

News from the Light:

New Physics Searches with Spectroscopy

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News from the dark 11 | IphT | September 29, 2026



The Standard Model is incomplete



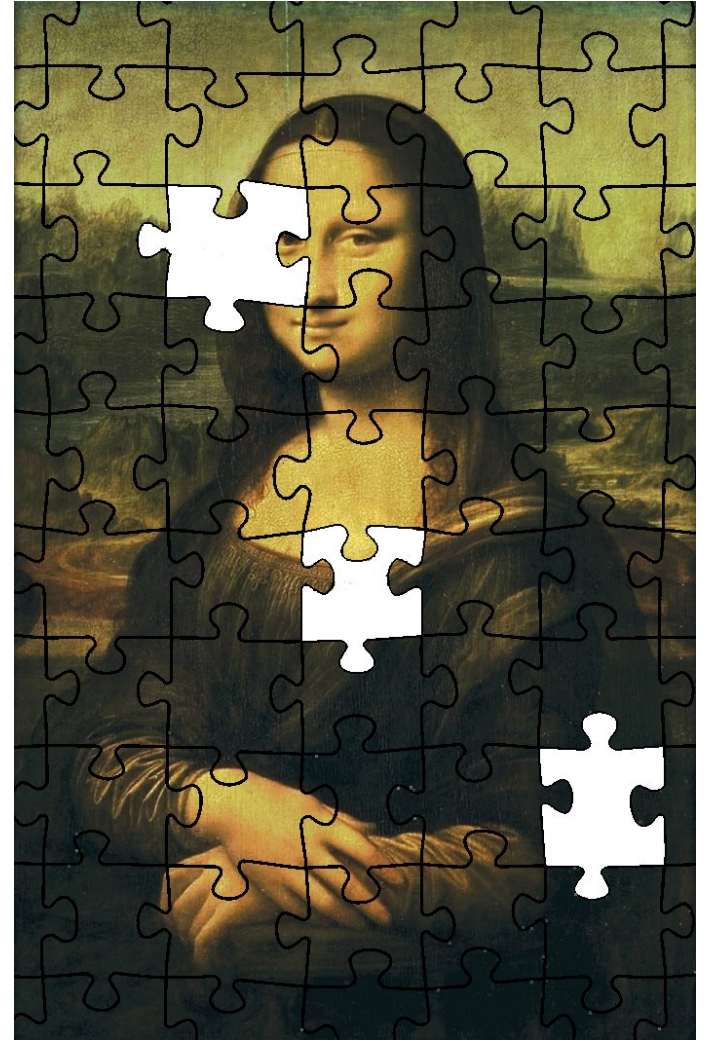
neutrino masses



dark matter

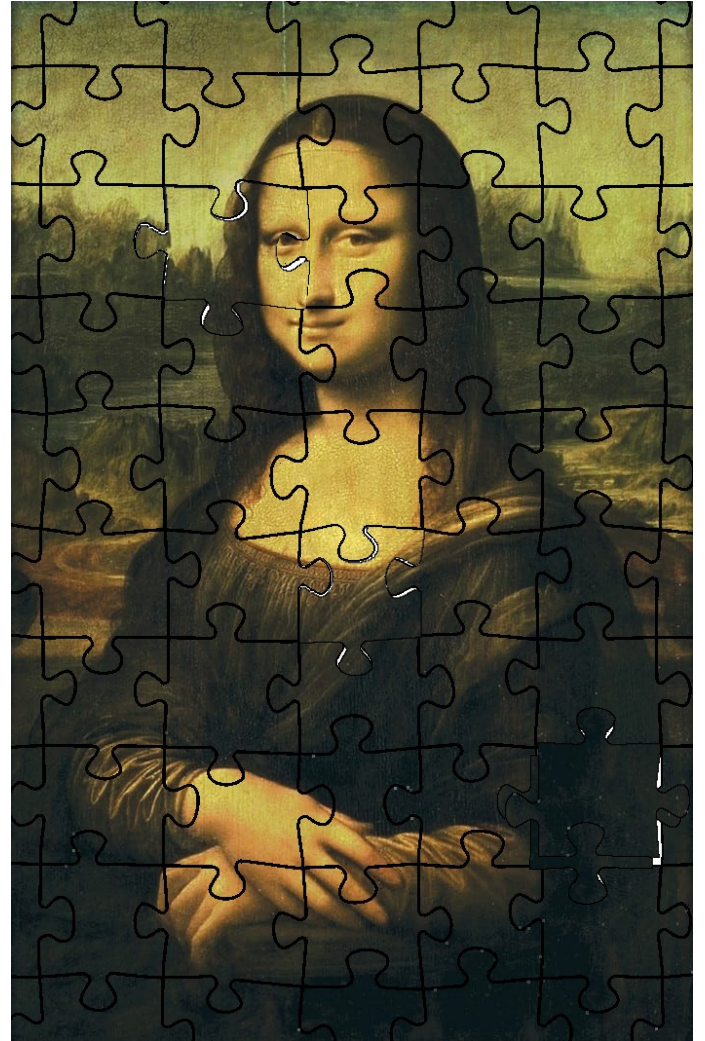


baryon asymmetry

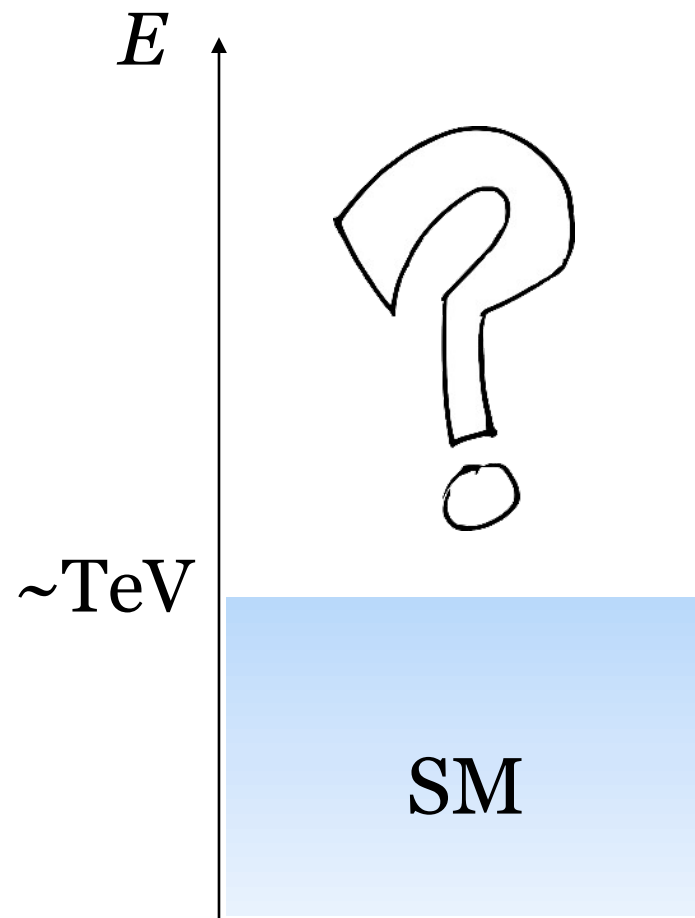


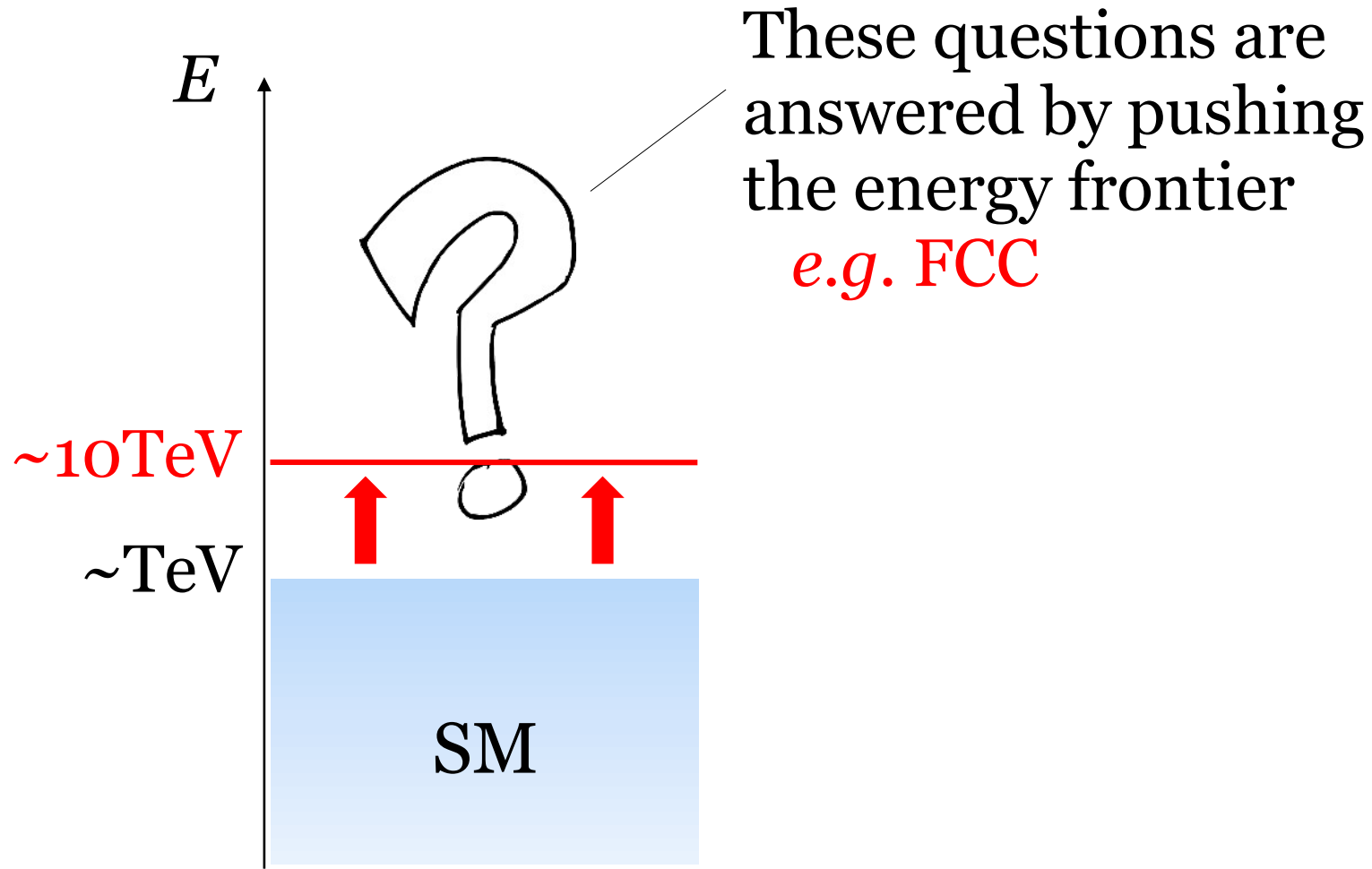
Even completed, there
are ‘aesthetical’ issues,
*crying out for a better
picture:*

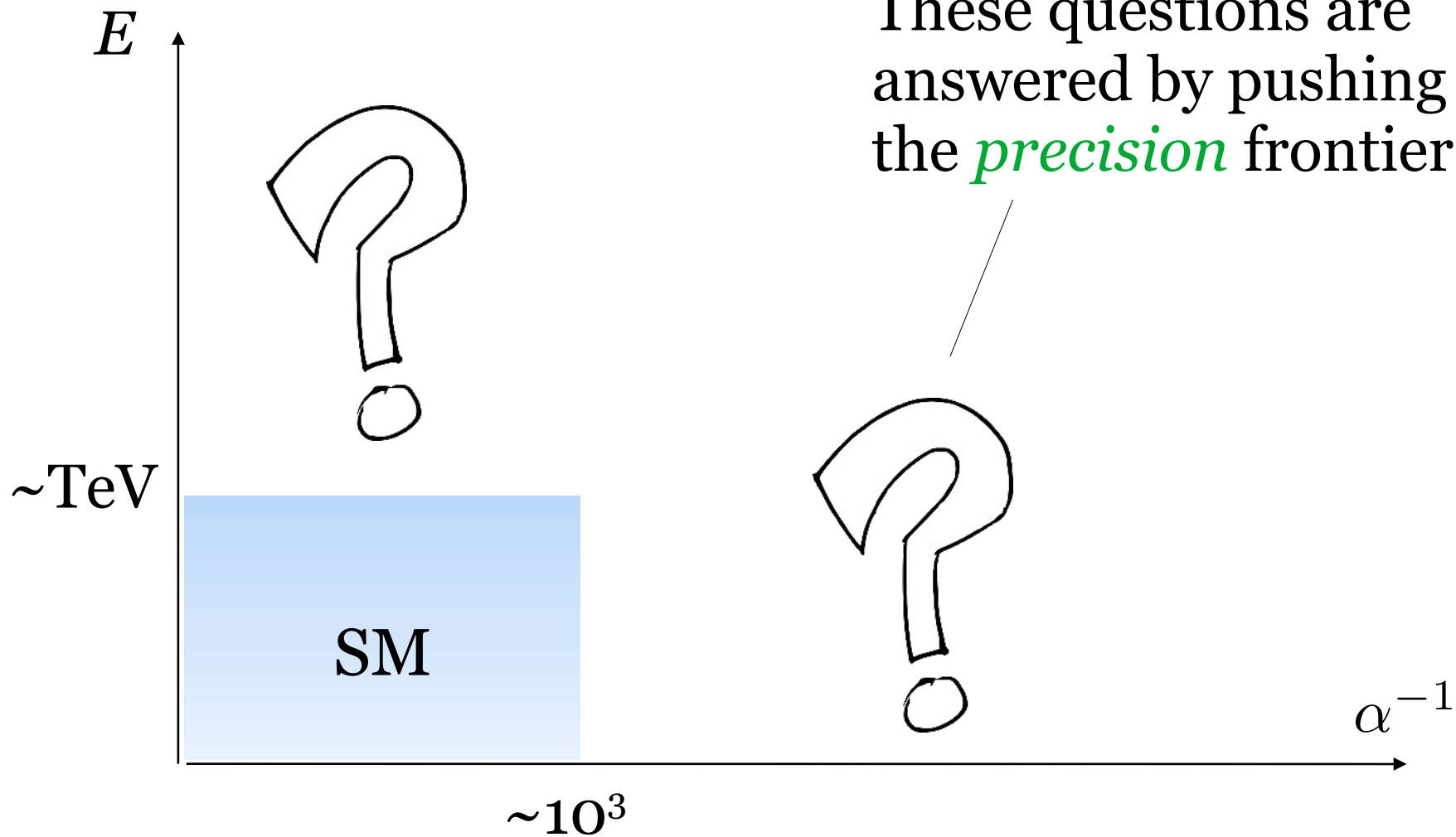
- *CC*
- *Higgs mass*
- *flavor*
- *(strong) CP*
- *etc?*



