



THU Gamma Ray
Integrated Detectors

GRID 天格计划

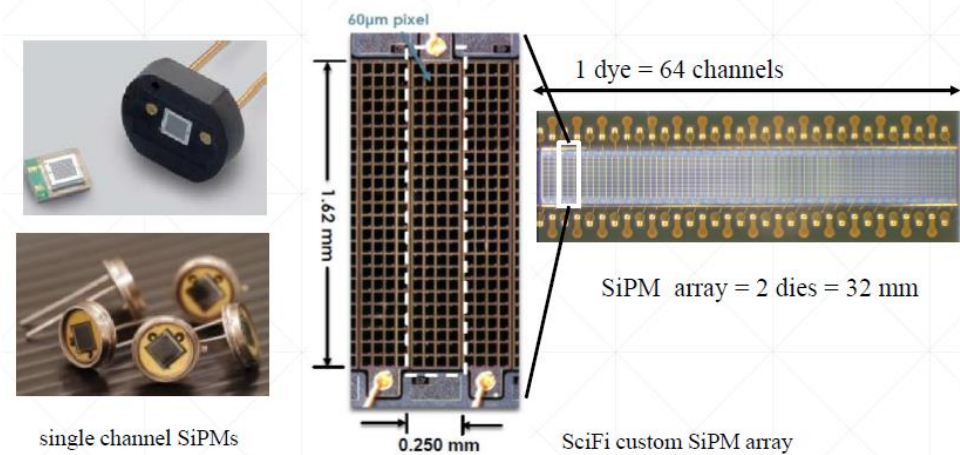
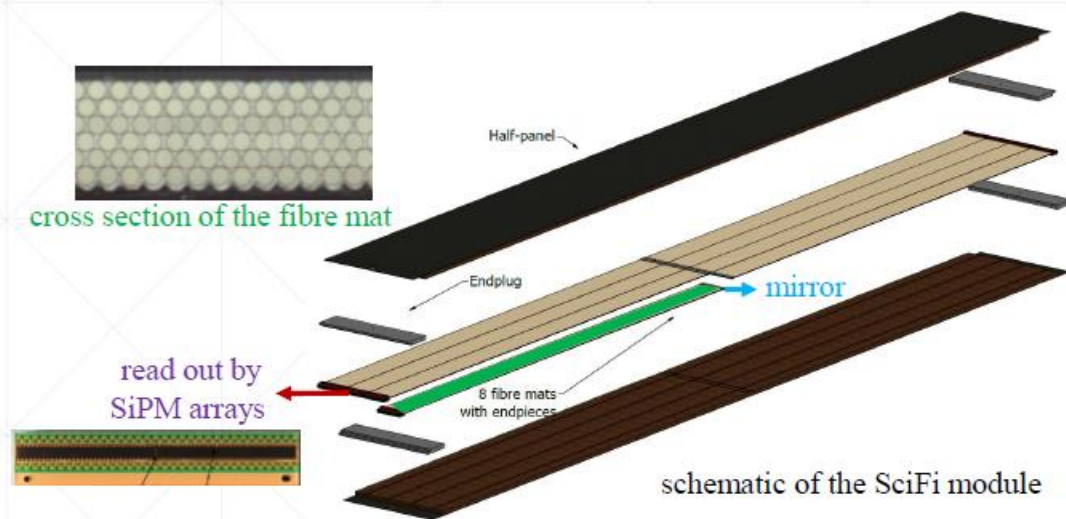
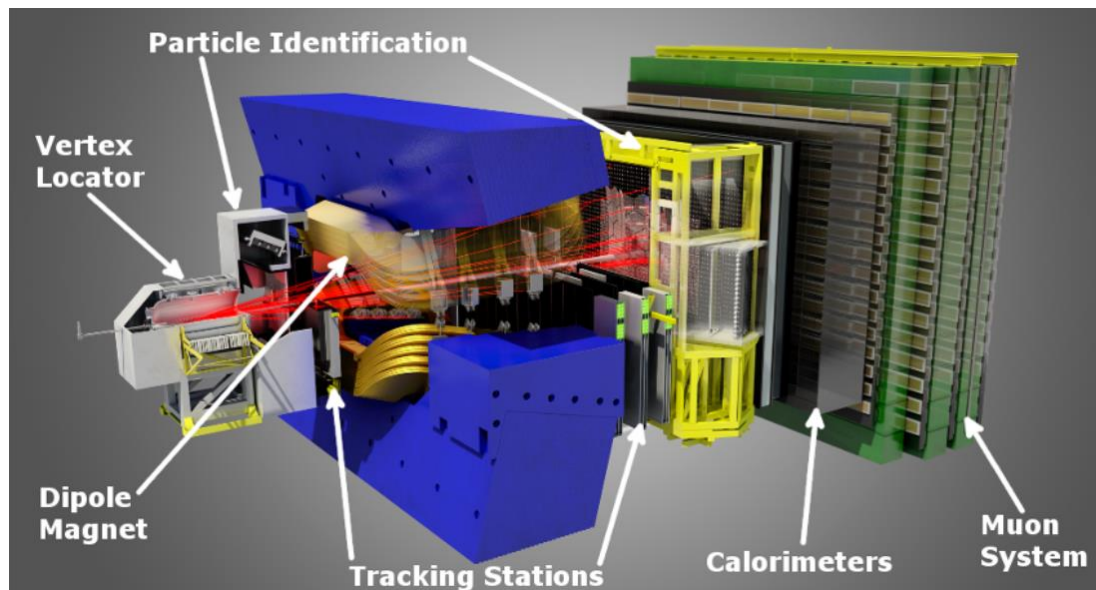
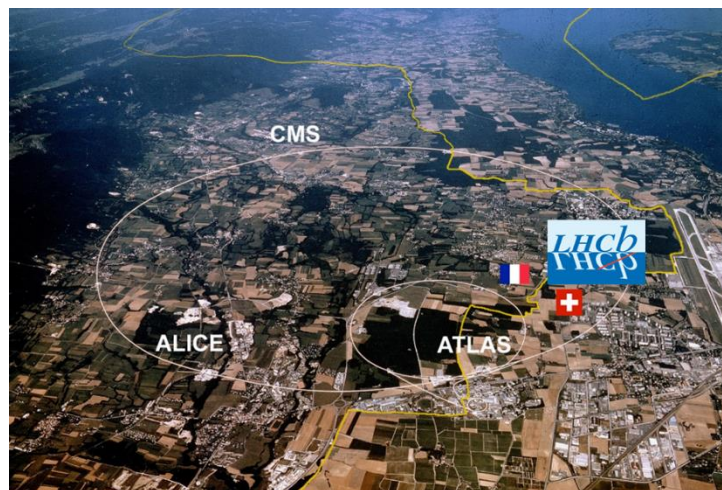
——微纳卫星空间探测技术

清华大学 曾鸣
2022年11月

第二十届全国核电子学与核探测技术学术年会



科与教如何融合?



524,000通道SiPM信号读出, 实现100µm粒子径迹探测

让学生更有兴趣学习核电子学与探测器?



核辐射物理及探测学
Nuclear Radiation Physics and Detection
Department of Engineering Physics, Tsinghua University

发现一门好课：核辐射物理及探测...
清华大学



张智 杨伟罡 等



长按识别看课程



ARM微控制与嵌入式系统
国家精品在线开放课程
清华大学 本科生课程 “数字电路与嵌入式系统”
清华大学 工程物理系 曾鸣

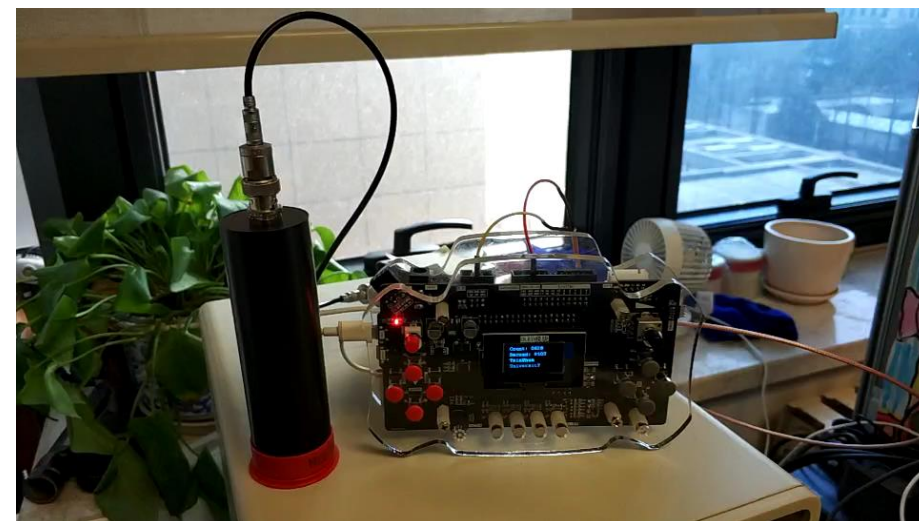
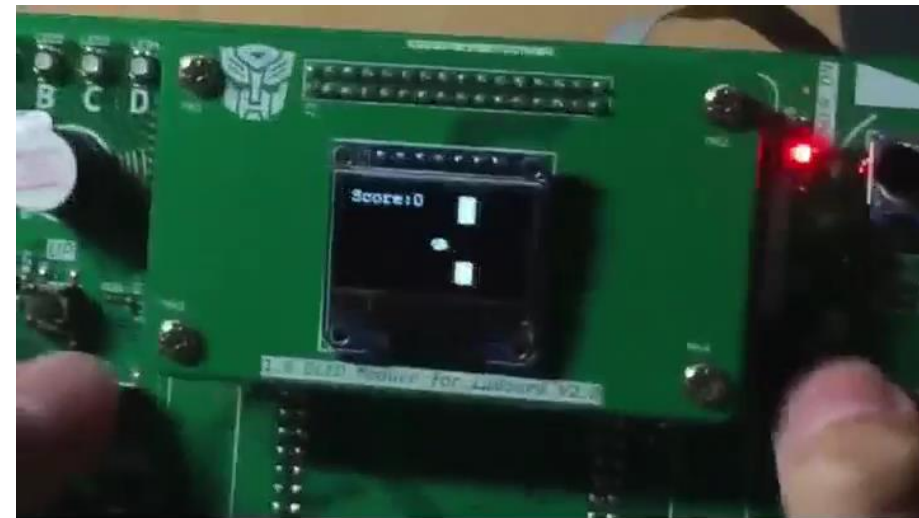
发现一门好课：ARM微控制器与嵌...
清华大学



曾鸣 薛涛 等

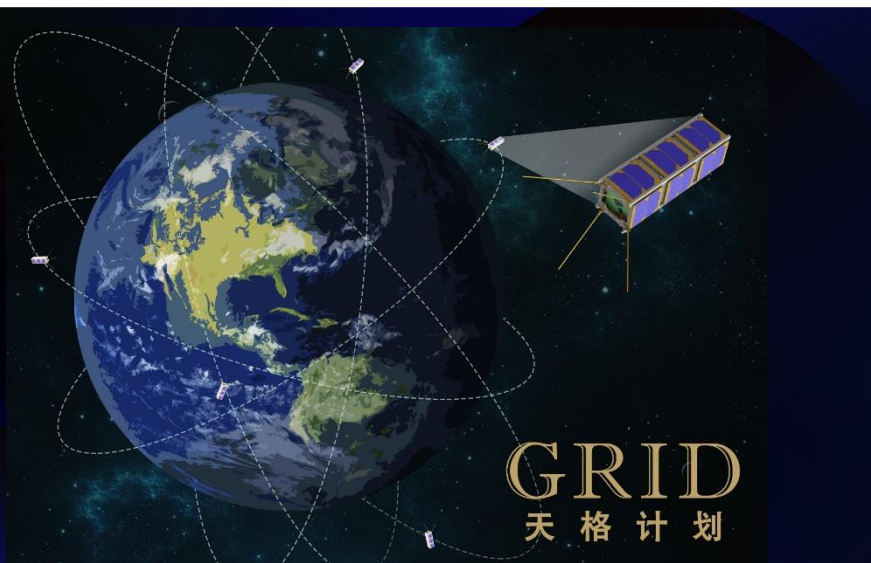


长按识别看课程



清华工物系的两门“国家级一流本科课程”

“天格计划” —— 科教融合 探索人才培养



Gamma Ray Integrated Detectors (GRID)

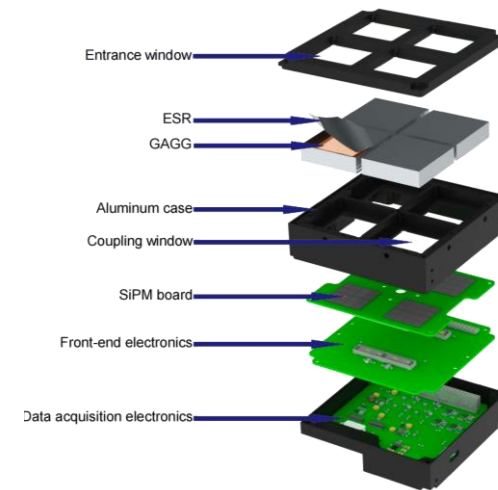
科学目标：寻找与引力波或快速射电暴成协的伽马射线暴 (GRB)

技术路线：微纳卫星搭载紧凑型空间伽马射线探测器、多星组网

“天格计划” 是一个以学生为主体的、面向基础科学前沿的科研实践项目，也是一个理工学科交叉的基础科学人才培养项目。

“前沿驱动、学科交叉”

“学生主体、立足培养”



天格计划：“追光少年”



追光少年
人民日报 6月7日

00:01 / 08:00 倍速

根据清华大学“天格计划”真实故事改编

观看 10万+

分享 收藏 赞 2229 在看 3.1万

2020年，清华大学招生宣传片“追光少年”

以“天格计划”作为原型改编

人民日报、新华网等转载

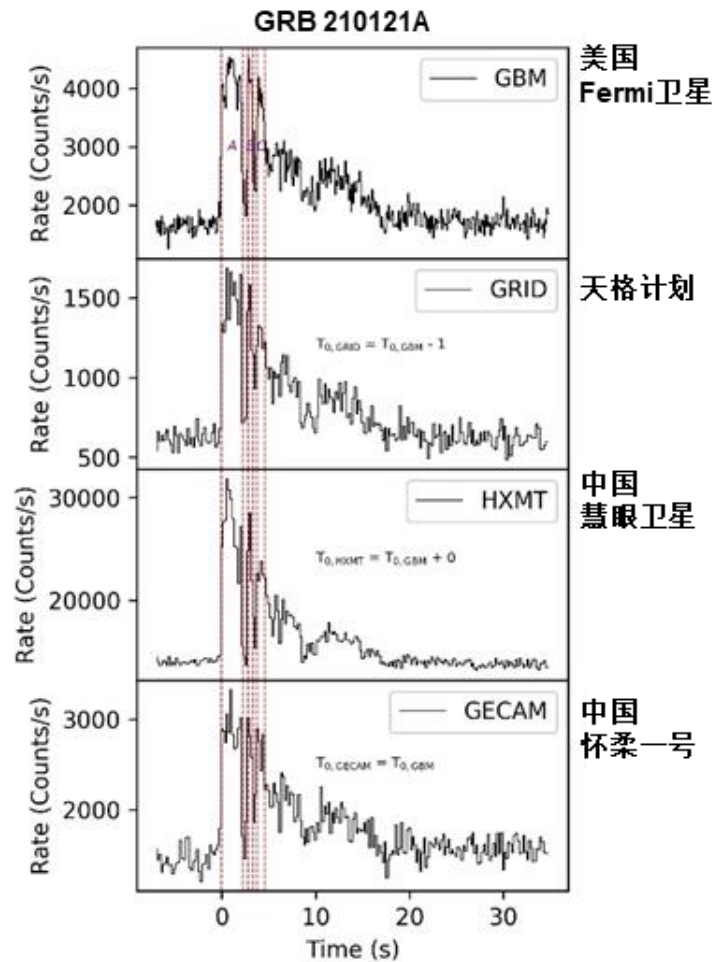
“拼尽全力、绝不言弃”

鼓舞2020年不平凡的考生们

立志核科学、天文系、航空航天.....

