# Intensity interferometry for ultralight bosonic dark matter detection

## WG Meeting of COST Action COSMIC WISPers

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on behalf of the GNOME collaboration

Helmholtz-Institut Mainz/JGU

February 1, 2024

# Introduction

- ALP and bosonic Dark Matter
- Fermionic Quadratic coupling $\rightarrow$ DC component
- Proposal for Quantum sensor low frequency broadband search

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- Fermionic Quadratic coupling → DC component
- Proposal for Quantum sensor low frequency broadband search

- Optical Magnetometers
- Optical clocks

$$\mathcal{L}_{\text{quad}} = \pm\tfrac{1}{f_q^2}\bar{\psi}_f\gamma^\mu\gamma_5\psi_f\partial_\mu\varphi^2(\boldsymbol{r},t),$$

$$\mathcal{L}_s = \hbar c \pm \frac{m_f c^2}{\Lambda_f^2}\bar{\psi}_f\psi_f \pm \frac{1}{4\Lambda_\gamma^2}F_{\mu\nu}^2\varphi^2(r,t)\ ,$$

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# Modeling signal via stochastic properties

- Classical field approximation

$$\varphi(\boldsymbol{r}, t) \approx \sum_{n=1}^{N} \frac{\varphi_0}{\sqrt{N}} \cos\left(\omega_n t - \boldsymbol{k}_n \cdot \boldsymbol{r} + \theta_n\right)$$

$$\omega_n \approx \omega_c \left(1 + \frac{v_n^2}{2c^2}\right),$$

- $\omega_n$ = oscillator frequency
- $\omega_c$ = Compton frequency
- $\kappa_n$ = wave vector

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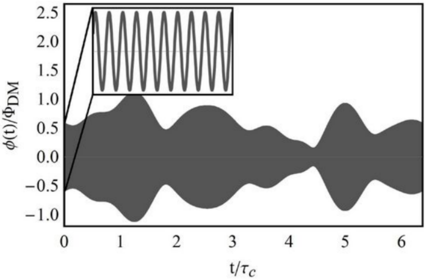
- Then $\varphi^2$ is

$$\varphi_s^2(r, t) = \frac{\varphi_0^2}{2N} \sum_{n,m=1}^{N} \cos(\omega_{nm} t +$$

$$-\mathrm{k}_{nm} \cdot r + \theta_{nm}); \quad \omega_{nm} = \omega_n - \omega_m$$



# Coherence time

- Degree of first-order coherence

$$g^{(1)}(\tau) = \frac{\langle \varphi^2(t)\varphi^2(t+\tau)\rangle_t}{\langle (\varphi^2)^2 \rangle_t}$$

- We can define a coherence time

$$\tau_c = \int_{-\infty}^{+\infty} \left| g^{(1)}(\tau) \right|^2 d\tau$$

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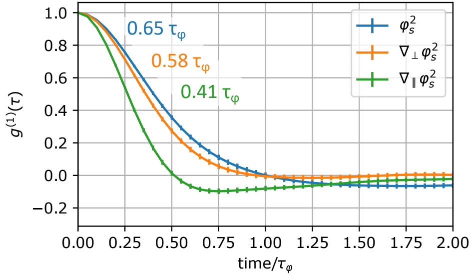


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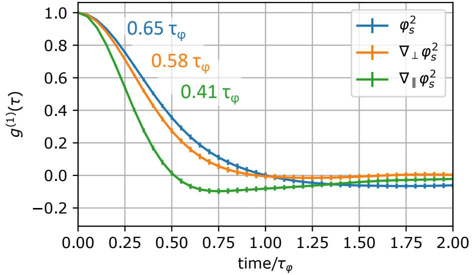


**How to search for it?**

With a network works best

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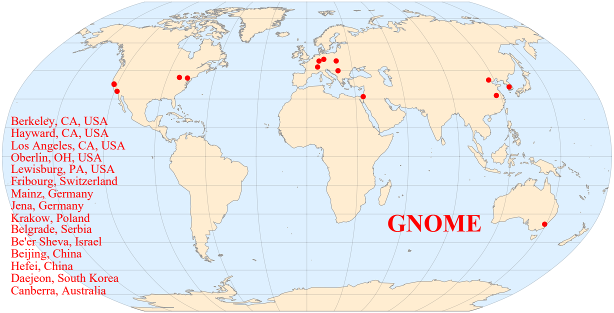
# What is a GNOME?[1]

- **G**lobal **N**etwork of **O**ptical **M**agnetometers for **E**xotic physics searches
- Looking for transient dark matter signals
- Sensitive to Axion-fermion coupling:

$$H_{li} = -\frac{\hbar c^{3/2}}{f_{li}} \frac{S_i}{|S_i|} \cdot \nabla\varphi \qquad H_{qi} = -\frac{\hbar^2 c^2}{f_{qi}^2} \frac{S_i}{|S_i|} \cdot \nabla\varphi^2 \; .$$




[1] Phys.Dark Univ. 22 (2018), 162-180

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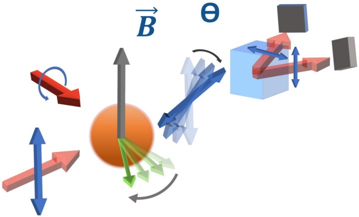
# How does a GNOME work?

