Report on WG4 Activities

Claudio Gatti - LNF INFN

Marin Karuza – Uni Rijeka

MC Meeting

of

COST Action COSMIC WISPers (CA21106)

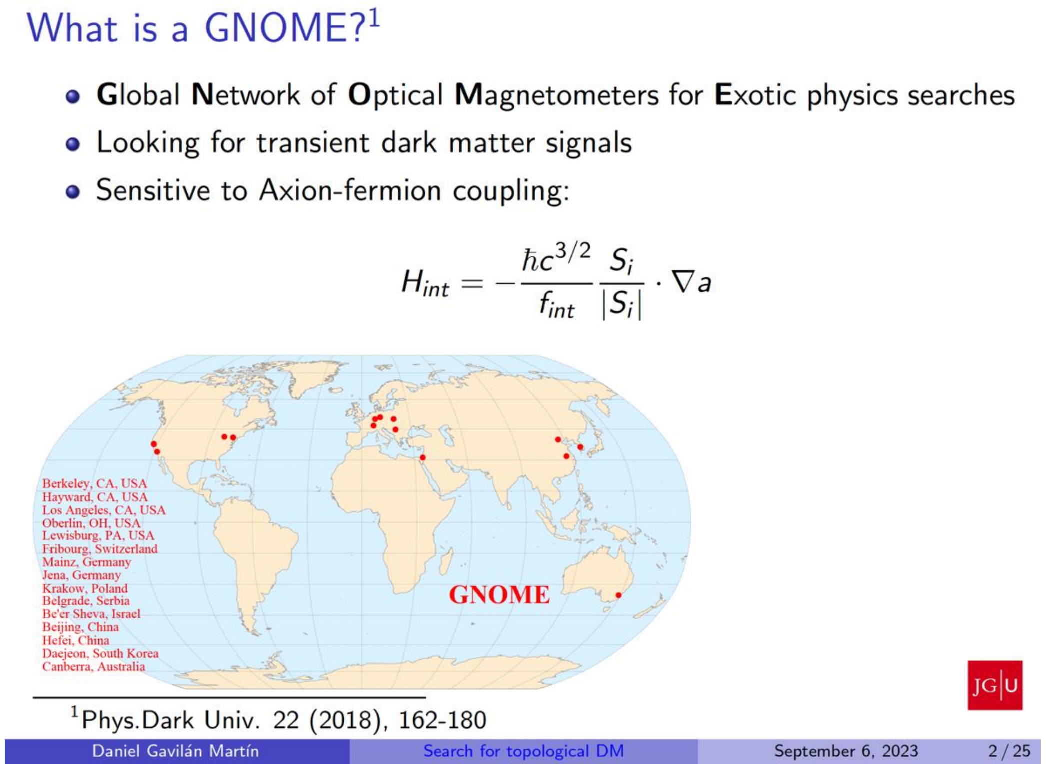
COSMIC WISPERS

CA 21106

Inputs from the meeting

Networks

1. Help extending existing networks
2. Create links for new networks
3. Create opportunities for joint proposal for axion experiments with multi detectors



See talk by Daniel Gavilán

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

HFGW

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

See also this week talks by Camilo Garcia Cely and Luca Visinelli

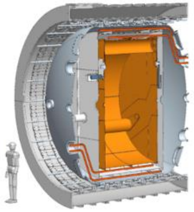
How to compute GW-cavity couplings

Numerical results and discussion

- For the calculations we have used realistic magnets:

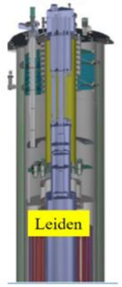
Cavity	V (L)	Magnet	B_0 (T)	T_{phys} (mK)	T_{sys} (K)
C1	9526.1056	KLASH [52]	0.6	4500	8
C2	9.5243	CAPP [53]	12	30	1
C3	0.0095	CAPP [53]	12	30	1

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



INFN-Frascati KLASH

Oxford - Leiden



- 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 :

