Recent In-orbit Results of GRID: a Student CubeSat Mission for Gamma-Ray Burst Observation

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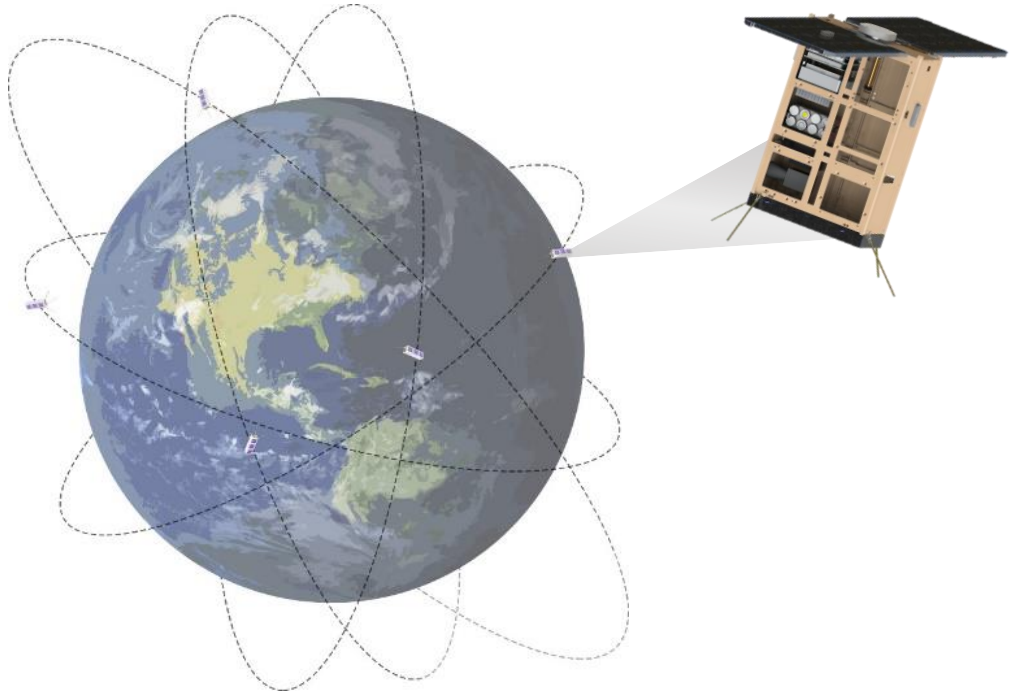
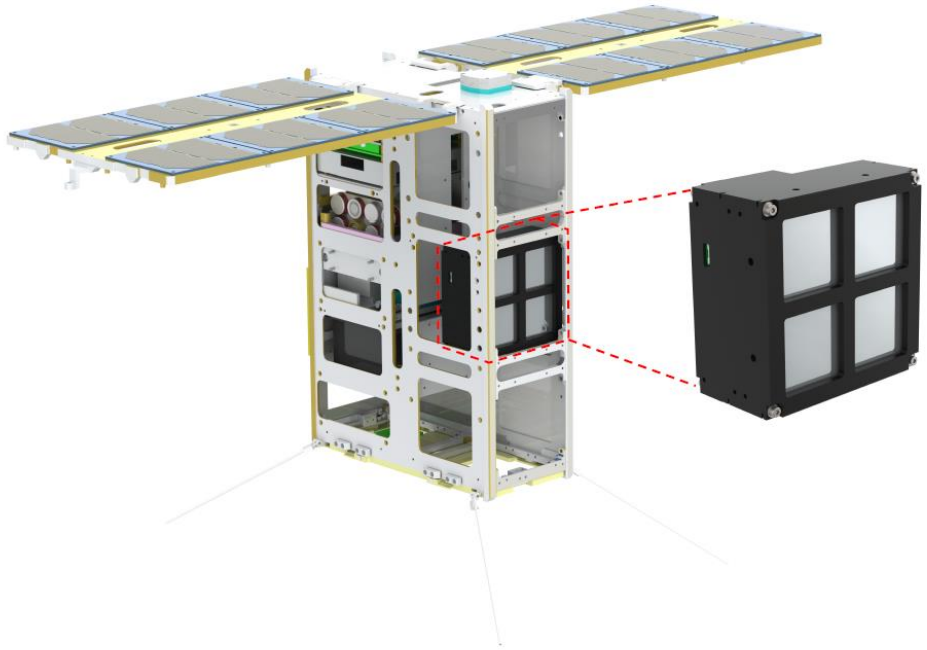
Tsinghua University, Beijing

The GRID Project and Detector



Gamma Ray Integrated Detectors (GRID) concept:

- 10 ~ 24 CubeSats scattered in low Earth orbits
- Compact gamma-ray detectors

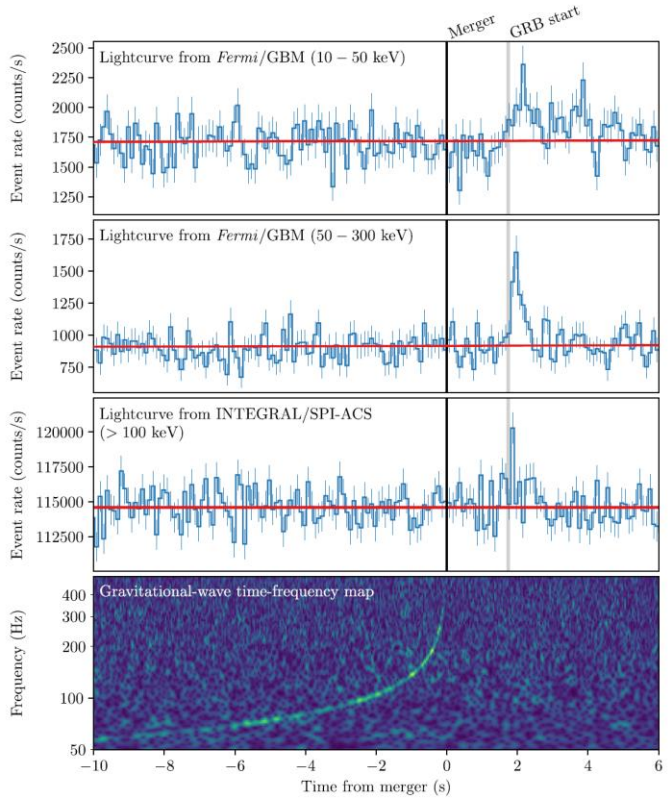


Schematic drawing of the 6U CubeSat developed by Spacety with the first GRID detector on it [2]

[2] Wen, J., Long, X., Zheng, X. *et al.* GRID: a student project to monitor the transient gamma-ray sky in the multi-messenger astronomy era. *Exp Astron* **48,** 77–95 (2019)

Scientific Goals

Joint, multi-messenger detection of GW170817 and GRB 170817A [1]



Detection of GRBs associated with future NS-NS mergers

- ✓ Confirmation of the EM counterparts
- ✓ Constrain the jet physics (structured vs. cocoon breakout)
- ✓ Possible improvement in position accuracy

Other gamma-ray transients

- ➢ Soft gamma-ray repeaters (SGRs)
- ➢ Magnetars
- ➢ Terrestrial gamma-ray flashes (TGFs)
- ➢ Terrestrial electron beams (TEBs)
- ➢ Solar flares
- ➢ Other high-energy transients

