apex Mk.2/Mk.3
Secure live transmission of the first flight of *Trichoplax adhaerens* in space

Nico Maas, DLR RB-MSC

Pi And More 14, 2026-09-26

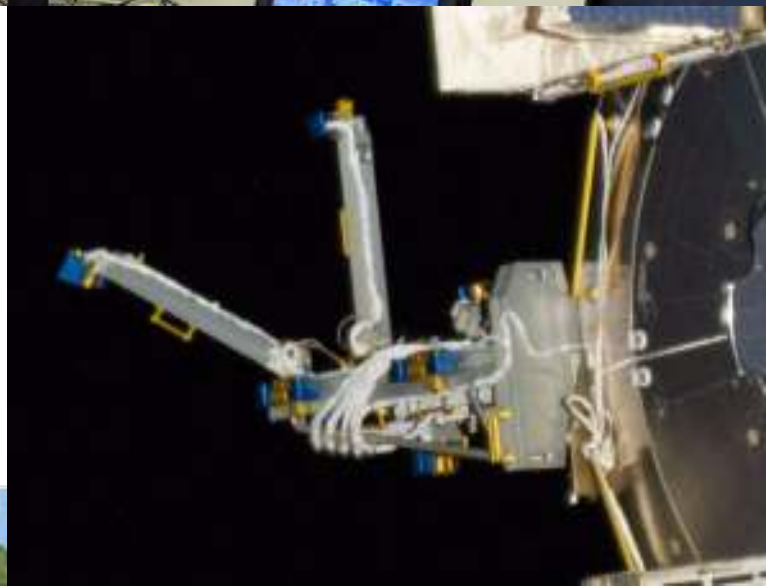
Vorstellung

- Nico Maas
- Master of Science
- IT Systemelektroniker
- IT / Ground Segment Architect @ DLR RB-MSC
- mail@nico-maas.de
- www.nico-maas.de
- Mastodon: @nmaas87@chaos.social

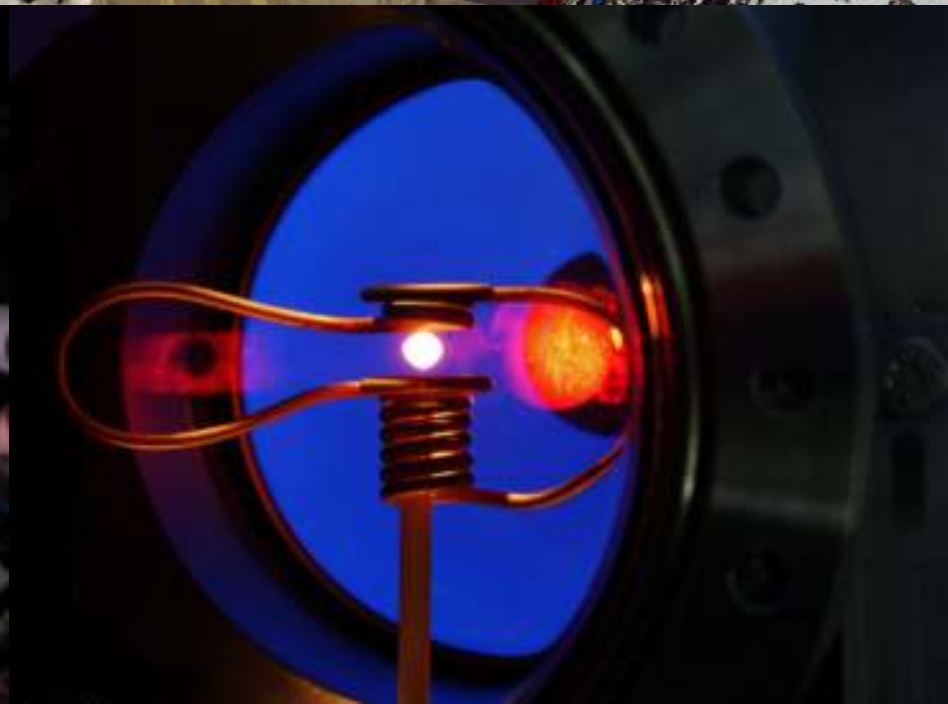
DLR / Raumflugbetrieb und Astronautentraining (RB)
Nutzerzentrum für Weltraumexperimente (MUSC) in Köln

- Unterstützung von Wissenschaftlern/Experimenten bei Vorbereitung, Entwicklung, Durchführung, Auswertung
- Unterhaltung von Kontrollräumen, Laboren, Datenarchiven, ...
- Unterschiedliche Plattformen: Falltürme, Parabellflüge, Sounding Rockets, Satelliten, Stationen, Sonden/Lander
- Experimente im erdnahen Orbit (großer Kontrollraum/ISS):
    - Columbus: EDR/EML, Biolab, DOSIS, SRM, …
    - Destiny: MSL
    - zukünftige:
        - Columbus: LCI, XRF
        - Bartolomeo: Exobiology
- Exploration des Weltraums (kleiner Kontrollraum/Multimission):
    - Eu:CROPIS
    - LUNA
    - Idefix (MMX)
    - apex (MAPHEUS-8 / MAPHEUS-10)
    - ehemalige: Philae (Rosetta), MASCOT (Hayabusa 2), HP3/Mole (InSight), M-42 (Astrobotic Peregrine),...

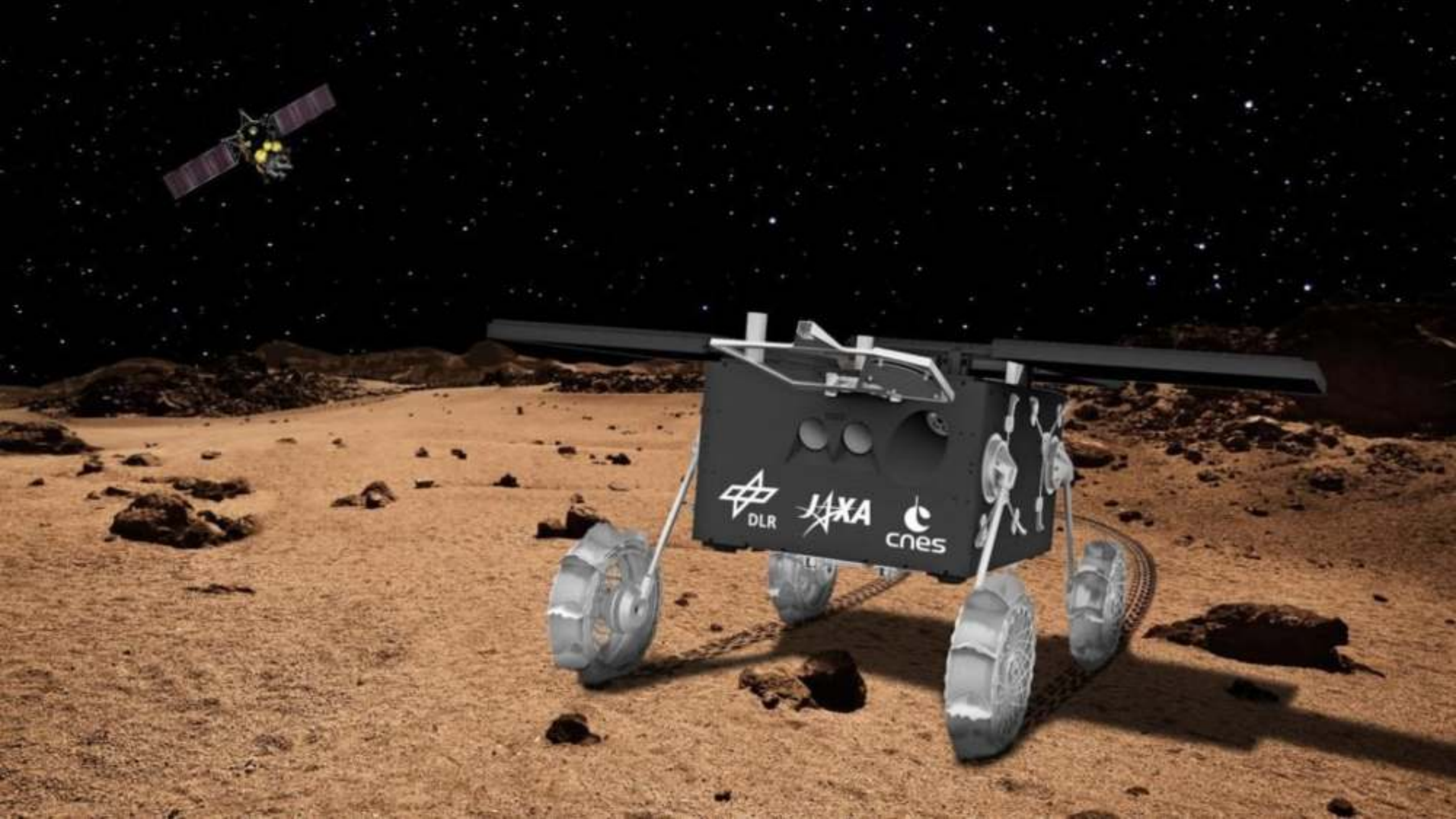
- Experimente im erdnahen Orbit (großer Kontrollraum/ISS):
  - Columbus: EDR/EML, Biolab, DOSIS, SRM, …
  - Destiny: MSL
  - zukünftige:
    - Columbus: LCI, XRF
    - Bartolomeo: Exobiology

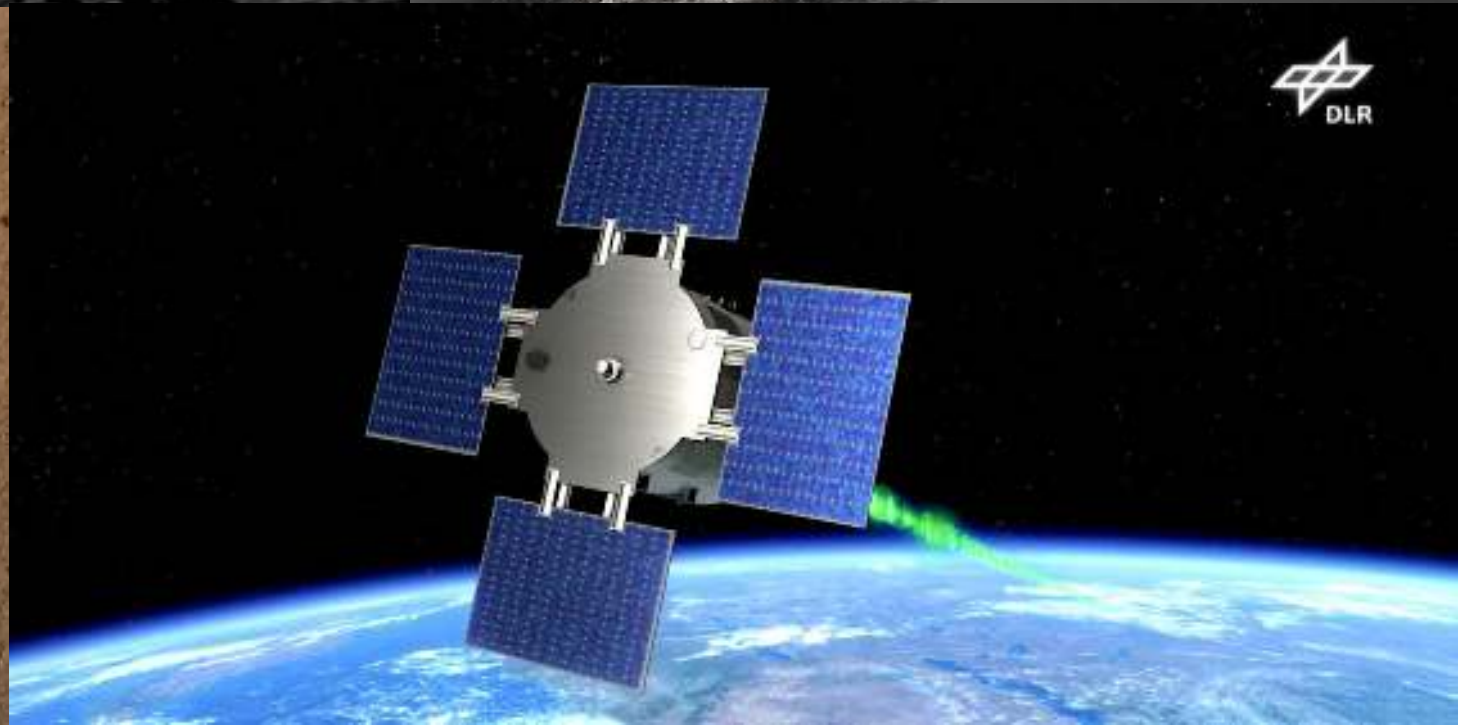


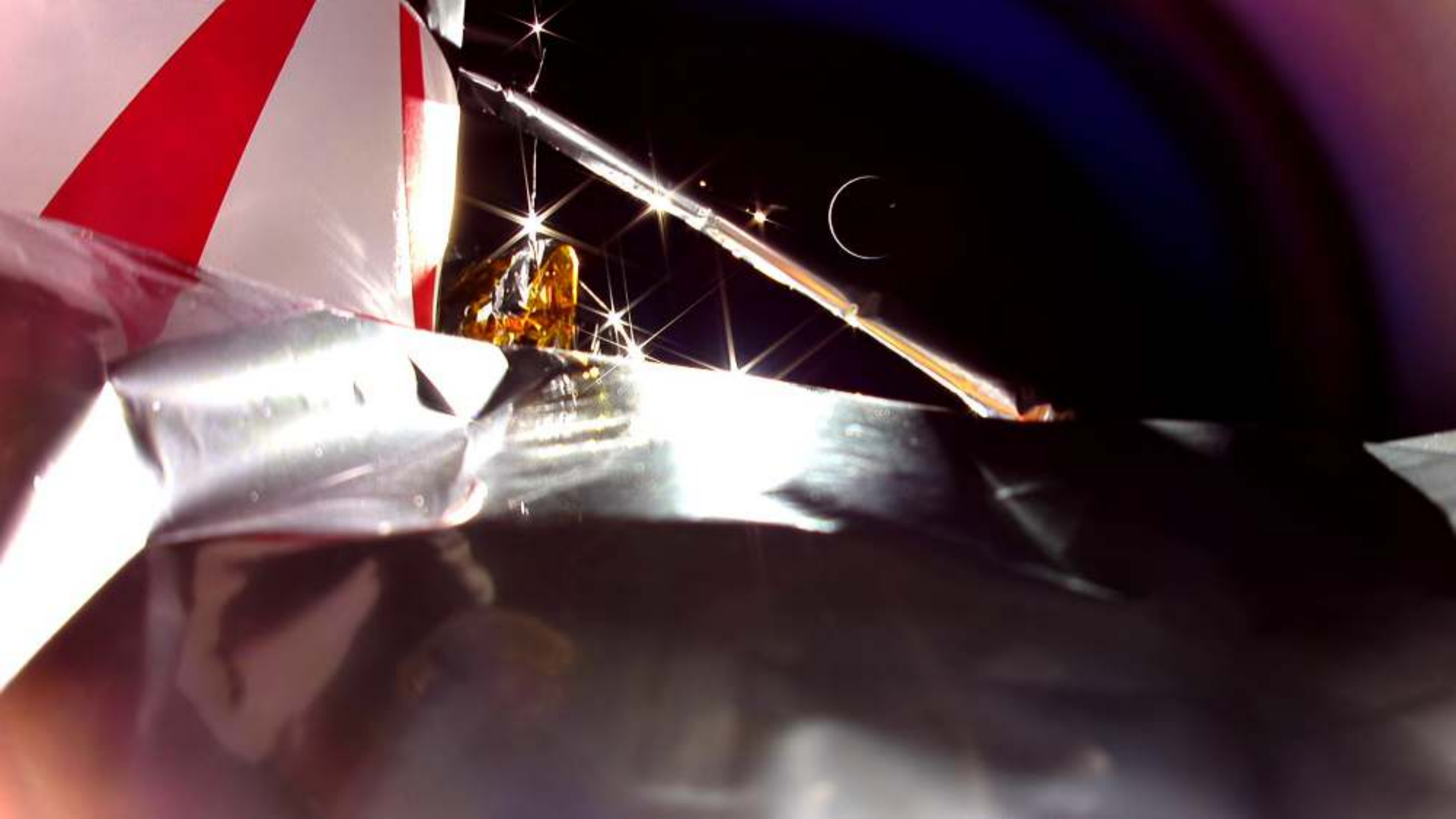

esa



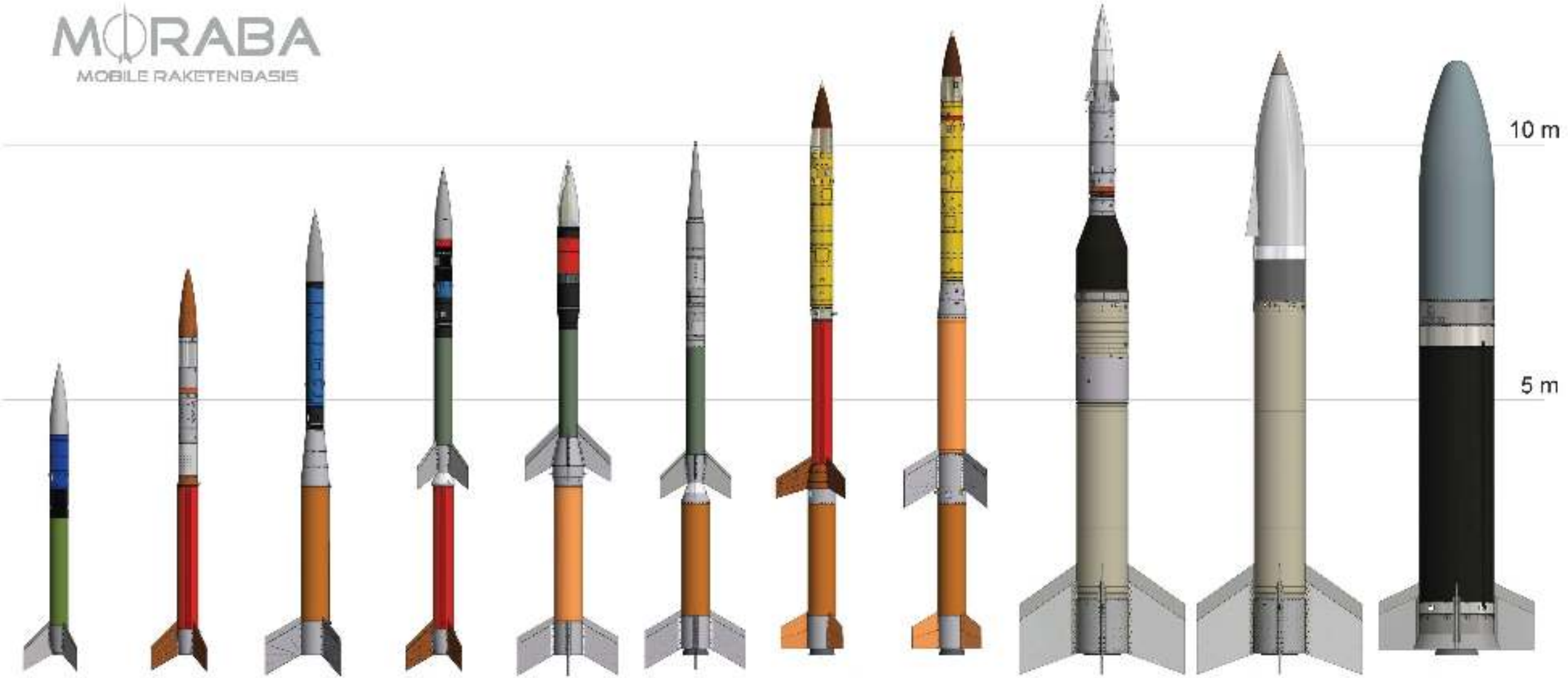
- Exploration des Weltraums (kleiner Kontrollraum/Multimission):
  - Eu:CROPIS
  - LUNA
  - Idefix (MMX)
  - apex (MAPHEUS-8 / MAPHEUS-10)
  - ehemalige: Philae (Rosetta), MASCOT (Hayabusa 2), HP3/Mole (InSight), M-42 (Astrobotic Peregrine),...


