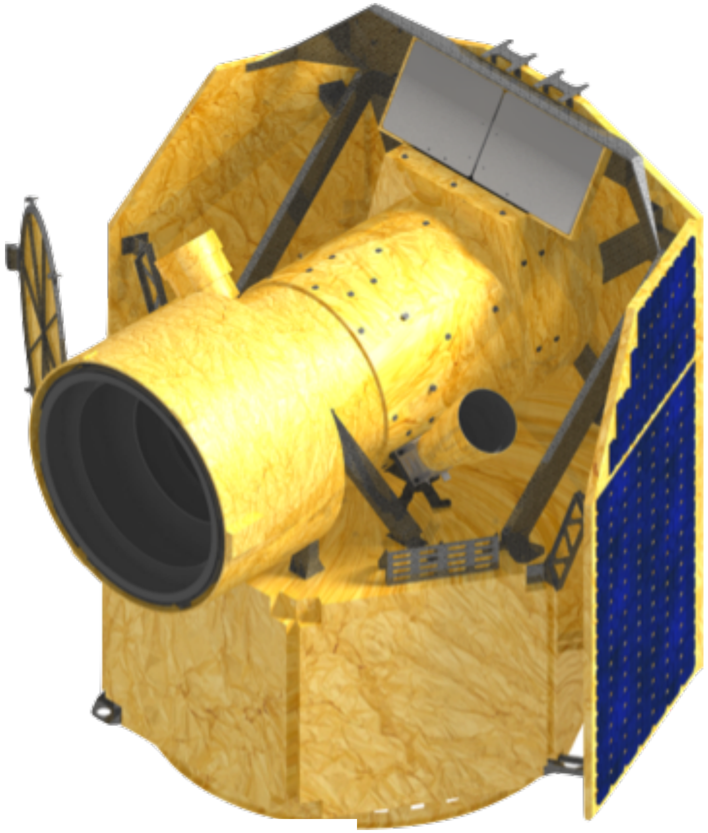
CHEOPS Instrument & Performance

III CHEOPS Science Workshop
Madrid, 17th July, 2015



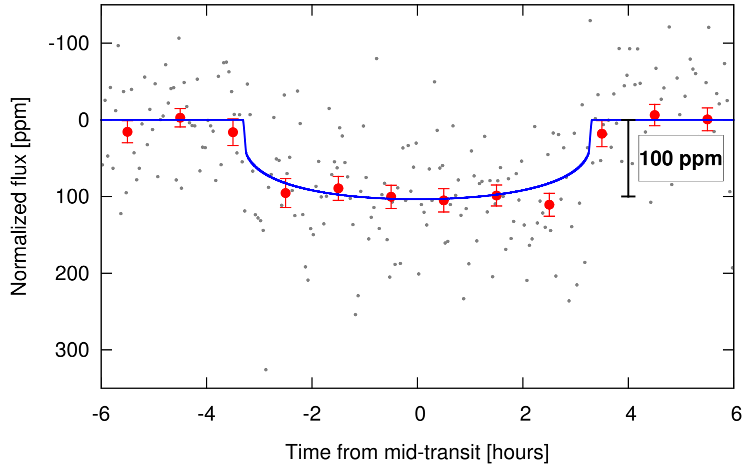
Prepared by
Andrea Fortier

Photometric accuracy

- **CHEOPS Science Requirements**

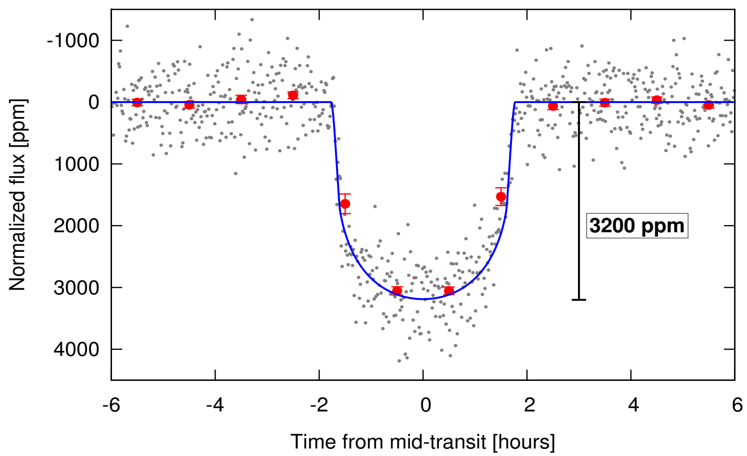
Photometric accuracy for Earth and Super-Earth detection: 20 ppm over 6 hour transit

6<V<9, G5 dwarf stars, P_{planet} ~ 50 days ➔ primary targets coming from RV surveys



Photometric accuracy for Neptune characterisation: 85 ppm over 3 hour transit

9<V<12, K dwarf stars, P_{planet} ~ 13 days ➔ primary targets coming from NGTS survey



CHEOPS Noise Budget

Nominal case

Table 3. Adopted values for the calculation of the nominal Noise Budget.

Parameter	Value
Radius PSF	15.6 px
Photometric aperture (radius)	30 px
Read Out Noise	10 e-/px
Quantisation	16 bits
Pixel Size	13 µm
Angular scale	1 arcsec/px
Pixel Full Well Cap.	60 000 e-
Image Size	200×200 px
Operating Temperature	233 K
Detector Temperature Stability	0.01 K
Dark Current	0.08 e-/px/s
Flat Field Knowledge	0.1%
Earth Stray Light	1.3 e-/px/s [3]
Zodiacal Light	5.43 e-/px/s
Detector Gain Variability	10 ppm
Detector QE variation with temp.	10 ppm
Timing error	2 ppm
Analog chain random noise	19 e-/px/readout
Analog electronics stability	10 ppm

Table 4. Noise Budget (nominal). Dominant Noise terms are emphasised in bold letters.

Case Number	**A**	**B**	**C**
Mv star	6 (ST = G)	9 (ST = G)	12 (ST = K)
Exposure time [s]	1	10	60
Integration time [h]	6	6	3
Global throughput (CCD+Optics)	65%	65%	62%
Shot noise [ppm]	2.0 [292]	**7.9** [368]	**41.1** [551]
Background (inc. dark) [ppm]	0.1 [13]	0.5 [24.7]	6.9 [92]
Cosmic rays [ppm]	2.6	2.6	3.7
Earth stray light [ppm]	0.4	5.0	**70**
Jitter + Flat Field [ppm]	5	5	5
Read out noise (CCD) [ppm]	0.3 [45.5]	1.6 [72]	12 [162]
Dark current variation noise [ppm]	0	0	0.1
CCD Gain variability [ppm]	**10**	**10**	10
Analog electronics stability [ppm]	**10**	**10**	10
QE change [ppm]	**10**	**10**	10
Timing error [ppm]	2	2	2
Quantization noise [ppm]	0 [0.6]	0 [1.0]	0.2 [2.2]
Analog chain random noise [ppm]	0.6 [86]	1.5 [71]	22.9 [307]
Error time average [ppm]	**18.5**	**20.9**	**84.5**

Grey = astronomical noise *[X] = error per exposure*
Purple = instrument noise *ST = Spectral Type of the star*

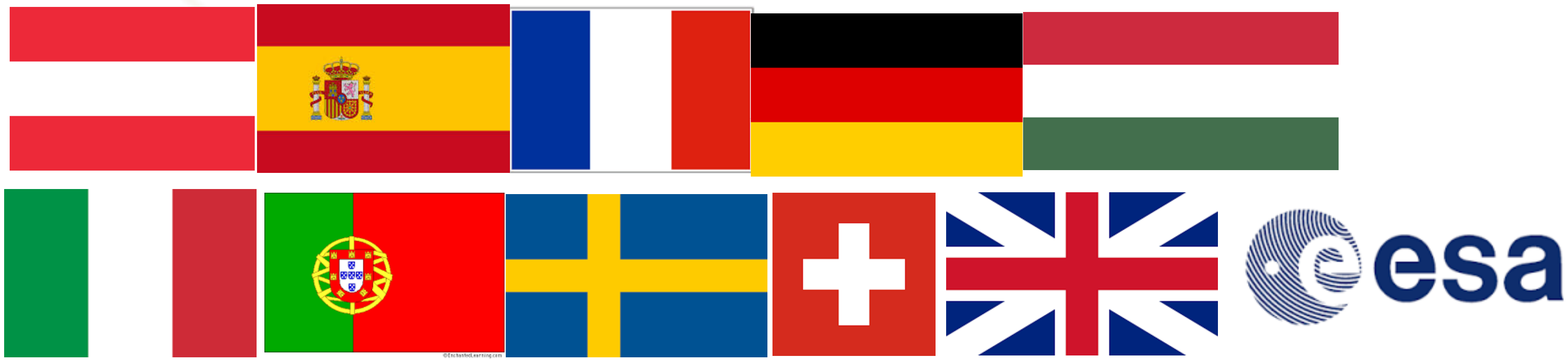
Noise Budget

- More updates are foreseen. These, however, rely on more complex models for which CHEOPSim and/or Data Reduction Pipeline and/or Instrumental Models are needed:
  - real flat fields (to be done asap)
  - better characterization of the noise due to Earth Stray Light
  - better estimation of the background contamination noise
  - Dark current, CCD Gain changes, electronic stability, CCD QE are determined by T, so probably correlated. A model is needed for a better determination of the noise
  - bad pixels

Science Team Working Group B3: Mission Performance

Science Team Working Group B3:

- Its aim is to advise the Science Team and, through it, the PI and ESA, on topics related to the **noise budget, calibration, mission planning, sky coverage, data reduction, etc.**
- the number of members continues to increase, now **~25** active members, **7** of which are Science Team members
- on average, two telecons per month with splinters when needed
- minutes available in the Science Team web page
- participants of almost every country of the consortium



Science Team Working Group B3: Mission Performance

Summary of recent activities:

- Impact of telescope breathing in the science performance
- Lessons learnt from similar missions: MOST and CoRoT share several similarities with CHEOPS (CCD, orbit altitude, etc.). Contact with team members of both missions has been established to learn from their experience.
- Monitoring and Characterisation activities: propose, define and study observation strategies that help to monitor and characterise the state of the instrument with time.

