SpaceWire use on future space systems

SpaceWire Working Group Meeting N°5
ISAS/JAXA, Japan - 15-17 November 2005

Olivier NOTEBAERT - Data Processing and Advanced Studies

- High speed data links on recent spacecrafts
- Needs for high speed data links
- High speed data links on future missions

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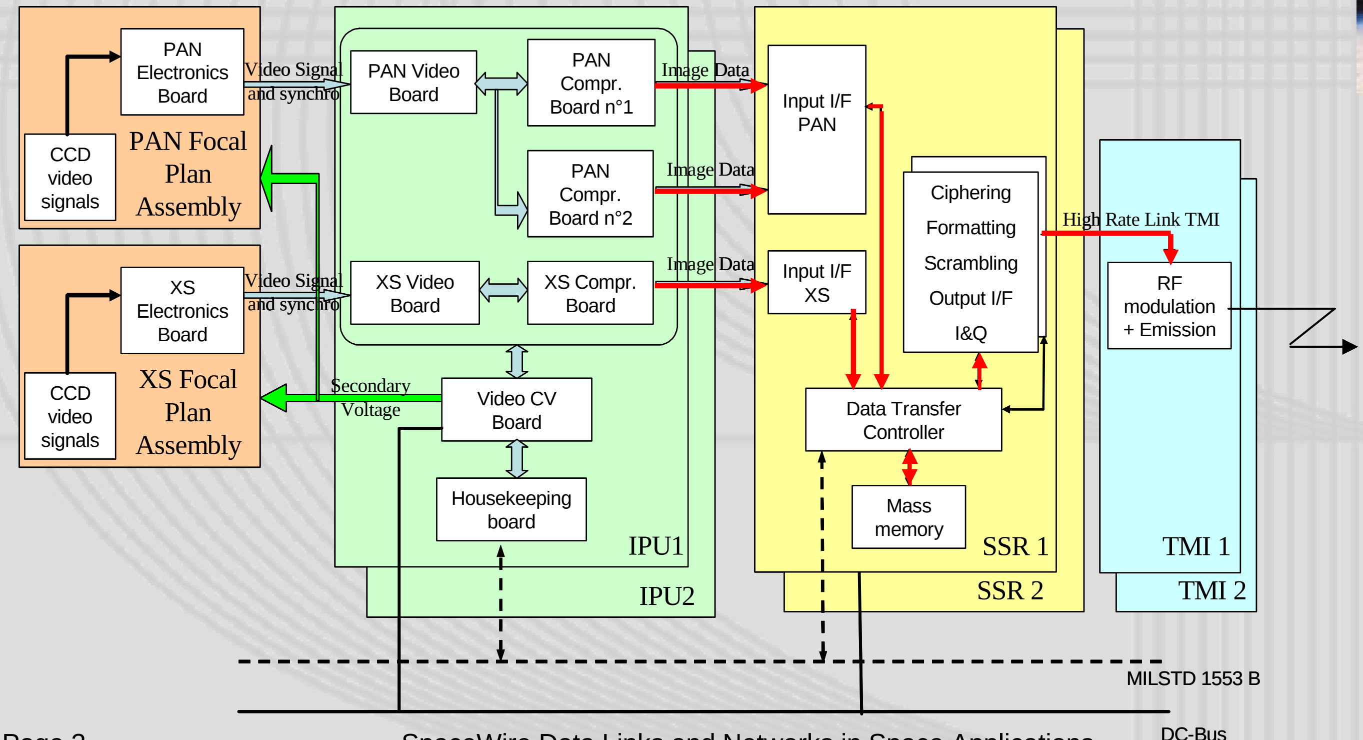
High speed data links on recent spacecrafts

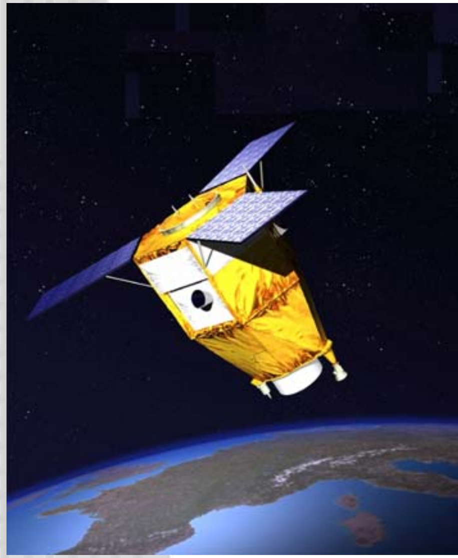
Rocsat 2 / Theos (export)

- Small/Medium size (750kg) on LEO
- Two observation instruments
  - ❑ Pan chromatic Telescope (10 Mpix/s ⇨ 240 Mbps digital)
  - ❑ Multispectral camera (5 Mpix/s ⇨ 60 Mbps digital)
- Specific high speed links for image data transmission

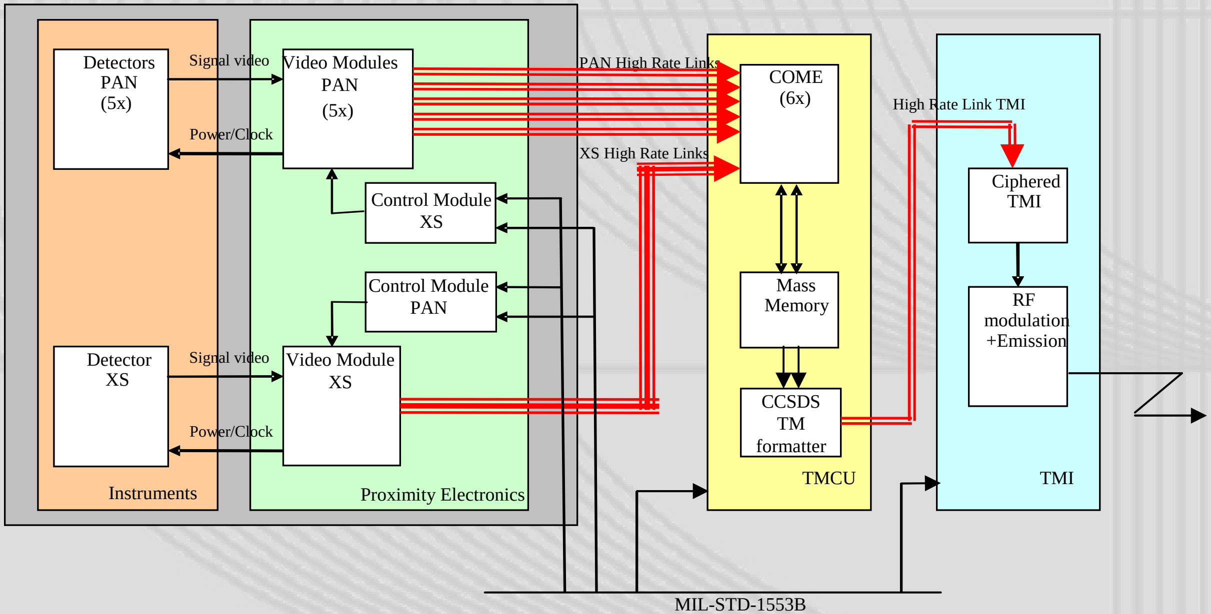


High speed data links on recent spacecrafts

Pleiades (Cnes)

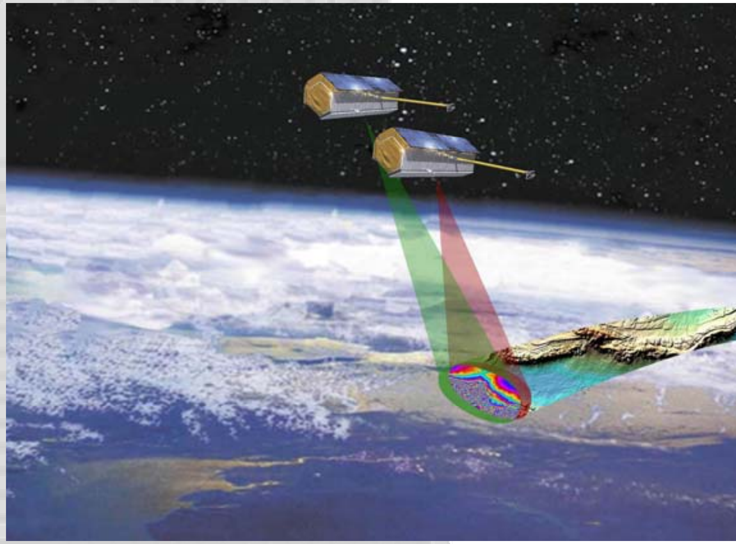


- Medium size (1500kg) on LEO
- Two observation instruments with proximity electronics for signal digitalisation
  - ❑ Pan chromatic Telescope (58 Mpix/s ⇨ 690 Mbps)
  - ❑ Multispectral camera (14 Mpix/s ⇨ 172 Mbps)
- Re-use the SPOT/Helios High Speed Links for image data transmission

