Overview of Control Software Development Activities at IAPS

Anna Maria Di Giorgio

IAPS Control Software group

- Anna Maria Di Giorgio 
- Emanuele Galli 
- J. Scige Liu 
- Stefano Pezzuto 

- Giovanni Giusi (TD) 
- Andrea Russi (TD) 
- Maria Farina (TD) 

Space missions payload control SW: ASI and INAF

At payload instruments level, in the past decade ASI put a particular effort in supporting the production of instrument control systems, thus allowing Italy to gain a leading role in this field → The involved Italian industries acquired an expertise that today allows them to compete at the same level of all the other major European companies.
Analogously, within the European Research Institutes Consortia providing payload instrumentation, the Italian Research Institutes can today be considered as the reference partners for the production of the payload control and data handling software.

Mission	instrument	HW contribution	SW contribution
ESA Infrared Space Observatory (ISO) - 1995	Long Wavelength Spectrometer	Instrument control and data handling electronics (CGS S.p.A.)	Instrument control and data acquisition SW (CNR IFSI)
NASA DAWN - 2007	VIR	Instrument control and data handling electronics (Selex-ES)	Instrument control and data acquisition SW (IAPS and Selex-ES)
ESA Herschel mission - 2009	All three focal plane instruments (PACS, SPIRE, HIFI)	Instrument control and data handling electronics (CGS S.p.A.)	Instrument control and data acquisition SW (CNR IFSI)
ESA Planck Mission - 2009	LFI	Instrument control and data handling electronics (Thales)	Instrument PI-ship (INAF IASF BO), integration and testing
ESA Euclid Mission	All two (VIS and NISP) payload instruments	Instrument control and data handling electronics (CGS S.p.A.)	Instrument control, data acquisition and compression SW(INAF IAPS, IASF, OATO, OAPD)
ESA Plato Mission	Payload computer	Instrument control and data handling electronics	Instrument control and data acquisition SW(INAF-IAPS)
ESA Athena Mission	IFU	Instrument control and data handling electronics	Instrument control, data acquisition and compression SW (INAF IASF, OATO, IAPS)
ESA Ariel Mission	AIRS spectrometer ICU	Instrument control and data handling electronics	Instrument control and data acquisition SW (INAF IAPS)
Chinese CSES 2 Mission	EFD DPU	Instrument control and data handling electronics	Instrument control and data acquisition SW (INAF IAPS)
ESA-JAXA SPICA Mission	All three focal plane instruments	Instrument control and data handling electronics	Instrument control and data acquisition SW (INAF IAPS
NASA OST Mission	HERO Instrument	Instrument control and data handling electronics	Instrument control and data acquisition SW (INAF IAPS)

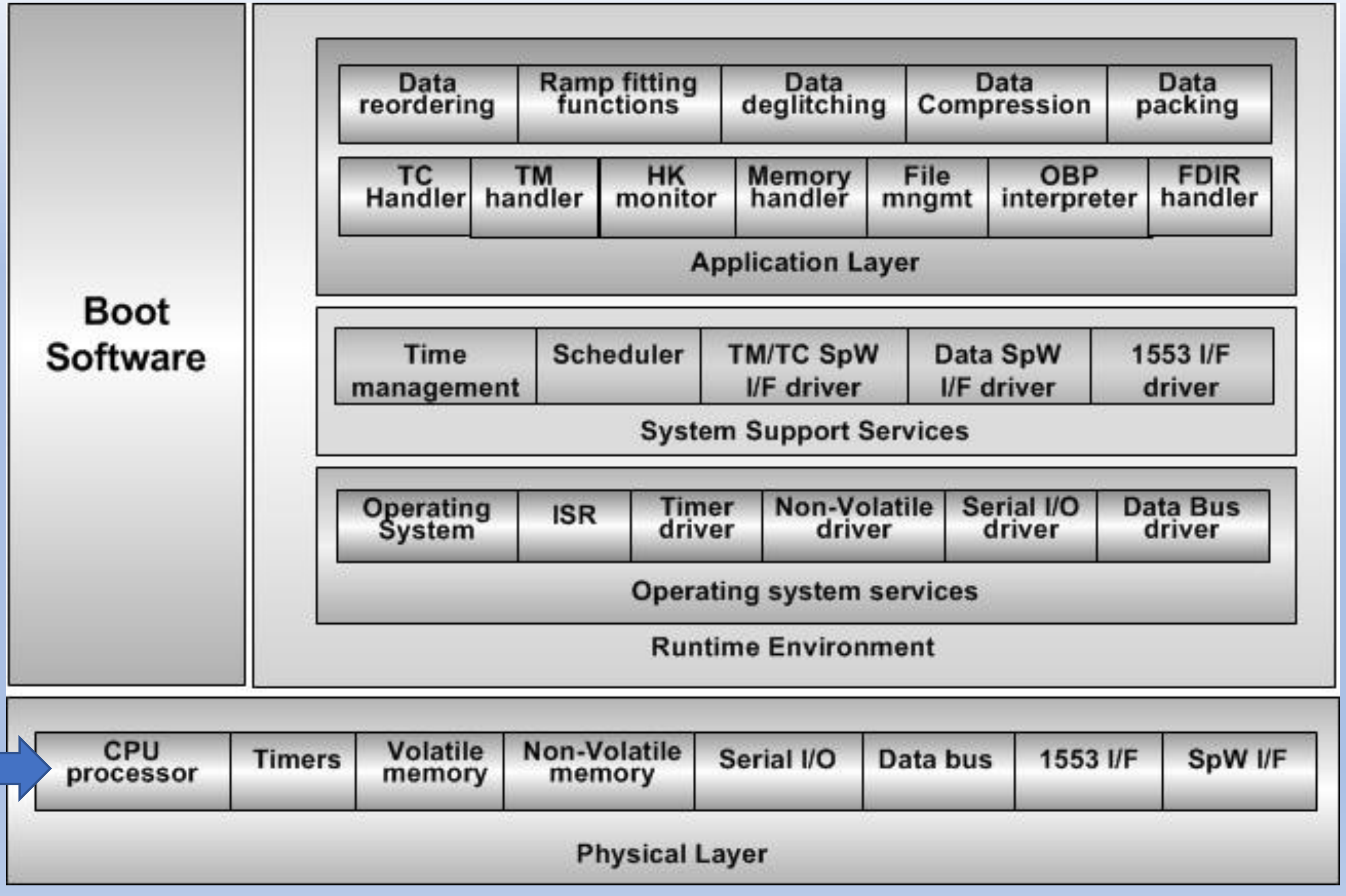
Space instrument control systems - characteristics

- Rad Hard
- Low power consumption
- Small volume
- Low mass

- Real time systems
- Deterministic
- Capability to operate autonomously
- Space Agencies SW development standards (on items and processes)

Space Control Systems Components

- Experience with the main flight qualified fault tolerant processors:
  - **DSP21020 (Herschel), LEON (Euclid, PLATO, ARIEL), PowerPC 750FX (Euclid), ARM Cortex-A.**
- Experience with the **MIL 1553 STD B** avionic standard for the TM/TC I/F (Herschel and Euclid)
- Experience with **SpaceWire** networks (Euclid, PLATO, ARIEL)
- Experience with **CAN bus** and RS422 (Herschel, CSES)

