Magnetometers and fundamental physics

A. Wickenbrock, D. Budker

QSNET, NPL, 22.03.2019

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The Cosmic Axion Spin Precession Experiment (CASPEr)

and a bit of GNOME

A. Wickenbrock for the CASPEr and GNOME collaborations

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Helmholtz Institute Mainz

Cooperation between the JGU and GSI

Since 2013
MAM section leader Dmitry Budker

FAIR
Facility for Antiproton and Ion Research in Europe GmbH

6 Sections:
EMP Hadron structure
SPECF Hadron spectroscopy
MAM Matter Antimatter Asymmetry
SHE Super heavy elements
ACID Accelerator design
THFL Theory

MAM
atomic physics branch
=> QUANTUM

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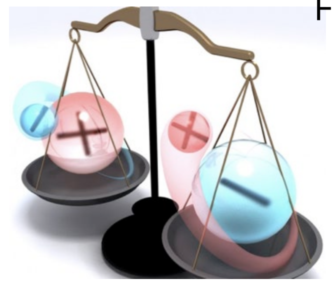
MAM research directions

HELMHOLTZ
Helmholtz Institute Mainz

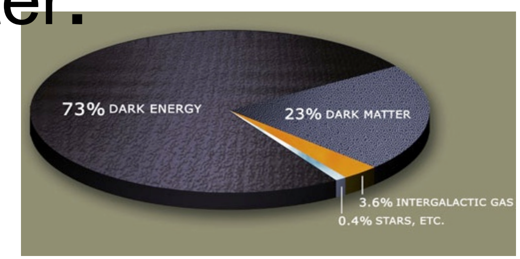
- Determining fundamental properties of matter and antimatter
  - Atomic-transition energies (e.g., expt vs theory in He and $\overline{p}$-He)
  - **Magnetic moments** ($\overline{p}$ vs p)
  - Gravity ($\overline{H}$ vs H)
  - *Novel experiments with $\overline{p}$: Antimatter on a chip (AMOC)*

Ficek et al., Phys. Rev. Lett. **120,**183002 May 2018



- Testing fundamental symmetries (P, T, CP, CPT, Lorentz Invariance, Equivalence, variation of "constants"…)
  Ytterbium, Dysprosium, **TACTICA**

- Searching for constitutents of Dark Matter:
  Axions, ALPs, Dark photons, Dilatons,…
  CASPEr, GNOME, Dysprosium…



- Developing enabling techniques & instruments
  - Precision magnetometry
  - Nuclear hyperpolarization, NMR
  - Targets/magnetometry for GSI/FAIR

QUTEGA
Quantentechnologie – Grundlagen und Anwendungen

European Commission

Ultrahigh-precision test of CPT via magn… nparison of p

Proton

3.3pbb!

0.3pbb!

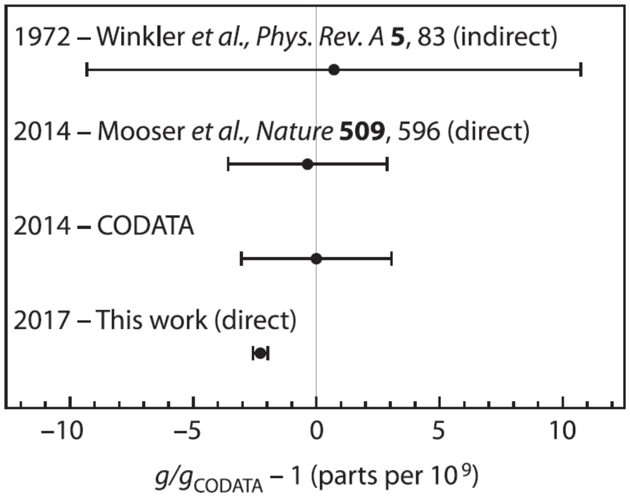
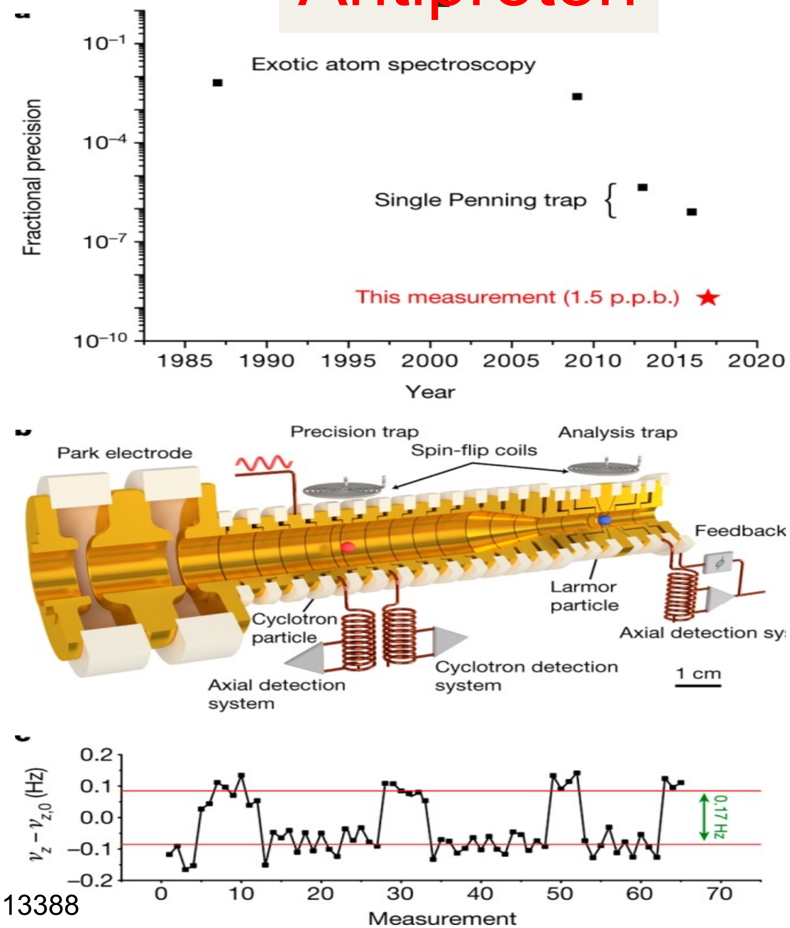


Fig. 1. Measurements of the *g* factor.

Antiproton



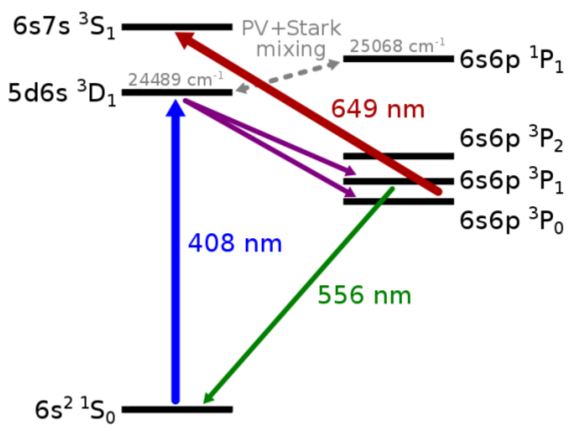
Further improvement possible!
Sympathetic cooling with Be^+ ion

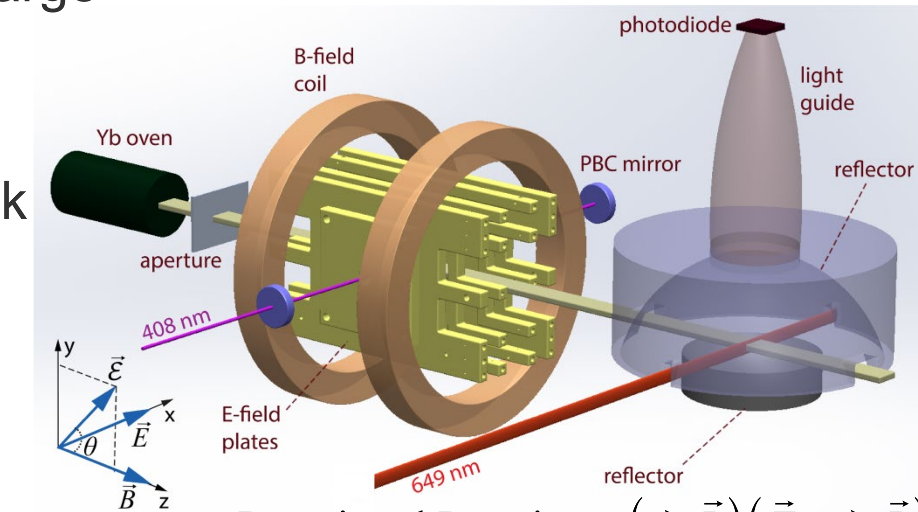
Nature **509**, 596-599 (2014) doi:10.1038/nature 13388
Nature **550**, 371–374 (2017) doi:10.1038/nature 24048
Science **358**, 1081–1084 (2017) doi:10.1126/science.aan0207

➢ Matter/antimatter symmetry holds at ppb level!

Atomic Parity violation in Ytterbium

- Verify the dependence of the weak charge on the neutron number
- Probe neutron skin of the Yb nucleus
- Study physics beyond the SM via weak interaction effects in atomic Ytterbium

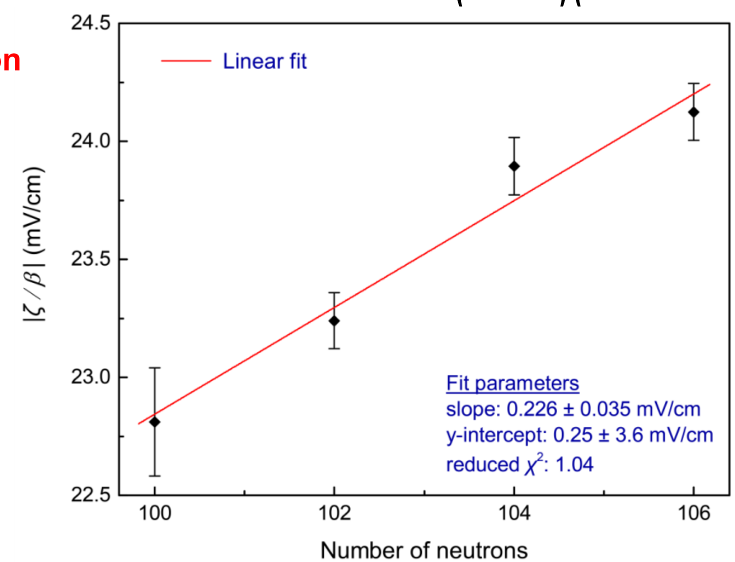




First observation of isotopic variation of atomic parity violation

2018 arXiv:1804.05747

Rotational Invariant: $(\vec{\varepsilon}\cdot\vec{B})(\vec{E}\times\vec{\varepsilon}\cdot\vec{B})$



- Define Handedness via B and E fields
- Excite $^1S_0 \rightarrow {}^3D_1$
- Flip handedness (reverse E and B fields)
- Excitation asymmetry can be related to weak interaction effects

Trapped and cooled Thorium ions via Calcium (TACTICa)

- Collaboration SHE and MAM (Düllmann, Schmidt-Kahler, Budker)
- ^{229m}Th uniquely sensitive to test fundamental symmetries (e.g. variation of constants)
- Precision determination of isotope shifts
- Quantum logic spectroscopy of the nuclear transition via the Ca^{+}

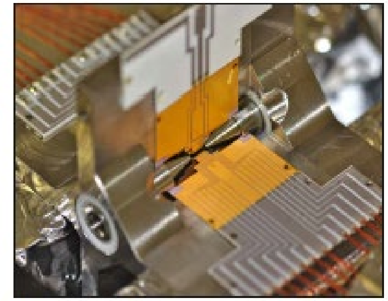
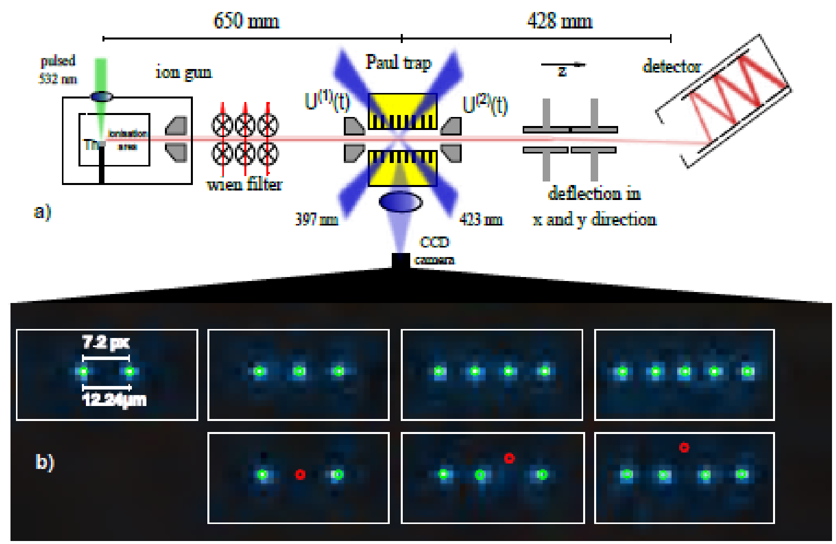


Photo of the segmented ion trap

- Trapping, cooling and ion identification has been achieved of $^{232}Th^{+}$ arXiv:1807.05975v1
- Apparatus being replicated and moved to Nuclear Chemistry



In general: timestamp + save data!

Search for ultralight scalar dark matter with atomic spectrosc

Ken Van Tilburg,[1,*] Nathan Leefer,[2,†] Lykourgos Bougas,[2,‡] and Dmitry Budker[2,

[1] *Stanford Institute for Theoretical Physics, Stanford University, Stanford, CA 94305, U*

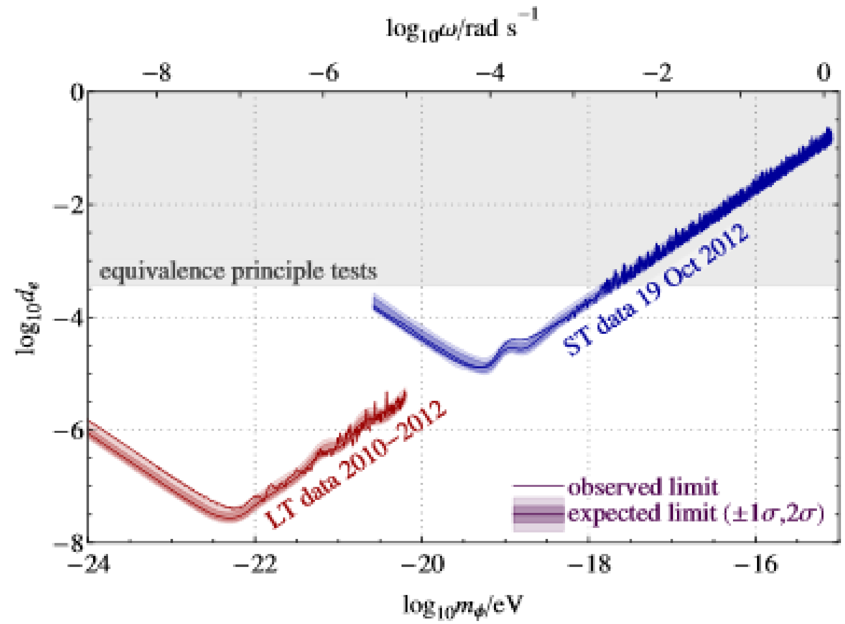
[2] *Helmholtz Institut Mainz, 55128 Mainz, Germany*

[3] *Institut für Physik, Johannes Gutenberg Universität-Mainz, 55128 Mainz, Germany*

[4] *University of California at Berkeley, Berkeley, CA 94720, USA*

(Dated: April 9, 2015)

We report new limits on ultralight scalar dark matter (DM) with dilaton-like couplings to pl that can induce oscillations in the fine-structure constant α. Atomic dysprosium exhibits a tronic structure with two nearly degenerate levels whose energy splitting is sensitive to char α. Spectroscopy data for two isotopes of dysprosium over a two-year span is analyzed for co oscillations with angular frequencies below 1 rad s^{-1}. No signal consistent with a DM coup identified, leading to new constraints on dilaton-like photon couplings over a wide mass rang der the assumption that the scalar field comprises all of the DM, our limits on the coupling those from equivalence-principle tests by up to 4 orders of magnitude for masses below $3 \cdot 10^{-}$ Excess oscillatory power, inconsistent with fine-structure variation, is detected in a control ch and is likely due to a systematic effect. Our atomic spectroscopy limits on DM are the first o kind, and leave substantial room for improvement with state-of-the-art atomic clocks.



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15.12.2016

nature physics

LETTERS

https://doi.org/10.1038/s41567-018-0312-8

Isotopic variation of parity violation in atomic ytterbium

D. Antypas[1*], A. Fabricant[2], J. E. Stalnaker[3], K. Tsigutkin[4], V. V. Flambaum[2,5] and D. Budker[1,2,6]

Including exclusion on Z' particle

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Bitte zerkleinern!

MAM Section September 2014

HIM Foyer 03.2015

MAM Section 2015

MAM Section January 2017

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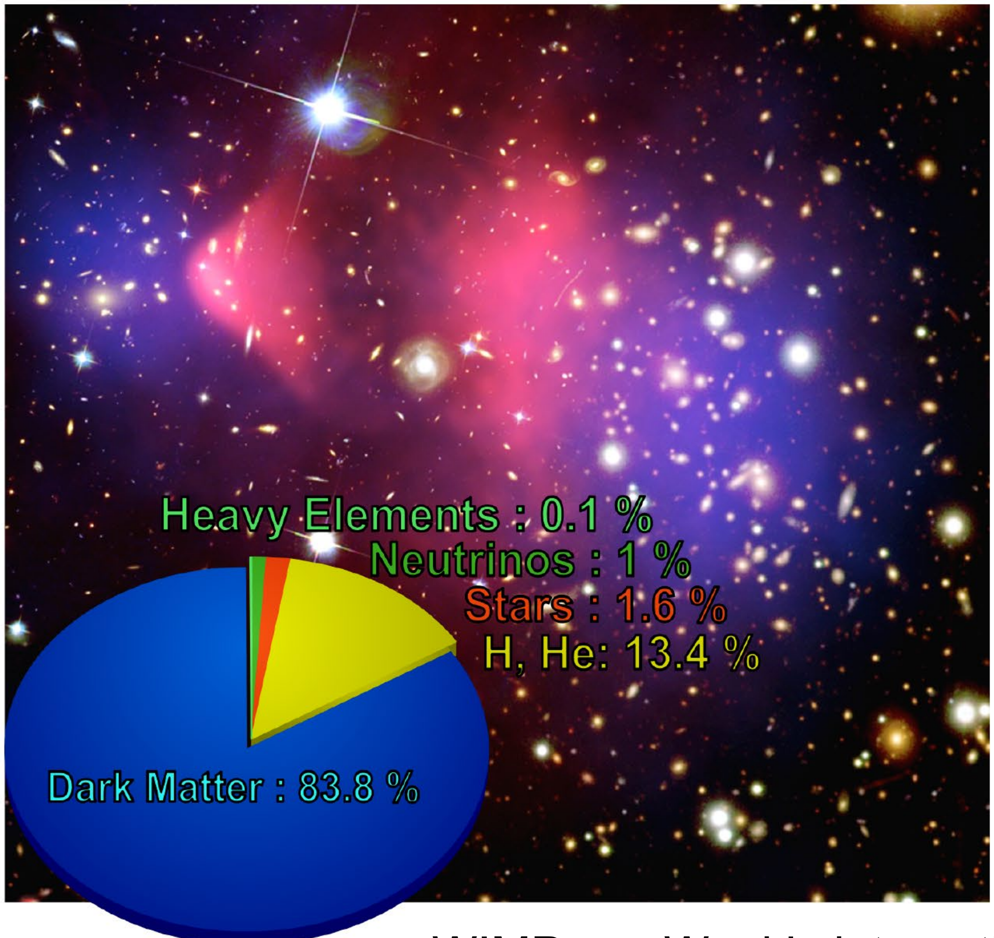
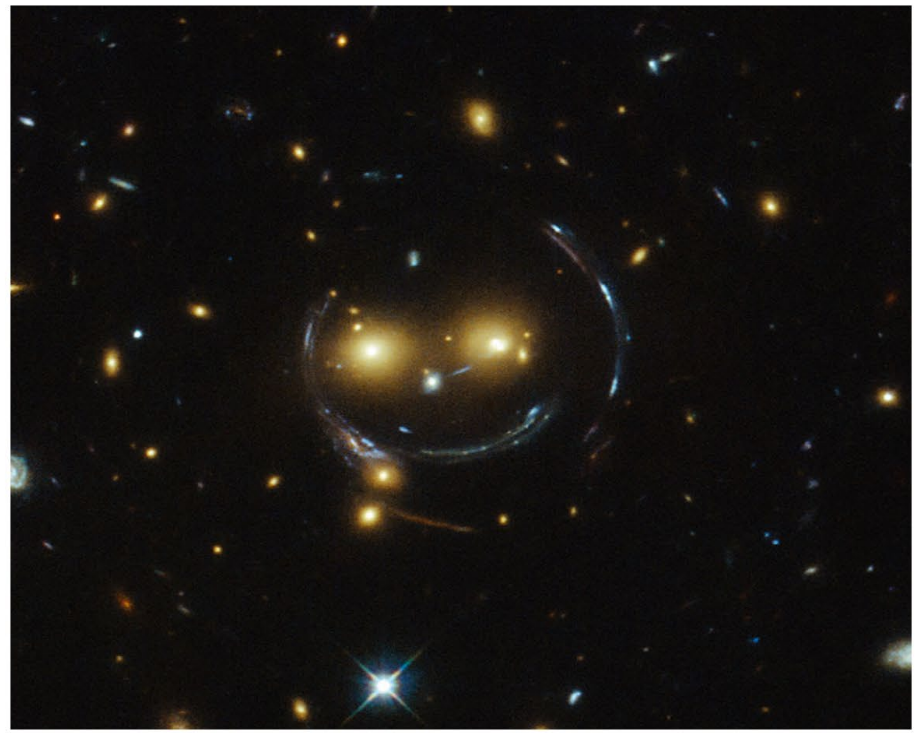
NMR Meets Dark Matter

The Cosmic Axion Spin Precession Experiment (CASPEr)

The dark matter problem



- **Axion-like particles (ALPs):**
  - very light bosons (unknown mass)
  - weakly interacting with "normal" matter
  - could be dark matter



WIMPs Weakly interacting massive particles
MACHOs Massive compact halo object
RAMBOs Robust associations of massive baryonic objects

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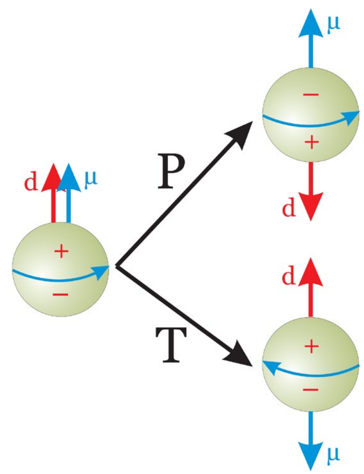
Axions

R. D. Peccei and Helen R. Quinn, Phys. Rev. Lett. 38, 1440 (1977)

Particle suggested to solve the strong CP problem:
Strong interaction does not
violate CP symmetry even though it could.

