U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Science Graduate Student Research

2022 Solicitation 2 - Application for: Tyler Chase Sterling

APPLICANT PROFILE

General Applicant Information

First Name:	Tyler
Middle Name:	Chase
Last Name:	Sterling
Previous Last Name(s):	
Primary Email Address:	ty.sterling@colorado.edu
Alternate Email Address 1:	
Alternate Email Address 2:	

Current Address

Country:	United States
Address:	4949 Eisenhower Dr. Apt. C
City:	Boulder
State/Province/Territory:	CO
Zip Code:	80303
Primary Phone Number:	254-368-8996
Alternate Phone Number:	

Permanent Address

Country:	United States
Address:	4949 Eisenhower Dr
City:	Boulder
State/Province/Territory:	CO
Zip Code:	80303-9137

Citizenship / Eligibility Information

I will be 18 years of age or older by the time the internship begins:	Yes
Are you a U.S. Citizen?	Yes

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EDUCATIONAL BACKGROUND

Undergraduate Education

College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Texas
College/University Name:	Texas State University
College/University Department:	Engineering
College/University Address:	Ingram School of Engineering 601 University Drive San Marcos, TX 78666
College/University City:	San Marcos
College/University Zip Code:	78666-4615
Major:	Other - Engineering - Manufacturing
Graduation Date:	05 / 2016
Degree:	B.S.
Cumulative GPA (on a 4.0 scale):	3.91

Graduate Education Status

Are you currently enrolled as a full-time graduate student in a Ph.D. program?	Yes
Do you plan to be enrolled as a full-time graduate student during the proposed research project period?	Yes
Current Status in Ph.D. Program:	Year 4

Current Graduate Institution

Have you obtained your Ph.D. candidacy at your current graduate institution?	Yes
Does your Official Graduate Transcript explicitly indicate your Ph.D. candidacy?	No
Alternative Official Ph.D. Candidacy Documentation Upload:	ProofOfCandidacy_TylerSterling_2022.pdf
College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Colorado
College/University Name:	University of Colorado Boulder
College/University Address:	2000 Colorado Ave, Boulder, CO 80309
Department Name:	Physics
Start Date of Enrollment:	08 / 2019
End Date of Enrollment:	12 / 2024
Field of Study:	Condensed Matter
Credit Type:	Semester
Credit Hours Enrolled/Completed:	63.00
Transcript:	40167424-OfficialElectronicPDFTranscript.pdf

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Additional Graduate Education

College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Colorado
College/University Name:	University of Colorado Boulder
College/University Department:	Materials Science
Graduation Date:	05 / 2019
Degree Completed:	M.S.
Field of Study:	Materials Science

Primary Graduate Thesis Advisor

Is your primary graduate thesis advisor at your current graduate institution?	Yes
College/University Country:	United States and U.S. Territories
College/University State/Province/Territory:	Colorado
College/University Name:	University of Colorado Boulder
College/University Address:	2000 Colorado Ave, Boulder, CO 80309
College/University City:	Boulder
College/University Zip Code:	80309-0001
First Name:	Dmitry
Last Name:	Reznik
Department Name:	Physics
Position Title:	Professor
Office Country:	United States
Office Street Address:	2000 Colorado Ave, Boulder, CO 80309
Office City:	Boulder
Office State/Province/Territory:	Colorado
Office Zip Code:	80309
Office Phone:	303-492-2031
Office Email:	dmitry.reznik@colorado.edu

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Graduate Thesis Abstract

Title of Graduate Thesis (or Working Title): Physics of Energy Materials Investigated by Neutron Scattering

Abstract:

"Energy materials" is a broad class with potential applications in energy technology. So far, even the atomic structures of many frontier energy materials are not well understood (cf. structure-function relationship). The complex nature of energy materials very often leads to novel basis physics and new phenomena. There is a need to understand the properties and basic physics to create new theories and technologies. Perhaps the most powerful method for studying materials is neutron scattering. Neutrons scatter from the atoms so are able to resolve both the structure and dynamics of the lattice ("lattice dynamics"). However, the scattering intensity is very complicated and its understanding can usually only be achieved when combined with atomistic models.

In this work, (i) the local atomic structure of hybrid perovskite $CH_3NH_3PbI_3$ is measured with neutron diffuse scattering and compared to intensity calculated from classical molecular dynamics. Within the "cubic" room temperature phase, two-dimensional regions of correlated rotations that locally look like "pancakes" of the tetragonal phase were identified. (ii) We show that occupational disorder in the Ga/Ge sublattice in the clathrate thermoelectric $Ba_8Ga_{16}Ge_{30}$ splits the low energy optical phonons. The splitting effectively flattens a larger energy range of the acoustic modes than in the absence of disorder, further suppressing the thermal conductivity by ~30%.

(iii) The electroluminescing (EL) state of relaxors is investigated via in situ neutron diffuse scattering and atomistic modelling. The EL state is a new phase of matter created by applying a moderate E-field to a crystal and then very briefly heating it above room temperature. The crystal begins to glow and the structure, mechanical, and optical properties change drastically. We use neutron scattering and modelling to resolve the local atomic structure of the EL state.

PROFESSIONAL BACKGROUND

Prior Scientific Research Experience

Experience #1: As an undergrad studying manufacturing engineering at Texas State University, I was involved in manufacturing research. I was tasked with prototyping some aluminum heat sinks; they were oddly shaped, so would eventually be 3D-printed to reduce manufacturing cost. I was supposed to machine the prototypes from fancy alloys and characterize their performance. I realized that the microstructure of the 3D-printed part would be very different from the alloy and that we needed to include this artifact into our study. I proposed to investigate this issue more carefully, but graduated and had to leave the project before I could make progress. This experience is what led me to pursue a PhD: initially I was a PhD student in materials science studying thermal transport. See research experience #2 for details of that experience.