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

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Benito Gimeno

A global network of detectors for HFGW

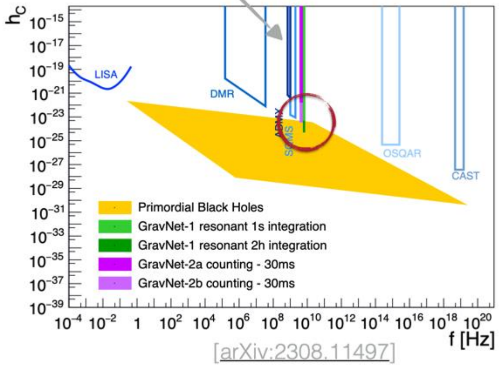
Summary

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

t_{int} > O(100s) [arXiv:2112.11465]

- Photon counting style experiments:
  - Recent advancements in single RF photon detection allows to use coincidences of several detectors
- Using 20 independent detectors:
  - Sensitivity: $h_0 < 3\times10^{-22}$ …. 3×10^{-24}

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



[arXiv:2308.11497]

Kristof Schmieden WG4 - Cosmic whispers 24

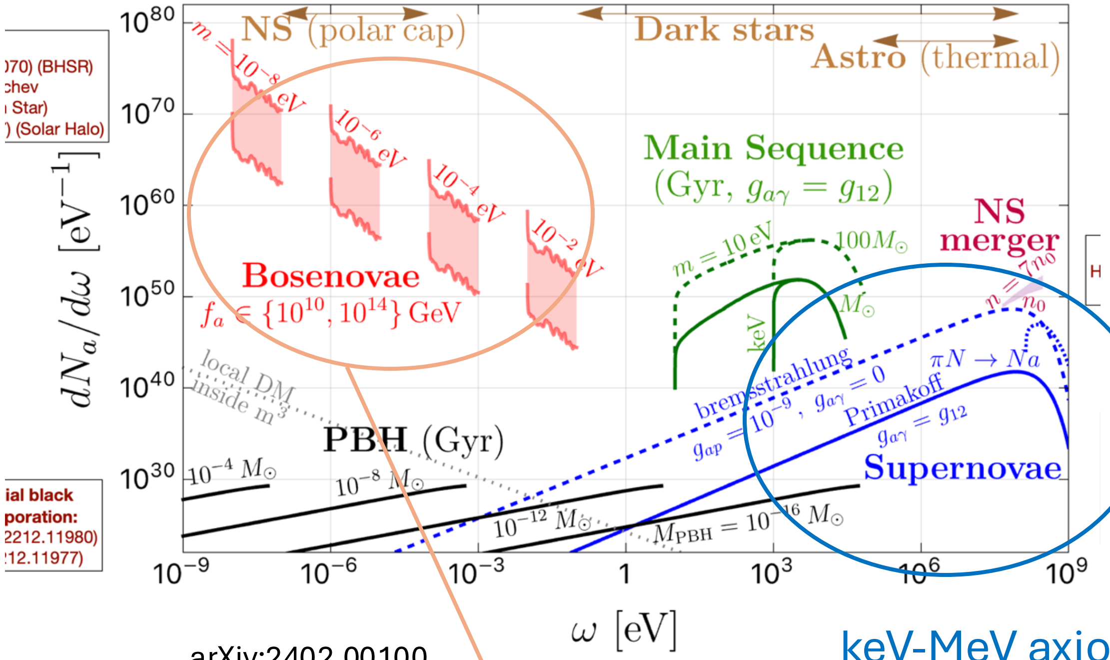
Kristof Schmieden

Axion Astrophysical Sources

See also this week talks by Maurizio and Elena Pinetti on JWST

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

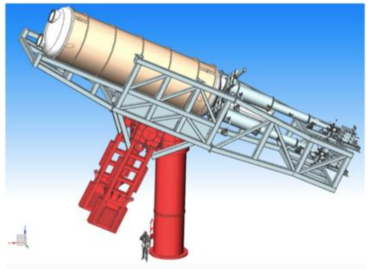
Sources of relativistic axion flux emission



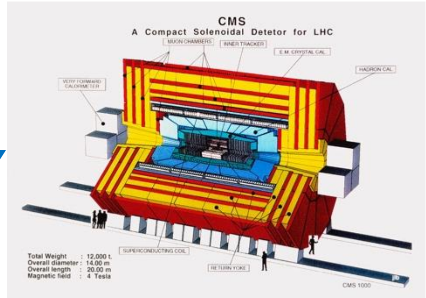
arXiv:2402.00100

keV-MeV axions

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

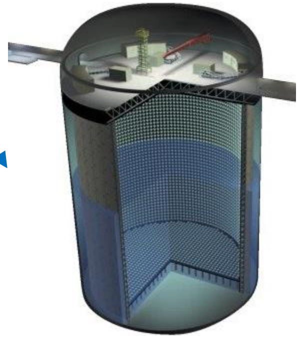


Helioscopes: Babylaxo



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?

