BurstCube: Concept, Performance, Status

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*A mission designed for gamma-ray counterparts to gravitational-wave events

Short Gamma-Ray Burst (SGRB) Science

- Jets that power GRBs are ultra-relativistic, highly-collimated beamed outflows
- Duration of light curves of **SGRBs are less than 2 seconds**, otherwise they are long GRBs
- Binary neutron star (BNS) mergers are progenitors of short gamma-ray bursts (SGRB)
- **SGRBs provide electromagnetic context** to gravitational-wave (GW) events from GW interferometers such as LIGO, Virgo, **KAGRA**, …
  - Radio (≥ MHz), UV, optical, IR, x-ray, gamma-ray (≤ MeV) **observations 1.7 sec to +260 days**
  - **GW170817 (aka G298048):** GCN Circ archive: LIGO, Fermi-GBM, INTEGRAL, IceCube, AstroSat-CZTI, IPN, Insight-HXMT, Swift-BAT, AGILE, optical, Fermi-LAT, VLA, Swift-UVOT/-XRT, MAXI/GSC, ASKAP, NuSTAR, CALET, H.E.S.S., LOFAR, LWA, HAWC, Pierre Auger Obs, uGMRT, KONUS-Wind, OVRO, HST, VLBI, MeerKAT
  - Additional interests at ICRC 2019: MAGIC, ANTARES, CTA, SuperTIGER, HNX
- SGRBs provide understanding of jet physics. With light curves and spectra we can understand GRB **energetics, emission mechanisms, jet composition, jet structure**

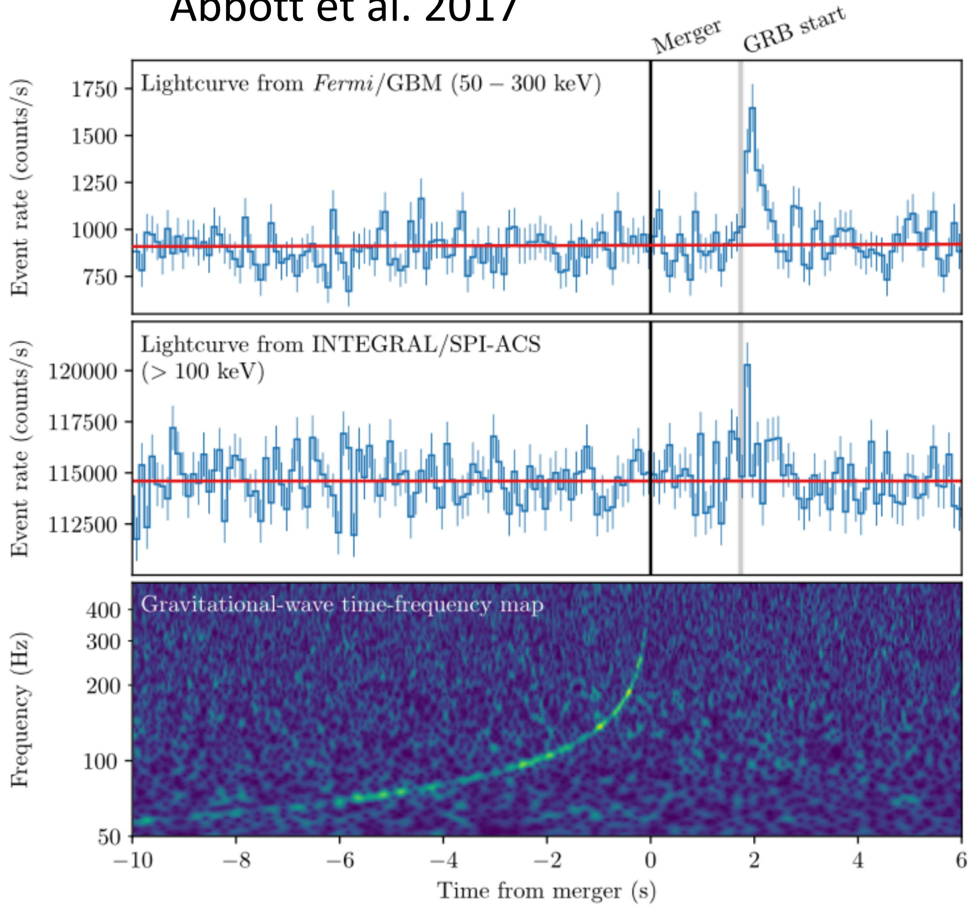
Search "astro2020 multimessenger" arXiv

https://gcn.gsfc.nasa.gov/burst_info.html

Coincident Detection of a SGRB and GW

- Fermi-GBM had the first verified joint detection of a SGRB (170817a) with a GW (170817)
  - GW was from a binary neutron star merger (BNS)
  - Other GW types: binary black hole (BBH), neutron star black hole (NSBH)-not detected
  - GRB 150101B is a candidate without a GW detection (similar features)
- Are the spectral properties observed in GRB 170817a common to all compact object merger events?
- What is the origin of gamma-ray emission?
- Are jets cocoon or structured?

