

# GLOBAL NETWORK OF OPTICAL MAGNETOMETERS AS NEW CHANNEL FOR MULTIMESSENGER ASTRONOMY

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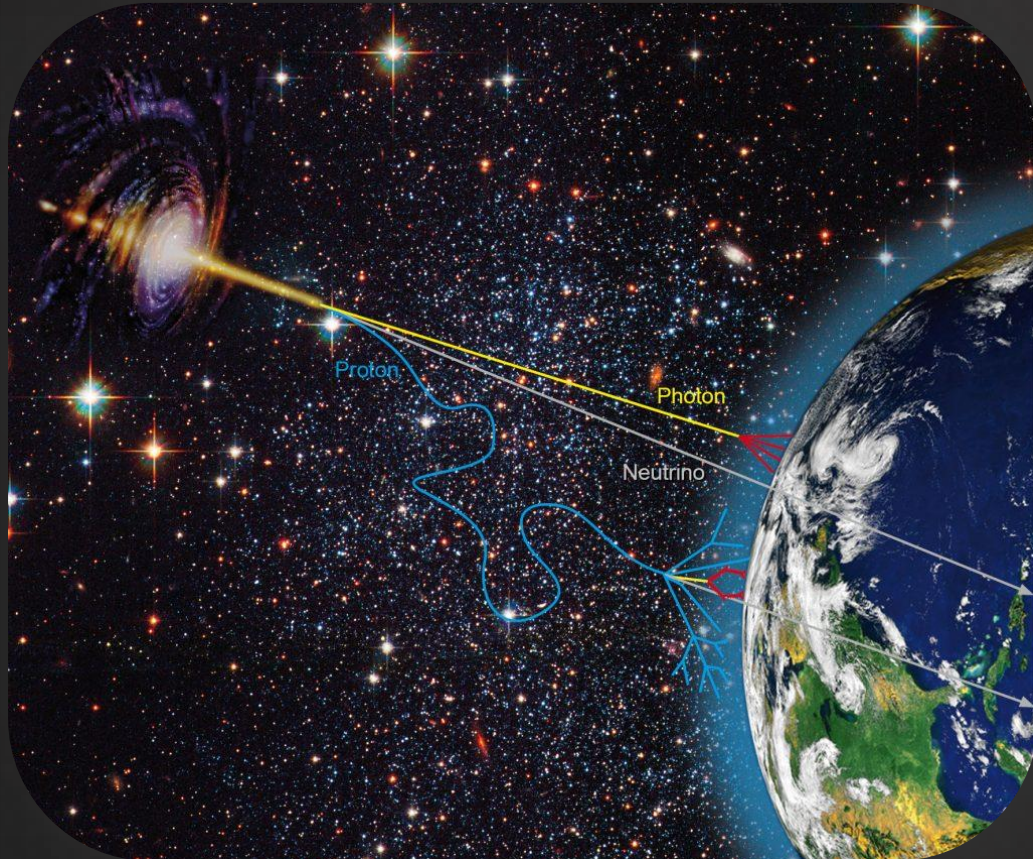
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**The GNOME  
Collabroation**

