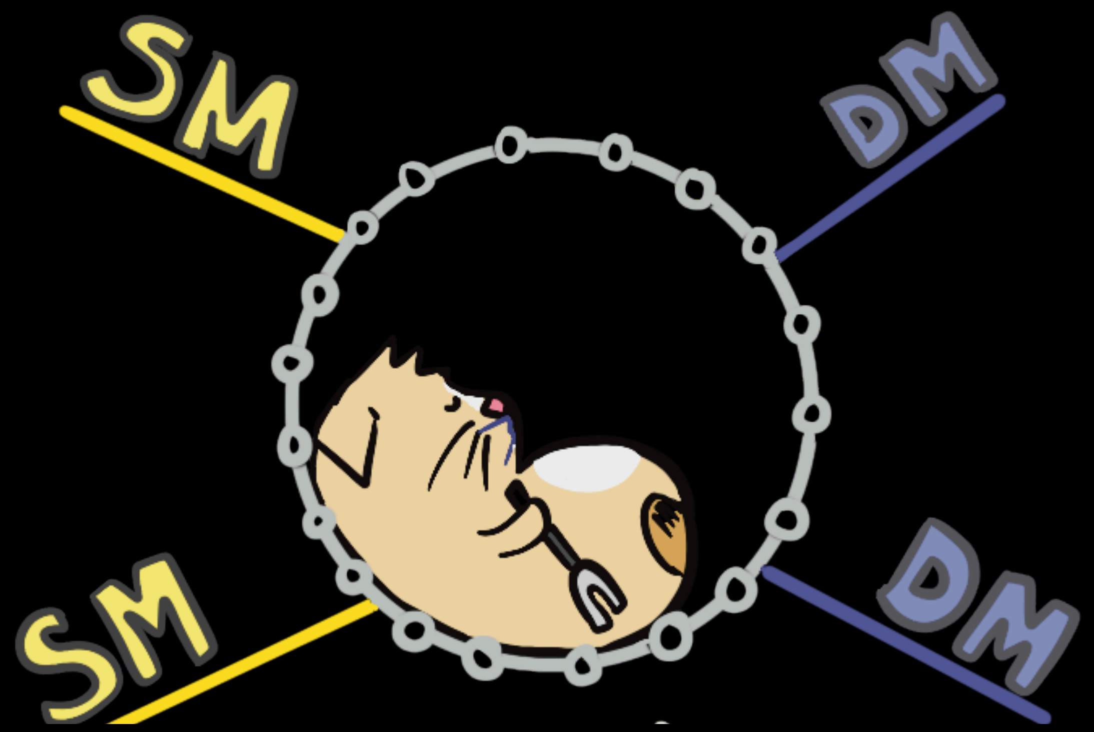
ONLY A LIMITED NUMBER OF RENORMALIZABLE OPERATORS!

1. Vector Portal
2. Axion Portal
3. Neutrino Portal
4. Scalar Portal

PARAMETERIZING NEW PHYSICS

DETERMINE PARTICLE TYPE

DETERMINE INTERACTION TYPE



ONLY A LIMITED NUMBER OF RENORMALIZABLE OPERATORS!

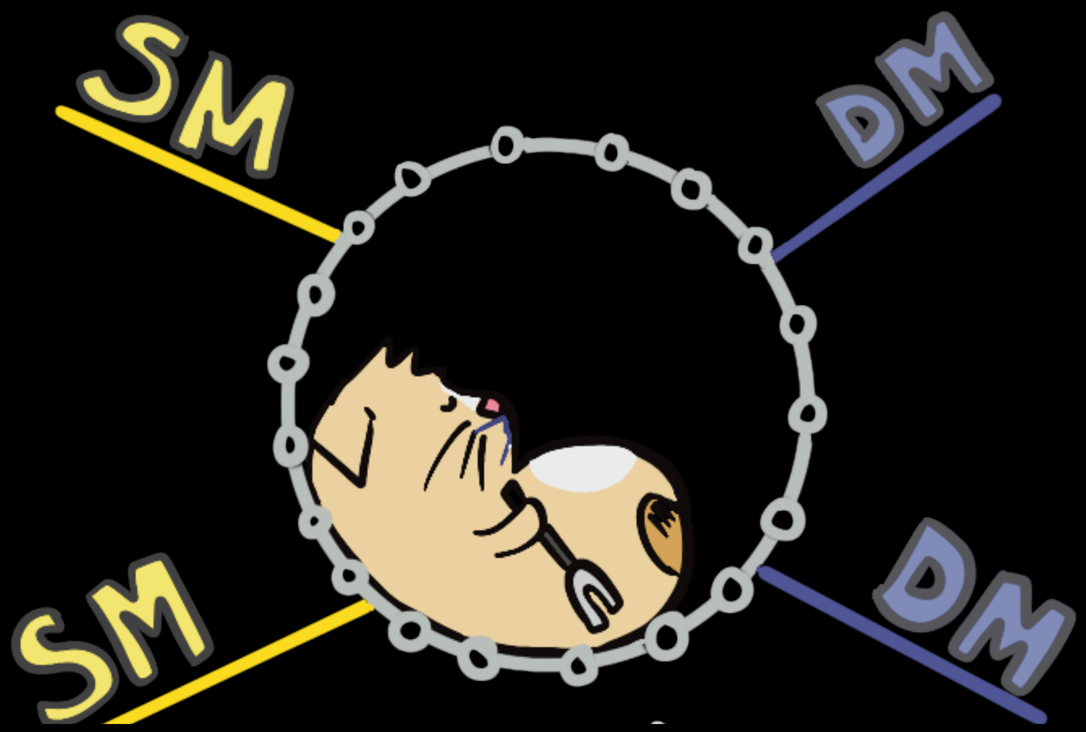
1. Vector Portal

$$\frac{\kappa}{2} F'_{\mu\nu}F^{\mu\nu} + g_\chi A'_\mu \bar{\chi}\gamma^\mu\chi$$

PARAMETERIZING NEW PHYSICS

Determine particle type

Determine Interaction type



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Dark U(1) that mixes with the SM U(1)

PARAMETERIZING NEW PHYSICS

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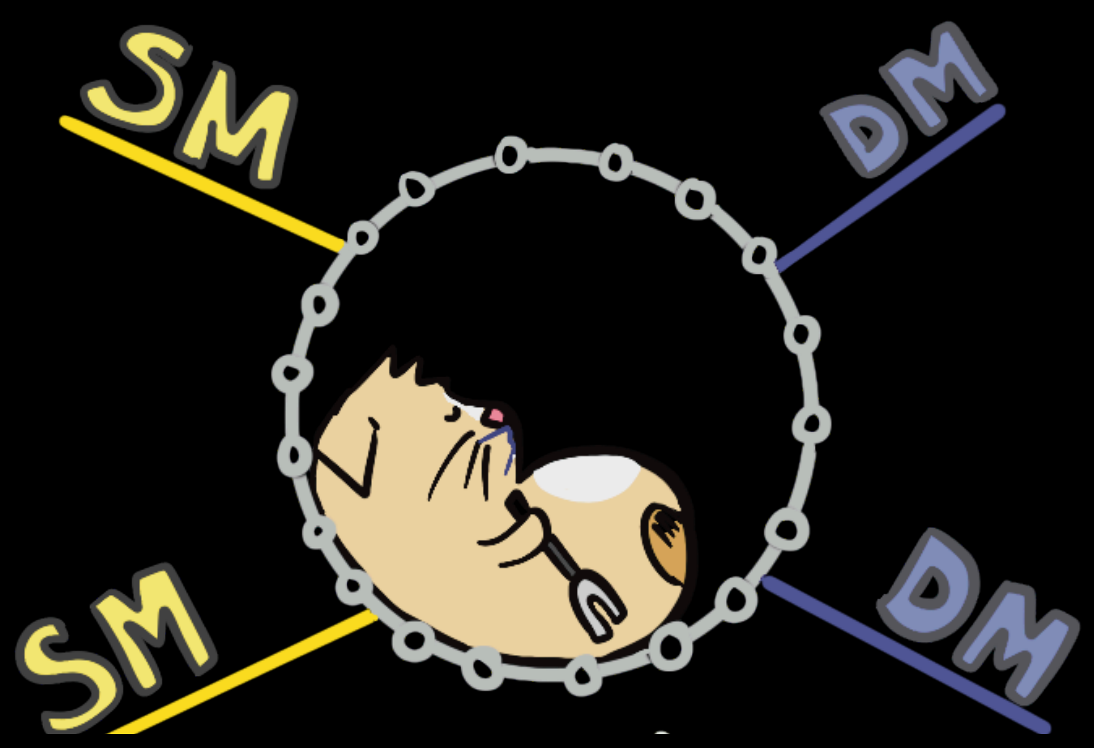

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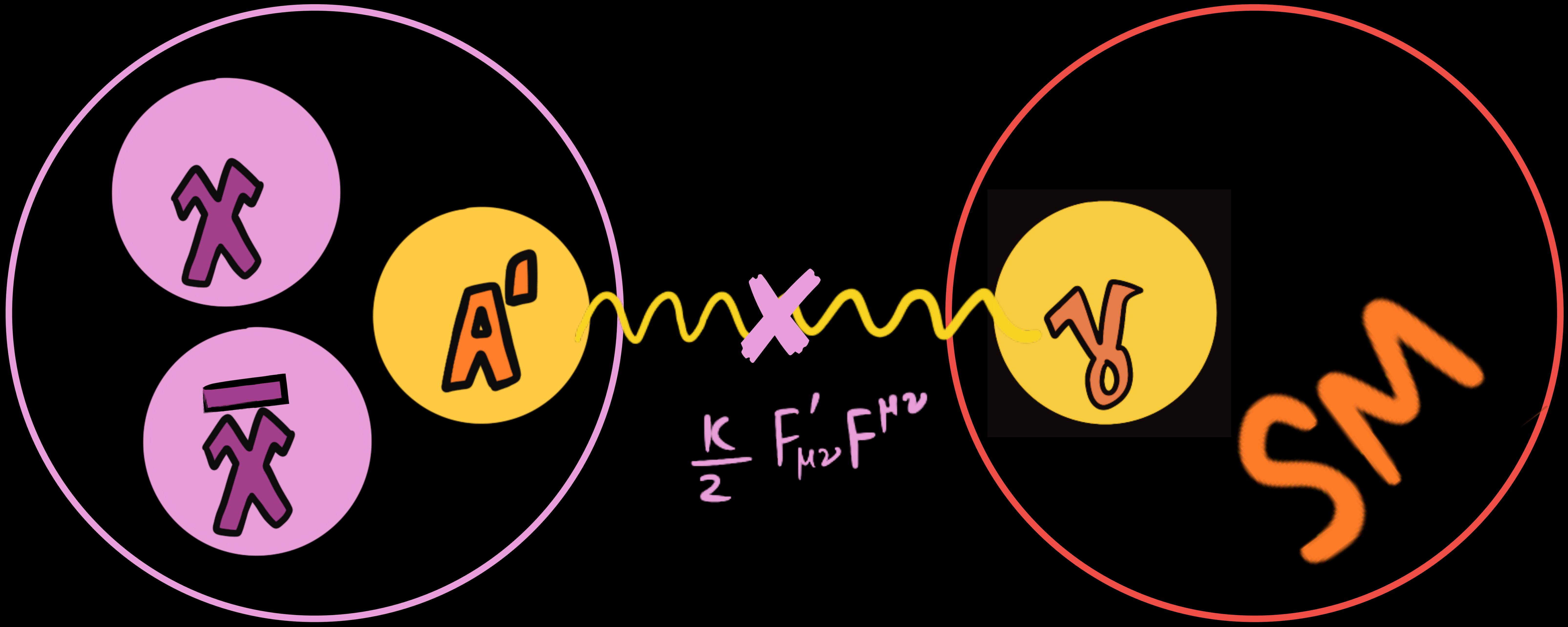
Dark U(1) that mixes with the SM U(1)

Additional particles charged under this U(1)

VECTOR PORTAL

BSM SECTOR

VECTOR PORTAL



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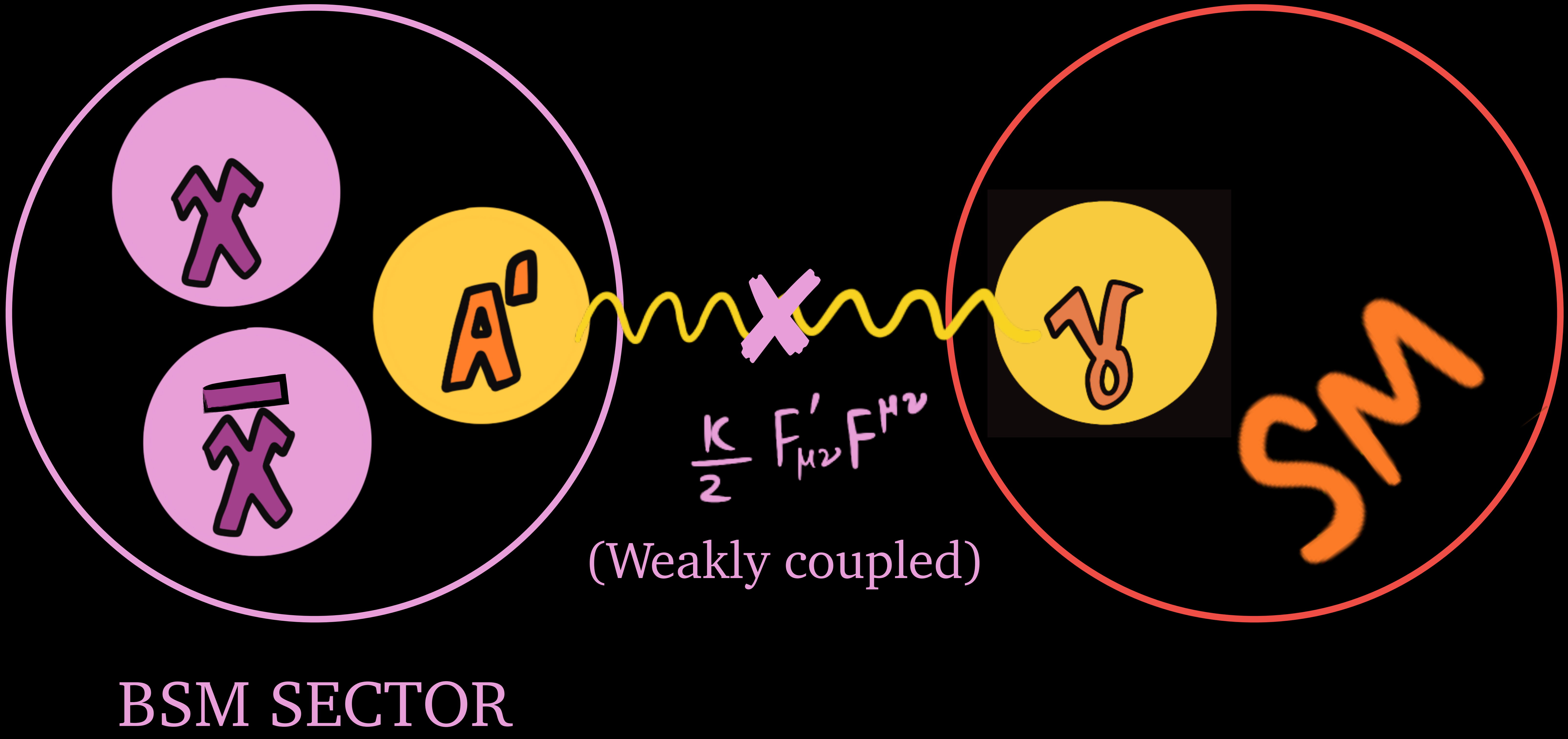
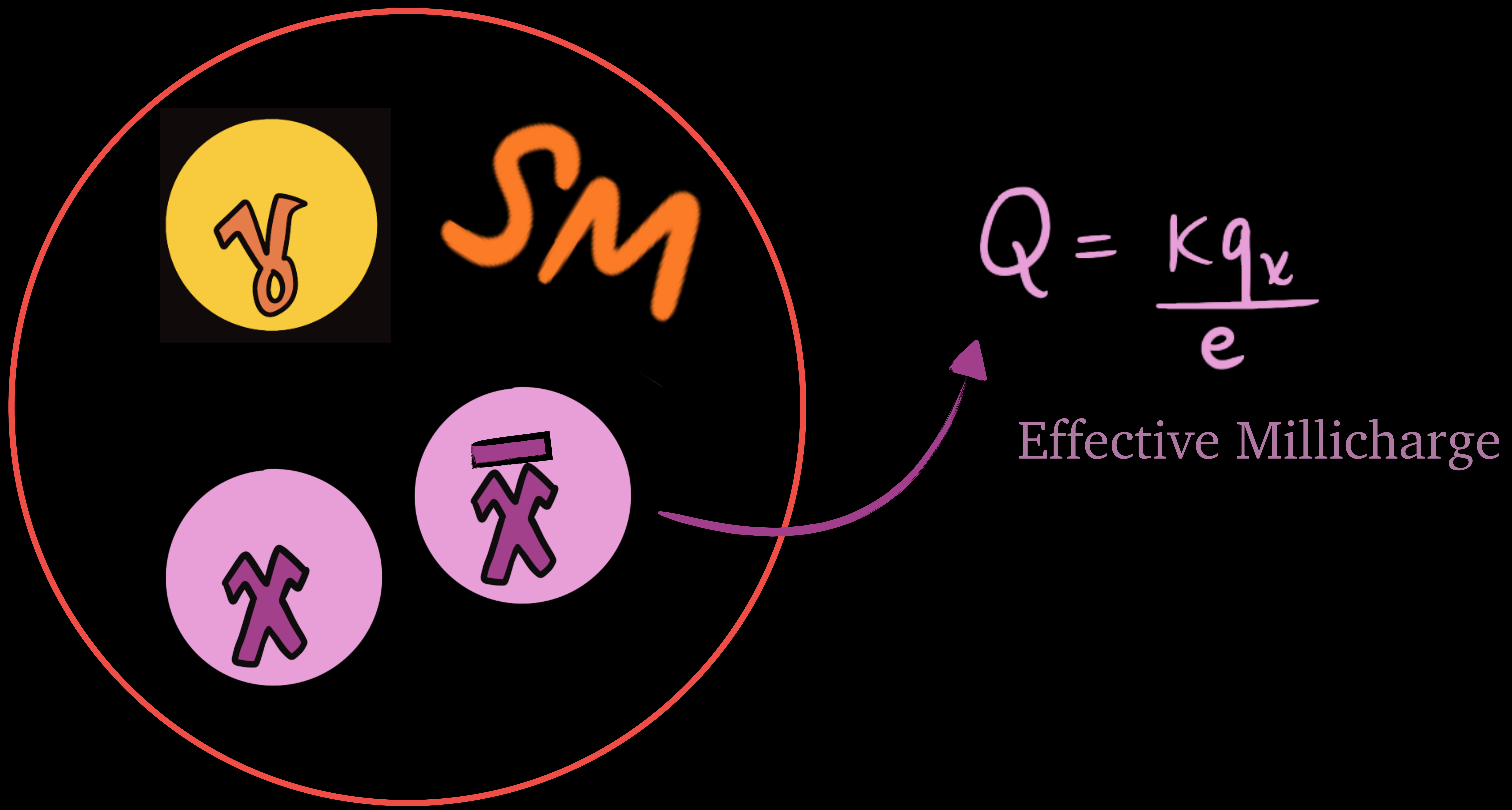


MILLICHARGED* PARTICLE (MCP)

IF THE DARK PHOTON IS LIGHT, FIELD REDEFINITIONS RESULT IN AN EFFECTIVE MILLICHARGE



*nothing milli about millicharged

1. HOW DO MCPS IMPACT **OBSERVABLES**?

2. REGARDLESS OF WHETHER MCPS ARE DARK MATTER, CAN WE USE THE **DARK MATTER EXPERIMENTAL PROGRAM** TO LOOK FOR THEM?

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MCPS IN ASTROPHYSICAL SYSTEMS

LIGHT MCPS CAN BE PRODUCED IN STARS THROUGH PLASMON DECAYS

MCPS IN ASTROPHYSICAL SYSTEMS

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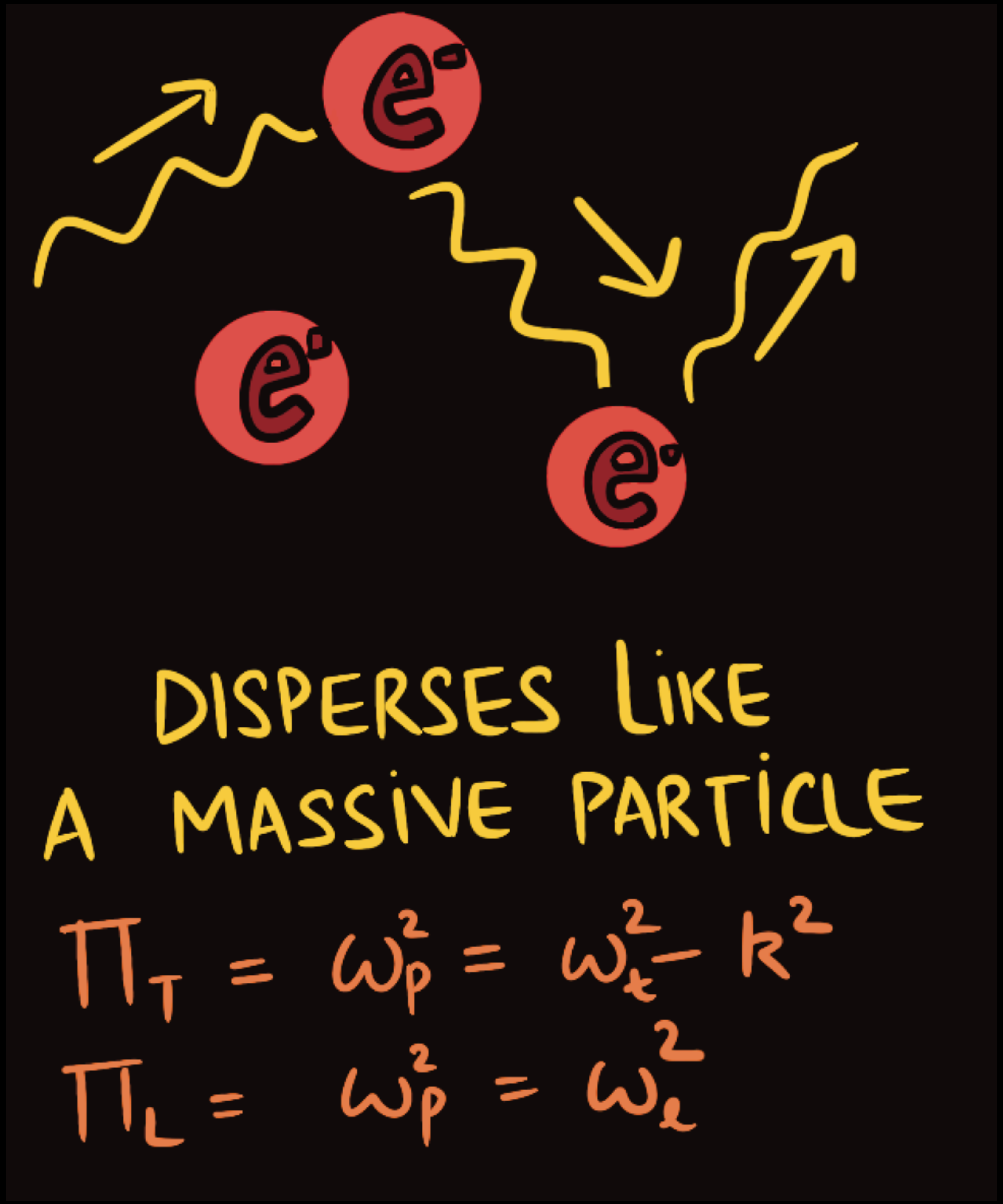

