MONSTER: Optical and Near-Infrared Telescope onboard HiZ-GUNDAM

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MONSTER Team

HiZ-GUNDAM (High-z Gamma-ray bursts for Unraveling the Dark Ages Mission)

Mission Objectives:
"**Early Universe Exploration**" and "**Multi-messenger Astronomy**"

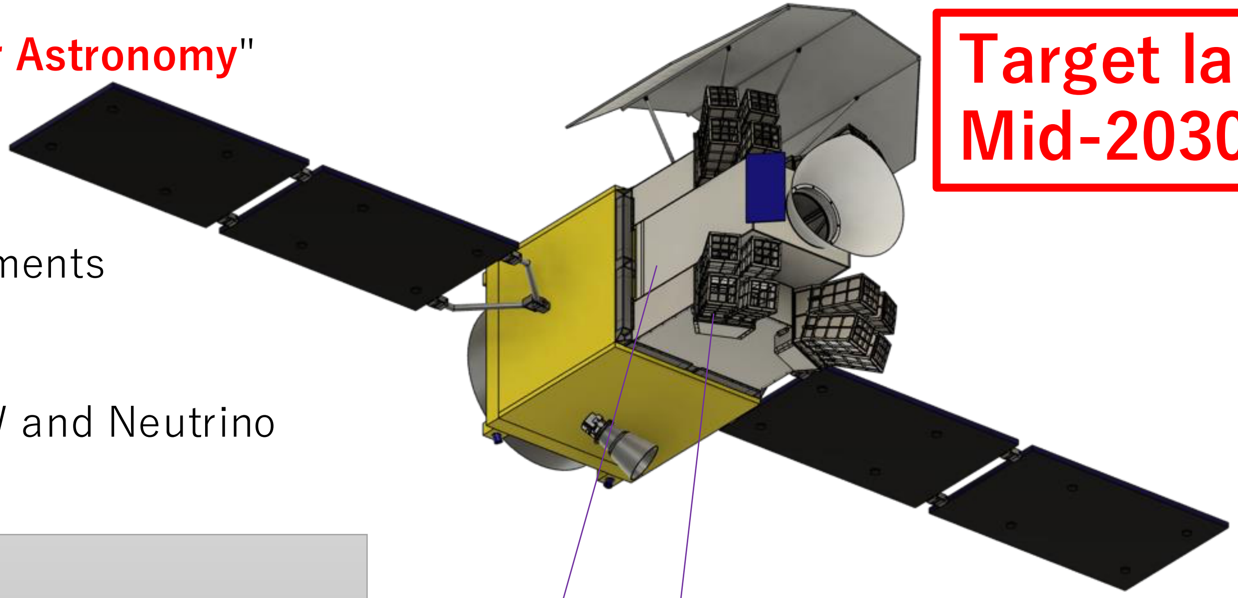
Target launch: Mid-2030s

Mission 1 ： **Exploration of the early universe**

- Detection of high-redshift GRBs ($9 < z < 12$)
- Probing the reionization history and first metal elements

Mission 2： **Multi-messenger astronomy**

- Localization of X-ray transient associated with GW and Neutrino
- Energy transition from jet – cocoon – kilonova



EAGLE (Wide-field X-ray monitor)
- Lobster-eye optics
- pnCCD

MONSTER (Visible/NIR telescope)
- Off-axis 30-cm telescope
- 5-band simultaneous observation

Observation Strategy

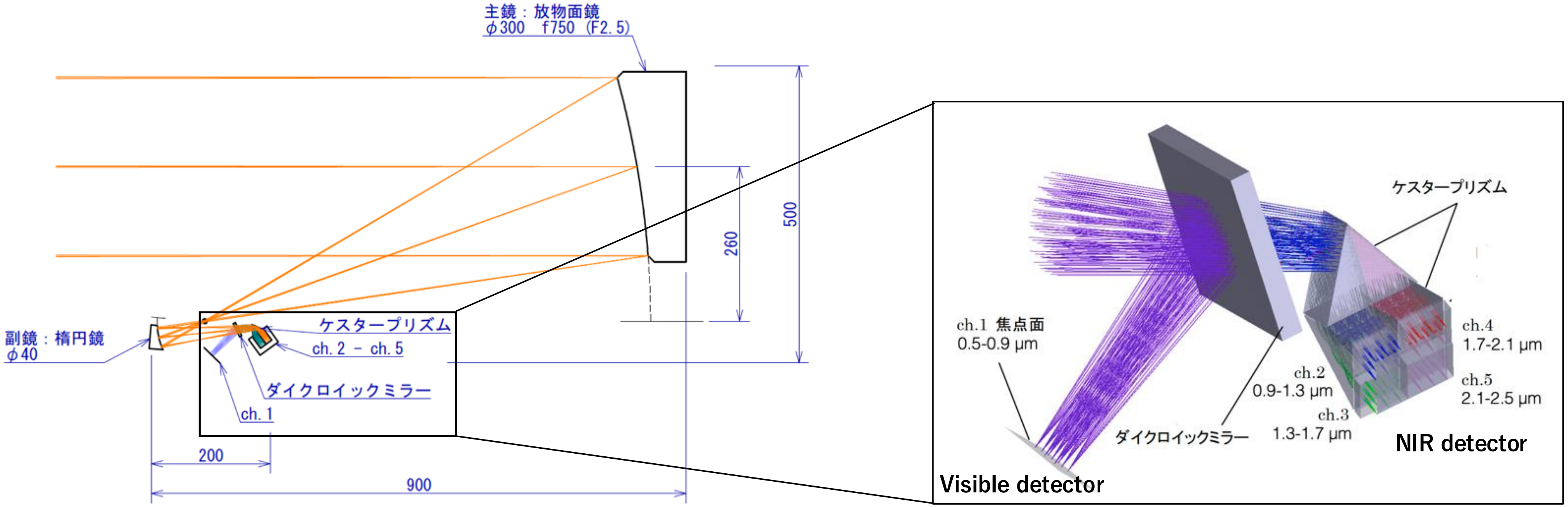
(1) Discovery of GRBs or X-ray transients by **EAGLE**
(2) Satellite attitude change by autonomous control (<300 sec)
(3) Identification of GRBs or kilonovae by **MONSTER** (<15 min)
(4) Transmission of alerts including location and photo-z. (<30 min)
(5) Spectroscopic follow-up observations with large telescopes.

EAGLE (Wide-field X-ray Monitor) Specifications	
Energy band (keV)	0.4 – 4 keV
Field of view	~0.5 sr
Detection sensitivity	10^{-10} erg/cm²/s (100 s exposure)
Time resolution	< 0.1 s
Localization accuracy	~6 arcmin

MONSTER (Visible/Near-Infrared Telescope) Specifications					
Telescope aperture	30 cm				
Field of view	15 arcmin × 15 arcmin				
Exposure time	10 min (2 min × 5 frames)				
Obs. band (μm)	0.5 – 0.9	0.9 – 1.3	1.3 – 1.7	1.7 – 2.1	2.1-2.5
Limiting mag. (AB) 10 min exp., S/N=10	21.3	20.9	20.6	20.5	20.4

MONSTER (Visible/Near-Infrared Telescope)

- **30 cm aperture** reflecting telescope
- **5-band simultaneous imaging** via dichroic mirror + Kösters prism (1 visible + 4 NIR bands)
- FoV 15 arcmin; 2 detectors (1 visible, 1 NIR)
- Telescope < 200 K, NIR detector < 120 K — **cooled by radiation only**
- **Athermal design** — manufacturing the parts from the same aluminum alloy, cancelling distortion
- Conceptual studies underway with manufacturers (optics, thermal/structural design, electronics)



MONSTER Spec.

