Review of Some Papers
~ Fall 2015 ~

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Papers to Review

- B. Wojtsekhowski, arXiv:1509.02754
On a sidereal time variation of the Lorentz force

- Y. Uesugi +, arXiv:1509.05840
Feedback-free optical cavity with self-resonating mechanism

- S. R. Parker +, arXiv:1510.05775
Cross-correlation measurement techniques for cavity-based axion and weakly interacting slim particle searches

- Y. Inoue, K. Ishidoshiro, arXiv:1509.08270
Hidden photon measurements using the long-baseline cavity of laser interferometric gravitational-wave detector

Anisotropy Search by Cyclotron

- B. Wojtsekhowski, arXiv:1509.02754
  On a sidereal time variation of the Lorentz force
- test the isotropy of the "maximum speed" of electrons/positrons (CPT test; not LI test)
- projected limit on one-way anisotropy: 1e-18 (current limit: dc/c < ~1e-15 (from out experiment))

On a sidereal time variation of the Lorentz force

B. Wojtsekhowski[1]

[1] *Thomas Jefferson National Accelerator Facility, Newport News, VA 23606*

(Dated: September 10, 2015)

We consider a search for a sidereal time variation of the beam trajectory in the cyclotron motion in a static magnetic field. The combination of two beams moving in opposite directions could allow a test of the radius stability with sensitivity approaching 10^{-10}. Such a level of variation of the Lorentz force, if it exists, would require a speed of light anisotropy on the level of 10^{-18}.

PACS numbers: 11.30.Cp, 98.80.-k

Method

- static magnetic field
- modified dispersion equation leads to modified Lorentz force

$$E^2 = m^2 + p^2 + \boxed{f\vec{e}\cdot\vec{p}} \longrightarrow \vec{v}\times\vec{B} + \boxed{\alpha\cdot\vec{e}(\vec{e}\cdot[\vec{v}\times\vec{B}])}$$

$\rightarrow$ modified beam trajectory

preferred direction

model parameter

- measure momenta in opposite directions (p_+ and p_-)
- electron beam and positron beam in opposite directions (p^e_+ , p^e_- , p^p_+ , p^p_-)
  $\rightarrow$ cancellation of sidereal drift
- pretty clever

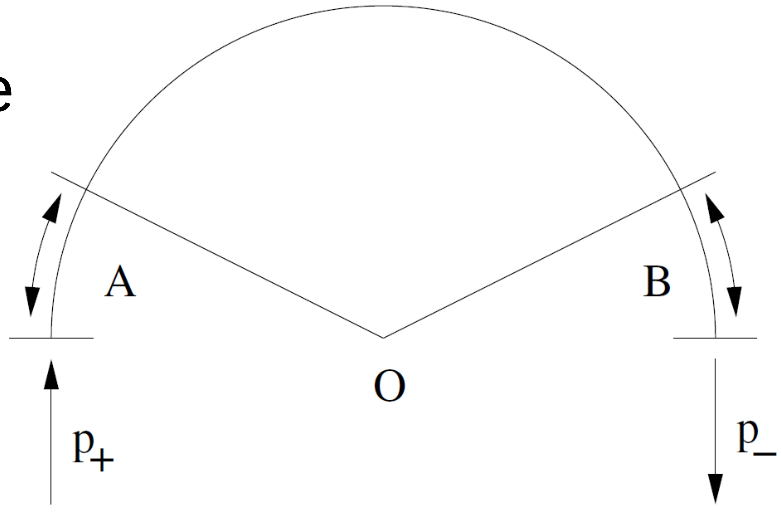

FIG. 1: Diagram for measurement of the beam momenta with a 180° arc magnet.

same figure also in
B. Wojtsekhowski, [Europhysics Letters, **108**, 31001 (2014)]

Questions

- anisotropy in the maximum attainable speed of electrons/positrons
- anisotropy in the speed of light (photons)
  Are these two the same??
- maybe not; the former is CPT violation, the latter is Lorentz violation
- formulation needed for implications of this experiment

Implications of the Lorentz force experiment: It would be interesting to find out the implication of the experimental limit on the VLF for the limit of the speed of light anisotropy. However, at present such a type of connection has not been formulated. It is not excluded that the charged particle trajectory in a static field is not sensitive to the SLA in spite of modification of the Lorentz force. At same time we can formulate reversed implications: The existing limit on the SLA of 10^{-14} restricts the value of possible VLF to below 10^{-6} for the beam energy of 5 GeV, and if the VLF signal exists it will naturally require a non-zero SLA. The current limit on

Self-Resonating Cavity

- Y. Uesugi +, arXiv:1509.05840
  Feedback-free optical cavity with self-resonating mechanism
- demonstration of high finesse (4.65e5) cavity without active feedback

Feedback-free optical cavity with self-resonating mechanism

Y. Uesugi and T. Takahashi*
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Y. Honda, A. Kosuge, T. Omori, and J. Urakawa
High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
(Dated: September 23, 2015)

We demonstrated the operation of a high finesse optical cavity without utilizing an active feedback system to stabilize the resonance. The finesse of the cavity was measured to be $465,000 \pm 3,000$, and the laser power stored in the cavity was 2.52 ± 0.13 kW, which is about 187,000 times greater than the incident power to the cavity. The stored power was stabilized with a fluctuation of 1.7%, and we confirmed continuous cavity operation for more than two hours. This result relaxes the technical requirement of stabilizing of the optical resonant cavity and expands possibilities for various applications such as laser-Compton scattering.

