

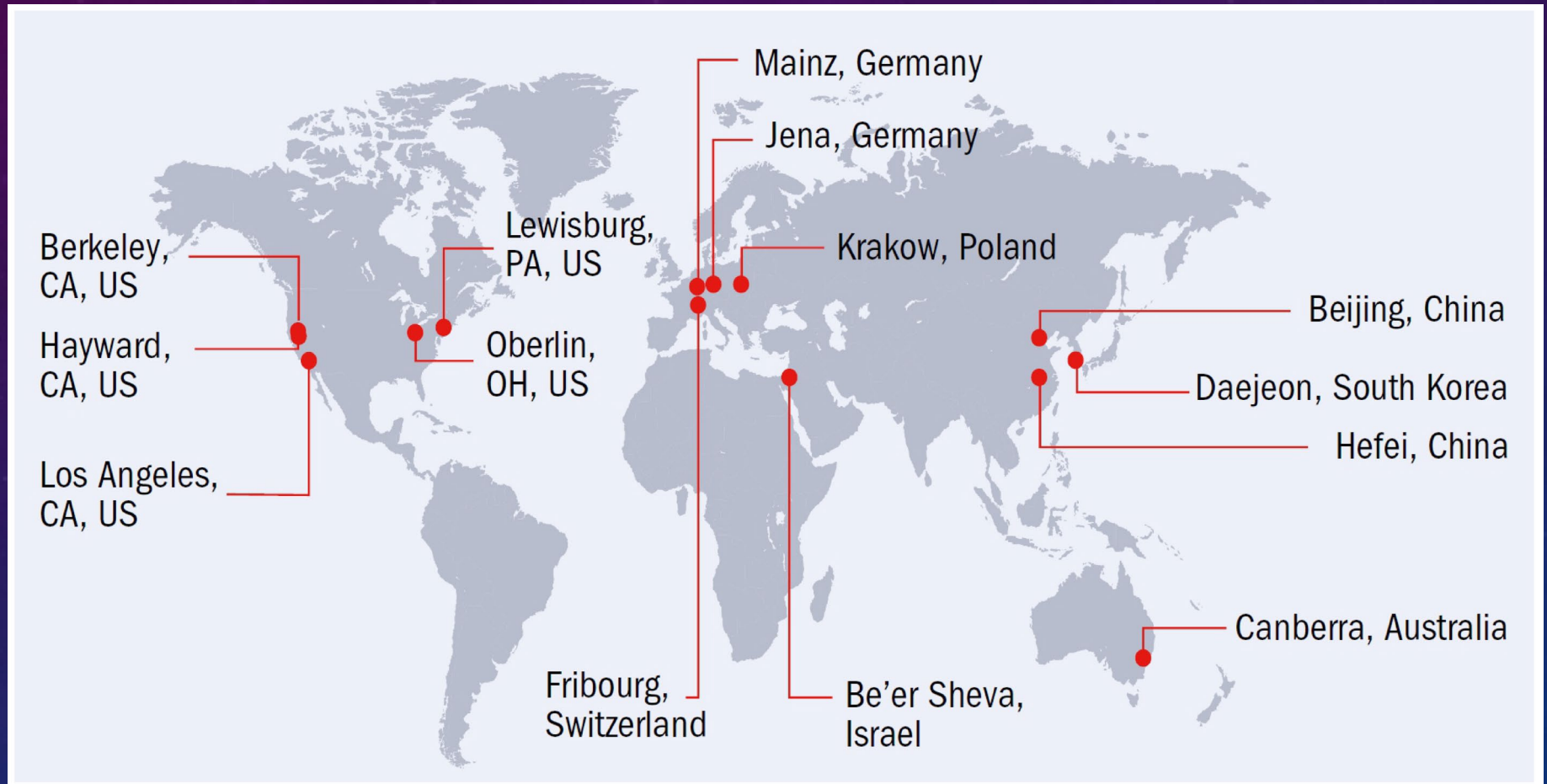


Global Network of Optical Magnetometers to search for Exotic Physics (GNOME)

Derek F. Jackson Kimball
California State University



GNOME COLLABORATION



Pustelny et al., *Annalen der Physik* **525**, 659 (2013);
Afach et al., *Physics of the Dark Universe* **22**, 162 (2018).



Axion/ALP coupling to atomic spins

$$\hat{H}_{\text{lin}} = -\frac{(\hbar c)^{3/2}}{f_L} \frac{\mathbf{S}}{\|\mathbf{S}\|} \cdot \nabla a(\mathbf{r}, t)$$

$$\hat{H}_{\text{quad}} = -\frac{\hbar^2 c^2}{f_Q^2} \frac{\mathbf{S}}{\|\mathbf{S}\|} \cdot \nabla |a(\mathbf{r}, t)|^2$$

$$\hat{H}_Z = -\gamma \mathbf{S} \cdot \mathcal{B}$$

Zeeman Hamiltonian:
ordinary interaction of spin
with magnetic field.

Hidden photons (interaction basis)

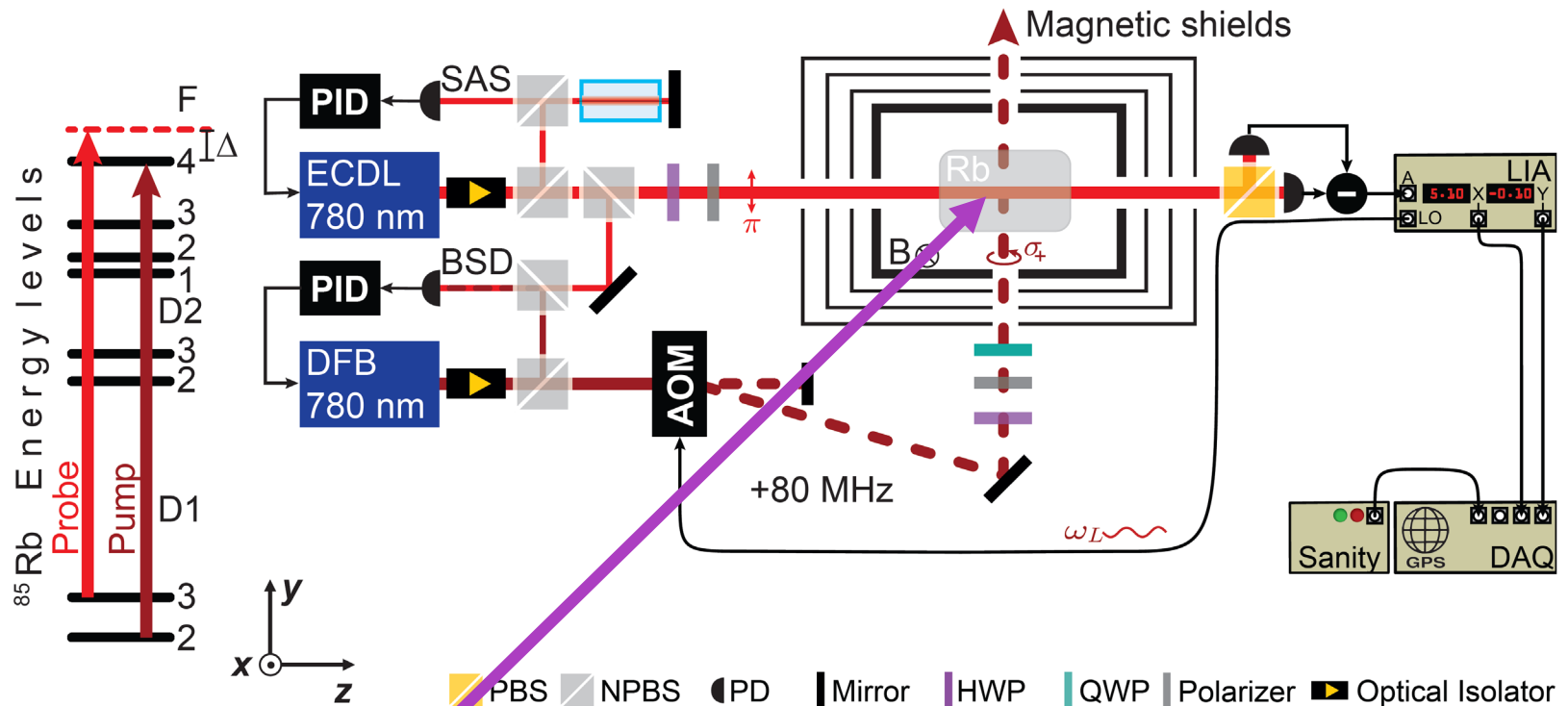
$$\mathcal{L} = -\frac{1}{16\pi} \left(\bar{F}_{\mu\nu} \bar{F}^{\mu\nu} + \bar{\mathcal{F}}_{\mu\nu} \bar{\mathcal{F}}^{\mu\nu} \right) + \frac{m_{\gamma'}^2 c^2}{2\hbar^2} \bar{\chi}_\mu \bar{\chi}^\mu - \frac{1}{c} J^\mu \bar{A}_\mu + \kappa \frac{m_{\gamma'}^2 c^2}{\hbar^2} \bar{\chi}^\mu \bar{A}_\mu .$$

$$\bar{\mathcal{J}}^\mu = -\kappa \frac{m_{\gamma'}^2 c^3}{\hbar^2} \bar{\chi}^\mu$$

Hidden photon electrodynamics is equivalent to presence of a pseudo-current.

