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Development of ^{129}Xe and ^{131}Xe co-existing masers with external feedback for the search for Xe atomic EDM

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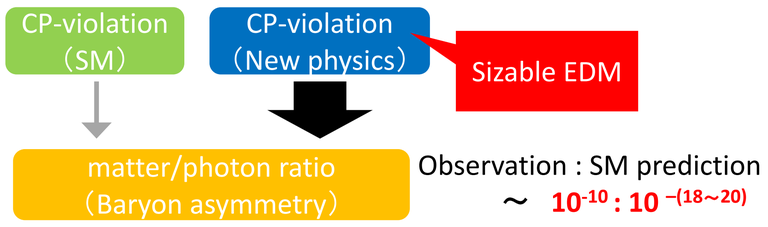
Introduction

EDM of an elementary particle

→ T-violation, hence CP-violation ∵CPT theorem



Current upper limit on the Xe atomic EDM

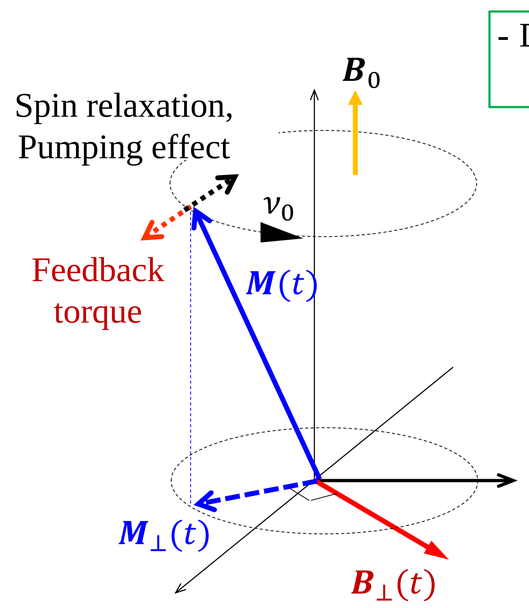
$|d(^{129}\mathrm{Xe})| < 4.1 \times 10^{-27}\ e\mathrm{cm}$

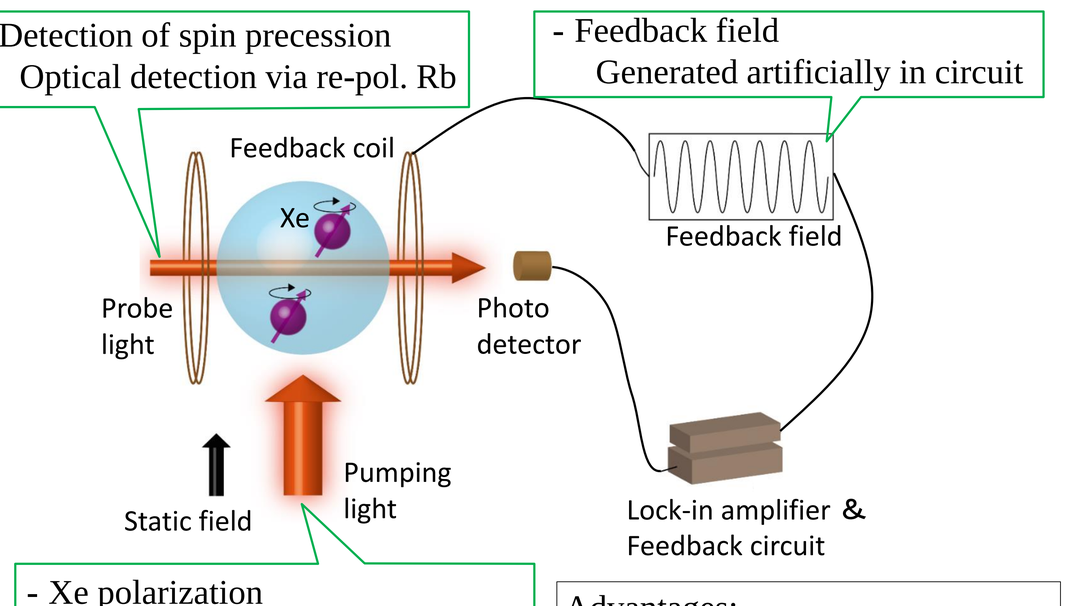
M.A. Rosenberry and T.E. Chupp, PRL 86, 22 (2001)