天道酬勤、格物致知

“天格计划” 科学结果

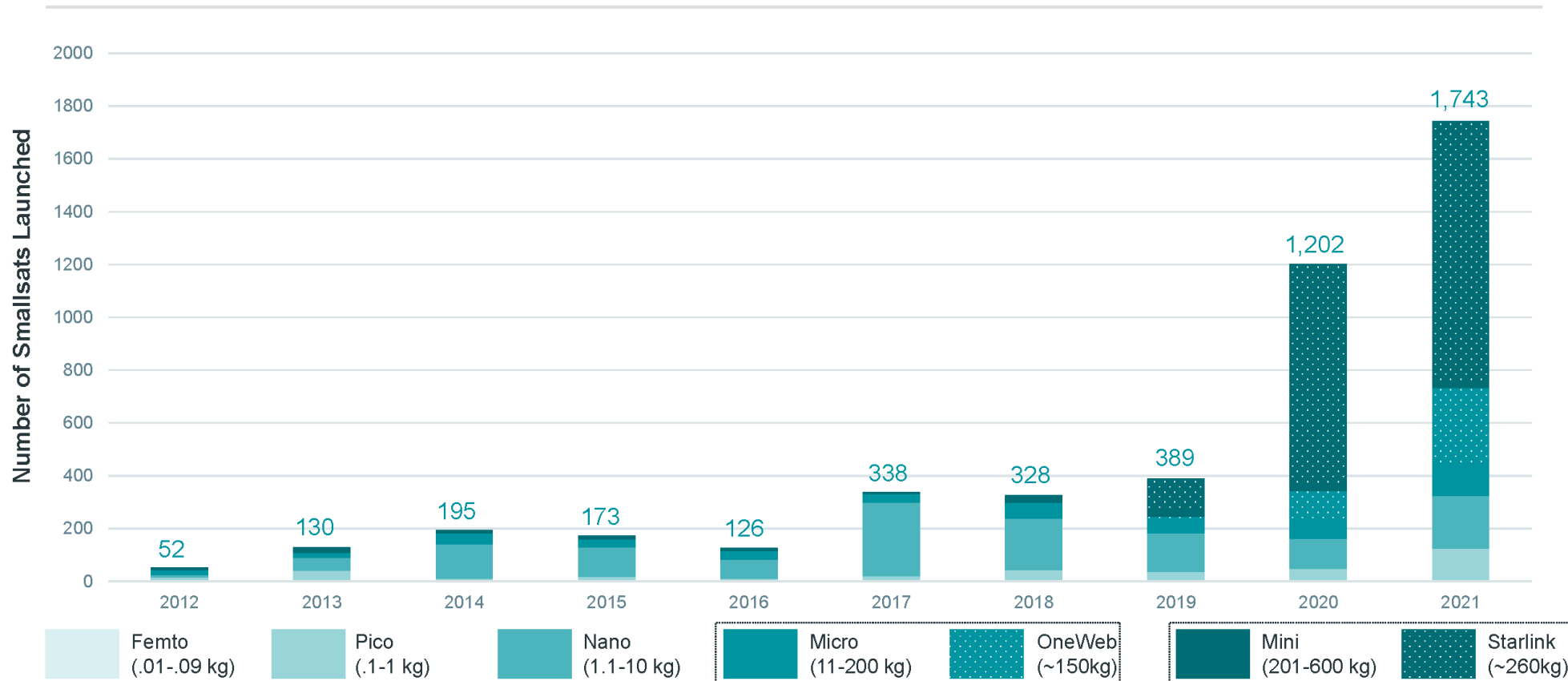


- “天格计划” 是国际上同类微纳卫星伽马暴探测项目中，第一个成功发射实现在轨科学观测的；也是其中唯一学生主力的项目
- GRB 210121A是国际上首例由纳卫星伽马暴探测器探测到、取得科学发现和论文发表的伽马暴事例，**
- 《The Astrophysical Journal》 (IF 5.877)
- 科学数据正式汇交 国家空间科学数据中心，将向科学界开放共享，首批数据包含几十个伽马暴事例

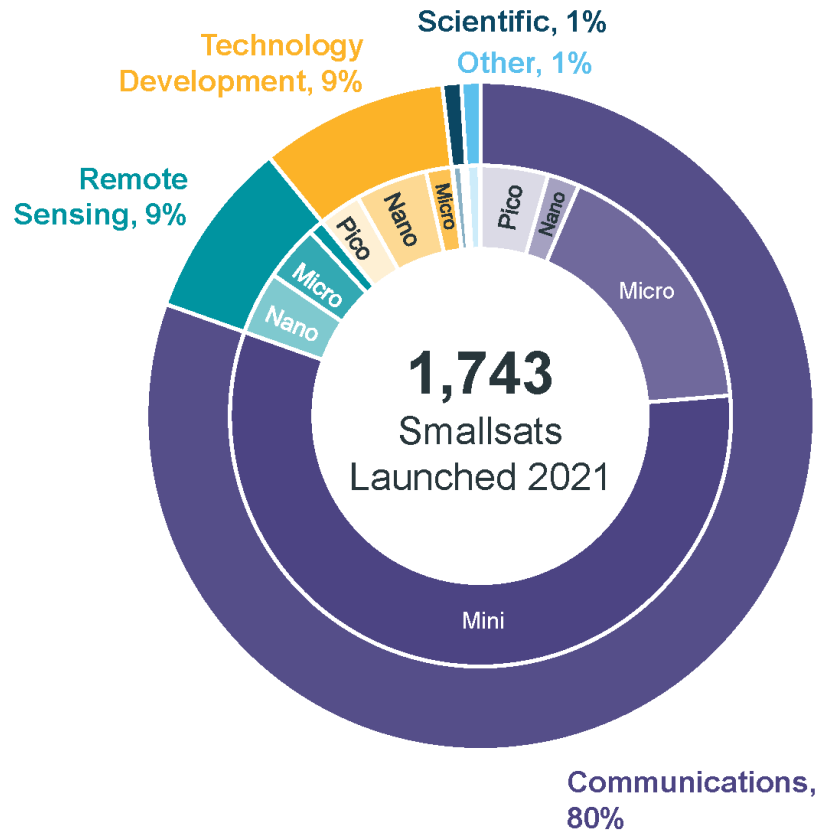
| 名称 | 发起单位 | 发起时间 | 发射时间 |
|-----------|------------|------|--|
| BurstCube | 美国NASA | 2017 | 未发射, 计划2022年初 |
| Moonbeam | 美国NASA | 2018 | 未发射, 待定 |
| GRID天格计划 | 中国清华大学 | 2016 | 2018年10月 (一号星) 2020年11月 (二号星) 2022年2月 (三号星) (四号星) |
| CAMELOT | 匈牙利/日本大学合作 | 2018 | 2021年3月22日 |
| HERMES | 意大利INAF | 2016 | 未发射, 计划2022年末 |
| EIRSAT | 爱尔兰都柏林大学 | 2016 | 未发射, 待定 |
| SkyHopper | 澳大利亚墨尔本大学 | 2018 | 未发射, 待定 |

Smallsats 2012 – 2021, by Mass Class, Starlink and OneWeb Breakout

Smallsats in Context and Operator/Mission Type Trends



2021 Smallsat Highlights



94% of spacecraft launched in 2021 = smallsats

43% of total 2021 spacecraft upmass = smallsats

37% of all smallsats in last 10 years launched in 2021 (69% 2020+2021)

80 launches in 2021 carried smallsats

6% of smallsats launched on small/micro launch vehicles in 2021



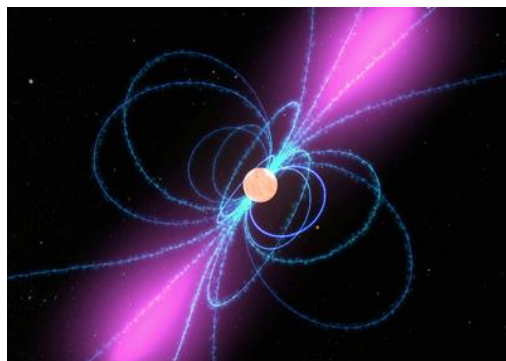
THU Gamma Ray
Integrated Detectors

Polarlight 极光计划

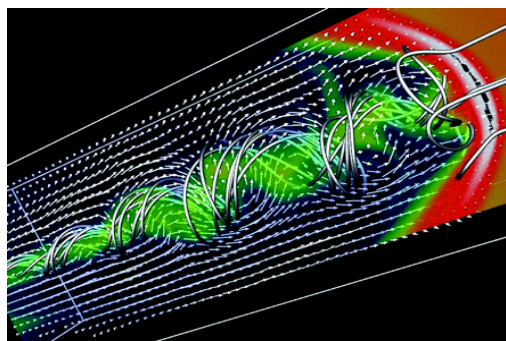


“极光计划” – X射线偏振探测

中子星与脉冲星



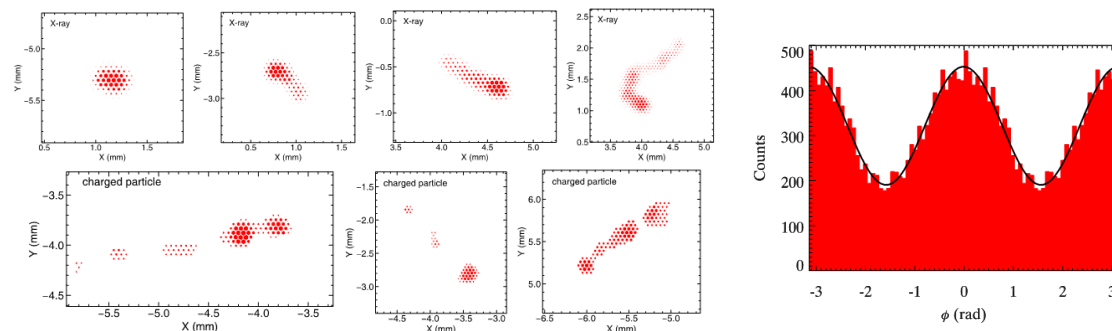
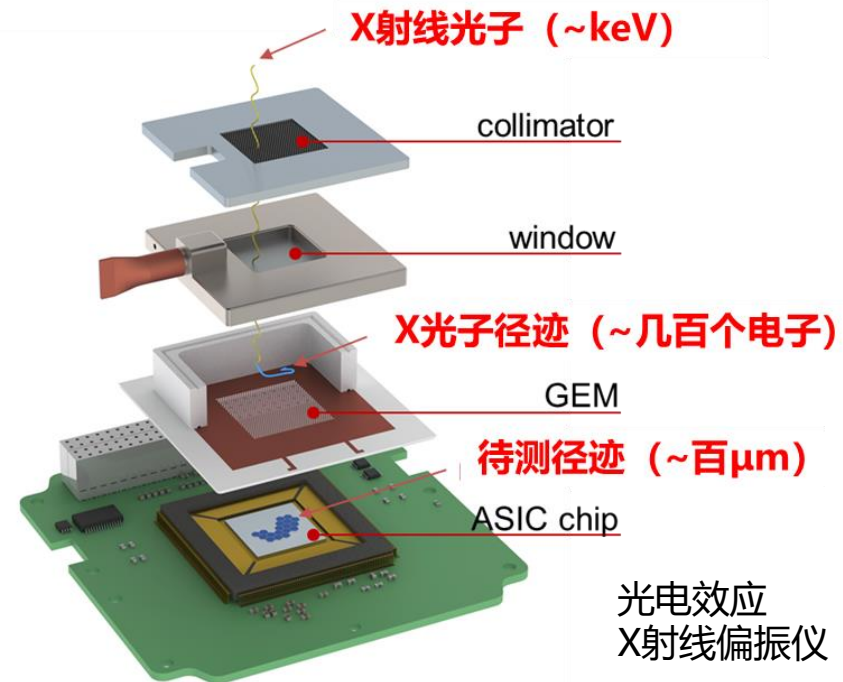
相对论喷流



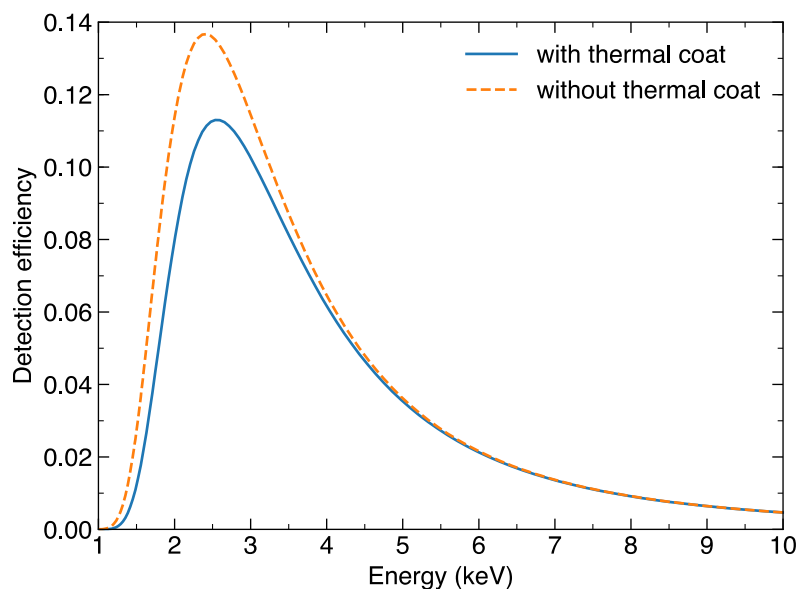
X射线的偏振携带了天体的结构和磁场等重要信息



人类由于技术困难
停滞了40多年的
天文探测窗口



A small detector based on a high-sensitivity technique



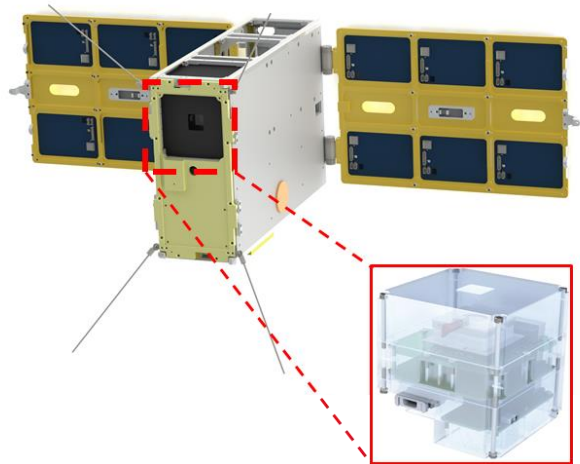
ASIC size: 15 mm * 15 mm (14 * 14 = 196 mm² in use)

Collimator open fraction: 71%

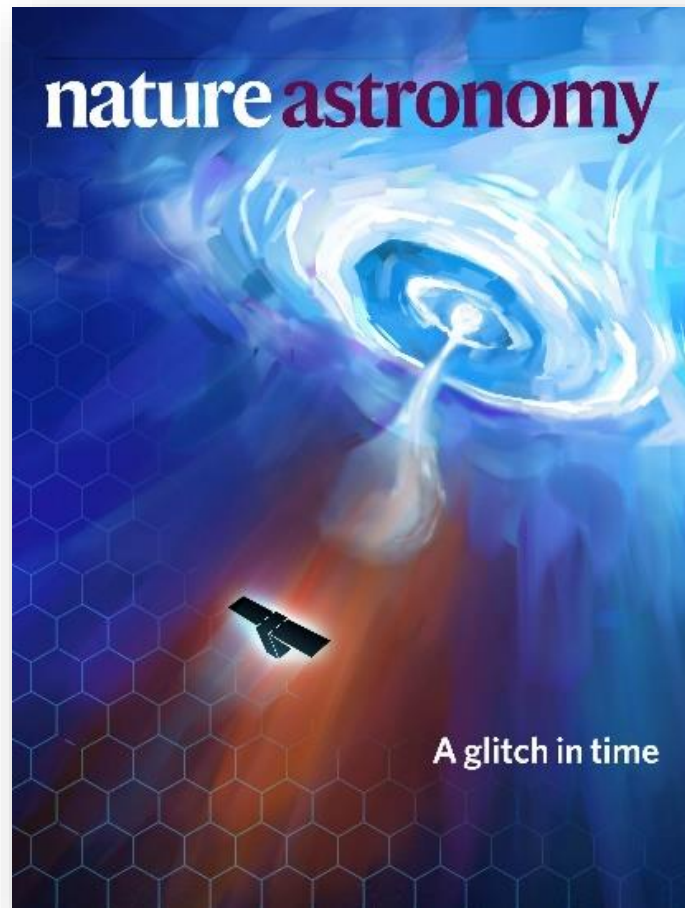
Peak detection efficiency: ~10%

Peak effective area: ~0.14 cm²

极光计划- “窗口重新开启”



极光计划
空间飞行器编号:43663



- 2018年，清华主导的中意合作空间项目“极光计划”成功研制发射纳卫星X射线偏振探测载荷；
- 2020年5月《Nature · Astronomy》封面文章

The success of the authors is threefold: they have reopened a polarimetric window that has been closed for more than 40 years, observed changes in the polarization

- “他们重新开启了已停滞了40多年的天文X射线偏振探测窗口”

—— 同期评论专家 Mozsi Kiss

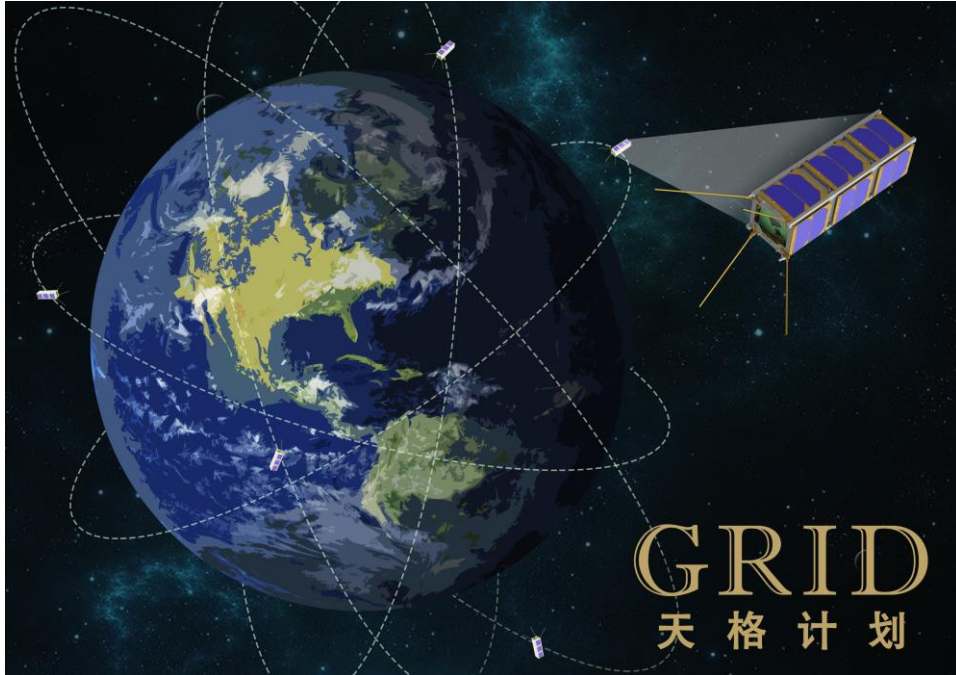


THU Gamma Ray
Integrated Detectors

GRID 天格计划



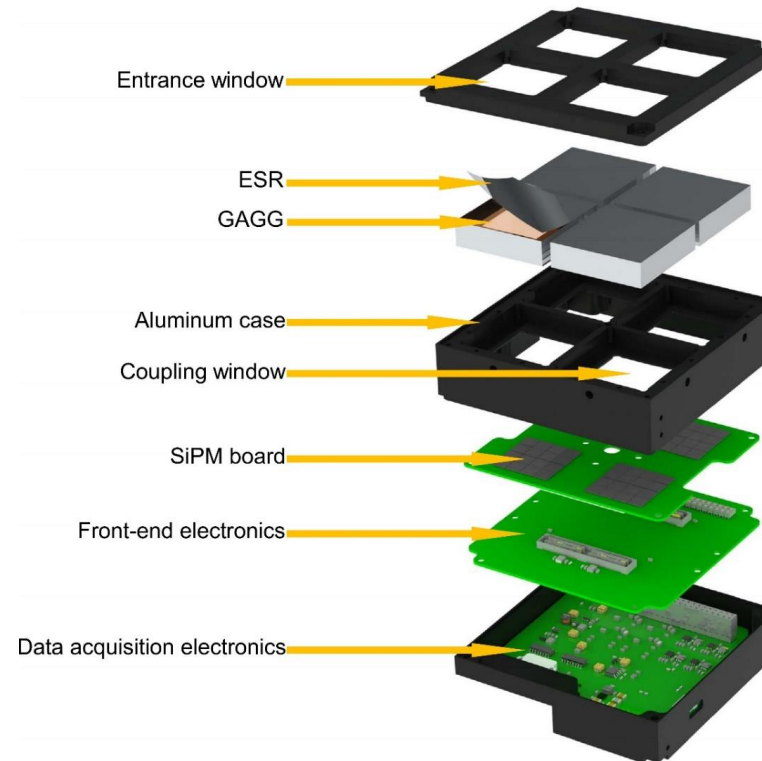
The GRID Project and Detector



Gamma Ray Integrated Detectors (GRID) concept: ^[1]

