

Search for topological defect dark matter with a global network of optical magnetometers (GNOME)

18th Patras Workshop

Daniel Gavilán Martín

on behalf of the GNOME collaboration

Helmholtz-Institut Mainz/JGU

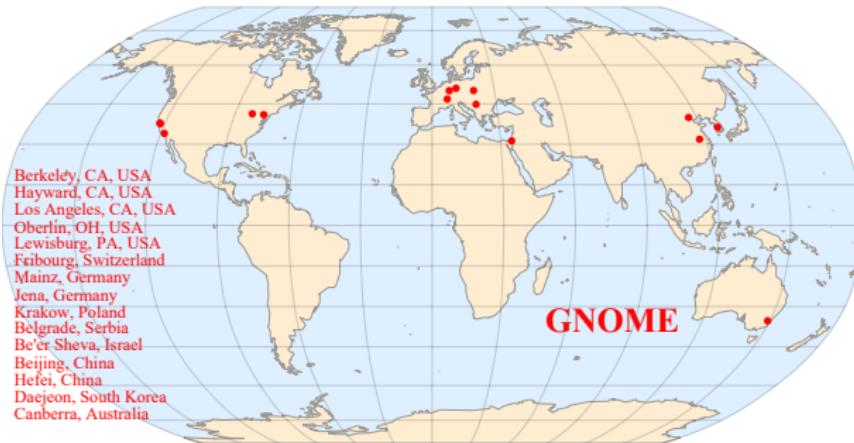
July 5, 2023



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:

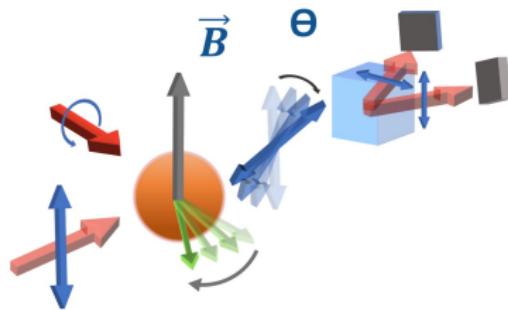
$$H_{int} = -\frac{\hbar c^{3/2}}{f_{int}} \frac{S_i}{|S_i|} \cdot \nabla a$$



¹Phys.Dark Univ. 22 (2018), 162-180

How does a GNOME work?

- Magnetometers as Dark Matter sensors



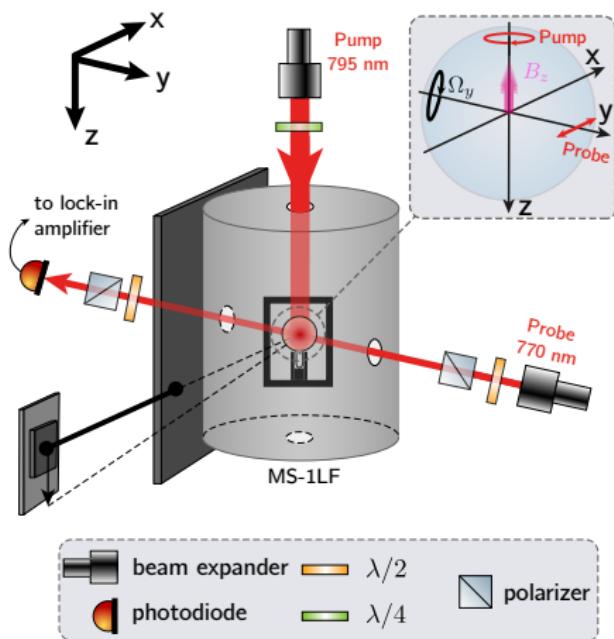
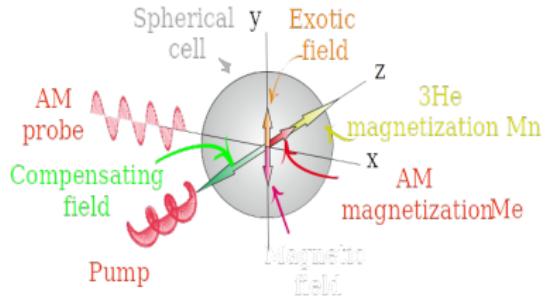
- 5 Science Runs since 2017
- Science Run 6 starting soon!