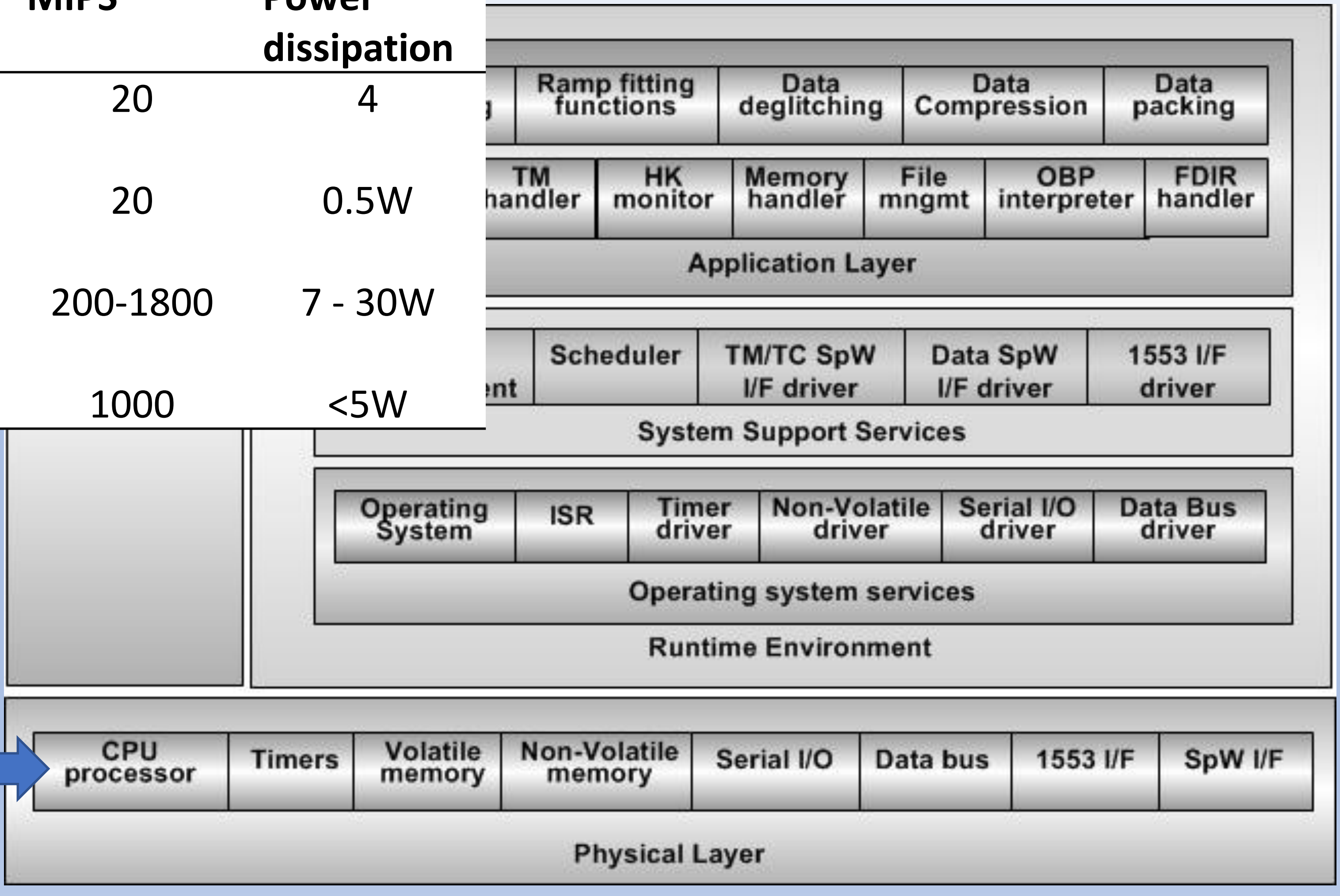


Space Control Systems Components

Processor	Clock frequency	MFLOPS	MIPS	Power dissipation
DSP 21020	20MHz	40	20	4
LEON3FT	25MHz	4	20	0.5W
SCS750 (PPC)	400-800MHz		200-1800	7 - 30W
GR740 quad core	250 MHz	1GFLOP	1000	<5W

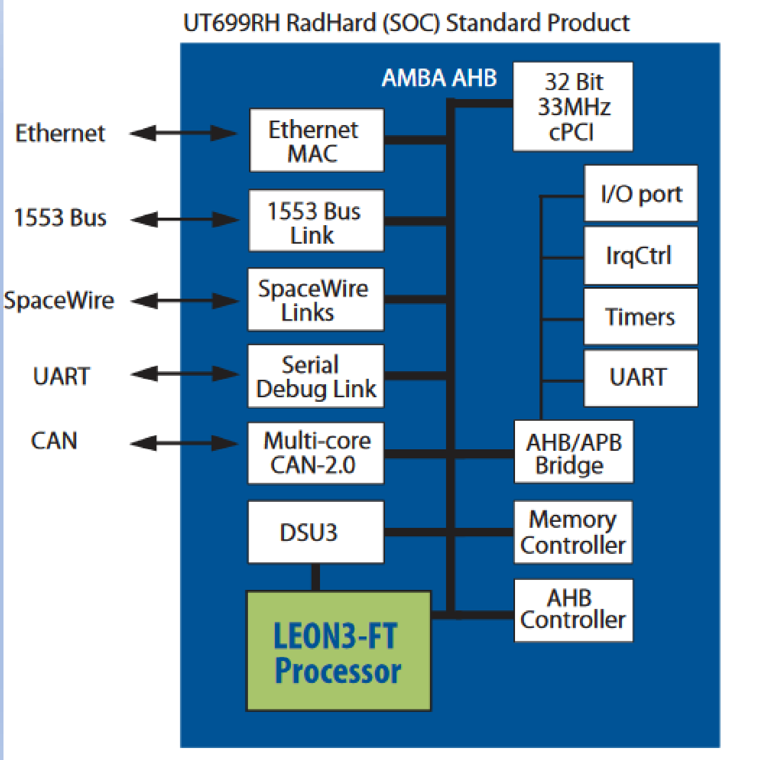
PLATO, ARIEL), PowerPC 750FX (Euclid), ARM Cortex-A.

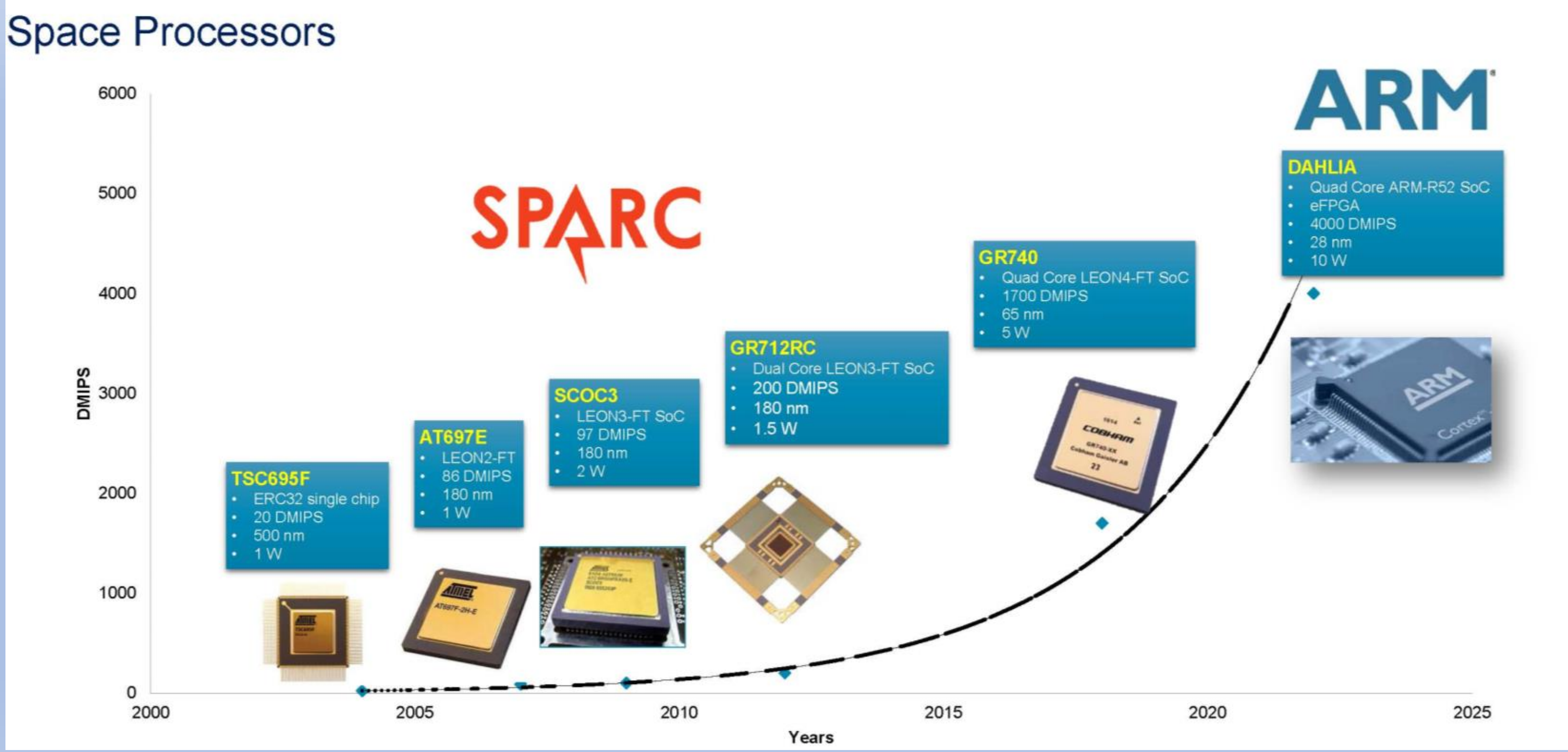
- Experience with the **MIL 1553 STD B** avionic standard for the TM/TC I/F (Herschel and Euclid)
- Experience with **SpaceWire** networks (Euclid, PLATO, ARIEL)
- Experience with **CAN bus** and RS422 (Herschel, CSES)



Space Processors - LEON

SPARC V8 processor developed by Gaisler Research: it is a synthesizable processor core for embedded applications. The LEON3 processor is part of the GRLIB package that is under continuous growth. On Board processor for many ESA missions in study phase (PLATO, ARIEL, ATHENA)





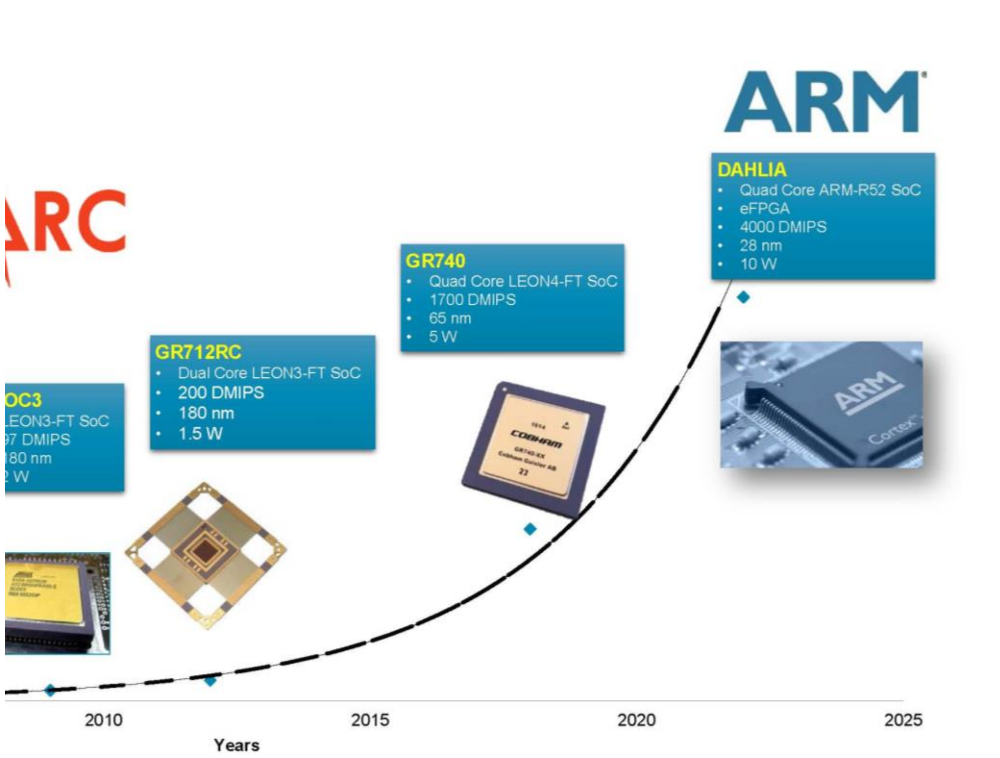
Space Processors - LEON

•4 x LEON4 fault tolerant CPU:s16 KiB L1 instruction cache
•16 KiB L1 data cache
•Memory Management Unit (MMU)
•IEEE-754 Floating Point Unit (FPU)
•Integer multiply and divide unit.
• MiBLevel-2 cache shared between the 4 LEON4 cores