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

3D model of the GRID detector ^[2]



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 |

[1] 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)

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

背景：宇宙伽马射线暴

宇宙伽马射线暴
的物理模型猜想
2008

“天格计划”
2016

第一例引力波成
协的伽马暴事例
2017

“天格计划”
一号星
2018

二号星目标：
取得科学结果
2020~2021

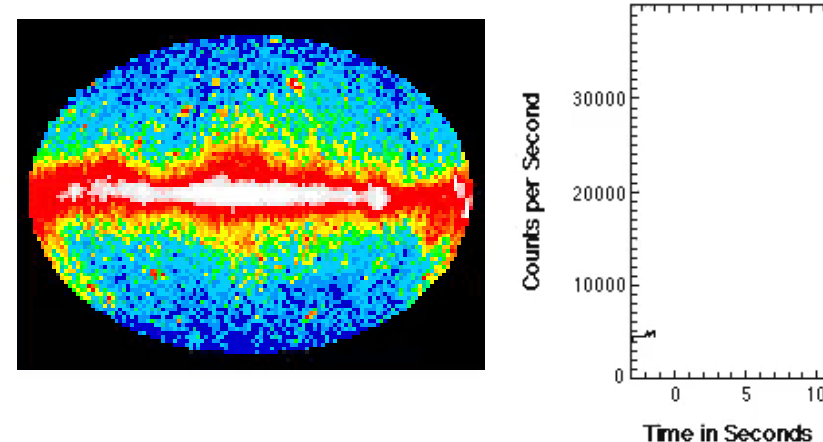
伽马射线暴是目前 **已知最剧烈的天体物理过程**，产生自极端能量密度环境。

伽马射线暴可能起源于 **超新星爆发、中子星并和** 等物理过程，与 **热核聚变、引力波** 等前沿物理问题相关。

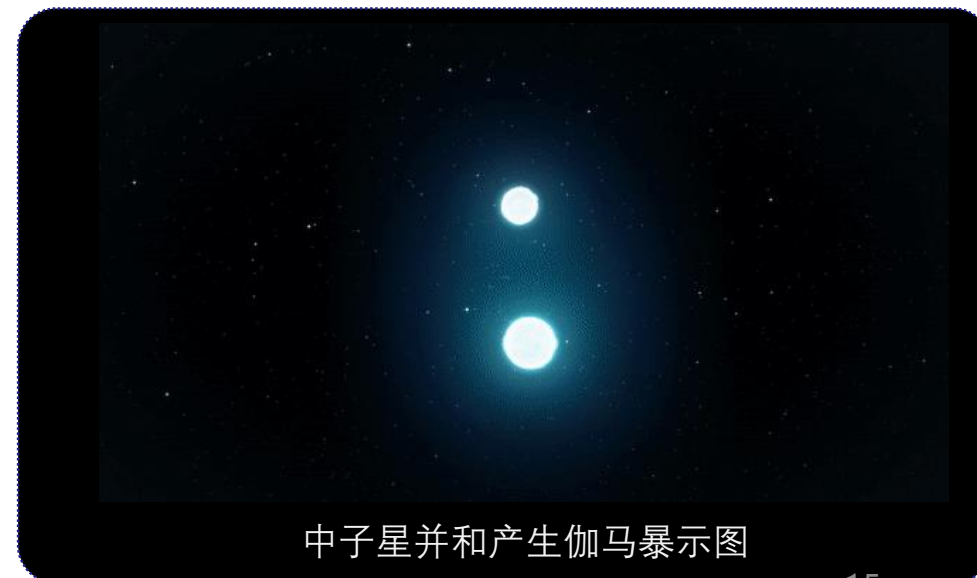
伽马暴的瞬时辐射机制有多种猜想

至今 **仍未有定论**：

- 2008年，相对论“火球”模型
(Asaf Pe'er, *ApJ* 682 463, 2008)
- 2009年，磁能释放主导的同步辐射模型
(Bing Zhang and Asaf Pe'er, *ApJ* 700 L65, 2009)
-



伽马射线天图与伽马暴光变曲线示意图



中子星并和产生伽马暴示意图

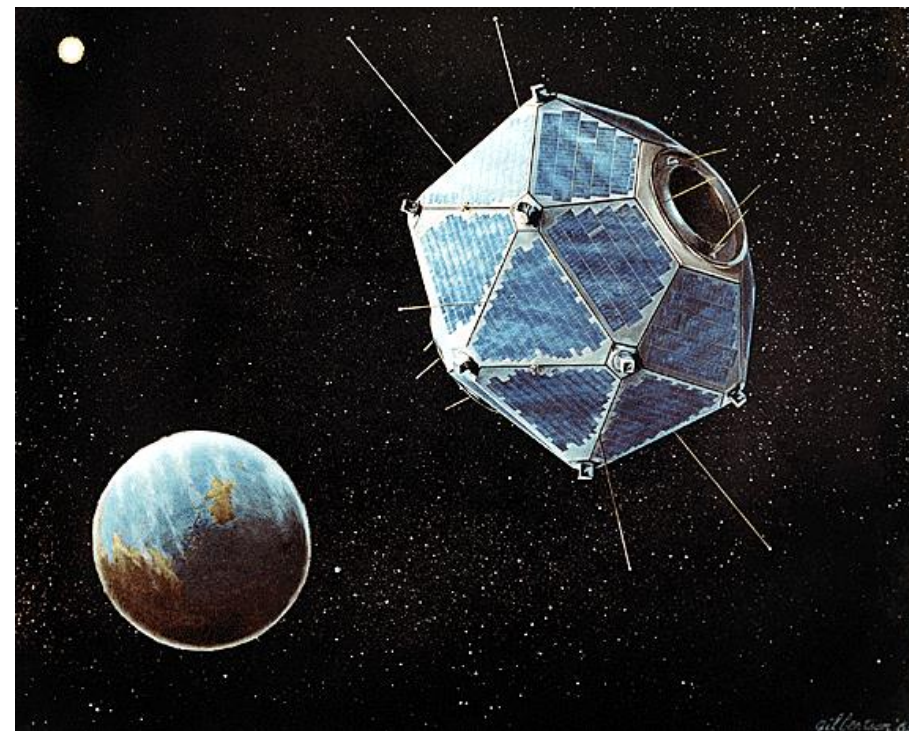
背景：宇宙伽马射线暴的发现

On July 2, 1967, at 14:19 UTC, the Vela 4 and Vela 3 satellites detected a flash of gamma radiation unlike any known **nuclear weapons** signature.

By analyzing the different arrival times of the bursts as detected by different satellites, we can determine rough estimates for the sky positions of sixteen bursts and definitively rule **out a terrestrial or solar origin**.

After thorough analysis, the findings were published in 1973 as an Astrophysical Journal article entitled "**Observations of Gamma-Ray Bursts of Cosmic Origin**".

Frequency: 1~3 one day



Vela 5B in orbit

背景：天格计划

宇宙伽马射线暴
的物理模型猜想
2008

“天格计划”
2016

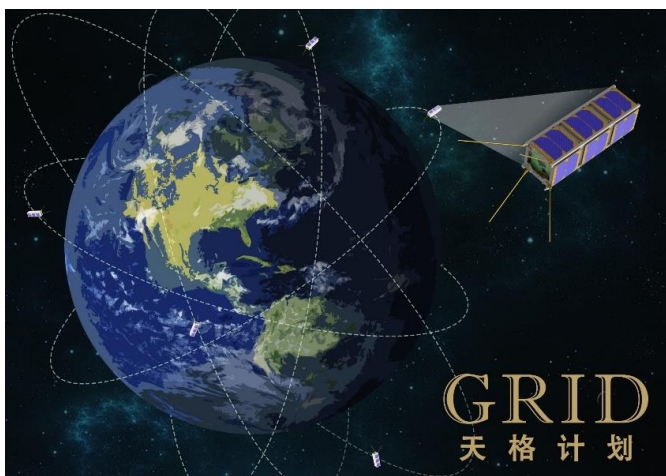
第一例引力波成
协的伽马暴事例
2017

“天格计划”
一号星
2018

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取得科学结果
2020~2021



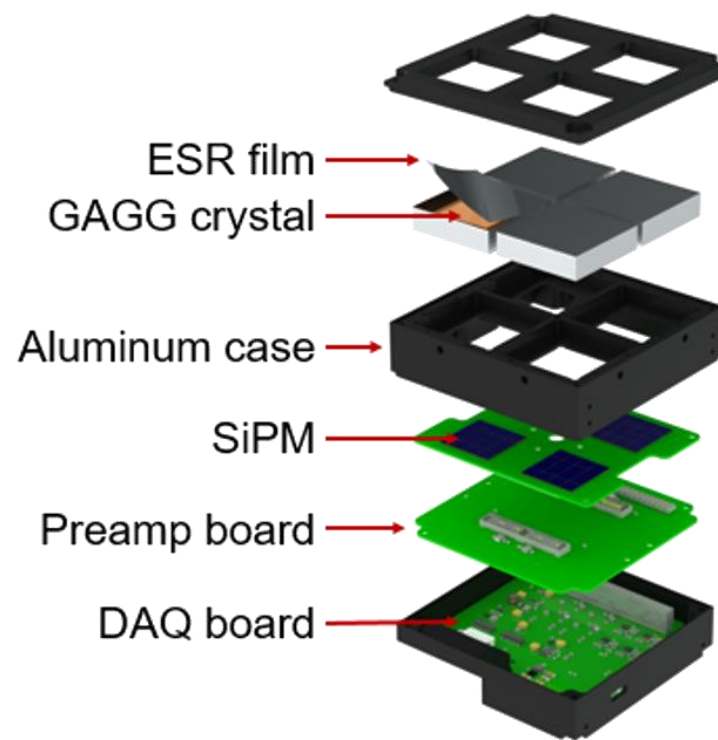
第一代成员 (2016)



2016年，我们天格学生团队 **勇敢地** 对这一 **前沿科学问题** 发起 **挑战**。

天格计划提出利用立方星搭载小型探测器，多星组网探测宇宙伽马暴。

我们的方案抓住了伽马暴的关键物理特点，**高亮度**，思路不同于传统大科学卫星。



探测器结构图

第一代 (原型) @ 2017年4月

学生团队:

- 近百次学术讨论;
- 两万字科学建议书
- 物理模拟与误差分析



电池组及电源管理模块

磁力矩器
• 姿态测控

UHF/VHF收发器

溴化铯探测器
• 伽马射线探测
• 前放、高压及分压等

读出电子学
• 模数转换
• 波形甄别

OBC
• 星上数据处理
• 中央控制

GPS
• 获取位置信息
• 时间同步

背景：伽马暴与引力波

宇宙伽马射线暴
的物理模型猜想
2008

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2016

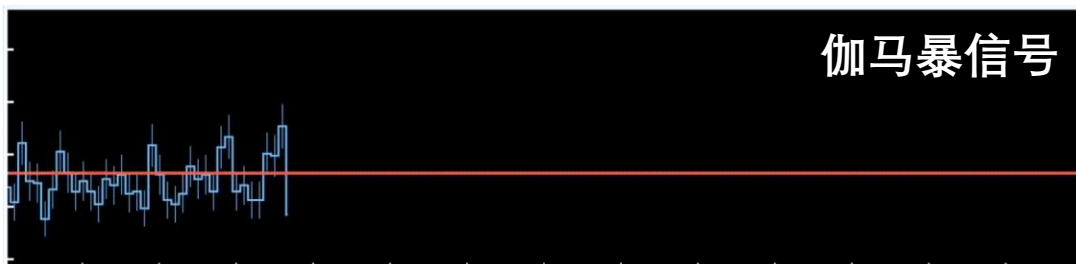
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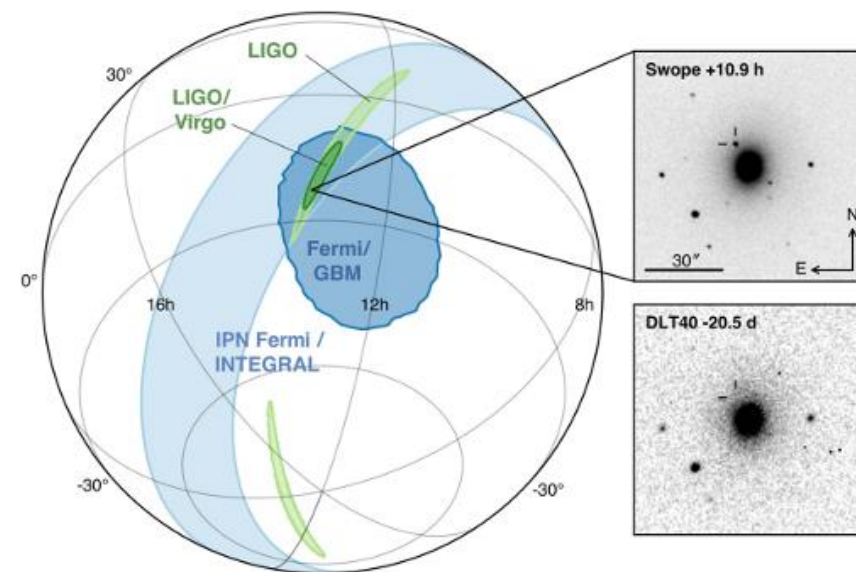
二号星目标：
取得科学结果
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目前 **唯一一例与引力波同时产生和到达** 的伽马暴 (GRB 170817A 和 GW170817)

天文观测的新窗口，天体物理的新契机，
标志着 **多信使天文学时代** 的到来。



GW 170817的引力波与伽马暴信号



中子星并和示意图

背景：观测热潮

宇宙伽马射线暴
的物理模型猜想
2008

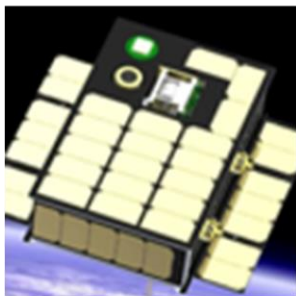
“天格计划”
2016

第一例引力波成
协的伽马暴事例
2017

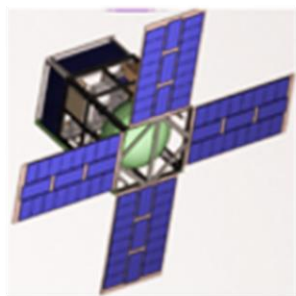
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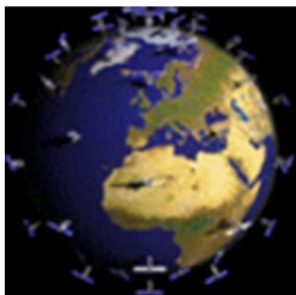
BurstCube



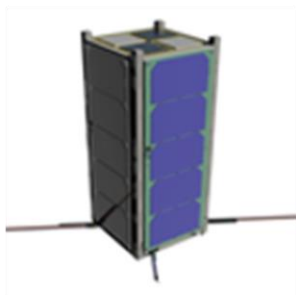
Moonbeam



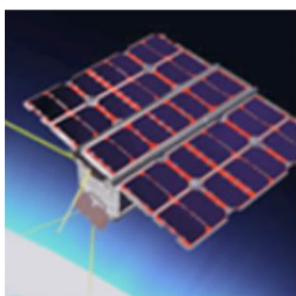
HERMES



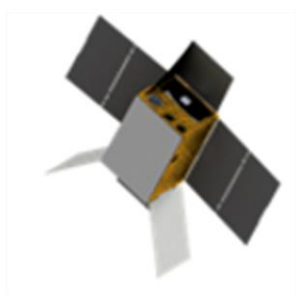
GIFTS&EIRSAT



CAMELOT



SkyHopper

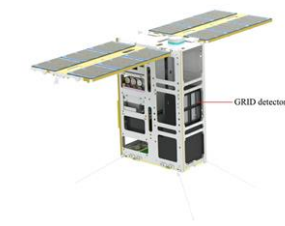
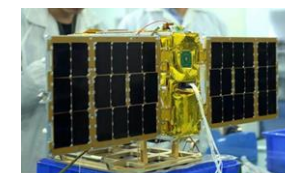


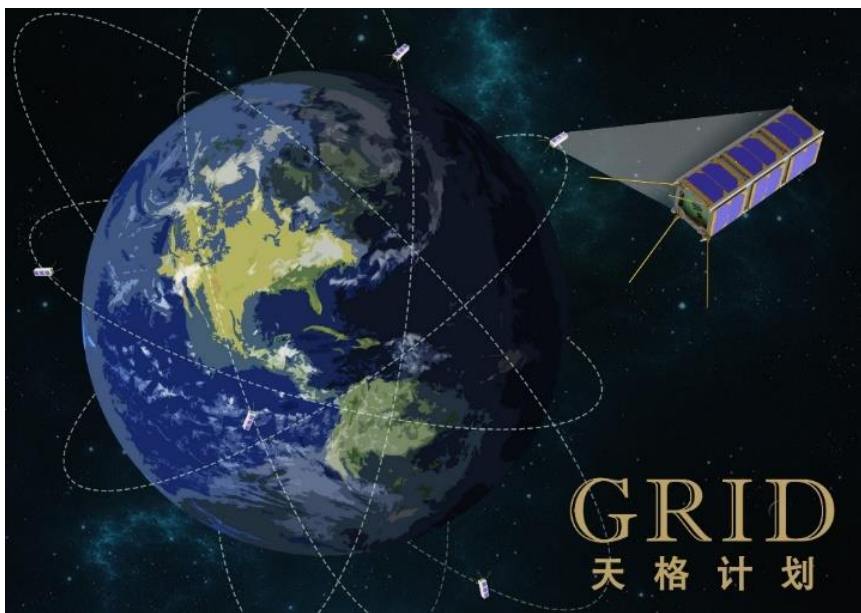
| 名称 | 发起单位 | 发起时间 | 发射时间 |
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| BurstCube | 美国NASA | 2017 | 未发射, 计划2022年初 |
| Moonbeam | 美国NASA | 2018 | 未发射, 待定 |
| GRID天格计划 | 中国清华大学 | 2016 | 2018年10月 (一号星) 2020年11月 (二号星) 2022年2月 (三号星) (四号星) |
| CAMELOT | 匈牙利/日本大学合作 | 2018 | 2021年3月22日 |
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| SkyHopper | 澳大利亚墨尔本大学 | 2018 | 未发射, 待定 |