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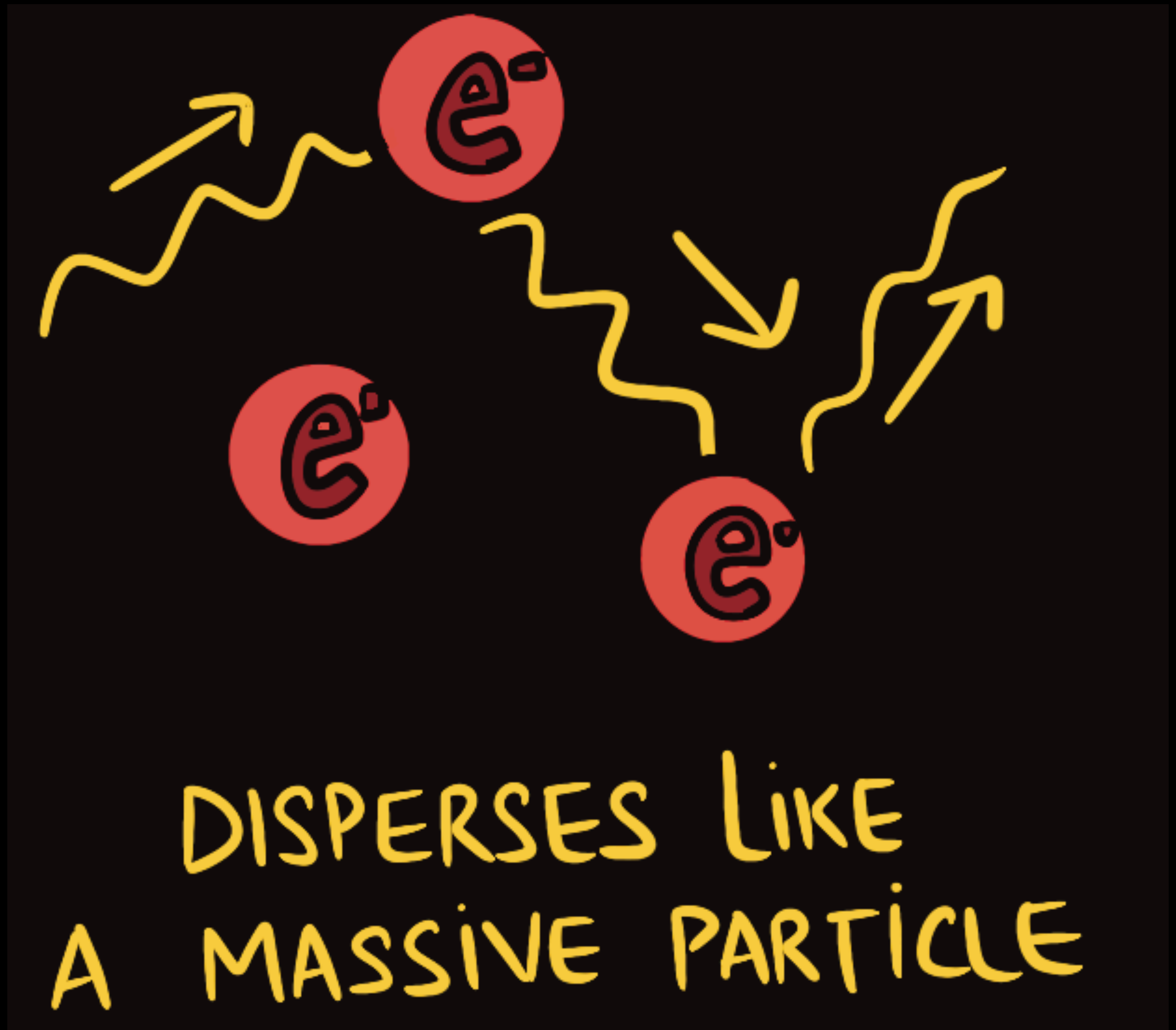
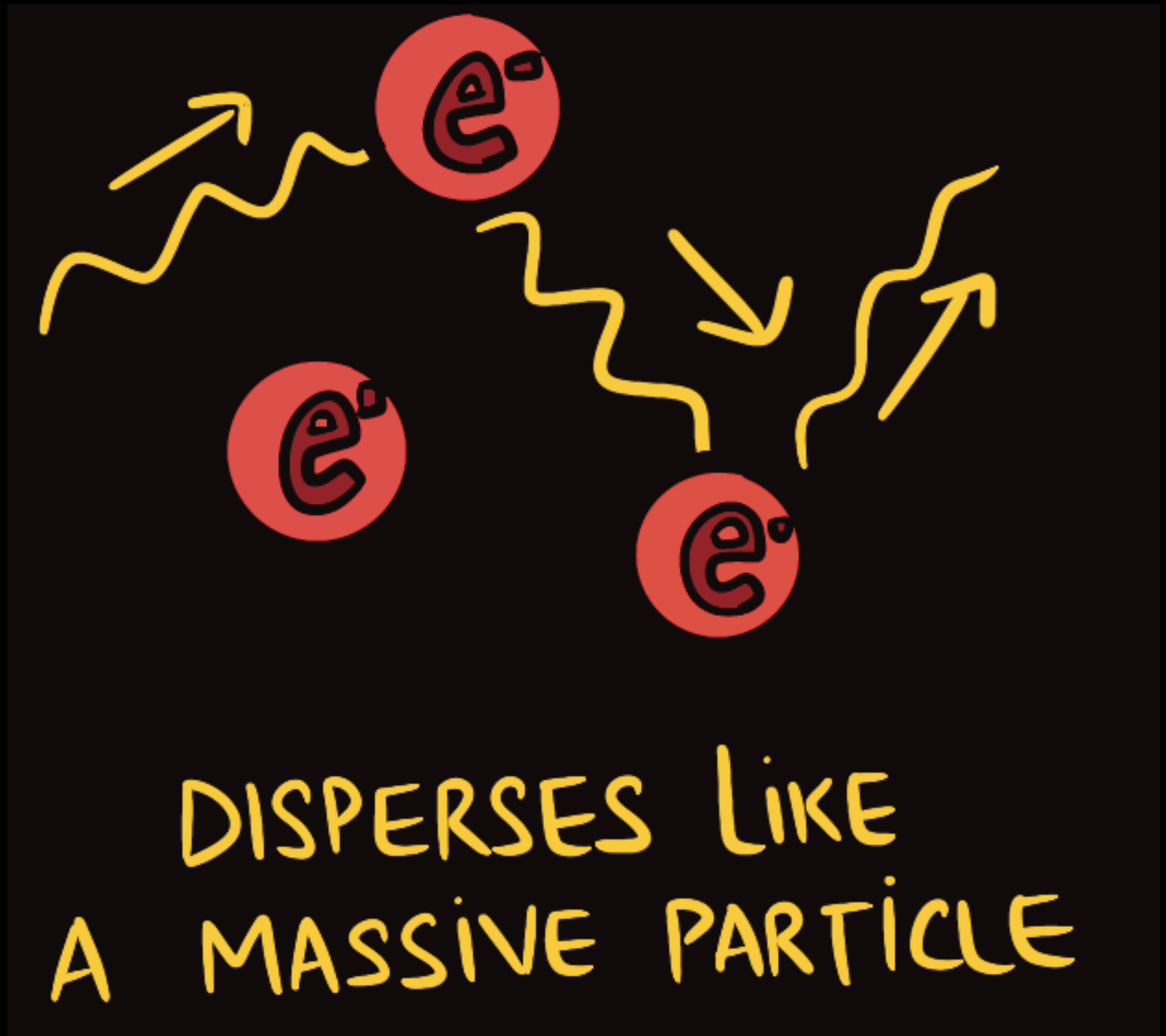


$$m^2_{\gamma,\mathrm{eff}} \sim \frac{\alpha n_e}{m_e}$$

MCPS IN ASTROPHYSICAL SYSTEMS



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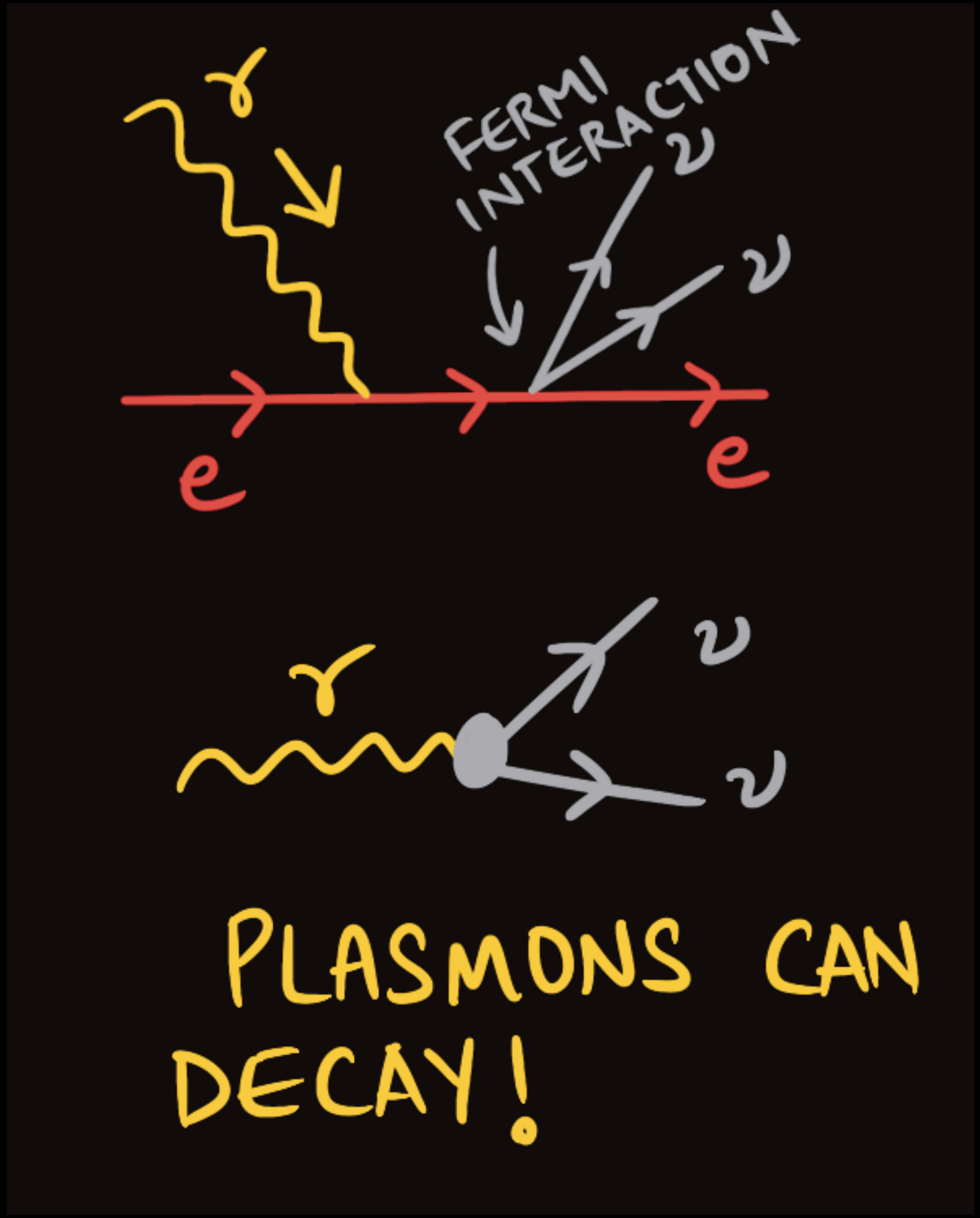
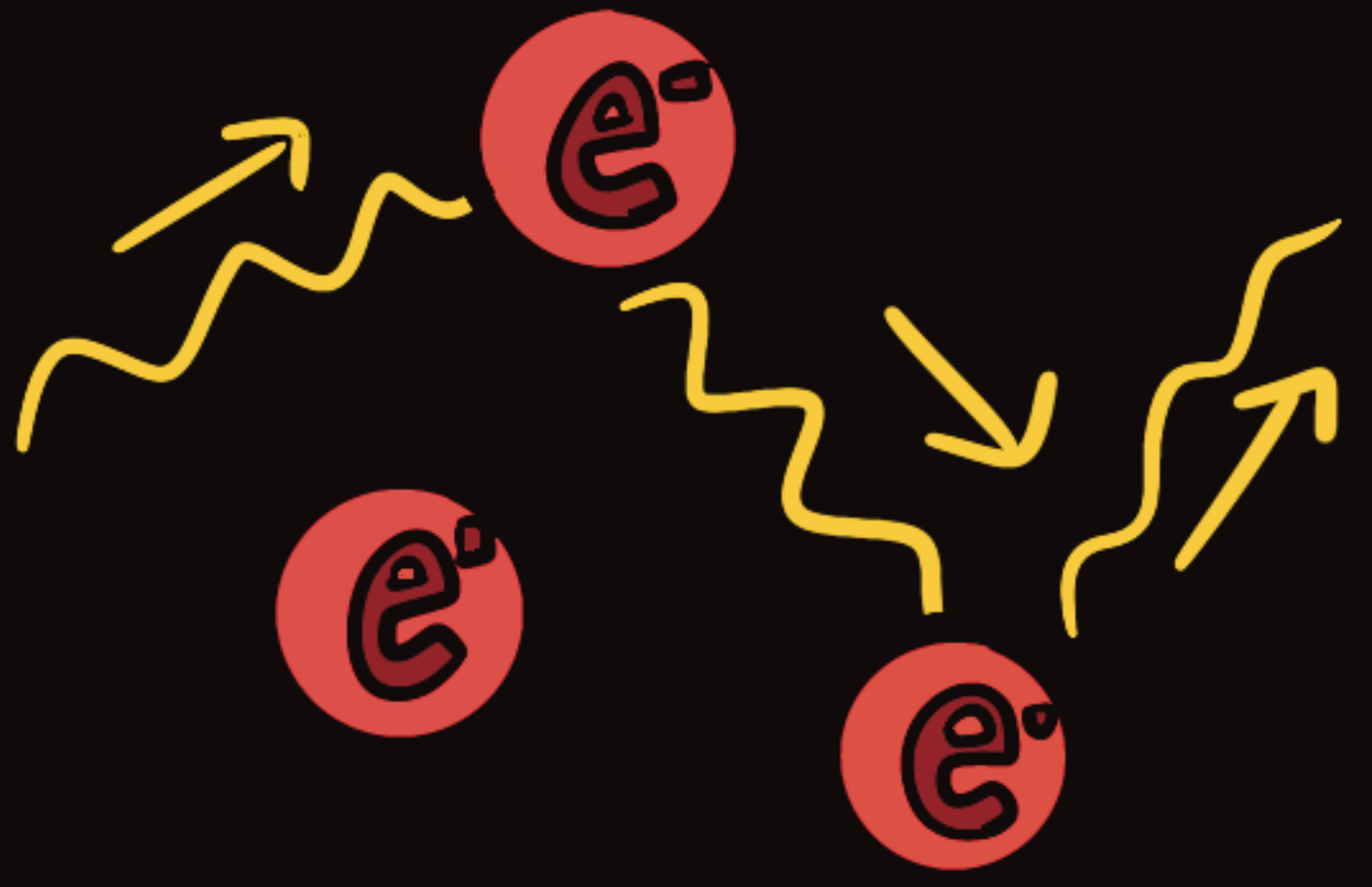


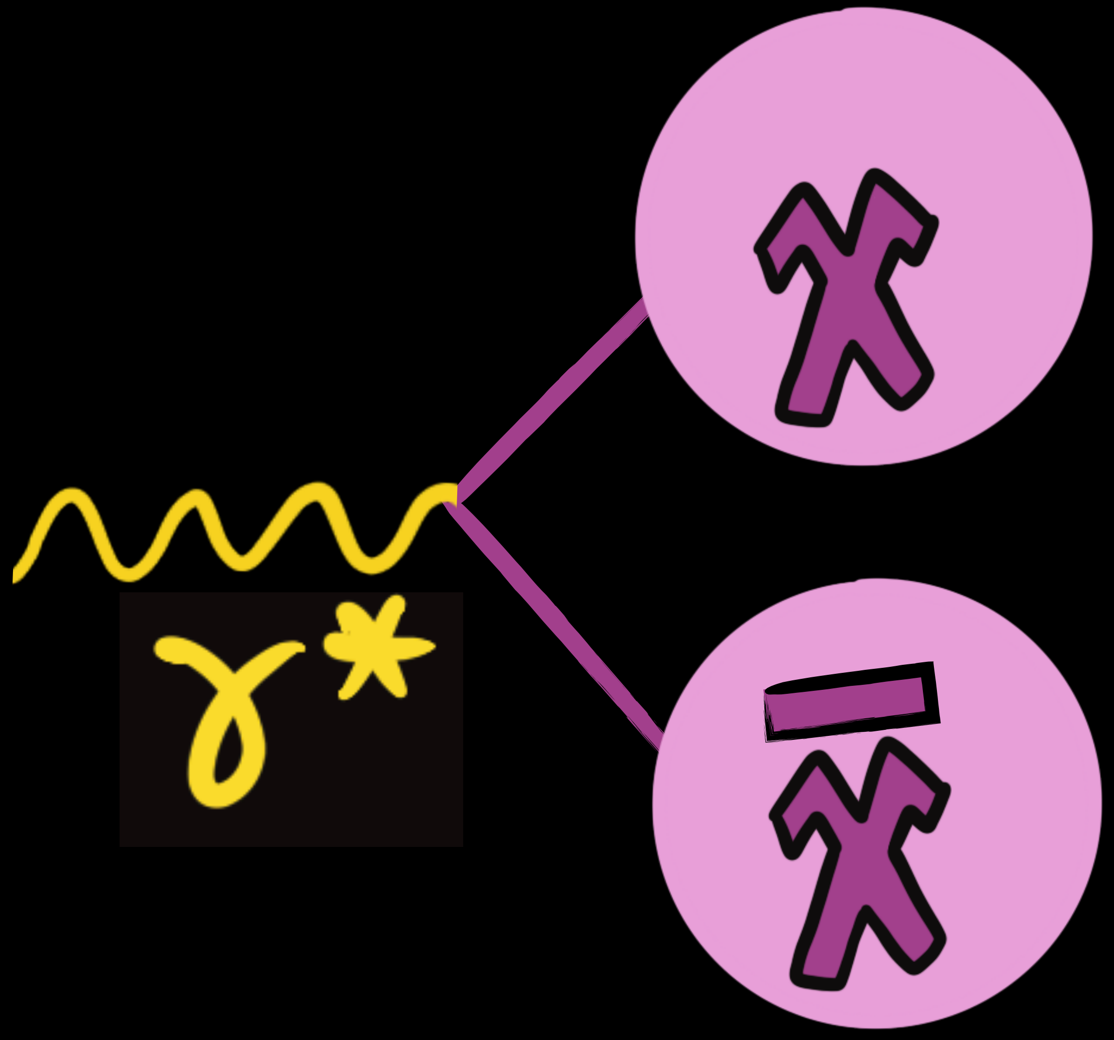
MCPS IN ASTROPHYSICAL SYSTEMS

$\mathcal{L} \supset eQA^{\mu}\bar{\chi}\gamma_{\mu}\chi$

$m_{\gamma}^{vac} = 0$



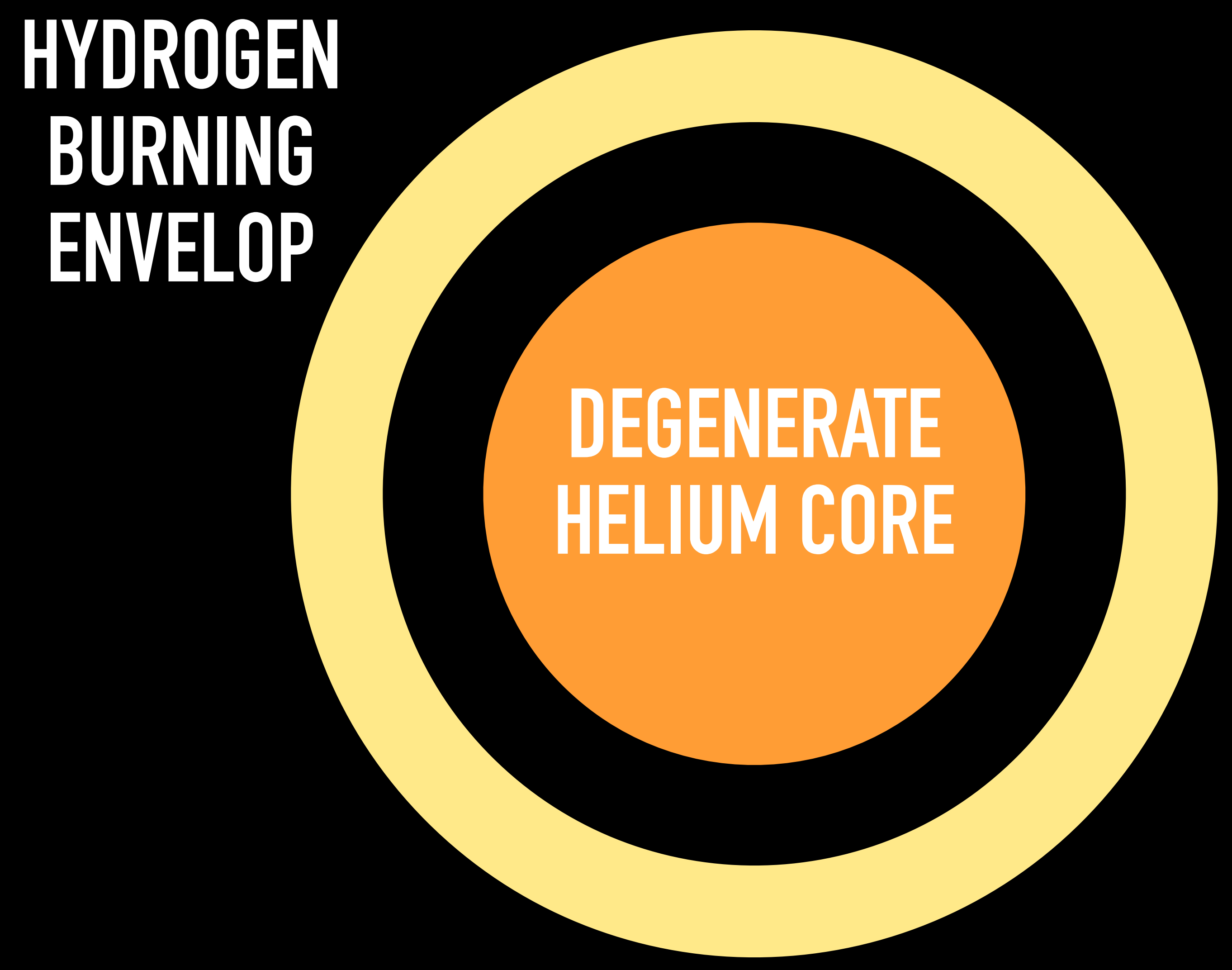
DISPERSES LIKE A MASSIVE PARTICLE



PLASMONS CAN DECAY!

MCPS IN ASTROPHYSICAL SYSTEMS

PLASMON DECAYS CHANGE STELLAR PROPERTIES!