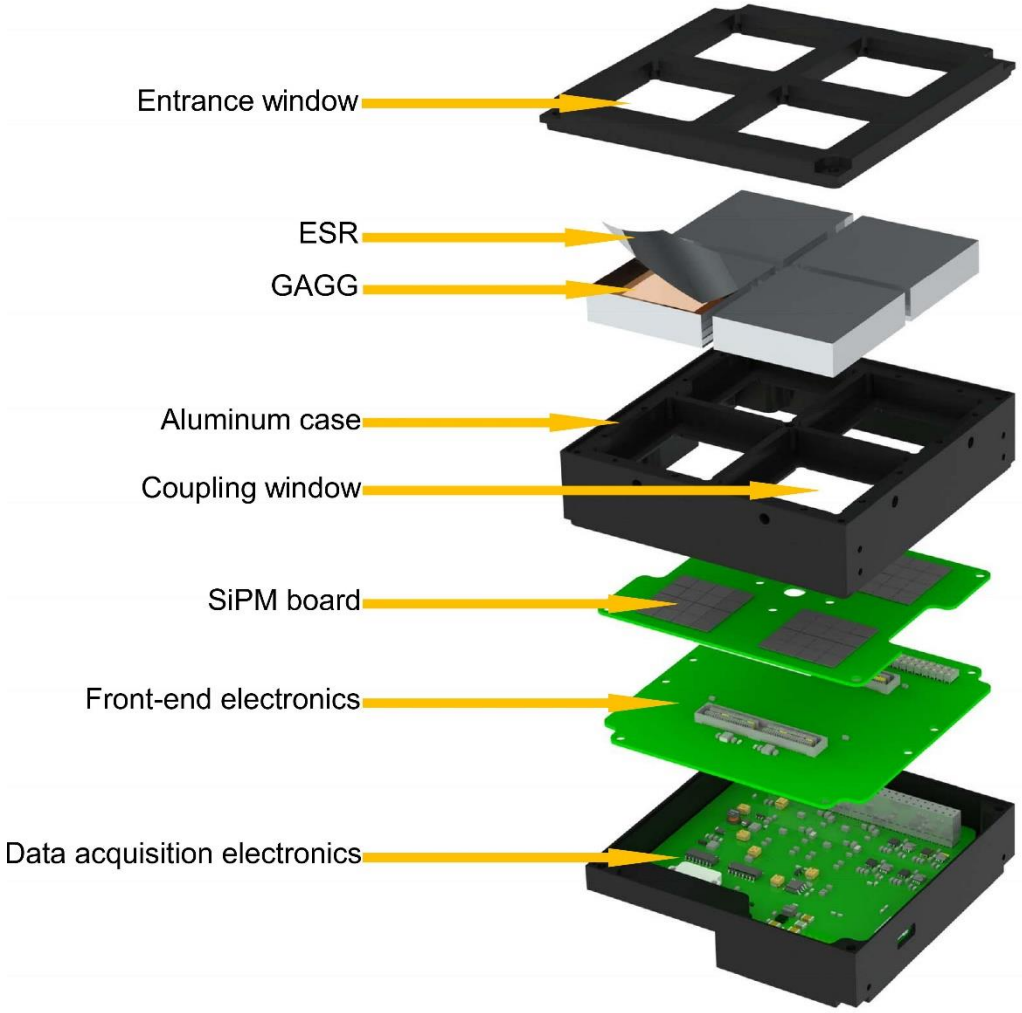
GRID: collect the first dozen GRBs associated with NS-NS mergers

[1] B. P. Abbott *et al* 2017 *ApJL* **848** L13

History of GRID since 2016

- The GRID concept was first proposed in October of 2016 by a group of undergraduate students, inspired by discussions with several professors.
- The first and second detector (GRID-01 & GRID-02) have been launched in 2018 and 2020 respectively.
- 25 universities and institutes in China have joined the GRID collaboration.

Instrument Design



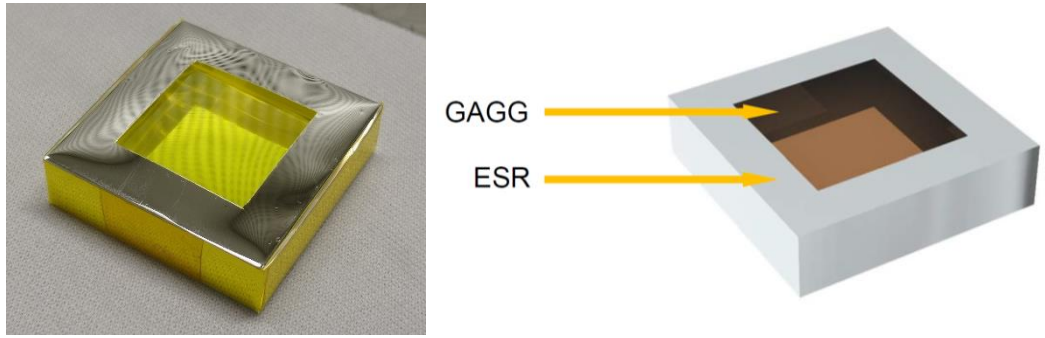
3D model of the GRID detector [3]

Specifications of GRID-02

Size	< 0.5U (9.4×9.4×5 cm^3)
Weight	~ 780 g
Power consumption	Typ. 2 W Max. 2.8 W
Geometric area	~ 58 cm^2
Field of view	2π
Energy range	Lower threshold < 15 keV Upper threshold ~ 2 MeV
Dead time	~ 20 us
Background count rate	Norm. ~ 2000 cps SAA > 8000 cps
Telemetry	~ 1 GB/day

[3] Wen, JX., Zheng, XT., Yu, JD. *et al.* Compact CubeSat Gamma-ray detector for GRID mission. *NUCL SCI TECH* **32,** 99 (2021)

GAGG:Ce Scintillator Crystal



Bottom view of a GAGG:Ce scintillator with the ESR package [3]

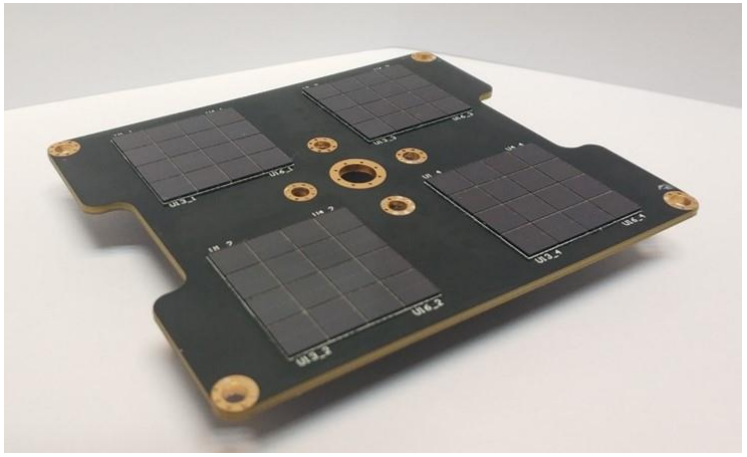
- Polished on all faces
- Wrapped with 65 μm Enhanced Specular Reflector (ESR) film
- 2.2 × 2.2 cm^2 window coupled with SiPM array

Crystal size	38×38×10 mm^3
Light yield	46000 ph/MeV
Density	6.63 g/cm^3
Effective Z	54
Energy resolution	6% @662 keV
Hygroscopic	No

Values from C&A Corporation

[3] Wen, JX., Zheng, XT., Yu, JD. *et al.* Compact CubeSat Gamma-ray detector for GRID mission. *NUCL SCI TECH* **32,** 99 (2021)