天格计划一号星

NORAD ID: 43663
Int'l Code: 2018-083B
Perigee: 511.9 km
Apogee: 528.7 km
Inclination: 97.5 °
Period: 94.9 minutes
Launch date: October 29, 2018
Launch site: Jiuquan Satellite
Launch Center, China (JSC)





Gamma Ray Integrated Detectors (GRID)
基于纳卫星的伽马射线空间探测网络

科学目标： 探测搜寻与引力波或快速射电暴成协的伽马暴事例；

- 从引力波 到 中子星并和引力波事例

| 电磁波段 | 引力波暴电磁对应体探测特点 | 探测手段 |
|-------------------------|---------------------------|-----------------------|
| 射电 (余辉) | 优：事件率高 | 大型地面射电望远镜 或射电望远镜阵列 |
| | 缺：持续时间长、难以判断与引力波暴是否成协，强度弱 | |
| 光学 (余辉) | 优：定位精度高 | 地面大口径巡天望远镜 |
| | 缺：事件率较低、强度弱、全天干扰源项多、探测视场小 | |
| X射线 (余辉) | 优：特征明显、定位精度高 | X射线观测卫星 |
| | 缺：事件率较低、流强较弱、需要聚焦望远镜、视场小 | |
| γ 射线 (短伽马射线暴) | 优：非常明亮，干扰源少，与引力波暴时间成协度强 | 伽马暴探测卫星 |
| | 缺：喷流张角小，可探测事件率可能极低，定位精度较低 | |

- 新的技术路线：** 纳卫星 + 紧凑型空间伽马射线探测 + 组网

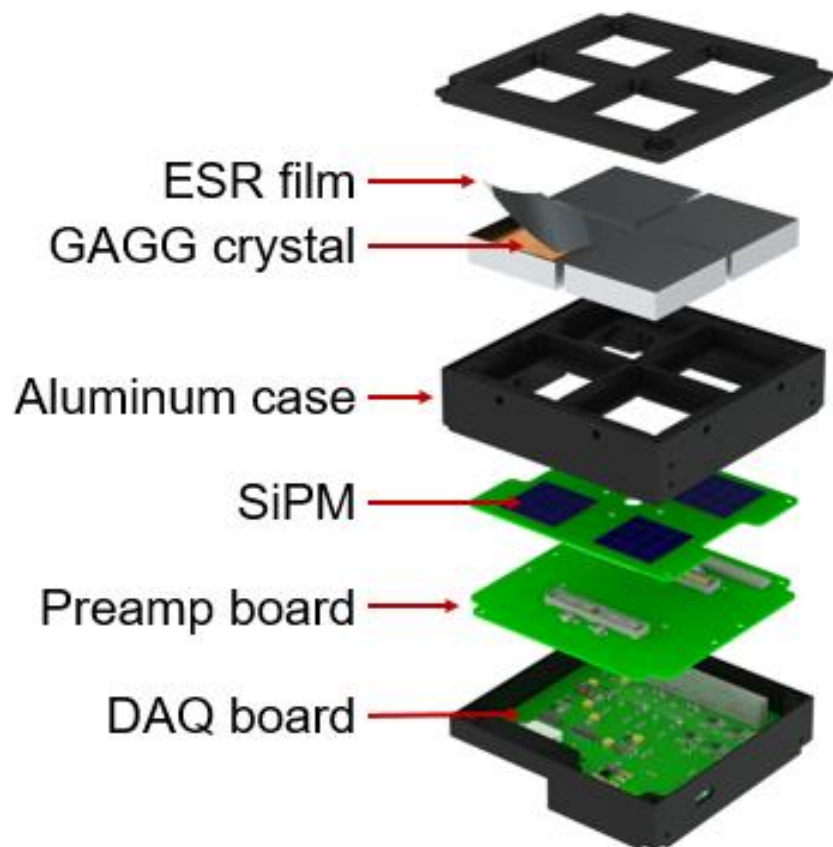
← **2016年10月 发起 “天格计划”**

- 新的组织形式：** 指导学生团队（本科生）为主体开展

- 国际同类项目的提出：** 2017年，GW 170817 / GRB 170817A 事例

1.3亿光年远的NGC 4993星系中两颗中子星的合并

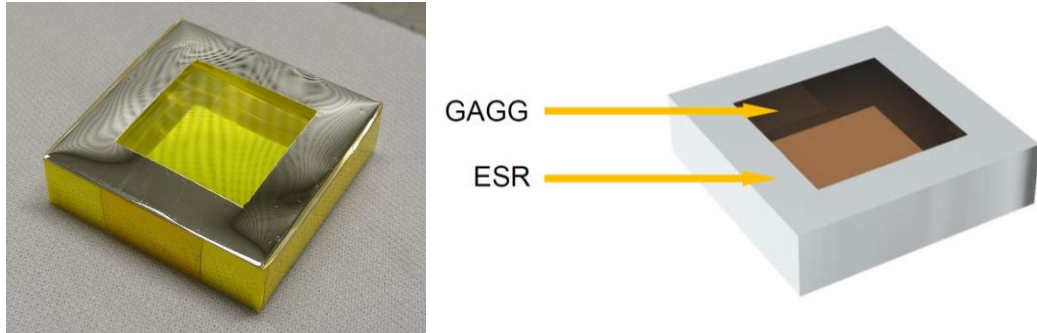
“天格计划” 探测器载荷



| | 天格01设计值 | 天格01实际值(在轨) | 天格02实际值(地面) |
|-----------|----------------------|--|---|
| 体积 | 0.5U | < 0.5U (9.4×9.4×5 cm ³) | < 0.5U (9.4×9.4×5 cm ³) |
| 质量 | / | ~ 780 g | ~ 780 g |
| 功耗 | 3 W | Typ. 2.4 W Max. 3 W | Typ. 2 W Max. 2.8 W |
| 探测面积 | ~ 58 cm ² | / | / |
| 视场 | 2π | Depend on attitude | / |
| 能量范围 | 10 keV ~ 2 MeV | 40 keV ~ 2 MeV | Lower threshold < 15 keV Upper threshold ~ 2 MeV |
| 死时间 | 10 us | ~ 50 us | ~ 20 us |
| 本底 计数率 | ~ 500 cps | Norm. ~ 200 cps SAA > 3000 cps | / |
| 数据量 | ~ 1 GB/day | ~ 64 MB/day | / |

3D model of the GRID detector [3]

GAGG:Ce Scintillator Crystal



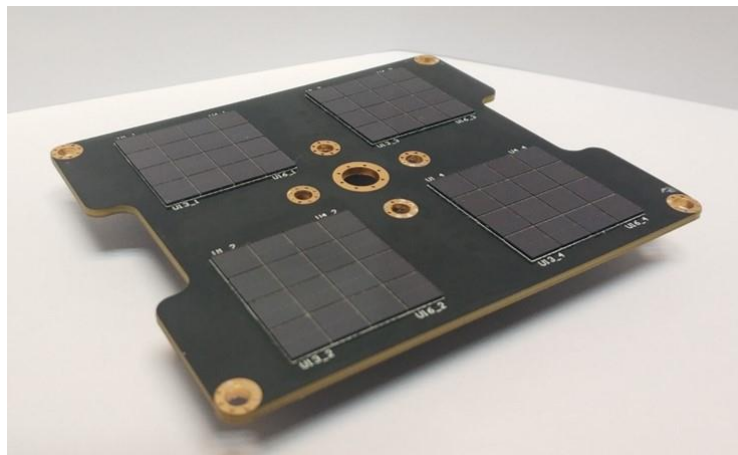
Bottom view of a GAGG:Ce scintillator with the ESR package
[3]

- Polished on all faces
- Wrapped with 65 μm Enhanced Specular Reflector (ESR) film
- $2.2 \times 2.2 \text{ cm}^2$ window coupled with SiPM array

| | |
|-------------------|---------------------------------------|
| Crystal size | $38 \times 38 \times 10 \text{ mm}^3$ |
| 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

Silicon Photomultiplier



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

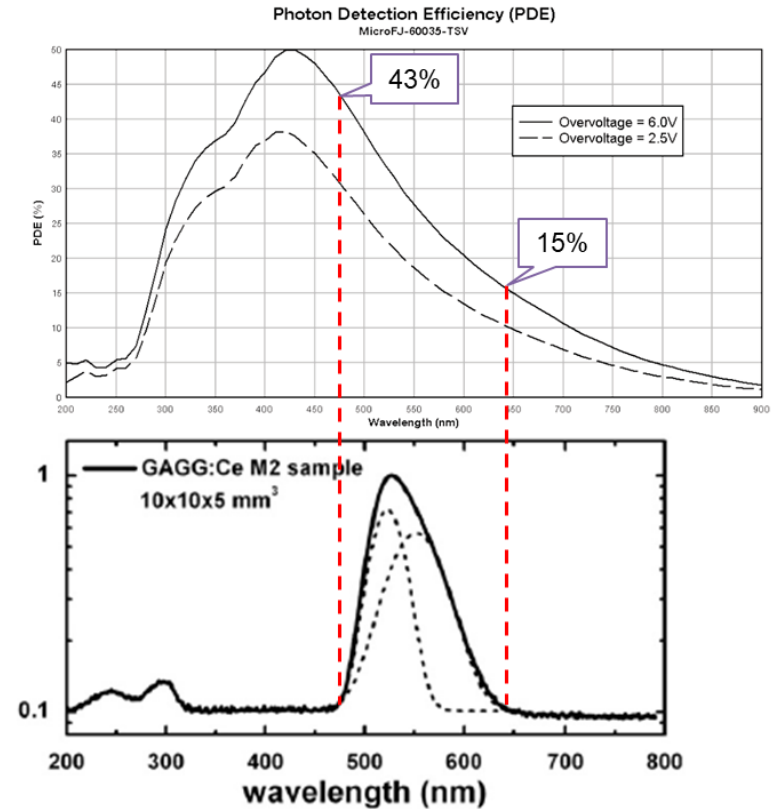
Operation voltage
(No H.V. needed) $\sim 30\text{ V}$

Photon detection
efficiency $> 25\%$

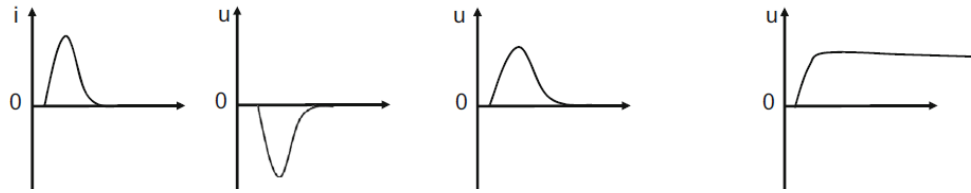
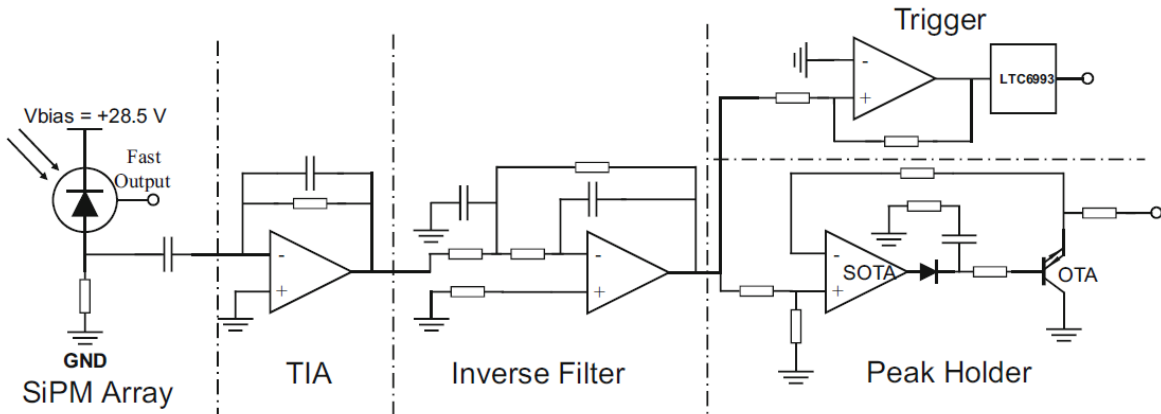
Dark count rate ~ 150
 kHz/mm^2

Temperature
dependence of V_{br} $21.5\text{ mV}/^\circ\text{C}$

Gain is a function
of temperature



Front-End Electronics



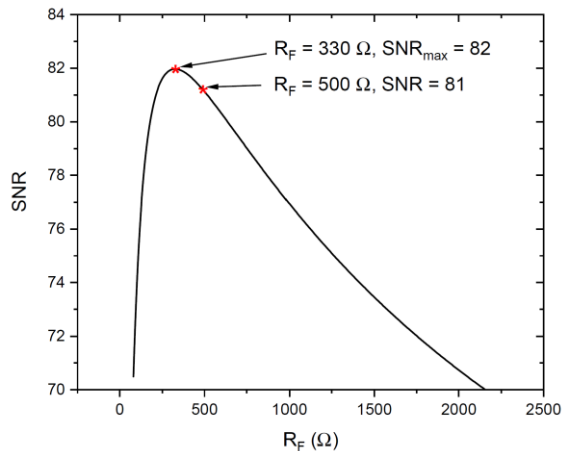
$$SNR = \frac{\max(Pulse(t))}{\sqrt{Vn_{SiPM}^2 + Vn_{TIA}^2}}$$

$$Pulse(t) = E \times LY \times CE \times PDE \times e \times G \times \mathcal{L}^{-1}[H_G(s)H_S(s)H_T(s)](t)$$

$$Vn_{SiPM}^2 = \left((I_N R_F)^2 + 4kTR_F + E_N^2 + \frac{(E_N 2\pi C_D R_F F_0)^2}{3} \right) \times F_0$$

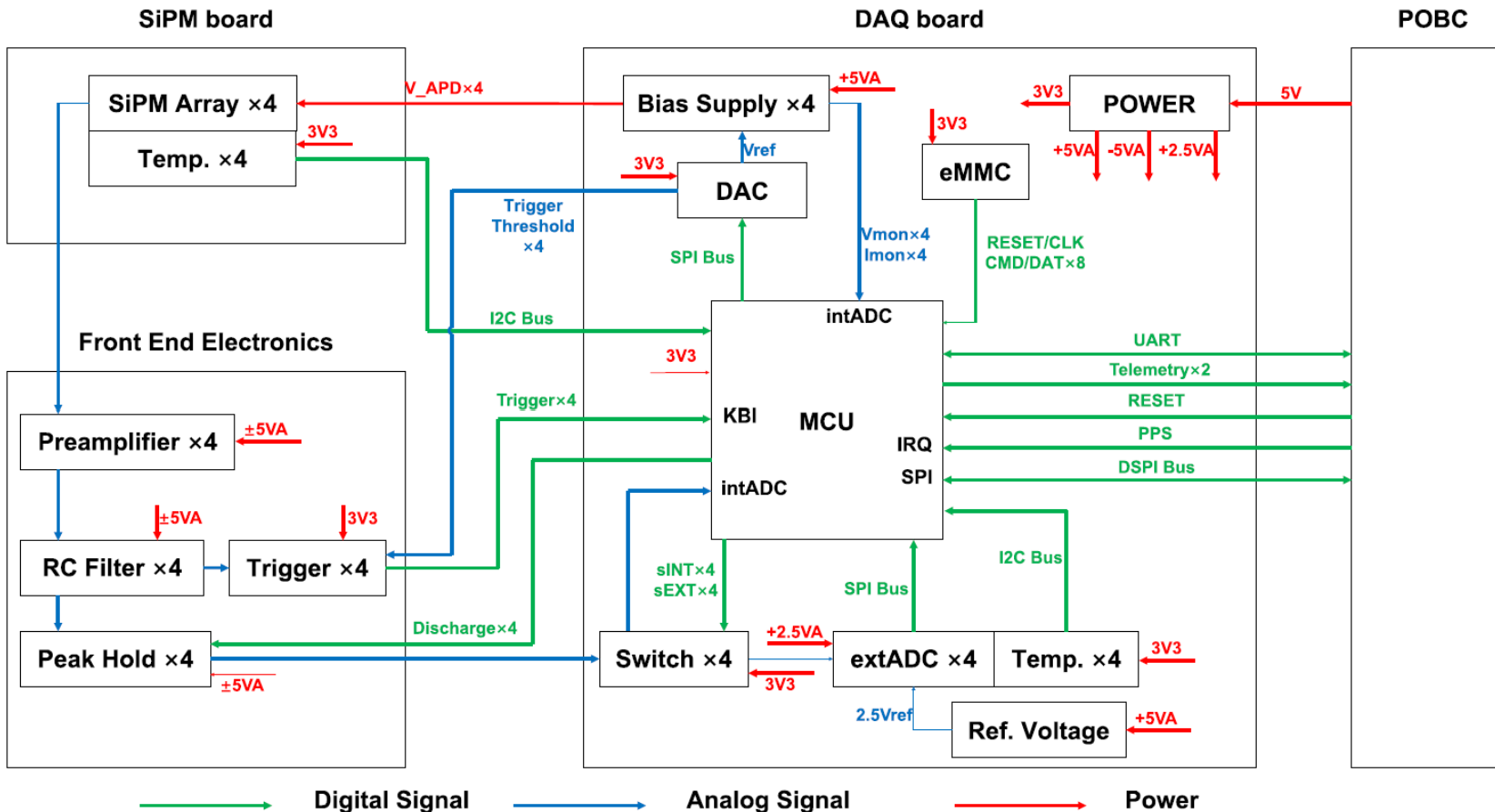
$$Vn_{TIA}^2 = \bar{n} \int_{-\infty}^{+\infty} h^2(t) dt$$