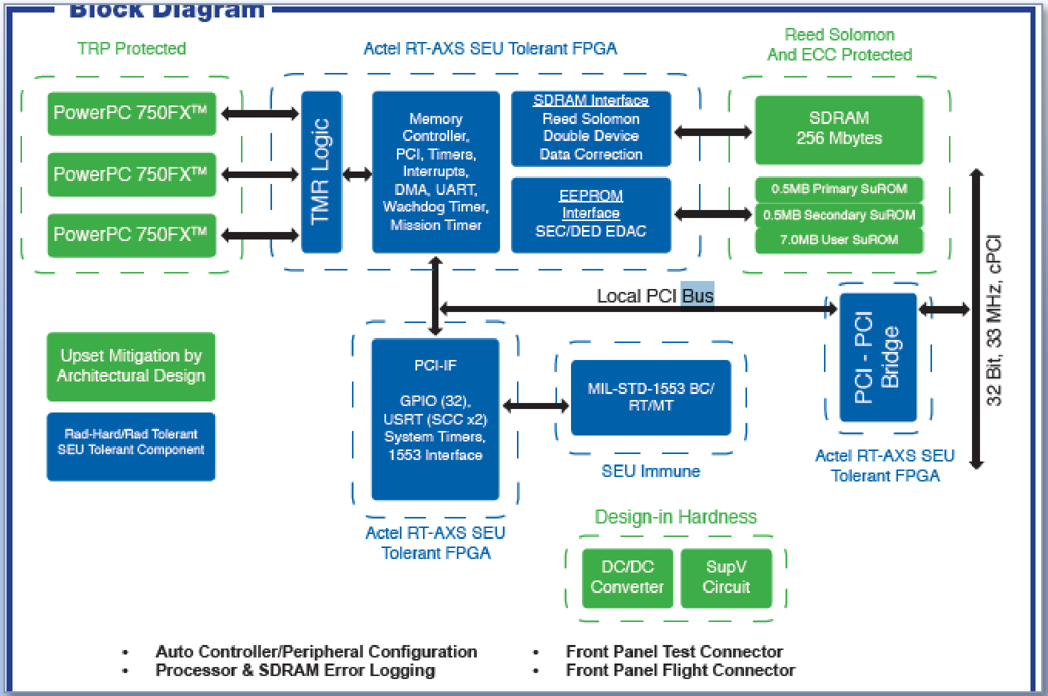
System clock (CPU:s, L2Cache, on-chip buses)
•Nominal frequency is 250 MHz, generated by PLL from external 50 MHz clock
•Full temp range (-40 to +125)
•4 CPUs - 250 MHz - 1000DMIPS

Communication Interfaces:
• 8-port Spacewirerouter with on-chip LVDS
• 2 x 1Gbit/100Mbit Ethernet MAC
• PCI master/target with DMA, 33 MHz
• Dual-redundant CAN
• MIL-STD-1553B interface (bus A/B)
• 2 x UART
• 16 x GPIO

ple processor core for embedded applications.
nuous growth. On Board processor for many ESA



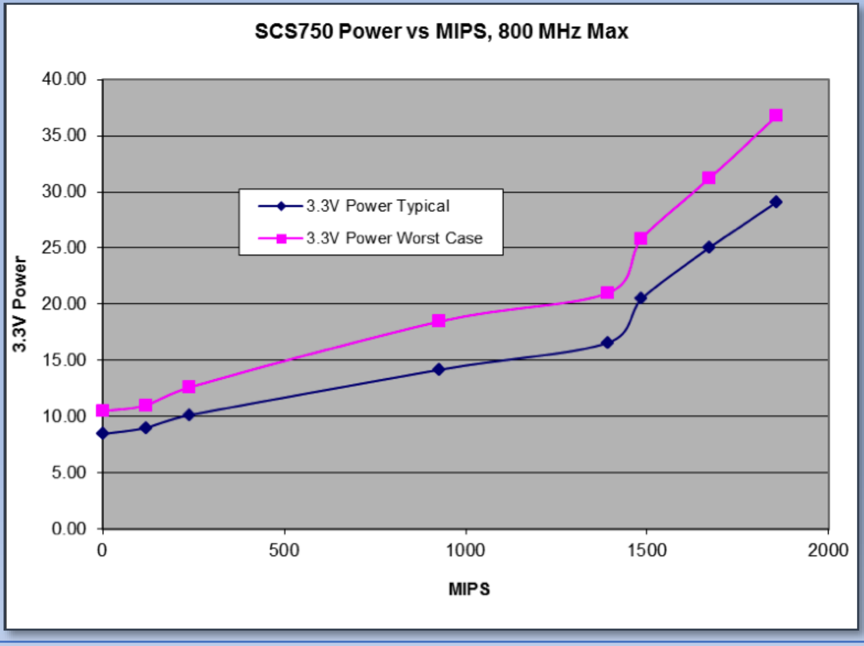
Space Processors – SCS750 (rad-hard PowerPC)



3 FULLY TMR PROTECTED PROCESSORS PowerPC 750FXTM
- > 1800 Dhrystone MIPS @ 800MHz
- 400 to 800MHz - Software selectable core clock rate

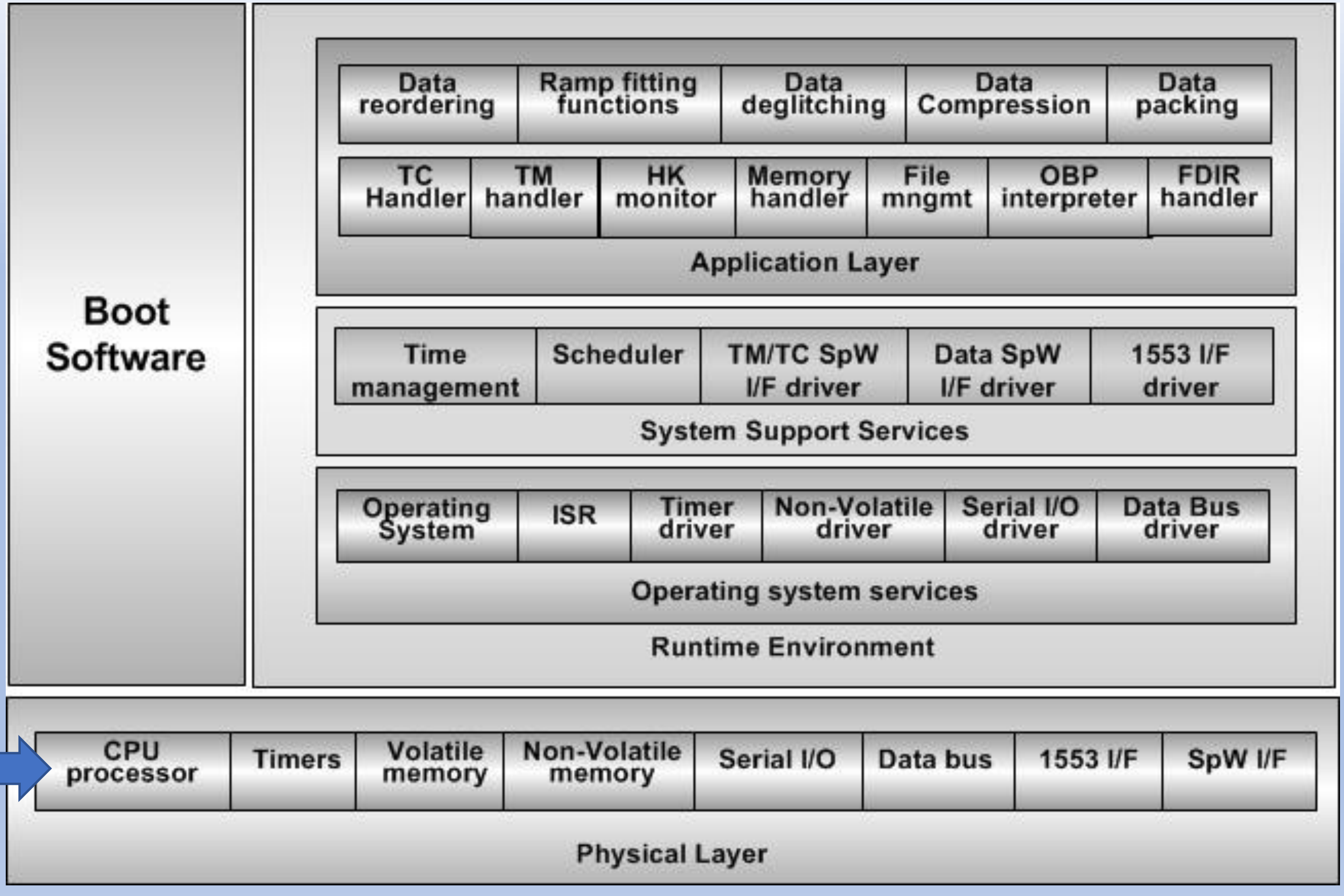
- 256 MByte SDRAM
- 8 MByte EEPROM - ECC protected
  - -7.0 MByte EEPROM available to user
  - -0.5 MByte Primary SuROM –
  - -0.5 MByte Secondary SuROM