The legacy of the *LHC*







Ultralight fields are *whispers* of
high-scale dynamics :

spontaneous breaking
in the UV: $\mathcal{G} \xrightarrow{f \gg \text{TeV}} \mathcal{H}$

weakly-coupled *pNGB*
in the deep IR:

small *explicit* breaking

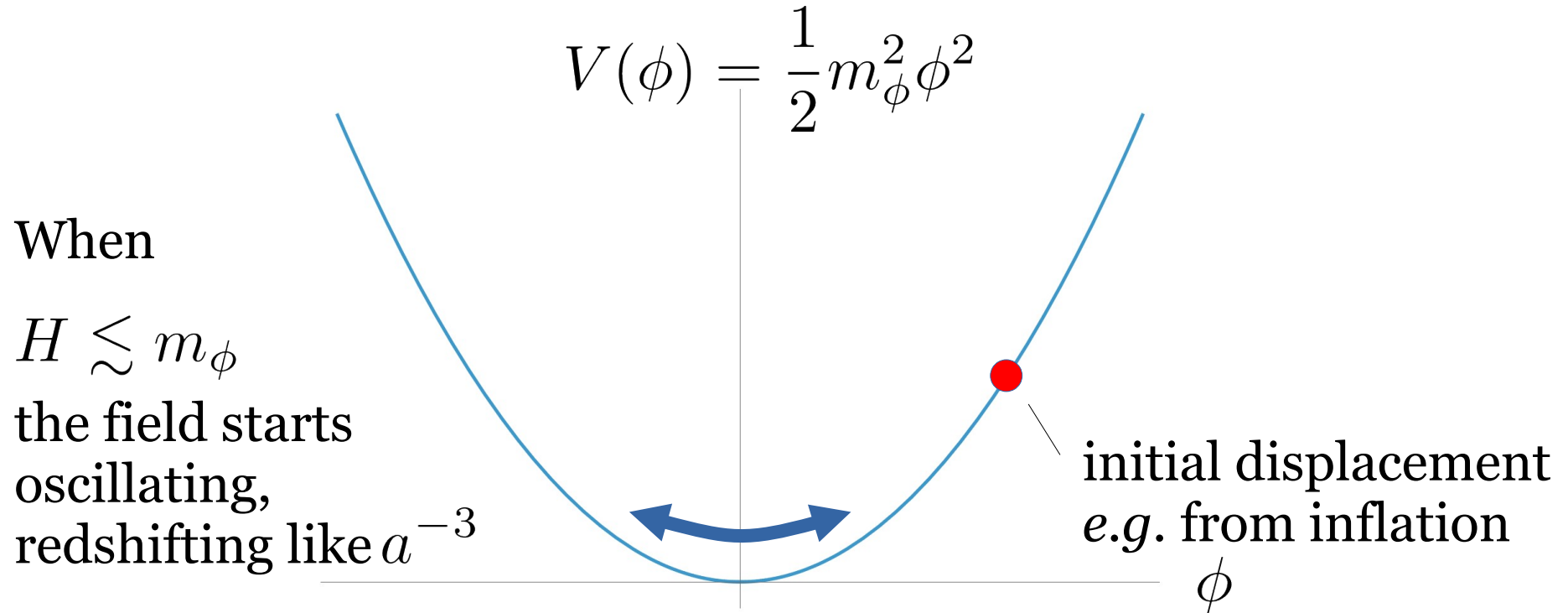
$$\mathcal{L}_{\text{eff}} \supset -\boxed{m_\phi^2} \frac{\phi^2}{2} + \frac{\partial_\mu \phi}{f} \mathcal{O}_{\text{SM}}^\mu + \boxed{\epsilon} \frac{\phi^n}{f^n} \mathcal{O}_{\text{SM}}$$

$m_\phi^2 \propto \epsilon$

Prominent examples
include:

- Axion(-like): $\mathcal{L} \supset \frac{\phi}{f} G_{\mu\nu} \tilde{G}^{\mu\nu}$
- Relaxion: $\mathcal{L} \supset \frac{\phi}{f} H^\dagger H$
- Dilaton: $\mathcal{L} \supset \frac{\phi}{f} [\beta(g) G^{\mu\nu} G_{\mu\nu} + m_\psi \bar{\psi} \psi]$

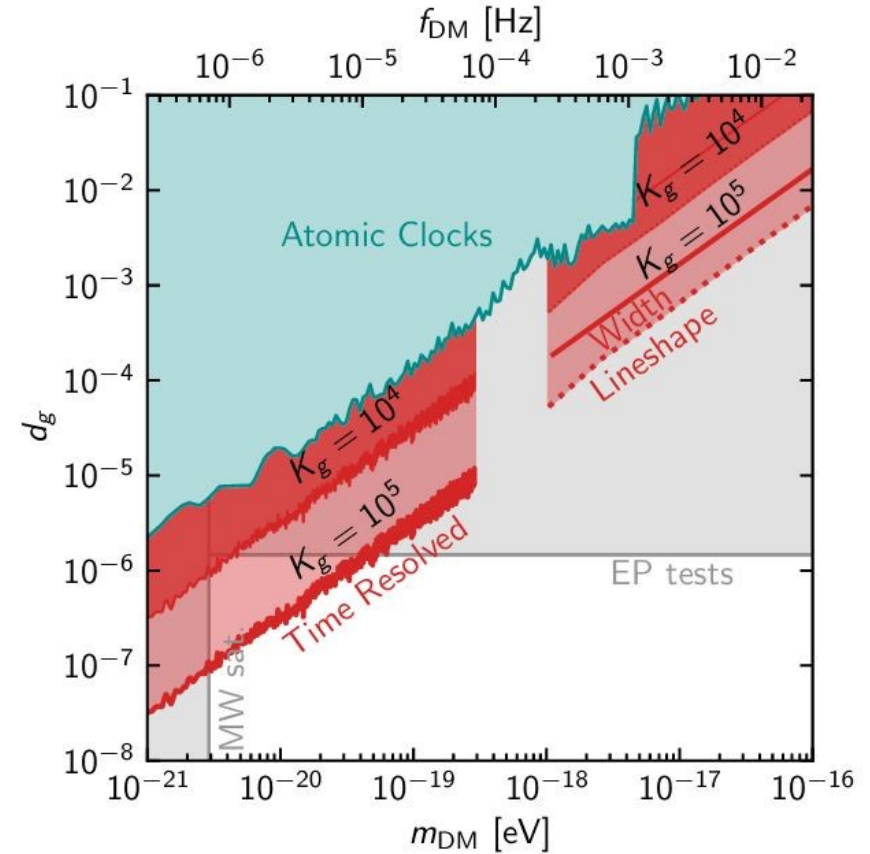
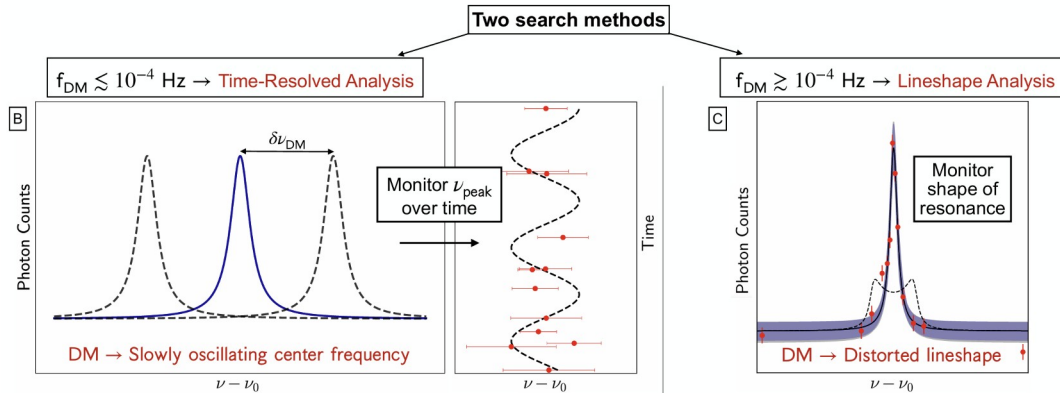
For $m_\phi \lesssim \text{eV}$, such states could be dark matter:



ULDM coupled to QCD:

$$\mathcal{L}_{\text{int}} = -d_g \frac{\beta(g)}{8\pi M_{\text{Pl}}} \phi G_{\mu\nu}^a G^{\mu\nu a}$$

with $\phi(t) = \frac{\sqrt{2\rho_{\text{DM}}}}{m_\phi} \cos(m_\phi t)$

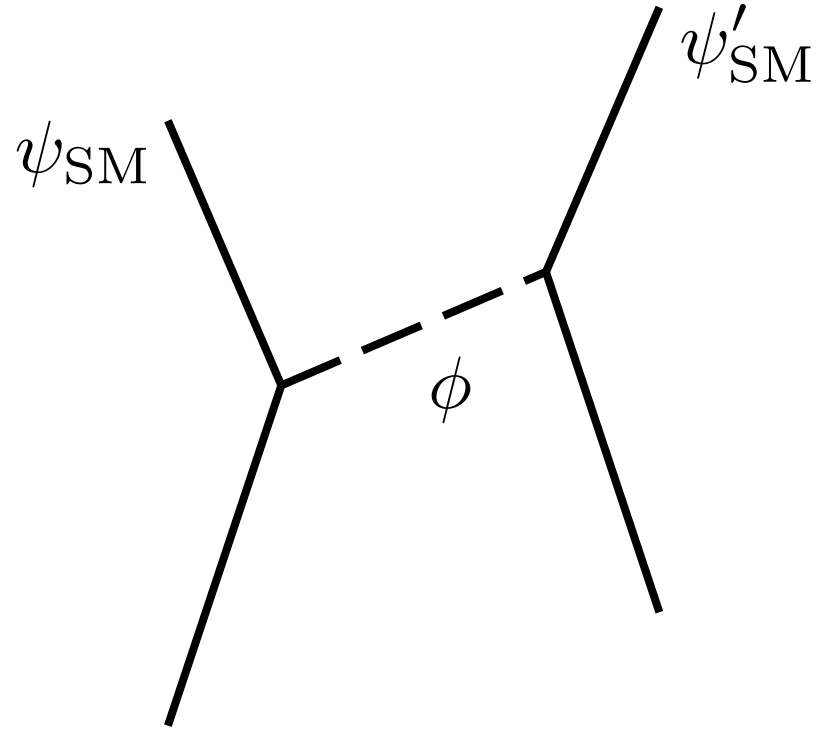


Aragawa et al. 2602.16804

These light states
also induce *static*
new forces

$$\mathcal{O} \sim \textcolor{red}{\phi} \bar{\psi}_{\text{SM}} \psi_{\text{SM}}$$

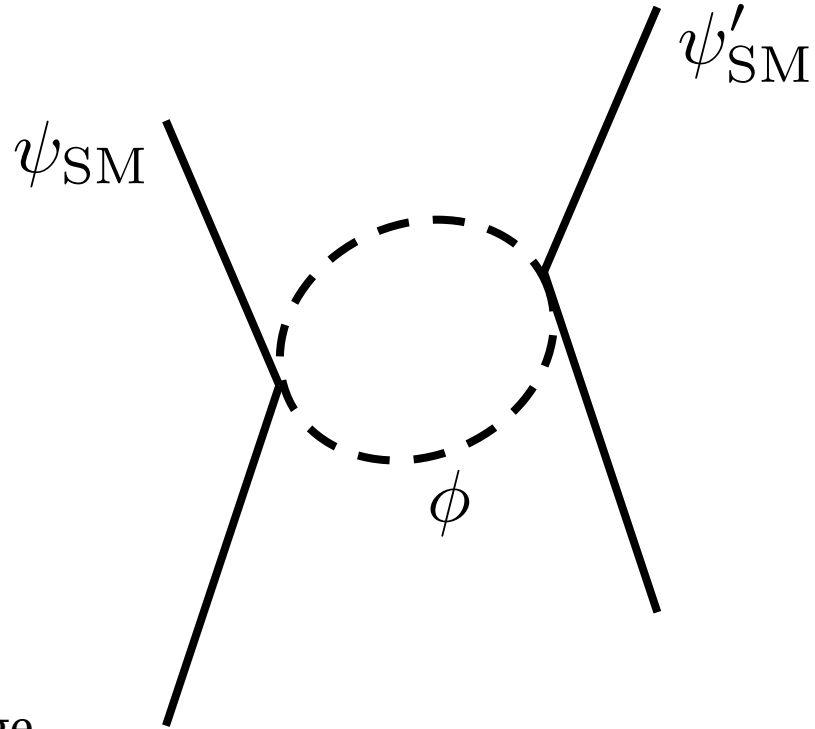
$$V(r) \sim \frac{e^{-m_\phi r}}{r}$$



These light states
also induce *static*
new forces

$$\mathcal{O} \sim \phi^2 \bar{\psi}_{\text{SM}} \psi_{\text{SM}}$$

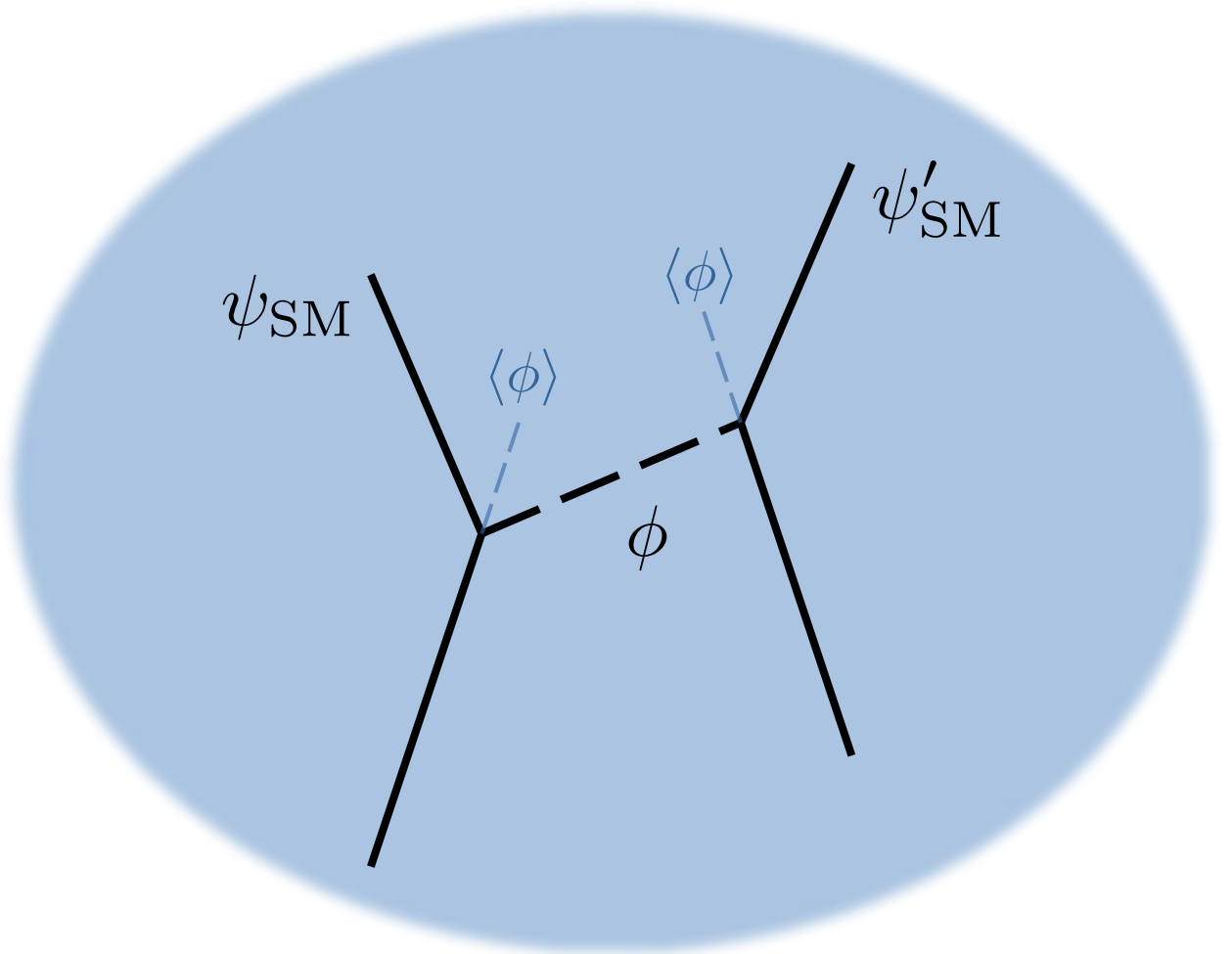
$$V(r) \sim \frac{e^{-m_\phi r}}{r^3} \quad \text{short range}$$



