Alexander von Humboldt
Stiftung/Foundation

Testing a Hidden CMB with ALPS and SHIPS

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DESY, Hamburg

Kosmologietag 5-6 May, Bielefeld University

Outline

- Hidden Photons and Kinetic Mixing.

- Formation of a Hidden CMB and its consequences.

- ALPS and SHIPS experiments: Prospects and discovery potential.

- Conclusions.

Hidden Photons and Kinetic Mixing

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For $M_S \sim \mathcal{O}(\mathrm{TeV})$ $m_{\gamma'} \sim \mathcal{O}(\mathrm{meV})$ **Finding HPs may help to probe the string scale!**

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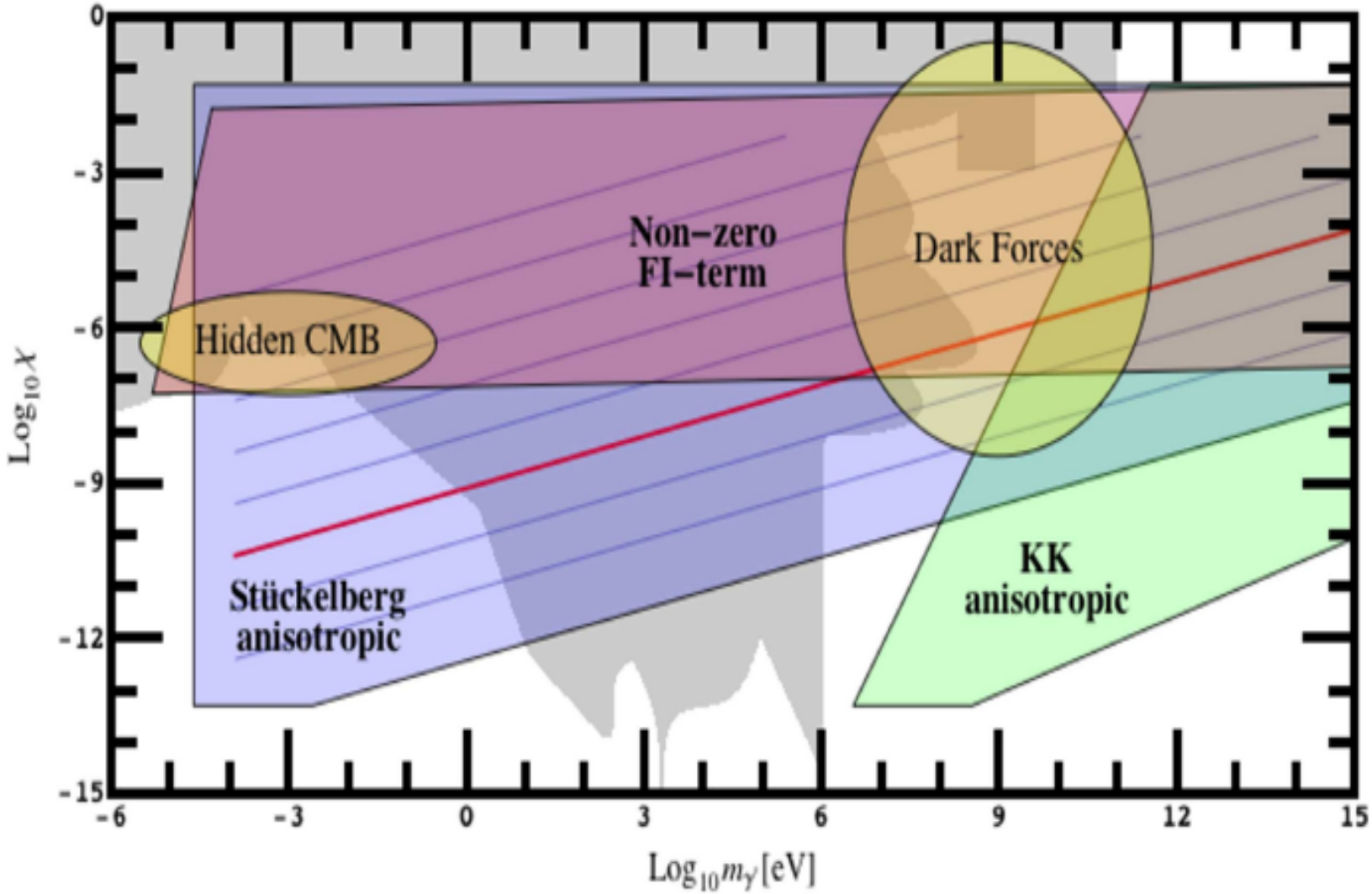
The dominant interaction with our SM is through gauge kinetic mixing

$$\mathcal{L}_{\rm int} = -\frac{\chi}{2} F_{\mu\nu} B^{\mu\nu}$$

χ Is the mixing parameter.

Hidden Photons and Kinetic Mixing



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Full Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{\chi}{2}F_{\mu\nu}B^{\mu\nu} + \frac{m_{\gamma'}^2}{2}B_\mu B^\mu$$

Mixing in the kinetic sector

$$\mathcal{L} = -\frac{1}{4}\mathcal{F}^T\mathcal{K}\mathcal{F} + \frac{1}{2}\mathcal{A}^T\mathcal{M}\mathcal{A}$$

$$\mathcal{K} = \begin{pmatrix} 1 & \chi \\ \chi & 1 \end{pmatrix}$$

$$\mathcal{M} = \begin{pmatrix} 0 & 0 \\ 0 & m_{\gamma'}^2 \end{pmatrix}$$

$$\mathcal{F} = \begin{pmatrix} F^{\mu\nu} \\ B_{\mu\nu} \end{pmatrix} \quad A = \begin{pmatrix} A_\mu \\ B_\mu \end{pmatrix}$$

Once we diagonalise by means of an unitary transformation

$$\mathcal{A} \to U\mathcal{A}$$ such that $$U^T\mathcal{K}U \to \mathcal{K}_D$$

$$\mathcal{L} = -\frac{1}{4}\mathcal{F}^{\mathcal{T}}\mathcal{K}_D\mathcal{F} + \frac{1}{2}\mathcal{A}^{\mathcal{T}}\mathcal{M}_{\mathrm{mix}}\mathcal{A}$$