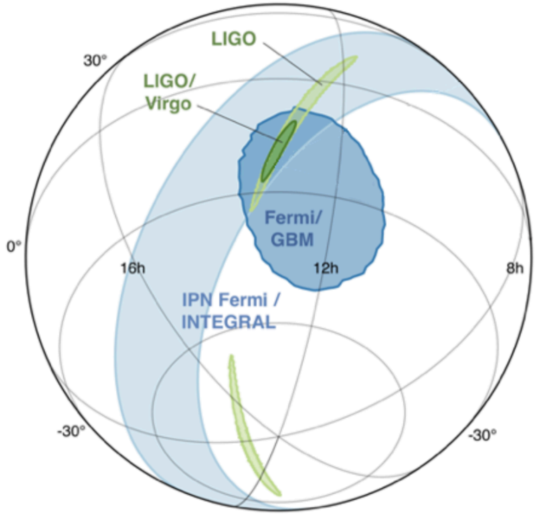
Abbott et al. 2017

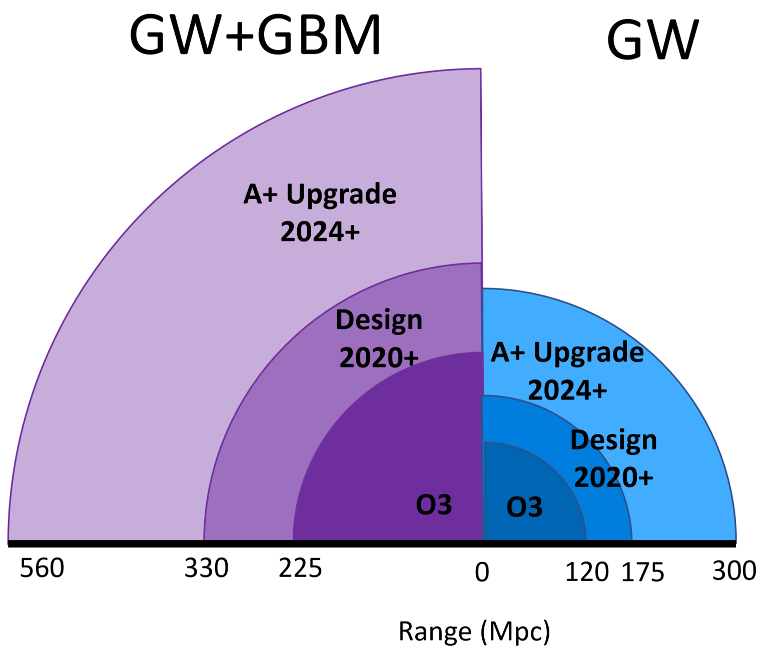


Joint GRB-GW

- Independent confirmation of GW triggers
- Improved localization constraints in real-time
- Additional NS mergers detected through GWs
- More science!

Joint LIGO/Virgo sky map 5 hours post merger GW170817

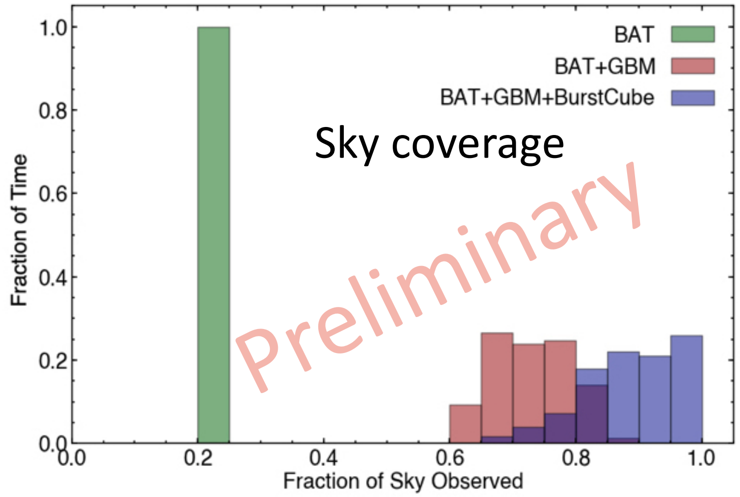




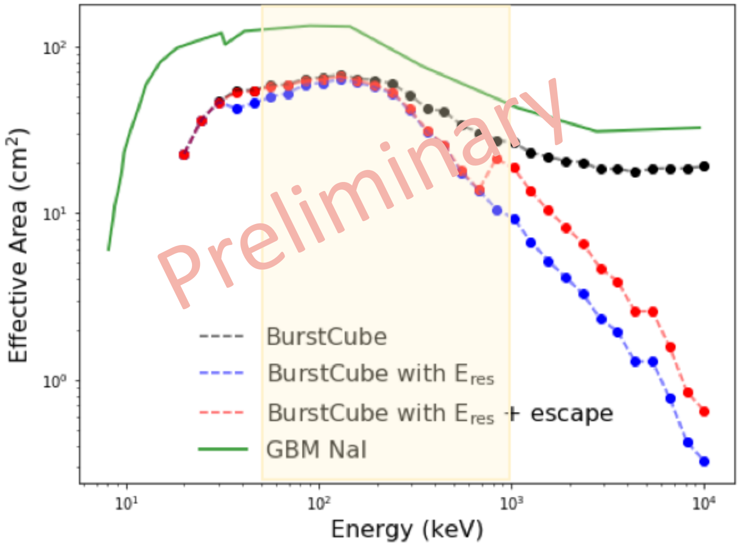
BurstCube: A CubeSat for GW Counterparts

- Current science needs from gamma-ray experiments are continued sensitivity and broad-band sky coverage
- BurstCube will enable and complement future GRB, GW, and BNS science by **detecting, localizing, and characterizing SGRBs**
- BurstCube will measure energy response of GRBs 50 keV - 1 MeV
- BurstCube will provide rapidly available high-resolution temporal, spectral and location data; expecting ~20 SGRB/year
- BurstCube is currently in its development and testing phase to prepare for launch readiness in the fall of 2021

Racusin et al. arXiv:1708.09292v1



Simulated BurstCube Effective Area



Total sky coverage for GRBs is enhanced with BurstCube

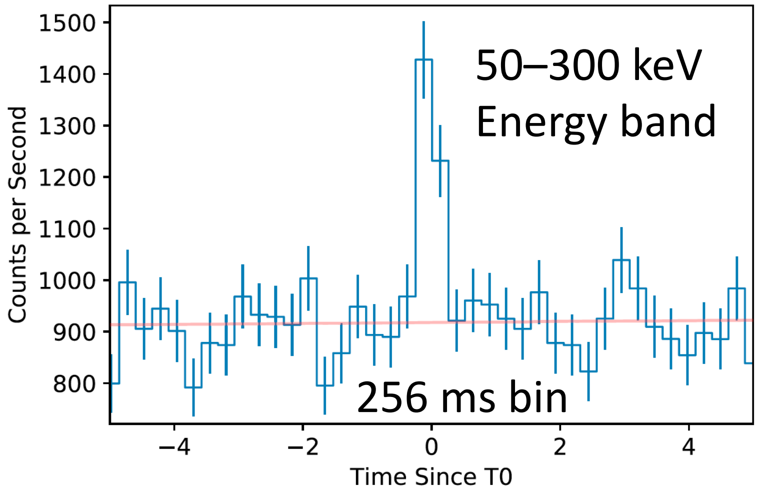
BurstCube will produce light curves similar to Fermi/GBM

BurstCube's effective area represents sensitivity to gamma-rays and is comparable to Fermi/GBM (green line)