These light states
also induce *static*
new forces

$$\mathcal{O} \sim \phi^2 \bar{\psi}_{\text{SM}} \psi_{\text{SM}}$$

$$V(r) \sim \frac{e^{-m_\phi r}}{r}$$



Today, I will present **two strategies**
to probe such *static forces* at different ranges:

- Atomic & molecular spectroscopy

$$\text{keV} \lesssim m_\phi \lesssim \text{MeV}$$

- Nuclear clock ‘quintessometers’

$$m_\phi \ll \text{eV}$$

Probing New Physics at the Atomic Frontier

Transition frequencies in atoms
are *extremely* well measured:

Optical clock transition
e.g. $^1S_0 \rightarrow ^3P_0$ $f \sim 100$ THz
BACON collaboration, Nature 2021

$$\frac{f_{\text{Yb}}}{f_{\text{Sr}}} = 1.207\ 507\ 039\ 343\ 337\ 848\ 2\ (82)$$

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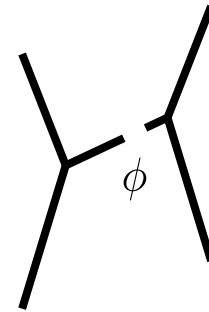
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$$\frac{f_{\text{Yb}}}{f_{\text{Sr}}} = 1.207\,507\,039\,343\,337\,848\,2 \quad (82)$$

$$\delta f_\phi \sim \frac{\alpha_\phi}{a_0(2 + m_\phi a_0)^2}$$

Bohr radius

$$a_0^{-1} = \alpha m_e \approx 4 \text{ keV}$$



$$\alpha_\phi = 1$$

$$m_\phi \sim \text{MeV}$$

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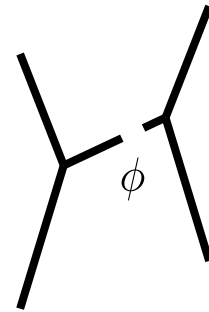
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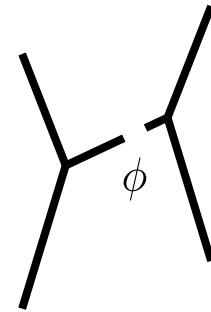
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Bohr radius

$$a_0^{-1} = \alpha m_e \approx 4 \text{ keV}$$



$$\alpha_\phi = 1$$
$$m_\phi \sim \text{TeV}$$

However, they are poorly known *theoretically*:

Optical clock transition
e.g. $^1S_0 \rightarrow ^3P_0$ $f \sim 100$ THz
BACON collaboration, Nature 2021

$$\frac{f_{\text{Yb}}}{f_{\text{Sr}}} = 1.20$$

These atoms have tens of electrons, each of which is subject to e.m. repulsion from the others

Many-body atomic calculations have typically **1% uncertainty**

However, they are poorly known *theoretically*:

Optical clock transition
e.g. $^1S_0 \rightarrow ^3P_0$ $f \sim 100$ THz
BACON collaboration, Nature 2021

$$\frac{f_{\text{Yb}}}{f_{\text{Sr}}} = 1.207\,507$$

Another important obstacle
is nuclear finite size effect

$$\alpha m_e / \Lambda_{\text{QCD}} \sim 10^{-5}$$

Nuclear charge distribution (radius,...) can be extracted from data

However, new forces of range shorter than Λ_{QCD} cannot be resolved!

Unless it breaks symmetries of QED/QCD: (C)P or time translation

To extract new physics, one has two options:

Direct comparison of
theory and experiment

e.g. using *simple atoms*
for which high precision
QED calculations are
available, $\sigma_{\text{th}} < \sigma_{\text{exp}}$

vs.

Theory-independent
observable comparison

e.g. leveraging factorization
of nuclear/electronic scales
→ *isotope shifts & King plots*

Probing New Physics at the Atomic Frontier

Simple atoms

$H, D, He, \mu H, \mu D, HD^+, H_2^+$

Hydrogen absorption lines are also measured very precisely:

$$u_{1S-2S}^H = 4.2 \times 10^{-15}$$

Parthey et al., PRL 2011

$$f_{1S-2S}^H = 2\,466\,061\,413\,187\,035\,(10)\,\text{Hz}$$

The theory prediction is also well known:

$$f_{1S-2S}^H = \frac{3R_\infty c}{4(1 + \mu_{ep})} \left[1 + \delta_{1S-2S}^{\text{QED}}(\alpha) + \delta_{1S-2S}^{\text{FNS}}(r_p) \right]$$

$R_\infty \equiv \frac{\alpha^2 m_e c}{2h}$ *Rydberg constant*

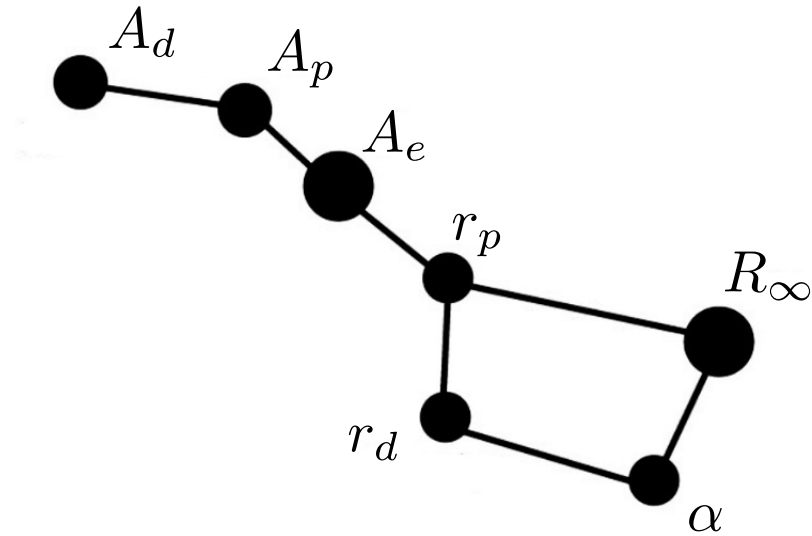
$\mu_{ep} \equiv \frac{m_e}{m_p}$ *nuclear recoil*

$\delta_{1S-2S}^{\text{QED}}(\alpha)$ *QED 1+2 loop, uncertainty 2Hz*

$\delta_{1S-2S}^{\text{FNS}}(r_p)$ *finite nuclear size effect 1MHz*

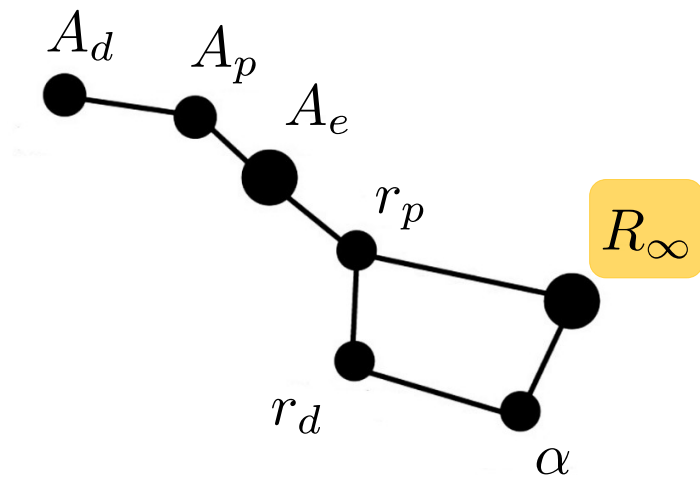
but requires the precise determination of a few *fundamental constants*

Fundamental constants are
intertwined with several observables



and must be extracted together in a global fit,
performed by the **CODATA collaboration**

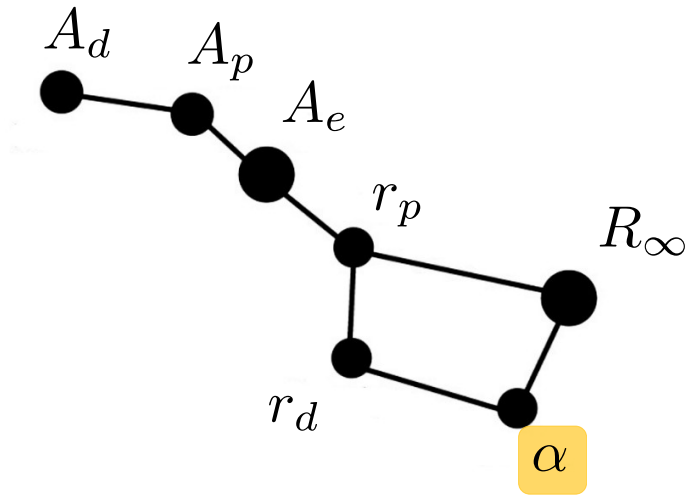
Fundamental constants are *intertwined* with several observables



Hydrogen & deuterium lines
fix the Rydberg constant

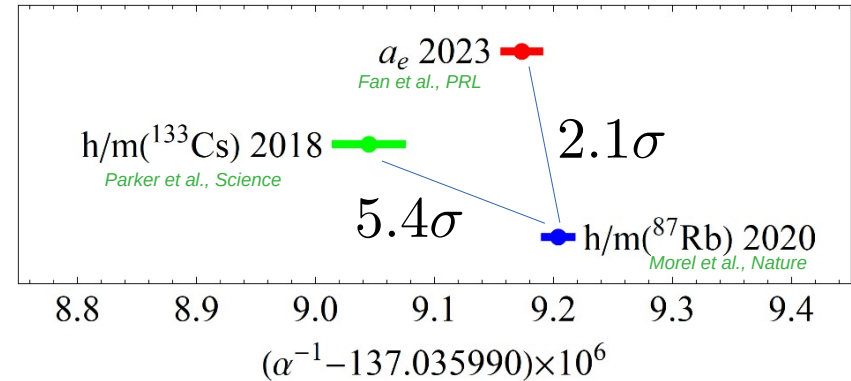
	Reference	Lab.	Energy interval(s)	Reported value $\Delta\mathcal{E}/h$ (kHz)	Rel. stand. uncert. u_r
A1	Weitz <i>et al.</i> (1995)	MPQ	$\Delta\mathcal{E}_H(2S_{1/2}-4S_{1/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	4 797 338(10)	2.1×10^{-6}
A2			$\Delta\mathcal{E}_H(2S_{1/2}-4D_{5/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	6 490 144(24)	3.7×10^{-6}
A3			$\Delta\mathcal{E}_D(2S_{1/2}-4S_{1/2}) - \frac{1}{4}\Delta\mathcal{E}_D(1S_{1/2}-2S_{1/2})$	4 801 693(20)	4.2×10^{-6}
A4			$\Delta\mathcal{E}_D(2S_{1/2}-4D_{5/2}) - \frac{1}{4}\Delta\mathcal{E}_D(1S_{1/2}-2S_{1/2})$	6 494 841(41)	6.3×10^{-6}
A5	Parthey <i>et al.</i> (2010)	MPQ	$\Delta\mathcal{E}_D(1S_{1/2}-2S_{1/2}) - \Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	670 994 334.606(15)	2.2×10^{-11}
A6	Parthey <i>et al.</i> (2011)	MPQ	$\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	2 466 061 413 187.035(10)	4.2×10^{-15}
A7	Matveev <i>et al.</i> (2013)	MPQ	$\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	2 466 061 413 187.018(11)	4.4×10^{-15}
A8	Beyer <i>et al.</i> (2017)	MPQ	$\Delta\mathcal{E}_H(2S_{1/2}-4P)$	616 520 931 626.8(2.3)	3.7×10^{-12}
A9	Grinin <i>et al.</i> (2020)	MPQ	$\Delta\mathcal{E}_H(1S_{1/2}-3S_{1/2})$	2 922 743 278 665.79(72)	2.5×10^{-13}
A10	de Beauvoir <i>et al.</i> (1997)	LKB/ SYRTE	$\Delta\mathcal{E}_H(2S_{1/2}-8S_{1/2})$	770 649 350 012.0(8.6)	1.1×10^{-11}
A11			$\Delta\mathcal{E}_H(2S_{1/2}-8D_{3/2})$	770 649 504 450.0(8.3)	1.1×10^{-11}
A12			$\Delta\mathcal{E}_H(2S_{1/2}-8D_{5/2})$	770 649 561 584.2(6.4)	8.3×10^{-12}
A13			$\Delta\mathcal{E}_D(2S_{1/2}-8S_{1/2})$	770 859 041 245.7(6.9)	8.9×10^{-12}
A14			$\Delta\mathcal{E}_D(2S_{1/2}-8D_{3/2})$	770 859 195 701.8(6.3)	8.2×10^{-12}
A15			$\Delta\mathcal{E}_D(2S_{1/2}-8D_{5/2})$	770 859 252 849.5(5.9)	7.7×10^{-12}
A16	Schwob <i>et al.</i> (1999)	LKB/ SYRTE	$\Delta\mathcal{E}_H(2S_{1/2}-12D_{3/2})$	799 191 710 472.7(9.4)	1.2×10^{-11}
A17			$\Delta\mathcal{E}_H(2S_{1/2}-12D_{5/2})$	799 191 727 403.7(7.0)	8.7×10^{-12}
A18			$\Delta\mathcal{E}_D(2S_{1/2}-12D_{3/2})$	799 409 168 038.0(8.6)	1.1×10^{-11}
A19			$\Delta\mathcal{E}_D(2S_{1/2}-12D_{5/2})$	799 409 184 966.8(6.8)	8.5×10^{-12}
A20	Bourzeix <i>et al.</i> (1996)	LKB	$\Delta\mathcal{E}_H(2S_{1/2}-6S_{1/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-3S_{1/2})$	4 197 604(21)	4.9×10^{-6}
A21			$\Delta\mathcal{E}_H(2S_{1/2}-6D_{5/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-3S_{1/2})$	4 699 099(10)	2.2×10^{-6}
A22	Fleurbaey <i>et al.</i> (2018)	LKB	$\Delta\mathcal{E}_H(1S_{1/2}-3S_{1/2})$	2 922 743 278 671.5(2.6)	8.9×10^{-13}
A23	Brandt <i>et al.</i> (2022)	CSU	$\Delta\mathcal{E}_H(2S_{1/2}-8D_{5/2})$	770 649 561 570.9(2.0)	2.6×10^{-12}
A24	Berkeland <i>et al.</i> (1995)	Yale	$\Delta\mathcal{E}_H(2S_{1/2}-4P_{1/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	4 664 269(15)	3.2×10^{-6}
A25			$\Delta\mathcal{E}_H(2S_{1/2}-4P_{3/2}) - \frac{1}{4}\Delta\mathcal{E}_H(1S_{1/2}-2S_{1/2})$	6 035 373(10)	1.7×10^{-6}
A26	Newton <i>et al.</i> (1979)	Sussex	$\Delta\mathcal{E}_H(2P_{1/2}-2S_{1/2})$	1 057 862(20)	1.9×10^{-5}
A27	Lundeen and Pipkin (1981)	Harvard	$\Delta\mathcal{E}_H(2P_{1/2}-2S_{1/2})$	1 057 845.0(9.0)	8.5×10^{-6}
A28	Hagley and Pipkin (1994)	Harvard	$\Delta\mathcal{E}_H(2S_{1/2}-2P_{3/2})$	9 911 200(12)	1.2×10^{-6}
A29	Bezginov <i>et al.</i> (2019)	York	$\Delta\mathcal{E}_H(2P_{1/2}-2S_{1/2})$	1 057 829.8(3.2)	3.0×10^{-6}