RED GIANT BRANCH

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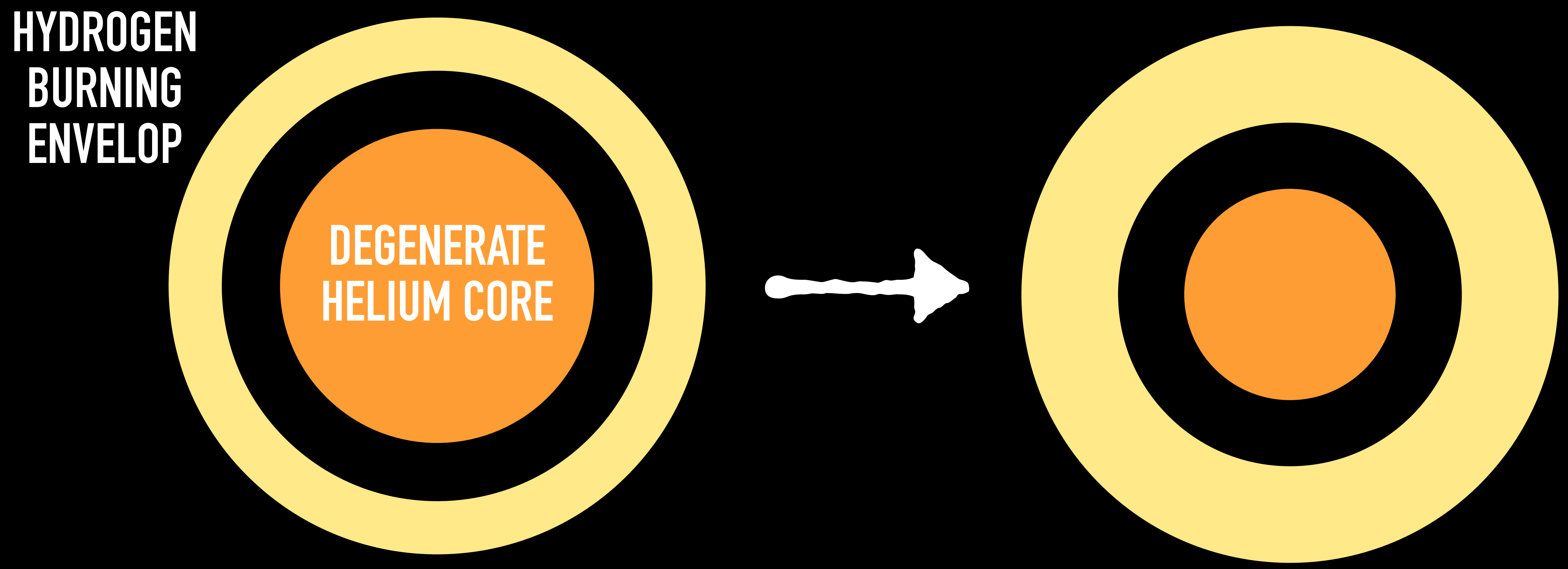

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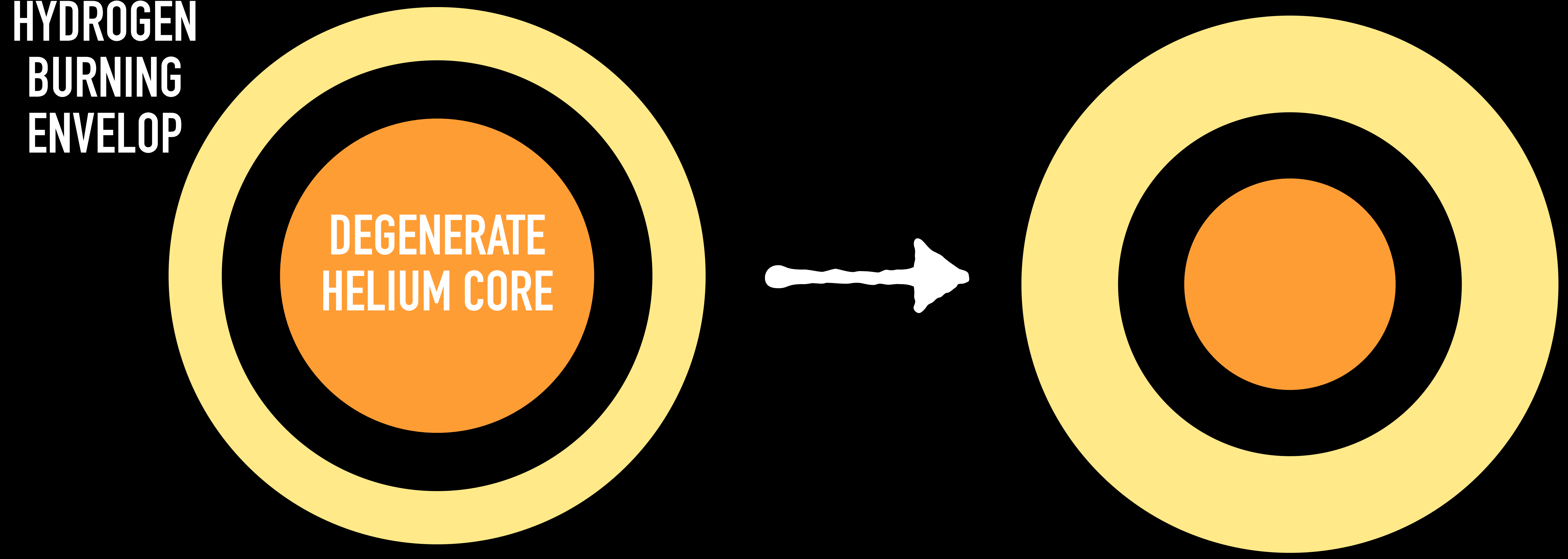

STAR BECOMES
BRIGHTER AND REDDER

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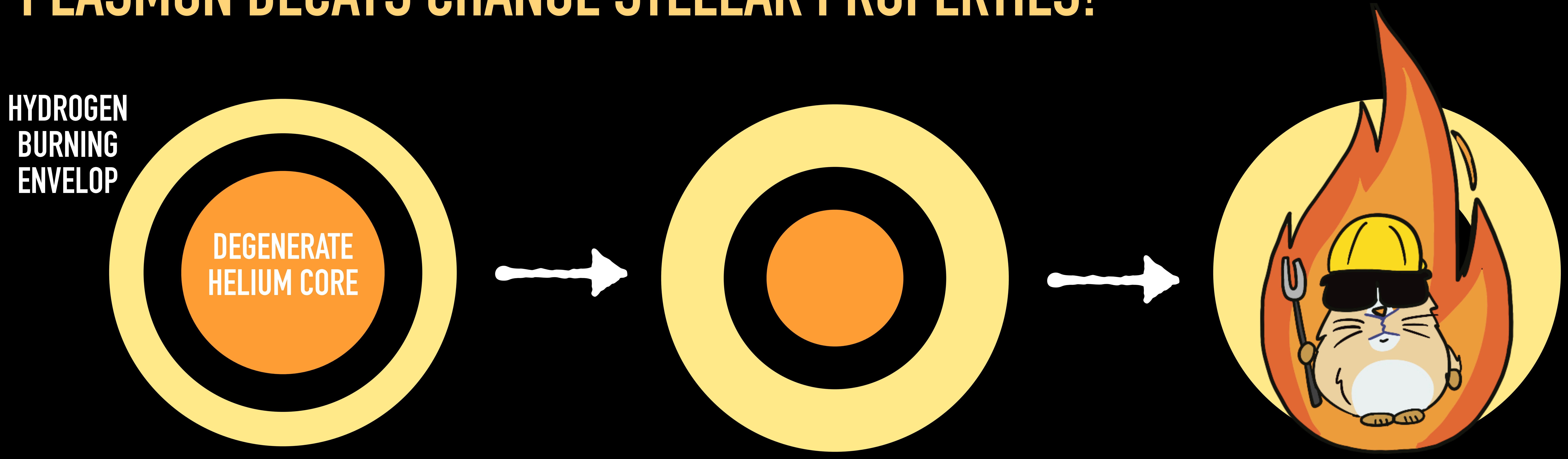


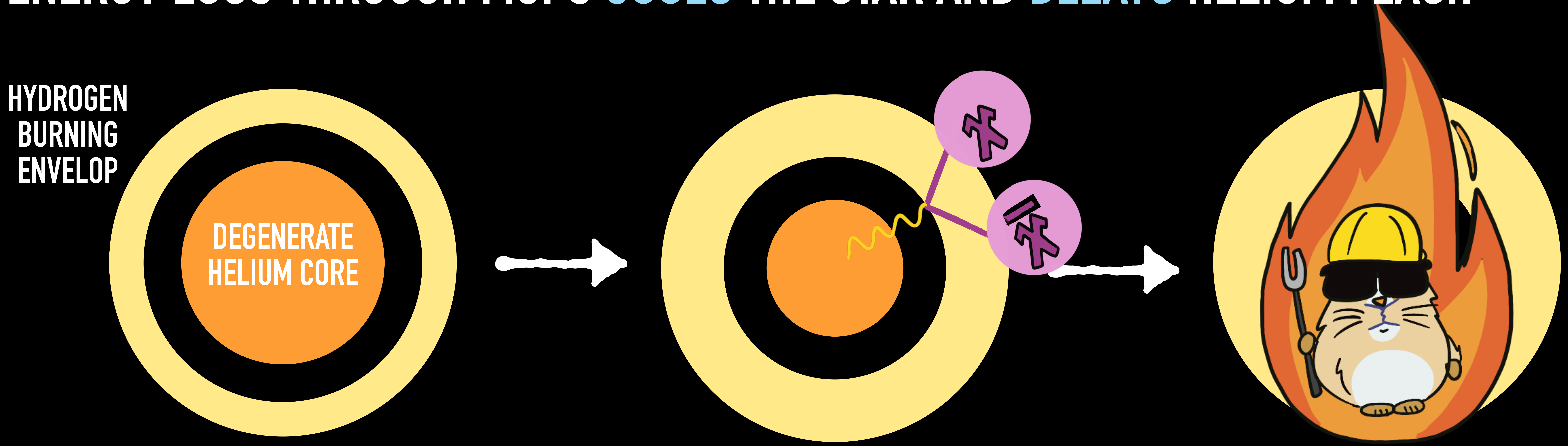
STAR BECOMES BRIGHTER AND REDDER

HELIUM FLASH
(TIP OF THE RED GIANT BRANCH)

RED GIANT BRANCH

MCPS IN ASTROPHYSICAL SYSTEMS

ENERGY LOSS THROUGH MCPS COOLS THE STAR AND DELAYS HELIUM FLASH



STAR BECOMES BRIGHTER AND REDDER

HELIUM FLASH
(TIP OF THE RED GIANT BRANCH IS BRIGHTER!)

RED GIANT BRANCH

MCPS IN ASTROPHYSICAL SYSTEMS

PLASMON DECAYS ARE AN EFFICIENT MECHANISM OF ENERGY LOSS IN STARS!

Fung, SH, Schutz et al (2023)

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INCREASE THE BRIGHTNESS OF THE TRGB!

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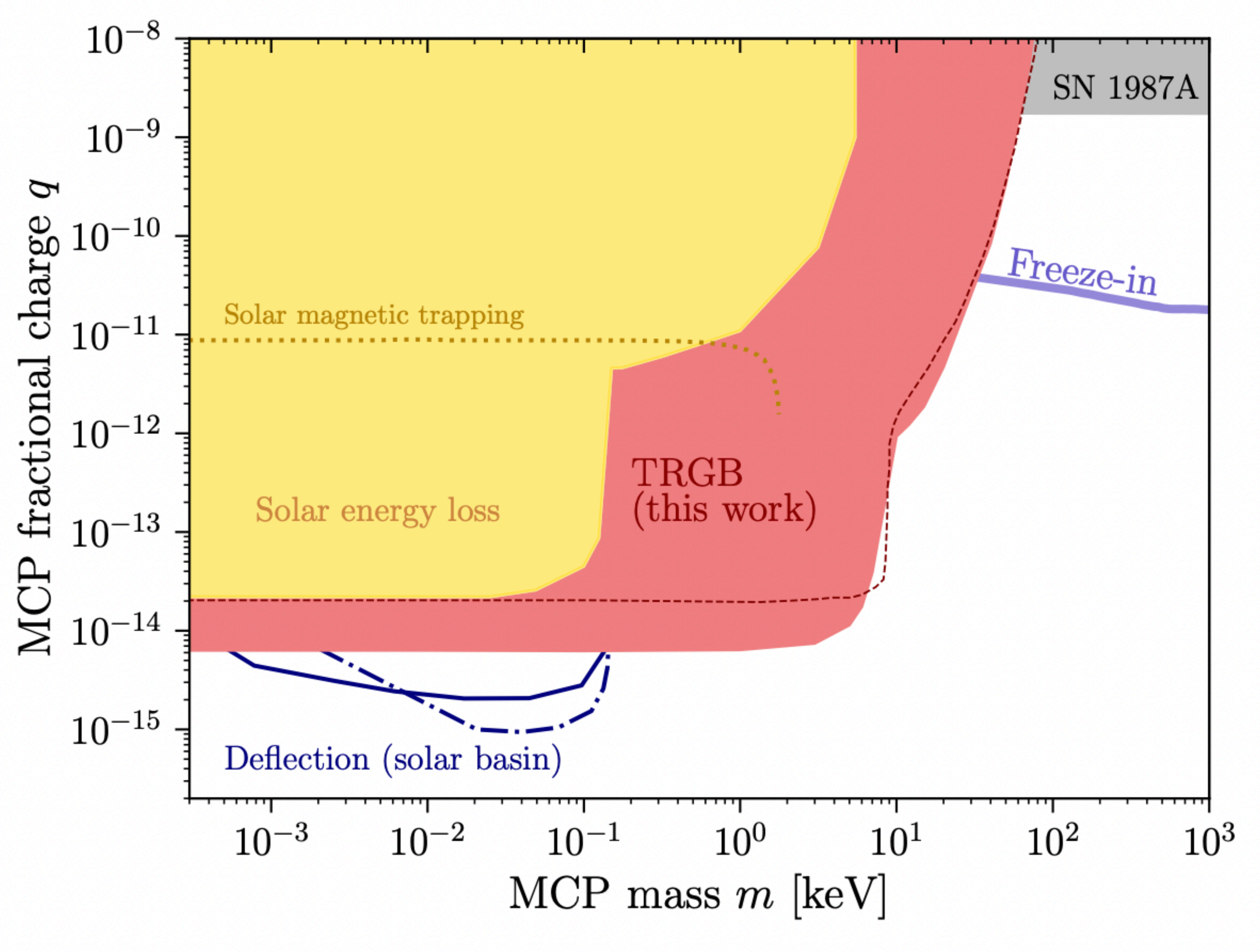
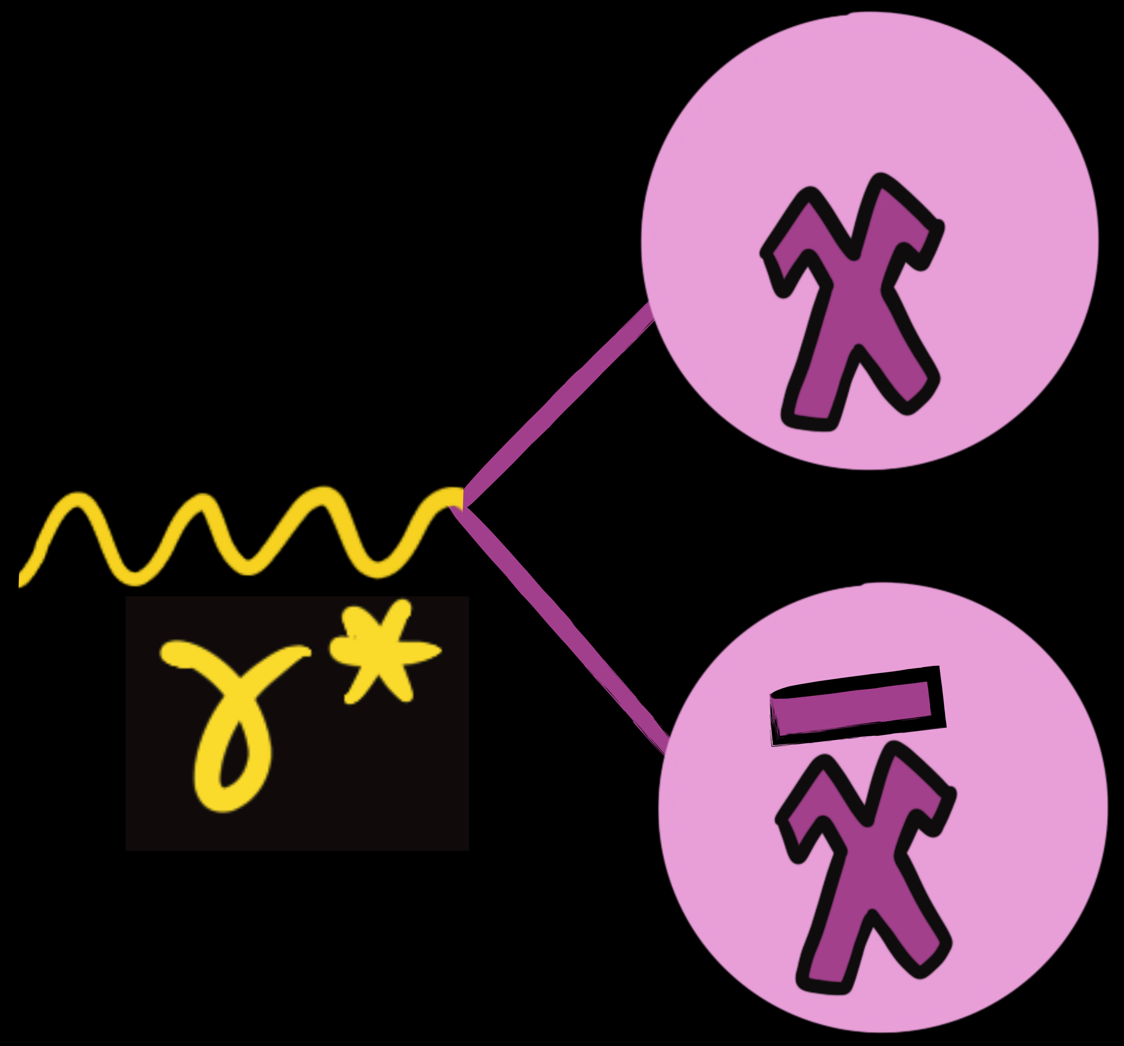


Fung, SH, Schutz et al (2023)

MUCH LIKE STARS TODAY, THE EARLY UNIVERSE WAS ALSO A HOT MESS...

MCPS WILL BE PRODUCED IN THE EARLY UNIVERSE THROUGH FREEZE-IN

FREEZE-IN ABUNDANCE THROUGH PLASMON DECAYS



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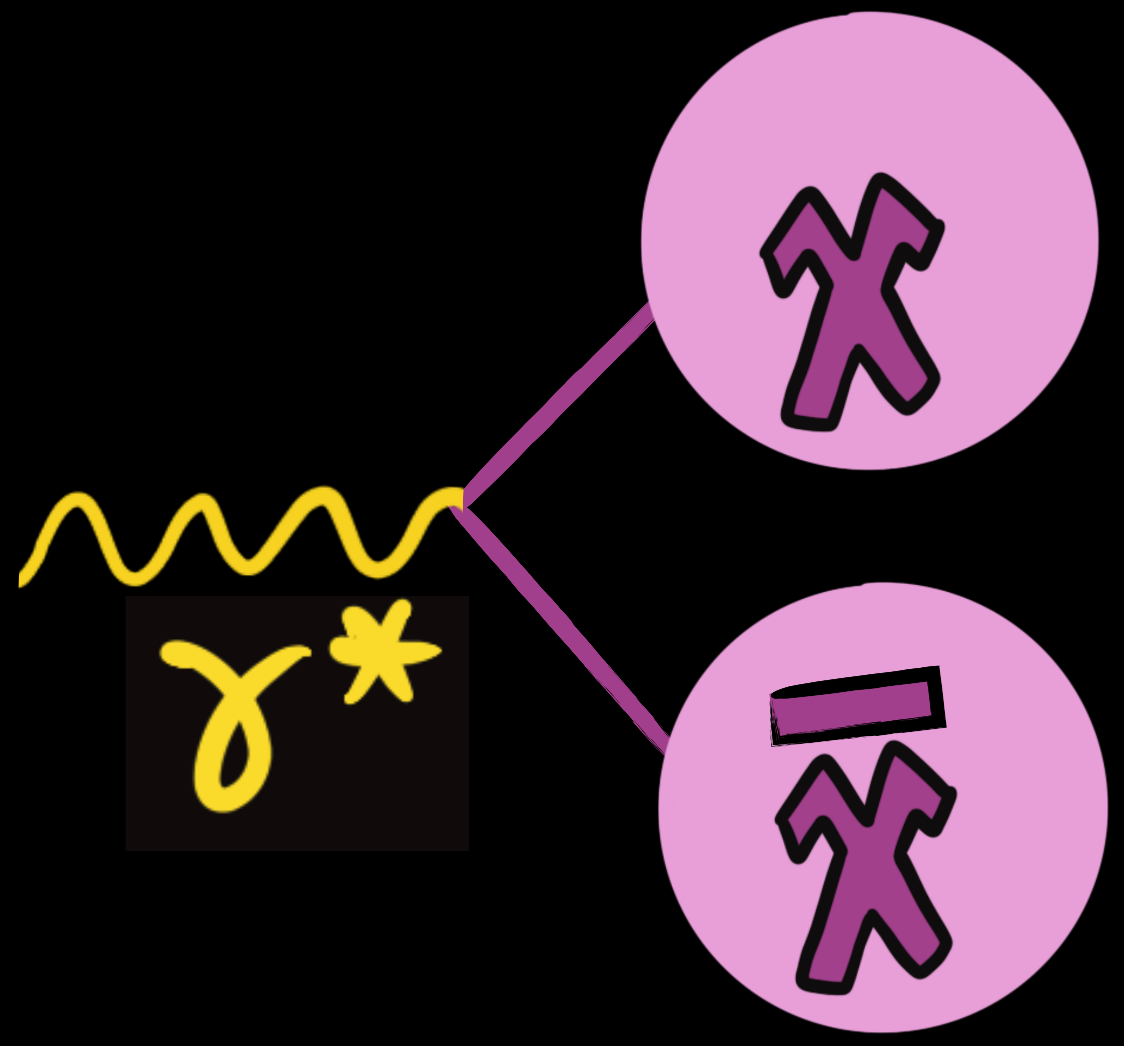