DLR
JAXA
cnes

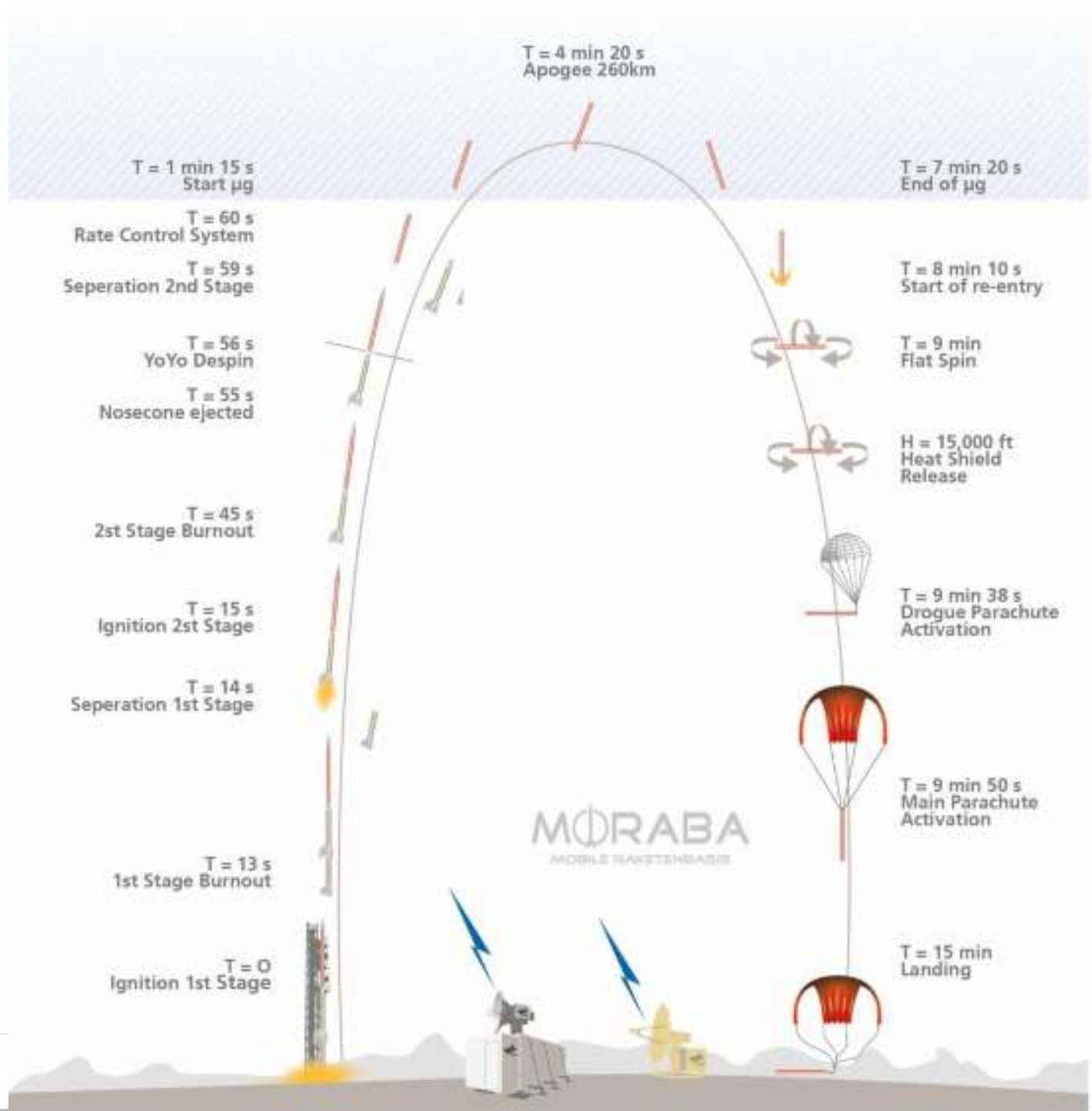

DLR



MORABA
MOBILE RAKETENBASIS



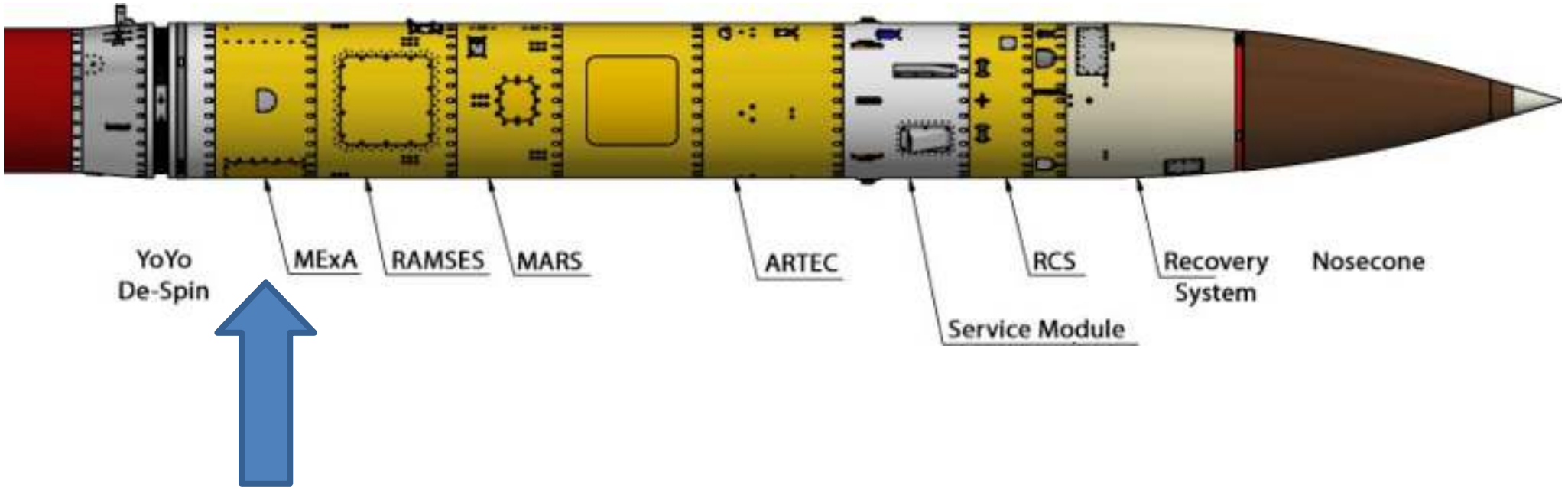
DLR


T = 4 min 20 s
Apogee 260km
T = 1 min 15 s
Start µg
T = 7 min 20 s
End of µg
T = 60 s
Rate Control System
T = 59 s
Seperation 2nd Stage
T = 8 min 10 s
Start of re-entry
T = 56 s
YoYo Despin
T = 9 min
Flat Spin
T = 55 s
Nosecone ejected
H = 15,000 ft
Heat Shield
Release
T = 45 s
2st Stage Burnout
T = 9 min 38 s
Drogue Parachute
Activation
T = 15 s
Ignition 2st Stage
T = 14 s
Seperation 1st Stage
T = 9 min 50 s
Main Parachute
Activation
MORABA
MOBILE RAKETENBASIS
T = 13 s
1st Stage Burnout
T = 15 min
Landing
T = O
Ignition 1st Stage

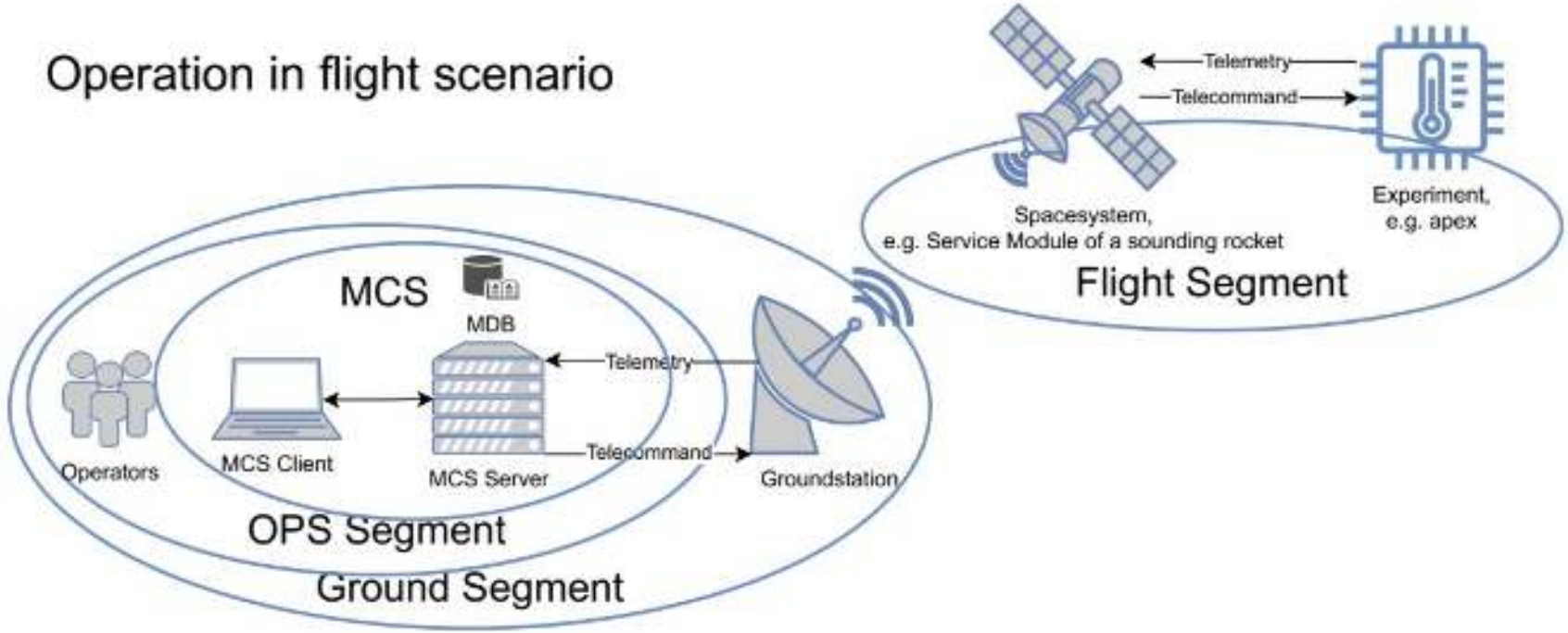
DLR

MAPHEUS 10

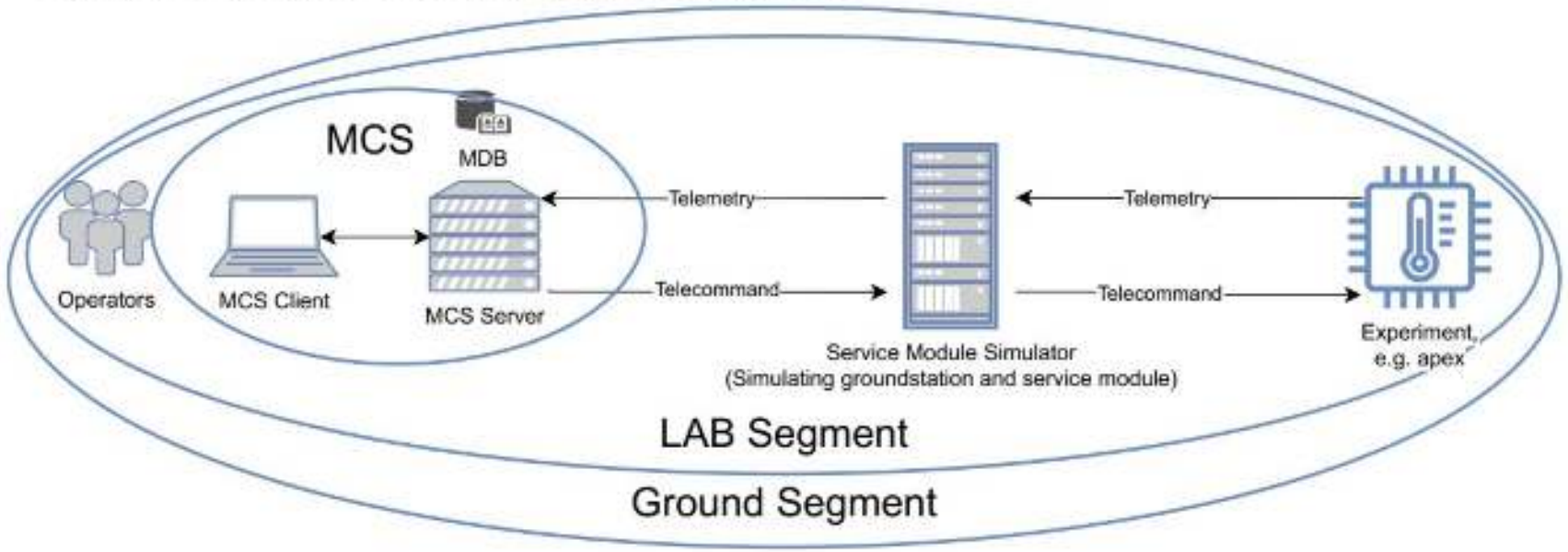
MAPHEUS 10 Detail



Operation in flight scenario



Operation in ground reference scenario




DLR MICROGRAVITY USER SUPPORT CENTER, COLOGNE • DLR INSTITUTE OF AEROSPACE MEDICINE, COLOGNE • DLR INSTITUTE OF MATERIAL PHYSICS IN SPACE, COLOGNE • DLR MOBILE ROCKET BASE, MUNICH •
APEX
ADVANCED PROCESSORS,
ENCRYPTION AND SECURITY EXPERIMENT

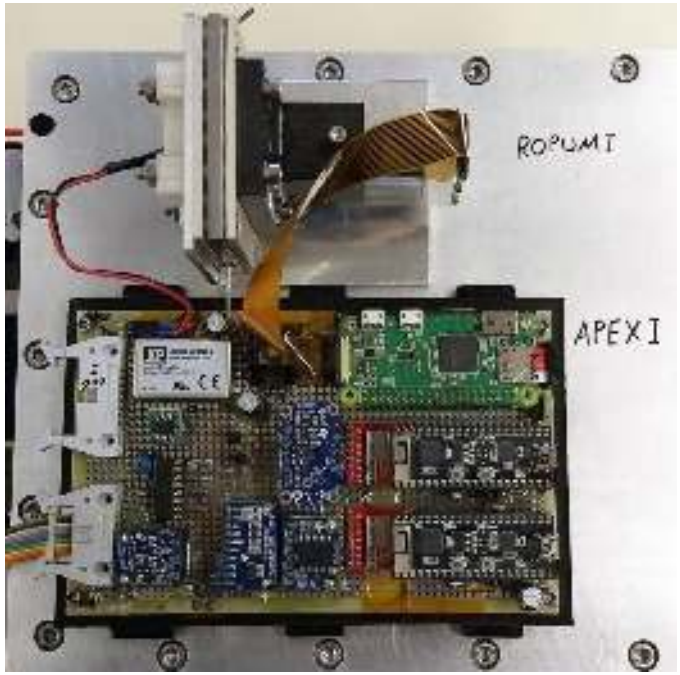
apex (Dec. 2017 – Oct. 2019)

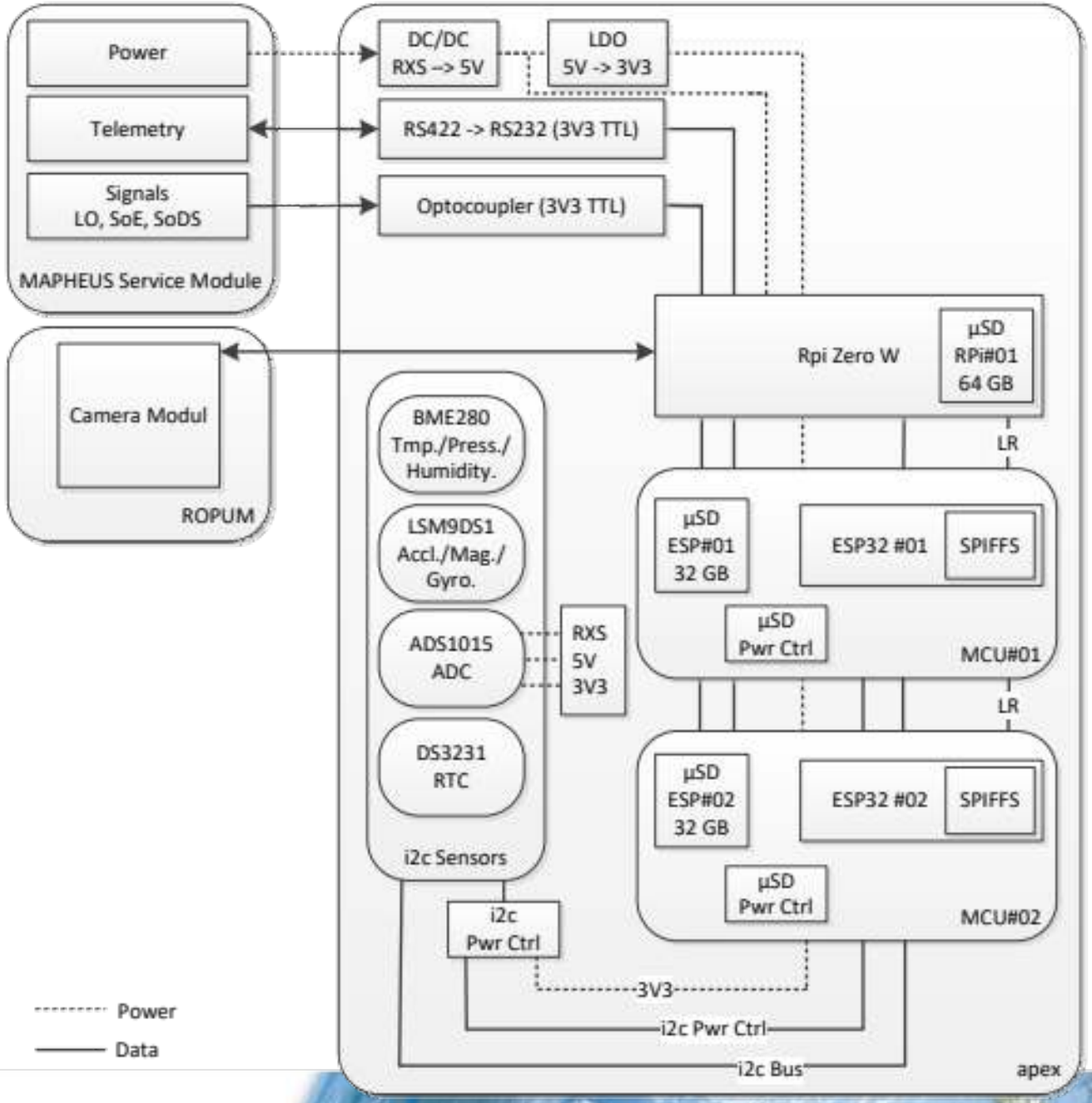
Arduino-based fixed Sensorsystem for Studentprojects

- RB-MSC / MUSC Interpretation:
  - Changes: Arduino-compatible, variable Sensor Loadout
  - Addition: Linux Singleboard Computer with high-resolution camera

  - Emphasis on:
    - Use of cost-effective COTS components (e.g. Automotive area)
    - 3D printing for harness / support structures
    - Iterative Design & Rapid Prototyping
    - Open Source components

- Successful flight 13.06.2019 on MAPHEUS 8 / ATEK
  as environmental sensor and camera for ME experiment ROPUM

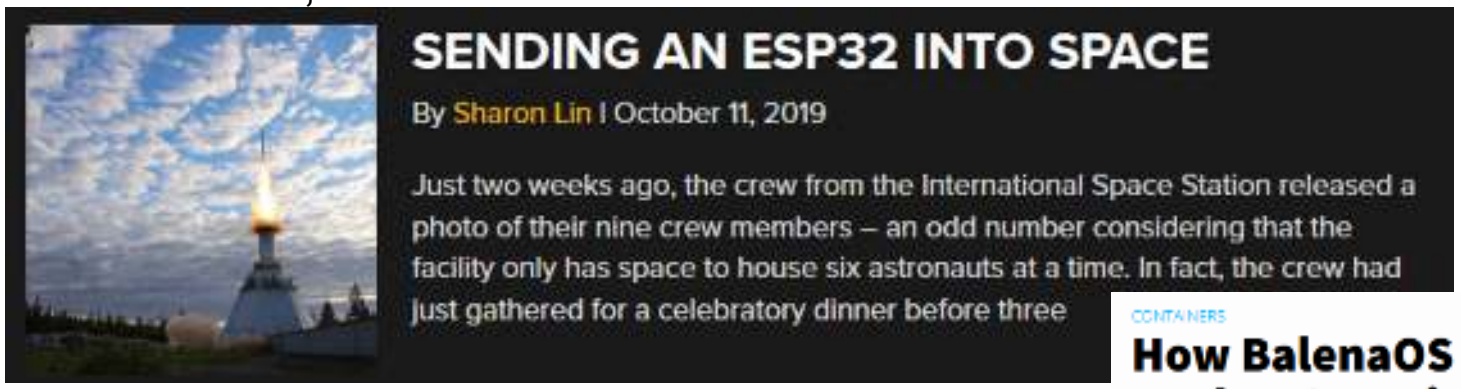



Power
Telemetry
Signals
LO, SoE, SoDS
MAPHEUS Service Module
Camera Modul
ROPUM
DC/DC
RXS -> 5V
LDO
5V -> 3V3
RS422 -> RS232 (3V3 TTL)
Optocoupler (3V3 TTL)
Rpi Zero W
µSD
RPi#01
64 GB
LR
BME280
Tmp./Press./
Humidity.
LSM9DS1
Accl./Mag./
Gyro.
ADS1015
ADC
DS3231
RTC
i2c Sensors
RXS
5V
3V3
µSD
ESP#01
32 GB
ESP32 #01
SPIFFS
µSD
Pwr Ctrl
MCU#01
LR
µSD
ESP#02
32 GB
ESP32 #02
SPIFFS
µSD
Pwr Ctrl
MCU#02
i2c
Pwr Ctrl
3V3
i2c Pwr Ctrl
i2c Bus
apex
Power
Data

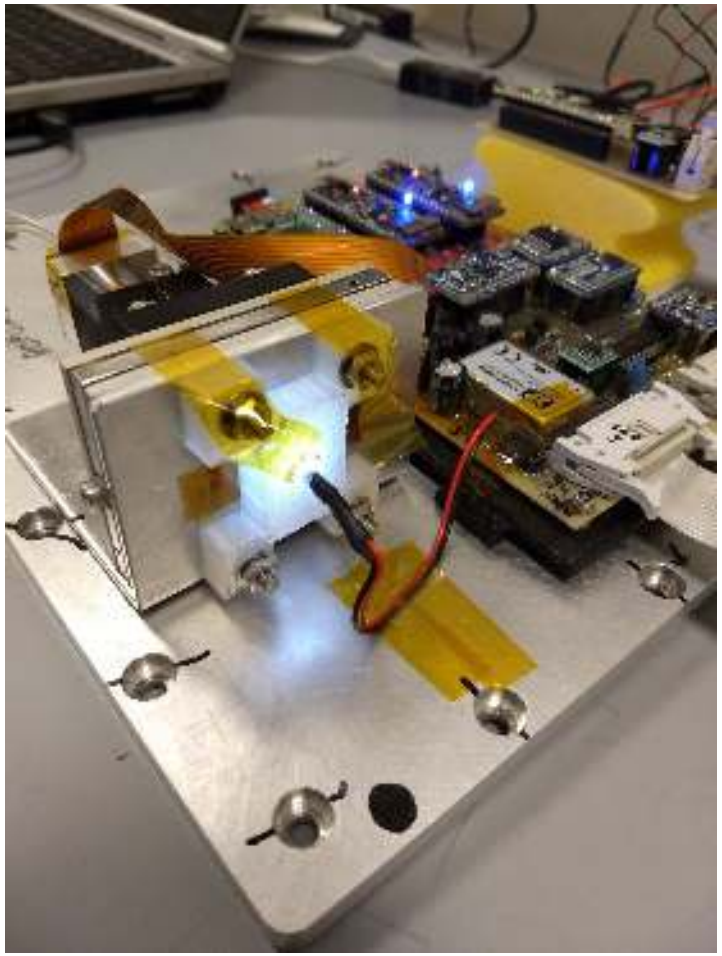
apex (Dec. 2017 – Oct. 2019)
Results

Paramecium in Microgravity

- Successful experiment execution and data recording
- Publication (https://elib.dlr.de/129725/)
  - Nomination J. Hauslage / N. Maas as DLR contact person for the area „Usage of COTS Components under microgravity conditions“
- First use of ESP32 in space (provision of Engineering Samples by Espressif Systems)
- First use of Docker / Moby compatible Containers in space (with company balena)
- Press by balena, Hackaday, TheNewStack, ...



