



# **NinjaSat: A 6U CubeSat Observatory for Bright X-ray Sources**

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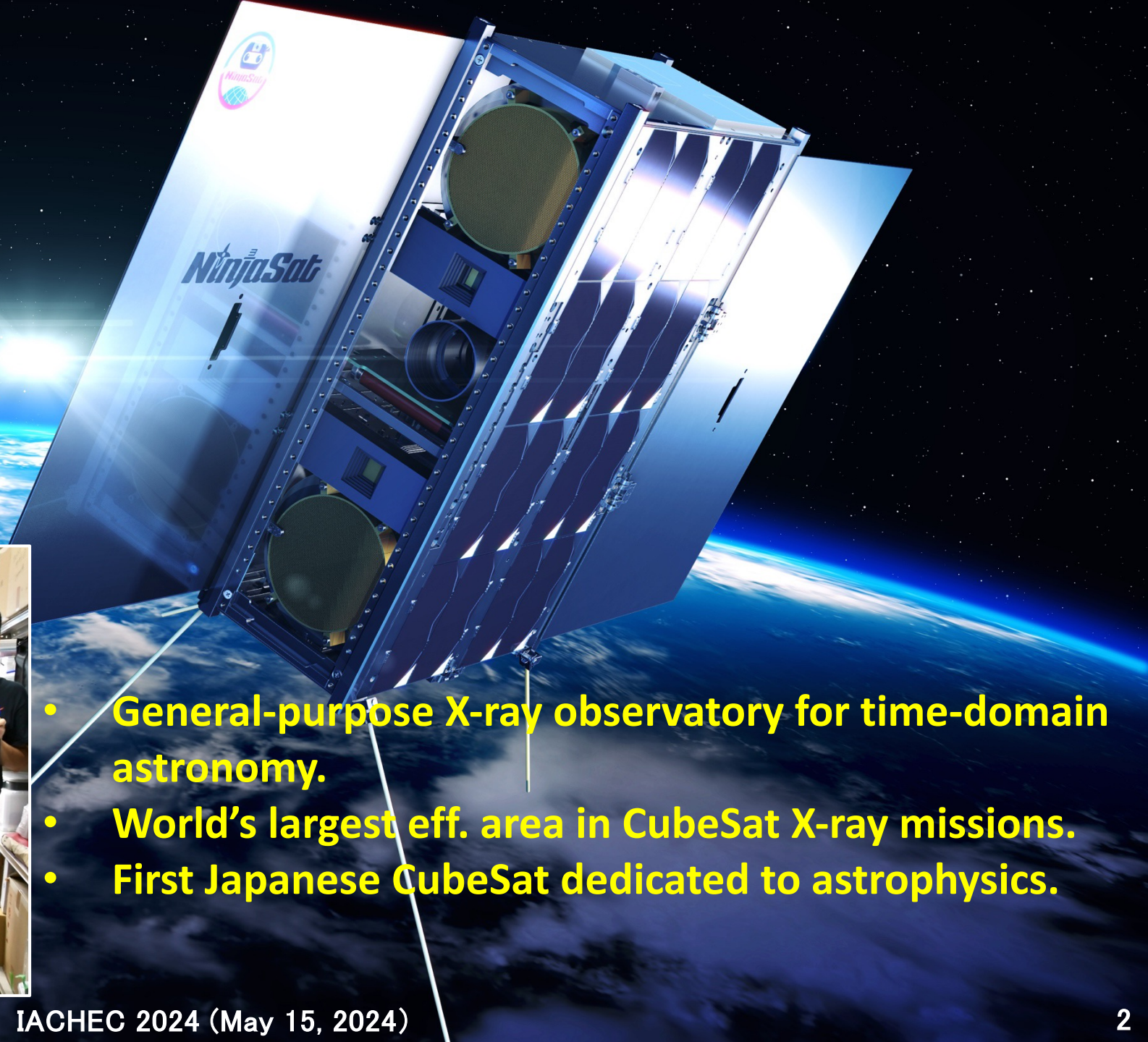
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**M6P bus provided by Kongsberg NanoAvionics via Mitsui Bussan Aerospace**

[https://twitter.com/ninjasat\\_xray](https://twitter.com/ninjasat_xray)

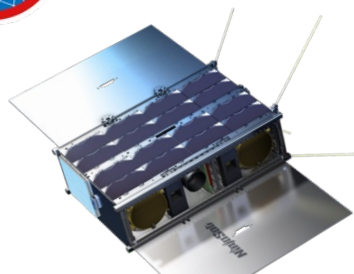
# The NinjaSat Project



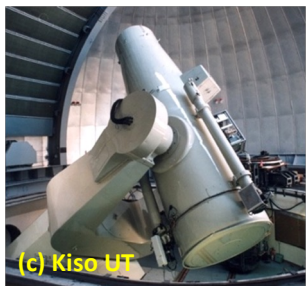
- General-purpose X-ray observatory for time-domain astronomy.
- World's largest eff. area in CubeSat X-ray missions.
- First Japanese CubeSat dedicated to astrophysics.



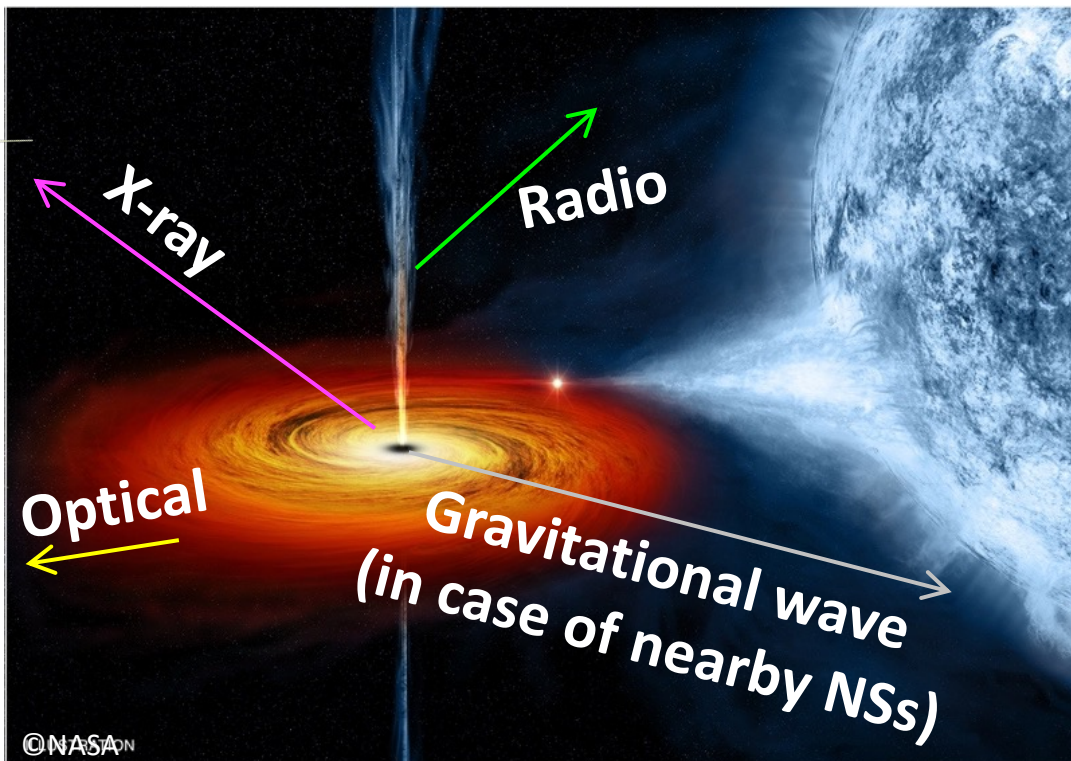
# Time-domain astronomy with CubeSats



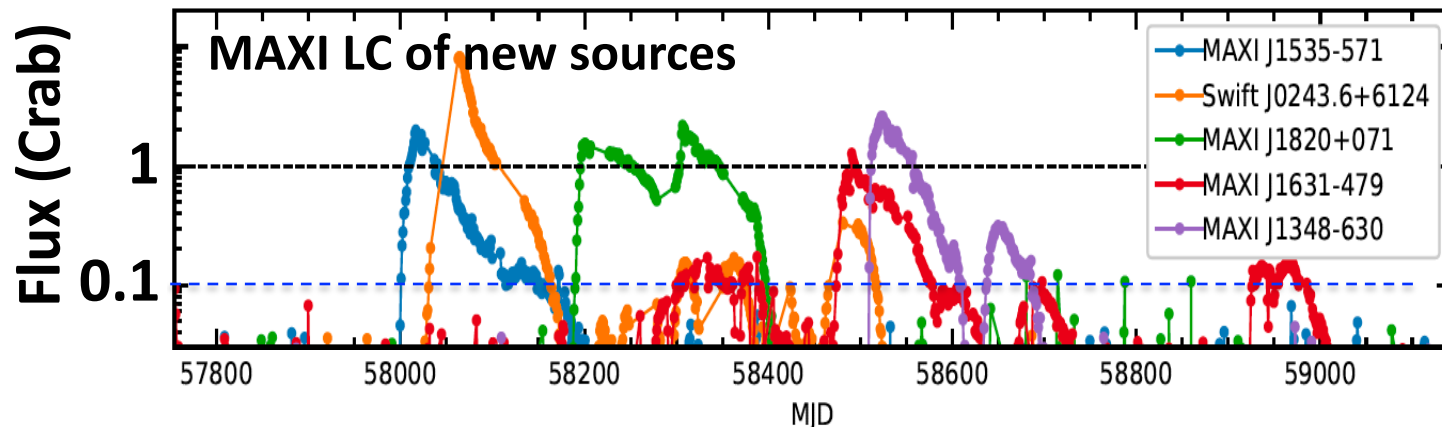
X-ray CubeSat



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- **Time-domain** astronomy
  - Multi-**wavelength** observations
  - Multi-**messenger** observations
- **Long-term X-ray observations on a single source.**
  - Variability, burst activity, etc.
  - Hard to monitor long with large satellites due to limited time allocation.
  - **Dedicated CubeSat** is a suitable tool for **monitoring bright X-ray objects long-term!**
- **Fill the gaps between MAXI's intermittent observations**



