Solar Neutron and Gamma-ray Detector for a 3U CubeSat

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ICRC 2019 @ Madison, USA, July 30th, 2019

Agenda

- Introduction
  - Importance of solar neutron observations
  - Past observations
- Detector design and detector realized for the 50-kg class satellite ChubuSat-2
- Detector for a 3U (10x10x30cm) CubeSat and its status

  SOlar Neutron and Gamma-ray Spectroscopy (SONGS) Mission
- Summary

Solar Neutron Observations

- Solar flares: caused by magnetic reconnection

→ But how, when and where are particles

(especially protons and heavy ions) accelerated?

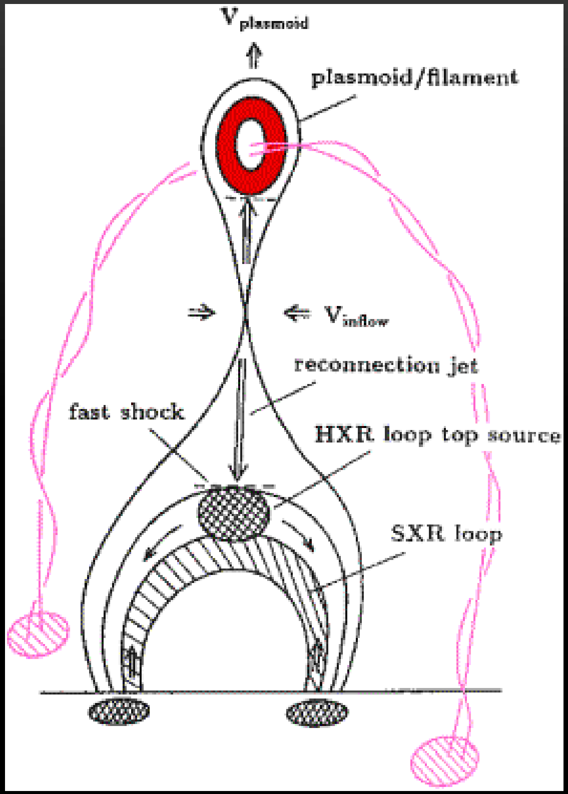
- Solar flares have been mainly studied via

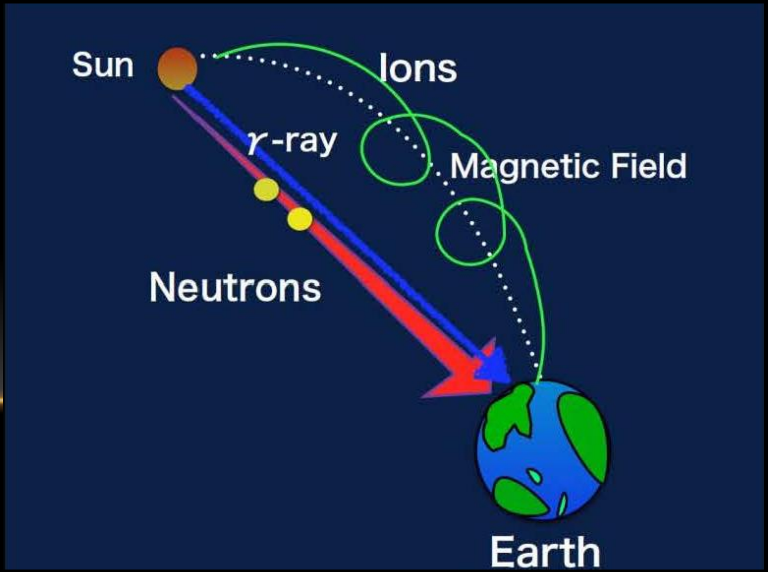
★ Electro-magnetic waves

(radio, optical, UV, X / gamma-rays etc..)

★ Charged particles (protons, electrons, ions)

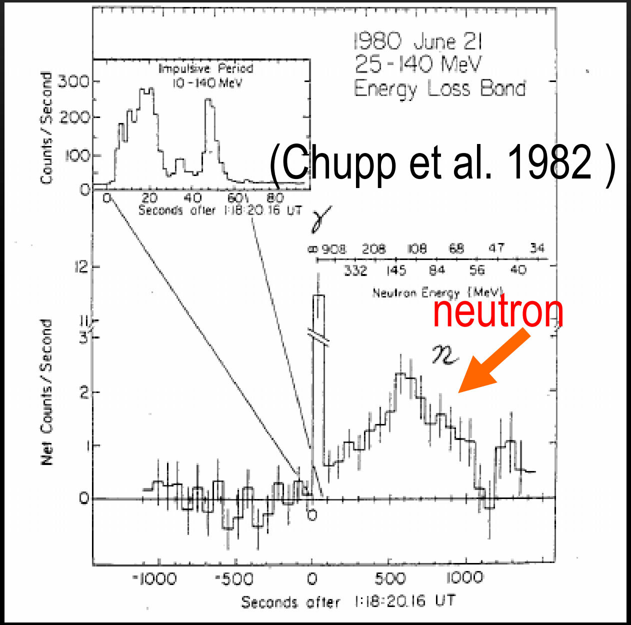
→ **Neutrons can be direct probes for understanding ion acceleration mechanisms in the Sun.**





