Benjamin M. Roberts – Publications

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Research Articles

[1] *R. B. Cserveny** and B. M. Roberts, *Theoretical characterisation of the Barium II and Radium II ions*, Physical Review A (Under Review) (2025), [arXiv:2505.05230]

Motivated by recent experimental advances, including the ongoing development of an optical atomic clock in singly ionised radium, we perform a detailed theoretical characterisation of Ra^{+} and its lighter analogue, Ba^{+}. Both ions are of interest for precision studies, including for atomic parity violation and searches for new physics beyond the standard model. Using the all-orders correlation potential method, including Breit and radiative quantum electrodynamics corrections, we perform high-accuracy calculations of electric-dipole (E1), electric-quadrupole (E2), and magnetic-dipole (M1) transition matrix elements between the low-lying s, p, and d states of these ions, as well as the excited-state lifetimes, polarizabilities, magic wavelengths, and magnetic dipole (A) hyperfine structure constants. By combining lifetime measurements with precise theoretical ratios, we extract high-accuracy determinations of the s-$d_{1/2}$ and s-$d_{3/2}$ E2 matrix elements. By combining hyperfine measurements with atomic theory, we extract parameters of the nuclear magnetisation distribution (the Bohr-Weisskopf effect) for ^{135,137}Ba and ^{223,225}Ra. These results provide theoretical input for ongoing and future experimental programs in fundamental physics and precision metrology.

[2] J. Vandeleur, G. Sanamyan, B. M. Roberts, and J. S. M. Ginges, *Hyperfine anomaly in mercury and test of the Moskowitz-Lombardi rule*, Physical Review A **111**, L050801 (2025), [arXiv:2411.09912]

We test the Moskowitz-Lombardi rule, originally formulated for mercury, which gives a simple relation between the magnetic moment of an atomic nucleus and the effect of its radial distribution on the hyperfine structure: the magnetic hyperfine anomaly or Bohr-Weisskopf (BW) effect. While the relation for the differential effect between isotopes may be completely determined experimentally, the value for the additive constant that is needed to give the BW effect for a single isotope has remained unverified. In this work, we determine the BW effect in H-like, singly ionized, and neutral mercury isotopes from experimental muonic-199Hg data together with differential anomalies and our atomic calculations. We check this result by directly extracting the BW effect from the measured hyperfine constant for 199Hg+ using state-of-the-art atomic many-body calculations. From this we deduce an empirical value for the additive constant in the Moskowitz-Lombardi rule, which differs significantly from the values advocated previously. This result allows for increased precision in calculations of the hyperfine structure and improved tests of atomic and nuclear theory.

- Featured on front page of Physical Review A website

[3] *J. C. Hasted*†, *C. J. Fairhall*†, O. R. Smits, B. M. Roberts, and J. S. M. Ginges, *Vacuum polarization corrections to hyperfine structure in many-electron atoms*, Physical Review A **111**, 032812 (2025), [arXiv:2409.17979]

We perform a theoretical study of vacuum polarization corrections to the hyperfine structure in many-electron atoms. Calculations are performed for systems of interest for precision atomic tests of fundamental physics belonging to the alkali-metal atoms and singly ionized alkaline earths. The vacuum polarization is considered in the Uehling approximation, and we study the many-body effects core relaxation, core polarization, and valence-core correlations in the relativistic framework. We find that for s states, the relative vacuum polarization correction may be well approximated by that for hydrogenlike ions, though for all other states an account of the many-body effects, in particular, the polarization of the core, is needed to obtain the correct sign and magnitude of the correction.

[4] M. Filzinger, *A. R. Caddell*†, *D. Jani**, M. Steinel, L. Giani, N. Huntemann, and B. M. Roberts, *Ultralight Dark Matter Search with Space-Time Separated Atomic Clocks and Cavities*, **Physical Review Letters 134**, 031001 (2025), [arXiv:2312.13723]

We devise and demonstrate a method to search for nongravitational couplings of ultralight dark matter to standard model particles using space-time separated atomic clocks and cavity-stabilized lasers. By making use of space-time separated sensors, which probe different values of an oscillating dark matter field, we can search for couplings that cancel in typical local experiments. This provides sensitivity to both the temporal and spatial fluctuations of the field. We demonstrate this method using existing data from a frequency comparison of lasers stabilized to two optical cavities connected via a 2220 km fiber link [Schioppo et al., Nat. Commun. 13, 212 (2022)], and from the atomic clocks on board the global positioning system satellites. Our analysis results in constraints on the coupling of scalar dark matter to electrons, d_{m_e}, for masses between 10^{-19} and $2\times10^{-15}\,\mathrm{eV}/c^2$. These are the first constraints on d_{m_e} alone in this mass range.

† My PhD students, * My honours/masters students

- Covered in *Cosmos*: *Atomic clocks and lasers could help find dark matter*, as well as *phys.org*, *scientias*, others

[5] *A. R. Caddell*†, V. V. Flambaum, and B. M. Roberts, *Accurate electron-recoil ionization factors for dark matter direct detection in xenon, krypton, and argon*, Physical Review D **108**, 083030 (2023), [arXiv:2305.05125]

While most scintillation-based dark matter experiments search for Weakly Interacting Massive Particles (WIMPs), a sub-GeV WIMP-like particle may also be detectable in these experiments. While dark matter of this type and scale would not leave appreciable nuclear recoil signals, it may instead induce ionization of atomic electrons. Accurate modelling of the atomic wavefunctions is key to investigating this possibility, with incorrect treatment leading to a large suppression in the atomic excitation factors. We have calculated these atomic factors for argon, krypton and xenon and present the tabulated results for use with a range of dark matter models. This is made possible by the separability of the atomic and dark matter form factor, allowing the atomic factors to be calculated for general couplings; we include tables for vector, scalar, pseudovector, and pseudoscalar electron couplings. Additionally, we calculate electron impact total ionization cross sections for xenon using the tabulated results as a test of accuracy. Lastly, we provide an example calculation of the event rate for dark matter scattering on electrons in XENON1T and show that these calculations depend heavily on how the low-energy response of the detector is modelled.

[6] B. M. Roberts, *C. J. Fairhall*†, and J. S. M. Ginges, *Electric dipole transition amplitudes for atoms and ions with one valence electron*, Physical Review A **107**, 052812 (2023), [arXiv:2211.11134]

Motivated by recent measurements for several alkali-metal atoms and alkali-metal-like ions, we perform a detailed study of electric dipole (E1) transition amplitudes in K, Ca$^+$, Rb, Sr$^+$, Cs, Ba$^+$, Fr, and Ra$^+$, which are of interest for studies of atomic parity violation, electric dipole moments, polarizabilities, and atomic clocks. Using the all-orders correlation potential method, we perform high-precision calculations of E1 transition amplitudes between low-lying s, p, and d states. We perform a robust error analysis, and compare our calculations to many amplitudes for which there are high-precision experimental determinations. We find excellent agreement, with deviations at the level of 0.1% or less. We also compare our results to other theoretical evaluations, and discuss the implications for uncertainty analyses of theoretical methods. Further, combining calculations of branching ratios with recent measurements, we extract high-precision experimental values for several E1 amplitudes of Ca$^+$, Sr$^+$, Cs, Fr, and Ra$^+$.

[7] R. Hamilton, B. M. Roberts, S. K. Scholten, C. Locke, A. N. Luiten, J. S. M. Ginges, and C. Perrella, *Experimental and theoretical study of dynamic polarizabilities in the $5S-5D_{5/2}$ clock transition in rubidium-87 and determination of electric dipole matrix elements*, Physical Review Applied **19**, 054059 (2023), [arXiv:2212.10743]

The interaction between light and an atom causes perturbations in the atom's energy levels, known as the light-shift. These light-shifts are a key source of inaccuracy in atomic clocks, and can also deteriorate their precision. We present a study of light-shifts and associated dynamic polarizabilities for a two-photon atomic clock based on the $5S_{1/2}$-$5D_{5/2}$ transition in rubidium-87 over the range 770 nm to 800 nm. We determine experimental and theoretical values for a magic wavelength in this range and the electric dipole (E1) matrix element for the $5P_{3/2}$-$5D_{5/2}$ transition. We find a magic wavelength of 776.179(5) nm (experimental) and 776.21 nm (theoretical) in the vicinity of the $5P_{3/2}$-$5D_{5/2}$ resonance, and the corresponding reduced E1 matrix element 1.80(6) ea_0 (experimental) and 1.96(15) ea_0 (theoretical). These values resolve a previous discrepancy between theory and experiment.

