

# Microwave Hidden Sector Photons at UWA

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In these proceedings we present the latest progress on our microwave cavity light shining through a wall hidden sector photon experiment, as well as introduce a new method of hidden sector photon detection. Our new experiment uses a high Q superconducting Niobium emitter cavity and moderate Q room temperature copper detector cavity separated by ample shielding. The projected sensitivity of our setup to the kinetic mixing factor is  $\chi \sim 1.8 \times 10^{-8}$  at a hidden sector photon mass of  $52.1 \mu\text{eV}$ . A new technique for detecting hidden sector photons using a threshold crossing is also presented.

## 1 Introduction

Many extensions to the standard model of particle physics predict an extra hidden U(1) gauge symmetry [1, 2]. Within this hidden sector of particles the only interaction to standard model matter is through kinetic mixing between the hidden sector photon  $\gamma'$  and ordinary photon  $\gamma$  [3, 4]. The possibly massive hidden sector photon belongs to a class of hypothetical particles known as WISPs (Weakly Interacting Slim/Sub-eV Particles) [5] and is characterized by its unknown mass  $m_{\gamma'}$  and the hidden sector kinetic mixing parameter  $\chi$ .

A range of different experiments using the light shining through a wall (LSW) phenomenon [3, 6] and photon regeneration technique have been conducted to search for hidden sector photons. Within the laboratory [7–11] the majority of experiments have been carried out with lasers [12–22], however microwaves are now also being used [23, 24]. Since 2009 UWA has been actively involved in microwave cavity experiments searching for hidden sector photons.

## 2 Microwave cavity LSW experiment

After completing a prototype experiment work has now begun on a microwave cavity light shining through a wall experiment that will provide new limits on the hidden sector photon. The basic premise of the experiment [11] is to have two microwave cavities of the same resonance frequency separated by an impenetrable wall. An on resonance microwave signal is then used to excite the emitter cavity, whilst a detector is operated on the detector cavity. With enough shielding between the cavities standard photons are unable to directly excite the detector cavity. The presence of a hidden sector however would allow photons to oscillate into hidden sector photons, travel through the wall, and regenerate into photons inside the detector cavity. The

probability of this transmission taking place is

$$\begin{aligned}\mathbb{P}_{\text{trans}} &= \frac{P_{\text{det}}}{P_{\text{emit}}} = \chi^4 Q_{\text{emit}} Q_{\text{det}} \left( \frac{m_{\gamma'} c^2}{\hbar \omega_{\gamma}} \right)^8 |\mathcal{G}|^2 \\ &= \chi^4 Q_{\text{emit}} Q_{\text{det}} \left( 1 - \frac{k_{\gamma'}^2}{k_{\gamma}^2} \right)^4 |\mathcal{G}|^2\end{aligned}$$

where  $P$ s are the powers in and out of the emitter and detector cavities respectively,  $Q$ s are the cavity quality factors,  $\omega_{\gamma}$  is the angular (and cavity resonance) frequency of the photons,  $k_{\gamma}$  is the photon wavenumber,  $k_{\gamma'}$  is the hidden sector photon wavenumber and  $\mathcal{G}$  is

$$\mathcal{G} \left( \frac{k_{\gamma'}}{k_{\gamma}} \right) = k_{\gamma}^2 \oint_{V_{\text{emit}}} \oint_{V_{\text{det}}} \frac{e^{i k_{\gamma'} |\mathbf{x}-\mathbf{y}|}}{4\pi |\mathbf{x}-\mathbf{y}|} A_{\text{emit}}^j(\mathbf{y}) A_{\text{det}}^j(\mathbf{x}) d^3\mathbf{x} d^3\mathbf{y}$$

where  $A$  is the gauge field vector within the cavity.

The new experiment being set up at UWA will use a superconducting Niobium cavity in a cryo-cooler with a  $Q \sim 10^8$  as the emitter cavity and a room temperature copper cavity in a vacuum chamber with a  $Q \sim 10^4$  as the detector cavity. Having the two cavities in separate chambers provides a great deal of shielding and significantly reduces microwave leakage. The lower quality factor detector cavity means it has a wider resonance bandwidth and is easier to match with the emitter cavity. A loop oscillator will be used on the emitter cavity to ensure it is always driven on the cavity resonance. The detector cavity output will be mixed down by an offset frequency inside the vacuum chamber to allow for a spectrum analyzer measurement and to ensure the exterior circuit is unaffected by microwave leakage. A schematic of the full setup is given in Fig. 1

Both cavities have a radius  $R \approx 20.91$  mm and length  $L \approx 39.65$  mm which using the  $\text{TM}_{020}$  mode have a resonance frequency of 12.595 GHz. The mode was chosen as the most sensitive whilst also compatible with our microwave components operating in the X-band range of microwave frequencies. Given these conditions we obtain a peak  $|\mathcal{G}| \approx 0.28$  and  $\mathcal{F}^2 \approx 37000$ . The projected limit on  $\chi$ , compared with other microwave experiments, is given in Fig. 2.

