Hidden Photon as Dark Matter Candidate

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VII PATRAS Workshop - 30th June, 2011

Work in progress: M. Goodsell, J. Jaeckel, J. Redondo, A. Ringwald

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The hidden sector of particle physics

A prominent messenger from an extra Abelian $U(1)$ sector is the so called *hidden photon* or *paraphoton*.
The theoretical motivation, as well as the current experimental searches as been nicely discussed in dedicated talks to HP:

- Experimental talks: R. Povey, M. Schwartz, E. von Seggern, etc
- Theoretical: S. Troitsky, J. Redondo, P. Ko, S. Andreas, etc

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Hidden photon community in expansion!

Effective Mixing Lagrangian

The interaction of the hidden sector with our visible sector, at low energies reads

$$\mathcal{L}_{\rm mix} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + A^{\mu}J_{\mu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B^{\mu}B_{\mu} - \frac{\chi}{2}F_{\mu\nu}B^{\mu\nu}.$$

- The kinetic mixing between photon-HP reflects the non-orthogonality between both $\{A_\mu, B_\mu\} \Rightarrow$ **Well known oscillations**

If we are interested in physics cases where a media is present, we can include the photons interaction with the media via the polarization tensor $\Pi^{\mu\nu}$,

$$\mathrm{Re}\{\pi\} \equiv m^2_{\gamma}, \quad \text{and} \quad \mathrm{Im}\{\pi\} \equiv -\omega D, \quad m^2_{\gamma} \gg \omega D$$

Applying the diagonalisation procedure, we switch to the propagation basis $\left\{\tilde{A}, \tilde{S}\right\}$, $S \Rightarrow$ orthogonal to A and sterile

$$A_\mu \to \tilde{A}_\mu + \chi\frac{m^2_{\gamma'}}{m^2_{\gamma} - m^2_{\gamma'} - i\omega\Gamma}\tilde{S}_\mu, \quad S_\mu \to \tilde{S}_\mu + \chi\frac{m^2_{\gamma'}}{m^2_{\gamma'} - m^2_{\gamma} + i\omega D}\tilde{A}_\mu$$

Matter Matters

Therefore, in presence of a media, the coupling constant is effectively changed as

$$\chi^2 \to \chi^2_{\rm eff} = \chi^2 \frac{m^4_{\gamma'}}{\left(m^2_\gamma - m^2_{\gamma'}\right)^2 + (\omega D)^2}$$

For coupling to photons and matter (through $J^\mu A_\mu$).

The oscillation probability between photon and the sterile state is

$$P_{A\to S} = 4\chi^2_{\rm eff} \sin^2\left(\frac{\sqrt{\left(m^2_\gamma - m^2_{\gamma'}\right)^2 + (\omega D)^2} L}{4\omega}\right).$$

Matter Matters

Main features from matter effects:

For $m_{\gamma'} \ll m_\gamma$

High suppression of $\chi_{\rm eff}$,
$\chi_{\rm eff} = \chi m_{\gamma'}^2/m_\gamma^2$

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$m_{\gamma'} = m_\gamma$

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Resonant oscillation

Media effects can truly change the expected interaction of HP with photons and matter:

- Extremely sensible in Cosmology, where the photon is immerse in an ionized plasma !! (and more!)

Hidden photon condensate from the early Universe?

Recently in:

hep-ph: 1105.2812

Dark Light, Dark Matter and the Misalignment Mechanism

Ann E. Nelson and Jakub Scholtz

May 16, 2011

Abstract

We explore the possibility that the dark matter is a condensate of a very light vector boson. Such a condensate could be produced during inflation, provided the vector mass arises via the Steuckelberg mechanism. We derive bounds on the kinetic mixing of the dark matter boson with the photon, and point out several potential signatures of this model.

Motivation: A hidden photon, with a mass generated by a Stueckelberg mechanism, very light is of theoretical and phenomenological interest. The spatial component of the field satisfies

$$\ddot{S} + 3H\dot{S} + m^2_{\gamma'} S = 0,$$

Initial conditions?? After the epoch $m_{\gamma'} \sim H$ the field starts to oscillate and dark matter is produced.

Successful CDM: should not decay in the early universe nor in vacuum.

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Strong thermalisation process $\gamma' + e \to \gamma + e$ " Compton evaporation"

Hidden photon condensate from the early universe?

Main Issues:

- This translates into the conclusion: The highest T the better as a probe. High temperature gives the most stringent bound on thermalisation due to the number of electrons in the plasma was the highest. If survived this epoch, then survives the subsequent ones.
- the analysis suggest that for the range of masses $m_{\gamma'} \sim 10^{-6}$eV a HP with $\chi \lesssim 10^{-11}$ would be a valid CDM candidate

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- the analysis suggest that for the range of masses $m_{\gamma'} \sim 10^{-6}$eV a HP with $\chi \lesssim 10^{-11}$ would be a valid CDM candidate
- **Does not take into account matter effects!**

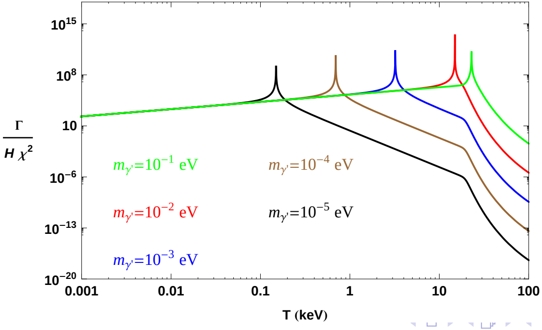
Unfortunately, as mentioned before, matter effects change the naive picture quite dramatically!