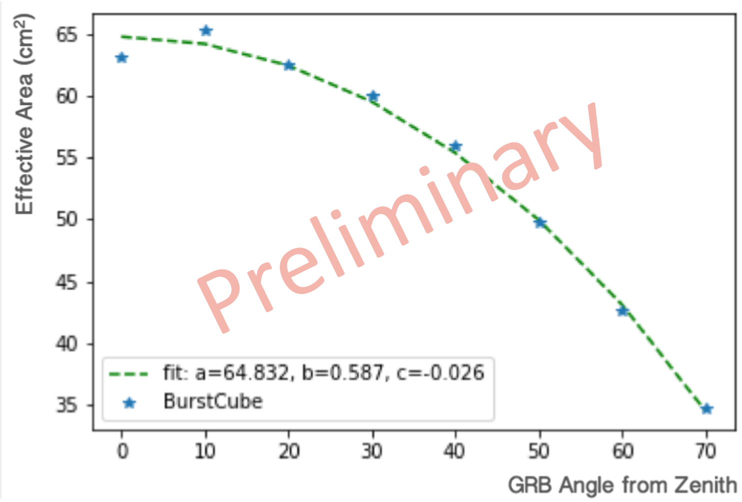
Cosine dependence on GRB incident angle represents BurstCube's localization

GRB Localization is based on relative rates between the detectors

Goldstein et al. 2017
Fermi/GBM light curve of GRB170817A

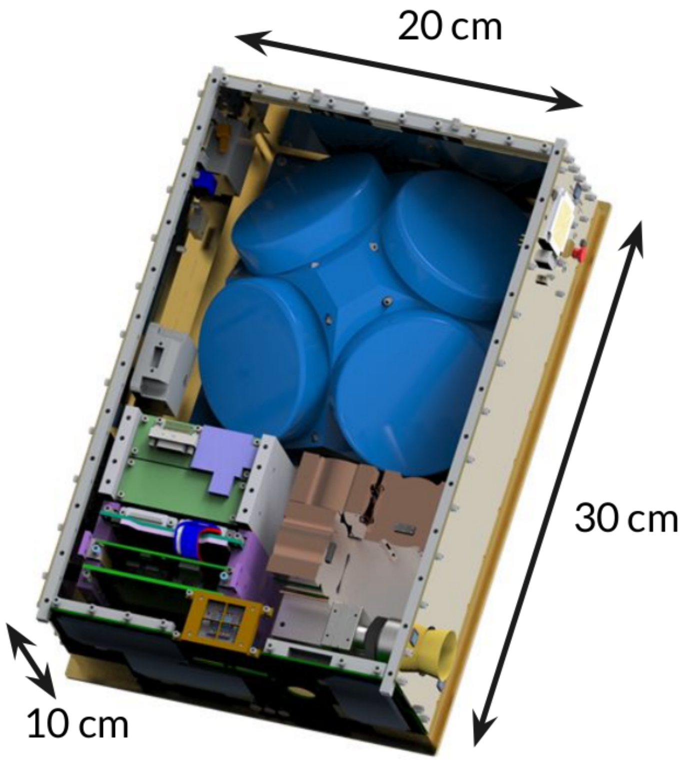


Simulated BurstCube cosine dependence



BurstCube: Instrument Design

- BurstCube is a 6U CubeSat
  - Deployable Solar Panels & full ACS
  - Low-earth orbit, Nanoracks deployed (ISS orbit)
- Instrument Package
  - 4 CsI(Tl) scintillator crystals coupled to arrays of low-power Silicon Photo-Multiplier (SiPM)s with custom electronics
  - 90 mm diameter, 20 mm thick
  - 116 SiPMs summed per crystal
- Communications
  - BurstCube will relay data to the ground via TDRSS
    - 5-15 minute goal with an updated Vulcan radio



Launch Delivery Goal: Late 2021

BurstCube Spacecraft Components

Solar Arrays

Batteries

Power Distribution

Radio

Temp Sensors

C&DH
-Flight software
-On board computer
-Special services

ACS
-Sun sensor
-reaction wheels
-Star Tracker
-GPS

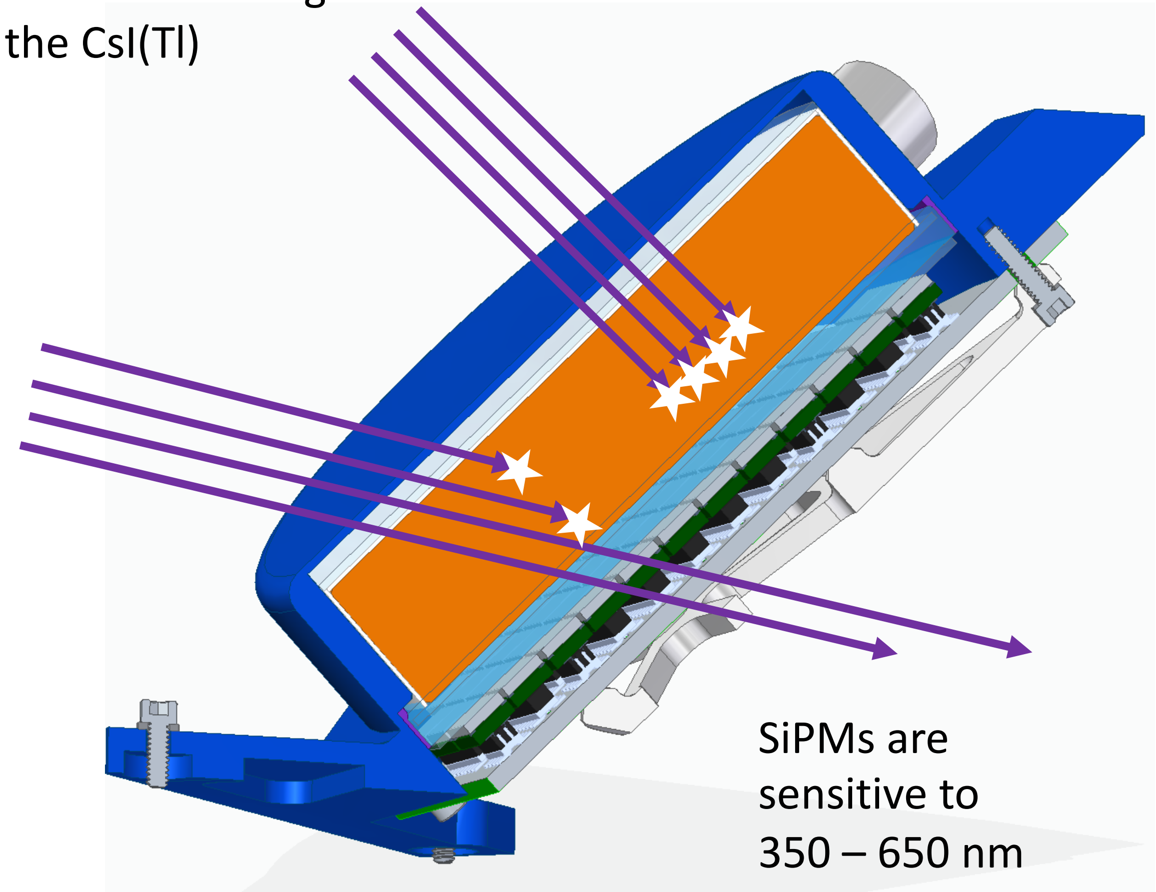
BurstCube Instrument

Mass, power, volume budget is low compared to large satellites
BurstCube instrument (4U) uses ~ 4 W power and mass is 4.5 kg

