Polarisation of photons emitted by decaying dark matter

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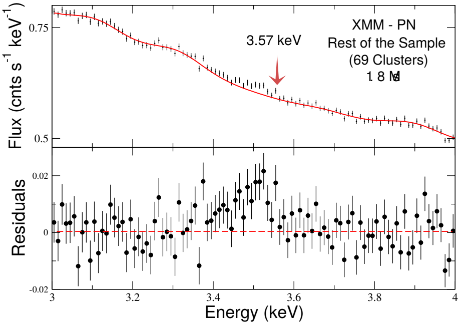
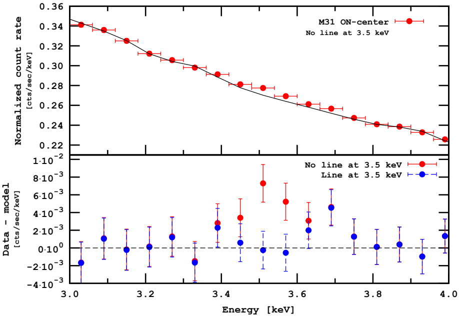
Indications of the unidentified X-ray line

E.Bulbul et al., Astrophys.J. 789 (2014) 13, arXiv:1402.2301



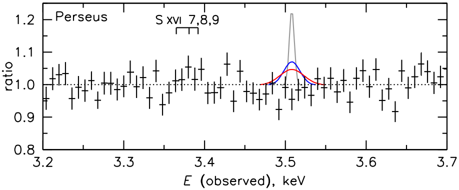
A.Boyarsky et al., Phys.Rev.Lett. 113 (2014) 251301, arXiv:1402.4119



X-ray line non-confirmed by Hitomi

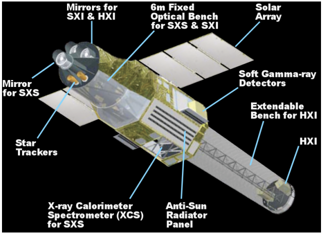
Hitomi Collaboration (Felix A. Aharonian et al.),

arXiv:1607.07420



The next mission is needed...

X-ray telescope Hitomi (Astro-H) destroyed 26th of March 2016. It worked 37 days instead of 3 years planned.



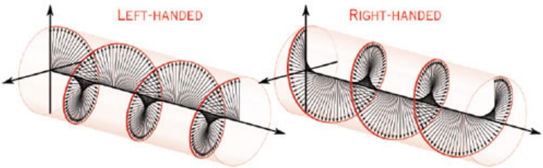
Radiative keV dark matter models

- Sterile neutrino (νMSM)
- Axion or axion-like particle
- SUSY: axino, gravitino
- Majoron
- Excited dark matter
- Annihilating dark matter
- ... about 300 papers explaining 3.5 keV line!

How to choose?

Two polarization states

$|L\rangle$ $|R\rangle$



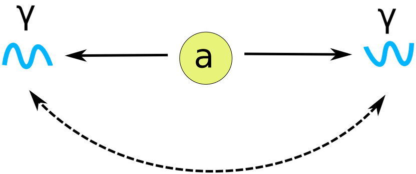
Spin projection:

$(sk) = -1$ $(sk) = 1$

Which particles may emit polarized photons?

Scalar and pseudoscalar decay

$$L = \frac{1}{\Lambda}\phi F_{\mu\nu}F^{\mu\nu}, \quad L = \frac{1}{\Lambda}aF_{\mu\nu}\tilde{F}^{\mu\nu}, \ \Lambda \sim M_P$$



entangled

$(|LL\rangle \pm |RR\rangle)/\sqrt{2}$

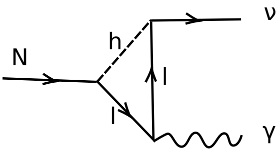
$\rho = (|L\rangle\langle L| + |R\rangle\langle R|)/2$

$$\rho = \frac{1}{2}\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

Fermion effective interaction with photon

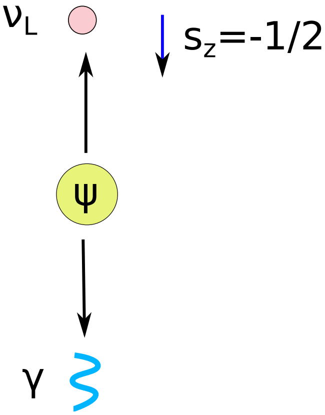
Higgs portal:

$$L_{\nu MSM} = f\, \bar{l}_L N \tilde{\mathcal{H}} + h.c.\ .$$

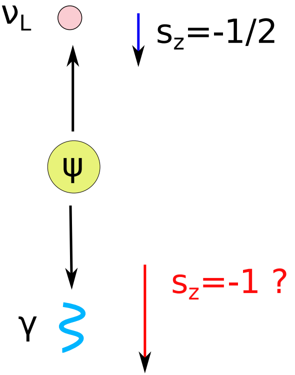


$$L = \frac{v}{\Lambda^2}\, \bar{\nu}_L \sigma_{\mu\nu} N\, F^{\mu\nu} + h.c.$$

Dirac fermion decay



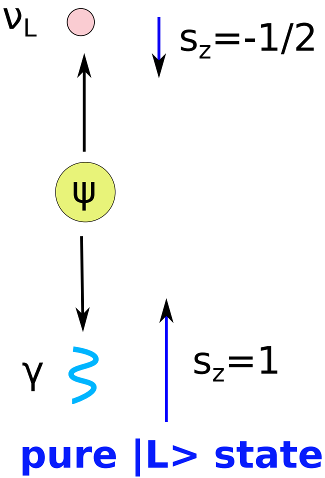
Dirac fermion decay



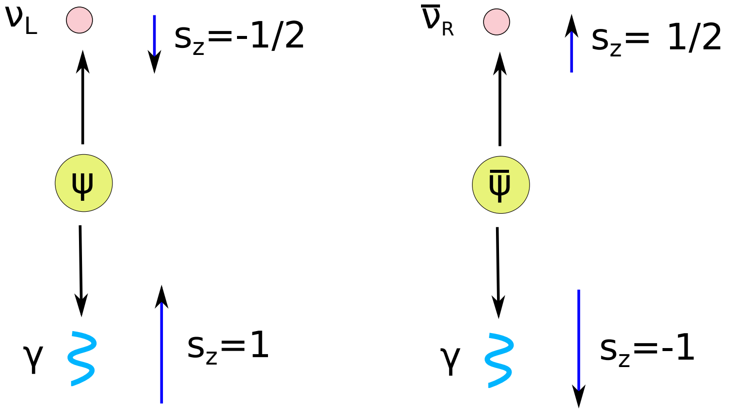
- wrong because $s_z(\psi)=-3/2$ - impossible

No |R> state!

Dirac fermion decay



Dirac fermion decay



pure |L> state **pure |R> state**

Majorana fermion decay

- Each particle may decay both to ν and $\bar{\nu}$
- The state of photon is defined by the state of N which depends on the production mechanism
- Thermal production or inflaton decay:

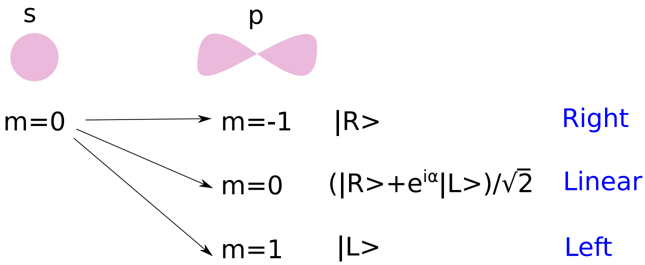
$$\rho = \frac{1}{2}(|R\rangle\langle R| + |L\rangle\langle L|).$$

- Resonant production (Shi, Fuller, Phys. Rev. Lett. **82**, 2832 (1999)): common pure state

$$|\gamma\rangle = \begin{cases} \sqrt{1-\beta}|L\rangle + \sqrt{\beta}e^{i\alpha}|R\rangle, & \text{with probability } \frac{1}{2}, \\ \sqrt{1-\beta}|R\rangle + \sqrt{\beta}e^{i\alpha}|L\rangle, & \text{with probability } \frac{1}{2}. \end{cases}$$

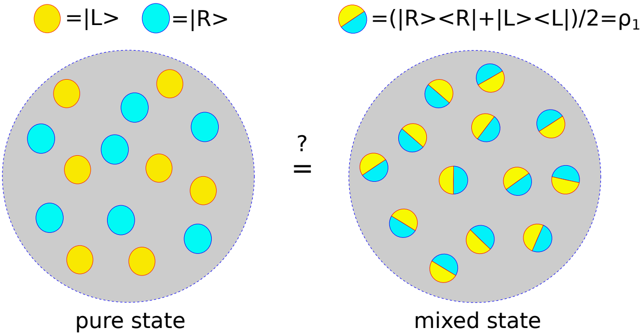
Polarisation of photon from atomic transition

Dipolar transition:



$$|\gamma\rangle = \begin{cases} |R\rangle, \text{ with probability } \frac{1}{3}, \\ |L\rangle, \text{ with probability } \frac{1}{3}, \\ \frac{1}{\sqrt{2}}(|R\rangle + e^{i\alpha}|L\rangle), \text{ with probability } \frac{1}{3}. \end{cases}$$

Pure or mixed state?



measured:

$\langle\Psi|O_1(x_1)\ldots O_n(x_n)|\Psi\rangle$ $\qquad$ $\mathrm{Tr}[\rho_N\, O_1(x_1)\ldots O_n(x_n)]$

O - any gauge invariant operator containing photon field

Dispersion of correlators

Theorem: (S.LLoyd)
Difference between measurement for pure and mixed state is smaller than the dispersion (mistake) for mixed state.

$$\langle (\langle \Psi | A | \Psi \rangle - \mathrm{Tr}(\rho A))^2 \rangle_{|\Psi\rangle} = \frac{\mathrm{Tr}(\rho A^2) - (\mathrm{Tr}(\rho A))^2}{N+1}$$

- $A = O_1 ... O_n$ – product of gauge invariant operators
- N – number of considering photons
- $\rho \sim 1$ – maximally mixed state

Conclusion: all discussed cases provide equivalent result.

Asymmetric Dirac fermionic dark matter

$$n_{\psi} \neq n_{\bar{\psi}} \Rightarrow \text{circular polarization}$$

$$\rho = \frac{1}{n + \bar{n}} \begin{pmatrix} \bar{n} & 0 \\ 0 & n \end{pmatrix} = \frac{1}{2} \left(1 - \eta_{\psi} \sigma_3\right),$$

The example of model:

Dirac sterile neutrino instead of Majorana.

Production:

- Resonant conversion of SM neutrinos to sterile (Shi, Fuller)
- The SM lepton asymmetry (if large enough) directly goes to DM asymmetry
- Natural to have $\eta_{\psi} \sim 1$.

Summary

- Polarization of photons from DM line may give some information about the dark sector
- CP-symmetric dark matter will always provide unpolarized flux of photons. It is impossible to distinguish between scalar, spinor, dark transition, self-annihilation models.
- Asymmetric Dirac fermionic DM will emit circularly polarized line
- Circular polarization of X-ray photons may be a smoking gun of CP asymmetry in the dark sector
- It looks as a good motivation for future observations sensitive to the circular polarization

Thanks for your attention!