JAGIELLONIAN UNIVERSITY
IN KRAKÓW

Global Network of Optical Magnetometers for Exotic physics searches (GNOME)

16.01.2024
1st CREDO Visegrad Workshop 2024
IFJ PAN in Kraków

Grzegorz Łukasiewicz
on behalf of the GNOME Collaboration

Outline

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- Introduction to Ultralight Dark Matter
- Global Network of Optical Magnetomters for Exotic physics searches (GNOME)
  - Optical magnetometers
  - Advanced GNOME
  - Network Characteristics
- Search Tagets

Why do we think there is Dark Matter?

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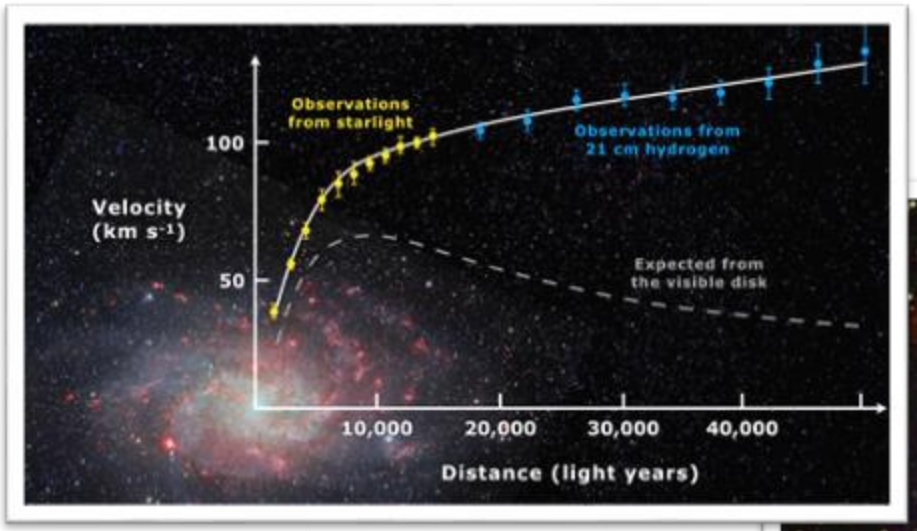
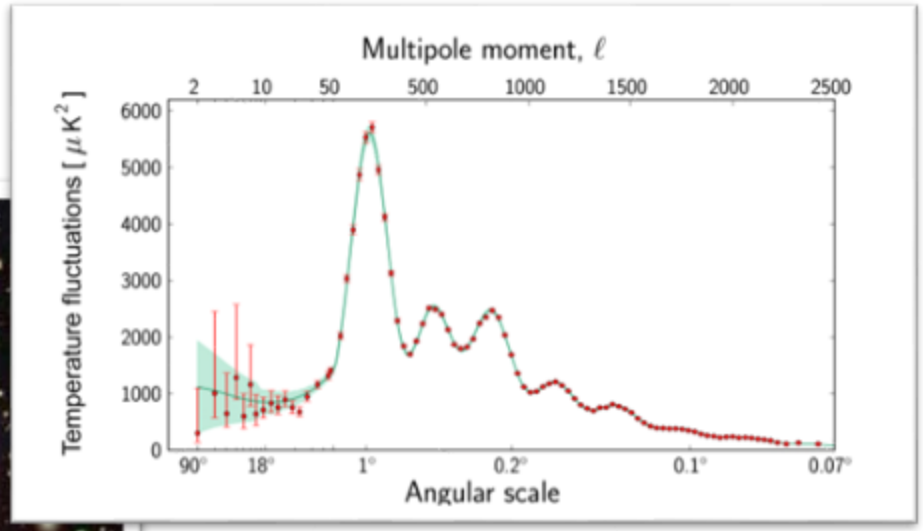
- Galaxy Rotation Curves
- Bullet Cluster (gravitational lensing in empty space)
- Cosmic Microwave Background (CMB)

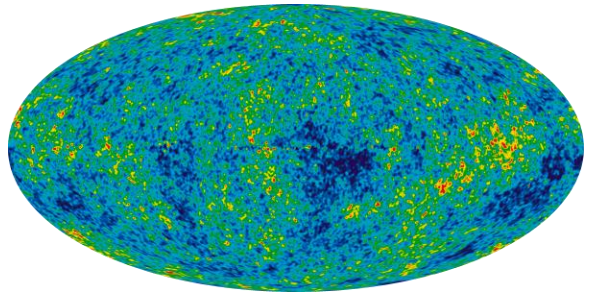


Wikipedia / Galaxy Rotation Curves

NASA/IPAC Extragalactic Database



Planck Collaboration Results 2013



What could dark matter be?

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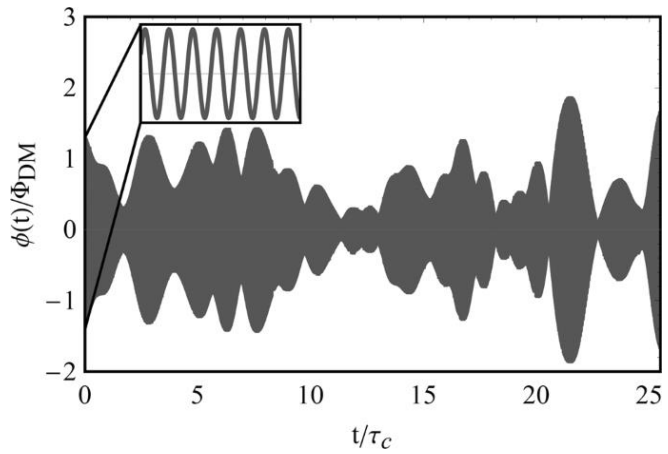
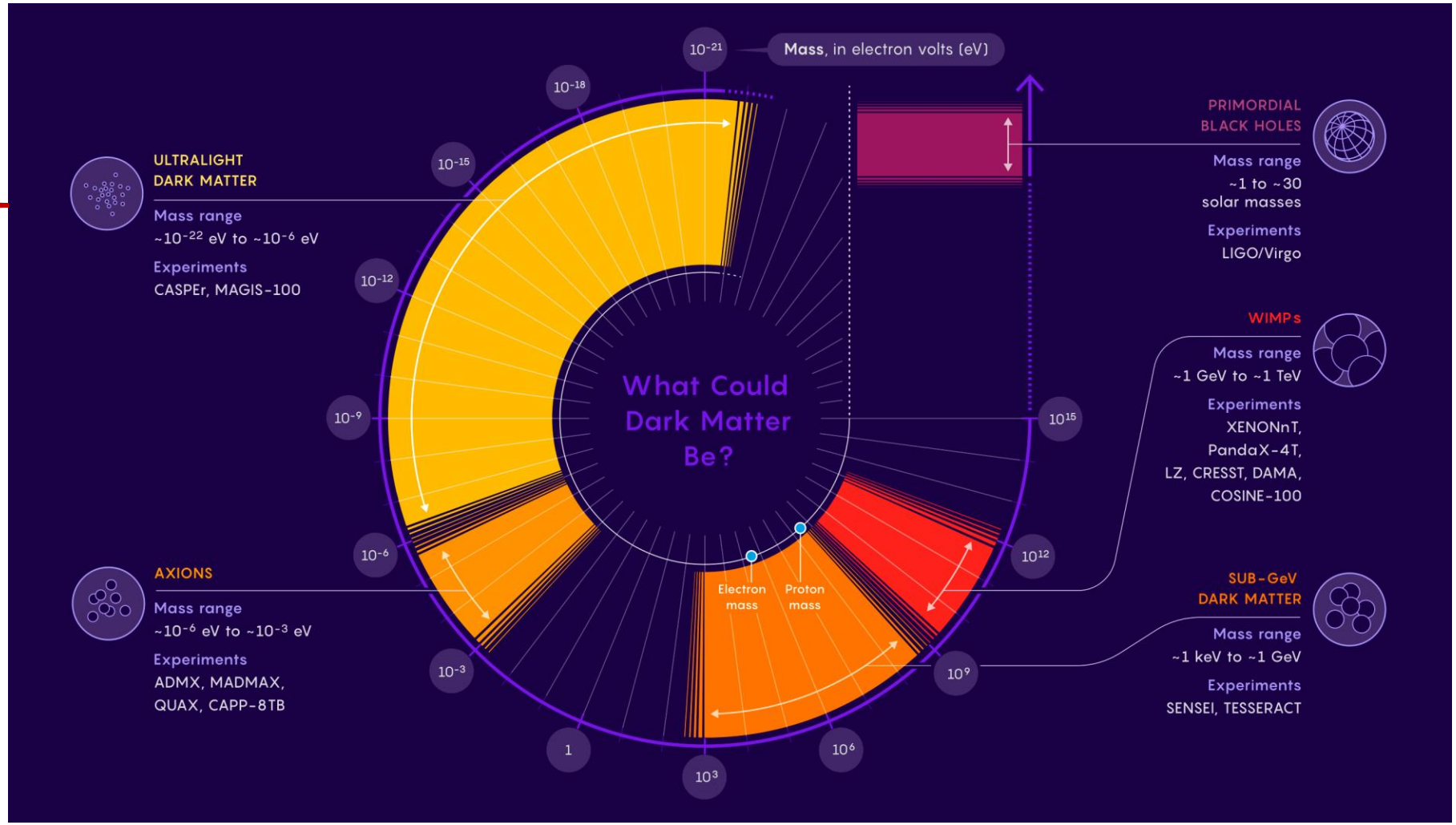
- Ultralight Bosonic DM
- Wave-like DM
- Axion-Like Particles (ALPs)