We end it up with a non diagonal mass matrix! $\mathcal{M}_{\mathrm{mix}} \to U^{\mathcal{T}}\mathcal{M}U$

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The probability of such oscillation is given by

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$$P_{\gamma\to\gamma'} = \frac{16m_{\gamma'}^4\chi^4}{\Delta m^2 + \omega^2\Gamma^2}\left(e^{-\Gamma L} - 2e^{-\Gamma L/2}\cos\left(\frac{\Delta m^2 L}{2\omega}\right)\right)$$

$$\Delta m = m_{\gamma'}^2 - m_\gamma^2 \qquad 2\omega^2(1-n) = m_\gamma^2 - i\omega\Gamma$$

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Maximal oscillations in resonance!! $m_\gamma = m_{\gamma'}$

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Formation of a Hidden CMB and its consequences

Jaeckel, Redondo & Ringwald 08

Environment for resonant oscillations: Cosmic plasma induces anomalous dispersion relation.

$$\omega_P^2 \simeq \frac{4\pi\alpha n_e}{m_e}$$

Using BBN central value:

$$\omega_P^2 \simeq (0.16\ \mathrm{meV})^2 \left(\frac{T}{\mathrm{keV}}\right)^3$$

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In the range of the meV a thermal population of HP can be created trough resonant oscillations after BBN but before CMB decoupling (before BBN, the production of HPs is suppressed $\chi_{\mathrm{eff}} \simeq \chi \left(\frac{m_{\gamma'}}{\omega_P}\right)^2$ and $\frac{m_{\gamma'}}{\omega_P} \ll 1$ for)

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They behave identically like neutrinos

Energy stored in the hCMB contributes to the expansion of the Universe as if they were additional neutrinos

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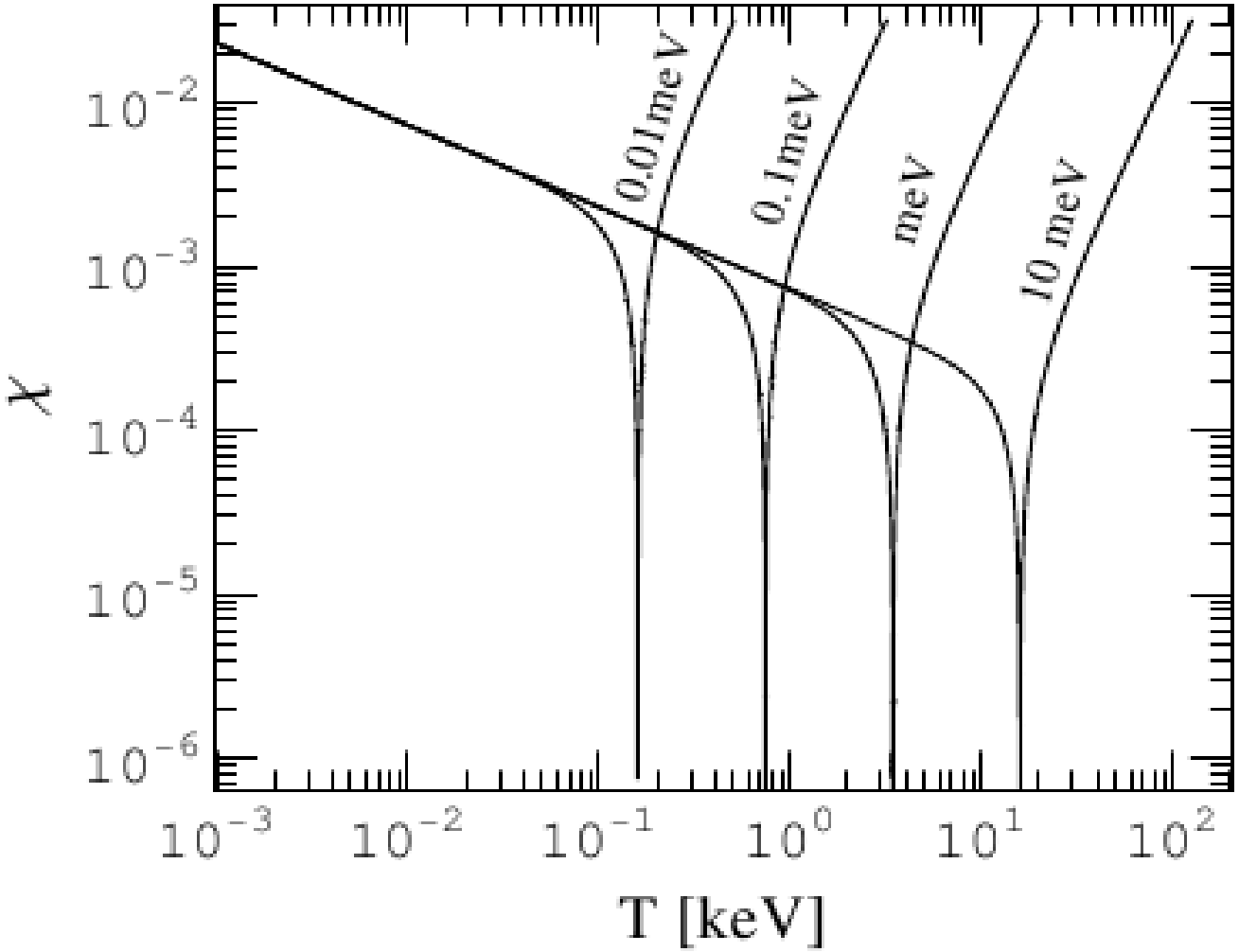

