

Hongwan Liu

PERSONAL DATA

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ADDRESS The Department of Physics at Boston University
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Boston, MA 02215
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WEBSITE <https://hongwanliu.github.io>

EMPLOYMENT

2024 – Assistant Professor of Physics, **Boston University**

2023 – 2024 Fellow, **Kavli Institute for Cosmological Physics, University of Chicago**
Schramm Fellow in Theoretical Astrophysics, **Fermilab**

2019 – 2023 Postdoctoral Associate, **New York University**
Postdoctoral Associate, **Princeton University**

EDUCATION

2014 – 2019 Doctor of Philosophy in Physics, **Massachusetts Institute of Technology**
Dark Matter Energy Deposition and Production from the Table-Top to the Cosmos
Advisor: Tracy R. Slatyer
Committee: Tracy R. Slatyer, Jesse Thaler, Kerstin Perez

2018 – 2019 Visiting Graduate Student, **Institute for Advanced Study**
Advisor: Tracy R. Slatyer

2007 – 2011 Bachelor of Arts, **Cornell University**
Physics, *summa cum laude* | Mathematics, *cum laude*

RESEARCH INTERESTS

I search for physics beyond the Standard Model. My work focuses on 1) the impact of new physics on the cosmic history of our Universe, 2) the particle physics of dark matter, and 3) new experimental and statistical methods to transform our search for new physics.

HONORS AND AWARDS

- 2023 **Schramm Fellowship in Theoretical Astrophysics**, Fermilab
- 2022 **Physics Magazine Focus**, *Dark Matter as an Intergalactic Heat Source*, based on Bolton et al., Phys. Rev. Lett. 129, 211102 (2022)
- 2022 **Physical Review Letters Editors' Suggestion** for Giovanetti et al., Phys. Rev. Lett. 129, 021302 (2022)
- 2021 **American Astronomical Society NOVA Research Highlight**, *Filling in the Blanks with Machine Learning*, based on Dropulic et al., ApJL 915, L14 (2021)
- 2019 **Andrew M. Lockett III Memorial Fund Award**, MIT Physics Department
- 2018 **PITT PACC Travel Award**, University of Pittsburgh PITT PACC
- 2016 **Henry Kendall Teaching Award**, MIT Physics Department
- 2016 **Physical Review D Kaleidoscope** for Liu et al., Phys. Rev. D 94, 063507 (2016)
- 2011 **Yennie Prize**, Cornell Physics Department

PUBLICATIONS AND PREPRINTS

All authors listed alphabetically following the high-energy physics convention, except [†].

- [29] Cara Giovanetti, Mariangela Lisanti, Hongwan Liu, Siddharth Mishra-Sharma and Joshua T. Ruderman, **LINX: A Fast, Differentiable, and Extensible Big Bang Nucleosynthesis Package**, to be submitted to *Physical Review D*, [arXiv:2408.14538](#)
- [28] Cara Giovanetti, Mariangela Lisanti, Hongwan Liu, Siddharth Mishra-Sharma and Joshua T. Ruderman, **Cosmological Parameter Estimation with a Joint-Likelihood Analysis of the Cosmic Microwave Background and Big Bang Nucleosynthesis**, to be submitted to *Physical Review Letters*, [arXiv:2408.14531](#)

PUBLICATIONS AND PREPRINTS (CONTINUED)

All authors listed alphabetically following the high-energy physics convention, except [†].

