Searching for O (100 MeV) lines and sources with eAstrogam

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2nd e-ASTROGAM Workshop
13-14 October 2017

Jump into the unknown

- WIMP miracle – particle with mass ~ O(100 GeV) suitable for a dark matter candidate
  - Weakly interacting
  - Correct matter density in the Universe

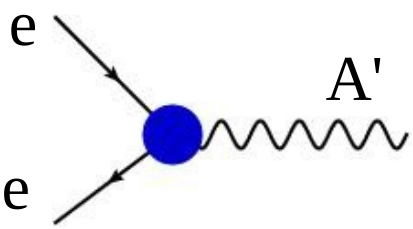
However … no particle with such characteristics discovered so far…

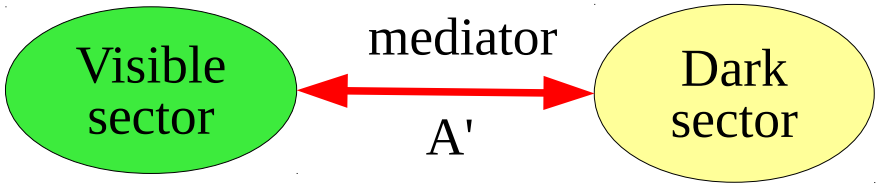
- Multiparticle structure of the Standard Model
  - Why the DM should be composed of a single particle?
- The picture should be simple, but not simpler than necessary

The childhood of DM is over and it is time to stop believing in miracles

New interactions

- The simplest effective interaction that can be studied is





$$\boldsymbol{L} \sim g' q' \,\overline{\Psi}\,(\gamma_\mu + \alpha'_a\,\gamma_\mu\,\gamma^5)\Psi\,A'^{\,\mu},\ \ usually\ \alpha'_a = 0$$

  - $q_f \rightarrow 0$ for some flavours

- Such textbook scenario could address the (g_μ-2) discrepancy, abundance of antimatter in cosmic rays, signals for DM scattering
  - General U'(1) and kinetic mixing with B (A', Z')
    - Universal coupling proportional to the q_{em}
    - Just single additional parameter – ϵ

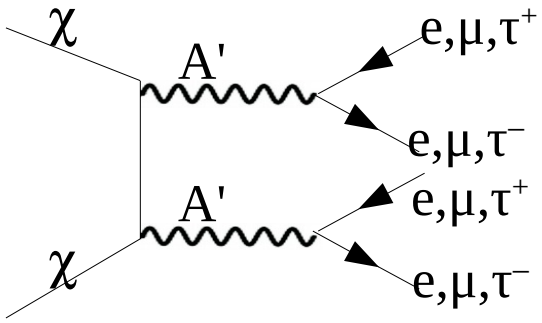
$$L_{mix} = -\frac{\epsilon}{2} F^{QED}_{\mu\nu} F^{\mu\nu}_{dark}$$

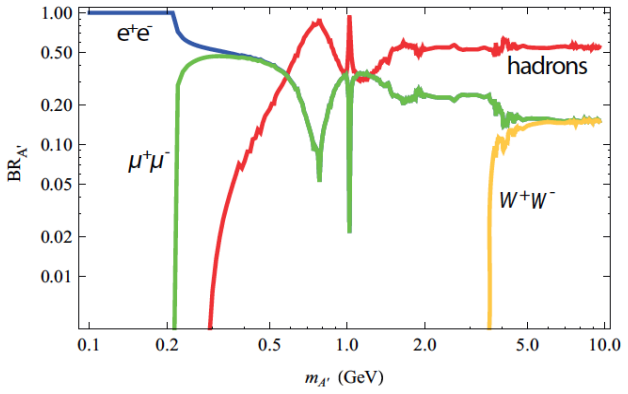
  - Leptophilic/leptophobic dark photon
- Other messenger types possible (neutrino, higgs, ALP)
- **Rich dark sector?**

Dark mediator phenomenology

- Production mechanisms
  - DM annihilation
- Decays
  - To SM model particles if nothing in the DS lighter than A'
    - Note that that it is not “fundamentally” granted that the mediator will decay with the same strength to positrons (if at all) and to heavier leptons!
  - A' → γγ, if M(A') < $2m_e$, small width, A' quasi stable
  - To DS particles with Br(A' → χχ) = 1
- Contribution to g-2:
  - About 3 σ discrepancy theory vs experiment

