Enabling more affordable space instrumentation with LUVCam

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***Abstract*—The cost of quality scientific instruments has limited access to space-based astronomy. The Little UV Camera (LUVCam) project intend to rectify this and make space astronomy more accessible. LUVCam is a low-cost alternative to existing space-qualified cameras without compromising data quality while enabling cutting-edge science. The project presented in this paper is a 0.5U, 287.3g payload integrated into a 2U CubeSat called GRBBeta. It was launched aboard Ariane 6 on July 9 and has been operational since then. The camera structure is mainly made of glass-reinforced PEEK. A clear anodized aluminum plate was used as a radiator to dissipate the heat generated by the image sensor. A copper strap conductively transfers the heat from the image sensor to the radiator. The optical systems comprise a UV filter, three lenses, and a mirror that directs light to the image sensor. The three lenses have a diameter of 21 mm, with a clear aperture diameter of 18.23 mm. Detailed thermal modeling showed that the camera could be thermally controlled by following a specific operating procedure. The goal is to achieve a technology readiness level (TRL) of 7 and to enable more space observations.**

***Index Terms*—LUVCam, mechanical design, thermal analysis, CubeSat, new space**

I. INTRODUCTION

Space-based astronomy is crucial for our understanding of the Universe and our place in it. These facilities enable data acquisition on various topics, allowing generations of scientists to analyze them. However, the high cost of space-based astronomy projects has limited participation and constrained scientific opportunities. Historically, state-of-the-art projects, such as the James Webb or Hubble Space Telescope, are built as one-of-a-kind and cost many billions. However, a shift is underway in the industry. Academia is increasingly launching CubeSats that are significantly more affordable for conducting scientific research in space.

Recent advances in private spaceflight have reduced launching costs. Satellites are getting smaller and are launched closer to Earth. Satellites are more standardized, which reduces non-recurring engineering costs. Launching a satellite has never been cheaper. All these factors contribute to a "New Space" era. This era should render space more accessible to academia, but the costs of quality space astronomy instrumentation have limited their ability to participate in it. Especially for UV astronomy, quality image sensors are expensive. Also, they have been limited by the low sensitivity of the sensor operating in this wavelength.

The LUVCam project aims to provide a more affordable image sensor that does not compromise on data quality, while enabling cutting-edge science. The LUVCam is a versatile, space-grade camera that will facilitate the development of low-cost astronomical instruments, enabling individual academic institutions to design, develop, and launch world-class telescopes on SmallSats at a rapid pace and low cost. LUVCam is composed of commercial off-the-shelf (COTS) components, including optics, electronics, and an image sensor. It utilizes a large-format, high-pixel-count sensor with low noise and high quantum efficiency, a COTS backside-illuminated (BSI) complementary metal–oxide–semiconductor (CMOS) image sensor, custom-built readout electronics, and a thermal and mechanical structure. It is ITAR-free and can be fully built for a fraction of the price of a heritage camera. The camera is designed to enable many scientific applications and missions.

This paper will focus on the mechanical design and the thermal analysis of the LUVCam. A brief explanation of the reasons for selecting the image sensor and an overview of the space mission are provided. It is essential to recognize that LUVCam was designed, built, and launched in space within a year.

II. IMAGE SENSOR

The image sensor's selection process was achieved in [1], where they found that the CMOS image sensor GSENSE 4040 BSI from Gpixel was the best option available. It is the only affordable image sensor that can offer high performance in the UV wavelength. For comparison, a UV sensor with space heritage, such as the Teledyne e2V CCD47-20, would cost 10 times more. Apart from its affordability, the GSENSE image sensor enables open-source programming and custom-made electronics, aligning it more closely with the LUVCam program's goals: to have an affordable and commercially available off-the-shelf image sensor that can be quickly integrated into a spacecraft, enabling academia to launch more scientific payloads into space. Table I presents the key technical specifications of the camera sensor, along with the corresponding scientific justification.