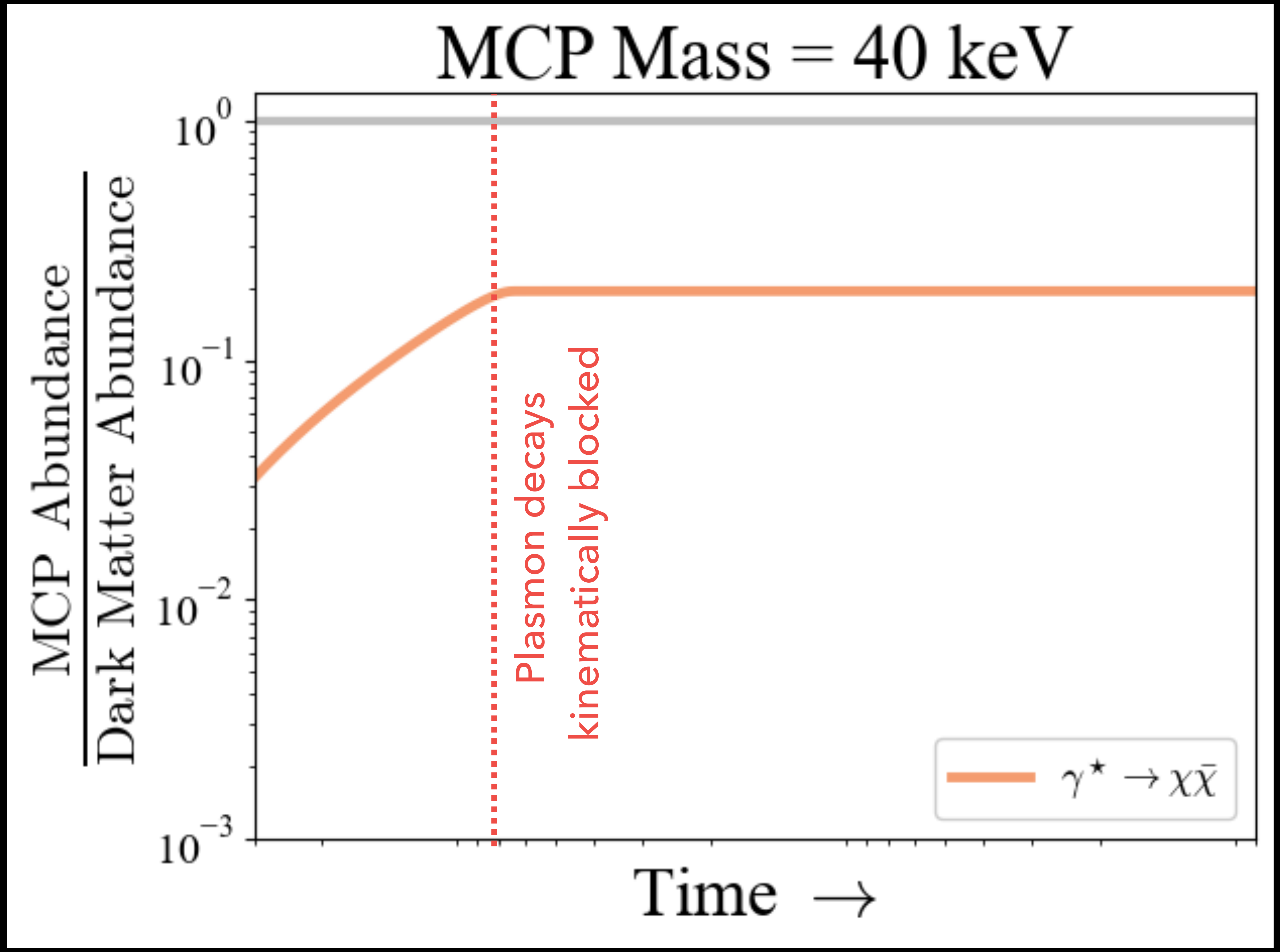

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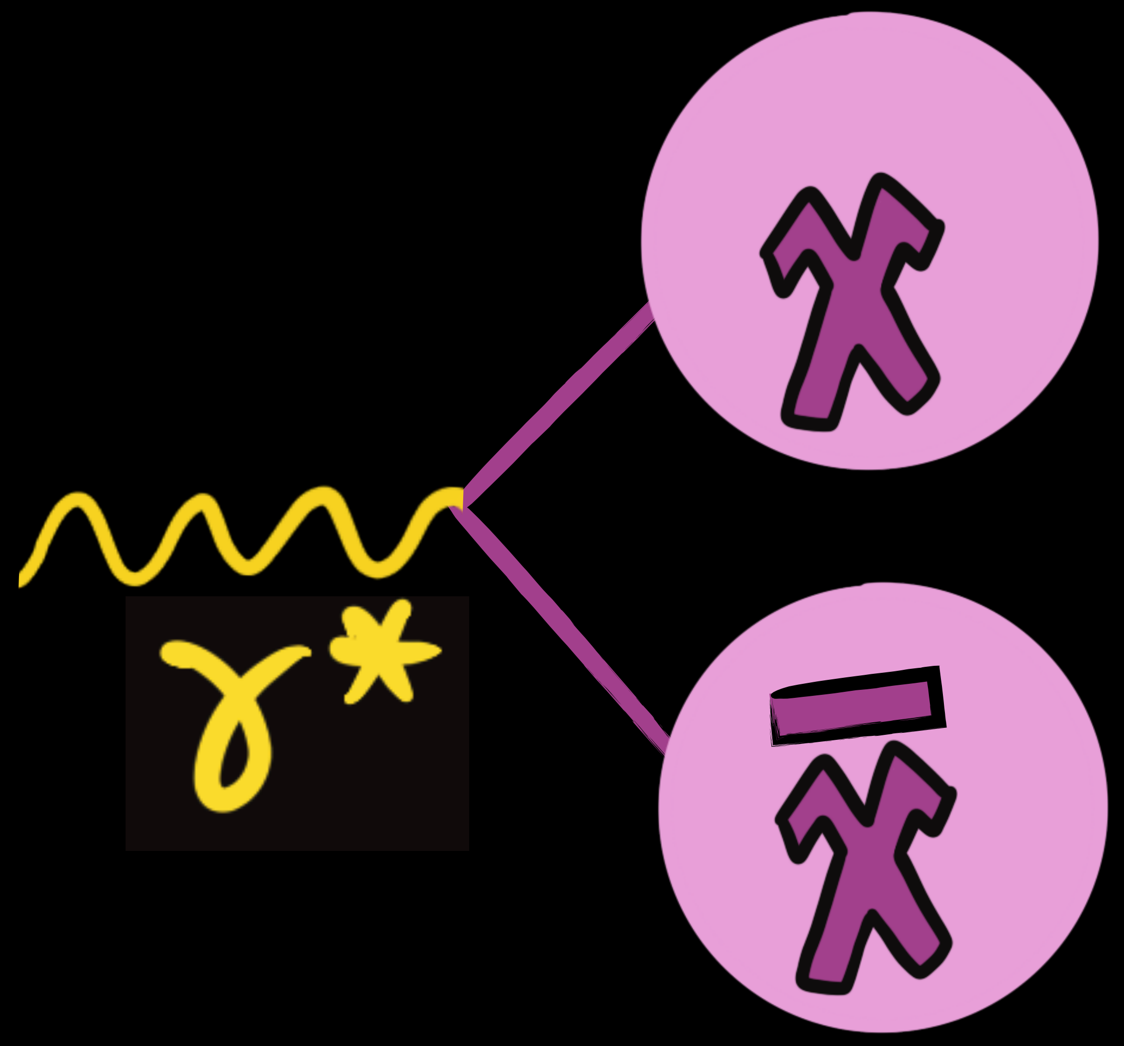

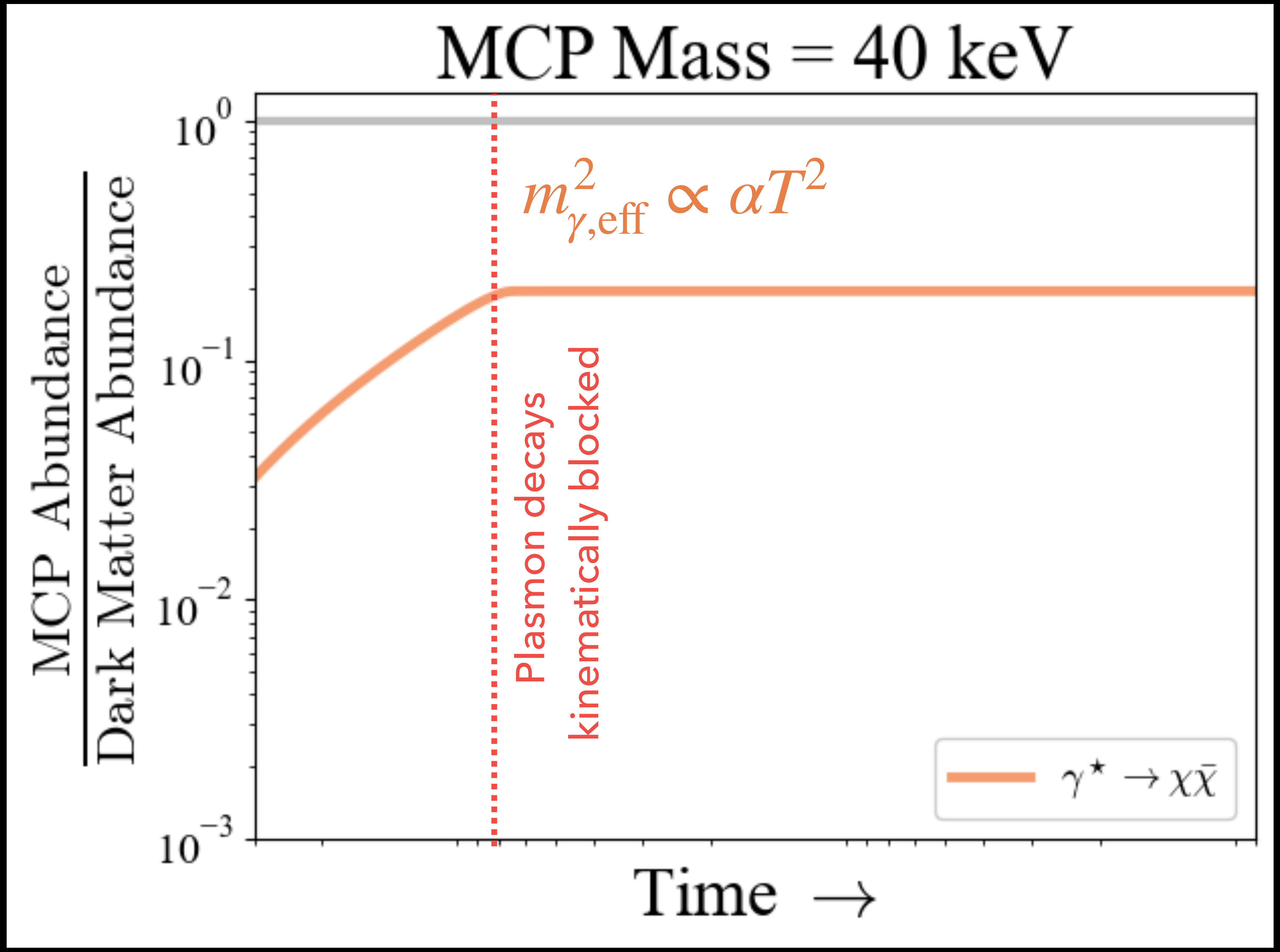

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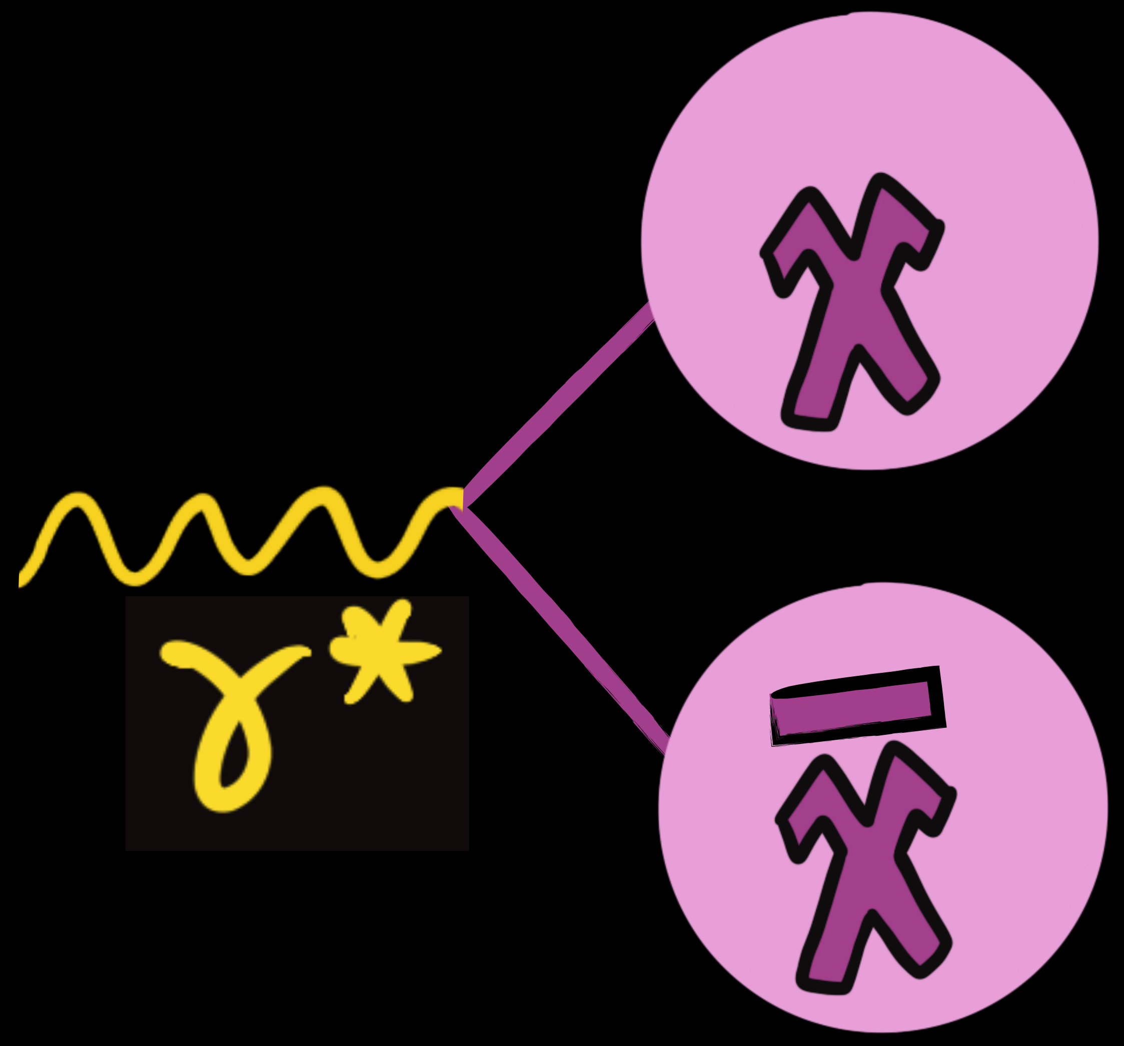
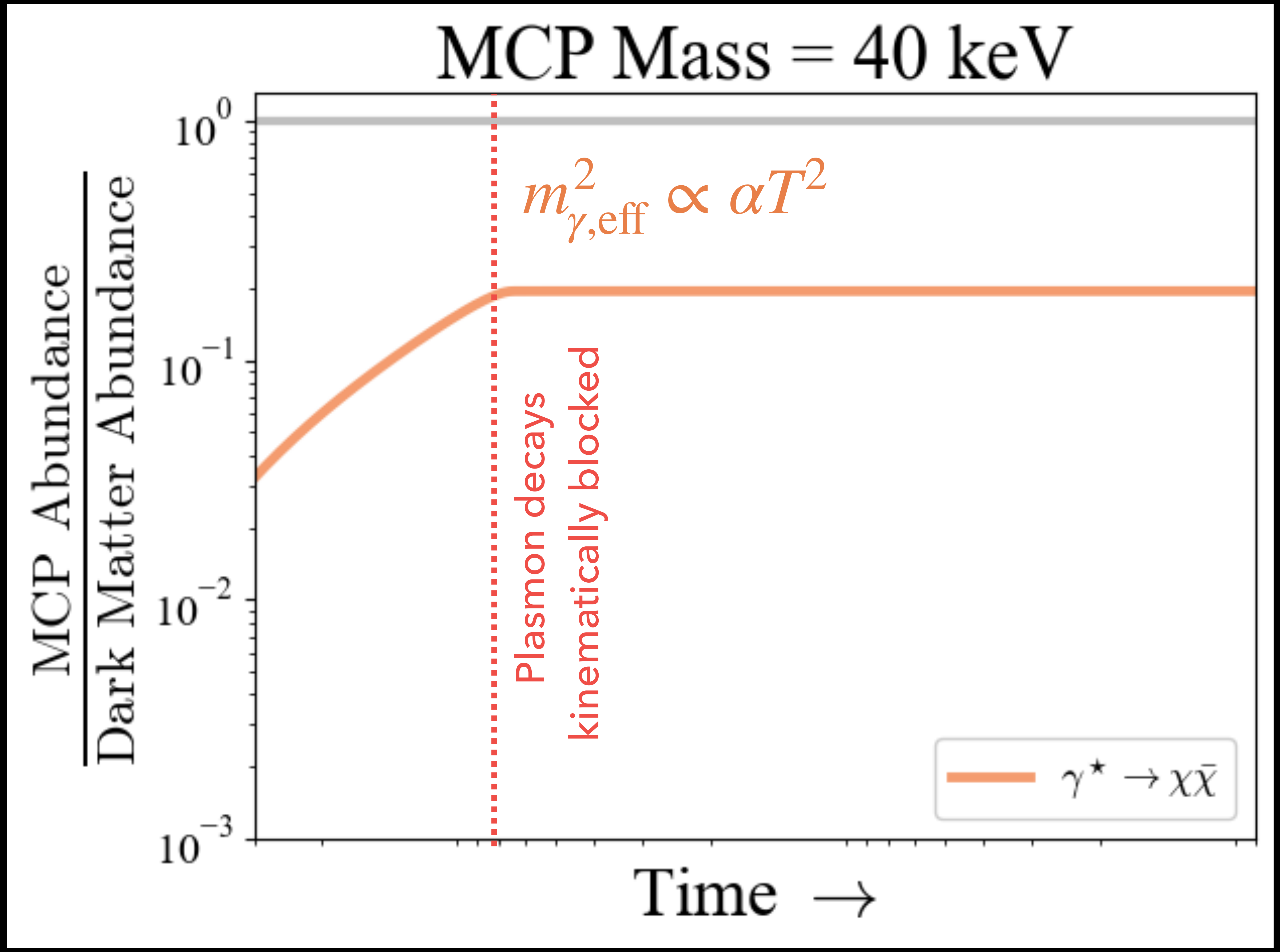


$$Y_\chi^{\gamma^*} = 2\times 10^{-10}\left(\frac{Q}{10^{-12}}\right)^2\left(\frac{1\ \mathrm{MeV}}{m_\chi}\right) \quad \text{if } m_\chi \gtrsim 10\ \mathrm{keV}$$

Decays stop when plasma frequency is smaller than the MCP mass



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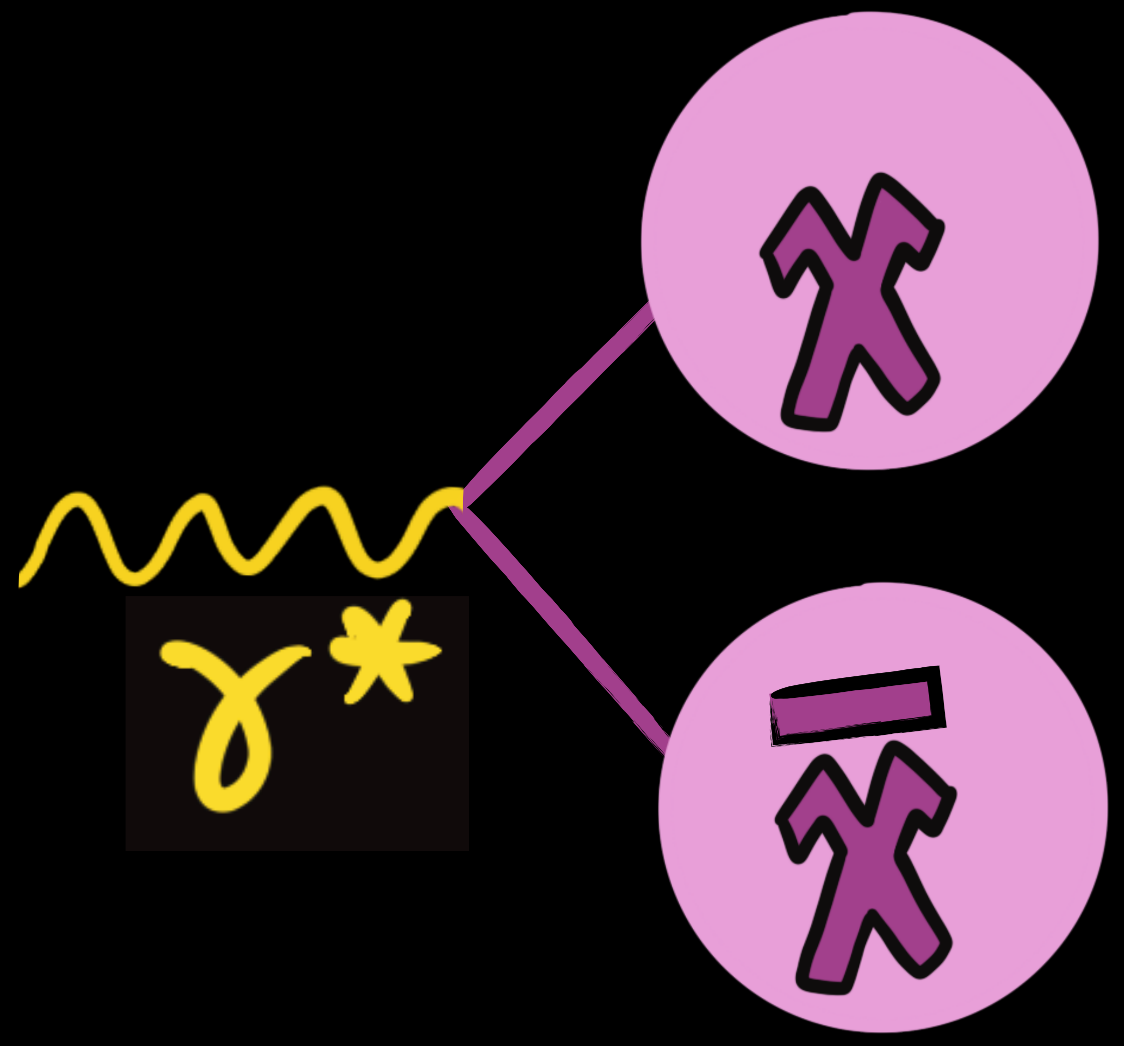
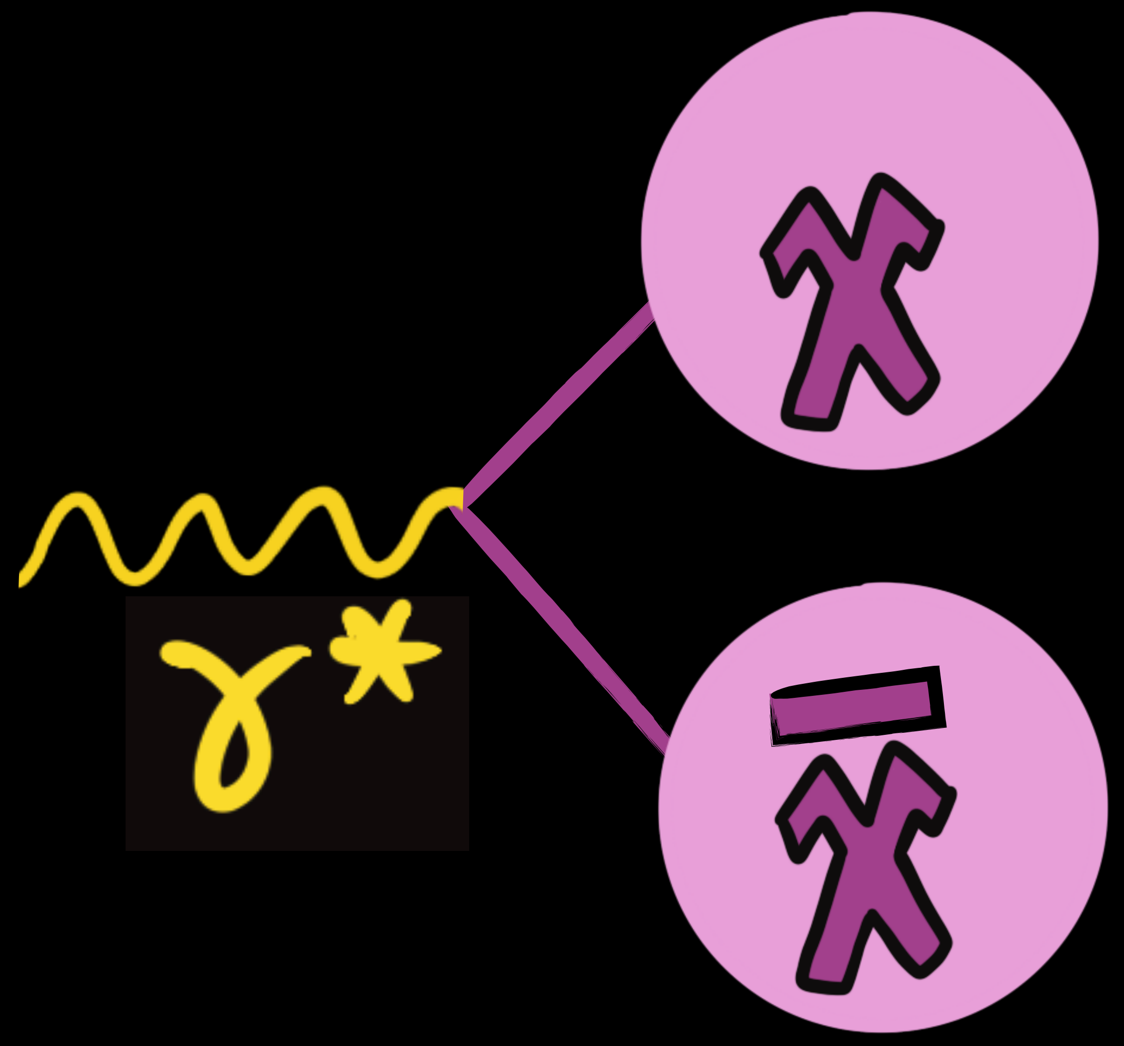


$$Y_\chi^{\gamma^*} = 3 \times 10^{-8} \left(\frac{Q}{10^{-12}} \right)^2 \quad \text{if } m_\chi \lesssim 10 \text{ keV}$$

