LEIDEN, NETHERLANDS - DECEMBER 2015

THE FUTURE OF ISS UTILIZATION: AN INDUSTRY PERSPECTIVE

NANORACKS

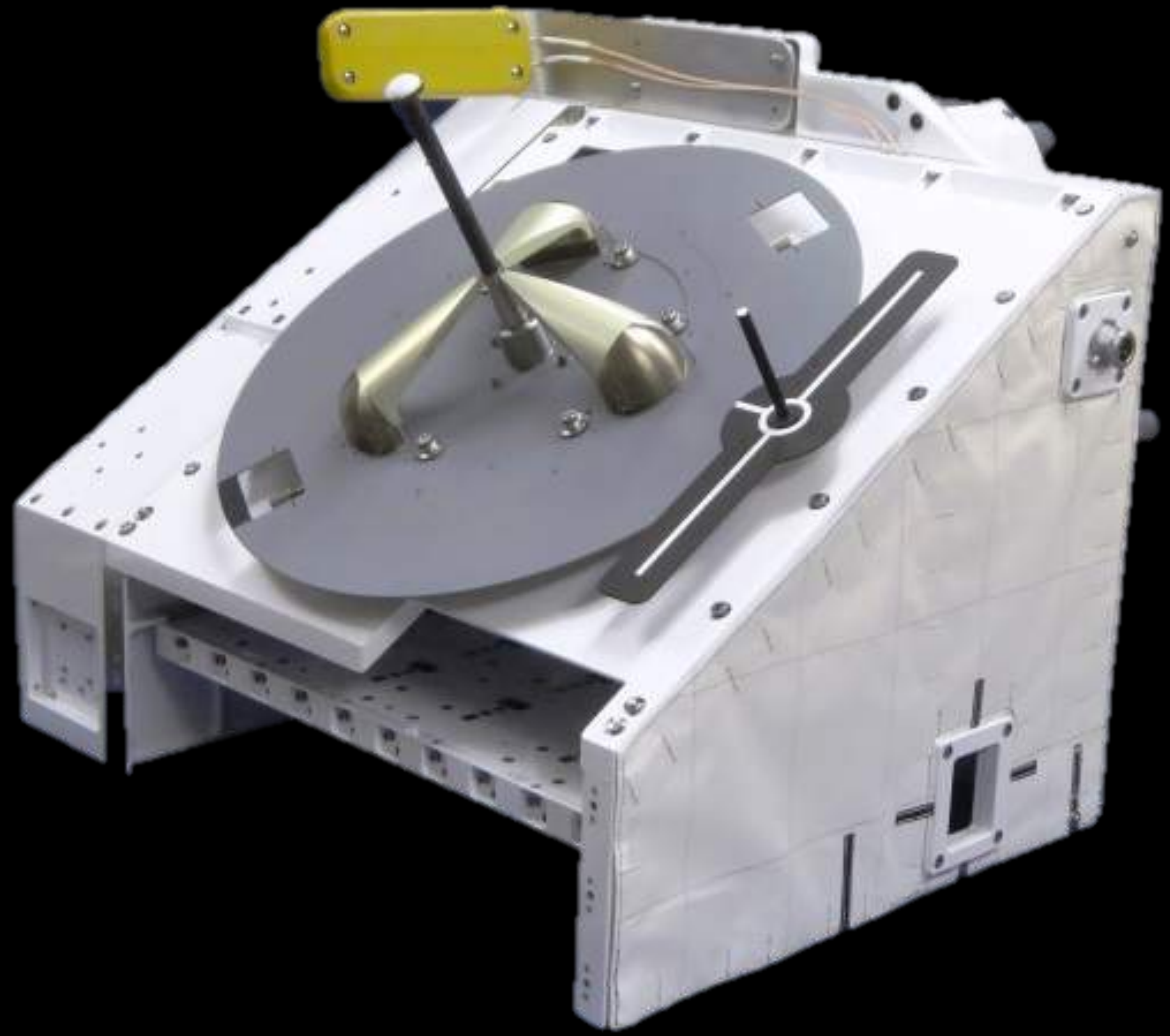
BLUE ORIGIN

AIRBUS DEFENCE & SPACE

#FUTUREISS

NANORACKS EXTERNAL PAYLOAD PLATFORM

NANORACKS & AIRBUS PARTNERSHIP



#FUTUREISS

NanoRacks External Payload Platform

Manufactured by Airbus DS

New Mission Opportunities for Small Size Hosted Payloads

Why Outside ISS?

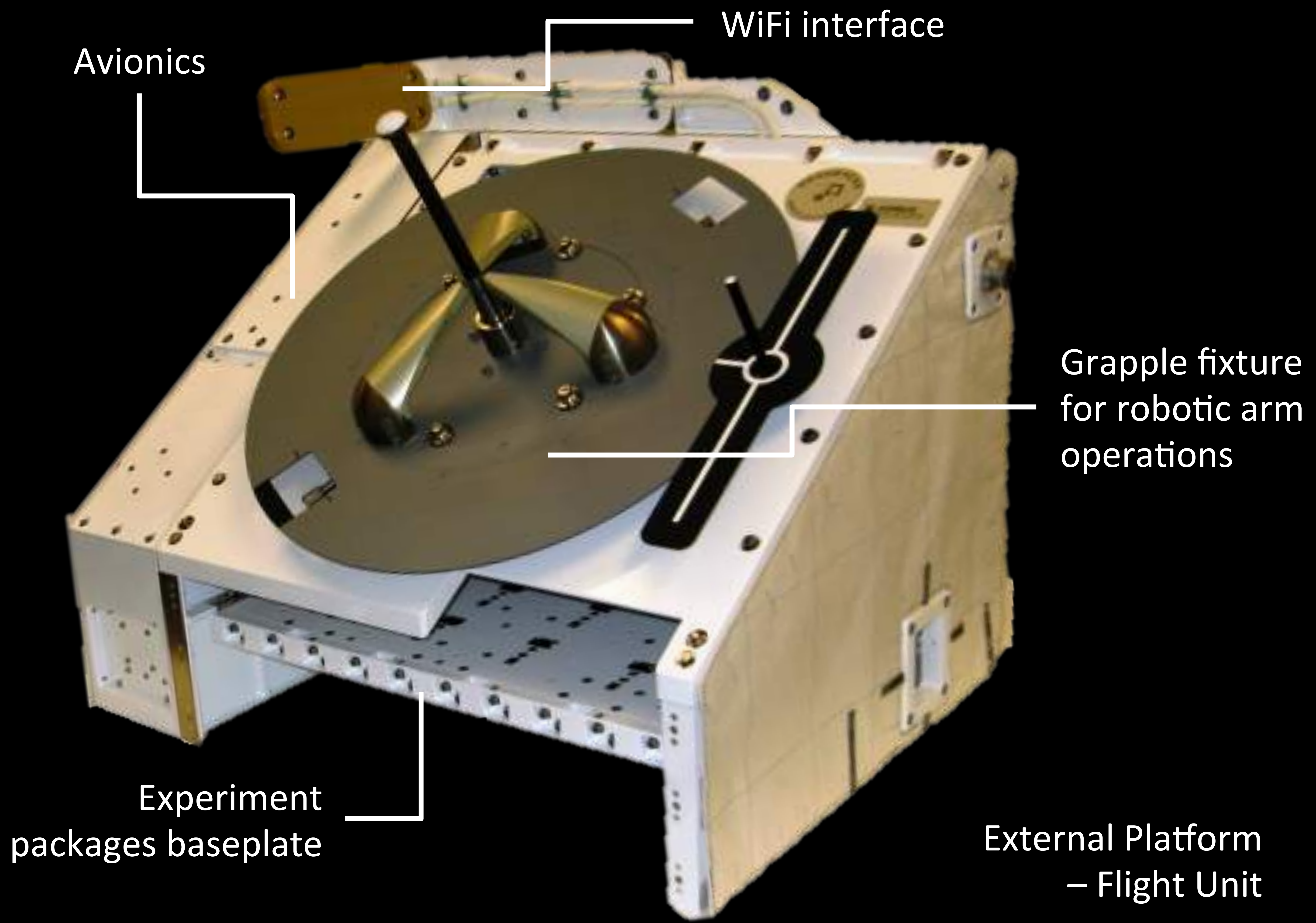
- Earth Remote Sensing
- Space Research
- Astrophysics
- Technology Demonstration
- On-Orbit Assembly
- Commercial Utilization
- Sample Return
- **Space Environment Exposure**

External Payload Platform on JEF-Exposed Facility

NREP System Design

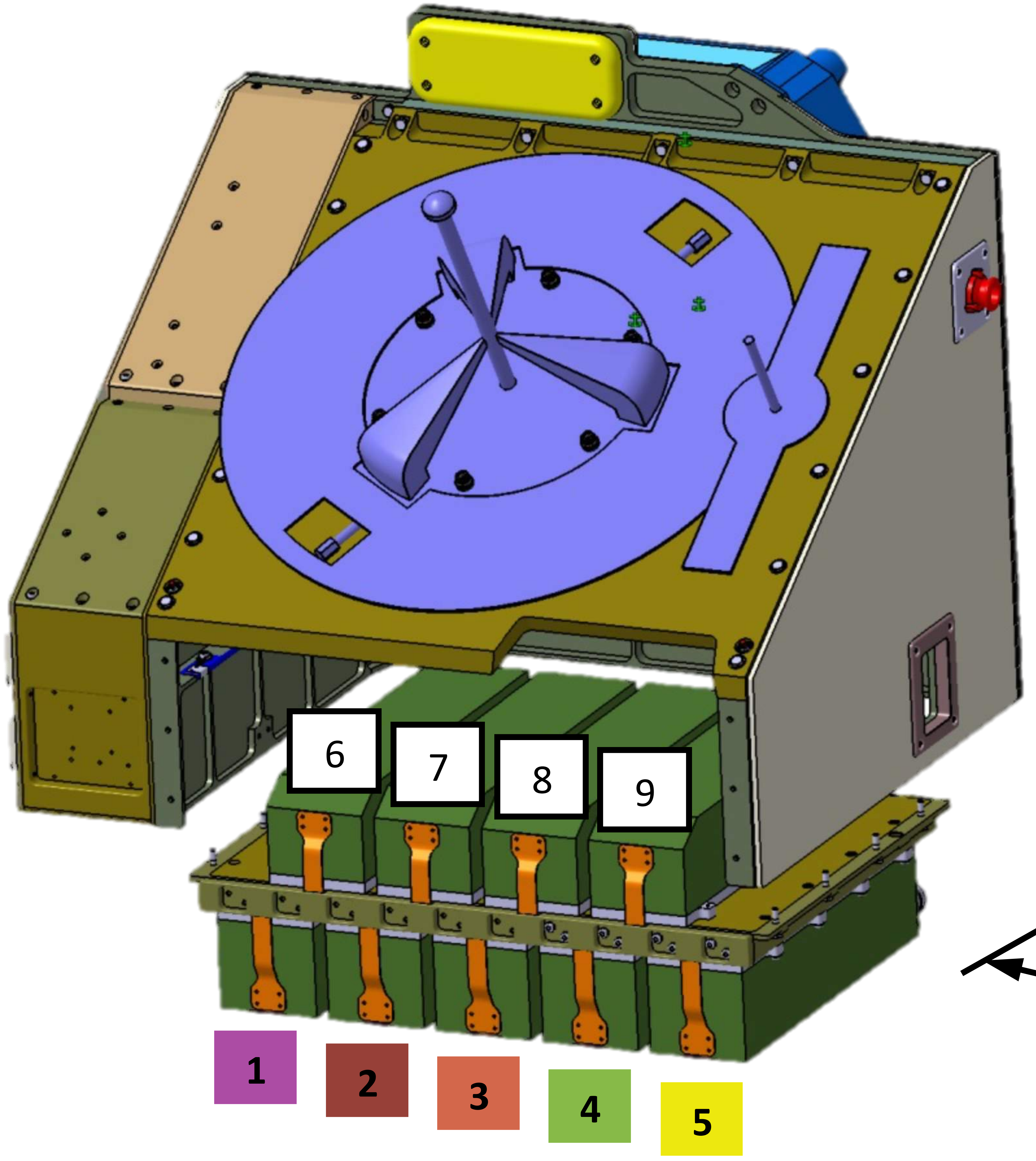
Standard payload provisions	
Voltage	28 VDC +/- 2 V or 120 VDC as option
Total power	30 W at 28 Vdc
Maximum current	2A
USB 2.0 bus	5 VDC/ 500mA non-switchable
Total payload data rate	Up to 8 Mbit/s

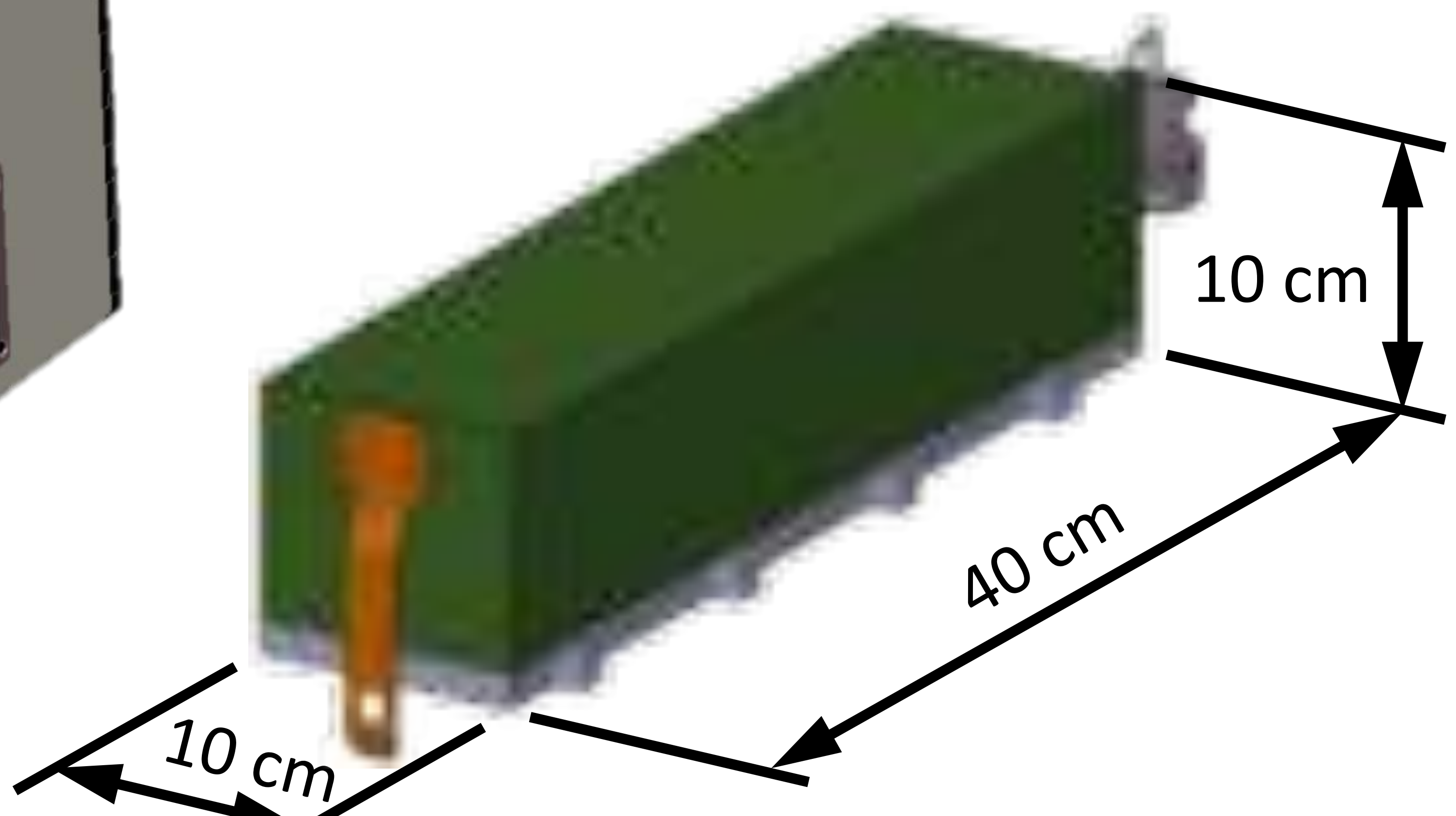
- EP provides all functions of the conventional spacecraft bus
- Ideal platform for small size hosted payloads
- No further subsystems necessary
- Improved anomaly resolution by human in the loop