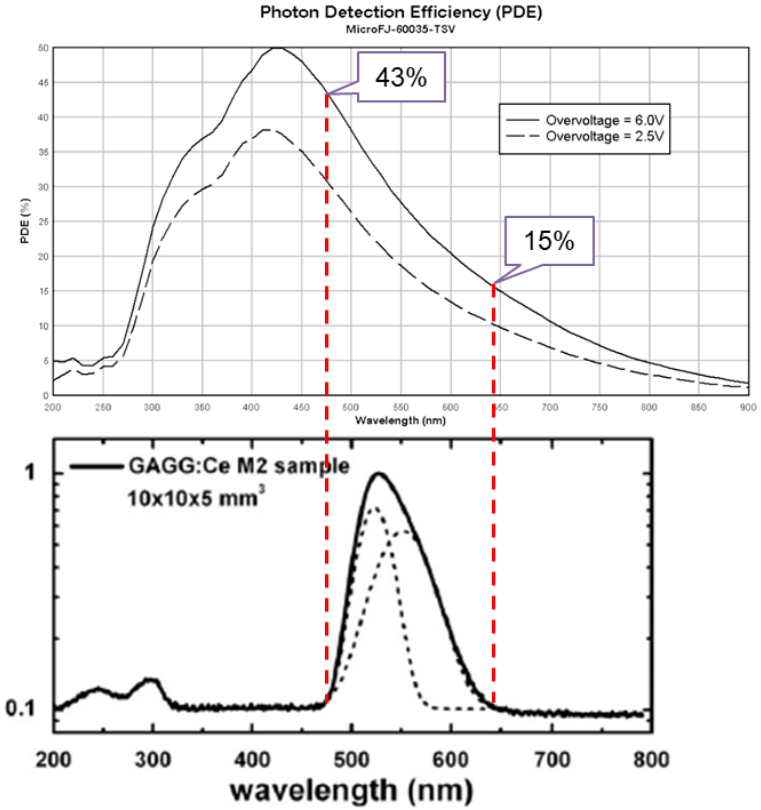
Silicon Photomultiplier



SensL MicroFJ-60035 SiPM chip (top) and the GRID SiPM array board (bottom)

Operation voltage **(No H.V. needed)**	~ 30 V
Photon detection efficiency	> 25%
Dark count rate	~ 150 kHz/mm^2
Temperature dependence of V_{br}	21.5 mV/℃

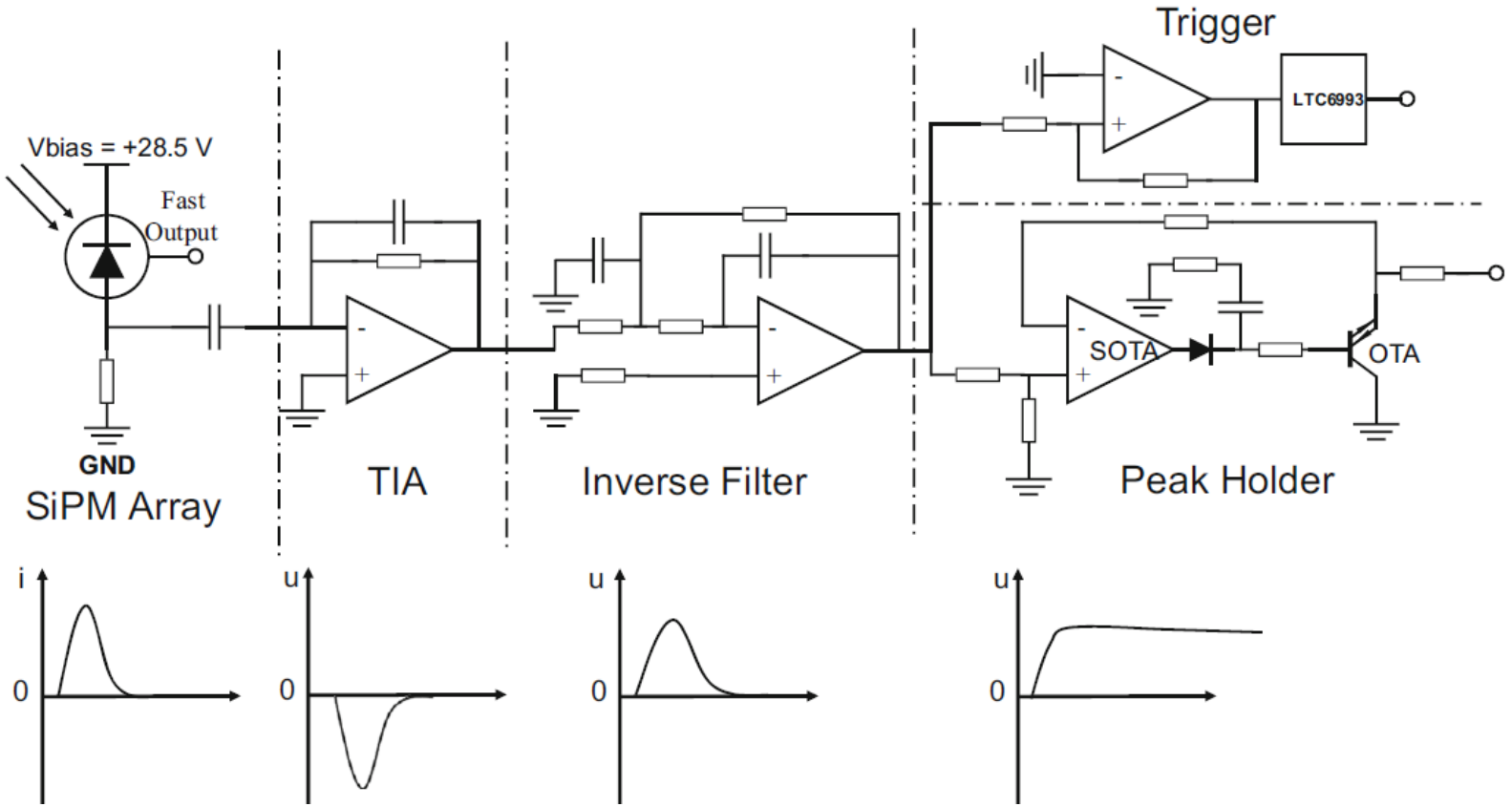
Gain is a function of temperature



Emission spectra of GAGG:Ce [4] compared with SiPM detection efficiency

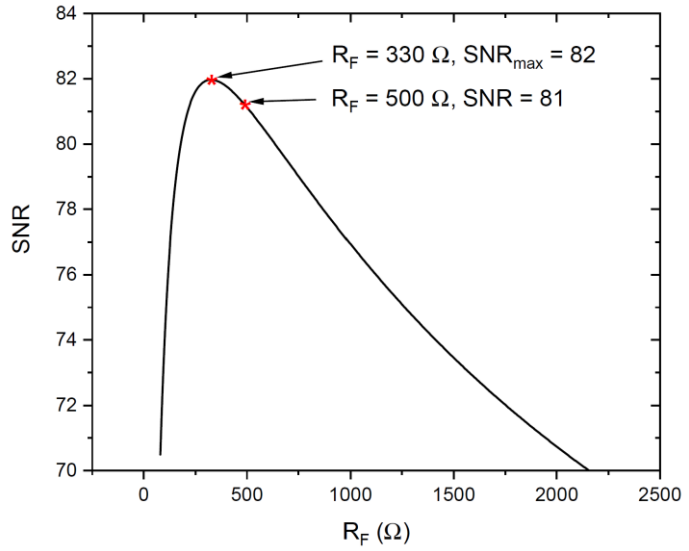
[4] J. Iwanowska et al., Performance of cerium-doped $Gd_3Al_2Ga_3O_{12}$ (GAGG) scintillator in gamma-ray spectrometry. *Nucl. Instrum. Methods Phys. Res. Sect. A.* **712**, 34–40 (2013)

