La missione CHEOPS

ASI, 25 Sep 2013

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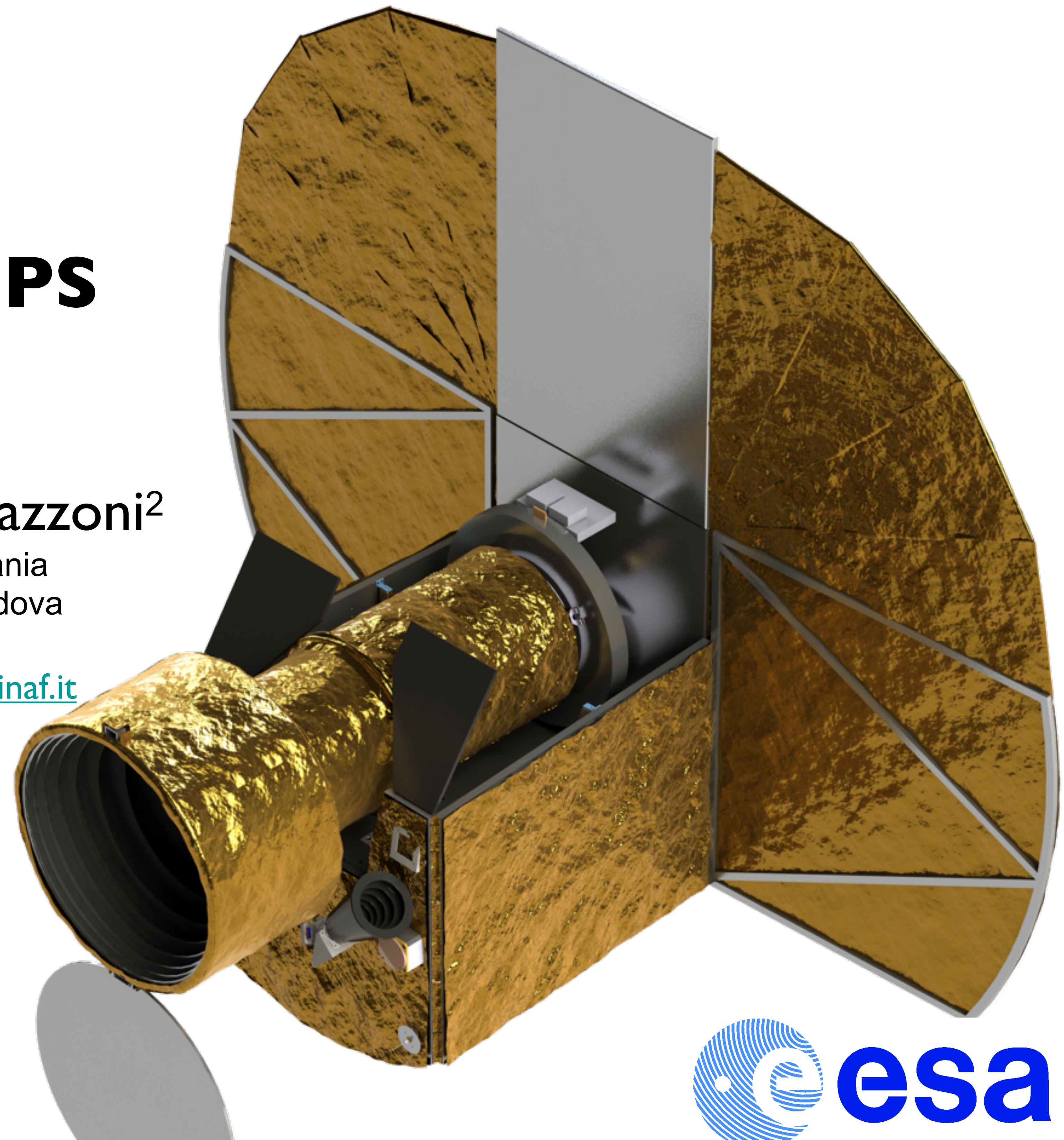


