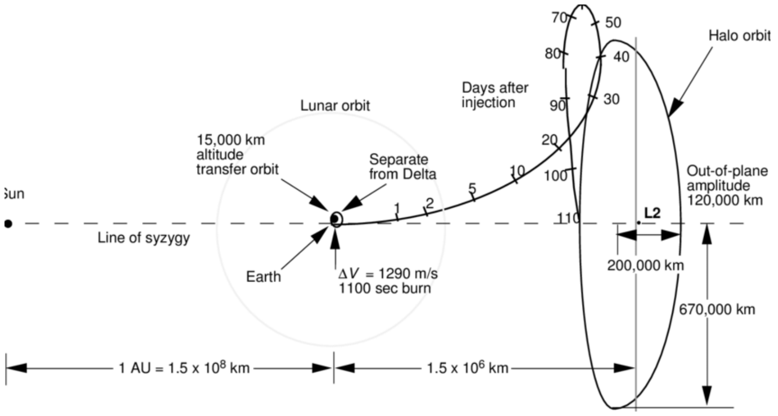
The PLATO On-board data-processing System – A Comprehensive Overview

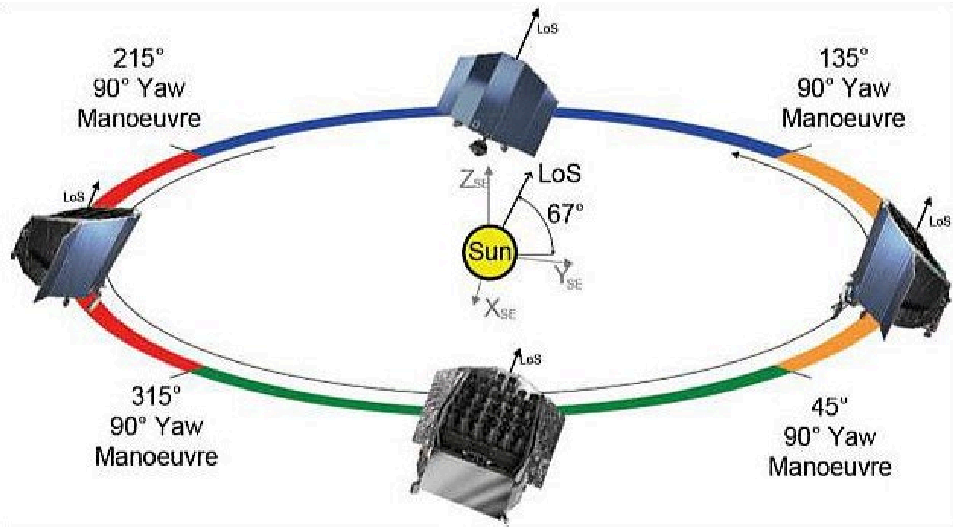
November 13th, 2023

17th ESA Workshop on Avionics, Data, Control and Software Systems

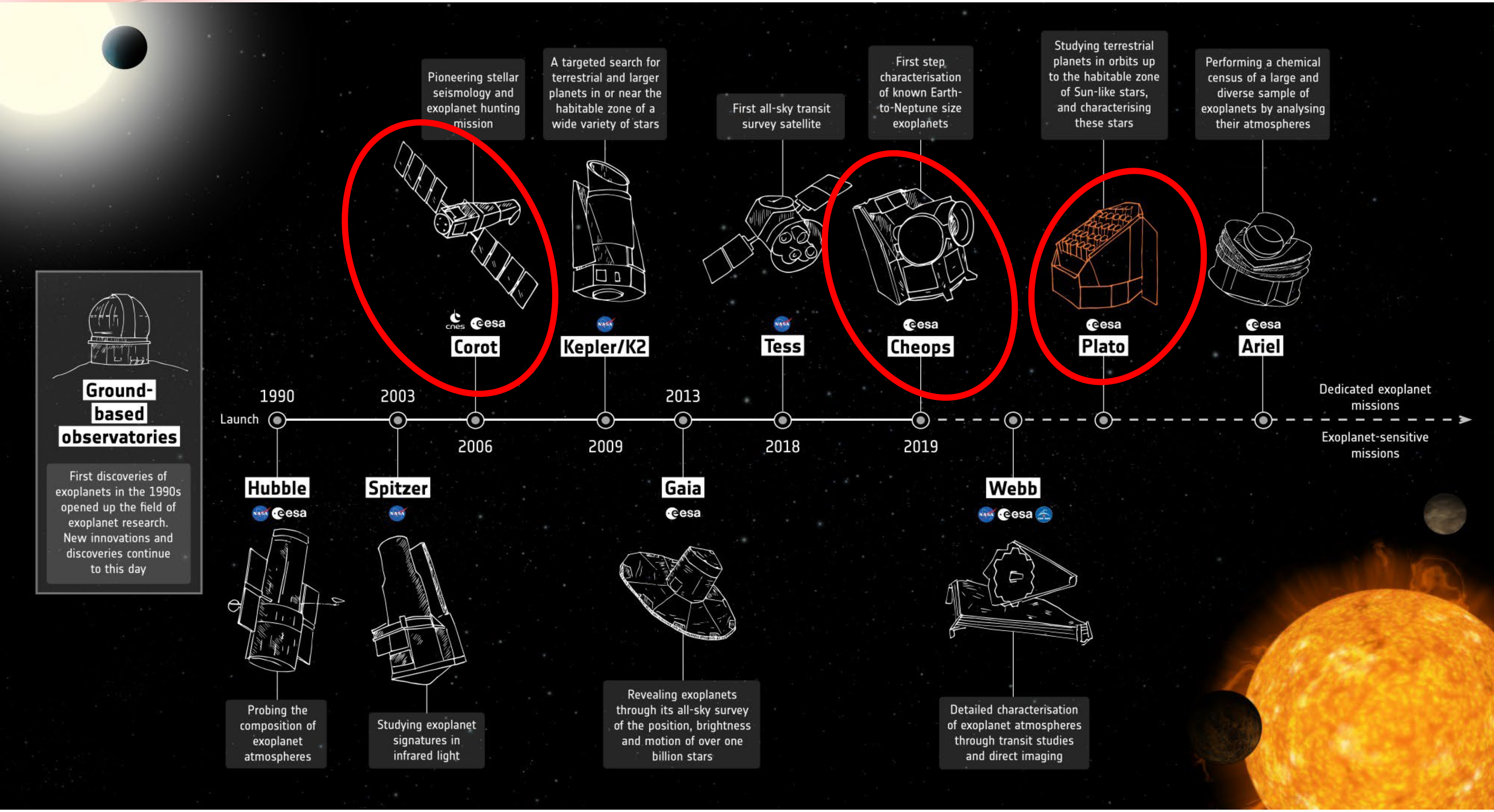
Claas Ziemke on behalf of the PLATO Team

- 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: end-of 2026
- Down-link budget:
  435 Gbit/day ~ 5.15 Mbit/s