(more general term)



Centers, G.P. et al. Nat Commun 12, 7321 (2021).



Samuel Velasco/Quanta Magazine

What could wavy DM do?

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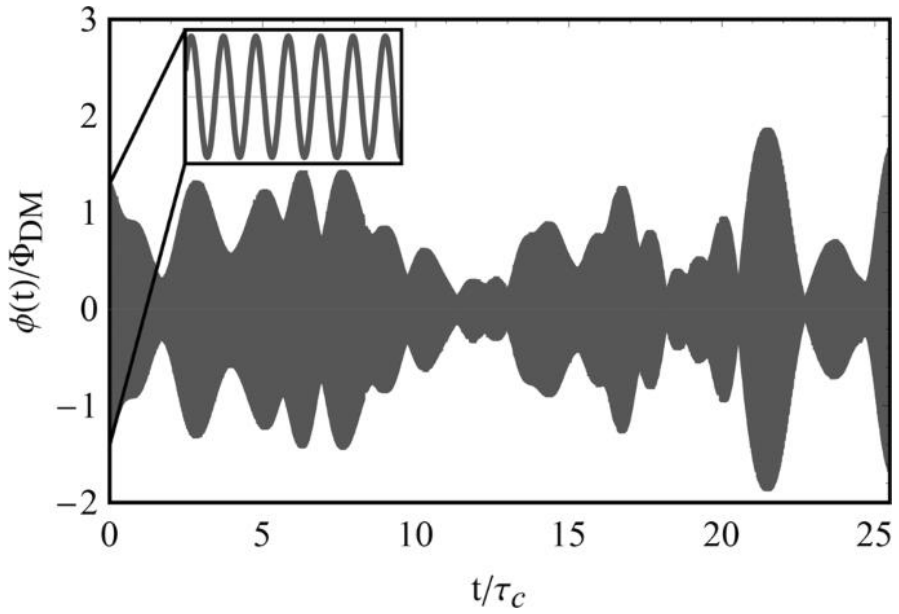
- Create photons
- Generate currents
- Excert forces
- Change values of fundamental constants
- **Cause spin precession** (e, p, n)

- S. Rajendran, **New Directions in the Search for Dark Matter** arXiv:2204.03085 (2022)
- F. Chadha-Day et al., **Axion dark matter: What is it and why now? Sci**. Adv.8, eabj3618 (2022).
- Y. K. Semertzidis & S. Youn, **Axion dark matter: How to see it? Sci**. Adv.8, eabm9928 (2022).



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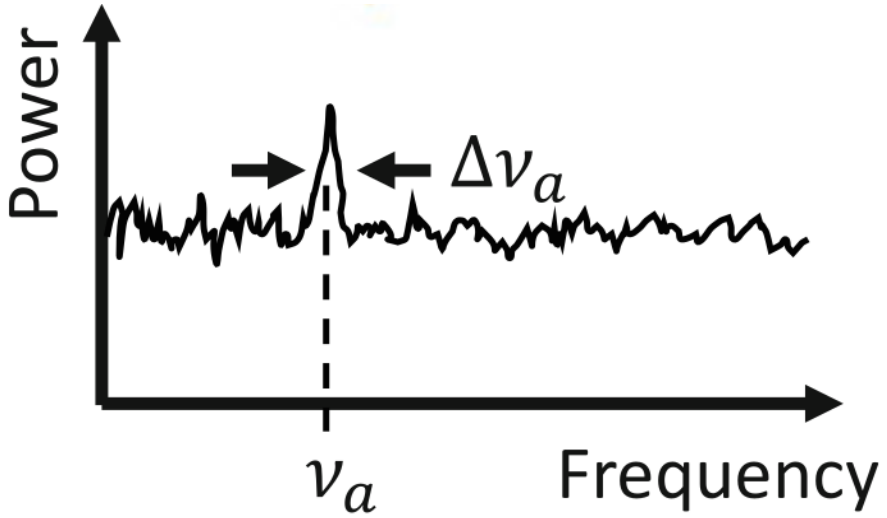

D. F. Jackson Kimball, *The Search for Ultralight Dark Matter* (2023).

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Optical Magnetometer = Spin Perturbation Sensor