BurstCube Detector

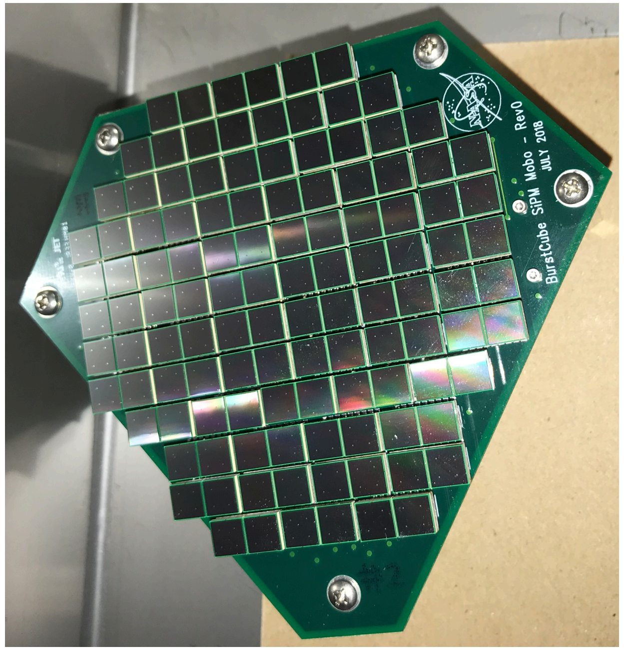
Gamma-rays produce 475 – 625 nm light in the CsI(Tl)

90 mm diameter
20 mm thick



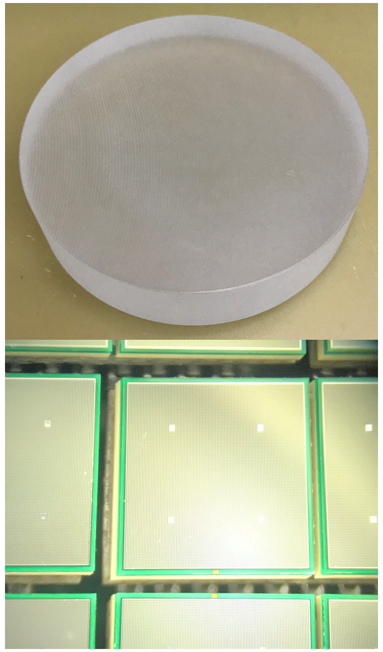
SiPMs are sensitive to 350 – 650 nm

116 SiPMs summed per crystal on the BurstCube front-end electronics (FEE) board



Summed signal is proportional to energy of incident gamma-ray

Proteus CsI(Tl) crystal



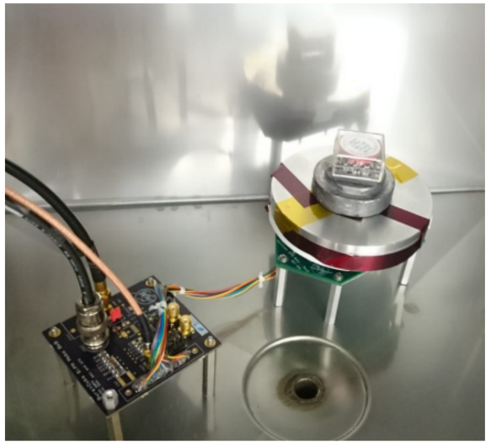
Hamamatsu
S13360-6050VE
6 x 6 mm^2

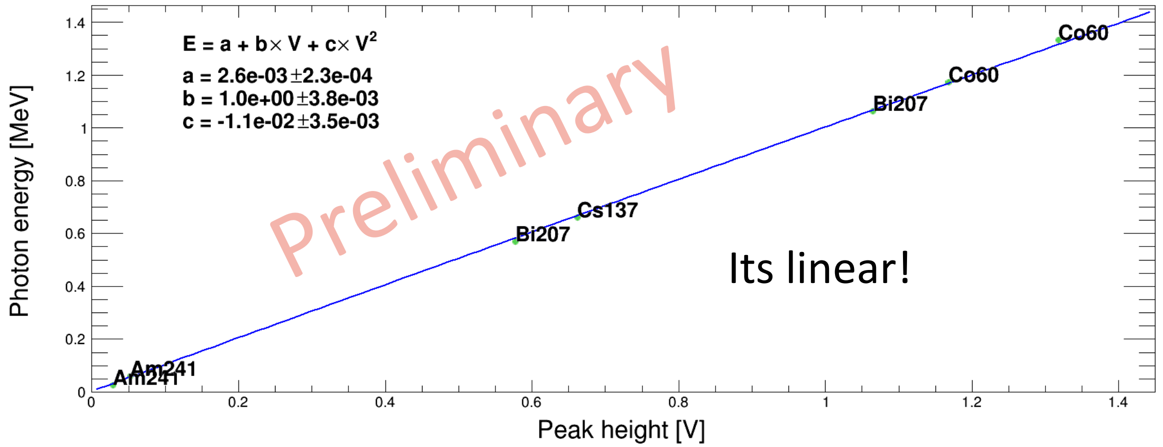
BurstCube 116-SiPM Array FEE Board

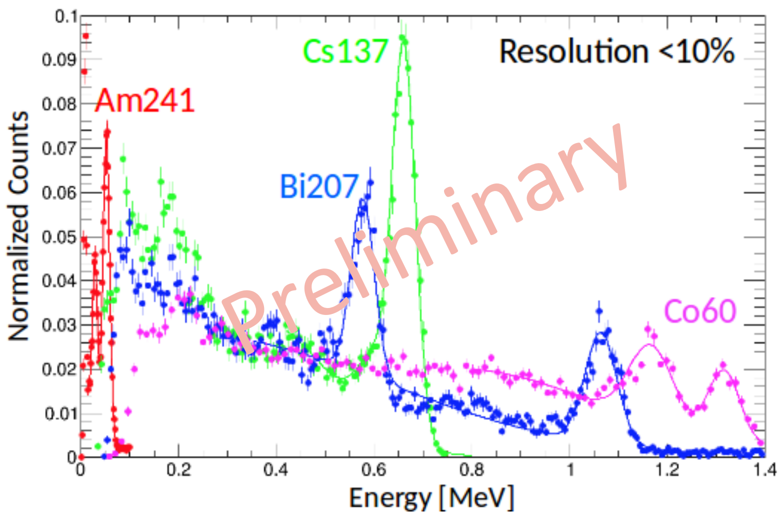
SiPM FEE board was tested with gamma-ray radiation sources 26 keV – 1.33 MeV

