QUANTUM SENSING FOR NEW PHYSICS, MITP
OCTOBER 30, 2024

QUANTUM SENSORS FOR NEW-PHYSICS DISCOVERIES IN THE LABORATORY AND IN SPACE

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Q-SEnSE
An NSF Quantum Leap Challenge Institute

https://www.colorado.edu/research/qsense/

thorium nuclear clock

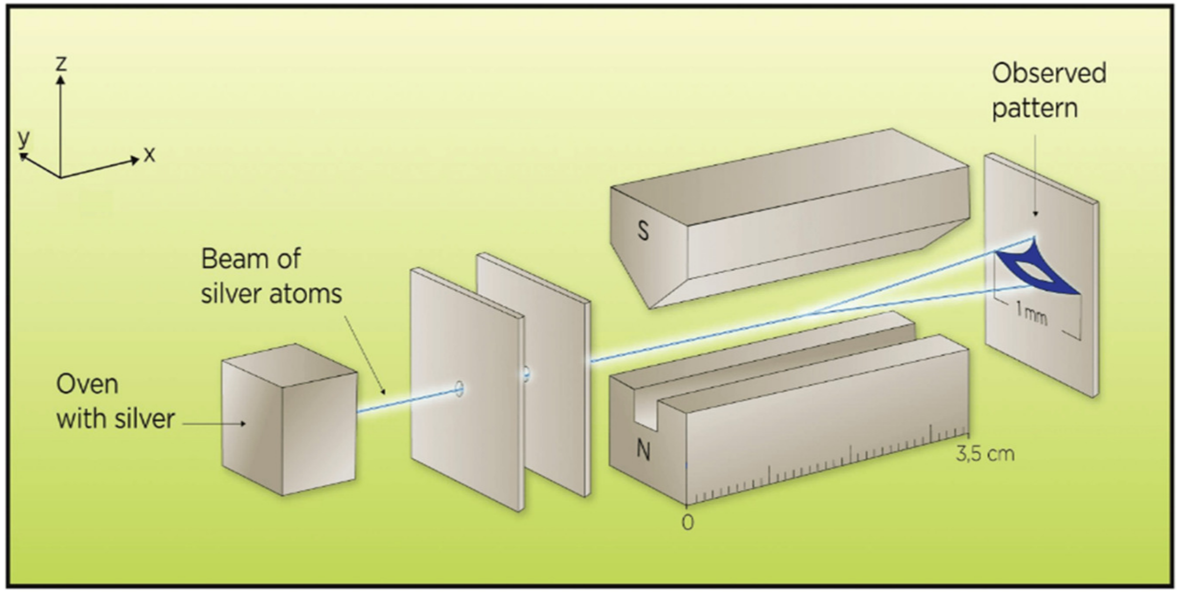
https://thoriumclock.eu/

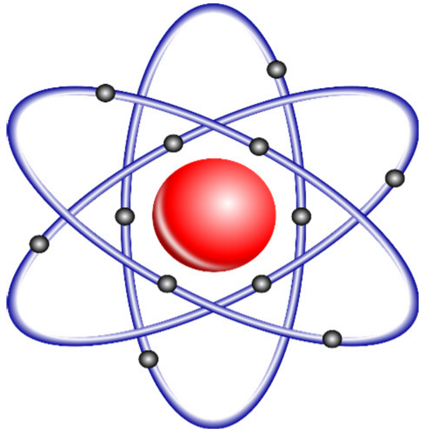
European Research Council

1924

100 YEARS AGO

WE DID NOT KNOW WHAT ATOMS ARE MADE OF





Puzzles of atomic spectra

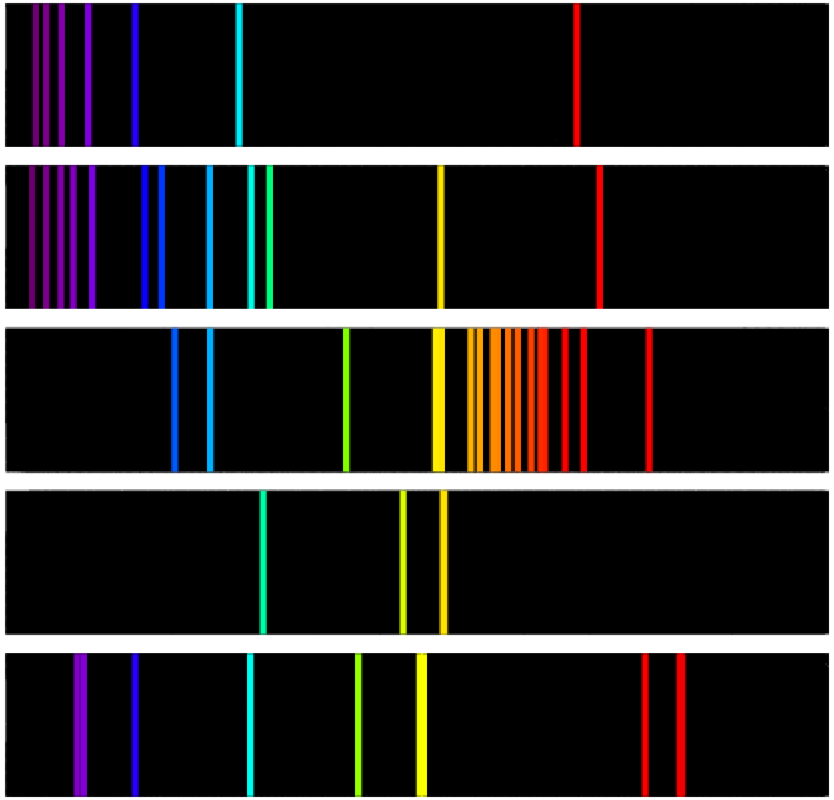
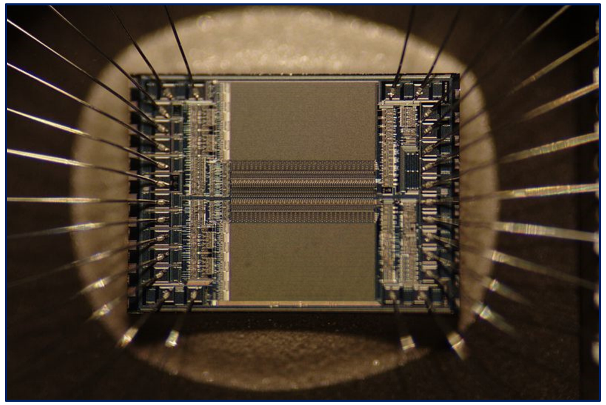


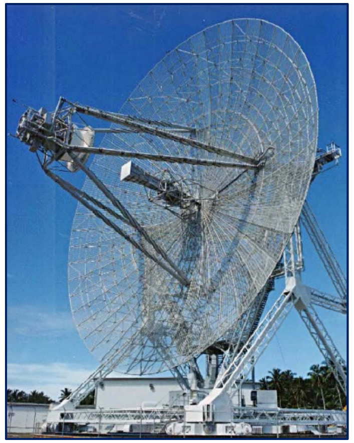
Figure credits: Entropy 2017, 19, 186, practical-chemistry.com

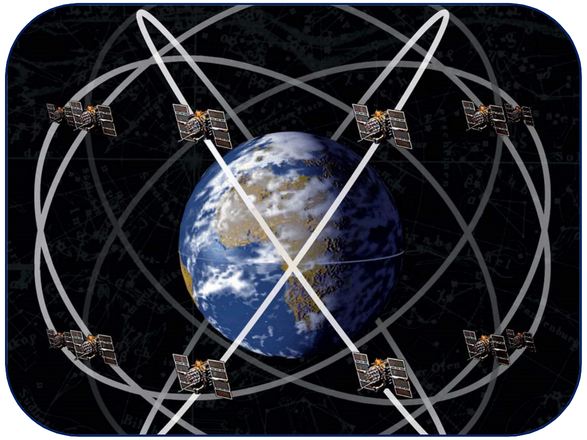
SOLVING PHYSICS PUZZLES: QUANTUM MECHANICS

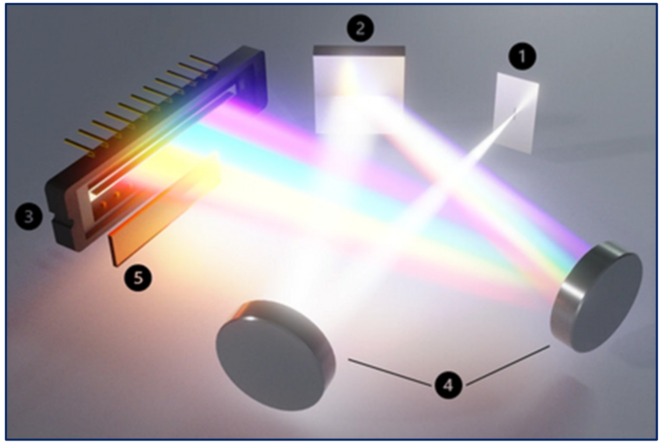

Computer technologies


Lasers


Solar cells


Radars


Navigation



Spectrometers, other detectors

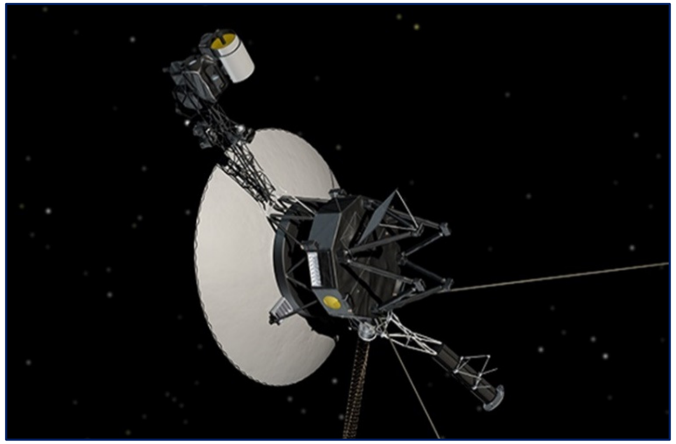
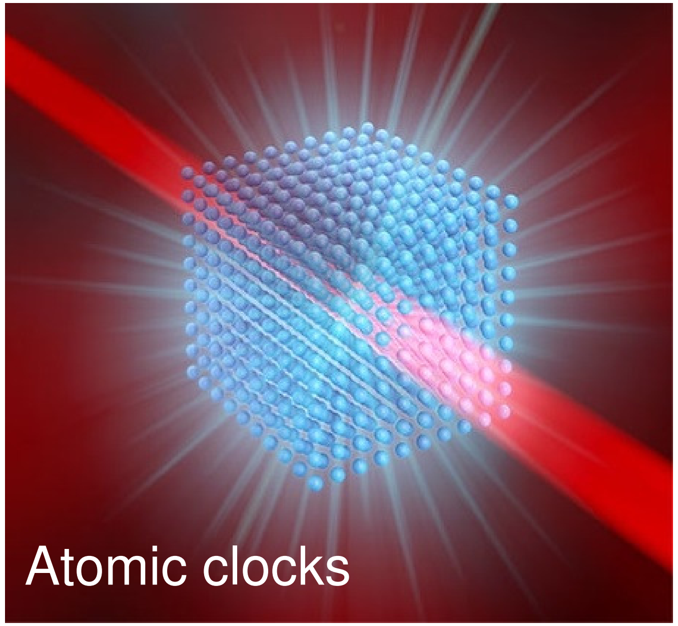
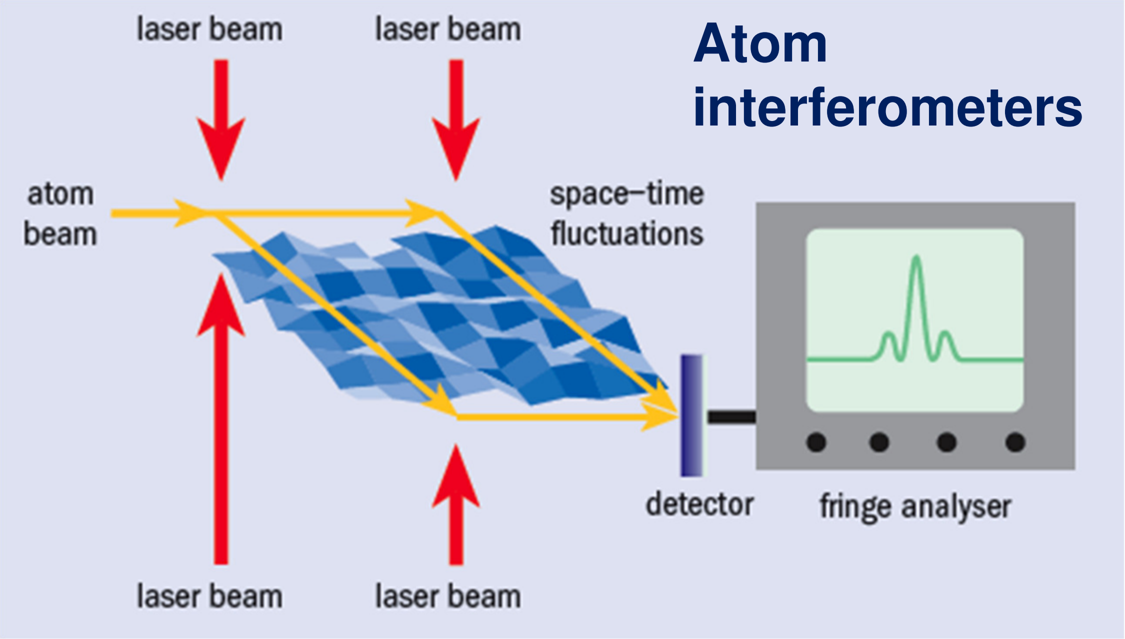

Nuclear technologies

Image credits: Wiki, NASA, National Air and Space Museum

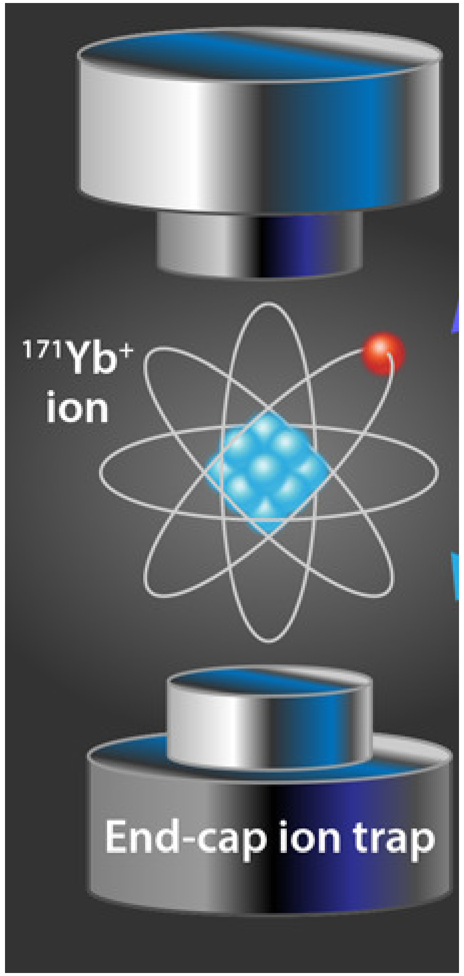
2024 100 YEARS LATER: QUANTUM SENSORS



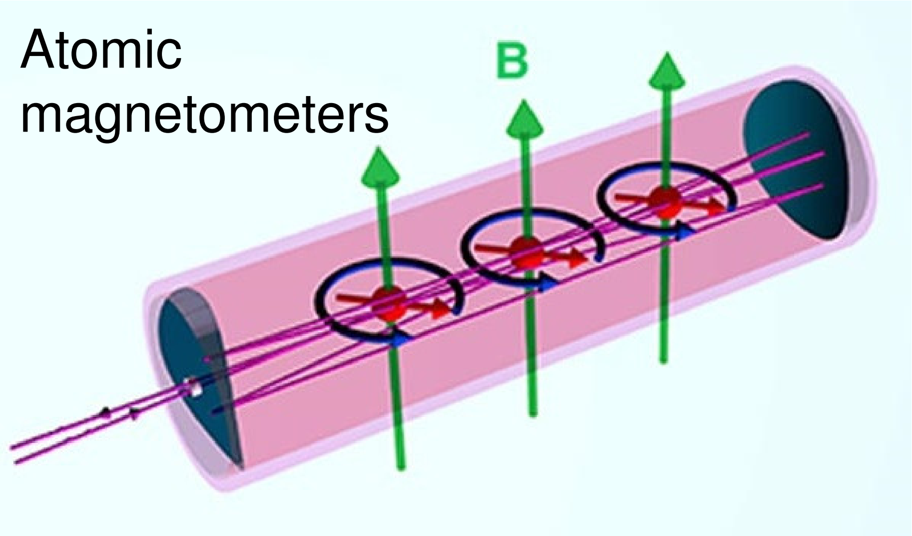
Atomic clocks



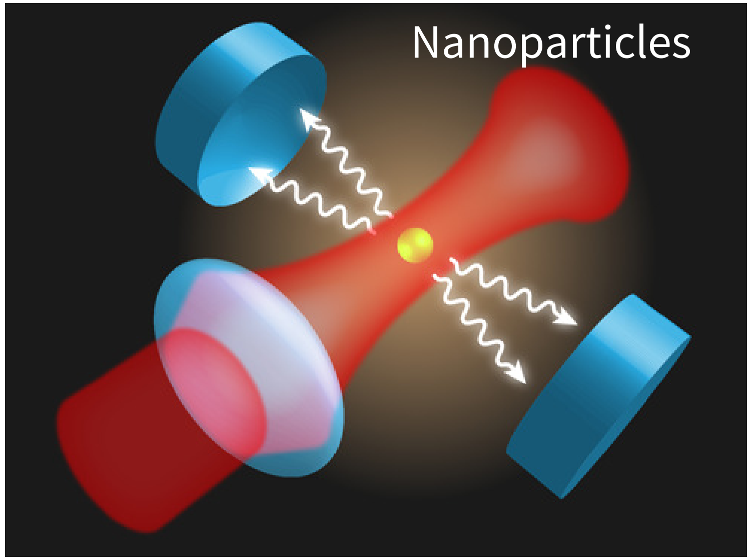
Atom interferometers



Trapped ions



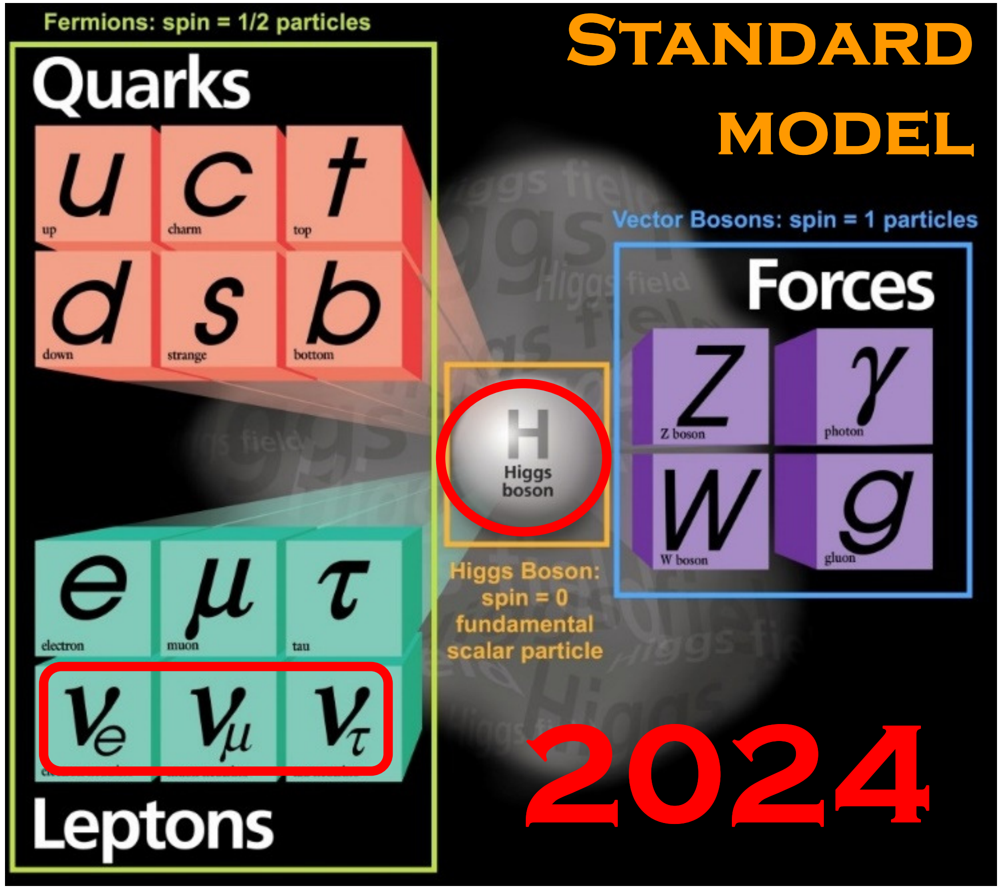
Atomic magnetometers



Nanoparticles

Image credit: JILA, APS/Alan Stonebraker, https://cerncourier.com/a/can-experiment-access-planck-scale-physics/, http://physicsworld.com/cws/article/news/2013/apr/24

