On-board software technology trends in space applications

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Olivier Notebaert
On-board Data processing expert
Defence and Space Engineering

April 2018

AIRBUS

Airbus is an international pioneer in the aerospace industry

We make it fly

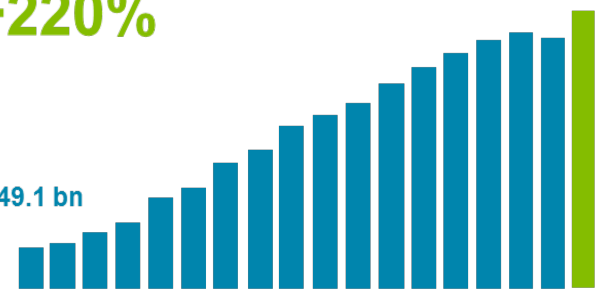
Airbus is the largest aeronautics and space company in Europe.
A worldwide leader in designing, manufacturing, and delivering aerospace products, services and solutions to customers on a global scale.

Global Company

* as of December 2016

129,000 employees
from **135** nationalities

Located across **35** countries
on more than **180** sites



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DON’T
PANIC

Space Selfie:

This talk is not about automotive in space

The red cabriolet and the Planet Earth

On-board software technology trends in space applications

- Space
- Vision
- Targets
- Technologies

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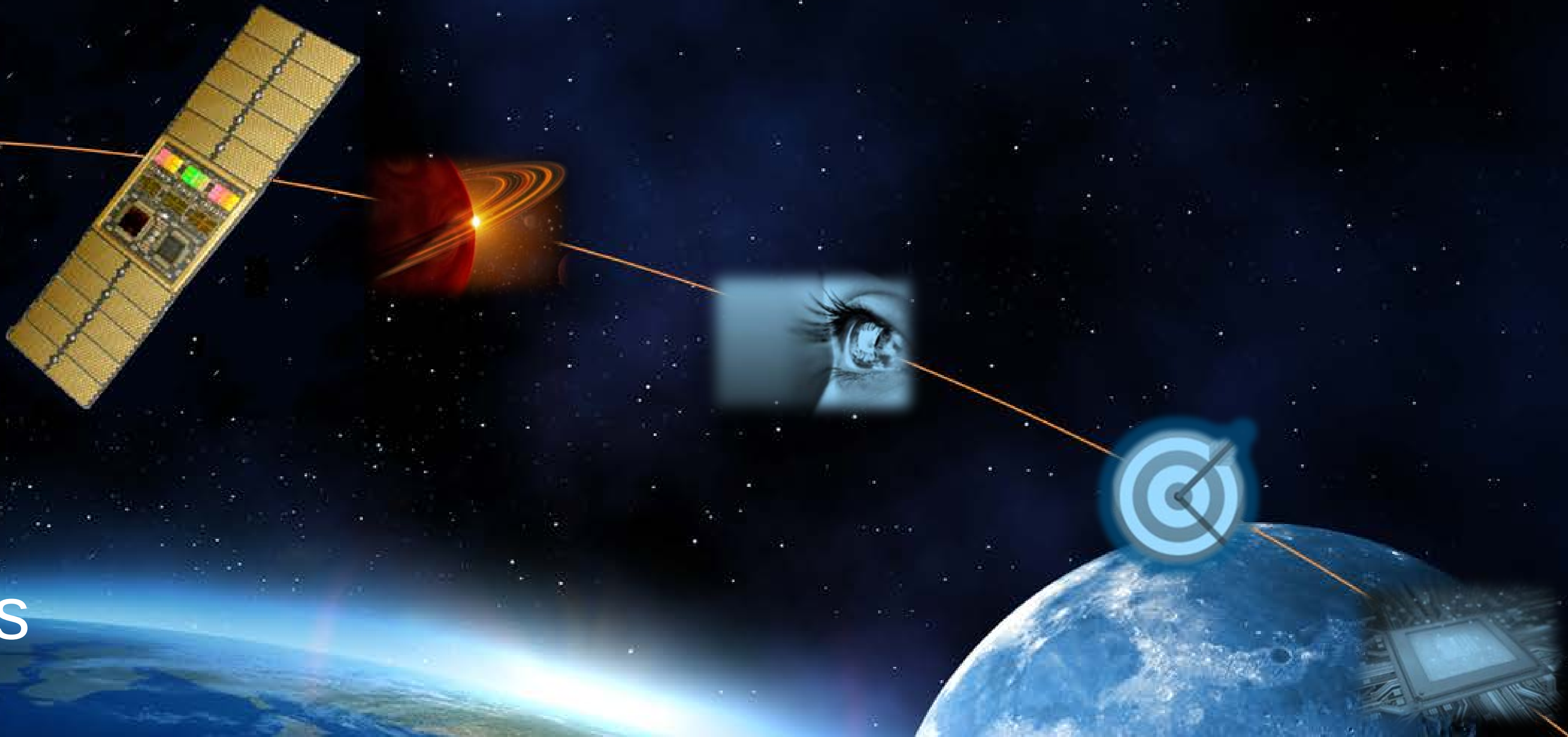

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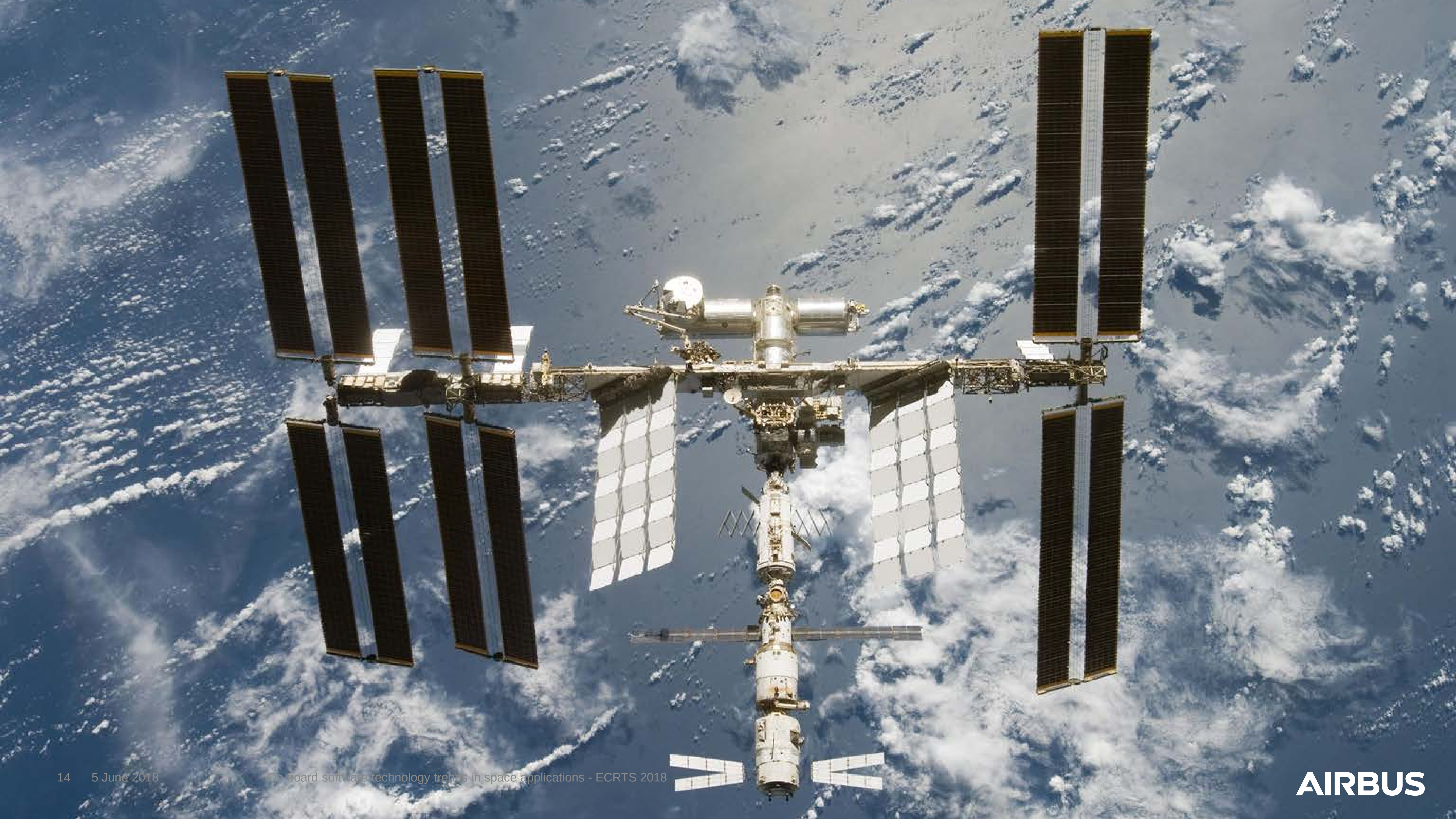

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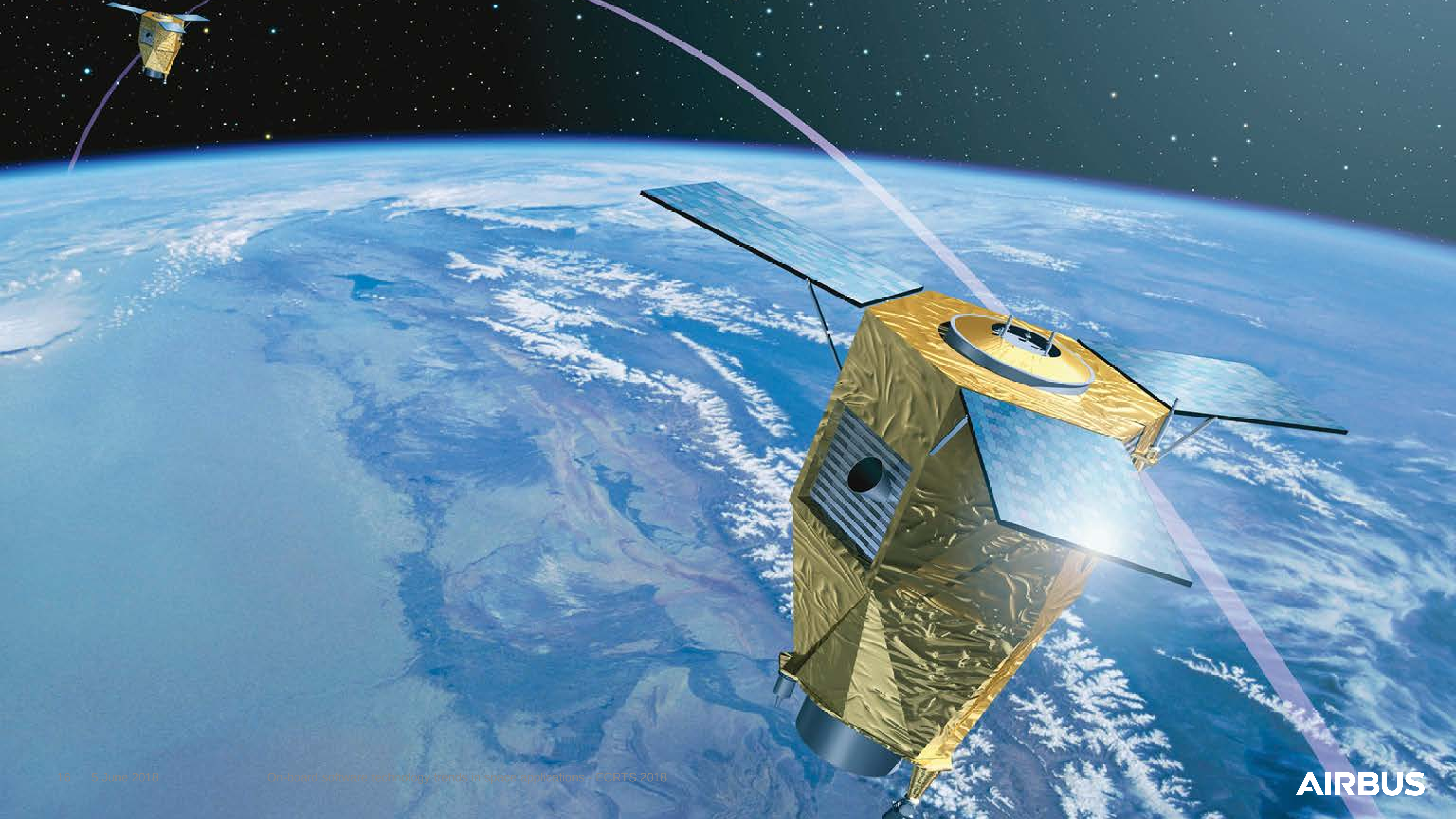