OPTICAL ATOMIC MAGNETOMETER

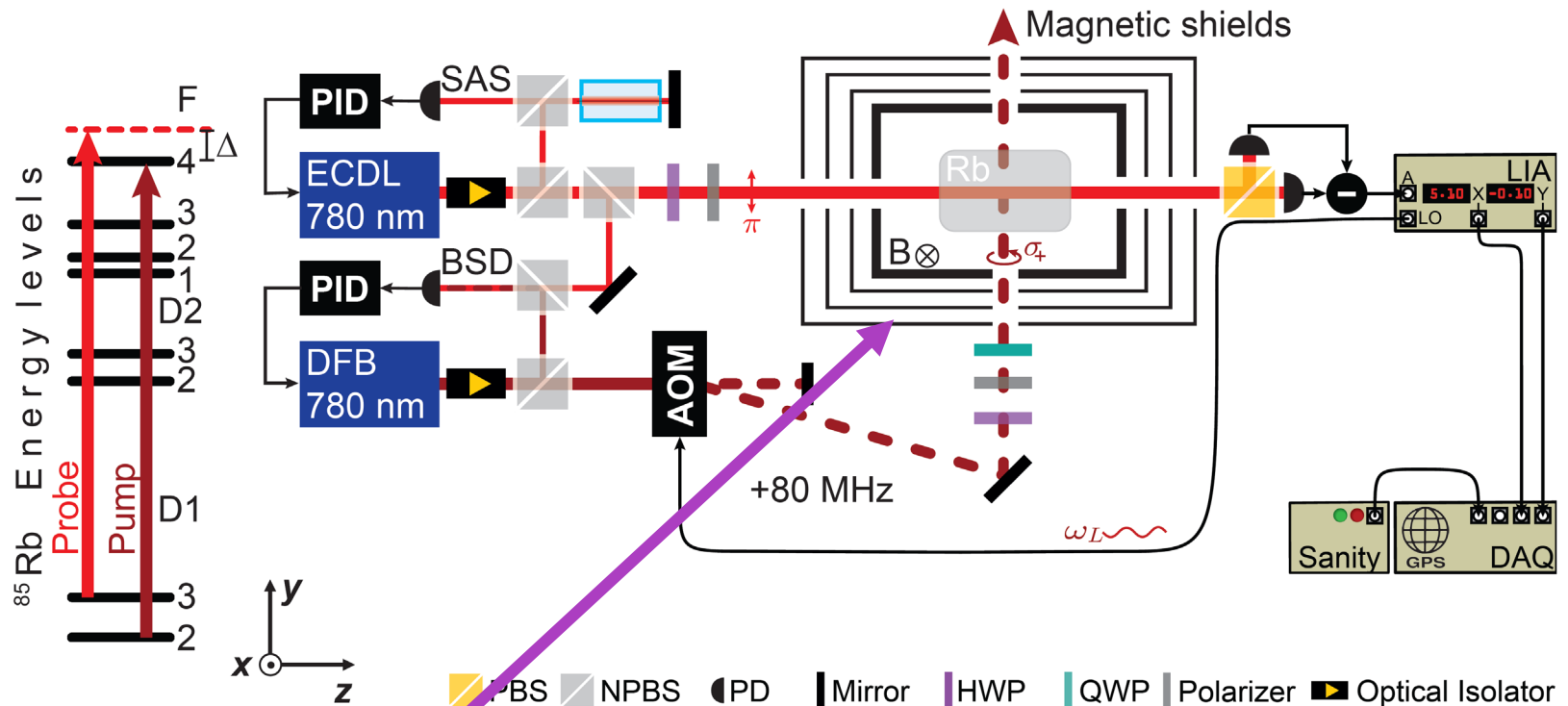
Hayward GNOME station



Atomic vapor

OPTICAL ATOMIC MAGNETOMETER

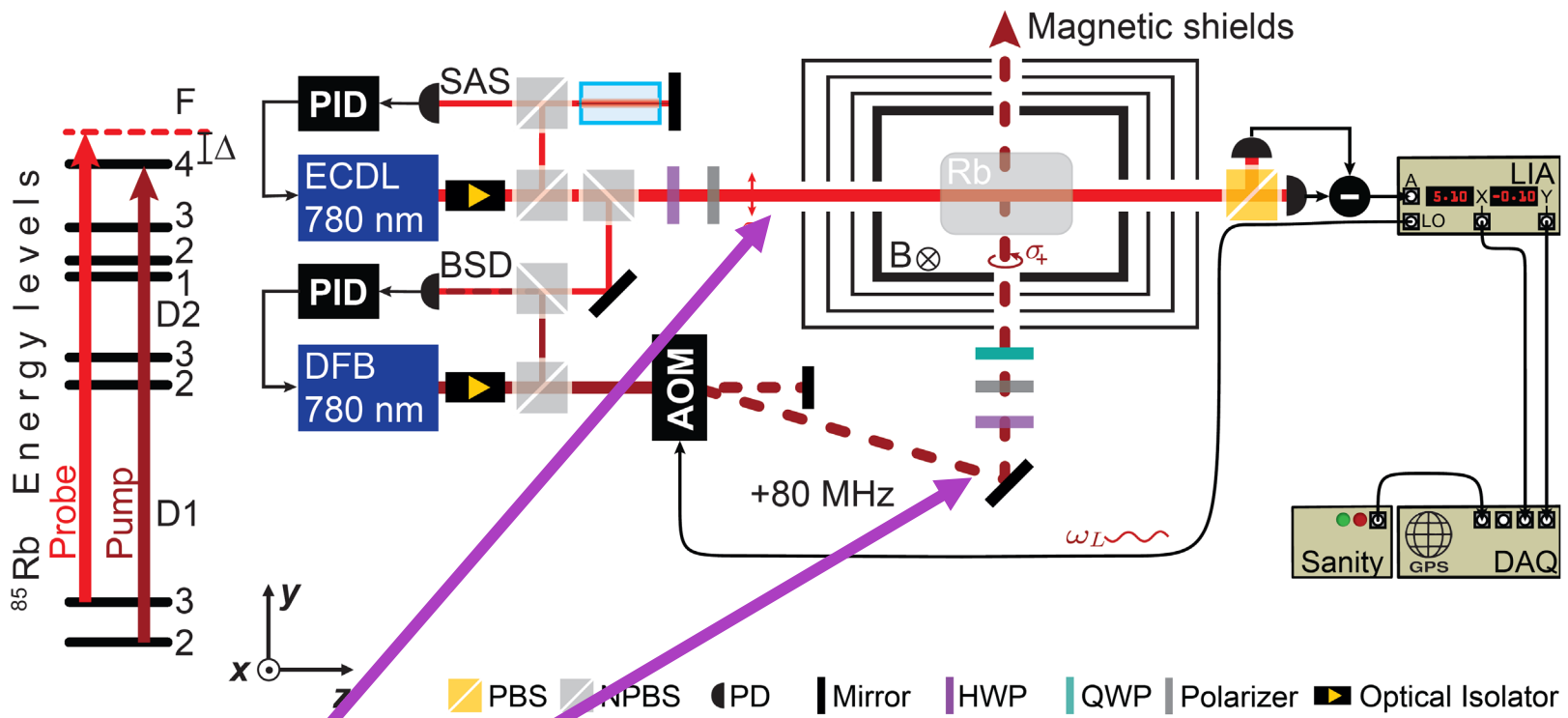
Hayward GNOME station



Multi-layer magnetic shield

OPTICAL ATOMIC MAGNETOMETER

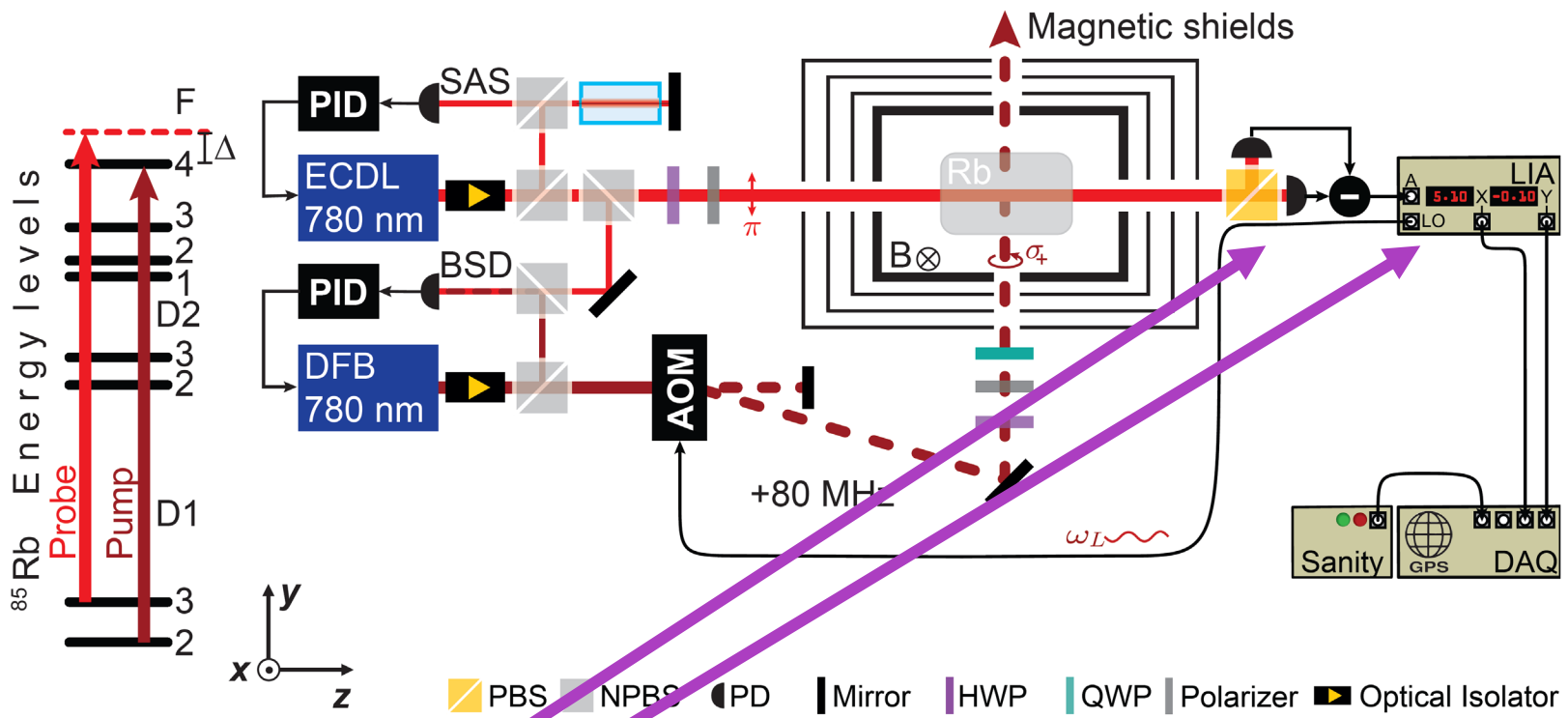
Hayward GNOME station



Pump and probe laser beams

OPTICAL ATOMIC MAGNETOMETER

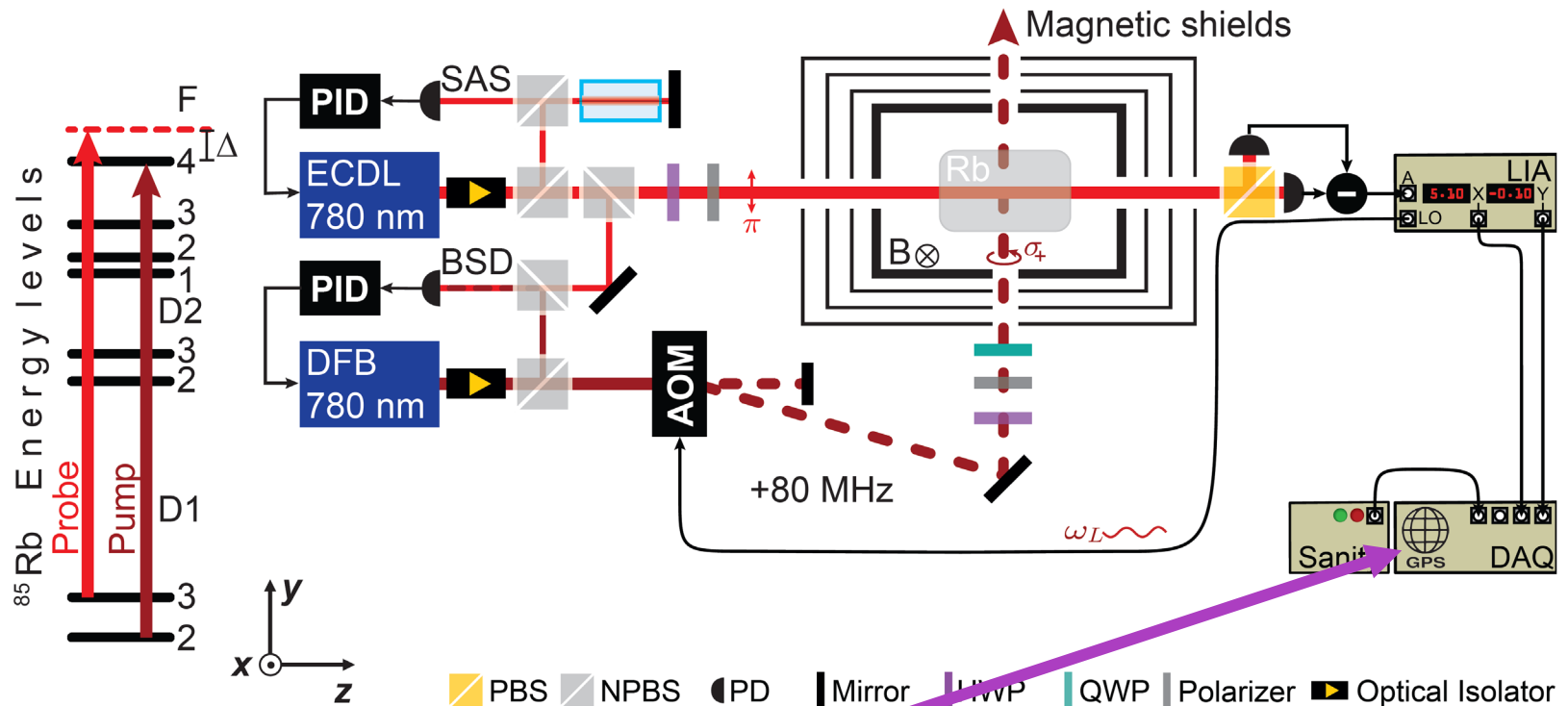
Hayward GNOME station



Polarimeter and detection electronics

OPTICAL ATOMIC MAGNETOMETER

Hayward GNOME station

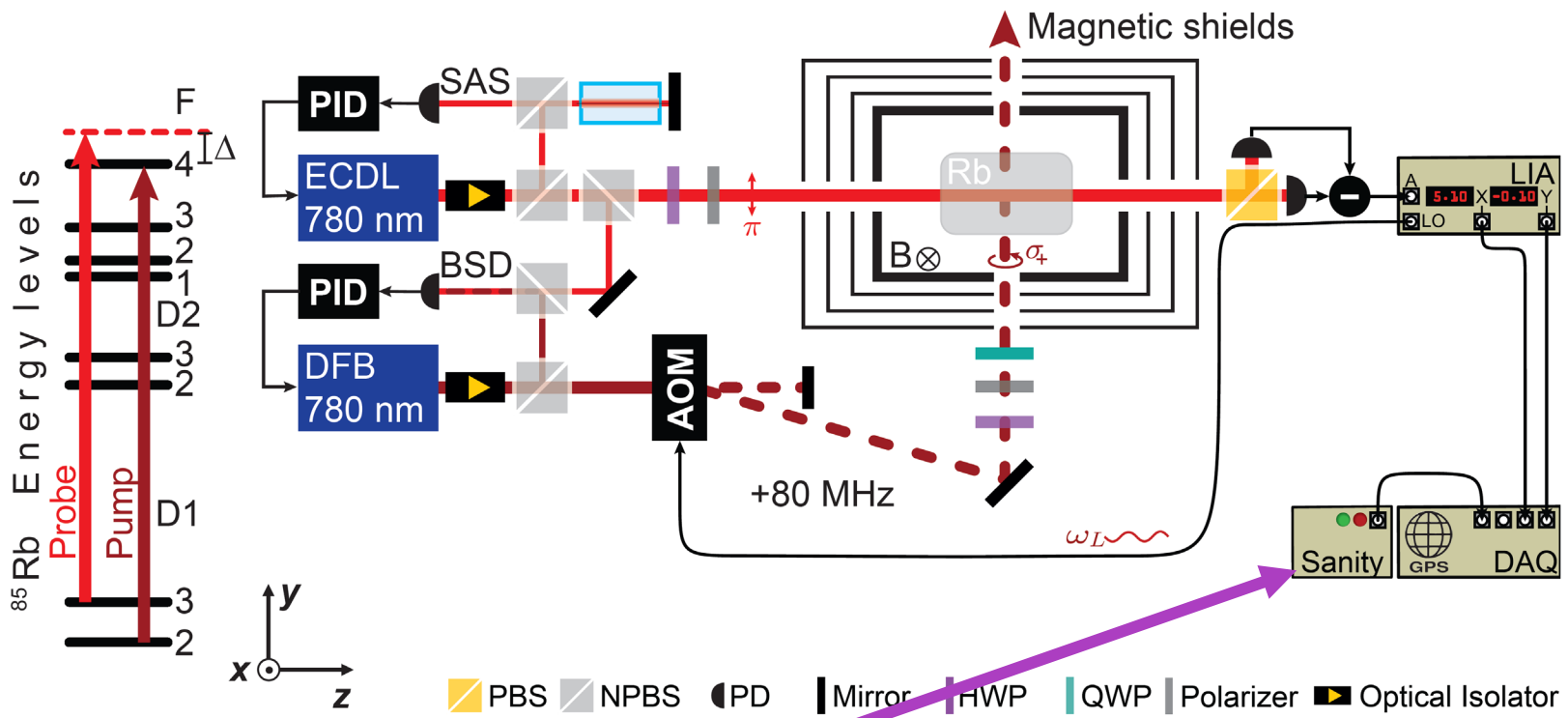


GPS-disciplined data acquisition system

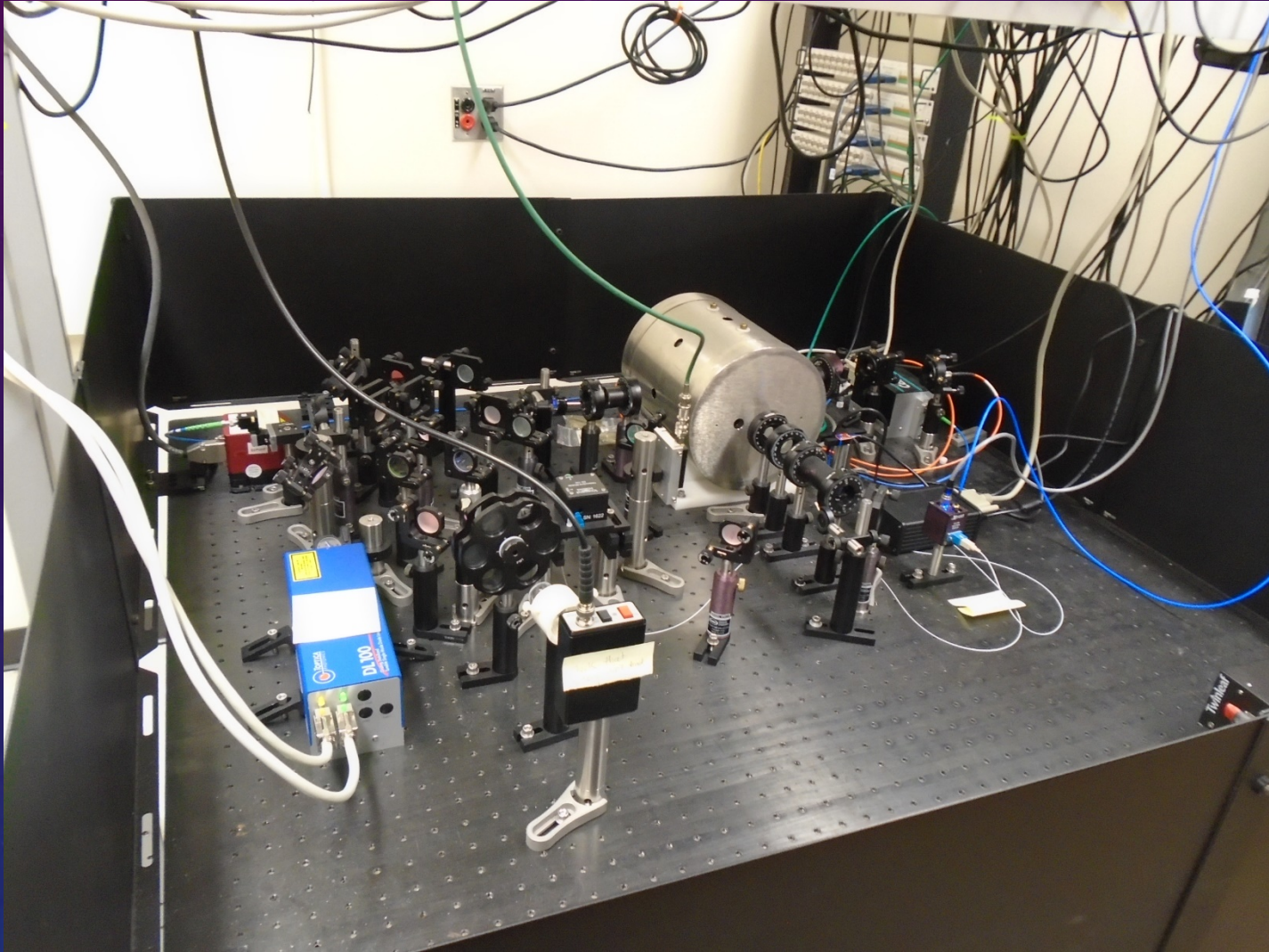
Afach et al., *Physics of the Dark Universe* **22**, 162 (2018);
 Włodarczyk et al., *Nucl. Instrum. Methods. Phys. Res. A* **763**, 150 (2014).

OPTICAL ATOMIC MAGNETOMETER

Hayward GNOME station



Auxiliary sensors to monitor/flag glitches



DATA TRANSFER TO SERVERS IN GERMANY AND SOUTH KOREA

GNOME Synchronizer - Version 1.1.1

Connect to server

Server Address: budker.uni-mainz.de:22111

Username: hayward01 Password:

File transfer

ds\Desktop\GNOME Acquirer DATA from GPS Data Logger\

2016, 2016

	Sun	Mon	Tue	Wed	Thu	Fri	Sat
17		24	25	26	27	28	29
18	1	2	3	4	5	6	7
19	8	9	10	11	12	13	14
20	15	16	17	18	19	20	21
21	22	23	24	25	26	27	28
22	29	30	31	1	2	3	4