2024: What we know now

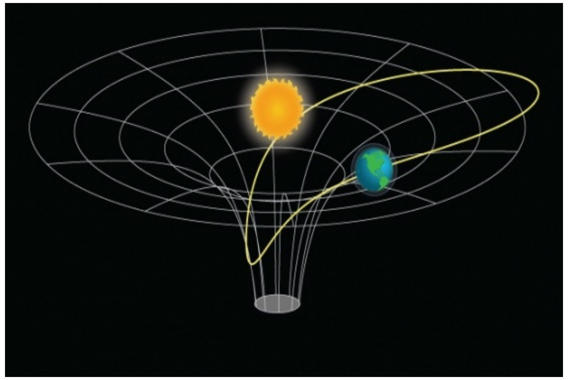


Quantum mechanics

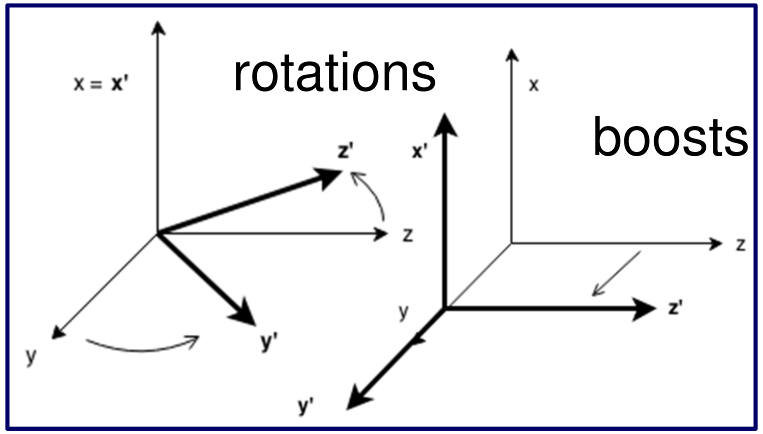
General relativity

Fundamental physics postulates

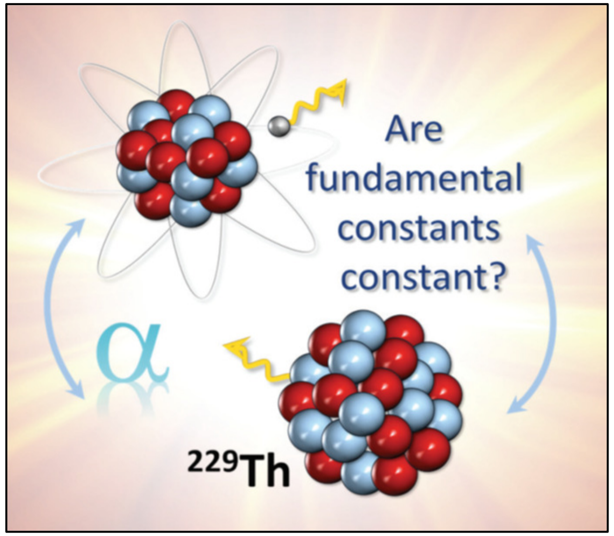
Position invariance



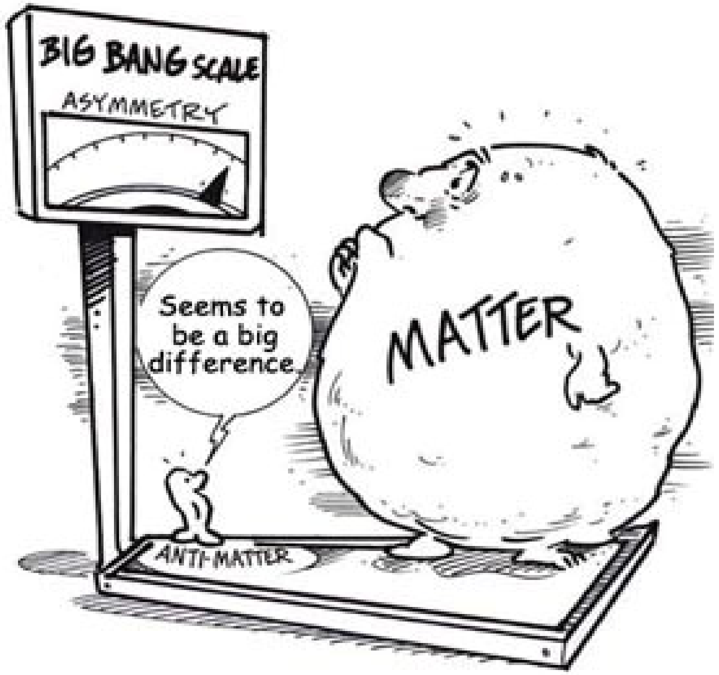
Lorentz invariance

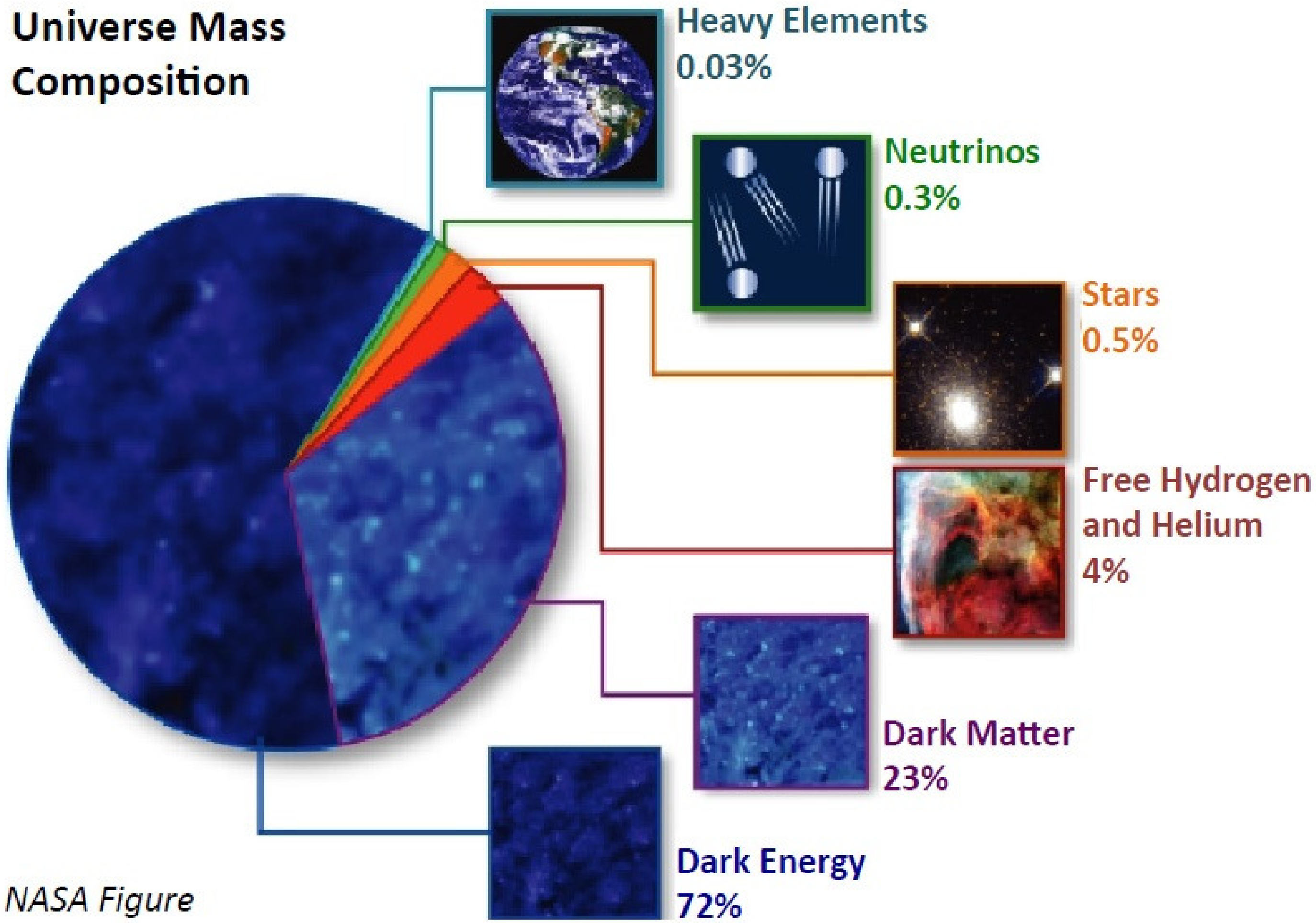


Weak equivalence principle



2024: NEW SET OF FUNDAMENTAL PHYSICS PUZZLES





NASA Figure

WE DO NOT KNOW WHAT UNIVERSE IS MADE OF

100 years ago: quantum mechanics was a solution to fundamental physics problems of that time (atomic spectra, etc.) revolutionizing our technology

EXCEPTIONAL IMPROVEMENT IN PRECISION OF

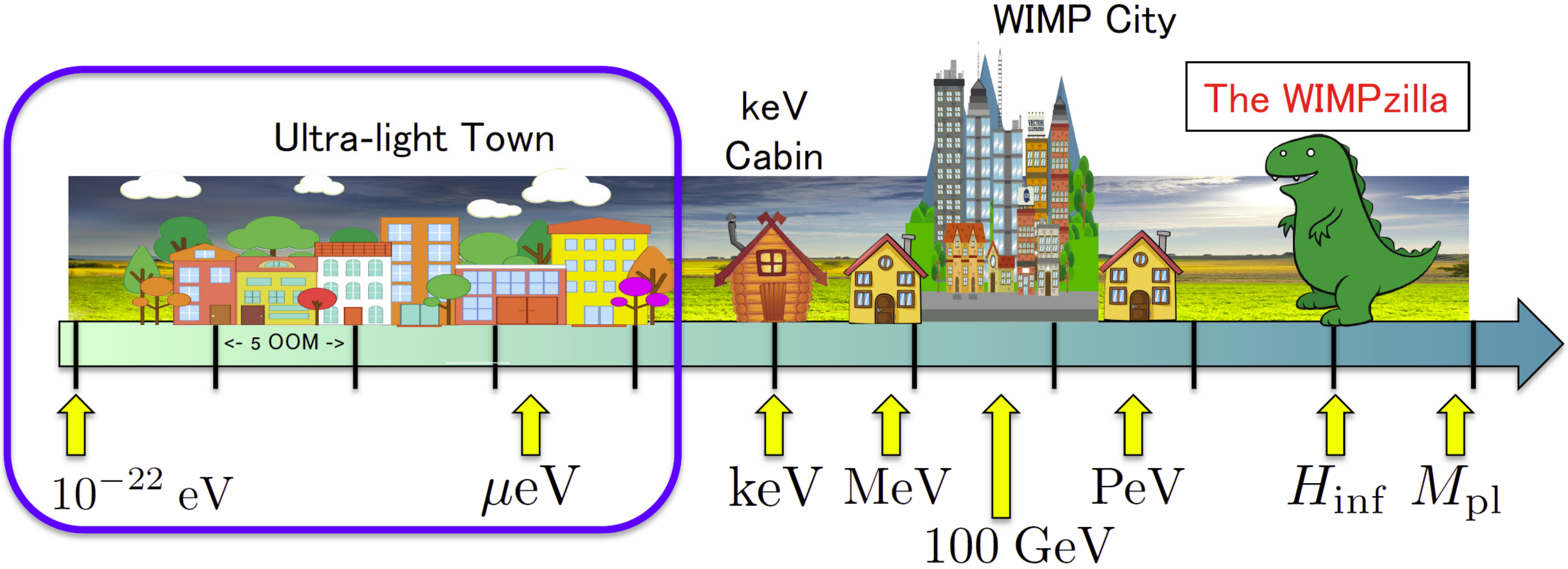
QUANTUM SENSORS

OPENS NEW WAYS TO SOLVE NEW PUZZLES OF THE UNIVERSE

OUR GOAL: SEARCH FOR NEW PHYSICS

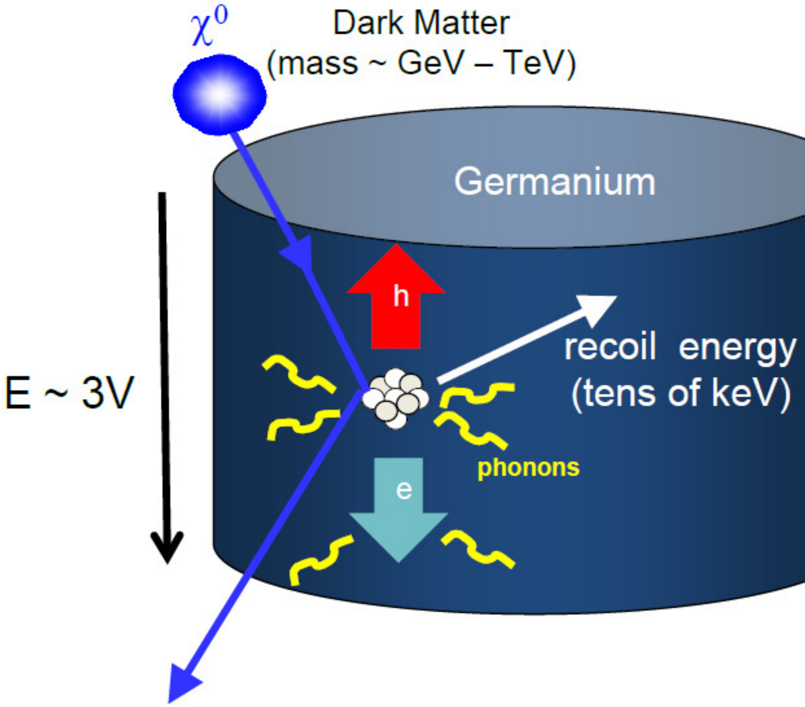
Slide from Andrew Long’s 2018 LDW talk

The landscape of dark matter masses

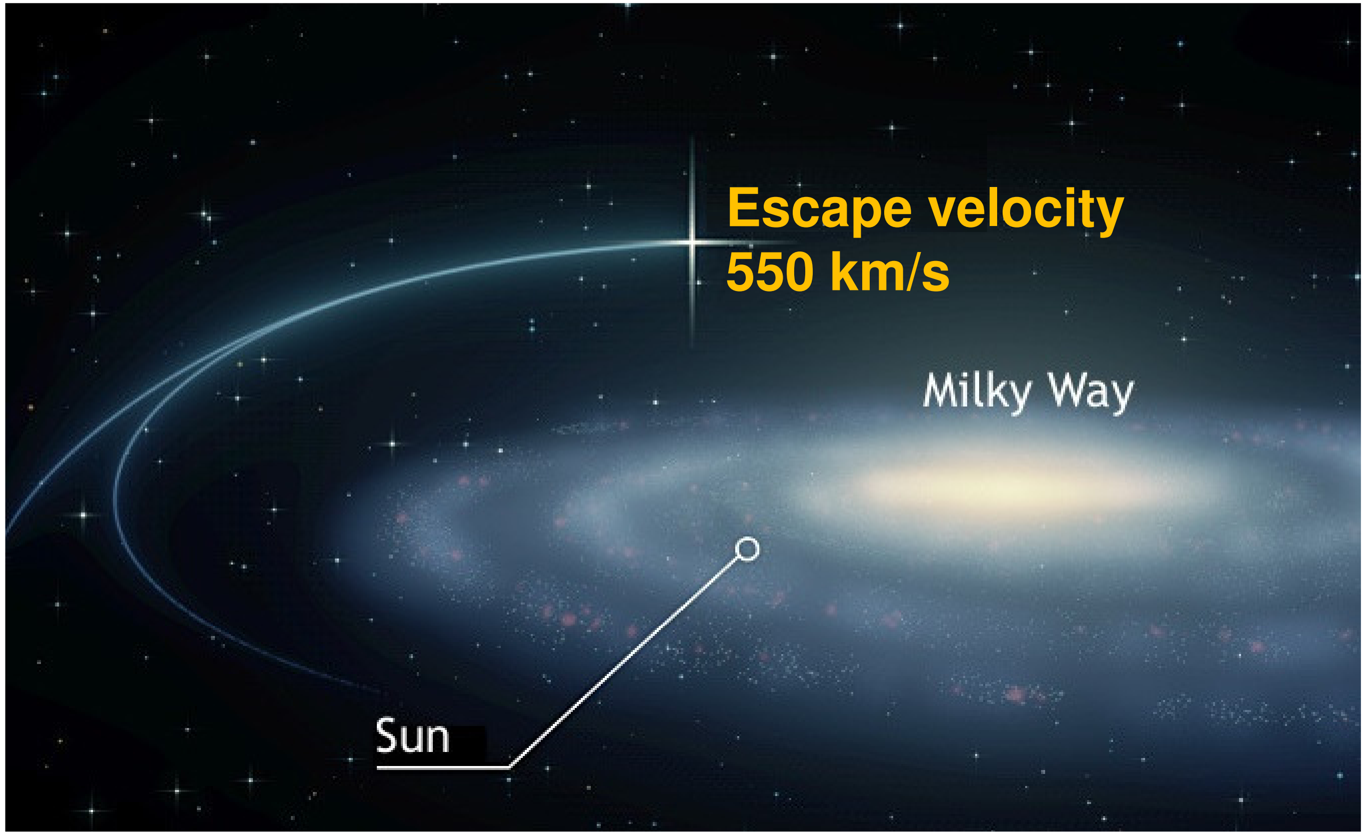


DARK MATTER DETECTION

Particle dark matter detection:
DM particle scatters and deposits energy
We detect this energy



Fermi velocity for DM with mass <10 eV is higher than our Galaxy escape velocity.



Ultralight dark matter has to be bosonic.

