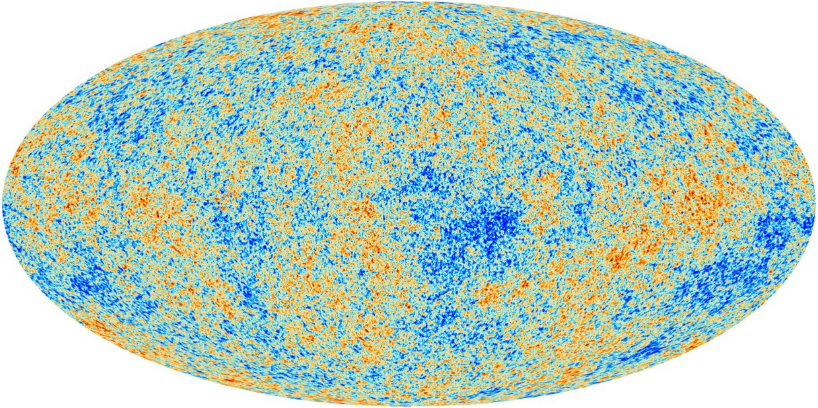
Rijeka, $3^{\rm rd}$ July 2023

Probing the blue axion with cosmic optical background anisotropies

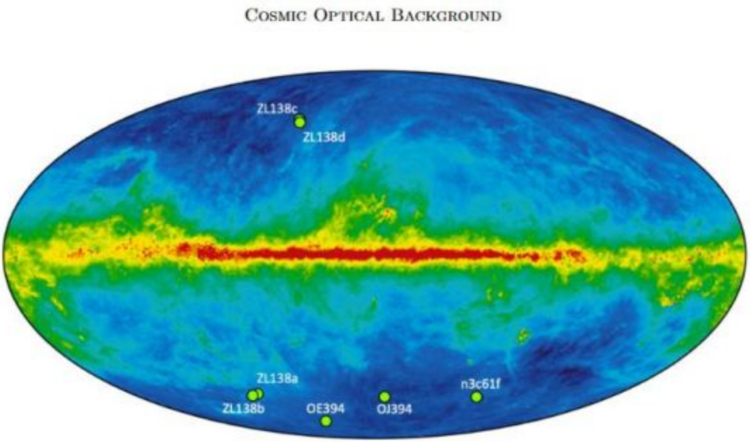
Based on
PC, G. Lucente and E. Vitagliano,
Phys. Rev. D **107** (2023) no.8, 083032

Pierluca Carenza

We are familiar with this....

