COSI, a Low Earth Orbit Gamma-Ray Telescope

(Technical Paper)

Choosing Scientific Missions

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

There is so much that is unknown about deep outer space. It is the last frontier for exploration. The final unknown. There are countless scientists and engineers who devote their lives to uncovering the mysteries that space holds. There is so much to learn. What happened during the big bang? What is dark matter? What causes gamma-ray bursts? Discovering more about outer space will help to enable us to learn more about the mysteries of our universe and learn more about fundamental science. In particular there is a whole area of study devoted to learning more about cosmic gamma-rays. Gamma-rays are high energy photons that are emitted from a variety of different sources in outer space [1]. If we are able to detect and measure both the energy levels and the direction of the gamma-rays it can tell us a lot of information about what is happening in the universe.

In order to learn more about space and the universe NASA frequency funds missions proposed by different groups to observe different phenomena. One category that NASA offers funding for is the small explorers mission class (SMEX) [2]. These missions are not as large scale and don't cost billions as some of the more re-known missions such as Curiosity or Perseverance do [3], but they serve an important role in learning more about Astro and Helio physics. It allows for many different scientists to compete to get funding in order to verify their ideas and predictions.

Technical Description:

This past summer I worked at the Naval Research Lab (NRL) Space Science Division. There I helped to build the readout electronic for COSI, a low earth orbit gamma-ray telescope funded by NASA. The goal of COSI is to detect and measure both the energy levels and the origin of gamma-rays in space. With this information we are able to understand where nucleosynthesis is occurring in the galaxy. That is to say it will help us to discover the location of element formation which leads us to discover the location of stars formation and star death [4]. My role in the project was working on the readout electronics for the detector. In order to actually detect and measure the gamma-rays we have large germanium strip detector. It consists of 36 strips of germanium laid out next to each other. Whenever a gamma-ray hits a strip, it scatters off of the strip and hits a strip below. The photon scatters because of Compton Scattering or the Compton Effect. What happens is that the incident photon hits an electron in the lattice and bounces or scatters off of it. This scattering depends on the incident angle of the photon as well as the photons energy level [5]. Therefore, if we can measure the scattering, precisely where it hit each strip, we would be able to re-construct the original event and know the energy level as well as the original position of the gamma-ray. I worked on the readout electronics for the detector. That is the electronics that actually read the energy and position values of the gamma-rays and then passes that data up the data-path. For measuring gamma-rays, the measurement equipment needs to be very precise. There is a small margin for error and minimal electrical noise can drastically distort the data [6]. The way we do this is with Application Specific Integrated Circuits (ASICs). ASICs are a piece of silicon hardware that is custom made for one specific task [7]. I wasn't involved in any of the design work for the ASICs as those were contracted out to a third party but there was a lot to be done on verifying and validating their operating status. These ASICs were custom made to readout the detector. This was done for the reasons stated above to be able to perform readout precisely with minimum noise. There are large upfront costs to ASIC development. It can easily cost over one million dollars to develop an ASIC [8]. It is not a cheap endeavor to run a spin, or fabricate, a batch of ASICs. There is a lot of complex engineering that has to go into the photolithography needed for ASIC fabrication, as well as a lot of expensive tools, increasing the price [9]. Additionally, due to how complicate some of the design for the ASICs are, multiple revisions are necessary before it works as we specified it to. These tradeoffs between cost and efficiency had to be carefully deliberated between before choosing whether or not to use ASICs for the detector. I spent a lot of the summer testing the operating conditions of the readout electronics and ASICs and making sure that they are working properly in different operating conditions.

STS Topic:

The discovery of new knowledge is always a hard task to go about. Science and technology is such a broad field, so often times it gets difficult to choose what to learn and what could be gained from the scientific exploration. Many factors need to go into deciding whether a space exploration mission is viable. Cost of the mission is one of the defining factors for the scope of the mission, but the other primary factor is the goal. Space science is a popular field, with many different scientists and researchers all with different experimental ideas, competing to get funding for their mission. NASA has the privilege and responsibility to go through all of the mission proposals and pick the best one. The way they do that is by foster competition between the proposals and providing preliminary funding for different proposals to pursue their ideas and then compare [10]. It is important they NASA goes about it in a fair and systematic way so larger companies don't have an unfair advantage against university and lab groups since this could lead to less creative ideas and less innovation since there would not be as much competition. This environment of competition is what NASA hopes to stir innovation and new ideas.

