

Appendix G

An overview of CHEOPS Instrument thermal design and analysis

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Abstract

CHEOPS (CHaracterizing ExoPlanet Satellite) is the first ESA S-class mission and is dedicated to search for planet transits by means of ultrahigh precision photometry on bright stars already known to host planets. The University of Bern is in charge of the CHEOPS instrument, which is a single aperture, high accuracy photometer operating between 0.4 and 1.1 micron. The focal plane detector consists of a single CCD operated at $-40\text{ }^{\circ}\text{C}$ and requires a thermal stability better than 10 mK. The presentation will provide an overview of the thermal design and of the thermal analysis of the instrument.

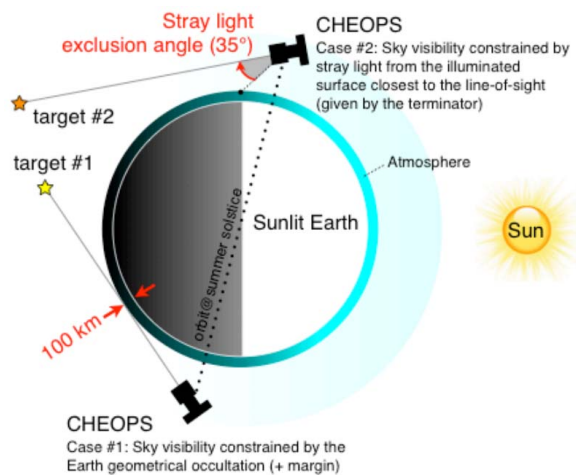
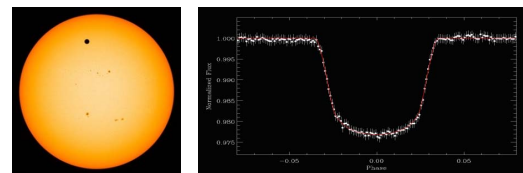
An overview of CHEOPS Instrument thermal design and thermal analysis

Giordano Bruno (University of Bern)
Romain Peyrou-Lauga (ESA)

Thermal analysis workshop – ESTEC – 14-15 Oct. 2014

CHEOPS MISSION

- CHEOPS is the first ESA’s Science Programme of class S (Small mission).
- The purpose of the mission is to characterise already known exoplanets: it will measure the bulk density of «super-Earth»- and «Neptune»-mass planets, for future in-depth characterisation studies of exoplanets in these mass ranges.
- A sun synchronous LEO orbit has been chosen with LTAN 6:00 am and altitude from 620 to 800 km.
- The Satellite Attitudes/pointings have been defined on the basis of the allowed observation field, which in turn, must respect the Earth stray light exclusion angles.

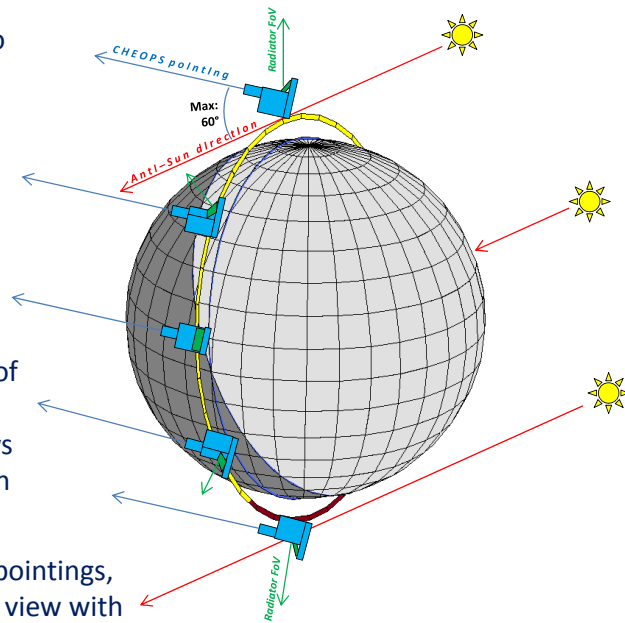


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OVERVIEW OF CHEOPS ORBIT (1/2)



- CHEOPS instrument must be able to point any star up to 60° away from the anti-Sun direction (combined azimuth / elevation angle)
- A rotation around the Telescope axis is possible (and used) to avoid (or minimize) the radiators field of view with the Earth.
- As a result, the Instrument is most of the time in the shade of the Sunshield and a constant spin allows the radiators never to face the Earth (for low off-axis pointings)
- BUT... for Instrument large off-axis pointings, radiators have an inevitable field of view with the Earth once per orbit – always above one of the Polar regions. Besides, the Telescope has also a large view factor with the Earth once per orbit.



