On the Feeding and Care of CubeSats

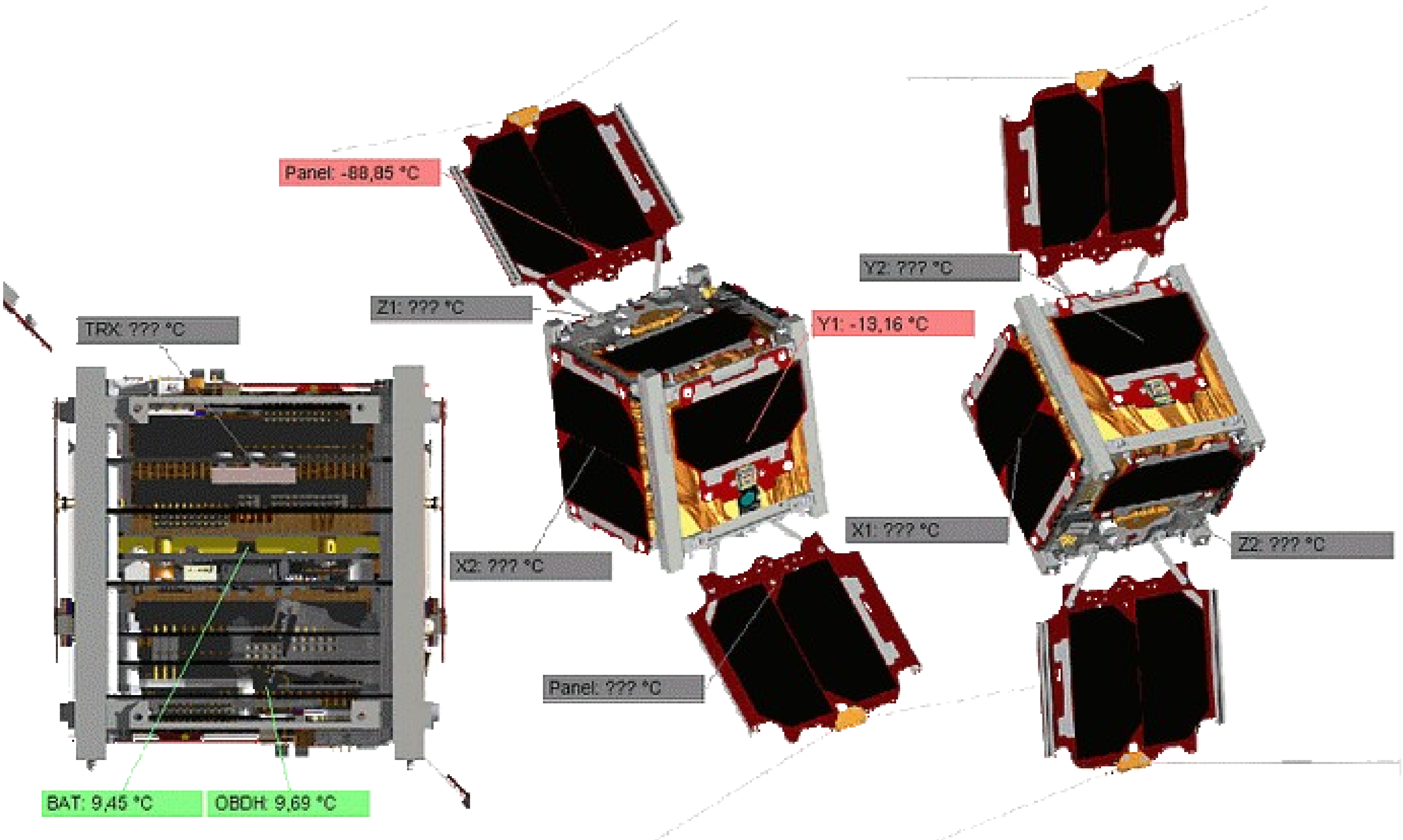
Lessons Learned from Two University CubeSats

"It's just a CubeSat!"

By Christian M. Fuchs

Leiden Institute of Advanced Computer Science
Leiden University


Image Source: ISC Kosmotras


Panel: -88,85 °C
Z1: ??? °C
TRX: ??? °C
Y1: -13,16 °C
Y2: ??? °C
X1: ??? °C
Z2: ??? °C
X2: ??? °C
Panel: ??? °C
BAT: 9,45 °C
OBDH: 9,69 °C

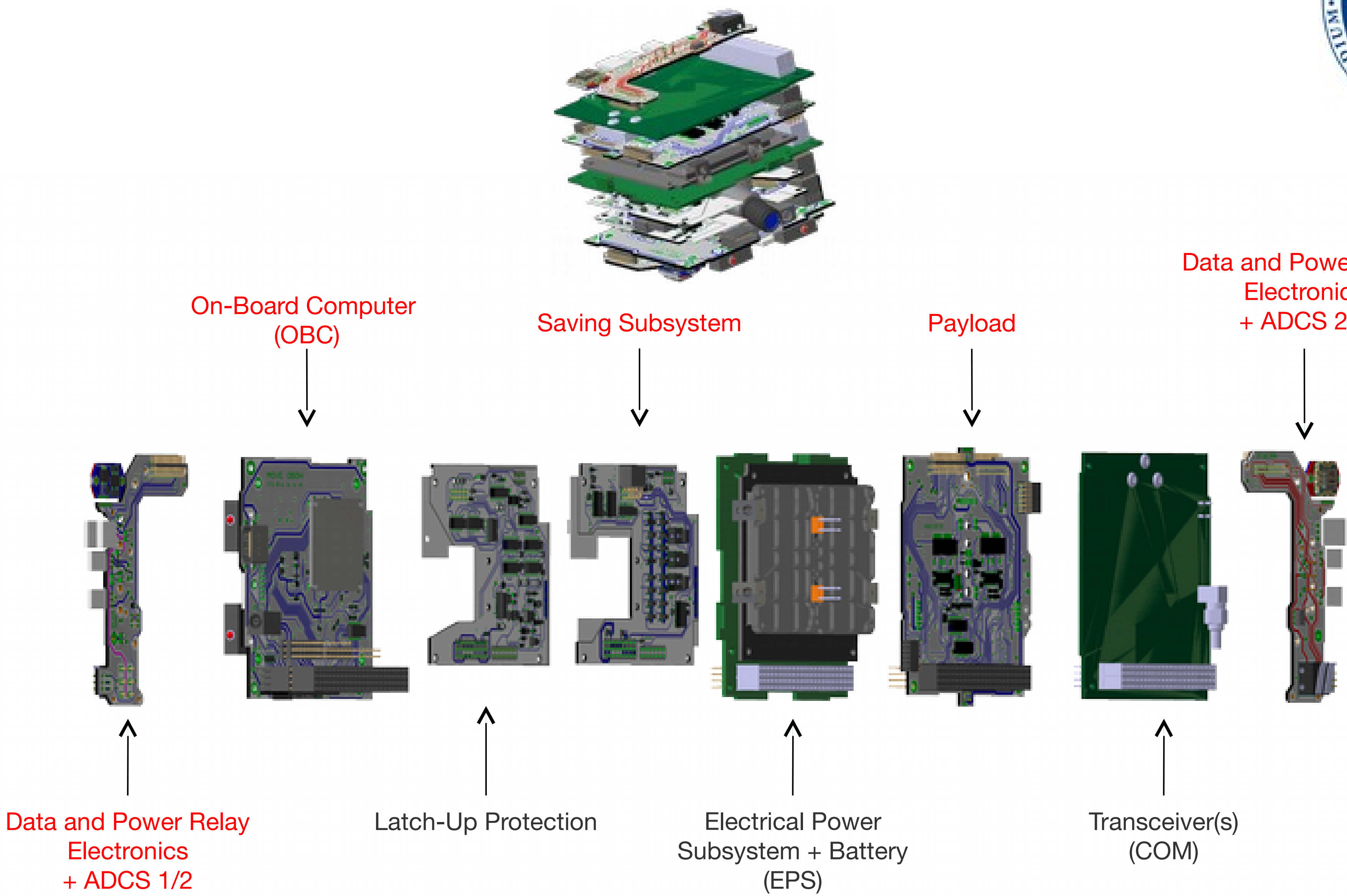
First-MOVE

- Launched in 2013
- 1 Unit CubeSat, 912g

- NORAD ID: 39439
- INTL Code: 2013-066Z

- UHF up- VHF downlink
- Foldable solar panels
- ARM926 based µC
- 512KB MRAM
- 256MB Flash
- 200mW - 1.4W power consumption
- FreeRTOS

- Cost: ~200k USD/EUR incl. launch


On-Board Computer (OBC)
Saving Subsystem
Payload
Data and Power Relay Electronics + ADCS 2/2
Data and Power Relay Electronics + ADCS 1/2
Latch-Up Protection
Electrical Power Subsystem + Battery (EPS)
Transceiver(s) (COM)

Launch Admission

- Drastically Reduced compared to non-CubeSat
- Standardized Process across Industry

- Pre-Launch Testing minimum
  - Thermal/Vacuum Chamber Testing
  - Vibration Testing } Shaker
  - Shock Testing } Shaker
  - Adherence to the CubeSat Standard Specs
- Certificates required for Launch Broker, Launch Vehicle Operator and Launching State

Image Source: ESA, for public use

Image Source: ESA, for public use

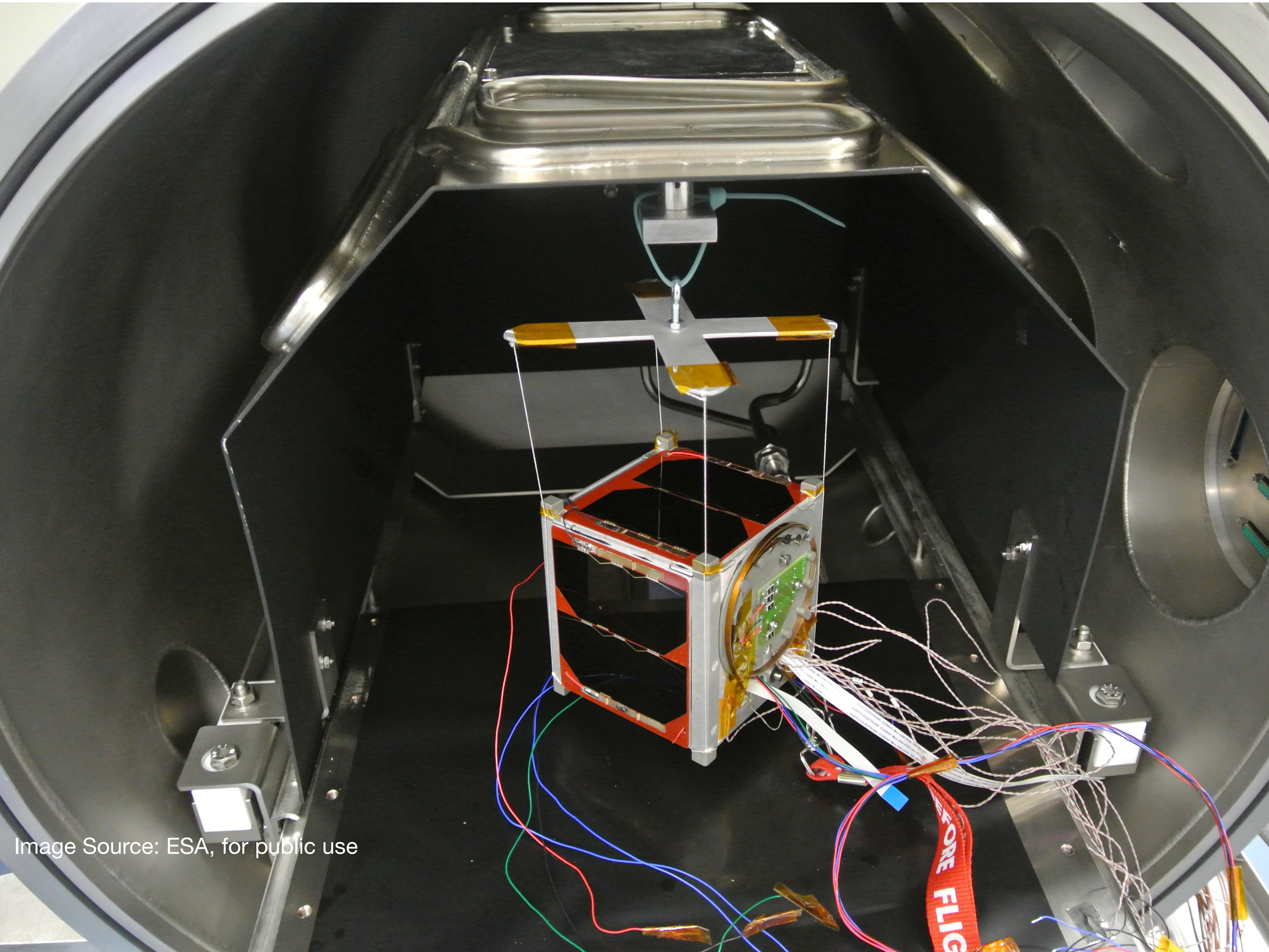


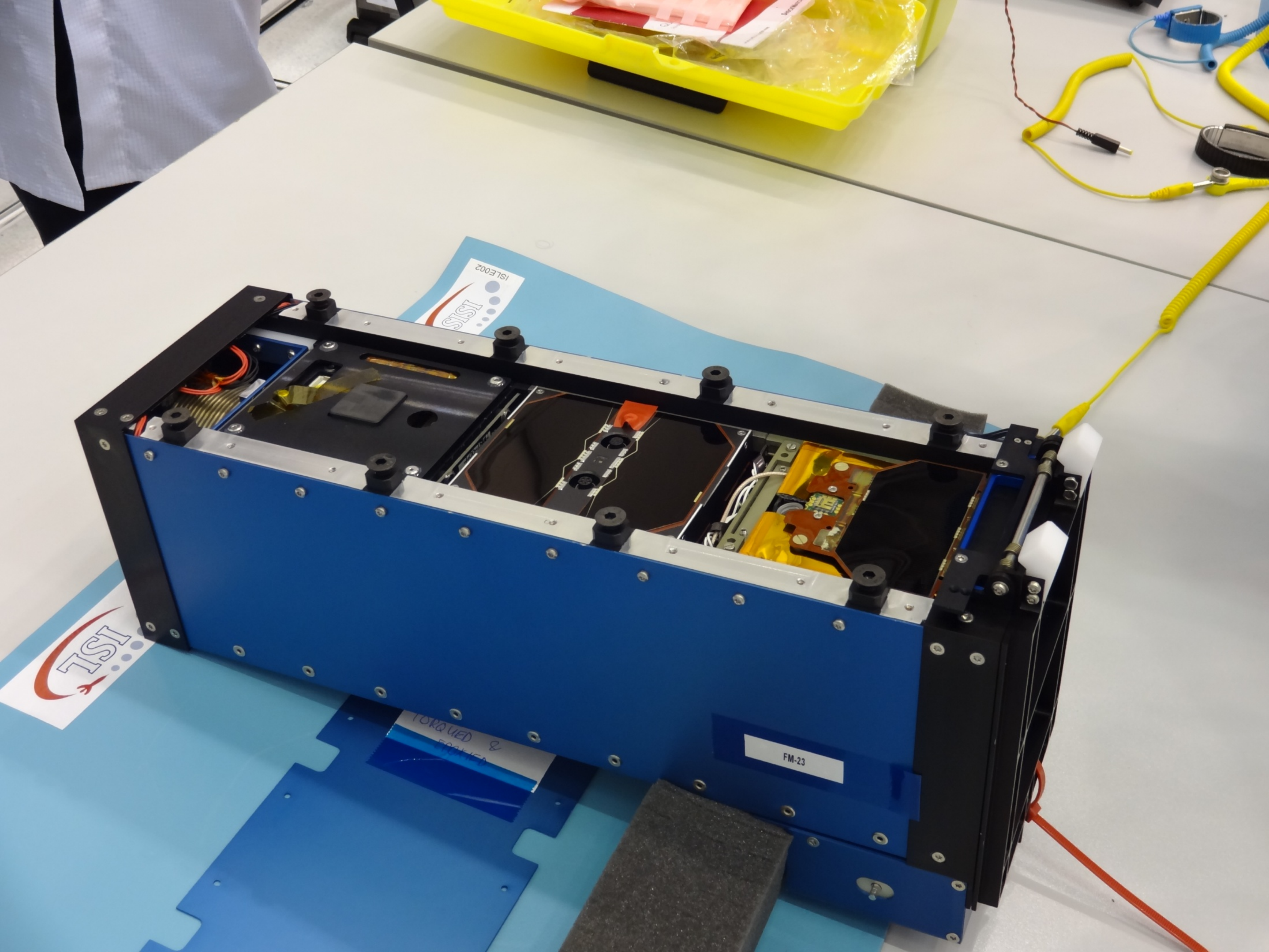
Image Source: ESA, for public use

Pre-Launch – Final Changes

- Access to your CubeSat before Launch is possible
  - Last-Minute Recharging
  - Software-Update
  - Did I forget something?

- Just leave it alone, unless you really have to, ‘cuz:
  - Access Time Window is Limited
  - Few Resources and Tooling
  - Launch Operator will try to help but get annoyed easily
  - Never a good idea to make last-minute changes