TABLE I
TECHNICAL SPECIFICATION FOR THE SCIENCE SENSOR GSENSE4040BSI AND THE SCIENTIFIC JUSTIFICATION FOR EACH RELEVANT SPECIFICATIONS

Parameter	Specification	Justification
Peak in band Quantum Efficiency (QE) (250-300nm)	55%	The relatively high QE maximizes the efficiency/sensitivity of the observatory. It is essential for rapid survey speed for the transient surveys.
Detector Size Imaging Pixel Array Pixel size	36.8 x 36.8 mm 4096 x 4096 9 x 9 microns	The large format and pixels of the detector enable the large field of view (FOV) while still meeting resolution requirements for the plate scale.
Read Noise Dark Current (0 °C)	2.3 e^- 0.3 e^- /pix/s	The low read noise and relatively low dark current allow for both sensitive and fast imaging as well as deep exposure background-limited observations.
Full Well Capacity Analog-to-Digital Converter	39,000 e^- 12-bit	The well capacity, combined with the firmware's internal stacking functionality and relatively low read noise, allows for tuning the dynamic range to meet the requirement for a variety of science goals.

III. THE GRBBETA SPACE MISSION

The LUVCam project was offered a 0.5U volume in a 2U CubeSat, GRBBeta, made and operated by Spacemanic. Its primary objective is to detect gamma-ray bursts (GRBs). It is the follow-up to the successful 1U Cubesat, GRBAlpha, also made and operated by Spacemanic. GRBAlpha aimed to demonstrate the feasibility of making a gamma-ray detector small enough to fit in a 1U CubeSat. They achieve this objective by characterizing the GRB 221009A event [2]. GRBAlpha and GRBBeta are stepping stones for a more significant space mission called CAMELOT (*CubeSat Applied for MEasuring and LOcalising Transients*). This mission aims to deploy a fleet of 3U CubeSats to survey the entire sky and detect transient events, such as GRBs [3].

GRBBeta was launched on the inaugural flight of Ariane 6 on July 9, 2024. This was possible by collaborating with a multidisciplinary, international team composed of Hungarian, Czech, Japanese, and Canadian members. The Hungarian Konkoly Observatory led the development of the gamma-ray burst detector. Spacemanic made the satellite platform. The Czech Masaryk University led the science and data analysis. The Japanese Hiroshima University helped with the hardware development. The University of Toronto developed the extra scientific payload, the little UV space camera, LUVCam.

The primary objective of LUVCam with GRBBeta was to demonstrate that the image sensor and its electronics could withstand the space environment. It was also to demonstrate the lab's capability to rapidly design a working space camera. Most of the mission requirements were not chosen but imposed upon us. The final orbit given by Ariane 6 was imposed. The design of the spacecraft was imposed. LUVCam had to accommodate already existing hardware. Those requirements were not optimal for LUVCam, but the team did its best to devise the best working solution within one year.

IV. MECHANICAL DESIGN

The most crucial design criterion used was flexibility. The design had to accommodate quick turnarounds, fast prototyping, rapid manufacturing, and short procurement lead times. To achieve this, the team utilized 3D printing manufacturing to enable fast prototyping and customization. Ideally, we would have used a more generic design approach to limit the amount of one-of-a-kind design, but we were forced onto that path. At the time, the CubeSat had already been designed, and we had to integrate our camera into their design, which was never intended to have a 0.5U UV camera payload. The delivered product weighed 0.287 kg and had a volume of 96 x 96 x 45.5 mm^3. Figure 1 shows LUVCam fully assembled, and Figure 2 shows GRBBeta fully assembled. Figures 3 and 4 show the CAD model of the LUVCam.

A. Material Selection

Most components were 3D printed using poly-ether-ether-ketone (PEEK) reinforced with glass fibre (GF). The GF30 PEEK has a low density, good-enough tensile strength, and low conductivity. It is also 3D printable and has space heritage. This combination of properties made it an ideal candidate for this project, where mass was the primary concern for our design. When we needed a material with higher hardness, we used CRES304, a type of stainless steel. It was used on the different lens spacers, which had to be ground to a specific thickness with strict tolerances. A strap made of copper was used to carry heat from the image sensor to the radiator. Copper is a highly thermal conductive material, making it ideal for this role. An aluminum alloy, the 6061-T6, commonly used in space hardware, was used for the radiator plate and the thermal pad. This alloy was used for its low density and thermal conductivity. The divergent lens and the UV filter were