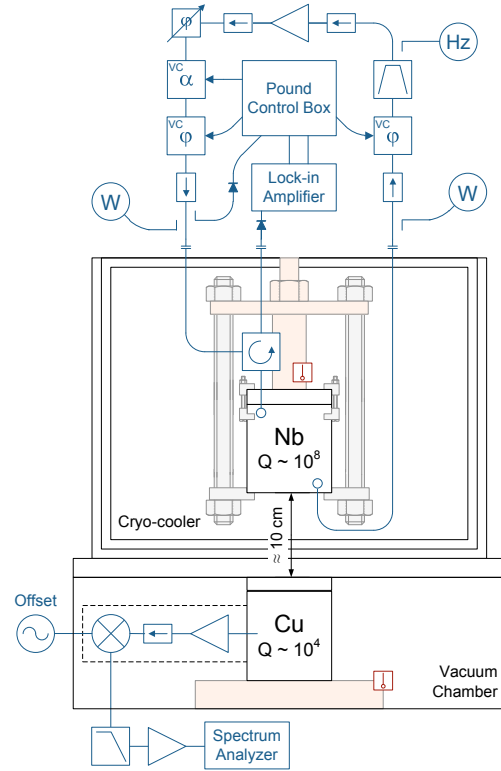


Figure 1: Diagram of the new UWA microwave cavity light shining through a wall experiment.

### 3 Hidden sector photon threshold crossing

Here we give a brief introduction to a new experimental method of searching for hidden sector photons using microwave cavities. In this approach we use only one microwave cavity, i.e. no photon regeneration, and hence are not faced with the difficulties of microwave leakage and resonance matching two cavities. The drawback is a narrow hidden sector photon mass search range but this can be useful for testing and refining a positive signal from another experiment.

For a photon to oscillate into a hidden sector photon it must have an energy greater than the rest mass energy of the hidden sector photon. This gives us a hidden sector photon threshold frequency, whereby only photons of greater frequency can mix into hidden sector photons. If a microwave cavity is driven on resonance and slowly tuned over this threshold frequency there will be a sudden drop in circulating power as photons oscillate into hidden sector photons and escape. Thus we are able to search for hidden sector photons at particular frequencies, and hence of particular masses, by looking for this drop in circulating power.

To model this effect we calculate a hidden sector photon quality factor,  $Q_{\gamma'} = \omega_{\gamma'} \times$  time average stored energy in cavity / power loss to hidden sector photons. We calculate this by obtaining the stress-energy-momentum tensor and then determining the stored energy in the cavity from photons and the energy flow out of the cavity from hidden sector photons. The description of the hidden sector photon field [11], however, includes an unsolvable integral that requires us to take a Taylor series approximation. The hidden sector photon quality factor is optimized by the  $TM_{010}$  mode and at a 0th order approximation comes out to be

$$\frac{1}{Q_{\gamma'}} \approx \frac{2\chi^2 L}{3} \left(\frac{c}{\omega_{\gamma'}}\right)^4 \left(\frac{c}{\hbar} m_{\gamma'}\right)^4 \sqrt{\left(\frac{\omega_{\gamma'}}{c}\right)^2 - \left(\frac{c}{\hbar} m_{\gamma'}\right)^2}$$

where  $L$  is the cavity length. Plots showing the hidden sector quality factor with the predicted effect are given in Fig. 3. When the threshold is crossed there is a sudden spike in  $1/Q_{\gamma'}$ .

The hidden sector photon quality factor can be related to the unloaded quality factor and couplings to the cavity. These in turn are related to the incident, reflected and transmitted power levels which can be measured in an experiment. Tuning the cavity can be carried out by temperature or tuning rods and to keep it excited on resonance a loop oscillator can be used. Using state-of-the-art equipment limits of  $\chi < 10^{-10}$ , well below current limits, may be achievable.

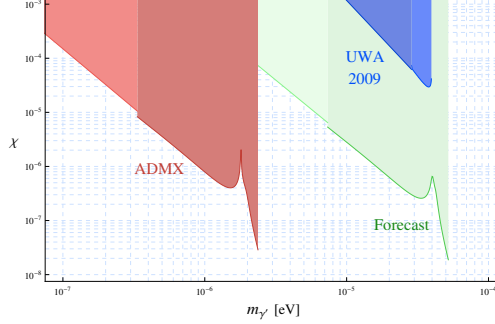


Figure 2: Plot of the predicted hidden sector photon limit from the new experiment against limits established by other microwave experiments.