Fundamental constants are
intertwined with several observables

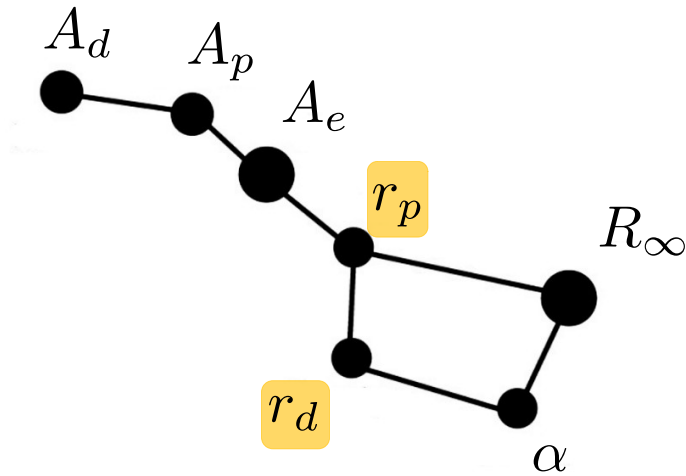


The fine-structure constant
is now best determined
by *recoil measurements*

$$\alpha^2 = \frac{2R_\infty}{c} \times \frac{m_{\text{At}}}{m_e} \times \frac{h}{m_{\text{At}}}$$

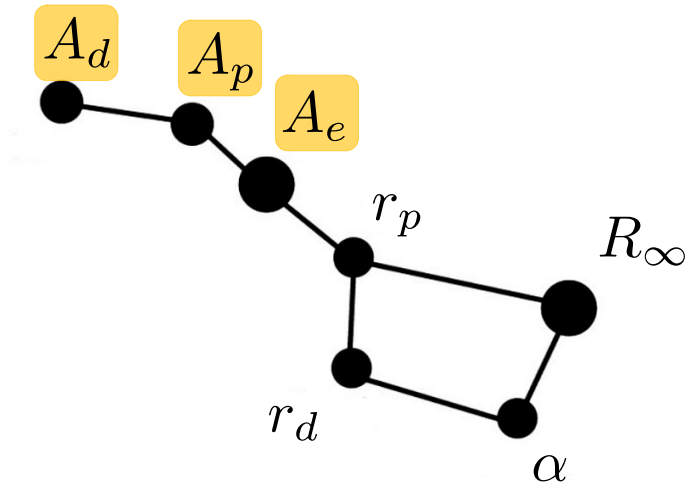


Fundamental constants are
intertwined with several observables



Lamb shift of μH & μD
are most sensitive to the
proton and deuteron
charge radii
due to 'lower' orbits of the
heavy muon

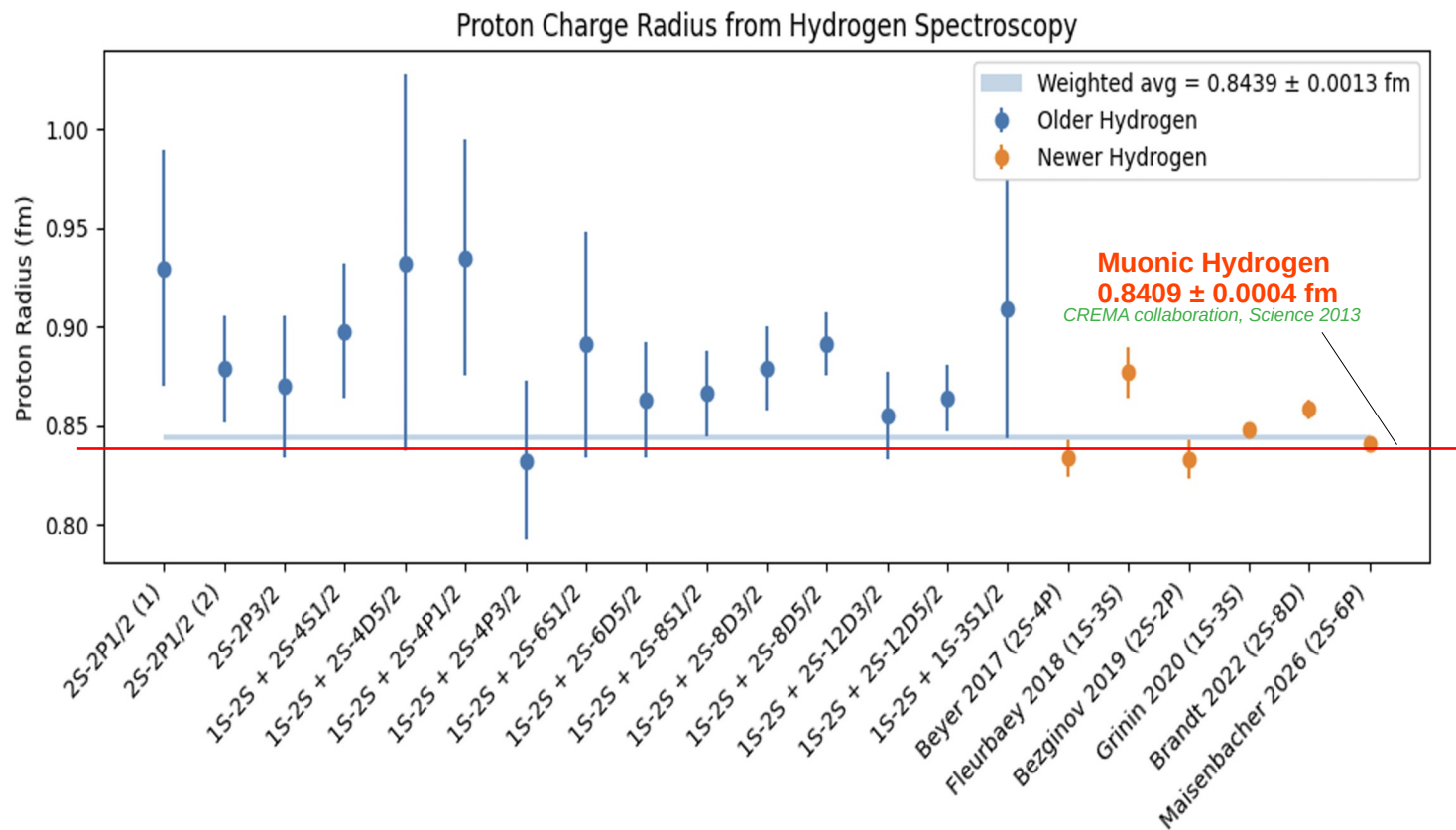
Fundamental constants are *intertwined* with several observables



Lamb shift of μH & μD
are most sensitive to the
proton and deuteron
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due to 'lower' orbits of the
heavy muon

Mass ratios are now
extracted from molecular
 HD^+ & H_2^+ rovibration lines

By the way, there is no longer a *proton size puzzle*:



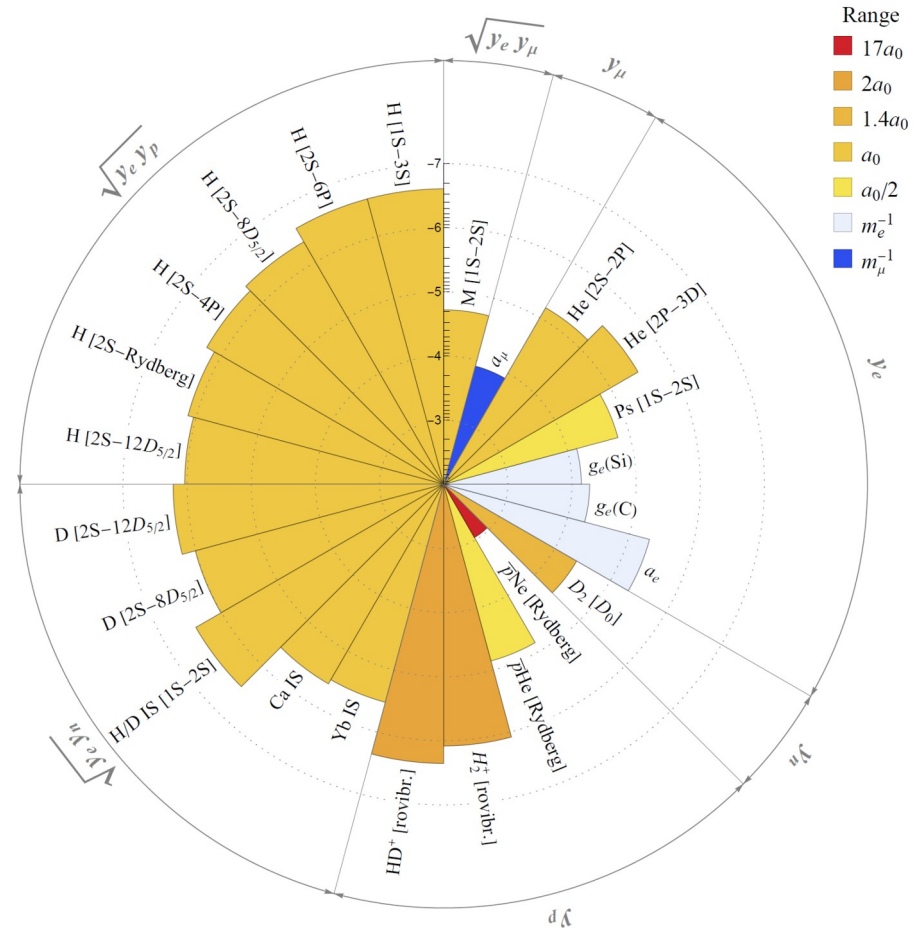
New physics affects all CODATA inputs

$$\mathcal{L} \supset - \sum_{\psi=e,\mu,p,n} y_{\psi} \phi \bar{\psi} \psi$$

As well as other observables:

- muon magnetic anomaly $\propto y_{\mu}^2$
- helium, positronium $\propto y_e^2$
- muonium $\propto y_e y_{\mu}$

CD-Karr-Soreq, Ann. Rev. 2026



We adapted the CODATA fit, systematically including New Physics effects:

$$\mathcal{O}_{\text{th}} = \mathcal{O}_{\text{SM}}(g_{\text{SM}}) + \mathcal{O}_{\text{NP}}(g_{\text{SM}}, \alpha_{\phi}, m_{\phi}) + \delta\mathcal{O}_{\text{th}}$$

Diagram illustrating the components of the theoretical observable $\mathcal{O}_{\text{th}}$:

- $\mathcal{O}_{\text{SM}}(g_{\text{SM}})$: state-of-the-art SM prediction
- $\mathcal{O}_{\text{NP}}(g_{\text{SM}}, \alpha_{\phi}, m_{\phi})$: correction from new physics at leading order in α_{ϕ}
- $\delta\mathcal{O}_{\text{th}}$: SM theory uncertainty

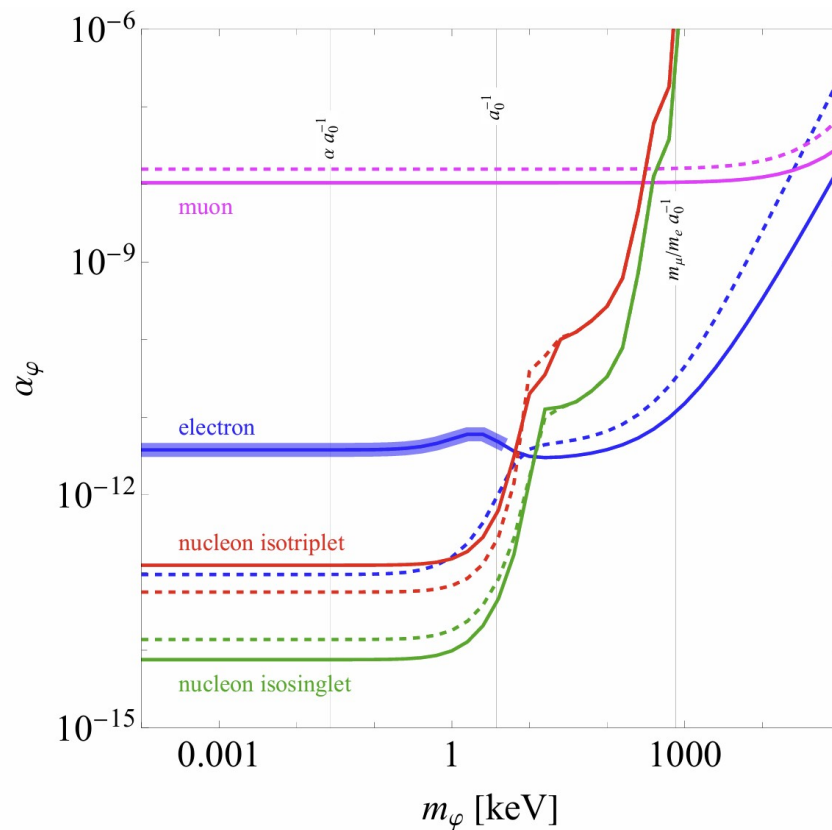
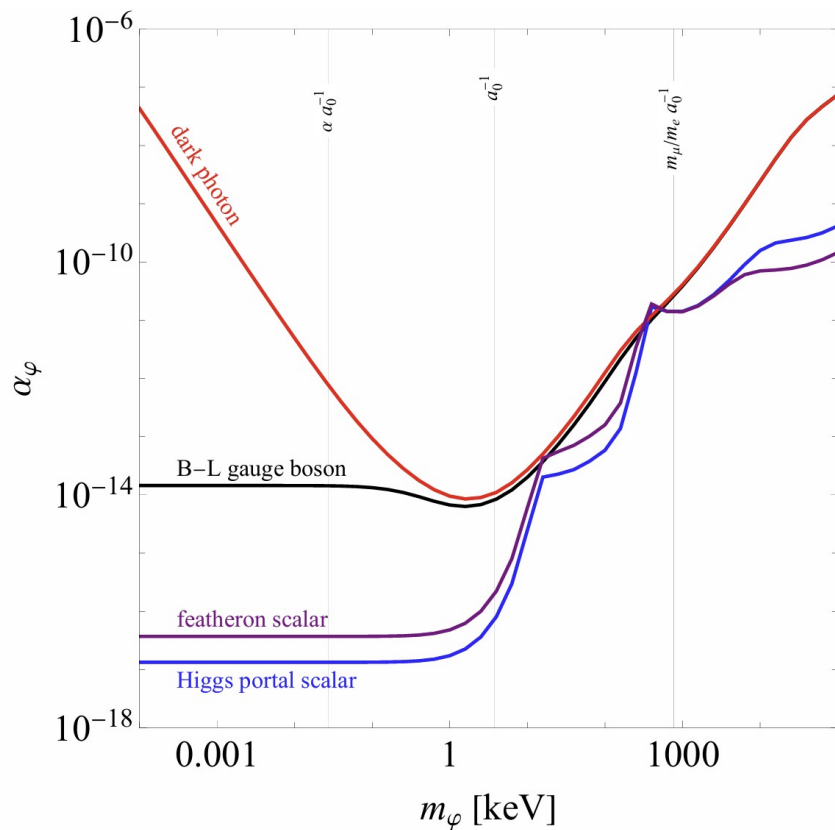
The parameters g_{SM} are determined by the fundamental constants $R_{\infty}, \alpha, r_p, \dots$.

and extracted FCs and New Physics parameters *together*

CD-Karr-Kitahara-Koelemeij-Soreq-Zupan, PRL 2023

New physics bounds:

CD-Karr-Soreq, Ann. Rev. 2026



Probing New Physics at the Atomic Frontier

Isotope shifts & King plots

The nuclear charge Z sets atomic frequencies, up to small nuclear effects:

$$f_i^{AA'} \equiv f_i^A - f_i^{A'} \sim \mathcal{O} \left(\frac{\alpha m_e}{\Lambda_{\text{QCD}}} \right) f_i^A \ll f_i^A$$

still challenging to calculate *ab initio*
but $\Lambda_{\text{QCD}} \sim 10^6 \alpha m_e$ allows EFT description

The nuclear charge Z sets atomic frequencies,
up to small nuclear effects:

$$f_i^{AA'} \equiv f_i^A - f_i^{A'} = K_i \mu_{AA'} + F_i \delta r_{AA'}^2 + \cdots$$

subleading effects
/ in $\epsilon \equiv r_A/a_0$

mass shift

$$\mu_{AA'} \equiv \frac{m_{A'} - m_A}{m_A m_{A'}}$$

precisely measured at $\sim 10^{-11}$
using spin-precession in traps

field shift

$$\delta r_{AA'}^2 \equiv \langle r_A^2 \rangle - \langle r_{A'}^2 \rangle$$

poorly known in general

The nuclear charge Z sets atomic frequencies, up to small nuclear effects:

$$f_i^{AA'} \equiv f_i^A - f_i^{A'} = K_i \mu_{AA'} + F_i \delta r_{AA'}^2 + \dots$$

‘electronic’ constants

independent of nuclear parameters
but depending on atomic states

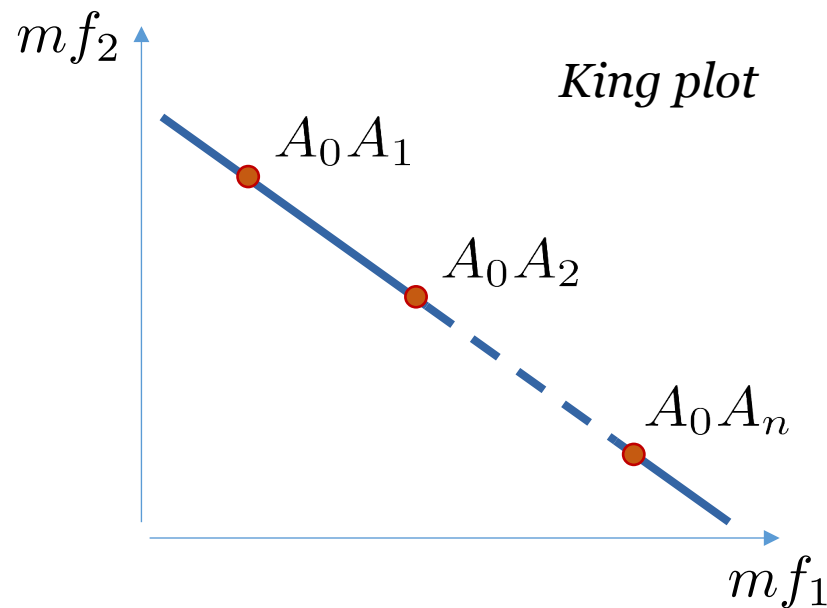
This factorization of scales permits theory-independent comparison of isotope shifts:

modified IS

$$mf_i \equiv \mu^{-1} f_i$$

$$mf_2^{AA'} = \frac{F_2}{F_1} mf_1^{AA'} + \left[K_2 - \frac{F_2}{F_1} K_1 \right]$$

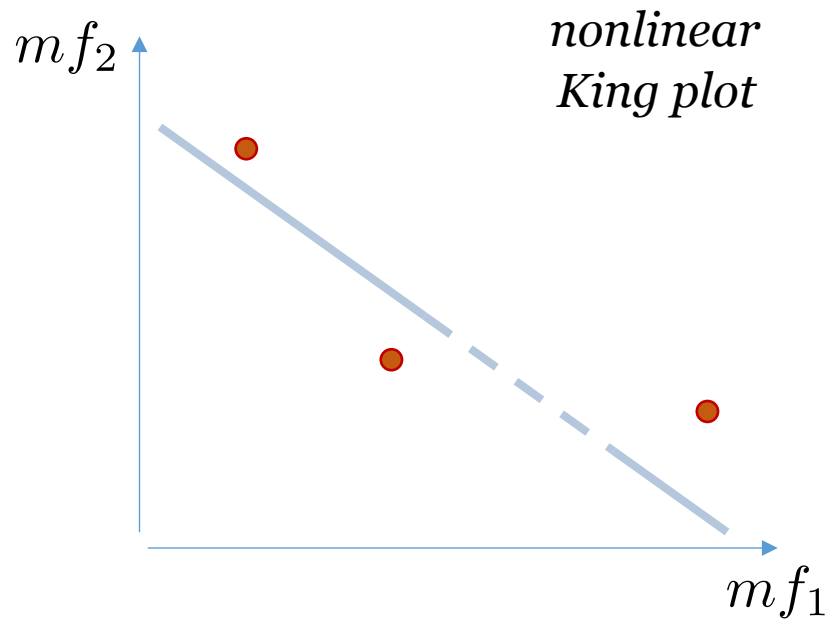
predicting a *linear relation*
among isotope shift data
(independently of K_i, F_i)



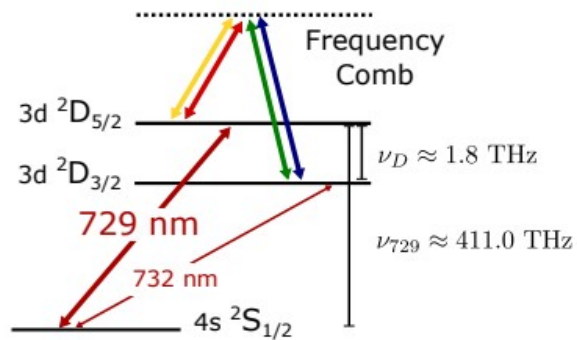
New Physics forces violate King's linearity

$$f_i^{AA'} \rightarrow f_i^{AA'} + \alpha_\phi X_i (A - A')$$

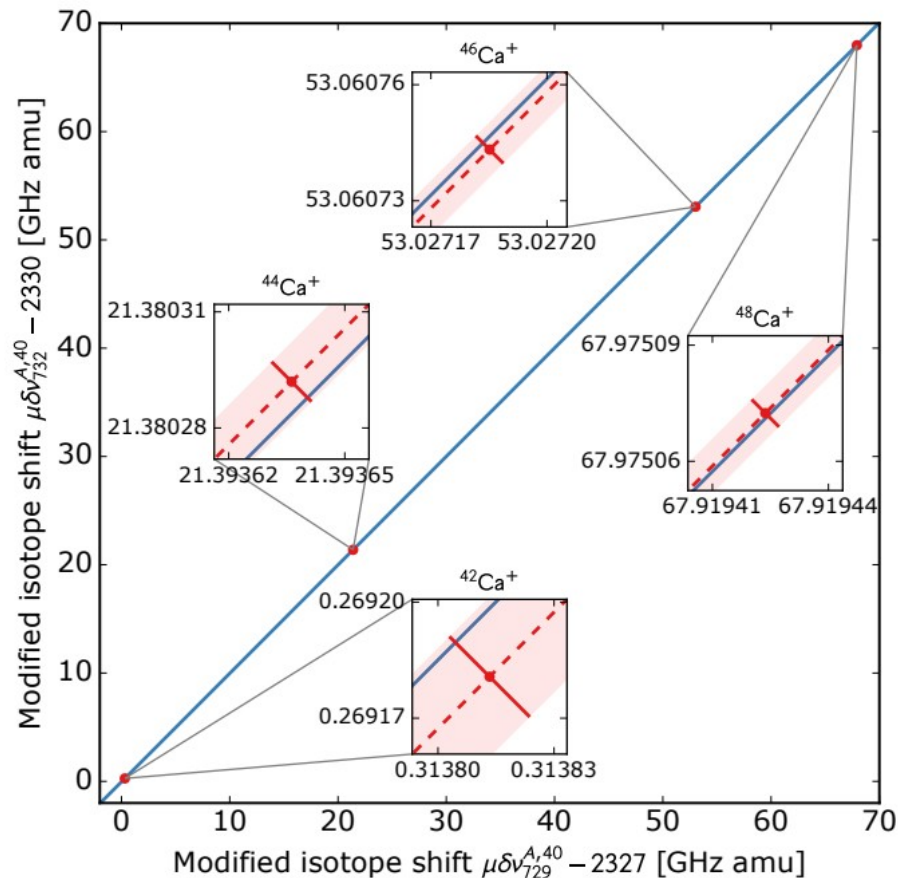
$$mf_2^{AA'} = \frac{F_2}{F_1} mf_1^{AA'} + \left[K_2 - \frac{F_2}{F_1} K_1 \right] \\ + \alpha_\phi \left[X_2 - \frac{F_2}{F_1} X_1 \right] \frac{A - A'}{\mu_{AA'}}$$



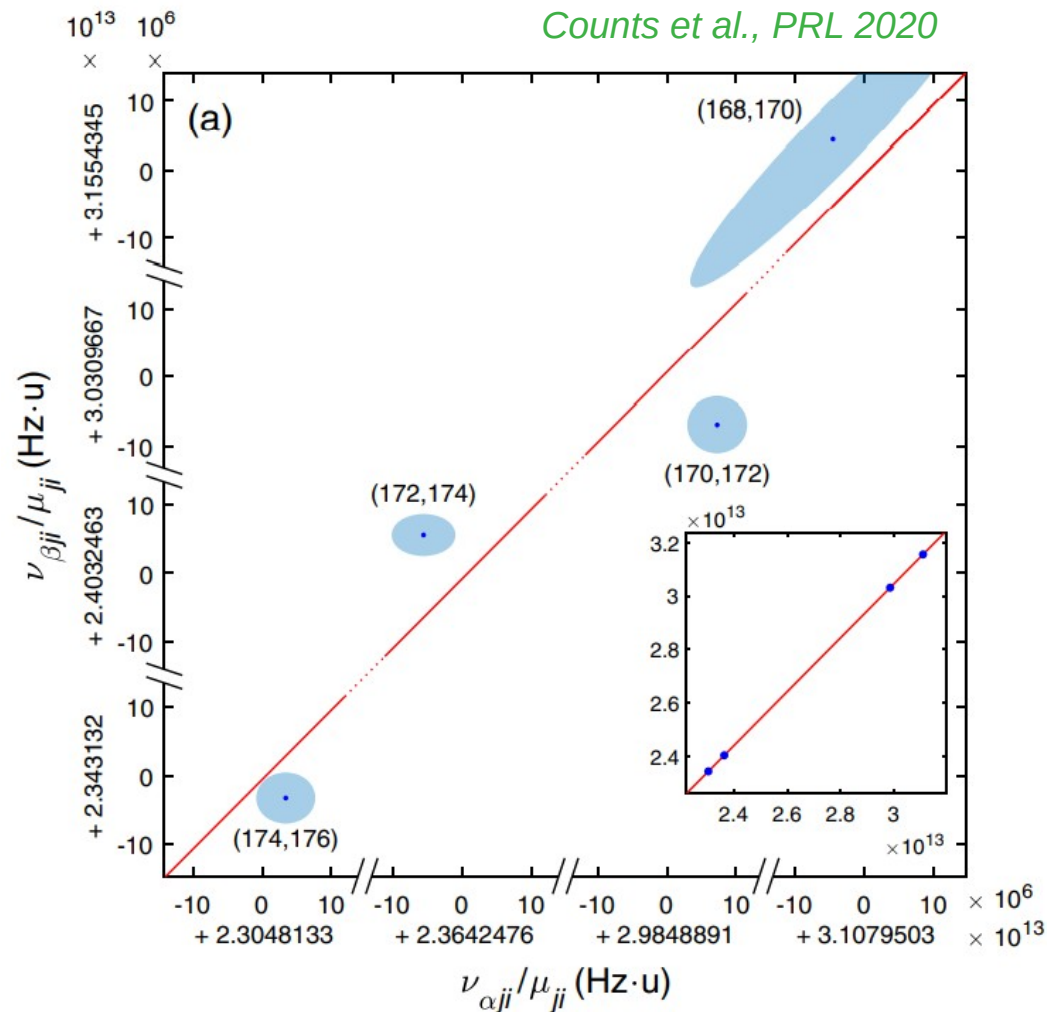
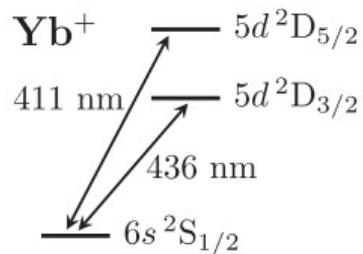
Measurements with
calcium ions
 consistent with
 linearity at $\sim \mathcal{O}(10^{-13})$



