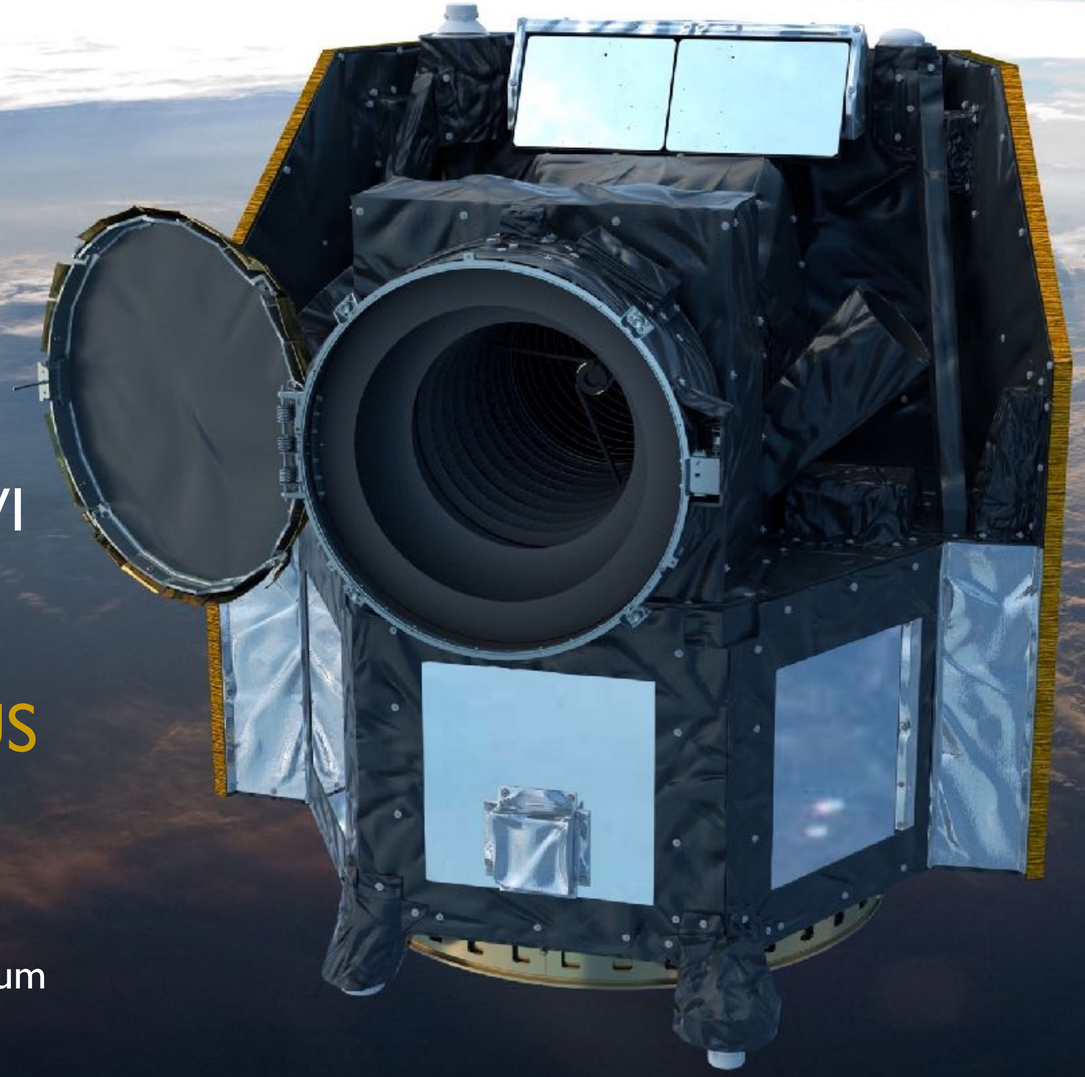
SPACE RESEARCH & PLANETARY SCIENCES
UNIVERSITY OF BERN

UNIVERSITÄT BERN

CHEOPS
CHARACTERISING EXOPLANET SATELLITE



CHEOPS Science Workshop VI
online, 11-13 January 2022

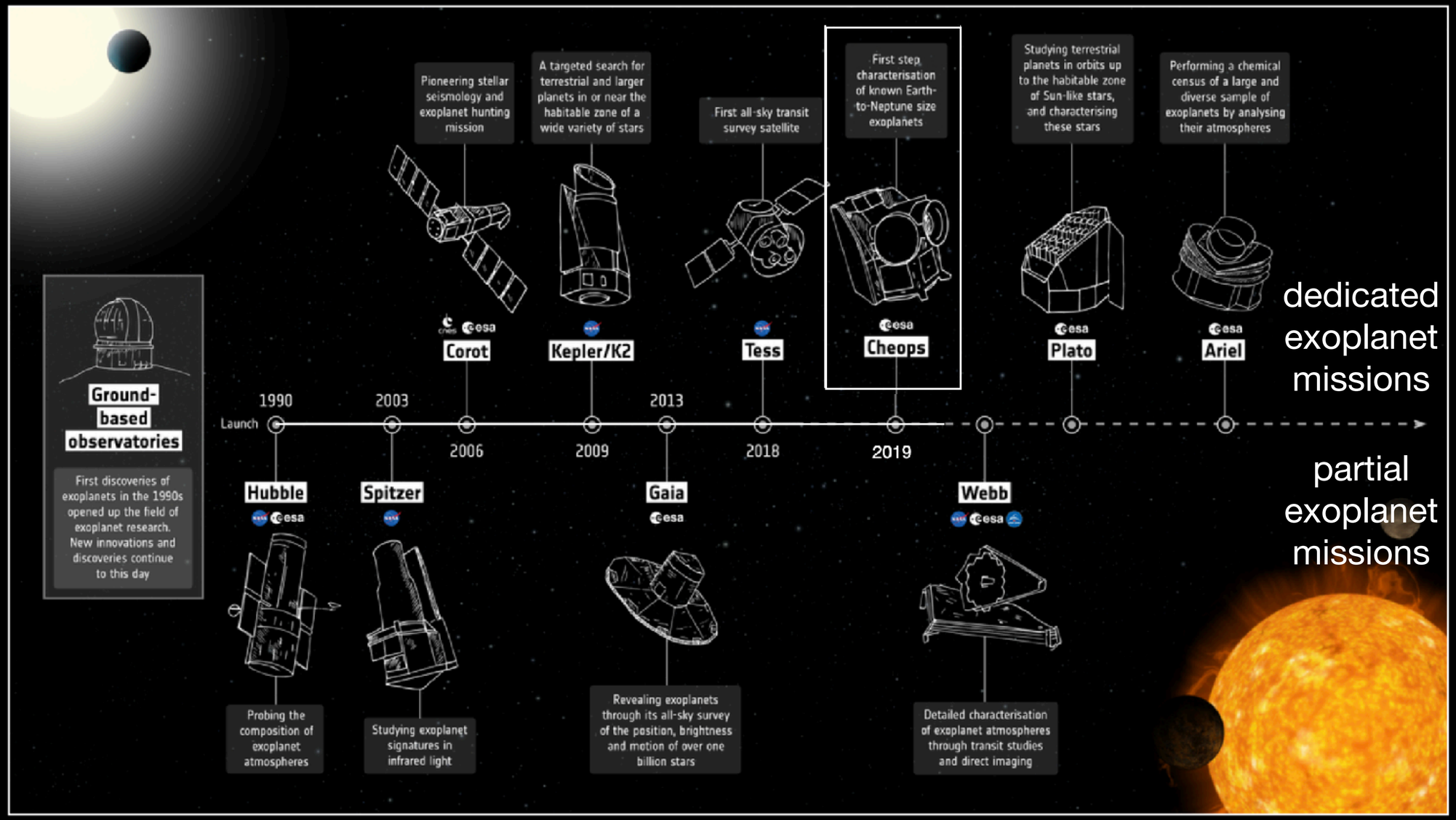
CHEOPS MISSION STATUS

Christopher Broeg
CHEOPS Mission Manager
CSH University of Bern
On behalf of the CHEOPS mission consortium

CHEOPS Talk Outline

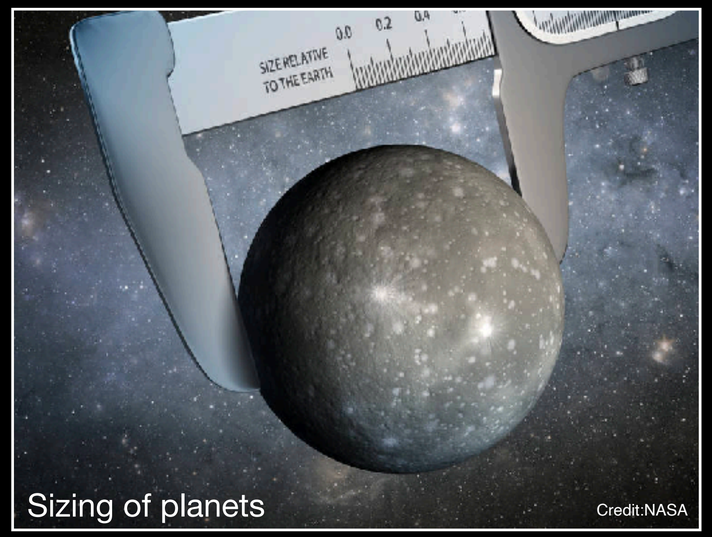
- Mission overview and history
- Status of space segment
- Operational performance today and onwards
- “programming the space telescope”
- Public data and data analysis
- Summary