Research Questions and Methods:

Our end goal for the mission is to observe cosmic gamma-rays, determine their origin in the galaxy and to learn what caused them. In gamma-ray astronomy, events, or gamma-ray photons, are not common occurrences. This is why our design prioritized low noise and high precision, to be able to observe as many events as we possible can. Once we get the data, we are going to be able to analyze it to create two different plots, an energy spectrum and a position graph. An energy spectrum is going to show the distribution of energies that the gamma rays have. Each gamma-ray is going to have different energy levels and knowing the energy level of one single gamma-ray won't tell us very much. We need to look at it as a collective to be able to tell what the emission looks like. That's why we have to look at the whole spectrum histogram chart. We will be able to see at what energy levels the number of events peaks at to determine what the energy of the bulk of the gamma-rays are and thereby what are the majority of elements being formed. This information is going to get paired with position data to be able to tell us where each energy level of gamma rays is coming from. From our apparatus and the fact that we are using Compton-Scattering to detect the gamma-rays, there is a limit of about 6 degrees of error on the position. So, we are going to be able to get a range of positions in the sky that the gamma-rays could be coming from.

Conclusion:

This project is very relevant to the field of space sciences, particularly astrophysics. The experiments that we are planning on running with COSI are going to allow us to understand a lot more about our observable universe and make new discoveries that we're possible with the equipment we have before. It will help to uncover the location of new stars in the galaxy as well as tell us how far along they are in their lifecycle. This is very important since it is furthering the collective knowledge of humanity and enabling us to know more about the galaxy and about the unknown. Who knows what we are going to be able to discover.

Citations:

[1] NASA. (n.d.). *Gamma rays*. NASA. Retrieved September 27, 2022, from https://science.nasa.gov/ems/12_gammarays

[2] NASA. (n.d.). *Explorers program*. NASA. Retrieved November 2, 2022, from https://explorers.gsfc.nasa.gov/smex.html#punch

[3] Dreier, C. (n.d.). *The cost of perseverance, in context*. The Planetary Society. Retrieved November 2, 2022, from https://www.planetary.org/articles/cost-of-perseverance-in-context

[4] *Cosi*. COSI. (n.d.). Retrieved September 27, 2022, from https://cosi.ssl.berkeley.edu/

[5] *Compton scattering*. Compton Scattering - an overview | ScienceDirect Topics. (n.d.). Retrieved November 2, 2022, from https://www.sciencedirect.com/topics/medicine-and-dentistry/compton-scattering#:~:text=Compton%20scattering%20describes%20the%20situation,and%20some%20loss%20of%20energy.

[6] *What is electrical noise and where does it come from? - technical articles*. All About Circuits. (n.d.). Retrieved September 27, 2022, from https://www.allaboutcircuits.com/technical-articles/electrical-noise-what-causes-noise-in-electrical-circuits/

[7] *What is an ASIC: Application specific integrated ciruit*. Electronics Notes. (n.d.). Retrieved November 2, 2022, from https://www.electronics-notes.com/articles/electronic_components/programmable-logic/what-is-an-asic-application-specific-integrated-circuit.php

[8] Lankshear, I. (n.d.). *The economics of Asics: At what point does a custom SOC become viable ...* The Economics of ASICs: At What Point Does a Custom SoC Become Viable? Retrieved November 2, 2022, from https://www.electronicdesign.com/technologies/embedded-revolution/article/21808278/ensilica-the-economics-of-asics-at-what-point-does-a-custom-soc-become-viable

[9] By. (2022, August 16). *How much does it cost to make a semiconductor Fab?* Compound Semiconductor News. Retrieved November 2, 2022, from https://www.csfusion.org/semiconductor/how-much-does-it-cost-to-make-a-semiconductor-fab/#:~:text=How%20much%20does%20it%20cost%20to%20build%20a%20chip%20fab,chips%20that%20automakers%201%20need.

[10] NASA. (n.d.). *NASA Researcher FAQs*. NASA. Retrieved November 2, 2022, from https://science.nasa.gov/researchers/sara/faqs#5