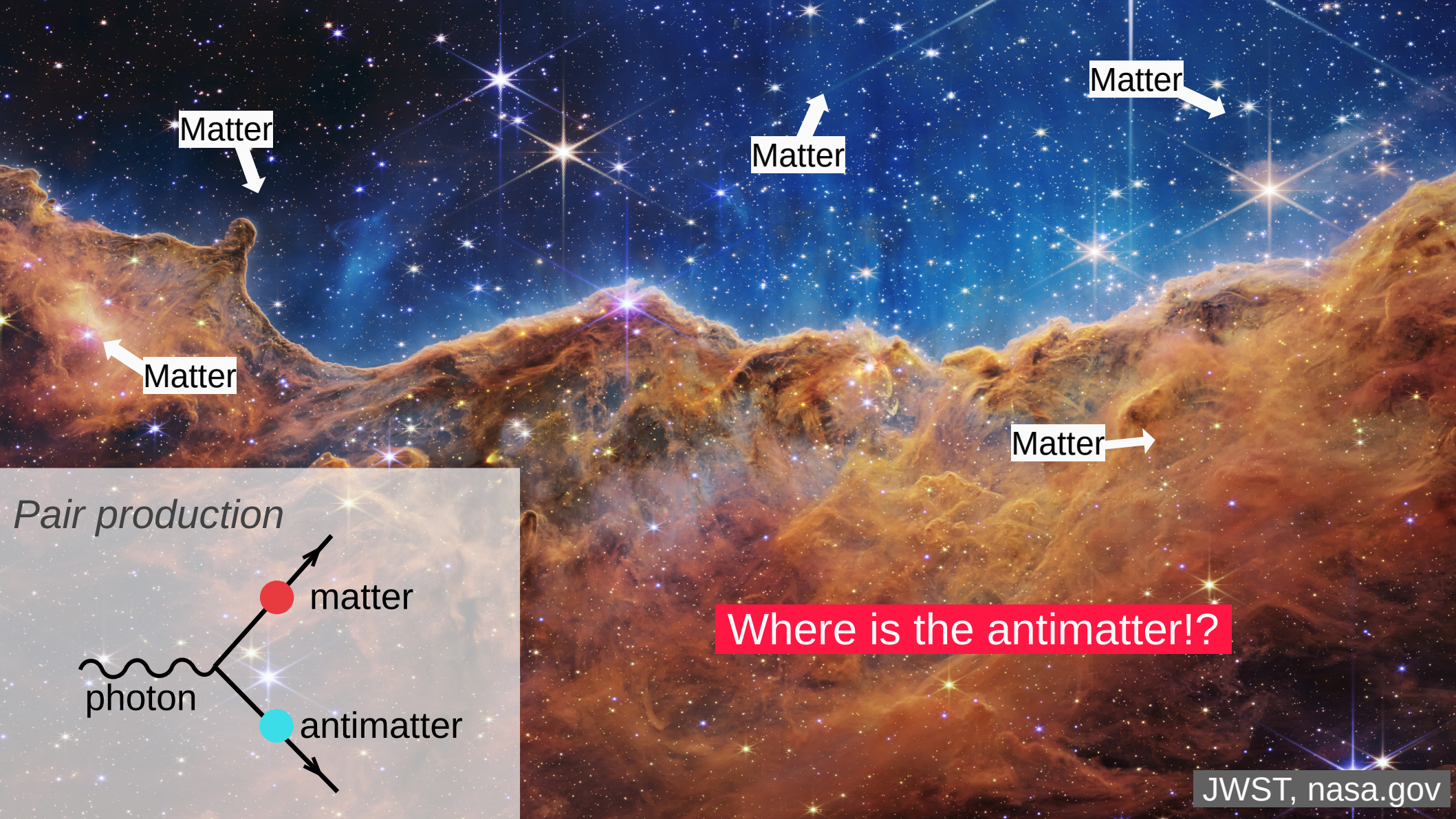
Tabletop Experiment for beyond Standard Model Physics: Electron EDM in a Cryogenic Matrix

Sebastian Lahs, Thomas Battard, Daniel Comparat

LAC / ISMO / LPL / CIMAP


Matter
Matter
Matter
Matter
Matter
Pair production
matter
photon
antimatter
Where is the antimatter!?
JWST, nasa.gov

Andrei Sakharov

Sakharov conditions 1967:

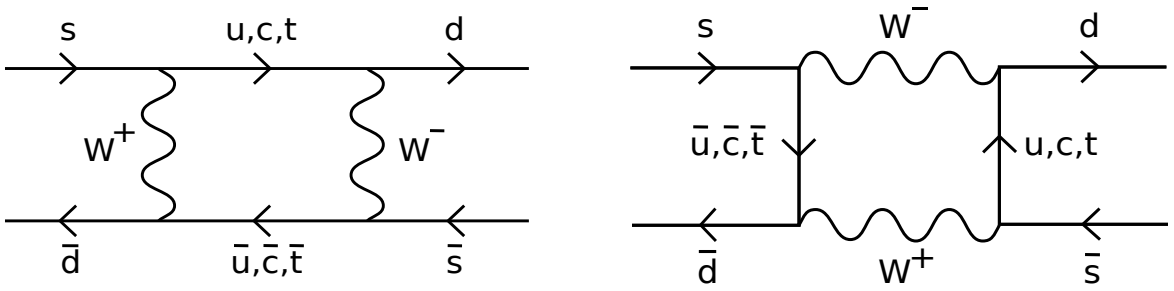
- Baryon number B violation
- *C* and *CP*-symmetry violation
- Interactions out of thermal equilibrium

