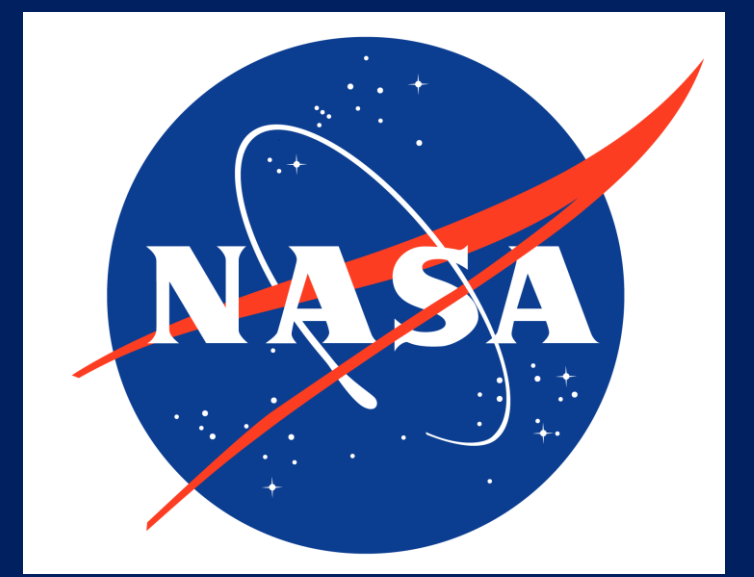




Alignment Monitoring System for the Hard X-Ray Balloon-Borne Telescope SuperHERO

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Introduction

SuperHERO is a hard X-ray balloon-borne telescope being developed by NASA at the Marshall Space Flight Center (MSFC). It aims to develop the clearest and most precise images of several celestial objects, with its focus being the Crab Nebula. The telescope consists of 7 sets of X-ray optics with a focal length of 12 meters, fine-pitch CdTe cross-strip detectors located at the focal point of each mirror, all carried by an approximately 12 meter long carbon-fiber-aluminum composite truss, pointed with sub-arcsecond precision using the Wallops Arc-Second Pointer (WASP) [1]. During flight, the truss of the telescope is susceptible to angular deflections due to thermal expansion, contraction, and gravitational bending, which causes source blurring within the final image. To mitigate the source blurring, the Alignment Monitoring System (AMS) will track the angular deflections of the truss to an accuracy of 10 arcseconds, then use these deflections to correct and re-trace the incoming X-ray photons' position in the sky.