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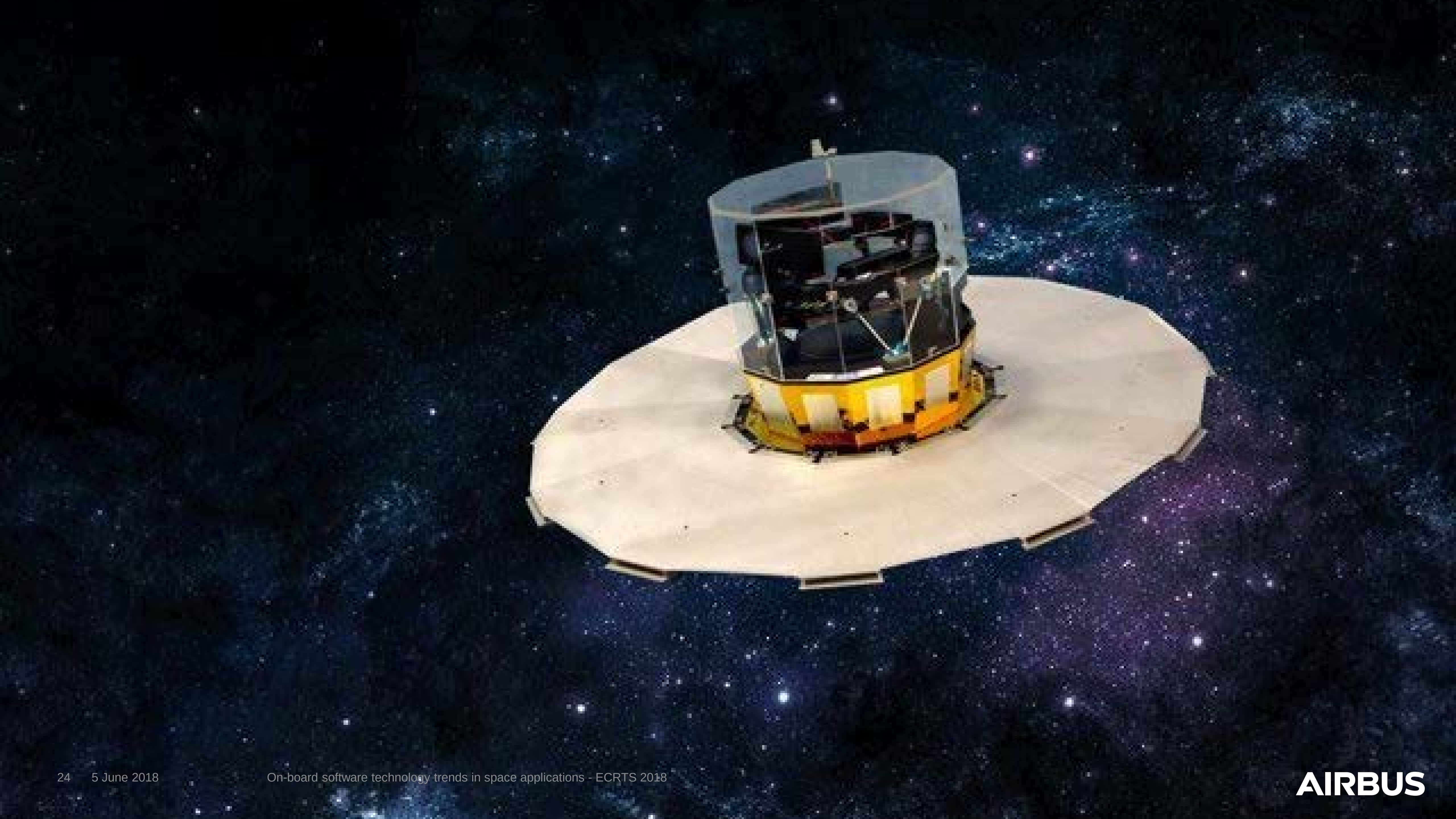
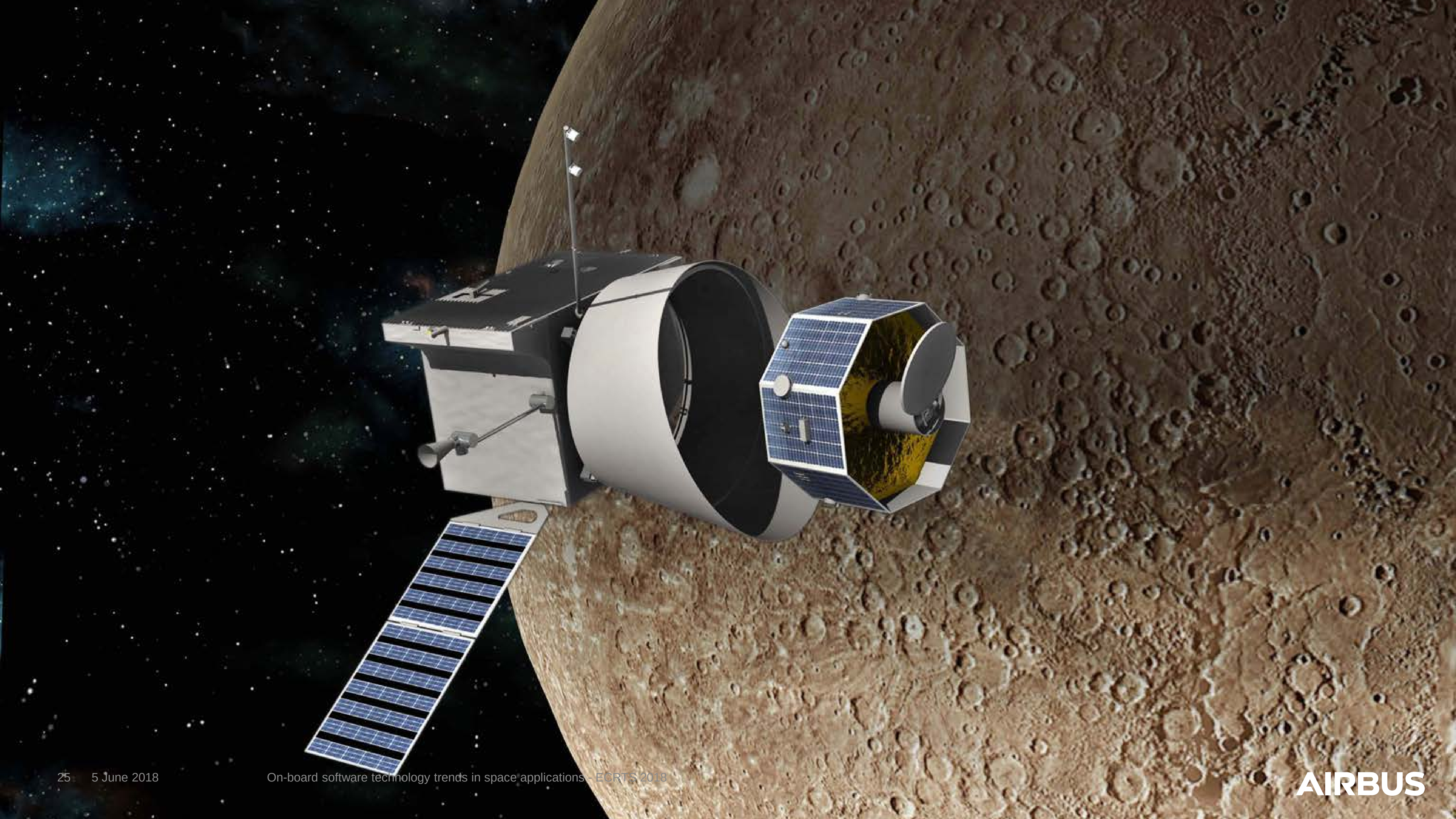
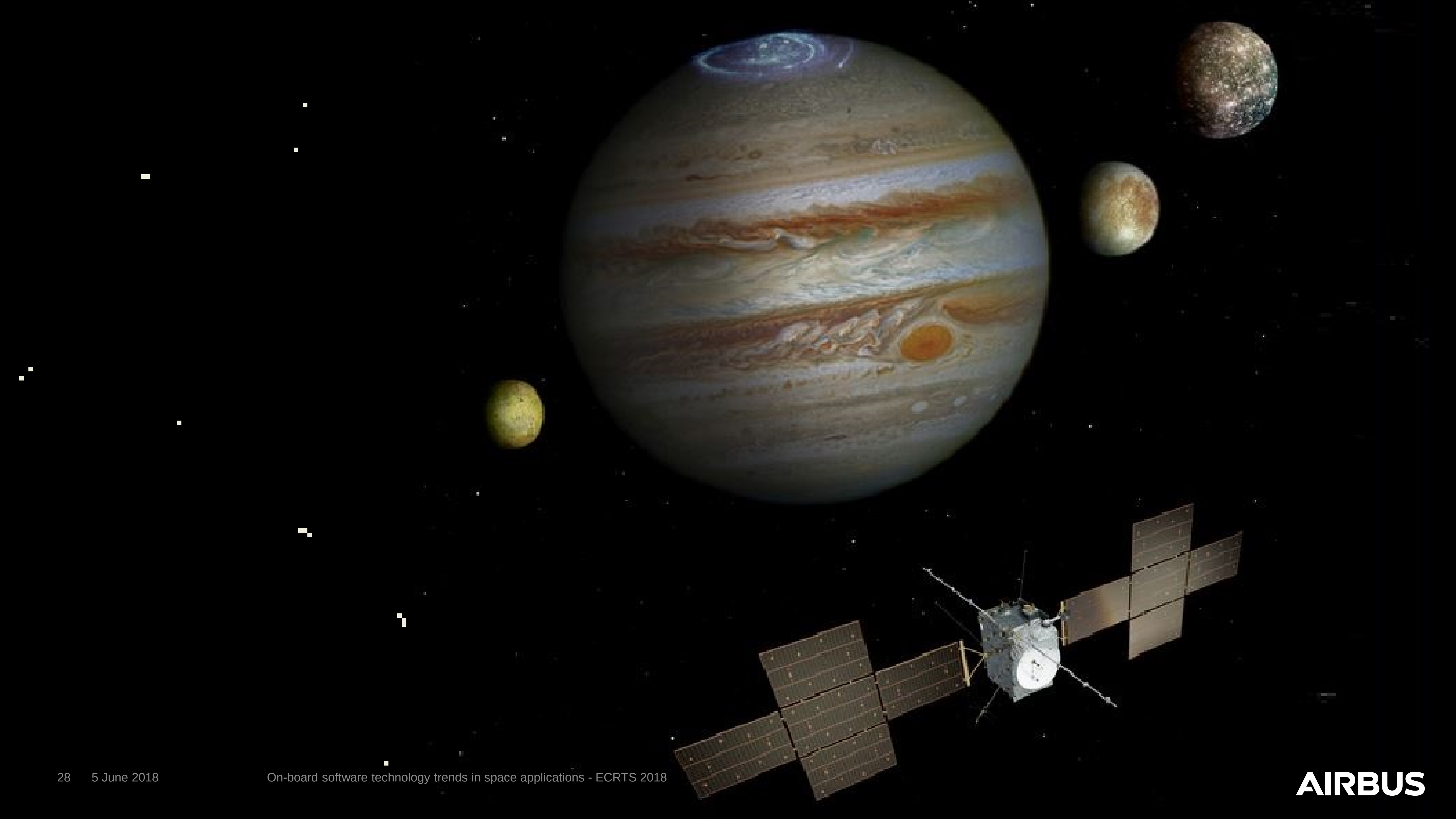
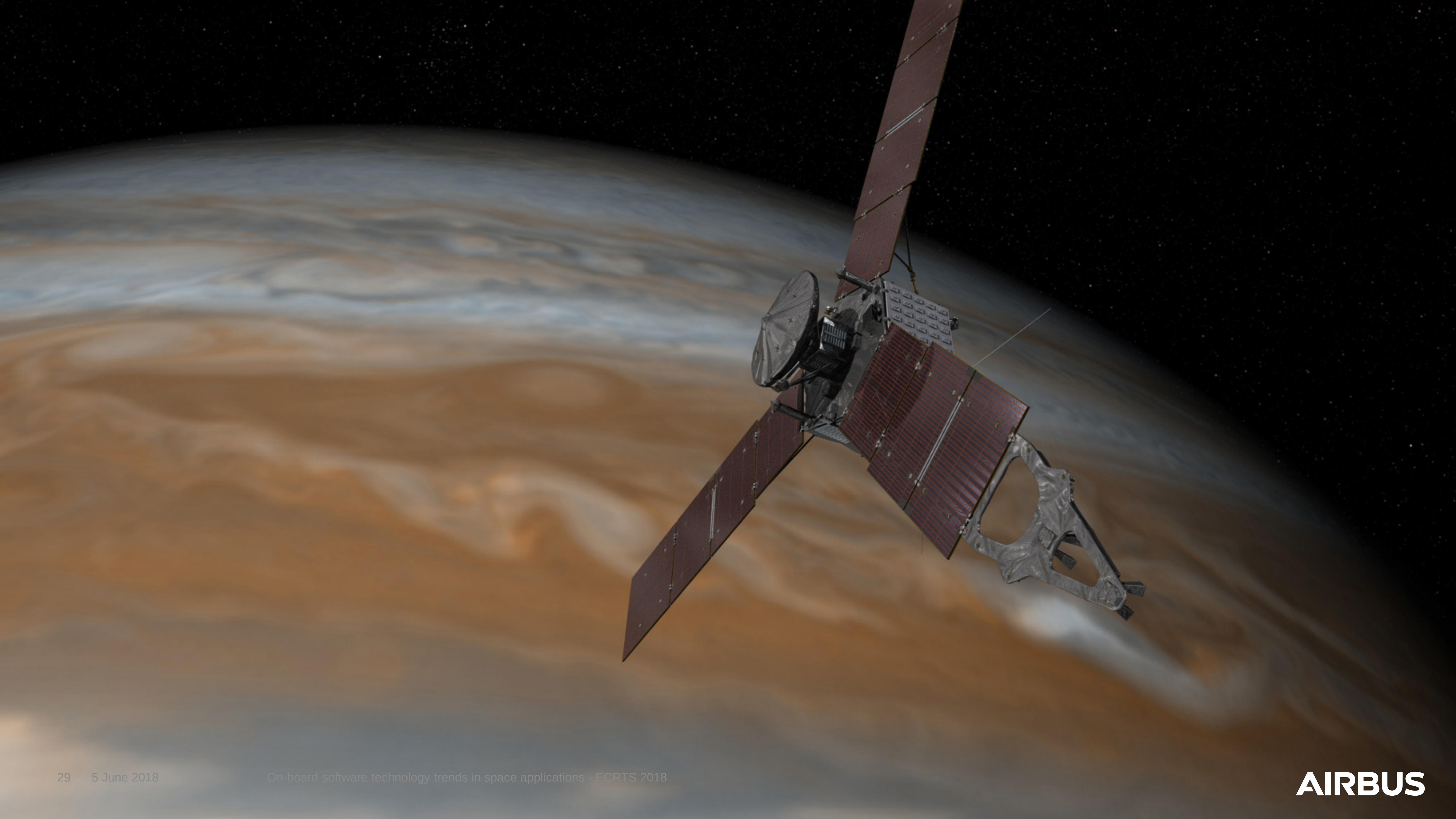
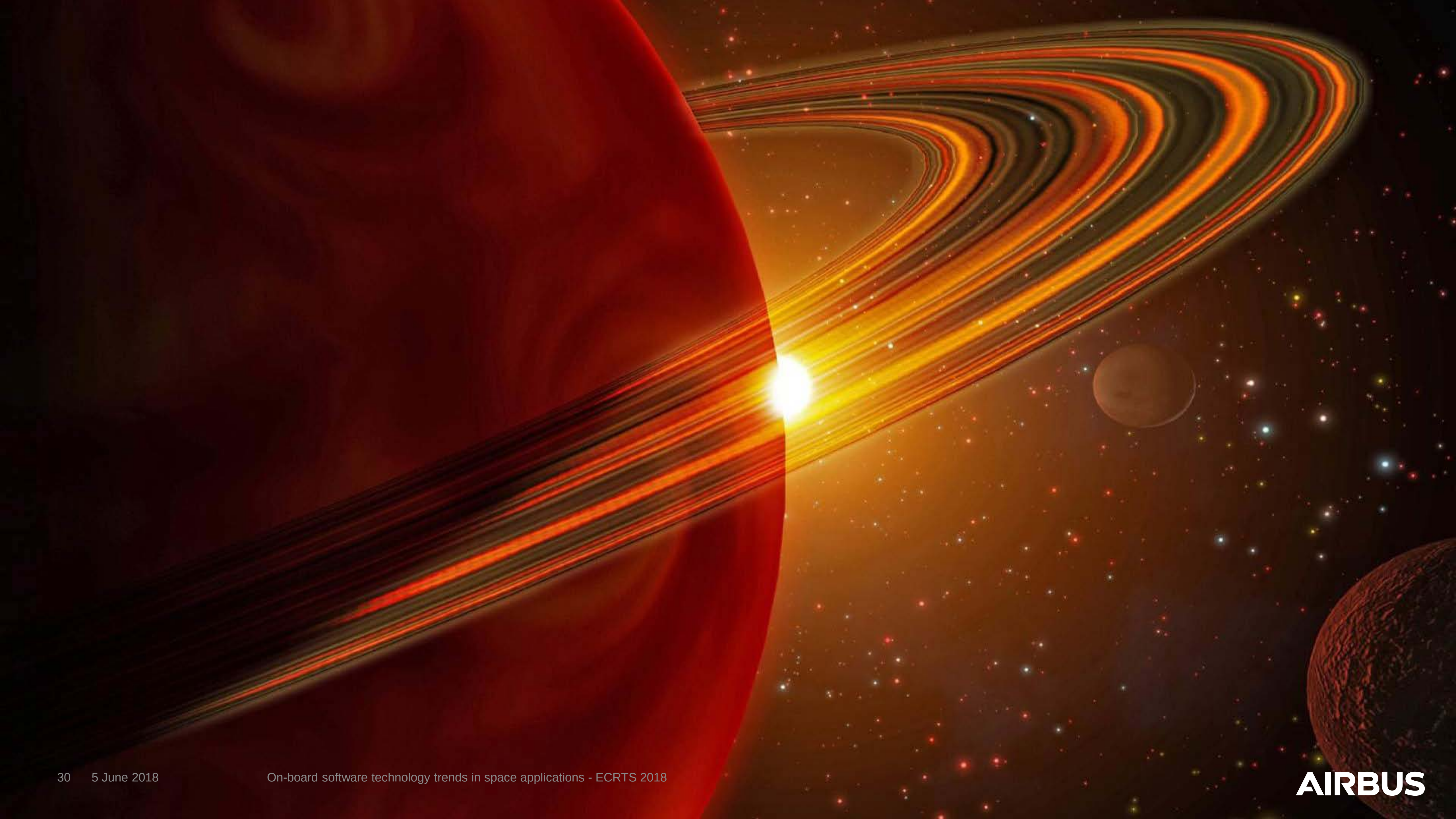