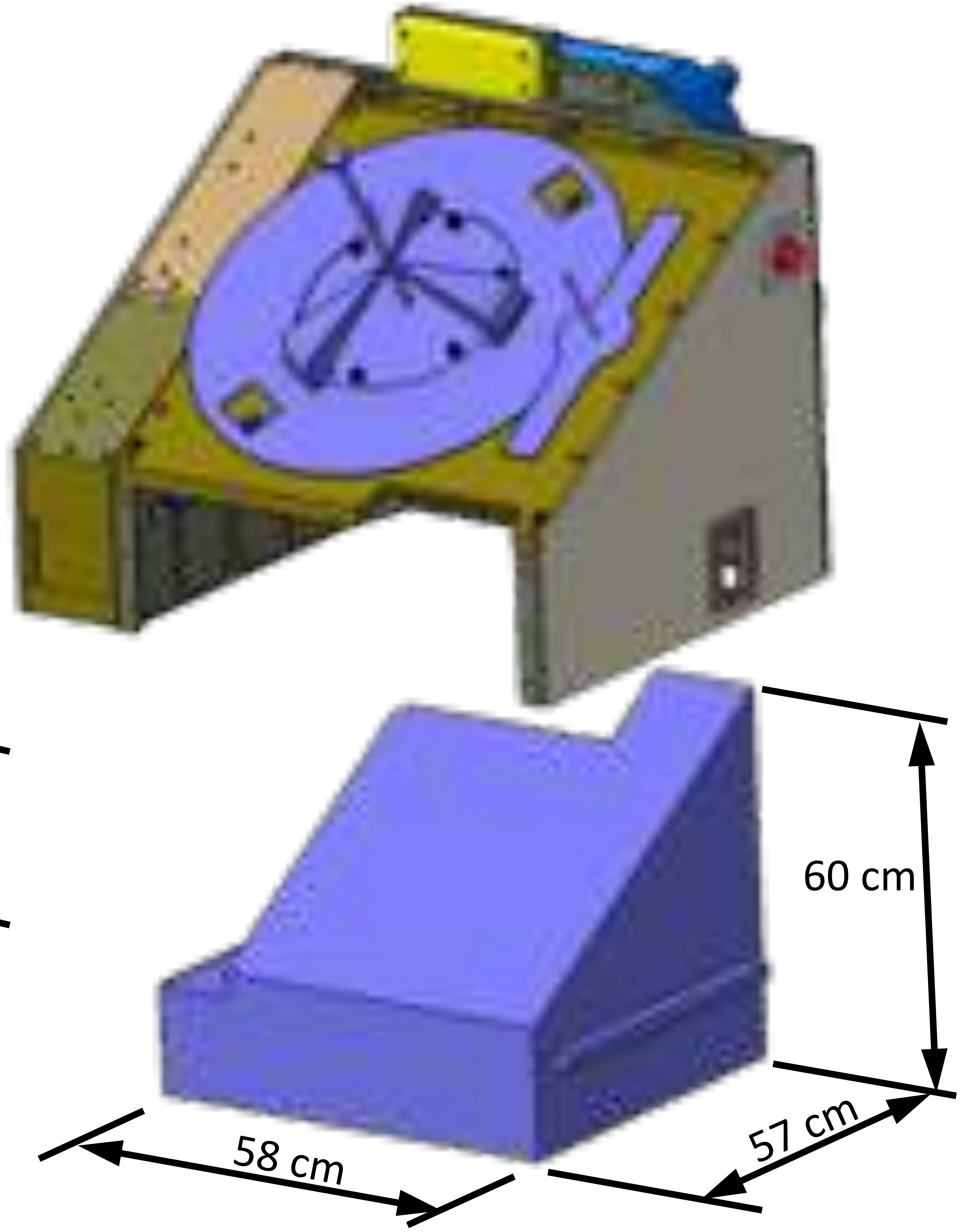
External Platform – Flight Unit

NREP Configurations





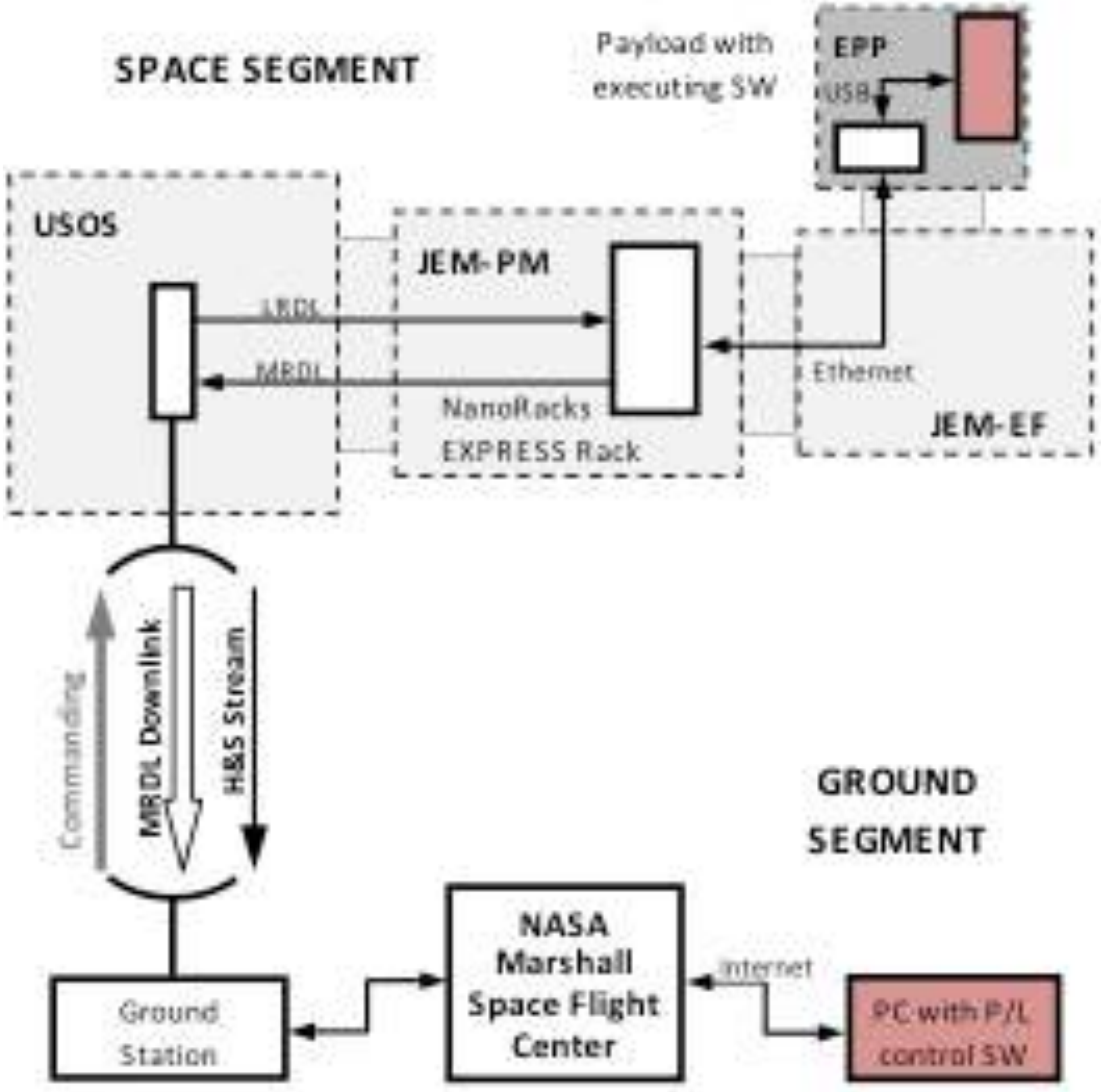
EPP-P standard 4U size payload package



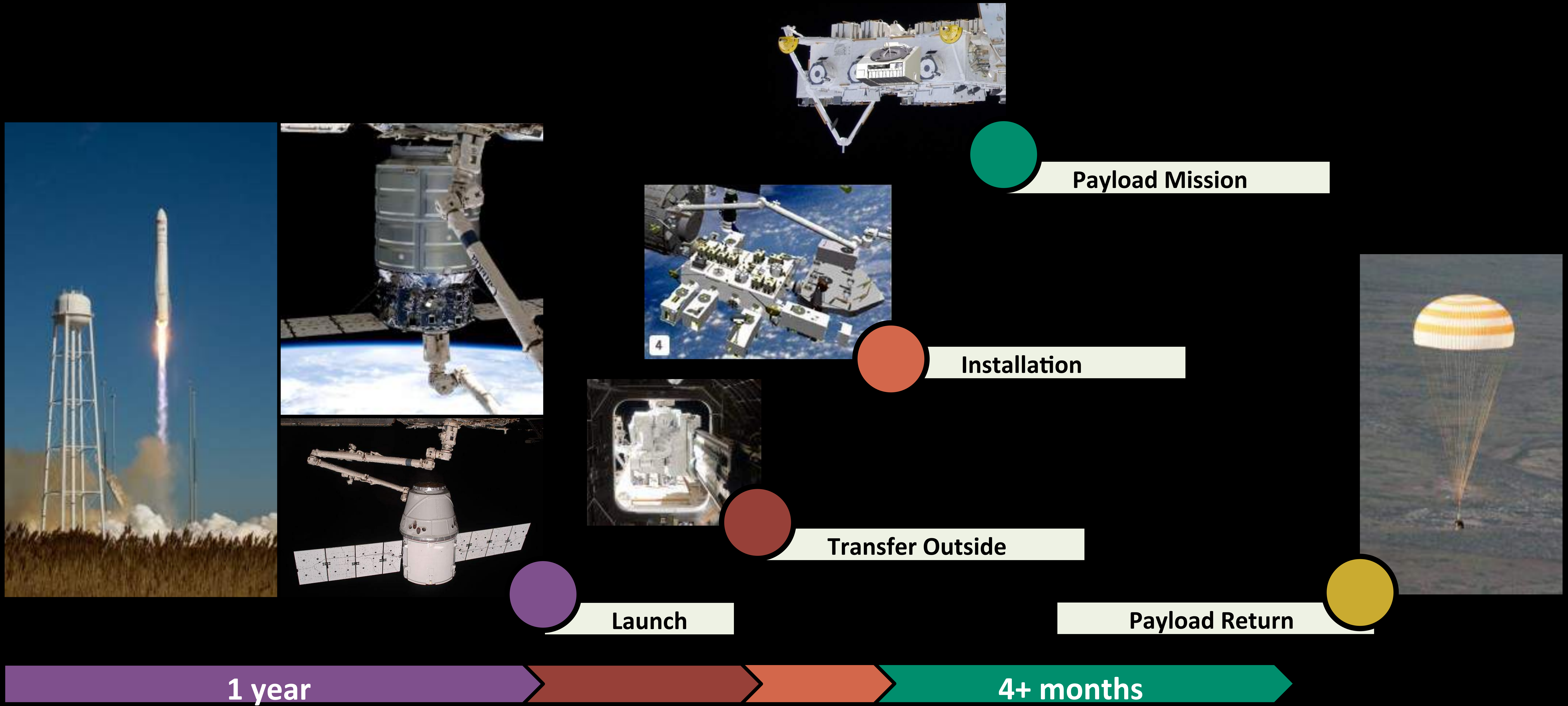
Unique payload configuration

NREP Communications

- End-to-end communication with your payload covered by the EP Service
  - Console on your own desk
  - Near-real time data link available
- On-board data management by EP-DHS
  - Data storage in NanoRacks' EXPRESS rack in JEM-PM
  - Handling of downlink data by ISS data management system
- Complete ground segment provided by ISS
  - Communication front end MSFC



End-to-End Services



NREP OVERVIEW VIDEO

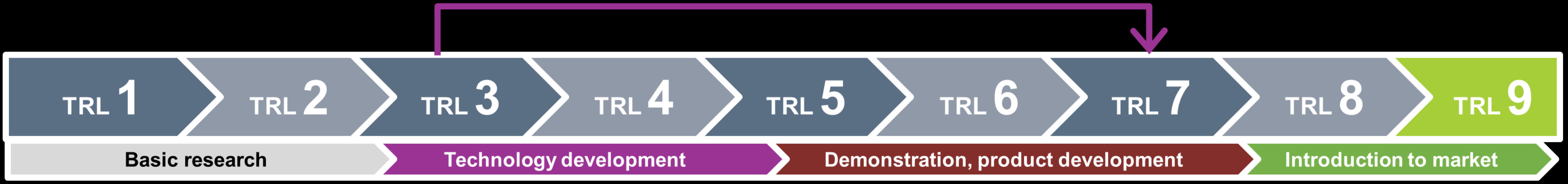
Generic Payload Integration Schedule

Time to launch	Customer	Service Provider
L-14 to L-8 months	Contract and ICA core baseline signature, appendix development • Payload functional description • Interface drawings • Material identification and usage list • Budget report	Initiation of ISS safety process
L-9 months	Payload thermal model	• Upload manifesting • Integrated thermal analysis until L-7
L-6 months	Description of flight operations	Review of flight operations with ISS program
L-4 months	Payload handover to service provider	Environmental and functional tests until L-1
L-1 months		Certification for flight and handover to launcher
L		Launch
L+2 months	Flight Operations for 15 weeks	Payload installation on NREP
L+12 months		Payload return to customer

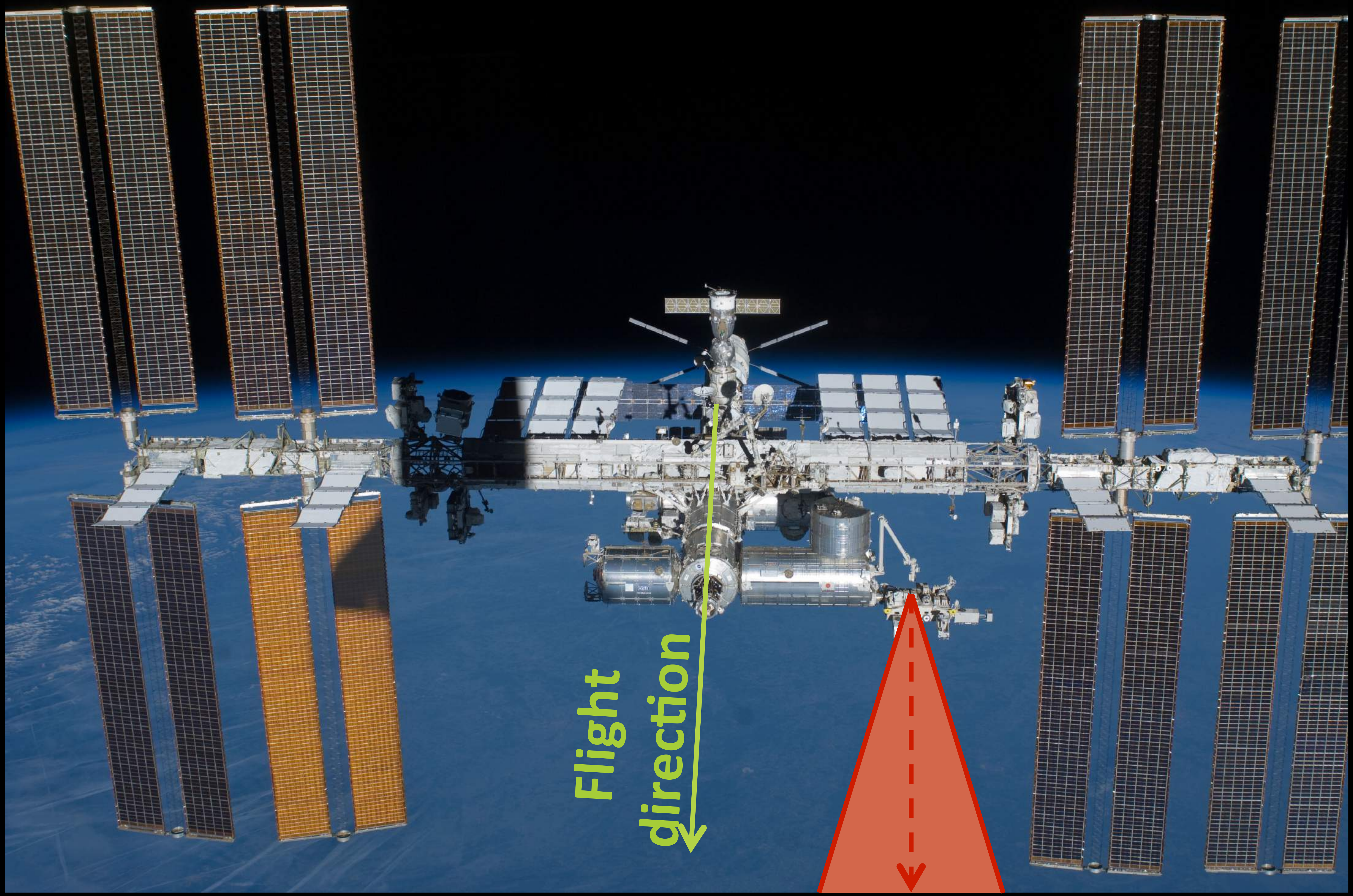
NREP-Based In-Orbit Testing & Demonstration