Heraeus-Stiftung Seminar  
Kraków, 10 November 2022

# CHANNELS OF MULTIMESSANGER ASTRONOMY



## ELECTROMAGNETIC WAVES

- Radio waves
  - Microwaves
  - Light
  - Gamma rays
- 

## PARTICLES

- Neutrinos
  - Protons
- 

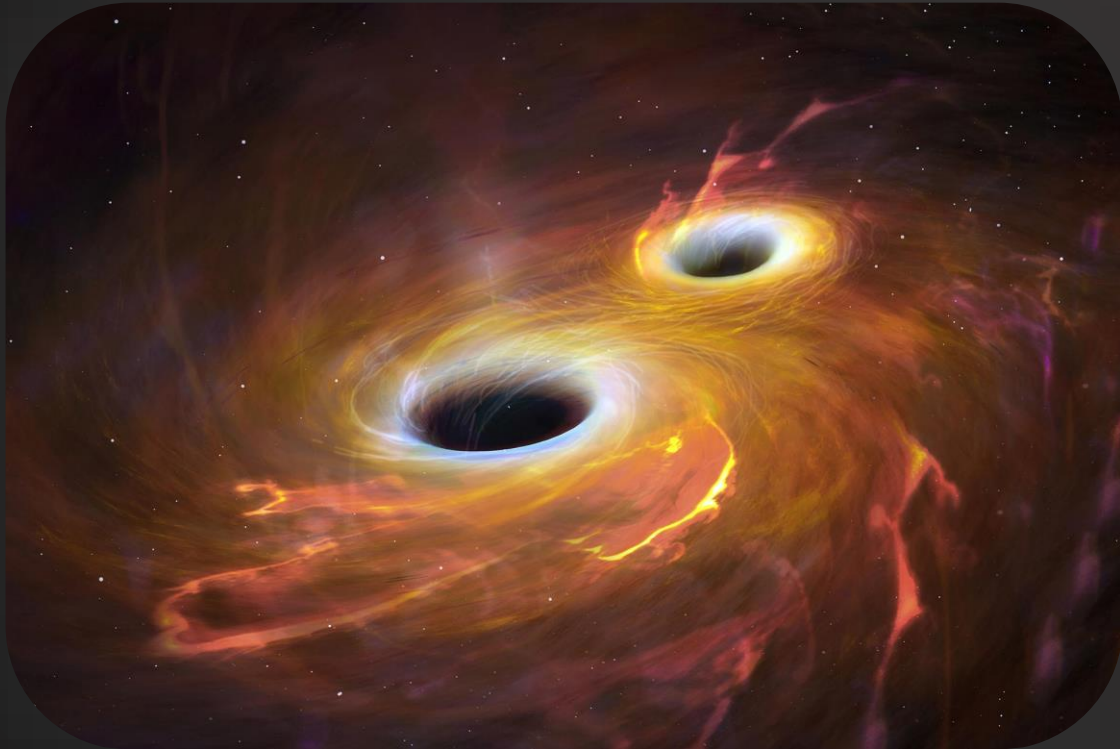
## GRAVITATIONAL WAVES

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## POTENTIAL SOURCE

- Dark-matter particles
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# DARK-MATTER PARTICLE EMISSION



Nature Astronomy 5,  
150-158 (2021).

## CREATION PROCESS

Gigantic energy release - Creation of dark-matter particles

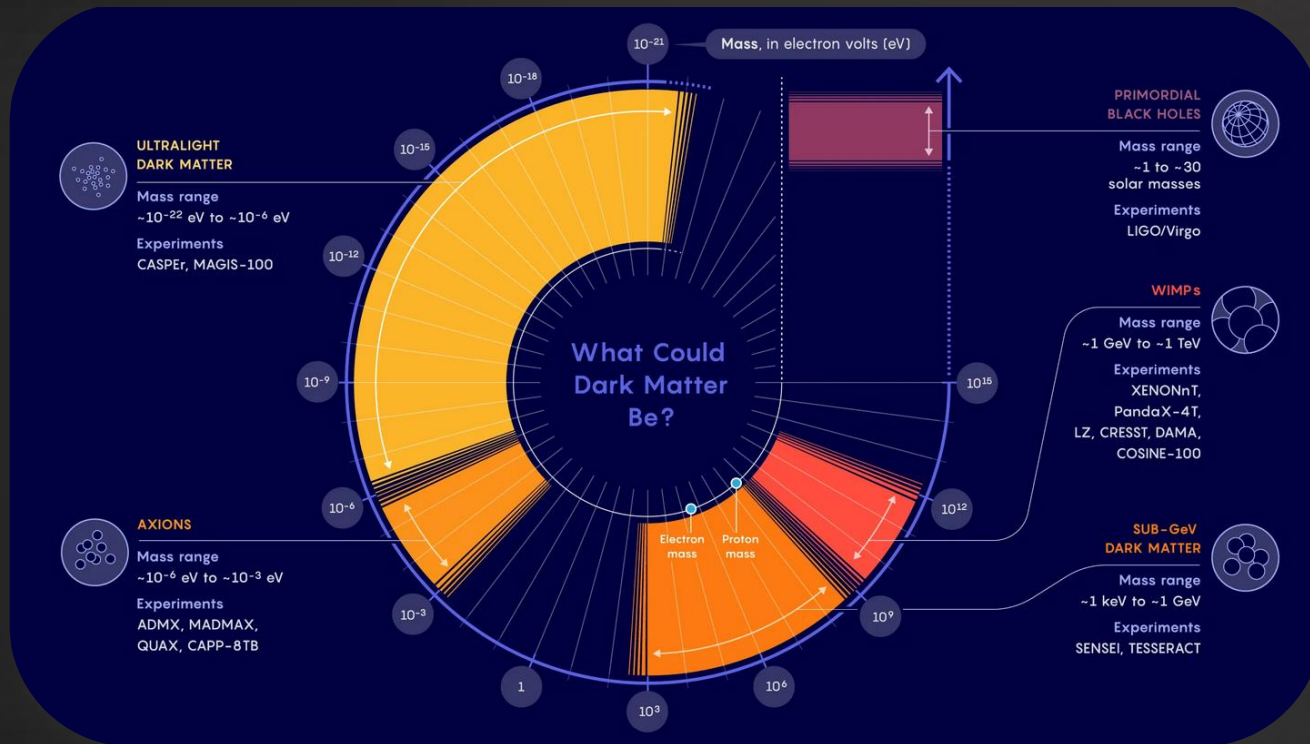
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## SHOCK-WAVE RELEASE