PACS numbers: 42.60.By,42.60.Da,42.60.Pk

By the way: Authors

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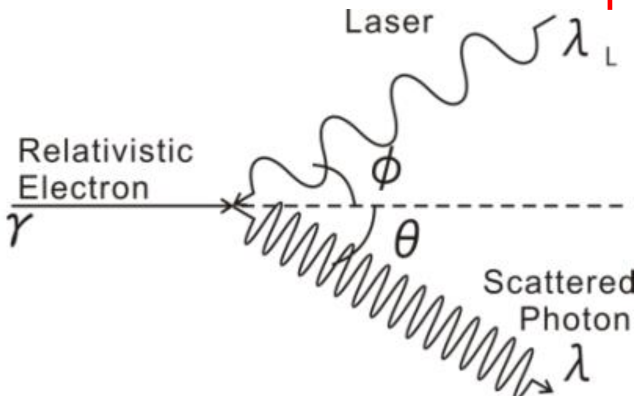
http://www.huhep.org/

- self-resonating cavity was developed for laser-Compton photon sources

from laser-Compton source



make
x-rays
gamma rays

- this group also does weak measurement

スタッフ

- 高橋徹（准教授）
- 飯沼昌隆（助教） ← weak measurement

大学院生

- 川田真一（D4）HP
- 鈴木佑太朗（D4）
- 上杉祐貴（D3） ← the author
- 宮本麻裕（M2）
- 中野雅之（M1） ← !
- 川居亮太（M1）

学部生

- 石川研太朗（B4）
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- 山口月（B4）
- 渡壁光太（B4）

Setup

ADVANCED THIN FILMS

- cavity mirrors from ATF, R > 99.999% guaranteed
- PBS/QWPs to prevent backward scattering
- much like laser oscillation

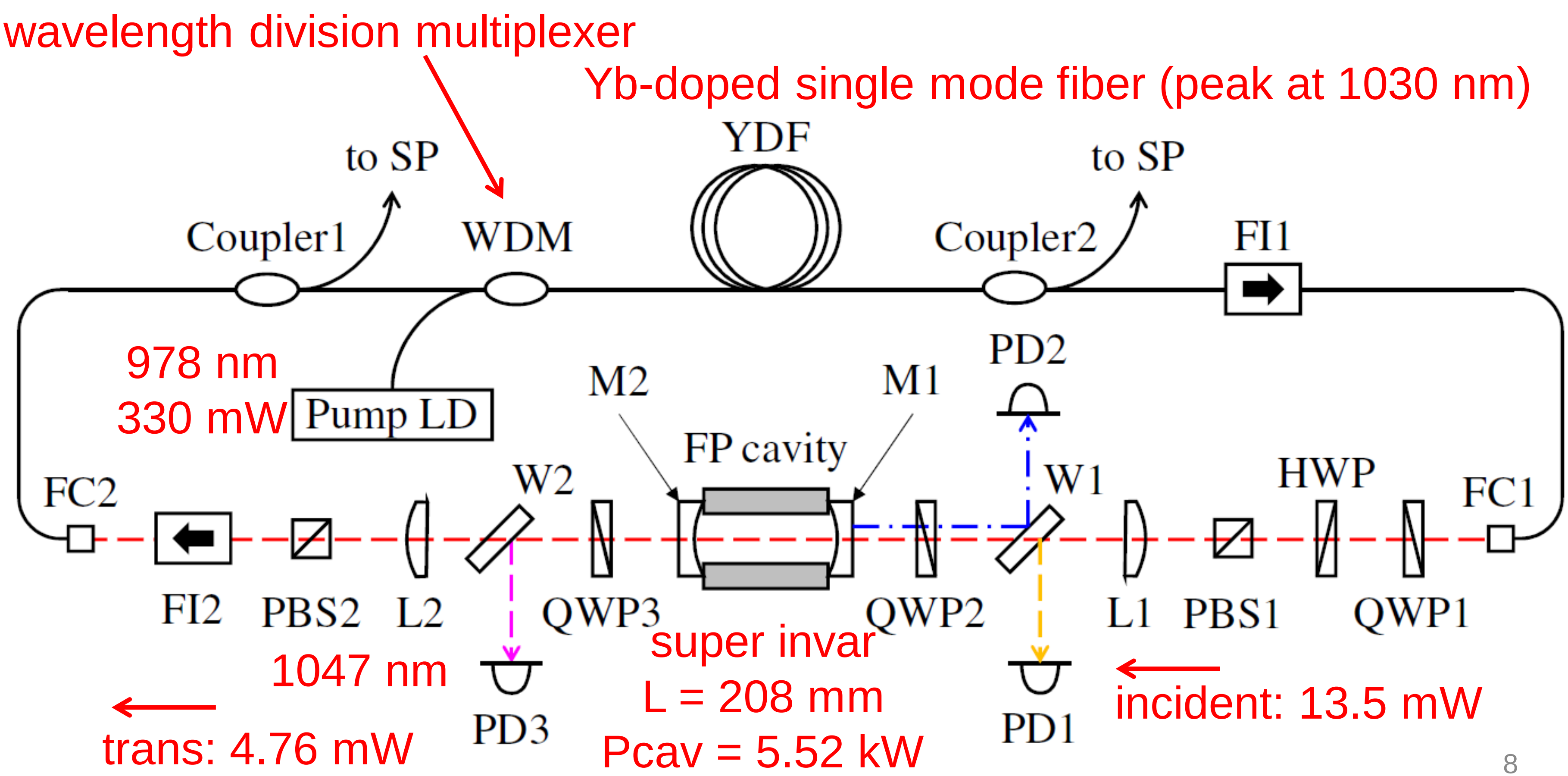

FIG. 1. The optical setup used to demonstrate the feedback-free optical cavity with the self-resonating mechanism.