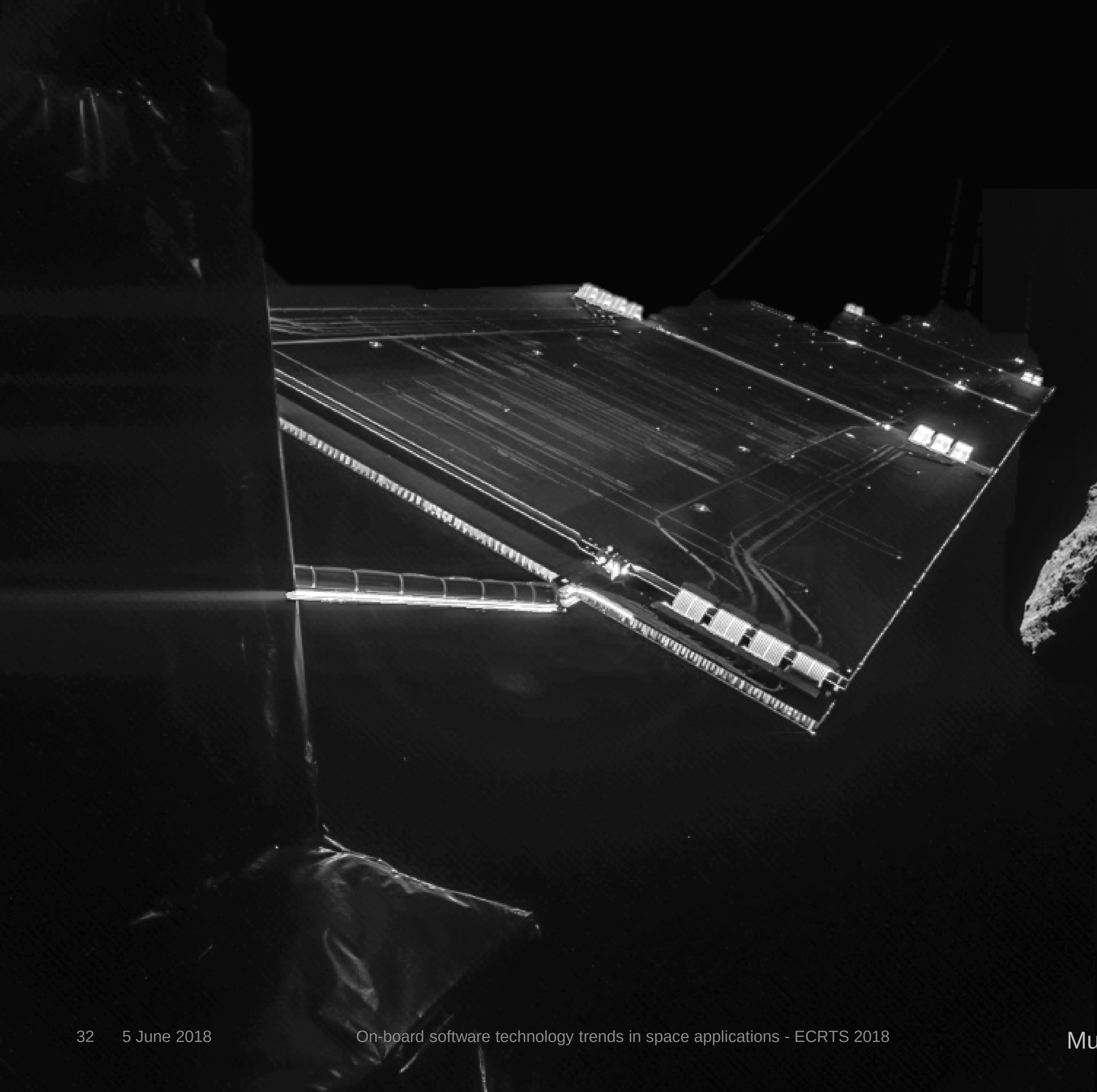








Another Space Selfie
Rosetta and the Comet Tchuri



Music from David Bowie « Life on Mars »

Another Space Selfie
Rosetta and the Comet Tchuri

Music from David Bowie « Life on Mars »

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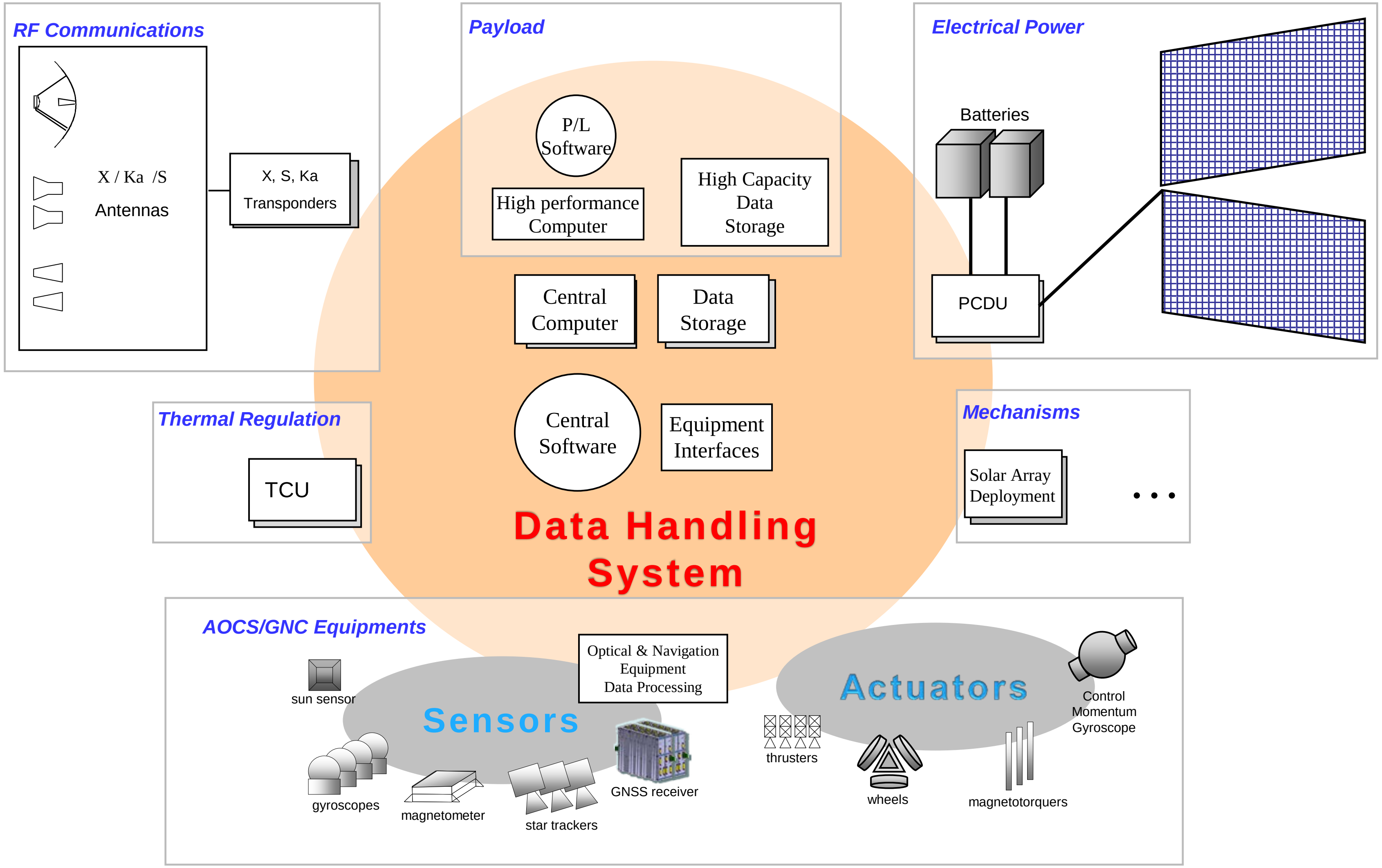
Spacecraft Avionics Systems

On-board software main functions

On-board Software within Spacecraft Avionics Systems



Spacecraft avionics

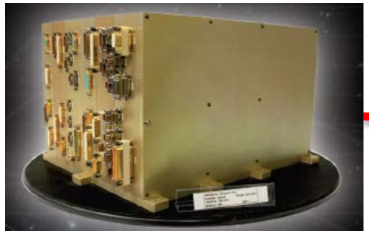
DHS
Data Handling System

- On-board Electronics
- On-board Software

AOCS / GNC
Attitude and Orbit Control System / Guidance, Navigation and Control

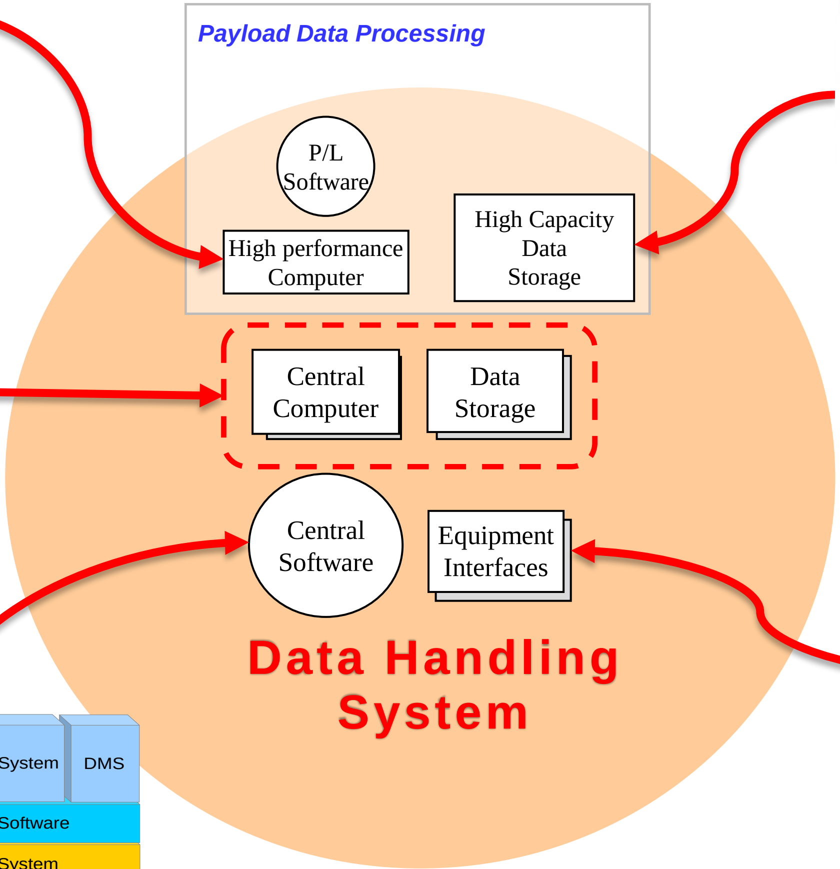
- Sensors & Actuators

On-board Software within Spacecraft Avionics Systems



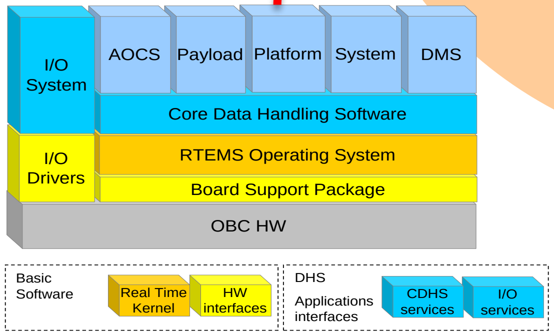
Data Processing Unit

On Board Computer



Solid State Mass Memory

Remote Interface Unit



CSW – Central Software

On-board Software

DHS Central Software

- Platform Control
- Generic architecture
- Execution platform
- Low Data Volume
- High Reliability

Payload Data Processing

- Instruments specific
- Mission dependant
- High Data Volumes
- High Data rates
- High Performance

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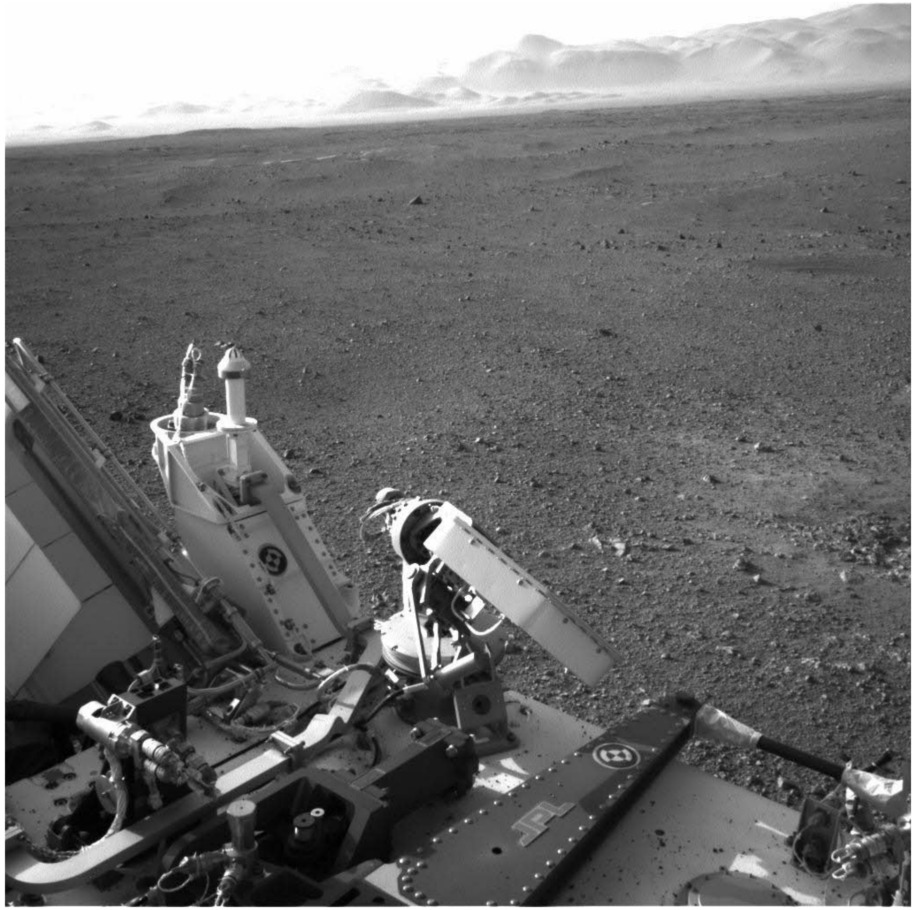
Main Data Handling System functions

- Communications
- Vehicle Guidance, Navigation and Control
- Spacecraft operations, Housekeeping and Mission management
- Fault management
- Spacecraft equipment management
- Payload control, data processing and on-board data storage



Curiosity explores the surface of MARS © NASA

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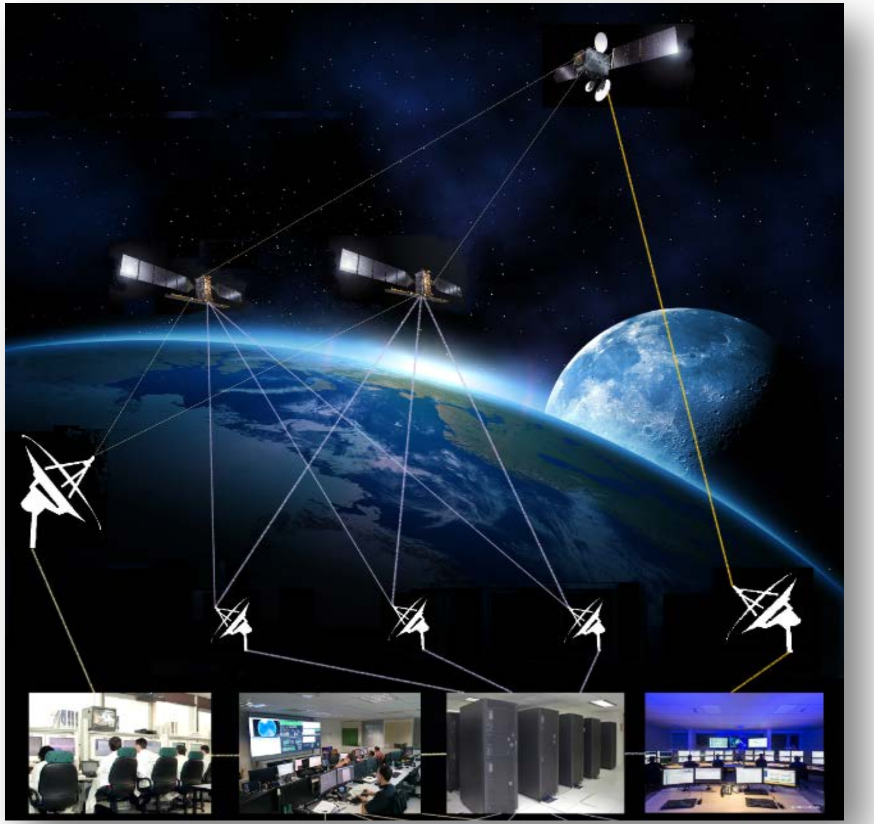
Communications

- **Telecommand**
  - Low data rate
  - Minimal capability ensured by survival mode
  - Security (de-cyphering, authentication)
- **Telemetry**
  - Large range of data rates
    - Low rate mission data
    - High rate payload data
  - Security (cyphering)
- **Limited availability**
  - Permanent in Geostationary Orbit
  - Submitted to visibility windows in LEO, MEO or Deep Space
  - May be augmented through Space Data Relays
- **Standardisation**
  - CCSDS (Consultative Committee for Space Data System)
    joint organisation with participation of major space agencies (NASA, ESA, JAXA,...).
    ⇨ **International interoperability** (e.g TC/TM communications)
  - ECSS (European Cooperation for Space Standardisation)
    ⇨ **European interoperability and technology harmonisation**



CCSDS
Consultative Committee for Space Data Systems

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Vehicle Guidance, Navigation and Control

- **Orbit transfer and special manoeuvres**
  - Guidance and navigation for the Orbit transfer
    - 3 to 6 months for a GTO to GEO transfer with electric propulsion
    - Target detection, approach, landing, docking…
- **Attitude and Orbit Control**
  - Knowledge and control of the systems position and attitude
  - Instrument and antennas pointing
  - Interactions (Platform, solar panels, instruments)
- **Operational Modes Control**
  - Orbit transfer mode
  - Nominal mode
  - Survival mode
    - easy attitude control e.g. sun pointing)
    - Limited power consumption
    - Minimal TC/TM communications