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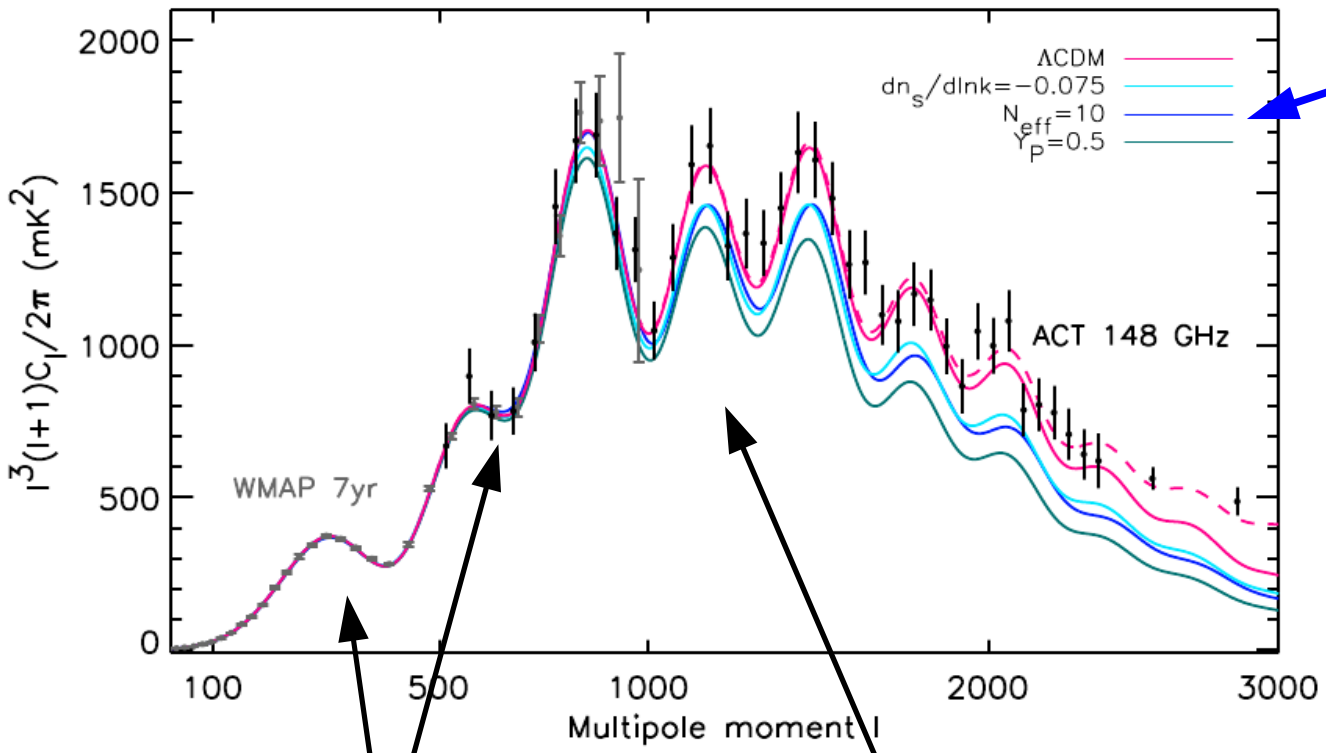
Signatures in CMB angular spectrum

Atacama Cosmology Telescope 2010



Effective number of neutrinos: 10

Enhancement of first two peaks

Suppression of higher peaks
Shift peak positions to higher multipole moment

$$x \equiv \frac{\rho_{\gamma'}}{\rho_\gamma}$$

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$$N_\nu^{\rm eff} = \frac{N_\nu^{\rm SM}}{1-x} + \frac{x}{1-x}\frac{8}{7}\left(\frac{11}{4}\right)^{4/3}$$

$$N_\nu^{\rm SM} = 3.046$$

$$x \simeq 3.9 \times 10^{-2}\left(\frac{\chi}{10^{-6}}\right)^2$$ for $m_{\gamma'} \sim \mathrm{meV}$

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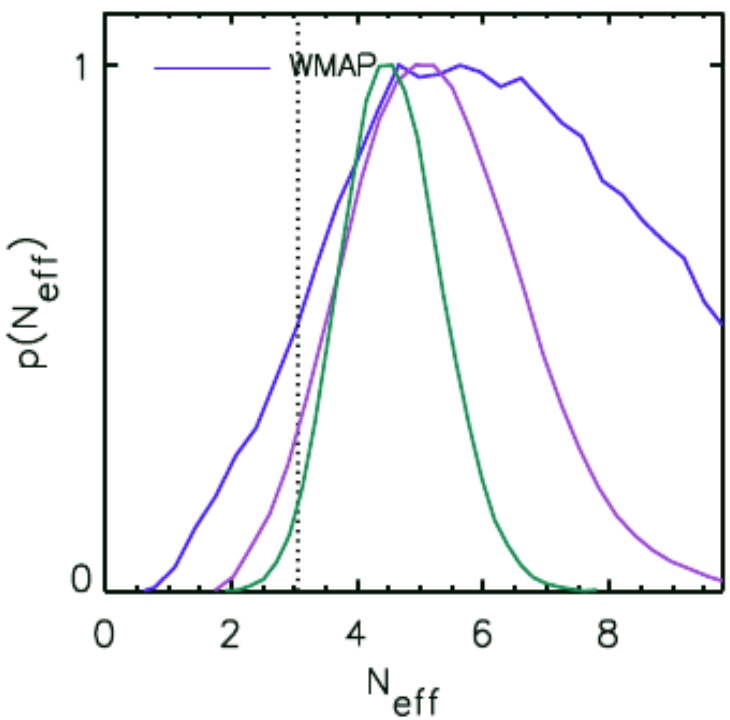