FREEZE-IN ABUNDANCE THROUGH PLASMON DECAYS



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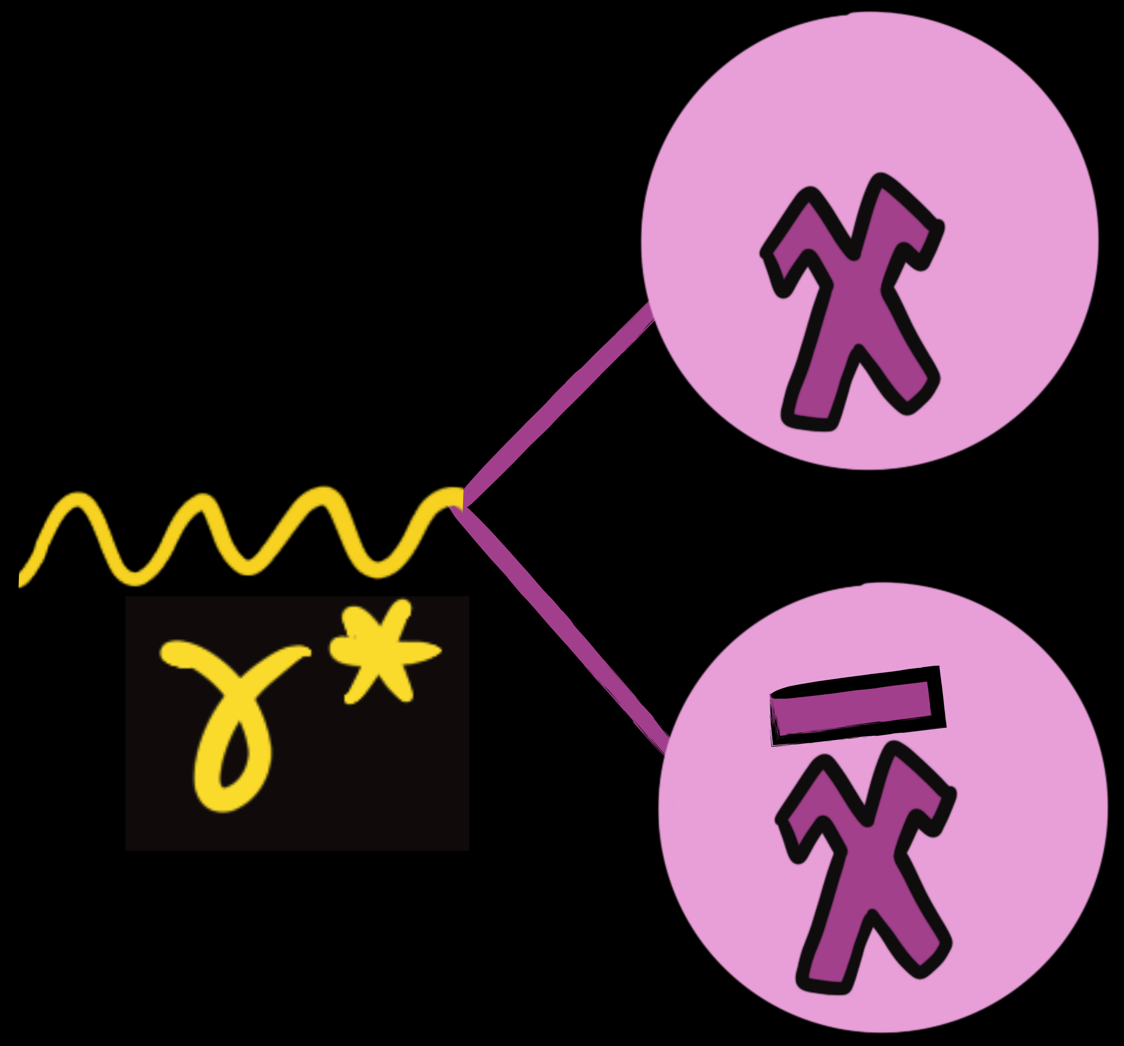

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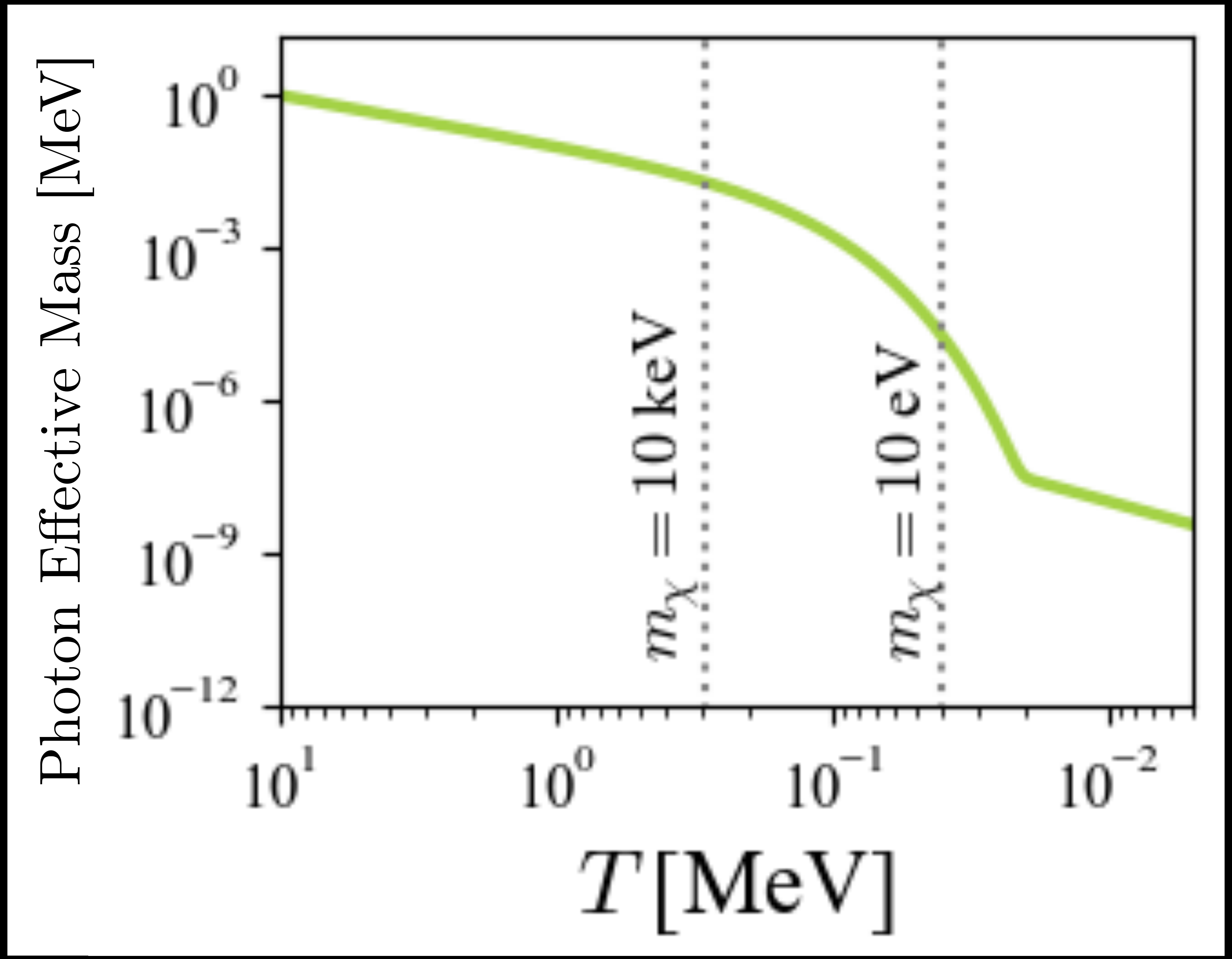
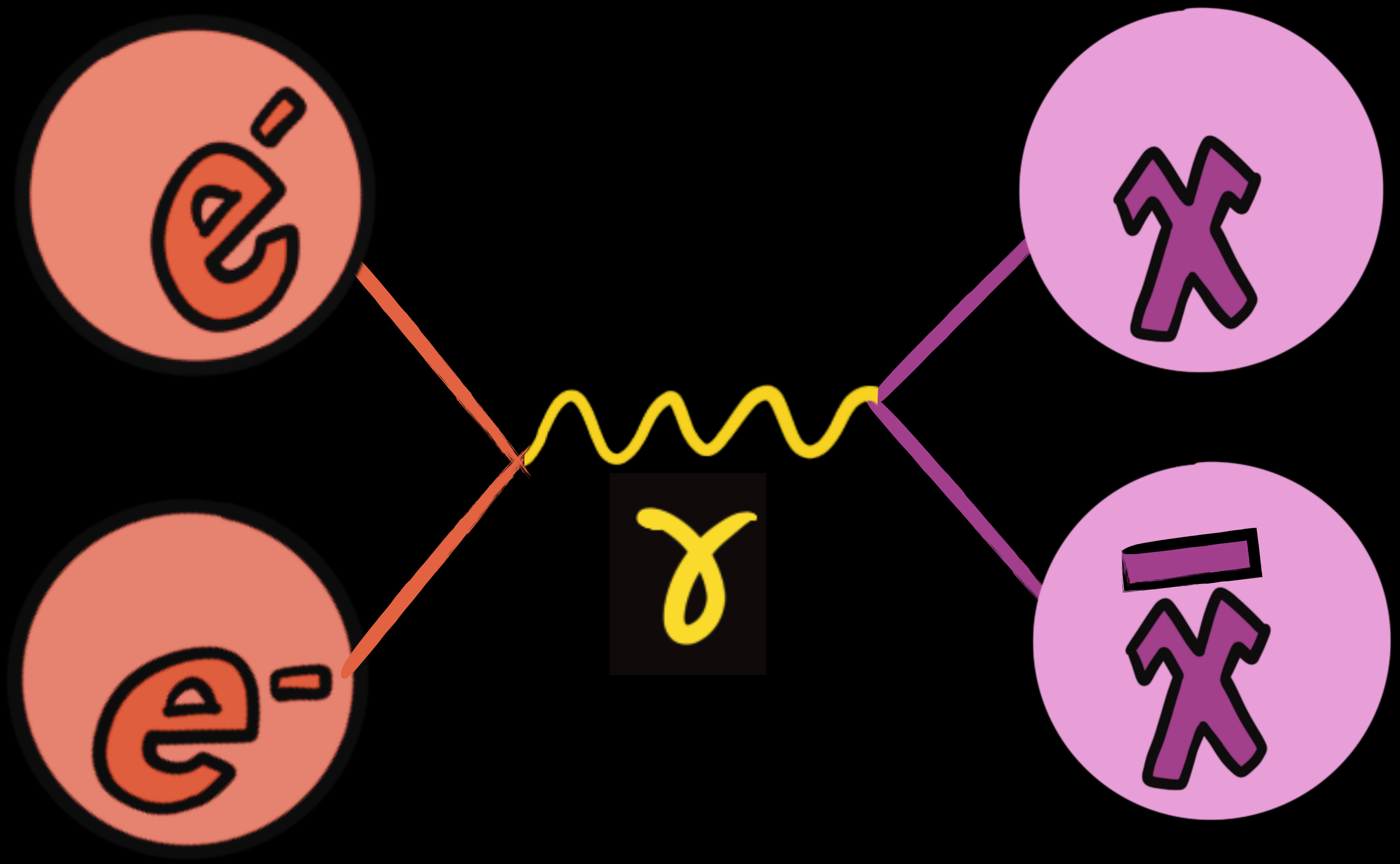


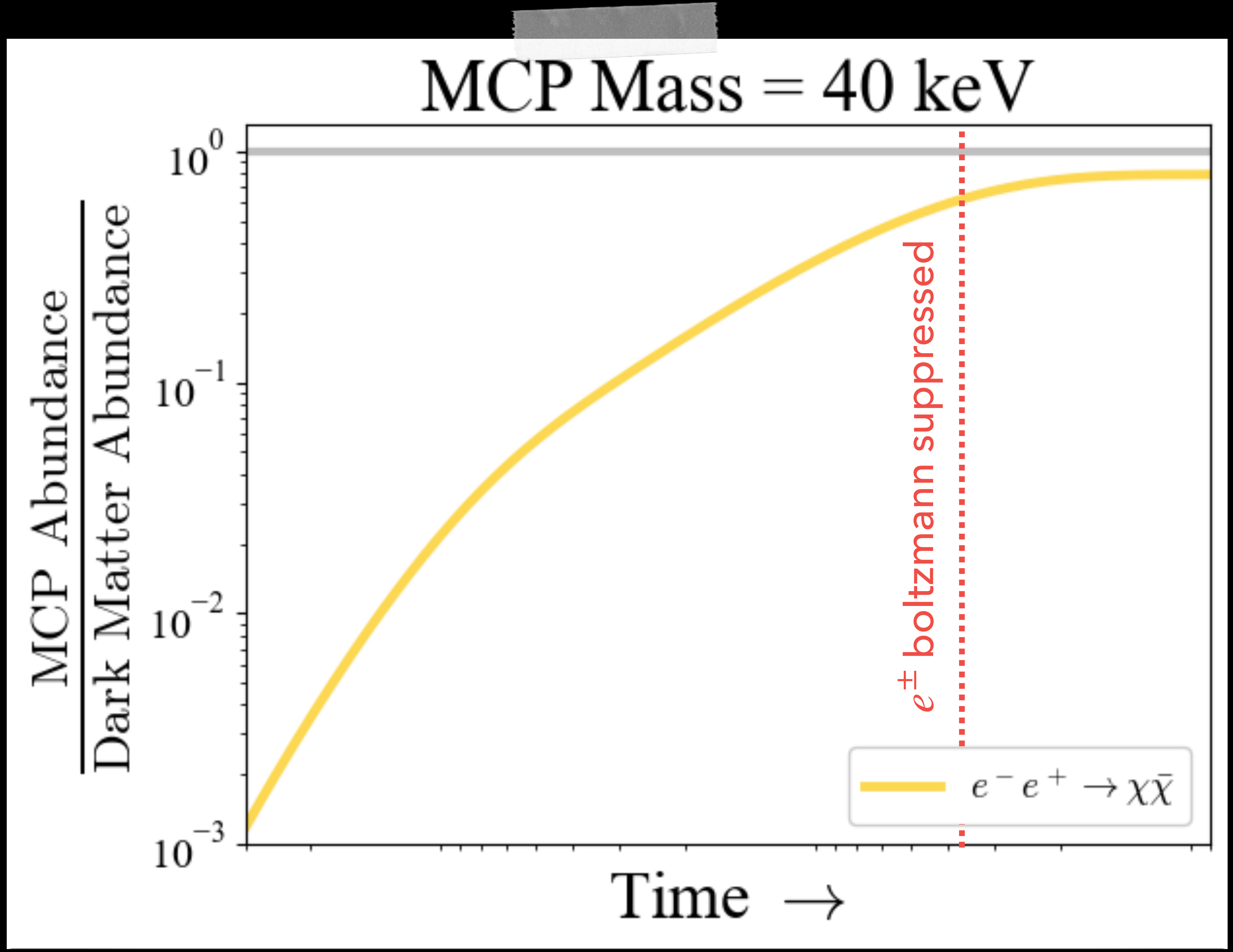
If MCPs are very light, electron freeze-out quenches the production!

$$m_{\gamma,\text{eff}}^2 \sim \frac{\alpha n_e}{m_e}$$

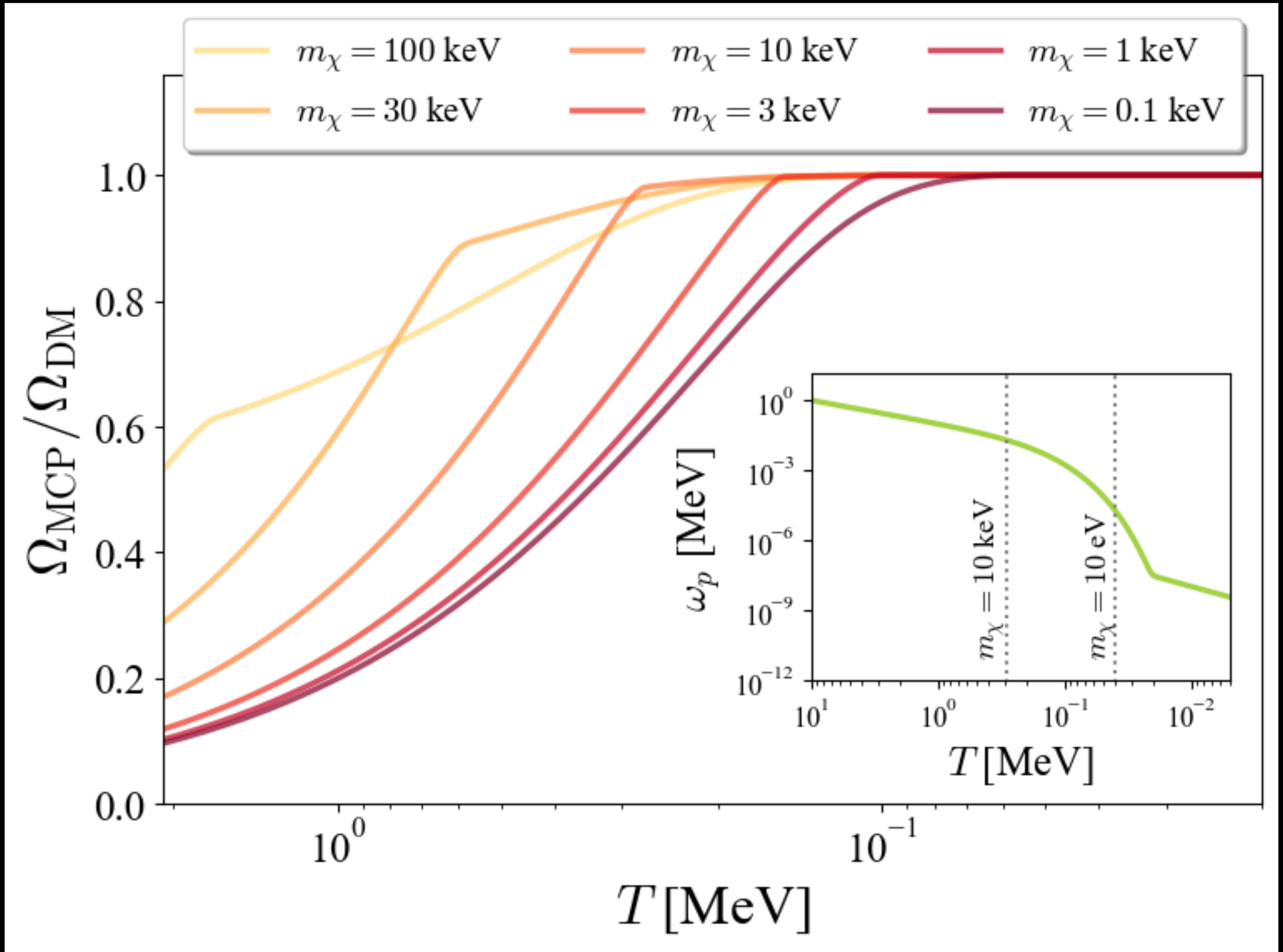
FREEZE-IN ABUNDANCE THROUGH ANNIHILATIONS



$$Y_\chi^{e^+e^-} = 1\times 10^{-9}\left(\frac{Q}{10^{-12}}\right)^2\left(\frac{1\ \text{MeV}}{\max(m_\chi, m_e)}\right)$$



IF MILLICHARGED PARTICLES EXIST, THEY WILL ALWAYS HAVE AN IRREDUCIBLE ABUNDANCE BECAUSE OF FREEZE-IN



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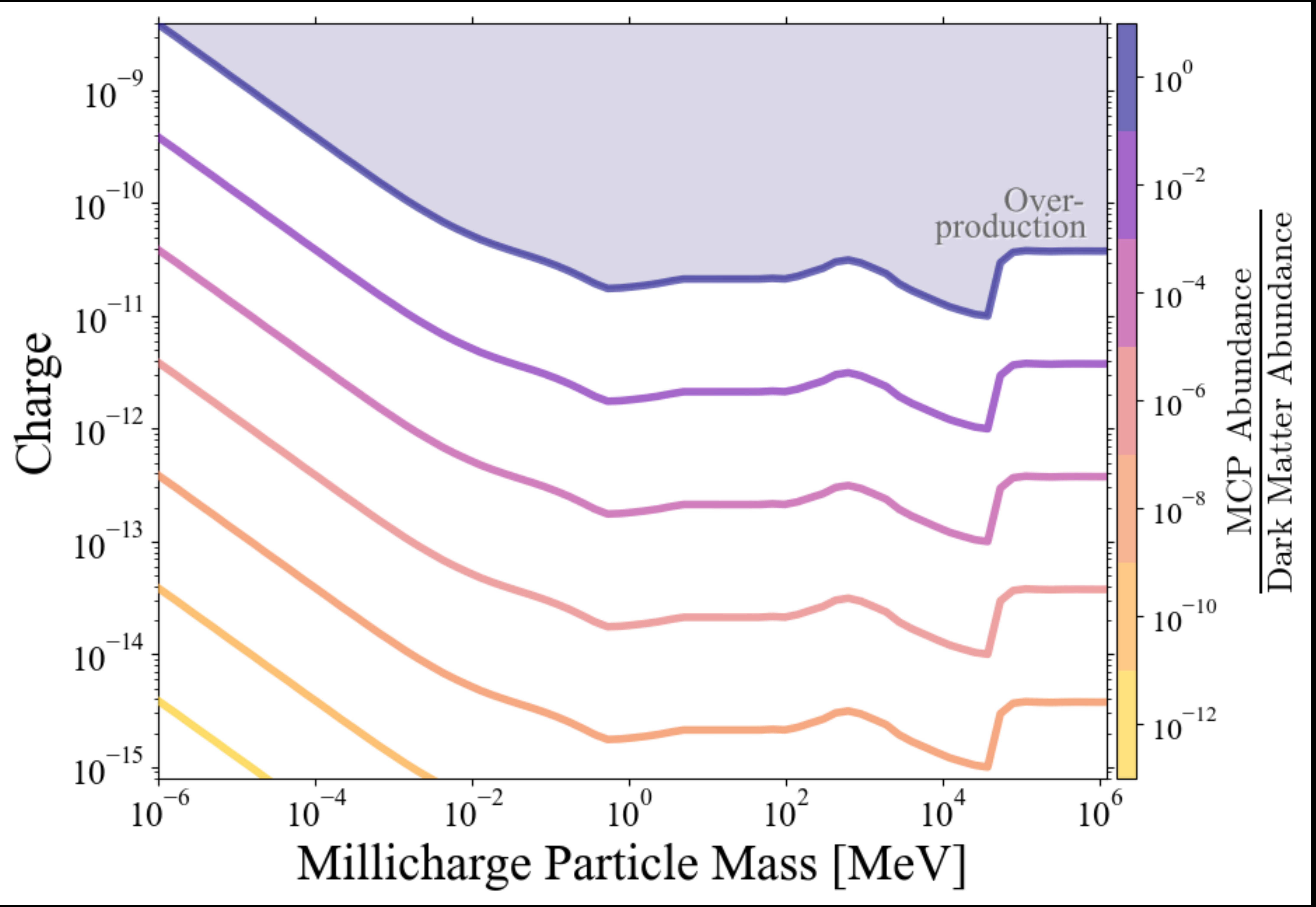

