Professional Evaluation and Growth Plan

Jordan C Hanson, PhD

August 5, 2021

Contents

Chapter 1

Introduction

1.1 Beginning

Friends,

I have compiled a report on my progress as a liberal arts educator in the Department of Physics and Astronomy for the period of 2019 through 2021. The following is a reflection on the development of my educational and scholarly practices, and the service I have performed for the College as a mentor, advisor, and committee member. I strive to perfect my teaching abilities, and I am pleased to report that my students are learning and growing. In our last communication, after my supplemental PEGP from 2019, you concurred that my practices are serving the students well, and that meant a great deal to me. One note that stood out was a request to enrich my teaching philosphy by reflecting on how it serves the liberal arts. The given example was about the utility of physics to non-STEM students. I have put a lot of thought into this enrichment, I have progress to share with you.

I have included in my teaching philosphy (Sec. 2.1) my vision for the intersection of broader liberal arts education with physics, mathematics, computer science, and engineering, as I teach all of these. Further, I have created and taught new liberal arts courses in the *Connections 2* and *Culture 3* categories, as well as a College Writing Seminar on scientific and technical writing. I used these courses to show my students how physics, mathematics, and engineering intersect with the history of our ancestors and how we all use scientific modes of thought to thrive. In my College Writing Seminar, we sharpened the skills of conciseness, precision and clarity, and organization in writing. Though these skills apply to physics, they are useful in all writing in which abstract or difficult ideas are communicated.

At a PEGP workshop, a colleague emphasized weaving a narrative about who we are. I have shared my academic origins, and my vision for multi-disciplinary teaching and scholarship at Whittier College (Sec. 1.1.1). I have also written about my family and working during the pandemic (Sec. 1.1.2). I hope these sections provide you with helpful insight about our family and how we hope to serve Whittier College. We thank the FPC in advance for what is sure to be a difficult year of service. We also express our gratitude for allowing us to postpone the PEGP for one year. This helped my family avoid a difficult situation. My spouse is considered an essential worker, and was called back after a shortened maternity leave. I have been working as a full-time professor and a full-time parent *by myself* each day since that happened. Thankfully, my *suegra* (mother-in-law) has stepped in to help. I look forward to seeing you this Fall, and from our family to yours, we hope you are well.

Sincerely, Prof. Jordan C. Hanson

1.1.1 Academic Origins

We all share a common theme as professors, in that we encounter ideas that inspire us in college and graduate school. When I was an undergraduate at Yale University, my family was nudging me towards engineering. My curiousity, however, kept returning me to physics courses. In my heart, I knew that I wanted to offer fresh discoveries about the Universe to people, and I fell in love with enlightening others. I learned that the laws of physics morph and merge into one another as the energy of matter increases to relativistic scales where particles move near the speed of light. I also learned that deep from within the Universe originates a mysterious flux of sub-atomic particles ten thousand times more energetic than any human has ever created: *the cosmic rays*. The physics that explains their origin has remained unknown for a over a century, and it could reveal new fundamental laws of Nature. I applied for graduate school in the hopes of one day becoming a professor of physics.

The University of California at Irvine (UCI) is a pioneering institution in the field of cosmic-ray research. In particular, my colleagues at UCI began focusing on the study of cosmic ray *neutrinos*, also known as ultra-high energy neutrinos (UHE-ν), beginning with the Radio Ice Cherenkov Experiment (RICE) [1] and Antartic Impulsive Transient Antenna (ANITA) [2] collaborations. Neutrinos do not have electric charge, while cosmic rays do. Thus, neutrinos propagate in straight lines through the Universe, while any electromagnetic field would bend the trajectory of cosmic rays. Thus, UHE-ν could reveal the locations of the cosmic ray accelerators, thereby teaching us about fundamental physics unexplored on Earth [3] [4]. UHE-ν observations would, for example, provide insight into quantum mechanics at record-breaking energies [5].

Detection of UHE-ν has been a goal of the physics community for three decades. When UHE-ν have energies aboev a certain threshold, they create cascades of particles in matter that radiate in the radio-frequency (RF) bandwidth, a process known as the Askaryan effect [6] [7] [8] [9, 10]. The IceCube Collaboration published the observations of extra-solar neutrinos using optical techniques at record-breaking energies [11], and later showed that the flux is strikingly close to theoretical predictions [12] [13]. IceCube analyses have not found UHE-ν events, however, with energy greater than 10^{15} electron-volts [14]. It is above this energy that the UHE-ν could one day reveal the source of cosmic rays and new physics. The authors of [14] conclude that Askaryan-class detectors are the logical next step. My colleagues have decided to upgrade IceCube to include RF detectors in a project known as IceCube Generation 2, or IceCube Gen2 (`https://icecube.wisc.edu/`).

Askaryan-class detectors improve UHE-ν prospects because Askaryan radiation is in the RF bandwidth [15]. UHE-ν must strike some material in the Earth's crust that produces an observable radio pulse. It turns out that radio waves travel ≈ 1 km in *Antarctic ice* [16] [17] [18]. Thus, we can create stations comprised of RF antenna channels, supporting electronics, and solar panels [19], separated by 1 km to cover enormous volumes of ice. This is important because the expected UHE-ν flux is low. When a potential signal arrives, stations are triggered to read out the RF channel data [20]. The overall dataset is then comprised of RF waveforms representing signals from all the stations. The data will be used to reconstruct UHE-ν interactions [21] [22]. This type of detector is called an *in-situ* array. As a graduate student at UCI, I led two Antarctic expeditions to create a prototype *in-situ* array: the Antarctic Ross Ice Shelf Antenna Neutrino Array (ARIANNA).

We began by measuring the ice shelf thickness and radio transparency in Moore's Bay, Ross Ice Shelf, Antactica [23]. We deployed prototype ARIANNA stations in two separate missions. I designed systems that managed station power consumption and recorded environmental data [19] [24]. We demonstrated with computer simulations that a 30 x 30 array would reach target UHE-ν sensitivity. Further, the sensitivity doubled in Moore's Bay through *reflected* events, in which signals reflect from the ocean beneath the ice shelf. We completed the prototype array, and published upper limits on the UHE-ν flux [25]. We also observed cosmic rays [26] (though we cannot determine their original direction), and completed a second UHE-ν search [27]. UHE-ν interact more rarely in dense matter, and thus the flux is lower than that of the cosmic rays.

