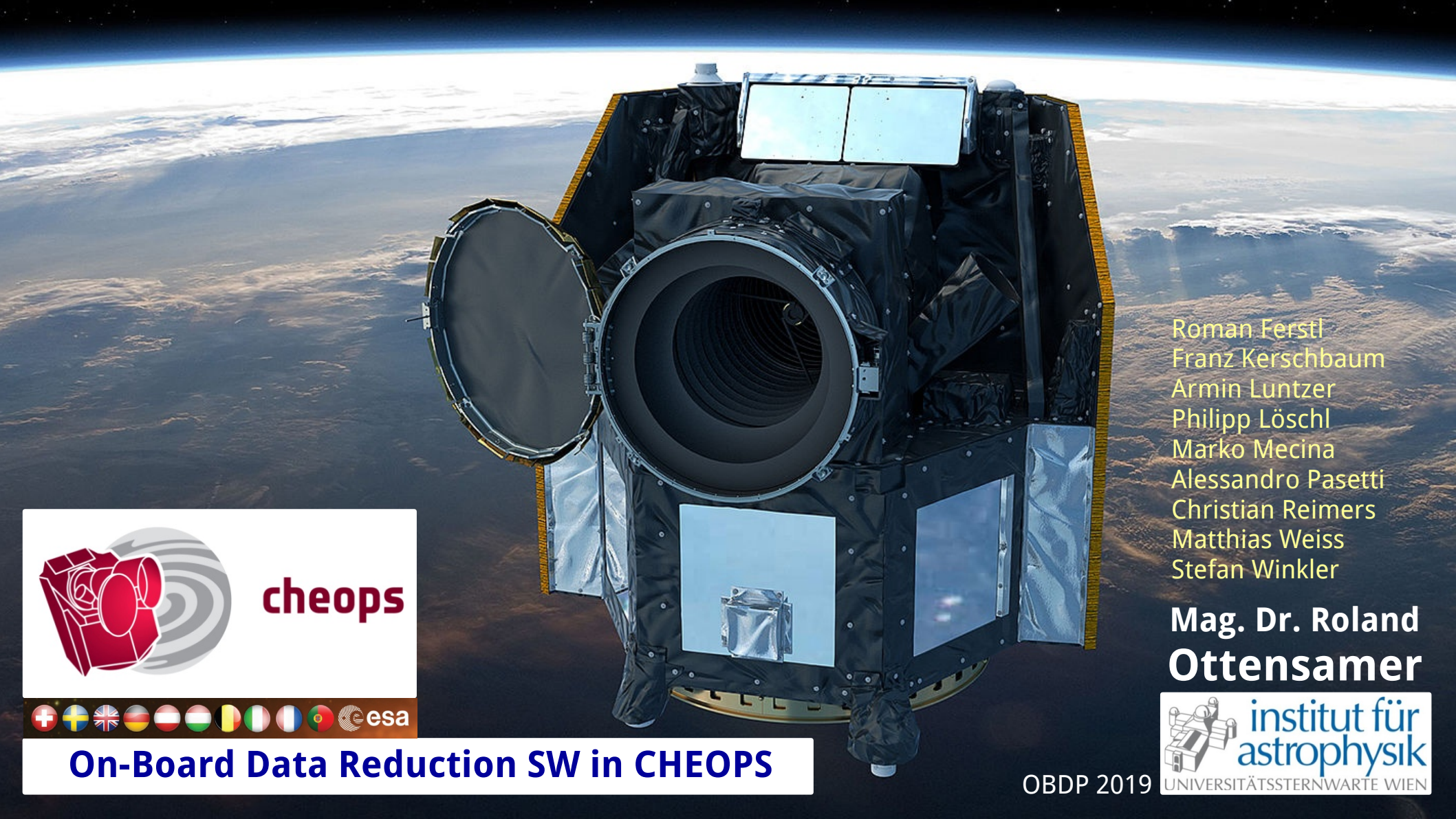

cheops

esa

On-Board Data Reduction SW in CHEOPS

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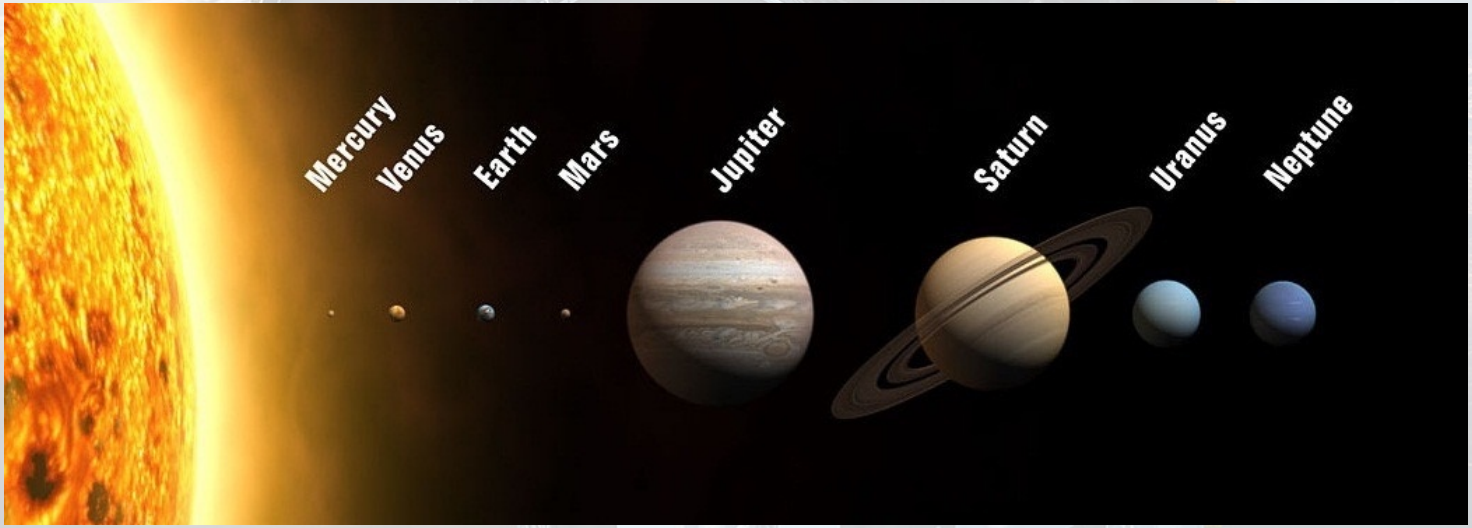
OBDP 2019

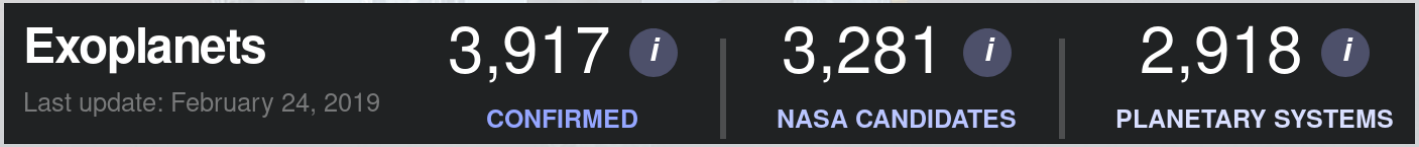
CHEOPS is ready for launch: 15.10–14.11.2019
Soyuz, together with Cosmo Second Generation 1