Aperture: 30 cm

FoV: 15 arcmin
(>50% throughput)

Cooling required

For details on MONSTER, see:

Tsumura et al. (2025)
JATIS 11(3), 034002

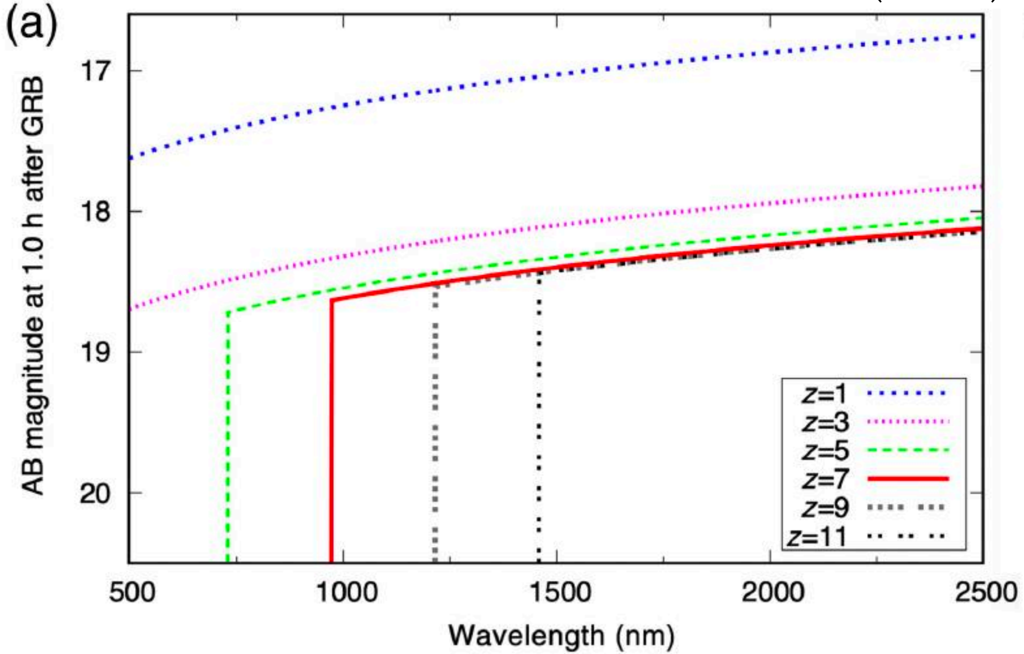
5-band simultaneous photometry

Item	Description				
Telescope type	Offset Gregorian				
Aperture size (A)	30 cm				
Focal length	1800 mm				
F number	F6				
Throughput (η)	0.6 (telescope throughput and quantum efficiency of the detector)				
FoV	15 arcmin $\times$ 15 arcmin				
FoV per pixel (Ω)	2 arcsec $\times$ 2 arcsec (9.2×10^{-11} sr)				
Image size (n)	3 pixels $\times$ 3 pixels				
Temperature (T)	Telescope: <200 K; detector: <120 K				
Integration time (t)	10 min (2 min $\times$5 frames)				
Imaging detector	HyViSI	HgCdTe (2.5-μm cut)			
Readout noise (N_{rn})	17 e^-				
Dark current (I_{dk})	0.3 e^-/s				
Thermal radiation (I_{th}) at 200 K	$<10^{-23}$ e^-/s	$<10^{-12}$ e^-/s	$<10^{-7}$ e^-/s	$<10^{-3}$ e^-/s	0.17 e^-/s
Observation band	0.5 to 0.9 μm	0.9 to 1.3 μm	1.3 to 1.7 μm	1.7 to 2.1 μm	2.1 to 2.5 μm
Bandwidth ($\Delta\lambda$)	0.4 μm				
Zodiacal light (λI_{ZL})	900 nW/m^2/sr	700 nW/m^2/sr	500 nW/m^2/sr	300 nW/m^2/sr	200 nW/m^2/sr
	7.4 e^-/s	5.8 e^-/s	4.1 e^-/s	2.5 e^-/s	1.7 e^-/s
Sensitivity (S/N = 10)	21.3 AB mag	20.9 AB mag	20.6 AB mag	20.5 AB mag	20.4 AB mag