ATV docking to the International Space Station

Spacecraft operations, Housekeeping and Mission management

- **Basic functions for system operation**
  - Telemetry / Telecommand
  - On-board Data Management and storage
  - System's operations autonomy
  - On-board operations scheduling (mission plan)
  - On-board mission data storage
  - On-board Software maintenance
- **System Monitoring and Housekeeping**
  - Thermal system control
    - thermal sensors on spacecraft structure and equipment + heaters control
  - Power system control
    - battery management, solar panels control and orientation, power distribution
  - On-board Equipment monitoring
- **Failure Detection, Isolation & Recovery (FDIR)**
  - Next slide

Fault management: **Failure Detection, Isolation & Recovery**

- **Different kind of failure origin**
  - Electrical, electronic or mechanical element failure
  - Software fault
  - External event (space debris, meteorite, …)
  - External disturbance (optical sensor dazzling, electro-magnetic effect, solar flares…)
  - Operational fault (or intentional attack)
- **Failures can propagate**
  - Too slow diagnosis
  - Bad diagnosis
  - Amplification through a looped system
- **Systems require failure tolerance**
  - Capacity to detect, isolate and report the failure
  - Capacity to configure itself into a safe mode
  - Capacity to restore nominal operations
  - Minimum data losses & availability
  - Stronger requirements for manned missions

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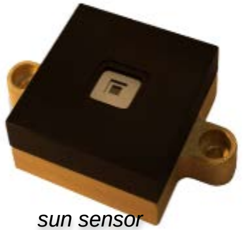
Equipment management

- **Two kind of equipment**
  - ***Dumb*** Devices
    - without processing capability
      - Simple Sun Sensors
      - Gyroscopes, first generation optical sensors
  - ***Smart*** devices
    - with processing capability with cabled dialog protocol
      - Gyroscopes, second generation optical sensors
      - on-board processing, mass memory

- **Equipment Management is complex**
  - Many suppliers
  - Variety of interfaces and communication protocols
  - In-orbit on-board software maintenance


Thermistor


Magnetotorquer


sun sensor


Magnetometer


Reaction wheel

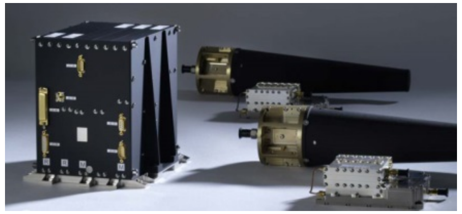

Gyroscope


sun sensor


camera


Star sensors


Inertial systems


GNSS devices


Mass memories

Payload control, data processing and on-board data storage

Observation & Science

- Image & Radar processing (compression, ciphering…)
- Scientific data processing
- Mostly data stream processing
- few missions with real-time control loops

Telecommunications

- Modulation, Demodulation, (de)ciphering, Channel Switching
- Software Defined Radio

Main characteristics

- Huge data volume
- High capacity modular data compression and Mass Memory Units
- Specific Instruments Control
- Specific Payload data processing and control systems
  - Wide variety of functions

On Board Mass Memory Unit

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Spacecraft Avionics Systems

Main Constraints for on-board electronics

- Space environment
- Industrial constraints

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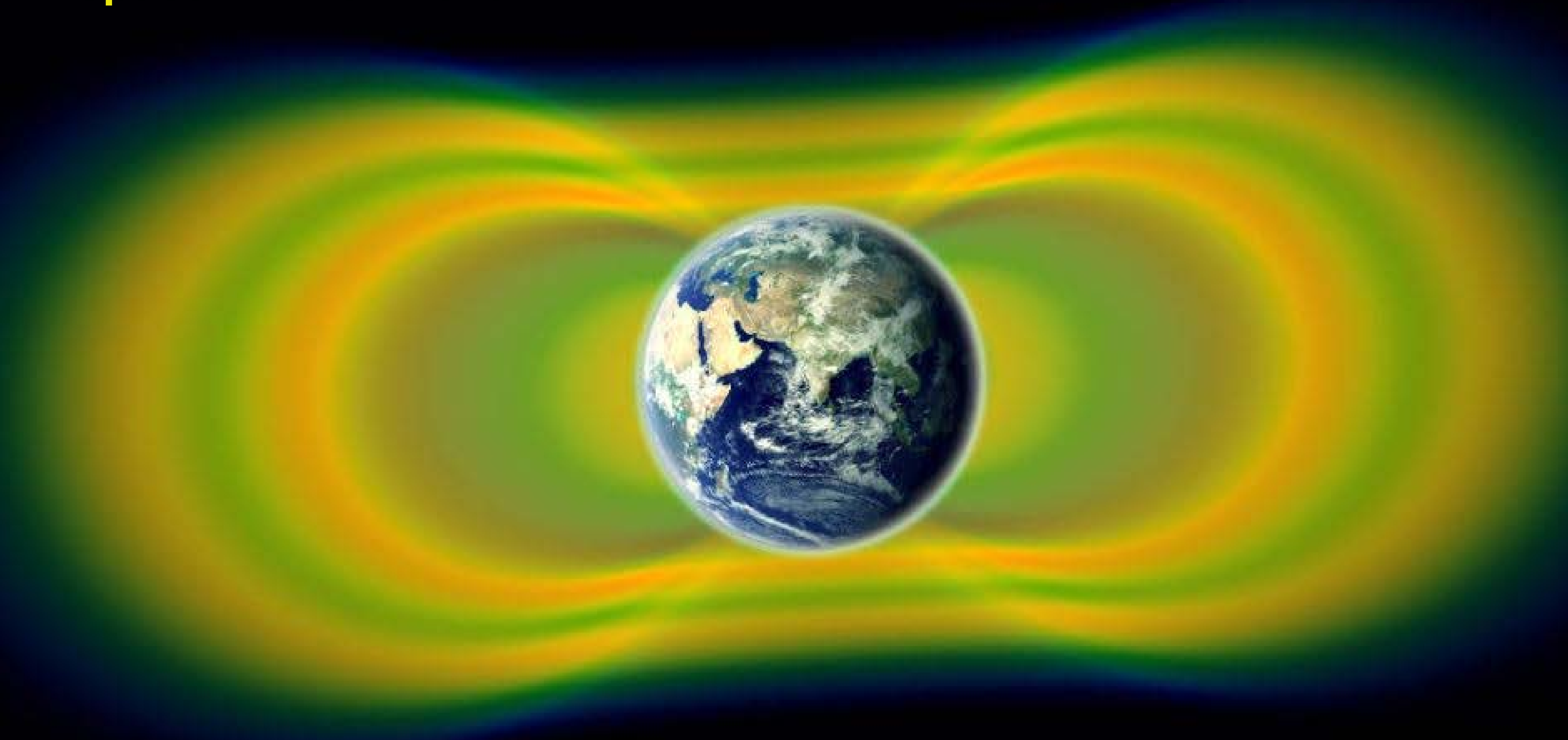
Space Environment : the radiation issue



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Space Environment : the radiation issue

Atmospheric

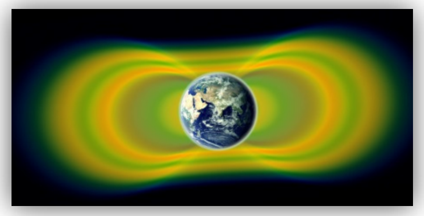
Neutrons
Alpha particles
Muons
Solar flares

Low Earth Altitude

Neutrons
Protons
Heavy ions
Solar flares

Medium Earth Altitude

Radiation belts
Trapped particles
Solar flares

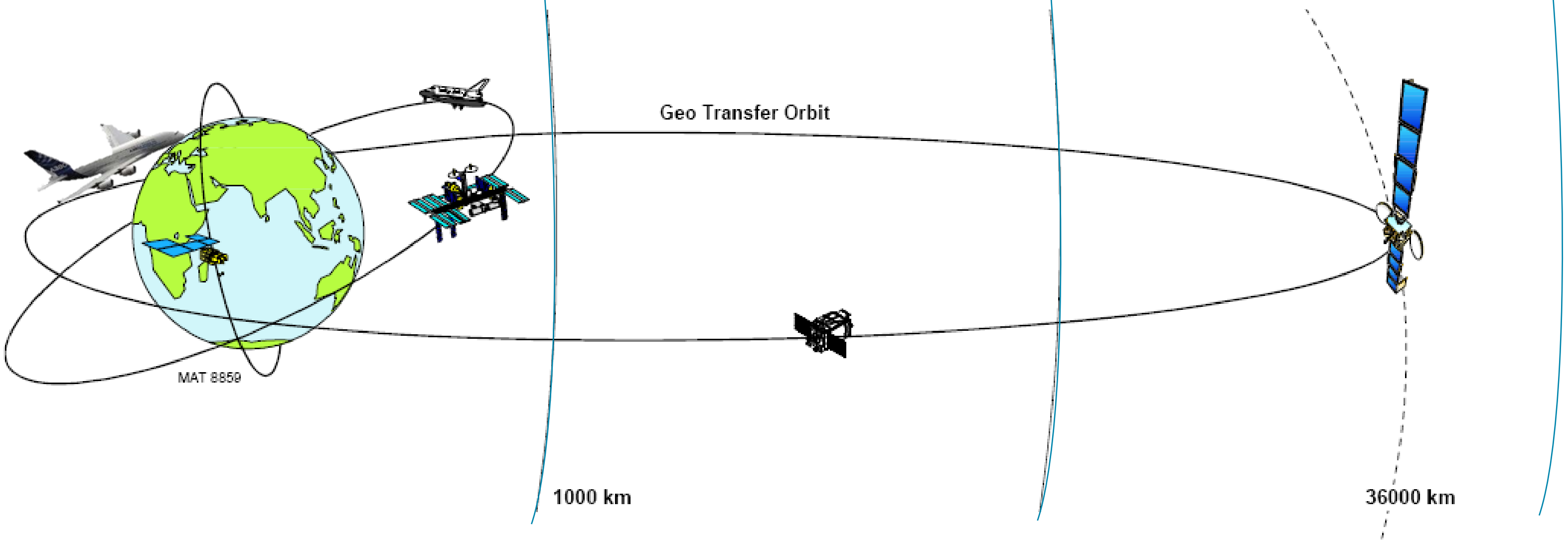


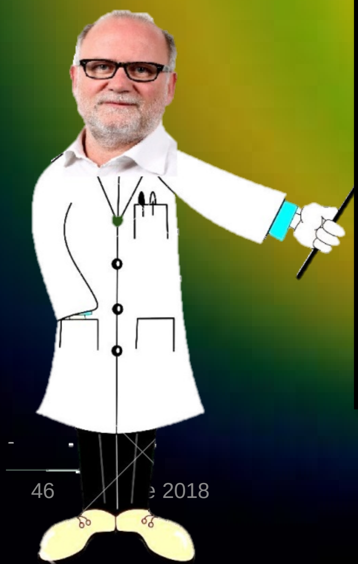
Geo Synchronous

Cosmic rays
Heavy ions
Protons
Gamma rays
Solar flares
…

Deep Space

Cosmic rays
Heavy ions
Protons
Gamma rays
Solar flares
Planets radiation belts
…





Environmental constraints

Tolerance to radiations for on-board electronics

Problems

- Destructive effects (latch-up)
- Cumulated radiation dose
  - Limits component time-life
- Transients errors due to space particles
  - Upsets generate software faults or functional interuption

Solutions

- Robust silicon technologies (e.g. Silicon On Isolator)
- Fault-tolerant design inside the chips (e.g. ECC, TMR…)
- Fault-tolerant systems architecture with COTS components

Drawbacks

- Poor electronics components and devices catalogue
- Lower processing performance
- Radiation characterisation & qualification

Energy

- Solar Energy only
- Becomes rare when far from the Sun
- Unpredictable on Planetary surfaces

Mechanical and Thermal constraints

- Vacuum and thermal variations
- Extreme and variable operational conditions
  - Assembly Integration and Tests
  - Ground, air and sea Transport
  - Launch
  - Orbital LEO short night/day cycles, GEO, Deep Space

Result: Specific and complex electronics, heavy investments, long development, limited performances

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Industrial constraints

Variety of missions

- Generic platforms: Requirement domain without precise mission selection
- Standard Product families: Customisation for adaptation to mission

Make or Buy decision

- Interfaces standardisation, inter-operable products catalogue
- International partnerships, GEO return, ITAR constraints

Testability

- Complexity of systems makes full test coverage difficult
- Improvement of production, integration and validation methods and tools

Quality

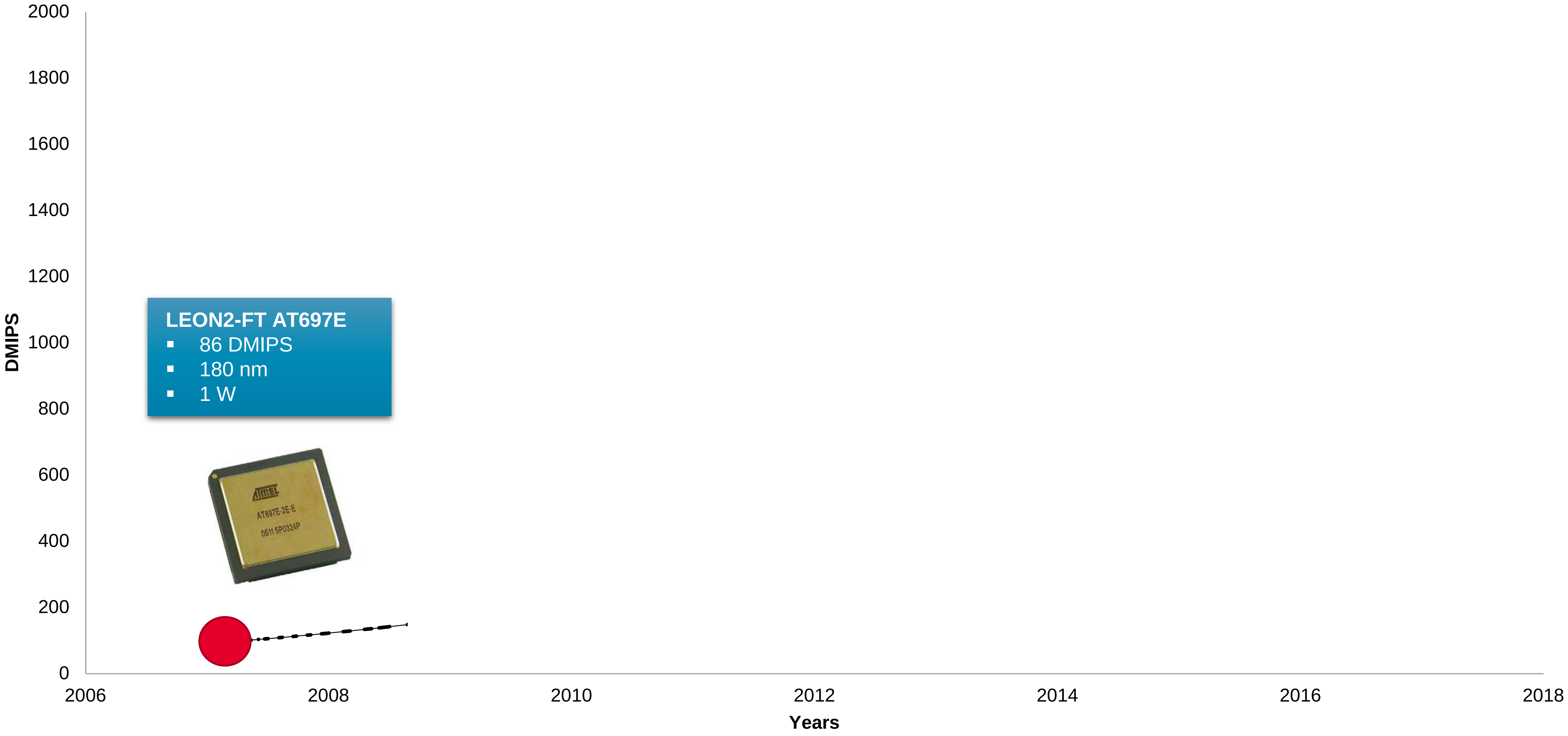
- cost of non-quality is very difficult to predict and it is not easy to repair defects in space
- Rigorous standards for development and manufacturing processes

