Development of the EUCLID's Data Processing Unit Application Software – TETIS 2020

https://euclid.baltig-pages.infn.it/DPU-ASW/index.html

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M. D'Alessandro (INAF-OATo) - Retired
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Software life cycle – Waterfall Model with Feedback

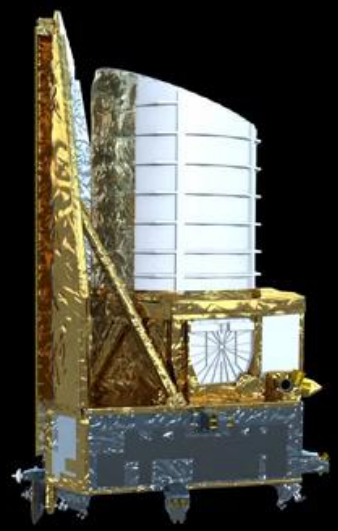
Concept Exploration

- Statement of need

next step

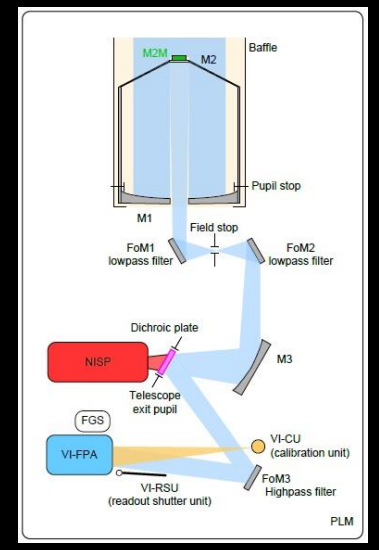
feedback

EUCLID Mission

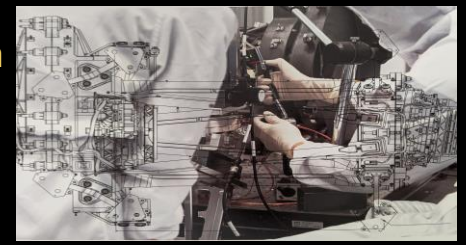


- Partners: ESA, TAS, Airbus DC, Euclid Consortium
- Overall mass ≈ 2020 kg, Power: 1920 W
- Telescope (T=125K, passive)
  1.2 m aperture primary,
  3 mirror Korsch anastigmat
  0.53 deg^2 FoV
- 2 Instruments (VIS, NISP) T = 100-140K (passive)

  - Wide field instrument VIS:
    4k x 4k px^2 CCDs, 0.55 < λ < 0.92 μm;
  - Near Infrared Photo-Spectrometer NISP:
    0.92 < λ < 2.05 μm, R>250;
    16 H2GR HgCdTe detectors (64 Mpx);
    power 200 W, mass 16 kg, dim 1mx0.5mx0.5m
    - Photometry (Y, J, H)
    - slitless Spectrometry (using grisms)



Telescope optical model



artistic view by C. Corbasson©

- Downlink rate: X/X + K-band to Ground Station 55 Mbits/s (850 Gbit/day transferred 4h/day)
- Ground segment: 1.5 billon galaxies for Weak Lensing, 30 million redshifts,12 billion sources (3 sigma)
- L2 orbit; Launch vehicle: Soyuz-Fregat
- Launch date 2022, Kourou space port
- 6.25 years mission + additional survey
- Main surveys: 15 000 deg^2 + 40 deg^2 deep survey
- Science drivers: Dark Energy

FM - Telescope

FM - SVM

arXiv:1110.3193 [astro-ph CO]

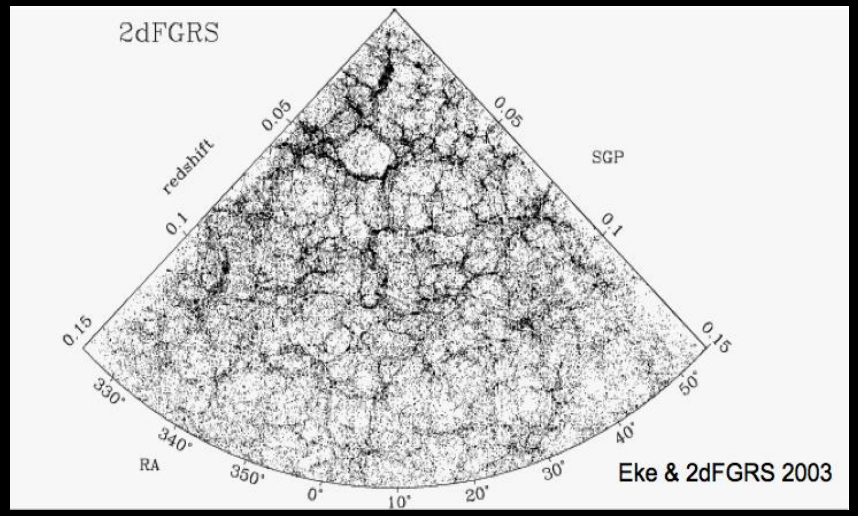
Dark Energy can be study measuring the Hubble expansion rate H(z), mapping the large-scale structure (up to z ~ 2)

$$H^2(z) = \frac{8\pi G}{3}\left[\rho_{\rm matter}(0)(1+z)^3 + \rho_{\rm de}(z)\right]$$

with high accuracy and robust control of systematics → **two cosmological probes:**

Galaxy clustering

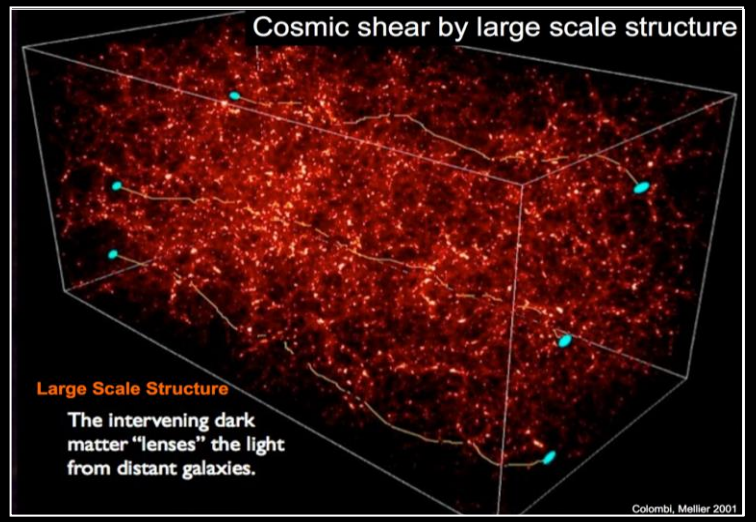
- Barionic Acoustic Oscillation
- Redshift-space distortion



- 3D distribution of Galaxies
- 50 millions spectroscopic redshift
- 0.9 < z < 2

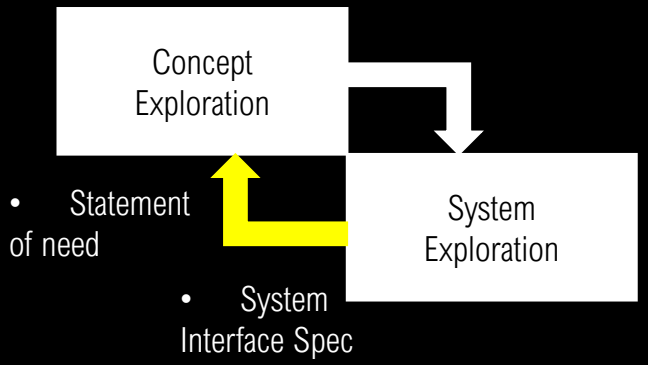
Weak lensing

- measuring distortion of Galaxies images by mass inhomogeneities along the line-of-sight



- 10 slices in z
- 0 < z < 2
- 1.5 billion sources with shapes

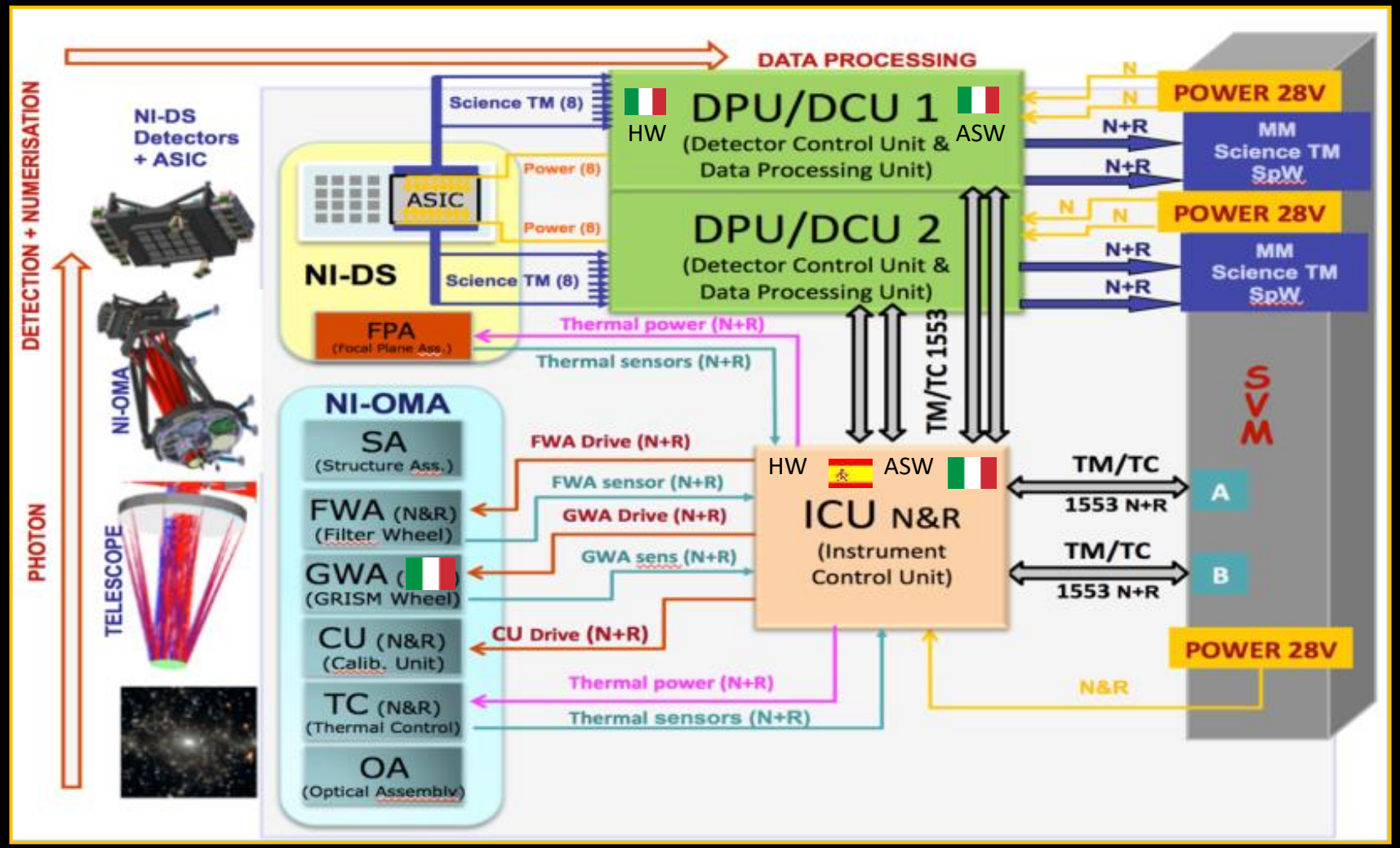
Software life cycle – Waterfall Model with Feedback