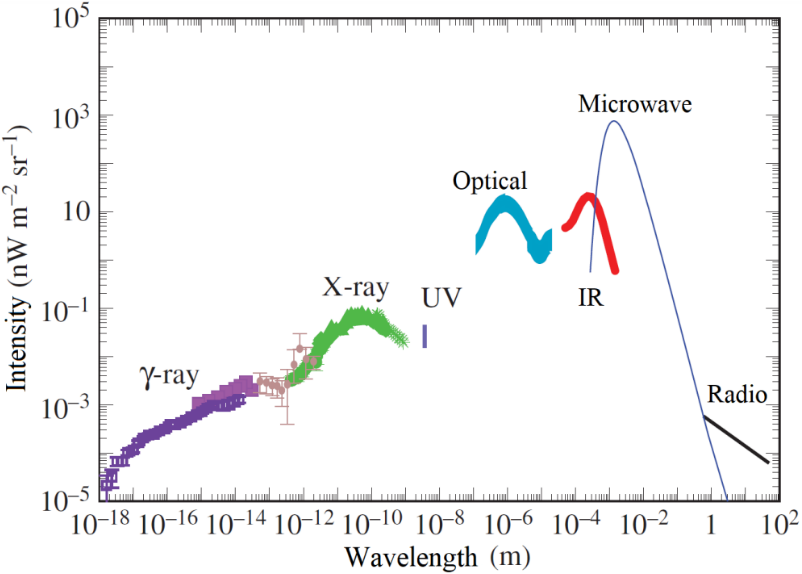


… but less familiar with this

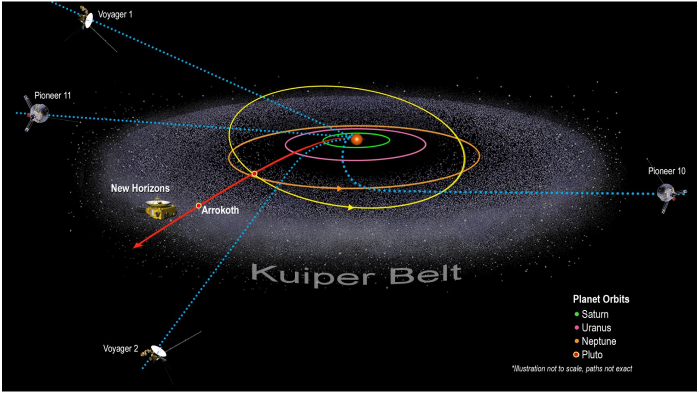


The Cosmic Optical Background

A. Cooray, [arXiv:1602.03512 [astro-ph.CO]]



Some consistency checks



- Direct detection (Pioneer 10/11, New Horizons)
- Galaxy counts (Hubble Space Telecope)
- Gamma-ray attenuation from Blazars: redshift evolution (HESS, MAGIC)

The Cosmic Optical Background: foregrounds

T. R. Lauer *et al.*, Astrophys. J. Lett. **927** (2022) no.1, L8

We look for a really diffuse COB by excluding various known sources

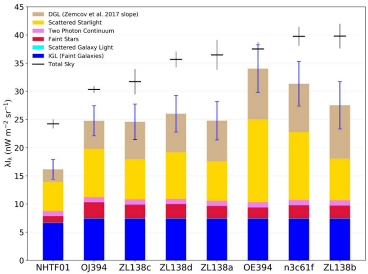


Table 1
Sky Flux Decomposition

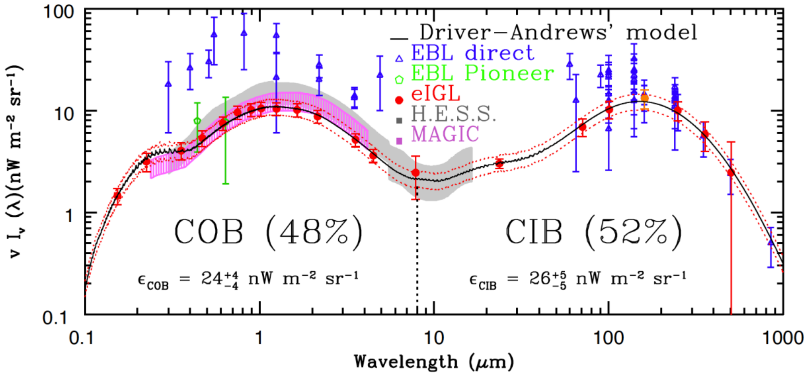
Component	nW m^{-2} sr^{-1}	Stat.	Sys.
Total Sky	24.22 ± 0.80	0.80	0.00
−Scattered Starlight (SSL)	5.17 ± 0.52	0.00	0.52
−Scattered Milky Way Light (DGL)	2.22 ± 1.00	0.32	0.95
−Faint Stars (FSL)	1.16 ± 0.18	0.06	0.17
−Two-photon continuum (2PC)	0.93 ± 0.47	0.00	0.47
−Scattered Galaxy Light (SGL)	0.07 ± 0.01	0.00	0.01
+Bright Field Galaxies	1.70 ± 0.07	0.04	0.06
= **Cosmic Optical Background**	16.37 ± 1.47	0.86	1.19
− Integrated Galaxy Light (IGL)	8.31 ± 1.24	0.78	0.97
= **Anomalous Flux**	8.06 ± 1.92	1.16	1.53