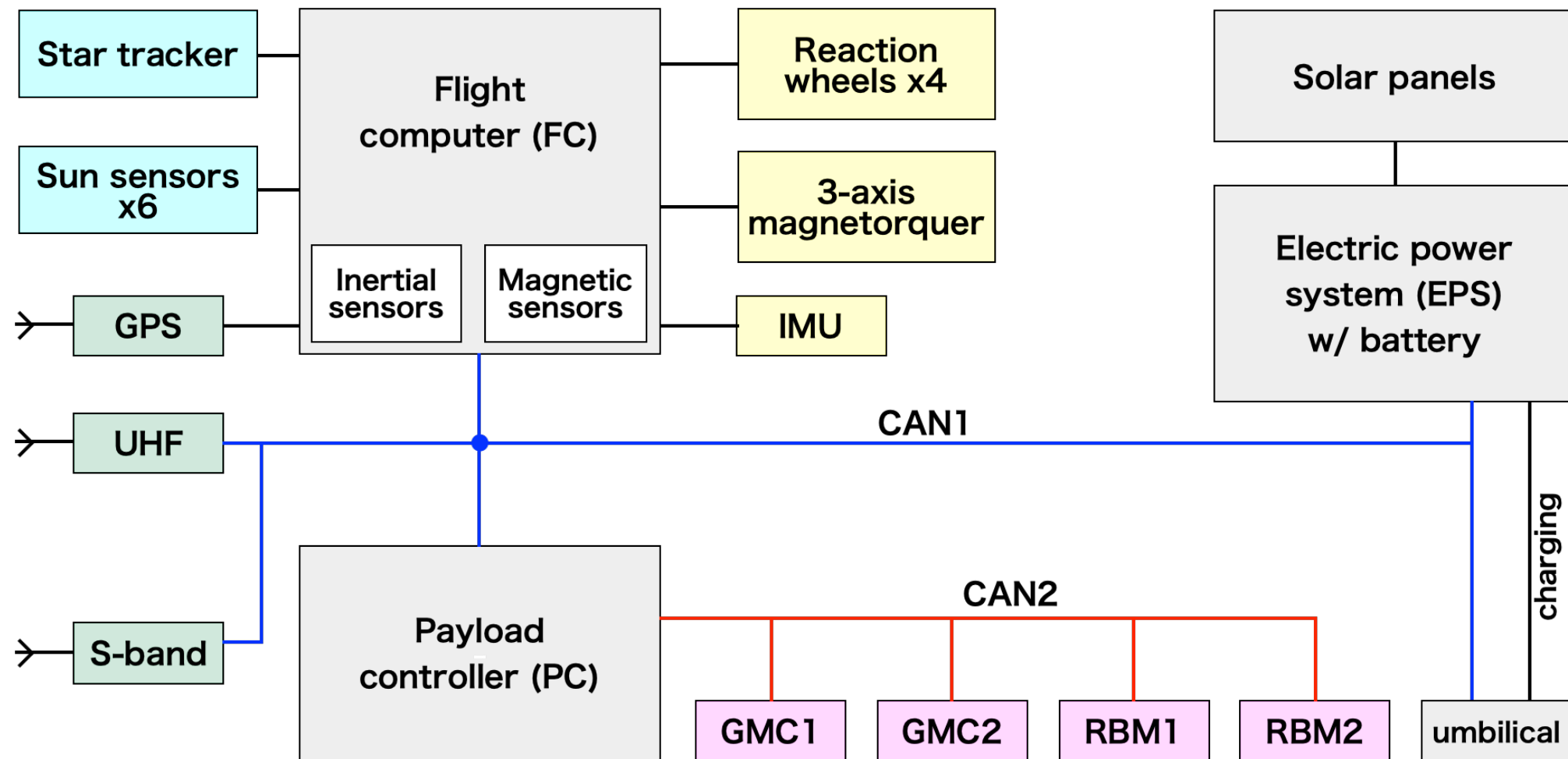
# The satellite

## Key feature of NinjaSat:

- **6U CubeSat** (10 cm x 20 cm x 30 cm) using NanoAvionics M6P bus
- **Two non-imaging X-ray detectors**, two radiation belt monitors
- **Pointing capability < 0.1 deg**
- **Sun avoidance 40deg (20deg possible)**
- **High slew rate 5 deg/s (w/ 4 RWs)**
- **Weight 8.1 kg, Power 16 W**
- **Sun Synchronous Orbit**, 530 km, LTDN 10:50 am
- **S-band communication**



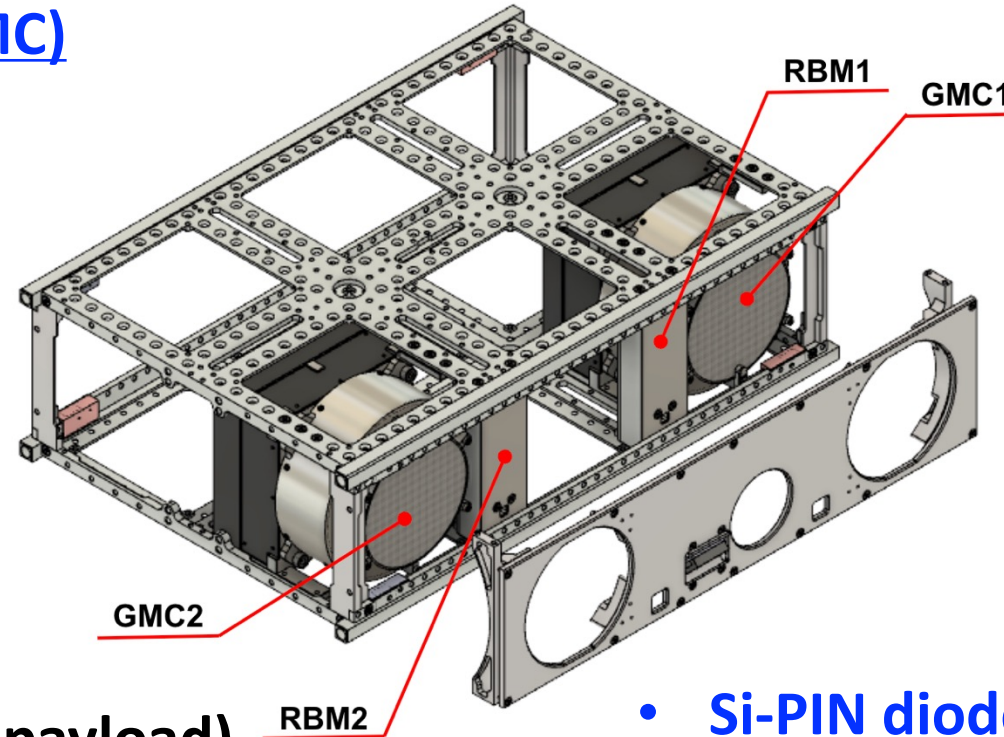
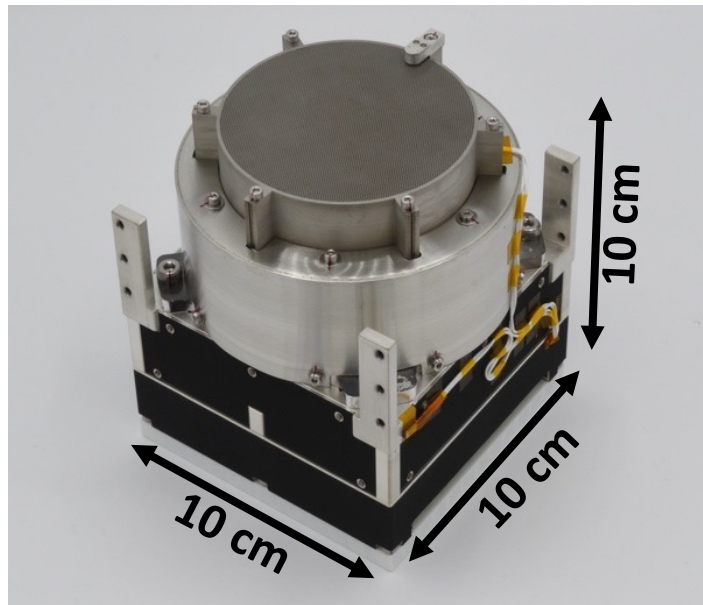
# Satellite function diagram



