Solar Neutron and Gamma-ray Detector for a Small Satellite

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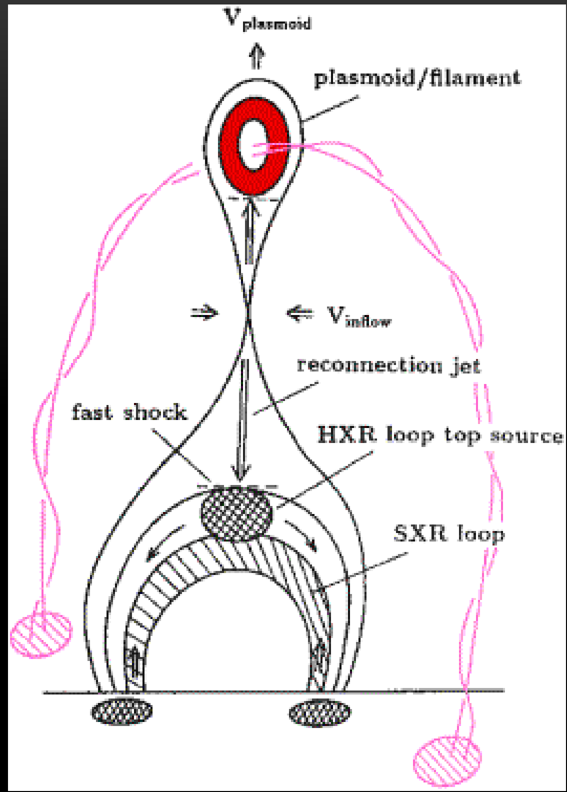
Solar Neutron Observations

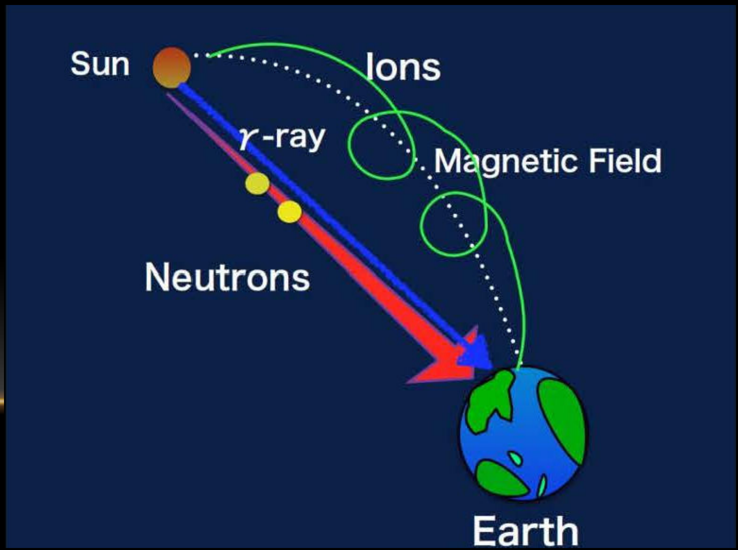
- Ion acceleration mechanism in solar flares is still unknown. Magnetic Reconnection ?

→ 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)

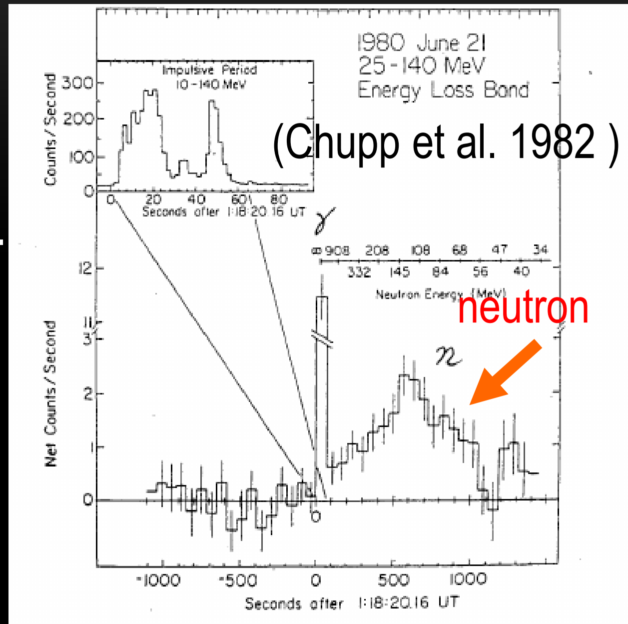
→ **Neutrons can be direct probes for understanding ion acceleration mechanisms in the Sun.**



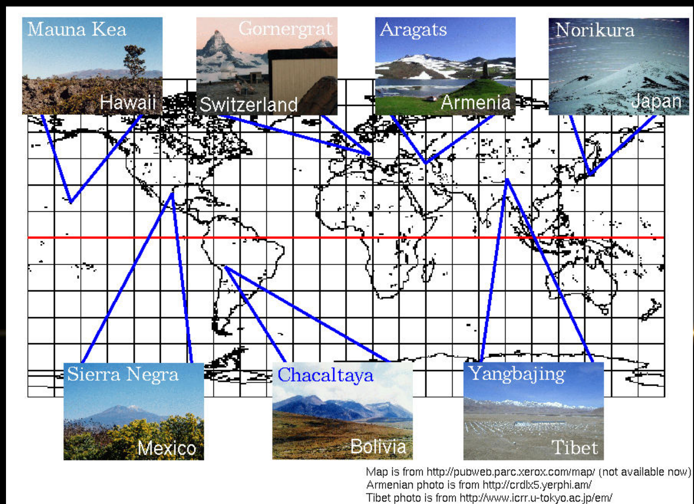


Previous and Current Solar Neutron Observations

- Discovery of solar neutrons with the Solar Maximum Mission (SMM) in 1980 (Chupp et al. 1982)
- Observations have been carried out from ground and space.
  - ★ Ground: Neutron telescopes in the world-wide network
  - ★ 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)