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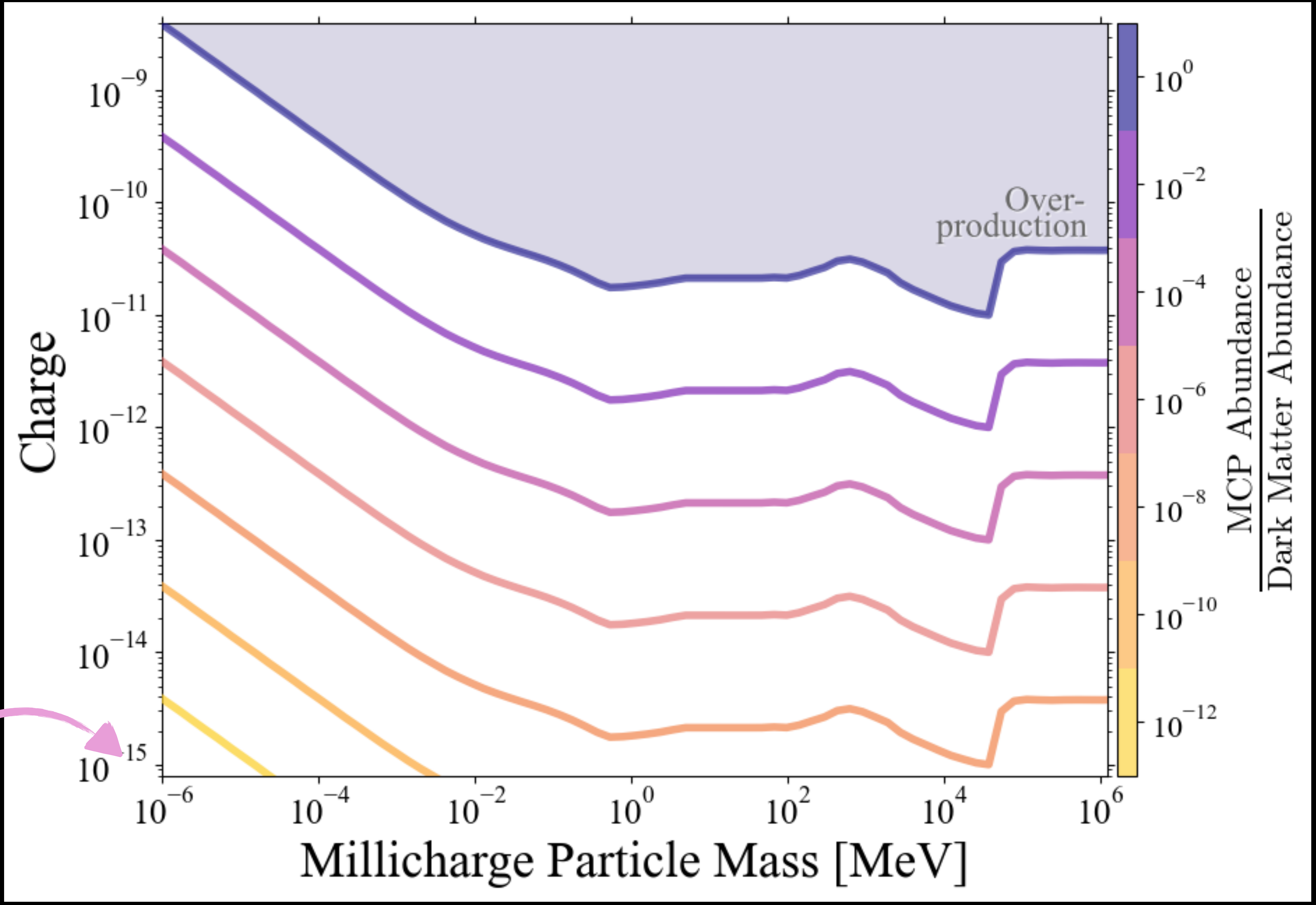

Lighter MCPs wouldn't cluster!

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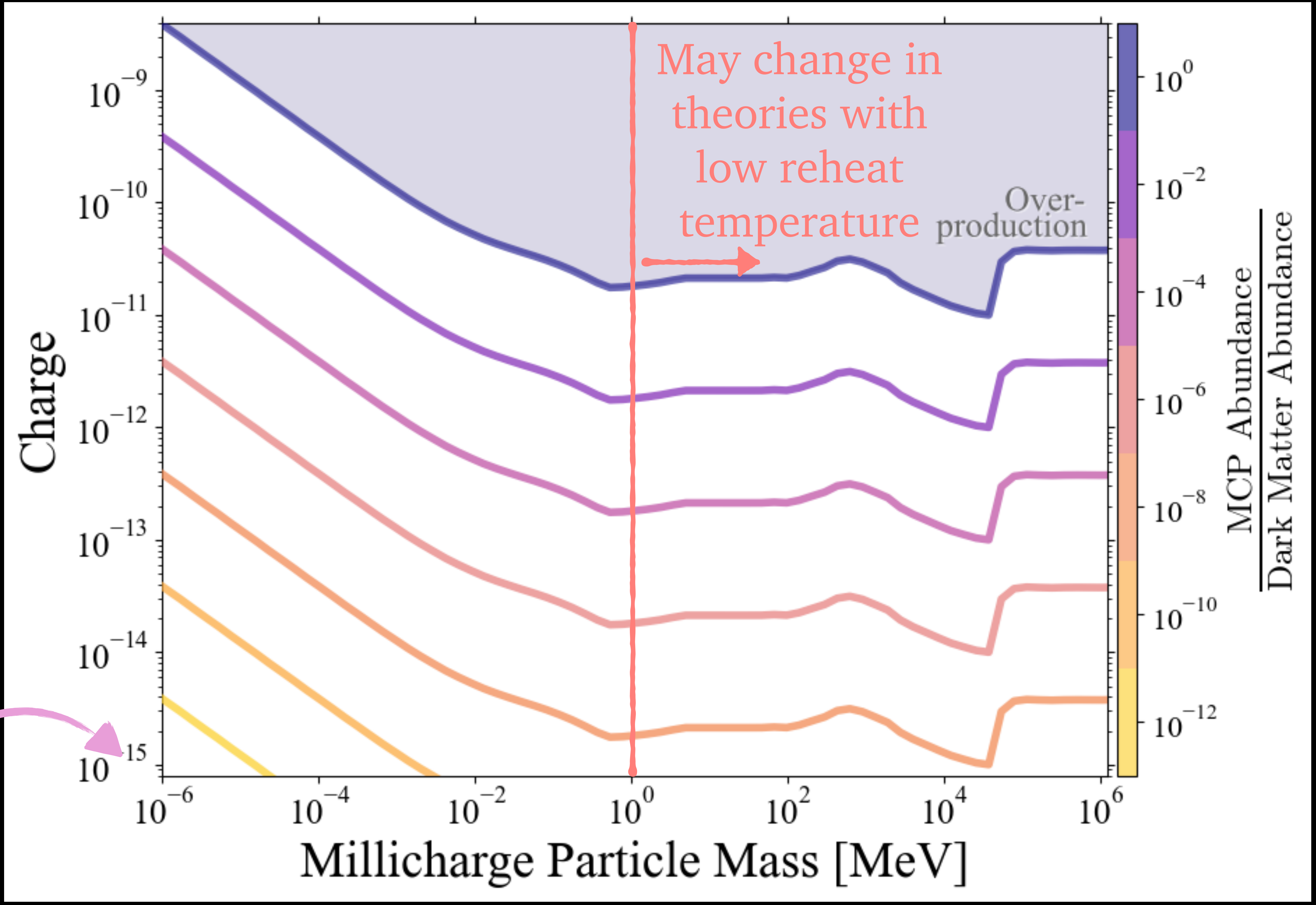

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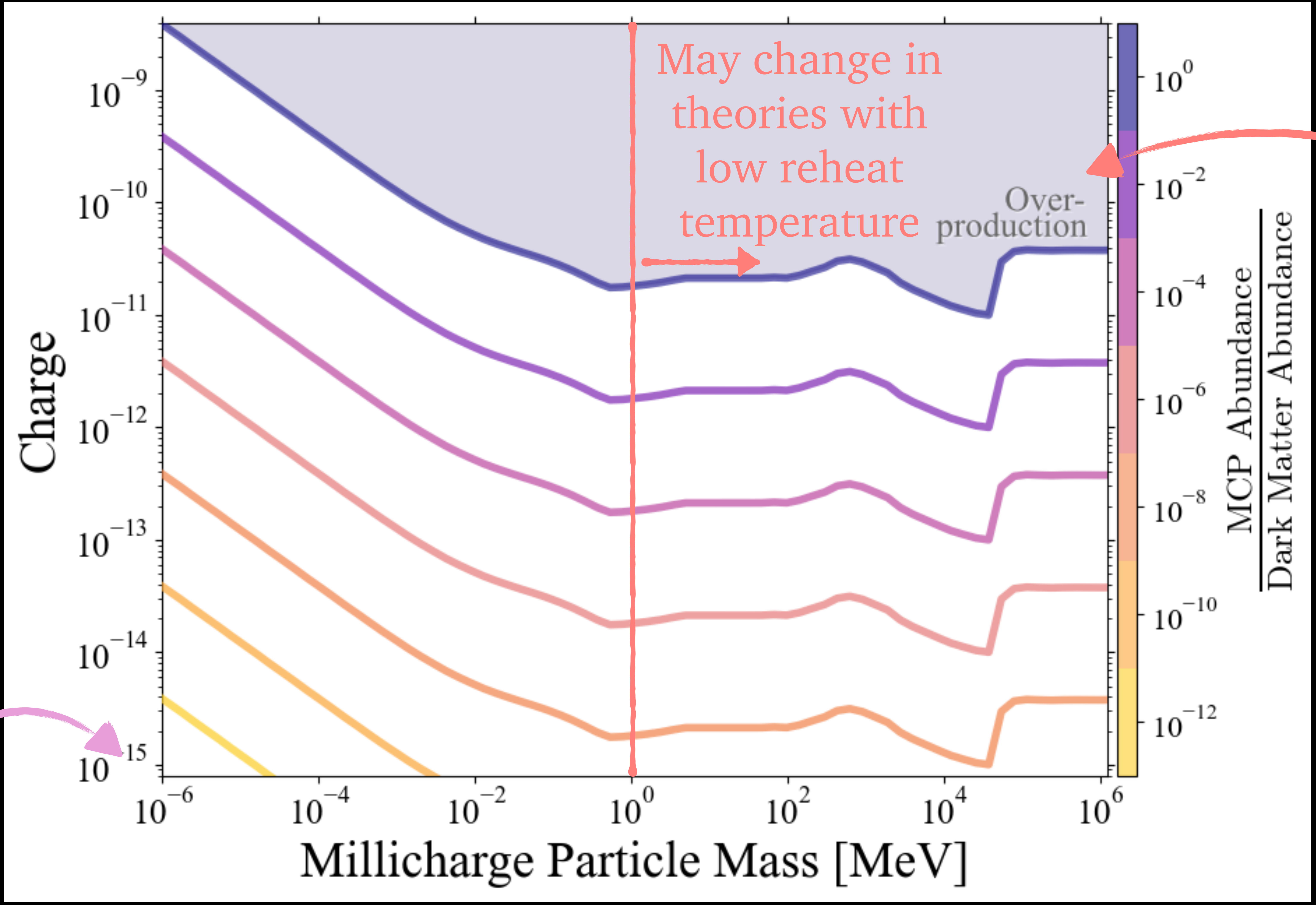
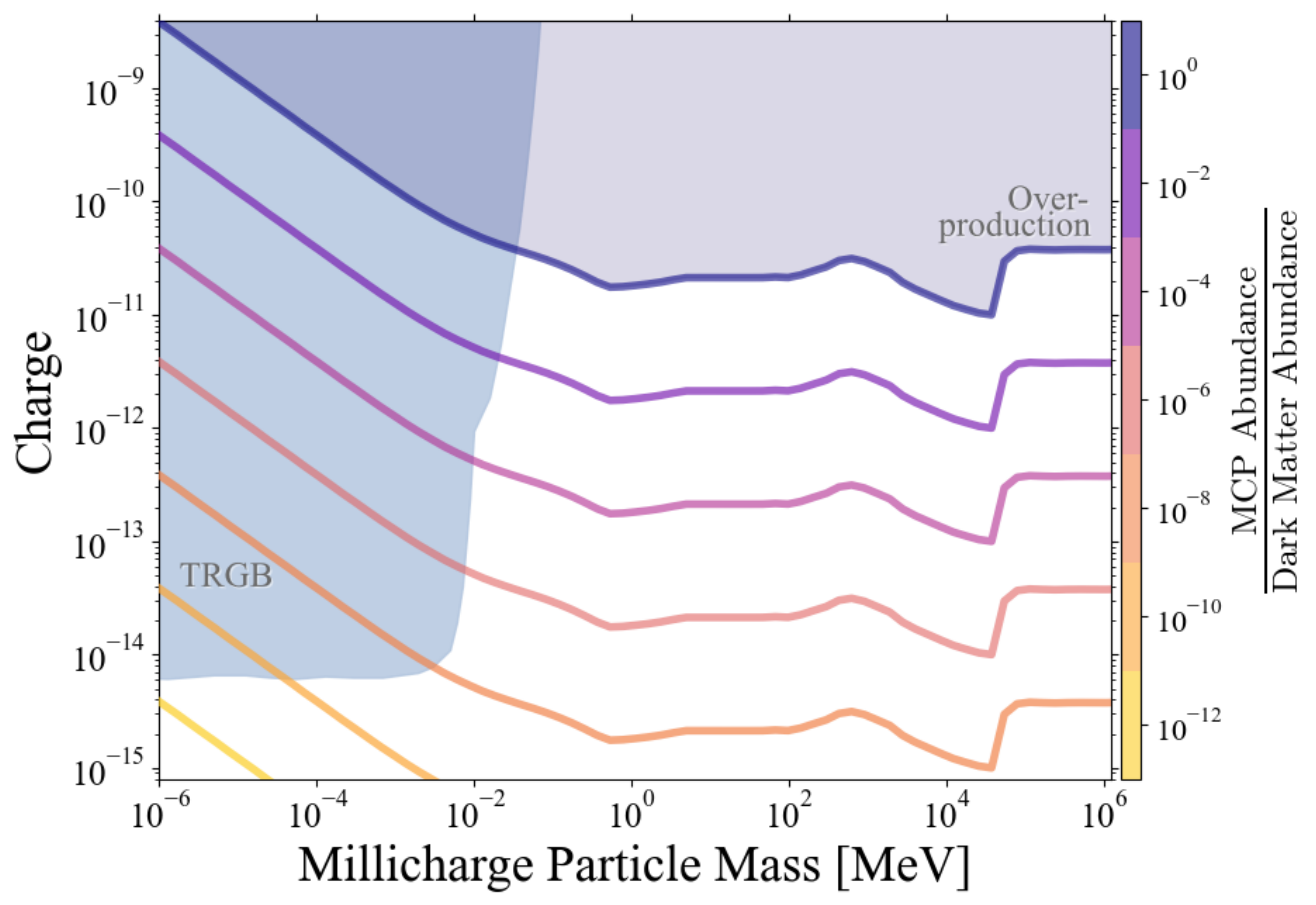


May be alleviated if $\chi\chi \to A'A'$ efficient

Lighter MCPs wouldn't cluster!

IF MILLICHARGED PARTICLES EXIST, THEY WILL ALWAYS HAVE AN IRREDUCIBLE ABUNDANCE BECAUSE OF FREEZE-IN

Part of the parameter space already excluded by astrophysics!



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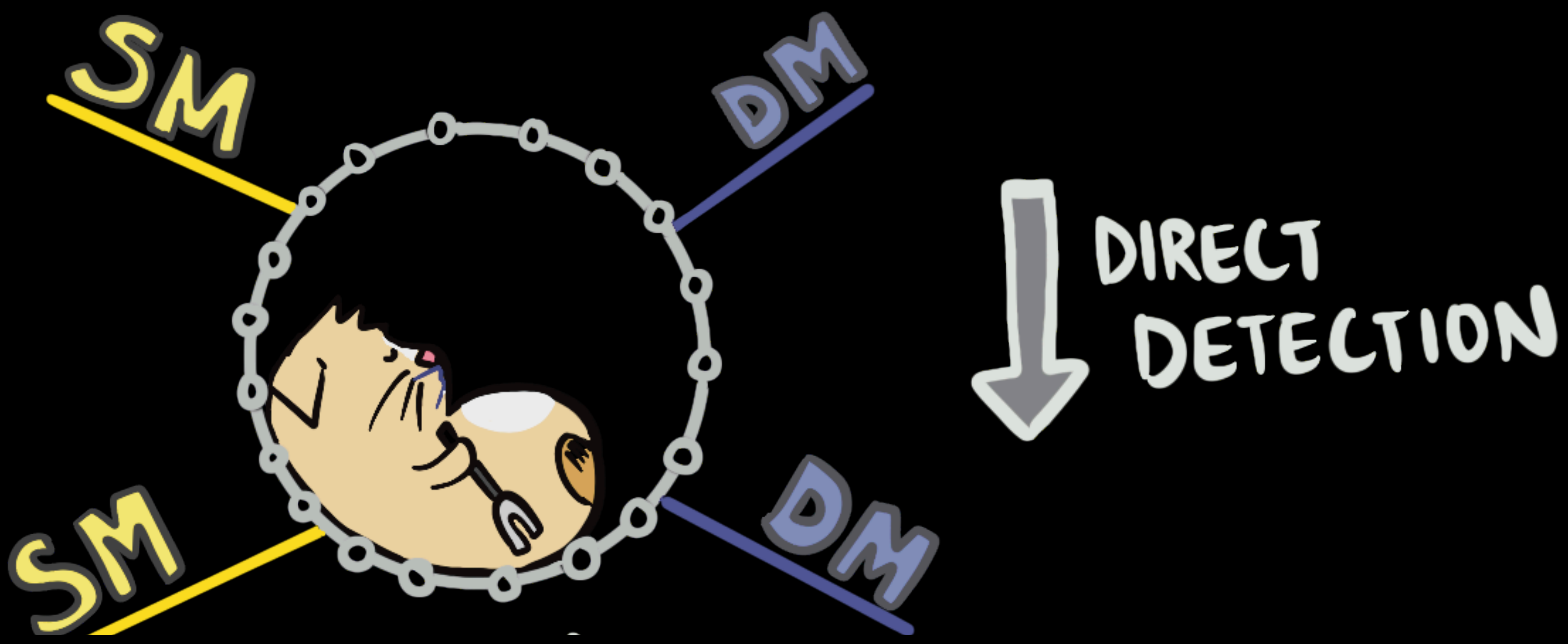
DIRECT DETECTION EXPERIMENTS ARE SENSITIVE TO THE AMBIENT DARK MATTER DENSITY



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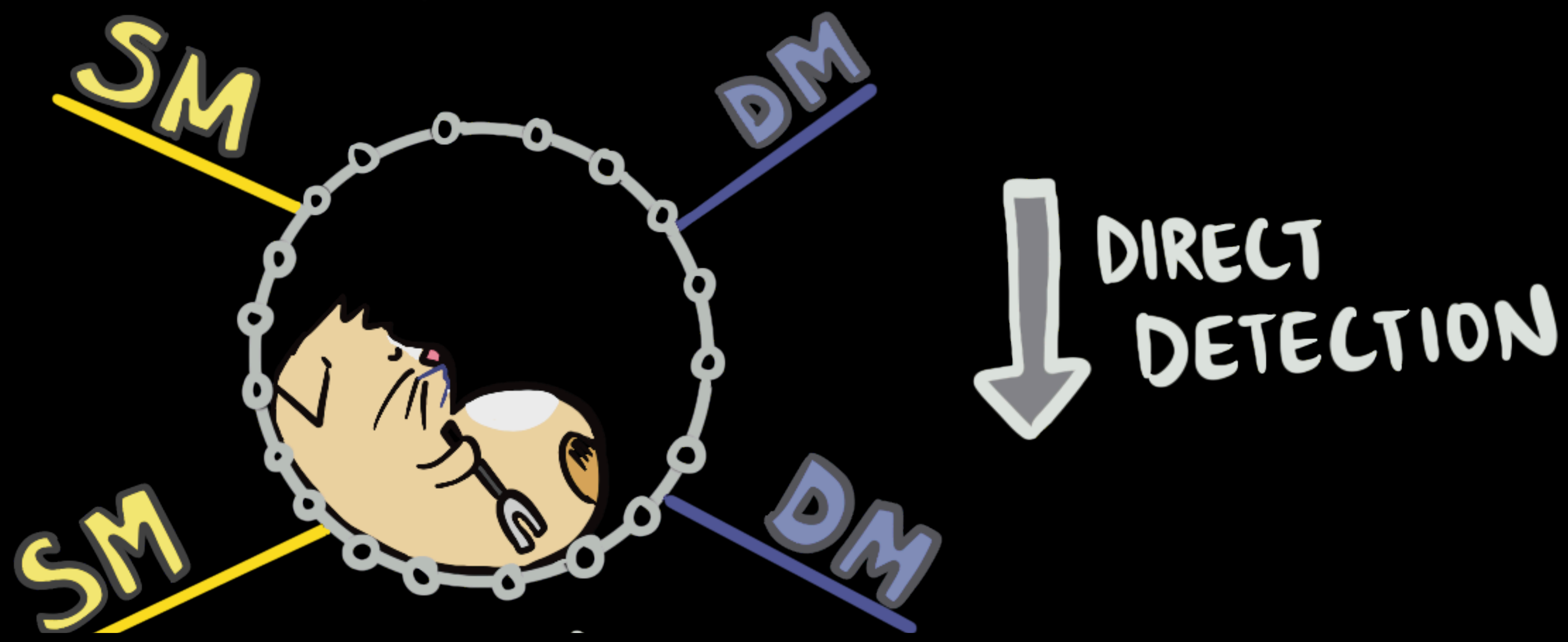
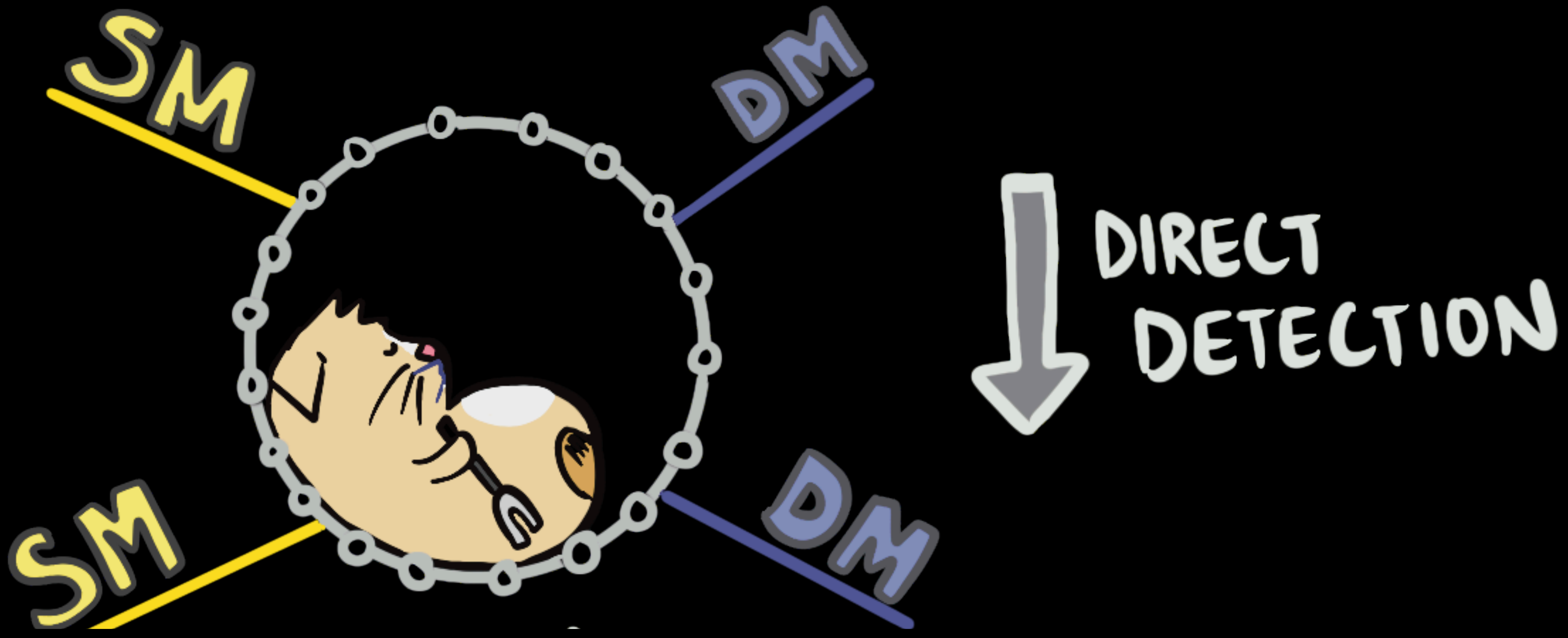