Front-End Electronics



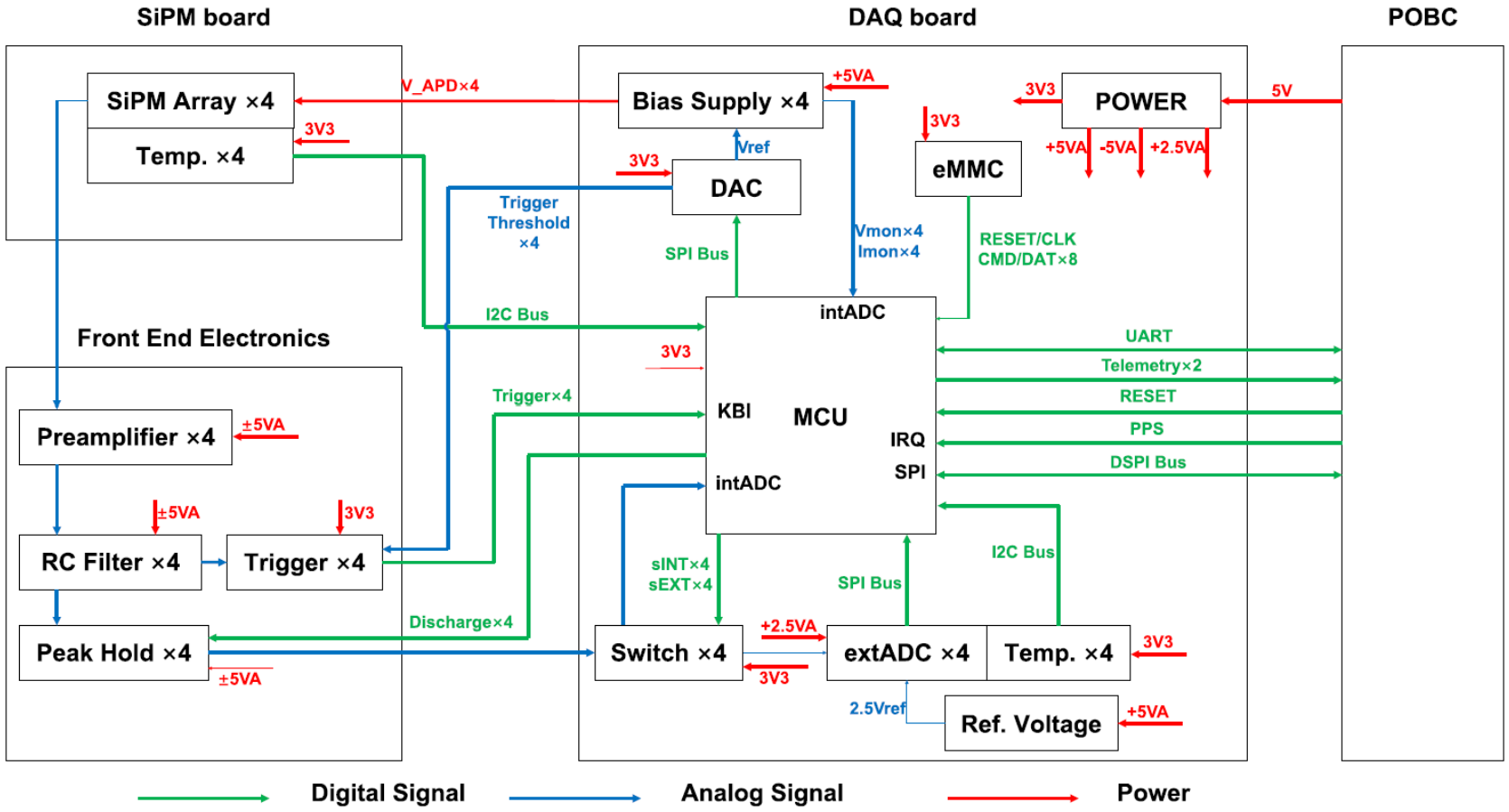
↑Schematic diagram and output pulse shape of the FEE [3]

SNR vs. R_F [3]



[3] Wen, JX., Zheng, XT., Yu, JD. *et al.* Compact CubeSat Gamma-ray detector for GRID mission. *NUCL SCI TECH* **32,** 99 (2021)

Data Acquisition Electronics

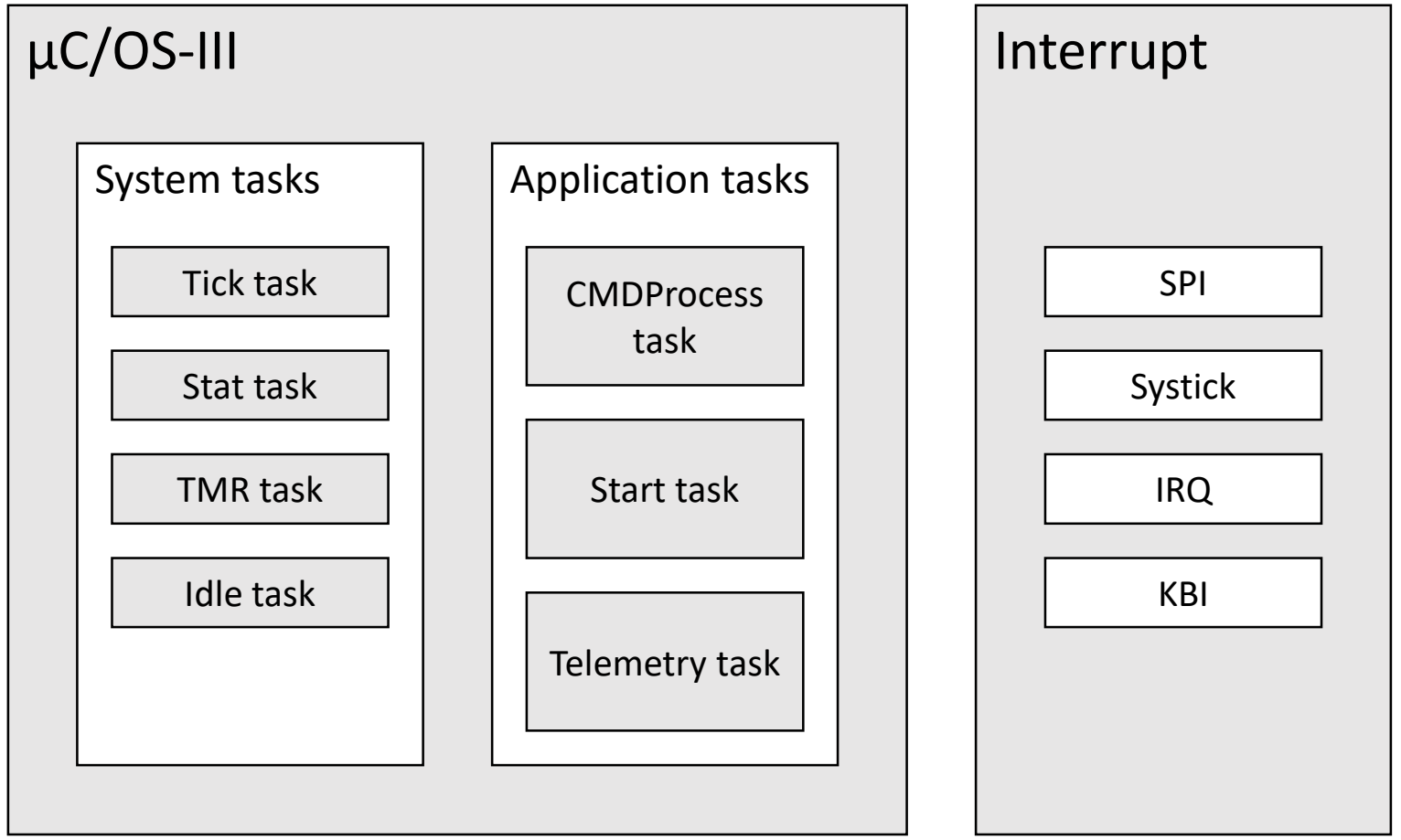


- ARM Cortex M0+ MCU
  - Automotive-grade
  - running at 40 MHz
  - low power consumption
- 16-bit 1MSPS external ADC
- eMMC data storage
  - 512 MB
  - SLC cell
- Advanced control functions
  - Adjustable SiPM bias supply
  - Charge injection module