Questions

- difference between usual laser?
  gain medium will get damaged with high intra-cavity power
- what was the finesse?
  - 646000 ± 3000
    from ring down measurement
    (at 1064 nm)
  - 465000 ± 3000
    from transfer function
    measurement
    (linewidth 1.5 kHz)
  - linewidth was
    1.1 THz (2 nm) from
    laser spectrum

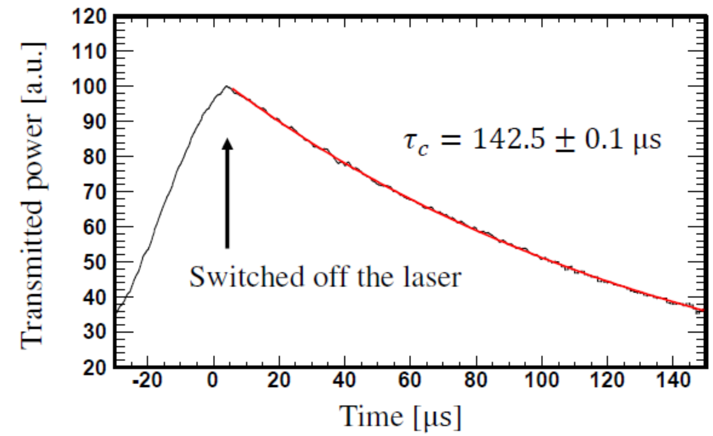

FIG. 2. The decay of the transmitted power from the cavity. The transmitted power was observed while scanning the cav- … was switched off at its peak. … best fit with the function … g fitting parameters.

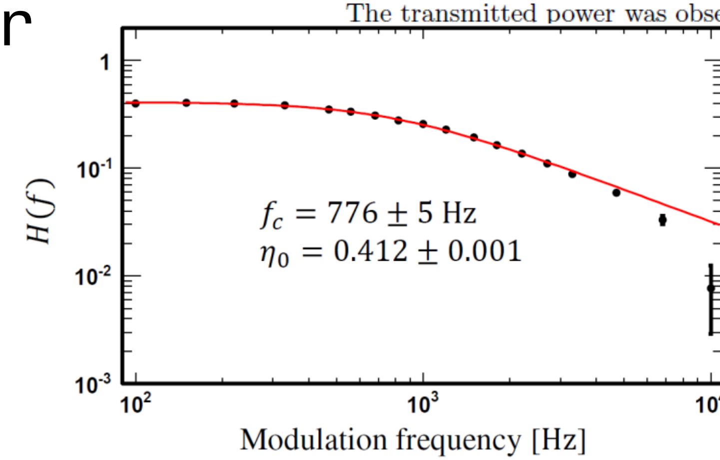

FIG. 6. The transfer function $H(f)$ with respect to the modulation frequency of pump LD.

Maximum Stored Power to Date

- Current maximum: 670 kW (average power of pluses)
  H. Carstens +, [Optics Letters **39**, 2595 (2014)]

Megawatt-scale average-power ultrashort pulses in an enhancement cavity

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We investigate power scaling of ultrashort-pulse enhancement cavities. We propose a model for the sensitivity of a cavity design to thermal deformations of the mirrors due to the high circulating powers. Using this model and optimized cavity mirrors, we demonstrate 400 kW of average power with 250 fs pulses and 670 kW with 10 ps pulses at a central wavelength of 1040 nm and a repetition rate of 250 MHz. These results represent an average power improvement of one order of magnitude compared to state-of-the-art systems with similar pulse durations and will thus benefit numerous applications such as the further scaling of tabletop sources of hard x rays (via Thomson scattering of relativistic electrons) and of soft x rays (via high harmonic generation).

OCIS codes: (140.4780) Optical resonators; (140.7240) UV, EUV, and X-ray lasers.
http://dx.doi.org/10.1364/OL.39.002595

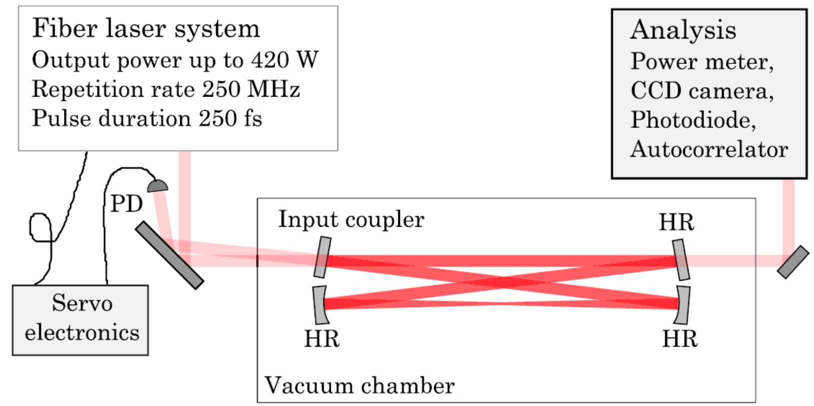

Fig. 1. Schematic of the experimental setup. PD, photodiode; HR, highly reflective.

- Advanced LIGO: 745 kW (finesse 450)
- Advanced Virgo: 650 kW (finesse 450)
- KAGRA: 410 kW (finesse 1530)
- Einstein Telescope HF: 3 MW (finesse ~900?)

WISP Search Using Cavities

- S. R. Parker +, arXiv:1510.05775
  Cross-correlation measurement techniques for cavity-based axion and weakly interacting slim particle searches
- WISPs are dark matter candidates

Cross-correlation measurement techniques for cavity-based axion and weakly interacting slim particle searches