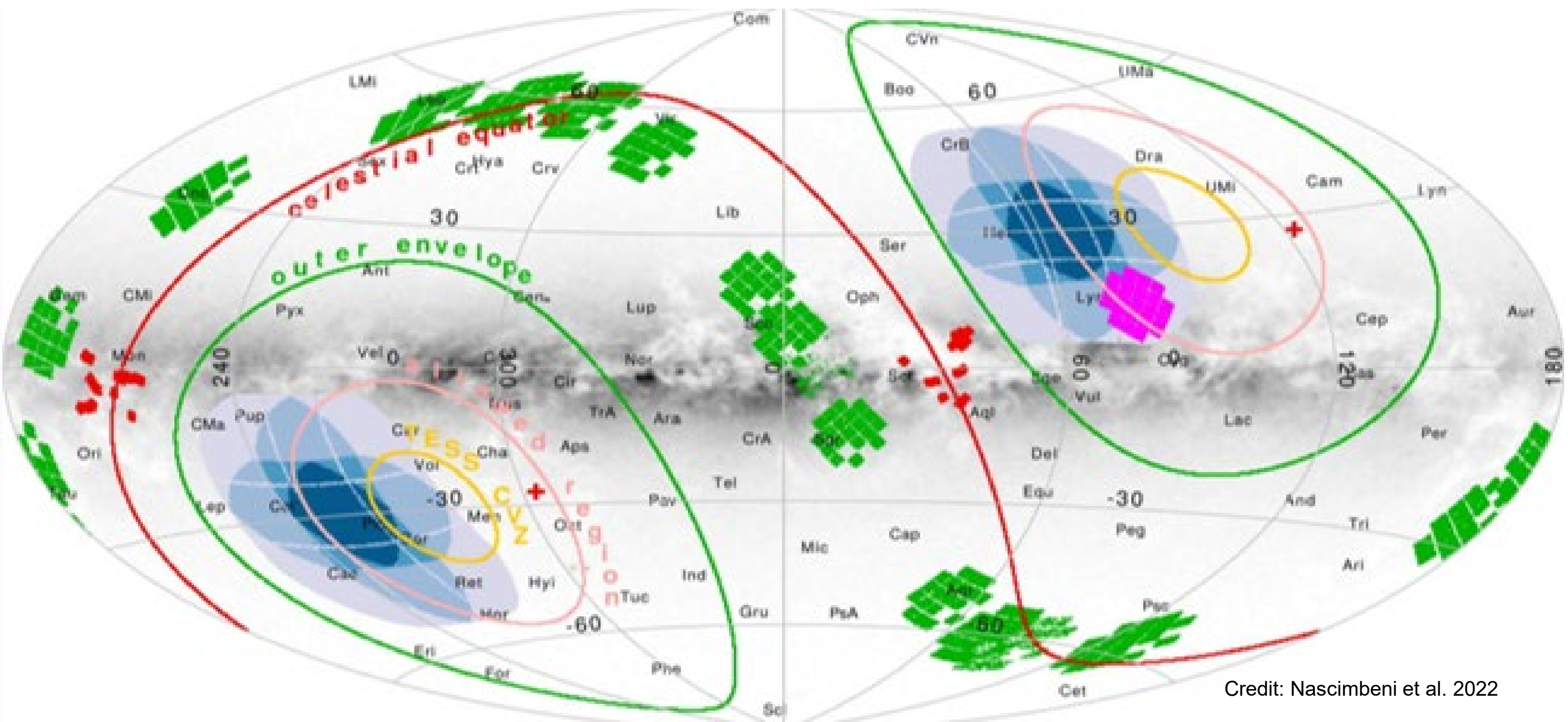


PREVIOUSLY ON EXOPLANETS (1)



PREVIOUSLY ON EXOPLANETS (2)

Mission	Launch	CCDs	MPixel	Targets
CoRoT	2006	4	16.78	12k
Kepler	2008	42+4	94.62	170k
TESS	2018	16	67.11	>10k
PLATO	~2026	96+8	1952.6	3600k



Credit: Nascimbeni et al. 2022

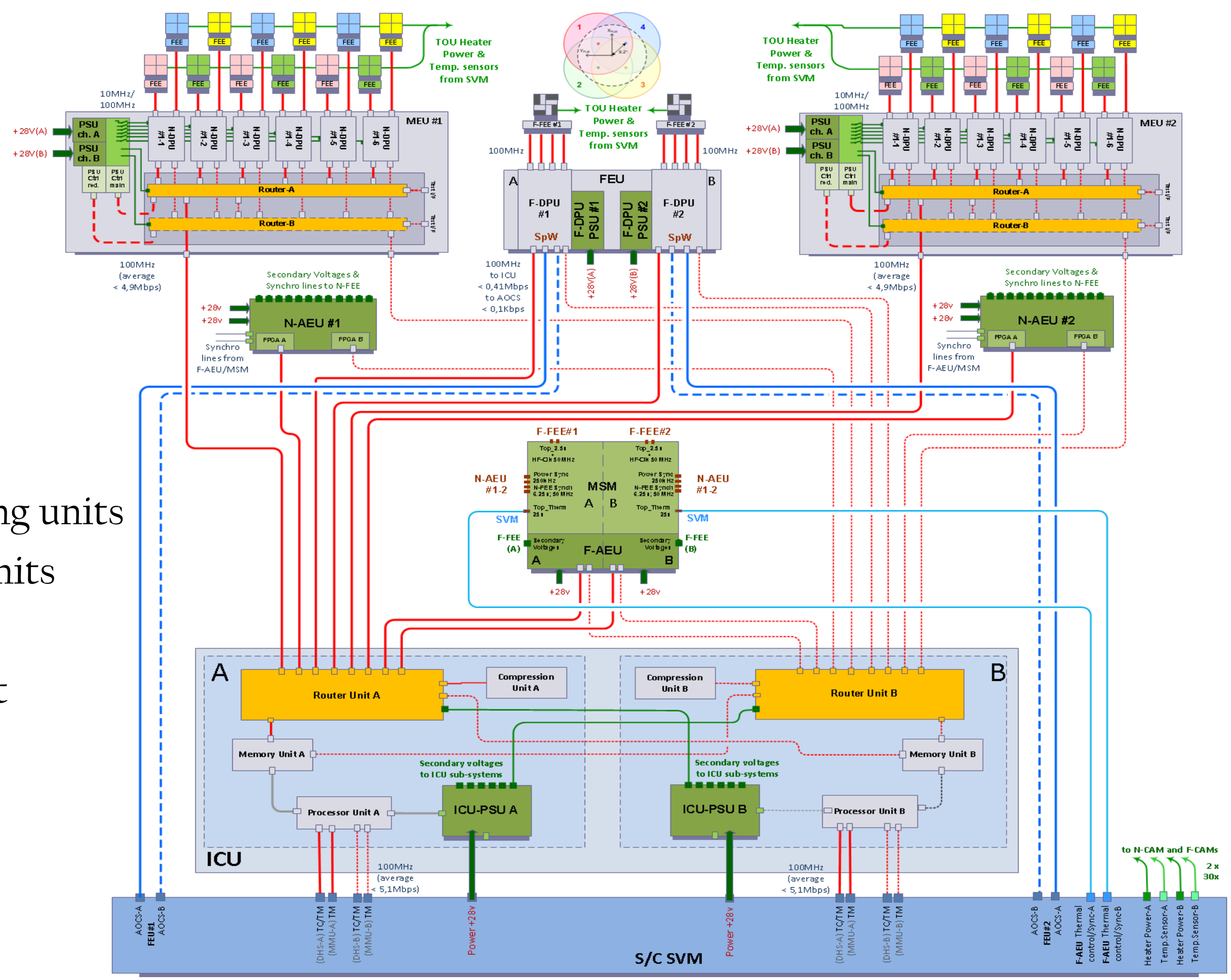
THE CAMERA(S)