As a post-doctoral fellow at the University of Kansas, I published the first complete analysis of the ice in Moore's Bay [16]. This research was an intersection of glaciology and physics, for we need to understand our detector and our detector is an ice shelf. I also published the first complete calibration of the ARIANNA RF chain [28]. Using the results, we showed simulations of our detector accurately modeled Askaryan signal strength. We created UHE-ν signal *template waveforms* that account for both the theoretical Askaryan signal and the aforementioned calibration. These templates now serve as the primary UHE-ν search criterion when cross-correlated with data collected in Antarctica [25] [27]. As a CCAPP Fellow at The Ohio State University[1], I improved upon the templates by developing a new analytic theory of Askaryan pulses [15].

[1] Center for Cosmology and Astro-Particle Physics

Once I joined Whittier College, I turned my attention to the complex path taken by Askaryan pulses through Antarctic ice. The path is curved because the speed depends on the ice density, which changes with depth. An undergraduate student and I worked out solutions for the ray-path of the signals through ice given the density profile [29]. These calculations became a central component of our current software that we use to predict detector sensitivity to UHE-ν [30] [31]. Meanwhile, another student and I designed firmware upgrades to auto-calibrate the RF channel thresholds and presented the results at SCCUR, twice [32] [33]. These tools facilitate expansion and automation of our detector. The pandemic has prevented deployment of these upgrades in ARIANNA, but they will be incorporated in IceCube Gen2. For both projects, I included undergraduate students. The first was a young lady who went on to become a physics researcher for the LIGO project (gravity waves). The second was a student of color and Whittier native who majored in ICS/Math, and who is applying to graduate schools for engineering and machine learning.

I recently returned to the theory of Askaryan radiation, and have begun to study computational electromagnetism (CEM). For the first time, I have created an analytic time-domain model of Askaryan radiation [34]. We are happy to report that the work will be published in Physical Review D, and that it will be incorporated into IceCube Gen2 software. This achievement was made possible by a collaboration with a wonderful undergraduate student who has become a good friend over the past two years amid the pandemic. I describe the importance of this result in Sec. 3. Regarding CEM, I have won two Summer Faculty Research Fellowships with the Office of Naval Research (ONR), in which we apply CEM to radar design. This is an example of the liberal arts mindset in action: I was able to identify a connection between two seemingly unconnected fields, and form a mutually beneficial partnership.

Using CEM, my student and I have created a 3D printed radar design [35]. Knowing that Whittier College cannot afford to subscribe to every IEEE engineering journal, I selected an open-access journal named Electronics Journal so that our students have access to the research. I view choices like these as part of our mission to foster equity and inclusion. Our paper won Top 10 Most Notable Papers in the Electronics Journal for 2020-21 (see Sec. 3). Recently, my colleagues at the naval laboratory fabricated the 3D printed design, and they have provided powerful lab equipment to Whittier College for testing it. It is worth mentioning that this equipment is prohibitively expensive, and thus our partnership with my naval colleagues is opening new doors scientifically. If we succeed, this research has applications to UHE-ν physics (by creating new and better antennas), 5G communication, and radar applications. I describe in Sec. 3 my vision for a partnership with the Navy, and how this will benefit our students.

Finally, I would like to share with you my recent venture into the Whittier Scholars Program (WSP). A student heard of my scholarship regarding Antarctica, and sat down in my office one afternoon. He showed me photographs of glaciers he had taken while visiting family in Norway, and said that he'd like to perform a comparative photographic analysis with historical photos of glaciers all over the world, in order to assess the loss of ice due to global warming. We lept into a partnership that sent him to Norway, Iceland, Alaska, and the National Outdoor Leadership School (NOLS). He began by taking one of my new *Connections 2* courses about the history and current status of science in Antarctica. The research was at the intersection of glaciology, physics, climate science, and environmental social justice.

The work came together as my student gained experience living in the field. I did everything in my power to add him to one of my Antarctic expeditions. Alas, that particular mission was cancelled due to budget cuts and the pandemic. We had hoped to include photos of the glaciers near ARIANNA. These are the same glaciers passed by Robert Falcon Scott and Roald Amundsen as they raced for the discovery of the South Pole. I have been there twice and taken photos, but there were no similar photos to which we could compare. I helpd my student gain admission to the WSP, and our final project gave a holistic view of the environmental, agricultural, and cultural impact of glaciers around the world. My student, who graduated this Spring, told me that he is beginning a book with colleagues he met in Iceland, and that this book will feature our work. I enjoyed the project so much I have decided to help support WSP by serving on the WSP Advisory Board. My offer was accepted and I will begin this semester. Thus, I have come full circle regarding the FPC invitation to serve in the liberal arts. I will share more on this in Sec. 5.

1.1.2 My Family, East Los Angeles, and COVID-19

When I first came to Whittier, I lived down the street on Bright Avenue. I had met a wonderful young woman and we fell in love. In the summer of 2019 we married, and I moved to East Los Angeles to live with her family.

My wife's family is quite extraordinary. Her family is originally from Jalisco, Mexico. The family immigrated to Los Angeles, and dealt with gangs and poverty where they originally lived. My wife and all six of her siblings worked hard in school and went to college. We strongly value higher education in our family. My wife and I share our Catholic faith, and we care about our children's education.

Even before I met my spouse, I knew that becoming fluent in Spanish would be helpful living in Whittier. I already spoke a little, and in my first year joining the Whittier community I decided to formalize my Spanish skill by taking Spanish 120. Prof. Doreen O'Conner-Gómez was kind enough to let me audit her course that Fall. She remarked that this was the first time she had seen a STEM professor audit a language course. It turned out to be wonderfully necessary in my family, because our older generation usually does not speak English at home. Our family as a whole is highly diverse, with Mexican, Romanian, American, and Filipino roots. Given the dark and divisive trends that have arisen within our broader culture, and as a Christian and someone who considers himself a loving person, I felt a genuine desire to share this with you.

In my first years as part of the Whittier community, I recognized the same diversity in the families of my students. Many of our students speak Spanish at home with their parents, but English at school. There have been times when I have helped the mother or guardian of a student navigate campus by speaking Spanish, and it has made them more comfortable. As part of a statistics course I taught for the Whittier Summer Session II (2020), I was gathering data from the Whittier College Factbook. It reveals two important numbers about our students. About seventy percent of our students are students of color, and about forty percent are first-generation. My spouse and every single one of her siblings are all first-generation students. Back when we were teaching in person, sometimes colleagues would explain to me over lunch about "the first-generation experience," assuming that the white male physicist was new to the concept. I would always smile inwardly, since my entire family has shared this experience with me.