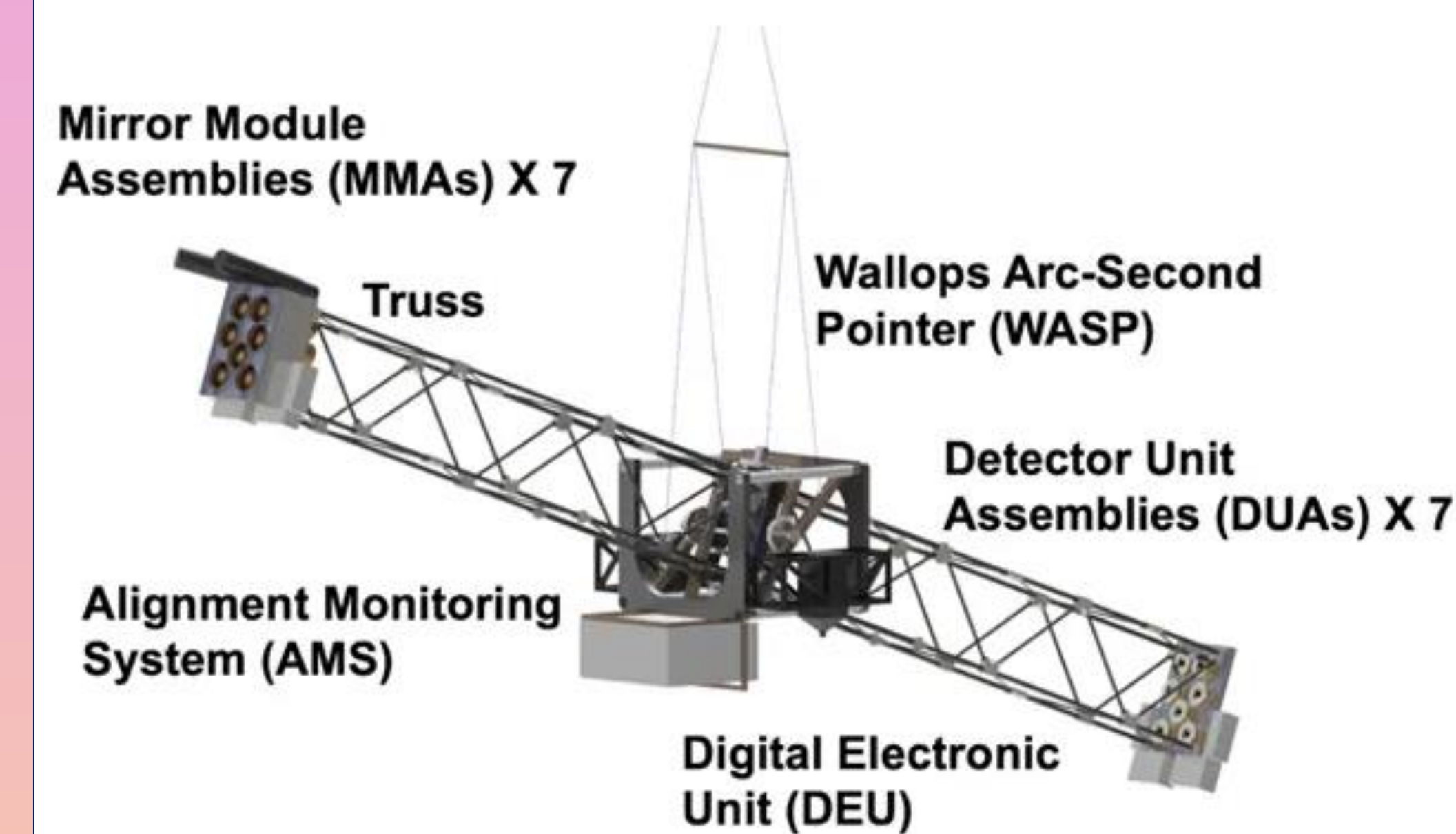


Figure 1. SuperHERO Payload.

Requirements & Constraints

The AMS works by taking images of LED patterns located at each MMA and DUA, then analyzing the image to find the re-constructed center point of the LED pattern. The displacement of the center point is then used to correct the X-ray photon positions.

Optics

- 4 cameras to view all MMAs and DUAs
- Very high spatial resolution to track LEDs precisely
- Camera and lens must not interfere with the optical path of the X-rays
- Mitigation of bright/overexposed images due to direct sunlight

Mechanical/Electrical Aspects

- Must meet NASA balloon-flight requirements [2]
- Similar camera mount designs to reduce production cost
- LED patterns must have low power consumption and be considerate of MMA and DUA requirements

