Cosmic Axion Spin Precession Experiment (CASPEr) Mainz

Olympia Maliaka for the CASPEr collaboration, Mainz

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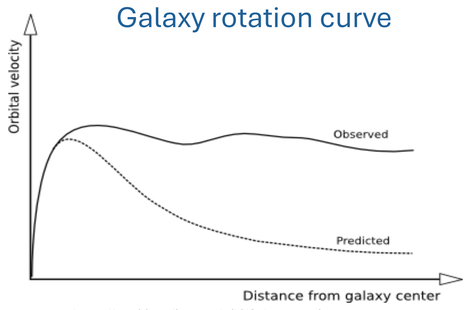
GSI

Dark matter motivation

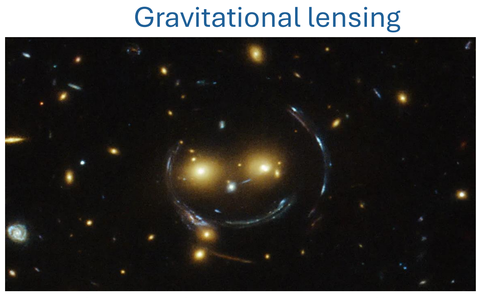
Examples of evidences supporting the existence of dark matter:

Galaxy rotation curve



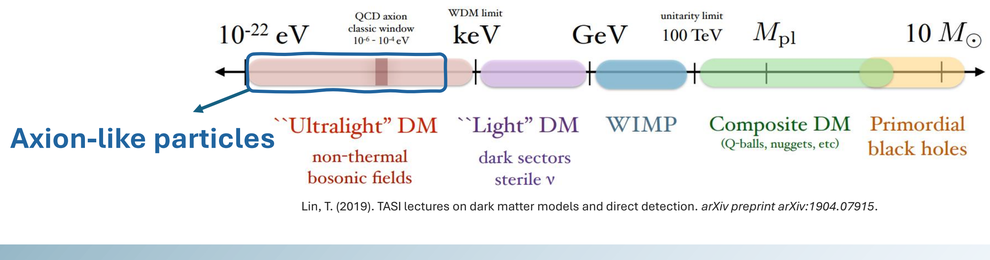
https://en.citizendium.org/wiki/Galaxy_rotation_curve

Gravitational lensing



https://science.nasa.gov/missions/hubble/hubble-sees-a-smiling-lens

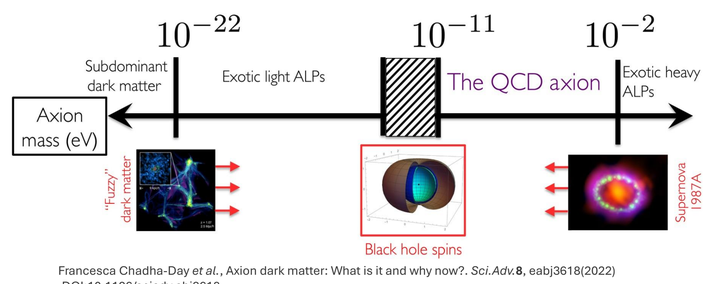
Dark matter candidates



Lin, T. (2019). TASI lectures on dark matter models and direct detection. *arXiv preprint arXiv:1904.07915*.

Axion-like particles (ALPs)

Properties	
1.	Light (<10 eV) particles
2.	Pseudoscalar bosons
3.	Axions solve the strong CP problem
4.	Weak coupling to SM particles
5.	Can be approximated as: $\alpha(t) \propto \cos(\omega_\alpha t)$



Francesca Chadha-Day *et al.*, Axion dark matter: What is it and why now?. *Sci.Adv.***8**, eabj3618(2022) .DOI:10.1126/sciadv.abj3618

ALP coupling to nuclear spin:
$H_\alpha = g_{\alpha NN} \nabla\alpha(t) \cdot \mathbf{I}$

Nuclear magnetic resonance (NMR):
$H_{NMR} = -\hbar\gamma_I \mathbf{B} \cdot \mathbf{I}$

$B = \omega_L/\gamma_I$ → gyromagnetic ratio

Larmor frequency

ALPs: pseudo-magnetic field oscillating at Compton frequency ω_α

$$B_{ALP} \propto g_{\alpha NN} v_\alpha \sqrt{2\rho_{DM}} \sin(\omega_\alpha t)$$

coupling constant; ALPs velocity; DM density; $\omega_\alpha = m_\alpha c^2/\hbar$

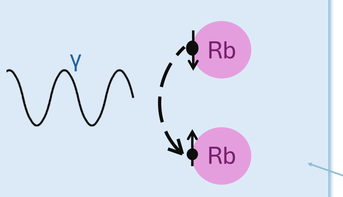
CASPEr is like NMR

D. Budker et al., *Phys. Rev. X* **4**, 021030 (2014)

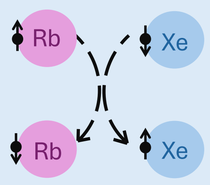
Spin exchange optical pumping (SEOP)