Given these experiences, I am keenly aware of the importance of our curricular theme of *belonging*. Despite the challenges brought upon Whittier by the pandemic, I have put effort into making that theme a reality. I socialize on Zoom with my first-year advisees and research students in order to make them all feel that they belong. I ensure that I account for equity and inclusion in each decision I make. One stark example was when a student in my section of INTD100 connected to class via Zoom *while at work in CostCo.* I learned to arrange my schedule to account for students' jobs, knowing that many were supporting themselves and loved ones. Being inflexible would have made class accessible only for the wealthy students. Regarding belonging, I am often reminded of a basic fact: *even though my heritage is different from my family and my community, they have accepted me as one of their own.* In the Gospels, we find the Golden Rule to treat others as we would like to be treated. I am called therefore to ensure the students feel that they belong.

Inspiration for New Courses

Inspired by my family, and the theme of belonging, I have created two new courses that serve our current liberal arts curriculum. One is entitled *A History of Science in Latin America,* which was assigned a *Culture 3* and *Connections 2* designation. I could tell there was a hunger for this course. Our students needed to see that *all* of our ancestors performed science. One aspect of that course was the ideas of *central* and *peripheral* scientific communities. Taking STEM courses alone might lead a student to believe that European and American cities have been central to scientific progress, and that Latin American communities have been *peripheral*. Peripheral, in this sense, refers to a community that merely adopts discoveries from the central ones and rarely produces progress. By honestly covering the colonial period in Latin America, we found examples in which Latin American communities were *central* and their European counterparts were *peripheral.* A more accurate description of scientific progress for Latin America and Europe would be a full two-way exchange of knowledge (Sec. 2). I invited colleagues from the Wardman Library to introduce my students to digital storytelling. The students used this skill to create final projects that wove together their cultural heritage, history, mathematics, and scientific discovery.

The second liberal arts course I have created was inspired by the theme of belonging, and my research. It is called *Safe Return Doubtful: History and Current Status of Modern Science in Antarctica.* At first glance, the connection between themes like inclusion and belonging and Antarctica is not obvious. This course is a metaphor for self-exploration. We address three main areas, interwoven throughout the semester. First, we address the history of the race to discover the South Pole in the early 20th century. Second, we cover current scientific endeavors in Antarctica. Third, we perform weekly journal activities that invite the students to look inside themselves and to discover their potential for exploration. The connection to inclusion and belonging emerges as we learn that the winner of the race for the South Pole was a person who took indigenous science seriously. This was the same captain who completed the Northwest Passage, before trying the South Pole. In Northern Canada, the explorers encountered the *Netsilik* people. The European explorers observed how the Netsilik *used physics and engineering strategies* to travel through the harsh environment, rather than assuming their technology was better. These strategies were adapted to the Ross Ice Shelf, and *that group won the race for the South Pole.* Thus the course connects inclusion and belonging to survival and exploration. The students learn through history, science, and self-reflection that their survival in new areas of life will be enhanced if they are able to include knowledge earned by those *indigenous* to that area.

Keeping a Sense of Humor under Quarantine

My fellow tenure-track colleagues and I sometimes discuss if it's appropriate to add a "COVID-19 Impact Statement" to our PEGP. At first I thought, no, just stick to the important, serious stuff. But I also thought it would be a good laugh. So here goes.

For those with a sense of humor, this section is for you. For those without a sense of humor, I have to ask, like, how are you still here? After we duct-taped together a way to teach our students online in spring 2020, we watched the world lose its freaking mind that summer. Then, the module system, for *a year.* But hooray! The vaccines arrived. Funny thing about vaccines, though, is that you have to go *get them.* Ugh, who has time, right? Seriously, a few people in my family flatly refuse. Here's a fun exercise: try teaching a science course on Zoom and hearing in the background an argument about how *the scientists are wrong* in Spanish. Focus, focus ... *just get the blasted shot already* ... "Ok students, let's talk about ... friction! Am I right?" Ay yay yay.

Teaching students remotely was like watching those YouTube channels where people crash into stuff. What I mean is, students would log in to class while driving. Had to make a rule against that. Everyone survived, but ... wow. I thought one of my students was driving on the wrong side of the road while Zooming, but it's ok, he was in India. Another rule I had to make for class: wear clothes. I don't wanna see that. This is a family establishment. After 2.1 seconds of research, I found the Zoom button to have the camera off by default.

My spouse always says that she has the worst luck. I always reassure her: "Have faith honey. We'll be alright." After years of searching, we find each other, marry, and then BAM. Pandemic. Whoops. Our daughter was born right in the exact middle (like, literally within the error of the mean) of the first wave of COVID-19. Whyyyy. The nurses weren't going to let me in the hospital. For the birth of my child. What. Actually they weren't really that keen on letting my wife in either. *Just hang out in the parking garage*, they told my wife, *who was in labor.* After the required amount of suffering took place, they let us come inside to give birth.

Working from home during summer 2020 did make it easier to care for our daughter. We were quarantined, but I managed to convince the ONR that we could perform the research project remotely. My spouse is a dentist, and the state provided maternity leave. For added spice, they took it away, though, after 12 weeks. Right at the beginning of Fall semester. No vaccines were available yet, so I had to just teach and parent alone. The upside is that I got to spend more time with the baby. My spouse bravely went back to work to help pay her student loans. She treats patients who are supposed to test negative for COVID-19, but the positives sneak past the guard. So basically The Hunger Games for dentists, who tend to be around a lot of, you know, mouths and noses and throats.

Here's another fun exercise: try teaching college-level physics with a six-month-old pooping in your lap. Keep composure. Another one: the baby is napping in her seat, and all is quiet and ready for class. My chihuahua looks at me like he wants to bark at the dogs outside. *Don't you do it, Lobo! I swear...* Does it anyways. So I trained him not to bark, but my neighbors responded by buying a rooster. They. Bought. A. Rooster. In the city. Not chickens! Chickens I would understand for the eggs. We love eggs. Fun fact about cities: they sell alarm clocks. Quirky thing about roosters: they don't have a snooze. This particular rooster sucked though because he made the dog bark which woke the baby during class, and not you know, when the sun came up. Bad rooster.

Joking aside, my students were wonderfully accepting of my child being there. The same is true for my colleagues in committee meetings. I like to think she brightened people's day a little. A female research colleague from another institution who gave birth recently lamented to me that it has been *so hard* lately, for she and her husband (both physicists working from home) hadn't had child care in *six whole weeks!* I died a little inside. It had been almost a year for me flying solo. Once we all got vaccinated, my *suegra* (mother-in-law) who lives next door, started to come each day to help. Que santa, no? (What a saint, no?). My family has supported us, and we are so grateful. My parents, who live in Oklahoma, are sore that they haven't been able to see the baby more, but airports are full of La Rona.