Target sensitivity : ~ 10^{-28} *e*cm ≈ nHz (*E*=10kV/cm)

- High statistics
- Control of systematic errors are required

Spin maser with external feedback





Advantages:
- Low field (～mG) operation
- Signal procession in the circuit

New co-magnetometry: ^{131}Xe spin maser

Comagnetometry:

reduction of common systematic effect by phase comparison

^{129}Xe maser frequency :

$$\nu_{^{129}\mathrm{Xe}} = \frac{\gamma_{^{129}\mathrm{Xe}}}{2\pi} B_0 + \frac{\gamma_{^{129}\mathrm{Xe}}}{2\pi} \kappa_{\mathrm{Rb}-^{129}\mathrm{Xe}} [\mathrm{Rb}] P_{\mathrm{Rb}} \pm \frac{2 d_{^{129}\mathrm{Xe}}}{h} E$$

comagnetometry frequency :

$$\nu_{\mathrm{comag}} = \frac{\gamma_{\mathrm{comag}}}{2\pi} B_0 + \frac{\gamma_{\mathrm{comag}}}{2\pi} \kappa_{\mathrm{Rb}-\mathrm{comag}} [\mathrm{Rb}] P_{\mathrm{Rb}} \pm \frac{2 d_{\mathrm{comag}}}{h} E$$

Zeeman — Contact interaction with pol. Rb atoms — EDM

κ : Strength factor for pol. Rb contact interaction
[Rb] : Number density of Rb
P_{Rb} : Polarization of Rb

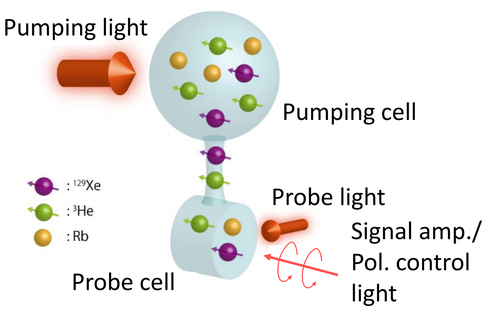
κ is different for atomic species

Is there good candidate for comagnetometry for Xe-EDM measurement?

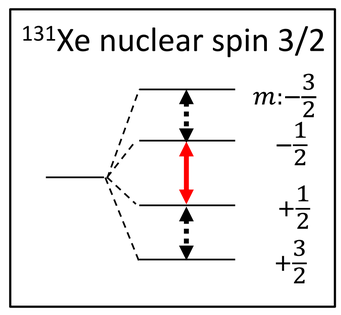
Comparison of comagnetometry

▪ ^{129}Xe-^{3}He
- Widely used in precision measurement
- Small EDM compared to Xe
- Strength factor κ : 100 times difference
- Double cell geometry
  →Reduction of Rb pol. in probe cell