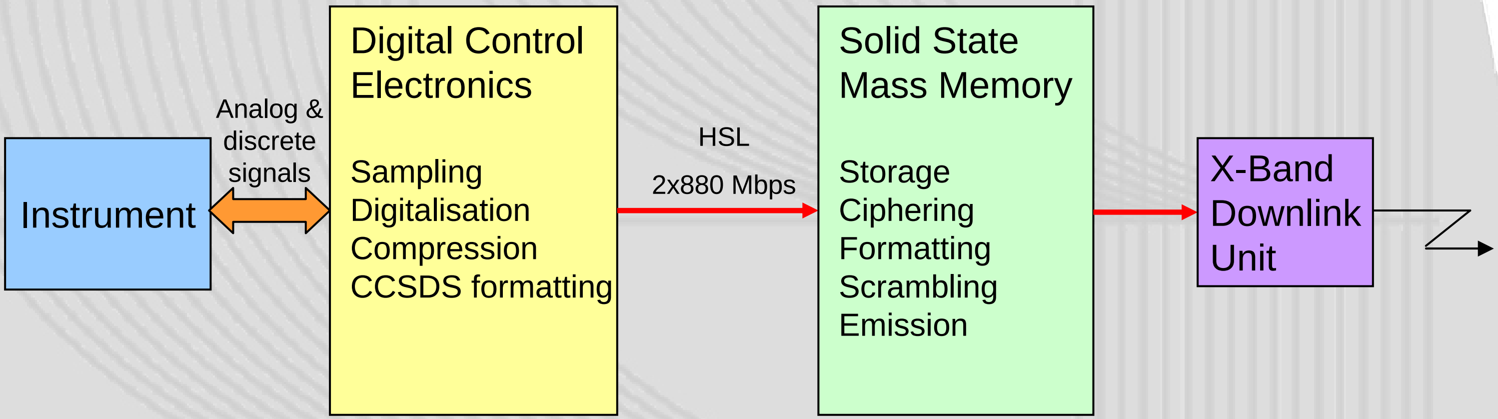


High speed data links on recent spacecrafts

TerraSAR-X (DLR)

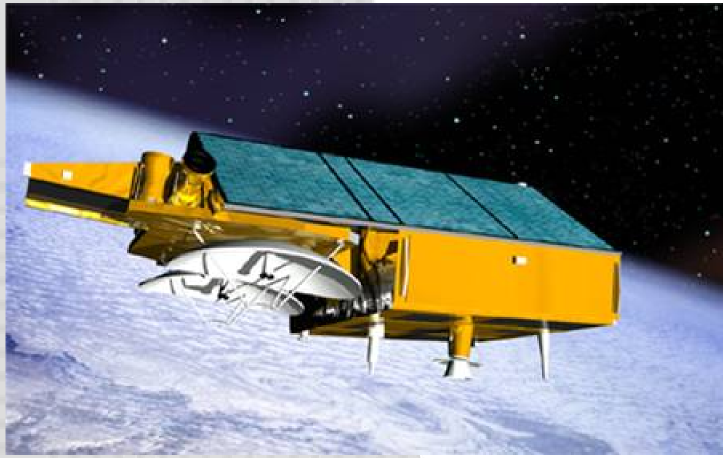


- Earth observation (DLR)
- Two spacecrafts system
- One complex instrument
  - X-Band Synthetic Aperture Radar (SAR)
  - Specific Digital Control Electronic
    - Instrument close loop control
    - P/L data processing and delivery to Solid State Mass Memory (880Mbps on G-link)

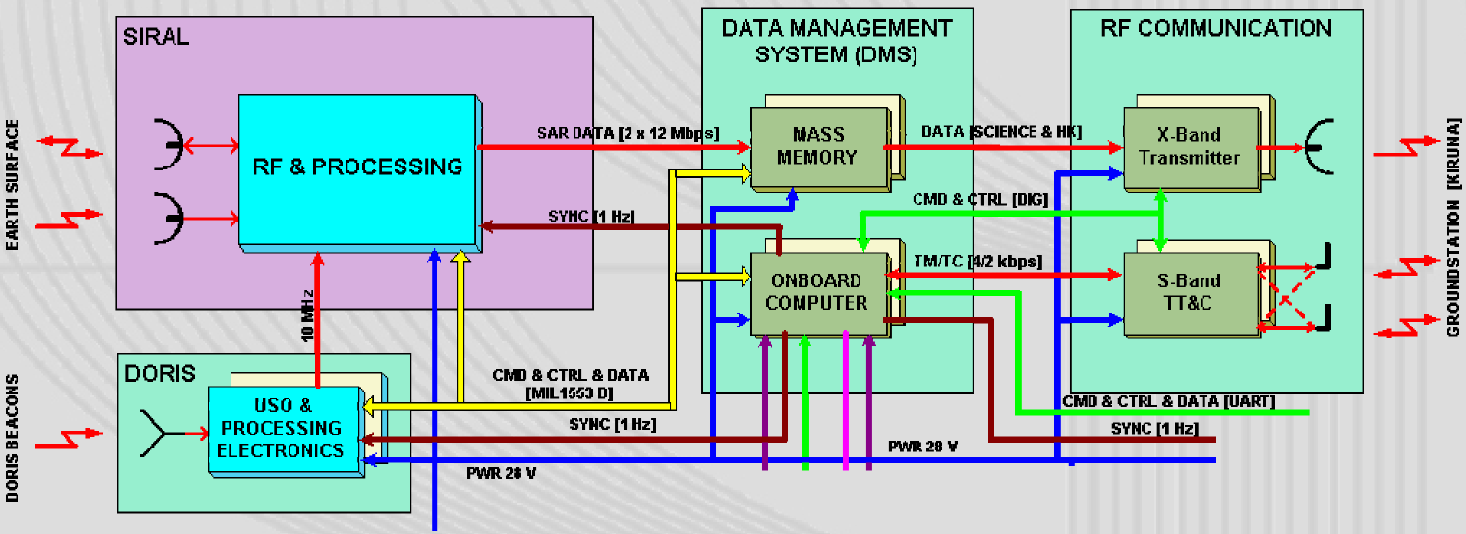


High speed data links on recent spacecrafts

Cryosat (ESA)



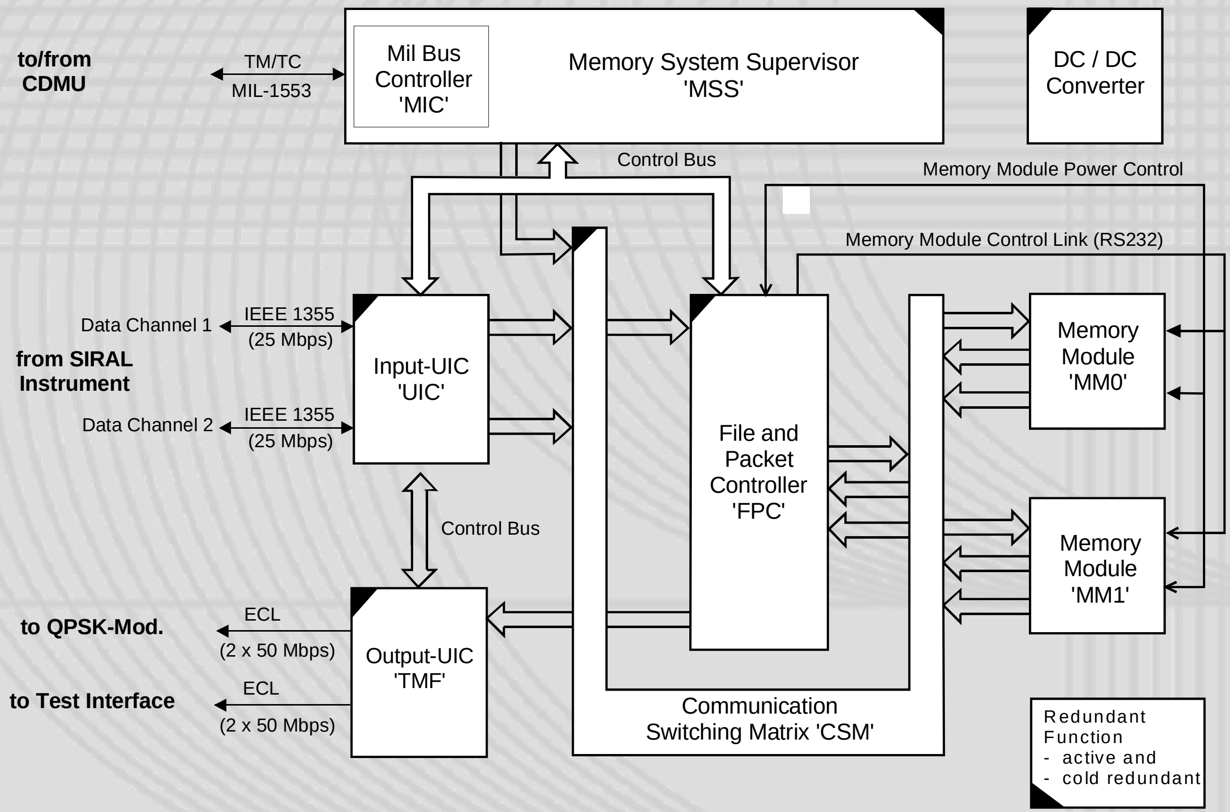
- Earth watch
- Ice thickness survey (polar orbit)
- Two instruments:
  - SIRAL: SAR/Interferometric Radar Altimeter that measures the ice elevation
  - DORIS: Doppler Orbit and Radio Positioning Integration by Satellite that allows very precise orbit determination



High speed data links on recent spacecrafts

Cryosat (ESA)

- File and Packet Control (FPC)
  - Interfaces between MMS, UIC, TMF and the Memory Modules
  - Controls the data flow via a Switching Matrix
  - SW handling of files and packets