Code

- Image is taken every 10 second
- Identify all LEDs in a pattern

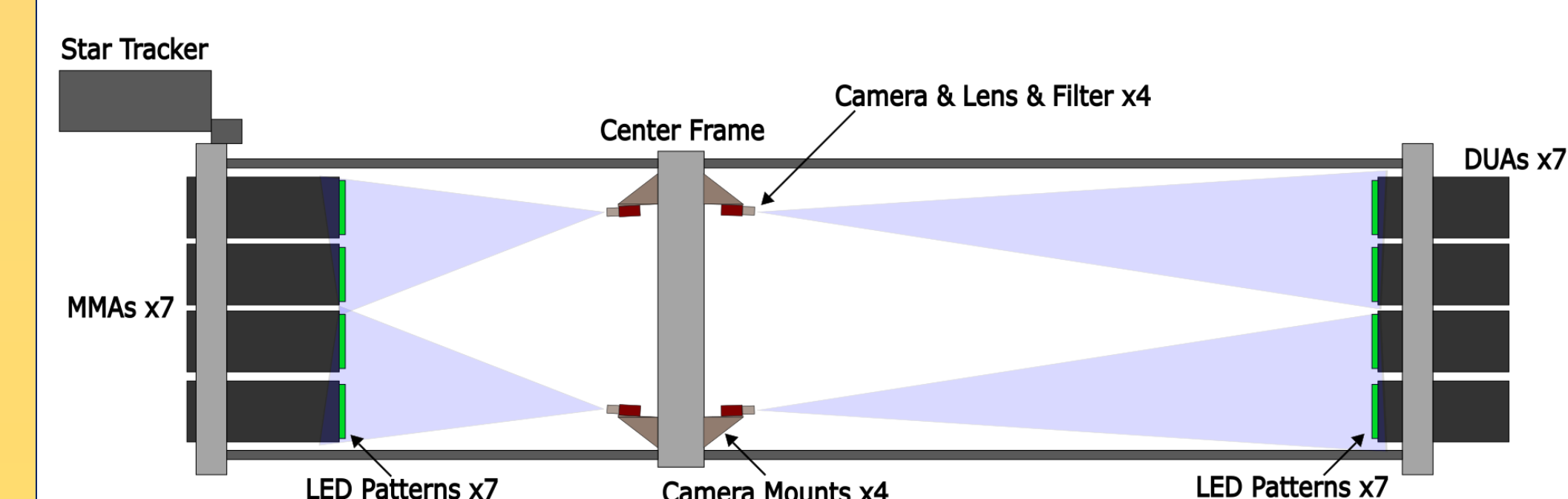


Figure 2. Drawing of SuperHERO AMS components on the truss.