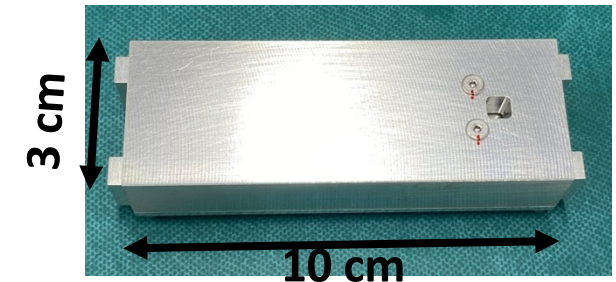
## Scientific Payloads

- **ADCS: STT, 6 Sun Sensors, 4 RWs, 3-axis MTQ, IMU, mag, and inertial sensors (controlled by FC). => Pointing accuracy: <math>< 0.1^\circ</math> (0.05° APE)**

## Gas Multiplier Counter (GMC)



## Radiation Belt Monitor (RBM)

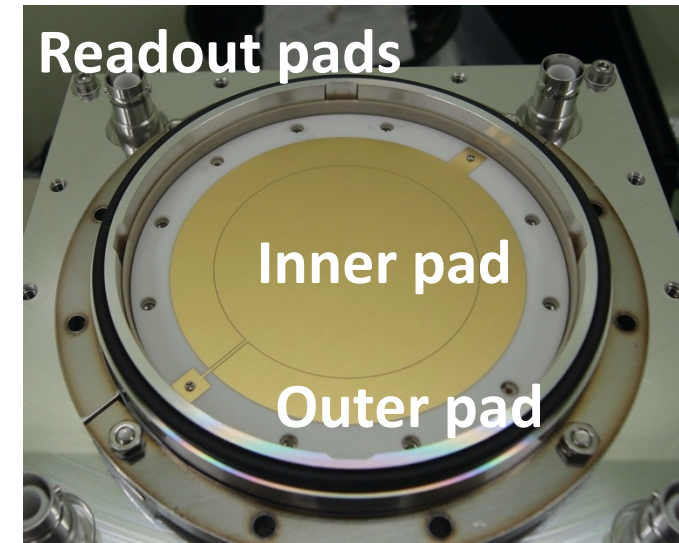
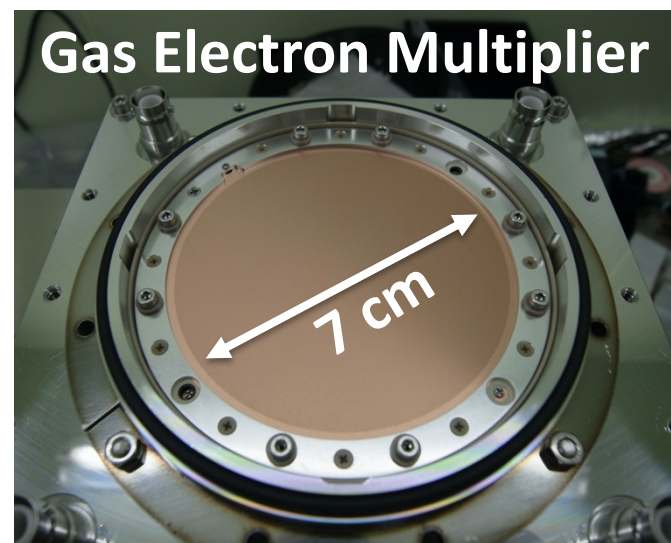
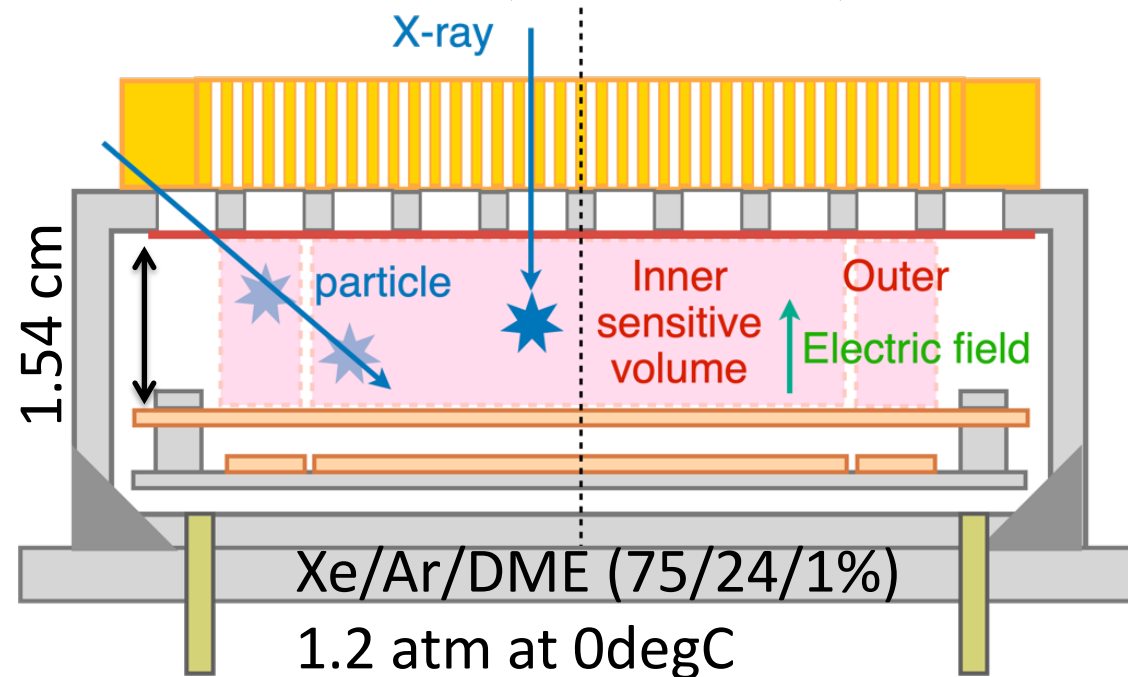
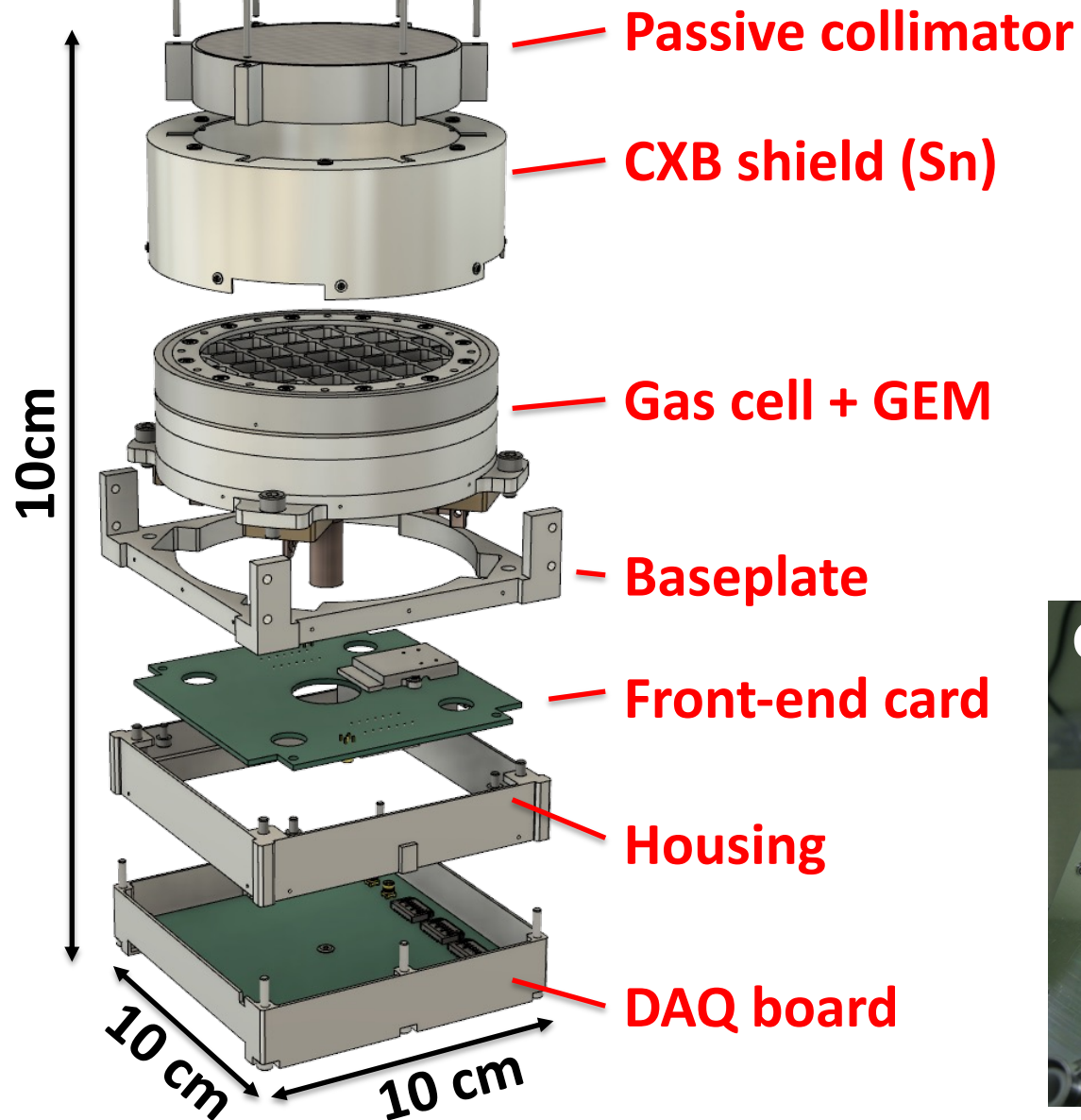