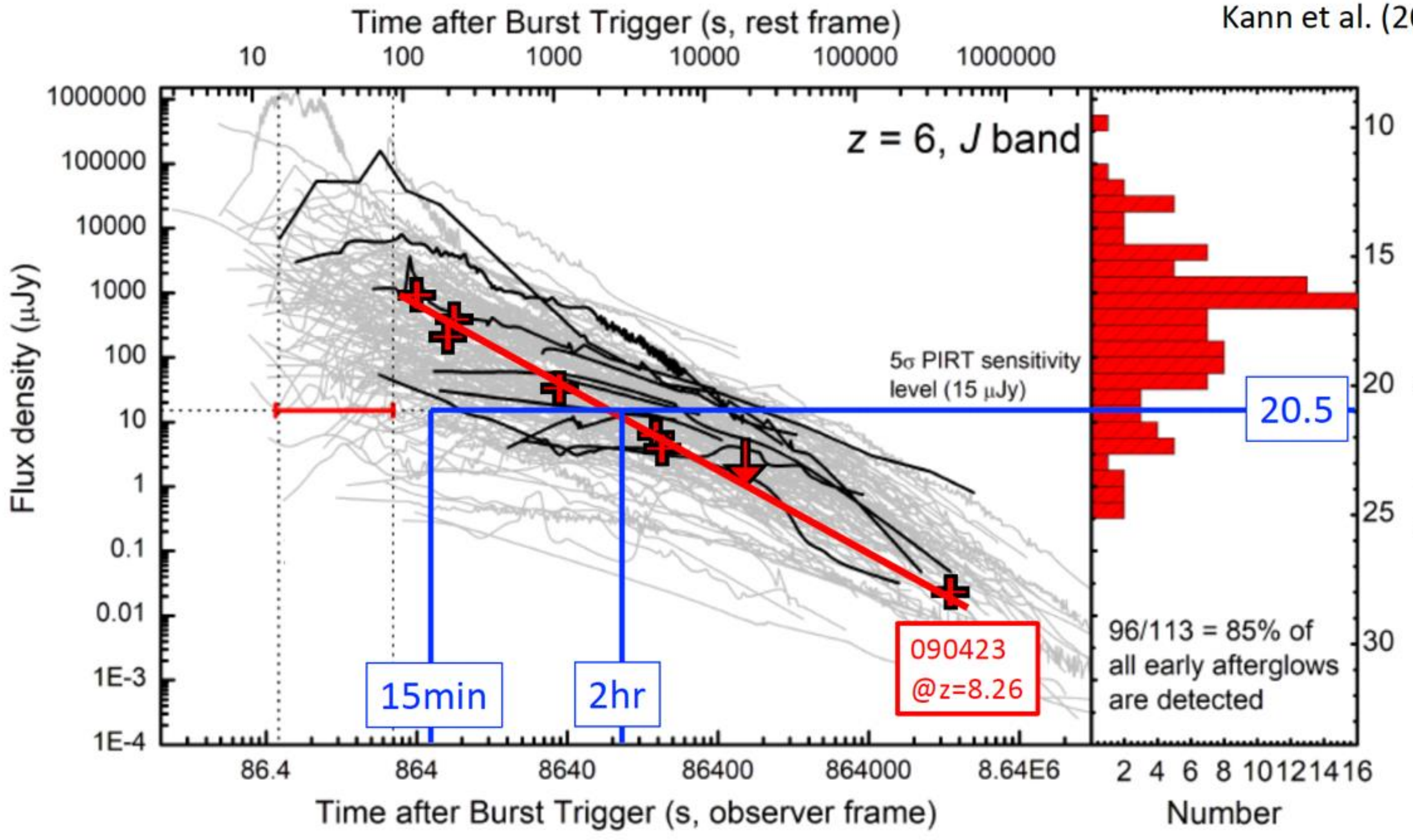
Requirement to Aperture

- For z > 6, the brightness at wavelengths longer than the Lyman break is largely independent of redshift.
- The sensitivity required to detect 85% of GRBs with z > 6 two hours after their occurrence is **20 magnitudes**.
- Aperture required to achieve this sensitivity is **30 cm**

Tsumura et al.(2025)

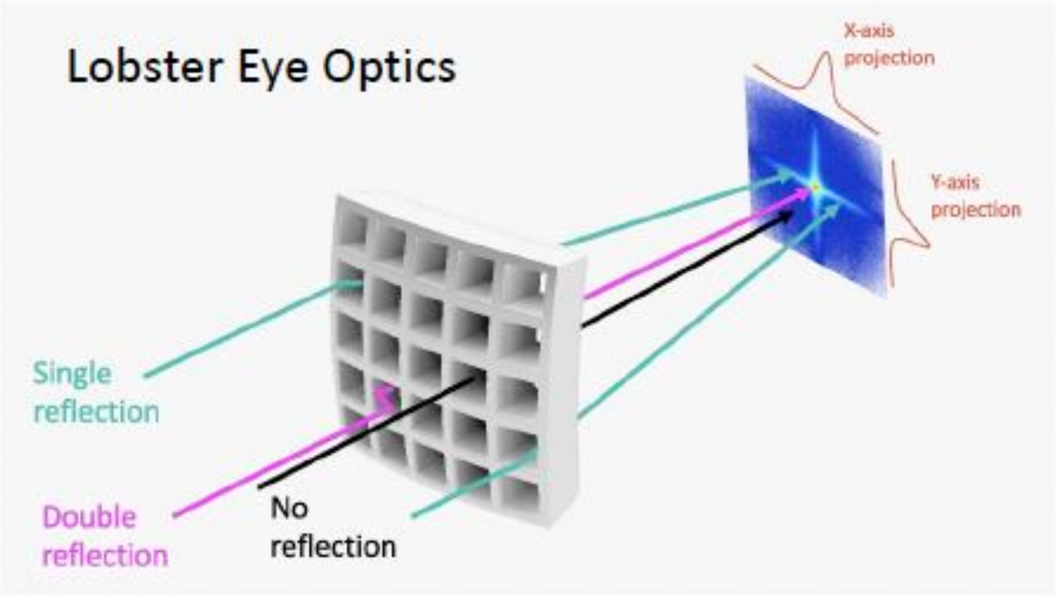


Kann et al. (2024)

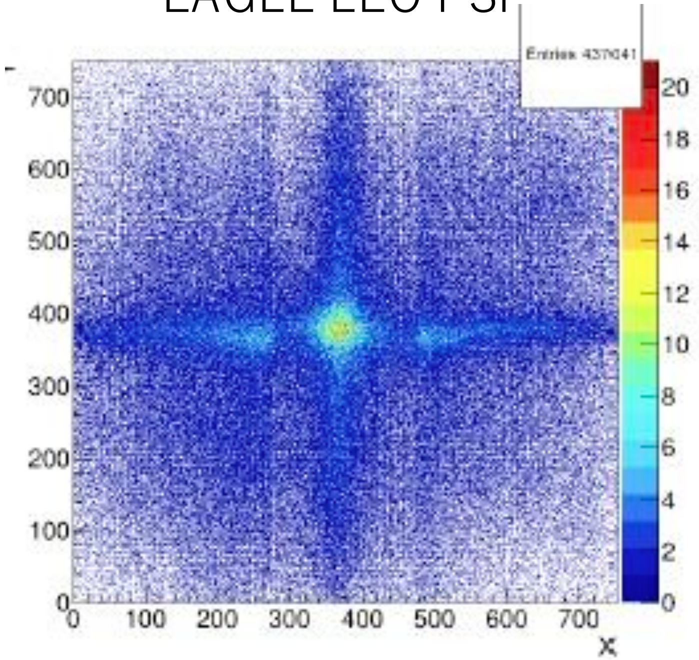


Requirement to FoV

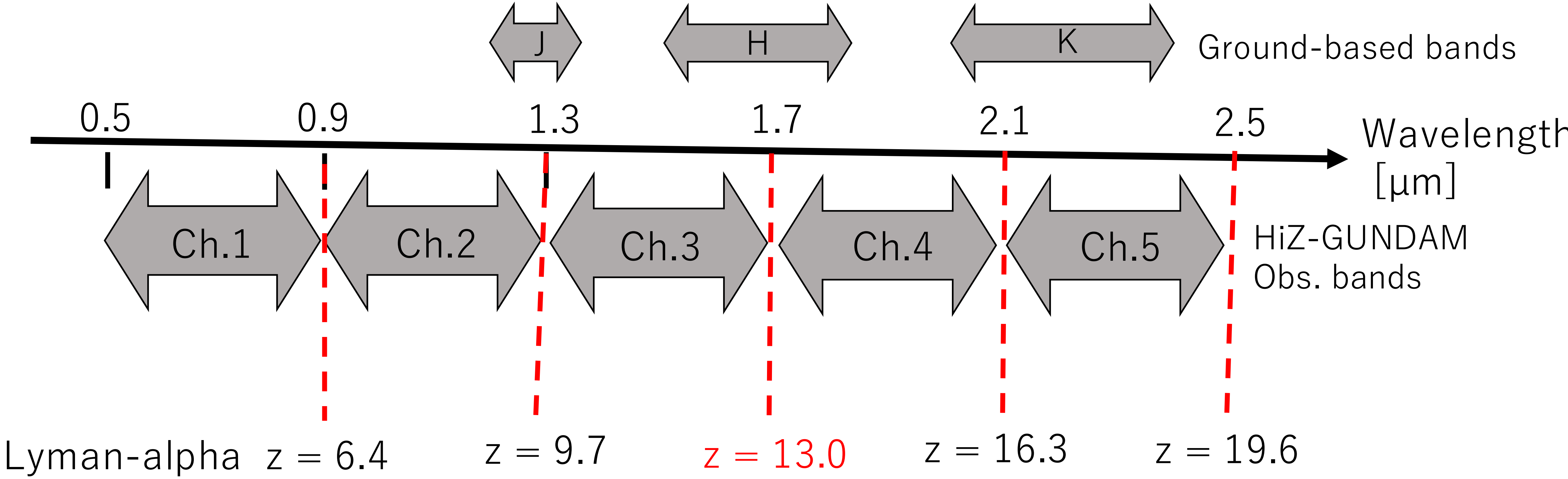
- The first step of HiZ-GUNDAM is GRB candidate detection by EAGLE
- EAGLE achieves high sensitivity with Lobster Eye Optics (LEO)
- Localization accuracy of EAGLE: 6 arcmin
- MONSTER needs FoV > 12 arcmin (×2 margin) to capture an EAGLE GRB candidate in one pointing
  → MONSTER's FoV:
  12 ×12 arcmin^2 for ~100% effective throughput
  15 ×15 arcmin^2 for >50% effective throughput