Exoplanet space missions

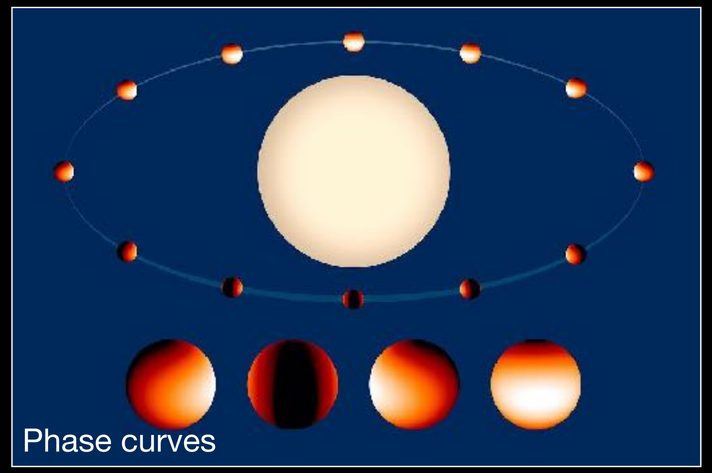


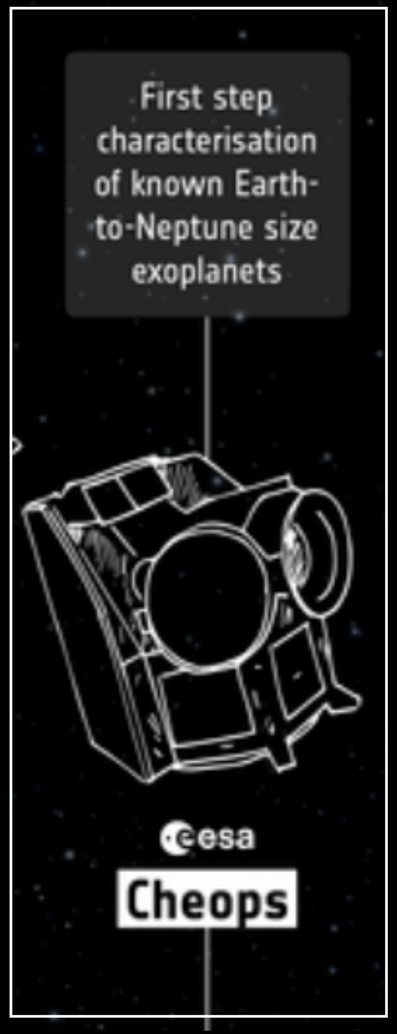
Courtesy: ESA

CHEOPS: precision photometry



Sizing of planets Credit:NASA


Phase curves

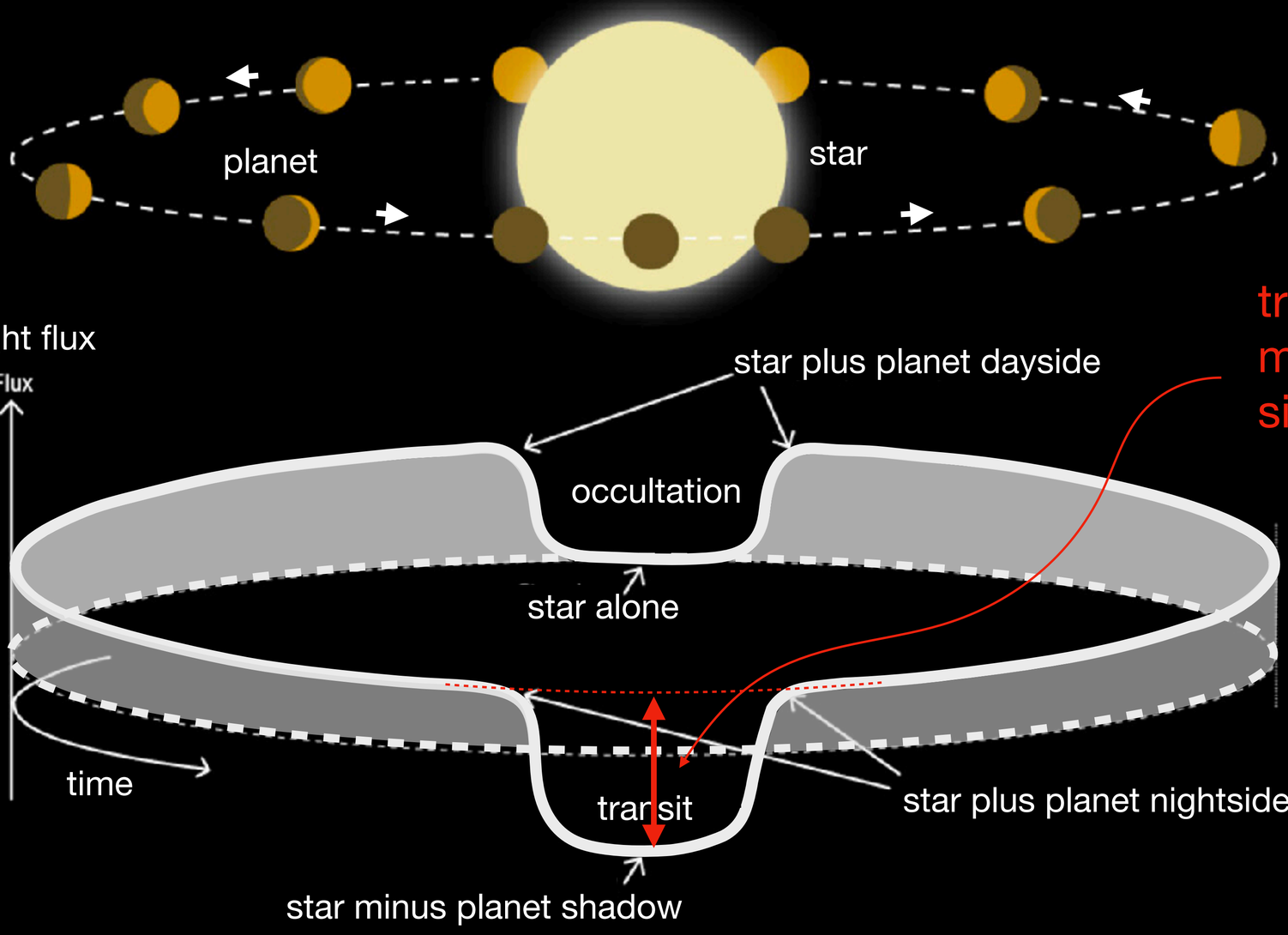


A unique mission:

- First space mission dedicated to study known exoplanets
  ⟶ **first follow-up mission**
- First “small” mission in ESA’s science mission portfolio
  ⟶ **cost & development time capped**
- First mission with a joint leadership Switzerland-ESA

Credit:ESA

Planetary transit



transit depth:
measure of the relative size planet/star

Jupiter-sized: ~ 1%
Earth-sized: ~ 0.01%

Defines the precision at which light has to be measured to obtain a given precision on the determination of the planetary radius

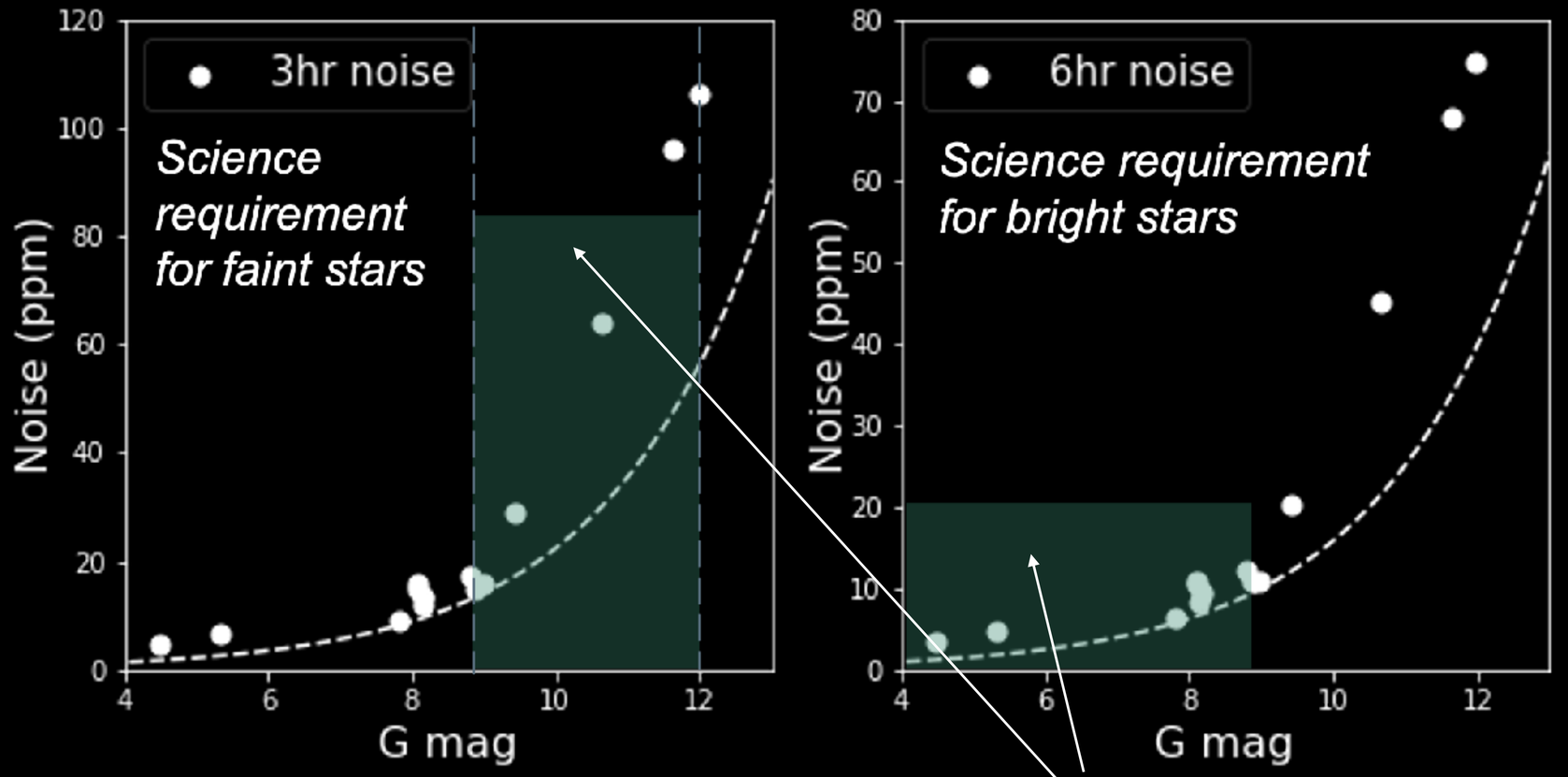
CHEOPS precision requirements/performances

