Curriculum Vitae

Michael Bishof

- Assistant Physicist - Medium Energy Physics, TRACER Center, Argonne National Laboratory
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Research Interests

Using atomic physics techniques for broader scientific impact: precision measurement, many-body physics, quantum information science, trace radio-isotope analysis, and physics beyond the standard model.

My thesis research centered on using ultracold, optical-lattice-trapped strontium atoms to develop the most stable and accurate clock and study many-body physics. As an essential prerequisite to both achievements, we first established a thorough understanding of atomic interactions in our system. On one hand, interactions are an important systematic effect that needs to be understood with extremely high precision to advance clock performance. On the other hand, the clock itself can be an extremely precise probe of subtle perturbations due to many-body interactions. Our work identified the many-body nature of interactions in our system and established the SU(10) symmetric nature of interactions among the 10 nuclear-spin sublevels in both ground and excited clock states. This work paved the way for future studies of engineered quantum systems using trapped ultracold alkaline earth atoms (AEAs).

In particular, I am now working toward using similar systems to perform quantum simulations of strongly-interacting many-body systems that are relevant to nuclear physics. Here, I am using neutral ytterbium (Yb) atoms trapped in re-configurable optical tweezer arrays. This system combines "bottom-up" individual atom control with the long coherence times one can achieve using optical clock transitions in AEA-like Yb atoms. In addition, we can initiate on-demand strong interactions via coupling to Rydberg states. This project will establish a foundational platform for quantum simulation with an initial goal of simulating quark-level effective theories for quantum chromodynamics. We will leverage this experimental platform to build towards simulations of poorly understood systems that are difficult or impossible to model using classical computation techniques.

As a member of Argonne's Trace Radioisotope Analysis Center (TRACER), I work to improve the atom trap trace analysis (ATTA) technique and expand its scientific impact. By detecting rare isotopes of krypton in a magneto-optical trap we determine the residence time of ground water and polar ice at time scales outside the range of radiocarbon dating. We recently built a second, state-of-the-art ATTA instrument which can measure environmental krypton samples with unprecedented speed and precision. In parallel to performing sample measurements, we also work to develop improvements to the ATTA technique, such as our current project investigating and implementing new methods to populate noble gas atoms into the metastable state that is required for laser trapping. This work could dramatically improve the sensitivity of the ATTA technique, enabling the use of ATTA for extremely small samples and short lived isotopes.

I also contribute to the radium EDM collaboration, a project which tests for an asymmetrical charge distribution of the radium atom that violates the combined charge-conjugation parity (CP) symmetry. This asymmetry manifests as a permanent electric dipole moment (EDM), which we measure using cold, laser-trapped, radium atoms. The standard model (SM) of physics does not contain enough CP violation to explain the prevalence of matter over anti-matter in the universe; however, extensions of the SM naturally include additional CP violation that both explains the matter—anti-matter asymmetry and enhances the EDM of radium. Our measurements will limit possible extensions to the SM and the observation of an EDM in radium would demonstrate the existence of physics beyond the SM. We demonstrated the first proof-of-principle radium EDM measurement which placed an upper limit of 5×10^{-22} e·cm on the EDM of radium (95% confidence level). The next year, we improved this limit over an order of magnitude to 14×10^{-24} e·cm by dramatically improving our atom interrogation time. An upper limit at the 10^{-25} e·cm level would constrain extensions of the SM and we believe our next measurement will achieve this goal by implementing an improved atom detection scheme. Long term developments such as more plentiful sources of radium and atom cooling and slowing based on a stronger atomic transition at 483 nm will further push statistical sensitivity to the 10^{-28} e·cm level.

Biographical Sketch

- 2018-Present — Assistant Physicist, Medium Energy Physics, Argonne National Laboratory, Argonne, IL
- 2014-2017 — Director's Fellow, Medium Energy Physics, Argonne National Laboratory, Argonne, IL
- 2014 — Ph.D, *Physics*, University of Colorado at Boulder, Boulder, CO. Thesis: *"Understanding interactions in an optical lattice clock and using them to study many-body physics,"* advisor, Jun Ye
- 2011 — M.S., *Physics*, University of Colorado at Boulder, Boulder, CO
- 2007-2008 — Research Associate, Prof. Zheng-Tian Lu, Medium Energy Physics, Argonne National Laboratory, Argonne, IL
- 2007 — B.A., *Physics with Honors*, University of Chicago, Chicago, IL
- 2007 — B.S., *Mathematics with Honors*, University of Chicago, Chicago, IL
- 2005-2007 — Undergraduate Research Assistant, Prof. Donald G. York, University of Chicago, Chicago, IL, Department of Astronomy and Astrophysics

Teaching and Outreach

- 2008-2010 — Scientific Advisor, Partnerships for Informal Scientific Education in the Community (PISEC), Boulder, CO.
- 2008-2009 — Teaching Assistant, University of Colorado at Boulder, Boulder, CO

Awards

- 2020 — U.S. Department of Energy Office of Science Early Career Research Program Award
- 2014 — Director's Fellowship, Argonne National Laboratory

