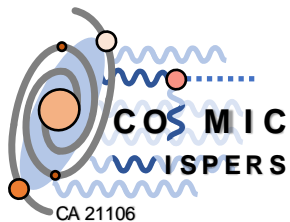


Report on WG4 Activities

Claudio Gatti - LNF INFN
Marin Karuza – Uni Rijeka

2nd General Meeting
of
COST Action COSMIC WISPers
(CA21106)



WG4 Tasks

- **T4.1:** Review of present and future WISPs experiments (including DM ones) in order to assess their discovery potential.
 - **Subtask 4.1.1:** Perform an update of summary plots of present limits for various WISPs models (axion, hidden photons, chameleons etc.). For the axion constraints on the coupling with photons, electrons, nucleons. For HP, bounds on the kinetic mixing angle. Reinterpretation of existing experimental limits with new WISPs models.
 - **Subtask 4.1.2:** Combination of experimental results with astrophysical and cosmological limits to extract summary plots.
 - **Subtask 4.1.3:** Highlight regions of the parameter space not yet covered by experiments and discuss feasibility of the experimental searches in these regions. Discuss the feasibility of testing all the couplings (to leptons, photons, baryons etc.) in all the parameter space.
- **T4.2:** Identify progress need in the key technologies and techniques (data analysis, signal filtering) for present and future experiments needed to cover the theoretically motivated region in the parameter space.
 - **Subtask 4.2.1:** perform a survey of technology (materials, detection, sources, cryogenics, magnets, high resolution detectors) needed in WISP experiments.
 - **Subtask 4.2.2:** perform a survey of solutions available (in SME or academic research) and of the competences available.

WG4 - General organization



- WG4 meetings one per month



- Report on direct detection and Tech. Forums: Overleaf LATEX



- WG4 documents on Drive/Dropbox



- Mailing List cosmicwisperwg4@lists.infn.it
- INDICO meetings <https://agenda.infn.it/category/1831/>

Contact Persons



- WG contact persons:
 - WG1 Mario Reig
 - WG2 Jose Cembranos
 - WG3 Maurizio Giannotti, Federico Urban
 - WG5 Loredana Gastaldo, Serkant Ali Cetin
- Contact person with CERN-PBC Technology working group: Giovanni Cantatore, Pierre Pugat
- Contact person with ECFA Quantum Sensing WG (tbd)

Talks in 2024

Link to agenda: <https://agenda.infn.it/category/1835/>

Experiments and Experimental Techniques

ALPHA Plasma Experiment - Pierluca Carenza

Intensity interferometry for ultralight bosonic dark matter detection – Daniel Gavilan

Nuclear Reactors and Haloscopes - Fernando Arias-Aragon

The IAXO experiment - Jaime Ruz Armendariz

Recent results of QUAX@LNF – Alessio Rettaroli

Gravitational waves detection based on cubic resonant cavities in the microwave frequency range – Benito Gimeno

Cavities for UHFGW and Axion detection at the SUPAX experiment - Kristof Schmieden