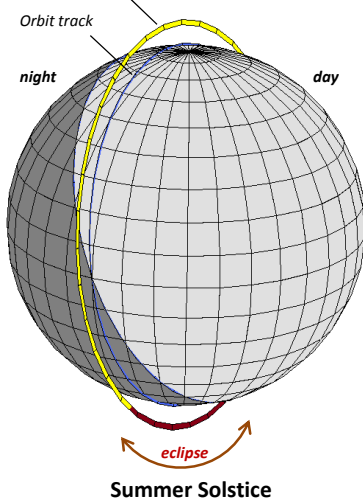
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OVERVIEW OF CHEOPS ORBIT (2/2)

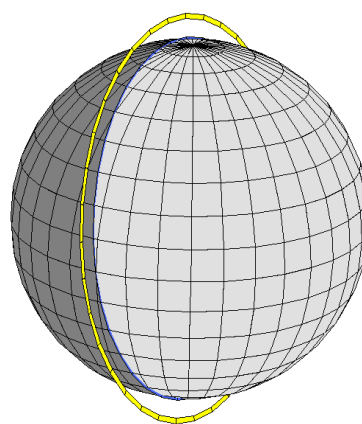


- CHEOPS orbits is shown here at different periods of the year
- Eclipse occurs twice a year, around solstices.

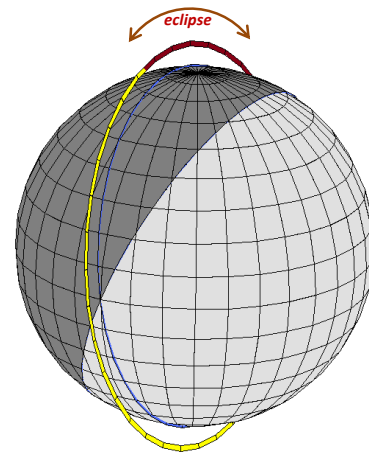
Sun-synchronous Orbit
800 km, LTAN: 06:00



Summer Solstice



10 Apr. & 30 Aug.



Winter Solstice

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CHEOPS SPACECRAFT

CHEOPS Instrument

CHEOPS Platform

Solar Arrays panels

- Enveloping dimensions: 1.5 m × 1.4 m × 1.5 m
- Spacecraft overall mass < 250 kg
- 60 W of continuous power provided to the Instrument by the Spacecraft
- Instrument radiators dimension is limited by the max allowed volume for the Spacecraft accomodation in the launcher

Instrument Radiators

Sunshield

Instrument Cover (open)

Platform radiators

Star Tracker

Sunshield

Solar Arrays panels

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CHEOPS INSTRUMENT THERMAL REQUIREMENTS

FPA Radiator:
-70°C to +40°C

FEE Radiator:
-70°C to +40°C

Telescope tube (TEL):
Set-point: -10°C
Stability < 10 K

Telescope baffle (BCA):
-80°C to +60°C

Front End Electronic (FEE):
set-point +4°C
Stability < 50 mK

FPA CCD:
set-point -40°C
Stability < 10 mK

Thermal insulation

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CHEOPS INSTRUMENT THERMAL ARCHITECTURE: COATINGS THERMO-OPTICAL PROPERTIES