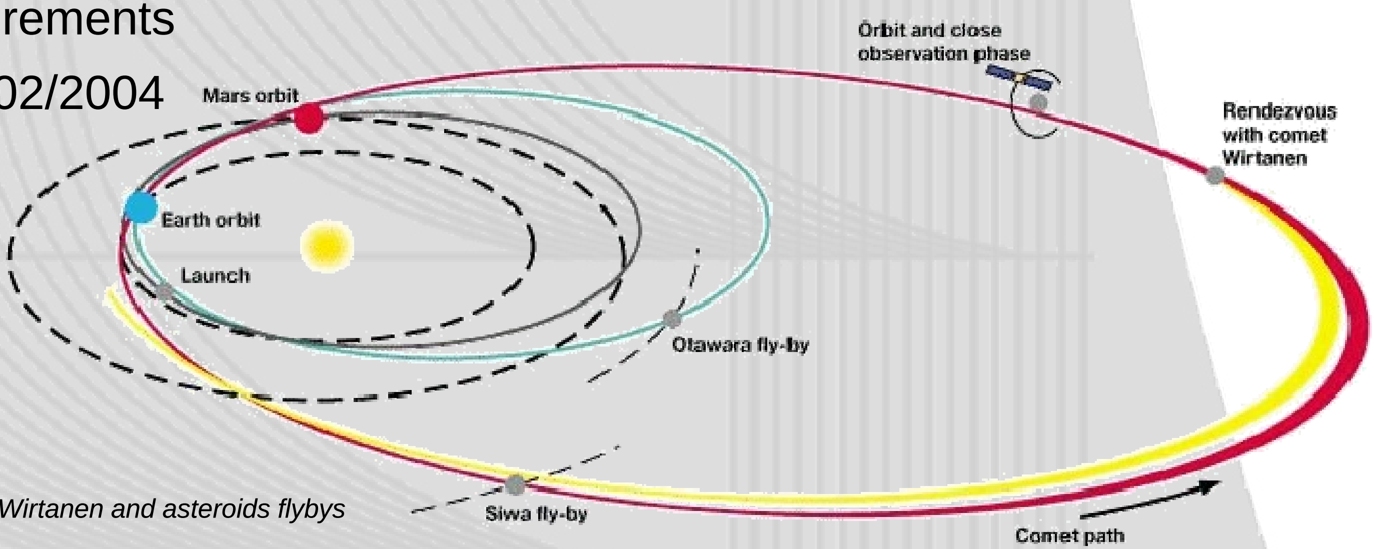
CryoSat Memory Module and Formatting Unit

High speed data links on recent spacecrafts

Rosetta (ESA)

Rosetta Mission

- 10-years long cruise toward comet 67P/Churyumov-Gerasimenko
- Fly-by at least one asteroid during the cruise phase.
- In-orbit comet scientific observations during one year down to the comet perihelion
- Land smoothly on the comet surface a Science Package (named RoLand) for in-situ measurements
- Launched in 02/2004



Initial scenario with comet Wirtanen and asteroids flybys

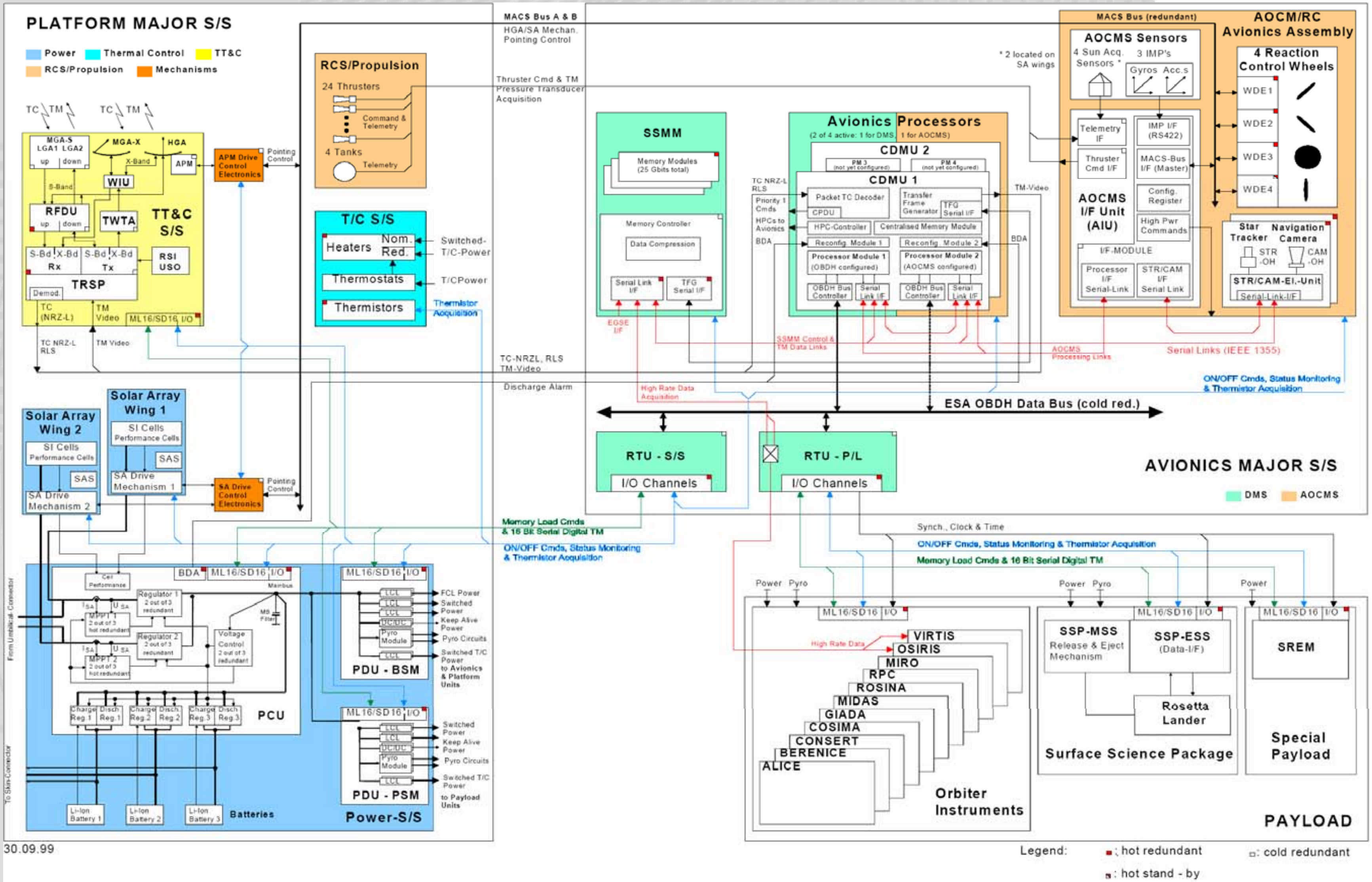
High speed data links on recent spacecrafts

Rosetta: On board communications

- Standard Avionics Command Control on OBDH
- Remote Terminal Units on OBDH with discrete links to instruments (11 P/L instruments)
- IEEE 1355 serial data link between the different data processing nodes and the Solid State Mass Memory
  - 2 P/L Instruments (VIRTIS@400Kbps, OSIRIS@4Mbps)
  - Navigation camera
  - 4 Avionics processor modules (5Mbps, redounded)
  - Redounded link to Transfer Frame Generator for telemetry
- Mass memory access with File management System

High speed data links on recent spacecrafts

Rosetta (ESA)



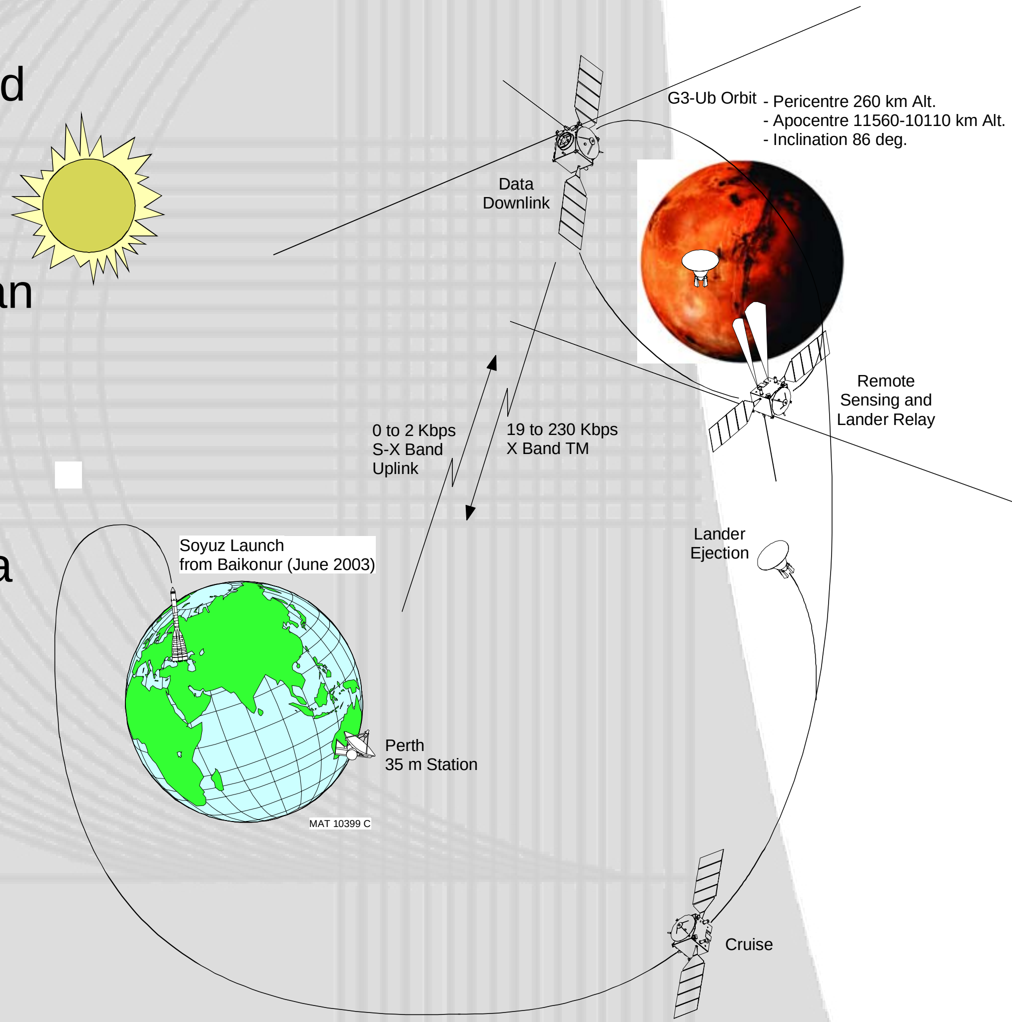
1355 (SpaceWire) links

High speed data links on recent spacecrafts

Mars Express (ESA)

