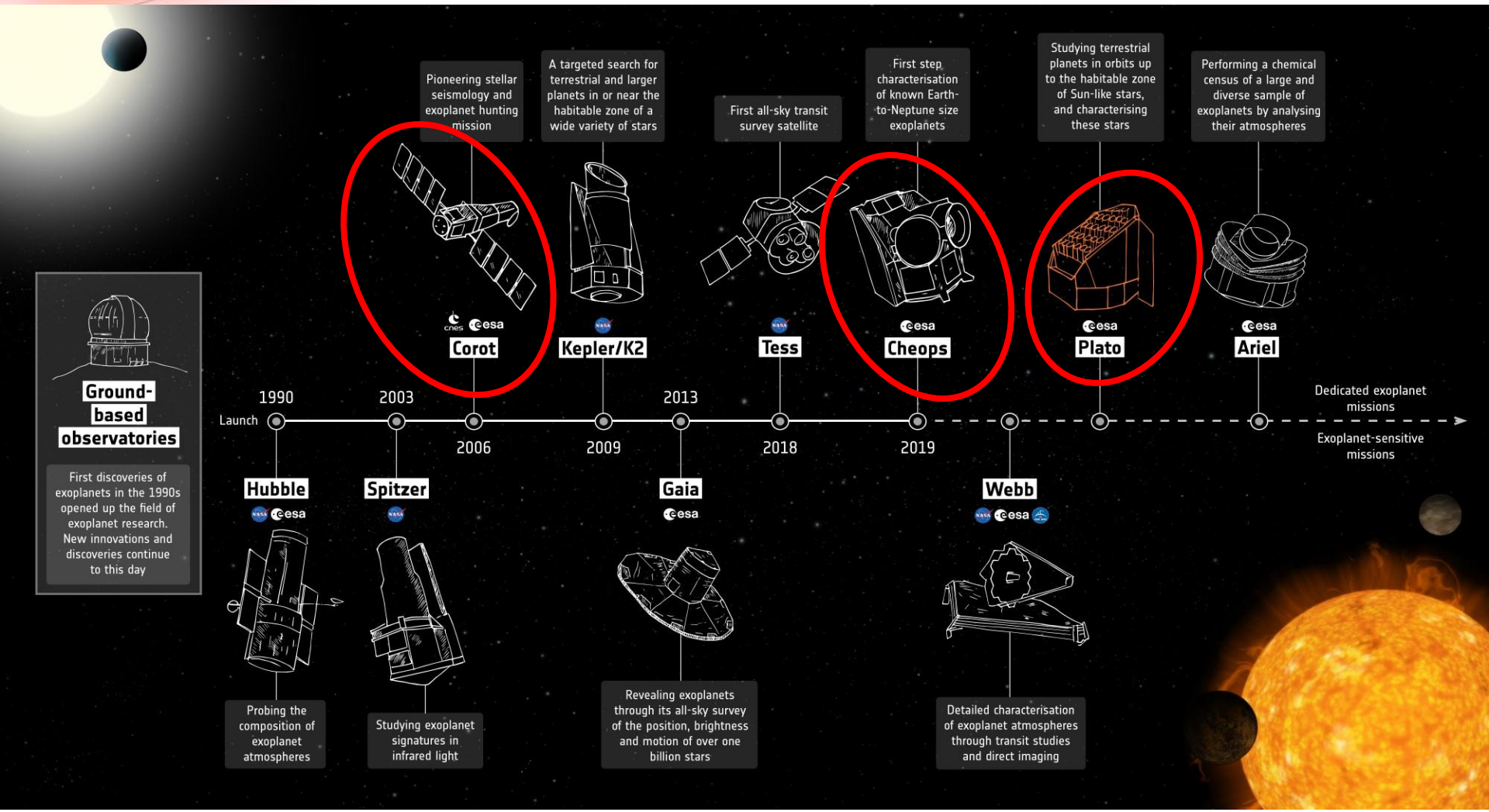
PLATO DPS: State of the art on-board processing for Europe's next planet-hunter June 14th, 2021