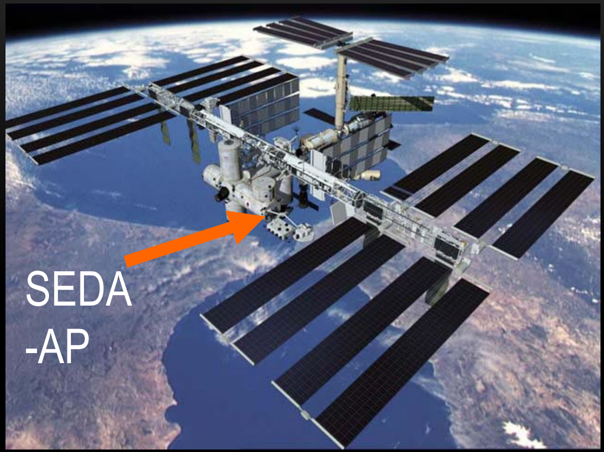


→**only ~40 detections** for 38 years, and **no space mission** at this moment

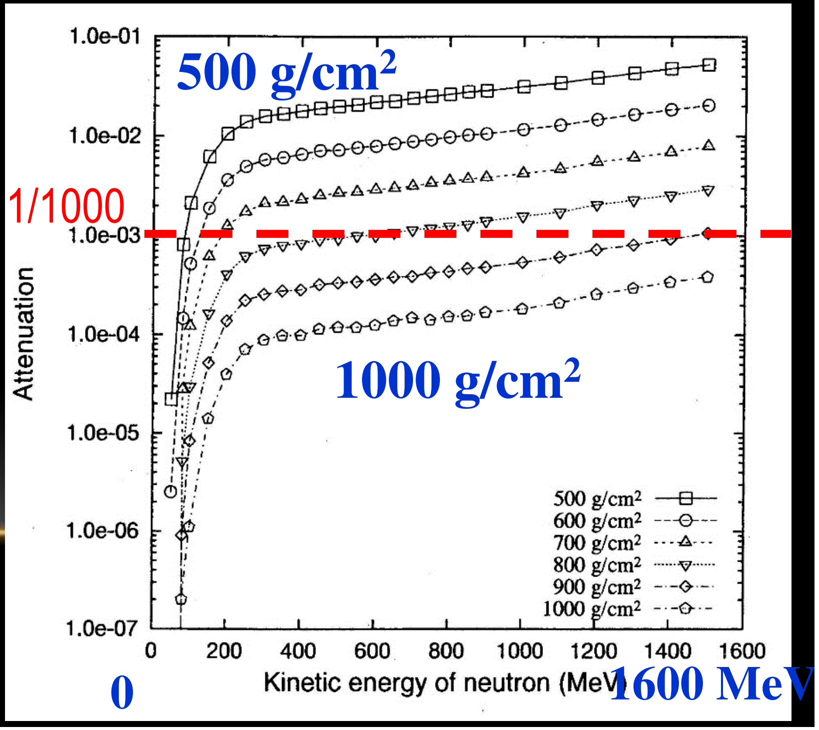


Merits of Microsatellite Observations

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



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



3. Long and un-interrupted observations
   e.x. Sun-synchronous orbit

→ High sensitive observations are possible using microsatellites.

Detector Concept (I)

★The detector is originally designed based on SEDA-AP FIB, and gamma-ray detection function has been added (GRB observations are possible.).

★Detection Principle

1. Neutron Detection Part: Multi-layered Plastic Scinti

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

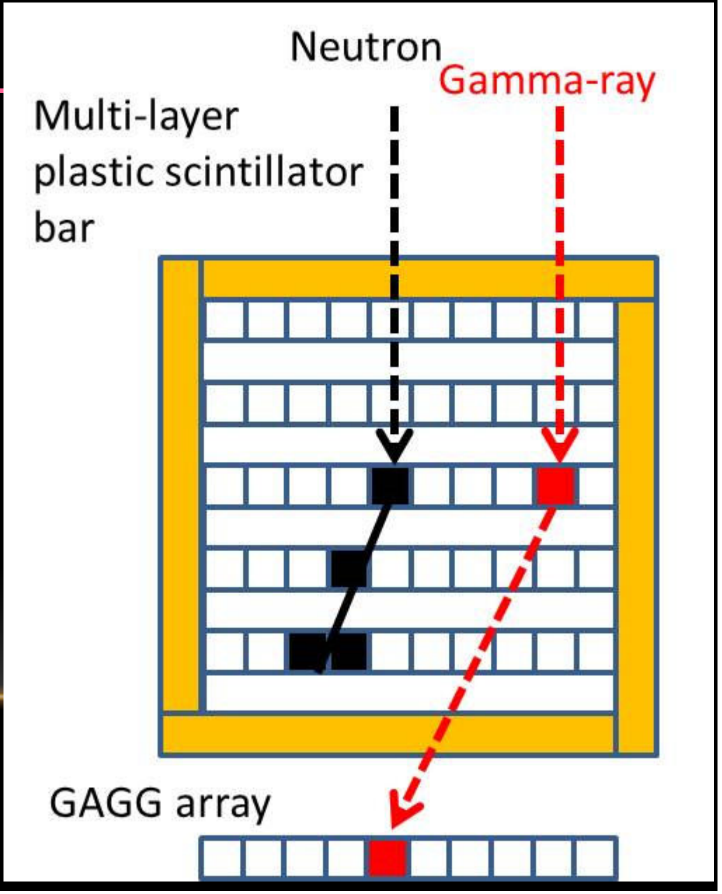
  Incident neutron energy $En = Ep / \cos^2\theta$
- The same technique is used in SEDA-AP FIB.

2. Gamma-ray Detection Part: Inorganic Scintillators

- Detected via Compton scattering and/or photo-electric absorption.

3. Anti-coincidence Detector Part

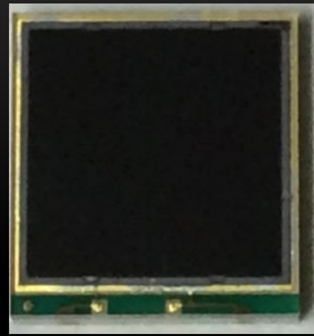
- Covered by plastic scintillators to reject charged particles.