Radiators:
White paint
 $\epsilon = 0.8, \alpha_{EOL} = 0.25$

External black MLI:
 $\epsilon = 0.84, \alpha = 0.93$

Internal VDA MLI:
 $\epsilon = 0.05$

Thermal insulation

Mirror front side: silver coating:
 $\epsilon = 0.03, \alpha = 0.12$

Mirror rear side: bare zerodur:
 $\epsilon = 0.8, \alpha = 0.5$

TEL + BCA vanes: black paint:
 $\epsilon = 0.9, \alpha = 0.95$

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CHEOPS INSTRUMENT THERMAL ARCHITECTURE: FPA THERMAL DESIGN

FPA radiator front side:
white painted
 $\epsilon = 0.8, \alpha_{EOL} = 0.25$

FPA radiator back side:
Alodine 1200 + VDA MLI

CCD survival heater line + thermistors (ON/OFF)

FPA CCD operational heater line (PID controller)

Beryllium capacitor gold coated

Thermal filler

Silver thermal strap

Thermal filler

FPA cold-block: gold coated

CCD housing

Flex PCB

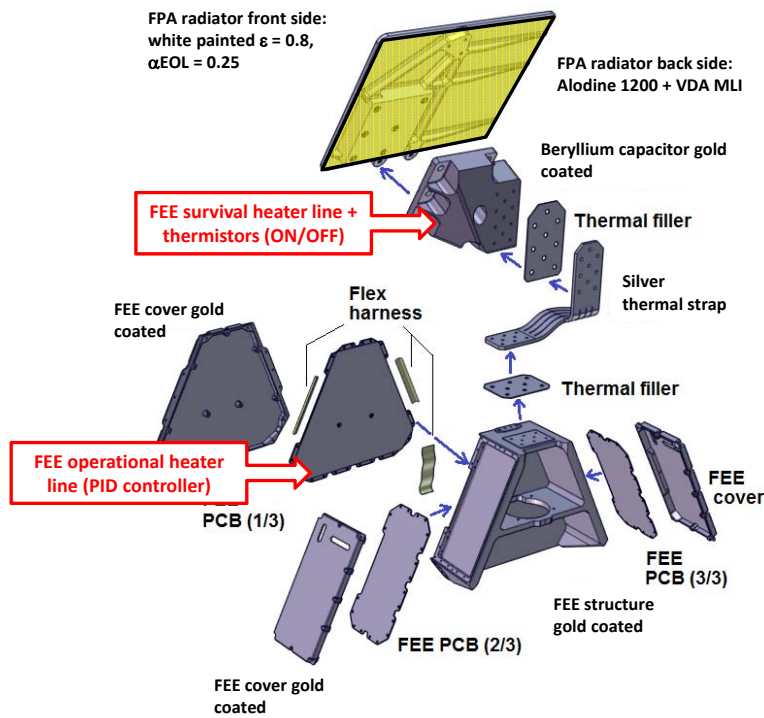
CCD cover: black inside, gold outside

The FPA thermal control includes:

- High conductance thermal path between the detector and the radiator (high conductance materials)
- High thermal inertia capacitor to help temperature stabilization
- Mechanical decoupling between the detector and the radiator
- Thermal insulation from the radiative and conductive environment
- PID law controlled heating line

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**CHEOPS INSTRUMENT THERMAL ARCHITECTURE:
FEE THERMAL DESIGN**

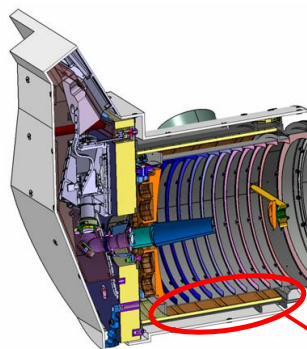


The FEE thermal control presents similar features than the FPA (as seen previously):

- High conductance
- High thermal inertia
- Mechanical decoupling
- Thermal insulation
- PID law

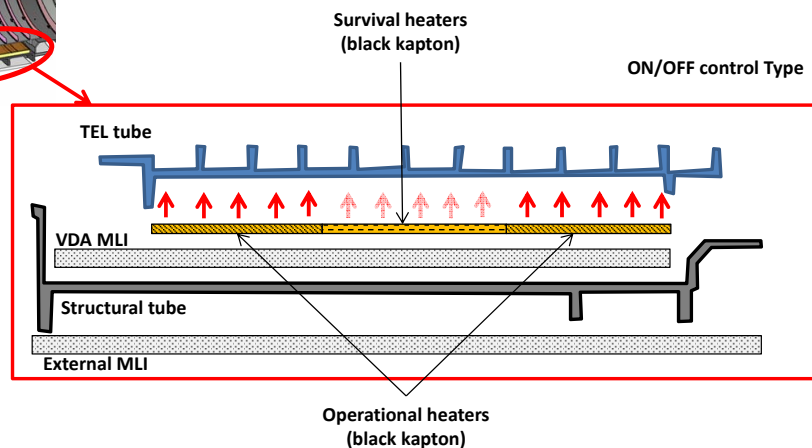
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**CHEOPS INSTRUMENT THERMAL ARCHITECTURE:
TELESCOPE THERMAL CONTROL**



