Dark Matter Induced Axion Gradient

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Many thanks to my collaborators: Mario Reig, Edward Hardy

Axions and the Dark Sector

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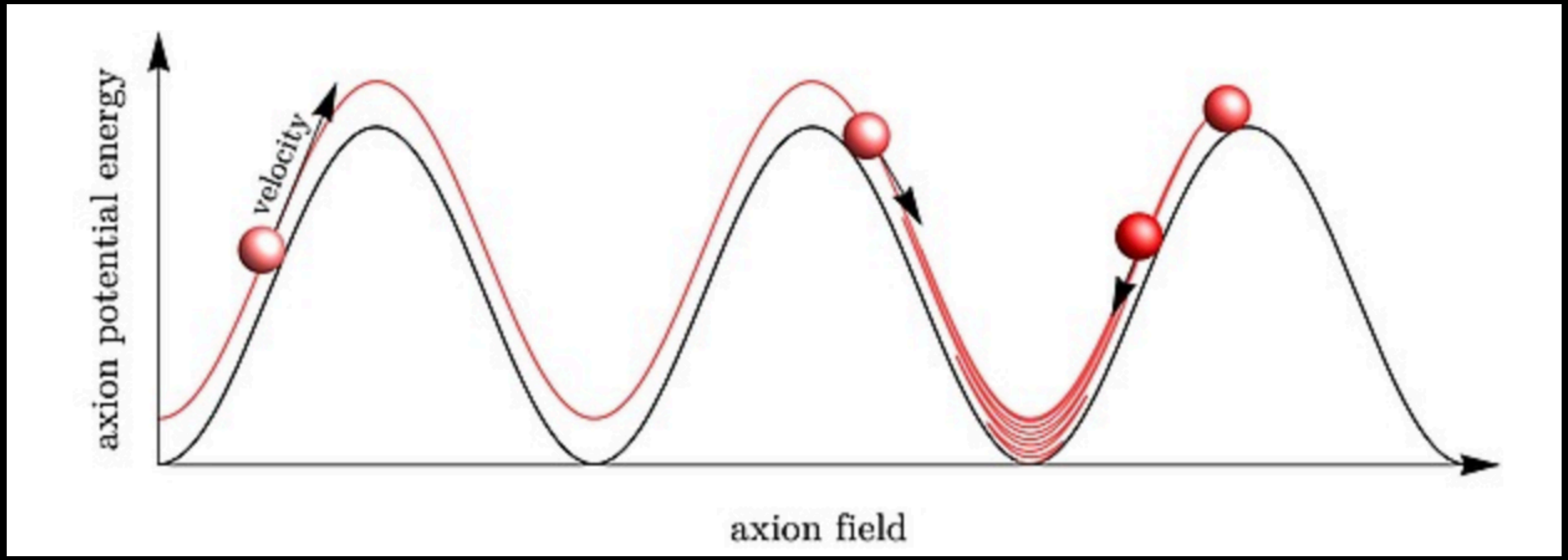
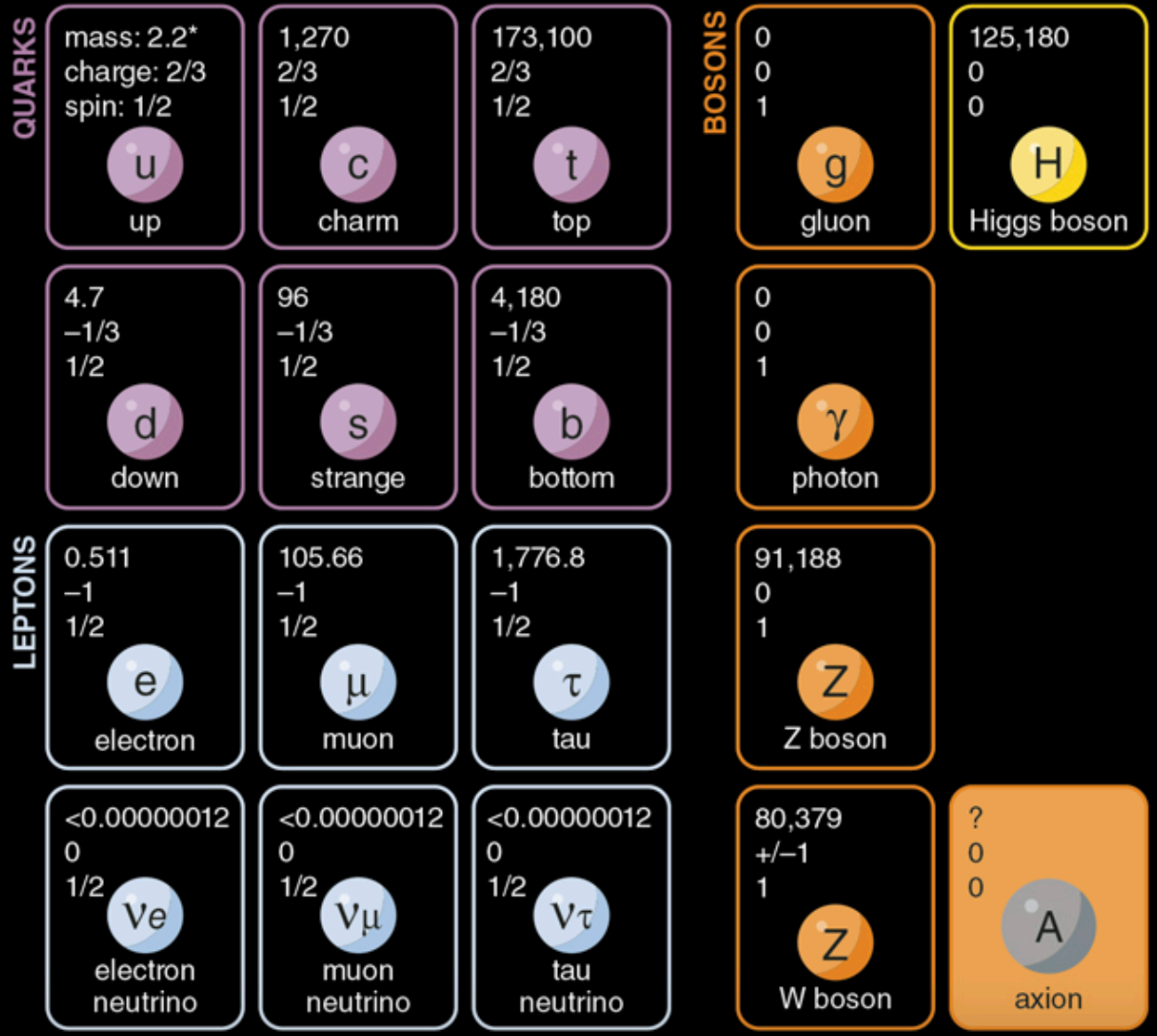
Expecting light Pseudo-scalars