- Association for Computing Machinery (ACM) Cite (Communications of the ACM, March 2026 Cover Story „A Decade of Docker Containers“ by Anil Madhavapeddy, David J. Scott, and Justin Cormack




DLR MICROGRAVITY USER SUPPORT CENTER, COLOGNE • DLR INSTITUTE OF AEROSPACE MEDICINE, COLOGNE • DLR INSTITUTE OF MATERIAL PHYSICS IN SPACE, COLOGNE • DLR MOBILE ROCKET BASE, MUNICH
APEX MK.II
Science Camera Platform


DLR MICROGRAVITY USER SUPPORT CENTER, COLOGNE • DLR INSTITUTE OF AEROSPACE MEDICINE, COLOGNE • DLR INSTITUTE OF MATERIAL PHYSICS IN SPACE, COLOGNE • DLR MOBILE ROCKET BASE, MUNICH
APEX MK.III
Student Experiment Sensorboard

apex Mk.II / Mk.III (Jul. 2019 – Sep. 2025)

Two systems:

- Mk.II Science Camera Platform
  - Sensor / Camera Platform for ME Trichoscope with Live Video Downlink
  - Integrated TM/TC MCU + MUX: Mk.II, Payload SIM, Mk. III

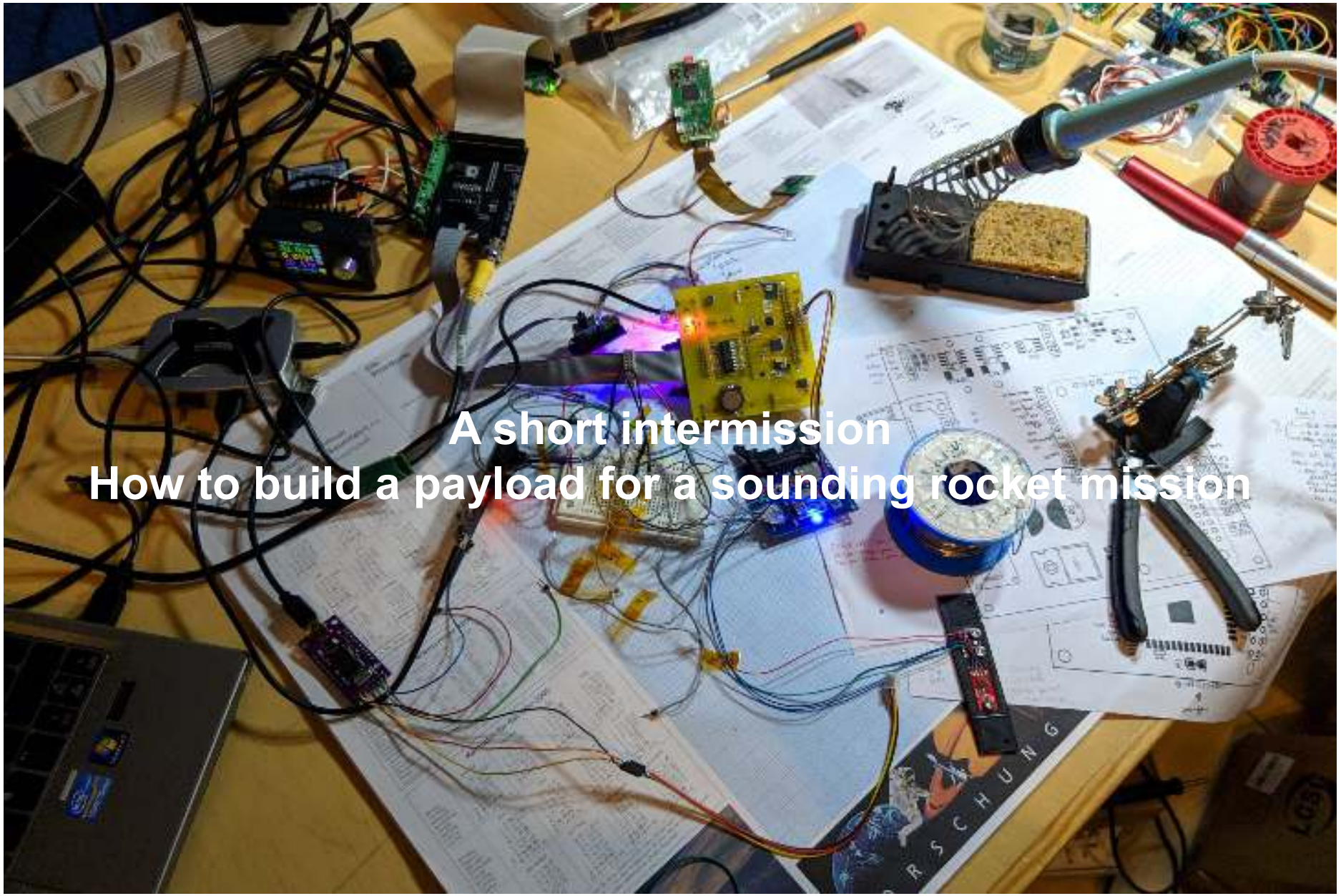
- Mk.III Student Experiment Sensorboard
  - Direct connection to MAPHEUS Service Module
  - Facilitates a open Sensorbus / enables fast development of own experiments

- Development MAPHEUS Service Module Simulator v2
- Additional development of EGSE components enables secure realtime transmission of Video / Telemetry and allows Telecommanding
- Own Ground Segment in MUSC
- Successful flight on 06.12.2021 on MAPHEUS 10 in experiment MExA as e.g. Environmentalsensor / Camera for ME Experiment Trichoscope

apex Mk.II / Mk.III (Jul. 2019 – Sep. 2025) Results (Overview)

Trichoplax adhaerens in Microgravity

- Successful experiment execution and data recording
- First flight of *Trichoplax adhaerens* (oldest ancestor of all animals and humans)
  - Support for cancer research
  - Live Stream of Microscope Video + TM to Youtube & Twitch
  - PR Event on Twitter
- First Ground Segment on base of Open Source Components
  - Telecommanding / Telemetry via MUSC
- Publications
  - apex Mk.2/Mk.3: Secure live transmission of the first flight of Trichoplax adhaerens in space based on components of the shelf: https://doi.org/10.3390/eng6090241
  - apex MCC: A blueprint of an open source, secure, CCSDS compatible ground segment for sounding rocket, cubesat and small lander missions: https://doi.org/10.3390/eng6090246
  - apex MRMSS: A multi-role mission support system and service module simulator for payloads of sounding rockets and other space applications: https://www.mdpi.com/2673-4117/6/9/247
- Use of components for next iteration
- Usage of apex Live Video Systems in the security critical ESA USOC EDR/EML context allows for execution of ISS/EML experiments within original planing despite of COVID-19 pandemic

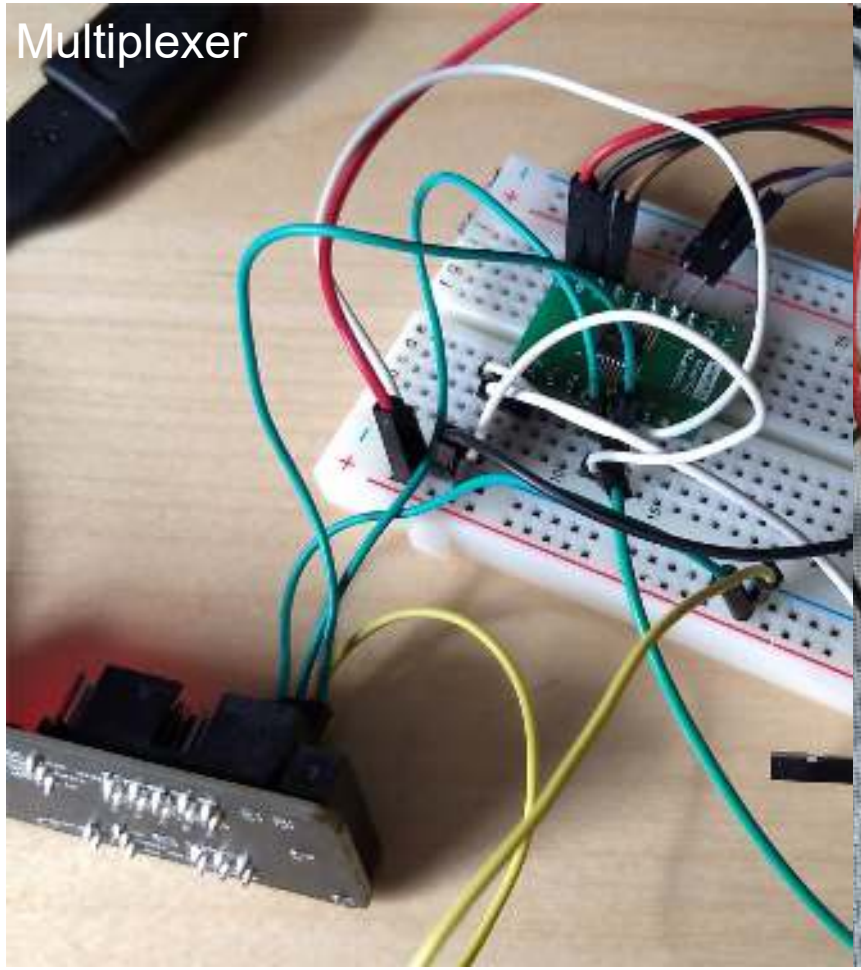


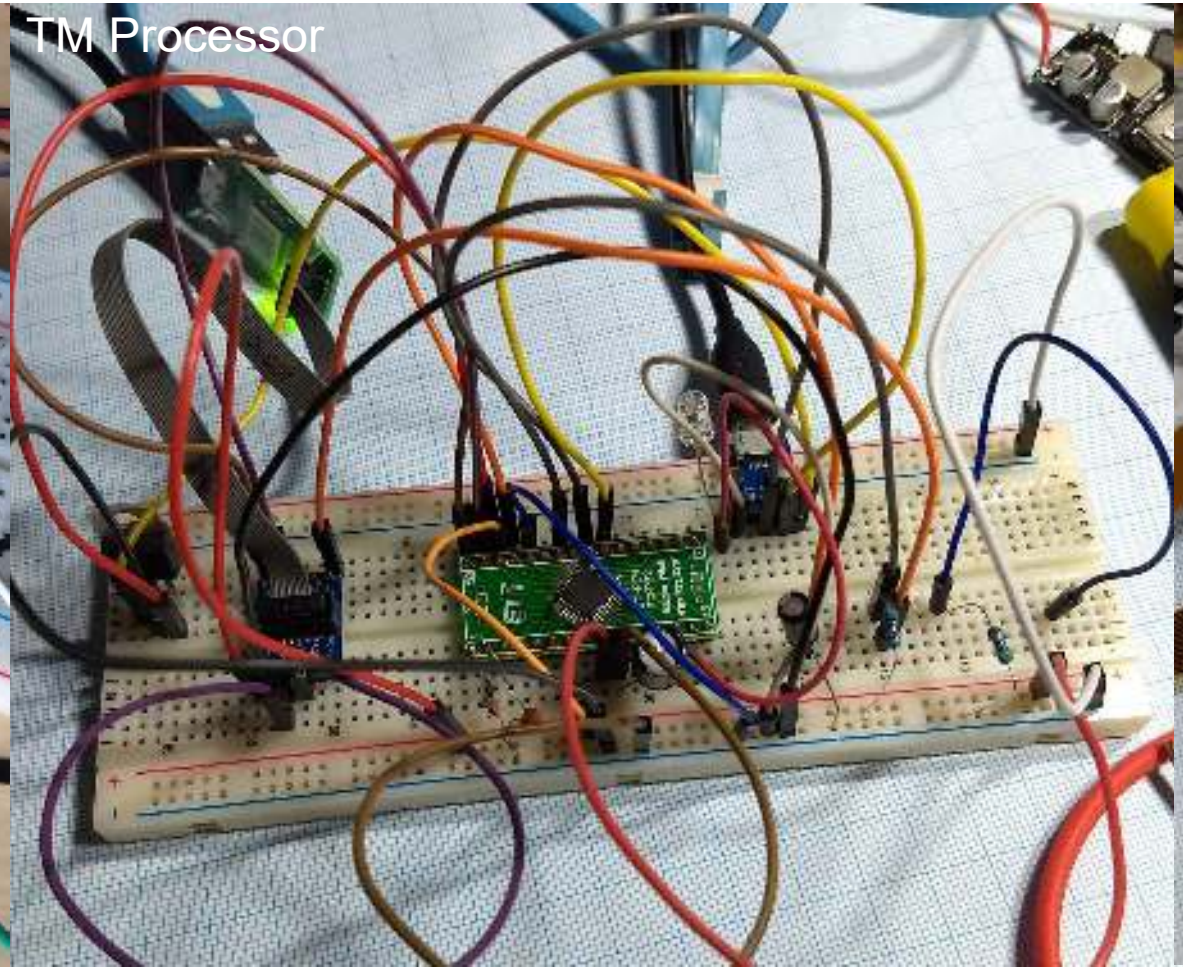
A short intermission
How to build a payload for a sounding rocket mission

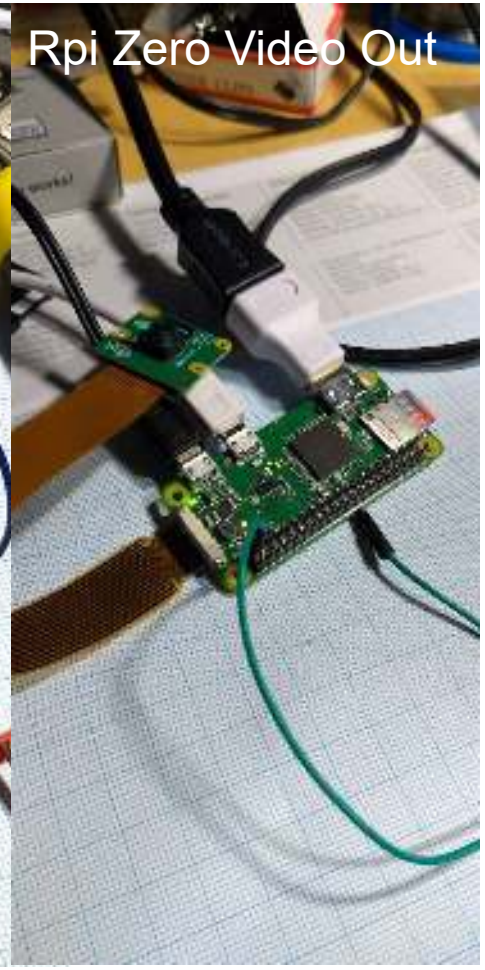
Design Phase
Initial Design / Plan and rough sketch

- What shall the payload do / scientific objective?
  - Camera for Trichoscope (+ Live Video Downlink)
  - Sensors for augmenting camera data with environment variables (e.g. temperature, forces, etc with TM/TC)
- Secondary functions
  - TM/TC system for multiple subsystems
    - TM/TC processor, multiplexer, payload dummy and RS422 converter for connection to MAPHEUS
- Necessary functions
  - Power subsystems (3v3 and 5v) including Voltmeters / Amperemeters
  - Signal coupling to MAPHEUS Service Module
  - Always keep in mind power / data / video / thermal constrains of MAPHEUS and used rocket motors (forces)
- Continue the design choices of the first apex
  - COTS components (and Automotive parts)
  - silicone cables + leaded solder
  - stabilize nuts and cables with resin + secure delicate parts with 3D printed brackets (i.e. Micro SD Cards)
  - “recycling” of proven parts to reduce cost and risk (e.g. evolution of Rpi camera subsys, same DC/DCs, …)
  - Adding “missing parts” and lesson learned from earlier missions (e.g. Diagnose LED, USB Xfer, Video Out, higher quality resin, etc.)

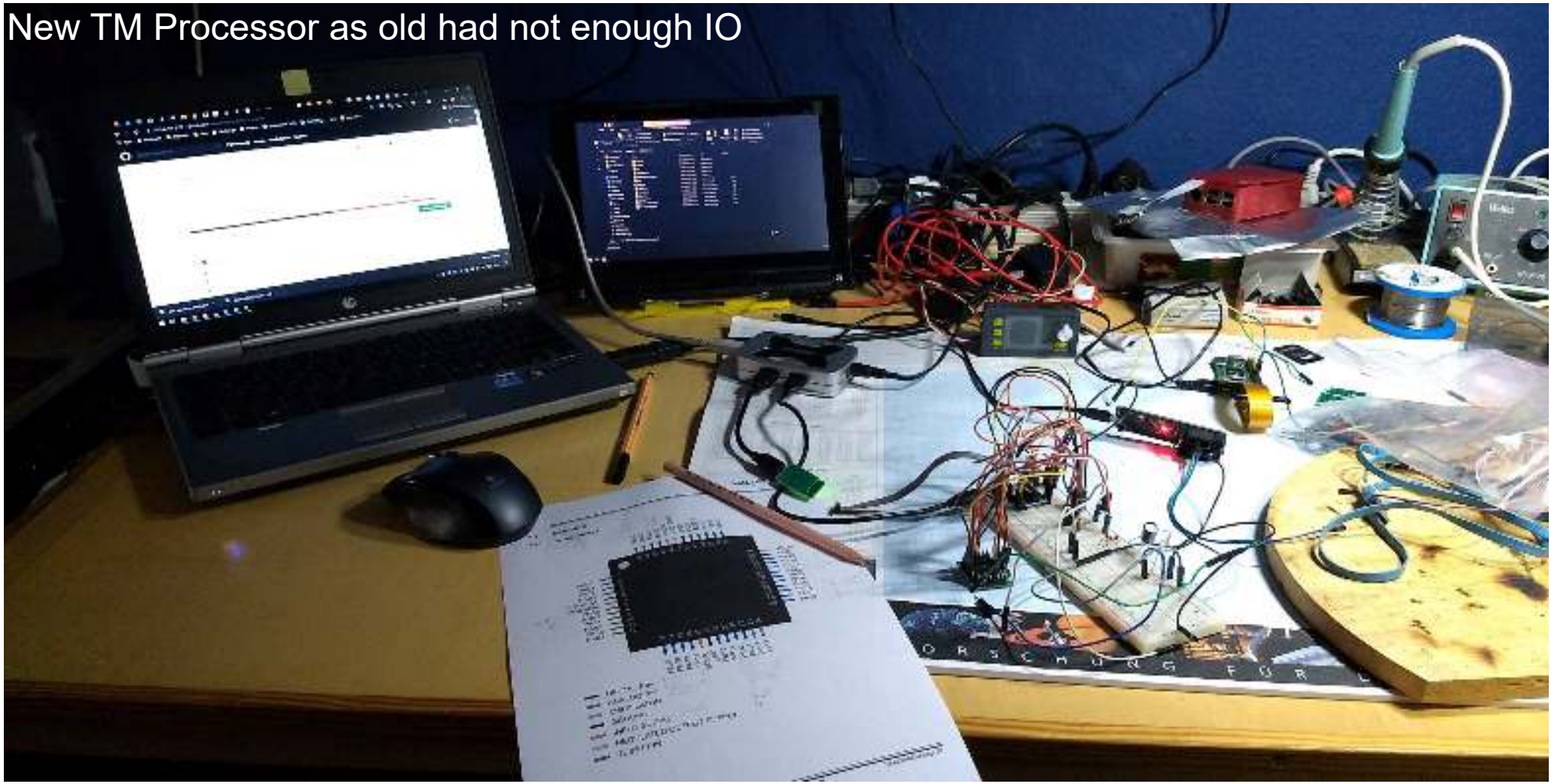
Design Phase
Selection & Test of Components