Limit set by nEDM
measurements:
(10 orders of mag.)



Axion:
Very light (mass 10^{-12}-1eV/c^2)
Spin 0
Minimal interaction

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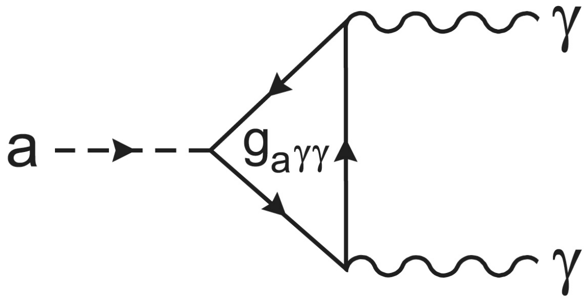
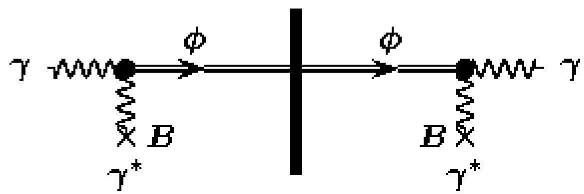
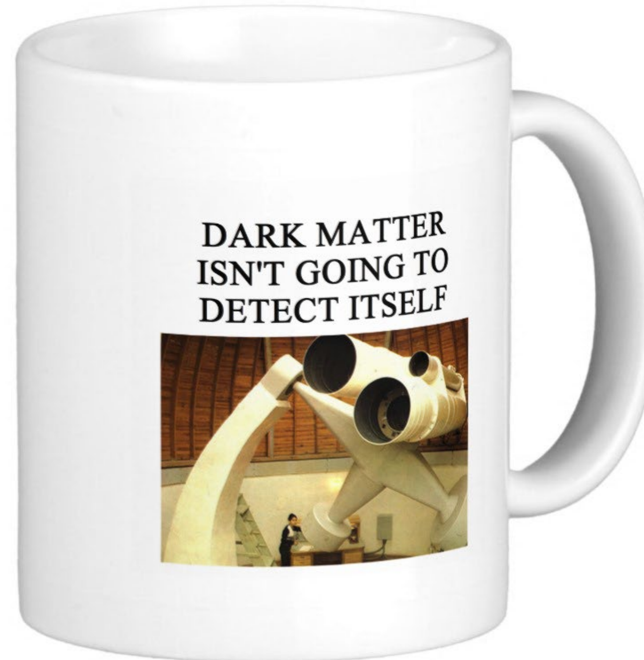
Axion experiments

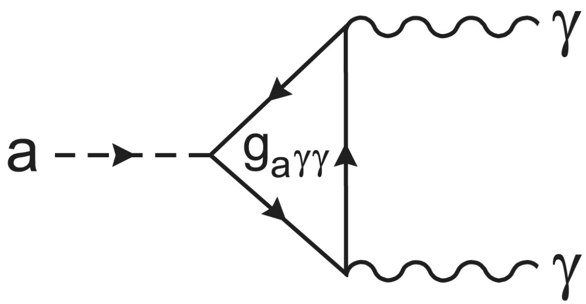


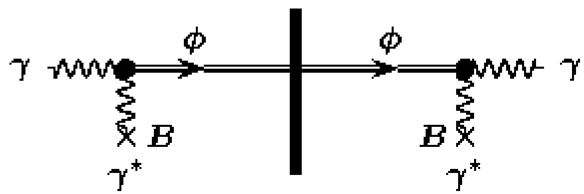


e.g. CAST (Cern Axion Solar Telescope)



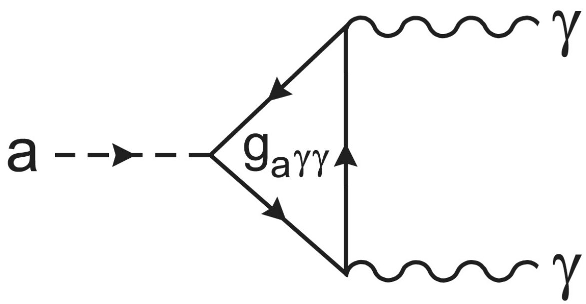
Axion experiments

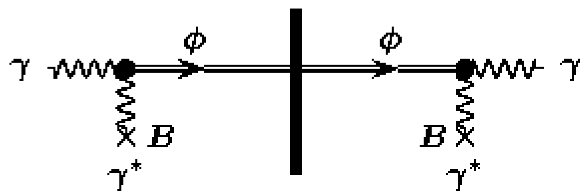




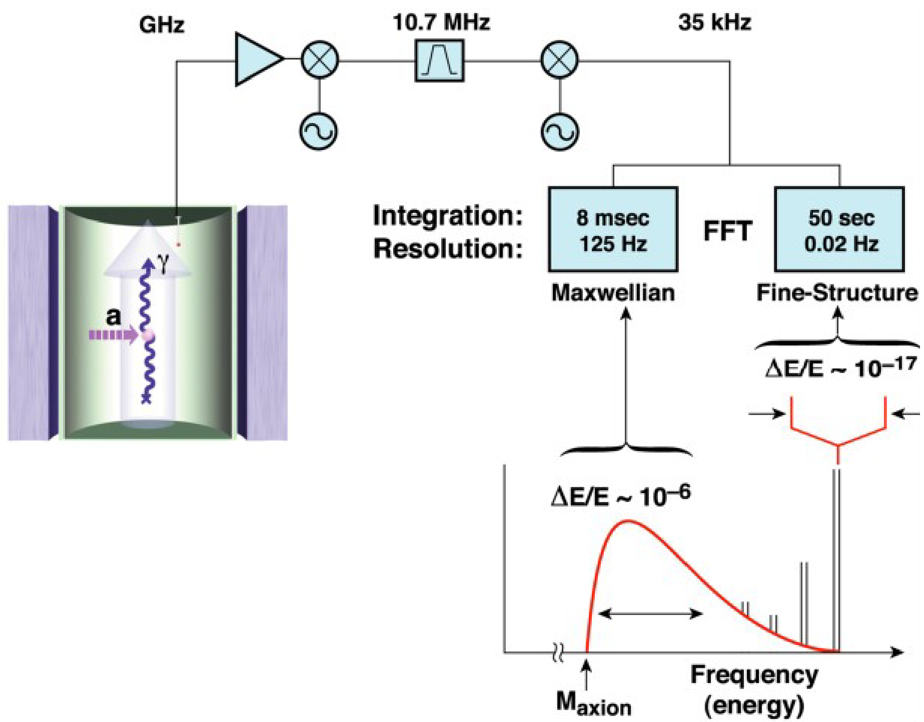
e.g. ALPS @ DESY (Light shining through a wall)

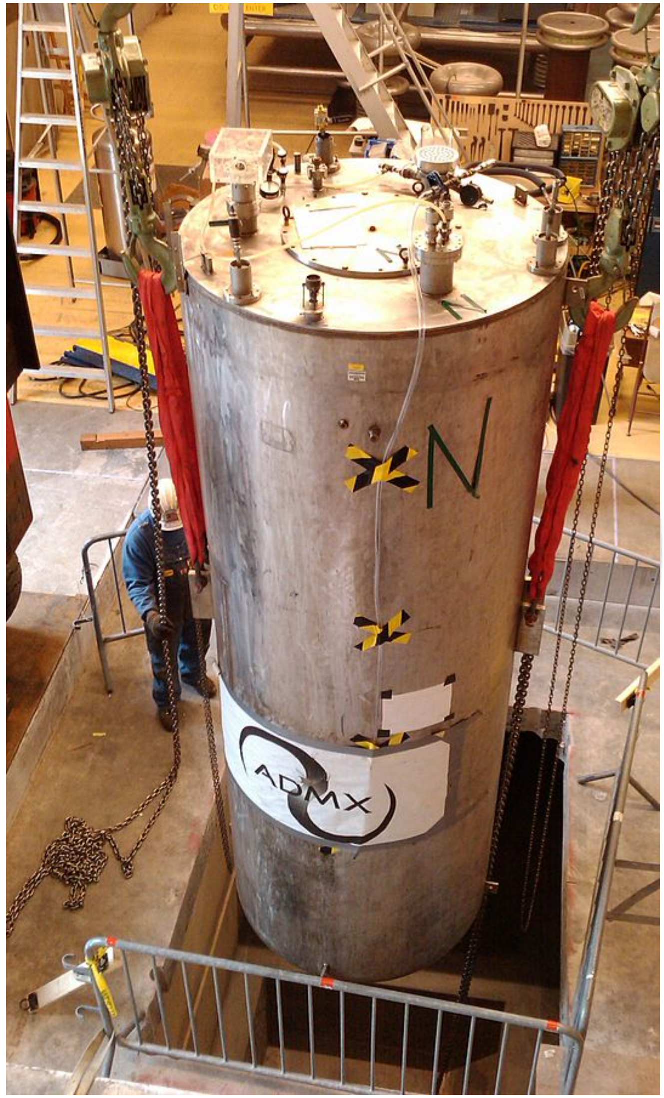
Axion experiments



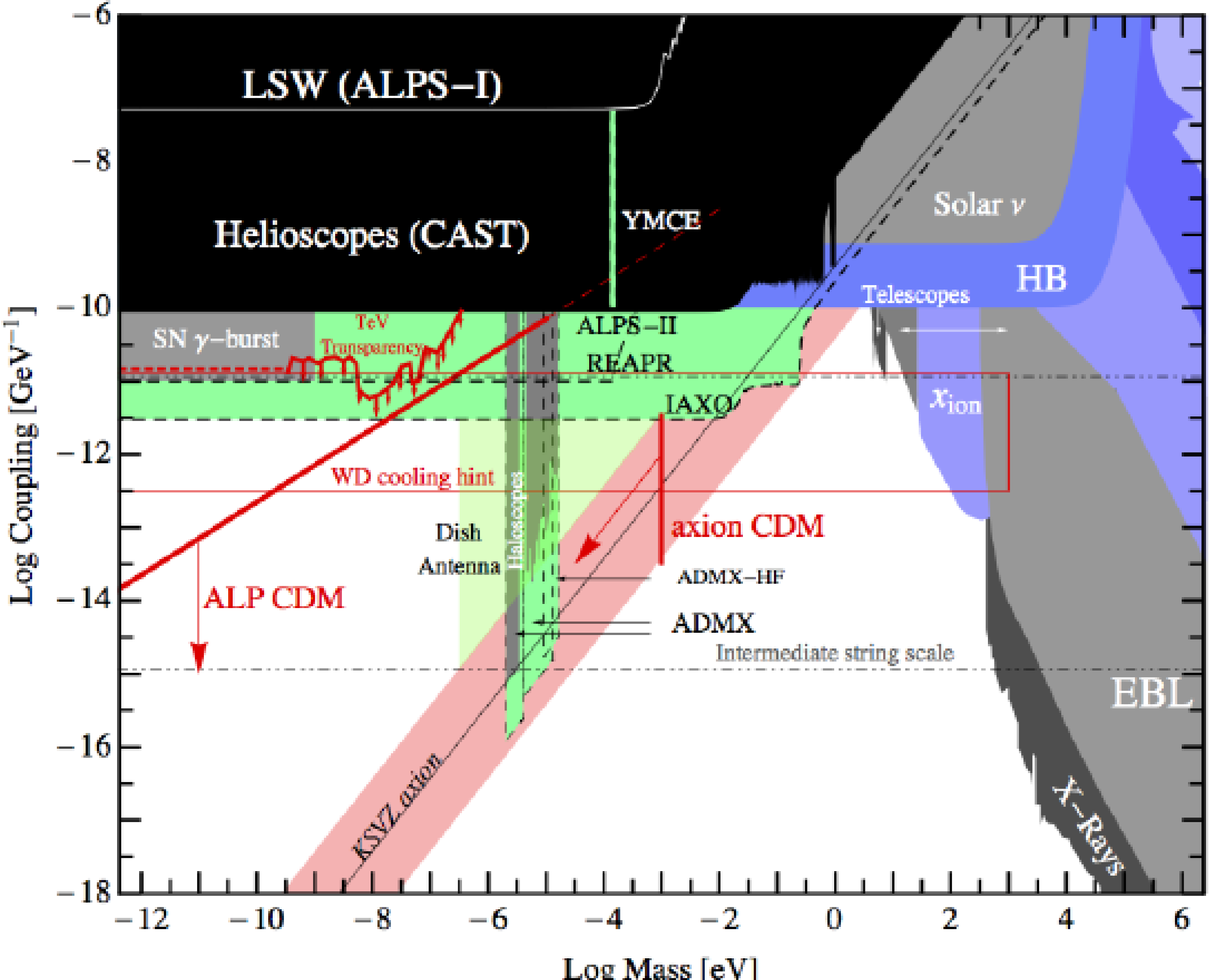


e.g. ADMX (*Axion Dark Matter eXperiment*)

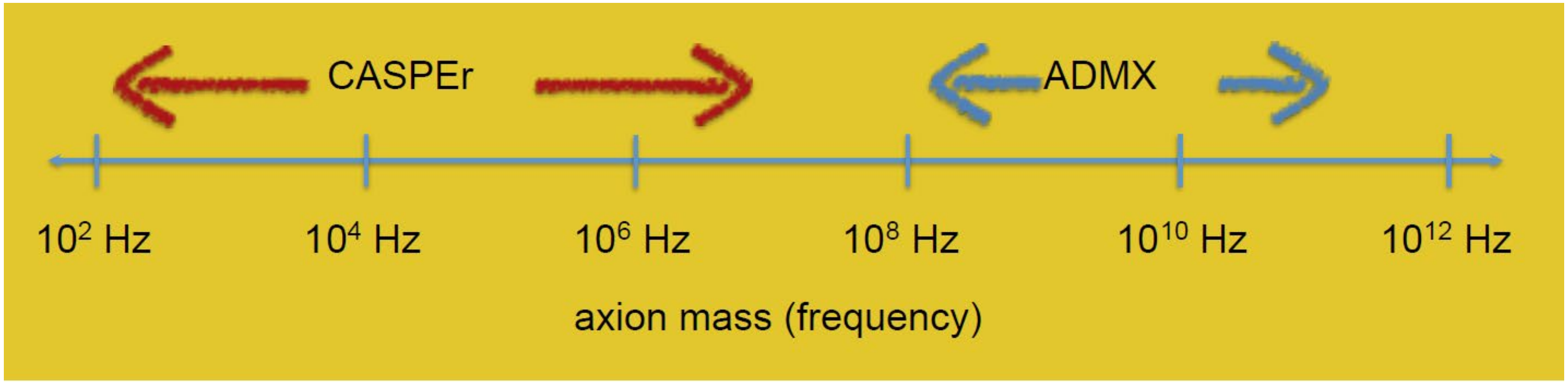


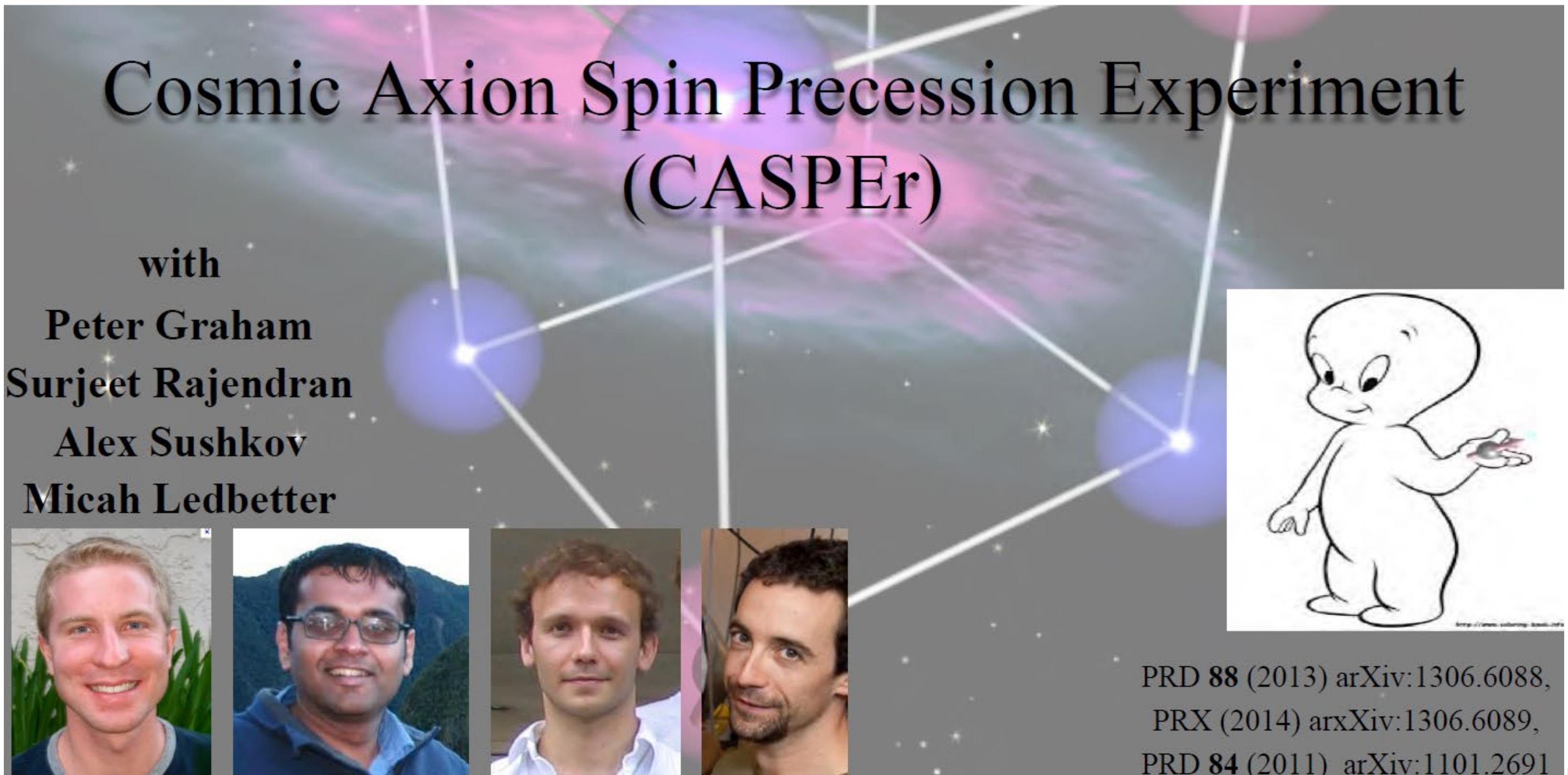


"ADMX magnet installation" by Lamestlamer



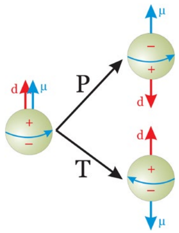
LSW (ALPS–I)
Helioscopes (CAST)
YMCE
SN γ–burst
TeV Transparency
ALPS–II
REAPR
IAXO
WD cooling hint
Dish Antenna
Haloscopes
axion CDM
ALP CDM
ADMX–HF
ADMX
Intermediate string scale
KSVZ axion
Solar ν
HB
Telescopes
x_{ion}
EBL
X-Rays
Log Coupling [GeV^{-1}]
Log Mass [eV]

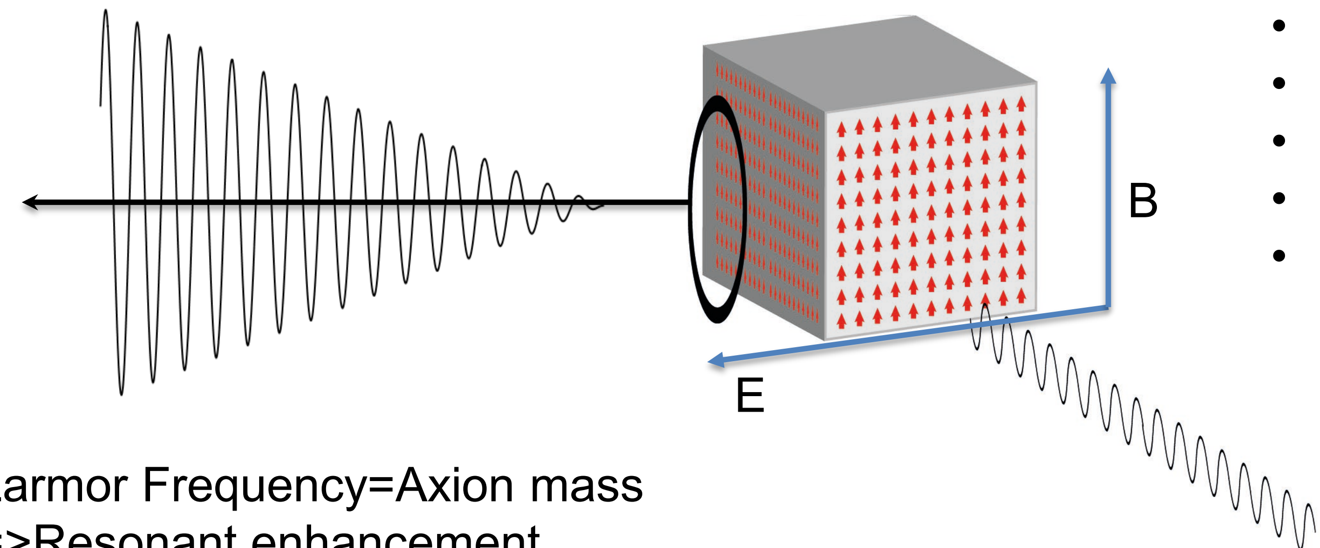

CASPEr
ADMX
10^2 Hz
10^4 Hz
10^6 Hz
10^8 Hz
10^{10} Hz
10^{12} Hz
axion mass (frequency)


Cosmic Axion Spin Precession Experiment
(CASPEr)
with
Peter Graham
Surjeet Rajendran
Alex Sushkov
Micah Ledbetter
PRD **88** (2013) arXiv:1306.6088,
PRX (2014) arxXiv:1306.6089,
PRD **84** (2011) arXiv:1101.2691

CASPEr – Electric idea

Detecting oscillating induced electric dipole moment with NMR





- Polarized nuclear spins
- B field
- E field perp to B
- Axion induces EDM
- ->Oscillating torque on spins
- Pickup with SQUIDs

$$\frac{a}{f_a} G_{\mu\nu}\tilde{G}^{\mu\nu}$$

Larmor Frequency=Axion mass
=>Resonant enhancement

Cosmology: $Q=10^6$!