Recoil dark-matter particles trapped in gravitational field

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# WHAT CAN BE EMITTED?



## POTENTIAL DARK-MATTER PARTICLES

- Neutrinos
- Weakly-Interacting Massive Particles (WIMPs)
- Supersymmetric particles
- Dark photons
- ...
- Ultralight bosons (e.g., axions and axion-like particles)

## AXIONS AND ALPs

Electromagnetically noninteracting particles with masses between  $10^{-30} \text{ eV}/c^2$  and  $1 \text{ eV}/c^2$

# CHARACTERISTICS OF "SIGNAL"

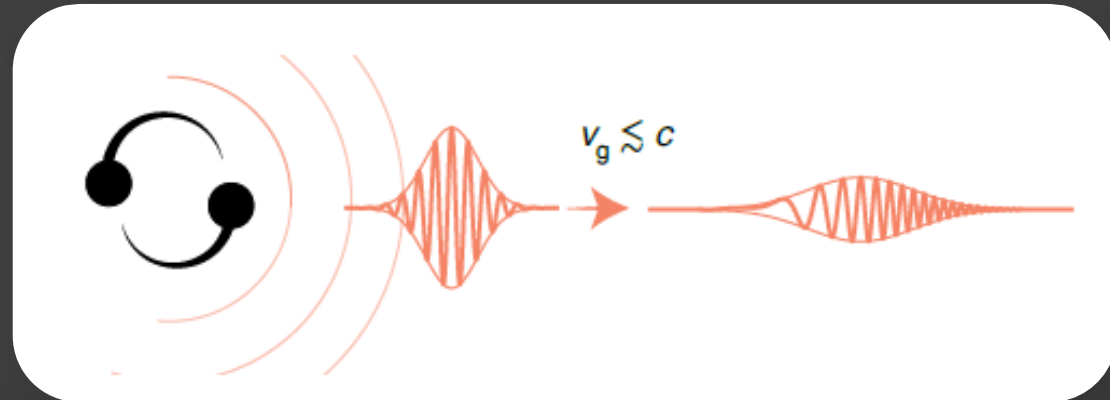
## ULTRALIGHT BOSONS AS FIELDS

Due to their extremely low masses ultralight bosons manifest as exotic fields

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## DISPERSION OF EXOTIC-FIELD PULSE