European Workshop on On-Board Data Processing

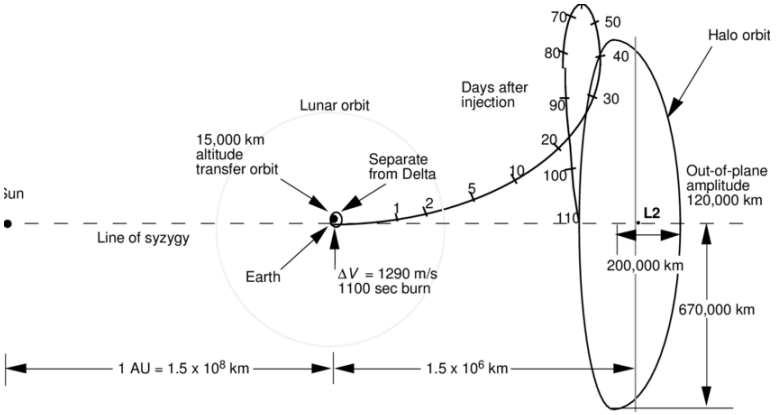
PLATO DPS Team

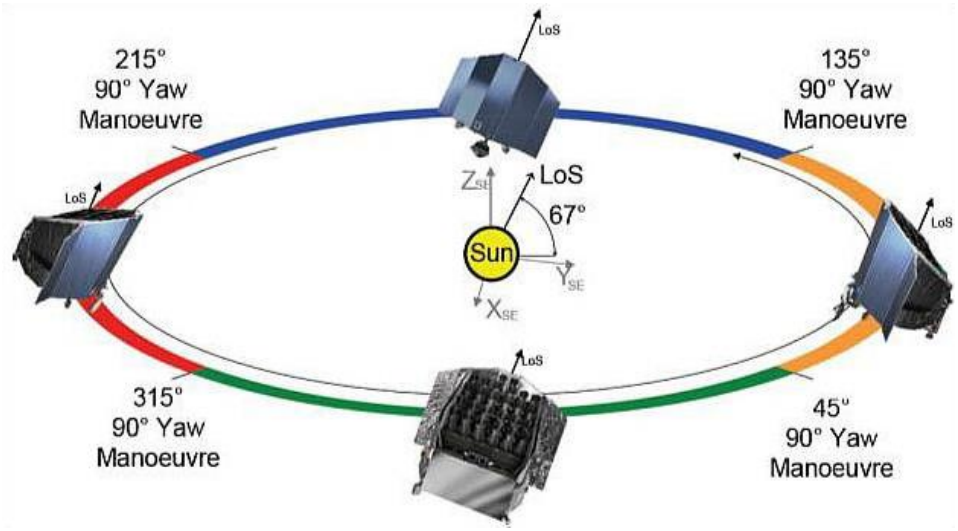
PREVIOUSLY ON EXOPLANETS



THE PLATO MISSION

- ESA Cosmic Vision 3 Mission (M3)
- Science Goals
  - Detect terrestrial exoplanets in the habitable zone of solar-type stars
  - Characterize their bulk properties
- Orbit: L2 Halo
- Quaterly 90 degree roll
- Launch: 2026
- Down-link budget:
  435 Gbit/day ~ 5.15 Mbit/s





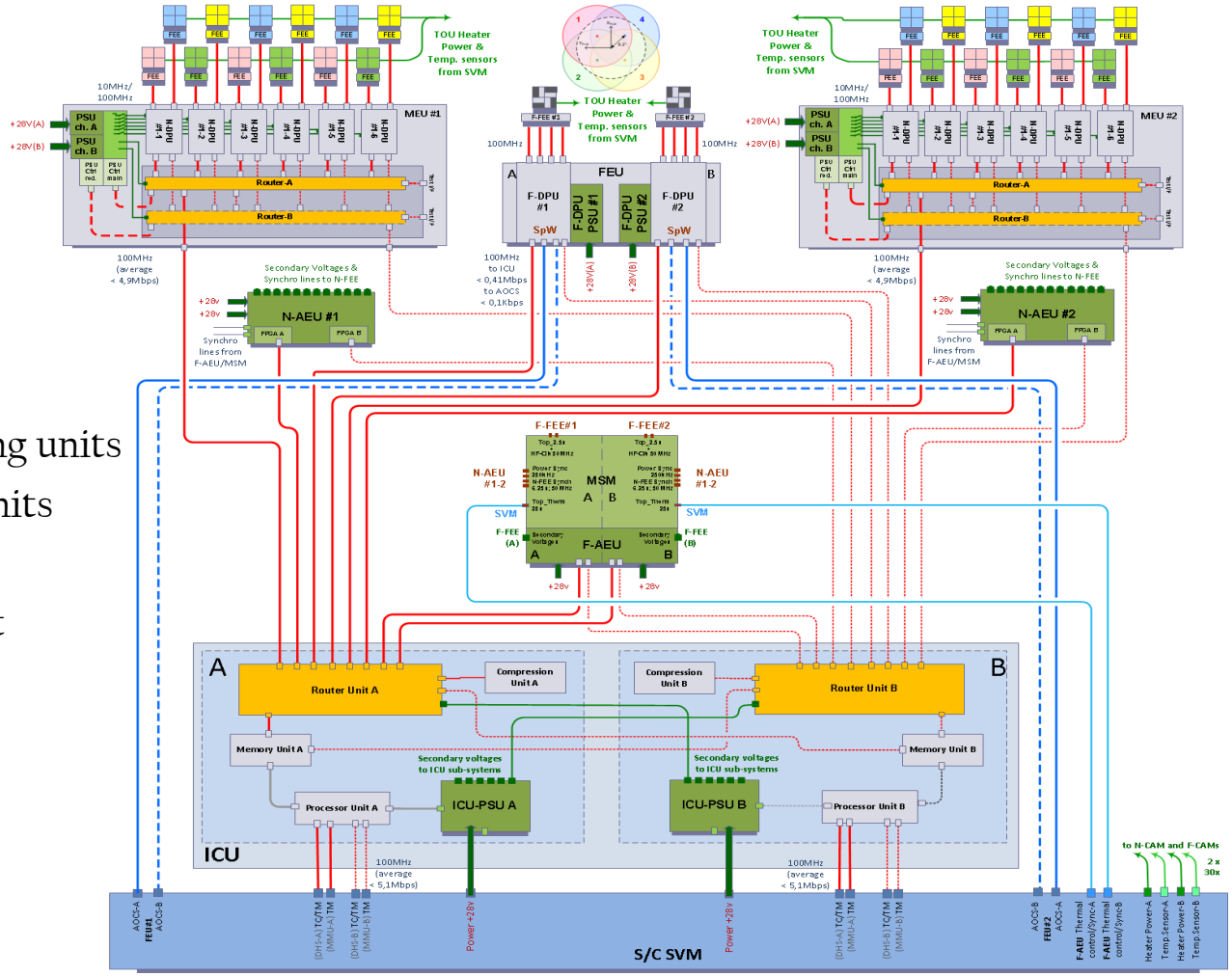
THE CAMERA(S)

