"Space is big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the drug store, but that's just peanuts to space." – Douglas Adams

Investigating Low-Temperature Scintillation Properties of Bismuth Germanate

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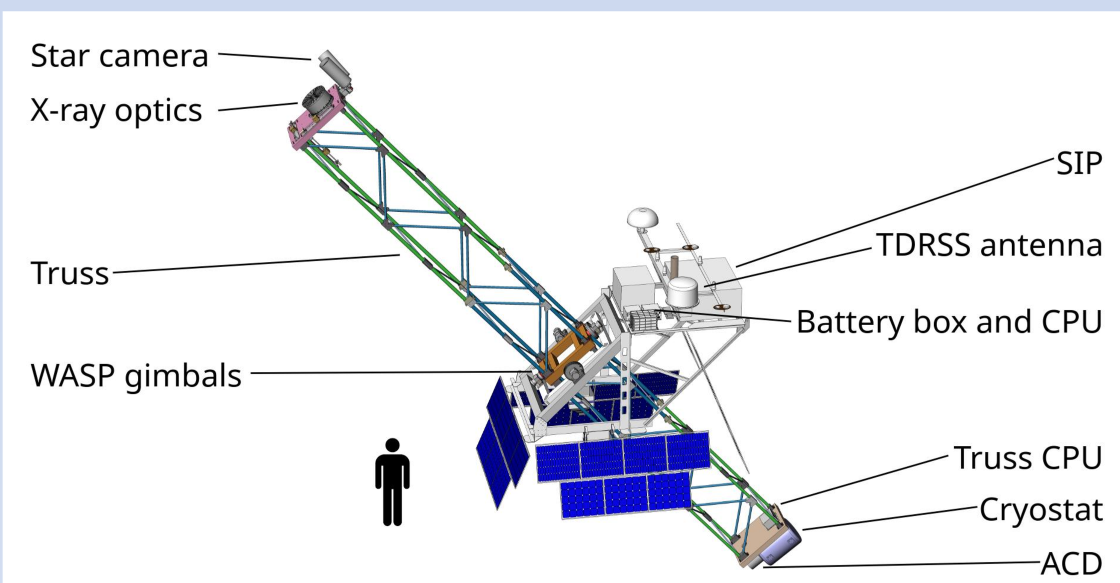
Background

ASCENT, or ***A Superconducting Energetic X-ray Telescope***, is a proposed balloon-borne gamma-ray observatory whose purpose is to observe the distribution and redshift of Titanium-44 (Ti-44) in the supernova remnant Cas A. Armed with transition-edge sensors (TESs), the telescope will be able to differentiate frequencies of incident gamma rays with a higher energy resolution than previously accomplished. By observing how the frequencies of light we collect shift higher or lower, we can use the relativistic doppler shift to allow us to distinguish Ti-44 velocities with a novel Full-Width Half-Maximum (FWHM) of 270 km/s.