ESA small missions requirements

Science

top rated science in any area of space science

Cost

total cost < 150 M€

cost to ESA: not to exceed 50 M€

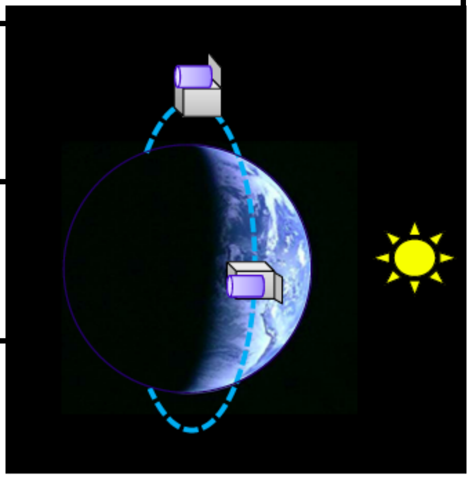
Schedule

developed and launched within 4 years (end of 2017)

call issued	March 3, 2012
proposal due	June 15, 2012
mission selection	October 19, 2012
mission adoption	Nov 2013/ Feb 2014
launch	2017

Mission summary

Name	CHEOPS (CHaracterizing ExOPlanet Satellite)
Primary science goal	Measure the radius of planets transiting bright stars to 10% accuracy
Targets	Known exoplanet host stars with a V-magnitude < 12.0 anywhere on the sky
Wavelength	Visible range : 400 to 1100 nm
Telescope	707 cm^2 effective aperture reflective on-axis telescope (30 cm 亙)
Orbit	LEO sun-synchronous, LTAN 6am, 620-800 km
Lifetime	3.5 years
Type	S-class