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How to search for Axions (ALPs) ?

Axion (ALP) Interactions

Gravity

+

Gauge Fields

$$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu} \qquad \frac{a}{f_a} G_{\mu\nu}\tilde{G}^{\mu\nu}$$

Most Searches

(CASPEr-E)

Fermions

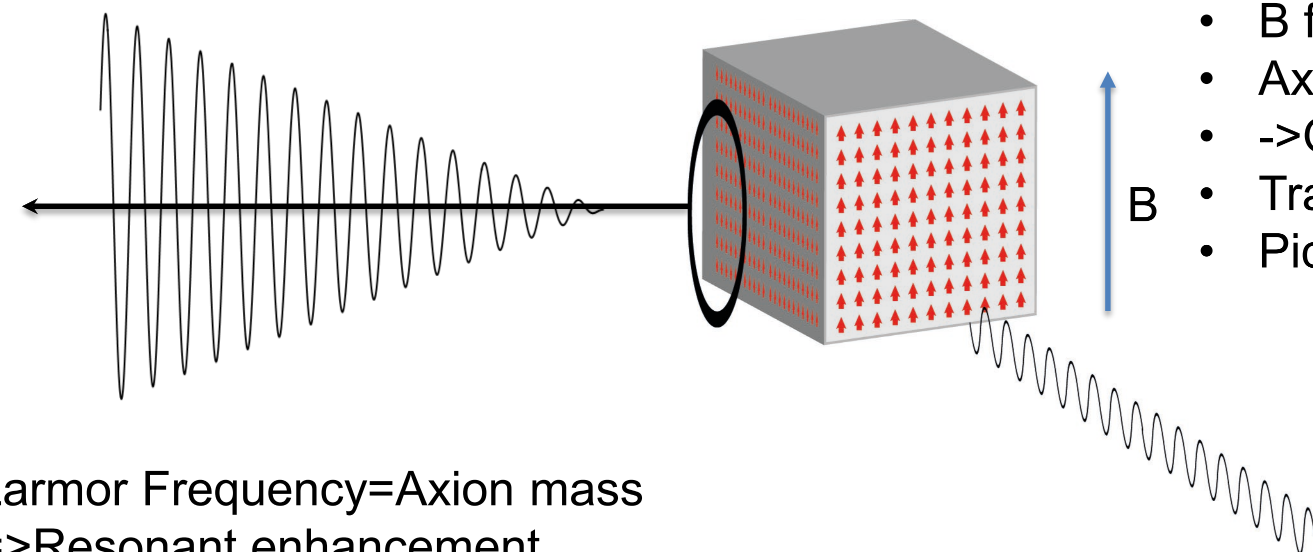
$$\frac{\partial_\mu a}{f_a} \bar{\Psi}_f \gamma^\mu \gamma_5 \Psi_f$$

(CASPEr-Wind, GNOME, QUAX)

CASPEr – Wind idea

Detecting oscillating torque on nuclear spins

$$\frac{\partial_\mu a}{f_a}\bar{\Psi}_f\gamma^\mu\gamma_5\Psi_f$$



- Polarized nuclear spins
- B field
- Axion gradient couples to spins
- ->Oscillating torque on spins
- Transversal magnetization
- Pickup (somehow)

Larmor Frequency=Axion mass
=>Resonant enhancement

CASPEr stages

CASPEr now → Analysing existing data (low frequency)

CASPEr Wind → Measurement of axion field gradient (Wind) with nuclear spins in magnetic field

-ultra low field (optical magnetometer)

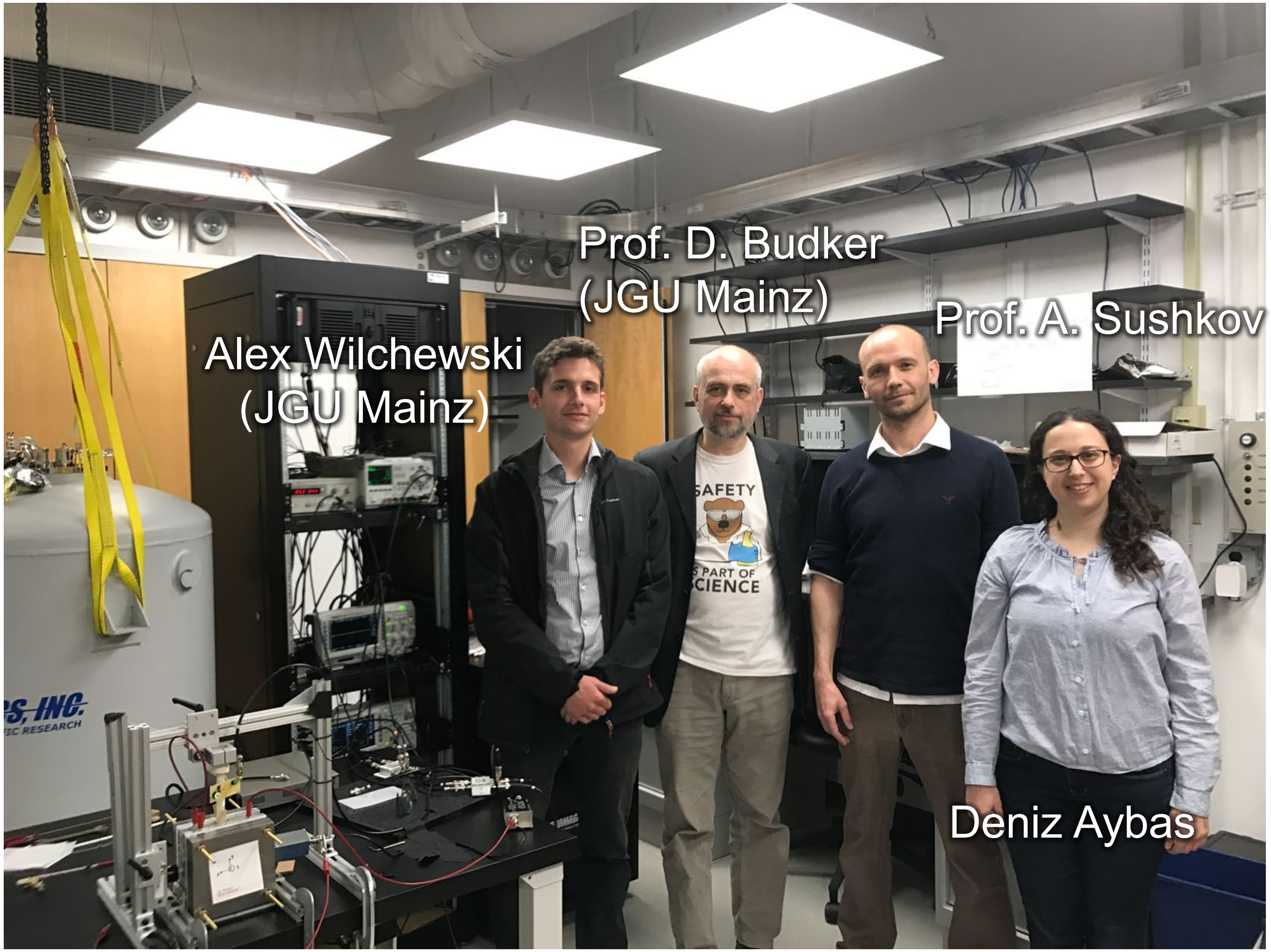
-low field (Super conducting quantum interference devices)

-high field (inductive pick-up)

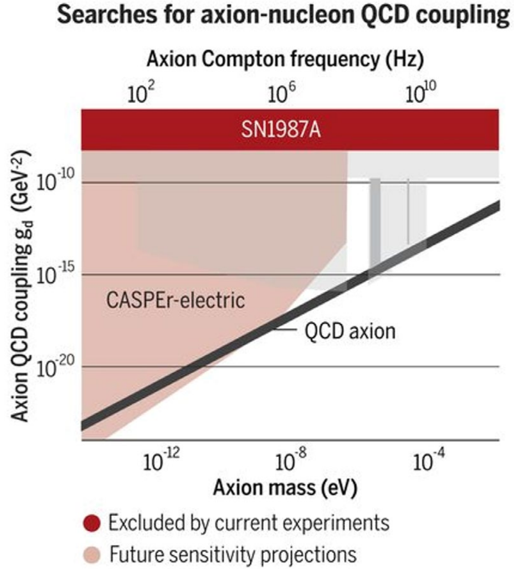
CASPEr Electric → Applying additional electric field

Alex Sushkov et al @ Boston university

CASPER Electric



$$\frac{a}{f_a} G_{\mu\nu} \tilde{G}^{\mu\nu}$$

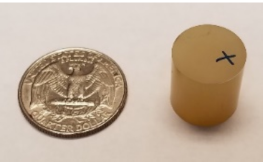


QCD Axion < 100neV

David DeMille, John. Doyle, and Alexander Sushkov. Science 2017;357:990-994

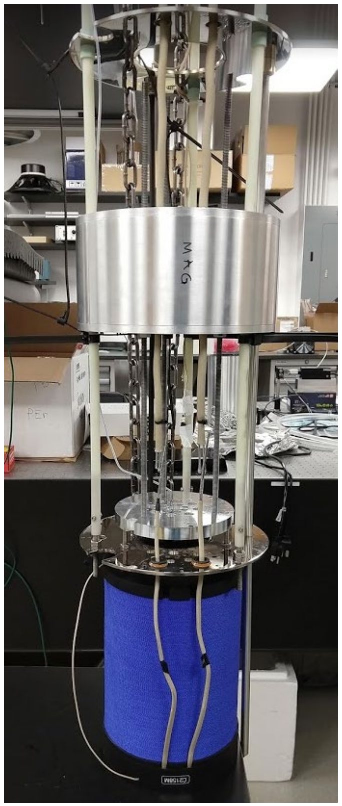
CASPEr Electric Boston University

search for axion-gluon coupling $\rightarrow \frac{a}{f_a} G_{\mu\nu}\tilde{G}^{\mu\nu}$

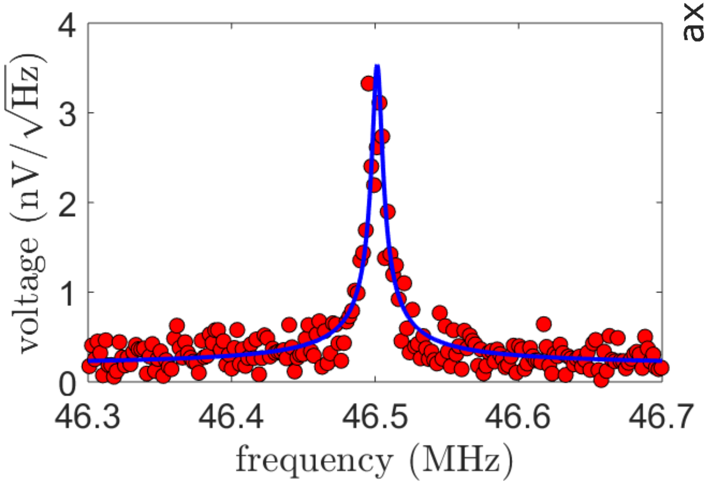


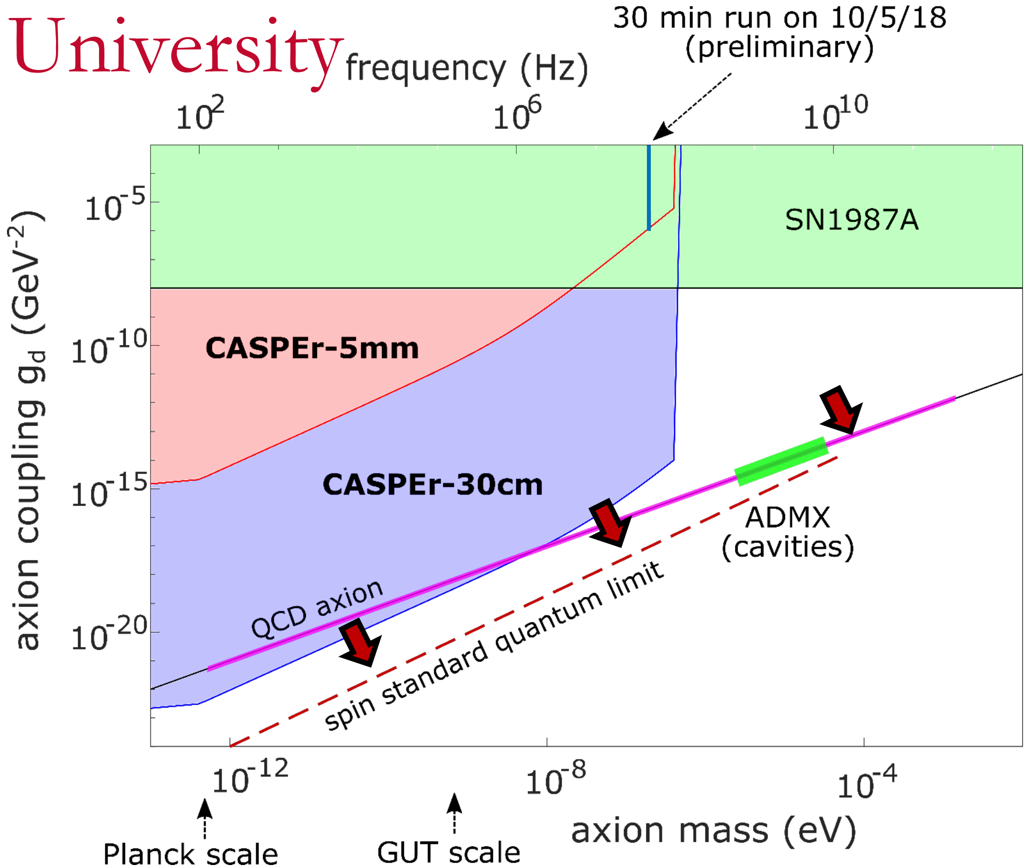
^{207}Pb nuclear spins in ferroelectric PMN-PT

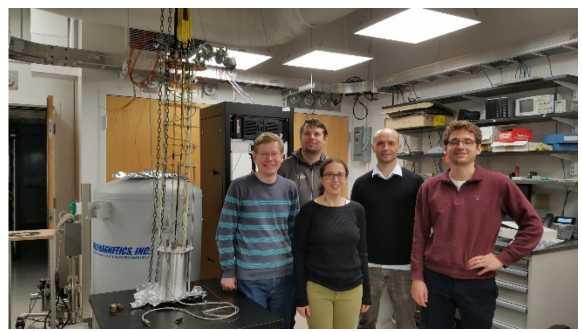
$$H_e \propto g_d a \vec{\sigma} \cdot \vec{E}^*$$



first ^{207}Pb NMR at 4 K







© Alex Sushkov BU

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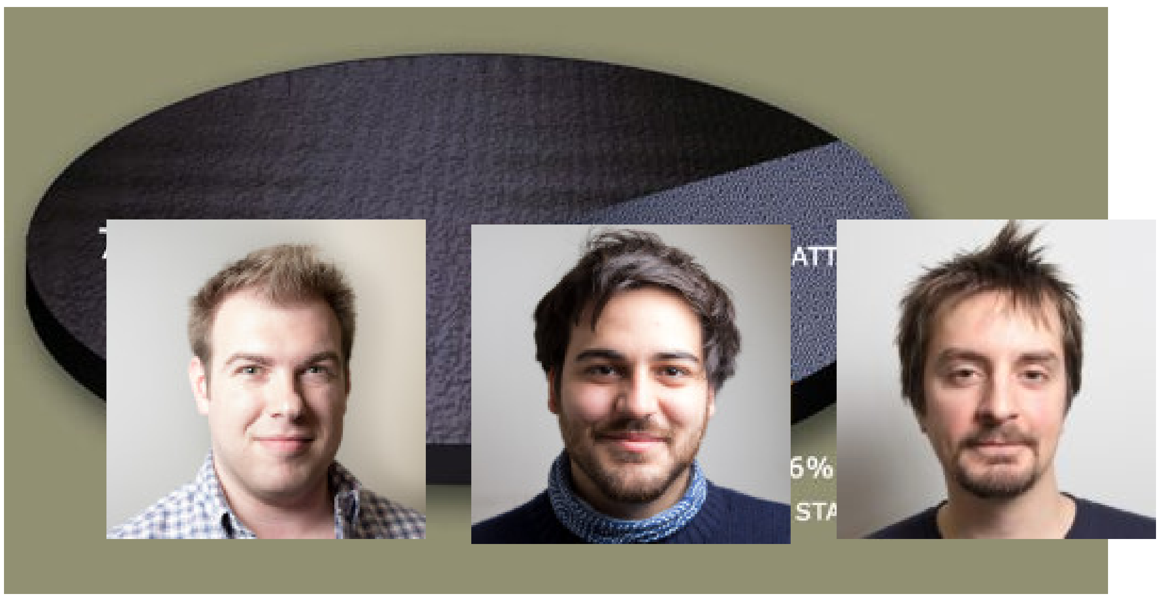
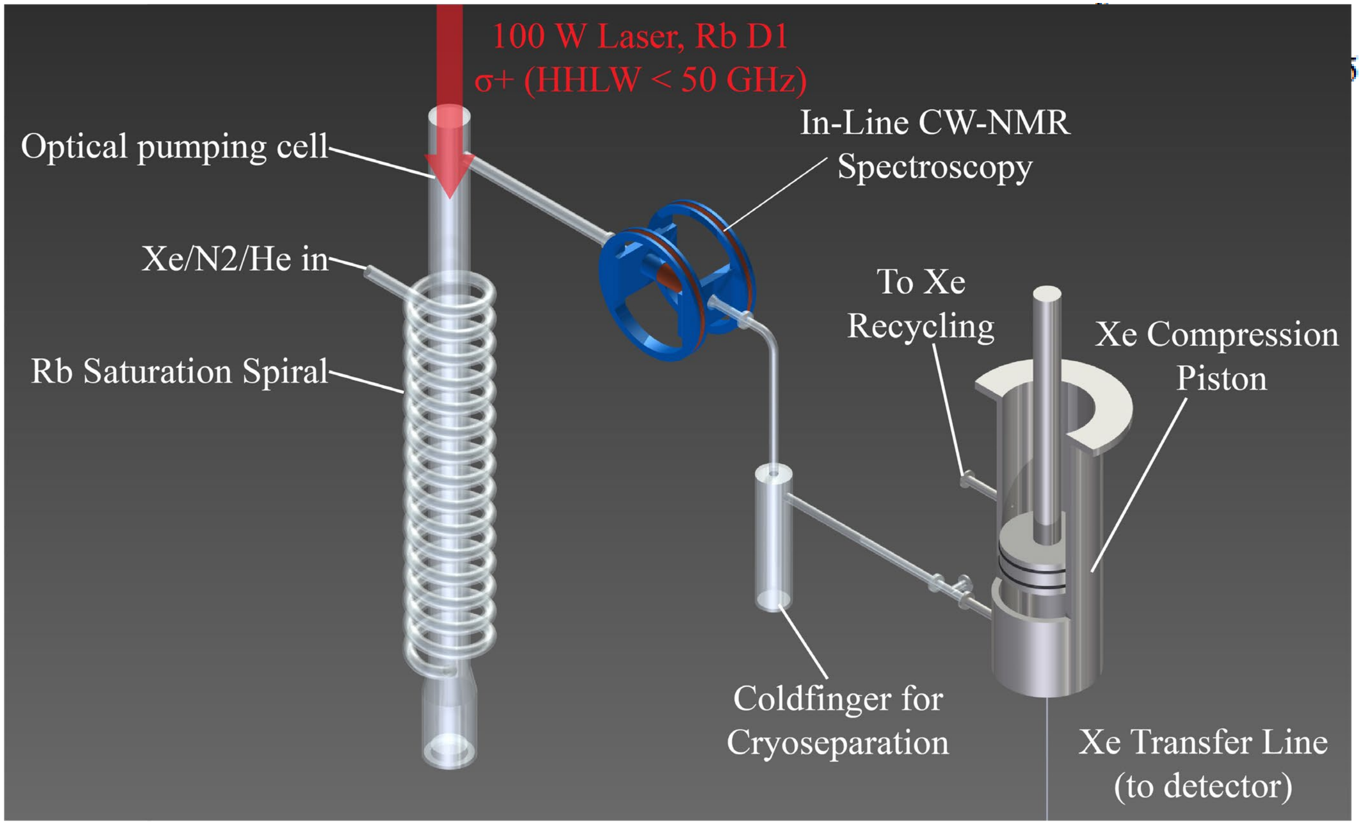
CASPEr Wind in Mainz