Obsolescence

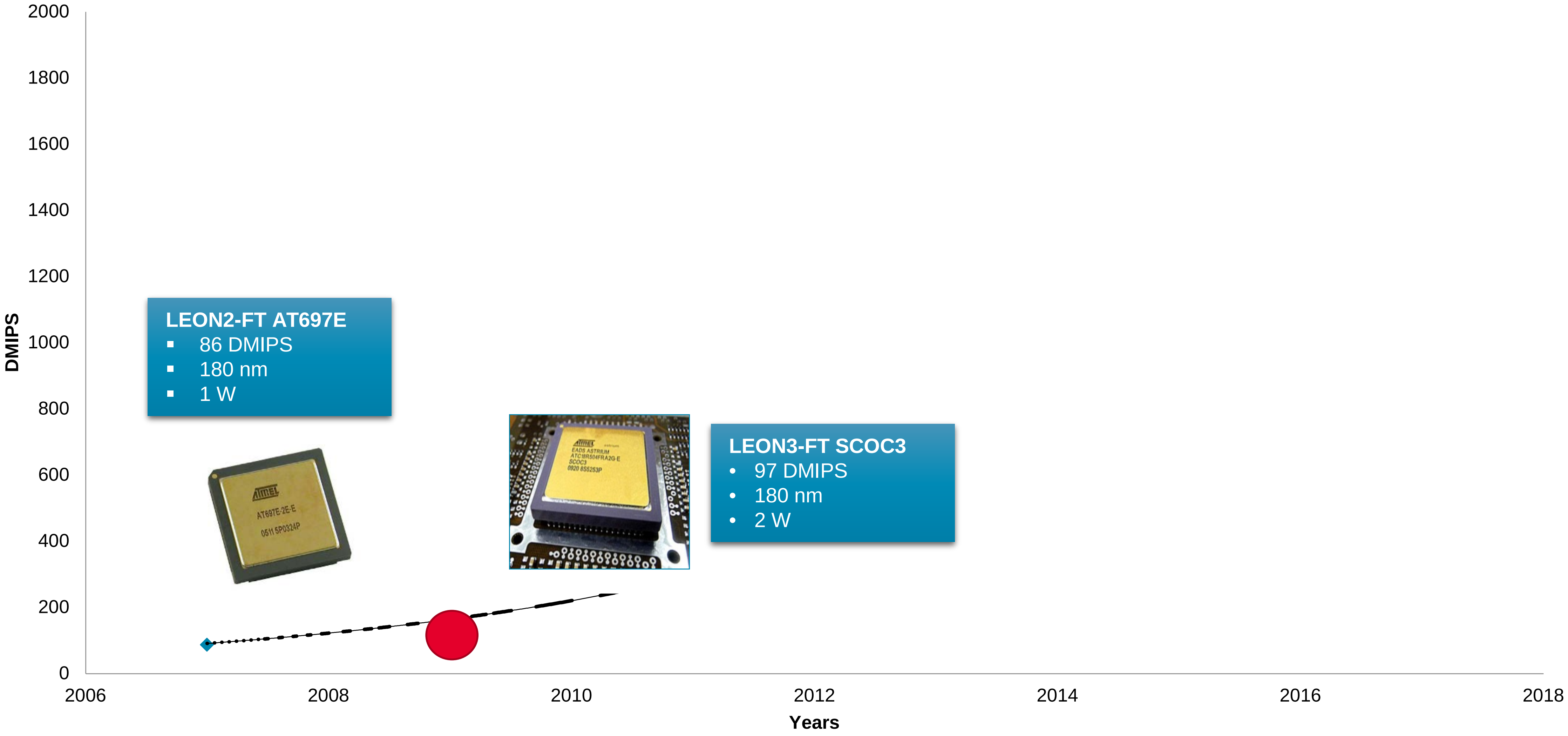
- Maintenance of critical components manufacturing capability
- Strategic stocks for key products

Spacecraft On-board Computer

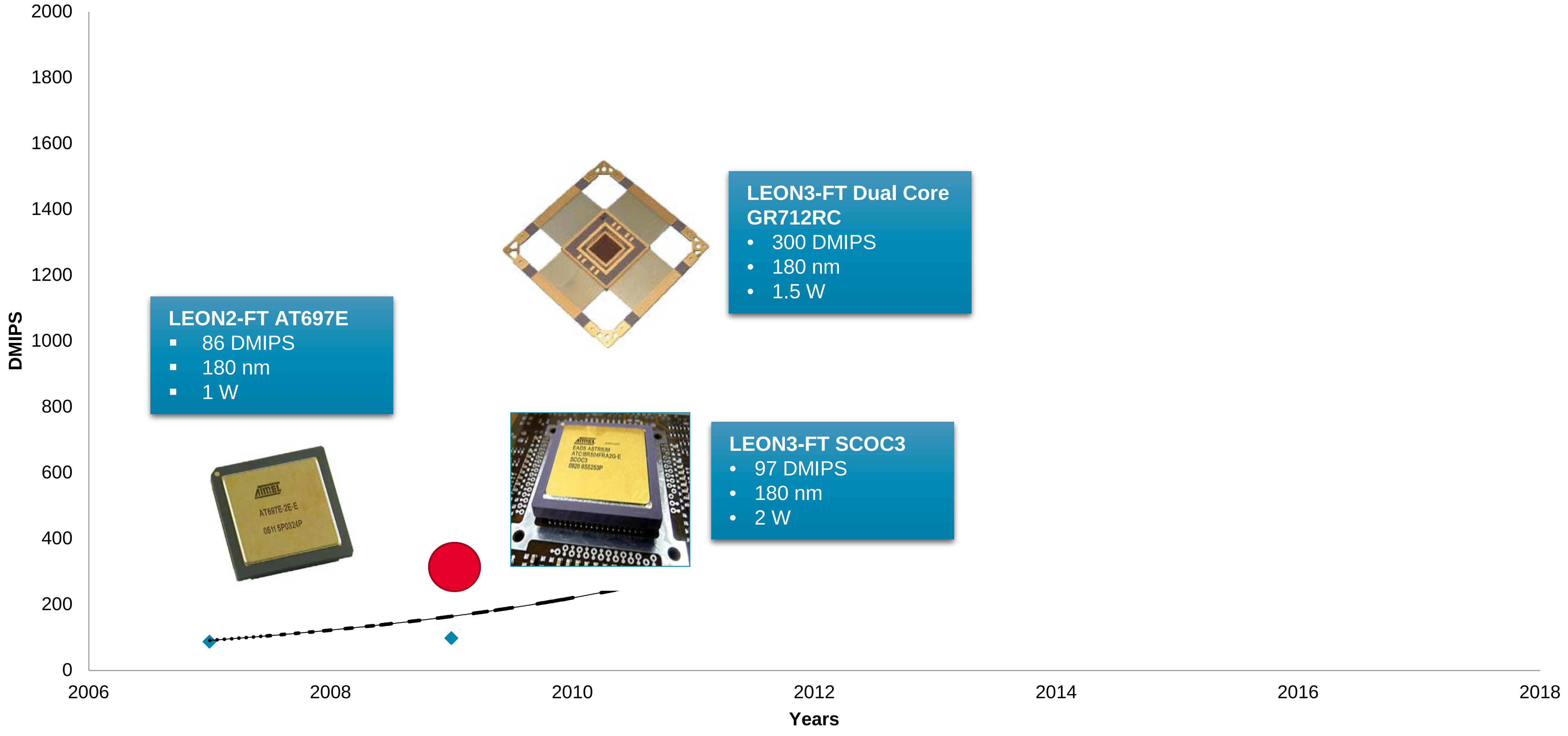
Space Processors Roadmap



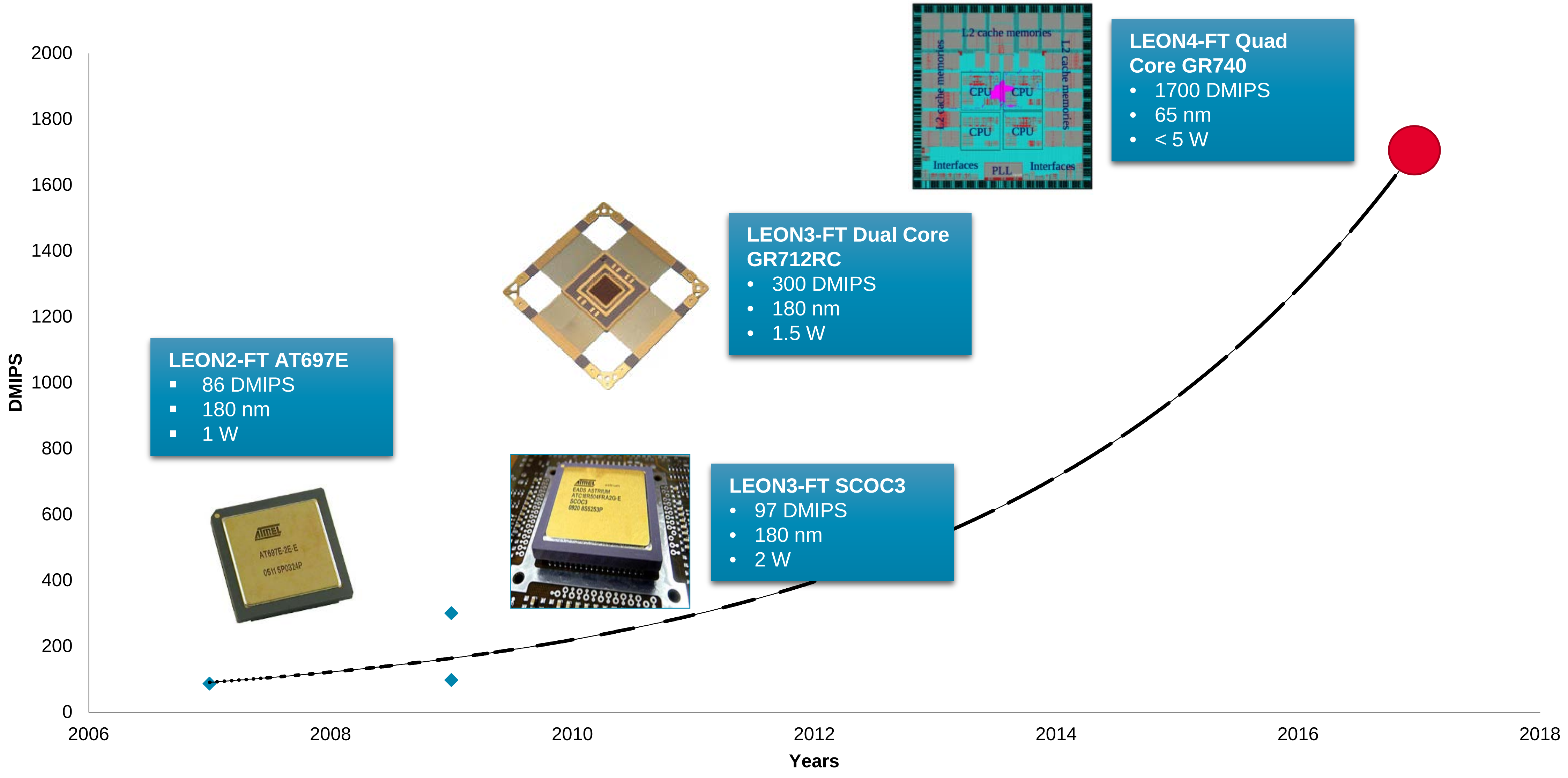
Space Processors Roadmap



Space Processors Roadmap



Space Processors Roadmap



Satellite Platform Computer: OSCAR

SCoC3

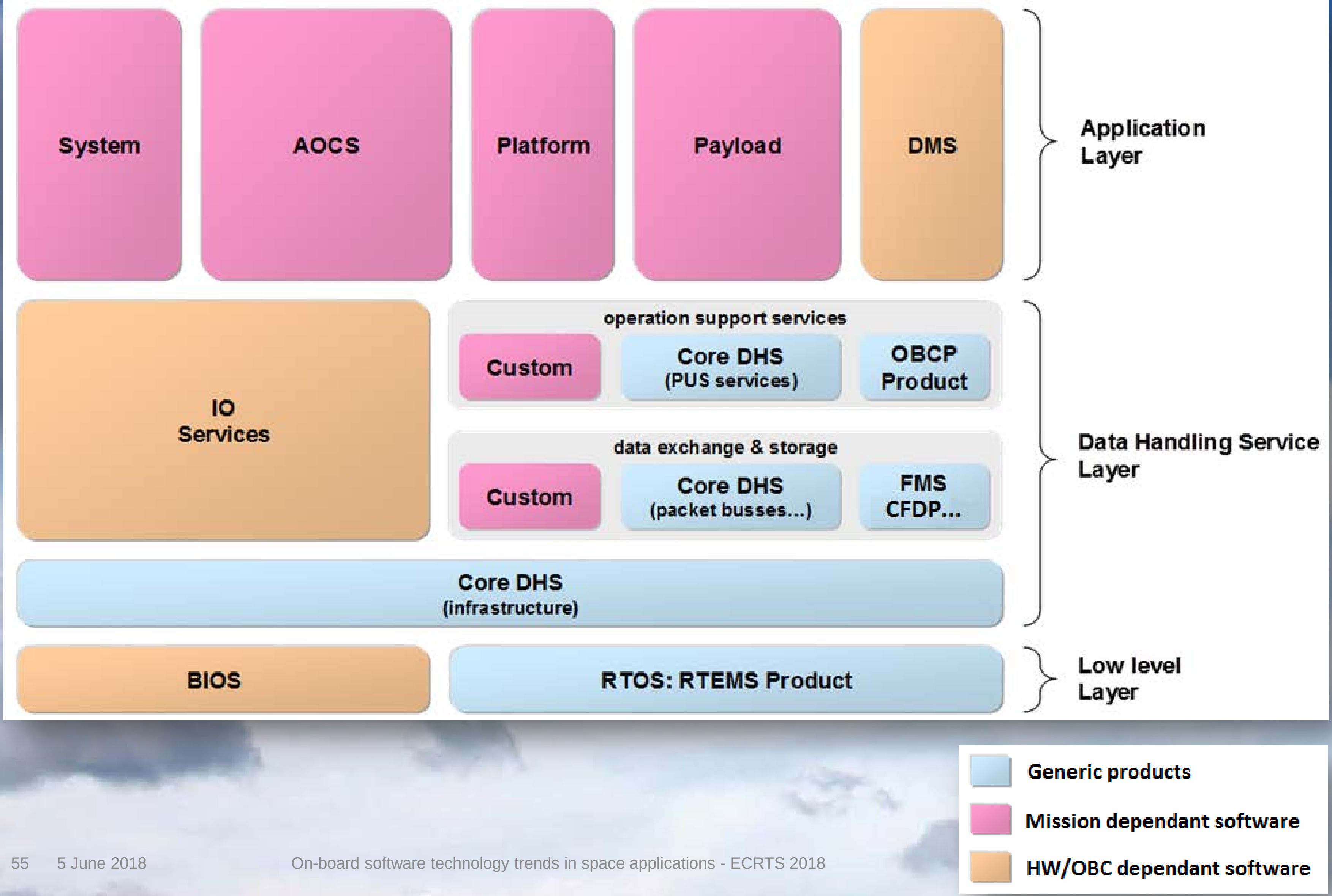
SpaceCraft Controller on a Chip

97 DMIPS
2 Watts
0.18 µm ATMEL
RAD-HARD with TMR
Built-in debug support

OSCAR

Satellite Platform Computer

OSCAR Central Software



Satellite Central Software

RTEMS

Core DHS Library

- PUS services

LEON 2

- COLE and MDPA

LEON 3

- SCoC3

SDE

- Eclipse
- C language
- Autocoded AOCS
- Numerical Simulation and Validation Facility