Experience #2: As a PhD student in materials science, I spent 2 years using classical molecular dynamics simulations to study phonons and lattice thermal conductivity in various materials. Mostly I worked on semiconductor heterostructures: superlattices, different geometries, etc. I was specifically interested in thermal conductance as a function of phonon frequency. I also studied the effects of interstitial defects in bulk silicon (we published this work in Phys. Rev. B 99, 014207). I became gradually more fascinated by the fundamental aspects of lattice dynamics. In particular, I wanted to understand how dispersions (something very familiar from calculations but otherwise very abstract) were observed in real life. I eventually was “in too deep” and changed both majors and labs to study physics in earnest.

Experience #3: As a PhD student in physics, I have applied neutron scattering combined with modelling to many problems: (i) In the parent compound of high-Tc superconductors, La_2CuO_4, I studied the coupling of the optical phonons to the charge through the Hubbard-U correction to DFT (Phys. Rev. B 104, 134311). The results were compared to inelastic scattering experiments on different hole concentrations across the metal-insulator transition. We deduced that certain optical phonons anomalously soften due to a decrease in the charge compressibility in the metal phase. (ii) The phonon calculations for this project were later used to study a low temperature structural phase transition in La_2CuO_4 (Phys. Rev. B 104, 014304). (iii) More recent work was done on $La_{1.75}Sr_{0.25}NiO_4$. We measured the dispersions across a static-to-dynamic CDW phase transition and found anomalies in the phonons that couple strongly to the charge. I will model this system using many body methods.

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Scientific Publications and Presentations

Publication Type:	Archival Publication - Peer Reviewed Scientific or Technical Journal Article
Article Title:	Effect of the electronic charge gap on LO bond-stretching phonons in undoped La2CuO4 calculated using LDA+U
Author(s):	Tyler C. Sterling, Dmitry Reznik
Journal Name:	Physical Review B
Publication Volume:	104
Publication Issue Number:	13
Publication Page Numbers:	134311
Publication Publisher:	2021
Publication Type:	Archival Publication - Peer Reviewed Scientific or Technical Journal Article
Article Title:	Reinvestigation of crystal symmetry and fluctuations in La2CuO4
Author(s):	Aashish Sapkota, Tyler C. Sterling, Pedro M. Lozano, Yangmu Li, Huibo Cao, Vasile O. Garlea, Dmitry Reznik, Li Qiang, Igor A. Zaliznyak, Genda D. Gu, John M. Tranquada
Journal Name:	Physical Review B
Publication Volume:	104
Publication Issue Number:	
Publication Page Numbers:	014304
Publication Publisher:	2022
Publication Type:	Presentation - Conference, Workshop, or Symposium
Title of Talk:	The Nature of Local Dynamic Order in CH3NH3PbI3
Author(s):	Tyler C. Sterling, Nicholas J. Weadock, Ballal Ahammed, Elif Ertekin, Michael Toney, Dmitry Reznik
Conference, Workshop, or Symposium Name:	American Conference on Neutron Scattering
Presentation Type:	Oral Presentation
Conference, Workshop, or Symposium Location:	Boulder, CO
Conference, Workshop, or Symposium Date:	6/6/2022

Academic Awards & Honors

None entered

PROGRAM INFORMATION

Eligibility

Are you currently conducting research at a DOE Laboratory? **OR** **Have you conducted graduate level research at a DOE Laboratory for an accumulative duration of 3 or more months in the past?**	No

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Association with DOE Office of Science

Research Area:	BES - Data and Computational Sciences for Materials and Chemical Sciences
Current Status:	I am a graduate student in the university group working under a faculty member who is currently a Principal Investigator (PI) on an Office of Science research award.

Current Graduate Support

Type of Support:	Combination of Research Assistantship and Teaching Assistantship
Support Level:	$2,400
Funding Source:	U.S. Federal Government
Funding Agency or Organization:	U.S. Department of Energy
DOE Award Number:	DE-SC0006939
Project Title:	Inelastic Neutron and X-ray Scattering Investigation of Electron-Phonon Effects in Quantum Materials

Previous Participation

None entered

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RESEARCH PROPOSAL

Host DOE Laboratory and Collaborating DOE Laboratory Scientist

Proposed Host DOE Laboratory:	Oak Ridge National Laboratory (ORNL)
Collaborating Scientist First Name:	Feng
Collaborating Scientist Last Name:	Ye
Collaborating Scientist Division/Department:	Neutron Scattering Division
Collaborating Scientist Position Title:	Instrument Scientist
Collaborating Scientist Email:	yef1@ornl.gov
Collaborating Scientist Phone:	865-576-0931
Collaborating Scientist State:	Tennessee

Proposed Research Project

Title of SCGSR Research Proposal	Probing the Non-Equilibrium Process of Electroluminescence Via in situ Neutron Diffuse Scattering
SCGSR Research Proposal Abstract:	It was recently demonstrated that application of a moderate electric field at elevated temperatures modifies materials' structural, electrical, optical, and other properties turning them effectively into new materials. When the field is applied and the material is heated above room temperature very briefly, its electrical conductivity increases dramatically and it begins to glow in an electroluminescence (EL) like phenomenon described as "flash." The physical mechanisms behind this process and the properties of the new materials that it creates are not understood. Even more puzzling, it was recently shown that applying a magnetic field to a sample undergoing EL causes nearby materials to EL too. We propose to perform in situ neutron diffuse scattering (NDS) experiments under simultaneous electric and magnetic fields. An apparatus for in situ electric field experiments already exists and we have used it to prove that in situ NDS can be used to probe the EL state. We plan to modify the apparatus to work under simultaneous electric and magnetic fields. We will apply these new tools to a technologically important class of materials: relaxors. The first step will be to solve for the response of the local atomic order to applied fields. Then we will develop computational models for the non-equilibrium many body processes involved in EL.
Research Proposal:	SCGSR_TylerSterling_2022.pdf