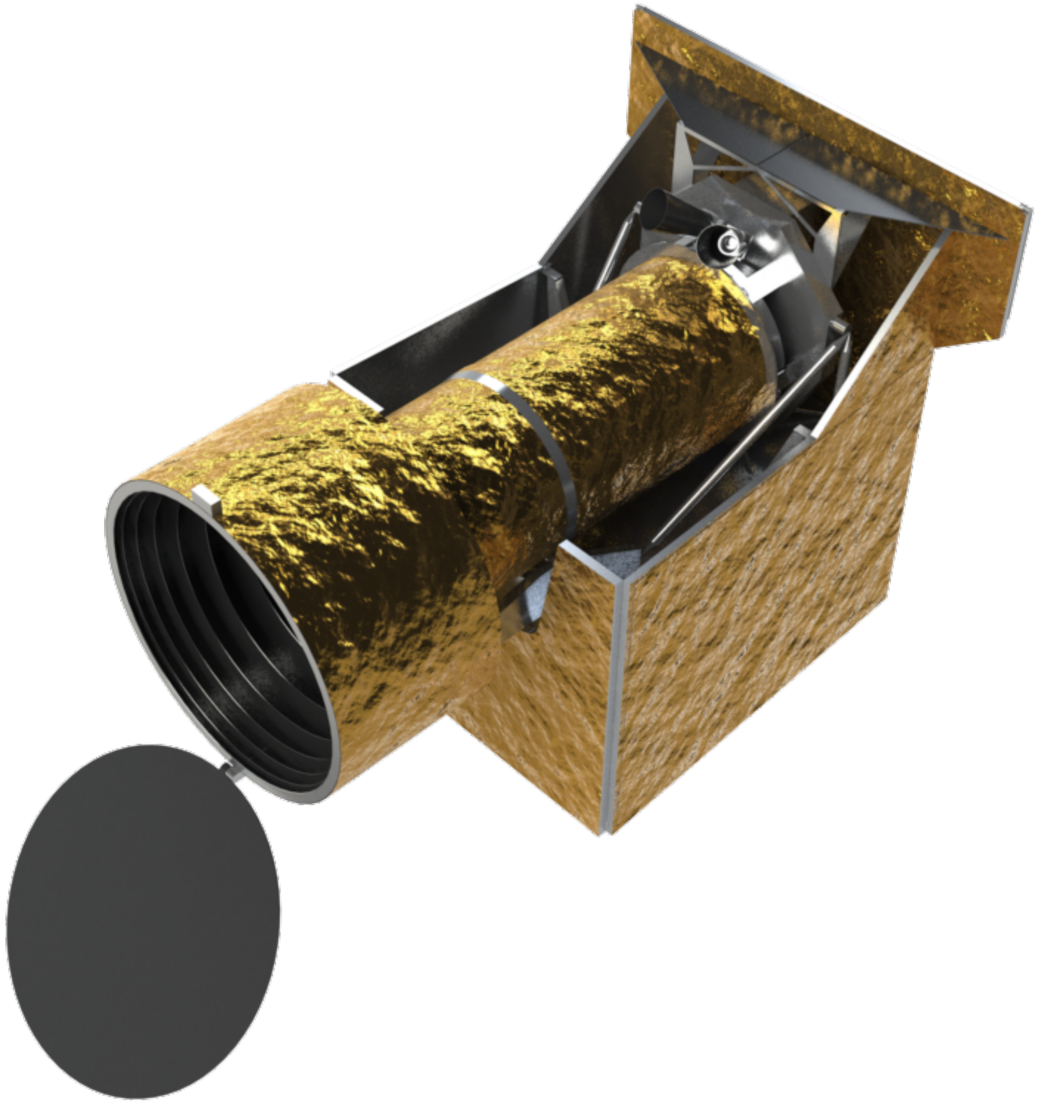


Country	Institutes	Contacts
CH	University of Bern (project lead) University of Geneva Swiss Space Center (EPFL) ETH-Z	Willy Benz, Nicolas Thomas Didier Queloz Anton Ivanov Michael Meyer
Austria	Institut für Weltraumforschung, Graz	Wolfgang Baumjohann
Belgium	Centre Spatial de Liège Université de Liège	Etienne Renotte Michaël Gillon
France	Laboratoire d'astrophysique de Marseille	Magali Deleuil
Germany	DLR Institute for Planetary Research DLR Institute for Optical Sensor Systems	Tilman Spohn
Hungary	Konkoly Observatory	Laszlo Kiss
Italy	Osservatorio Astrofisico di Catania – INAF Osservatorio Astronomico di Padova - INAF Università di Padova	Isabella Pagano Roberto Ragazzoni Giampaolo Piotto
Portugal	Centro de Astrofisica da Universidade do Porto Deimos Engenharia	Nuno C. Santos Antonio Gutiérrez
Sweden	Onsala Space Observatory, Chalmers University University of Stockholm	R. Liseau G. Olofsson
UK	University of Warwick	Don Polla