$R \propto$

Event Rate

DIRECT DETECTION EXPERIMENTS ARE SENSITIVE TO THE AMBIENT DARK MATTER DENSITY

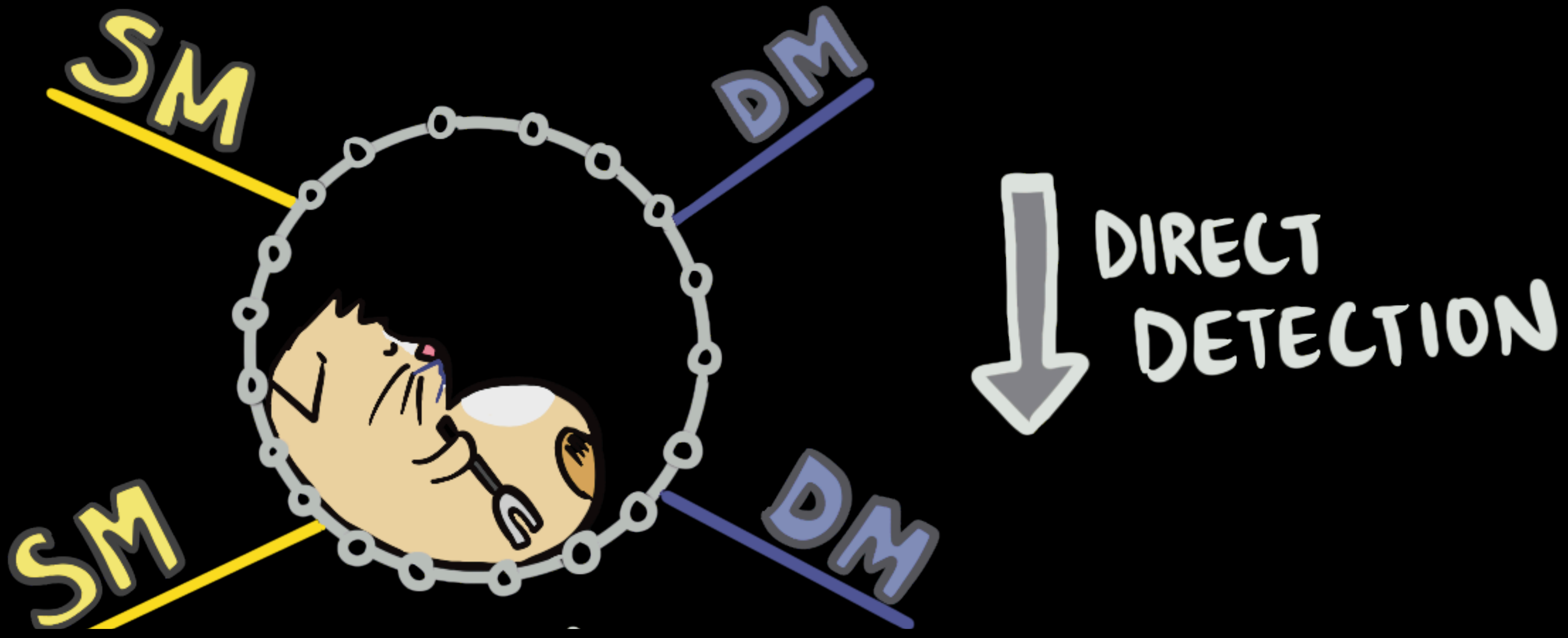


$$R \propto \frac{\rho_{\mathrm{DM}}}{m_{\mathrm{DM}}}$$

Event Rate

DM Number density

Direct detection experiments are sensitive to the ambient dark matter density



$$R \propto \frac{\rho_{\rm DM}}{m_{\rm DM}} \bar{\sigma}_e$$

Event Rate

DM Number density

Interaction cross-section

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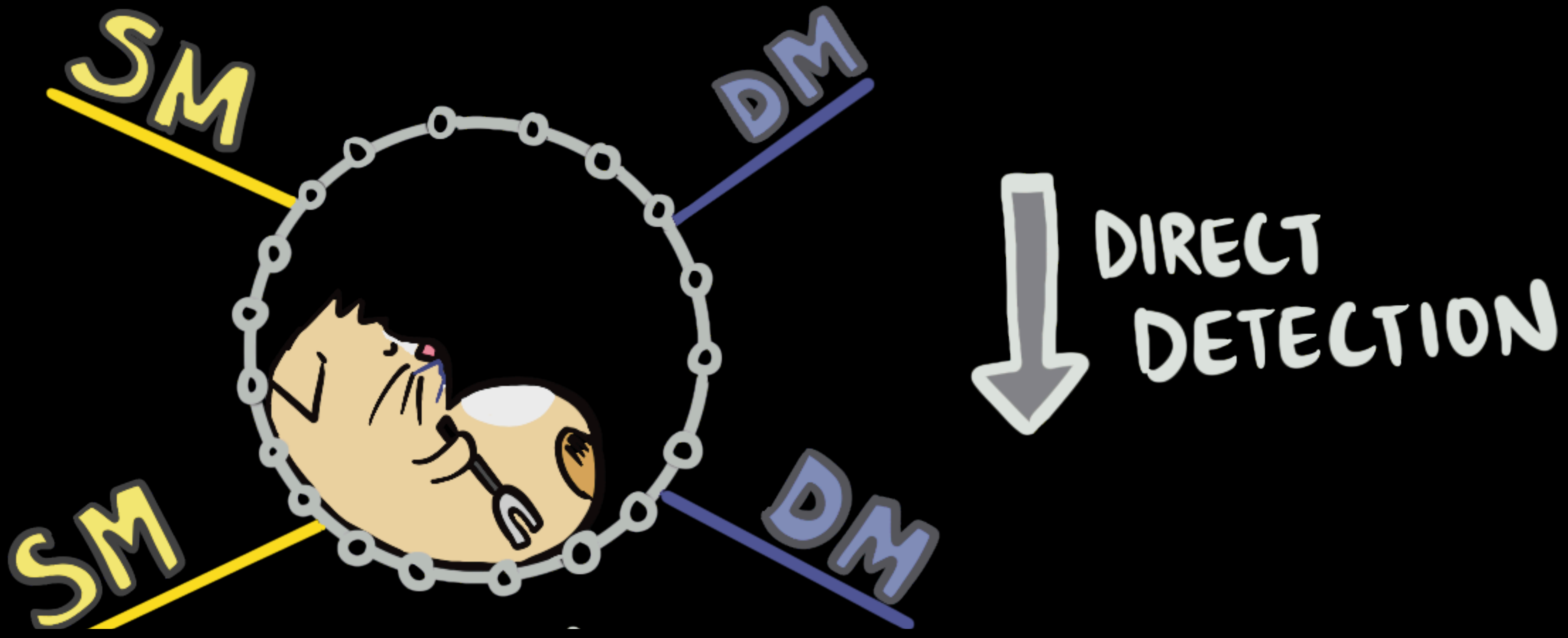

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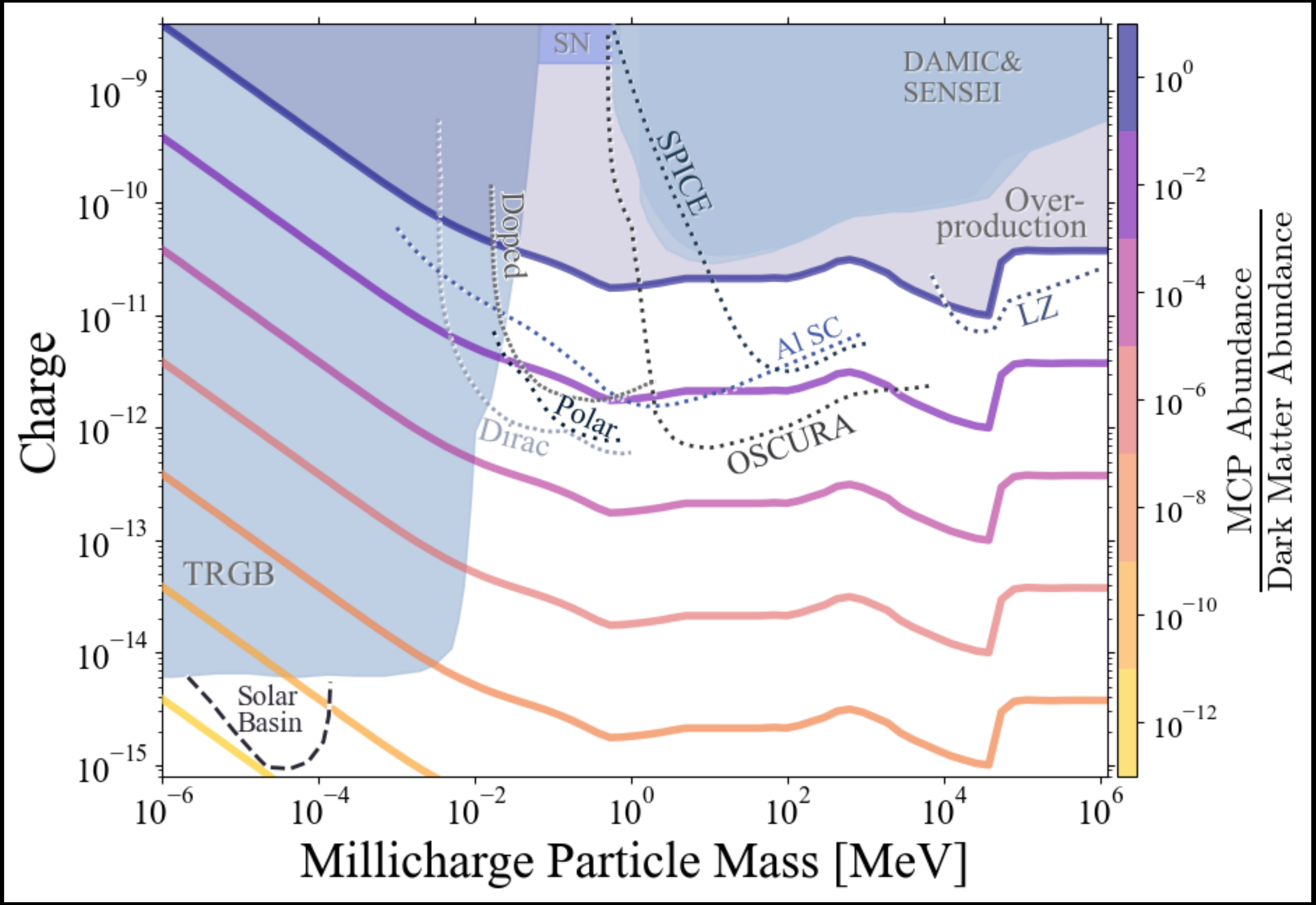
Event Rate

DM Number density

Interaction cross-section

For the MCP background, limits on $\bar{\sigma}_e$ can be interpreted as limits on $\bar{\sigma}_e \times \rho_{\rm MCP}/\rho_{\rm DM}$!

DIRECT DETECTION EXPERIMENTS WILL BE SENSITIVE TO THE MCP PARAMETER SPACE!



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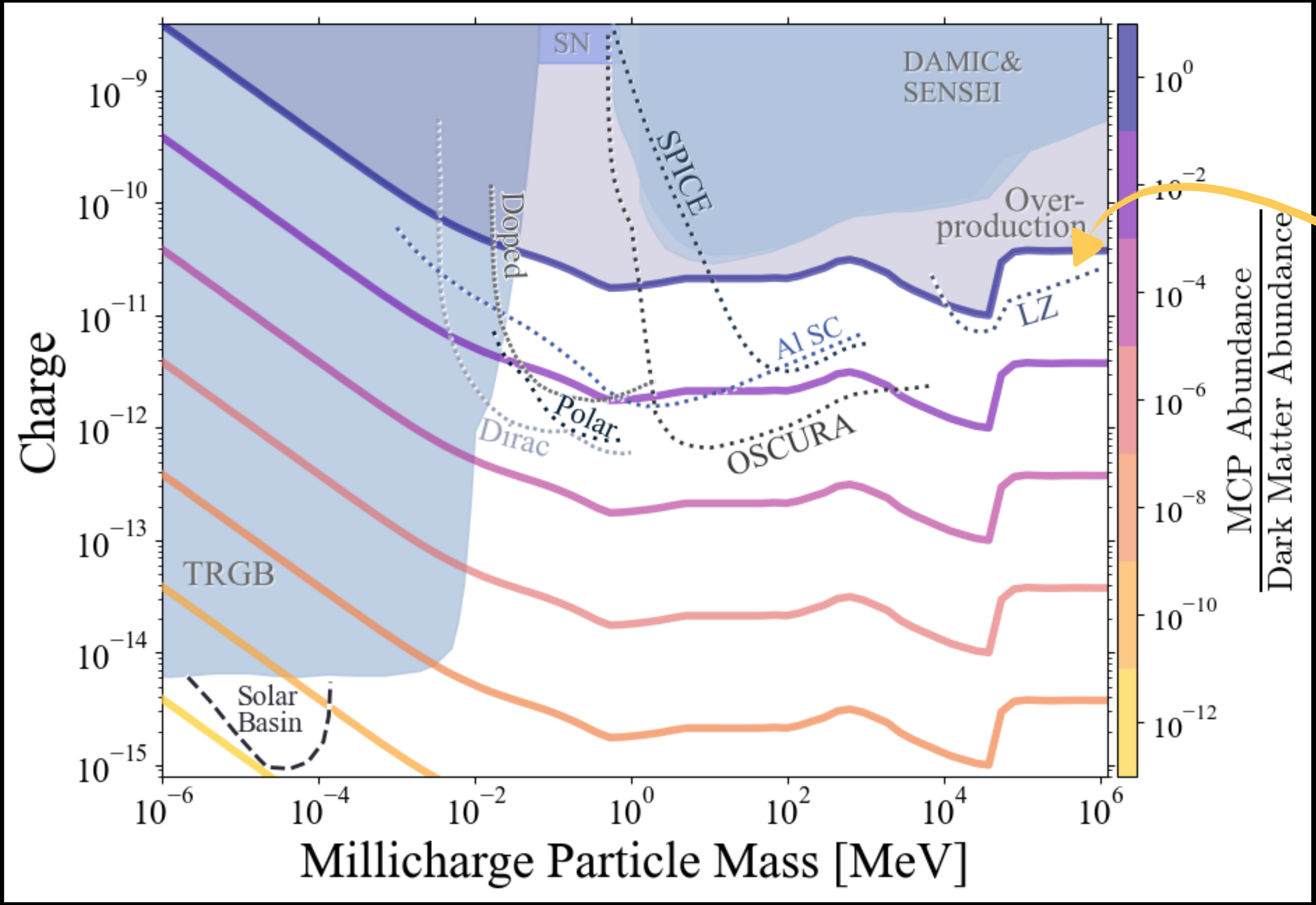
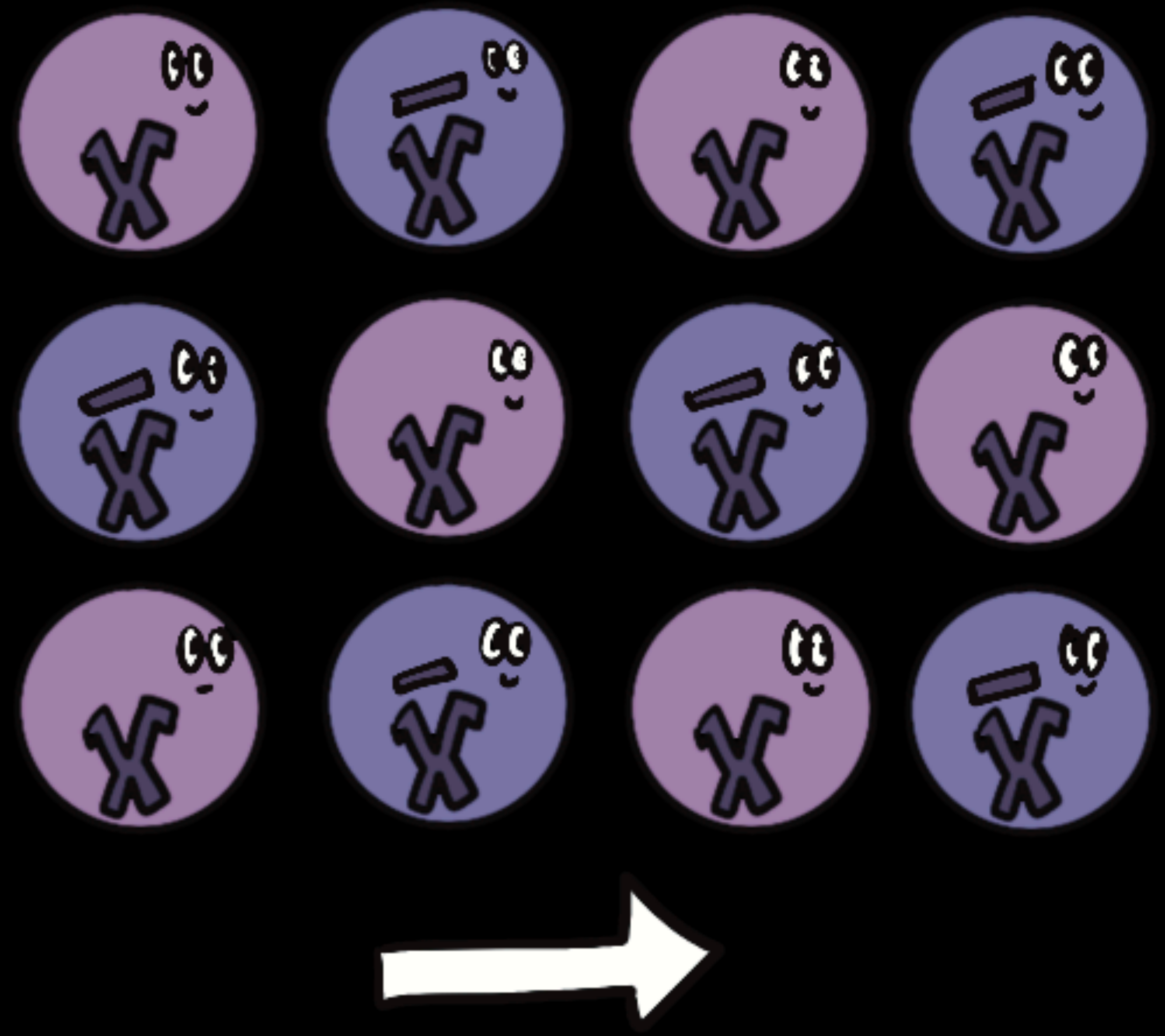


Nuclear recoil bounds recast for the case of light mediators (Hamby et al. PRD 2018)