[8] *C. J. Fairhall*†, B. M. Roberts, and J. S. M. Ginges, *QED radiative corrections to electric dipole amplitudes in heavy atoms*, Physical Review A **107**, 022813 (2023), [arXiv:2212.11490]

We use the radiative potential method to perform a detailed study of quantum electrodynamics (QED) radiative corrections to electric dipole (E1) transition amplitudes in heavy alkali-metal atoms Rb, Cs, Fr, and alkali-metal-like ions Sr$^+$, Ba$^+$, and Ra$^+$. The validity of the method is checked by comparing with the results of rigorous QED in simple atomic potentials. We study the effects of core relaxation, polarization of the core by the E1 field, and valence-core correlations on QED, which are shown to be important in some cases. We identify several transitions for which the QED contribution exceeds the deviation between atomic theory and experiment.

[9] *G. Sanamyan**, B. M. Roberts, and J. S. M. Ginges, *Empirical Determination of the Bohr-Weisskopf Effect in Cesium and Improved Tests of Precision Atomic Theory in Searches for New Physics*, **Physical Review Letters 130**, 053001 (2023), [arXiv:2209.05099]

The finite distribution of the nuclear magnetic moment across the nucleus gives a contribution to the hyperfine structure known as the Bohr-Weisskopf (BW) effect. We have obtained an empirical value of -0.24(18)% for this effect in the ground and excited s states of atomic Cs-133. This value is found from historical muonic-atom measurements in combination with our muonic-atom and atomic many-body calculations. The effect differs by 0.5% in the hyperfine structure from the value found using the uniform magnetization distribution, which has been commonly employed in the precision heavy-atom community over the last several decades. We also deduce accurate values for the BW effect in other isotopes and states of cesium. These results enable cesium atomic wave functions to be tested in the nuclear region at an unprecedented 0.2% level, and are needed for the development of precision atomic many-body methods. This is important for increasing the discovery potential of precision atomic searches for new physics, in particular for atomic parity violation in cesium.

- Covered in *The Brisbane Times*: *'Unusual' atom helps search for dark matter – and a quicker car ride*, as well as *The Sydney Morning Herald*, *The Age*, and *WA Today*. Also featured in *phys.org* and others

[10] B. M. Roberts, *P. G. Ranclaud**, and J. S. M. Ginges, *Bohr-Weisskopf effect: From hydrogenlike-ion experiments to heavy-atom calculations of the hyperfine structure*, Physical Review A **105**, 052802 (2022), [arXiv:2111.12954]

In this paper we study the influence of electron screening on the Bohr-Weisskopf (BW) effect in many-electron atoms. The BW effect gives the finite-nucleus magnetization contribution to the hyperfine structure. Relativistic atomic many-body calculations are performed for s and $p_{1/2}$ states of several systems of interest for studies of atomic parity violation and time-reversal-violating electric dipole moments – Rb, Cs, Fr, Ba$^+$, Ra$^+$, and Tl. For s states, electron screening effects are small, and the relative BW correction for hydrogenlike ions and neutral atoms is approximately the same. We relate the ground-state BW effect in H-like ions, which may be cleanly extracted from experiments, to the BW effect in s and $p_{1/2}$ states of neutral and near neutral atoms through an electronic screening factor. This allows the BW effect extracted from measurements with H-like ions to be used, with screening factors, in atomic calculations without recourse to modelled nuclear structure input. It opens the way for unprecedented accuracy in accounting for the BW effect in heavy atoms. The efficacy of this approach is demonstrated using available experimental data for H-like and neutral Tl-203 and Tl-205.

[11] B. M. Roberts and J. S. M. Ginges, *Comment on "New physics constraints from atomic parity violation in ^{133}Cs"*, Physical Review D **105**, 018301 (2022), [arXiv:2110.11621]

In a recent Letter [B. K. Sahoo, B. P. Das, and H. Spiesberger, Phys. Rev. D 103, L111303 (2021)], a calculation of the parity violating 6S-7S E1 amplitude in Cs is reported, claiming an uncertainty of just 0.3%. In this Comment, we point out that key contributions have been omitted, and the theoretical uncertainty has been significantly underestimated. In particular, the contribution of missed QED radiative corrections amounts to several times the claimed uncertainty.

[12] B. M. Roberts and J. S. M. Ginges, *Hyperfine anomaly in heavy atoms and its role in precision atomic searches for new physics*, Physical Review A **104**, 022823 (2021), [arXiv:2101.09924]

We report on our calculations of differential hyperfine anomalies in the nuclear single-particle model for a number of atoms and ions of interest for studies of fundamental symmetries violations. Comparison with available experimental data allows one to discriminate between different nuclear magnetization models, and this data supports the use of the nuclear single-particle model over the commonly-used uniform ball model. Accurate modelling of the nuclear magnetization distribution is important for testing atomic theory through hyperfine comparisons. The magnetization distribution must be adequately understood and modelled, with uncertainties well under the atomic theory uncertainty, for hyperfine comparisons to be meaningful. This has not been the case for a number of atoms of particular interest for precision studies, including Cs. Our work demonstrates the validity of the nuclear single-particle model for Cs, and this has implications for the theory analysis of atomic parity violation in this atom.

[13] E. Savalle, A. Hees, F. Frank, E. Cantin, P.-E. Pottie, B. M. Roberts, L. Cros, B. T. McAllister, and P. Wolf, *Searching for Dark Matter with an Optical Cavity and an Unequal-Delay Interferometer*, **Physical Review Letters 126**, 051301 (2021), [arXiv:2006.07055]

We report an experiment that compares the frequency of a clock (an ultra-stable optical cavity in this case) at time t to its own frequency some time $t-T$ earlier, by "storing" the output signal (photons) in a fibre delay line. In ultra-light oscillating dark matter (DM) models such an experiment is sensitive to coupling of DM to the standard model fields, through oscillations of the cavity and fibre lengths and of the fibre refractive index. Additionally, the sensitivity is significantly enhanced around the mechanical resonances of the cavity. We report no evidence of DM for masses in the $[4.1\times10^{-11}, 8.3\times10^{-10}]$ eV region. In addition, we improve constraints on the involved coupling constants by one order of magnitude in a standard galactic DM model, at the mass corresponding to the resonant frequency of our cavity. In a recently proposed model of a DM relaxation halo around the Earth we improve on existing constraints over the whole DM mass range, by up to 6 orders of magnitude.

[14] B. M. Roberts and A. Derevianko, *Precision Measurement Noise Asymmetry and Its Annual Modulation as a Dark Matter Signature*, Universe **7**, 50 (2021), [arXiv:1803.00617]

Dark matter may be composed of self-interacting ultralight quantum fields that form macroscopic objects. An example of which includes Q-balls, compact non-topological solitons predicted by a range of theories that are viable dark matter candidates. As the Earth moves through the galaxy, interactions with such objects may leave transient perturbations in terrestrial experiments. Here we propose a new dark matter signature: an asymmetry (and other non-Gaussianities) that may thereby be induced in the noise distributions of precision quantum sensors, such as atomic clocks, magnetometers, and interferometers. Further, we demonstrate that there would be a sizeable annual modulation in these signatures due to the annual variation of the Earth velocity with respect to dark matter halo. As an illustration of our formalism, we apply our method to 6 years of data from the atomic clocks on board GPS satellites and place constraints on couplings for macroscopic dark matter objects with radii R $<$ 104 km, the region that is otherwise inaccessible using relatively sparse global networks.