Required performances

Bright stars: CHEOPS shall be able to detect Earth-size planets transiting G5 dwarf stars (stellar radius of 0.9$R_\odot$) with V-band magnitudes in the range 6 ≤ V ≤ 9 mag. achieving a photometric precision of **20 ppm** (goal: 10 ppm) in 6 hours of integration time

Faint stars: CHEOPS shall be able to detect Neptune-size planets transiting K-type dwarf stars (stellar radius of 0.7$R_\odot$) with V-band magnitudes V≤12 mag (goal: V=13 mag) achieving a photometric precision of **85 ppm** in 3 hours of integration time

Measured performances



Photometric performances are well within specs for G<11

requirements

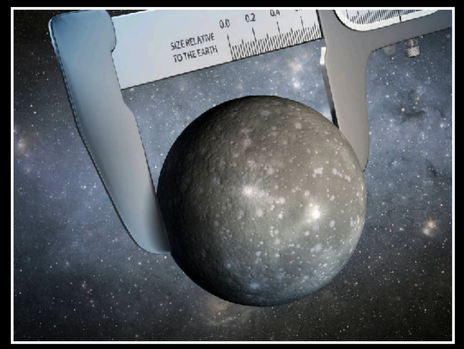
CHEOPS Science

- Garanteed Time Observations (GTO, 80%): defined by the CHEOPS science team
- Guest Observers (GO, 20%): competitive basis, AO issued by ESA and discretionary programme (DP)

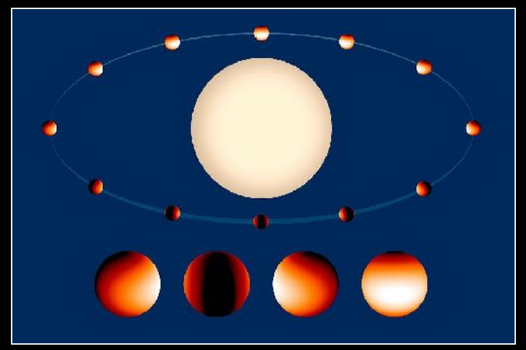
CHEOPS Science

- Garanteed Time Observations (GTO, 80%): defined by the CHEOPS science team
- Guest Observers (GO, 20%): competitive basis, AO issued by ESA and discretionary programme (DP)

accurate sizing: mass-radius relation

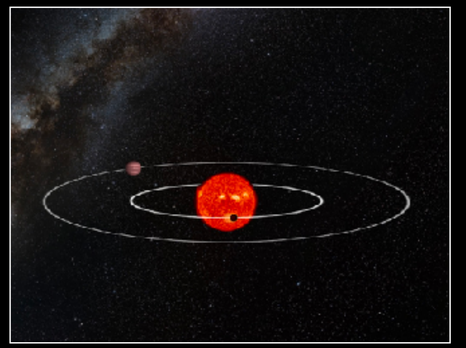


atmospheres: phase curves



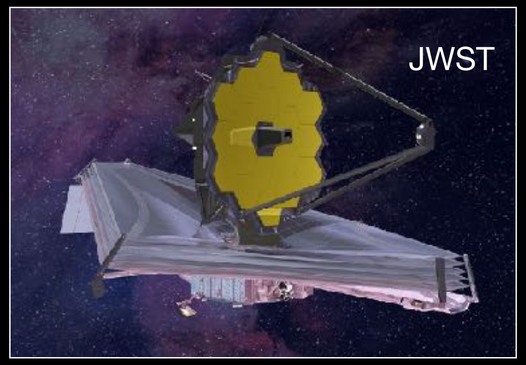
exomoons, rings, etc.

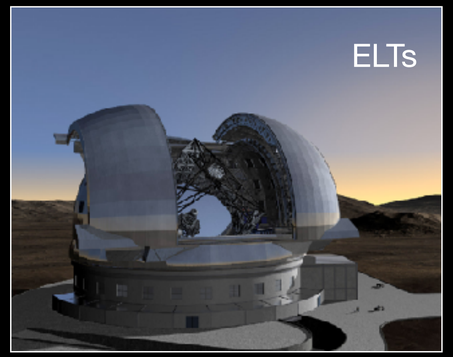
discovery and masses (TTVs)



CHESS
CHEOPS-TESS collaboration

golden targets for future facilities





CHEOPS Organisation

Payload & satellite

Switzerland
Payload system engineering & AIT
telescope structure

ESA
Mission architect
platform procurement
CCD procurement

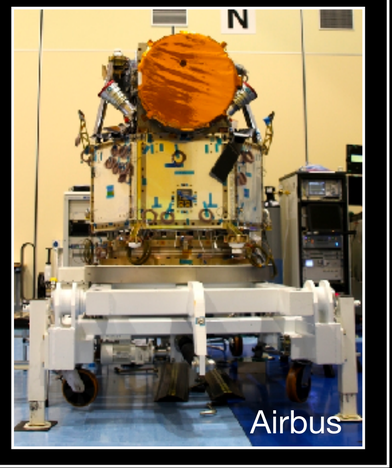
Austria
DPU, PSDU
flight software

Belgium
baffle

Germany
Focal Plane Assembly

Hungary
radiators

Italy
optical system



Airbus

Science operations

Switzerland
Operations
Data products

France
Data Reduction Software

Portugal
Mission Planning, Archive, & Data Reduction Software

Sweden
data simulator

UK
Quick look

Italy
mirror archive


Geneva Obs.

Mission operations

Spain
Mission Operations Center

Switzerland
Mission Manager
Project office

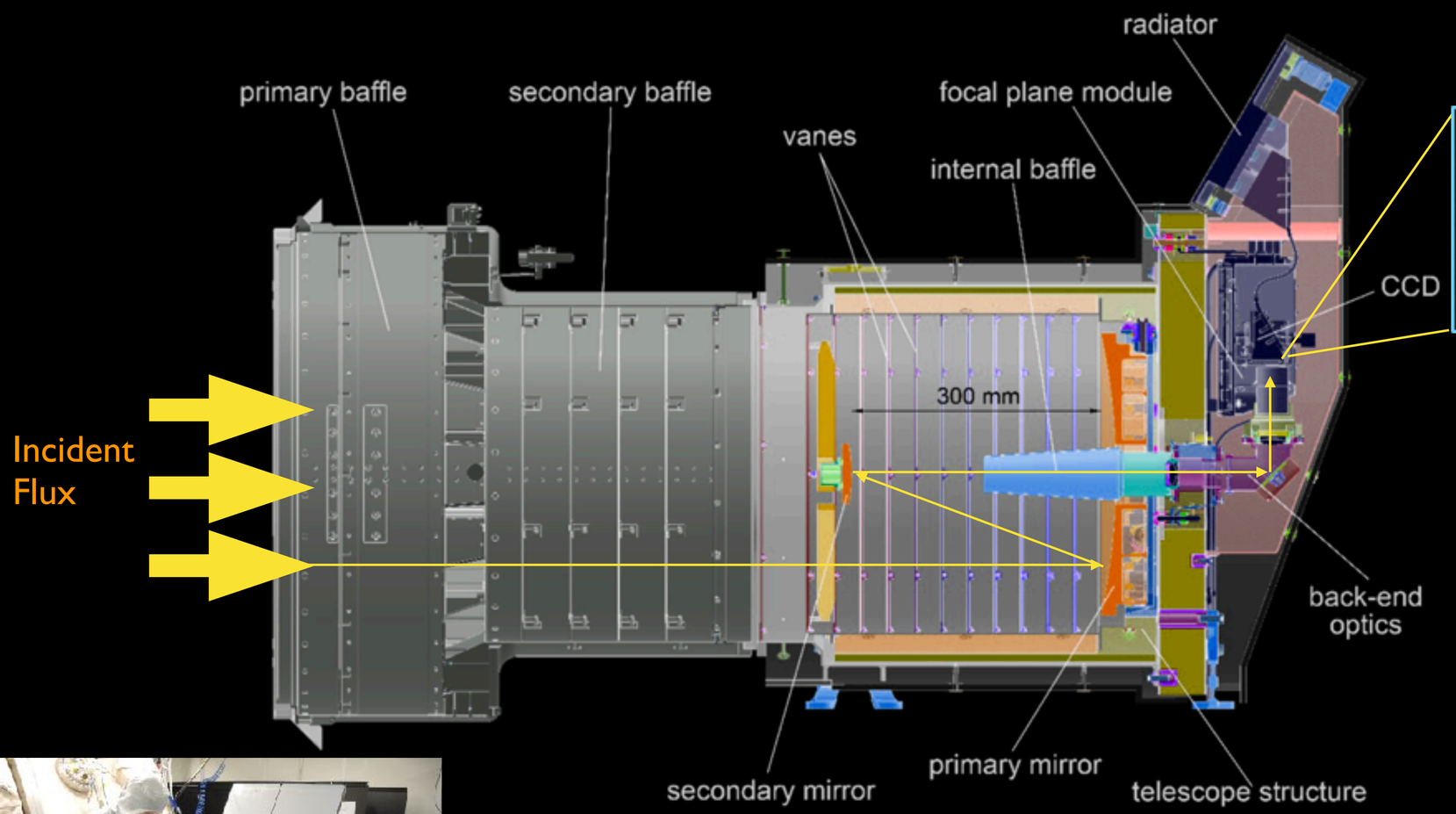
ESA
Launch services
Space debris services
Guest observers programme


