Probing Atomic Parity Violation by way of Forbidden transitions in Optically Trapped Francium

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Why Parity Violation?

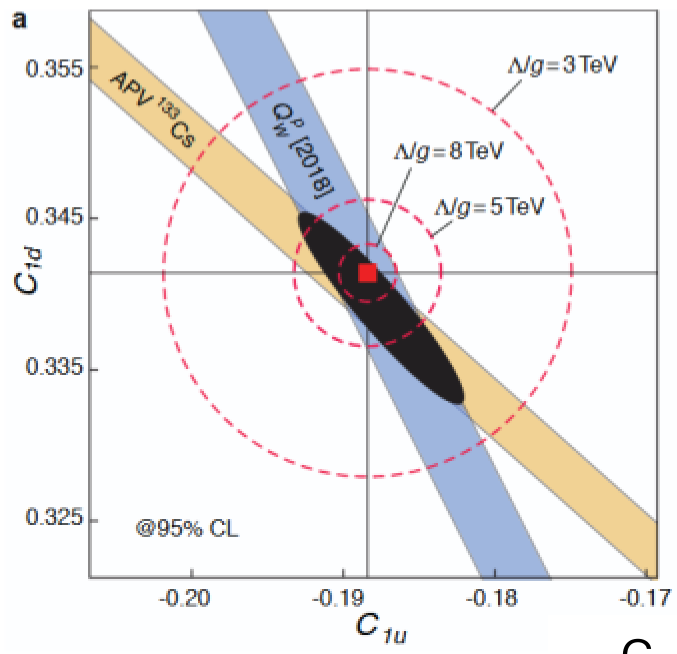
$$H_{PV} = \frac{G}{\sqrt{2}}\left(\frac{Q_W}{2}\gamma_5 + (\eta_{axial} + \eta_{hf} + \eta_{NAM})\mathbf{I}\cdot\boldsymbol{\alpha}\right)\rho(\mathbf{r})$$

Nuclear Distribution

Nuclear Spin Independent (Dominant)

Nuclear Spin Dependent

D. Androic et al., Nature 557, 207 (2018).



$$Q_W = (2Z + N)Q_{Wu} + (Z + 2N)Q_{Wd}$$

$$C_{1u} = -\frac{1}{2}Q_{Wu} \qquad C_{1u} = -\frac{1}{2}Q_{Wd}$$

Why Francium?

Heavy

$Q_W \propto N$

$\gamma_5 \propto Z^2$

Therefore

$H_{NSI} \propto Z^3$

$$H_{NSI} = \frac{G}{2\sqrt{2}} Q_W \gamma_5 \rho(r)$$

Francium gives ~18x enhancement effect to PV than cesium

Alkali

Single valence electron makes atomic calculation simpler

Laser Trappable

Isotope	Half Life	I	Advantage
Fr_{211}	3.1 min	$9/2^-$	Fast Deacy Chain
Fr_{223}	22 min	$3/2^-$	Octupole Deformation

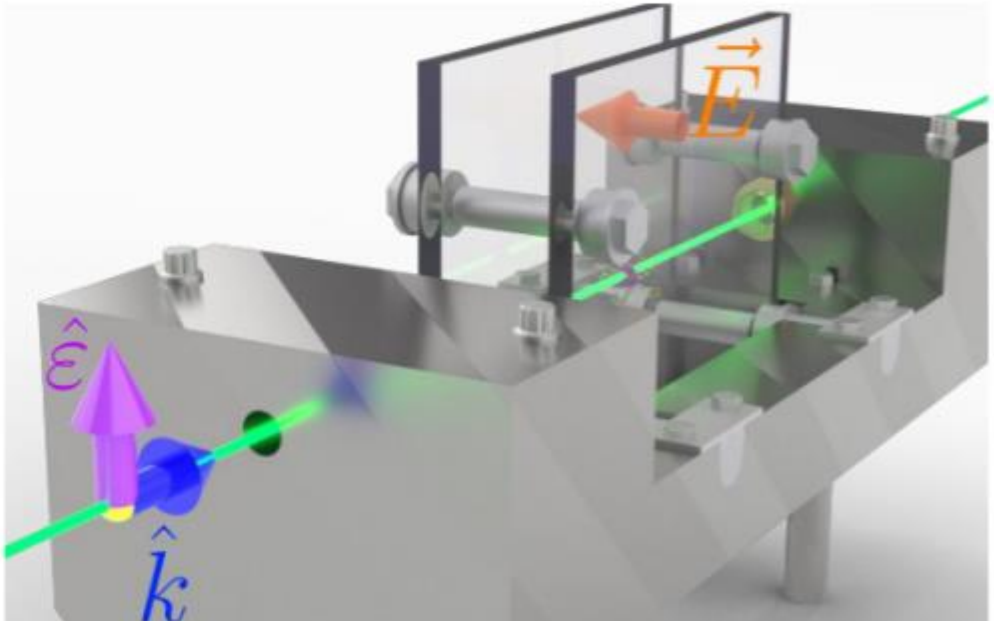
Why Stark Interference?