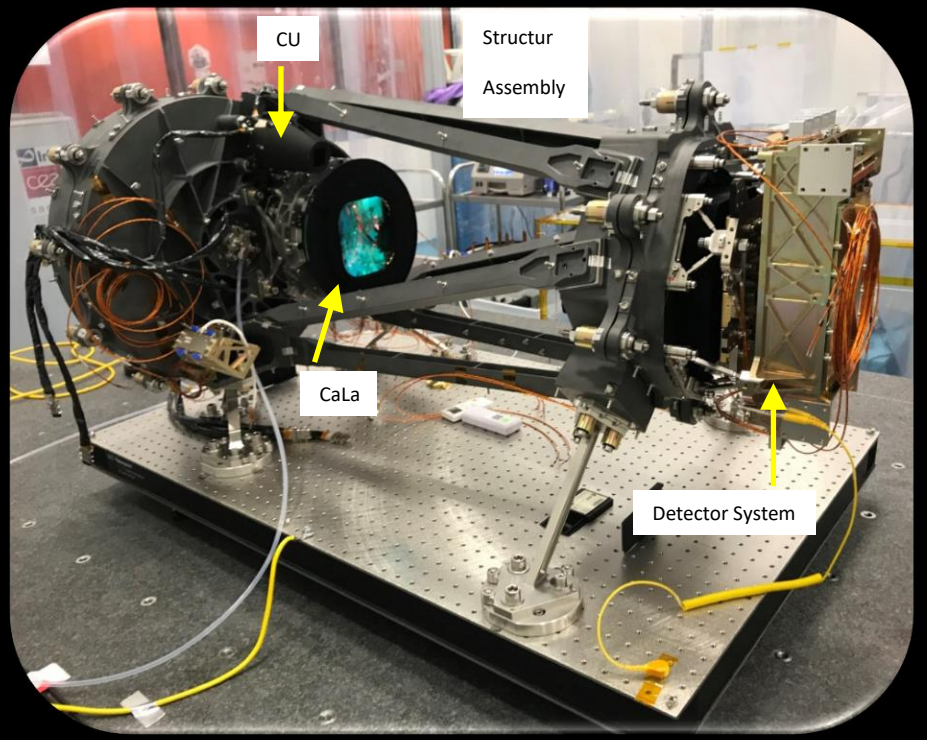
next step

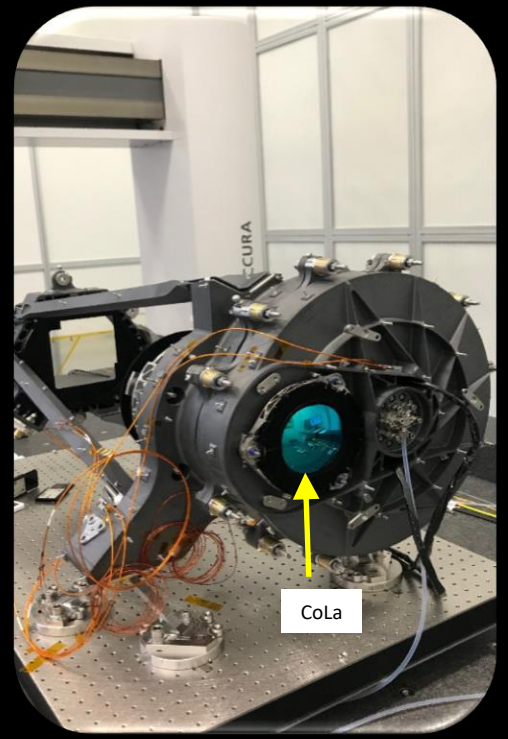
feedback

detector ~95 Kº ⟵ NISP Warm Electronics 293 Kº ⟶ Spacecraft



NISP instrument

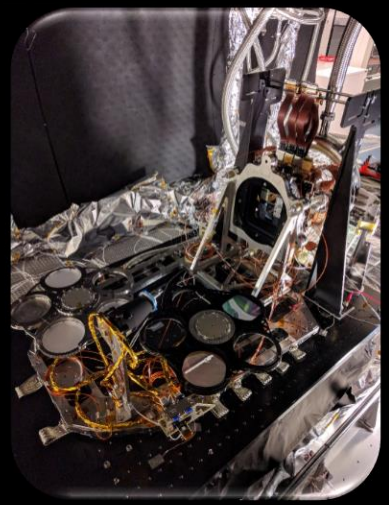




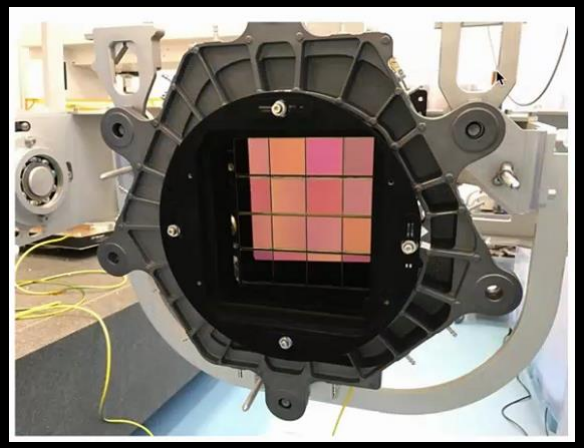
FM - Optical Assembly

NISP (Near Infra-Read Spectro-Photometer)

- SiC structure assambly
- Optical assembly (Corrector & Camera lenses)
- 3 NIR filters (photometry):
  Y (0.92 – 1.15 μm), J (1.15 – 1.37 μm), H (1.37 – 2 μm)
- 4 Grisms (spectrometry): 1 «Blue» 0°; 3 «Red» 0°, 90°, 180°
- Focal Plane: 16 HgCdTe NIR detectors 2k×2k px^2 (each);
  0.3 arcsec/pixel; sensitivity range: 0.9 – 2 μm
- Warm Electronics (293 K) – next slide:
  ICU – Instrument Control Unit
  2xDPU – Data Processing Units



FM – FWS & GWS



FM – Focal Plane

Proc. of SPIE Vol. 9904 99040T-2

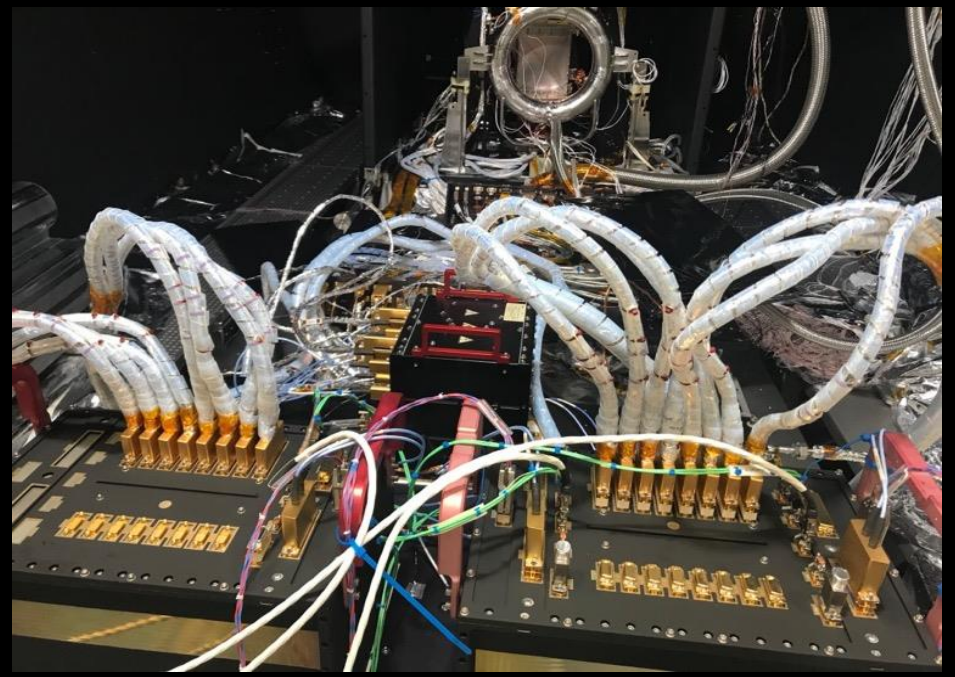
NISP Data Processing Unit(s)

NISP is composed of two identical DPU units

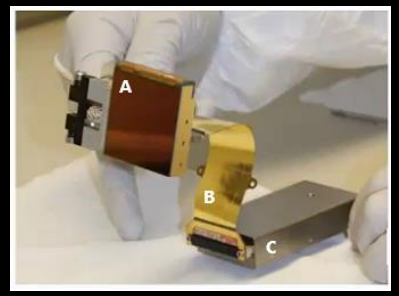
- a single DPU units hosts:

  - 8x Detector Control Units (DCU)
  - CPU (N/R):
    - Maxwell™ 3xSCS750®-PPC, 400 MHz clock
      error detection (1 ms), Radiation Tolerant class S
  - Memories (N/R):
    - SRAM 256 MB, EDAC protected
    - E2PROM 8 MB, ECC protected
    - DBB 6 GB Data Buffer Board
    - DRB: 127 MB Space Wire Router Board (N/R)
  - Power Supply Board (PSB) (N/R)
  - Communication Interfaces (N/R):
    - 1553 MILBUS interface with ICU
    - Space Wire interface with DCUs and MMU

- each DCU is connected to 1x SCS system:
  H2RG SCA (A) + Flex cable (B) + SCE (C)
  and handles the data acquisition