Optics

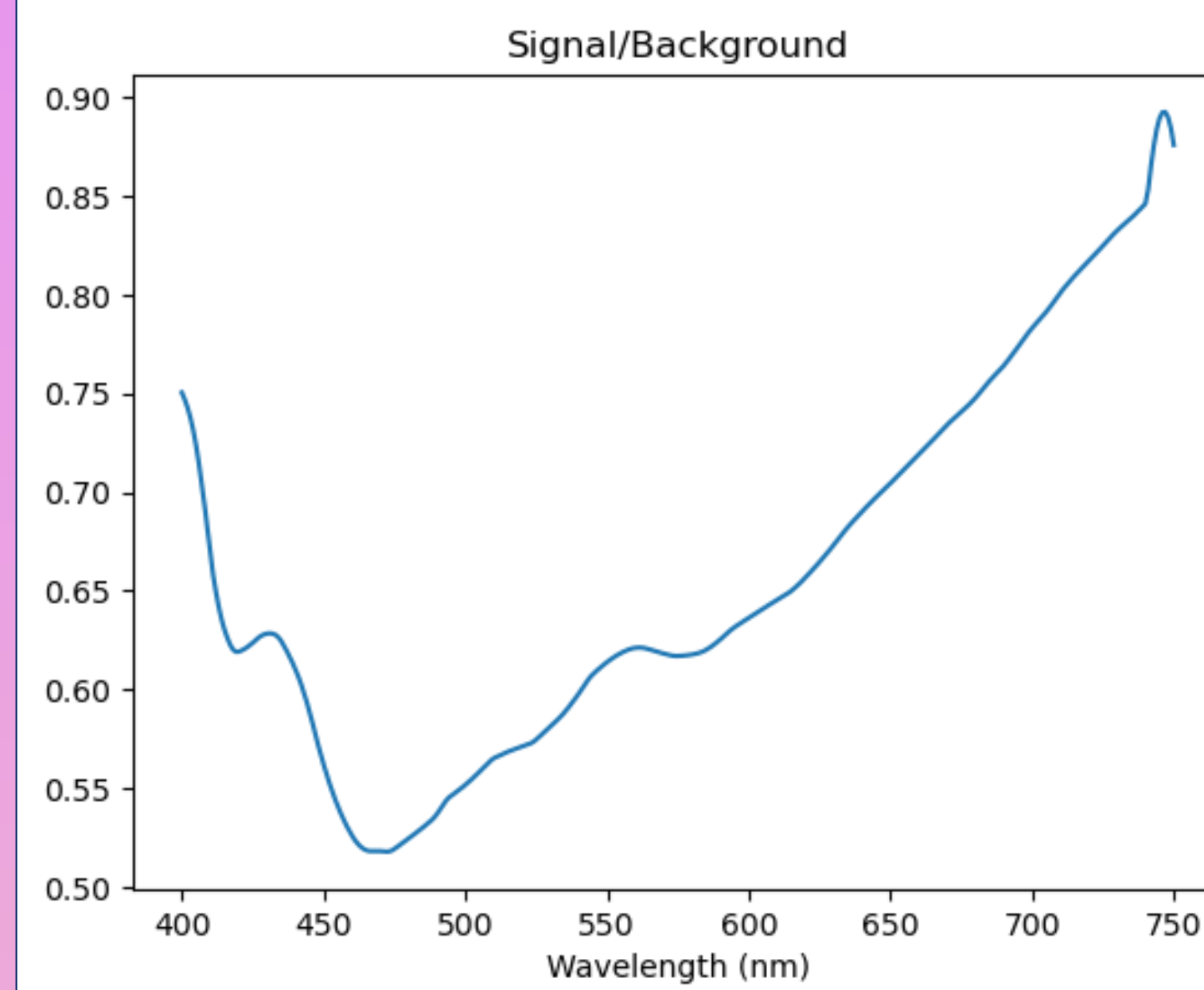


Figure 3. Signal to background ratio for the selected camera using a 20nm rectangular wave to model the narrow bandpass filters, and a normal distribution to model single color LEDs. The camera loses sensitivity beneath 400nm, so it was concluded that wavelengths closer to infrared work better.

Lens Selection & Placement

- The camera is the Prosilica GT-2460 C-Mount
- Hand calculations to provide a list of potential lenses
- 50mm C Series Fixed Focal Length Lens for MMA viewing, 100mm C Series Fixed Focal Length Lens for DUA viewing
- Two camera placed on both sides of the center frame with the top cameras upside-down

LED-Filter Trade Study

- Python was used to find the best signal to background ratio

$$S = \int_{400}^{750} Q_E(\lambda) * T_F(\lambda) * I_L(\lambda) d\lambda$$

$$B = \int_{400}^{750} Q_E(\lambda) * T_F(\lambda) * I_S(\lambda) d\lambda$$

S: Signal
B: Background
Q_E: Camera Quantum Efficiency
T_F: Filter Transmission
I_L: LED Relative Intensity
I_S: Sun Irradiance

- Tested several real-world LED-filter pairs
- Selected 660nm LED and 660nm narrow 10nm bandpass filter