- [27[†]] Yitian Sun, Joshua W. Foster, Hongwan Liu, Julian B. Muñoz and Tracy R. Slatyer, **Inhomogeneous Energy Injection in the 21-cm Power Spectrum: Sensitivity to Dark Matter Decay**, submitted to *Physical Review D*, [arXiv:2312.11608](#)
- [26[†]] Wenzer Qin, Julian B. Muñoz, Hongwan Liu and Tracy R. Slatyer, **Birth of the First Stars Amidst Decaying and Annihilating Dark Matter**, *Physical Review D* 109, 103026 (2024), [arXiv:2308.12992](#)
- [25] Hongwan Liu, Wenzer Qin, Gregory W. Ridgway and Tracy R. Slatyer, **Exotic Energy Injection in the Early Universe II: CMB Spectral Distortions and Constraints on Light Dark Matter**, *Physical Review D* 108, 043531 (2023), [arXiv:2303.07370](#)
- [24] Hongwan Liu, Wenzer Qin, Gregory W. Ridgway and Tracy R. Slatyer, **Exotic Energy Injection in the Early Universe I: A Novel Treatment for Low-Energy Electrons and Photons**, *Physical Review D* 108, 043530 (2023), [arXiv:2303.07366](#)
- [23] Asher Berlin, Hongwan Liu, Maxim Pospelov and Harikrishnan Ramani, **The Terrestrial Density of Strongly-Coupled Relics**, *Physical Review D* 109, 075027 (2024), [arXiv:2302.06619](#)
- [22] Rennan Barkana, Anastasia Fialkov, Hongwan Liu and Nadav Joseph Outmezguine, **Anticipating a New-Physics Signal in Upcoming 21-cm Power Spectrum Observations**, *Physical Review D* 108, 063503 (2023), [arXiv:2212.08082](#)
- [21] James S. Bolton, Andrea Caputo, Hongwan Liu and Matteo Viel, **Comparison of Low-Redshift Lyman- α Forest Observations to Hydrodynamical Simulations with Dark Photon Dark Matter**, *Physical Review Letters* 129, 211102 (2022), [arXiv:2206.13520](#)
- [20] Andrea Caputo, Hongwan Liu, Siddharth Mishra-Sharma, Maxim Pospelov and Joshua T. Ruderman, **Radio Excess from Stimulated Dark Matter Decay**, *Physical Review D* 107, 123033 (2023), [arXiv:2206.07713](#)

PUBLICATIONS AND PREPRINTS (CONTINUED)

All authors listed alphabetically following the high-energy physics convention, except [†].

- [19[†]] Adriana Dropulic, Hongwan Liu, Bryan Ostlie and Mariangela Lisanti, **Revealing the Milky Way’s Most Recent Major Merger with a *Gaia* EDR3 Catalog of Machine-Learned Line-of-Sight Velocities**, *Monthly Notices of the Royal Astronomical Society* 521, 1633-1645 (2023), [arXiv:2205.12278](#)
- [18] Asher Berlin, Hongwan Liu, Maxim Pospelov and Harikrishnan Ramani, **Low-Energy Signals from the Formation of Dark Matter-Nuclear Bound States**, *Physical Review D* 105, 095028 (2022), [arXiv:2110.06217](#)
- [17] Cara Giovanetti, Mariangela Lisanti, Hongwan Liu and Joshua T. Ruderman, **Joint Cosmic Microwave Background and Big Bang Nucleosynthesis Constraints on Light Dark Sectors with Dark Radiation**, *Physical Review Letters* 129, 021302 (2022), [arXiv:2109.03246](#)
- [16] Patrick J. Fitzpatrick, Hongwan Liu, Tracy R. Slatyer and Yu-Dai Tsai, **New Thermal Relic Targets for Inelastic Vector-Portal Dark Matter**, *Physical Review D* 106, 083507 (2022), [arXiv:2105.05255](#)
- [15[†]] Adriana Dropulic, Bryan Ostlie, Laura J. Chang, Hongwan Liu, Timothy Cohen and Mariangela Lisanti, **Machine Learning the 6th Dimension: Stellar Radial Velocities from 5D Phase-Space Correlations**, *The Astrophysical Journal Letters* 915, L14 (2021), [arXiv:2103.14039](#)
- [14] Patrick J. Fitzpatrick, Hongwan Liu, Tracy R. Slatyer and Yu-Dai Tsai, **New Pathways to the Relic Abundance of Vector-Portal Dark Matter**, *Physical Review D* 106, 083517 (2022), [arXiv:2011.01240](#)
- [13] Andrea Caputo, Hongwan Liu, Siddharth Mishra-Sharma, Maxim Pospelov, Joshua T. Ruderman and Alfredo Urbano, **Edges and Endpoints in 21-cm Observations from Resonant Photon Production**, *Physical Review Letters* 127, 011102 (2021), [arXiv:2009.03899](#)

PUBLICATIONS AND PREPRINTS (CONTINUED)

All authors listed alphabetically following the high-energy physics convention, except [†].