$$\mathcal{L}_a = \frac{1}{2}(\partial_\mu a)^2 + \frac{a}{f_a}\frac{\alpha_s}{8\pi}G_{\mu\nu}\tilde{G}^{\mu\nu} + \frac{1}{4}\,a\,g^0_{a\gamma\gamma}F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{\partial_\mu a}{2f_a}\,j^\mu_{a,0}$$





CP-violating Dark Matter Coupling

$$\mathcal{L}_{\text{eff}} \supset g_s^\chi \phi \bar{\chi}\chi + c_\psi \frac{\partial_\mu \phi}{f_\phi} \bar{\psi}\gamma^\mu \gamma^5 \psi - \frac{1}{2} m_\phi^2 \phi^2 \,,$$

CP - violaing
with dark matter

CP - conserving
SM fermions

Galactic Axion Source

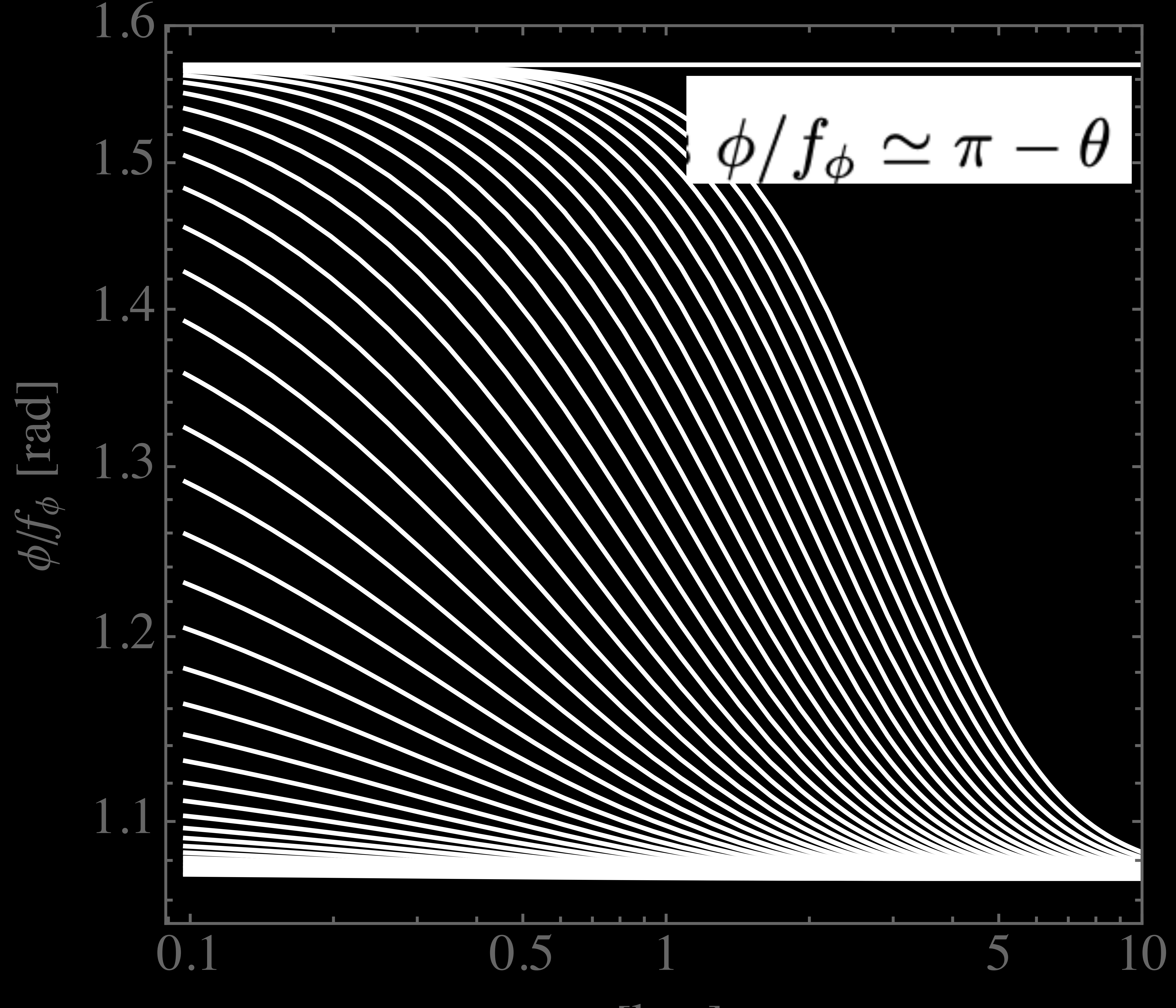
The Galactic Halo Sources a coherent field