Technology Demonstration	
TRL 1	Basic principle
TRL 2	Technology concept
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment
TRL 6	Technology demonstrated in relevant environment
TRL 7	System prototype demo in operational environment
TRL 8	System complete and qualified
TRL 9	System in operational environment

- Accelerated improvement of available technologies, system concepts and abilities
- Reduction of the time to market of space-related products
- Cost-optimization of mission scenarios
- Fast demonstrations of mission scenarios

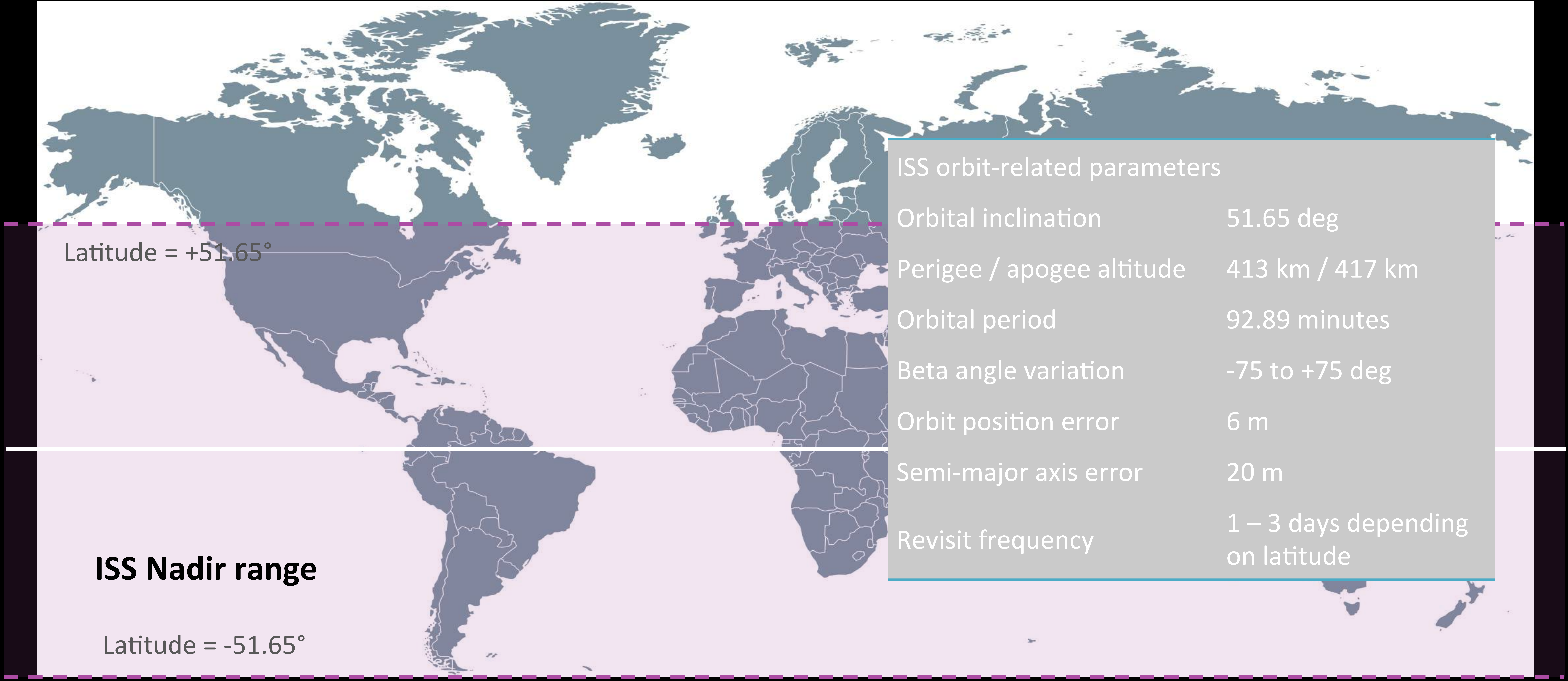


NREP-Based Remote Sensing



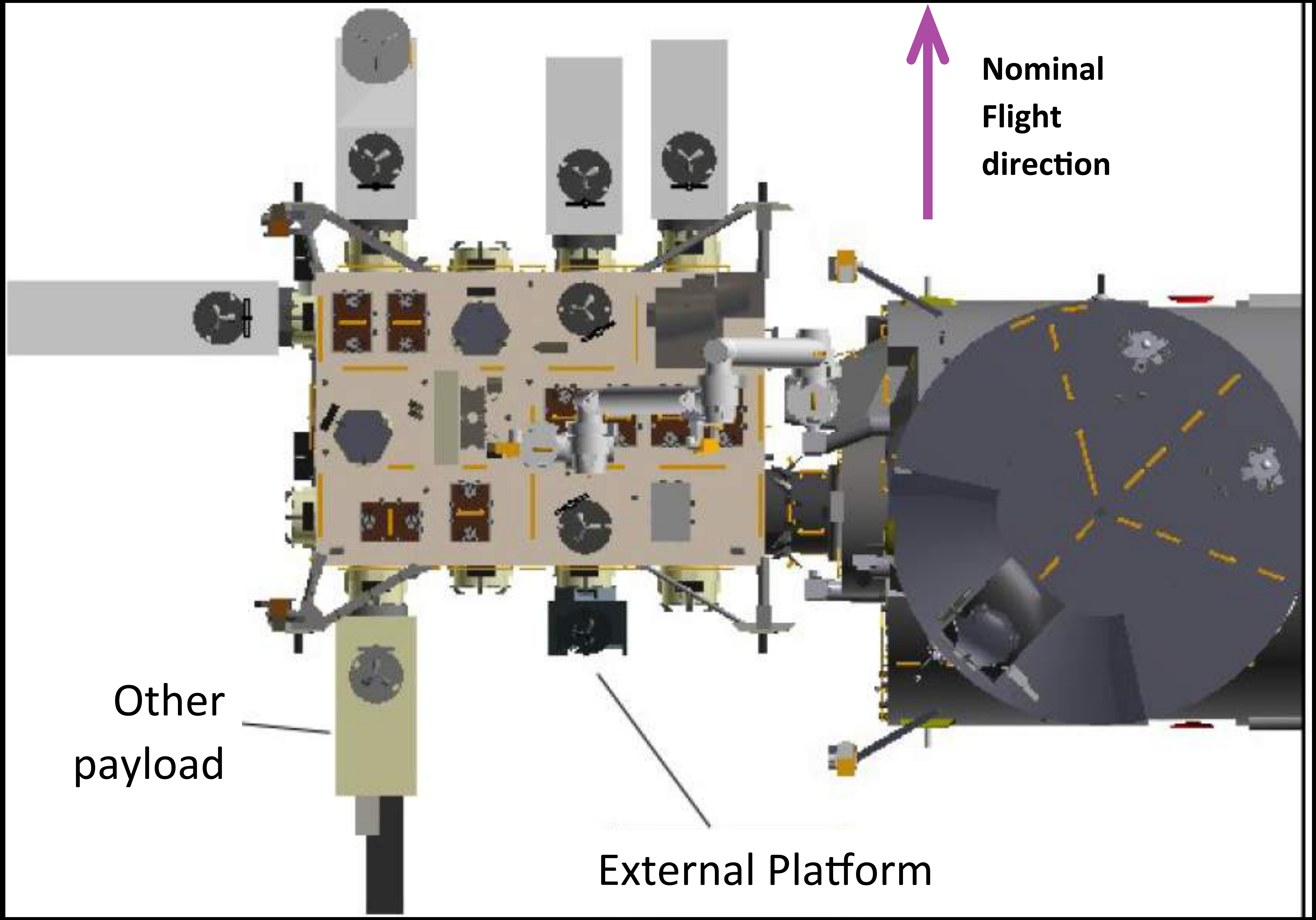
ISS attitude-related parameters	
Nominal attitude	Z Nadir (Only 6 hours per year in other z-orientation)
Operational attitude	Roll, Yaw ±15 deg Pitch +10 to -20 deg
Attitude accuracy	±3.5 deg per axis
Attitude estimation	0.5 deg per axis (3 sigma)
Attitude stability	0.01 deg/s per axis (3 sigma)

NREP-Based Remote Sensing



ISS orbit-related parameters	
Orbital inclination	51.65 deg
Perigee / apogee altitude	413 km / 417 km
Orbital period	92.89 minutes
Beta angle variation	-75 to +75 deg
Orbit position error	6 m
Semi-major axis error	20 m
Revisit frequency	1 – 3 days depending on latitude

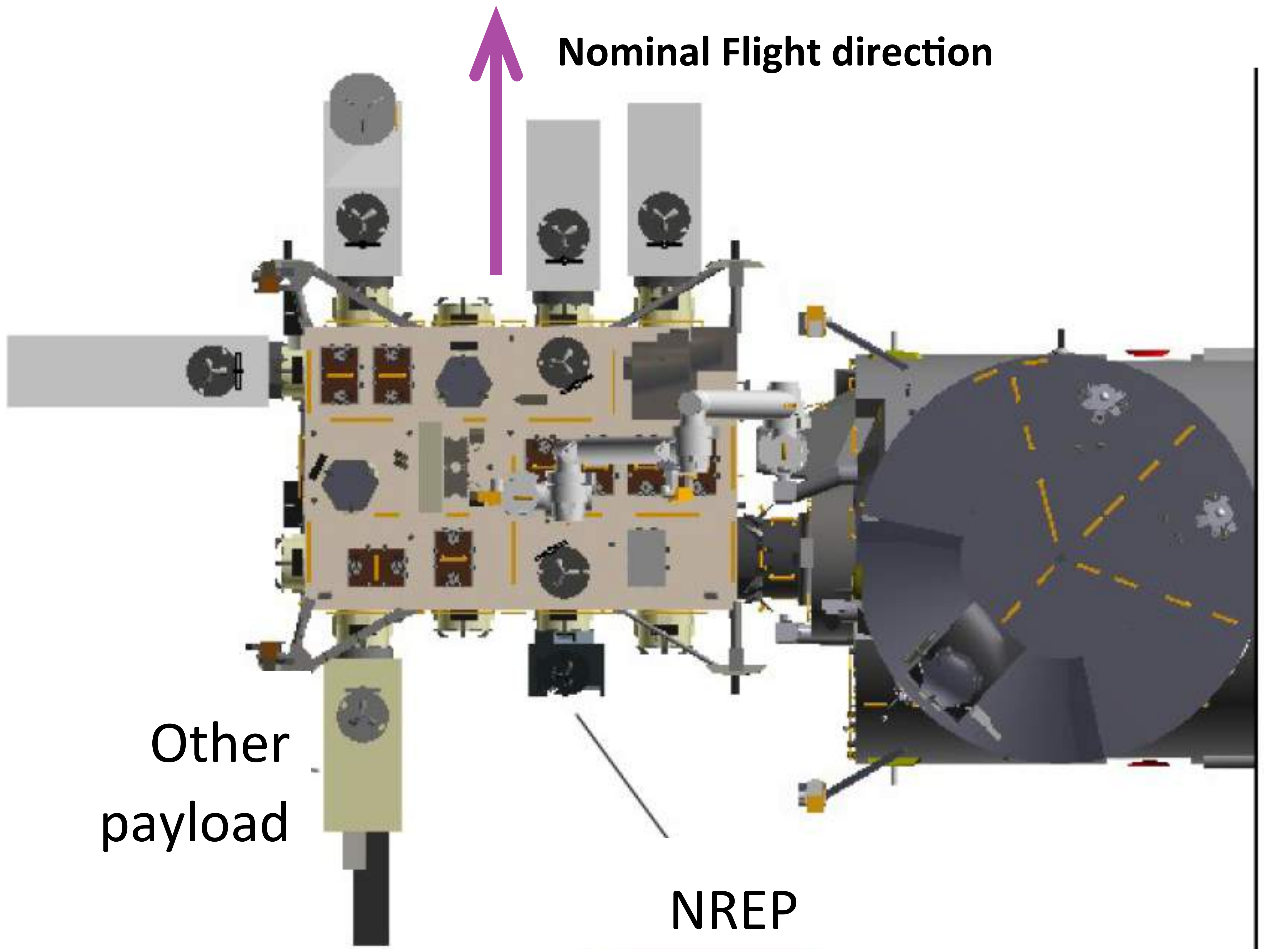
NREP Field of View

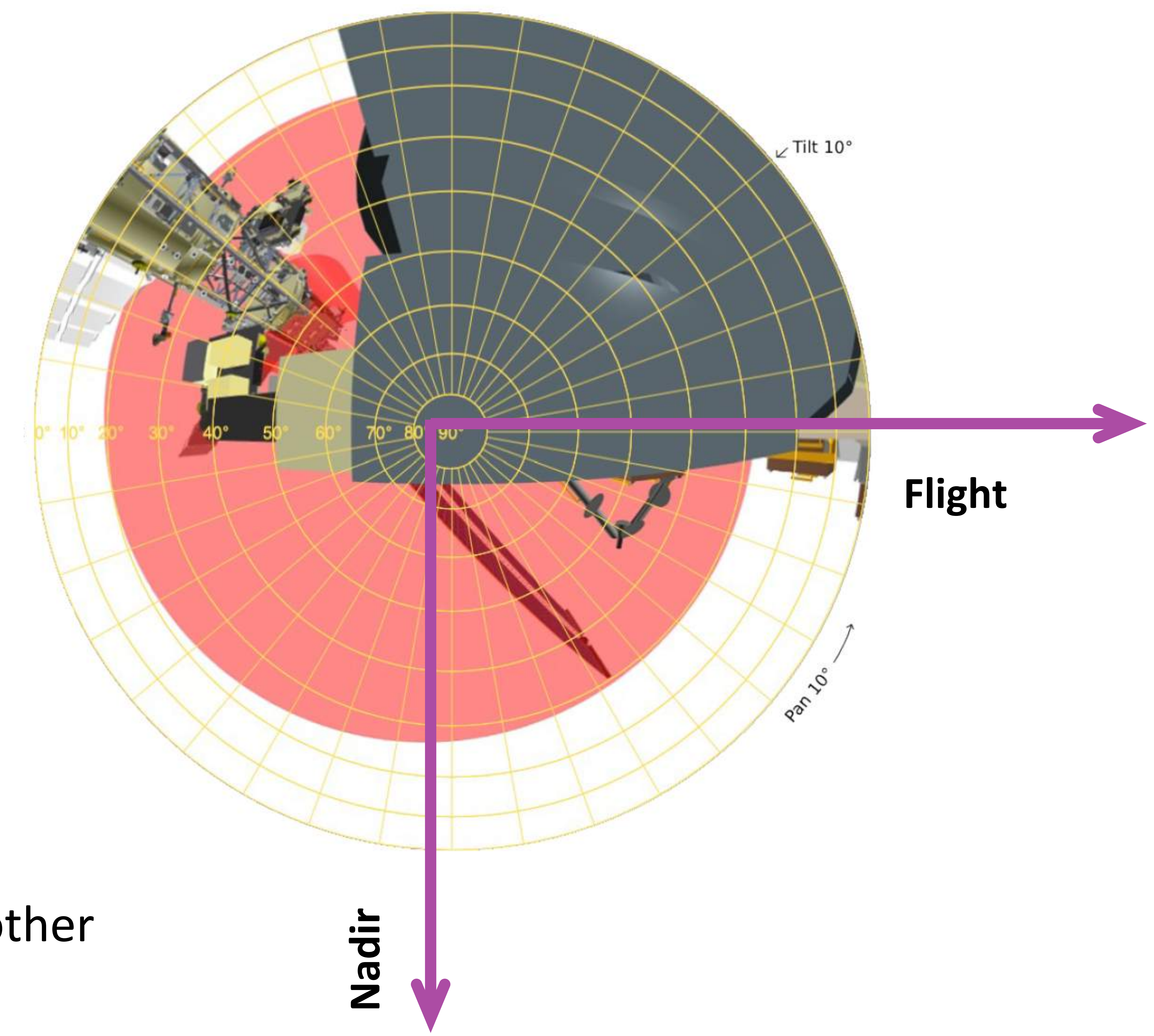


Japanese Exposed Facility (JEM-EF) in currently manifested payload configuration.