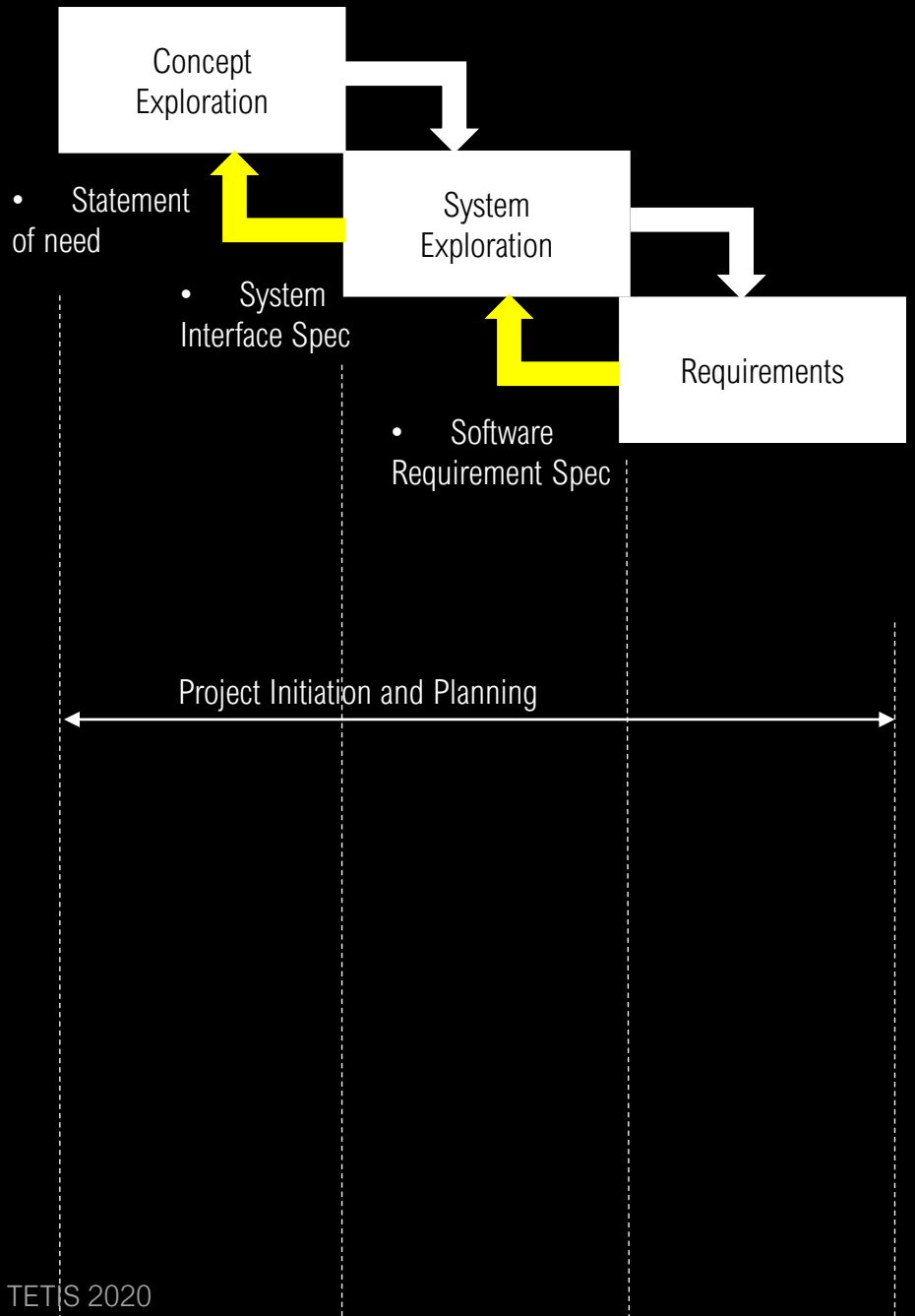


DPUs and ICU - FMs



Detector system - SCS

Software life cycle – Waterfall Model with Feedback



next step

feedback

DPU-ASW requirements / development choices

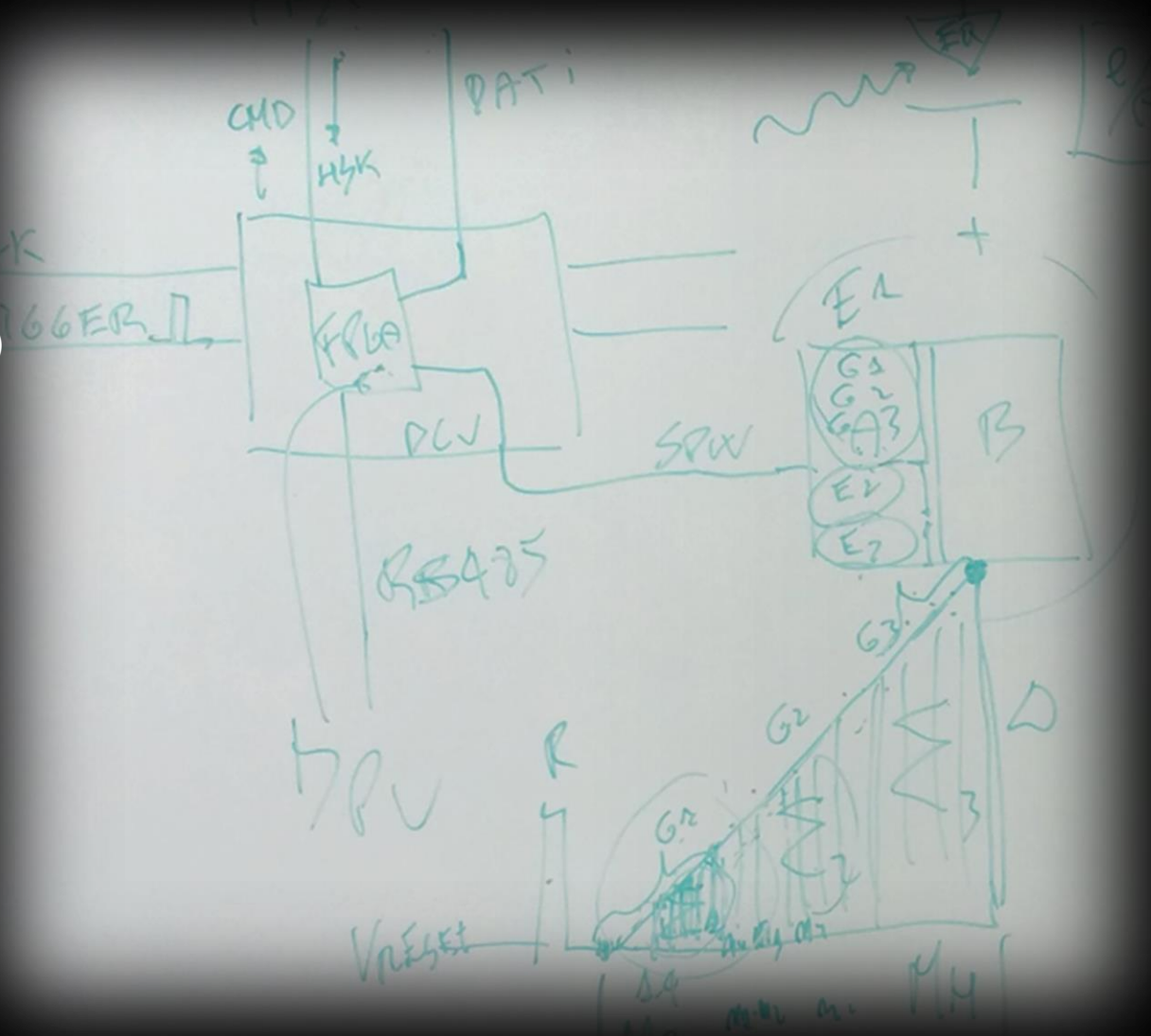
DPU high-level requirements

- DPU (including Focal Plane) commandability / telemetry retrieval
- science data acquisition and on-board pre-processing compression and transmission to SpC Mass Memory Unit (MMU)
- commandability interface
- DPU control: FDIR Faul Detection Isolation and Recovery
- Timing management (time-package distributed by SpC re-sync/s) and propagated through all the sub-systems (sync of two DPUs)

DPU software development choices

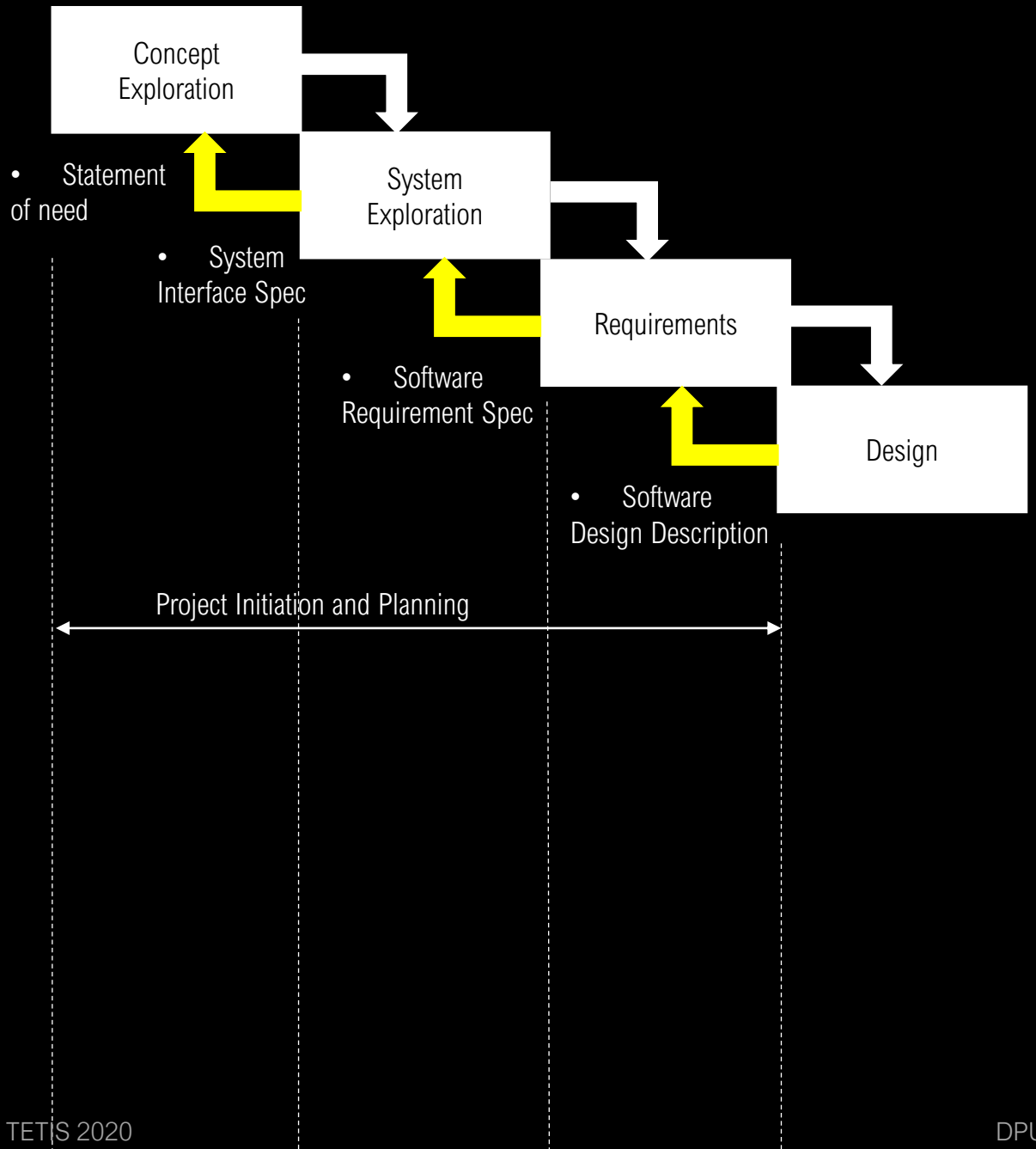
- VxWorks 5.1 RTOS
- ansi-C language
- WindRiver Tornado 2.2 platform for cross-compiling in a Win host ccppc compiler
- ECSS Space Missions Code Standards & MISRA 2004
- Optimized communication interfaces:

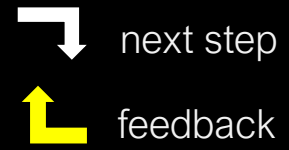
 - protocol MILBUS1553 for commands interface (Maxwell™ drivers)
 - SpaceWire protocol for scientific data



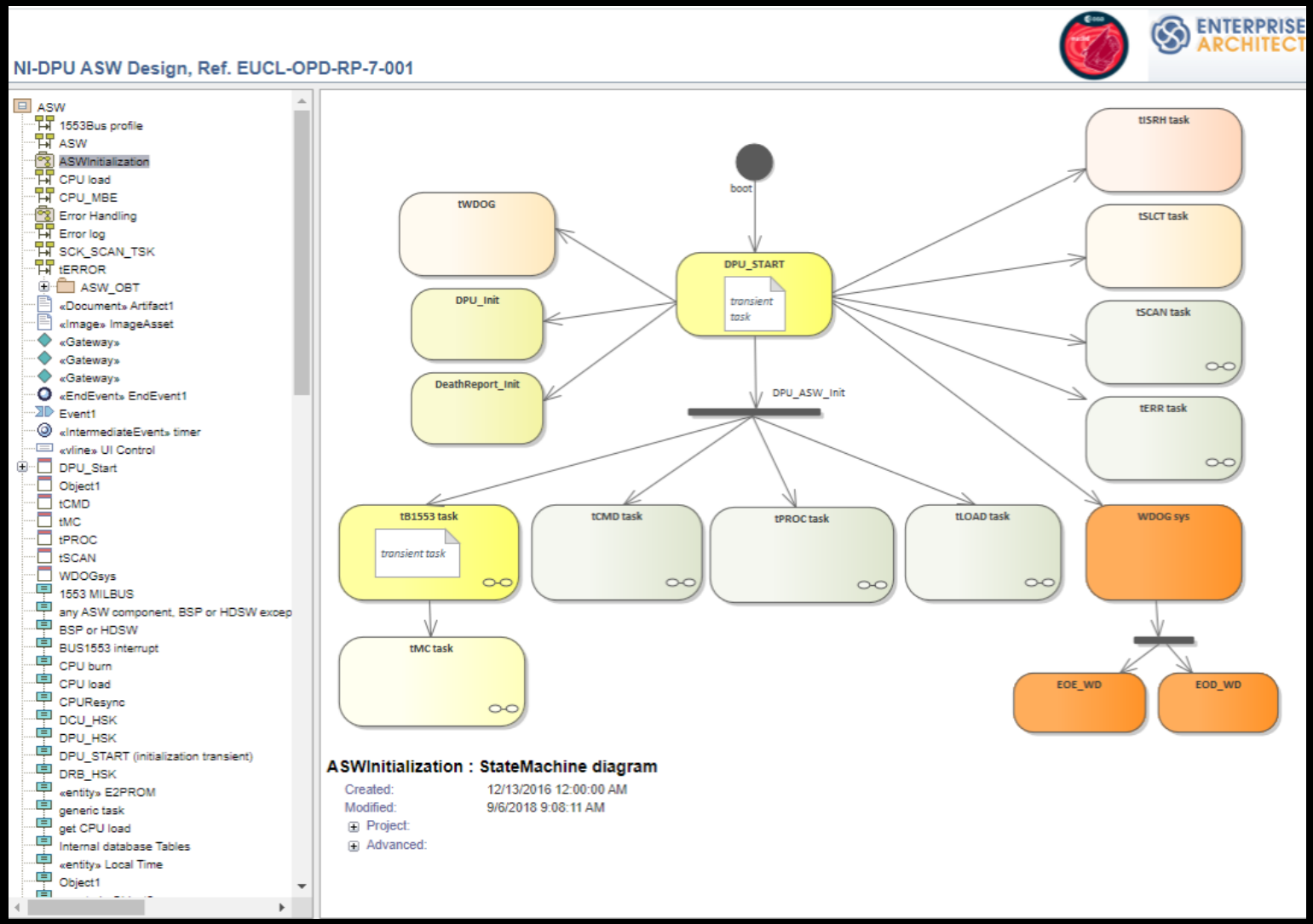
in memory of F. Bortoletto's Tech Specs…

Software life cycle – Waterfall Model with Feedback



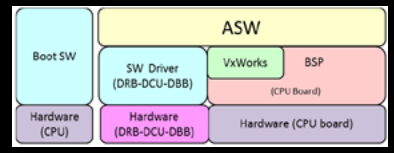


DPU-ASW architecture



UML State machine of DPU-ASW tasks

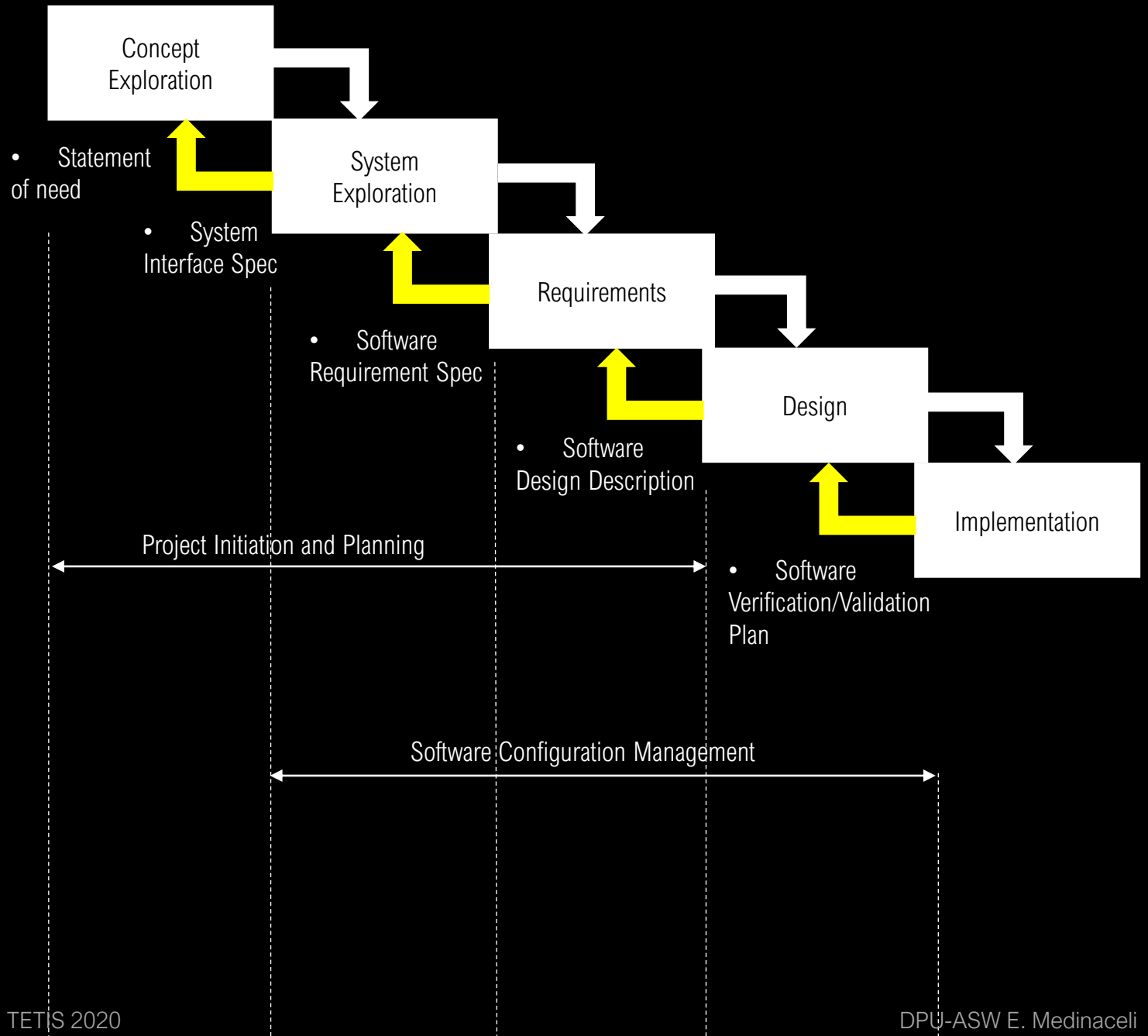
- modelled using UML2.0 language
- driven by science and based on HW choices
- dependencies:
  - HDSW (Maxwell™)
  - BSP & BootSW (OHB-I)

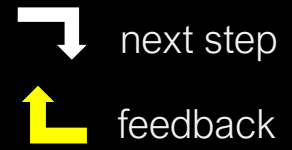


- multi-task preemptive scheduling algorithm
  - 2 initialization tasks (yellow) +
    12 permanent tasks
- Implement two watchdog systems (orange)
- Implement hardware interrupt triggers
- Implement VxWorks event/messages among tasks
- Implement event queues

https://euclid.baltig-pages.infn.it/DPU-ASW/ASW_UML2.0_model/DPU-ASW_model/index.htm

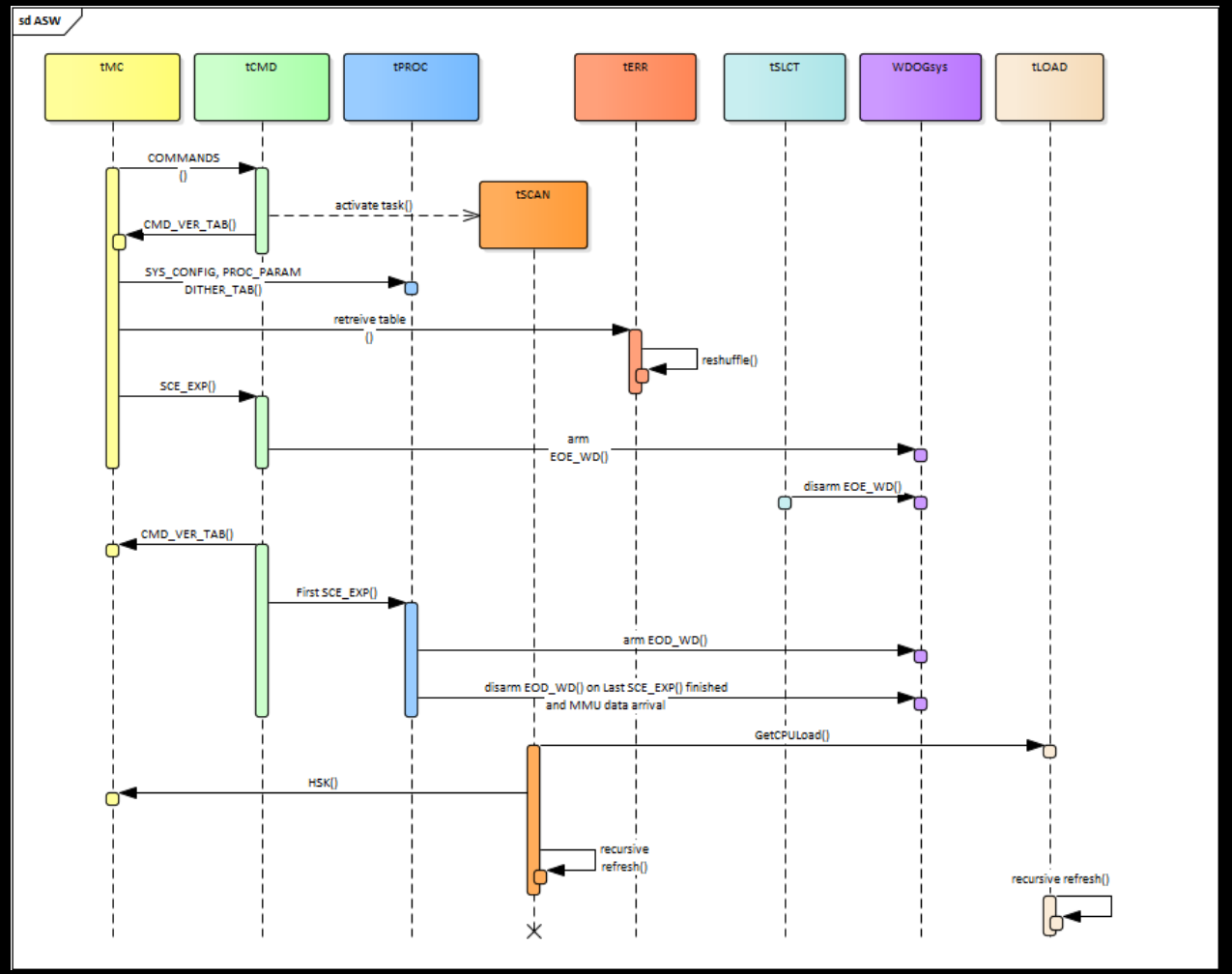
Software life cycle – Waterfall Model with Feedback