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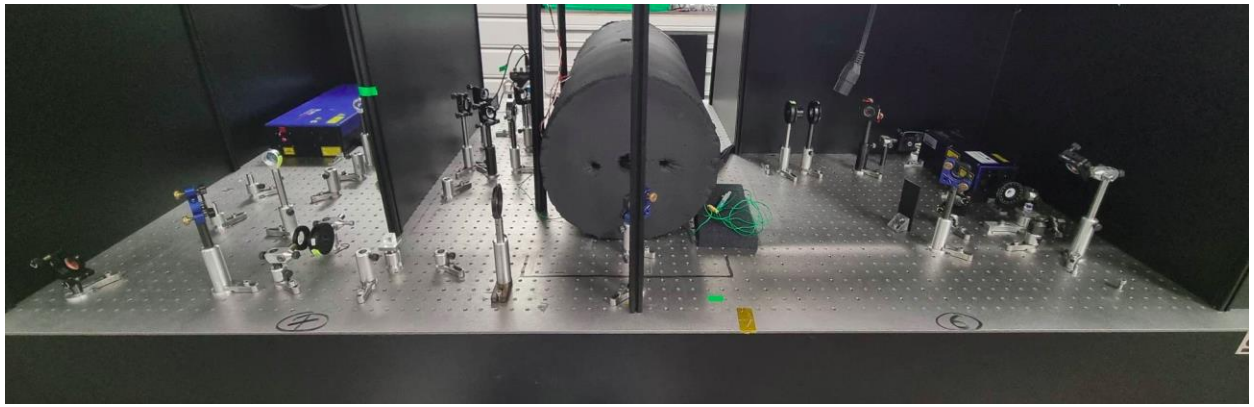
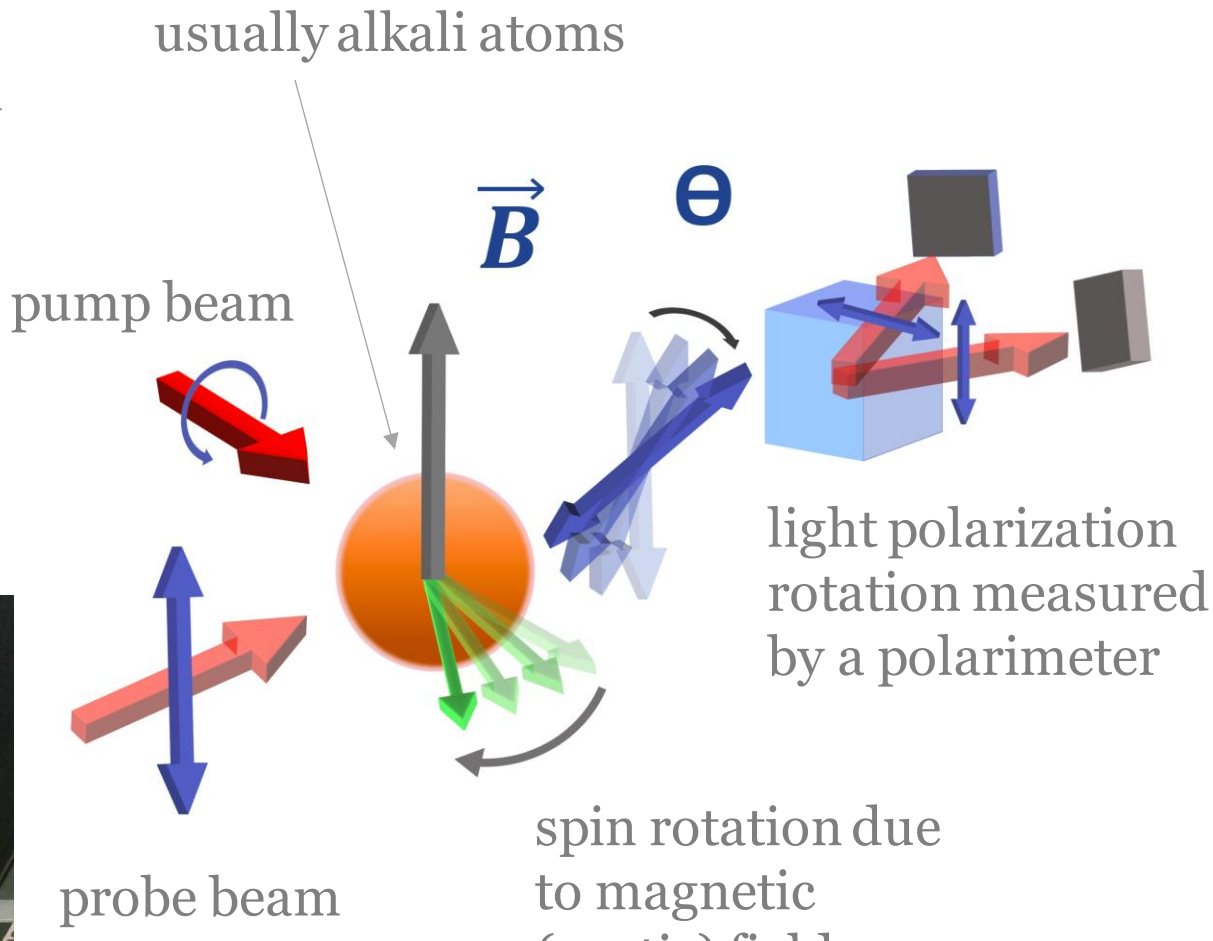
$$\mathcal{H}_B = g_F \mu_B \boldsymbol{F} \cdot \boldsymbol{B}$$

exotic field $\sim \nabla\varphi$

$$\mathcal{H}_\Upsilon = -\sum_i g_{\Upsilon i} \sigma_i \frac{\boldsymbol{F}}{|F|} \cdot \boldsymbol{\Upsilon}$$





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$$\mathcal{H}_B = g_F \mu_B \boldsymbol{F} \cdot \boldsymbol{B}$$

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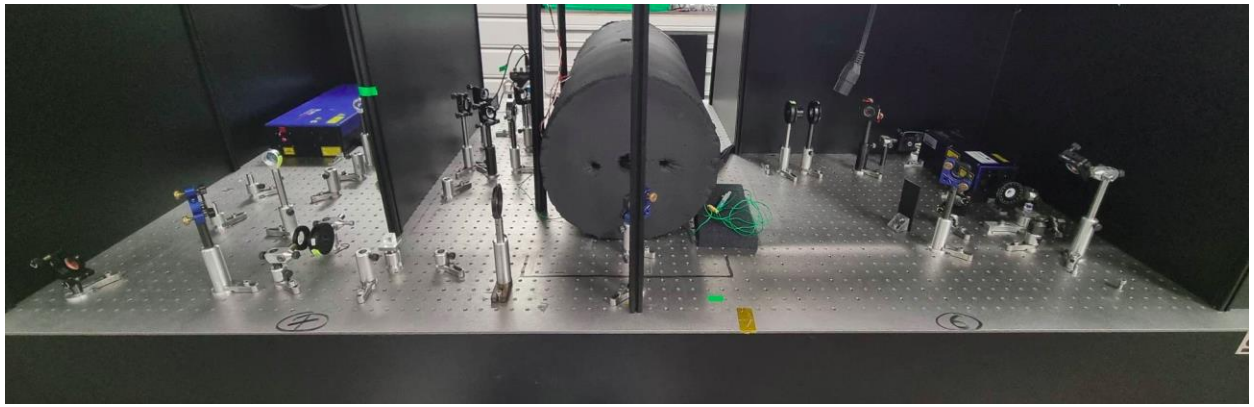
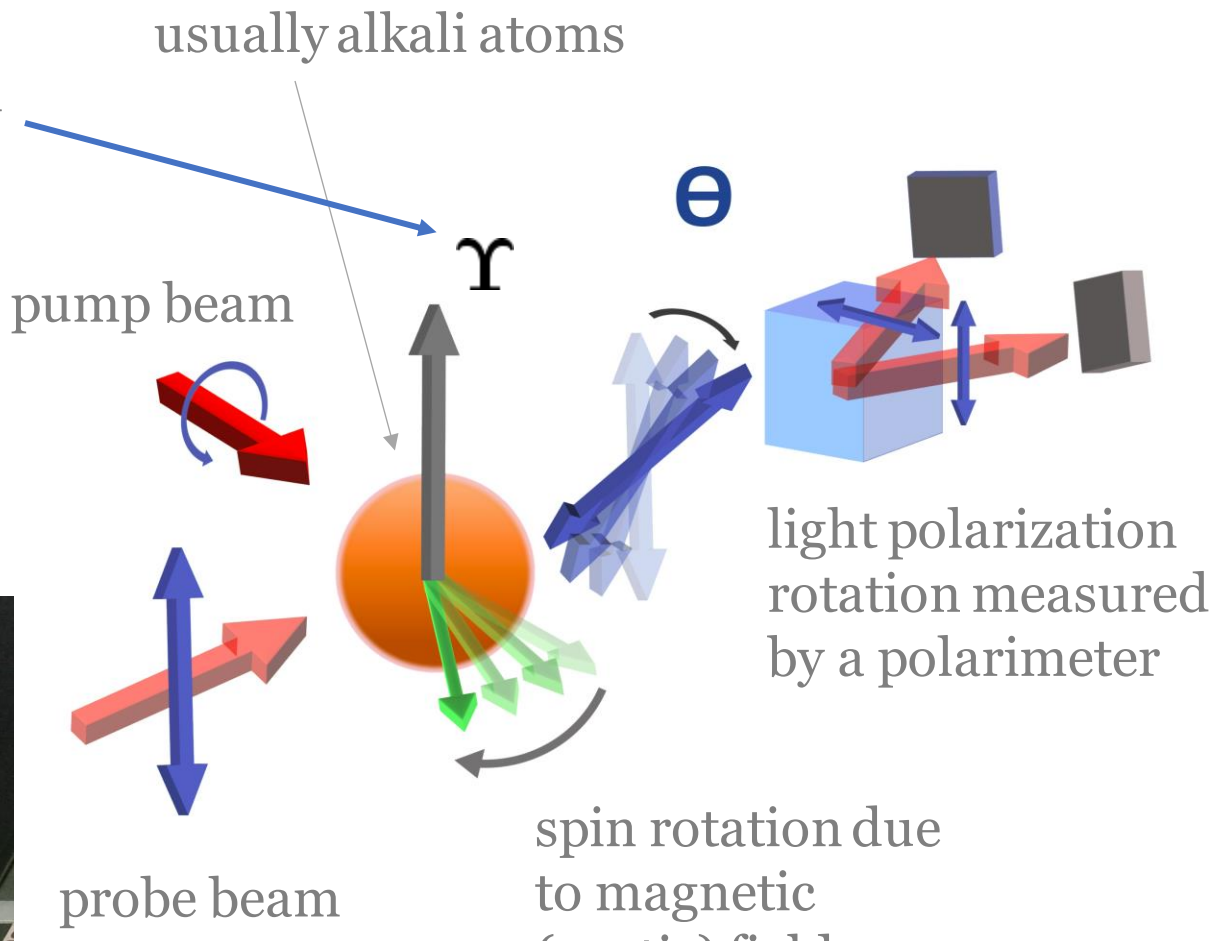
exotic field