Solaro et al., PRL 2020

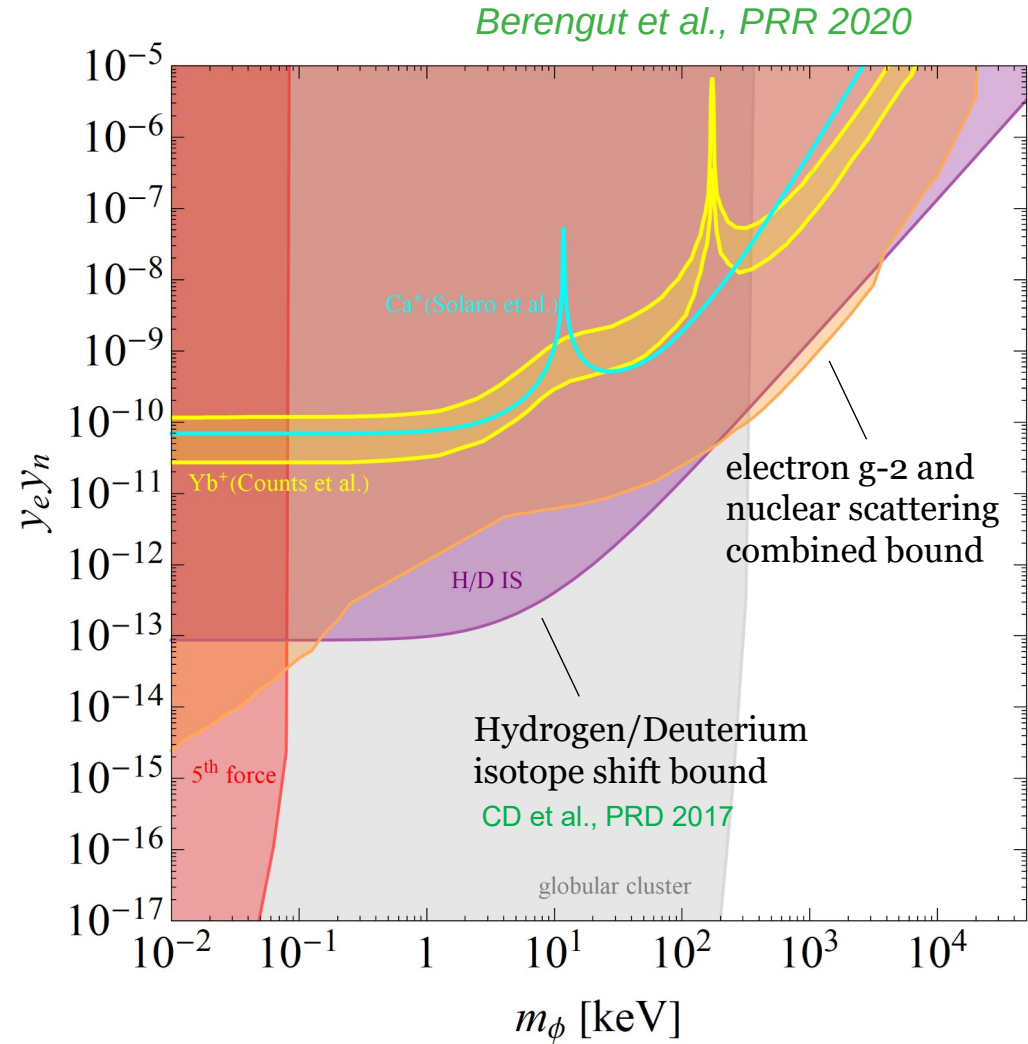


Other measurements
with *ytterbium ions*
reveal nonlinearities
at $\sim 3\sigma$



Assuming new physics interpretation, these results are marginally consistent

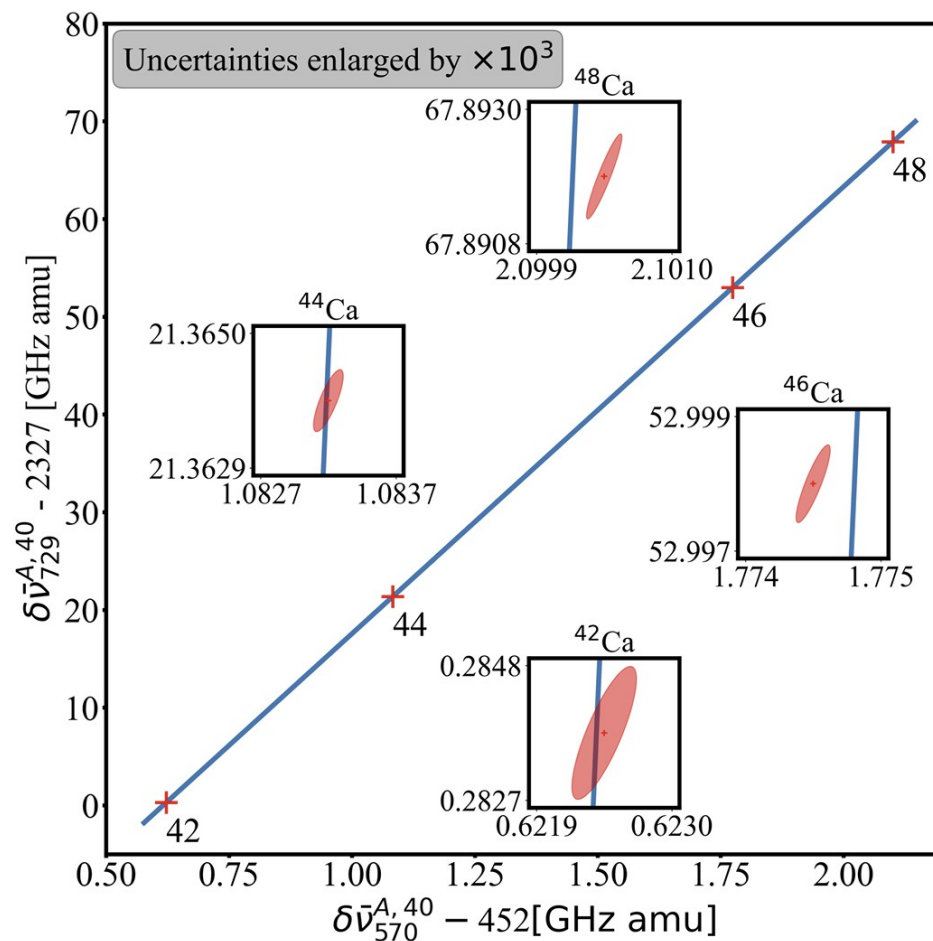
but excluded by other observables



100-fold improved
measurements with
calcium ions
are highly nonlinear
at $\sim 900\sigma$

*So what are we
possibly seeing here?*

Wilzewski et al., PRL 2025



Experimentalists begin to resolve
subleading nuclear effects

$$f_i^{AA'} = K_i \mu_{AA'} + F_i \delta r_{AA'}^2 + G_i \delta r_{AA'}^4 + \dots$$

One can try to absorb them, generalizing linearity
to higher dimensions.

Berengut et al., PRR 2020

More isotopes & transitions are needed!

Probing New Physics with nuclear clock 'quintessometers'

Seeking new physics
with highly stable device

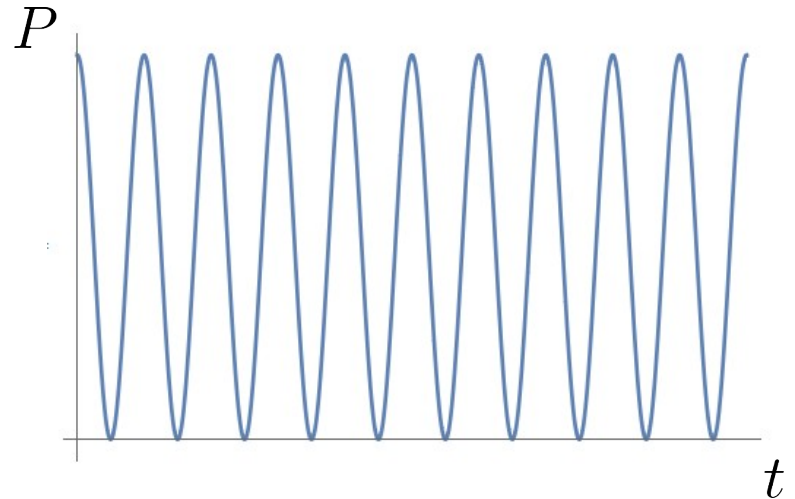
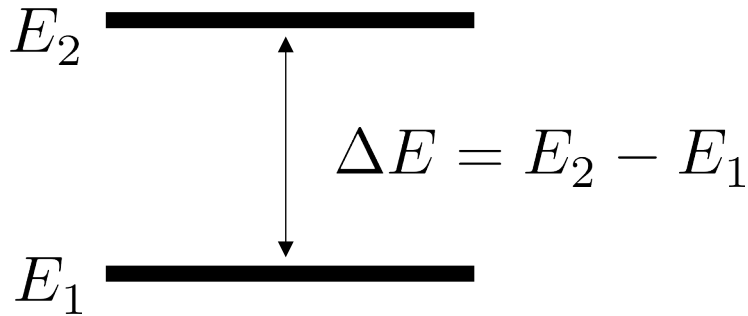


Quantum mechanics
provides the most
stable/accurate *oscillators*

$$|\psi_0\rangle = \frac{|1\rangle + |2\rangle}{\sqrt{2}}$$

$$P = |\langle\psi_0|\psi(t)\rangle|^2 = \cos^2 \omega t$$

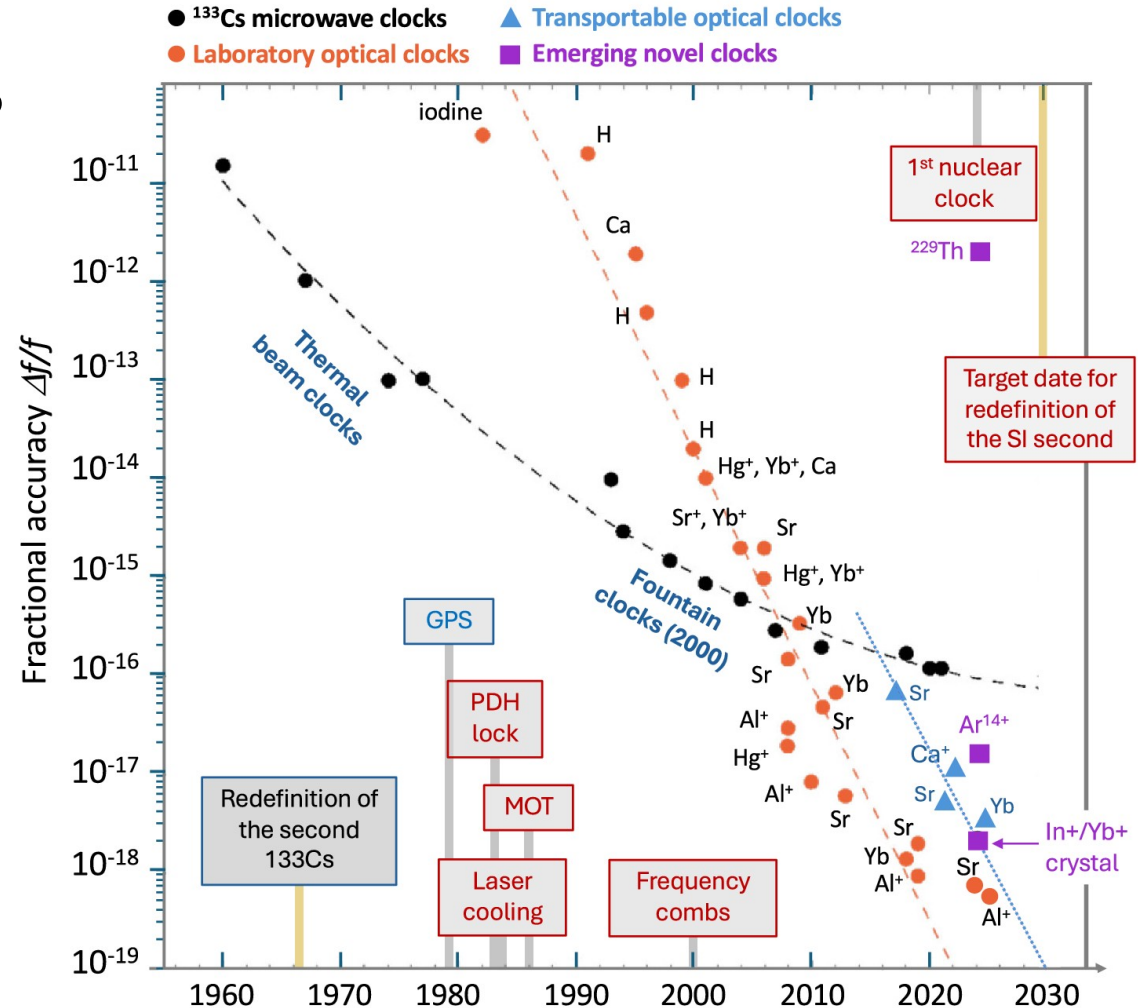
$$\omega \equiv \Delta E / (2\hbar)$$



Quantum oscillators
are the basis of
modern clocks

state-of-the-art
atomic clocks

$$\frac{\delta f}{f} \sim 10^{-19}$$



A *nuclear clock* is based on nuclear states instead of electronic states

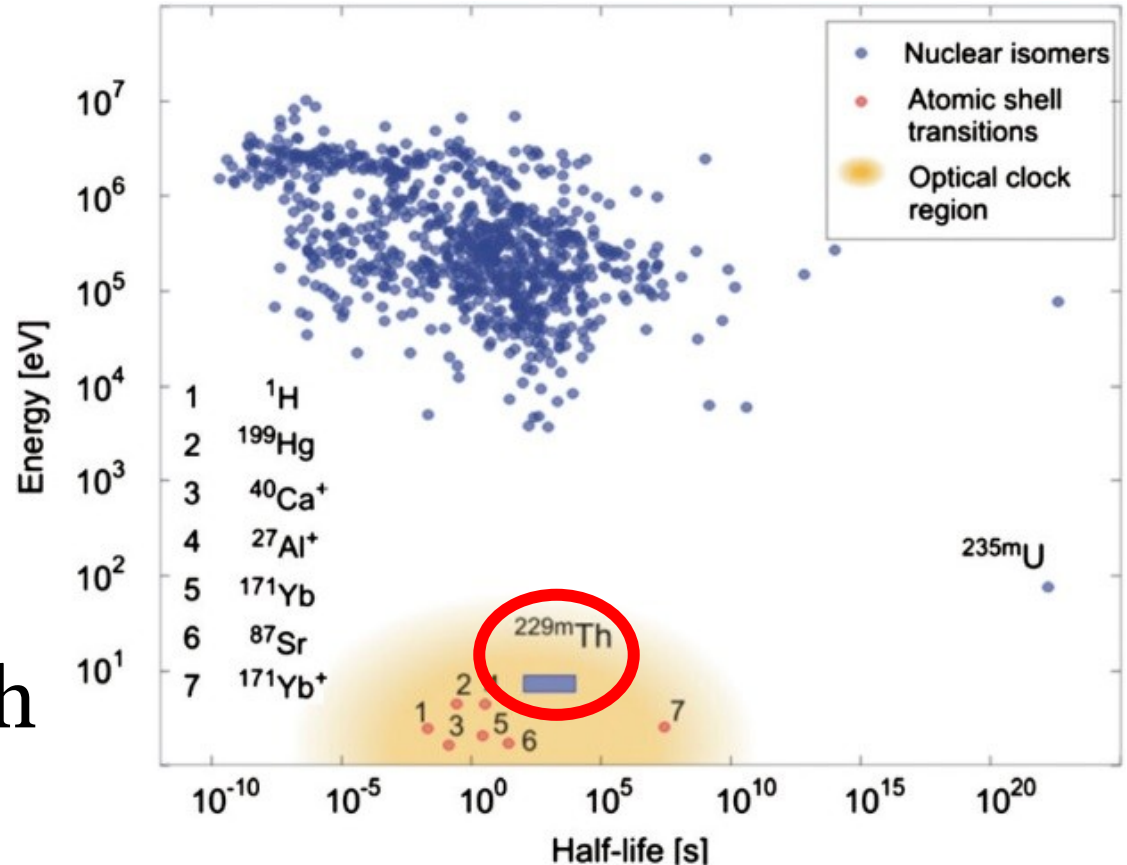
- The main benefit = external fields are screened
- The main issue = splittings are generally $\sim \text{MeV}$ (no laser)

except one nucleus

thorium 229
~8eV

which reachable with
VUV laser

Peik et al., QST 2021



The small splitting in
thorium 229 is
probably accidental

$$\Delta E = E_{\text{nuclear}} + E_{\text{Coulomb}}$$
$$8 \text{ eV} \sim \text{MeV} - \text{MeV}$$

Therefore, small changes in
 E_{nuclear} (or E_{Coulomb})
are *amplified* in the frequency

$$\frac{\delta f}{f} \sim K \frac{\delta E_{\text{nuclear}}}{E_{\text{nuclear}}}$$

