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BlackCAT Overview

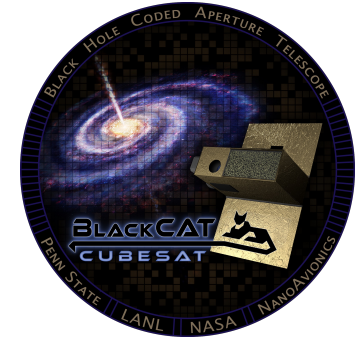
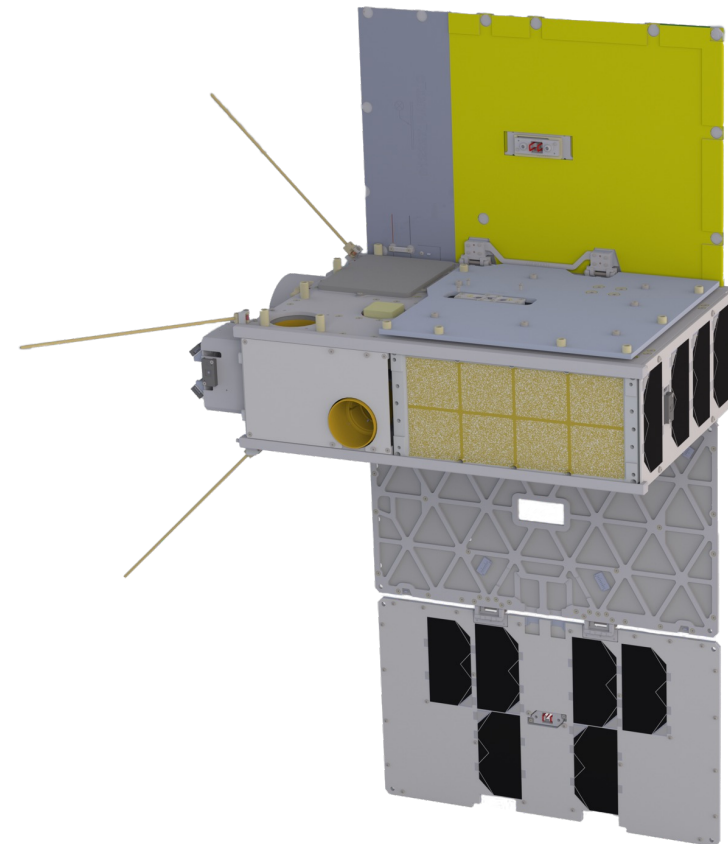


Table 1. Mission overview	
Instrument	Soft X-ray (0.5-20 keV) coded mask telescope with hybrid CMOS detectors ~0.85 Sr FOV ~40" position centroiding (bright GRBs)
Spacecraft	Standard 6U CubeSat
Launch	Expected launch: Jan 11, 2026
Orbit	Sun-synchronous LE orbit
Science	Detection of EM counterparts of high redshift GRBs (enabling studies of star formation rate and properties), gravitational wave counterparts, and x-ray transients WFOV monitoring and rapid alerts for multi-messenger follow-up
Technology	Soft X-ray coded aperture mask Demonstrate latest X-ray Hybrid CMOS detectors in-orbit





Collaborator Acknowledgements:

Kongsburg NanoAvionics provided our spacecraft bus and has worked with us as a team

Teledyne and Penn State have had a longstanding detector development relationship, and these engineering-grade detectors have been adapted for flight

Luxel worked with us to provide a novel x-ray coded mask with an integrated optical blocking filter

Thanks !!

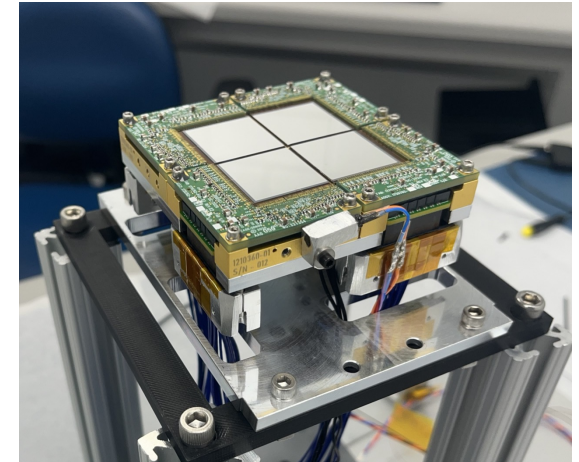
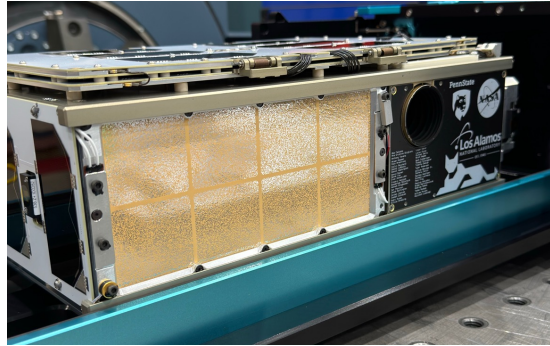