EAGLE LEO PSF



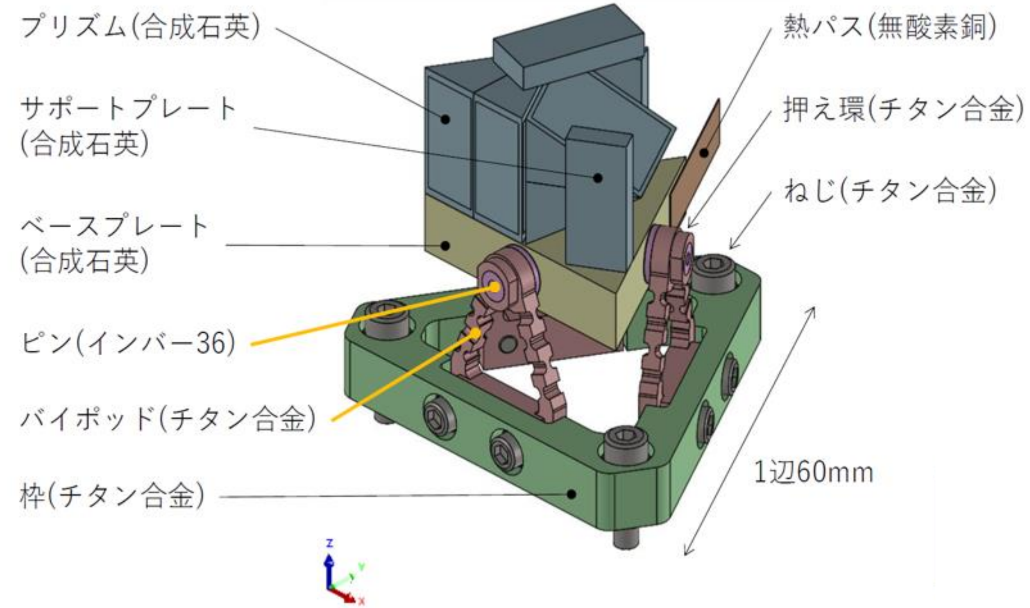
Observation Wavelength vs. Redshift

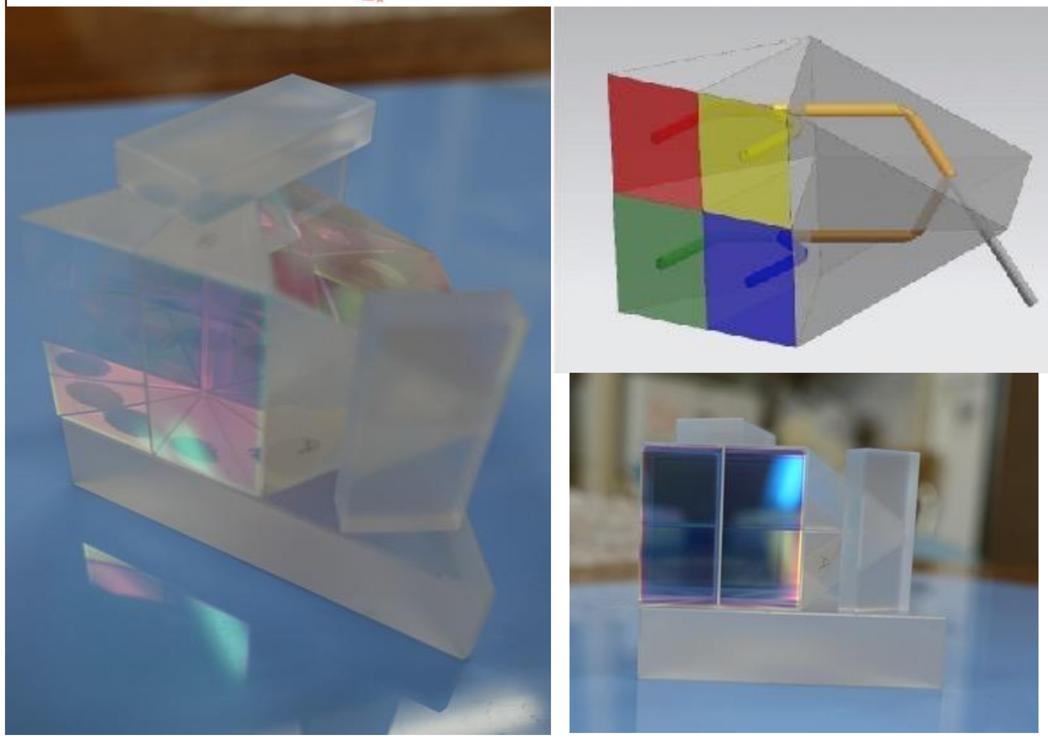


- Detection in the 2 longest-wavelength bands is needed to distinguish high-z objects from dust-reddened sources
- Photometric redshifts can be accurately determined up to $z < 13.0$
- In principle, detectable up to $z < 19.6$

Kösters Prism

- Multi-wavelength observation of a rapidly fading GRB is essential
  - Sequential photometry by rotating a filter wheel is too slow
- Köster prism adopted for compact simultaneous multi-band observation
- Kösters prism splits incident light into multiple-band channels
  - Total internal reflection at the prism hypotenuse aligns the output beams
- Two prisms stacked orthogonally form a double Kösters prism, achieving 2 × 2 splitting

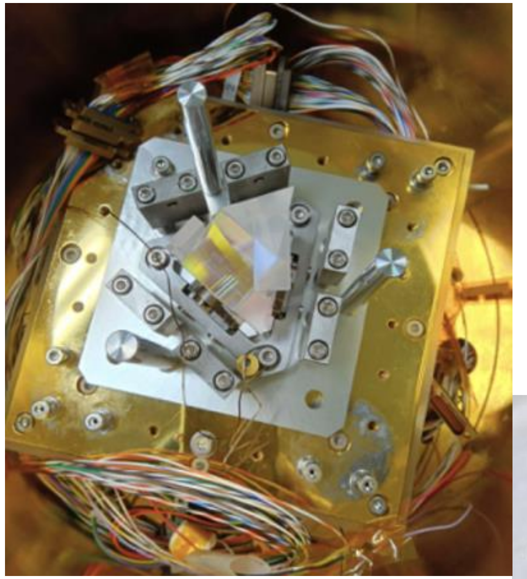




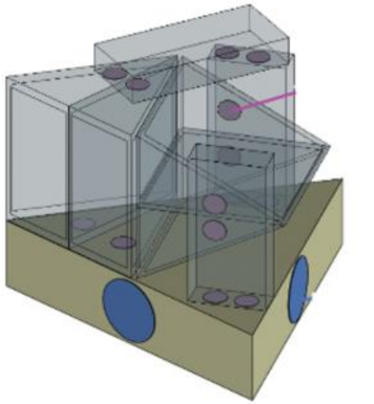
Kösters Prism Prototype

Köster Prism Development Status

- Prototype fabricated; various tests underway
- Adhesive selection and testing
  - Cooling test
  - Strength test
  - Radiation test
- Spectral transmittance measurement
  - Ch.5 (2.1–2.5 μm) measurement: future work
- Holder design and testing
  - Vibration test (in preparation)
- Hori et al. (2026 in prep.)
  - Hiroshima Univ. student