This is what LORRI on New Horizons measured

The Cosmic Optical Background

S. P. Driver *et al.*, Astrophys. J. **827** (2016) no.2, 108

Counting galaxies allows to reconstruct the EBL from IR to UV



Disagreement with local EBL measurements in the optical

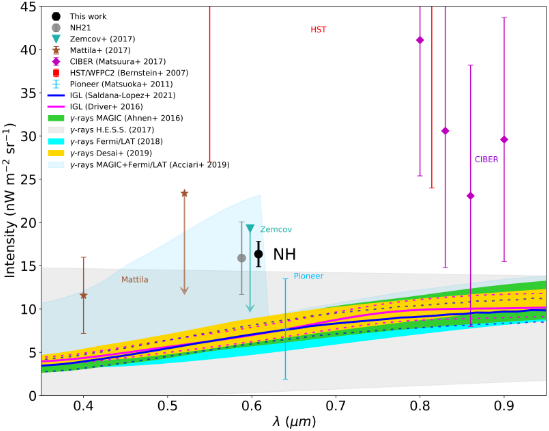
Zodiacal light: a contamination source

Zodiacal light above the Very Large Telescope, Atacama desert

So we understand everything....

T. R. Lauer *et al.*, Astrophys. J. Lett. **927** (2022) no.1, L8

Latest measurements of New Horizons



roughly 50% more light than expected??

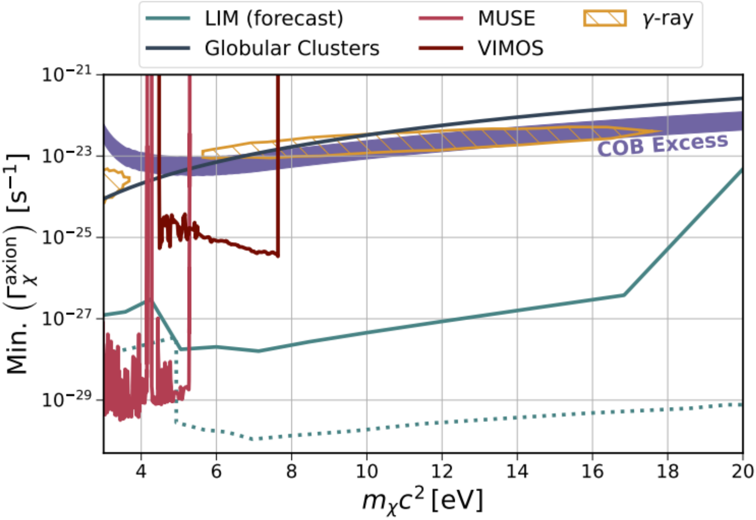
Let's try to explain

B. Yue *et al.*, MNRAS 431 (2013) 383 and MNRAS 433 (2013) 1556

- High-redshift galaxies ($z > 5$)? Not enough light, only 4%
- More intermediate mass black holes? It wouldn't explain the abundance of supermassive BHs
- Only decaying dark matter is left XD

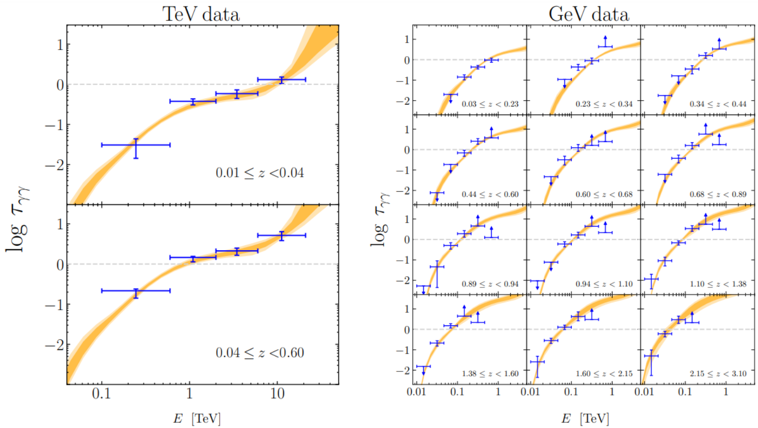
Hint of eV-ish dark matter?