Detector Concept (II)

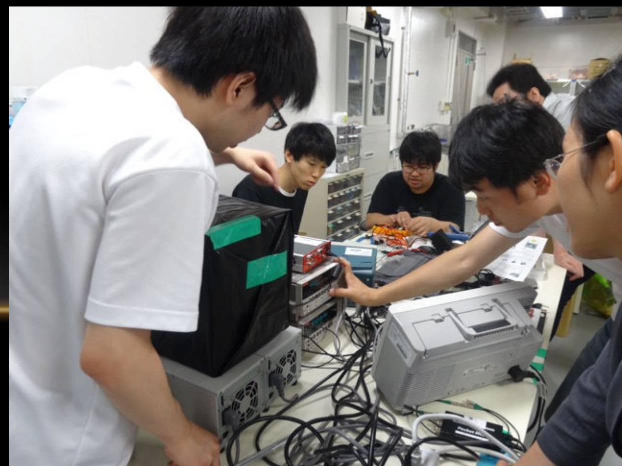
- New sensor technology has been used
  - Si PM (MPPC in Hamamatsu K.K.)
    - Very compact and light weight
    - Low bias voltage +55 V (cf. ~1000 V for PMT)
  - GAGG scintillator ($Gd_3Al_2Ga_3O_{12}$)
    - High density: (6.63 g / cm^3)
    - High Light Output: ~57000 photons/MeV
- This mission was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

6.85 mm



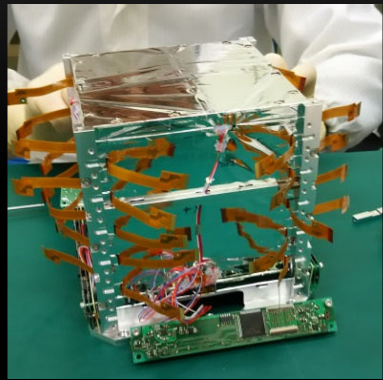
7.35 mm

Leadership Development Program
for Space Exploration and Research
Nagoya University Program for Leading Graduate Schools

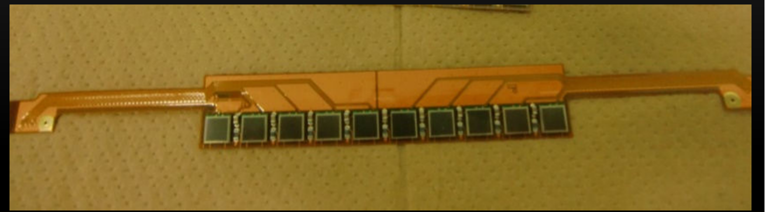


Realized Structure
for the 50-kg class satellite ChubuSat-2

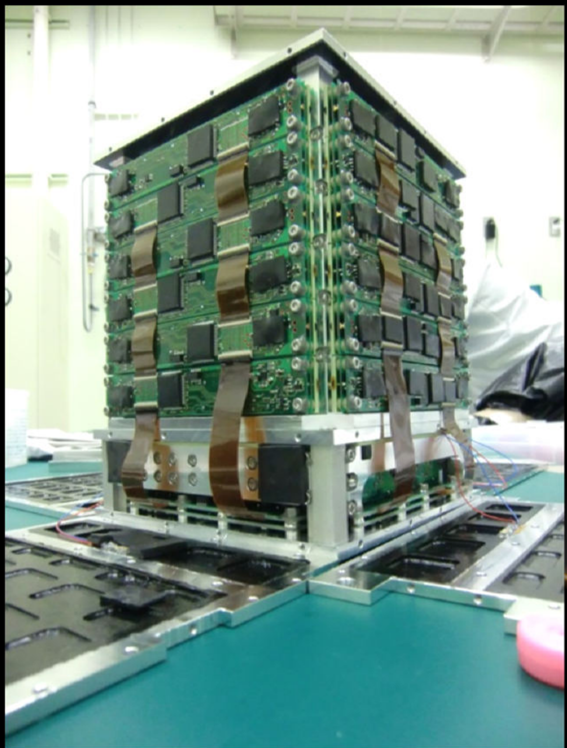
- Sensors and electronics packaged in an Aluminum box
  → Very compact (~6 kg)
- Fabrication at facilities of Nagoya Univ.

