LAC / ISMO / LPL / CIMAP

Cesium in Cryogenic Matrices: Towards a Measurement of the eEDM

Presented by Sebastian Lahs,
PhD student in the group of prof.
Daniel Comparat

New CP violating particle $\leftrightarrow$ electron EDM

$$\Delta E = d_e \, \vec{\sigma} \cdot \vec{\mathcal{E}}$$

Energy shift eEDM spin Electric field

Statistical uncertainty

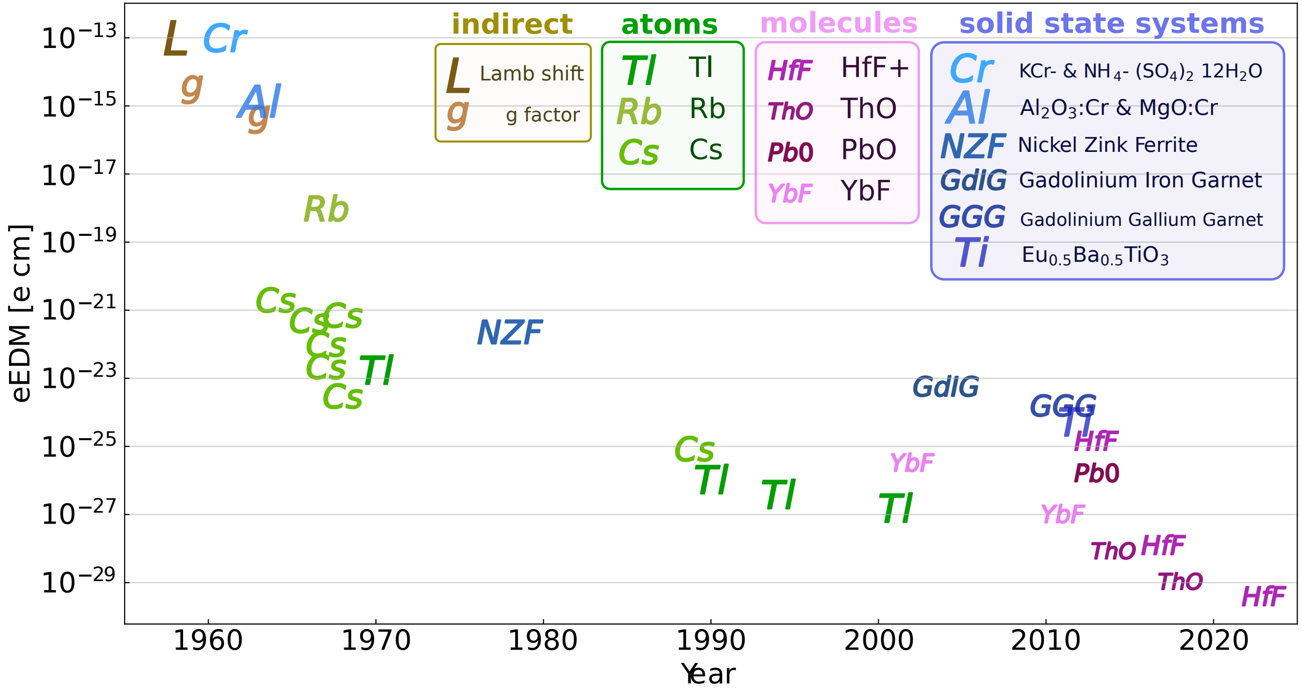
$$\Delta d_e \approx \frac{\hbar}{E_{\text{eff}} \sqrt{\tau t \, N}}$$