I hope you are all safe and sound. It turns out that some people in my extended family in the Midwest were not so lucky. My cousin's husband, who was a well-loved football coach and mentor to many junior college students, already needed a lung transplant before COVID-19 arrived. He finally got the lung transplant three years ago and recovered beautifully. And then someone gave him the virus, and he's gone now, along with his father. We pray for them each night now. If any of you have lost loved ones, we will pray for them as well. I've had students miss class to go to funerals. Even though we have all suffered, and perhaps lost loved ones, I still believe it's important to keep a smile on. We are still here, and Whittier College needs us. Soon the students will return, and Whittier College will grow and thrive.

Chapter 2

Teaching

2.1 Teaching Philosophy: A Philosophy of Growth

A

Elec

B

2.2 Addressing Equity and Inclusion

A

2.2.1 Open Educational Resources (OER)

B

2.2.2 Making Arrangements for a Diverse Group of Students

C (10to8) (Take-home tests) (Flexibility) (Arranging assessment schedule) (Take-home final projects)

2.2.3 Engaging with the Center for Engagement with Communities: Artemis Program

2.2.4 Influences on Course Creation: Latin American Science

2.3 Methods of Teaching Physics

A

2.3.1 Physics Education Research (PER) Modules

B

2.3.2 Traditional Teaching Modules

C

2.3.3 Laboratory Modules

D

2.3.4 Online Modules

E

2.4 Introductory Course Descriptions

Don't forget intro to statistics!

Algebra-Based Physics

B

2.5 Analysis of Course Evaluations: Introductory Courses

A

Hickisy Pickisy

B

2.6 Advanced Course Descriptions

A

Elec

B

2.7 Analysis of Course Evaluations: Advanced Courses

A

Elec

B

2.8 Liberal Arts Course Descriptions

A

Elec

B

2.9 Analysis of Course Evaluations: Liberal Arts Courses

A

Elec

B

2.10 College Writing Seminar Course Descriptions

A

Elec

B

2.11 Analysis of Course Evaluations: College Writing Seminar

A

Elec

B

2.12 Outlook

A

Elec

B

Chapter 3

Scholarship

A

3.1 The History of IceCube, Cosmic Rays, and Neutrinos from Deep Space

B

3.1.1 Why Antarctica?

C

3.1.2 Radio Expansions: IceCube Generation 2

D

3.2 My Professional Background

E

3.2.1 Prior to Whittier College

F

3.2.2 Successes with Our Students at Whittier College

G

3.2.3 Forming Connections with the Office of Naval Research (ONR)

H

A

3.3 Five Areas of Research Focus

B

3.3.1 Computational Electromagnetism

Observable Askaryan signals originate in bulk ice, and then propagate to *in situ* RF channels. The RF pulse follows approximately a ray-tracing solution that depends on the index of refraction: $n(z)$. The speed of light in the ice is c/n, making the speed a function of depth. The effect is that light travels not in straight lines, but in curved paths called ray-traces. The index depends on depth (z) because the surface is snow ($\rho \approx 0.4$ g cm^{-3}) that is compressed to solid ice ($\rho \approx 0.917$ g cm^{-3}) over millenia [16]. A classical physics approach called the Lagrangian method minimizes the optical path length of the ray. Combining the Lagrangian approach with a smooth $n(z)$ function fit to $n(z)$ and density data results in a differential equation for the ray tracing solution. The solution admits: (1) straight-line paths in deep ice (where the speed is constant), (2) quadratic paths near the surface (where the speed changes), and (3) a general form stitching the two together.

The official simulation software used by IceCube Gen2 is named NuRadioMC [30]. NuRadioMC is built on four pillars: (1) UHE-ν generation, (2) Askaryan emission, (3) ray tracing, and (4) RF channel simulation. My analytic ray-tracing solution is pillar (3). We assume a functional fit for $n(z)$ that is motivated by glaciology. Snow accumulates at the top of the ice sheet at a certain rate, depending on the yearly conditions. It is slowly compressed over millenia, steadily increasing in density, which in turn decreases the speed of light within it. The function is constrained by density and radio measurements [29]. The key finding of [29], however, was RF *horizontal propagation* not predicted by ray-tracing. I can correct my ray-tracing framework with a *perturbed* Lagrangian to produce horizontal solutions. I showed in my PhD dissertation that the effect depends on frequency [36], and therefore cannot be explained with ray-tracing alone. Horizontal propagation has been noted as an interesting Askaryan detection scheme in the past [37].

The inaccuracy of ray-tracing is compounded by the selection of phased arrays as triggers of *in situ* stations. In this context, phased-arrays are vertical arrangements of identical antennas. One can think of received signal in terms of relative phase between antennas. For example, in transmitting mode, the elements of a phased array at fixed frequency are given signals slightly shifted in time, and the time shift increases linearly across the array. The result is a plane wave emitted at the desired direction. Conversely, the arrival direction of plane waves from Askaryan signals from UHE-ν can be deduced with ray-tracing. However, this all assumes a constant index $n(z)$, and we know it is not constant. Knowing that sensitivity of IceCube Gen2 *in situ* designs depends on the phased array precision, I have created a solution that leaves behind ray-tracing all together.

Beyond Ray-Tracing: Open-Source Parallel FDTD Methods

I have received two **Summer Faculty Research Internship grants** from the Naval Surface Warfare Center (NSWC) Corona Division, in Corona, CA. My group focuses on phased-array radar development. My colleagues at other institutions do not always think like scholars in the liberal arts. Sometimes I am asked how is related to IceCube Gen2 or ARIANNA. Phased-arrays are useful for testing and verification of all other radar systems because they can mimic a radar reflection that moves without using moving parts. I adapted a Python3 software packaged called MEEP, originally designed for μm wavelengths, to work for radio wavelengths [35]. From there, I developed phase-array models in which I could control things like the speed of light versus depth (i.e. the problem we face in IceCube Gen2). I performed design studies for single-frequency and broadband arrays, and the computed properties matched phased-array antenna theory beautifully. Intriguingly, the work represents the first time MEEP, originally designed for μm-wavelength applications, had been applied to phased array design. The results have been published in Electronics Journal [38], where the work has been named among the Top 10 most notable articles of 2020-21[1].