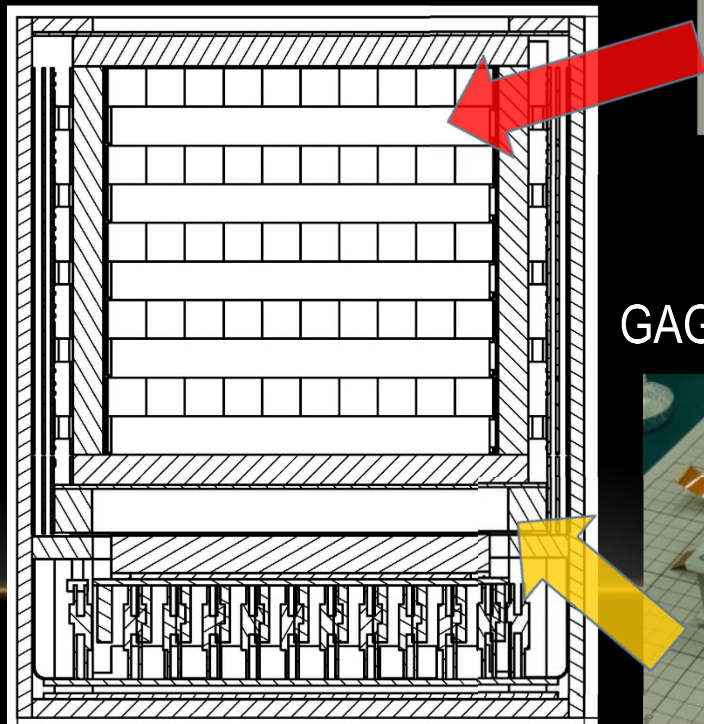


Flexible board for SiPMs

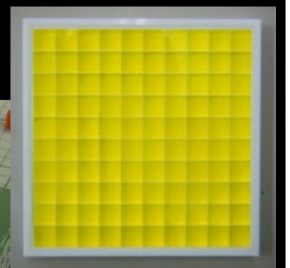


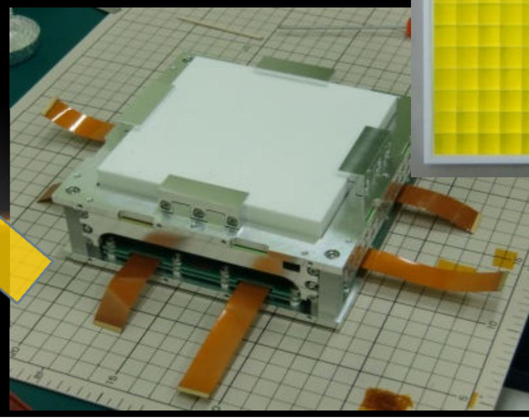
100 Plastic Scintillator Bars





GAGG 10 x 10 Array





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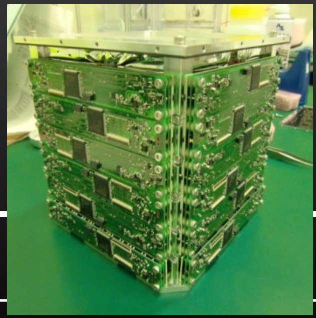
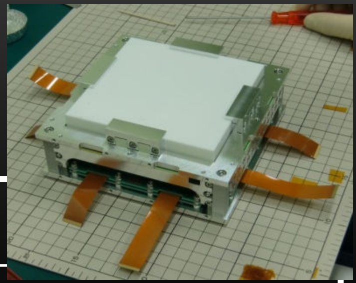
Characteristics of the Solar Neutron Detector



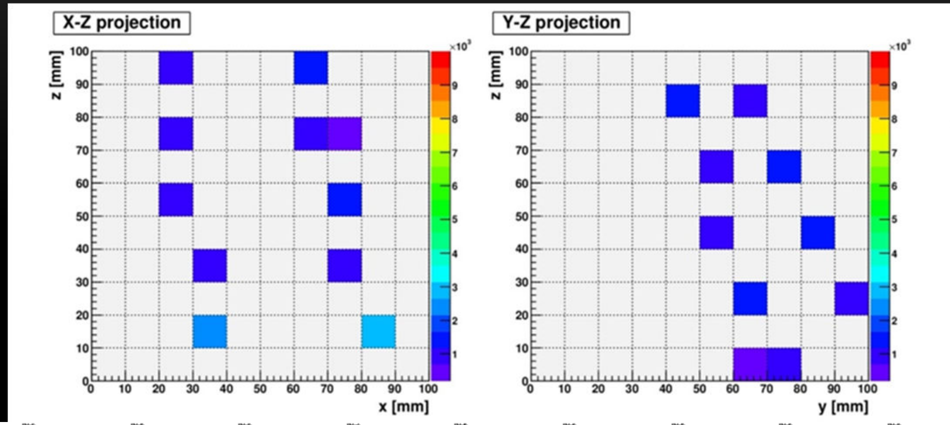


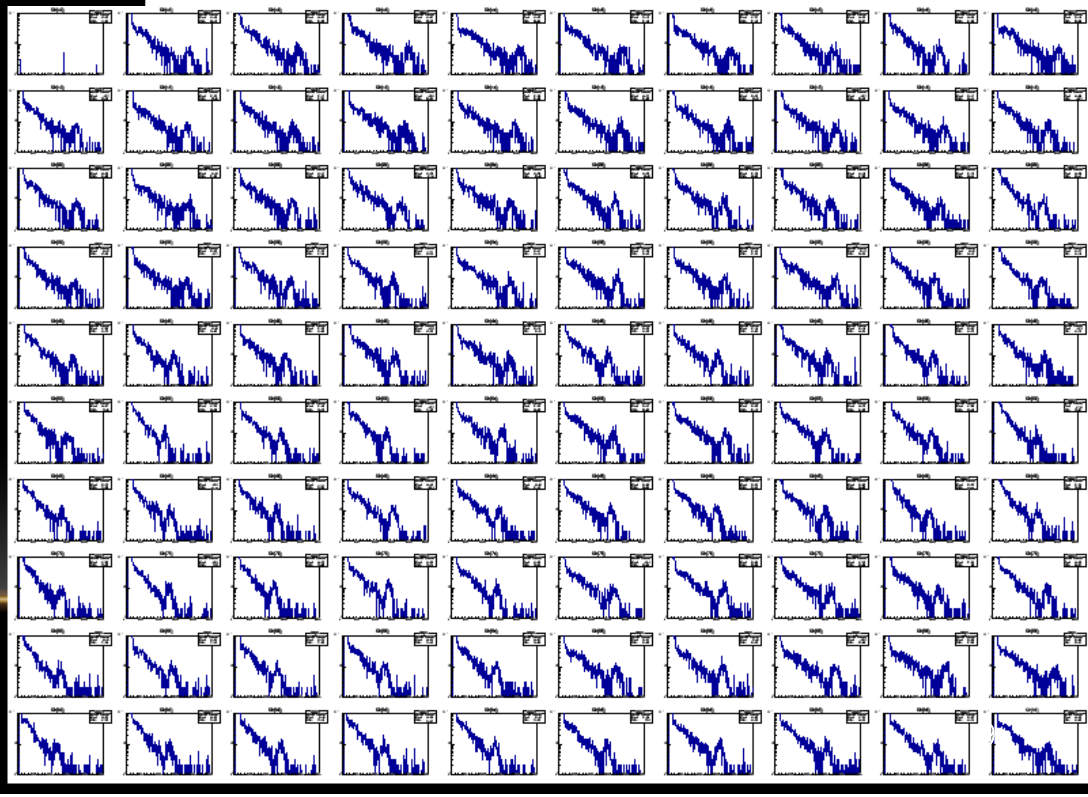
Items	Specification
Detectors	Upper part: Plastic scintillators 10x10 bars Lower part: GAGG scintillators with 10x10 array of 1cm-cubic read out with MPPC
Number of processing signals	Total: 312: 200 (Plastic Scintillators), 12 (Anti-coincidence detector), 100 (GAGG)
Size	15 cm x 17 cm x 18.5 cm (Detector area ~100 cm^2)
Weight	6.2 kg
Power	12 W (Operation Voltage 4 V, Current 3 A)
Onboard Memory size	1 Gbyte
Downlink data size	About 5Mbyte (assuming 3 contact pass per day and 100 kbps in the S-band)