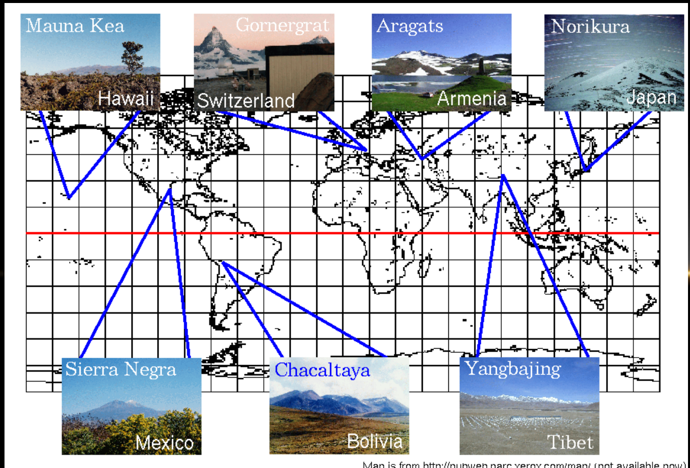
Review of Solar Neutron Observations

- Discovery of solar neutrons with the Solar Maximum Mission (SMM) in 1980 (Chupp et al. 1982)
- Observations have been carried out from
  - ★ Ground: a network of neutron telescopes at high altitude
  - ★ Space: FIBer detector of the SEDA-AP on the International Space Station (ISS) Aug. 2009 – Apr. 2018 (Muraki et al. 2012, Koga et al. 2017)



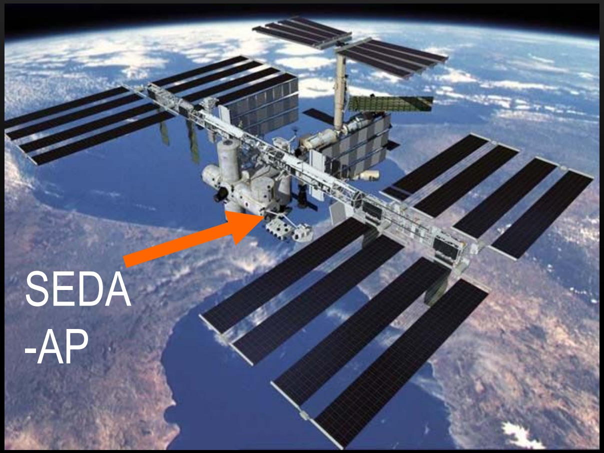
→only ~50 (12 for Ground + 36 for Space) detection so far

+ No space mission in a near future

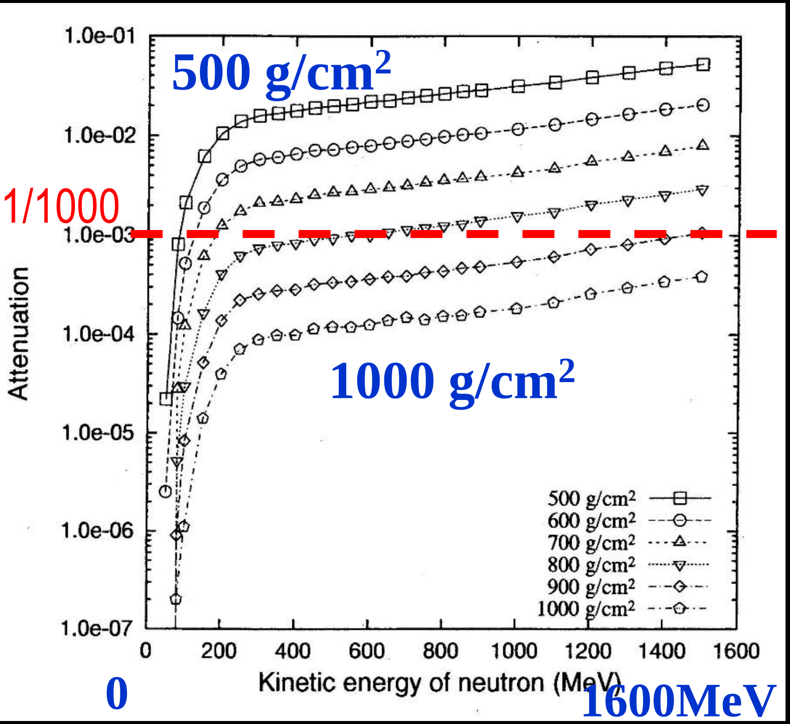


Merits of Microsatellite Observations

1. The SEDA-AP observations on the ISS were affected by secondary neutron background produced in the ISS with a mass of 420 ton. → A smaller satellite (<100 kg) should have smaller neutron background.



2. Neutron fluxes on the ground are strongly attenuated by a factor of 1/100-1/1000 by the Earth atmosphere.
   → Good statistics even for small detector in space
   e.x. 1 m^2 @ ground telescopes
   VS 10-100 cm^2 @ space



3. Long solar-pointing observations

→ **High sensitive observations are possible using micro-satellites.**

Detector Concept (I)

★Our detector is sensitive to both neutrons and gamma-rays.

★Detection Principle

1. Neutron Detection Part: Multi-layered Plastic Scintillator Bars

- Detected by elastic scattering with Hydrogen atoms
- A recoiled proton loses its energy (Ep) in the bars.

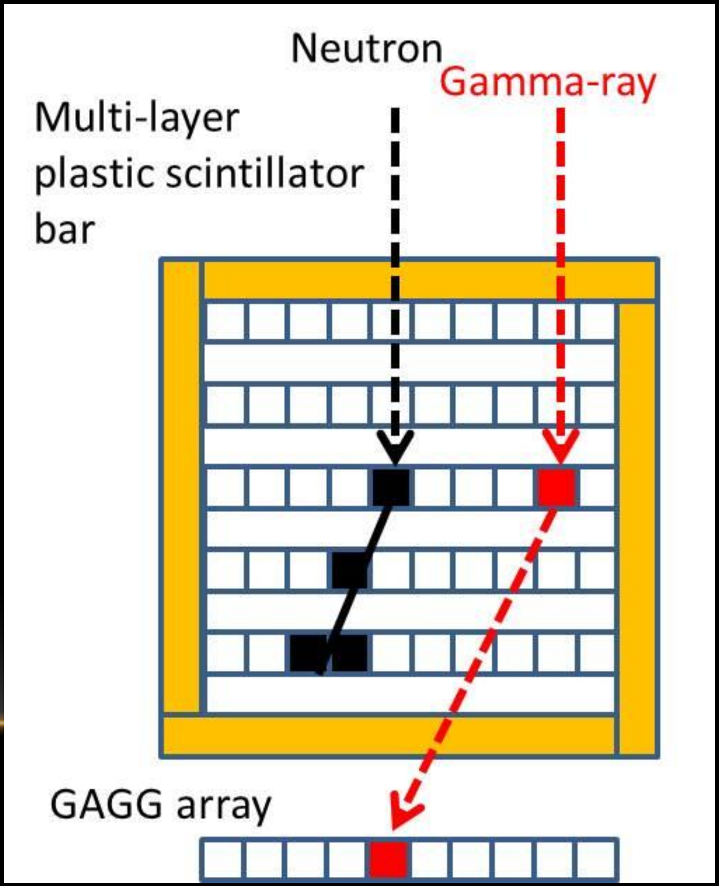
  Incident neutron energy $En = Ep / \cos^2\theta$
- The same technique is used in SEDA-AP FIB.