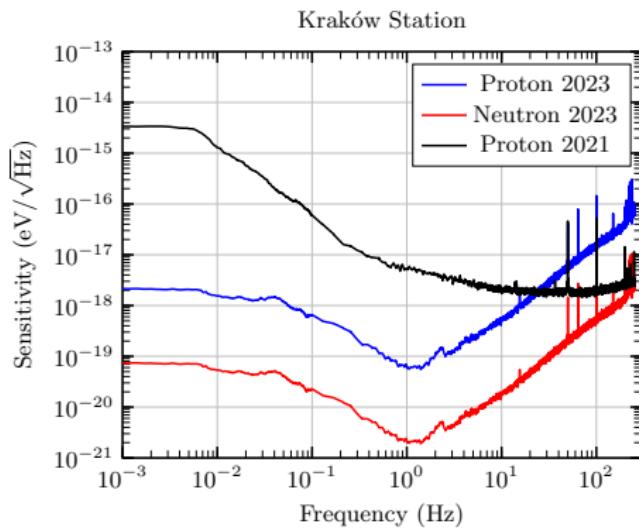
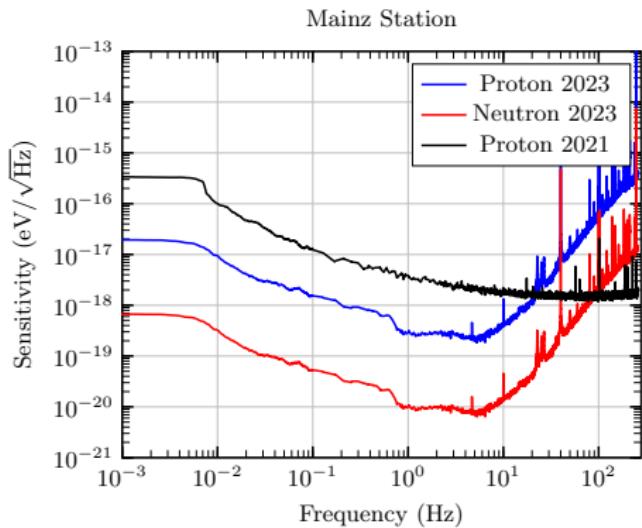
¹Phys.Dark Univ. 22 (2018), 162-180

Advanced GNOME: Comagnetometers

- Noble gas and Alkali metal in vapor cell with high spin density
- Compensation magnetic field
- Insensitive to first order magnetic perturbations

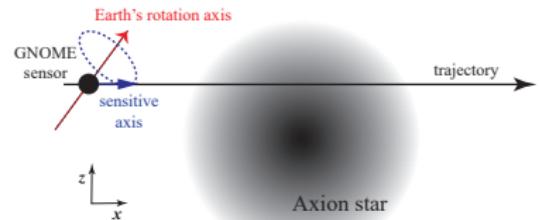
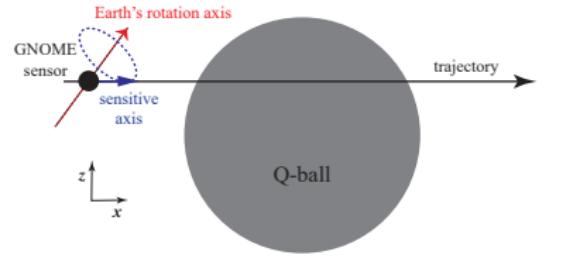
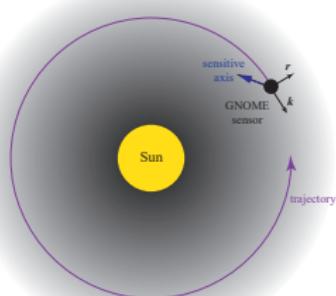


Advanced GNOME: Sensitivity



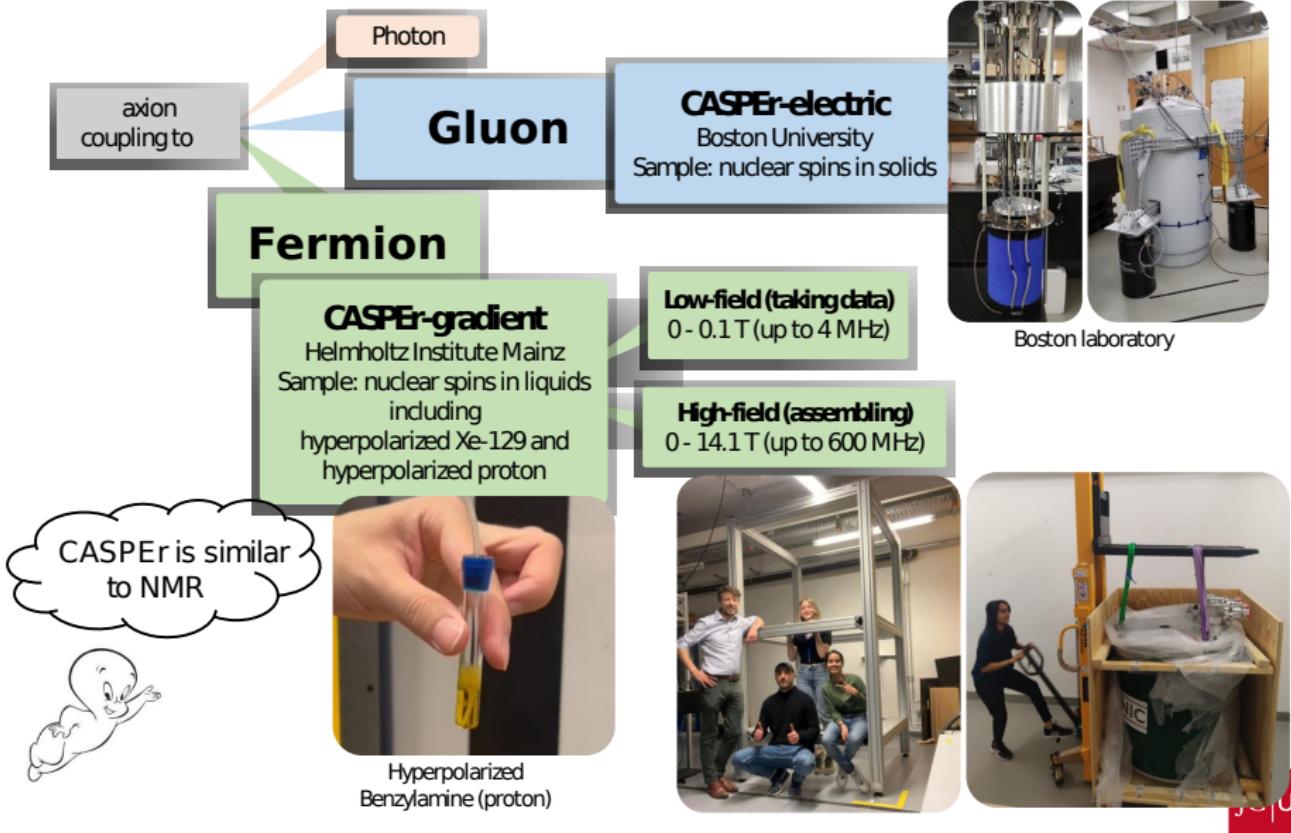
What can a GNOME do?