Future activities:

- CCD ageing: how can it affect the precision of the measurements?
- Images obtained during passages over the SAA: can they be used?
- Consolidation of the instrumental noise

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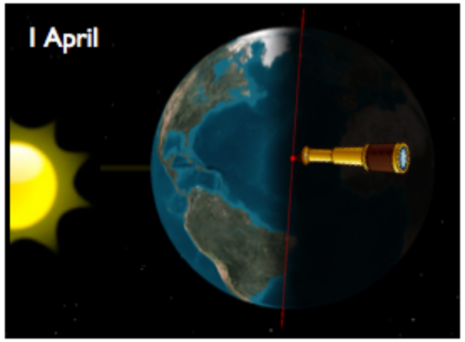
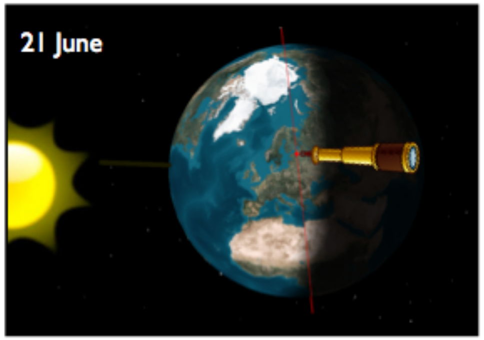
The sky of CHEOPS

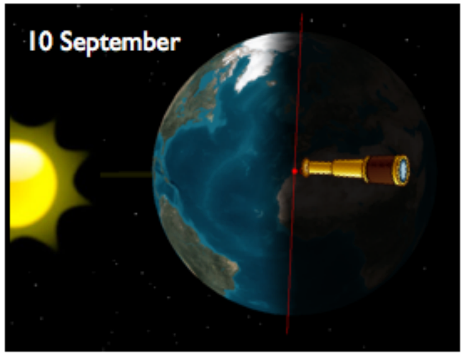
CHEOPS orbit

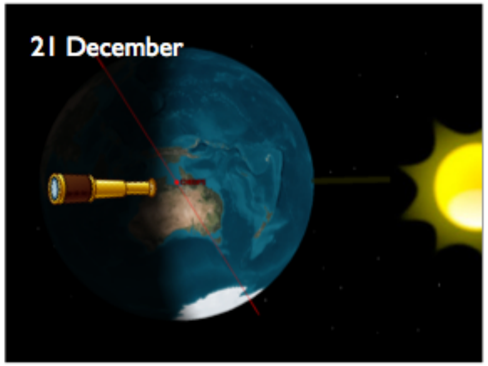
Sun Synchronous, Low Earth Orbit, LTAN 6am/6pm (dawn-dusk: the satellite rides the day-night terminator)

Possible altitudes: 650, 700, 800 km

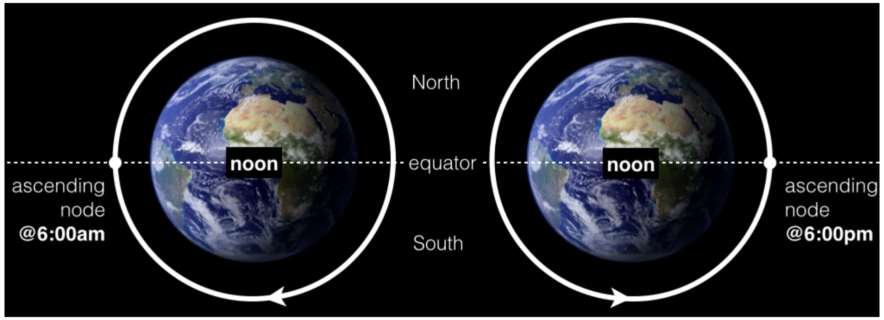








- A Sun-synchronous orbit is a geocentric orbit which combines altitude and inclination in such a way that an object on that orbit will appear to orbit in the same position, from the perspective of the Sun, during its orbit around the Earth. More technically, it is an orbit arranged in such a way that it precesses once a year. The nodes of an orbit are the two intersection points of the orbital trajectory with the equatorial plane of the Earth. The point where the satellite passes from the southern hemisphere to the northern hemisphere is the ascending node.



CHEOPS Launcher

- ❑ CHEOPS will be the second passenger, therefore we have to look for launch opportunities
- ❑ ESA will release an ITT in July to search for launcher candidates
- ❑ The selection will be by the end of 2015 (before the System Critical Design Review)
- ❑ So far, we are aware of two potential candidates:

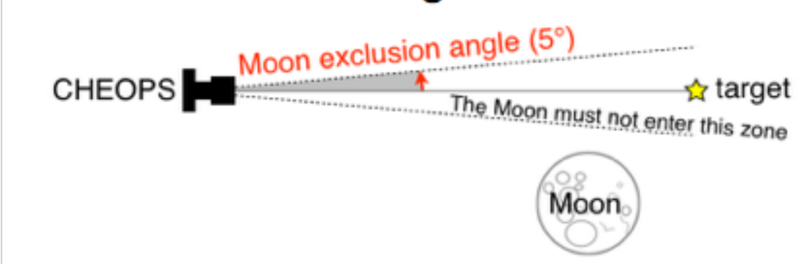
- End 2017: Rocket: Soyuz; From: Kourou, French Guiana → Orbit 6 am
- End 2018: Rocket: Falcon 9; From: USA (?) → Orbit 6 pm

The sky of CHEOPS

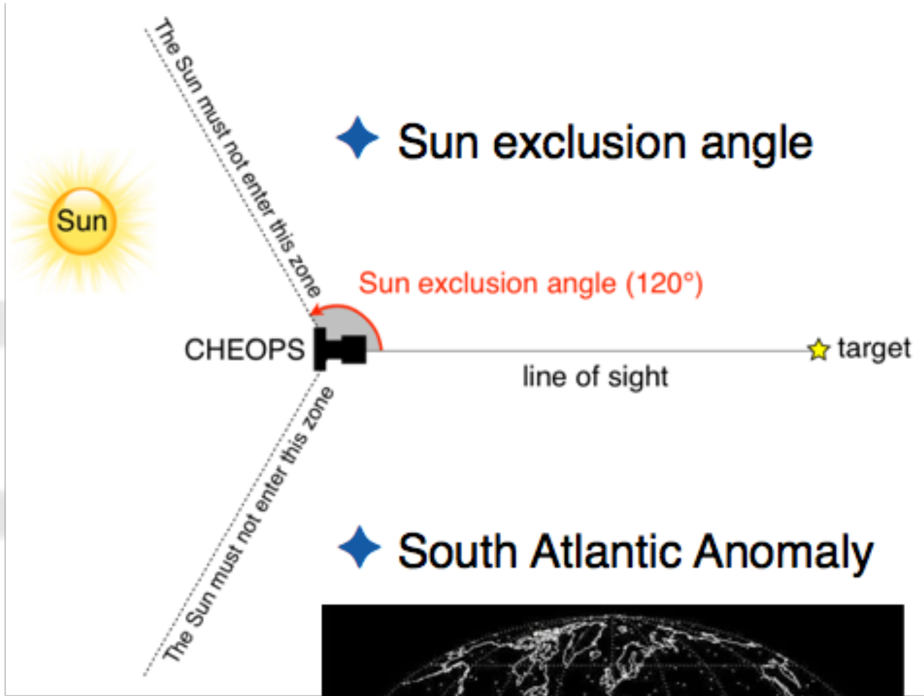
Observability constraints

- Earth occultation & stray light exclusion angle

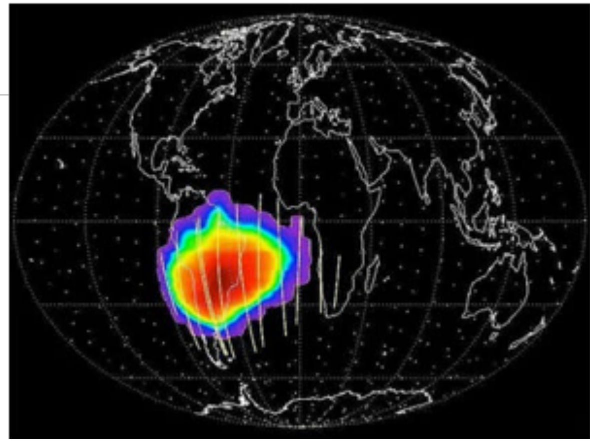
- Moon exclusion angle



- Sun exclusion angle



- South Atlantic Anomaly



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The sky of CHEOPS

Observability requirements

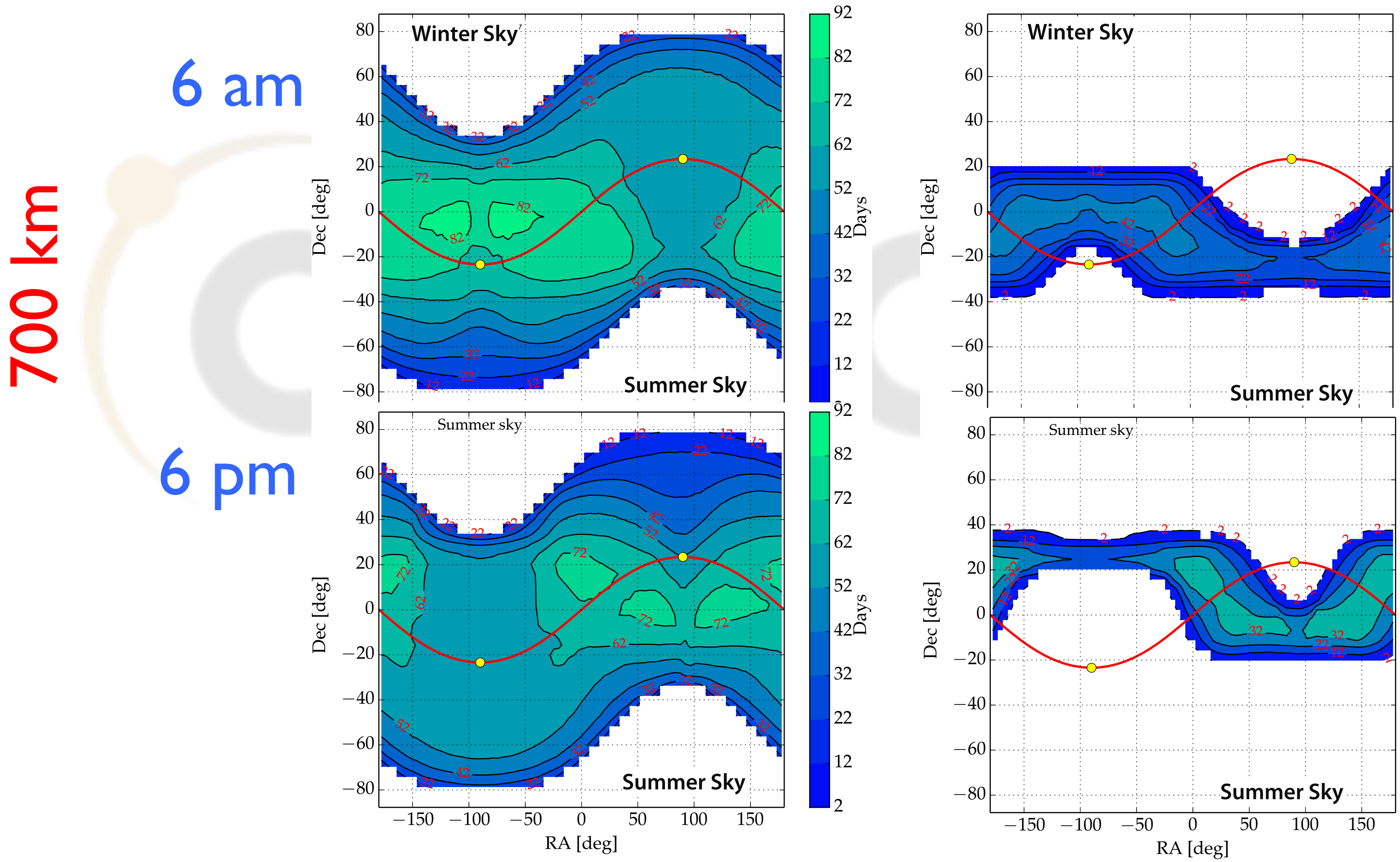
Science Requirements on sky coverage are different for different target groups:

