Variation of α from a Dark Matter Force

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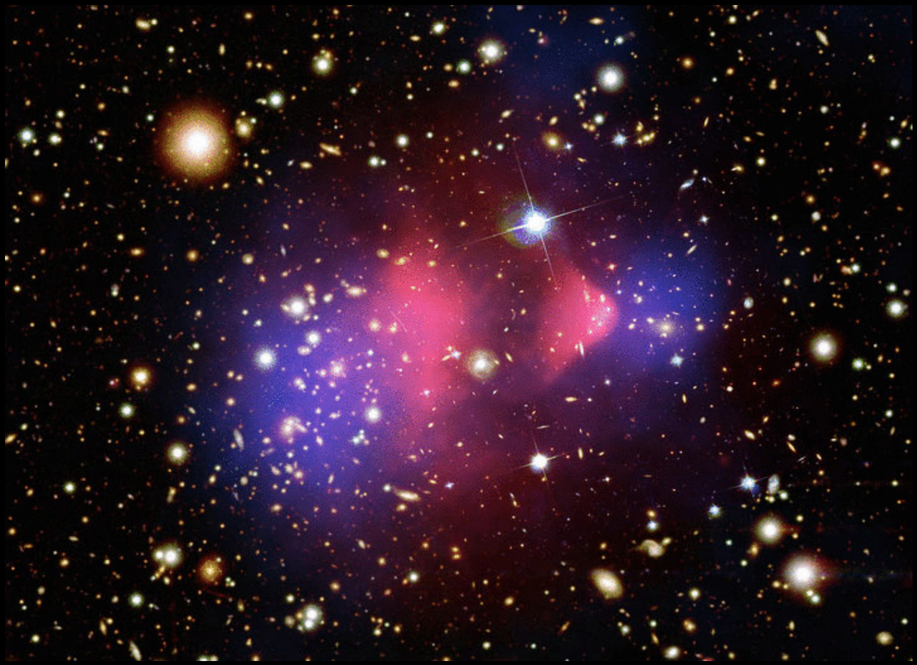


Based on: H.D. and P.P. Giardino, arXiv:1804.01098 [hep-ph]

Pheno 2018, University of Pittsburgh, May 7-9, 2018

- **There are good reasons to look for new physics:**

- Dark matter (DM) not explained in Standard Model (SM)
- Neutrino masses ($\lesssim 0.1$ eV) and mixing require new states

\- Right-handed neutrinos, . . .

- Theoretic or conceptual hints

\- Why is gravity so weak?

\- . . .

- **In this talk:**

- DM as a new sector with its own forces
- Long range scalar force acting on DM and unstable SM states

\- Challenging to probe (no macroscopic population of unstable states)

\- We focus on the muon

\- For concreteness, DM mass of ~ 1 GeV

- Prediction: variations of α in space and time

Some previous work with long range DM forces: Frieman, Gradwohl, Phys. Rev. Lett. 67, 2926 (1991); Gradwohl, Frieman, Astrophys. J. 398, 407 (1992); Dolgov, Phys. Rept. 320, 1 (1999); Farrar, Peebles, Astrophys. J. 604, 1 (2004); Gubser and P. J. E. Peebles, Phys. Rev. D70, 123511 (2004); Phys. Rev. D70, 123510 (2004); Nusser, Gubser, and P. J. E. Peebles, Phys. Rev. D71, 083505 (2005); Kesden and M. Kamionkowski, Phys. Rev. D74, 083007 (2006); Phys. Rev. Lett. 97, 131303 (2006); Farrar, Rosen, Phys. Rev. Lett. 98, 171302 (2007)

- Scalar ϕ, mass $m_\phi^{-1} \sim 100$ kpc coupled to DM X and the muon
- $m_\phi \sim 10^{-28}$ eV