- Mars exploration
  - 6 months cruise to Mars followed by planetary observation from orbital position
  - First contribution of the European nations to Mars exploration
  - High Resolution stereoscopic Camera producing 25Mbps of digitalised and compressed data
- Large re-uses of the Rosetta design with adaptations

High Resolution Stereoscopic Camera



Processed image from the Mars express High Resolution Stereoscopic Camera

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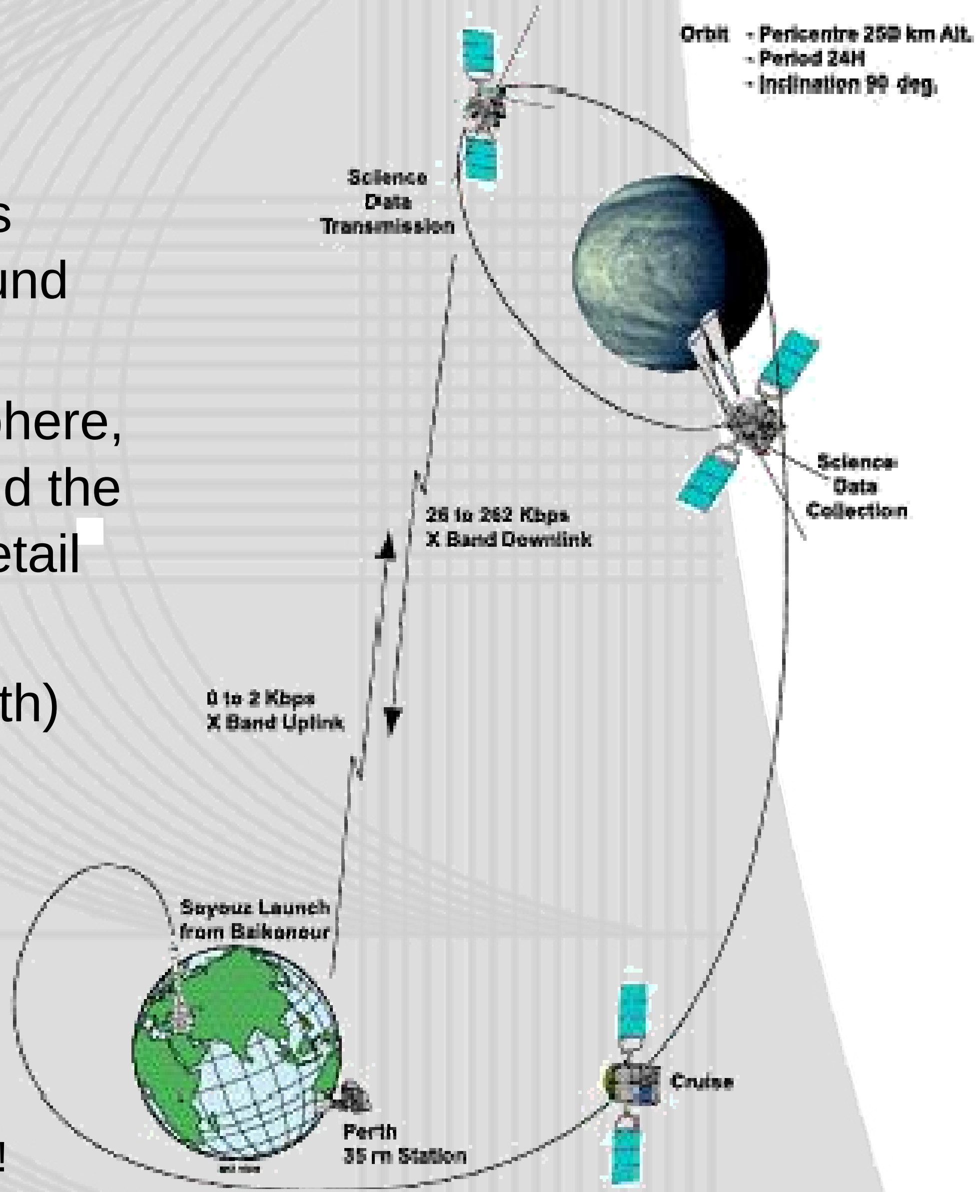
High speed data links on recent spacecrafts

Venus Express (ESA)

- Venus Exploration
  - 5 months cruise to Venus
  - 5 days to manoeuvre into its operation orbit, looping around the poles of the planet
  - 2 days* to study the atmosphere, the plasma environment, and the surface of Venus in great detail
  - 7 Instruments
  - Just launched (November 9th)
- Re-uses the design of Mars express with adaptations



* 2 days on Venus = 500 Earth days !

High speed data links on recent spacecrafts

Summary

Missions	Payload Data	Data links	Data rate	**Number** (without redundancies)
ROCSAT 2 THEOS	300 Mbps	LVDS	300 Mbps	3 (Instruments data)
Pleïades	860 Mbps	LVDS	200 Mbps	13 (Instruments data)
TerraSAR-X	880 Mbps	Glink	880 Mbps	1 (SAR Instrument)
CRYOSAT	25 Mbps	1355 (SpaceWire)	25 Mbps	1 + redundant (Siral instrument)
Rosetta	10 Mbps	1355 (SpaceWire)	10 Mbps	2 payload instruments (VIRTIS + OSIRIS) 1 AOCS sensor (navigation camera)
Mars Express	25 Mbps	1355 (SpaceWire)	25 Mbps	2 Payload instruments (HRSC + OMEGA) 1 AOCS sensor (StarsTracker)
Venus Express	10 Mbps	1355 (SpaceWire)	10 Mbps	2 payload instruments (VIRTIS + VMC) 1 AOCS sensor (StarsTracker)

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The need for High Speed data-links

General trend for future missions

- New missions call for new requirements
  - Robotics, Autonomy, Security, formation flying…
  - New instruments technology generates more on-board data (and TM rates cannot increase accordingly)
  - SW development techniques raises CPU use & data volumes
- ↳ General increase of on-board data processing needs (performance, volumes and transfer rates)
- Need for overall budget reductions
  - Power consumption reduction
  - Mass and Volume reduction
  - Operational costs: reduction of the satellites dependence beside ground (i.e. mission autonomy)
  - Manufacturing delay reduction (parallel development, AIT)
  - Costs
- ↳ Technology upgrade enforcing re-usable solutions

The need for High Speed data-links

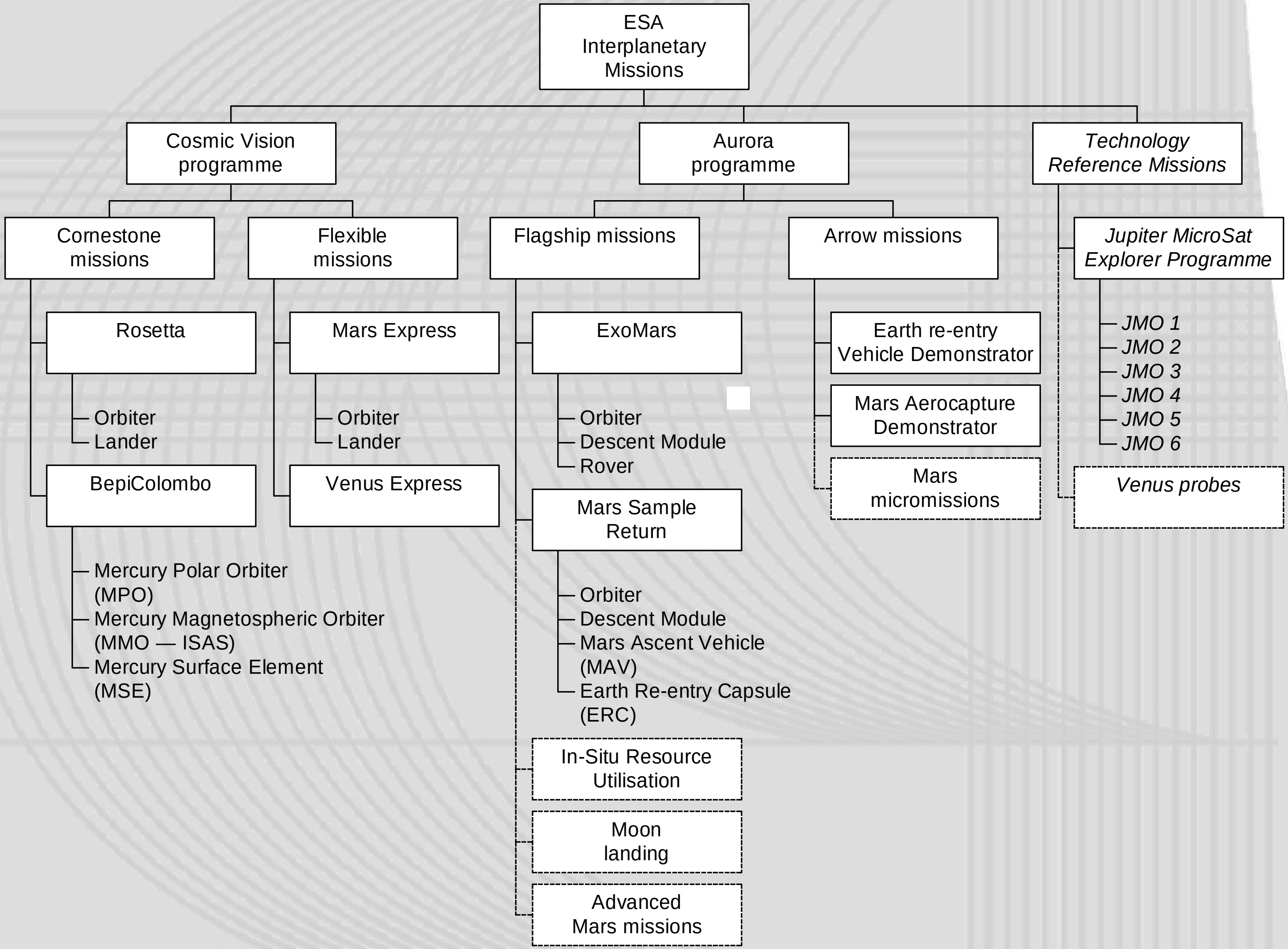
Advanced studies in support to future applications