Targets from Doppler surveys: detection of transits of super-Earths ➡ 50% of sky accessible for 50 days per year and per target with <50% interruption per orbit

Targets from ground-based transit surveys: Characterising transits of Neptune-size planets ➡ 25% of sky accessible for 13 days per year per target with <20% interruptions

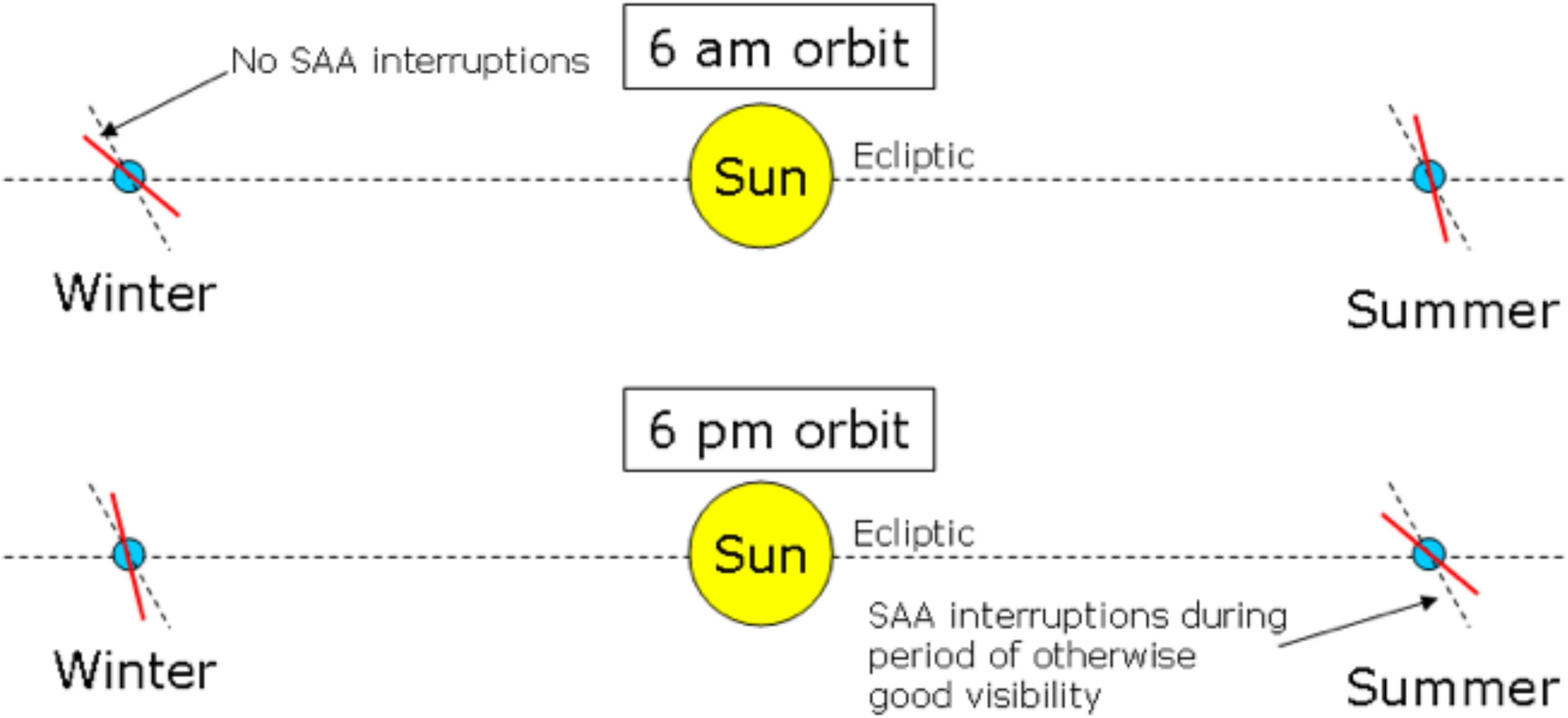
The sky of CHEOPS

- **6am/6pm orbits**



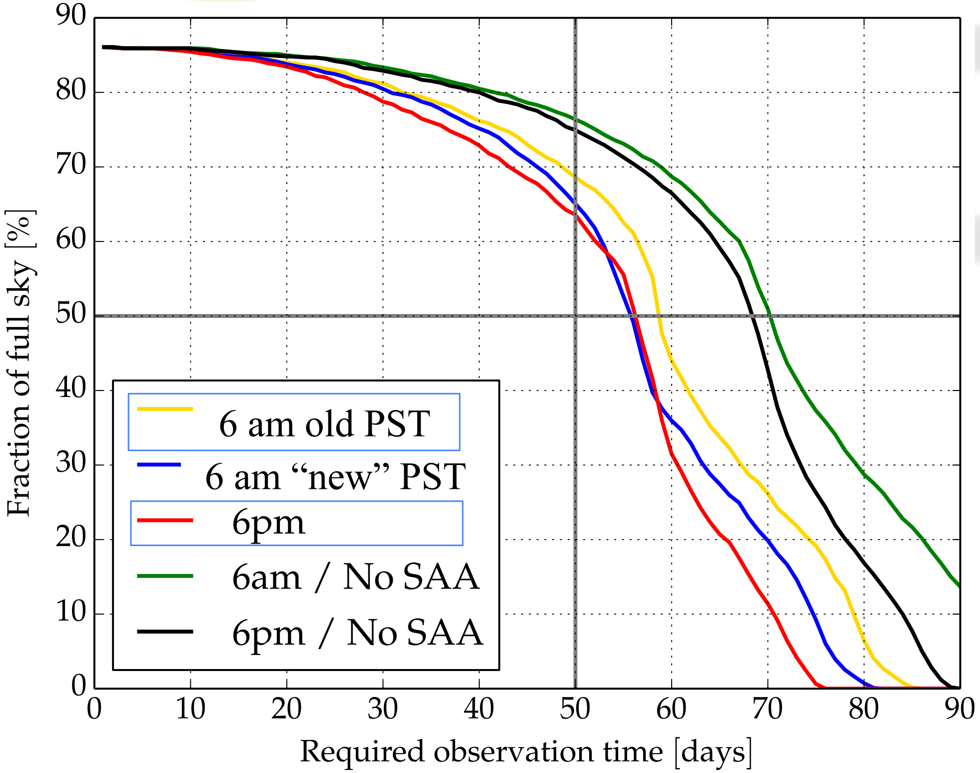
The sky of CHEOPS

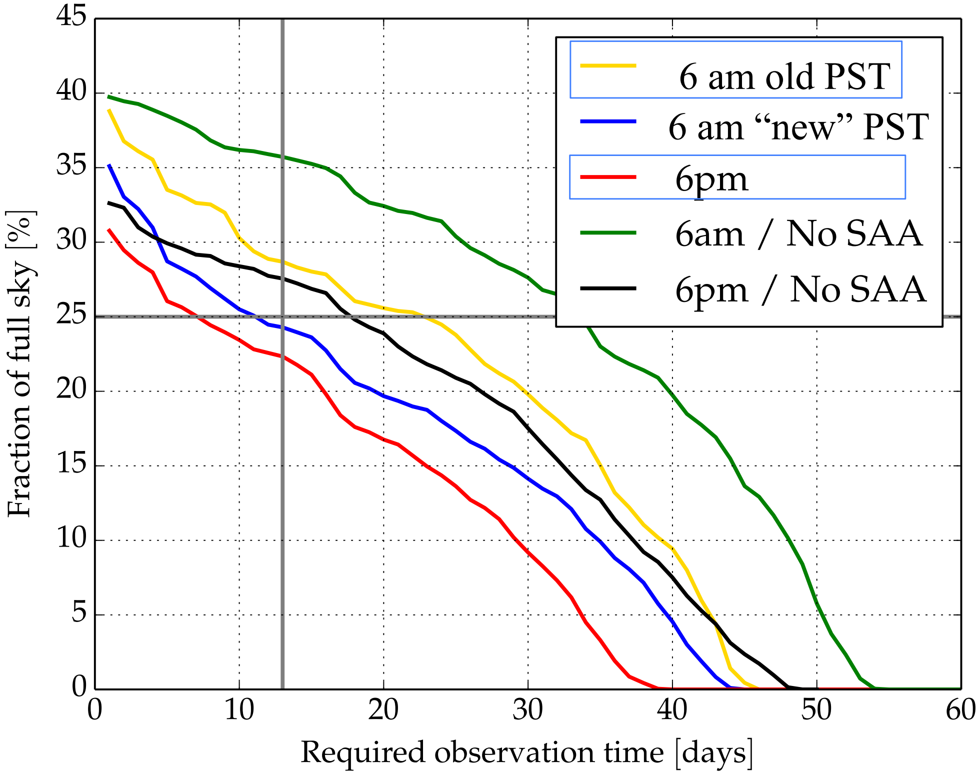