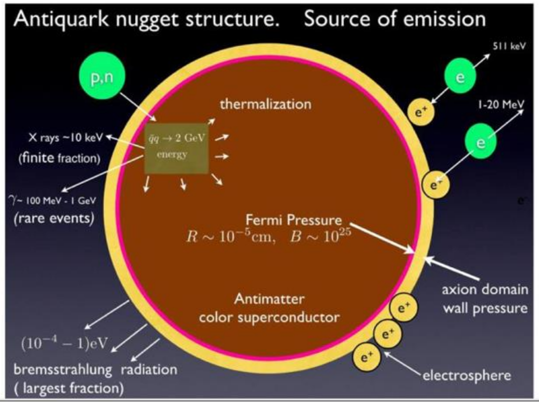
Detection of relativistic axions with cavities

$$C \propto \int dV\, e^{ikx}\, E \cdot B$$

Axion Quark Nugget (AQN) Model

- Originally proposed by Ariel Zhitnitsky (2003) to explain $\Omega_{DM} \sim \Omega_{visible}$.
- Also explain other mysteries (core-cusp, solar corona etc).
- Composite particles with axion domain walls.
- Relativistic axions with $<u_a> \sim 0.6c$ are emitted from AQNs as they penetrate the Earth.
- Production mechanism would cause:
  1. **Daily modulation (~10-20%).**
  2. **Seasonal phase shift.**

DFSZhitnitsky



See talk by Kaan Özbozduman

A network to detect Axions Stars?
See talk by Edward Hardy "More axion stars from strings" during WG2 session

Properties of the substructure

- Mass o(0.1 meV)
- 1 event every 5 years
- 8h signal duration

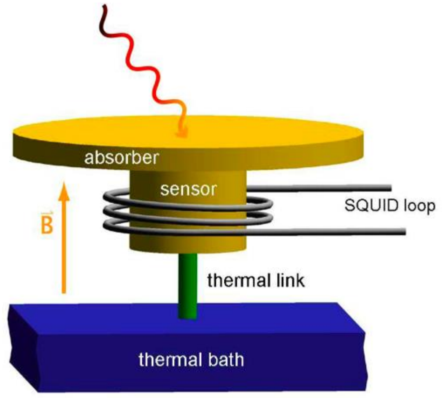
$$\tau_{\oplus} = 5\ \text{yrs} \left(\frac{r_{0.1}}{r}\right)^2 \left(\frac{0.1}{f_{\text{star}}}\right) \left(\frac{\bar{M}_s}{10^{-19} M_{\odot}}\right)^3 \left(\frac{10^{10}\ \text{GeV}}{f_a}\right)^4$$

$$\Delta t \simeq \frac{2\ r_{0.1}}{v_r}\sqrt{1 - \frac{r^2}{r_{0.1}^2}} = 8\ \text{hrs} \left(\frac{10^{-19} M_{\odot}}{\bar{M}_s}\right) \left(\frac{f_a}{10^{10}\ \text{GeV}}\right)^2 \sqrt{1 - \frac{r^2}{r_{0.1}^2}}$$

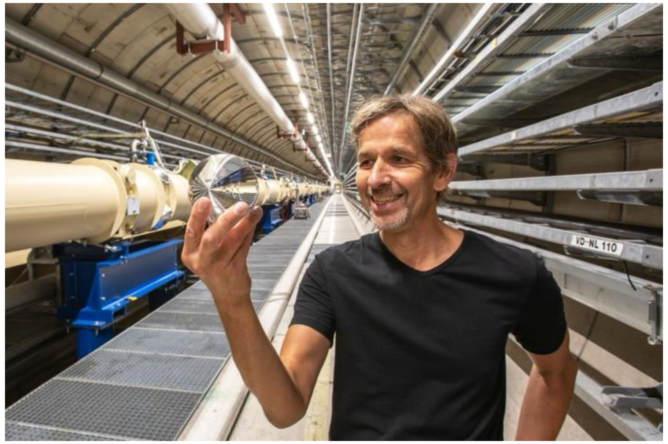
Factor $\gtrsim 10^6$ enhancement compared to background DM density