J. L. Bernal *et al.*, Phys. Rev. Lett. **129** (2022) no.23, 231301



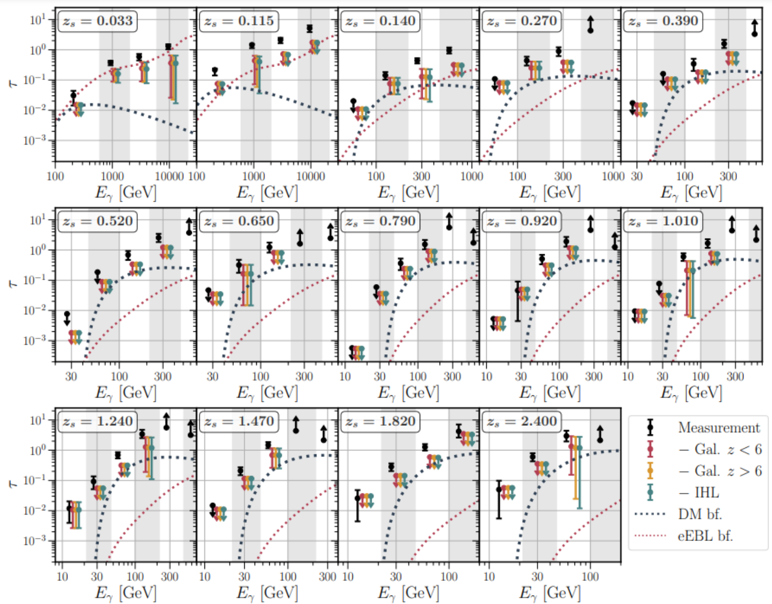
Let's go back to do what we know: γ-ray attenuation

A. Desai *et al.*, Astrophys. J. Lett. **874** (2019), L7



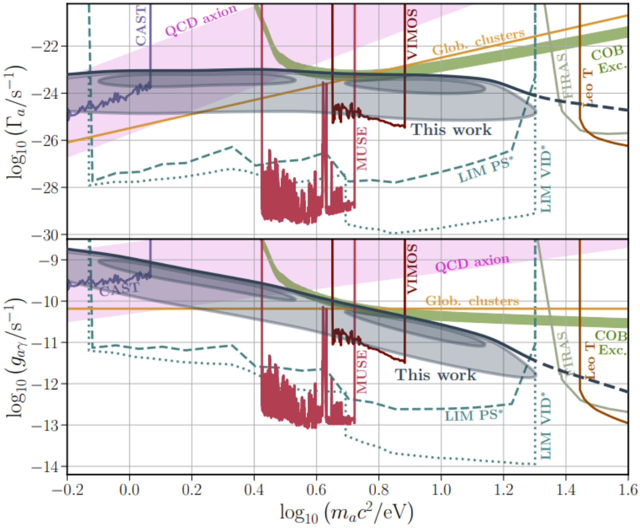
Wrong again??

J. L. Bernal *et al.*, Phys. Rev. D **107** (2023) no.10, 103046



Towards an ALP explanation of this excess

J. L. Bernal *et al.*, Phys. Rev. D **107** (2023) no.10, 103046



At this point....

- Indication of decaying eV-scale dark matter from EBL direct measurement
- Indication of decaying eV-scale ALPs from γ-ray attenuation

Could it be true?