**PhD thesis*.

- [12] Hongwan Liu, Wenzer Qin, Gregory W. Ridgway and Tracy R. Slatyer, **Lyman- α Constraints on Cosmic Heating from Dark Matter Annihilation and Decay**, *Physical Review D* 104, 043514 (2021), [arXiv:2008.01084](#)
- [11] Masha Baryakhtar, Asher Berlin, Hongwan Liu and Neal Weiner, **Electromagnetic Signals of Inelastic Dark Matter Scattering**, *Journal of High Energy Physics* 06, 047 (2022), [arXiv:2006.13918](#)
- [10] Andrea Caputo, Hongwan Liu, Siddharth Mishra-Sharma and Joshua T. Ruderman, **Modeling Dark Photon Oscillations in Our Inhomogeneous Universe**, *Physical Review D* 102, 103533 (2020), [arXiv:2004.06733](#)
- [9] Andrea Caputo, Hongwan Liu, Siddharth Mishra-Sharma and Joshua T. Ruderman, **Dark Photon Oscillations in Our Inhomogeneous Universe**, *Physical Review Letters* 125, 221303 (2020), [arXiv:2002.05165](#)
- [8] Hongwan Liu, Nadav J. Outmezguine, Diego Redigolo and Tomer Volansky, **Reviving Millicharged Dark Matter for 21-cm Cosmology**, *Physical Review D* 100, 123011 (2019), [arXiv:1908.06986](#)
- [7*] Hongwan Liu, **Dark Matter Energy Deposition and Production from the Table-Top to the Cosmos**, [arXiv:1907.04324](#)
- [6] Hongwan Liu, Gregory W. Ridgway and Tracy R. Slatyer, **DarkHistory: A Code Package for Calculating Modified Cosmic Ionization and Thermal Histories with Dark Matter and other Exotic Energy Injections**, *Physical Review D* 101, 023530 (2020), [arXiv:1904.09296](#)
- [5[†]] Hongwan Liu, Brodi D. Elwood, Matthew Evans and Jesse Thaler, **Searching for Axion Dark Matter with Birefringent Cavities**, *Physical Review D* 100, 023548 (2019), [arXiv:1809.01656](#)

PUBLICATIONS AND PREPRINTS (CONTINUED)

All authors listed alphabetically following the high-energy physics convention, except [†].

**PhD thesis*.

- [4] Hongwan Liu and Tracy R. Slatyer, **Implications of a 21-cm Signal for Dark Matter Annihilation and Decay**, *Physical Review D* 98, 023501 (2018), [arXiv:1803.09739](#)
- [3] Gilly Elor, Hongwan Liu, Tracy R. Slatyer and Yotam Soreq, **Complementarity for Dark Sector Bound States**, *Physical Review D* 98, 036015 (2018), [arXiv:1801.07723](#)
- [2] James M. Cline, Hongwan Liu, Tracy R. Slatyer and Wei Xue, **Enabling Forbidden Dark Matter**, *Physical Review D* 96, 083521 (2017), [arXiv:1702.07716](#)
- [1] Hongwan Liu, Tracy R. Slatyer and Jesús Zavala, **Contributions to Cosmic Reionization from Dark Matter Annihilation and Decay**, *Physical Review D* 94, 063507 (2016), [arXiv:1604.02457](#)

COLLOQUIA

Mar 2023 **University of Delaware**, *Discovering the Particle Physics of Dark Matter with Cosmology*

INVITED SEMINARS

[†] *Upcoming*.

May 2024 **Stanford University**, SITP Seminar, *Fast and Differentiable Big-Bang Nucleosynthesis*

Apr 2024 **National University of Singapore**, *Discovering Dark Matter with Cosmology*

Mar 2024 **University of Oklahoma**, High-Energy Physics Seminar, *Fast and Differentiable Big-Bang Nucleosynthesis*

University of Oregon, Institute of Fundamental Sciences Seminar, *Fast and Differentiable Big-Bang Nucleosynthesis*

INVITED SEMINARS (CONTINUED)

