Results and Prospects: Search for Axion-like Domain Walls with the Global Network of Optical Magnetometers for Exotic physics searches (GNOME)

Hector Masia Roig for the GNOME collaboration

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

HELMHOLTZ Helmholtz-Institut Mainz

Contents

- Current GNOME
  - Principle
  - Network
  - Performance
- Dark matter search
  - Domain walls
  - ALP Constraints
  - Improvements

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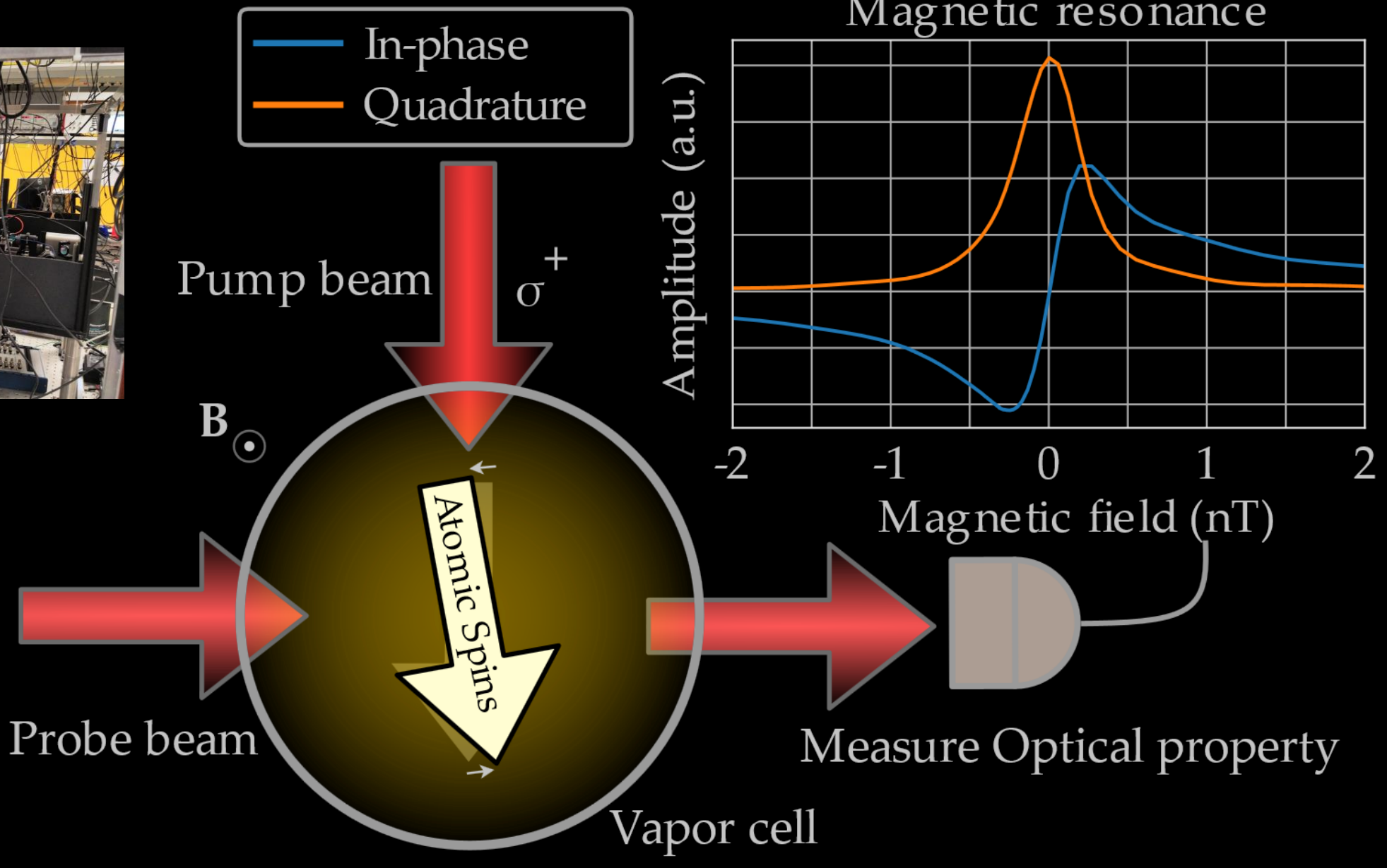
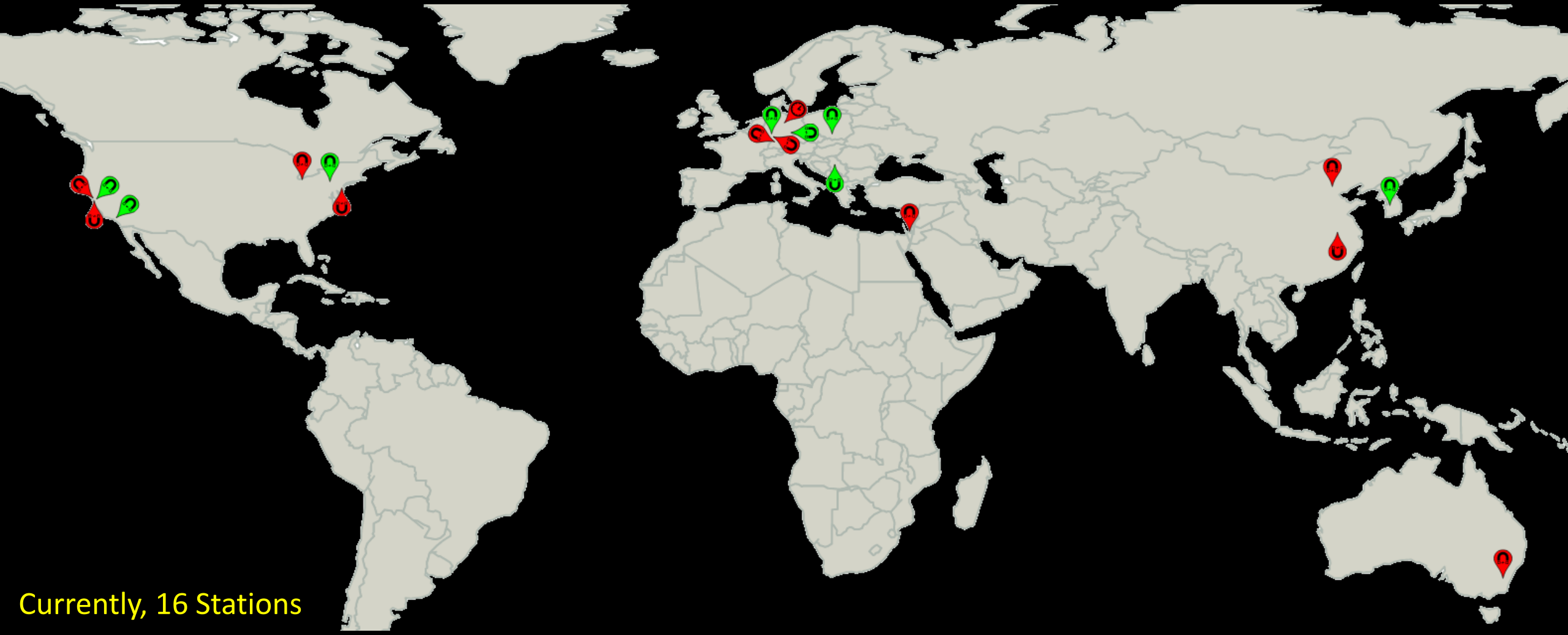
An Optical magnetometer



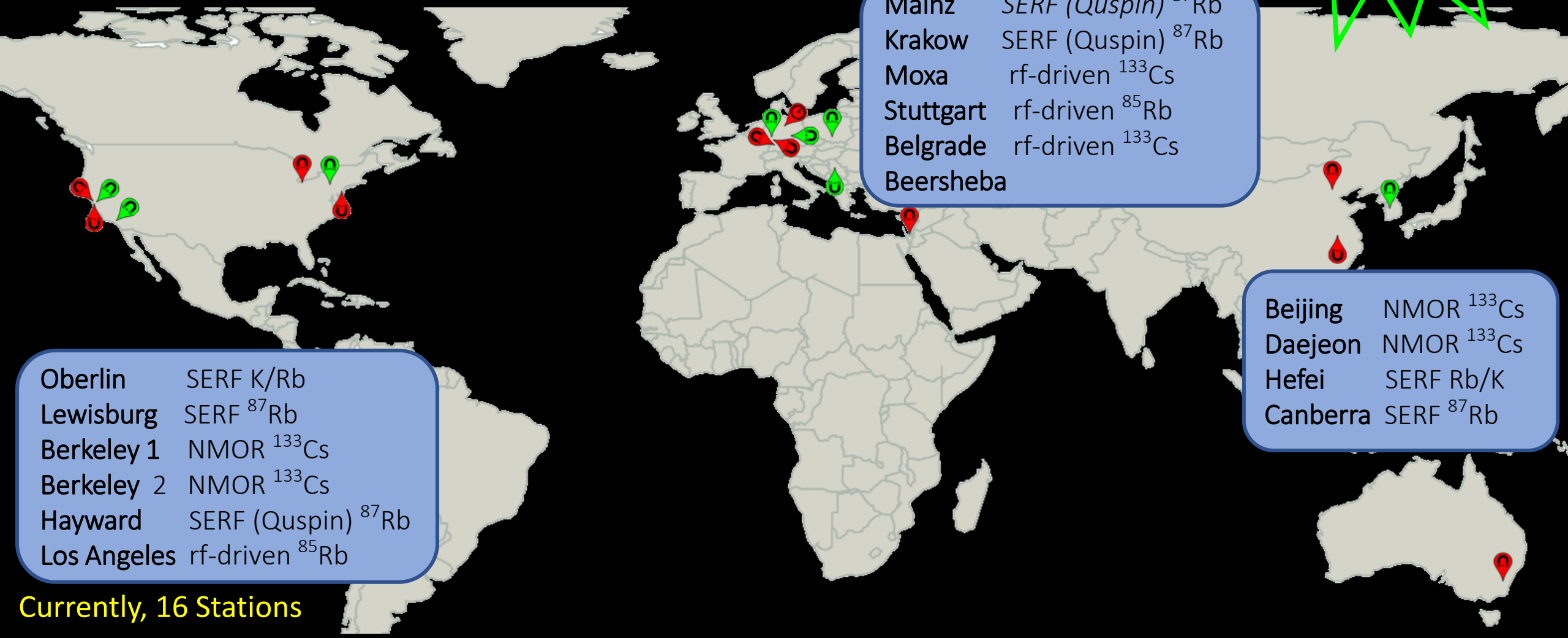
The Global Network of Optical Magnetometers for Exotic physics



Currently, 16 Stations

The Global Network of Optical Magnetometers for Exotic physics

Science Run 5



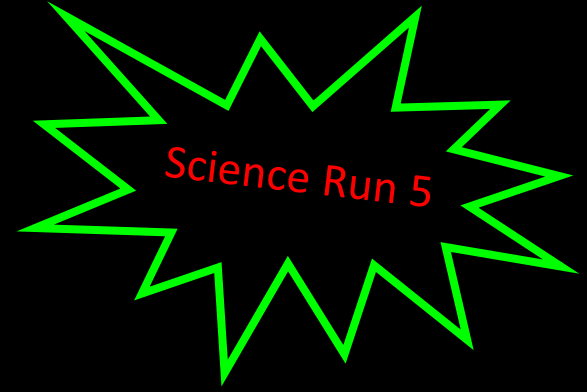
Mainz	*SERF (Quspin)* ^{87}Rb
Krakow	SERF (Quspin) ^{87}Rb
Moxa	rf-driven ^{133}Cs
Stuttgart	rf-driven ^{85}Rb
Belgrade	rf-driven ^{133}Cs
Beersheba	