[15] B. M. Roberts and J. S. M. Ginges, *Nuclear Magnetic Moments of Francium-207–213 from Precision Hyperfine Comparisons*, **Physical Review Letters 125**, 063002 (2020), [arXiv:2001.01907]

We report a fourfold improvement in the determination of nuclear magnetic moments for neutron-deficient isotopes of francium-207–213, reducing the uncertainties from 2% for most isotopes to 0.5%. These are found by comparing our high-precision calculations of hyperfine structure constants for the ground states with experimental values. In particular, we show the importance of a careful modeling of the Bohr-Weisskopf effect, which arises due to the finite nuclear magnetization distribution. This effect is particularly large in Fr and until now has not been modeled with sufficiently high accuracy. An improved understanding of the nuclear magnetic moments and Bohr-Weisskopf effect are crucial for benchmarking the atomic theory required in precision tests of the standard model, in particular atomic parity violation studies, that are underway in francium.

- Featured in phys.org: *Improved modelling of nuclear structure in francium aids searches for new physics*

[16] A. Hees, T. Do, B. M. Roberts, A. M. Ghez, S. Nishiyama, R. O. Bentley, A. K. Gautam, S. Jia, T. Kara, J. R. Lu, H. Saida, S. Sakai, M. Takahashi, and Y. Takamori, *Search for a Variation of the Fine Structure Constant around the Supermassive Black Hole in Our Galactic Center*, **Physical Review Letters 124**, 081101 (2020), [arXiv:2002.11567]

Searching for space-time variations of the constants of Nature is a promising way to search for new physics beyond General Relativity and the standard model motivated by unification theories and models of dark matter and dark energy. We propose a new way to search for a variation of the fine-structure constant using measurements of late-type evolved giant stars from the S-star cluster orbiting the supermassive black hole in our Galactic Center. A measurement of the difference between distinct absorption lines (with different sensitivity to the fine structure constant) from a star leads to a direct estimate of a variation of the fine structure constant between the star's location and Earth. Using spectroscopic measurements of 5 stars, we obtain a constraint on the relative variation of the fine structure constant below 10^{-5}. This is the first time a varying constant of Nature is searched for around a black hole and in a high gravitational potential. This analysis shows new ways the monitoring of stars in the Galactic Center can be used to probe fundamental physics.

- Editors' Suggestion; featured on front-page of PRL website
- Featured in APS Physics Synopsis [*Constants Still Constant Near Black Holes*]
- Covered in: Spektrum (DE), Science News, and several other outlets
- Co-authored with Prof. Andrea Ghez, 2020 Physics Nobel Prize winner

[17] B. M. Roberts, P. Delva, A. Al-Masoudi, A. Amy-Klein, C. Bærentsen, C. F. A. Baynham, E. Benkler, S. Bilicki, S. Bize, W. Bowden, J. Calvert, V. Cambier, E. Cantin, E. A. Curtis, S. Dörscher, M. Favier, F. Frank, P. Gill, R. M. Godun, G. Grosche, C. Guo, A. Hees, I. R. Hill, R. Hobson, N. Huntemann, J. Kronjäger, S. Koke, A. Kuhl, R. Lange, T. Legero, B. Lipphardt, C. Lisdat, J. Lodewyck, O. Lopez, H. S. Margolis, H. Álvarez-Martínez, F. Meynadier, F. Ozimek, E. Peik, P.-E. Pottie, N. Quintin, C. Sanner, L. De Sarlo, M. Schioppo, R. Schwarz, A. Silva, U. Sterr, C. Tamm, R. Le Targat, P. Tuckey, G. Vallet, T. Waterholter, D. Xu, and P. Wolf, *Search for transient variations of the fine structure constant and dark matter using fiber-linked optical atomic clocks*, New Journal of Physics **22**, 093010 (2020), [arXiv:1907.02661]

We search for transient variations of the fine structure constant using data from a European network of fiber-linked optical atomic clocks. By searching for coherent variations in the recorded clock frequency comparisons across the network, we significantly improve the constraints on transient variations of the fine structure constant. For example, we constrain the variation in alpha to $< 5\times10^{-17}$ for transients of duration 10^3 s. This analysis also presents a possibility to search for dark matter, the mysterious substance hypothesised to explain galaxy dynamics and other astrophysical phenomena that is thought to dominate the matter density of the universe. At the current sensitivity level, we find no evidence for dark matter in the form of topological defects (or, more generally, any macroscopic objects), and we thus place constraints on certain potential couplings between the dark matter and standard model particles, substantially improving upon the existing constraints, particularly for large ($\gtrsim 10^4$ km) objects.

- Featured Article (chosen by the editors for "novelty, significance and potential impact")

[18] G. Panelli, B. M. Roberts, and A. Derevianko, *Applying the matched-filter technique to the search for dark matter transients with networks of quantum sensors*, EPJ Quantum Technology **7**, 5 (2020), [arXiv:1908.03320]

There are several networks of precision sensors in existence, including networks of atomic clocks, magnetometers, and gravitational wave detectors. These networks can be re-purposed for searches of exotic physics, such as direct dark matter searches. Here we explore a detection strategy for macroscopic dark matter objects with such networks using the matched-filter technique. Such "clumpy" dark matter objects would register as transients sweeping through the network at galactic velocities. As a specific example, we consider a network of atomic clocks aboard the Global Positioning System (GPS) satellites. We apply the matched-filter technique to simulated GPS atomic clock data and study its utility and performance. The analysis and the developed methodology have a wide applicability to other networks of quantum sensors.

[19] S. J. Grunefeld, B. M. Roberts, and J. S. M. Ginges, *Correlation trends in the hyperfine structure for Rb, Cs, and Fr, and high-accuracy predictions for hyperfine constants*, Physical Review A **100**, 042506 (2019), [arXiv:1907.02657]

We have performed high-precision calculations of the hyperfine structure for ${}^2S_{1/2}$ and ${}^2P_{1/2}$ states of the alkali-metal atoms Rb, Cs, and Fr across principal quantum number n, and studied the trend in the size of the correlations. Our calculations were performed in the all-orders correlation potential method. We demonstrate that the relative correlation corrections fall off quickly with n and tend towards constant and non-zero values for highly-excited states. This trend is supported by experiment, and we utilize the smooth dependence on n to make high-accuracy predictions of the hyperfine constants, with uncertainties to within 0.1% for most states of Rb and Cs.

[20] E. Savalle, B. M. Roberts, F. Frank, P.-E. Pottie, B. T. McAllister, C. Dailey, A. Derevianko, and P. Wolf, *Novel approaches to dark-matter detection using space-time separated clocks*, arXiv preprint (2019), [arXiv:1902.07192]

We discuss the theoretical analysis and interpretation of space-time separated clock experiments in the context of a space-time varying scalar field that is non-universally coupled to the standard model fields. If massive, such a field is a candidate for dark matter and could be detected in laboratory experiments. We show that space-time separated experiments have the potential to probe a fundamentally different parameter space from more common co-located experiments, allowing decorrelation of previously necessarily correlated parameters. Finally, we describe such a space-time separated clock experiment currently running at the Paris Observatory, and present some preliminary results as a proof of principle.