Advanced studies

- Aurora Avionics Architecture System Definition (A3SysDef)
- Payload Data Processing Architectures (PaDaPAr)
- Generic Architecture for Mass Memory Access (GAMMA)
- Distributed Core SW (DISCO)

Aurora Avionics Architecture System Definition

Context for Planetary Exploration Missions



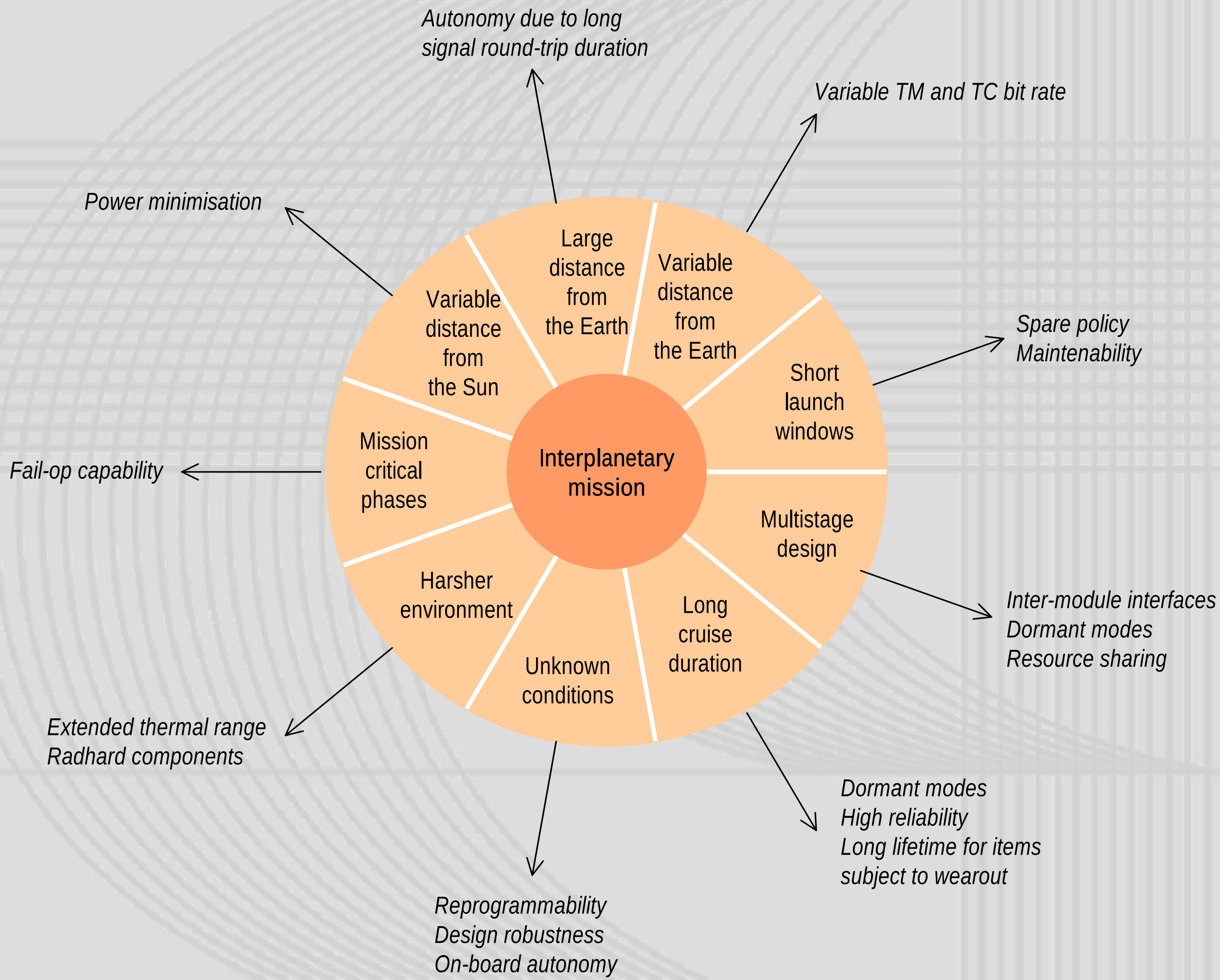
Aurora Avionics Architecture System Definition

Study Objective

- To define an avionics reference architecture suitable to support different Mars exploration missions and vehicles
  - Taking into account Bepi-Colombo pre-development assets (Highly Integrated Control and Data System-HICDS)
  - Based on a core of mission independent functions
  - Consistent with the communication standardisation (CCSDS/SOIS)
  - Able to ease the integration of new technology items during the long time frame of the Aurora Programme

Aurora Avionics Architecture System Definition

Main User Requirements & Design Drivers



Aurora Avionics Architecture System Definition

Functional Architecture and Performance Requirements

- Very large scale of functions and performances
  - We can define generic data processing functions
    - Communications (on-board, between spacecrafts, with ground)
    - Command and Control
    - Failure Detection Isolation and Recovery
    - Autonomy
  - Need to cope with different properties…
    - Wide range of spacecrafts bus and instruments performances
    - Reliability, Availability, Safety issues
    - Operational and maintenance requirements
    - Mission profile (Technology constraints, Qualification levels…)

MODULAR ARCHITECTURE

Need for a scalable set of HW and SW building blocks interconnected on a flexible architectural system

Aurora Avionics Architecture System Definition

Constraints

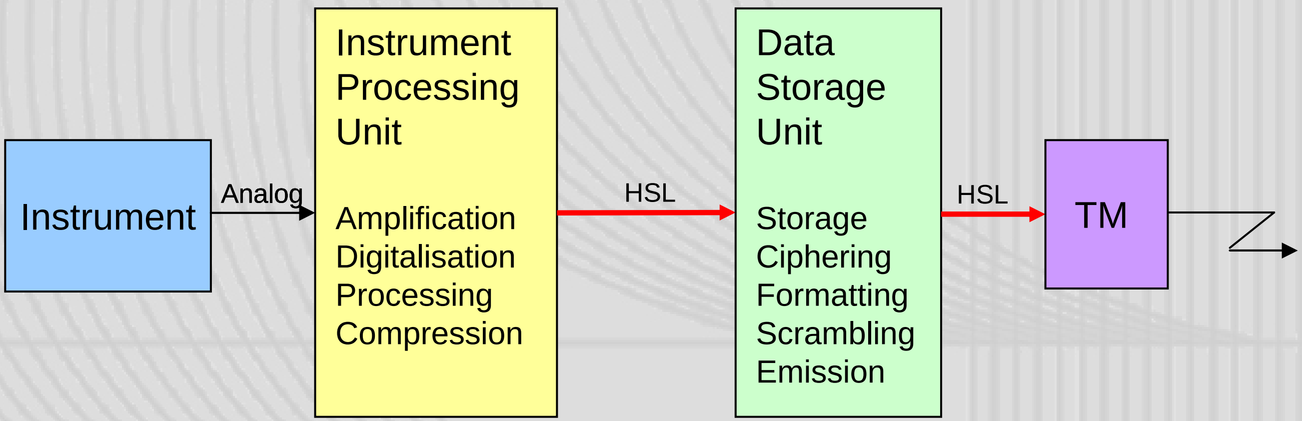
- Harsh physical environment (Radiations, Mechanic, Thermic…)
  - Induces high costs for development and qualification programs
  - Mission and phase dependant (Launch, Orbital, Deep space, landing…)
  - Limited resources in space for embedded electronics
    - Communication Link (rates and delays)
    - Power budget (electrical and propulsion)
    - Mass and volume (launch cost, life-time…)
- Fast evolution of the technologies induces obsolescence risks
- Evolution of systems needs for the development of new functions and performance range

EVOLUTIVE TECHNOLOGY
Need to focus the necessary development efforts on a limited set of standardised solutions

Payload data processing architecture

PaDaPAr Study overview

- Study overview
  - Functional analysis of current and future P/L architecture
  - Definition of typical generic functional architecture versus instruments performance requirements
  - Definition of typical building blocks (toolbox)
  - Benchmark the toolbox on current/future missions

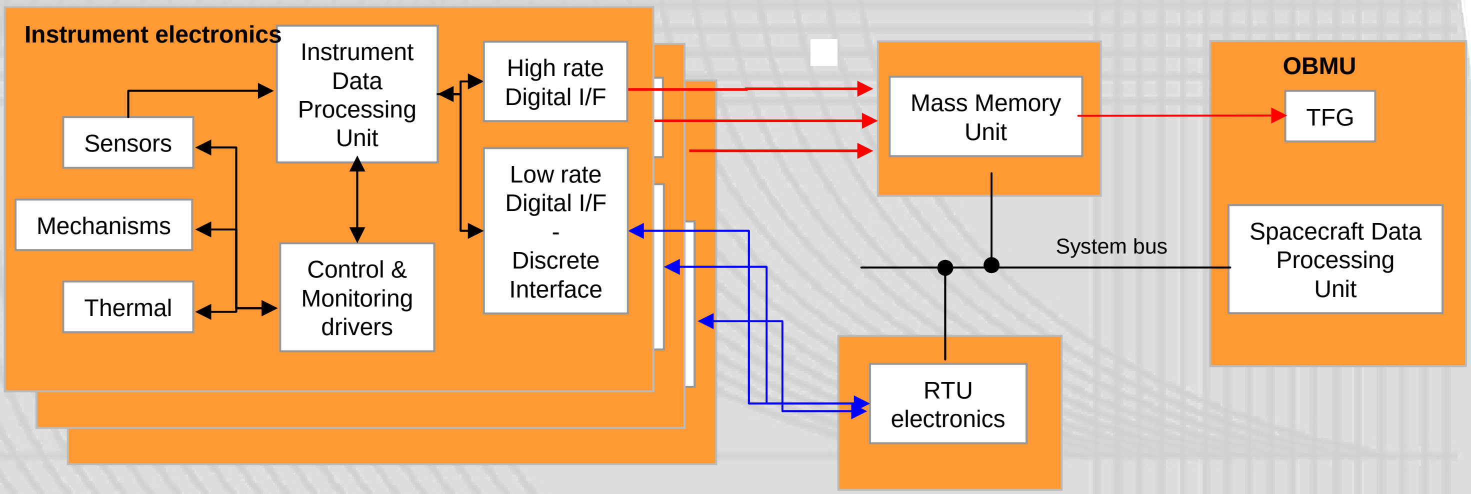


Example of a typical High Performance Instrument On-board Data communication chain