[National Aeronautics and Space Administration, JEM EFU Site 4 NanoRacks FOV View, Manipulator Analysis Graphics and Interactive Kinematics (MAGIK) Team, AI 2610, 2012]

NREP Field of View



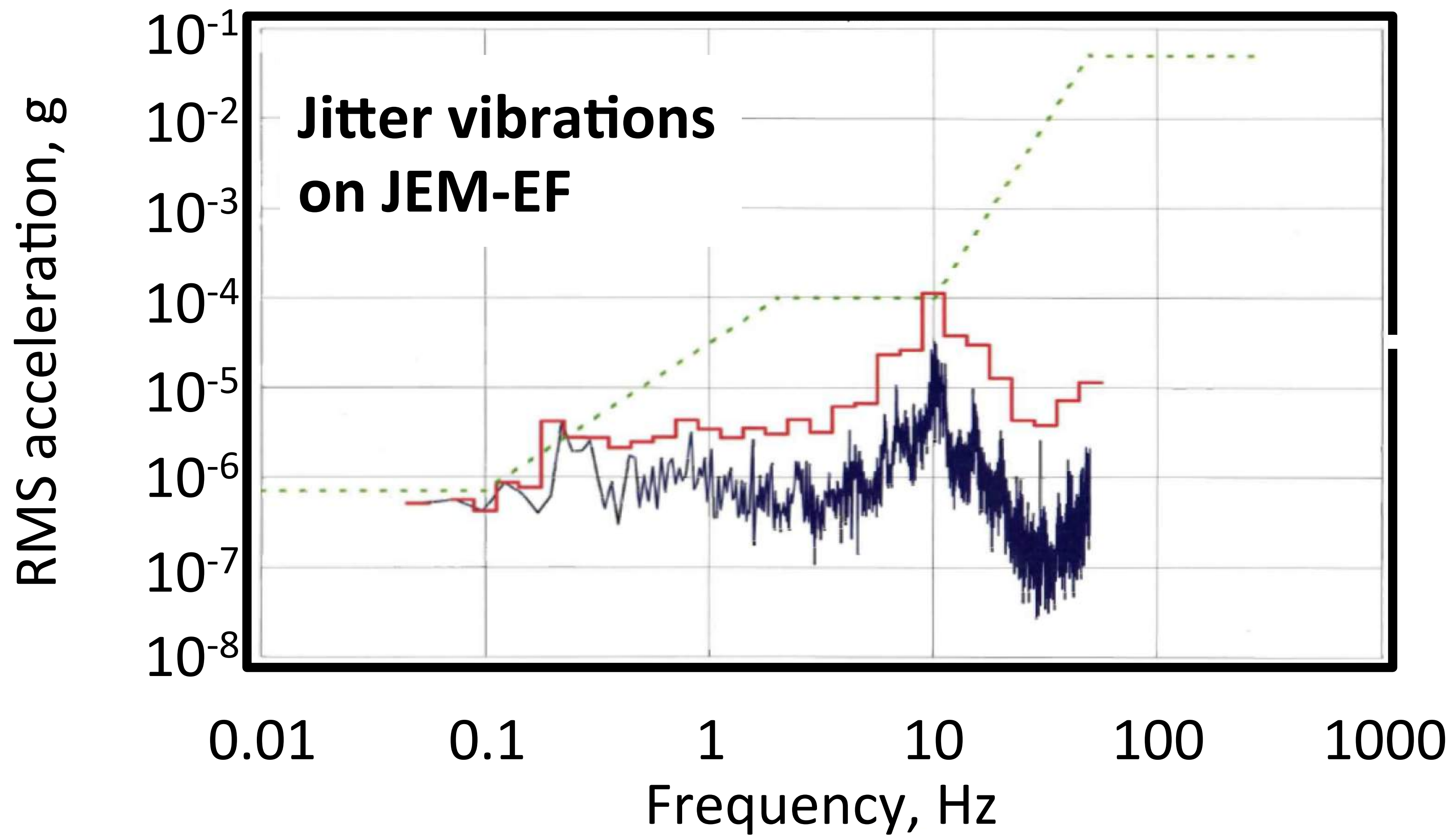


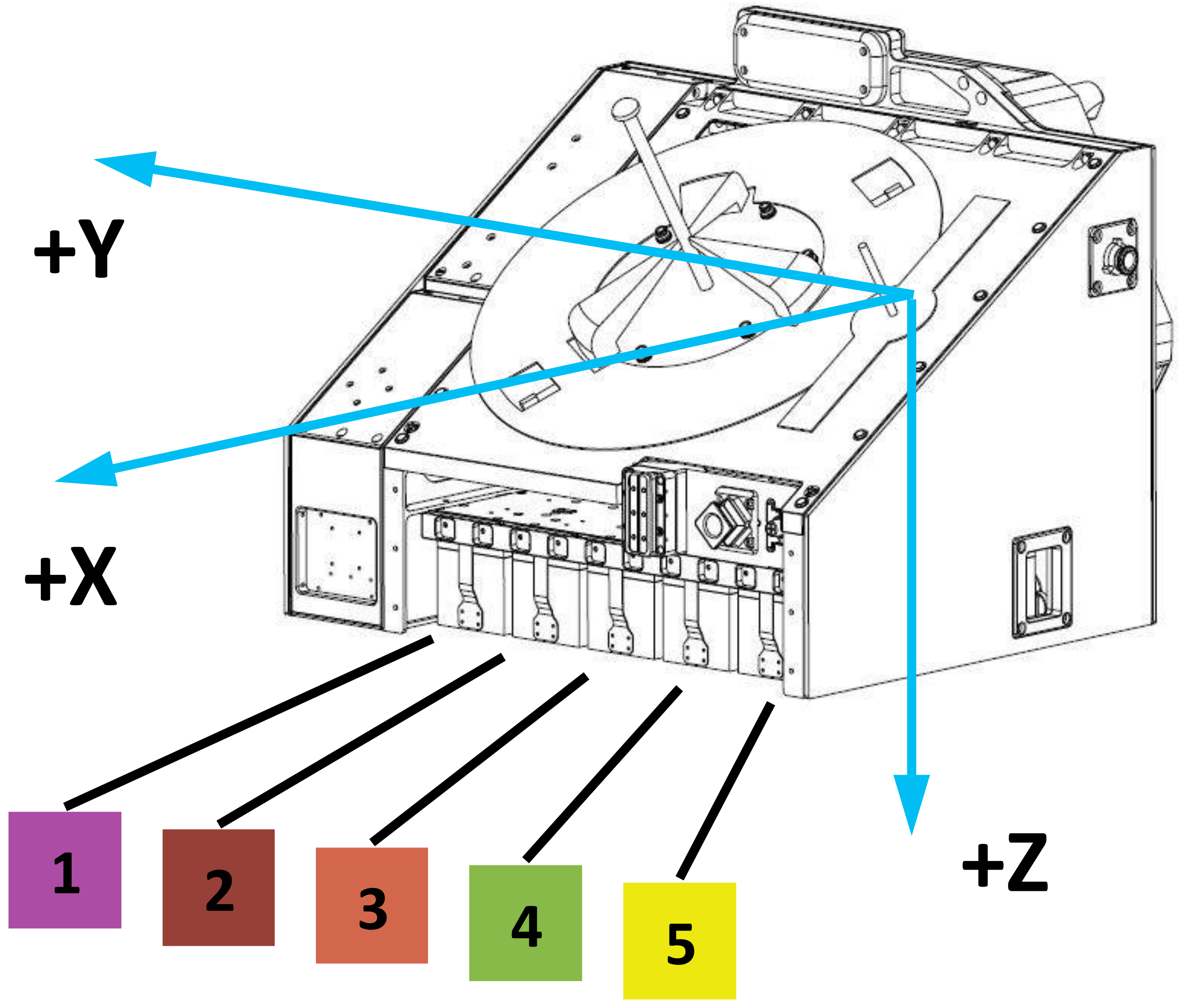
Fisheye Field of View at JEM-EF site 4 towards ISS port side with other payload on JEM-EF Site 8.

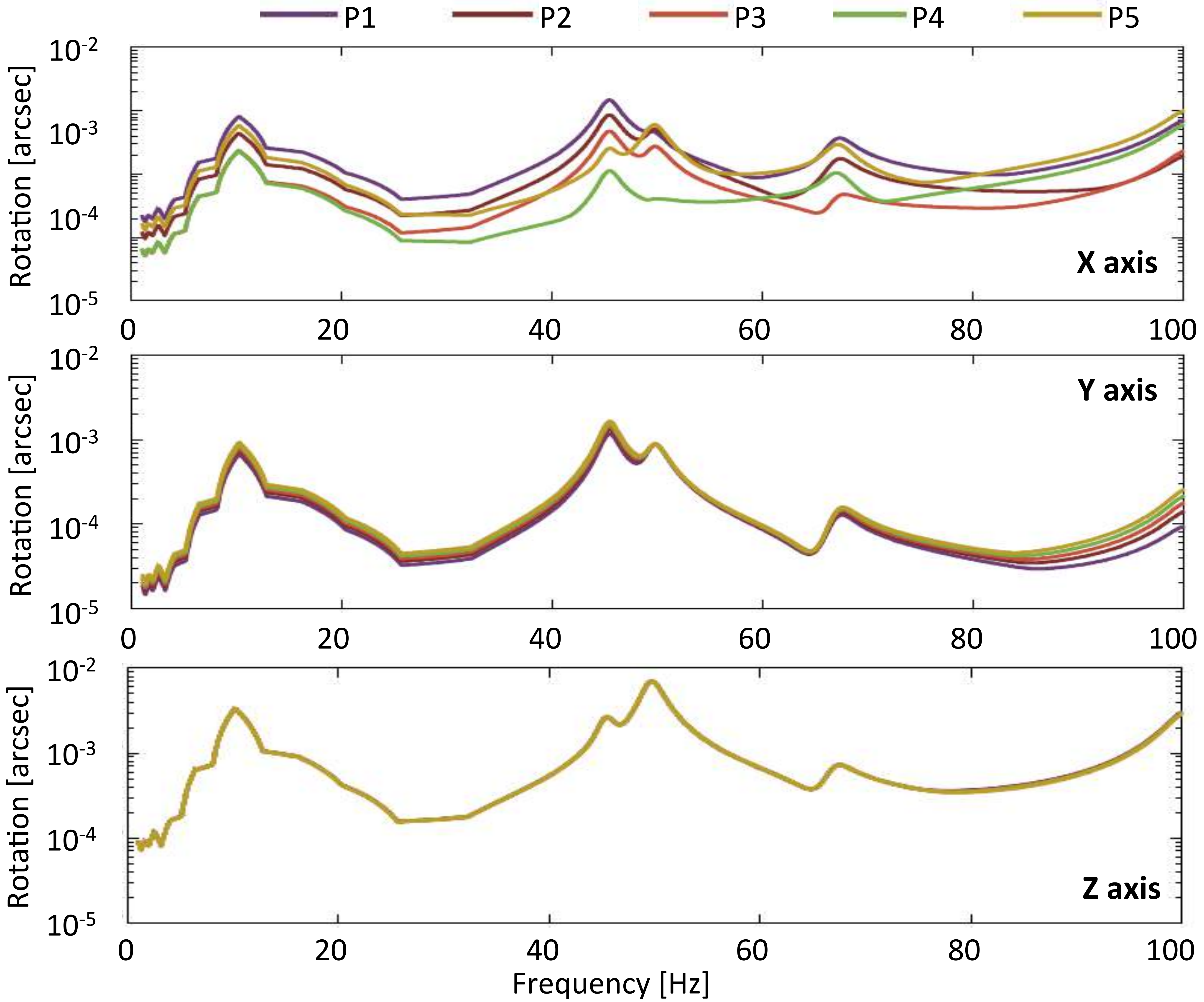
[National Aeronautics and Space Administration, JEM EFU Site 4 NanoRacks FOV View, Manipulator Analysis Graphics and Interactive Kinematics (MAGIK) Team, AI 2610, 2012]

