Colorado State University

First laboratory bounds on ultra-light dark photons from precision atomic spectroscopy

Amit Bhoonah

PHENOMENOLOGY 2022 SYMPOSIUM
May 9th - 11th 2022.

Based on work with Joshua Berger
(To Appear)

Overview

1. **Ultra-light dark photons.**
2. **Search for dark photons using high precision atomic spectroscopy.**

Introduction: Ultra-light dark photon (ULDP) dark matter

Extend Standard Model by a massive U(1) gauge boson

$$\mathcal{L} = \mathcal{L}_{\rm SM} - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + m^2 A'_\mu A'^\mu - \frac{e}{(1+\epsilon)^2} (A_\mu + \epsilon A'_\mu) J^\mu_{\rm EM},$$

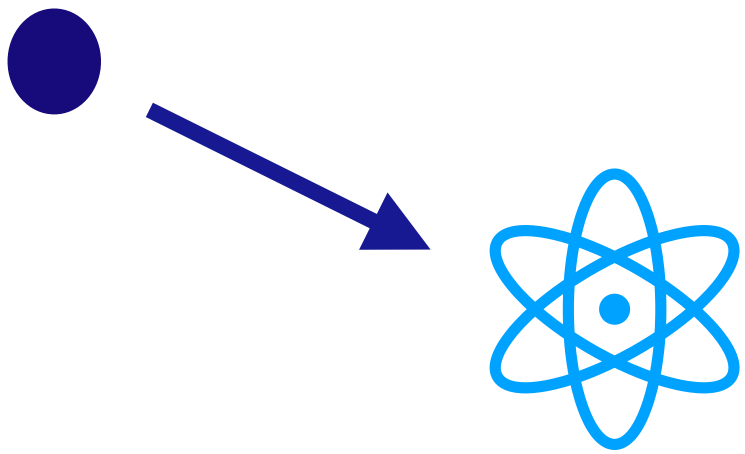
"Dark" Electromagnetism with a massive photon

Stable DM candidate for $m \ll 2m_e$

Ultra-light regime, $m \simeq \mathcal{O}\left(10^{-21}\right)$ eV, motivated by puzzles in galactic structure formation simulations

Introduction: WIMP vs ULDM

WIMP



Low number density

Single particle deposits small amount of energy to atom or nucleus

Low threshold detectors

ULDP

High number density

Single particle picture
not applicable: coherent source

Energy deposit too small to trigger even low threshold detectors

Detecting ULDP using High Precision Atomic Spectroscopy

Need new detection techniques that exploit coherent nature of ULDP

Can think of ULDP as a background Electromagnetic Field

$$\mathbf{E} \simeq \sqrt{2\rho_{DM}}\epsilon \sin\left(\frac{m_{\gamma'} c^2 t}{\hbar} + \phi_0\right)\hat{\mathbf{n}}$$

Time varying Stark shift in atoms

Time varying Zeeman shift in atoms

$$\mathbf{B} \simeq v\sqrt{2\rho_{DM}}\,\epsilon \sin\left(\frac{m_{\gamma'} c^2 t}{\hbar} + \phi_0\right)\hat{\mathbf{n}}'$$

