SW di controllo per Missioni Spaziali - situazione attuale e prospettive future

INAF – ICT Workshop 2018
10 – 14 Settembre 2018
Catania

Astrophysics Instrumentation Software Development

Instrument commanding

Instrument health monitoring and control

Data Acquisition & pre-processing

Data packetization and formatting

Digital Signal Processing

Instrument Remote commanding

Instrument Real time monitoring

Requirements Analysis

SW criticality analysis

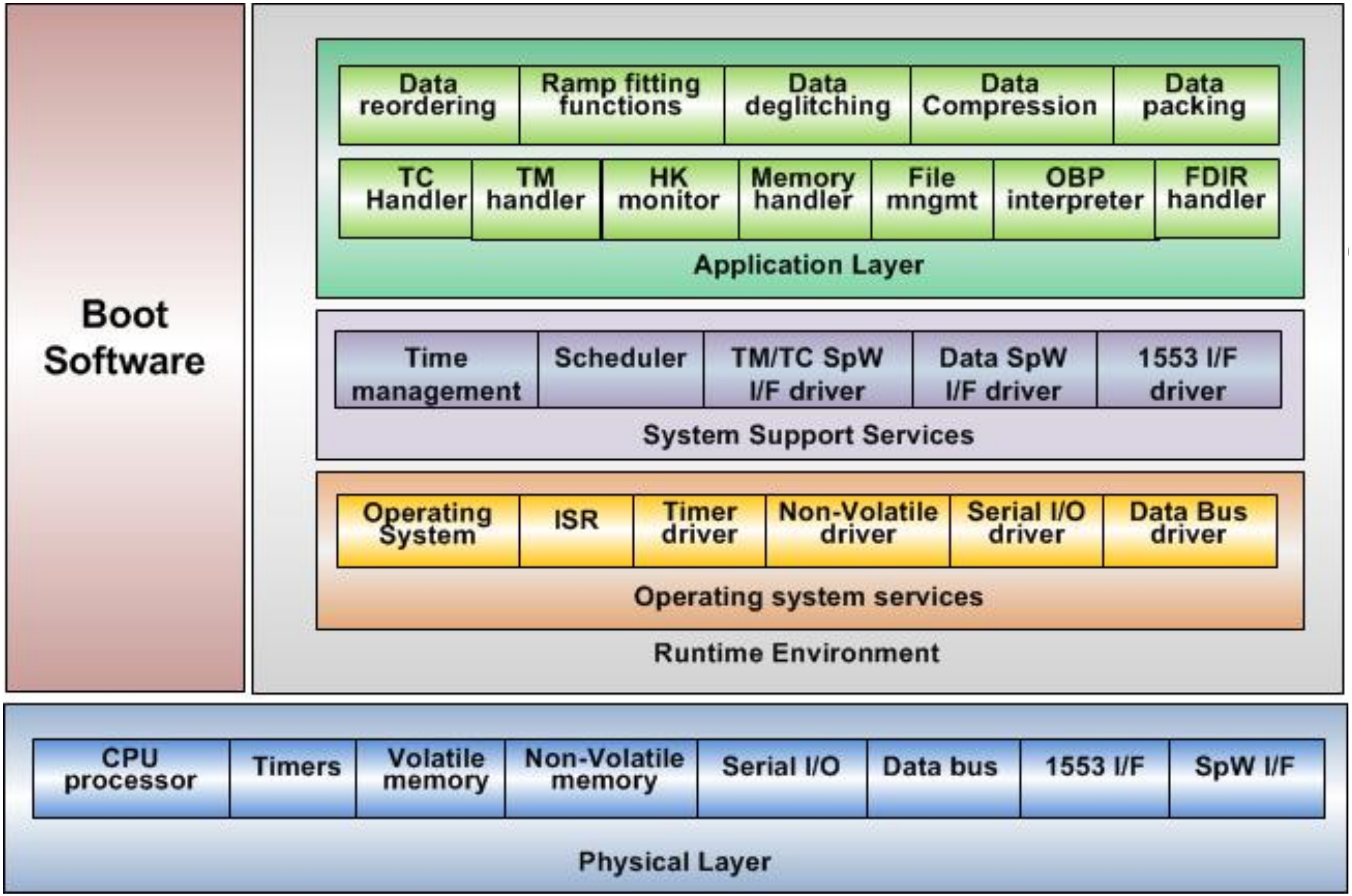
SW Design

SW development

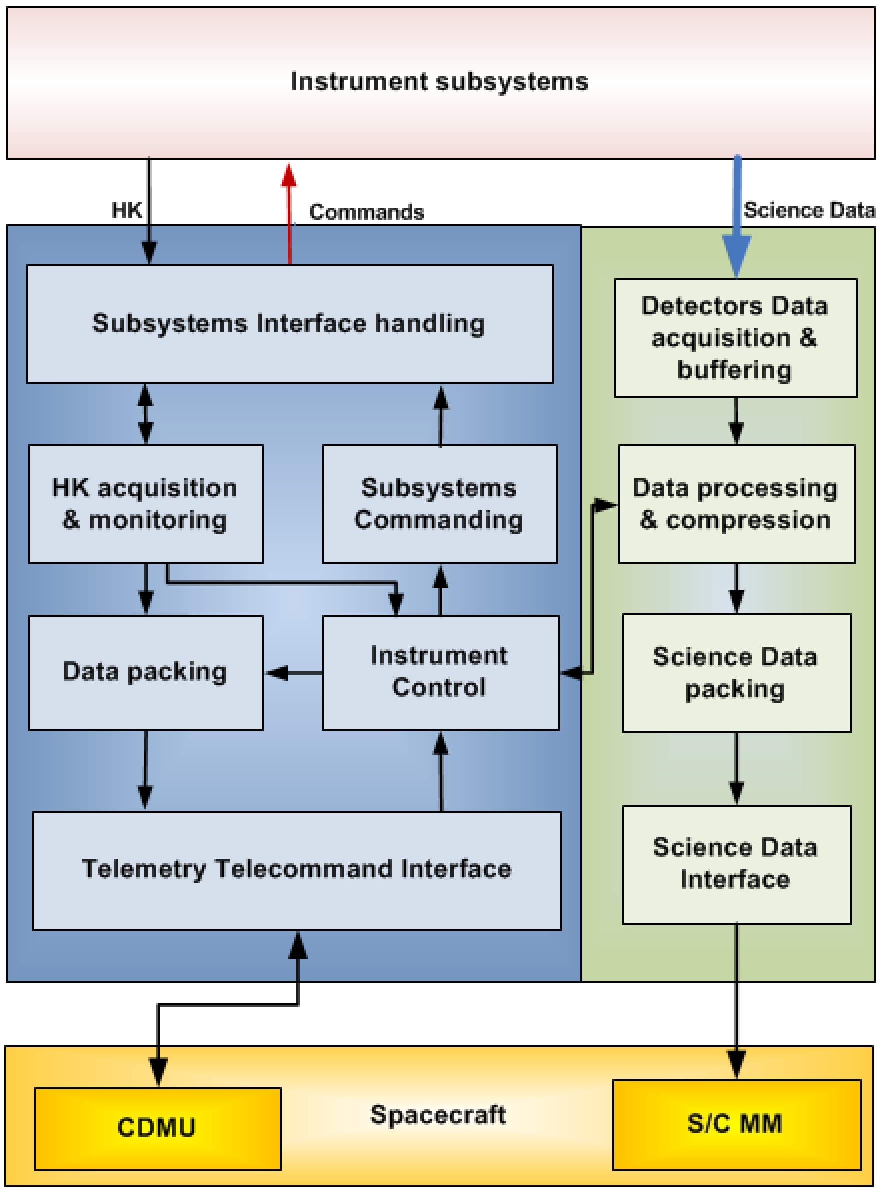
SW testing

SW Validation and Qualification

Control Systems Components



Space Instruments Control Software



Specific INAF expertise

- Experience with the main flight qualified fault tolerant processors:
  - **DSP21020 (Herschel), LEON (Euclid, PLATO, ATHENA), PowerPC 750FX (Euclid).**
- Experience with the **MIL 1553 STD B** avionic standard for the TM/TC I/F (Herschel and Euclid)
- Experience with **SpaceWire** networks (Euclid, PLATO, ATHENA)
- 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, ATHENA)
- Deep Knowledge of ESA ECSS standards and procedures
- Experience with **CCSDS standard lossless compression** algorithms implementation and optimisation (Euclid)