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[1] *School of Physics, The University of Western Australia, Crawley 6009, Australia*
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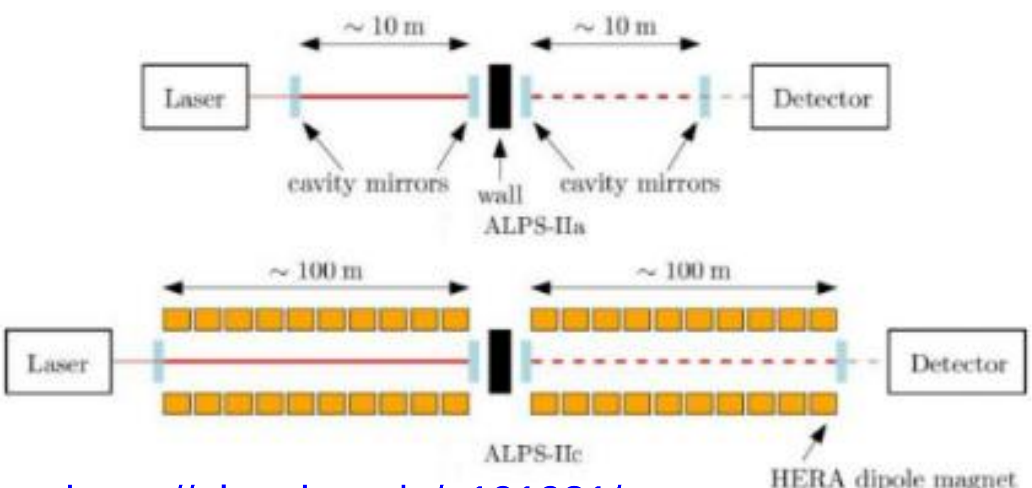
(Dated: October 21, 2015)

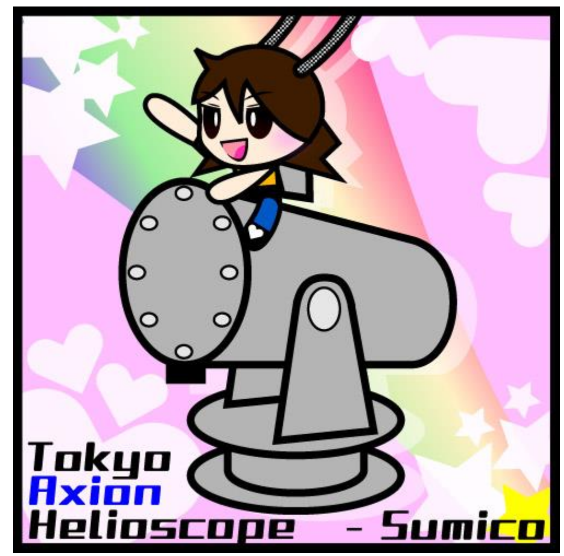
Weakly Interacting Slim Particles (WISPs), such as axions, are highly motivated dark matter candidates. The most sensitive experimental searches for these particles exploit WISP-to-photon conversion mechanisms and use resonant cavity structures to enhance the resulting power signal. For WISPs to constitute Cold Dark Matter their required masses correspond to photons in the microwave spectrum. As such, searches for these types of WISPs are primarily limited by the thermal cavity noise and the broadband first-stage amplifier noise. In this work we propose and then verify two cross-correlation measurement techniques for cavity-based WISP searches. These are two channel measurement schemes where the cross-spectrum is computed, rejecting uncorrelated noise sources while still retaining correlated signals such as those generated by WISPs. The first technique allows for the cavity thermal spectrum to be observed with an enhanced resolution. The second technique cross-correlates two individual cavity/amplifier systems that can be spatially well-separated, thereby opening up opportunities for characterizing candidate dark matter WISP signals.

Previous WISP Searches

- WISP: weakly interacting slim particle (sub-eV mass)
  - axion
    axion-photon conversion under magnetic field
  - hidden sector photon
    mixing analogous to neutrino flavor
- WISP searches
  - haloscope
  - light shining through a wall (LSW)

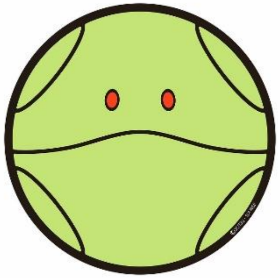


https://alps.desy.de/e191931/



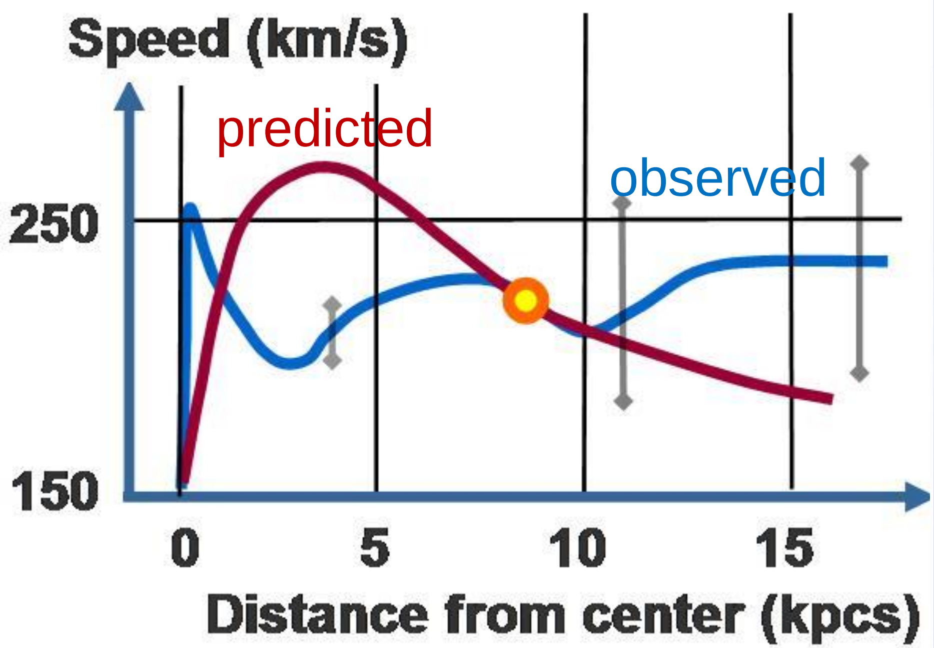
http://www.icepp.s.u-tokyo.ac.jp/~minowa/Minowa_Group.htm