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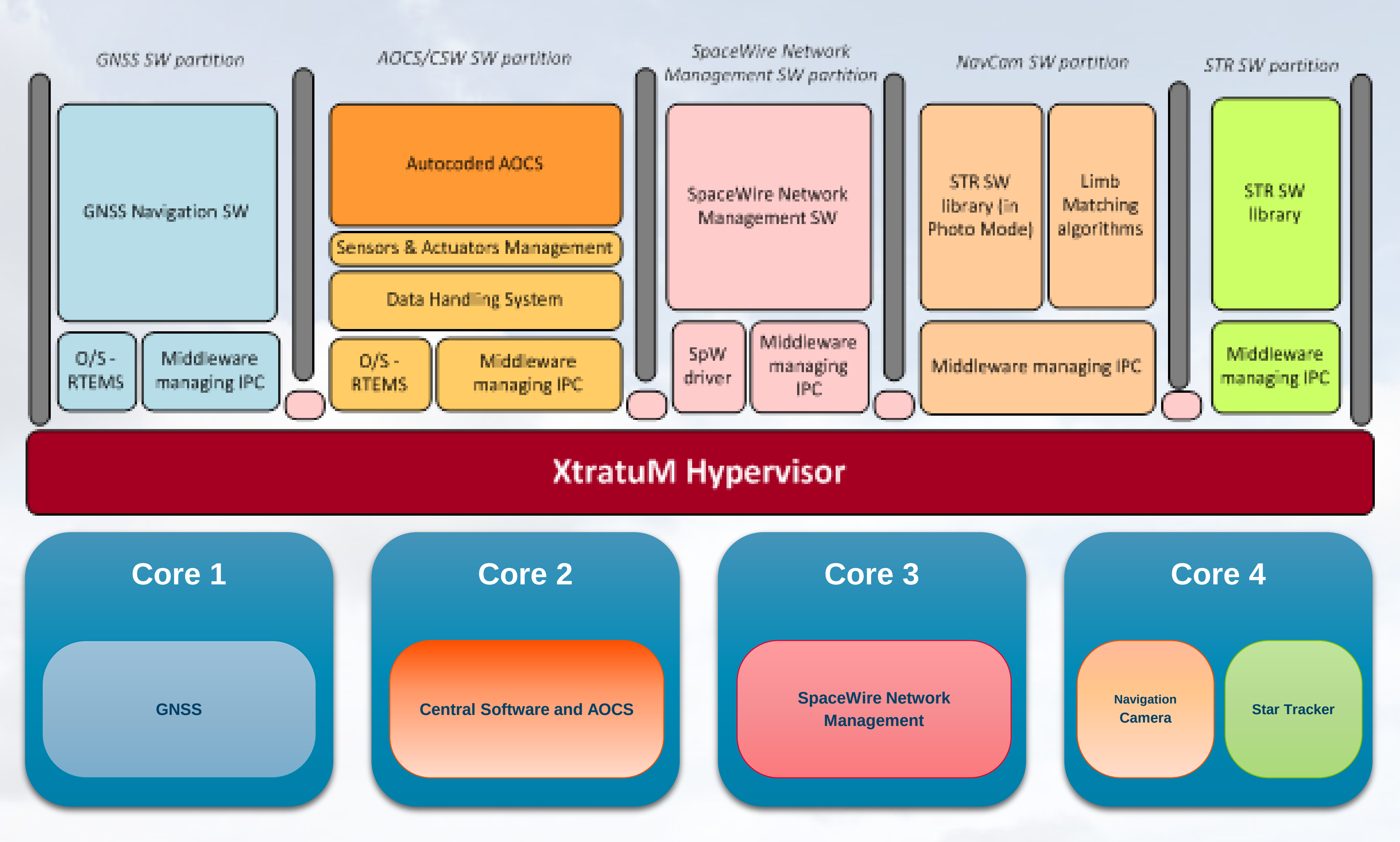
Central Software with Very Integrated Avionics



Satellite Central Software

- TSP Hypervisor
  - Xtratum / PikeOS
- RTEMS / Linux
- Asymmetrical Multi Processing
  - Static partition mapping

- LEON 4 (GR740)
- Multicore ARM

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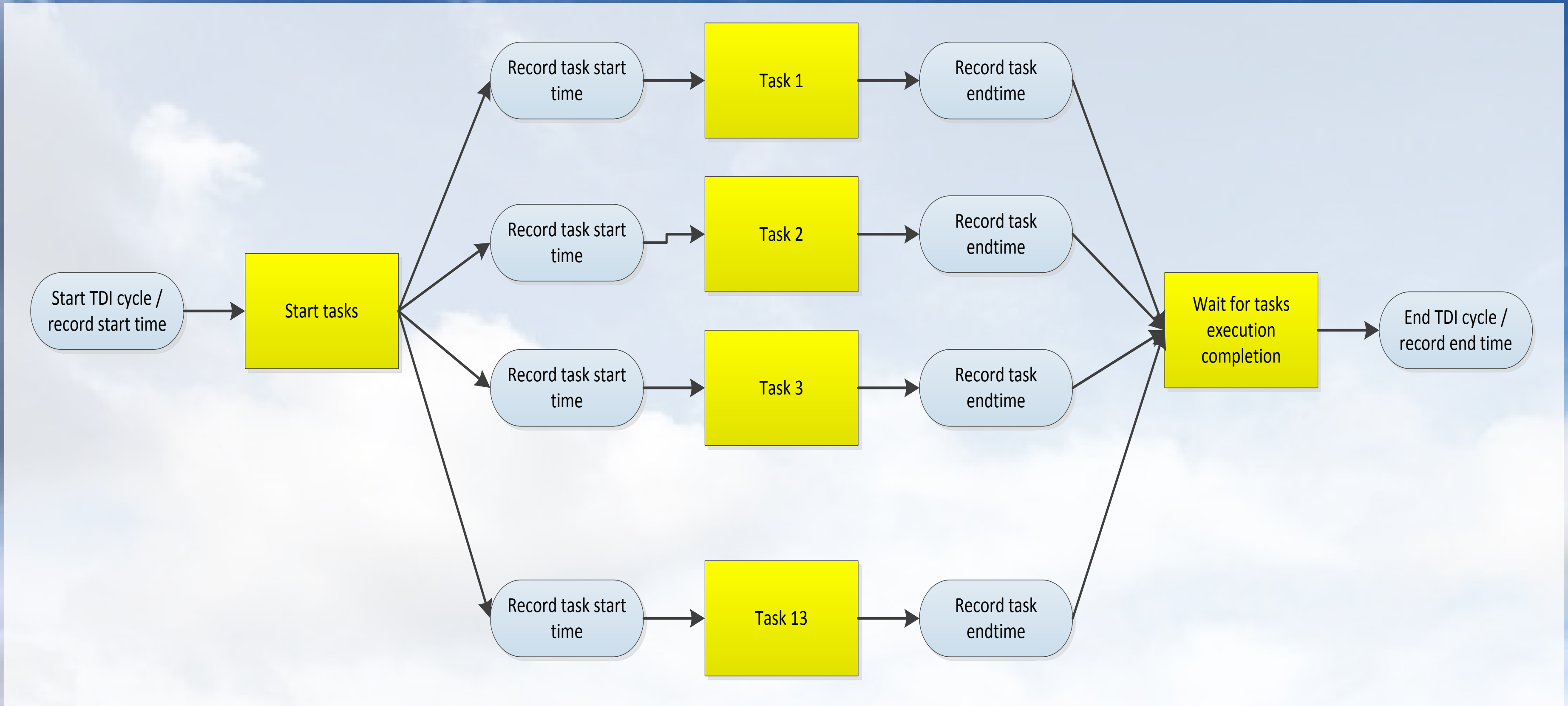
High Performance Payload Data Processing



For Highest Performance → ASIC or FPGA

Payload Software

S/W Parallelisation

- RTEMS MTAPI
- OpenMP

Multicores

- LEON 4 (GR740)
- Multicore ARM

Manycores

- HPDP (Airbus)
- MPPA (Kalray)
- RC64 (RamonChips)
- GPUs

On-board software technology trends in space applications

Space

Vision

Targets

Technologies

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On-board software technology trends in space applications

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NEW SPACE

AIRBUS DEFENCE AND SPACE STARTS A NEW ERA IN SPACE

WITH ONEWEB CONSTELLATION…

TOTAL COVERAGE

Internet to everyone, everywhere on Earth

A REVOLUTION IN SATELLITE MANUFACTURING

No one has ever built a satellite in one day… we will build several every day!

GLOBAL LOW EARTH ORBIT CONSTELLATION

Providing high-speed internet connectivity equivalent to terrestrial fiber-optic networks

ONEWEB

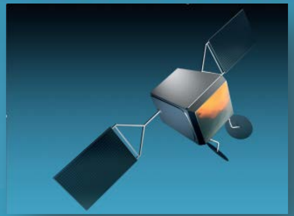
Facts & Figures

size

less than **150 kg**
weight

up to **4**
built every day

900
satellites to be built



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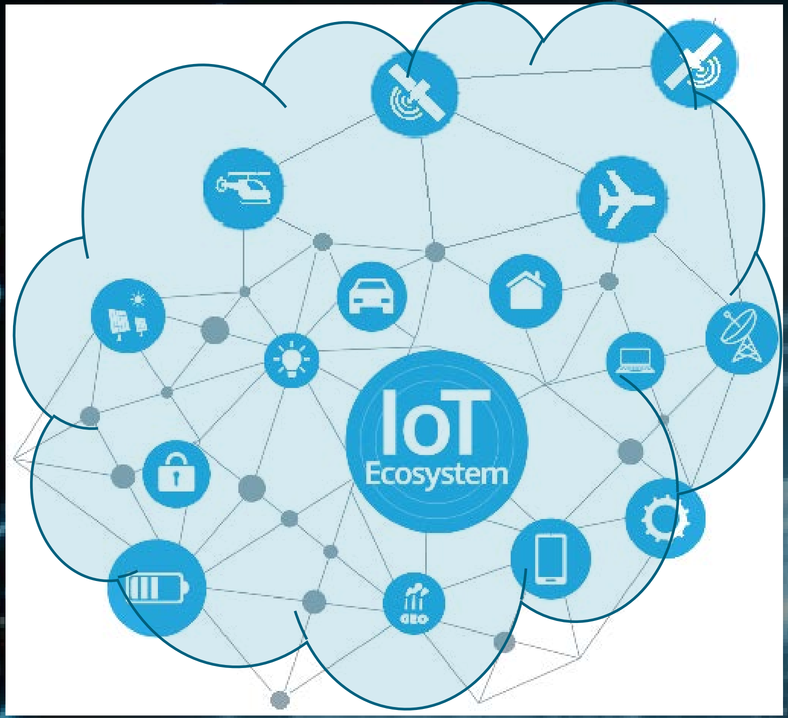
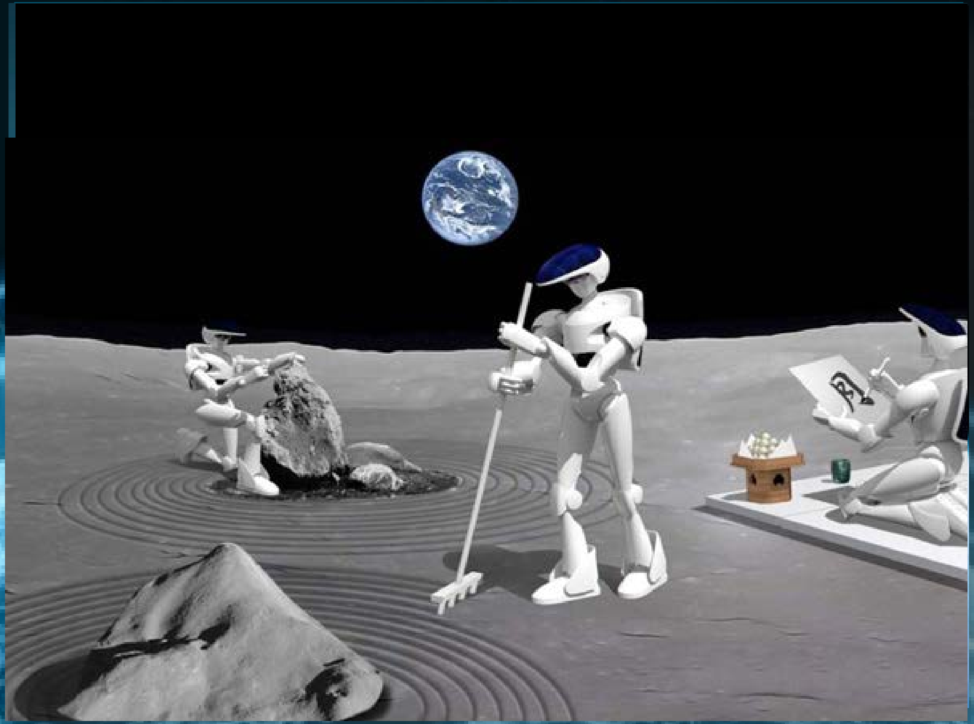
Our future is IoT @ any-time everywhere

Internet of Things
Connected smart machines



Smart vehicles and robots in smart cities
Electrical, Connected and Autonomous



Machine learning | Big Data | Cloud | Artificial intelligence

SOFTWARE | Data Processing

Electronics

Today IoT

Tomorrow

- **V**ehicles
- **R**obots
- **A**utonomous
- **C**onnected

20th Century On-board Data systems are outdated

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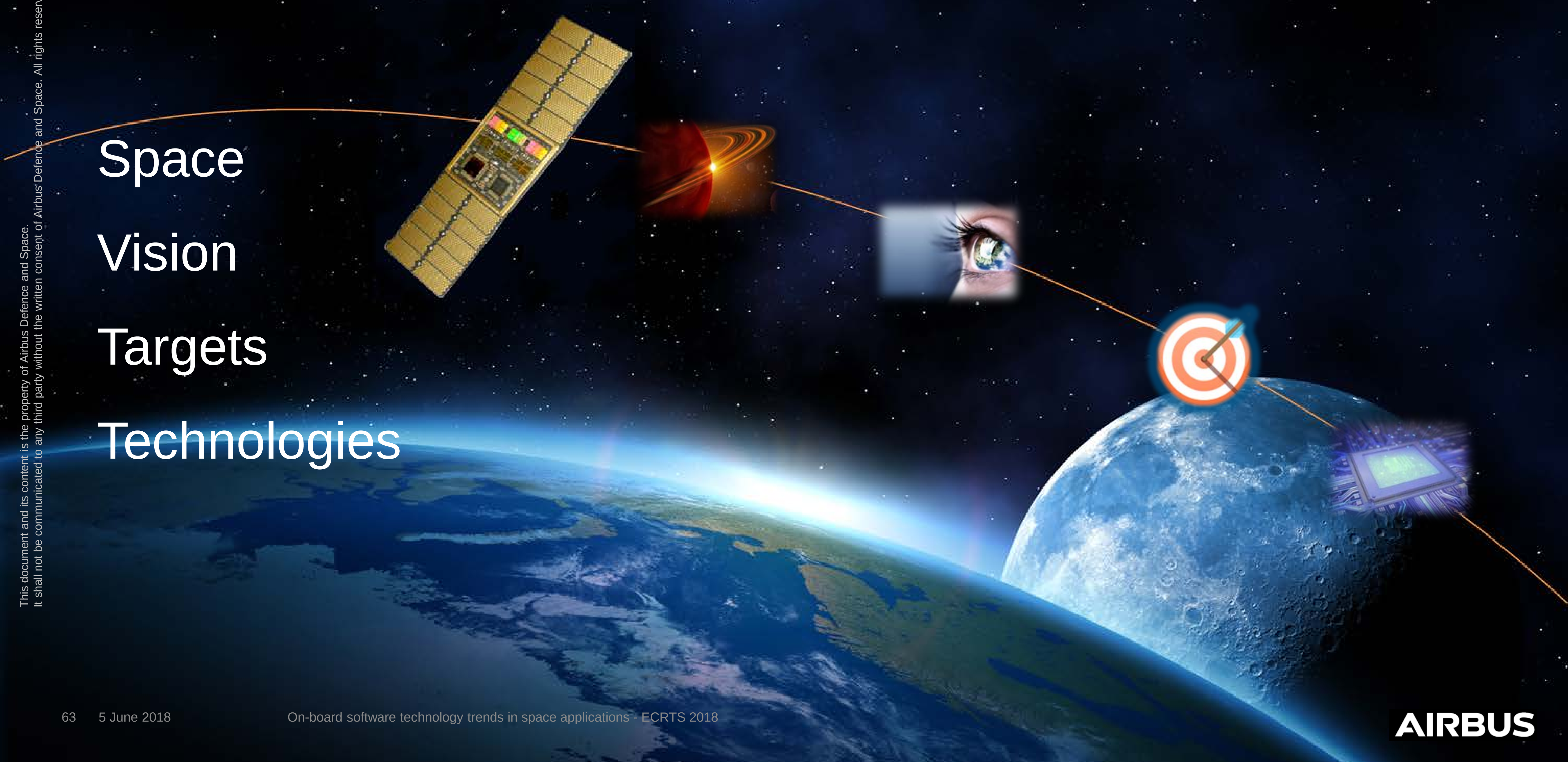
On-board software technology trends in space applications