Functional block diagram of DAQ and its connection with FEE, SiPM Carrier, and payload on-board computer board (POBC) [3]

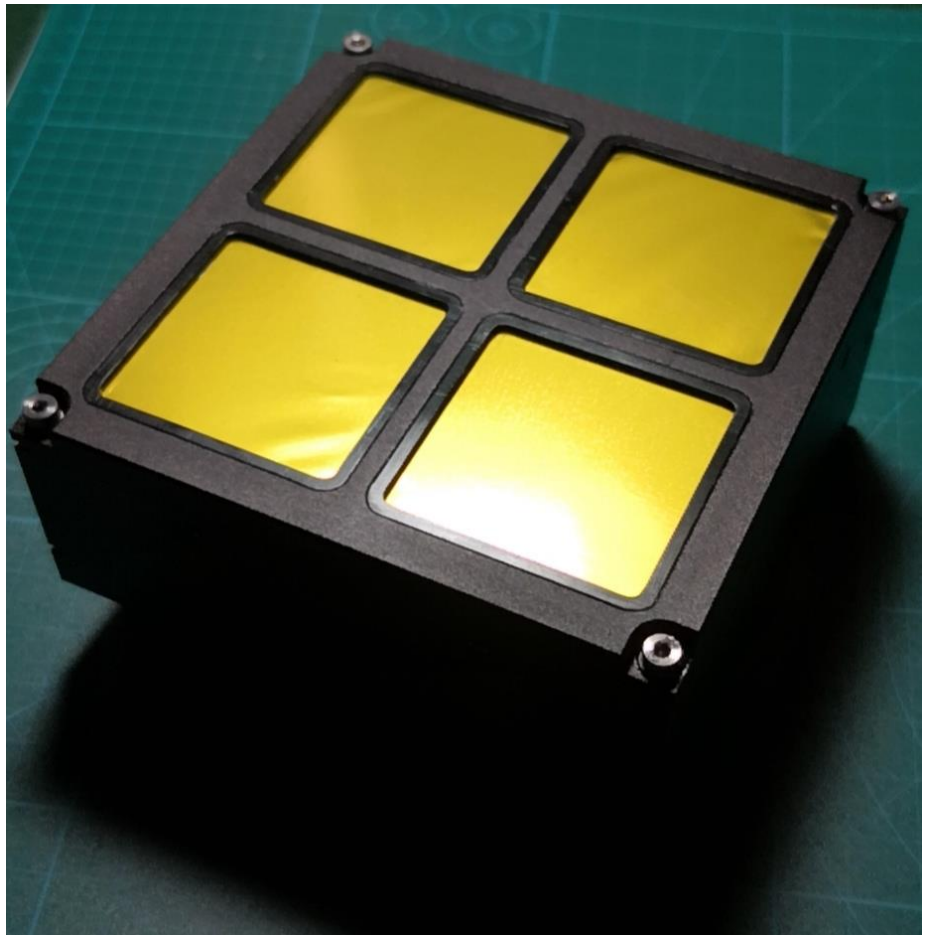
[3] Wen, JX., Zheng, XT., Yu, JD. *et al.* Compact CubeSat Gamma-ray detector for GRID mission. *NUCL SCI TECH* **32,** 99 (2021)

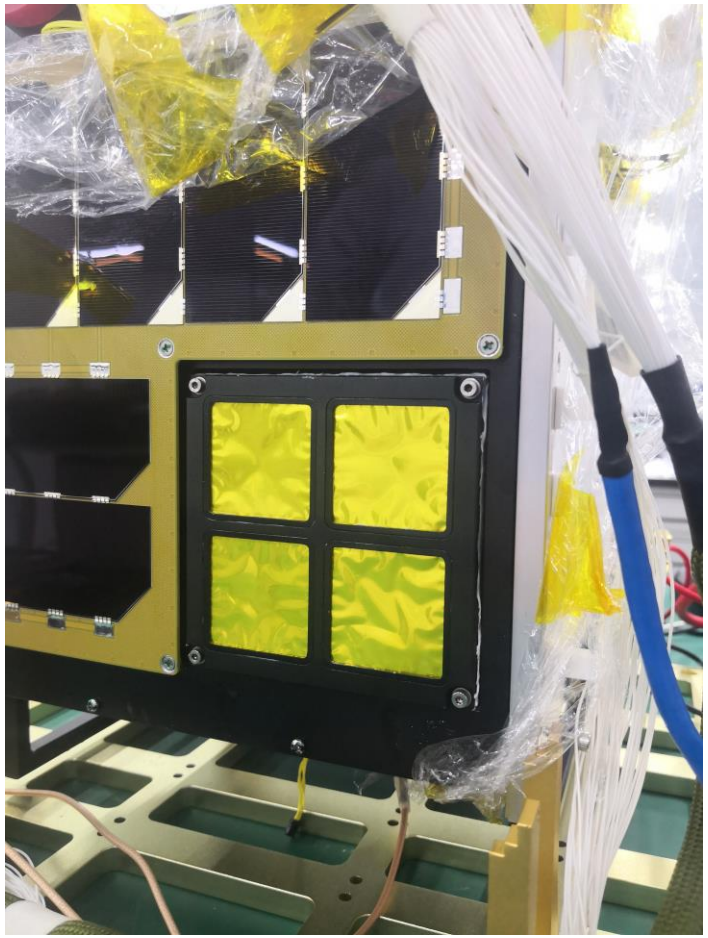
Firmware



- Multi-task firmware based on real-time operating system (µC/OS-III)
- Basic functions
  - Data acquisition, storage and transmission
  - Instruction control
- Monitor functions
  - SiPM bias & current monitor
  - Temperature sensor
  - Close-loop control of SiPM bias supply
- Extra verification functions
  - SiPM I-V measurement
  - Charge injection test

GRID-02 Flight Model





GRID-02 Launched on Nov. 6 2020

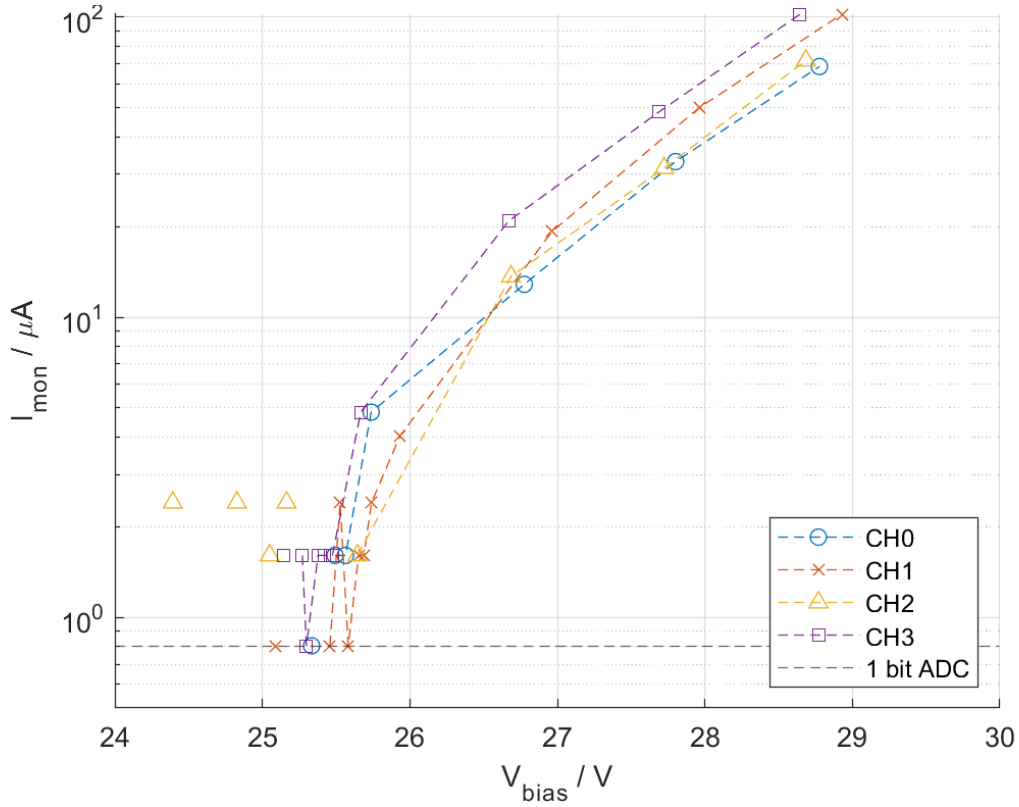
Designation

Spacetrack catalog number	46838
COSPAR ID	2020-079-M
Orbit	460×471 km, 97.2°
Country/organization of origin	China
Date (UTC)	06 November 2020 03:19
Launch site	Taiyuan Space Launch Center, China
Launch vehicle	Long March 6