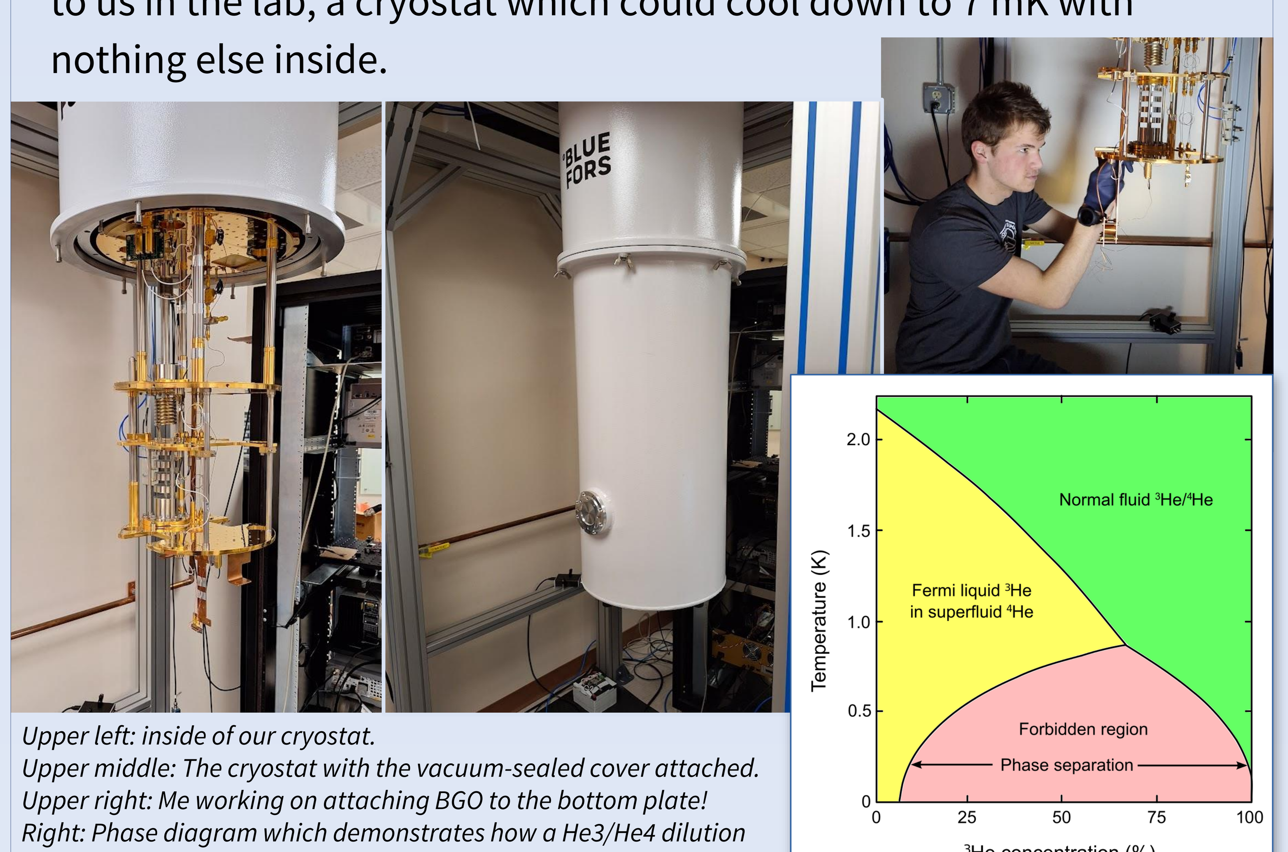
ASCENT proposed model, with person for scale.

Mission

ASCENT focuses on improving the energy resolution of gamma rays in the Ti-44 region, using TES detectors, to answer questions about supernovae such as what the source of neutron star "kicks" are, what the dominant production pathway of Ti-44 is, and whether the convective engine of Cas A is unique or not.