- 24 + 2 Cameras are mounted on a single optical bench
  - 4 Camera Groups
  - 6 Normal Cameras per Group
- Refractor
  - 4 Full frame CCDs by e2v
  - 4510x4510 pixel each
- 25s (nominal) cadence
  - Staggered readout
  - One CCD every 6.25s
- Using multiple cameras increases
  - Signal to noise ratio
  - Robustness
  - Field-of-view

Picture courtesy of RUAG

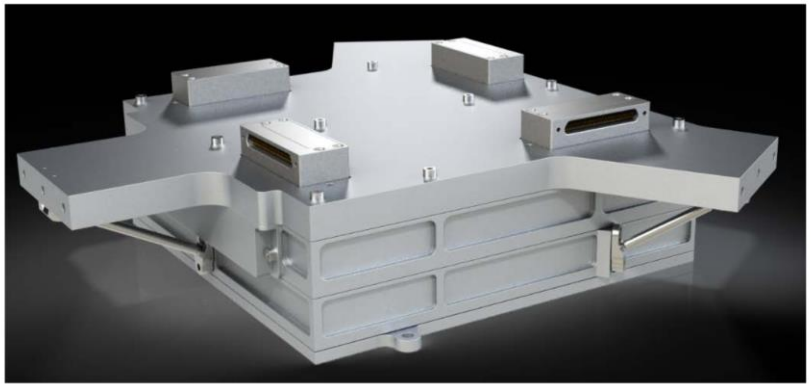
THE PLATO INSTRUMENT

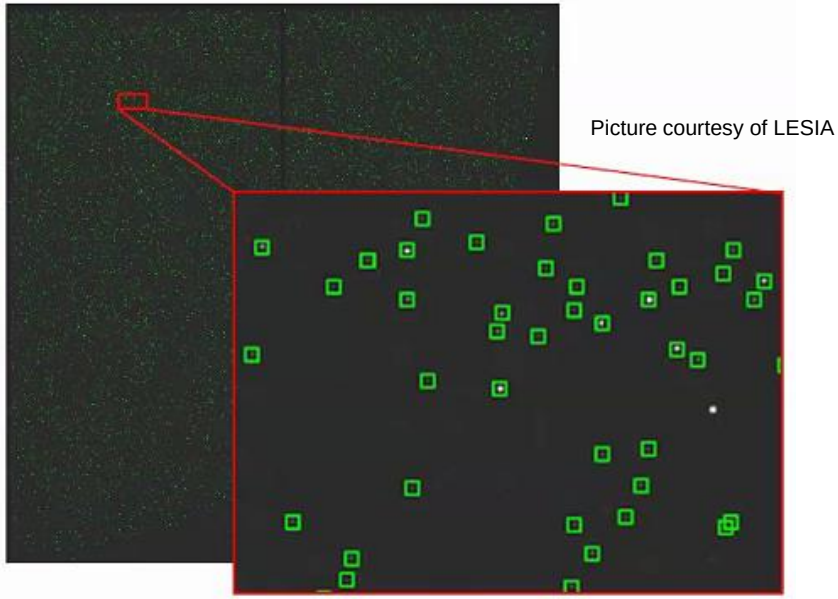
- Camera Subsystem
  - 24 Normal cameras
  - 2 Fast cameras
  - 2 Normal AEUs
  - 1 Fast AEUs
- DPS Subsystem
  - 12 Normal data processing units
  - 2 Fast data processing units
  - Routers and PSUs
  - Instrument Control Unit



THE FRONT-END ELECTRONICS

- Analog Part
  - CCD Management
  - High-Precision HKs
- Digital-Part
  - FPGA
  - Buffer
  - SpW Transceivers
    - One SpW link per N-FEE
    - DPU → FEE = 10Mhz
    - FEE → DPU = 100MHz
  - Windowing
    - One CCD ~38MByte
    - 38MB/6.25s ~50Mbps
    - Up to 300.000 windows per camera
    - Up to 10% of the whole CCD can be selected