However…
Effect of Rb still remains

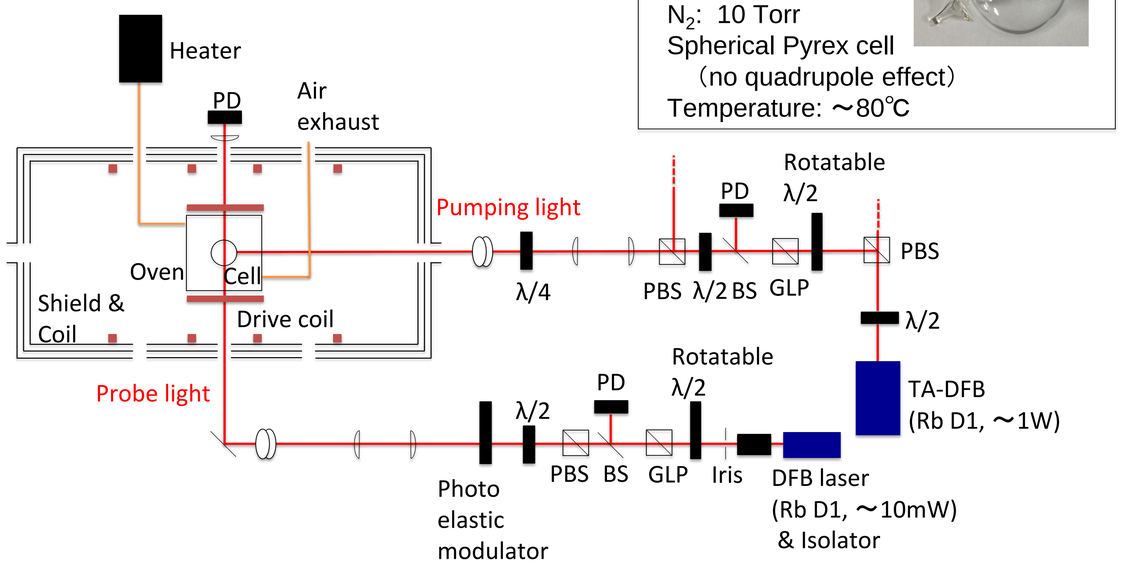


▪ ^{129}Xe-^{131}Xe (Our proposal)
- Small difference in interaction strength
  $\delta = 0.0017(1)$ M. Bulatowicz et al., PRL 111, 102001 (2013)
- Spherical cell geometry
- Spin *I*=3/2 system
  Active spin maser is suitable
- Size of EDM should differ for ^{129}Xe and ^{131}Xe due to the difference of nuclear structure



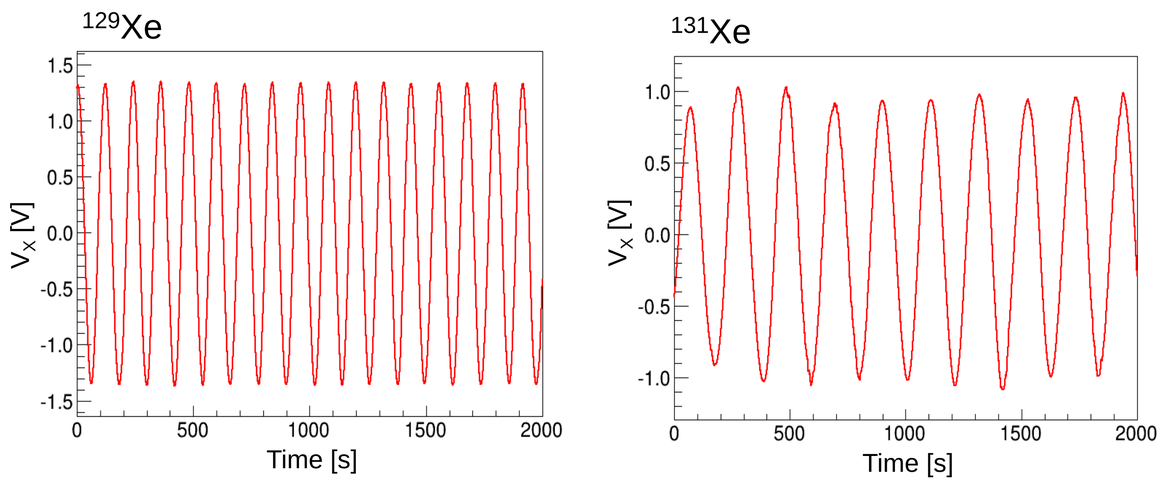
First operation of ^{129,131}Xe co-existing maser with external feedback

Setup



^{129}Xe: 1 Torr
^{131}Xe: 25 Torr
^{3}He: 200 Torr
N_2: 10 Torr
Spherical Pyrex cell
(no quadrupole effect)
Temperature: ～80℃