Interest of IT in GS to be discussed and defined soon

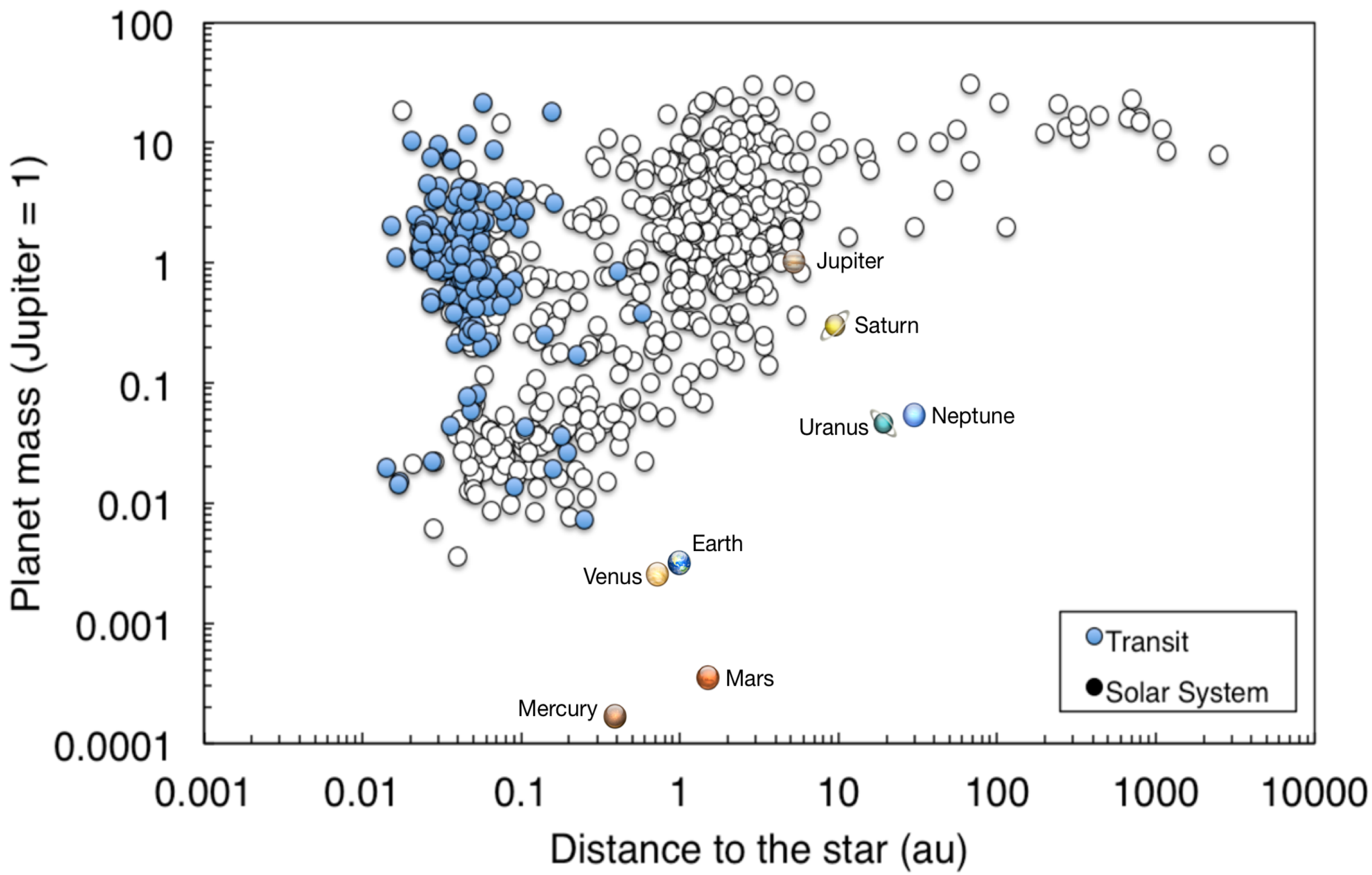
Payload

Ground segment



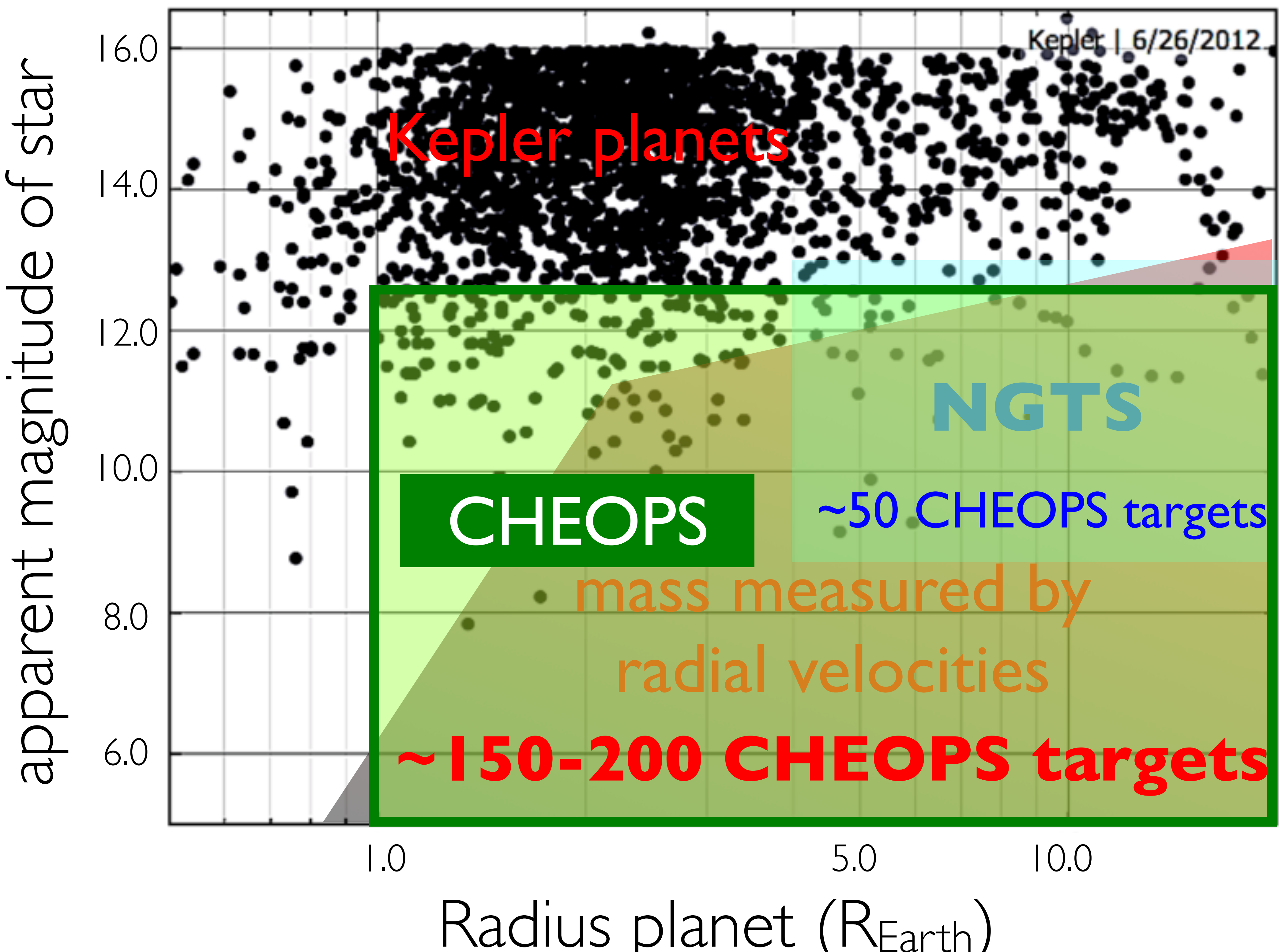
CHEOPS SCIENCE OBJECTIVES

CHEOPS driver: we need planetary sizes