SQUIDs and their applications – Michael Mueck

Development of superconducting circuits in Italy – Federica Mantegazzini

Quantum Sensing and the Dark Quantum project - Takis Kontos

} Light DM experiments

} HFGW

} Quantum Sensing

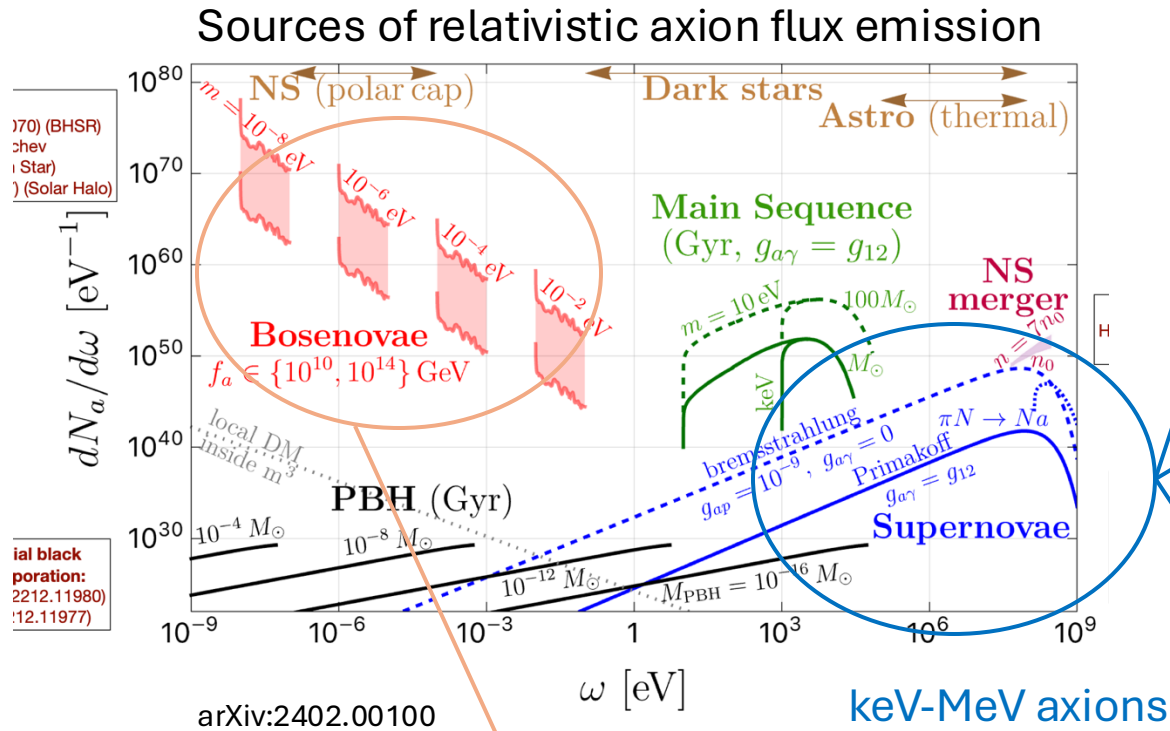
Axion Astrophysical Sources

Diffuse Axion Background - Joshua Eby

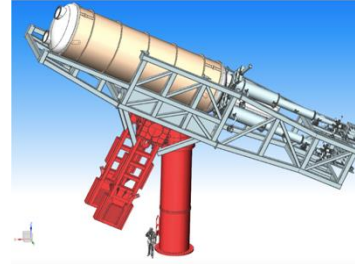
Getting the most on supernova axions - Alessandro Lella

Axion Astrophysical Sources

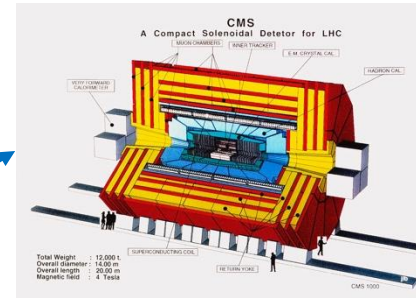
<https://agenda.infn.it/event/41392/>



How to detect bursts of relativistic nHz-THz-IR axions?

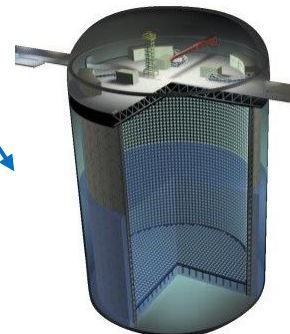


Helioscopes: Babylaxo



LHC detectors

Observing Axion Emission from Supernova with Collider Detectors arXiv:2203.01519



Neutrino detectors

Cross section for supernova axion observation in neutrino water Cherenkov detectors arXiv:2306.17055

What else?

HFGW

https://agenda.infn.it/event/40062/

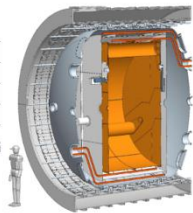
How to compute GW-cavity couplings

Numerical results and discussion

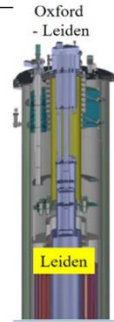
- For the calculations we have used realistic magnets:

Cavity	V (L)	Magnet	B_0 (T)	T_{phys} (mK)	T_{sys} (K)
C1	9526.1056	KLASH [52]	0.6	4500	8
C2	9.5243	CAPP [53]	12	30	1
C3	0.0095	CAPP [53]	12	30	1