2. Gamma-ray Detection Part: Inorganic Scintillators

- Detected mainly via Compton scattering.

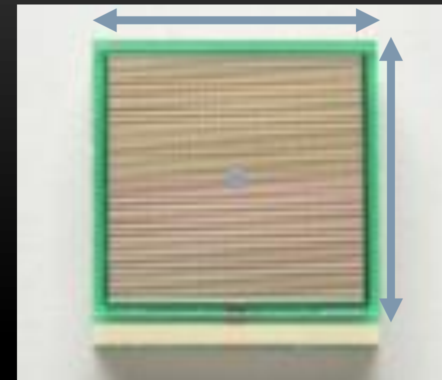
3. Anti-coincidence Detector Part

- Covered by plastic scintillators to reject charged particles.



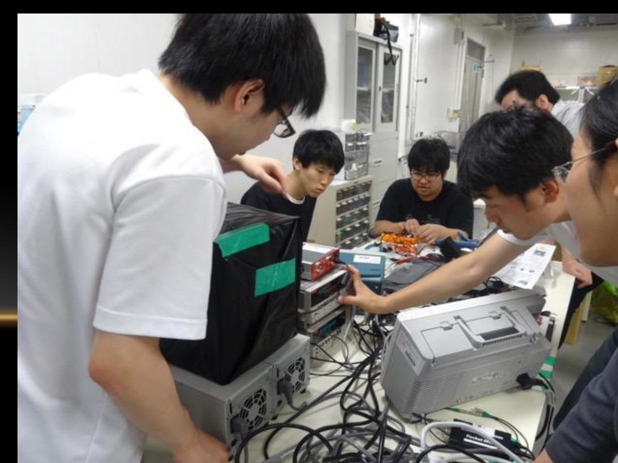
Detector Concept (II)

- New sensor technologies have been used
  - Si PM (MPPC in Hamamatsu K.K.)
    - Very compact and light weight
    - Low bias voltage 55 V (cf. ~1000 V for PMT)
  - GAGG scintillator ($Gd_3Al_2Ga_3O_{12}$)
    - High density: 6.63 g/cm^3
    - High Light Output: ~57000 photons/MeV
- This mission was originally proposed by graduate students who belong to the educational program.



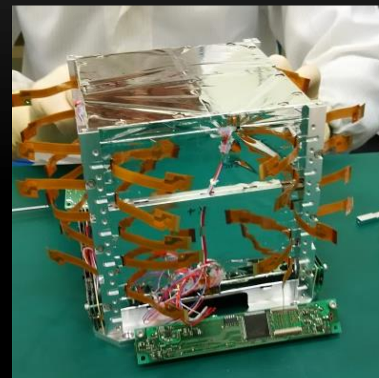
Leadership Development Program for Space Exploration and Research

Nagoya University Program for Leading Graduate Schools

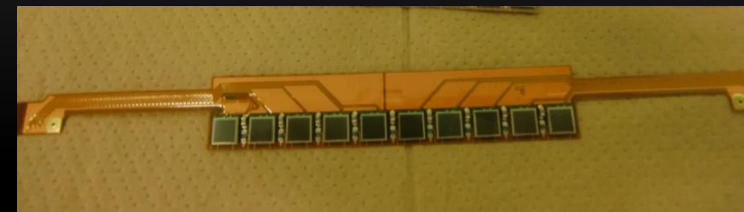


Realized Structure for the 50-kg class satellite ChubuSat-2

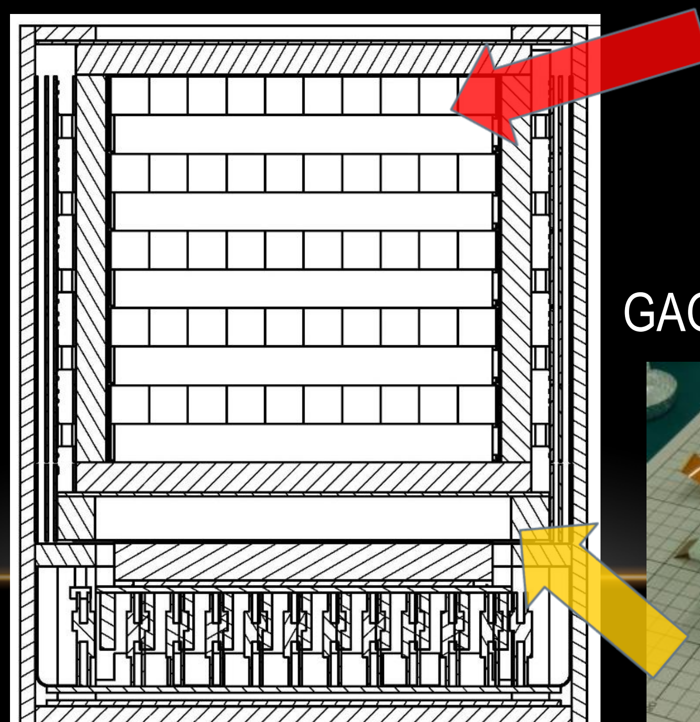
- Sensors and electronics packaged in an aluminum box with a size of 15x17x18.5 cm → Very compact (~6 kg)
- Fabrication at facilities of Nagoya Univ. in 2015.