- 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

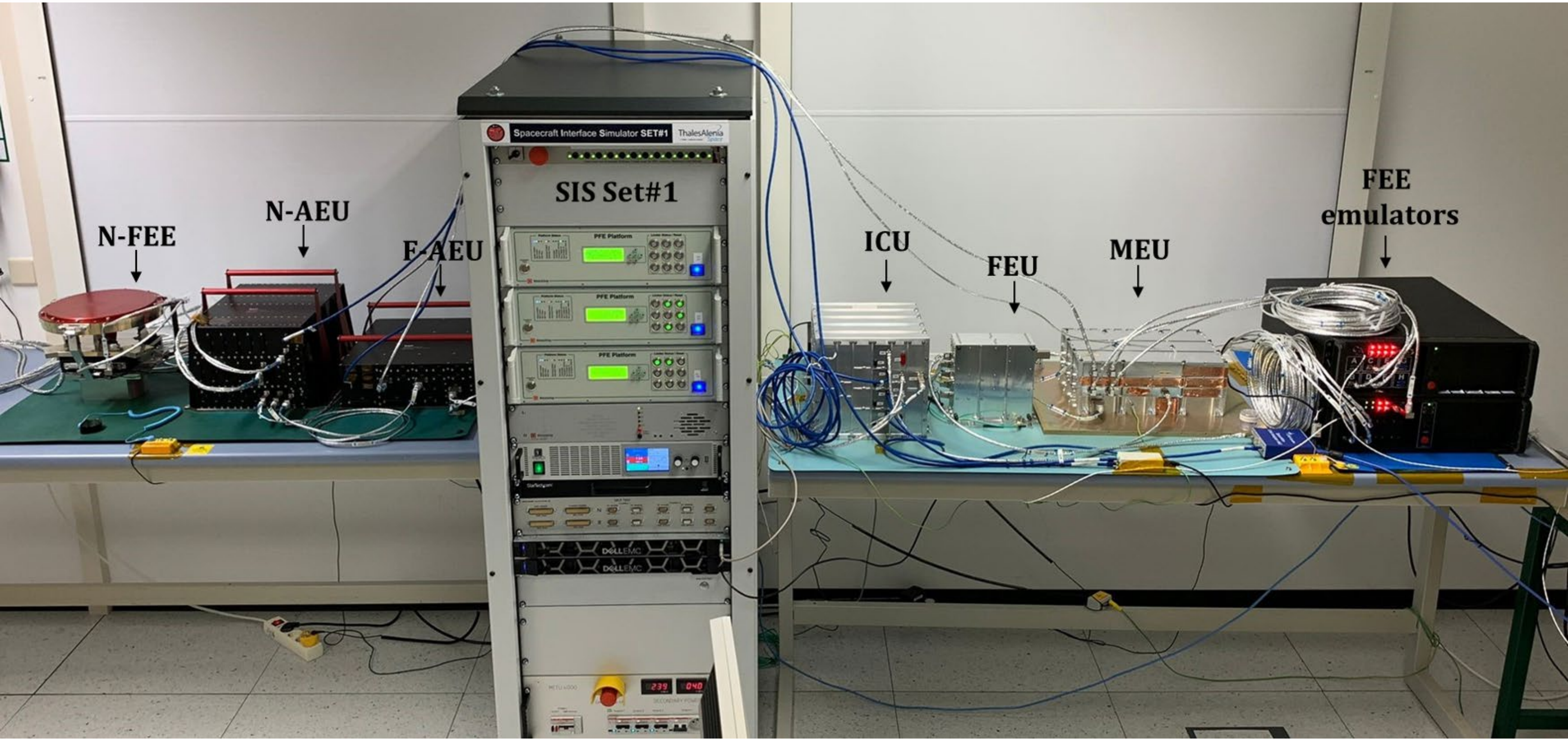
Cameras on optical bench (Mechanical-Therma-Dummies)

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



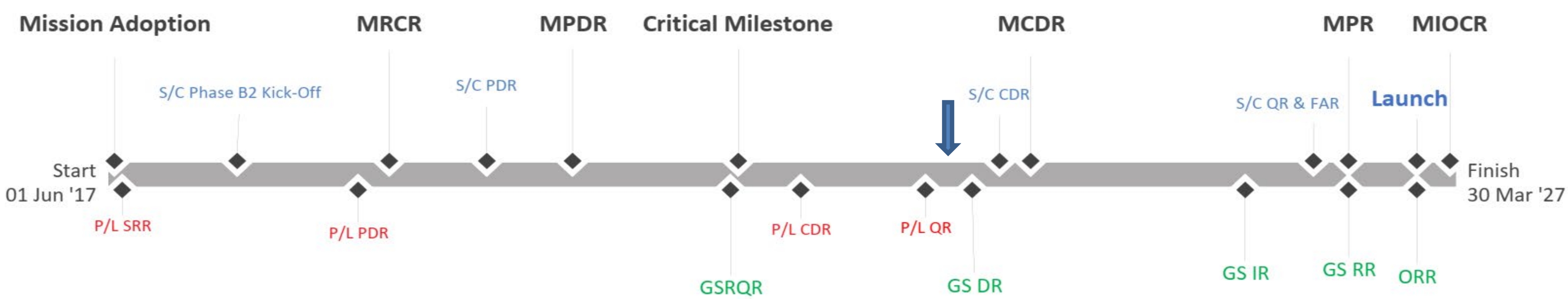
EM BENCH @ DLR BERLIN



AVM BENCH @ TAS-F CANNES

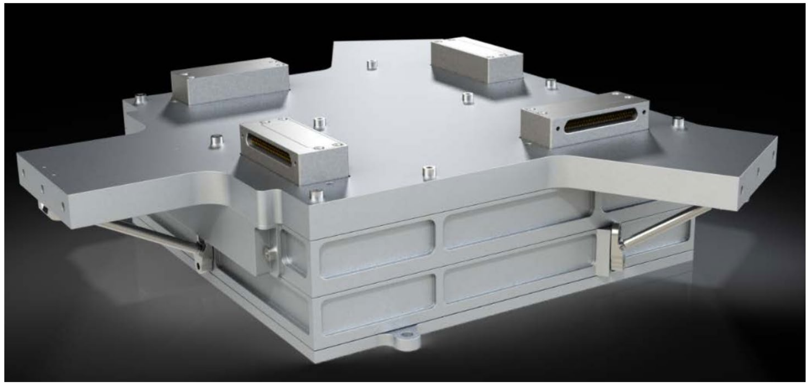
STATUS AND SCHEDULE

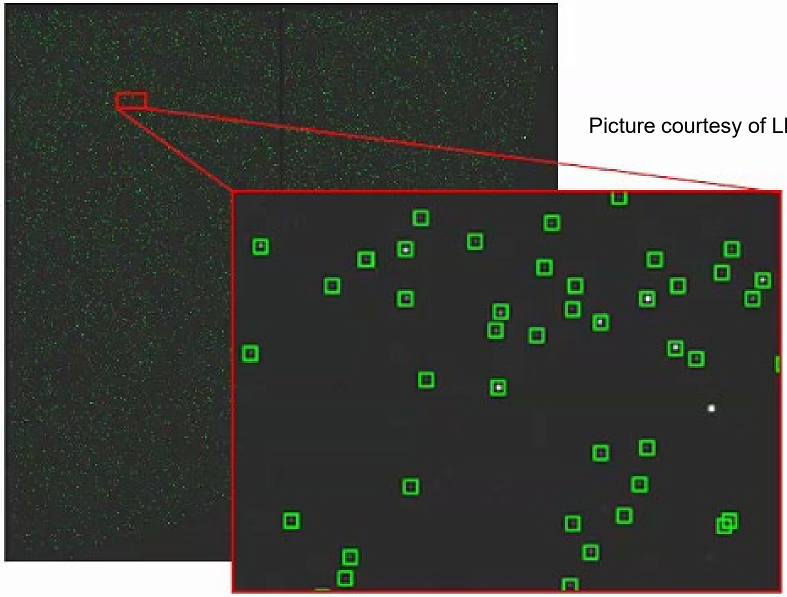
- Critical Milestone successfully passed
- All Payload Unit CDRs successfully passed
- Payload QR on-going
- On-board software CDRs successfully passed or in progress
- Telescope FM serial manufacturing & calibration has started
- S/C CDR currently planned for Q1 2024
- Ground-segment design review currently planned for Q1 2024
- Launch end-of 2026