Table 4. Characteristics of the magnets and parameters for the data acquisi



INFN-Frascati
KLASH



- The form factor accounts for the coupling between the GW and the resonant modes as a function of the GW incidence angle θ in the XZ, YZ and XY planes :

$$\tilde{\eta}_{m+,x} = \frac{\left| \int_V \vec{E}_m(\vec{r}) \cdot \vec{J}_{+,x}(\vec{r}) dV \right|}{V^{1/2} \left| \int_V \vec{E}_m(\vec{r}) \cdot \vec{E}_m(\vec{r}) dV \right|^{1/2}}$$

A global network of detectors for HFGW

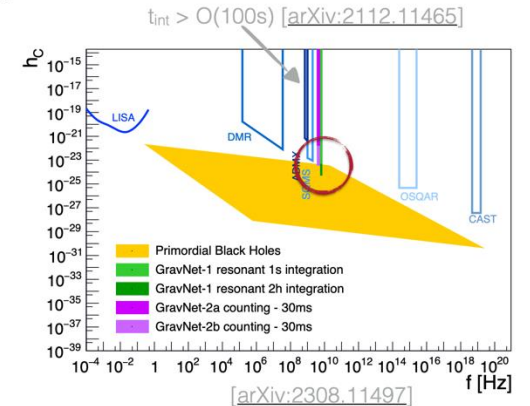
Summary

- To increase the sensitivity of halo scope style experiments we suggest to build a **global network of detectors**
 - Remember: SNR scales linear with number of detectors!
- Integrating measurement:
 - Sample RF data, combine phase aligned, integrate
- Typical integration times too long to be sensitive to BH merges!

- Photon counting style experiments:
 - Recent advancements in single RF photon detection allows to use coincidences of several detectors
- Using 20 independent detectors:
 - Sensitivity: $h_0 < 3 \times 10^{-22} \dots 3 \times 10^{-24}$

Requires large meta material cavities
(high frequency @ large volume)

- Single frequency sufficient to hunt for PBH mergers!
- Could even combine measurements at different frequencies



WG4 Report

Link to Report: <https://www.overleaf.com/4678842289cfhfndnmvtyr>

CosmicWispers WG4 Report: WISPs direct searches

Claudio Gatti¹, Alessio Rettaroli¹, Marin Karuza², Mario Reig^{3,4}, Marios Maroudas⁵, Michele Gallinaro⁶, Sebastian A. R. Ellis⁷, Alejandro Díaz-Morcillo⁸, Francisco R. Candón⁹, Maurizio Giannotti⁹, Jaime Ruz⁹, Igor G. Irastorza⁹, Julia K. Vogel⁹, Cristina Margalejo Blasco⁹, Daniel Gavilan-Martin^{10,11}, Michael Staelens¹², Vasiliki A. Mitsou¹², Venelin Kozhuharov^{13,1}, Olympia Maliaka^{10,11}, Dmitry Budker^{10,11,14}, Ophir M. Ruimi^{10,11,15}, Jordan Gué¹⁶, Luca Marsicano¹⁷, and Giovanni Grilli di Cortona¹⁸ ...

Editors:

- *WG4 leaders*

- *Michael Staelens (IFIC, CSIC – Universitat de Valencia), michael.staelens@ific.uv.es*

- *Ophir Ruimi (HUJI & HIM/JGU), ophir.ruimi@mail.huji.ac.il*

- *Alessio Rettaroli (INFN - LNF), alessio.rettaroli@lnf.infn.it*

WG4 Report

2 EU Experiments

Pure lab (LSW, collider etc.)

Has set a limit

- ALPS
- BMV
- CROWS
- NA64
- OSQAR
- PVLAS
- QUAX-gp gs

In progress/planned

- ~~ALPS-II~~
- VMB@CERN
- ~~WISPEI~~
- ~~MoEDAL-MAPP~~

Concept

- STAX
- ALPS-III
- STE-QUEST

Helioscopes

Has set a limit

- CAST
- SHIPS

In progress/planned

~~• BabyIAXO~~

- IAXO
Planned/concept
- IAXO+
- TASTE (Russian)

Haloscopes

Has set a limit

- BRASS
- CASPEr-gradient
- CASPEr-electric (but it's in the US)

- CASPEr-ZULF
- CAST-CAPP
- FUNK
- GrAHal
- JEDI
- MADMAX
- NASDUCK (Israel)

- QUAX
- RADES
- SHUKET
- WISPDMX
- SUPAX

In progress/planned

- AION
- CADEx
- FLASH

- WISPLC

Concept

- AEDGE
- DALI
- STE-QUEST (!! also appears in Pure lab)
- TOORAD

Beam dump (M<1 GeV)

