SHUR (year/semester) Grant Applicant: Name
Research Advisor: Name

Advancing Radio Astronomy Through Machine Learning: A Quest for Exomoons

Summary

Our radio astronomy research group at Gustavus Adolphus College aims to secure funds for educational resources, for our machine learning and computational physics research lab. Our group leverages NASA's Radio JOVE project to push scientific boundaries, and while Radio JOVE introduces radio astronomy via Jupiter-Io magnetic storm observation, our goal is demonstrating its potential for innovative research accessible to diverse researchers and amateur astronomers, prioritizing environmental stewardship and cultural respect. Leveraging computing resources, we aim to develop a machine learning algorithm using Jupiter-Io data, recognizing signals in other solar systems to potentially confirm exomoons—an achievement showcasing technology's prowess and our commitment to inclusiveness. With this funding and a pending grant from the New York Community Trust's Fund for Astrophysical Research, we will take a step forward in our venture to discover the first exomoon by creating a machine learning algorithm which categorizes the storms of the Jupiter-Io system.

Introduction

The discovery of the first exoplanet in 1992[1] marked the beginning of a remarkable era in astronomy, leading to the confirmation of over 5000 exoplanets to date[2]. This exploration of distant worlds has given rise to a multitude of scientific disciplines, from exoplanet geochemistry to exoplanet climate science. Yet, amidst these exciting discoveries, a significant piece of the cosmic puzzle remains elusive: exomoons[3]. Despite the crucial role our own moon plays in Earth's habitability, there have been no confirmed detections of exomoons. It is our mission to change this narrative through our innovative project.

Numerous proposed methods for detecting exomoons exist[4,5,6], but our focus lies on a unique approach involving Io-controlled decametric emissions[7]. By utilizing this method as a baseline to identify similar signals from other solar systems, we aspire to confirm the existence of a potentially volcanically active exomoon orbiting a gas giant, akin to the dynamic relationship between Io and Jupiter. While this method may not lead to the discovery of moons around terrestrial planets, its success would constitute a significant milestone, much like the excitement generated by the first exoplanet discovery.

The concept of exomoon discovery through Io-controlled emissions was initially conceived in 2014[4]. Despite a brief attempt with the Long Wavelength Array in Eastern California, this approach has been largely overshadowed. However, we believe that advances in data analysis techniques since 2014 position us to overcome the challenges that previously hindered this endeavor.

The landscape of scientific discovery has been transformed by the rapid growth of machine learning since 2018[8]. With the support of this grant, we aim to harness the burgeoning power and prevalence of machine learning, particularly through the utilization of the PyTorch framework, to enhance our ability to analyze data from our radio telescope. PyTorch, striking a balance between the efficiency of lower-level frameworks like TensorFlow and the user-friendliness of higher-level platforms like Keras, has emerged as the preferred choice among academic researchers. By building our neural network with PyTorch, we aim to democratize access to these powerful tools, fostering an environment where both our intended audience and others can explore, understand, and implement similar techniques in their research.
Our belief in the wide-reaching potential of machine learning is reinforced by the fact that all physics, mathematics, and computer science majors at our institution possess at least an intermediate level of

proficiency in calculus, linear algebra, and Python—the foundational pillars of machine learning. We have already witnessed the impactful use of machine learning in various summer research projects, both within the Gustavus community and at external institutions. With this grant, our primary objective is to help build a resilient data collection system and commence data analysis utilizing machine learning techniques. As we make significant progress in our research, we also aspire to extend the resources for learning these concepts, within the context of machine learning and their implementation using the PyTorch framework, to the entire campus community. By the end of the project, we will have finished our remote data collection system and written a machine learning algorithm which categorizes magnetic storms between Jupiter and its moon Io–the first step in our goal of finding an exomoon.

Methods and Materials

Our research initiative centers around the operation and management of a permanent square array radio telescope. Over the past two years, we have been utilizing a temporary setup constructed from PVC pipes and guy lines. This makeshift arrangement required us to assemble it, wait for data collection, and then disassemble it whenever there was an opportunity for observation which could be anytime from midday to the early hours of the morning. This year, our foremost objective has been to establish a permanent setup, thereby eliminating these logistical challenges and enhancing the capabilities of our dual-dipole telescope by transforming it into a square array.

The physics department teaches using Arduino and Raspberry Pi technology, first with Arduino Megas in our introductory physics class, then Raspberry Pi Pico W's in our Electronics class. Over the summer, our research group used Raspberry Pi devices to create a remote data collection system. We use a Raspberry Pi 4B computer as a remote USB port connected to our group's machine over Wi-Fi, as well as a Raspberry Pi Pico W microcontroller to monitor the ambient temperature and humidity the computer is running in and notify us when it is in dangerous conditions. While this project has made significant strides, we acknowledge ongoing challenges, particularly related to the Pico's connectivity with Gustavus's network which we aim to resolve by the end of fall semester.

Once the data collection system is fully operational, we will shift our focus towards creating a machine learning model to analyze our telescope's data. As part of this process, we will harness the educational resources requested, including "Inside Deep Learning: Math, Algorithms, Models," "The Quick Python Book," and "Deep Learning with PyTorch: Build, train, and tune neural networks using Python tools." These resources will not only deepen our understanding of machine learning principles but also provide practical guidance for implementing complex algorithms, fostering interdisciplinary learning within our research group. We will start by creating simple neural networks for practice, then use our previously collected data to start classifying magnetic storms from the Jupiter Io system we have already observed. We plan on getting this working by the end of next semester and presenting this at the Celebration of Creative Inquiry. Over the coming summer, we will observe as much data as possible to improve our model and prove it works in real time.