- Magnetometers as Dark Matter sensors

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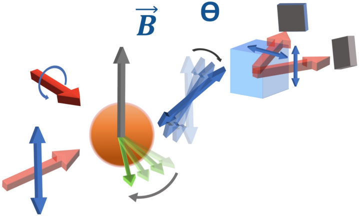
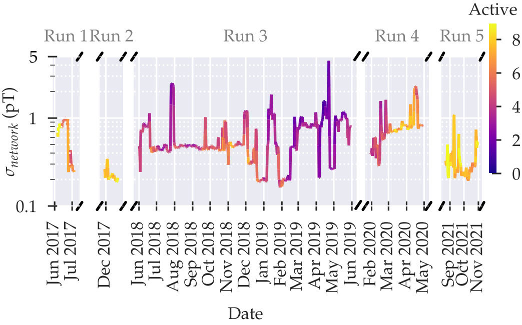



- 5 Science Runs since 2017
- Science Run 6 starting soon!

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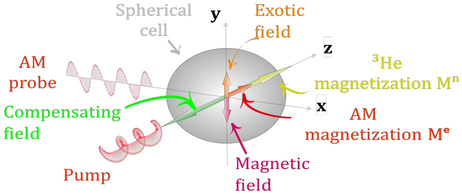
# Advanced GNOME: Comagnetometers

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



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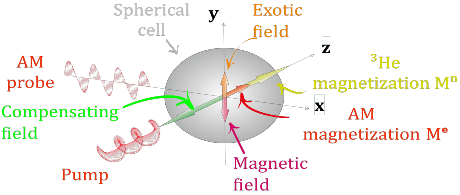


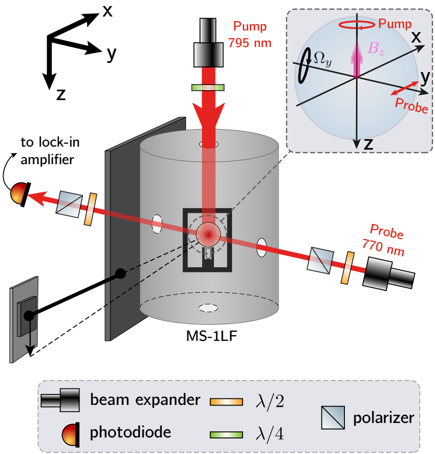


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# Expected Signal

- Magnetometers
  - UBDM interaction like Zeeman Hamiltonian

$$H_\varphi = \frac{2\hbar^2 c^2}{f_q^2} S \cdot \nabla\varphi^2(r,t) \ .$$

$$\mathcal{B}_q \approx \frac{2\hbar^2 c^2}{g_F \mu_B f_q^2} \nabla\varphi^2(\boldsymbol{r},t),$$

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- Optical clocks
  - Change in fundamental constants like $\alpha$ affects frequency of atomic transitions

$$\frac{\delta\nu(t)}{\nu} = \kappa_\alpha \frac{\delta\alpha(t)}{\alpha} \ ,$$

$$\frac{\delta\nu}{\nu} \approx \kappa_\alpha \frac{2\hbar^3 \rho_{dm}}{\Lambda_\gamma^2 m_\varphi^2 c} \ .$$

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# Cross-Correlating a network

- $g^{(1)}_{AB}(\tau) = \frac{\langle S_A(t) S_B(t+\tau)\rangle_t}{\sqrt{\langle S_A^2\rangle_t \langle S_B^2\rangle_t}}$ .
- Look at $g^{(1)}_{AB}(0)$
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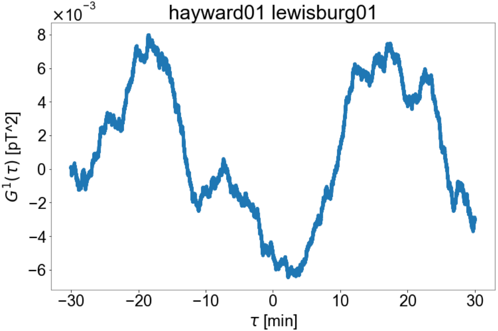


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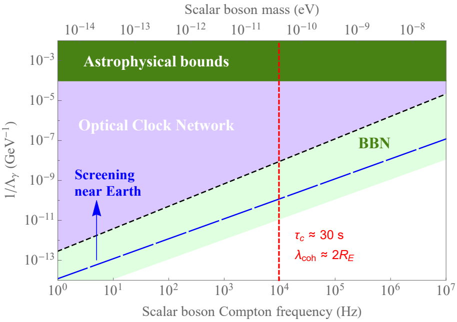
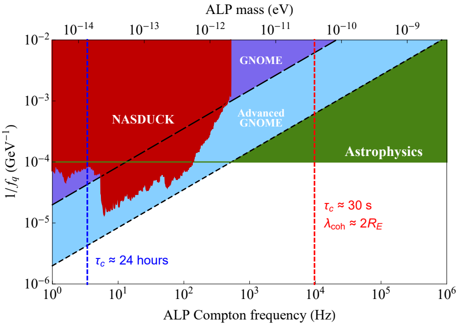
# Sensitivity



# Conclusions

- Quadratic couplings have a quasi-DC contribution
- Stochastic properties of UBDM field have to be taken in consideration
- Broadband search
- Magnetometers and optical clocks are sensitive to DC changes

# Acknowledgements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