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

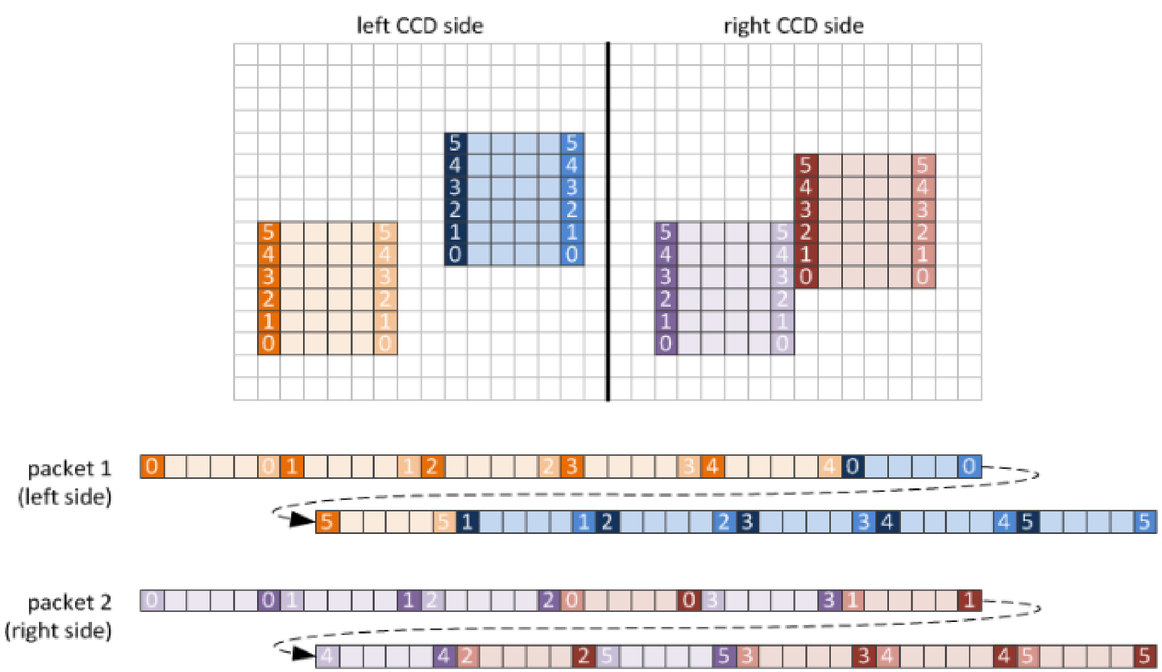




Picture courtesy of LESIA

DATA REDUCTION AT THE SOURCE

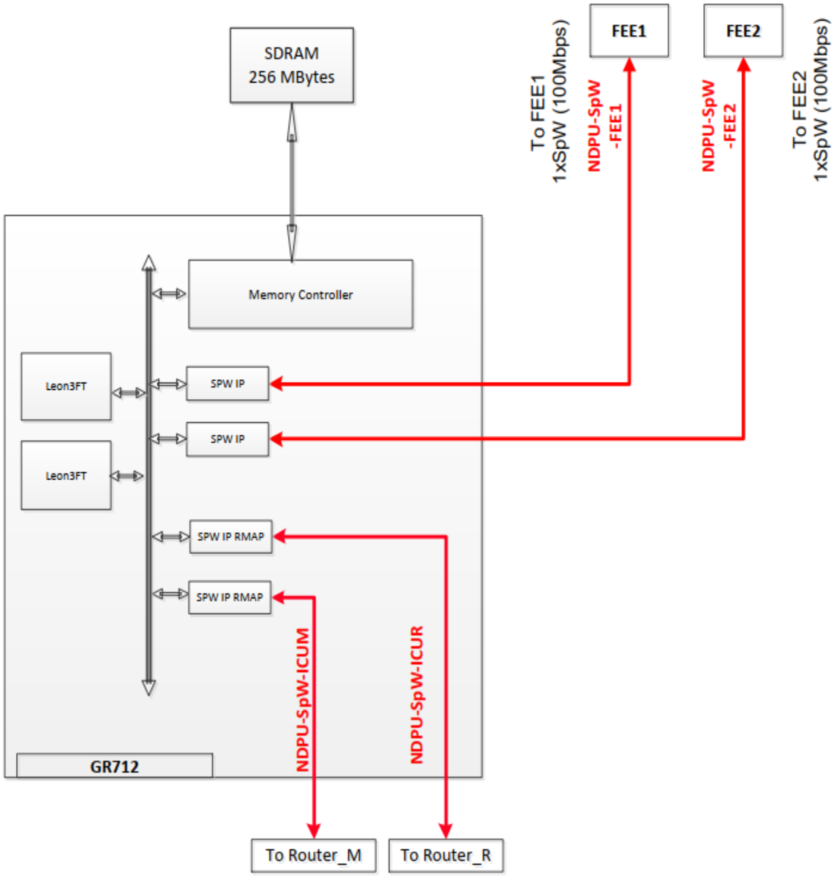
- Data that is not produced does not need to be processed
- If production is mandatory (only full CCD lines can be digitized) it is most efficient to discard not needed data immediately



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)