- Propagation speed smaller than  $c$
- Pulse reaching Earth is chirped



## AMPLITUDE OF THE SIGNAL

- Number of particles reaching the sensor
  - Coupling strength
-

# CAN WE DETECT THE PARTICLES?

## INTERACTION LAGRANGIAN

$$L = \frac{1}{f_n^n} J^\mu \partial_\mu \phi^n + \left( - \sum_f \Gamma_f^{(n)} m_{f,0} c^2 \bar{\psi}_f \psi_f + \frac{\Gamma_\alpha^{(n)}}{4} F_{\mu\nu} F^{\mu\nu} \right) (\hbar c)^{n/2} \phi^n$$

### PSEUDOSCALAR COUPLING

EXOTIC FIELD GRADIENT GENERATES  
PSEUDOMAGNETIC FIELD

#### DETECTABILITY

- Optical magnetometer

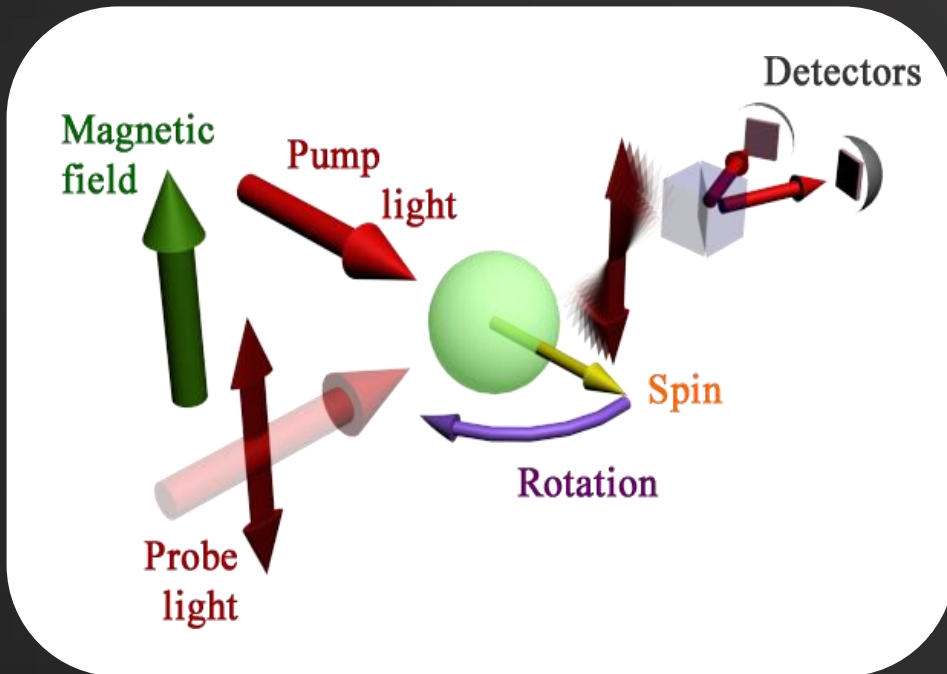
### SCALAR COUPLING

MODIFICATION OF FUNDAMENTAL CONSTANTS

#### DETECTABILITY

- Clocks
- Gravimeters
- Optical cavities

# OPTICAL MAGNETOMETER



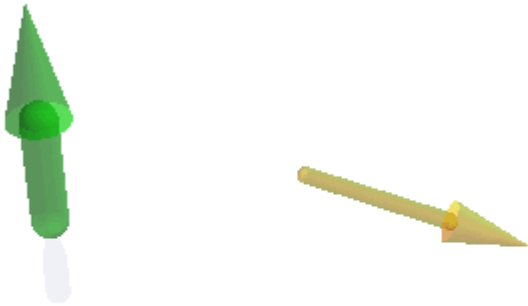
## OPTICAL MAGNETOMETER

Sensor measuring magnetic field by optical detection of spin evolution

## FEATURES

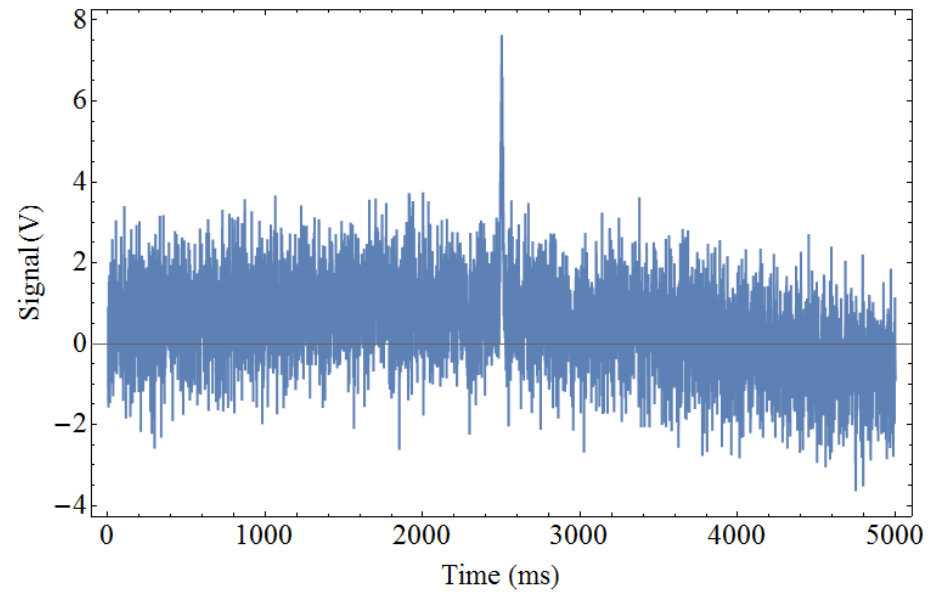
- Sensitivity:  $<10 \text{ fT/Hz}^{1/2}$
- Bandwidth:  $\sim 100 \text{ Hz}$
- Dynamic range:  $10 \text{ nT}$  or  $100 \text{ }\mu\text{T}$
- Directional sensitivity
- Coupling to electrons, protons or neutrons