Image credits: CDMS: https://www.slac.stanford.edu/exp/cdms/
https://astronomynow.com/2016/04/14/speeding-binary-star-discovered-approaching-galactic-escape-velocity/

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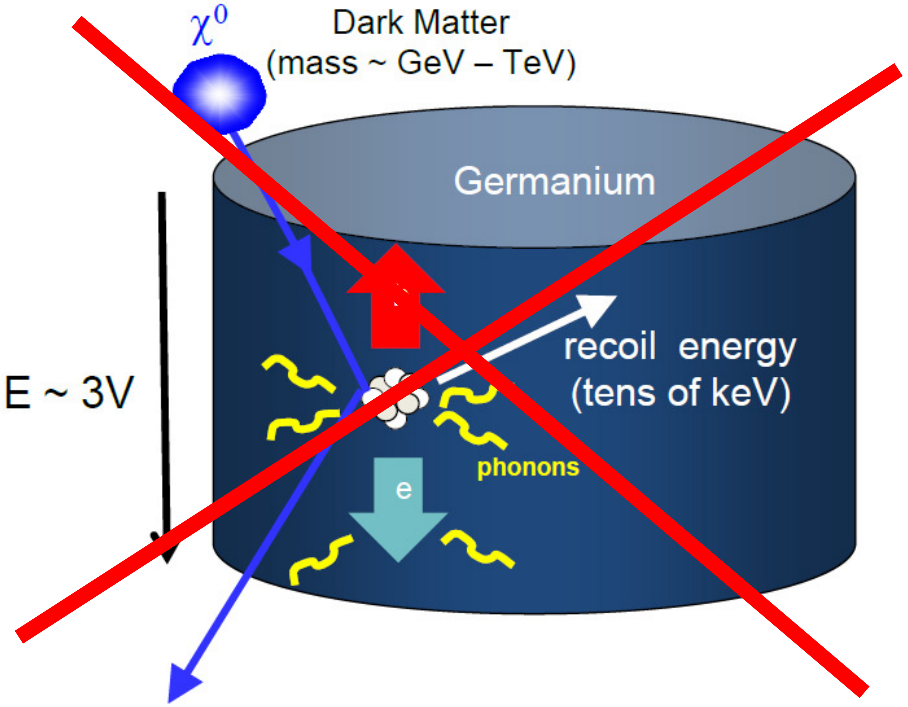

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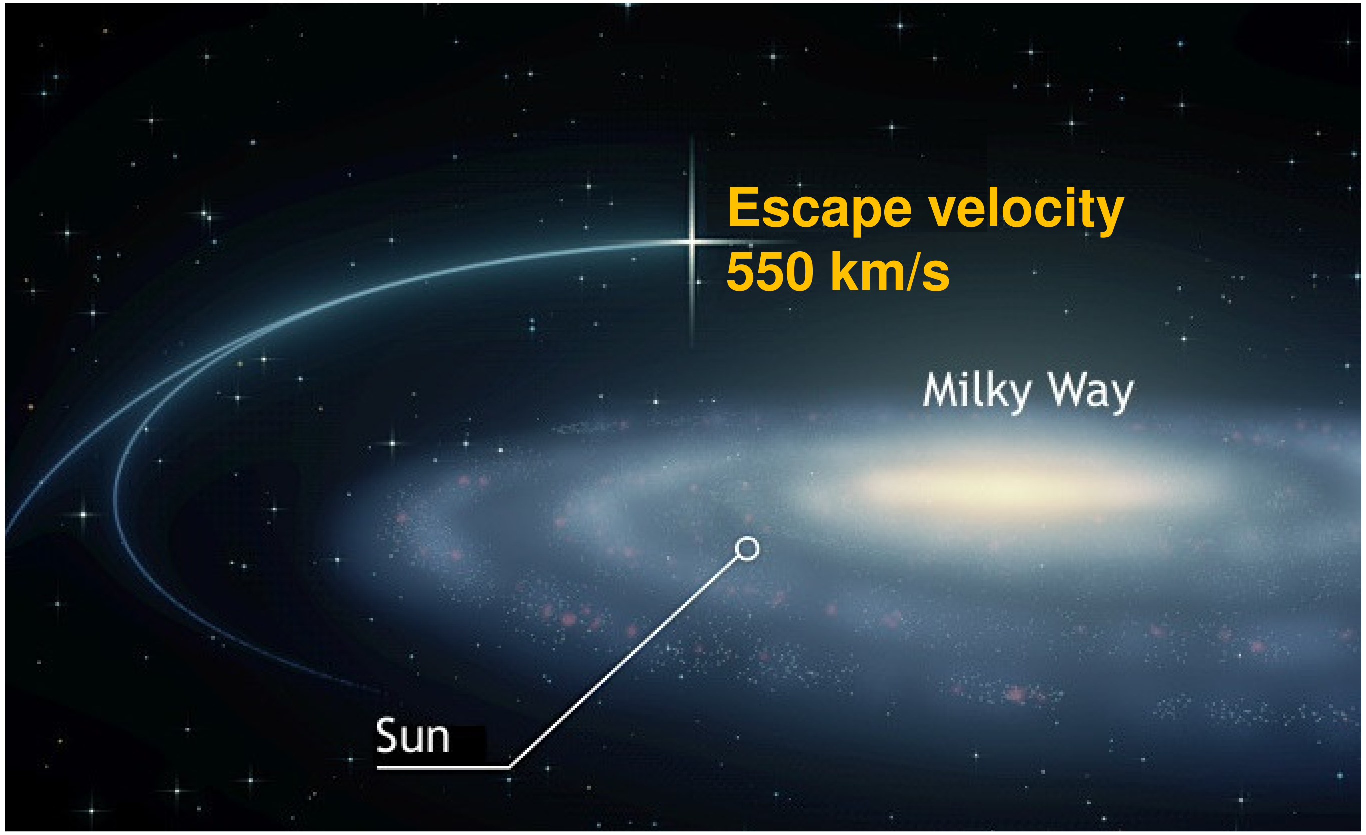

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ULTRALIGHT DARK MATTER $(m_\phi \lesssim 10 \text{ eV})$

The key idea: ultralight dark matter (UDM) particles behave in a “wave-like” manner.

$$\boxed{\phi(t) \approx \phi_0 \cos(m_\phi t)}$$

$$\lambda_{\rm coh} \sim 10^3 (2\pi / m_\phi c)$$

$$N_{\rm dB} = n_\phi \lambda_{\rm coh}^3 \gg 1$$

UDM: coherent on the scale of detectors or networks of detectors.

$$\phi_0 \sim \sqrt{2\rho_{\rm DM}}/m_\phi$$

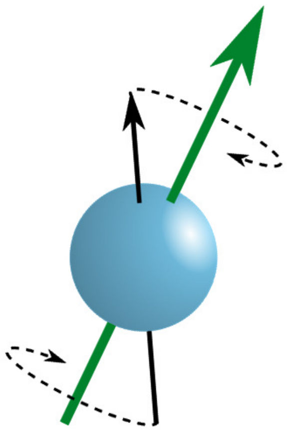
Dark matter field amplitude

Dark matter density

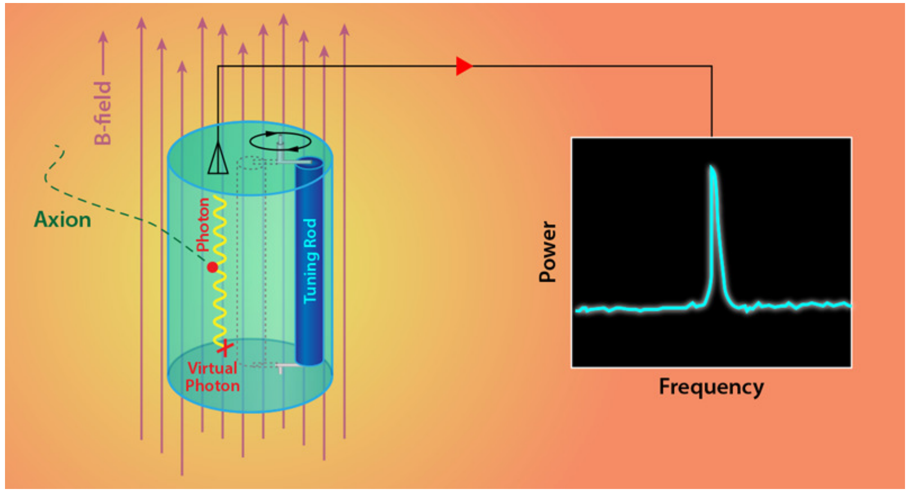
Dark matter mass

Need different detection strategies from particle dark matter.

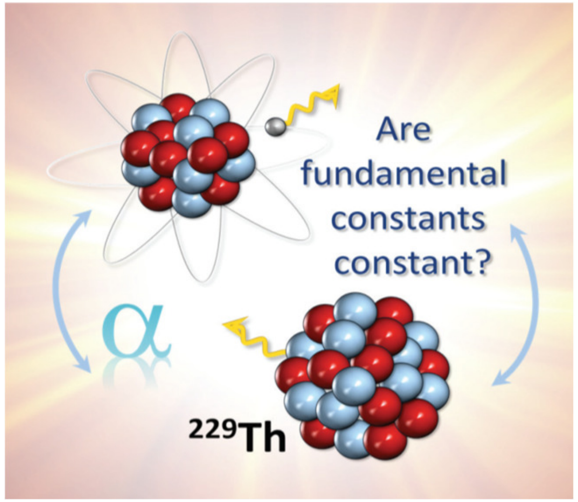
OBSERVABLE EFFECTS OF ULTRALIGHT DARK MATTER



Precession of nuclear or electron spins



Driving currents in electromagnetic systems, produce photons



Modulate the values of the fundamental "constants"

Induced equivalence principle-violating accelerations of matter

DETECTORS: Magnetometers, Microwave cavities, Trapped ions & other qubits, Atom interferometers, Laser interferometers (includes GW detectors), Optical cavities, Atomic, molecular, and nuclear clocks, Other precision spectroscopy

RMP 90, 025008 (2018)

Picture sources and credits: Wikipedia, Physics 11, 34 C. Boutan/Pacific Northwest National Laboratory; adapted by APS/Alan Stonebraker, modulate the values of the fundamental "constants" of nature

SCALAR ULTRALIGHT DARK MATTER

Coupling of scalar UDM to the standard model:

$$\kappa = (\sqrt{2} M_{\mathrm{Pl}})^{-1}$$

$$\phi(t) \approx \phi_0 \cos(m_\phi t)$$

$$\downarrow$$

$$\mathcal{L}_{\mathrm{int}}^{\mathrm{lin}} = \kappa\phi \left\{ \left[\overset{\text{photons}}{\frac{d_e F_{\mu\nu} F^{\mu\nu}}{4}} - \overset{\text{electrons}}{d_{m_e} m_e \bar{\psi}_e \psi_e} \right] - \left[\overset{\text{gluons}}{\frac{d_g \beta_3 G^a_{\mu\nu} G^{a\mu\nu}}{2 g_3}} + \overset{\text{quarks}}{\sum_{q=u,d,s} \left(d_{m_q} + \gamma_m d_g \right) m_q \bar{\psi}_q \psi_q} \right] \right\}$$

$$\alpha \to \frac{\alpha}{1 - \kappa d_e \phi(t)} \approx \alpha \left(1 + \kappa d_e \phi(t) \right) \qquad m_e \to m_e + \kappa m_e d_{m_e} \phi(t)$$

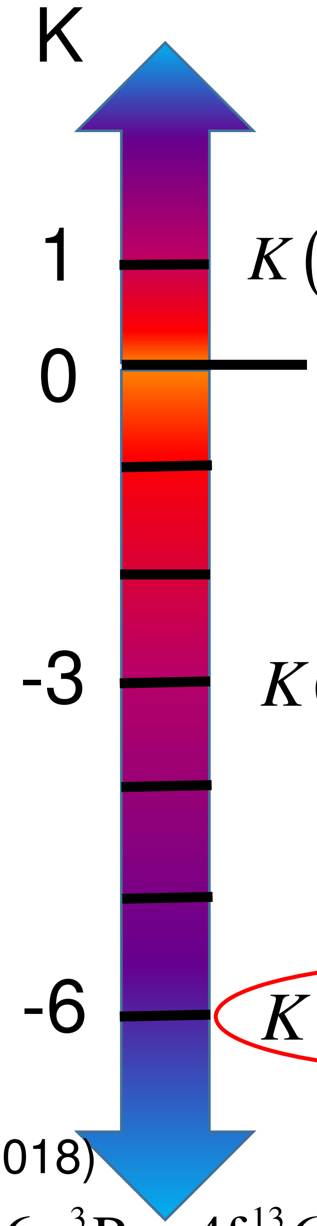
Scalar UDM will cause **oscillations** of the electromagnetic fine-structure constant α, strong interaction constant and fermion masses

Dimensionless constants: $\alpha, \dfrac{m_e}{m_p}, \dfrac{m_q}{\Lambda_{\mathrm{QCD}}}$

Key point: different (types) of clocks have different sensitivity to different constants

Observable: clock frequency ratios

Enhancement (sensitivity) factor K for clocks



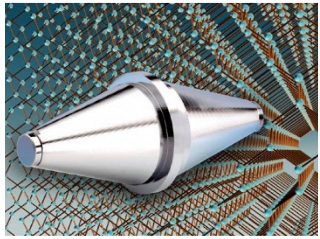
$K(Sr^+) = 0.4$
$K(Yb) = 0.3$

$K(Hg) = 0.8, \quad K(Yb^+ E2) = 1$

$K(Al^+) = 0.01, \; K(Sr) = 0.06, \; K(Ca^+) = 0.1$

$K(Hg^+) = -2.9$

$K(Yb^+ E3) = -6$



Cavity K=1
Effective Sr/cavity K=1

$$\boxed{\frac{\partial}{\partial t}\ln\frac{\nu_2}{\nu_1} = (K_2 - K_1)\frac{1}{\alpha}\frac{\partial \alpha}{\partial t}}$$

Future clocks:

$K(Cf^{15+} / Cf^{17+}) \approx 110$

Nuclear clock $K = ?$

Safronova et al.,
PRL120, 173001 (2018)

$K(Yb \;\; 4f^{14}6s6p\,{}^3P_0 \text{ - } 4f^{13}6s^2 5d\,) = 15$

HOW TO DETECT ULTRALIGHT DARK MATTER WITH CLOCKS?

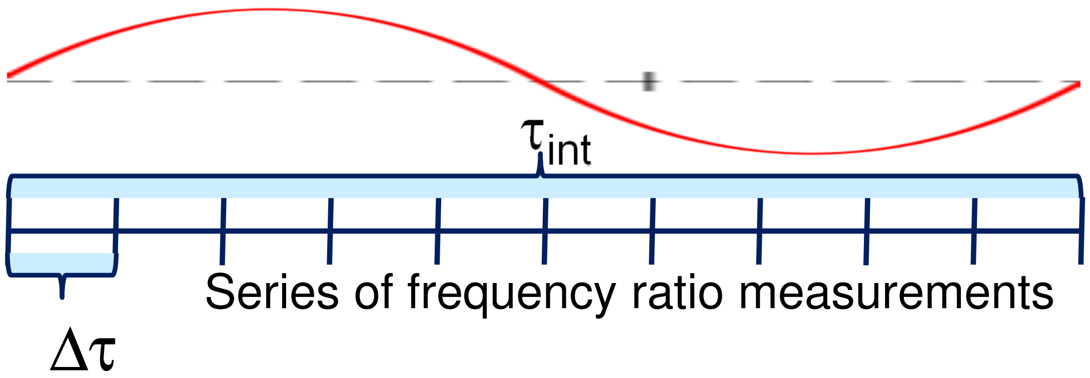
Dark matter field couples to electromagnetic interaction and “normal matter”

Fundamental coupling constants and mass ratios now oscillate

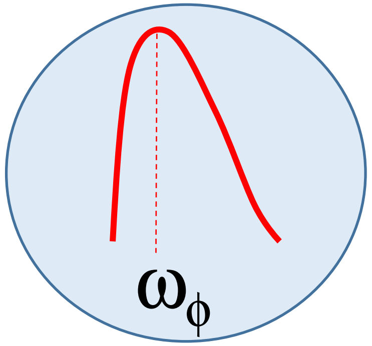
Atomic, molecular, nuclear energy levels will oscillate so clock frequencies will oscillate

Measure ratios of clock frequencies over time (or clock/cavity).

Discrete Fourier transform of time series gives a frequency peak



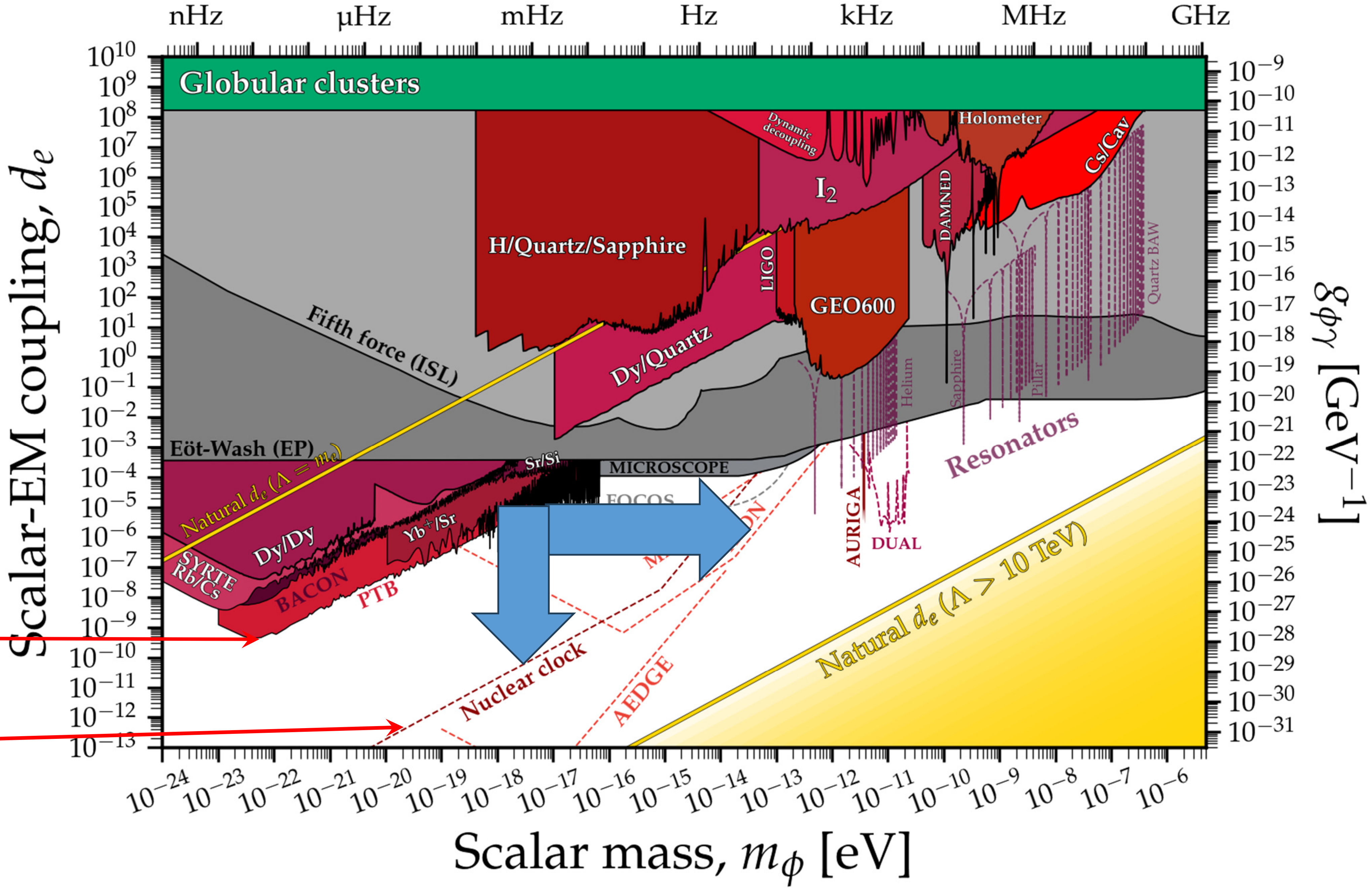
Series of frequency ratio measurements



Dark matter Compton frequency

$f = 2\pi/m_\phi$ [Hz]	m_ϕ [eV]
1 MHz	4×10^{-9}
1 kHz	4×10^{-12}
1	4×10^{-15}
1 mHz	4×10^{-18}
10^{-6}	4×10^{-21}