- **Gas X-ray detector** (primary payload)
- 1U, 1.2 kg, 1.8 W each
- **2-50 keV** (Xe/Ar/DME gas filled)
- Timing resolution **61 micro sec**
- Effective area **32 cm<sup>2</sup>** for two GMCs
- FoV (w/ collimator) **2.3deg** (FWHM)

- **Si-PIN diode**, 70 g, 1 W each.
- Issue alert in high radiation region.
- Threshold: **150 keV (e), 300 keV (p)**

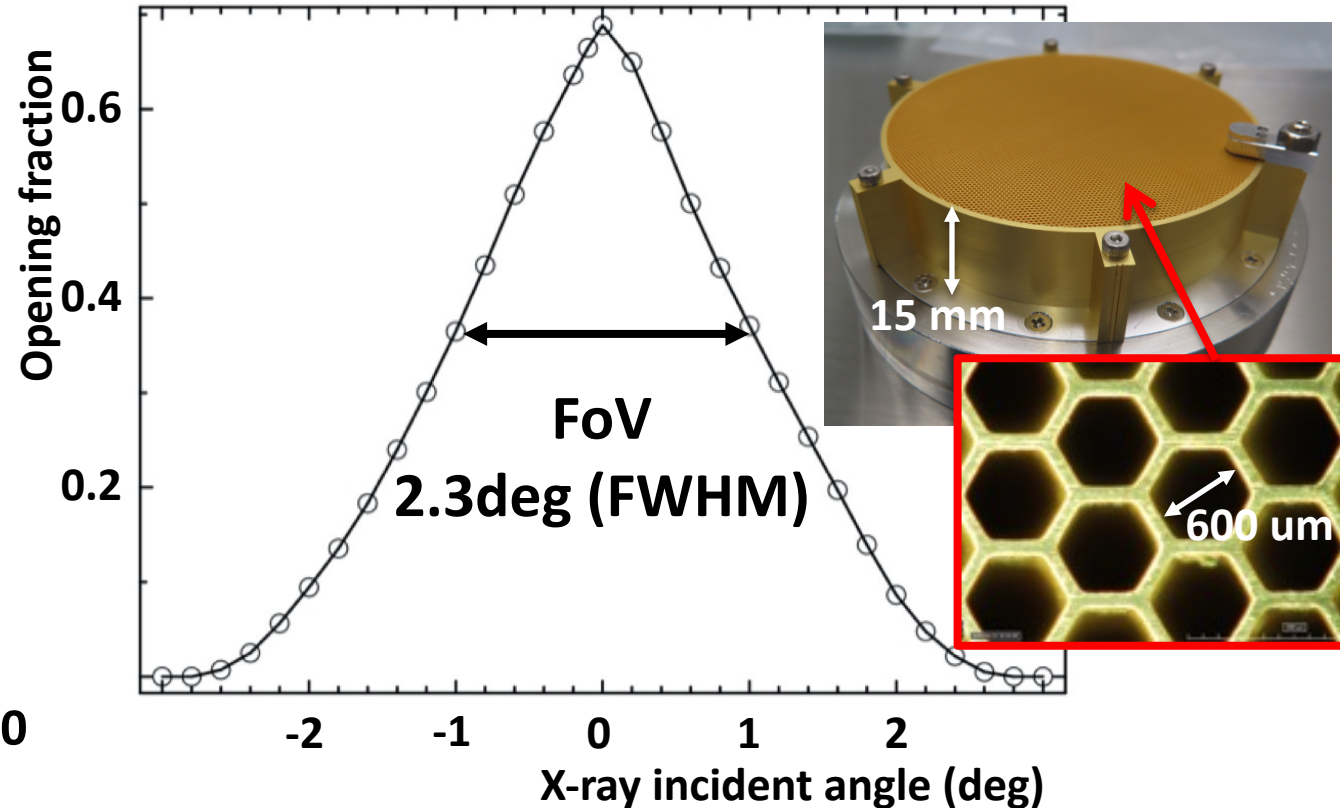
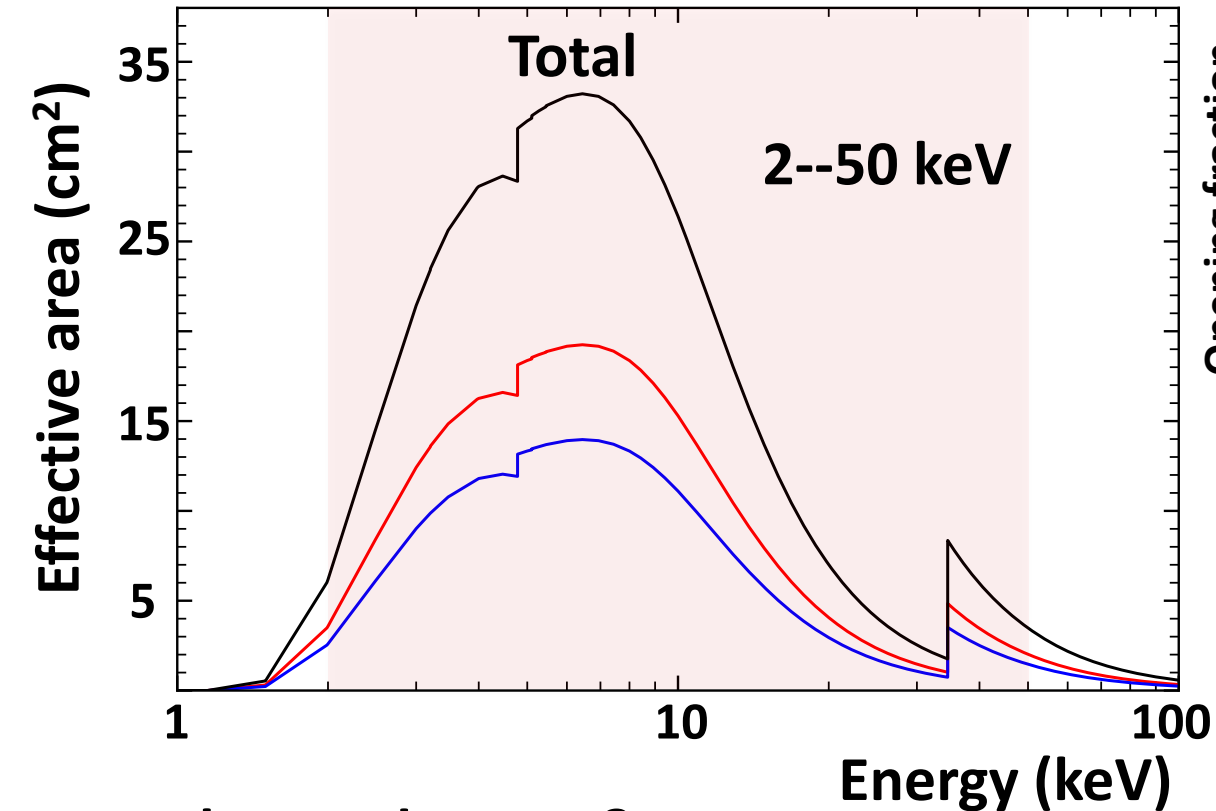
- Payloads were integrated at RIKEN.
- Functional and environment tests were performed for each payload before shipping.