Parity ***P*** : x → -x

Time reversal ***T*** : t → -t

Charge conjugation ***C*** : q → -q

CP-violation in the Standard Model

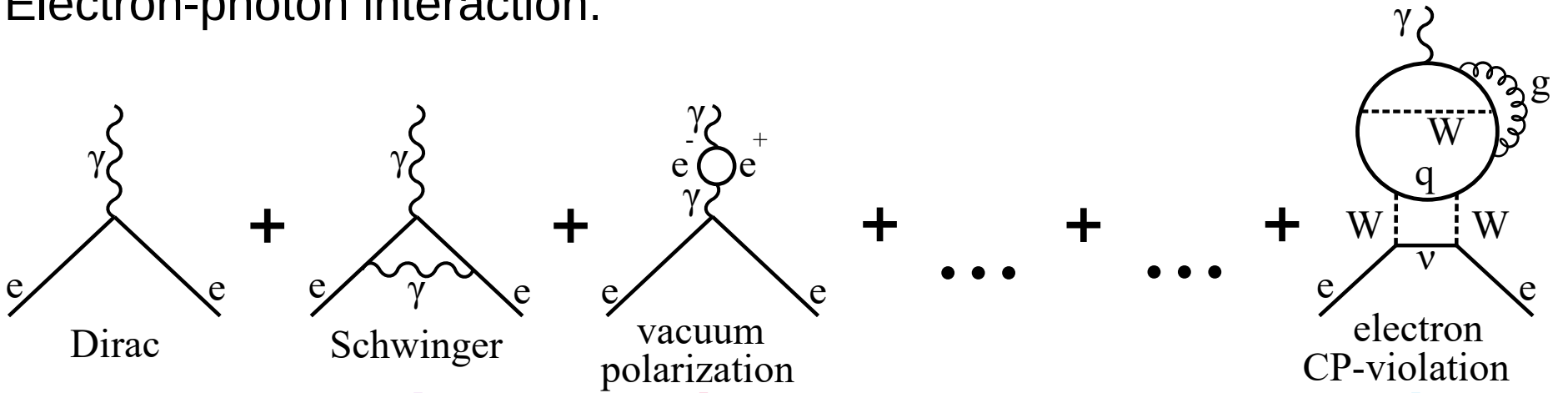


1964: *CP*-violation in Kaon decay

- *CP*-symmetry is violated in the weak interaction between quarks
- Not strong enough to satisfy 2nd Sakharov condition
- Beyond standard model physics needed

How to find new elementary particles in tabletop (atomic physics) experiments?

Electron-photon interaction:



anomalous magnetic moment g-2

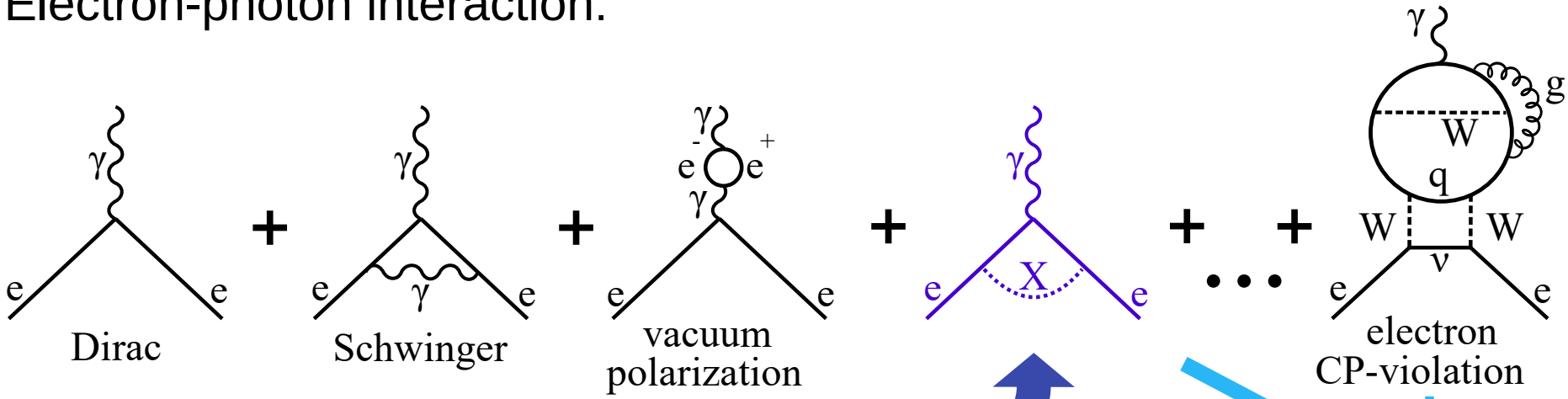
Lamb shift

EDM

$d_e \sim 10^{-39}\, e\,\mathrm{cm}$

How to find new elementary particles in tabletop (atomic physics) experiments?

Electron-photon interaction:



Beyond standard model physics

(Supersymmetry, Multi-Higgs, Seesaw-mechanism, ...)

EDM

Energy shift: $$\Delta\mathcal{E} = \vec{\sigma} \cdot \left(d_e \vec{E} + \mu \vec{B} \right)$$

Statistical uncertainty: $$\Delta d_e \propto \frac{1}{E \tau \sqrt{N}}$$

electric field

decoherence time

particle number

$$\Delta d_e \propto \frac{1}{E\tau\sqrt{N}}$$

ACME II: $d_e = (4.3 \pm 3.1_{\text{stat}} \pm 2.6_{\text{syst}}) \times 10^{-30} e\,\text{cm}$

SM: $d_e \sim 10^{-39}\, e\,\text{cm}$

Ramsey spectroscopy on beam of ThO
- very large E inside the molecule
- τ limited by length/velocity
- N~10^{13}

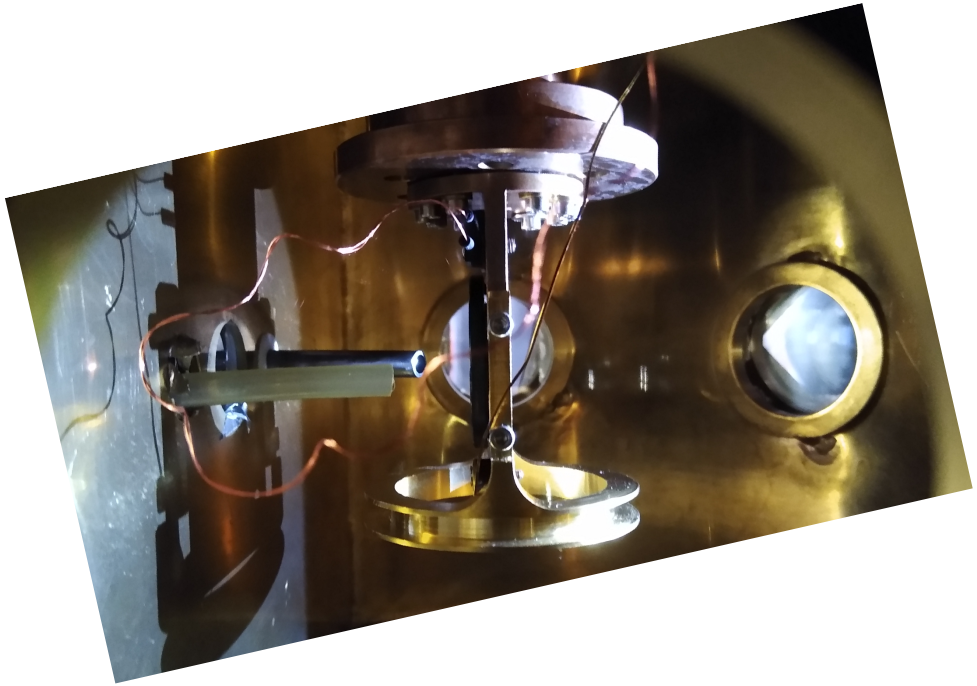
go to solid
- Particle *trapped* ➡ large τ
- N up to Avogadro's number 10^{23}