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



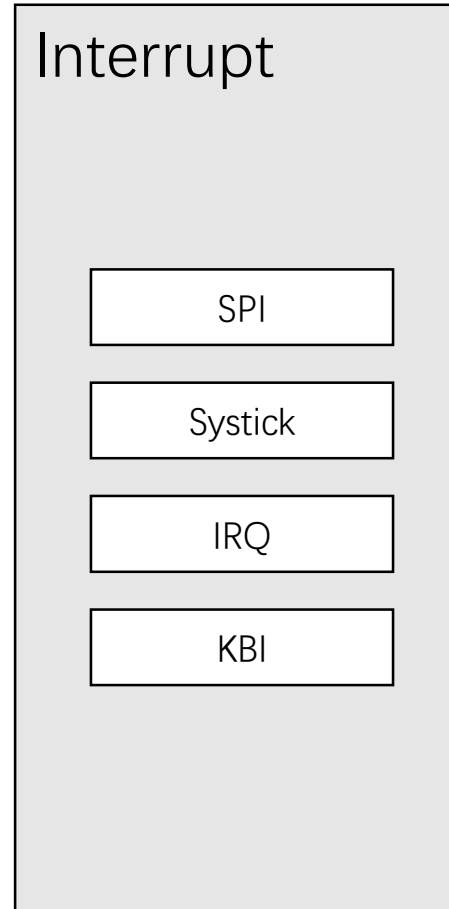
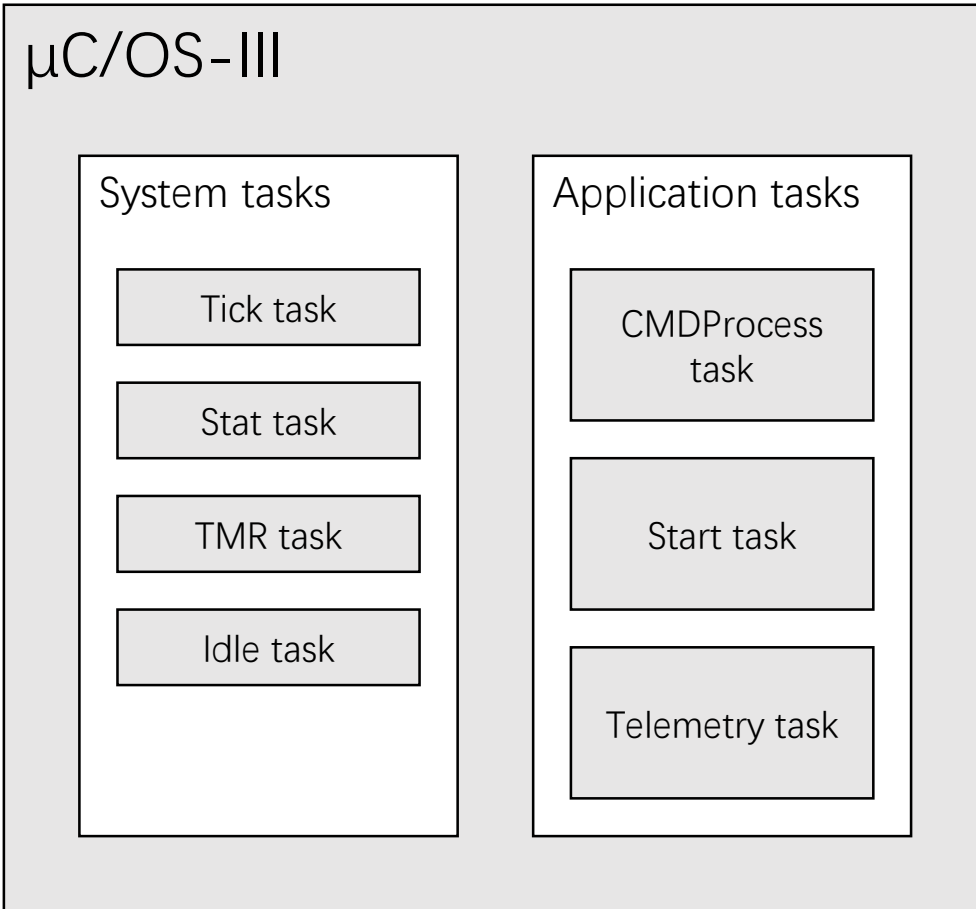
← SNR vs. R_F [3]

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]

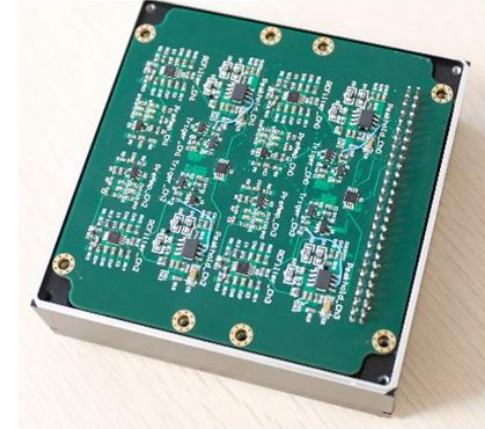


- Multi-task firmware based on real-time operating system (μ C/OS-III)
- Basic functions
 - Data acquisition, storage and transmission
 - Instruction control
- Monitor functions
 - SiPM bias & current monitor
 - Temperature sensor
 - Close-loop control of SiPM bias supply
- Extra verification functions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

GRID-02 Flight Model



SiPM Array

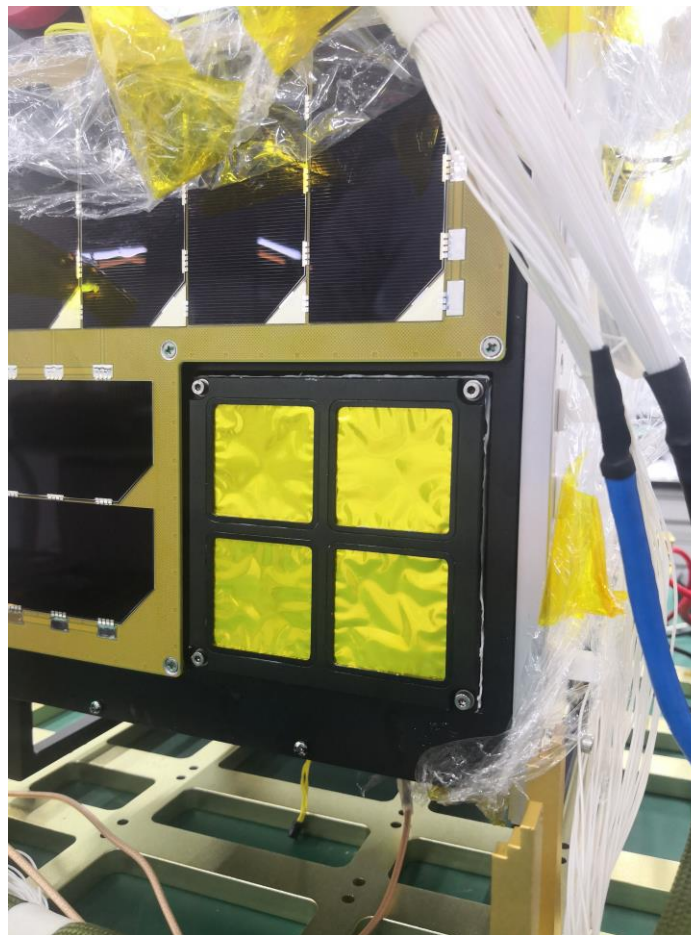
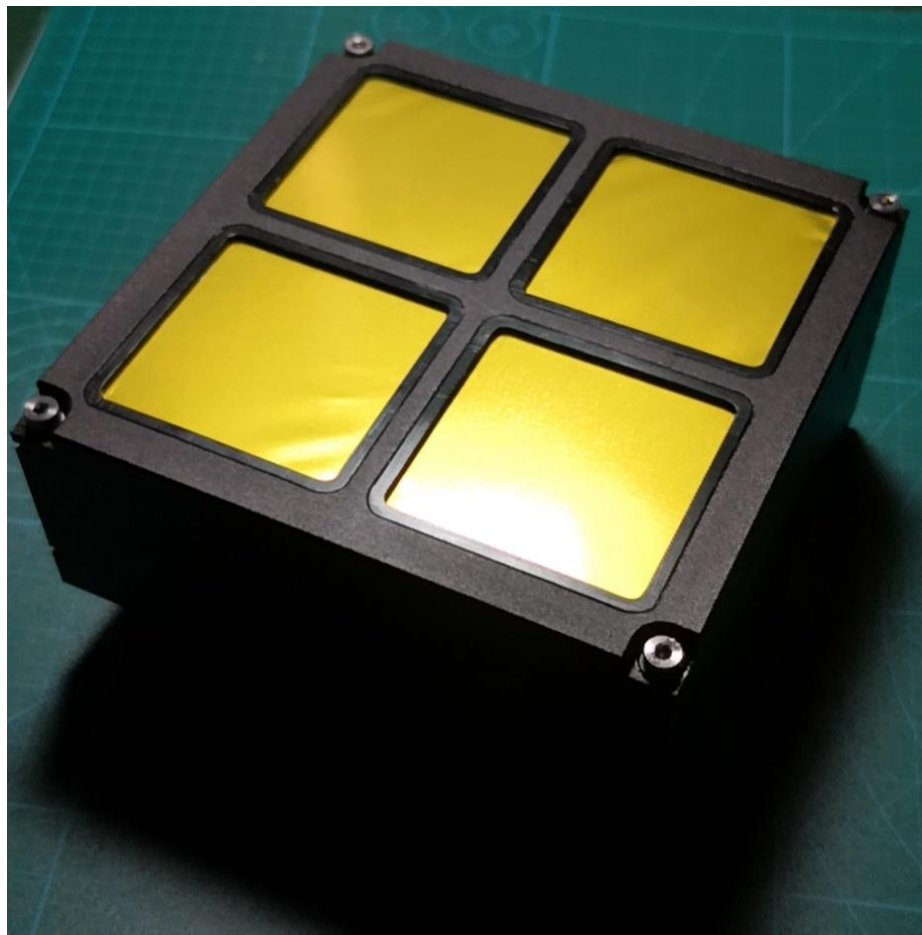


Front-end electronics (FEE)

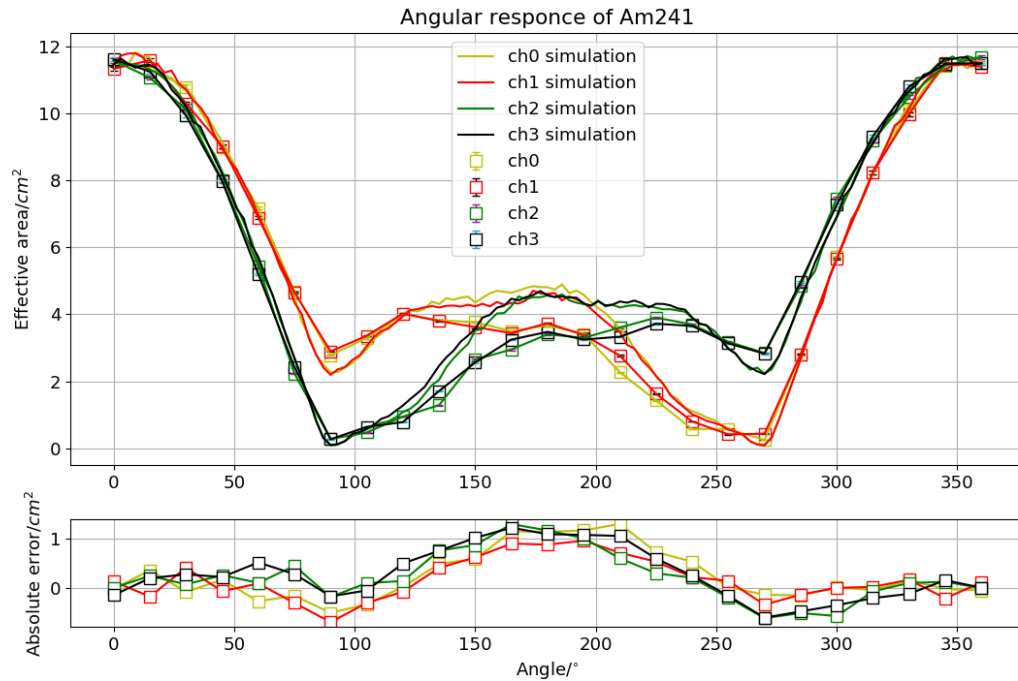


Back-end electronics (BEE) & Control electronics (CE)

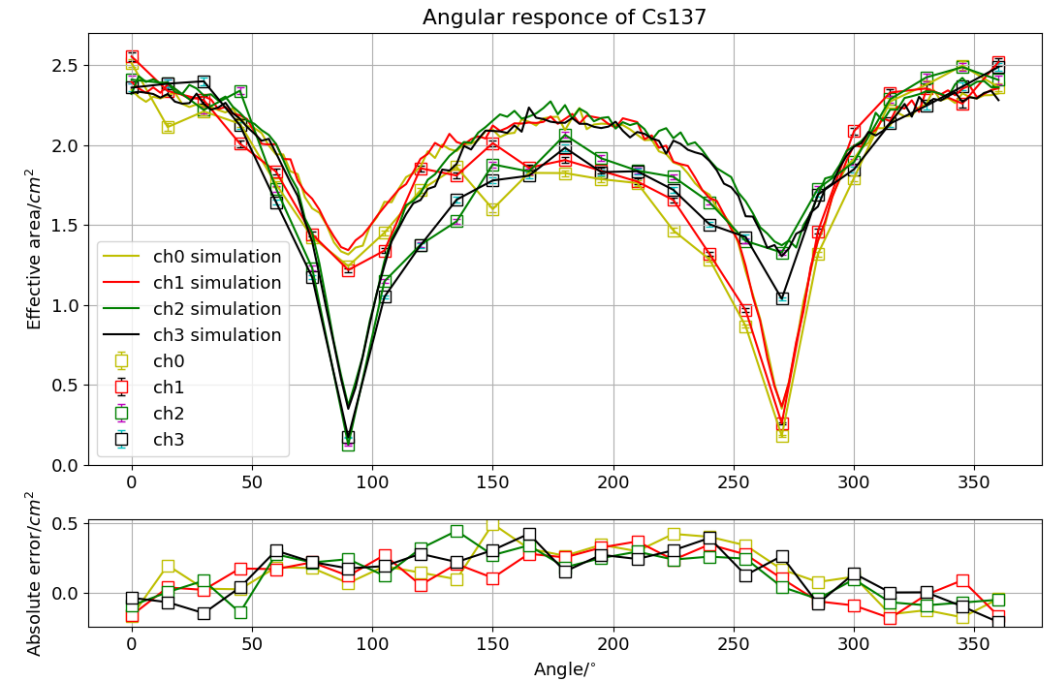
GRID-02 Flight Model



Calibration



Angular response - Am-241



Angular response - Cs-137

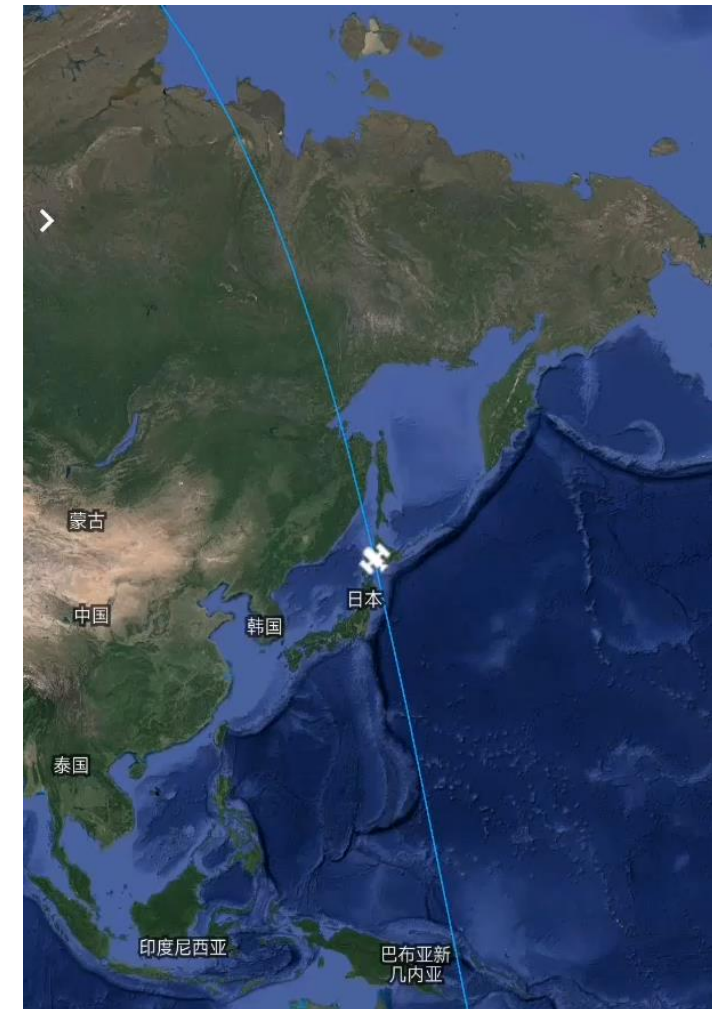
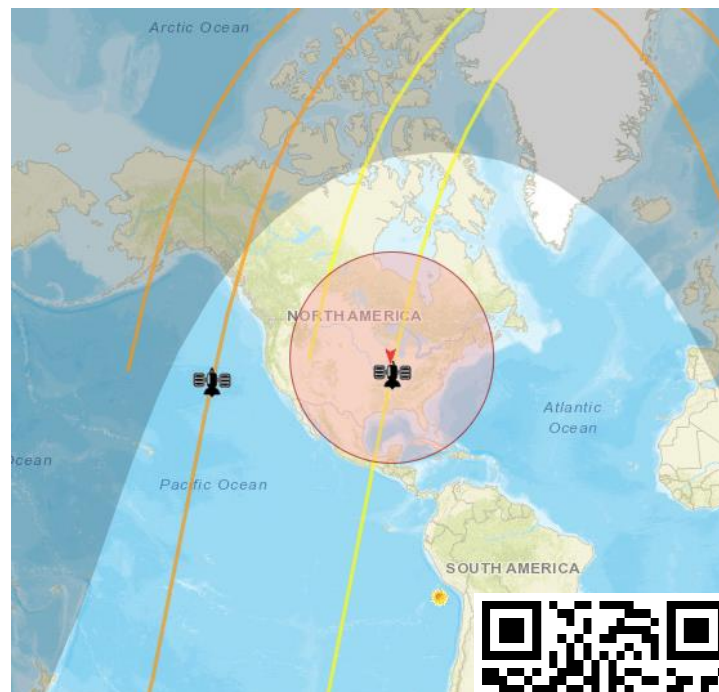
GRID-01 & GRID-02 卫星载荷