# Gas Multiplier Counters (GMCs)



Xe/Ar/DME=75/24/1%, 1.2atm@0degC

Passive collimator

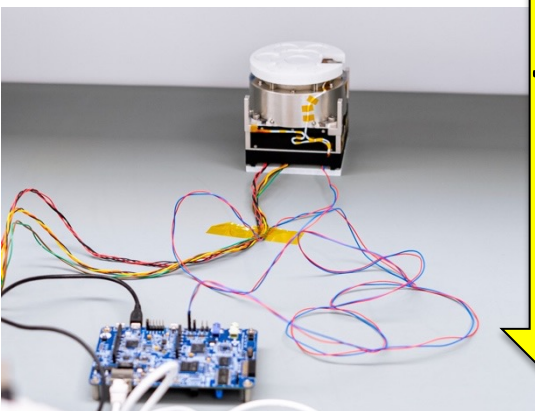
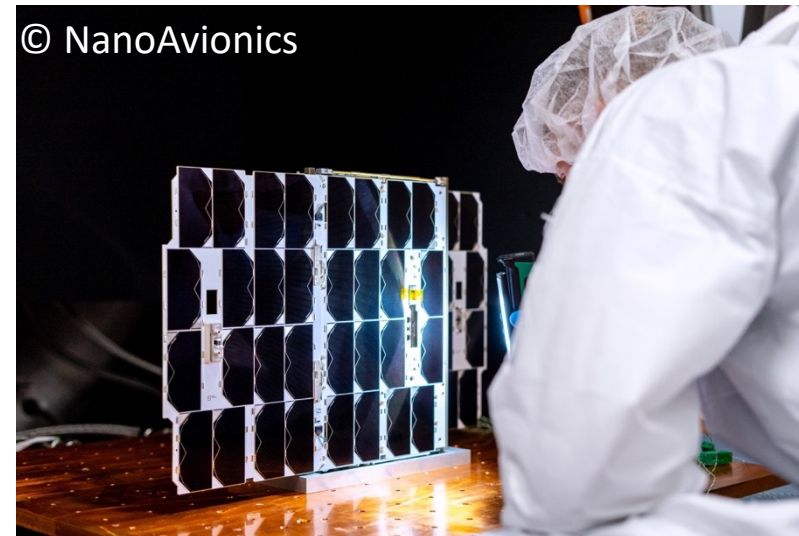
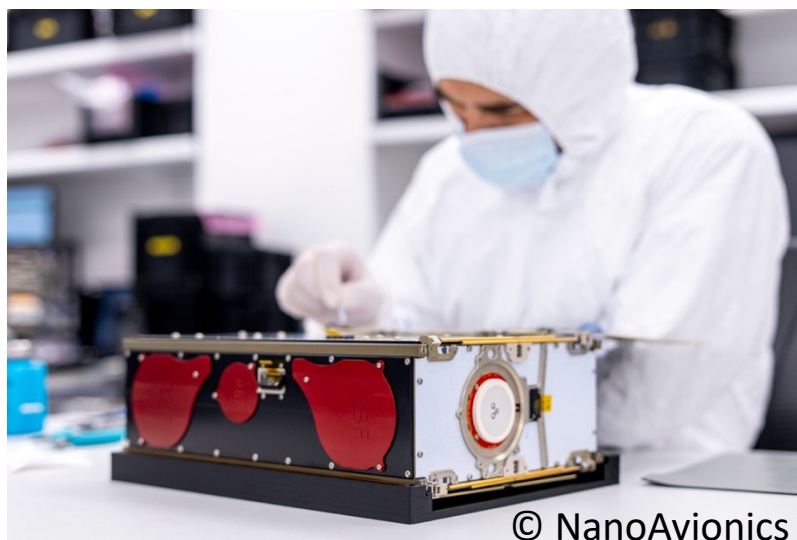


## Why gas detector?

- Less expensive for enlarging effective area
- No need to cool down the sensor, low power consumption, good for thermal control.
- Insensitive to the temperature fluctuation



# History of NinjaSat project



3.5 yrs (2.5 yrs)

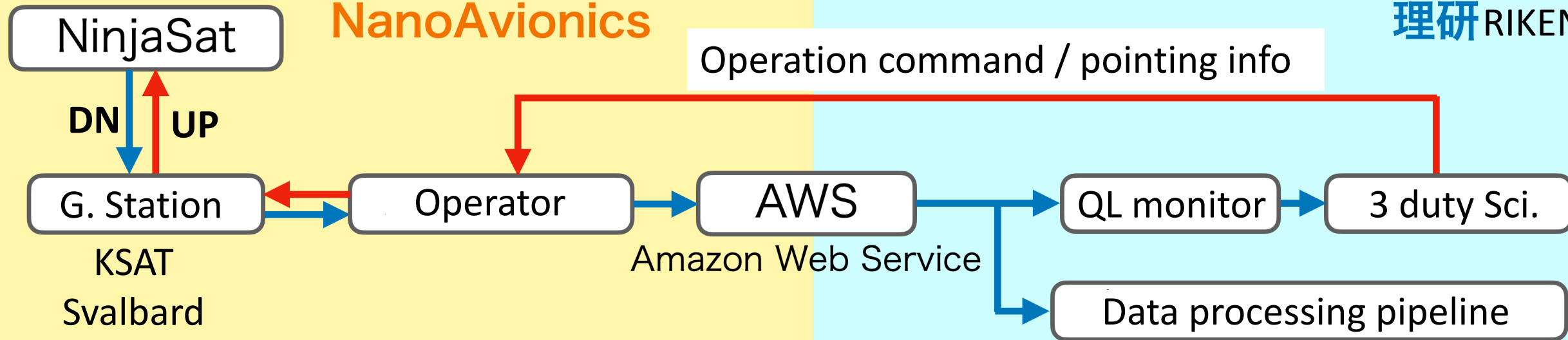
- 2020 **Start** the NinjaSat project, payload BBM (function, radiation, etc.)
- 2021 **EM** payload fabrication and tests, then FM fabrication **Japan**
- 2022 **FM** payload tests and delivered to NanoAvionics in August.
- 2023/03 Payload **integration** into the M6P bus.
- 2023/04 TVAC and vibration **tests** **Lithuania**
- 2023/5-7 Satellite **quality assurance** tests **(& Germany, Poland)**
- 2023/8 Ship to ExoLaunch and then to the US
- 2023/11/11 **Launch** at VSFB (SpaceX Transporter-9 rideshare) **US**

## SpaceX Transporter-9



- 1) Launch November 11, 2023
- 2) Functional verification of the satellite until **January 23, 2024**
- 3) RBM1/2 startup (~ 1 week) => **mapping particle environment** in the orbit.
- 4) GMC1 startup (~ 1 week) => **HV ramp-up, function, background level.**
- 5) Pointing an X-ray source => Crab observation **on Feb. 10-11**. Measure flux, spectrum, and check alignment.
- 6) GMC2 startup (~ 1 week) => same procedure as GMC1
- 7) Multiple pointing observations of Crab for optical-axis cross-alignment among STT and GMCs.
- 8) Start scientific observations from **Feb. 23**. Any target can be observed if sun angle < 40 (20) degrees.

## NanoAvionics



A corner of an office

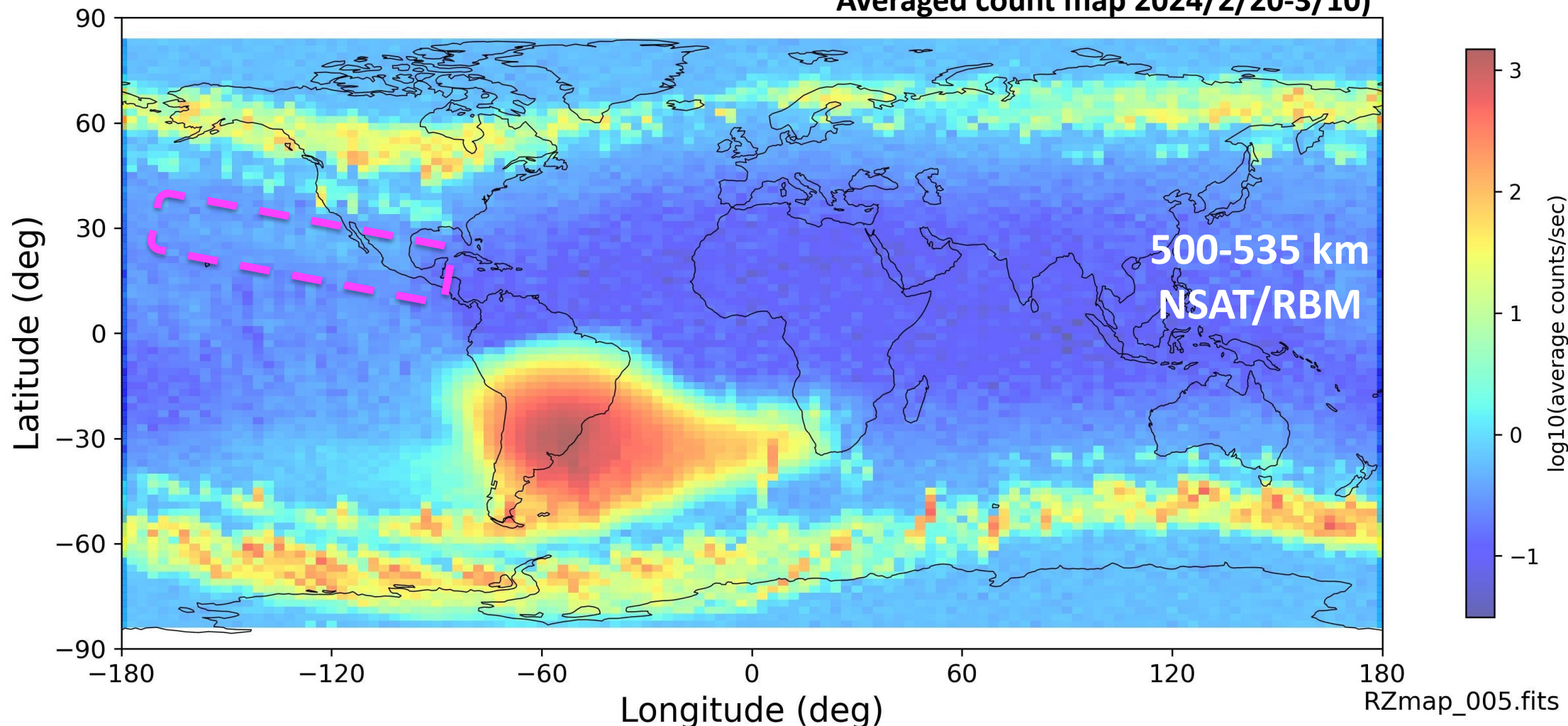
- NanoAvionics is responsible for satellite ops.
- NinjaSat team is responsible for science ops.
- 3 duty scientists are assigned.
- Send ops command (2-3 hrs before uplink), pointing list (one day before uplink)
- Data can be analyzed using a standard method.