Mass-distance diagram for exoplanets (white) and Solar System planets. Confirmed transiting exoplanets are shown in blue.

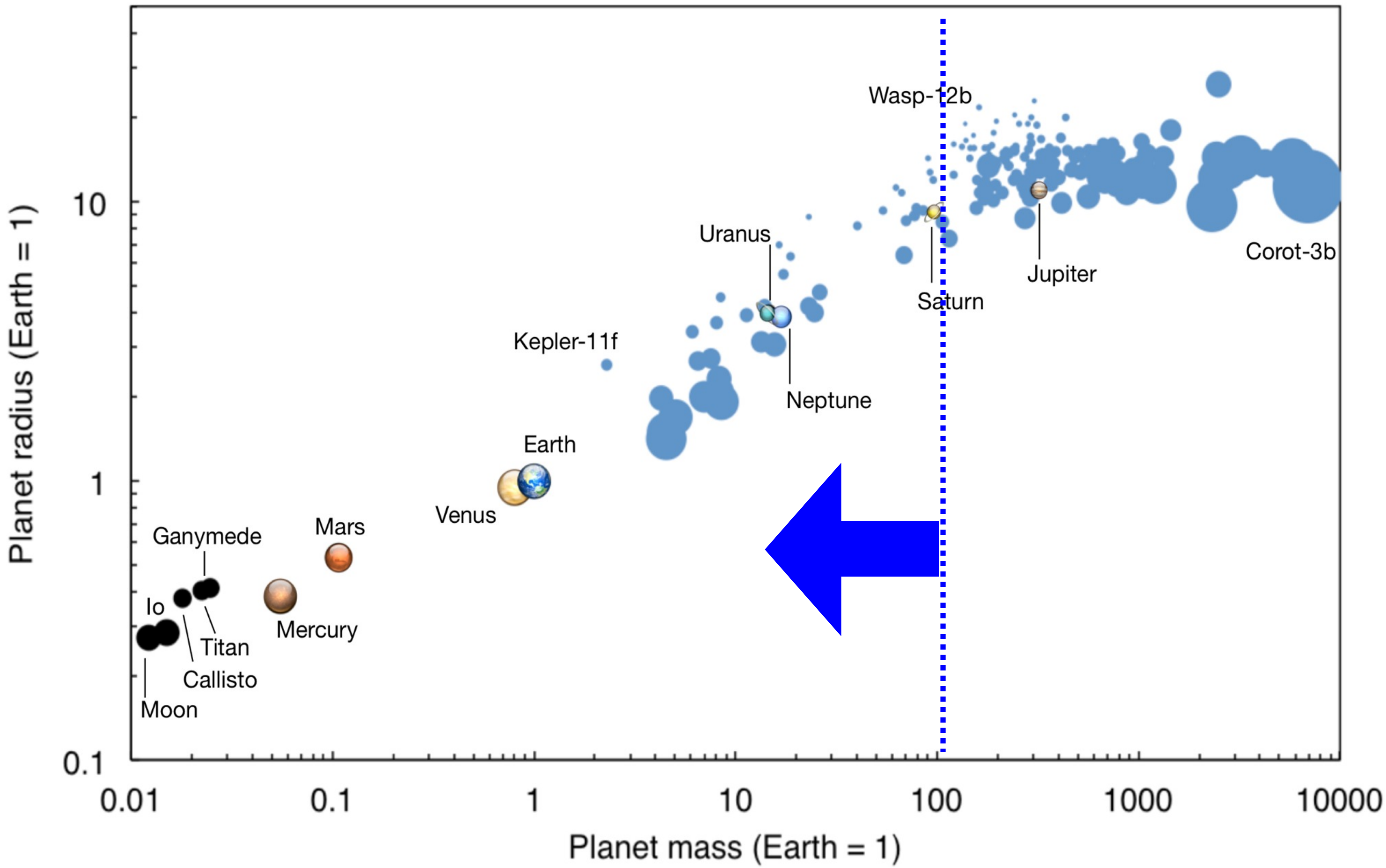
Kepler sizes not enough?