# AXION SIGNAL IN OPTICAL MAGNETOMETER



 **With coupling**

 **Without coupling**



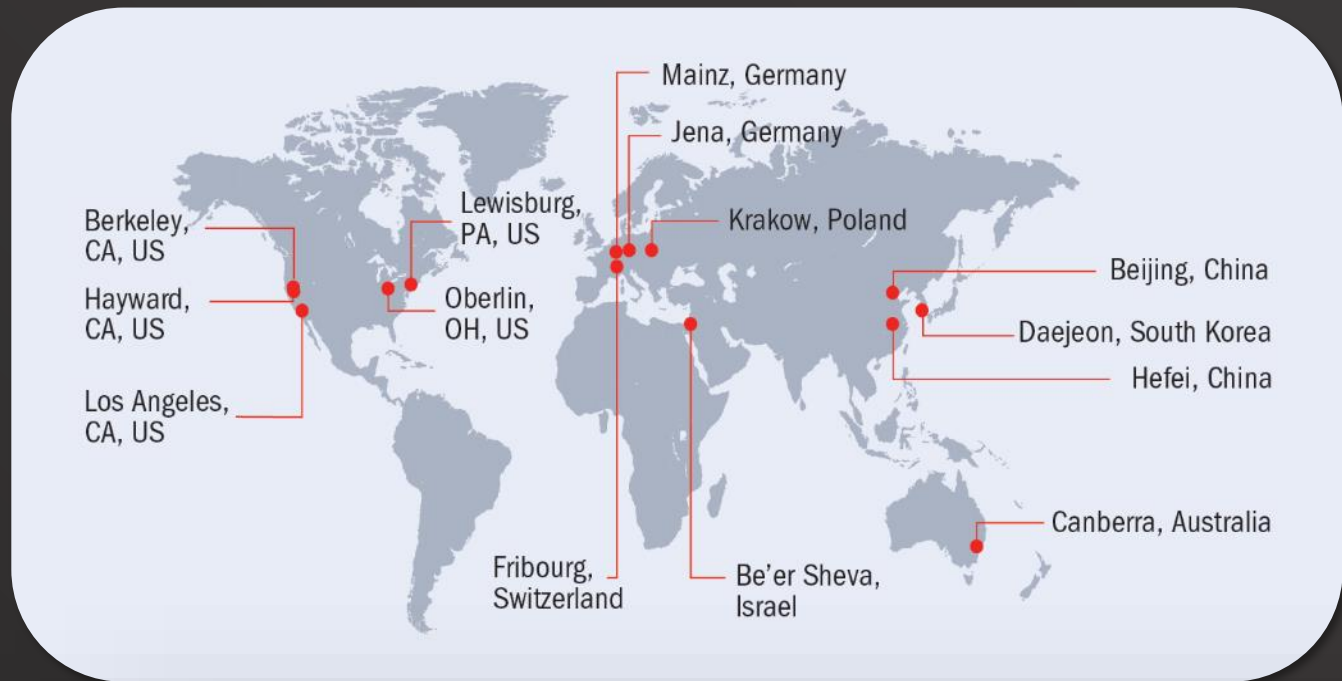
## SIGNAL

Coupling to axion-like field manifests as transients signal in magnetometer readout

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# GLOBAL NETWORK OF OPTICAL MAGNETOMETERS FOR EXOTIC PHYSICS SEARCHES