Also, many thanks to NASA!!

This **low-cost program to fly CubeSats within APRA** is a critical method for enabling:

- 1) **space-flight technology development** that couldn't happen on larger missions
- 2) Hands-on experience and leadership **experience in space-flight programs for students, postdocs, and early career researchers**

BlackCAT Tech Dev Motivation



Astro2020 Decadal Review Panel prioritized the following:

- a) **Time-domain astronomy**
- b) Astrophysical science that could be achieved by a ***future large X-ray mission*** (Lynx-like) and/or upcoming **X-ray probe-class X-ray mission**
- c) **enabling X-ray technology** for flagship of the following decade and/or upcoming time-domain X-ray missions

X-ray hybrid CMOS detectors can enable the paths above that require large-format Megapixel detectors, with fast readout and/or fine angular resolution

(along with low-power and radiation hardness)

BlackCAT is advancing these X-ray hybrid CMOS detectors for larger missions (e.g. Lynx) and/or future arrays of CubeSats (e.g. BlackCAT-10)

BlackCAT is also advancing a new type of X-ray coded mask, made by Luxel



BlackCAT Science

The BlackCAT CubeSat is a soft X-ray sky monitor, transient finder, and gamma ray burst detector providing rapid alerts and time-resolved X-ray data for high-energy and multi-messenger astrophysics

- **Soft X-ray response with wide-FOV** is tuned to discover **high-redshift Gamma Ray Bursts** and probe the epoch of **cosmic star formation** in the early universe
- locate potential electromagnetic **counterparts of gravitational wave events** with arcminute accuracy (as well as multi-messenger events such as HE neutrinos)
- **Monitor the transient sky** and trigger **rapid alerts** from Galactic transients, blazars, Short GRBs, tidal disruption events, XRFs, supernova shock breakouts, etc. using wide sky nearly continuous X-ray monitoring

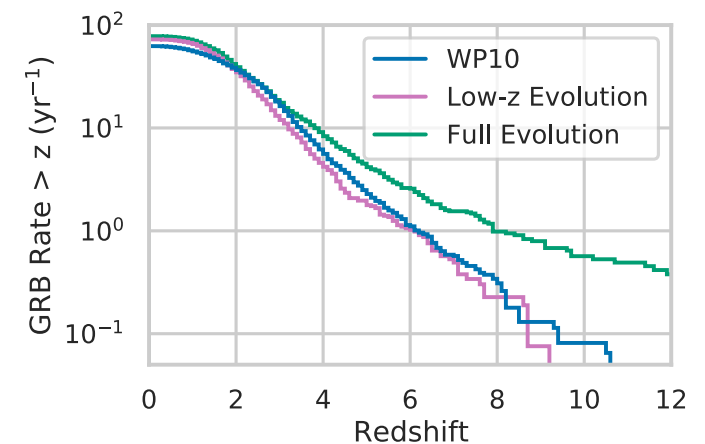
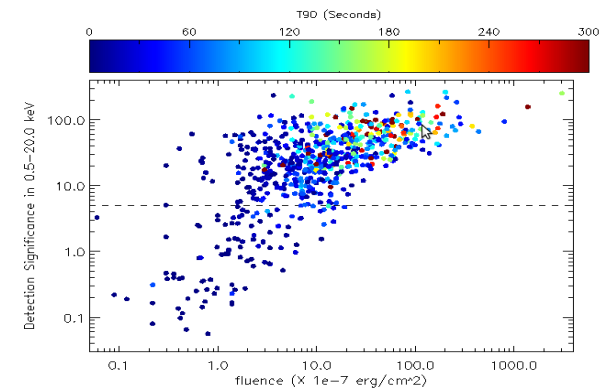
High redshift GRB Science w/BlackCAT

Measure the cosmic star formation rate over $5 < z < 12$ by detecting and observing high-redshift gamma-ray bursts and their afterglows.