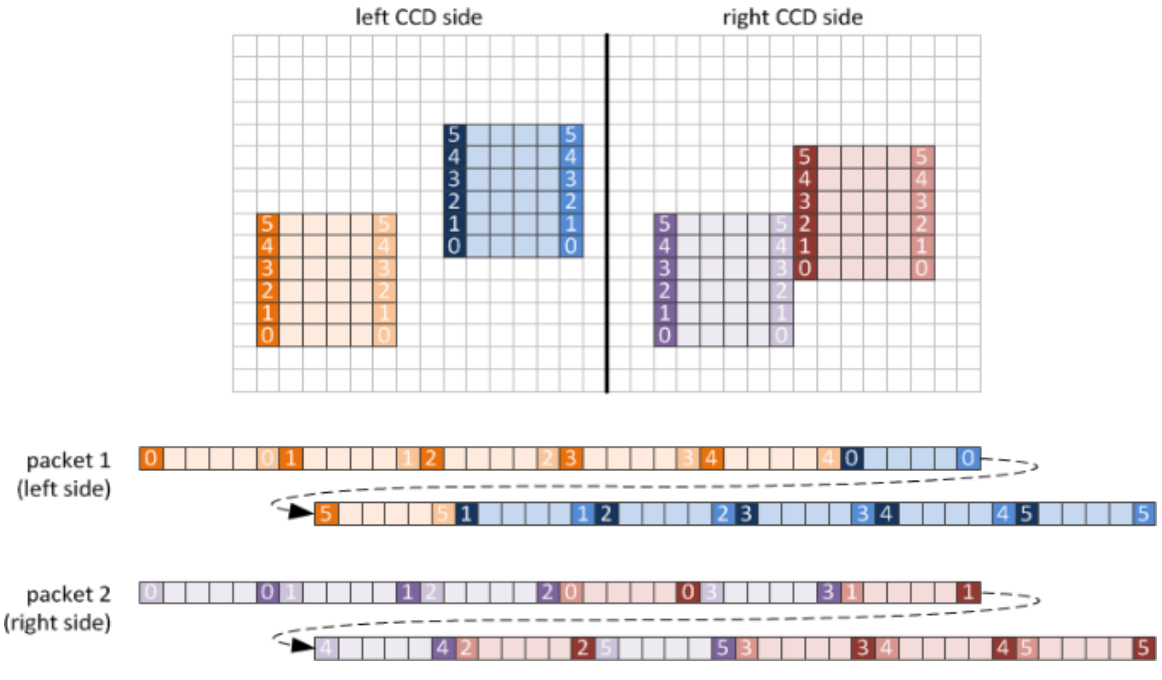




Picture courtesy of LESIA

DATA REDUCTION AT THE SOURCE

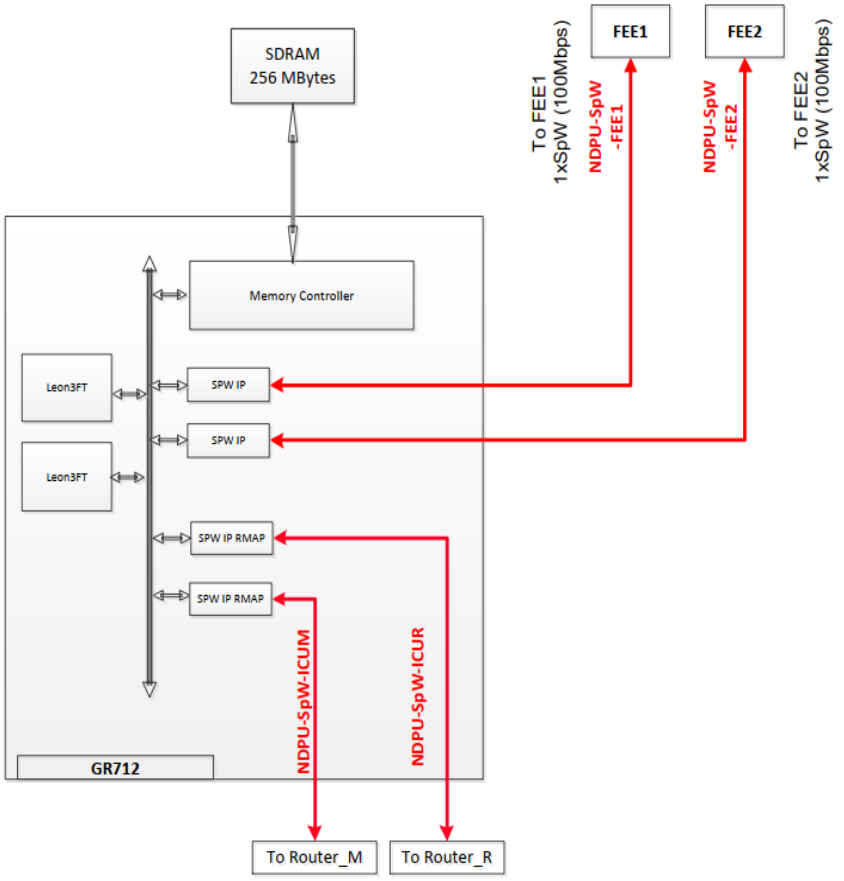
- Data that is not produced does not need to be processed
- If production is mandatory (only full CCD lines can be digitized) it is most efficient to discard not needed data immediately



0	logical address = 0x50
1	protocol id = 0xF0
2	length (MSB)
3	length (LSB)
4	type (MSB)
5	type (LSB)
6	frame counter (MSB)
7	frame counter (LSB)
8	sequence counter (MSB)
9	sequence counter (LSB)
10	resevered
11	header CRC
12	data (big endian)
length+10	
length+11	data CRC