Science objectives

1. Mass-radius relation for planets below the mass of Saturn

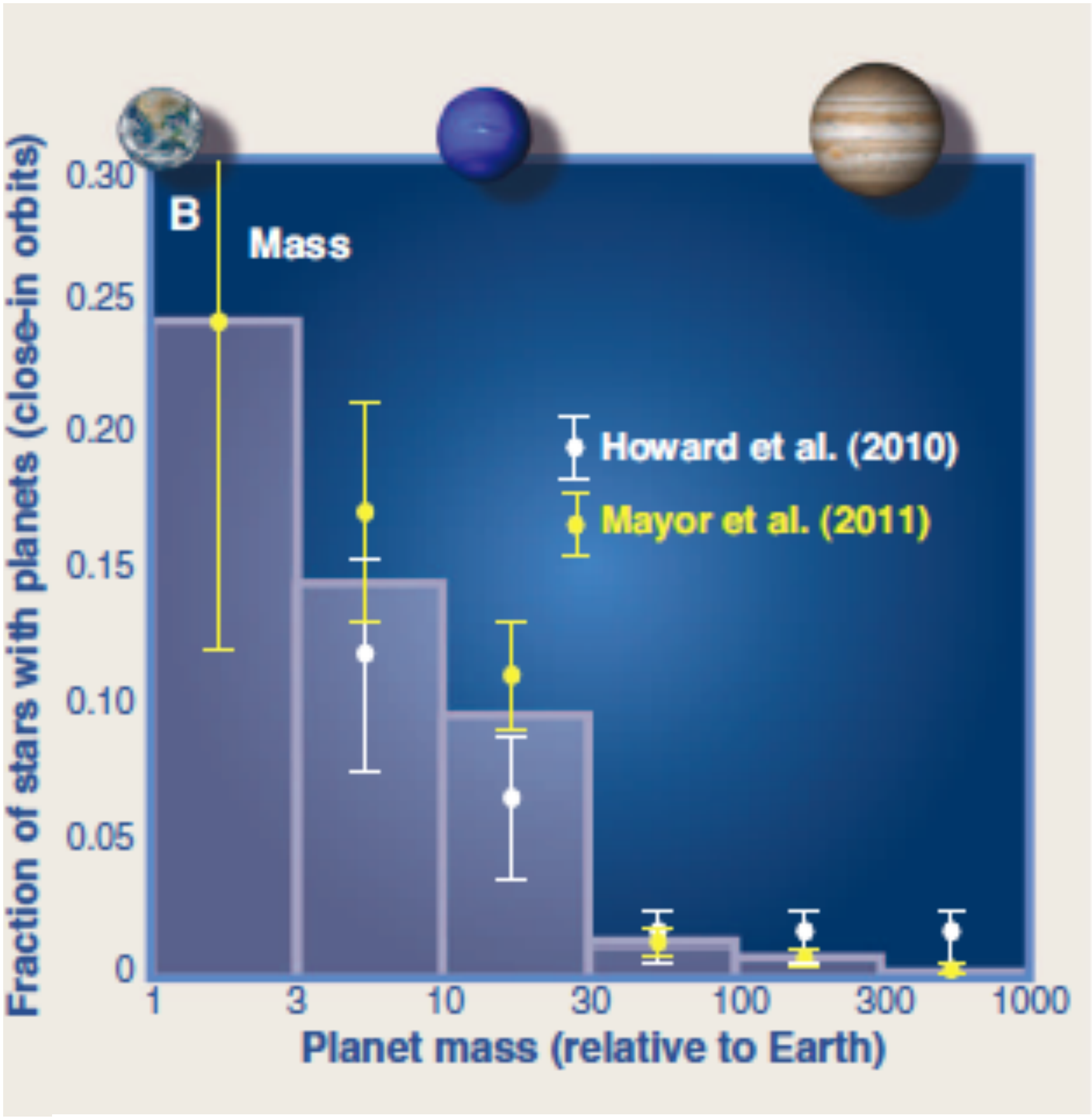
Mass-radius diagram for exoplanets (blue) and Solar System planets and largest moons. For exoplanets, the radius is measured from the transit light curve and the mass from velocimetry. The mean density is represented by the size of the points; The larger the symbol, the denser the planet.