- *Single module* will detect many bursts at $z > 4$, and could detect $\sim 1/\text{year}$ at $z > 8$ (more modules would enhance rates)
- redshift derived from ground follow-up data
- Burst redshifts will provide data for determining the cosmic star formation rate over $5 < z < 12$
- Stellar light was likely the dominant cause of the cosmic reionization
- Star formation estimates are crucial to constructing a full picture of reionization
- Recent JWST results imply current star formation rates at high redshift may be underestimated
 - **BlackCAT measurements of stellar death at high redshift could be even higher than expected and enlightening**

Peak energy for high-z GRBs is redshifted to X-ray band

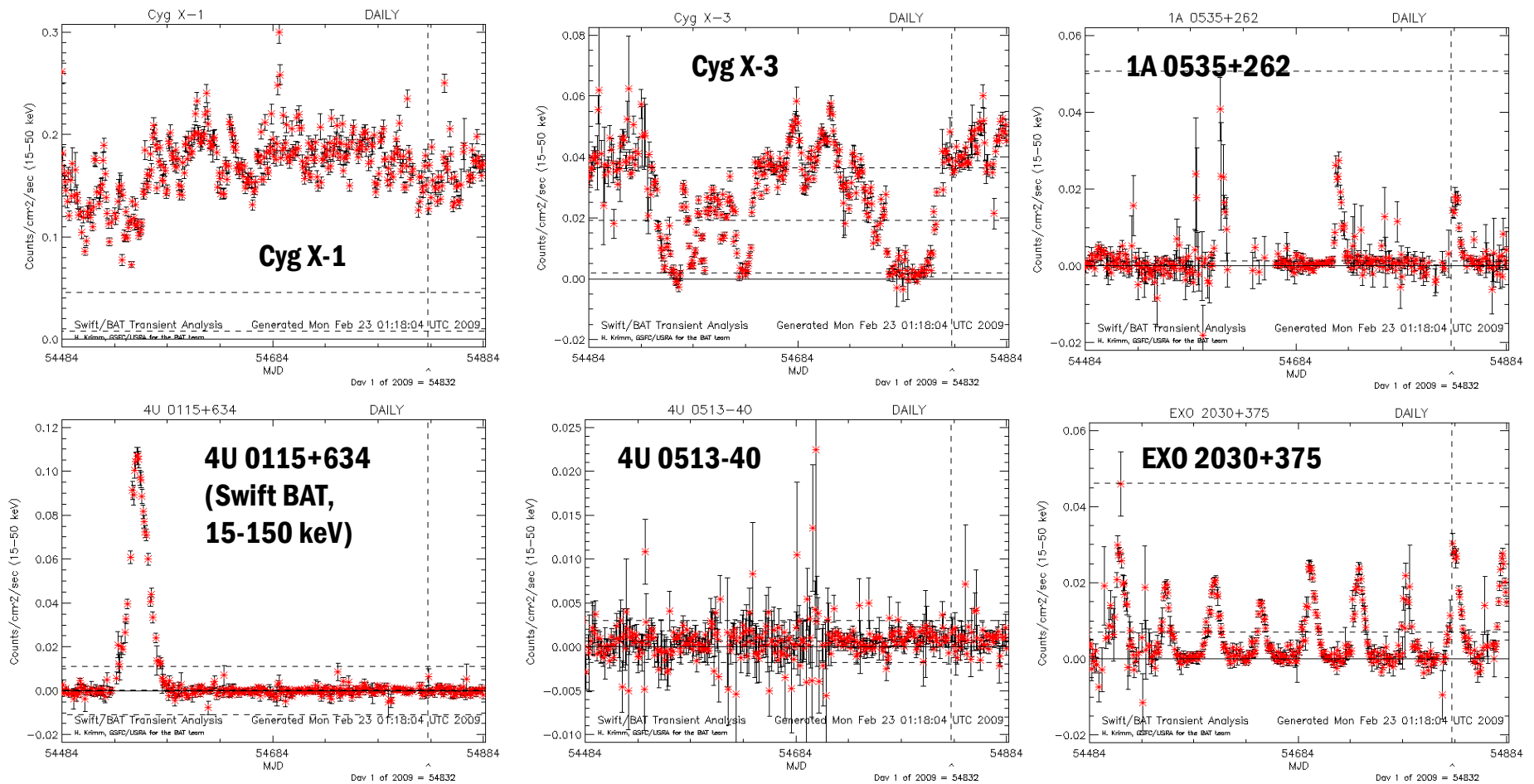
→ **BlackCAT has selection effect to find cosmological high-z GRBs**