Working principle:

(a) Optical polarization of Rb:

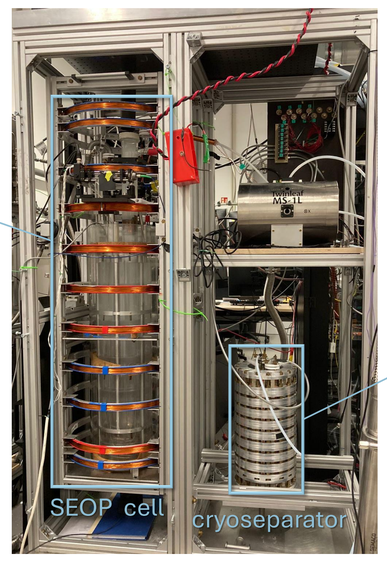


(b) Polarization transfer to ^{129}Xe:



Thermal polarization (165 K, 0.1 T) ≈ 10^{-7}

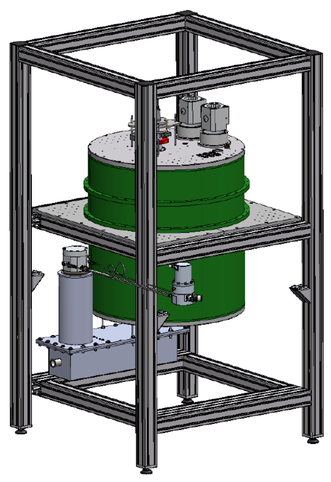
Goal with SEOP > 0.7



Hyperpolarized Xe

Higher polarization = higher sensitivity to ALPs

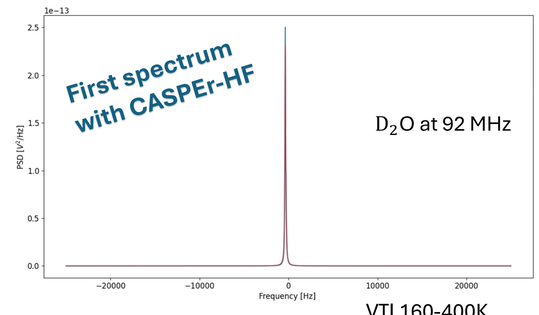
CASPEr-HF setup

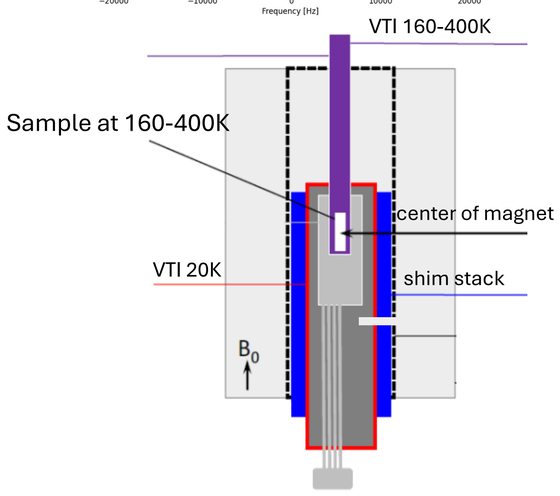


14.1 T tunable superconducting magnet

Assembled in beginning of 2024

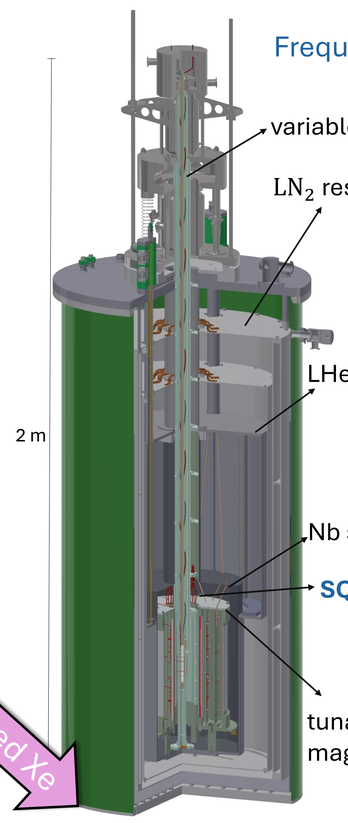
Frequency range: 4.2 MHz to 600 MHz

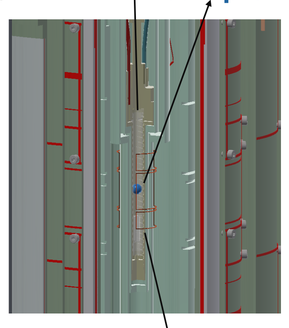




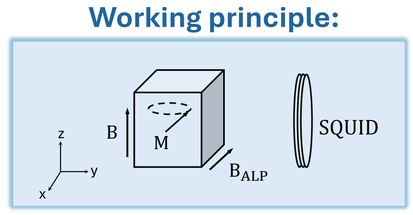
CASPEr-LF setup

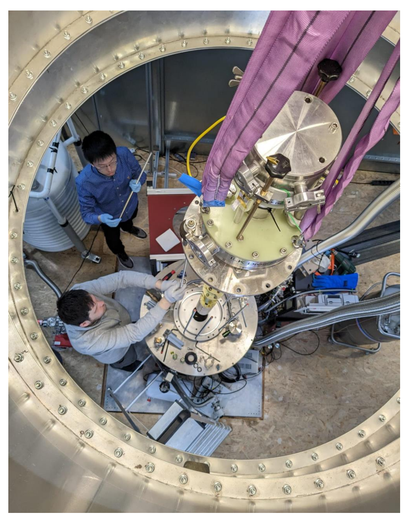
Frequency range: 1 kHz to 4.2 MHz





Working principle:





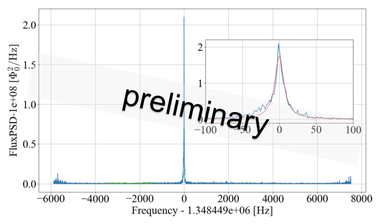