DPU-ASW features

- Cyclic actions, dictated by a communication protocol: T = 1 s with granularity of 16 ms
- t_{global} distributed by the SpC, t_{local} re-sync each second (sync between DPUs bellow 10 ns)
- Handles multiplicity 8x (Data Control Units / SCE)
- Periodic (programmable) Housekeeping production
- commandability link:
  MAX rate TC = 1 Hz(~ 512 bits), TM = 40 Hz(~ 18 Kbits)
- scientific data link:
  MAX data rate ~ 290 Gbit/day
- The main task of the ASW: on-board data pre-processing (new feature in space missions)

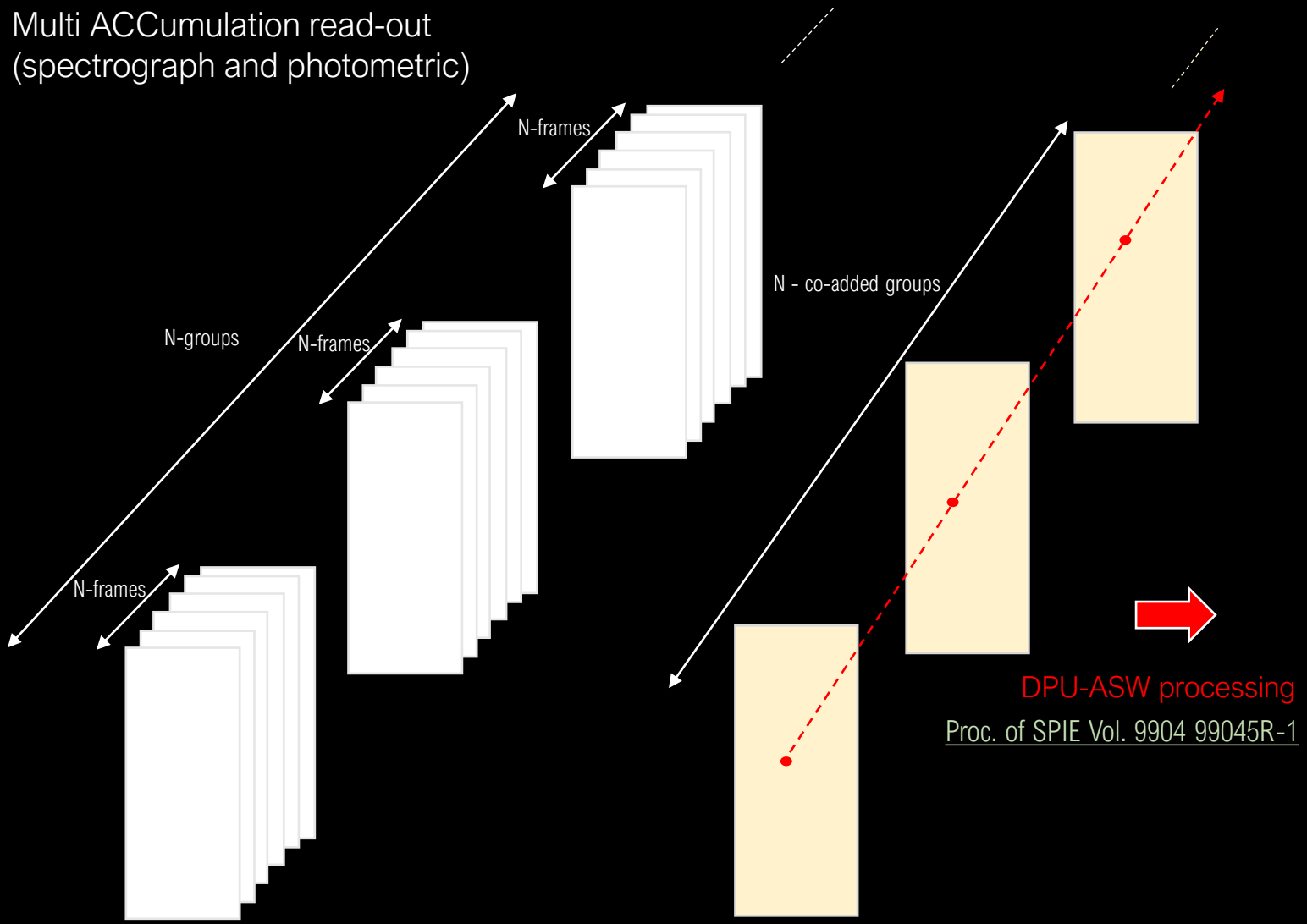


UML Sequence diagram of DPU-ASW

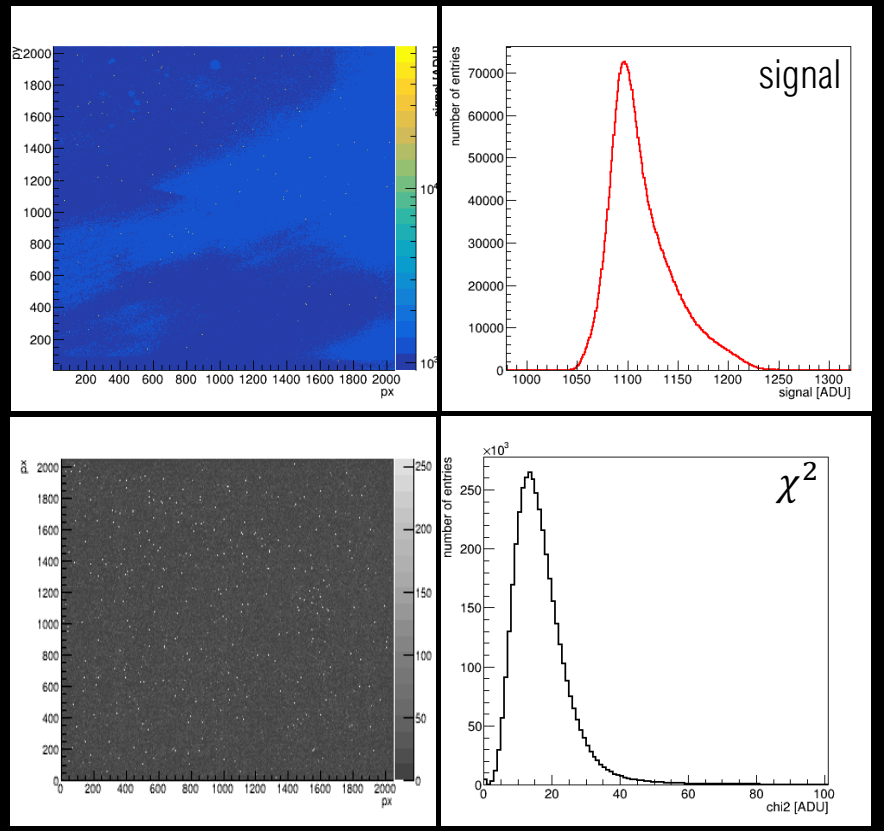
https://euclid.baltig-pages.infn.it/DPU-ASW/ASW_UML2.0_model/DPU-ASW_model/index.htm

DPU-ASW on-board processing

Multi ACCumulation read-out
(spectrograph and photometric)



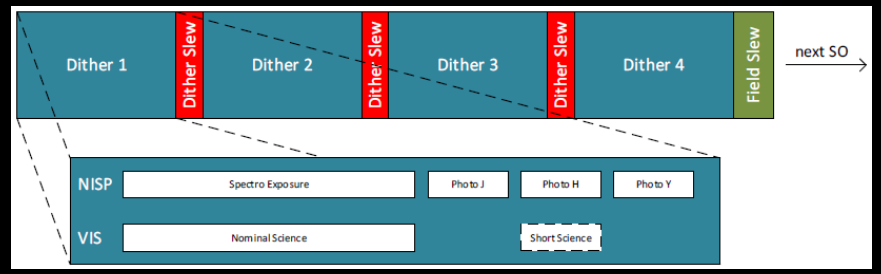
- image corrections (Cosmic Rays identification)
- least square linear fit on accumulated charge ramp / px
- evaluation of the χ^2 fit quality estimator / px

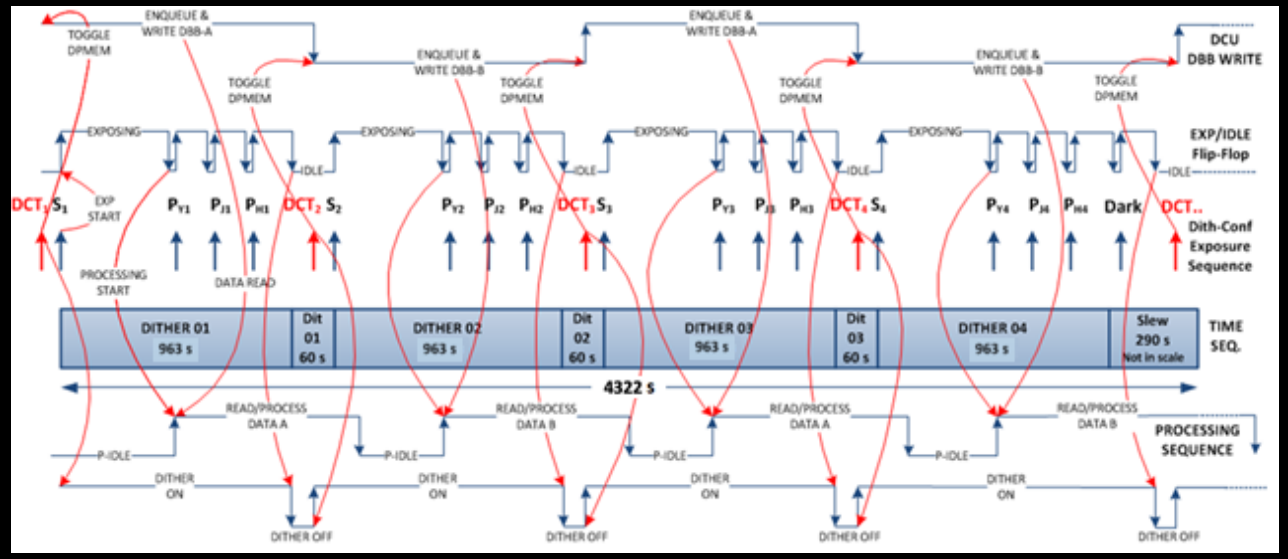


output:
- compression algorithm (CFITSIO-NASA)
- signal frame
- χ^2 frame (different resolutions for Specto/Photo)
- telemetry (acquisition, detector, errors)
- 5 raw lines of un-processed signal