Data from https://www.heavens-above.com/

Debug Phase (finished on Nov. 19 2020)

2020.11.06	Launched
2020.11.08	Payload power on ✓
2020.11.10 - 2020.11.11	Communication interface test ✓ Low bias test (about 20 V) ✓
2020.11.12 - 2020.11.13	UTC synchronization test ✓ Data transmission test ✓
2020.11.14	Normal bias test (about 28 V) ✓ Charge injection test ✗ (bias shift)
2020.11.15 - 2020.11.18	Charge injection test ✓
2020.11.19	Current - Voltage curve scan ✓ Charge injection test ✓ **Observation** ✓



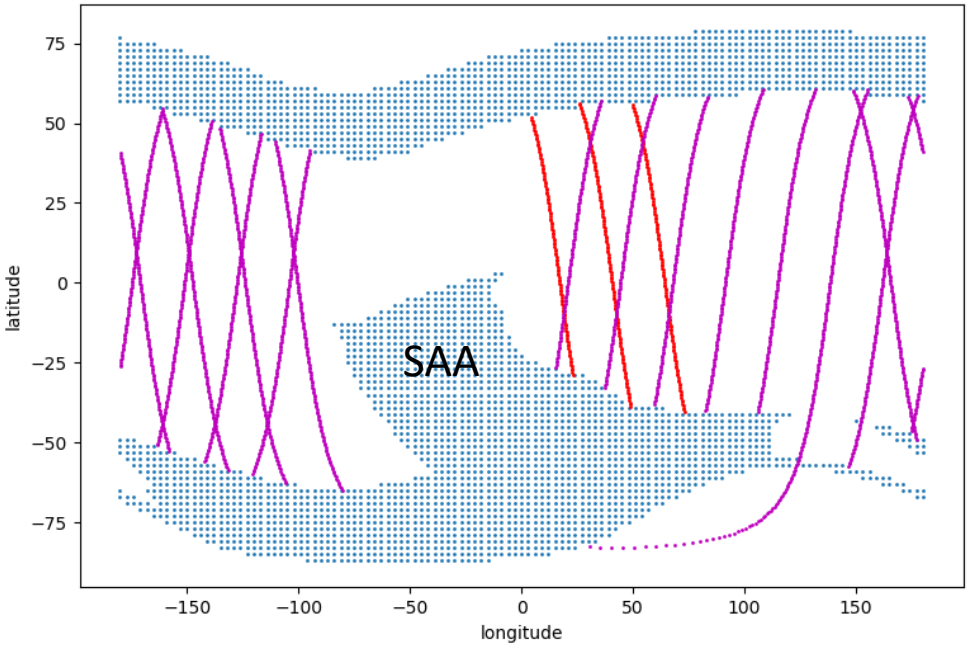
I-V measurement result on Nov. 19, 2020

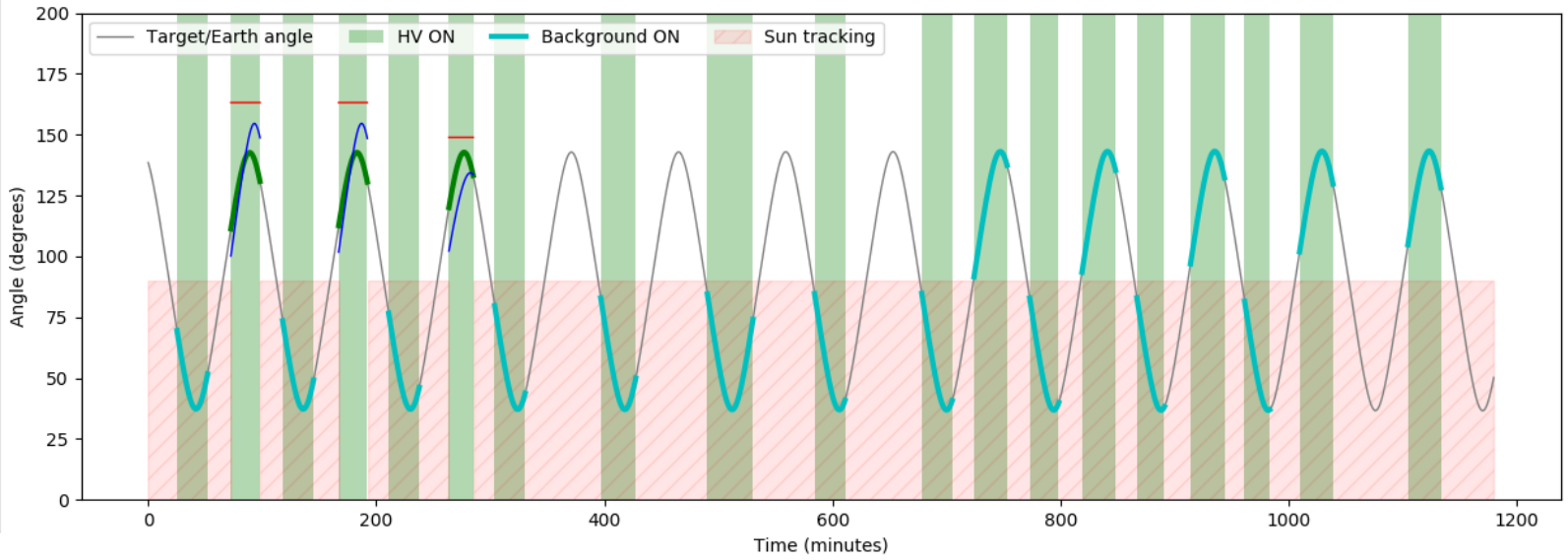
Daily Observation Phase

- Undergraduate students on duty make observation plan every day
- 10 ~ 20 observations per day, 20 ~ 40 minutes each (depends on other payloads and CubeSat platform)
- Shutdown in South Atlantic Anomaly (SAA) and high-latitude region

✓ Targeting observation: point to Crab (Inertial pointing mode)