Julian and Yuzhe inserting the VTI into the cryostat

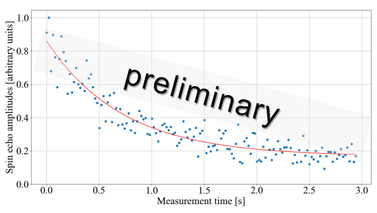
Hyperpolarized Xe

Future sample: hyperpolarized liquid xenon

DM search-demonstration with CASPEr-LF

DM-search procedure	
1.	Signal characterization (NMR)
2.	Carr-Purcell-Meiboom-Gill pulse sequence (T_2^* measurement)
3.	100 s record data
4.	Ramp field (Helmholtz coils)
5.	Repeat

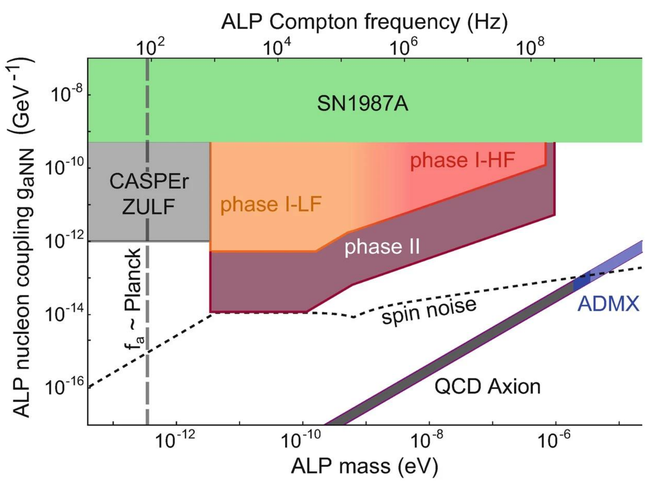




Sample: thermally polarized liquid methanol

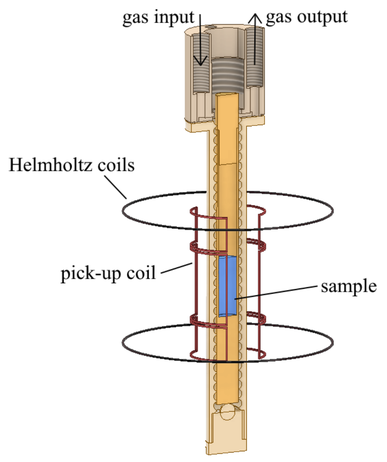
Scanning range: 240 Hz around 1.34 MHz

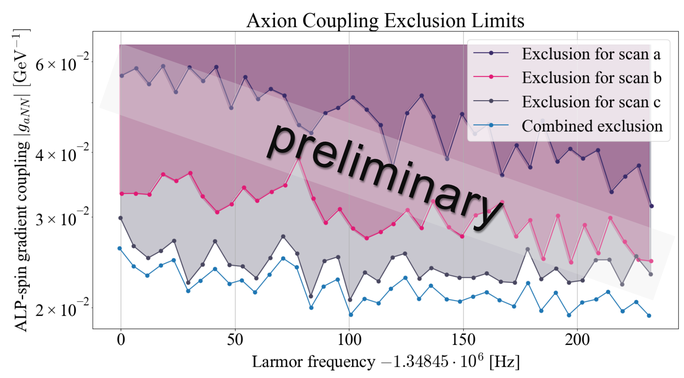
What is next?



1. Transport and liquefaction of hyperpolarized xenon
2. Dark matter searches with hyperpolarized xenon
3. Dark matter searches with pre-polarized samples

.... and more





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