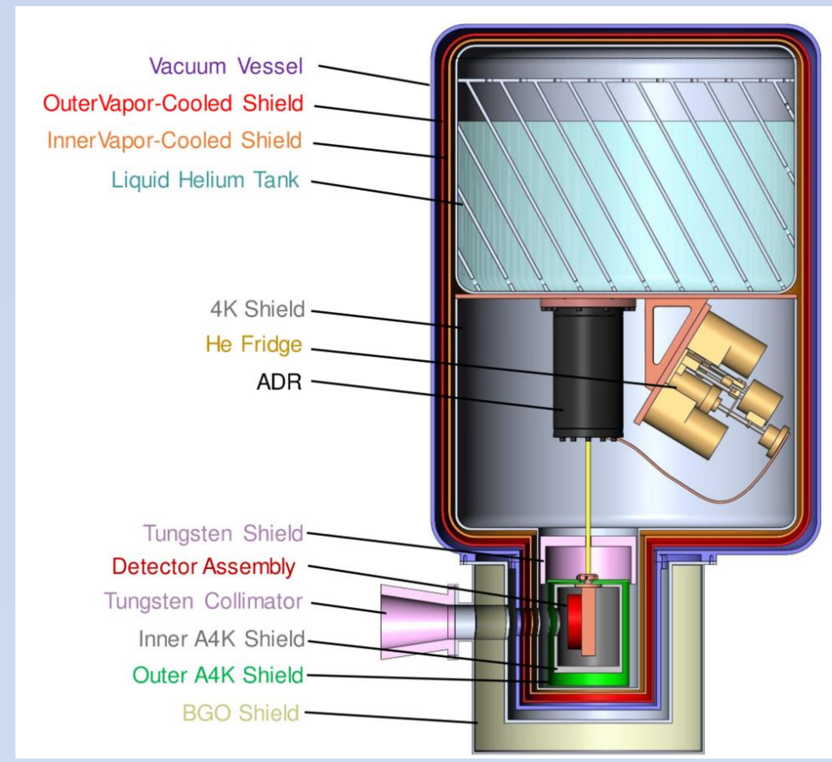
Cryostats

For TES sensors to work, they require superconducting temperatures, which will be about 120 mK for ASCENT (although it will have the capacity to operate at around 70 mK). We had, available to us in the lab, a cryostat which could cool down to 7 mK with nothing else inside.



Upper left: inside of our cryostat.
Upper middle: The cryostat with the vacuum-sealed cover attached.
Upper right: Me working on attaching BGO to the bottom plate!
Right: Phase diagram which demonstrates how a He3/He4 dilution refrigerator works.

Passive & Active Shielding



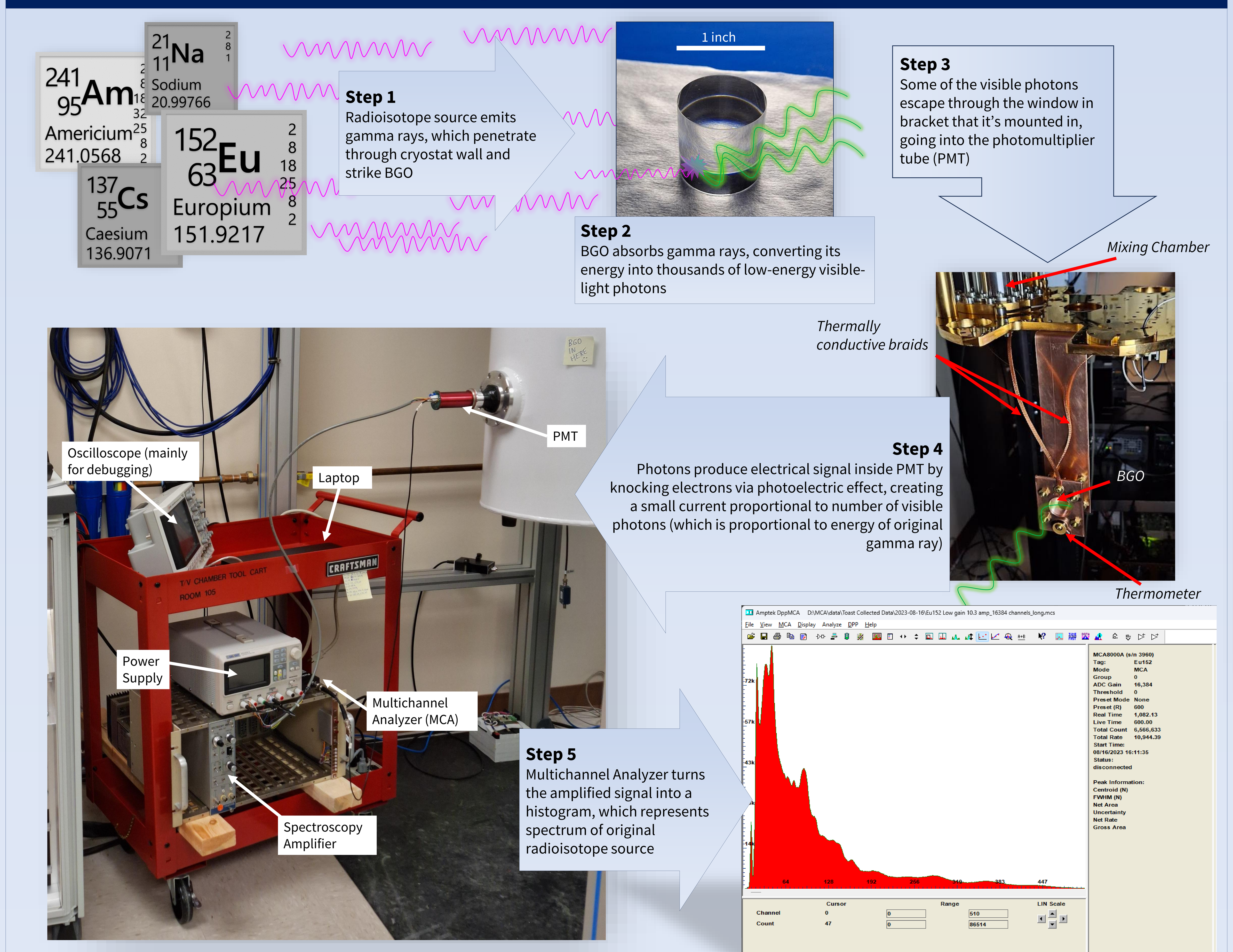
*Original design of the ASCENT cryostat. Note how the BGO Shield layer is placed conservatively outside the cryostat in this design – BGO is heavy, this project could help reduce that weight to a fraction of the previous design's **and** shield the TES sensors better than before.*