Performance of the ChubuSat-2 Solar Neutron Detector on the 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.



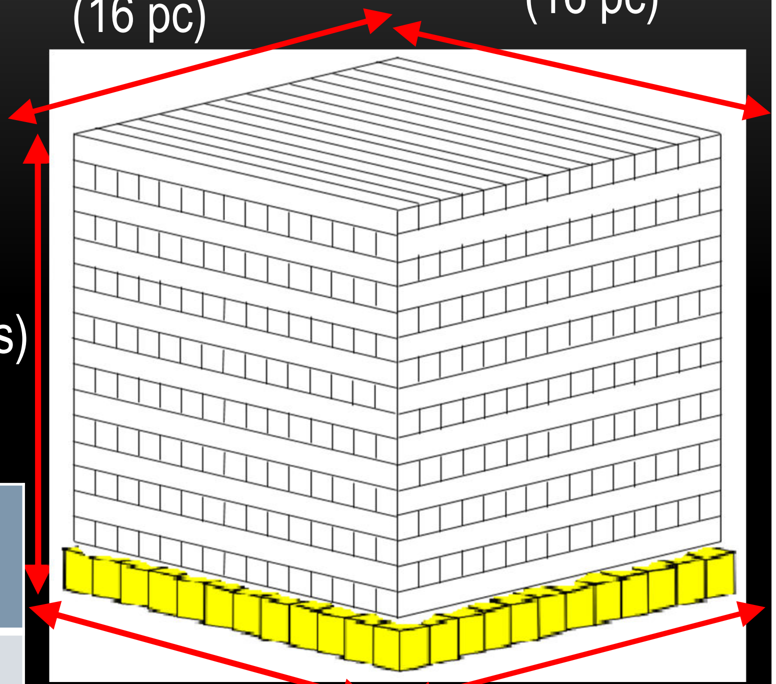


We launched ChubuSat-2 on Feb. 17, 2016. However, the detector has not been turned on In orbit.

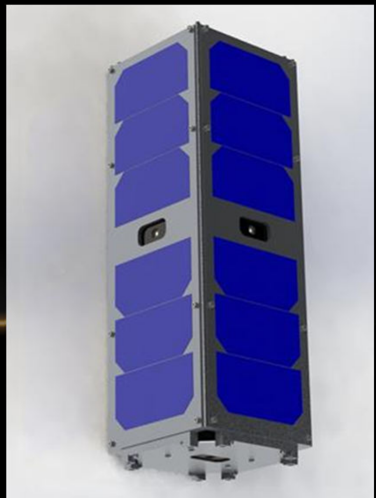
Next step to a 3U CubeSat

Further constraints

- Need more compact and higher performance
- Reduction of large power consumption (12 W→< 3 W)