- Q-balls
- Axion Stars
- Solar Axion Halo
- Stochastic fluctuations of galactic DM
- Bursts of Exotic Low-mass Fields (ELF)
- Axion Domain Walls

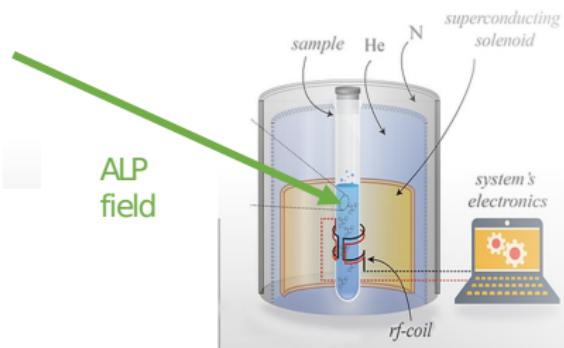


²S. Afach et al. arxiv.org/abs/2305.01785 (2023)

Cosmic Axion Spin Precession Experiment (CASPER)

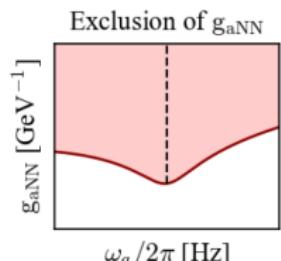
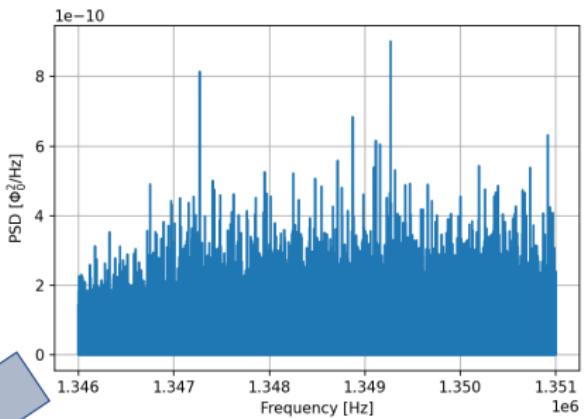


ALP-DM search at CASPER-gradient low-field



ALP field induces transverse magnetization in a sample close to resonance frequency

Christmas 2022" Proof-of-concept" ALP search:
Scanning bandwidth of ~230 Hz around 1.348 MHz
ALP Compton frequency for ALP signals



Exclusion of g_{aNN}
Slice of PSD (Power Spectral Density) of sample transverse magnetization

Data analysis currently being done!

Contents

- 1 Axion Domain Walls
- 2 New algorithm for DW signal
- 3 Results
- 4 Exclusion plot

Contents

1 Axion Domain Walls

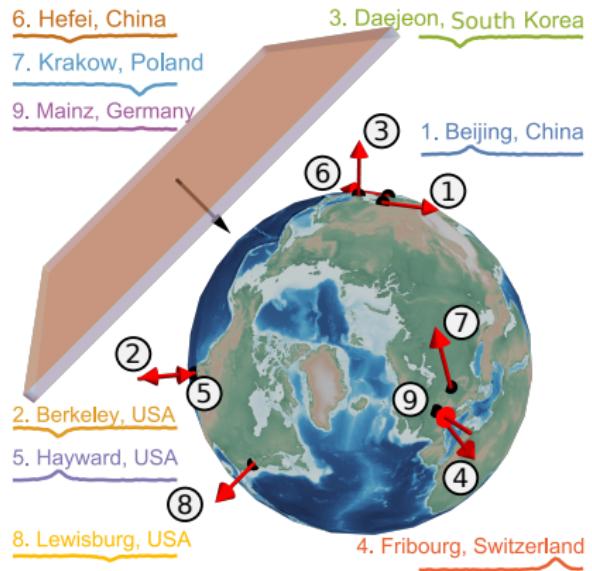
2 New algorithm for DW signal

3 Results

4 Exclusion plot

Axion Domain Walls³

- Compact spatial regions
- Regions of space with different axion vacuum
- Effective magnetic field
- Correlated time measurement