Beijing	NMOR ^{133}Cs
Daejeon	NMOR ^{133}Cs
Hefei	SERF Rb/K
Canberra	SERF ^{87}Rb

Oberlin	SERF K/Rb
Lewisburg	SERF ^{87}Rb
Berkeley 1	NMOR ^{133}Cs
Berkeley 2	NMOR ^{133}Cs
Hayward	SERF (Quspin) ^{87}Rb
Los Angeles	rf-driven ^{85}Rb

Currently, 16 Stations

The Global Network of Optical Magnetometers for Exotic physics



Interlock System

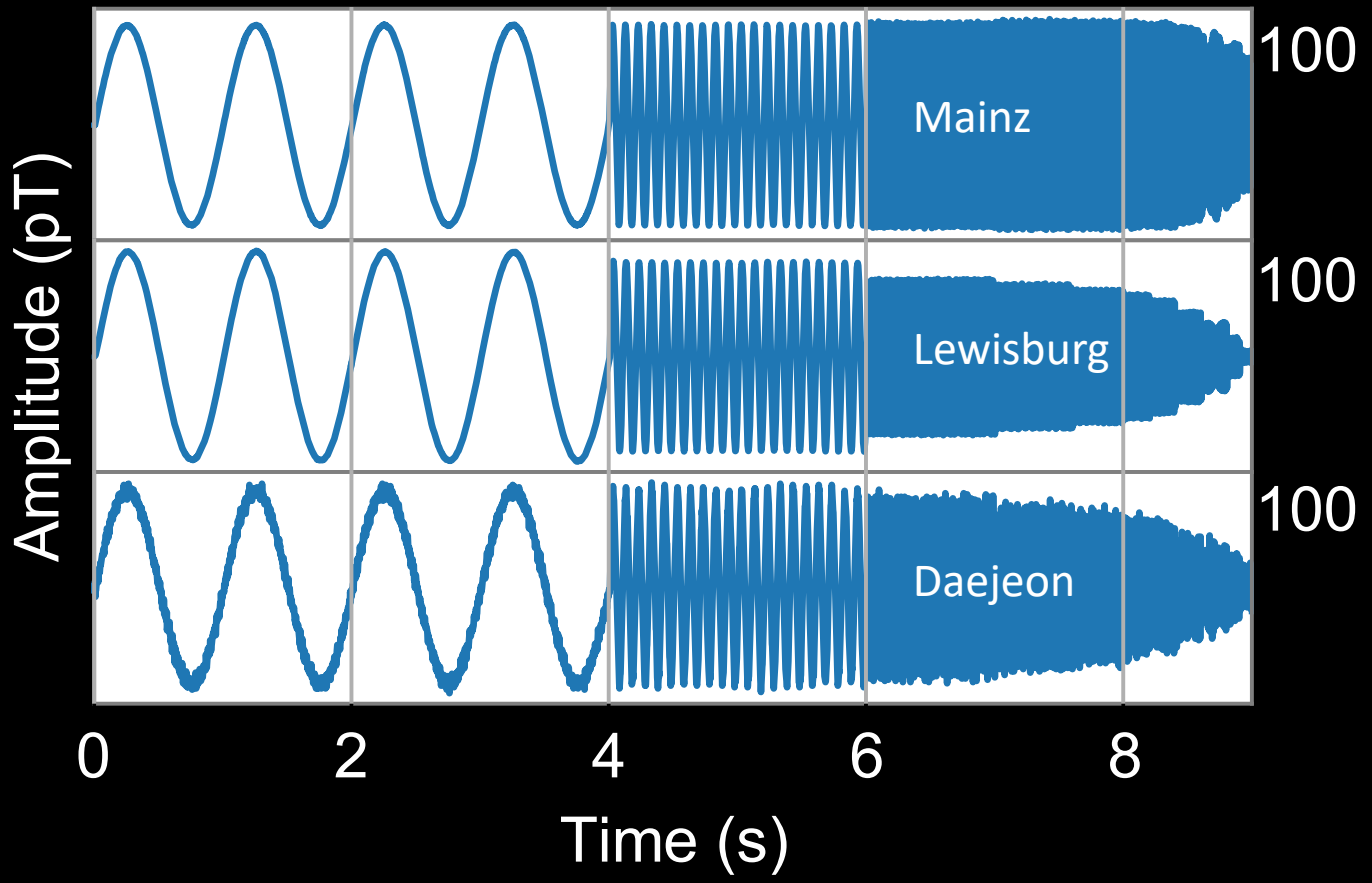
S. Afach et. al., Physics of the Dark Universe, 22, 2018, 162-180

The Global Network of Optical Magnetometers for Exotic physics

Science Run 5

Interlock System

Calibration Pulses



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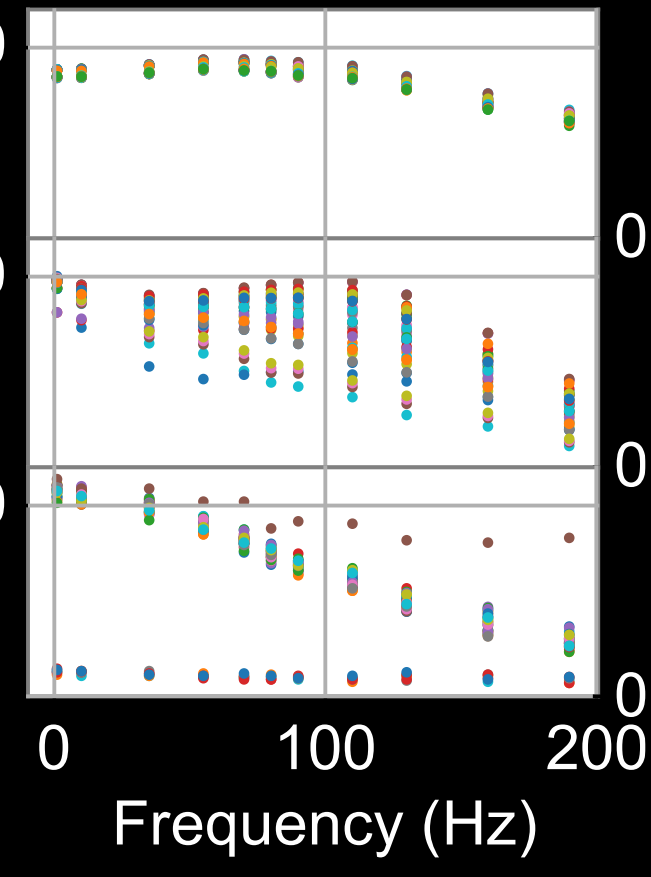
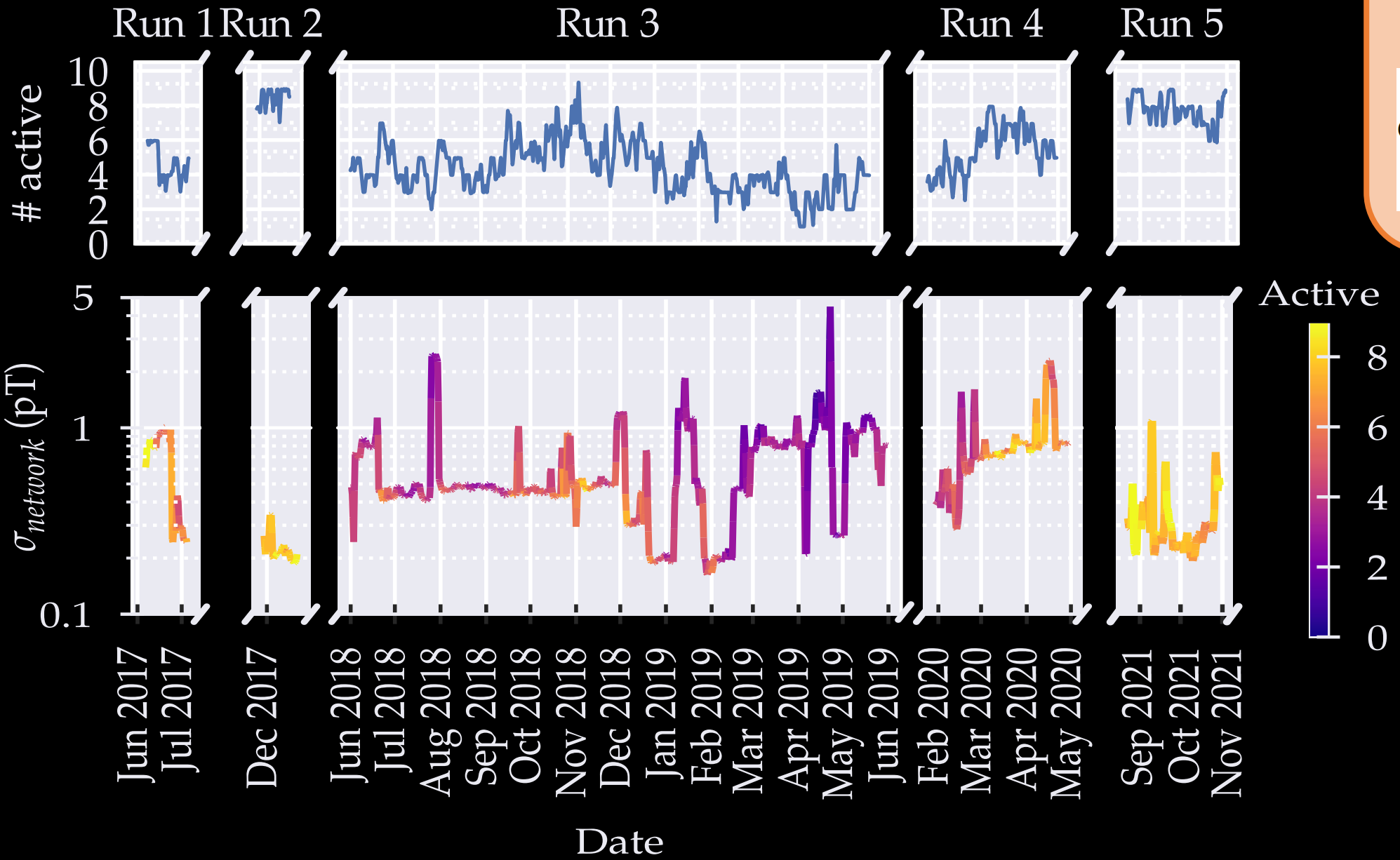