$\rho_{DM} \simeq 0.3$ **GeV cm^{-3} DM energy density**

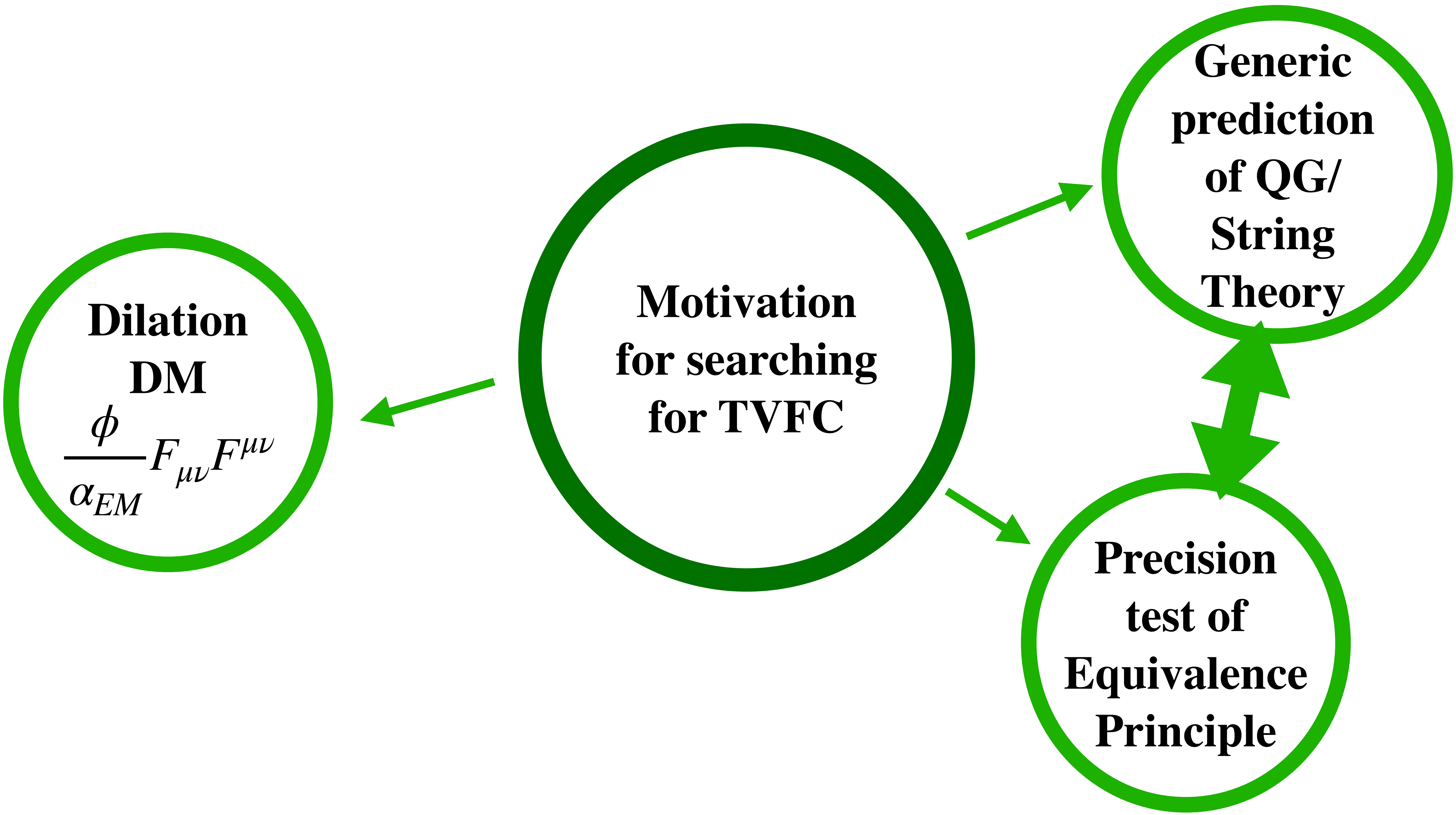
$v \simeq 10^{-3}\, c$ **DM velocity**

Detecting ULDP using High Precision Atomic Spectroscopy

Time varying shift in atomic frequencies

↓

Time variation of fundamental constants (TVFC)



Detecting ULDP using High Precision Atomic Spectroscopy

Three atomic clocks at NIST/JILA Boulder.