Light from Dark Matter ALP decay

O. E. Kalashev *et al.*, Phys. Rev. D **99** (2019) no.2, 023002

The average light intensity is

$$
\begin{aligned}
I(\omega) &= \frac{\omega^2}{4\pi}\frac{dN_\gamma}{dS\,d\omega\,dt} = \\
&= \frac{\omega^2}{4\pi}\int_0^\infty \frac{dz}{H(z)}\,\frac{\rho_a}{m_a}2\Gamma_{a\to\gamma\gamma}\delta\left[\omega(1+z)-\frac{m_a}{2}\right] \\
&= \frac{\omega}{4\pi}\frac{\rho_a}{m_a}\frac{2\Gamma_{a\to\gamma\gamma}}{H\left(\frac{m_a}{2\omega}-1\right)}
\end{aligned}
$$

We use also anisotropies

$$
\delta I(\omega,\hat{\mathrm{n}}) = I(\omega,\hat{\mathrm{n}}) - \bar{I}(\omega) = \sum_{l,m} a_{lm}(\omega) Y_{lm}(\hat{\mathrm{n}})
$$

COB Anisotropy: observations

$$C_l(\omega) = \frac{1}{2l+1} \sum_{m=-l}^{+l} |a_{lm}(\omega)|^2 =$$

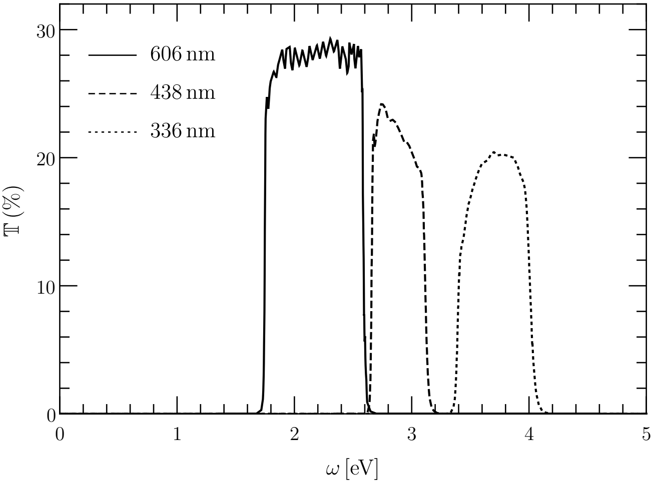
$$= \int_0^\infty dz \left[\frac{1}{4\pi} \frac{2\omega^2}{m_a H(z)} \frac{\rho_a}{m_a} 2\Gamma_{a\to\gamma\gamma} \right]^2 \left[\epsilon\left(\frac{m_a}{2(1+z)} \right) \right]^2$$

$$\times \frac{H(z)}{r(z)^2} P_\delta \left[k = \frac{l}{r(z)}, r(z), r(z) \right]$$

where P_δ is the DM power spectrum and ϵ throughput function

- This formulation is valid for Cold DM and also for Warm DM
- We expect suppressed anisotropies on small scales in the WDM case

We want to observe in the orange, blue and violet



For cold colors we expect stronger bounds: ALPs decaying at smaller redshift, where there are more structures

eV-ish ALP DM production mechanisms: summary

CDM

- Misalignment$\rightarrow$ not easy for QCD axion
- Topological defects decay$\rightarrow$ reasonable for ALPs

WDM

- Freeze-out$\rightarrow$ very natural,

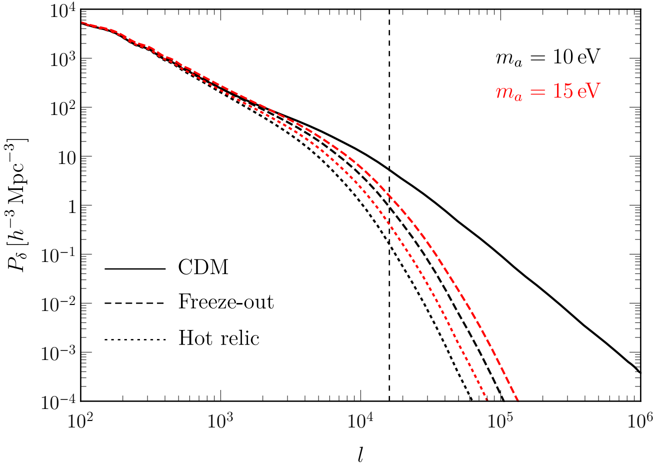
$$\Omega_a h^2 = \frac{m_a}{13\mathrm{eV}} \frac{1}{g_{*,s}(T_F)} \qquad \frac{T_a}{T_\gamma} = \left(\frac{g_{*,s}(T_0)}{g_{*,s}(T_F)}\right)^{1/3}$$