Fig. 1. LUVCam fully assembled

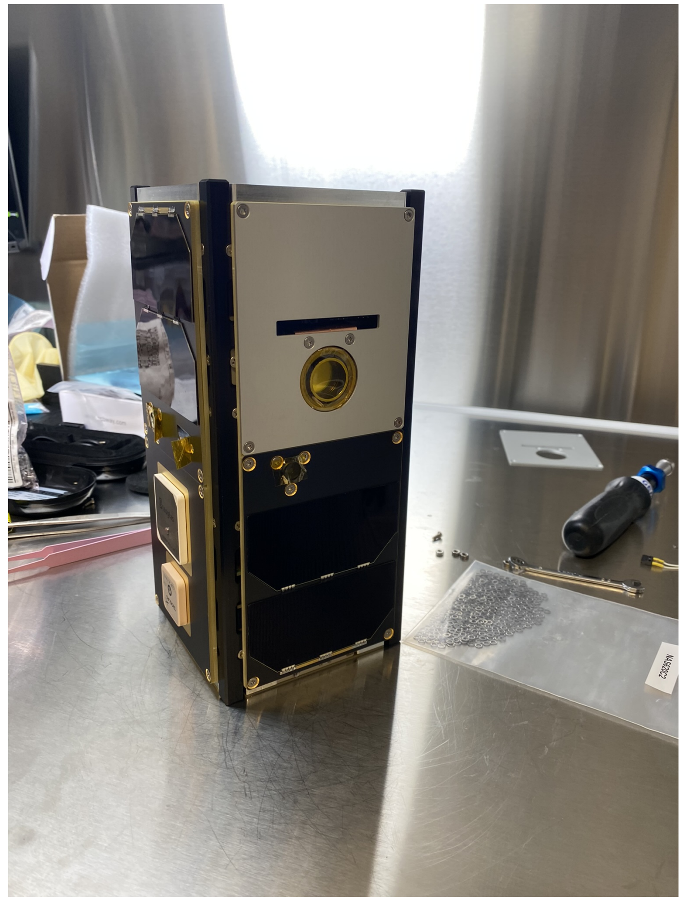

Fig. 2. GRBBeta fully assembled

made with fused silica, and the convergent lens was made with CaF_2. Screws, nuts, washers and helicoil inserts were made in steel A-286, a commonly used material for this.

B. Design Process

To design, manufacture, assemble, and integrate within the one-year time frame, we had to follow a strict schedule, anticipate problems early in the design process, and utilize multiple parallel paths to mitigate risks. Additionally, by following a standard approach and respecting established norms and guidelines, we were able to design a working solution, thereby reducing development time. We could not afford to use all of our time in the design phase of the product development. We had to come up quickly with a prototype on which we could test the optics and the assembly process.

The most critical components, such as the main frame that supports the entire camera assembly, were manufactured in multiple copies and two different materials. One version was made of GF30 PEEK, while the other was made of aluminum 6061-T6. This was done to reduce the risk of the GF30 PEEK frame being insufficiently strong. The aluminum frame was heavier and stiffer, but it required a longer manufacturing time. Therefore, it had to be ordered simultaneously with the GF30 PEEK to ensure it was ready if needed.