Atom	Transition	Energy (eV)
Al^+	$3s^2\ {}^1S_0 - 3s3p\ {}^3P_0$	4.643
Sr	$5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$	1.776
Yb	$4f^{14}6s^2\ {}^1S_0 - 4f^{14}6s6p\ {}^3P_0$	2.145

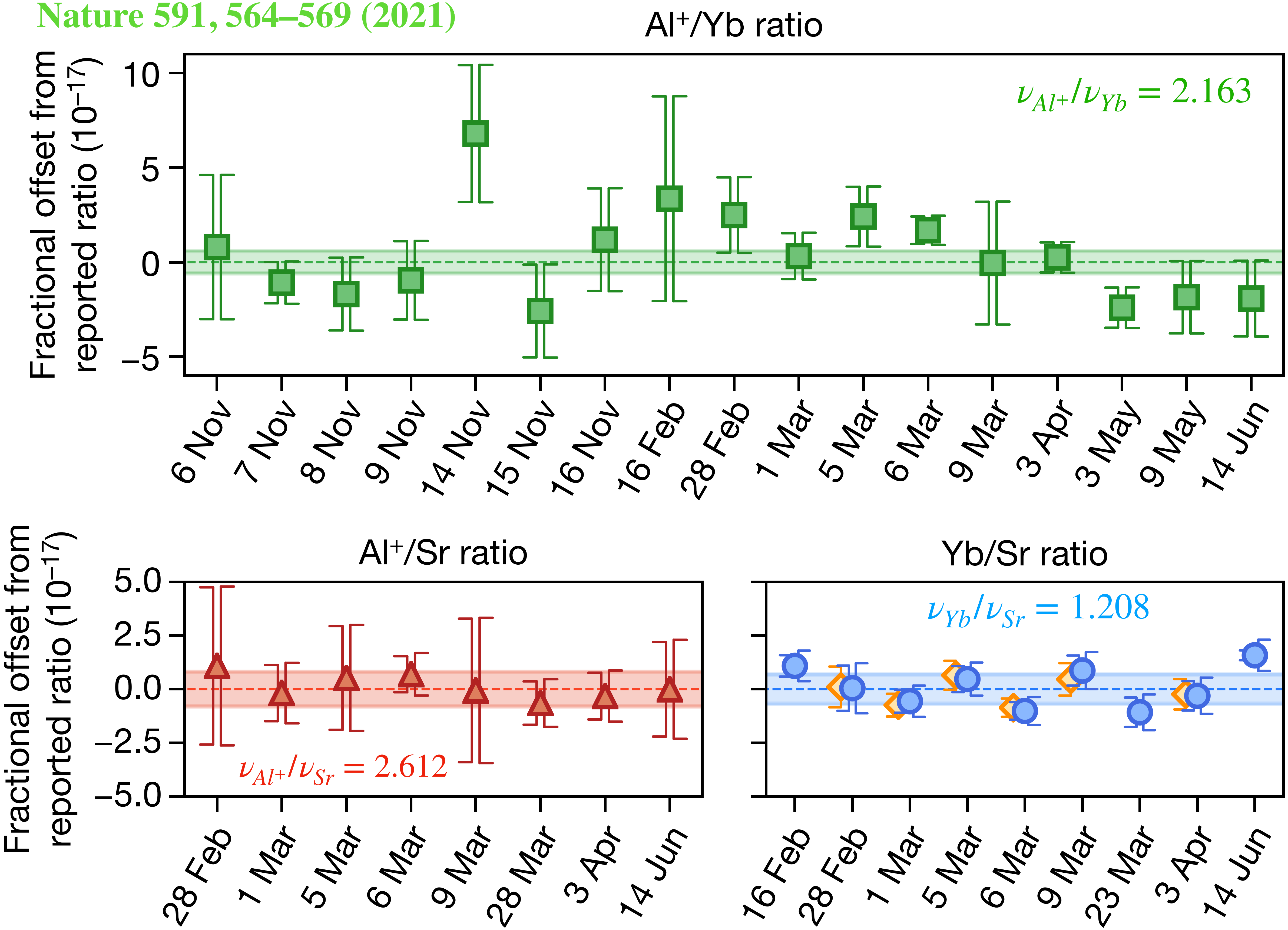
MOTIVATIONS

Better fractional uncertainty

${}^1S_0 \rightarrow {}^3P_0$ relatively insensitive to external B and E fields. No first order Zeeman shift. Better background control