2016\05\23\Hayward_20160523_223423.h5
2016\05\23\Hayward_20160523_223523.h5

Log

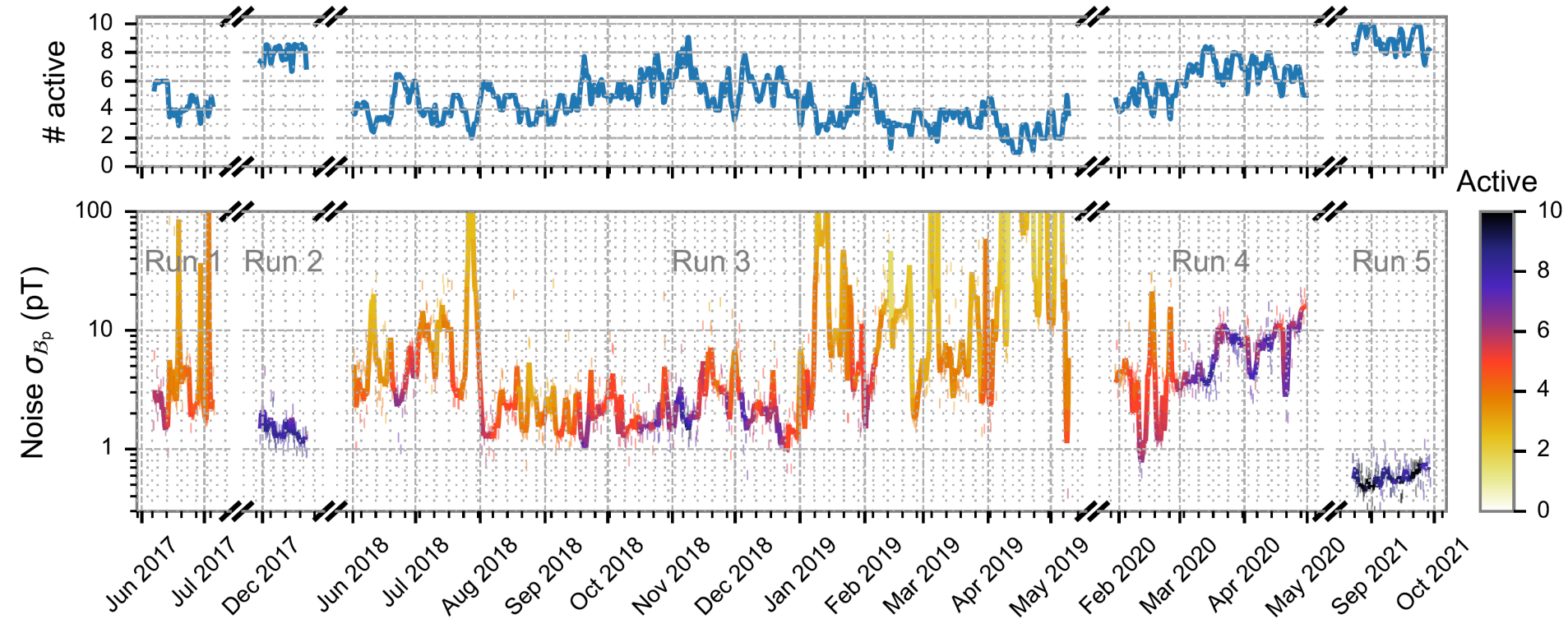
```

23.May.2016-22:32:12-UTC: Initializing HDF5 library successful.
23.May.2016-22:32:12-UTC: Log file opened in ClientLog.htm
23.May.2016-22:35:48-UTC: Successfully received and parsed HDF5 model. Found 2 models.
23.May.2016-22:35:48-UTC: Connecting to budker.uni-mainz.de:22111...
23.May.2016-22:35:48-UTC: List of failed files will be written to C:\Users\Gnome\Downloads\Desktop\GNOME Acquirer DATA from GPS Data Logger\FailedFiles.log
23.May.2016-22:35:48-UTC: Connecting to budker.uni-mainz.de through port 22111...
23.May.2016-22:35:50-UTC: CommProtocol: Login successful!
23.May.2016-22:36:40-UTC: Watcher enabled...
23.May.2016-22:36:48-UTC: Preparing to send file 2016\05\23\Hayward_20160523_223123.h5
