Axion detection with ^{3}He A1 phase

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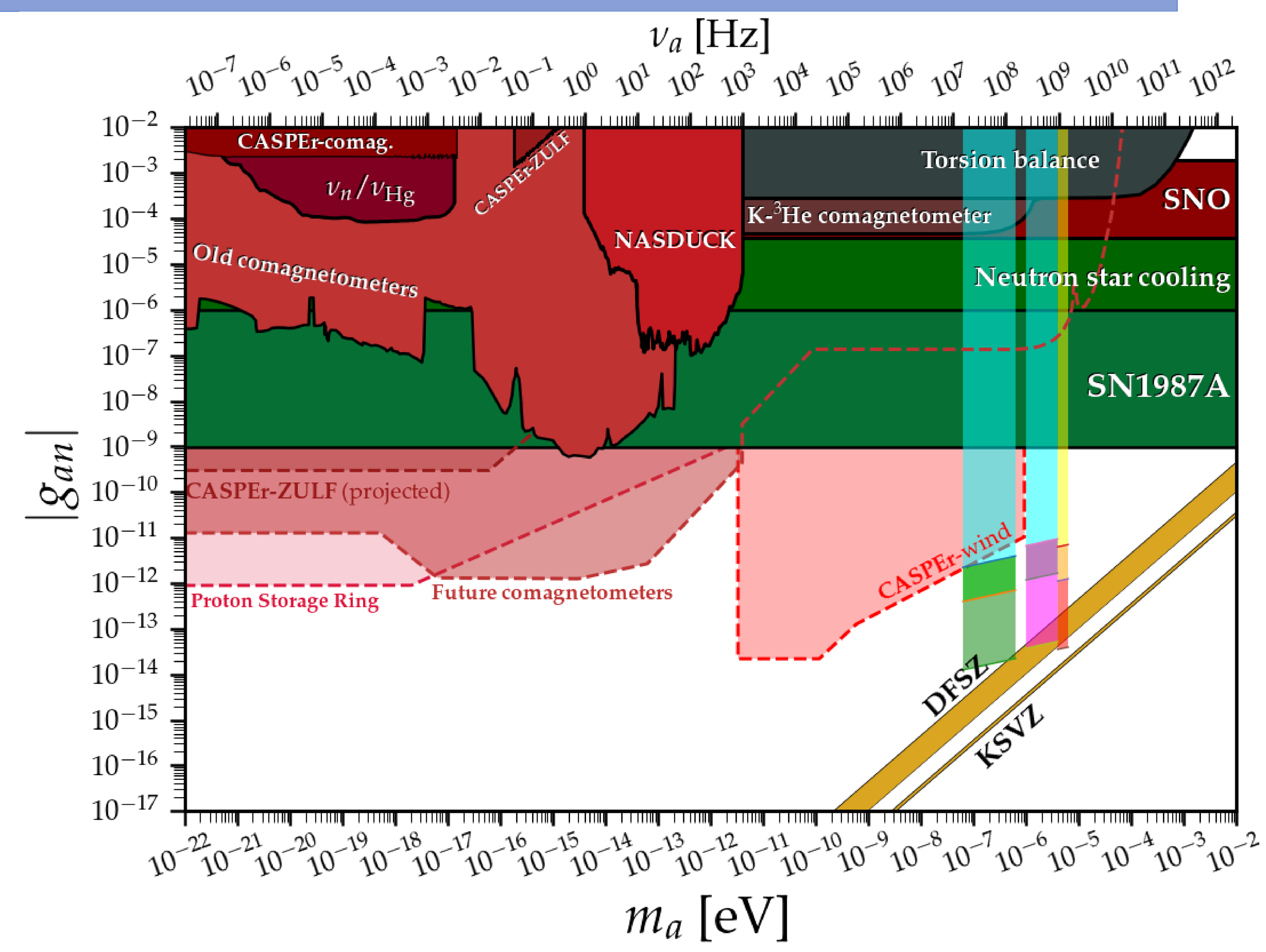
Take home message