Processors

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

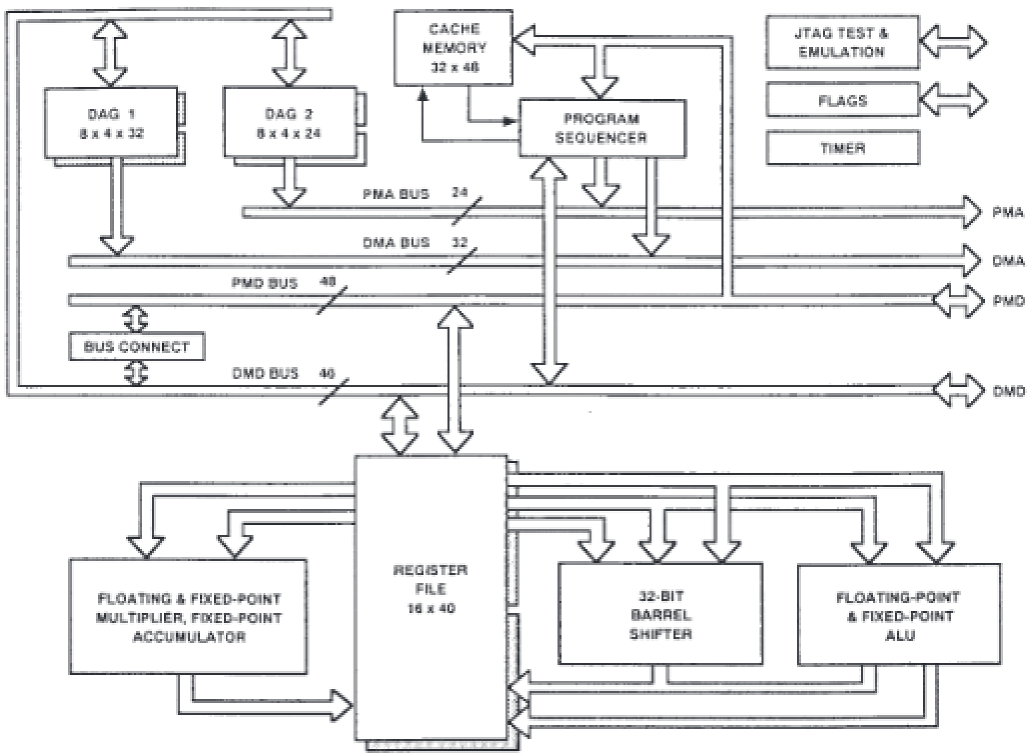
Processors – DSP 21020

Single-chip floating-point processor optimized for digital signal processing applications.
Three Computation Units (ALU, Multiplier, and Shifter) with a Shared Data Register File

- Two Data Address Generators (DAG 1, DAG 2)
- Program Sequencer with Instruction Cache
- 32-bit Timer
- Memory Buses and Interface
- JTAG Test Access Port

Space qualified Real Time Operating System?