The Global Network of Optical Magnetometers for Exotic physics

Science Run 5

Active times

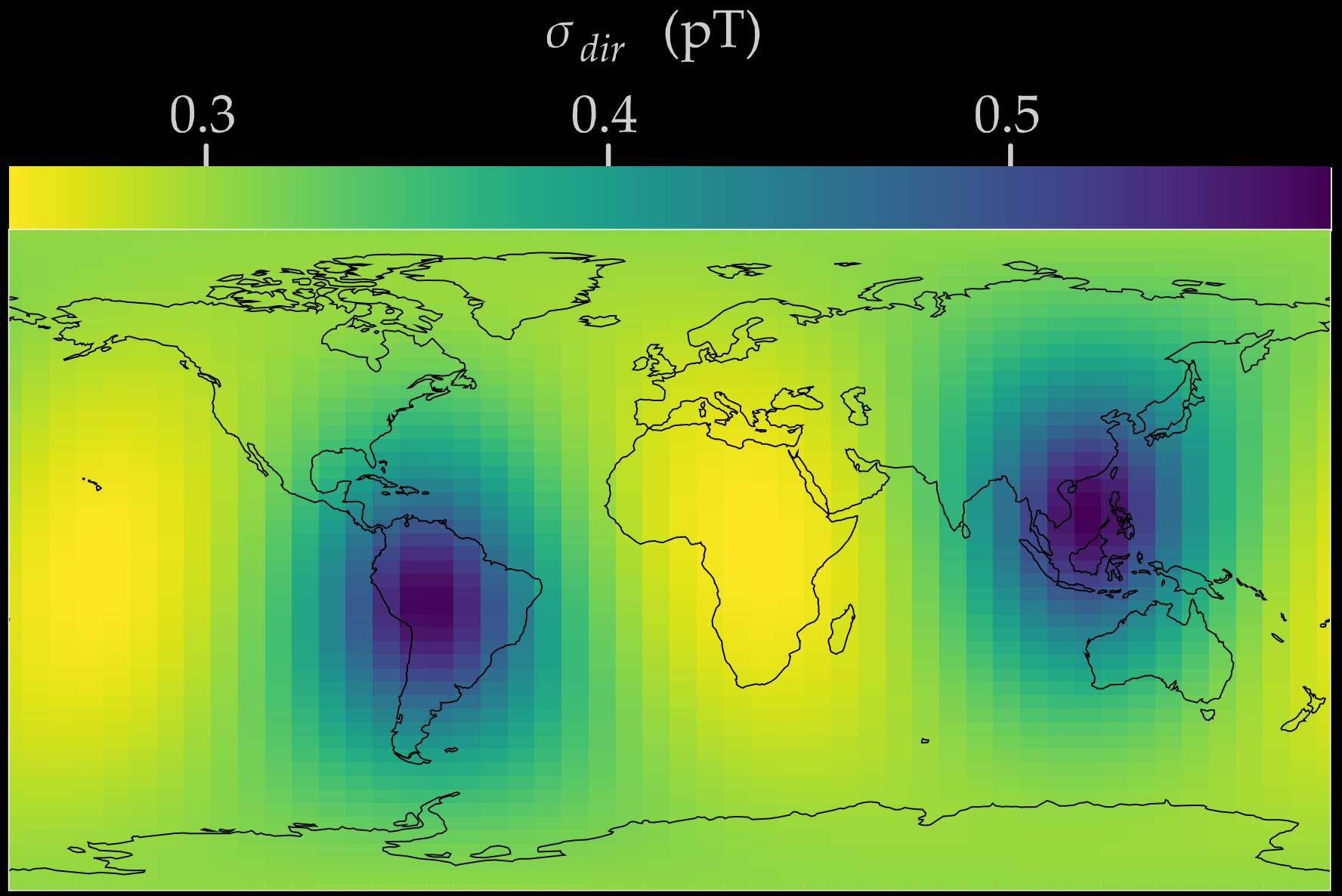
Sensitivity and Duty time



Simple Sensitivity Evaluation

$$\sigma_{\text{network}} = \sqrt{\frac{1}{\sum_j \frac{1}{\sigma_j^2}}}$$

Directional Sensitivity

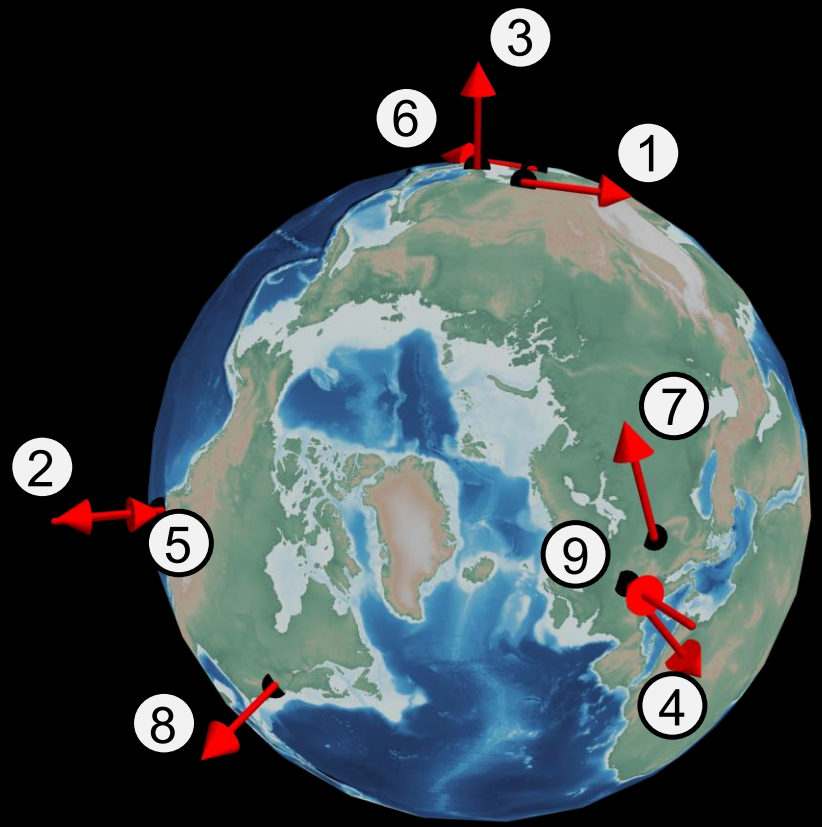


Simple Sensitivity Evaluation

$$\sigma_{\hat{\mathbf{n}}_{dw}} = \sqrt{\frac{1}{\sum_j \frac{(\hat{\mathbf{n}}_{dw} \cdot \hat{\mathbf{n}}_j)^2}{\bar{\sigma}_j^2}}}$$

Dark Matter Search: Domain Walls

Science Run 2



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6. Hefei, China
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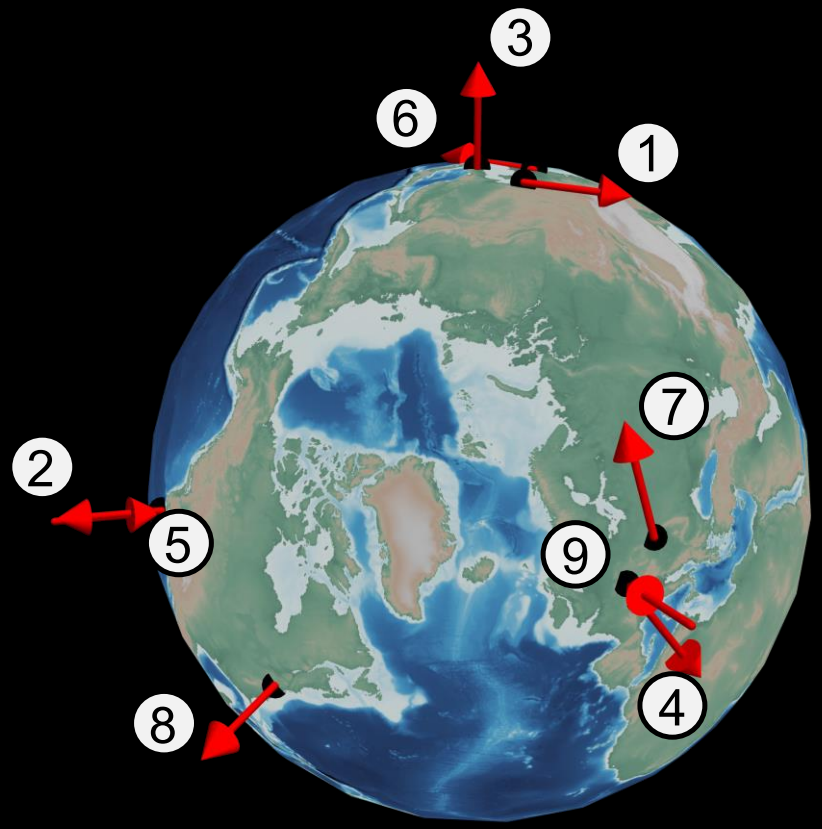
9. Mainz, Germany

S. Afach et. al., Physics of the Dark Universe, 22, 2018, 162-180

Dark Matter Search: Domain Walls

Science case



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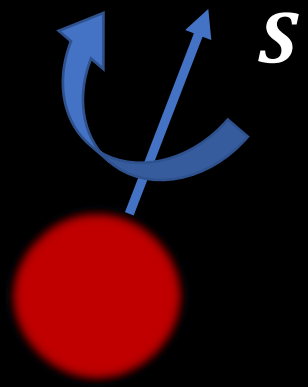
Larmor precession