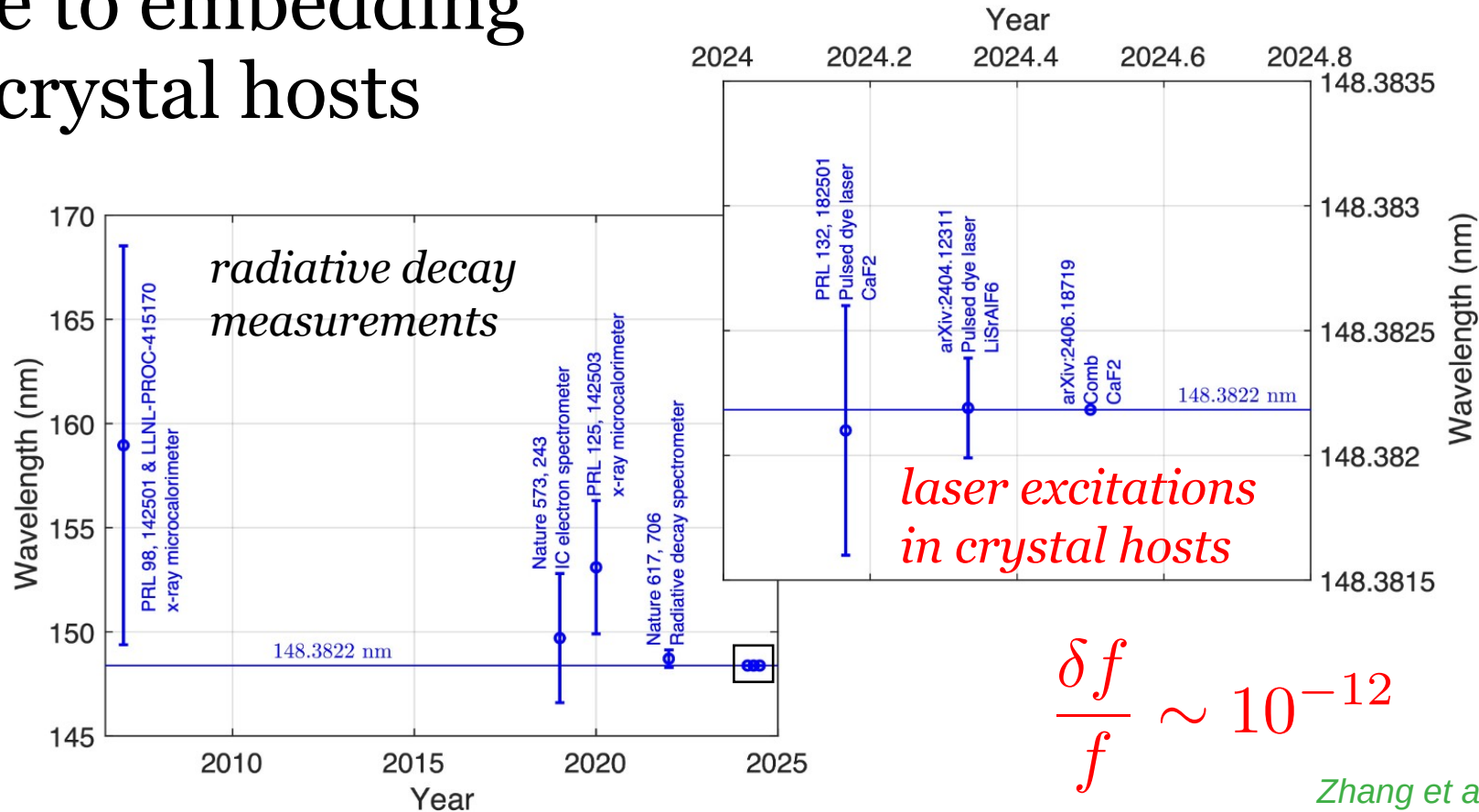
$$K \sim \frac{\text{MeV}}{8 \text{ eV}} \sim 10^5$$

In comparison, changes in nuclear parameters in atomic energies are *suppressed* in the frequency $K \sim 10^{-5}$

$$E_{\text{nuclear}} \sim \frac{\alpha m_e}{\Lambda_{\text{QCD}}} \ll E_{\text{Coulomb}}$$

At same accuracy, nuclear clock is more sensitive than atomic clocks to new physics coupled to QCD by $\sim 10^{10} !$

Rapid progress recently, due to embedding in crystal hosts



$$\frac{\delta f}{f} \sim 10^{-12}$$

Zhang et al. Nature 2024

Consider a scalar field
linearly coupled to QCD

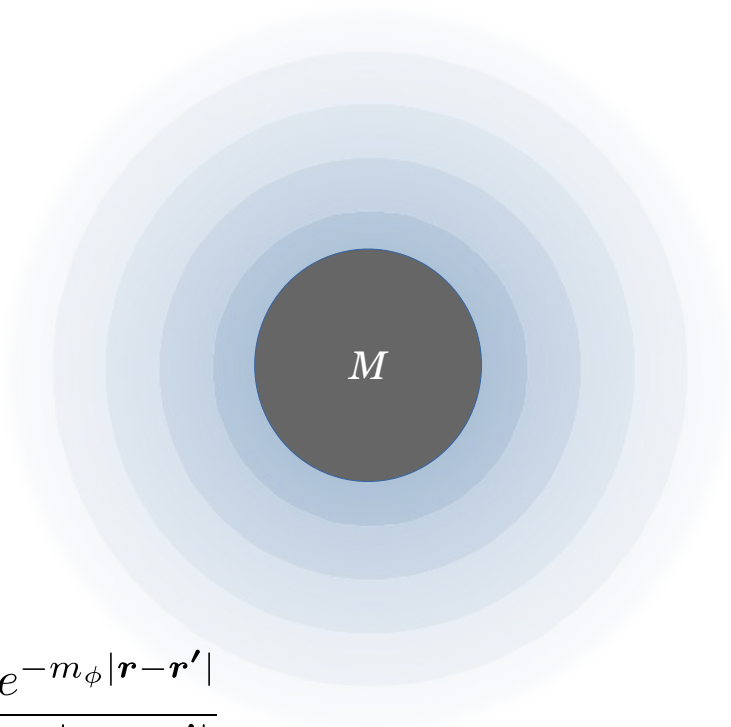
$$\mathcal{L} \supset -d_g \frac{\beta(\alpha_s)}{2\alpha_s} \frac{\phi}{M_{\text{Pl}}} G_{\mu\nu} G^{\mu\nu}$$

Massive bodies will source
a background field around them

$$(\nabla^2 - m_\phi^2)\phi(\mathbf{r}) = \frac{d_g}{M_{\text{Pl}}} \rho(\mathbf{r})$$

$$\phi(\mathbf{r}) = \frac{d_g}{M_{\text{Pl}}} \int d^3\mathbf{r}' G(\mathbf{r}, \mathbf{r}') \rho(\mathbf{r}')$$

$$G(\mathbf{r}, \mathbf{r}') = -\frac{e^{-m_\phi|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|}$$



There are two limiting regimes of interest

$$M = \frac{4\pi}{3}\rho R^3$$

$$r \gg R$$

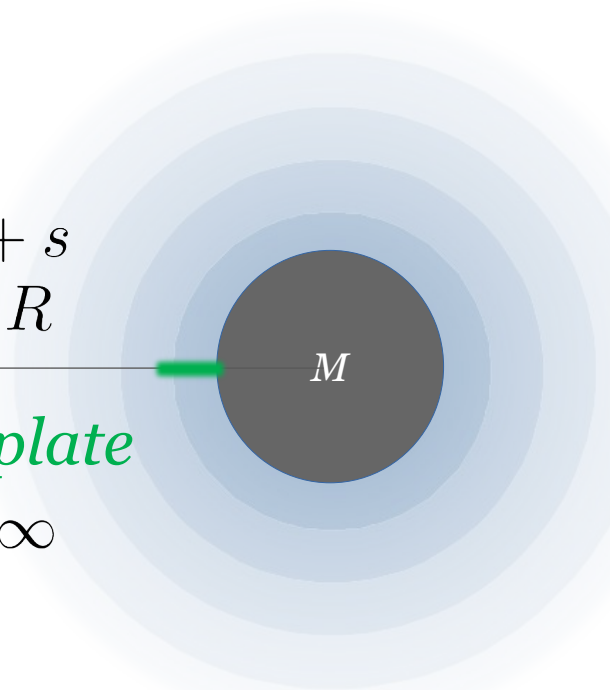
r
point-source
 $m_\phi R \rightarrow 0$

$$\phi_{\text{point}}(r) \simeq -\frac{d_g M}{M_{\text{Pl}}} \frac{e^{-m_\phi r}}{4\pi r}$$

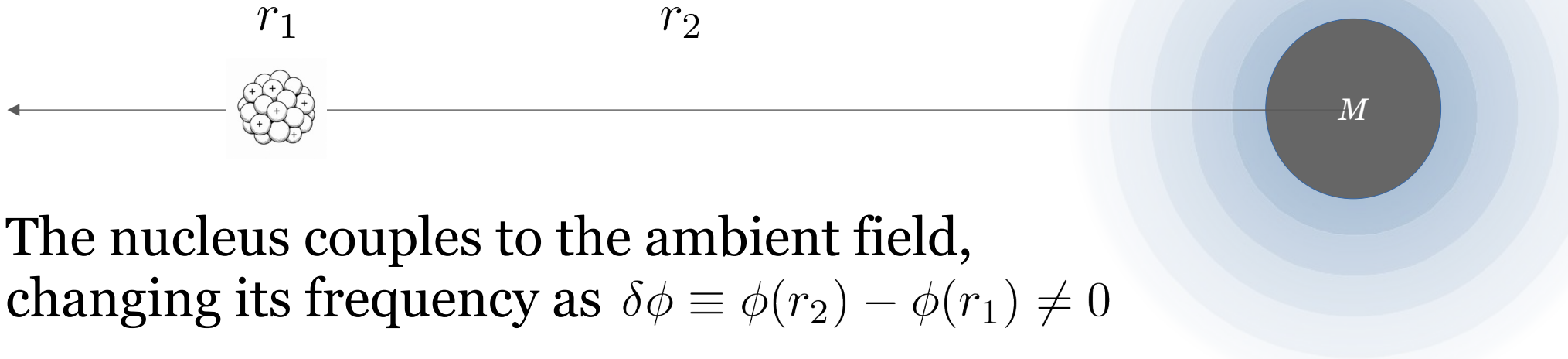
$$r = R + s$$
$$|s| \ll R$$

infinite-plate
 $m_\phi R \rightarrow \infty$

$$\phi_{\text{plate}} \simeq -\frac{d_g \rho}{2M_{\text{Pl}} m_\phi^2} e^{-m_\phi s}$$



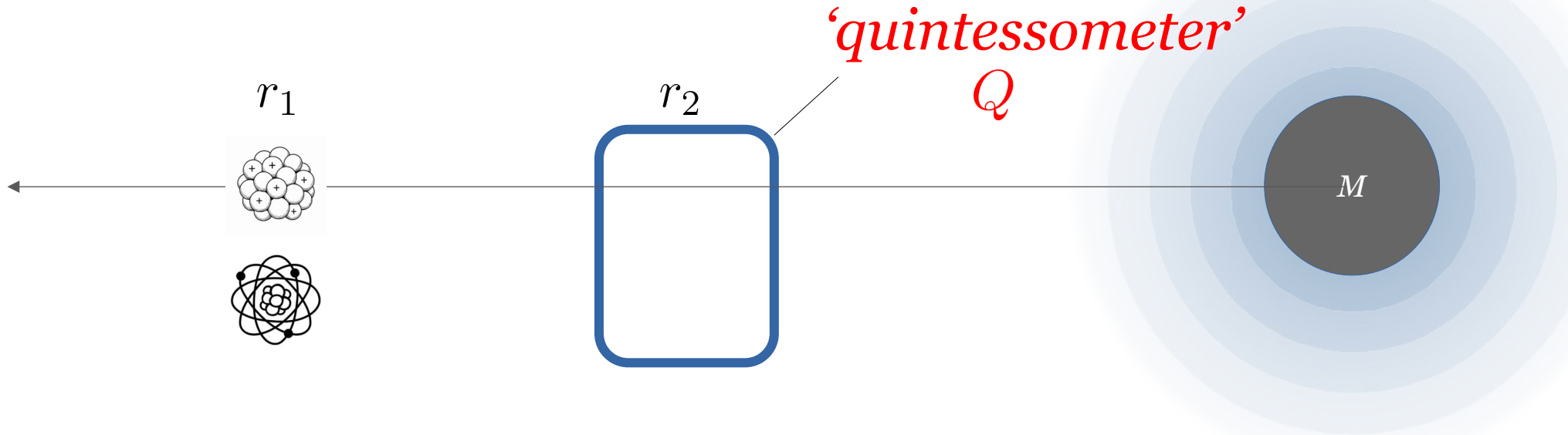
Probe the field's gradient with a nuclear clock



The nucleus couples to the ambient field,
changing its frequency as $\delta\phi \equiv \phi(r_2) - \phi(r_1) \neq 0$

$$\frac{\delta f}{f} = K \frac{d_g \delta\phi}{M_{\text{Pl}}} + \text{time-dilation from gravitational field's gradient}$$

‘Monitor’ gravity field with another atomic clock



$$\frac{\delta(f_{\text{Th}}/f_{\text{At}})}{f_{\text{Th}}/f_{\text{At}}} = (K_{\text{Th}} - K_{\text{At}}) \frac{d_g \delta \phi}{M_{\text{Pl}}} \simeq K_{\text{Th}} \frac{d_g \delta \phi}{M_{\text{Pl}}}$$

I will now describe several applications of this basic scheme :

- Long distance probes using the Earth as a source
- Tabletop experiments at shorter distances

Probing New Physics
with nuclear clock
'quintessometers'

Long distance probes

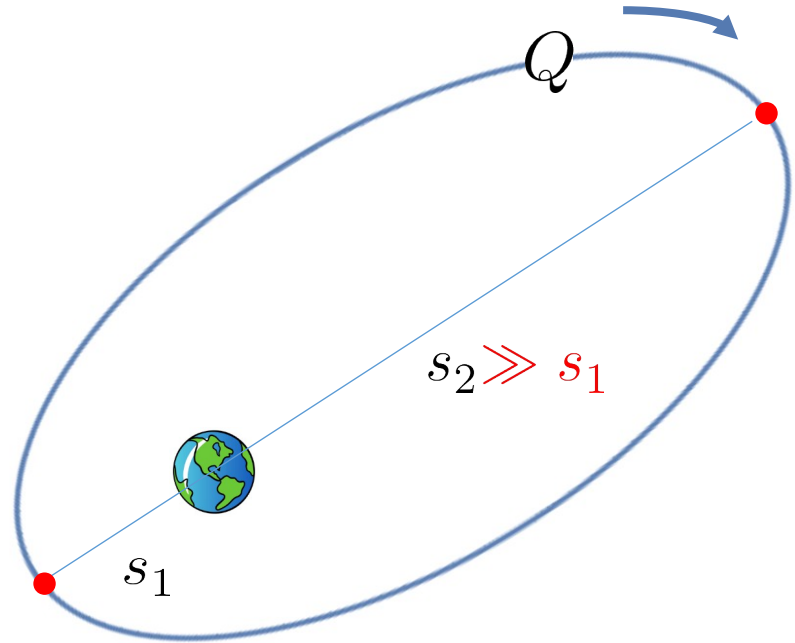
Space-born missions

Monitor a quintessometer
along an elliptic orbit
around the Earth

$$m_\phi \lesssim R_\oplus^{-1} \approx 3 \times 10^{-14} \text{ eV}$$

$$s_2 \gg s_1 \gtrsim R_\oplus$$

$$\delta\phi_{\text{max}} \sim \frac{e^{-m_\phi s_1}}{s_1}$$



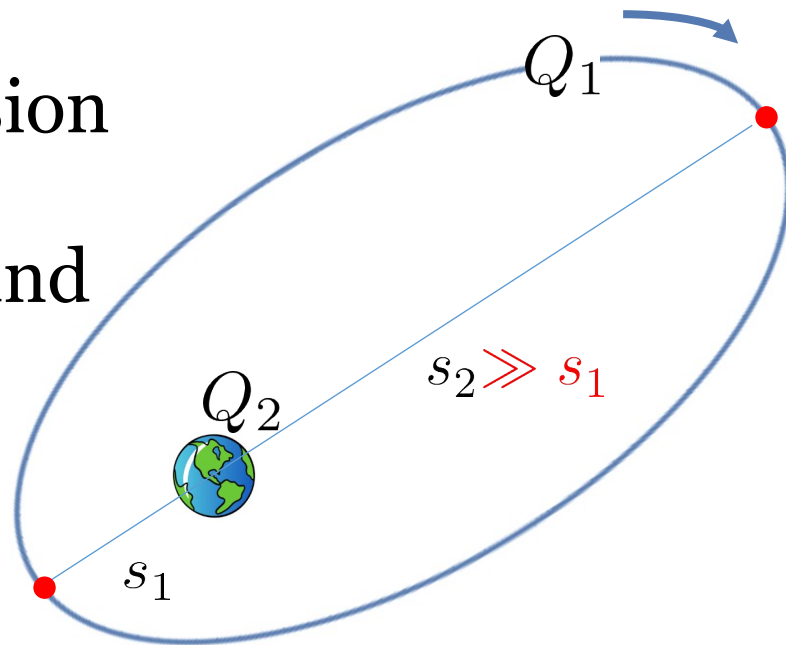
Space-born missions

Evade the altitude suppression
by comparing to another
quintessometer on the ground