Figure 1. TSC21020F Block Diagram



Real Time Operating Systems

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		■	■		■	■	■	■				■		■

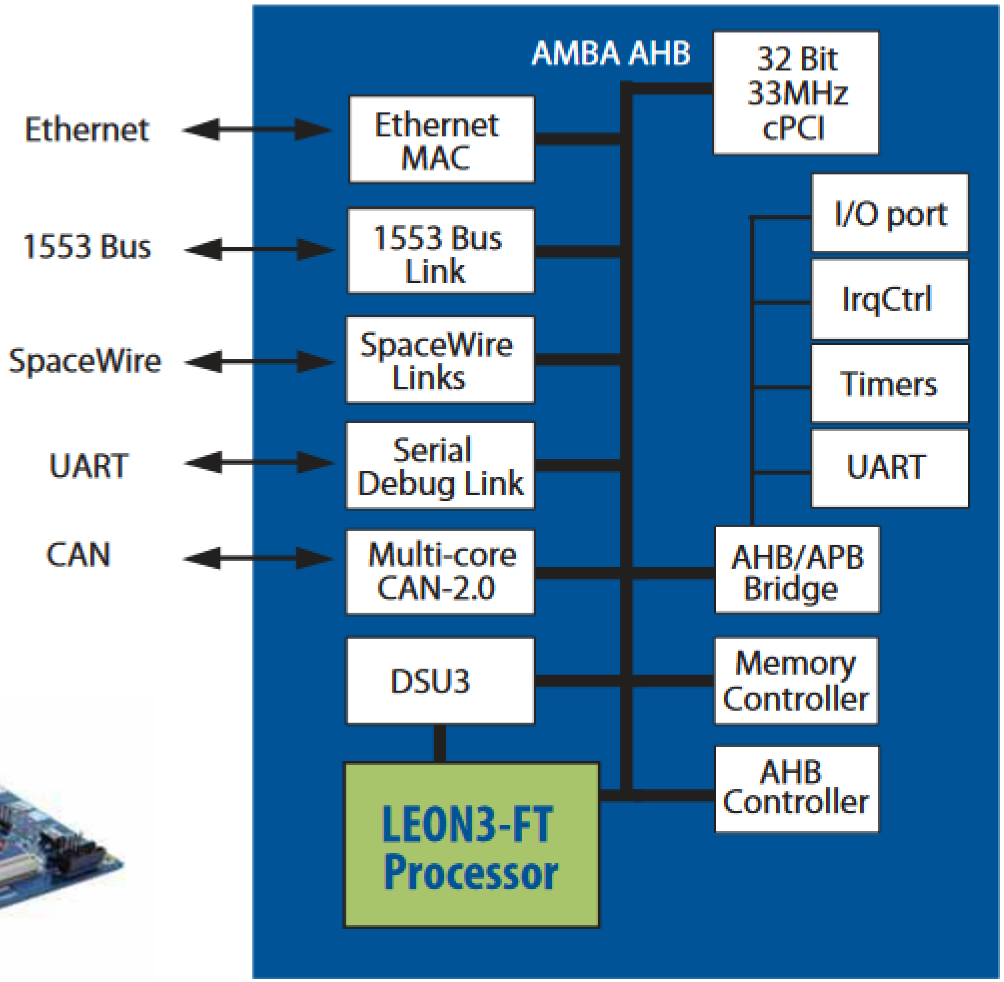
Processors – LEON3FT

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, THOR, ATHENA)