[21] B. M. Roberts and V. V. Flambaum, *Electron-interacting dark matter: Implications from DAMA/LIBRA-phase2 and prospects for liquid xenon detectors and NaI detectors*, Physical Review D **100**, 063017 (2019), [arXiv:1904.07127]

We investigate the possibility for the direct detection of low mass (GeV scale) WIMP dark matter in scintillation experiments. Such WIMPs are typically too light to leave appreciable nuclear recoils, but may be detected via their scattering off atomic electrons. In particular, the DAMA Collaboration [R. Bernabei et al., Nucl. Phys. At. Energy 19, 307 (2018)] has recently presented strong evidence of an annual modulation in the scintillation rate observed at energies as low as 1 keV. Despite *a strong enhancement in the calculated event rate at low energies, we find that an interpretation in terms of electron-interacting WIMPs cannot be consistent with existing constraints. We also demonstrate the importance of correct treatment of the atomic wavefunctions, and show the resulting event rate is very sensitive to the low-energy performance of the detectors, meaning it is crucial that the detector uncertainties be taken into account. Finally, we demonstrate that the potential scintillation event rate can be much larger than may otherwise be expected, meaning that competitive searches can be performed for m_χ ~ 1 GeV scale WIMPs using the conventional prompt (S1) scintillation signals. This is important given the recent and upcoming very large liquid xenon detectors.*

[22] V. A. Dzuba, V. V. Flambaum, and B. M. Roberts, *Calculations of the atomic structure for the low-lying states of actinium*, Physical Review A **100**, 022504 (2019), [arXiv:1905.02365]

We employ a technique that combines the configuration interaction method with the singles-doubles coupled-cluster method to perform calculation of the energy levels, transition amplitudes, lifetimes, g-factors, and magnetic dipole and electric quadrupole hyperfine structure constants for many low-lying states of neutral actinium. We find very good agreement with existing experimental energy levels and make accurate predictions for missing levels. It has been noted that some of the levels have been previously misidentified; our analysis supports this claim. If spectroscopy is performed with actinium-225, our calculations will lead to values for nuclear structure constants. The accuracy of this can be constrained by comparing with actinium-227.

[23] B. M. Roberts, G. Blewitt, *C. Dailey**, and A. Derevianko, *Search for transient ultralight dark matter signatures with networks of precision measurement devices using a Bayesian statistics method*, Physical Review D **97**, 083009 (2018), [arXiv:1803.10264]

We analyze the prospects of employing a distributed global network of precision measurement devices as a dark matter and exotic physics observatory. In particular, we consider the atomic clocks of the Global Positioning System (GPS), consisting of a constellation of 32 medium-Earth orbit satellites equipped with either Cs or Rb microwave clocks and a number of Earth-based receiver stations, some of which employ highly-stable H-maser atomic clocks. High-accuracy timing data is available for almost two decades. By analyzing the satellite and terrestrial atomic clock data, it is possible to search for transient signatures of exotic physics, such as "clumpy" dark matter and dark energy, effectively transforming the GPS constellation into a 50,000km aperture sensor array. Here we characterize the noise of the GPS satellite atomic clocks, describe the search method based on Bayesian statistics, and test the method using simulated clock data. We present the projected discovery reach using our method, and demonstrate that it can surpass the existing constrains by several order of magnitude for certain models. Our method is not limited in scope to GPS or atomic clock networks, and can also be applied to other networks of precision measurement devices.

[24] B. M. Roberts, G. Blewitt, *C. Dailey**, M. Murphy, M. Pospelov, A. Rollings, J. Sherman, *W. Williams**, and A. Derevianko, *Search for domain wall dark matter with atomic clocks on board global positioning system satellites*, **Nature Communications 8**, 1195 (2017), [arXiv:1704.06844]

Cosmological observations indicate that 85% of all matter in the Universe is dark matter (DM), yet its microscopic composition remains a mystery. One hypothesis is that DM arises from ultralight quantum fields that form macroscopic objects such as topological defects. Here we use GPS as a ~ 50,000 km aperture DM detector to search for such defects in the form of domain walls. GPS navigation relies on precision timing signals furnished by atomic clocks hosted on board GPS satellites. As the Earth moves through the galactic DM halo, interactions with topological defects could cause atomic clock glitches that propagate through the GPS satellite constellation at galactic velocities ~ 300 km/s. Mining 16 years of archival GPS data, we find no evidence for DM in the form of domain walls at our current sensitivity level. This allows us to improve the limits on certain quadratic scalar couplings of domain wall DM to standard model particles by several orders of magnitude.

- Covered in Science [doi: 10.1126/science.aal0676], and Eos (AGU) [doi: 10.1029/2018EO104623]
- Also covered in Quanta, NBC News, Cosmos Magazine, MIT Tech. Review, and others

[25] V. V. Flambaum, B. M. Roberts, and Y. V. Stadnik, *Comment on "Axion induced oscillating electric dipole moments"*, Physical Review D **95**, 058701 (2017), [arXiv:1507.05265]

In the recent work [Phys. Rev. D 91, 111702(R) (2015)], it is claimed that the axion electromagnetic anomaly induces an oscillating electron electric dipole moment of frequency m_a and strength $\sim 10^{-32}\,e$ cm, in the limit $v/c \to 0$ for the axion field. Here, we demonstrate that a proper treatment of this problem in the lowest order yields no electric dipole moment of the electron in the same limit.

[26] B. M. Roberts, V. V. Flambaum, and G. F. Gribakin, *Reply to 'Comment on: Ionization of Atoms by Slow Heavy Particles, Including Dark Matter'*, **Physical Review Letters 117**, 089302 (2016)

[27] B. M. Roberts, V. A. Dzuba, V. V. Flambaum, M. Pospelov, and Y. V. Stadnik, *Dark matter scattering on electrons: Accurate calculations of atomic excitations and implications for the DAMA signal*, Physical Review D **93**, 115037 (2016), [arXiv:1604.04559]

We revisit the WIMP-type dark matter scattering on electrons that results in atomic ionization, and can manifest itself in a variety of existing direct-detection experiments. Unlike the WIMP-nucleon scattering, where current experiments probe typical interaction strengths much smaller than the Fermi constant, the scattering on electrons requires a much stronger interaction to be detectable, which in turn requires new light force carriers. We account for such new forces explicitly, by introducing a mediator particle with scalar or vector couplings to dark matter and to electrons. We then perform state of the art numerical calculations of atomic ionization relevant to the existing experiments. Our goals are to consistently take into account the atomic physics aspect of the problem (e.g., the relativistic effects, which can be quite significant), and to scan the parameter space: the dark matter mass, the mediator mass, and the effective coupling strength, to see if there is any *part of the parameter space that could potentially explain the DAMA modulation signal. While we find that the modulation fraction of all events with energy deposition above 2 keV in NaI can be quite significant, reaching $\sim$ 50%, the relevant parts of the parameter space are excluded by the XENON10 and XENON100 experiments.*

[28] B. M. Roberts, V. V. Flambaum, and G. F. Gribakin, *Ionization of Atoms by Slow Heavy Particles, Including Dark Matter*, **Physical Review Letters 116**, 023201 (2016), [arXiv:1509.09044]

Atoms and molecules can become ionized during the scattering of a slow, heavy particle off a bound electron. Such an interaction involving leptophilic weakly interacting massive particles (WIMPs) is a promising possible explanation for the anomalous 9σ annual modulation in the DAMA dark matter direct detection experiment [R. Bernabei et al., Eur. Phys. J. C 73, 2648 (2013)]. We demonstrate the applicability of the Born approximation for such an interaction by showing its equivalence to the semiclassical adiabatic treatment of atomic ionization by slow-moving WIMPs. Conventional wisdom has it that the ionization probability for such a process should be exponentially small. We show, however, that due to nonanalytic, cusp-like behaviour of Coulomb functions close to the nucleus this suppression is removed, leading to an effective atomic structure enhancement. Crucially, we also show that electron relativistic effects actually give the dominant contribution to such a process, enhancing the differential cross section by up to 1000 times.

[29] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Parity and Time-Reversal Violation in Atomic Systems*, **Annual Review of Nuclear and Particle Science 65**, 63 (2015), [arXiv:1412.6644]

Studying the violation of parity and time-reversal invariance in atomic systems has proven to be a very effective means for testing the electroweak theory at low energy and searching for physics beyond it. Recent developments in both atomic theory and experimental methods have led to the ability to make extremely precise theoretical calculations and experimental measurements of these effects. Such studies are complementary to direct high-energy searches, and can be performed for just a fraction of the cost. We review the recent progress in the field of parity and time-reversal violation in atoms, molecules, and nuclei, and examine the implications for physics beyond the Standard Model, with an emphasis on possible areas for development in the near future.