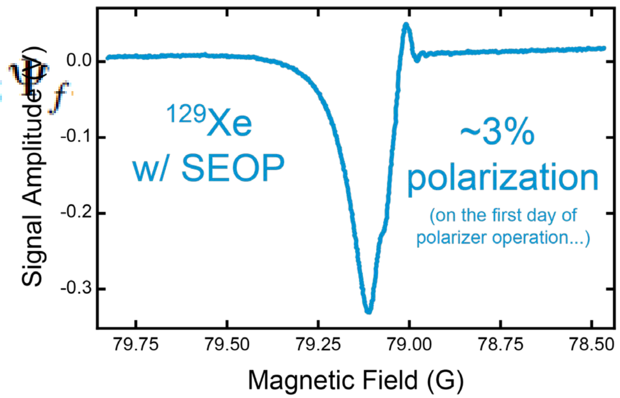
Cosmic Axion Spin Precession experiment (CASPEr)

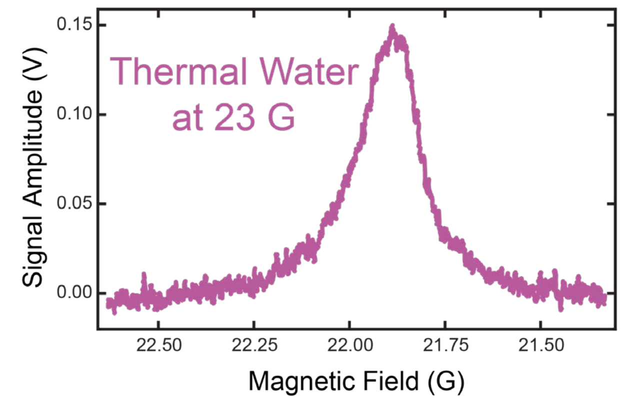
Hyperpolarized Xenon NMR
driven by axion-like dark matter



CASPEr Wind – inline Xenon polarization







CASPEr Wind LF status

Actively stabilized magnet
-0-1500G (up to 2-3MHz)
-superconducting shims 1ppm
-magnetically shielded

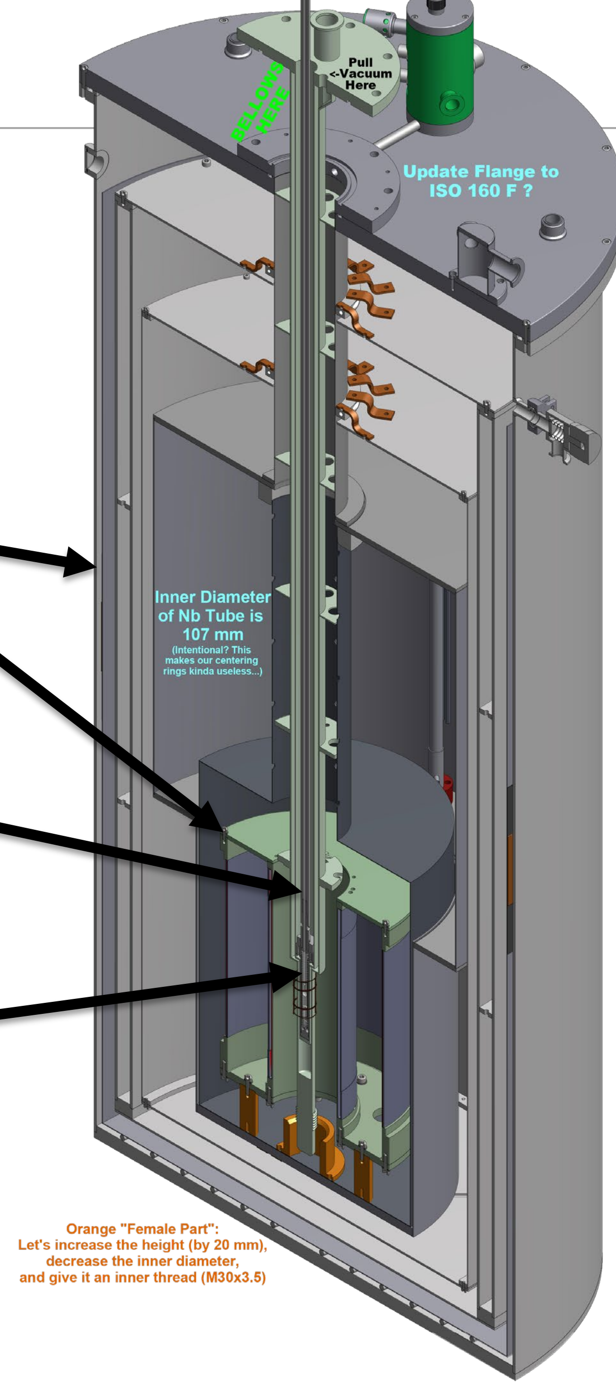
Ordered-> 11/18

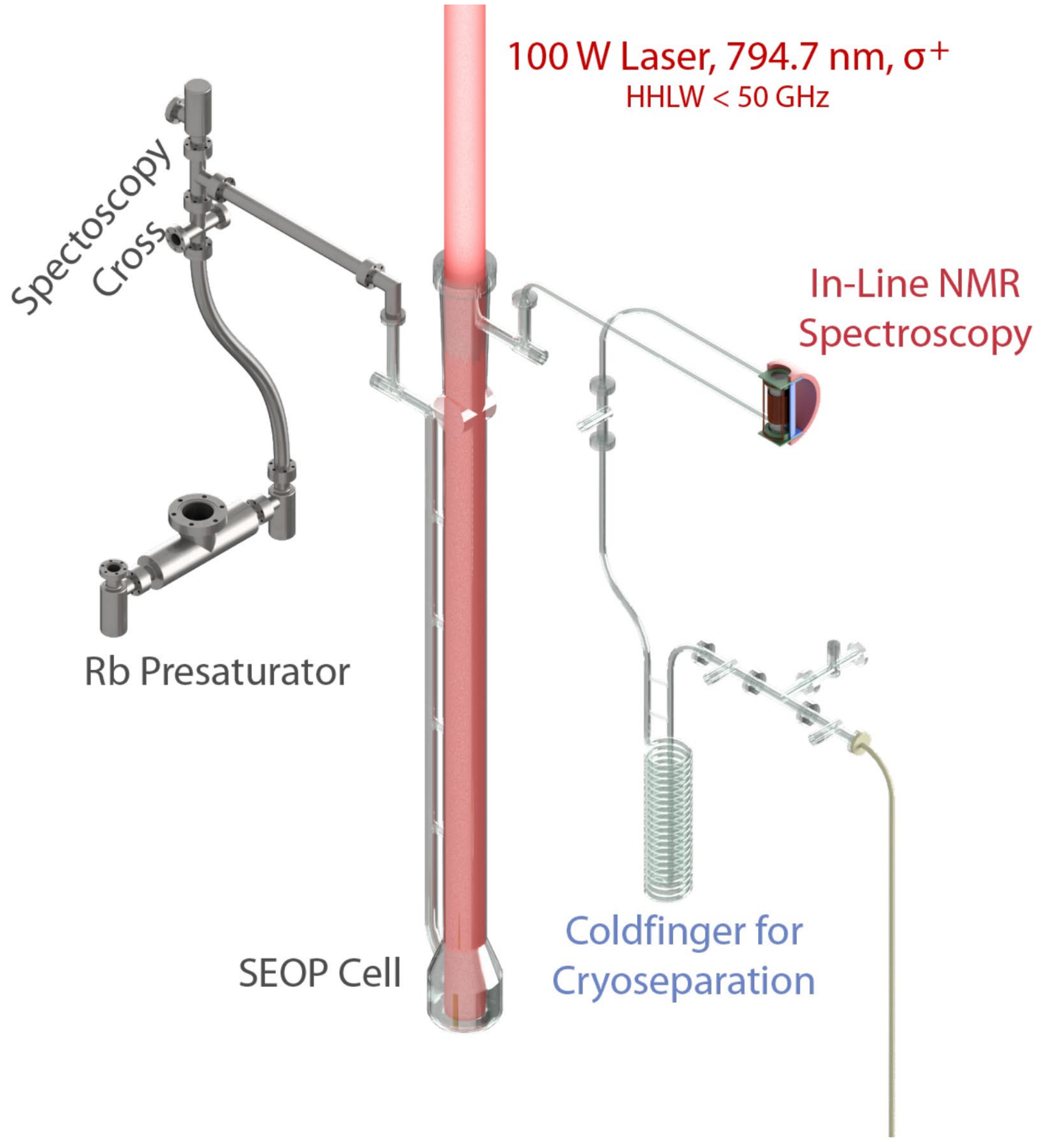
Variable temperature insert
- 160-180K

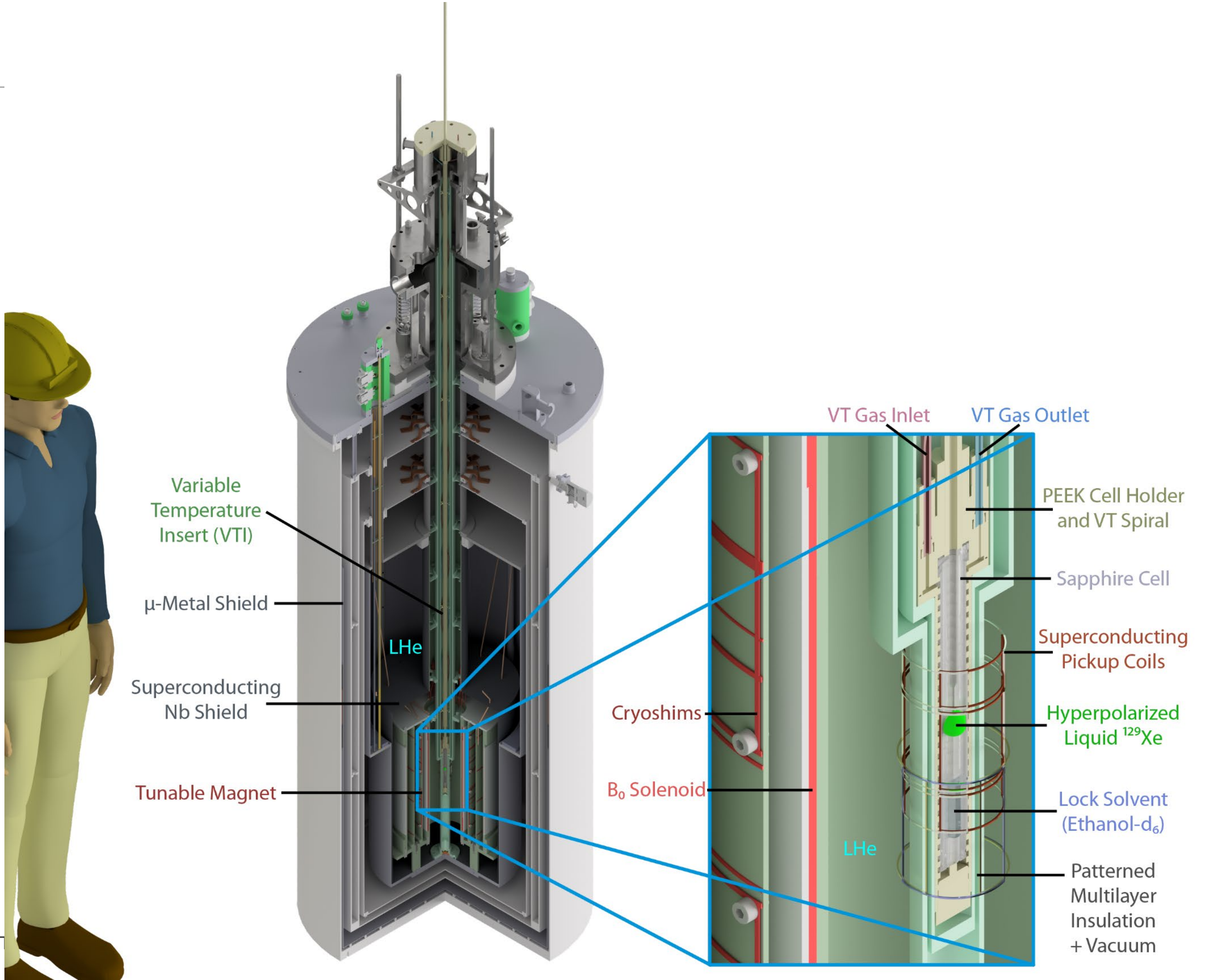
Ordered-> 11/18

Super-conducting pick-up coils
Triple SQUID system

Ordered-> 11/18

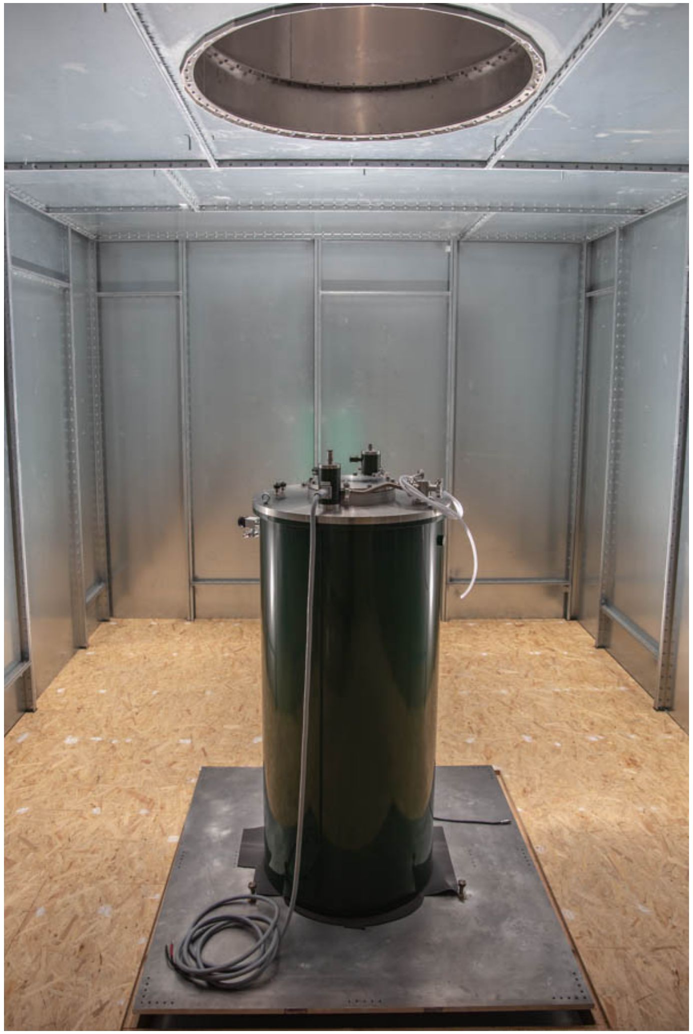



100 W Laser, 794.7 nm, σ+
HHLW < 50 GHz
Spectoscopy
Cross
In-Line NMR
Spectroscopy
Rb Presaturator
SEOP Cell
Coldfinger for
Cryoseparation



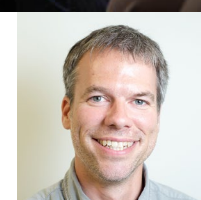
Variable Temperature Insert (VTI)
µ-Metal Shield
LHe
Superconducting Nb Shield
Tunable Magnet
VT Gas Inlet
VT Gas Outlet
PEEK Cell Holder and VT Spiral
Sapphire Cell
Superconducting Pickup Coils
Cryoshims
Hyperpolarized Liquid ^{129}Xe
B_0 Solenoid
Lock Solvent (Ethanol-d_6)
LHe
Patterned Multilayer Insulation + Vacuum

November 2018



Stockholm University

Jan Conrad
Alfredo Ferella
Matthew Lawson



CAL STATE EAST BAY

Derek J Kimball

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Summary CASPEr Wind LF (+HF)

- Wind LF is technically designed (90%)
- Crucial components are ordered or already there
- Limited currently by delivery times of the SQUIDS
- **First measurement campaign to start in 2019**

- High field magnet is designed and waits to be ordered (15.4T)
  - Xenon 129: 180 MHz
  - Helium 3: 490 MHz (ADMX 1: 461 MHz, PRD 69, 011101 (2004))
  - Protons: 640 MHz (overlapping with ADMX)