ISL
ISL
ISL03-13
ISL03-11
ISL03-09


ISLE002
ISIS
ISL
TORQUED &
FM-23

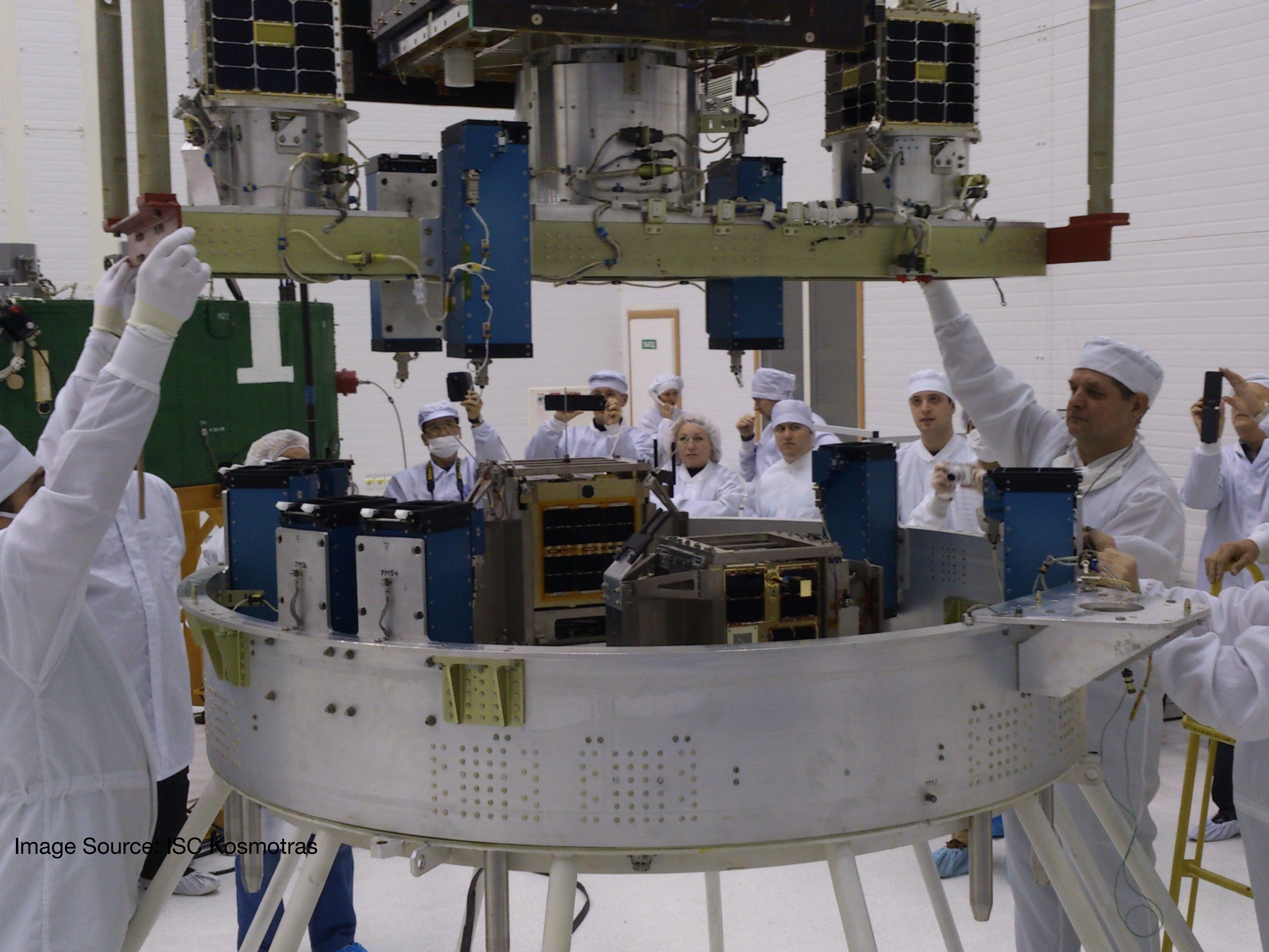
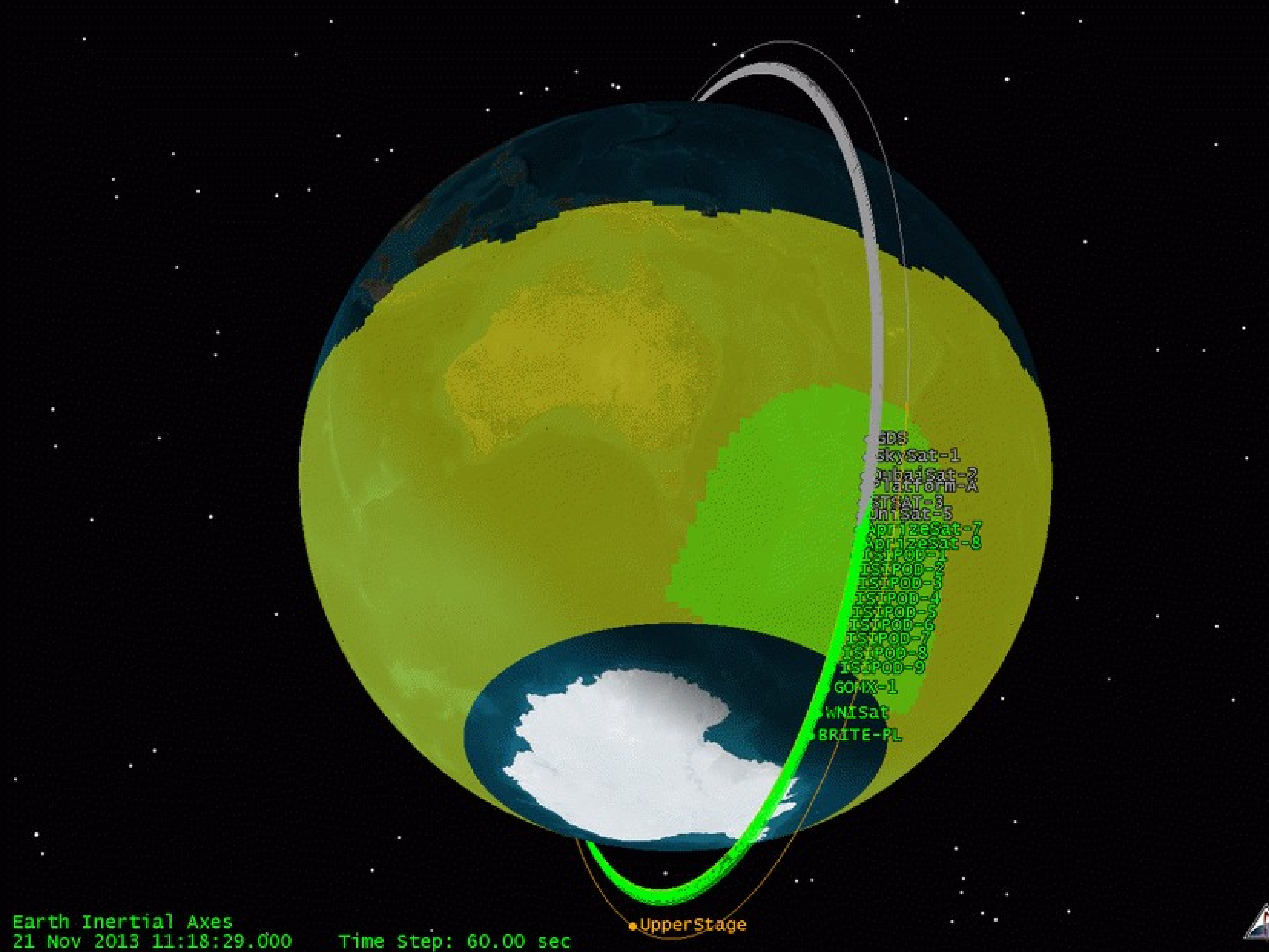
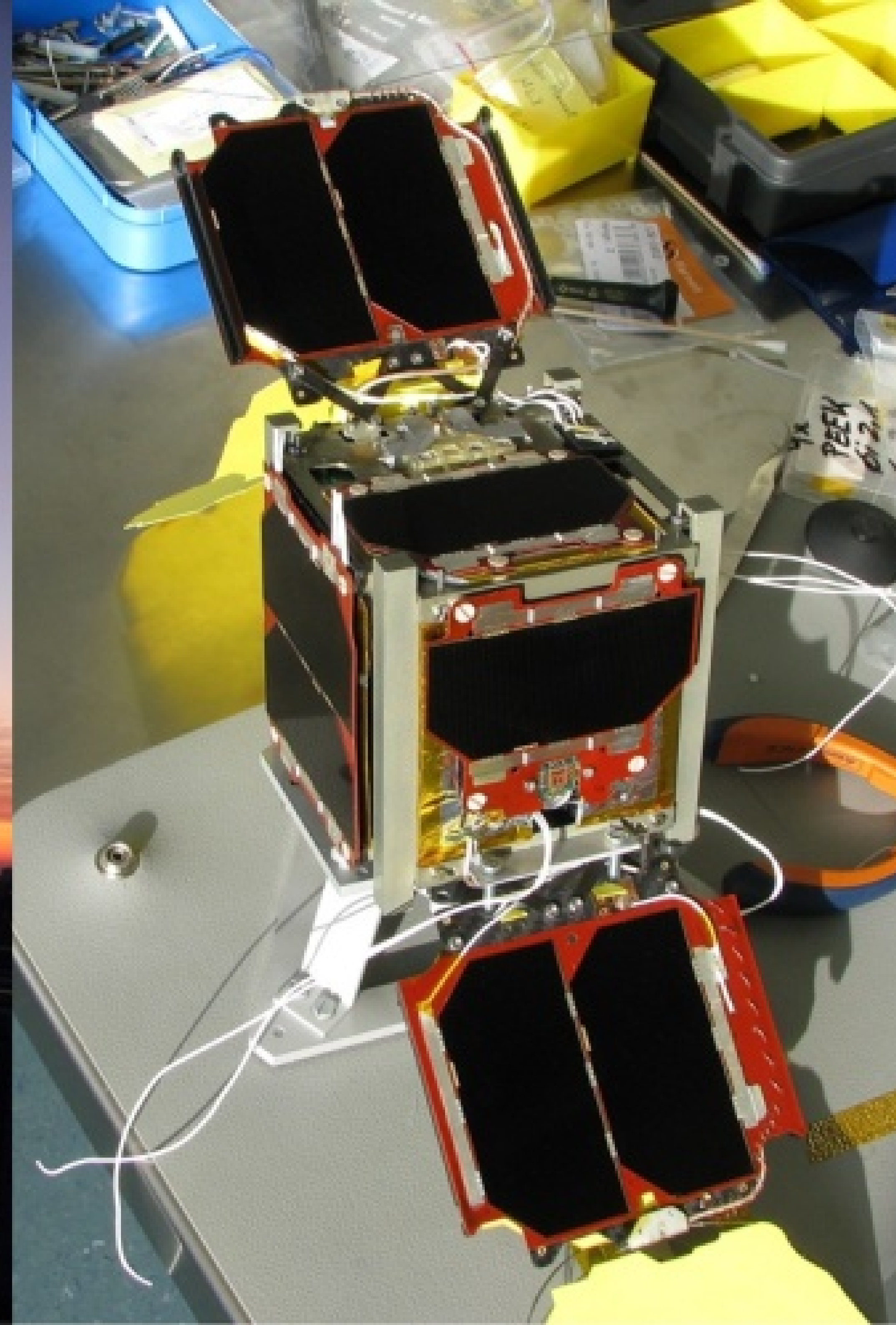


Image Source: ISC Kosmotras

Image Source: ISC Kosmotras

Image Source: ISC Kosmotras

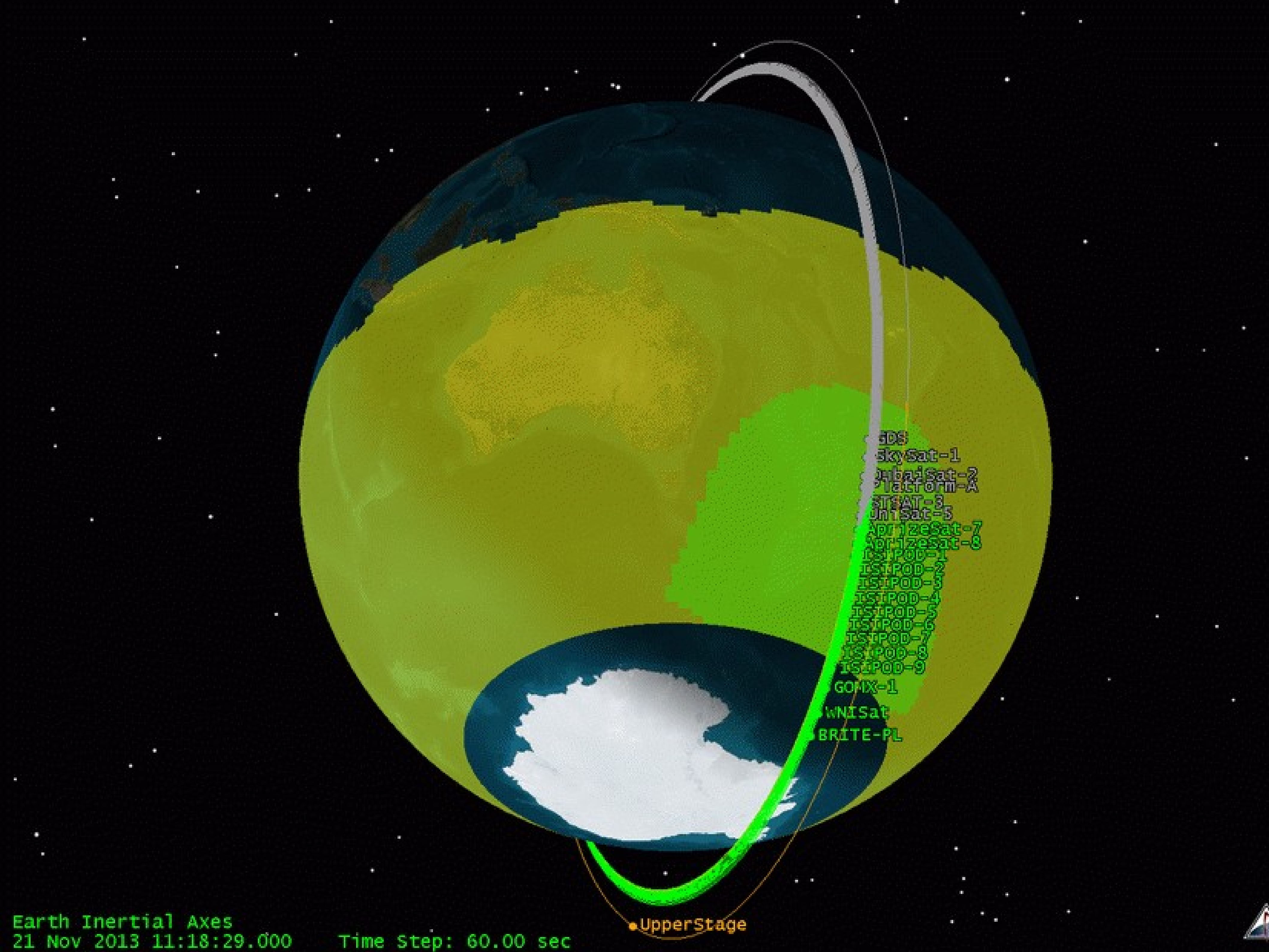

GDS
SkySat-1
DubaiSat-2
Platform-A
STSAT-3
UniSat-5
AprizeSat-7
AprizeSat-8
ISIPOD-1
ISIPOD-2
ISIPOD-3
ISIPOD-4
ISIPOD-5
ISIPOD-6
ISIPOD-7
ISIPOD-8
ISIPOD-9
GOMX-1
WNISat
BRITE-PL
UpperStage
Earth Inertial Axes
21 Nov 2013 11:18:29.000
Time Step: 60.00 sec



With what and where to Launch?

- Depends on your lifetime and desired orbit
- LEO in general is easy & cheap

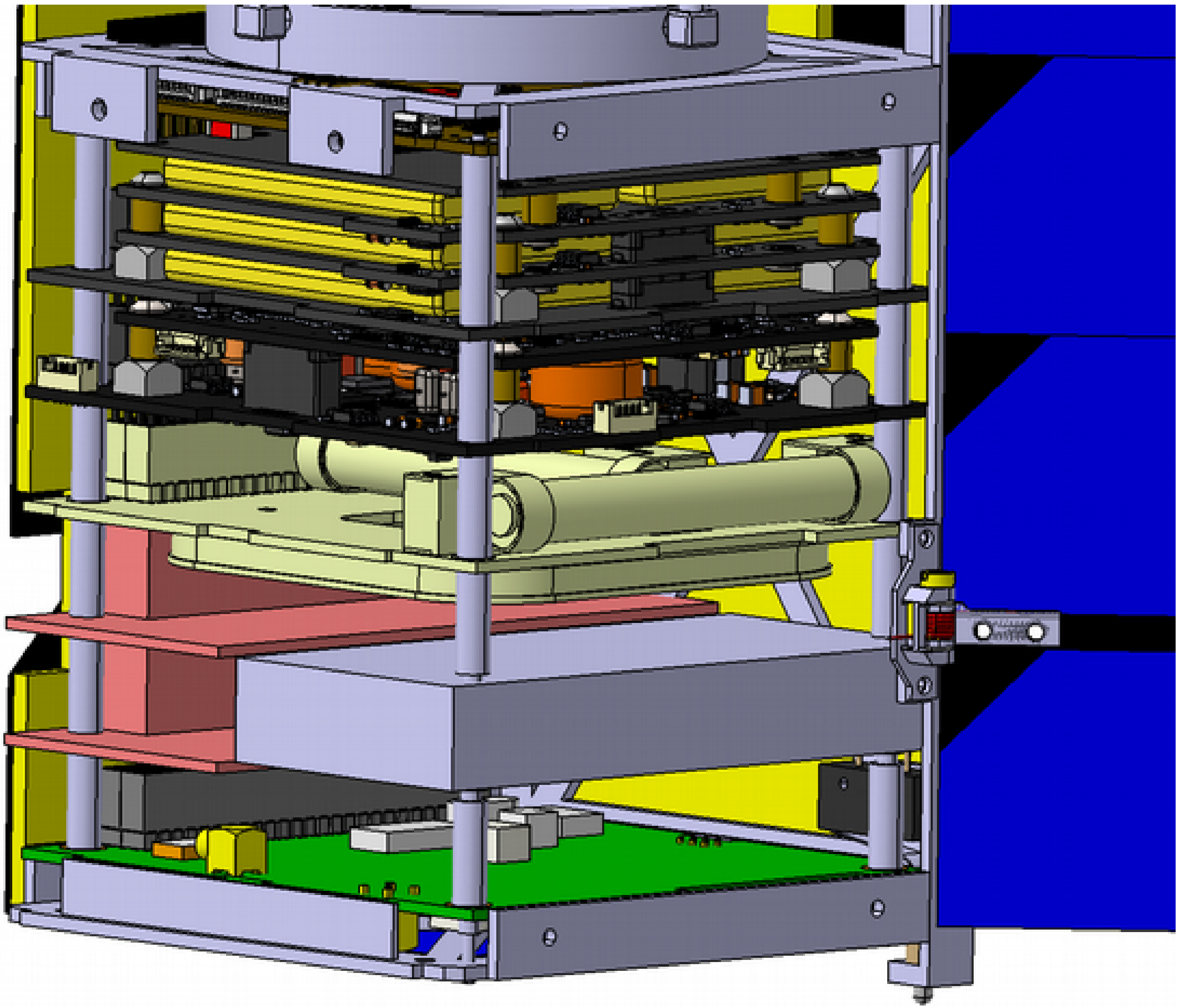
- Deployment from ISS possible
  - Political question – sometimes extremely cheap
  - Short lifetime (1 - 2 months to deorbit!)
- Secondary Payload on a Rocket
  - Target Orbit depends on primary payload
  - Multi-Orbit CubeSat launch vehicles emerging
  - Smaller launchers increasingly popular

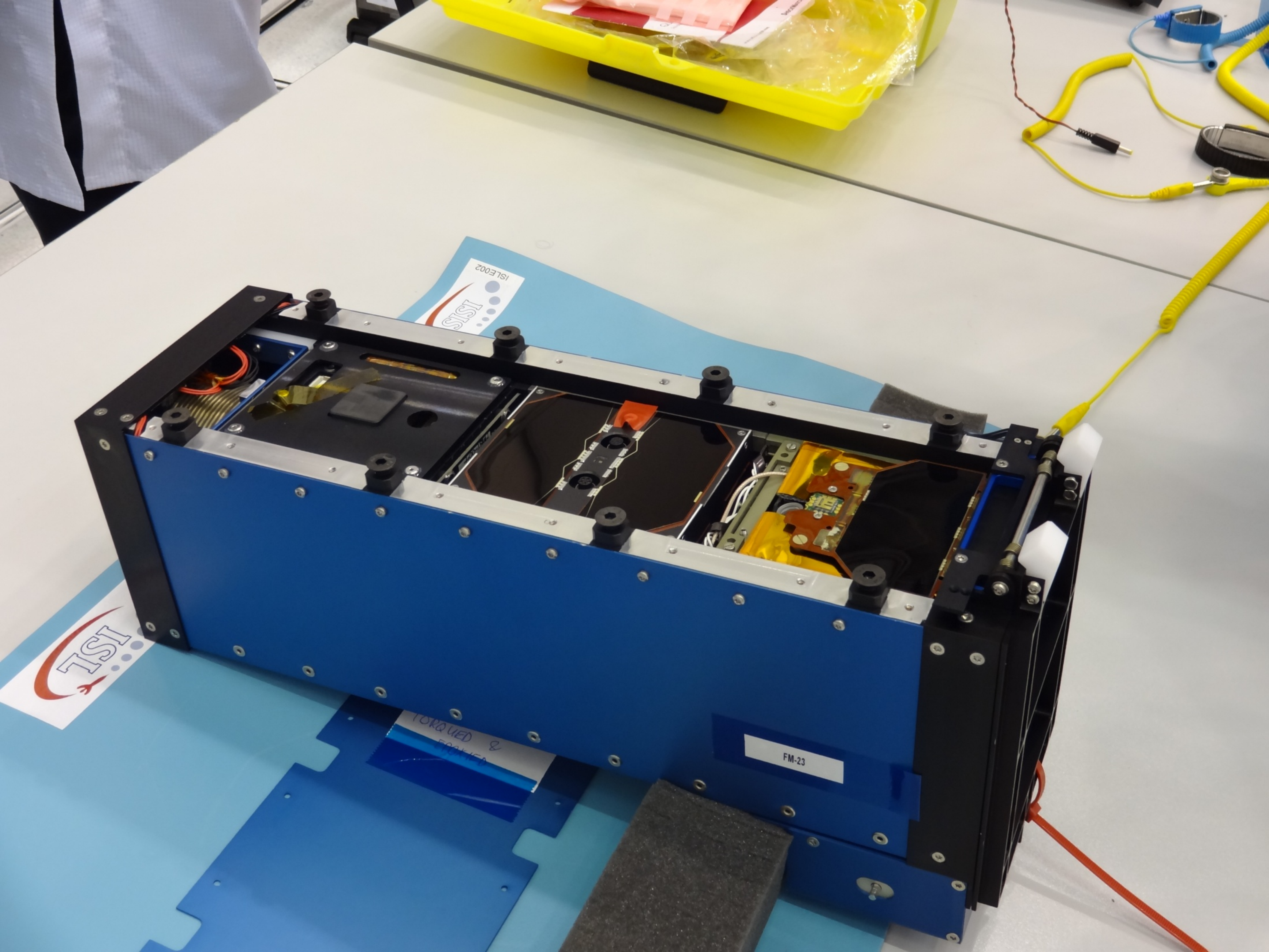

GDS
SkySat-1
DubaiSat-2
Platform-A
STSAT-3
UniSat-5
AprizeSat-7
AprizeSat-8
ISIPOD-1
ISIPOD-2
ISIPOD-3
ISIPOD-4
ISIPOD-5
ISIPOD-6
ISIPOD-7
ISIPOD-8
ISIPOD-9
GOMX-1
WNISat
BRITE-PL
UpperStage
Earth Inertial Axes
21 Nov 2013 11:18:29.000 Time Step: 60.00 sec

Deployers & Physical Limitations

- Many different deployer sizes
- Cost depends on other payload
- If you do not fit, it’s your problem

- Always Stick to CubeSat Specs
  - Other CubeSats may and will violate them
  - Expect your neighbor to violate the standard
  - Do not plan with 0 tolerance!