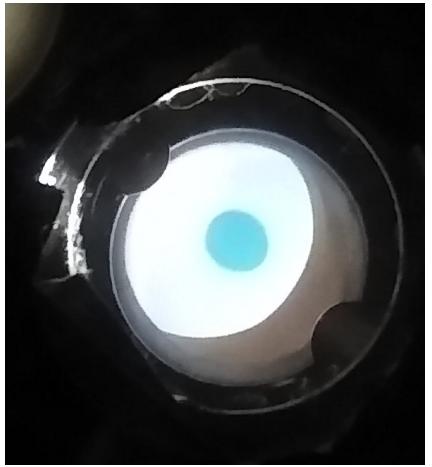
Proposal: dope noble gas matrix with atoms

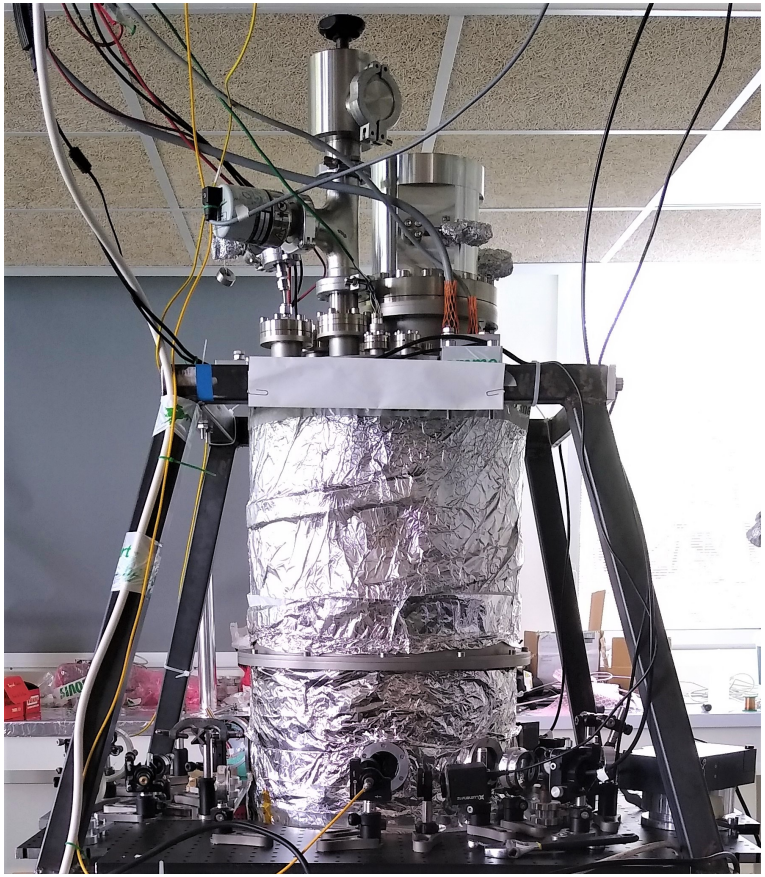
^{40}Ar: spin=0

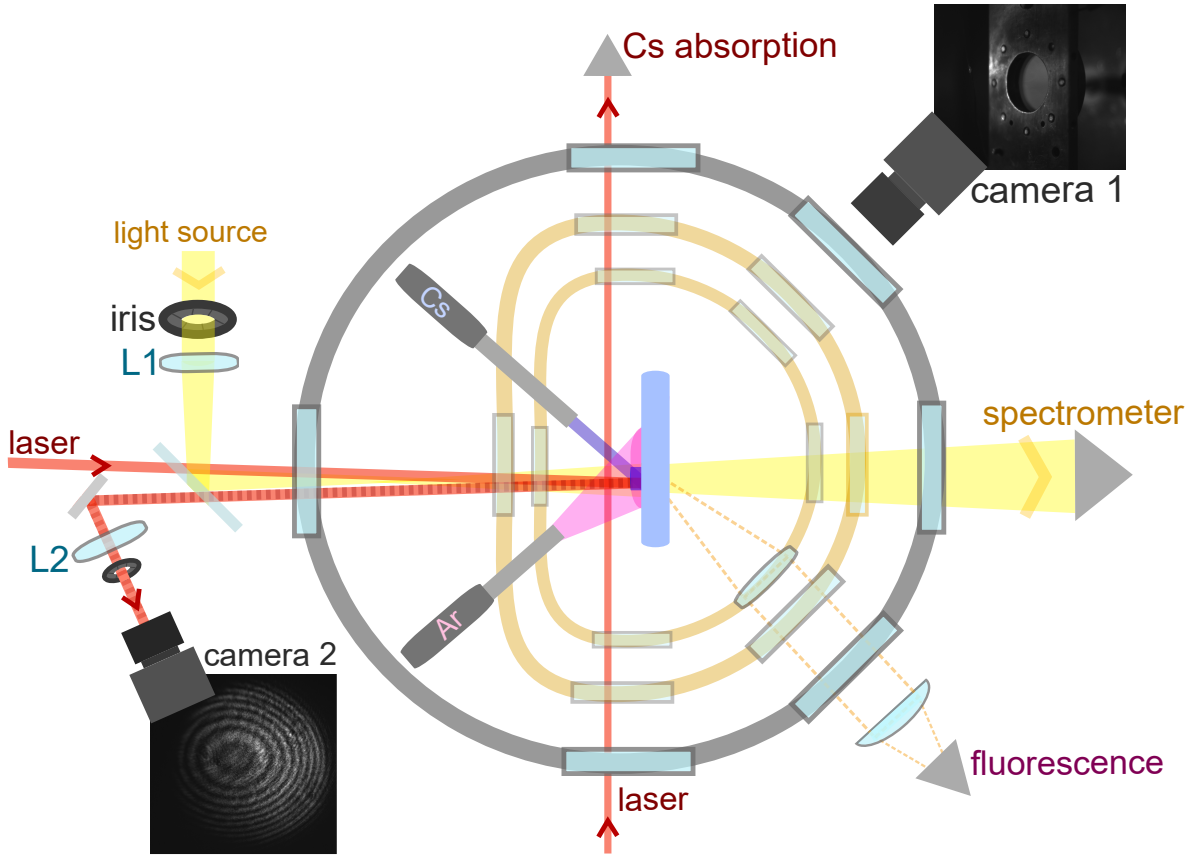
Alkali atoms are best understood

Cs is most sensitive to eEDM