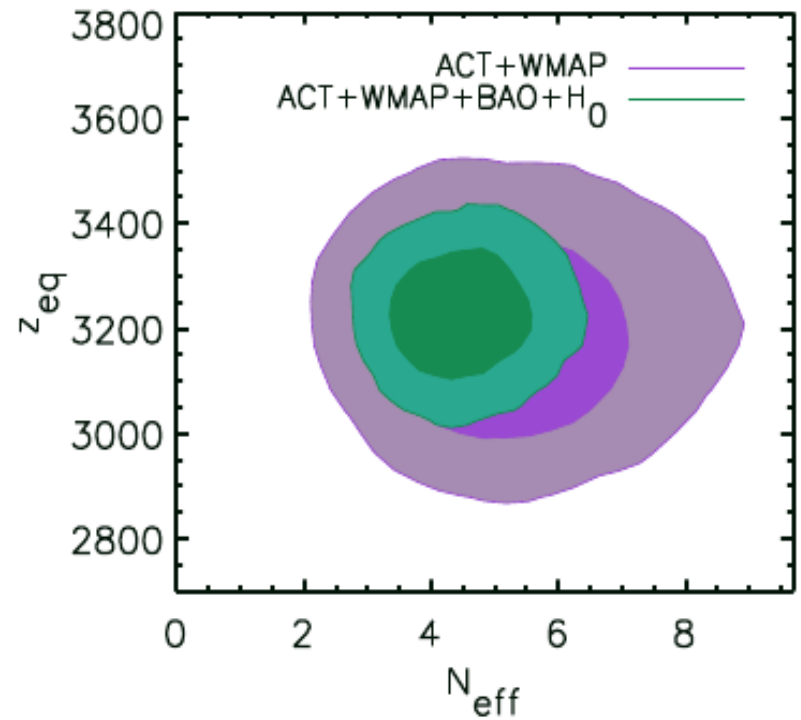

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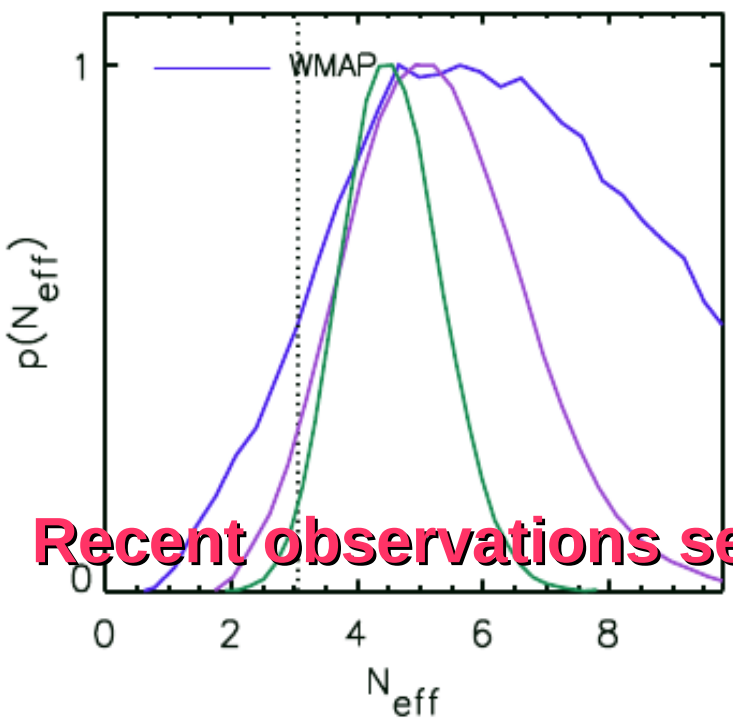
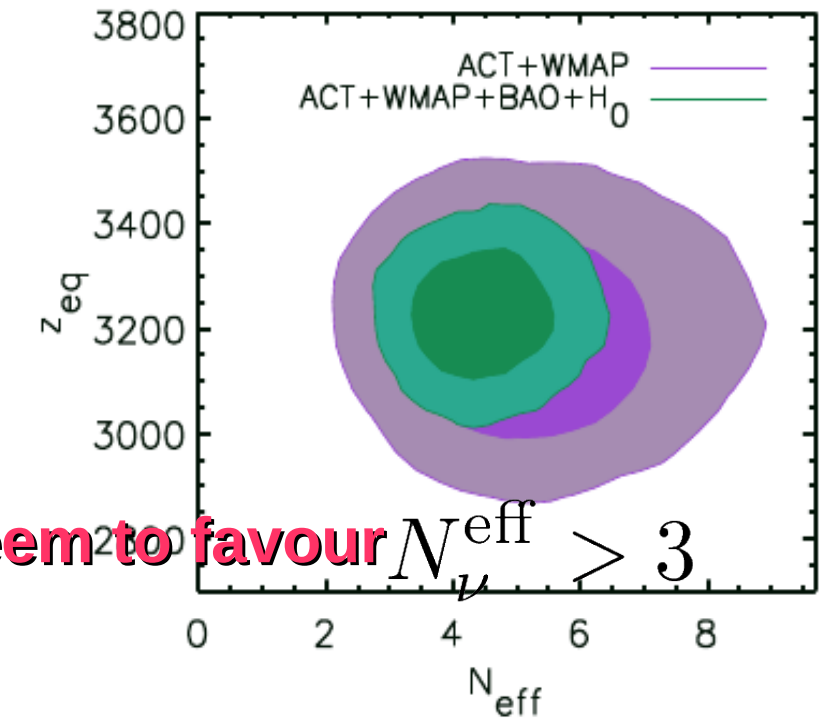




Recent observations seem to favour $N_\nu^{\rm eff} > 3$

Atacama Cosmology Telescope 2010

This excess could be explained with a HP with mass in the meV range and $\chi \sim 10^{-6}$