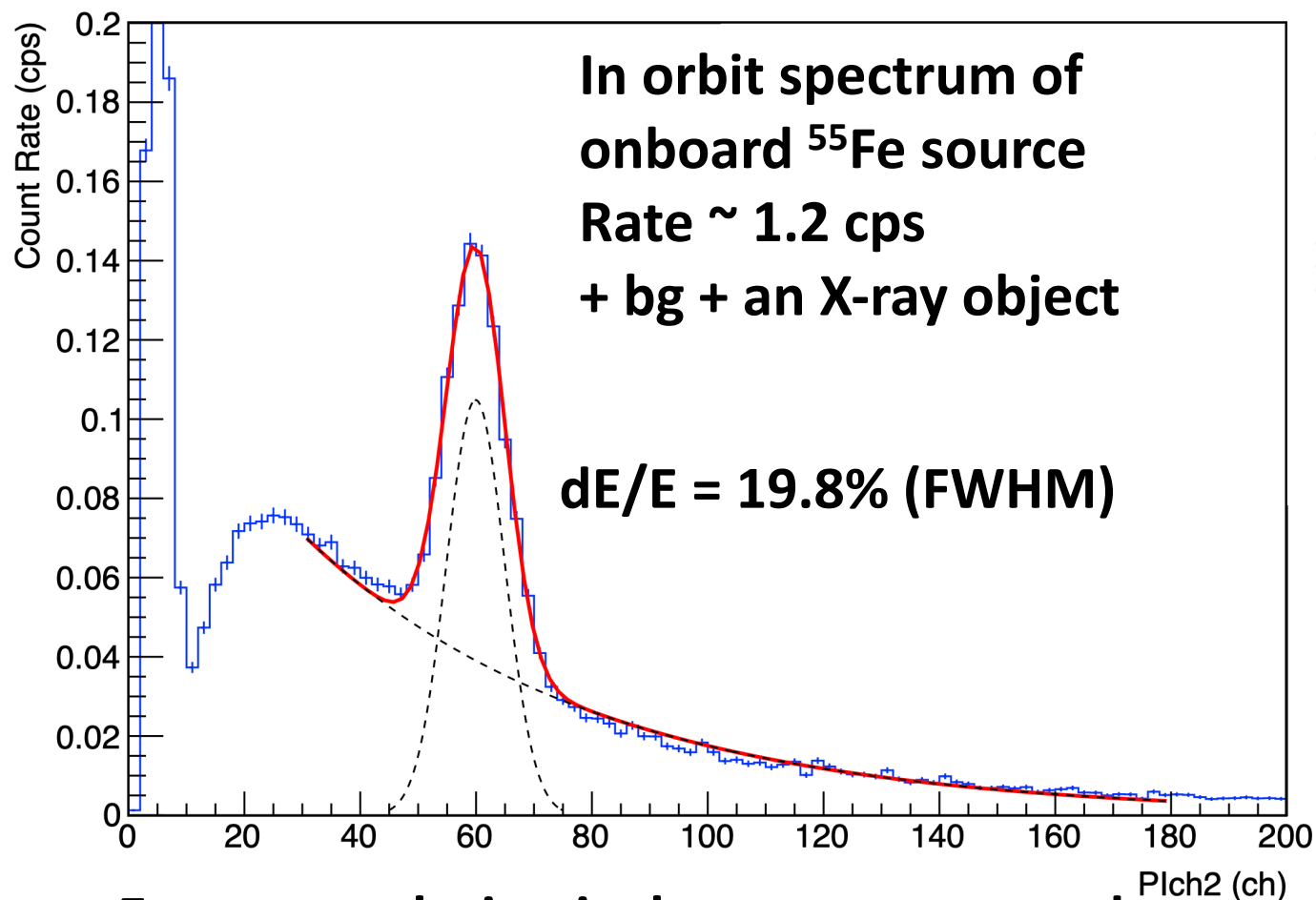
# Particle count rate in orbit



Averaged count map 2024/2/20-3/10)

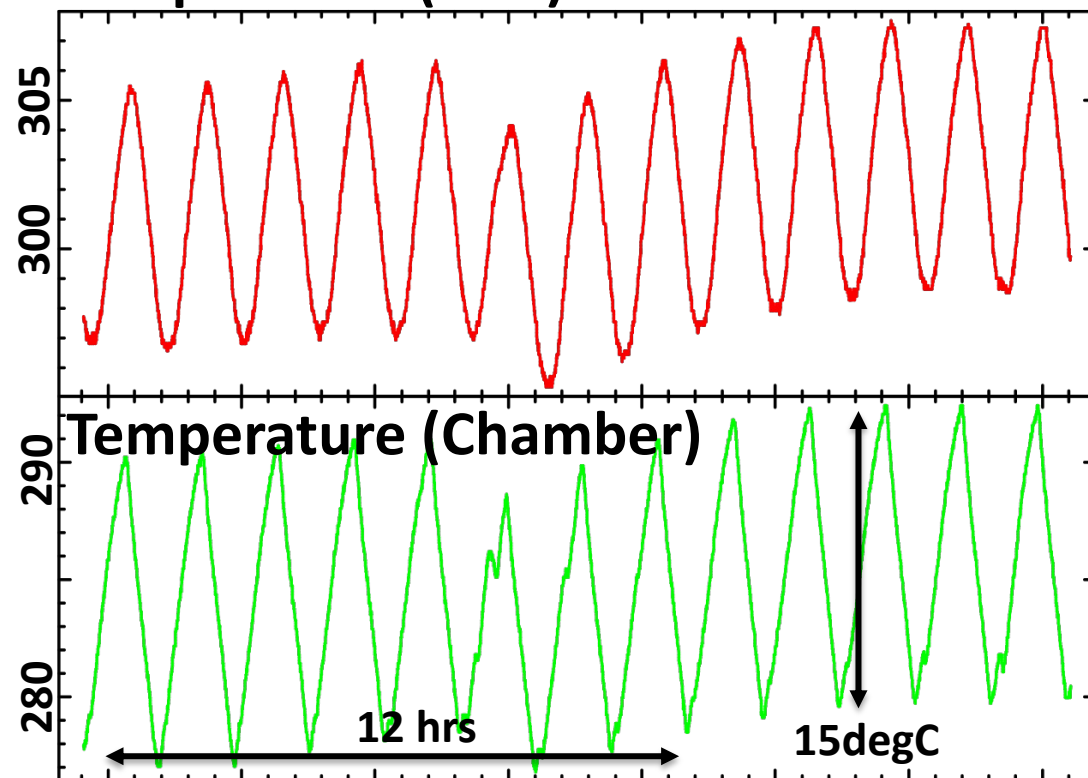


- **NinjaSat RBM scans the entire globe every 6 days.**
- **Sometimes, unusual high radiation regions seen depend on solar activities.**



- Energy resolution is the same as ground measurement.
- 20% jump in gas gain from ground, but keep constant in orbit