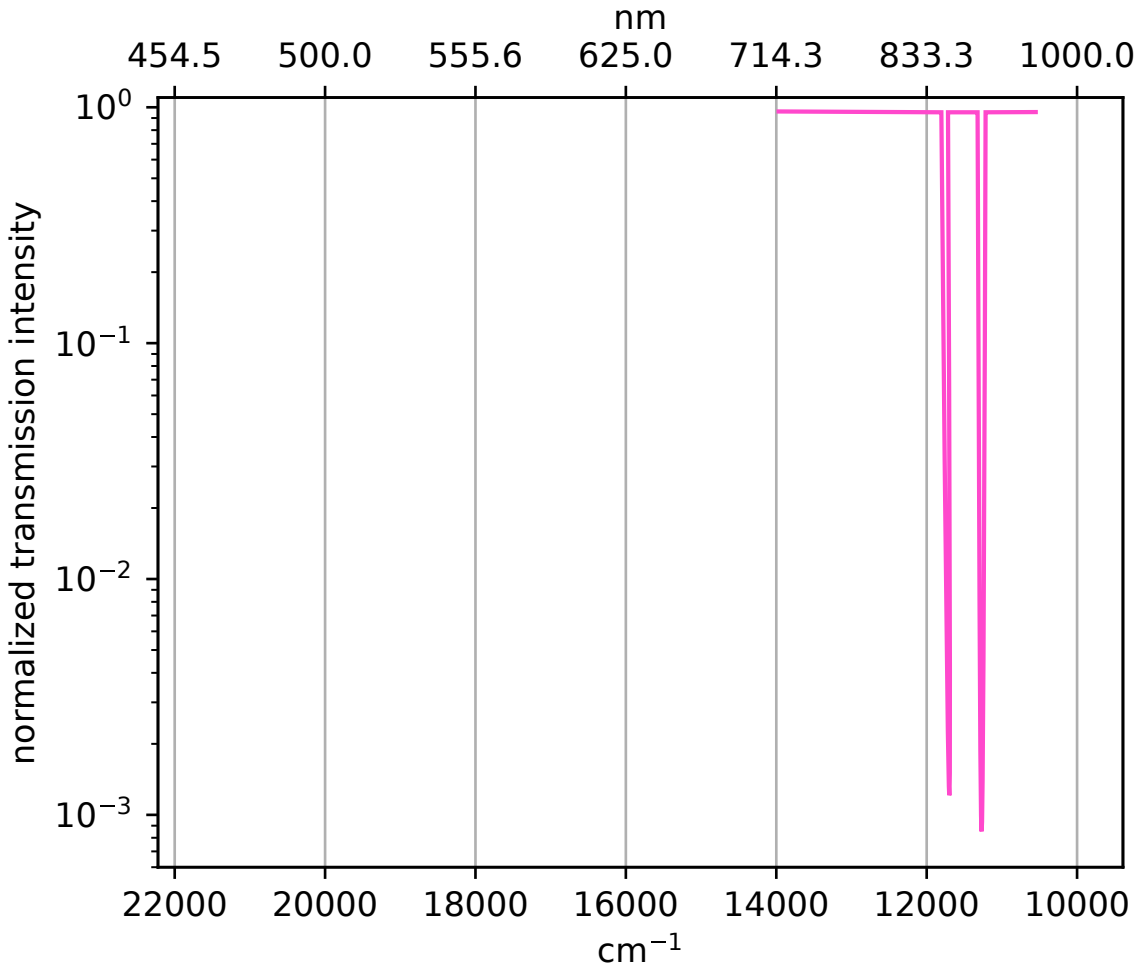


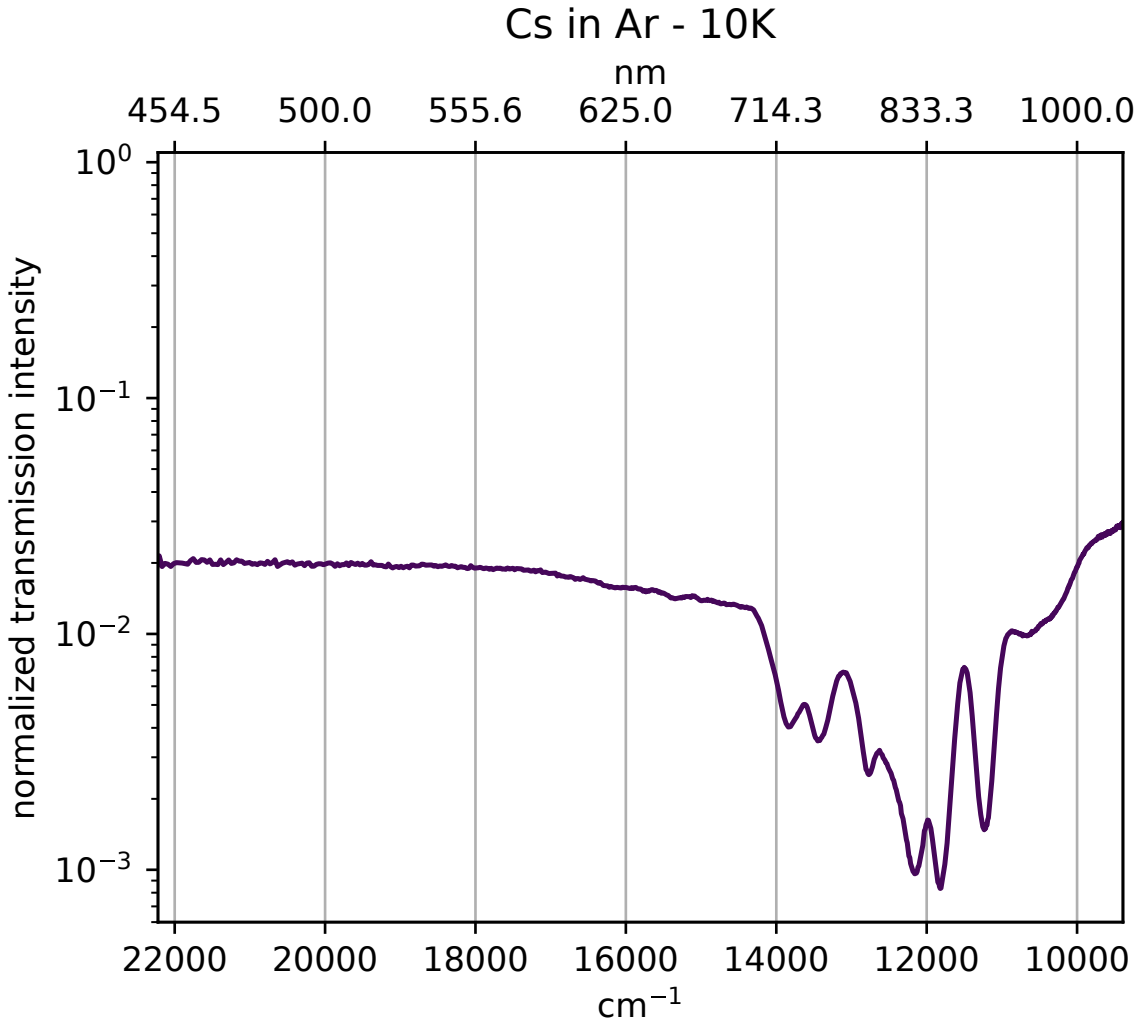


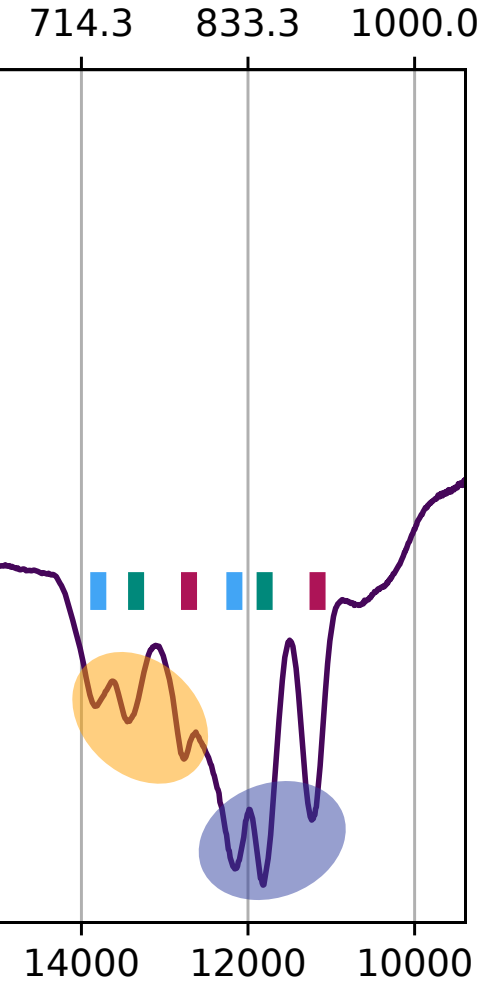



Cs absorption
camera 1
light source
iris
L1
Cs
spectrometer
laser
L2
Ar
camera 2
fluorescence
laser

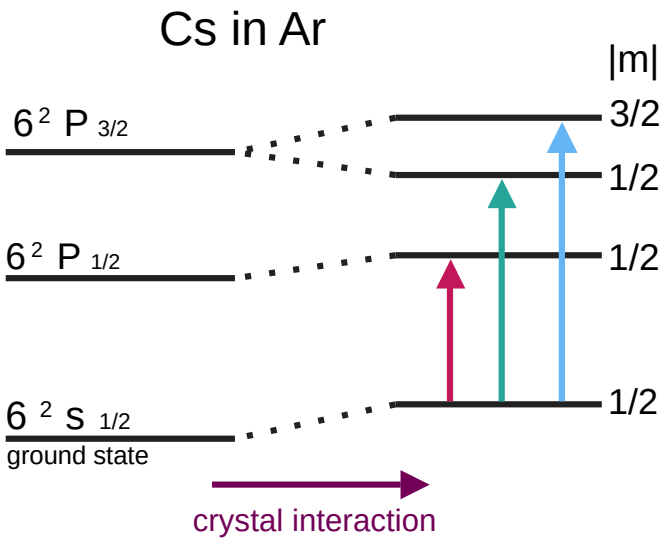