$$H_{int} \sim \boldsymbol{S} \cdot \boldsymbol{\nabla} a(\boldsymbol{r})$$

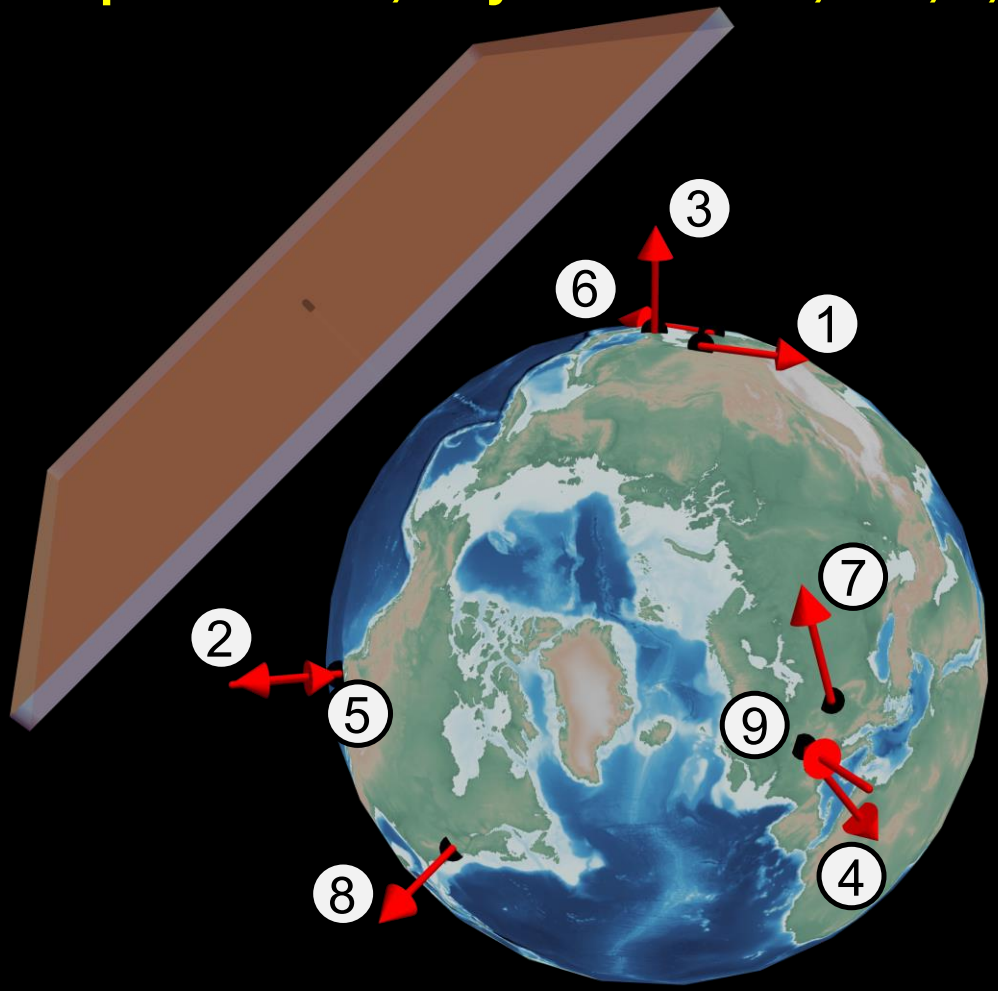
Exotic spin interactions

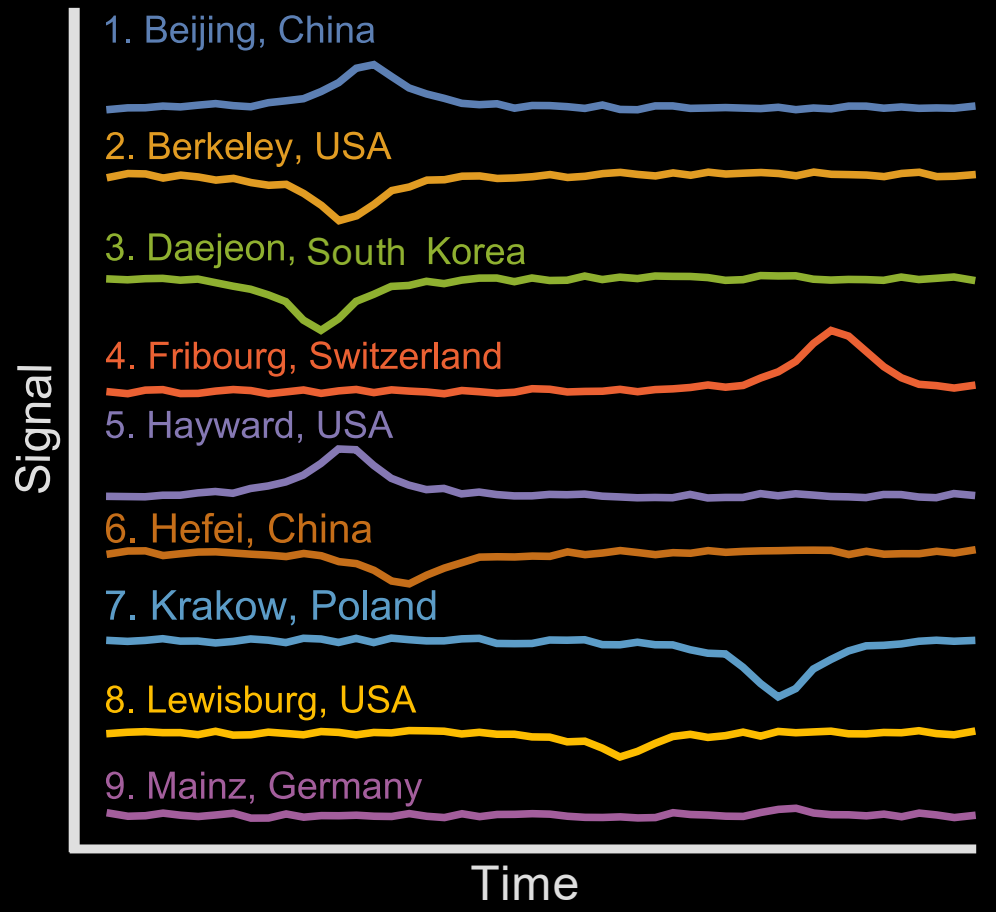
S. Afach et. al., Physics of the Dark Universe, 22, 2018, 162-180

Dark Matter Search: Domain Walls

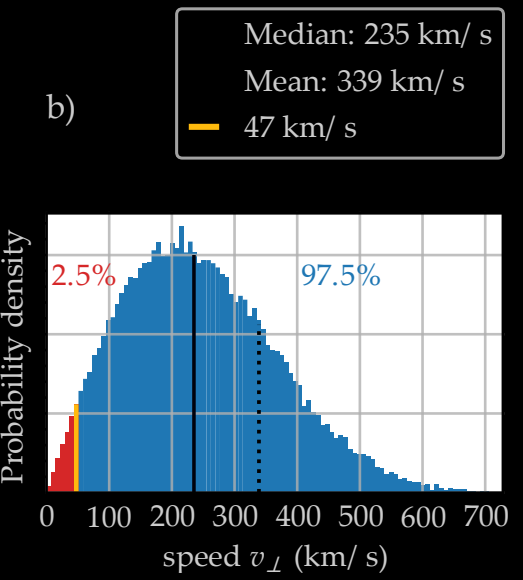
Pospelov et. al., Phys. Rev. Lett., 110, 2, 021803, 2013

$$\Delta t_j = \left(\vec{x}_j - \vec{x}_0\right) \frac{\vec{v_\perp}}{|v_\perp|^2}$$





SHM



H. Masia-Roig, J. A. Smiga et. al.,Physics of the Dark Universe, 28, 10049, 2020

Dark Matter Search: Domain Walls

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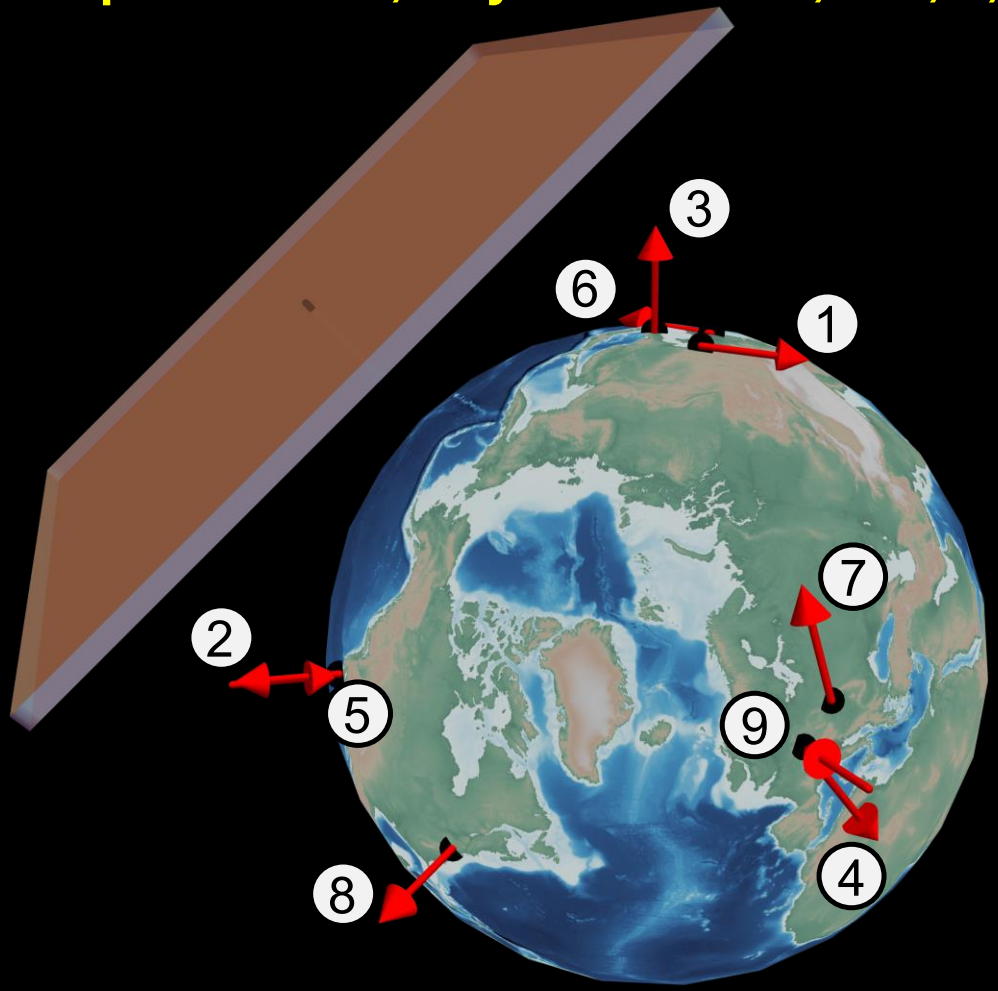
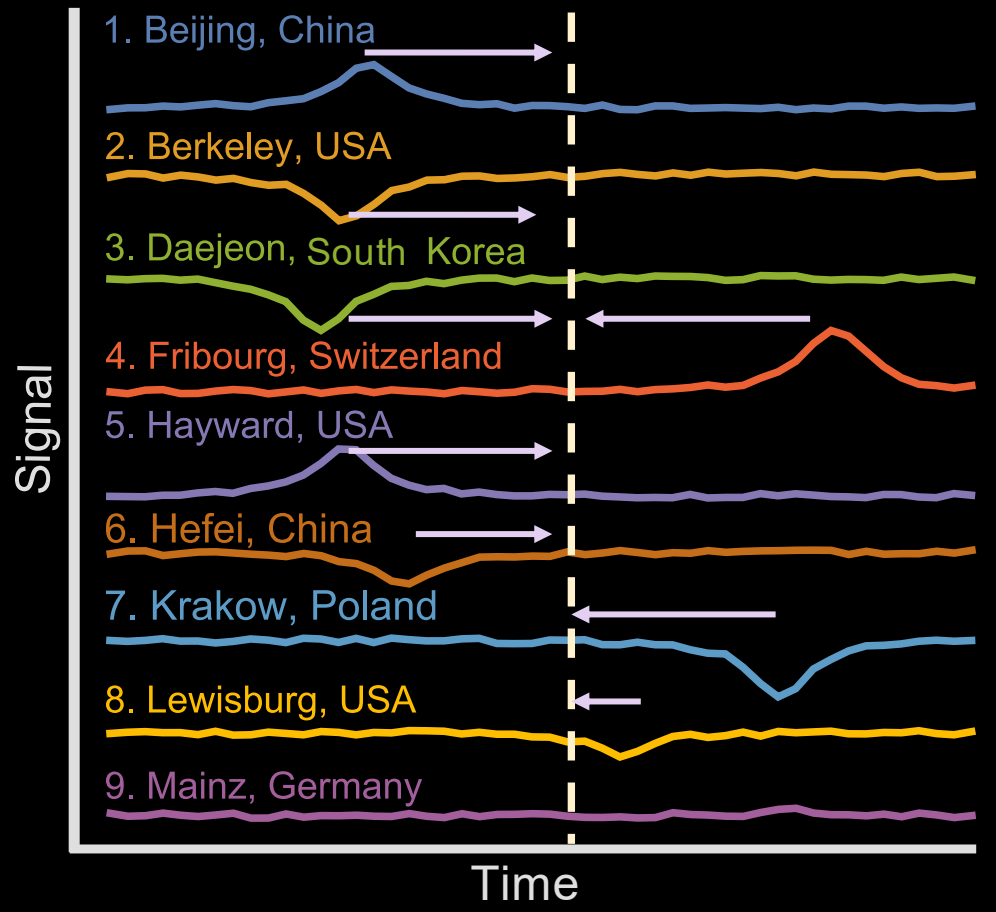
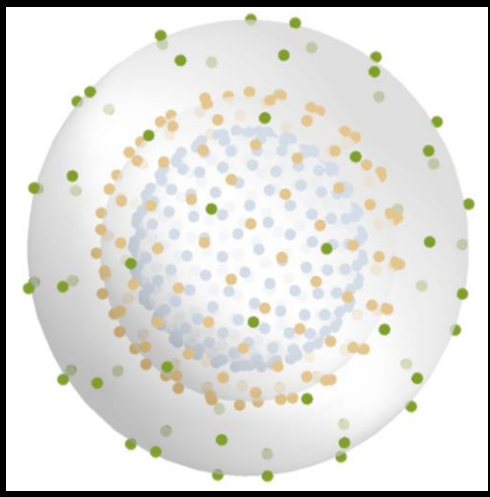