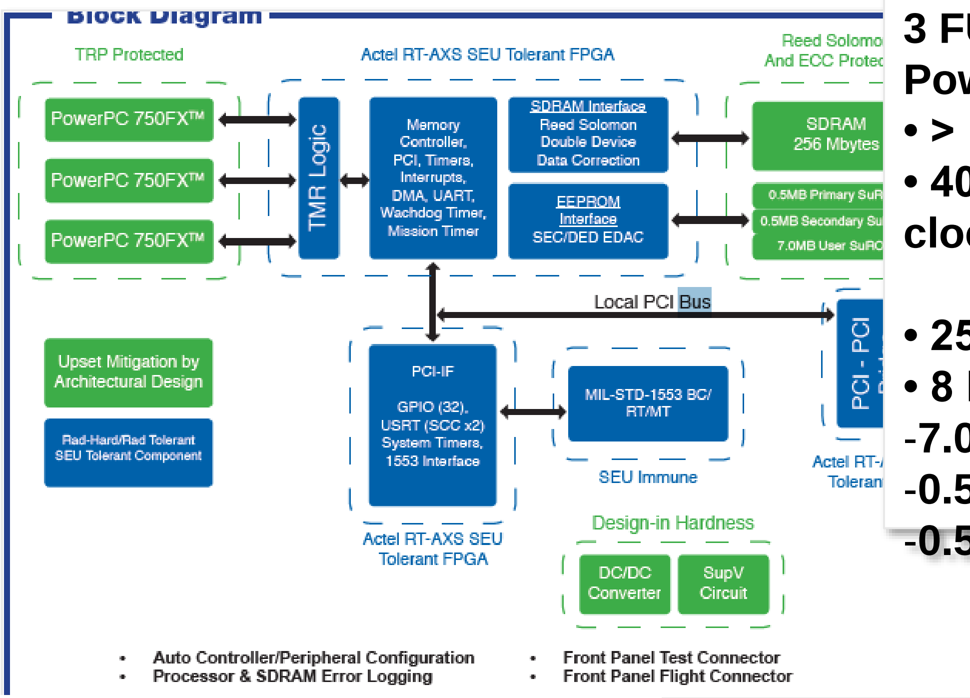
UT699RH SOC

3 Watts/ 34 Grams

UT699RH RadHard (SOC) Standard Product



Processors – SCS750 (rad-hard PowerPC)

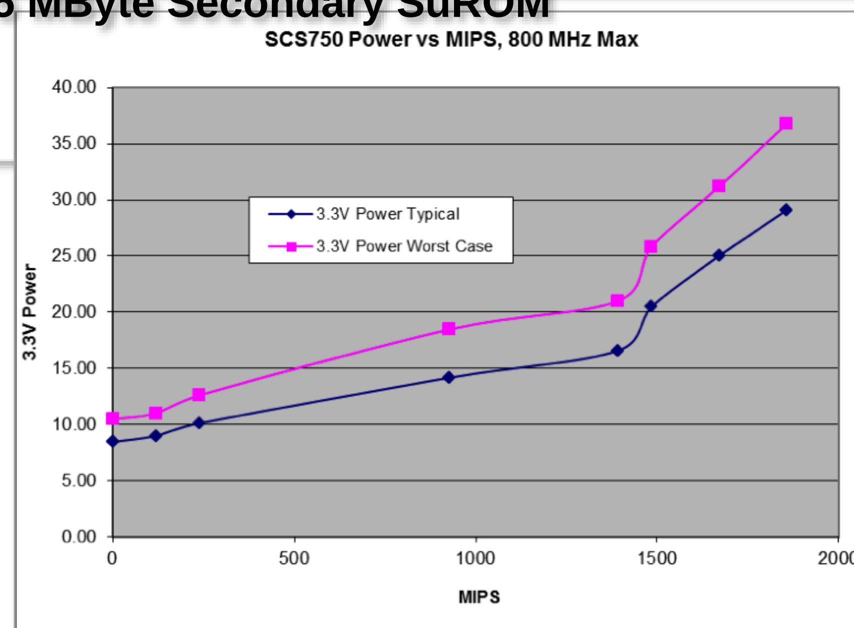


3 FULLY TMR PROTECTED PROCESSORS PowerPC 750FXTM

- > 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

Processors – GR740 rad-hard quad-core LEON4FT

•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 cacheShared 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

Processors – GR740 rad-hard quad-core LEON4FT

• CCSDS 121 Lossless compression Lossless RICE compression according to the Recommended Standard CCSDS 121.0-B-2.C
Reference software provided by ESA.
→2.06 seconds for 1 MB input image (16-bit samples) = 0,24 Msamples/s

On Euclid (SCS750 powerPC)
→10 Gbit image compressed in 280sec = 2.16 Msamples/sec

• CCSDS 123 Hyperspectral Compression Lossless compression for hyperspectral and multispectral images according to the Draft Recommended Standard CCSDS 123.0-R-1.C
Reference software provided by ESA.
→644.21 seconds for 35 MB input image.

