SIONYX IARPA SINTRA Capabilities Statement

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I. SIONYX SINTRA Capability Matrix

SIONYX capabilities specifically relevant to the SINTRA mission.

Capability Description	Status	TRL
Low light, VISNIR cameras for space applications	More than a dozen cameras on-orbit	TRL 9, Excellent space radiation performance
Imaging to Mag 15 with a 2 inch aperture optic	Demonstrated Mag 9 on-orbit with a smaller aperture. Latest sensors are 10x more sensitive	TRL 6, Latest sensors are in production and use the same processes as space proven devices
High sensitivity from 400 nm to 1100 nm	Core technology demonstrated in on-orbit cameras	TRL 9, Process is in high volume production
High volume delivery of low noise, high sensitivity imagers	Processes fully qualified. Delivering production volumes on multiple products.	TRL 9, Same processes as used for the demonstrated on-orbit cameras
Next generation sensitivity capability	Looking to move forward with development	TRL 3, Working to integrate established, high sensitivity processes

II. SIONYX Space Based Demonstrations

A key capability for IARPA's Space debris Identification and Tracking (SINTRA) mission will be the imaging of small objects in space. Much higher sensitivity than is available in existing space surveillance systems will be required to capture the small amounts of light reflected by debris less than 10 cm in diameter. SIONYX currently produces highly sensitive visible/near infrared sensors and has demonstrated their performance in space[1,2].

SIONYX demonstrated star tracking in an extremely compact nanosatellite at performance levels rivaling large satellite star tracking performance. Our sensors and their high near infrared sensitivity enabled the use of small optics and much smaller baffling, successfully demonstrating a path to creating robust and accurate start tracking modules that are much smaller and lighter than previous solutions. These capabilities translate directly to IARPA's SINTRA mission for cataloging small debris in space by enabling better than Magnitude 15 object at 15 frames per second imaging with only a 2 inch diameter lens. This enables scaling up to observe much smaller particle sizes over a much larger volume of space through a relatively small constellation of nanosatellites.

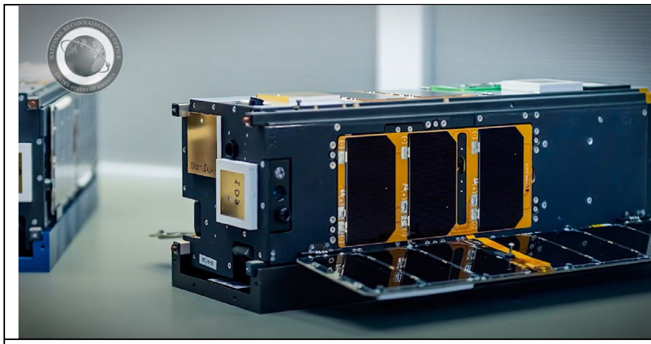
Figure 1. IMPACT CubeSat with SiOnyx star tracker

In the next decade, thousands of small satellites will be put into orbit and reduction in size of the star tracker module can lead to hundreds of millions in cost savings. The target for our star tracker effort was to achieve 1 arcsec performance for a single stand-alone unit, but at a weight under 1 kg, a power consumption under 4 W, and a length that fits into a standard 1U CubeSat of 10 x 10 x 10 cm^3.

Our demonstrated milestones today are:

- Proven imaging below 1 mLux @ 60Hz (first CMOS solution to achieve this milestone)
- Successful integration and launch into the IMPACT satellites (Figure 1)
- 3 arcsec star RMS in an extremely low SWAP star tracker
- Successfully matching magnitude 9 stars – 3 orders of magnitude better than incumbent sensors with the same sized optic

We provided image sensors, operational and design information, electrical design support, engineering support, and radiation testing to help create, in collaboration with Aerospace Corporation, the first star imaging cameras using our image sensors. We demonstrated robust and accurate star tracking modules that were placed on IMPACT CubeSats (Figure 1) and are much smaller and lighter than previous solutions.