Common R&D

Create 4 sub-groups, and swg-leaders, for discussion on common R&D and related technologies



(Quantum) Sensors



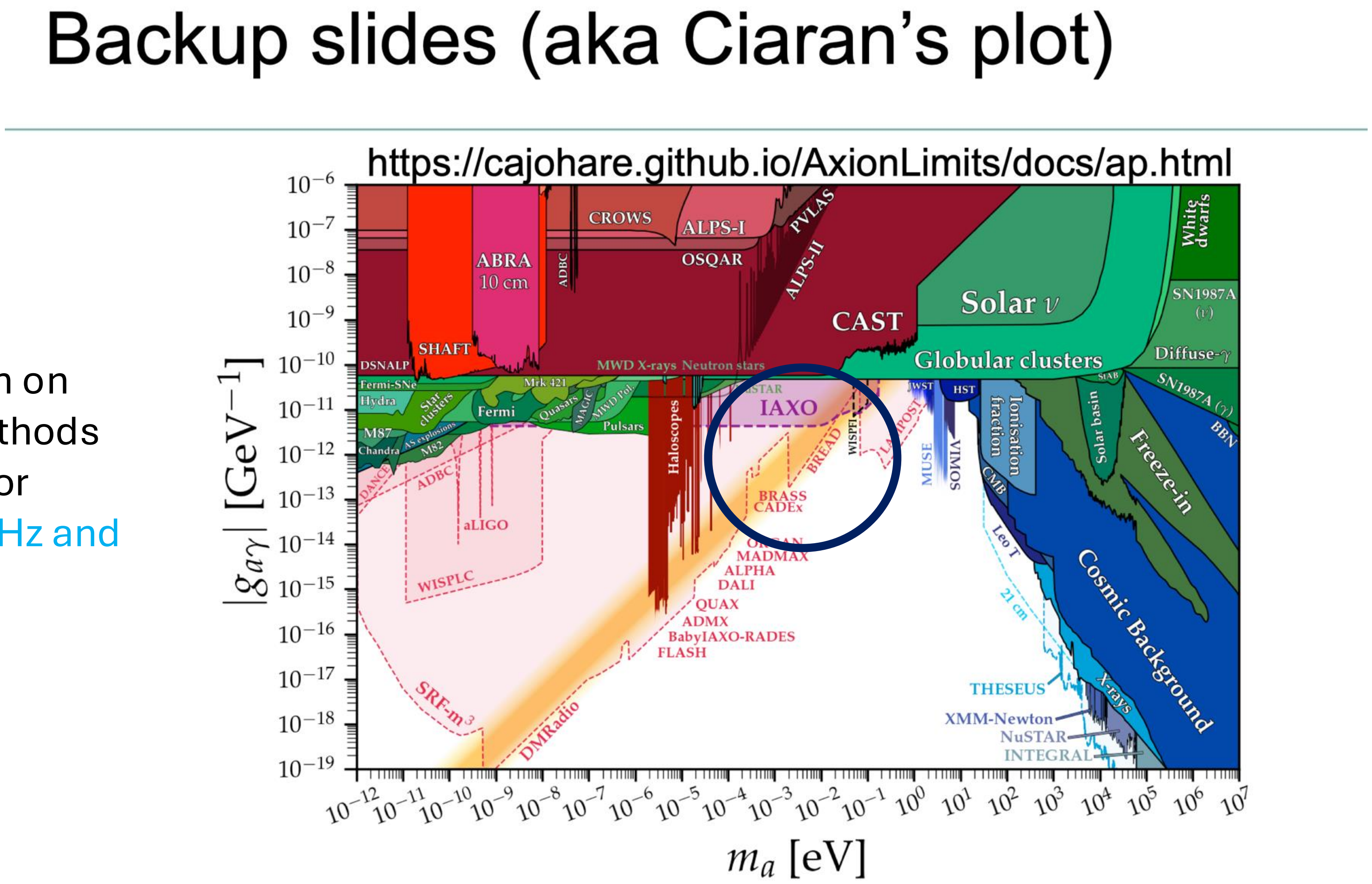
Quality optics, mirrors, cavities

Resonant cavities (materials, tuning ...)