$$\boxed{\phi F_{\mu\nu}F^{\mu\nu}}$$



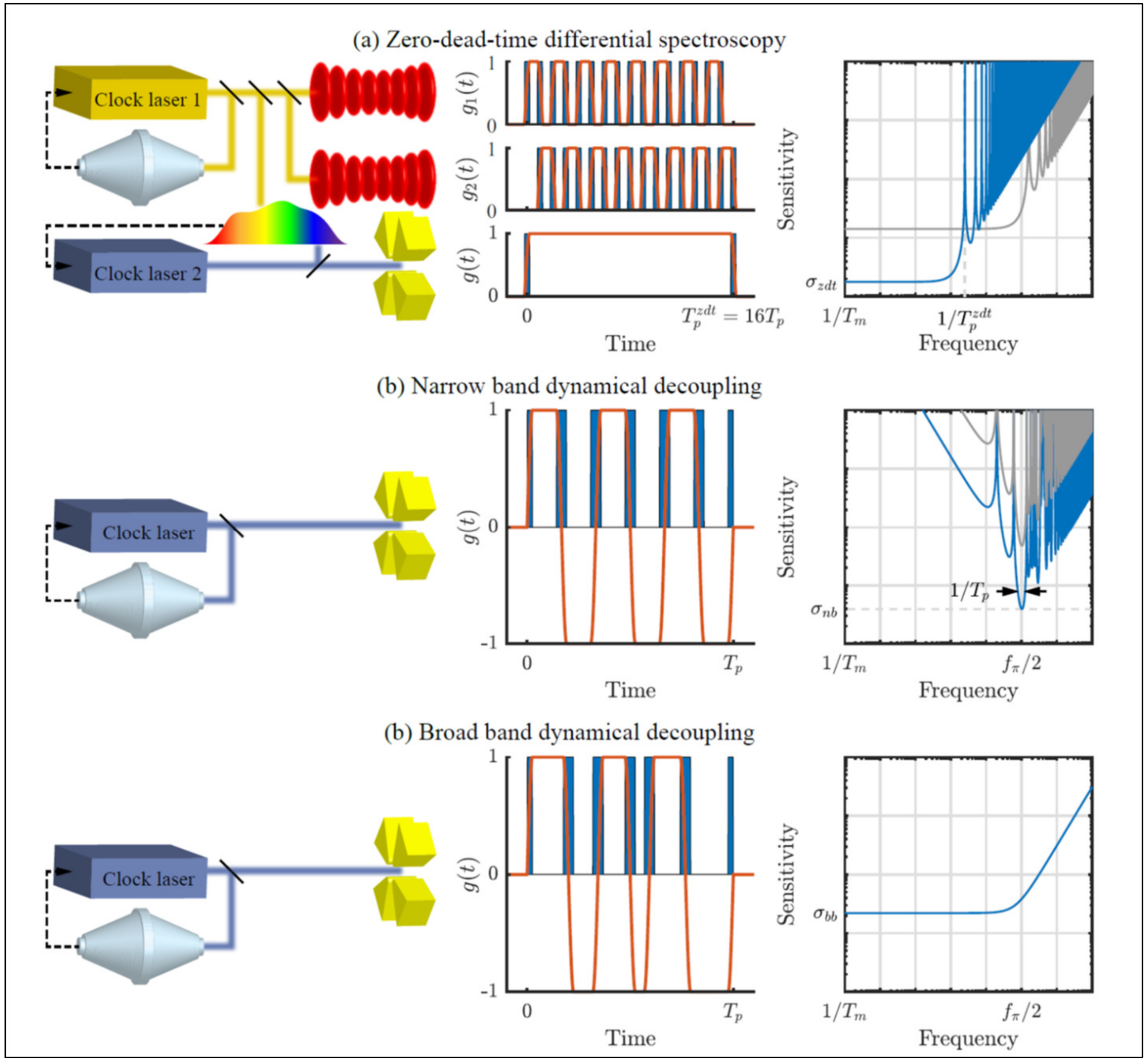
Present
clock limits

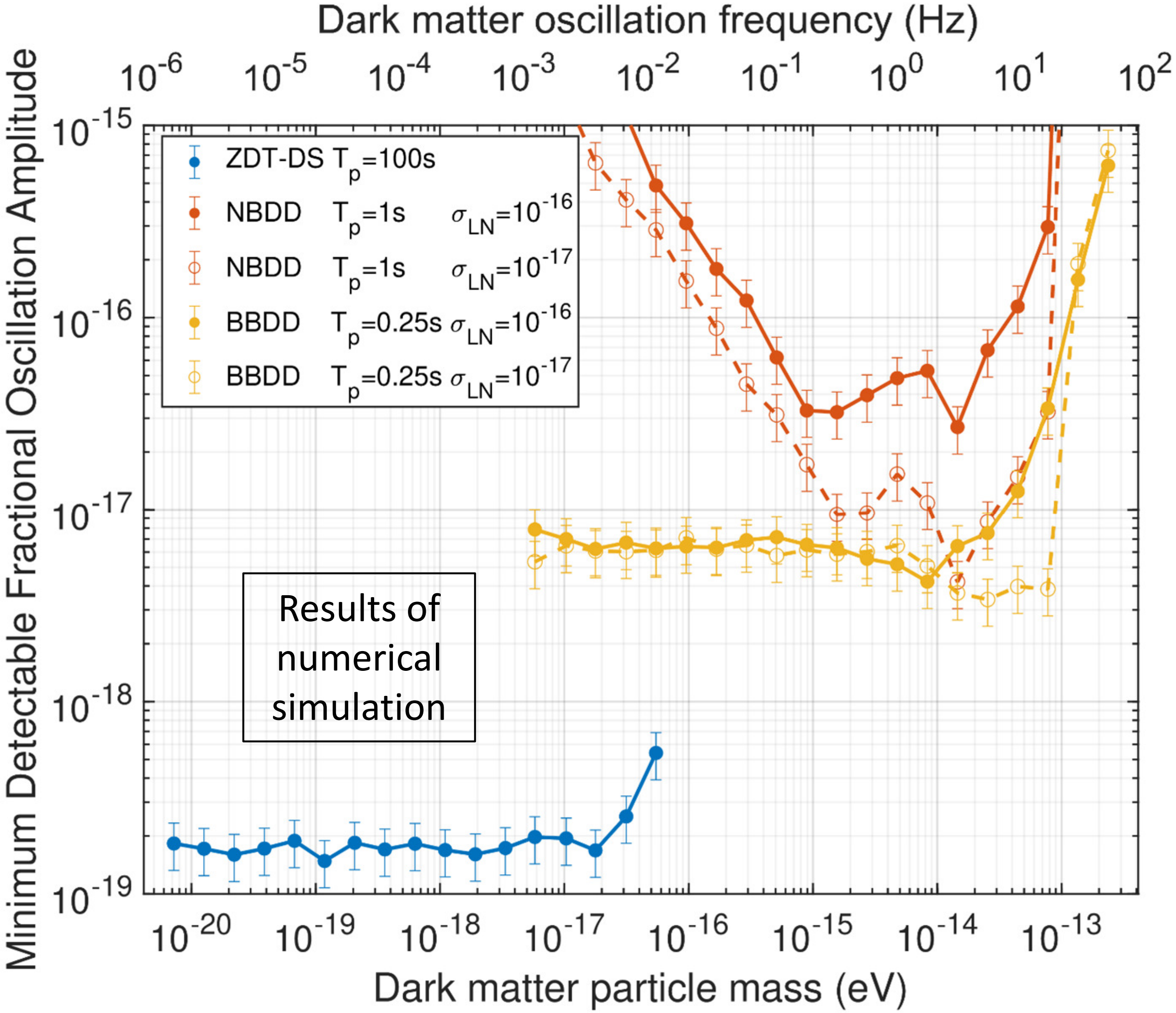
Projected
clock limits

arXiv:2203.14915

Ultralight DM limits: https://cajohare.github.io/AxionLimits/

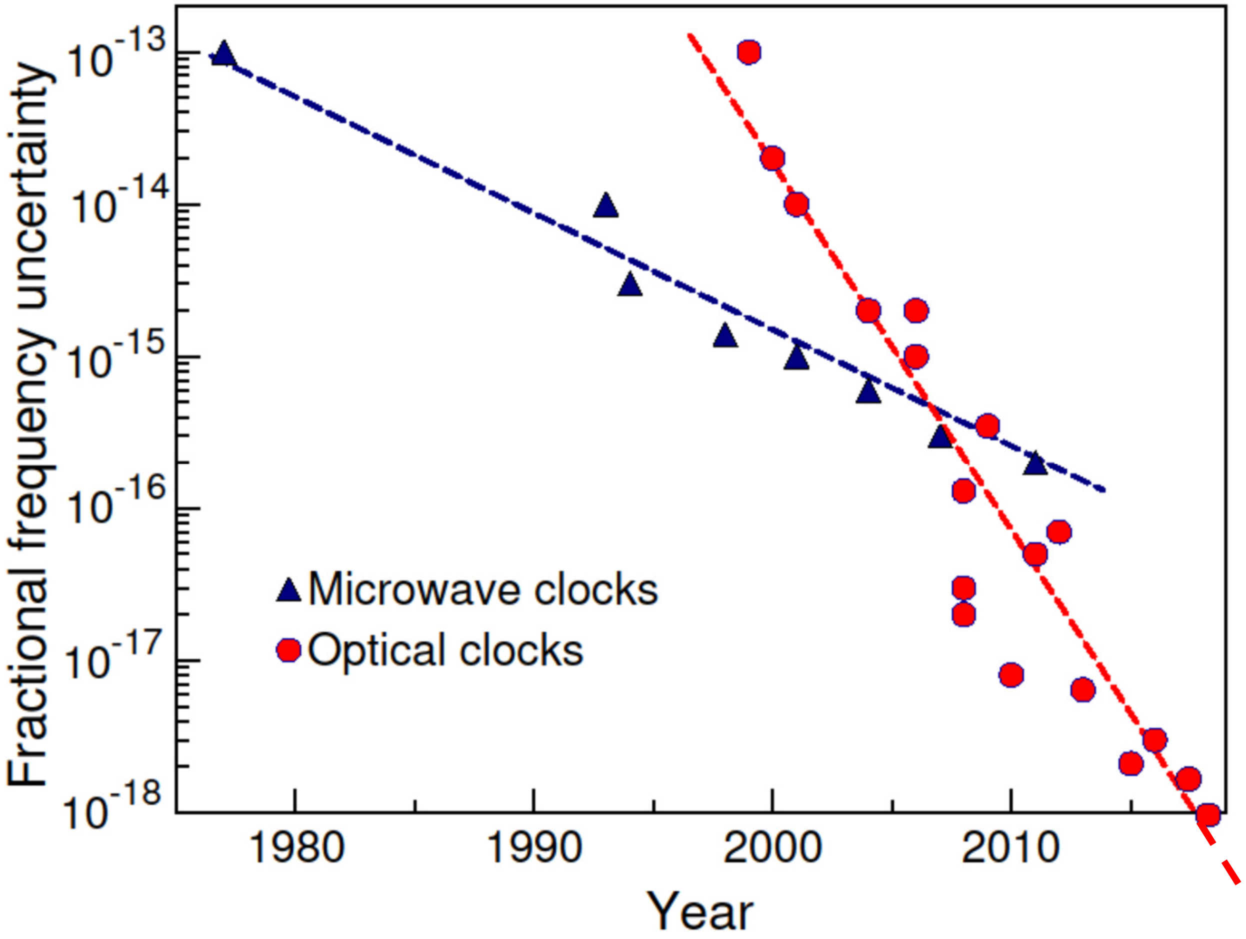
QUANTUM METROLOGY ALGORITHMS FOR DARK MATTER SEARCHES WITH CLOCKS





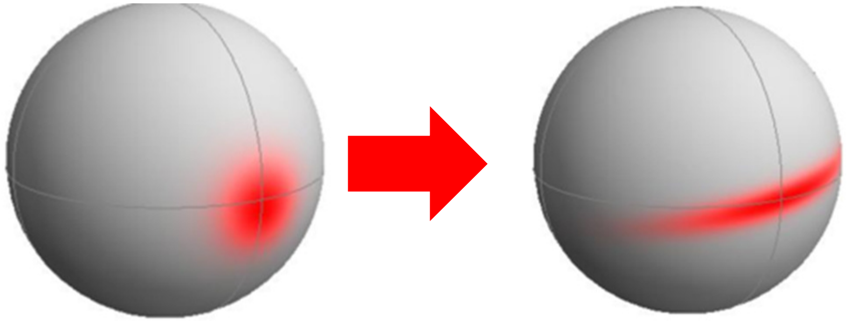
M. H. Zaheer, N. J. Matjelo, D. B. Hume, M. S. Safronova, D. R. Leibrandt, arXiv:2302.12956, in press, PRA (2024)

OPTICAL CLOCKS WILL CONTINUE TO IMPROVE

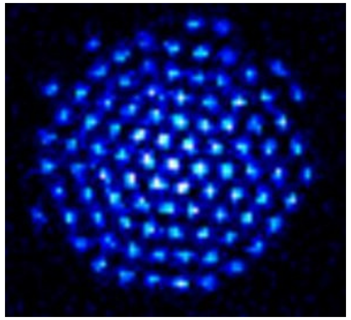


Build different clocks: highly-charged ion clocks, nuclear clocks, molecular clocks

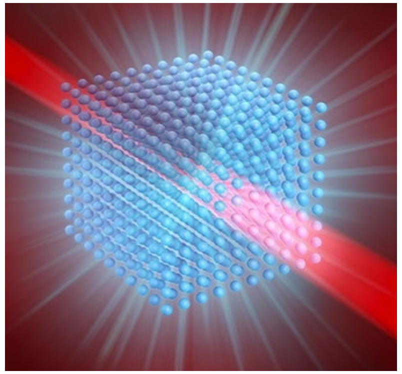
?



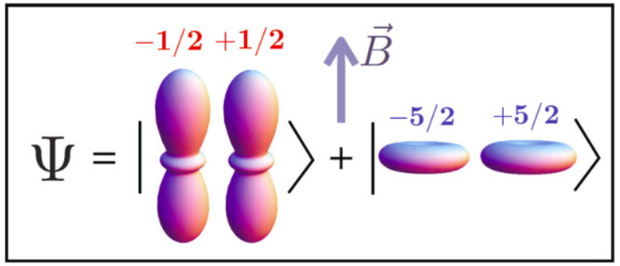
Measurements beyond the quantum limit



Large ion crystals

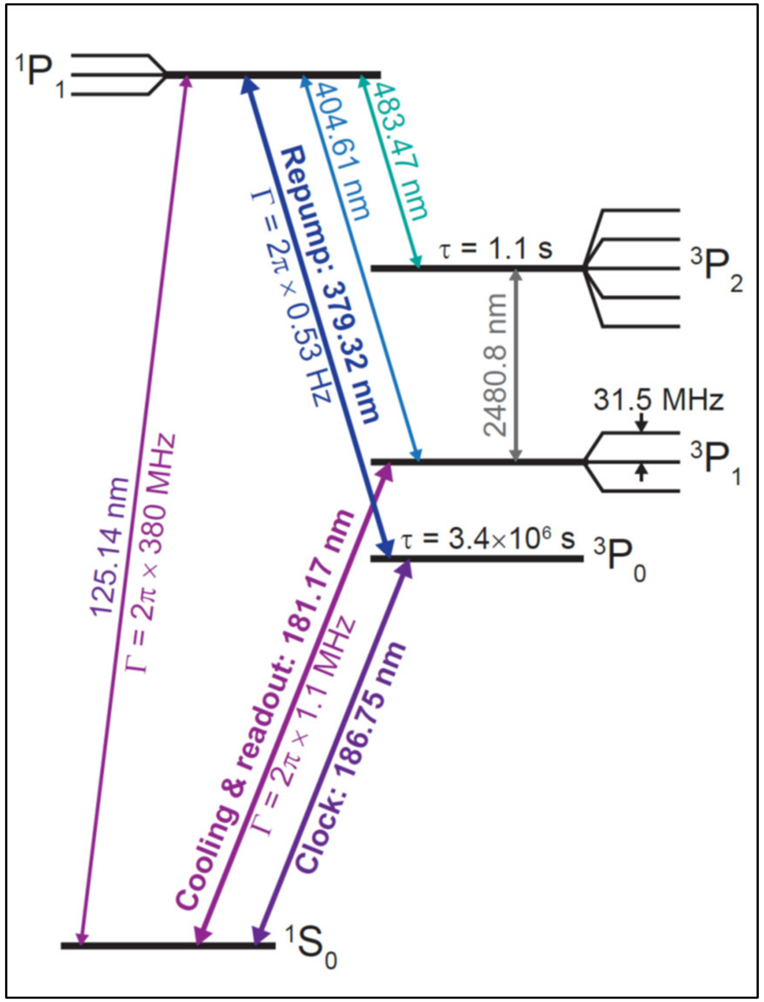


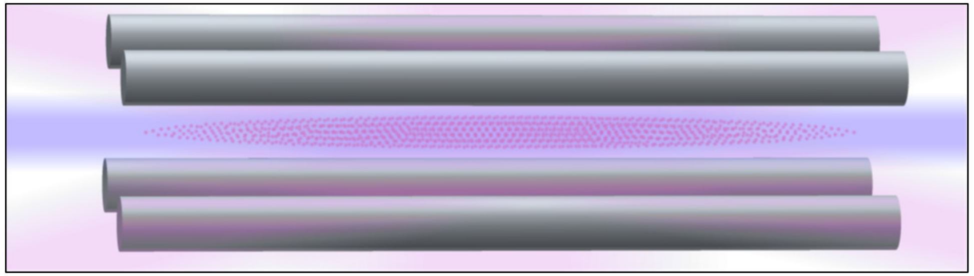
New designs for lattice clocks

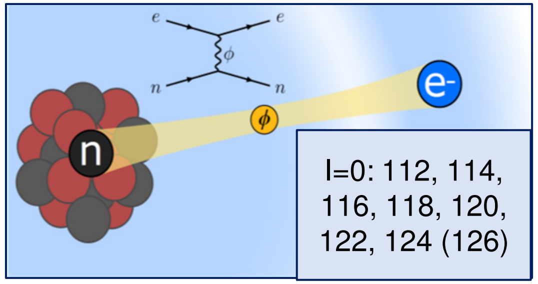


Entangled clocks

Prospects of a thousand-ion Sn^{2+} Coulomb-crystal clock with sub-10^{-19} inaccuracy







I=0: 112, 114, 116, 118, 120, 122, 124 (126)

I = J = F = 0 → no linear Zeeman or quadrupole shifts

$\Delta\alpha = -0.96(4)\ a_0^3$ → no micromotion shift at $\Omega/(2\pi) = 225(5)$ MHz, 5×10^{-18} room temperature BBR shift

7.5 stable even isotopes → ideal platform for new boson searches

+10 stable enough (over 1 sec)

Effect	Shift (10^{-20})	Uncertainty (10^{-20})
Secular motion	-24	7.2
Blackbody radiation shift	515	3.4
Micromotion	28	2.8
Quadratic Zeeman shift	-366550	2.3
Probe laser Stark shift	19753	2.0
Total	-346278	9.0

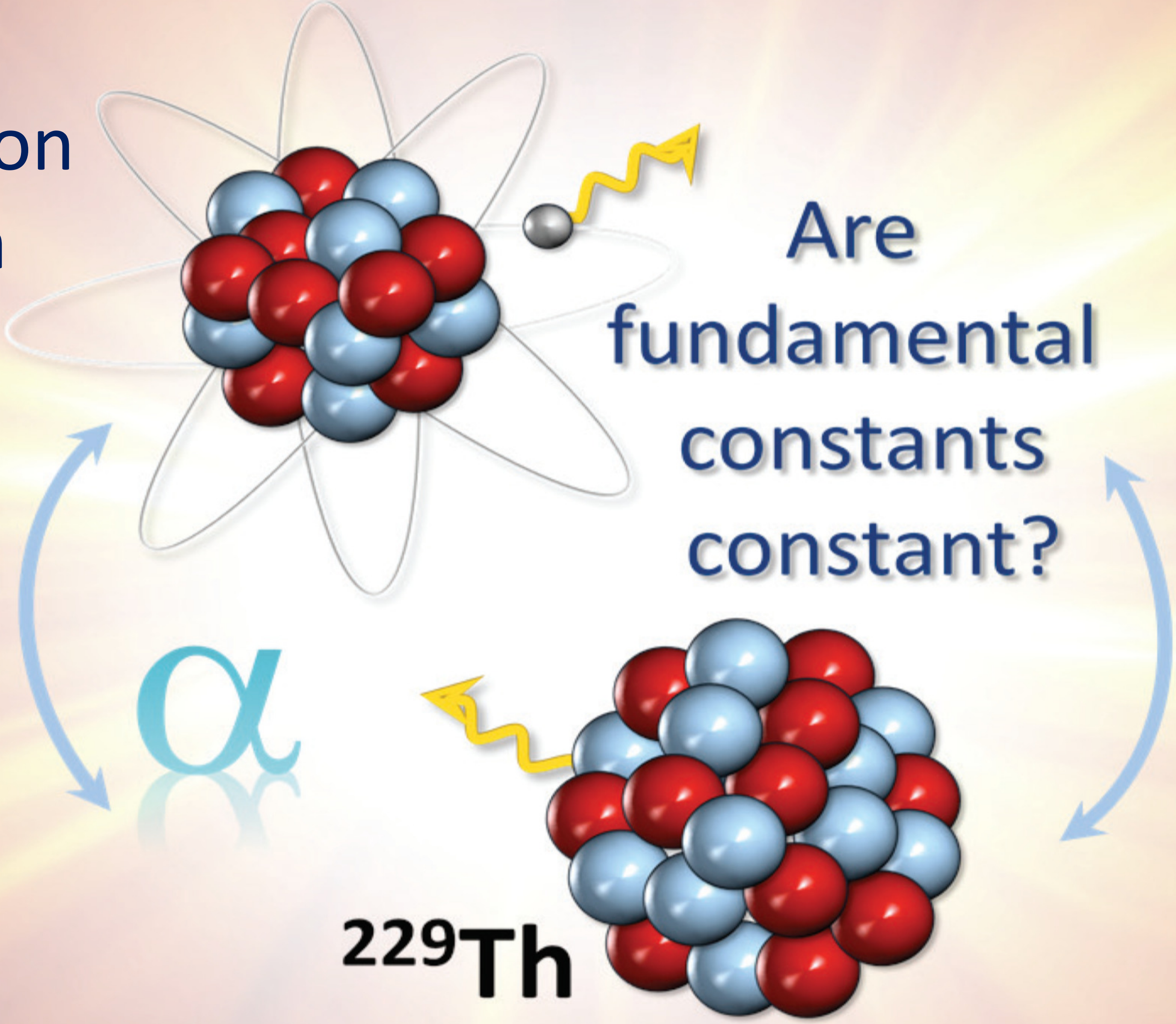
A 1000-ion clock

$$\sigma_{y,proj}(\tau) = \frac{4\times10^{-18}}{\sqrt{T\tau}}$$

David R. Leibrandt, Sergey G. Porsev, Charles Cheung, and Marianna S. Safronova,
Nature Communications 15, 5663 (2024).