ISLE002
ISIS
ISL
FM-23

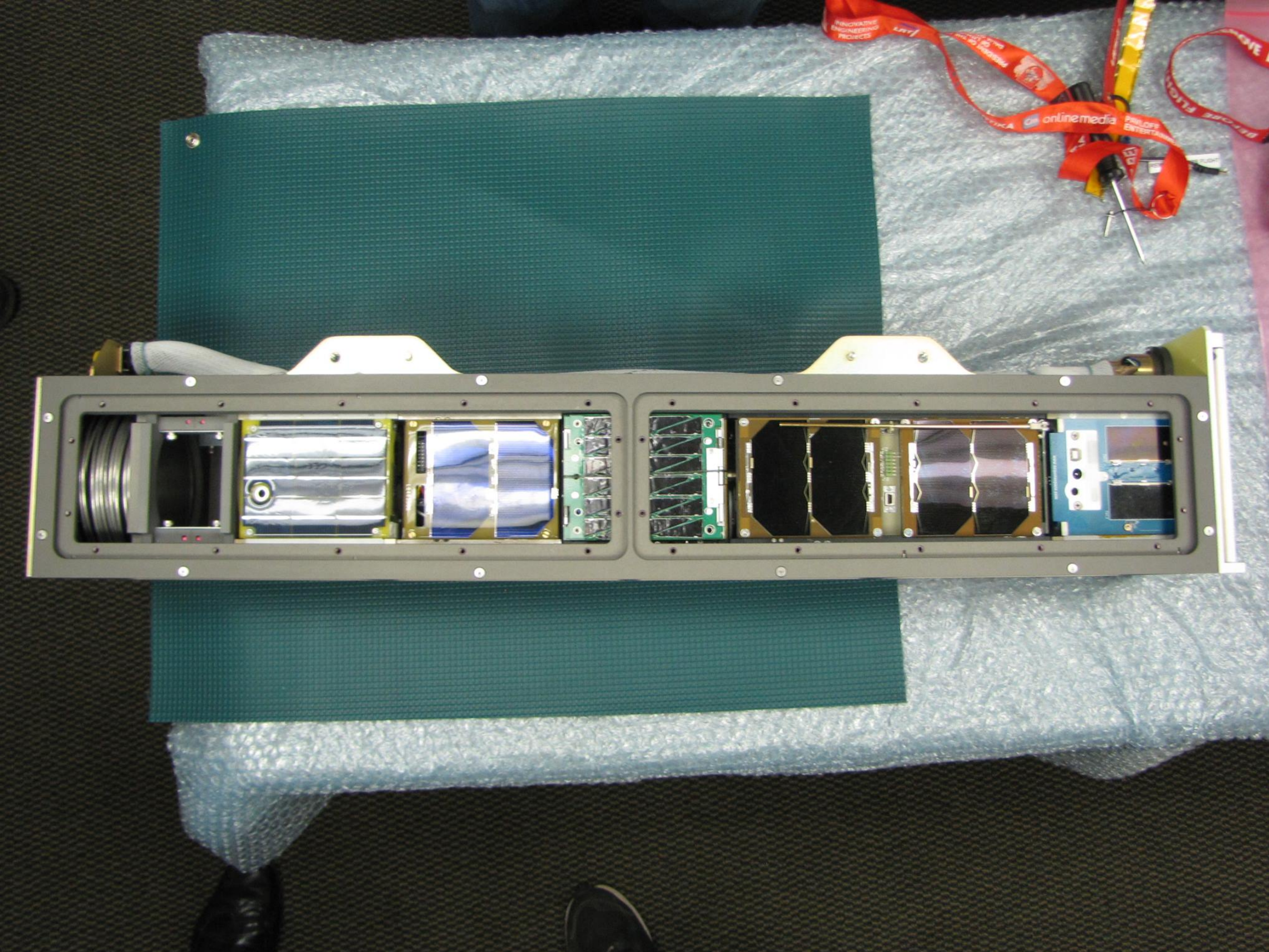

onlinemedia

Image Source: NASA, Public Domain

Image Source: NASA, Public Domain

Image Source: NASA, Public Domain

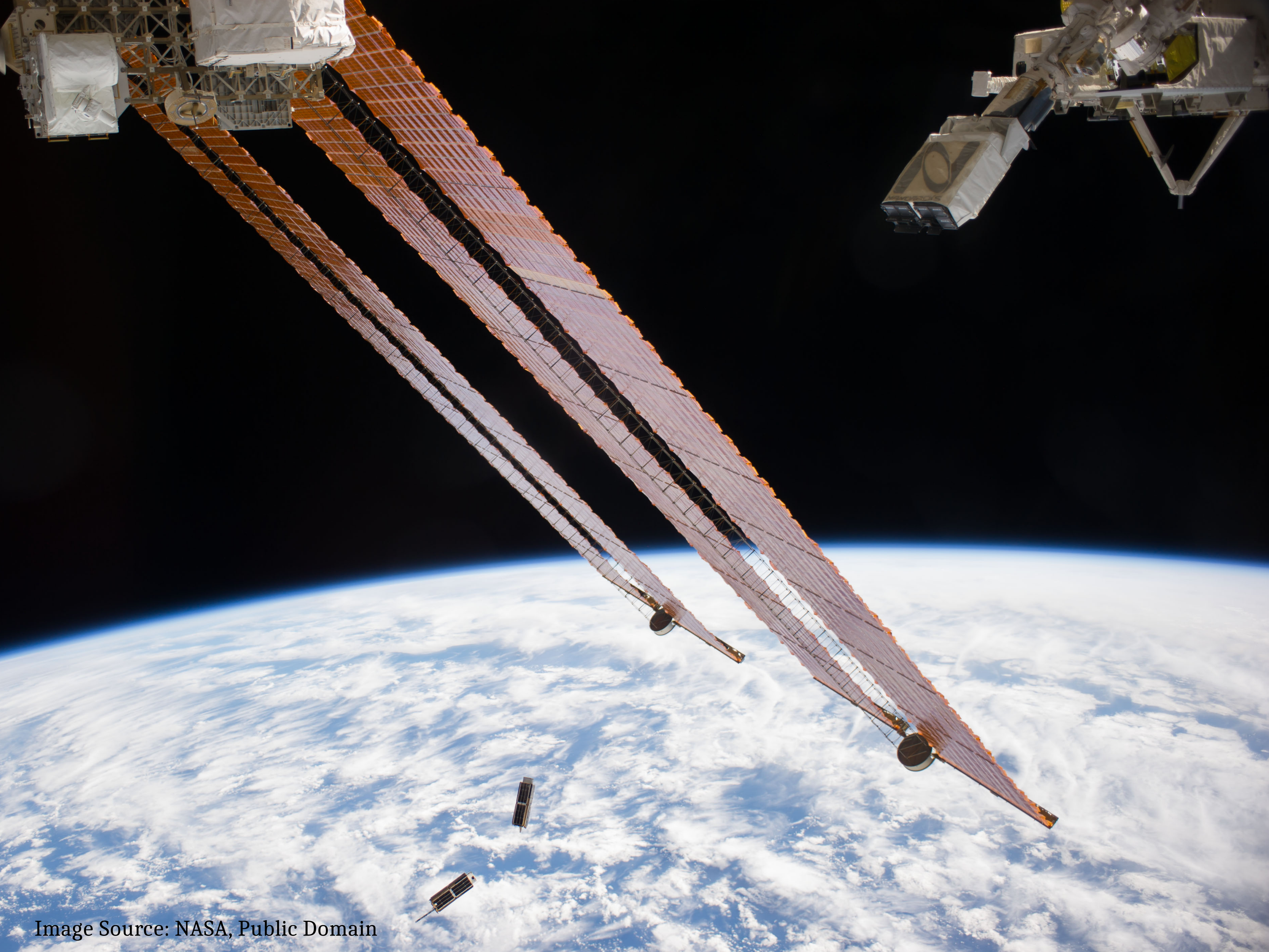


Image Source: NASA, Public Domain

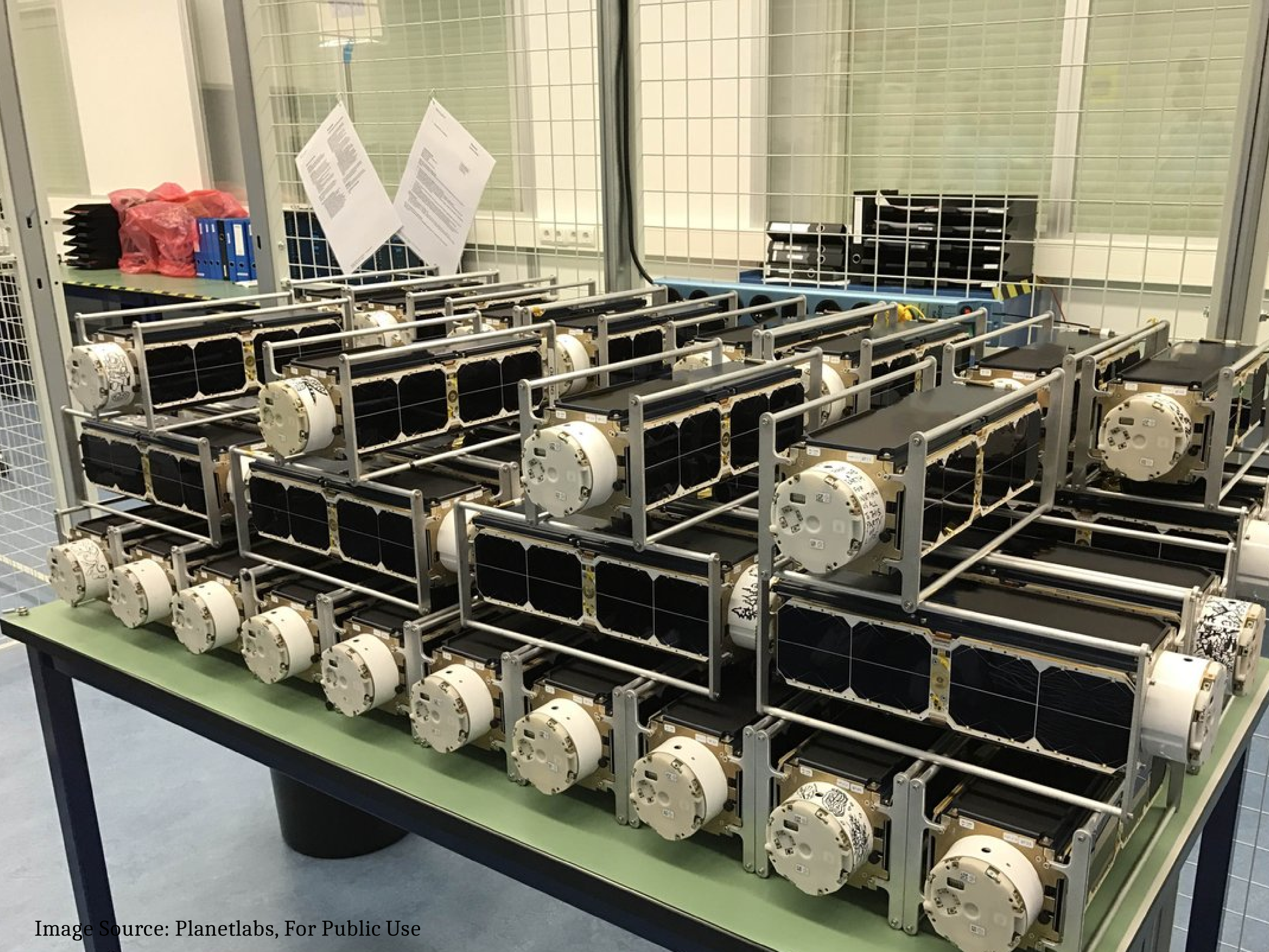


Image Source: Planetlabs, For Public Use

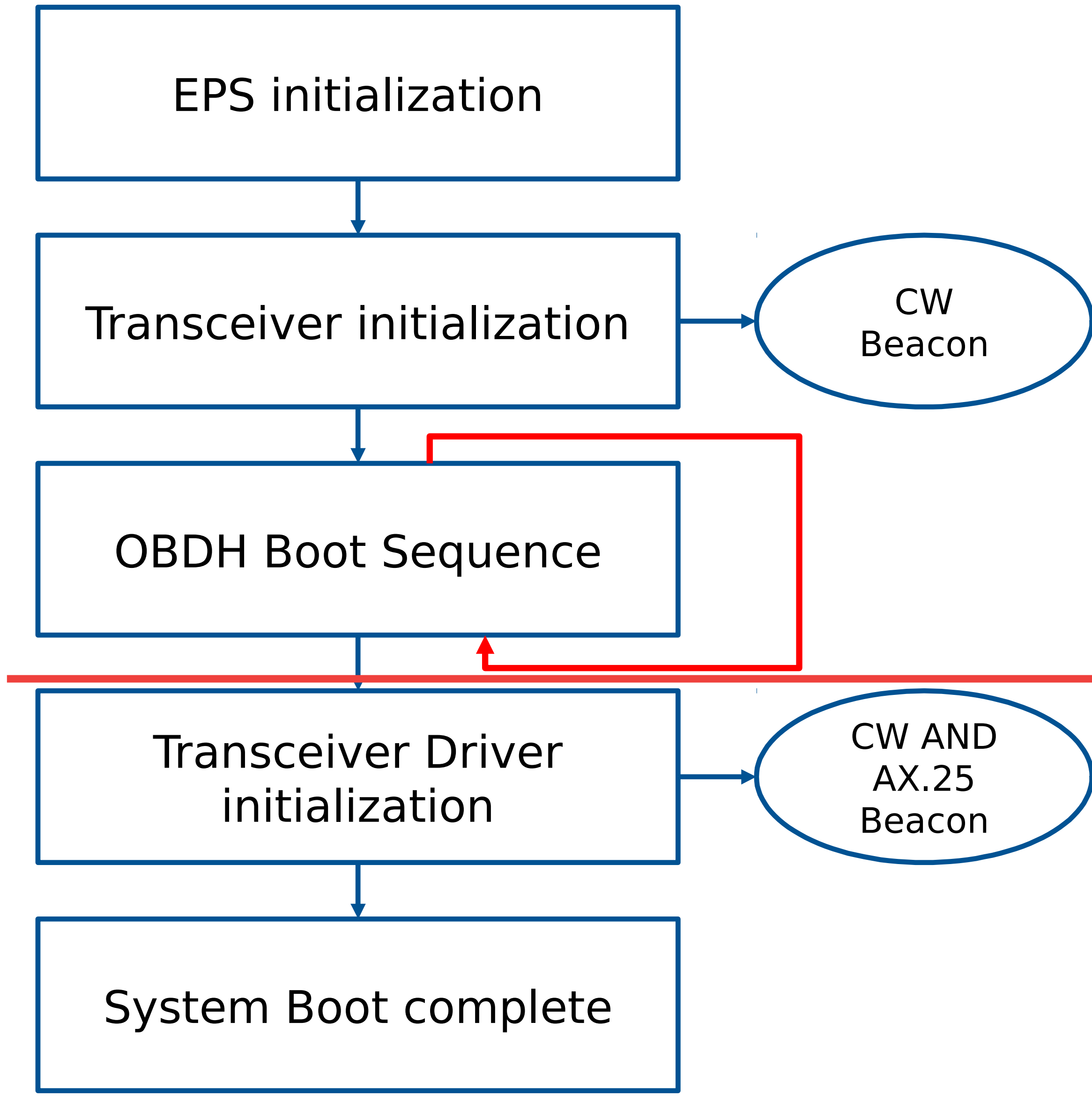
Image Source: Indian Space Research Organization, Public Domain

Image Source: Indian Space Research Organization, Public Domain

First-MOVE‘s Fate

- After 1 month, frequent reboots
- Seemingly no cause
- In Operation until 19.12.2013
- Then: bootloop

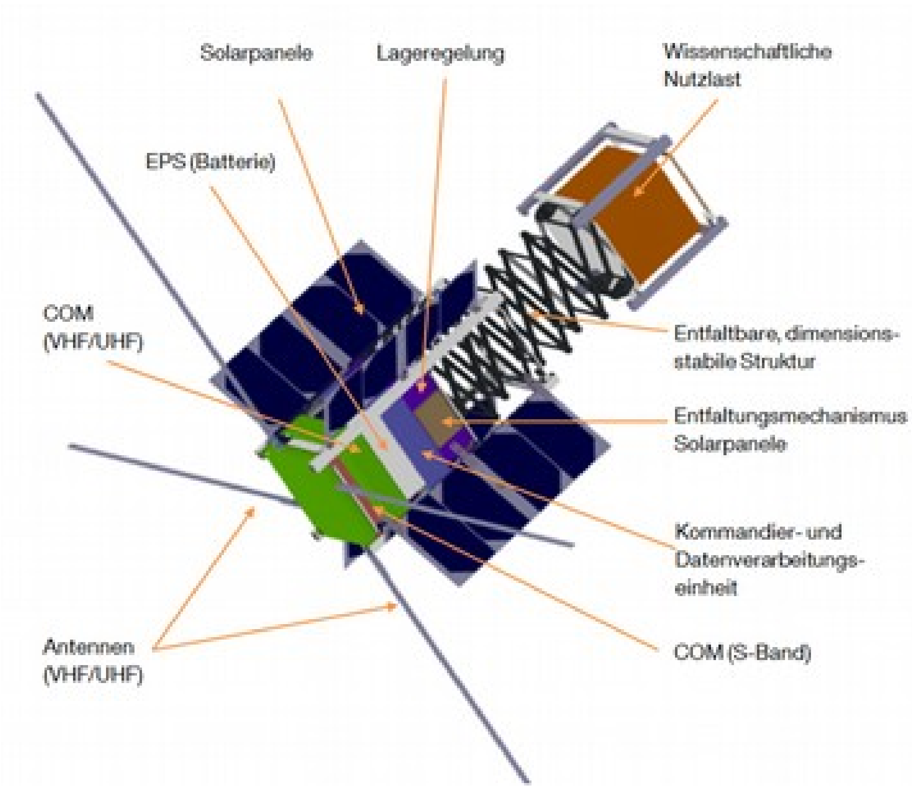
- Critical Issues:
  - No fallback/failsafe mode
  - No debugging possible
  - No software update
  - No statistics
  - No failover
  - No options



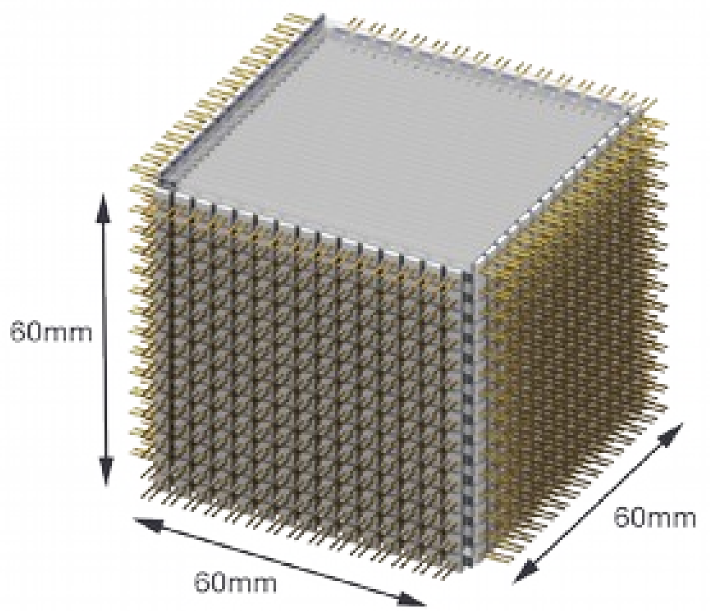
MOVE-II Preliminary System Concept (2013)

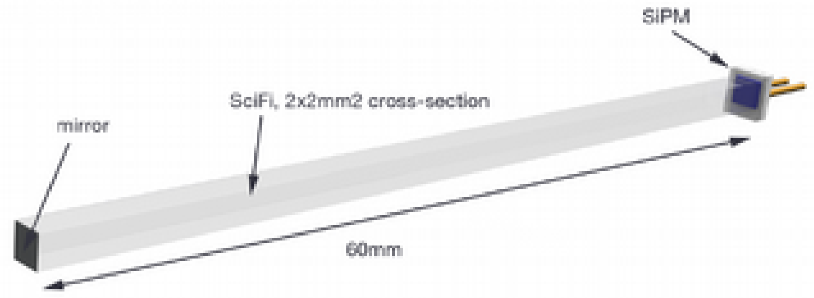
- 3U CubeSat
- Communication via UHF/VHF + S-Band
- Custom OBC, ADCS & COM
- 2 Payloads
- Objective: Science
- 12W power budget