Payload data processing architectures

Modular functional architecture

- Performance oriented architecture
  - Independent instruments data processing units chains
  - Full availability of SPW bandwidth through Direct interfaces to Mass Memory for high rate science data
  - Instrument control through system bus and Remote Terminal Units (RTU)

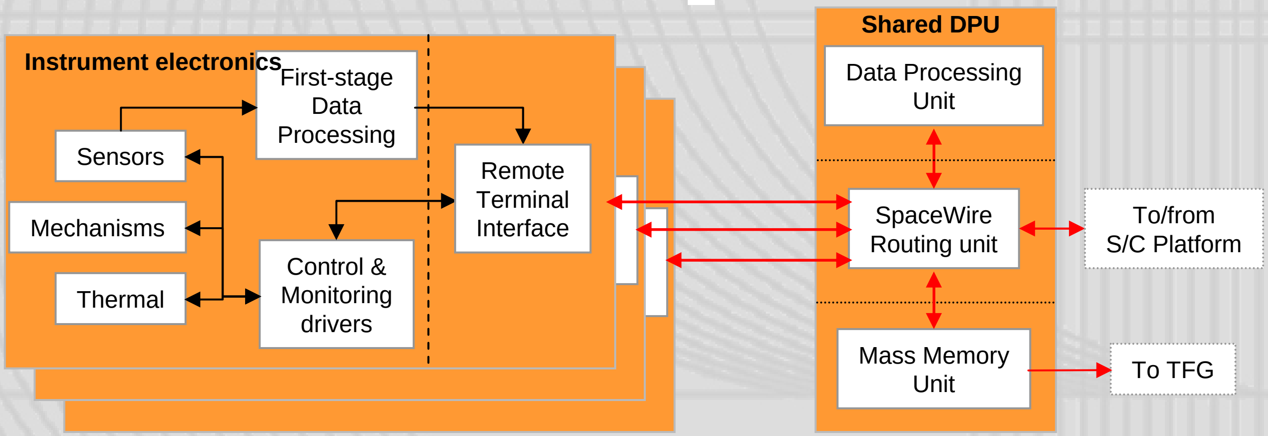


Recommended for high data processing requirements on P/L

Payload data processing generic architectures

Modular functional architecture

- Resource optimisation oriented architecture
  - Instrument pre-processing chains connected to SpaceWire Network
  - Share of common data processing functions and resources
  - Lower number of nodes and links variants
  - Can be combined with platform avionics resources



Recommended for multi instruments P/L and medium data processing requirements

Generic Architecture for Mass Memory Access (GAMMA)

Concept overview

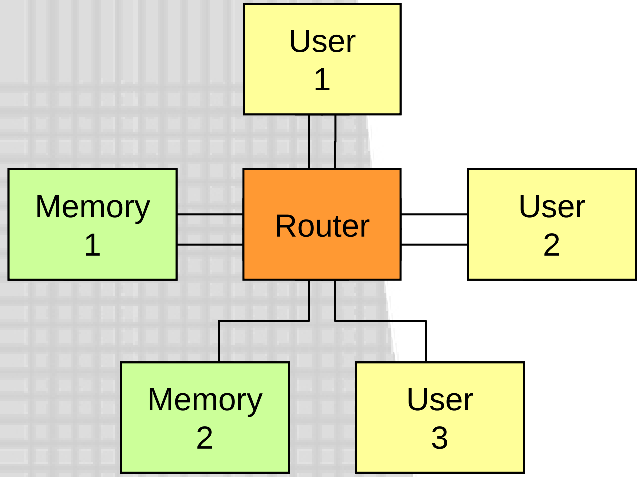
- Distributed architecture for data storage management
  - Several memory users (Calculators, instruments, …)
  - Several memory modules
    - Manage concurrent data accesses
    - Protect transactions
    - Ensure data consistency
  - Virtual Memory Management
    - Logical partitions can be composed of several physical storage areas.
    - The memory mapping is transparent to the applications.

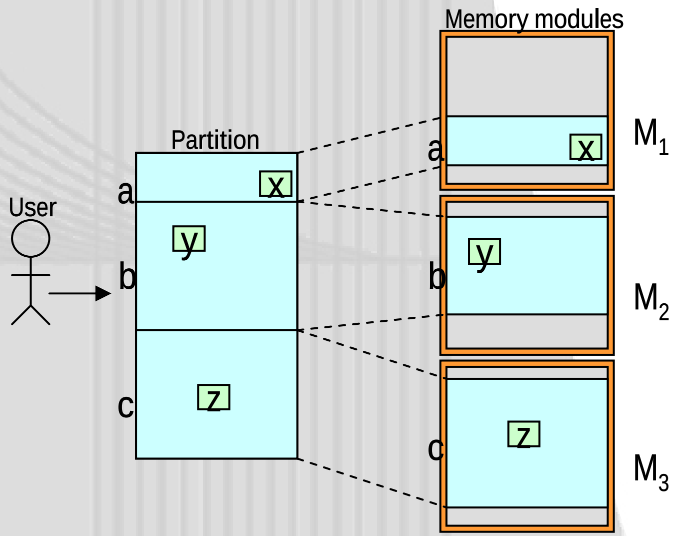
⇒ Increase security

⇒ Increase maintainability

⇒ Support transparent reconfiguration

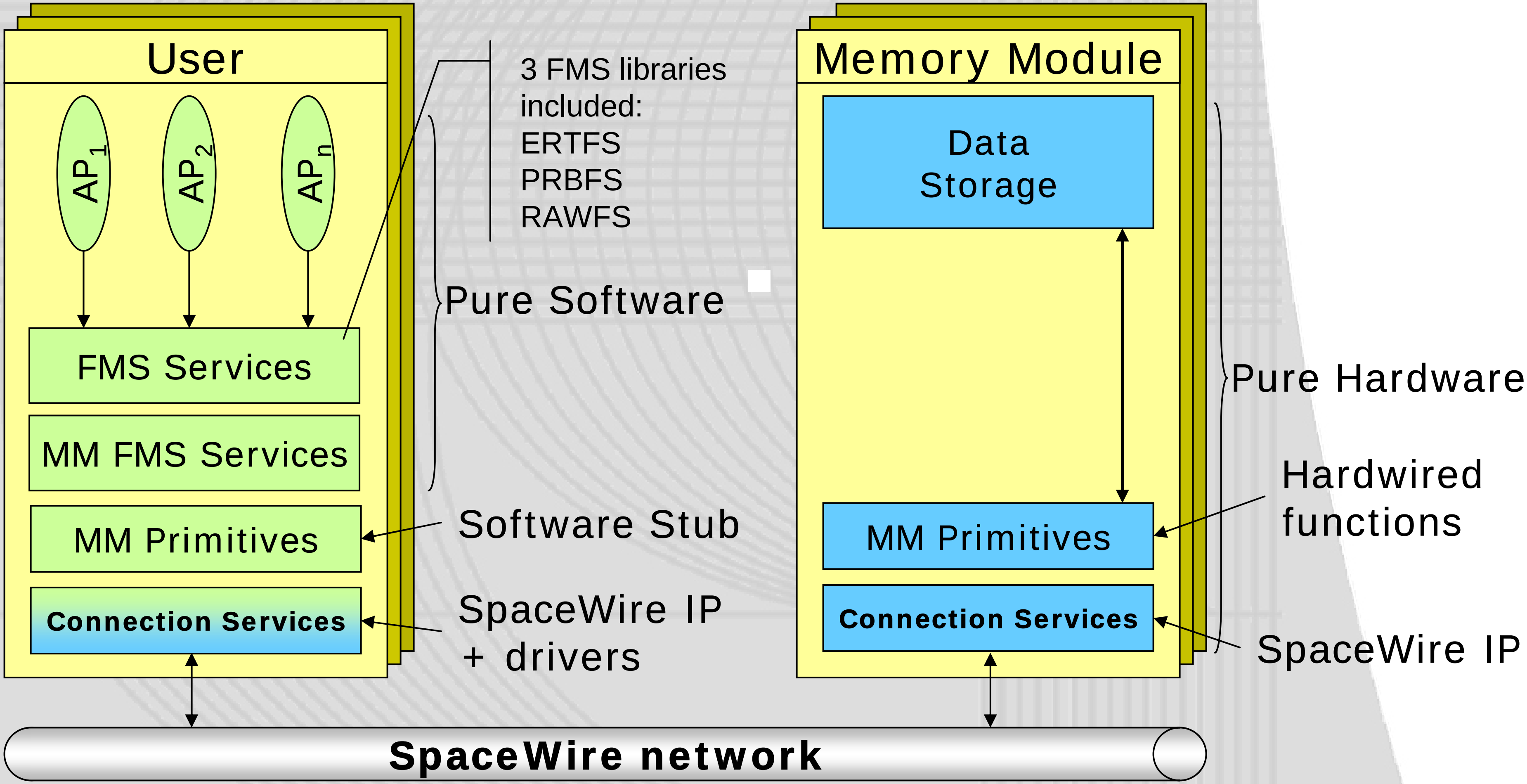
⇒ Optimize performance





Generic Architecture for Mass Memory Access (GAMMA)