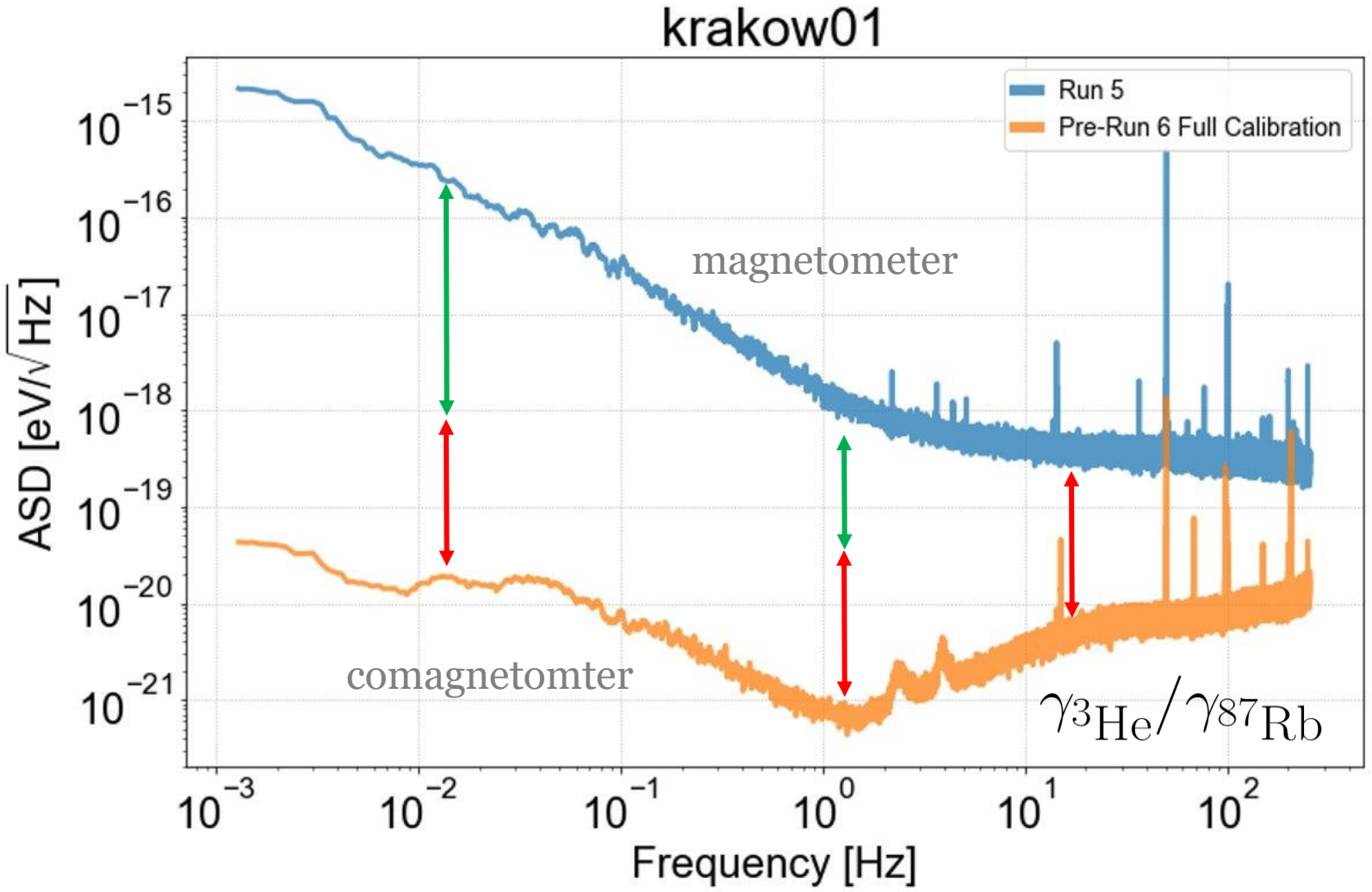
$\sim \nabla \varphi$



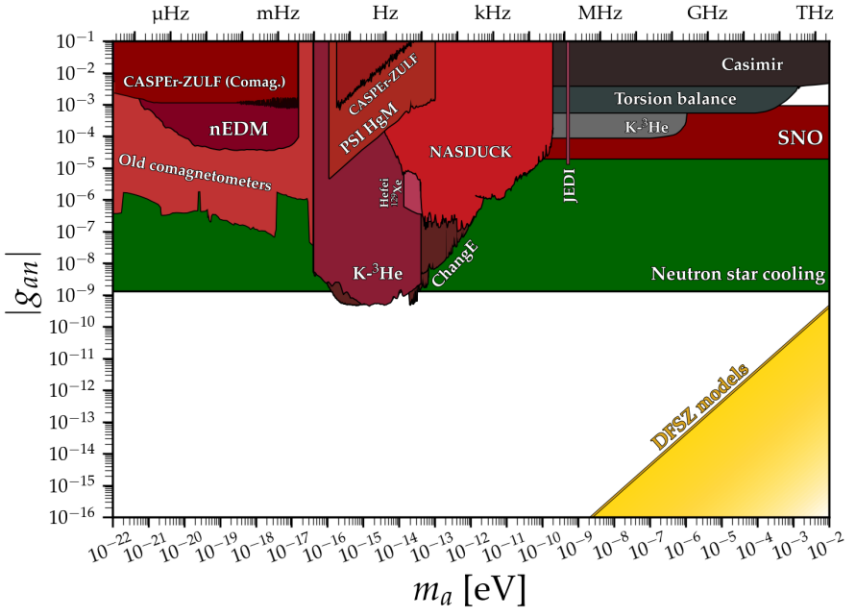


Magnetometer vs Comagnetometer

T. W. Kornack & M.V. Romalis, Phys. Rev. Lett. 89 (2002)



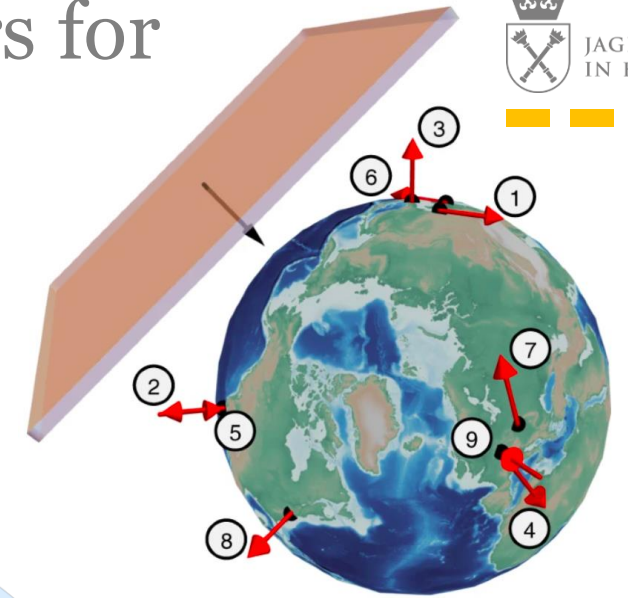
Comagnetometers set most stringent limits on axion-neutron coupling