$$A_{Stark} = \alpha \mathbf{E}_S \cdot \boldsymbol{\varepsilon} \delta_{Fm,F'm'} + i\beta(\mathbf{E}_S \times \boldsymbol{\varepsilon}) \cdot \langle F'm'|\boldsymbol{\sigma}|Fm\rangle$$

$$A_{PV} = i\mathrm{Im}(E1_{PV})\boldsymbol{\varepsilon} \cdot \langle F'm'|\boldsymbol{\sigma}|Fm\rangle$$

$$R_{ns-(n+1)s} = \frac{2}{c\varepsilon_0\hbar^2}\tau I|A_{stark} + A_{PV} + A_{M1}|^2$$

$A_{stark}A_{PV}$ reverses sign with $\mathbf{E}_S$!



$A \propto f$

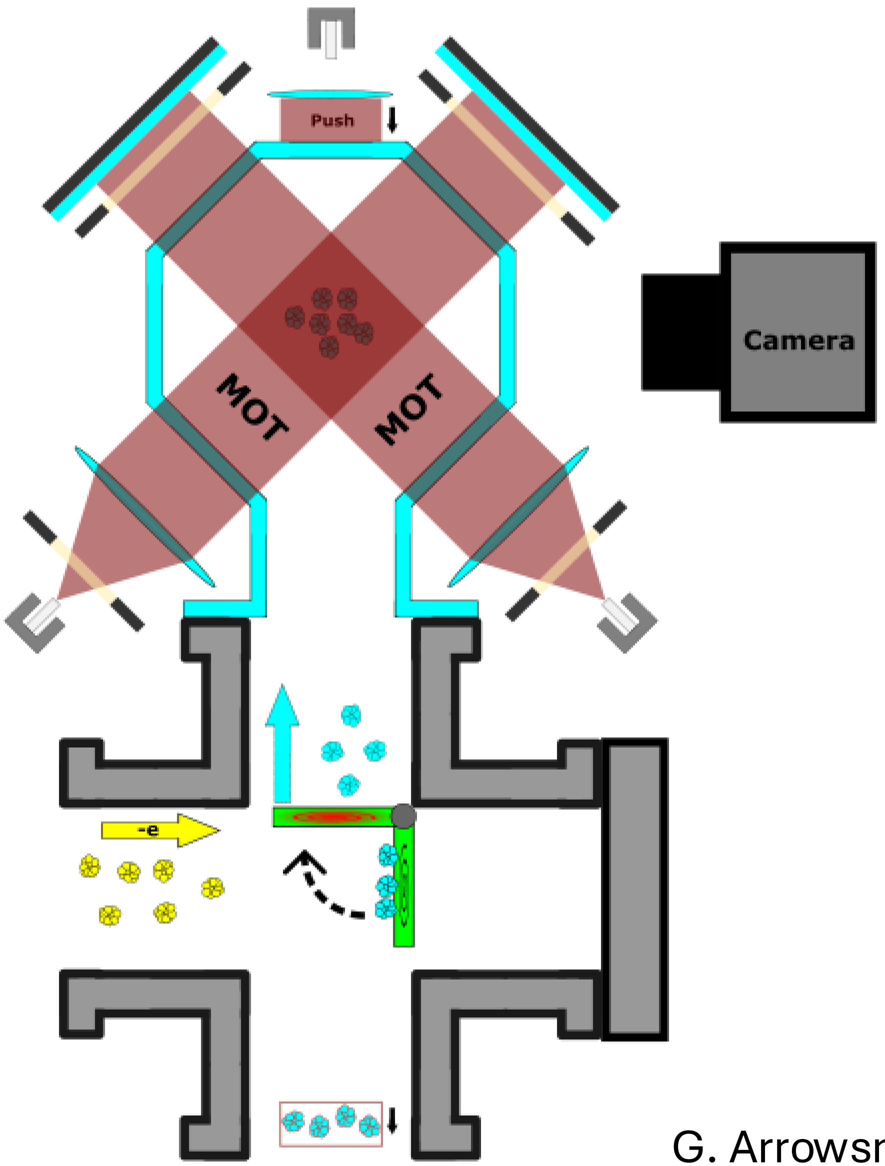
$f_{E1} \approx 1$

$f_{Stark} \approx 10^{-10}$

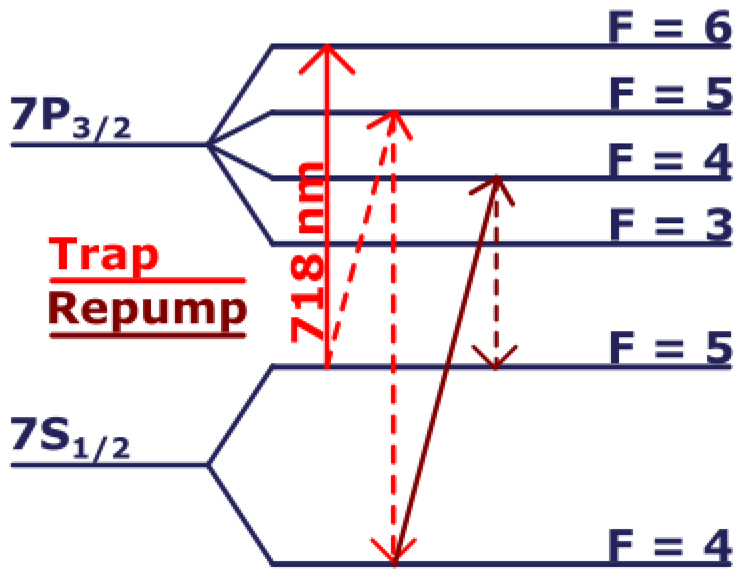
$f_{M1} \approx 10^{-13}$

$f_{PV} \approx 10^{-21}$

Francium Neutralization and Capture



Laser	Power	Transition
Trap	105 mW	$7S_{1/2}$ F=5 → $7P_{3/2}$ F=6
Repump	75 mW	$7S_{1/2}$ F=4 → $7P_{3/2}$ F=4
Push	330 μW	$7S_{1/2}$ F=5 → $7P_{3/2}$ F=6