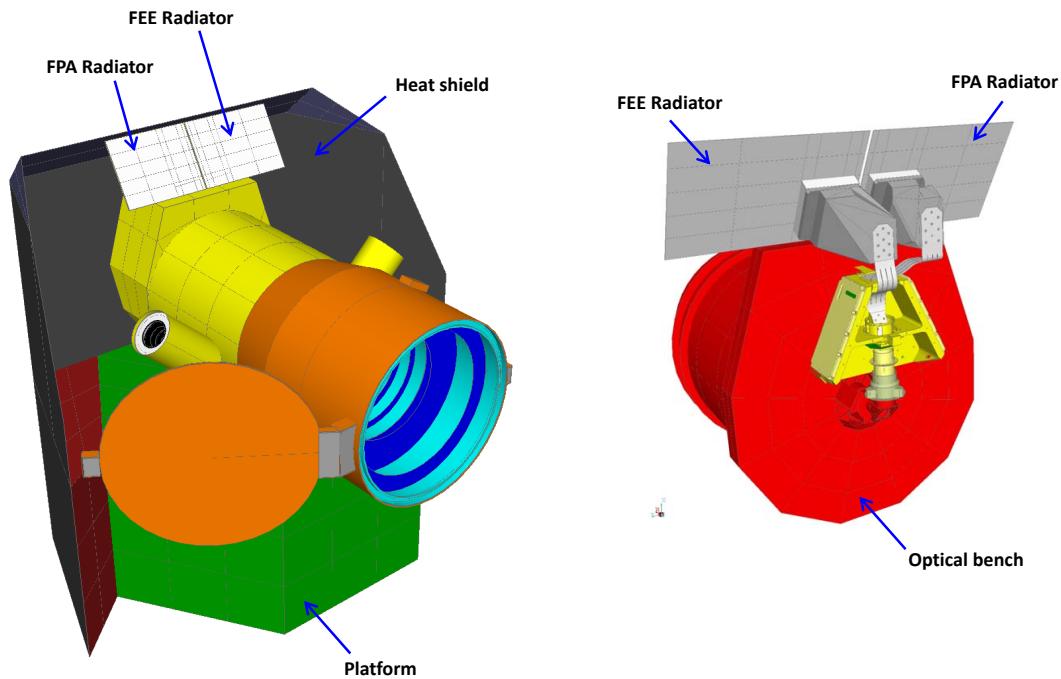
The Telescope thermal control includes:

- 2 sets of MLI (one for each tube)
- Several local heating lines to counter gradients



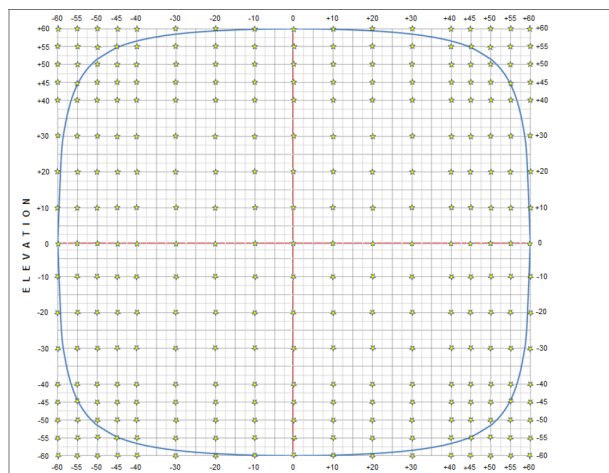
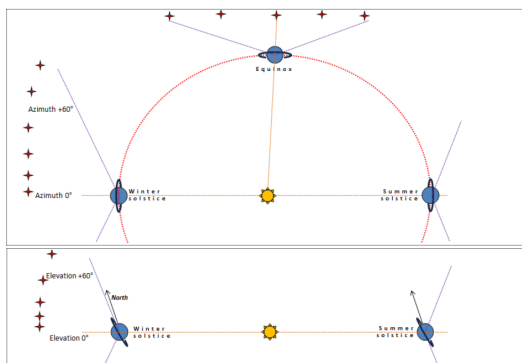
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UP-TO-DATE CHEOPS GEOMETRICAL MODEL