One issue with gamma-ray astronomy is the gamma-rays' tendency to penetrate through most materials. Gamma rays come from many sources: some of which are supernova remnants, and some come from cosmic rays interacting with the atmosphere. The former interests us, the latter would get in the way of this experiment (but is also interesting). The simple solution to this is to shield sensors with a thick and electron-dense material such as lead (the electrons will absorb x- and gamma-rays), but this cannot completely filter out interstellar background. In addition, the extra mass from adding an additional layer of thick lead will increase the mass, which is prohibitive in space applications. This method is called *passive* shielding.

Instead, we use *scintillators*, which are materials which emit visible light when struck by high-energy particles. These allow us to utilize *active* shielding. One material in particular, Bismuth Germanate (BGO), shows promise for our application.

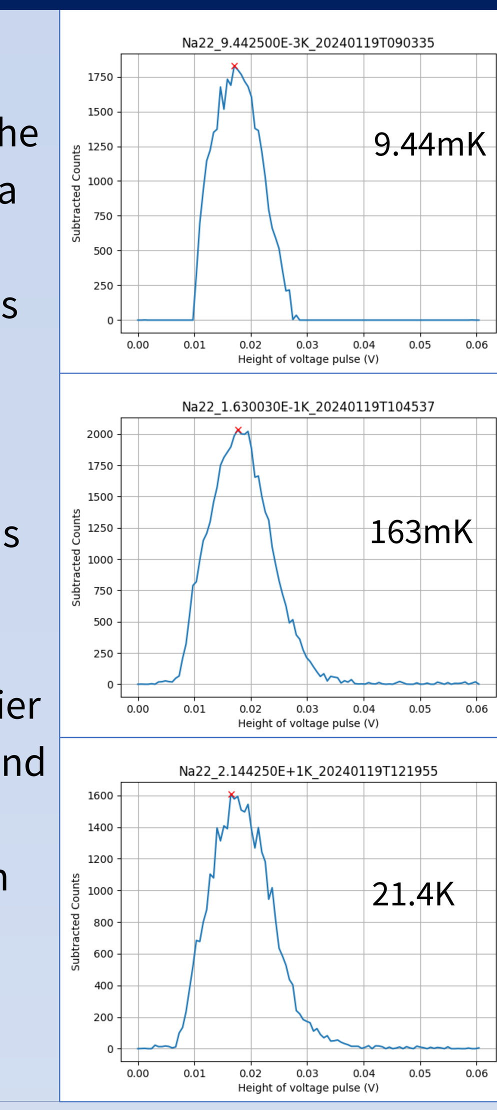
Initially, ASCENT was planned to have active shielding *outside* of the cryostat (see Figure 4), but here we describe an experiment to determine the performance of BGO down to temperatures as low as 9.4 mK, which could demonstrate that active shielding *inside* the cryostat is viable for ASCENT.