❖ **6am/6pm orbits**



The sky of CHEOPS

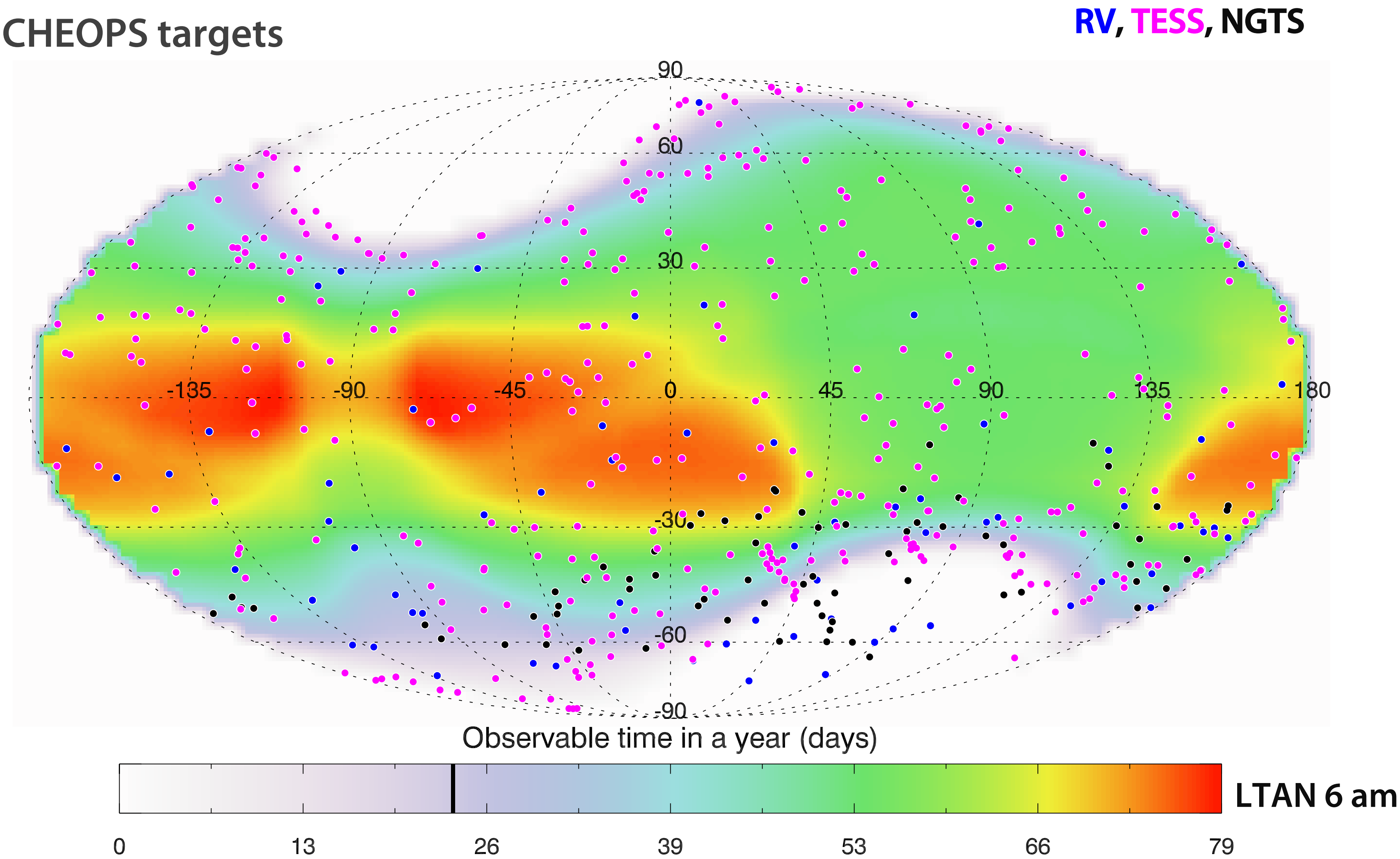
- Compare yellow (am) and red (pm) line





The sky of CHEOPS

- CHEOPS targets

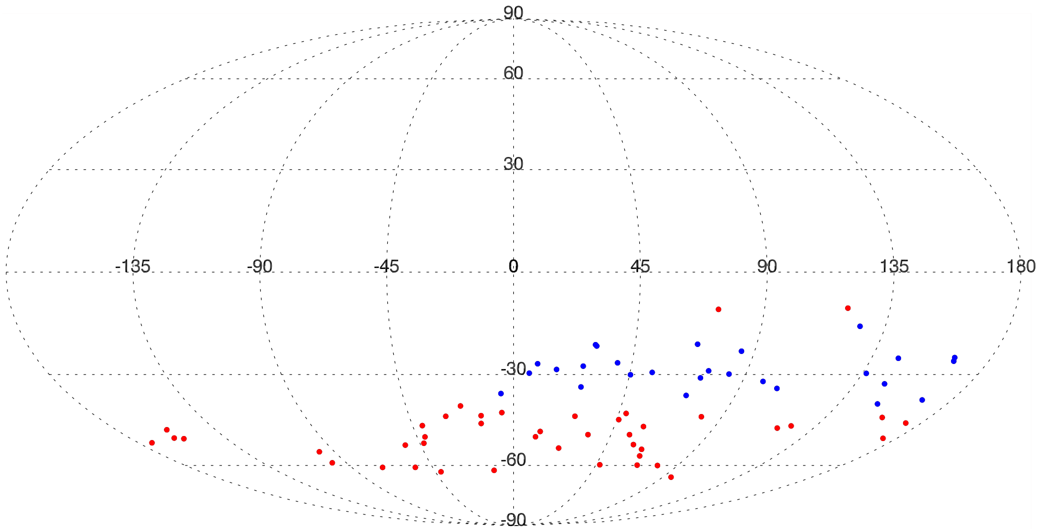


The sky of CHEOPS

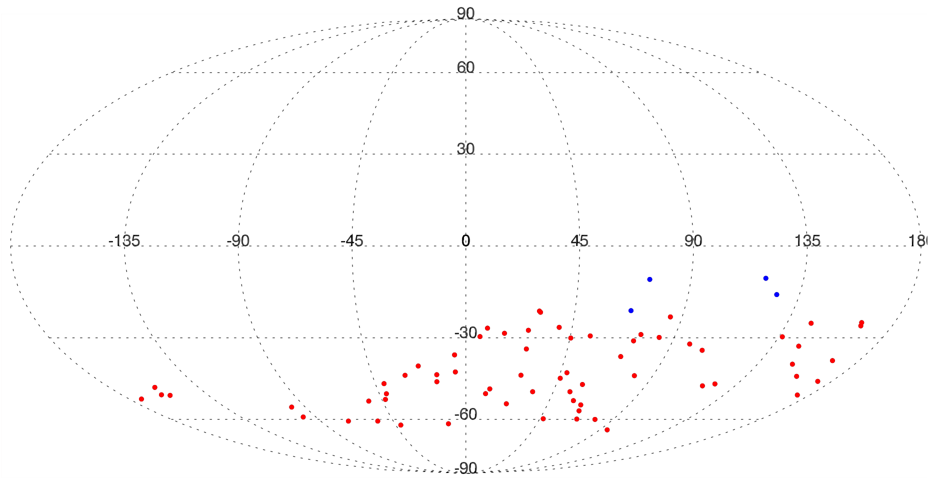
❖ 6am/6pm orbits

❑ NGTS targets (70)

LTAN 6 am
observable (27), not observable



LTAN 6 pm
observable (4), not observable

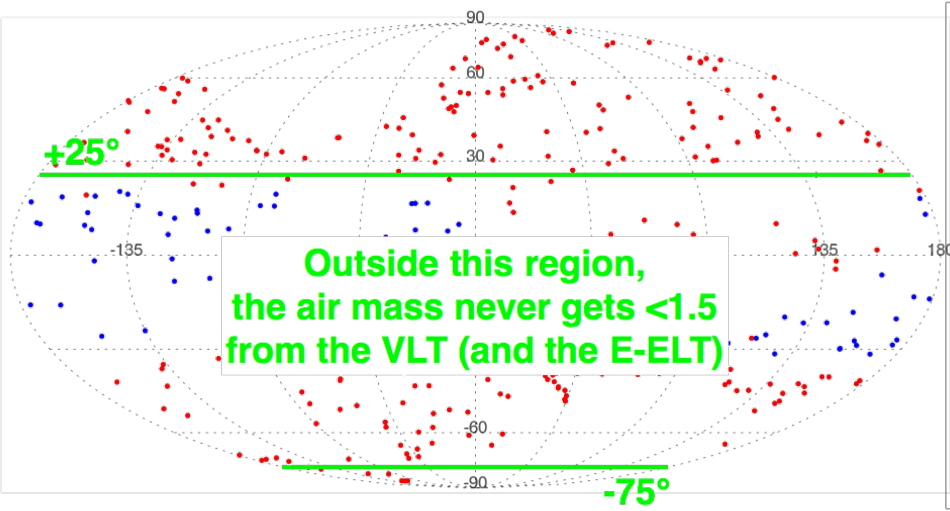


The sky of CHEOPS

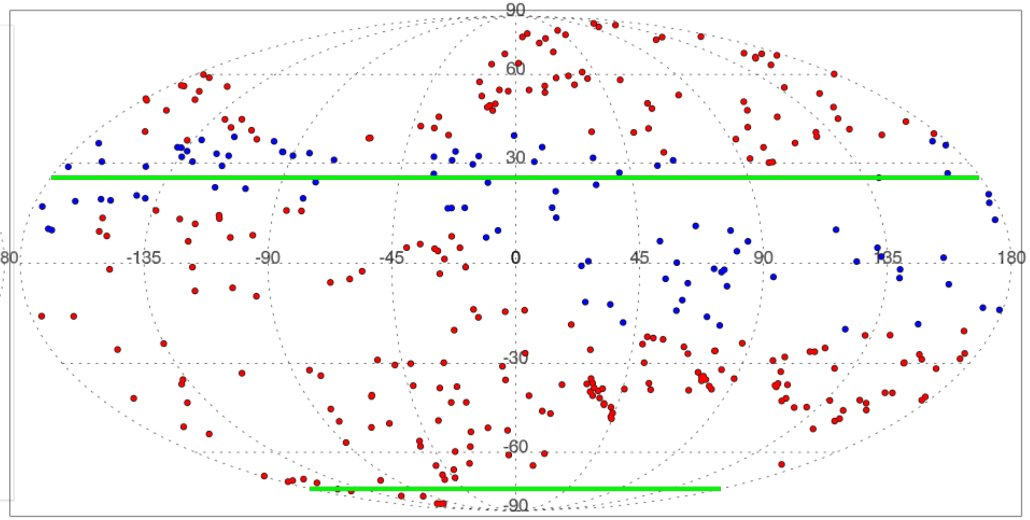
6am/6pm orbits

- TESS targets (366)