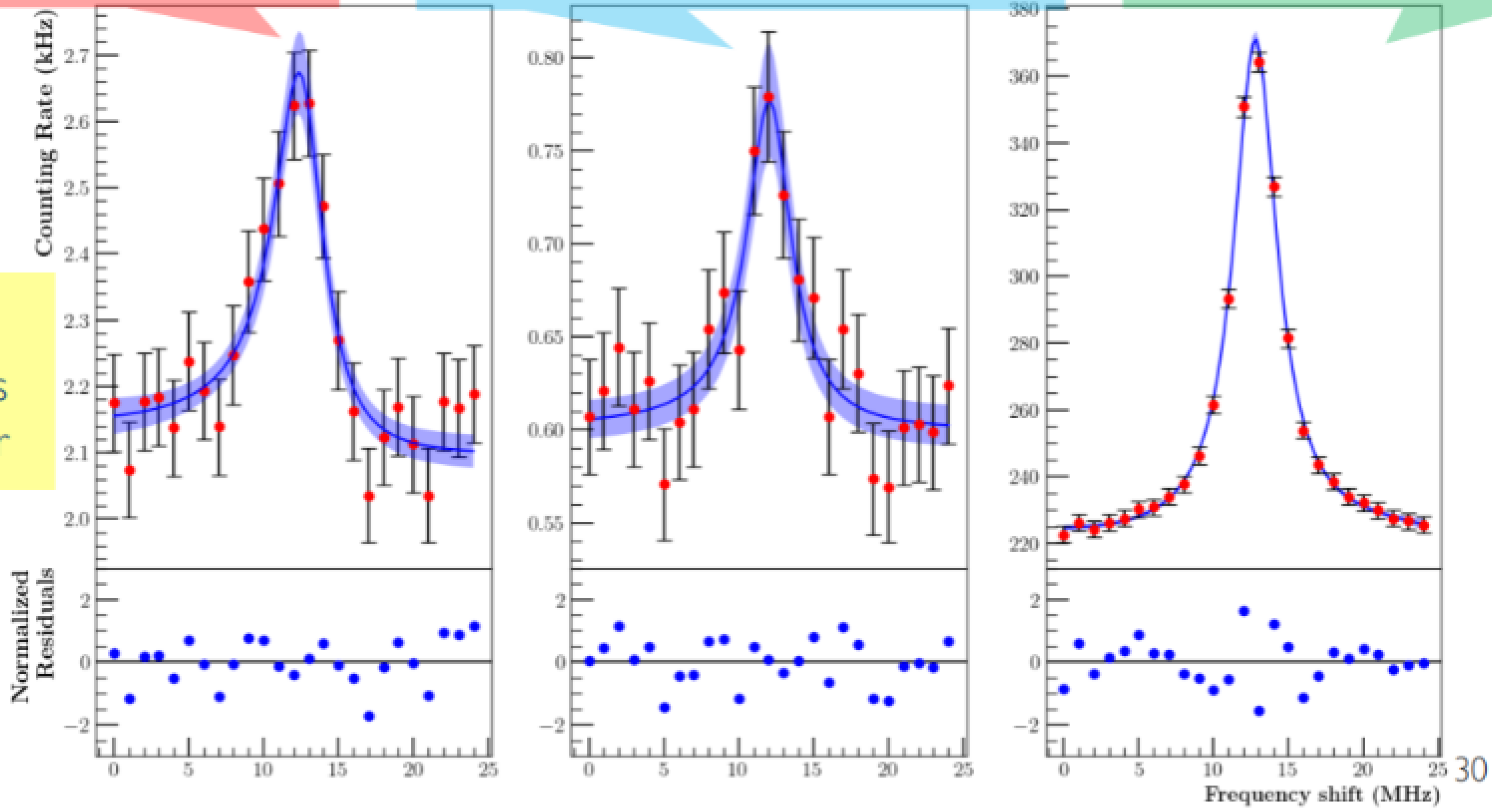
Signal Enhancement

2018: First observation of β at E=6123 V/cm, SNR ~ 0.4.

2021: First observation of M1 using PBC, SNR ~ 0.23. M1 ~2647x smaller than β at E=6123 V/cm

2023: M1 using PBC and burst, SNR ~ 9.2 a 40-fold improvement

7s-8s transitions using ^{211}Fr



M1/β Measurement

$$R_{ns\text{-}(n+1)s} = \frac{2}{c\varepsilon_0\hbar^2}\tau I|A_{stark} + A_{PV} + A_{M1}|^2$$

- A^2_{stark}
- $A_{stark}A_{PV}$
- A^2_{M1} — Have to know well!