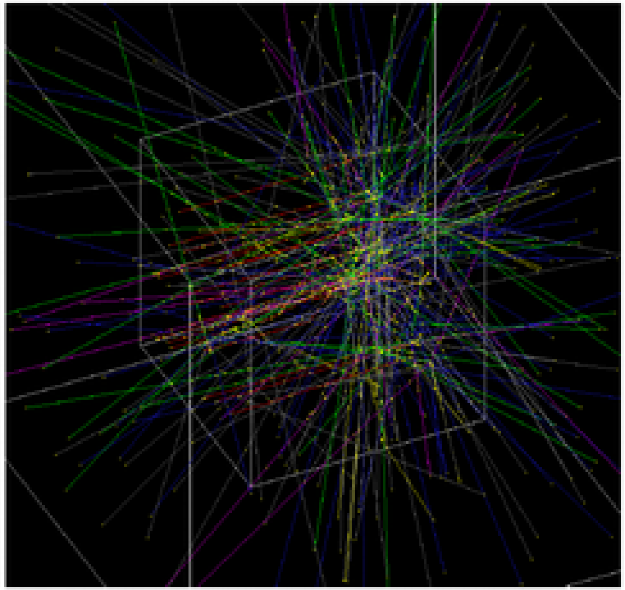
- Preliminary CDH Hardware
  - ARM Cortex-A5
  - ECC-DRAM
  - MRAM
  - NAND-Flash for Payload Data
  - Standard OS

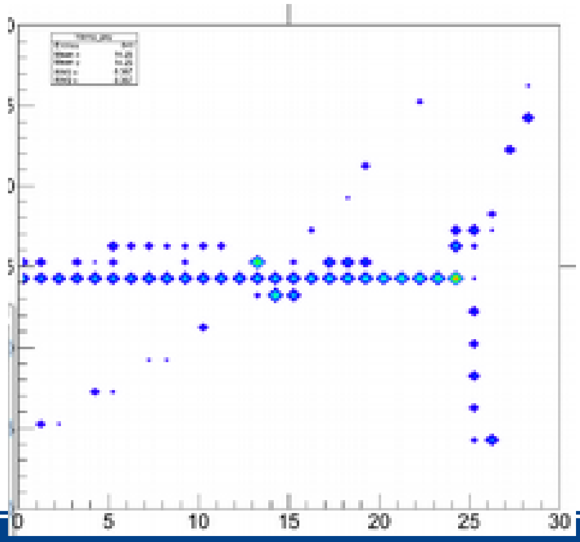


MOVE-II Payload

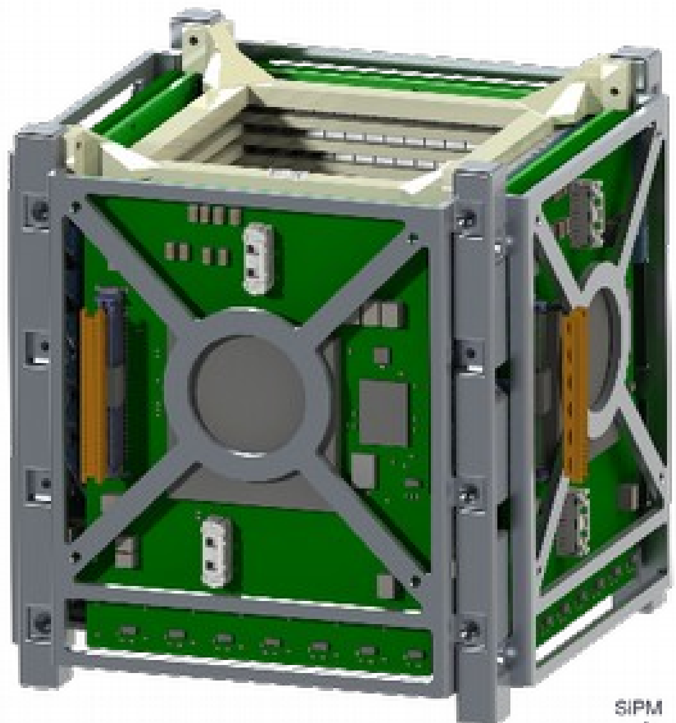


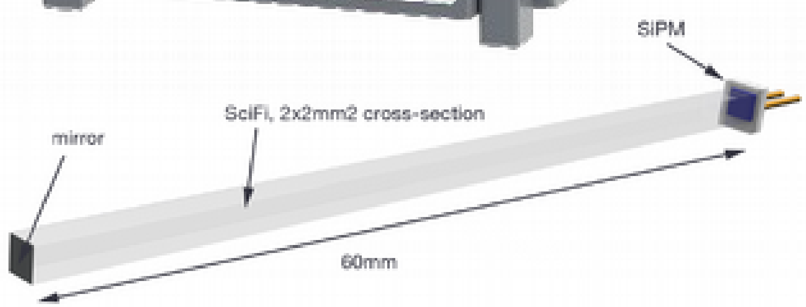


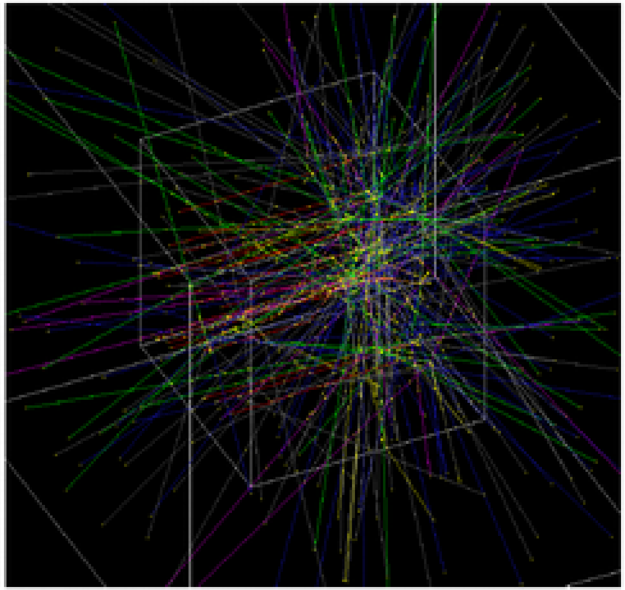


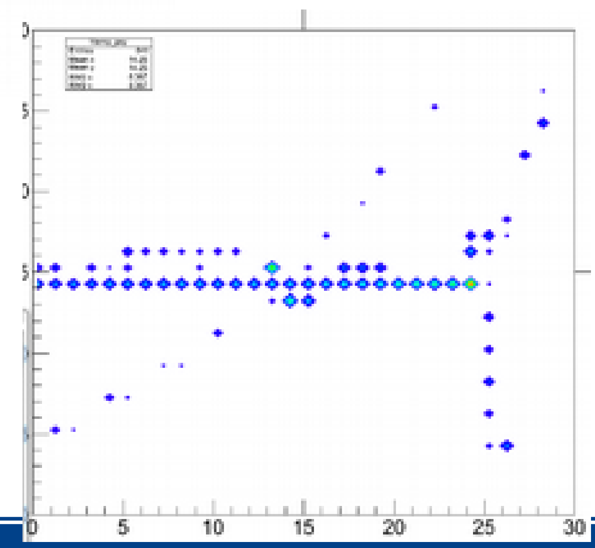


MOVE-II Payload









MOVE-II (2014)

- 2U CubeSat built at TUM
- 1U Modular CubeSat Bus
- 1U Scientific Payload

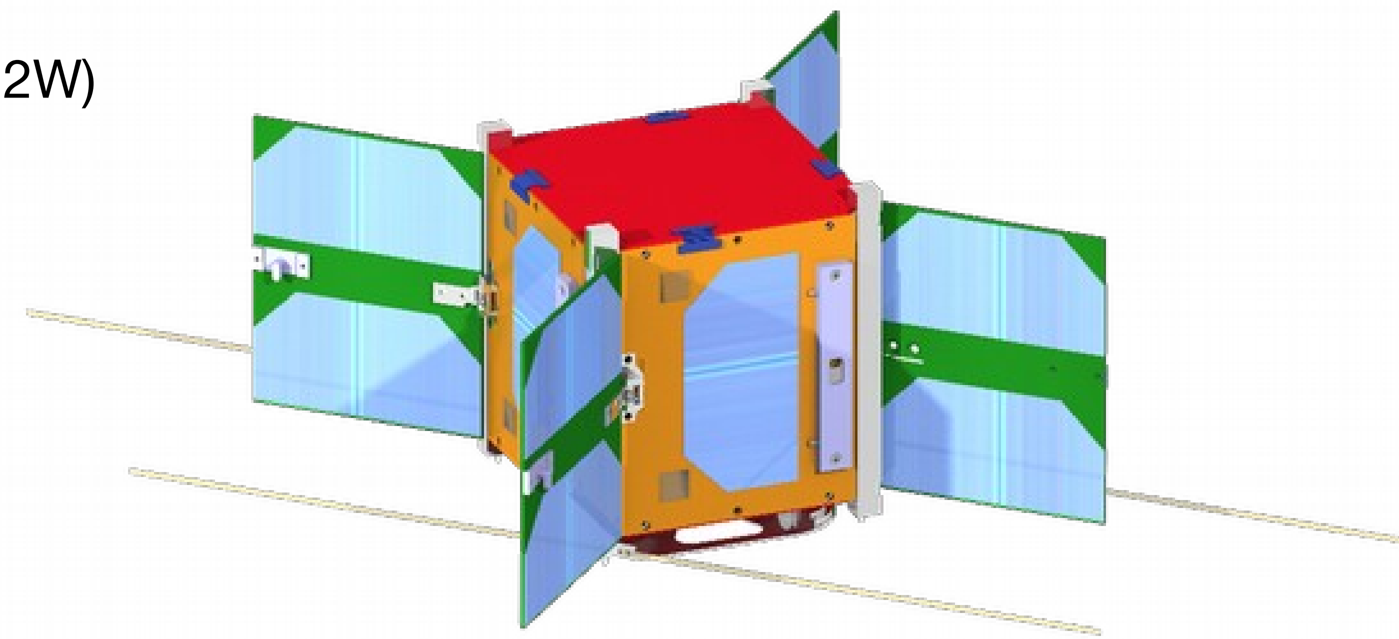
- 9W Average Power Budget
- 2W OBC Power Budget
- UHF/VHF + S-Band Com

- On-Board Computer
  - Cortex-A5 or LEON3 on FPGA
  - 64 MB ECC-SDRAM
  - 8MB MRAM for the OS
  - NAND-Flash for Payload Data
  - Linux

The MOVE-II Nanosatellite (2015)

- 1U CubeSat
- 8W power budget
- UHF/VHF + S-Band Comm

- On-Board Computer (~2W)
  - LEON3 SoftCore
  - 64 MB ECC-SDRAM
  - 8MB MRAM
  - NAND-Flash
  - SPI + GPIO
  - Linux

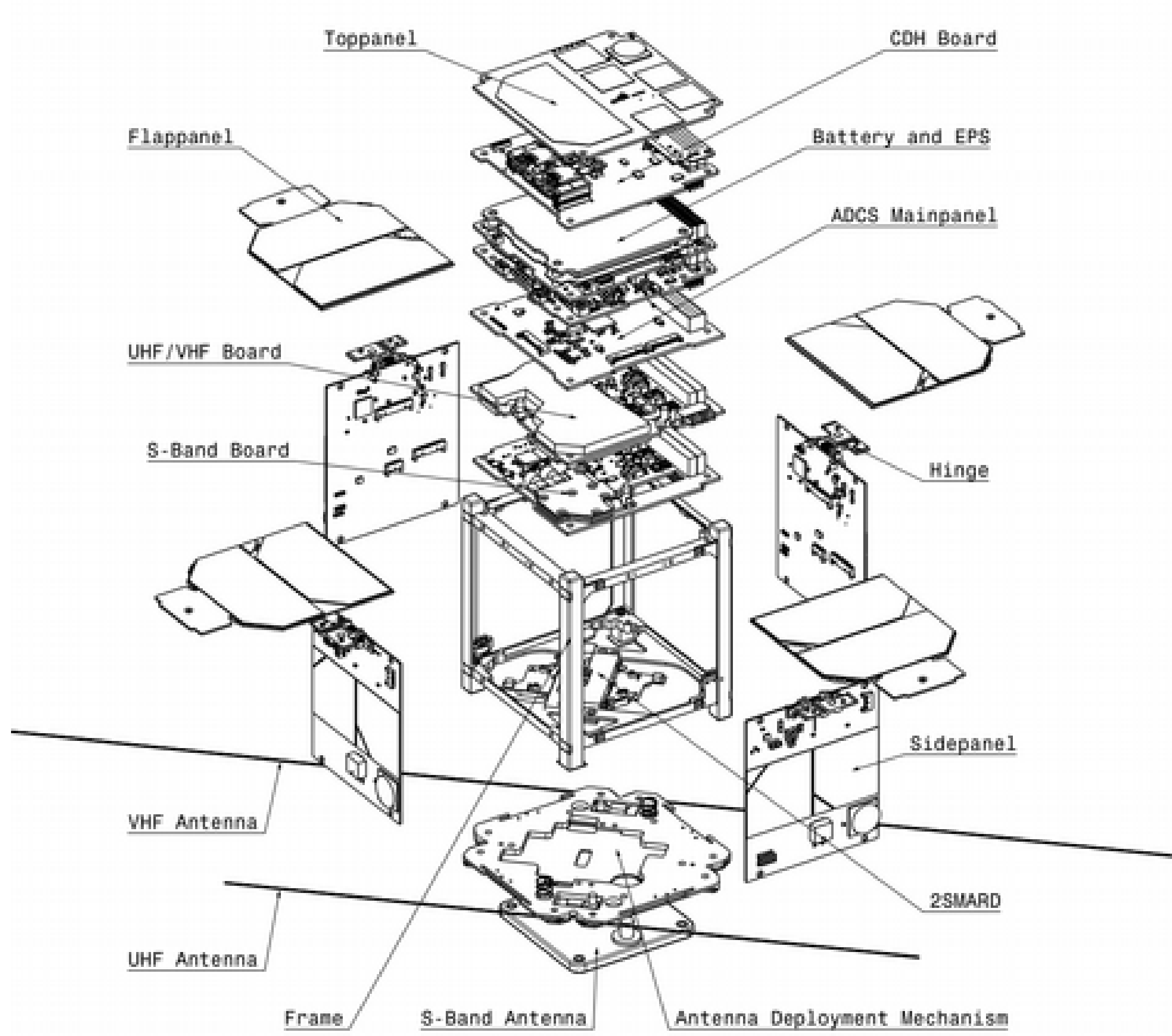


The MOVE-II Nanosatellite (2016)

- 1U CubeSat
- 8W power budget
- UHF/VHF + S-Band Comm

- On-Board Computer (~2W)
  - LEON3, Cortex A5/M5?
  - 64 MB RAM
  - Nand Flash
  - SPI + GPIO

- Autonomous debugging
- Efficient protocol stack
- Size optimized standard OS

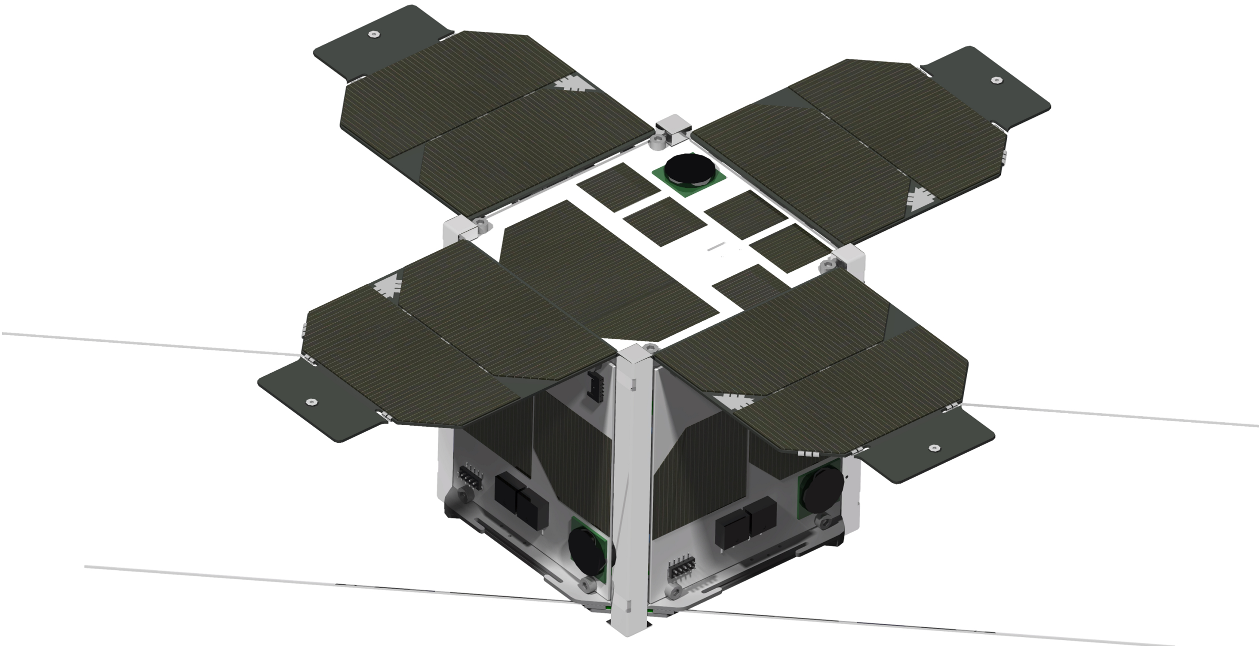


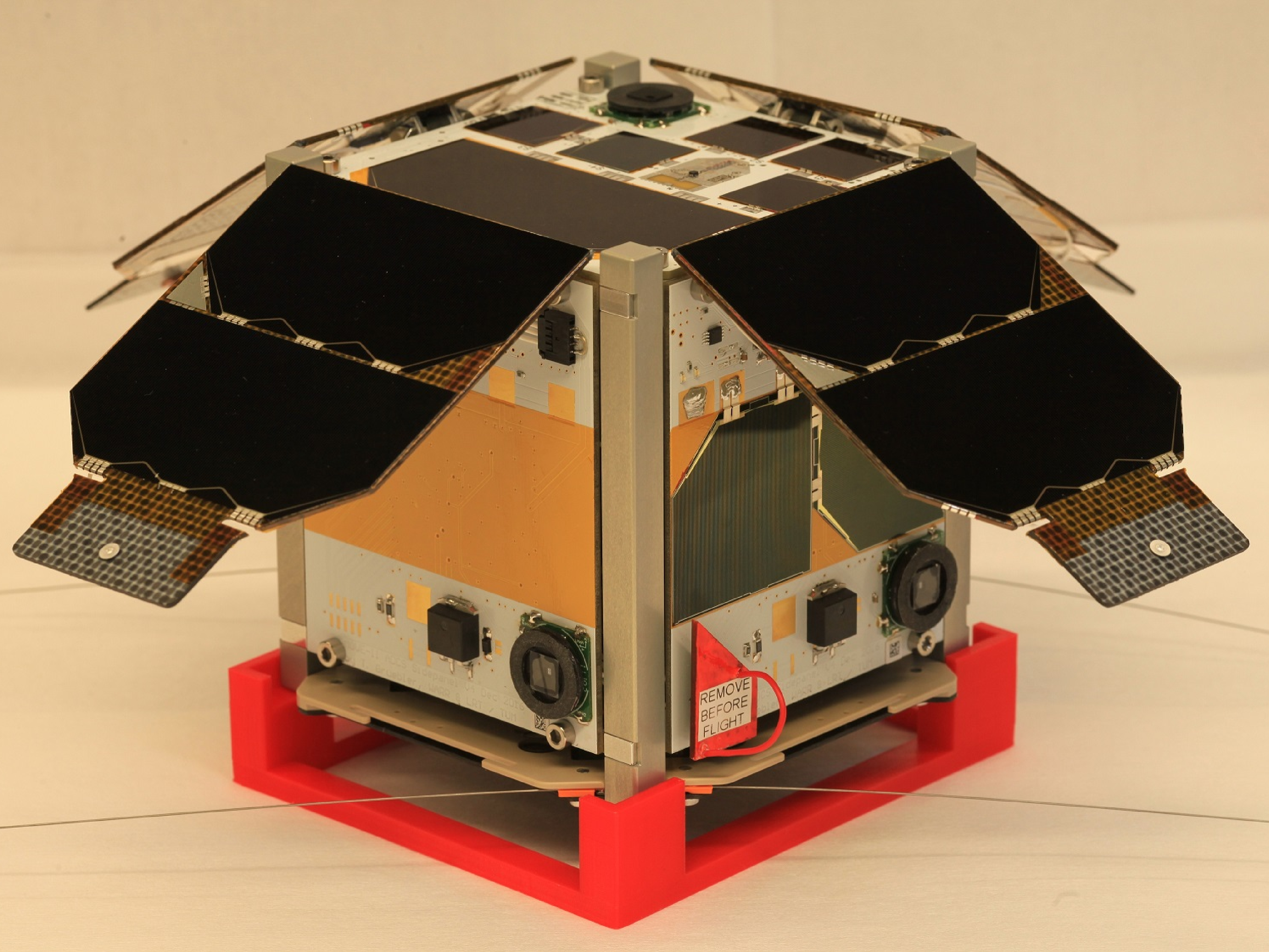
The MOVE-II Nanosatellite (2017)