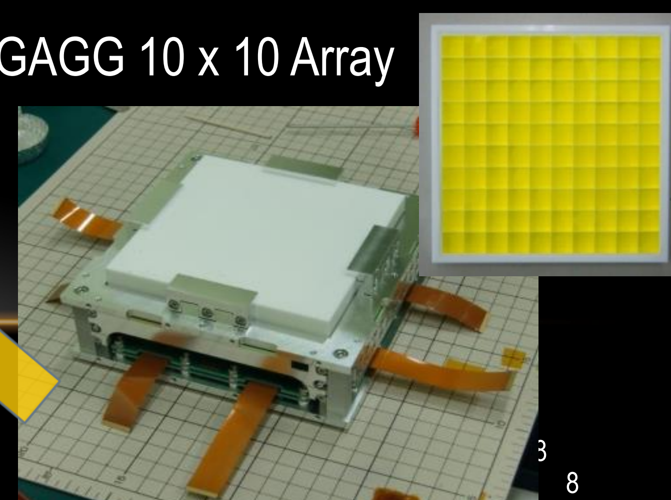
Flexible board for Si PMs



100 Plastic Scintillator Bars



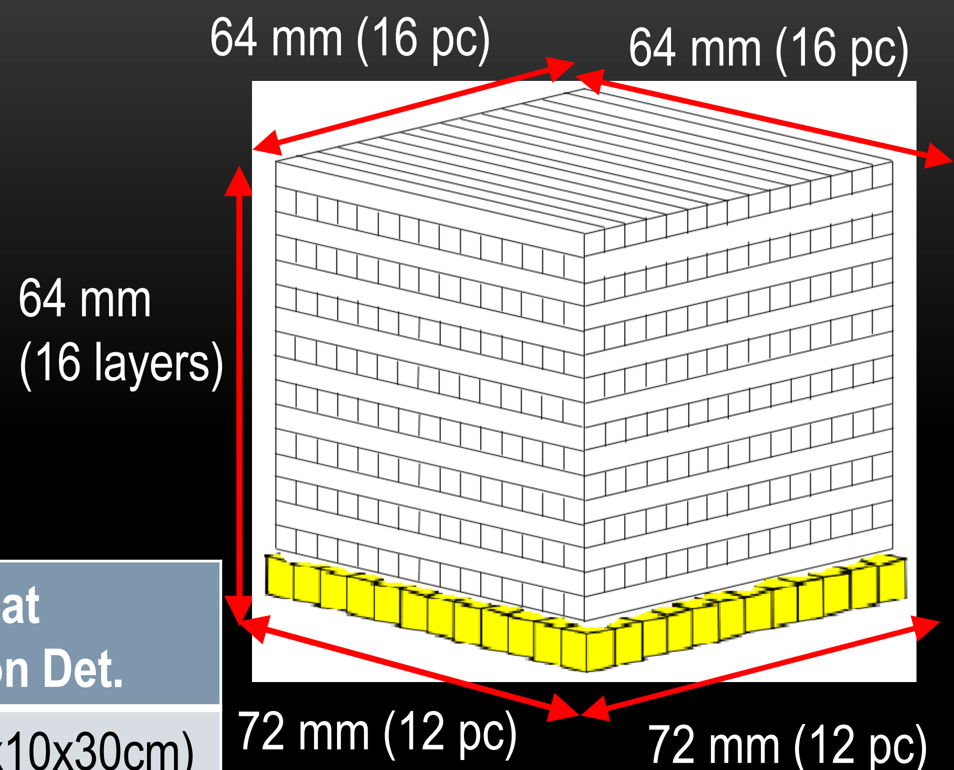
GAGG 10 x 10 Array



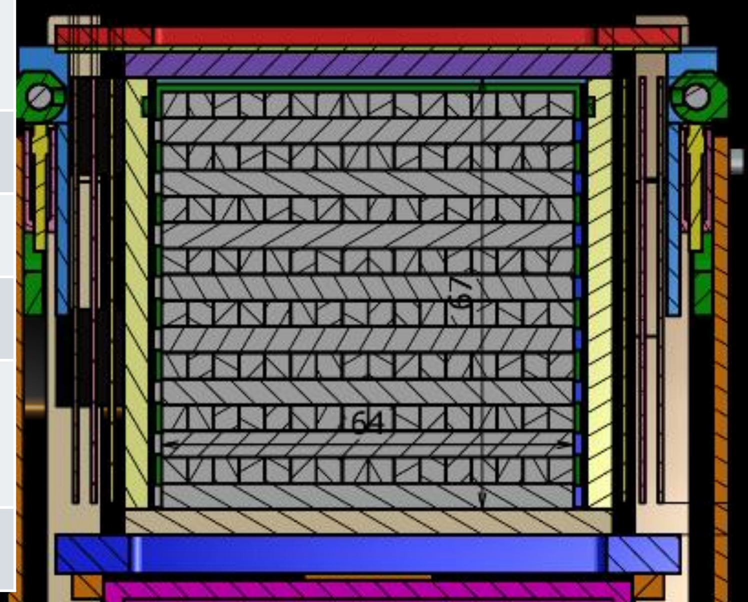
Toward a 3U CubeSat

<u>Further constraints</u>

- Reduction of large power consumption: 12 W → 3 W
- Finer structure to have higher energy resolution