- PADME

Non-WISP focused experiments with ability to detect WISPs

Has set a limit

- ATLAS (collider - $\tilde{\chi}$ heavy ALP/dark photon)
- AURIGA (GW detector - $\tilde{\chi}$ scalar DM detection)
- CMS (collider - $\tilde{\chi}$ heavy ALP/dark photon)
- BASE (antiproton trap - $\tilde{\chi}$ lumped element axion haloscope)
- DAMIC (underground detector - $\tilde{\chi}$ ALP/dark photon absorption)
- ~~DarkSide~~ (underground detector - $\tilde{\chi}$ ALP/dark photon absorption)
- EDELWEISS (underground DM detector - $\tilde{\chi}$ ALP/dark photon absorption)
- GERDA (Neutrinoless double beta decay - $\tilde{\chi}$ ALP/dark photon absorption)
- GEO600 (GW detector - $\tilde{\chi}$ scalar/vector DM)
- LOFAR (Radio telescope - $\tilde{\chi}$ dark photon DM)
- NOMAD (Neutrino detector - $\tilde{\chi}$ light shining through wall)
- XENON (Underground DM detector - $\tilde{\chi}$ solar axion/dark photon, DM absorption)

Still many EU experiments missing!
Use template to add your experiment.
And the list must be updated too.

Instructions

For those interested in contributing to the WG4 report, here is the link to the overleaf project:

<https://www.overleaf.com/4678842289cfhfndnmvtyr>

To insert a new experiment/facility/R&D/Experimental Scheme:

1) copy the corresponding TemplateFile.tex (TemplateExperiment, TemplateFacility, TemplateRD, TemplateExperimentalScheme) to a new file.

2) Include in the new file your text and pictures

3) upload the pictures to the overleaf project

4) Include references in the file references.bib

5) Add a subsection and the file in main.tex:

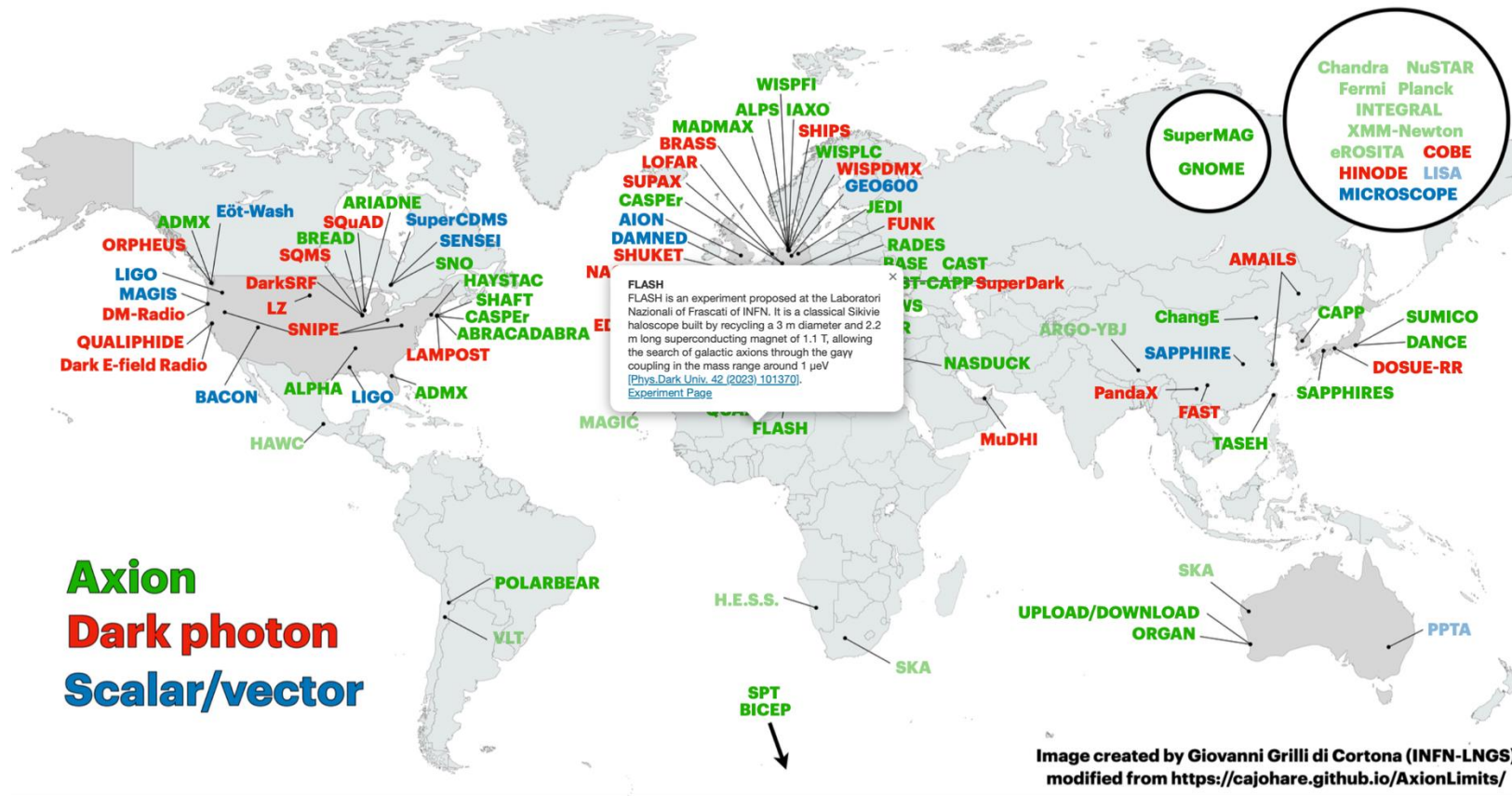
```
\subsection{My Experiment Something}
```

```
\subfile{LatexFileName}
```