Scan directions



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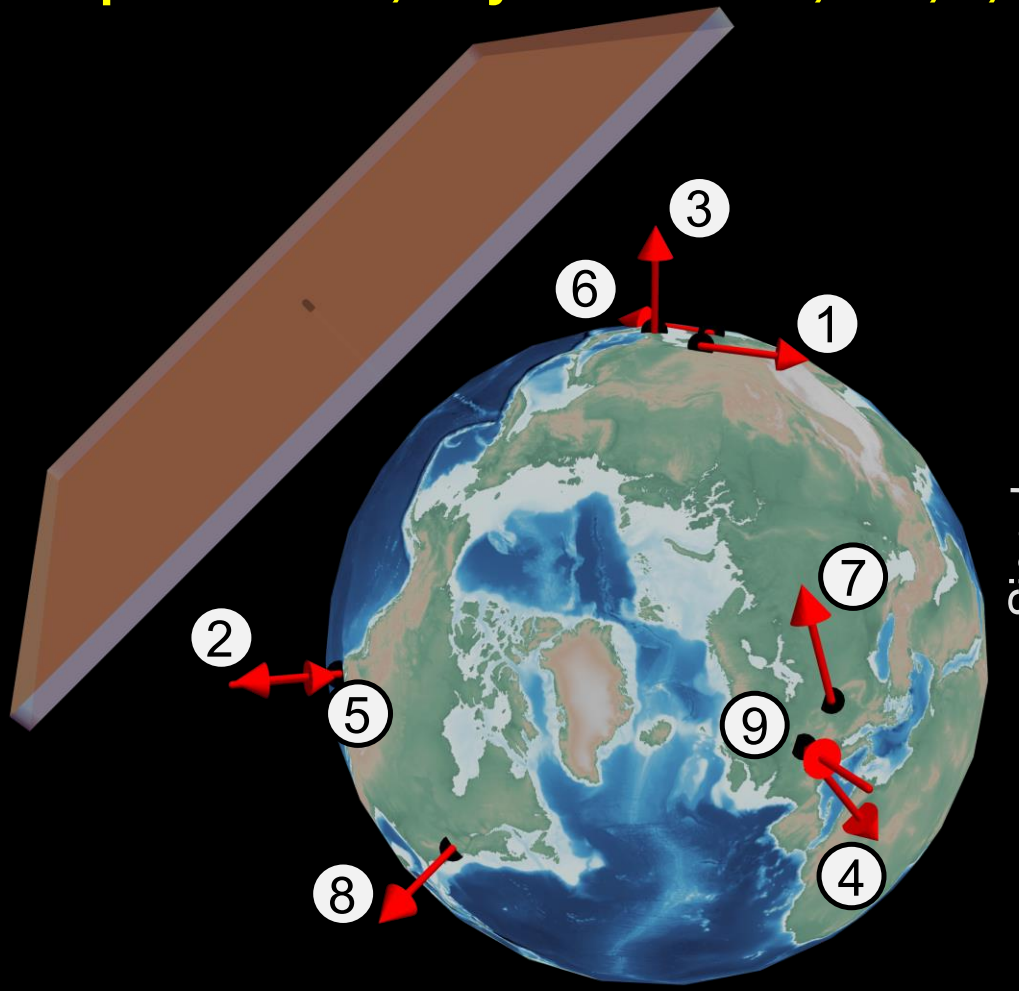
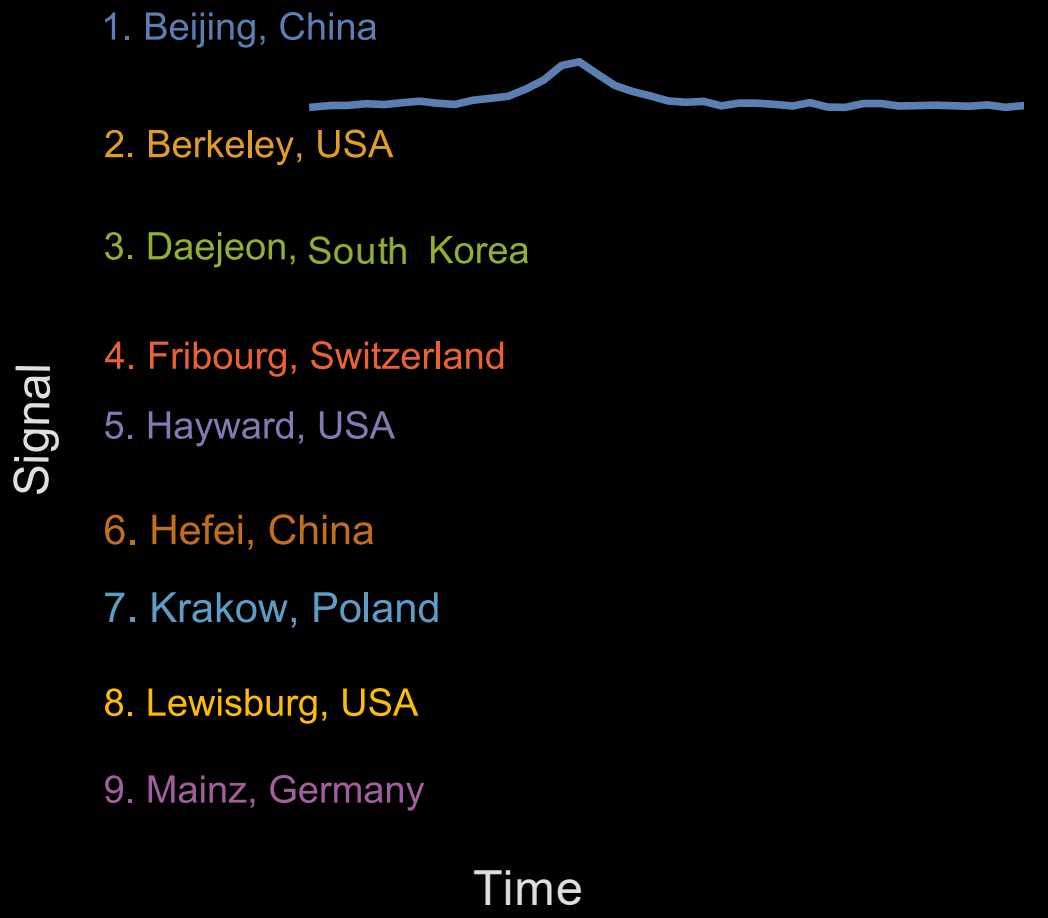
Dark Matter Search: Domain Walls