Data analysis, combination etc.

Fill the Gaps! From Edoardo's talk

Start a discussion on experimental methods and techniques for searches in the THz and IR regions!

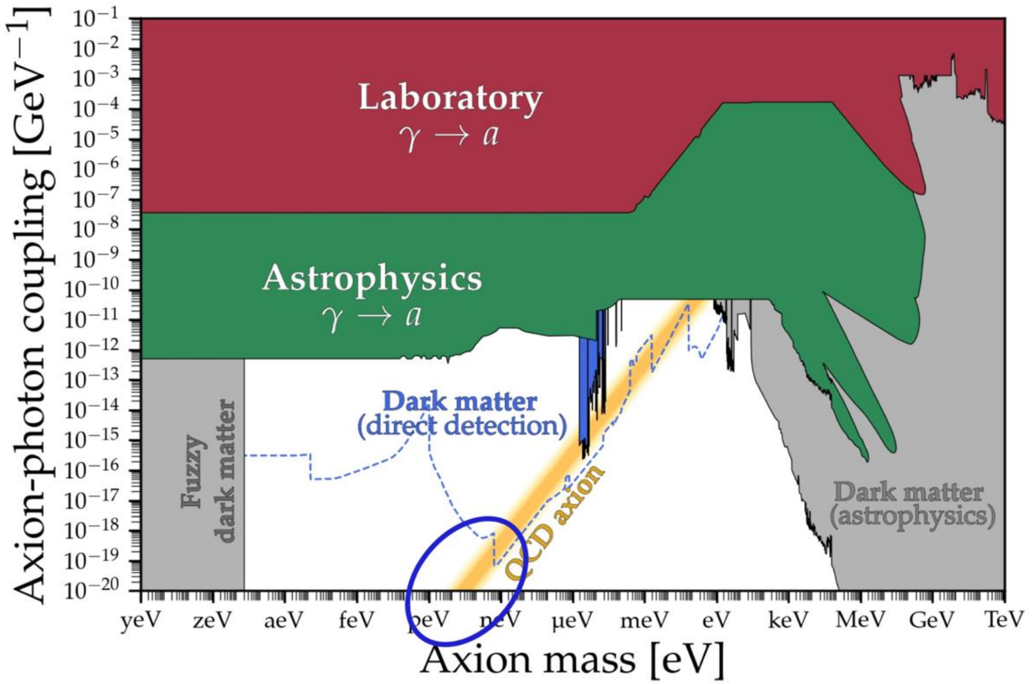


Andrea’s talk

Coverage of Parameter Range in Future

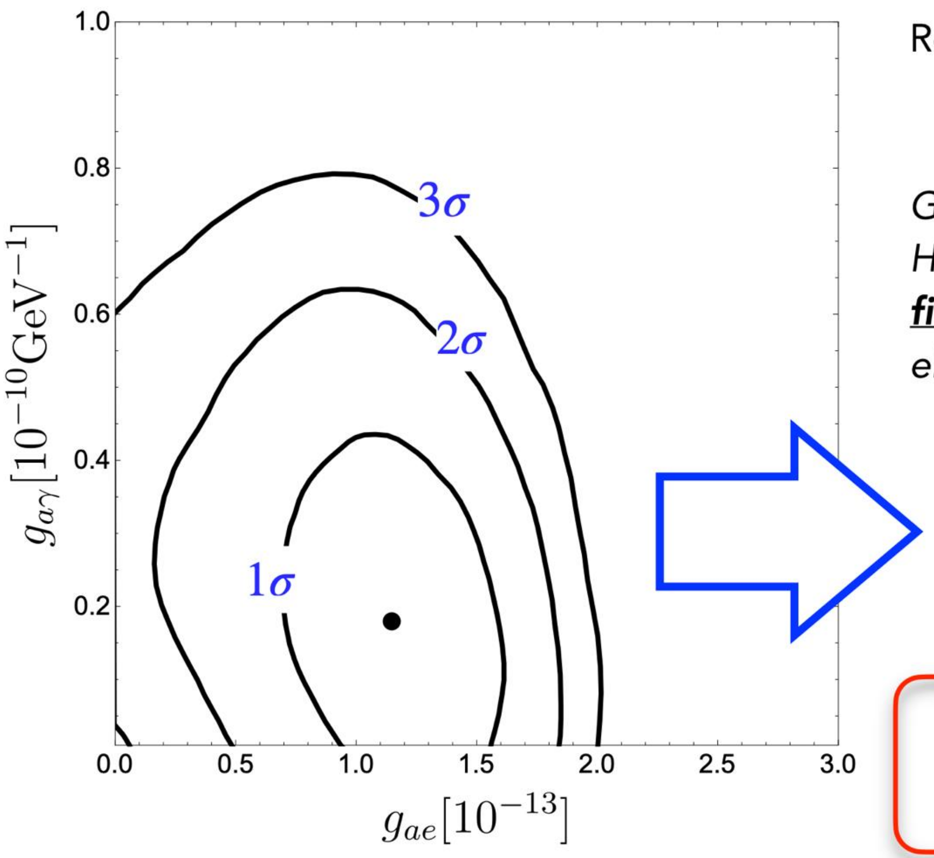
In 2036:

- Seems that we are in a good way to cover the most plausible mass and coupling ranges of the axion by DM direct detection
- Caveats:
  - Local axion DM density could be much less than average 0.4 GeV/cm^3
  - Sensitivity holes around
    - peV to neV mass ($M_P > f_a > M_{GUT}$)



From Maurizio's talk

The Road Ahead



Di Luzio, Fedele, M.G., Mescia, Nardi, arXiv:2109.10368 (2021)

Revise stellar bounds/hints

Global analysis of WDs, RGB and HB stars shows a ***preference for finite axion couplings*** *with electrons and photons*

For QCD models →
meV to ~100 meV mass region

Is this a sweet spot to study across the different groups?

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Experimental Schemes

9 New experimental schemes for WISPS searches **39**

9.1 Template Experimental Scheme 39

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 LETTERS 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

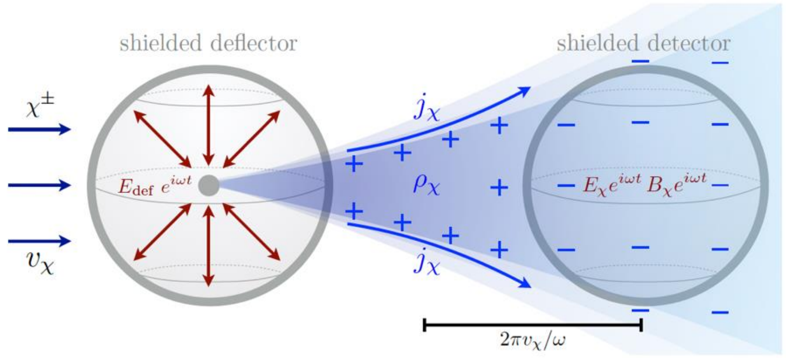
9.10 Proposal for gravitational direct detection of dark matter PHYSICAL REVIEW D 102, 072003 (2020) 47

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!



Scalar field production in the Sun

New ideas for experiments!