³Pospelov et al. Phys.Rev.Lett. 110 (2013) 2, 021803

Parameters of Domain Walls

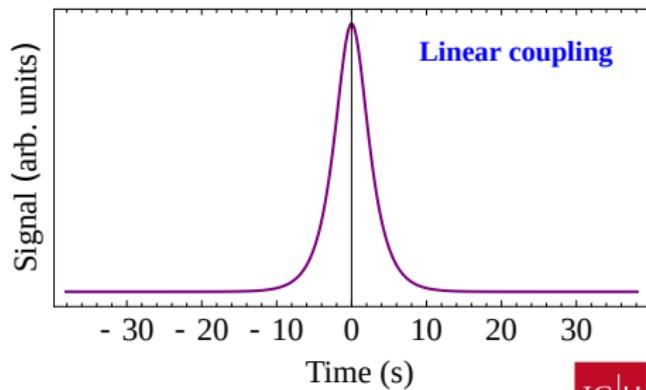
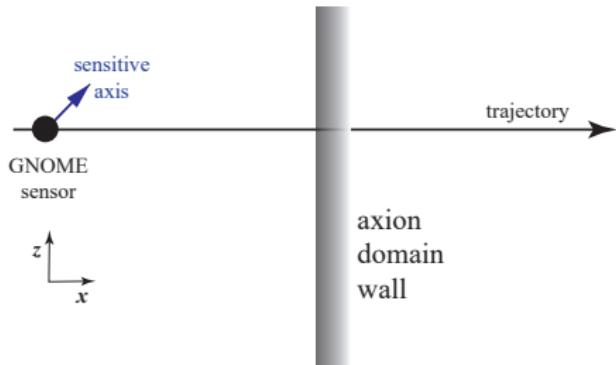
- Coupling ratio $\xi = \frac{f_{\text{SB}}}{f_{\text{int}}}$

- Duration $\Delta t \propto \frac{1}{m_a}$

- Pseudo magnetic field
$$\mathcal{B}'_{\text{p}} = \frac{4m_a\xi}{\mu_B}$$

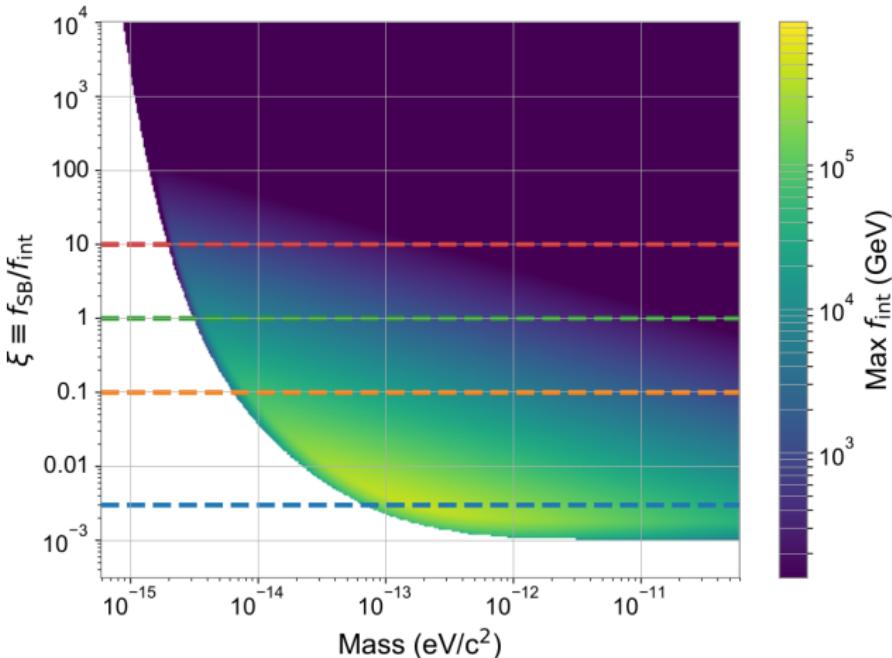
- Rate of encounters

$$r = \frac{\bar{v}\rho_{\text{DW}}}{\sigma_{\text{DW}}} = \frac{\bar{v}\rho_{\text{DW}}}{8m_a f_{\text{SB}}^2}$$