Mechanical/Electrical Aspects

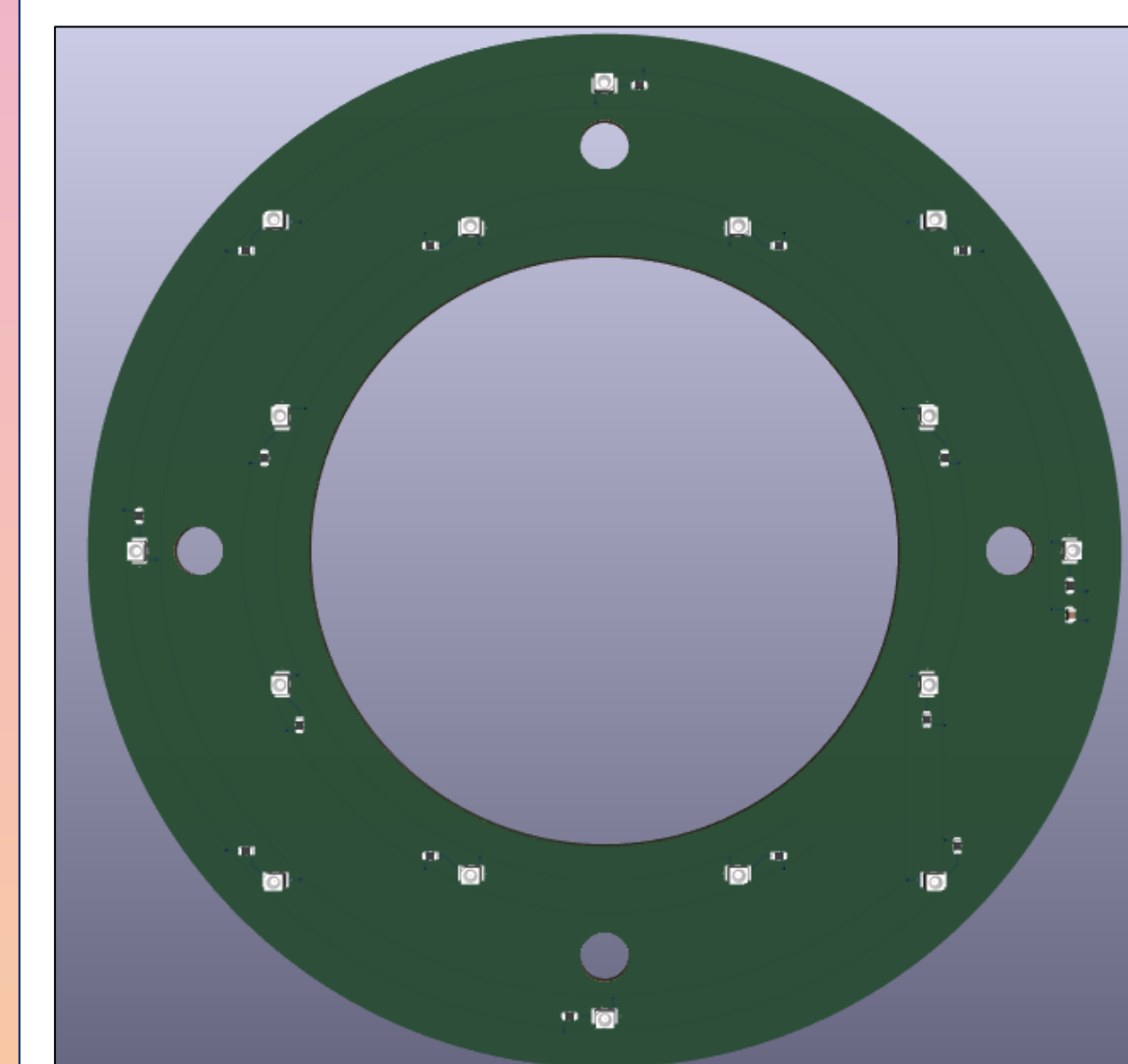


Figure 4. LED pattern with two concentric rings of LEDs and resistors, offset by 22.5 degrees.

LED Pattern

- KiCad was used to design the LED pattern schematic and 3D model. The design consists of 16 LEDs and current limiting resistor pairs in parallel, one decoupling capacitor, and four mounting holes, all on a black annulus with inner diameter 4 inches and outer diameter 7 inches