I can envision a wide range of CEM applications for IceCube Gen2. The phased array trigger for IceCube Gen2 must be designed accounting for the changing index of refraction. *I plan to combine a Python3 machine learning package with MEEP to optimize and study phased array trigger output given the index of refraction profile and Askaryan emission proerties.* These computations could be performed in parallel on a small dedicated cluster we would assemble. I'm currently searching for the right NSF grant to do this, however I do have some startup grant funding remaining that can be used for computer hardware. If successful, the *in situ* trigger would thus be trained to detect the smallest hint of a UHE-ν signal. Theoretically, we expect a higher UHE-ν flux with smaller amplitudes, so in this way we would be maximizing the scientific output.

My proposed CEM computation cluster would serve a separate physics collaboration called PUEO for another reason [39]. PUEO will seek UHE-ν signals with arrays of RF elements flown in the atmosphere. PUEO antennas

[1] The notice of these awards is included in the supplemental material.

are the same class as the ones I designed for the Navy, and would be flown on a weather balloon gondola. PUEO is therefore dubbed an *in air* version of Askaryan-class detector. PUEO faces a computational requirement that *in situ* detectors do not: refraction from the snow surface to the air. The Antarctic snow surface roughness has been measured [40]. Those results could serve as boundary conditions, and radiation propagating from bulk ice, refracting from the ice-air interface would be tracked to PUEO arrays with near-to-far-field projection. In my work published recently in Electronics Journal [38], I produced this type of refraction. It would not be difficult to add the effect of the rough snow surface at the ice-air interface.

Connection to Teaching and Academic Mentorship

We always attempt to form connections between our research and teaching, and my work for the Navy has required me to teach. My contacts are Dr. Christopher Clark, Dr. Eisa Osman, and Dr. Gary Yeakley, who work on active seeking radar. Dr. Clark relayed a compliment I received from Dr. Yeakley, who had this to say about my 1-2 hour lectures given once per week in Summer 2020.

> One of the most stunning compliments Prof. Hanson received was from my Senior RF Engineer, Mr. Gary Yeakley (who has been working developing, designing, and testing radar since the 1970s), where Gary stated "every week I learn new RF Physics from Jordan [Prof. Hanson]."

I have included a letter of advocacy in the supplemental materials from Dr. Clark. Researching a new subject, mastering it, and teaching it to colleagues in the Navy was a rewarding experience, and I was grateful to serve. My Navy contacts invited me back for Summer 2021 to teach an RF Field Engineering Course. In practice, this amounted to creating tutorial videos my colleagues can download. This content will also be useful for digital signal processing (DSP), my upcoming January term course.

This past summer (2021), I included in this work a student named Adam Wildanger through a Fletcher-Jones Fellowship. Adam is a great help, because he has taught me computer assisted design (CAD). The process begins with me creating an antenna design using CEM tools. Next, Adam ports my work as a machine-readable design using his favorite CAD programs. Third, Adam sends the machine-readable design to our Navy colleagues, who fabricate it using a 3D printer. Finally, they have sent the fabricated components to me. Adam and I will test them in my laboratory in the Science and Learning Center using equipment provided by ONR. The key is to use 3D printer material that conducts some amount of electric current at high frequencies. If successful, this collaborative effort has applications as diverse as UHE-ν research, radar development, 5G mobile communications, and remote sensing for climate science (`https://cresis.ku.edu/`). The key lesson here is that sometimes, the mentor can learn new things from the student. I am working on securing Adam an position at the national lab where my ONR colleagues are based. That has been Adam's dream job throughout college.

3.3.2 Mathematical Physics

In 2015, I became a CCAPP Fellow at The Ohio State University, where I began to work on an analytic Askaryan radiation model. At the time, the simulation package for IceCube Gen2 (NuRadioMC) was under development. The two *in situ* groups, ARIANNA and the Askaryan Radio Array (ARA), relied on the MC codes ShelfMC and AraSim, respectively. Both ShelfMC and AraSim were derived from the same legacy code. We learned, however, that ShelfMC and AraSim did not always produce the same results, and were cumbersome to compare. Further, the Askaryan models in both were 5-10 years old, and derived from *semi-analytic* parameterizations.

The results of foundational work in Askaryan effect simulated every single sub-atomic particle in the cascade initiated by the UHE-ν, and the corresponding radiation [41]. Overall radio pulse amplitude was found to be proportional to the energy of the neutrino. A distribution of radiated power was observed to radiate in a special direction: the Cherenkov angle. Such models were called *full-MC* models. By tradition, physics simulations are sometimes called *Monte Carlo* simulations (MC). Semi-analytic parameterization models provide part of the electric field at the Cherenkov angle, and simulate the cascade development along the UHE-ν direction. Mixing these two results produces the electric field (radio wave) at a variety of angles [10].

Frequency-Domain Model

Missing from the 2018 ShelfMC/AraSim integrations was a common analytic understanding of Askaryan radiation. I responded by developing a fully analytic model[2] that accounted for several important effects [15]. The

[2] In this sense, analytic means a set of equations, not a simulation.

independent variable in the equations is the frequency of the radio wave, so the model is classified as a *frequency-domain* model. I was inspired by work by Prof. John Ralston and Roman Buniy [42]. Using GEANT4 MC simulations on the Ohio Supercomputing Cluster (OSC), we determined the shape of the electric charge distribution in the UHE-ν induced cascades with total energies of 10^{17} electron-volts.

We then wrote a function that followed this shape, and finished the ensuing electromagnetic calculations to obtain the radio wave. My model produces template waveforms for UHE-ν searches with IceCube Gen2 [15]. The community began to use the model after I presented it at workshops at KICP (Univ. of Chicago), and TeVPA conferences. Colleagues shared with me that a time-domain model at all angles relative to the Cherenkov angle would be highly useful. In the final section of [15], we did provide an example, but only if the viewing angle equals the Cherenkov angle.

Time-Domain Model

There are four main advantages of analytic time-domain models. First, when they are matched to observed radio waveforms, UHE-ν cascade properties like total energy may be derived directly from waveform shapes. Second, evaluating a fully analytic modelmtechnically provides a speed advantage in software compared to the semi-analytic parameterizations. Third, when analytic models are combined with RF antenna properties (derived using CEM), the resulting template can be embedded in detector firmare to form a filter that enhances the probability that a passing UHE-ν signal is detected, rather than be mistaken for radio noise. Fourth, parameters in analytic models may be scaled to account for snow density in addition to ice density. This application is useful for understanding potential signals in the Antarctic firn, or the upper 100-meter layer of snow that rests on top of the ice. My student, Raymond Hartig, and I are proud to announce that our work will be published in Physical Review D [34]. My vision for the future of this work at is expansive, and involves striving for progress along three tracks.