  This is the 'freeze-out' case

- Freeze-in$\rightarrow$ negligible contribution

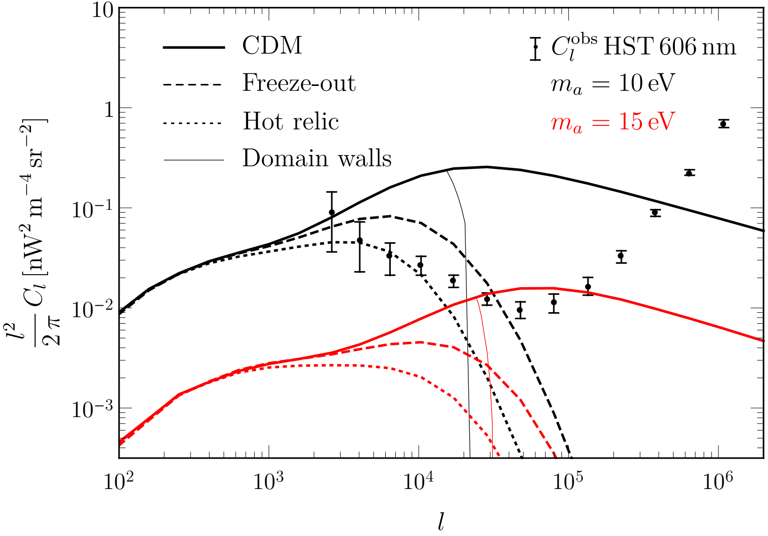
$$\Omega_a h^2 = 10^{-2} \left(\frac{m_a}{\mathrm{keV}}\right) \left(\frac{g_{a\gamma}}{10^{-8}\ \mathrm{GeV}^{-1}}\right)^2 \left(\frac{T_{\mathrm{RH}}}{5\ \mathrm{MeV}}\right)$$

The role of the power spectrum



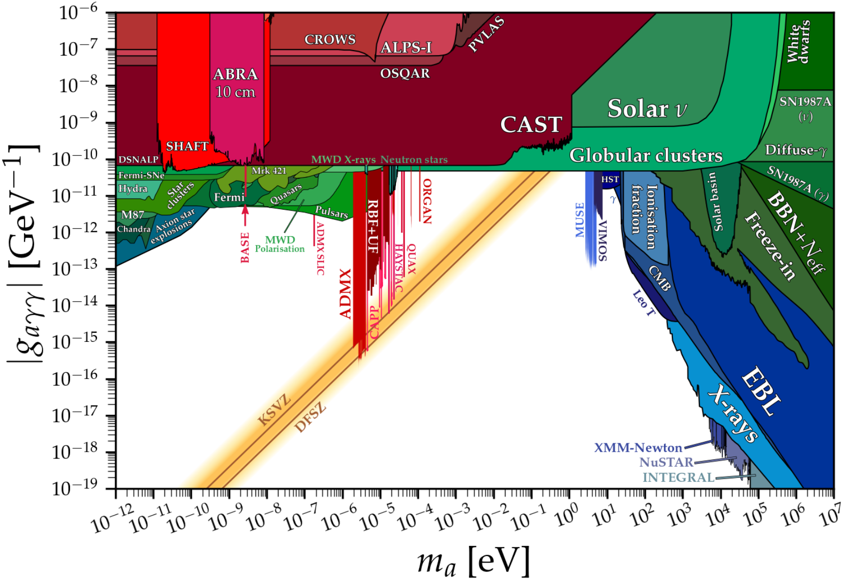
WDM has a power spectrum given by $(\mathcal{T}_{\mathrm{WDM}}/\mathcal{T}_{\mathrm{CDM}})^2 P_{\mathrm{CDM}}$