- 2010 NSF Graduate Research Fellowship
- 2010 National Defense Science and Engineering Graduate (NDSEG) Fellowship
- 2010 JILA Scientific Achievement Award
- 2003 College Honor Scholarship, University of Chicago

Selected Publications (Full List from Google Scholar)

1) R. Ram, R. Purtschert, E. M. Adar, M. Bishof, W Jiang, Z. T. Lu, P. Mueller, A. Sy, C. Vockenhuber, Y Yechieli, R. Yokochi, J. C. Zappala, and A. Burg, Controls on the ^{36}Cl/Cl input ratio of Paleo-groundwater in arid environments: New evidence from ^{81}Kr/Kr data, *Science of the Total Environment* **762**, 144106 (2021).
2) D. W. Booth, T. Rabga, R. Ready, K. G. Bailey, M. Bishof, M. R. Dietrich, J. P. Greene, P. Mueller, T. P. O'Connor, and J. T. Singh, Spectroscopic study and lifetime measurement of the 6d7p $^3F_2^o$ state of radium, Spectrochimica Acta Part B 172, 105967 (2020).
3) M. Bishof, *et al.*, Improved limit on the ^{225}Ra electric dipole moment, Phys. Rev. C **94**, 025501 (2016).
4) S. L. Bromley, B. Zhu, M. Bishof, X. Zhang, T. Bothwell, J. Schachenmayer, T. L. Nicholson, R. Kaiser, S. F. Yelin, M. D. Lukin, A. M. Rey, and J. Ye, Collective atomic scattering and motional effects in a dense coherent medium, *Nature Comm.* **7**, 11039 (2016)
5) R. H. Parker, M.R. Dietrich, M. R. Kalita, N. D. Lemke, K. G. Bailey, M. Bishof, J. P. Greene, R. J. Holt, W. Korsch, Z.-T. Lu, P. Mueller, T. P. O'Conner, and J. T. Singh, First Measurement of the Atomic Electric Dipole Moment of ^{225}Ra, Phys. Rev. Lett. **114**, 233002 (2015).
6) L. A. Straka, P. Noterdaeme, R. Srianand, S. Nutalaya, V. P. Kulkarni, P. Khare, D. Bowen, M. Bishof, and D. G. York, Galactic nebular lines in the fiber spectra of background QSOs: Reaching a hundred QSO-galaxy pairs with spectroscopic and photometric measurements, *MNRAS* **447**, 3856-3872 (2015).
7) X. Zhang, M. Bishof, *et al*., Spectroscopic observation of SU(N)-symmetric interactions in Sr orbital magnetism, Science, **345**, 1467-1473 (2014).
8) P. Kómár, E. M. Kessler, M. Bishof, L. Jiang, A. S. Sørensen, J. Ye, and M. D. Lukin, A quantum network of clocks, *Nature Phys.* **10**, 582-587 (2014).
9) E. M. Kessler, P. Kómár, M. Bishof, *et al*., Heisenberg-Limited Atom Clocks Based on Entangled Qubits, *Phys. Rev. Lett.* **112**, 190403 (2014).
10) B. J. Bloom, T. L. Nicholson, J. R. Williams, S. L. Campbell, M. Bishof, *et al*., An optical lattice clock with accuracy and stability at the 10^{-18} level, *Nature* **506**, 71-75 (2014).

A. M. Rey, A. V. Gorshkov, C. V. Kraus, M. J. Martin, M. Bishof, *et al*., Probing many-body interactions in an optical lattice clock, *Annals of Physics* **340**, 311-351 (2014).

11) L. A. Straka, Z. L. Whichard, V. P. Kulkarni, M. Bishof, D. Bowen, P. Khare, and D. G. York, Galaxies with background QSOs – II. An automated search for multiple galaxy emission lines, *MNRAS* **436**, 3200-3223 (2013).
12) M. J. Martin, M. Bishof, *et al*., A quantum many-body spin system in an optical lattice clock, *Science* **341**, 632-636 (2013).
13) M. Bishof, X. Zhang, M. J. Martin, and J. Ye, Optical Spectrum Analyzer with Quantum-Limited Noise Floor, *Phys. Rev. Lett.* **111**, 093604 (2013).
14) T. L. Nicholson, M. J. Martin, J. R. Williams, B. J. Bloom, M. Bishof, M. D. Swallows, S. L. Campbell, and J. Ye, Comparison of Two Independent Sr Optical Clocks with 1×10^{-17} Stability at 10^3 s, *Phys. Rev. Lett.* **109**, 230801 (2012).