Luca Visinelli

Axions and scalars from the Sun

New exploration frontier: Scalar field production in the Sun

We have considered solar chameleons produced from

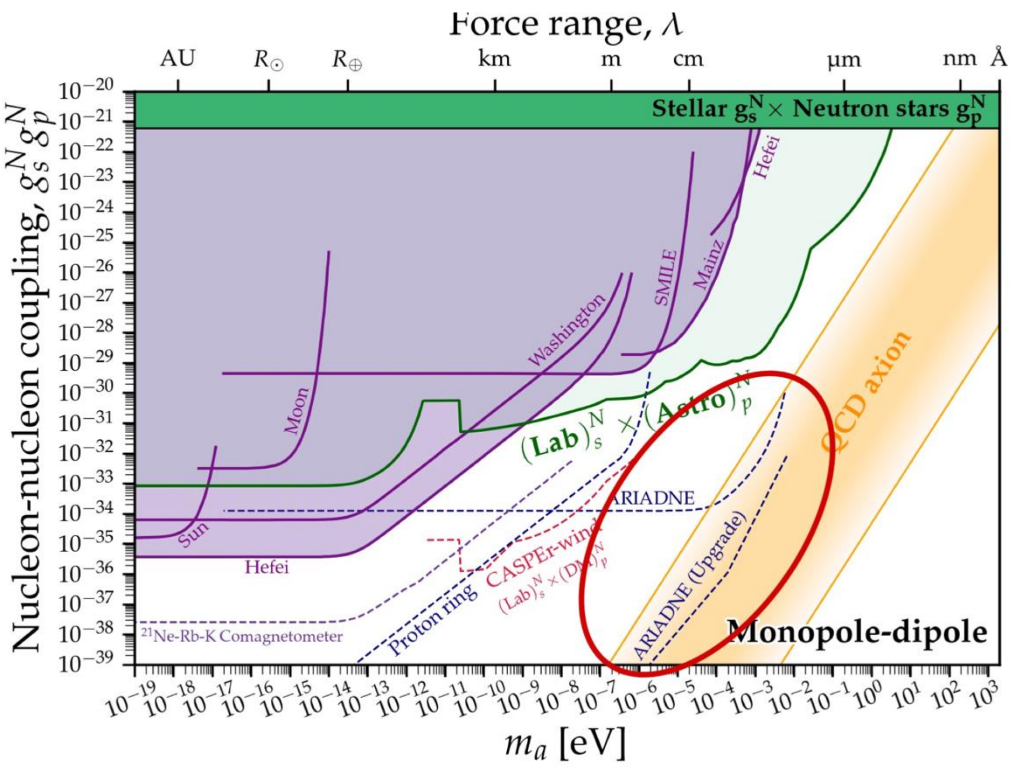
$$S = \int \mathrm{d}^4x\sqrt{-g}\left[-\frac{1}{2}(\partial_\mu\phi)(\partial^\mu\phi) - V_{\rm eff}(\phi) + \frac{1}{M_\gamma^4}(\partial_\mu\phi)(\partial_\nu\phi)T_\gamma^{\mu\nu}\right] + S_{\rm SM}$$

$$V_{\rm eff}(\phi) = V_{\rm self}(\phi) + \frac{\beta_m}{M_{\rm Pl}}\rho_m\phi + \frac{\beta_\gamma}{M_{\rm Pl}}\phi\frac{1}{4}F^{\mu\nu}F_{\mu\nu} \qquad V_{\rm self} \sim \Lambda^4$$

See the talk by **Anne Davis** right after mine

See also talk by Anne Davis and Tom O’Shea → 5th force experiments

Exotic/new interactions



[O'Hare, Vitagliano, 2010.03889]

Monopole-philic axion

$$\left(\partial^2 + m_a^2\right) a = -\left(g_{a\gamma} - g_{am}\right) \mathbf{E}_0 \cdot \mathbf{B}_0 \,,$$

$$\boldsymbol{\nabla} \times \mathbf{B}_a - \dot{\mathbf{E}}_a = g_{a\gamma} \left(\mathbf{E}_0 \times \boldsymbol{\nabla} a - \dot{a} \mathbf{B}_0\right) \,,$$

$$\boldsymbol{\nabla} \times \mathbf{E}_a + \dot{\mathbf{B}}_a = -g_{am} \left(\mathbf{B}_0 \times \boldsymbol{\nabla} a + \dot{a} \mathbf{E}_0\right) \,,$$

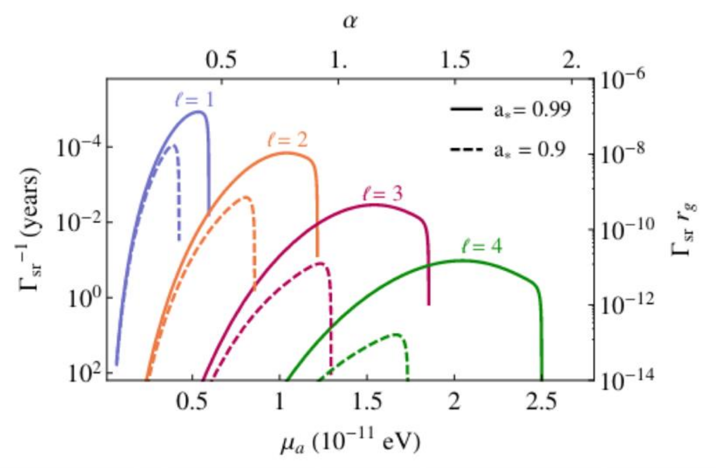
$$\boldsymbol{\nabla} \cdot \mathbf{B}_a = -g_{am} \, \mathbf{E}_0 \cdot \boldsymbol{\nabla} a \,,$$