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

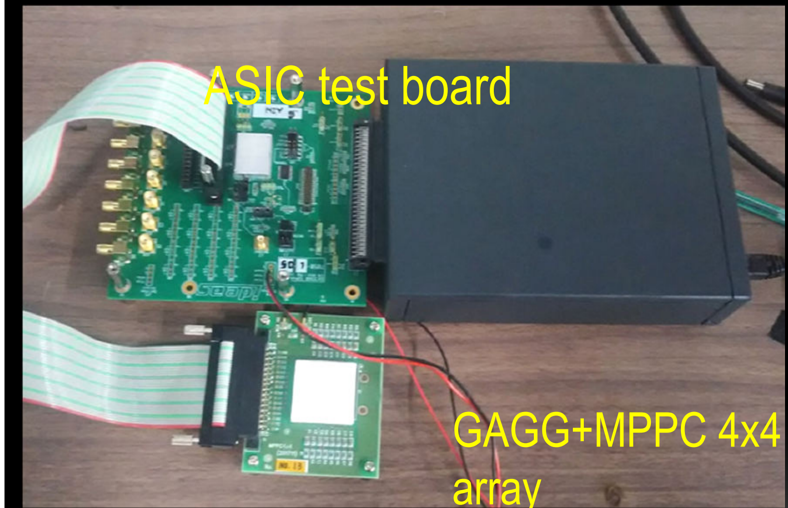


Basic evaluation: ASIC

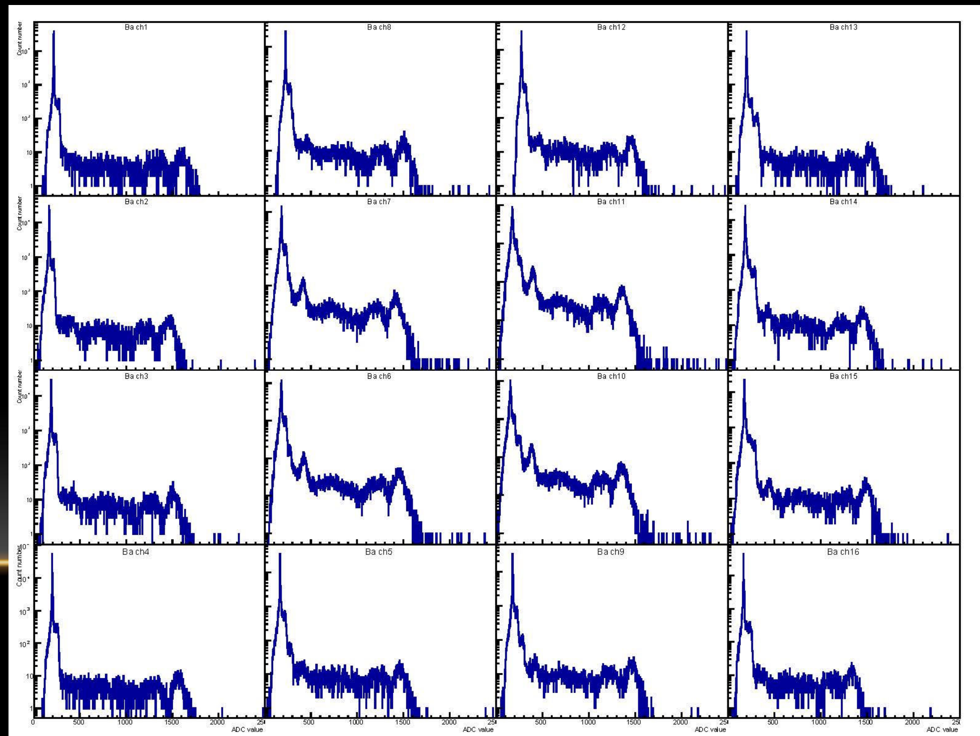
- Large power consumption 12 W for ChubuSat-2

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

- ASIC readout of MPPC+GAGG 4x4 array



^{133}Ba Spectra



We have successfully read out the detector array with ASIC.

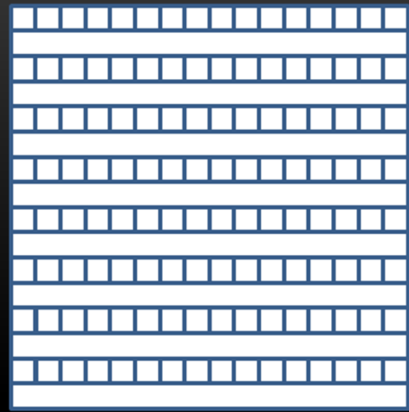
Summary

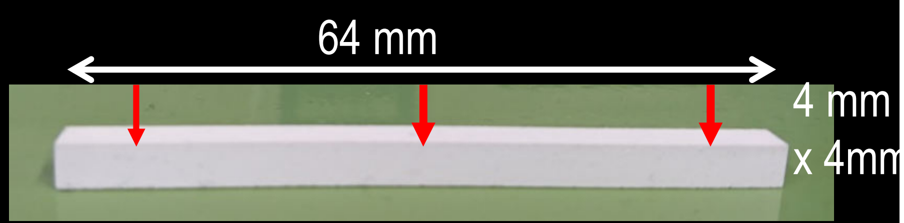
- Nagoya University have proposed solar neutron observations using microsatellites.
- Solar neutron detector was realized in the 50-kg class ChubuSat-2 satellite, but it was not turned on yet.
- We have just moved to the next step to recover the mission for a 3U CubeSat (NuSAT or NuCube) in new collaboration with people at department of aerospace engineering.
- The launch of 3 3U CubeSat will be aimed at 2021-2022.

Basic evaluation: Scintillator bars

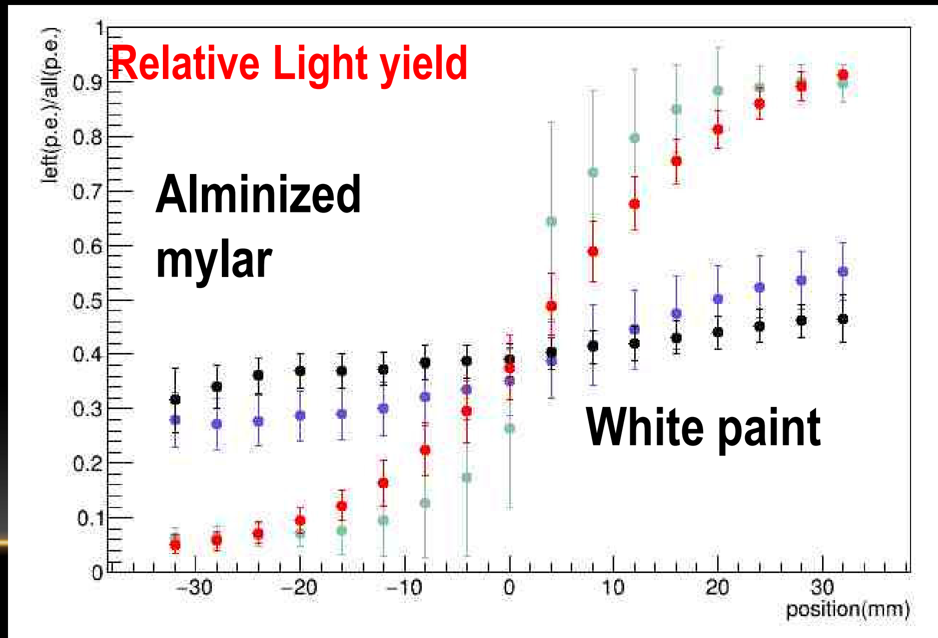
- We have studied a position capability by reading out from both sides of scintillator bars.