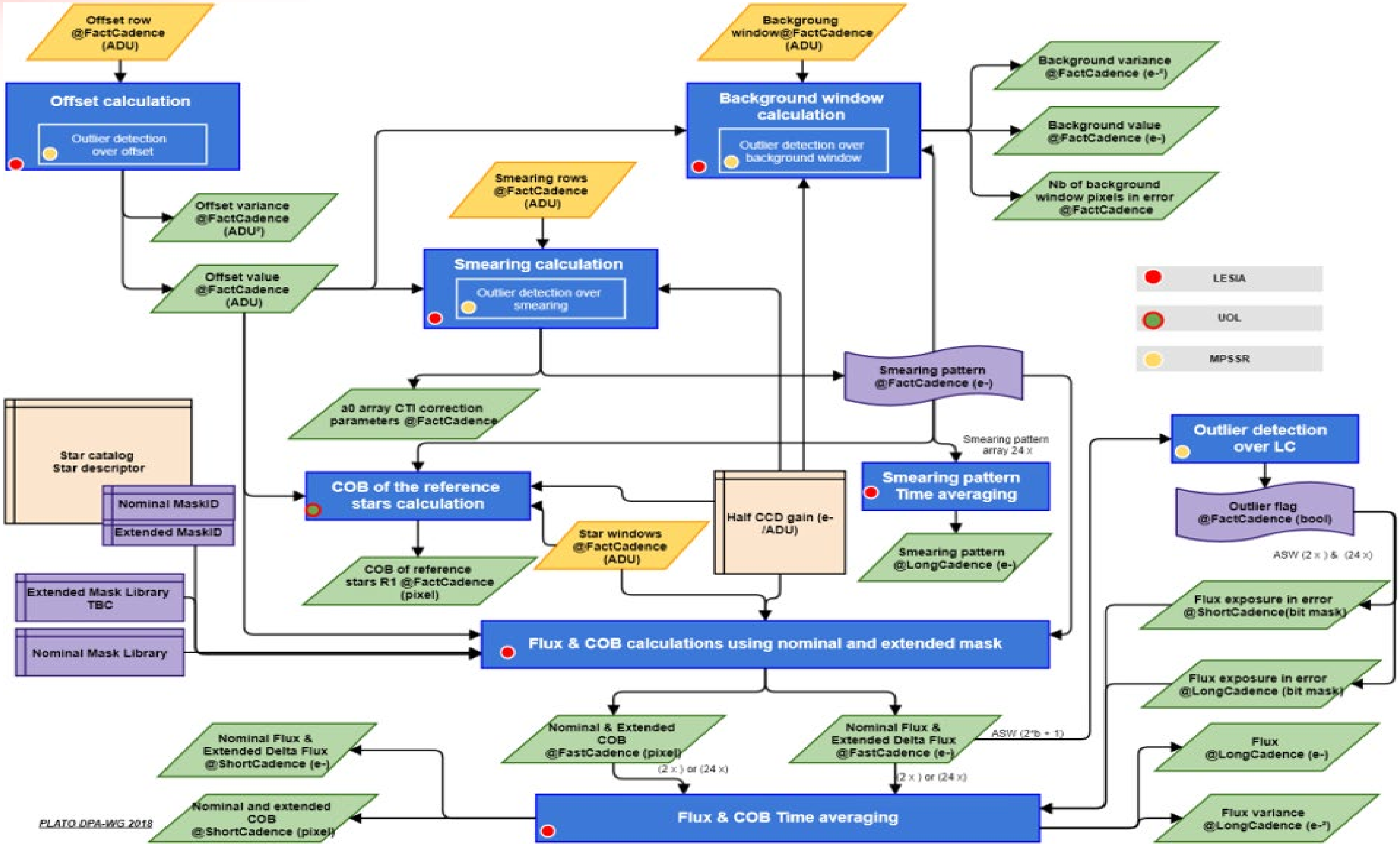
PLATO DATA PRODUCTS

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

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

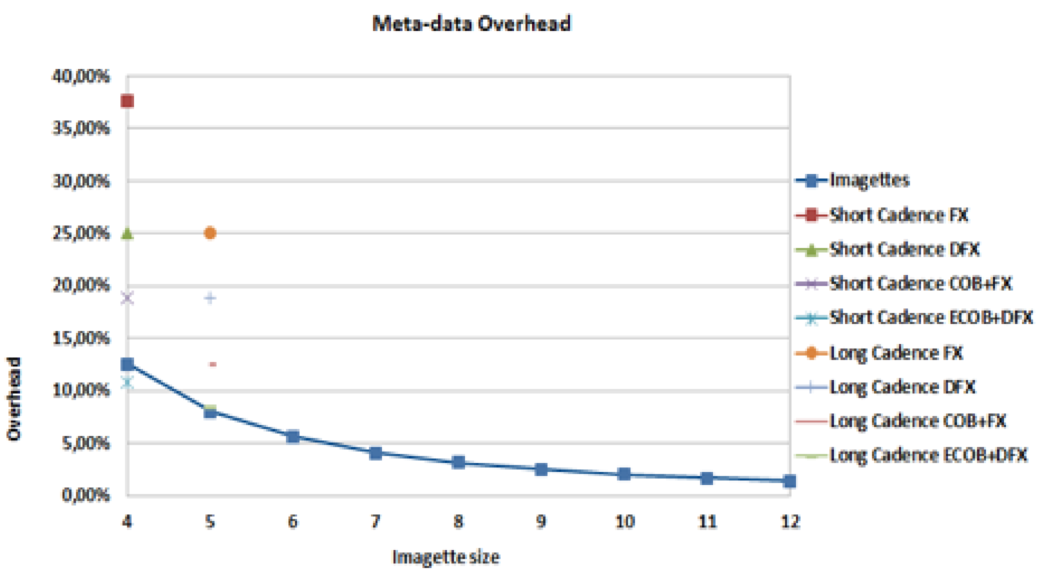
Source	Name	Description	Number	Bits
N-DPU	IMG	Imagette (6x6 Pixel)	27500	576
N-DPU	S_FX	Flux (Lightcurve) 50s	25050	40
N-DPU	S_FX_EFX	Extended Flux (Lightcurve) 50s	2600	72
N-DPU	S_FX_NCOB	Flux + Centroid 50s	3300	104
N-DPU	S_FX_EFX_NCOB_ECOB	Extended (Flux + Centroid) 50s	400	200
N-DPU	L_FX	Flux (Lightcurve) 600s	63200	88
N-DPU	L_FX_EFX	Extended Flux (Lightcurve) 600s	6600	120
N-DPU	L_FX_NCOB	Flux + Centroid 600s	3300	216
N-DPU	L_FX_EFX_NCOB_ECOB	Extended (Flux + Centroid) 600s	400	312
N-DPU	SAT_IMG	Saturated Imagette	1185	1130
N-DPU	BACKGROUND	Background Values	3000	80
N-DPU	OFFSET	Offset Values	8	64
N-DPU	SMEARING	Smearing Pattern	18040	20
F-DPU	IMG	Imagette (6x6 Pixel)	325	576
F-DPU	FGS_IMG	FGS Imagette	40	576
F-DPU	BACKGROUND	Background Values	100	80
F-DPU	OFFSET	Offset Values	8	64
F-DPU	FINE_GUIDANCE_DATA	Fine guidance data	1	952