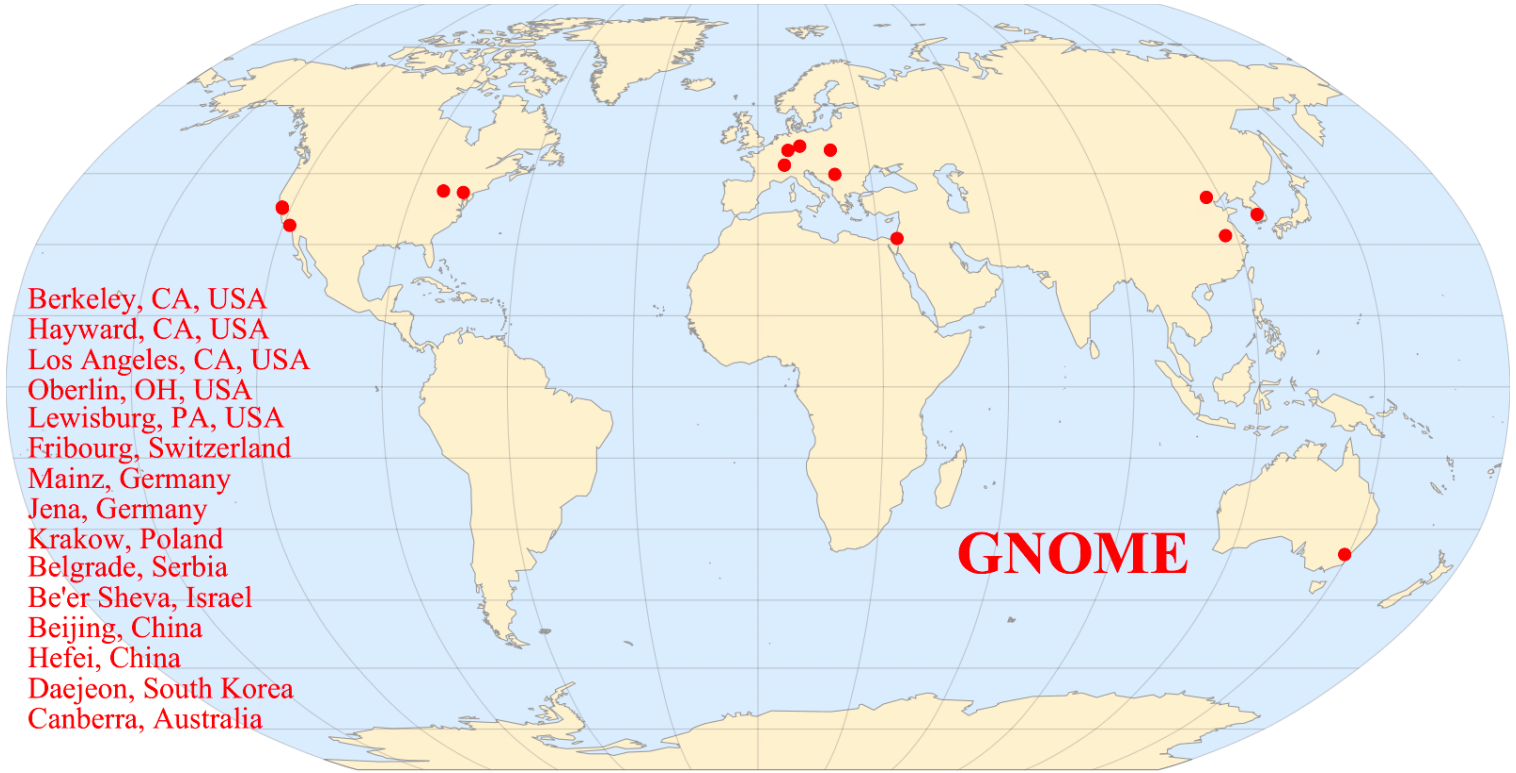


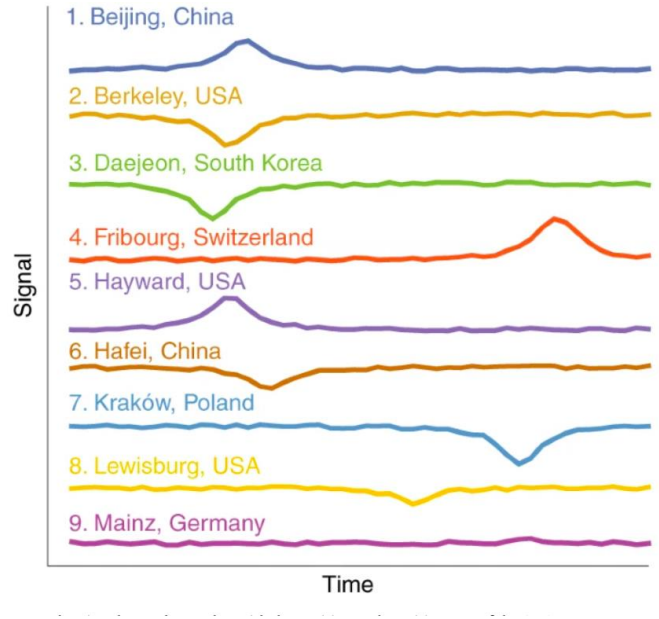
cajohare.github.io/AxionLimits

Global Network of Optical Magnetometers for Exotic physics searches

- Transient events
- Correlations



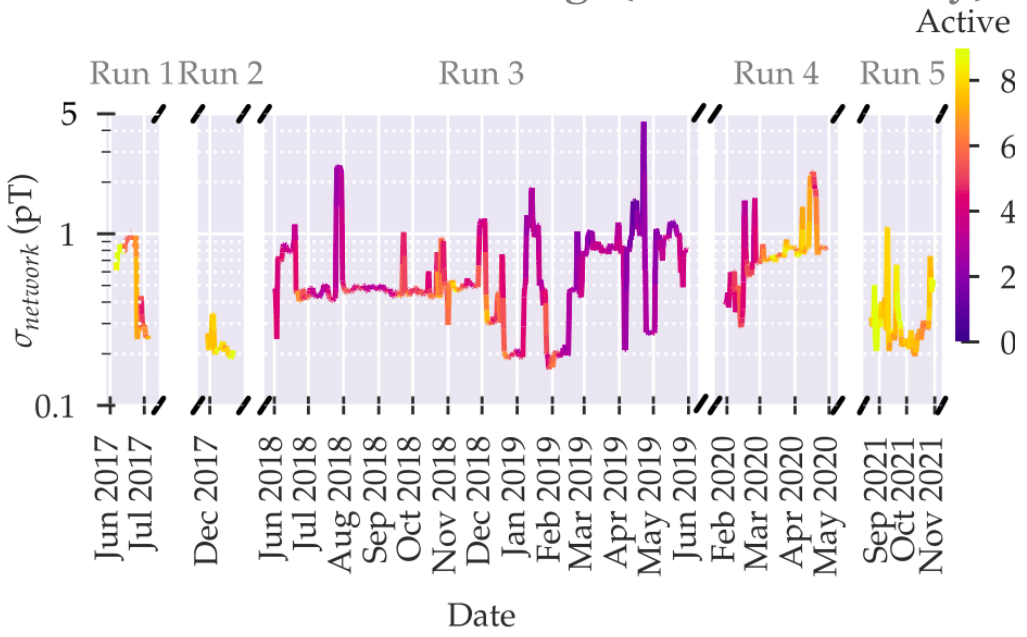


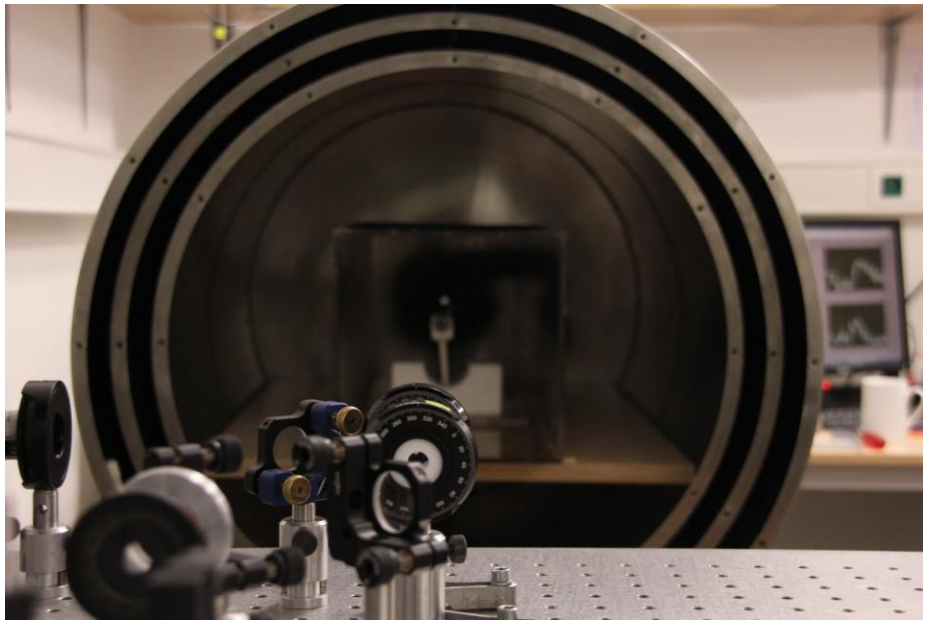


S. Afach et al., Nat. Phys. 17, 1396–1401 (2021)

GNOME Network Features

- Magnetic shielding
- Sensitive axis
- Bandwidth: DC-100 Hz
- Data Acquisition System
  - Time stamping precision: 50 ns
  - Sampling rate: 512 Hz
  - Sanity channel (anables to veto suspicious signals)
- Data storage and remote access
- Advanced GNOME coming! (2 stations ready)





DM Technologies

Outline