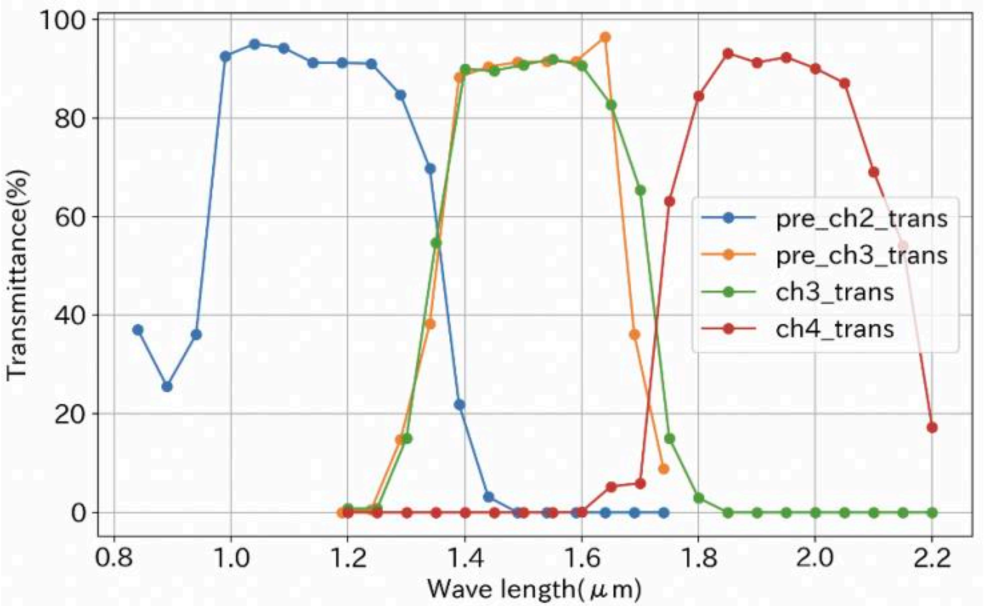


Cooling test



Adhesive sampl

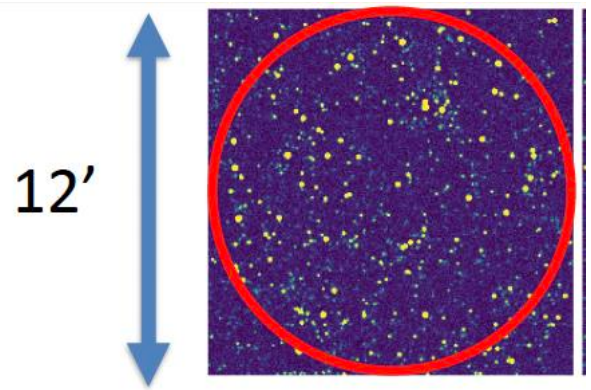
Spectral transmittance

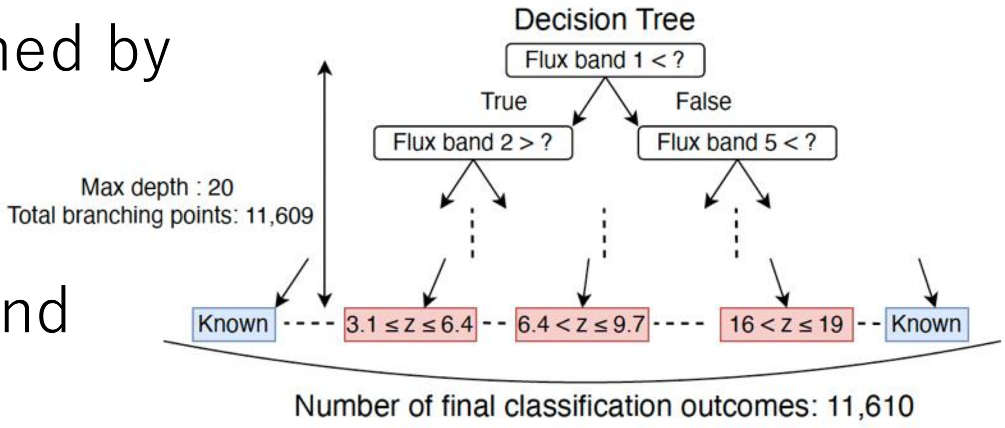


Onboard Selection of GRB Candidates

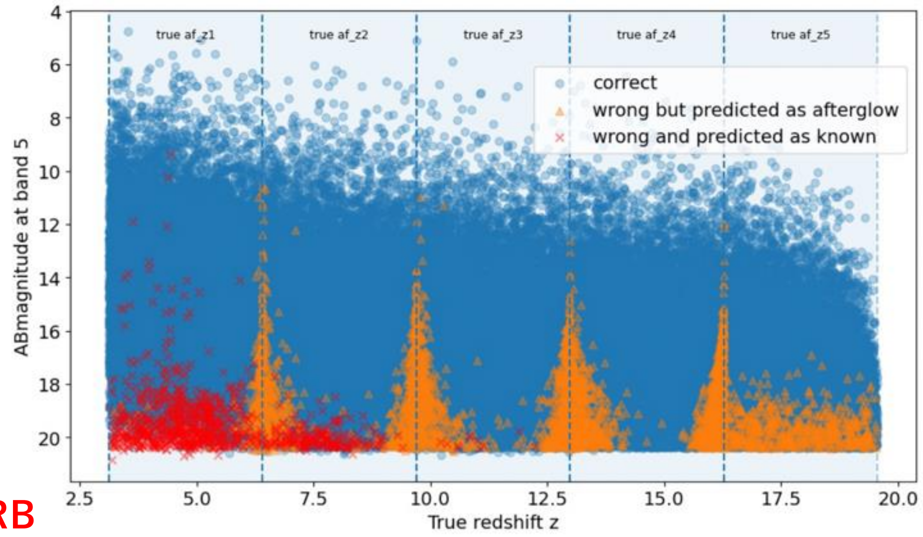
- GRB candidates must be selected from ~1000 sources in the MONSTER FoV.
- Onboard computing resources are limited
- GRB candidates extracted via a decision tree trained by ground-based machine learning

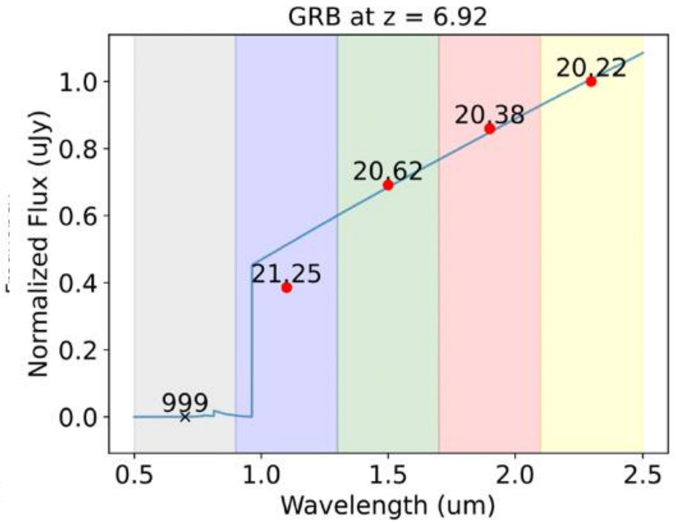
  → Reduces candidates to < 100 objects
- Positions and magnitudes transmitted to the ground for catalog matching and alert distribution