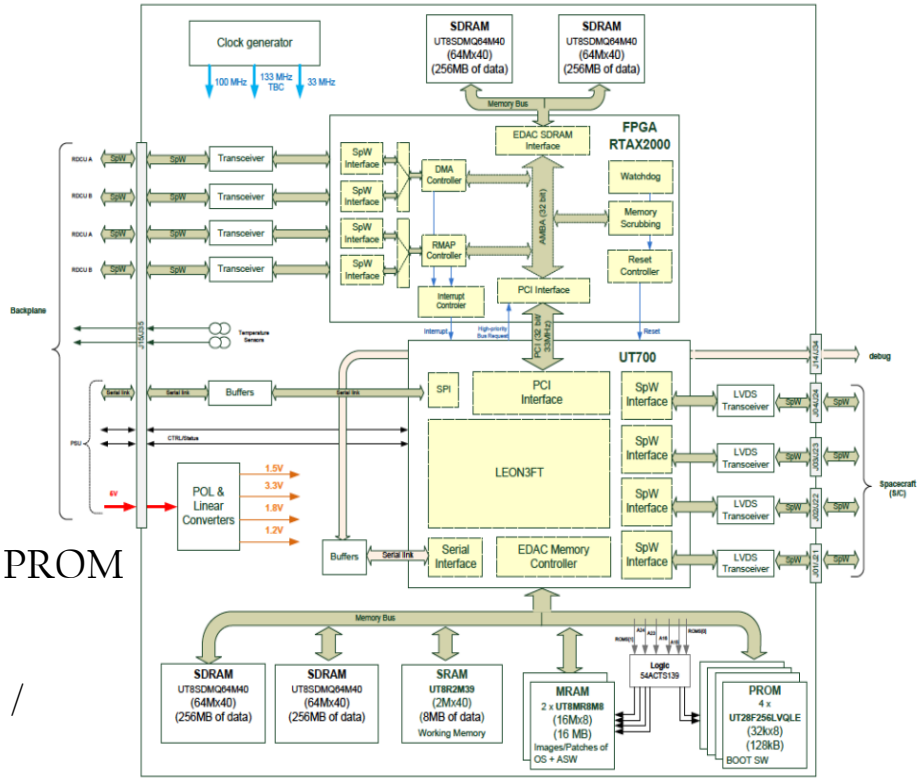
NORMAL DATA PROCESSING UNITS

- Functions
  - Camera management (2 Cams per DPU)
  - Science / Data reduction
- Hardware
  - GR712RC - Dual-core Leon3 CPU
  - 256 MB SDRAM
  - No Non-volatile memory
- Software
  - RTEMS 4.8 (Qualifiable version)
  - Mixed C/C++ implementation (based on LESIA proprietary lib)



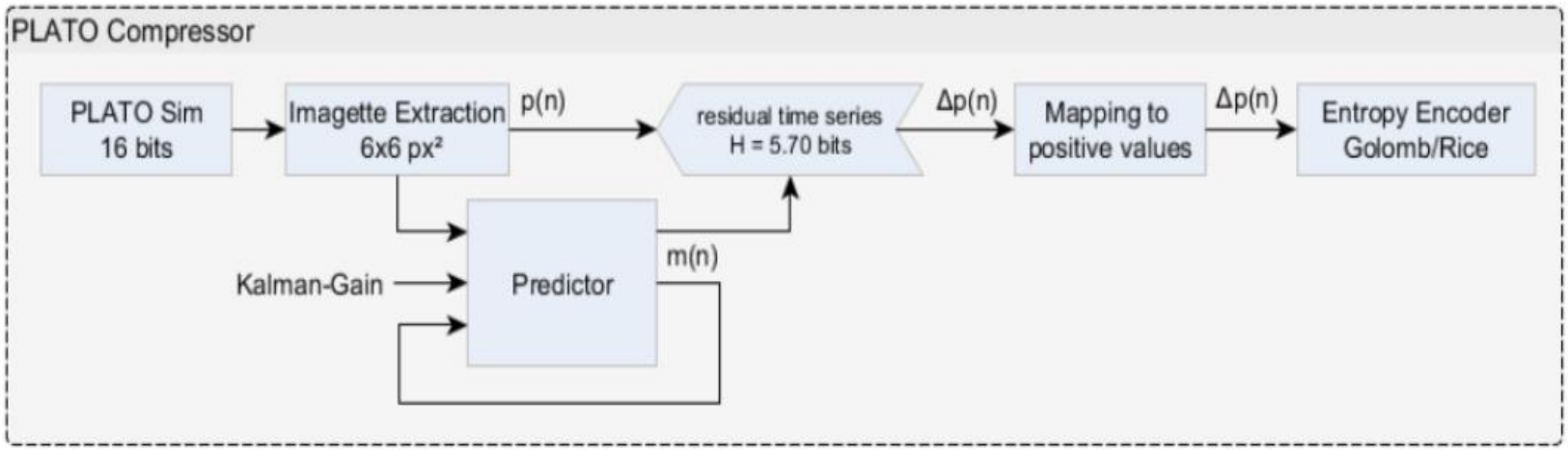
INSTRUMENT CONTROL UNIT

- Functions
  - Instrument management
    - Booting DPUs
    - SpW network management
  - Data reduction (Compression)
  - Payload level FDIR & Autonomy
- Hardware
  - UT700 single core Leon3 CPU
  - FPGA Compression Board
  - 2 x 512 MB SDRAM + 16 MB MRAM + PROM
- Software
  - ASW RTEMS 4.8 (Qualifiable version) / C implementation
  - BSW Bare-metal C super-loop



COMPRESSION

- Golomb-code with custom pre-processing implemented in FPGA
  - Difference between data and "model" is taken
  - The remainder is basically noise
  - Overlap and interleave is applied (0, -1, 1, -2, 2, -3, etc.)
  - Result an array of small integers (around 5 bits)
  - These will be encoded using a Golomb-code
  - "model" is updated