6) Add your name and institution in the author list. (new: add your name also in the template file)

Map of WISPs Experiments

<https://ggrillidc.github.io/experiments-map/>



Please provide here a short text and a link for your experiment:

https://docs.google.com/document/d/1tGzO6U9HQDaXylyGosc8Lk3TksxXNs ee/edit?%20usp=share_link

Inputs from the last meeting in DESY

Common R&D:

- a) magnets
- b) quantum technologies
- c) quality optics, mirrors, cavities
- d) actuators
- e) detectors (radio,THz, IR, optics, xray, gamma)

Data taking and analysis (cloud computing)

Data preservation and access

Data combination

Closer collaboration within WGs:

- Modelling for HFGW with wisps detectors
- Cross sections calculations
- Sensitivity/exclusion plots prescriptions
- List of models/signals/etc to widen physics reach of experiments or modification to experiments
- Outreach: wih are the tools, how to contribute? How to give new suggestions, social media etc.

Axion astrophysics:

- a) EU Networks for astrophysical objects (GNOME-like)
- b) Supernova axions
- c) Link neutrino and axions
- d) HFGW

Collaborations

“EU Funding Agency” problem

Connection with PBC@CERN and DRDC

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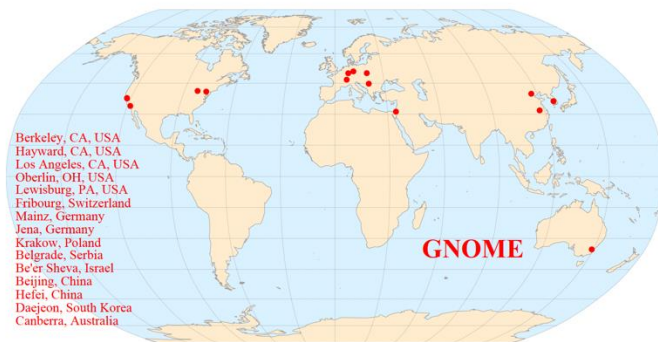
Networks

Can we extend existing networks? Can we create new networks? submit some joint proposal for axion experiment which needs more detectors?

What is a GNOME?¹

- **Global Network of Optical Magnetometers for Exotic physics searches**
- Looking for transient dark matter signals
- Sensitive to Axion-fermion coupling:

$$H_{int} = -\frac{\hbar c^{3/2}}{f_{int}} \frac{S_i}{|S_i|} \cdot \nabla a$$



GNOME



¹Phys.Dark Univ. 22 (2018), 162-180

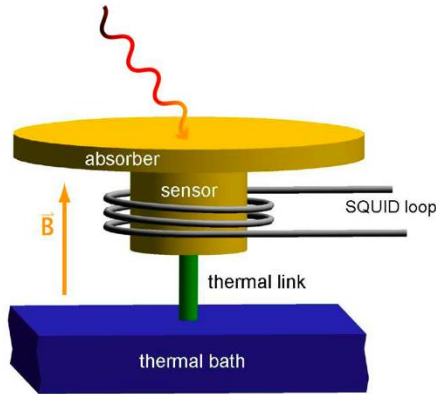
See talk by Daniel Gavilán



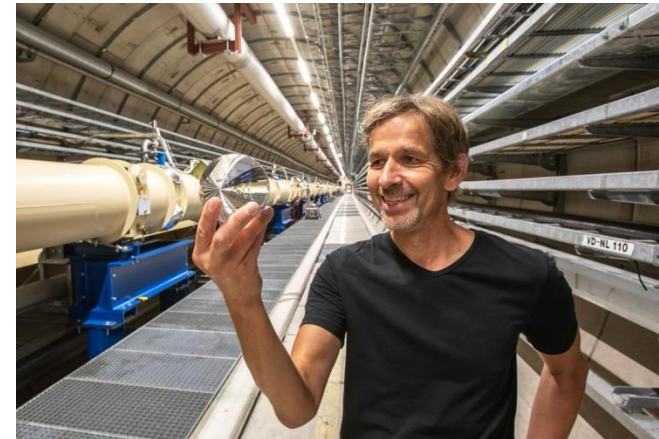
<https://www.pi.uni-bonn.de/gravnet/en>

Common R&D

A real discussion about common R&D didn't started yet ...
Organize dedicated meetings?
Create sub-groups?
Compare different experiences?



(Quantum) Sensors



Quality optics, mirrors, cavities



Resonant cavities (materials, tuning ...)



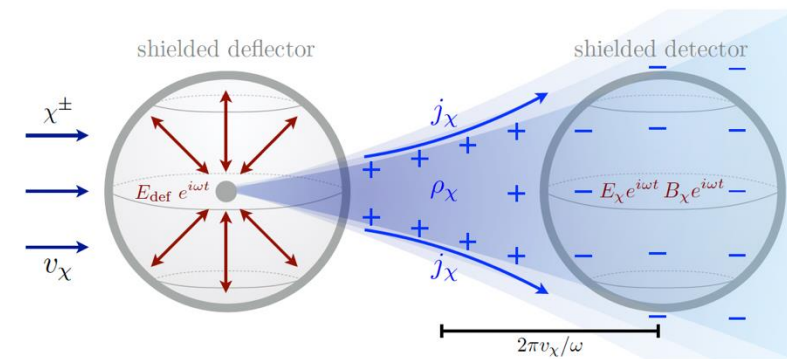
Data analysis, combination etc.

Experimental Schemes

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9.2	The Piezoaxionic Effect arXiv:2112.11466	40
9.3	Search for Dark Photon in microwave cavities with Rydberg atoms (PRD 108, 035042 (2023))	40
9.4	Production and detection of an axion dark matter echo arXiv:1902.00114	42
9.5	Directly Deflecting Particle Dark Matter PHYSICAL REVIEW LET- TERS 124, 011801 (2020)	42
9.6	Searching for millicharged particles with superconducting radio-frequency cavities PHYSICAL REVIEW D 102, 035010 (2020)	46
9.7	Sound of Dark Matter: Searching for Light Scalars with Resonant- Mass Detectors PRL 116, 031102 (2016)	46
9.8	Axion production in unstable magnetized plasmas. Phys. Rev. D 101, 051701(R)	46
9.9	Searching for axion forces with spin precession in atoms and molecules arXiv:2309.10023	46
9.10	Proposal for gravitational direct detection of dark matter PHYSICAL REVIEW D 102, 072003 (2020)	47
9.11	Intensity interferometry for ultralight bosonic dark matter detection PHYSICAL REVIEW D 108, 015003 (2023)	47
9.12	A Diffraction Grating for the Cosmic Neutrino Background and Dark Matter arXiv:2303.04814	47

From WG4 report

Continue collecting ideas on new WISPs experiments.
Discussion already ongoing on proposed schemes!
Report at WG4 about new articles/ideas on new schemes!



Things to do

1. Start over with monthly meetings. Choose a fixed date/day and avoid too many doodles
2. Finalize the review on the experiments in the Report (soon a meeting with editors)
3. Organize discussion on common R&D. Volunteers? Suggestions?
4. Networks! Any idea from theory groups?
5. Other?