FROM ATOMIC TO NUCLEAR CLOCKS!

Clock based on transitions in atoms



Only one known nucleus with a suitable transition

M. S. Safronova, Annalen der Physik 531, 1800364 (2019)

^{229}Th NUCLEAR CLOCK

Th^{3+} ion clock
Solid state clock

European Research Council

Thorsten Schumm, TU Wein
Ekkehard Peik, PTB
Peter Thirolf, LMU
Marianna Safronova, UD

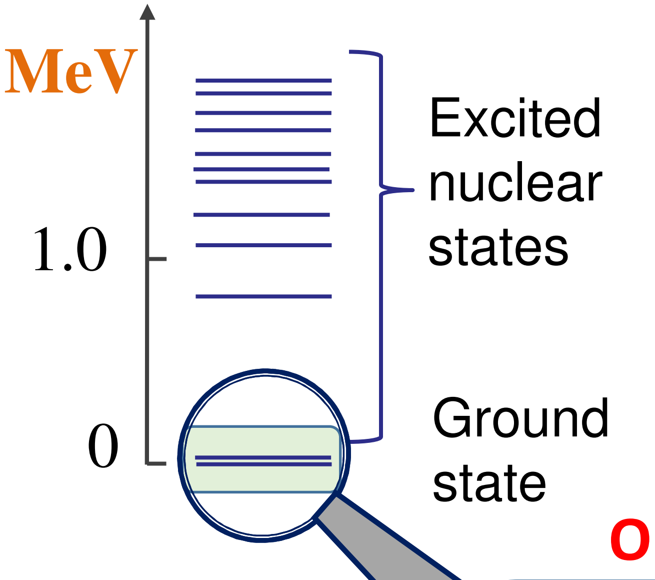
Review & ERC Synergy project plan:
E. Peik, T. Schumm, M. S. Safronova, A. Pálffy, J. Weitenberg, and P. G. Thirolf, QST 6, 034002 (2021).

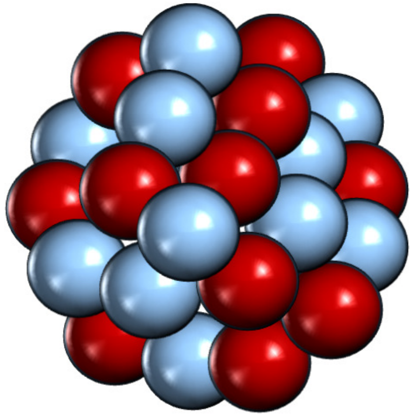
Observation of the radiative decay of the ^{229}Th nuclear clock isomer
S. Kraemer et al., Nature 617, 706 (2023)

First Laser Excitation of the Th-229 Nucleus
J. Tiedau, Phys. Rev. Lett. 132, 182501 (2024)

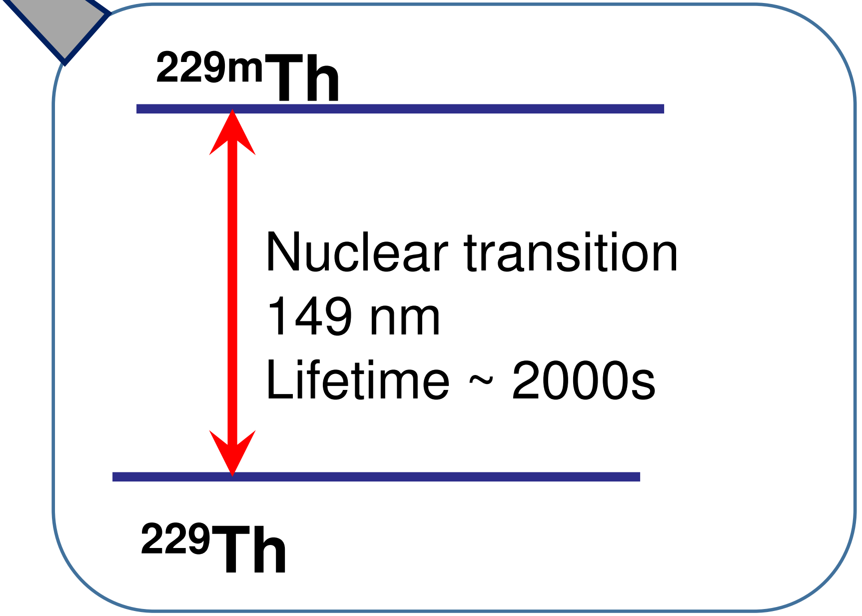
Laser Excitation of the 229 Th Nuclear Isomeric Transition in a Solid-State Host, R. Elwell et al., Phys. Rev. Lett. 133, 013201 (2024)

Dawn of a nuclear clock: frequency ratio of the 229mTh isomeric transition and the 87Sr atomic clock, C. Zhang, arXiv:2406.18719





Only ONE exception!

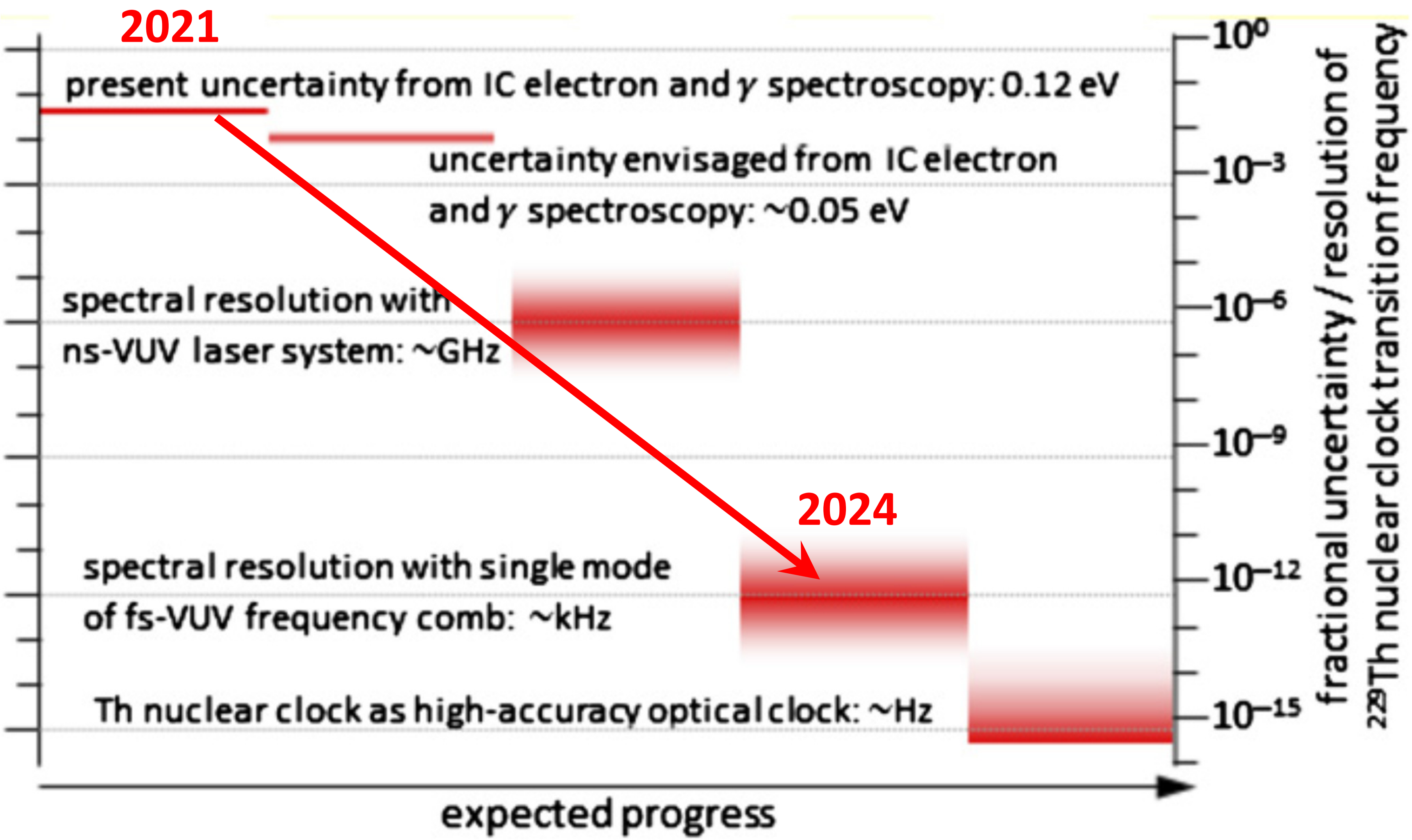


HOW TO BUILD A NUCLEAR CLOCK?

Nature 617, 706 (2023)

PRL 132, 182501 (2024)
PRL 133, 013201 (2024)

arXiv:2406.18719
2 020 407 384 335(2) kHz

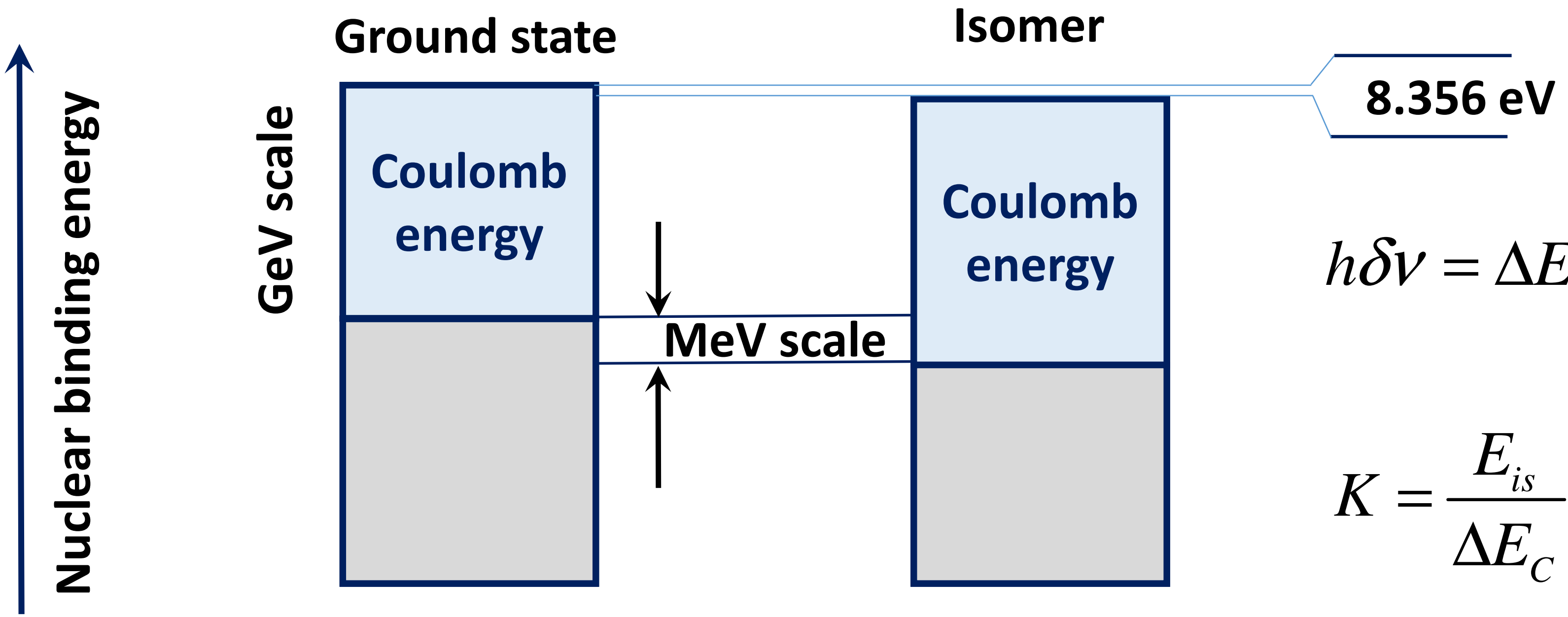


Quantum Science and Technology 6, 034002 (2021)

^{229}Th: VERY HIGH SENSITIVITY TO VARIATION OF FUNDAMENTAL CONSTANTS

“Unlikely cancellation” argument

V. V. Flambaum,
PRL 97, 092502 (2006)



Nuclear binding energy

GeV scale

Ground state

Isomer

Coulomb energy

Coulomb energy

MeV scale

8.356 eV

Sensitivity to α variation

$$h\delta\nu = \Delta E_C \frac{\delta\alpha}{\alpha} \qquad \frac{\delta\nu}{\nu} = K\frac{\delta\alpha}{\alpha}$$

$$K = \frac{E_{is}}{\Delta E_C} = \frac{8.356\,eV}{\Delta E_C \approx MeV} \approx 10^5$$

Too much cancellation to compute Coulomb energy difference accurately enough:

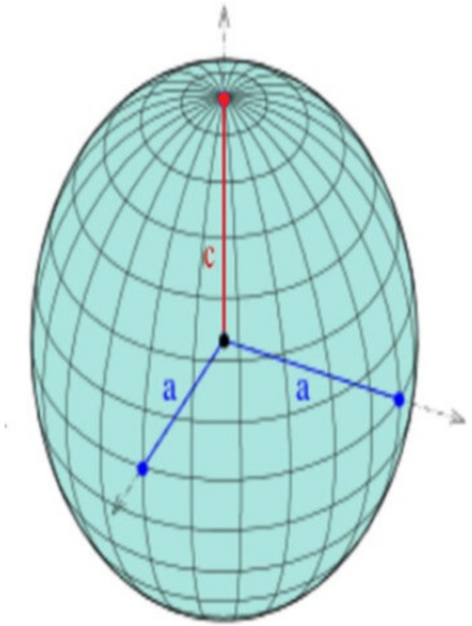
SkM∗ (HFB) model gave the Coulomb energy difference $V_C = -0.307$ MeV = (924.854 − 925.161) MeV
SIII (HFB) gave $V_C = 0.001$ MeV.

Elena Litvinova, Hans Feldmeier, Jacek Dobaczewski, and Victor Flambaum, Phys. Rev. C 79, 064303 (2009)

How to extract Coulomb energy difference from nuclear properties

J. C. Berengut, V. A. Dzuba, V. V. Flambaum, and S. G. Porsev, Phys. Rev. Lett. 102, 210801 (2009)

Geometric model: assume that both the ground state nucleus and the lowest-energy isomer are uniform, hard-edged, prolate ellipsoids. **Goal: express Coulomb energy vis observables nuclear properties.**



Prolate

$$e^2 = 1 - \frac{a^2}{c^2}$$

$$\langle r^2 \rangle = \int r^2 \rho(r) d^3 r = \frac{1}{5}\left(2a^2 + c^2\right)$$

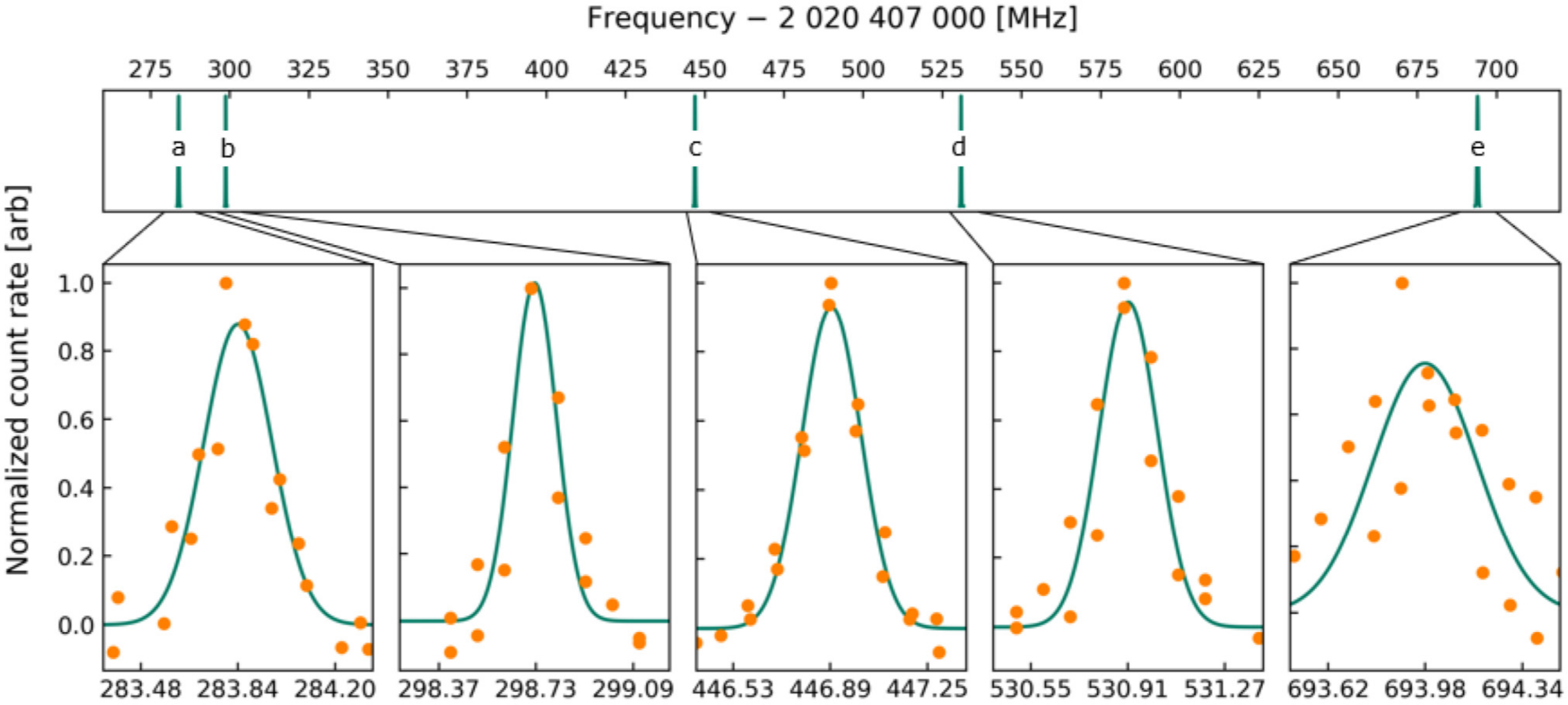
$$Q_0 = 2\int r^2 P_2(\cos\theta)\rho(r) d^3 r = \frac{2}{5}\left(c^2 - a^2\right)$$

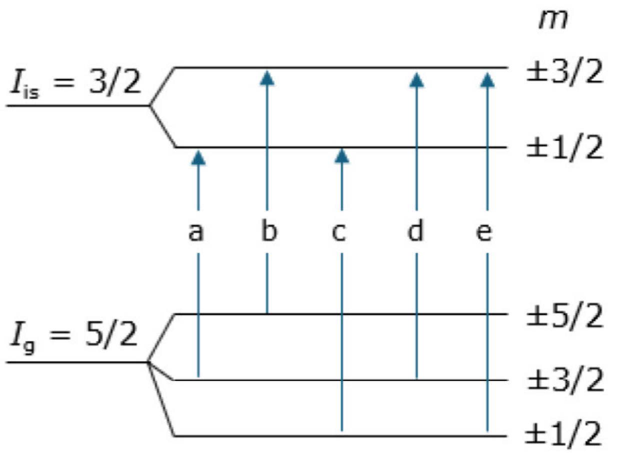
Use these expression to express a, c, and e via Q_0 and $<r^2>$ and compute Coulomb energy for ground state and isomer.