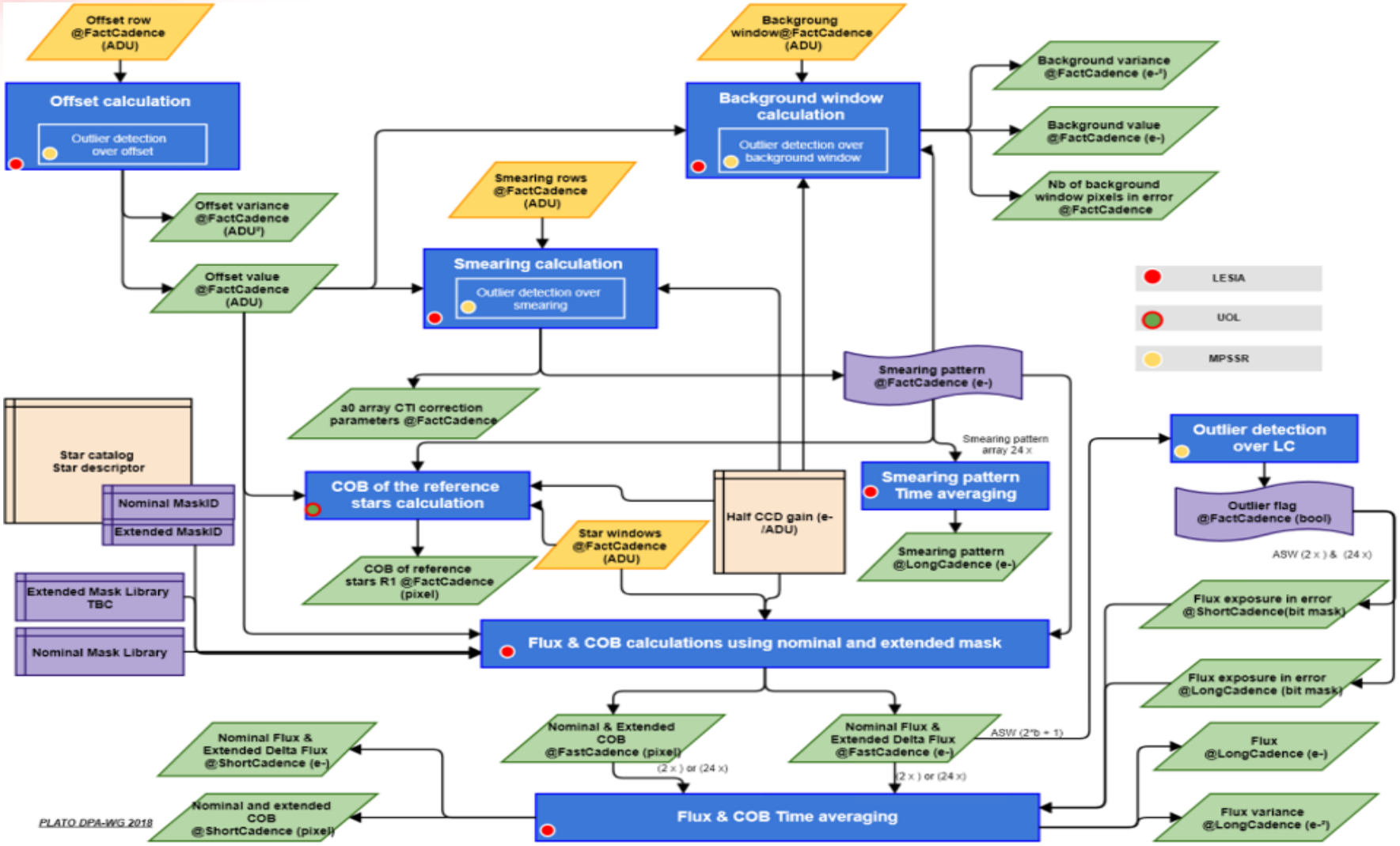
PLATO DATA PRODUCTS

- Number of science targets is still larger then down-link capacity
- Further data reduction by the DPUs is needed

- Data products
  - Imagettes
  - Flux (Lightcurves)
  - Centroid
  - Background
  - Offset
  - Smearing

Number (#) of data products	UC#1 [# / Cam]	UC#2 [# / Cam]	UC#3 [# / Cam]	UC#4 [# / Cam]
24 x N-Camera / 12 x N-DPU				
Light (50 s)	31350	31350	31350	31350
Light, Centroid/COB (50 s)	3700	3700	3700	3700
Light (600 s)	**73500**	**48605**	**46855**	**50355**
Background (25 s)	3000	3000	3000	3000
Imagettes [36pixel] (25 s)	**11000**	**20650**	**22400**	**18900**
Offset (25 s)	8	8	8	8
Smearing (600 s)	18040	18040	18040	18040
Science HK (6,25 s / 25 s)	56	56	56	56
2 x F-Cameras / 2 x F-DPU				
Imagettes [36pixel] (2,5 s)	325	325	325	325
Background (2,5 s)	100	100	100	100
Offset (2,5 s)	8	8	8	8
Science HK (2,5 s / 25 s)	40	40	40	40
FGS data (2,5 s)	40	40	40	40
TM data budget (ICU to SVM) [Gbit/day]	**297**	**435**	**435**	**435**
Margin vs max. daily TM volume [%]	**46**	**0**	**0**	**0**

ON-BOARD DATA PROCESSING



FAST DATA-PROCESSING UNITS

- Functions
  - Camera management
  - Fine guidance
  - Science
- Hardware
  - MDPA single core Leon2 CPU
  - Acceleartion FPGA
  - 8MB SRAM + 128MB DRAM
  - PROM
- Software
  - RTEMS 4.8 (Qualifiable version)
  - Mixed C/C++ implementation (C++ only for GNC algorithms)