- Niinuma et al. (2026 in prep.)
  - Yamagata Univ. student





Blue: Correctly identified as GRB

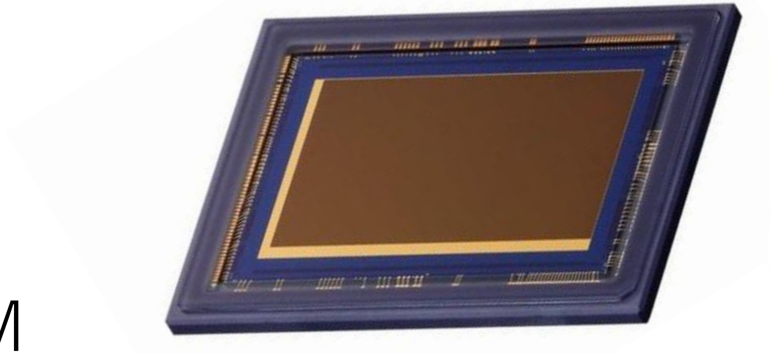
Orange: Selected as GRB but redshift estimate was wrong;

Red: Known source incorrectly selected as GRB

Detectors

[Visible-light Detector]

- Teledyne HyViSI or Canon LI3030SAM
- HyViSI is the baseline but expensive
  → Exploring domestic CMOS detector alternatives
  - Low-temperature operation test (assuming use at > 0 °C)
  - Investigation of technical challenges for space-grade operation
  - Temperature dependence evaluation of dark current and noise
  - Radiation test assuming 5 years in orbit



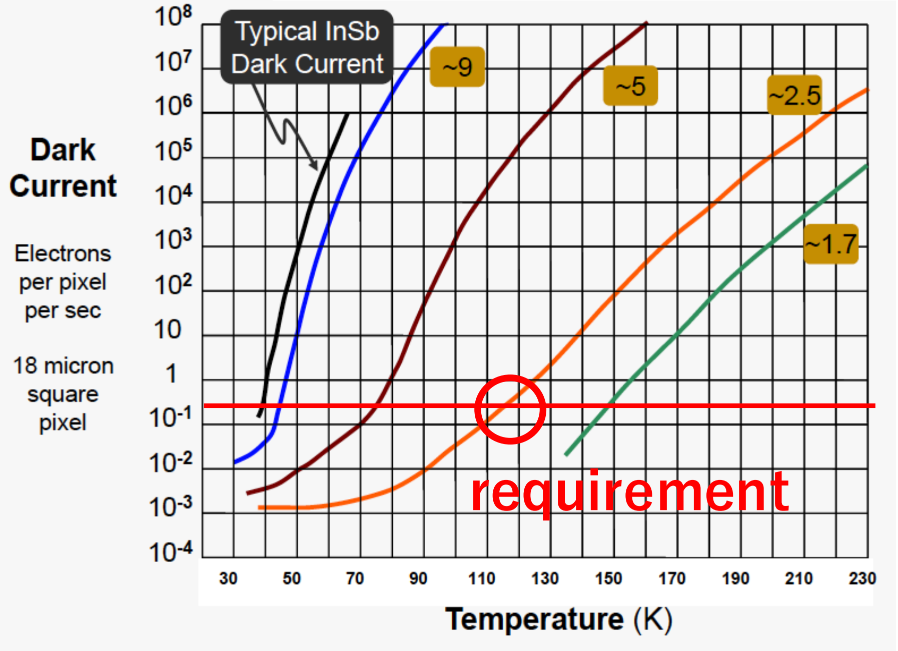
Canon LI3030SAM

TeledyneH1RG

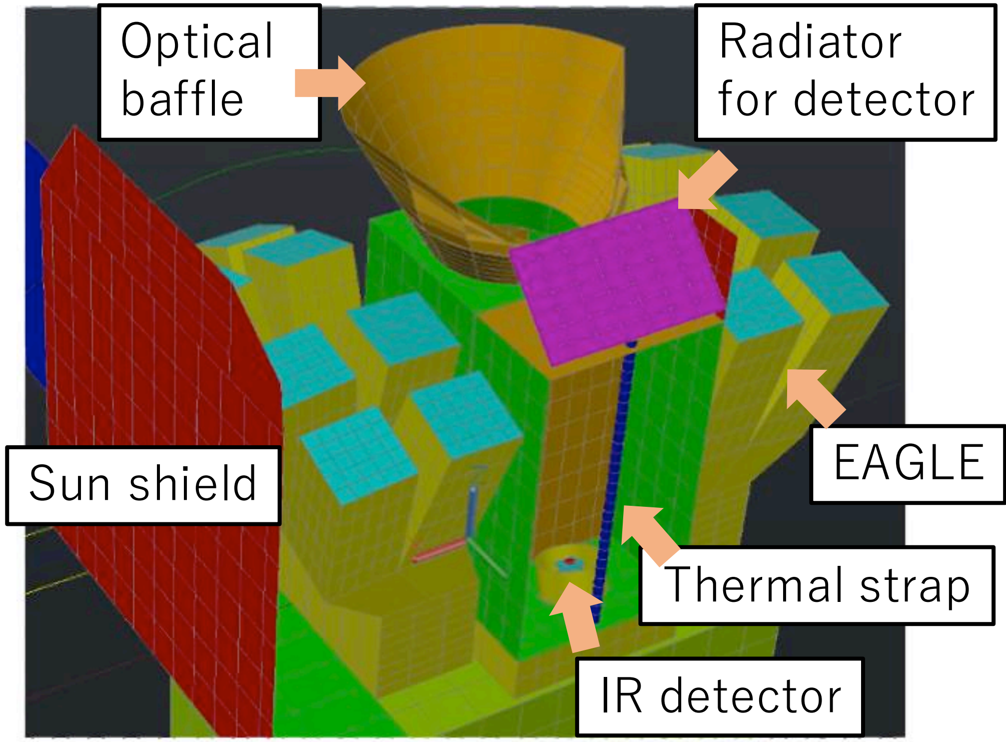
SIDECAR ASIC Focal Plane Electronics

[Near-Infrared Detector]

- Teledyne H1RG + SIDCAR ASIC
- Dark current must be < 0.3 e^{-}/s to meet sensitivity requirement
  → Temperature requirement: **< 120 K**