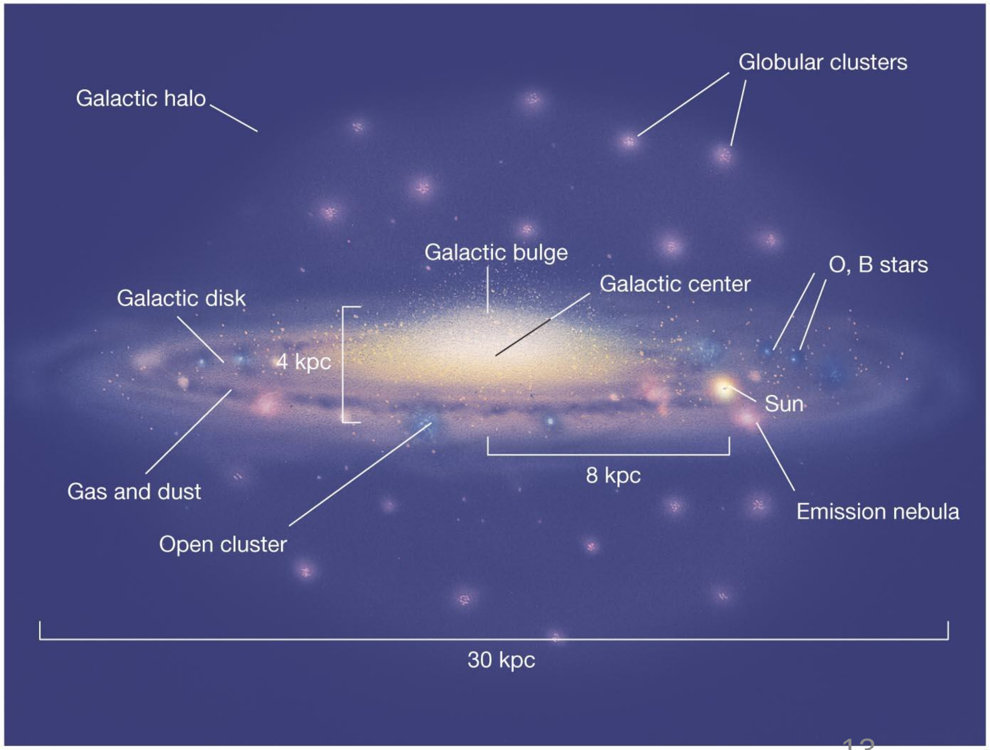
Dark Matter Halo



- to explain galaxy rotation curve
- observed speed of rotation is faster than prediction from stellar mass and gas
- due to dark matter (or modification of gravitational law) ?

https://en.wikipedia.org/wiki/Dark_matter_halo



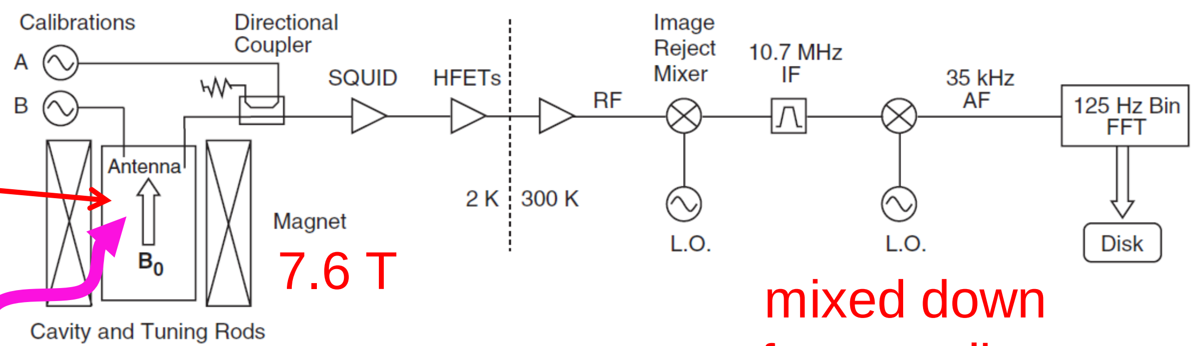


http://pages.uoregon.edu/jimbrau/astr123/Notes/Chapter23.html

Haloscope

- inverse Primakoff effect
  axions → microwave photons (under magnetic field)
- S. J. Asztalos +, [Phys. Rev. Lett. **104**, 041301 (2010)]
  SQUID-Based Microwave Cavity Search for Dark-Matter Axions

Cu-plated microwave cavity
(tune resonant freq. with rod;
500 MHz to 1 GHz)



mixed down
for sampling

axions from halo

FIG. 1. Schematic of the ADMX experiment. Photons, created in the cavity by the conversion of axions, are picked up by the antenna and amplified by the SQUID and HFETs. The signal is mixed in two stages, with band-limiting filtering between, to audio frequencies. The audio spectrum is measured and stored to disk. Sweep oscillator *A* provides a reflection measurement to enable adjustment of antenna coupling; oscillator *B*, weakly coupled, allows measurement of the cavity resonant frequency.