- Yukawa couplings to DM and muons:

$$\mathcal{L}_i = -g_X \phi \bar{X} X - g_\mu \phi \bar{\mu} \mu$$

$$\mathcal{L}_m = -m_X \bar{X} X - m_\mu \bar{\mu} \mu - \frac{1}{2} m_\phi^2 \phi^2 \quad \textit{(in vacuo)}$$

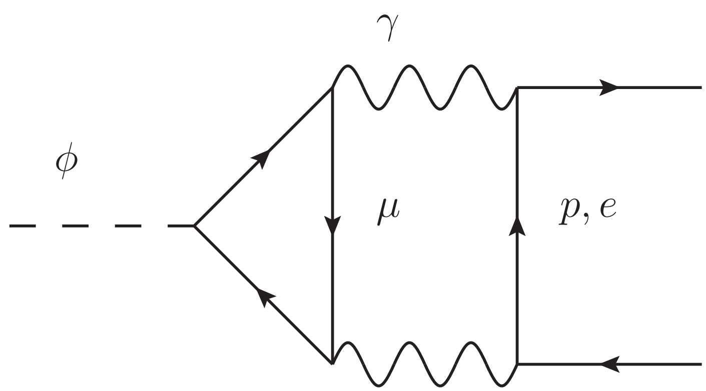
- Equation of motion: $(\Box + m_\phi^2)\phi = -g_X \bar{X} X = -g_X n_X \langle \sqrt{1 - v^2} \rangle \mathrm{sgn}(\phi)$
- v velocity of X

- Uniform, static, sufficiently large DM population: $\Box\phi \approx 0$

$$\Rightarrow \quad \boxed{\phi \approx -\frac{g_X n_X}{m_\phi^2}}$$

Formalism adapted from, *e.g.*, S. Gubser and Peebles, Phys. Rev. D70, 123511 (2004)

- Assuming galactic range for ϕ, we consider $g_X \lesssim m_X/M_P$
- Sub-gravitational g_X to avoid conflict with DM dynamics on large scales
- Coupling to muon constrained by loop-induced e, p couplings



$$g_p \sim \frac{\alpha^2}{(4\pi)^2}\frac{m_\mu}{m_p} g_\mu \qquad (g_e \propto m_e/m_\mu)$$

- Tests of Equivalence Principle: $|g_{p(e)}| \lesssim 10^{-24\,(25)} \Rightarrow |g_\mu| \lesssim 10^{-17}$