Thermal Model

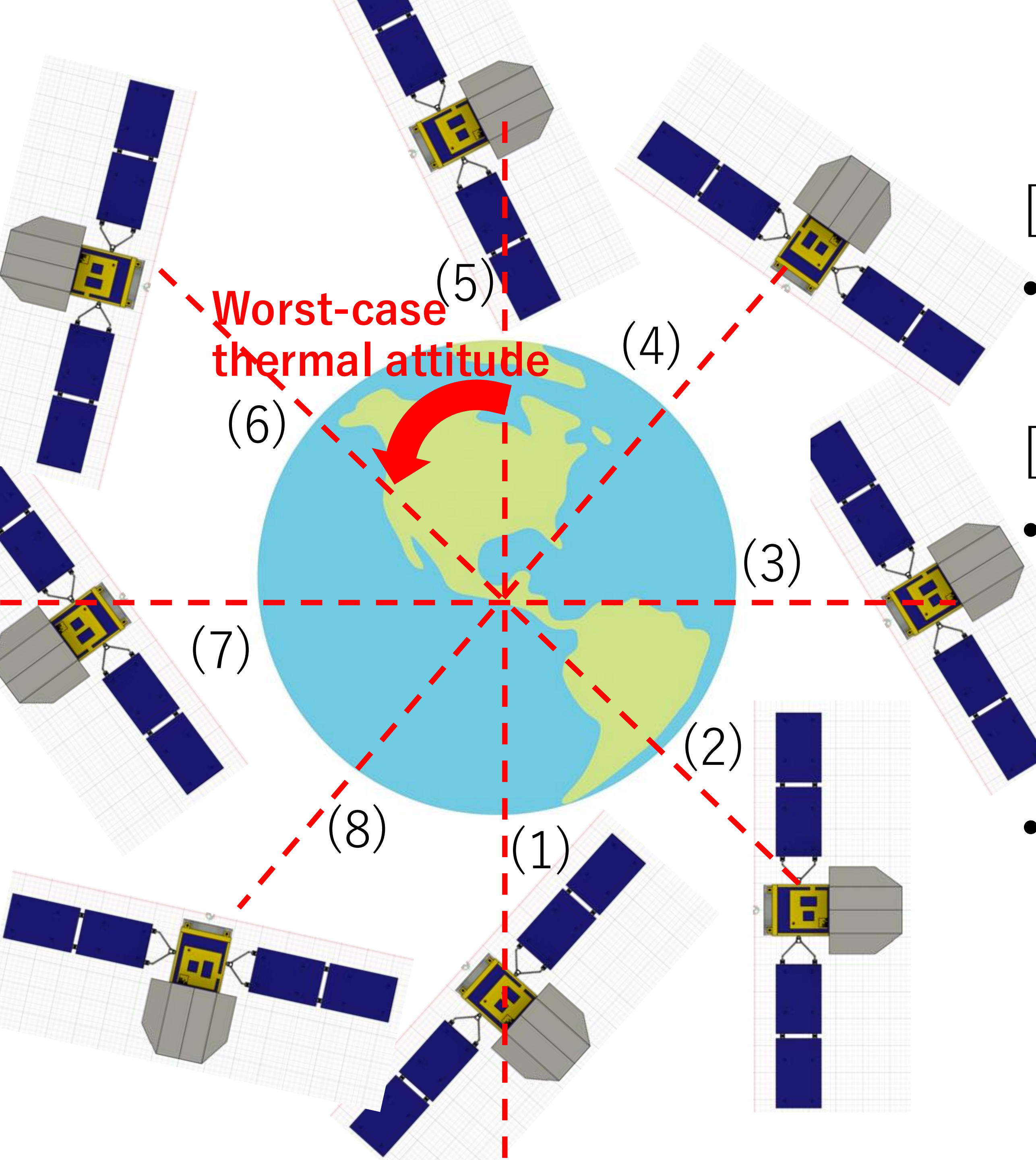


[Thermal Requirements]
- Telescope & enclosure: < 200 K
- NIR detector: < 120 K
- Radiative cooling (no mechanical cooler)

[Thermal Model]
- Science instruments (MONSTER, EAGLE, etc.) modeled in-house
  → Thermal analysis with Thermal Desktop

- Science instruments shielded from solar input by a sun shield.
- A dedicated radiator installed to cool the NIR detector

- Kageyama et al. (2026 in prep.)
  - Kanazawa Univ. students



Thermal Analysis

[Orbit]

- Sun-synchronous dawn-dusk polar orbit

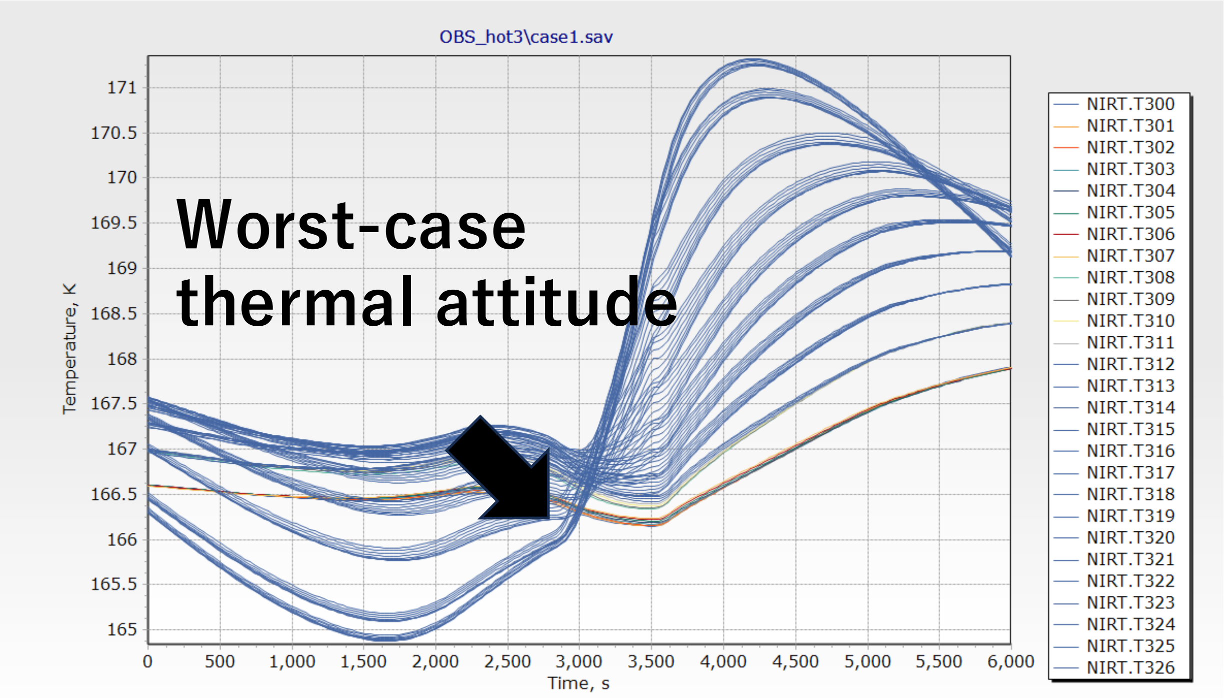
[Nominal Satellite Attitude]

- GRB survey attitude: 8 orientations per orbit
  - Anti-solar direction: 30 deg
  - Along-track: 50 ± 10 deg
  - Inertially fixed
- Slews to GRB direction upon detection
  - In this analysis, pointing to GRB at (5)
  - Worst-case thermal attitude at the north pole during summer solstice
    - Anti-solar direction: 60 deg
    - Along-track: −20 to −60 deg