Characterizing Exoplanets

- **until 1995 we knew 8 planets …**



- **current figure:**

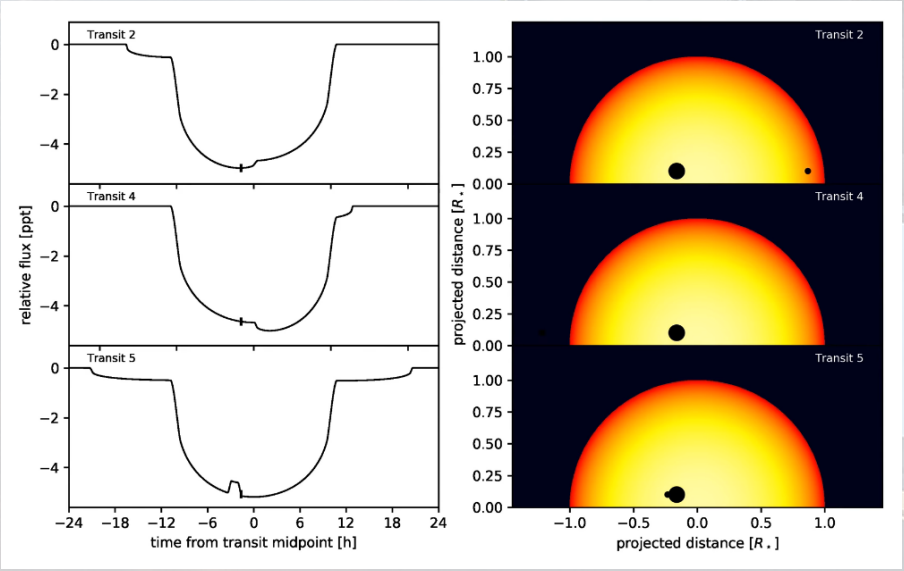


exoplanets.nasa.gov

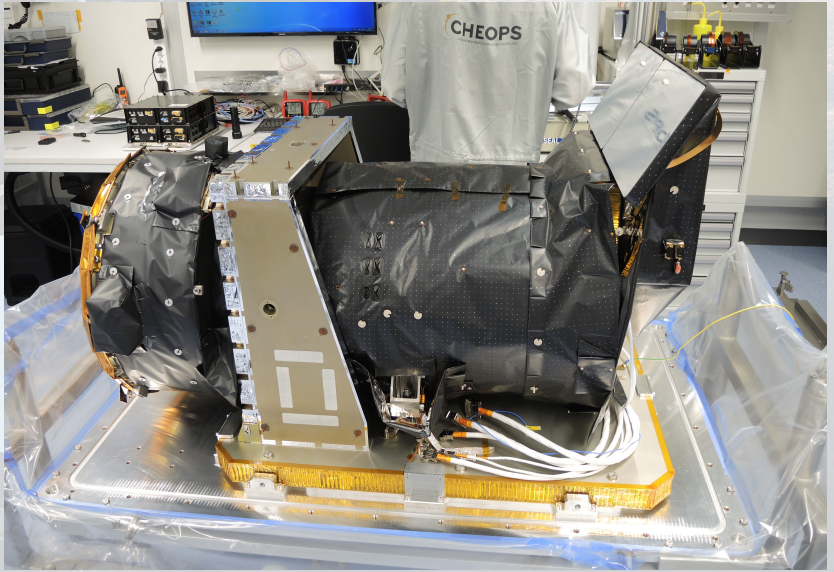
CHEOPS Primary Science Goal

- observe **KNOWN** transits to **measure exoplanet radii to 10%** and derive bulk density

- **classification of exoplanets**
- **detection of atmosphere**
- **properties of gas giants**



Rodenbeck et al.



instrument shipping prep. (Uni Bern)