BlackCAT Transient Survey



BlackCAT will also survey the sky and produce light curves (0.5-20 keV) of hundreds of transient X-ray sources

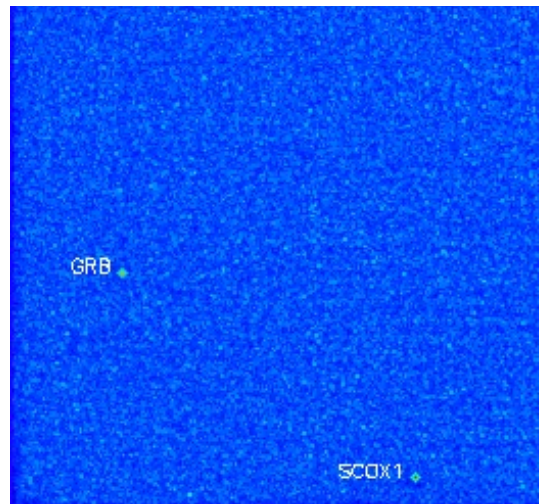


Response and localization



- BlackCAT detects and localizes Gamma Ray Bursts, transients, and potential GW counterparts
 - determines GRB position onboard to ~40" for bright GRBs/sources (and ~60-90" for threshold detections)
 - Rapidly (~30 seconds) sends position to S/C and to ground with Iridium network using Nearspace Eystar S4
 - telemeters light curve and spectral info

Simulated BlackCAT GRB Image

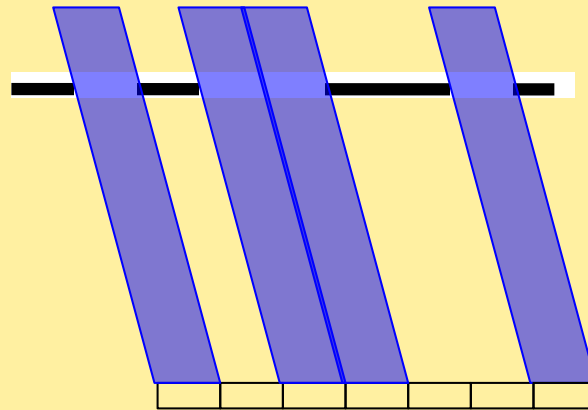




Coded Mask Imaging

Coded Aperture Mask + Silicon Hybrid CMOS Detectors

Source 1



*Same technique as INTEGRAL
IBIS and Swift BAT, but at
lower energies.*

- Mask pattern casts X-ray shadows on detector for $E < 20$ keV.



Coded Mask Imaging

Coded Aperture Mask + Silicon Hybrid CMOS Detectors

Source 1 **Source 2**

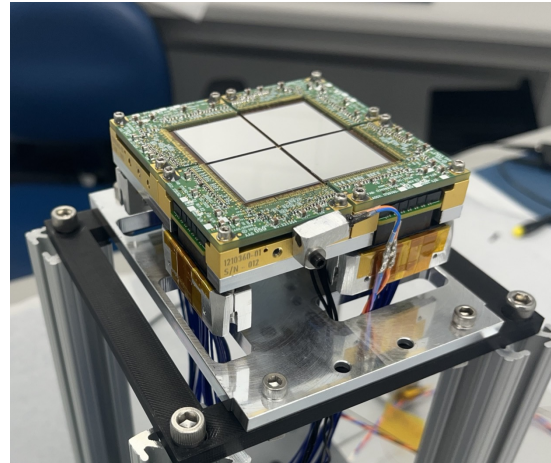
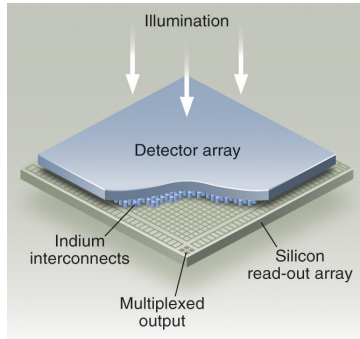
*Same technique as INTEGRAL
IBIS and Swift BAT, but at
lower (soft X-ray) energies.*

- Mask pattern casts X-ray shadows on detector for $E < 20$ keV.
- Deconvolution of detector image with mask pattern produces sky image