NORAD ID: 43663
Int'l Code: 2018-083B
Perigee: 511.9 km
Apogee: 528.7 km
Inclination: 97.5 °
Period: 94.9 minutes
Semi major axis: 6891 km
RCS: Unknown
Launch date: October 29, 2018
Source: People's Republic of China (PRC)
Launch site: Jiuquan Satellite Launch Center, China (JSC)

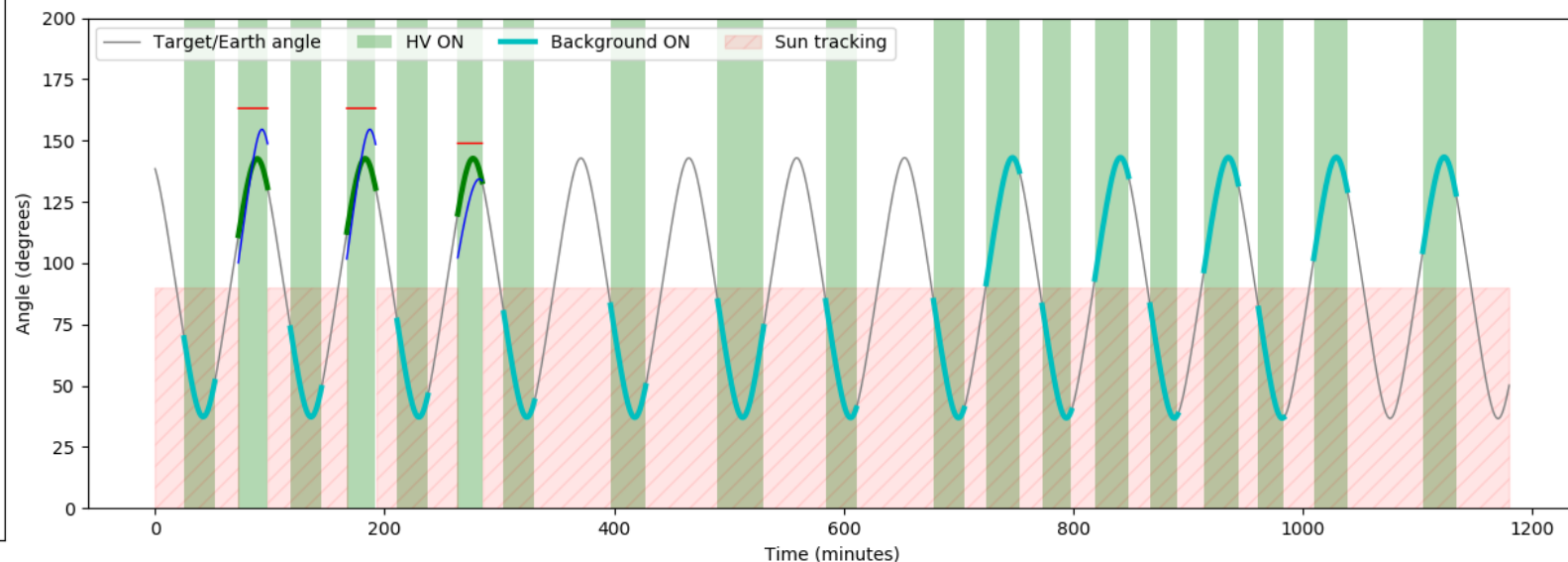
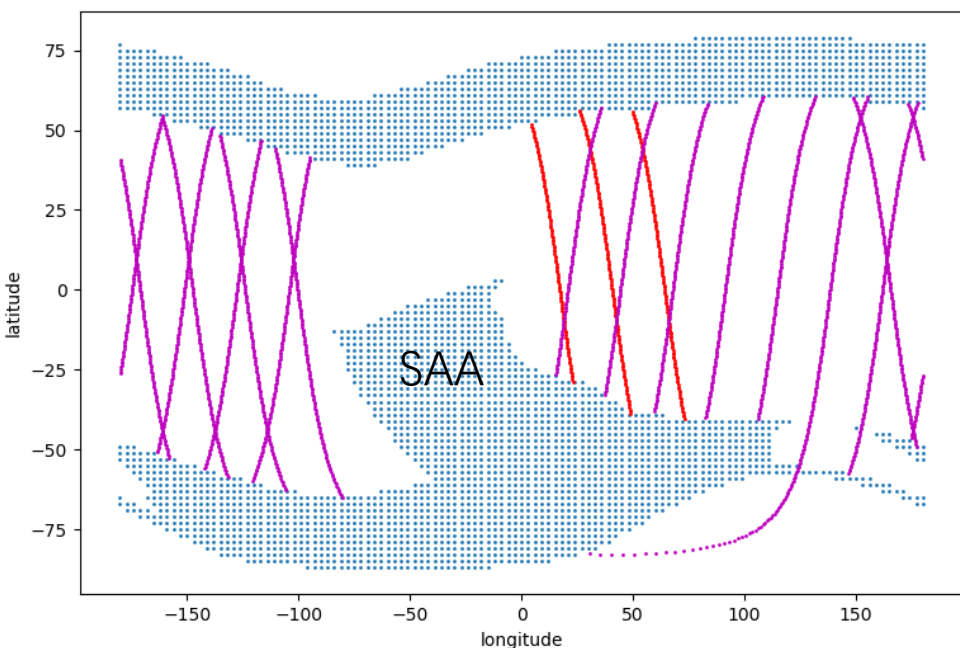


NORAD ID: 46838
Int'l Code: 2020-079M
Perigee: 471.1 km
Apogee: 481.2 km
Inclination: 97.3 °
Period: 94.0 minutes
Semi major axis: 6847 km
RCS: Unknown
Launch date: November 6, 2020
Source: People's Republic of China (PRC)
Launch site: Taiyaun Space Center, China (TSC)



在轨科学观测 – 卫星遥测

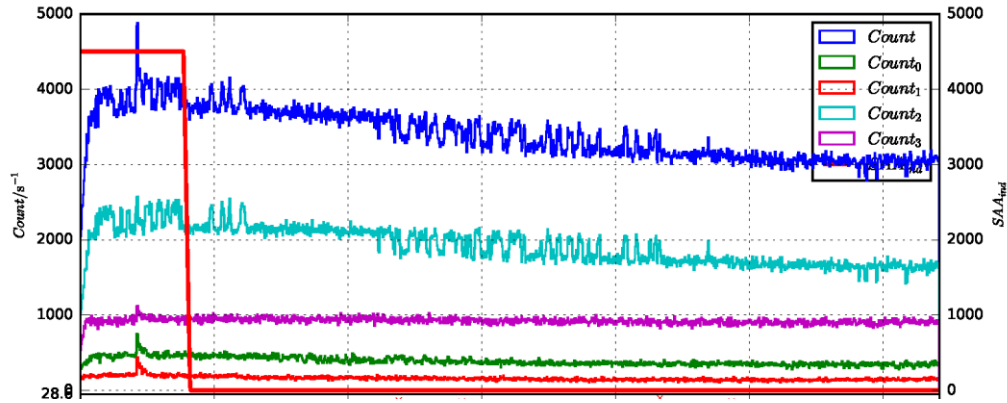
- Undergraduate students on duty make observation plan every day
- 10 ~ 20 observations per day, 20 ~ 40 minutes each (depends on other payloads and CubeSat platform)
- Shutdown in South Atlantic Anomaly (SAA) and high-latitude region
- ✓ Targeting observation: point to Crab (Inertial pointing mode)
- ✓ Non-targeting observation: random orientation (Inertial or magnetic sun tracking mode)



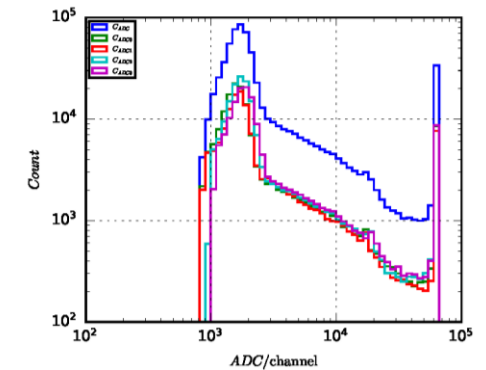
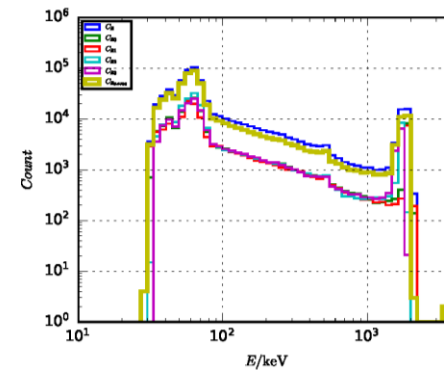
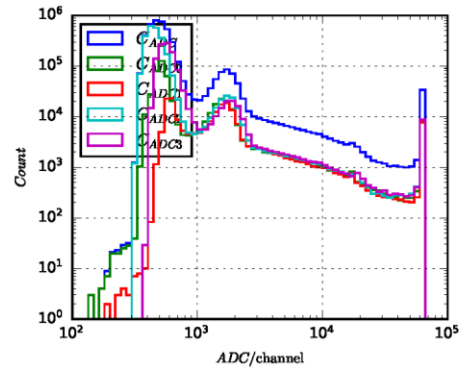
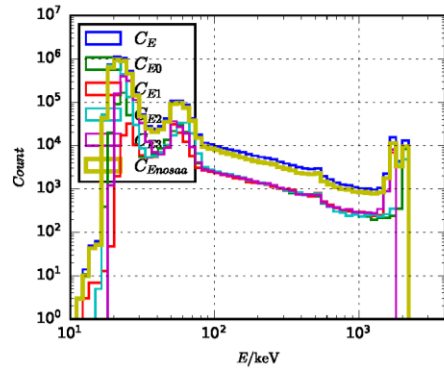
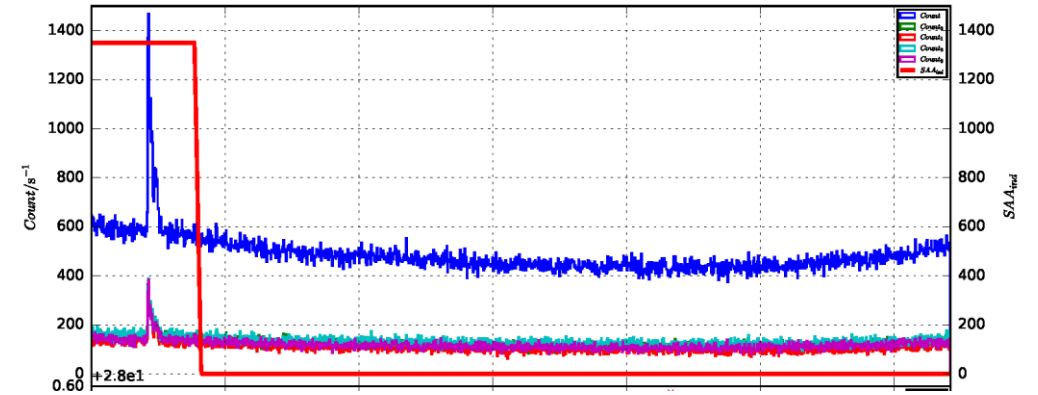
Example observation plan during Nov. 29 2020 17:00 ~ Nov. 30 2020 12:30 (UTC)

GRB 210121A: GRID-02 Detection

2021.01.21.18:40:25



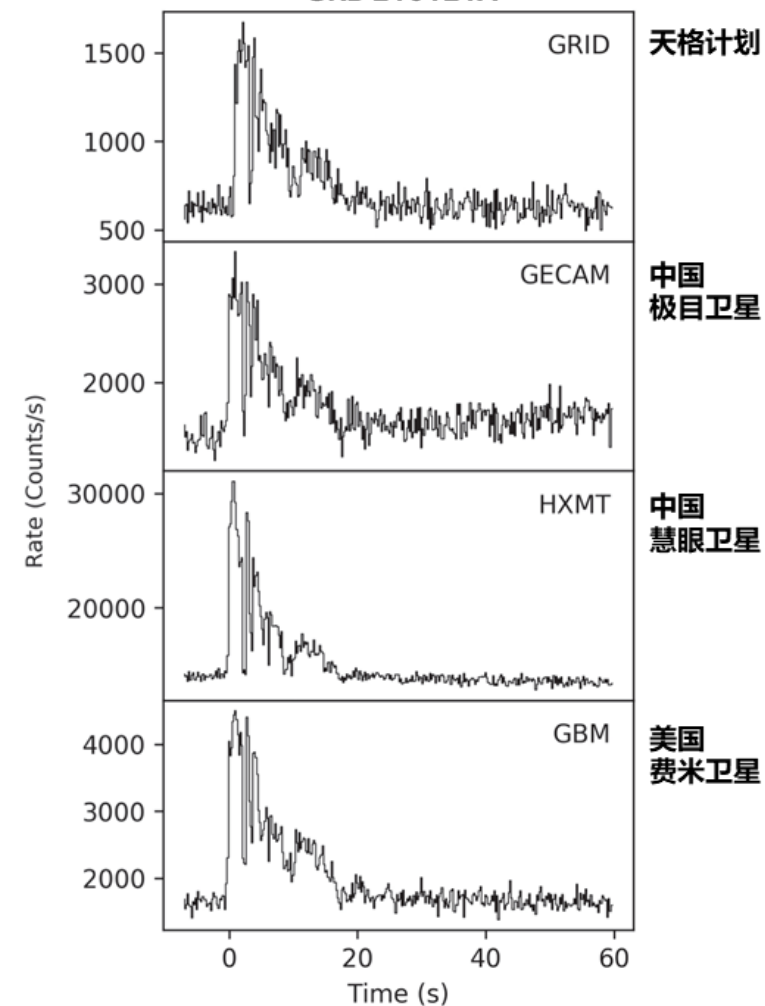
2021.01.21.18:40:25



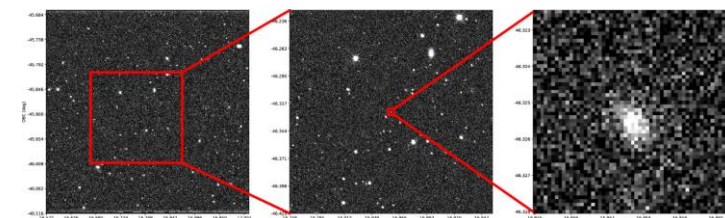
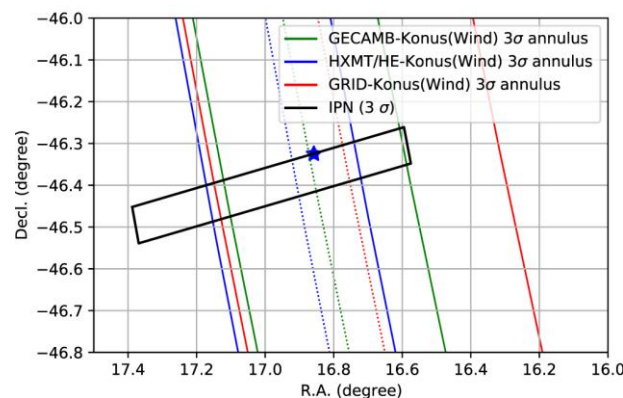
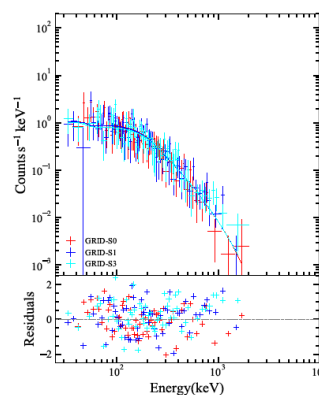
6σ cut-off
dark count noise

GRB 210121A: GRID Detection

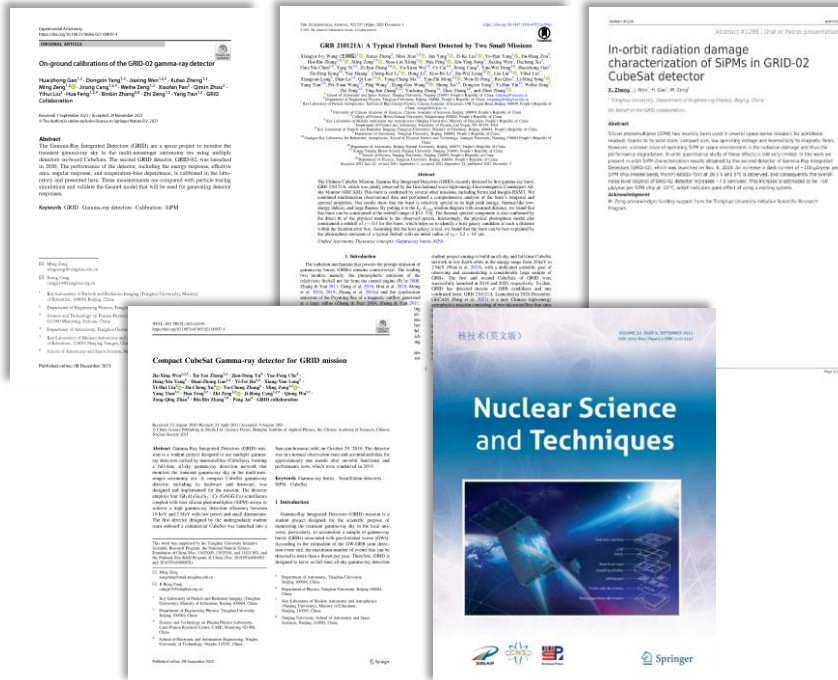
GRB 210121A



- “天格计划”是国际上同类微纳卫星伽马暴探测项目中，第一个成功发射实现在轨科学观测的；也是其中唯一学生主力的项目；
- GRB 210121A是国际上首例由纳卫星伽马暴探测器探测到、取得科学发现和论文发表的伽马暴事例，
- The Astrophysical Journal (IF 5.877) ；
- GRB 210121A的观测数据，重建出光子的能谱和时间，有力支持了科学界对于伽马暴“火球”模型的猜想。



成果：数据与论文



- 学术论文发表在 *Astrophysical Journal*、*Experimental Astronomy*、*Nuclear Science and Techniques* 等刊物；
- 在 IEEE NSS/MIC 2021 等国际学术会议进行口头报告。