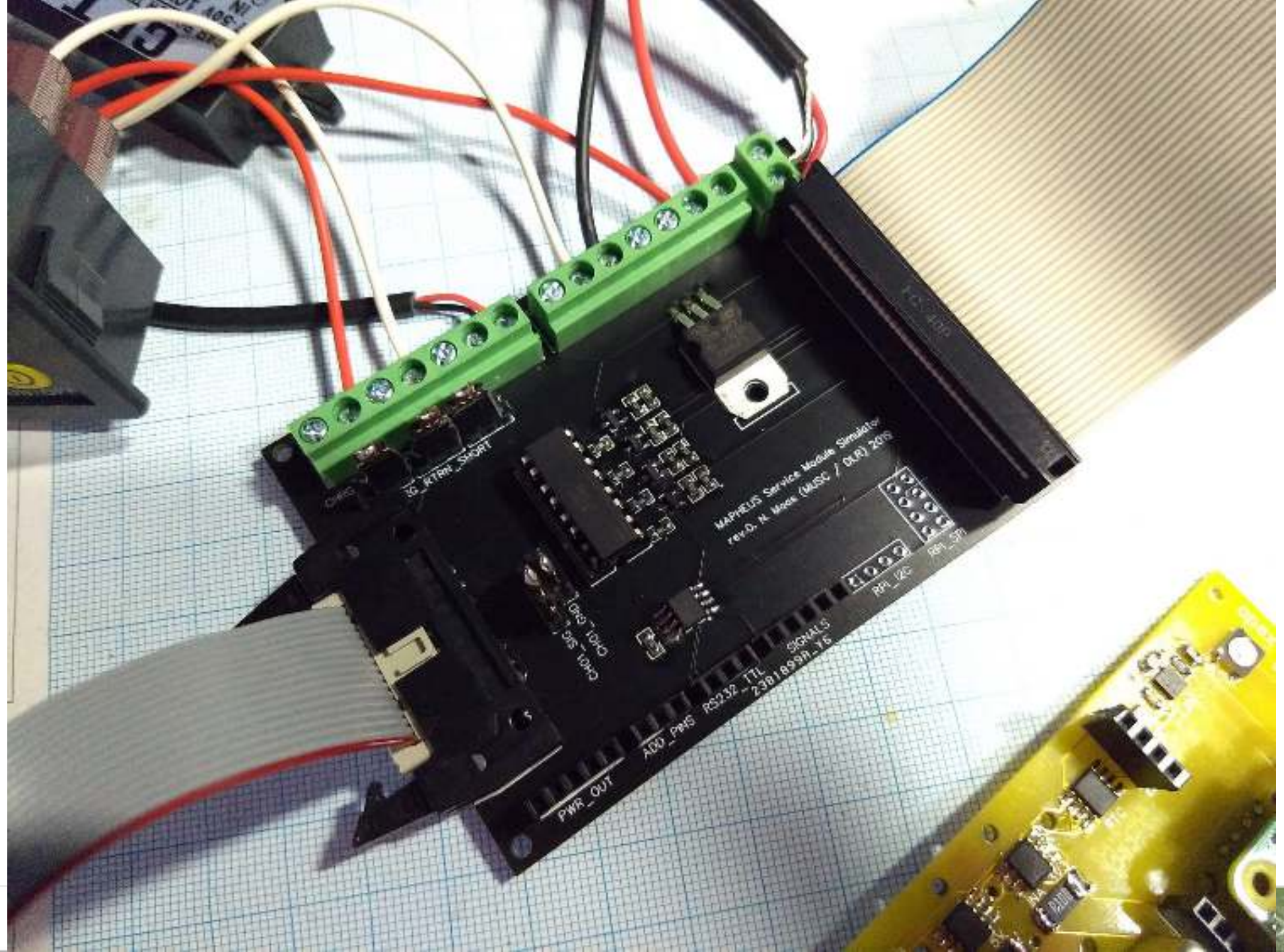






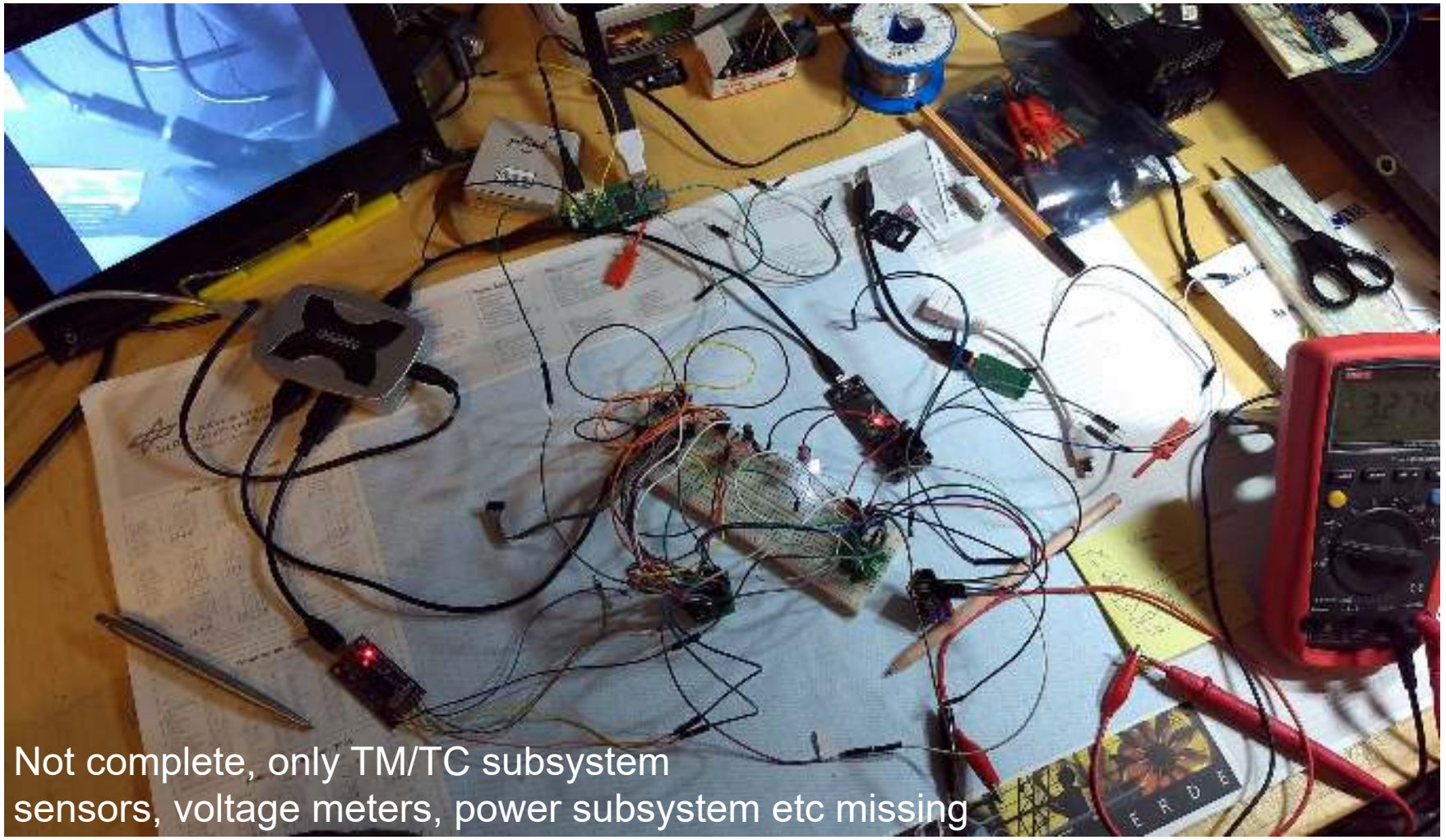
Design Phase Iteration

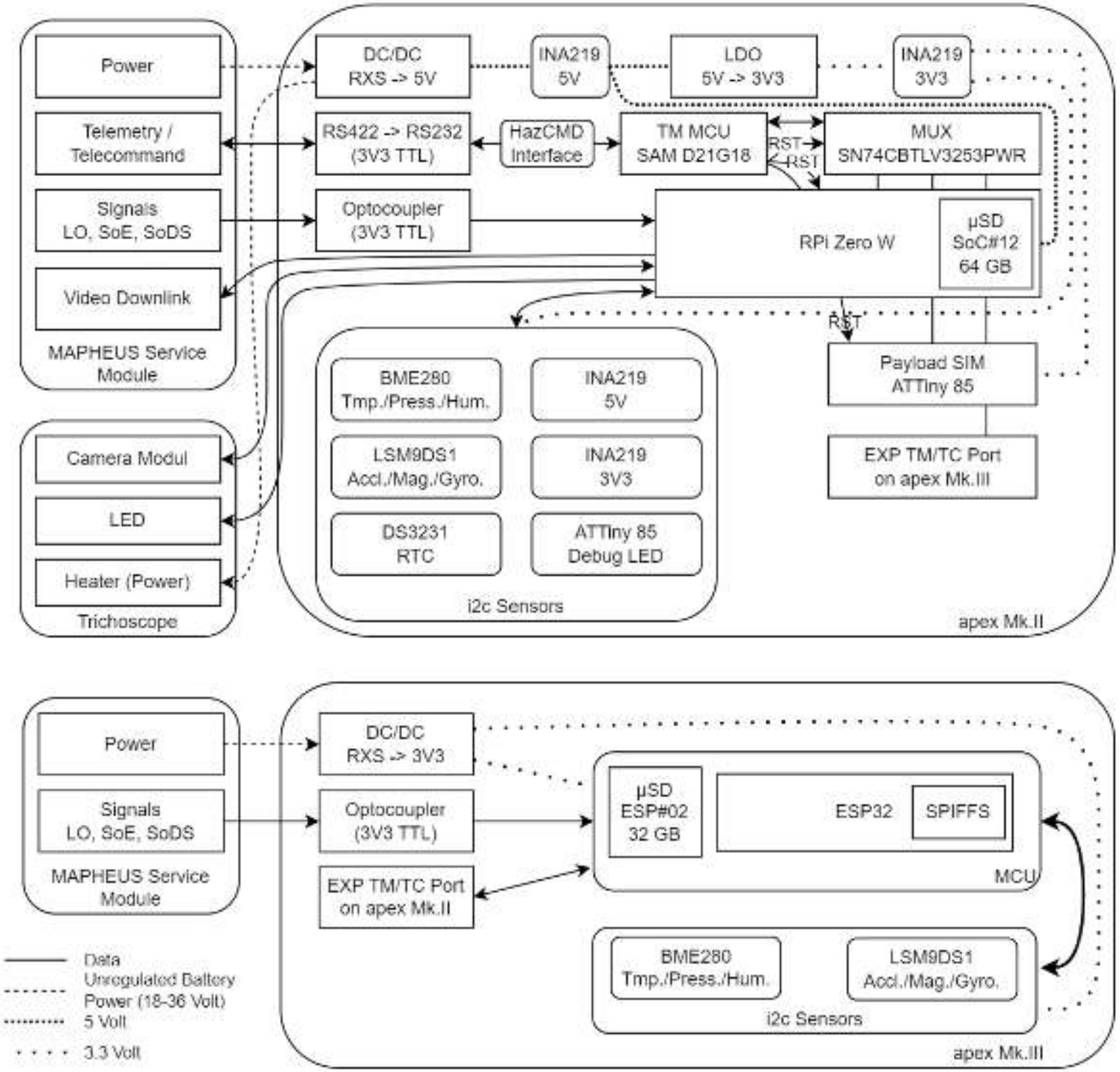



MAPHEUS Service Module Simulator
rev.0, N. Maas (MUSC / DLR) 2015
PWR_OUT
ADC_PWS
RS232_TTL
SIGNALS
23818998R_Y6
RPI_I2C
RPI_SPI

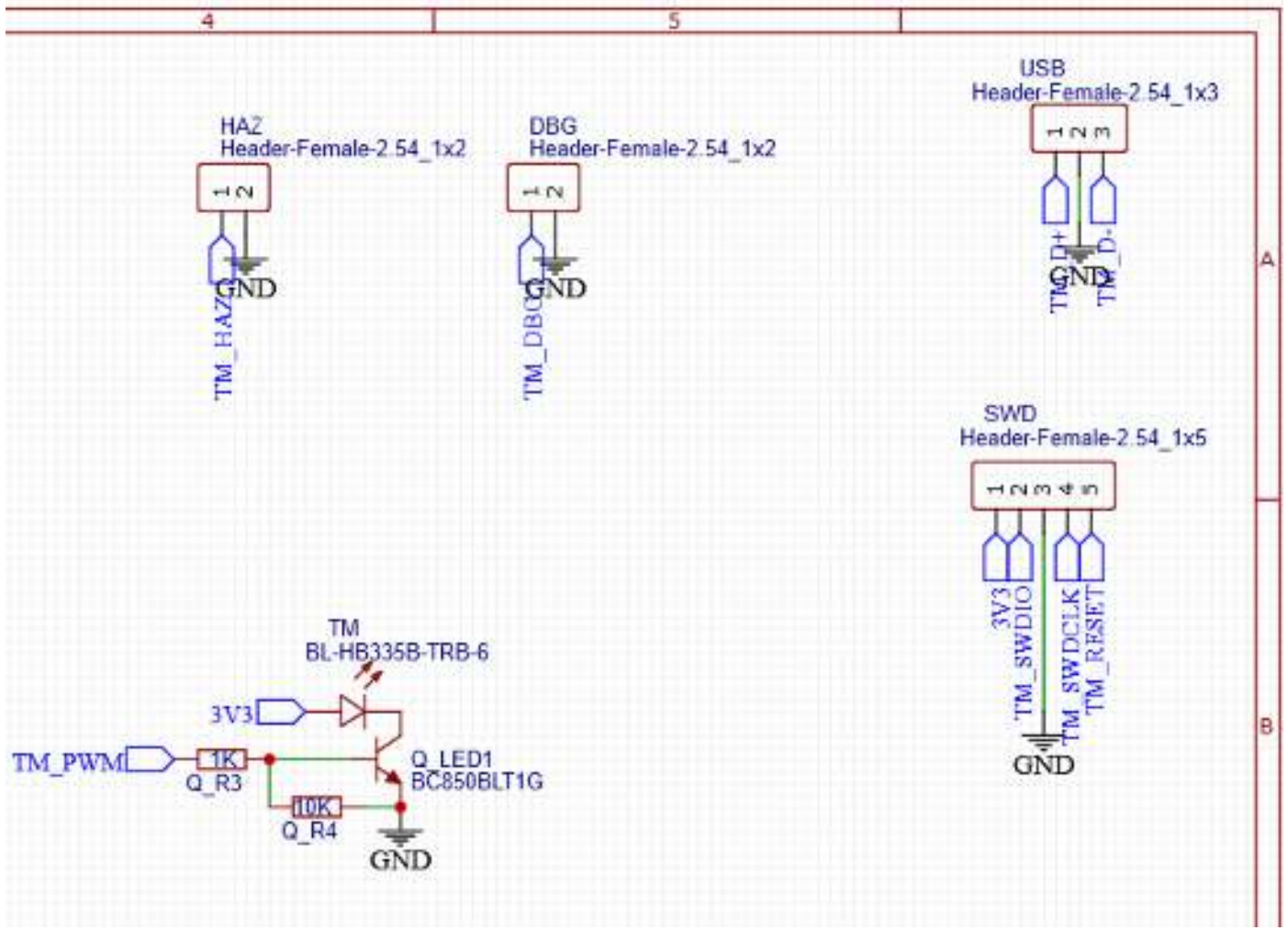
DLR

Design Phase
Breadboard Verification

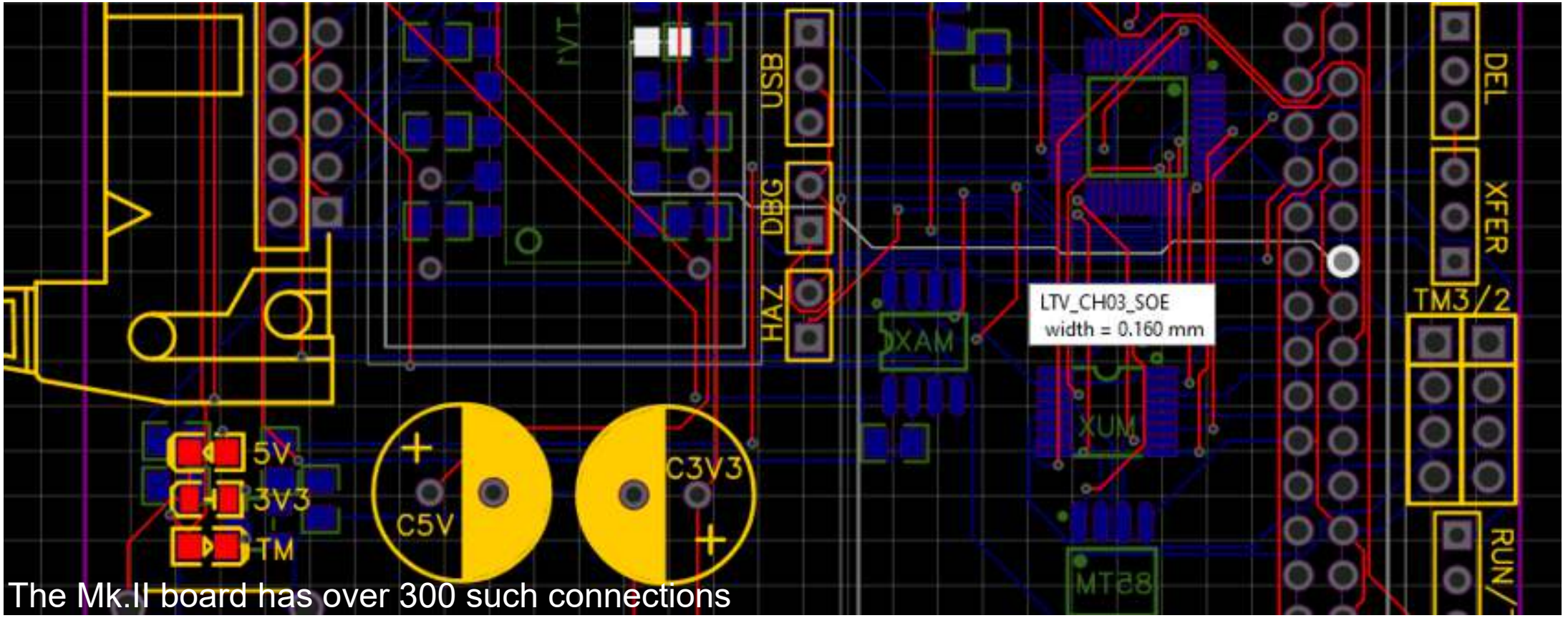



Power
Telemetry / Telecommand
Signals LO, SoE, SoDS
Video Downlink
MAPHEUS Service Module
DC/DC RXS -> 5V
INA219 5V
LDO 5V -> 3V3
INA219 3V3
RS422 -> RS232 (3V3 TTL)
HazCMD Interface
TM MCU SAM D21G18
RST
RST
MUX SN74CBTLV3253PWR
Optocoupler (3V3 TTL)
RPi Zero W
µSD SoC#12 64 GB
RST
Payload SIM ATTiny 85
EXP TM/TC Port on apex Mk.III
BME280 Tmp./Press./Hum.
INA219 5V
LSM9DS1 Accl./Mag./Gyro.
INA219 3V3
DS3231 RTC
ATTiny 85 Debug LED
i2c Sensors
apex Mk.II
Camera Modul
LED
Heater (Power)
Trichoscope
Power
Signals LO, SoE, SoDS
MAPHEUS Service Module
DC/DC RXS -> 3V3
Optocoupler (3V3 TTL)
EXP TM/TC Port on apex Mk.II
µSD ESP#02 32 GB
ESP32
SPIFFS
MCU
BME280 Tmp./Press./Hum.
LSM9DS1 Accl./Mag./Gyro.
i2c Sensors
apex Mk.III
Data
Unregulated Battery Power (18-36 Volt)
5 Volt
3.3 Volt

Design Phase
Implementation of Design in EDA

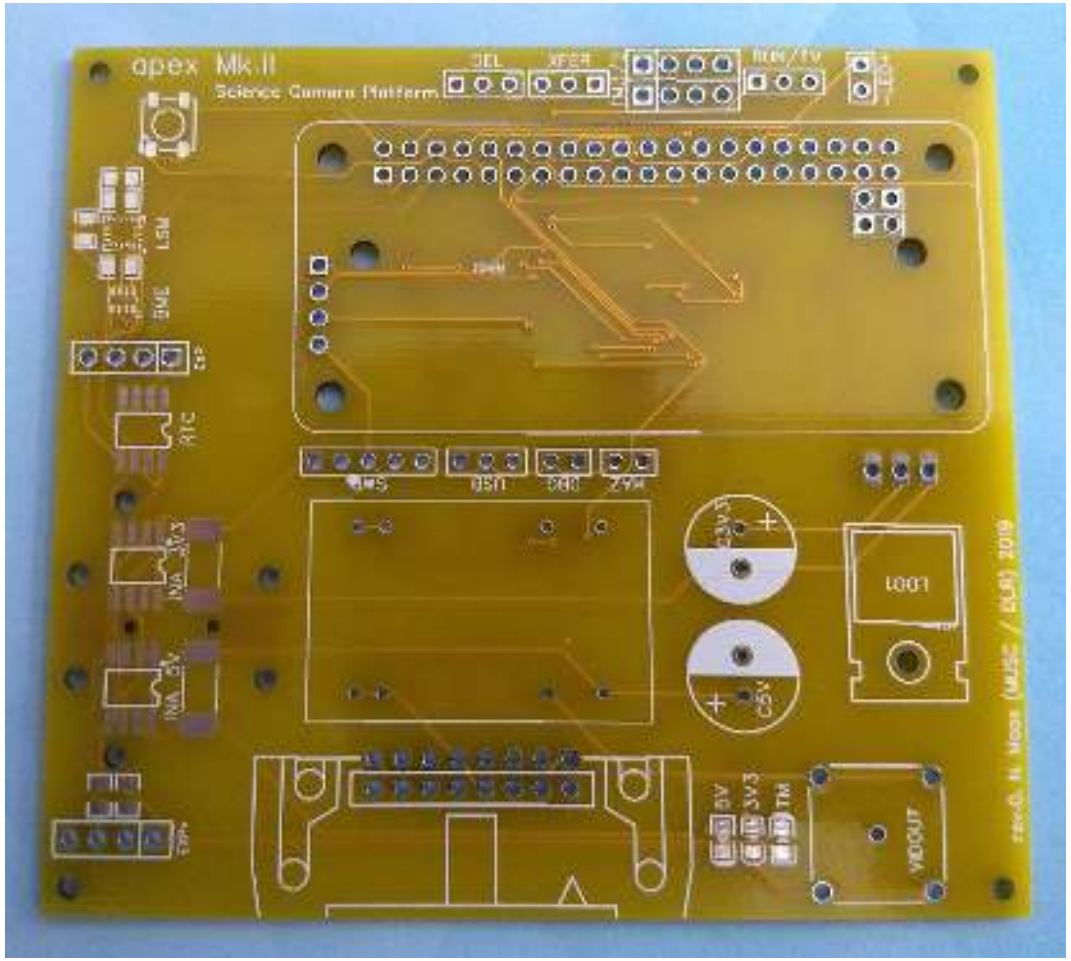


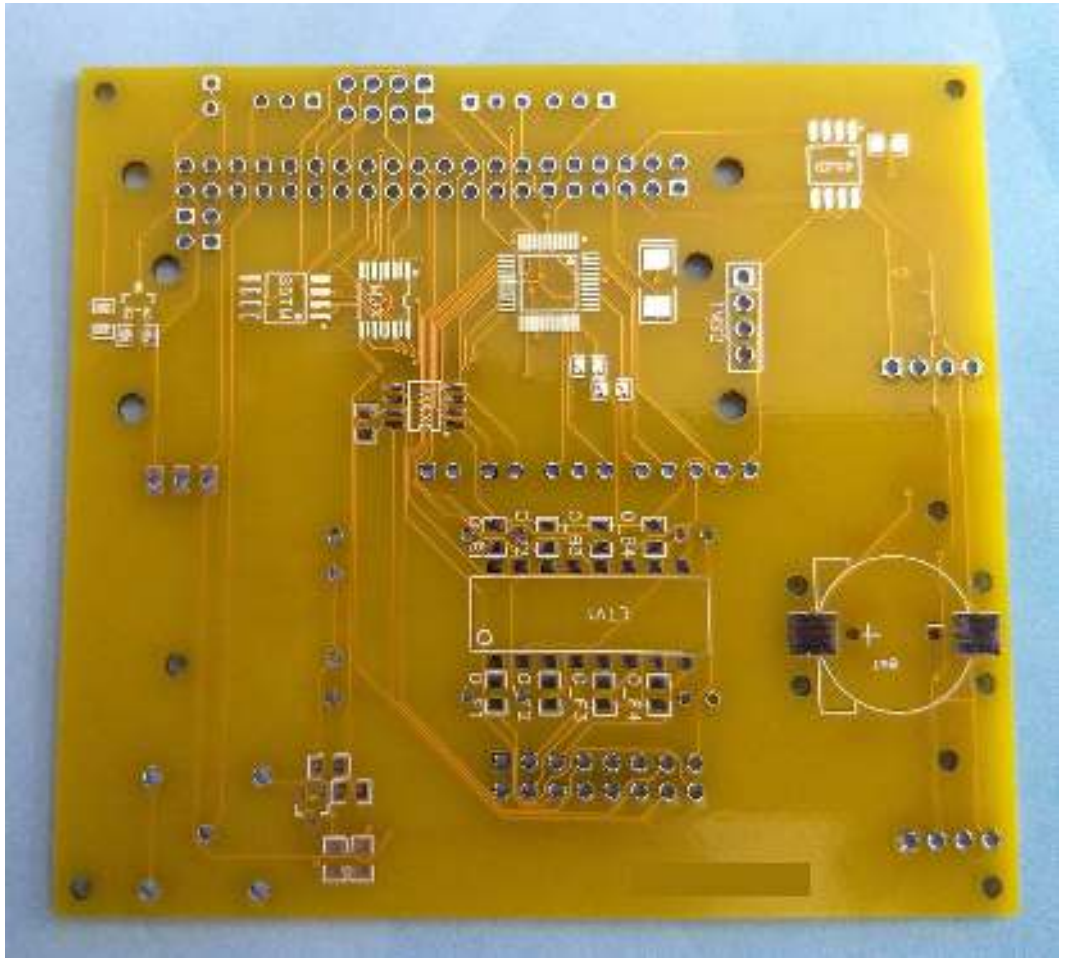
Design Phase
PCB Layout (component placement and wire routing) in EDA