Payload Attitude Stability

Rotational Response







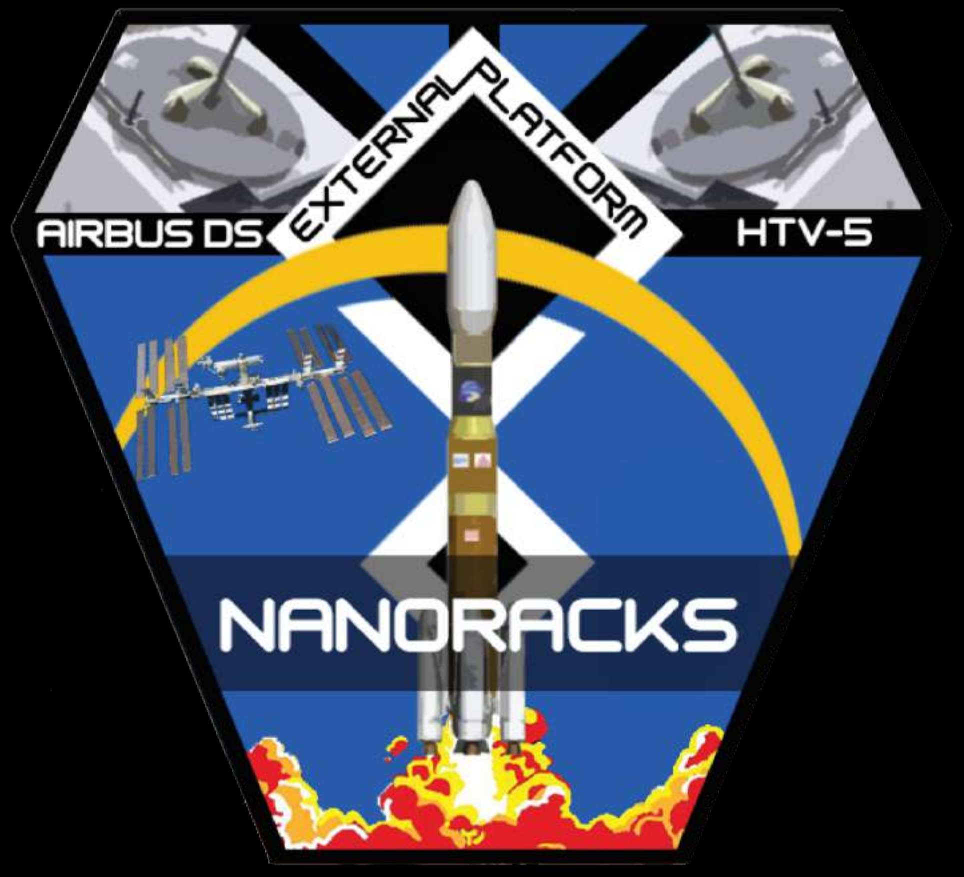
What Our Launching Customers Do…

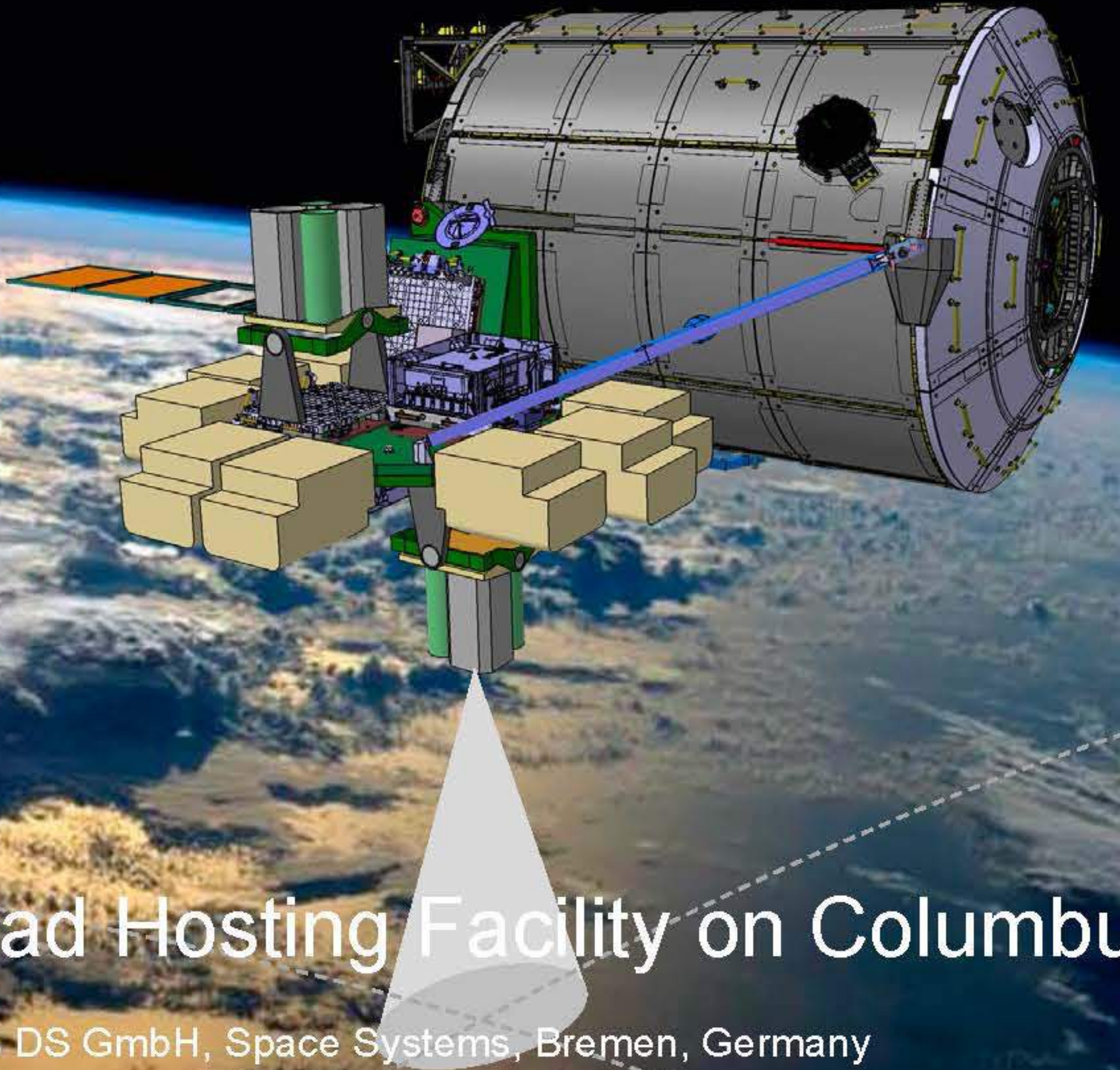
Customer	Payload	Mission scope
Yosemite Space	GumstixTM	▪ Principal investigator Kathleen Morse, Ph.D. ▪ Space-based radiation studies to investigate the feasibility of the Gumstix Computer On Module (COM) technology for use in non-critical computationally intensive space applications
Georgia Tech	Solar Cells CNT	▪ Principal investigator Jud Ready, Ph.D. ▪ Test response of carbon nanotube (CNT) based textured photovoltaic (PV) cells using earth abundant photoabsorber material copper zinc tin sulfide (CZTS)
Florida Institute of Technology	Development and Deployment of Charge Injection Device (CID) Sensors for Space-Based Extreme Contrast Ratio Imaging	▪ Principal investigator Daniel Batcheldor, Ph.D. ▪ Space-based test of an innovative and novel Charge Injection Device (CID) imager technology in the space environment
A-76 Technologies	Characterization of A-76 Corrosion Inhibitors in the Space Environment	▪ Characterize effectiveness of A-76 corrosion inhibitors and lubricants for metals in the space environment
Honeywell and Morehead State University, Space Sciences Center	TRL7 Validation of Dependable Multiprocessor (DM) Technology	▪ Principal investigators John Sampson, Ph.D., Benjamin Malphrus, Ph.D. ▪ Benchmark performance and radiation-induced computational errors of DM Technology while conducting computationally intensive processing in the space environment
Arquimea Ingeniería, S.L.U. (Spain)	REsettable Hold-Down and Release ACTuator (REACT)	▪ EU Horizon 2020 funded project with multiple European project partners (Arquimea Ingeniería, S.L.U., EADS CASA Espacio, Surrey Satellite Technology Ltd., AVS, Universidad del Pais Vasco, ESR Technology Ltd., Spacetech GmbH) ▪ In-orbit test of SMA-based actuators

Conclusion and Outlook

Type of mission	External Platform Opportunity
Remote Sensing	▪ Nadir view with 40 deg swath ▪ Unconstrained view from wake to ram direction ▪ Maximum contaminant deposition $1x10^{-14}$ g $cm^{-2}s^{-1}$
Use of microgravity	Quality up to 10^{-6} g on JEM-EF with single distortion effects
Use of vacuum	Vacuum quality approx. 10^{-5} Pa depending on ISS orbit altitude and solar activity
Meteoroids, space debris monitoring	JEM-EF site no.6 can be made available for ISS ram view
Antenna testing and RF utilization	▪ Frequency coordination with ISS ▪ ITU license necessary
Space Environment Exposure	▪ Radiation flux studies ▪ Solar illumination ▪ UV light incidence ▪ Upper atmospheric research

- NREP has been delivered to ISS
- Four payloads to launch on OA6 Mar 3, 2016
- NREP IOC 2QTR2016





Bartolomeo - Multi-purpose Payload Hosting Facility on Columbus

Dr. Christian Steimle, Uwe Pape, Airbus DS GmbH, Space Systems, Bremen, Germany
Ronald Dunklee, Airbus DS Space Systems Inc., Houston, Texas
Bill Corley, Teledyne Brown Engineering, Huntsville, Alabama

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

AIRBUS DEFENCE & SPACE

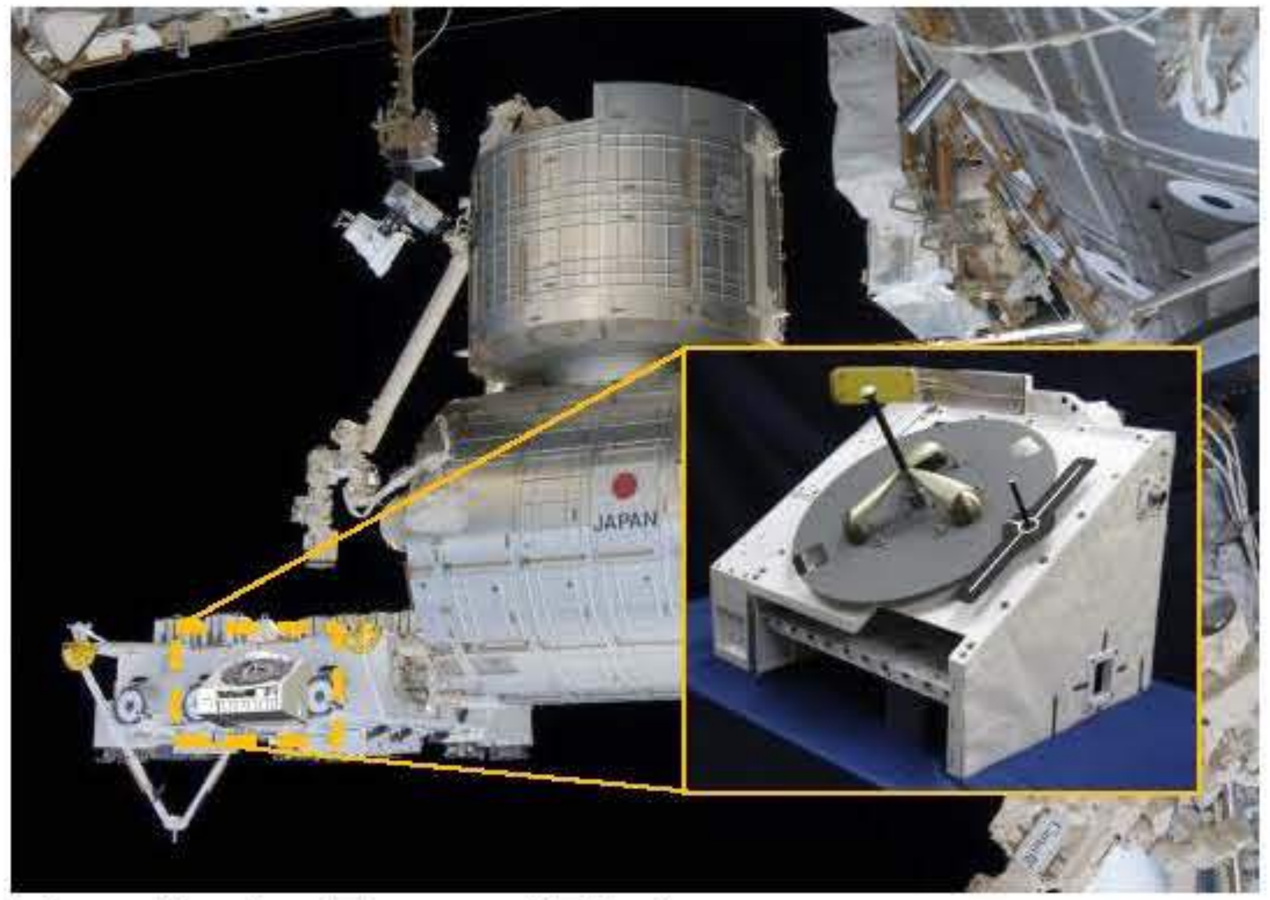
Airbus DS and Teledyne Brown Engineering – Bringing together experience from two worlds


Airbus DS Integrated Cargo Carrier


European Columbus Module


European Automated Transfer Vehicle


Airbus DS External Stowage Pallets



NanoRacks External Platform

Teledyne Brown MUSES Platform

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

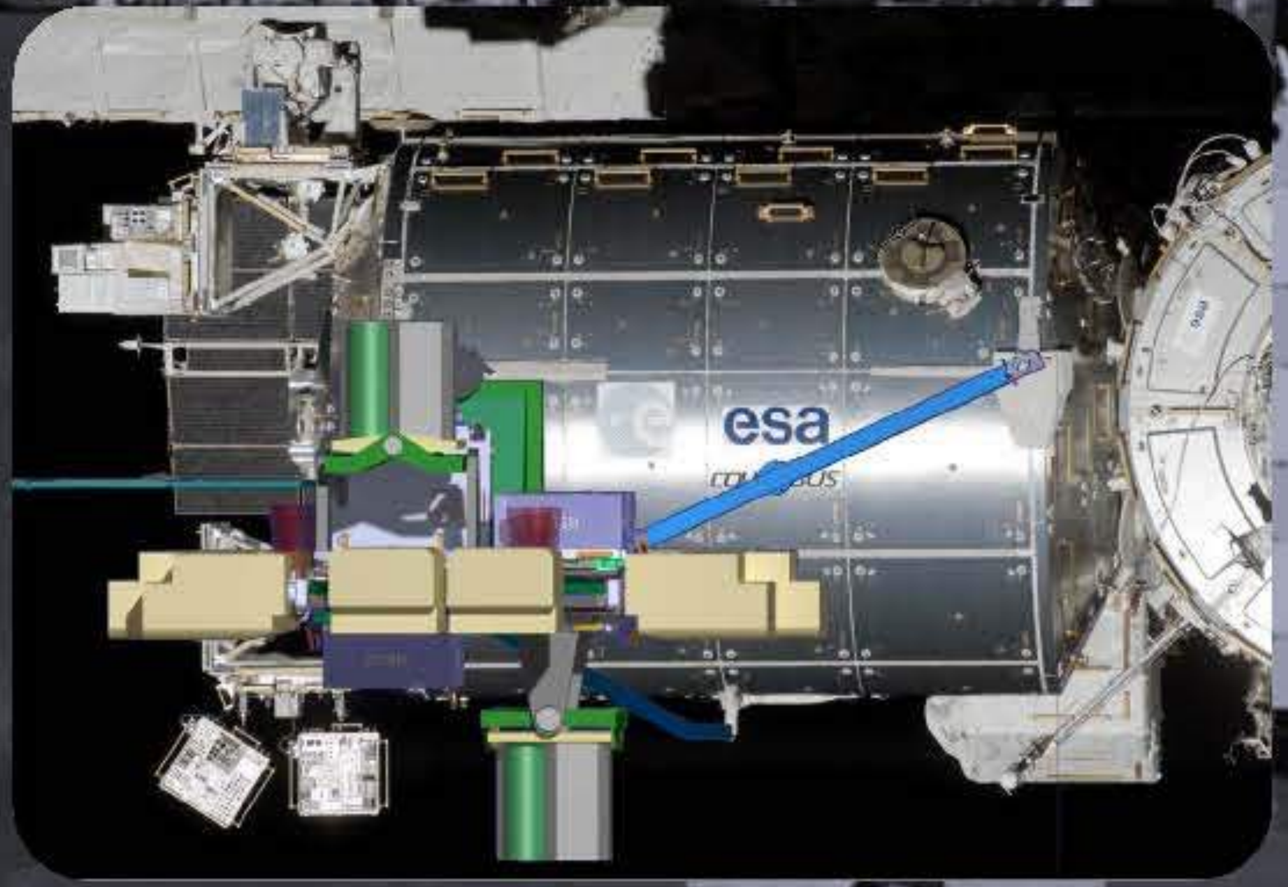
AIRBUS DEFENCE & SPACE

Bartolomeo Use Cases

Earth Remote Sensing
- Unconstrained Nadir view from the platform
- Stabilization and pointing with the Teledyne Brown MUSES facility
- Near-real time data capability of ISS