- Introduction to Dark Matter
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- Search Targets

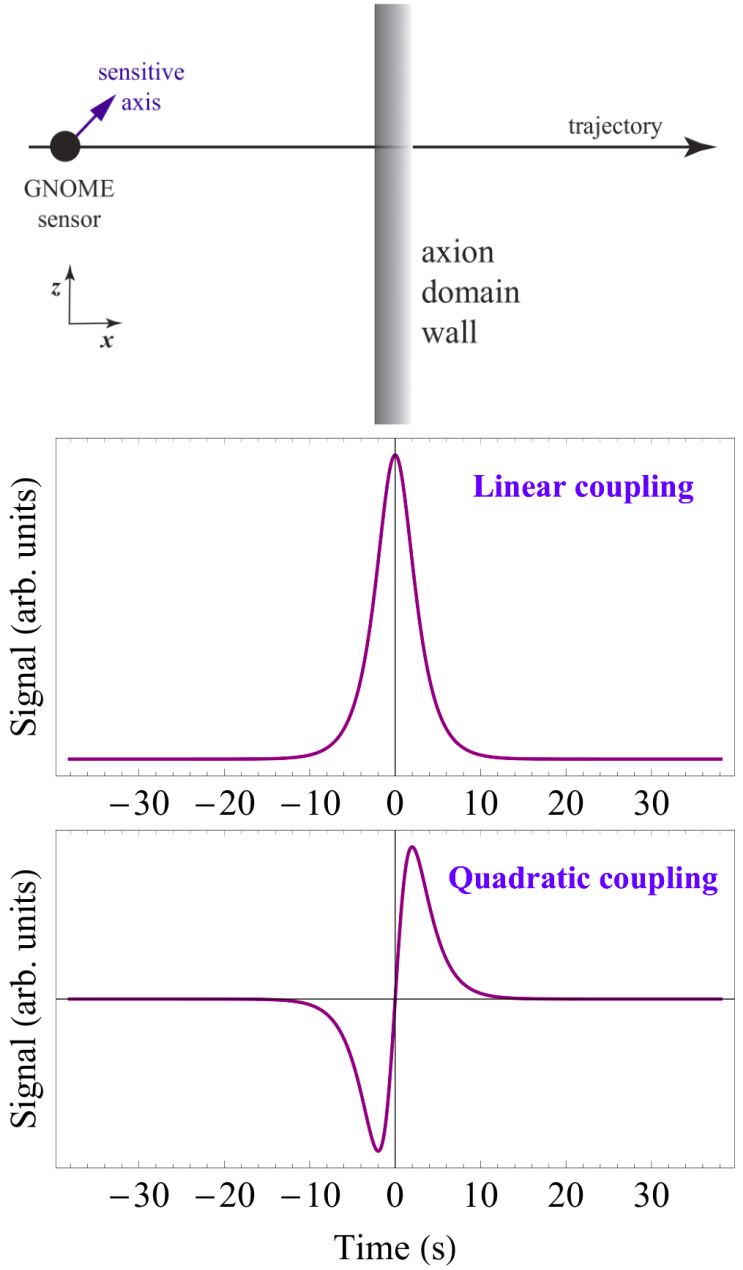
Domain Walls Search

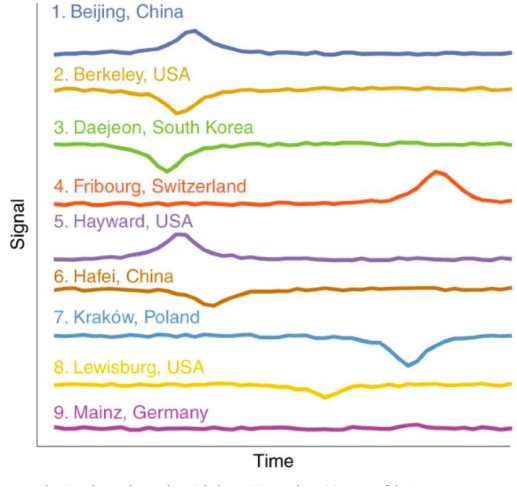
Results from SR2 published,
new results coming soon.

$$\varphi(x) = \varphi_0 \arcsin\left[\tanh\left(x/\lambda_c\right)\right]$$

$$\boldsymbol{\Upsilon}_l = \boldsymbol{\nabla}\varphi(x) = \frac{\varphi_0}{\lambda_c}\,\mathrm{sech}\left(x/\lambda_c\right)\hat{\boldsymbol{x}}$$

$$\boldsymbol{\Upsilon}_q = \boldsymbol{\nabla}\varphi^2(x) = \frac{2\varphi_0^2}{\lambda_c}\arcsin\left[\tanh\left(x/\lambda_c\right)\right]\mathrm{sech}\left(x/\lambda_c\right)\hat{\boldsymbol{x}}$$