The first track involves UHE-ν template analysis. Our simulation for IceCube Gen2, NuRadioMC, is broken into four pillars (steps). Currently, UHE-ν are simulated first as *events* (NuRadioMC pillar (1)) and the *RF emissions* (Askaryan signals) are generated next (NuRadioMC pillar (2)). Our ability to match simulated waveforms to potential UHE-ν waveforms from the detector is limited because we cannot scan through properties of the simulated *cascades*, only UHE-ν with a single RF emissions model. For example, two UHE-ν with the same energy could generate different cascades with different shapes of electric charge. The effect of the cascade shape is important for the interpretation of future IceCube Gen2 data. Conversely, if the effect of the cascade shape is well-understood, it becomes possible to measure the UHE-ν energy by templates to observed data [34].

The second track involves embedding the model itself in detector firmware. Potential UHE-ν signals are recorded alongside noise, but all data has to be shipped with limited bandwidth. Embedding the model on the detector would allow us to flag priority events. The physics community expects IceCube Gen2 to provide an alert system so that other physics and astronomy collaborations could search for any UHE-ν or cosmic-ray sources we identify. This is not possible if the data has to first shipped back to the United States and then be searched with powerful algorithms. Sending priority events that already correlate with analytic predictions is a strategy that solves the problem.

The third track involves the connection between CEM and our Askaryan model. In NuRadioMC the simulated signal is created by code in pillars (1)-(4) sequentially. That is, the basic Askaryan model is mixed with detector response *after* ray-tracing. In reality, the radiation flows immediately from the cascade according to the details of the index of refraction of the ice. It is a wave that *generally* follows ray-tracing, but that reflects from internal ice layers, propagates horizontally, and can change shape. In other words, all the effects *not captured* by the original index of refraction function. In this regard, fully-analytic Askaryan models have a unique advantage: analytic equations can be implemented as MEEP sources, and MEEP *can* account for all those effects, while ray-tracing cannot. The analytic model is in a unique position to provide advanced insight into the effect of 3D propagation previously unexplored.

3.3.3 Firmware, Software, and Hardware Development

E

3.3.4 Open-source Antenna Design

F

3.3.5 Drone Development and The Whittier Scholars Program

G

3.4 Invitation to Become a Member Institution of IceCube

H

A

3.5 CEM and Engineering with the ONR

B

3.5.1 CEM Phased Array Design for Radar

C

3.5.2 3D Printing of RF Antennas

D

3.5.3 Connections to Neutrino Physics Research

E

3.5.4 Broader Applications

F

Don't forget the italians. A

3.6 My Vision for Collaboration between ONR and Whittier College

B

3.6.1 Building Student Success after Whittier College

C

3.6.2 Equipping Whittier College Laboratories

D

3.6.3 Financial Support

E

Chapter 4

Advising and Mentoring

4.1 Connections to Teaching and Service

4.1.1 Inclusion, Community, and a Sense of Belonging

4.2 Advising and Mentoring First Year Students

A

4.2.1 First Year Advising, by the Numbers

B

4.2.2 Navigating the First Year

C

4.2.3 Discernment of Major

D

4.2.4 Equity of Access

E

4.2.5 Inclusion and Belonging: Activities with First Year Advisees

4.3 Advising and Mentoring Majors in Physics, ICS, and 3-2 Engineering

A

4.3.1 Discernment within STEM: Major Selection, and Diverse Pathways to Graduation

B

4.3.2 Graduate School

C

4.3.3 Private Sector

D

Reverse Engineering Social Media

E

4.3.4 Letters of Recommendation

F

4.4 Advising and Mentoring Whittier Scholars Program Majors

A

4.4.1 Interdisciplinary Connections and Recruiting Students

B

4.4.2 Organization of Field Deployments

C

United States Antarctic Program

Describe the attempt to deploy Nicolas to Antarctica

4.4.3 Organizing the Program of Study and Executing

E

4.4.4 Polishing the Finished Product

F

Chapter 5

Service

5.1 Committee Service

Admissions sub-committee, data analysis, maybe a graph

5.1.1 Enrollment and Student Affairs Committee, Years 1 and 2

Write about how I learned about orientation issues from these meetings
Interactions with Falone Serna

5.1.2 Educational Resources and Digital Liberal Arts Committee

Creation of senior thesis archival program

5.1.3 Whittier Scholars Program Advisory Board

I was invited! Sort of.

5.2 Departmental Service

This one can be stronger, maybe

5.2.1 Departmental Self-Study

5.2.2 Departmental Annual Assessment

5.3 First Year Orientation

A

5.3.1 Connection to Teaching and Advising

B

5.3.2 Inclusion and Belonging

C

5.4 Open Educational Resources (OER) Workshops

openstax, oercommons, and openstax tutor, dspguide.com

5.4.1 Open Educational Resources (OER) and Equity

5.4.2 The Tradition of Open Access/Open Source in STEM

The OpenStax Platform

Integrations with Machine Learning

Open Access in Digital Signal Processing

5.4.3 Lectures at Wardman Library Collaboratory

5.5 Center for Engagement with Communities: The Artemis Program

A

5.5.1 Equity and Inclusion in STEM

B

5.5.2 Connections to Teaching at Whittier College

5.6 Summer Working Group Contribution

A

Elec

B

Chapter 6

Conclusion

Jordan C. Hanson, PhD
Assistant Professor, Department of Physics and Astronomy
Science and Learning Center, 212
Whittier College
562.907.5130
jhanson2@whittier.edu

Chapter 7

Supporting Materials

Bibliography

[1] I. Kravchenko, S. Hussain, D. Seckel, D. Besson, E. Fensholt, J. Ralston, J. Taylor, K. Ratzlaff, and R. Young, "Updated results from the RICE experiment and future prospects for ultra-high energy neutrino detection at the south pole," *Phys. Rev. D*, vol. 85, p. 062004, Mar 2012.

[2] P. W. Gorham et al, "Constraints on the ultrahigh-energy cosmic neutrino flux from the fourth flight of ANITA," *Phys. Rev. D*, vol. 99, p. 122001, Jun 2019.

[3] Ahlers, M, et al, "Astro2020 science white paper: Astrophysics uniquely enabled by observations of high-energy cosmic neutrinos," *Bull. Am. Astron. Soc.*, vol. 51, no. 185, 2019.

[4] Ahlers, M, et al, "Astro2020 science white paper: Fundamental physics with high-energy cosmic neutrinos," *Bull. Am. Astron. Soc.*, vol. 51, no. 185, 2019.