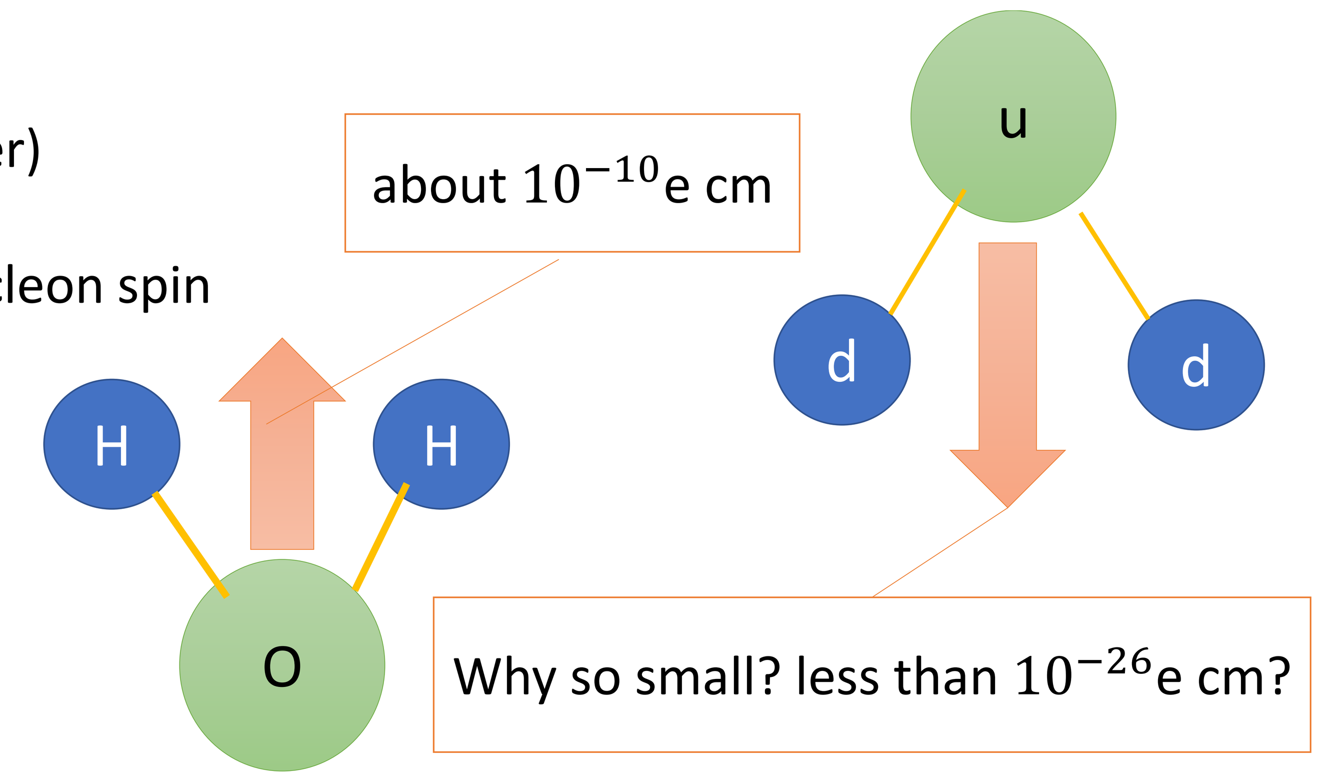
・With ^{3}He nucleon spin, both KSVZ and DFSZ type axions are detectable in principle.

・To reach the QCD band, we expect future quantum technologies.



Axion

Axion … one of promising dark matter candidates
QCD axion … axion with capability of explaining the small neutron electric dipole moment (c.f. water)
Primary candidates of QCD axions…
KSVZ axion…only coupled to nucleon spin ↔DFSZ axion …coupled to various spins other than nucleon spin
→**With ^{3}He nucleon spin, we can target both types of QCD axion**.