INTA, Madrid

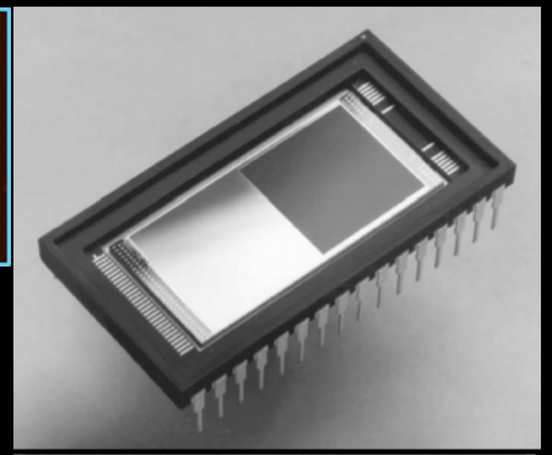
At peak time, a total of more than 150 scientists and engineers in 11 countries and at ESA were involved in CHEOPS

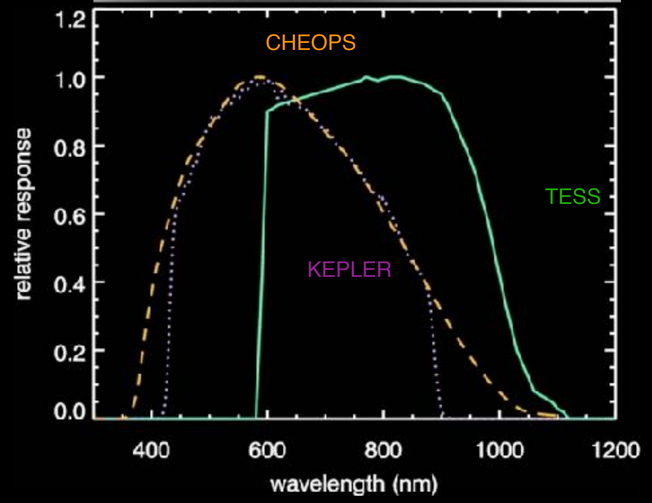
CHEOPS Telescope

Length: 1.5m Total weight: 60 kg

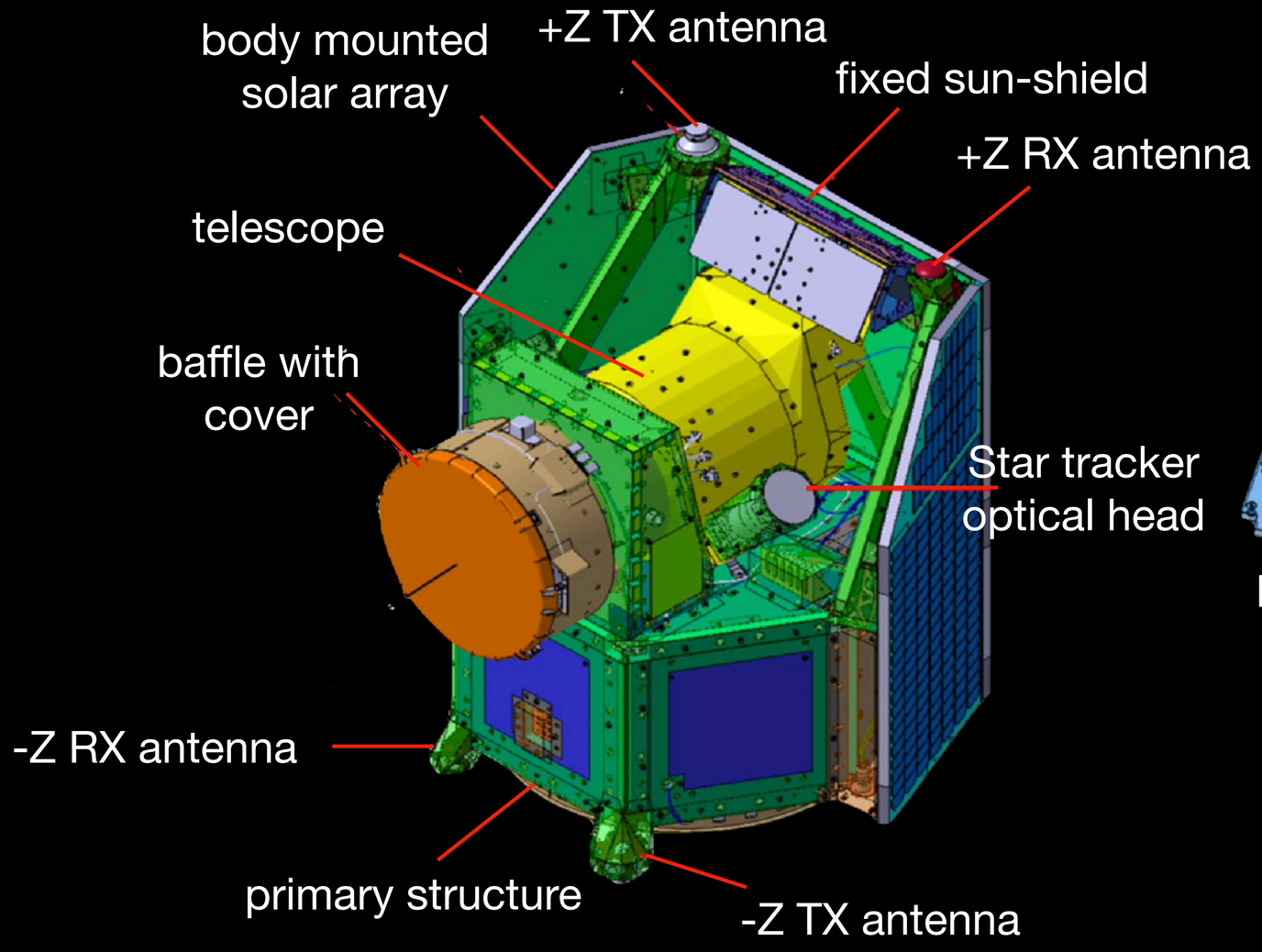


Frame-transfer CCD, e2v CCD47-20, AIMO

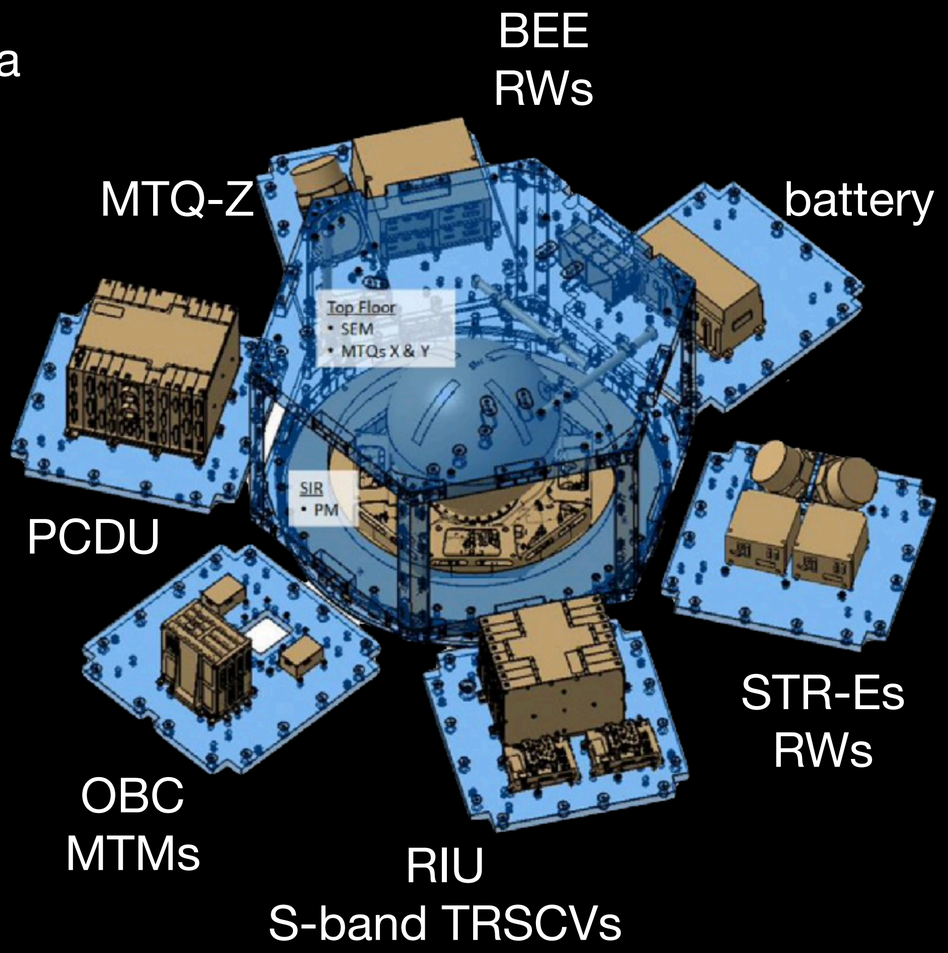




CHEOPS Spacecraft configuration/accomodation

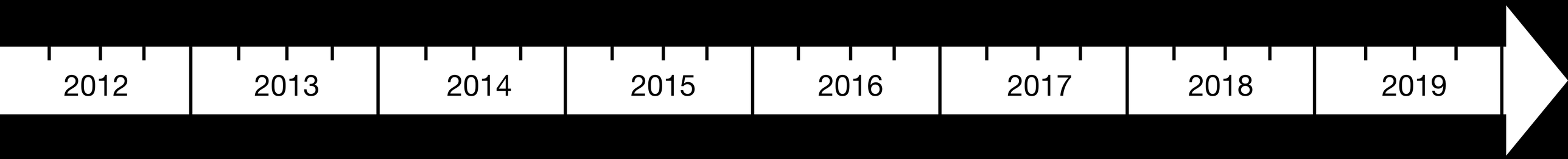


Platform: Airbus Defense & Space, Madrid

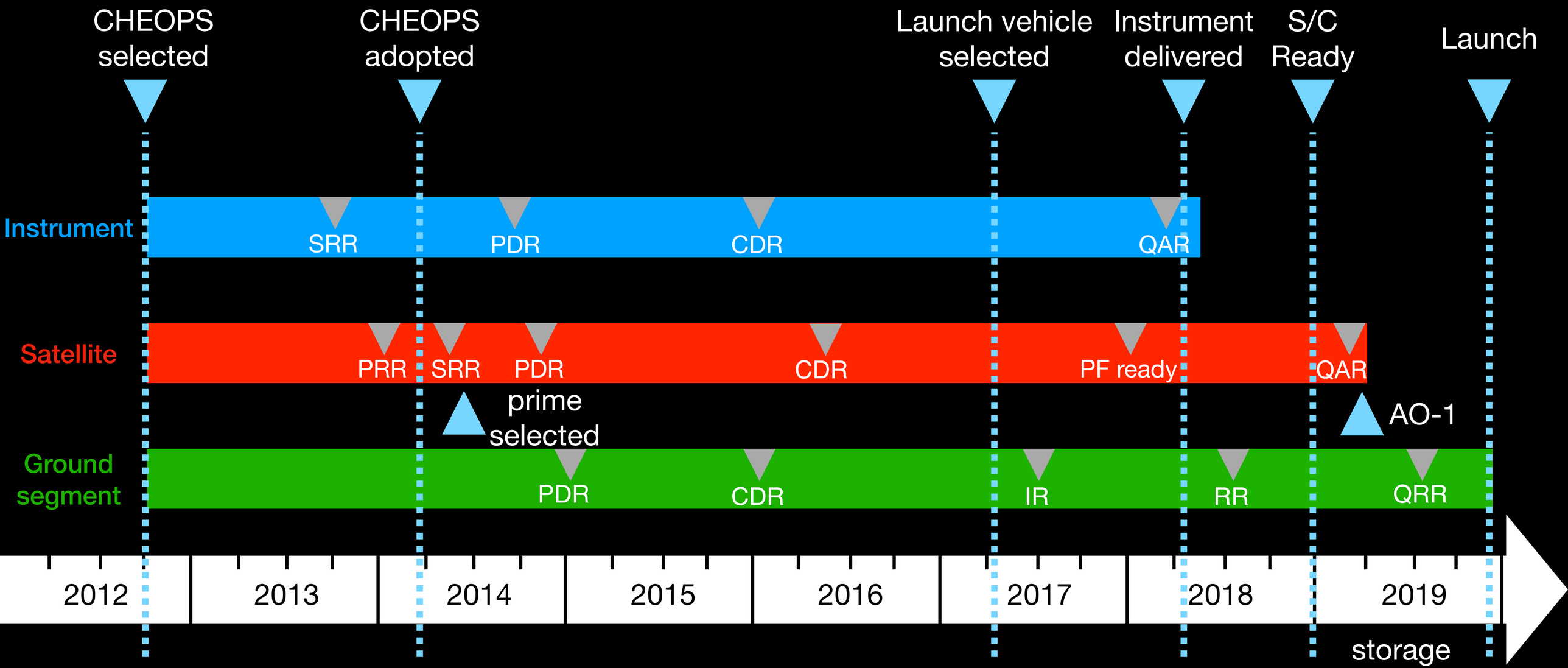


Dimensions: 1.5m x 1.5m x 1.5m Total weight: 280 kg

CHEOPS timeline & milestones



CHEOPS timeline & milestones