Experimental Setup



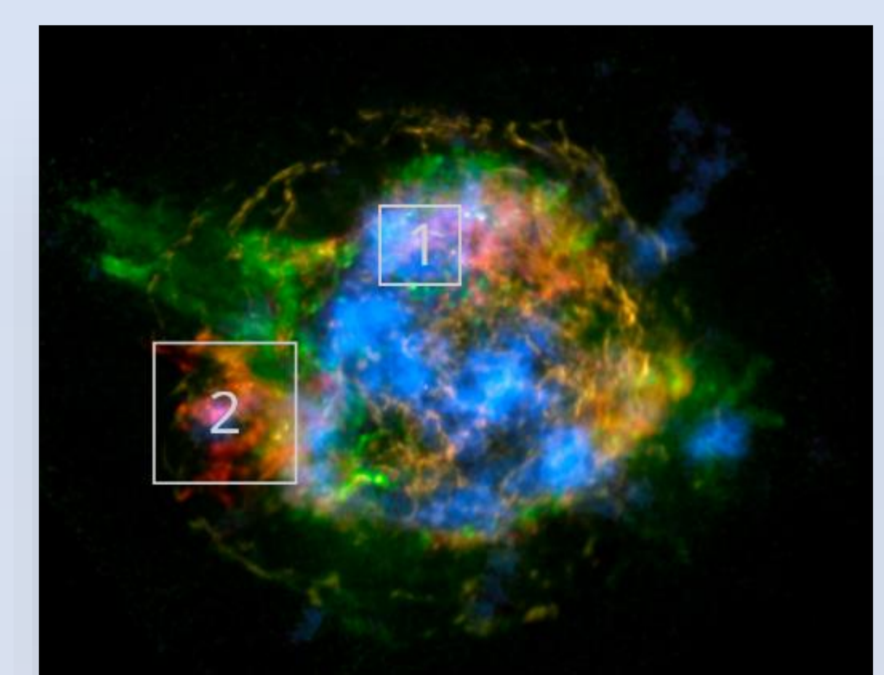
Results & Interpretations

Unfortunately, once background measurements were subtracted from the source measurements, most of the data looked too similar to identify a temperature correlation, even in ranges where a temperature dependence on light yield was expected. Among the spectra shown here, the overall peaks should be expected to shift to the left as the temperature increases. We believe that the radioisotope sources caused false-positives inside the photomultiplier tube by penetrating through the PMT and causing electrons to knock off their anodes (versus letting visible light from BGO doing that), causing more false positives than signal.



Future Plans

- Cryostat is currently non-functional, but once it has been repaired, we would like to re-run this experiment.
- We need to ensure that PMT is properly shielded from radioisotope source (or far enough away that it isn't problematic).
- Once the data are correct (and consistent with previous results), I hope to write a journal article on this topic and/or present it at a non-undergraduate research conference.



Cassiopeia A Supernova Remnant (SNR), false color. Red is iron, stable and readily formed, while blue is Ti-44, which is far more sensitive to pressure and temperature conditions to form. If Ti-44 is present, that provides valuable information on the structure of the supernova before it exploded.

References

Kislat, Fabian, et al. *ASCENT - A Balloon-Borne Hard X-Ray Imaging Spectroscopy Telescope Using Transition Edge Sensor Microcalorimeter Detectors*. 2023. *DOI.org (Datacite)*, https://doi.org/10.48550/ARXIV.2301.01525.

Verdier, M. A., et al. "Scintillation Properties of Bi4Ge3O12 down to 3 K under γ Rays." *Physical Review B*, vol. 84, no. 21, Dec. 2011, p. 214306. *DOI.org (Crossref)*, https://doi.org/10.1103/PhysRevB.84.214306.

Acknowledgements: I would like to offer my most sincere gratitude to Dana Hamel (as this project was funded by the Undergraduate Research Award, possible due to his donations), Kasun Wimalasena and Adrika Dasgupta for their help handling the radioisotope sources, Jason Legere for offering his expertise in PMT spectroscopy, Fabian Kislat for the guidance and opportunity to do this work, and my mother, for making this project possible despite my knee injury.