effective electric field

decoherence and measuring time

number of atoms/molecules

Progress of electron EDM sensitivity over time



Statistical uncertainty

$$\Delta d_e \approx \frac{\hbar}{E_{\mathrm{eff}}\sqrt{\tau t\, N}}$$

effective electric field

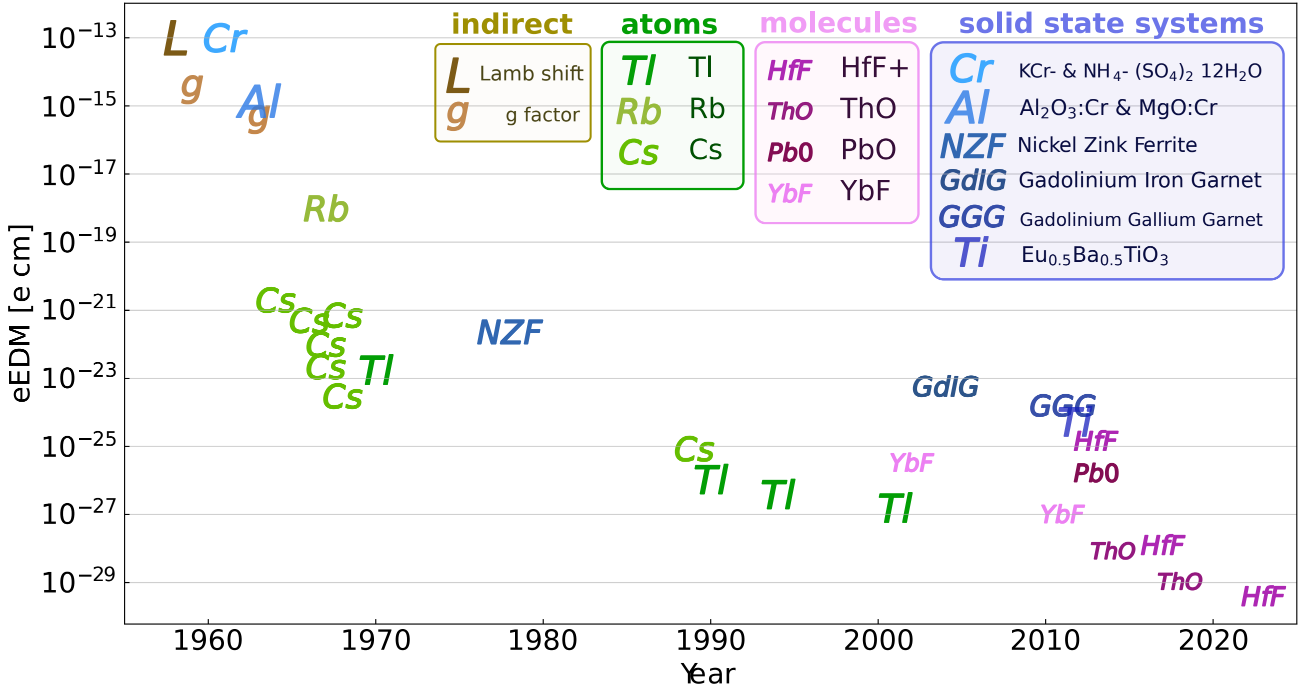
decoherence and measuring time

number of atoms, molecules

system	E_{eff}	τ	N	sensitivity to d_e for 24h of measurement
HfF^+	23 $GVcm^{-1}$	3000 ms	10^2	10^{-29} ecm

Dec 2022 Cornell group: Measurement of HfF+ ions with µHz precission, arxiv: 2212.11841