[30] B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer, and D. Budker, *Parity-violating interactions of cosmic fields with atoms, molecules, and nuclei: Concepts and calculations for laboratory searches and extracting limits*, Physical Review D **90**, 096005 (2014), [arXiv:1409.2564]

We propose methods and present calculations that can be used to search for evidence of cosmic fields by investigating the parity-violating effects, including parity nonconservation amplitudes and electric dipole moments, that they induce in atoms. The results are used to constrain important fundamental parameters describing the strength of the interaction of various cosmic fields with electrons, protons, and neutrons. Candidates for such fields are dark matter (including axions) and dark energy, as well as several more exotic sources described by standard-model extensions. Existing parity nonconservation experiments in Cs, Dy, Yb, and Tl are combined with our calculations to directly place limits on the interaction strength between the temporal component, b_0, of a static pseudovector cosmic field and the atomic electrons, with the most stringent limit of $|b_0^e| < 7\times10^{-15}$ GeV, in the laboratory frame of reference, coming from Dy. From a measurement of the nuclear anapole moment of Cs, and a limit on its value for Tl, we also extract limits on the interaction strength between the temporal component of this cosmic field, as well as a related tensor cosmic-field component d_{00}, with protons and neutrons. The most stringent limits of $|b_0^p| < 4\times10^{-8}$ GeV and $|d_{00}^p| < 5\times10^{-8}$ for protons, and $|b_0^n| < 2\times10^{-7}$ GeV and $|d_{00}^n| < 2\times10^{-7}$ for neutrons (in the laboratory frame) come from the results using Cs. Axions may induce oscillating P- and T-violating effects in atoms and molecules through the generation of oscillating nuclear magnetic quadrupole and Schiff moments, which arise from P- and T-odd intranuclear forces and from the electric dipole moments of constituent nucleons. Nuclear-spin-independent parity nonconservation effects may be enhanced in diatomic molecules possessing close pairs of opposite-parity levels in the presence of time-dependent interactions.

- Editors' Suggestion; featured on front-page of PRD website
- Covered in *Physics Today* [doi: 10.1063/PT.3.2896]

[31] Y. V. Stadnik, B. M. Roberts, and V. V. Flambaum, *Tests of CPT and Lorentz symmetry from muon anomalous magnetic dipole moment*, Physical Review D **90**, 045035 (2014), [arXiv:1407.5728]

We derive the relativistic factor for splitting of the g-factors of a fermion and its anti-fermion partner, which is important for placing constraints on dimension-5, CPT-odd and Lorentz-invariance-violating interactions from experiments performed in a cyclotron. From existing data, we extract limits (1σ) on the coupling strengths of the temporal component, f^0, of a background field (including the field amplitude), which is responsible for such g-factor splitting, with an electron, proton, and muon: $|f_e^0| < 2.3\times10^{-12}\ \mu_B$, $|f_p^0| < 4\times10^{-9}\ \mu_B$, and $|f_\mu^0| < 8\times10^{-11}\ \mu_B$, respectively, in the laboratory frame. From existing data, we also extract limits on the coupling strengths of the spatial components, $d^\perp$, of related dimension-5 interactions of a background field with an electron, proton, neutron, and muon: $|d_e^\perp| \lesssim 10^{-9}\ \mu_B$, $|d_p^\perp| \lesssim 10^{-9}\ \mu_B$, $|d_n^\perp| \lesssim 10^{-10}\ \mu_B$, and $|d_\mu^\perp| \lesssim 10^{-9}\ \mu_B$, respectively, in the laboratory frame.

[32] B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer, and D. Budker, *Limiting P-Odd Interactions of Cosmic Fields with Electrons, Protons, and Neutrons*, **Physical Review Letters 113**, 081601 (2014), [arXiv:1404.2723]

We propose methods for extracting limits on the strength of P-odd interactions of pseudoscalar and pseudovector cosmic fields with electrons, protons and neutrons. Candidates for such fields are dark matter (including axions) and dark energy, as well as several more exotic sources described by standard-model extensions. Calculations of parity nonconserving amplitudes and atomic electric dipole moments induced by these fields are performed for H, Li, Na, K, Rb, Cs, Ba^+, Tl, Dy, Fr, and Ra+. From these calculations and existing measurements in Dy, Cs and Tl, we constrain the interaction strengths of the parity-violating static pseudovector cosmic field to be 7×10^{-15} GeV with an electron, and 3×10^{-8} GeV with a proton.

[33] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Strongly enhanced atomic parity violation due to close levels of opposite parity*, Physical Review A **89**, 042509 (2014), [arXiv:1401.6262]

We present calculations of nuclear-spin-dependent and nuclear-spin-independent parity-violating amplitudes in Ba, Ra, Ac+, Th, and Pa. Parity nonconservation in these systems is greatly enhanced due to the presence of very close electronic energy levels of opposite parity, large nuclear charge, and strong nuclear enhancement of parity-violating effects. The presented amplitudes constitute several of the largest atomic parity-violating signals predicted so far. Experiments using these systems may be performed to determine values for the nuclear anapole moment, a P-odd T-even nuclear moment given rise to by parity-violating nuclear forces. Such measurements may prove to be valuable tools in the study of parity violation in the hadron sector. The considered spin- independent transitions could also be used to measure the ratio of weak charges for different isotopes of the same atom, the results of which would serve as a test of the standard model and also of neutron distributions. Barium, with seven stable isotopes, is particularly promising in this regard.

[34] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Nuclear-spin-dependent parity nonconservation in s-$d_{5/2}$ and s-$d_{3/2}$ transitions*, Physical Review A **89**, 012502 (2014), [arXiv:1311.2373]

We perform calculations of s-$d_{5/2}$ nuclear-spin-dependent parity nonconservation amplitudes for Rb, Cs, Ba^+, Yb^+, Fr, Ra^+, and Ac^{2+}. These systems prove to be good candidates for use in atomic experiments to extract the so-called anapole moment, a P-odd T-even nuclear moment important for the study of parity-violating nuclear forces. We also extend our previous works by calculating the missed spin-dependent amplitudes for the s-$d_{3/2}$ transitions in the above systems.

[35] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Double-core-polarization contribution to atomic parity-nonconservation and electric-dipole-moment calculations*, Physical Review A **88**, 042507 (2013), [arXiv:1309.3371]

We present a detailed study of the effect of double core polarization (the polarization of core electrons due to the simultaneous action of the electric dipole and parity-violating weak fields) for amplitudes of the ss and sd parity-nonconserving transitions in Rb, Cs, Ba^+, La^{2+}, Tl, Fr, Ra^+, Ac^{2+}, and Th^{3+} as well as electron electric-dipole-moment enhancement factors for the ground states of the above neutral atoms and Au. This effect is quite large and has the potential to resolve some disagreement between calculations in the literature. It also has significant consequences for the use of experimental data in the accuracy analysis.

[36] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Parity nonconservation in Fr-like actinide and Cs-like rare-earth-metal ions*, Physical Review A **88**, 012510 (2013), [arXiv:1304.7591]

Parity nonconservation amplitudes are calculated for the $7s - 6d$ transitions of the francium isoelectronic sequence (Fr, Ra^+, Ac^{2+}, Th^{3+}, Pa^{4+}, U^{5+} and Np^{6+}) and for the 6s-5d transitions of the cesium isoelectronic sequence (Cs, Ba^+, La^{2+}, Ce^{3+} and Pr^{4+}). We show in particular that isotopes of La^{2+}, Ac^{2+} and Th^{3+} ions have strong potential in the search for new physics beyond the standard model – the PNC amplitudes are large, the calculations are accurate and the nuclei are practically stable. In addition, $^{232}Th^{3+}$ ions have recently been trapped and cooled [C. J. Campbell et al., Phys. Rev. Lett. 102, 233004 (2009)]. We also extend previous works by calculating the s-s PNC transitions in Ra^+ and Ba^+, and provide new calculations of several energy levels, and electric dipole and quadrupole transition amplitudes for the Fr-like actinide ions.