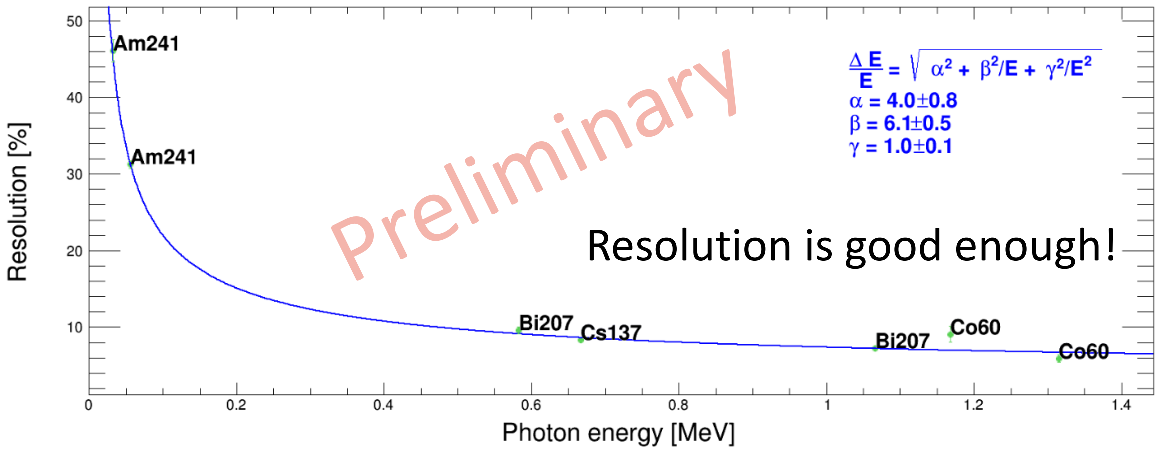
Temperatures tested span -8 °C to +50 °C