Progress of electron EDM sensitivity over time



Statistical uncertainty

$$\Delta d_e \approx \frac{\hbar}{E_{\mathrm{eff}}\sqrt{\tau t}\, N}$$

effective electric field

decoherence and measuring time

number of atoms, molecules

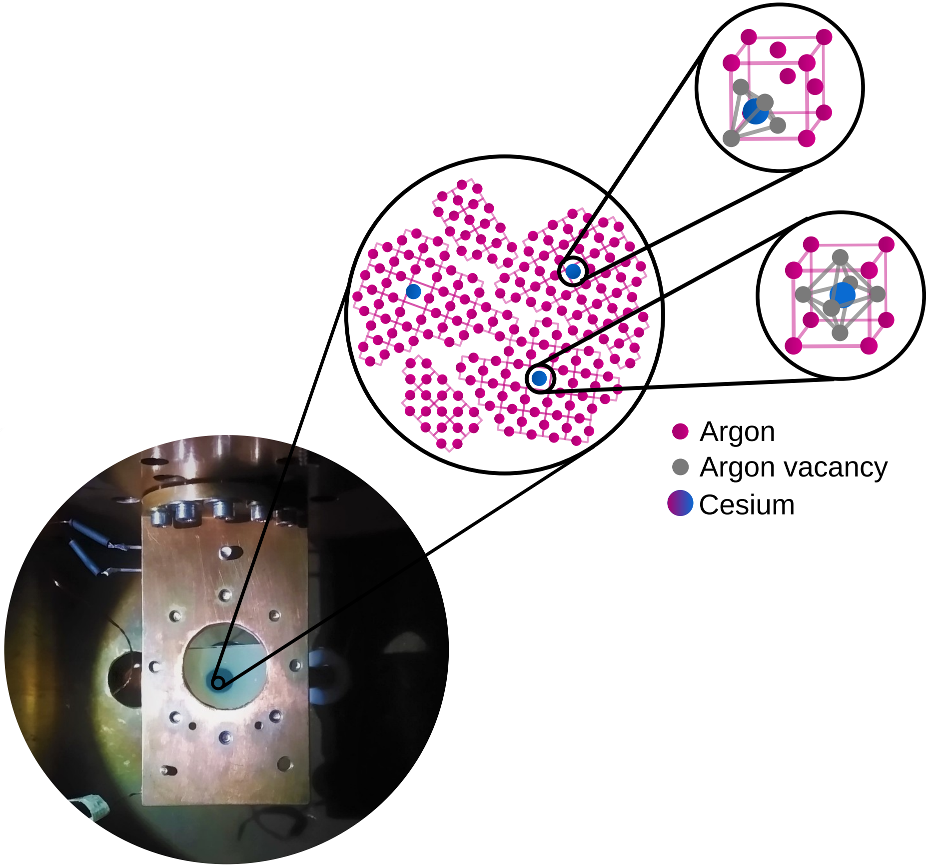
system	E_{eff}	τ	N	sensitivity to d_e for 24h of measurement
HfF^+	23 GVcm^{-1}	3000 ms	10^2	10^{-29} ecm

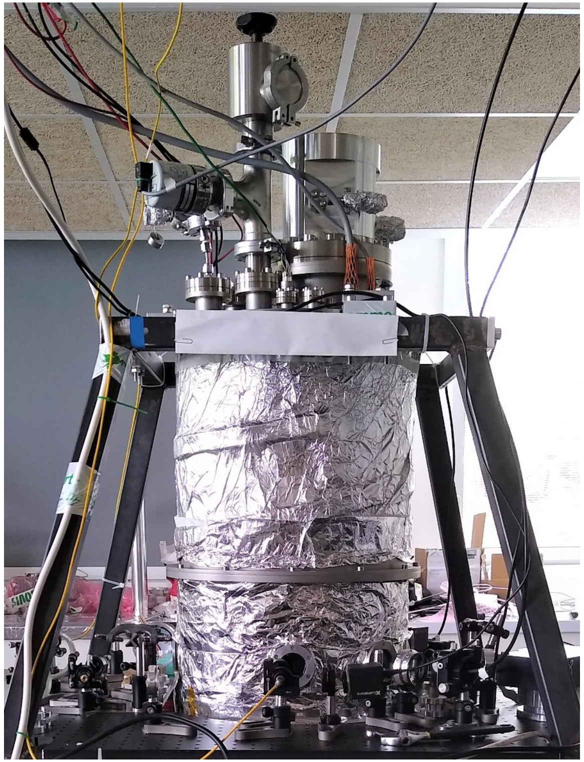
How to probe many atoms at once?