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





Measurement Setup



Position (mm)

Backup Slides

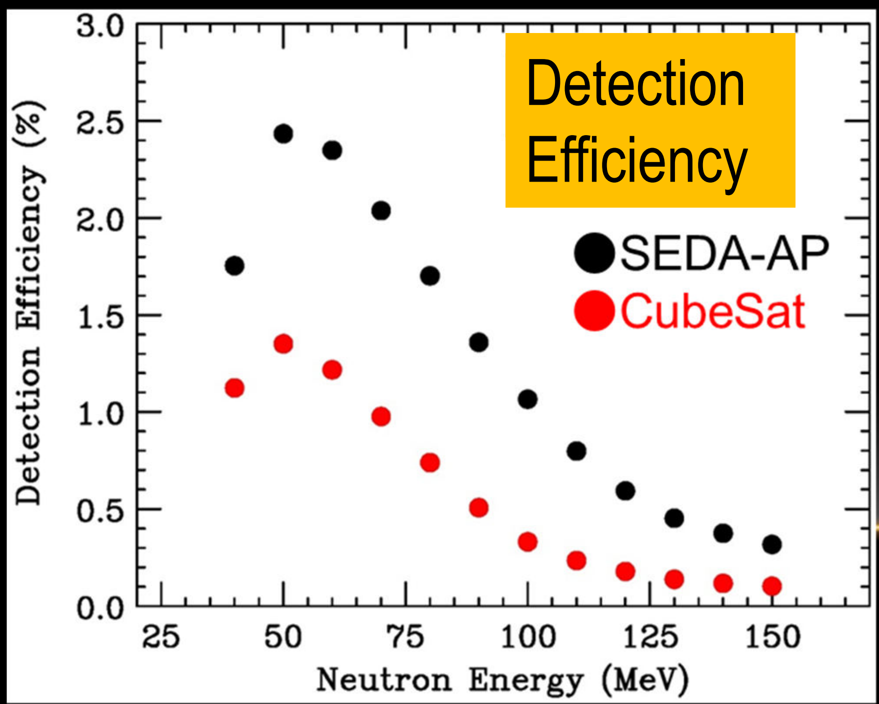
Comparison between SEDA-AP and CubeSat

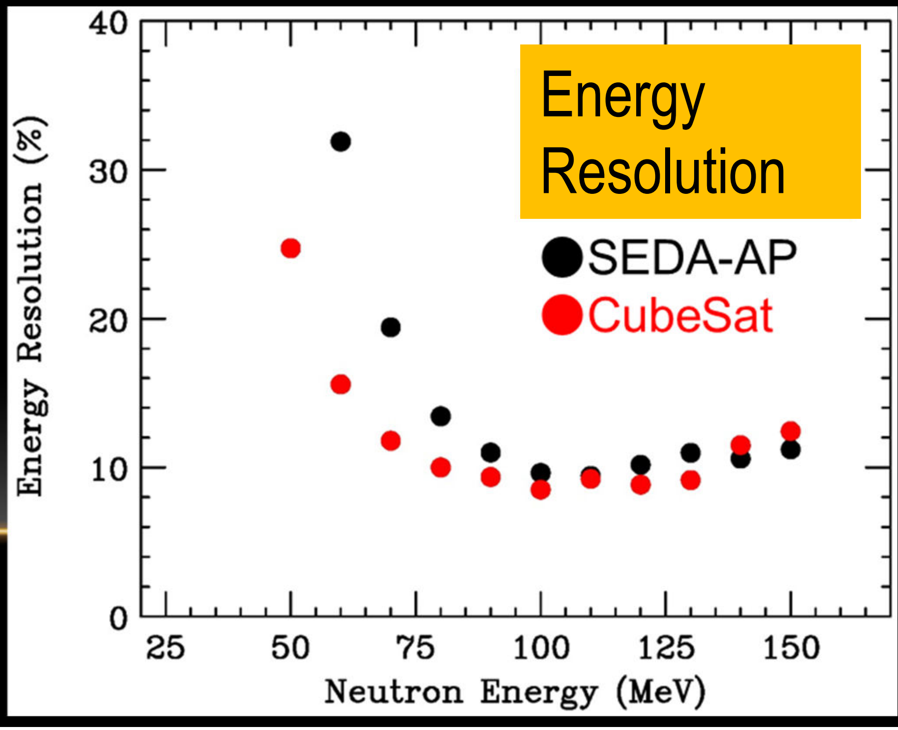
- Neutron events are selected by passing through at least 4 layers of plastic scintillators.
- Detection efficiency is smaller than that of SEDA-AP due to thickness of the detector.

→ A use of GAGG at the bottom can increase the efficiency ?

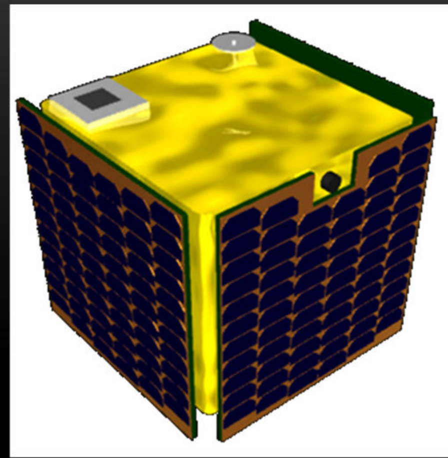
- Energy resolution is better than that of SEDA-AP due to smaller size of each plastic scintillator.

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



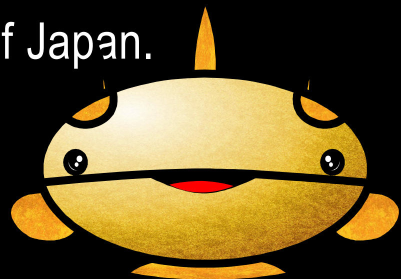


ChubuSat-2



ChubuSat

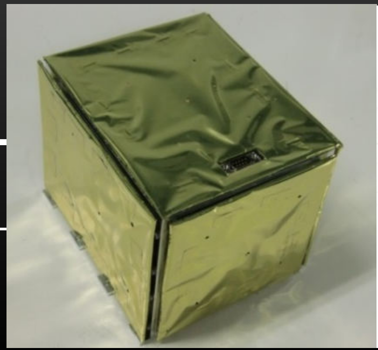
- A series of 50 kg-class microsatellite
- Developed by Nagoya University, Daido University, Mitsubishi Heavy Industry (MHI), and other small or medium-sized companies around the Chubu (I.e. central part) region of Japan.