Our experience has shown that the intersection of radio astronomy and machine learning offers immense potential for groundbreaking discoveries. As we work towards developing machine learning models to analyze radio astronomy data, we are committed to making the knowledge and resources for mastering these concepts accessible to our entire campus community. Our aspiration is to promote a culture of continuous learning and skill development, similar to the inclusivity and availability of our department's makerspace and woodshop facilities.

In summary, our research methodology encompasses the establishment of a permanent radio telescope array, the development of a remote data collection system, and the utilization of machine learning techniques for data analysis. These approaches are enriched by educational resources, facilitating both our research objectives and the educational growth of our team members and students.

Timeline

Time	Expected progress
October	Finish remote data collection system, start working through PyTorch text and start with example problems
January	Complete PyTorch study and start working with previously collected data
March	Complete program for analyzing past magnetic storm data
April	Finish analyzing data, create poster presentation
May	Present results at Celebration of Creative Inquiry

References

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Budget

Item	Use	Vendor	Cost
Inside Deep Learning: Math, Algorithms, Models	Mathematical background of machine learning	Amazon	$59.99
The Quick Python Book	Background to the python programming language	Amazon	$39.99
Deep Learning with PyTorch: Build, train, and tune neural networks using Python tools	Instructional text for using the PyTorch machine learning framework	Amazon	$49.99
Pre-soldered Raspberry Pi Pico W Starter Kit x2	Added functionality of radio telescope - data collection	Amazon	$85.98
Arduino Mega Starter Kit x2	Added functionality of radio telescope - developing machine learning algorithms	Amazon	$119.98
		Total	**$355.93**

Justification for literature request:

We request the following books by Manning Publications— "Inside Deep Learning: Math, Algorithms, Models," "The Quick Python Book," and "Deep Learning with PyTorch: Build, train, and tune neural networks using Python tools"—is integral to the success of our research endeavors. These resources serve as invaluable references and instructional materials that significantly contribute to our research progress in the fields of radio astronomy and machine learning.

1. **Comprehensive Learning**: "Inside Deep Learning: Math, Algorithms, Models" provides an in-depth understanding of the mathematical foundations, algorithms, and models that underpin deep learning. This comprehensive resource equips our research team with the knowledge needed to effectively design and implement complex machine learning algorithms for analyzing radio astronomy data.
2. **Python Proficiency**: "The Quick Python Book" serves as a foundational resource for enhancing our team's proficiency in Python programming. While most of our researchers have experience with Python, we want to provide necessary resources for those without a firm grasp on the

fundamental concepts and reference for everyone else.

3. **PyTorch Mastery**: "Deep Learning with PyTorch" is tailored to the specific framework we intend to utilize in our research. PyTorch is a leading platform for deep learning, and this resource provides insights into building, training, and fine-tuning neural networks using Python tools. It is directly aligned with our research goals and will facilitate the development of machine learning models for our radio astronomy projects.
4. **Interdisciplinary Learning**: The books collectively bridge the gap between radio astronomy and machine learning, fostering interdisciplinary learning within our research group. They empower our team members with the knowledge and skills required to navigate the intersection of these fields and contribute meaningfully to cutting-edge research.
5. **Educational Impact:** Beyond their immediate relevance to research, these books offer educational value by enhancing the learning experiences of our students. By providing access to these resources, we promote a culture of continuous learning and skill development, benefiting both our research projects and the broader academic community.

The request for these books aligns with our commitment to conducting high-impact research while fostering a culture of learning and skill development among our team members and students. These resources are pivotal in equipping us with the knowledge and tools needed to push the boundaries of radio astronomy and machine learning research.

Justification for hardware request:

While our physics department currently possesses Raspberry Pi Picos and Arduino kits, it is essential to clarify the necessity for acquiring additional units specifically for research purposes. The existing devices are primarily allocated to students registered for specific courses, ensuring their availability for educational instruction. However, our objectives extend beyond the scope of coursework and require dedicated resources to propel our investigations into radio astronomy and machine learning:

1. **Research Expansion:** The Raspberry Pi Picos and Arduino kits are incredible tools for conducting experiments, collecting data, and developing hardware solutions tailored to our research goals. By acquiring additional units, we extend the reach of our research beyond the confines of the classroom and enable our team to engage in innovative projects that advance the field of radio astronomy.
2. **Data Collection and Analysis:** Our research relies on the reliable operation of Raspberry Pi and arduino devices for remote data collection. These devices are important in monitoring environmental conditions and ensuring the safety of our equipment.
3. **Student Involvement:** Beyond catering to the immediate needs of our research, the acquisition of these materials serves to enrich the educational experience of our students. By involving them in research projects that utilize cutting-edge technology like Raspberry Pi Picos and Arduino kits, we offer valuable hands-on learning opportunities that enhance their skills and knowledge.

The request for additional Raspberry Pi Picos and Arduino kits is driven by the need to facilitate robust data collection, engage students in research, and ensure the scalability and continuity of our radio astronomy endeavors. These materials are not merely supplementary but foundational to the success of our research objectives, positioning us to make significant contributions to the field while enriching our student’s educational experience.