10^{18} Cs atoms embedded in Ar

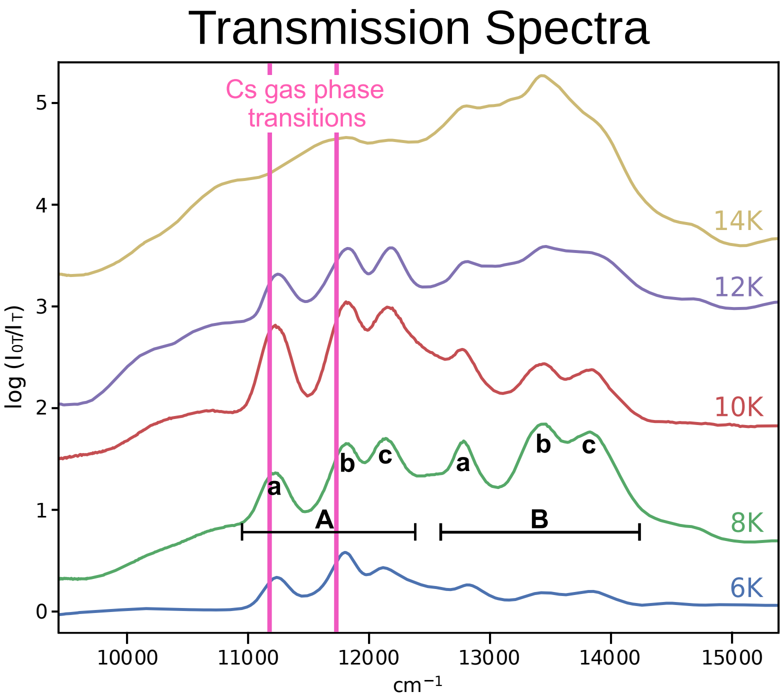
Cs: simple system (alkali atom) with very high sensitivity to eEDM
Ar: noble gas. All naturally occuring isotopes do not possess nuclear spin