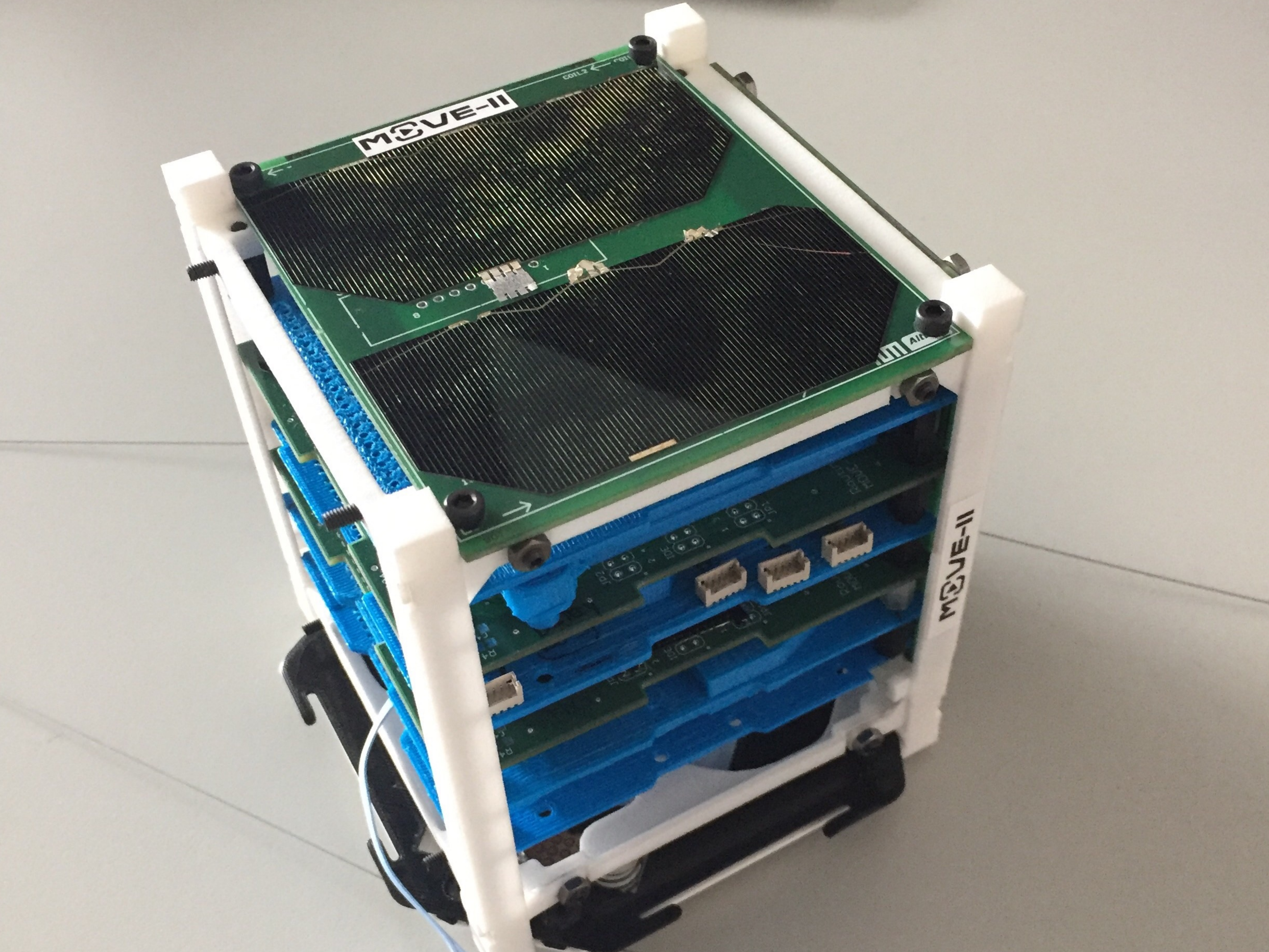
- 1U CubeSat
- 8W power budget
- UHF/VHF + S-Band Comm

- On-Board Computer (~2W)
  - Cortex M5
  - 512 MB DDRAM
  - 512 MB Nand Flash
  - SPI + GPIO + I^2C

- Autonomous debugging
- Efficient protocol stack
- Size optimized standard OS




REMOVE
BEFORE
FLIGHT

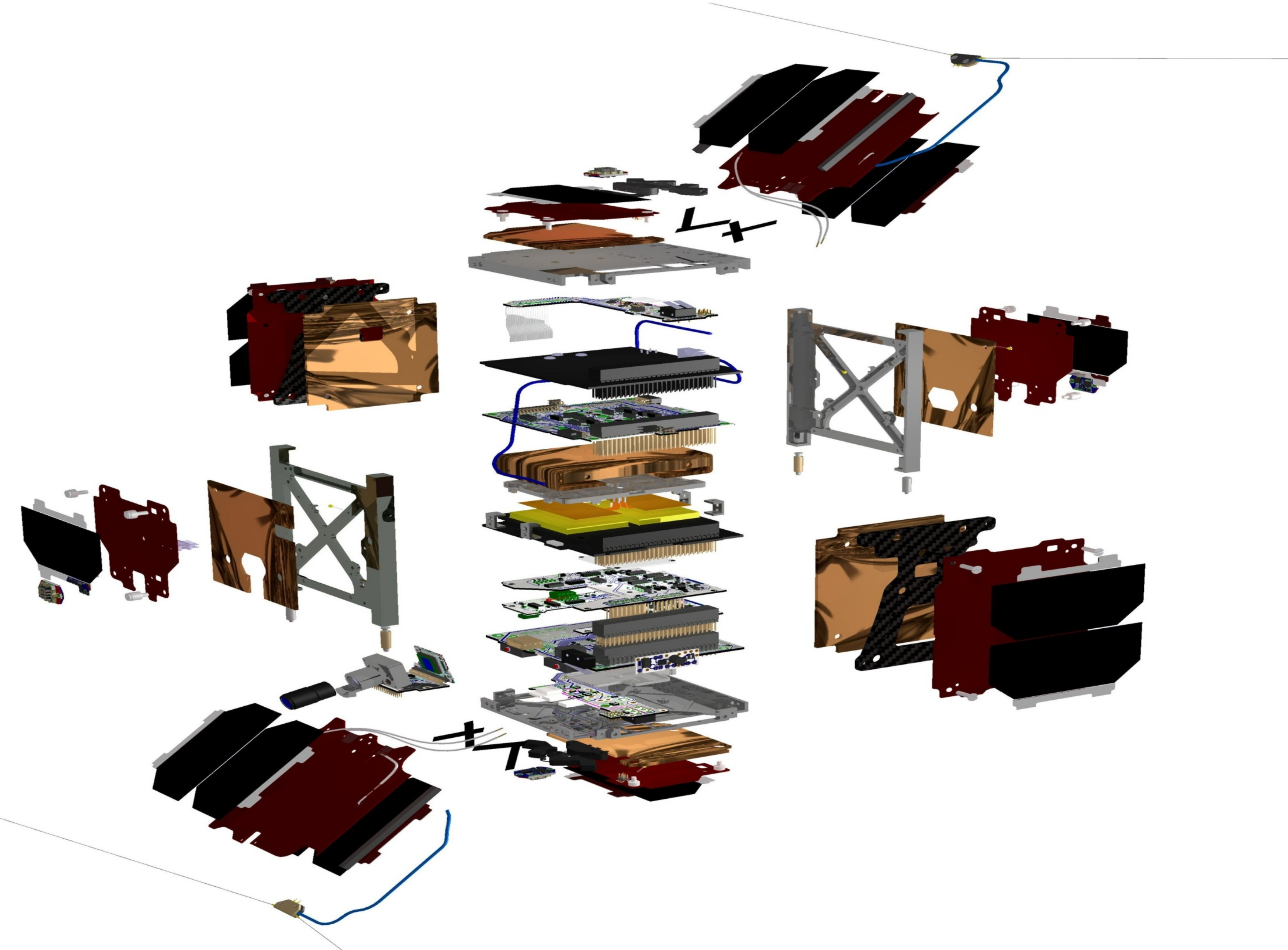

MOVE-II
MOVE-II

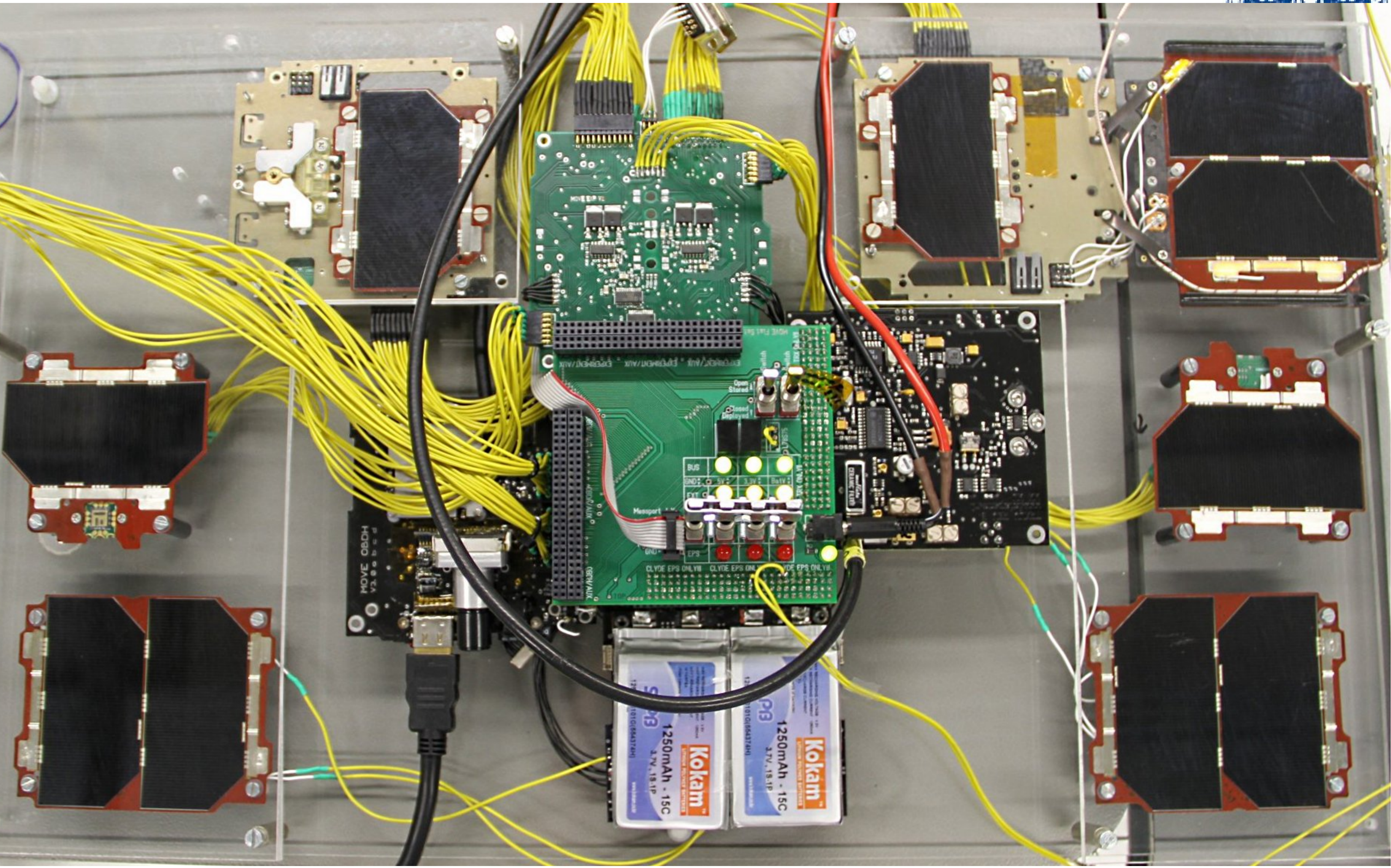
Most CubeSats are built by 5-10 people, rest is “along for the ride”

Active Members:	Total Members:	Studies:	Ages:	Nationalities:
60	>130	Mechanical and Electrical Engineering, Informatics, Physics, Economics, Earth Oriented Space Science	21-31	10

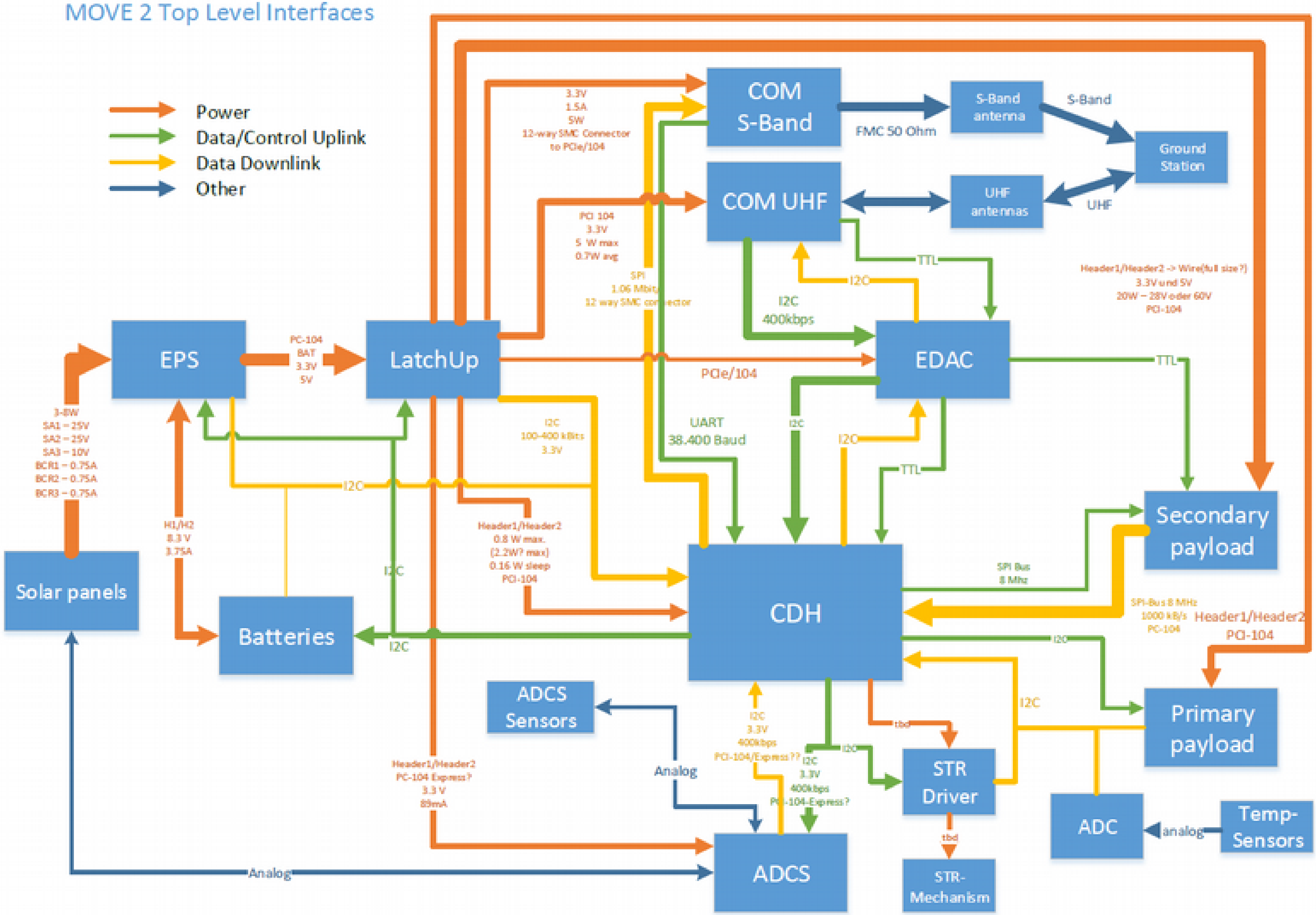
Most CubeSats are built by 5-10 people, rest is “along for the ride”

Active Members:	Total Members:	Studies:	Ages:	Nationalities:
10: * 5 (Bsc/Msc) * 2 (PhD/Pdoc) * 1 Elecronics Technican	30-40 at any given time (who show up more than once, e.g.: Semester Projects, built a test-bench, ...)	EE, Comp-Sci, Physics, Mech-Eng, Space-Sciences, Outreach, Publicity, Media	21-31	10