Additional Project Information

Proposed Project Period Start Date:	6/12/2023
Proposed Project Period End Date:	5/31/2024
Will any Office of Science scientfic user facilities be used in your project?	Yes
User Facility:	Spallation Neutron Source (SNS)
Is the proposed work contingent upon successful selection of a pending proposal to a user facility?	No
Will the access and time to the scientific facility be secured in time for the proposed research project period?	Yes

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Anticipated Graduate Training

Graduate Training and Research Skills:	I have 2 learning goals: (i) I want to be an expert at the hands-on parts of neutron scattering. A 1 year stay at ORNL is the ideal way to achieve this. I have experience running experiments on ARCS, but neutron scattering is complicated and there is much to learn about data reduction and the instrumentation before I am confident that I produce reliable results. (ii) I want experience developing computational materials science codes. I have written codes for analyzing data and post processing calculations, but I have not developed cutting edge packages. To that end, we plan to measure a novel, non-equilibrium phase of matter. Since the properties of this phase are unknown, it is expected that tools to model it do not exist. To model the new phase, I will learn to add new functionality to existing codes. These goals are critical to learn during my stay at ORNL because I plan to mentor my own students in the future and can only pass these skills on if I learn them myself now.

Relevance of Proposed Research Project to the DOE Office of Science Mission Areas

Proposed SCGSR Research Project Alignment with BES - Data and Computational Sciences for Materials and Chemical Sciences:	The proposed research is closely aligned with 3.f: *Data and Computational Sciences for Materials and Chemical Sciences.* In particular, we are proposing to study the novel field-driven, non-equilibrium, electroluminescing (EL) phase in relaxors using neutron diffuse scattering and modelling. This work, which is related to both data science and computational methods, can be divided into two "stages": (i) NDS provides "big-data" requiring novel methods and tools. We will create enormous experimental datasets that will serve as both reference data and for coming up with new models. We will also need to develop new tools for modelling the structure: algorithms and codes exist for modelling diffuse scattering, but new types of previously unknown defects may exist in the EL state and identifying the local order will require developing new tools. (ii) Once we have identified the structure of the non-equilibrium EL phase, the heavy modelling work begins: we will need to use many body tools to understand the non-equilibrium physics involved in creating the EL state. EL is a new phenomenon, representing a new phase of matter: it's unlikely that methods exist to model it.

LETTERS OF SUPPORT

Letter of Support 1:	**First Name:** Dmitry **Last Name:** Reznik **Email:** dmitry.reznik@colorado.edu **Type:** Primary Graduate Thesis Advisor **Status:** Received 11/6/2022
Letter of Support 2:	**First Name:** Feng **Last Name:** Ye **Email:** yef1@ornl.gov **Type:** Collaborating DOE Laboratory Scientist **Status:** Received 11/8/2022

It was recently demonstrated that application of a moderate electric field (E-field) at elevated temperatures modifies structural, electrical, optical, and other properties of a vast majority of crystalline and polycrystalline materials effectively turning them into new materials. For example, when a $\sim$100 V/cm E-field is applied to a single crystal of rutile TiO_2, and it is very briefly heated far above room temperature, its electrical conductivity increases dramatically and it begins to glow in an electroluminescence (EL) like phenomenon described as "flash" [1]. Materials revert to their original state when the E-field has been removed, but the new state can be effectively frozen in via a liquid nitrogen quench. EL in polycrystalline materials was originally attributed to Joule heating at grain boundaries [1], but the discovery of EL in single crystals casts doubt on this model, revealing that little is understood. This is a very active area of basic science as well as technology (e.g. ceramics sintering). The discovery paper has been cited nearly 1000 times [2], 100's of papers have already have been published, and many patents issued in the last 15 years.

There are two main challenges in this field: (i) to understand the underlying microscopic mechanism and (ii) to learn how to harness it to create new materials. Both will be addressed in the proposed project where we aim to investigate the effect of EL under the E-field as well as under a combination of the E-field and magnetic field (B-field) on materials with great scientific and technological importance: relaxor ferroelectrics ("relaxors"). Relaxors exhibit strongly frequency and temperature dependent dielectric properties; this behavior is believed to be related to "short ranged polar order" (SRPO) itself due correlated ordering of the ions in the crystal. Relaxors form polarized domains that respond non-trivially to applied fields: the field response makes them novel candidates to study under EL conditions.

To understand the local ordering and its response to applied fields, we plan to probe the crystal at the atomic scale by neutron diffuse scattering. Diffuse scattering provides a huge volume of extremely complicated data ("big-data") requiring the use of advanced analysis tools and simulations. Moreover, the only way to make sense of the physics encoded in the data is with novel computational models: the physics we aim to study involves an interacting system of electrons, photons, and phonons driven far from equilibrium. Modelling this phenomenon will require the use and development of cutting-edge tools (cf. the *Computational Materials Science* program). We propose to use a hybrid approach combing the big-data from neutron diffuse scattering (NDS) with advanced computational methods to study the EL state in the classic relaxor PMN-PT. Precisely what advanced computation tools are needed (density functional theory, molecular dynamics simulations, Monte Carlo, many body methods, etc.) will remain unknown until the local structure of the EL state is understood: this is our first goal.