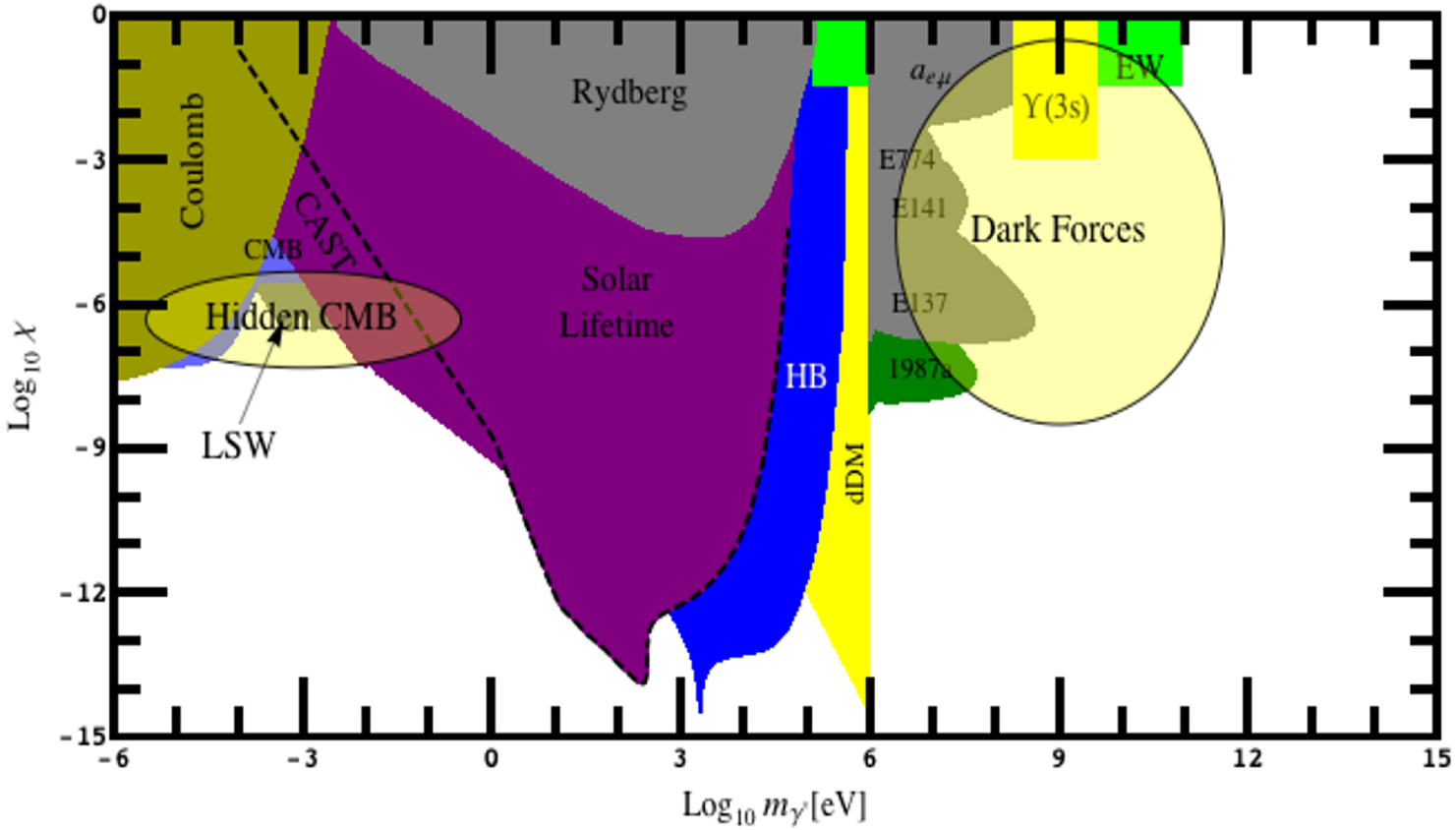
Combining WMAP+BAO+Ho $N_\nu^{\rm eff} = 4.34^{+0.86}_{-0.88}, \Rightarrow \chi = 2.29^{+0.73}_{-1.03} \times 10^{-6}$

ACT+WMAP+BAO+Ho $N_\nu^{\rm eff} = 4.56^{+0.75}_{-0.75}, \Rightarrow \chi = 2.51^{+0.65}_{-0.77} \times 10^{-6}$

PLANCK satellite is expected to have better sensitivity, confirming or ruling out neutrino excess

Testing the Hidden CMB with ALPS and SHIPS

HP hunt with high precision laboratory experiments. Controlled sources



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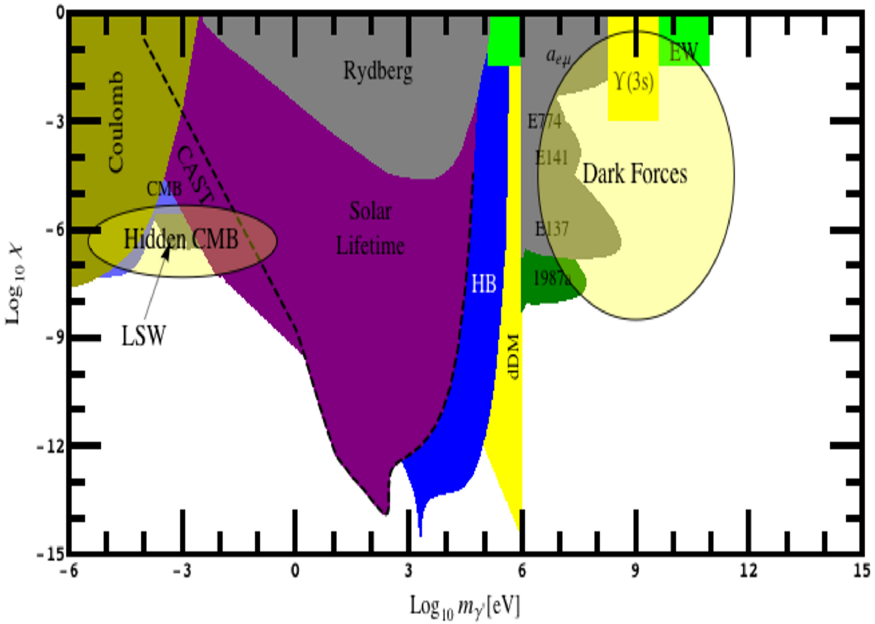
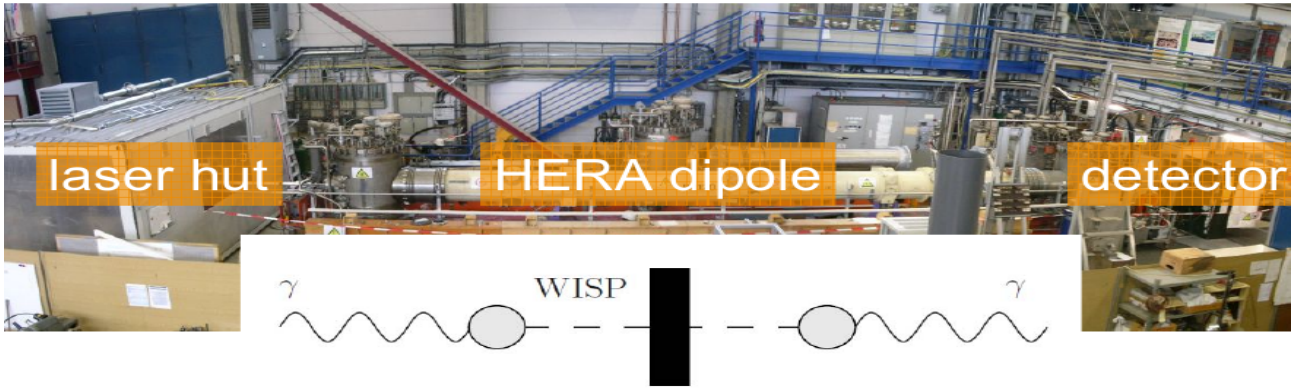