[37] B. M. Roberts, V. A. Dzuba, and V. V. Flambaum, *Quantum electrodynamics corrections to energies, transition amplitudes, and parity nonconservation in Rb, Cs, Ba^+, Tl, Fr, and Ra^+*, Physical Review A **87**, 054502 (2013), [arXiv:1302.0593]

We use the previously developed radiative potential method to calculate quantum electrodynamic (QED) corrections to energy levels and electric dipole transition amplitudes for atoms which are used for the study of the parity nonconservation (PNC) in atoms. The QED shift in energies and dipole amplitudes leads to noticeable change in the PNC amplitudes. This study compliments the previously considered QED corrections to the weak matrix elements. We demonstrate that the QED corrections due to the change in energies and dipole matrix elements are comparable in value to those due to the change in weak matrix elements and therefore must be included.

[38] V. A. Dzuba, V. V. Flambaum, and B. M. Roberts, *Calculation of the parity-violating 5s-6s E1 amplitude in the rubidium atom*, Physical Review A **86**, 062512 (2012), [arXiv:1211.0075]

Currently, the theoretical uncertainty limits the interpretation of the atomic parity-nonconservation (PNC) measurements. We calculate the PNC 5s-6s electric dipole transition amplitude in rubidium and demonstrate that rubidium is a good candidate to search for new physics beyond the standard model since accuracy of the atomic calculations in rubidium can be higher than in cesium. PNC in cesium is currently the best low-energy test of the standard model; therefore, similar measurements for rubidium present a good option for further progress in the field. We also calculate the nuclear spin-dependent part of the PNC amplitude, which is needed for the extraction of the nuclear anapole moment from the PNC measurements.

[39] V. A. Dzuba, J. C. Berengut, V. V. Flambaum, and B. M. Roberts, *Revisiting Parity Nonconservation in Cesium*, **Physical Review Letters 109**, 203003 (2012), [arXiv:1207.5864]

We apply the sum-over-states approach to calculate partial contributions to the parity non-conservation (PNC) in cesium [Porsev et al*, Phys. Rev. D* **82**, *036008 (2010)]. We have found significant corrections to two non-dominating terms coming from the contribution of the core and highly excited states ($n > 9$, the so called* tail*). When these differences are taken into account the result of Porsev* et al*, $E_{\rm PNC} = 0.8906\,(24) \times 10^{-11} i(-Q_W/N)$ changes to $0.8977\,(40)$, coming into good agreement with our previous calculations, $0.8980\,(45)$. The interpretation of the PNC measurements in cesium still indicates reasonable agreement with the standard model ($1.5\,\sigma$), however gives new constraints on physics beyond it.*

- Allowed highest-precision low-energy test of electroweak theory; cited in *Particle data Group* reports

Conference Proceedings

[40] T. Do, A. Hees, A. Ghez, G. D. Martinez, D. S. Chu, S. Jia, S. Sakai, J. R. Lu, A. K. Gautam, K. Kosmo O'neil, E. E. Becklin, M. R. Morris, K. Matthews, S. Nishiyama, R. Campbell, S. Chappell, Z. Chen, A. Ciurlo, A. Witzel, E. Gallego-Cano, W. E. Kerzendorf, J. E. Lyke, S. Naoz, H. Saida, R. Schödel, M. Takahashi, Y. Takamori, G. Witzel, P. Wizinowich, and B. M. Roberts, *Testing Fundamental Physics With Stellar Orbits at the Galactic Center*, ASP Conference Series: New Horizons in Galactic Center Astronomy and Beyond **528**, 249 (2019)

[41] E. Savalle, A. Hees, F. Frank, E. Cantin, P.-E. Pottie, B. M. Roberts, L. Cros, B. T. McAllister, and P. Wolf, *The DAMNED experiment! New constraints on ultralight dark matter scalar field oscillations*, Proceedings of the 55th Rencontres de Moriond - Gravitation Session, 17 (2021)

[42] E. Savalle, B. M. Roberts, F. Frank, P.-E. Pottie, B. T. McAllister, C. Dailey, A. Derevianko, and P. Wolf, *DAMNED - DArk Matter from Non Equal Delays New test of the fundamental constants variation*, 2019 Joint Conference of the IEEE International Frequency Control Symposium and European Frequency and Time Forum (EFTF/IFC) (2019)

[43] E. Savalle, B. M. Roberts, F. Frank, P.-E. Pottie, B. T. McAllister, C. B. Dailey, A. Derevianko, and P. Wolf, *The damned experiment: dark matter from non equal delays*, Proceedings of the 54th Rencontres de Moriond - Gravitation Session, 241 (2019)

[44] A. Hees, O. Minazzoli, E. Savalle, Y. V. Stadnik, P. Wolf, and B. M. Roberts, *Violation of the equivalence principle from light scalar fields: from Dark Matter candidates to scalarized black holes*, Proceedings of the 54th Rencontres de Moriond - 2019 Gravitation, 175 (2019), [arXiv:1905.08524]

[45] B. M. Roberts, Y. V. Stadnik, V. V. Flambaum, and V. A. Dzuba, *Searching for Axion Dark Matter in Atoms: Oscillating Electric Dipole Moments and Spin-Precession Effects*, Proceddings of the 11th PATRAS Workshop on Axions, WIMPs and WISPs (2015), [arXiv:1511.04098]

[46] Y. V. Stadnik, B. M. Roberts, V. V. Flambaum, and V. A. Dzuba, *Searching for Scalar Dark Matter in Atoms and Astrophysical Phenomena: Variation of Fundamental Constants*, Proceddings of the 11th PATRAS Workshop on Axions, WIMPs and WISPs (2015), [arXiv:1511.04100]

[47] B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer, and D. Budker, *ICPEAC2015: New Atomic Methods for Dark Matter Detection*, Journal of Physics: Conference Series **635**, 022033 (2015)

[48] V. V. Flambaum, V. A. Dzuba, M. Pospelov, A. Derevianko, and B. M. Roberts, *ICPEAC2015: Atomic Ionization by Dark Matter Particles*, Journal of Physics: Conference Series **635**, 022012 (2015)

Other Research Outputs

[49] GPS-analysis, B. M. Roberts, *A. R. Caddell*†, and M. Filzinger (2024). Open-source python program to analyse GPS data for oscillating shifts in the frequency of the on board atomic clocks. github.com/benroberts999/gps-analysis

- Companion code to paper: **Physical Review Letters 134**, 031001, (2025)

[50] AtomicIonisation, *A. R. Caddell*† and B. M. Roberts (2023). Open-source C++ and python programs to calculate example DM-electron-induced ionisation rates. Also provides tables of high-accuracy atomic ionisation factors (matrix elements), which are required to calculate atomic ionisation rates, including from dark matter electron scattering. github.com/benroberts999/AtomicIonisation

- Companion code to paper: Physical Review D **108**, 083030, (2023)
- Employed by NEON Collaboration for their dark matter interpretation [arXiv:2407.16194].