With the technical help from the SNS engineering team, we have already designed and commissioned an apparatus for *in situ* NDS measurements of samples under controlled E-field and high temperatures at the CORELLI diffractometer. CORELLI combines the high efficiency of white-beam Laue diffraction with energy discrimination, which enables users to measure both elastic scattering and total scattering signals from a single experiment over large volumes of reciprocal space, with sufficient Q resolution to distinguish the diffuse signal from strong Bragg peaks.

The first set of measurements using this *in situ* apparatus on a prototypical "flash" material, rutile TiO_2, has already completed and the analysis/simulations are well under way (Fig. 1). The original hypothesis for the mechanism of EL in TiO_2 was based on a formation of Frenkel pairs where oxygen atoms jump into interstitial sites [1]. However, our simulations based on this model predict broad diffuse scattering shoulders (Fig. 1**c**), whereas the experiment shows "porcupine"-like structures with long needles in reciprocal space implying planar dislocations (Fig. 1**a**). Our

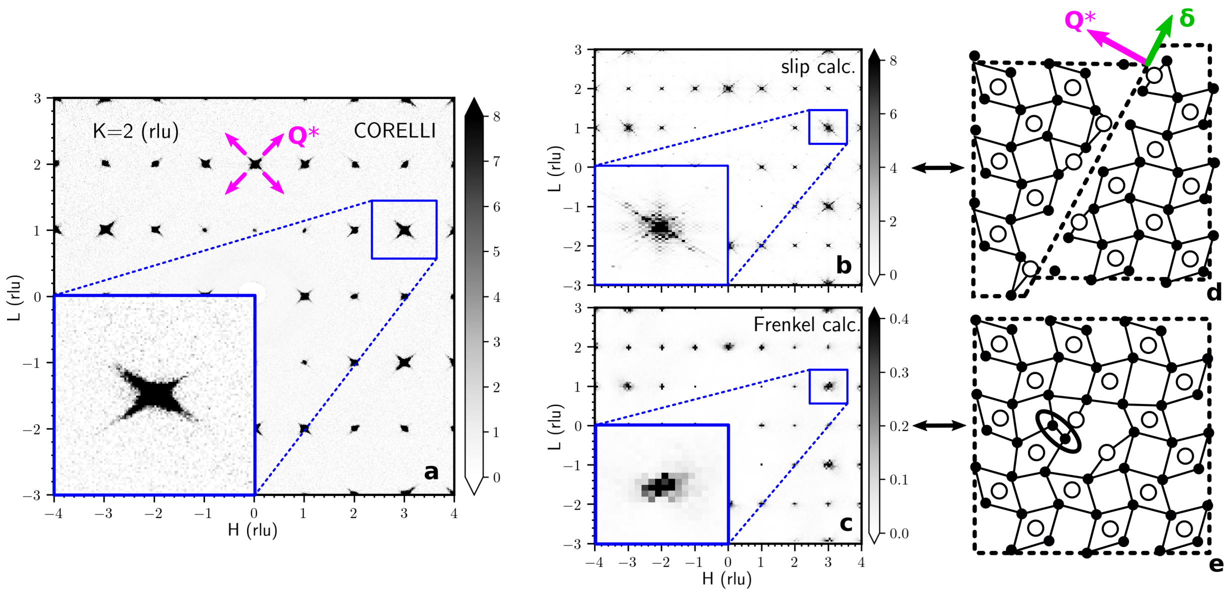

Figure 1: Quenched electroluminescing rutile TiO_2 measured on CORELLI **a** compared to calculations with planar slip defects **b** and with oxygen Frenkel defects **c**. Only the slip defects reproduce the needles seen in the NDS experiment. **d** A cartoon diagram of a slip defect in TiO_2. **e** A cartoon of an oxygen Frenkel defect. The atoms relax contributing the broad scattering in **c**.

new calculations based on planar defects describe the experimental data well (Fig. 1**b**). The next step is to understand the effect of these dislocations on bulk properties as well as the origin of their formation: we will use computational modelling where Tyler C. Sterling has expertise. The work on TiO_2 proves the feasibility of this proposal and can be considered as a "seed" of a much broader and deeper effort.

This proposal is also based on another recent development. Our collaborators at the University of Colorado (Raj group) have discovered a "proximity effect": an electroluminescing sample under applied magnetic field ($\sim$ 0.05 Telsa) induces EL of another piece of ceramic crystal placed in close proximity (patent pending). This discovery points to a way to use EL to manipulate samples to which electrical leads cannot be attached (e.g. rapid sintering of dental crowns is under development). Development of an *in situ* apparatus that allows simultaneous application of a moderate B-field with the E-field with temperature from 100 K to 750 K is expected to be complete by the start of the fellowships. The sample environment upgrade will make it possible perform *in situ* experiments under simultaneous E and B-fields on CORELLI and other neutron scattering instruments at the SNS. Tyler will then use these new capabilities for *in situ* experiments on relaxors.

It has been definitively shown that polycrystalline $BaTiO_3$ based relaxors can enter the EL state [3]. However, no *in situ* analysis of the EL state has been carried out nor have there been any EL experiments on single crystal relaxors. Compared to the previous *in situ* experiments, the EL conditions introduce significant yet controlled structural defects, which can be quenched by immersion into LN_2. The work we propose will investigate a classic, commercially available relaxor PMN-PT. We will require $\sim$7 days of beam time at CORELLI (coordinated by the collaborating scientist Dr. Feng Ye) for the NDS experiment. The experiment (and its analysis) can be divided into 3 conceptual stages that are aimed to address the following specific scientific problems:

(i) **"Reference" material:** previous NDS experiments have revealed several different features that correspond to different types of local order. Most have only looked at one of the features, the "butterfly," in a small subset of reciprocal space ("Q-space"). Recent experiments by Dr. Feng Ye and collaborators [4] showed that the features vary in an unexplained way in other parts of Q-space and that the "butterfly" scattering is uncorrelated with relaxor behavior. Both of these discoveries exemplify the need to look at a larger volume of Q-space to understand the ground state of relaxors. Other (non-EL) experiments under applied E-field [5] have shown how the diffuse scattering responds to E-field: this puts important constraints on a valid model for SRPO. However, the studies under applied field have looked mainly at the butterfly in small regions of Q-space. By measuring and simulating a larger volume of Q-space outside of the EL state, we will gain new insights into the normal nonluminescing phase and establish a necessary "reference" with which to compare measurements in the EL state.