$$\phi(\vec{r}) = g_s^\chi \int_V d^3\vec{r}' \, \frac{n_\chi(\vec{r}')\, e^{-m_\phi|\vec{r}-\vec{r}'|}}{4\pi|\vec{r}-\vec{r}'|}$$

$$\phi(r) \simeq \frac{g_s^\chi\, N_{\rm eff}}{\lambda_\phi} \simeq \frac{g_s^\chi\, n_\chi(r)}{m_\phi^2}\,.$$

$$|\boldsymbol{\nabla}\phi(R)| \simeq \begin{cases} g_s^\chi\; |\boldsymbol{\nabla} n_\chi(R)|\,/m_\phi^2 & \text{if } 1/m_\phi < \lambda_\chi, \\ g_s^\chi\, N_\chi(R)/R^2 & \text{if } 1/m_\phi > \lambda_\chi\,, \end{cases}$$

Axion Field Saturation



$$V \supset \Lambda \bar{\chi} \chi \cos(\phi/f_\phi + \theta) \ .$$

Searching for the Axion Gradient

Halo Sourced Axion Gradient

$$H_\phi = -\frac{c_\psi}{f_\phi} \nabla\phi \cdot \mathbf{S}$$

$$1/\lambda_\chi \simeq 4 \times 10^{-28} \ \text{eV}$$

$$\lambda_\chi \equiv n_\chi / |\nabla n_\chi|$$

$$\Delta E \simeq \begin{cases} c_\psi g_s^\chi \, |\mathbf{S}| \, |\nabla n_\chi(R)| / (f_\phi m_\phi^2) & \text{if } 1/m_\phi < \lambda_\chi \,, \\ c_\psi g_s^\chi \, |\mathbf{S}| \, N_\chi(R) / (f_\phi R^2) & \text{if } 1/m_\phi > \lambda_\chi \,. \end{cases}$$