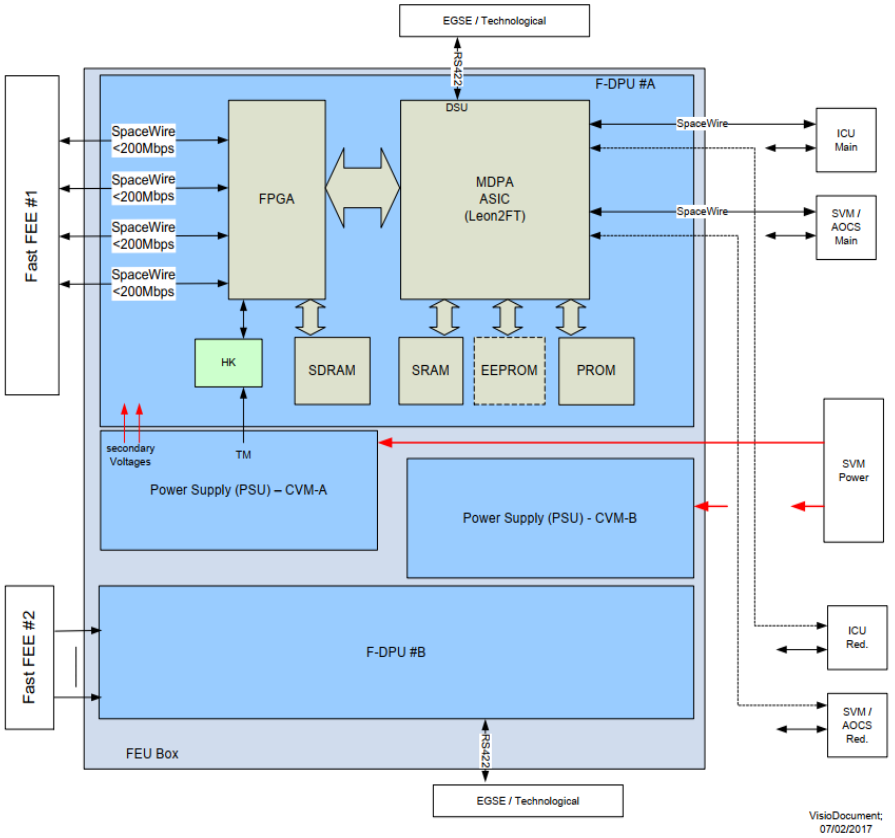


Figure 2-1: FEU Block Diagram

FINE-GUIDANCE

- S/C attitude sensors are not precise enough
- Fast-cameras can be used as high-precision star trackers
- Performance
  - Max. latency 2500ms => 300ms for SW
  - Noise Equivalent Angle (NEA) 25 milliarcseconds (x/y)
- FGS packet every 2.5s to S/C
  - Quaternion
  - OBT
  - Quality flags

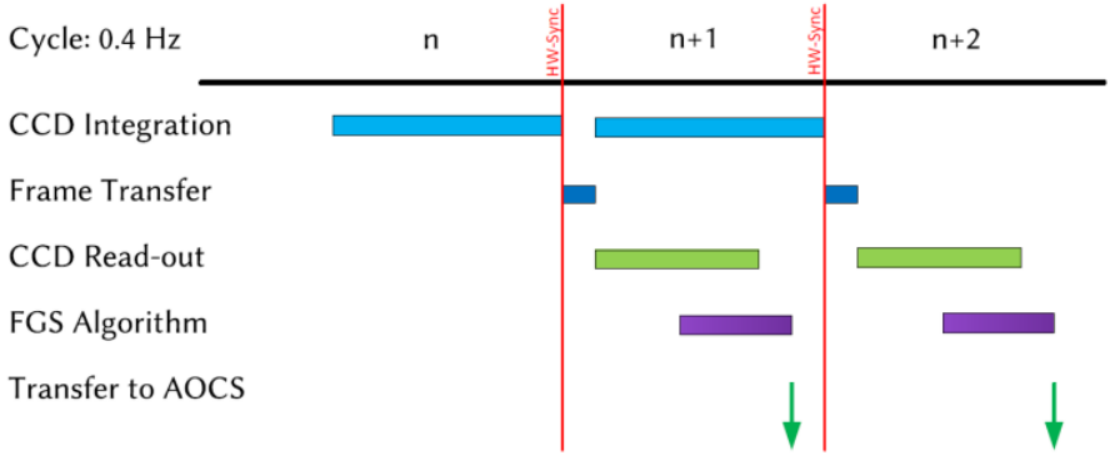


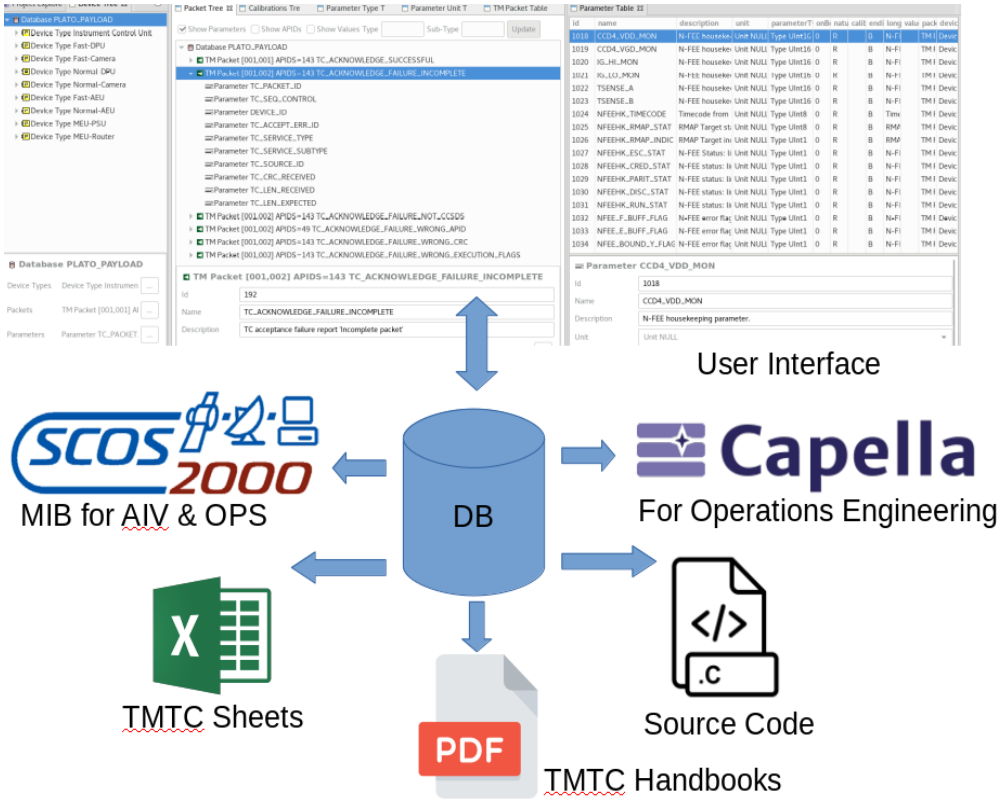
Figure 5-26: Fine Guidance Data Transfer Timeline