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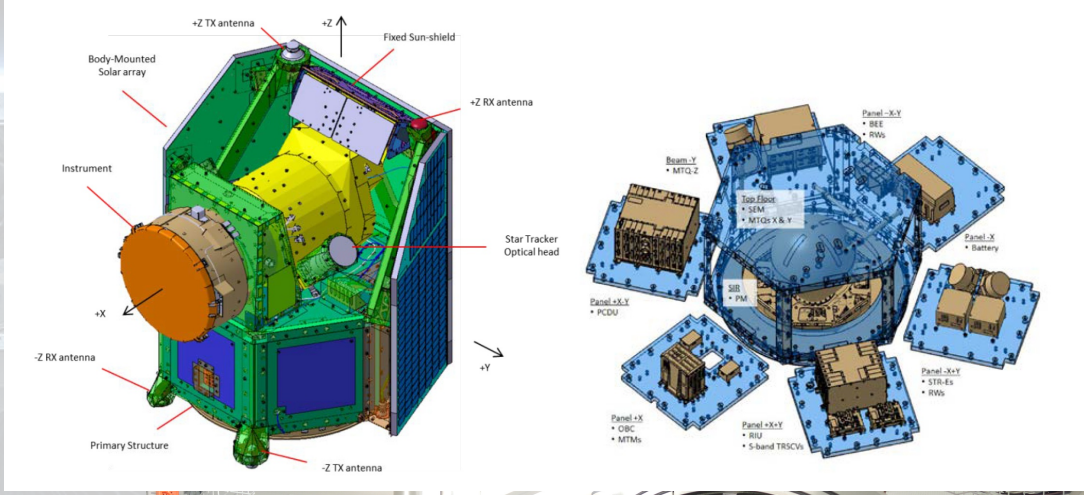
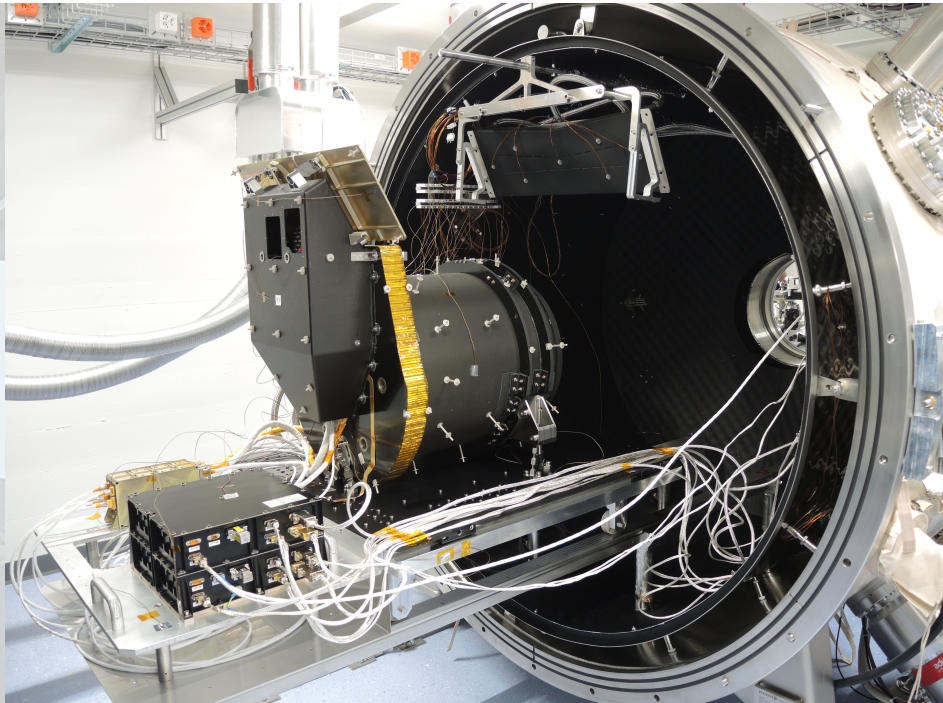
The Spacecraft

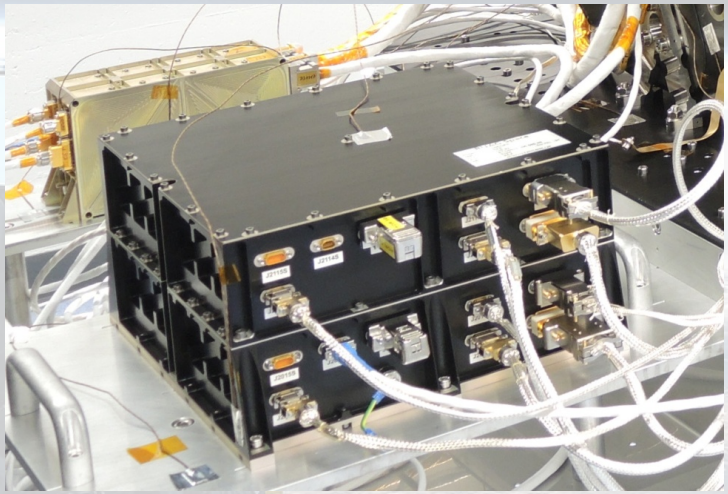
- **ESA-S**, 1.5m per side, 280 kg
- **Platform** AIRBUS DEFENCE & SPACE
  - Guiding < 8“
  - 60 W, S-Band ~150 MB/day (Torrejón)
- **Instrument** esa
  - consortium led by **Uni Bern**
  - 60 kg, Telescope D=32 cm, f=2.7m
  - 1k x 1k CCD, 400-1100 nm, 1“/px
  - 2x2 LEON3-based computers