Coulomb energy: $$E_C = \frac{3}{5}\frac{q_e^2 Z^2}{R_0}\frac{\left(1-e^2\right)^{1/3}}{2e}\ln\left(\frac{1+e}{1-e}\right)$$

R_0 is the equivalent sharp spherical radius $R_0^3 = a^2 c$

DIRECT SPECTROSCOPIC MEASUREMENT OF NUCLEAR ELECTRIC QUADRUPOLE STRUCTURE





m_g	m_{is}	ν_{Th} [MHz]
3/2	1/2	2 020 407 283.847(4)
5/2	3/2	2 020 407 298.727(4)
1/2	1/2	2 020 407 446.895(4)
3/2	3/2	2 020 407 530.918(4)
1/2	3/2	2 020 407 693.98(2)

Result: measured ratio of the quadrupole moments is $Q_{is} / Q_g = 0.57003(2)$

Chuankun Zhang, Tian Ooi, Jacob S. Higgins, Jack F. Doyle, Lars von der Wense, Kjeld Beeks, Adrian Leitner, Georgy Kazakov, Peng Li, Peter G. Thirolf, Thorsten Schumm, Jun Ye, Nature 633, 63-70 (2024).

Estimating sensitivity of Th nuclear clock to α-variation

$$\Delta E_C = \langle r^2\rangle \frac{\partial E_C}{\partial\langle r^2\rangle}\frac{\Delta\langle r^2\rangle}{\langle r^2\rangle} + Q_0\frac{\partial E_C}{\partial Q_0}\frac{\Delta Q_0}{Q_0}$$

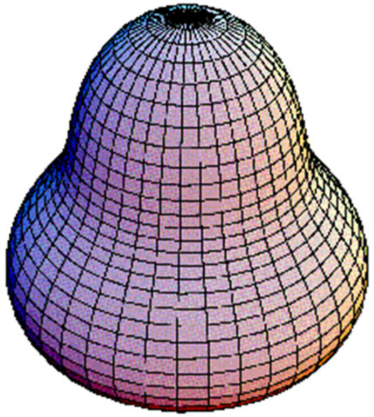
$$\Delta E_C = -485\,\mathrm{MeV}\,\frac{\Delta\langle r^2\rangle}{\langle r^2\rangle} + 11.3\,\mathrm{MeV}\left(\frac{Q_0^m}{Q_0}-1\right)$$

$$\Delta E_C = -0.154(19)\,\mathrm{MeV} + 0.203(4)\,\mathrm{MeV} = 0.049(19)\,\mathrm{MeV}$$

$$K = \frac{\Delta E_C}{8.356\,\mathrm{eV}} = \underbrace{-18400(2300)}_{\langle r^2\rangle\,\mathrm{term}} \; + \; \underbrace{24300(400)}_{Q_0\,\mathrm{term}} \; = \; 5900(2300)$$

Beeks at al., arXiv:2407.17300 (2024)

OCTUPOLE DEFORMATION



$$r(\theta) = R_s\left[1 + \sum_{n=1}^{N} \beta_n Y_{no}(\theta)\right]$$

β_n are deformation parameters and $Y_{n0}(\theta)$ are spherical harmonics

R_s is defined by normalizing the volume to that of the spherical nucleus with equivalent sharp spherical radius R_0,

$$\int r\rho(r)\, d^3r = 1$$

For a pear shaped nucleus with quadrupole and octupole deformation, N = 3.

The Coulomb energy is given by

$$E_C = \frac{3}{5}\frac{q_e^2 Z^2}{R_0}\left(1 - \frac{1}{4\pi}\beta_2^2 - \frac{5}{14\pi}\beta_3^2\right)$$

The nuclear properties are related to the β coefficients via rms and Q_0 formulas

β_2 and β_3 are the quadrupole and octupole deformations, $O(\beta^3_n)$ terms are omitted.

$$K = 6300(2300)$$

WHAT IF OCTUPOLE DEFORMATION CHANGES?

Model changing octupole deformation between ground state and isomer:

Change in β_3 between isomer and ground state

$1\% \rightarrow \Delta K = 2800$

$3\% \rightarrow \Delta K = 8600$

$5\% \rightarrow \Delta K = 14500$

$K = 6300+2800=9100$

$K = 6300-2800=3500$

Larger β_3 of the isomer gives a positive change in K.
In this case, K will increase.

Estimate electric octupole moment $Q_{30} = 2\int r^3(\theta) P_3(\cos\theta)\rho(r) d^3r = 35-44 \text{ fm}^3$

$\beta_2=0.22$ obtained from experimental data, $\beta_3 = 0.11 - 0.145$ from PRC 103, 014313 (2021)

Conclusions

- Need to measure $<r^2>$ difference better
- Need to know at least the sign of the change in octupole deformation from ground state to isomer
- Higher moments can also be important! Charge distributions is important
- Need better model that can relate experimental quantities to Coulomb energy difference

NEXT DECADE OF SPACE RESEARCH

What quantum technologies will be sent to space?

What new physics can one search for in space better then on Earth?

NASA Decadal Survey: Biological and Physical Sciences in Space
https://science.nasa.gov/biological-physical/decadal-survey
May 2023: Establishment of NASA Fundamental Physics Analysis group
https://www.jpl.nasa.gov/go/funpag

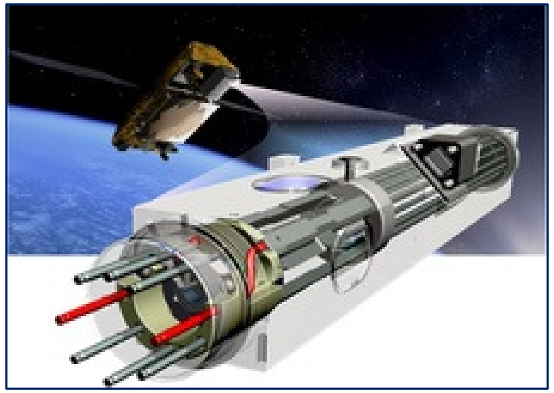
Europe: Community workshop on cold atoms in space (September 2021)
Cold Atoms in Space: Community Workshop Summary and Proposed Road-Map, Alonso et al., EPJ Quantum Technology 9, 1 (2022)

Image credits: NASA, ESA

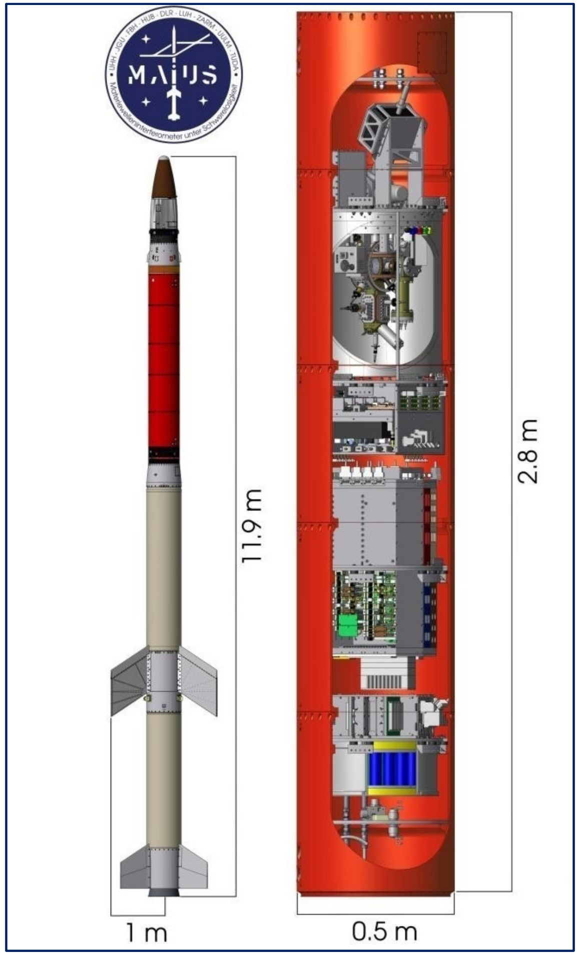
QUANTUM TECHNOLOGIES IN SPACE

GPS, “hot” atoms,
Microwave, Cs or Rb

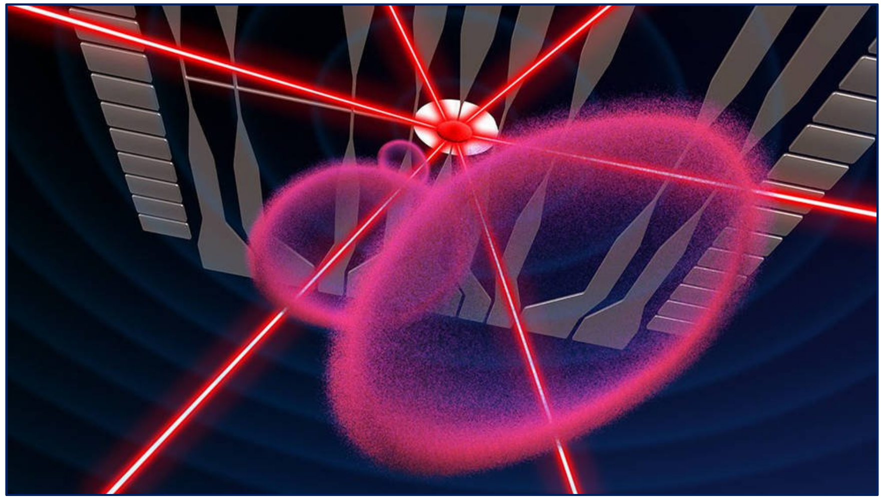
2017 CACES (Tiangong-2), China,
microwave Rb cold atom clock



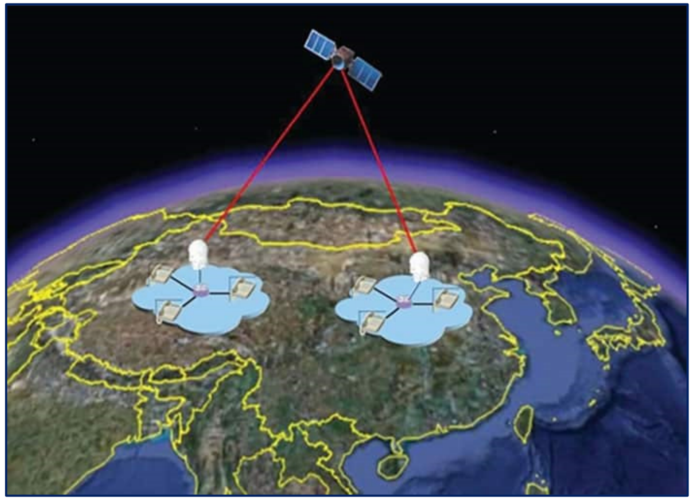
2019 NASA Deep Space
Atomic Clock (DSAC),
microwave, Hg^+ ions



2016 MAUS-1 sounding
rocket, cold Rb atoms, BEC,
atom interferometry, DLR



2018, Cold Atom Lab, ISS, NASA



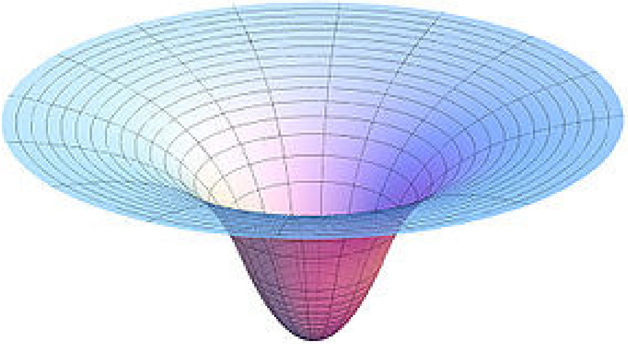
2016 QUESS, Entanglement distribution, China

Image credits: JPL, NASA, CMSE, NSSC,
DLR/Leibnitz, University of Hannover

WHY TO SEARCH FOR NEW PHYSICS IN SPACE?

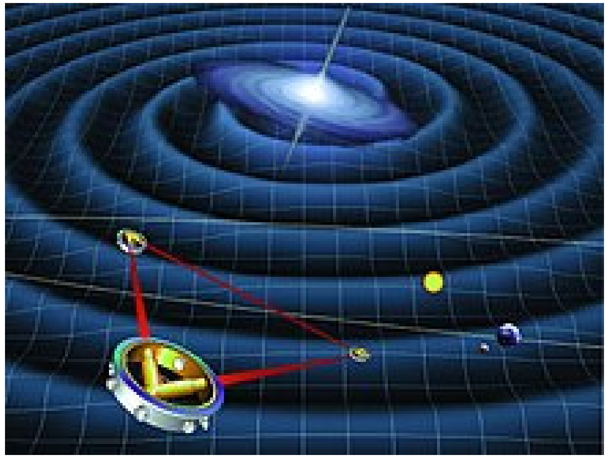
Quantum sensors in space enables discovery of new physics not possible on Earth
Many orders of magnitude improvements or principally different experiments are possible

Need to be away from Earth surface

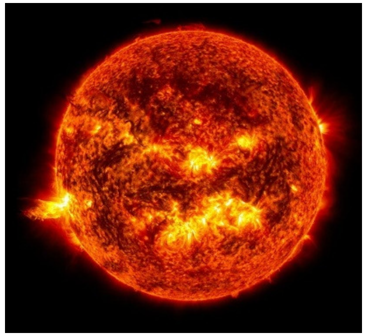


Tests of gravity are hindered by Earth gravity
Optical time transfer to link Earth clocks
Dark energy and some dark matter (screening)
Tests of fundamental postulates (WEP, LLI)

Need access to **variable gravitational potentials**



Long baselines: gravitational waves, dark matter (especially transients), dark energy



Sun: Dark matter halo bound to the Sun? Extreme overdensities possible

Moon: laser ranging, low seismic activity, permanent cryogenic environment

Asteroids: test masses

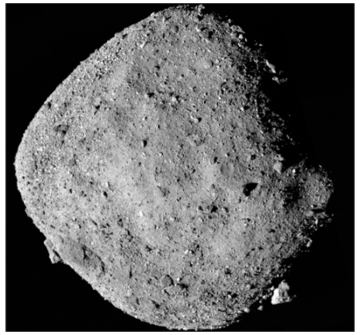
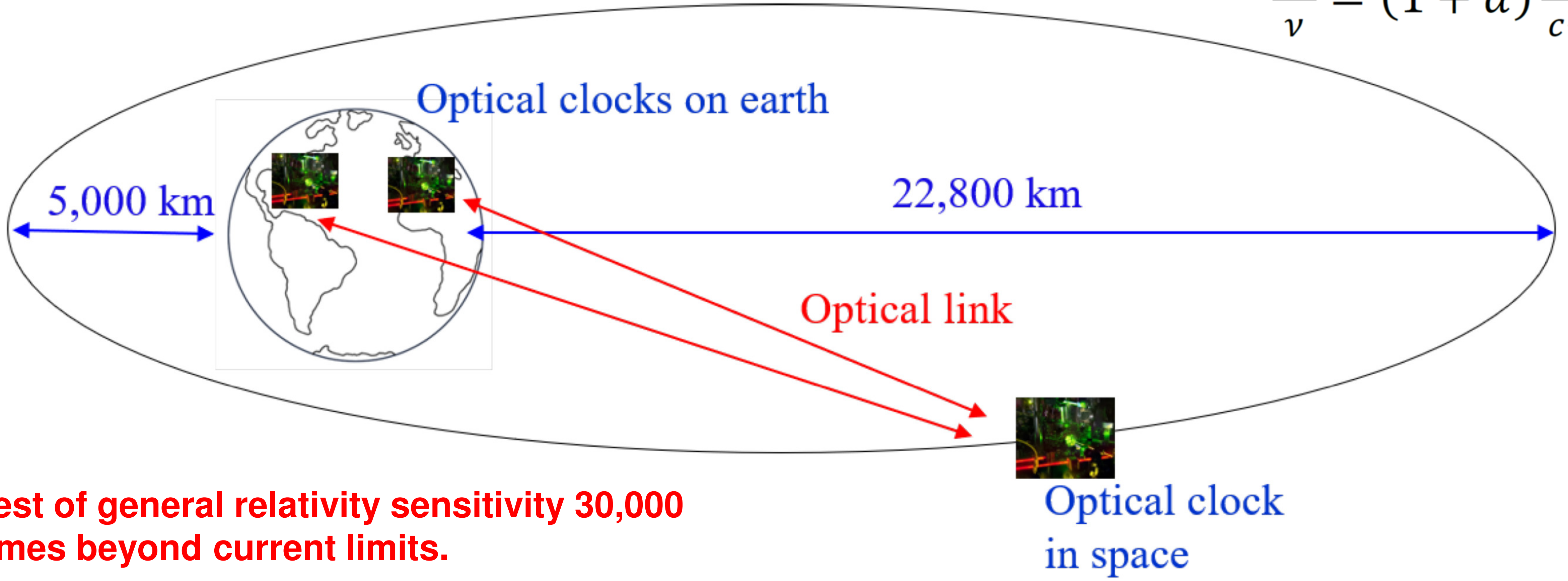


Image credits:
NASA, Wikipedia

FUNDAMENTAL PHYSICS WITH A STATE-OF-THE-ART OPTICAL CLOCK IN SPACE

Andrei Derevianko, Kurt Gibble, Leo Hollberg, Nathan R. Newbury, Chris Oates,
Marianna S. Safronova, Laura C. Sinclair, Nan Yu, Quantum Sci. Technol. 7, 044002 (2022)