2021 Domain Wall search ^{4,5}

- Computer intensive procedure
- Not sensitive to short width DW



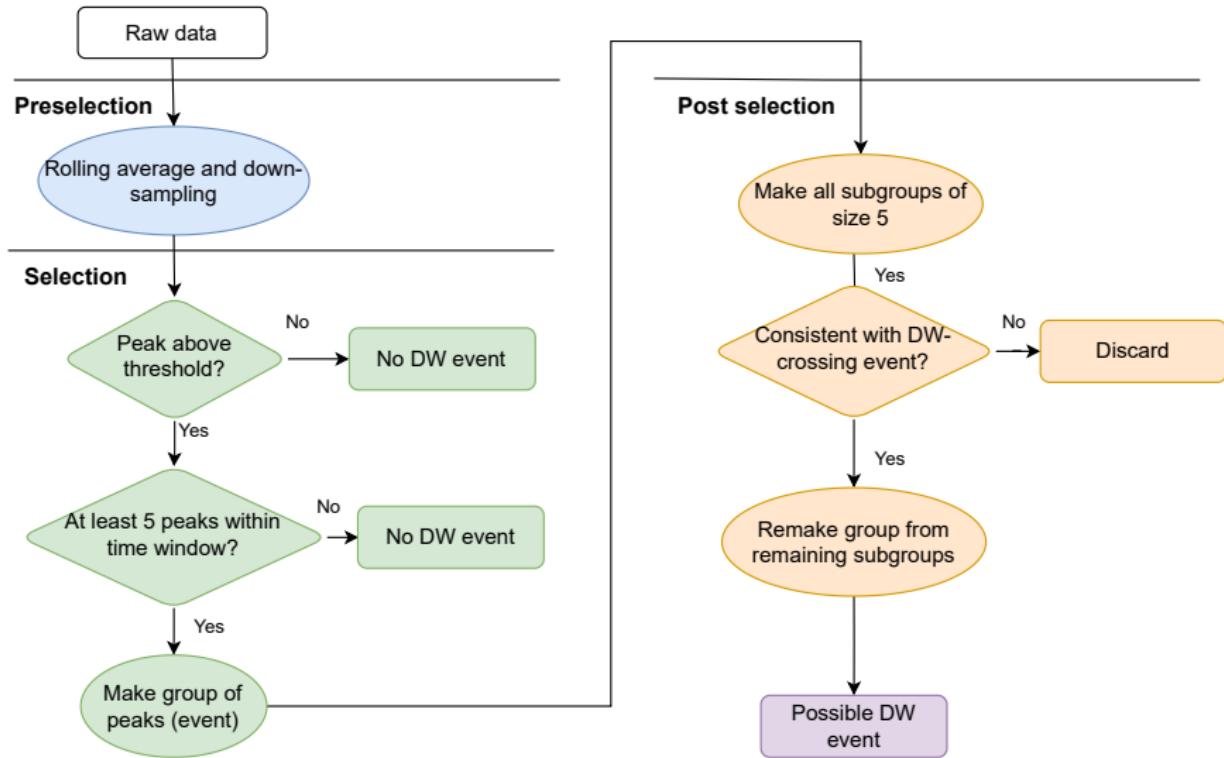
⁴Masia-Roig et al. Phys.Dark Univ. 28 (2020), 100494

⁵Afach et al. Nat. Phys. 17, 1396–1401 (2021).

Contents

- 1 Axion Domain Walls
- 2 New algorithm for DW signal
- 3 Results
- 4 Exclusion plot

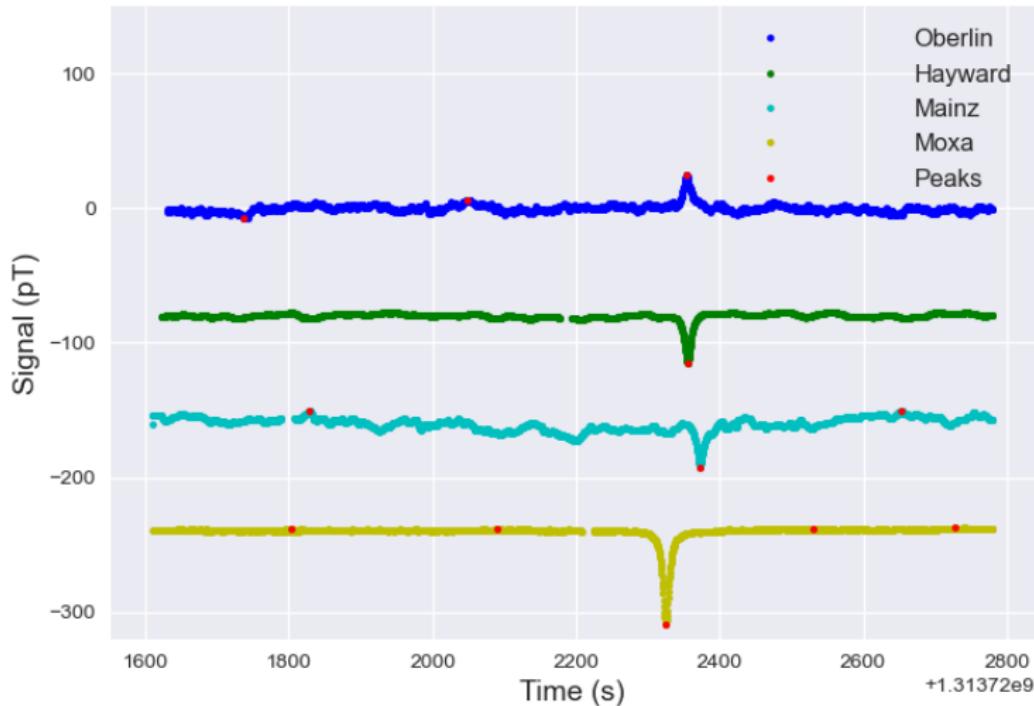
New analysis pipeline



Candidates for DW signal

- Peak info: time, amplitude, width, station, average noise
- Make groups of peaks from different stations