Extremely expensive
ITAR protected
Used on GAIA, Euclid



Space Control Systems Components

- Experience with the main flight qualified fault tolerant processors:
  - **DSP21020 (Herschel), LEON (Euclid, PLATO, ARIEL), PowerPC 750FX (Euclid), ARM Cortex-A.**
- Experience with the **MIL 1553 STD B** avionic standard for the TM/TC I/F (Herschel and Euclid)
- Experience with **SpaceWire** networks (Euclid, PLATO, ARIEL)
- Experience with CAN bus and RS422 (Herschel, CSES)



Interfaces - SpaceWire Standard

The standard ECSS-E-ST-0-12C (first definition Jan 2003) can be downloaded from http://spacewire.esa.int

Based on LVDS the standard provides prescriptions for :

- Physical Level provides connectors, cables and EMC specifications
- Signal Level defines signal encoding, voltage levels, noise margins and data rates
- Character Level specifies the data and control characters used to manage the data flow
- Exchange Level covers the protocol for link initialisation, flow control, fault detection and link restart
- Packet Level details how a message is delivered from a source node to a destination node

SpaceWire for Space

SpaceWire is supported by several radiation tolerant ASICs designed for ESA, NASA and JAXA. Current radiation tolerant devices are capable of up to 200 Mbits/s data signalling rate with a data-rate of 160 Mbits/s per link or 152 Mbits/s bi-directional per link.

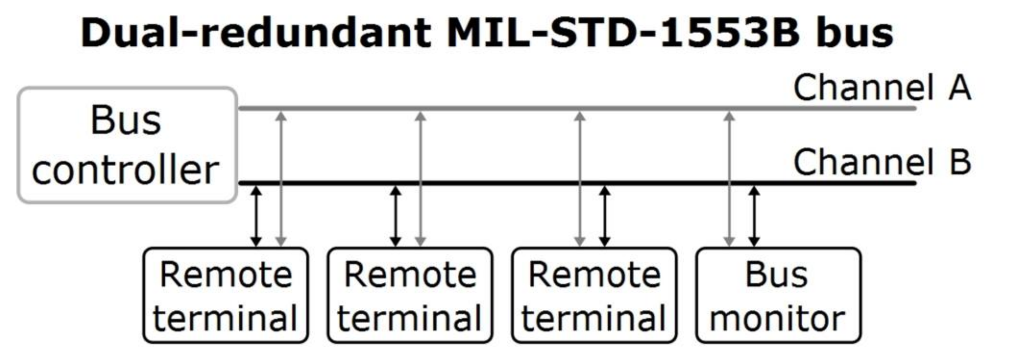
New Standard High Level Protocols under study to allow for a “deterministic” use of SpaceWire Networks

Presently used in SOLO, Euclid (link to MMU), PLATO, Bepi Colombo (S/C network), ARIEL, ATHENA
Proposed for SPICA (S/C network)

Interfaces – MIL-STD-1553 Standard

- First standard draft published by SAE in 1968
- Mil-Std-1553A released in 1975 and the B version adopted in 1978.
- military and aerospace applications (US Force, NATO, MoD, NASA ESA, etc).
- the Bus is a terminated transmission line based on a twisted and shielded pair cable, Bus controller and the Remote terminals are connected to the line through stubs and couplers
- Bus data rate: 1 Mbits/s
- dual standby redundant architecture.

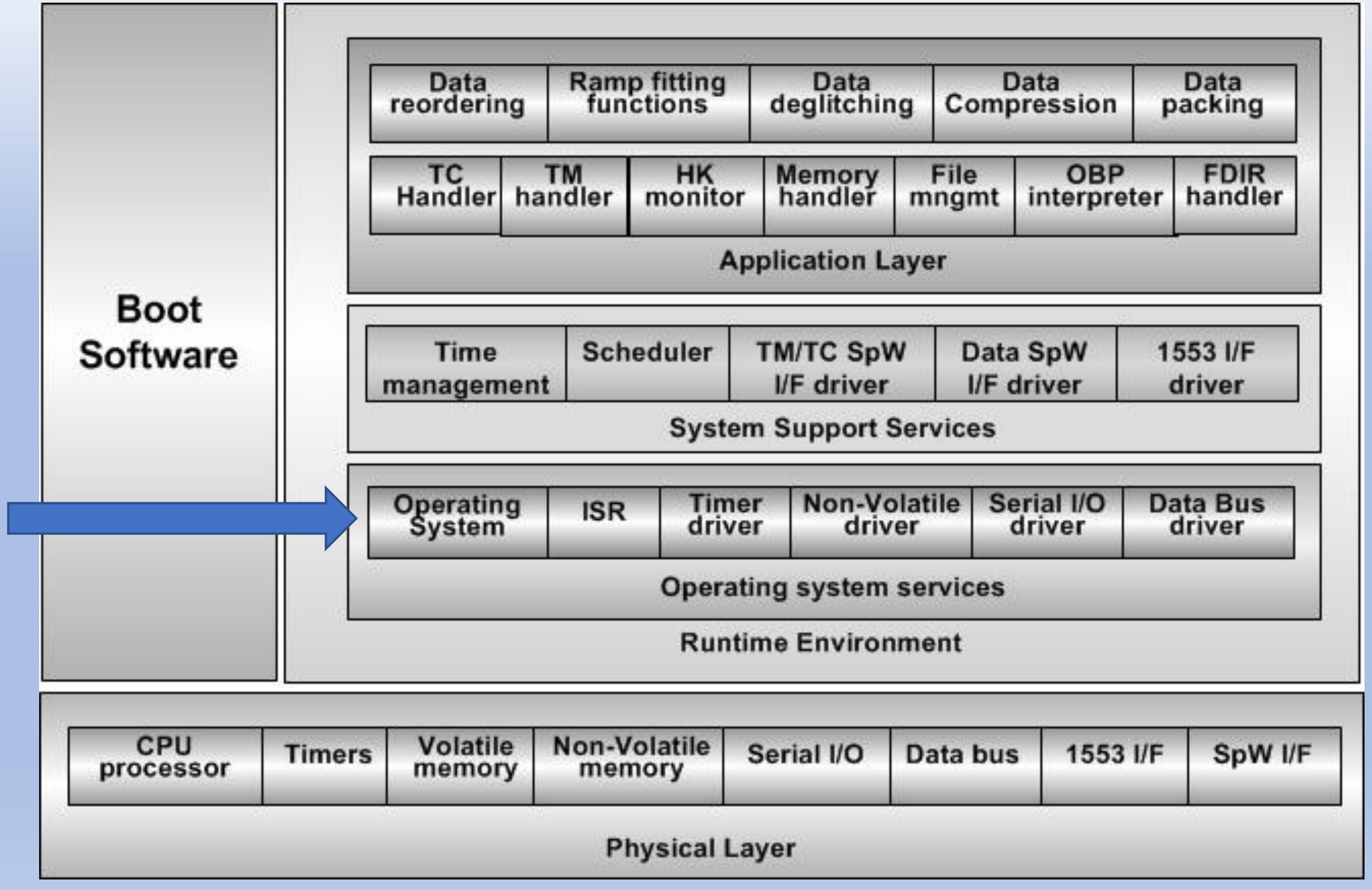
MIL-STD-1553 defines three types of bus users, called terminals: Bus Controller (BC), Remote Terminal (RT) and Bus Monitor (BM). The transaction on the bus is of type Command/Response. The BC acts as the master and initiates all the transactions. The RTs, commanded by the BC, provide the interface between 1553 bus and the relevant unit/sub-system. The BM is passive and record the bus traffic.