- limited by
  thermal noise
  + first amp noise

Cross-Correlation

- reduce uncorrelated noise
  typically 20 - 30 dB
- nothing new

reduction of first amp noise
(can also be used for better characterization of the cavity; e.g. Q-factor)

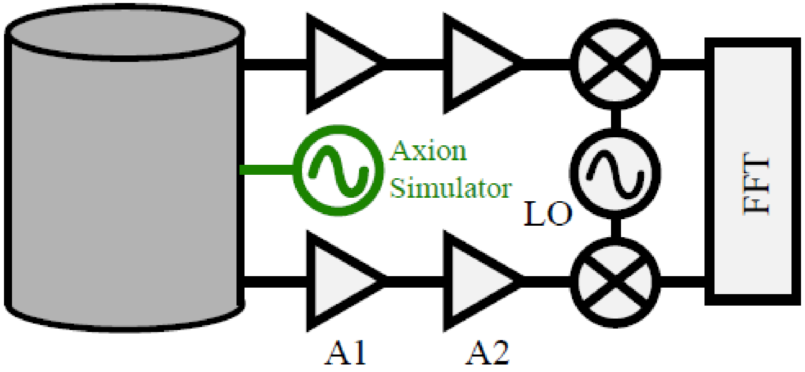


FIG. 5. Schematic of the first cross-correlation measurement technique. The axion simulator (green) is used in Sec. V to perform proof-of-concept measurements.

reduction of cavity thermal noise
- axion signal remains if cavities are close enough (<10-100 m; de Broglie wavelength of the axion)
- can be used to measure coherence length
- have to tune resonant freqs

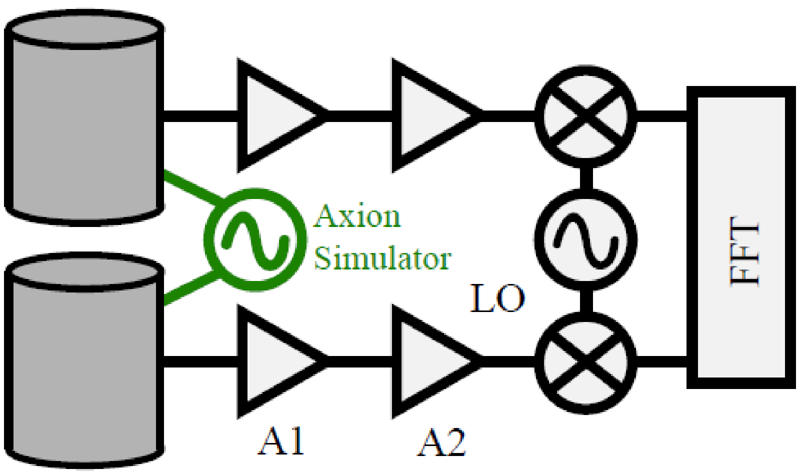


FIG. 6. Schematic of the second cross-correlation measurement technique. The axion simulator (green) is used in Sec. V to perform proof-of-concept measurements.

Hidden Photon Using GW Detector

- Y. Inoue, K. Ishidoshiro, arXiv:1509.08270
  Hidden photon measurements using the long-baseline cavity of laser interferometric gravitational-wave detector
- can reach hidden Higgs, cold dark matter region

Hidden photon measurements using the long-baseline cavity of laser interferometric gravitational-wave detector

Y. Inoue[a], K. Ishidoshiro[b]

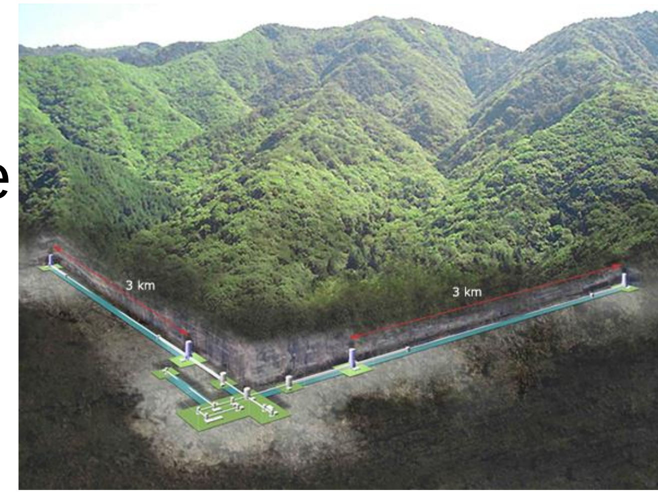
[a]The Graduate University for Advanced Studies, Kanagawa, Japan
[b] Tohoku univercity, Miyagi, Japan

ABSTRACT

We suggest a new application for the long-baseline and high powered cavities in a laser-interferometric gravitational-wave (GW) detector to search for WISPs (weakly interacting sub-eV particles), such as a hidden U(1) gauge boson, called the hidden-sector photon. It is based on the principle of a light shining through the wall experiment, adapted to the laser with a wavelength of 1064 or 532 nm. The transition edge sensor (TES) bolometer is assumed as a detector, which the dark rate and efficiency are assumed as 0.000001 s^{-1} and 0.75, respectively. The TES bolometer is sufficiently sensitive to search for the low-mass hidden-sector photons. We assume that the reconversion cavity is mounted on the reconversion region of hidden-sector photons, which number of reflection and length are assumed as 1000 and 10, 100, and 1000m. We found that the second-point-five and the second generation GW experiments, such as KAGRA and Advanced LIGO with a regeneration cavity and TES bolometers. The expected lower bounds with these experiments wit the reconverted mirror are set on the coupling constant $\chi = 2 \times 10^{-9}$ for hidden-sector photon with a mass of 2×10^{-5} eV within 95% confidence level. The third generation detector, Einstein Telescope, will reach $\chi = 1 \times 10^{-9}$ at a mass of 1×10^{-5} eV within 95% confidence level. Although the operation and construction of the RC will demand dedicated optical configurations, the cavities used in GW detection are expected to measure the strong potential for finding the hidden-sector photons.