ON-BOARD DATA PROCESSING



SCIENCE DATA FORMAT

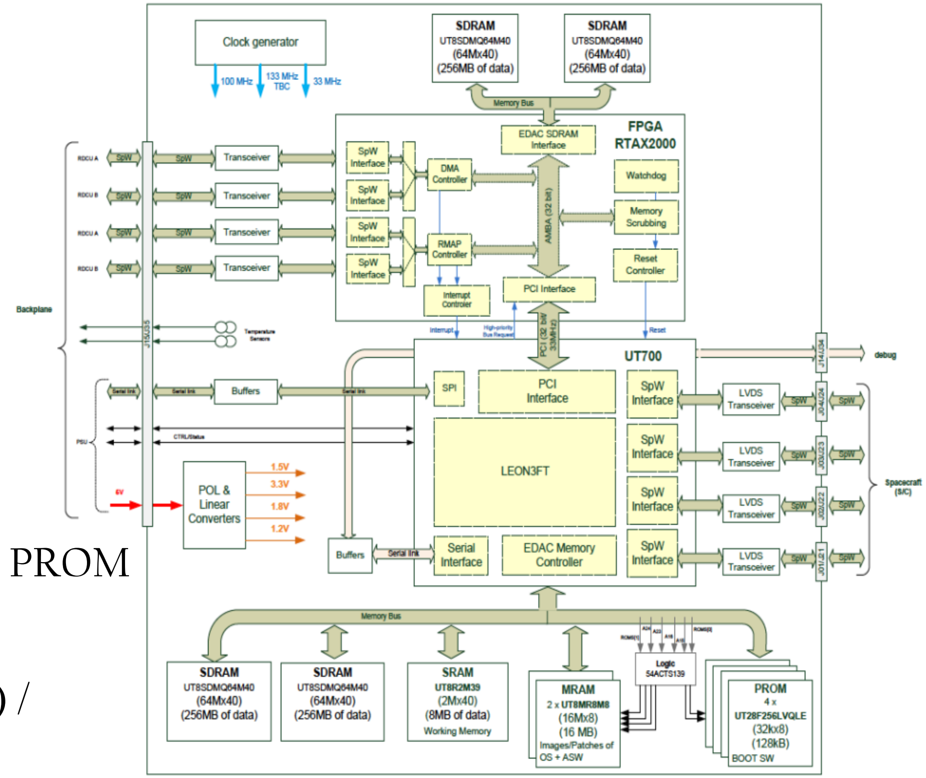
- In order to optimize compression efficiency and throughput
  - The Science packets contain nearly no meta-data
  - Each science packet is referred-to as "Collection"
  - Each "Collection" is accompanied by a "Companion packet" specifying the Collection's contents



	0–7	8–15
0	Packet Version (0–2), Type (3), Sec. (4), APID = NCxx_S (5–15)	
1	Seq. (0–1), Sequence Counter (2–15)	
2	Packet Length	
3	PUS Version, S/C Ref. Time	Service = 212
4	Subservice = 3	Message Type Counter MSB
5	Message Type Counter LSB	Destination ID MSB
6	Destination ID LSB	Packet Timestamp Coarse MSB
7	Packet Timestamp Coarse Cont.	Packet Timestamp Coarse Cont.
8	Packet Timestamp Coarse LSB	Packet Timestamp Fine MSB
9	Packet Timestamp Fine LSB	Spare
10	Exposure Timestamp Coarse MSW	
11	Exposure Timestamp Coarse LSW	
12	Exposure Timestamp Fine	
13	Configuration ID (0-65535)	
14	QL (0), Collection ID (0-32767)	
15	Imagette 1 Pixel 1	
...	Imagette 1 Pixel 2	
...	...	
...	Imagette 1 Pixel A	
...	Imagette 2 Pixel 1	
...	Imagette 2 Pixel 2	
...	...	
...	Imagette 2 Pixel B	
...	...	
...	Imagette N Pixel 1	
...	Imagette N Pixel 2	
...	...	
...	Imagette N Pixel Z	

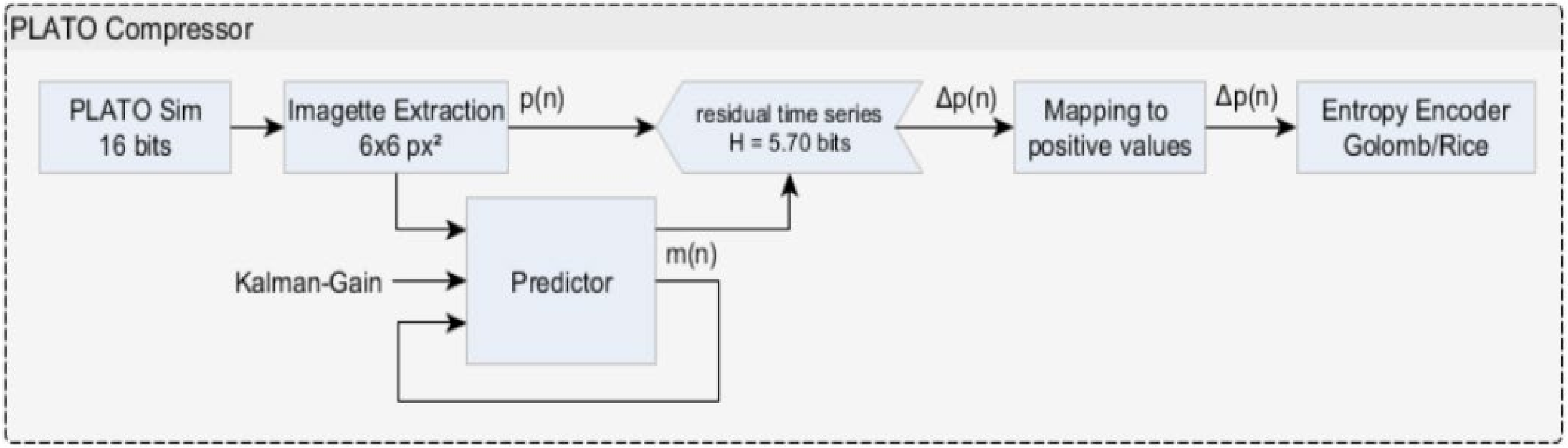
INSTRUMENT CONTROL UNIT

- Functions
  - Instrument management
    - Booting DPUs
    - SpW network management
  - Further 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



LOSSLESS COMPRESSION

- Golomb-code with custom pre-processing implemented in FPGA
  - Difference between data and data model (running average) 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
  - Model is reset after 8 cadences



FAST DATA-PROCESSING UNITS

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

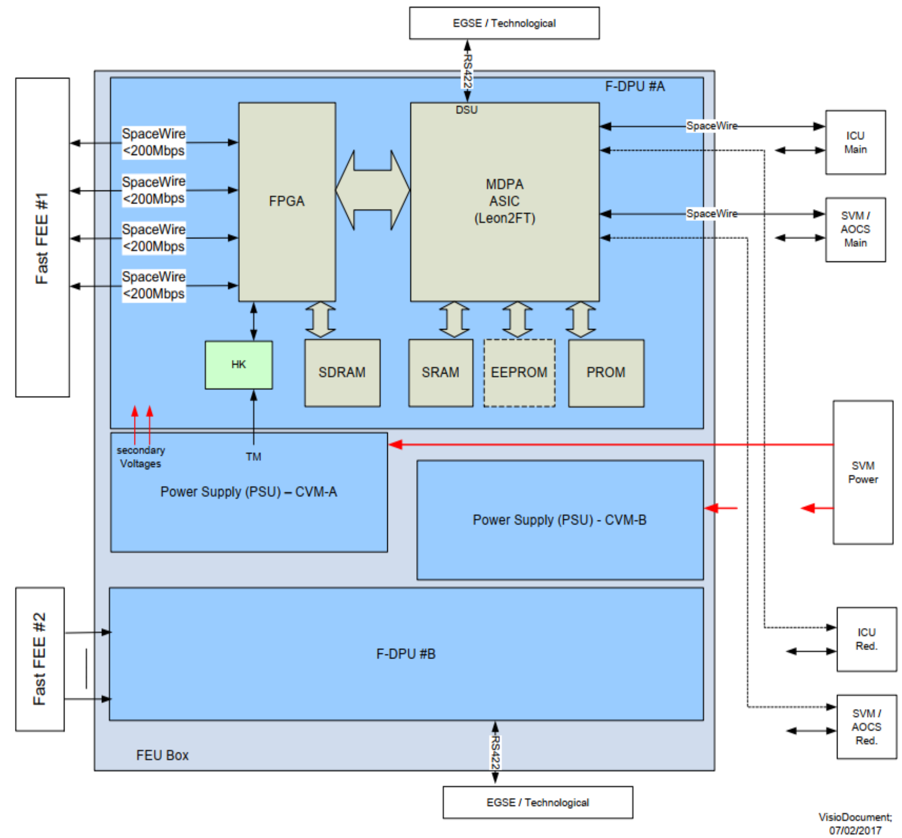


Figure 2-1: FEU Block Diagram

FINE-GUIDANCE

- S/C attitude sensors are not precise enough
- Fast-cameras will be used as high-precision star trackers
- Performance
  - Max. latency 3750ms (relative to middle of integration) => 300ms for SW
  - Noise Equivalent Angle (NEA) 25 milliarcseconds (x/y)
- FGS packet every 2.5s to S/C
  - Quaternion
  - OBT
  - Quality flags