I2C sensor integrated on FEE

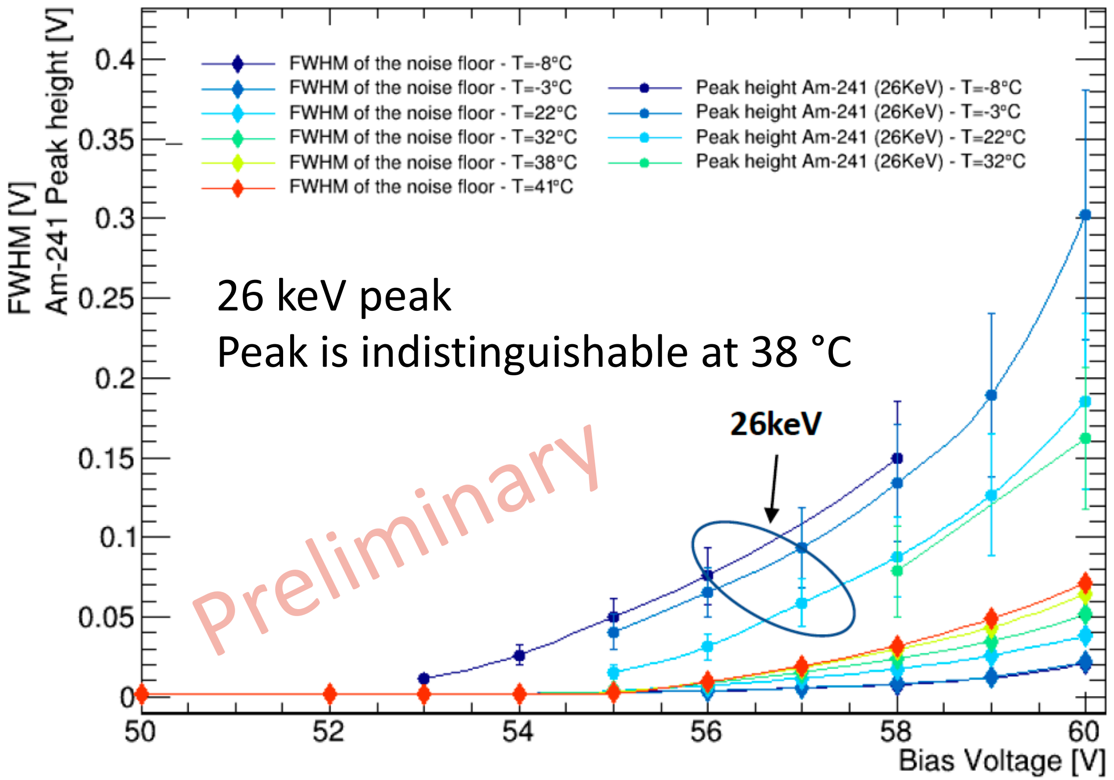


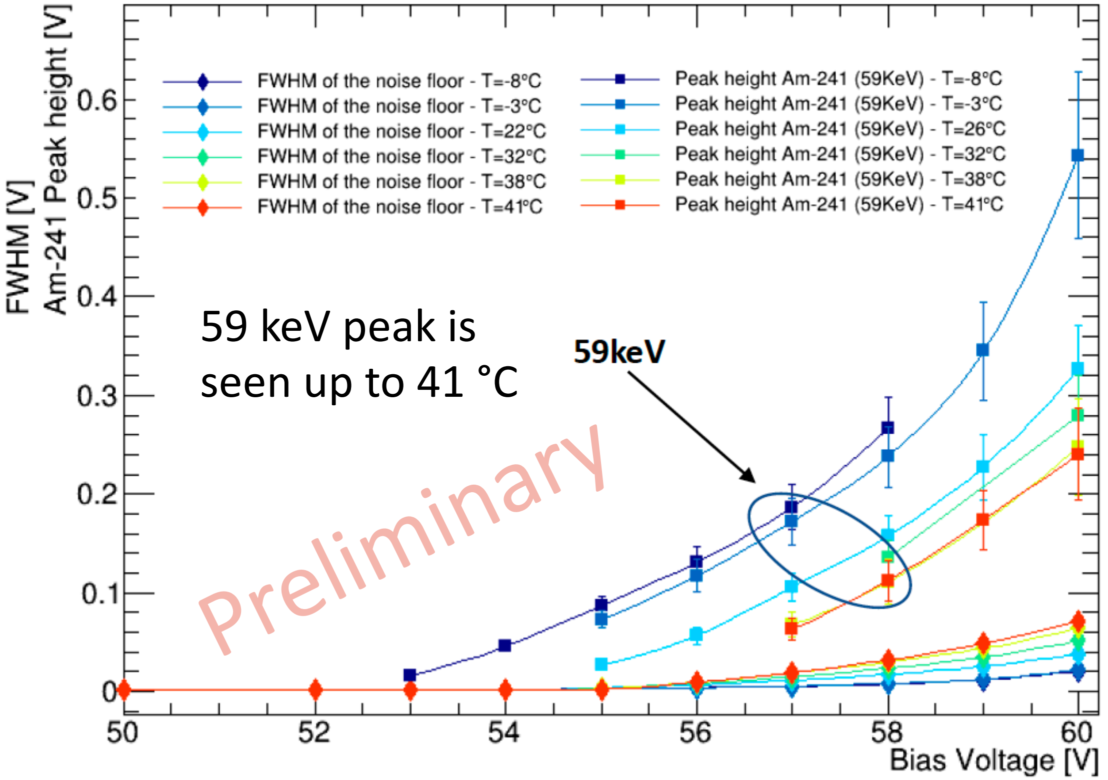






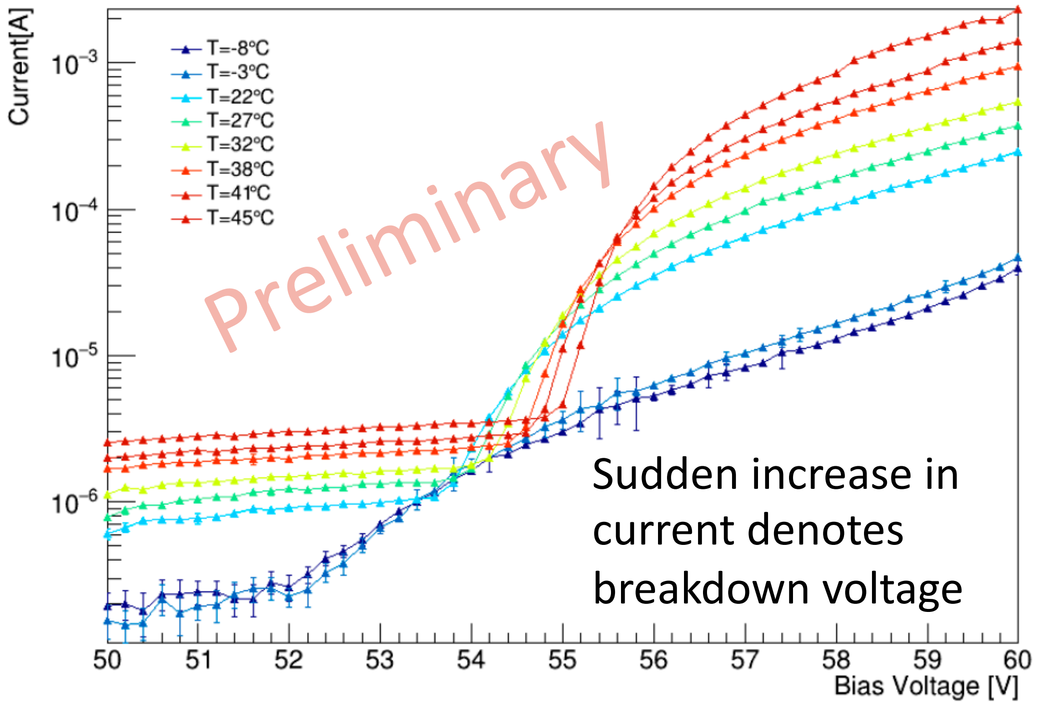
SiPM FEE Noise with Am-241 Source

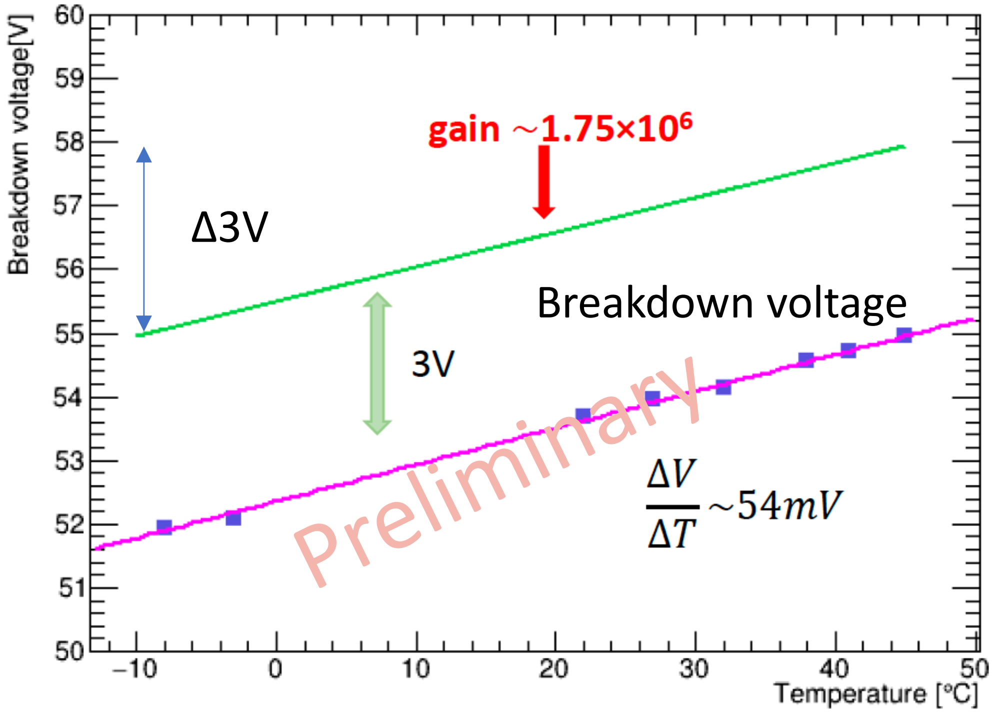




- Gaussian fits to noise (FWHM) and peak (mean) are plotted vs. applied bias voltage from -8 °C to +41 °C
- Thermal analyses show expected temperature range during BurstCube flight is within +5 °C to +33 °C
- **BurstCube can operate beyond the required energy range for the mission**