23.May.2016-22:36:48-UTC: Reading file: 2016\05\23\Hayward_20160523_223123.h5
23.May.2016-22:36:48-UTC: Reading file done.
23.May.2016-22:36:48-UTC: Uploading...
23.May.2016-22:36:54-UTC: File upload successful
23.May.2016-22:36:54-UTC: Preparing to send file 2016\05\23\Hayward_20160523_223223.h5
23.May.2016-22:36:54-UTC: Reading file: 2016\05\23\Hayward_20160523_223223.h5
23.May.2016-22:36:54-UTC: Reading file done.
23.May.2016-22:36:54-UTC: Uploading...
23.May.2016-22:36:58-UTC: File upload successful
23.May.2016-22:36:58-UTC: Preparing to send file 2016\05\23\Hayward_20160523_223323.h5
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23.May.2016-22:36:58-UTC: Reading file done.
23.May.2016-22:36:58-UTC: Uploading...

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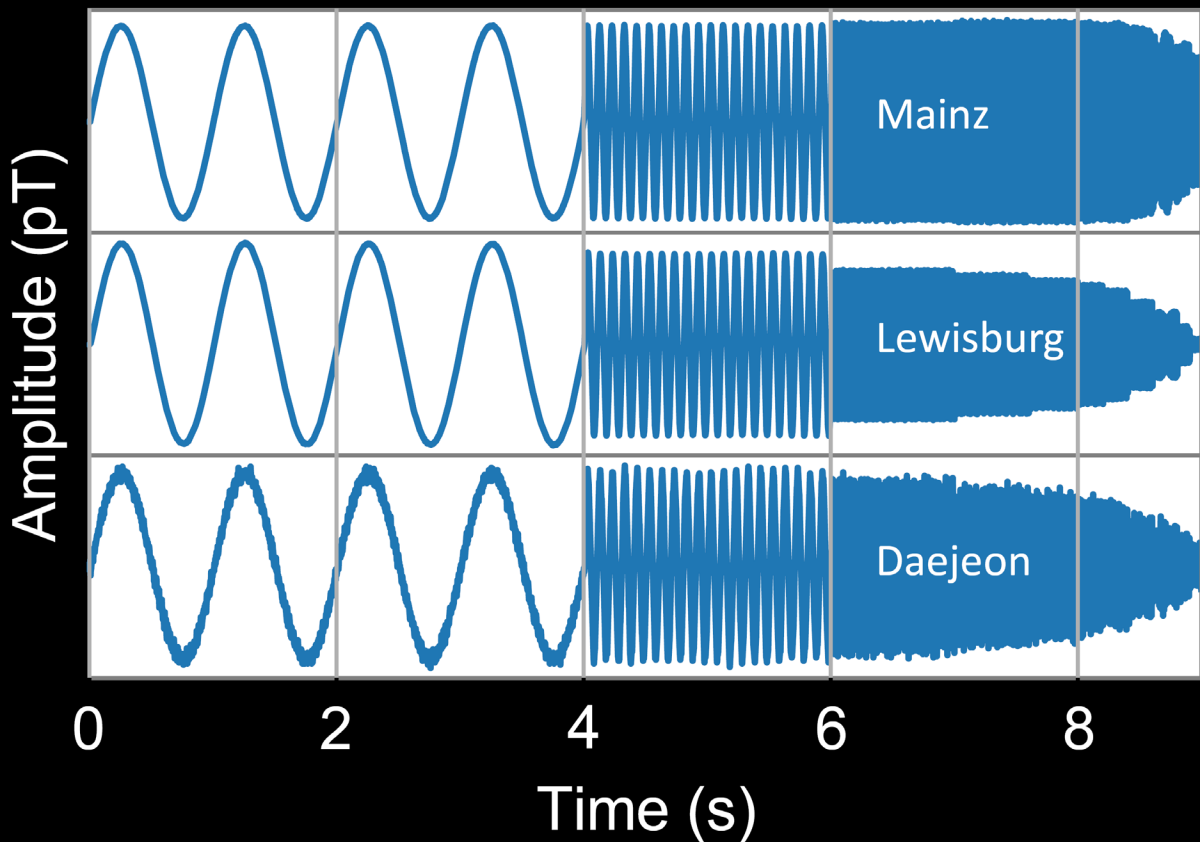
Upload from selected date on...