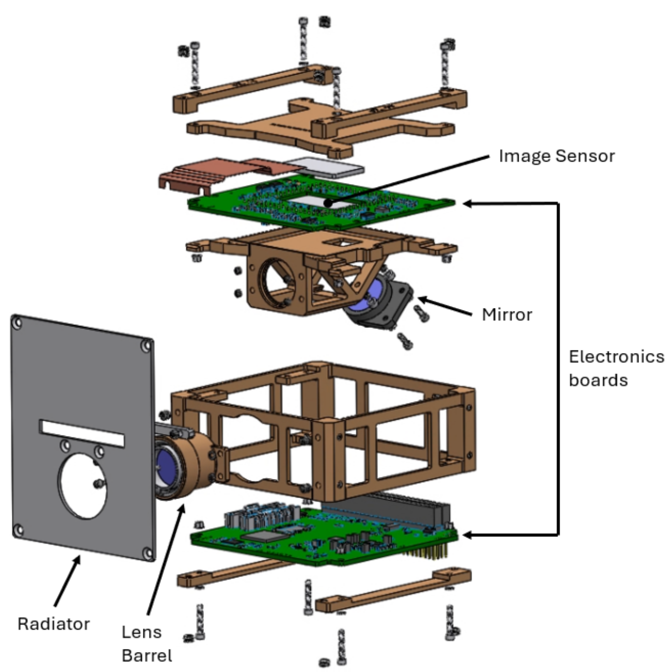

Fig. 3. LUVCam payload exploded view

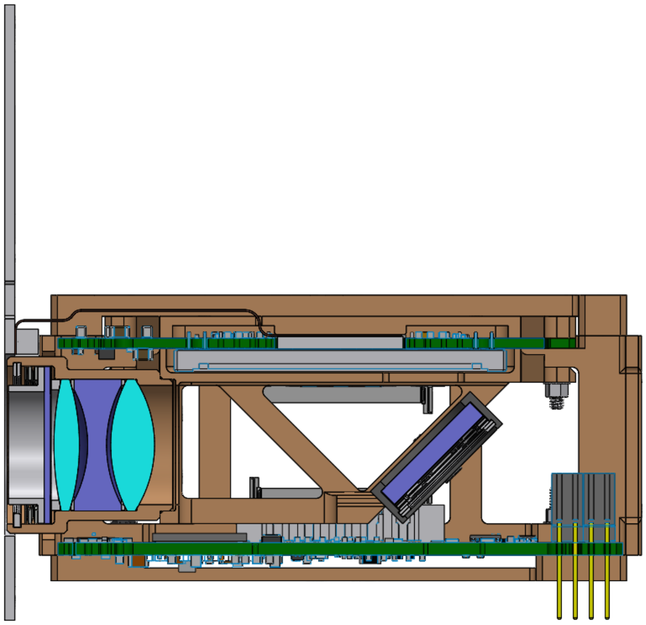

Fig. 4. LUVCam payload cut view

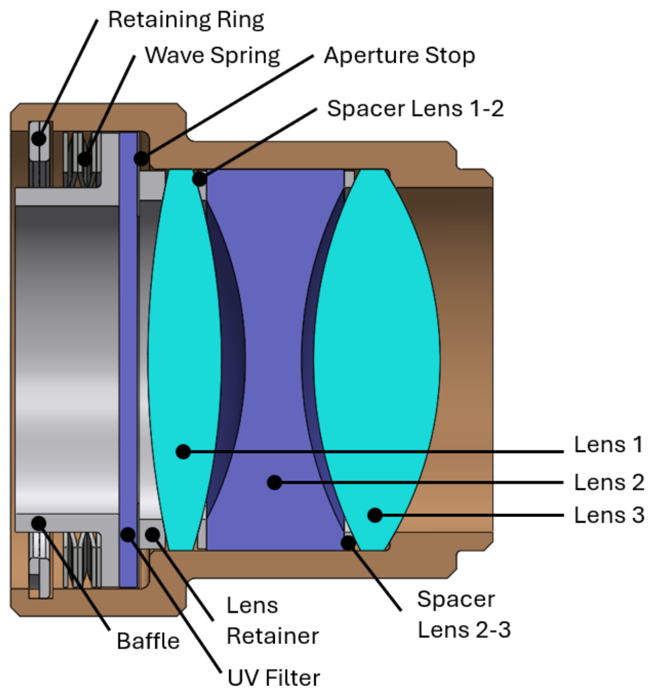

Fig. 5. LUVCam,s telescope cut view

Another critical component was the telescope. Figure 5 shows a cut view with all the telescope components. It contains the optical system, which allowed us to test in space if the image sensor was working or not. It also assessed the image sensor's performance evolution over time as it is exposed to the space environment. Our experienced team of optical experts achieved the optical design relatively quickly. Although optics require precise alignment and positioning, which can lead to vibration and thermal concerns, we were able to design solutions that mitigate these issues. We employed a stacking process in which a spring was used to push on the optical stack, maintaining it firmly in place. Spacers were carefully manufactured to keep the spacing between the different lenses. The force of the spring can be adjusted by varying the amount of compressive deformation. The telescope was in GF30 PEEK, effectively decoupling the lens temperature from the rest of the spacecraft and payloads.

During the design process, we had to choose which tests were necessary for LUVCam. Since we were designing a light payload and only CubeSat-level vibration testing was required, we performed no payload-level vibration testing or analysis. We determined that thermal analysis was necessary to predict the temperature of the image sensor and ensure it would neither overheat nor become too cold. The image sensor and its electronics were also extensively tested to ensure they would work. The final calibration of the image sensor was done by tuning the mirror's position. Throughout this project, we followed a good-enough design approach. There is a tendency to overanalyze, spend excessive time on design, and undertake time-consuming work that does not significantly add value to the project. In this good-enough approach, you focus on work that adds value to the project and accept to take more well-identified and characterized risks. Our primary concern was to ensure that our payload would not harm the other GRBBeta payloads.