CHEOPS was built within schedule and within budget

Soyuz VS-23 fairing at French Guyana Space Center
December 2019

CHEOPS!

Credits: Arianespace

Soyuz VS-23 fairing at French Guyana Space Center
December 2019

CHEOPS!

Credits: Arianespace

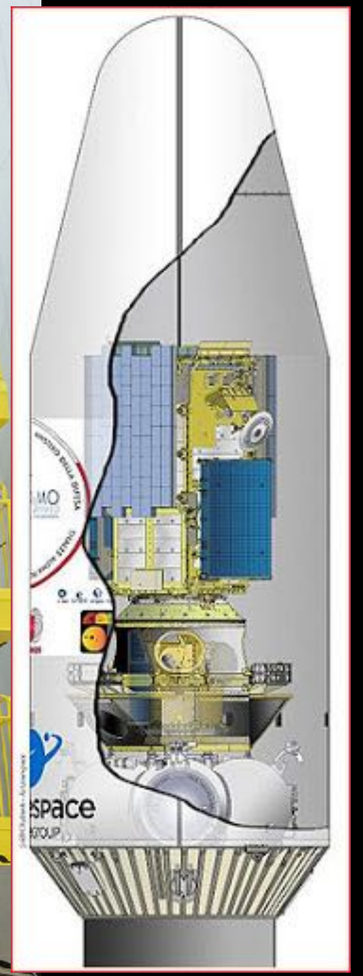
Soyuz VS-23 fairing at French Guyana Space Center
December 2019

CHEOPS!

Credits: Arianespace

Soyuz VS-23 fairing at French Guyana Space Center
December 2019

CHEOPS!



Credits: Arianespace

CHEOPS launch 18.12.2019

Kourou, French Guyana
Soyouz-Fregat rocket
December 18, 2019
5h54 local time

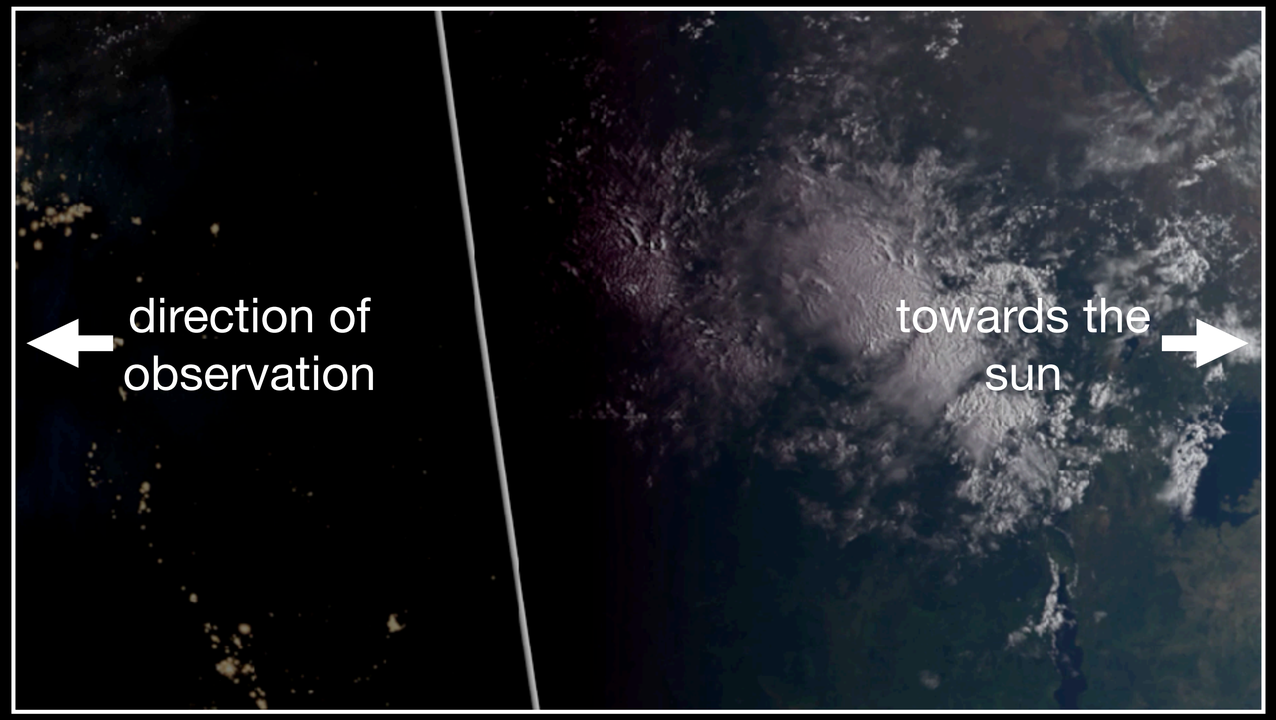
Commissioning activities: 7.1.2020 - 25.3.2020 (IOCR✓)