Induced Energy Shifts

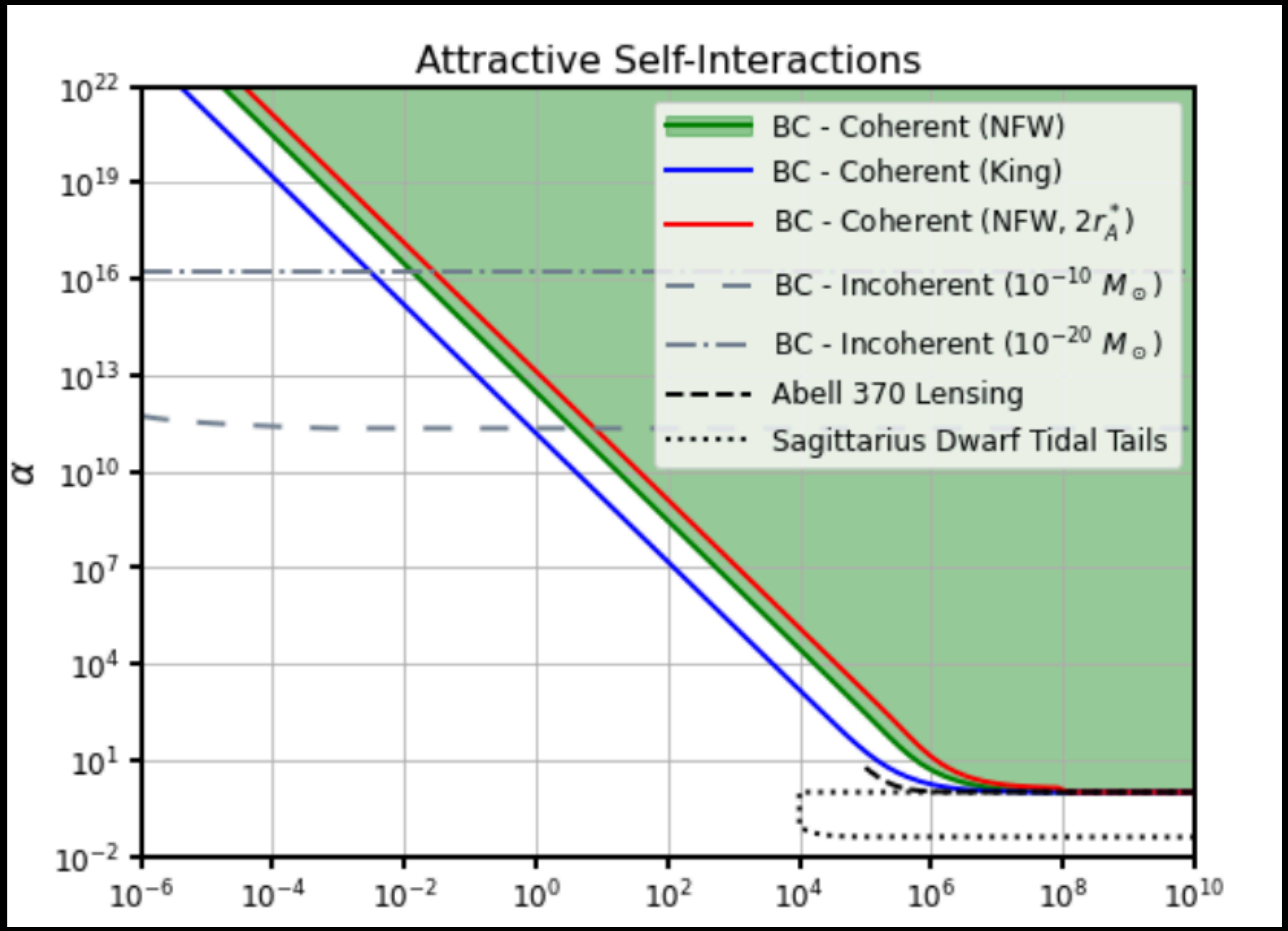
$$\Delta E \simeq 3 \times 10^{-24}\ \text{eV}\, \kappa \begin{cases} 1/\left(\lambda_\chi m_\phi\right)^2 & \text{if } m_\phi > 1/\lambda_\chi\,, \\ 1 & \text{if } m_\phi < 1/\lambda_\chi\,, \end{cases}$$

$$\kappa = |\mathbf{S}| \left(\frac{g_s^\chi}{m_\chi/M_\text{P}}\right)\left(\frac{10^9 \quad \text{GeV}}{f_\phi/c_\psi}\right)$$