Cs spectrum expectations

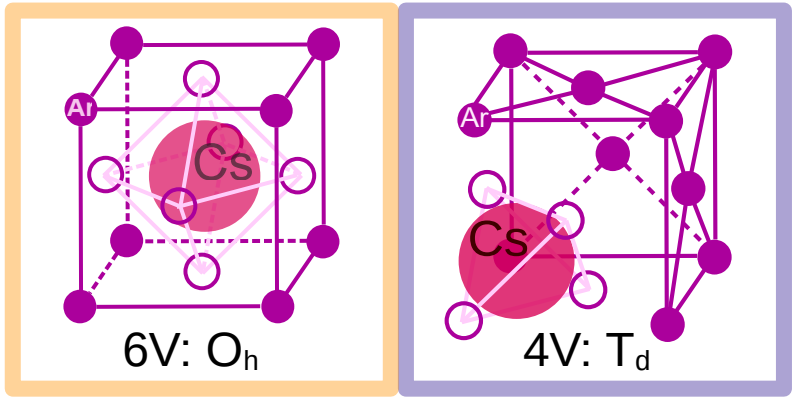



Cs in Ar - 10K
nm
454.5
500.0
555.6
625.0
714.3
833.3
1000.0
10^{0}
10^{-1}
10^{-2}
10^{-3}
normalized transmission intensity
22000
20000
18000
16000
14000
12000
10000
cm^{-1}