Commercial Utilization
- Access to LEO with high technical and schedule reliability
- Short mission lead times of 12 to 18 months
- Turnkey mission prices
- End-to-end service concept

Astrophysics Heliophysics
- Unconstrained Zenith view from the platform
- Stabilization and pointing with the Teledyne Brown MUSES facility
- Near-real time data capability of ISS



On-orbit Assembly
- Testing of concepts for on-orbit assembly
- Use of ISS robotic systems

Space Research
- Exposure of payload to space environment
- Capability to return payload back to Earth

Technology Demonstration
- ISS as laboratory in space
- Access to ISS with low TRL
- Capability to return payload back to Earth

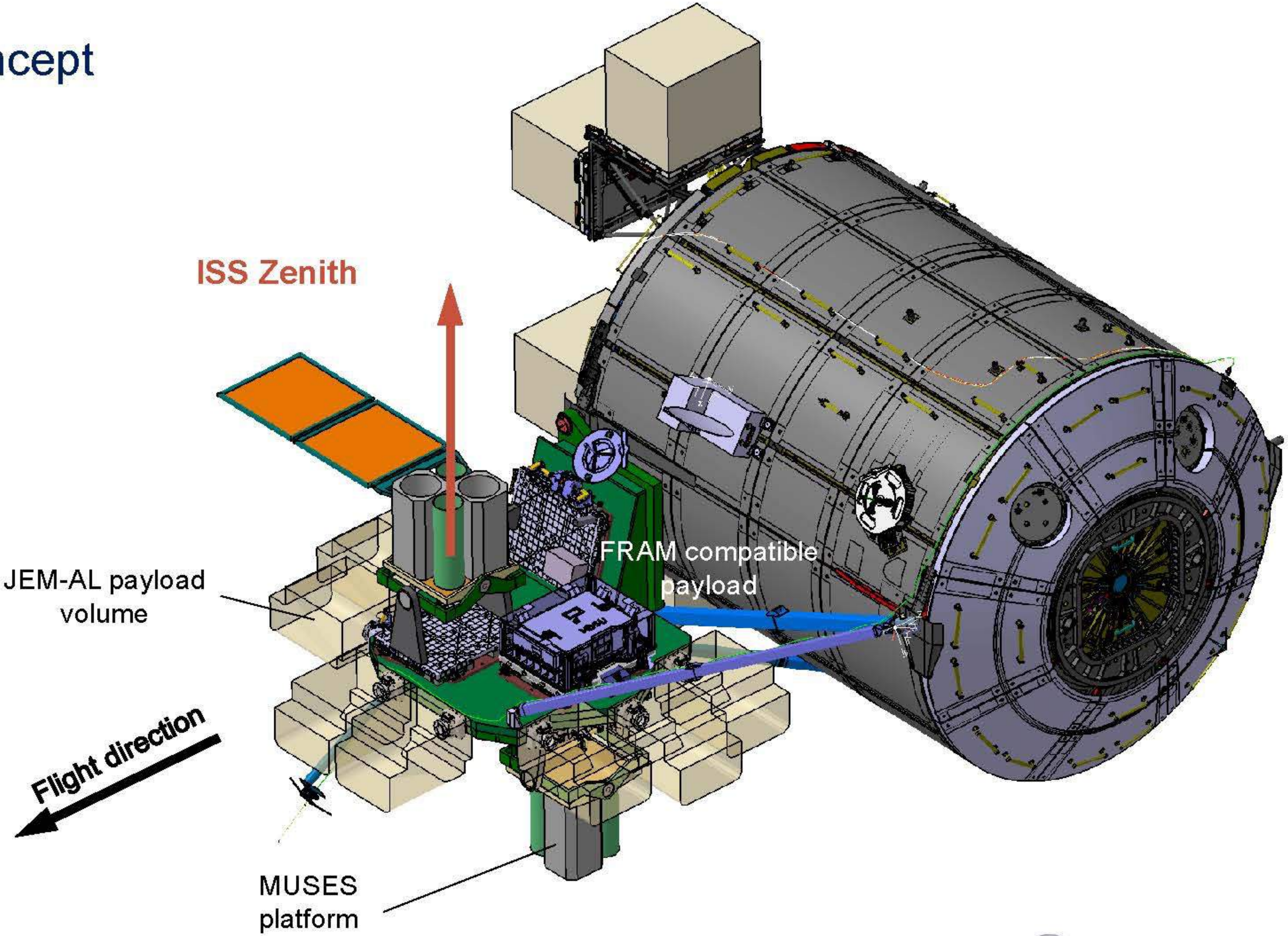
Propulsion Testing
- Power available for testing of low thrust electric propulsion systems

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

AIRBUS DEFENCE & SPACE

Bartolomeo System Concept

- Mechanical attachment with 2 Ram Trusses and 1 Keel Truss
- 2 principal payload classes
  - JEM-AL compatible (pressurized upload)
  - FRAM standard (unpressurized upload)
- Flight configuration compatible with SpaceX *Dragon* Trunk

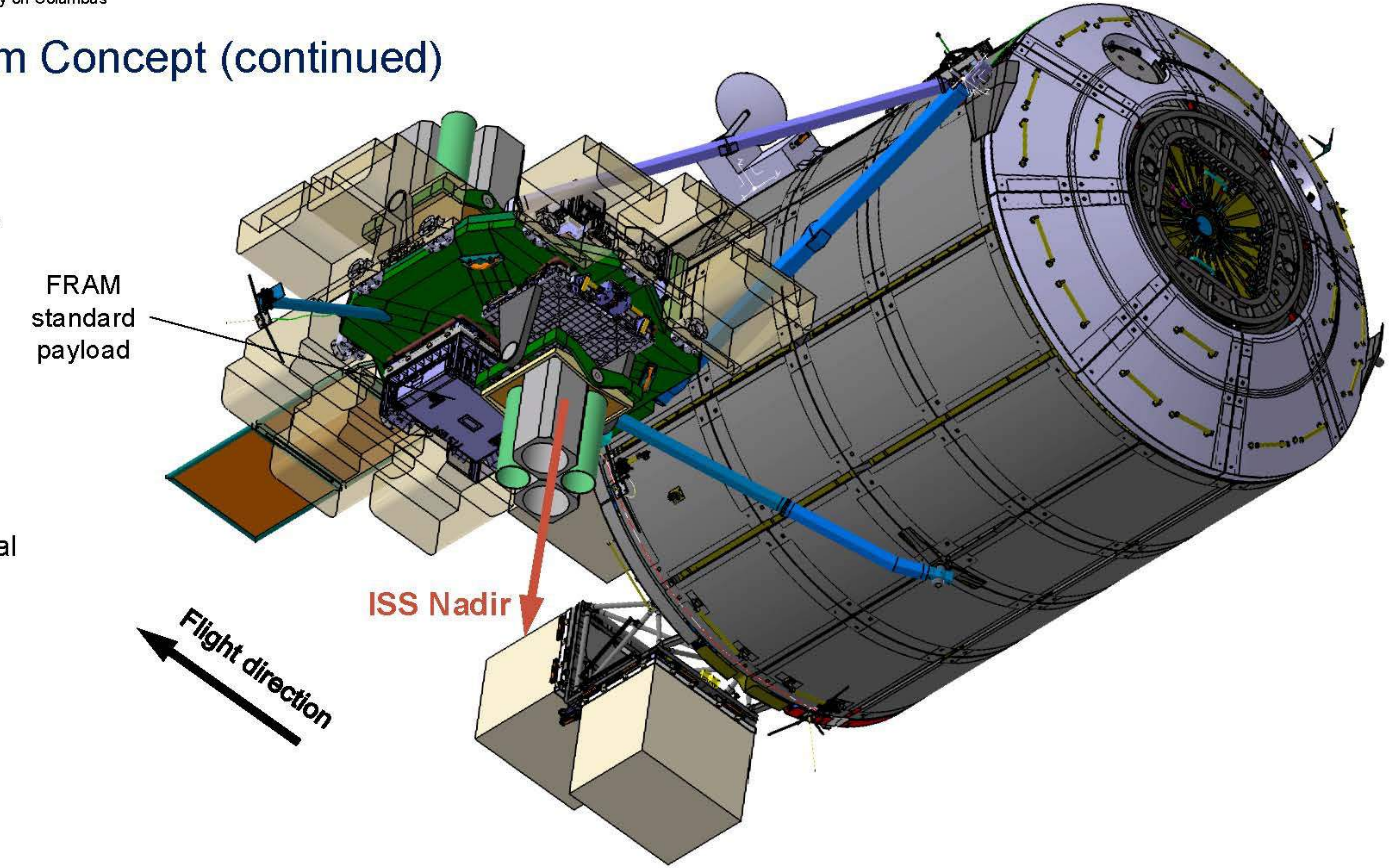


TELEDYNE BROWN ENGINEERING Everywhereyoulook™

AIRBUS DEFENCE & SPACE

Bartolomeo System Concept (continued)

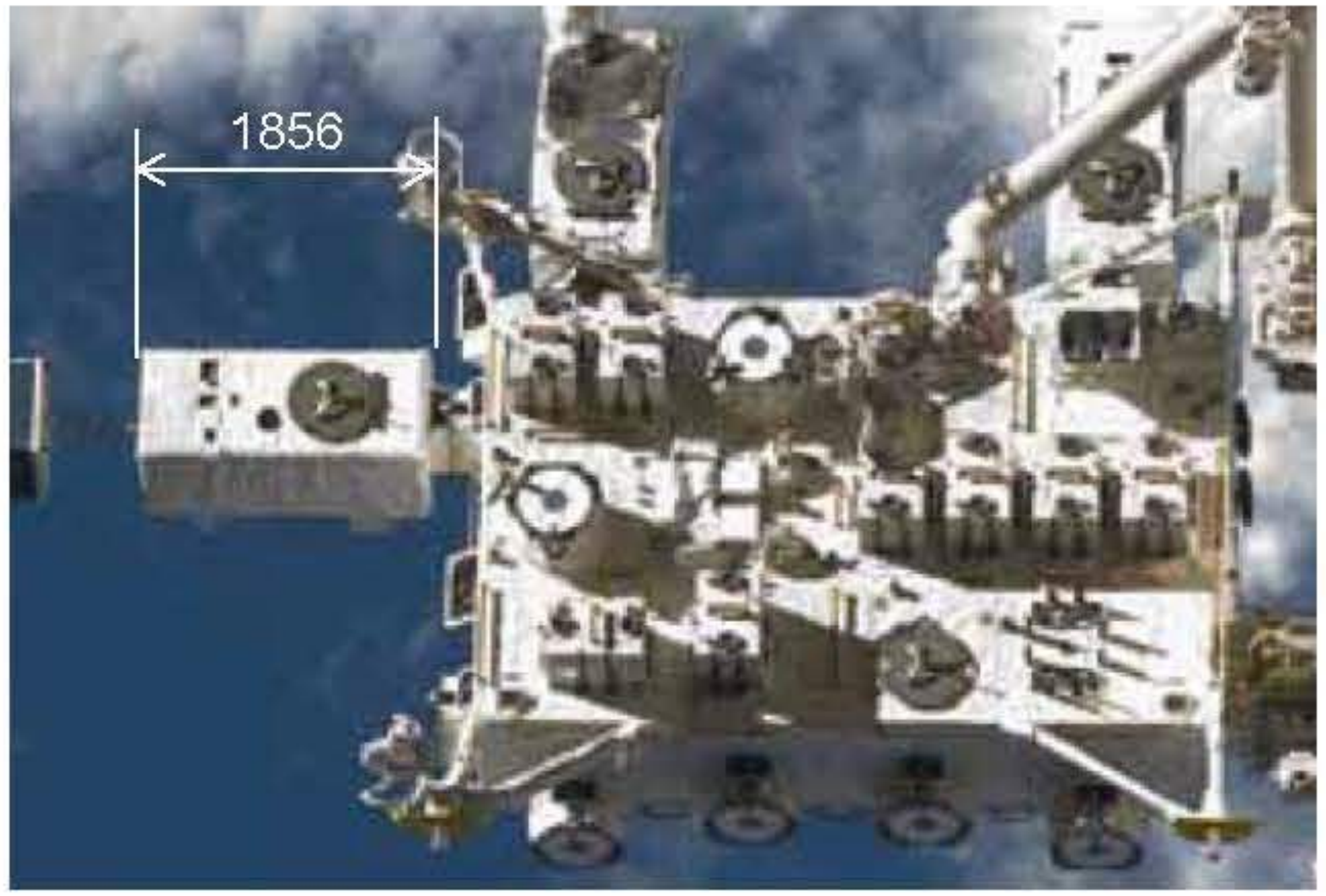
- Optimal positioning of payloads for best Zenith / Nadir / Limb viewing conditions
- Active cooling system for payloads
- Own power and data management unit
- Payloads accommodated using standard mechanical / electrical / robotic interfaces
- Full EVR compatibility
- No EVA required for payload installation / de-installation during service phase