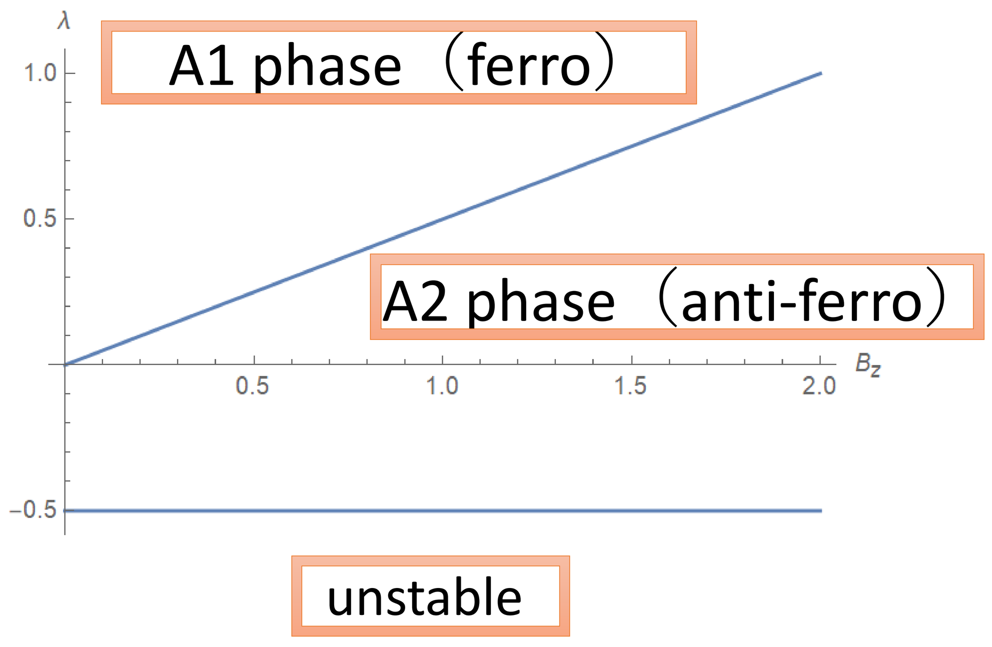


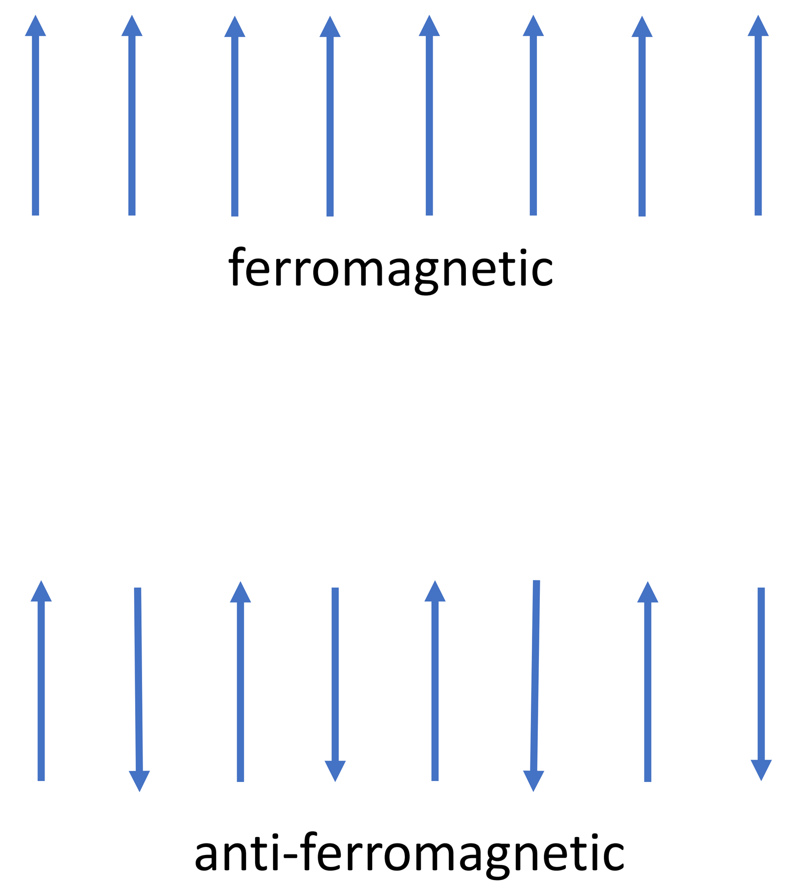
Superfluid ^{3}He

Superfluid… (Cooper pairs) orbital angular momentum + spin angular momentum
^{3}He…electrically neutral → angular momentum expected to be unexcited by axion or photon
∴ Fix angular momentum $L_z = 1$, study spin degree of freedom
$\vec{\phi} = (\phi_1, \phi_2, \phi_3)$ (spin (-1,1,0) respectively)
The following potential characterizes the ground state.