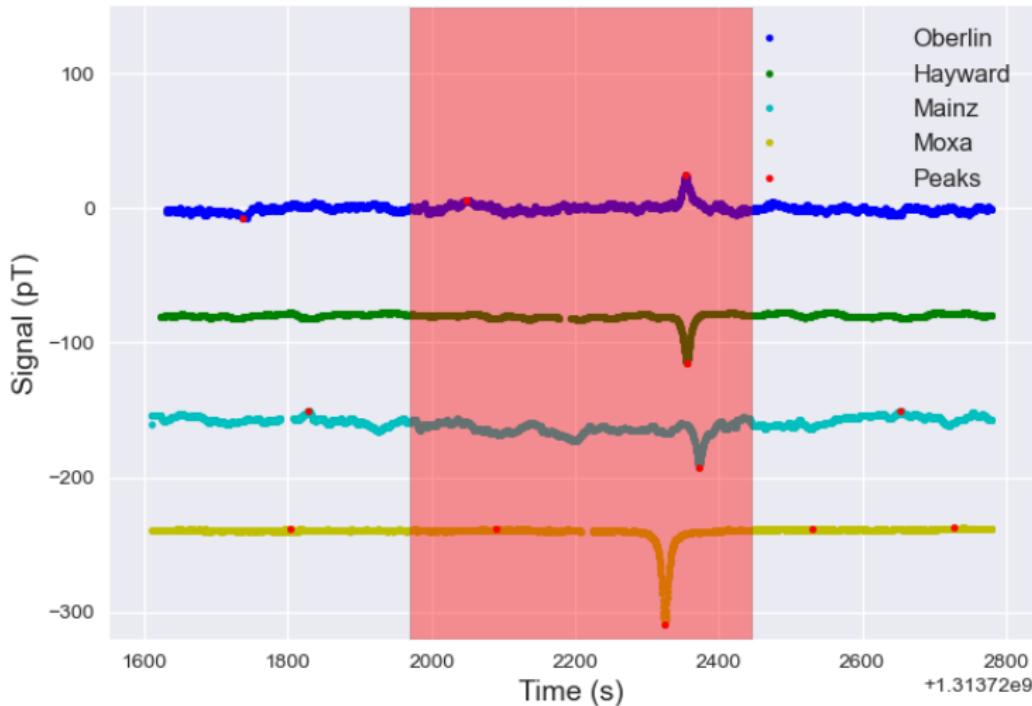
Insertion of a domain wall at different stations.



Candidates for DW signal

- Peak info: time, amplitude, width, station, average noise
- Make groups of peaks from different stations

Insertion of a domain wall at different stations.