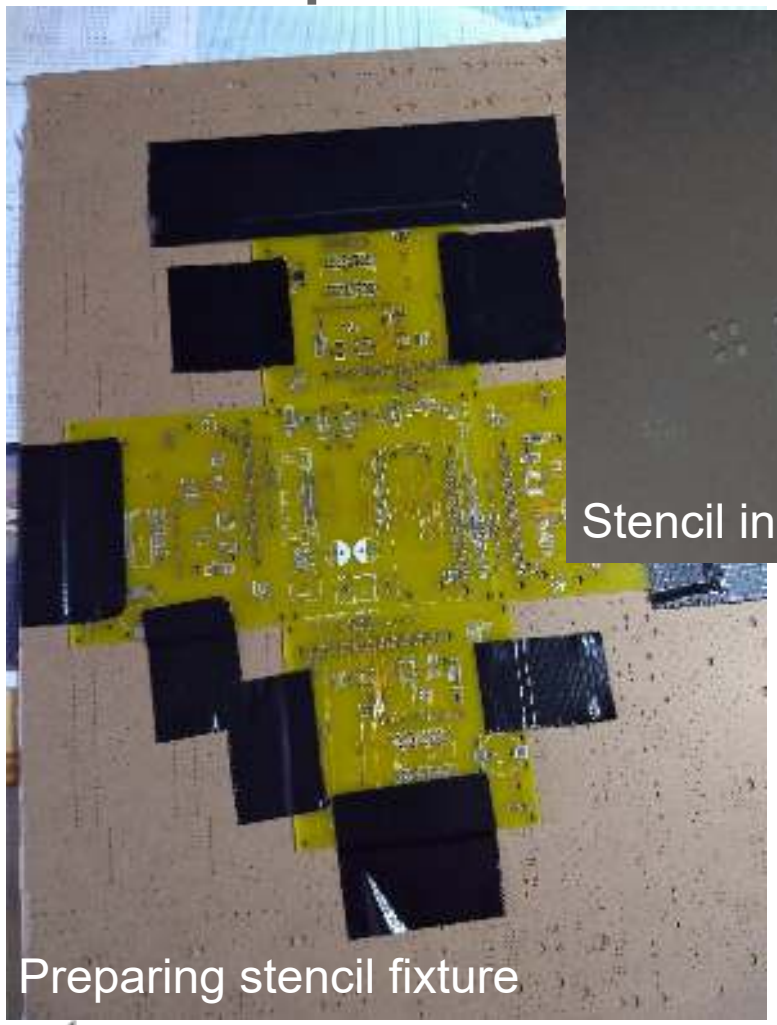
The Mk.II board has over 300 such connections

Implementation Phase
PCB Produced



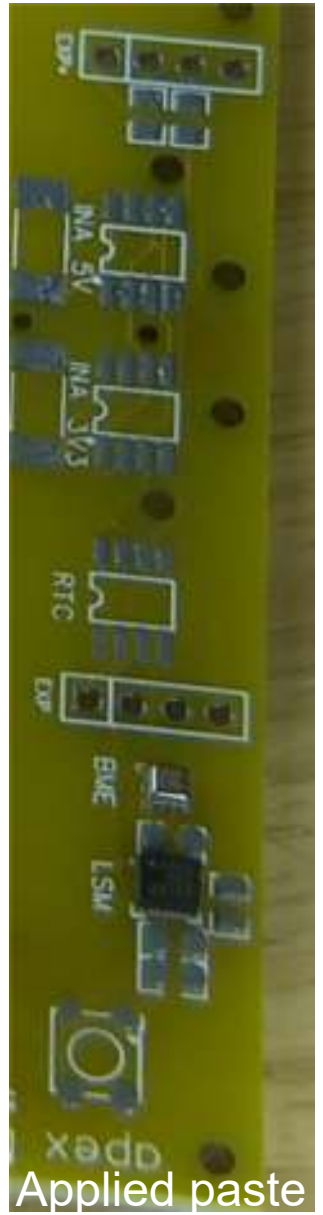


Implementation Phase
PCB Component Placement


Preparing stencil fixture

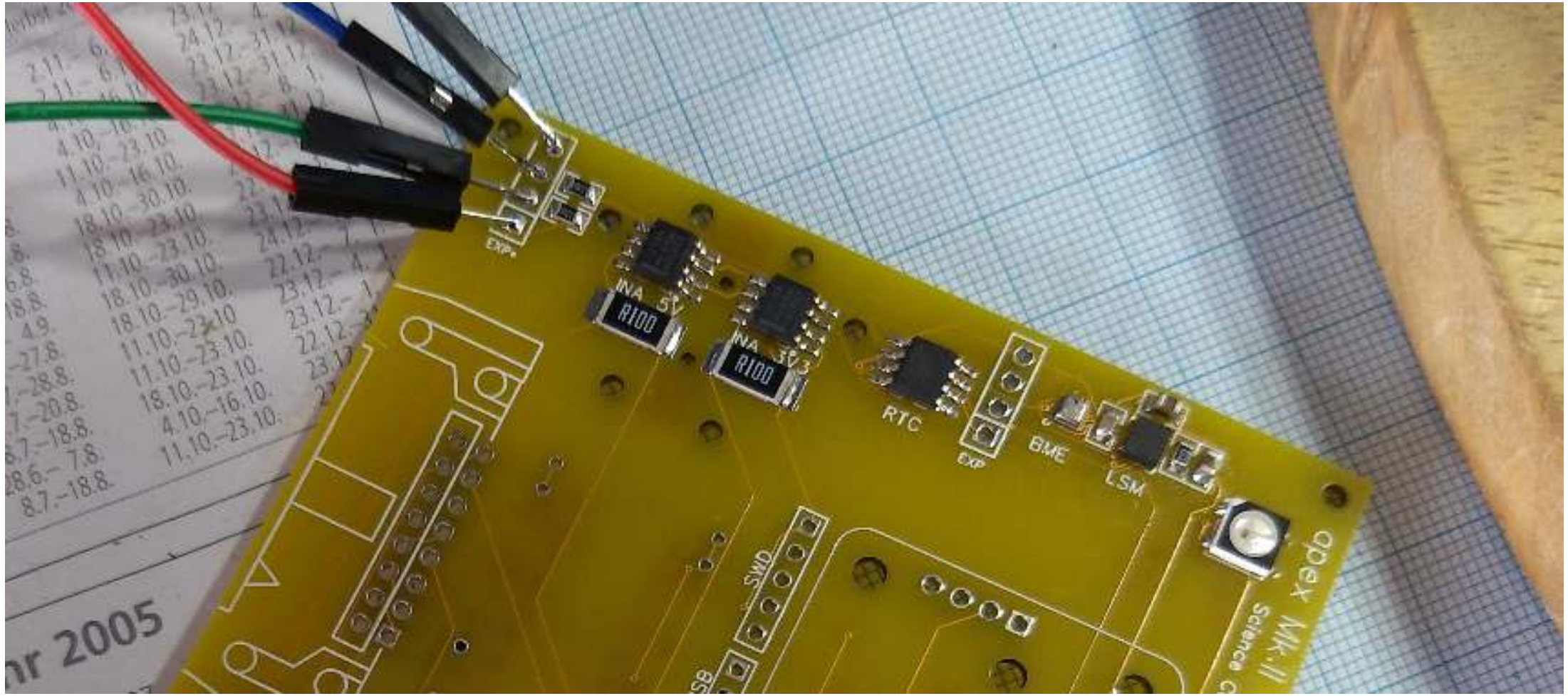

Stencil in place


Apply leaded solder paste

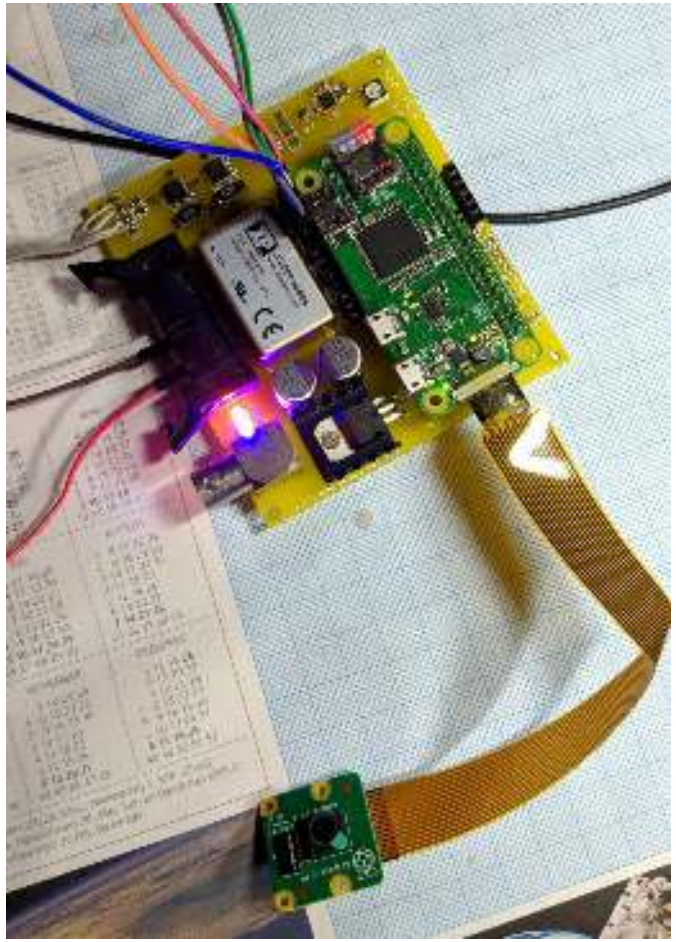


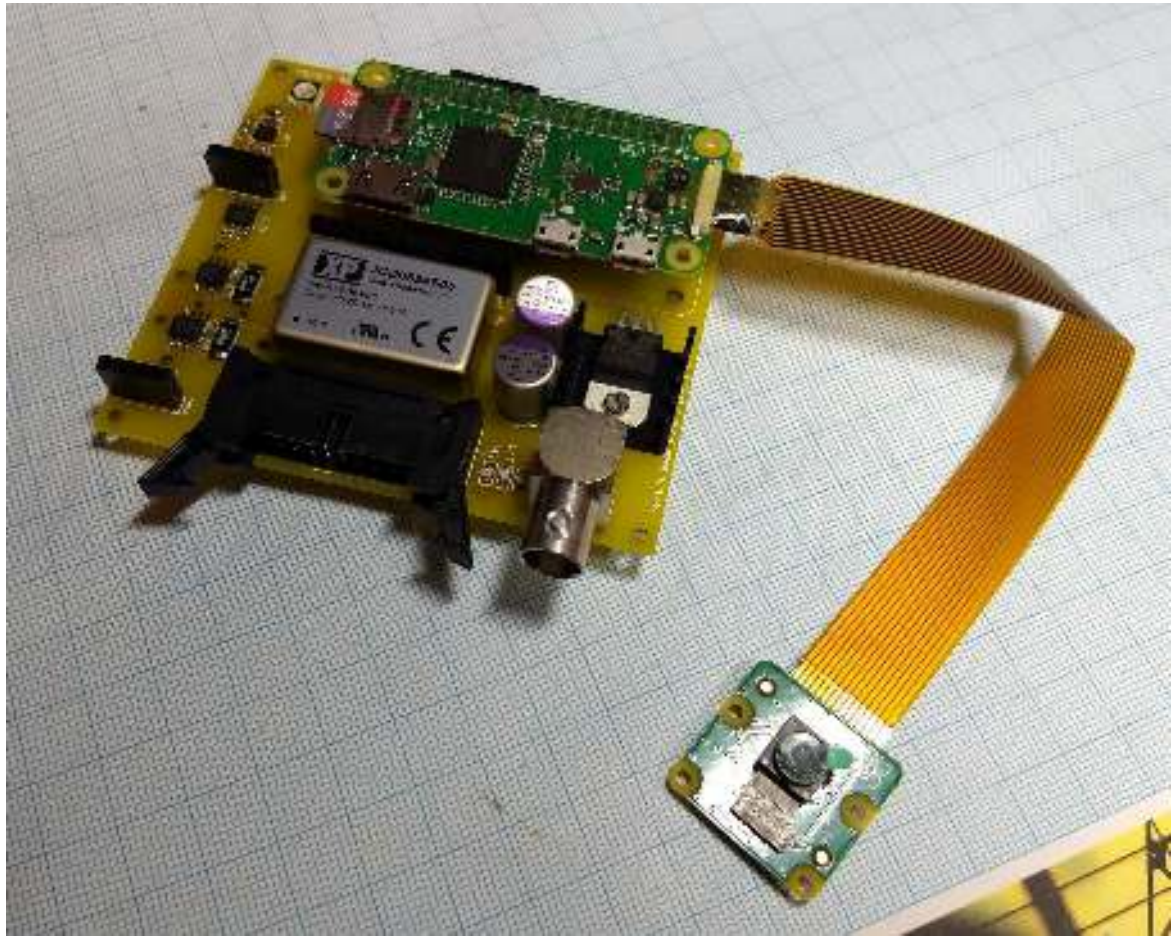
Applied paste

Implementation Phase
PCB Component Placement and verification



Implementation Phase
Initial build done





Implementation Phase

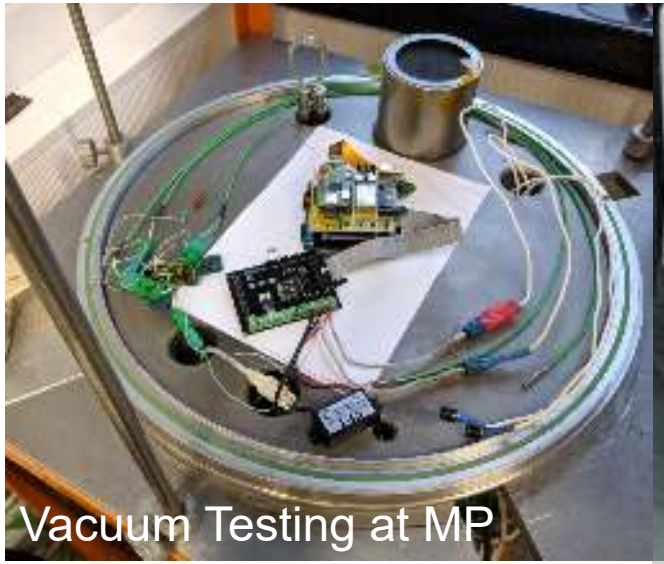
- At this point we have a nice looking and extremely useless paper weight

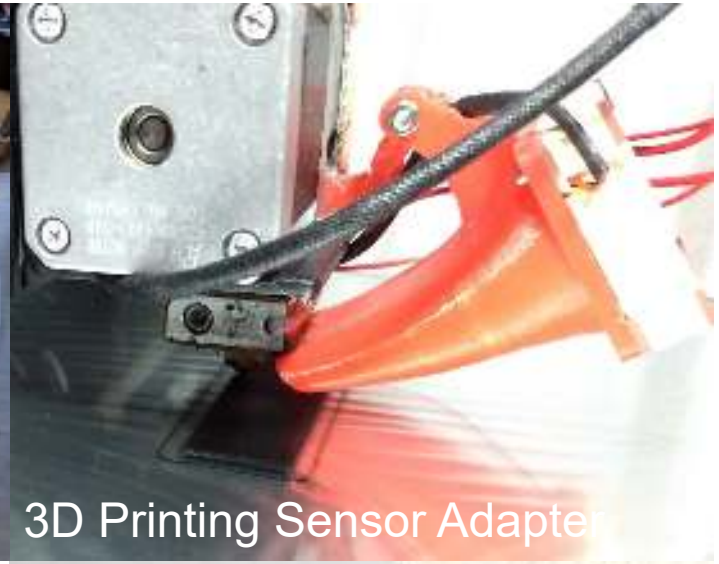
- Mk. II uses 4 microcontrollers and computers on board which need firmware / programming
  - RPi Zero W
    - “Big computer”, ARMv7, Singlecore, 32 bit, Linux, programmed in Python
    - needs to have its own operating system specially crafted to be robust enough for space (Yocto)
  - AT SAM D21
    - TM/TC processor, ARM Cortex M0+, Singlecore, 32 bit, C/C++
  - AT Tiny 85 Payload SIM
    - Payload Simulator, AT Tiny Architecture, Singlecore, 8 bit, C/C++
  - AT Tiny 85 LED
    - Diagnose LED, AT Tiny Architecture, Singlecore, 8 bit, C/C++

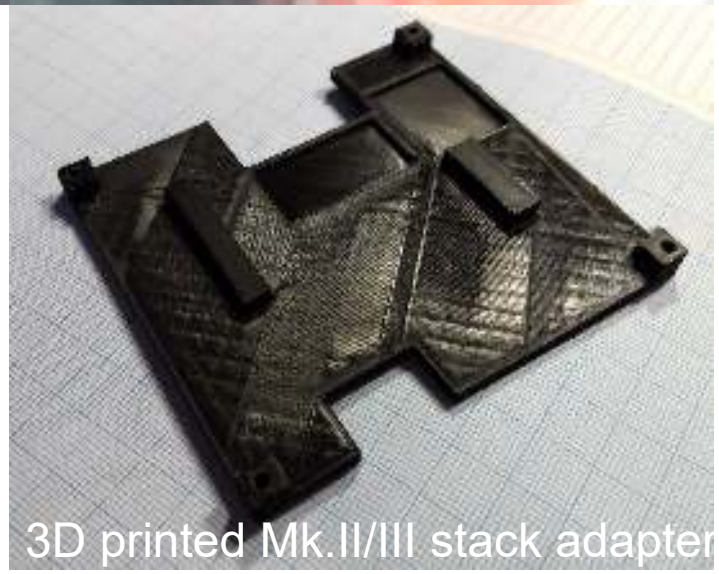
- Mk. III has only one, but again, different architecture
  - ESP32
    - Main OBC, Tensilica Architecture, Duo/Tricore, 32 bit, C/C++

Also we need …

- Payload
  - CAD & 3D printing of harness structures
  - Electrical harness
  - …
- Ground Segment
  - EGSEs
    - LAB EGSE with own MAPHEUS Service Module Simulator v2
    - Flight EGSE to connect MORABA antenna data to MUSC
  - MUSC / Controlroom
    - Data Archive
    - Incoming Video Handling
    - MCS + Mission database
    - Grafana
    - Videostreaming Subsystems, Cutter and Caster
  - …
- Component identification & procurement, Tests, Verifications, FR & Reviews, Export control, Acknowledgements by DLR PR Social Media, PR CI/CD, PR Management, News Team, ME, MP, RB-MRB, PIs, …