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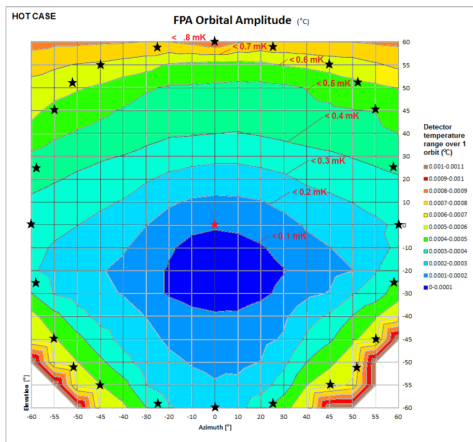
THERMAL ANALYSIS AT SRR



- An extensive survey has been performed by ESA at SRR, of all the possible attitudes, with Azimuth and Elevation steps of 5°/10° inside the required range (blue line in the picture)
- Azimut has been defined wrt the ecliptic plane, while the Elevation wrt to ortogonal plane to the ecliptic plane, containing the Sun and the Satellite

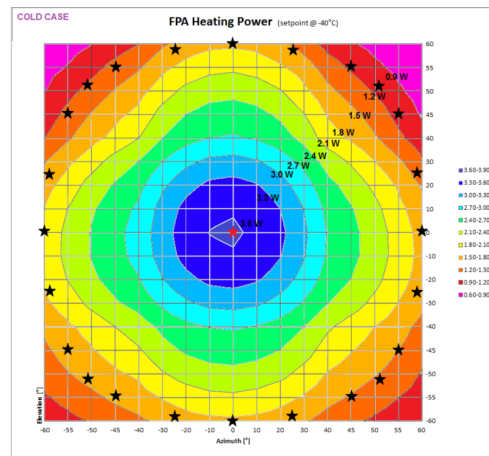
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THERMAL ANALYSIS AT SRR



- The stability/gradients maps of the TEL tube, Mirrors, FPA CCD and FEE have been worked out, allowing to identify the attitude worst condition.

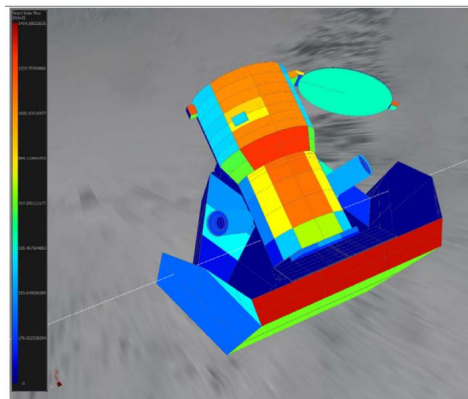
- Two worst cases have been identified:
 - cold case: 10th of April in anti-sun pointing
 - hot case: winter solstice, pointing at the boundary of the observed field



THERMAL ANALYSIS AT PDR



- The insights of the SRR have been developed by Unibe in Systema / Thermica
- The margin policy has been consolidated:
 - an uncertainty of -10°C on the FPA and FEE set-points in hot condition, for the FPA and FEE radiators design
 - An uncertainty of $+10^{\circ}\text{C}$ on the FPA and FEE set-points in cold condition, for the TC power sizing