We also captured images of other CubeSats at long and close ranges while on orbit, showing the potential for the space situational awareness capabilities of these small systems. The CubeSats had warm-gas propulsion to move them closer to

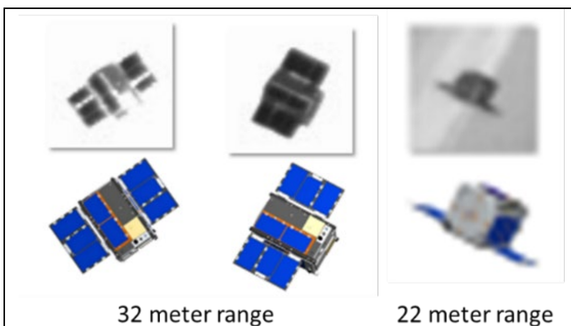

Figure 2. Satellite inspection from the IMPACT CubeSat with SIONYX star tracker.

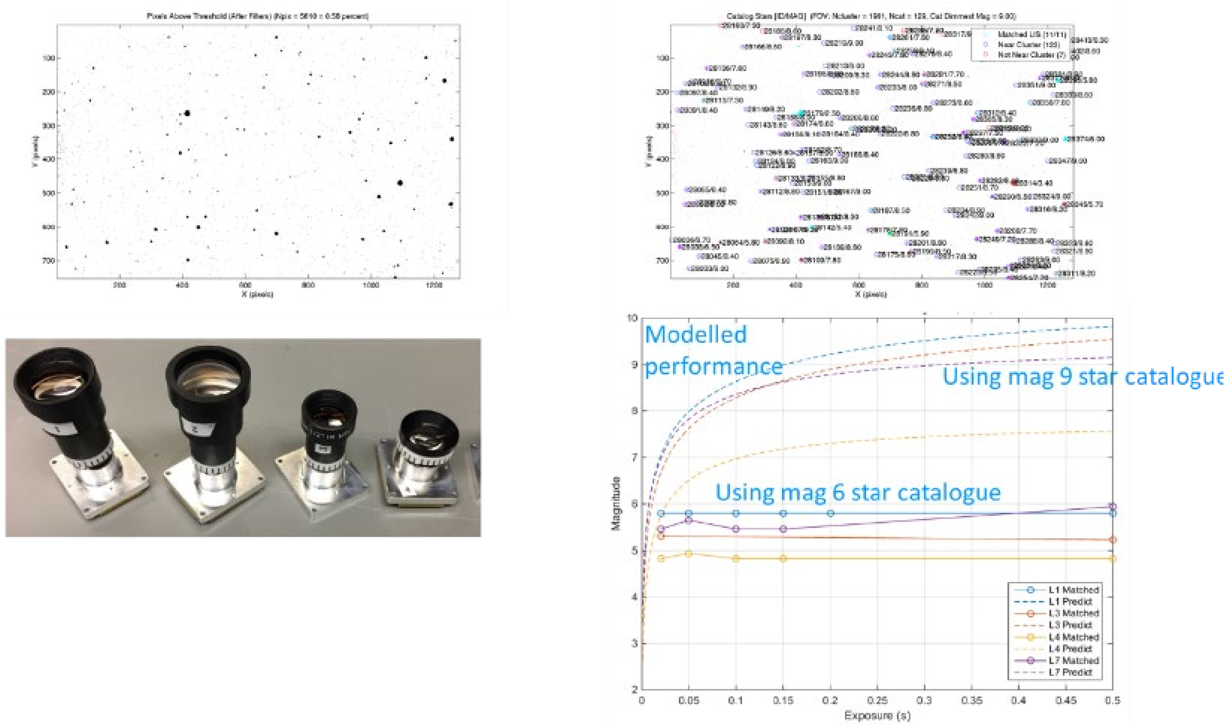

Figure 3. Testing and modeling results achieved using the SIONYX XQE-0920.[4]

each other. Initially, the CubeSats were separated by more than 1000 km, but were brought together and operated within about 20 km of each other. Once the primary missions were accomplished, three sets of close approaches were initiated in Q2, 2021. The closest of these put the two CubeSats within 22 meters of each other and one CubeSat was able to capture an image of the other with up to 0.8 cm resolution using our XQE-0920 sensor (Figure 2)[3].

Our latest generation sensor, the XQE-1350, is 10x more sensitive than the sensor used to gather the data in Figure 3[5,6], giving 2.5 additional magnitudes of observability compared to the demonstrated Mag 9 capability. That study assumed the small aperture used on the IMPACT satellite and shorter integration times than our estimated Mag 15 calculation, so extending to Magnitude 15 and higher is achievable with these sensors. This capability provides a big step forward for space surveillance capabilities and we have approaches that we are investigating to improve our capabilities to even higher magnitude (dimmer) objects.