Thermal Analysis Results

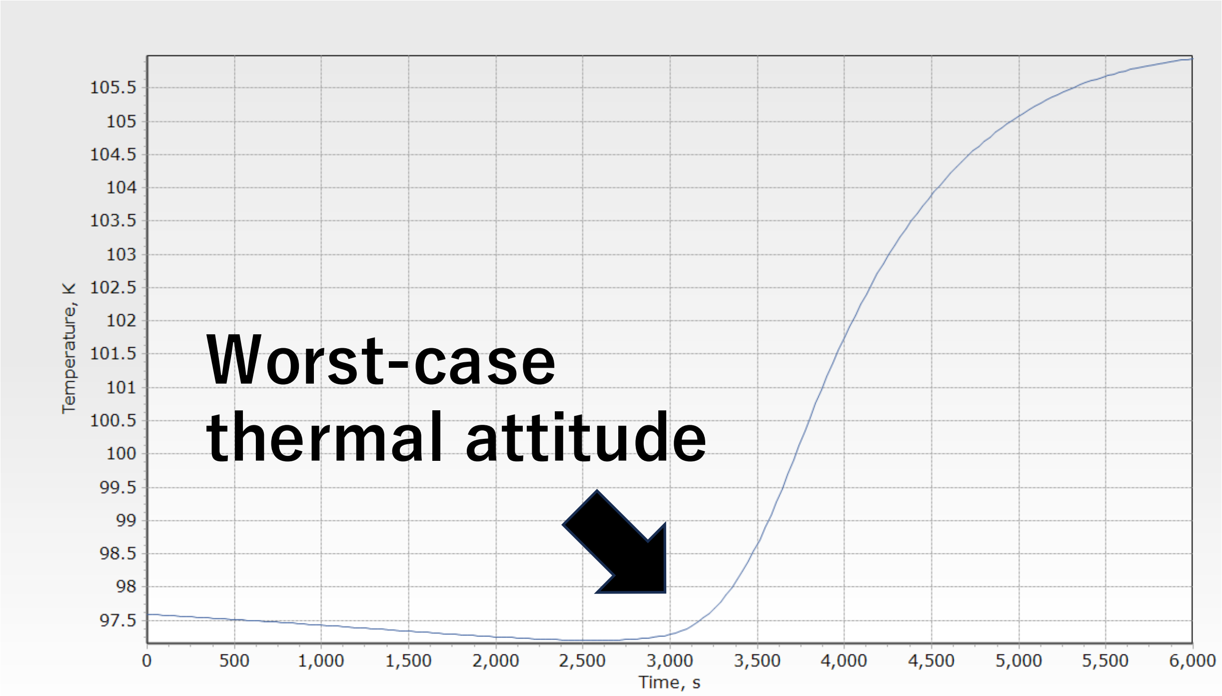
- Thermal feasibility confirmed even under worst-case attitude
  - Telescope enclosure: < 172 K (req.: < 200 K)
  - NIR detector: < 106 K (req.: < 120 K)

Telescope enclosure



5800 s (1 orbit)

NIR Detector

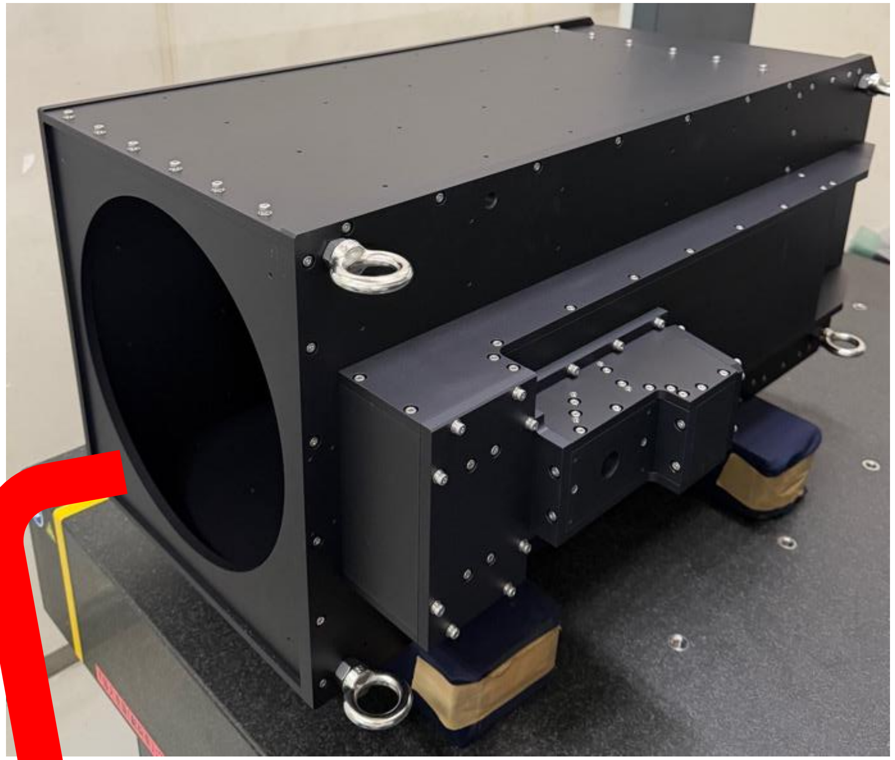


5800 s (1 orbit)

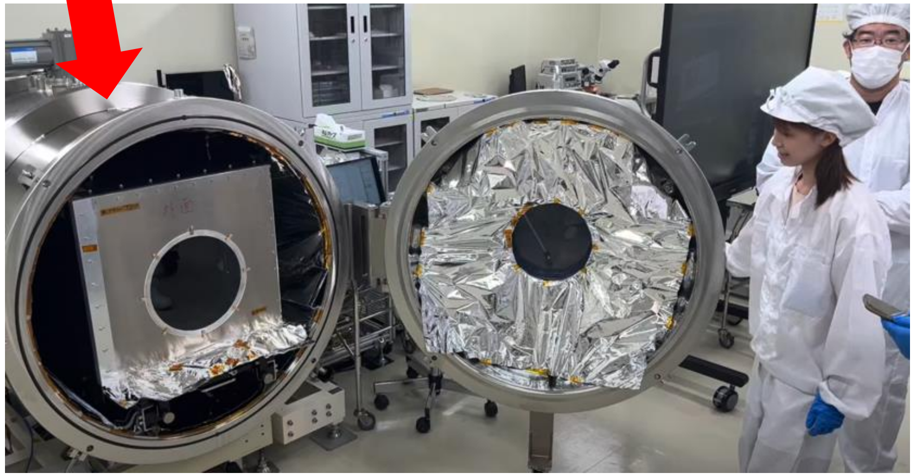
BBM Cooling Optical Test

- Fabricating the telescope BBM, cooling it, and evaluating optical performance
  - Using the vacuum chamber at Kanazawa University
  - **Demonstrate the athermal design concept** by performing optical adjustments at room temperature and then cooling the system to evaluate its optical performance.
  - Multiple thermometers and heaters on the BBM evaluate the relationship between temperature gradient and optical performance degradation

- Preparing to cryogenic optical test
  - BBM fabrication completed !
  - Room-temperature optical performance verified (meets requirements)
  - **Cooling test is currently ongoing at Kanazawa Univ.**
  - Optical performance test at cold is planned



BBM is under cooling test now !



Summary

- HiZ-GUNDAM is a satellite mission to advance early-universe exploration and multi-messenger astronomy through GRB observations

- Rapid follow-up of GRBs discovered by the onboard NIR telescope
  - 30 cm aperture reflecting telescope
  - 5-band simultaneous imaging with Kösters prism (0.5–2.5 μm)
  - Athermal optical system with aluminum mirrors
  - Radiative cooling (telescope < 200 K, NIR detector < 120 K)

- We are currently conducting cooling optical tests using the BBM.
  - Purpose: Experimental validation of the athermal design concept.
  - Manufacturing of the BBM is complete, and optical performance meeting the requirements has been achieved at room temperature.
  - Cooling tests are currently underway in a chamber at Kanazawa University.
  - We are preparing to conduct cooling optical tests next month.