V. Thermal Design

The image sensor is sensitive to thermal fluctuations, and its operating temperature influences its performance. Therefore, it was essential to maintain the operating temperature of the image sensor around 0°C. According to the image sensor specification data sheet, the safe operating temperature range is $-40\,°C$ to $+50\,°C$. To achieve this, we used a radiator plate made of aluminum 6061-T6 with a clear anodized surface finish. The radiator was thermally coupled to the image sensor with a copper strap. Figure 6 shows the thermal path. Initially, it was assumed that the image sensor would generate 1.4 watts of heat. The radiator had the maximum surface area that was allowed by the spacecraft. The initial analysis indicated that the radiator would be sufficient to dissipate the energy generated by the image sensor when it was turned on.

However, when the thermal model was completed, the results showed the radiator was not dissipating enough energy to maintain the sensor temperature within its optimal operating range for more than a minute. This was due to the spacecraft having no other way to dissipate heat. The radiator functioned as a heat sink for the entire spacecraft. This was solved by decoupling the radiator from the spacecraft by using PEEK screws and a FR-4 plastic spacer. One screw remained in steel for grounding purposes. Figure 7 shows the temperature of the image sensor after being activated for one minute at different beta angles. The one-minute operating time is

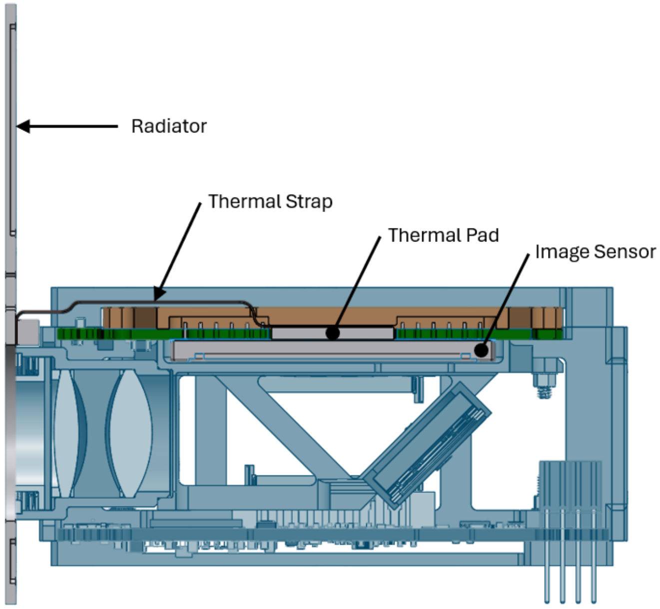

Fig. 6. Thermal path from the image sensor to the radiator

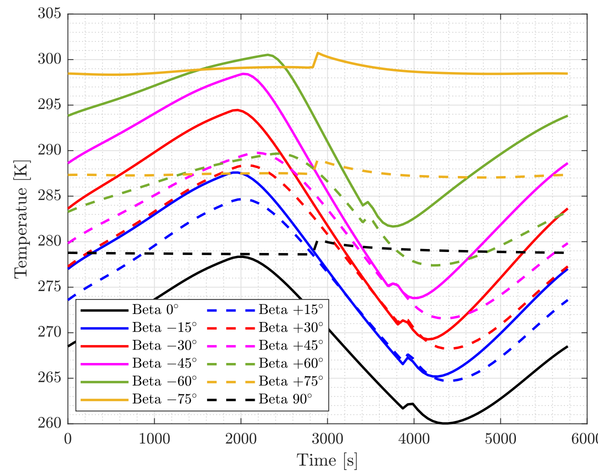

Fig. 7. Image sensor temperature

based on the assumption that it would take approximately one minute for the image sensor to capture an image. Table II contains the temperature of the image sensor and the radiator after one minute of activation. The margins for the image sensor represent the difference between the temperature of the image sensor predicted by the thermal model and the image sensor's safe operating temperature. A green cell indicates the temperature is within the sensor's safe operating range. The negative sign refers to the available margin before exceeding the safety margin. The margins for the radiator's temperature represent the difference between its optimal and actual surface temperatures. A red cell means the temperature is below the optimal temperature. A yellow cell means it is within 10 °C of the optimal temperature. A green cell means it is above the optimal temperature. The negative sign indicates the available margin before the temperature falls below optimal. The positive sign indicates the margin required to achieve the optimal temperature for the radiator.