➡ Nominal science operations: 15 April 2020


arianespace
ariane group
Soyuz launch VS-23 from French Guyana Space Center
18 December 2019
00 : 11
Credits: Arianespace

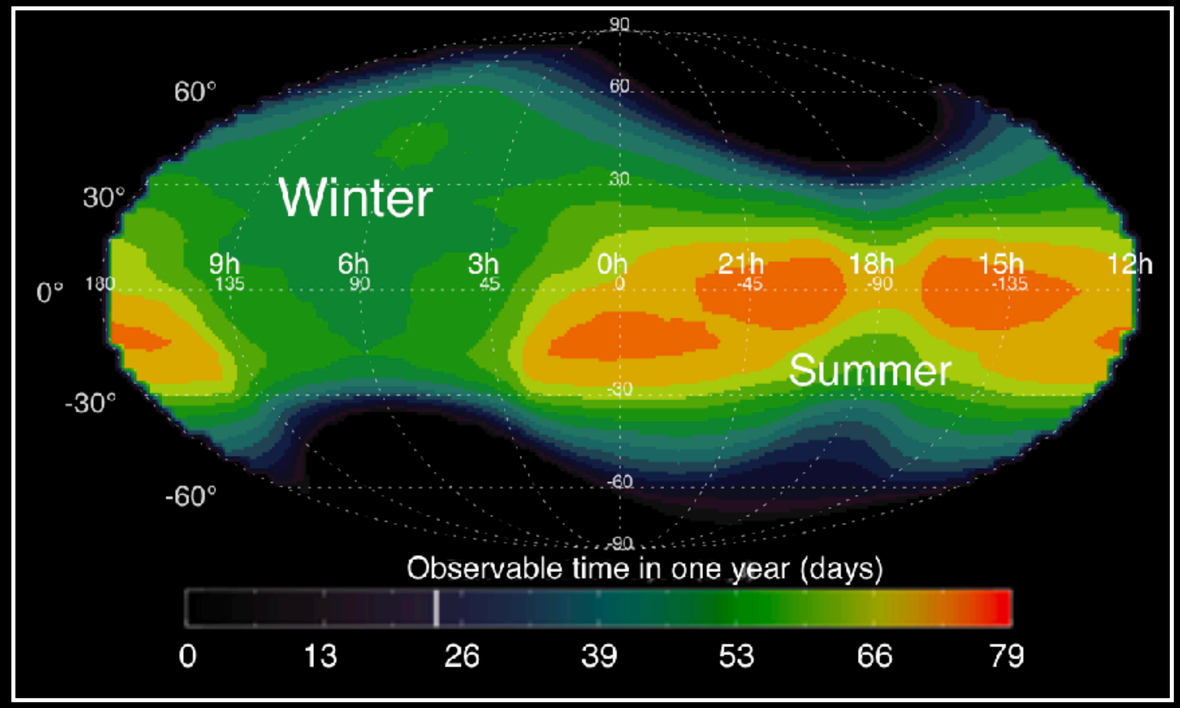
CHEOPS orbit

700 km altitude, sun-synchronous polar orbit



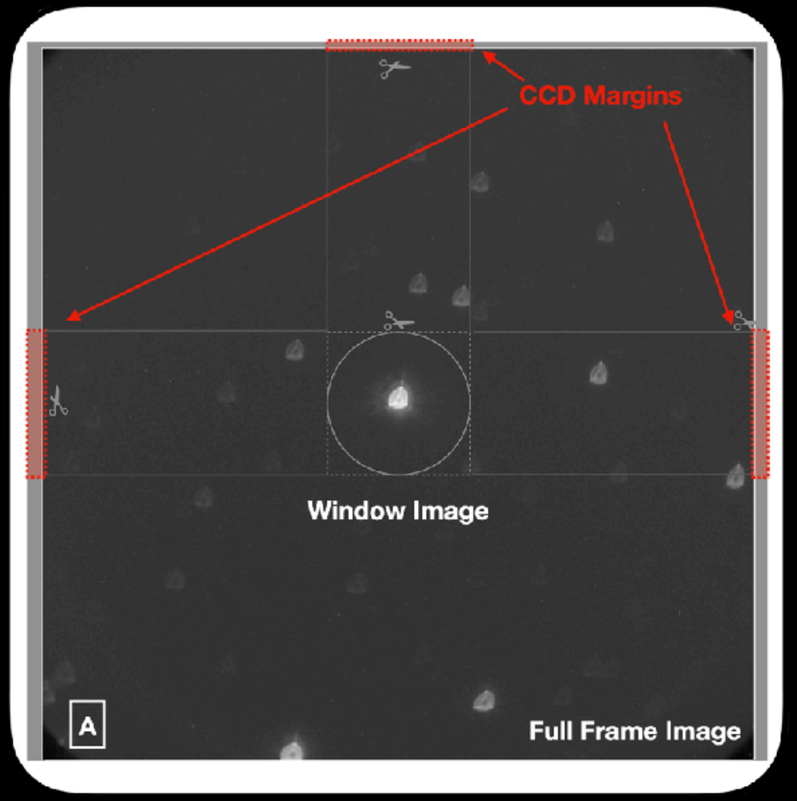
2 periods a day within reach of Madrid antenna