GAMMA Implementation



Generic Architecture for Mass Memory Access (GAMMA)

GAMMA prototype

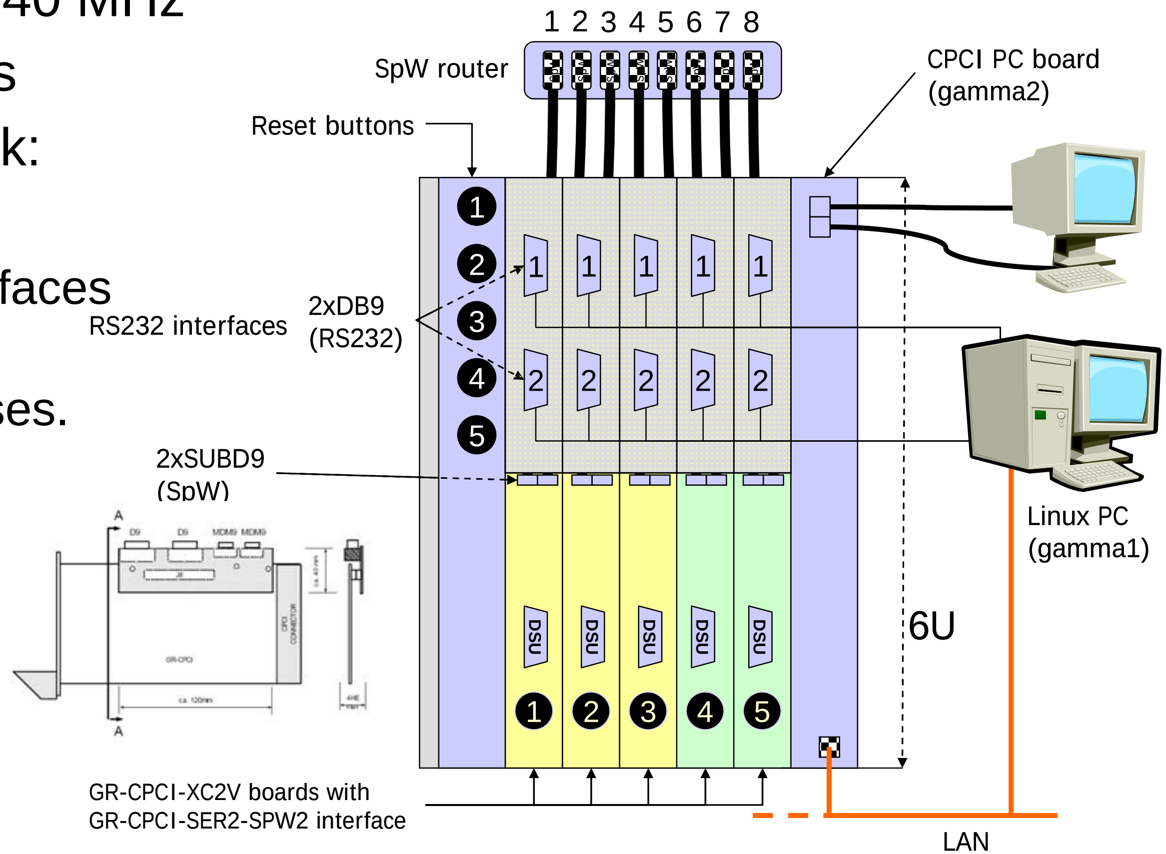
- **Demonstrator on a representative environment based on five identical commercial FPGA boards**

❑ 3 LEON2 users at 40 MHz

❑ 2 Memory Modules

❑ SpaceWire network:

- Over 200 Mbps
- 2 SpaceWire interfaces per board to test concurrent accesses.



Generic Architecture for Mass Memory Access (GAMMA)

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- ❑ 3 LEON2 users at 40 MHz
- ❑ 2 Memory Modules
- ❑ SpaceWire network:
  - Over 200 Mbps
  - 2 SpaceWire interfaces per board to test concurrent accesses.

Now operational at ESA/ESTEC premises

Generic Architecture for Mass Memory Access (GAMMA)

SpaceWire network data rates

- Data rates result (Mbps)

  - Useful data rate

	link 1 to link 2	link 2 to link 1	link 1 to link 2 & link 2 to link 1	
transmission rate	78,08	77,76	37,2	66,72
global board rate	156,16	155,52	207,84	

  - Raw data rate

	link 1 to link 2	link 2 to link 1	link 1 to link 2 & link 2 to link 1	
transmission rate	99,9424	99,5328	47,616	85,4016
global board rate	199,8848	199,0656	266,0352	

Distributed SW application

Distributed Core Software (DISCO)

- Objective
  - Development of a core software for complex payload requiring distributed processing
- Study plan
  - Analysis of future payload systems and definition of a reference mission requiring distributed processing.
  - Specification and development of a Space-Oriented Middleware prototype
  - Evaluation and refinement of the middleware prototype in the context of the reference mission, raising it to the level of a product.
- Implementation baseline on SpaceWire network

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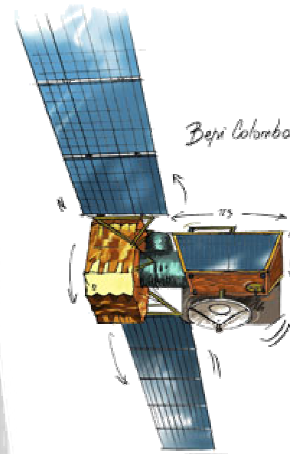
High speed data links on future missions

Bepi-Colombo mission characteristics

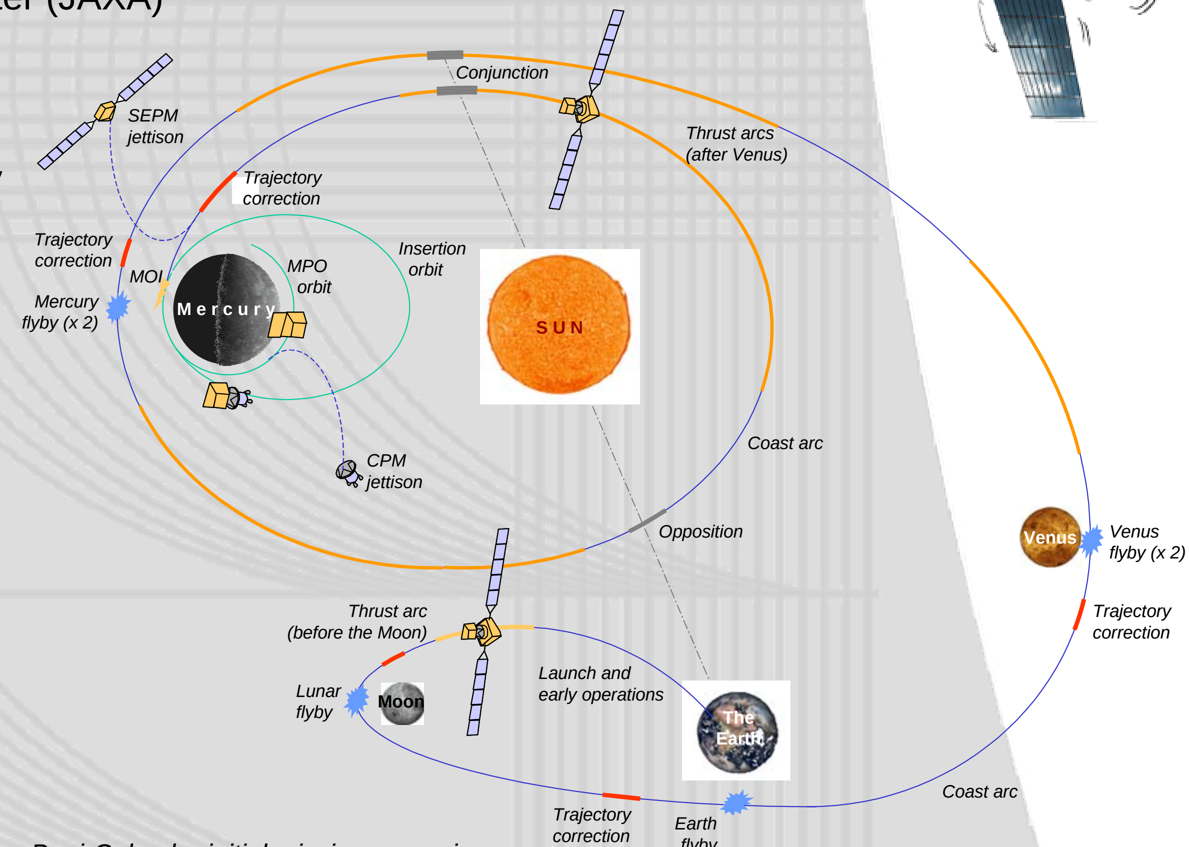


Mercury observation

- Composite vehicle built through European-Japanese cooperation
- Main Modules: MPO & MMO

  Mercury Planetary Observer (ESA)

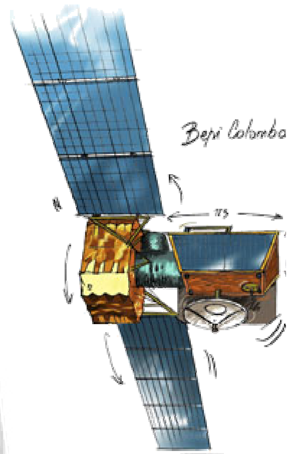
  Mercury Magnetospheric Orbiter (JAXA)
- 5 to 6 years long complex cruise phase including Moon, Venus and Mercury Fly-by's.
- Multiple instruments for data collection in several scientific areas
- Launch ~2012