Schlamminger et al., 2007; MICROSCOPE mission, 2017

Variation of α

H.D., Giardino, 1804.01098

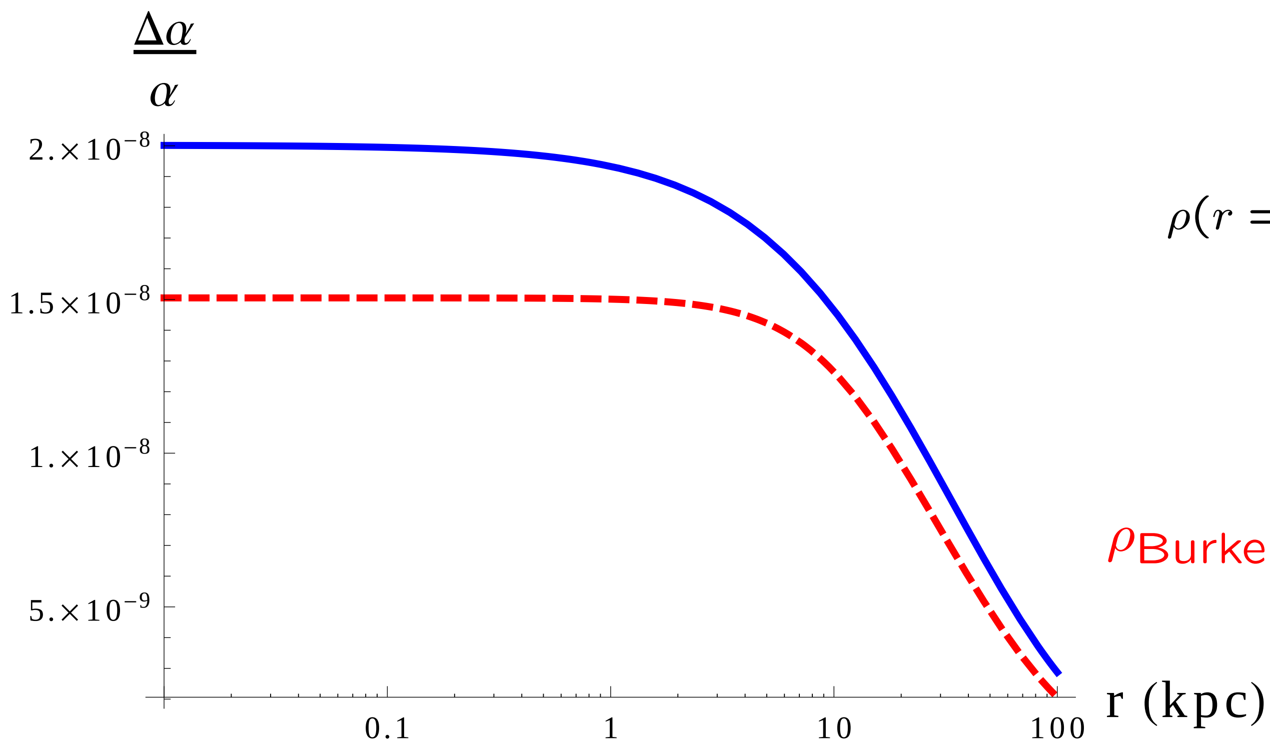
- Challenge for discovery if g_X and g_μ near gravitational strength
- No macroscopic population of μ available

- However, background ϕ sourced by DM $\to \Delta m_\mu = g_\mu \phi$

- Imprint on fine structure constant α (threshold effect)

$$\frac{\Delta\alpha}{\alpha} = \frac{2\alpha}{3\pi} \ln(1 + \frac{\Delta m_\mu}{m_\mu})$$

Similar considerations in different frameworks: Chacko, Grojean, Perelstein, 2002; Dent, 2003



$R = 20$ kpc, $r_c = 10$ kpc

$\rho(r = 8.5 \text{ kpc}) = 0.3 \text{ GeV/cm}^3$

$$\rho_{\text{NFW}} = \frac{\rho_n}{(r/R)(1+r/R)^2}$$

$$\rho_{\text{Burkert}} = \frac{\rho_b}{(1+r/r_c)(1+(r/r_c)^2)}$$

$m_\phi = 1/100 \text{ kpc}^{-1}$, $g_\mu = -2\times 10^{-18}$ and $g_X = 5\times 10^{-20}$, r distance from center of the Galaxy in kpc. Blue solid line NFW, red dashed line Burkert profile.

- Solve for ϕ with $\partial_r\phi|_{r=0} = \phi(\infty) = 0$; $\Delta\alpha \equiv \alpha - \alpha_{\text{vac}}$
- Oklo natural reactor bounds: $\frac{\Delta\alpha}{\alpha} \lesssim 10^{-8}$—$10^{-7}$ (2 billion years ago)