Imaging is a multi-step process using the same sophisticated algorithms used by the *Swift* BAT:

- Reconstruct sky image from projection on hybrid CMOS detector pixels, applying 2D convolution through mask

Detectors



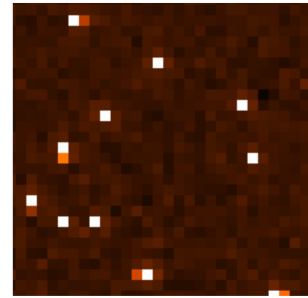
4 Packaged Speedster-EXD550 detectors mounted in BlackCAT focal plane array configuration

- Each focal plane detector consists of 4 Si hybrid CMOS detectors (Speedster-EXD550's)
- The intrinsic pixel pitch is 40 μm
- passively cooled to below $\sim -40\text{ C}$ to achieve sufficiently low dark current
- While these detectors are very fast, they have higher read noise than our best hybrid CMOS detectors (which we hope to fly on a future mission)

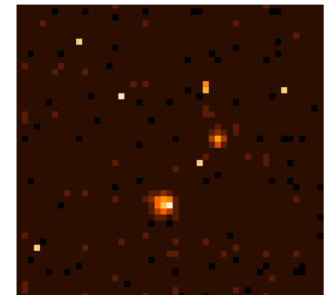
Parameter	Value
Type	Si Hybrid CMOS
Absorber material	Silicon
Absorber thickness	100 μm
Detector Format	550 x 550
Readout	Sparse Event-Driven, digital
Frame rate	150 frame/sec (full mode) 1-10 kHz (sparse mode)
Pixel Size	40 x 40 μm
Software binning	8 x 8
Power	$\sim 300\text{ mW}$
Operating Temp.	$\leq -40^\circ\text{ C}$
Time resolution	0.1-10 msec

Speedsters: Event Recognition

- Typical X-ray detectors, like CCDs, readout of entire image and off-chip extraction of X-ray events.

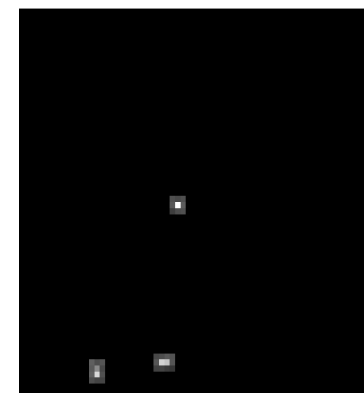
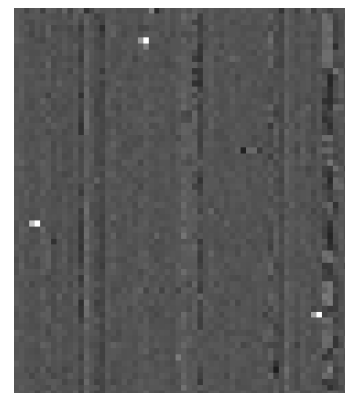
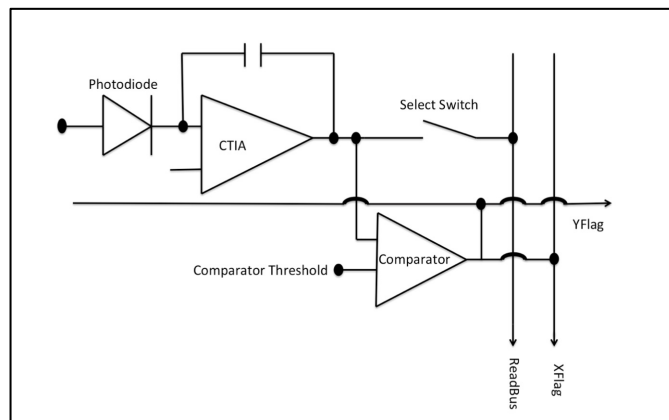


Left: CMOS lab data
XRT data



Right: Swift
XRT data

- The Speedster, with sparse readout, reads out only the pixels containing X-ray events.