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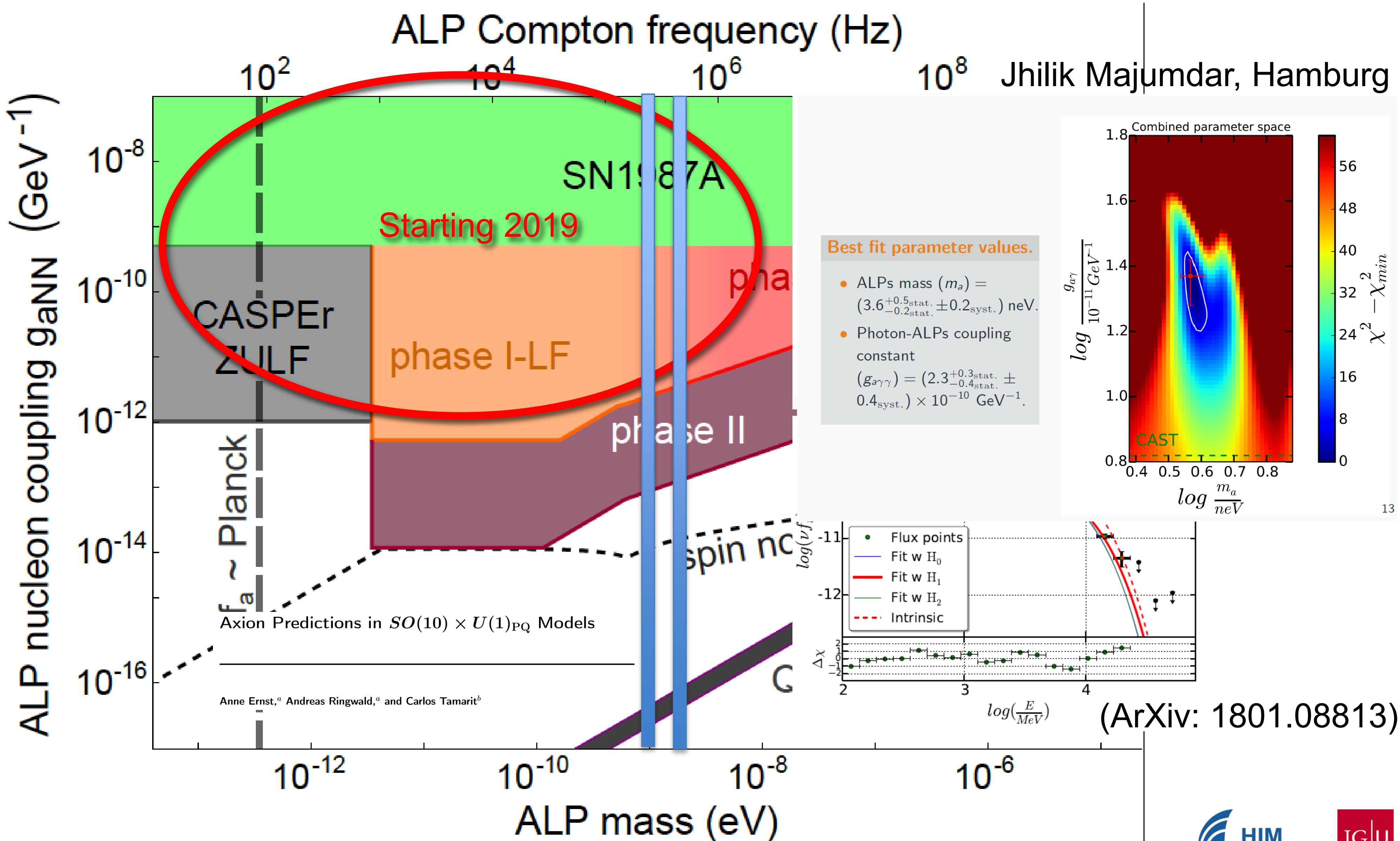
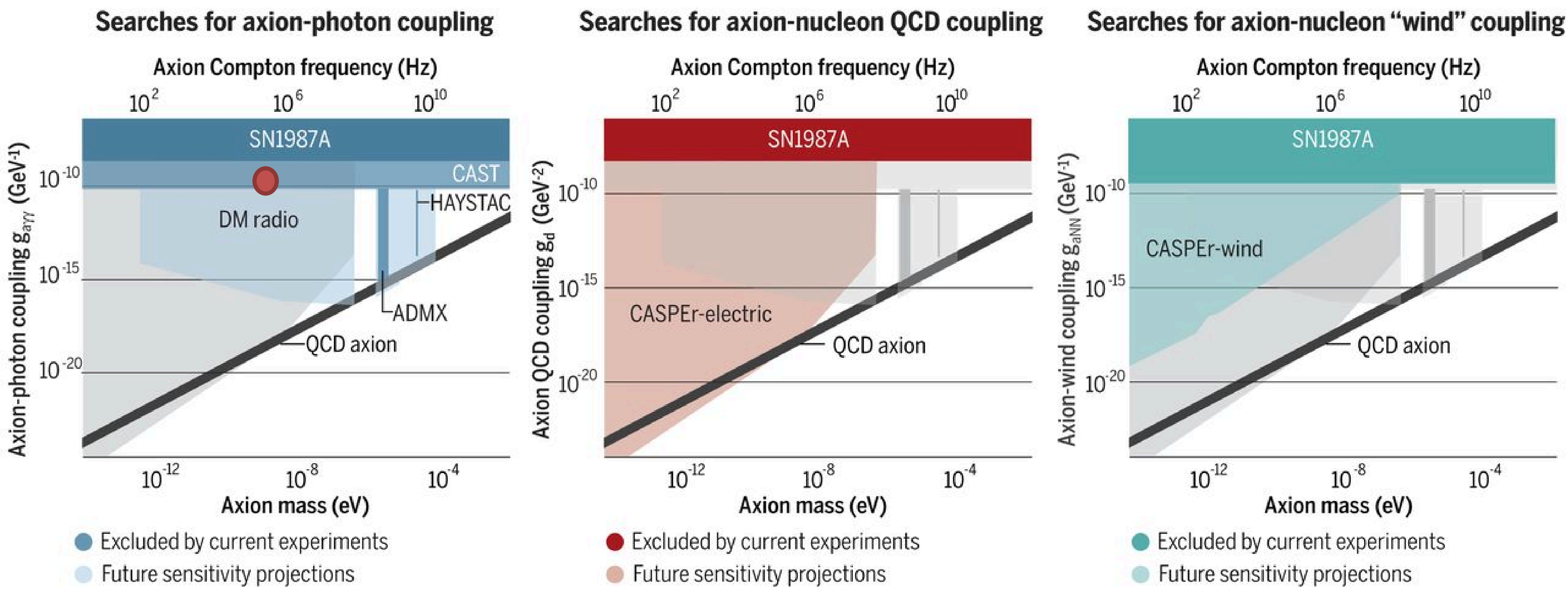


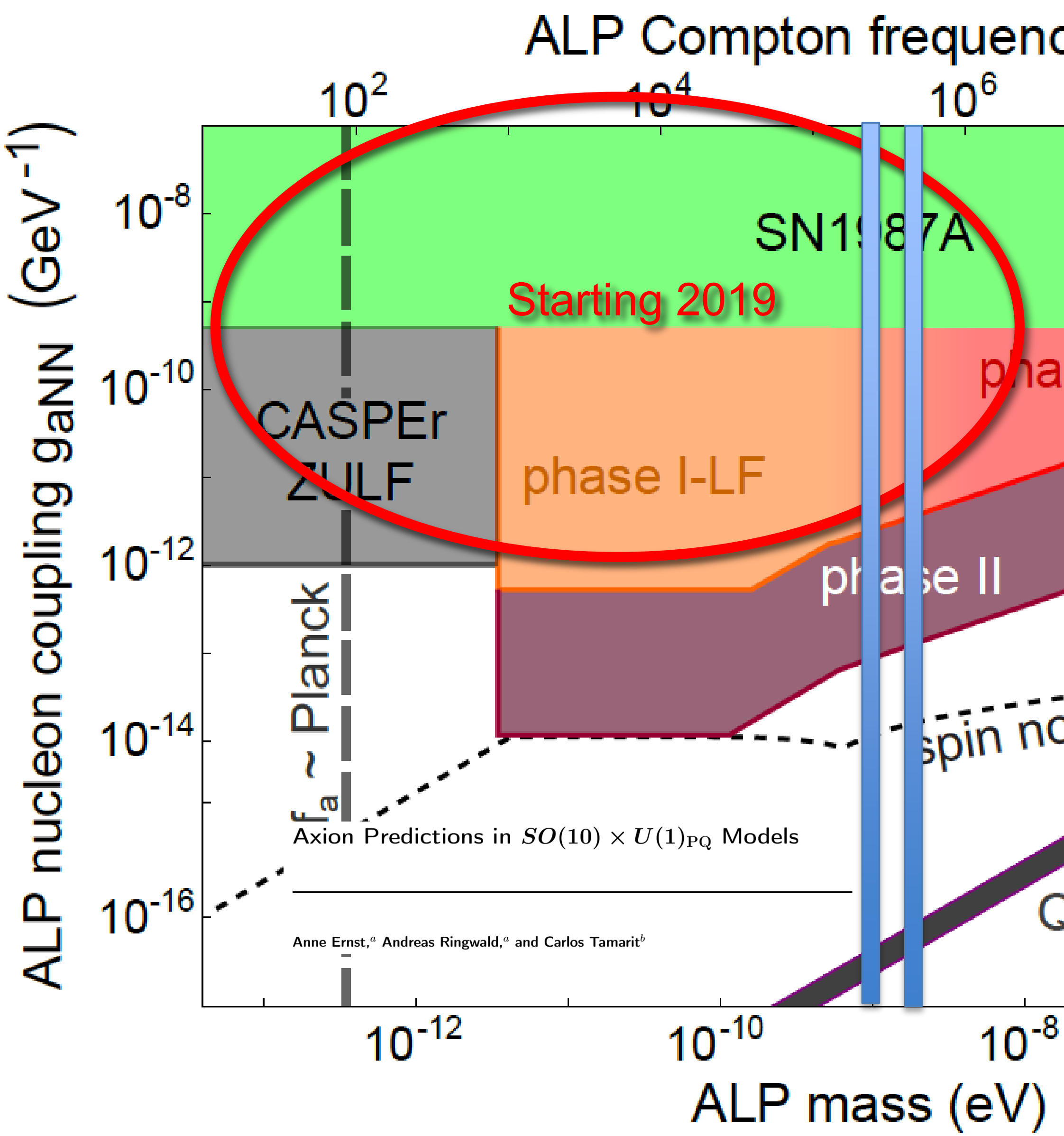
ALP Compton frequency (Hz)
10^2
10^4
10^6
10^8
Jhilik Majumdar, Hamburg
ALP nucleon coupling gaNN (GeV^-1)
10^-8
10^-10
10^-12
10^-14
10^-16
SN1987A
Starting 2019
CASPEr
ZULF
phase I-LF
phase II
spin no
fa ~ Planck
Axion Predictions in SO(10) × U(1)PQ Models
Anne Ernst, Andreas Ringwald, and Carlos Tamarit
10^-12
10^-10
10^-8
10^-6
ALP mass (eV)
Best fit parameter values.
ALPs mass (ma) = (3.6 +0.5stat. −0.2stat. ±0.2syst.) neV.
Photon-ALPs coupling constant
(gaγγ) = (2.3 +0.3stat. −0.4stat. ± 0.4syst.) × 10^−10 GeV^−1.
Combined parameter space
CAST
log ma/neV
χ² − χ²min
13
Flux points
Fit w H0
Fit w H1
Fit w H2
Intrinsic
log(E/MeV)
(ArXiv: 1801.08813)

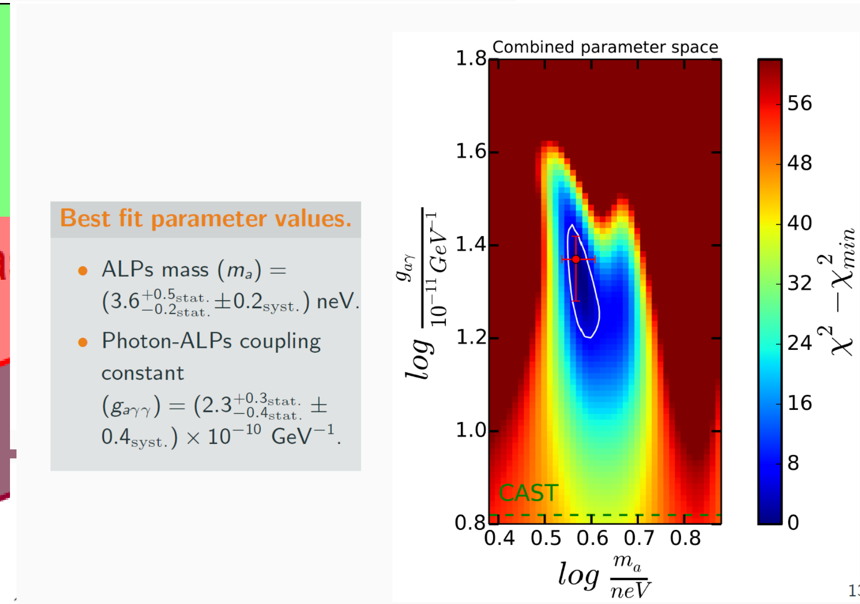
Experimental constraints and projected sensitivities of axion dark-matter searches

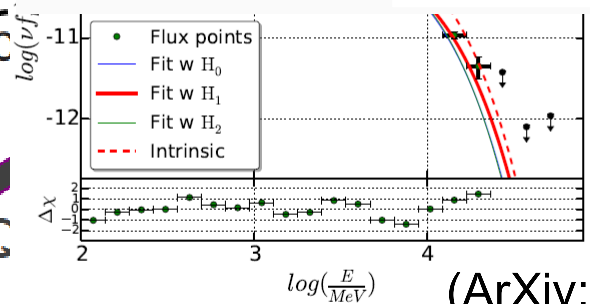


David DeMille, John. Doyle, and Alexander Sushkov. Science 2017;357:990-994

Jhilik Majumdar, Hamburg







(ArXiv: 1801.08813)

CASPEr ZULF

ACCEPTED MANUSCRIPT

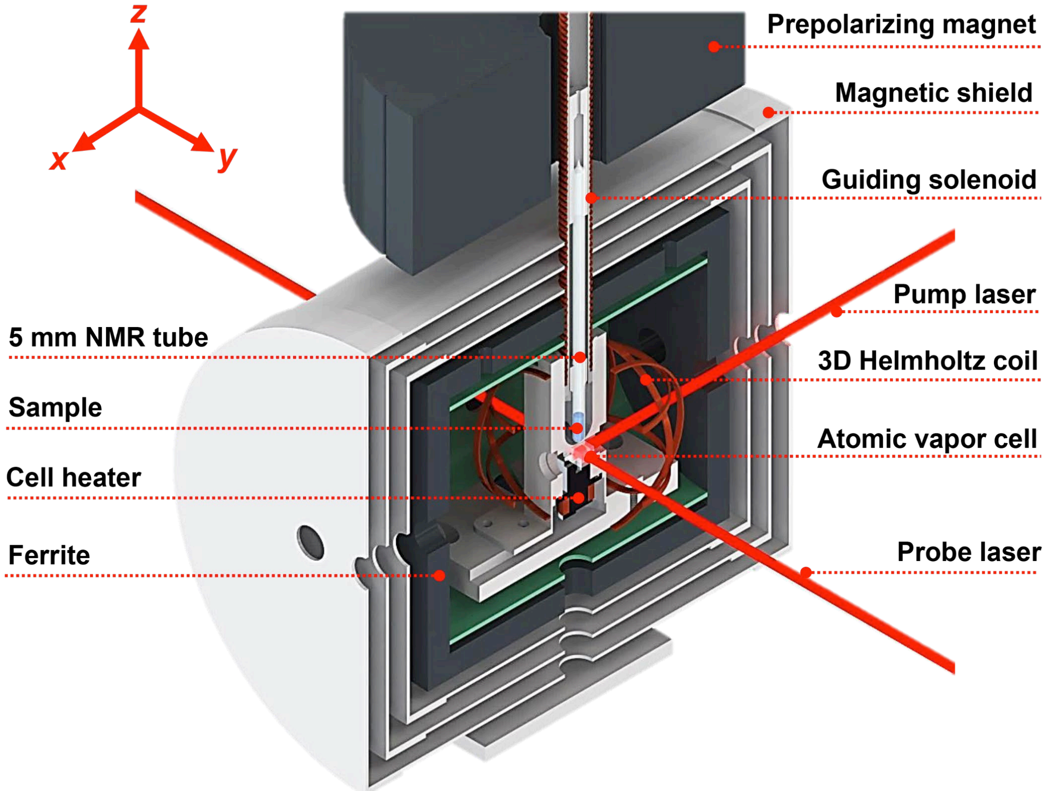
The Cosmic Axion Spin Precession Experiment (CASPEr): a dark-matter search with nuclear magnetic resonance.

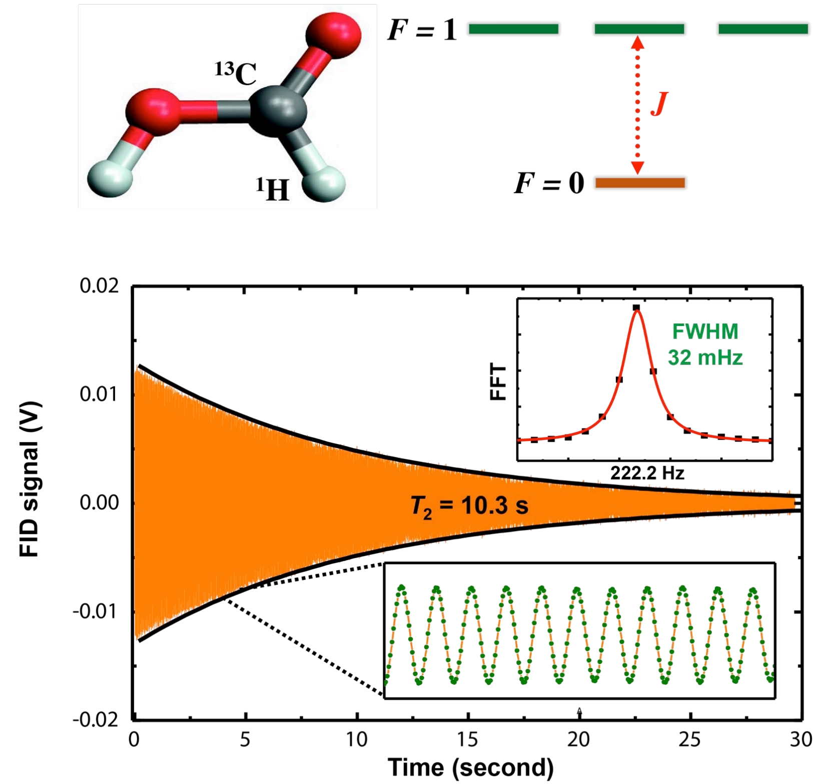
To cite this article before publication: Antoine Garcon *et al* 2017 *Quantum Sci. Technol.* in press https://doi.org/10.1088/2058-9565/aa9861

https://arxiv.org/abs/1707.05312

Suggestion:
Sideband detection using ZULF NMR
(zero-to-ultralow field)
Very light ALP dark matter