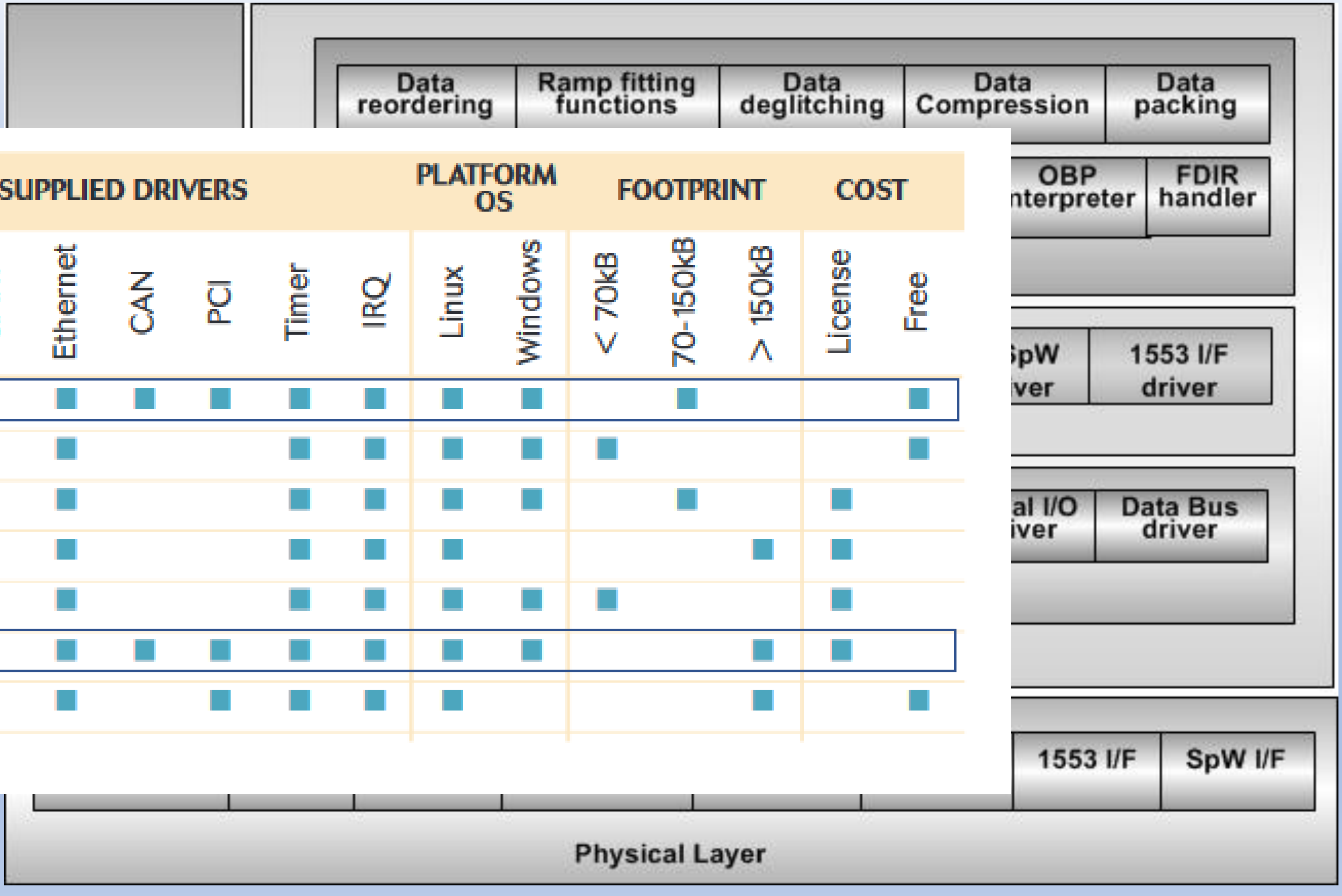
Currently used on the International Space Station (ISS) and in many other European and ESA spacecraft like Ariane 5, VEGA, Sentinels, IXV, Bepi Colombo, GAIA, Gallileo, SmallGeo, ATV, etc.
ESA issued the ECSS-E-50-13C standard

Space Control Systems Components

Experience with space qualified RTOS (Virtuoso, VxWorks, RTEMS, FreeRTOS)



Space Control Systems Components

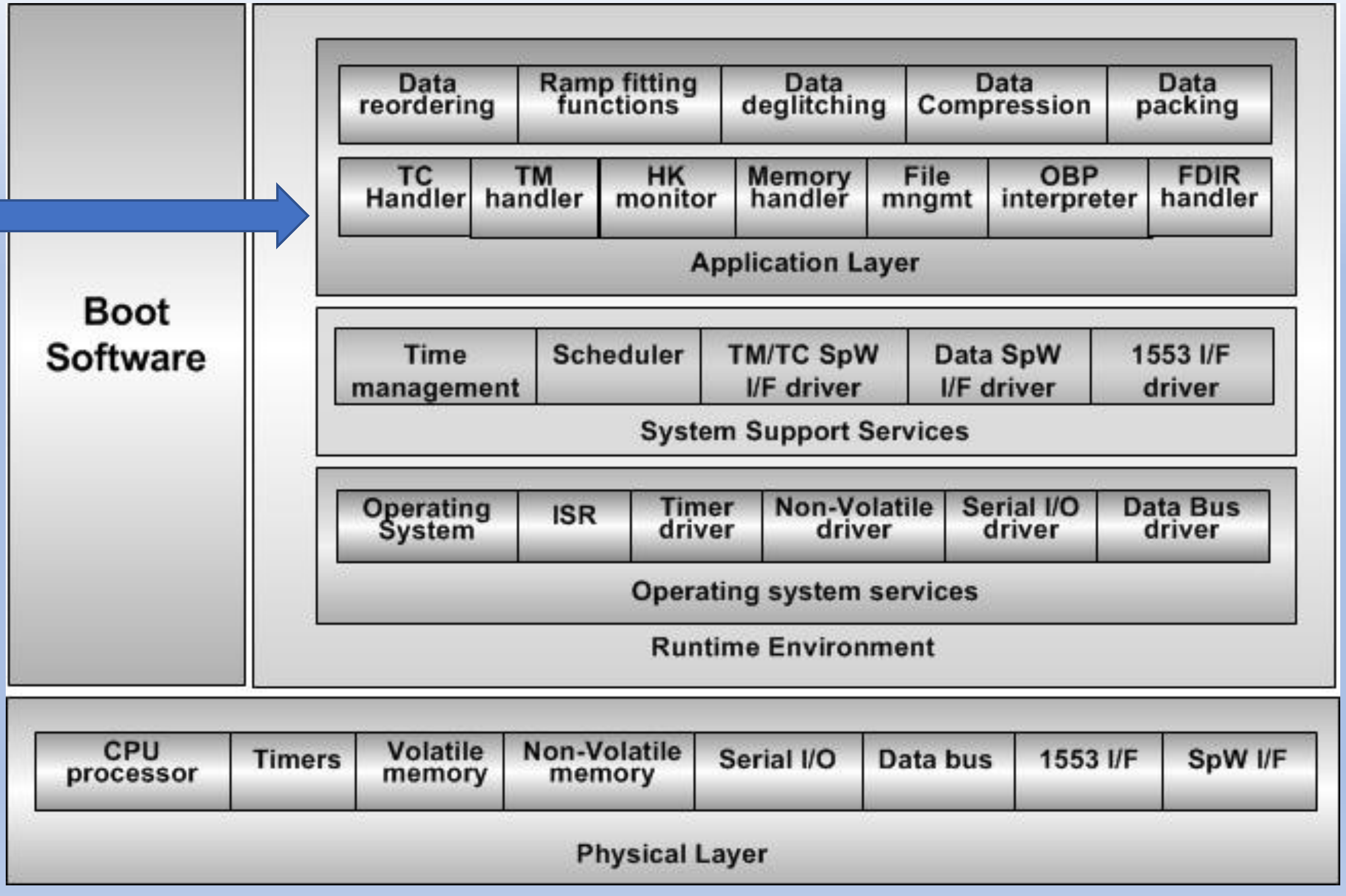


Experience with sp
(Virtuoso, VxWork

REAL-TIME OPERATING SYSTEMS	SUPPLIED DRIVERS							PLATFORM OS		FOOTPRINT			COST	
	SpW	UART	Ethernet	CAN	PCI	Timer	IRQ	Linux	Windows	< 70kB	70-150kB	> 150kB	License	Free
RTEMS	■	■	■	■	■	■	■	■	■		■			■
eCos		■	■			■	■	■	■	■				■
Nucleus		■	■			■	■	■	■		■		■	
LynxOS		■	■			■	■	■				■	■	
ThreadX		■	■			■	■	■	■	■			■	
VxWorks	■	■	■	■	■	■	■	■	■			■	■	
Snapgear Linux		■	■		■	■	■	■				■		■