Bepi-Colombo initial mission scenario

High speed data links on future missions

Bepi-Colombo mission characteristics



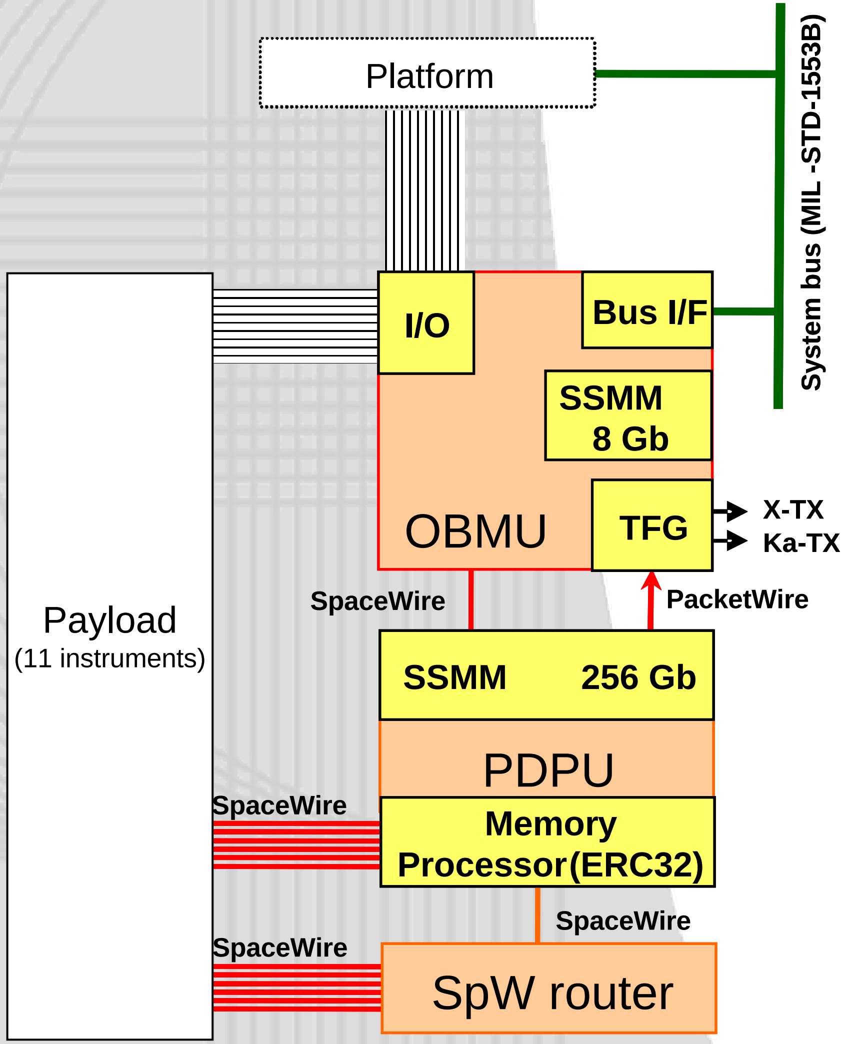
- Key Issues for Bepi-Colombo avionics architecture
  - Complex P/L which includes 11 instruments (50Mbps overall science data rate and 115Kbps C&C).
  - High level of autonomy (mission and FDIR)
  - Reliability of inter-modules communication links at separation time
  - Centralised versus decentralised architecture
  - Technology trade-off
    - SpaceWire network or direct links ?
    - P/L Command and Control dedicated links or over science data links ?
    - System on a Chip Computer core or reuse from flying and ongoing programmes ?

Bepi-Colombo initial mission scenario

High speed data links on future missions

Bepi-Colombo MPO proposed data links architecture

- Platform Central Computer (OBMU)
  - Platform C&C via 1553B and direct I/O system
  - Repeaters adapted from Ariane 5
- Payload Data Processing (PDPU)
  - science data acquisition
  - On-board processing
  - Compression and storage
  - PacketWire link to TM
- P/L data interface with SpaceWire links
  - Network with router for low-rate instruments
  - Direct links for High rate instruments
  - P/L C&C over SpaceWire links



High speed data links on future missions

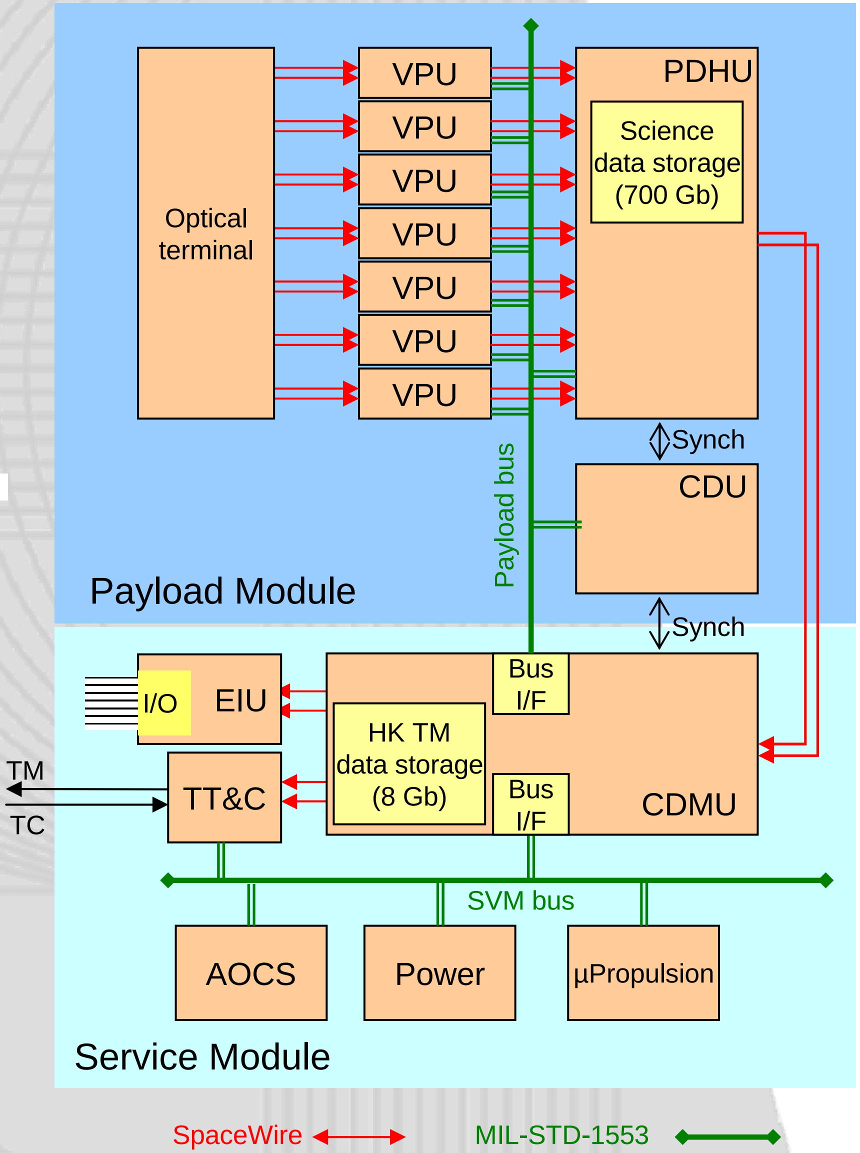
GAIA mission characteristics and main drivers

- Astronomy science mission
  - Lagrangian L2 point orbital position
  - Very high stability and fine pointing
  - Optical instrument with high data processing capability (for science algorithms)
  - Launched foreseen in 2012
- Key drivers
  - Modularity
  - Ease of AIT & operations
  - Performance of the video processing chain
  - Performance of Attitude and Orbit control
- Main data processing challenges
  - Video processors (~1000Mips)
  - On-board data reduction and storage
  - High rates of data from P/L instrument

High speed data links on future missions

GAIA proposed data links architecture

- Payload Module
  - ❑ Video Processing Units (VPU)
    - Optical Data Front end processing
    - All data on SpaceWire direct links
  - ❑ Payload Data Handling (PDHU)
    - science data acquisition, final, processing and storage
    - SpaceWire links to TM through CDMU internal Router
- Service Module
  - ❑ Central Distribution and Monitoring (CDMU)
    - Routing of SPW P/L science data to TM
    - Link with I/O system through SpaceWire
    - Command control
      - Avionics system through SVM 1553 bus
      - Payload through Payload 1553 bus



High speed data links on future missions

Other future missions calling for SpaceWire networks

- Mars Rover & Pasteur Payload (Exomars ~2012)
  - The Rover payload (Pasteur package) integrates 8 instruments, 5 for sample observation and 3 for environment observation.
  - A high level of autonomy and a large computing power for data/image compression is required for the platform.
  - Sharing of resources between Pasteur and Rover is expected (computing, mass memory)

- SolO (Solar Orbiter ~ 2014)
  - 14 instruments foreseen with a huge volume of raw data produced
  - Need for very efficient data reduction techniques as well as autonomous observation management.
  - A potential late adaptation of on-board algorithms has to be considered, claiming for a flexible approach.

Bepi-Colombo initial mission scenario

High speed data links on future missions

Conclusion for SpaceWire application

- SpaceWire provides a standard solution supporting the need for high data processing performance on future spacecrafts
  - Standard high speed data link for acquisition of a large range of payloads
  - Simple devices access with RMAP protocol
  - CCSDS TM/TC packet routing between intelligent terminals (e.g. complex instruments, star-trackers…)
  - Solution for on-board Network
    - Optimisation of on-board resources
    - Infrastructure for future on-board data processing performance increase
  - Contributes to the development of generic data processing architectures and Building Blocks