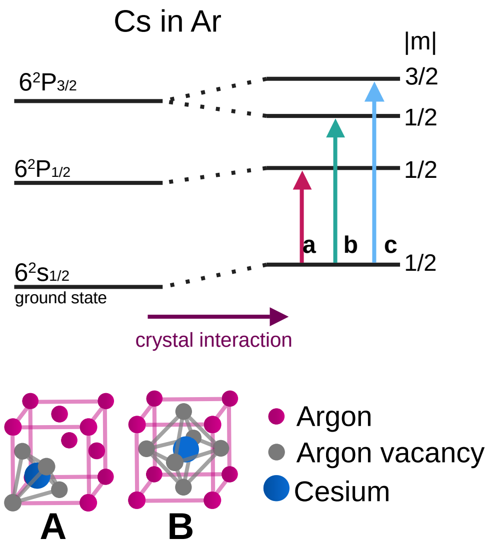
Ne
Kr
Xe



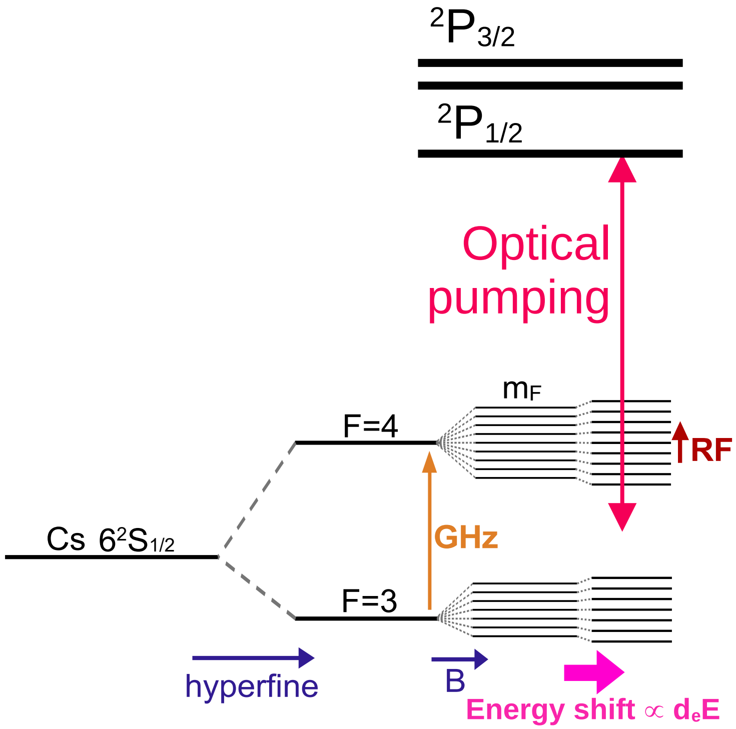


Cesium in Argon

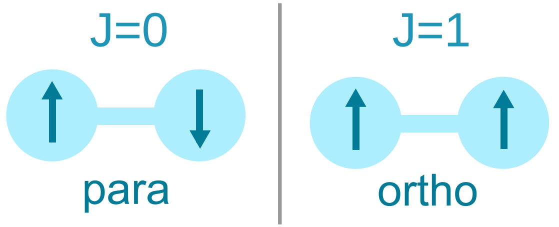


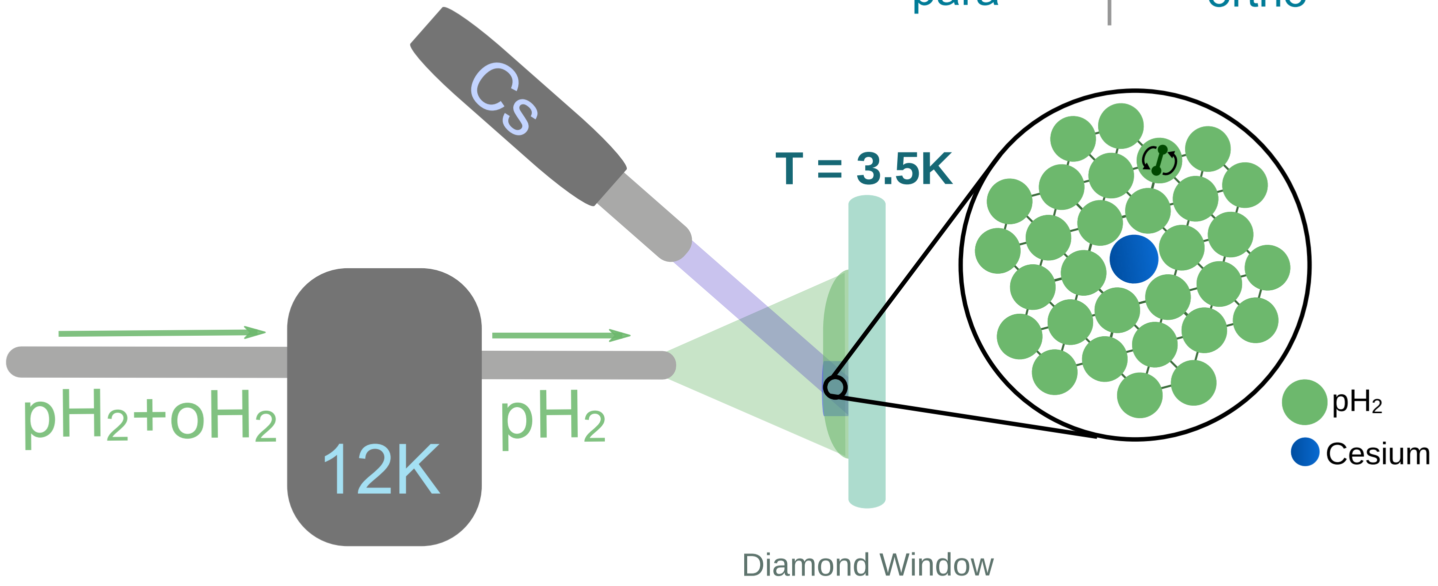


→ Phys. Rev. A 108, 042820



Cesium in para-hydrogen





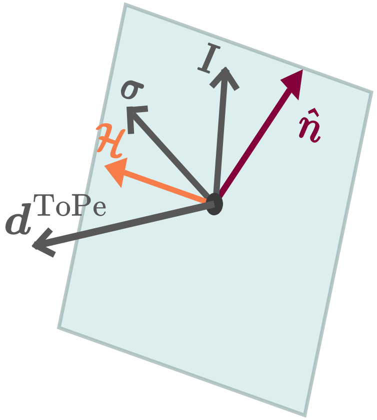
→ We expect even longer decoherence times

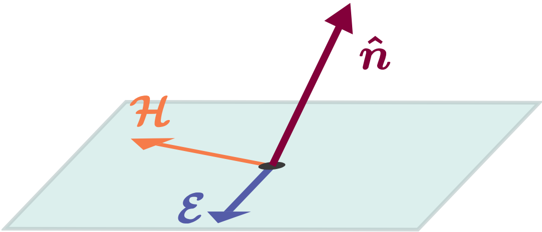
Sensitivity to the Cs anapole moment

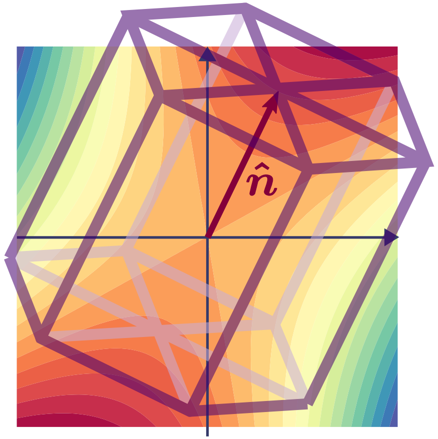
T-even electric dipole moment $\boldsymbol{d}^{Podd} \propto (\boldsymbol{I} \times \boldsymbol{\sigma})$≈$10^{-21}$ ecm