【证书号 第 QGX2021001号】

科学数据汇交凭证

项目名称：“天格计划”二号卫星空间伽马射线暴探测载荷研制

项目编号：20207020001

所属计划（专项）：清华大学大学生学术研究推进计划

项目牵头单位：清华大学

经国家空间科学数据中心审核，项目汇交“天格计划”二号卫星探测产生的科学数据集6个，数据质量符合科学数据管理汇交要求；该数据被国家空间科学数据中心收录，依据相关数据政策向科学界开放共享。

主任 邹自明

日期：2021年12月04日

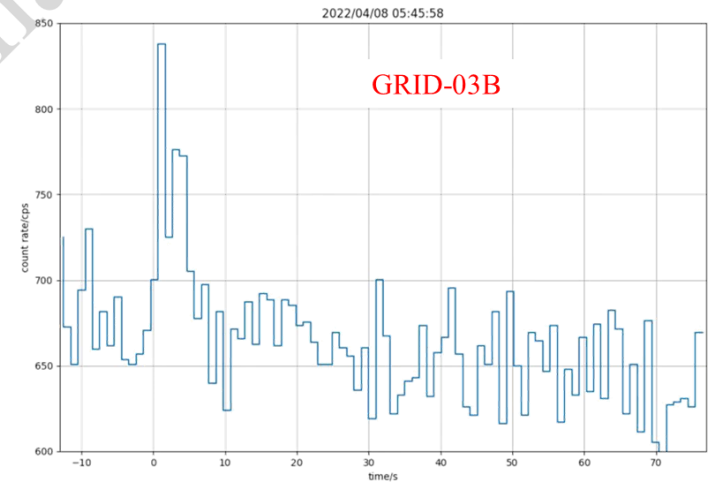
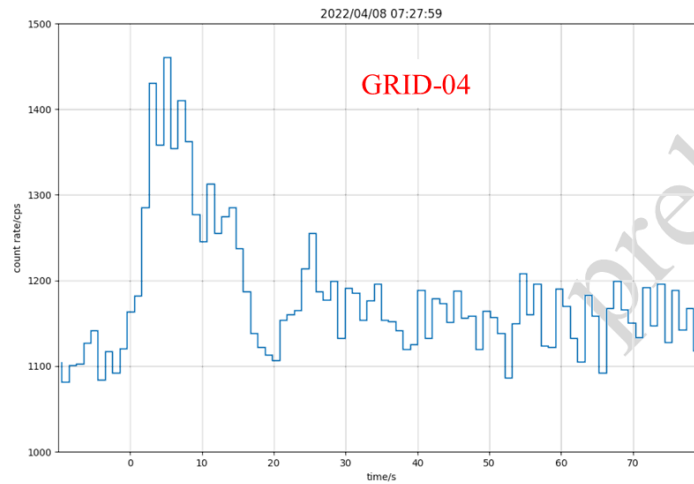
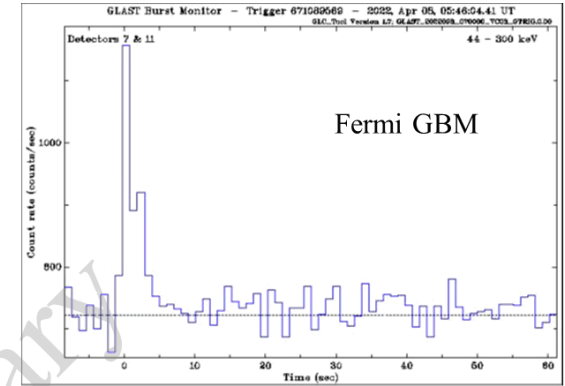
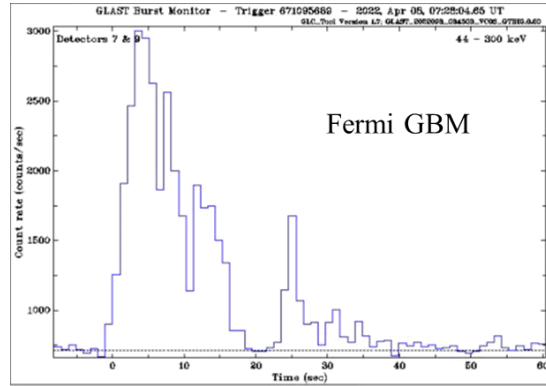
>300小时观测数据

30+伽马暴候选体

通过 国家空间科学数据中心

开放共享

Preliminary Results from GRID-03b & GRID-04



GRB 220408B

GRB 220408A

GRID-03B & GRID-04
Catalog number: 51830
Launched 02/27/2022

“天格计划” 的学生团队



2016年学生团队



2020年学生团队

- **四年间、两代完全不同的队员**， 100余名本科生来自7个不同院系学科
- **团队学生分组协作，全面承担**：科学载荷研制、探测器定标、在轨观测指令、科学数据分析 全流程
- **学术报告**：团队学生在中国天文学年会、香山会议、COSPAR国际空间科学大会等学术会议进行口头报告
- **学生获奖**：团队学生先后获得北京市首都挑战杯一等奖、清华大学挑战杯特等奖、清华大学学生年度人物等荣誉
- **学生去向**：温家星（中物院-激光聚变）、卢迪安（中科院等离子体所）、高怀众（中国辐射防护研究院）、蒋宇辰（中国原子能院-核天体物理）

“天格联盟”



- 2018年3月28日，天格计划第一次导师讨论会，20所兄弟院校和科研单位的30余名专家
- 2019年12月8日，“天格计划”2019年年会暨天格联盟成立会议
- 2020年，南京大学、四川大学、北京师范大学等，先后启动“天格”学生团队和探测器卫星载荷研制



Future Planning of GRID

- GRID-05B (Tsinghua Univ.)

Prof. Ming ZENG & Hua FENG



- GRID-06B (Nanjing Univ. & Sichuan Univ.)

Prof. Bin-bin ZHANG, Prof. Zhonghai WANG & Rong ZHOU



- GRID-07 (Beijing Normal Univ.)

Prof. Lin LIN, Yuanyuan LIU, Jianyong JIANG



- GRID-08B (Nanjing Univ. & Sichuan Univ.)

Prof. Bin-bin ZHANG, Prof. Zhonghai WANG & Rong ZHOU



微纳卫星 & 大科学项目



极光计划 & eXTP



天格计划 & GeCAM

Poalar2

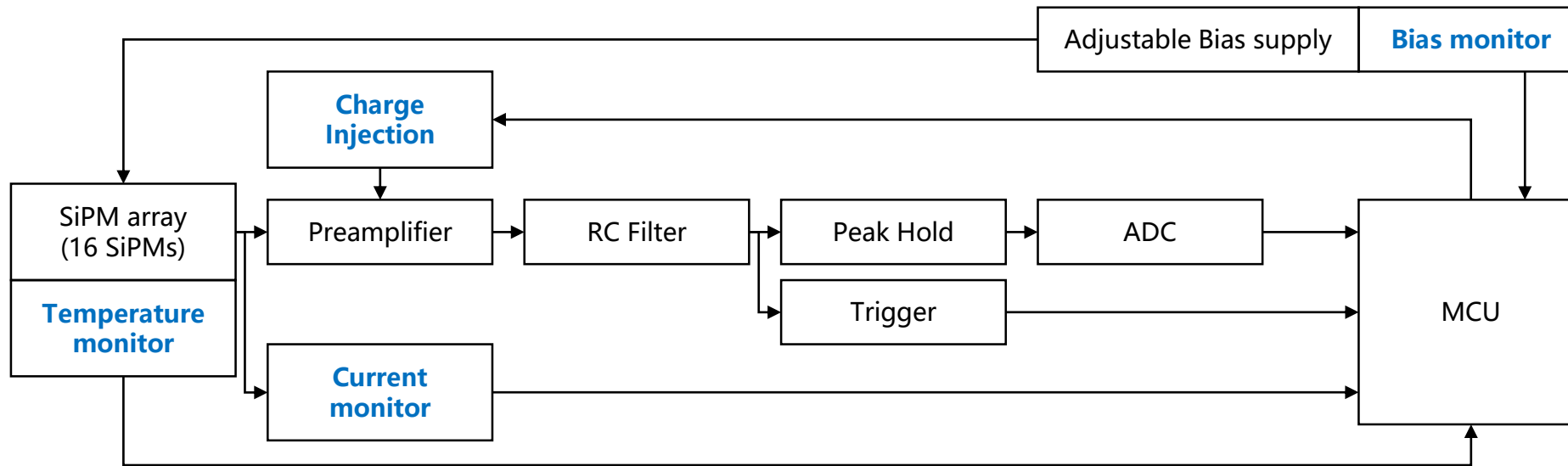


THU Gamma Ray
Integrated Detectors

SiPM 在轨辐射损伤



In-orbit Characterization Setup and Methods



Housekeeping data:

- Timestamp
- Bias voltage
- Current
- Temperature

Block diagram of the front-end electronics and characterization circuits of one channel in GRID detector. Details about GRID instrument design can be found in [2].

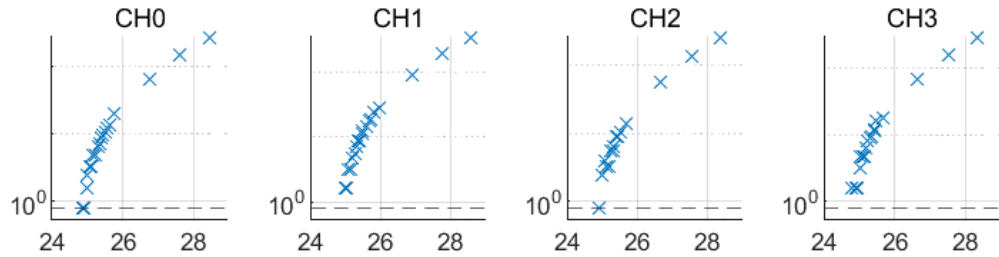
Scientific observation: ~20k seconds (5 ~ 6 hours) per day

- Housekeeping data recorded to analyze SiPM dark current

Daily characterization experiments:

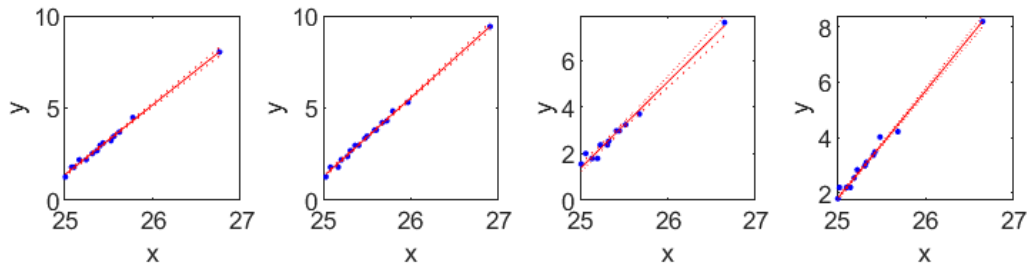
- I-V measurement at different bias voltage
- Charge injection test without and with bias voltage

Breakdown Voltage Determination

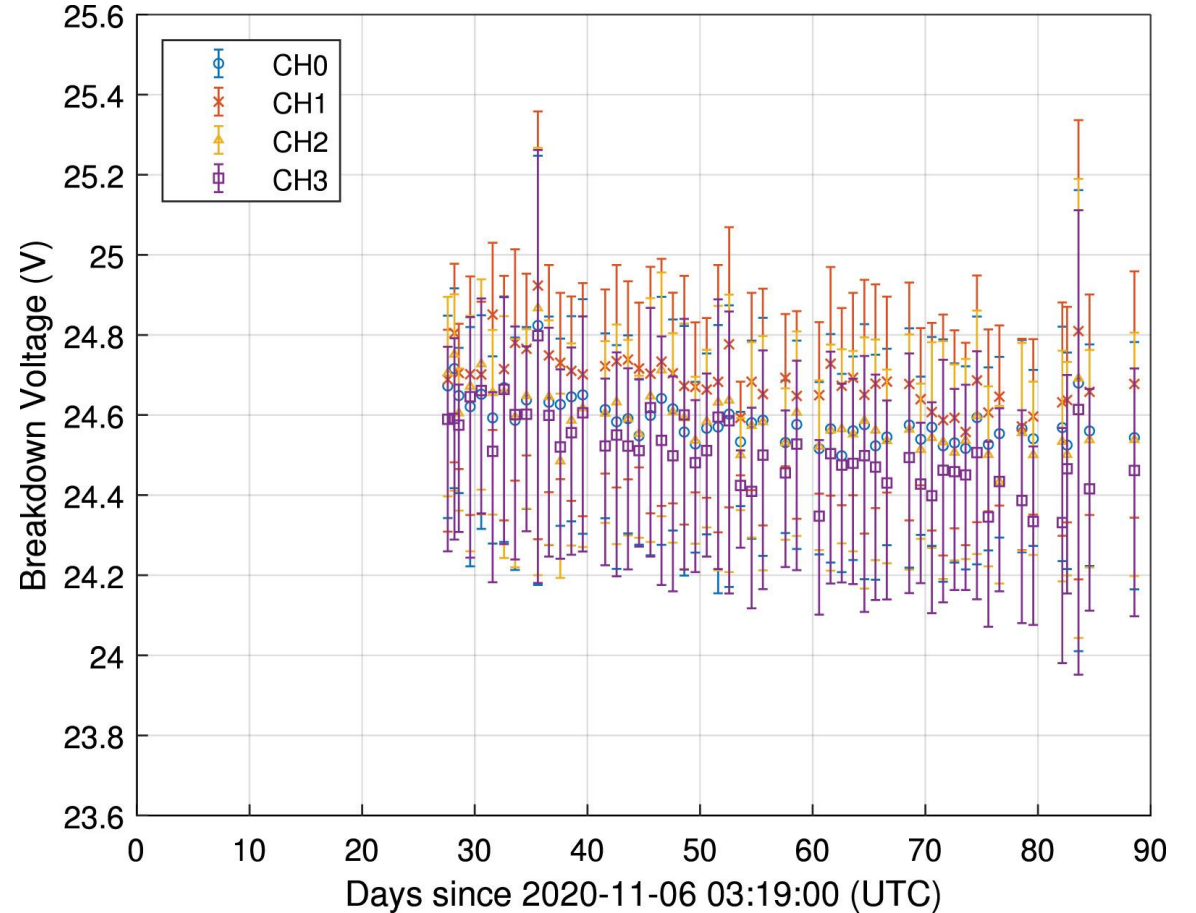


↑ I vs. V

↓ Fit of $\sqrt{I} = k \times (V - V_{BD})$



An example result of the daily I-V measurement at different bias voltages



V_{BD} corrected to 21°C with the 21.5 mV/°C temperature coefficient specified in datasheet

Dark Current Increase

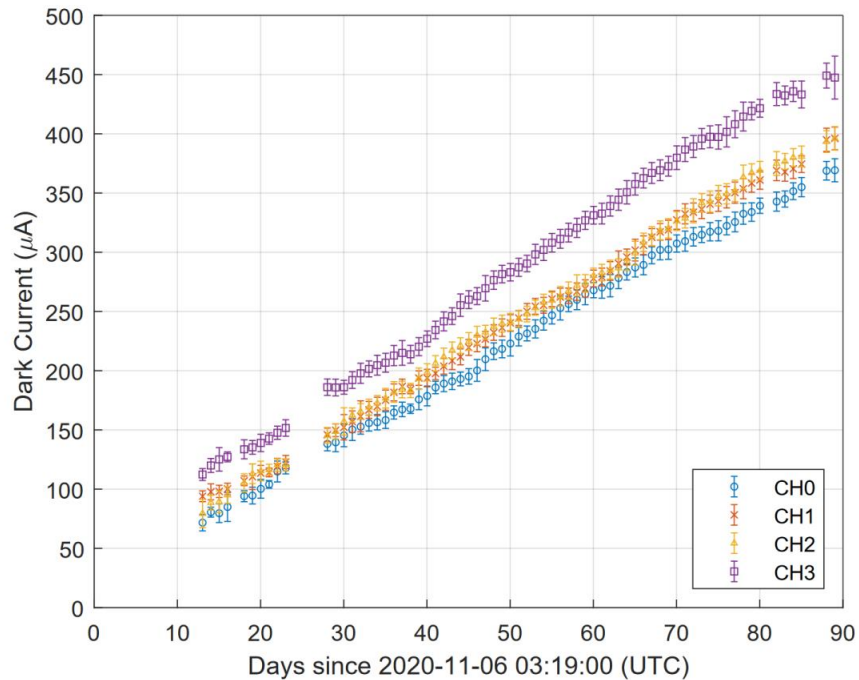


Figure 5: SiPM dark current (I_{dark}) at 28.5 V bias voltage as a function of time. The values are the sum of 16 SiPMs in the same channel and are unified to 5°C.

- Linear relationship between I_{dark} and radiation damage (dose or particle fluences) is found (model MicroFJ-60035-TSV):

GRID-02: ~ 93/96/98/110 μA / (year \cdot chip) @5 °C & 28.5 V

 ~ 50 μA / (year \cdot chip) @-20 °C & 28.5 V

SIRI-1: ~ 132 μA / (year \cdot chip) @28.5 V, temp. not mentioned (7.75 °C?)