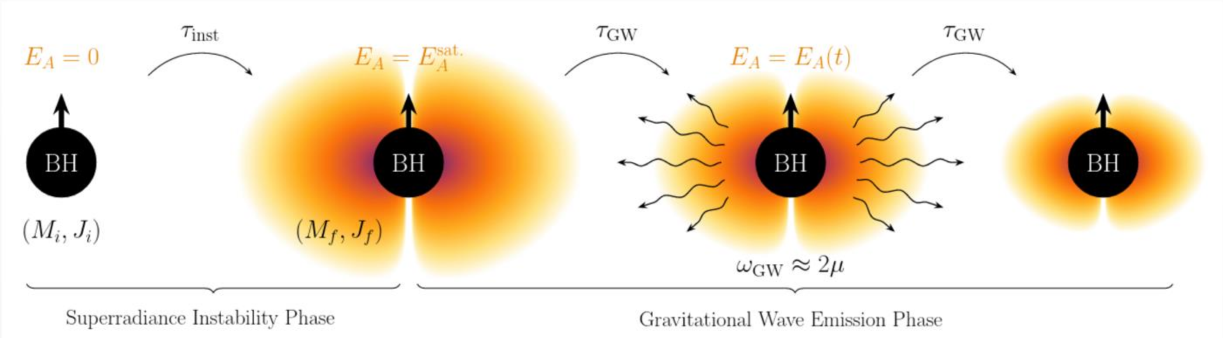
$$\boldsymbol{\nabla} \cdot \mathbf{E}_a = g_{a\gamma} \, \mathbf{B}_0 \cdot \boldsymbol{\nabla} a$$

Andrea's talk

New Sources/Superradiance

- Superradiant growth
  - ⋆ Baryonic/DM accretion → heavier clouds
    Hui+ [2208.06408]
- GW emission of the cloud
  $\tau_{\rm GW} \simeq 10^8 {\rm yr} \left(\frac{M}{10 M_\odot}\right) \times$
  $\left(\frac{\alpha}{0.07}\right)^{-14}_{|211\rangle}$ / $\left(\frac{\alpha}{0.2}\right)^{-18}_{|322\rangle}$





Refs: Arvanitaki+ [0905.4720, 1004.3558, 1411.2263]; Yoshino, Kodama [1312.2326]; Brito+ [1411.0686, 1706.06311, 1501.06570]; Siemonsen, May, East [2211.03845];
Fig: (U) Arvanitaki+ [1411.2263]; (D) Tsukada+ [2011.06995]

See talk by Mateja Boskovic

From Michele's talk

Motivate experiments in new regions of parameter space!

WG1: Future activities

- Contributions to organisation of meetings and training schools
- Dissemination talks at major conferences and outreach activities
- Monthly WG1 meetings:
  Same format for year 3: topical discussions, invitation of external speakers, recent papers…
- More STSM: please apply!
- In year 3: organise a 3-day WG1 workshop in person (in Bologna?)
  focused on a specific topic: axions? hidden photons? dark sector physics?
- Deliverables:
  i) talks at major conferences and workshops
  ii) publications on top refereed journals
  iii) contribution to the writing up of white paper and scientific reports
  iv) increase interactions with other WGs
  → predictions from UV motivated classes of models superimposed on exclusion plots
- Suggestions!

Inputs from WG1,2,3:

1 - Motivate regions of parameter space (from string-axions and axion-strings): from nHz to IR

2 - WISPS and HFGW sources (Sun, Supernova, early Universe, exotic objects)

3 - New interactions (fifth forces): ga,gv,gp,gs, monopole-philic axion

4 - New experimental schemes: e.g. scalars from the Sun

5 - Production and interaction rates (cross section, overlap integrals etc.): e.g. relativistic axion with cavities; MeV axion in particle detectors; HFGW interaction in axion experiments (and viceversa).

Expected outputs from WG4:

1 - Prospects for probing theoretically motivated regions

2 - Detection techniques for probing wisps from different sources (space missions?)

3 - Precision experiments for exotic interactions

4 - Investigate feasibility of new experimental schemes

5 - Compute experiment sensitivities

6 – Needed R&D

7 – Networks