GNOME SCIENCE RUNS 1 - 5

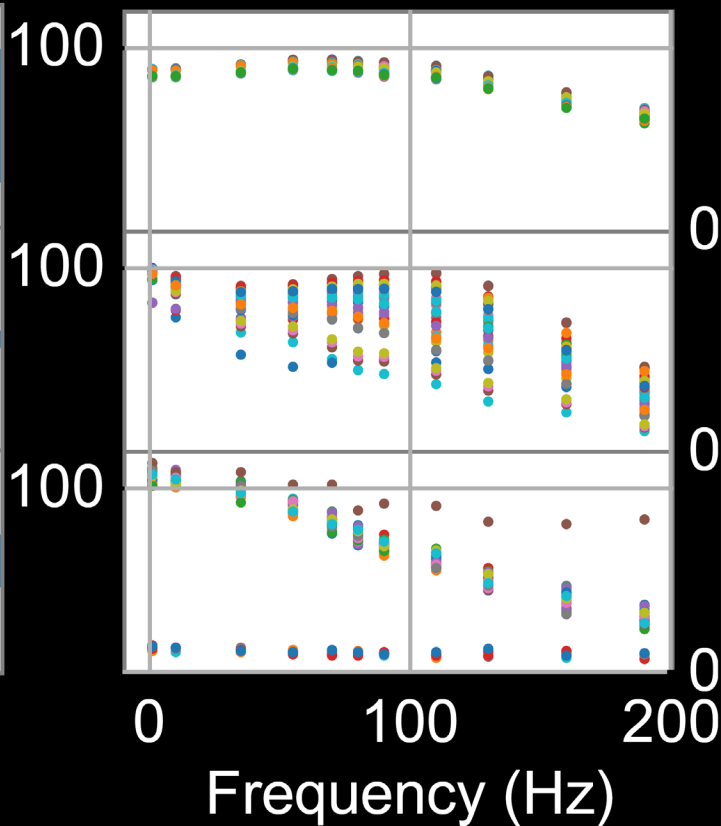


GNOME HOURLY CALIBRATION PULSE

Calibration Pulses



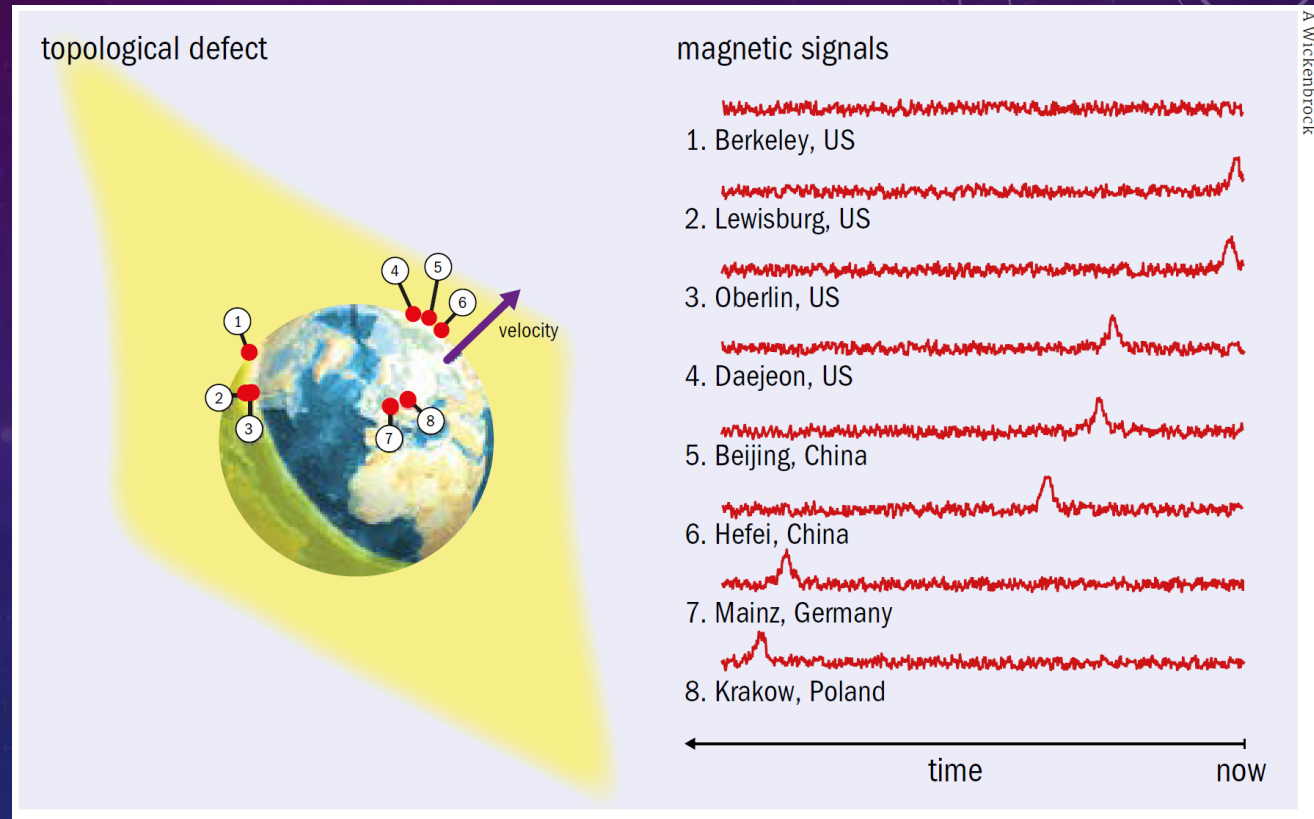
Bandwidth



TRANSIENT DARK-MATTER ENCOUNTERS

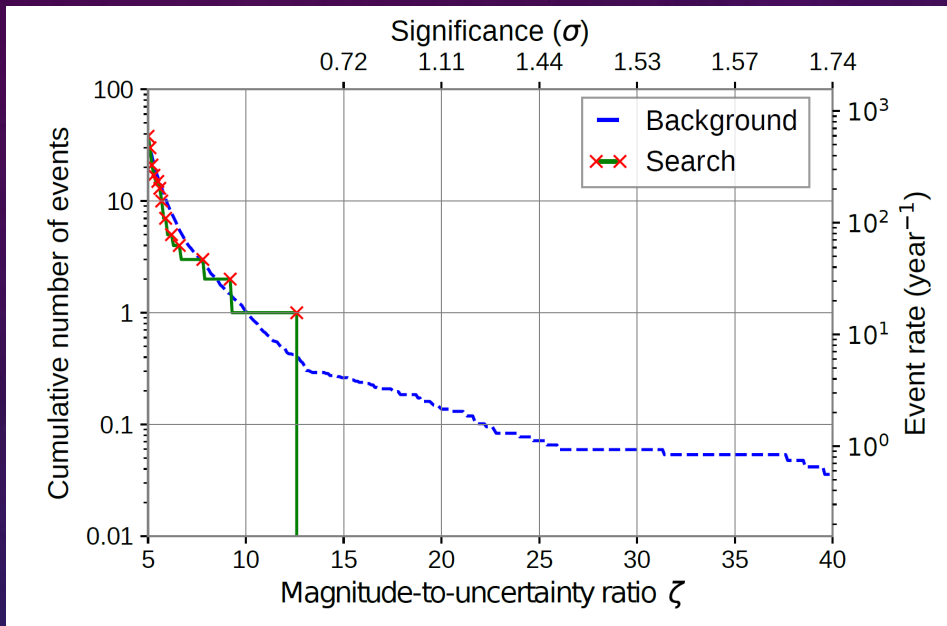
What can we say about transient encounters with compact, composite dark-matter objects?

A single sensor would struggle to distinguish signal from noise.



However, a geographically distributed array of sensors (like GNOME) can confidently detect transient events!

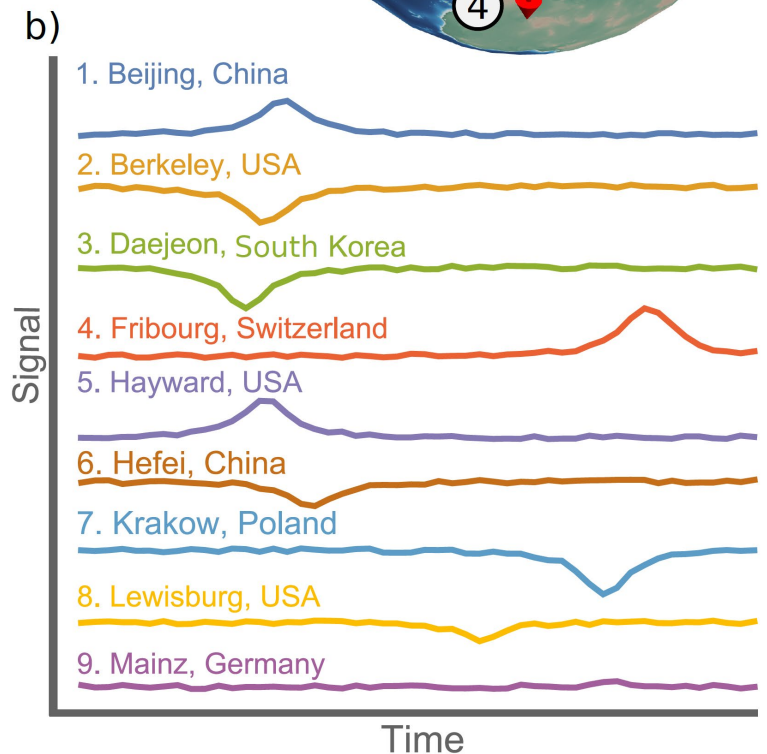
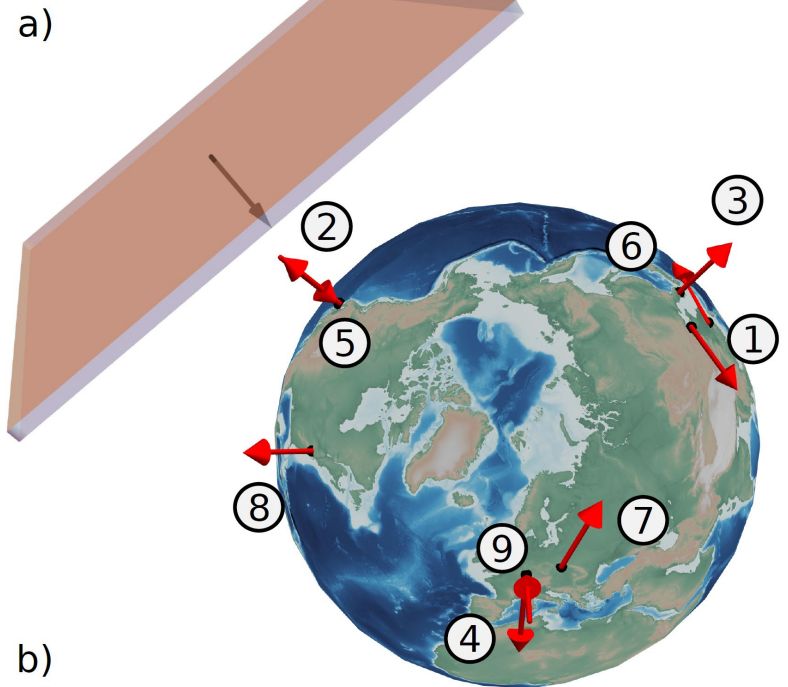
ALP DOMAIN WALL SEARCH



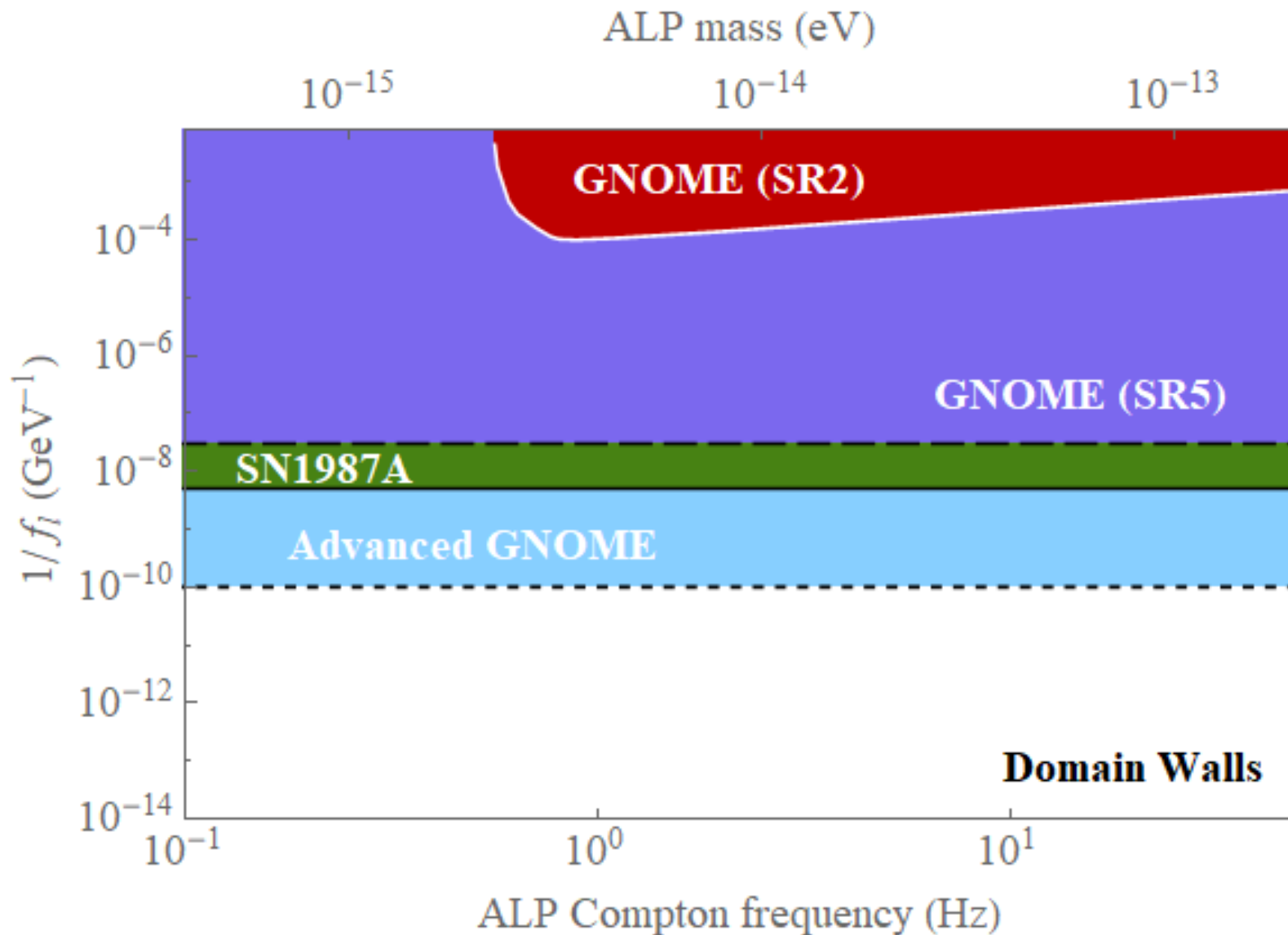
Pospelov et al., Phys. Rev. Lett. **110**, 021803 (2013);

Masia-Roig et al., Physics of the Dark Universe **28**, 100494 (2020);

Afach et al., arXiv:2102.13379 (2021) [accepted to *Nature Physics*].