- An approximate empirical equation around 5 °C:

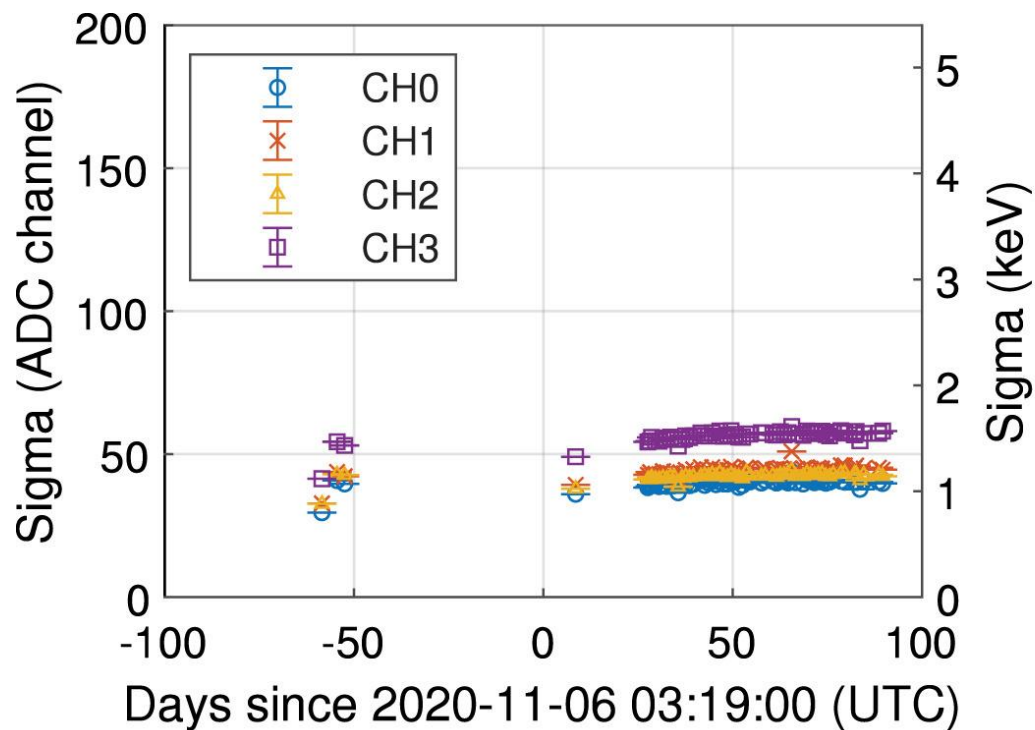
$$I_{\text{dark}}(\mu\text{A}) = 16 \cdot (0.2678 \cdot \text{Time}(\text{Days}) + 2.091) \cdot e^{0.03475 \cdot (T - 273.15 - 5)}$$

- **with SHIELDOSE-2 model, SPENVIS calculates cumulative dose:**

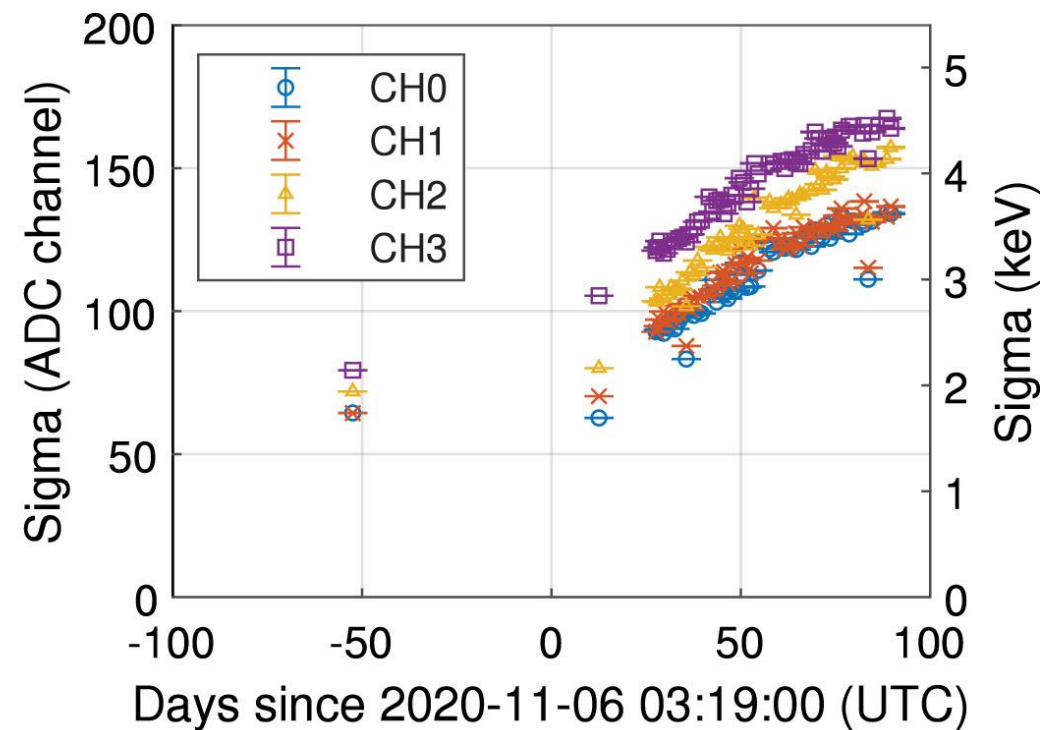
$$I_{\text{dark}}(\mu\text{A}) = 16 \cdot (195.5 \cdot \text{Dose}(\text{Gy}) + 2.091) \cdot e^{0.03475 \cdot (T - 273.15 - 5)}$$

| Mission | Operating temperature (° C) | Operating voltage (V) | Orbit | Dose in silicon (Gy) | Dark current increase rate per SiPM chip (μ A/year) | |
|---------|--------------------------------|--------------------------|--------------------|-------------------------|---|-----------|
| | | | | | Measured | Estimated |
| SIRI-1 | 7.75 | 28.5 | 567 × 589 km 97.7° | 0.9 | 132 | 194 |
| GRID-04 | 5 | 28.5 | 523 × 550 km 97.5° | 0.9 | 182 | 176 |

Noise Assessment Through Charge Injection



(a) bias voltage off



(b) 28.5 V bias voltage

- Overall noise includes dark count noise and electronics noise

$$\sigma_{\text{total}}^2 = \sigma_{\text{dark current}}^2 + \sigma_{\text{electronics}}^2$$

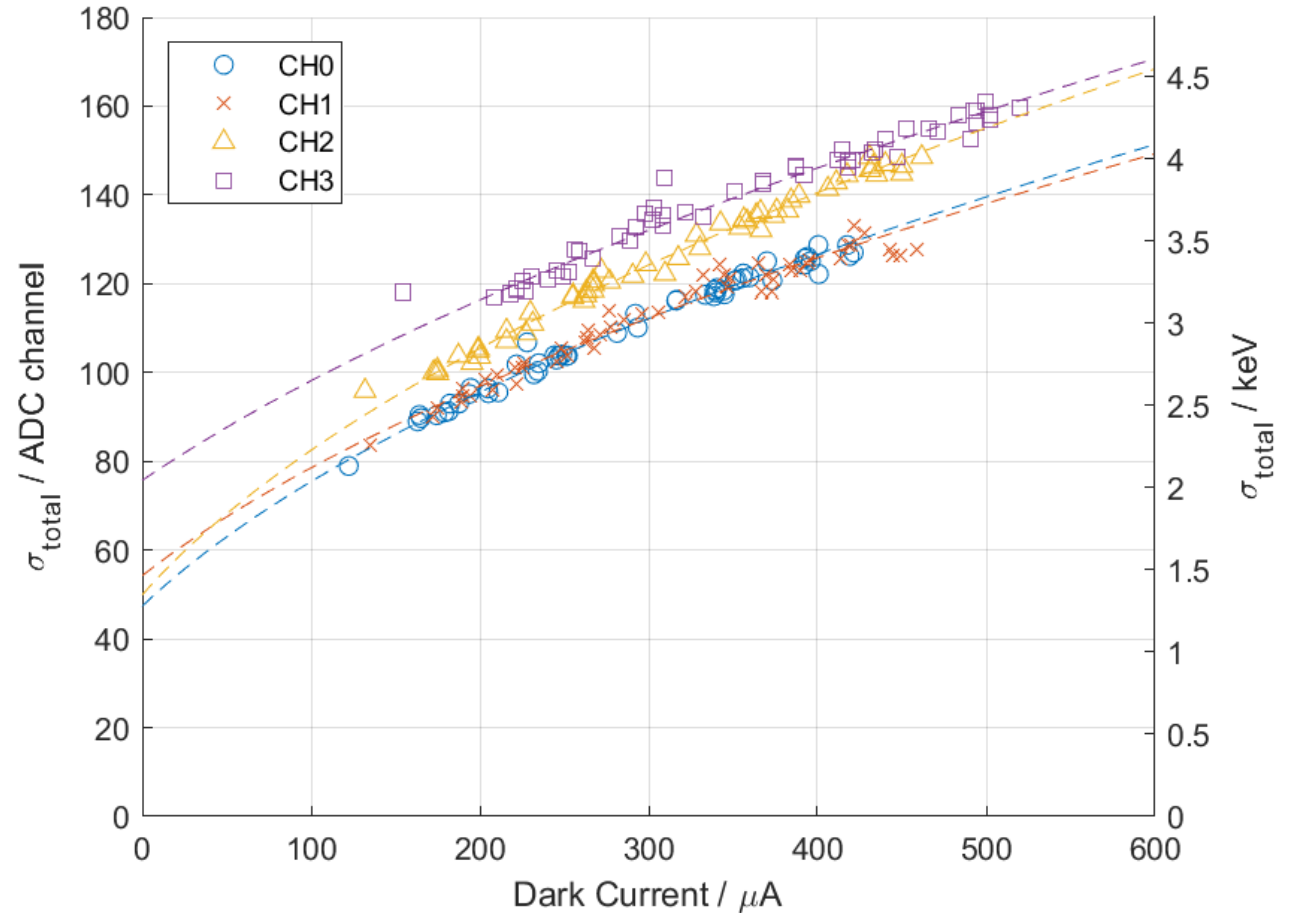
Noise Assessment Through Charge Injection

- Campbell's theorem gives

$$\sigma_{\text{dark current}}^2 = DCR \cdot (\text{Gain} \cdot e)^2 \cdot \int h^2(t) dt$$

$$\propto I_{\text{dark}} \cdot (V_{\text{bias}} - V_{\text{BD}})$$

GRID-02 energy-channel calibration result

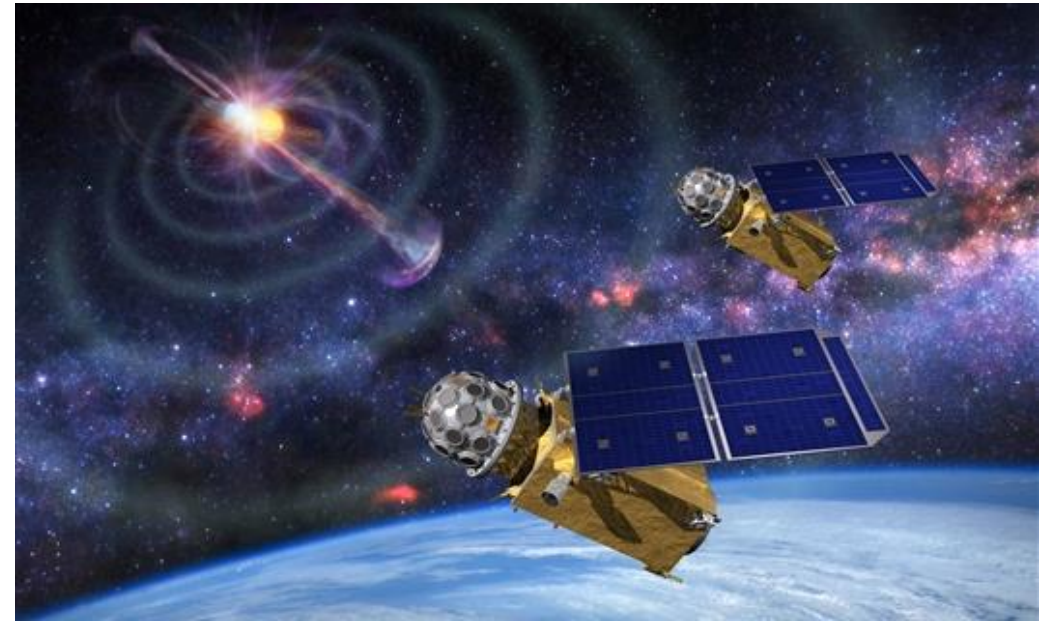


Noise (sigma) increasing rate: ~ 7.5 keV/year

微纳卫星 & 大科学项目



极光计划 & eXTP



天格计划 & GeCAM

Poalar2

空间实验平台架构

主试验载荷
SENSOR

天文探测

- 提供空间环境辐射数据在轨实时采集服务，为太空资源利用收集信息

标准载荷平台
DAQ



卫星平台
Satellite

多个扩展模块
EXT

芯片辐照

- 基于在轨实时空间环境辐射数据开展芯片辐照测试业务，为太空工业打造高可靠COTS器件库



天格传感器

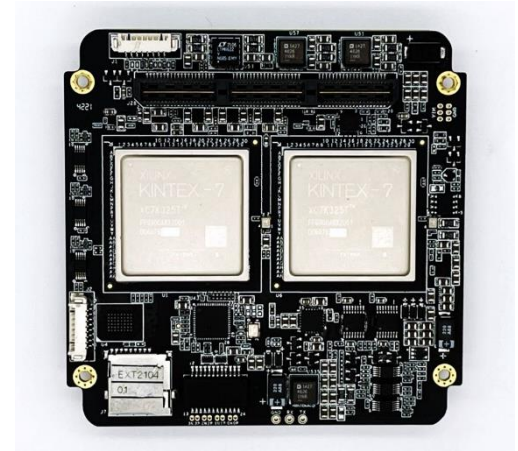
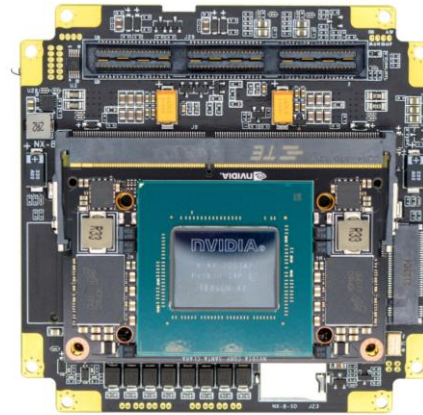
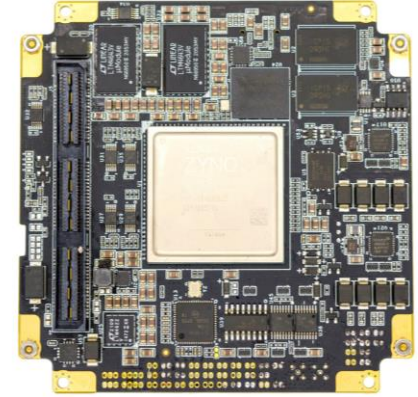
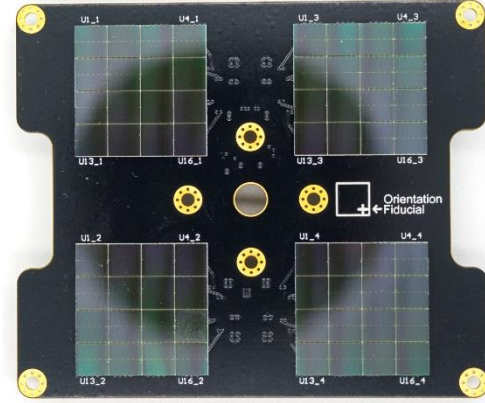
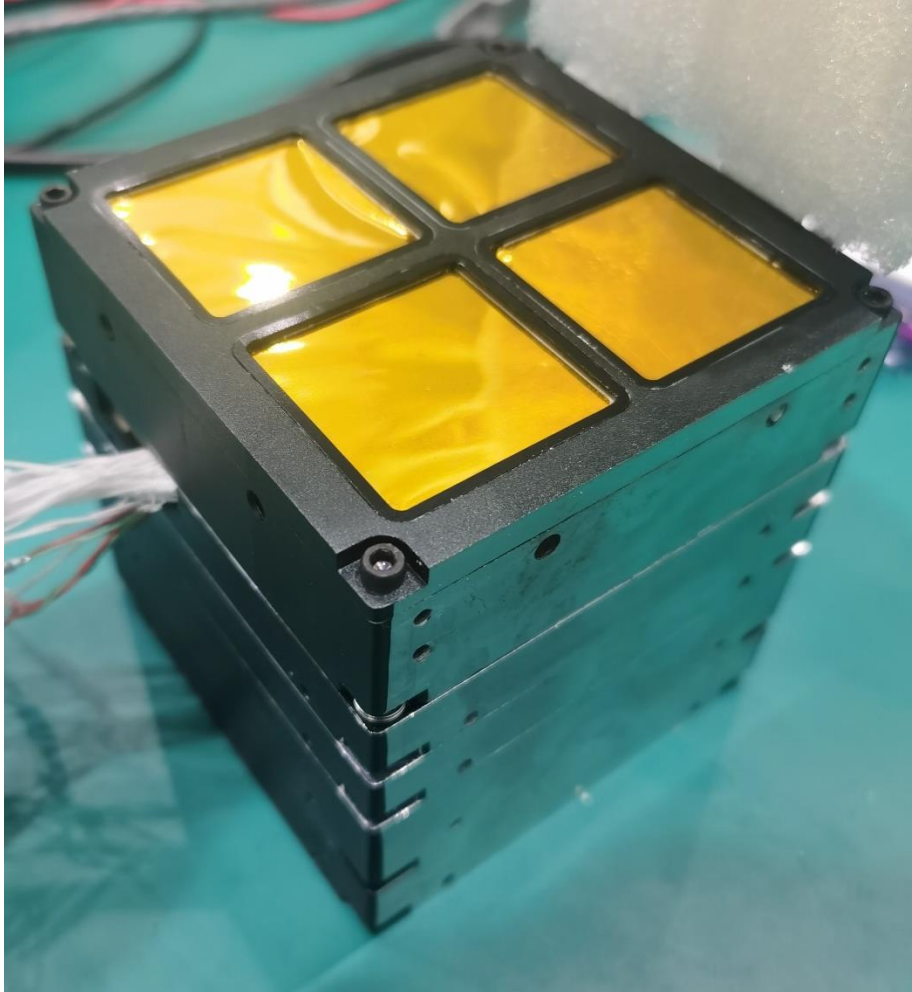
通用数采平台

待测GPU计算模组

待测激光通信模组

天格05B载荷架构图

天格05B实际案例



- 天格计划是一个以学生团队为主体的空间科学项目，以寻找与引力波或快速射电暴成协的伽马暴为主要科学目标，由清华大学发起、国内多所高校和研究所共同参与。近5年先后成功发射4颗探测器载荷，并观测到GRB 210121A等首批伽马射线暴事例。
- 微纳卫星空间探测技术发展迅速，微纳卫星空间天文科学观测成为了可能。
- 微纳卫星可以提供探测器电子学的在轨辐射损伤实验和空间技术验证平台。
- 极光计划、天格计划，与eXTP、GECAM、POLAR2等国家级空间科学项目合作紧密，在科学观测、技术验证等方面有望发挥更多作用。



THU Gamma Ray
Integrated Detectors

谢谢!