Energy shift $\Delta E \propto (\mathcal{H} \cdot \hat{\boldsymbol{n}})(\mathcal{E} \times \mathcal{H}) \cdot \hat{\boldsymbol{n}}$

magnetic field **electric field** **crystal axis**

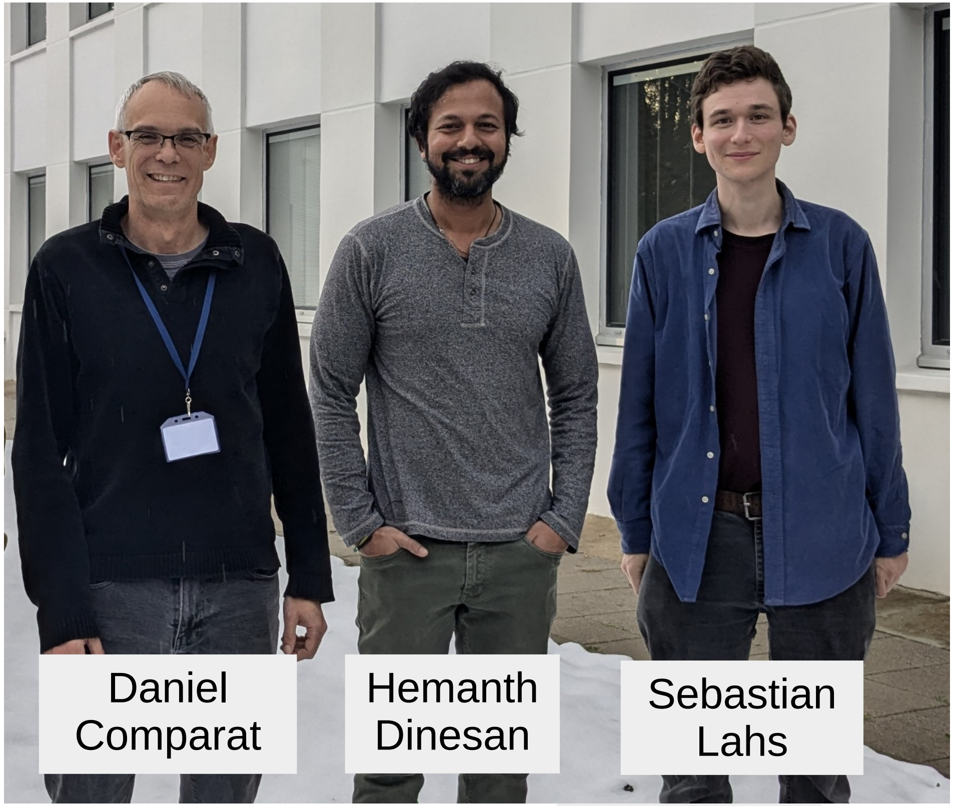






EDMMA - Team @ Laboratoire Aimé Cotton & ISMO

LAC / ISMO / LPL / CIMAP



Daniel Comparat

Hemanth Dinesan

Sebastian Lahs

Claudine Crépin

Wutharath Chin

T <u>without</u> P violation

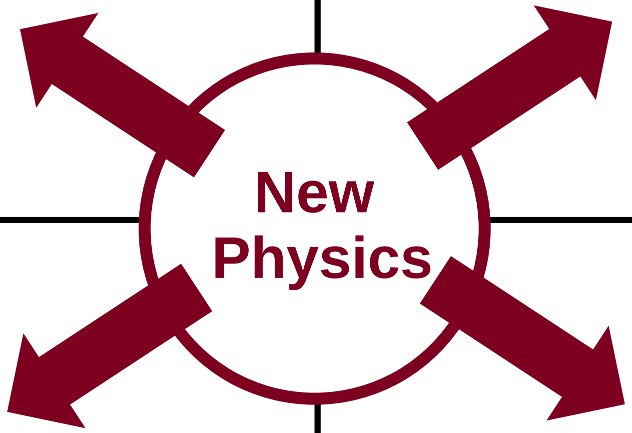
Parity **P** and Time reversal **T**

The 4 Fundamental Forces

	P even	P odd
T even	**General Relativity** **Electromagnetic Force** **Strong Force** **Weak Force** C even **Large**	C odd **Weak Force** **small**
T odd	**Weak Force** **very small** C odd	C even **Weak Force** **(Strong Force)** **very small**

Parity **P** and Time reversal **T**

	P even	**P odd**
T even	**General Relativity** **Electromagnetic Force** **Strong Force** **Weak Force** Large	**Weak Force** small
T odd	**Weak Force** very small	**Weak Force** **(Strong Force)** very small



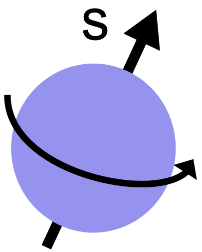
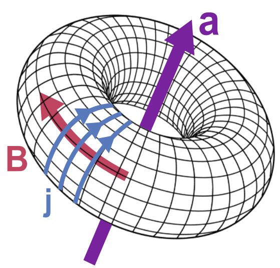
C and CP violation in effective field theories

Hakan Akdag,[a] Bastian Kubis[a] and Andreas Wirzba[b]