Vacuum Testing at MP

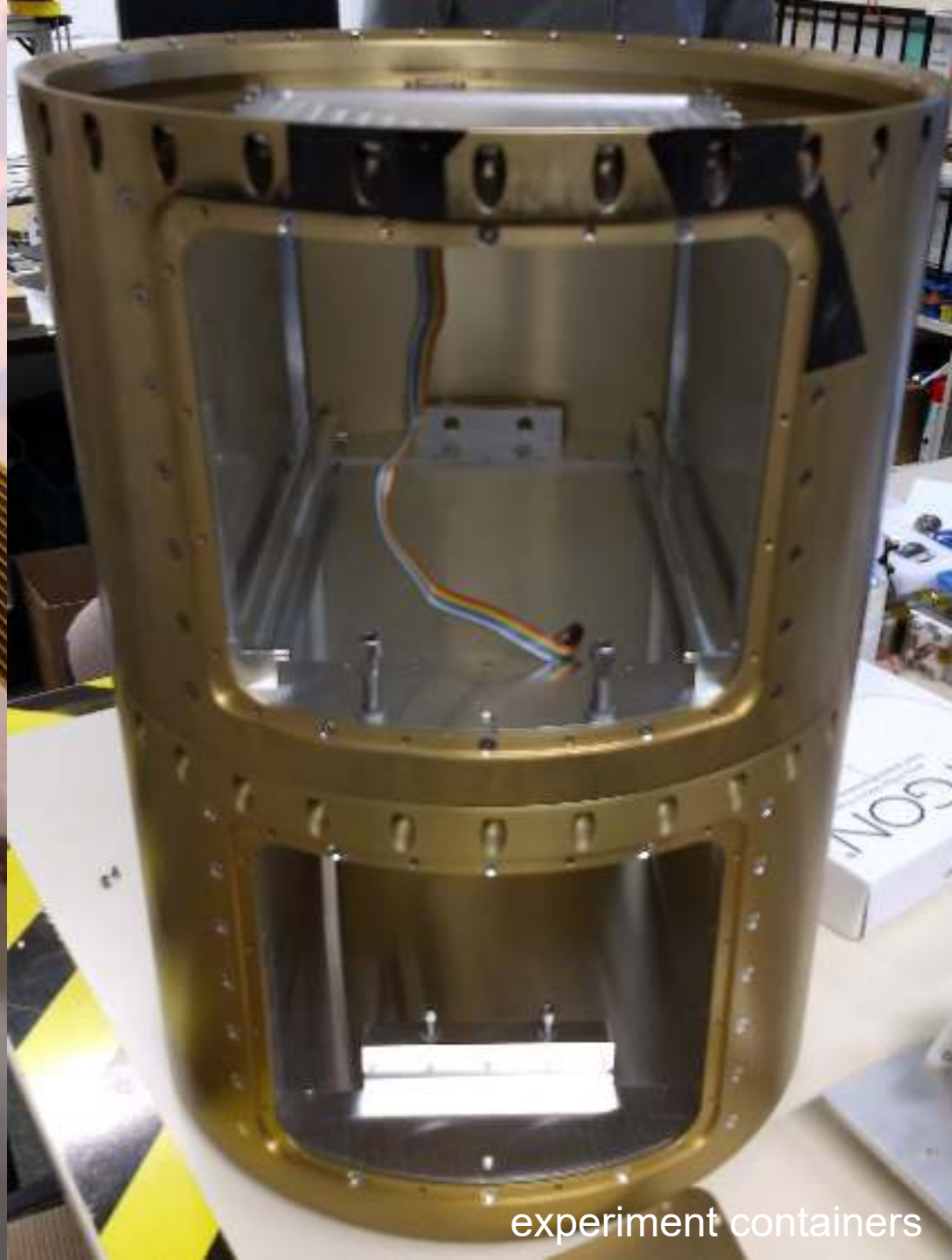

3D Printing Sensor Adapter


3D printed Mk.II/III stack adapter

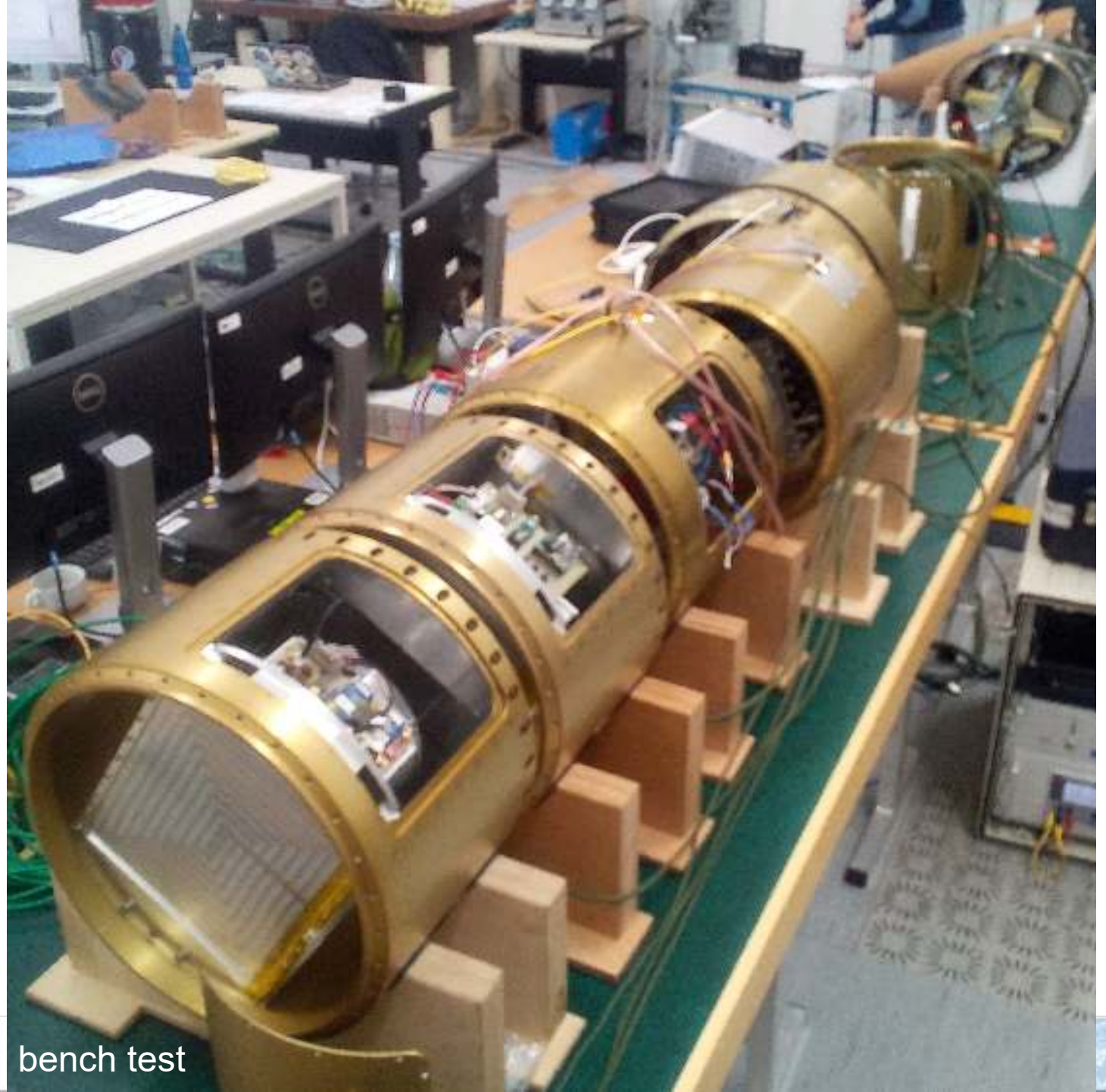
Why is space hardware so expensive?
We need a lot of people with different expertise to make this work

- 3D / CAD Design and Additive Manufacture (3D printing and structural harnesses)
- Thermal Design (thermal and electrical budget of rocket)
- Electrical Design (DC/DC powertrain)
- Electronics Design (chip selection and EDA work)
- Soldering (ESA conform)
- Embedded Developer Microcontroller (Firmware)
- Embedded Developer SBC (Rpi program, EGSEs)
- Container Virtualization Specialist (EGSEs, Ground Segment)
- Firewall / Networking / Storage / Virtualization Specialist (actually different jobs)
- Ground Controller (MCS setup / Data handling / CCSDS implementation)
- QA / QC (somewhere in here, Documentation and Papers…)
- PR
- …