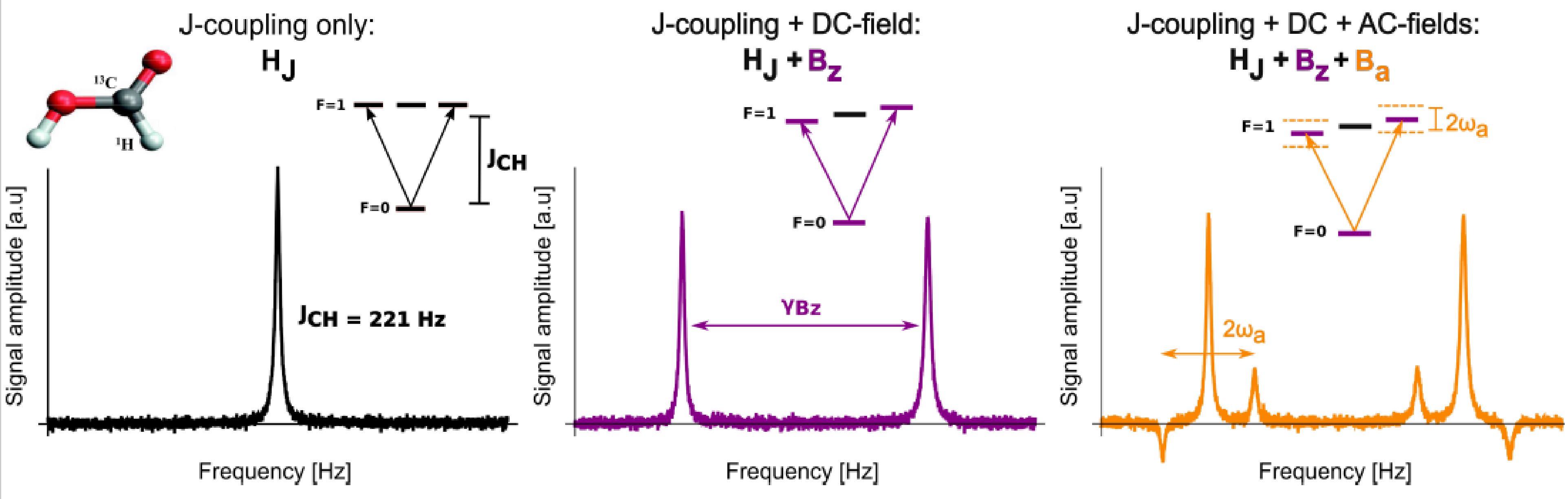
Zero-Field NMR





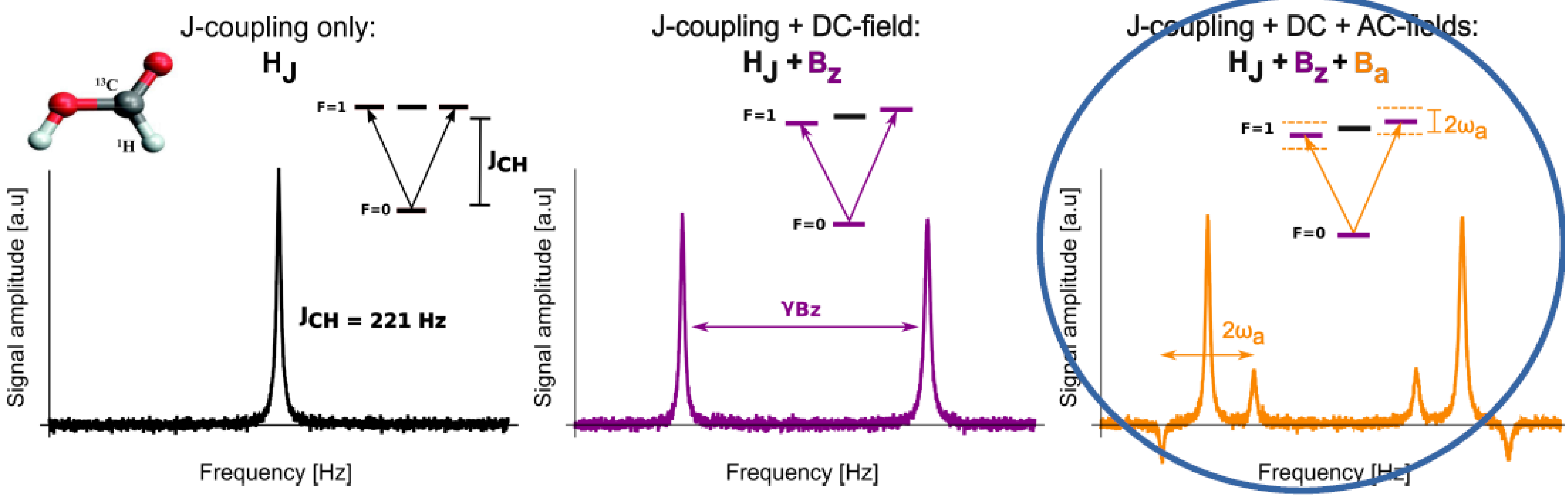
Formic acid

single J-coupling: ^{13}C-^{1}H

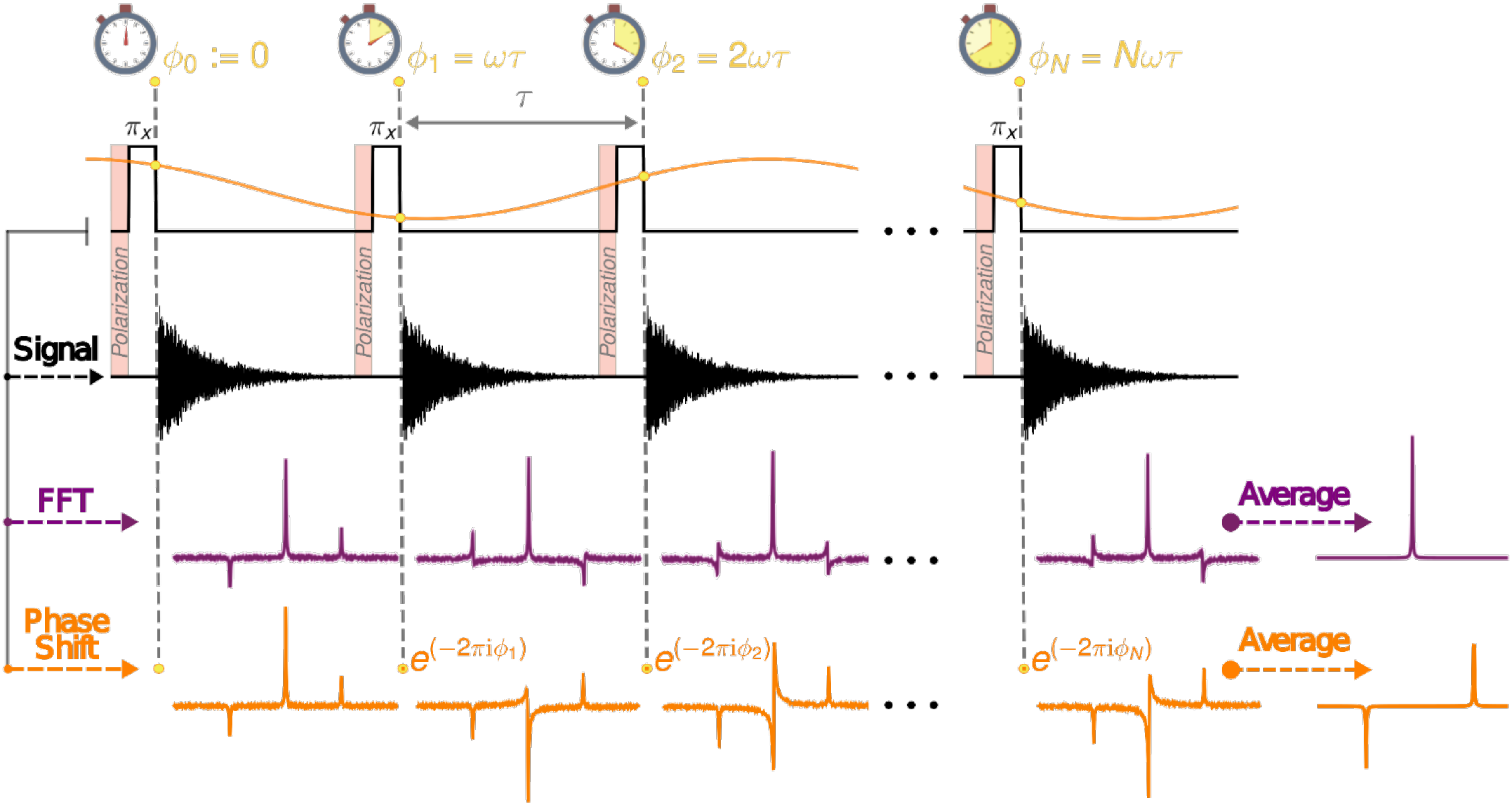


Dark-matter field induces sidebands !

sidebands amplitude $\propto B_{ALP}/\omega_{ALP}$



Coherent averaging – axion coherence time > T_2



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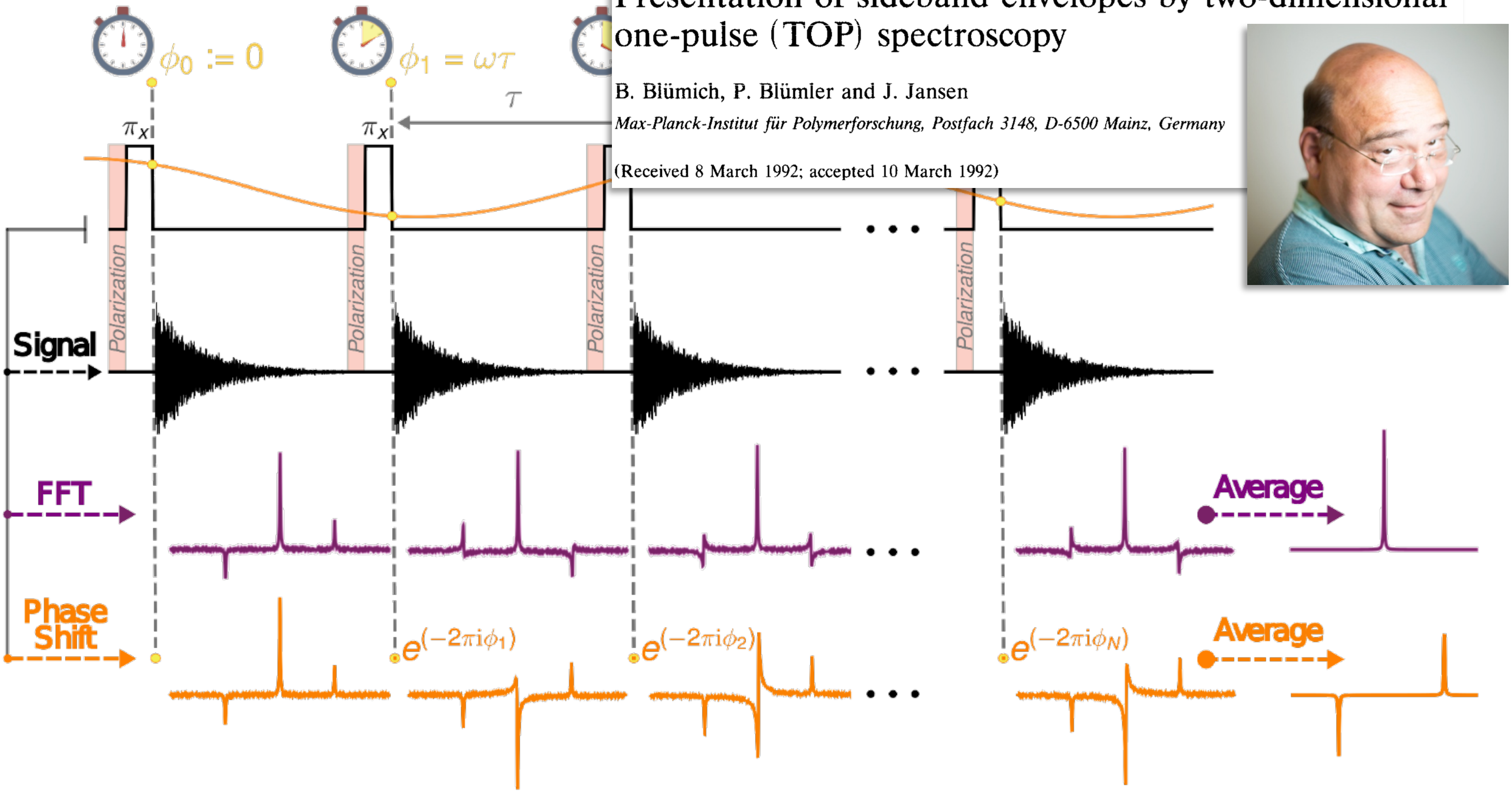
Coherent averaging – axion coherence time > T_2



Short Communication

Presentation of sideband envelopes by two-dimensional one-pulse (TOP) spectroscopy

B. Blümich, P. Blümler and J. Jansen

Max-Planck-Institut für Polymerforschung, Postfach 3148, D-6500 Mainz, Germany

(Received 8 March 1992; accepted 10 March 1992)

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Coherent averaging – axion coherence time > T_2

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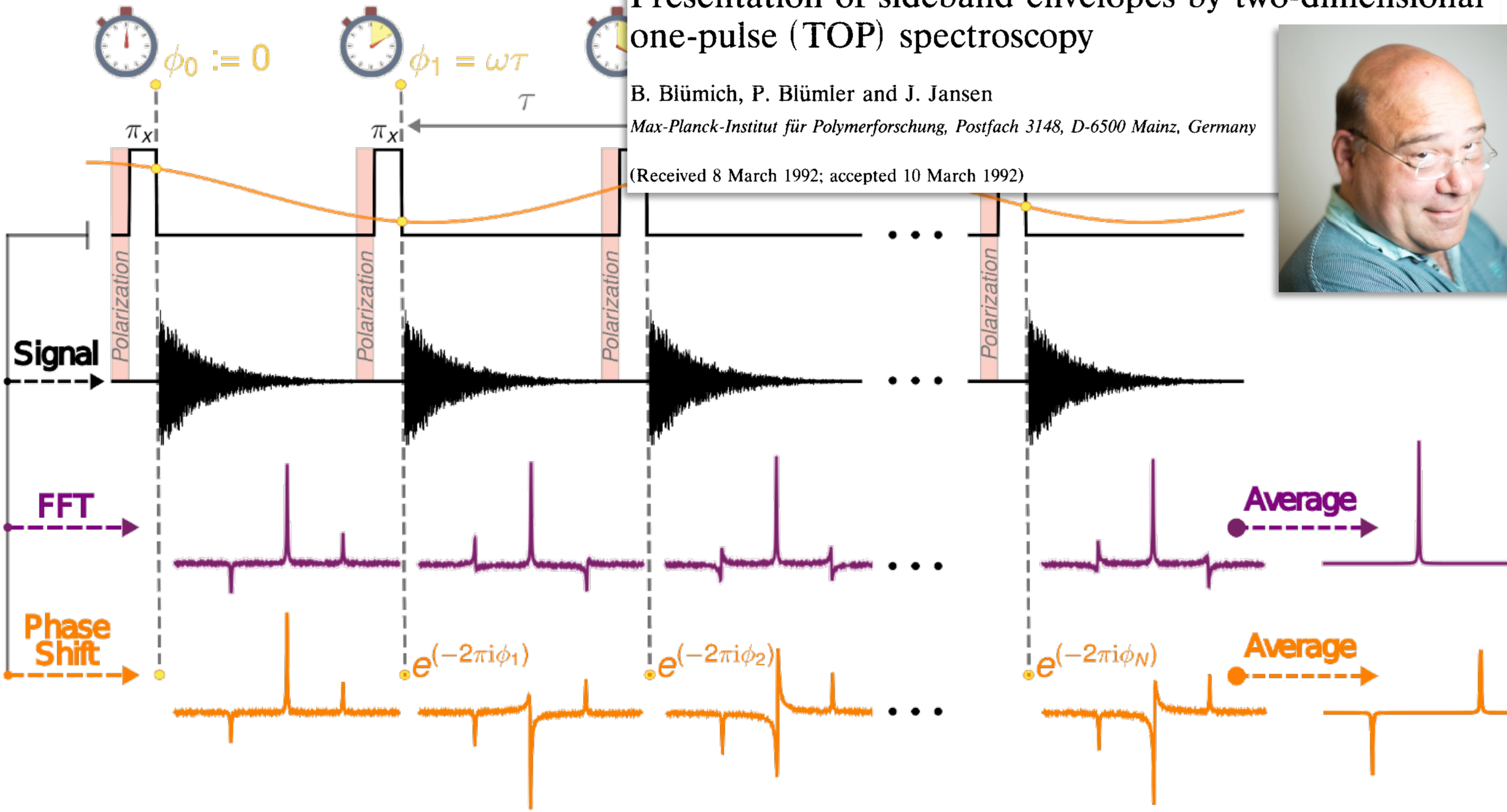

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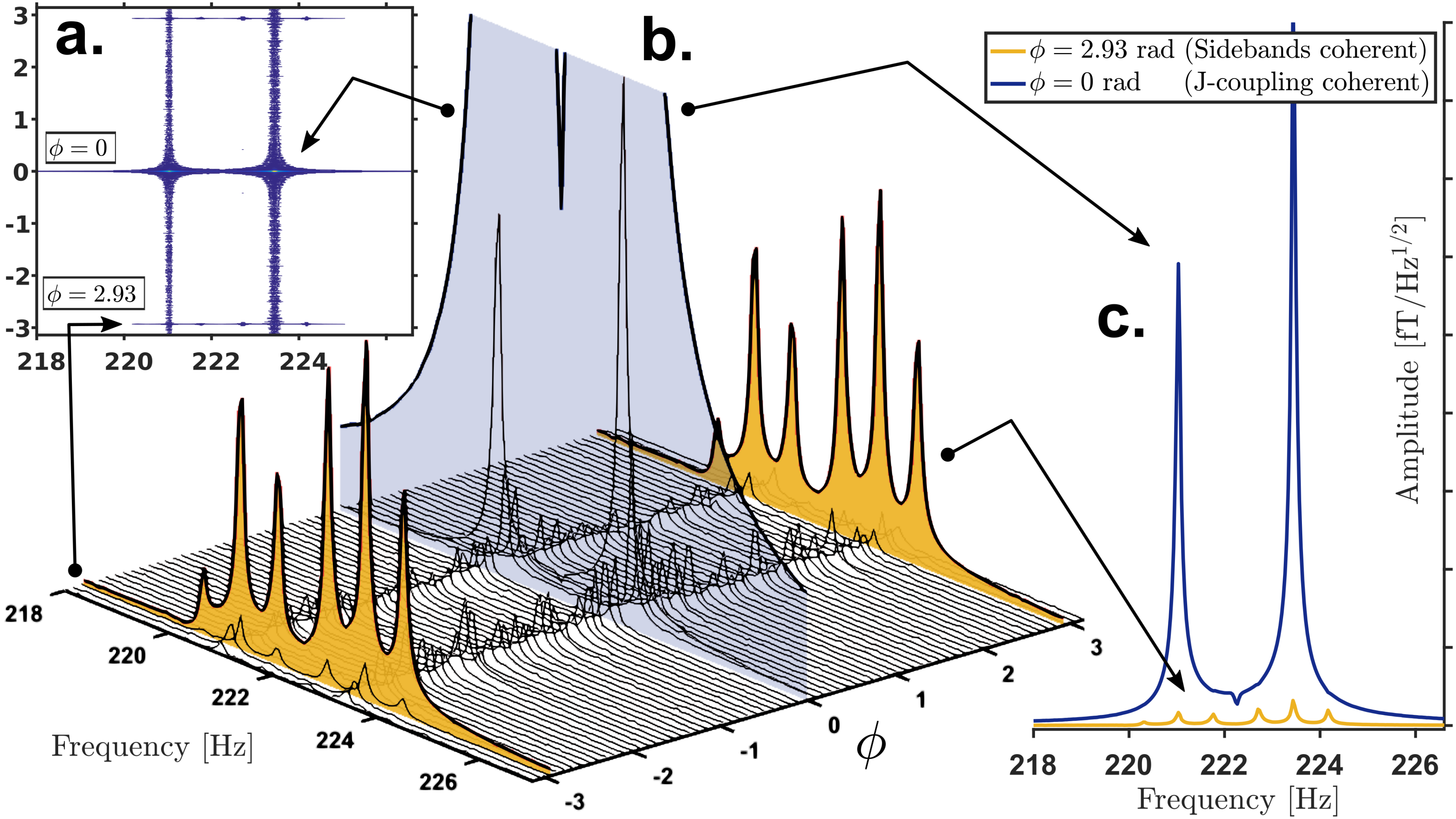
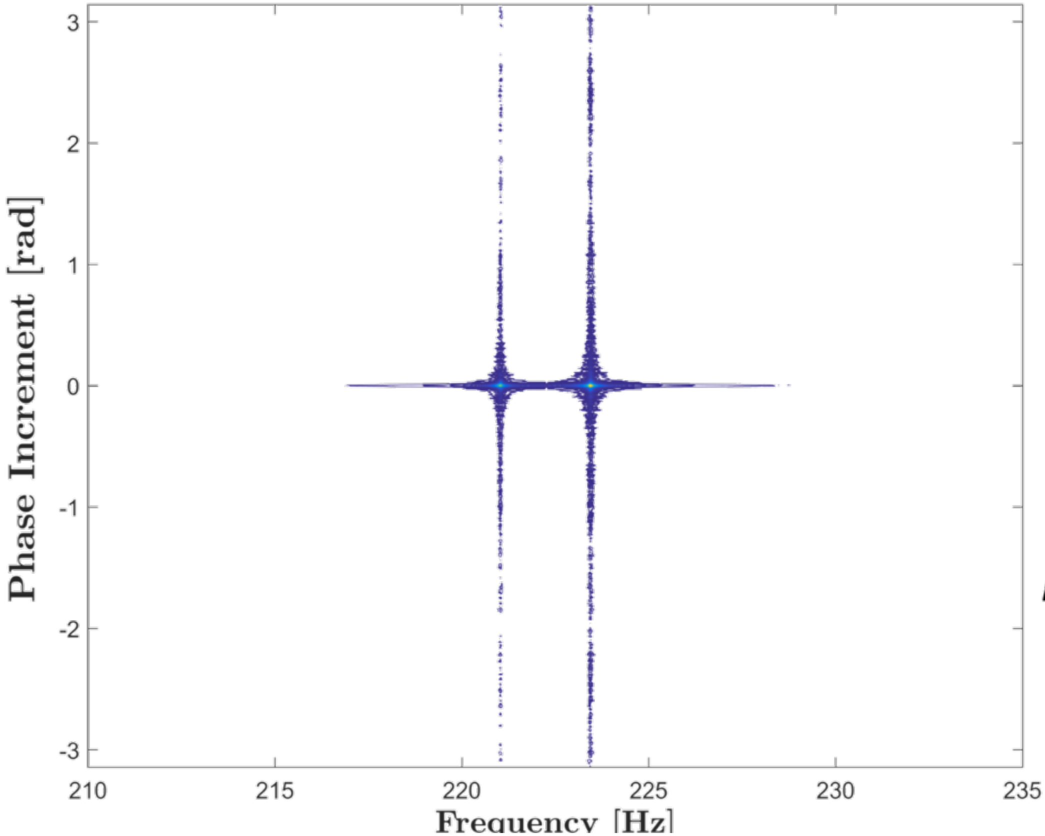
Proof of Principle: Measure a Small AC Field