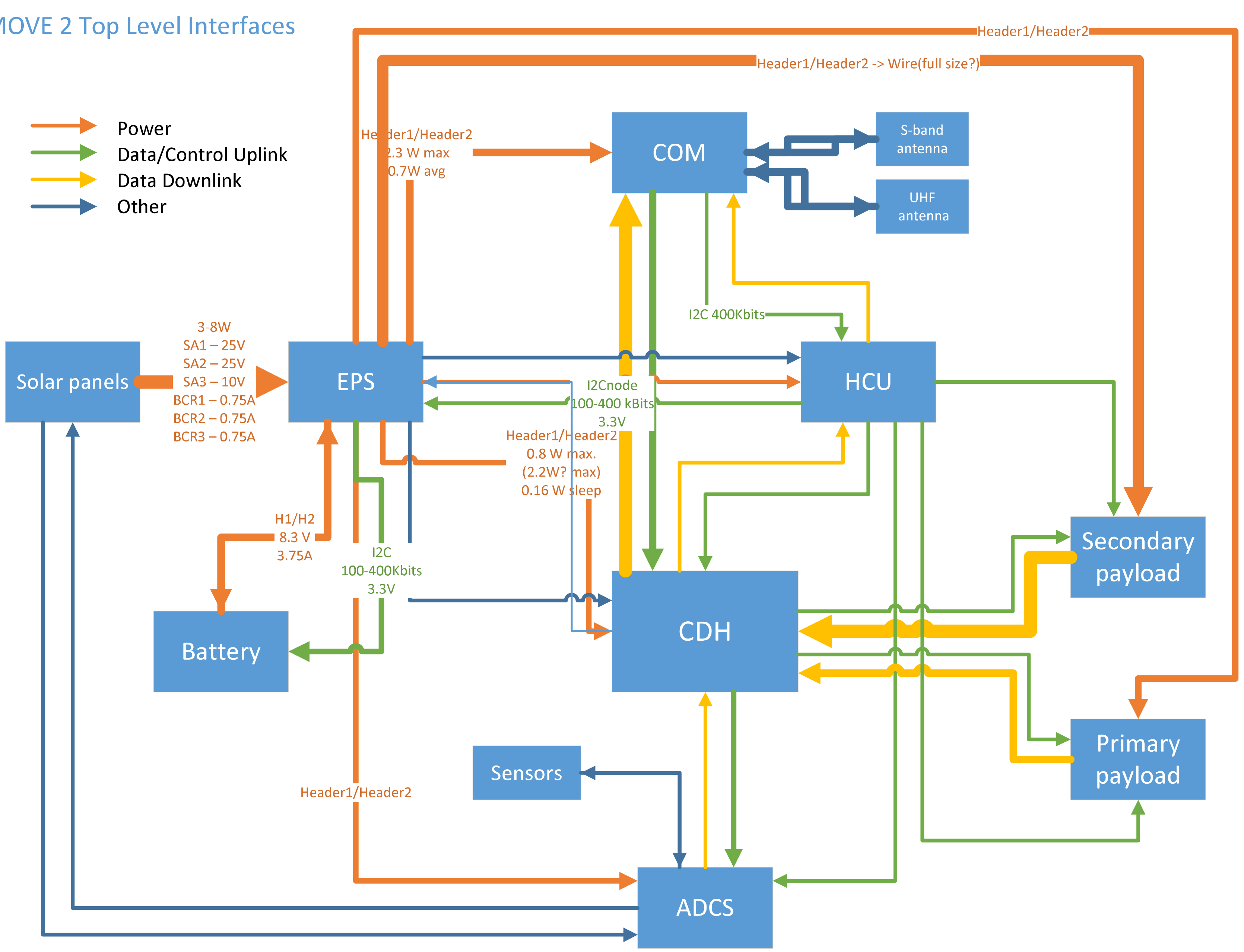




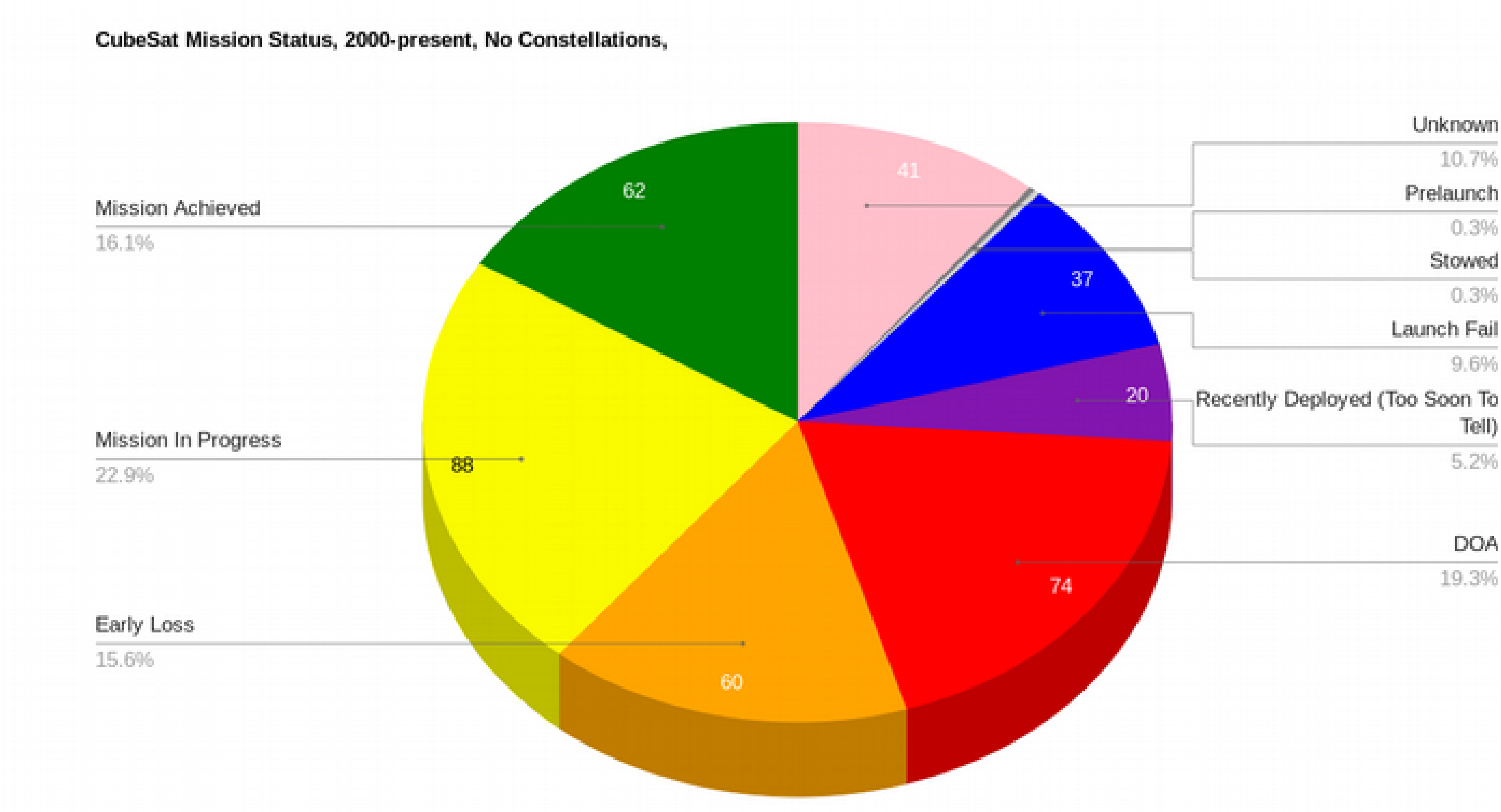
MOVE 2 Top Level Interfaces



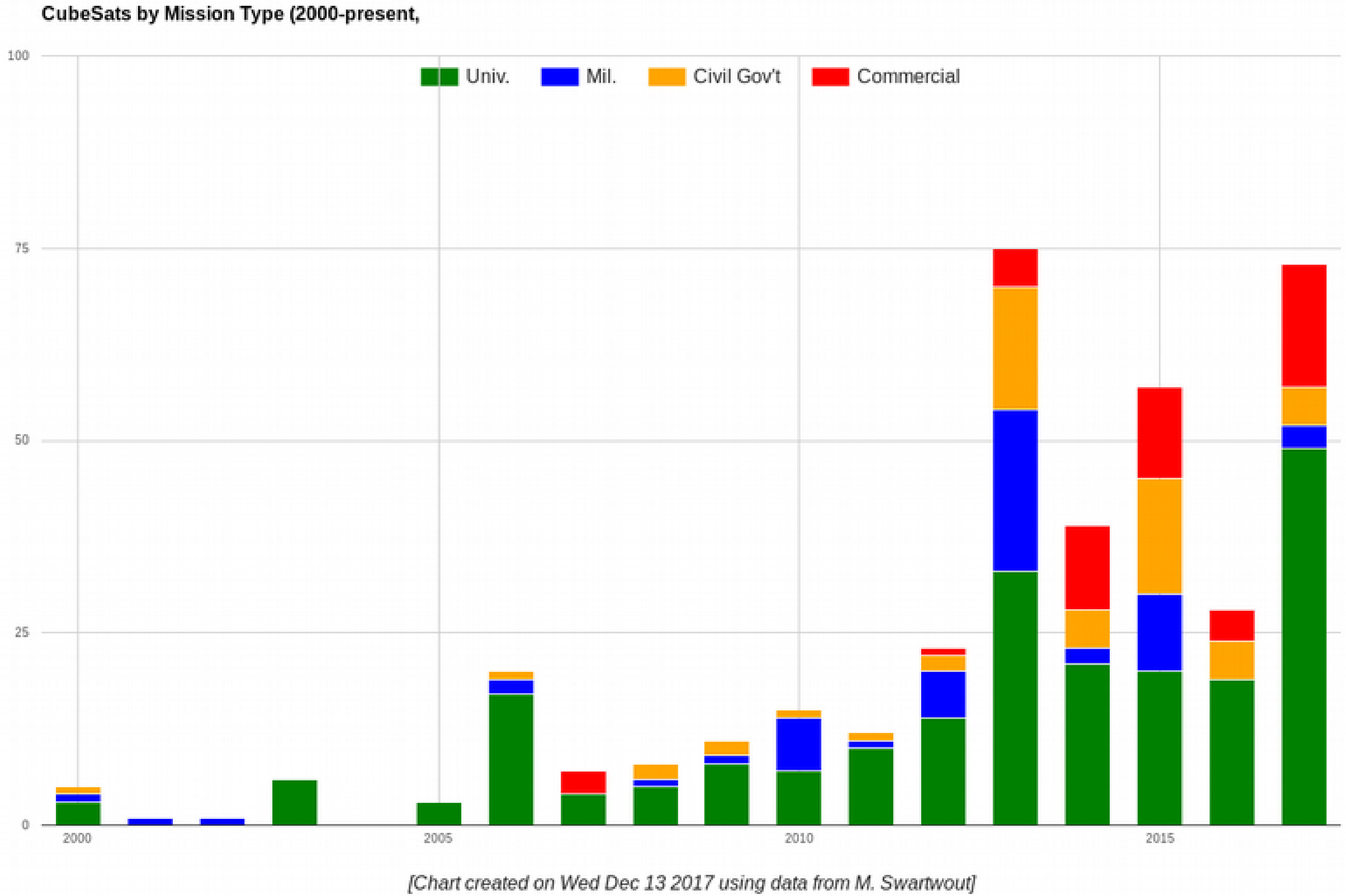
MOVE 2 Top Level Interfaces



Today’s Statistics according to Swartwout’s CubeSat Database

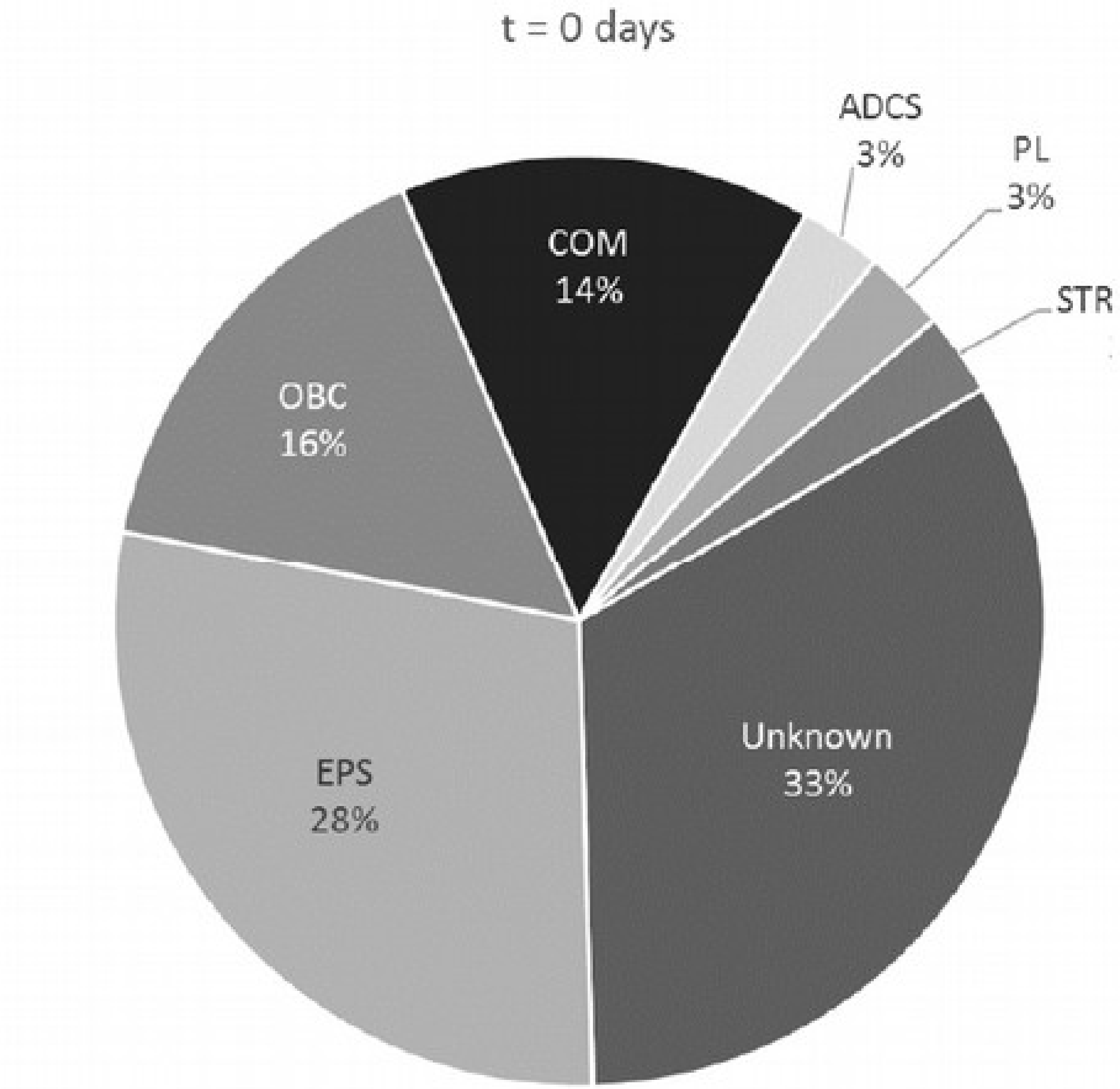


The CubeSat Database by Prof. M. Swartwout
https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database



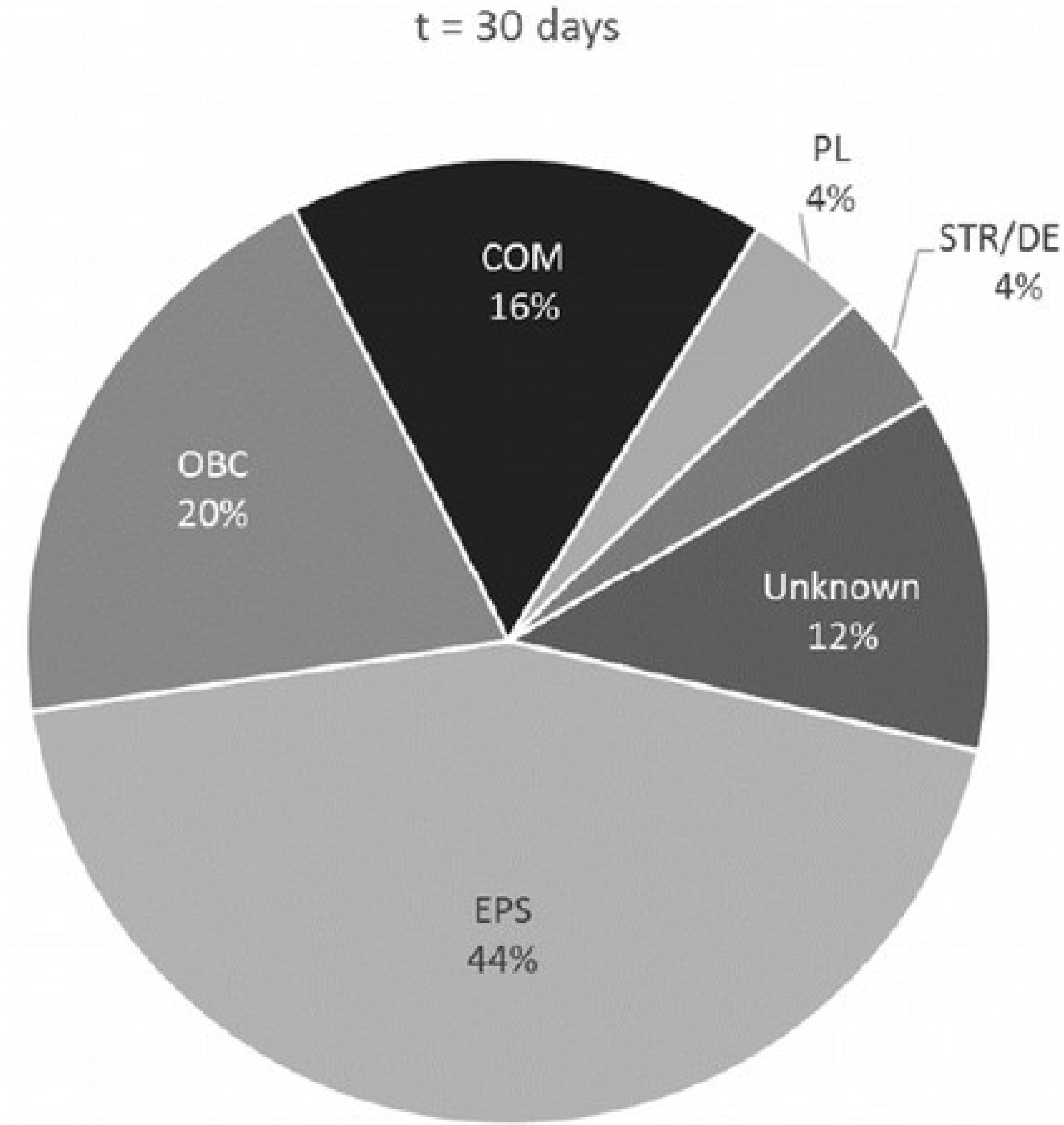
The CubeSat Database by Prof. M. Swartwout
https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

Failure Sources



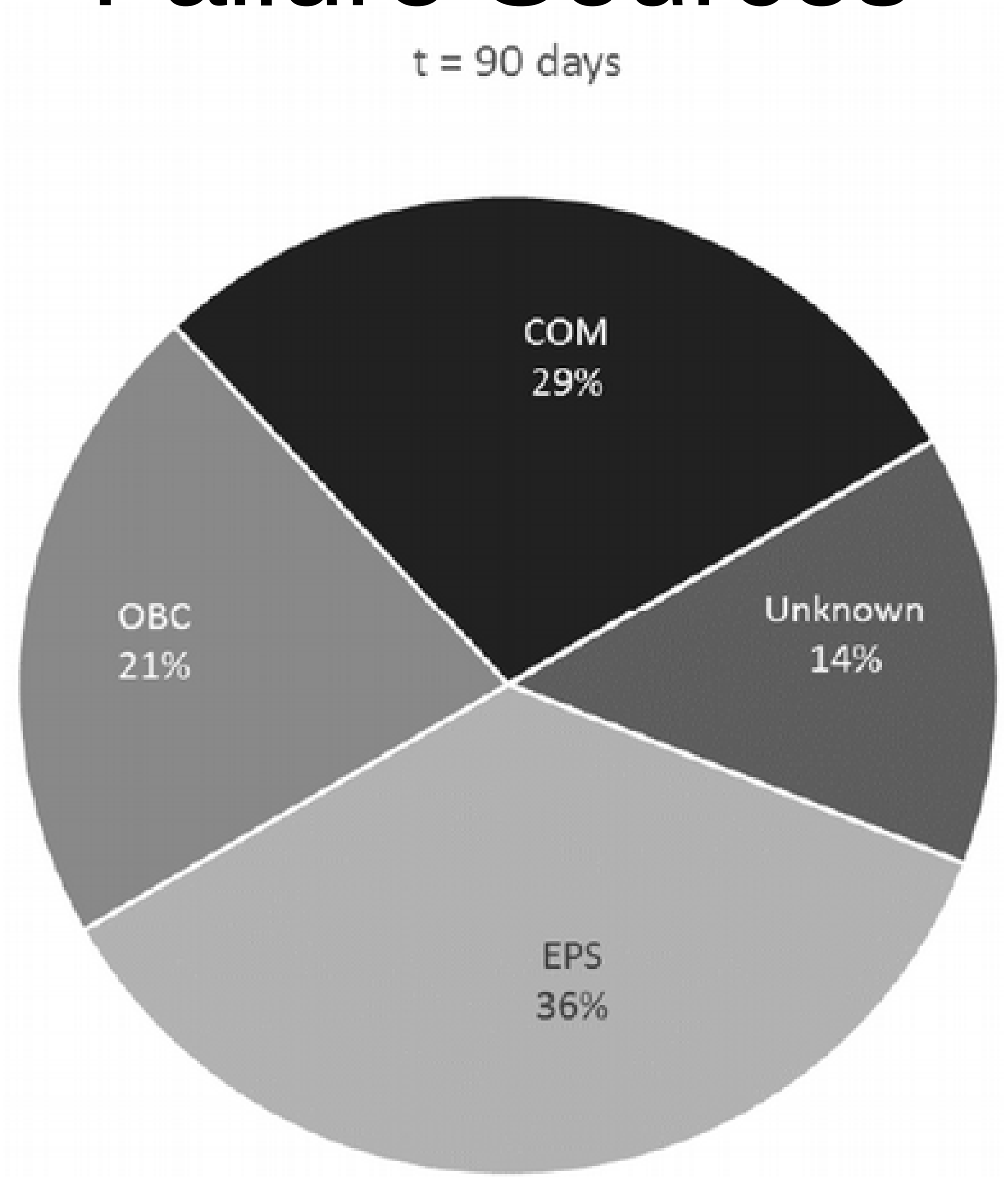
Langer, Martin, and Jasper Bouwmeester. "Reliability of cubesats–statistical data, developers' beliefs and the way forward." 30th Annual AIAA/USU Conference on Small Satellites. 2016.

Failure Sources



Langer, Martin, and Jasper Bouwmeester. "Reliability of cubesats–statistical data, developers' beliefs and the way forward." 30th Annual AIAA/USU Conference on Small Satellites. 2016.

Failure Sources

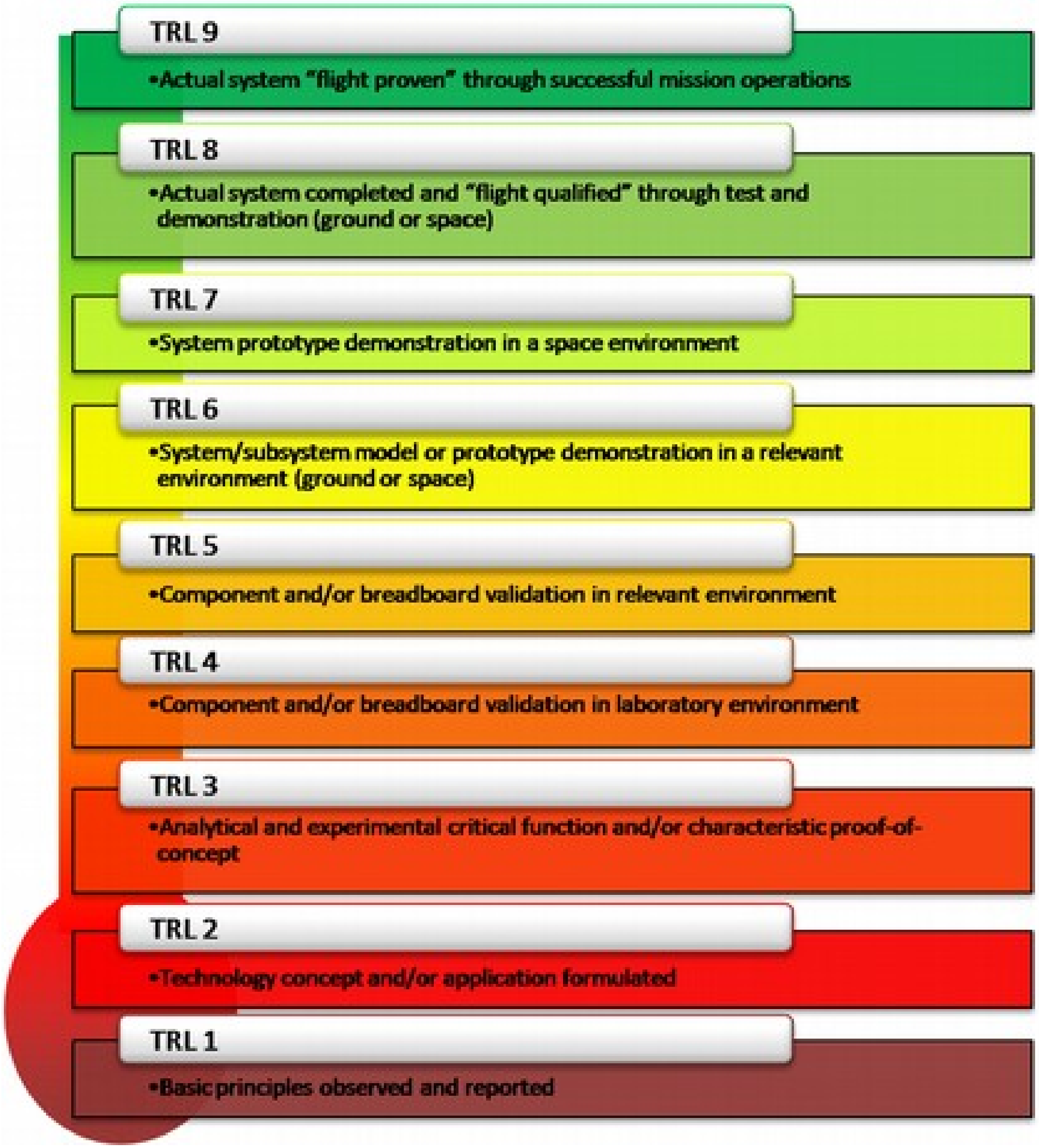


Langer, Martin, and Jasper Bouwmeester. "Reliability of cubesats–statistical data, developers' beliefs and the way forward." 30th Annual AIAA/USU Conference on Small Satellites. 2016.