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

$$D\vec{m} = \vec{s}$$

Network time-series



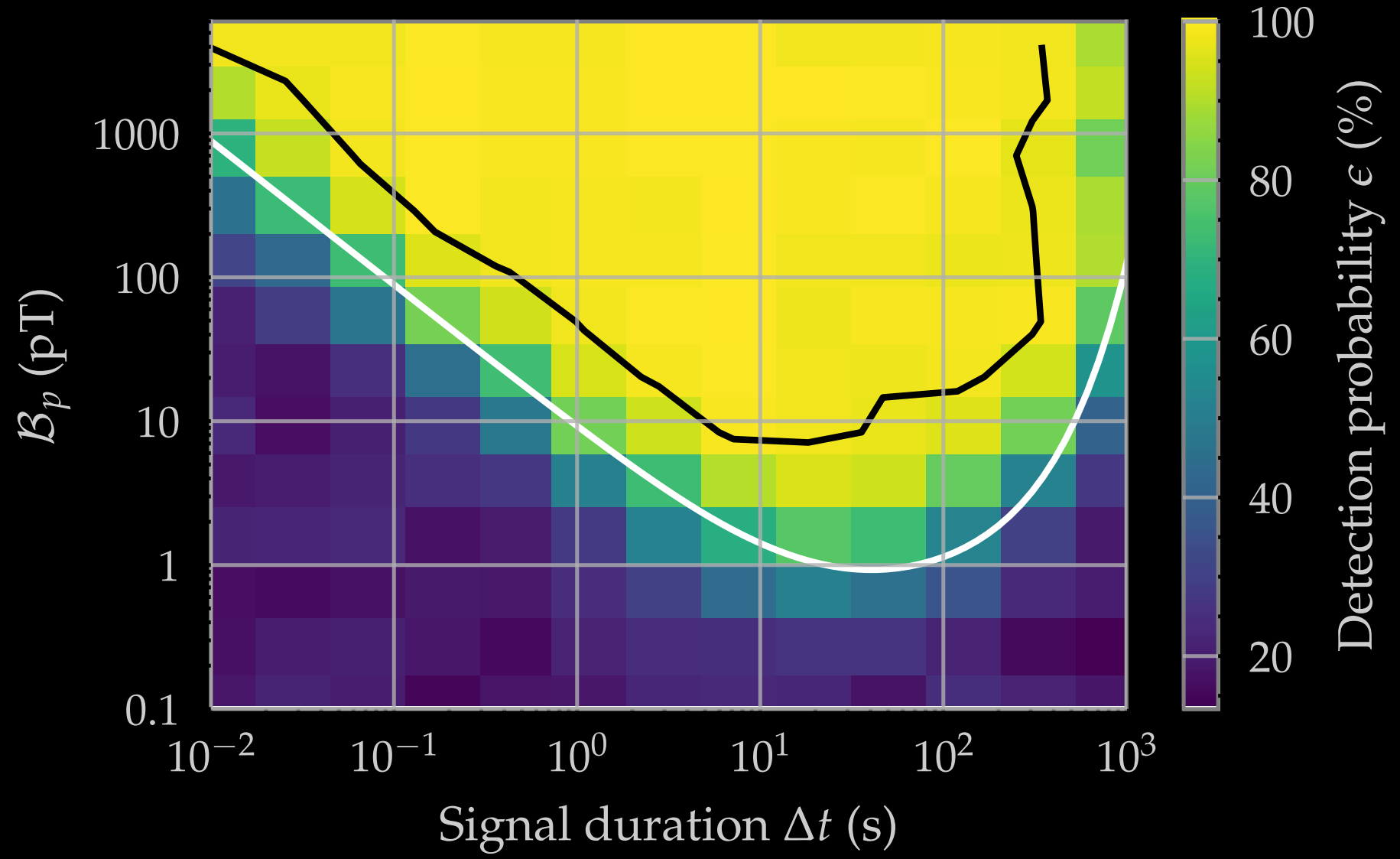


Domain Wall
- Magnitude
- Uncertainty
- Velocity
- p–value

H. Masia-Roig, J. A. Smiga et. al.,Physics of the Dark Universe, 28, 10049, 2020

Dark Matter Search: Domain Walls

Sensitivity

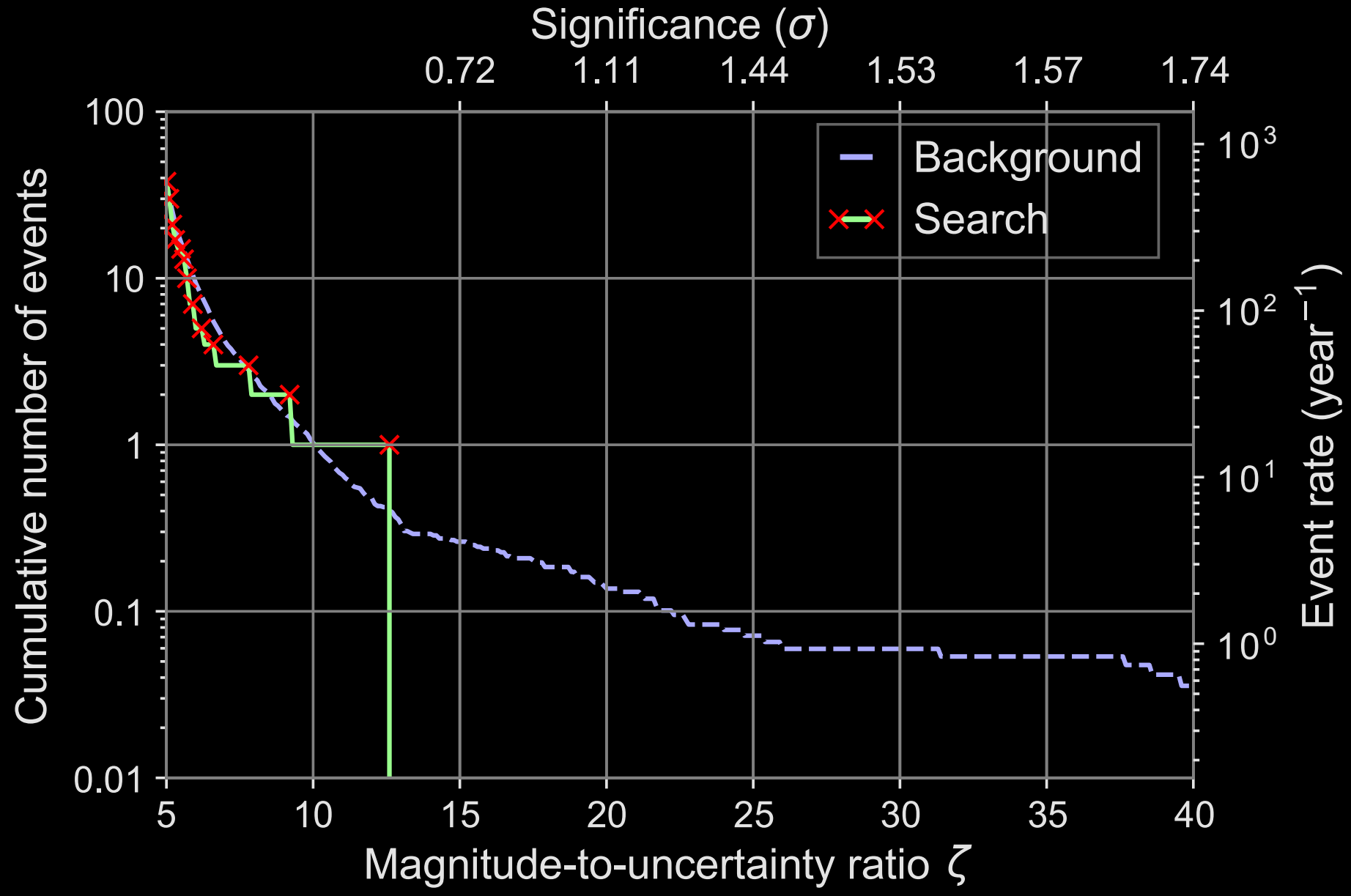


Insertions in Background data

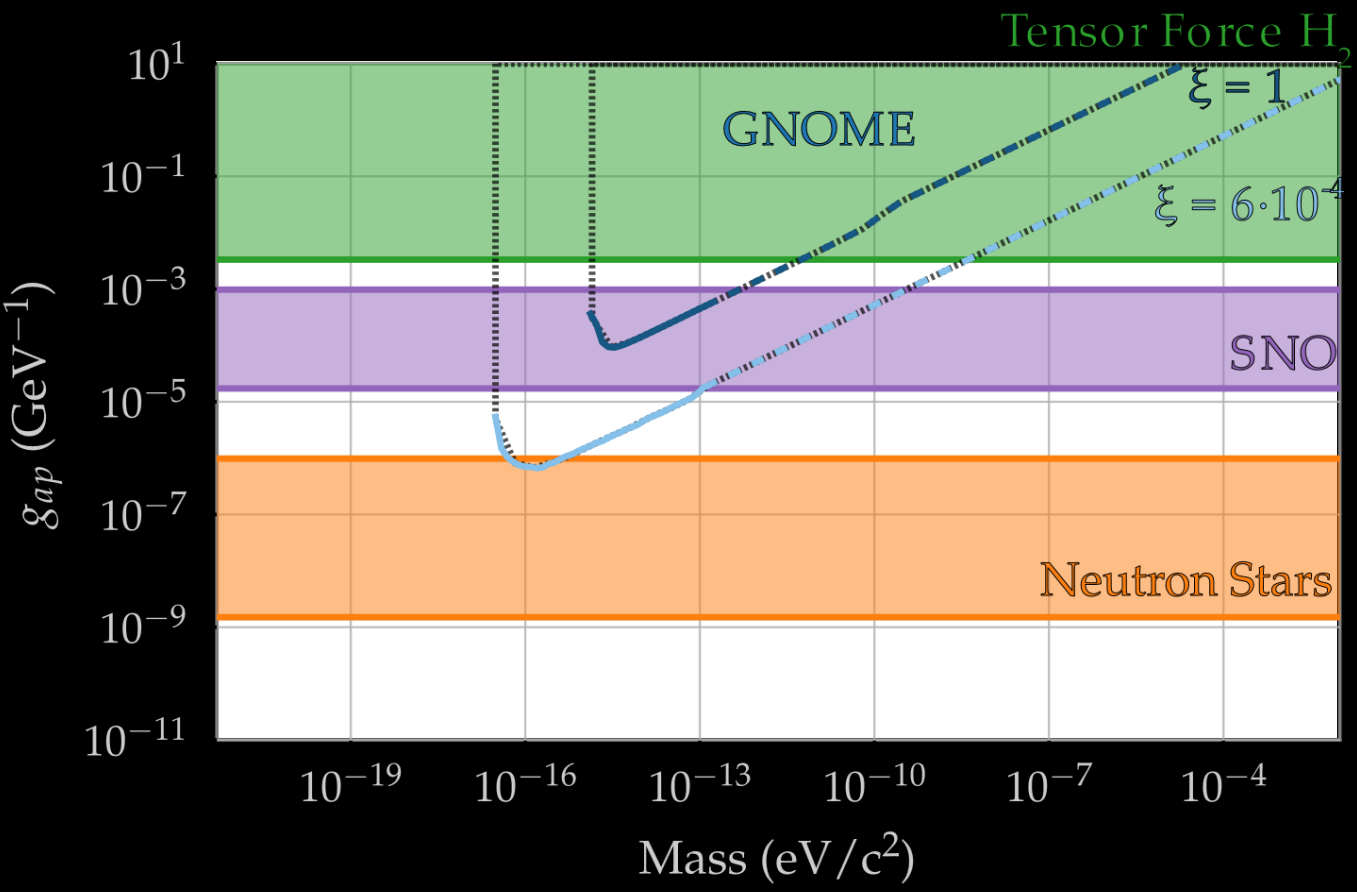
Dark Matter Search: Domain Walls

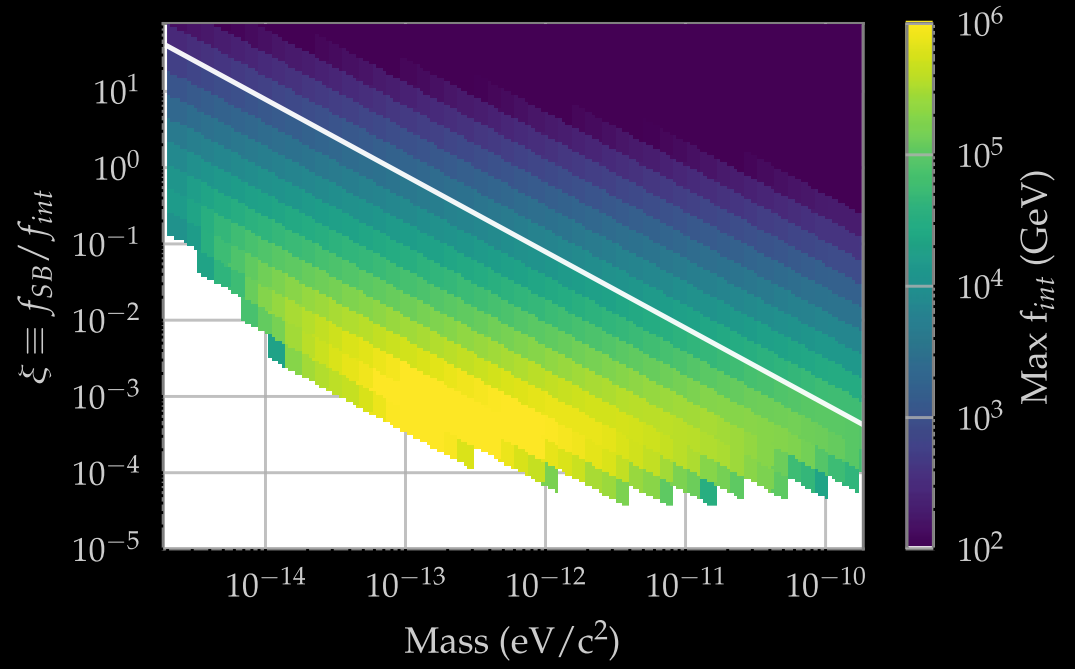
No significant signal found

One month measurement



Dark Matter Search: ALP constraints