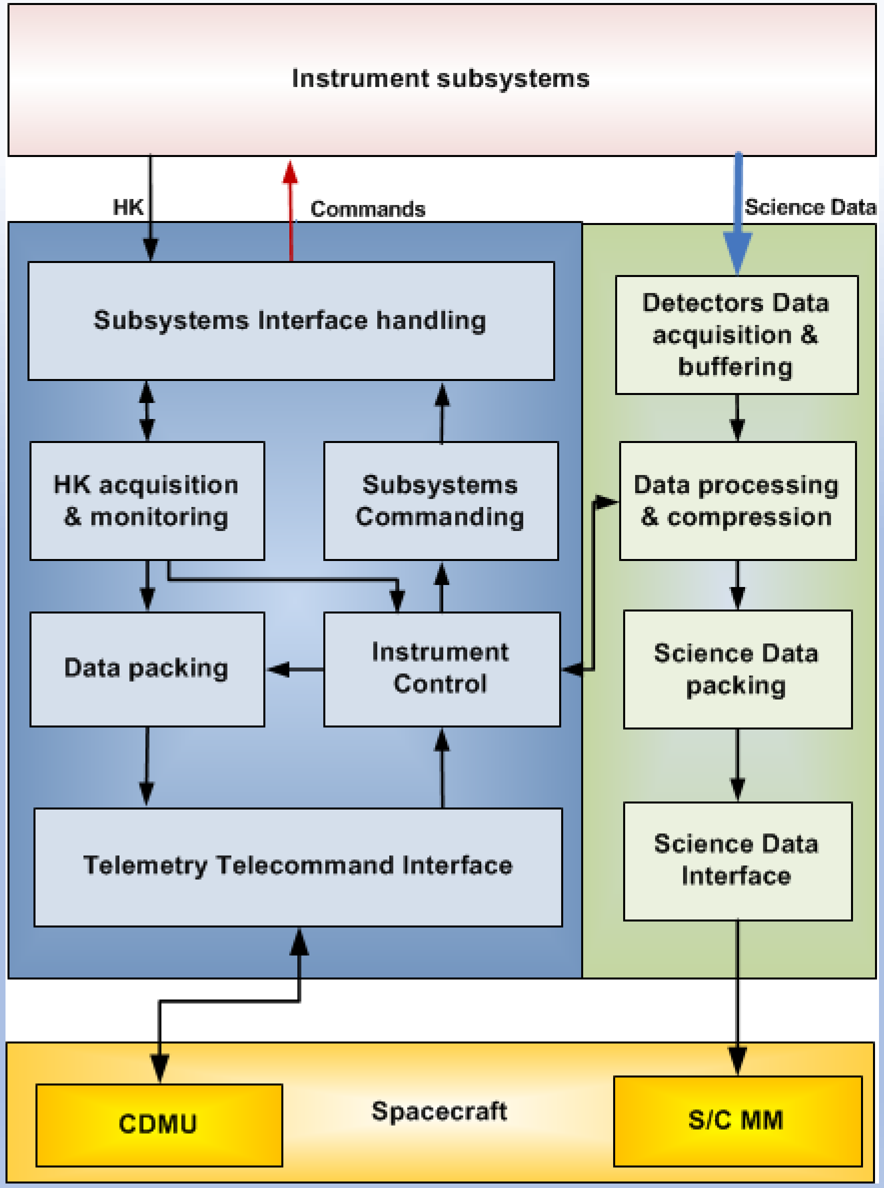
Space Control Systems Components

- Real Time SW design and development
- Experience with space qualified RTOS (Virtuoso, VxWorks, RTEMS)
- UML standard for system engineering
- Expertise in C, C++, Java, Python programming
- MISRA coding standards (Euclid, PLATO, ARIEL)
- Deep Knowledge of ESA ECSS standards and procedures
- Experience with **CCSDS standard lossless compression** algorithms implementation and optimisation (Euclid)



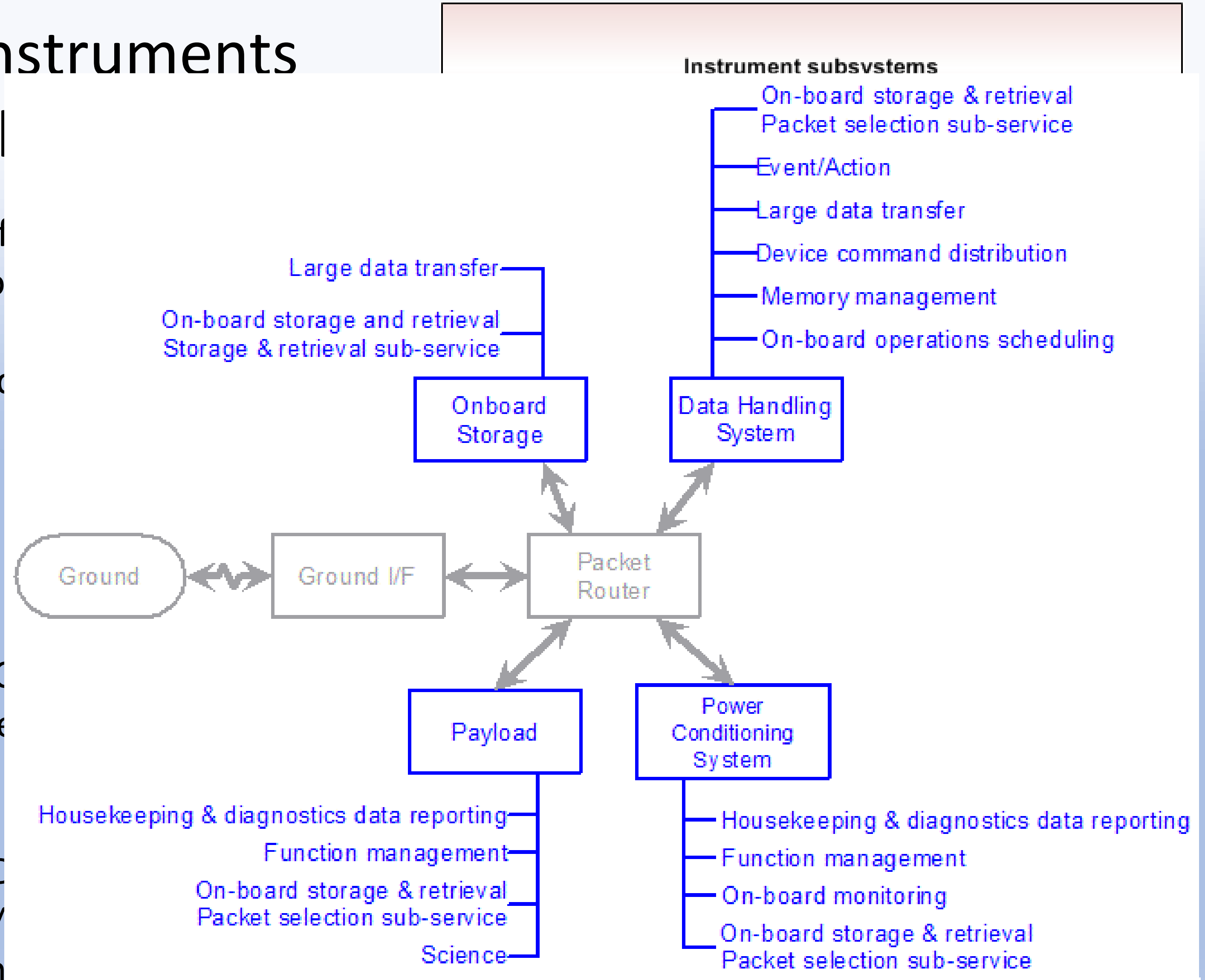
Space Instruments Control Software

- Acceptance of instrument commands from CDMU;
- Execution of predefined instrument command sequences;
- Instrument health/status monitoring;
- Implementation of pre-defined procedures on detection of instrument anomalies.
- HK data acquisition and packetisation;
- Science data acquisition, compression and packetisation;
- Transmission of data (HK, events and TC verification) from the instrument to S/C CDMS;
- Transmission of science data to the S/C MM.
- Capability to load, via TCs, replacement and/or additional SW (patches, tables, ICSs, TBC);
- Self test and SW verification facilities;
- Possibility to load and dump part of CDPU memory;
- Possibility to write and check EEPROM: possibility to inhibit these functions during flight operations

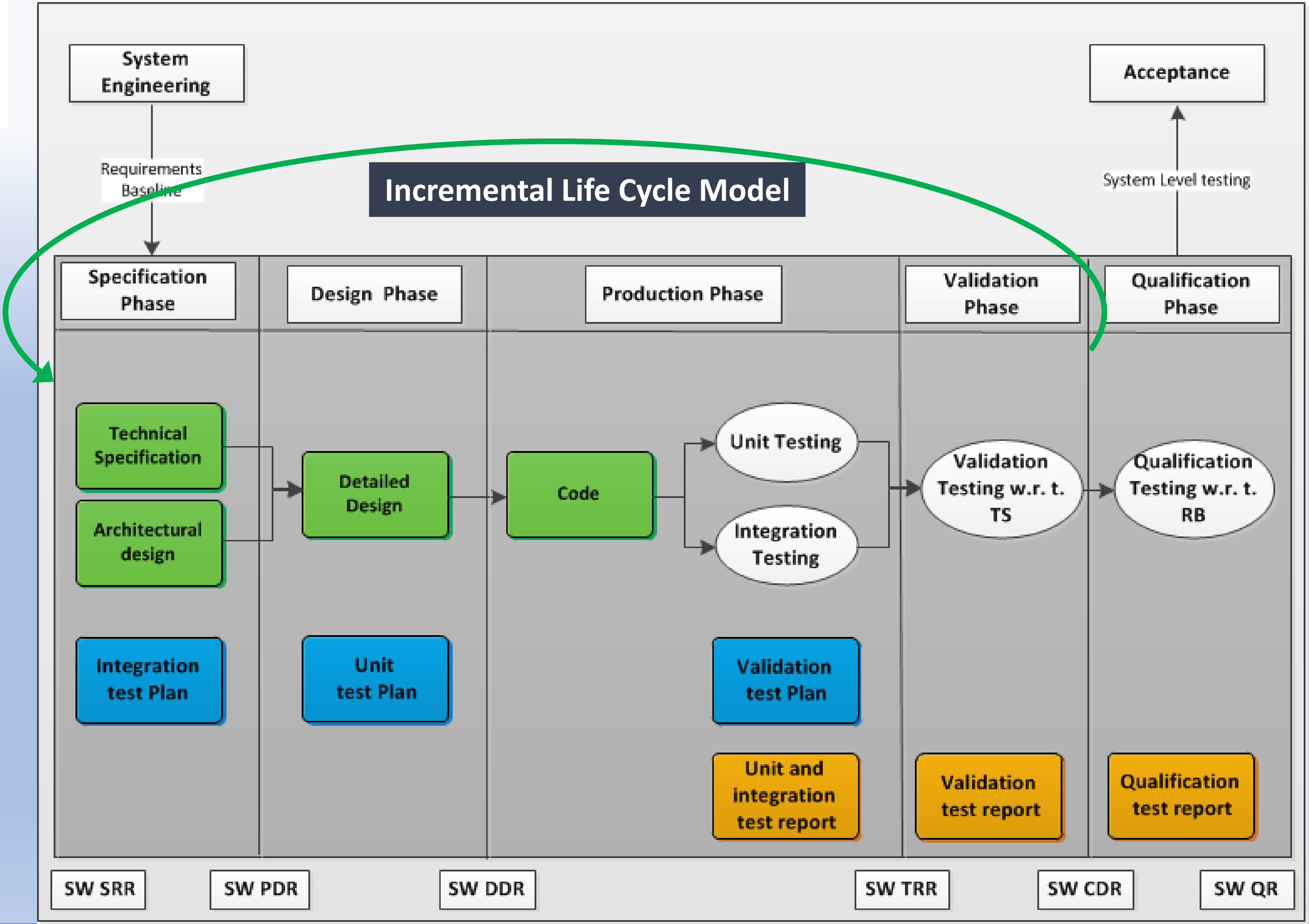


Space Instruments
Control

- Acceptance of instrument commands f
- Execution of predefined instrument co
- Instrument health/status monitoring;
- Implementation of pre-defined proced instrument anomalies.
- HK data acquisition and packetisation;
- Science data acquisition, compression
- Transmission of data (HK, events and the instrument to S/C CDMS;
- Transmission of science data to the S/C
- Capability to load, via TCs, replaceme SW (patches, tables, ICSs, TBC);
- Self test and SW verification facilities;
- Possibility to load and dump part of CD
- Possibility to write and check EEPROM these functions during flight operation