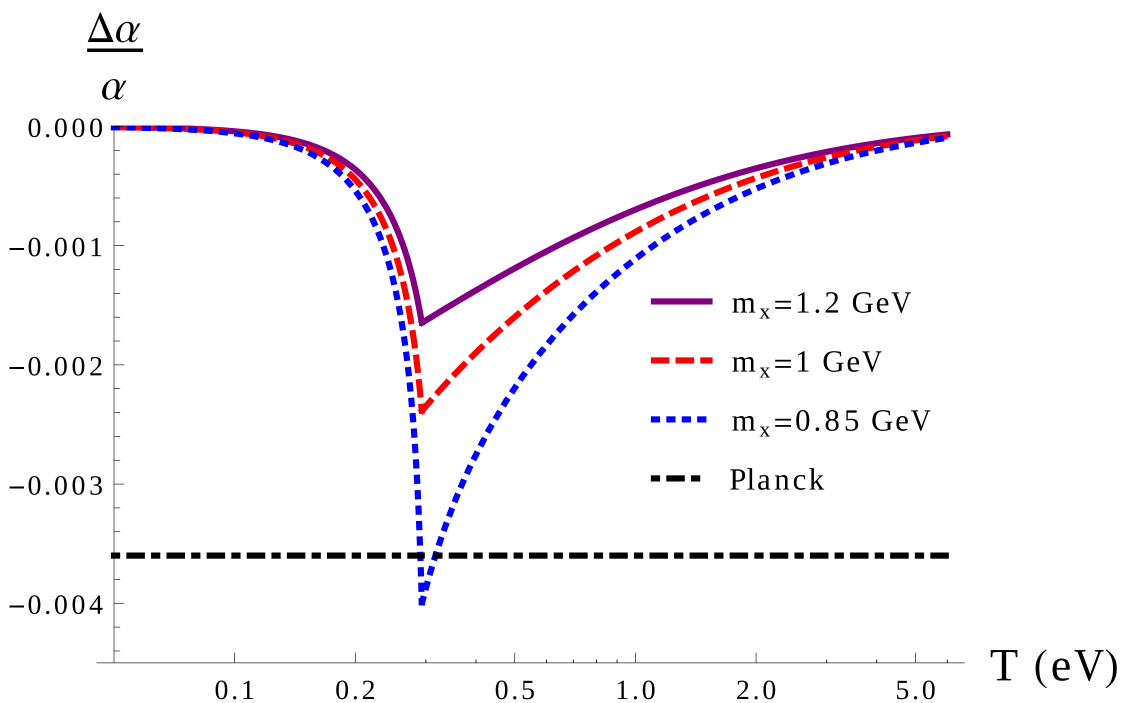
\- Allows $\mathcal{O}(1)$ change in Milky Way DM content

- Bounds from other galaxies less constraining: $\frac{\Delta\alpha}{\alpha} \lesssim 10^{-6}$

- Δm_μ effect grows with n_X ($\sim T^3$) until horizon size $< 1/m_\phi$

$$\phi \sim -g_X n_X d_{\text{hor}}^2 \propto \begin{cases} \text{consant} & \text{matter-dominated} \\ \frac{1}{T} & \text{radiation-dominated} \end{cases}, \qquad (d_{\text{hor}} \sim 1/H)$$

- Planck collaboration (2015): $(\boldsymbol{\alpha}_{\text{CMB}} - \boldsymbol{\alpha}_{\text{present}})/\boldsymbol{\alpha}_{\text{present}} = (\mathbf{-3.6 \pm 3.7}) \times \mathbf{10^{-3}}$



$\Delta\alpha/\alpha$, with $m_\phi = 1/300\ \text{kpc}^{-1}$, $g_\mu = 10^{-18}$ and $g_X = 2 \times 10^{-21}$, as a function of the temperature (T) of the Universe in eV.

- $g_X \lesssim 10^{-19}$ or else $\Delta m_X/m_X \gtrsim 1\%$, conflict with CMB data
- If Planck result holds: $g_\mu \gtrsim 10^{-19} \Rightarrow g_p \gtrsim 10^{-26}$ (2-loop effect)

$\therefore$ *Violations of Equivalence Principle not far from present bounds*

Concluding Remarks

A long range DM force can lead to interesting possibilities

- We focused on a scalar mediator

Variations of α:

- Gravitational level scalar coupling to DM, unstable SM states: challenge to detect

- Focus on muons: DM can source scalar potential to yield Δm_μ

- $\Delta m_\mu \to \Delta\alpha/\alpha$ (threshold effect)

- Modest Planck hint for $\Delta\alpha/\alpha \sim 10^{-3}$ can be accommodated

- Could imply detectable Equivalence Principle violation

- Discovery of an ultra light scalar: significant implications for physics on long and short distance scales