Processor development status:

- Development boards and prototype parts are available for purchase
- Additional characterization of silicon, resolving TBDs of datasheet values during 2016
- Radiation testing of prototypes during 2016
- Qualification phase expected 2016/2017

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), ATHENA
Proposed for ARIEL,THOR, SPICA (S/C network)

INAF experience

- ISO (Infrared Space Observatory) – 1995 first European infrared mission
  - DPU (IFSI, Italian industry) and instrument control SW (CNR IFSI) for the **Long Wavelength Spectrometer**

- Herschel – 2009 Far Infrared Telescope (3m)
  - DPU/ICU (IAPS, Italian industry) and instrument control SW (INAF IAPS) for the 3 focal plane scientific instruments SPIRE, PACS and HIFI

- Euclid – 2021 ESA Cosmic Vision M2 mission to map the geometry of the dark Universe
  - DPU-DCU/ICU (OAS, OATo, IAPS, Italian industry) and instrument control SW (INAF OAPD, OATO and IAPS) for the 2 focal plane scientific instruments VIS and NISP

- PLATO – 2026 ESA Cosmic Vision M3 mission to detect and characterize terrestrial exoplanets around bright solar-type stars
  - DPU/ICU (OACT, OAA, UniFi and Italian industry) and instrument control SW (INAF IAPS) for the scientific payload

- Athena – 2028 ESA Cosmic Vision L2 X-ray mission to study the hot gas present in large-scale structures and the supermassive black holes.
  - DPU/ICU (OATo, OAS, Italian industry) and instrument control SW (INAF OATo) for the X-IFU