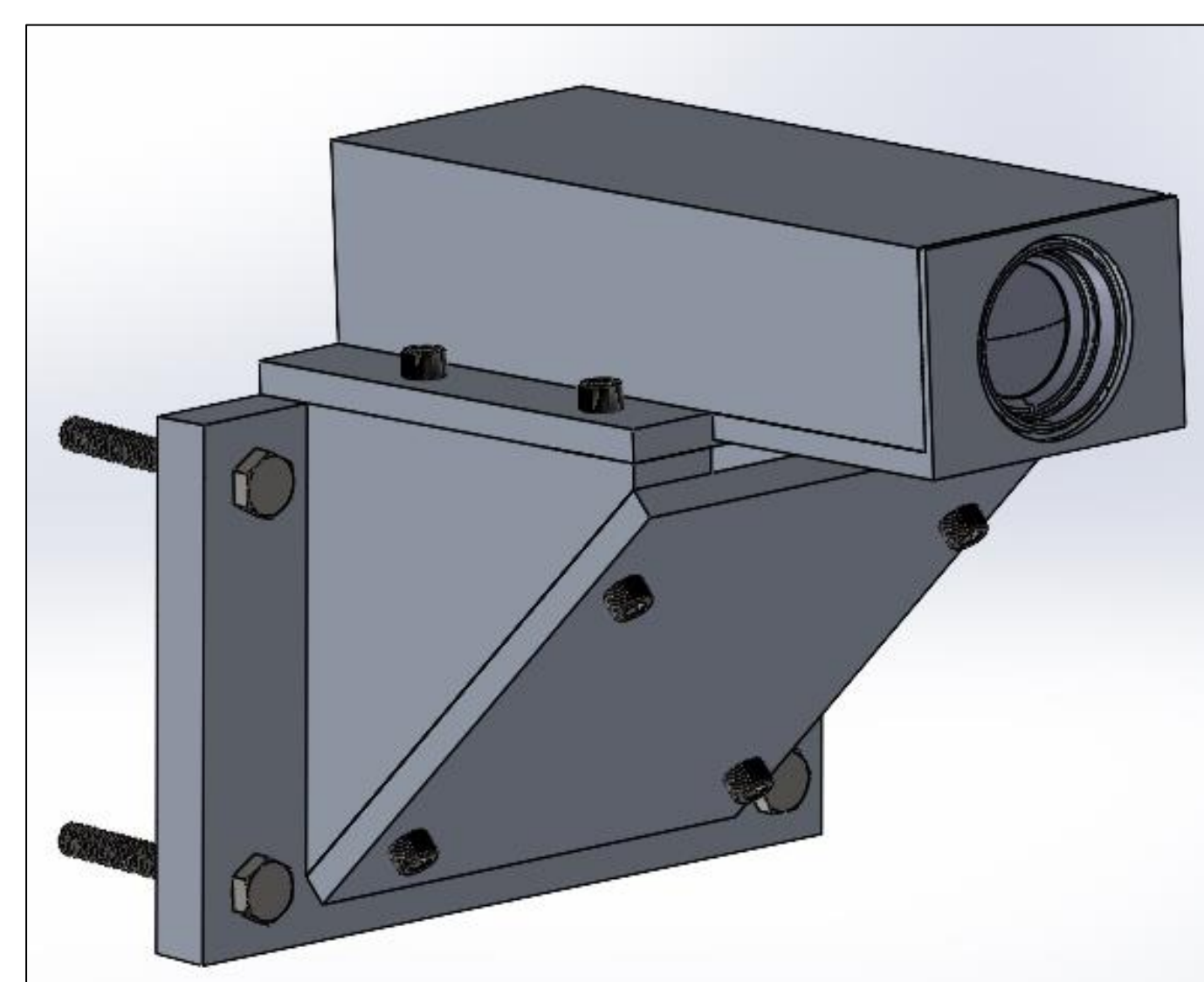


Figure 5. MMA camera mount with protective heat box to prevent overheating and for insulation installation.

Camera Mounts

- Designed in SolidWorks as 5 slabs made from 6061 aluminum alloy and 18-8 stainless steel bolts
- 3.15° inclination for viewing the MMAs, 1.65° inclination for the DUAs
- FEA analysis in SolidWorks to determine the factor of safety for the 4 load-bearing bolts
- Heat box to prevent overheating

Code

The LED finding algorithm was first prototyped in Python using the OpenCV library before being converted to and improved in C++.

Dark Image Analysis

Crop image → Apply cv2.threshold and cv2.connectedComponentsWithStats to find bright contours → Average the weighted centers of all contours

Bright Image Analysis

Crop image → Mask image → Apply cv2.threshold with a lower limit of 254 and an upper contour size → Store center points into x and y vectors → Apply cv2.morphologyEx with cv2.MORPH_OPEN and a small elliptical kernel once to eliminate noise → Iteratively apply the morphing with an increasing kernel size and store each iteration's center points that are beneath the upper contour size into the vectors → Find and delete all duplicate center points → Average all center points