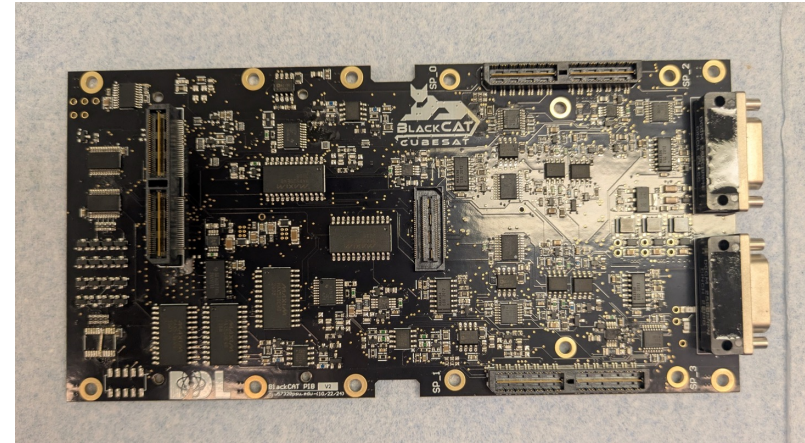
.... And it is fully digital-out

Electronics: Payload Interface Board

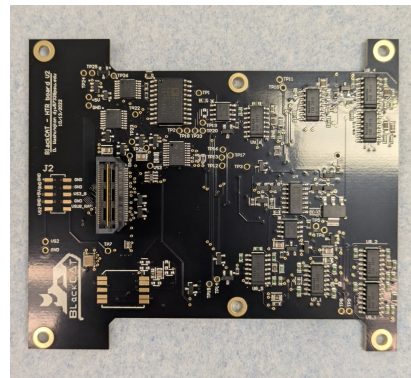
Our **custom-built electronics** controls and reads the focal plane array, while also performing **on-board imaging and onboard triggering** (similar to Swift BAT)

Sends data to spacecraft for telemetry

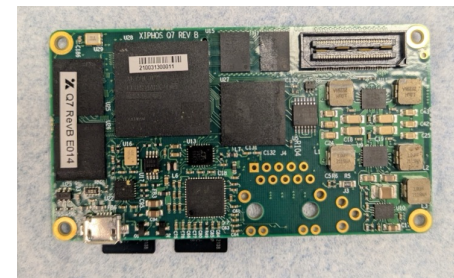
Sends **trigger alerts** to the Eystar S4 board for **rapid alert notification through the Iridium** network



PIB Main Board



HTR Daughter Board

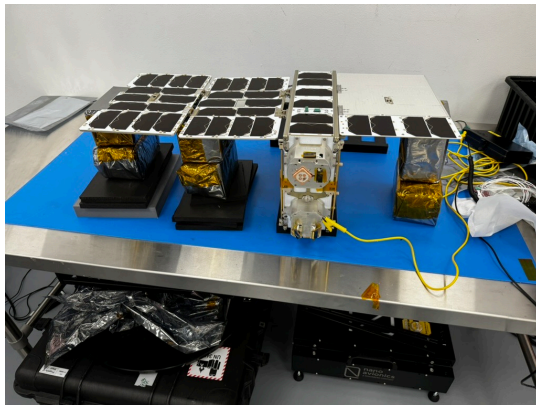
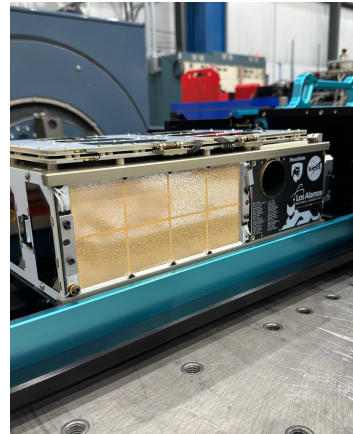
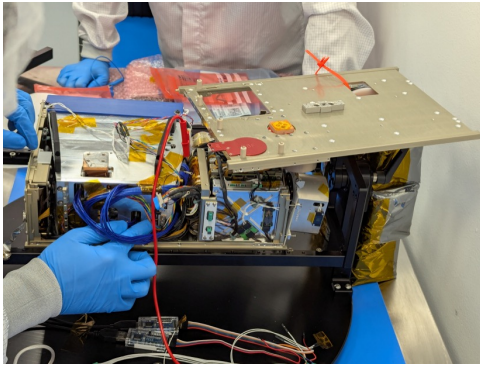


Xiphos Q7S Daughter Board

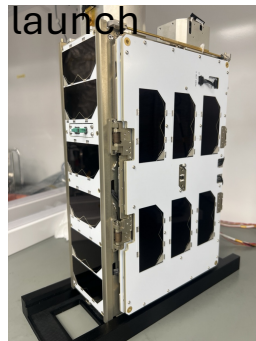
BlackCAT Status:

- Launched Jan 11, 2026 in ~600 km Sun-Synch Polar orbit
- daily S-band comms within 1 day of launch and continuing today

Integration activities and thermal vac activities



ready for launch



Deployment in orbit:



Spacecraft commissioning completed end of March

Payload commissioning ongoing:

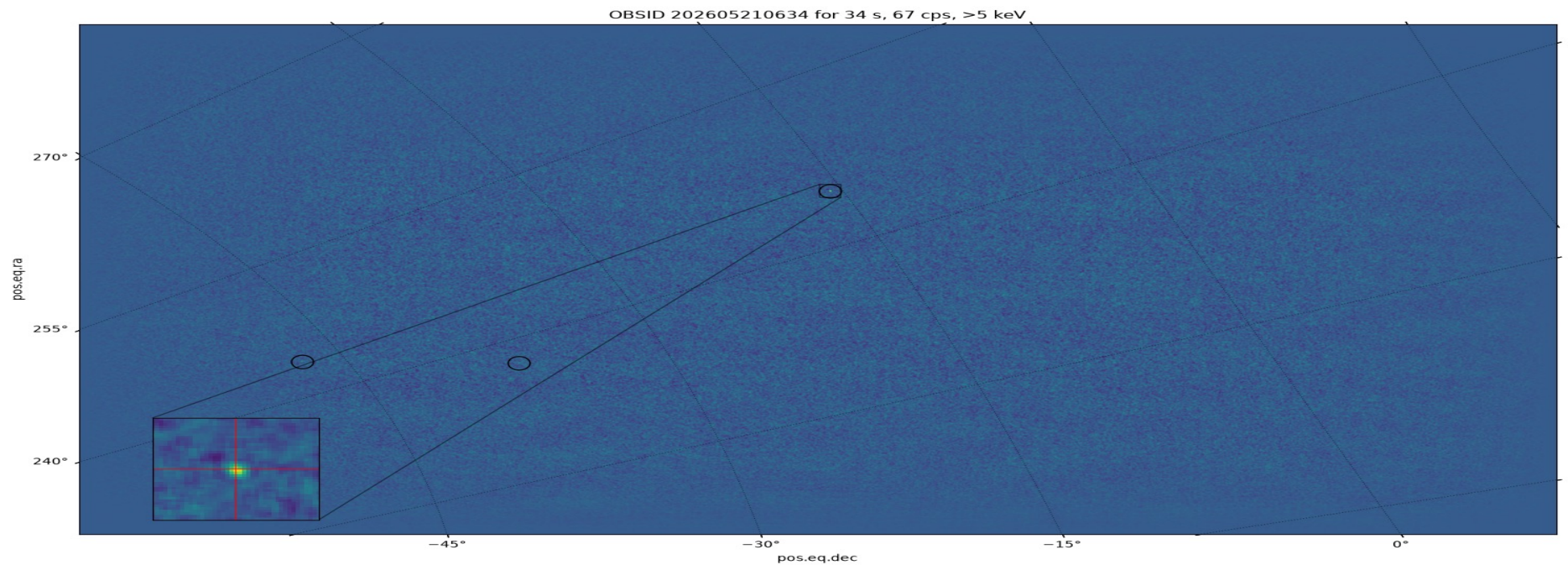
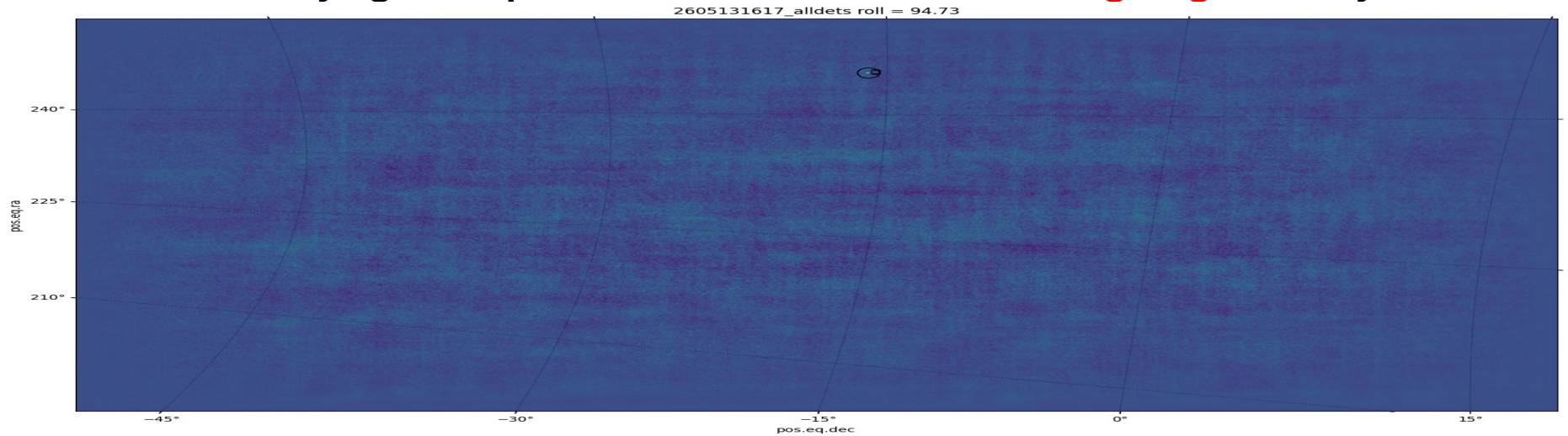
X-ray First light April 18