III. Digital, Low-Light Imaging

SIONYX's overall objective is to push digital low light imaging performance to match image intensification systems, improve the field-of-view (FOV) and resolution to exceed existing digital low light systems, and provide a fully digital interface to enable digital fusion of different sensor modalities. We are delivering the following cameras in quantity at low cost:

- 10K Lux to 0.5 mLux low power, miniaturized camera modules deployed in CubeSat, AR/VR headsets (IVAS), Weapon Sights, Vehicle Navigation and Drone applications

Figure 4. SIONYX's SCL3C camera module equipped with 65 deg. lens. Thousands of cameras have been delivered.

- Fully integrated, cloud connected IP6X NOD with active situational awareness (SA)
- Fully integrated IP6X IP camera imaging from noonday sun to moonless star light with no active illumination

Figure 5. The SIONYX Aurora digital nightvision action camera.

SIONYX is focused on producing the world's most accessible low light imaging platforms. We are doing this through a multi-pronged approach that is delivering rugged, low light imaging camera systems to the military (Figure 4) and commercial (Figure 5) markets. Our development of low light cameras for commercial applications gives us deep insight into techniques required to improve field-of-view while minimizing the size, weight, power and cost of these systems. The added benefits from this include:

- Reduced costs both by taking advantage of our low-cost, commercial scale supply chain already in place for our commercial products and by assembling hundreds of devices at once rather than processing individual sensors
- Maintaining small mechanical form factors critical for use in space applications
- Integration excellence across the full stack including optics, sensors, and embedded systems to deliver easy-to-use, rugged and effective camera systems

IV. Low Light Imaging Platform

The camera core built around the XQE-1350 CMOS sensor is low power and is very fast, features critical to space surveillance applications (Figure 4). The 90 fps power is measured at around 1.1W. We are presently working to reduce this power in half to optimize for applications in nanosats. We have also dramatically reduced the weight of the system. The mass of the core is 29g inclusive of the lens, enclosure, and all electronics.

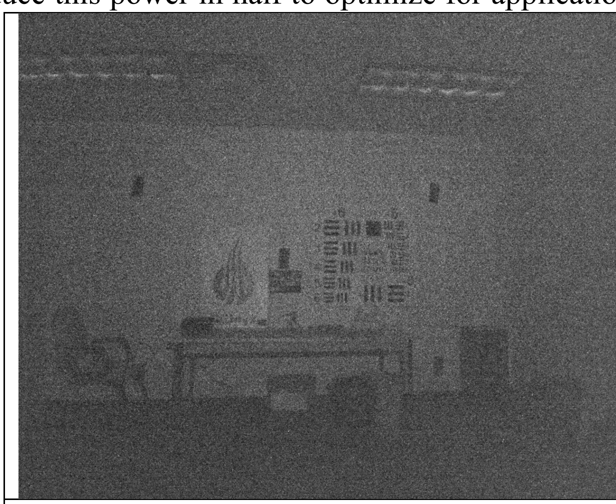
Figure 6. Example low light imaging performance captured at 90 fps and a light level of 0.5 mLux.

Figure 6 shows an example of the low light performance of the camera operating at 90 fps at a light level of 0.5 mLux (5e-5 ftcd). The image uniformity and low temporal noise are clearly evident in the scene. The row and column fixed and temporal noise sources are well below the pixel temporal noise making the image very flat and uniform.

We look to continue improving our performance in support of the SINTRA goal of sensing particles smaller than 10 cm.

References

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[2] D. Rowen, A. Utter, G. Kinum, H. Weiher, A. Wu, R. Dolphus, E. Alcid, D Galindo, C. Beltran, A. Berman, M. Mellick, and M. Pralle. "On-orbit Results from an Ultra-low SWaP Black Silicon Star Tracker," 34th Annual Small Satellite Conf. (2021).

[3] J.W. Gangestad, C.C. Venturini, D.A. Hinkley, and G. Kinum, "A Sat-to-Sat Inspection Demonstration with the AeroCube-10 1.5 U CubeSats," 35th Annual Small Satellite Conf (2021).

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[5] J.E. Carey, M.U. Pralle, et al. Final Report for Contract #NRO000-C-0134. June 2021.

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