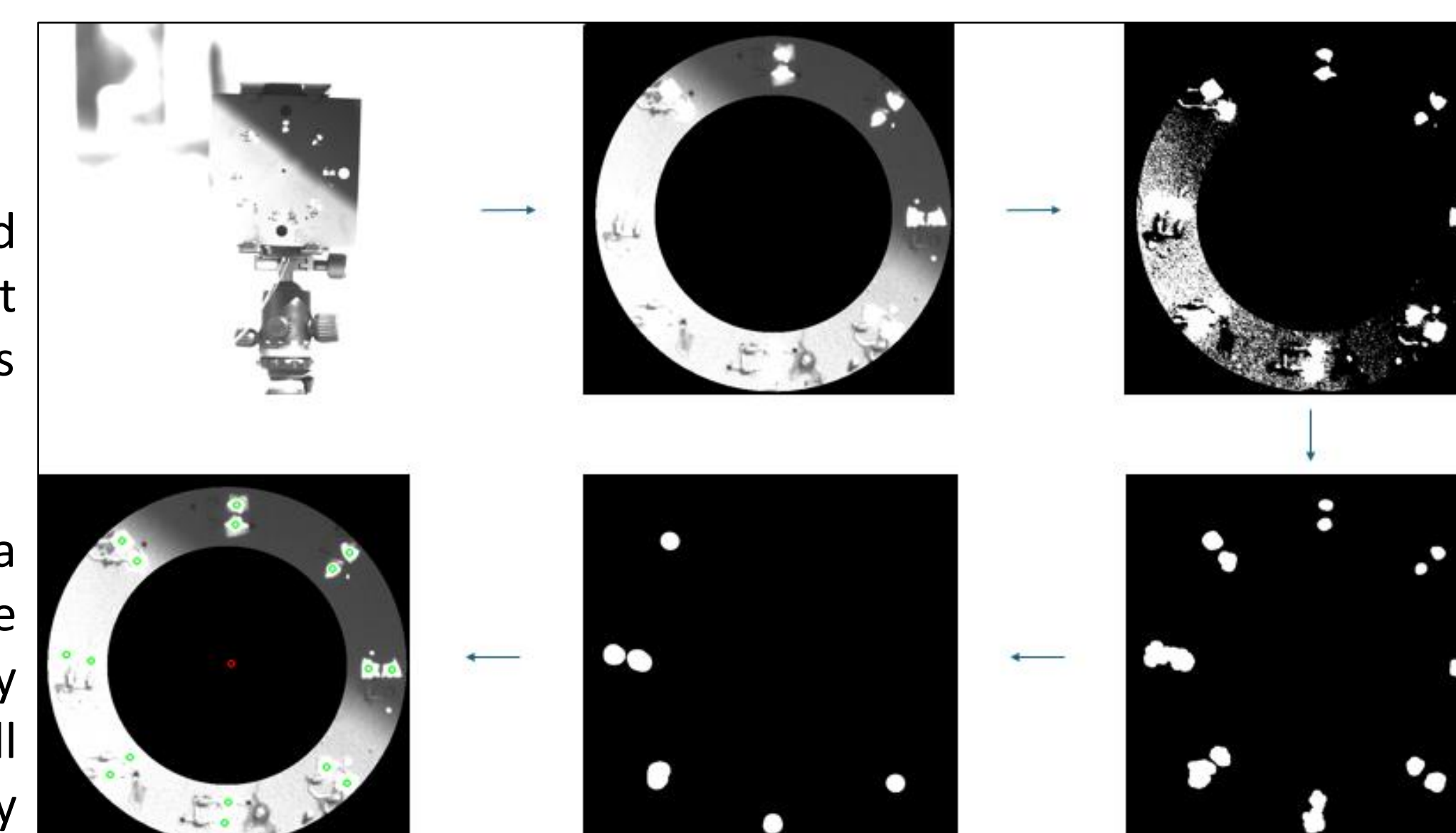


Figure 6. Simplified layout of the overexposed/bright image algorithm process.

Results

By normalizing the LED relative intensities, we find that the 660nm LED-filter pair has an 11-fold increase in signal to background ratio compared to the original white LED and no filter pair.

The FEA analysis gave a factor of safety of 3.56 for all 4 load-bearing bolts under an 8G vertical force. Against a 4G horizontal force, two bolts had a factor of safety of 3.91, and the other two were recorded at 4.17. All factors of safety are above the yield and ultimate of 1.25 and 1.4 respectively.

The dark image analysis is able to identify 16/16 LEDs in 92/104 images, 15/16 LEDs in 11/104 images and 17/16 LEDs in 1/104 images.

Conclusion

The imaging of the LED patterns will have very good spatial resolution along with several ways to help analyze otherwise bright images. The mounts which hold the cameras are structurally stable and simply designed for lower production cost. The LED patterns have low power consumption, no interference with the optical path of the X-rays entering the DUAs, and will not be in direct thermal contact with the MMAs. The code is able to analyze images to find LEDs in dark and bright images, but the success rate for bright images can be improved.

SuperHERO hopes to fly its first mission in late 2028 from Fort Sumner, New Mexico.

Future Work

Most of the material that will be used on the AMS must still be purchased.

Optics

- Construction of the thermal chamber camera mount
- Testing of lenses in the thermal chamber
- Baffling of the LED patterns to protect them from the Sun

Mechanical/Electrical Aspects

- Construction of the LED patterns
- Construction of camera mounts

Code

- Improvement of bright image analysis run-time and success rate
- Test precision of LED finding algorithm
- Final on-flight code

All models, code, and documentation for this project will be available to other members of the SuperHERO team.

Acknowledgements

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References

- [1] Thomas, Nicholas E. et al. "The SuperHERO (Super-High Energy Replicated Optics) High-Angular Resolution, Hard-X-Ray Telescope." *Spiedigitallibrary*, 18 Sept. 2025, www.spiedigitallibrary.org/conference-proceedings-of-spie/13626/3065795/The-SuperHERO-Super-High-Energy-Replicated-Optics-high-angular-resolution-hard/10.1117/12.3065795.full?tab=ArticleLink.
- [2] "Gondola Structural Design Requirements." NASA. Accessed: Dec. 14, 2025. [Online.] Available: <https://www.csbf.nasa.gov/documents/gondola/820-PG-8700.0.1A%20Gondola%20Structural%20Design%20Req.%2011.4.pdf>