apex Mk.2/Mk.3 stacked

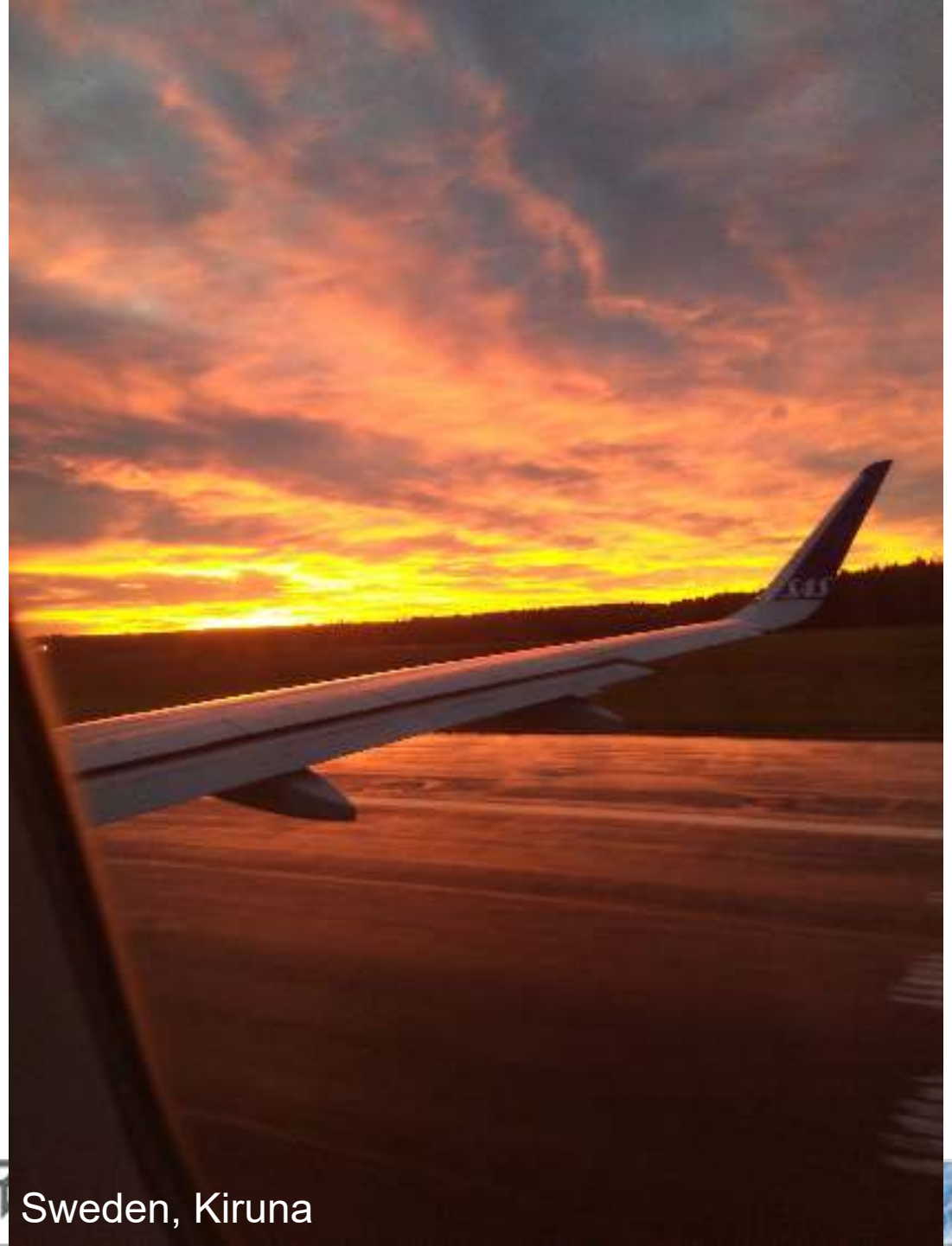


experiment containers



bench test

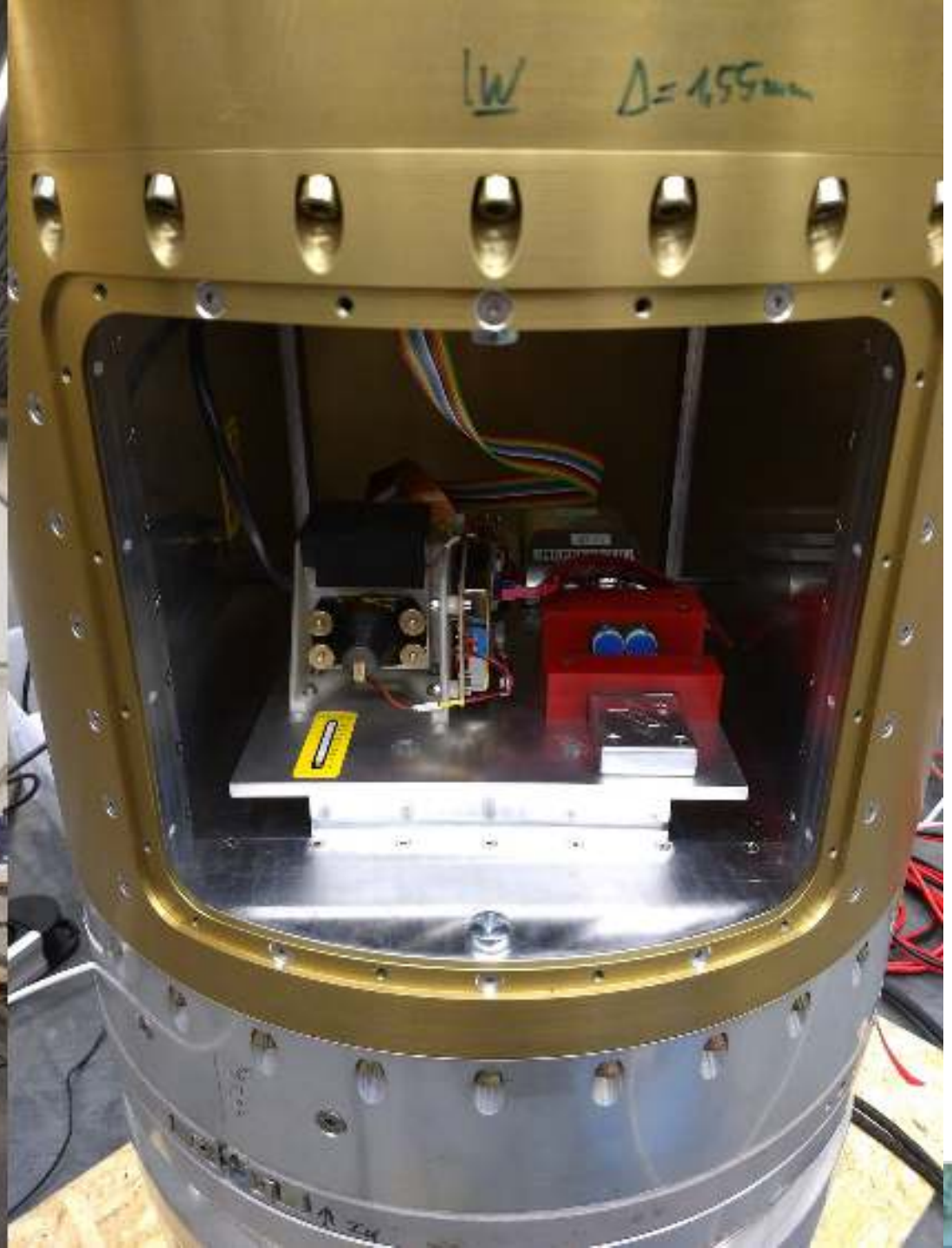
environmental test

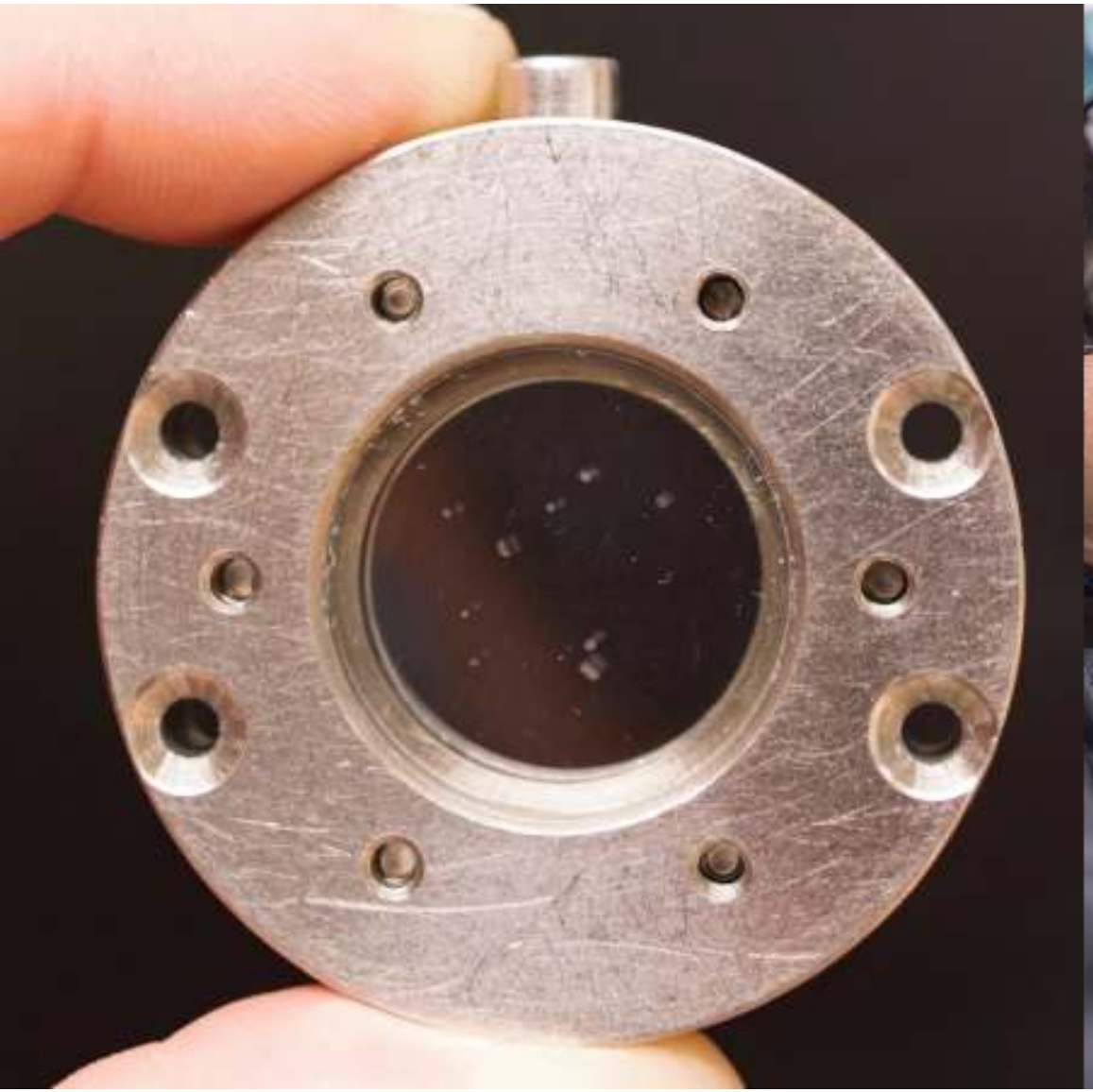


Sweden, Kiruna

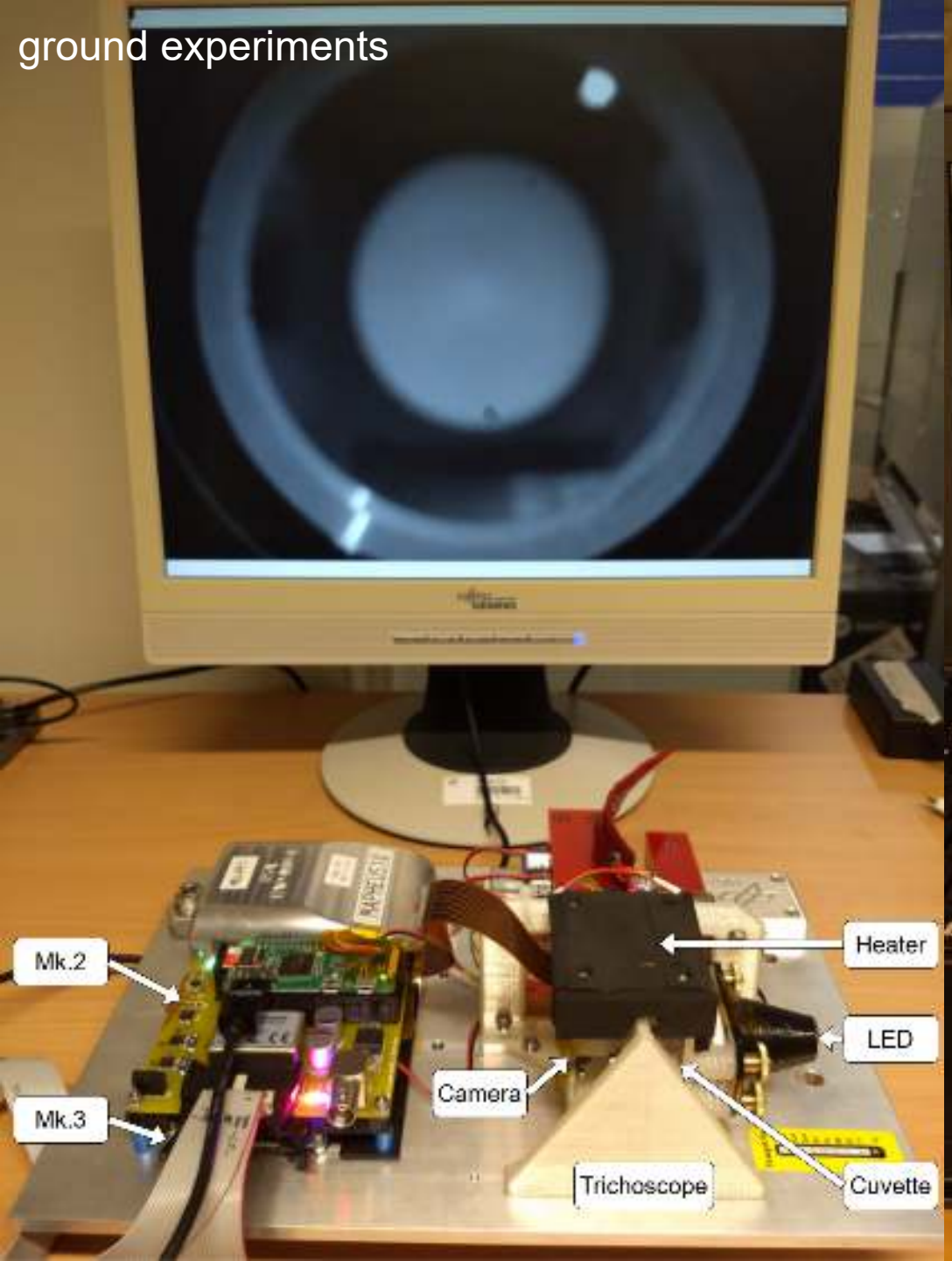
SSC Esrange

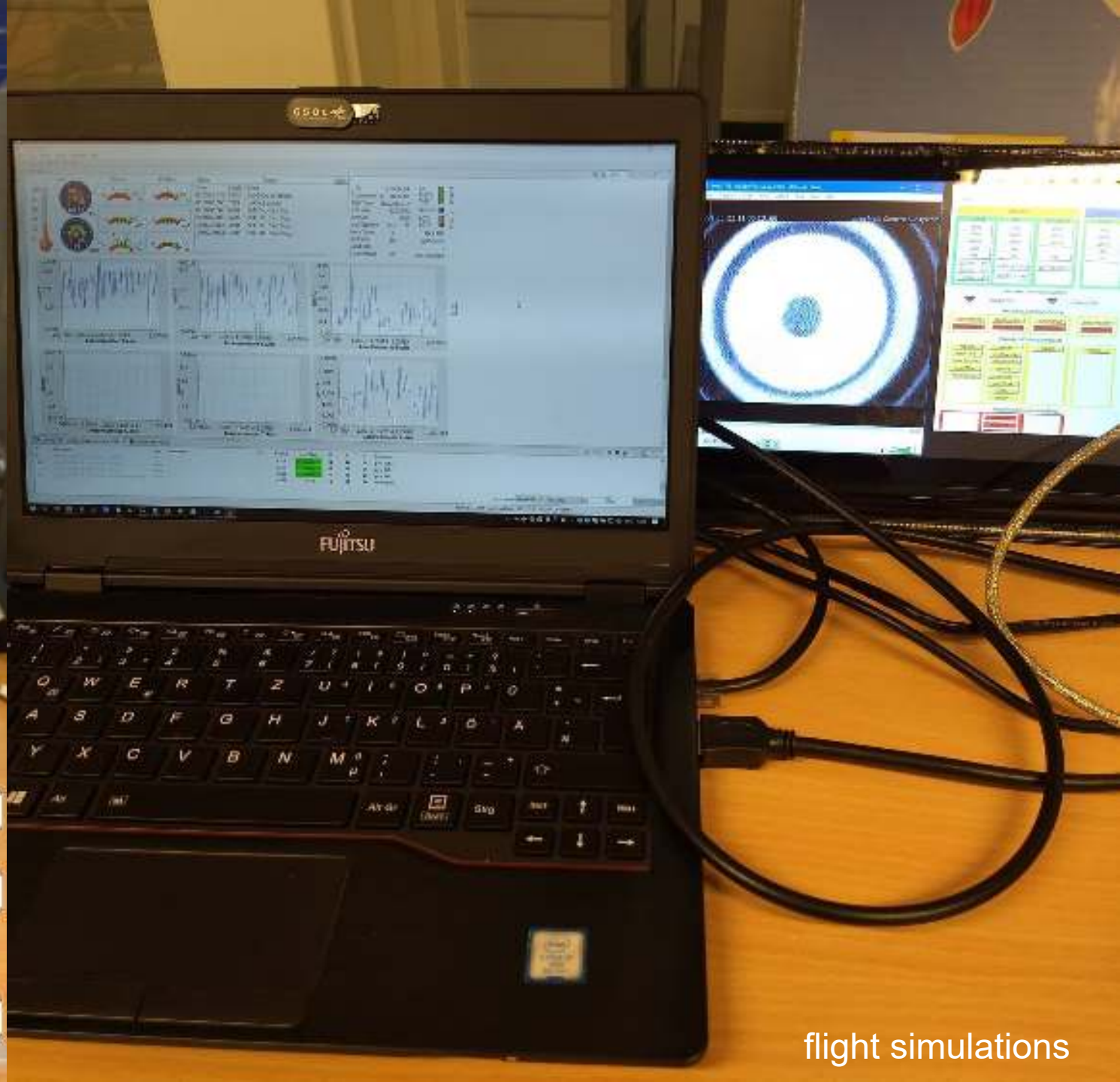
bench test and experiment stacking



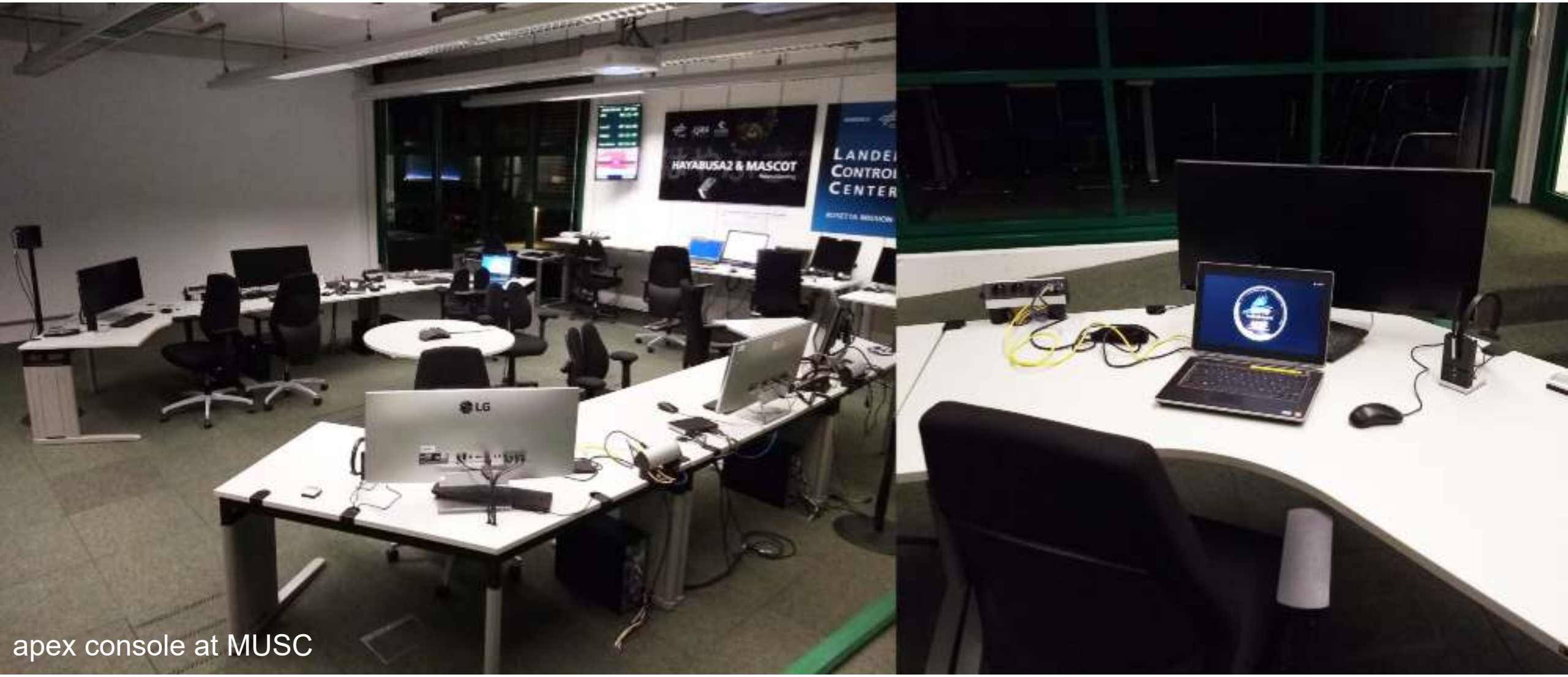


DLR


ground experiments
Mk.2
Heater
LED
Camera
Mk.3
Trichoscope
Cuvette


FUJITSU
flight simulations

apex console at Esrange



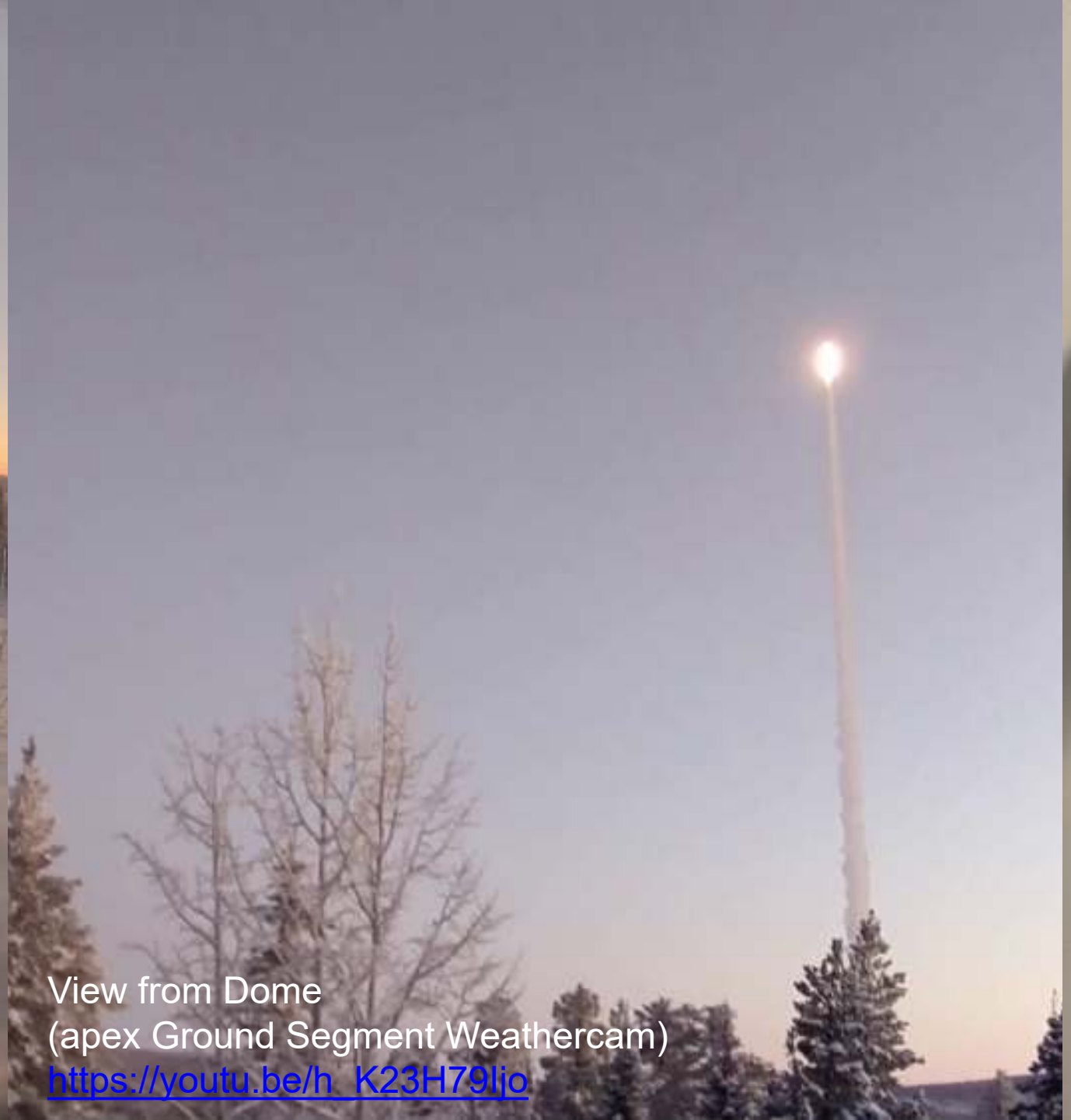
apex console at MUSC

Left: SSC Mainbuilding,
Center: MRB DTM

MAPHEUS-10 on launcher

Minutes before Liftoff

View from Radarhill
(RunCam 3S)
https://youtu.be/9N74bLjJrR0

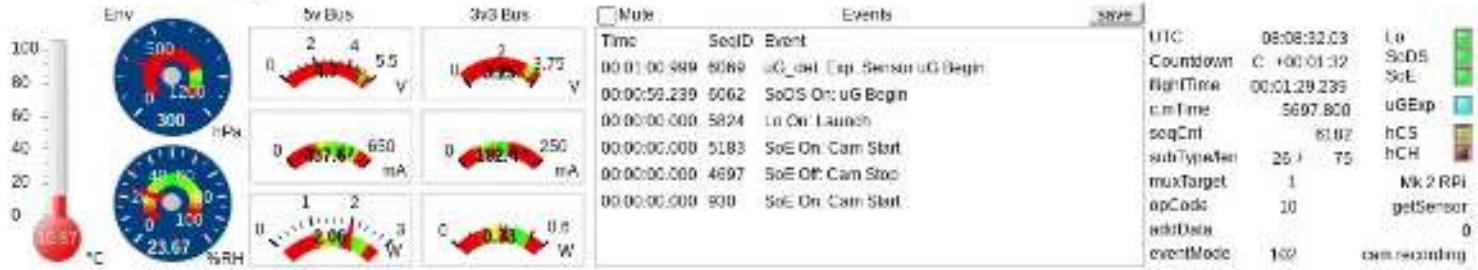


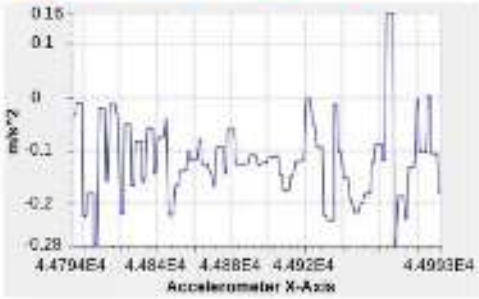
View from Dome
(apex Ground Segment Weathercam)
https://youtu.be/h_K23H79ljo

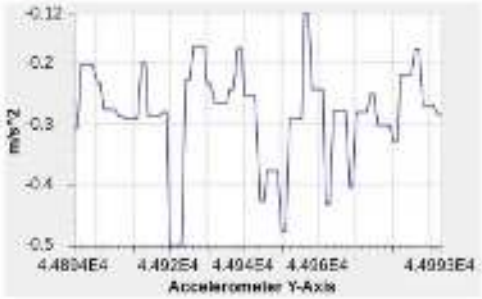
MAPHEUS 10 (MExA): apex Mk.II Livestream