Duration consistency and time fitting

- Same width for all peaks in the group

$$\frac{\sigma_{\text{width}}}{\bar{w}} \leq a$$

- Relation between observed time and velocity of DW

$$\vec{t} = \frac{1}{|\vec{v}|} L \hat{v} + t_0$$

Contents

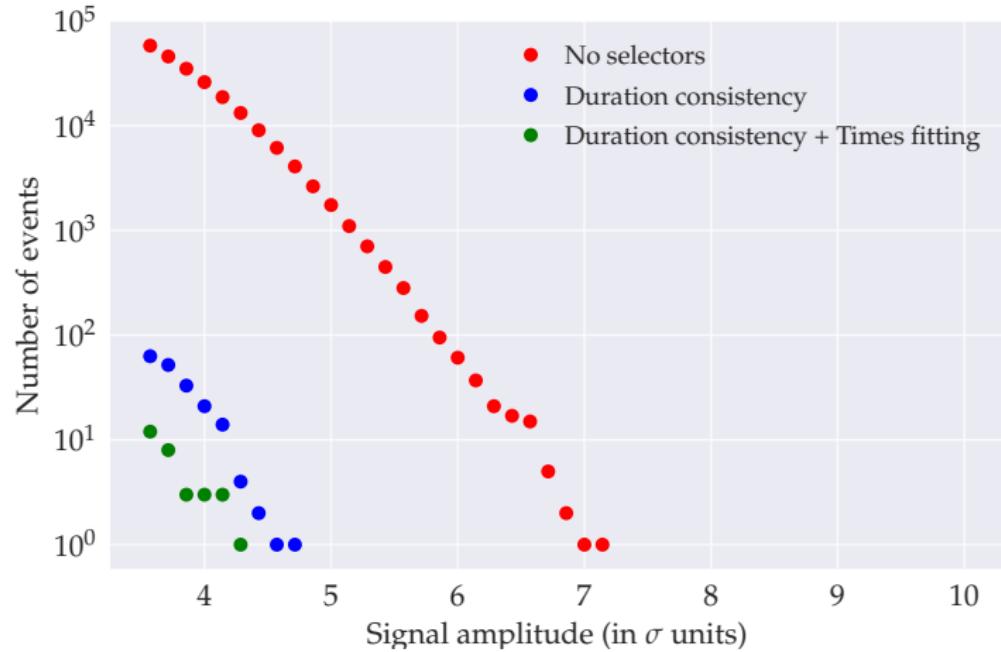
1 Axion Domain Walls

2 New algorithm for DW signal

3 Results

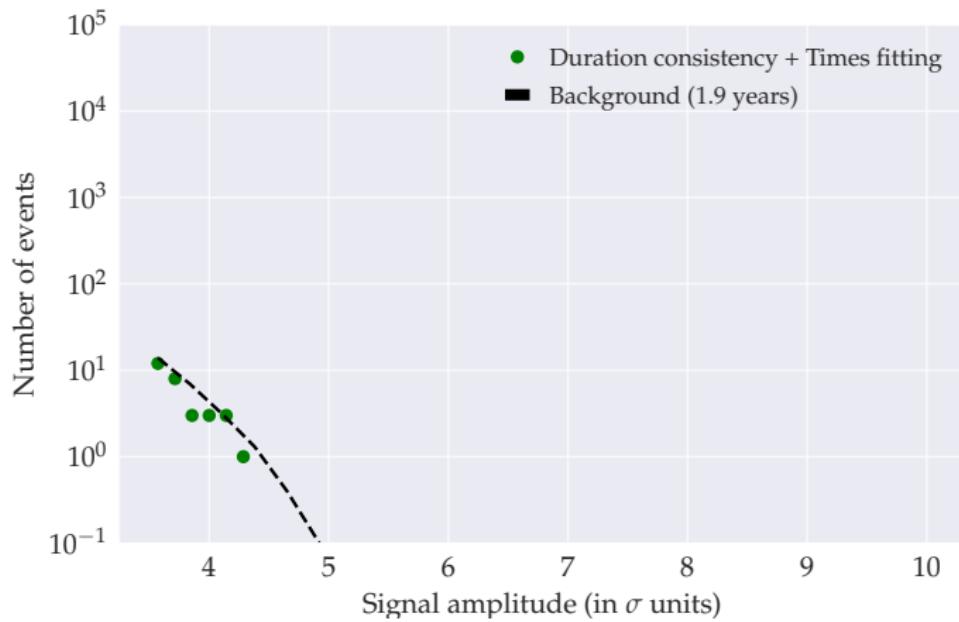
4 Exclusion plot

Events candidates for DW



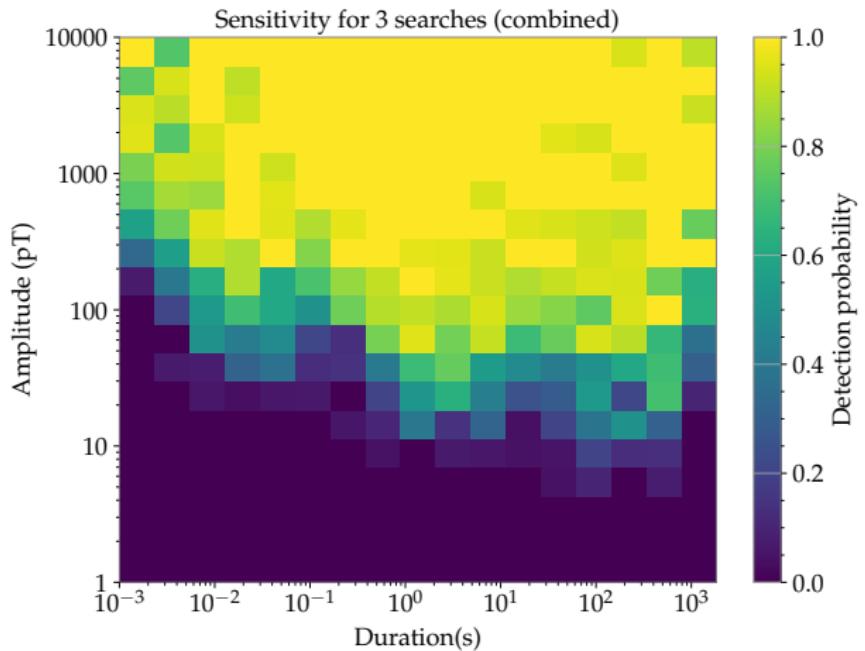
Events candidates for DW and background

- Time shuffled data scaled for background



Assesing the sensitivity

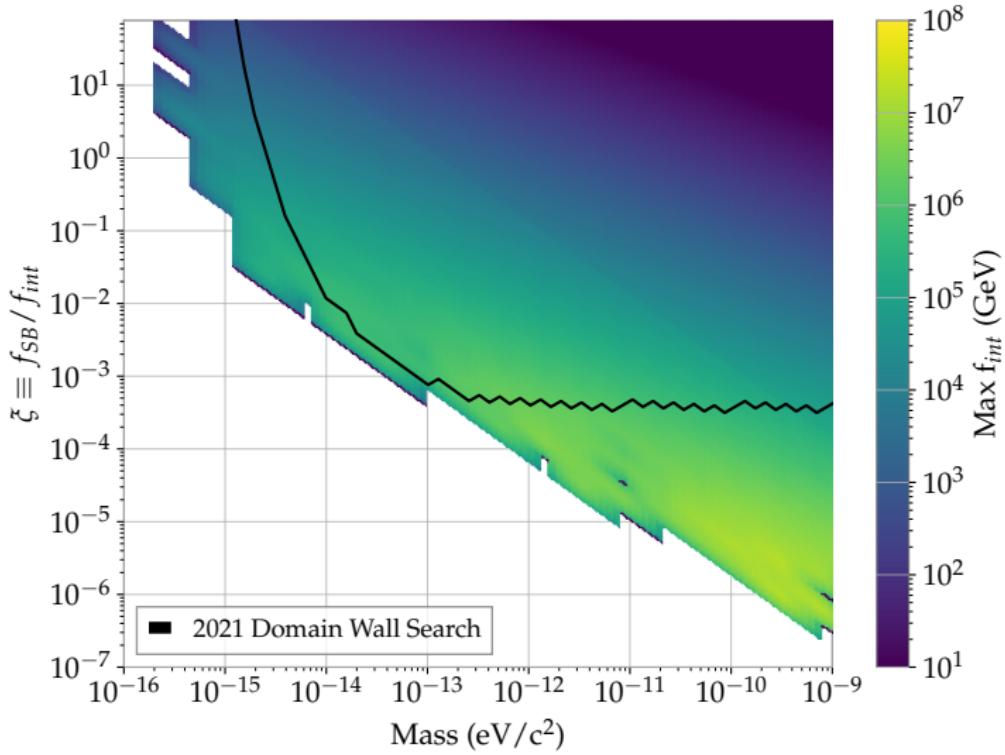
- DW-like signal inserted in time shuffled data