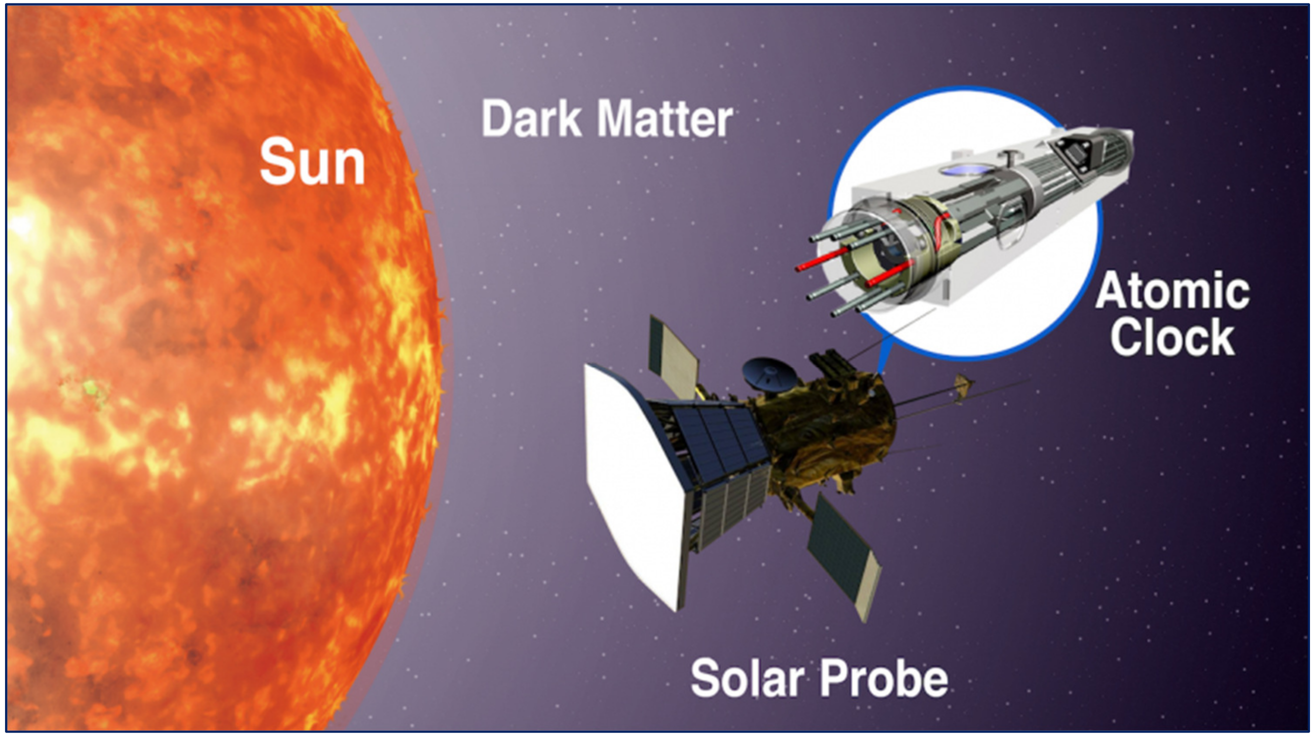
$$\frac{\Delta\nu}{\nu} = (1+\alpha)\frac{\Delta U}{c^2}$$

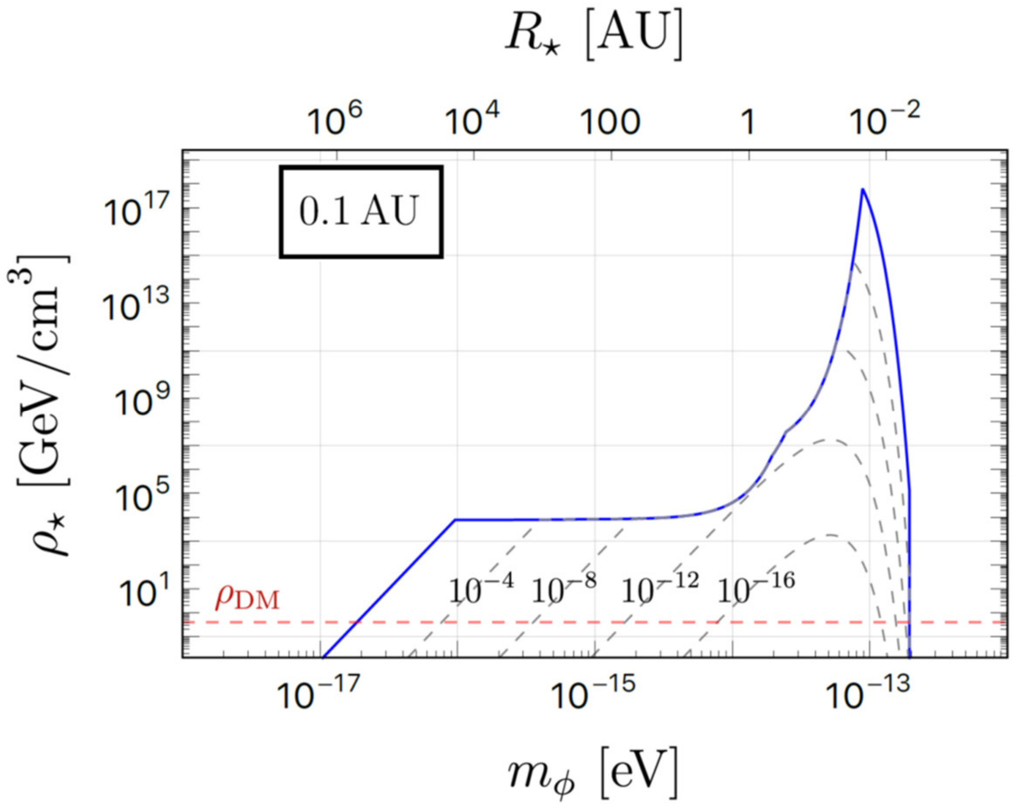


Test of general relativity sensitivity 30,000 times beyond current limits.

Schematic of the proposed mission to test Fundamental physics with an Optical Clock Orbiting in Space (FOCOS)

Direct detection of ultralight dark matter bound to the Sun with space quantum sensors





Yu-Dai Tsai, Joshua Eby, Marianna S. Safronova, Nature Astronomy, December 5 (2022)

Picture credit: Kavli IPMU

SEARCH FOR FAST-OSCILLATING FUNDAMENTAL CONSTANTS WITH SPACE MISSIONS

Dmitry Budker, Joshua Eby, Marianna S. Safronova, Oleg Tretiak, arXiv:2408.10324 (2024)

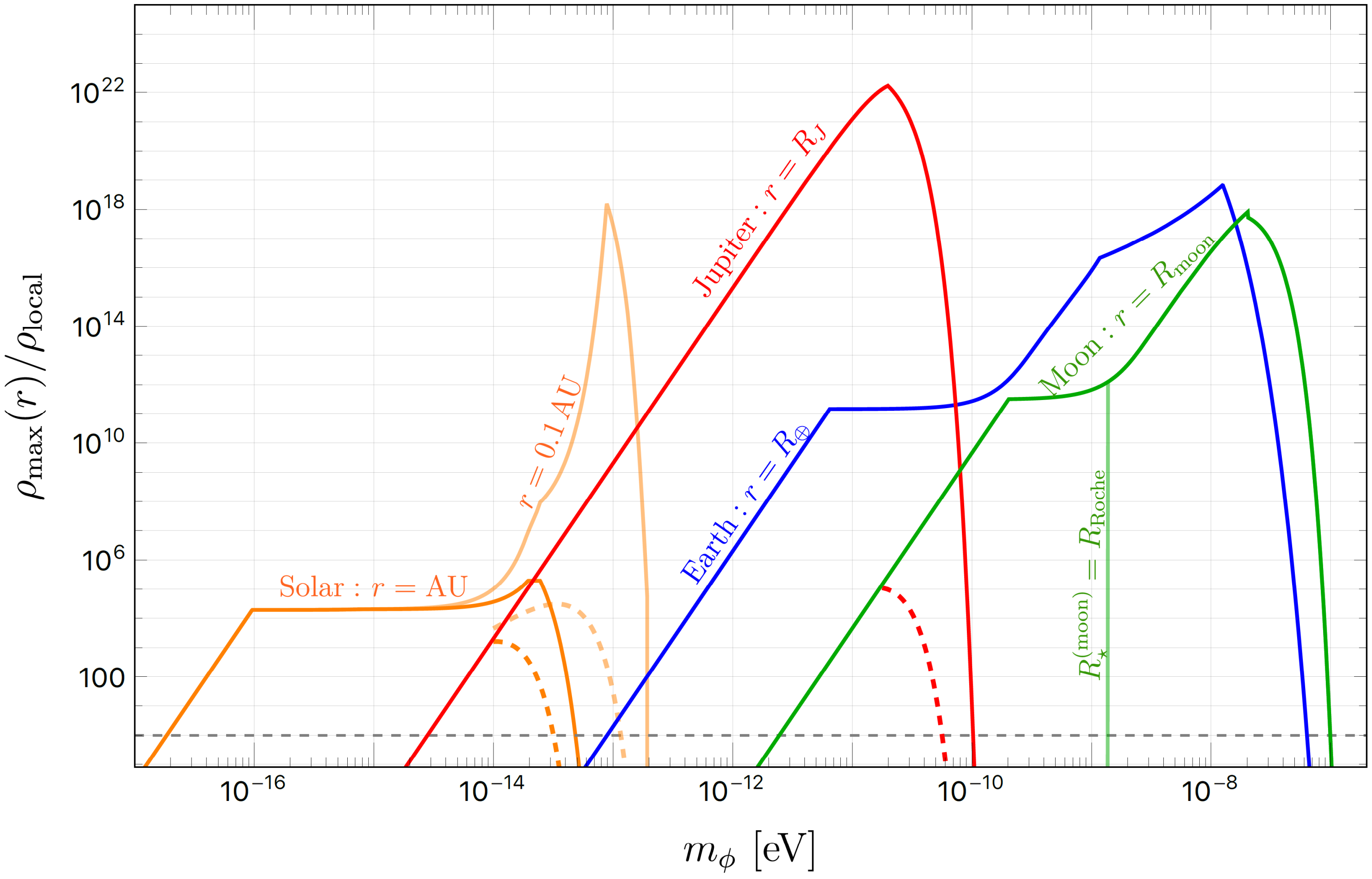


FIG. 1: Maximum gravitational atom density as a function of m_ϕ bound to the Sun (orange), Jupiter (red), Earth (blue) or moon (green). In each case the density is evaluated at a distance r from the center of the object as labeled. The dashed lines are the maximum density accumulated over 4.5 Gyr through the capture mechanism of [11].

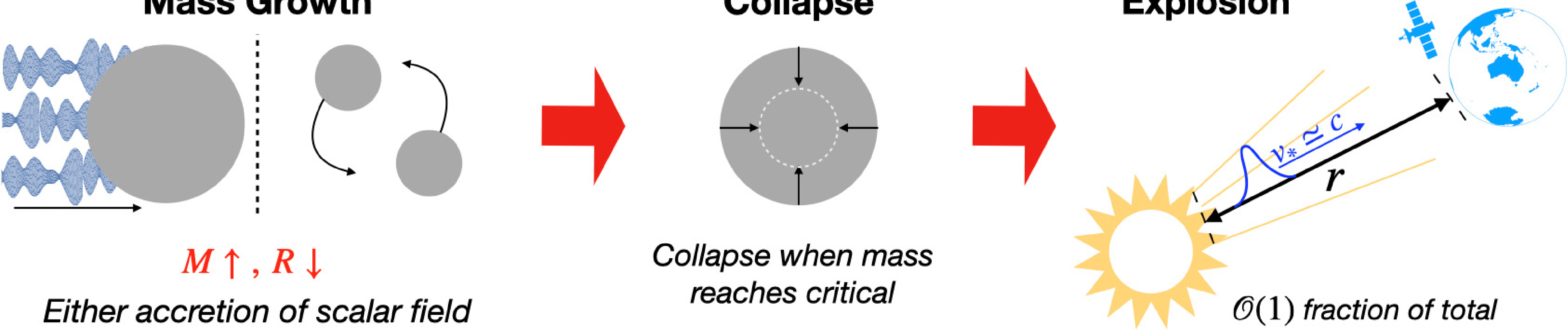
TRANSIENT DARK MATTER SIGNALS: BOSON STAR EXPLOSIONS AND BOSENOVA

1. Boson Star Mass Growth

2. Gravitational Collapse

3. Bosenova Explosion

Terrestrial & Space Searches



$M \uparrow, R \downarrow$

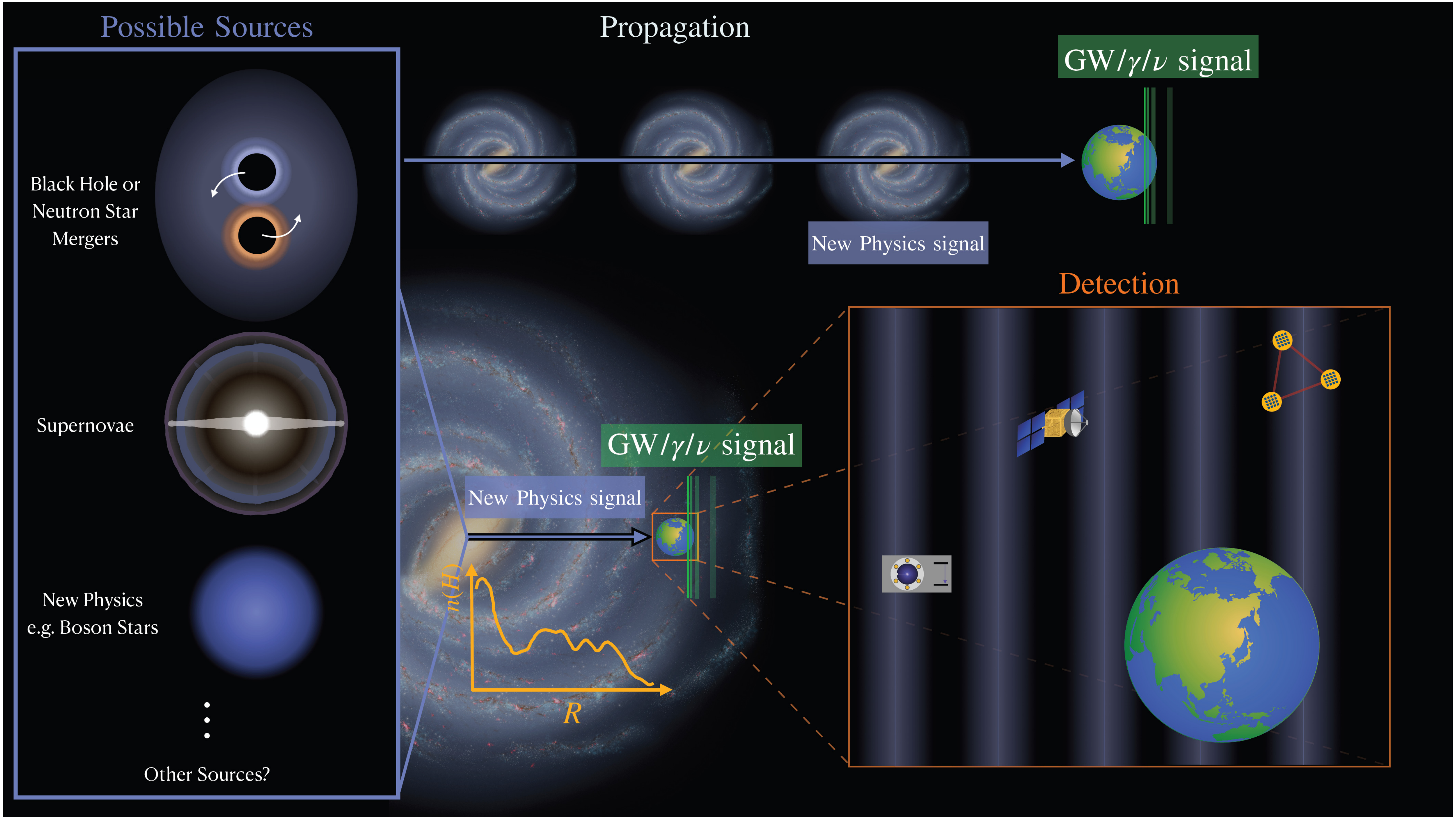
Either accretion of scalar field or merger events

Collapse when mass reaches critical

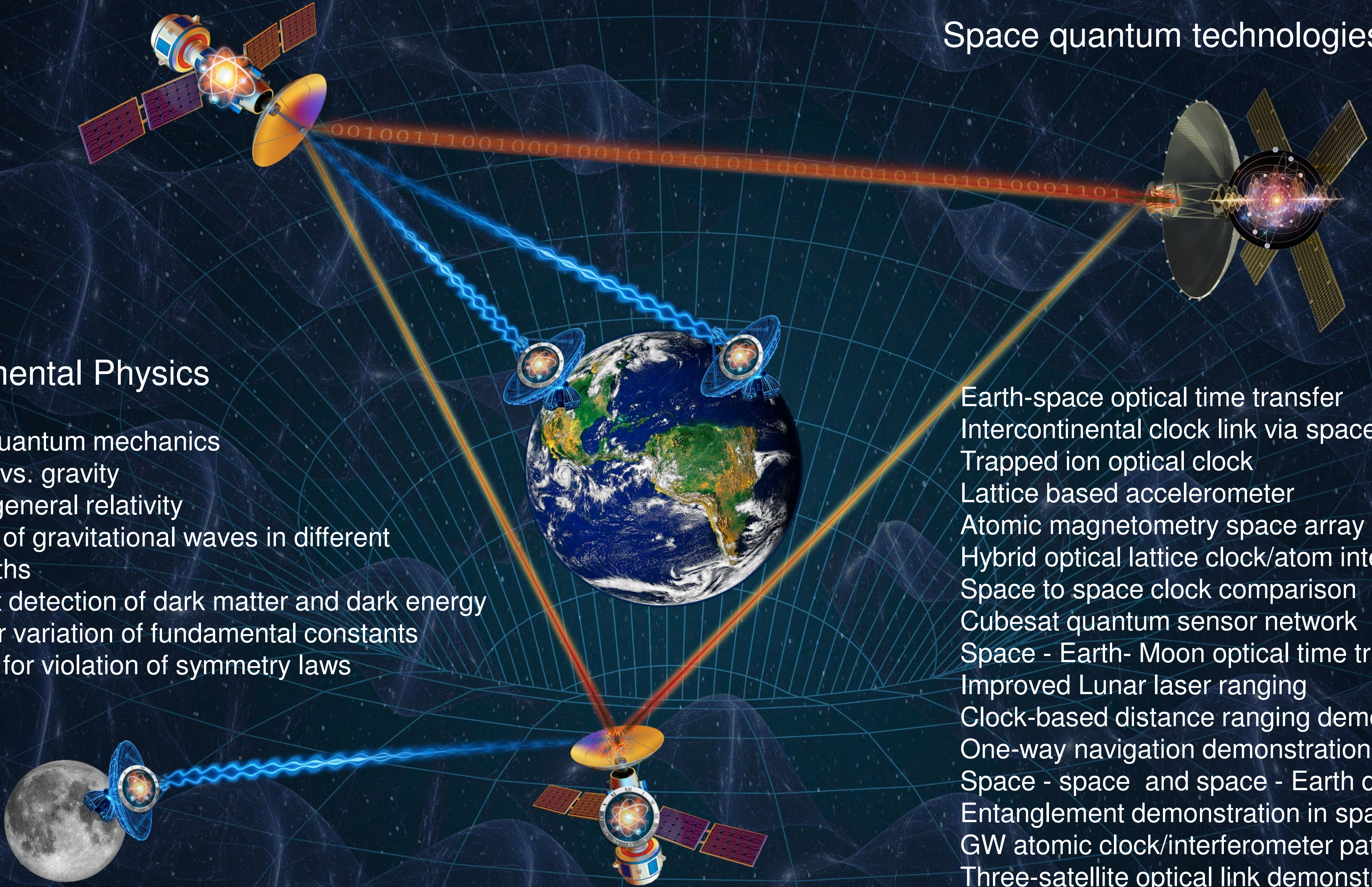
$M \simeq M_c$

$\mathcal{O}(1)$ *fraction of total boson star energy is emitted*

Detection of Relativistic Scalar Bursts with Quantum Sensors, Jason Arakawa, Joshua Eby, Marianna S. Safronova, Volodymyr Takhistov, and Muhammad H. Zaheer, Phys. Rev. D 110, 075007 (2024).