LTAN 6 am
observable (111), not observable



LTAN 6 pm
observable (96), not observable

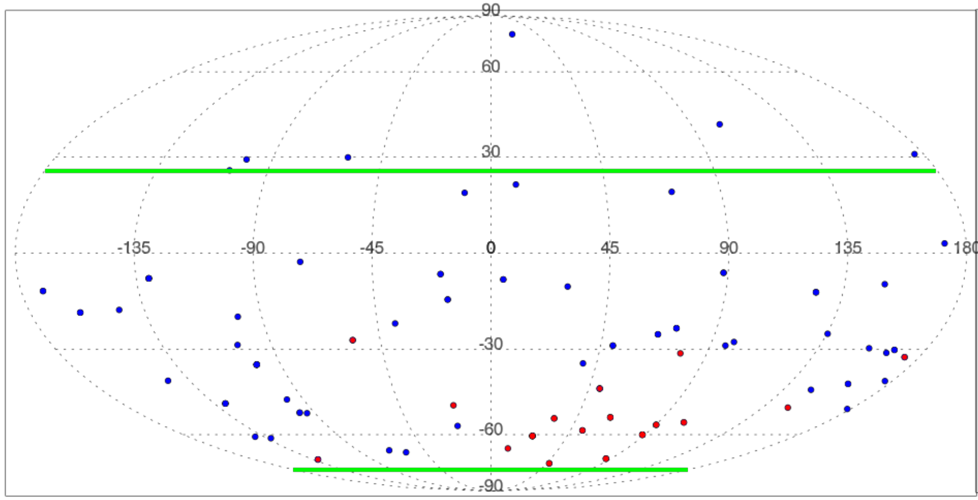


The sky of CHEOPS

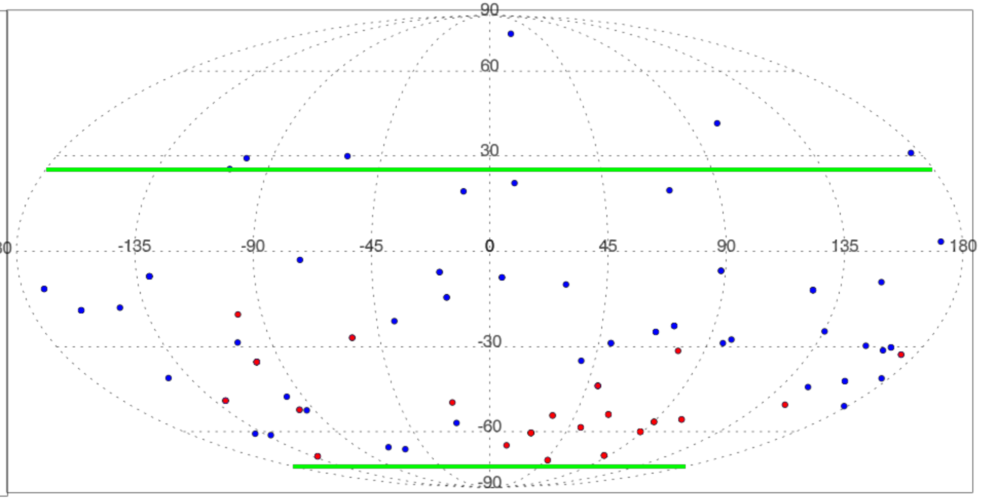
❖ 6am/6pm orbits

❑ RV targets (117)

LTAN 6 am
observable (82), not observable



LTAN 6 pm
observable (76), not observable



The sky of CHEOPS

Orbit trade-off

- **The selected orbit for CHEOPS is the LTAN 6am**
- 2nd orbit (6 pm) was flagged as less performant
- Analysis performend:
  - pm orbit loses all NGTS targets
  - RV / TESS targets are shifted 16 degree northward
  - Some targets will fall outside ELT observable range
  - TESS will start with northern hemisphere
- If, and only if, the instrument cannot make it for the 6am launch option we will go for the 6pm. Probably we will need to re-assess the observational strategy.