- Feb 2024 **University of Illinois Urbana-Champaign**, High-Energy Physics Seminar, *Fast and Differentiable Big-Bang Nucleosynthesis*
- Fermilab**, Theory Seminar, *Exotic Energy Injection in the Early Universe*
- Nov 2023 **University of Michigan**, Brown Bag Seminar, *Exotic Energy Injection in the Early Universe*
- Oct 2023 **City University of Hong Kong**, Research Seminar, *Exotic Energy Injection in the Early Universe*
- Hong Kong University of Science and Technology**, IAS Program on Particle Theory, *Exotic Energy Injection in the Early Universe*
- May 2023 **University of California, Davis**, QMAP Particles/Cosmology Seminar, *Cosmological Signatures of Dark Photons*
- Nanjing Normal University**, Particle Physics Online Seminar Series, *Cosmological Signatures of Dark Photons*
- Mar 2023 **Boston University**, High-Energy Theory Talk, *Discovering the Particle Physics of Dark Matter with Cosmology*
- Mar 2023 **University of Delaware**, Particle Theory Research Talk, *New Signatures of Dark Matter Energy Deposition*
- Dec 2022 **Fermilab**, Cosmic Physics Center Seminar, *A Large New Physics Signal in the 21-cm Power Spectrum*
- Sep 2022 **Lawrence Berkeley National Laboratory**, Particle Theory Seminar, *A Stimulating Explanation of the Extragalactic Radio Excess*
- May 2022 **Boston University**, High-Energy Theory Seminar, *A Stimulating Explanation of the Extragalactic Radio Excess*
- Apr 2022 **Johns Hopkins University**, Theoretical Particle Physics Seminar, *A Stimulating Explanation of the Extragalactic Radio Excess*

INVITED SEMINARS (CONTINUED)

- Apr 2022 **University of Southern California**, Cosmology Seminar, *A Stimulating Explanation of the Extragalactic Radio Excess*
- Mar 2022 **McGill Space Institute**, Astronomy Seminar, *A Stimulating Explanation of the Extragalactic Radio Excess*
- Dec 2021 **University of Maryland**, Elementary Particles Seminar, *Dark Photons and the Cosmic Radiation Background*
- Nov 2021 **Tsung-Dao Lee Institute/Shanghai Jiao Tong University**, DM+ ν Forum, *Low-Energy Signals from the Formation of Dark Matter-Nuclear Bound States*
- BSM PANDEMIC**, Virtual Seminar, *Low-Energy Signals from the Formation of Dark Matter-Nuclear Bound States*
- Cornell University**, Particle Theory Seminar, *Lyman-Alpha Constraints on Cosmic Heating from Dark Matter Annihilation and Decay*
- Oct 2021 **University of California, Berkeley**, 4D Seminar, *New Aspects of Vector-Portal Dark Matter*
- May 2021 **University of California, Los Angeles**, TEPAPP Seminar, *New Aspects of Vector-Portal Dark Matter*
- Apr 2021 **Caltech**, High-Energy Physics Seminar, *Dark Photons and the Cosmic Radiation Background*
- University of Michigan**, Brown Bag Seminar, *Dark Photons and the Cosmic Radiation Background*
- Perimeter Institute**, Particle Physics Seminar, *Dark Photons and the Cosmic Radiation Background*
- Feb 2021 **Stanford University**, SITP Seminar, *Dark Photons and the Cosmic Radiation Background*
- DESY**, Theory Seminar, *New Pathways to the Relic Abundance of Vector-Portal Dark Matter*

INVITED SEMINARS (CONTINUED)

- Jan 2021 **McDonald Institute**, McDonald Institute Seminar Series, *Lyman-Alpha Constraints on Cosmic Heating from Dark Matter Annihilation and Decay*
- Nov 2020 **Massachusetts Institute of Technology**, CTP LHC/DM/BSM/QCD Meeting, *Dark Photon Oscillations in Our Inhomogeneous Universe*
- Jun 2020 **Kavli Institute for Cosmological Physics, The University of Chicago**, KICP Seminar, *Dark Photon Oscillations in Our Inhomogeneous Universe*
- Dec 2019 **Nanyang Technological University**, Physics and Applied Physics Seminar, *Axions, Dark Matter and Light Polarization*
- Nov 2019 **Israeli Joint Particle Physics Meeting**, *Changing the History of the Universe During the Dark Ages*
- Dec 2018 **Fermilab**, Cosmic Physics Center Seminar, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- Perimeter Institute**, Particle Physics Seminar, *Searching for Axion Dark Matter with Birefringent Cavities*
- Dec 2018 **Princeton University**, Pheno & Vino, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- Nov 2018 **New York University**, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- Nov 2018 **The Ohio State University**, CCAPP Seminar, *DarkHistory: A Code for Computing Ionization and Thermal Histories with Dark Matter Energy Injection*
- Oct 2018 **Lawrence Berkeley National Laboratory**, LBNL Theory Seminar, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- SLAC National Accelerator Laboratory**, Elementary Particle Physics Theory Seminar, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*