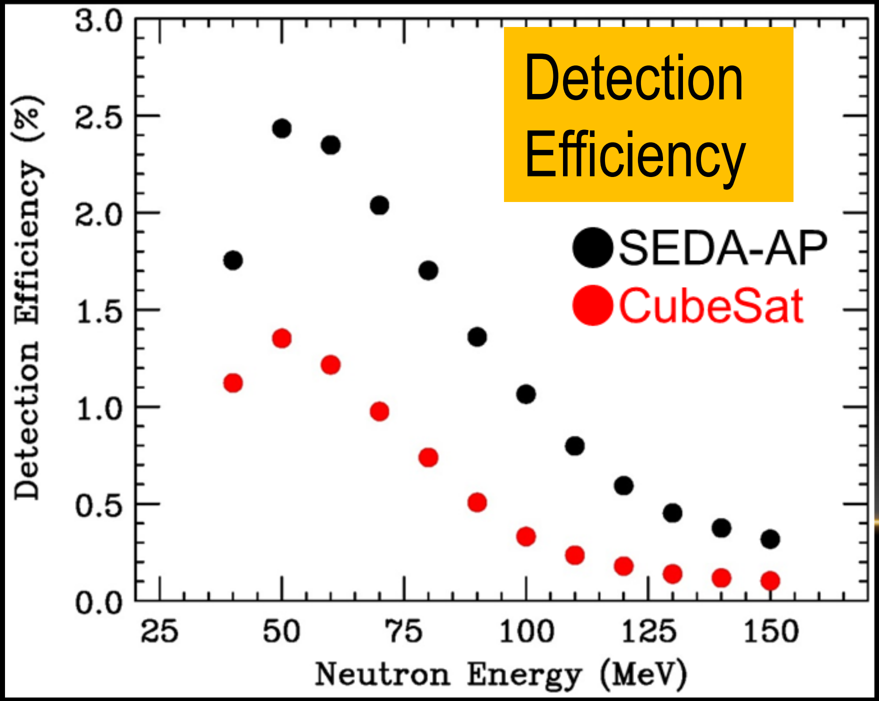
	SEDA-AP FIB	ChubuSat-2 Neutron Det.	CubeSat Neutron Det.
Satellite Size	(ISS)	50cm cubic	3U(10x10x30cm)
Detector Size (cm)	53.2x53.2 x17.1	15x17x18.5	10x10x12 (1.2U)
Weight (kg)	12.7	6.2	2
Power (W)	25.4	12	3
Sensor signals	518	312	668
Plastic Scintillators	3x6x96mm (512 pc)	10x10x100 mm (100 pc)	4x4x64mm (256 pc)
GAGG (Ce)	No	10 mm cubic	6 mm cubic

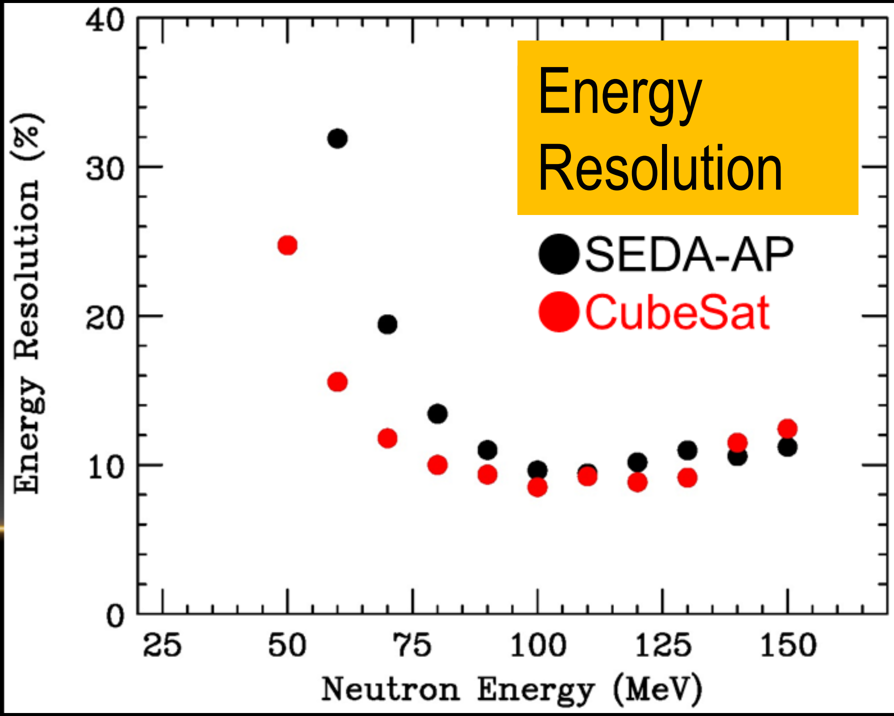


Performance Comparison between SEDA-AP and our CubeSat

- Neutron events are selected by passing through at least 4 layers of plastic scintillators.
- Detection efficiency is smaller than that of SEDA-AP due to thickness of the detector.
- Energy resolution is better than that of SEDA-AP due to smaller size of each plastic scintillator bar.

★SEDA-AP FIB
3x6x96 mm
96 mm thick
★CubeSat
4x4x64 mm
64 mm thick



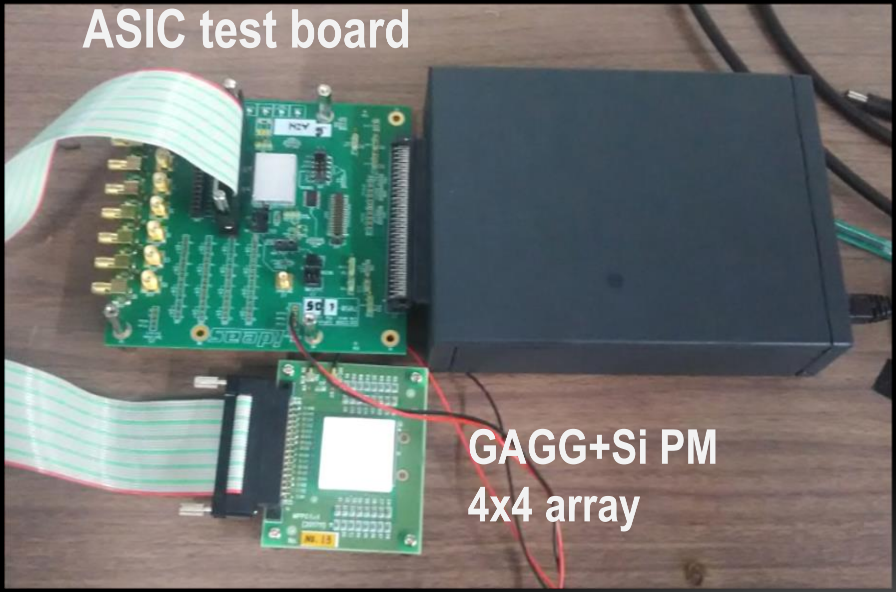


Readout of sensors with Integration circuits (ASIC)