Interpretation of the Cs spectrum





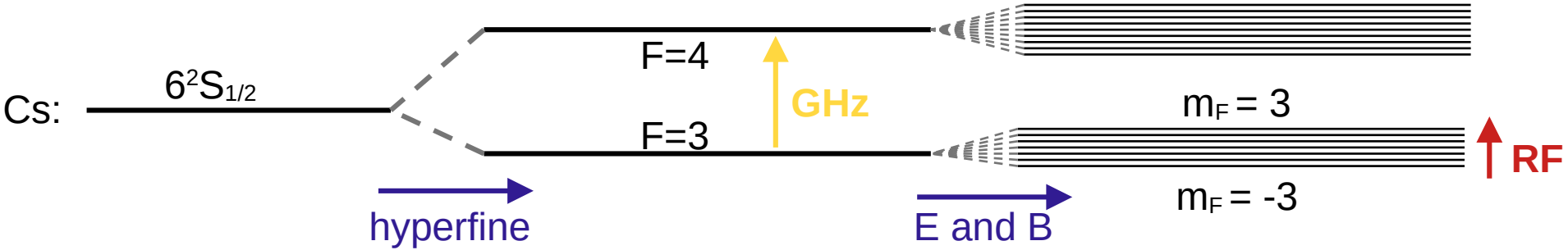
Need to understand trapping sites to know systematics!
(e.g. magnetoelectric mixing)

Next steps

-understanding the trapping sites
- magnetic circular dichroism
- fluorescence

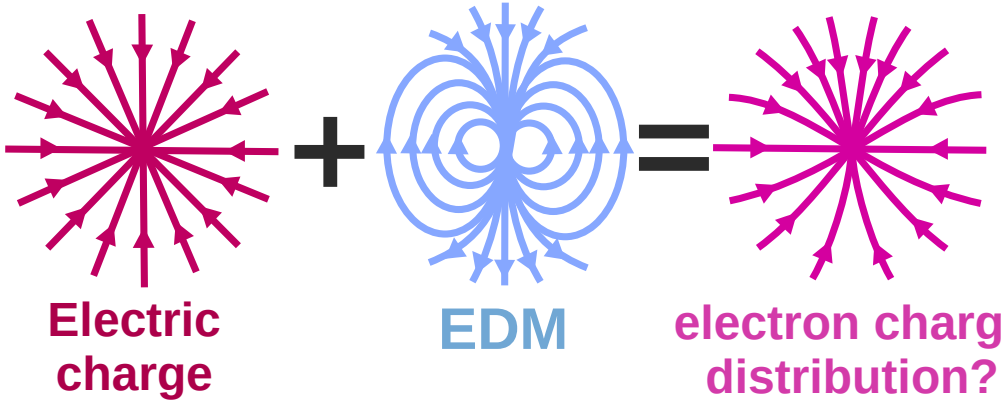
-demonstrate control of hyperfine states