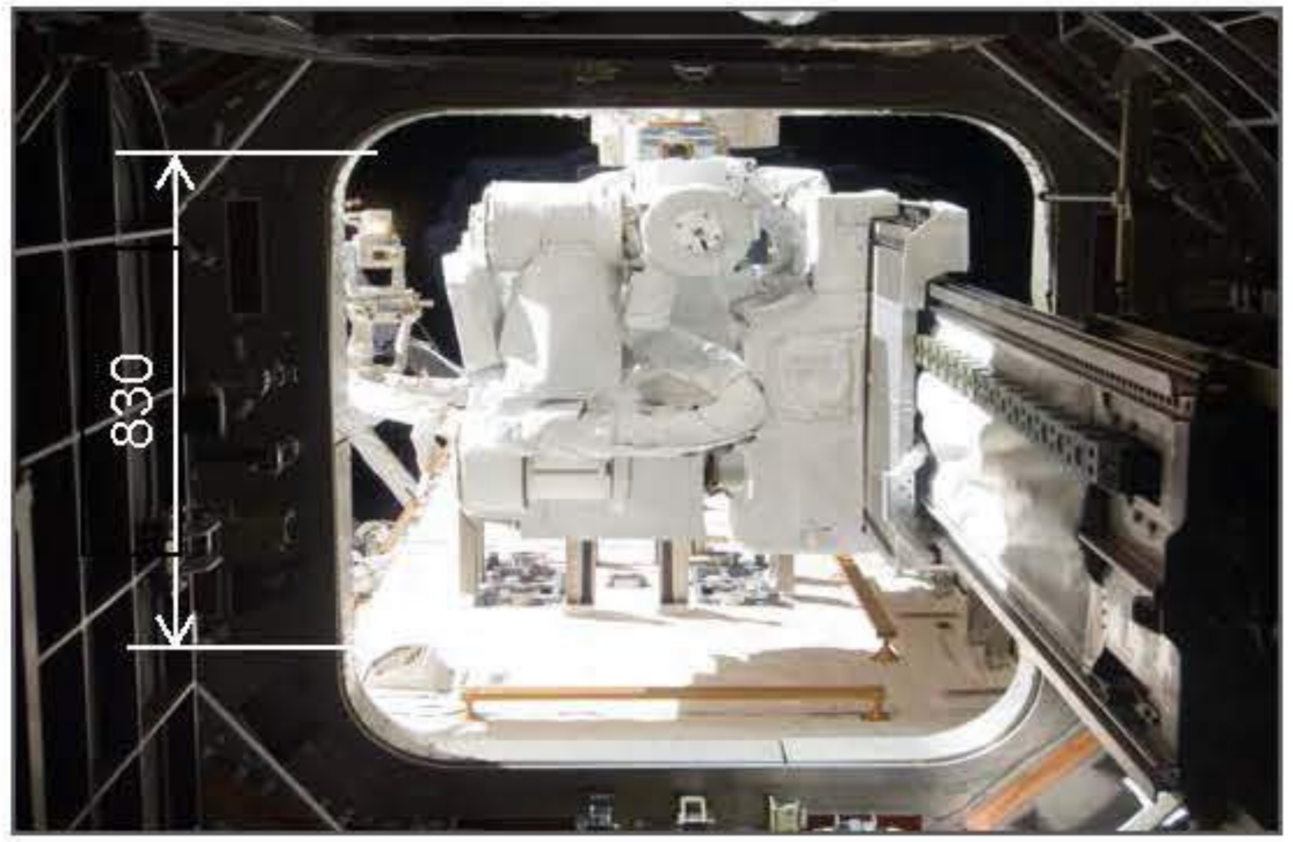


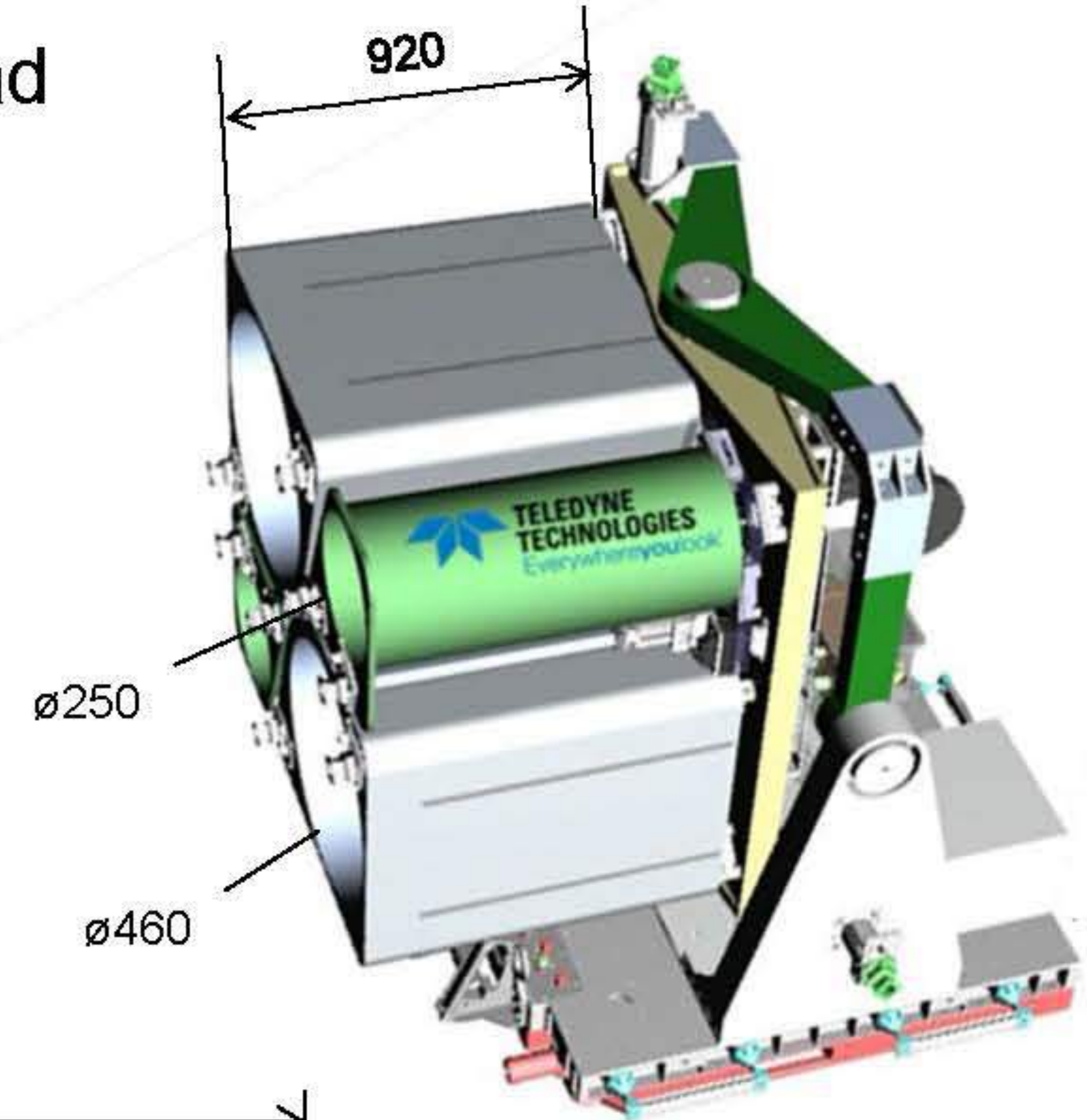
Bartolomeo System Concept (continued)

- *Bartolomeo* standard payload sizes

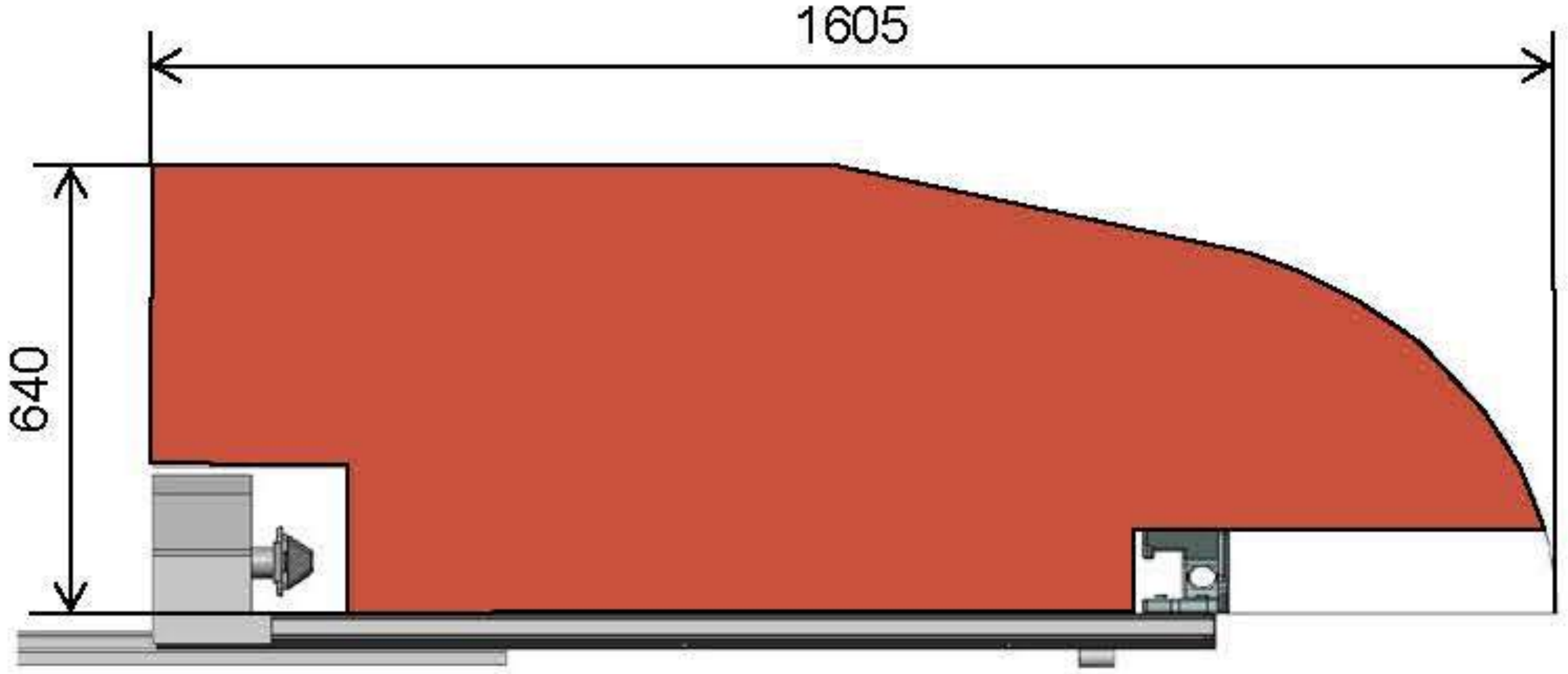
JEM-EF compatible



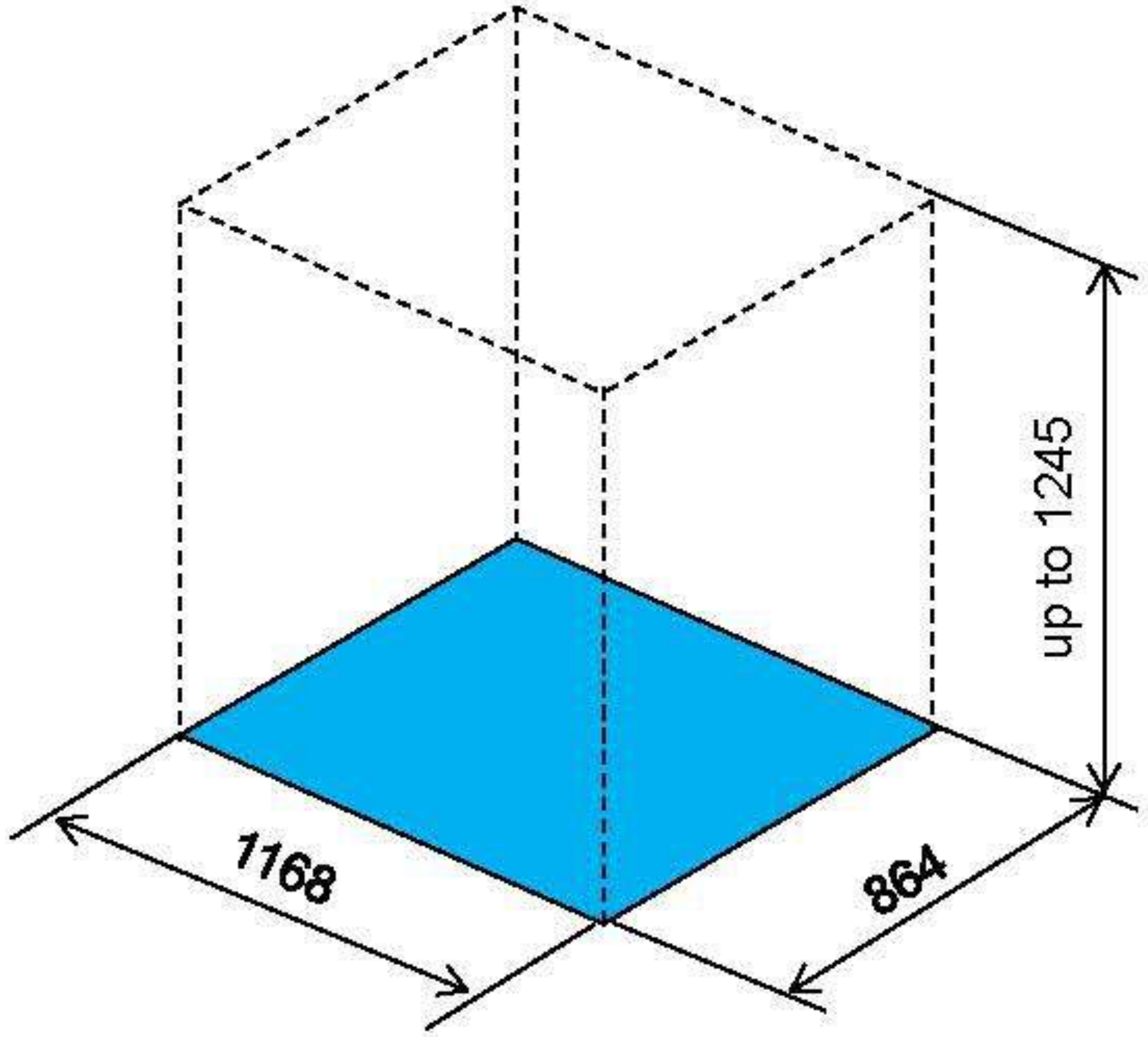




MUSES compatible



JEM-AL compatible



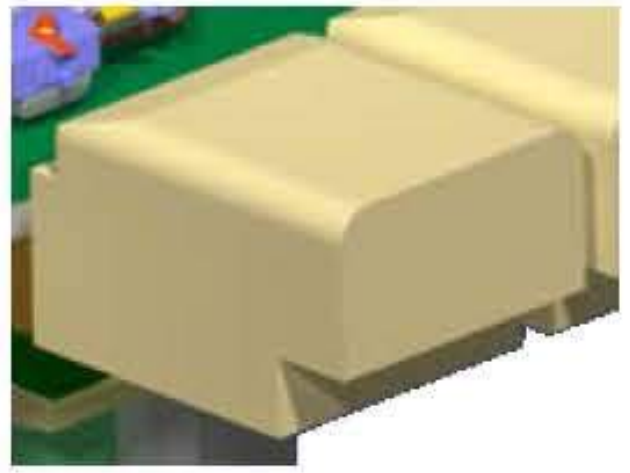
FRAM Standard

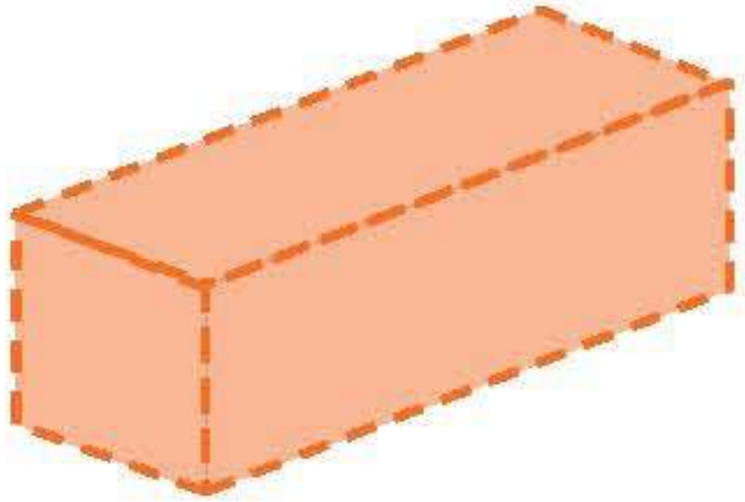
TELEDYNE BROWN ENGINEERING Everywhereyoulook™

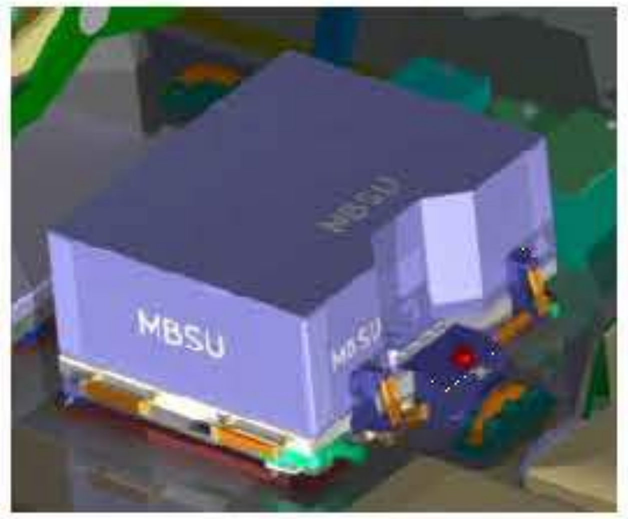
AIRBUS DEFENCE & SPACE

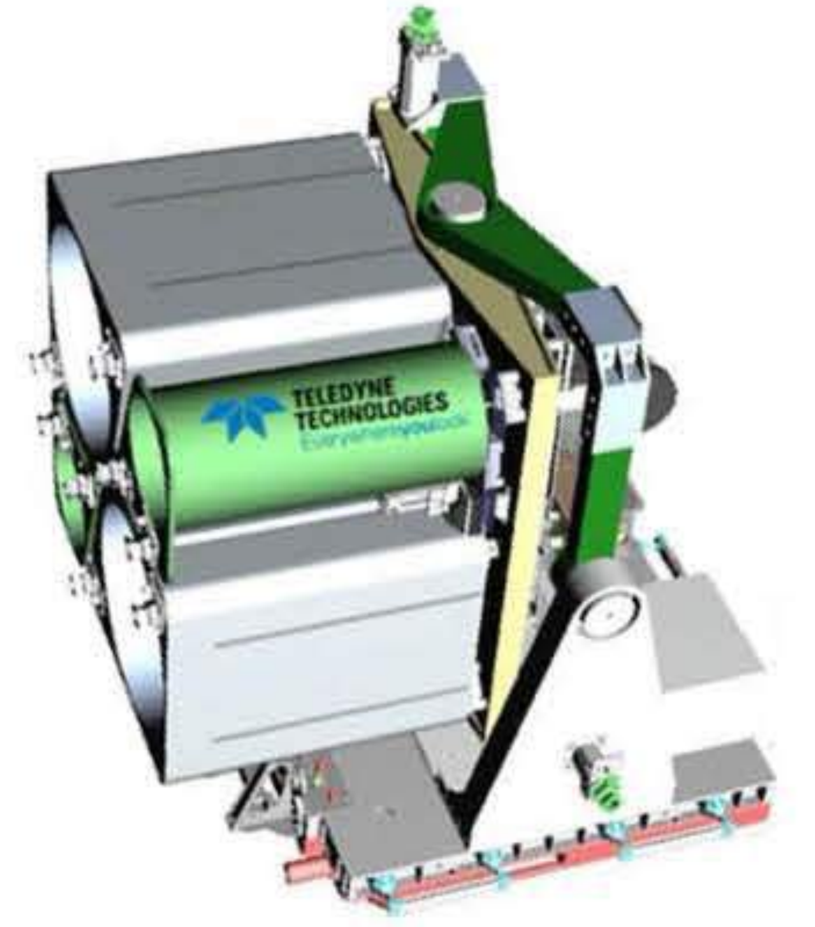
Bartolomeo System Concept (continued)