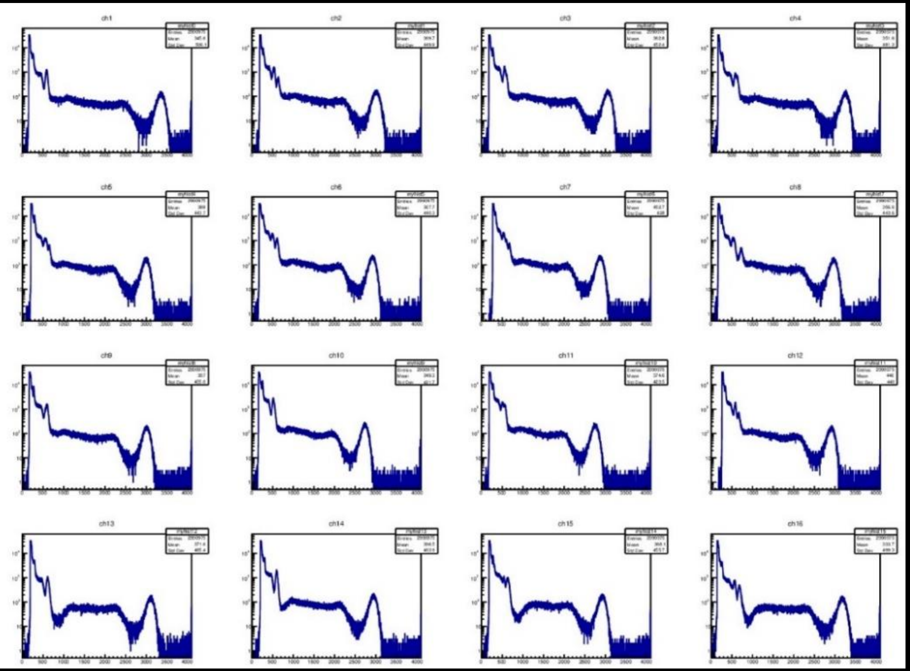
- Large power consumption 12 W for ChubuSat-2

  → We can reduce power consumption (~3 W) by using 16-channel IDEAS ASIC IDE3380 (< 2 mW per channel).

- ASIC readout of GAGG+Si PM 4x4 array



^{137}Cs 662 keV Spectra



We have successfully read out the detector array with ASIC.

Energy resolution 7-8% @ 662 keV

Summary

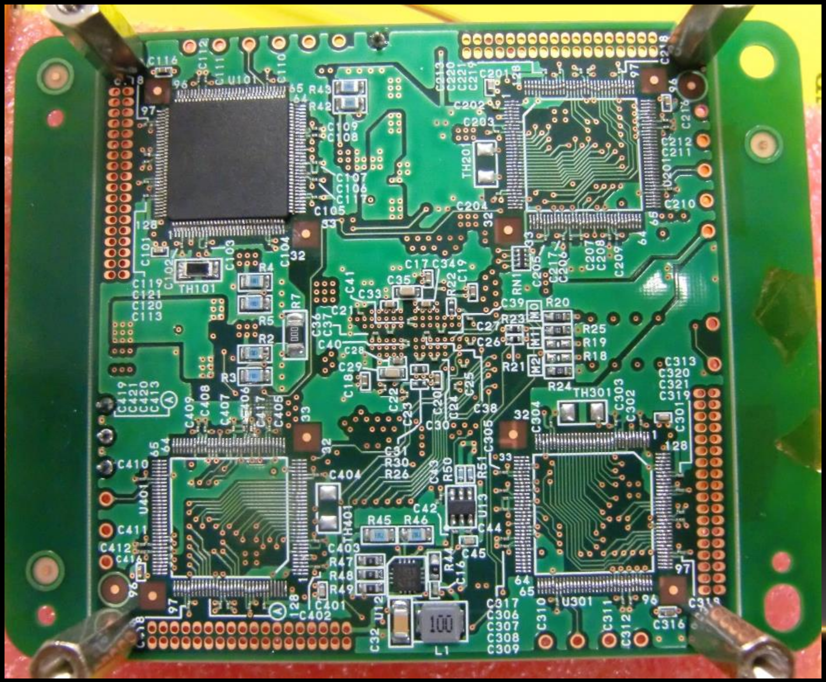
- Solar neutrons can be direct probes for understanding of ion acceleration mechanisms, but high sensitive observations have not been done yet.
- We have developed a new solar neutron detector for the 50-kg sagtellite ChubuSat-2, but it was not turned on.
- To recover the mission around 2022, we have started a new 3U CubeSat project, SONGS, in collaboration with those who belong to school of engineering from last year.
- Using ASIC for signal processing, several upgrades to fit a cubesat application can be realized
    - Lower power consumption for full operations (3 W).
    - Further compact structures to get fine 3-D particle tracks