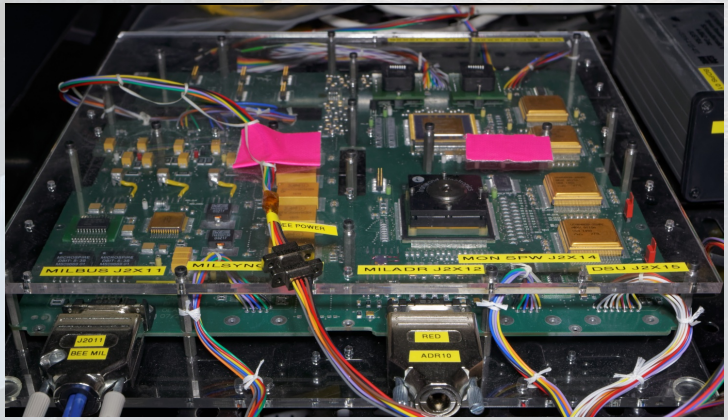




DPU Specs (and Bugs)

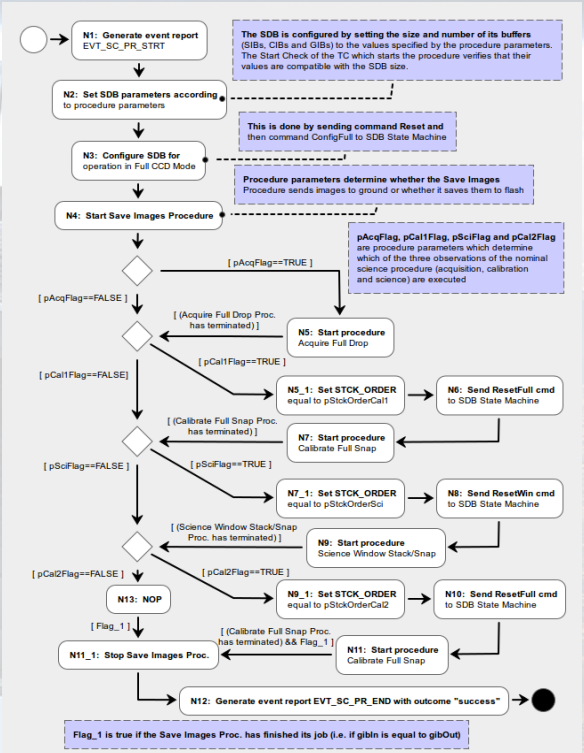
- GR712RC used @ 25 MHz, both cores and GRFPUs, DSU, 2 GRSPW2 cores, 1553
- 2 SRAM banks, each 32 MiB, 1 waitstate
- 16 GiB FLASH with EDAC
- HW Bugs ("Anti-Features")
  - several CPU bugs were solved by bcc updates
  - no read-modify-write access to SRAM2
  - 3 of 7 CPUs had a strange thermal problem on Core2 (the affected ones were proto-parts)
  - Milbus core (Microsemi v2.16) has buggy ping-pong mode