THE ALPS EXPERIMENT:

Any Light Particle Search

Light is shine onto a wall. We expect photon to HP oscillation in the production side
An opaque wall stop photons, while converted HP can pass through regeneration side



A "light-shining-through-a-wall" experiment

We look for reconverted photons

With 4.3 x 2 meters, 1.2 kW laser power in the production side ALPS managed to be the most sensitive LSW experiment looking for HPs:

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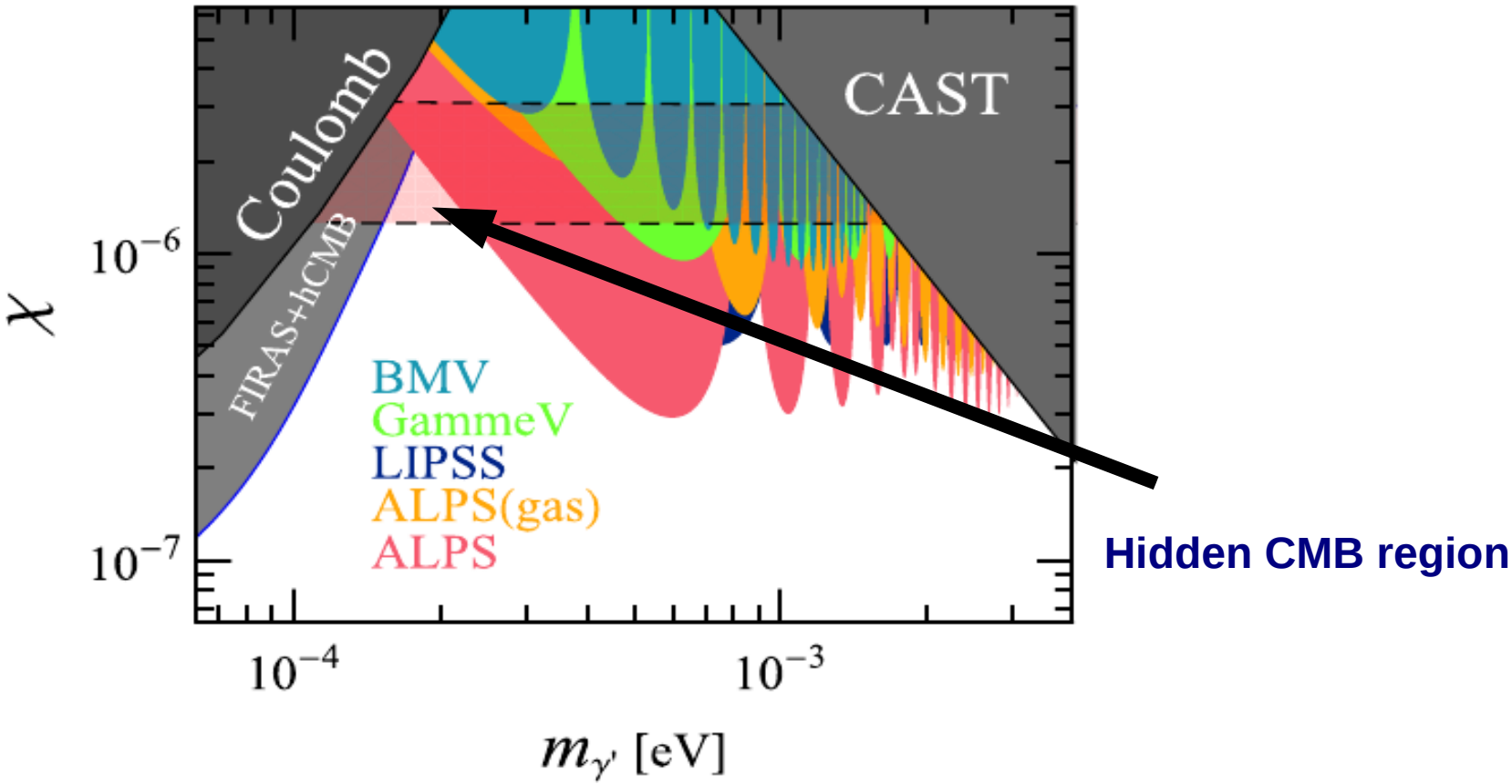

ALPS Collaboration 2010

ALPS experiment has contributed to ruled out an important part of the hCMB, but we still have a window!

ALPS experiment is towards its second phase, expected by 2014-2015. In the meantime a HP search is expected for 2012 in one of the HERA halls.

Expected Upgrades for 2012:

Parameter	ALPS-I	ALPS-2012
Effective Power Laser	1kW	150kW
Length	4.3 x 2 m	12.5 x 2
Power built-up In production and regeneration side	300-1	5000-40000
Detector Noise DC	0.01 1/s	0.0001 1/s