[5] A. Connolly, R. S. Thorne, and D. Waters, "Calculation of high energy neutrino-nucleon cross sections and uncertainties using the Martin-Stirling-Thorne-Watt parton distribution functions and implications for future experiments," *Phys. Rev. D*, vol. 83, p. 113009, Jun 2011.

[6] G. Askaryan, "Excess negative charge of an electron-photon shower and its coherent radio emission," *Soviet Physics JETP*, vol. 14, no. 441, 1962.

[7] G. Askaryan, "Coherent radioemission from cosmic showers in the air and dense media," *Soviet Physics JETP*, vol. 21, no. 658, 1965.

[8] D. Saltzberg, P. Gorham, D. Walz, C. Field, R. Iverson, A. Odian, G. Resch, P. Schoessow, and D. Williams, "Observation of the Askaryan Effect: Coherent Microwave Cherenkov Emission from Charge Asymmetry in High-Energy Particle Cascades," *Phys. Rev. Lett.*, vol. 86, pp. 2802–2805, Mar 2001.

[9] P. W. Gorham, S. W. Barwick, J. J. Beatty, D. Z. Besson, W. R. Binns, C. Chen, P. Chen, J. M. Clem, A. Connolly, P. F. Dowkontt, M. A. DuVernois, R. C. Field, D. Goldstein, A. Goodhue, C. Hast, C. L. Hebert, S. Hoover, M. H. Israel, J. Kowalski, J. G. Learned, K. M. Liewer, J. T. Link, E. Lusczek, S. Matsuno, B. Mercurio, C. Miki, P. Miočinović, J. Nam, C. J. Naudet, J. Ng, R. Nichol, K. Palladino, K. Reil, A. Romero-Wolf, M. Rosen, L. Ruckman, D. Saltzberg, D. Seckel, G. S. Varner, D. Walz, and F. Wu, "Observations of the Askaryan Effect in Ice," *Phys. Rev. Lett.*, vol. 99, p. 171101, Oct 2007.

[10] J. Alvarez-Muñiz, P. M. Hansen, A. Romero-Wolf, and E. Zas, "Askaryan radiation from neutrino-induced showers in ice," *Phys. Rev. D*, vol. 101, p. 083005, Apr 2020.

[11] M. G. Aartsen et al, "First Observation of PeV-Energy Neutrinos with IceCube," *Phys. Rev. Lett.*, vol. 111, p. 021103, Jul 2013.

[12] M. G. Aartsen et al, "A Combined Maximum-Likelihood Analysis of the High-Energy Astrophysical Neutrino Flux Measured with IceCube," *The Astrophysical Journal*, vol. 809, p. 98, aug 2015.

[13] E. Waxman and J. Bahcall, "High energy neutrinos from astrophysical sources: An upper bound," *Phys. Rev. D*, vol. 59, p. 023002, Dec 1998.

[14] M. G. Aartsen et al, "Differential limit on the extremely-high-energy cosmic neutrino flux in the presence of astrophysical background from nine years of IceCube data," *Phys. Rev. D*, vol. 98, p. 062003, Sep 2018.

[15] J. C. Hanson and A. L. Connolly, "Complex analysis of Askaryan radiation: A fully analytic treatment including the LPM effect and Cascade Form Factor," *Astroparticle Physics*, vol. 91, pp. 75–89, 2017.

[16] J. C. Hanson, S. W. Barwick, E. C. Berg, D. Z. Besson, T. J. Duffin, S. R. Klein, S. A. Kleinfelder, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. A. Walker, and L. Zou, "Radar absorption, basal reflection, thickness and polarization measurements from the Ross Ice Shelf, Antarctica," *Journal of Glaciology*, vol. 61, no. 227, pp. 438–446, 2015.

[17] J. Avva, J. Kovac, C. Miki, D. Saltzberg, and A. Vieregg, "An in situ measurement of the radio-frequency attenuation in ice at Summit Station, Greenland," *Journal of Glaciology*, 2014.

[18] S. Barwick, D. Besson, P. Gorham, and D. Saltzberg, "South polar in situ radio-frequency ice attenuation," *Journal of Glaciology*, vol. 51, no. 173, p. 231238, 2005.

[19] S. Barwick, E. Berg, D. Besson, T. Duffin, J. Hanson, S. Klein, S. Kleinfelder, K. Ratzlaff, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. Walker, R. Young, and L. Zou, "Design and Performance of the ARIANNA HRA-3 Neutrino Detector Systems," *IEEE Transactions on Nuclear Science*, vol. 62, no. 5, pp. 2202–2215, 2015.

[20] S. A. Kleinfelder, E. Chiem, and T. Prakash, "The SST Multi-G-Sample/s Switched Capacitor Array Waveform Recorder with Flexible Trigger and Picosecond-Level Timing Accuracy," *arXiv*, 2015.

[21] A. Anker, S. W. Barwick, H. Bernhoff, D. Z. Besson, N. Bingefors, D. Garca-Fernndez, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. A. Kleinfelder, R. Lahmann, U. Latif, J. Nam, A. Novikov, A. Nelles, M. P. Paul, C. Persichilli, I. Plaisier, T. Prakash, S. R. Shively, J. Tatar, E. Unger, S. H. Wang, C. Welling, and S. Zierke, "Neutrino vertex reconstruction with in-ice radio detectors using surface reflections and implications for the neutrino energy resolution," *arXiv*, vol. 2019, no. 11, pp. 030–030, 2019.

[22] Anker, A, et al, "Probing the angular and polarization reconstruction of the ARIANNA detector at the South Pole," *Journal of Instrumentation*, vol. 15, no. 09, pp. P09039–P09039, 2020.

[23] J. C. Hanson, "Ross Ice Shelf Thickness, Radio-frequency Attenuation and Reflectivity: Implications for the ARIANNA UHE Neutrino Detector," *32nd International Cosmic Ray Conference*, 2011.

[24] L. Gerhardt, S. Klein, T. Stezelberger, S. Barwick, K. Dookayka, J. Hanson, and R. Nichol, "A prototype station for ARIANNA: A detector for cosmic neutrinos," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 624, no. 1, pp. 85–91, 2010.