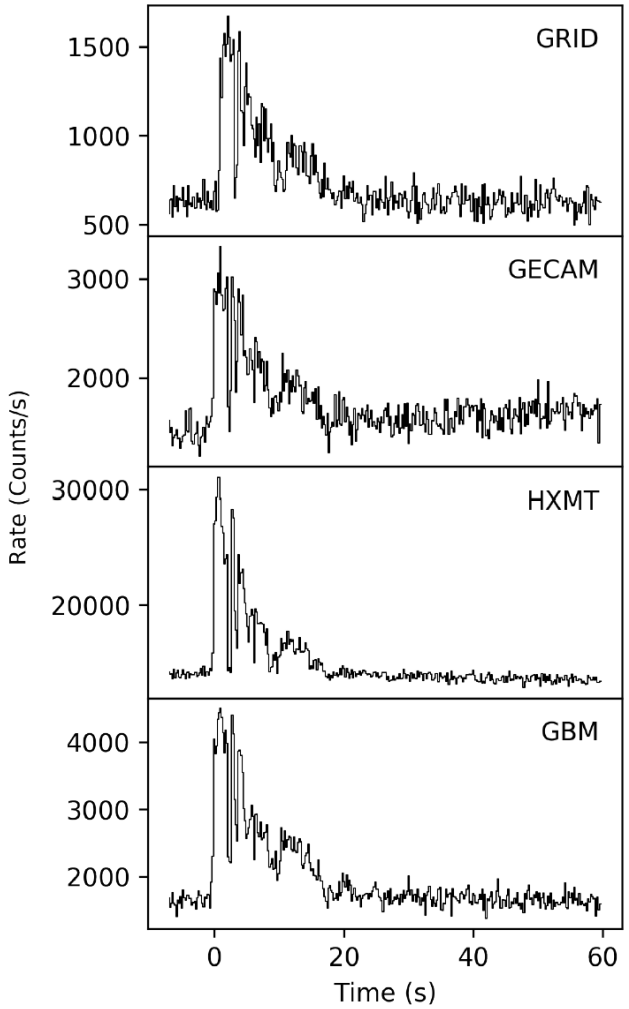
✓ Non-targeting observation: random orientation (Inertial or magnetic sun tracking mode)





Example observation plan during Nov. 29 2020 17:00 ~ Nov. 30 2020 12:30 (UTC)

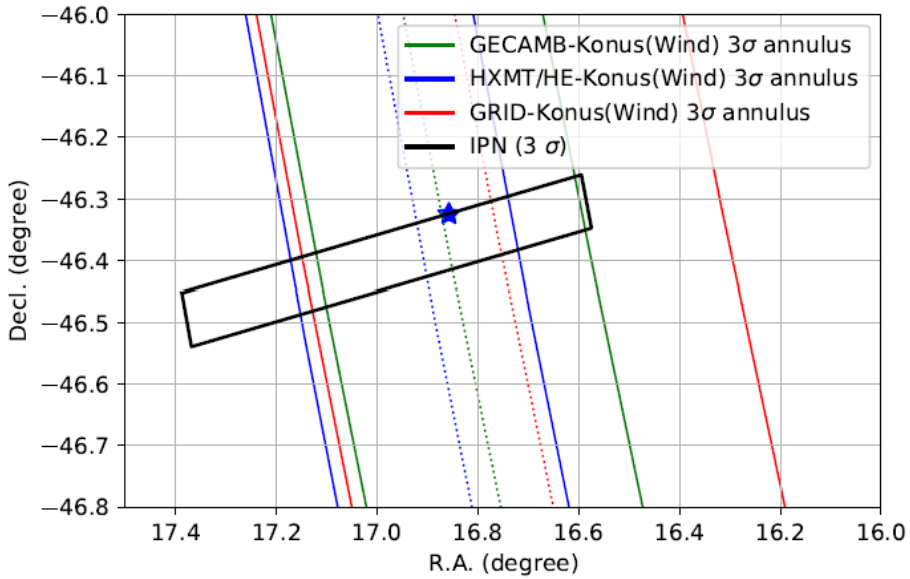
GRB 210121A: GRID Detection

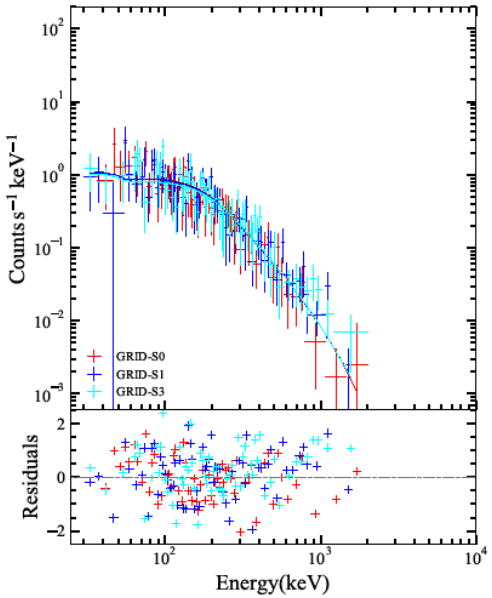


A joint detection of short GRB by GRID and other missions
More data release on China's National Space Science Data Center

←Light curves of the four missions [5]

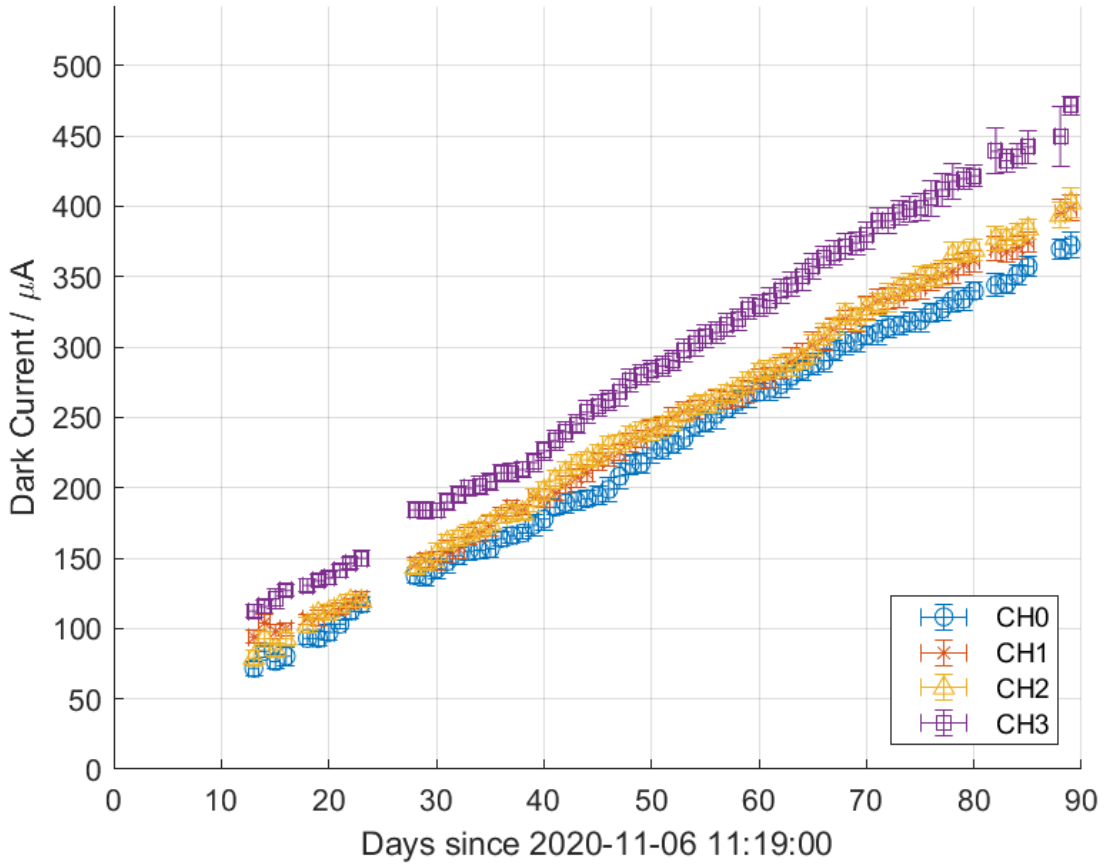
↓Localization of GRB 210121A [5]