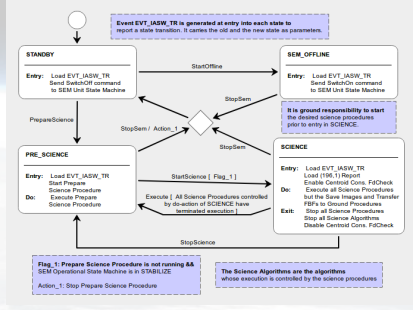


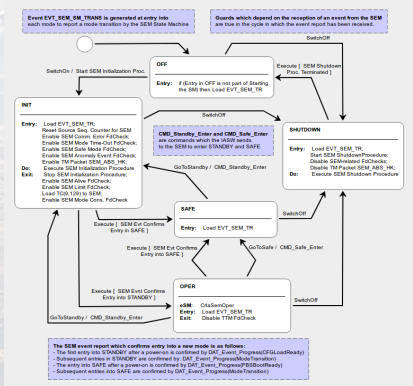
IASW Overview

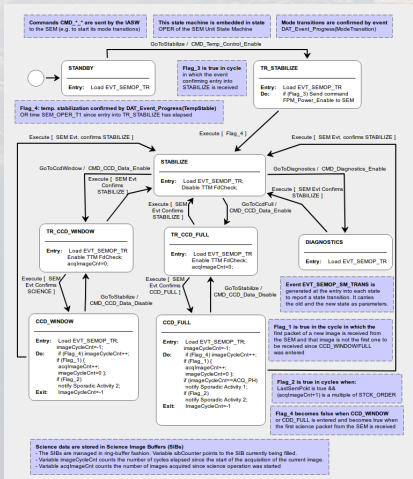
- ca. 25 person-years for …
- ~100 ECSS (Sub)Services
- 535 SW modules, 65327 loc
- Category C (B-C)
  - Spec + PA/QA by PnP Software
- OS: bare metal (~11kloc)
- CORDET Framework
  - ECSS Services, PUS packet routing
  - 7 State Machines and 24 SW Procedures
  - 13 FDIR (~4kloc) procedures monitoring 120 param., 5 recov proc.
- Science Algorithms (~20kloc)



procedure specified in FwProfile







nested state machine for detector unit

Key Requirements for Science DP

- Max sust. Science Data input rate up to 3.5 Mibit/s
- Max sust. output 128 kibit/s (Milbus)
- Science TM Budget: 10.5 kibit/s (S-Band, Polar Orbit)
- Centroiding < 1 pixel (we manage < 1/10)
- Telescope temp. control < 1 deg (we manage < 1/20)

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Real-time DP SW Architecture

- Core1: "System tasks"
  - 8 Hz IASW cycle
  - state machines and procedures
  - communication, FDIR, Thermal
  - centroiding on input images
  - FLASH access with SAA w/p
  - error log etc...
- Core2: "Science Data Processing"
  - Target Acquisition (Pattern Recognition)
  - Reduction and Compression

- both Cores use the same code image
- both cores are powered down when idle
- producer/consumer access to resources

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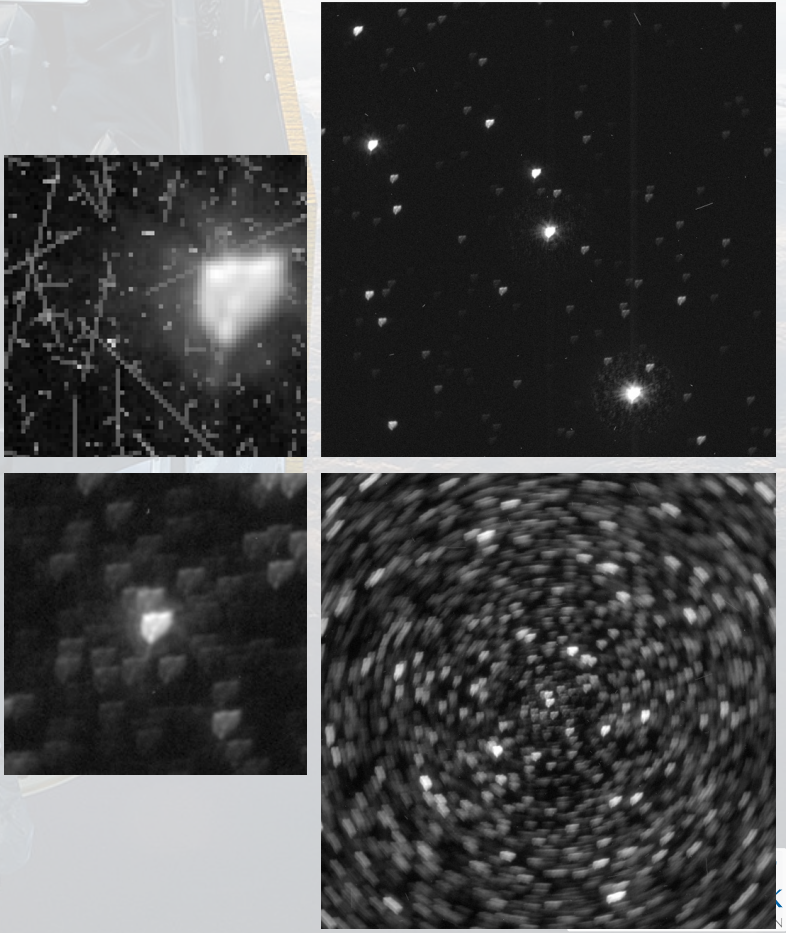
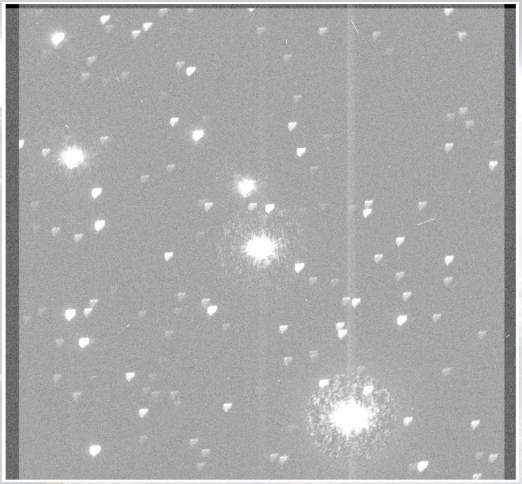
Data Processing tasks