Our work in progress is trying to asses this key point in the analysis.

Hidden photon condensate from the early universe?

As an exercise we consider low temperatures, $T \ll m_e$ where the density of electrons has dropped to $n_e \sim n_B$

A first estimation to test if at this scale a thermalisation could be possible we check Γ/H



Hidden photon condensate from the early universe?

The enhancement of the Compton evaporation process at $T = T_{\rm res}$ is huge compared to $T \neq T_{\rm res}$!

Matter Matters!!

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Matter Matters!!

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This invalidates the argument that the strongest constraint on the thermalisation of the hidden photon due to Compton evaporation comes from the highest temperatures at which the HP was present!!!. The strongest constraints on the thermalisation process come from resonant Compton evaporation (so far we have not referred to thermalisation due to resonant oscillations!)

Hidden photon condensate from the early universe?

Our findings seem to indicate that the HP can conform CDM..... MORE SOON!

Detection sensitivity?

ADMX bounds

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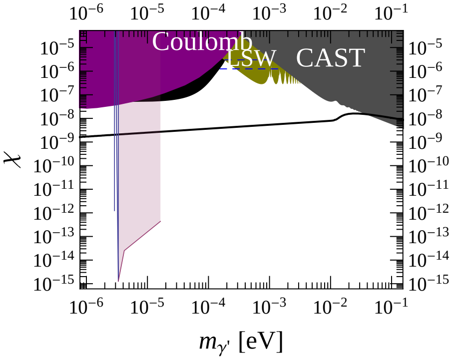


A hidden CMB?

Was suggested in

Signatures of a hidden cosmic microwave background

Joerg Jaeckel,[1] Javier Redondo,[2] and Andreas Ringwald[2]

[1]Institute for Particle Physics and Phenomenology, Durham University, Durham DH1 3LE, UK
[2]Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22607 Hamburg, Germany

If there is a hidden photon – i.e. a light abelian gauge boson γ' in the hidden sector – its kinetic mixing with the standard photon can produce a hidden cosmic microwave background (hCMB).

Resonant oscillations between meV hidden photons and photon plasma after BBN and before CMB decoupling can lead to an efficient production of a thermal bath of HP (*the so-called hCMB*).

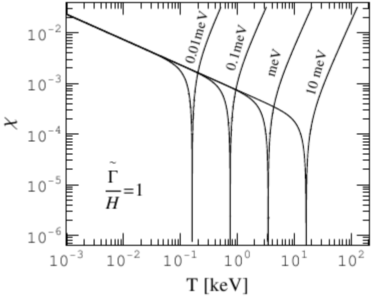
Main features

- Oscillations $\gamma \to \gamma'$ decrease n_γ and the energy density ρ_γ.
- Thermal hCMB contributes to the radiation energy density=HOT DARK MATTER RELIC!. This "invisible" energy can be accounted as extra neutrino degrees of freedom $\Rightarrow$ higher N_ν.

Signatures of a hidden CMB

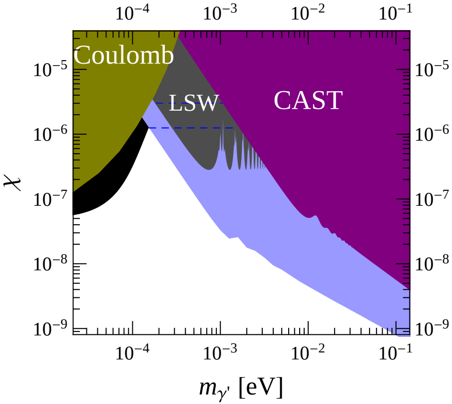
...Main features

- Baryon to photon ratio at decoupling increased.
- Inelastic processes (such as double Compton scattering) are effective after hCMB decoupling. Photons regain blackbody spectrum at a lower temperature.



Bounds and future tests

Using the observations of ALPS (see talk by E. von Seggern) and SHIPS (see talk by M. Schwarz) we can hopefully next year probe the hCMB!!!!
TSHIPS:



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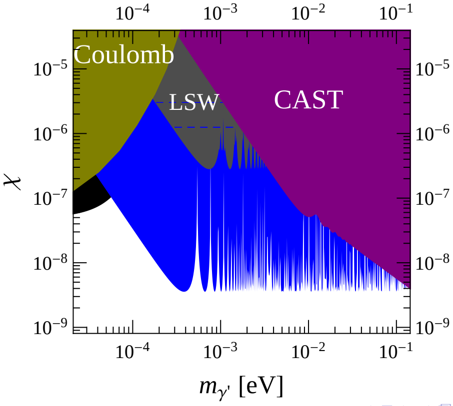
ALPS-2012 phase



Outlook y Conclusion

- The hidden photon as a CDM and hot DM candidate seems exciting from the theoretical point of view and encouraging for experimental searches and signatures.
- As we have seen, matter effects can change completely the physical picture. Further computations on CDM should fully include matter effects. The misalignment between photon and HP mass eigenstates "identically" mimic the famous neutrino oscillations, where also matter effects are known to be relevant.
- We should clarify the production of the HP condensate, the thermalisations processes that may interfere with the success of this candidate in the early universe and so on.
- The present Axion-CDM searches can be use to already constraint the parameter space and further experiments hopefully will join!
- The search for imprints in cosmology (but not only!) goes on, and hopefully very soon we would be able to test some of the hypothesis in the lab.