INVITED SEMINARS (CONTINUED)

*Invited talk. †Upcoming.

- Oct 2018 **University of California, San Diego**, Particle Physics Seminar, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- Brown University**, Astrophysics Seminar, *DarkHistory: A Code for Computing Ionization and Thermal Histories with Dark Matter Energy Injection*
- Sep 2018 **University of California, Irvine**, Joint Particle Seminar, *From the Table-Top to the Cosmos: Searching High and Low for Dark Matter*
- Harvard University**, Particle Physics In-House Luncheon, *Searching for Axion Dark Matter with Birefringent Cavities*
- May 2018 **Harvard-Smithsonian Center for Astrophysics**, Journal Club Seminar, *21-cm Implications for Dark Matter Annihilation and Decay*

CONFERENCES & WORKSHOPS

*Invited talk. †Upcoming.

- Jun 2024* **Kavli Institute for Theoretical Physics Workshop: Cosmic Signals of Dark Matter Physics**, *Fast and Differentiable Big-Bang Nucleosynthesis*, Santa Barbara, California, USA
- Apr 2024* **ALPS 2024**, *Fast and Differentiable Big-Bang Nucleosynthesis*, Obergurgl, Austria
- Dec 2023* **2023 National Center for Theoretical Sciences Annual Theory Meeting**, *Cosmological Probes of Dark Photons*, Taipei, Taiwan
- Nov 2022* **New Physics from Galaxy Clustering**, *Cosmological Signatures of Dark Photons*, CERN, Meyrin, Switzerland
- May 2022* **Physics of this Universe**, *A Stimulating Explanation of the Extragalactic Radio Excess*, Baltimore, Maryland, USA

CONFERENCES & WORKSHOPS (CONTINUED)

**Invited talk.*

- Mar 2022* **Aspen Winter Conference: New Methods and Ideas at the Frontiers of Particle Physics**, *Dark Photons and the Cosmic Radiation Background*, Aspen, Colorado, USA
- Dec 2021* **AstroDark 2021**, *Ionization and Thermal Histories with Dark Matter Energy Injection*, Virtual
- Nov 2021* **Computational Tools for High Energy Physics and Cosmology**, *DarkHistory: A Code for Computing Ionization and Thermal Histories with Exotic Energy Injection*, Virtual
- Aug 2021 **Aspen Summer: Dark Matter from the Laboratory to the Cosmos**, Aspen Center for Physics, Aspen, Colorado, USA
- Mar 2021* **Aspen Winter Conference: A Rainbow of Dark Sectors 2021**, *Cosmological Probes of Dark Matter Energy Deposition*, Virtual
- Jan 2020* **16th Rencontres du Vietnam: TMEX 2020**, *Axions and the Polarization of Light*, Quy Nhon, Vietnam
- Dec 2019 **TeVPA 2019**, *Reviving Millicharged Dark Matter for 21-cm Cosmology*, Sydney, Australia
- Jul 2019 **APS DPF Meeting 2019**, *New Aspects of Millicharged Dark Matter at 21-cm*, Boston, Massachusetts, USA
- Jul 2019 **PASCOS 2019**, *New Aspects of Millicharged Dark Matter at 21-cm*, Manchester, United Kingdom
- Oct 2018* **Beyond Standard Model: Where Do We Go from Here?**, *Axion Detection with Interferometry*, Galileo Galilei Institute, Florence, Italy
- Aug 2018 **TeVPA 2018**, *DarkHistory: A Code for Computing Ionization and Thermal Histories with Dark Matter Energy Injection*, Berlin, Germany
- Jul 2018 **IDM 2018**, *21-cm Implications for Dark Matter*, Providence, Rhode Island, USA