$$A_{M1} = M1_{rel} + (F - F')\,M1_{hf}$$

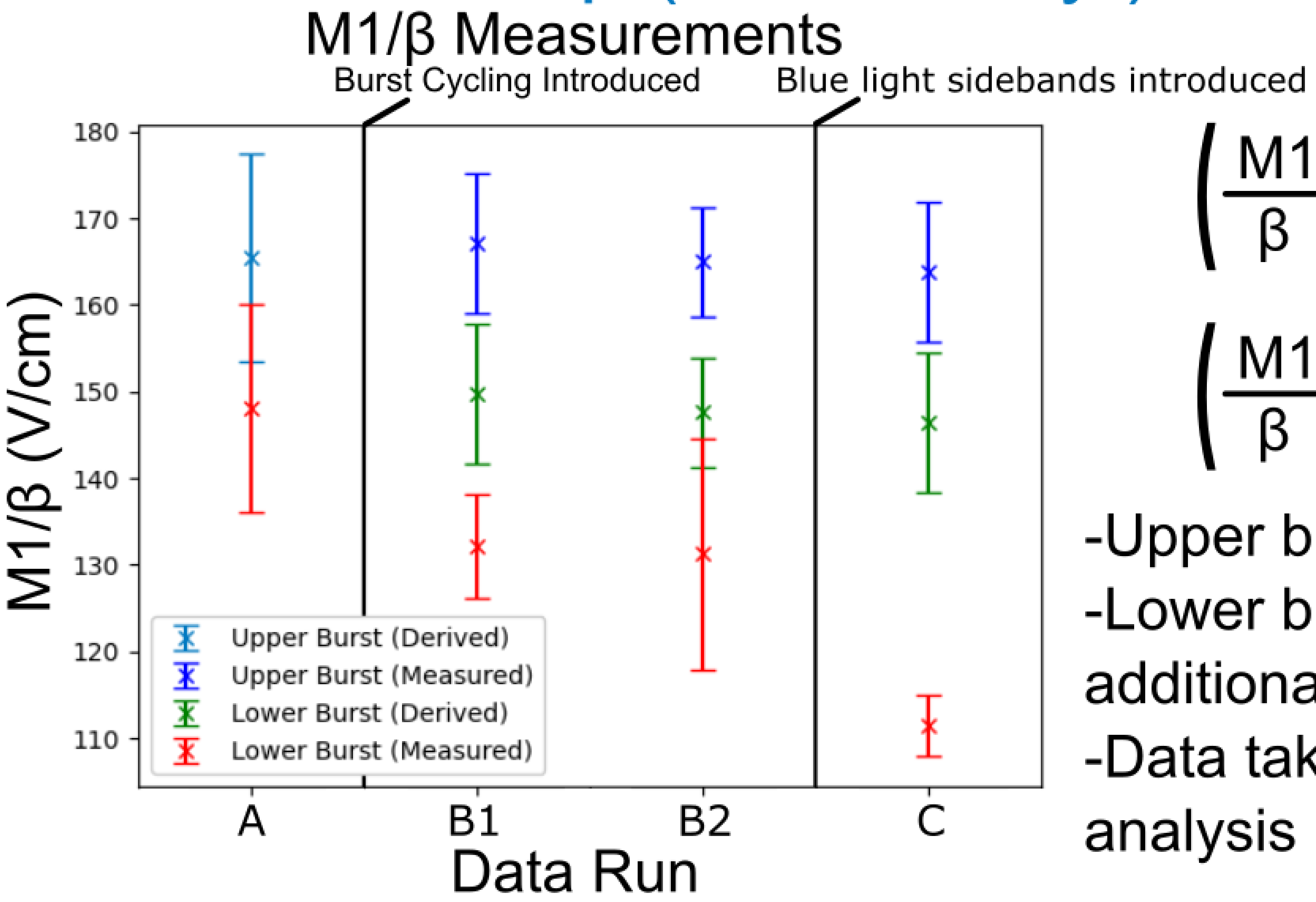
With $\boldsymbol{\varepsilon} \perp \mathbf{E}_s$, $R_{7s\rightarrow 8s} \propto \beta^2E^2 + (M1_{rel} \pm M1_{hf})^2$ For $\Delta F = \pm 1$

Value	Theory	Source
β	$74.3(7)a_0^3$	[1]
$M1_{hf}$	$-3.45\text{ E-}5\frac{\mu_B}{c}$	[2]
$M1_{rel}$	137.4 E-5	[1]

- True Value of β dependent on laser power, atom number, etc.
- Solution: Determine M1/β for ΔF = ±1, use theoretical values of $M1_{hf}$ and β as a check

[1] Phys. Rev. A 60, 4476 (1999)
[2] J. Phys. France 49, 2037-2044 (1988)

M1/β (Preliminary!) Results



$$\left(\frac{M1}{\beta}\right)_{LB} - \left(\frac{M1}{\beta}\right)_{UB} = \frac{2M1_{hf}}{\beta}$$

$$\left(\frac{M1}{\beta}\right)_{LB} + \left(\frac{M1}{\beta}\right)_{UB} = \frac{2M1_{rel}}{\beta}$$

-Upper burst remains steady

-Lower burst requires additional study

-Data taken in 2026 still under analysis

Thank you for your attention!

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