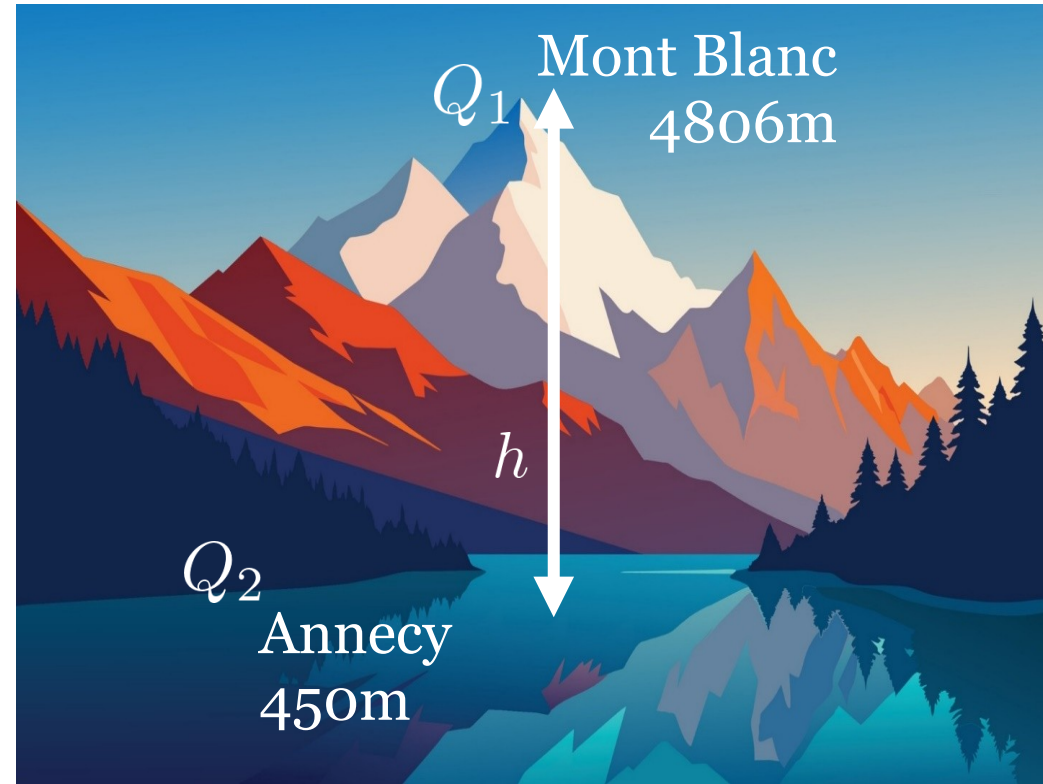
$$m_\phi \lesssim R_\oplus^{-1} \approx 3 \times 10^{-14} \text{ eV}$$

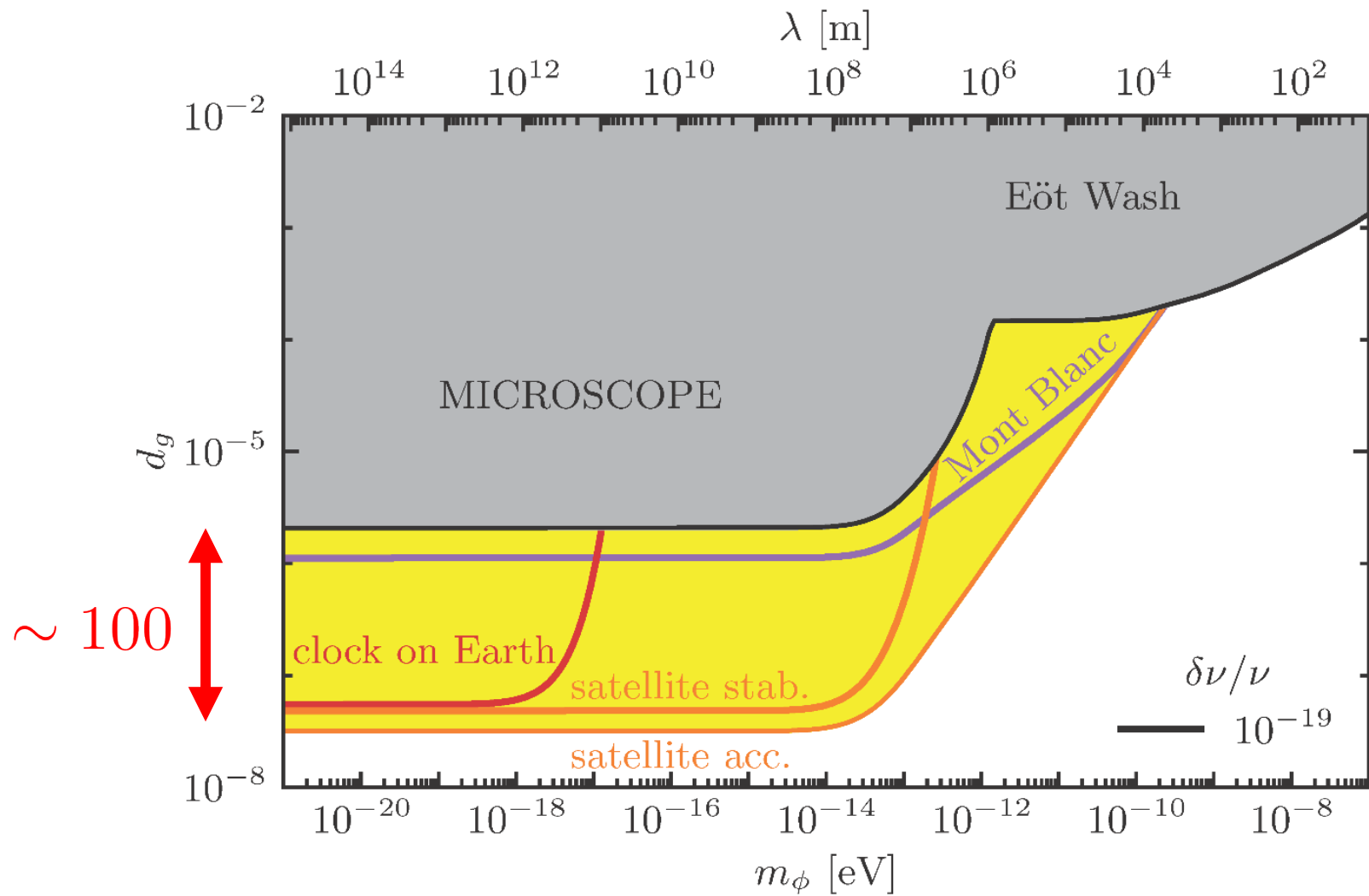
$$s_2 \gg s_1 \gtrsim R_\oplus$$

$$\delta\phi_{\text{max}} \sim \frac{e^{-m_\phi R_\oplus}}{R_\oplus}$$



Comparing
ground-based
quintessometers
at different altitudes





Probing New Physics
with nuclear clock
'quintessometers'

Small distance probes

Getting close to thorium, with a *rotating* holed disk

$$m_\phi \gg R^{-1}$$

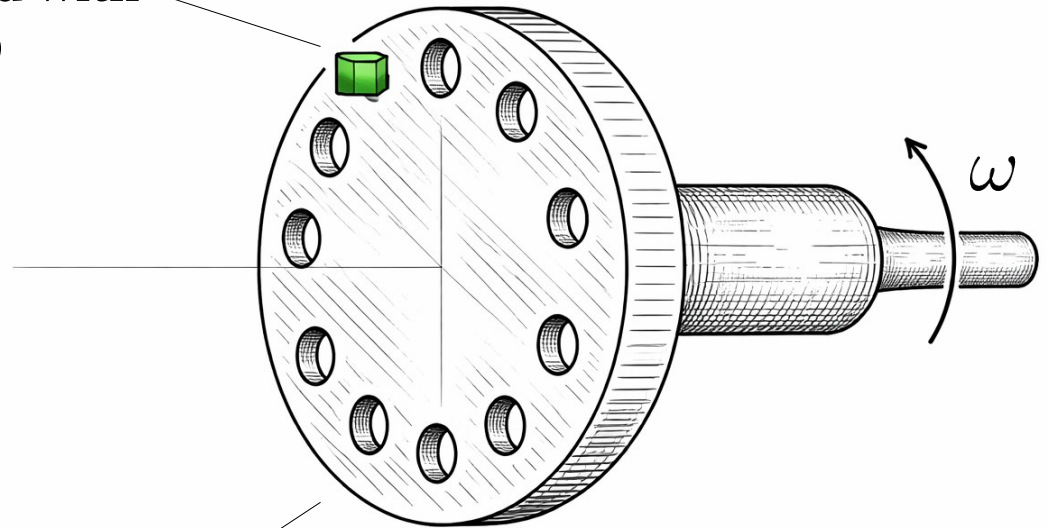
$$\delta\phi \propto m_\phi^{-2}$$

crystal doped with
thorium 229

Platinum thick disk

$$R \sim 1 - 10 \text{ cm}$$

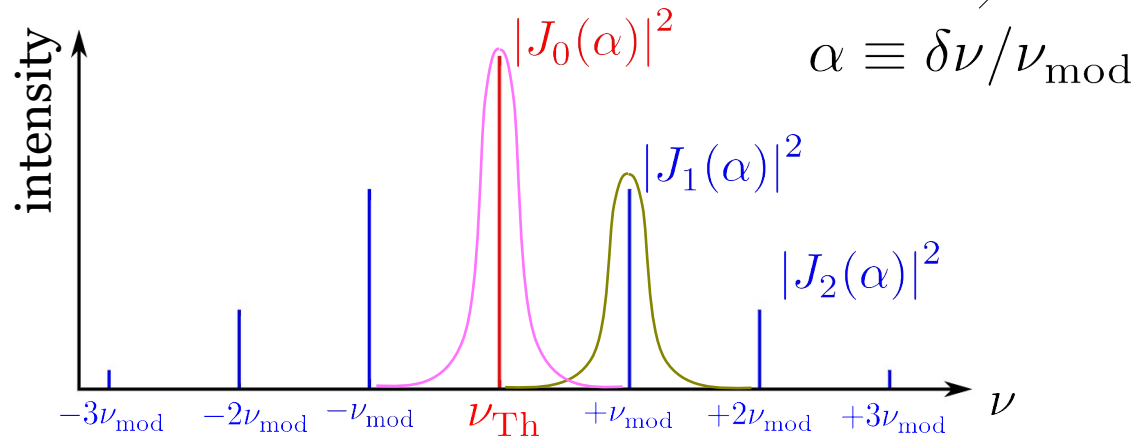
$d \sim 10 \text{ nm}$
separation

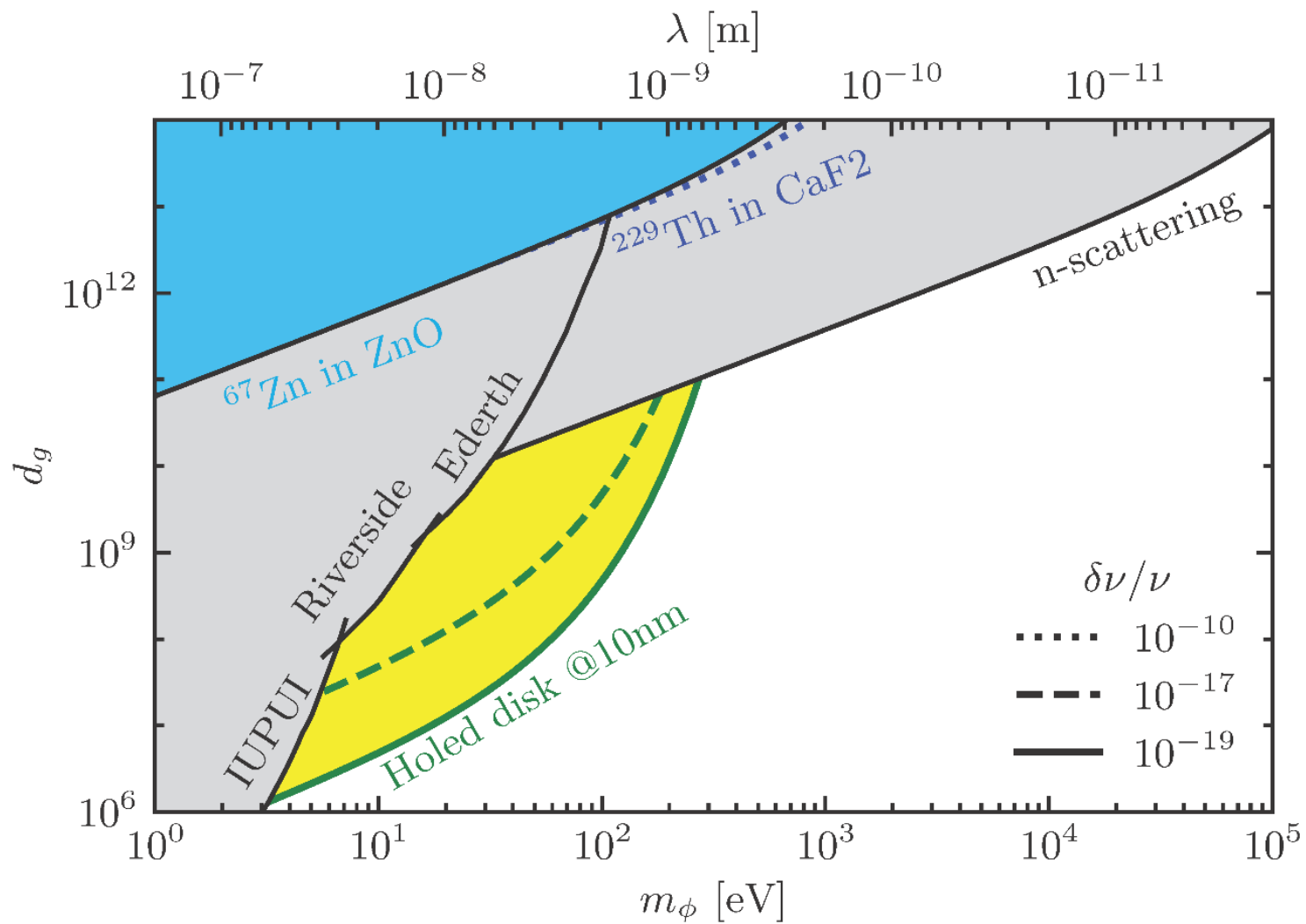


Field variation induces frequency modulation, and the spectrum develops sidebands

$$\nu_{\text{mod}} = N\omega/2\pi$$

peak heights
set by $\delta\phi$





Conclusions

*‘There’s plenty of room at the bottom’
for (ultra)light new physics*

Repurposing **Atomic & Molecular Optics for BSM physics searches** offers new perspectives on the fundamental laws of nature.