CHEOPS Mission: summary

◆ CHEOPS Consortium

Willy Benz
PI, U. Bern

Switzerland
Mission Lead
Instrument Team
Science Operations Center

❑ GROUND SEGMENT

Sweden
Data Flow Simulator

UK
Quick Look

France
Data Reduction Software

Portugal
Mission Planning, Archive, & Data Reduction Software

Spain
Mission operations centre

❑ INSTRUMENT

Germany
Focal Plane Assembly

Belgium
Baffle

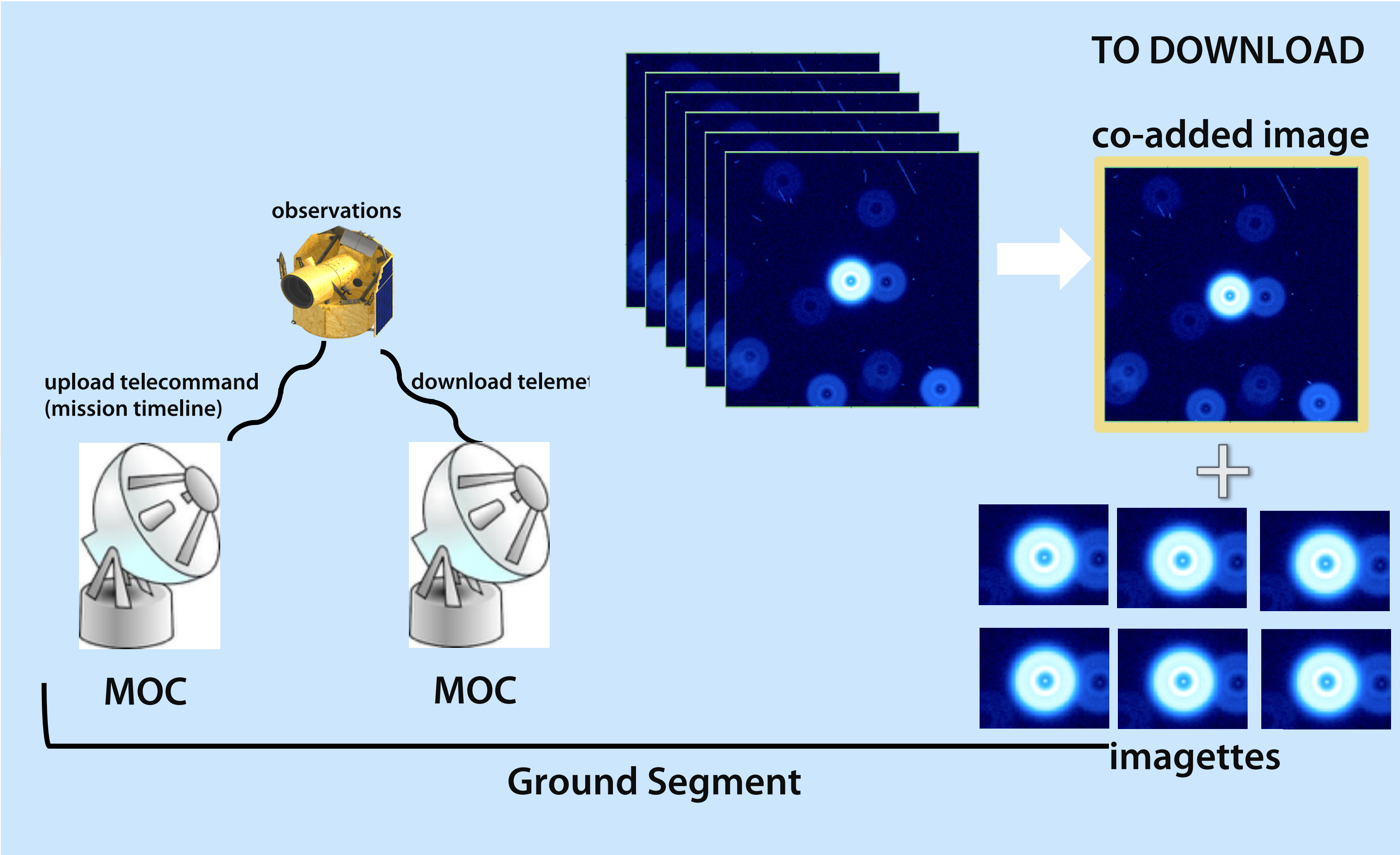
Italy
Optics

Austria
Digital Processing Unit, SW

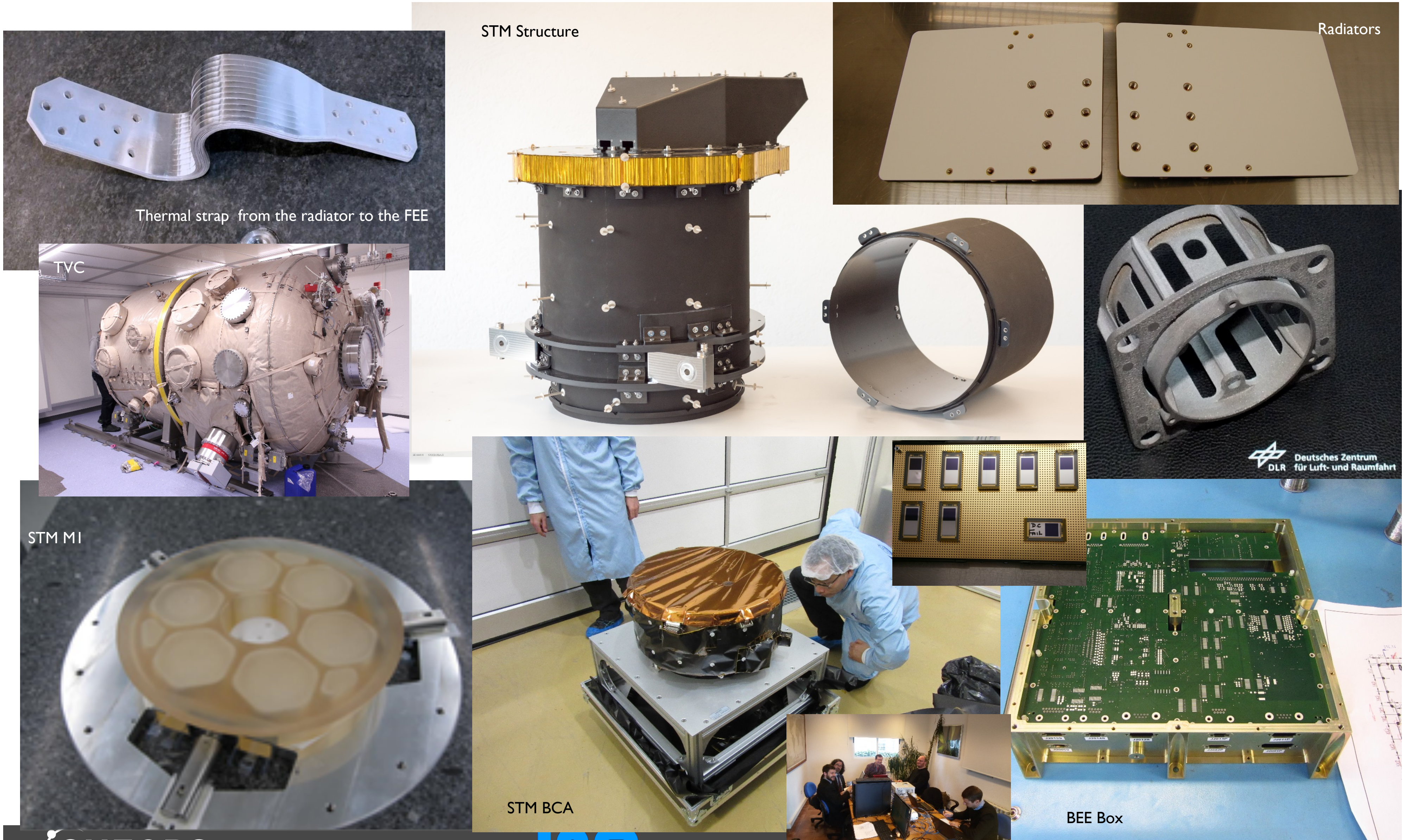
Hungary
Radiators

CHEOPS Ground Segment

- The process

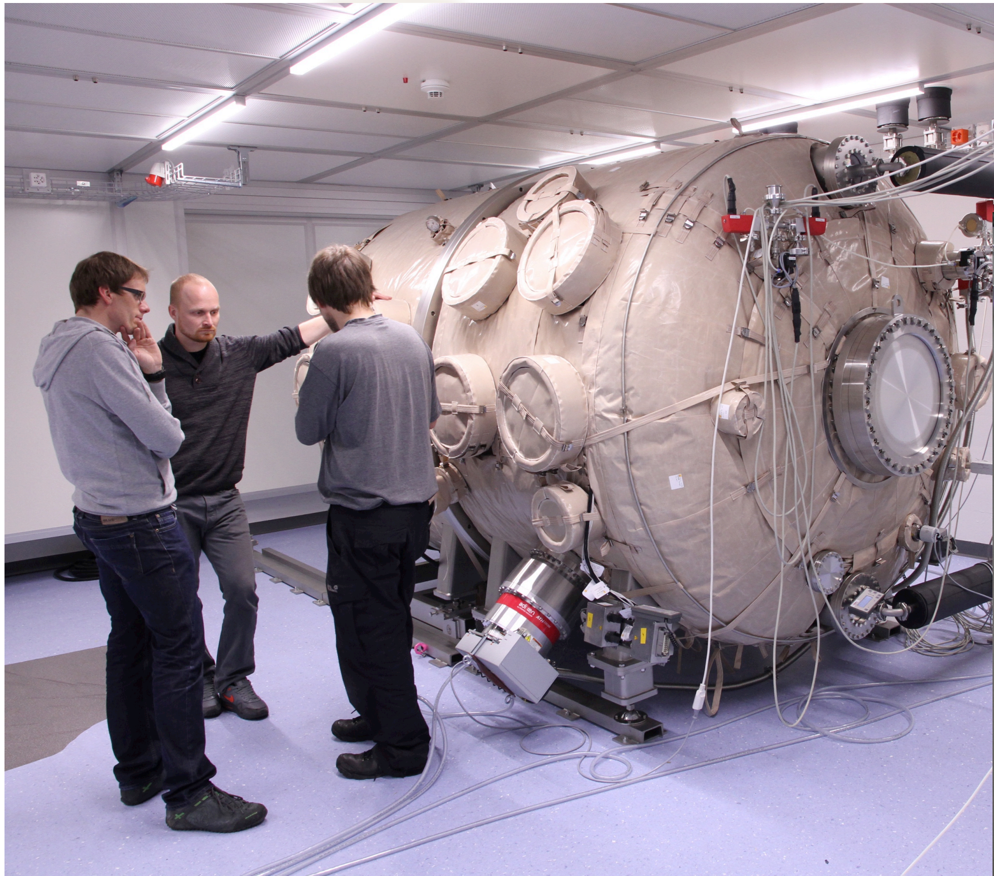


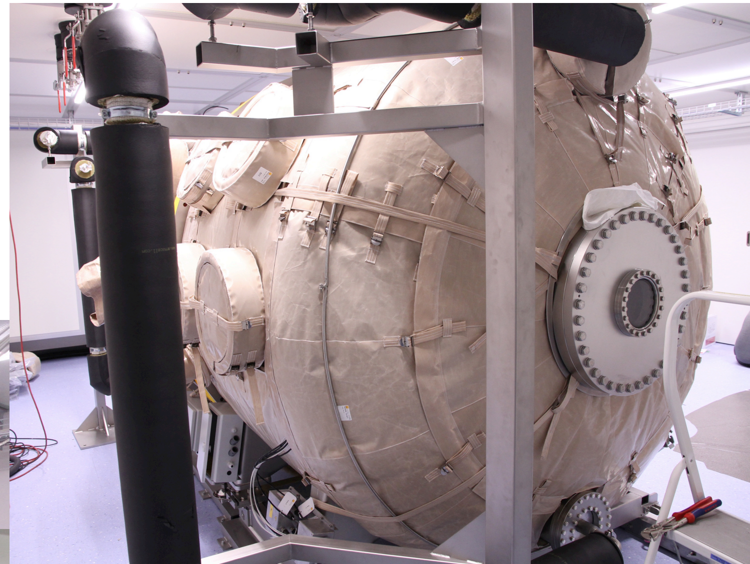
CHEOPS Instrument System (CIS)



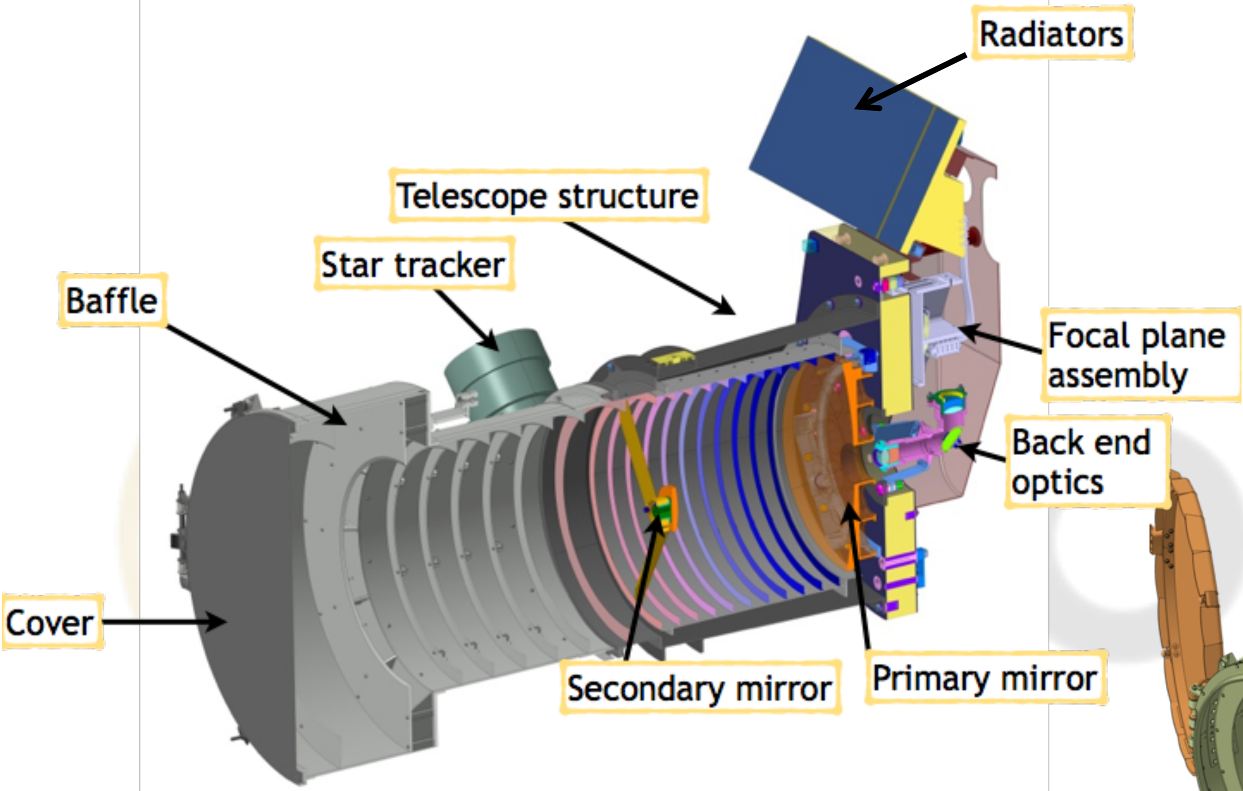
Lab @ UniBe

- Almost ready!
- TVC bake-out finished
- Clean room: cleaned!
- Fit check of the BCA collar and the BCA and first inspection on-going.

