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On-Board Data Reduction SW in CHEOPS

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

EADS

Characterizing Exoplanets

until 1995 we knew 8 planets ...

3,917 (

CONFIRMED

3,281 ()

NASA CANDIDATES

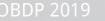
2,918 ()

PLANETARY SYSTEMS

current figure:

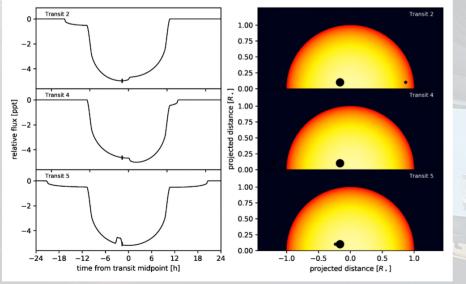
exoplanets.nasa.gov

Exoplanets



CHEOPS Primary Science Goal

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



Rodenbeck et al.

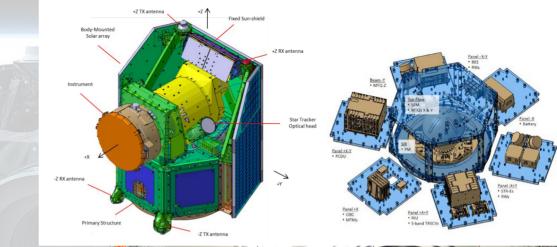
- classification of exoplanets
- detection of atmosphere
- properties of gas giants



instrument shipping prep. (Uni Bern)

The Spacecraft

- ESA-S, 1.5m per side, 280 kg
- Platform O AIRBUS DEFENCE & SPACE
 - Guiding < 8"
 - 60 W, S-Band ~150 MB/day (Torrejón)
- - 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 pingpong mode







Together ahead. **RUAG**



OBDP 2019

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)

nested state machine for detector unit

The SDB is configured by setting the size and number of its buffers

This is done by sending command Reset and

hen command ConfigEull to SDB State Machine

N5: Start procedur Acquire Full Drop

N5 1: Set STCK ORDER

N7: Start procedure Calibrate Full Snap

N7 1: Set STCK ORDER

N9: Start procedure Science Window Stack/Sna

N11: Start procedu

Calibrate Full Snap

N9 1: Set STCK ORDER

equal to pStckOrderCal2

equal to pStckOrderSci

[pAcgFlag==TRUE

(Acquire Full Drop Proc

[(Calibrate Full Snap F

pSciFlag==TRUE

Proc. has terminated) 1

[(Calibrate Full Snap Proc has terminated) && Flag_1

Flag 1 is true if the Save Images Proc. has finished its job (i.e. if gibln is equal to gibOut

procedure specified in FwProfile

has terminated)]

pCal1Flag==TRUE

(SIBs, CIBs and GIBs) to the values specified by the procedure parame The Start Check of the TC which starts the procedure verifies that their values are compatible with the SIDE size.

nine whether the Save Image

science procedure (acquisition and science) are executed

pAcqFlag, pCal1Flag, pSciFlag and pCal2Fl are procedure parameters which determine which of the three observations of the nomina

N6: Send ResetFull cmd

N8: Send ResetWin cm

N10: Send ResetFull cmd

to SDB State Mechine

to SDB State Machine

SDB State Mach

EVT SC PR STR

N2: Set SDB parameter

to procedure parameter

N3: Configure SDB for

operation in Full CCD Mc

N4: Start Save Images Procedur

[pAcgFlag==FALSE]

[pCal1Flag==FALSE]

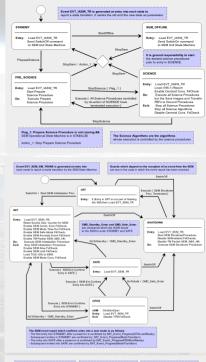
I nSciElega=EALSE

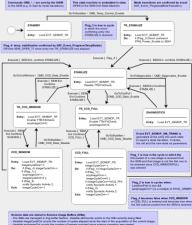
[pCal2Flag==FALSE]

N13: NO

[Flag_1]

N11 1: Stop Save Ir





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)</p>
- Telescope temp. control < 1 deg (we manage < 1/20)</p>



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

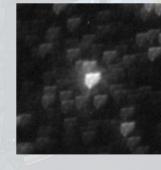


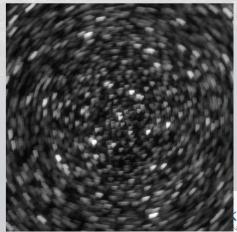
Data Processing tasks

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



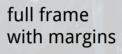


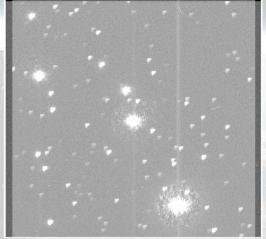


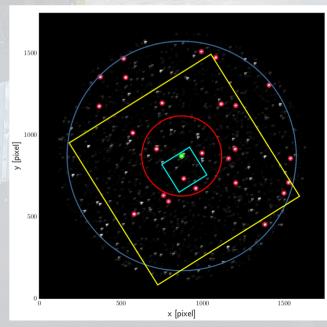


Target Acquisition

- 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



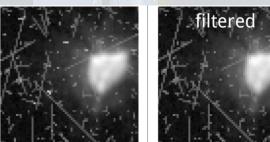




Centroiding (Payload in the loop)

- 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







medium

crowding

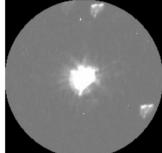
OBDP 2019

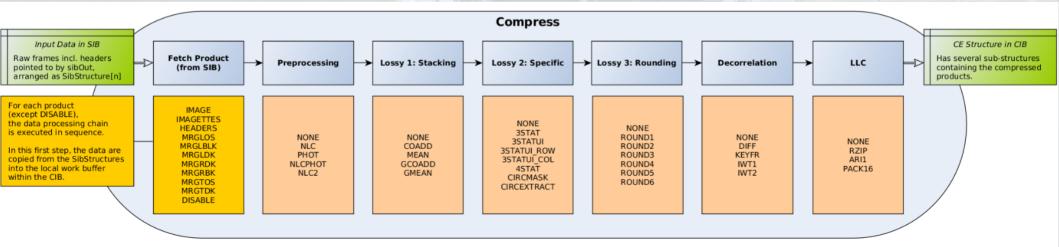
Science data reduction + compression

- 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