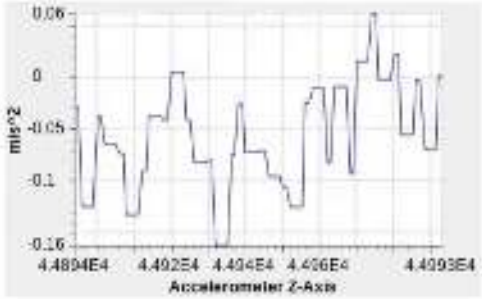
https://youtu.be/H4EP9TFVHm4

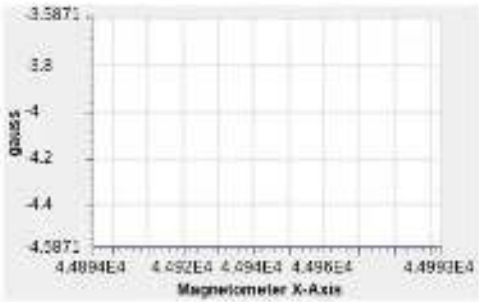
Telemetry

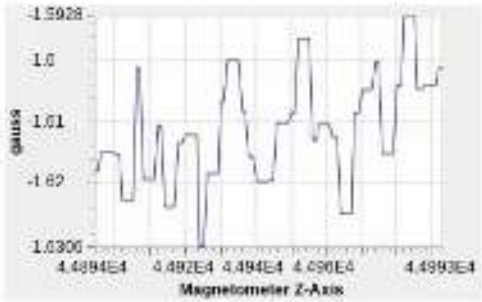


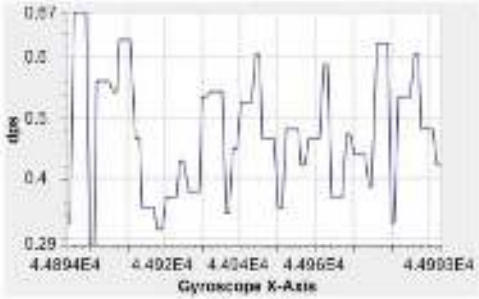


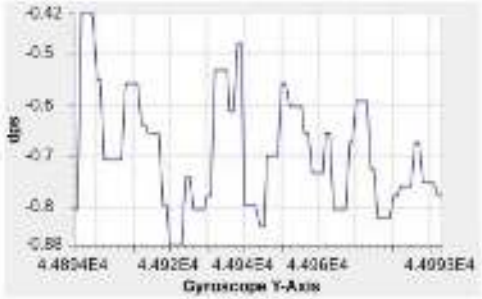


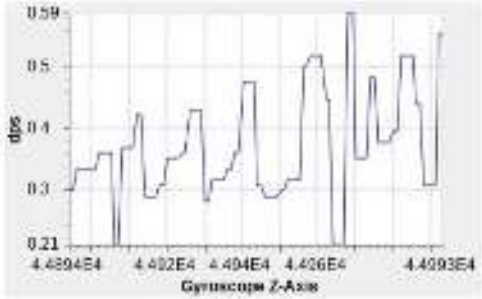




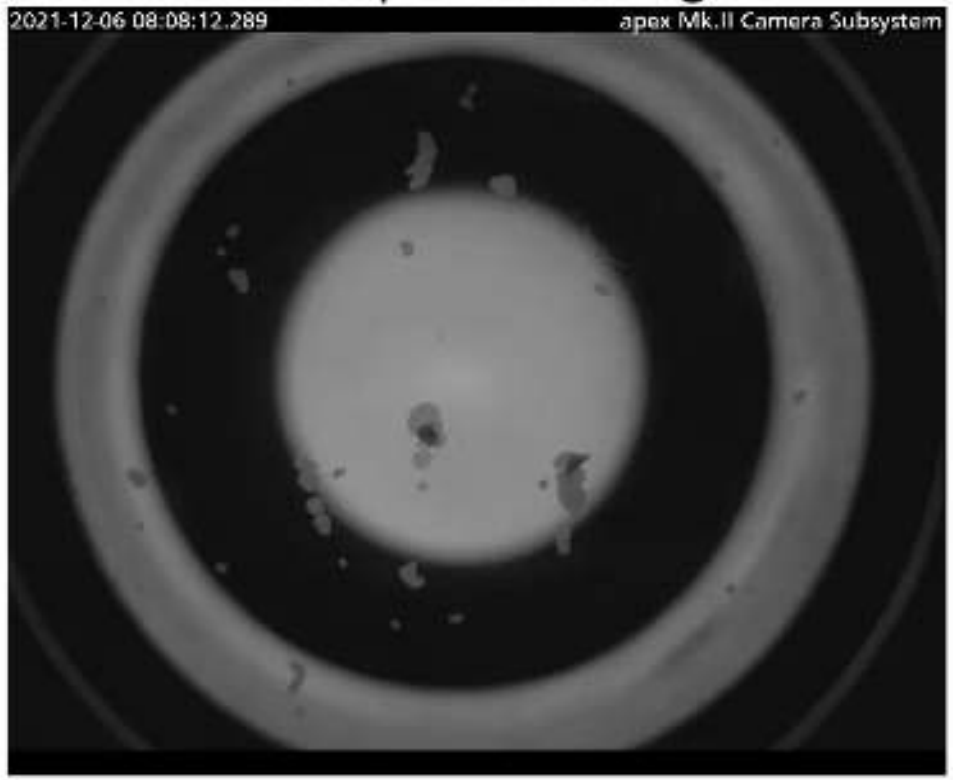


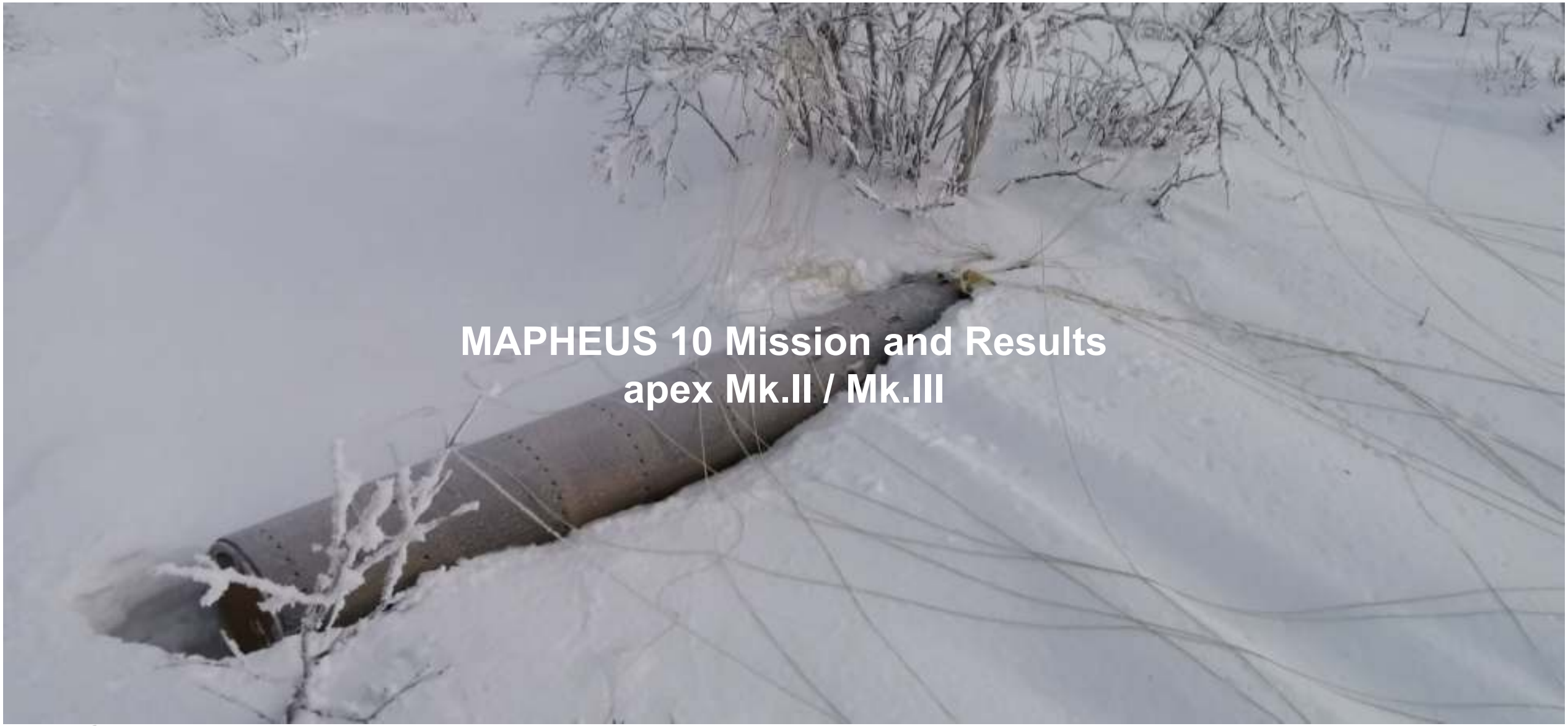






Live Trichoscope Still Images

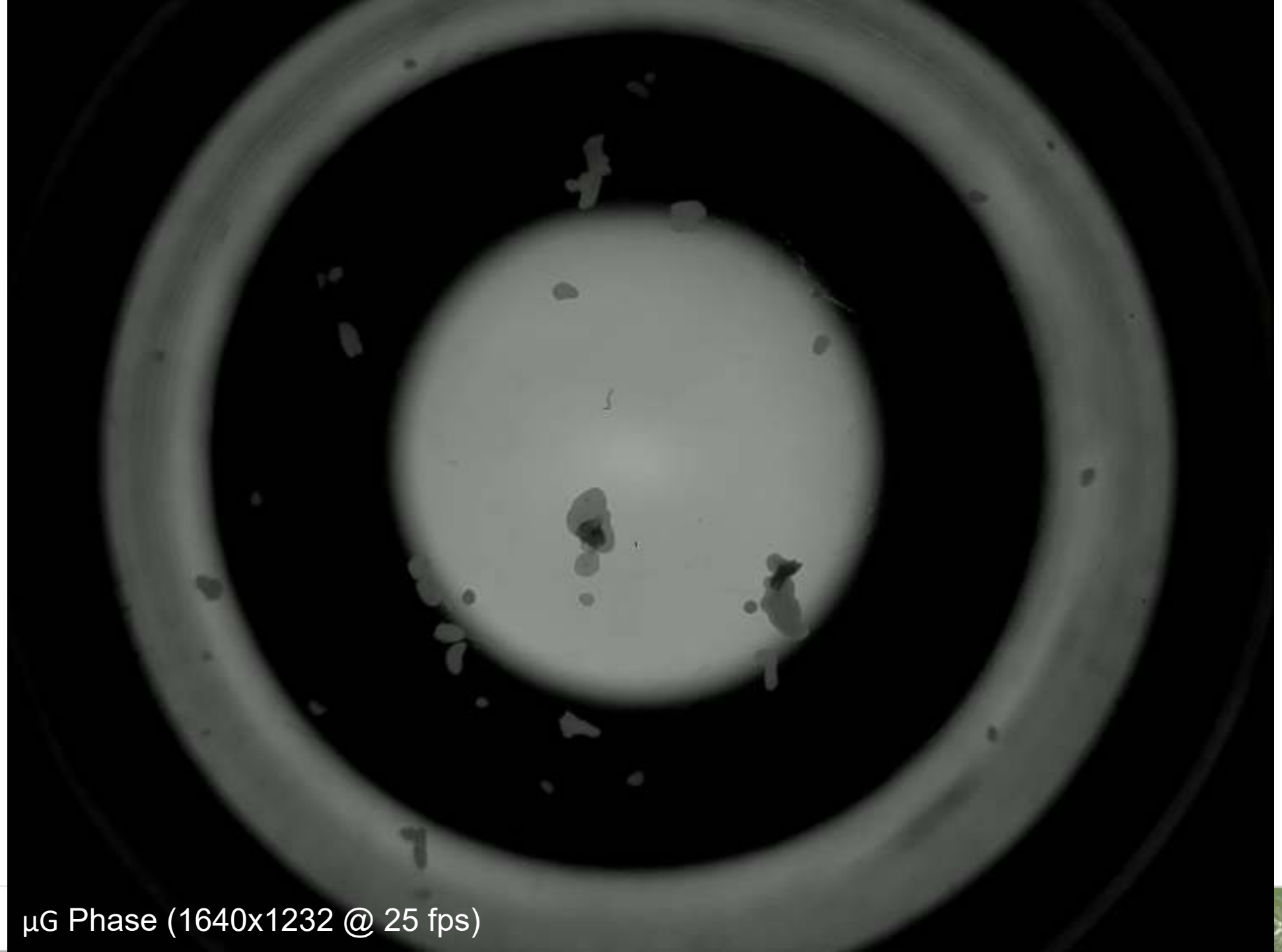




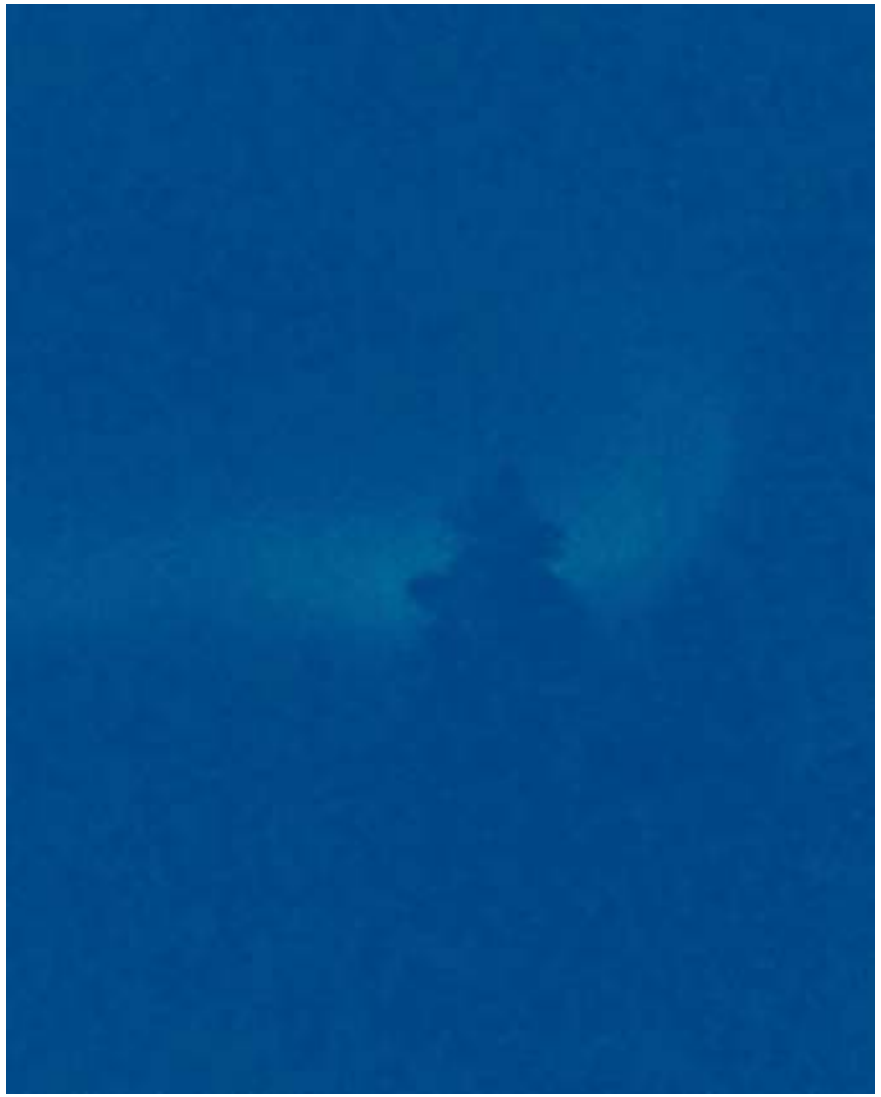
MAPHEUS 10 Mission and Results
apex Mk.II / Mk.III

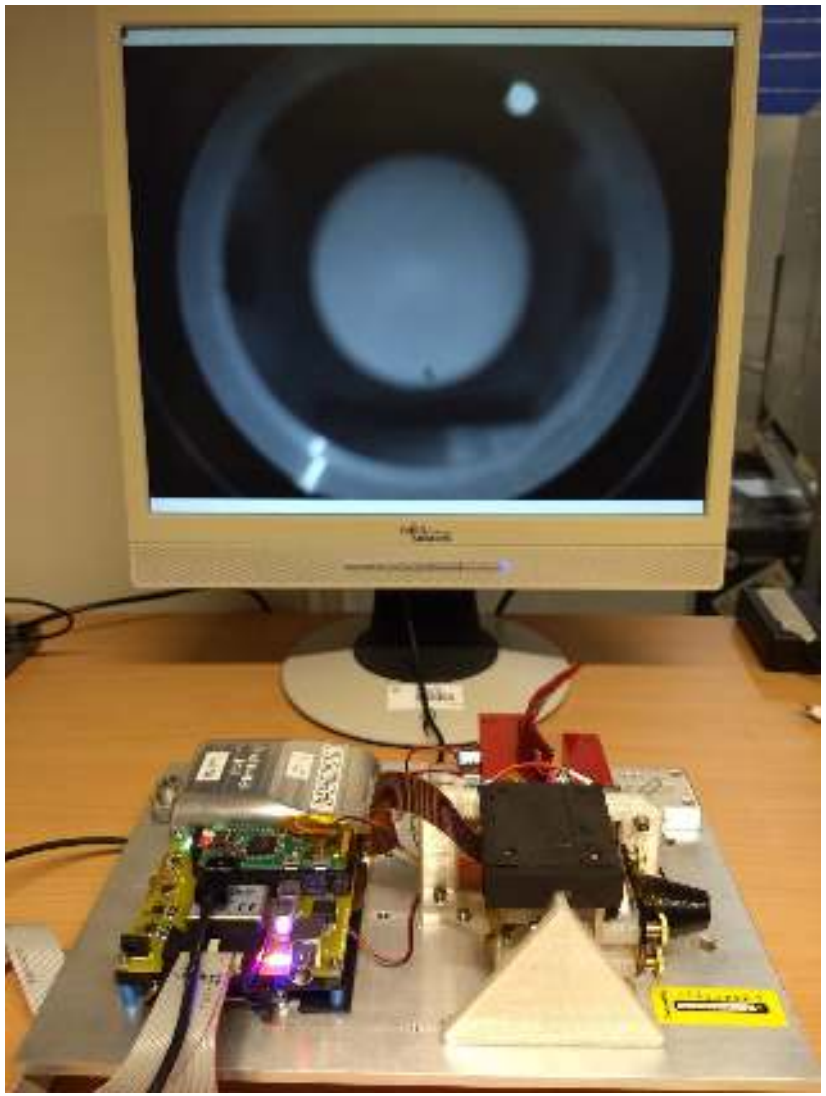
Results (Details)

- Basic functions of Mk.II / Mk.III completely met requirements
  - Video recording of Trichoscope reliable over whole mission (not one second data loss)
    - 85 minutes of ground recording (instead of planned 15 minutes) before LiftOff to increase power dissipation in rocket -> heating of experiment container
  - Sensors: No problems found (one display/calibration error of the pressure sensor)
  - Telemetry & Telecommand ok
    - TM/TC on Mk.II for Mk.II Rpi, Mk.II Payload Simulator and Mk.III tested successfully
    - MUX design not efficient enough for higher density payloads -> new design envisioned
- New extremes during the campaign
  - Power-on at < -3.7 °C without issues
  - „Hibernation“ after launch 26 h at < -25 °C: Working perfectly after de-frosting, no data loss
  - Undergone accelerations up to: 22.3 g
- Signal roundtrip times for TM/TC via MUSC VPN:
  - Sending TC Kiruna -> Köln (MCS) -> Kiruna (apex FW, apexnode, MORABA GS, SSC TC Antenna) -> MAPHEUS 10 Service Module -> apex Mk.II TM processor -> MAPHEUS 10 Service Module -> Kiruna (MORABA TM Antenna, MORABA GS, apexnode, apex FW) -> Köln (MCS) -> Receive TM Kiruna: ~550 ms
- Portable instance of apex GS („apexMCS“) tested succesfully in Kiruna before GSOC tested their „V3C“
  - But used TM/TC via MUSC as intended
  - same with „apexVGSE“ / local streaming (developed as emergency aid, but not needed)



µG Phase (1640x1232 @ 25 fps)





Concluded projects since MAPHEUS 10: Spin-offs of apex technology and recognition

- Video & AI
  - EML Videostreaming
    - Two factor secured transfer of EDR/EML TM and Video via public internet (COVID-19 relief)
  - labSentinel
    - Jetson AI Specialist awarded
  - labSentinel 2
    - AIoT contest winner
- Sensortechnology
  - MUSC Sensors
    - Monitoring of MUSC control- and equipment rooms, visualization with Grafana

apex MRMSS with MSMSv3

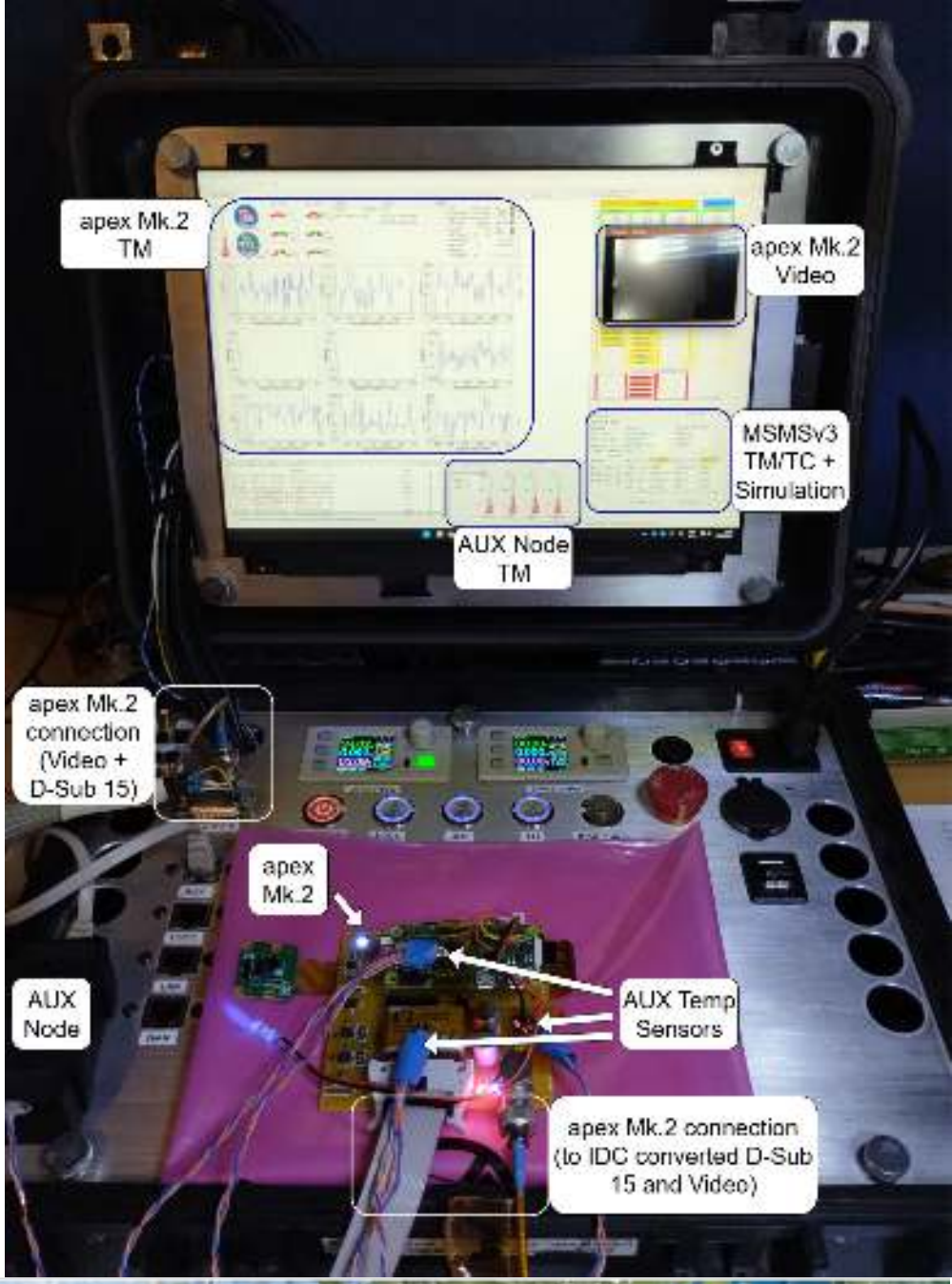
Multi-Role Mission Support System with Multiple Service Module Simulator v3

- Simulator
  - Support for payloads of
    - MAPHEUS (Phase. B,C,D)
      - TM/TC, Power, Signals, Video, Ethernet
    - REXUS
      - TM/TC, Power, Signals, Video
    - Astrobotic Peregrine
      - TM/TC, Power, Time Synchronization
    - …
  - SSC Countdown Clock Simulator
  - Integration in Yamcs and Standard Lab Software (*)
  - Fully automated test sequences and campaigns (*)
- Mobile Control Center
  - MCS + Video (+ VoCS)
  - HW Firewall, Router, Switch
  - GNSS NTP Clock with 1 PPS source for payloads

apex MRMSS with MSMSv3

Multi-Role Mission Support System with Multiple Service Module Simulator v3

- Mobile Ground Station
  - 1 Channel SDR
    - Weatherballon data downlink + decode
  - 2 to 4 Channel Full Duplex SDR (*)
    - Tracking Groundstation
    - LoRaWAN / IoT payload with specific vendor envisioned
- Base for new technologies
  - Integration of secure element
    - Transparent encryption and signing of TM/TC
  - AI + Video accelerators available for integration



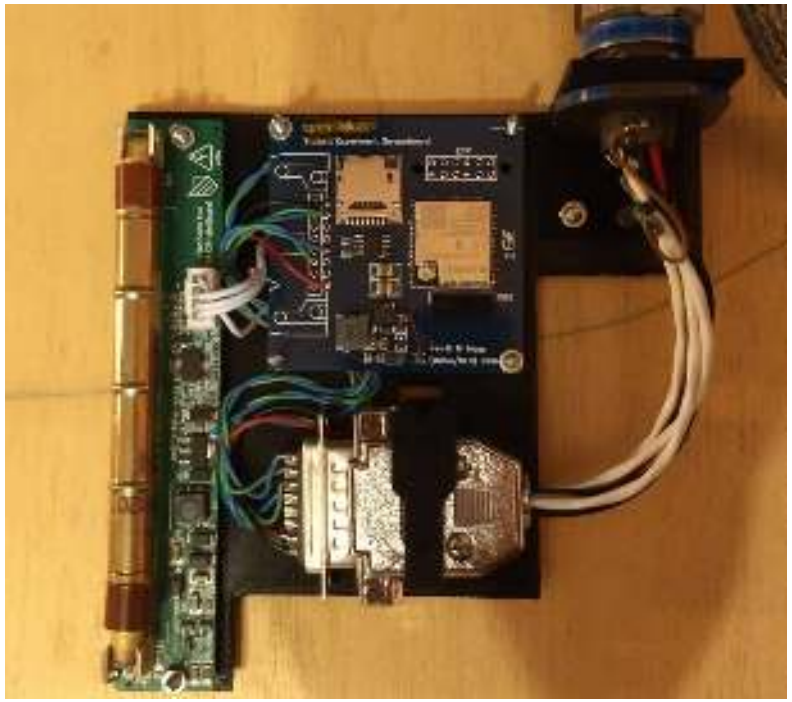
framework

(Motherboard sponsored as part of the framework Creators program)

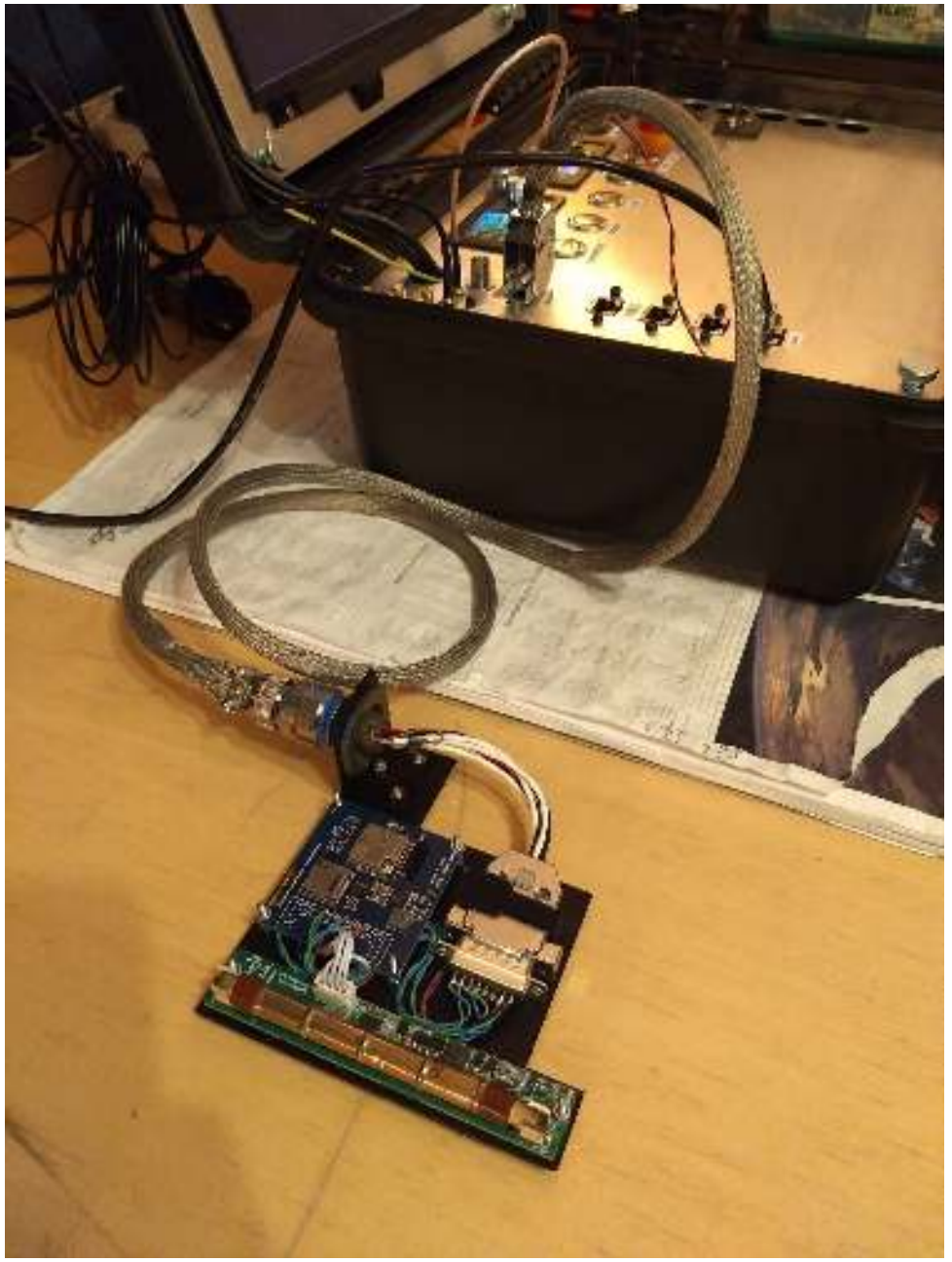
apex Mk.III P

Peregrine Interface Validation Payload

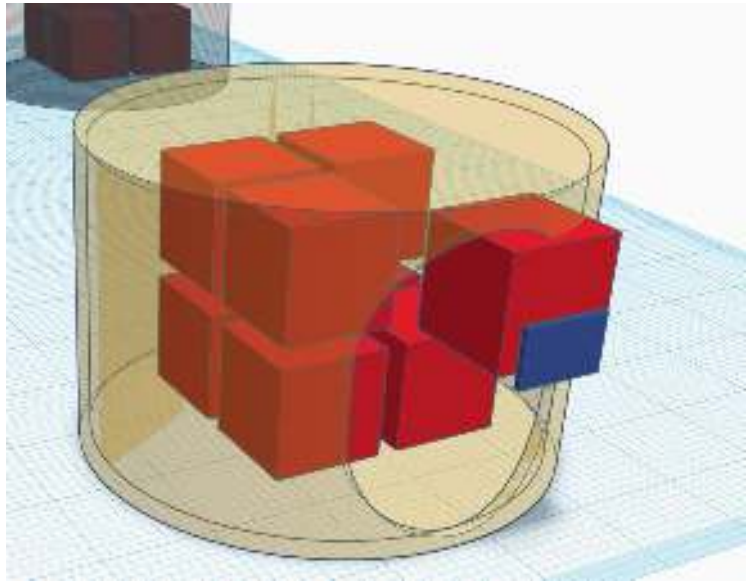
- Rapid prototyped using Mk.III board
- Supporting M-42 operations on ground



(Peregrine connectors and wires sponsored by ME-SBA)



Ideas for the future (Post apex Mk.II/Mk.III)



- Two new iterations envisioned
  - Payload Carrier / Class 1 Payload to integrate up to 8 smaller generic experiment containers within one MAPHEUS container
    - apex Mk.III Student Experiment Sensorboard within the containers
    - Ideal for Student projects / test of new sensors /external partners
    - MUSC as control center allowing external parties to control their own experiments via Web / Yamcs
  - Advancement of apex Mk.II SCP
    - Higher resolution camera (e.g. spectography) and quad head version (already tested)
    - Use with AI accelerators on Board (AI applications)
    - Integration of secure elements and CCSDS SDLS
- Publications
  - apex Mk.2/Mk.3: Secure live transmission of the first flight of Trichoplax adhaerens in space based on components of the shelf: https://doi.org/10.3390/eng6090241
  - apex MCC: A blueprint of an open source, secure, CCSDS compatible ground segment for sounding rocket, cubesat and small lander missions: https://doi.org/10.3390/eng6090246
  - apex MRMSS: A multi-role mission support system and service module simulator for payloads of sounding rockets and other space applications: https://www.mdpi.com/2673-4117/6/9/247
- Preparation for conference talks apex / COTS Components in Space

Conclusion

- apex has grown from single experiment to a complete ecosystem
  - Secure CCSDS compatible Ground Segment based on Open Source Technology
  - Dedicated Testing, Simulation & Checkout Equipment
  - Use of cost-effective COTS components
  - Iterative Design & Rapid Prototyping
  - Open Source components
- Many thanks to ME, MP, RB-MRB
- Financing?


Thank you for your attention!