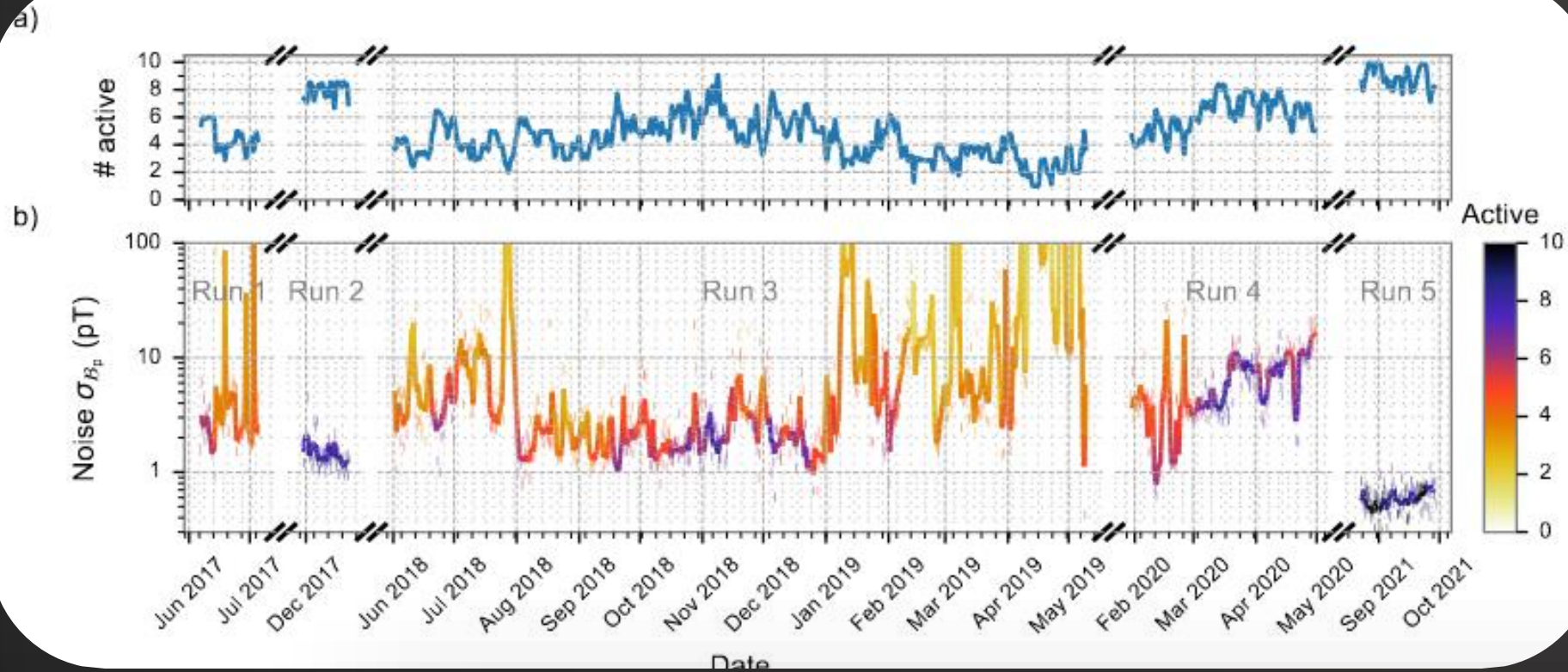
## GNOME

Global network of synchronized, magnetically-shielded optical magnetometers

## FEATURES

- Noise rejection
- Enhance sensitivity
- Triangulation
- Better coverage

# GNOME RUNS



Physics of Dark Universe  
28, 100494 (2020).

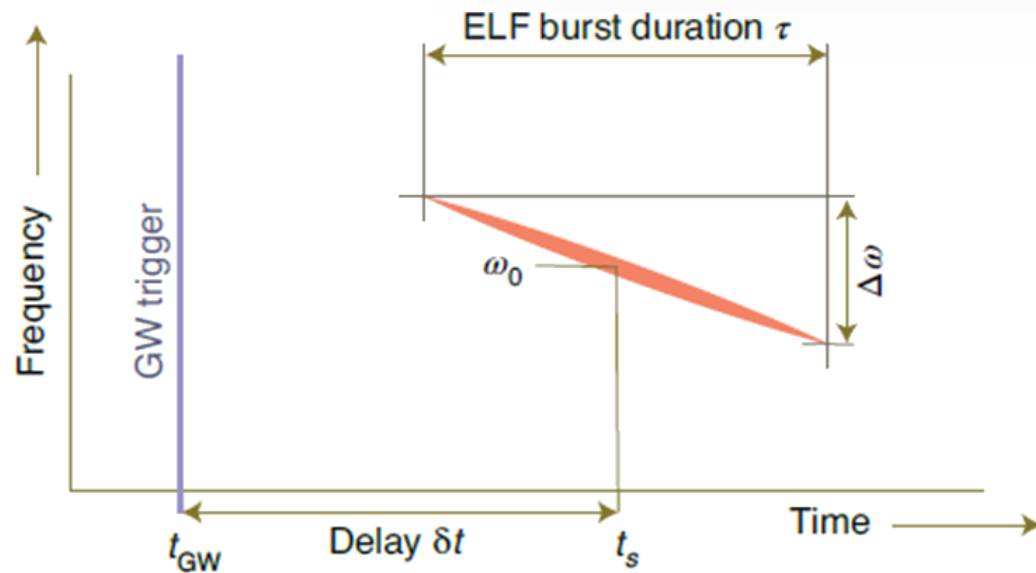
## SIGNALS

- 18 months of data
- Sensitivity 100 fT – 100 pT

# SEARCHES FOR CORRELATIONS

## EXOTIC SIGNALS

- Heralded with conventional signals
  - Specific spectroscopic signature
- 



## SIGNALS

- Energy emitted during event:  $m_s c^2$
  - Number of particles emitted during the event:  $10^{70}$  particles with  $10^{-12}$  eV/ $c^2$
  - Current reach:
    - 100 ly for linear coupling
    - 100,000 ly for quadratic coupling
  - Angular view:  $4\pi$
- 

Nature Physics 17,  
1396–1491 (2021).

## NULL RESULTS

Until now none of the gravitational-wave flagged regions (~10 event) showed any statistically significant signals

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# OUTLINE & QUESTIONS

## FUTURE PLANS

- Experimental
    - Next run (>3 months) scheduled since March 2023
    - 100-fold increase in the reach (next run)
    - More stations running
  - Theory
    - Analysis of several clumpy and wavy dark matter
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ARE THERE OTHER SCHEMES TO USE UTC-TIME STAMPED GNOME DATA FOR MULTIMESSANGER ASTRONOMY?

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Derek F. Jackson Kimball  
Karl van Bibber *Editors*

## The Search for Ultralight Bosonic Dark Matter

OPEN ACCESS

 Springer

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