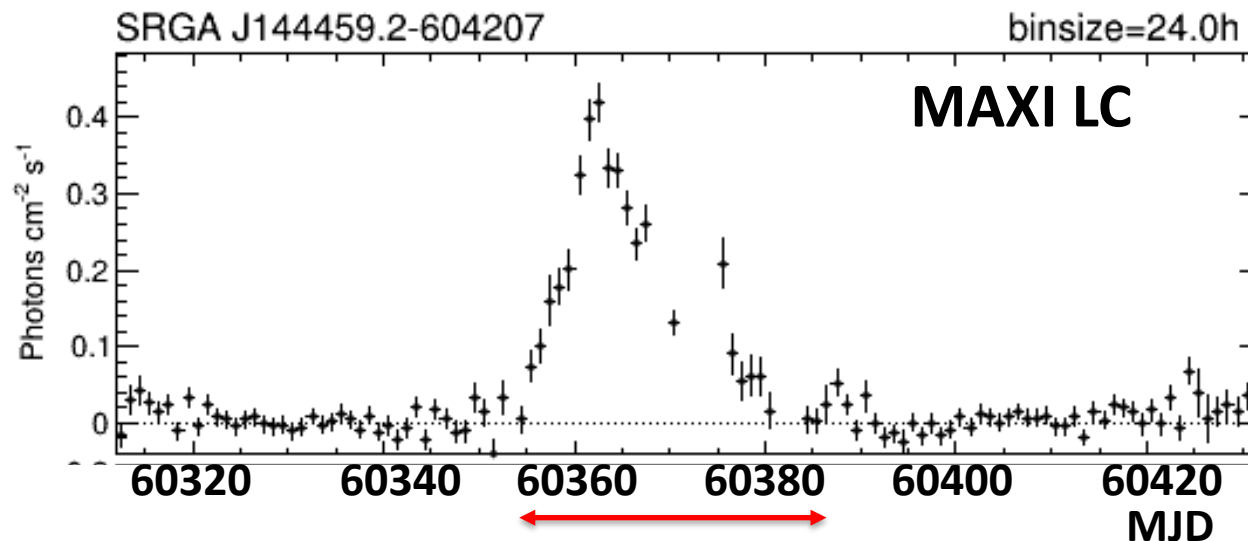
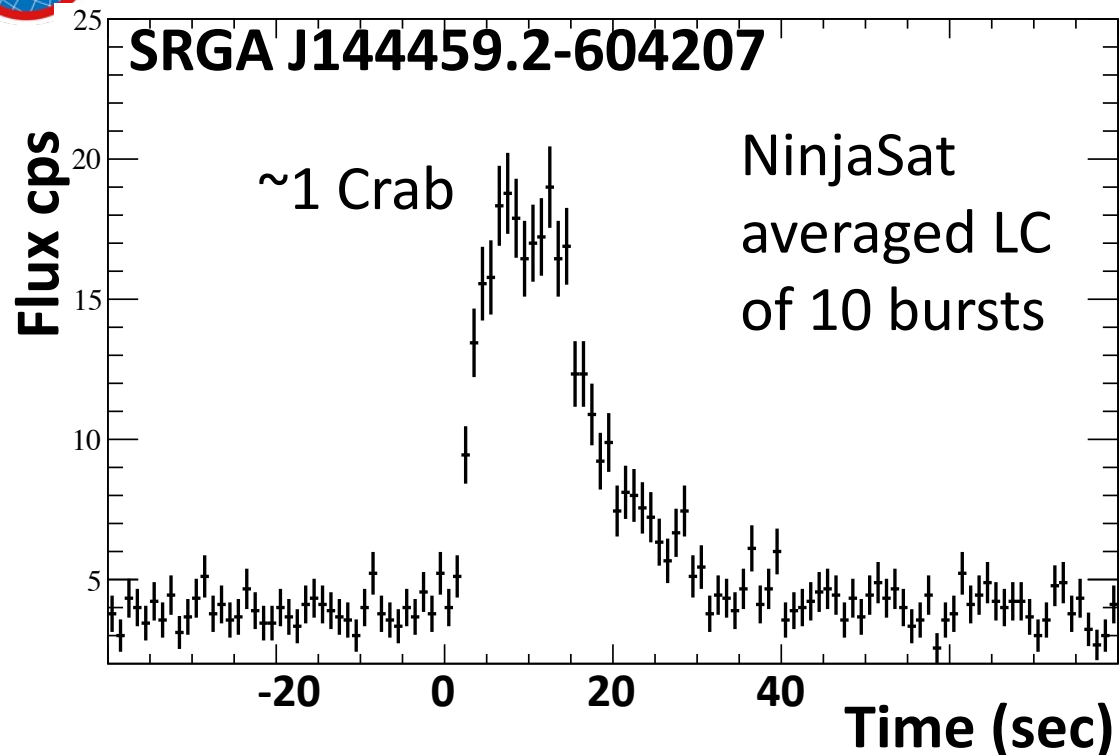
Temperature (CPU)



- **Background modeling & temp-dependent response file (in progress)**
- Timing calibration & verification given by Naoyuki Ota in the next talk.



# Scientific observations

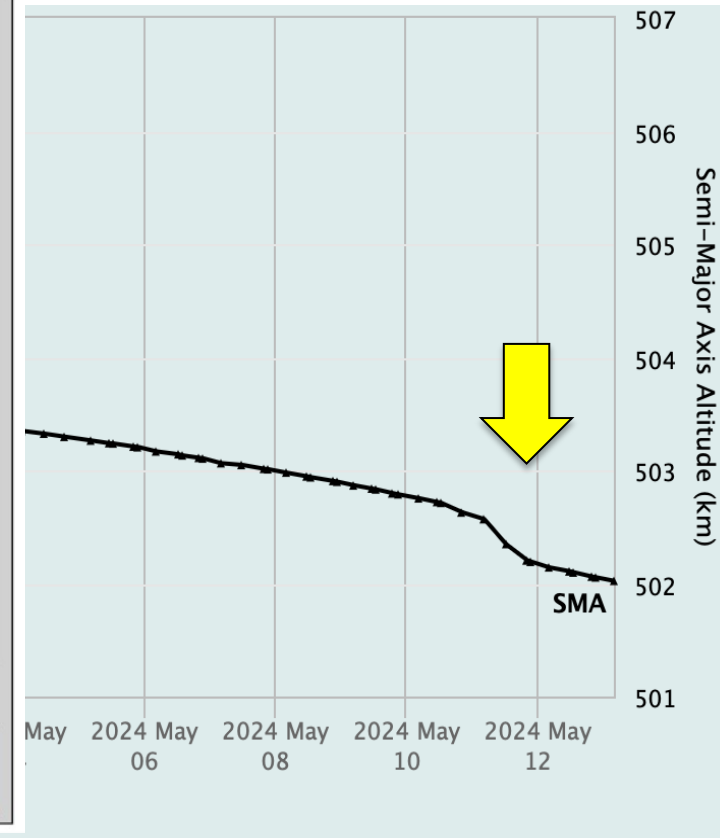
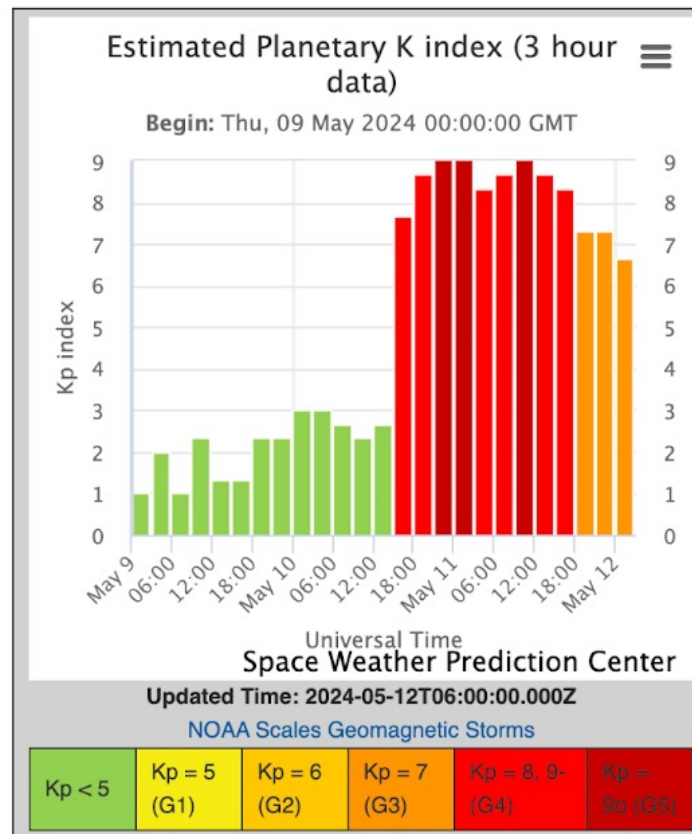
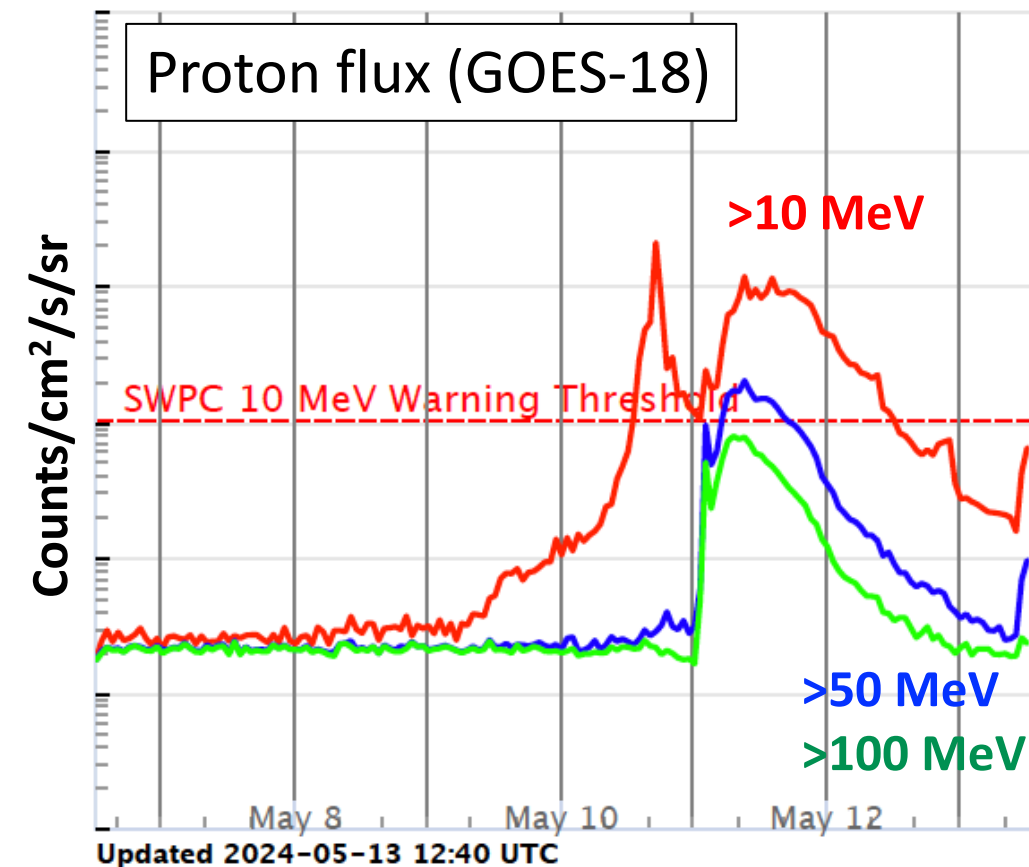


## Targets observed so far.

- SRGA J144459.2-604207 (accreting millisecond pulsar)
- Observed many Type I XRBs.
- Monitored long-term ~1 month.
- Detection limit ~ sub-10 mCrab for 1/3 day observation

- Crab
- **SRGA J144459.2-604207 (long-term)**
- Sco X-1
- Her X-1 (long-term)
- Cyg X-1
- 4U 0115+63
- GX 301-2

# Impact of recent solar activities



- We stopped observations to prevent an SD card from permanent failure.
- No effects on the satellite were observed.
- A rapid drop in altitude occurred.