-excite radio frequency transitions and measure decoherence time

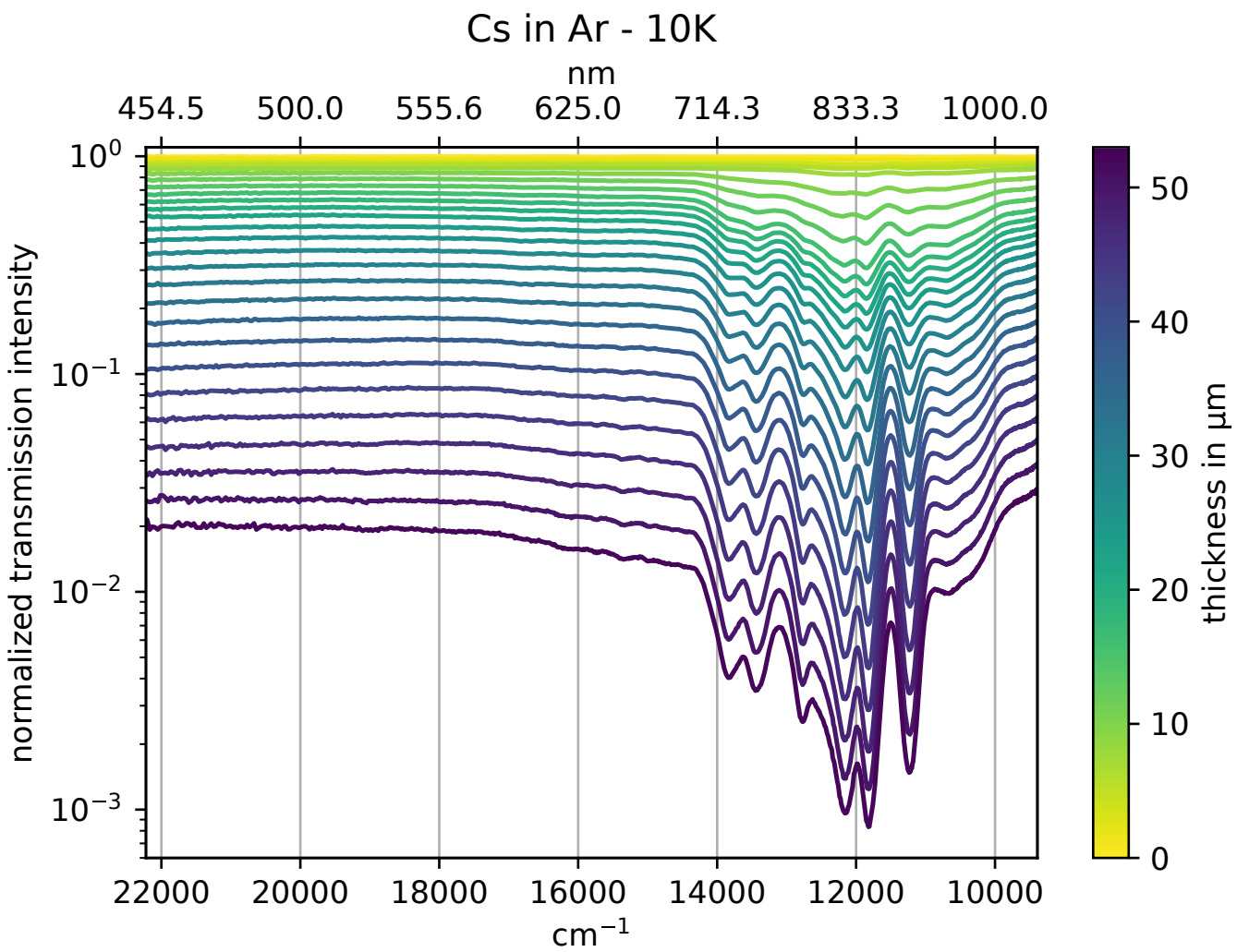


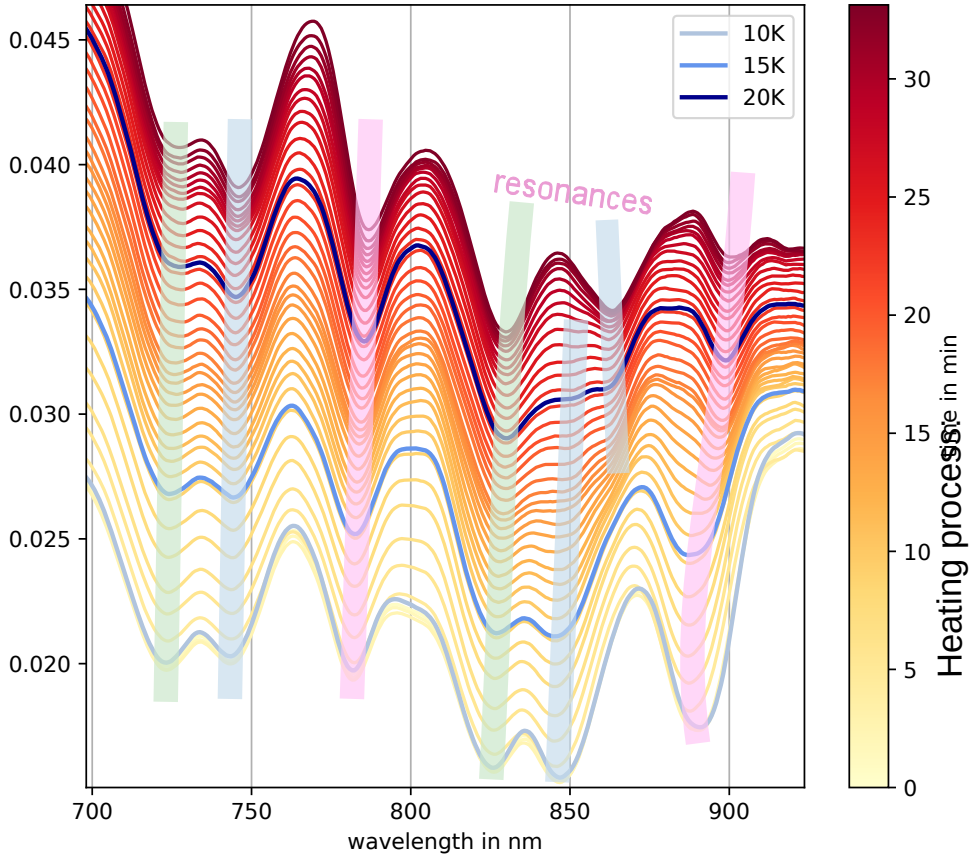
Summary:

- Electron EDM is sensitive prope to new physics
- The use of cryogenic matrices promises a large jump in precision
- Further studies of systematics of the system are needed

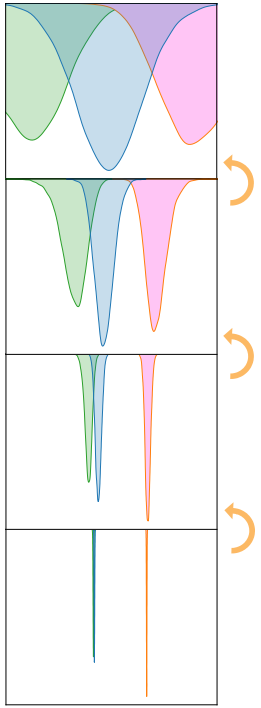


Bonus slides


Cs in Ar - 10K
nm
454.5
500.0
555.6
625.0
714.3
833.3
1000.0
normalized transmission intensity
10^{0}
10^{-1}
10^{-2}
10^{-3}
22000
20000
18000
16000
14000
12000
10000
cm^{-1}
thickness in µm
0
10
20
30
40
50



temperature dependence in an O_h trapping site



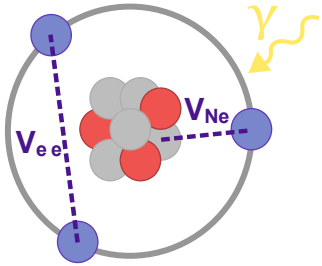
Axion & ALPs

Popular candidate for dark matter

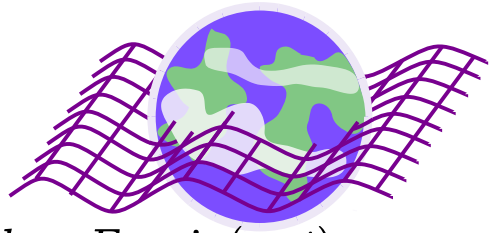
⇒ Lots of experiments

by Ciaran O'Hare

<u>EDM experiments can contribute as well</u>



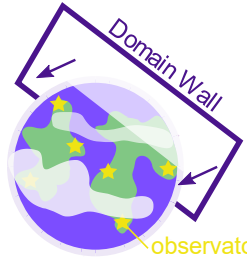
Axion as 5th force
→ static eEDM



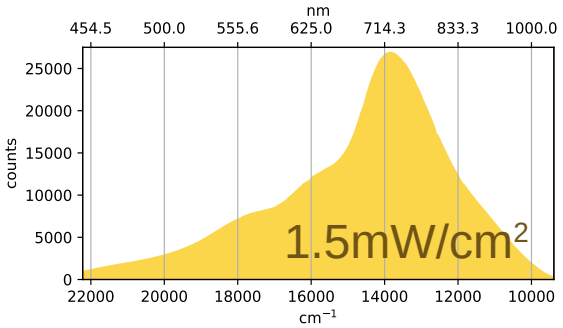
$$\Rightarrow d_e \propto E\, a_o \sin(m_a t)$$