sky visibility



> 50% of the sky is visible

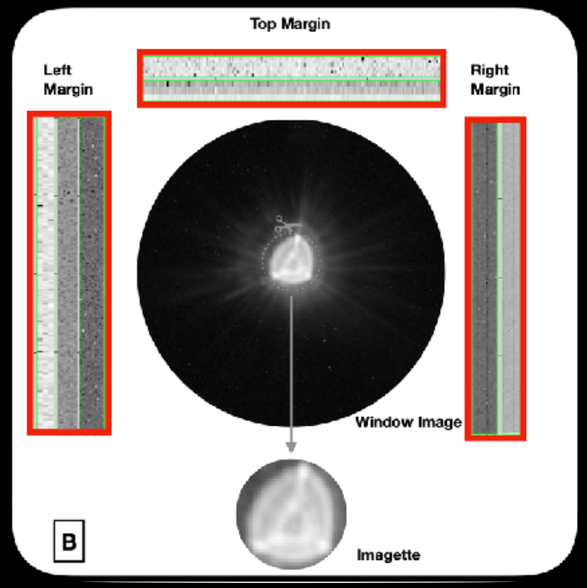
Data acquisition & onboard processing



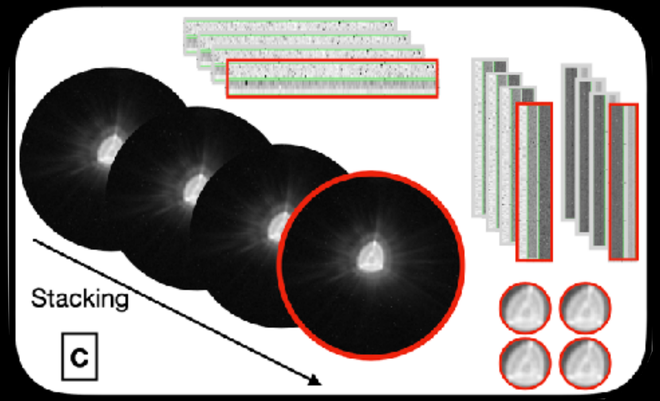
1 pixel =1“ on the sky

1024 x 1024

cropped 200 px diameter image



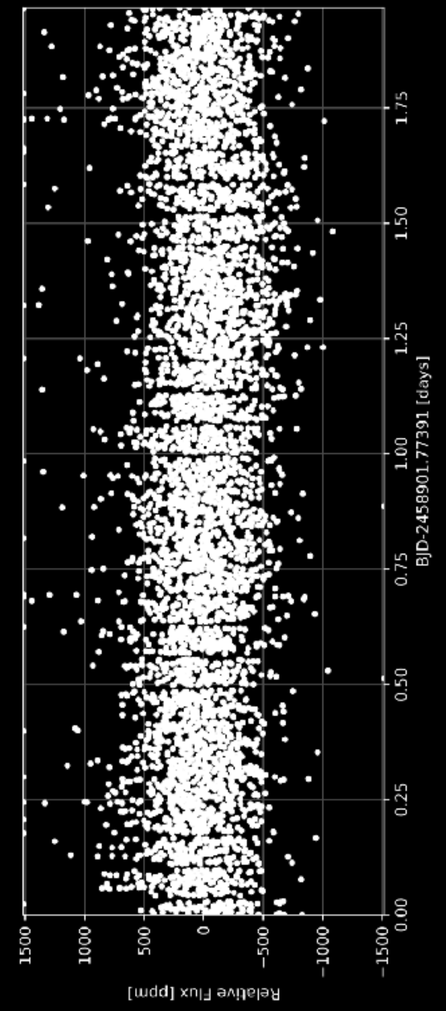
60 px diameter imagettes are cropped



If T_{exp} > 22.6 seconds all images are sent to ground

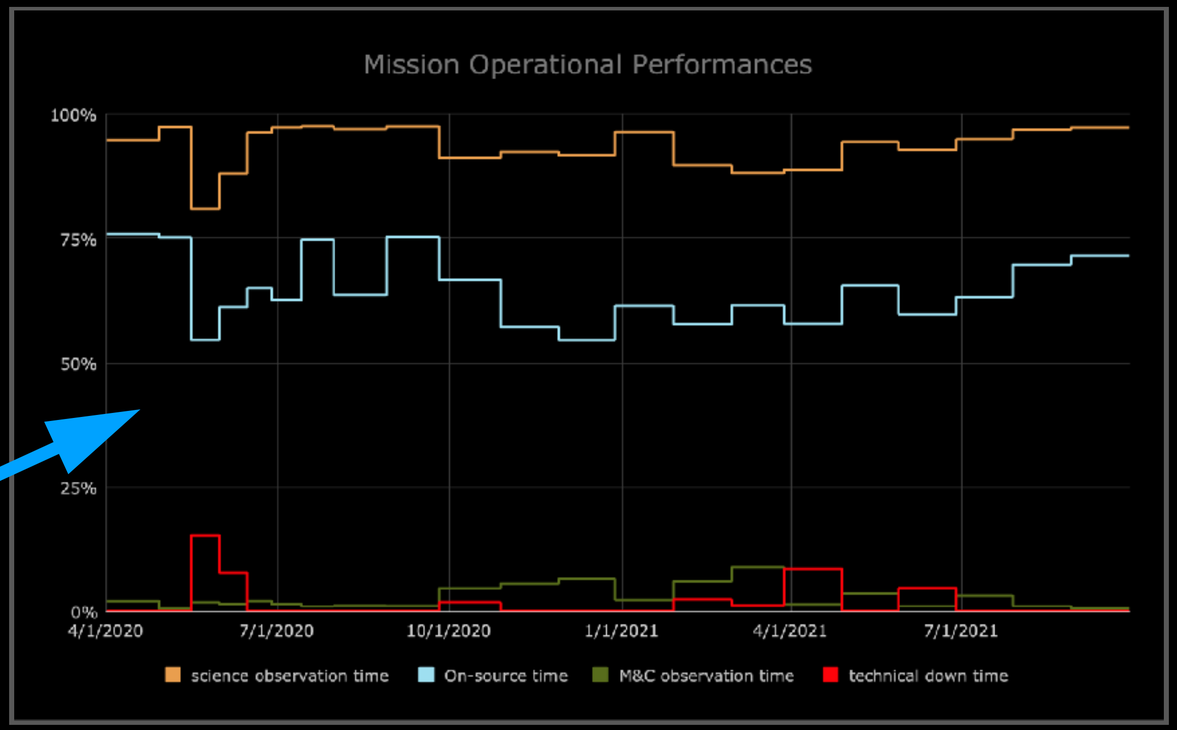
If T_{exp} ≤ 22.6 seconds stacked images and individual imagettes are sent to the ground

lightcurve extraction (on ground)



CHEOPS Status Today

- 2 years in orbit, 21 month routine operations
- Mission & Science Operations are nominal
- Space and Ground segments are in excellent shape and at full redundancy
- Operational performances are excellent
- Science performances are excellent although hot pixels continue to increase
  (see talk by A. Fortier)



CHEOPS Spacecraft health

- There is no anomaly in any subsystem based on OOL review, monitoring tasks and TM review.
- Performance:
  - Pointing performance absolute and PITL remains excellent
- Main concerns:
  - None
- Special mentions:
  - MEOR study showed no issues for operations until 2028

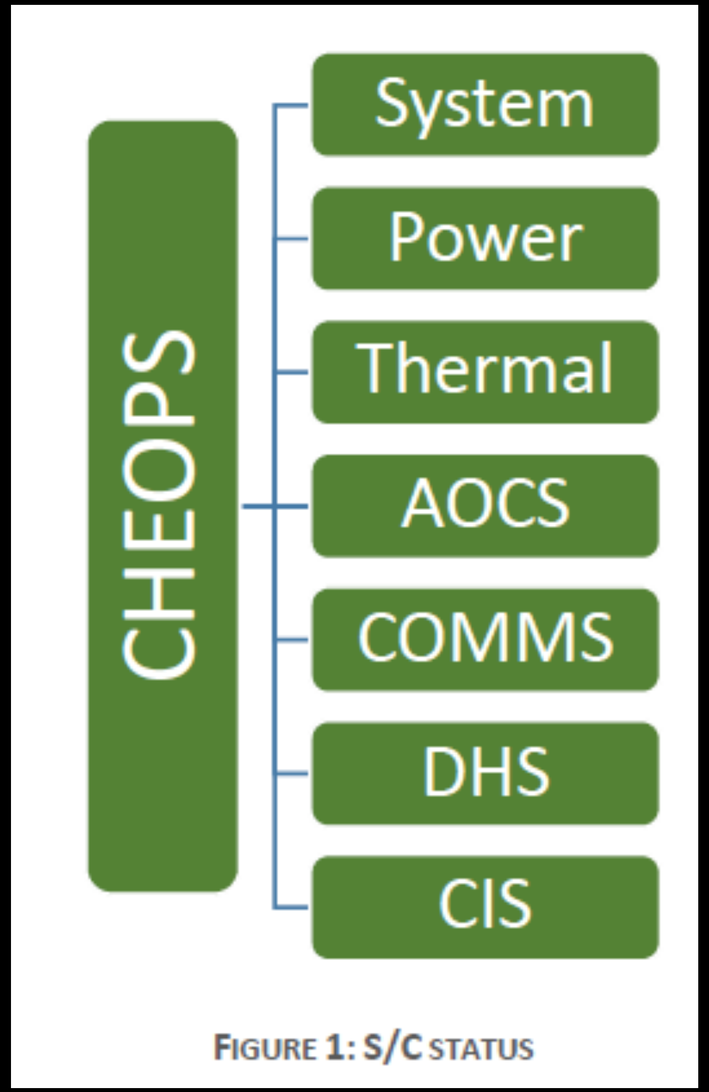


FIGURE 1: S/C STATUS

CHEOPS Instrument Status

- Pointing & Tracking:
  - ★ Excellent absolute pointing performance: targets are always successfully acquired
  - ★ Target tracking: attitude better than 2” (requirement: 4”)
- General Instrument Performance
  - ★ Bias, read-out noise, dark current, gain: compatible with on-ground calibration
  - ★ Quantum Efficiency: 4.2% lower than “expected” due to errors in the laboratory measurements.
- Electronics stability
  - ★ Bias Voltages: extremely stable (< ppm effect)
  - ★ Focal Plane Temperatures: extremely stable
    T_{bias} standard deviation ~ 1 mK (req. 50 mK),
    T_{CCD} standard deviation ~ 1 mK (req. 10 mK)

CHEOPS Operational Changes

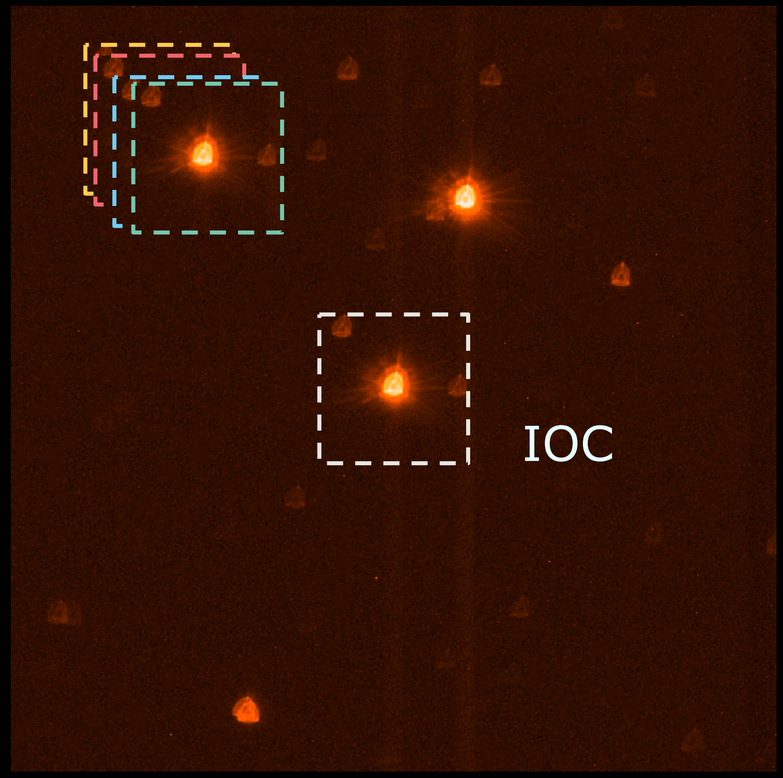
After launch during commissioning some changes to the operational parameters where implemented. Key Operational Changes:

- CCD Nominal Temperature changed from -40ºC to -45ºC to reduce the noise due to hot pixels
- Target tracking disabled during SAA and Earth occultations to prevent changes in the position of the star in the CCD during these events
- De-activate the Payload In The Loop functionality for faint stars (G mag > 11) to prevent spurious changes in the pointing (the S/C guidance is accurate enough to maintain the pointing stability)
- Increase of the Moon Exclusion Angle from 5º to 15º due to internal reflections observed in some images when the Moon was too close to the target.
- Increase in the imagette size: from 50 px to 60 px in diameter

CHEOPS Operational Changes

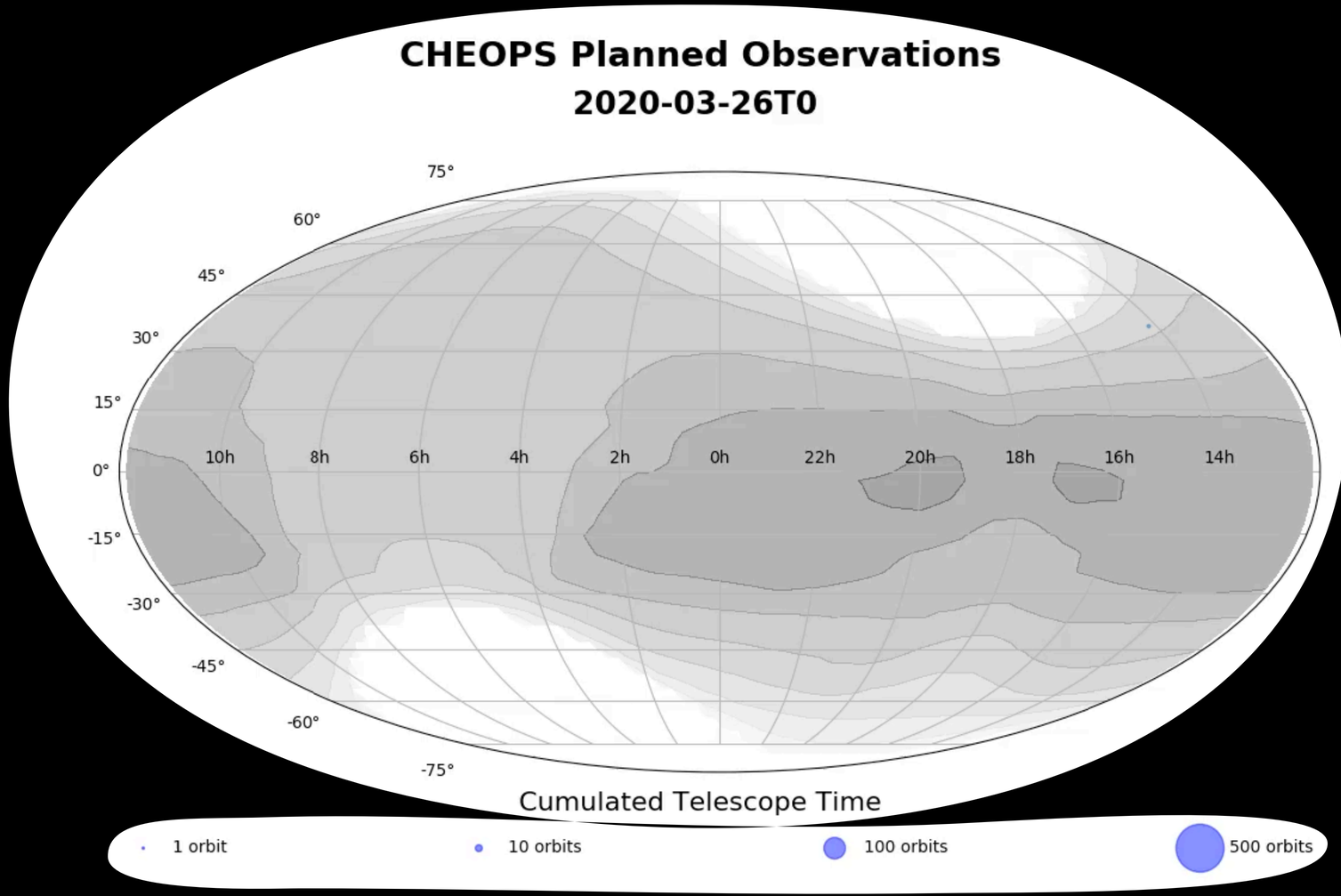
- Changes in the default science window location since the start of Routine Operations: the idea is to locate the Point Spread Function (PSF) of the target star in a region of the CCD where the noise due to hot pixels is minimised.

Date	Window location (bottom left corner)
IOC	(412, 412)
Apr. 2020	(157, 759)
June 2020	(163, 742)
Sept. 2020	(180, 728)
July 2021	(191, 730)



CHEOPS The past 2 years

- 2104 visits
  - 1875 science visits
  - homogeneous distribution over viewing zone
  - 229 M&C visits
- 9000 orbits
  - 93% science
  - 3.5% M&C
  - 1.5% down time
  - 1% idle time
  - 0.7% slew
- 45 GB of data



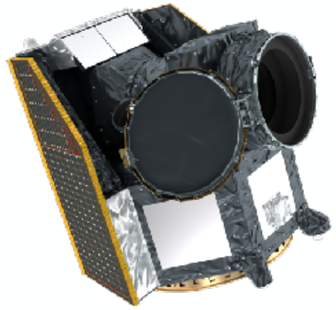
CHEOPS … the next 2 years …

- Continuing GTO/DP/GO… AO-3 coming soon
- CHEOPS nominal mission ends 09/2023
- We are in the process of negotiating a mission extension (2y3m + 3 years)
- ESA mission operation extension review revealed no technical obstacles for an extension
- CHEOPS requires very little consumables
- Photometric performance prediction to 2028 in line with requirements for mission extension science case

CHEOPS Using CHEOPS

- Day to day operations
- Ground segment & activity plans
- data, tools & information

Ground Segment Overview

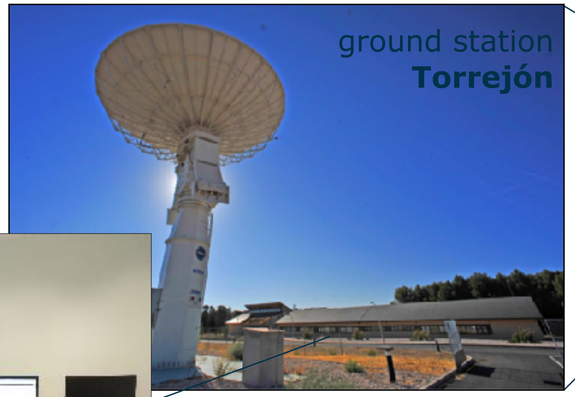


Spacecraft platform
ADS/CASA (via ESA)

SSO 700 km LTAN 6 am
downlink at ~1.2 Gbit/day typ. 6 am & 6 pm
3 day autonomy
Down-/uplink fully automated

On request for critical operations

Science Operation Center (SOC)



Mission Operation Centre (MOC)

Uplink 1 activity plan / week
Fully automated

Thanks to efforts at MOC for additional automation (uplink) fully Home-Office compatible

The ground segment is operated by the consortium

CHEOPS Programming the space telescope

How do we command CHEOPS?

- Each observation, a so-called visit, has to be requested in the PHT2 (proposal handling tool): target / coordinates / exposure time / number of images / transit time / period / priority / etc…
- Every Monday the SOC retrieves the latest changes from PHT2 and loads them in the MPS (mission planning system)
- All possible visits for the next 4 months are fed into the schedule solver which optimizes the next 4 months of observations
- After some manual checks by the operation scientist and the PSO the MPS creates the activity plan (AP) for next week running typically Saturday to Saturday
- The AP is sent to MOC
- The MOC converts the AP to a command sequence the MTL, checks for safety, and uplinks the AP to the SC
- The SC executes the commands in the MTL autonomously
- 1-2x per day the generated science data is downlinked to ground and transferred to SOC
- The SOC runs the DRP and pushes the data products to the archive - typically a few hours after data reception on ground

CHEOPS Data

- Data becomes public 1 year after the last observation or 1.5 years after the first
- Public data can be downloaded from the mission archive
  http://cheops.unige.ch/archive_browser
  or the mirror:
  https://cheops-archive.ssdc.asi.it/archive_browser/
  or DACE (at present incomplete)
  https://dace.unige.ch
- Please check out the observers manual online for more details:
  https://www.cosmos.esa.int/web/cheops-guest-observers-programme/cheops-observers-manual

CHEOPS Data analysis

- The data in the archive contains
  - images raw and calibrated (fits)
  - final lightcurve (fits)
  - DRP report (pdf)
- A dedicated python package has been developed by the consortium to further detrend and improve the data:
  - **pycheops** 1.0.0 — https://github.com/pmaxted/pycheops
    by P. Maxted (Maxted et al. 2021) — DOI:10.1093/mnras/stab3371
    ”Analysis of Early Science observations with the CHaracterising ExOPlanets Satellite (CHEOPS) using pycheops”
- As alternative to the DRP see
  PIPE https://github.com/alphapsa/PIPE
  by A. Brandeker

CHEOPS Summary

- **CHEOPS** is in excellent shape
- All systems nominal, fully redundant
- **Nominal mission** continues until 09/2023.
  Next AO-3 coming out soon! DP running!
- A Mission Extension is currently negotiated
- Consumables not limiting CHEOPS' lifetime
- The ability to (re-)observe any target makes **CHEOPS** unique

Benz et al. (2021) "The CHEOPS mission"
http://cheops.unibe.ch/
https://www.cosmos.esa.int/web/cheops-guest-observers-programme/