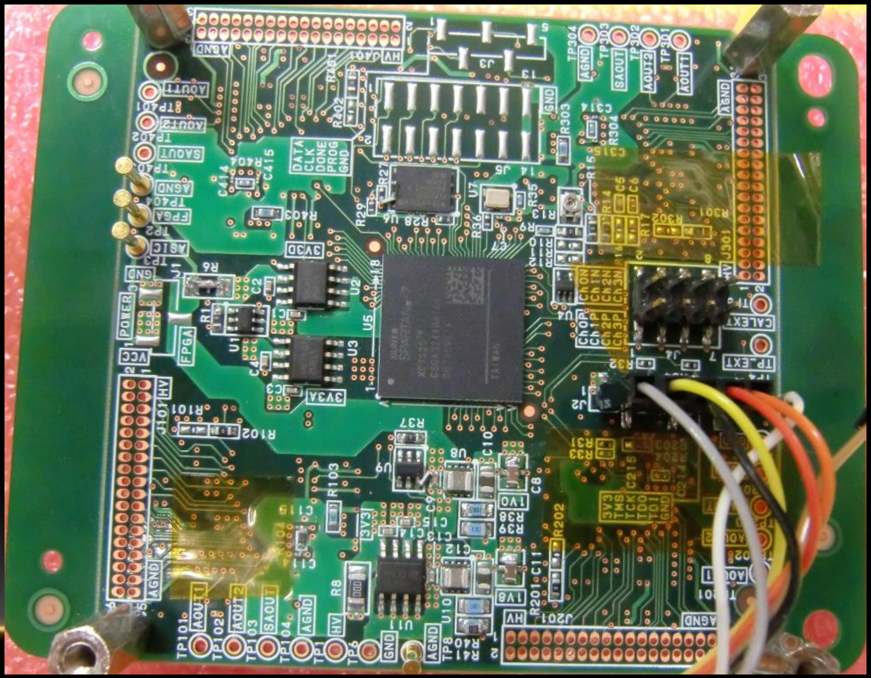
      (1.2 U size and 2 kg).
- The construction and testing of the BBM is under way.

Backup Slides

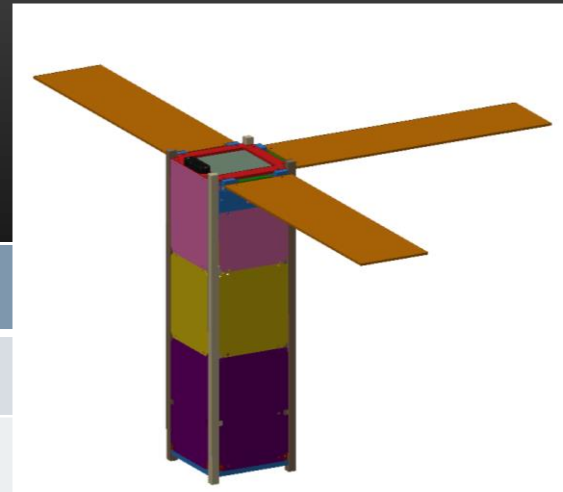
New ASIC+FPGA Board for bread-board model (BBM)

- The new board we have developed and have been currently testing
  - 4 ASICs with TQFP package + 1 FPGA
  - 1 DC/DC converter for a bias voltage of MPPCs





Mission Requirements



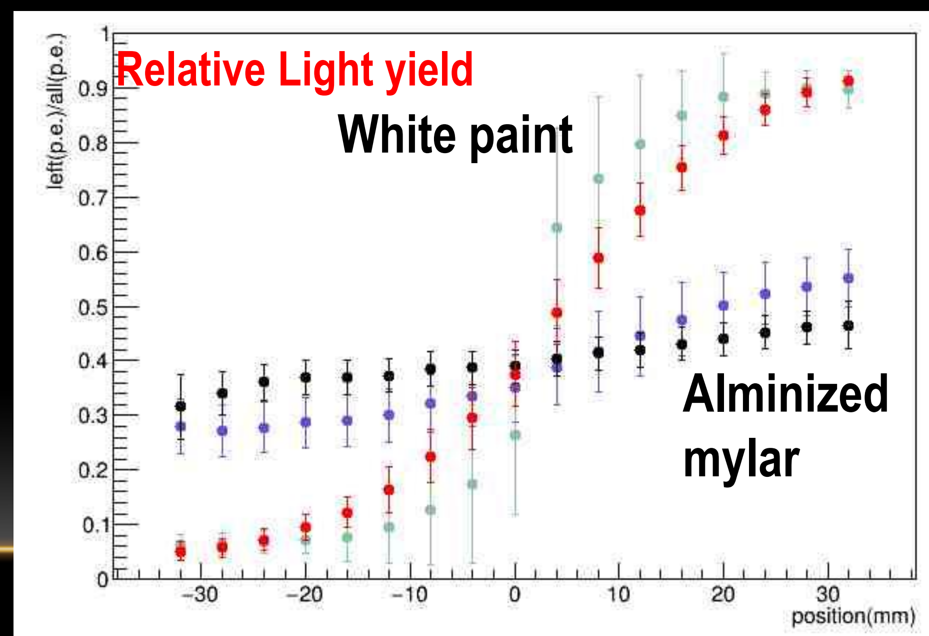
Items	Value	Requirement to the bus
Weight	2 kg	
Power	3 W	Deployable solar paddles
Size	10 x 10 x 12 cm	
Operation & Storage Temperature	-20～20 / -20～60 degree C	Radiator etc..
Attitude	Sun pointing (within10 degrees), Determination accuracy: 1-2 degrees	Earth edge sensor
Data size	~15 Mbyte / day(maximum) ~1 Mbyte / day (compressed)	S-band antenna & transceiver
Mission Life	More than half year (two years if possible)	
Absolute Timing Accuracy	~ 1 s (less than 1 msec if possible)	PPS signal in GPS
Others	Protect optical-UV lights from the Sun	

Basic evaluation: Scintillator bars

- We have studied a position capability by reading out from both sides of scintillator bars.

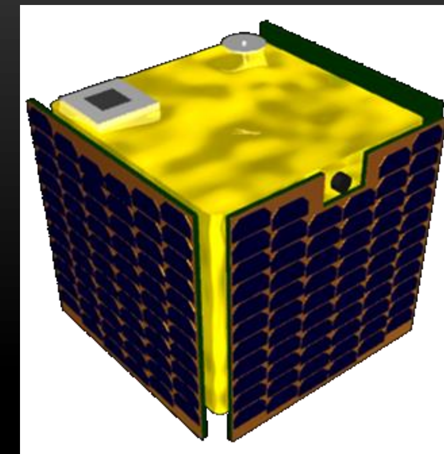
→ The scintillator bar can have a position resolution in its bar direction by using white paint as a reflector.