- images are intentionally defocused to mitigate individual pixel characteristics
- exposure times 0.1s – 60s
- data processing
  - target recognition
  - centroiding
  - reduction and compression

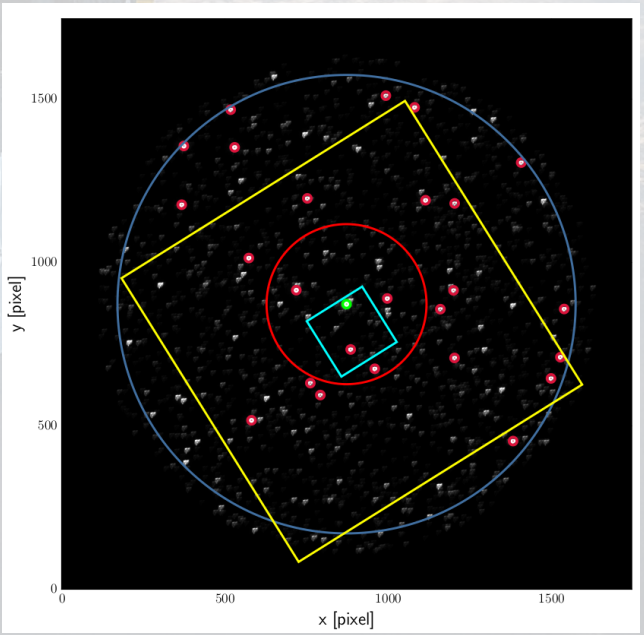


Target Acquisition

- pointing uncertainty on new targets:
  - up to 120px shift (thermoelastic)
  - rotation unknown
- Algorithms
  - Liebe-based angle method
  - magnitude validation
- performance is limited by source extraction

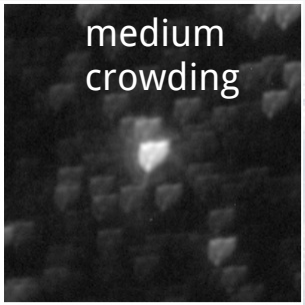


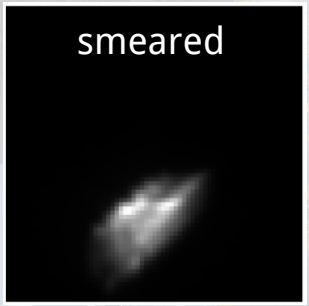
full frame
with margins

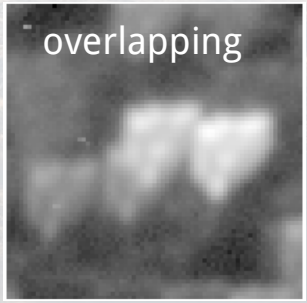


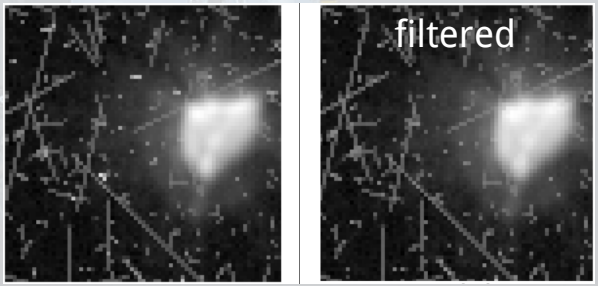
Centroiding (Payload in the loop)