Space

Vision

Targets

Technologies



Targets

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Targets

OPEN

Connectivity

data-centric
massive data volumes
Field/Ground/Cloud balance
Global Data access

Communications
Customization friendly
End to End Quality of Service

Trusted and Secure
Always up-to-date
in-depth cybersecurity protection

Autonomy

Onboard **Deep learning**
Artificial Intelligence
High computing power

Robotics
Image processing
Mission Autonomy

Open platform
evolutive flexible scalable
Virtualization
Onboard **IoT**

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Values

Cost

- Synergy with other domains
- Functional integration
- Development Tools

Flexibility

- Reconfigurable systems
- Modular architecture
- Standards

Robustness

- Reliability
- Determinism
- Availability

Performance

- Processing power (MIPS/Watts)
- Processing architecture
- Parallelization

On-board software technology trends in space applications

Space

Vision

Targets

Technologies

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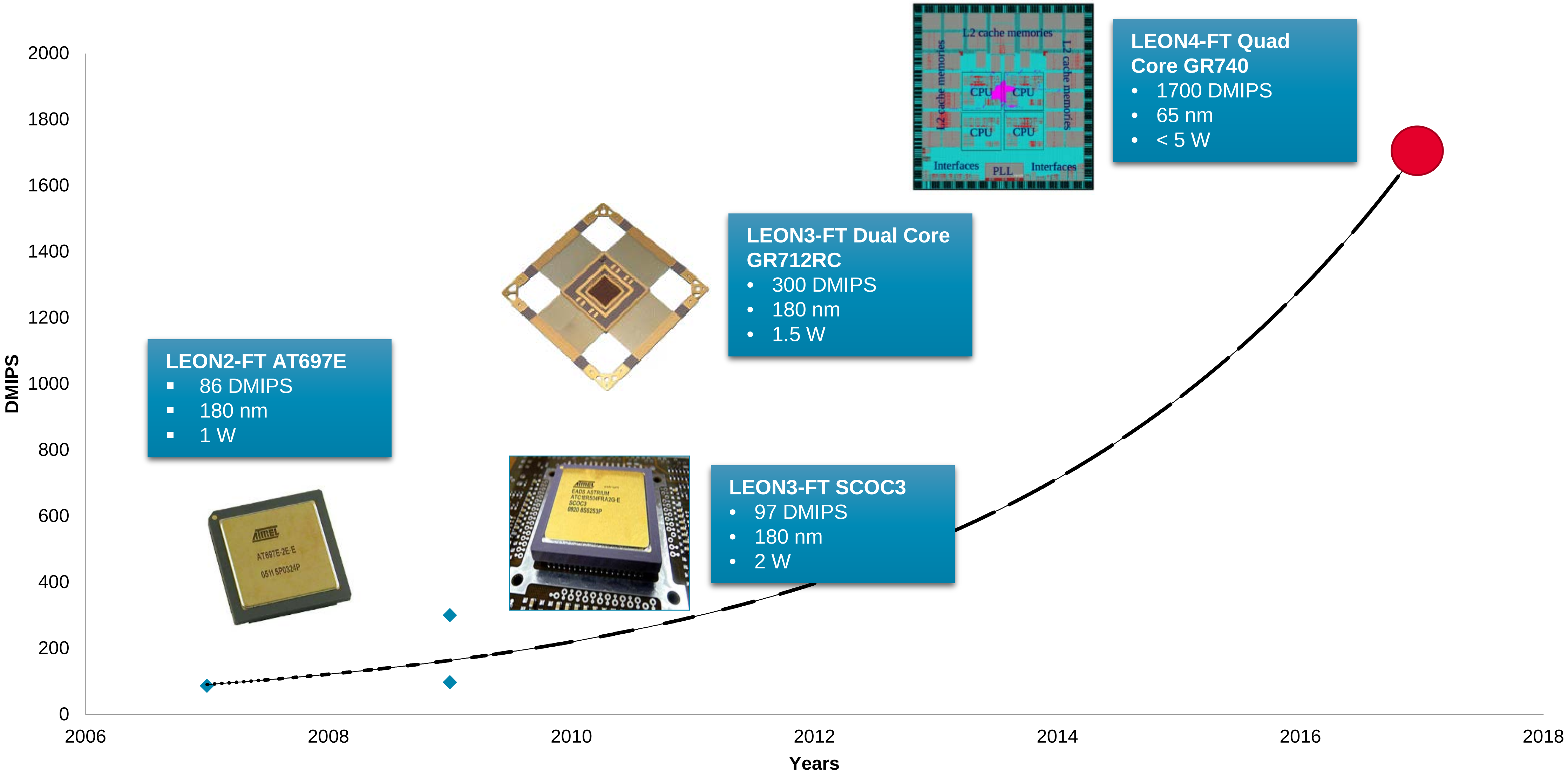
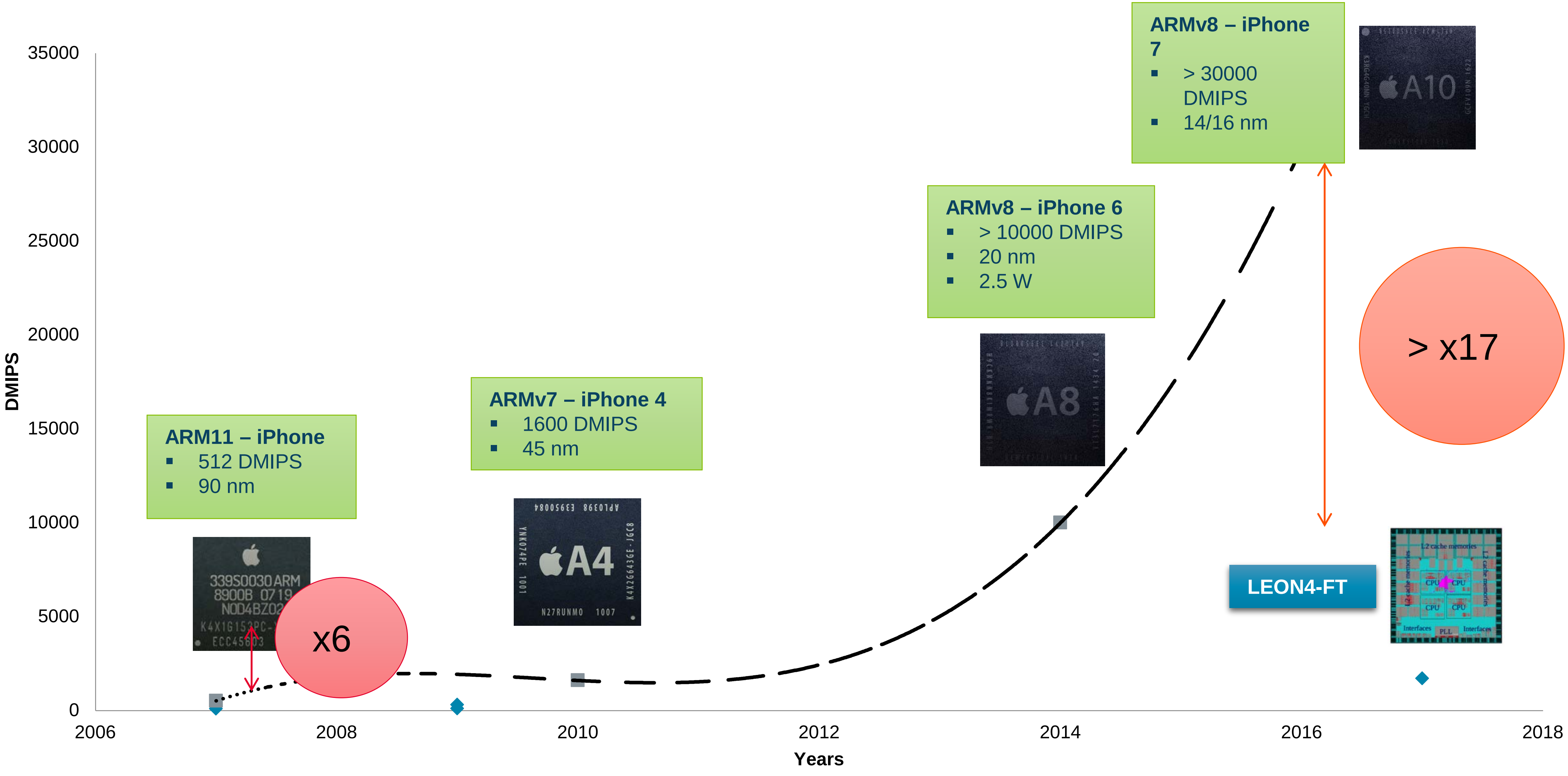
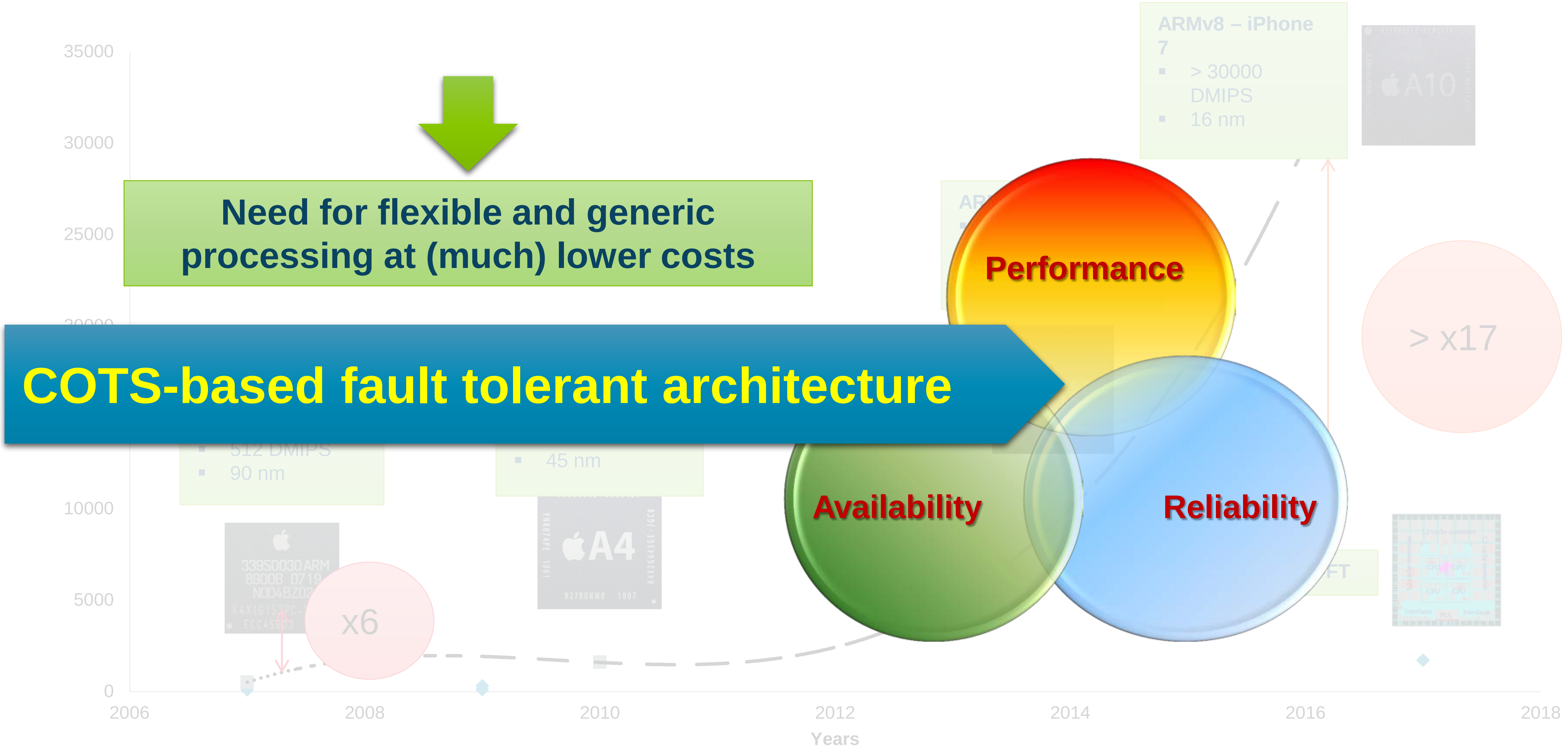
Space Processors Roadmap



Space Processors Roadmap vs Smartphone Roadmap



GPP/SoC: Space Roadmap vs Smartphone Roadmap



Why COTS ?

RAD-HARD

High NRC
High RC

Devices
- LEON family
- GR712, GR740
- BRAVE
- HPDP
- DALHIA

Techno
- 65 nm
- slow evolution

Software
- Specific development tools
- Small user community

Environment
- Robust in the space environment

COTS

Medium NRC
Low RC

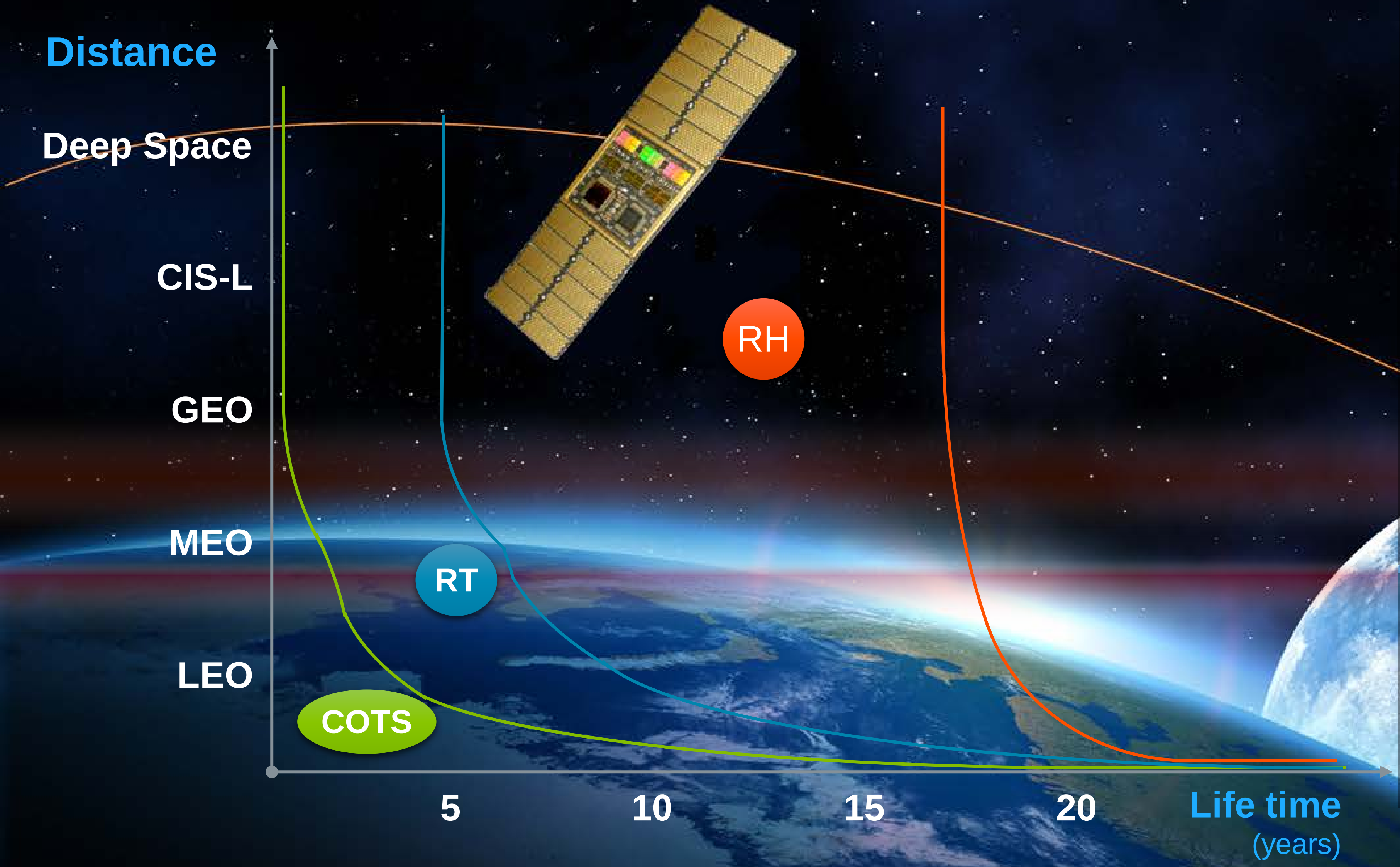
Devices
- ARM
- Multicores
- Reprogrammable FPGAs
- DSPs
- Many cores, GPUs
- MPSoC

Techno
- 16 nm
- Fast evolution

Software
- Good and mature tools
- Large user community

Environment
- Radiations vulnerability
- Requires mitigation
- Requires selection & Qualification for space use
- Rad-Tolerant with mitigation mechanisms

In Space with COTS based Computers ?