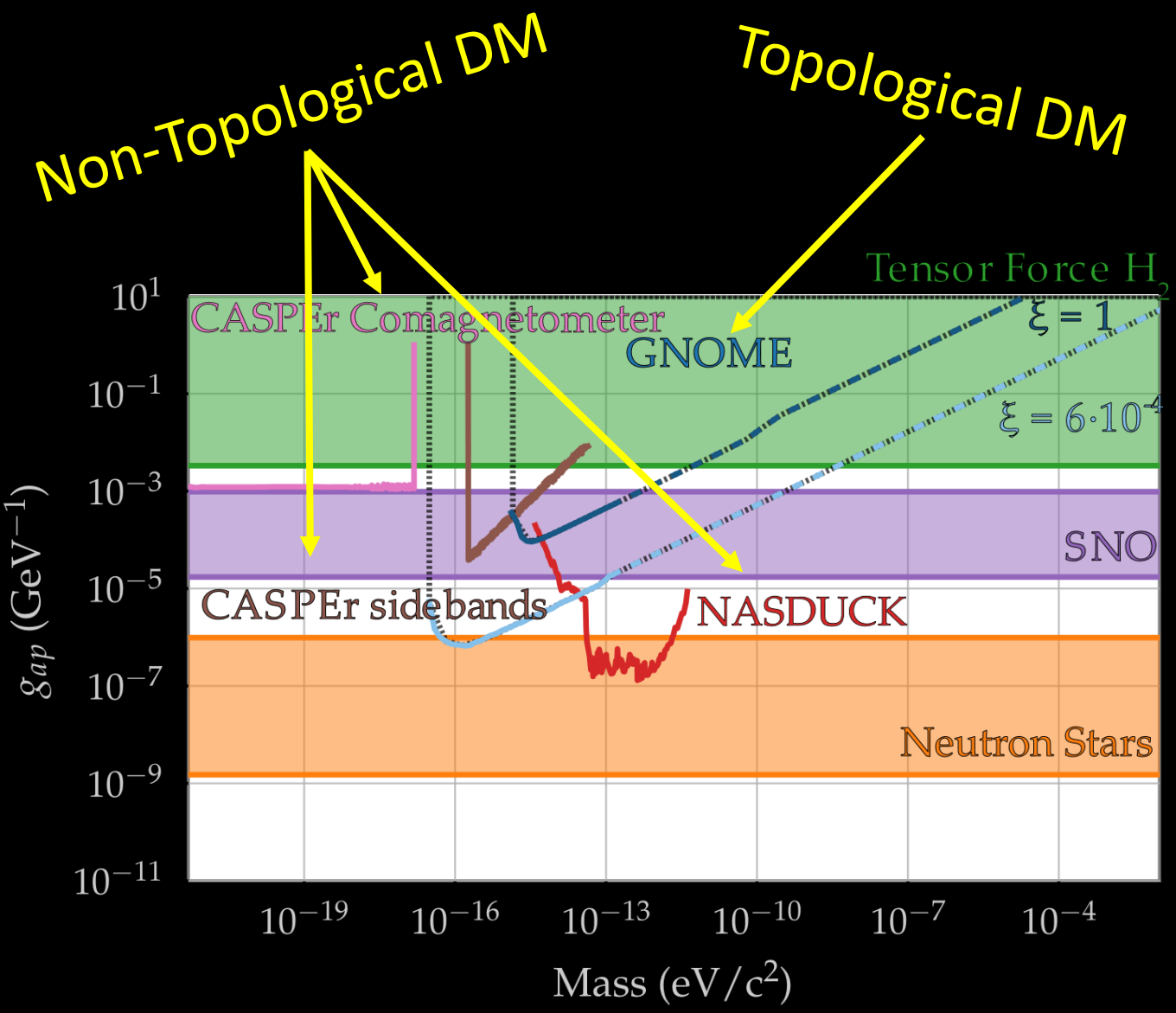


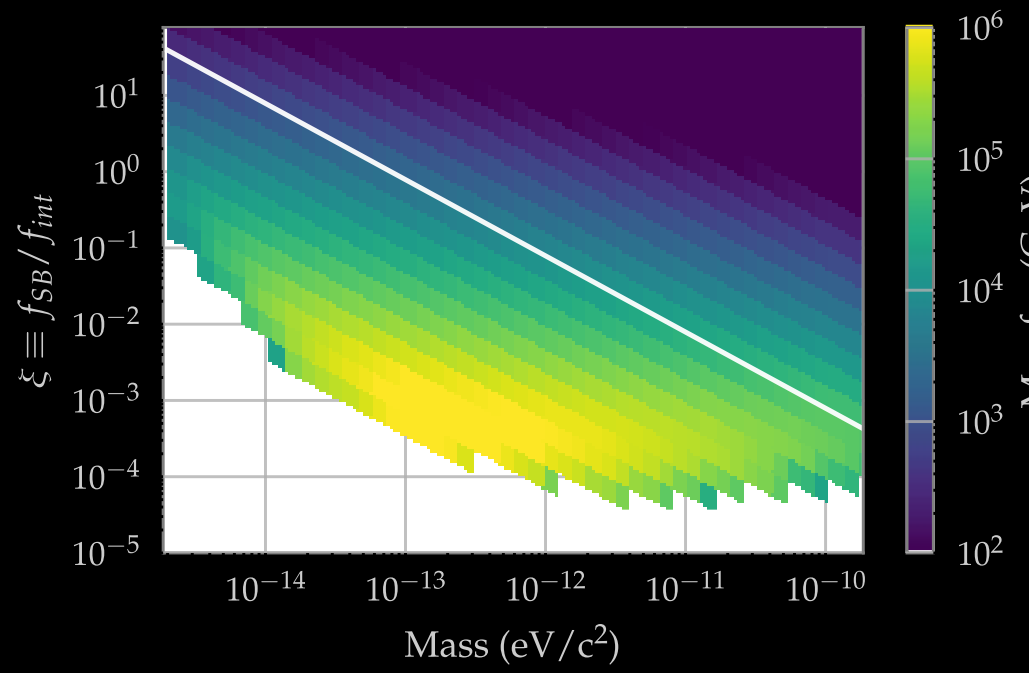
$$f_{int} \leqslant \frac{1}{\xi}\sqrt{\frac{-\bar{\nu}\rho_{DW}T}{8m_a \log(1-C)}}\varepsilon_s \epsilon(\Delta t, \mathcal{B}_p, \zeta)$$

$$\text{for} \quad \Delta t = \frac{2\sqrt{2}}{\bar{\nu} m_a} \quad \text{and} \quad \mathcal{B}_p = \frac{4 m_a \xi}{\mu_B}.$$

Constraints on the ALP field

Dark Matter Search: ALP constraints





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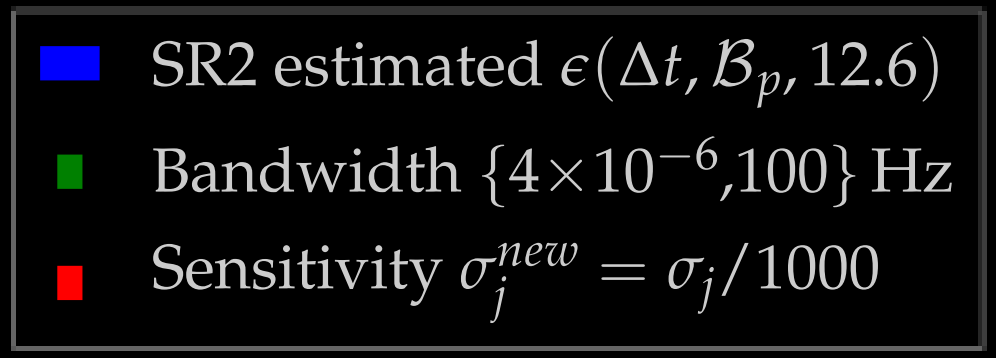
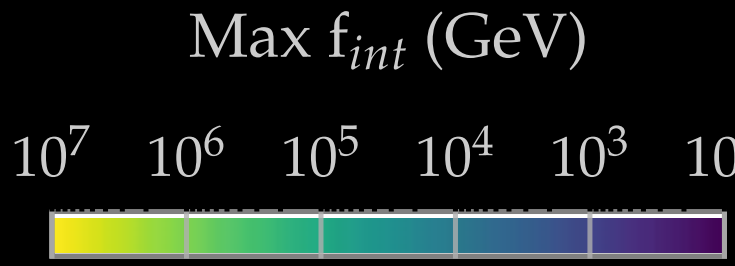
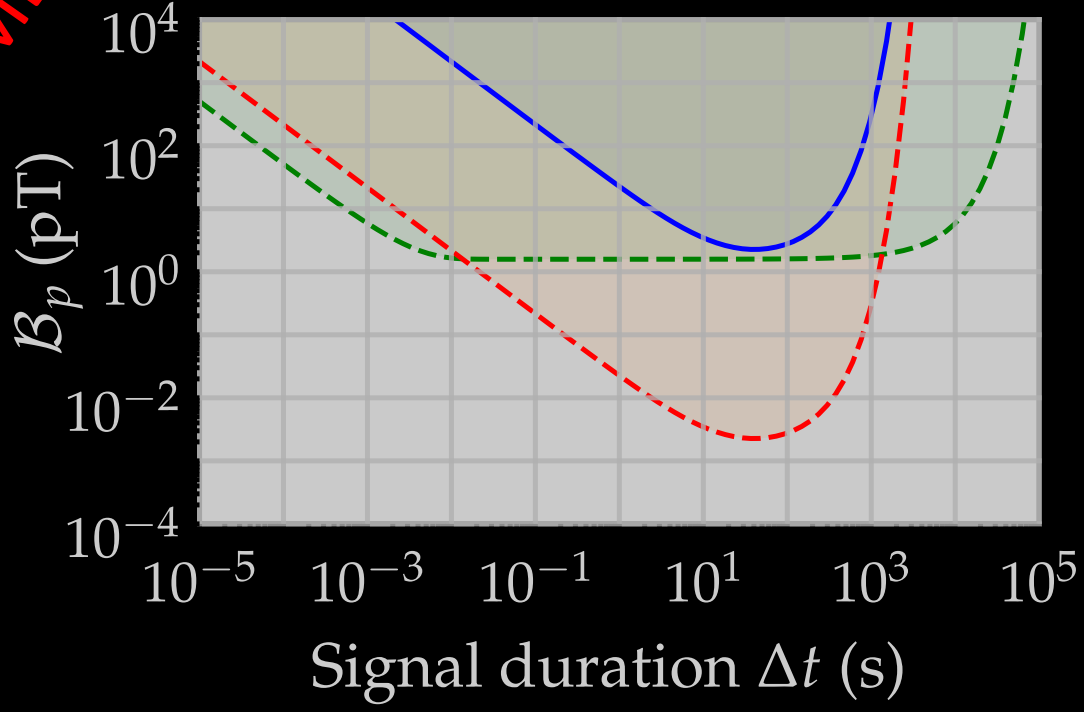
Constraints on the ALP field