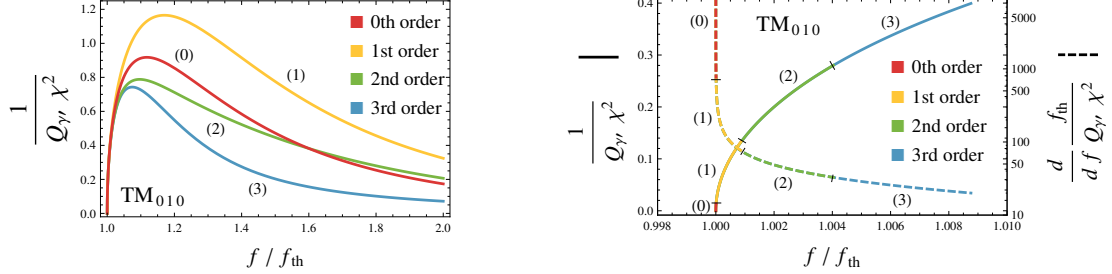


Figure 3: Plots of the 0th, 1st, 2nd and 3rd order approximations of  $1/Q_{\gamma'} \chi^2$  (solid line) and its derivative (dashed line) against frequency / threshold frequency for the  $\text{TM}_{010}$  mode in a cylindrical cavity of unity aspect ratio ( $L = 2R$ ) with tuning performed by changing the size of the cavity whilst maintaining the aspect ratio.

## References

- [1] S. A. Abel, M. D. Goodsell, J. Jaeckel, V. V. Khoze, and A. Ringwald, JHEP **07**, 124 (2008), arXiv:0803.1449.
- [2] M. Goodsell, J. Jaeckel, J. Redondo, and A. Ringwald, JHEP **11**, 027 (2009), arXiv:0909.0515.
- [3] L. B. Okun, Sov. Phys. JETP **56**, 502 (1982).
- [4] B. Holdom, Phys. Lett. B **166**, 196 (1986).
- [5] J. Jaeckel and A. Ringwald, Annual Review of Nuclear and Particle Science **60**, 405 (2010).
- [6] J. Redondo and A. Ringwald, (2010), arXiv:1011.3741.
- [7] K. Van Bibber, N. R. Dagdeviren, S. E. Koonin, A. K. Kerman, and H. N. Nelson, Phys. Rev. Lett. **59**, 759 (1987).
- [8] F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991).
- [9] P. Sikivie, D. B. Tanner, and K. van Bibber, Phys. Rev. Lett. **98**, 172002 (2007), arXiv:hep-ph/0701198.
- [10] G. Mueller, P. Sikivie, D. B. Tanner, and K. van Bibber, Phys. Rev. D **80**, 072004 (2009), arXiv:0907.5387.
- [11] J. Jaeckel and A. Ringwald, Phys. Lett. B **659**, 509 (2008), arXiv:0707.2063.
- [12] BFRT, R. Cameron *et al.*, Phys. Rev. D **47**, 3707 (1993).
- [13] BFRT, G. Ruoso *et al.*, Z. Phys. C **56**, 505 (1992).
- [14] BMV, C. Robilliard *et al.*, Phys. Rev. Lett. **99**, 190403 (2007), arXiv:0707.1296.
- [15] M. Ahlers, H. Gies, J. Jaeckel, J. Redondo, and A. Ringwald, Phys. Rev. D **76**, 115005 (2007), arXiv:0706.2836.
- [16] GammeV, A. S. Chou *et al.*, Phys. Rev. Lett. **100**, 080402 (2008), arXiv:0710.3783.
- [17] M. Ahlers, H. Gies, J. Jaeckel, J. Redondo, and A. Ringwald, Phys. Rev. D **77**, 095001 (2008), arXiv:0711.4991.
- [18] LIPSS, A. Afanasev *et al.*, Phys. Rev. Lett. **101**, 120401 (2008), arXiv:0806.2631.
- [19] BMV, M. Fouché *et al.*, Phys. Rev. D **78**, 032013 (2008), arXiv:0808.2800.
- [20] LIPSS, A. Afanasev *et al.*, Phys. Lett. B **679**, 317 (2009), arXiv:0810.4189.
- [21] ALPS, K. Ehret *et al.*, Nucl. Instrum. Meth. Phys. Res. A **612**, 83 (2009), arXiv:0905.4159.
- [22] ALPS, K. Ehret *et al.*, Phys. Lett. B **689**, 149 (2010), arXiv:1004.1313.
- [23] R. G. Povey, J. G. Hartnett, and M. E. Tobar, Phys. Rev. D **82**, 052003 (2010), arXiv:1003.0964v2.
- [24] ADMX, A. Wagner *et al.*, Phys. Rev. Lett. **105**, 171801 (2010), arXiv:1007.3766.