LSW with GW Detector

- light shining through a wall
- TES bolometer can be placed outside the mountain



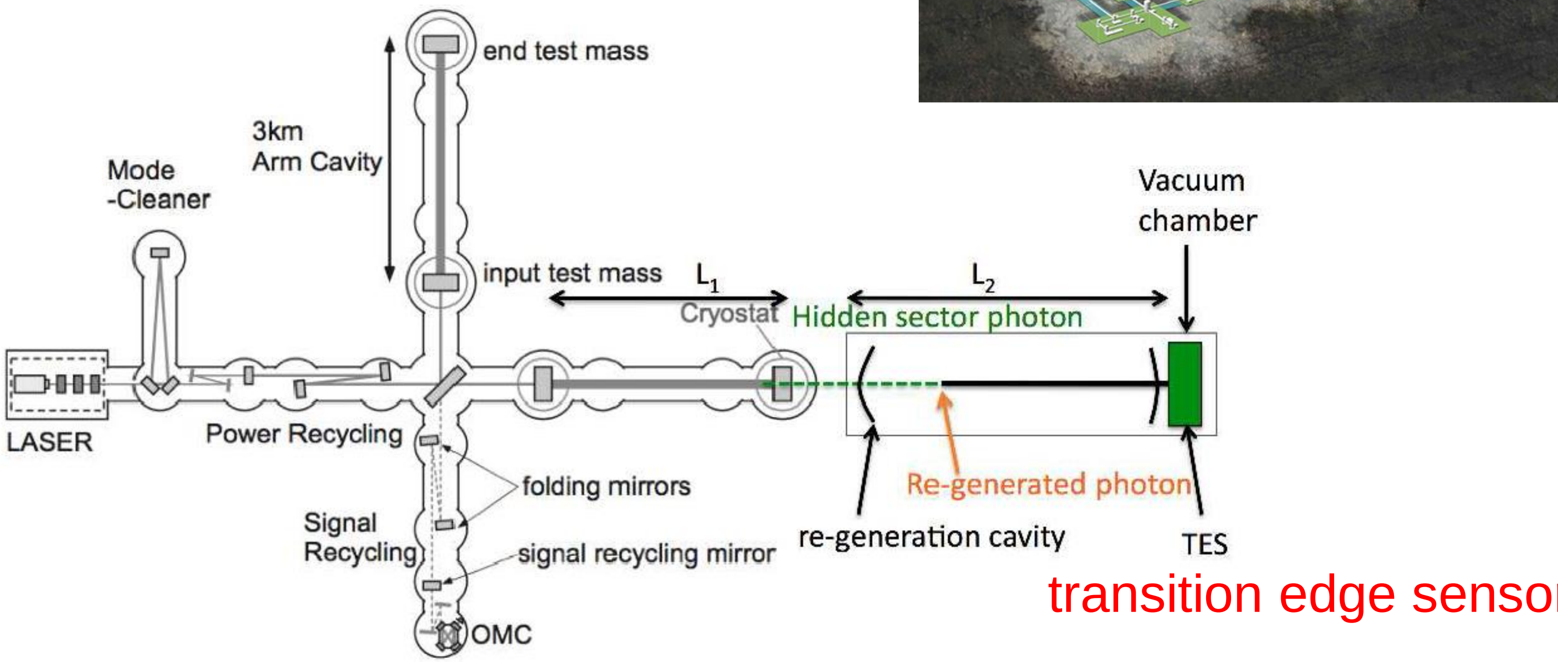


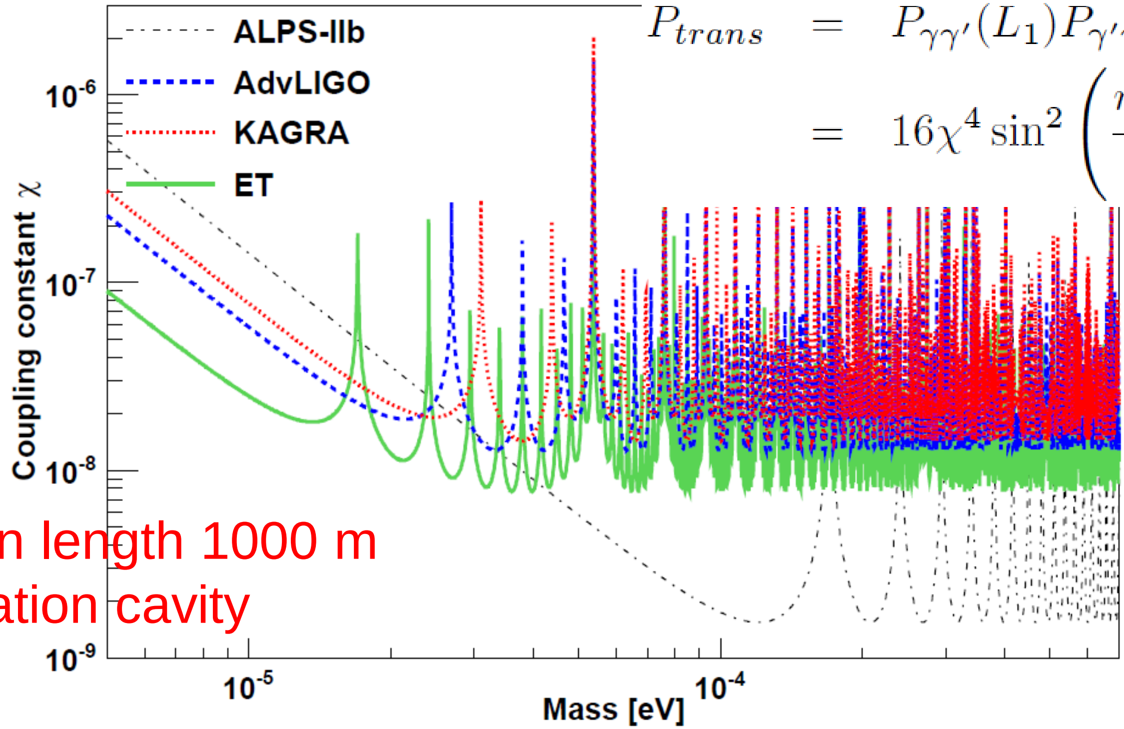
Figure 1. Schematic of the LSW gravitational wave experiment. The vacuum chamber is placed at the back of arm of the cavity. The RC is mounted in the vacuum chamber (from KAGRA[12,13]).