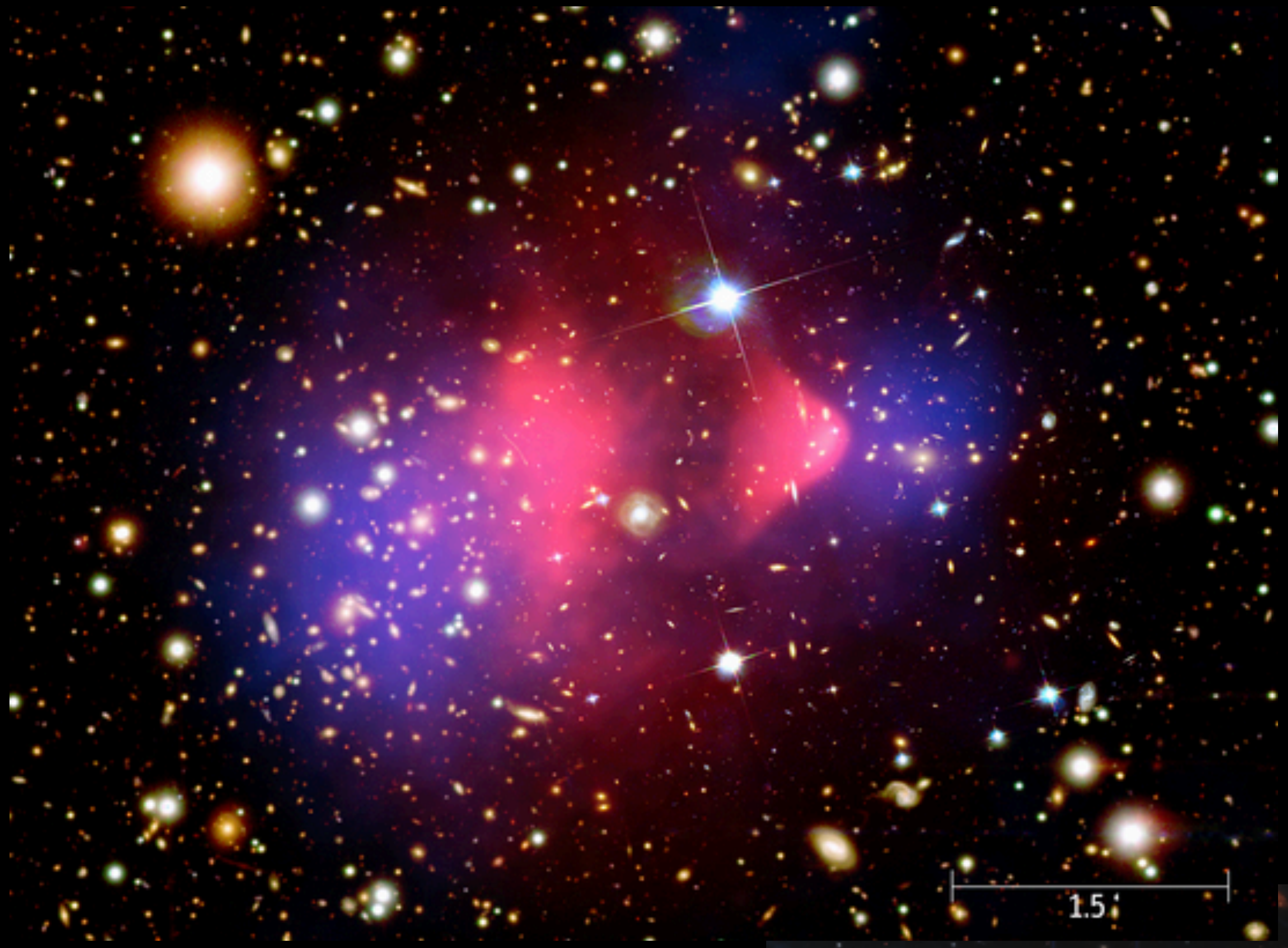
Experimental Reach

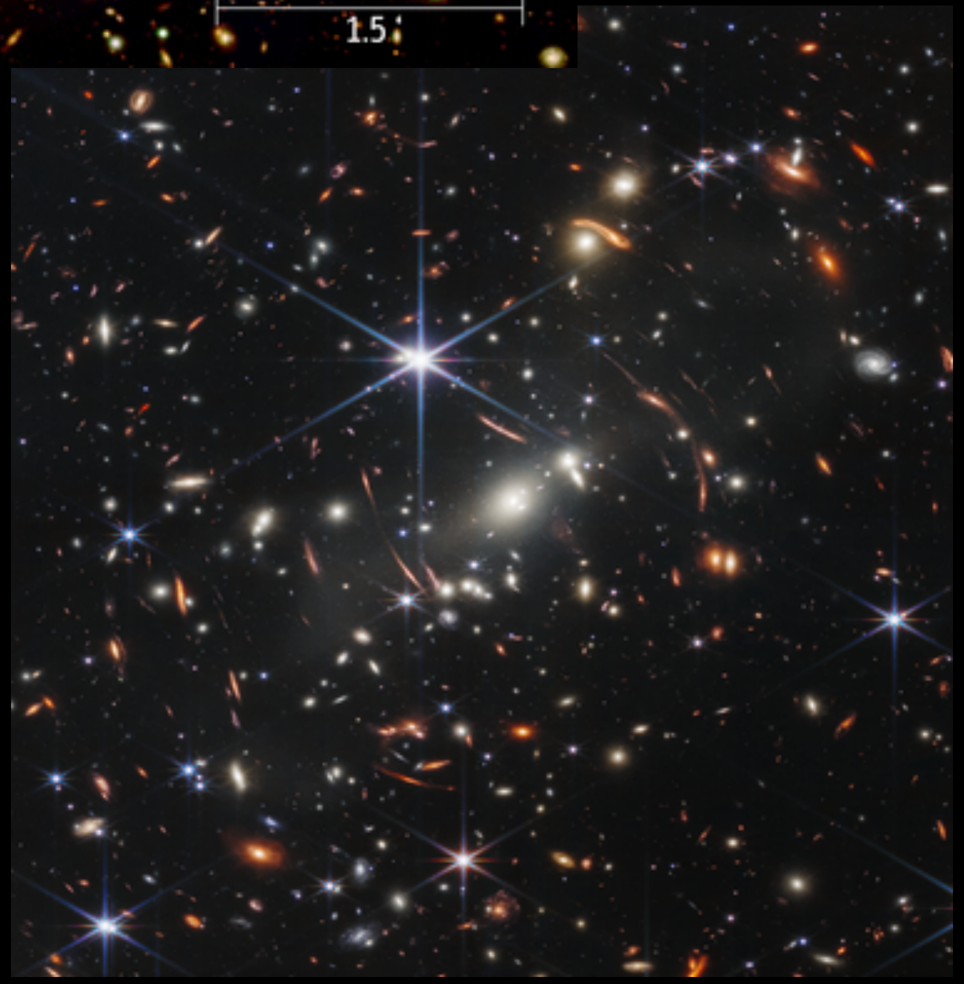
Long-range-force constraints

$$V(r) = -\frac{\alpha G_N m_\chi^2}{r} \exp(-r/l)$$



Bogorad et al. 2311.07648





Re-interpreting Lorentz Violation Searches

New limit on Lorentz and CPT-violating neutron spin interactions