# Summary and future



- **NinjaSat**
  - 6U X-ray observatory designed for **long-term monitoring of bright X-ray sources**.
  - World's highest X-ray sensitivity in CubeSat missions with good timing resolution 61  $\mu$ s. (key for **time-domain astronomy**).
  - First Japanese CubeSat dedicated to astronomical observations.
- NinjaSat launched on November 11, 2023, by SpaceX Transporter-9.
- NinjaSat is working normally in orbit and performing Scientific observations for seven targets.
- CubeSat is a **cost-effective way** to observe bright X-ray sources and **realize quickly**. We will launch 2<sup>nd</sup> and 3<sup>rd</sup> NinjaSat in the near future. Please let us know if you are interested.

**Thank you!**

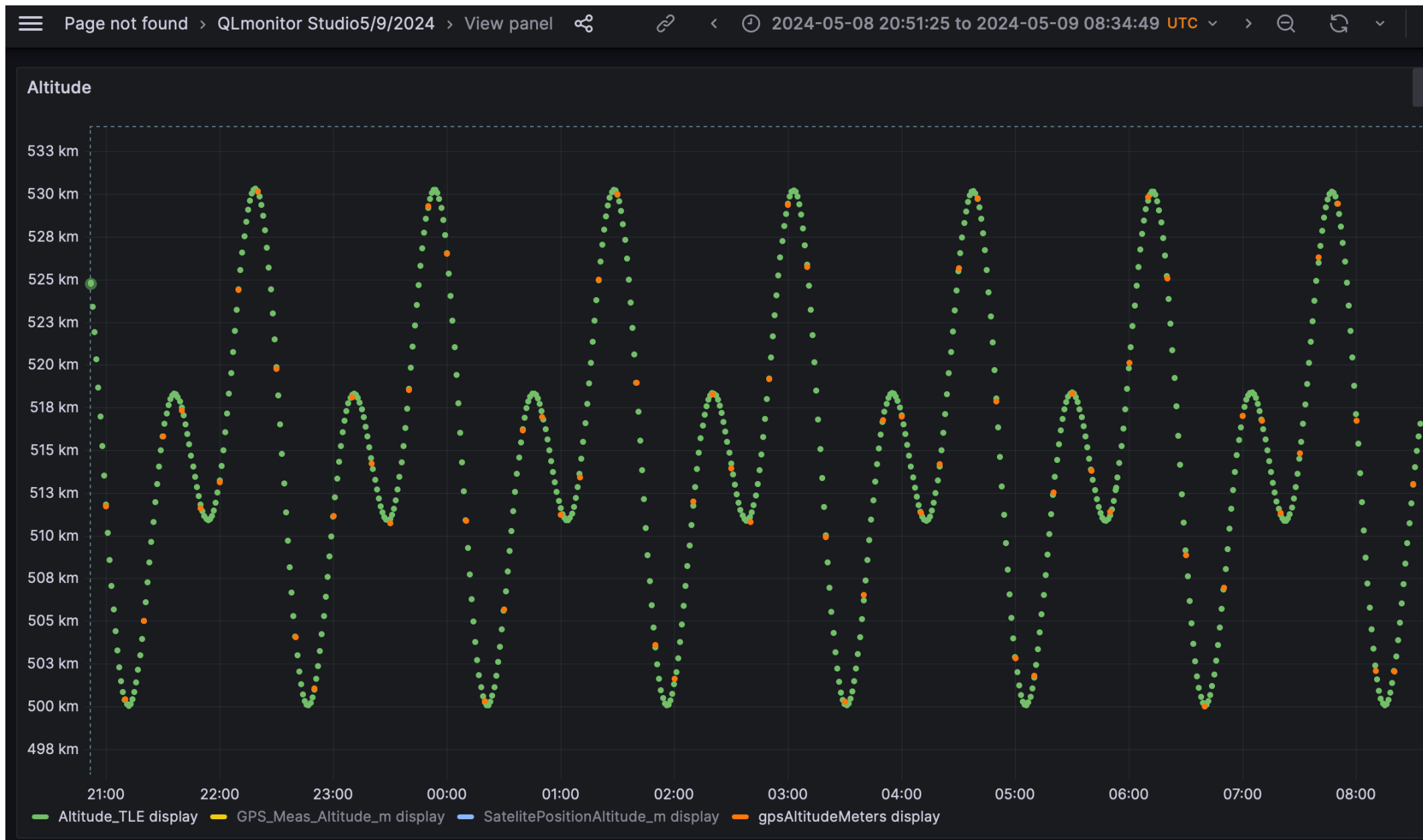




# Backup Slides

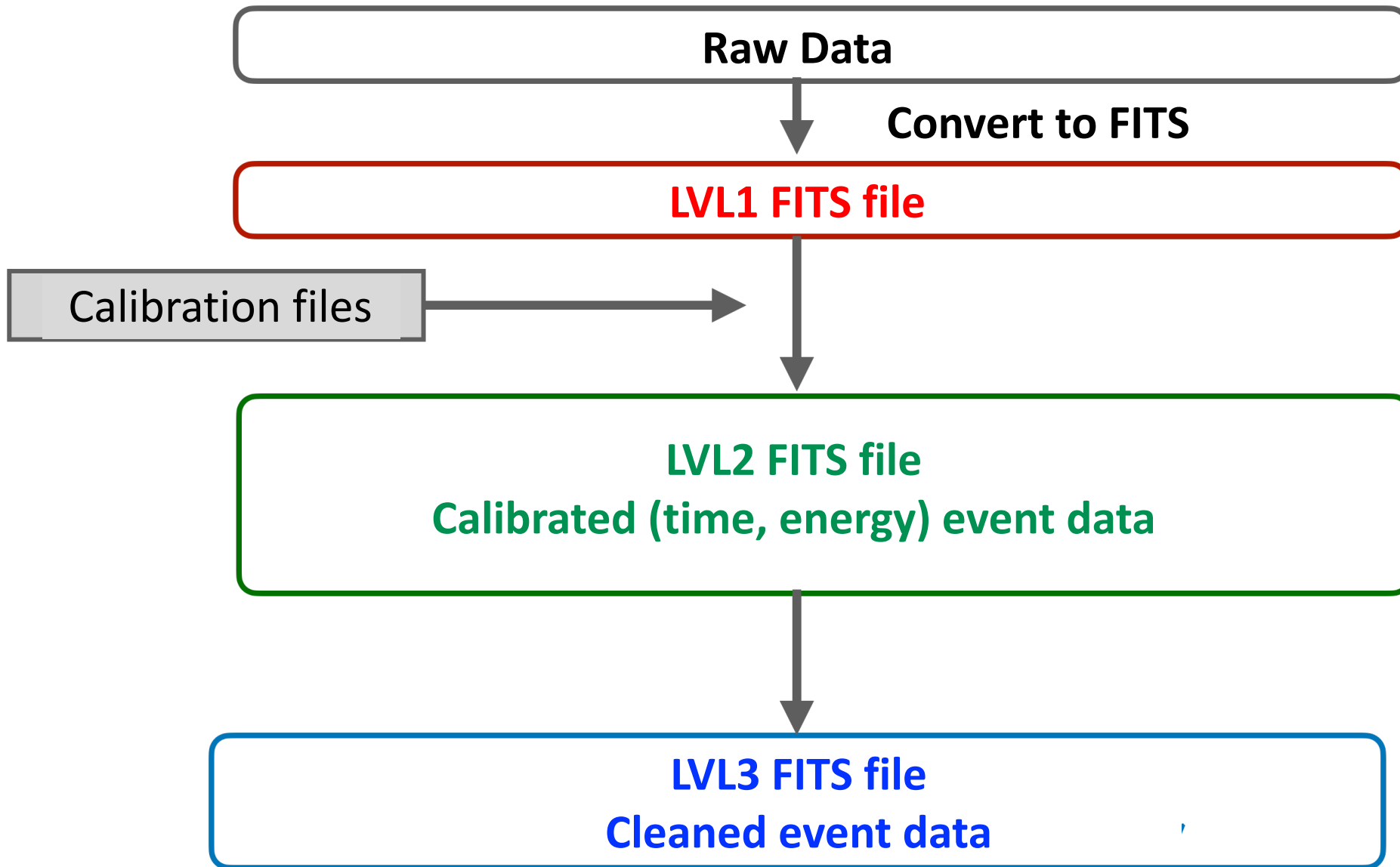


# True altitude at a given time





# Pipeline processes



# FEC & DAQ cards