[51] AdamsMoulton, B. M. Roberts (2023). An open-source C++ implementation of the Adams-Moulton method for solving general second-order ODEs. github.com/benroberts999/AdamsMoulton

[52] ampsci, B. M. Roberts (2022). An open-source C++ program for high-precision atomic structure calculations of single-valence systems. github.com/benroberts999/ampsci

- Used in many papers, including by other groups; first major publication: Physical Review A **107**, 052812, (2023)

[53] FGRP, B. M. Roberts (2022). An open-source C++ implementation of the Flambaum-Ginges radiative potential method, a method for including radiative quantum electrodynamics effects into calculations of atomic wavefunctions, including finite nuclear size corrections. github.com/benroberts999/FGRP

- Used in many papers, first in: Physical Review A **107**, 022813, (2023). Also used by other groups, e.g., Phys. Rev. A **107**, 042809 (2023)

[54] transientDM, B. M. Roberts (2019). An open-course C++ program for searching for transient dark matter signals in data from atomic clock networks. github.com/benroberts999/transientDM

- Companion code to paper: New Journal of Physics **22**, 093010, (2020)

[55] DM-ClockAsymmetry, B. M. Roberts (2018). An open-source python program for simulating dark matter induced asymmetries in atomic clock data, and their annual modulation. github.com/benroberts999/DM-ClockAsymmetry
- Companion code to paper: Universe **7**, 50, (2021)

[56] InverseNumericalCDF, B. M. Roberts (2017). An open-source C++ program that finds the inverse of numerical cumulative distribution functions for inverse transform sampling in Monte-Carlo methods.
github.com/benroberts999/InverseNumericalCDF
- Used in: **Nature Communications 8**, 1195, (2017)

Invited Seminars, Colloquiums

[1] Colloquium: Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, November 2024.
Talk: *Enlightening the search for dark matter (and exotic physics) with atomic phenomena*
Part of the "Virtual Seminar on Precision Physics and Fundamental Symmetries" series and of the *SFB DQ-mat colloquium* series: indico.cern.ch/category/12183/ – [Slides]

[2] Colloquium: CSIRO Space & Astronomy Colloquium, Marsfield, Sydney, July 2024.
Talk: *A brief history of time(-keeping): atomic clocks at the precision frontier of fundamental physics* [Slides]

[3] Seminar: University of Sussex, UK, QSNET Seminar (presented virtually), February 2024.
Talk: *Search for scalar dark matter and variation of fundamental constants with spatially separated sensors* [Slides]

[4] Colloquium: University of Melbourne, Astrophysics Colloquium (presented virtually), August 2023.
Talk: *Variation of fundamental constants: Search for new physics around a supermassive black hole*

[5] Colloquium: University of Queensland, Physics Colloquium, August 2023.
Talk: *Enlightening the search for dark matter (and exotic physics)* [Slides]

[6] Lecture: PhysTeV 2023, Physics at TeV Colliders and Beyond the Standard Model, Les Houches, France, June 2023.
Lecture for "precision low-energy school": *Atomic parity violation as a low-energy probe of electroweak theory*

[7] Seminar: University of Melbourne, particle physics seminar (virtual), March 2022.
Talk: *Dark matter induced atomic ionisation* [Slides]

[8] Seminar: Observatoire de Paris, Seminaire Temps & Frequencies (SYRTE seminar), May 2018.
Talk: *Searching for dark matter with GPS and global networks of atomic clocks*

Invited and Plenary Conference Presentations

[9] TMEX-2025, Theory Meets Experiment: Particle Astrophysics and Cosmology, 21st Rencontres du Vietnam, ICISE, Quy Nhon, Vietnam, January 2025.
Talk: *Atomic frontiers in dark matter detection* [Slides]

[10] 2023 MIAPbP (Munich Institute for Astro-, Particle, and Bio Physics) program: Particle & AMO physicists discussing quantum sensors and new physics 2023), Munich, Germany, September 2023.

[11] APV2022, The International Workshop on Atomic Parity Violation (virtual), November 2022.
Talk: *Study of electric dipole amplitudes for alkali-like atoms and implications for atomic parity violation* [Slides]

[12] ATMOP (AIP) Summer Workshop, Australian National University, Canberra, February 2020.
Talk: *Signatures of GeV-scale dark matter in liquid xenon experiments due to scattering off electrons and atomic ionisation*

[13] Frontiers in Quantum Matter Workshop, Australian National University (ANU), Canberra, November 2019.
Talk: *Dark matter signatures in EDM and precision physics experiments*

[14] 7th International Colloquium on Scientific and Fundamental Aspects of GNSS, ESA (European Space Agency), ETH Zürich, Zurich, Switzerland, September 2019.
Talk: *Searching for dark matter and exotic physics with space and ground-based atomic clocks*

[15] MG15 – Fifteenth Marcel Grossmann Meeting, University of Rome, La Sapienza, Rome, July 2018.
Talk: *Searching for transient dark matter signatures with atomic clocks*

[16] New Directions in Dark Matter and Neutrino Physics, Perimeter Institute for Theoretical Physics, Canada, July 2017.
Talk: *Searching for dark matter with GPS and global networks of atomic clocks* [Recording]

[17] The Ultra-Light Frontier, Mainz Institute for Theoretical Physics, Johannes Gutenberg University, Germany, June 2015.
Talk: *Axion-induced EDMs in paramagnetic systems* [Slides]

Contributed Conference Presentations

[18] Dark Matter and Stars: Multi-Messenger Probes of Dark Matter and Modified Gravity, Queen's University, Kingston, Canada, July 2025 *(upcoming)*.
Talk: *Enlightening the search for dark matter (and exotic physics) with atomic phenomena*

[19] DSU2025: The Dark Side of the Universe, Université de Montreal, Canada, July 2025 *(upcoming)*.
Talk: *Ultralight Dark Matter Search with Space-Time Separated Atomic Clocks and Cavities*

[20] Tabletop-scale Cosmology At Home, (virtual), May 2025.
Talk: *Searching for Ultralight Dark Matter with Space-Time Separated Quantum Sensors* [Slides]

[21] AIP-2024, Australian Institute of Physics Congress, Melbourne, December 2024.
Talk: *Ultralight Dark Matter Search with Space-Time Separated Atomic Clocks and Cavities* [Slides]
Talk: *Study of electric dipole amplitudes for alkali-like atoms and implications for atomic parity violation* [Slides]

[22] APS April Meeting 2024 , Sacramento, California, USA, April 2024.
Talk: *Search for scalar dark matter and variation of fundamental constants with spatially separated sensors* [Slides]

[23] 2023 AIP Summer Meeting, ANU, Canberra, Australia, December 2023.
Talk: *Atomic phenomena in the search for GeV scale WIMPs: enlightening the search for dark matter* [Slides]

[24] 9th Symposium on Frequency Standards and Metrology, Kingscliff, NSW, Australia, October 2023.
Poster: *Electric-dipole transition amplitudes for atoms and ions with one valence electron* [Poster]

[25] DAMOP 2023 (APS Division of Atomic, Molecular and Optical Physics), Spokane, WA, USA, June 2023.
Talk: *Using atomic phenomena to search for GeV scale dark matter* [Slides]
Talk: *Hyperfine anomaly in cesium: From exotic atoms to improved searches for new physics* [Slides]
Poster: *Electric-dipole transition amplitudes for atoms and ions with one valence electron* [Poster]

[26] AIP2022, Australian Institute of Physics Congress, Adelaide, December 2022.
Talk: *Search for a Variation of the Fine Structure Constant around the Supermassive Black Hole in Our Galactic Centre*
Poster: *High-precision study of E1 transition amplitudes for single-valence atoms and ions* [Poster]

[27] DSU2022, The Dark Side of the Universe, University of New South Wales, Sydney, Australia, December 2022.
Talk: *Search for a Variation of the Fine Structure Constant around the Supermassive Black Hole in Our Galactic Centre* [Slides]

[28] Australian Institute of Physics (AIP) Summer Meeting, QUT, Brisbane, December 2021.
Talk: *Search for a variation of the fine-structure constant around the supermassive Black Hole in our Galactic Centre*

[29] ASA2021, Astronomical Society of Australia Science Meeting, University of Melbourne (virtual), July 2021.
Talk: *Search for a variation of the fine-structure constant around the supermassive Black Hole in our Galactic Centre* [Slides]

[30] DAMOP, Portland, Oregon, USA (held virtually), June 2020.
Talk: *Electron-interacting dark matter: prospects for liquid xenon detectors and NaI detectors* [Slides]
Poster: *Do constants remain constant around a Supermassive Black hole?* [Poster]