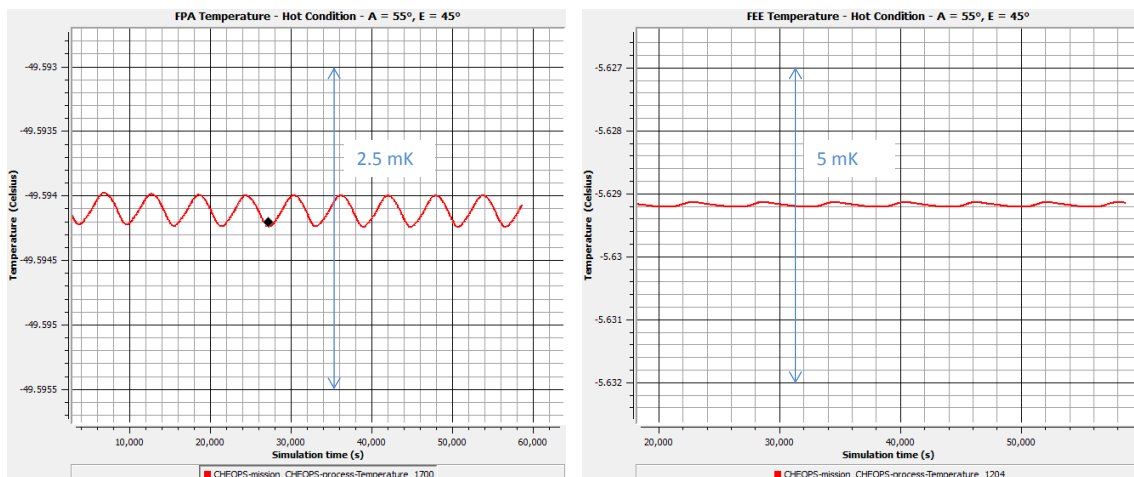
CHEOPS ABOVE SOUTH POLE: A=0°, E= 60°, Direct solar flux (Systema/Thermica)

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THERMAL ANALYSIS AT PDR



- The analysis results show that the demanding stability requirements for the FPA CCD and FEE (< 10 mK and < 50 mK respectively) are achievable, with a proper tuning of the PID controllers gains



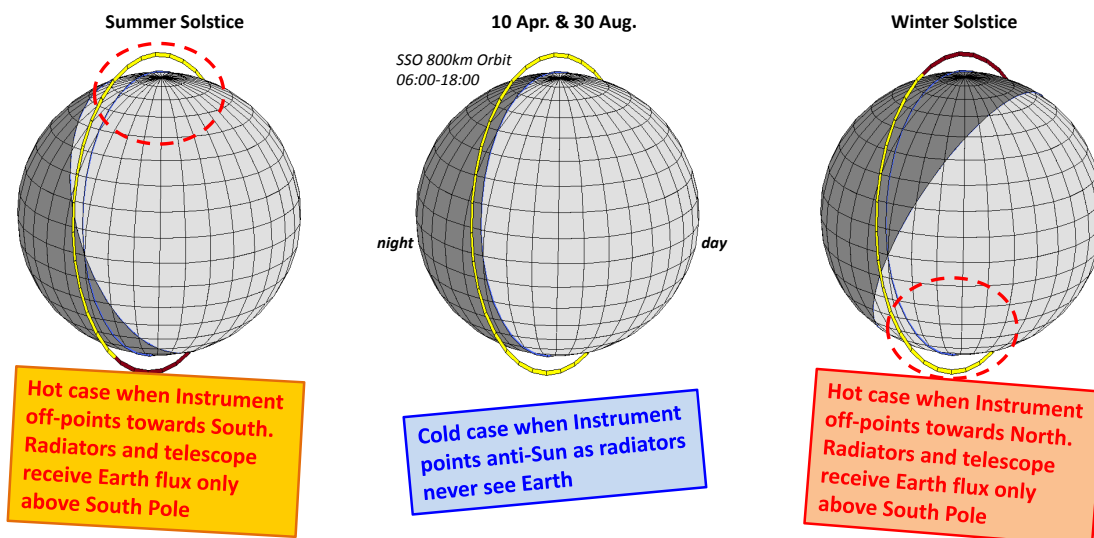
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EARTH ENVIRONMENT HYPOTHESES (Albedo, IR flux) (1)

Discussion for CHEOPS case...