(ii) **EL under E-field:** the EL state represent a dramatic change from the normal state: there are drastic changes to many properties, effectively resulting in a new phase of matter that is stabilized under non-equilibrium steady state conditions. To understand the nature of this phase, we first need to understand its local structure. We will do this with *in situ* NDS and modelling: the proposed experiment on CORELLI will measure a huge amount of Q-space with excellent resolution. Modelling these data will solve the local structure as was already done in TiO_2 in Fig. 1. Then we will develop computational models for the non-equilibrium many body processes involved in EL.

(iii) **EL under simultaneous E and B-fields:** Our collaborators found that even a small B-field on a sample in the EL state has a measurable and nontrivial effect on bulk properties, but little is known about how it modifies the local structure. With the apparatus proposed above, we will be able to investigate the non-equilibrium effects on the atomic structure directly via *in situ* NDS experiments. Based on observed changes to bulk propereties we expect to see a new behavior when the B-field is applied. The response of the local order will be apparent in the *in situ* NDS experiments, providing another angle from which to study the EL state and the non-equilibrium processes involved in its formation.

We estimate that about 6-8 days of beamtime (1 day to set up + 12 hrs per run, with runs with no field, E-field alone and combination of E and B-field) will be needed. These will be scheduled near the beginning of Tyler's stay. Then Tyler will work with Dr. Feng Ye and others to develop and use computational tools necessary to solve the local structure and go beyond. We hope to make tremendous progress on understanding the non-equilibrium physics of the EL state in relaxors.

This work will be central to Tyler C. Sterling's doctoral dissertation: *Physics of Energy Materials Investigated by Neutron Scattering*. Already several related projects have been completed. Some have required inelastic neutron scattering, some neutron and xray diffuse scattering, and all of them have included computational modelling. The work outlined in this proposal will combine existing tools and skills with newly developed instrumentation and models to explore both the basic physics and properties of non-equilibrium EL in relaxors. This latter work will be the main focus of Tyler's dissertation.

[1] Bola Yoon et al. In: *Journal of the American Ceramic Society* 101.5 (2018), pp. 1811–1817.
[2] Marco Cologna, Boriana Rashkova, and Rishi Raj. In: *Journal of the American Ceramic Society* 93.11 (2010), pp. 3556–3559.
[3] Ahmed Taibi et al. In: *Ceramics International* 47.19 (2021), pp. 26947–26954.
[4] Matthew J Krogstad et al. In: *Nature materials* 17.8 (2018), pp. 718–724.
[5] Guangyong Xu et al. In: *Nature materials* 5.2 (2006), pp. 134–140.

University of Colorado Boulder

Department of Physics

390 UCB
Boulder, Colorado 80309-0390
(303) 492-6952, Fax: (303) 492-3352

November 4, 2022

U.S. Department of Energy
Office of Science
Graduate Student Research Program

To the SCGSR Review Committee:

This letter serves to validate the candidacy of Tyler Sterling for a Ph.D. in Physics from the University of Colorado.

Tyler Sterling has maintained status as a full-time graduate student since Fall 2017 and has completed all the requirements for Ph.D. candidacy in the Department of Physics at the University of Colorado Boulder as of October 26, 2022.

The graduate program requirements for a PhD through the Department of Physics can be found on our website at https://www.colorado.edu/physics/academics/graduate-students/graduate-program-requirements-phd. In particular, the requirements for Admission to Candidacy include the prerequisites of passing Comprehensive Examination Parts I and II while maintaining a 3.0 GPA, which he has done. Passing Comprehensive Exam III, described at https://www.colorado.edu/physics/academics/graduate-students/graduate-program-requirements-phd/comps-iii, is the last step for Admission to Candidacy. Tyler passed this exam on October 26, 2022, and therefore has fulfilled all the requirements for Ph.D. candidacy.

Thank you for considering Tyler Sterling as a candidate for the Office of Science Graduate Student Research Program.

Sincerely,

Michael Ritzwoller
Professor, Chair, Department of Physics

University of Colorado
Boulder

Office of the Registrar
Transcripts Department
Regent Administrative Center 101
20 UCB
Boulder, Colorado 80309

t 303.492.6970
f 303.492.4884
transcriptinfo@colorado.edu

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NAME: Sterling, Tyler Chase
STUDENT NR: [redacted] BIRTHDATE : [redacted]
PRINT DATE: 10/20/2022

Issued To: DOCUMENTID: 004729500
Tyler Sterling

Requested By: Tyler Chase Sterling

Degrees, Certificates and Licensure

Master of Science DEC 19, 2019
CU Boulder
Coll Engineering & AppSci GRAD
Major : Materials Science&Engineering

Other Institutions Attended:

HIGHER EDUC. INSTITUTIONS: Central Texas College
Killeen TX 08/10 - 05/12

Texas State Univ
DEGREE: BAC 05/2016
San Marcos TX 08/12 - 05/16

COURSE TITLE	CRSE NR	UNITS	GRADE	PNTS
--------- Fall 2017 CU Boulder ------				
Coll Engineering & AppSci GRAD	Materials Science&Engineering			
Sp Tp: Mechnical Engineering	MCEN 5228	3.0	A	12.00
Microscale Heat Transfer				
Mat Sci Fundamentals	MSEN 5000	3.0	A	12.00
Special Topics in MSE	MSEN 5919	3.0	B+	9.90
Special Topics in MSE	MSEN 5919	3.0	A	12.00
Organic Materials				
ATT 12.0 EARNED 12.0 GPAHRS 12.0 GPAPTS 45.90 GPA 3.825				
--------- Spring 2018 CU Boulder ------				
Coll Engineering & AppSci GRAD	Materials Science&Engineering			
Materials Thermodynamics	MSEN 5370	3.0	A-	11.10
Statistical Mechanics	PHYS 7230	3.0	B-	8.10
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 19.20 GPA 3.200				

COURSE TITLE	CRSE NR	UNITS	GRADE	PNTS
--------- Fall 2018 CU Boulder ------				
Coll Engineering & AppSci GRAD	Materials Science&Engineering			
Energy Systems and Devices	ECEN 5555	3.0	B+	9.90
Independent Study	MSEN 5840	3.0	A-	11.10
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 21.00 GPA 3.500				
--------- Spring 2019 CU Boulder ------				
Coll Engineering & AppSci GRAD	Materials Science&Engineering			
Special Topics	ASEN 6519	3.0	A	12.00
Molecular Modeling of Material				
Special Topics	ECEN 5016	3.0	A-	11.10
Quantum Mechanics				
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 23.10 GPA 3.850				
--------- Fall 2019 CU Boulder ------				
Coll Engineering & AppSci GRAD	Materials Science&Engineering			
Intermed Math Physics 1	PHYS 5030	3.0	A-	11.10
Intro/Quantum Mechanic 1	PHYS 5250	3.0	A-	11.10
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 22.20 GPA 3.700				
--------- Spring 2020 CU Boulder ------				
College Arts & Sciences GRAD	Physics			
Pass/Fail grade option expanded due to COVID-19 global pandemic. See legend.				
Intermed Math Physics 2	PHYS 5040	3.0	A	12.00
Intro/Quantum Mechanic 2	PHYS 5260	3.0	A	12.00
Theory of Solid State	PHYS 7440	3.0	A	12.00
ATT 9.0 EARNED 9.0 GPAHRS 9.0 GPAPTS 36.00 GPA 4.000				
--------- Fall 2020 CU Boulder ------				
College Arts & Sciences GRAD	Physics			
Theoretical Mechanics	PHYS 5210	3.0	B+	9.90
Electromagnetic Theory 1	PHYS 7310	3.0	A	12.00
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 21.90 GPA 3.650				
--------- Spring 2021 CU Boulder ------				
College Arts & Sciences GRAD	Physics			
Statistical Mechanics	PHYS 7230	3.0	A	12.00
Electromagnetic Theory 2	PHYS 7320	3.0	A	12.00
ATT 6.0 EARNED 6.0 GPAHRS 6.0 GPAPTS 24.00 GPA 4.000				

Kristi Wold-McCormick, Ph.D., University Registrar
University of Colorado Boulder

NAME: Sterling, Tyler Chase
STUDENT NR: [redacted] BIRTHDATE : [redacted]
PRINT DATE: 10/20/2022

COURSE TITLE	CRSE NR	UNITS	GRADE	PNTS
--------- Fall 2021 CU Boulder ------				
College Arts & Sciences GRAD Physics				
Intro/Quantum Mechanic 3	PHYS 7270	3.0	A	12.00
Doctoral Dissertation	PHYS 8990	1.0	IP	0.00
ATT 4.0 EARNED 3.0 GPAHRS 3.0 GPAPTS 12.00 GPA 4.000				
--------- Spring 2022 CU Boulder ------				
College Arts & Sciences GRAD Physics				
Quantum Many Body Theory	PHYS 7250	3.0	A-	11.10
Doctoral Dissertation	PHYS 8990	1.0	IP	0.00
ATT 4.0 EARNED 3.0 GPAHRS 3.0 GPAPTS 11.10 GPA 3.700				
--------- Fall 2022 CU Boulder ------				
College Arts & Sciences GRAD Physics				
Theory of Solid State 2	PHYS 7450	(3.0)	***	0.00
Doctoral Dissertation	PHYS 8990	(1.0)	***	0.00
ATT 4.0 EARNED 0.0 GPAHRS 0.0 GPAPTS 0.00 GPA 0.000				

CUMULATIVE CREDITS :

	TR UNITS	CU UNITS	TOT UNITS	QUAL UNITS	QUAL PTS	GPA
GRAD	0.0	63.0	63.0	63.0	236.40	3.752

***** END OF ACADEMIC RECORD ****

Kristi Wold-McCormick
Kristi Wold-McCormick, Ph.D., University Registrar
University of Colorado Boulder

UNIVERSITY OF COLORADO GUIDE TO TRANSCRIPT EVALUATION

CAMPUS LOCATIONS

University of Colorado Boulder
20 UCB
Boulder, CO 80309-0020
303-492-6970
transcriptinfo@colorado.edu

University of Colorado Denver
Campus Box 116
P.O. Box 173364
Denver, CO 80217
303-315-2600
transcripts@ucdenver.edu

University of Colorado Colorado Springs
1420 Austin Bluffs Parkway
Colorado Springs, CO 80918-3733
719-255-3361
registrar@uccs.edu

University of Colorado Anschutz Medical Campus
13120 E 19th Avenue
Campus Box A054
Aurora, CO 80045
303-724-8000
registrar@cuanschutz.edu

The University of Colorado at Denver and the Health Sciences Center were consolidated into a single institution, University of Colorado at Denver and Health Sciences Center (UCDHSC) on July 1, 2004, and renamed to University of Colorado Denver (CU Denver) on October 29, 2007. The institution's campuses are now known as the University of Colorado Denver and the University of Colorado Anschutz Medical Campus.