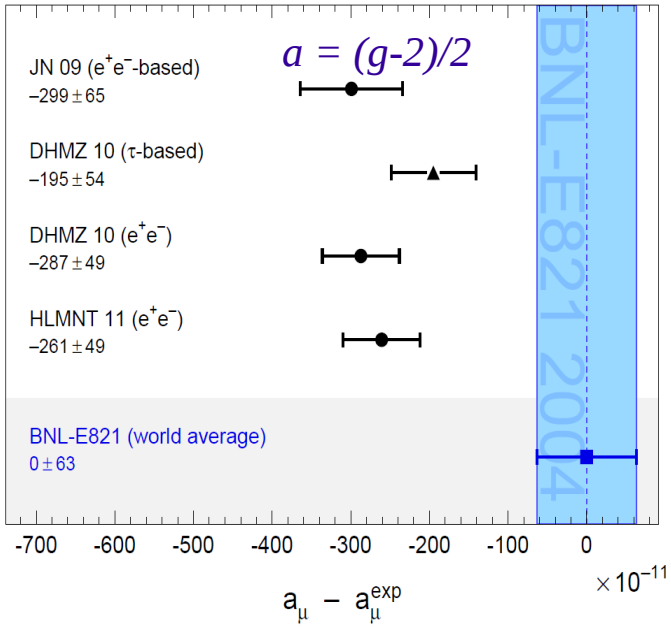
Dark matter annihilation





Lepton (non)universality

PDG:



- Electron case: *Phys.Rev.Lett.106:080801,2011*

$$|a_e^{th} - a_e^{exp}| = (1.06 \pm 0.82) \times 10^{-12}$$

- However, the theoretical value uses input for α_{EM} measured again with electrons and relying on the knowledge of g_e in bound states…
- In fact, the discrepancy is not in g_μ-2 itself, it's in the consistency of g_e & g_μ

- Proton radius: measured from Hydrogen spectrum

Beyer et al., Science 358, 79–85 (2017)

$R^{\mu H}_{\infty} = 10973731.568076(96)\ m^{-1}$

$r^{\mu H}_{p} = 0.8335(95)\ fm$

$> 3\ \sigma$

CODATA

$R_{\infty} = 10\ 973\ 731.568\ 508(65)\ m^{-1}$

$r_p = 0.8751(61)\ fm$

- The consistency of the electron measurements оф a_{EM} and anomalous magnetic moment might be misleading for the perfection of the theory and may be we already face a manifestation of violation of lepton universality (LUV)

Gammas, DM, and LUV

- Observation of 511 keV line indicates rich e^+ regions
  - Possible various production mechanism
- Can similar signature be observed in other channels?

- Muons: $M\mu = 105.66$ MeV, $\tau_\mu = 2.2$ μs
  - Short, but still much longer than the rest of the unstable elementary particles
- Sources of muons
  - High energy proton collisions → mesons production (π, K…) → decays
  - Exotic sources
    - DM annihilation, through a (possibly virtual) mediator
      - $\chi\chi \rightarrow A'A' \rightarrow \mu^+\mu^-\mu^+\mu^-$, $\chi\chi \rightarrow A'^* \rightarrow \mu^+\mu^-$
    - Due to finite lifetime low energy muons do not propagate far from the emission source, even for $M\chi = 100$ GeV → point like sources
- Signature of regions with high muon density: a gamma line of μμ annihilation!
  - $E\gamma = 105.66$ MeV, just within the sensitive region of eASTROGAM

Conclusions

- Physics goal: Perform an all sky mapping with O (100 MeV) gammas and search identifiable emission regions and point-like sources.
- Such a survey on the possible regions with μμ annihilation has not been performed so far
- There is no natural abundance of μ^- as for the case for e^-, both μ^+ and μ^- should be produced through a local mechanism
- The excess of signal in the abundance of positrons is intriguing, but any observation of a similar phenomena in the muon channel is equally important
- The signals in the electron mode and in muon mode might in fact be unrelated: if DM (and the mediator) possess lepton flavour violating characteristics, as seem to be preferred by some recent results, it might be that only the muons are the “golden” observation channel
- Apart from DM, also the possible creation of μ^+-μ^- atoms in astrophysical objects could be probed.