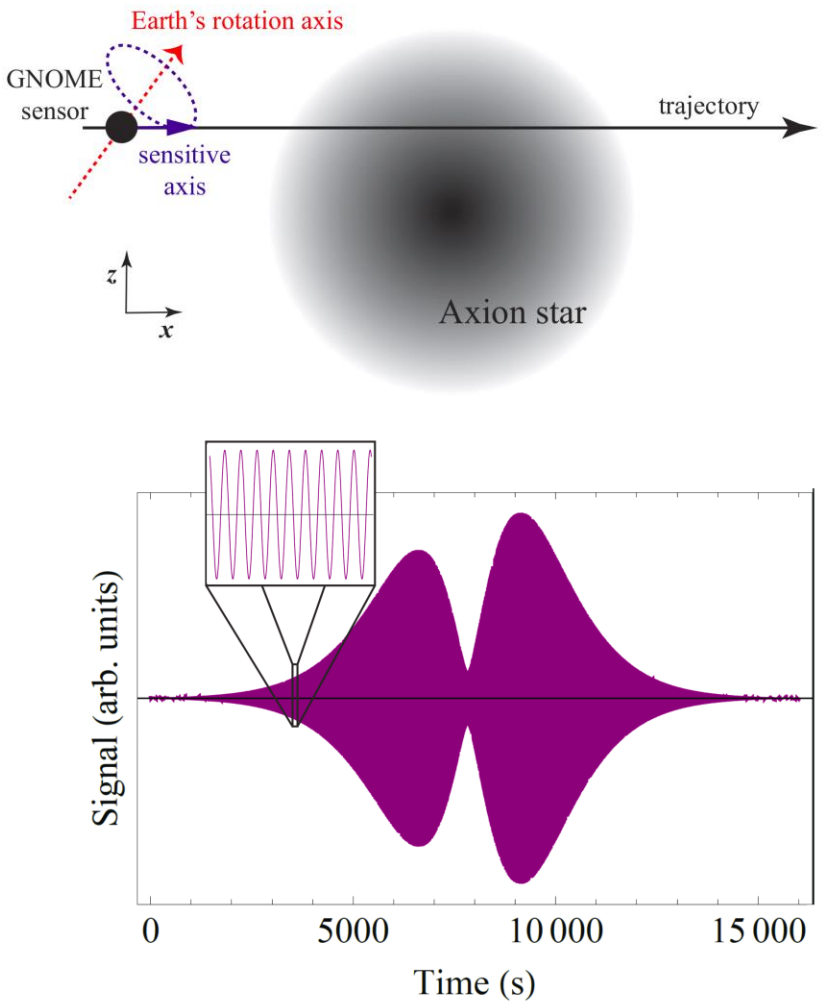


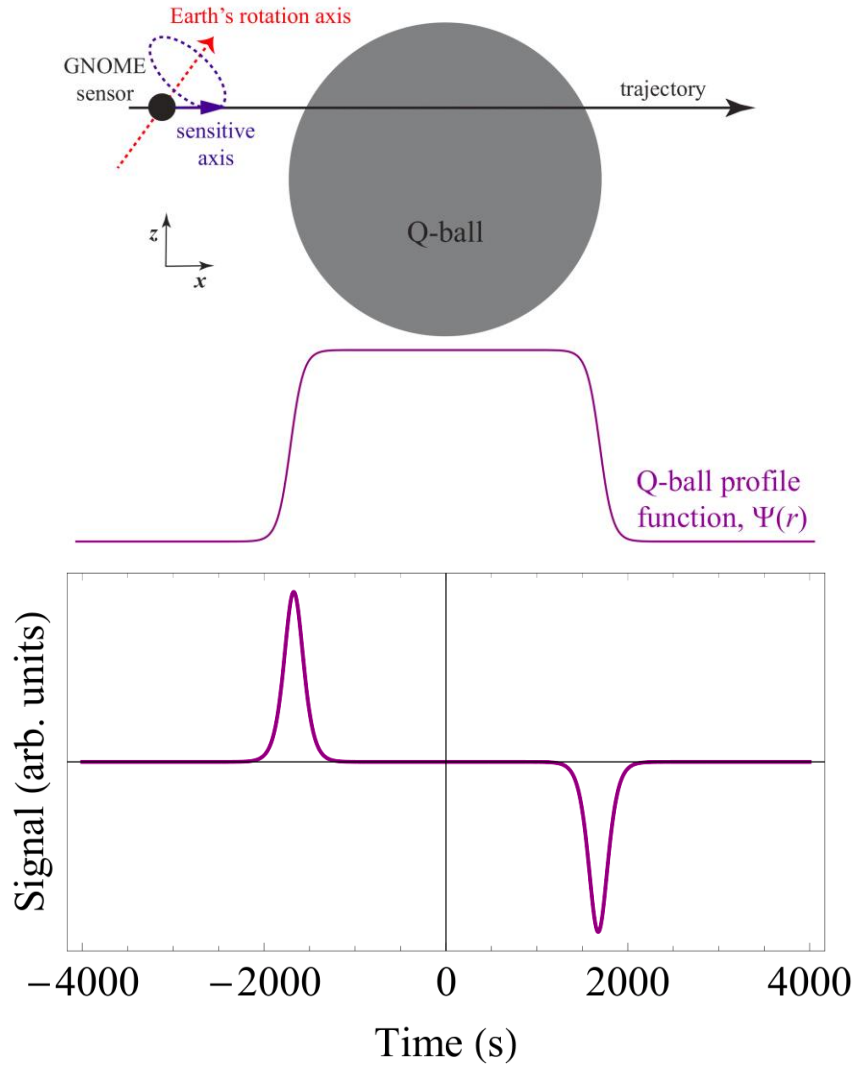


S. Afach et al., Annalen der Physik 2023, 2300083 (2023)

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

Axion Stars and Q-balls





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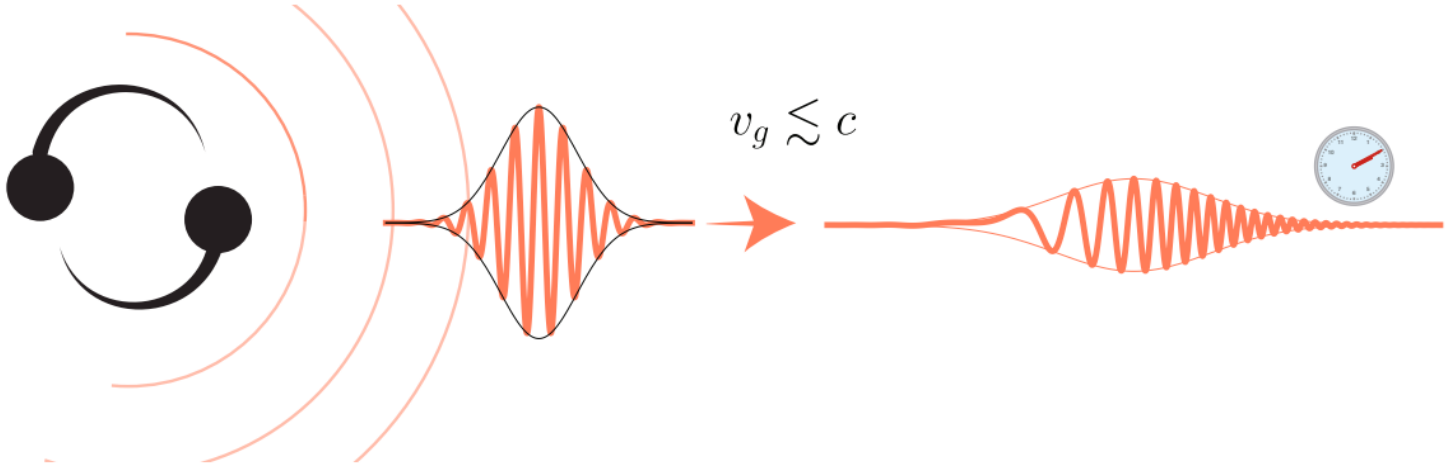
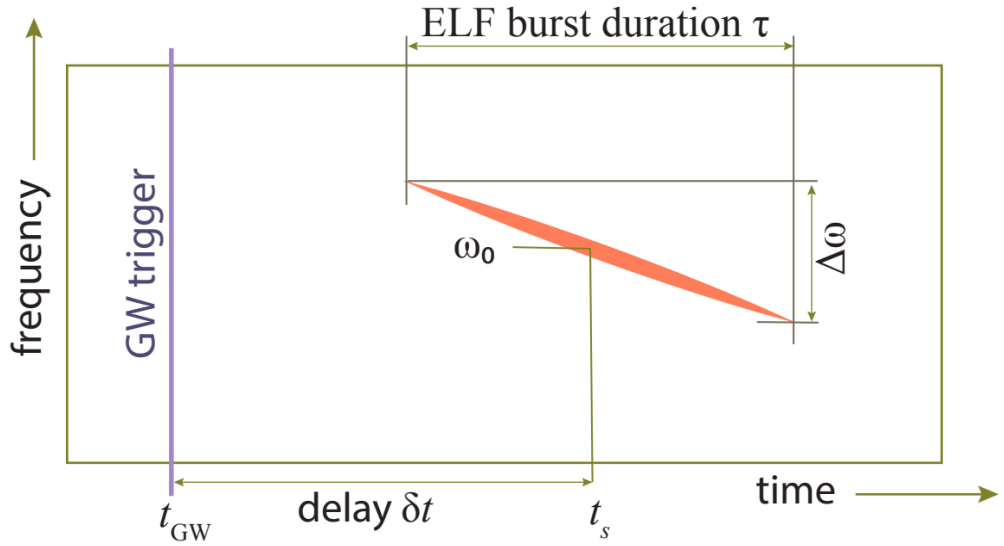
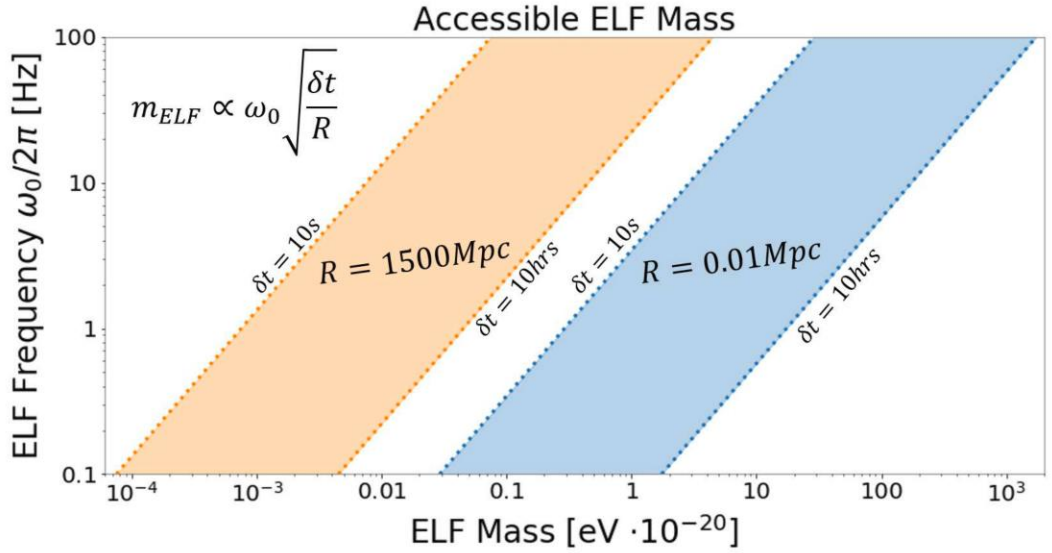
Exotic Low-mass Fields