Heritage and Legacy in CubeSats

- Heritage in larger Space Missions is considered extremely important
- Slows down Development, but is a safety net
- Effect is similar to buying an insurance
- Does not exist for CubeSat
  - Too short lifetime
  - Too few data points
  - Successful mission != good or even fully functional
  - Most COTS CubeSat Devices were hacked together by someone who had very little experience

Technology Readiness Levels

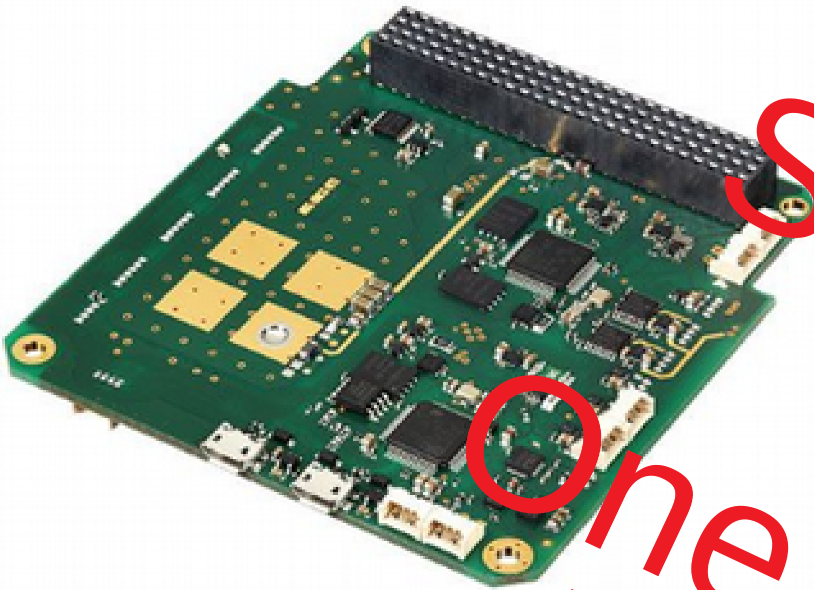


Electrical/Power Subsystem

- Batteries + Electronics + Latch-Up Protection
- Universal use of Lithium-Ion Batteries
  - Limited lifetime (~2-3 years)
  - Temperature Sensitive
  - Beware during Testing
- Beware of your power budget

- Standard Component – Buy!
- Bundle of Batteries + Electronics
- Good COTS Subsystems available

All-in-one Modules



Main Bus Unit "SatBus 3C1"

Basic Price € 9450

Is a highly integrated small satellite main bus unit containing advanced functionality combining:

- an on-board computer (OBC)
- attitude determination & control system (ADCS) and
- communication system (COMM)

Unit is optimized for small sized spacecrafts and complies with the CubeSat standard. Unit is designed to save customer's time and budget, minimize required integration effort and effectively increase volume for payload as well as overall system reliability through harmonized hardware.

SatBus 3C1 architecture is based on a high-performance, low power consumption ARM 32-bit Cortex™ M4 CPU core. All subsystems are provided with standard software package that includes a FreeRTOS Kernel and necessary software libraries for peripherals.

Separate combinations coupling individual subsystems are available for optimal design of the spacecraft.

Stay Away

One Size fits NOBODY

Attitude Determinitation and Control Subsystem

- Basic design has not changed since 1969
- Quite complex and many components
- Standard Components
  - Magnetorquer
  - Magnetometer
  - Sun Sensors
- Depending on pointing accuracy & stability
  - LEO GPS receiver
  - Reaction Wheels
- Buy this item COTS

On-Board Computer - Preface

- CubeSat Projects generally **do not have the manpower** for proper OS development, there are exceptions.
- CubeSat Projects generally **do not have the resources** for proper Software or Embedded Hardware development.
- The usual Results:
  - Commandeering via Telnet via RS232 via AX25 via UHF/VHF
  - Software written in a mix of ADA, Fortran, C and C++
  - OBC based on 16 different micrcontrollers with dedicated software
  - The single main developer left the project 6 months before launch
  - Proprietary, non-adaptable, fragile Satellite “Bus”
  - No – zero – usable documentation

On-Board Computer

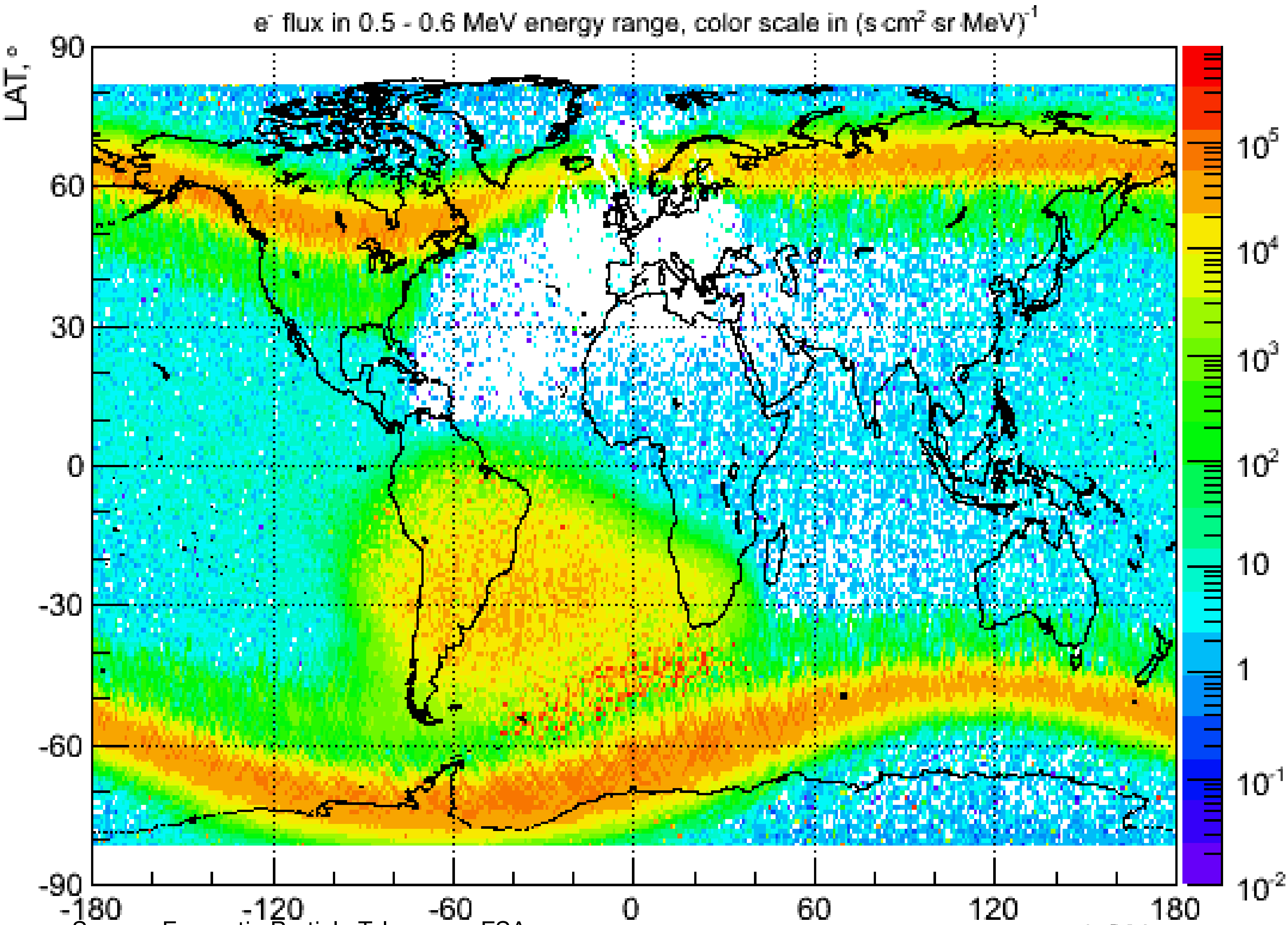
- COTS hardware available
- Buy COTS for Payload-centered CubeSat
- Choose Provider with Great Care
  - Most COTS OBCs are of extremely low quality
  - Usually generalizations of single-purpose designs
  - Many restrictive to the actual CubeSat Architecture
  - Often bloated/oversized or lackluster/spartanic
  - Beware of Vendor Lock-in

Rad-Hard Hardware

"Components designed or manufactured to withstand radiation dosages up to a certain given threshold."

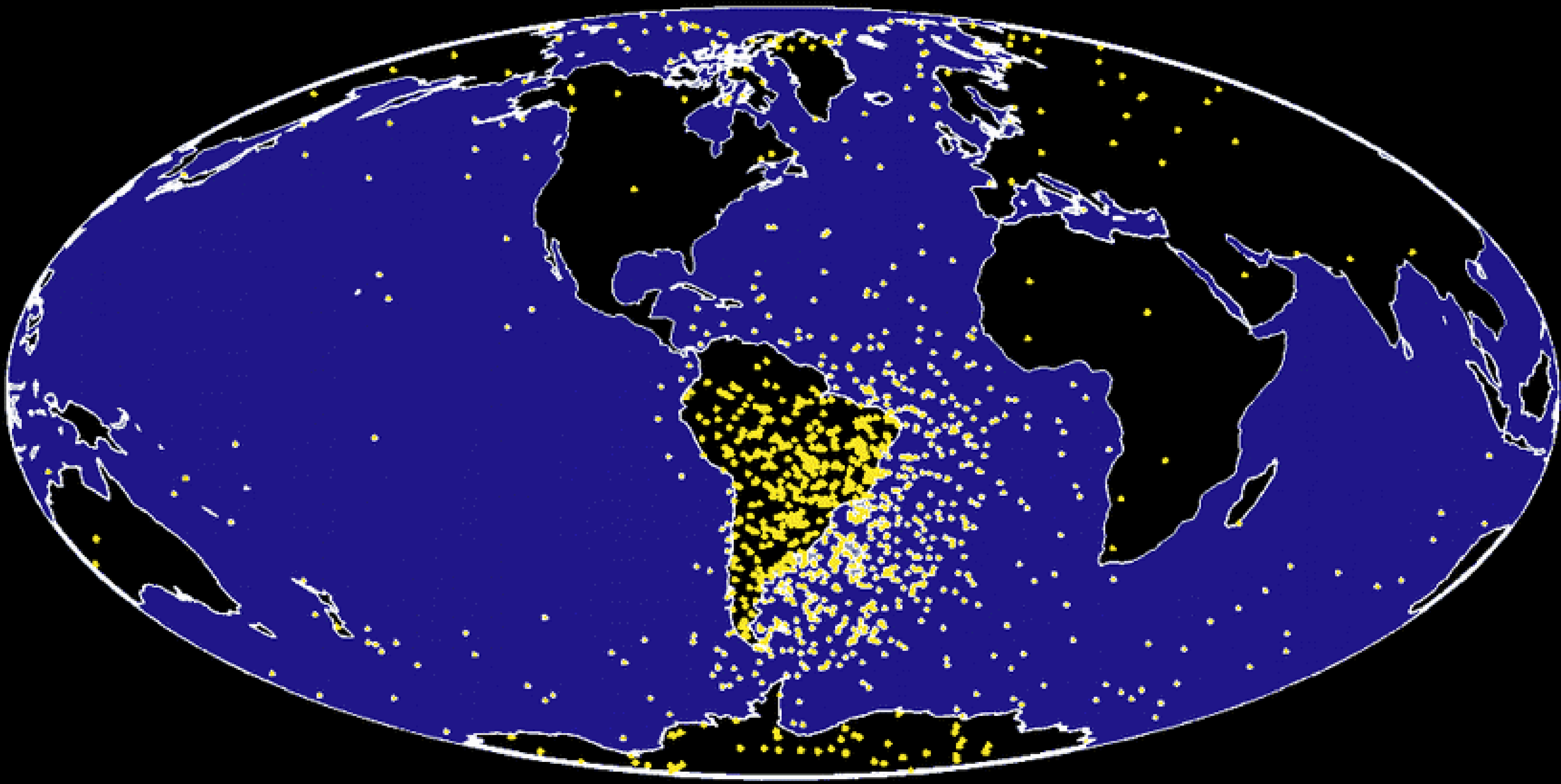
- Specialized manufacturing Techniques (FD-SoI, ...)
- Shielding using aluminium, lead, water, depleted boron, etc.
- Fault-Coverage Measures:
  - Fault detection, isolation & recovery (FDIR)
  - Error Detection And Correction (EDAC)
  - Fail-Over & Availability Preserving
- Extreme cost (> x1000 consumer/industrial grade)

Non-Options for CubeSat :-(



Source: Energetic Particle Telescope, ESA

UOSAT-2 Memory Upsets



ESA/ESTEC The Netherlands NOAA/NGDC Boulder

Forward Error Correction

Definition of Forward Error Correction:

"… Methods for controling errors in a one-way communication system. FEC sends/stores extra information along with the data, which can be used by the receiver to check and correct the data."

Courtesy of *The Internet.*

Non-Sense Testing Info: CubeSat Hardware is not "validated"

TBC == "to be confirmed" !!!

This spec pretends that rad-testing was conducted, however, this is misleading! No testing has been conducted. TBC makes this legally bullet proof.

Note: this will launch on MOVE-II, and if it works there, then 25krad will be considered confirmed. Again, this is also not proper testing, just one single data point, hope and guesswork.

HIGHLIGHTS

- Processor: ARMv7-A
- Clock frequency: 500 MHz
- Ram: 512 MB
- Storage: 512 MB of flash memory
- Linux-based operating system, with additions for improved radiation tolerance. Other operating systems on request.
- Plug-and-play ready design
- Primary components radiation tolerant to over 25 krad (Si) (TBC)
- Optional: Companion board with up to 7.5 Gb of radiation tolerant storage and over 64 GB of bulk data storage

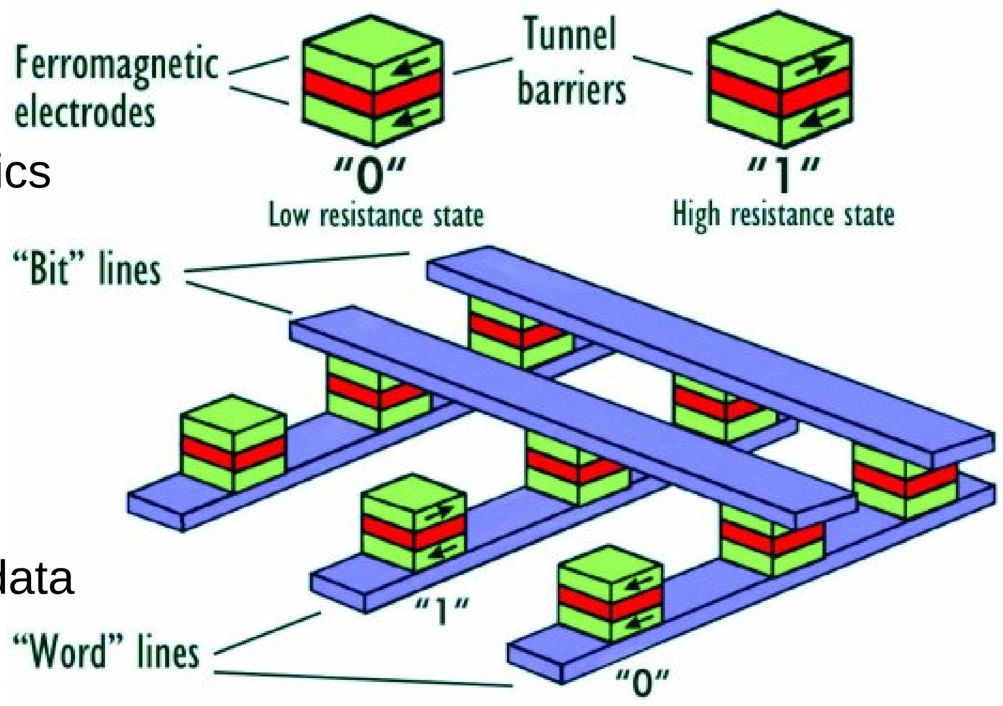
- Low mass: 7 g
- Low power: < 1000 mW peak
- Module dimensions: 20 x 50 x 10 mm

Memory Aboard a CubeSat

- Payload Data Storage
  - Scientific Experiment Data
  - Data Integrity as important as you want it to be!
  - Large - only lossy-technology available, NAND-flash

- Operating System Storage
  - System kernel, application code, diagnostics
  - Small, but data integrity is critical
  - Use MRAM or FeRAM, if possible at all!

- Volatile Memory
  - Used as main memory
  - Hard and soft faults have equal effect on data
  - Use ECC/Erasure Coding for protection



Source: Fert A, George J-M, Jaffres H, Mattana R and Seneor P, Europhysics News 34(6) 227, 2003

On-Board Computer Options

- FT Big-Space Solutions (non-option for CubeSat)

- µC based COTS
  - Many different flavors
  - Many different µC platforms
  - Every vendor has one or multiple designs
  - Almost all are hot-needle designs
  - Vendor lock-in by design

- Application Processor-based
  - Vendor-proprietary COTS Designs
  - Raspberry/BeagleBone mods
  - Open-Hardware derivatives
  - Sometimes implies vendor lock-in, but not always

µC vs Application Processor

µC Advantages

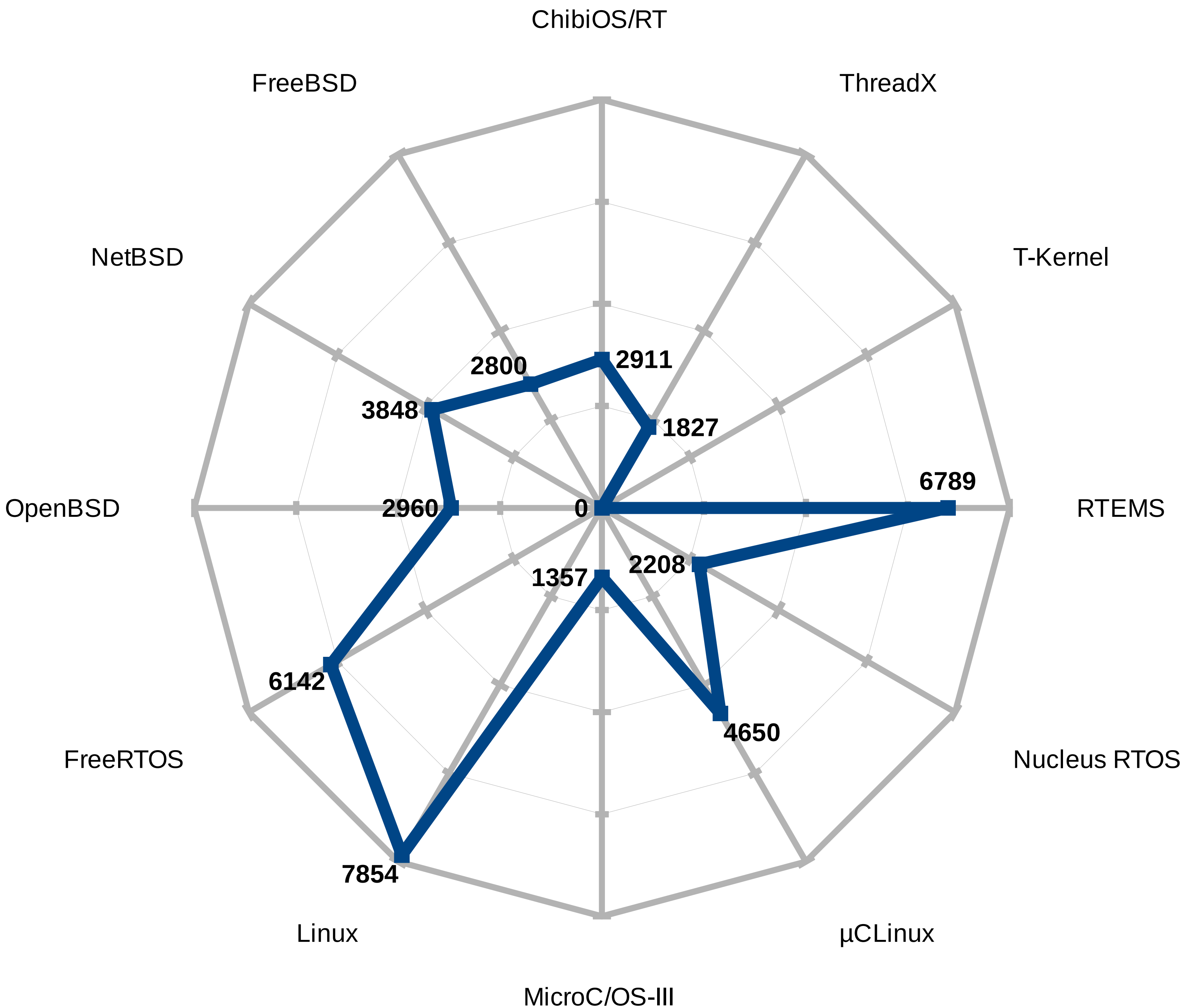
- Lower Power Consumption
- Smaller RTOS size
- Smaller physical size
- Less complex PCB