DPU-ASW on-board operations

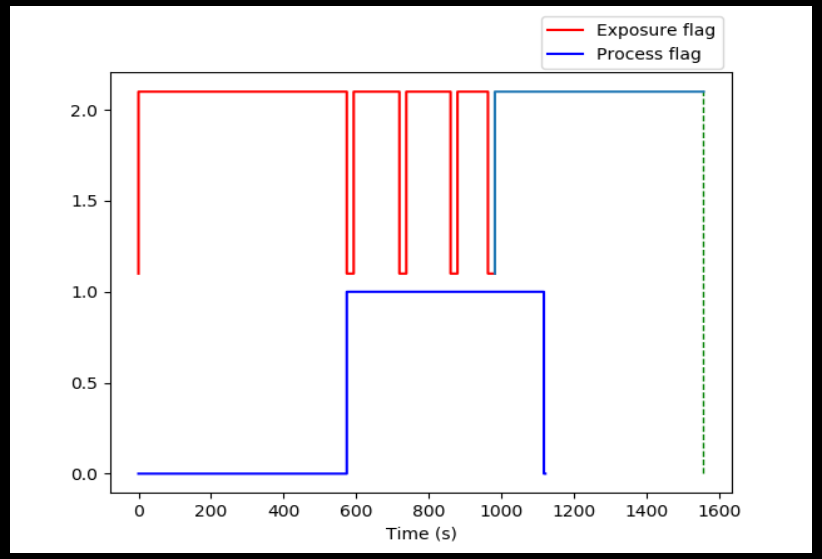
NISP nominal observation sequence





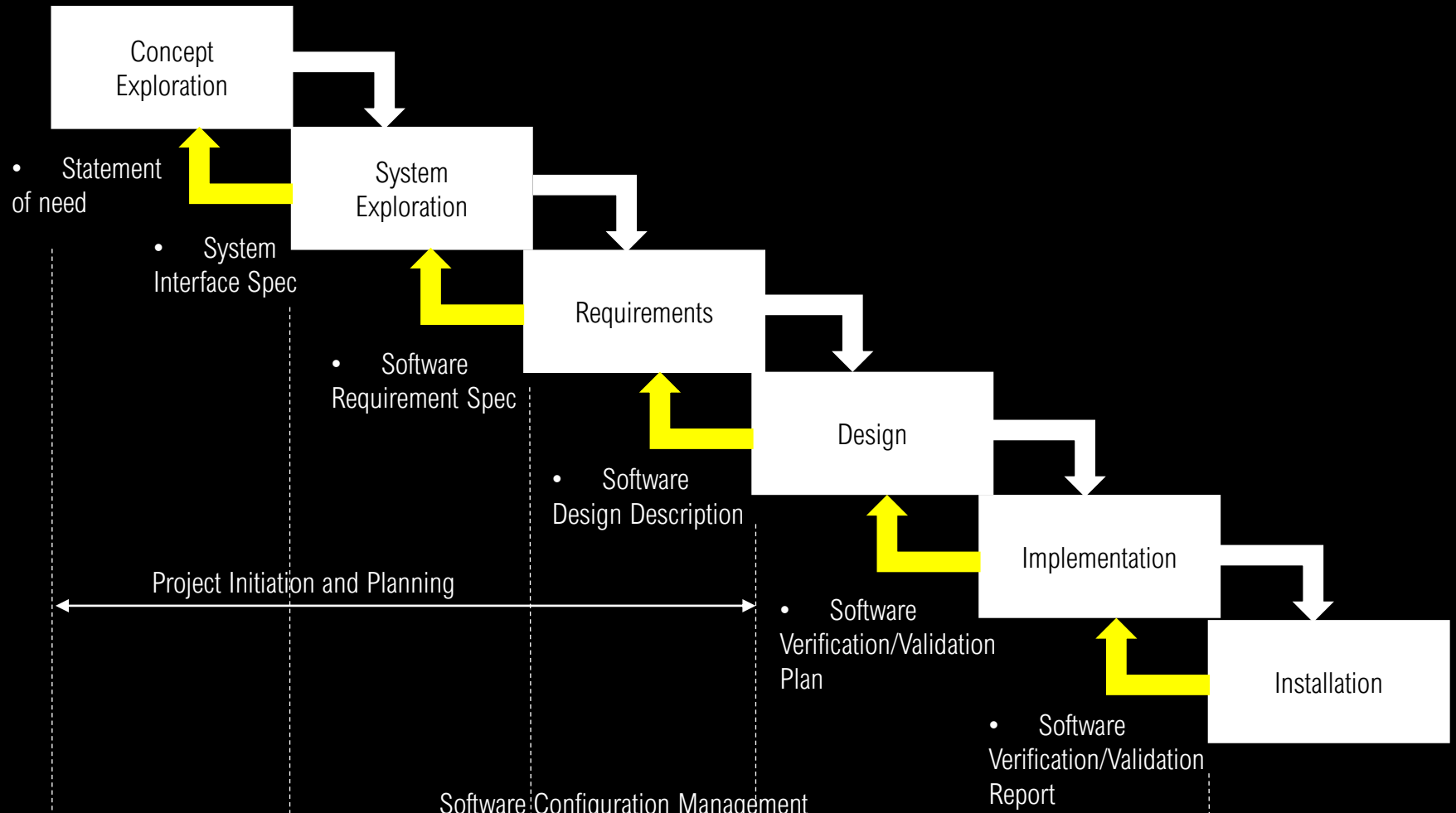
Single Dither cycle:
- 4 exposures (1 Spectrometric, 3 Photometric)
- Optimized sequence to perform parallel on-board image processing
- Optimized memory usage to perform series of observation sequences
- Optimized serialized (per detector) data processing and transmission

DPU-ASW main internal operations / Dither



Parallel data acquisition (broadcast) and serialized processing and transmission

Software life cycle – Waterfall Model with Feedback



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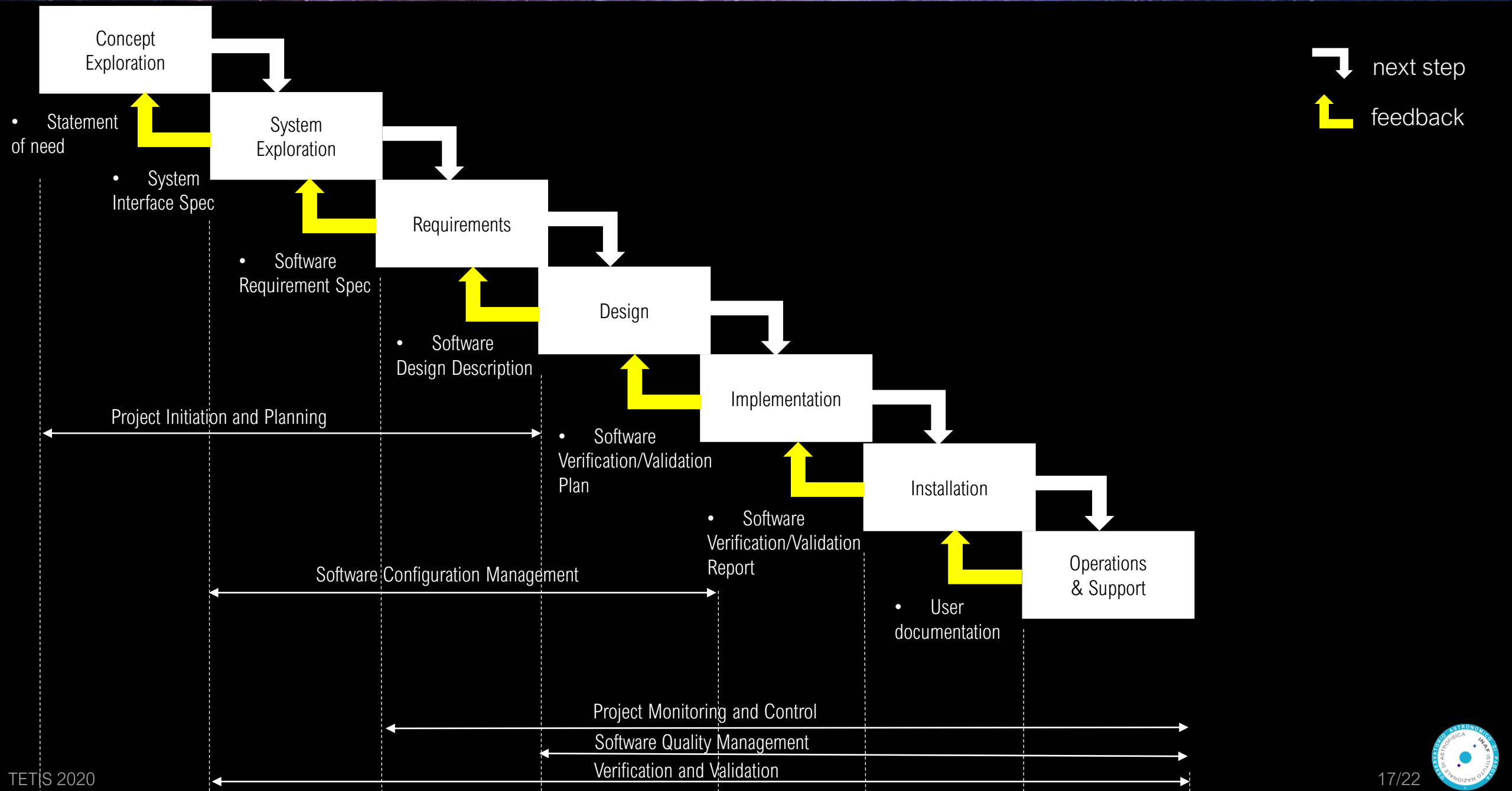
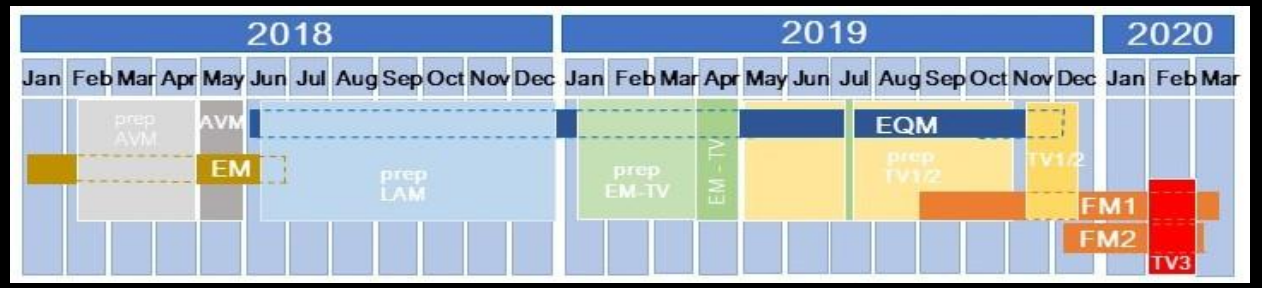
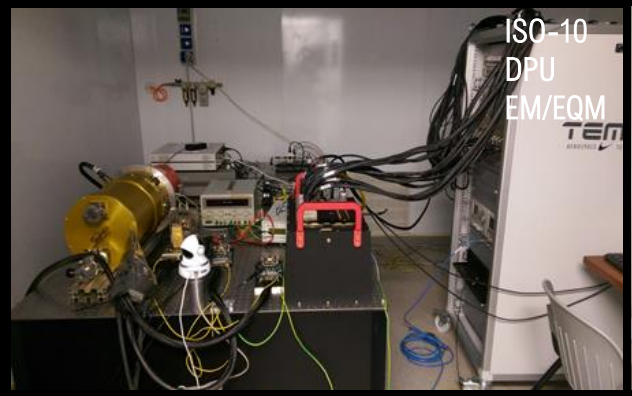
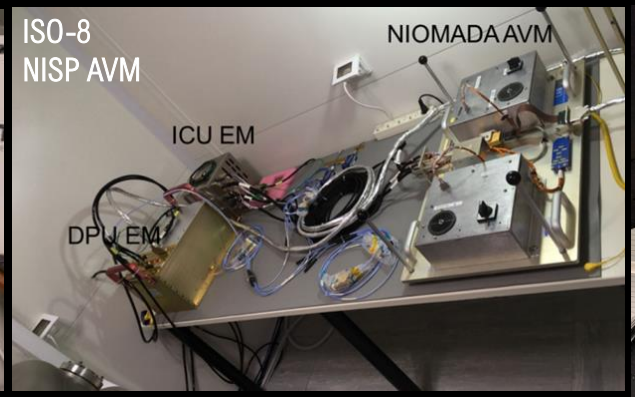