Breakdown Voltage of SiPM FEE Measured

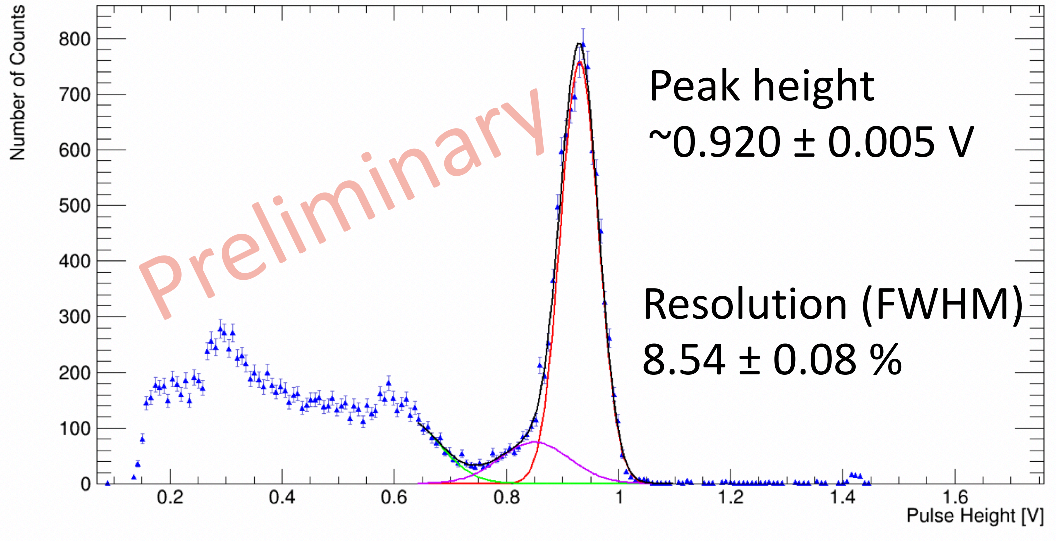


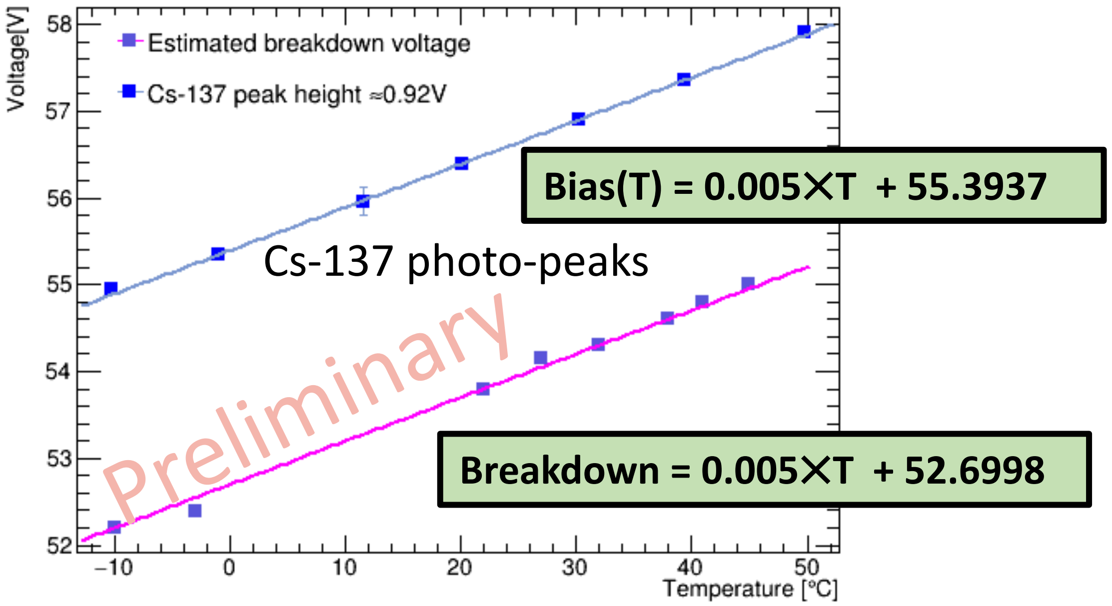


- SiPM breakdown voltage increases with increasing temperature and the gain must be compensated by adjusting the applied bias voltage
- **Measured breakdown voltage** sensitivity to temperature is linear for BurstCube SiPM array

Test of Compensation with Cs-137

Pulse heights shown for -5 °C and +33 °C





- Bias voltage is adjusted for each temperature to match pulse heights with Cs-137
- Overvoltage of ~2.7 V results in constant gain
- **Bias voltage can compensate for temperature variations well within the temp range of the mission**
- Temperature compensation was successfully applied during the thermal vacuum tests

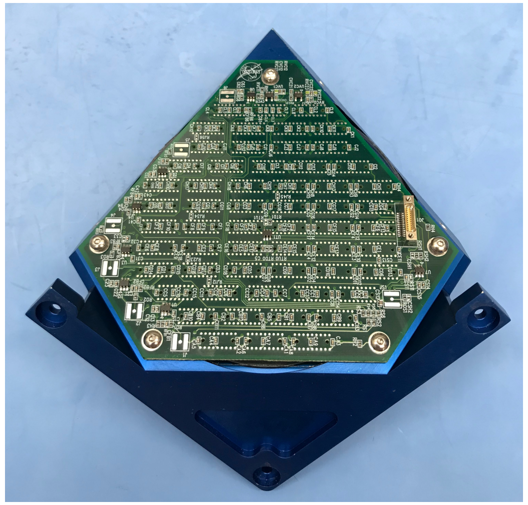
Pre-launch Environmental Tests*

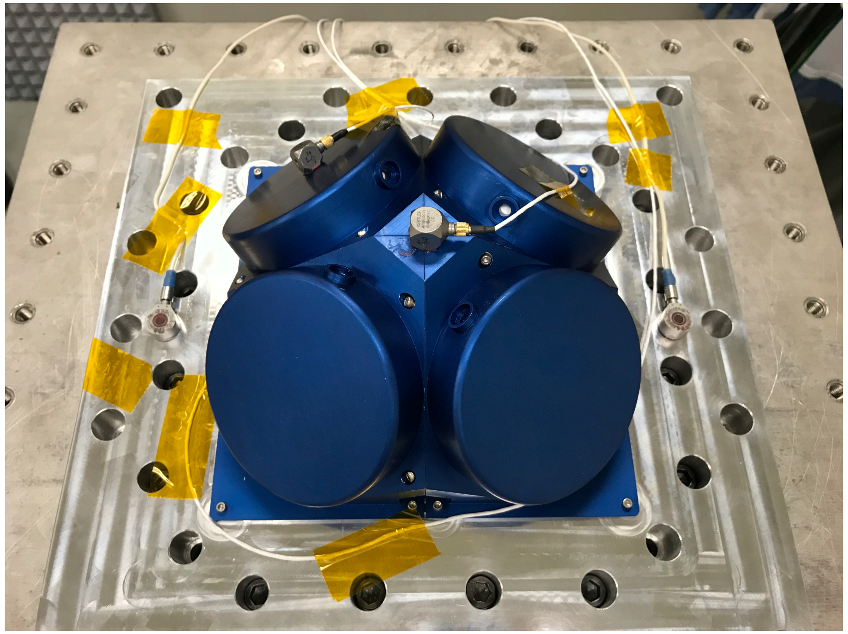
- Vibration Tests (vibe)
  - Verifies if instruments can survive rocket launch and deployment
- Thermal-Vacuum Tests (TVAC)
  - Verifies instrument performance in space vacuum over temperature variations
  - Tests workmanship of parts
  - Includes non-powered survival temps (-10 °C, +50 °C), hot operational (+45 °C), and cold operational (-5 °C)
- All tests successfully follow GEVS and were completed July 2019

