The Cosmic Axion Spin Precession Experiment (CASPEr) Progress and results A. Wickenbrock for the CASPEr collaborations



JOHANNES GUTENBERG UNIVERSITÄT MAINZ



Acknowledgements



NMR Meets Dark Matter

The Cosmic Axion Spin Precession Experiment (CASPEr)



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









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WIMPs Weakly interacting massive particlesMACHOs Massive compact halo objectRAMBOs Robust associations of massive baryonic objects





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Axion: Very light (mass 10⁻¹²-1eV/c²) Spin 0 Minimal interaction



Axion experiments $a \rightarrow - g_{a\gamma\gamma}$ $\gamma \rightarrow \cdots \gamma$ $g_{a\gamma\gamma}$ $\gamma \rightarrow \cdots \gamma$ $g_{a\gamma\gamma}$ $\gamma \rightarrow \cdots \gamma$ $g_{a\gamma\gamma}$ γ^{*} γ^{*}

e.g. CAST (Cern Axion Solar Telescope)









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







Axion experiments $a \rightarrow - g_{a\gamma\gamma}$ $\gamma \rightarrow \varphi$ γ

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













"ADMX magnet installation" by Lamestlamer HIM Helmholtz-Institut Mainz



JGU



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





04.06.2019, PATRAS, Freiburg



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







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Detecting oscillating induced electric dipole moments with NMR





• Polarized nuclear spins

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- Polarized nuclear spins
- B field

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- Polarized nuclear spins
- B field
- E field perp to B

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- ->Oscillating torque on spins

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Detecting oscillating induced electric dipole moments with NMR



Cosmology: Q=10⁶!

HIM

How to search for Axions (ALPs) ?



CASPEr – Wind idea

Detecting oscillating torque on nuclear spins









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CASPEr stages

CASPEr now \rightarrow Analysing existing data (low frequency)



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 $\begin{array}{rcl} \mbox{CASPEr Wind} & \rightarrow & \mbox{Measurement of axion field gradient} \\ & & (Wind) \mbox{ with nuclear spins in magnetic field} \end{array}$



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-high field (inductive pick-up)



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CASPEr Electric \rightarrow Applying additional electric field Alex Sushkov et al @ Boston university



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CASPER Electric – Talk at 9:36am



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Searches for axion-nucleon QCD coupling



QCD Axion < 100neV





 Low field (SQUID detection up to 2MHz) – Status and next steps



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3. In General: Haloscopes looking for sub neV ALPs might need to relax their experimental constraints.



1. CASPEr Wind Low Field (hyperpolarized Xenon)

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

Axion Gradient coupling Nuclear spins: 0.25ml liquid Xenon 129 Hyperpolarization P=1 Coherence time $T_1 \sim 1000s$ Resonance frequency: 11.83 MHz/T



1. CASPEr Wind Low Field (hyperpolarized Xenon)





CASPEr Wind LF status

 Update Flange to
ISO 160 F ? Inner Diameter of Nb Tube is 107 mm Orange "Female Part": Let's increase the height (by 20 mm), decrease the inner diameter, and give it an inner thread (M30x3.5)



04.06.2019, PATRAS, Freiburg



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-superconducting snims Tpp -magnetically shielded

Delivered

Variable temperature insert - 160-180K

Super-conducting pick-up coils Triple SQUID system

> Orange "Female Part": Let's increase the height (by 20 mm), decrease the inner diameter, and give it an inner thread (M30x3.5)

ner Diamete f Nb Tube is 107 mm





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

Delivered

Variable temperature insert - 160-180K

Super-conducting pick-up coils Triple SQUID system

On the horizon

Orange "Female Part": Let's increase the height (by 20 mm), decrease the inner diameter, and give it an inner thread (M30x3.5)

ner Diamete f Nb Tube is 107 mm















Jan Conrad Alfredo Ferella Matthew Lawson







Jan Conrad Alfredo Ferella Matthew Lawson





Derek J Kimball







Jan Conrad Alfredo Ferella Matthew Lawson







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 - Helium 3: 490 MHz (ADMX 1: 461 MHz, PRD 69, 011101 (2004))



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- High field magnet is designed and waits to be ordered (15.4T)
 - Xenon 129: 180 MHz
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 - Protons: **640 MHz** (overlapping with ADMX)
















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Helmholtz-Institut Mair





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Experimental constraints and projected sensitivities of axion dark-matter searches



Science

MAAAS

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



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2a+b. CASPEr Wind @ ultralow field



2a CASPEr Wind @ ultralow field - Sidebands



Looking for oscillating magnetic fields of unknown origin for ~1 day Sensitive to B-field fluctuations!

arXiv:1902.04644



2b. CASPEr Wind @ ultralow field - Comagnetometry



Different sample: Acetonitrile-2-13C Measurement time: 1 month







2. CASPEr Wind ZULF results





3. But: the underlying assumption of constant amplitude oscillations is not justified

Virialized lineshape results in amplitude uncertainty when t_{Measurement}<t_{Coherent} (Analogous to chaotic light)



Optical magnetometry in Germany August 2019!



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Next Step: Nuclear Spin Polarization



"Thermal" spin polarization at 1T, 300K: ~10⁻⁶

Possibilities:

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



Coherent averaging – axion coherence time > T_2





Proof of Principle: Measure a Small AC Field