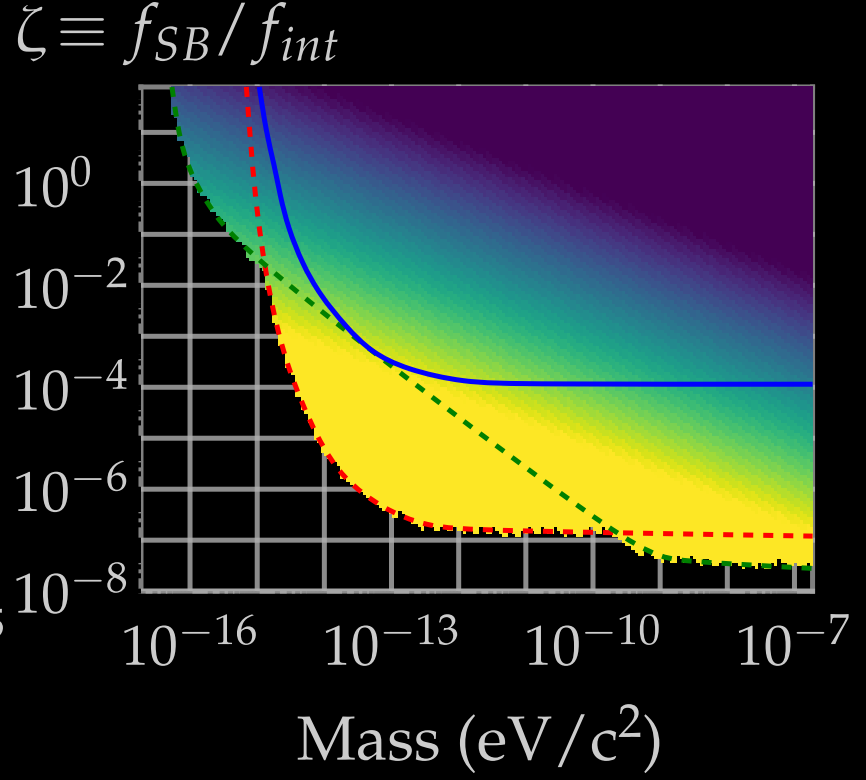
Improvements





Advanced GNOME

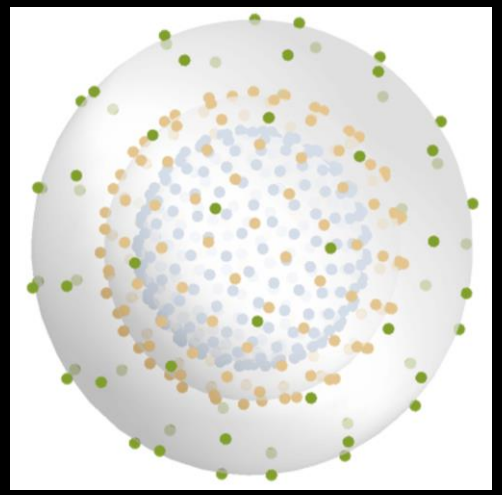




Projections for better sensitivity and bandwidth

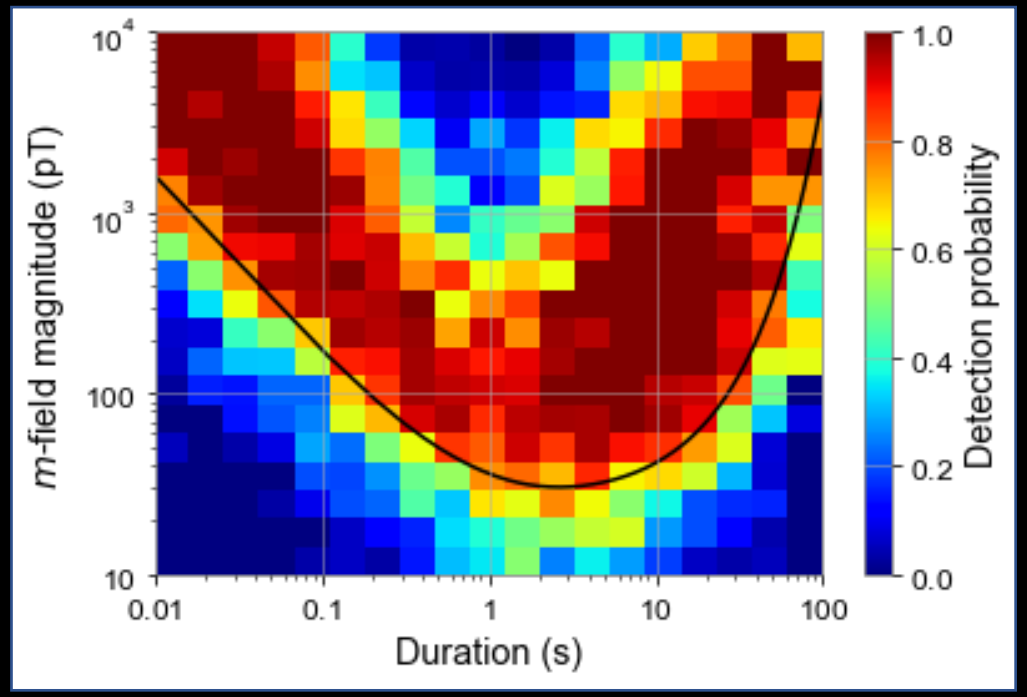
Improvements

Scan directions



$$N \propto \left(\frac{1}{\tau}\right)^4$$

Improve Bandwidth



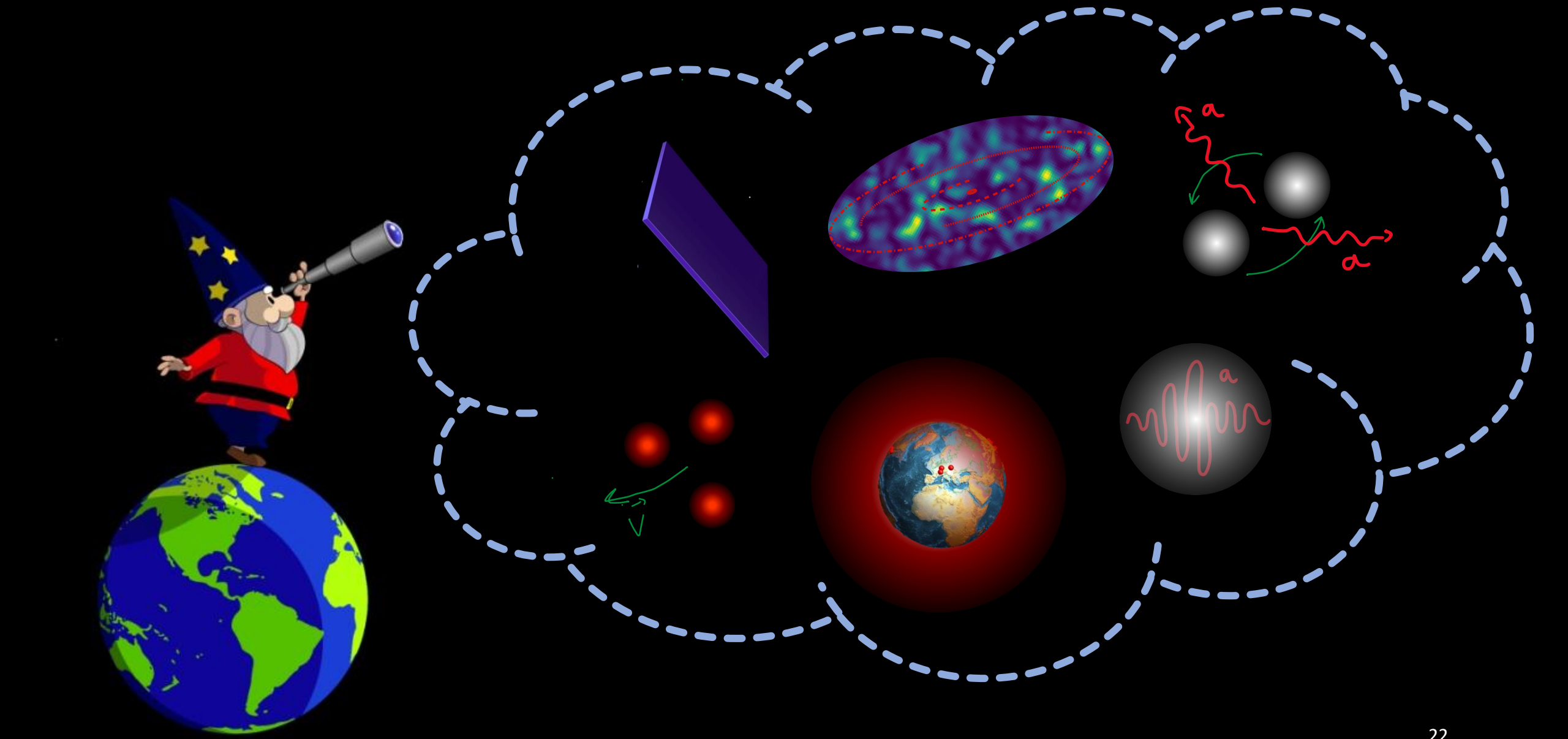
Large Domain walls not detected

Ideas?

- Divide analysis
  - Large magnitude
  - Small magnitude
- Pre-filter events
- Machine Learning algorithm
  - Delay + Amplitude
  - Yordan Raykov
- Move efforts to other searches

Software improvements

GNOME: dark matter cosmology observatory



Thanks for your attention

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

Dark Matter Search

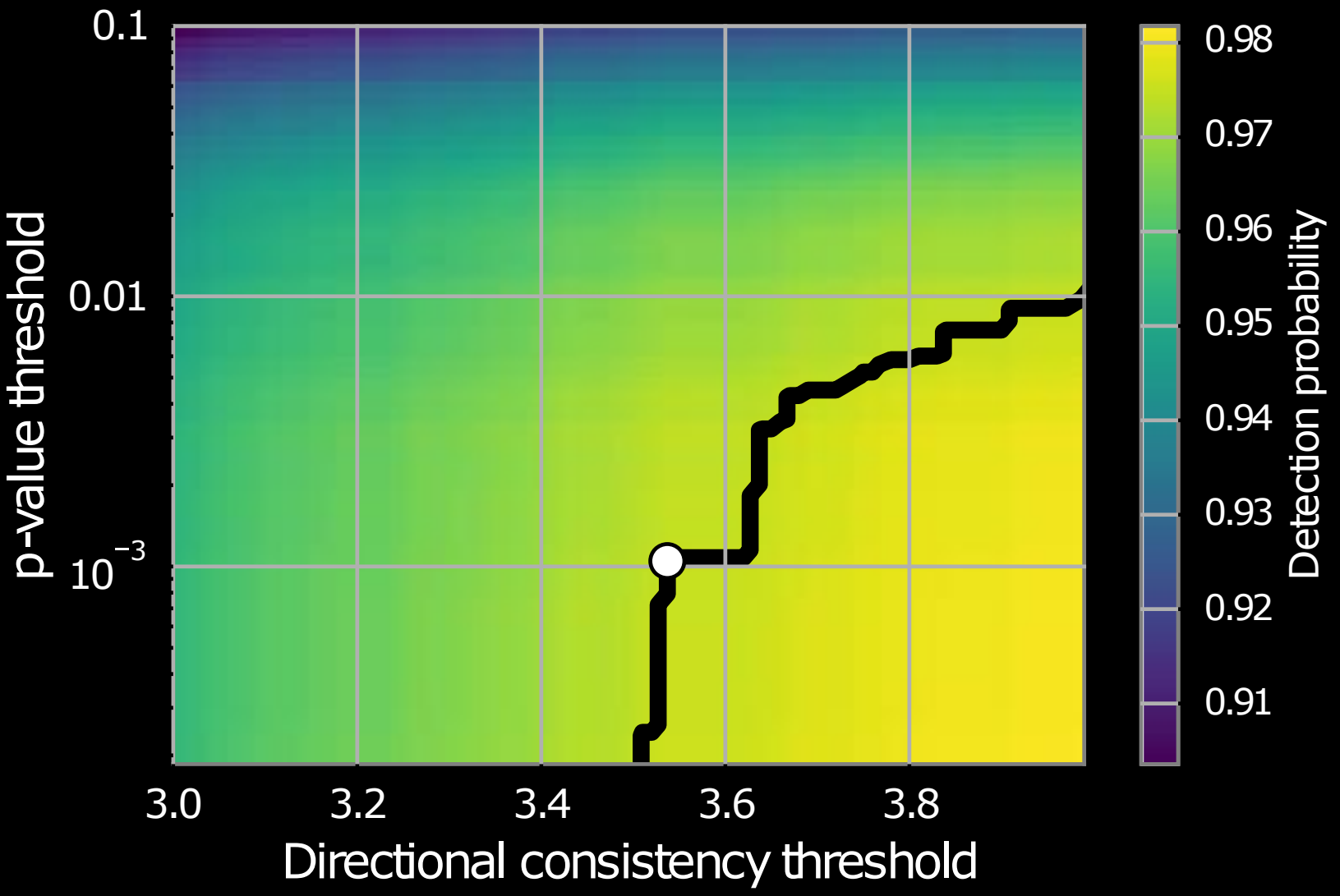
S. Afach et. al., 2021, 2102.13379, arXiv

Calibration

Insert domain walls

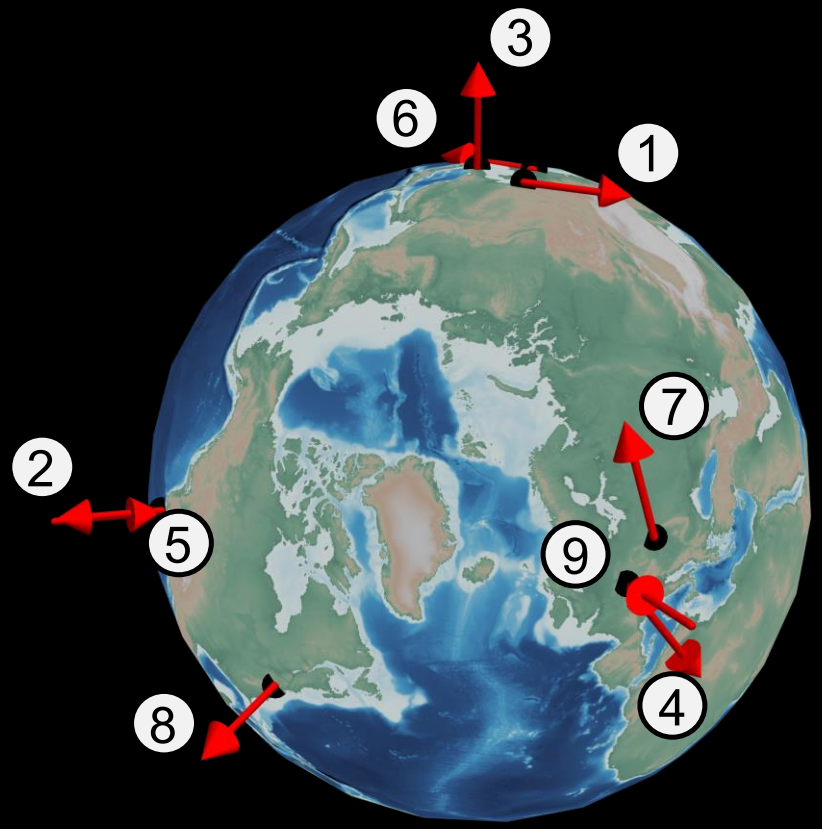
- $0.1 - 10^4$ pT
- $0.01 - 10^3$ s

Scan the detection parameters



Dark Matter Search

Science case



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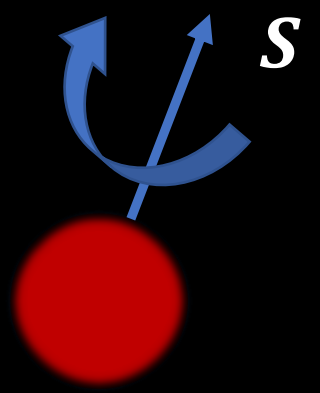
Larmor precession



$$H_{int} \sim \boldsymbol{S} \cdot \boldsymbol{\nabla} a(\boldsymbol{r})$$

Exotic spin interactions

Axion like particles (ALP)

Compact dark Matter objects
- ALP Domain Walls
- ALP Stars

ALP field features
- Burst astrophysics
- Continuous oscillations
- Stochastic behavior

S. Afach et. al., Physics of the Dark Universe, 22, 2018, 162-180