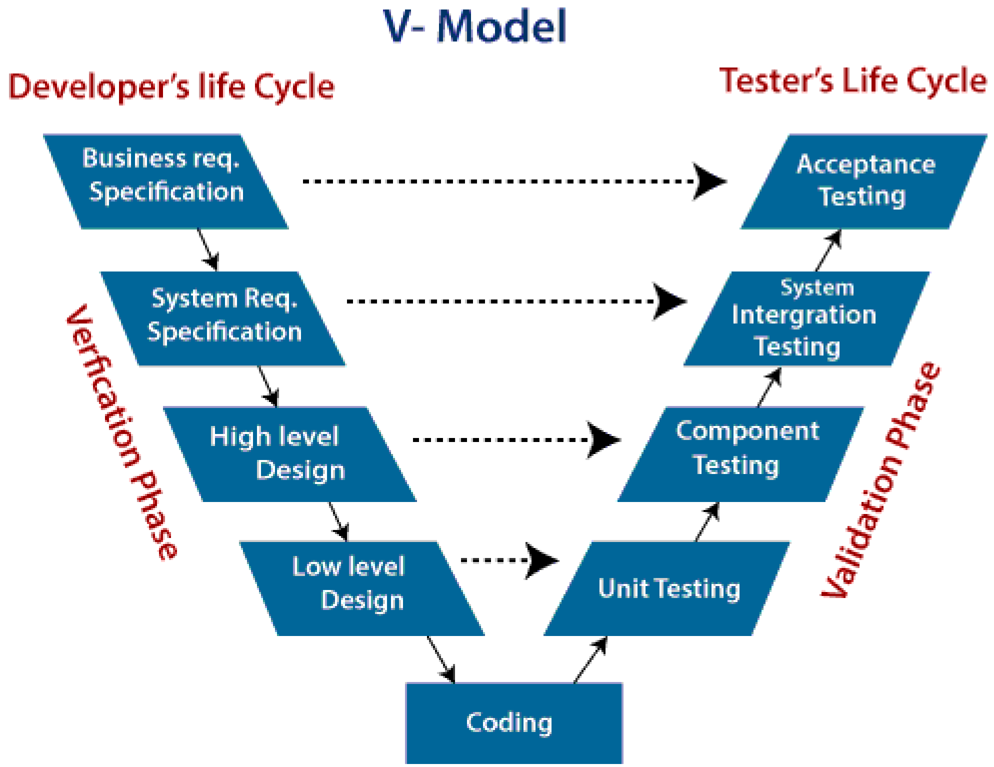


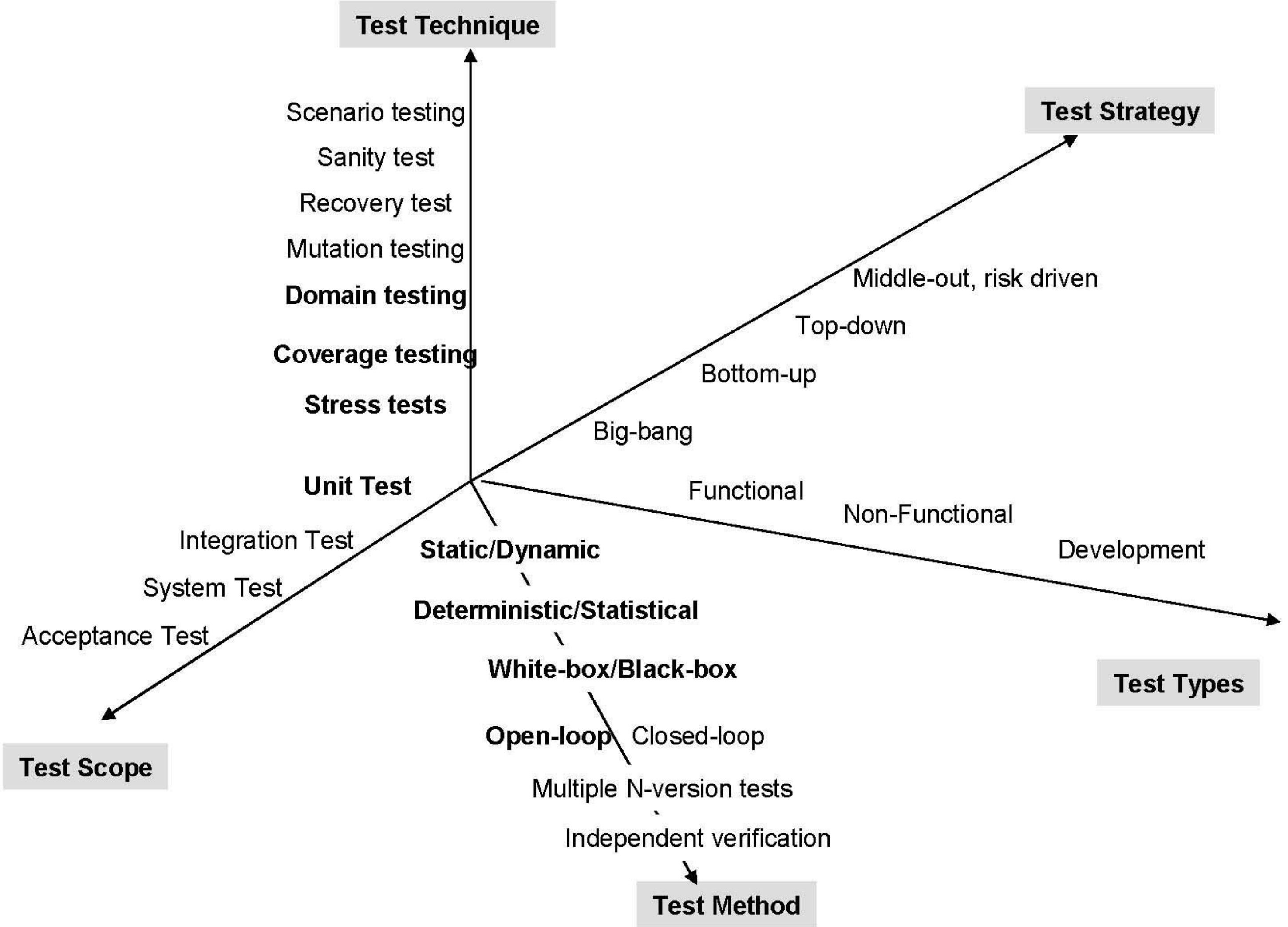
ESA Packets Utilization Standard - **ECSS-E-ST-70-41C**



System Engineering
Requirements Baseline
Incremental Life Cycle Model
Acceptance
System Level testing
Specification Phase
Design Phase
Production Phase
Validation Phase
Qualification Phase
Technical Specification
Architectural design
Detailed Design
Code
Unit Testing
Integration Testing
Validation Testing w.r. t. TS
Qualification Testing w.r. t. RB
Integration test Plan
Unit test Plan
Validation test Plan
Unit and integration test report
Validation test report
Qualification test report
SW SRR
SW PDR
SW DDR
SW TRR
SW CDR
SW QR