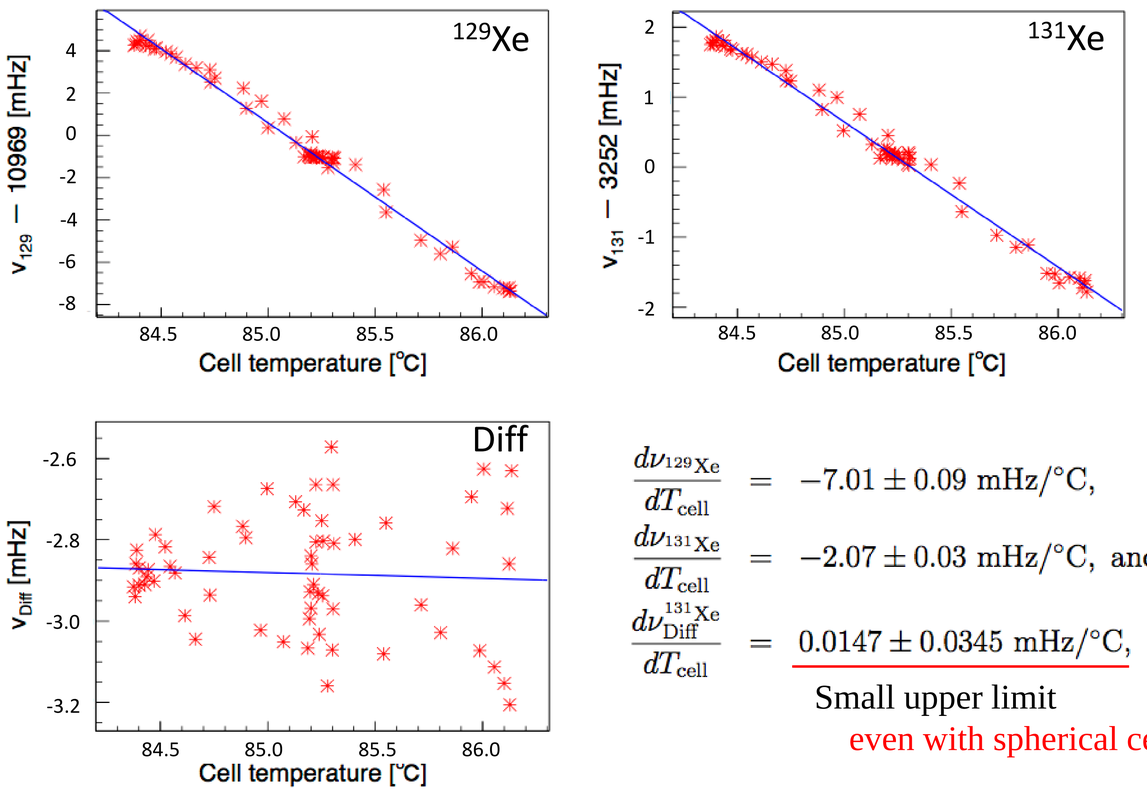
Maser signals



Frequency dependence on cell temperature

Frequency difference: $\nu_{\mathrm{Diff}}^{^{131}\mathrm{Xe}} = \nu_{^{129}\mathrm{Xe}} - \frac{\gamma_{^{129}\mathrm{Xe}}}{\gamma_{^{131}\mathrm{Xe}}} \nu_{^{131}\mathrm{Xe}}$

In perfect operation, dν/d(temperature) should be zero.



$$\frac{d\nu_{^{129}\mathrm{Xe}}}{dT_{\mathrm{cell}}} = -7.01 \pm 0.09\ \mathrm{mHz/°C},$$
$$\frac{d\nu_{^{131}\mathrm{Xe}}}{dT_{\mathrm{cell}}} = -2.07 \pm 0.03\ \mathrm{mHz/°C},\ \text{and}$$
$$\frac{d\nu_{\mathrm{Diff}}^{^{131}\mathrm{Xe}}}{dT_{\mathrm{cell}}} = 0.0147 \pm 0.0345\ \mathrm{mHz/°C},$$

Small upper limit
even with spherical cell

Advantage of the reduction of pol. Rb effect has been confirmed.
Further investigation of systematic errors is in progress.