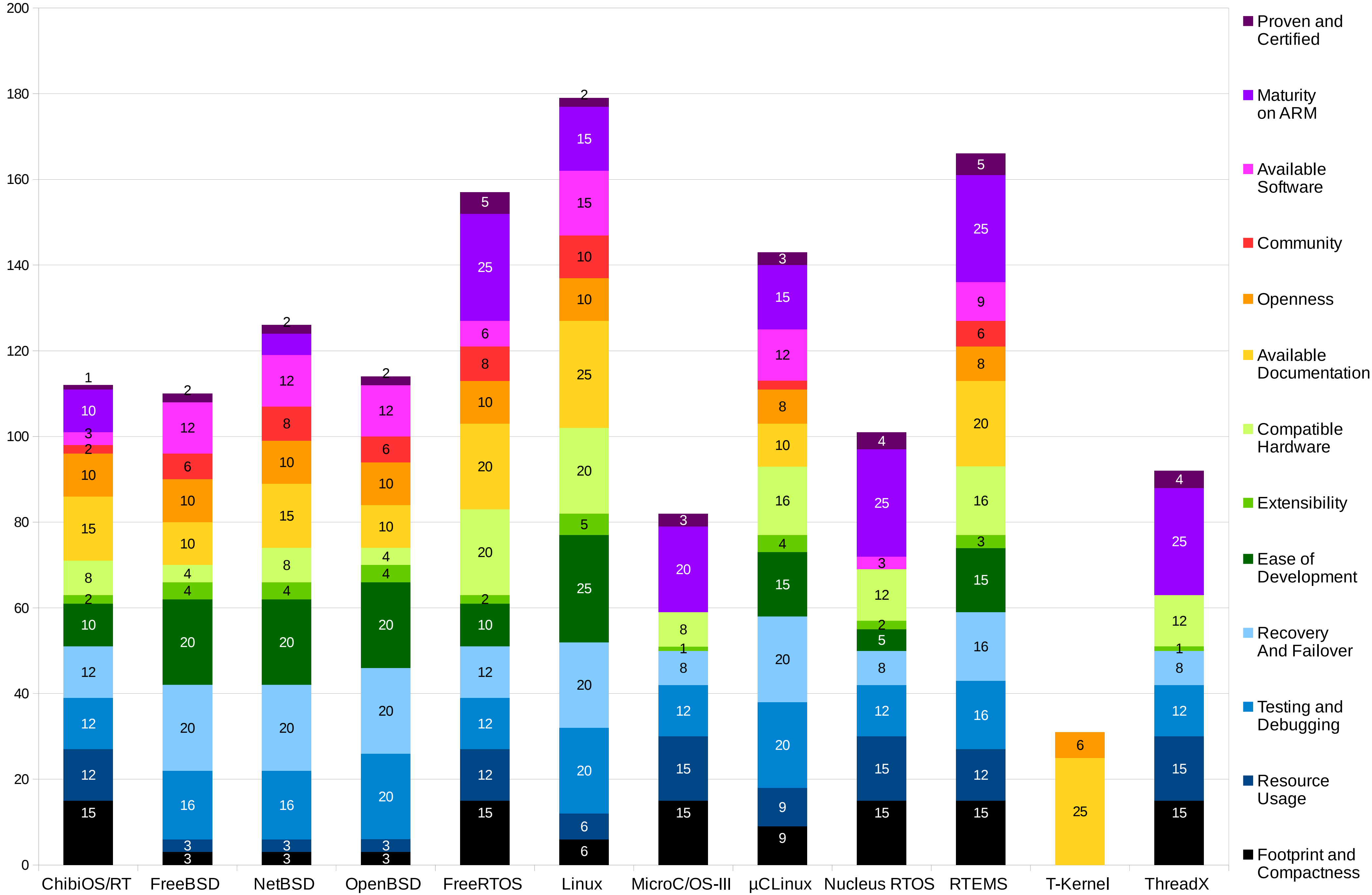
- MSP430, Cortex-M

CPU Advantages

- Standard OS/Linux
- Better toolchain
- Easier to develop
- More Flexibility
- On-orbit processing

- Cortex-A5/7/9/...


ChibiOS/RT
ThreadX
T-Kernel
RTEMS
Nucleus RTOS
µCLinux
MicroC/OS-III
Linux
FreeRTOS
OpenBSD
NetBSD
FreeBSD
2911
1827
6789
2208
4650
1357
7854
6142
2960
3848
2800
0


200
180
160
140
120
100
80
60
40
20
0
ChibiOS/RT
FreeBSD
NetBSD
OpenBSD
FreeRTOS
Linux
MicroC/OS-III
µCLinux
Nucleus RTOS
RTEMS
T-Kernel
ThreadX
Proven and Certified
Maturity on ARM
Available Software
Community
Openness
Available Documentation
Compatible Hardware
Extensibility
Ease of Development
Recovery And Failover
Testing and Debugging
Resource Usage
Footprint and Compactness

Beware: Specifications are often Useless/Incomplete/Deceitful

This specification would also fit all smartphones manufactured between 2008 and 2017. Such specs can not be trusted and are not sufficient even for planning a CubeSat concept!

No further details on the actual protection used is given, or even what radiation-tolerant here means. It is certainly not based upon radiation-hard/space grade components.

What little we know is that of 64gbit, 7.5gbit are useable, the rest is either unprotected or used as spare/parity blocks to compensate for faults. If the first is the case, then it would be better to use a simple SD-card instead, as an SD-card or SSD does include proper erasure coding for compensating wear due to regular use, and compensate instead for radiation-induced faults. In the second case, more than 80% capacity is necessary for erasure coding and spare-blocks. This would technically/algorithmically make no sense.

HIGHLIGHTS

- Processor: ARMv7-A
- Clock frequency: 500 MHz
- Ram: 512 MB
- Storage: 512 MB of flash memory
- Linux-based operating system, with additions for improved radiation tolerance. Other operating systems on request.
- Plug-and-play ready design
- Primary components radiation tolerant to over 25 krad (Si) (TBC)
- Optional: Companion board with up to 7.5 Gb of radiation tolerant storage and over 64 GB of bulk data storage

- Low mass: 7 g
- Low power: < 1000 mW peak
- Module dimensions: 20 x 50 x 10 mm

COMunications

- ”We had no clue about Communications”

- Extremely Limited Bandwidth
  - UHF/VHF: 1-10s of Kbps
  - S-Band: usually 64Kbps – 2Mbps
  - Other bands usually not used (but possible)

- Beacons & various Communication Protocols

On-Orbit Data Processing

- **Processor time on the ground is cheap!**
- **Processor time in space is expensive**

  Big Space Conclusion:
  - **Downlink EVERYTHING**
- However:
  - CubeSat Link Capacity is very low
  - Data Transmission is Costly (Energy)
  - Usually only 1 or few ground-stations
  - CubeSat Processors are Idle and energy efficient

  CubeSat Conclusions:
  - **On-Orbit Data Reduction** where possible!

MOVE-II Payload Data Estimation 2015
Anti-Proton Detector

Data Estimation of the Particle Physics Group

Data per Event: 3,6 kB
Event Frequency: 2,3 Hz
Signal/Noise: 10^{-2}

STK-Simulation

Time in SAA: up to 9,29%
Time per Pass: ca. 600 s
Time with ground contact: 6,93%

Results

Data pro SAA-Pass: 496,8 MB
Data rate (realtime): 828 kB/s
Data rate (offline): 92 kB/s
Data per year: 2425,8 GB

Theoretically transferable data (unrealistic): 273,2 GB (11,3%)

COMunications

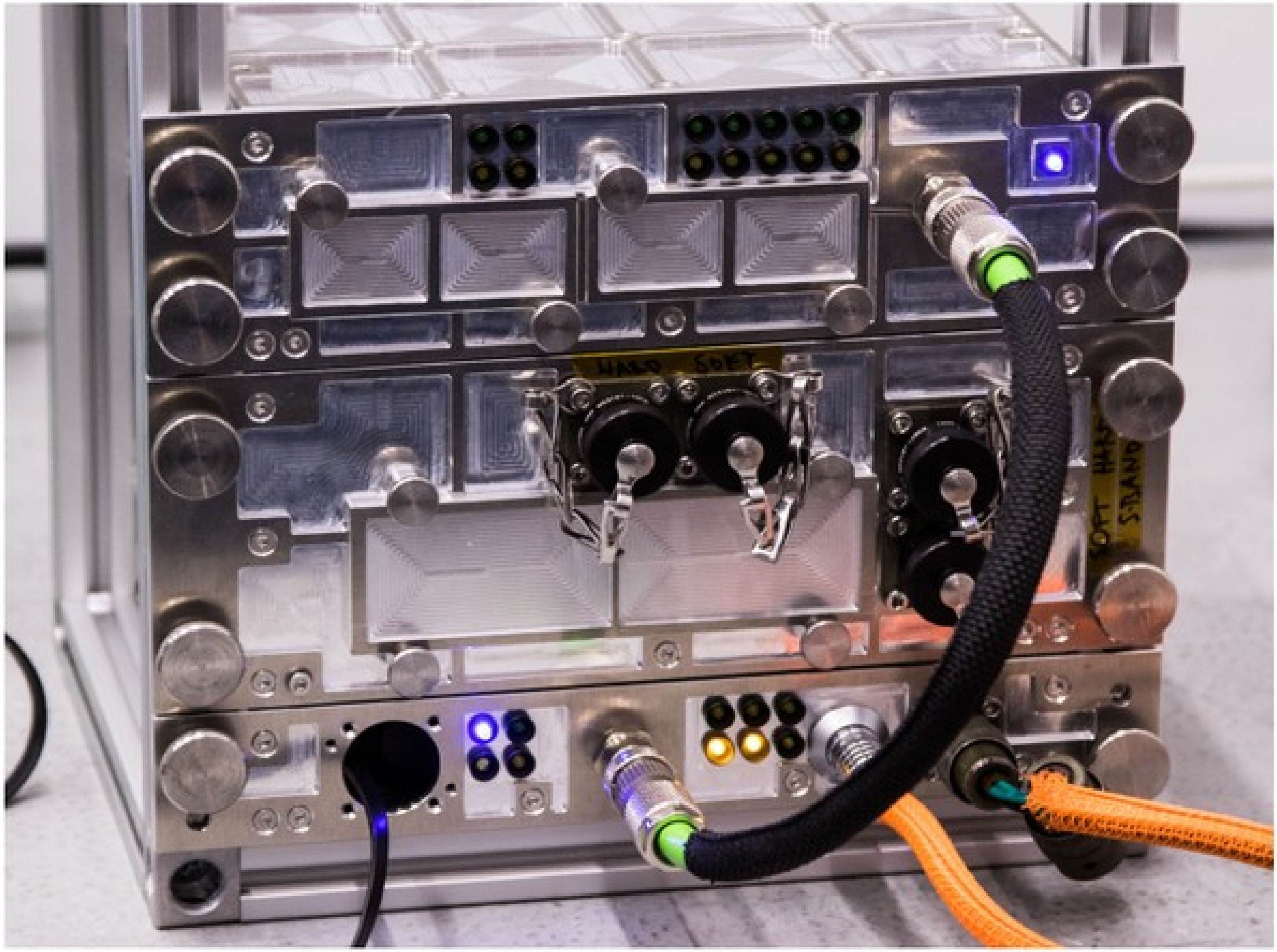
- Important to be able to adjust frequency
- Avoid Huge Buffers
- Software-Defined Radio is great…
- … but not common aboard CubeSat (Yet)

- Can be extremely pricey and low-quality
- AX.25 is common, but avoid at all costs
- Use a modern Protocol!

COMunications

- Pre-launch testing is essential
- How to test on the Ground
  - Artificial Dampening
  - Specialized Testing Equipment
  - Remote testing
    - Climb a mountain
    - Balloon Precursor Mission
    - Track aboard a helicopter
    - Airplane

TDP-3: Verification of a New Communication System for CubeSats on BEXUS 22



Means that this Component does not EXIST yet! It will be designed upon request!

CPUT UTRX

Request quote

CPUT High Bit-Rate S-Band Transmitter

$ 12,500

CPUT X-Band Transmitter

Request quote

CPUT S-Band CubeSat Transmitter

$ 8,900

CPUT VUTRX

$ 8,600

Good and Bad Transceivers

- **FSK/GMSK transceiver**
- **Frequencies:**
  - **TX: 120 – 150 MHz or 400-450 MHz**
  - **RX: 400 – 450 MHz or 120-150 MHz**
- **Receive sensitivity: -104.7 dBm @ BER 10^{-3}**
- **Output transmit power: 100 mW – 3 W**
- **Input voltages:**
  - **Logic: 3.3V**
  - **Transmitter 5-16V**
- **Power usage:**
  - **Receive: < 200 mW** [1]
  - **Transmit: < 6 W** [1]
- **Maximum data rate: 38.4 kbps (higher speeds under test)**
- **Full duplex**
- **Protocol support:**
  - **Subset of AX.25**
  - **User defined through a transparent byte-level interface.**
- **Serial interface: 3.3V UART**
- **Form factor (CubeSat Kit compatible):**
  - **Stand alone board**
- **Operating Temperature: -30 to +70 °C**

FEATURES

- Low-power Flash based FPGA
- CRC-16-CCITT (AX.25)
- Scrambling (GMSK)

Transmit Specifications

- DC Power 4 - 10 W (27 - 33 dBm)
- Frequency 420 - 450 MHz
- RF Power 27 - 33 dBm (3 dBm steps)
- Channel Spacing 25kHz
- Spurious Response < -65 dBc
- Frequency Deviation 3 kHz (FM)
- Frequency Stability ± 50 ppm

Receive Specifications

- DC Power < 250 mW
- Frequency Sensitivity 420 - 450 MHz,-120 dBm for 12 dB SINAD
- Noise Figure < 1.5 dB
- Channel Spacing 25kHz

Feature Creep

Highlighted Features

- Advanced high performance narrow-band transceiver for the 70-1050 MHz range
- FSK/MSK/GFSK/GMSK
- Data rates from 0.5 kbps to 115.2 kbps
- Sensitivity down to –137 dBm
- RF carrier frequency and FSK deviation programmable in 1 Hz steps
- Automatic frequency control (AFC)
- Transmitter with 27-33dBm at > 45 % PAE
- RF parameters are fully conf gurable in-fight. E.g. carrier frequen - cy, flter bandwidths, baud rate, framing etc. can be altered on the go.
- Adaptive frame format which can include (conf gurable):
  - HDLC / AX.25
  - HDLC + FEC
  - G3RUH scrambling
  - Sync word (32 bit)
- Multiple CSP data interfaces: I2C, UART, CAN
- FRAM for persistent conf guration storage
- 32MB SDRAM allowing large input/output buffers. This enables e.g. a telemetry or payload computer to "f re and forget" when sending large amounts of data over the spacelink.
- Built in over-temperature protection
- High-effeciency buck-converter for transmitter supply
- New compact daughter-board form-factor (compatible with Gom-Space's cubesat motherboard)
- Optional custom framing formats/modulation settings per request
- Operational temperature: -40 C to +60 C
- Dimensions: 65 mm x 40 mm x 6.5 mm
- Mass: 24.5 gram
- 20-position hard-gold plated FSI one-piece connector
- UART console interface for easy use in lab setup

Feature Creep

Highlighted Features

- Advanced high performance narrow-band transceiver for the 70-1050 MHz range
- FSK/MSK/GFSK/GMSK
- Data rates from 0.5 kbps to 115.2 kbps
- Sensitivity down to –137 dBm
- RF carrier frequency and FSK deviation programmable in 1 Hz steps
- Automatic frequency control (AFC)
- Transmitter with 27-33dBm at > 45 % PAE
- RF parameters are fully configurable in-flight. E.g. carrier frequency, filter bandwidths, baud rate, framing etc. can be altered on the go.
- Adaptive frame format which can include (configurable):
  - HDLC / AX.25
  - HDLC + FEC
  - G3RUH scrambling
  - Sync word (32 bit)
- Multiple CSP data interfaces: I2C, UART, CAN
- FRAM for persistent configuration storage
- 32MB SDRAM allowing large input/output buffers. This enables e.g. a telemetry or payload computer to “fire and forget” when sending large amounts of data over the spacelink.
- Built in over-temperature protection
- High-efficiency buck-converter for transmitter supply
- New compact daughter-board form-factor (compatible with Gom-Space’s cubesat motherboard)
- Optional custom framing formats/modulation settings per request
- Operational temperature: -40 C to +60 C
- Dimensions: 65 mm x 40 mm x 6.5 mm
- Mass: 24.5 gram
- 20-position hard-gold plated FSI one-piece connector
- UART console interface for easy use in lab setup

Feature Creep

Highlighted Features

- Advanced high performance narrow-band transceiver for the 70-1050 MHz range
- FSK/MSK/GFSK/GMSK
- Data rates from 0.5 kbps to 115.2 kbps
- Sensitivity down to –137 dBm
- RF carrier frequency and FSK deviation programmable in 1 Hz steps
- Automatic frequency control (AFC)
- Transmitter with 27-33dBm at > 45 % PAE
- RF parameters are fully conf gurable in-fight. E.g. carrier frequen - cy, flter bandwidths, baud rate, framing etc. can be altered on the go.
- Adaptive frame format which can include (conf gurable):
    - HDLC / AX.25
    - HDLC + FEC
    - G3RUH scrambling
    - Sync word (32 bit)
- Multiple CSP data interfaces: I2C, UART, CAN
- FRAM for persistent conf guration storage
- 32MB SDRAM allowing large input/output bufers. This enables e.g. a telemetry or payload computer to "f re and forget" when sending large amounts of data over the spacelink.
- Built in over-temperature protection
- High-efciency buck-converter for transmitter supply
- New compact daughter-board form-factor (compatible with Gom-Space's cubesat motherboard)
- Optional custom framing formats/modulation settings per request
- Operational temperature: -40 C to +60 C
- Dimensions: 65 mm x 40 mm x 6.5 mm
- Mass: 24.5 gram
- 20-position hard-gold plated FSI one-piece connector
- UART console interface for easy use in lab setup

Feature Creep

Highlighted Features

- Advanced high performance narrow-band transceiver for the 70-1050 MHz range
- FSK/MSK/GFSK/GMSK
- Data rates from 0.5 kbps to 115.2 kbps
- Sensitivity down to –137 dBm
- RF carrier frequency and FSK deviation programmable in 1 Hz steps
- Automatic frequency control (AFC)
- Transmitter with 27-33dBm at > 45 % PAE
- RF parameters are fully conf gurable in-fight. E.g. carrier frequen - cy, flter bandwidths, baud rate, framing etc. can be altered on the go.
- Adaptive frame format which can include (conf gurable):
    - HDLC / AX.25
    - HDLC + FEC
    - G3RUH scrambling
    - Sync word (32 bit)
- Multiple CSP data interfaces: I2C, UART, CAN
- FRAM for persistent conf guration storage
- 32MB SDRAM allowing large input/output buffers. This enables e.g. a telemetry or payload computer to "f re and forget" when sending large amounts of data over the spacelink.
- Built in over-temperature protection
- High-efficiency buck-converter for transmitter supply
- New compact daughter-board form-factor (compatible with Gom-Space's cubesat motherboard)
- Optional custom framing formats/modulation settings per request
- Operational temperature: -40 C to +60 C
- Dimensions: 65 mm x 40 mm x 6.5 mm
- Mass: 24.5 gram
- 20-position hard-gold plated FSI one-piece connector
- UART console interface for easy use in lab setup

What Now?

- Have concrete non-changing payload requirements for your payload
  - Required (realistic/minimal) Data Rate
  - Required Power Budget
  - Dimensions
  - Thermal requirements
  - Interface-requirements
  - Minimum necessary Lifetime
- Otherwise you will constantly change your CubeSat

- Be extremely careful with CubeSat Vendors
- Be critical of any and all specs received from Vendors
- Avoid vendor lock-in at all costs