ACCREDITATION
The University of Colorado is accredited by the Higher Learning Commission (hlcommission.org), a regional accreditation agency recognized by the U.S. Department of Education.

ISSUING CAMPUS FOR TRANSCRIPTS
Each campus has the authority to produce and issue a complete transcript that contains all courses attempted at all University of Colorado campuses, including their Continuing Education/Extended Studies Divisions. Official transcripts include the complete undergraduate, graduate, professional and non-degree academic record of all credit-based courses taken at all campus locations or divisions of the University of Colorado. Students may request a career-based transcript that produces a partial record. Questions concerning the issuance or authenticity of this transcript should be directed to the issuing campus. Questions concerning courses, grades, degrees, or other academic information on the transcript should be directed to the campus the student attended.

STUDENT PRIVACY/RELEASE OF INFORMATION
In accordance with the Family Educational Rights and Privacy Act of 1974, this transcript is provided upon the condition that the receiver or those acting on behalf of the receiver do not disclose or provide access to the information contained in it to any other party without explicit consent of the student.

TRANSCRIPT FORMAT
The academic record of a student enrolled both before and after 1988 may be composed of two separately formatted transcripts. If "SEPARATE RECORD OF PRIOR WORK ATTACHED" appears at the beginning of a transcript, both transcript formats must be present for the transcript to be complete.

TRANSCRIPT AUTHENTICITY
Electronic PDF transcripts bear the Adobe@ Blue Ribbon certification and a GeoTrust CA electronic certificate.

TRANSCRIPT NOTATIONS
Effective Fall 1995, Dean's List notations appear at the end of each term earned. Students are considered to be in good standing with the university and eligible to re-enroll unless stated otherwise on the transcript. Students who have been expelled or who have active non-academic suspensions from a CU campus have transcript notations that may indicate the general type of sanction, the effective date and duration of the separation/exclusion, and the issuing department. For more information, contact the appropriate department on the issuing campus.

GRADE POINT AVERAGE (GPA)
Grades earned in repeated courses are included in the GPA and cumulative totals unless otherwise noted. The GPA is computed by dividing the total grade points by the total of credit hours in which grade points were recorded. Transfer credit is not included in the University of Colorado GPA. In Fall 2019, Boulder and Denver and in Fall 2020, Colorado Springs implemented varying grade replacement and forgiveness policies. From Fall 2001 to Summer 2010 Boulder had a different course repetition policy. See respective campus for policy details.

ACADEMIC CALENDAR
Beginning Fall 1951, all campuses are on a 16-week fall and spring semester system unless otherwise noted. Summer terms, Study Abroad Programs, and Independent Learning vary in length but are reported in semester hours. As of Fall 2010, all prior coursework taken on a quarter system calendar at the Health Sciences Center (now Anschutz Medical Campus) has been retroactively converted to a semester system calendar.

UNIT/CREDIT HOURS
While there can be some variation to this structure amongst the campuses and programs, in most cases, the unit or credit hour is the numeric measure of the instructional, research and/or other academic work over the length of a semester, and the value of a unit is calculated based upon standard semester credit hour formulas.

CUMULATIVE CREDITS
Before 1972, cumulative totals were total hours and credit points used for calculation of the GPA only. After 1988, cumulative credits include hours earned and GPA based on the level of the student (undergraduate, graduate, graduate non-degree and professional careers). A student's transcript may include credits in more than one career level.

GT PATHWAYS PROGRAM
The Colorado State Legislature approved a set of general education courses guaranteed to transfer between state institutions. These courses appear on the transcript with the notation of "GT" followed by two characters that identify the subject area. See https://highered.colorado.gov/academics/transfers/gtpathways/curriculum.html.

RECIPROCAL AGREEMENT PROGRAM
Graduate credit taken through a reciprocal exchange agreement with another Colorado institution is indicated by a department listing of RCPR, RCSM, RCSU, and RUNC. Discontinued in Fall 2020.

COURSE DESCRIPTIONS
The four University of Colorado campuses do not share a common course catalog. Current catalogs and course descriptions may be found by accessing the home pages of each campus.

TRANSFER, STUDY ABROAD AND TEST CREDIT
Beginning 2016, accepted external credit is labeled "Transfer, Test and/or Study Abroad Credit Applied." Transfer credit converted from the prior student information system may appear as summary data on the transcript. This information is labeled "Advanced Standing."

For Study Abroad credit, beginning in 1988, a generic course number was used with the first digit of the course number followed by nines and an extension of SA. The first digit designated the level of the course. Although actual dates of enrollment may have varied, the courses were listed to coincide with the CU calendar. Effective Summer 2016, at the Boulder campus, Study Abroad courses appear as transfer credit earned under "Transfer, Test and/or Study Abroad Credit Applied" with a "See Study Abroad Credit" note in the semester the student studied abroad.

Test credit accepted, including International Baccalaureate (IB), College Level Examination Program (CLEP) and Advanced Placement (AP), reflects earned credit based on the equivalent course offered by the university. Effective Fall 2017, exam and equivalent course details, course number and title, are recorded on the transcript.

Credit earned through institutional course challenge exams is recorded as institutional credit in the term completed. CR is recorded to denote earned credit. The transcript reflects the name, catalog number and credits of the course(s) successfully challenged, and that the credit was earned via course challenge.

COURSE NUMBERING SYSTEM
Fall 1975 to Summer 1988, courses numbered 0–99 were remedial, 100–199 freshmen level, 200–299 sophomore level, 300–399 junior level, 400–499 senior level (open to graduates), 500–599 graduate level (open to qualified undergraduates), 600–699 graduate level, 700 master's thesis, and 800 doctoral dissertation.