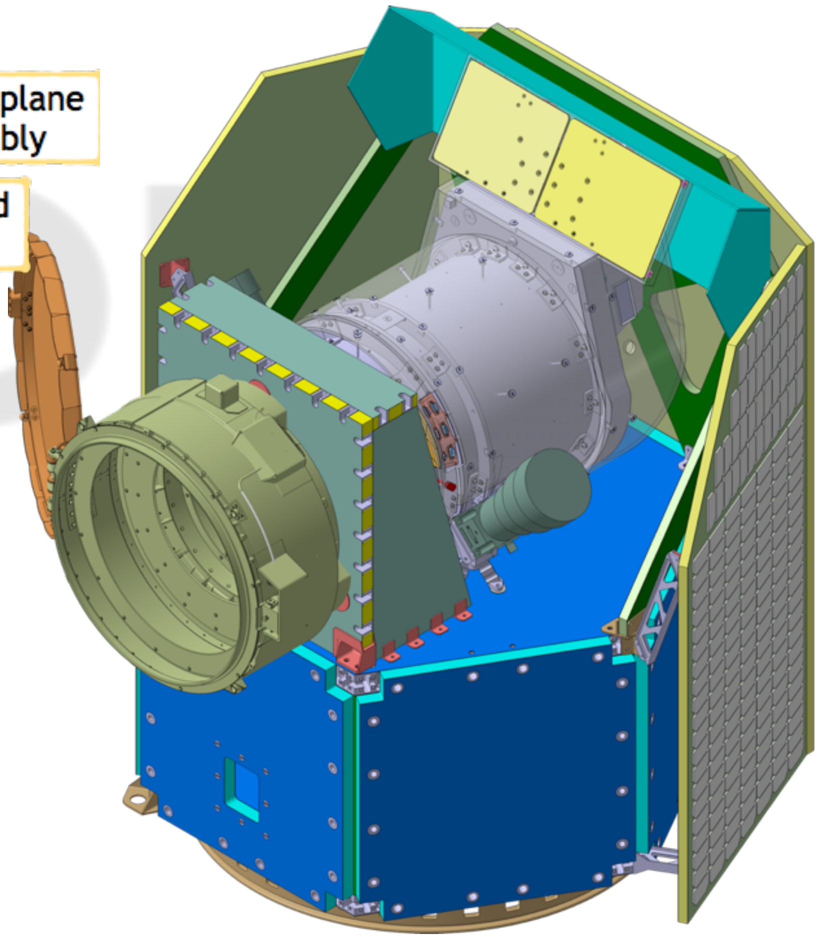




CHEOPS



Platform



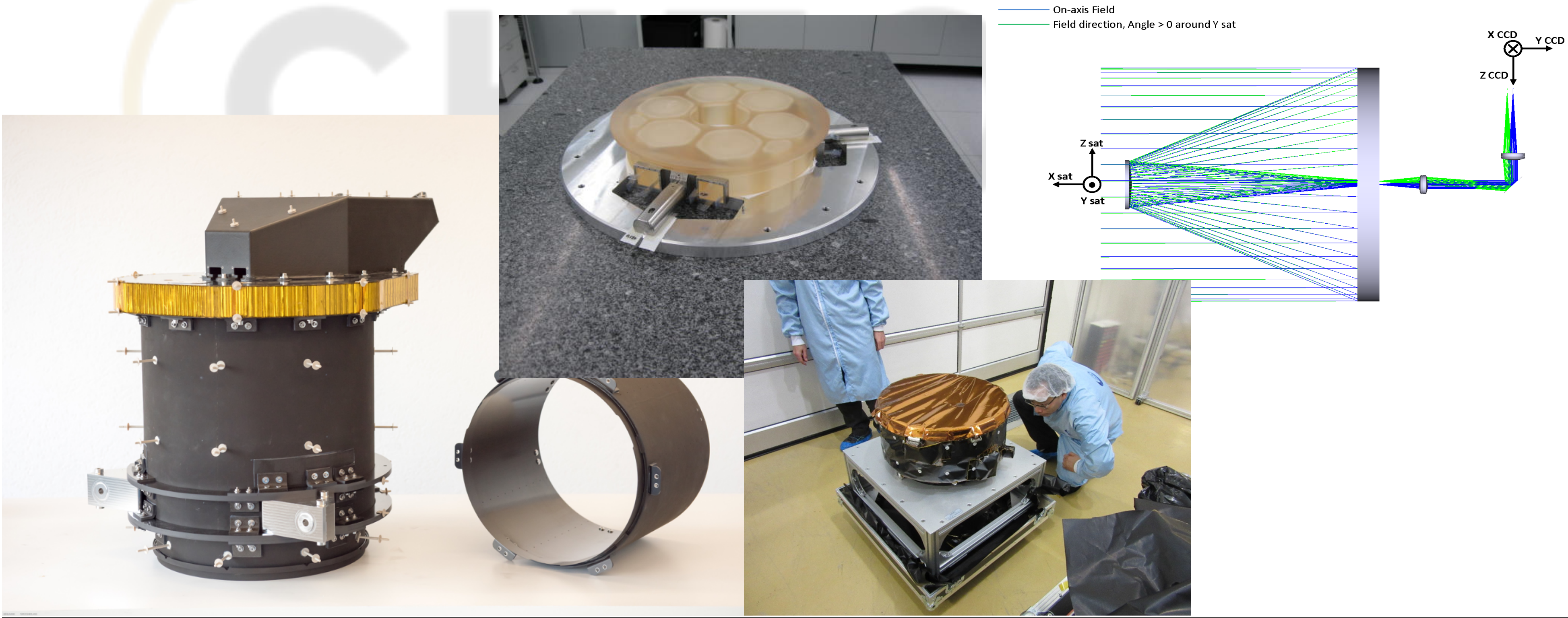
CHEOPS Instrument System

- ❑ 30 cm effective diameter on axis telescope
- ❑ payload mass: 60 kg

CHEOPS Instrument: summary

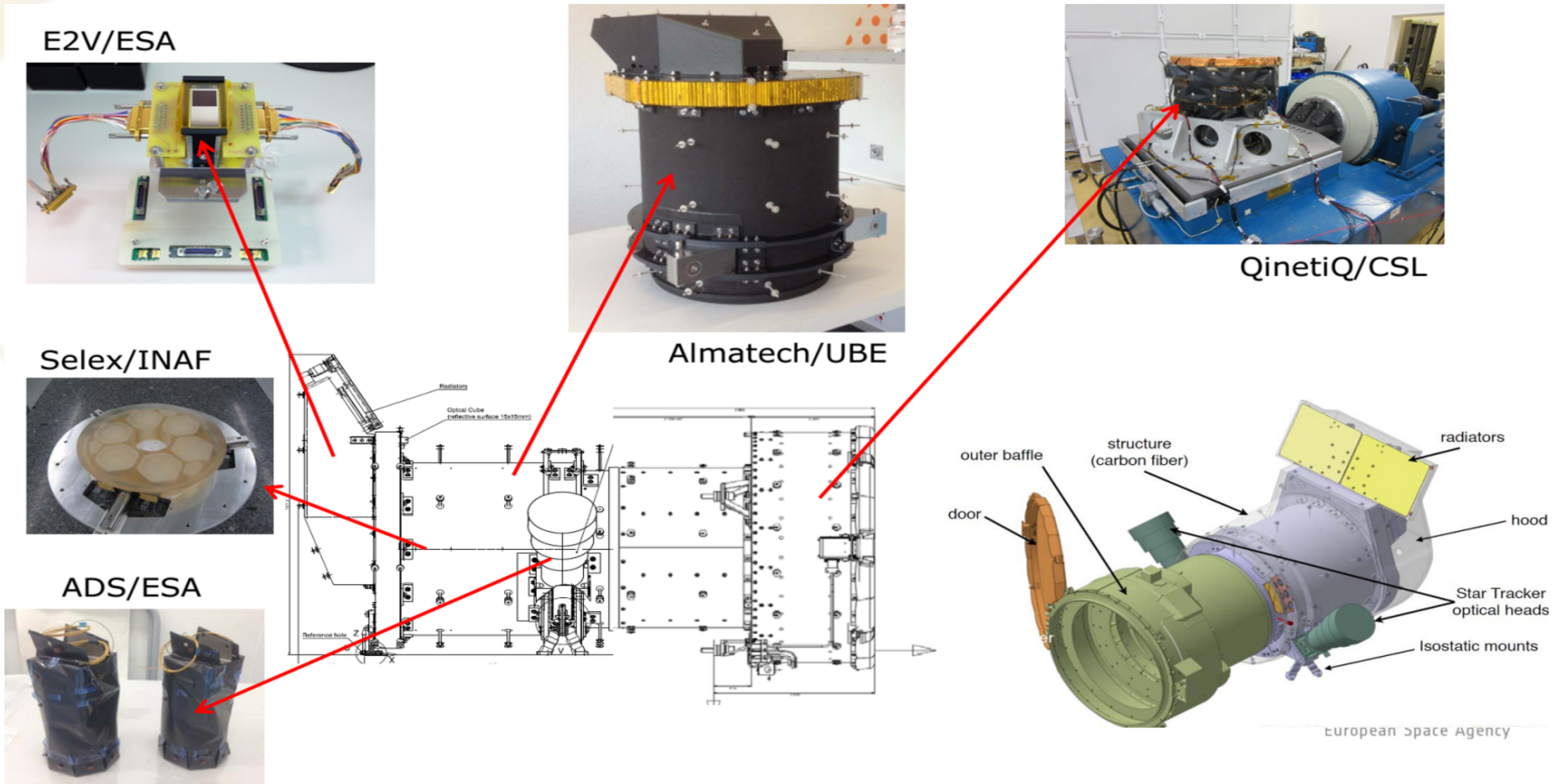
❑ Instrument building process

1. Structural Thermal Model 1 (STM-1): baffle, tube, dummy mirrors, radiators, no electronics and no Back End Optics will be assembled and tested. Then send to SC contractor for more tests.
2. Structural Thermal Model 2 (STM-2): whole instrument with “flight” components will be tested. If everything OK, it will be the flying model.



STM-1 status

- ❑ Baffle and Cover Assembly STM has been delivered to UBE
- ❑ Optical Telescope Assembly STM has completed mechanical qualification campaign
- ❑ Focal Plane Module STM has been delivered to UBE
- ❑ Radiators STM has been delivered to UBE
- ❑ Sensor Electronics Module and Back-End Electronics STMs expected to be delivered to Spacecraft contractor end of June



STM Status

- STM-1

- All mechanical tests already done
- Thermal tests to be done @ UNIBE before the end of August
- After tests are ready, the STM will be delivered to the Space Craft contractor

- STM-2

- Begin with STM-2 tests at mid August
- Optical-Stability tests will be performed on the STM-2
- Refurbished to FM from the structure point of view

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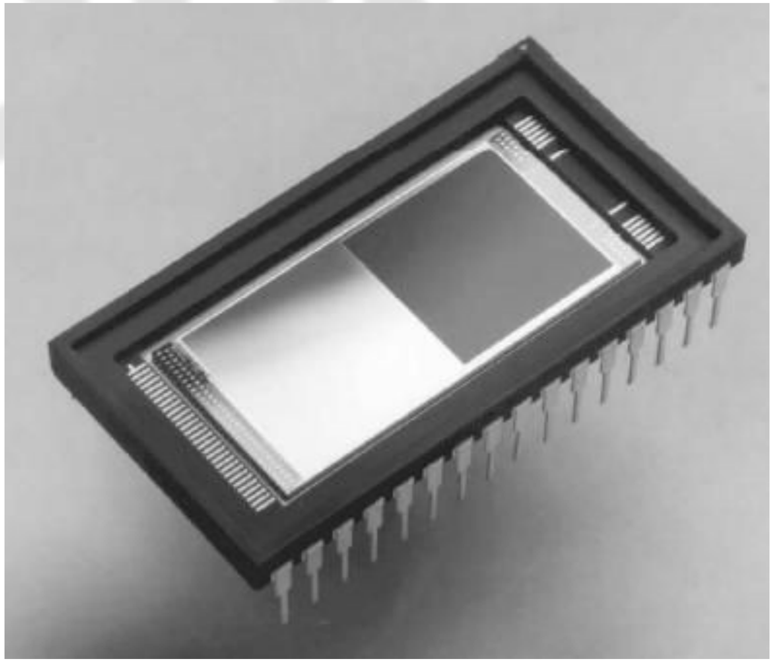
Thermal control