Axion mass

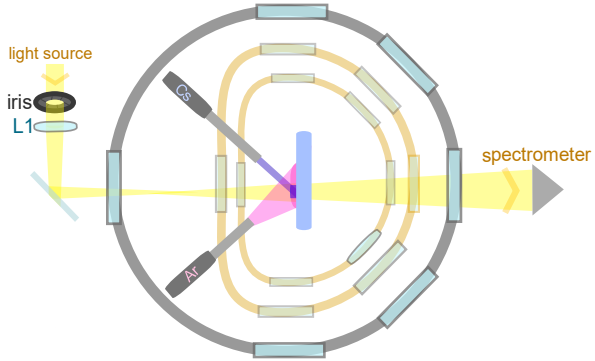
Axion as dark matter
→ osc. eEDM

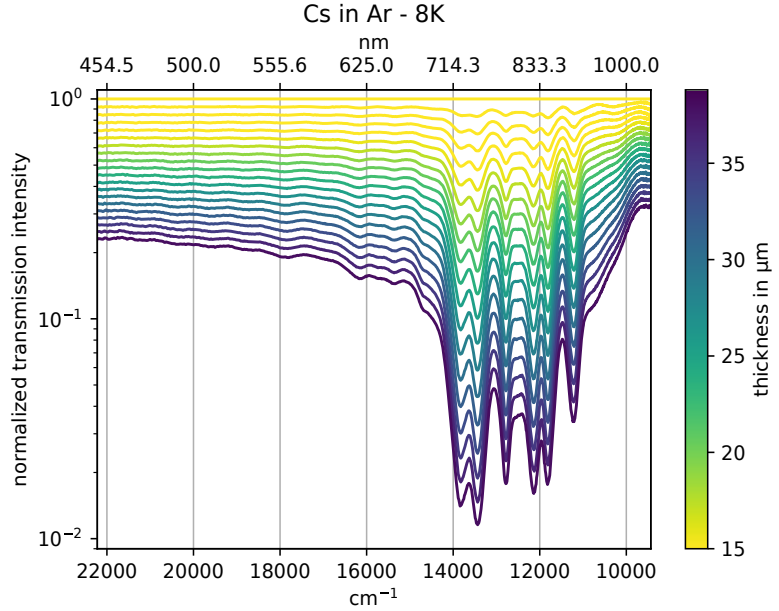


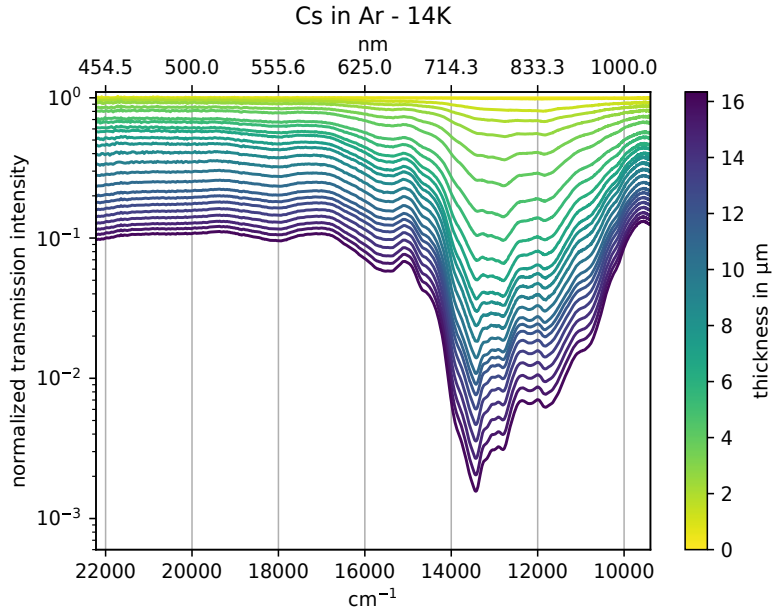
Exotic models (domain walls, boson stars, quark nuggets, cosmic bursts)
→ time varying signal



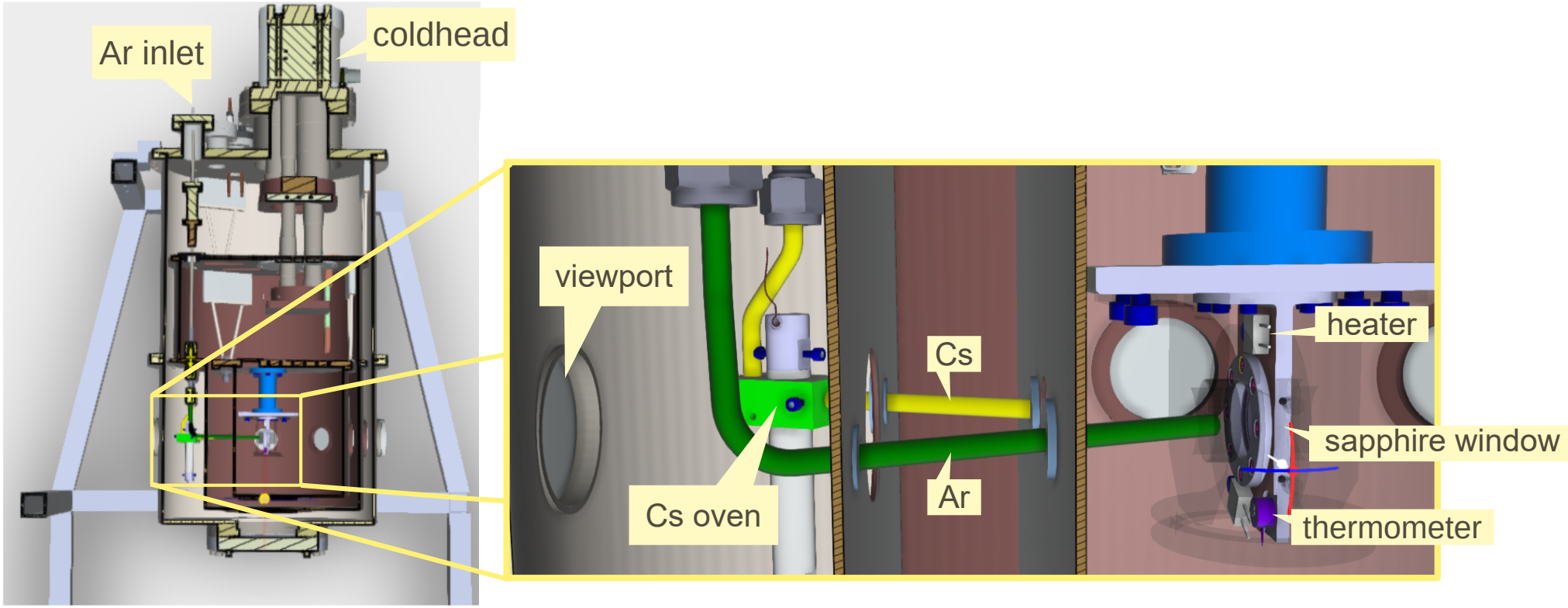
Transmission Specroscopy







Experimental setup



Parity $\boldsymbol{P}: x \rightarrow -x$

Time reversal $\boldsymbol{T}: t \rightarrow -t$

Charge conjugation $\boldsymbol{C}: q \rightarrow -q$