J. M. Brown, S. J. Smullin, T. W. Kornack, and M. V. Romalis
Department of Physics, Princeton University, Princeton, New Jersey 08544

Brown et al.
1006.5425

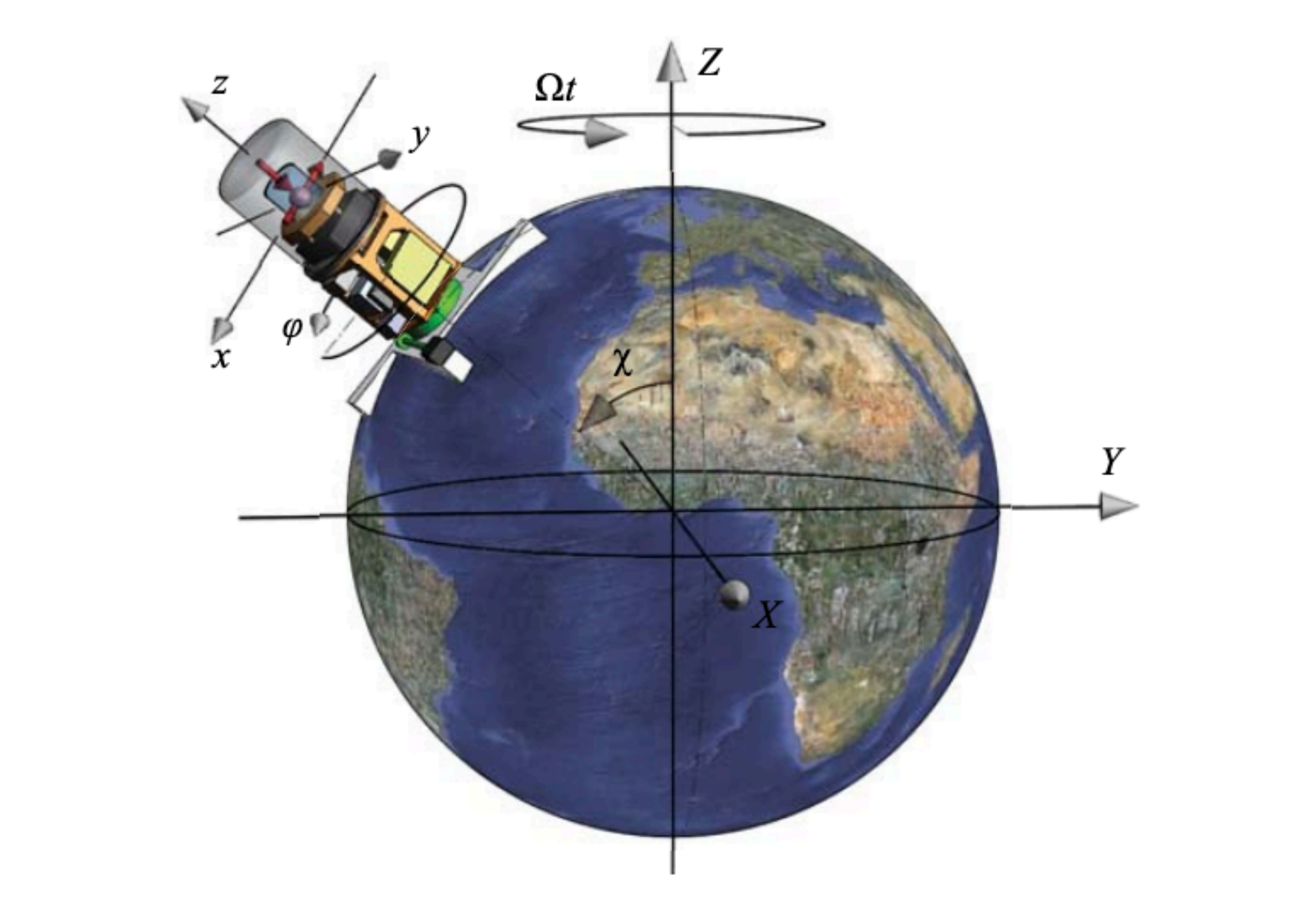
3He-K

$$\delta E = -\mu_{^3\mathrm{He}}\beta_i^N \sigma_i^N = -P_n \widetilde{b}_i^n \sigma_i^n - 2P_p \widetilde{b}_i^p \sigma_i^p$$