Detecting ULDP using High Precision Atomic Spectroscopy

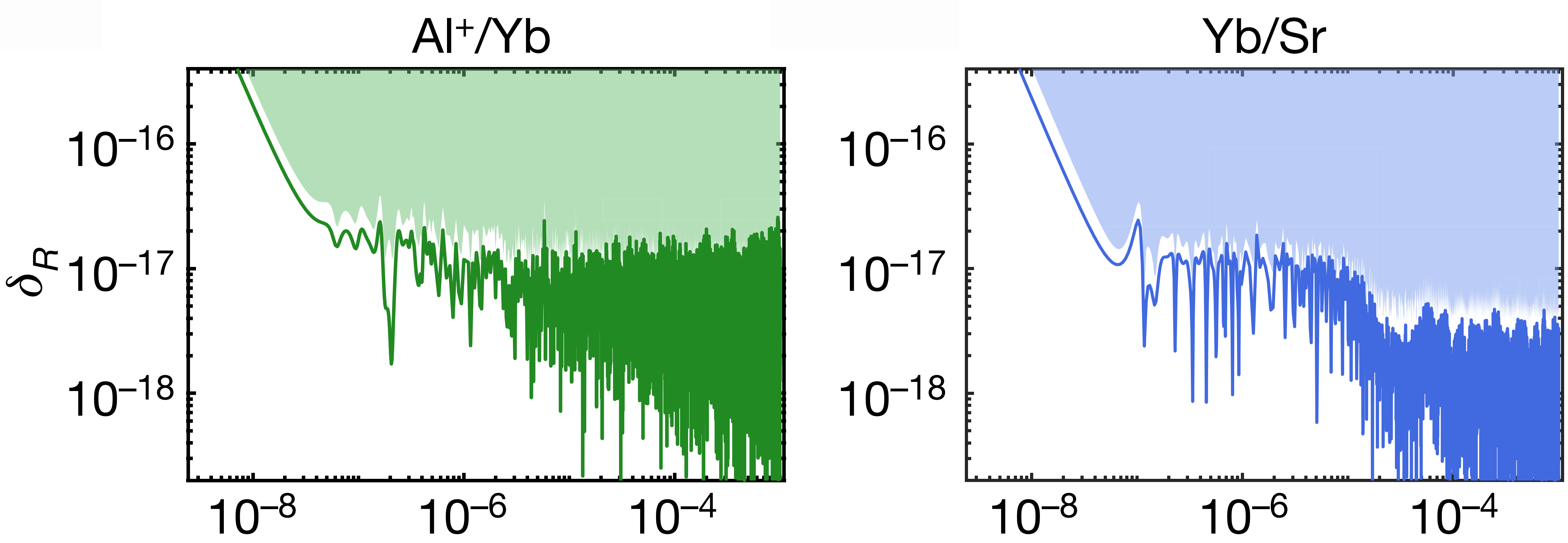
Nature 591, 564–569 (2021)



Detecting ULDP using High Precision Atomic Spectroscopy

Fit a sinusoidal signal to time series ratio data. Previously done for dilation DM

Fit Amplitude



Nature 591, 564–569 (2021)

Fit Frequency: dark photon mass $\sim \sin^2\left(mt + \phi_0\right)$

$$\delta_R = 2\,\pi\,\epsilon^2\,\rho_{\rm DM}\,a_0^3\,\left(\frac{\Delta\alpha_{D,1}}{\hbar\,\omega_1} - \frac{\Delta\alpha_{D,2}}{\hbar\,\omega_2}\right)$$

Preliminary Results