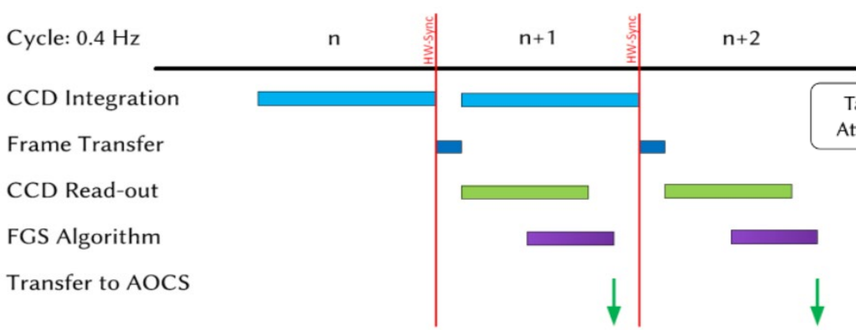
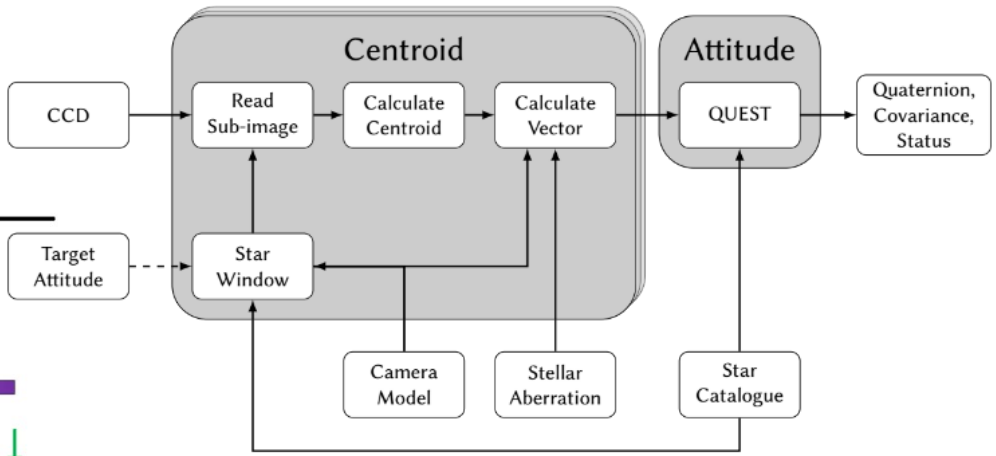


Figure 5-26: Fine Guidance Data Transfer Timeline

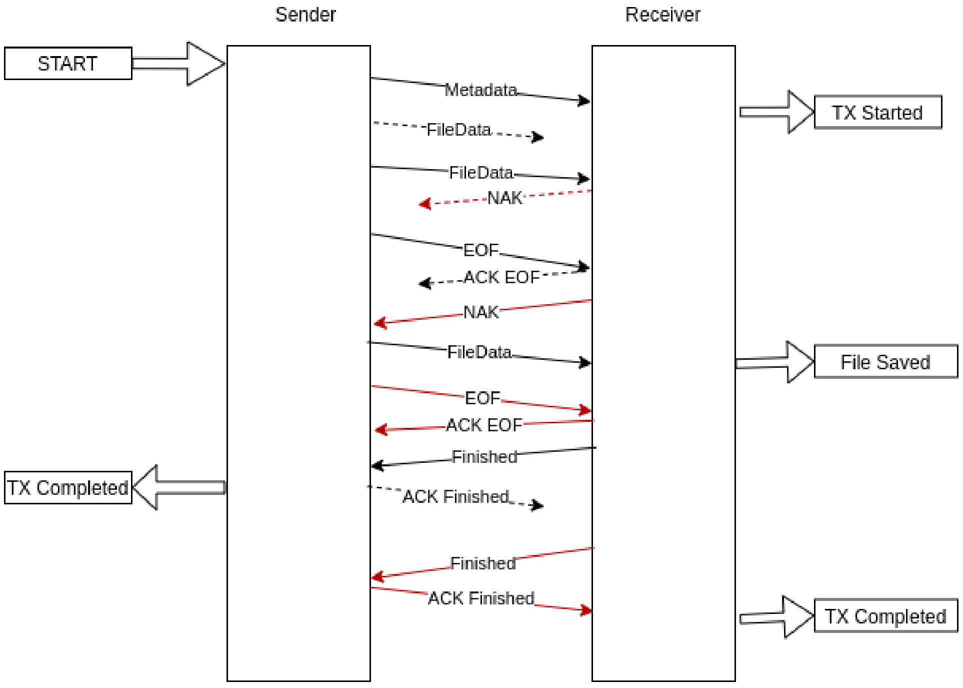


ON-BOARD DATA STORAGE

- SVM Solid-state mass-memory (SSMM)
  - ICU sends data to dedicated SpW Logical-Addresses
  - A SpW Logical-Address is allocated to a specific on-board file
  - The SSMM manages the opening and closing of files
  - The allocation of data-products to files is configurable
  - The PLATO Payload will use up to 35 SSMM files

FILE-BASED OPERATIONS

- During a GS communication window
  - The mission operations center requests the download of files from SVM SSMM
  - The data integrity and completeness is assured by the CCSDS File-delivery Protocol
  - The downloaded files can be deleted after complete reception



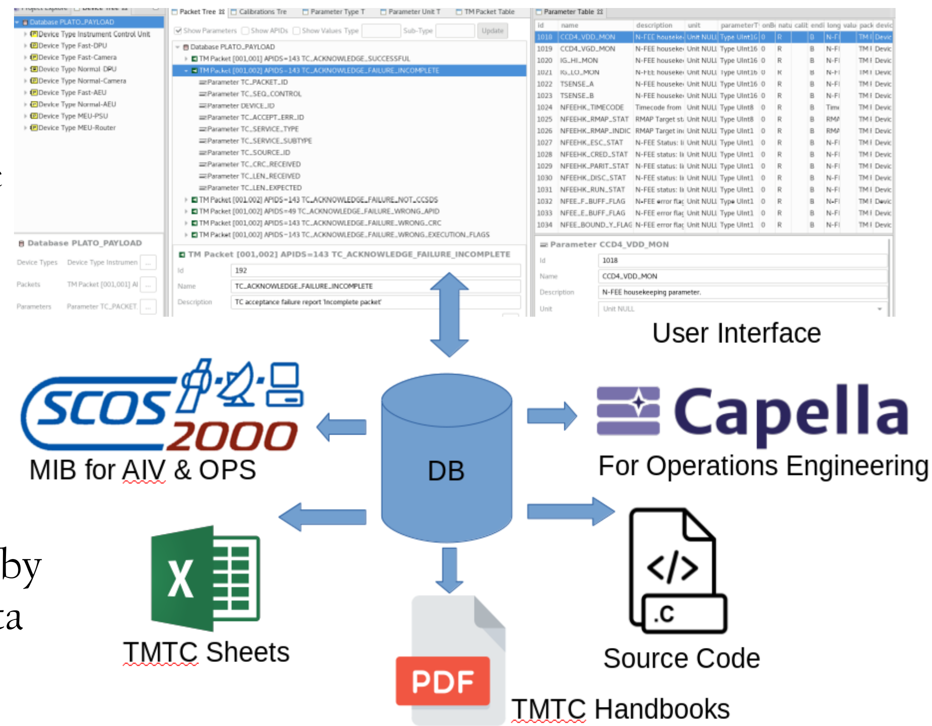
Dotted lines represent lost PDUs
Red lines represent retransmissions or retrasmissions requests