First 'Reconstructed Image' Light on May 13, 2026

BlackCAT Status:

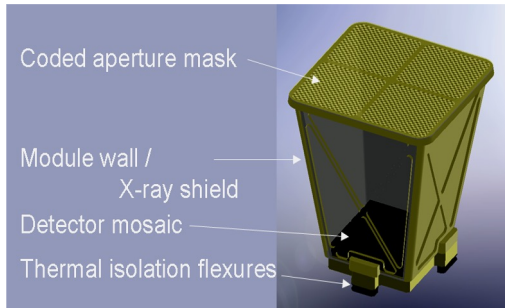
Payload commissioning ongoing

X-ray light in April and **First Reconstructed Image Light** in May 2026



The Future: BlackCAT-10

Parameters & Requirements



× **10**

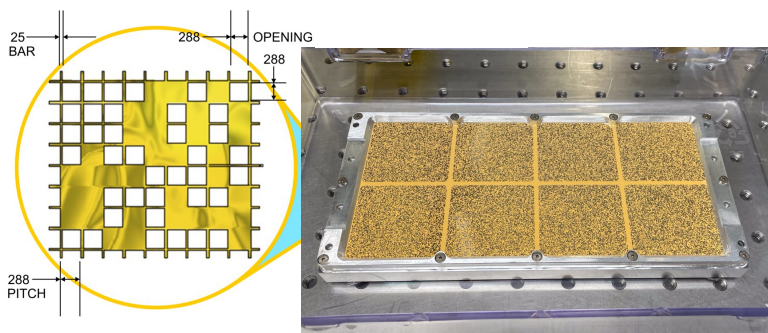
- N Independently flying identical modules ($N = 6 - 12$)
- Each module contains a coded mask in front of an array of 4 Si hybrid CMOS detectors

Parameter	BlackCAT single module
Bandpass	1 – 20 keV (goal 0.5-20 keV)
FoV	0.9 sr (~3.5 sr for 6 modules with anti-Sun offsets)
Angular Resolution	6.3 arcmin (FWHM)
Position Accuracy	1 arcmin (30 arcsec for bright GRBs)
Module opening area	17.0 x 8.8 cm
$\Delta E/E$	<5% at 5.9 keV (goal of <3%)
Δt	~7 msec (or as low as 0.1 msec)
DXRB rate	~ 540 cts s ⁻¹
Internal Bkgnd	< 1 cps
Pt Src Sensitivity	~ 240 mCrabs (7σ , 30s, 1 module)

EXTRA



Coded Mask



Mask fabricated by Luxel.

Has been vib tested, acoustic tested, and has completed thermal vac testing.

- The mask consists of a ribbed frame that supports electroformed Nickel coated with gold
- Closed cells have 17 μm of Ni plus 8 μm of Gold (4 μm on each side)
- Module walls provide X-ray shielding from sides
- Mask pitch of 320 μm

Table 2: BlackCAT Mask Parameters	
Parameter	Value
Focal Length	158 mm
Mask size (aperture)	176 x 80 mm
Mask element	320 x 320 μm
Detector superpixel (8 x 8 pixels)	320 x 320 μm
DM FOV (partially coded)	0.85 sr
Mask Transmission	>40%
Image Scale	52"/pixel
	6.9 arcmin/superpixel