- 3 searches with different time constant average



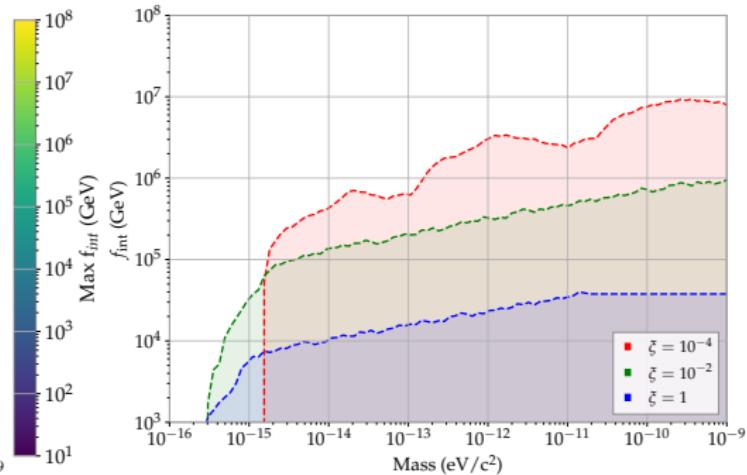
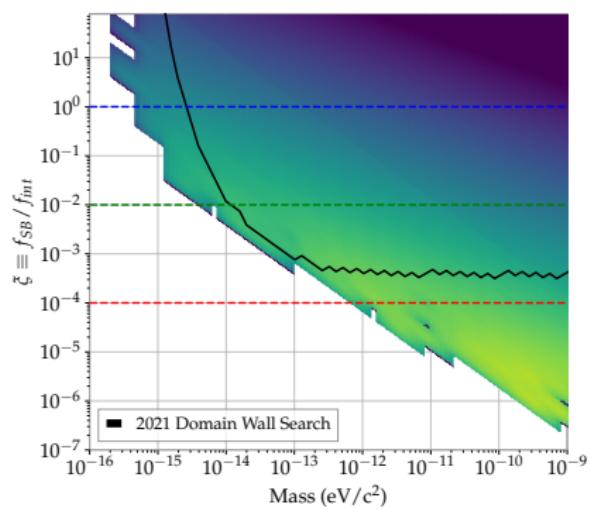
Contents

- 1 Axion Domain Walls
- 2 New algorithm for DW signal
- 3 Results
- 4 Exclusion plot

2023 Domain Wall Search (Preliminary)



2023 Domain Wall Search (Preliminary)



Conclusions

- New dataset with new analysis procedure for axion domain walls
- Sensitive to short width domain wall → exclude higher f_{int}
- Excluding up to $f_{\text{int}} = 10^8$ GeV for certain f_{SB}
- New run soon with comagnetometers that will increase our sensitivity (Advanced GNOME)

Acknowledgements



Grzegorz
Łukasiewicz



Hector
Masia-Roig