Omar A. Ashour

Physics PhD Student, UC Berkeley

ashour@berkeley.edu • omarashour.com
Google Scholar • oashour

Research Interests

I am interested in harnessing the interplay between topological order and collective excitations, primarily phonons and magnons, to develop new quantum sensing schemes for direct dark matter detection applications. My work employs various analytical and computational tools, such as density functional (perturbation) theory, tight-binding models, and spin Hamiltonians, to elucidate the electronic, magnetic, and vibrational properties of quantum materials. Additionally, I utilize effective field theories to study dark matter interaction with such materials.

Education

PhD, Physics 2019 – May 2025
University of California, Berkeley *Advisor:* Sinéad M. Griffin
Research Area: Theoretical and Computational Condensed Matter Physics

MA, Physics 2019 – 2020
University of California, Berkeley

MS, Applied Physics (AS&T, College of Engineering) 2017 – 2019
University of California, Berkeley
Thesis: The Nonlinear Schrödinger Hierarchy: from Quasi Rogue Waves to Nonlinear Talbot Carpets GPA: 3.90

BS, Electrical Engineering (Optics) 2013 – 2017
Texas A&M University
Thesis: Maximal Intensity Higher-Order Breathers of the Nonlinear Schrödinger Equation GPA: 4.00

Selected Research Projects

Advancing Quantum Sensing: Quantum Materials for Dark Matter Detection PI: Sinéad Griffin
Consortium: Quantum Information Science Enabled Discovery (QuantISED-HEP).

- Introduced a novel approach to direct dark matter detection by harnessing symmetry-breaking triggered by collective excitations (phonons and magnons) to gap out topological surface states.
- Utilized analytical models, effective field theories, and massively parallel numerical methods to demonstrate the validity of our proposal and estimate relevant energy, time, and length scales.
- Collaborated with high-energy physicists, quantum information scientists, and materials scientists to assess the feasibility of the proposed read-out mechanism given current, near-term, and next-generation experimental capabilities.
- Developed several Python and Julia packages, soon to be open-sourced, and contributed to Python and FORTRAN projects that were instrumental in calculating and analyzing material properties and interactions with dark matter.

Efficient Solvers for Nonlinear Schrödinger-type PDEs in Julia [arXiv] Independent Project

- Conceived and developed the Julia package `NonlinearSchrodinger.jl` from the ground up, specifically tailored for efficiently solving classically integrable nonlinear Schrödinger-type partial differential equations (PDEs).
- Implemented the Darboux transformation method to compute analytical solutions of PDEs with as many as 18 terms.
- Fine-tuned 32 numerical algorithms that optimize performance within this specialized problem domain, emphasizing an approach that enables rapid modeling on personal computers.
- Augmented the package with a user-friendly API and data visualization tools, enabling the computation and analysis of complex solutions with only a few lines of code.

Insights into the Nonlinear Schrödinger Hierarchy of PDEs PI: Siu Chin

- Derived and proved several mathematical results within the hierarchy, including the peak-height formula for arbitrary solutions and the Lax pair for analytically solving the quintic nonlinear Schödinger equation with up to 18 terms.
- Proposed the concept of quasi-rogue waves, nonlinear waves with destructively interfering periodic components, to explain the rarity of truly periodic higher-order solutions in nature.
- Devised an experimentally feasible scheme for generating complex solutions in optical fibers using frequency combs.
- Utilized analytical methods like Darboux transformations, complemented with numerical approaches such as finite differences and symplectic integrators implemented in MATLAB and C/C++ with CUDA and MPI.

Selected Fellowships and Awards

Ovshinsky Travel Award, American Physical Society, Division of Materials Physics 2024

Berkeley Graduate Fellowship, University of California, Berkeley 2017 – 2019

Anselmo J. Macchi Graduate Fellowship, University of California, Berkeley 2018 – 2019

Cornell Graduate Fellowship, Cornell University (declined) 2017

Richard E. Ewing Award for excellence in student research, Texas A&M Univeristy 2016

Skills and Tools

Condensed Matter and Materials	Density functional (perturbation) theory; many-body perturbation theory (GW/BSE); tight-binding models; spin Hamiltonians; linear spin wave theory; Wannier functions.
Numerical Skills	Nonlinear, coupled, and diffusion PDEs; finite differences; symplectic integrators.
Programming	Python; Julia; MATLAB; FORTRAN; C/C++.
High-Performance Computing	Nine years of experience with HPC clusters. Proficient in CPU (MPI, OpenMP) and GPU computing (OpenACC, CUDA-aware MPI) and massively parallel applications.
Dev Tools	Git; CI/CD; containerization (Docker, Singularity); Kubernetes.

Mentoring and Community Service

Undergraduate Mentoring (2021–): I have mentored multiple summer intern cohors at LBL, and supervised several undergraduate research projects.