Measurement Setup



Position (mm)

ChubuSat-2

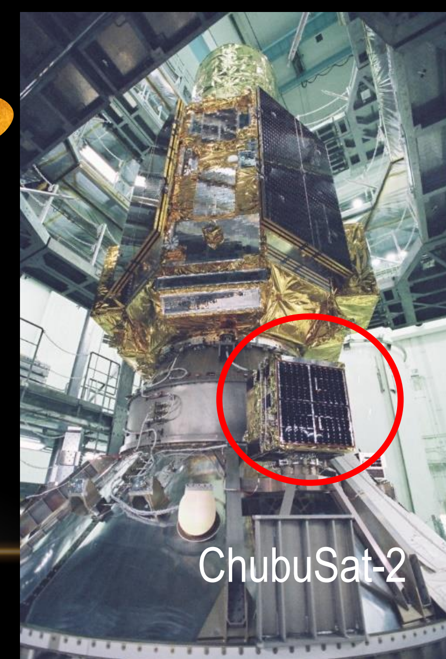


ChubuSat

- A series of 50 kg-class microsatellite
- Developed by Nagoya University, Daido University, Mitsubishi Heavy Industry (MHI), and other small or medium-sized companies around the Chubu (I.e. central part) region of Japan.

ChubuSat-2 (2nd satellite of ChubuSat)

- Selected as one of the four piggy-back satellites of the X-ray astronomical satellite ASTRO-H by JAXA on Aug. 27, 2015
- Mission
  - Radiation Monitor for the main satellite ASTRO-H
  - Message Exchange Service via amateur radio band.
- Launched on Feb. 17, 2016 from JAXA Tanegashima Space Center

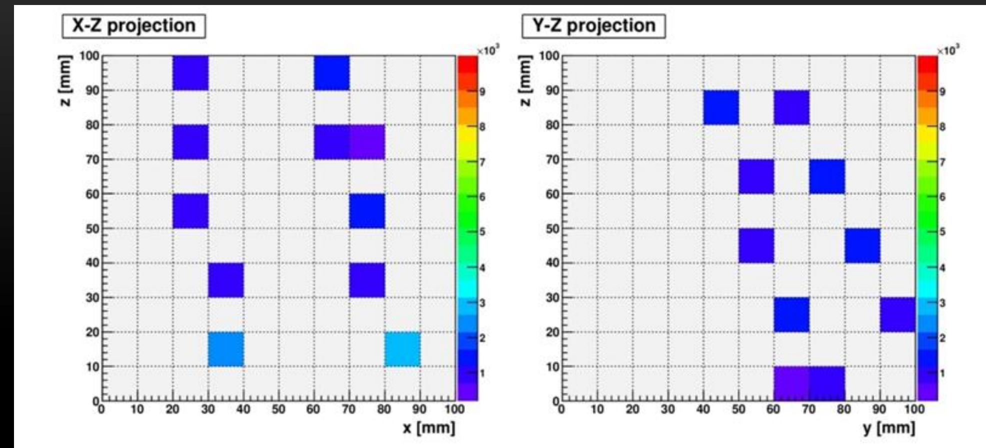


Performance of the ChubuSat-2 Solar Neutron Detector on Ground

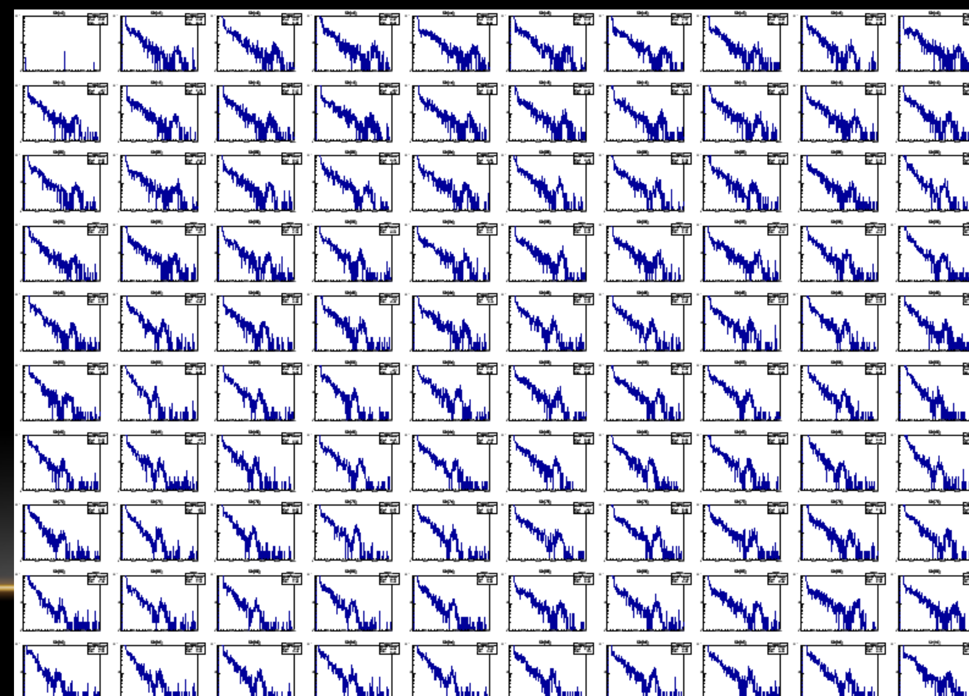
Almost of all the sensors were working well during a pre-flight operation test.

- Cosmic-ray muon track was clearly detected in plastic scintillator bars.
- 662 keV gamma-rays from ^{137}Cs source were also detected in the GAGG 10x10 array.

We launched the ChubuSat-2 on Feb. 17, 2016.
However, the detector was not turned on In orbit.



Muon track in plastic scintillator bars



662 keV gamma-ray spectra in GAGG array