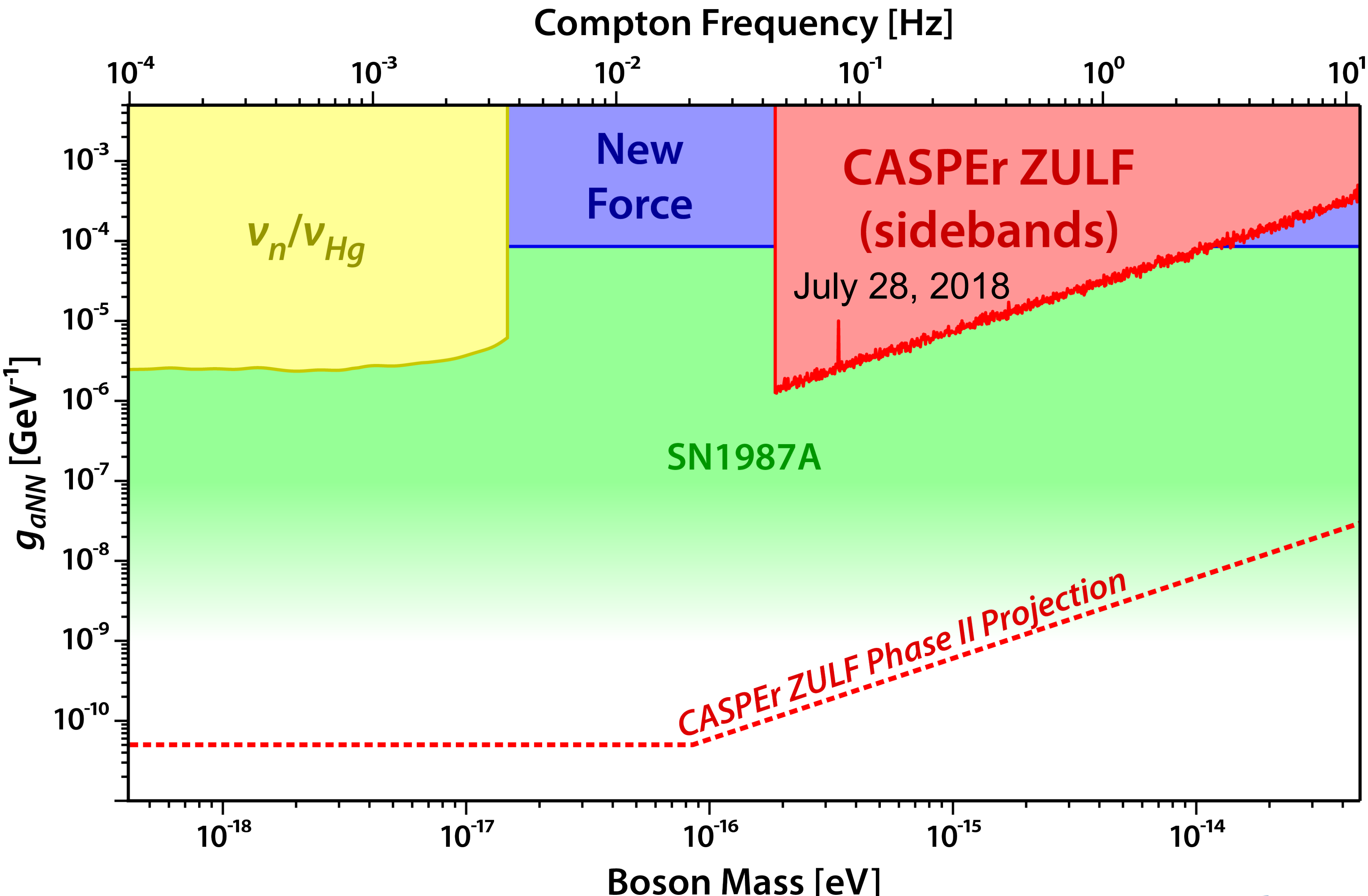
- No sidebands in *real* conditions

- New limits:
Amplitude & frequency

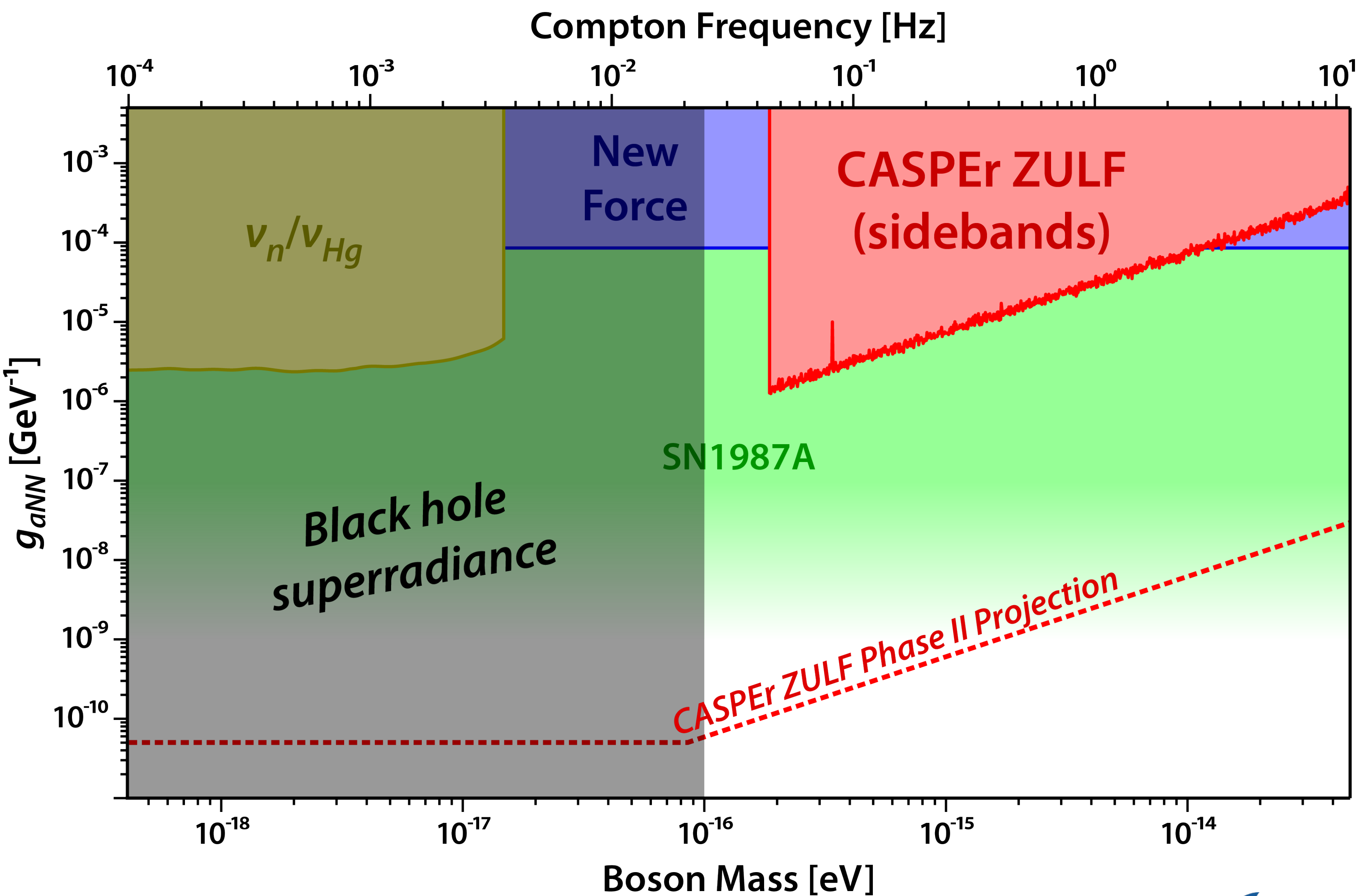
$$\vec{B}_{\mathrm{ALP}} \propto g_{\mathrm{aNN}} \cos(m_{\mathrm{ALP}} t) \vec{v}$$

New upper bounds at given frequencies

Limits!


Compton Frequency [Hz]
10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}
ν_n/ν_{Hg}
New Force
CASPEr ZULF (sidebands)
July 28, 2018
SN1987A
CASPEr ZULF Phase II Projection
g_{aNN} [GeV^{-1}]
10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10}
10^{-18} 10^{-17} 10^{-16} 10^{-15} 10^{-14}
Boson Mass [eV]

Limits!



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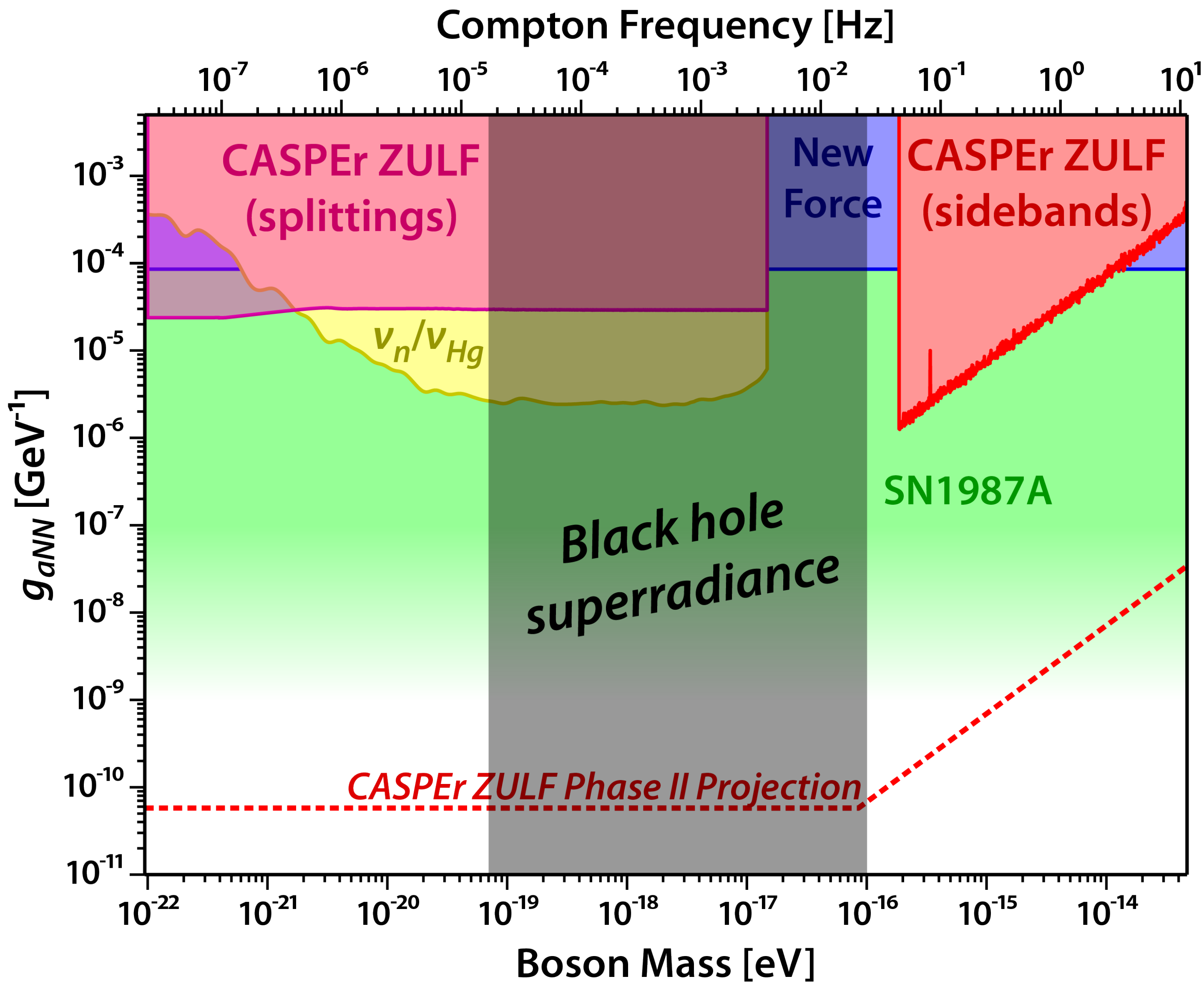
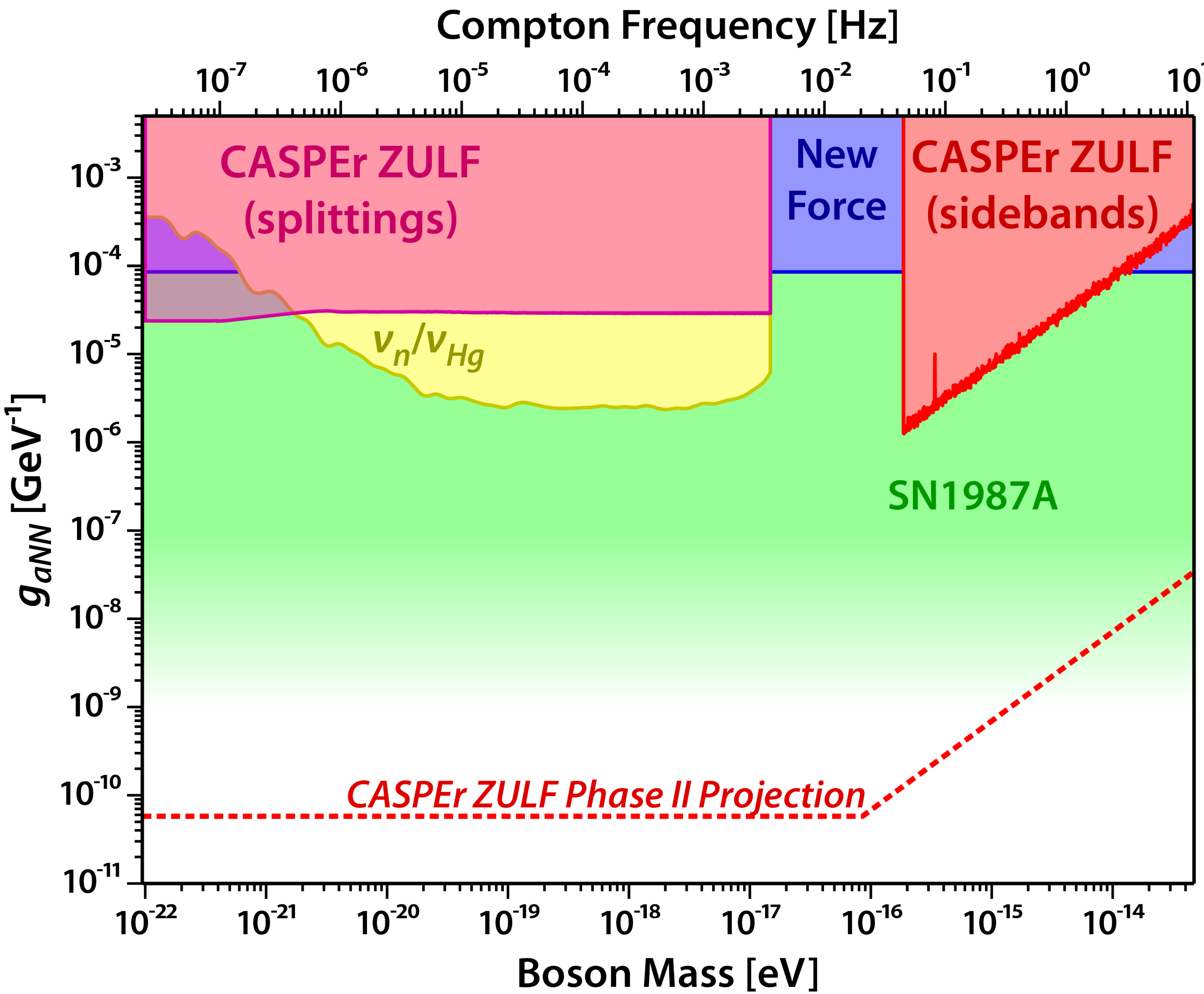
Limits!



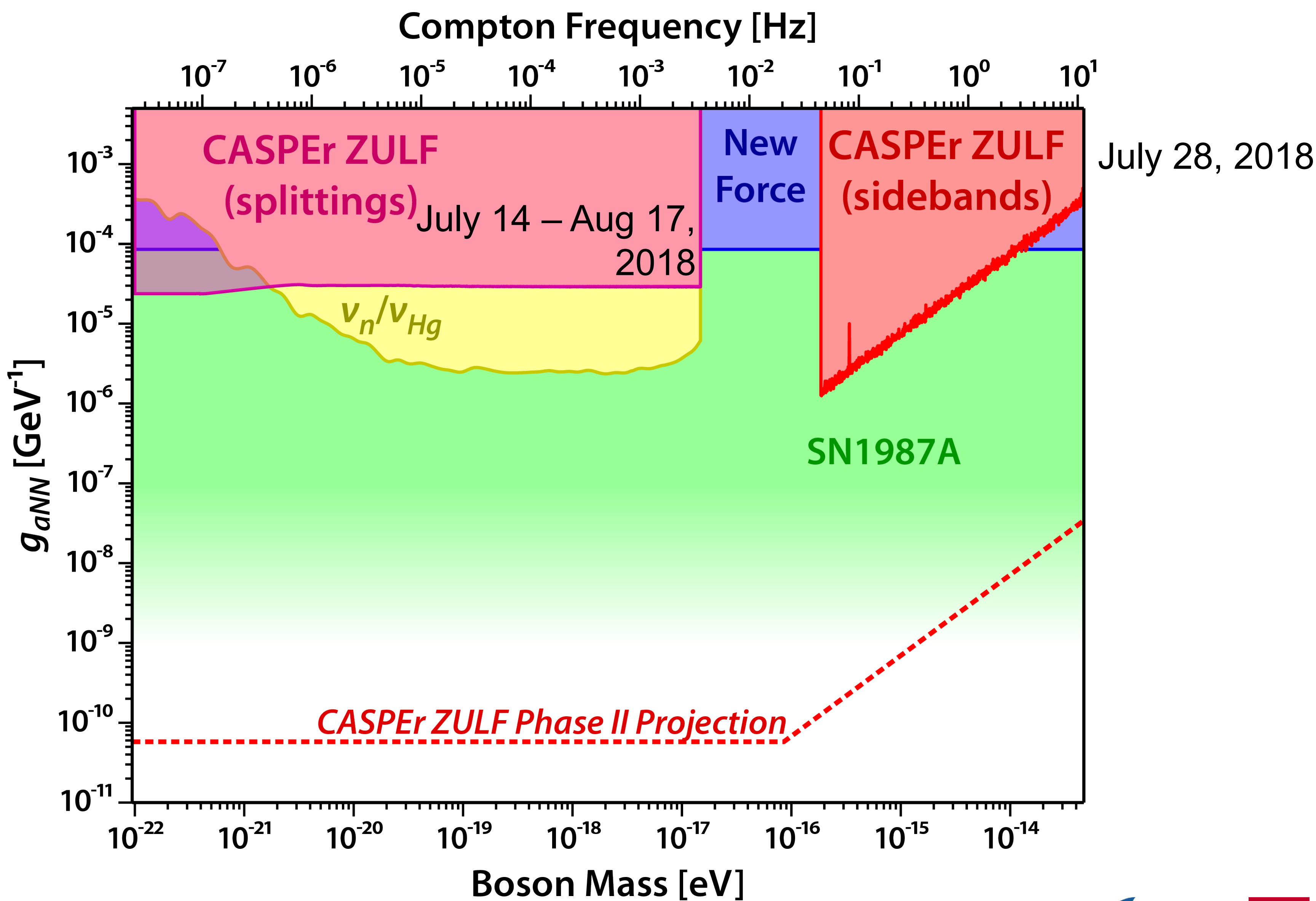
Compton Frequency [Hz]
10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0 10^1
CASPEr ZULF
(splittings)
New
Force
CASPEr ZULF
(sidebands)
νn/νHg
SN1987A
Black hole
superradiance
CASPEr ZULF Phase II Projection
gaNN [GeV^-1]
10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11
10^-22 10^-21 10^-20 10^-19 10^-18 10^-17 10^-16 10^-15 10^-14
Boson Mass [eV]

Limits!

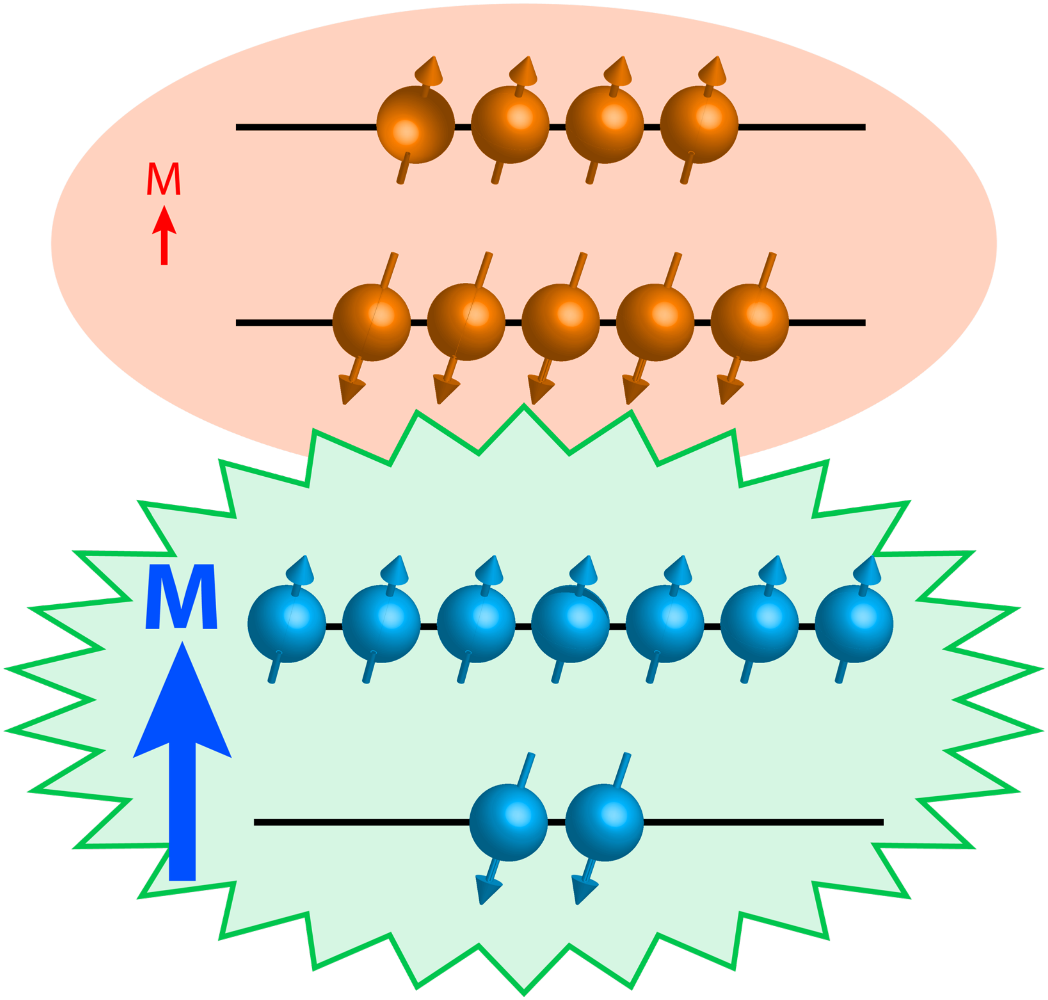


Compton Frequency [Hz]
10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0 10^1
CASPEr ZULF
(splittings)
New
Force
CASPEr ZULF
(sidebands)
ν_n/ν_{Hg}
SN1987A
CASPEr ZULF Phase II Projection
g_{aNN} [GeV^{-1}]
10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11
10^-22 10^-21 10^-20 10^-19 10^-18 10^-17 10^-16 10^-15 10^-14
Boson Mass [eV]

Limits!