Results about the anisotropies

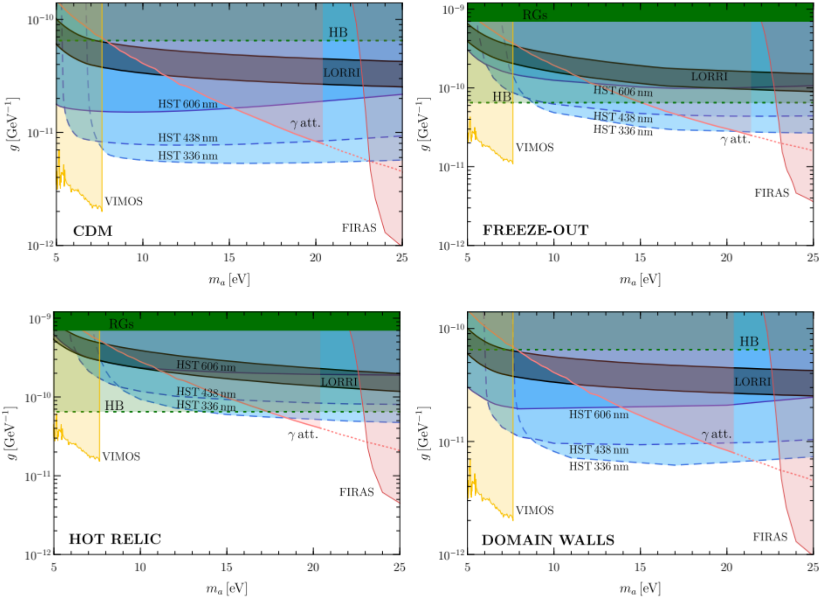


constant $\Gamma\,\rho = 10^{-29}$ s^{-1} GeV cm^{-3}. 'Relic' is the hottest WDM

A bit of context



Constraints



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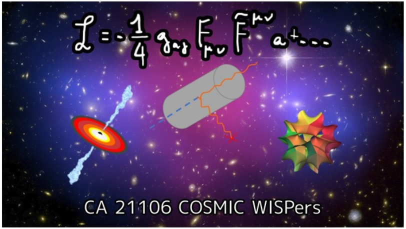
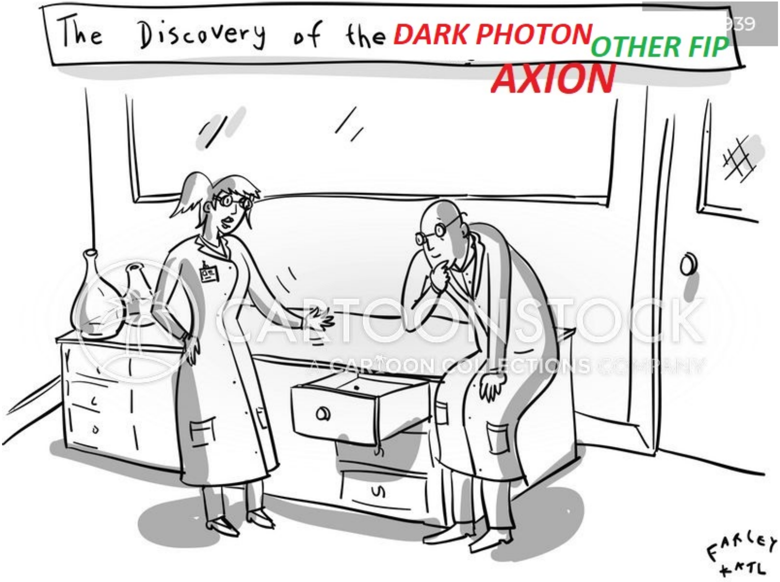


more info at https://www.cost.eu/actions/CA21106/

Conclusions



"Always the last place you look!"