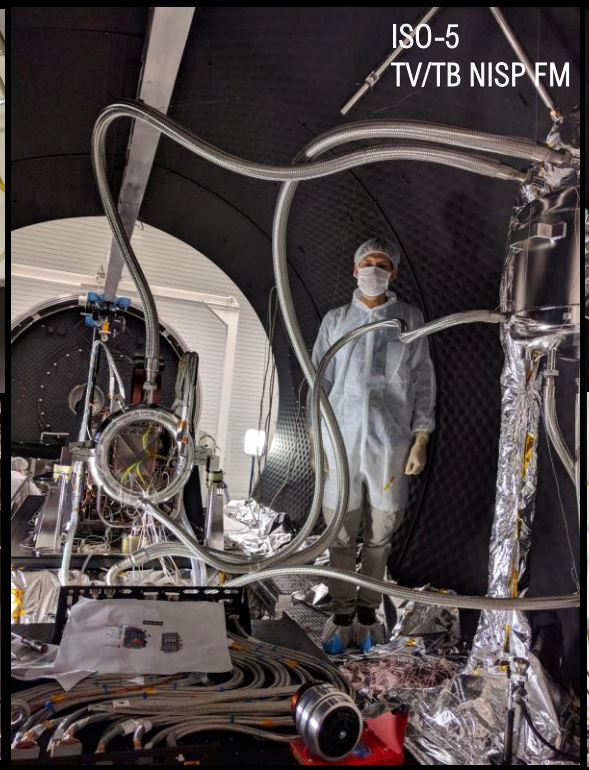
DPU-ASW validation campaigns

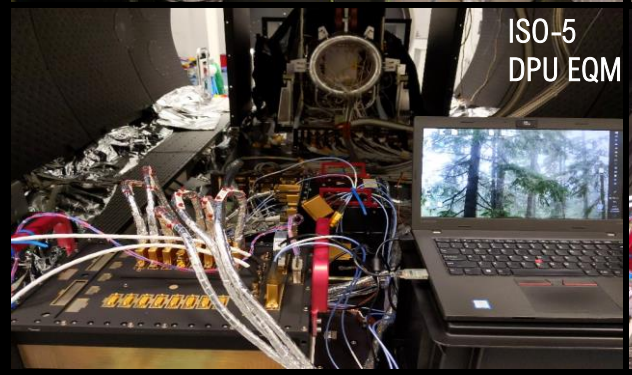


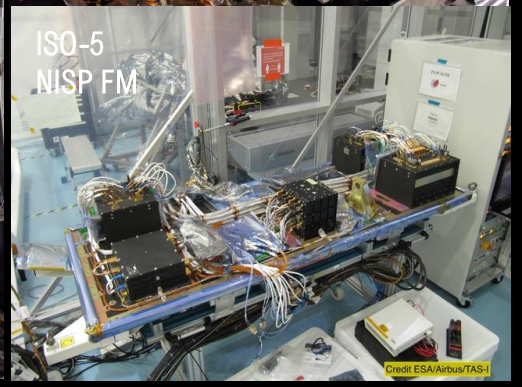
- industry (Alenia Space & Airbus)
- ESOC











- Different HW setups for dedicated tests
- Several integration tests, including final configuration (Laboratoire Astrofisique de Marseille – ERIOS vacuum chamber)
- Currently FM-HW under integration with the Satellite (Thales Alenia Space & Airbus)

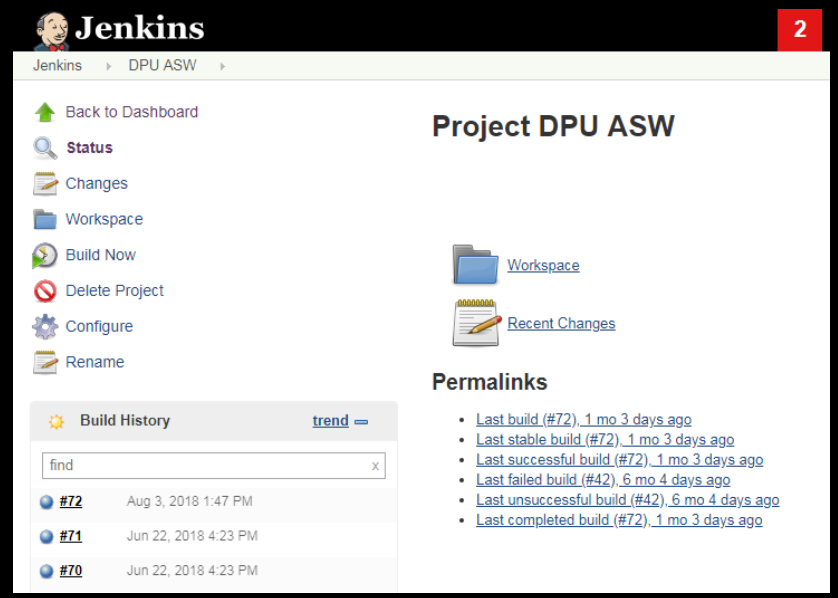
DPU-ASW continuous integration / regression tests

Static Tests:

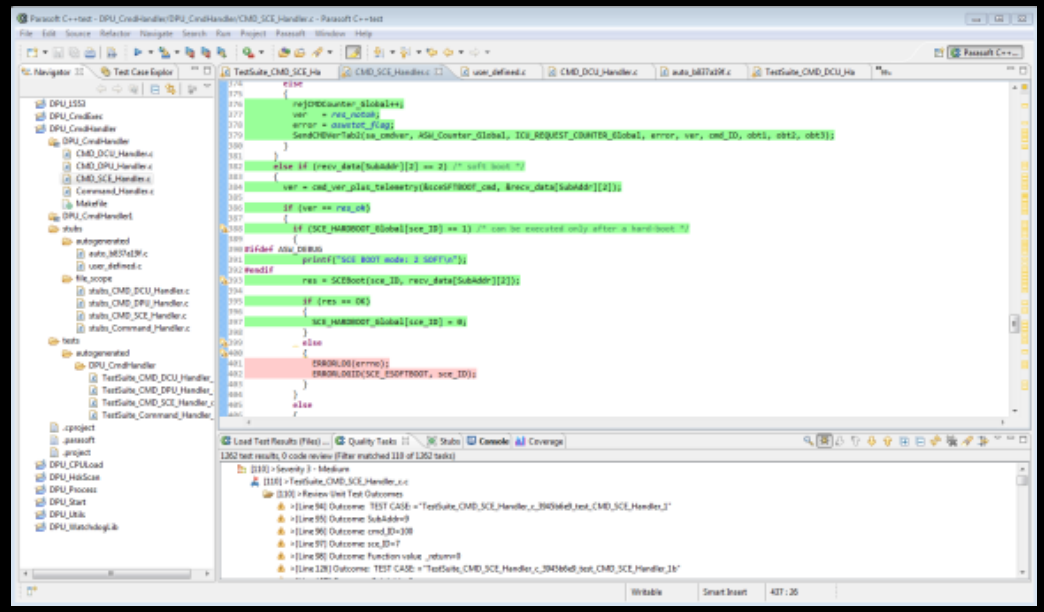
- **Code Style**: (*MISRA 2004 standard ansi-C*)
  - Clang Format scripting (open-source)
  - Parasoft C/C++ test tool-kit (under-license)
- **Compilation**: (*e.g. variable defs, declarations, shadowing, pointers, semantics, typedefs, access to arrays*)
  gcc pedantic compilation in Tornado environment (using VxWorks OS)
  - cross-compilation using the latest powerpc-linux-gnuspe-gcc-6 compiler (using a Linux OS)
- **Bug finding**: *(e.g. data race, double lock, unreached code, dead code, useless if, variable shadowing)*
  - Clang Static Analyser (open-source)
  - PolySpace Bug Finder tool-kit (ESTEC-licensed)
  - Coverity (ESTEC-licensed)

Unit Tests: (MISRA 2004 standards)

- Performed using C/C++Test (Parasoft) which supports for VxWorks RTOS
- The line coverage *per function* > 90%
- Tests are performed (loaded and run) on a RTOS target server (Maxwell™ board)



https://builder.oapd.inaf.it:8080/job/DPU%20ASW/



https://baltig.infn.it/euclid/dpu-asw_unittests

DPU-ASW validation process

Requirement spec & Product Assurance Plan

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Test Specification

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Test, product assurance management reports

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Tailoring:
Verification Control Document
Requirement Compliance Matrix
Full DPU-ASW documentation

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Qualification & Acceptance Review

DPU-ASW DATA-PACK:

1. EUCL-OPD-TN-7-007 DPU ASW FDIR
2. EUCL-OPD-PL-7-003 NI-DPU ASW Test Specifications,
3. EUCL-OPD-VCD-7-001 NI-DPU ASW Verification Control Document,
4. EUCL-OPD-RP-7-003 NI-DPU ASW Data Processing Definition and Justification,
5. EUCL-OPD-OTH-7-002 NI-DPU ASW Requirement Compliance Matrix
6. EUCL-OPD-ICD-7-004 NI-DPU ASW to Spacecraft Interface Control Document
7. EUCL-IBO-TR-7-003 DPU-ASW Integration Tests Report during NI-AVM-EM-TV, TV1/2/3
8. EUCL-IBO-PL-7-023 NI-DPU ASW Acceptance Test Plan,
9. EUCL-IBO-NOTE-7-004 NI-DPU-ASW QAR Organization Note,
10. EUCL-OPD-CS-7-001_DPU_ASW_ConfigurationControl-Issues
11. EUCL-OPD-ICD-7-003 NI-DPU ASW ICD
12. EUCL-OPD-MA-7-001 NI-DPU ASW User Manual
13. EUCL-OPD-RP-7-001 NI-DPU ASW Design Definition Document
14. EUCL-IBO-PL-7-024 NI-DPU-ASW Maintenance Plan
15. EUCL-OPD-LI-7-001_DPU_ASW_FileList
16. EUCL-OPD-PL-7-001 NI-DPU ASW Product Assurance Plan
17. EUCL-OPD-PL-7-005 DPU ASW Static & Unit Test Report
18. EUCL-OPD-RP-7-15 SW Product Assurance Management Report
19. EUCL-OPD-RS-7-001NI-DPU ASW Requirement Specifications
20. EUCL-OPD-TN-7-010-DPU ASW Handling Error Strategy
21. NI-DPU ASW v1.3.5 – Release Notes
22. EUCL-IBO-LI-7-021 DPU ASW Configuration Item Data List
23. EUCL-OPD-QR-7-002 NI-DPU ASW Risk Register

technical notes:

1. EUCL-IBO-TN-7-018 NISP Flight model SCE-SCA Telemetry Conversion to engineering units
2. EUCL-IBO-RP-7-029 DPU SpW error detection
3. EUCL-IBO-TN-7-016 NISP Broadcast and Single Detector Exposure configuration
4. EUCL-IBO-TR-7-001 Two DPU synch test
5. EUCL-OPD-TN-7-011 SCE/SCA setup for cold and room Temperature operations (~135/100 K)
6. EUCL-IBO-TN-7-023 Procedure to configurate NISP Focal Plane for room temperature operations

UML Model:

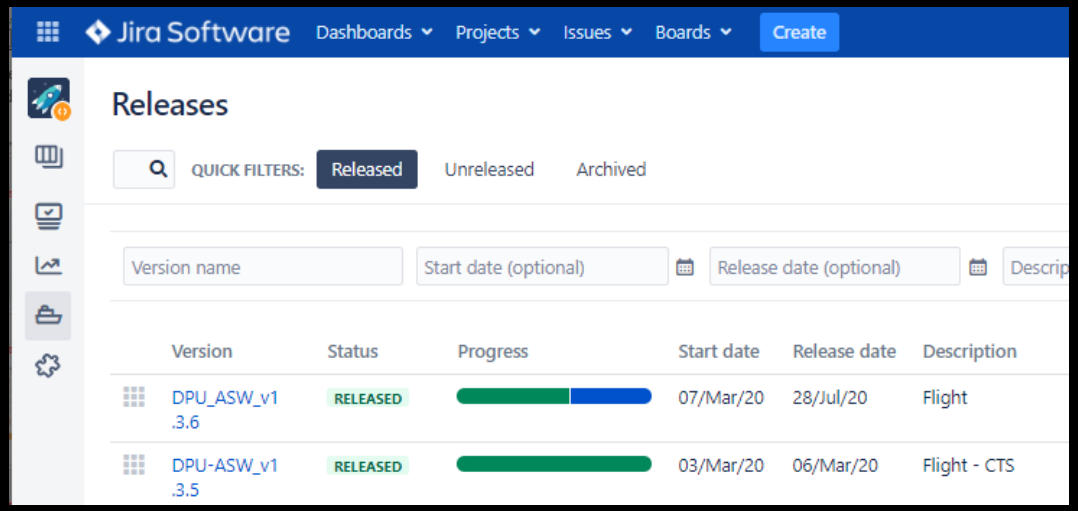
1. DPU-ASW UML2.0 model

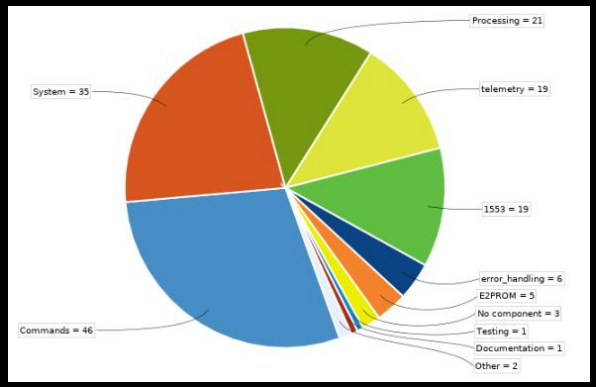
DPU-ASW configuration control / versioning

Configuration Control

https://issues.infn.it/jira/browse/EUNIDPUASW/

- On-line toolkit to track and document any change in a software version including:
  - new features
  - bug finding
  - NCR (Non-Conformity Report)
- Documentation storage: Owncloud https://owncloud.iasfbo.inaf.it/

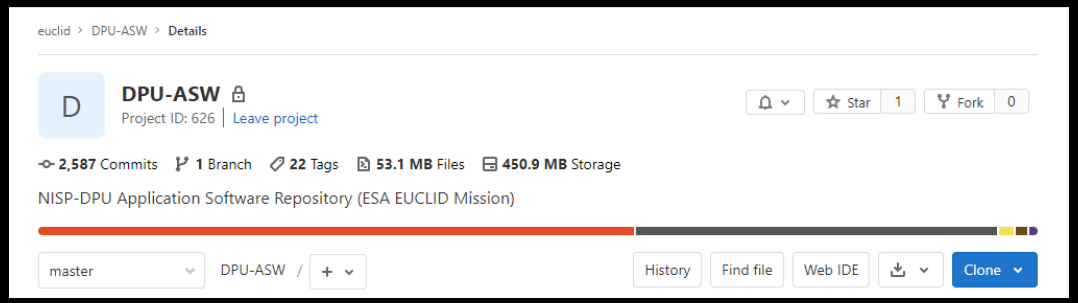


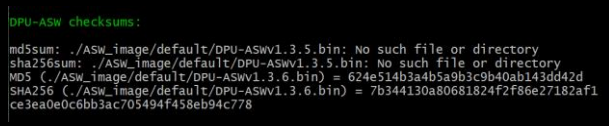


Versioning

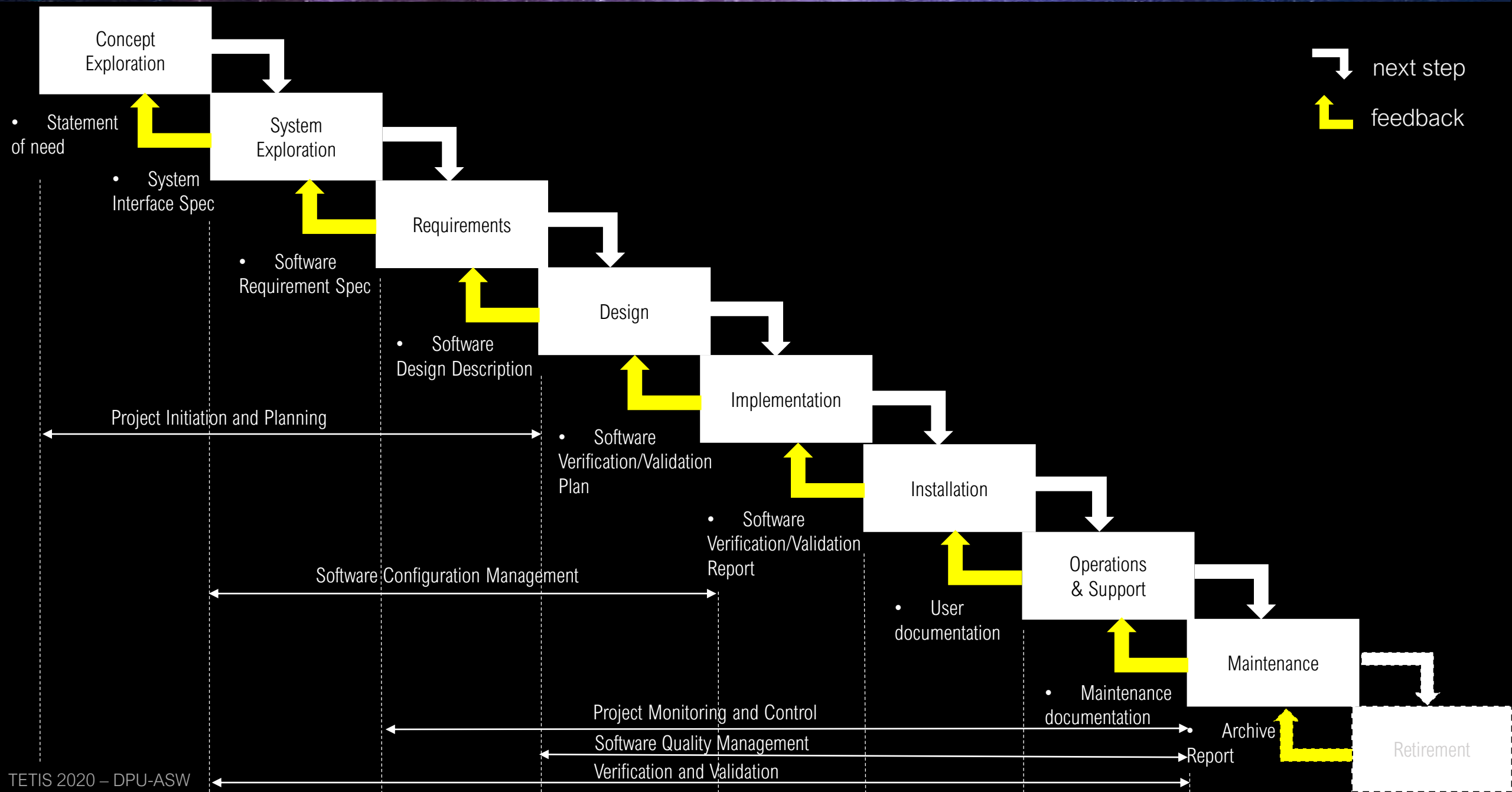
https://baltig.infn.it/euclid/DPU-ASW

- Gitlab repository (NISP Warm Electronics)
  - DPU-ASW source code
  - DPU-ASW unit tests code
- NISP Issue tracking
- Jobs:
  - Versioning checksums
  - Public Gitpages https://euclid.baltig-pages.infn.it/DPU-ASW/index.html
  - Doxygen documentation





Software life cycle – Waterfall Model with Feedback




thanks for your attention