Compton Frequency [Hz]
10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 10^0 10^1
CASPEr ZULF
(splittings)
July 14 – Aug 17, 2018
New Force
CASPEr ZULF
(sidebands)
July 28, 2018
νn/νHg
SN1987A
CASPEr ZULF Phase II Projection
gaNN [GeV-1]
10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11
10^-22 10^-21 10^-20 10^-19 10^-18 10^-17 10^-16 10^-15 10^-14
Boson Mass [eV]

Next Step: Nuclear Spin Polarization



"Thermal" spin polarization at 1T, 300K:

$\sim 10^{-6}$

Possibilities:

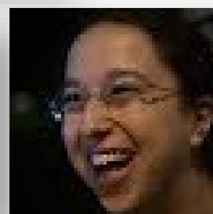
- Dynamic Nuclear Polarization
- Parahydrogen-Induced Polarization
- Other Tricks

Acknowledgements









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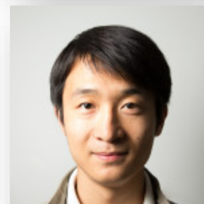
GSI

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

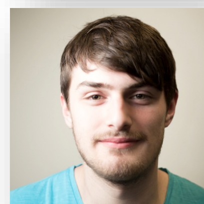
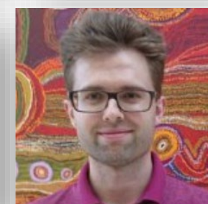
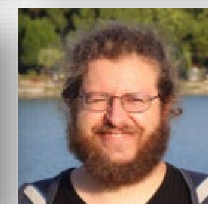
Stockholm University







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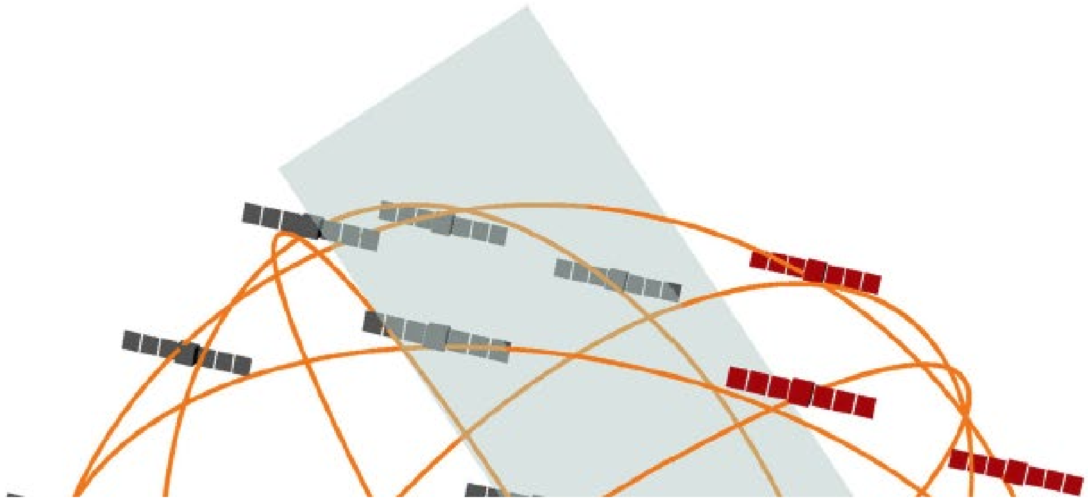
GNOME NETWORK 2017



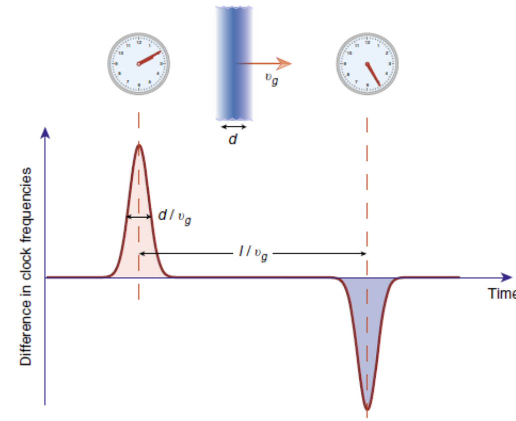
First observation with global network of optical atomic clocks aimed for a dark matter detection

P. Wcisło,[1,*] P. Ablewski,[1] K. Beloy,[2] S. Bilicki,[1,3] M. Bober,[1] R. Brown,[2] R. Fasano,[2] R. Ciuryło,[1] H. Hachisu,[4] T. Ido,[4] J. Lodewyck,[3] A. Ludlow,[2] W. McGrew,[2] P. Morzyński,[1,4] D. Nicolodi,[2] M. Schioppo,[2,5] M. Sekido,[4] R. Le Targat,[3] P. Wolf,[3] X. Zhang,[2] B. Zjawin,[1] and M. Zawada[1,†]

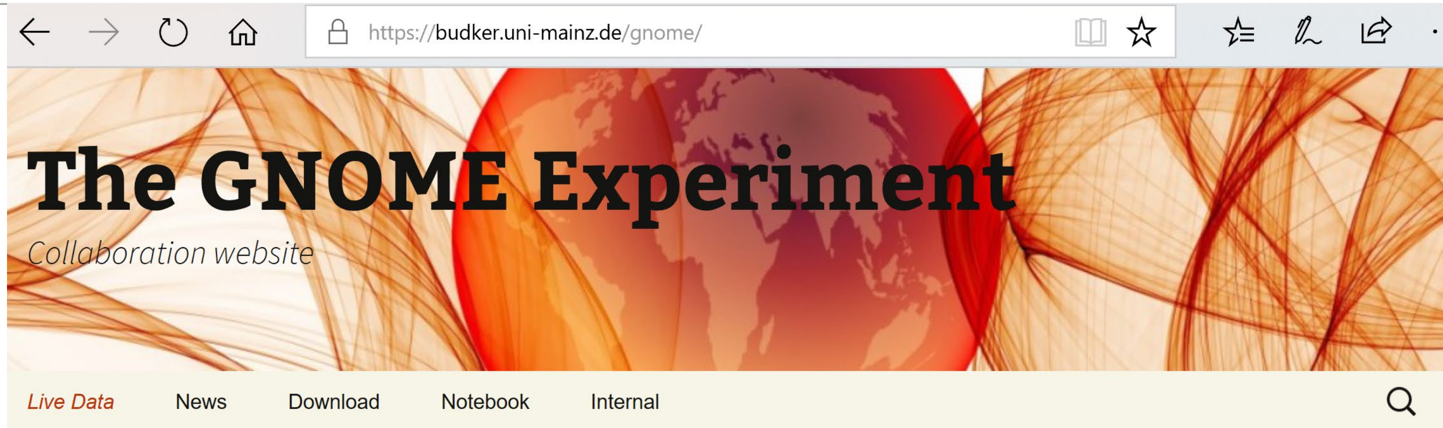
[1]*Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University, Grudziądzka 5, PL-87-100 Toruń, Poland*
[2]*National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA*
[3]*LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, 61 avenue de l'Observatoire 75014 Paris, France*
[4]*National Institute of Information and Communications Technology, 4-2-1 Nukuikitamachi, Koganei, 184-8795 Tokyo, Japan*
[5]*National Physical Laboratory (NPL), Teddington, TW11 0LW, United Kingdom*

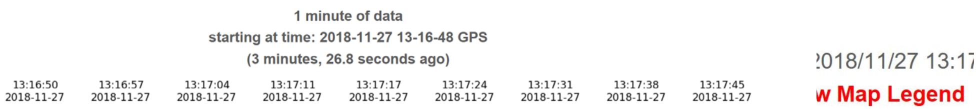
(Dated: June 14, 2018)

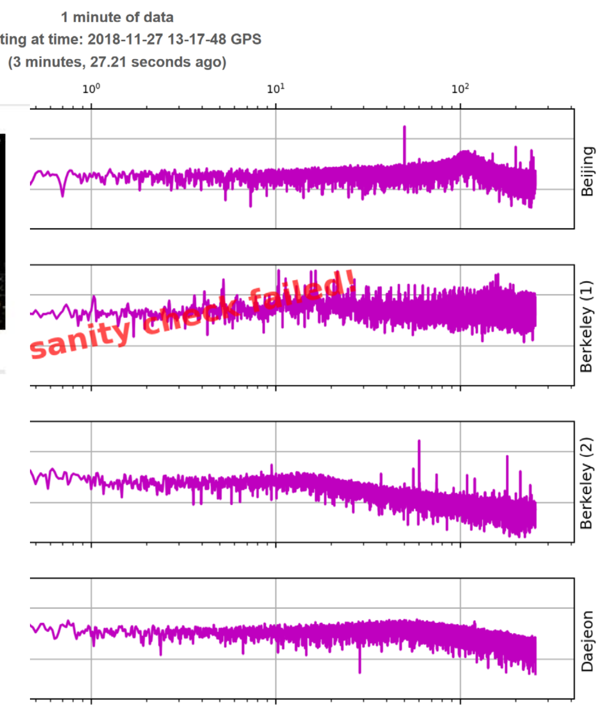
We report on the first earth-scale quantum sensor network based on optical atomic clocks aimed at dark matter (DM) detection. Exploiting differences in the susceptibilities to the fine-structure constant of essential parts of an optical atomic clock, i.e. the cold atoms and the optical reference cavity, we can perform sensitive searches for dark matter signatures without the need of real-time comparisons of the clocks. We report a two orders of magnitude improvement in constraints on transient variations of the fine-structure constant, which considerably improves the detection limit for the standard model (SM) - DM coupling. We use Yb and Sr optical atomic clocks at four laboratories on three continents to search for both topological defect (TD) and massive scalar field candidates. No signal consistent with a dark-matter coupling is identified, leading to significantly improved constraints on the DM-SM couplings.



50000km aperture
30s sampling intervals
16 years of data



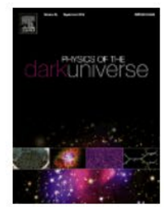




ELSEVIER

Physics of the Dark Universe

Volume 22, December 2018, Pages 162-180

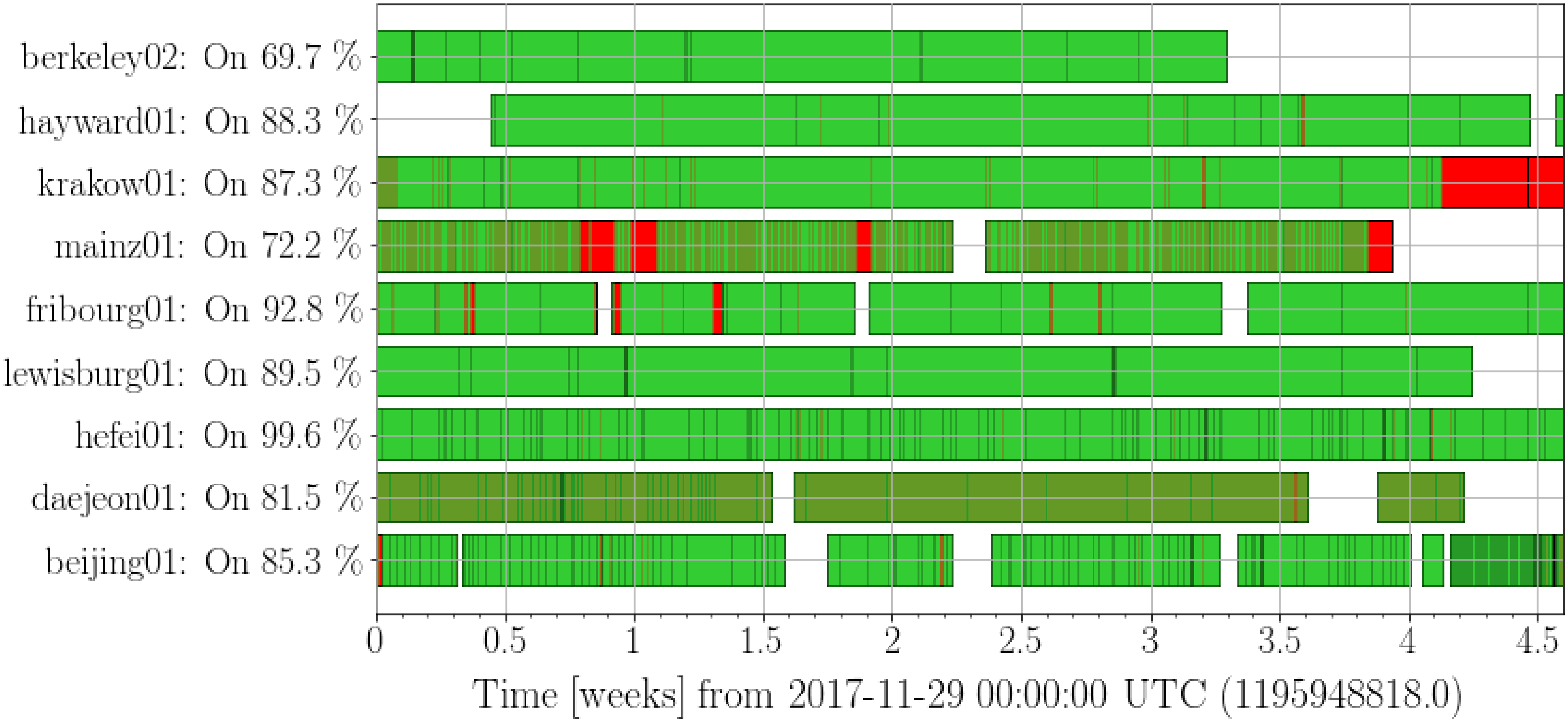


Characterization of the global network of optical magnetometers to search for exotic physics (GNOME)

S. Afach [a], D. Budker [a, b, c], G. DeCamp [d], V. Dumont [b], Z.D. Grujić [e], H. Guo [f], D.F. Jackson Kimball [d], T.W. Kornack [g], V. Lebedev [e], W. Li [f], H. Masia-Roig [a], S. Nix [h], M. Padniuk [i], C.A. Palm [d], C. Pankow [j], A. Penaflor [d], X. Peng [f], S. Pustelny [i] … D. Wurm [k]

- Magnetometers Network

Coordinated run



Detecting axion stars with GNOME

PHYSICAL REVIEW D **97**, 043002 (2018)

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. Wickenbrock[2]

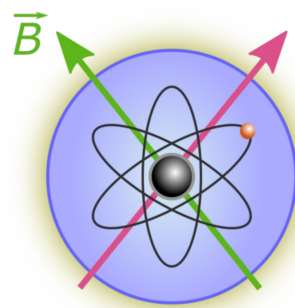
Optical magnetometry in Germany August 2019!

Sun, 11th	Mon, 12th	Tue, 13th	Wed, 14th	Thu, 15th	Fr, 16th	Sat, 17th
QSM	**QSM**	**QSM**	**QSM->WOPM**	**WOPM**	**WOPM**	**GNOME**
Bad Honnef	Bad Honnef	Bad Honnef	BH/Mainz	Mainz	Mainz	Mainz

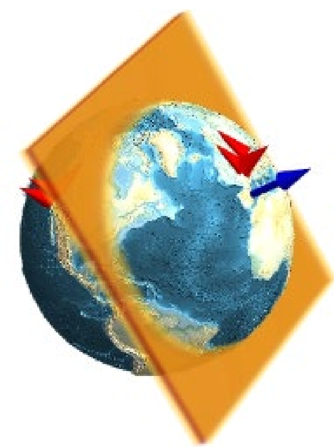
Sun, 18th
GNOME
Mainz

https://magnetometry.org/

WOPM 2019



7th Workshop on Optically Pumped Magnetometers



HIM Helmholtz-Institut Mainz JG|U

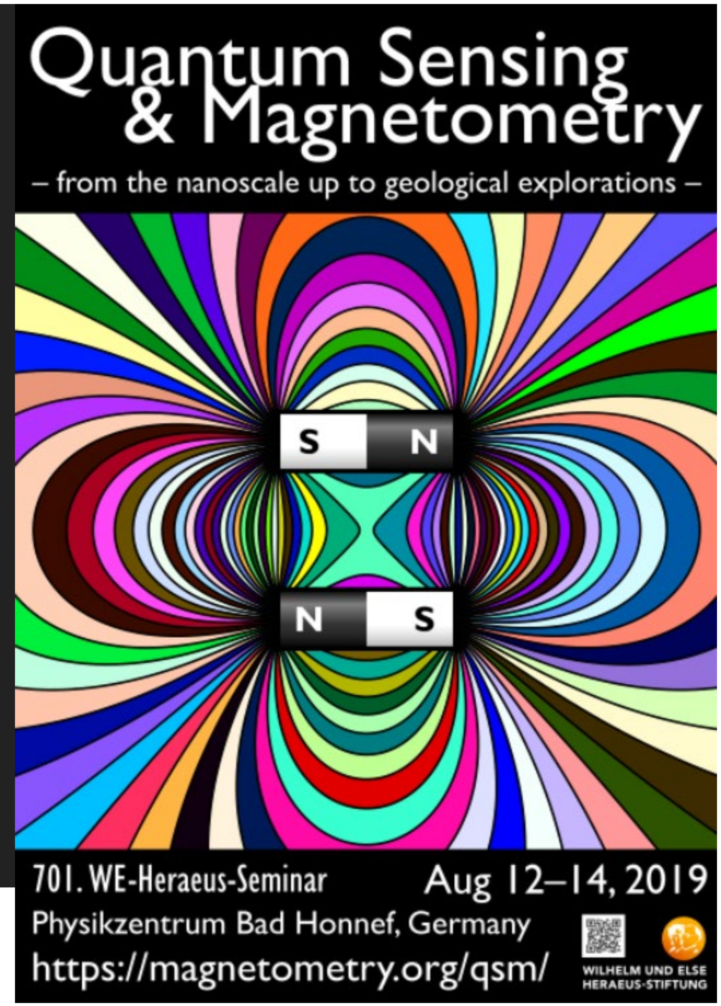
QSM WOPM GNOME

Scientific organizers:

- Lutz Trahms – (Physikalisch-Technische Bundesanstalt, Berlin)
- Fedor Jelezko – (Ulm University, Ulm)
- Ilja Gerhardt – (Max Planck Inst. for Solid State Research, Stuttgart)

Invited speakers (confirmed):

- Georg Bison (Schweiz)
- Dmitry Budker (Mainz)
- Corey Cochrane (Pasadena)
- Svenja Knappe (Boulder)
- Rainer Körber (Berlin)
- Morgan Mitchell (Casteldefells)
- Eugene Polzik (Kopenhagen)
- Erling Riis (Glasgow)
- Mike Romalis (Princeton)
- Piet Schmidt (Braunschweig)
- Justin Schneiderman (Gothenburg)
- Ronny Stolz (Jena)
- Phillip Walther (Wien)
- Jörg Wrachtrup (Stuttgart, NV-center magnetometry)



7th Workshop on Optically Pumped Magnetometers

List of topics:

Optically **P**umped **M**agnetometers

- (alkali) atoms
- noble gases
- nitrogen-vacancies
- & other defect centers
- Hybrid sensors
- Bulk sensing

Novel OPM methods and techniques

OPM applications in

- medicine
  - magnetocardiography
  - magnetoencephalography
- biology
- materials science
- (aero-)space
- geology

OPM applications in

- fundamental science
  - dark matter detection
  - electric dipole moment searches

OPM theory

WOPM 2019

Key dates:

- Abstracts/ Registration: June 14, 2019
- Acceptance notice: July 19, 2019

Scientific committee:

- Peter Schwindt, Chair
  Sandia National Labs
- Svenja Knappe
  University of Colorado & Fieldline
- Tetsuo Kobayashi
  Kyoto University
- Lauri Parkkonen
  Aalto University & MEGIN
- Tilmann Sander
  PTB Berlin
- Arne Wickenbrock
  Helmholtz-Institut Mainz

Organizers:

- Ilja Gerhardt
- Arne Wickenbrock

https://magnetometry.org/wopm/

wopm@magnetometry.org

August 14-16, 2019

Helmholtz-Institut Mainz

JG|U

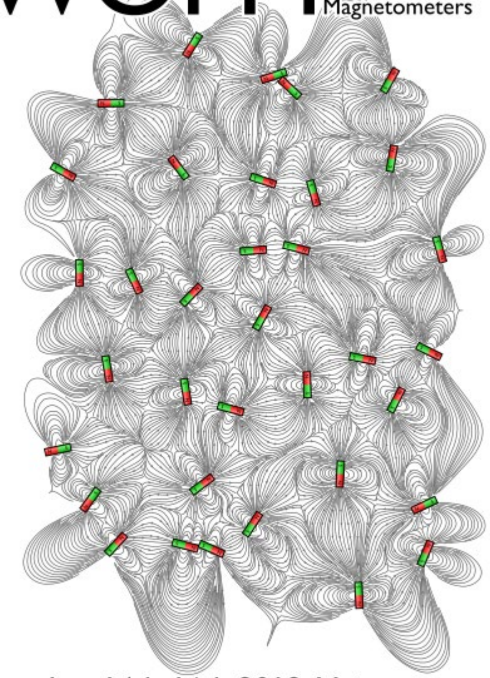
Optical magnetometry in Germany August 2019!

Sun, 11th	Mon, 12th	Tue, 13th	Wed, 14th	Thu, 15th	Fr, 16th	Sat, 17th
QSM	**QSM**	**QSM**	**QSM->WOPM**	**WOPM**	**WOPM**	**GNOME**
Bad Honnef	Bad Honnef	Bad Honnef	BH/Mainz	Mainz	Mainz	Mainz

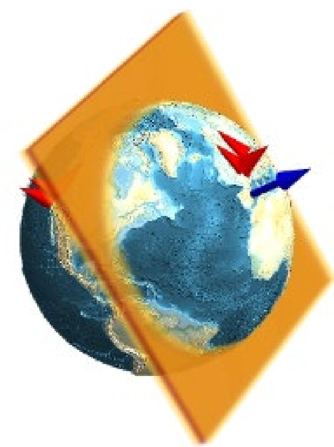
Sun, 18th
GNOME
Mainz

https://magnetometry.org/

WOPM 7th annual Workshop on Optically Pumped Magnetometers



Aug 14th-16th 2019, Mainz
https://magnetometry.org/wopm/



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