- *Bartolomeo* standard payload sizes



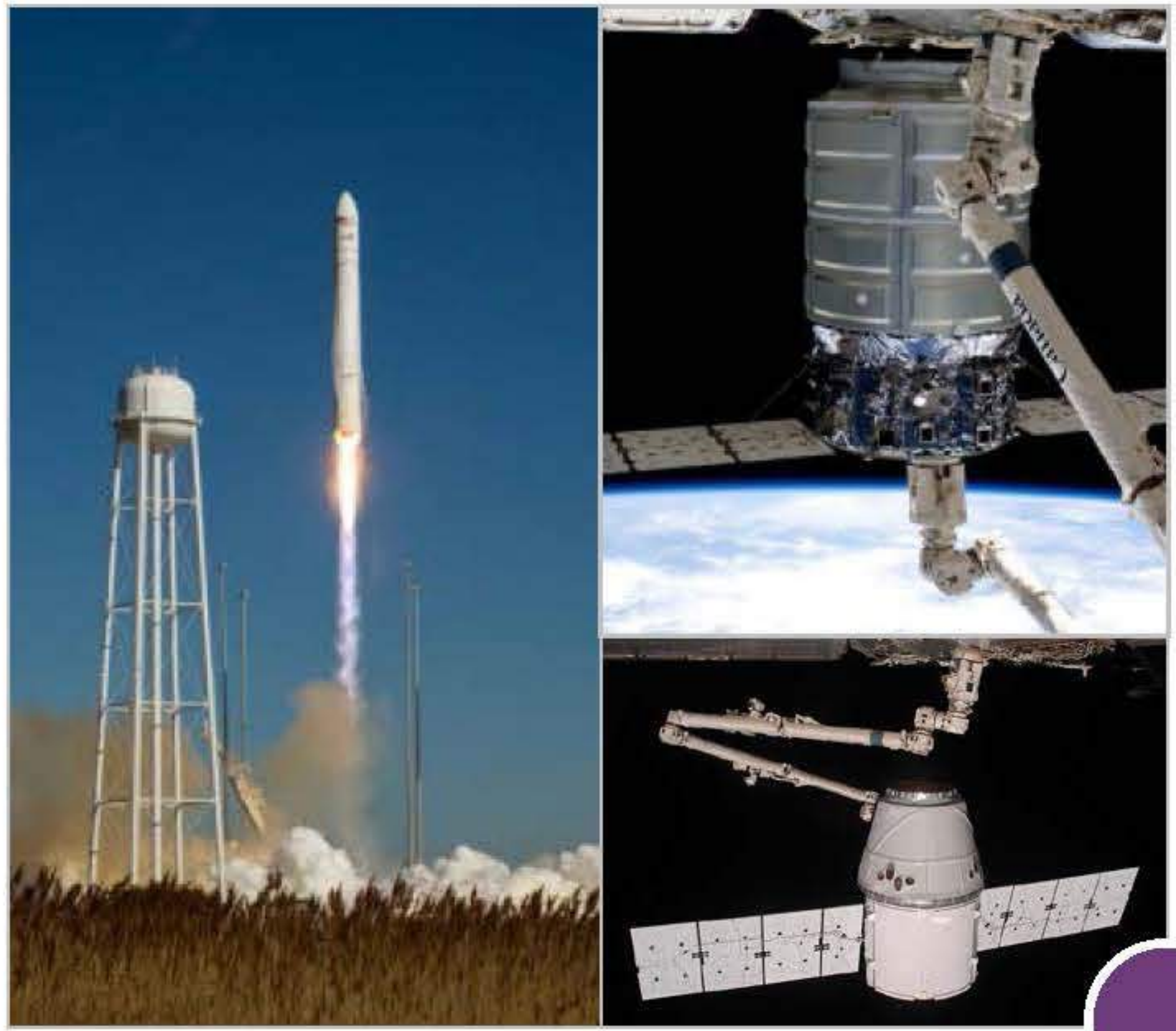


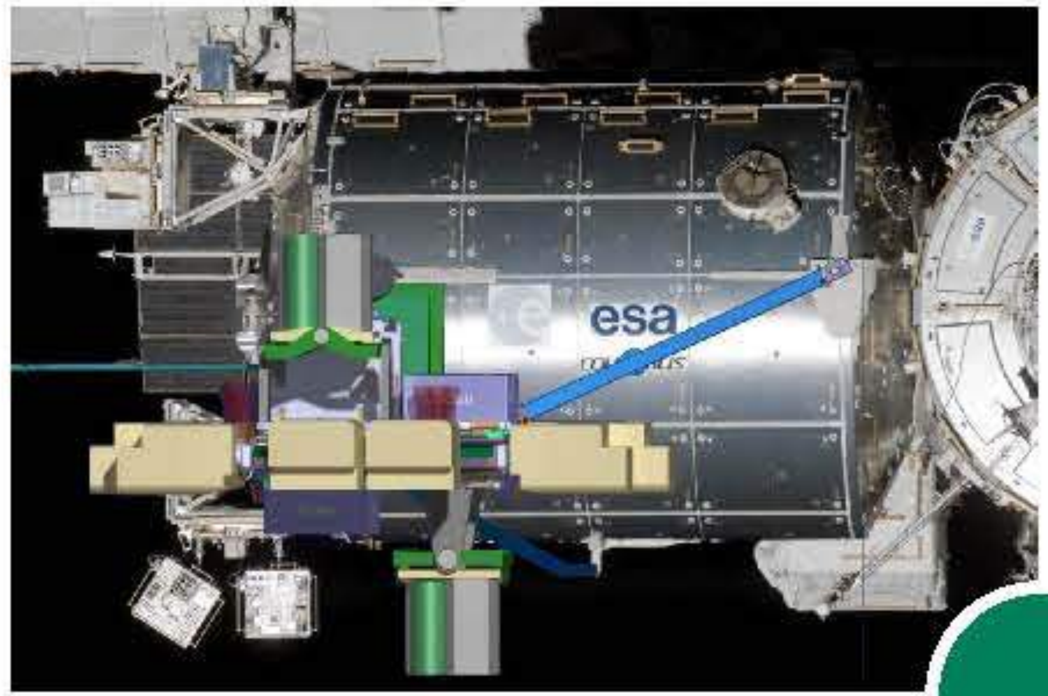




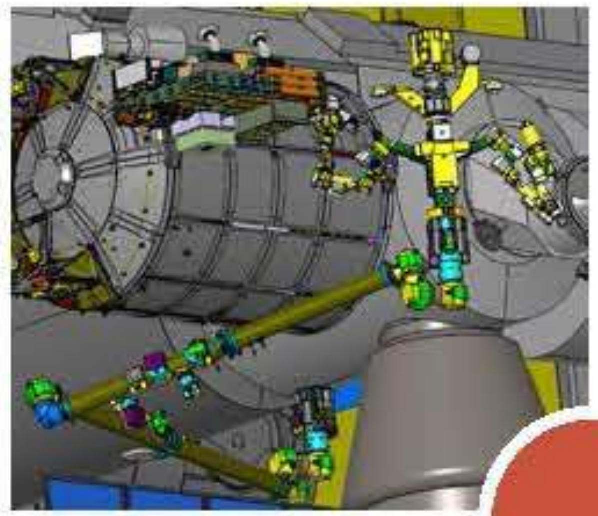
Item	JEM-AL compatible	JEM-EF envelope cmptbl.	FRAM-based	MUSES compatible
Concept of operations	• Pressurized launch in soft stowage • Transfer through JEM-AL • Robotic installation	• Unpressurized upload • Robotic installation	• Unpressurized upload • Robotic installation	• Pressurized upload • Transfer through JEM-AL • Robotic installation
Maximum dimensions	640 x 830 x 1000 mm	816 x 1037 x 1856 mm	864 x 1168 x 1245 mm	ø 250 x 920 mm ø 460 x 920 mm
Mass	up to 100 kg	up to 500 kg (TBC)	up to 500 kg	up to 100 kg
Power	up to 200 W @ 120 V up to 280 W @ 28 V	up to 200 W @ 120 V up to 280 W @ 28 V	up to 1200 W @ 120 V up to 100 W heater power	up to 224 W @ 28 Vdc
Data link to avionics	up to 100 Mbit/s	up to 100 Mbit/s	up to 100 Mbit/s	up to 100 Mbit/s
Cooling capability	up to 1.5 kW in total for all payloads			
Robotic interface	SPDM micro fixture	SPDM micro fixture	SPDM micro fixture	SPDM micro fixture
Payload to platform interface	MDA wedge adapter	MDA wedge adapter	FRAM	MUSES standard interface

Bartolomeo End-to-end Service Concept





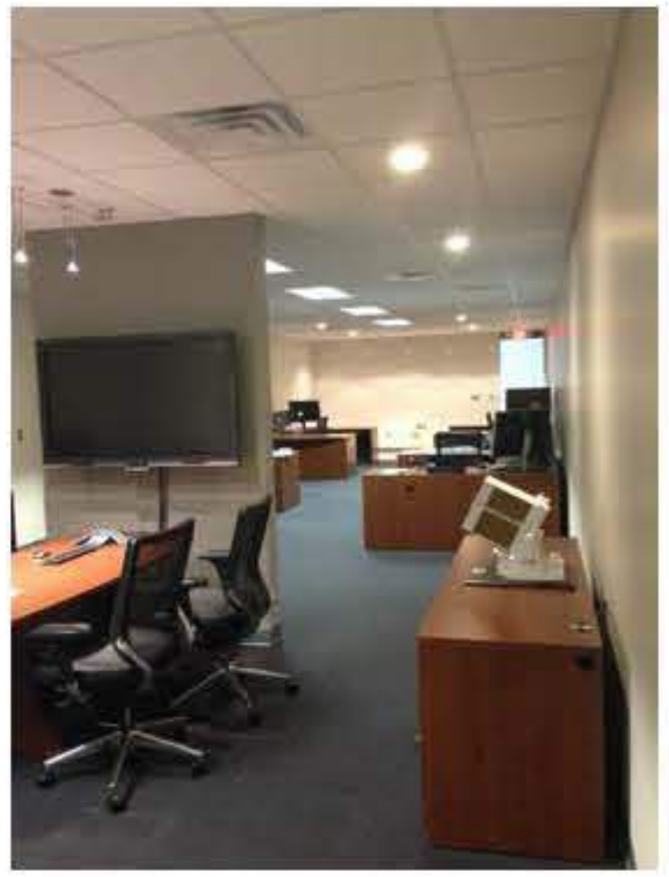
Payload mission



Payload robotic installation

Payload transfer to outside

Payload launch



Payload data processing

1 – 1.5 years

1 – 10 years

TELEDYNE BROWN ENGINEERING Everywhereyoulook™

AIRBUS DEFENCE & SPACE

Bartolomeo Collaboration with CASIS

CASIS™

14 November 2015

Mr. Uwe Pape
Senior Manager, Commercial ISS Operations
Airbus Defence and Space

Send electronically to: uwe.pape@airbus.com

Dear Mr. Pape:

The purpose of this memorandum is to express the support of the Center for Advancement of Science in Space (CASIS) for your "Bartolomeo" project concept: the development, integration and operation of a multi-user, multi-purpose commercial external platform on the International Space Station (ISS).

The CASIS mission is to exploit the capabilities of the ISS to conduct research and explore technologies for humanitarian, commercial, and educational benefit. Utilization of the ISS for earth observation offers great opportunities to the remote sensing community. The provision of remote sensing imagery, data, and other products to benefit both the private/commercial sector as well as humanitarian needs is a major element of a CASIS Campaign entitled "Good Earth". However, the available ISS infrastructure and resources required to address this demand appropriately is extremely limited. A recent ISS gaps and needs analysis conducted on behalf of CASIS recommended the following action: *"Expand the number of nadir mounting points. Despite existing ISS payload capabilities, nadir mounting points are expected to soon reach capacity. Increasing the number of nadir viewing mounting options (e.g., expanding existing ELCs, adding new ELCs, or adding a new dedicated remote sensing platform) will facilitate deployment of more Earth observing sensors."*

This memorandum in support of the Airbus "Bartolomeo" project concept is intended to provide a level of commitment from CASIS, the managers of the ISS U.S. National Laboratory. Given the limited capacity of ISS to accommodate external payloads, CASIS is hopeful this support will assist in discussions and negotiations with other ISS partners, external ISS payload operators, and other ISS stakeholders at large. You are welcome to contact Mr. Ken Shields, kshields@iss-casis.org, for clarification and confirmation of CASIS support.

Regards,

Ken Shields

Ken Shields
Director, Operations
Center for the Advancement of Science in Space
CASIS

Bartolomeo Hosted Payload Compared to Satellite-based Mission

Parameter	Small Satellite	Medium Satellite	Large Satellite	Bartolomeo
Maximum payload mass	50 kg	150 kg	200 kg	50 – 500 kg
Orbit parameters		Fully selectable		ISS orbit
Average payload power @ EOL	50 W	140 W	386 W	up to 1000 W
Data downlink rate	80 Mbit/s	105 Mbit/s	105 Mbit/s	approx. 30 Mbit/s
Life time			5 - 10 years in LEO	
Time to launch	31 months	31 months	39 months	12 – 18 months
Estimated operations cost for customer per year	1.5 MUSD	1.5 MUSD	1.5 MUSD	2 - 7 MUSD
Platform price / initial payment per customer	17 MUSD	24 MUSD	36 MUSD	0 MUSD
Launch cost	2.5 – 7 MUSD	10 – 15 MUSD	30 MUSD	SAA?
Estimated mission cost at commissioning	26 MUSD	40 MUSD	68 MUSD	2 - 7 MUSD
Estimated Mission cost after 5 years	35 MUSD	50 MUSD	75 MUSD	15 – 35 MUSD

Contact

Dr. Christian Steimle
Project Manager External Payloads Program
ISS Commercial Applications
Airbus Defence and Space, Bremen, Germany
Email: per-christian.steimle@airbus.com
Mobile: +49 151 277 677 74

Ronald Dunklee
President and CEO
Airbus DS, Space Systems, Inc., Houston, Texas
Email: rdunklee@airbusdshouston.com
Mobile: +1 (281) 414-3617