STANDARDIZED INTERFACES

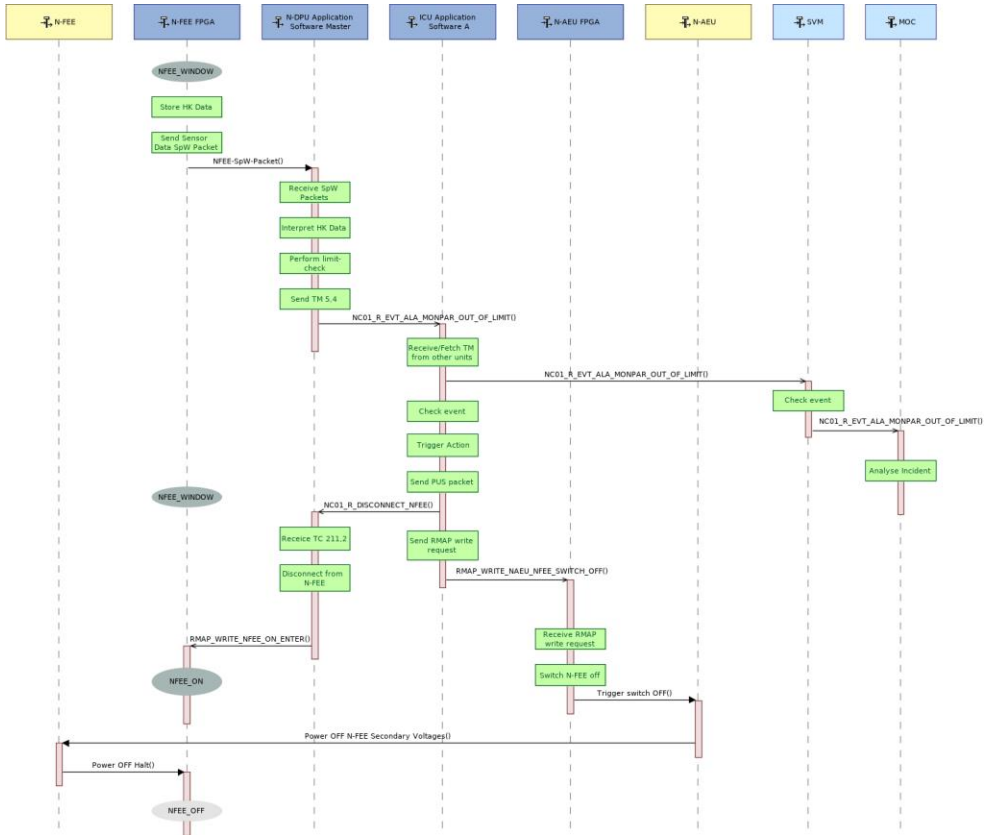
- Only SpaceWire between units
  - RMAP only for non-intelligent units (AEUs, Routers) and DPU Booting
  - CPTP (PUS) for all other communication
  - CPTP between ICU and Space-Craft
- No low-speed interfaces (like MIL-1553)
- No discrete signals (in DPS Subsystem, only sync pulses in Camera Subsystem)
- Standard PUS services
  - Service 5, 14, 18, 19 for flexible FDIR implementation
  - Allows decoupling and minimal dependencies between units

TM/TC INTERFACE ENGINEERING

- DLR inhouse developed Tool
  - Based on Eclipse eco-system (EMF, CDO, OCL, Acceleo, etc.)
- PLATO specific features
  - Packet structure defined once, allocated to multiple APIDs
  - Parameters defined once, allocated to multiple HW units
  - Calibration curves can be allocated to Parameter/Unit combination
- Exporters
  - MIB
  - TM/TC Excel Sheets
  - Documentation (Handbooks)
  - Source Code
  - Capella Model



- Capella MBSE Tool (Also Based on Eclipse eco-system)
- Used for
  - Operations and FDIR scenarios
  - Functional allocation
  - Unit modes design
  - Tracing design to Reqs.
  - Etc.
- Importers
  - ReqIF (Reqs.) from DOORS
  - TM/TC Packets from DB
- Exportes
  - Documents (User Manual)
  - PROTOS (DLR inhouse tool for generating MOIS procedures) is currently investigated



THE WHOLE PLATO TEAM SAYS: THANK YOU!

DLR AIRBUS DEFENCE & SPACE INSTITUTO de ASTROFISICA de ANDALUCIA CSIC IAA INSTITUTO DE ASTROFISICA DE CANARIAS IAC INAF ISTITUTO NAZIONALE DI ASTROFISICA IWF SPACE RESEARCH INSTITUTE KAYSER ITALIA l'Observatoire de Paris LESIA THALES esa