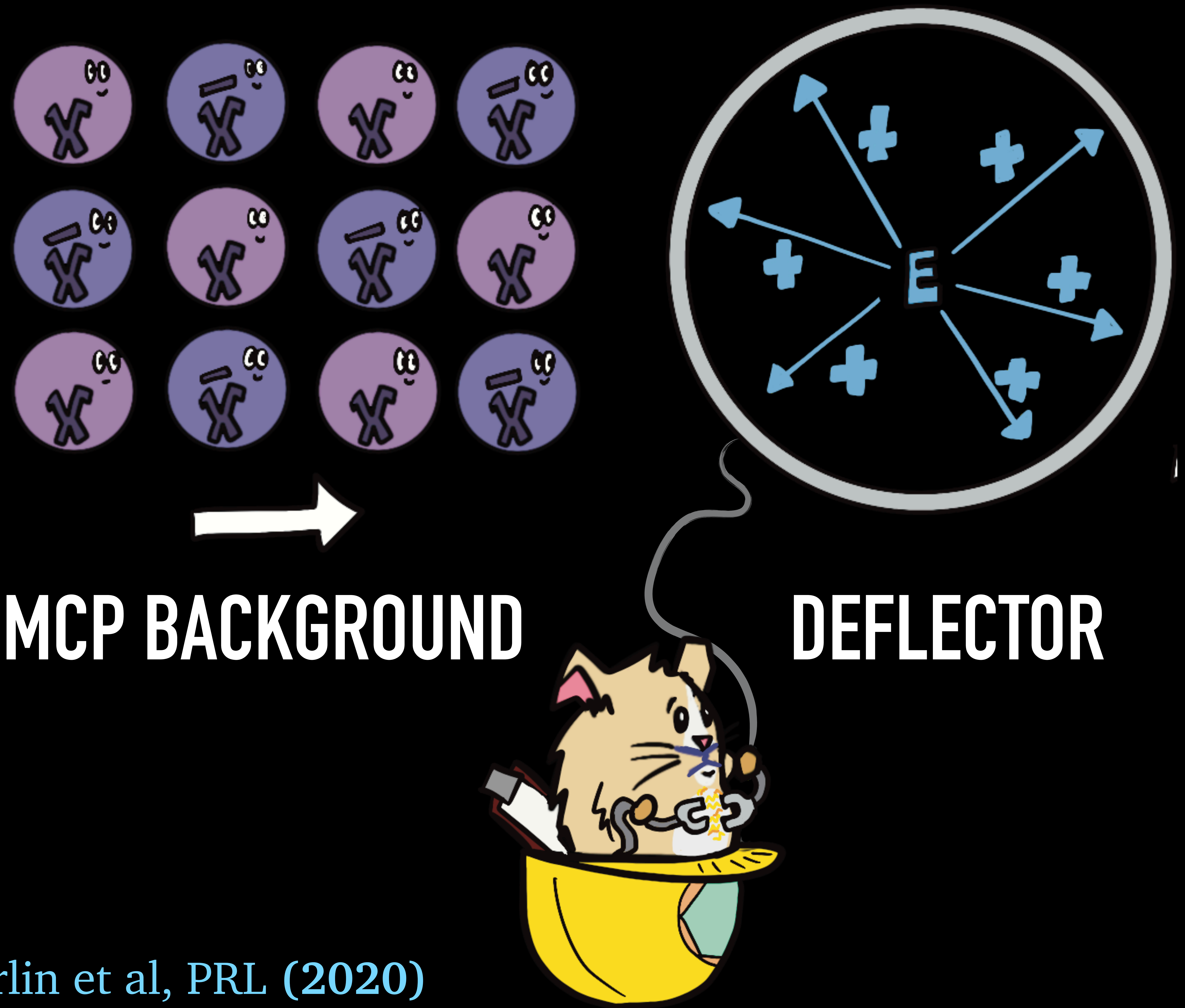
DIRECT DEFLECTION



MCP BACKGROUND

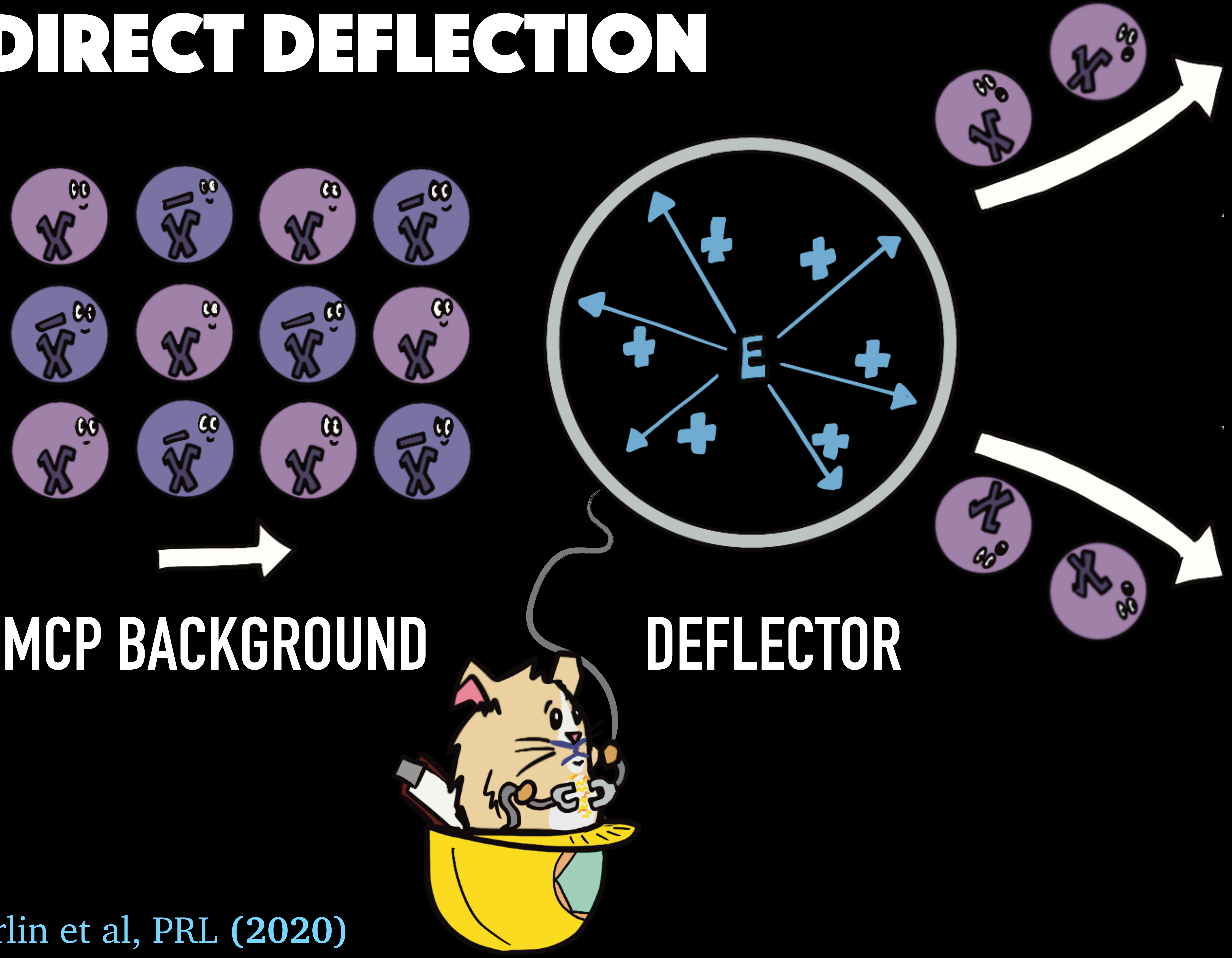
Berlin et al, PRL (2020)

DIRECT DEFLECTION



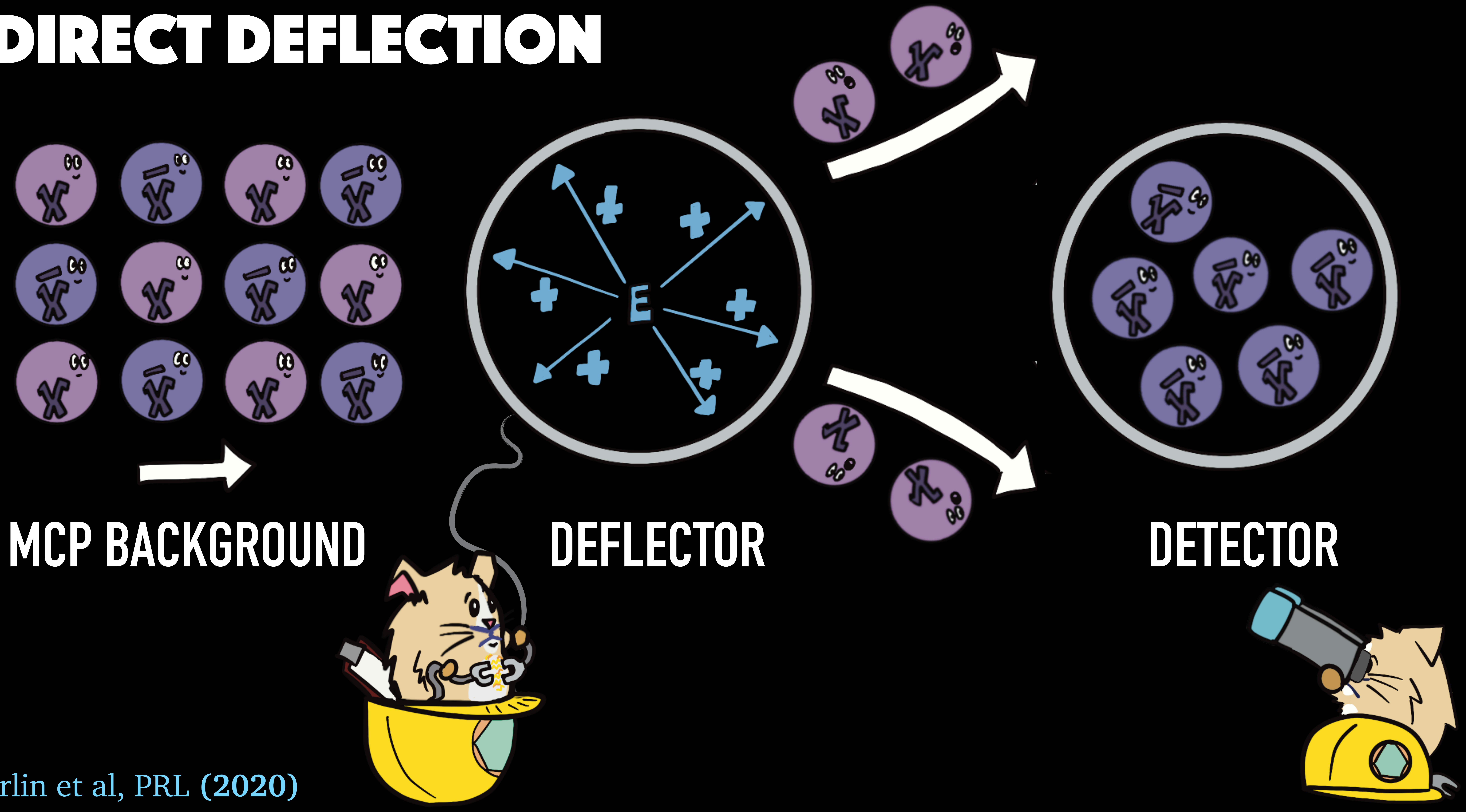
Berlin et al, PRL (2020)

DIRECT DEFLECTION



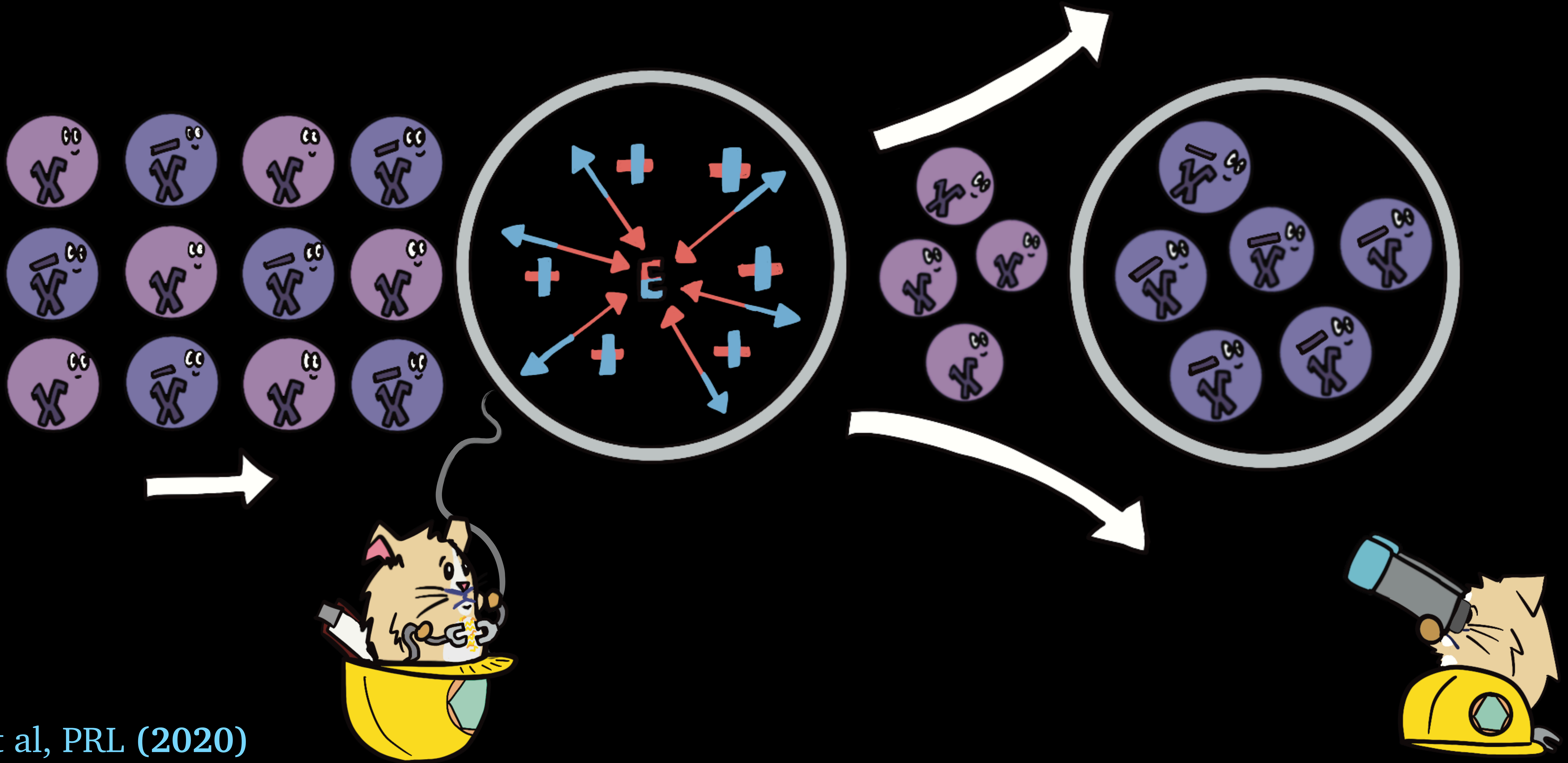
Berlin et al, PRL (2020)

DIRECT DEFLECTION



Berlin et al, PRL (2020)

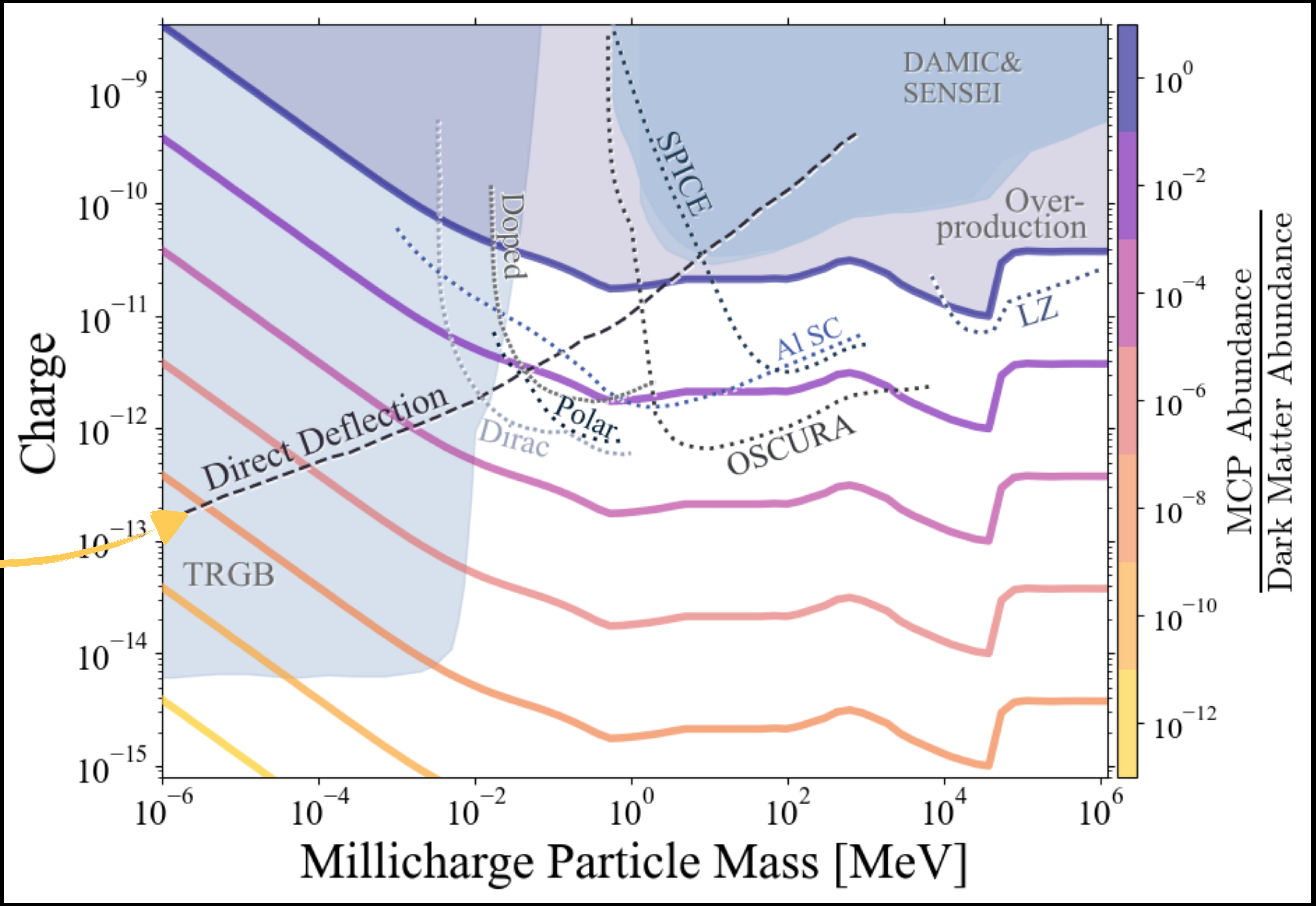
THE ALTERNATING ELECTRIC FIELD IN THE DEFLECTOR SETS UP AN ALTERNATING MCP CURRENT IN THE DETECTOR!



Berlin et al, PRL (2020)

DIRECT DEFLECTION EXPERIMENTS WILL BE SENSITIVE TO THE MCP PARAMETER SPACE!

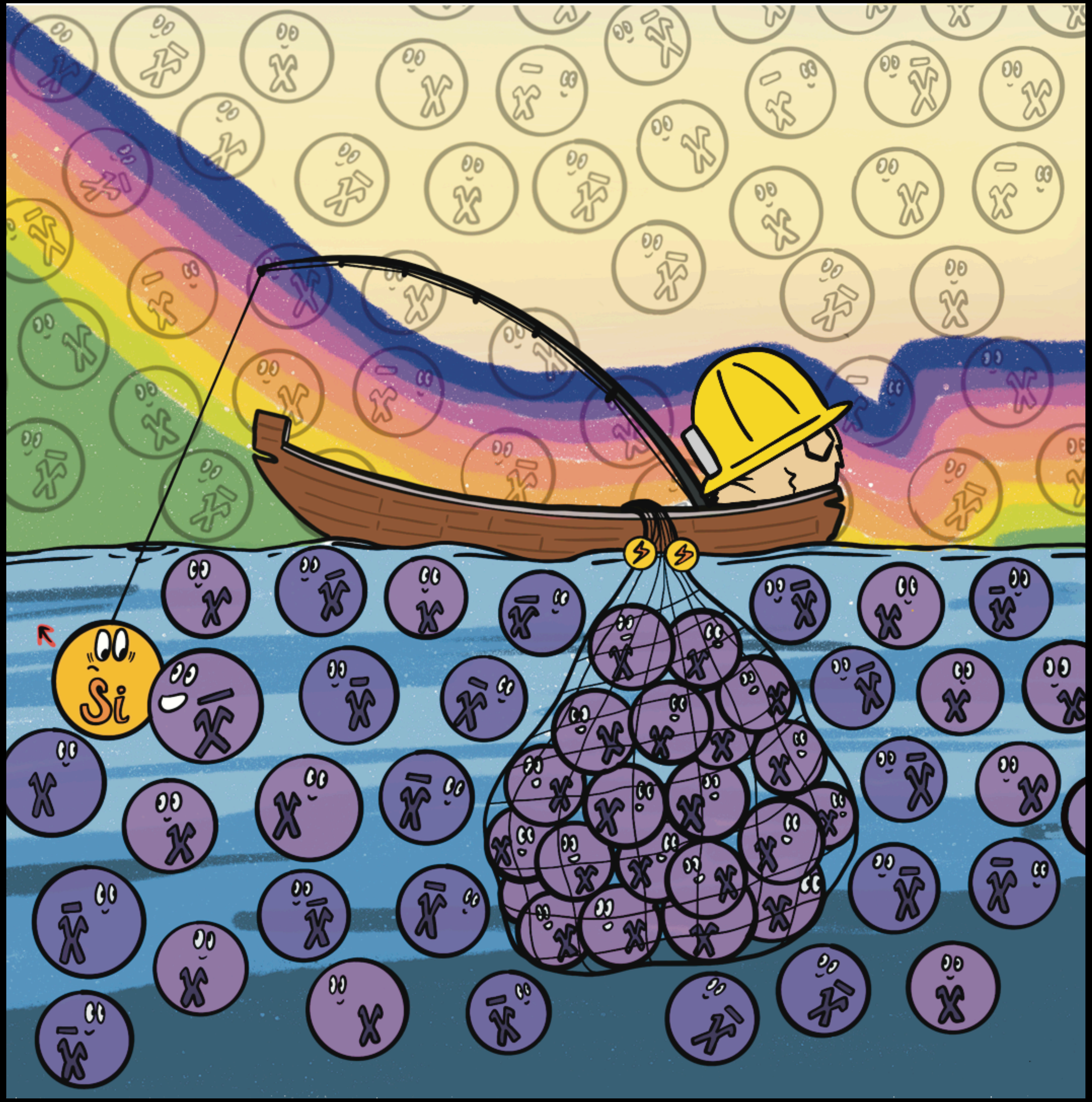
Idealized deflector setup, (Berlin et al, PRL 2020)

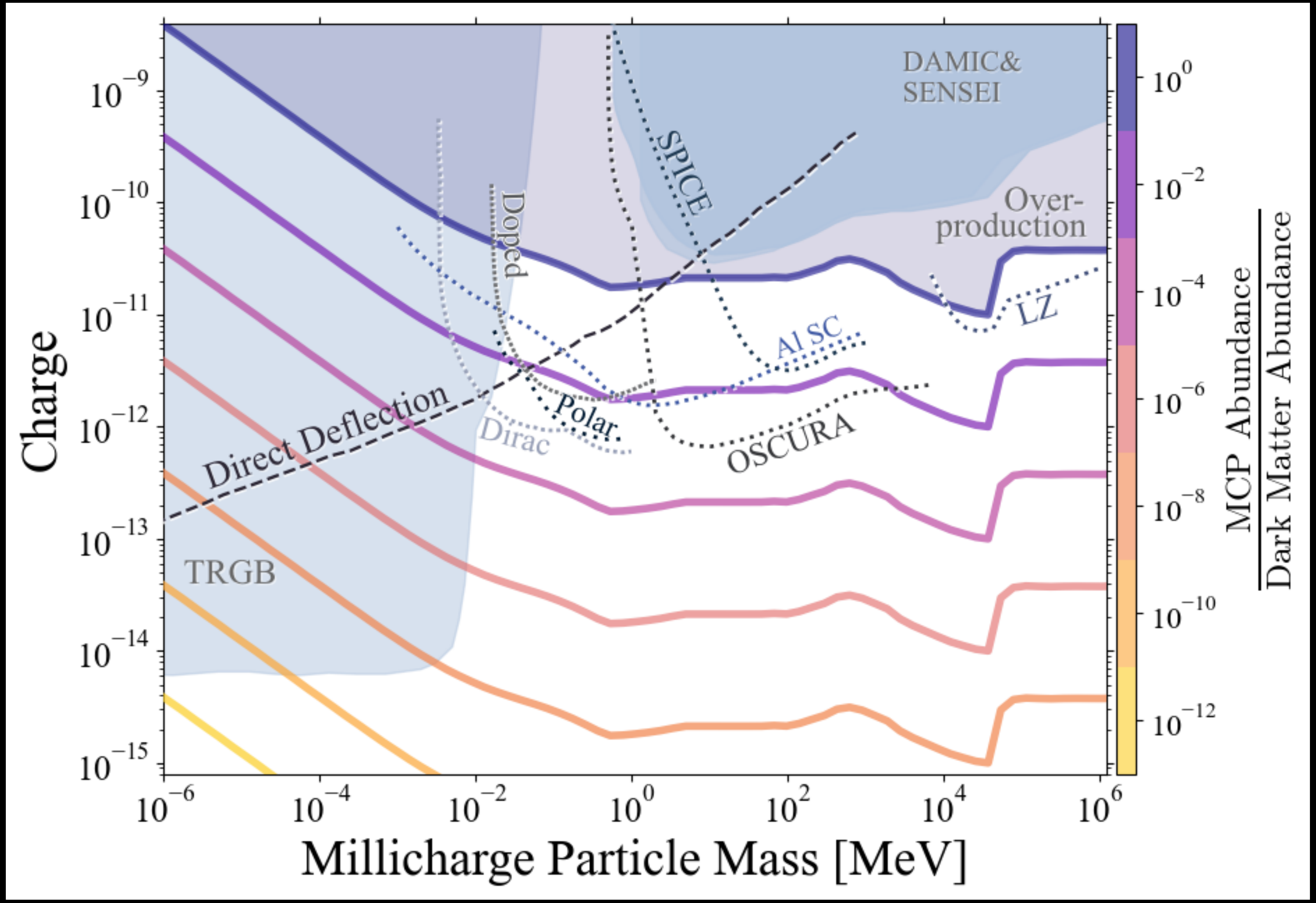


TAKEAWAYS:

1. MCPS ARE **MINIMAL EXTENSIONS** OF THE STANDARD MODEL
2. IF MCPS **EXIST**, THEY WILL BE **IRREDUCIBLY PRODUCED** IN THE EARLY UNIVERSE THROUGH **FREEZE-IN**

3. DIRECT DETECTION EXPERIMENTS ARE SENSITIVE TO THE IRREDUCIBLE MILLICHARGED BACKGROUND!





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