In Table II, the image sensor temperature is always within its safe operating temperature range regardless of its position on the orbits. This is why the thermal model was important. It highlighted that we had to operate the image sensor carefully when it was in orbit. The radiator's temperature indicates that some orientations would be more problematic since the radiator cannot dissipate enough heat. This would lead to a higher sensor temperature if activated for over one minute. Of course, the thermal model could have been refined, and further analysis could have been conducted to find an alternative solution. However, following our good enough approach, we consider this satisfactory. Other options, such as painting the radiator white, would have helped dissipate more heat. Again, each decision was made considering its impact on the schedule and added value. The assessment for painting the radiator was

TABLE II
IMAGE SENSOR'S AND RADIATOR'S TEMPERATURE WHEN ACTIVATING IT FOR 60 s

Beta Angle [°]	**Sensor's Temperature [K]**	**Margin**		**Radiator's Temperature [K]**	**Margin**
		Hot	**Cold**		
0	262 (−11 °C)	**-46**	**-14**	247 (−26 °C)	**+7.6**
15	267 (−6 °C)	**-41**	**-19**	250 (−23 °C)	**+4.6**
30	271 (−2 °C)	**-37**	**-23**	254 (−19 °C)	**+0.6**
45	275 (2 °C)	**-33**	**-37**	257 (−16 °C)	**-2.4**
60	282 (9 °C)	**-26**	**-34**	265 (−8 °C)	**-10.4**
75	289 (16 °C)	**-19**	**-41**	283 (10 °C)	**-28.4**
90	280 (7 °C)	**-28**	**-32**	275 (2 °C)	**-20.4**
-75	301 (18 °C)	**-17**	**-53**	299 (26 °C)	**-44.4**
-60	284 (11 °C)	**-24**	**-36**	263 (−10 °C)	**-8.4**
-45	275 (2 °C)	**-33**	**-27**	256 (−17 °C)	**-1.4**
-30	271 (−2 °C)	**-37**	**-23**	253 (−20 °C)	**+1.6**
-15	267 (−5 °C)	**-41**	**-19**	250 (−23 °C)	**+4.6**

that it would take too much time and did not add enough value.

When GRBBeta was launched, the team added a temperature sensor on the radiator to monitor its temperature. This can validate the thermal model and provide an approximate temperature reading for the image sensor. This helps us determine if the image sensor is too hot or cold before activating it. The team successfully established communication with GRBBeta and monitored the various systems. The camera can receive commands, take pictures and send them to us.

VI. Conclusion

To conclude, this article focused on the mechanical design and thermal analysis of the LUVCam. It highlighted that designing, building, manufacturing, assembling, and integrating a complex payload into a spacecraft is possible within a year. However, a good enough design approach must be followed to achieve this, and the focus must be on adding value. Some analysis and testing must be omitted when working on such a tight schedule. They must be carefully thought out, and their respective risks must be thoroughly assessed. It is tough to follow a good enough approach because it is natural to analyze to mitigate risk or rework the design to improve it. A good enough approach means understanding the project's primary goal and reserving future improvements for subsequent iterations. However, it does not mean making uninformed decisions to speed up the process. It is a fine balance between accepting more well-defined risk and achieving a working product. Of course, it does not apply to every situation. Still, as the industry shifts towards smaller satellites closer to Earth, it becomes even more important to build rapidly than to have over-designed satellites.

Using this approach, LUVCam successfully achieved its objectives of reaching space and demonstrated that it is possible to have affordable and high-performing UV space astronomy instrumentation, enabling the performance of fascinating science. This is not the end for LUVCam. Future projects are coming. First, BRNOSat, a 6U CubeSat, is scheduled to launch in Q2 2026. Secondly, there is QUVIK (Quick Ultra-VIolet Kilonova surveyor). It is supposed to launch in 2029. For both projects, the team's future role will be to design the mechanical support for the image sensors and electronics, incorporating the appropriate interface, and provide thermal control for the image sensor and related electronics. Much more exciting work remains with LUVCam to ensure it reaches its ultimate goal of providing more affordable access to space astronomy.

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