From Fall 1975 to Summer 1988, only courses numbered 500 and above were offered for graduate credit. (Exception: Independent Study courses were numbered 900–929 for lower division, 930–949 for upper division, and 950–979 for graduate level.)

Beginning Summer 1988, the course numbering system changed from three digits to four digits for all campuses except Colorado Springs. Courses since Summer 1988 are numbered 1000–2999 for lower division; 3000–4999 for upper division; 5000–6999 for graduate, master's level or first and second year professional; and 7000–8999 for graduate, doctoral level or third and fourth year professional. As of Fall 2010, all campuses use the four-digit course numbering standard.

GRADING SYSTEM

Standard Grades		**Grade Points**	**Numeric Grades (Law)**
A	Superior/Excellent	4.0	93–99
A-		3.7	90–92
B+		3.3	86–89
B	Good/Better than Average	3.0	83–85
B-		2.7	80–82
C+		2.3	76–79
C	Competent/Average	2.0	73–75
C-		1.7	70–72
D+		1.3	66–69
D		1.0	63–65
D-	Minimum Passing	0.7	60–62
F		0.0	50–59

***	Student is currently enrolled in the course or a final grade has not been submitted
ALX	Accommodates conversion of pre-1988 statistics. Placeholder classes created with three-character grades that equate to students' pre-1988 GPA.
CN	Conditional F until cleared (Discontinued Fall 1974)
CR	Credit (Excluded from GPA)
H	Honors/Highest Achievement (Specified courses at the Anschutz Medical Campus or for Honors Department courses on other campuses. Excluded from GPA)
HP	High Pass (School of Medicine at the Anschutz Medical Campus. Excluded from GPA)
I	Incomplete (Converted to F if not completed within one year. Effective Spring 2009); Law School converts to F if not completed in succeeding term (excludes summer).
IC	Incomplete (Discontinued Fall 1974)
IF	Incomplete (Converted to F if not completed within one year. Discontinued Fall 2008)
IP	In Progress (Thesis/dissertation at the graduate level or other specified courses)
IW	Incomplete (Converted to W if not completed within one year. Discontinued Fall 2008)
NC	No Credit or Audit (Excluded from GPA and credit totals)
NP	No Pass (Used with the P+/P/NP grading basis. Denver and Anschutz campuses, Spring and Summer 2020. Excluded from GPA)
NR	Not Reported (Class grades were not submitted when final grades were processed)
P	Passing (Under Pass/Fail option, undergraduate/graduate grades of D- and above convert to a P. P is equivalent to D+, D or D- beginning Spring 2020. See P+ below. Specified courses may also be graded on a Pass/Fail basis. Law School requires a grade of 72 or above to Pass. Excluded from GPA)
P+	Pass (Under Pass/Fail option, undergraduate/graduate grades of C- and above converted to P+ beginning Spring 2020 to address non-standard grading during a global pandemic. Excluded from GPA)
PR	Pass with Remediation (Anschutz Medical Campus. Excluded from GPA)
S	Satisfactory (Course requirements satisfied or expectations met. Excluded from GPA)
U	Unsatisfactory (Course requirements not satisfied or expectations not met. Excluded from GPA)
W	Withdrew
Y	Class grades not submitted by instructor (Discontinued 1988)

CU DENVER
Beginning 1970, students enrolled at the CU Denver Downtown Campus have been able to cross register for courses at Metropolitan State University of Denver and Community College of Denver. These courses are identified on University of Colorado transcripts by notations of "MSC," "CCD," "4M," or "Course Offering of Metropolitan State Univ of Denv" in the course titles. Since Spring 1988, Metropolitan State University of Denver courses are not included in the University of Colorado grade point average, but are included in the hours earned at the University of Colorado. Students must transfer in any credit earned through the Community College of Denver, which will appear as transfer credit hours earned, and are not included in the University of Colorado grade point average. Questions regarding such listings should be referred to the CU Denver Registrar's Office.

LAW SCHOOL GRADING AND RANKING
Effective with students matriculating in Fall 2010 or later, by action of the faculty, the mandatory median grade in each Law School course is B+. From 1994 to 2010, the recommended median grade was 84 (B). Prior to 1994, the median grade was typically 78 (C+) in first-year courses, and 80 (B-) in large, upper-division courses, and higher than 80 in smaller courses. GPAs are calculated from letter grades using the conversion table. Prior to Fall 2010, numeric grades were used to calculate GPAs. Since Fall 2010, the Law School has used the Letter Points to calculate GPAs. Numeric GPAs were carried out to two decimal points and were not rounded up to the nearest whole number, i.e., 84.75 not 85. Good standing and eligibility to continue are based on the numeric GPAs. A 2.0 average is generally required to be in good standing and to graduate. Class ranking displays on Law career transcripts for students in the top third of the class based on grades. University of Colorado Law School: 401 UCB, Boulder, CO 80309, 303-492-8047 or www.colorado.edu/law/academics/rules-law-school.

ADDITIONAL INTERPRETATION OF TRANSCRIPTS OF PRE-1988 RECORDS
To the left of the course title is the code designating the CU campus attended:

- 1 – University of Colorado Boulder – "SAVE" indicates enrollment on Boulder Campus via Continuing Education registration
- 3 – University of Colorado Health Sciences Center (on quarter hours through Summer 1988)
- 4 – University of Colorado Denver
- 5 – University of Colorado Colorado Springs
- 9 – Division of Continuing Education
- W – Boulder Continuing Education
- X – Denver Continuing Education
- Y – Colorado Springs Continuing Education
- Z – Health Sciences Center Continuing Education