The first P-even, T-odd operators appear are of mass dimension 7:

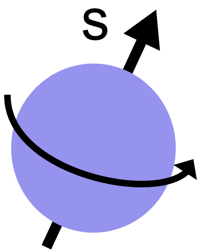
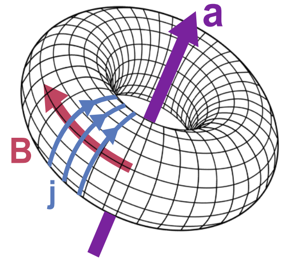
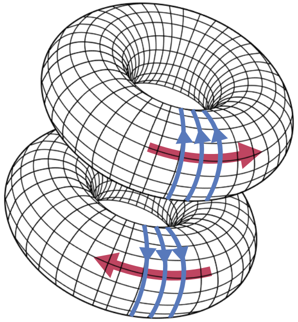
$$\bar{\psi}\overleftrightarrow{D}_\mu\gamma_5\psi\bar{\chi}\gamma^\mu\gamma_5\chi\,,$$
$$\bar{\psi}\sigma_{\mu\nu}\lambda^a\psi F^{\mu\lambda}G^{a\nu}_{\lambda}\,,$$
$$\bar{\psi}\sigma_{\mu\nu}\psi F^{\mu\lambda}Z^{\nu}_{\lambda}\,,$$

Parity **P** and Time reversal **T**

	P even	**P odd**
T even	Magnetic Dipole moment  Electric Quadrupole, Magnetic Octupole,...	Anapole moment 
T odd	?	Electric Dipole moment  Magnetic Quadrupole, Electric Octupole,...

P&T violating moments

Parity **P** and Time reversal **T**

	P even	**P odd**
T even	Magnetic Dipole moment  Electric Quadrupole, Magnetic Octupole,...	Anapole moment 
T odd	Tetrapole moment 	Electric Dipole moment  Magnetic Quadrupole, Electric Octupole,...

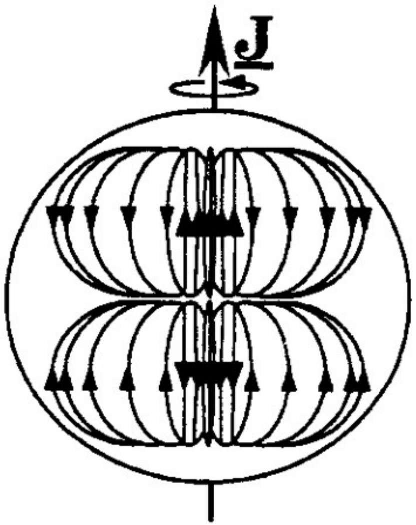
P&T violating moments

Effect of *T*-odd nuclear forces on atomic levels

A. N. Moskalev and S. G. Porsev

Leningrad Institute of Nuclear Physics, Academy of Sciences of the USSR

(Submitted 25 July 1988)
Yad. Fiz. **49**, 1266–1272 (May 1989)