$$V = -\mu\, \overrightarrow{\phi^*} \cdot \vec{\phi} + \frac{\mu}{2v^2}\left(\vec{\phi} \cdot \overrightarrow{\phi^*}\right)^2 - \lambda\left(\overrightarrow{\phi^*} \times \vec{\phi}\right) \cdot \left(\overrightarrow{\phi^*} \times \vec{\phi}\right) + i\mu_N\, \vec{B} \cdot \left(\vec{\phi} \times \overrightarrow{\phi^*}\right)$$

A1 phase… $\vec{\phi} = (a, ia, 0)$ expected **ferro magnetic**
A2 phase… $\vec{\phi} = (a, ib, 0)$ expected anti ferro magnetic
Which is deeper in potential ?
For $\vec{B} = (0,0,B)$, turning point is $\lambda = \mu_N B\ /\ 2v^2$

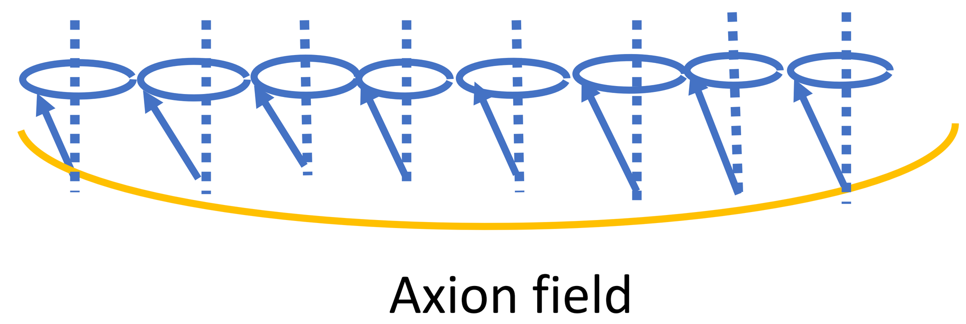




How to detect the axion ?

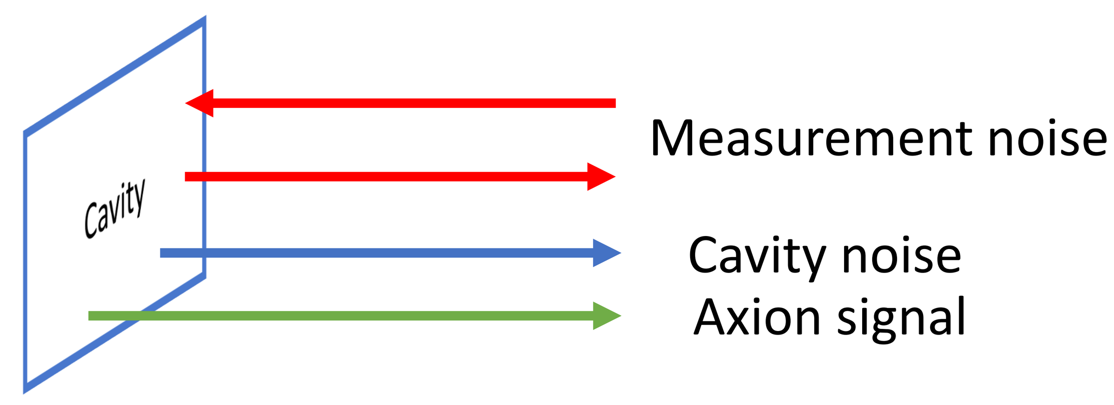
^{3}He nucleus consist of two protons (anti-symmetric) and a neutron → axion has interaction with neutron $L \supset \frac{C_{ann}}{2f_a}\partial_\mu a\, \bar{n}\gamma^\mu\gamma_5 n$

In non-relativistic $H_{int} = -\frac{C_{ann}}{f_a}\rho_a^{\frac{1}{2}}\ \overrightarrow{v_a} \cdot \overrightarrow{s_N}$ … **axion couples to the spin to excite** them (**magnon**).
If axion mass m_a resonantly matches Larmor frequency $g\mu_N B$, magnon excitation happens.
We will **catch the converted signal from the magnon to photon**.



Technical stuff

Thermal noise + Quantum noise
Thermal noise… the cooler, the smaller. We do not care so much in low temperature environment.
Quantum noise … measurement produces noise (**standard quantum limit**).
Recent and future technologies attempt to **beat the standard quantum limit**.
Ex … Josephson parametric amplifier (JPA). By **squeezing**, they can reduce the amount of potential quantum noise. It **makes signal to noise clearer**.



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