Deep Space
Medium to very long duration
High radiations levels
Mostly institutional missions
⇨ **Rad-Hard technology**

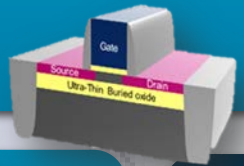
MEO/GEO
Medium to long duration
Medium to high radiations levels
Commercial + institutional market
⇨ **Rad-Tolerant** or **Rad-Hard**

LEO applications
Low to medium duration
Low to medium radiations levels
Commercial + institutional market
⇨ **Qualified COTS or Rad-Tolerant**

Atmospheric applications
Low to very long duration (maintainable)
Less radiations but many more devices
High commercial market pressure
Critical (human transport or assets)
⇨ **Qualified or Certified COTS**

Micro-electronics Technology trends

Technology



Miniaturization

180nm
150nm
90nm
65nm
28nm
22nm
16nm
14 nm
12nm
10nm

Transistors

CMOS
Bulk
Fin-FET
SOI
FD-SOI
FD-SOI UTB

Design

Architecture

FPGA
Multi/many-cores
SoC & MP-SoC
Hybrid devices
High Speed Interfaces
Digital/Analog

Software

Development environment
OS & Hypervisors
SMP AMP
MTAPI
OpenMP / OpenCL
SystemC
VHDL
HDL HLS

Challenges

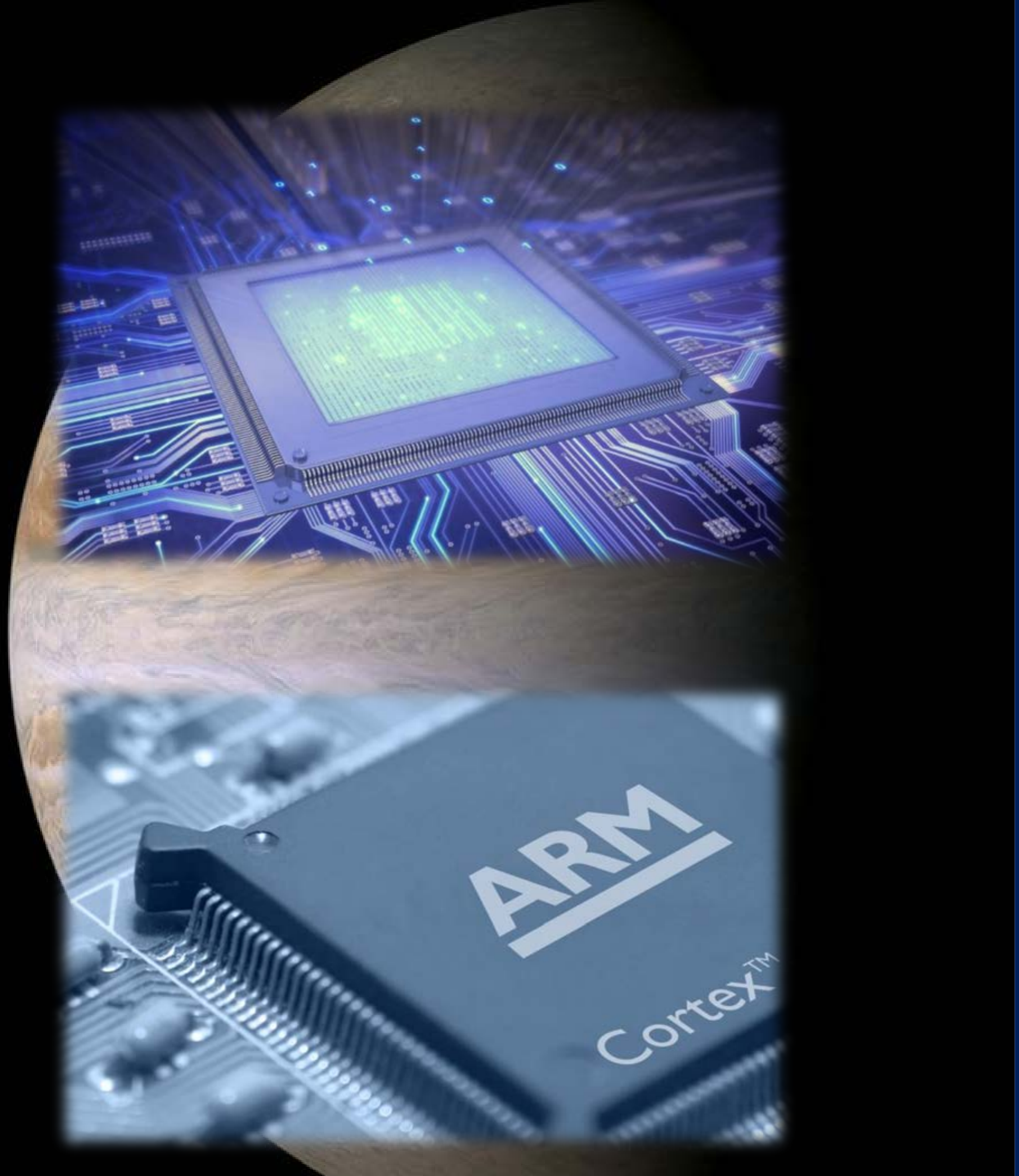
Complexity management

Resource sharing
Parallelization
Memories
Caches
IOs
Functional integration
verification
Process
COST

Values

Reliability
Robustness
Power Efficiency
Safety
Security
Certification

Technology enables future applications



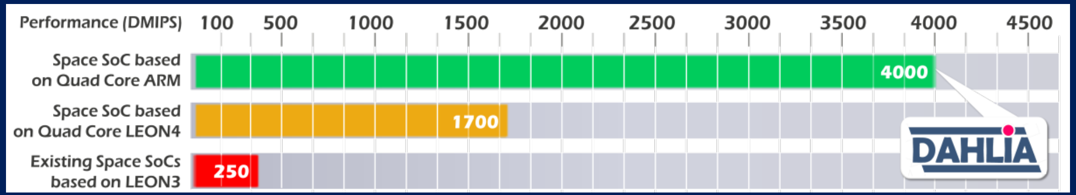
STM 28nm FD-SOI Technology

- High performance with low power consumption
- High robustness in radiation environment

a powerful combination of innovative technology adapted for Space

ARM Cortex-R52

- ARM's most advanced processor for safety



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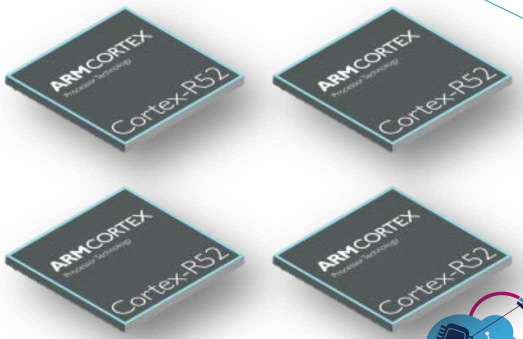
DAHLIA

Deep sub-micron microprocessor for spAce

dahlia-h2020.eu

- Context & Objectives
  - Horizon 2020 project focusing “Critical Space Technologies for European Strategic Non-Dependence”
  - Covers the development of a rad-hard high performance MPSoC based on the **ARM® Cortex® R52** implemented in **28nm FDSOI technology**
  - Beyond space applications, the adoption of the ARM® processor will enable the convergence with terrestrial applications benefiting from the strong ARM® ecosystem.



Schedule

2017: Kick-off

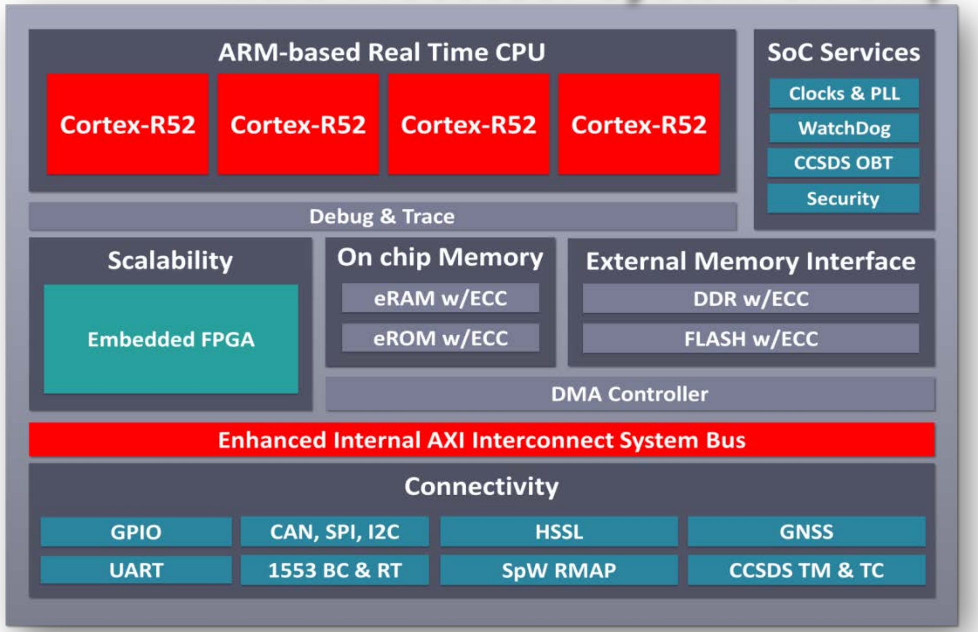
2018: FPGA prototype

2019: DAHLIA product

- 7 partners from 4 countries
  - STMicroelectronics (coordinator) France
  - Airbus D&S Germany & France
  - Thales Alenia Space Italy & France
  - ISD Greece
  - NanoXplore France

AIRBUS ThalesAlenia Space ST life.augmented ISD S.A. Integrated Systems Development NanoXplore

Multi-Processor System on Chip



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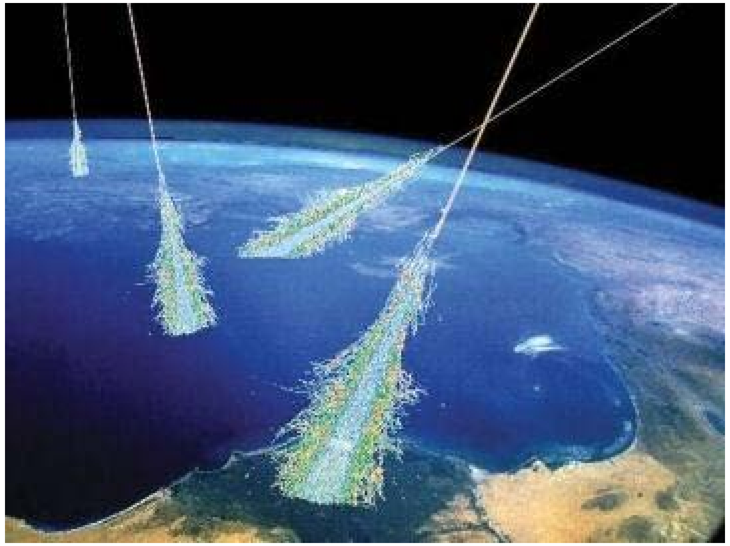
Why FD-SOI ?

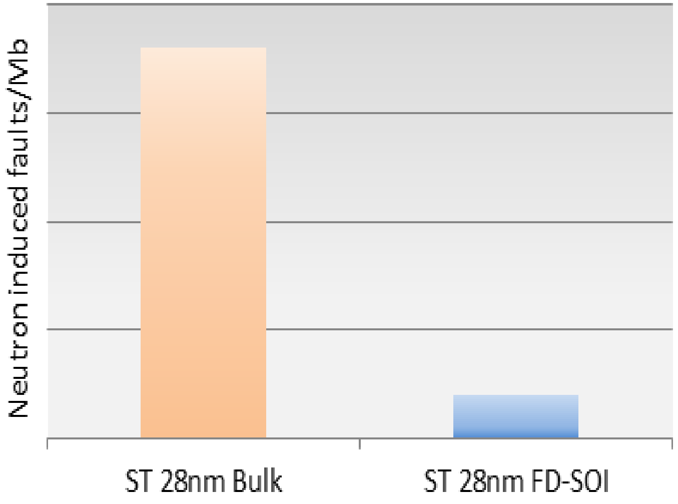
Values
Reliability
Robustness
Power Efficiency
Safety
Security
Certification

Radiations induce Bit flips, latch-up, leakage currents

- **FD-SOI improves upset rates by 100× to 1000×**
  - against neutrons, alphas, heavy ions, protons, muons, thermals, low energy protons…
  - due to both very small sensitive volume and very low bipolar gain
- **The reduced pitch size provides good tolerance to total Ionization Dose**
- **Intrinsically immune to Latch-up**



Atmospheric neutrons



Soft Error Rate

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Why FD-SOI ?

Power/Performance/Cost tradeoffs

- **FD-SOI improves power efficiency**
  - Technology allowing very low supply voltages (<0.5V)
- **Very important value for autonomy in embedded systems**
  - Mobile devices, automotive, UAV’s, space exploration and robotics…
  - e.g. AUDI A8 includes 6.000 to 8.000 semiconductor components

Values
Reliability
Robustness
Power Efficiency
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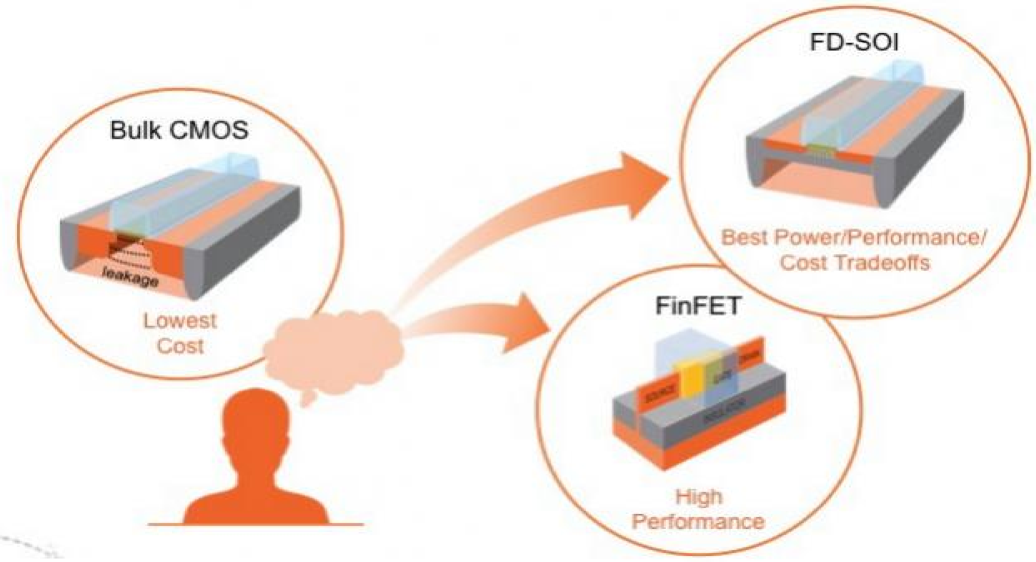

Source: Global Foundries

Source: www.robotzeitgeist.com

Source: Airbus Defence and Space

Source: Audi

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Cortex-R52

ARM's most advanced processor for safety

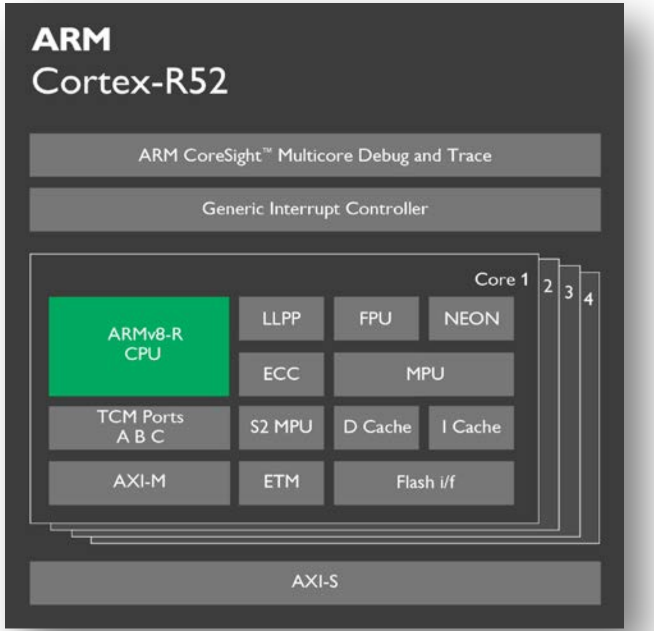
- Dedicated for safety applications including automotive, industrial and healthcare
- Simplifies integration of software in complex safety critical systems

Safety features

- ECC protected memory
- Software BIST libraries
- Error management
- Memory Protection Unit
- New privilege level
- …

ARM CoreSight™

- Debug and Trace
- Health Monitoring



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This keynote was not about automotive in space…

This keynote was not about automotive in space… but who knows…?

Creating a better connected,
safer and more prosperous world

Thank you for your attention !

Questions ?

Acknowledgements

Airbus, ESA , CNES, NASA and SpaceX for their great images of space vehicles
to David Bowie for his great song “life on Mars”
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Olivier.notebaert@airbus.com
Arbus Defence and Space
31 rue des cosmonautes
31402 Toulouse Cedex 4
France

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