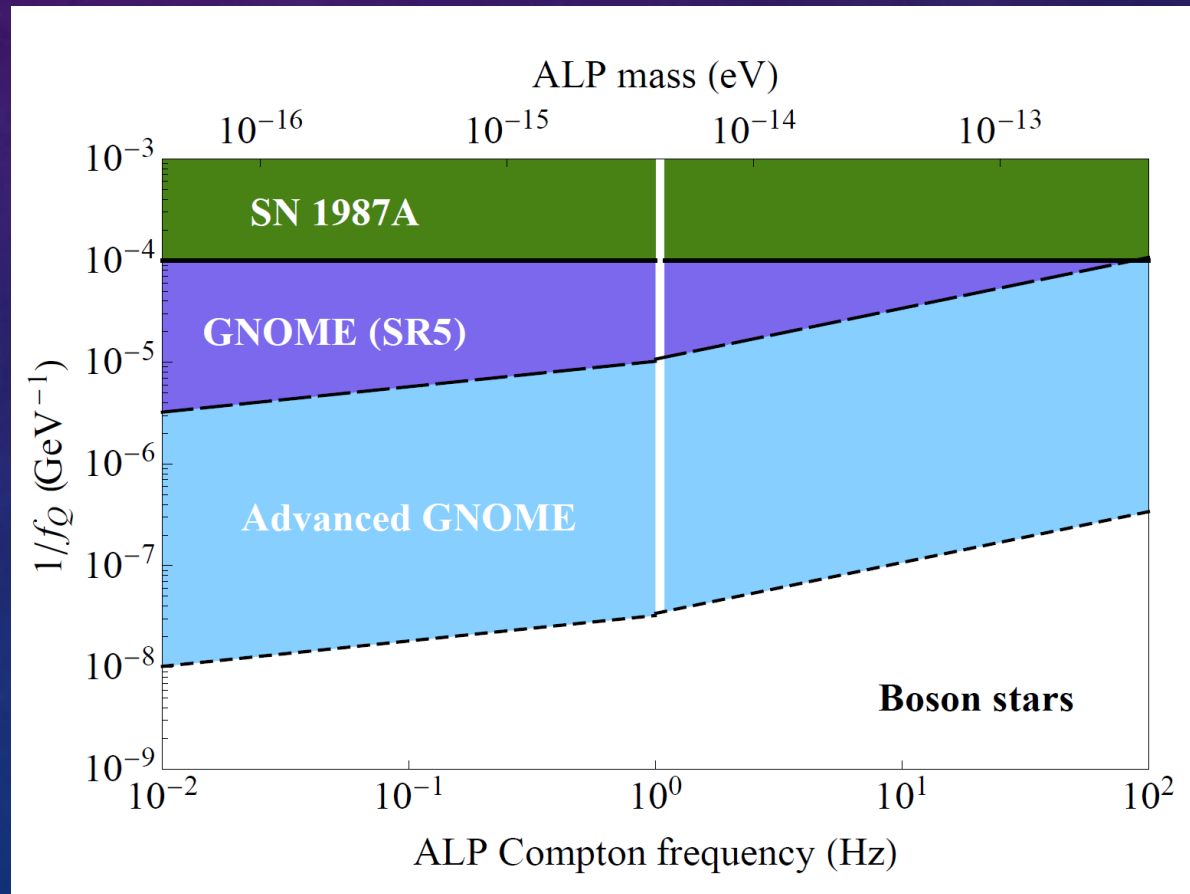


ALP DOMAIN WALL SEARCH



Searching for axion stars and Q -balls with a terrestrial magnetometer network

D. F. Jackson Kimball,^{1,*} D. Budker,^{2,3,4,5} J. Eby,^{6,7} M. Pospelov,^{8,9} S. Pustelny,¹⁰ T. Scholtes,¹¹
 Y. V. Stadnik,^{2,3} A. Weis,¹¹ and A. Wickenbrock²



Detecting dark blobs

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²*Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*

³*Kavli Institute for Physics and Mathematics of the Universe (WPI), University of Tokyo,
Kashiwa, 277-8583, Japan*



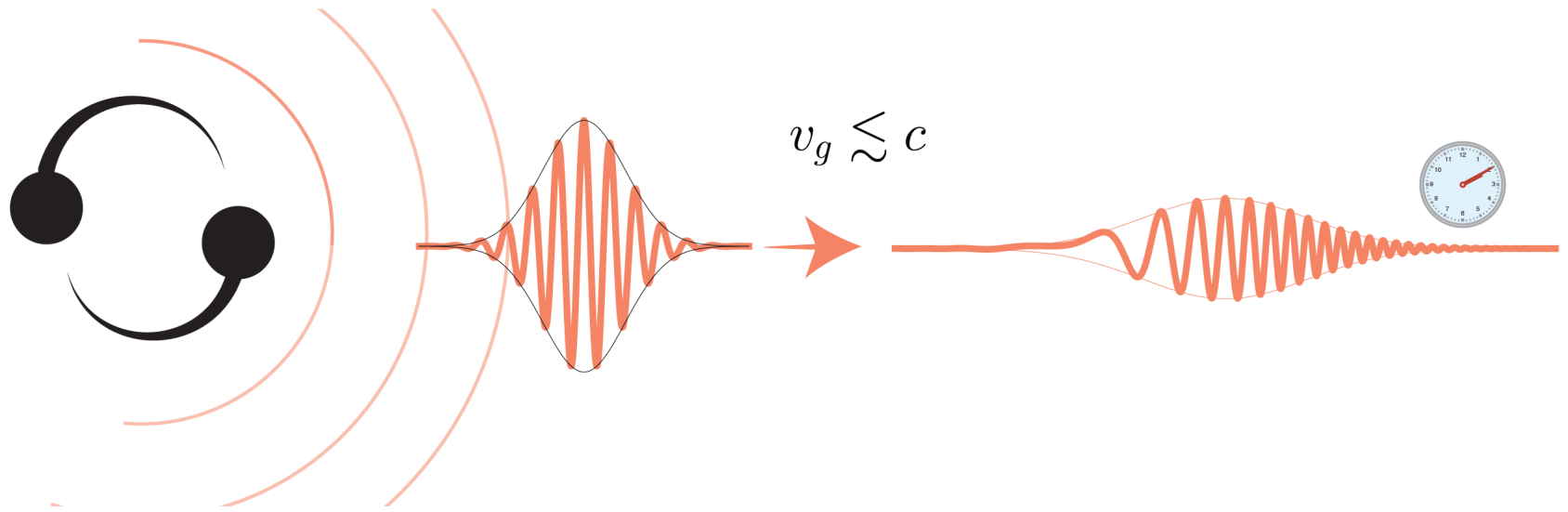
(Received 7 August 2018; published 13 December 2018)



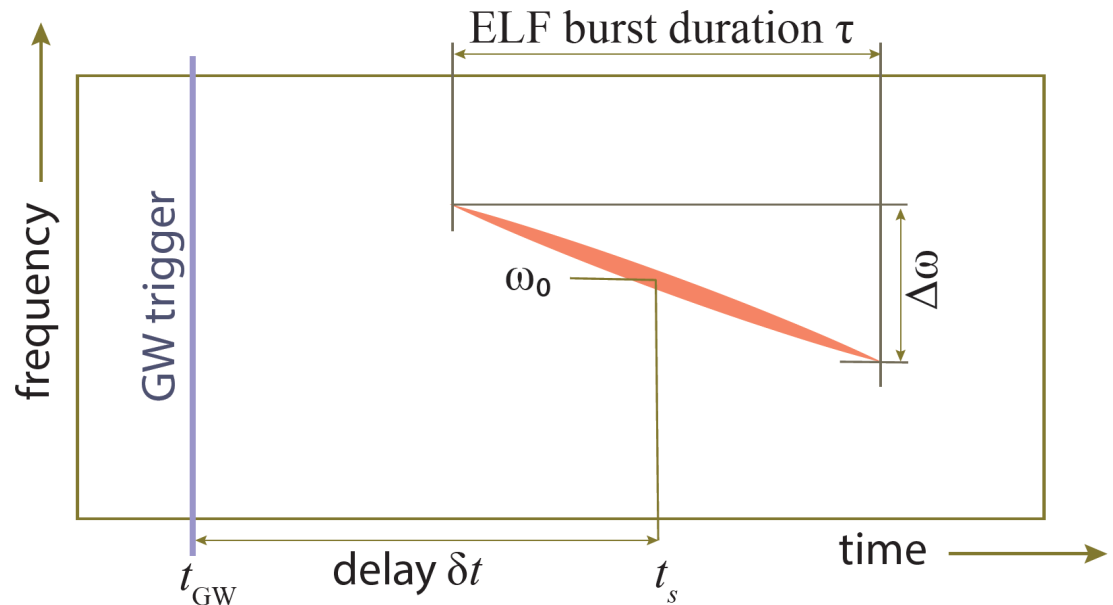


High-energy astrophysical events like black hole mergers could produce intense bursts of exotic low-mass fields (ELFs) that could be detected by GNOME or atomic clocks (like the GPS constellation).