CONFERENCES & WORKSHOPS (CONTINUED)

**Invited talk.*

Jun 2018* **PASCOS 2018**, *21-cm Implications for Dark Matter Annihilation and Decay*, Cleveland, Ohio, USA

May 2018 **Pheno 2018**, *Complementarity for Dark Sector Bound States*, Pittsburgh, Pennsylvania, USA

Aug 2017 **TeVPA 2017**, *Enabling Forbidden Dark Matter*, Columbus, Ohio, USA

May 2017 **Pheno 2017**, *Enabling Forbidden Dark Matter*, Pittsburgh, Pennsylvania, USA

Aug 2016 **Cosmo 2016**, *The Darkest Hour Before Dawn: Contributions to Cosmic Reionization from Dark Matter Annihilation and Decay*, Ann-Arbor, Michigan, USA

TEACHING

Overall student evaluation ratings shown in parentheses.

Massachusetts Institute of Technology

Teaching Assistant 2017 Spring 8.323 **Relativistic Quantum Field Theory I** (6.4/7.0)

2016 Fall 8.033 **Relativity** (6.4/7.0)

2015 Fall 8.033 **Relativity** (6.9/7.0)

MENTORING

Graduate Students

2023 – **Tony Zilu Zhou**, NYU (Advisor: Neal Weiner)

2023 – **Xucheng Gan**, NYU (Advisor: Joshua T. Ruderman)

2022 – 2023 **Zachary Gelles**, Princeton (Advisor: Mariangela Lisanti)

MENTORING (CONTINUED)

- 2022 – **Yitian Sun**, MIT (Advisor: Tracy R. Slatyer)
- 2021 – 2023 **Shira Jackson**, NYU (Advisor: Neal Weiner)
- 2021 – **Giorgi Arsenadze**, NYU (Advisor: Joshua T. Ruderman)
- 2020 – 2023 **Wenzer Qin**, MIT (Advisor: Tracy R. Slatyer)
- 2020 – **Cara Giovanetti**, NYU (Advisor: Ken Van Tilburg)
- 2019 – 2022 **Patrick Fitzpatrick**, MIT (Advisor: Tracy R. Slatyer)
- 2018 – 2022 **Gregory W. Ridgway**, MIT (Advisor: Tracy R. Slatyer)

Undergraduate Students

- 2022 – 2023 **Andreas Tsantilas**, NYU (Advisor: Neal Weiner)
- 2022 – 2023 **Noah Luch**, Princeton (Advisor: Mariangela Lisanti)
- 2019 – 2020 **Cara Giovanetti**, Princeton (Advisor: Mariangela Lisanti)
- 2018 **Brodi D. Elwood**, MIT (Advisor: Matthew Evans)
- 2017 – 2019 **Cannon M. Vogel**, MIT (Advisor: Tracy R. Slatyer)
- 2016 – 2017 **Shi-Fan Stephen Chen**, MIT (Advisor: Tracy R. Slatyer)

High School Students

- 2016 **Gabriel Mintzer**, Research Science Institute, MIT (Advisor: Tracy R. Slatyer)

PROFESSIONAL ACTIVITIES & SERVICE

<i>Peer Review</i>	2019 –	Physical Review Letters, Journal of High Energy Physics, Physical Review D, Physics Letters B, Journal of Cosmology and Astroparticle Physics, The European Physical Journal C.
<i>Conference Organizer</i>	2022	Cosmological and Astrophysical Probes of New Physics, Princeton Center for Theoretical Physics, Princeton
<i>Seminar Organizer</i>	2023 – 2024	Funch, KICP
	2021 – 2022	High-Energy Theory Seminar, NYU
	2021	BSM PANDEMIC Delta Series, Virtual
	2020 – 2021	Pheno & Vino Off-Shell, Princeton, Virtual
	2020	BSM PANDEMIC Double Feature, Virtual
	2019 – 2020	Pheno & Vino, Princeton
	2017 – 2018	Beyond the Standard Model Seminar, MIT

OUTREACH

2022	Presentation to Leonia High School, Leonia, NJ, USA, Online
2022	Presentation to The Bement School, Deerfield, MA, USA, Online
2020	Presentation to Milton Hershey School, Hershey, PA, USA, Online