- Detector functionality tests and analysis verify success or failure (not an option).
  - Measure energy response with a gamma-ray radiation source
  - Tests ran during TVAC with temperature compensation applied
- **Following an independent review of the technology readiness level (TRL), BurstCube will be at TRL-6** (TRL-1: do unicorns exist?, TRL-9: this unicorn is from space)

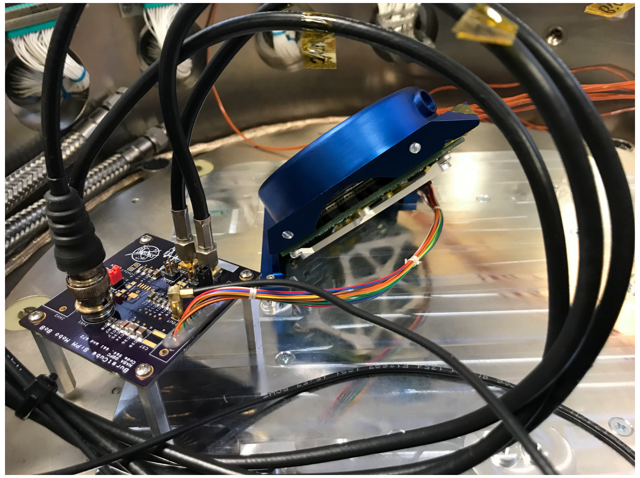
*per NASA Goddard's General Environmental Verification Standard (GEVS)

Proto-flight Instrument Quarter

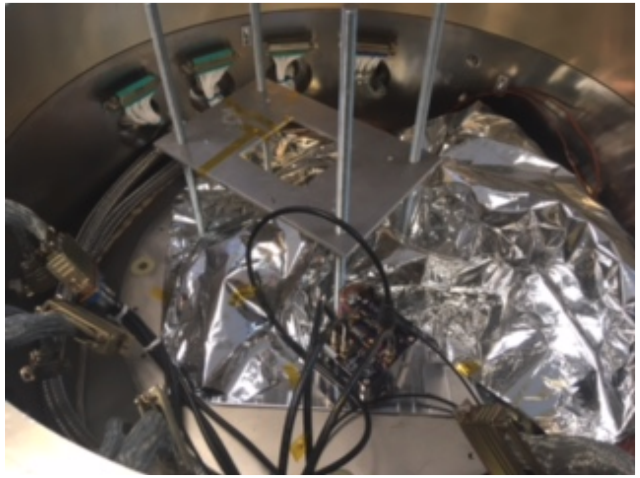




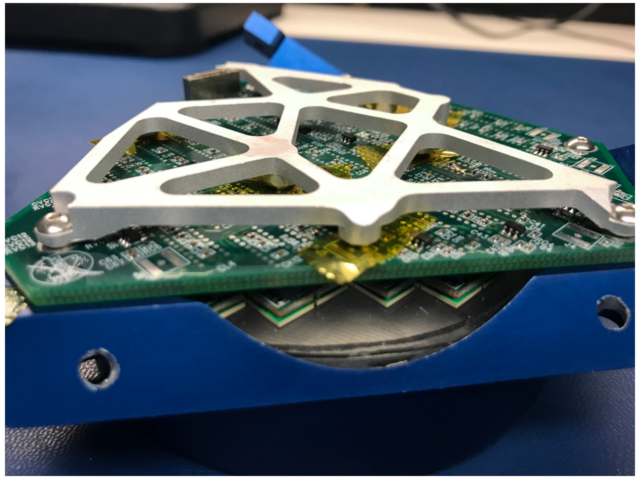
BurstCube on the vibe table



Proto-flight in the TVAC chamber

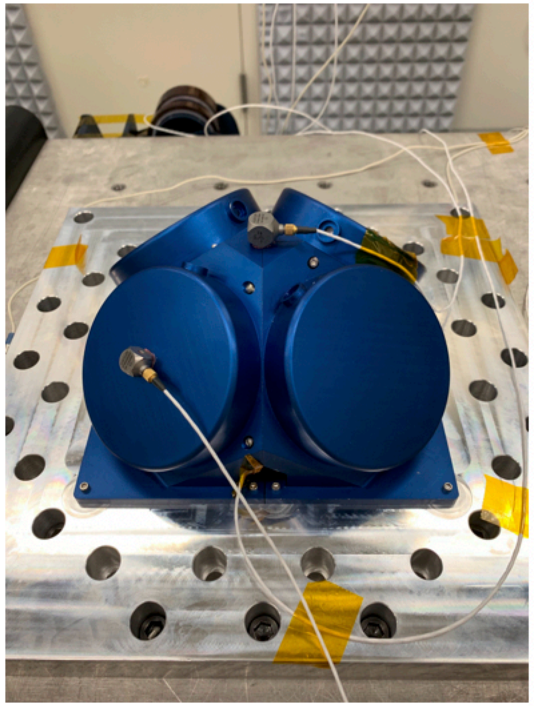


The real experts



Sideview of instrument quarter

BurstCube Current Status



- First BurstCube proto-flight detector has been constructed
- Design, integration and test of the 116-SiPM FEE board has been completed and **exceeds requirements**
- Proto-flight detector has **successfully completed environmental** vibration and thermal vacuum testing in July 2019
- Pending an independent TRL review, **BurstCube will be at TRL 6**
- Instrument digital (FPGA) electronics design and prototyping has begun
- Requirement documentations for interfaces to the spacecraft, Instrument flight software, ground pipelines and analysis, and calibration and simulations are in work
- **Flight hardware build** is expected to begin end of this year
- **Expected delivery of spacecraft to launch vehicle is planned for 2021**

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