Possible Sources
Propagation
GW/γ/ν signal
Black Hole or Neutron Star Mergers
New Physics signal
Detection
Supernovae
GW/γ/ν signal
New Physics signal
$n(H)$
New Physics e.g. Boson Stars
R
Other Sources?

Space Network of Quantum Sensors



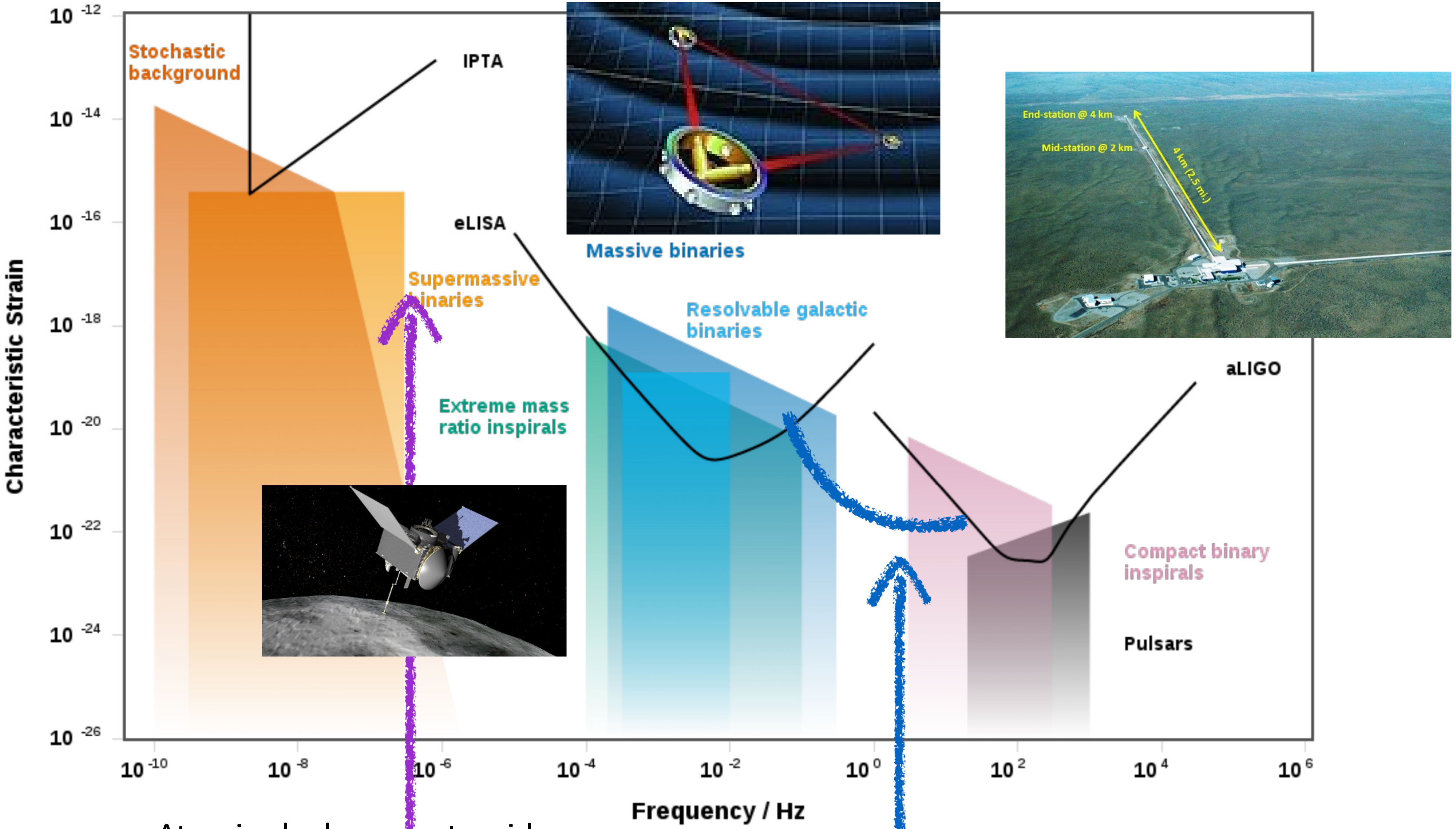
Fundamental Physics

Tests of quantum mechanics
Quantum vs. gravity
Tests of general relativity
Detection of gravitational waves in different wavelengths
The direct detection of dark matter and dark energy
Search for variation of fundamental constants
Searches for violation of symmetry laws

Space quantum technologies

Earth-space optical time transfer
Intercontinental clock link via space
Trapped ion optical clock
Lattice based accelerometer
Atomic magnetometry space array
Hybrid optical lattice clock/atom interferometry facility
Space to space clock comparison
Cubesat quantum sensor network
Space - Earth- Moon optical time transfer
Improved Lunar laser ranging
Clock-based distance ranging demonstration
One-way navigation demonstration
Space - space and space - Earth quantum communications
Entanglement demonstration in space
GW atomic clock/interferometer pathfinder
Three-satellite optical link demonstration for GW prototype

Figure is from Peter Graham's talk at KITP 2021: https://online.kitp.ucsb.edu/online/novel-oc21/



Atomic clocks on asteroids

PRD 105, 103018 (2022)

open band

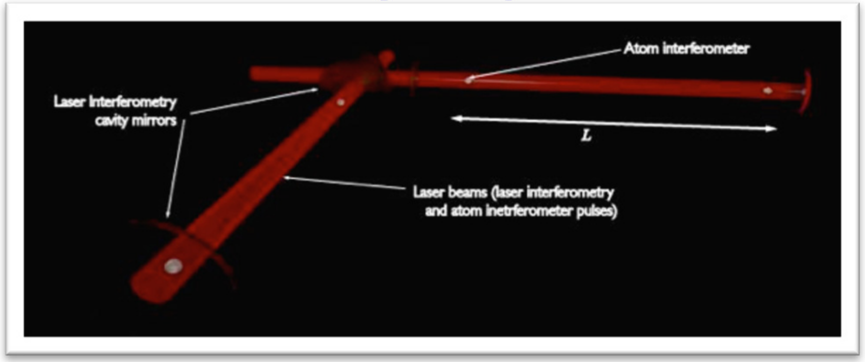
~ 10^{-7} Hz - 10^{-4} Hz

atoms (MAGIS, clocks, MIGA, AION...)

Atom interferometers: from 10 meters to 100 meters to 1km to space

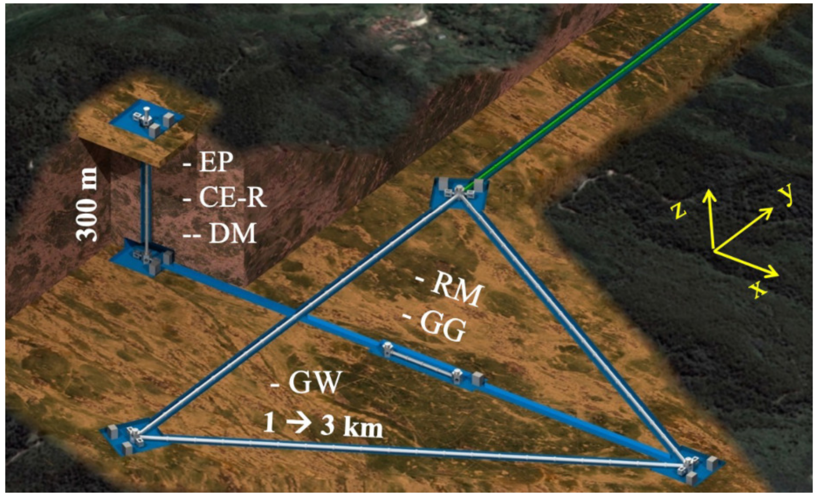
MIGA: Terrestrial detector using atom interferometer at O(100m)

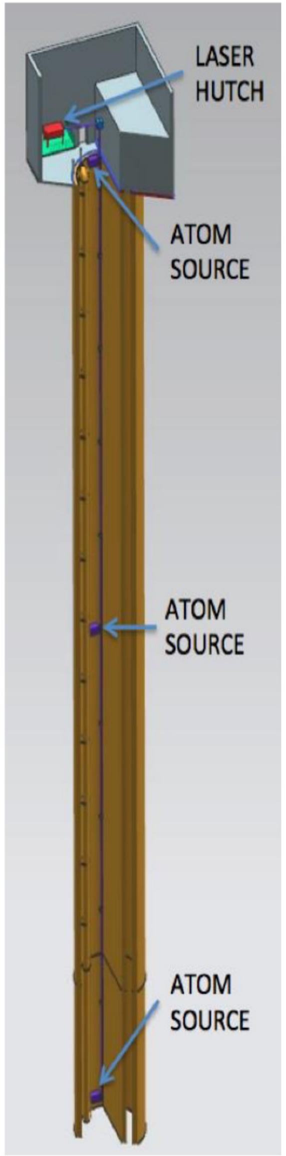
(France)



ZIGA: Terrestrial detector for large scale atomic interferometers, gyros and clocks at O(100m)

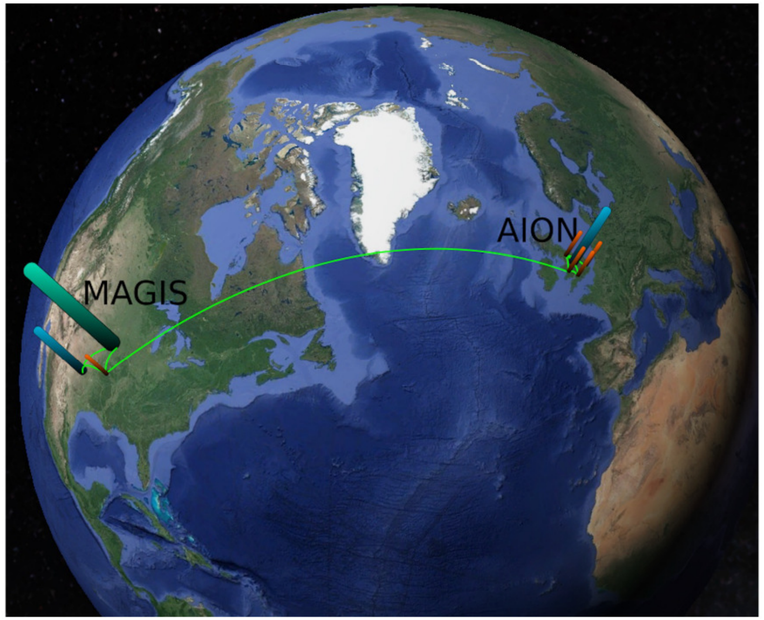
(China)





AION: Terrestrial shaft detector using atom interferometer at 10m – O(100m) planned

(UK)

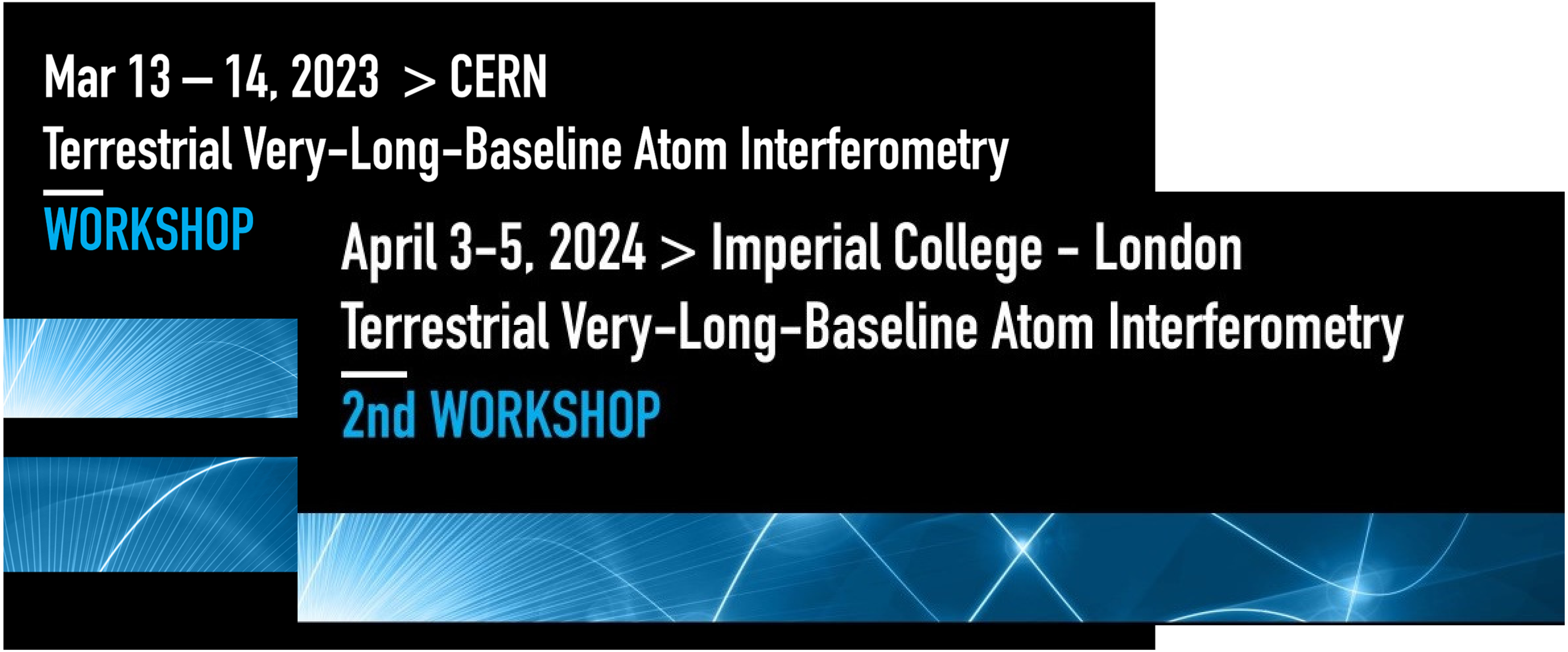


MAGIS: Terrestrial shaft detector using atom interferometer at O(100m)

(US)

Planned network operation

Figures are from : talk by Oliver Buchmueller, Community Workshop on Cold Atoms in Space,https://indico.cern.ch/event/1064855/timetable/



Mar 13 – 14, 2023 > CERN
Terrestrial Very-Long-Baseline Atom Interferometry
WORKSHOP

April 3-5, 2024 > Imperial College - London
Terrestrial Very-Long-Baseline Atom Interferometry
2nd WORKSHOP

https://indico.cern.ch/event/1208783, https://indico.cern.ch/event/1369392

Terrestrial Very-Long-Baseline Atom Interferometry: Workshop Summary, Sven Abend at al., AVS Quantum Sci. 6, 024701 (2024).

University of Delaware is member of the Proto collaboration for Terrestrial Very Long Baseline Atom Interferometer (TVLBAI) study. The main goals are to develop a Roadmap for the design and technology choices for one or several km-scale detectors to be ready for operation in the mid 2030s, which is supported by the cold atom community and the potential user communities interested in its science goals.

PUBLIC RELEASE OF OUR USER-FRIENDLY CODE PACKAGE:

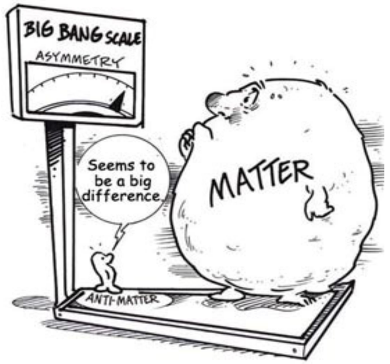
pCI: a parallel configuration interaction software package for high-precision atomic structure calculations, Charles Cheung, Mikhail G. Kozlov, Sergey G. Porsev, Marianna S. Safronova, Ilya I. Tupitsyn, Andrey I. Bondarev, submitted to Computer Physics Communications, arXiv:2410.06680 (2024).
Developer's repository link: https://github.com/ud-pci/pCI

Neural network optimization code will be released in 2025.

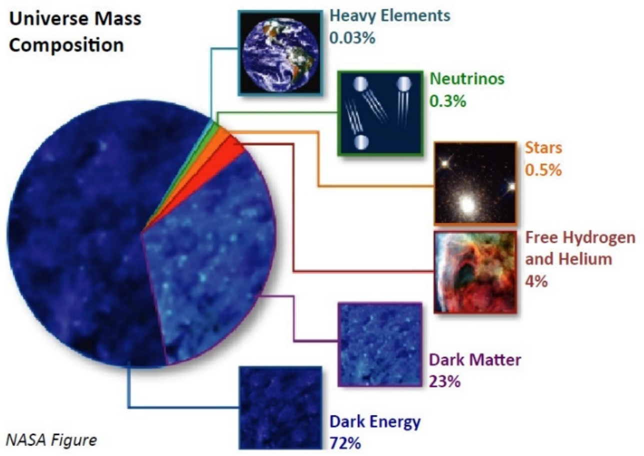
Atomic data portal: https://www.udel.edu/atom
Version 3 will be released shortly.

2024

SOLVING PHYSICS PROBLEMS OF 1924 GAVE US QUANTUM MECHANICS – A FOUNDATION OF MODERN TECHNOLOGY.



WHAT NEW WONDERS DISCOVERY OF NEW PHYSICS WILL BRING?



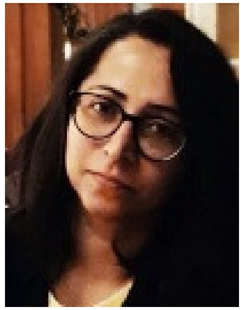
NASA Figure

2124

UD team and collaborators

Online portal team

Prof. Rudolf Eigenmann
UD (EECS)



Prof. Bindiya Arora
Guru Nanak Dev U., India

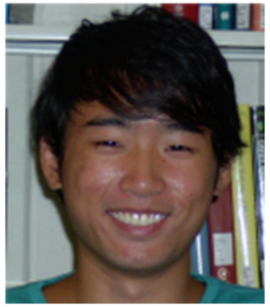
Parinaz Barakhshan
UD (CE)
Grad. St.

Adam Marrs
UD (Physics)
Graduated August 2021

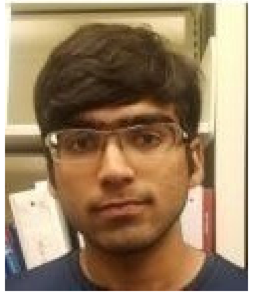
Akshay Bhosale
UD (CE)
Grad. St.

Dr. Sergey Porsev
Research Associate III

Dr. Dmytro Filin
Research Associate III



Dr. Charles Cheung
Postdoc



Hani Zaheer
Grad. St.

Jason Arakawa
Postdoc

Aung Naing
Graduated
August 2021

Collaborators:

ERC Synergy: Thorsten Schumm, TU Wein Ekkehard Peik, PTB, Peter Thirolf, LMU, Adriana Pálffy (FAU) Q-SEnSE: Jun Ye, Dave Leibrandt, Leo Hollberg, Nate Newbury

Particle physics: Josh Eby (IPMU, Tokyo), Volodymyr Takhistov (QUP, Tokyo), Gilad Perez' group (Weizmann Institute of Science, Israel), Yu-Dai Tsai (UC Irvine),

Dmitry Budker, Mainz and UC Berkeley, Andrew Jayich, UCSB, Murray Barrett, CQT, Singapore, José Crespo López-Urrutia, MPIK, Heidelberg , Piet Schmidt, PTB, University of Hannover, Nan Yu (JPL), Charles Clark, JQI, and many others!

Open postdoc position in Quantum Algorithms for New Physics Searches with Quantum Sensors