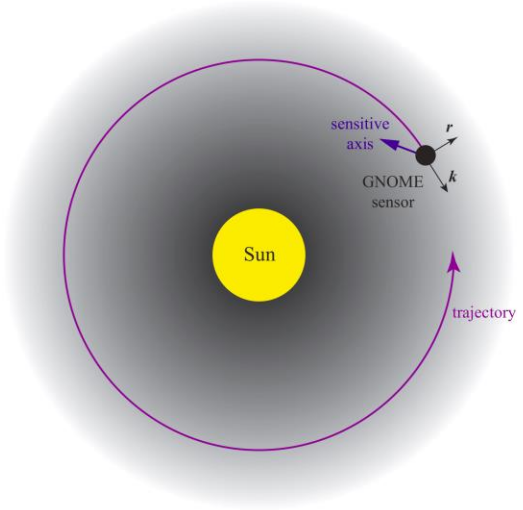


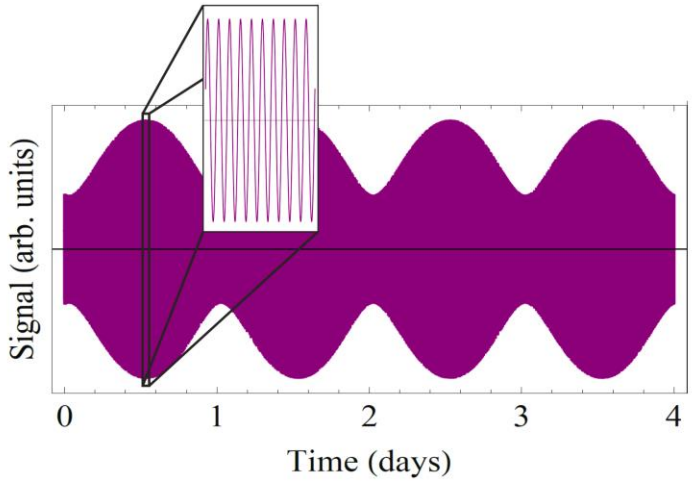




S. Afach et al., Annalen der Physik 2023, 2300083 (2023)

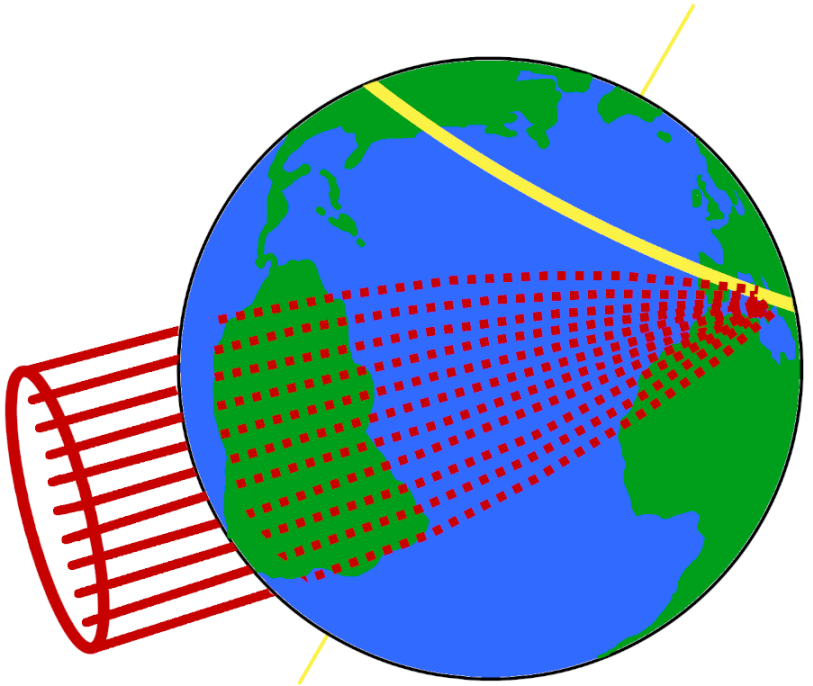
Solar Axion Halo and DM Streams





S. Afach et al., Annalen der Physik 2023, 2300083 (2023)

Gravitational focusing of slow DM



Summary

- GNOME is searching for ultralight Dark Matter candidates.
- The main field of interest contain transient signals and global correlations.
- Advanced GNOME = up to 4 orders of magnitude improvement in sensitivity.

https://budker.uni-mainz.de/gnome/

https://pustelny.eu/

GNOME Collaboration

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What Can a GNOME Do? Search Targets for the Global Network of Optical Magnetometers for Exotic Physics Searches

Samer Afach, Deniz Aybas Tumturk, Hendrik Bekker, Ben C. Buchler, Dmitry Budker, Kaleb Cervantes, Andrei Derevianko, Joshua Eby, Nataniel L. Figueroa, Ron Folman, Daniel Gavilán-Martín, Menachem Givon, Zoran D. Grujić, Hong Guo, Paul Hamilton, Morgan P. Hedges, Derek F. Jackson Kimball, Sami Khamis, Dongok Kim, Emmanuel Klinger, Abaz Kryemadhi, Xiyu Liu, Grzegorz Łukasiewicz, Hector Masia-Roig, Mikhail Padniuk, Christopher A. Palm, Sun Yool Park, Heather R. Pearson, Xiang Peng, Maxim Pospelov, Szymon Pustelny, Yossi Rosenzweig, Ophir M. Ruimi, Theo Scholtes, Perrin C. Segura, Yannis K. Semertzidis, Yun Chang Shin, Joseph A. Smiga, Yevgeny V. Stadnik, Jason E. Stalnaker, Ibrahim A. Sulai, Dhruv Tandon, Kenneth Vu, Antoine Weis, Arne Wickenbrock, Tatum Z. Wilson, Teng Wu, Wei Xiao, Yucheng Yang, Dongrui Yu, Felix Yu, Jianwei Zhang, Yixin Zhao

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