Space Control Systems Testing

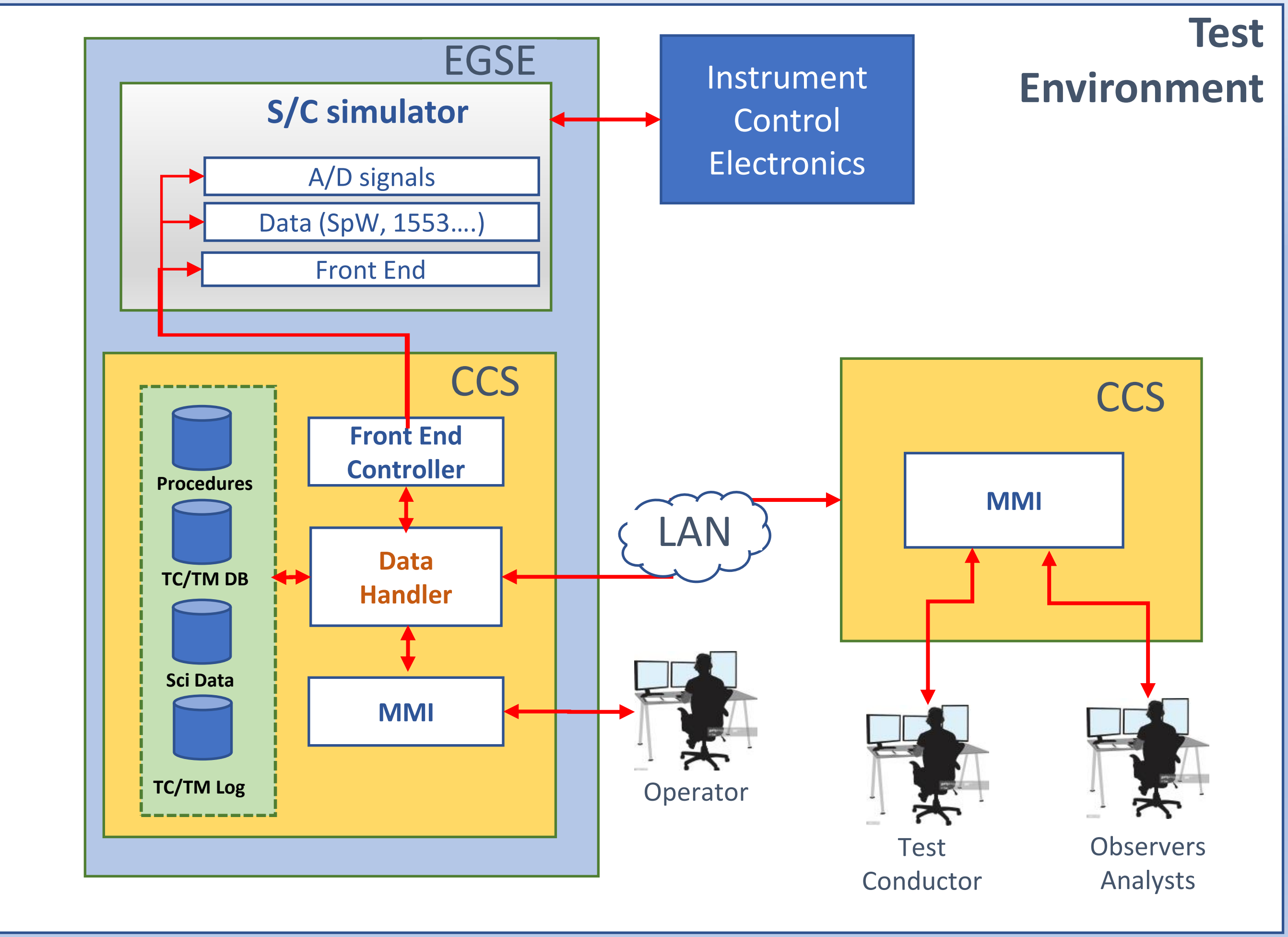




Major Effort

Possible Collaborations

Space Instruments Control Software Validation and Testing – EGSE and CCS



Telemetry Telecommand packets Database
SCOS2000

Space Instruments Control Software PA

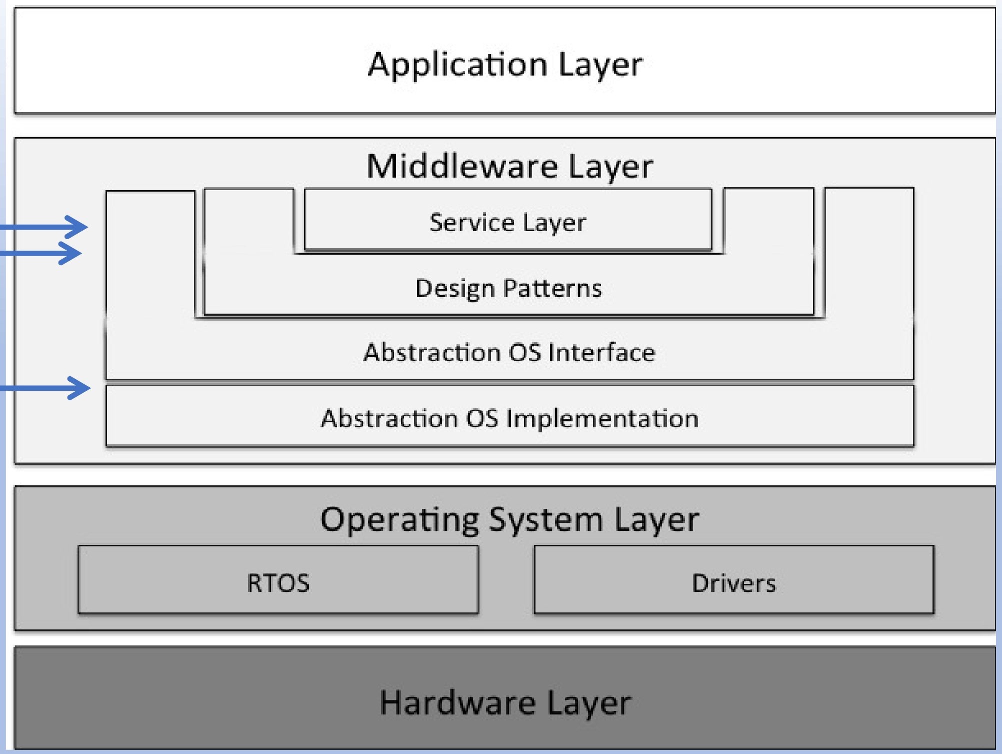
Major Effort
Possible Collaborations

Plans for future developments

ESA Packet utilisation standard
→ homogeneize the library of PUS services already implemented at IAPS and OATO
+ use of CORDET framework (see R. Ottensamer presentation)

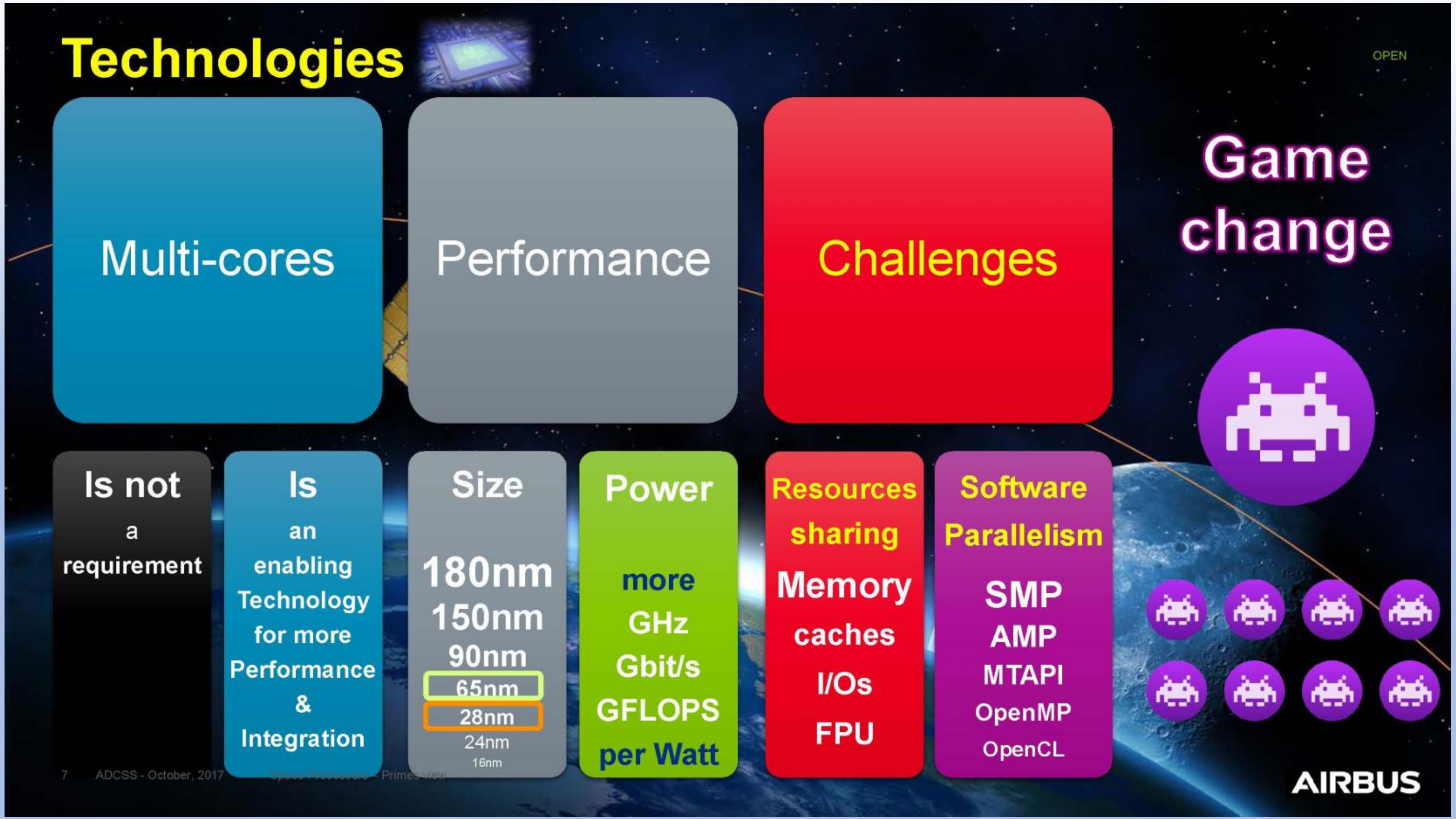
Data compression:
→ develop a data compression functions library

An implementation of RTEMS OS and SpaceWire interface abstraction functions already available at IAPS.



→ develop the abstraction layers for the VxWorks OS and for the MIL-STD-1553B interface.
This fundamental building blocks will allow developing the other higher layer blocks without any direct call to OS peculiar services.

Plans for future developments



It will be not possible any more to face what technology is expected to provide within the small IAPS group.
New collaborations with other INAF experts is necessary.