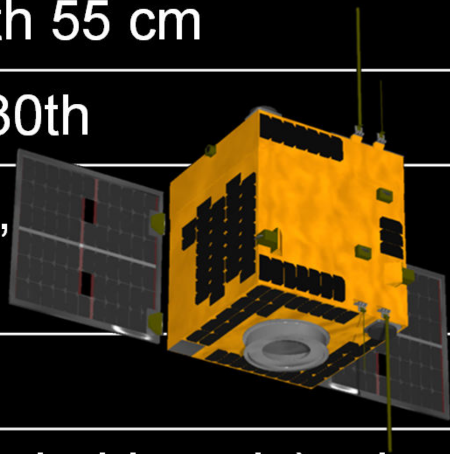
ChubuSat-2 (2nd satellite of ChubuSat)

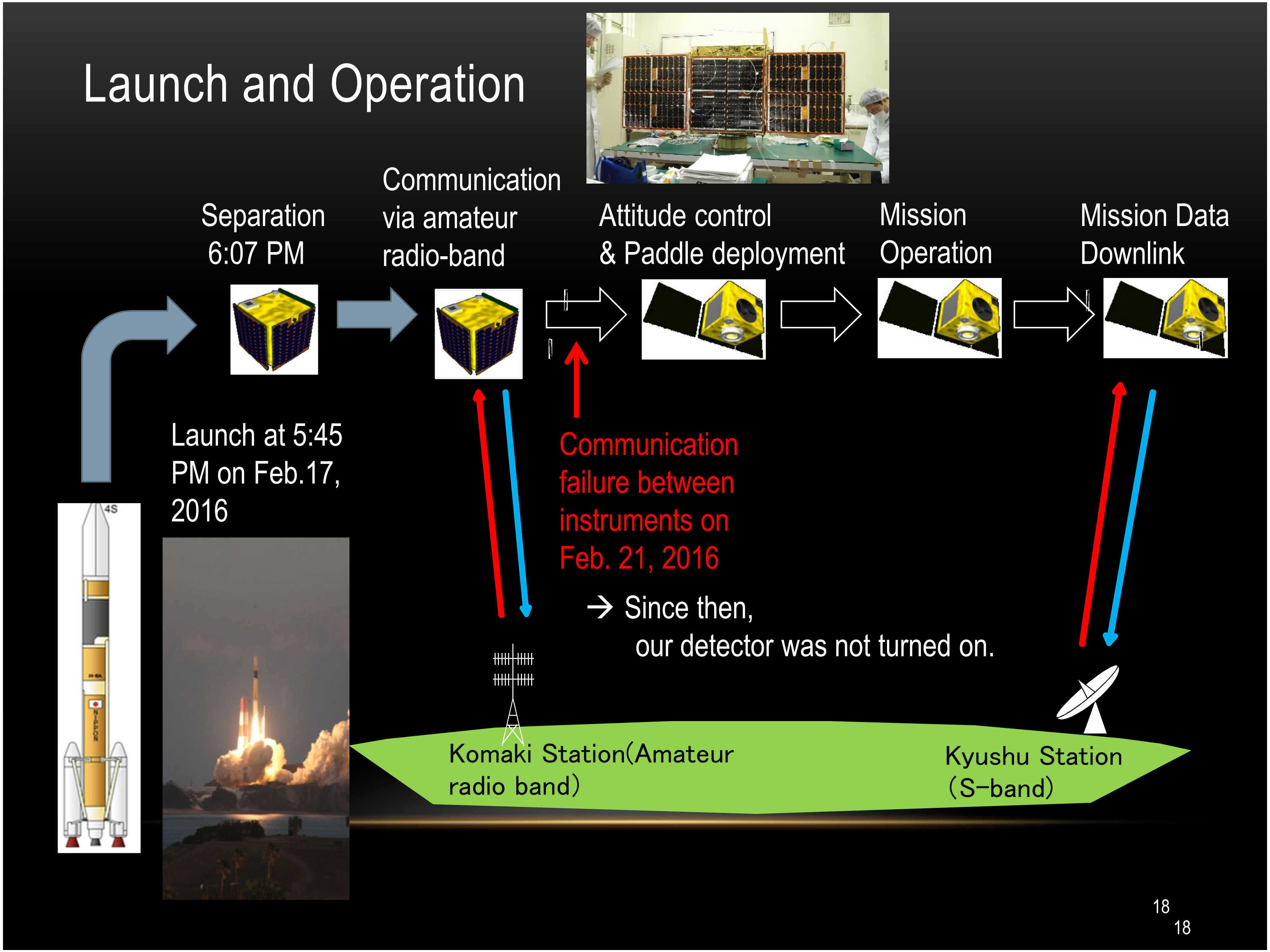
- Selected as one of the four piggy-back satellites of the X-ray astronomical satellite ASTRO-H by JAXA on Aug. 27, 2015
- Mission
  - Radiation Monitor for the main satellite ASTRO-H
  - Message Exchange Service via amateur radio band.
- Launched on Feb. 17, 2016 from JAXA Tanegashima Space Center

Characteristics of Chubusat-2




Items	Specification
Mission Instrument	* Solar Neutron Detector * Infrared Camera
Weight	About 50 kg
Size	Height 65 cm x Width 56 cm x Depth 55 cm
Launch Date	February 17, 2016 by H-IIA rocket 30th
Orbital information	Circular LEO Orbit (575 km altitude, 31 degree inclination angle)
Mission Life	More than half year
Consumption Power	12 W (low power mode), 25 W (safe hold mode), about 50 W(nominal operation)
Communication System	S band (Uplink/Downlink Mission data) Amateur VHF (Uplink), UHF (Downlink HK data)




Launch and Operation
Separation
6:07 PM
Communication
via amateur
radio-band
Attitude control
& Paddle deployment
Mission
Operation
Mission Data
Downlink
Launch at 5:45
PM on Feb.17,
2016
Communication
failure between
instruments on
Feb. 21, 2016
→ Since then,
our detector was not turned on.
Komaki Station(Amateur
radio band)
Kyushu Station
(S-band)
18
18