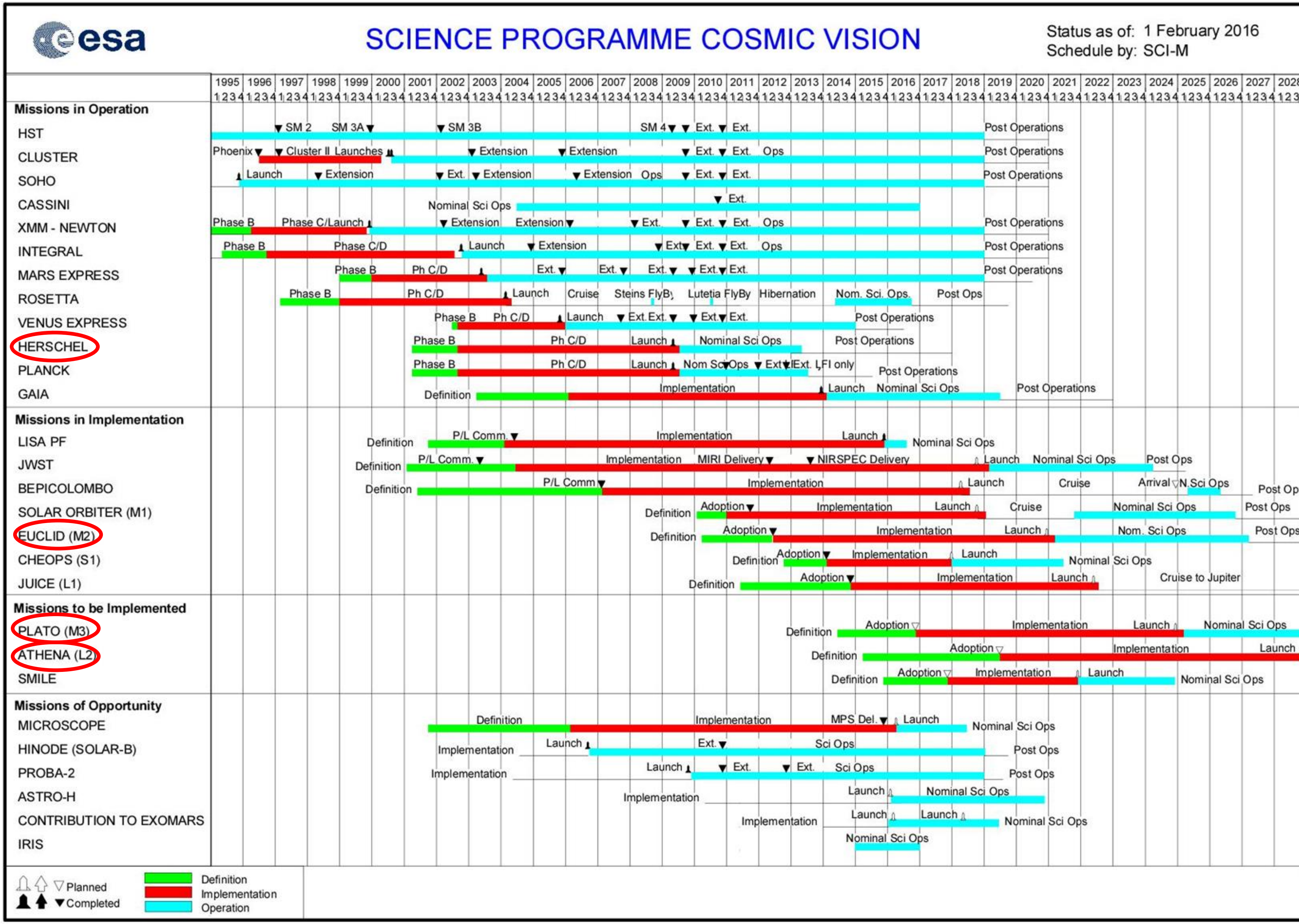
The roadmap to the (not too far) future

- ARIEL – 2028 ESA Cosmic Vision M4 mission to study the atmospheres of hundreds of planets orbiting different types of stars with the aim of understanding what are the conditions for planet formation and for the emergence of life. (selected, to be adopted)
- ICU (OAA, OACT, UniFi, Italian industry) and instrument control SW (INAF IAPS) for the scientific payload
- SPICA – 2030 ESA Cosmic Vision M5 mission to study the cold Universe in the FIR (to be selected in 2021)
  - DPU/ICU (Italian industry) and instrument control SW (INAF IAPS) for the scientific payload
- NASA OST – 2035 to be proposed at the NASA Decadal Survey in 2019: FIR observatory (6m telescope, actively cooled)
  - ICU (IAPS, Italian industry) and instrument control SW (INAF IAPS) for the HERO instrument

Access to the space observatories (SPICA, NASA OST, ATHENA) guaranteed time

"Expert" access to the survey data since the first releases (Euclid, PLATO, ARIEL)

"Expert" support to the observation planning and to the data reduction



+ ARIEL (M4 - 2028) + SPICA (M5 - 2030) + NASA OST (2035)

Instrument Control Software Development is a Key Activity

Part of every major INAF project

Enable our participation in many international programs

Ensures our access to instruments data, even if not released to public

Increases our capability to cross correlate data from different sources

Increases our capability to produce up-to-date publications

High costs if outsourced - we have in house know how

→ **Improves our competitiveness**

What we need

RESPECT we need to address software development as a **first class citizen** in the panorama of our research activities.

MANPOWER we must understand that instrument control software cannot be simply bought. It should be developed by scientists and engineers, with a specific expertise. We now have these extperts in INAF and we cannot afford to loose them.

INVESTMENT and a better planning. We must understand that resources have to be allocated to software projects, and the investment must be done promptly and from the planning phases.

BEST PRACTICES Big software projects and participation in international contexts impose the use of software engineering standards both at process and project level.

EXCHANGE of know-how and tools between INAF structures and people.

What we plan

To build a “collaborative” network between all INAF realities with expertise in the field of instrument control SW and, more generally, in the field of SW real time design and development

With the aim of :

- **Sharing know-how, tools, applications**
- **Building a "register" of INAF experts in this field**
- **Optimizing the efficiency of our work, avoiding duplications**
- **Exploring new technological solutions and improving our capability of doing research also in this field**

First steps:

- **Set up an initial group of “reference” experts for ground and space SW**
- **Organize the first INAF workshop dedicated to the Instrument Control SW within March 2019**