- The recent thermal analysis activities led a specific reflection about the environment hypothesis in the peculiar case of CHEOPS combined orbit/ pointings.
- For Instrument large off-axis pointings, radiators and telescope have an inevitable field of view with the Earth once per orbit – always above one of the Polar regions.



- So the legitimate question is whether albedo/ Earth IR are adequately modeled for those specific cases.

EARTH ENVIRONMENT HYPOTHESES (Albedo, IR flux) (2) CHEOPS CHARACTERISING EXOPLANET SATELLITE

Common hypotheses...

Min albedo: 0.2 to 0.25 Max albedo: 0.35 to 0.4

Min Earth IR temp: 240 K to 244 K (201 W/m² to) Max Earth IR temp: 260 K to 264 K

Gilmore Handbook proposes a set of albedo / IR flux hypotheses depending on the latitude and the season:

Yearly average albedo (Gilmore Hdbk)

Yearly average Earth IR temp. (Gilmore Hdbk)

For the SRR and PDR, usual values of albedo and IR flux were used. Min albedo + min IR flux were cumulated with min Sun flux (winter), which is conservative. As the radiators can receive Earth flux only above the Polar regions, we legitimately wonder if our hypothesis were not too conservative, leading to oversize the FPA and FEE radiators

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EARTH ENVIRONMENT HYPOTHESES (Albedo, IR flux) (3) CHEOPS CHARACTERISING EXOPLANET SATELLITE

Using measured values of albedo/IR flux

- The idea is then to use real data of albedo / IR flux to get a realistic environment for the thermal simulation. NASA's CERES experiment provide daily geolocalised data for both albedo and IR flux (<http://ceres.larc.nasa.gov/>)

Earth IR flux
W/m²

Albedo

- Alex Green (PhD UCL/ESA) has computed 5 years of CERES data (2007-2011) to obtain averaged albedo /IR flux depending on the latitude, the season but also the orbit.
 - Average yearly IR Earth temp. as viewed from SSO 800km LTAN 6h appears to **250 ±4K**.
 - Average yearly albedo as viewed from SSO 800km LTAN 6h appears to **0.38 ± 0.07**.



Statistic orbital averaged value of Earth IR temperature for SSO 800km LTAN:6h (CERES data 2007-2011)

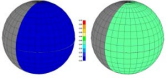
Statistic orbital averaged value of Albedo for SSO 800km LTAN:6h (CERES data 2007-2011)

EARTH ENVIRONMENT HYPOTHESES (Albedo, IR flux) (4)

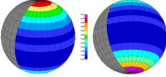
Measured albedo / IR flux (CERES 2007-2012):

- Another possibility of using CERES data is to take into account local value (depending on latitude):

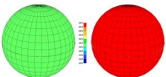





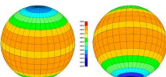
Earth IR temp. (PDR hyp.)



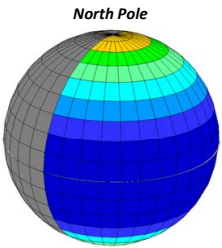
Yearly average albedo temp. (Gilmore data)



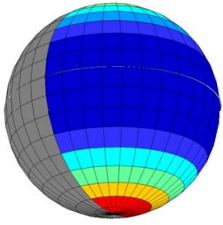
Earth IR temp. (PDR hyp.)



Yearly average Earth IR temp. (Gilmore data)

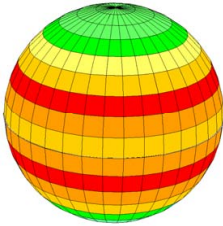


North Pole

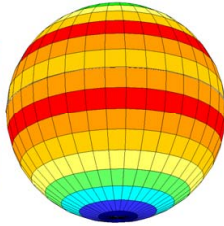


South Pole

Yearly average albedo (CERES data) (shown in Winter solstice)

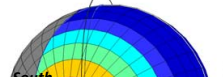


North Pole

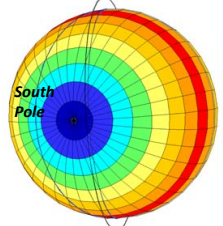


South Pole

Yearly average Earth IR temp. (CERES data)



South Pole



South Pole

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THANK YOU !
Any questions...?