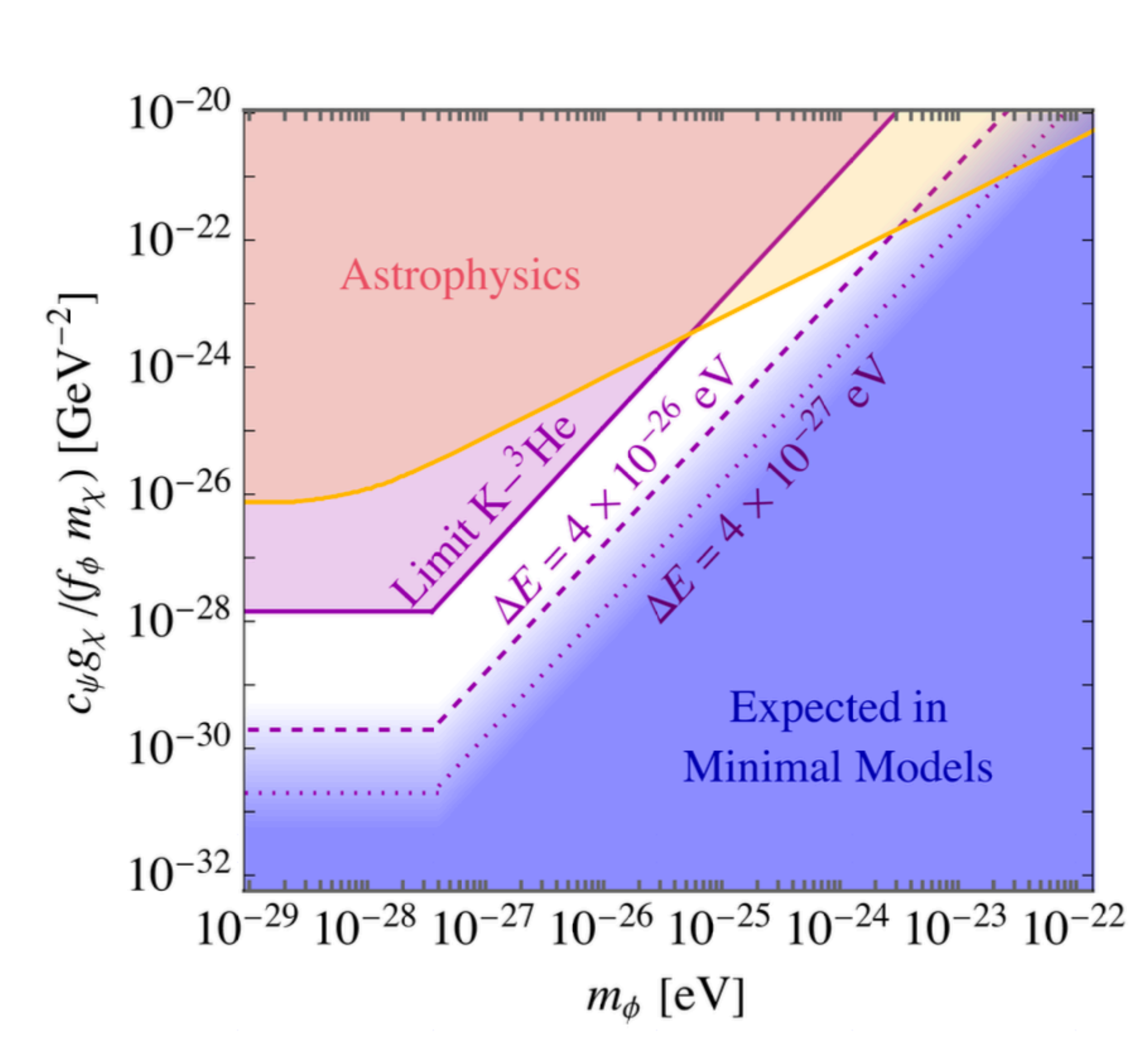
$P_n = 0.87$ and $P_p = -0.027$

$$|\widetilde{b}_{XY}^n| < 3.7 \times 10^{-33}\ \mathrm{GeV}$$

$$\Delta E \simeq 3 \times 10^{-24}\ \mathrm{eV}\,\kappa \begin{cases} 1/\left(\lambda_\chi m_\phi\right)^2 & \text{if } m_\phi > 1/\lambda_\chi\,, \\ 1 & \text{if } m_\phi < 1/\lambda_\chi\,, \end{cases}$$