- ❑ The thermal stability in the telescope tube has been very much improved. The nominal temperature of the tube is -10° C. We expect an amplitude in the temperature variation of less than 1° C for the nominal case operation scenario. In cases of optimal conditions the temperature shifts will be much less than 1° C

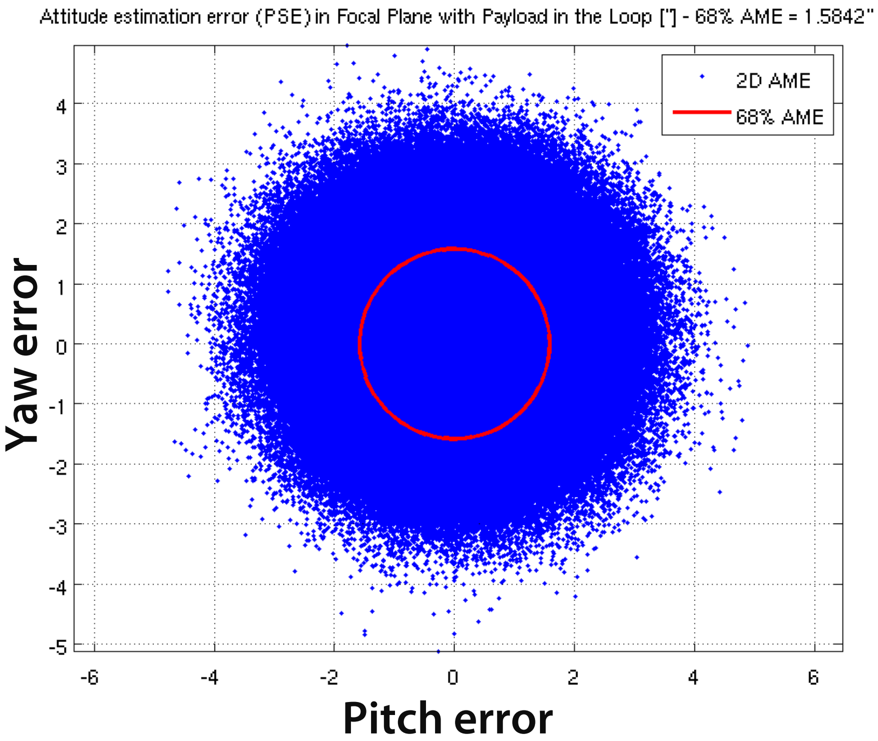
- ❑ The nominal temperature at the focal plane is -40° C, being:
  - The thermal stability at CCD level is expected to be less than 10 miliK
  - The thermal stability of the electronics is expected to be less than 50 miliK

Flight CCD

- 3 CCDs have already been delivered to the University of Geneva, where the calibration will be performed
- The first CCD has already been integrated on a cryostat and the optical set up is ready to start measurements
- After all three CCD are tested they will be sent to DLR for integration



Attitude and Orbital Control System



AOCS time series: expected values for 4 reaction wheels + two optical heads working (nominal scenario).

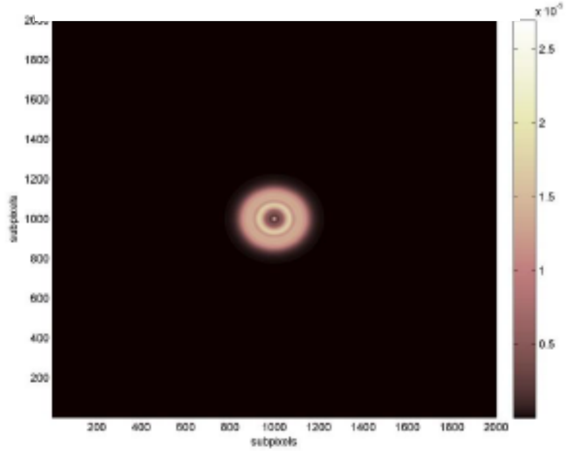
- ❑ **Average pitch error value = 1.8 x 10^{-3} arcsec**
- ❑ **Average yaw error value = 3.9 x 10^{-3} arcsec**
- ❑ Average pointing error value = 1.2 arcsec
- ❑ Standard deviation pitch/yaw = 0.95 arcsec
- ❑ Standard deviation pointing = 0.62 arcsec

AOCS time series for 48 hours without interruptions.

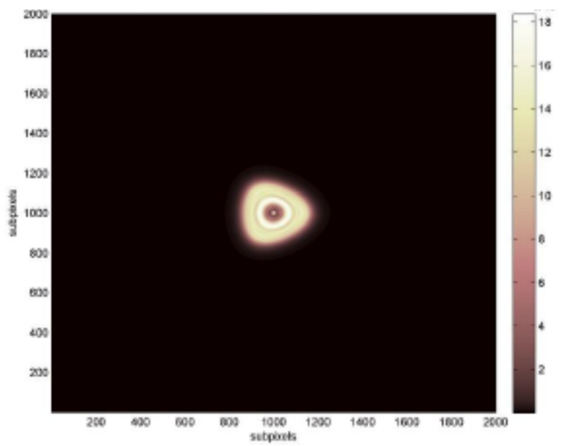
PSF

CHEOPS is designed to have a defocus PSF. It is specified that 90% of the encircled energy should be in a radius of 15.6 px. The aim is to counteract the combined effect of the pointing jitter and flat field.
Due to the need of changing the design of the primary mirror mounting (to resist the launch) the resulting PSF could likely have a "triangular shape". The expected "true" shape is still under investigation, as well as the impact it could have in the reduction of the images.

Expected PSF in the lab (20°C)



Simulated PSF on board (-10°C)

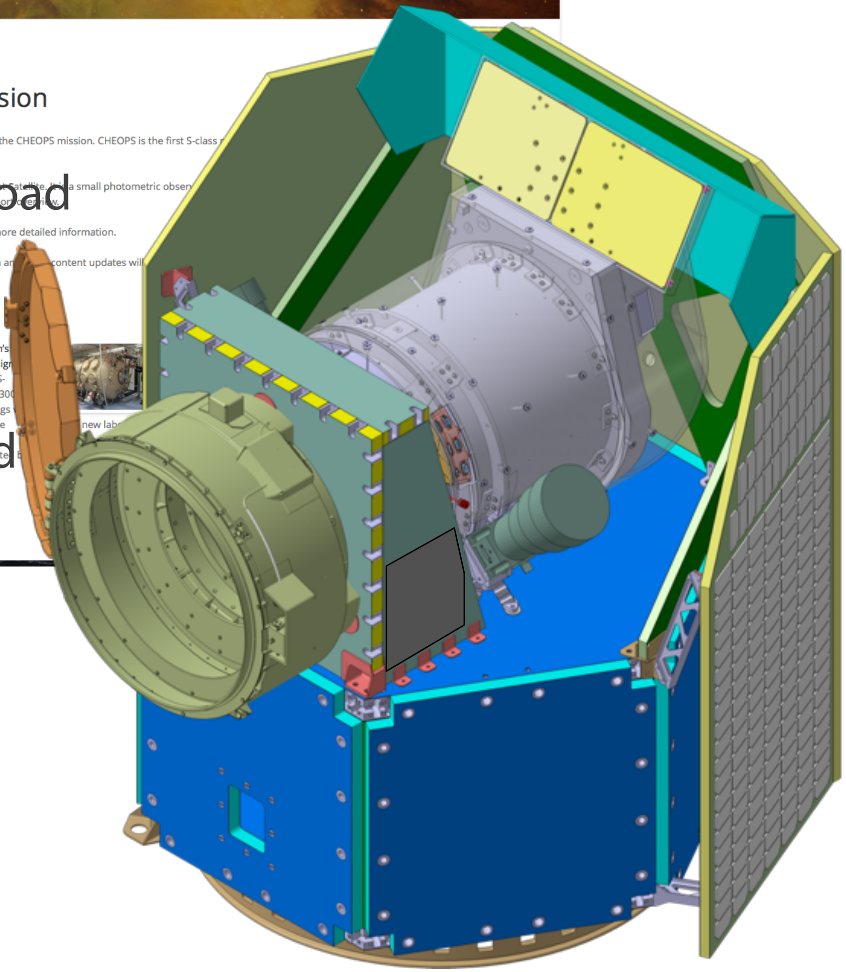


Critical Design Review

- Next big milestone: CDR
- Instrument
  - Opto-mechanical CDR will take place after stability tests on STM-2 to be completed by Mid-September.
  - Electrical SubSystem CDR will take place after Electrical Model tests ➔ to be completed by October
  - One CDR of Optical and Electrical SubSystems together if possible
  - CIS CDR expected for October
- CIS SW: February 2016 (TBC)
- GS: October 2015 (TBC)
- SC / System: December 2015 (TBC)

Outreach

- CHEOPS website in new look
  - CHEOPS paper model for download
  - Transit simulator paper model for download (PlanetS)
- School plate
  - drawing collection information online
  - Location of school plate defined (detailed interface on-going)
  - Drawing format defined
  - First Swiss drawings collected
- CHEOPS model built



THANK YOU!

Ground Segment status

- Ground Segment Preliminary Design Review
  - Ground Segment PDR was at the beginning of 2015

PDR successful for SOC

PDR not successful for MOC: lack of Operator

MOC Delta PDR passed successfully in April

Phase 1 (development) will be under the responsibility of GMV

Phase 2 (after launch) will be under the responsibility of and operator designated by CDTI (INTA?)

- Integration Test Team Coordinator

(will coordinate the MOC/SOC interface, in charge of test plan with S/C contractor)

Funding approved, in search for the candidate

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Ground Segment status

Prototype Deliveries

Many prototypes have been already delivered. The most advanced ones:

- ❑ Mission Planning
- ❑ Archive

CHEOPS Data Reduction Pipeline

Lot of work has been done on the Data Reduction Pipeline, where several algorithms have been developed and tested