- every science frame at up to 1 Hz is used for centroiding
- Performance trades
  - "age" of centroid information is critical
  - PSF (shape of target star) varies with position and spectral type
  - cosmics need to be filtered
  - no prior knowledge is kept between images
- implemented algorithm
  - intensity weighted centre of gravity with thresholded median filter





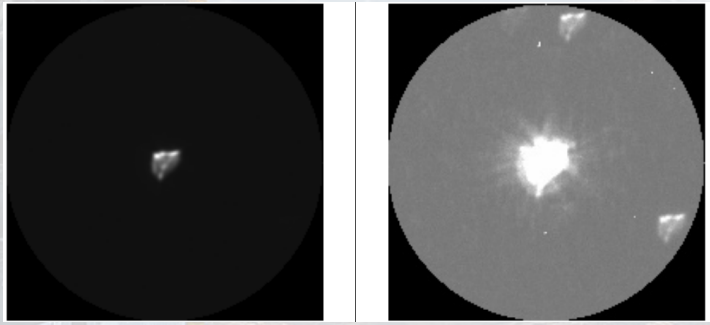


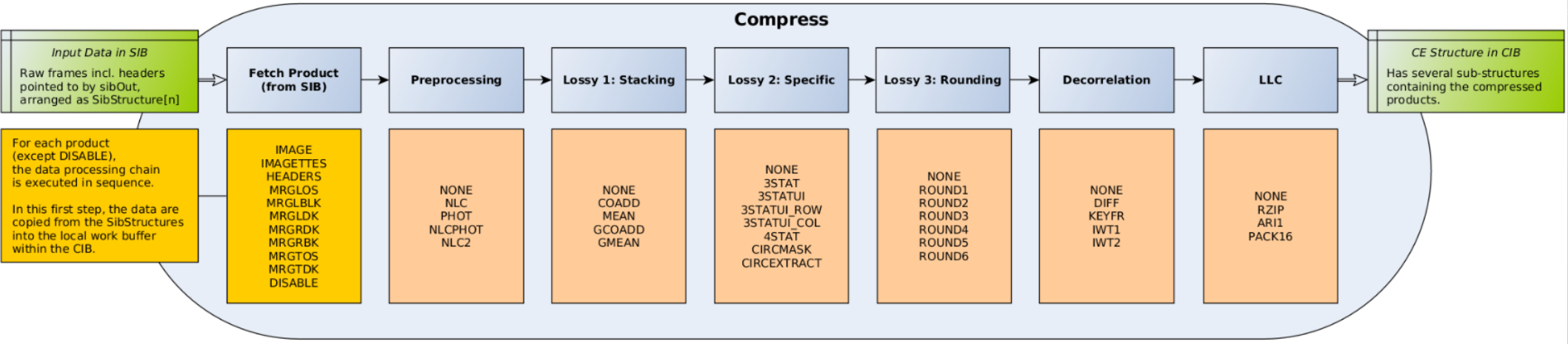


Science data reduction + compression

- some re-use from HERSCHEL/PACS
- full frames or windows + margin areas enter the DP chain
- product-specific keys define the steps to take
- schedulability is up to the observer (=SOC)
- limitations are:
  - input cadence vs execution speed
  - output bandwidth over Milbus

example for a science window





Lessons Learned from CHEOPS

- minimize external dependencies
  - on SW that is part of the FSW, SW that generates it, development tools, test environment, Instrument Database, Document Generation, ...
- new qualification testing paradigm
  - UVIE Test Specification Tool
- new document generation workflow
  - based on LaTeX

Future of CHEOPS – and of UVIE

- **CHEOPS WAS DONE IN 5 YEARS!**
- **CHEOPS launch window 15.10.-14.11. 2019**
- **CHEOPS IASW Sources**
  - **https://ghe.phaidra.org/space**

"I've analysed 36 mission codebases so far during my tenure at ESTEC – and I can honestly say that CHEOPS code is a shining star in terms of static analysis."

- **UVIE is currently working on:**
  - **IASW for SMILE/SXI, ARIEL-FGS, ATHENA-WFI, SAFARI**
  - **FPGA compression for PLATO**

last SW update Dec. 2018