Experimental Constraints and Sensitivity

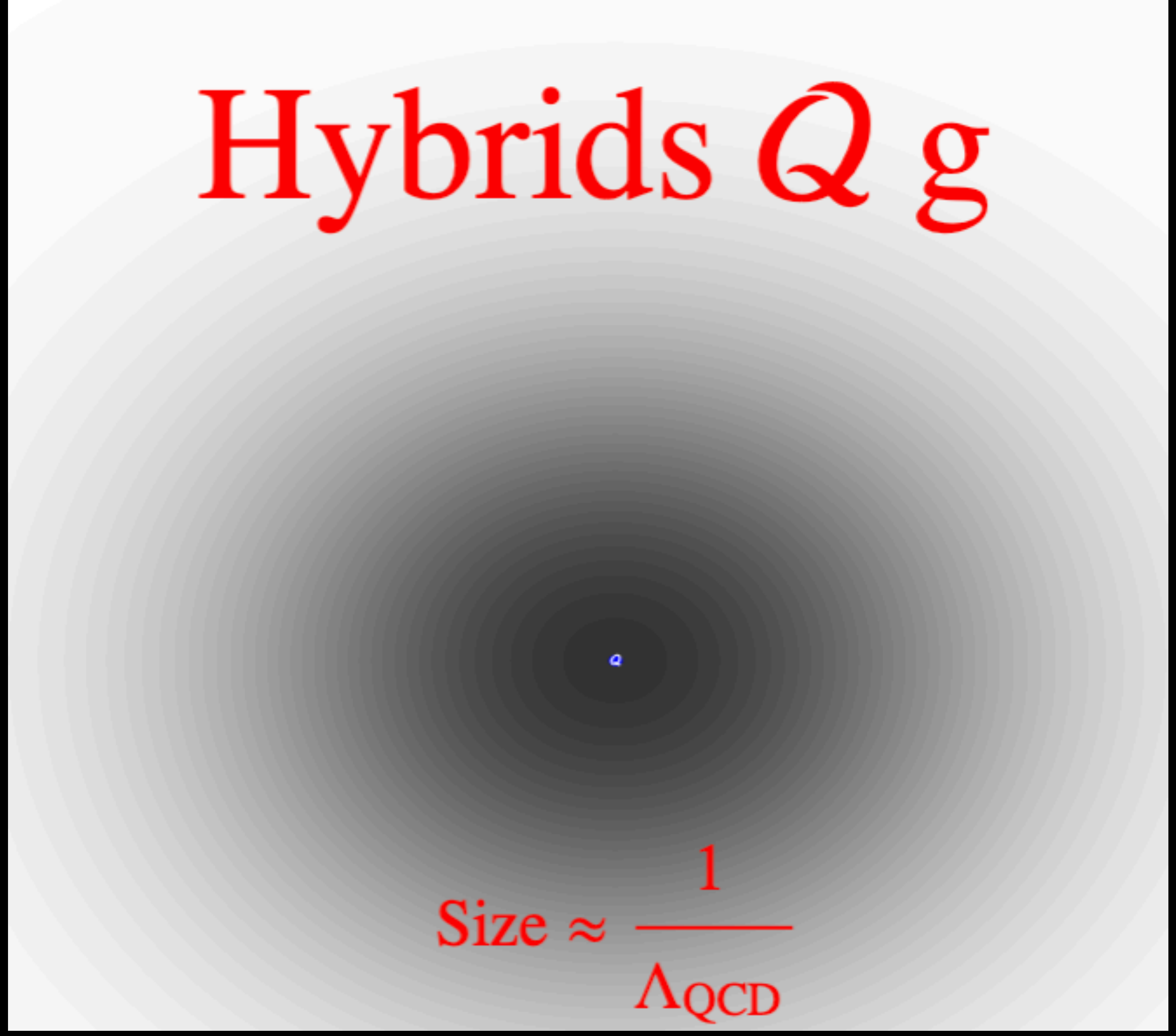


$$1 < c_\psi < 100.$$

21Ne-Rb-K
1106.0738...

Example of a UV Embedding

DM with a new Confinement Scale



Colored DM
1801.01135

$$\chi \sim Qg$$

$$r \sim \Lambda^{-1} \gg m_Q^{-1}$$

$$\Lambda \lesssim 10^{-3}\ \mathrm{eV}$$

$$g_s^{\chi} \sim \theta\Lambda/f_{\phi}$$

$$f_{\phi} \sim 10^{9}\ \mathrm{GeV}$$

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Thanks

Backup

Axion Field Saturation

$$V = -\Lambda^4 \cos\left(\frac{\phi}{f_\phi}\right) - \Lambda'^4 \cos\left(\frac{\phi}{f_\phi} + \delta\right) \ .$$

$$\phi \mapsto \phi - f_\phi \theta$$

$$V \supset \Lambda \bar{\chi}\chi \cos\left(\frac{\phi}{f_\phi}\right) \ .$$

$$\phi/f_\phi \simeq \pi - \theta$$

$$V \supset \Lambda \bar{\chi}\chi \cos(\phi/f_\phi + \theta) \ .$$

$$\mathcal{L} \supset \sin(\theta)\Lambda/f_\phi \phi \, \bar{\chi}\chi \, .$$