[31] CHEP 2019, 24th International Conference on Computing in High Energy and Nuclear Physics, Adelaide, Australia, November 2019.
Talk: *Searching for dark matter signatures in 20 years of GPS atomic clock data*

[32] Rencontres de Moriond, Gravitation Session, La Thuile, Valle d'Aosta, Italy, March 2019.
Talk: *Search for dark matter and transient variations in α using fibre-linked optical atomic clocks* [Slides]

[33] AIP2018, Australian Institute of Physics Congress, University of Western Australia, Perth, December 2018.
Talk: *Searching for transient dark matter signatures with atomic clock networks*
Talk: *Ionisation signatures of GeV–scale dark matter due to absorption and scattering off electrons*

[34] ACES Workshop, Technical University of Munich, Germany, October 2018.
Talk: *Searching for transient dark matter signatures with atomic clock networks*

[35] NASA Fundamental Physics Workshop, La Jolla, CA, USA, April 2018.
Talk: *Searching for dark matter and exotic physics with atomic clocks and GPS* [Slides]

[36] DAMOP (APS Division of Atomic, Molecular and Optical Physics), Sacramento Convention Center, CA, USA, June 2017.
Talk: *Searching for dark matter and exotic physics with atomic clocks and the GPS constellation*
Poster: *Electron-interacting WIMPs: Can dark matter scattering on electrons explain the DAMA annual modulation signal?* [Poster]

[37] APS April Meeting, Marriott Wardman Park, Washington DC, USA, January 2017.
Poster: *Electron-interacting WIMPs: Can dark matter scattering on electrons explain the DAMA annual modulation signal?* [Poster]
Talk: *First Results of the GPS.DM Observatory: Search for Dark Matter and exotic Physics with Atomic Clocks and GPS Constellation*

- Talk was the focus of an article in *Science* Magazine [10.1126/science.aal0676].

[38] GPMFC Workshop (Topical Group on Precision Measurement & Fundamental Constants Pre-Meeting Workshop: Ultra-light Dark Matter), Marriott Wardman Park, Washington DC, USA, January 2017.
Poster: *GPS.DM: Search for Dark Matter and Exotic Physics with Atomic Clocks and GPS Constellation*

[39] CosPA (13th Conference in the Symposium on Cosmology and Particle Astrophysics), Sydney Nanoscience Hub, University of Sydney, Australia, December 2016.
Talk: *First Results of the GPS.DM Observatory: Search for Dark Matter and Exotic Physics with Atomic Clocks and GPS Constellation*

[40] DAMOP 2016 (APS Division of Atomic, Molecular and Optical Physics), Rhode Island Convention Center, Providence, RI, USA, May 2016.
Talk: *Atomic ionization from dark matter–electron scattering: Implications for DAMA and XENON interpretation*
Poster: *GPS.DM: Search for Dark Matter and Exotic Physics with Atomic Clocks and GPS Constellation*

[41] PATRAS (11th Patras Workshop on Axions, WIMPs and WISPs), Universidad de Zaragoza, Spain, June 2015.
Talk: *Axion and WIMP phenomena in atomic systems* [Slides]
Talk: *New Effects of Dark Matter which are Linear in the Interaction Strength (on behalf of Victor Flambaum)* [Slides]
Poster: *Axion Dark Matter: New atomic detection schemes*

[42] SSP (6th International Symposium on Symmetries in Subatomic Physics), Victoria BC, Canada, June 2015.
Talk: *Atomic Methods for Dark Matter Detection* [Slides]
Poster: *Axion Dark Matter: New atomic detection schemes*
Poster: *Atomic Symmetry Violation: New applications for tests of fundamental physics*

[43] CosPA (10th Conference in the Symposium on Cosmology and Particle Astrophysics Series), University of Auckland, New Zealand, December 2014.
Talk: *Manifestations of dark matter and cosmic fields in atomic phenomena* [Slides]

[44] AIP2014, Australian Institute of Physics Congress, Australian National University, Canberra, December 2014.
Talk: *Violations of fundamental symmetries in atoms and tests of unification theories* [Slides]
Poster: *Limits on P-odd interactions of cosmic fields with electrons, protons and neutrons*

[45] Australian Institute of Physics Congress, UNSW Australia, December 2012.
Poster: *Parity nonconservation in cesium and the search for physics beyond the standard model*

Public Talks and Outreach

[46] Junior Physics Odyssey (JPhO) lecture, UQ, Brisbane, Australia, July 2024.
Introduction to relativity and space-time – Lecture to year 10 students with UQ 'Junior Physics Odyssey' program

[47] Public Outreach Talk: Pint of Science, Brisbane, Australia, May 2024.
Talk: *The next frontier in fundamental physics* [Slides]

[48] Public Lecture: National Quantum and Dark Matter Roadshow, Brisbane QLD, August 2023.
qdmroadtrip.org/event/public-lecture-brisbane/
Talk: *Enlightening the search for dark matter* [Slides]

[49] Public Talk: UQ ASA (student society) outreach talk, University of Queensland, Australia, April 2022.
Talk: *Variation of fundamental constants: Search for new physics around a supermassive black hole* [Slides]

Selected Coverage in Popular Press

[1] *Atomic clocks and lasers could help find dark matter*, Imma Perfetto, Cosmos Magazine, 10 February 2025.

> "Scientists will now be able to investigate a broader range of dark matter scenarios and perhaps answer some fundamental questions about the fabric of the universe"

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[4] *A Minimalist Approach to the Hunt for Dark Matter*, Sophia Chen, WIRED, 2 August 2022

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[5] *Improved modelling of nuclear structure in francium aids searches for new physics*, phys.org, 5 August 2020.

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[6] *This fundamental constant remains the same even near a black hole*, Emily Conover, Science News, 28 March 2020.

"...'The work is very important because it denotes the beginning of a new type of study' says physicist John Webb"

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[9] *Harnessing the GPS Data Explosion for Interdisciplinary Science*, G. Blewitt, W. C. Hammond and C. Kreemer, Eos (American Geophysical Union), 24 September 2018.

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[10] *Is This A Good Time To Start Looking For Dark Matter?*, C. Orzel, Forbes, 4 June 2018.

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[11] *Ultra-Accurate Clocks Lead Search for New Laws of Physics*, G. Popkin, Quanta, 16 April 2018.

"...reported in fall 2017 that they had found no dark matter-induced hiccups in 16 years' worth of GPS data, tightening the lid on theories of such "topological" dark matter by a factor of 10^3 to 10^5..."

[12] *GPS satellites "the largest dark matter detector ever built"*, R. A. Lovett, Cosmos, 10 November 2017.

"...'The electrons and the nucleus 'feel' the effect of the dark matter, and this can change their properties temporarily,' says Benjamin Roberts, an Australian postdoctoral researcher working with Derevianko in Reno...."

[13] *The search for dark matter just took a big step forward*, Brad Bergan, NBC News, 3 November 2017.

"...'While there is no definitive evidence after looking at 16 years of data, it could be that the interaction is weaker or that the defects cross paths with the Earth less often,' Benjamin Roberts, lead author of team's paper..."

[14] *One step closer to defining dark matter*, AAAS EurekAlert, 1 November 2017.

"...'What we looked for was clumps of dark matter in the shape of walls, using a model that – if it exists – would have collisions that are evidenced in irregularities in the atomic clock signals,' Benjamin Roberts, postdoctoral associate and lead author for the Nature paper, said...."

[15] *Astrophysicists turn GPS constellation into giant dark matter detector*, MIT Technology Review, 4 May 2017.

"...Enter Roberts and co. They start with a different vision of what dark matter may consist of. Instead of small particles, another option is that dark matter may take the form of topological defects in space-time left over from the Big Bang..."

[16] *Hunting dark matter with GPS data*, Adrian Cho, Science, 30 January 2017.

"...Now, Benjamin Roberts and Andrei Derevianko, two physicists at the University of Nevada in Reno, and their colleagues say they have performed the most stringent search yet for topological dark matter, using archival data from the constellation of 31 orbiting GPS satellites..."