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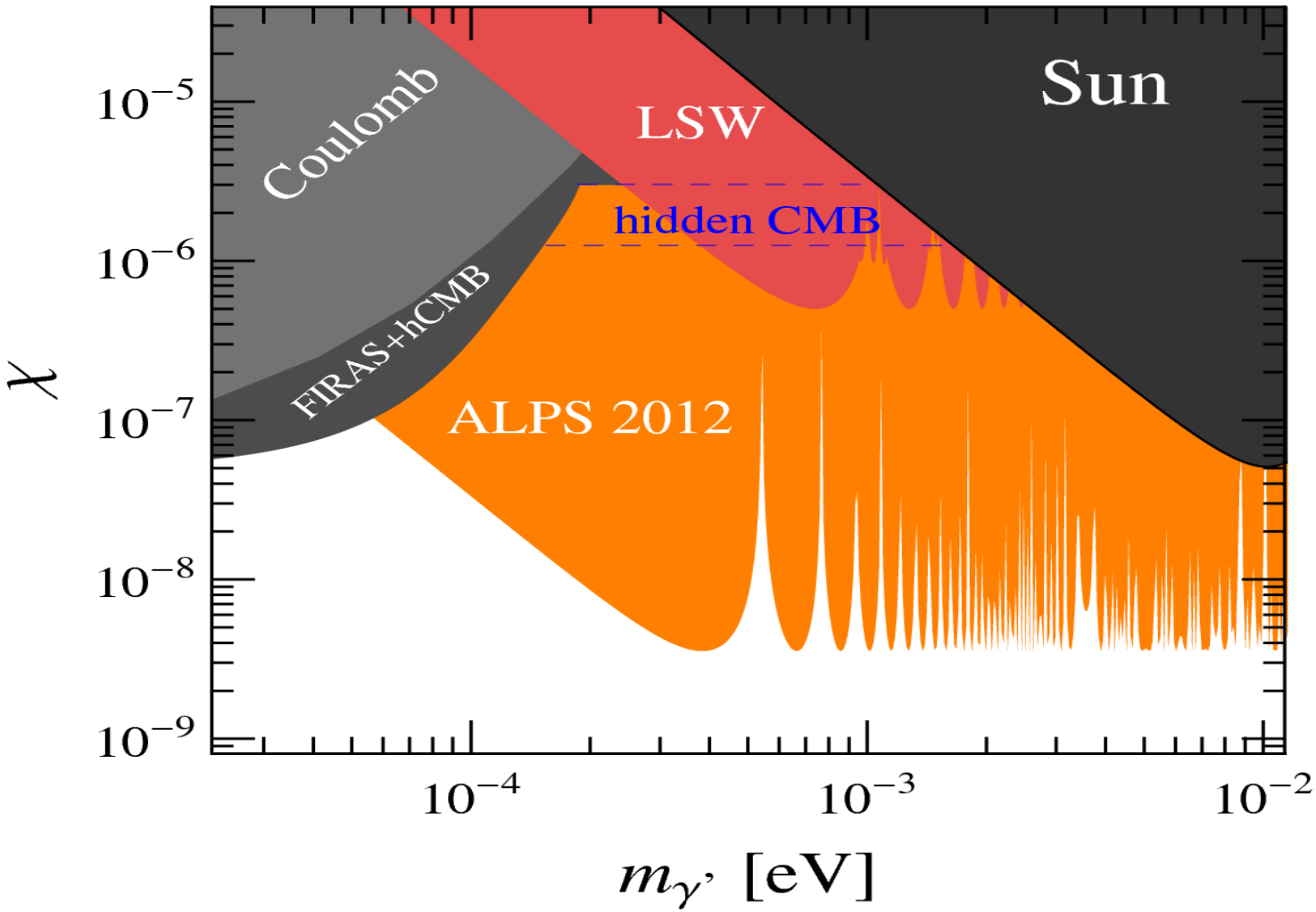
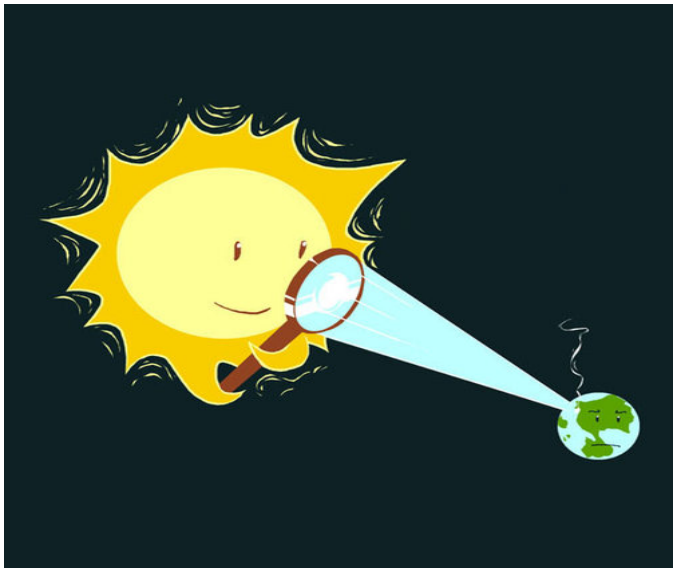


Hidden Photon hunt with SHIPS

Solar Hidden Photon Search

The idea is the same as with LSW experiments, but we replace the laser beam with photons coming from the sun



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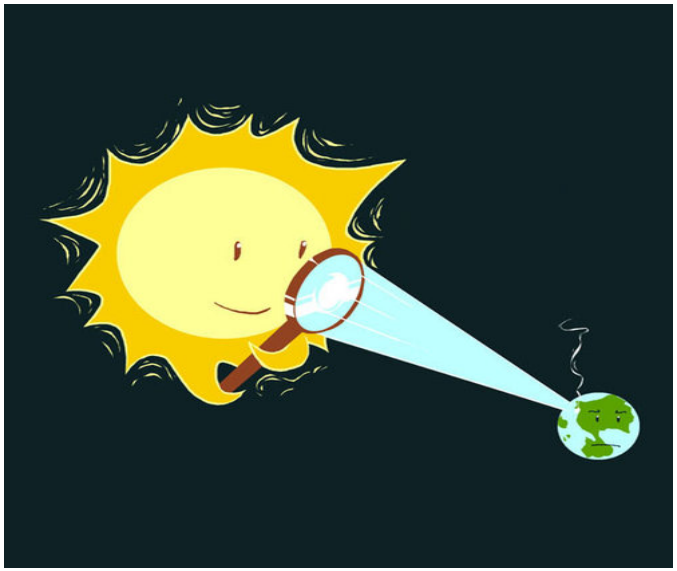

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SHIPS is a joint project from DESY and Hamburg Observatory

Oscillations between photons and HPs take place at different places in the Interior of the sun.