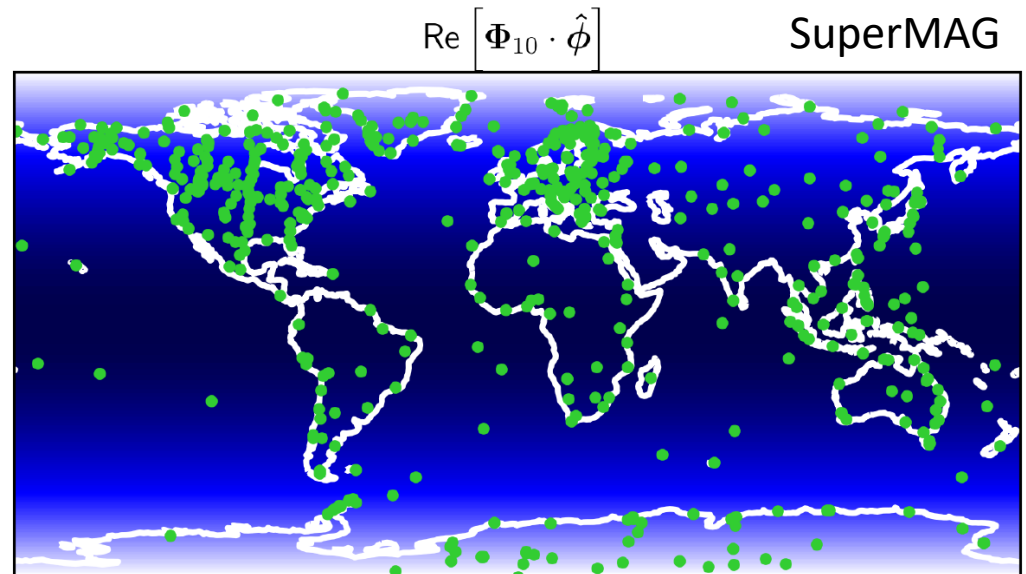
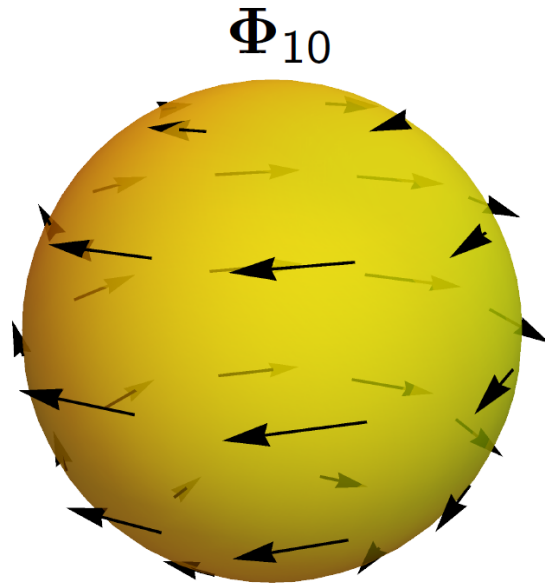
Dailey et al., *Nature Astronomy* 5, 150 (2021).



Notable feature is the dispersion in frequency due to the fact that the bosons have mass unlike photons.

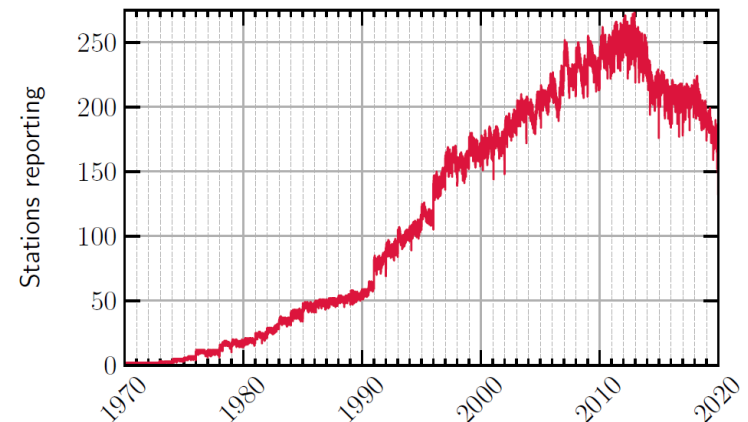


EARTH AS A HIDDEN PHOTON TRANSDUCER

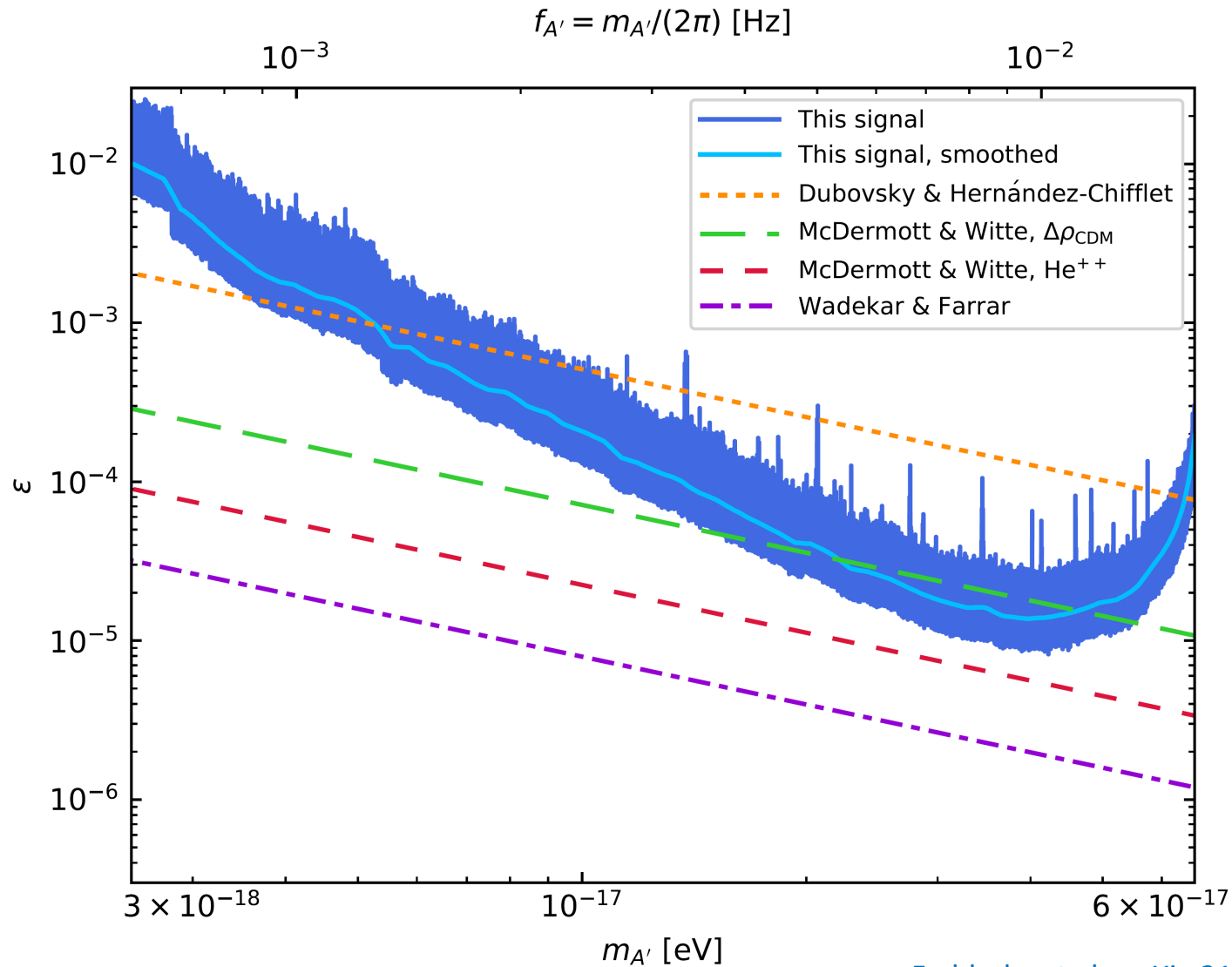


Hidden photon dark matter generates a real oscillating magnetic field with a particular global pattern measurable with unshielded magnetometer networks.

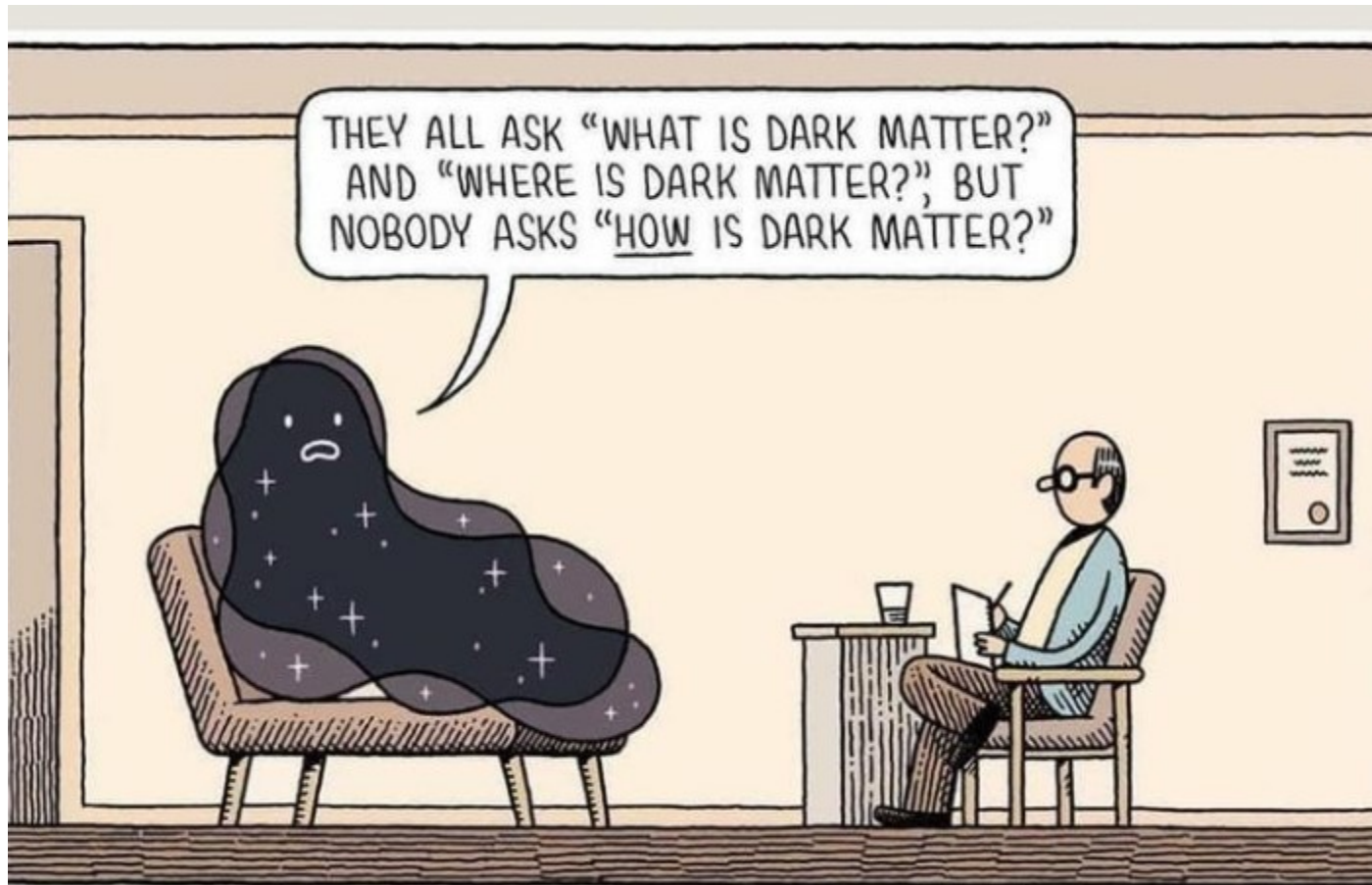
Fedderke et al., *arXiv:2106.00022* (2021)
[to be published in Phys. Rev. D];
Fedderke et al., *arXiv:2108.08852* (2021).



EARTH AS A HIDDEN PHOTON TRANSDUCER



Thank you!!



TOM GAULD for NEW SCIENTIST