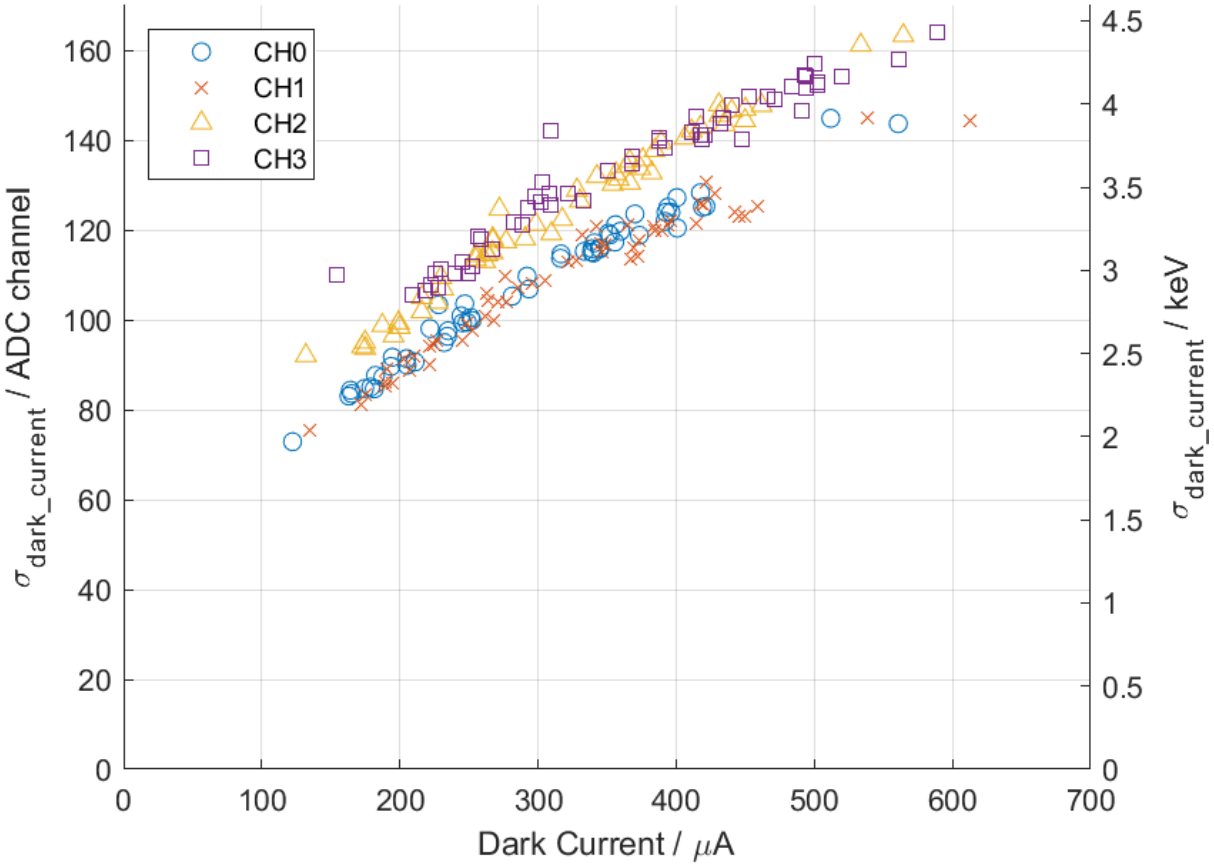


[5] X. I. Wang, X. Zheng, S. Xiao, et al., GRB 210121A: A Typical Fireball Burst Detected by Two Small Missions, ApJ 922, 237 (2021).
[6] H. Gao, D. Yang, J. Wen, et al., *On-Ground Calibrations of the GRID-02 Gamma-Ray Detector*, Exp Astron (2021).

In-orbit Radiation Damage Characterization of SiPMs



Dark current increasing rate:
~ 93/96/98/110 μA / (year · piece) @5 ℃ & 28.5V bias



Noise (sigma) increasing rate: ~ 7.5 keV / year

The GRID Collaboration

The 1st and 2nd GRID collaboration meeting

- Started since 2016 October at Tsinghua
- More than 100 Students from 17 universities have joined the GRID collaboration by now

Open source framework

✓ Fix the design with 1-2 launches

✓ 100% open to member institutes

✓ Member institutes can build their own detector/ground station/satellite

Conclusion

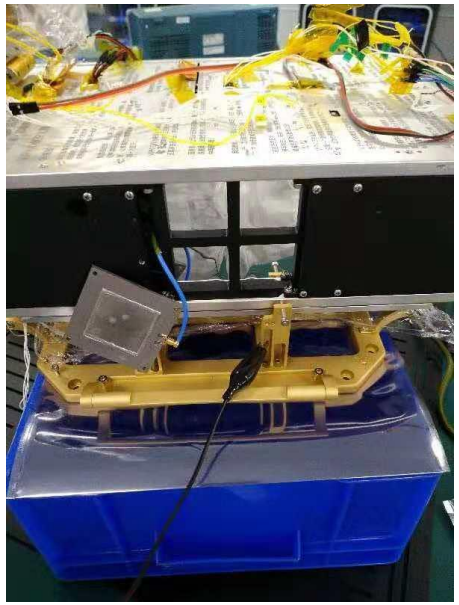
- GRID is a student CubeSat mission for gamma-ray burst observation.
- Two CubeSats equipped with GRID detector have been launched in 2018 and 2020 respectively.
- GRID have observed its first dozen of GRBs. Close cooperation between GRID and other GRB missions (e.g. GECAM) is established.
- Several universities in China have joined the GRID collaboration. More detectors will be ready for launch in 2022.

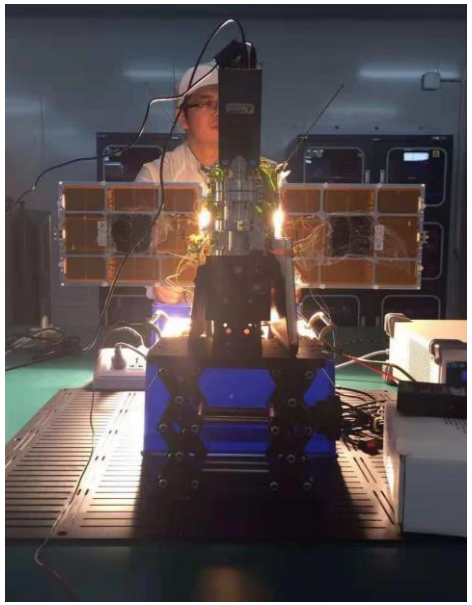
Thanks for your attention

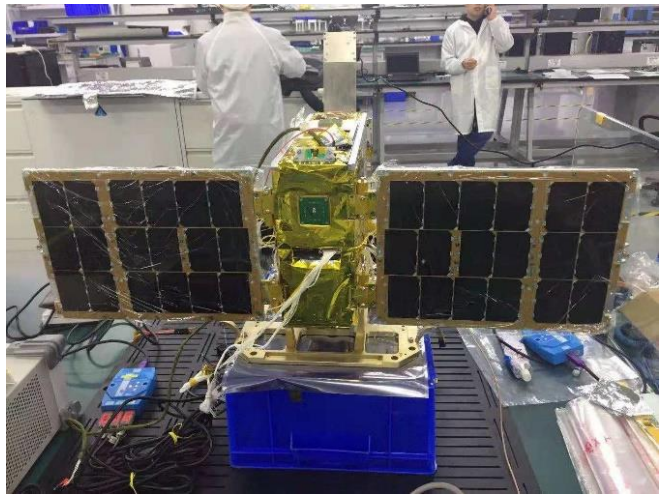
Acknowledgement:

This work was supported by the Tsinghua University Initiative Scientific Research Program.

GRID-01 Flight Model







GRID-01 Launched on Oct. 29 2018

Designation

Spacetrack catalog number	43663
COSPAR ID	2018-083-B
Orbit	509×524 km, 97.5°
Country/organization of origin	China
Date (UTC)	29 October 2018 00:43
Launch site	Jiuquan Satellite Launch Center, China
Launch vehicle	Chang Zheng 2C