Sensitivity

- larger the better, higher power the better
- more number of reflections the better
- further sensitivity increase with re-generation cavity

How do we align and mode-match re-generation cavity?

$$P_{trans} = P_{\gamma\gamma'}(L_1)P_{\gamma'\gamma}(L_2)$$
$$= 16\chi^4 \sin^2\left(\frac{m_{\gamma'}^2}{4\omega}L_1\right)\sin^2\left(\frac{m_{\gamma'}^2}{4\omega}L_2\right)$$



1 year obs.
re-generation length 1000 m
no re-generation cavity

Figure 2. Projected sensitivity of the LSW experiments to $\gamma\gamma'$ oscillations detected by the TES bolometer and the converted region of 1000 m. The y-and x-axes represent the coupling constant and mass of hidden-sector photon, respectively. The measurement time is assumed as 1 year. Black dash-dotted curve is the expected sensitivity of the future ALPS-IIb experiment with a 100 m cavity. Dashed blue, dotted red, and solid green curves are the sensitivities of AdvLIGO, KAGRA, and ET, respectively.

Comparison with Previous

- can reach hidden Higgs, cold dark matter region with re-generation cavity

PRL **111**, 041302 (2013)

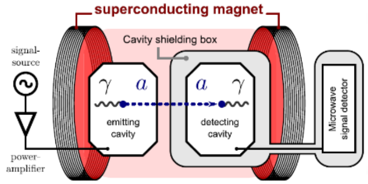
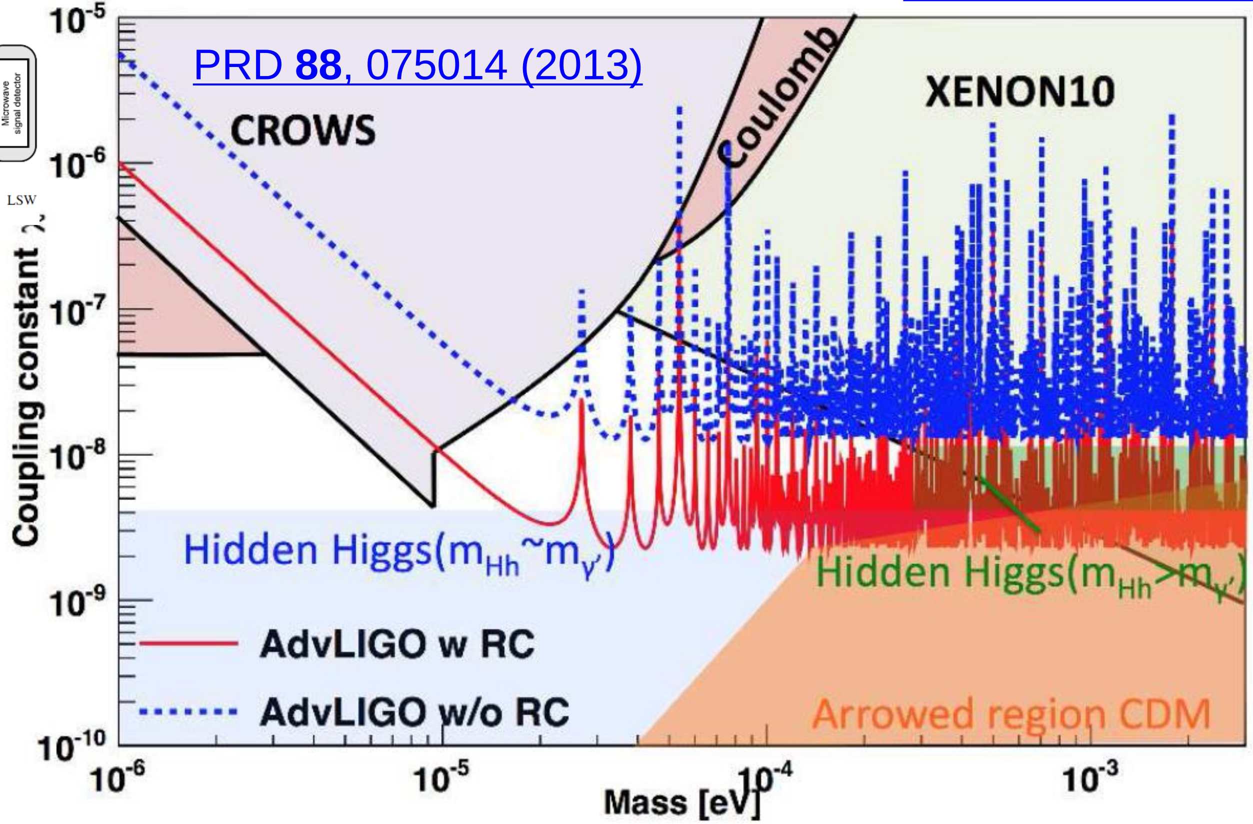


FIG. 1 (color online). Schematic of a microwave LSW experiment.



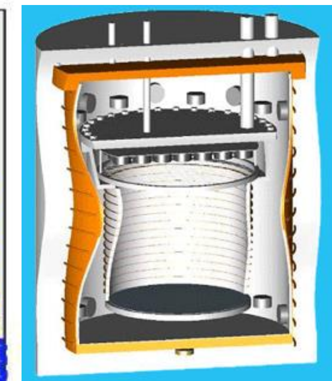


Figure 4. Same as Figure 2 except the previous experiment and the allowed regions of the hidden Higgs and cold dark matter.[16,18] The AdvLIGO sensitivity is over-plotted in same figure. theXENON10 is a new dark matter search experiment, aiming to increase the fiducially liquid xenon.[19] The CROWS is microwave based LSW experiments.[10] The Coulomb region is excluded from tests of the inverse square law of the Coulomb interaction.[20]

Summary

- cavities are interesting