Scientist Ambassador (2020): I spent four weeks as an ambassador to a first-grade class, teaching them about the day-to-day life of a scientist.

Be A Scientist (2018): I worked with students at a local middle school for six weeks to design and conduct science experiments and foster critical thinking skills.

Addendum: Publications and Preprints

⋆ Equal Contribution † Corresponding Author

2024 **Omar A. Ashour** and Sinéad M. Griffin. Solid helium as a pressure tunable dark matter detector, *(in preparation)* (2024).

2024 **Omar A. Ashour** and Sinéad M. Griffin. Phonon-based topological quantum sensors for dark matter detection, *(in preparation)* (2024).

2023 Na Hyun Jo⋆, **Omar A. Ashour**⋆, Zhixue Shu, Chris Jozwiak, Aaron Bostwick, Sae Hee Ryu, Kai Sun, Tai Kong, Sinéad M. Griffin, and Eli Rotenberg. On the effects of strain, defects, and interactions on the topological properties of $HfTe_5$ (2023). [arXiv:2303.10836]

2023 Thomas F. Harrelson, Ibrahim Hajar, **Omar A. Ashour**, and Sinéad M. Griffin. Theoretical investigation of decoherence channels in athermal phonon sensors (2023). [arXiv:2109.10988]

2022 **Omar A. Ashour**†, Siu A. Chin, Stanko N. Nikolić, and Milivoj R. Belić. Higher-order breathers as quasi-rogue waves on a periodic background, *Nonlinear Dynamics*, **107**, 3819–3832 (2022).

2022 Stanko N. Nikolić, Sarah Alwashahi, **Omar A. Ashour**, Siu A. Chin, Najdan B. Aleksić, and Milivoj R. Belić. Multi-elliptic rogue wave clusters of the nonlinear Schrödinger equation on different backgrounds, *Nonlinear Dynamics*, **108**, 479–490 (2022).

2022 Thais Chagas⋆, **Omar A. Ashour**⋆, Guilherme Ribeiro, Wendell Silva, Zhenglu Li, Rogério Magalhães-Paniago, Yves Petroff, and Steven G. Louie. Multiple strong topological gaps and hexagonal warping in Bi_4Te_3, *Physical Review B*, **105**, L081409 (2022).

2022 Milivoj R. Belić, Stanko N. Nikolić, **Omar A. Ashour**, and Najdan B. Aleksić. On different aspects of the optical rogue waves nature, *Nonlinear Dynamics*, **108**, 1655–1670 (2022).

2021 **Omar A. Ashour**†. NonlinearSchrodinger: higher-order algorithms and Darboux transformations for nonlinear Schrödinger equations (2021). [arXiv:2103.14469]

2019 Stanko N. Nikolić, **Omar A. Ashour**, Najdan B. Aleksić, Yiqi Zhang, Milivoj R. Belić, and Siu A. Chin. Talbot carpets by rogue waves of extended nonlinear Schrödinger equations, *Nonlinear Dynamics*, **97**, 1215–1225 (2019).

2019 Stanko N. Nikolić, **Omar A. Ashour**, Najdan B. Aleksić, Milivoj R. Belić, and Siu A. Chin. Breathers, solitons and rogue waves of the quintic nonlinear Schrödinger equation on various backgrounds, *Nonlinear Dynamics*, **95**, 2855–2865 (2019).

2017 Stanko N. Nikolić, Najdan B. Aleksić, **Omar A. Ashour**, Milivoj R. Belić, and Siu A. Chin. Systematic generation of higher-order solitons and breathers of the Hirota equation on different backgrounds, *Nonlinear Dynamics*, **89**, 1637–1649 (2017).

2017 Runze Li, **Omar A. Ashour**, Jie Chen, H. E. Elsayed-Ali, and Peter M. Rentzepis. Femtosecond laser induced structural dynamics and melting of Cu (111) single crystal: an ultrafast time-resolved x-ray diffraction study,*Journal of Applied Physics*, **121**, 055102 (2017).

2017 Siu A. Chin, **Omar A. Ashour**, Stanko N. Nikolić, and Milivoj R. Belić. Peak-height formula for higher-order breathers of the nonlinear Schrödinger equation on non-uniform backgrounds, *Physical Review E*, **95**, 012211 (2017).

2016 Siu A. Chin, **Omar A. Ashour**, Stanko N. Nikolić, and Milivoj R. Belić. Maximal intensity higher-order Akhmediev breathers of the nonlinear Schrödinger equation and their systematic generation, *Physics Letters A*, **380**, 3625–3629 (2016).

2015 Siu A. Chin, **Omar A. Ashour**, and Milivoj R. Belić. Anatomy of the Akhmediev breather: cascading instability, first formation time, and Fermi-Pasta-Ulam recurrence, *Physical Review E*, **92**, 063202 (2015).