MISSION OPERATIONS

- PLATO will be operated by ESOC with EGS-CC

- The Payload SRDB exchange format is still S2K MIB (ICD v7.1)
- The Payload Flight-Operational Procedure exchange format is MOIS XML
- The FOPs are generated with the DLR Tool PROTOS and will be validated by running them on GECCOS and the EQM bench at DLR

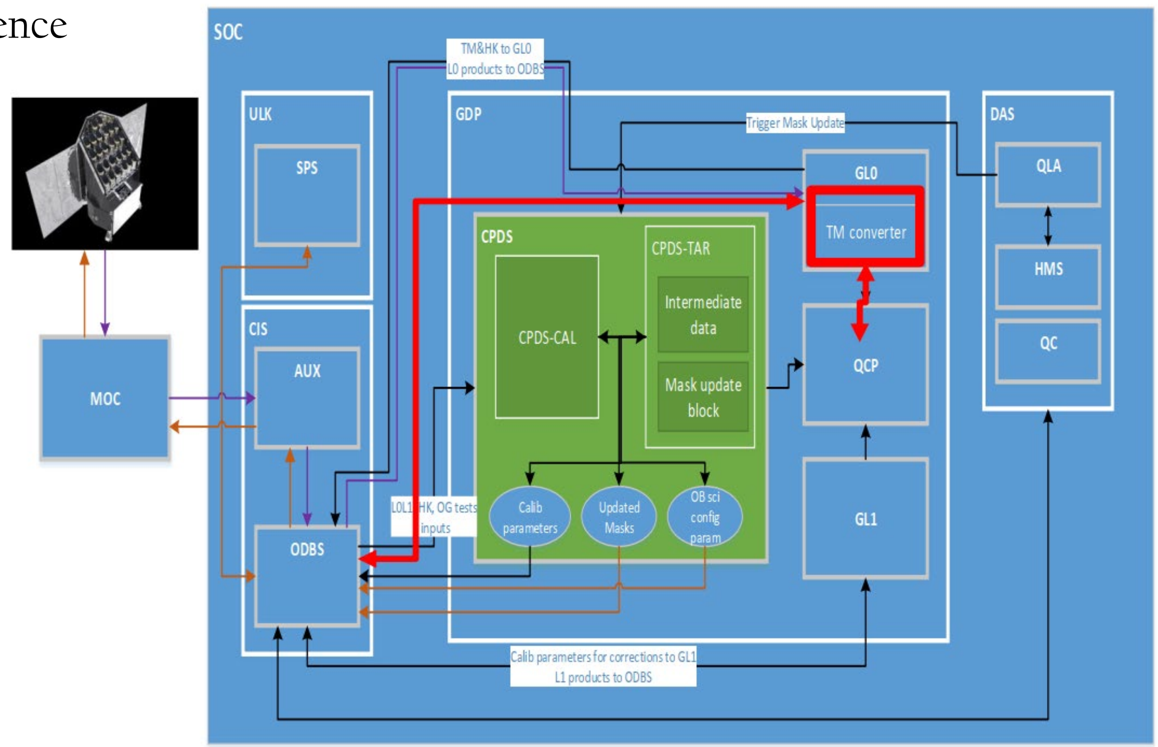
- MIB and FOPs will be ingested/converted by ESOC into the corresponding EGS-CC data formats



SCIENCE OPERATIONS CENTER

- PLATO science operations center will be ESAC

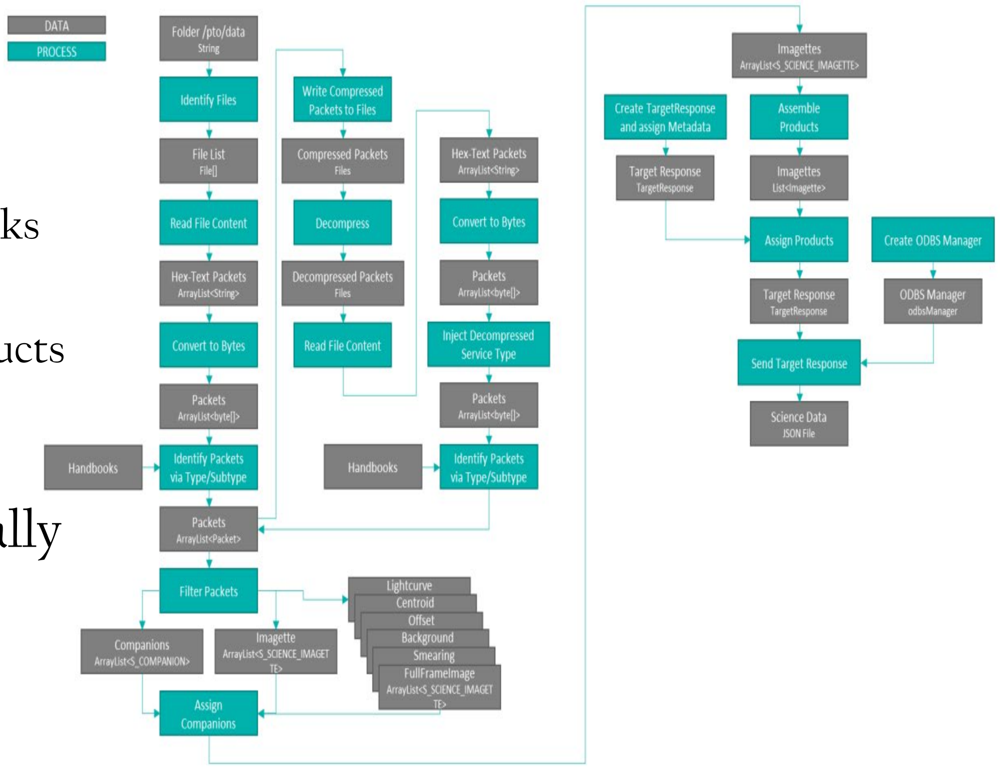
- SOC is responsible for
- Receiving and decoding science files from MOC
- Running the TM Decoder
- Running the L0/L1 Pipeline
- Running the target programming tool



- The TM Decoder is provided by the PLATO Calibrations and Operations team (PCOT)

- The TM decoder is
- Re-assembling the compression chunks
- Decompressing the chunks
- Re-assembling the science data-products using the companion packets

- Will be deployed as horizontally scalable Docker containers



THE WHOLE PLATO TEAM SAYS: THANK YOU!

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