[25] S. Barwick, E. Berg, D. Besson, G. Binder, W. Binns, D. Boersma, R. Bose, D. Braun, J. Buckley, V. Bugaev, S. Buitink, K. Dookayka, P. Dowkontt, T. Duffin, S. Euler, L. Gerhardt, L. Gustafsson, A. Hallgren, J. Hanson, M. Israel, J. Kiryluk, S. Klein, S. Kleinfelder, H. Niederhausen, M. Olevitch, C. Persichelli, K. Ratzlaff, B. Rauch, C. Reed, M. Roumi, A. Samanta, G. Simburger, T. Stezelberger, J. Tatar, U. Uggerhoj, J. Walker, G. Yodh, and R. Young, "A first search for cosmogenic neutrinos with the ARIANNA Hexagonal Radio Array," *Astroparticle Physics*, vol. 70, pp. 12–26, 2015.

[26] S. Barwick, D. Besson, A. Burgman, E. Chiem, A. Hallgren, J. Hanson, S. Klein, S. Kleinfelder, A. Nelles, C. Persichilli, S. Phillips, T. Prakash, C. Reed, S. Shively, J. Tatar, E. Unger, J. Walker, and G. Yodh, "Radio detection of air showers with the ARIANNA experiment on the Ross Ice Shelf," *Astroparticle Physics*, vol. 90, pp. 50–68, 2017.

[27] A. Anker, S. W. Barwick, H. Bernhoff, D. Z. Besson, N. Bingefors, D. Garca-Fernndez, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. A. Kleinfelder, R. Lahmann, U. Latif, J. Nam, A. Novikov, A. Nelles, M. P. Paul, C. Persichilli, I. Plaisier, T. Prakash, S. R. Shively, J. Tatar, E. Unger, S. H. Wang, and C. Welling, "A search for cosmogenic neutrinos with the ARIANNA test bed using 4.5 years of data," *Journal of Cosmology and Astroparticle Physics*, 2019.

[28] S. Barwick, E. Berg, D. Besson, T. Duffin, J. Hanson, S. Klein, S. Kleinfelder, M. Piasecki, K. Ratzlaff, C. Reed, M. Roumi, T. Stezelberger, J. Tatar, J. Walker, R. Young, and L. Zou, "Time-domain response of the ARIANNA detector," *Astroparticle Physics*, vol. 62, pp. 139–151, 2015.

[29] S. W. Barwick, E. C. Berg, D. Z. Besson, G. Gaswint, C. Glaser, A. Hallgren, J. C. Hanson, S. R. Klein, S. Kleinfelder, L. Kpke, I. Kravchenko, R. Lahmann, U. Latif, J. Nam, A. Nelles, C. Persichilli, P. Sandstrom, J. Tatar, and E. Unger, "Observation of classically 'forbidden' electromagnetic wave propagation and implications for neutrino detection.," *Journal of Cosmology and Astroparticle Physics*, vol. 2018, no. 07, pp. 055–055, 2018.

[30] C. Glaser, D. Garca-Fernndez, A. Nelles, J. Alvarez-Muiz, S. W. Barwick, D. Z. Besson, B. A. Clark, A. Connolly, C. Deaconu, K. D. d. Vries, J. C. Hanson, B. Hokanson-Fasig, R. Lahmann, U. Latif, S. A. Kleinfelder, C. Persichilli, Y. Pan, C. Pfendner, I. Plaisier, D. Seckel, J. Torres, S. Toscano, N. v. Eijndhoven, A. Vieregg, C. Welling, T. Winchen, and S. A. Wissel, "NuRadioMC: simulating the radio emission of neutrinos from interaction to detector," *The European Physical Journal C*, vol. 80, no. 2, p. 77, 2020.

[31] C. Glaser, A. Nelles, I. Plaisier, C. Welling, S. W. Barwick, D. Garca-Fernndez, G. Gaswint, R. Lahmann, and C. Persichilli, "NuRadioReco: a reconstruction framework for radio neutrino detectors," *The European Physical Journal C*, vol. 79, no. 6, p. 464, 2019.

[32] J. C. Hanson and J. P. Gómez-Reed, "A 100 MHz Frequency-Counter Deployed in FPGA for RF Neutrino Research in Antarctica," in *Proceedings of the Southern California Conference for Undergraduate Research*, sccur.org, 2018.

[33] J. C. Hanson and J. P. Gómez-Reed, "Communications between an onboard fpga and microcontroller system for antarctic neutrino research," in *Proceedings of the Southern California Conference for Undergraduate Research*, sccur.org, 2019.

[34] J. C. Hanson and R. Hartig, "Complex Analysis of Askaryan Radiation: A Fully Analytic Model in the Time-Domain," *arXiv*, 2021.

[35] A. F. Oskooi, D. Roundy, M. Ibanescu, P. Bermel, J. Joannopoulos, and S. G. Johnson, "Meep: A flexible free-software package for electromagnetic simulations by the FDTD method," *Computer Physics Communications*, vol. 181, no. 3, pp. 687–702, 2010.

[36] J. Hanson, *The Performance and Initial Results of the ARIANNA Prototype.* PhD thesis, University of California at Irvine, 2013.

[37] J. Ralston, "Radio surf in polar ice: A new method of ultrahigh energy neutrino detection," *Physical Review D*, vol. 71, no. 1, 2005.

[38] J. C. Hanson, "Broadband rf phased array design with meep: Comparisons to array theory in two and three dimensions," *Electronics*, vol. 10, no. 4, 2021.

[39] P. Allison, J. Alvarez-Muñiz, J. J. Beatty, D. Z. Besson, P. Chen, Y. Chen, J. M. Clem, A. Connolly, L. Cremonesi, C. Deaconu, P. W. Gorham, K. Hughes, M. Israel, T. C. Liu, C. Miki, J. Nam, R. J. Nichol, K. Nishimura, A. Novikov, A. Nozdrina, E. Oberla, S. Prohira, R. Prechelt, B. F. Rauch, Q. Abarr, J. M. Roberts, A. Romero-Wolf, J. W. Russell, D. Seckel, J. Shiao, D. Smith, D. Southall, G. S. Varner, A. G. Vieregg, S. A. Wissel, E. Zas, and A. Zeolla, "The Payload for Ultrahigh Energy Observations (PUEO): A White Paper," *arXiv*, 2020.

[40] P. W. Gorham et al, "Antarctic surface reflectivity measurements from the anita-3 and hical-1 experiments," *Journal of Astronomical Instrumentation*, vol. 06, no. 02, p. 1740002, 2017.

[41] E. Zas, F. Halzen, and T. Stanev, "Electromagnetic pulses from high-energy showers: Implications for neutrino detection," *Physical Review D*, vol. 45, no. 1, p. 362, 1992.

[42] R. V. Buniy and J. P. Ralston, "Radio detection of high energy particles: Coherence versus multiple scales," *Physical Review D*, vol. 65, no. 1, 2001.