$$V_t = i t_{ij} \alpha_i \left[\partial_j \delta(\boldsymbol{r})\right]$$

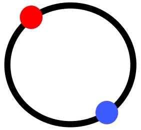
$$t_{jk} = \frac{\pi}{21} \int 4(\boldsymbol{r}\cdot\boldsymbol{j}) r_j r_k + 2(\boldsymbol{j}\cdot\boldsymbol{r}) r^2 \delta_{jk} - 5\left(r_j j_k + r_k j_j\right) r^2 d^3 r$$

$$Q_T \sim \frac{p}{m}\frac{\langle U_T\rangle}{\Delta E} r_0^{\,3}, \quad I \geq 1$$,Z⁴-scaling

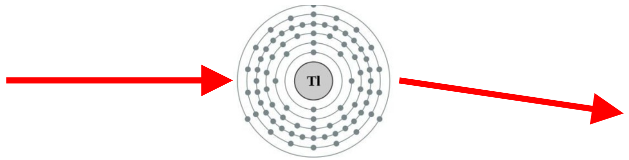
How to measure P-even, T-odd physics?

-Only induces imaginary matrix elements
-no associated quantum number

positronium



Transition strength ~ kE



I=1/2

Time-reversal tests with nuclei

Barry R. Holstein

AIP Conf. Proc. 270, 140–152 (1991)

https://doi.org/10.1063/1.43016

Entropy can be a problem

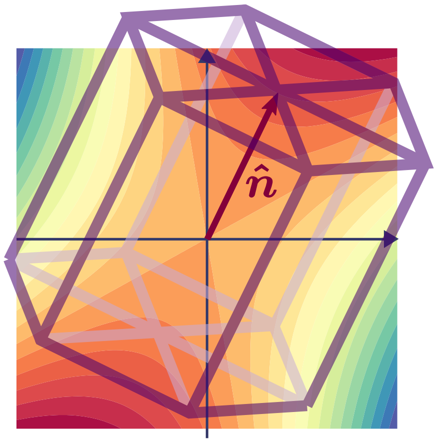
Polarizabilities as probes for P, T, and PT violation

Sebastian Lahs* and Daniel Comparat

Magnetic moment: $\boldsymbol{\mu} \propto (\boldsymbol{\sigma} \times \boldsymbol{I})$

Static energy shift:

$$\Delta E \propto (\boldsymbol{\mathcal{E}} \cdot \hat{\boldsymbol{n}})(\boldsymbol{\mathcal{H}} \times \boldsymbol{\mathcal{E}}) \cdot \hat{\boldsymbol{n}}$$



- The EDM^3 experiment led by E. Hessels in Canada implants BaF molecules into neon matrices [187].
- The PHYDES collaboration in Italy led by G. Carugno plan to implant BaF molecules into a parahydrogen matrix [188].
- The EDM3 project led by J. Singh in the USA works towards future experiments with radium containing molecules and protactinium atoms embedded in cryogenic matrices [189].
- The group of A. Vutha in Canada wants to perform a measuremrent of the Schiff moment of europium ions doped into yttrium orthosilicat [190].

multipole	symbol	order	dim	OS T	OS P	$\langle \ldots \rangle \neq 0$ T	$\langle \ldots \rangle \neq 0$ P	$I \geq$
electric dipole	d_i	1	1	+	-	-	-	$^1/_2$
magnetic dipole	μ_i	2	1	-	+	+	+	$^1/_2$
electric quadrupole	Q_{ij}	2	2	+	+	+	+	1
magnetic quadrupole	M_{ij}	3	2	-	-	-	-	1
electric octupole	$O_{ij\varkappa}$	3	3	+	-	-	-	$^3/_2$
mean-square electric dipole (Schiff moment)	S_i	3	1	+	-	-	-	$^1/_2$
anapole	a_i	3	1	-	-	+	-	$^1/_2$
tetrapole	t_{ij}	4	2	-	+	-	+	1