However, resonant production at sub eV-eV masses is produced in the outer layers of the sun. Leading to a considerable amount of hidden photon flux!!

J. Redondo '10

Conservative estimations lead to

for $m_{\gamma'} < 0.1$ meV, $\omega(1-10)eV$

$$\frac{d\Phi_{\gamma'}}{d\omega} \gtrsim \frac{4.2 \times 10^5}{\mathrm{cm^2 s\ eV}} \left(\frac{m_{\gamma'}}{0.18\ \mathrm{meV}}\right)^4 \left(\frac{\chi}{2 \times 10^{-6}}\right)^2$$

The hidden photon flux can be reconverted into visible photons by oscillations inside the helioscope, and therefore detected as regenerated photons with a photodetector

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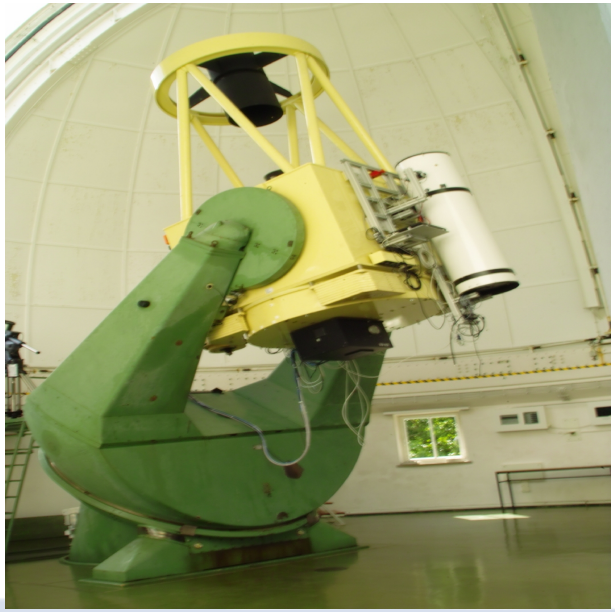
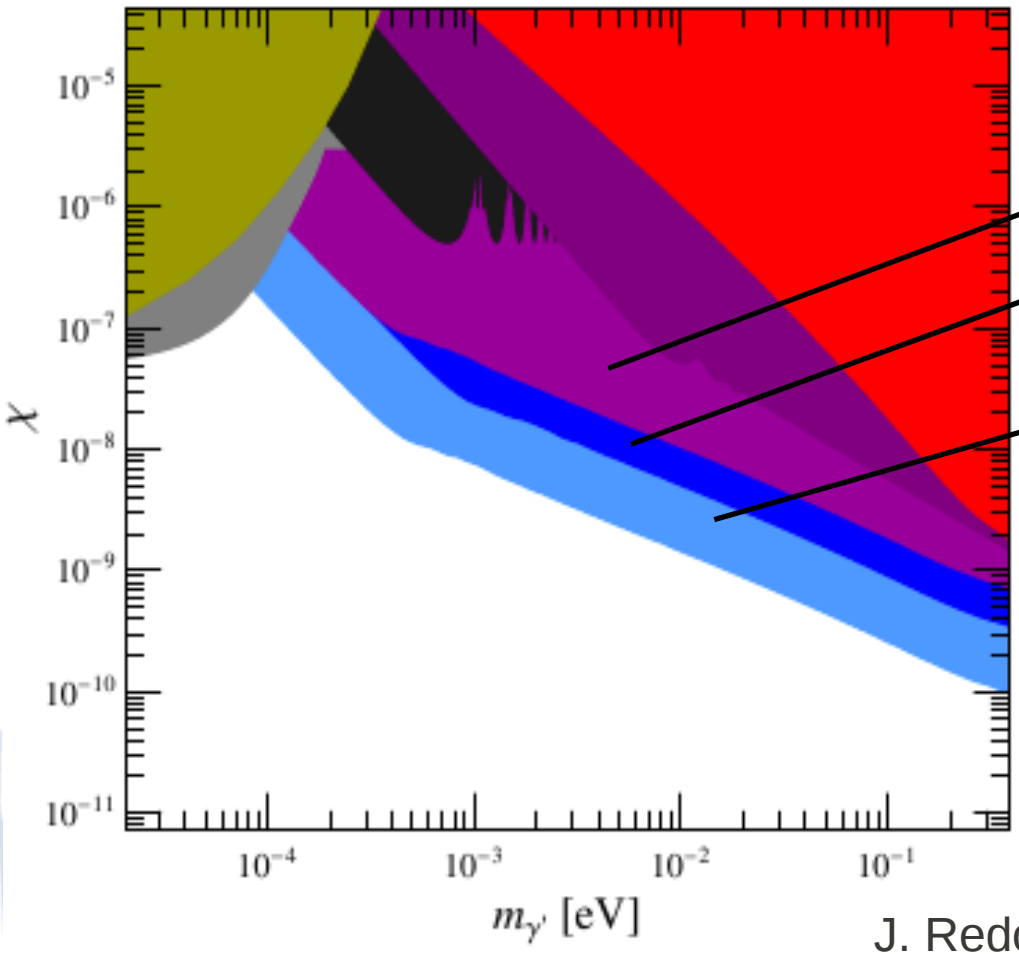
In a first stage, called Toy-SHIPS a vacuum tube with 2m long and 26cm diameter will (soon!) be mounted into the Oskar Luehning Telescope at Hamburg Observatory



The expected sensitivity for T-SHIPS (to be operative this year!!!) will probe already the hCMB hypothesis



Projected CAST
(CERN Axion Solar Telescope)

Toy SHIPS (already 2011)

Projected SHIPS

J. Redondo

Conclusions

- Hidden photons are by now well motivated candidates for WISPs (Weakly Interacting Slim Particles). Their discovery can even probe fundamental physics at very high energies, as the string scale.

- The hidden CMB hypothesis is an interesting possibility if neutrino excess is confirmed by PLANCK.

- Independently, the hCMB can be probe with laboratory experiments very soon: SHIPS (2011) and ALPS (2012)

- Further updates of these experiments are expected in the near future, allowing to probe smaller masses and coupling constant, continuing the WISP hunting!

Thank you!