15) D. G. York, L. A. Straka, M. Bishof, *et al*., Galaxies with Background QSOs – I. A serch for Strong Galactic H-alpha Lines, *MNRAS*, **423**, 3692-3708 (2012).
16) M. D. Swallows, M. J. Martin, M. Bishof *et al*., Operating a ^{87}Sr optical lattice clock with high precision and at high density, *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* **59**, 416 – 425 (2012).
17) M. Bishof, *et al*., Inelastic collisions and density-dependent excitation suppression in a ^{87}Sr optical lattice clock, *Phys. Rev. A* **84**, 052716 (2011).
18) M. Bishof, Y. Lin, M. D. Swallows, A. V. Gorshkov, J. Ye, and A. M. Rey, Resolved atomic interaction sidebands in an optical clock transition, *Phys. Rev. Lett.* **106**, 250801 (2011).
19) M. D. Swallows, M. Bishof, Y. Lin, S. Blatt, M. J. Martin. A. M. Rey, J. Ye, Suppression of collisional shifts in a strongly interacting lattice clock, *Science* **331**, 1043-1046 (2011).
20) L. M. Hobbs, D. G. York, J. A. Thorburn, T. P. Snow, *et al*., Studies of the diffuse interstellar bands. III. HD 183143, *Astrophys. J.* **705**, 32-45 (2009).
21) A. Sulai, Q. Wu, M. Bishof, G. W. F. Drake, Z.-T. Lu, P. Mueller, and R. Santra, Hyperfine Suppression of 2 $^3S_1$ - 3 ^3P_J Transitions in ^{3}He, *Phys. Rev. Lett.* **101**, 173001 (2008).
22) L. M. Hobbs, D. G. York, T. P. Snow, T. Oka, J. A. Thorburn, M. Bishof, S. D. Friedman, B. J. McCall, B. Rachford, P. Sonnentrucker, and D. E. Welty, A catalog of diffuse interstellar bands in the spectrum of HD 204827, *Astrophys. J.* **680**, 1256–1270 (2008).

Scientific Talks:

1) M. Bishof, Quantum simulation of nuclear physics, *Physics Division Seminar,* Argonne National Laboratory, Argonne, IL, March 2 (2020).
2) M. Bishof, Detecting single krypton atoms to determine groundwater age, *Experimental Techniques in Quantum Sensing and Information Workshop*, March, 21 (2019).
3) M. Bishof, Argonne's TRACER CENTER: expanding the applications of atom trap trace analysis, *Midwest Cold Atom Workshop*, Urbana, IL, Nov. 9 (2018).
4) M. Bishof, K. Bailey, M. R. Dietrich, J. P. Greene, R. J. Holt, M. R. Kalita, W. Korsch, N. D. Lemke, Z.-T. Lu, P. Mueller, T. P. O'Connor, R. H. Parker, T. Rabga, J. T. Singh, An improved limit on the EDM of ^{225}Ra, *47th Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics*, Providence, Rhode Island, May 23-27 (2016).
5) M. Bishof, A New Year, A New Limit on the ^{225}Ra EDM, *Physics Division Seminar*, Argonne National Laboratory, Argonne, IL, Jan. 4 (2016).
6) M. Bishof, Improved limit on the ^{225}Ra electric dipole moment, *The 2015 Midwest Cold Atom Workshop*, Madison, Wisconsin, Nov. 14 (2015).
7) M. Bishof, K. Bailey, M. R. Dietrich, J. P. Greene, R. J. Holt, M. R. Kalita, W. Korsch, N. D. Lemke, Z.-T. Lu, P. Mueller, T. P. O'Connor, R. H. Parker, T. Rabga, J. T. Singh, Improved experimental limit on the EDM of ^{225}Ra, *2015 Fall Meeting of the APS Division of Nuclear Physics*, Santa Fe, New Mexico, Oct. 28-31, (2015).
8) M. Bishof, The first experimental limit on the EDM of radium-225, *Twelfth International Conference on the intersections of particle and nuclear physics*, Vail, Colorado, May 19-24 (2015).
9) M. Bishof, The first experimental limit on the EDM of radium-225, *Physics Division Seminar*, Argonne National Laboratory, Argonne, IL, Jan. 19 (2015).
10) M. Bishof, X. Zhang, M. J. Martin, and J. Ye, Laser spectral analysis using ^{87}Sr atoms with a quantum projection limited noise floor, *Joint Meeting of the APS Division of Atomic,*

Molecular & Optical Physics and the CAP Division of Atomic, Molecular & Optical Physics, Canada, Quebec City, Canada, June 3-7 (2013).

11) M. Bishof, M. J. Martin, M. D. Swallows, C. Benko, and J. Ye, Using state-of-the-art ultrastable lasers to understand ^{87}Sr interactions, *4th ESA Int'l Workshop on Optical Atomic Frequency Standards & Clocks*, Trani, Italy, October 24-27 (2011).
12) M. Bishof, M. D. Swallows, M. J. Martin, S. Blatt, C. Benko, and J. Ye, The JILA ^{87}Sr lattice clock: Moving into the next decades of stability and accuracy, *Optical Clocks Workshop*, Torino, Italy, Dec. 1-3 (2010).
13) M. Bishof, I. A. Sulai, Z.-T. Lu, K. Bailey, P. Mueller, T. O'Connor, G. W. F. Drake, and Qixue Wu, Observed Suppression of an E1 Allowed Transition in ^{3}He, *Michigan Quantum Summer School*, Ann Arbor, Michigan, June 16-27 (2008).