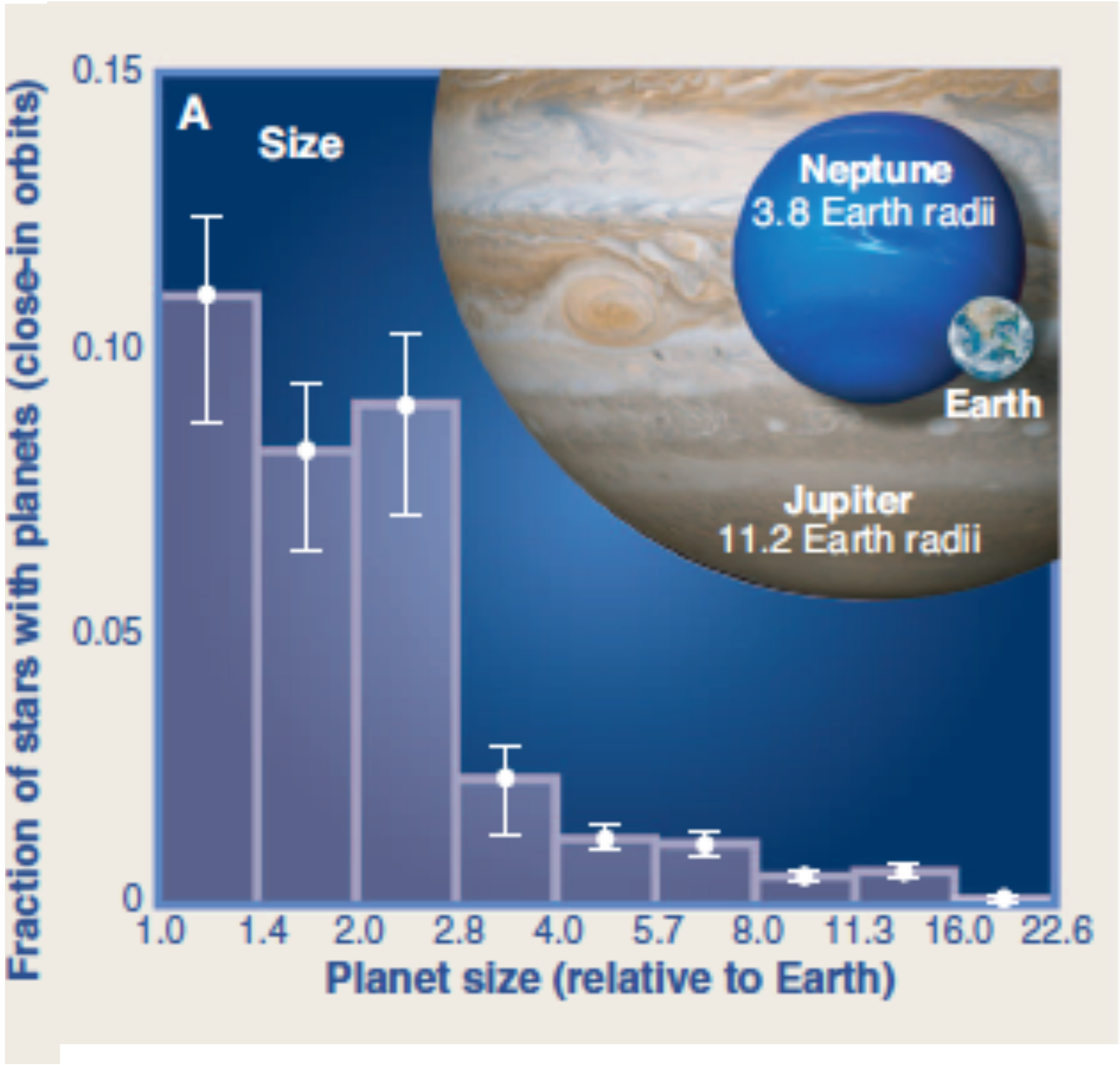


CoRoT-3b is a brown dwarf

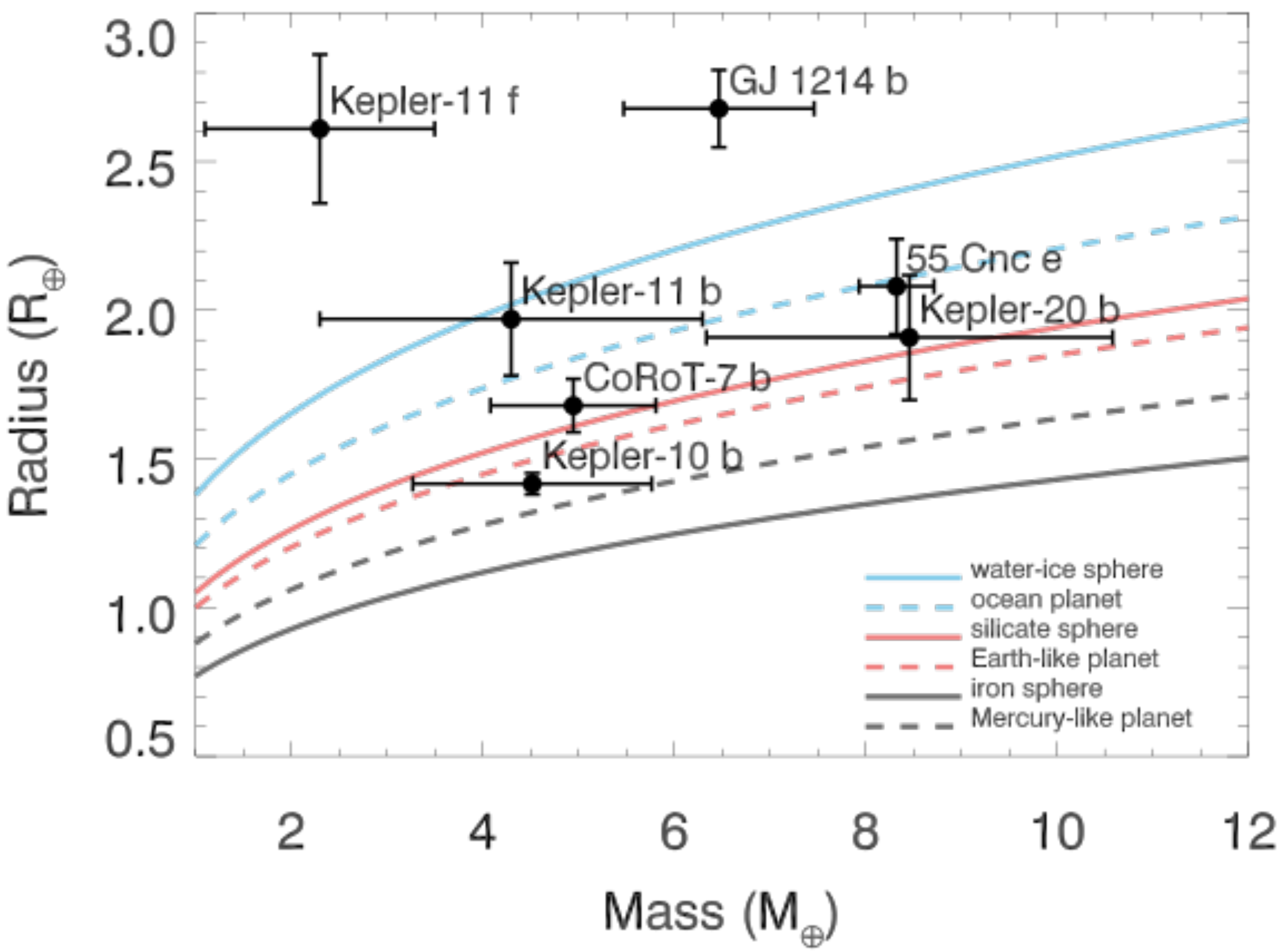
Size & mass distributions of planets orbiting G- and K-type stars.

corrected for survey incompleteness for small/low-mass planets





Howard, 2013, Science 340, 572



CHEOPS provides direct insights into the structure (e.g. presence of a gaseous envelope) and/or composition of the planet.

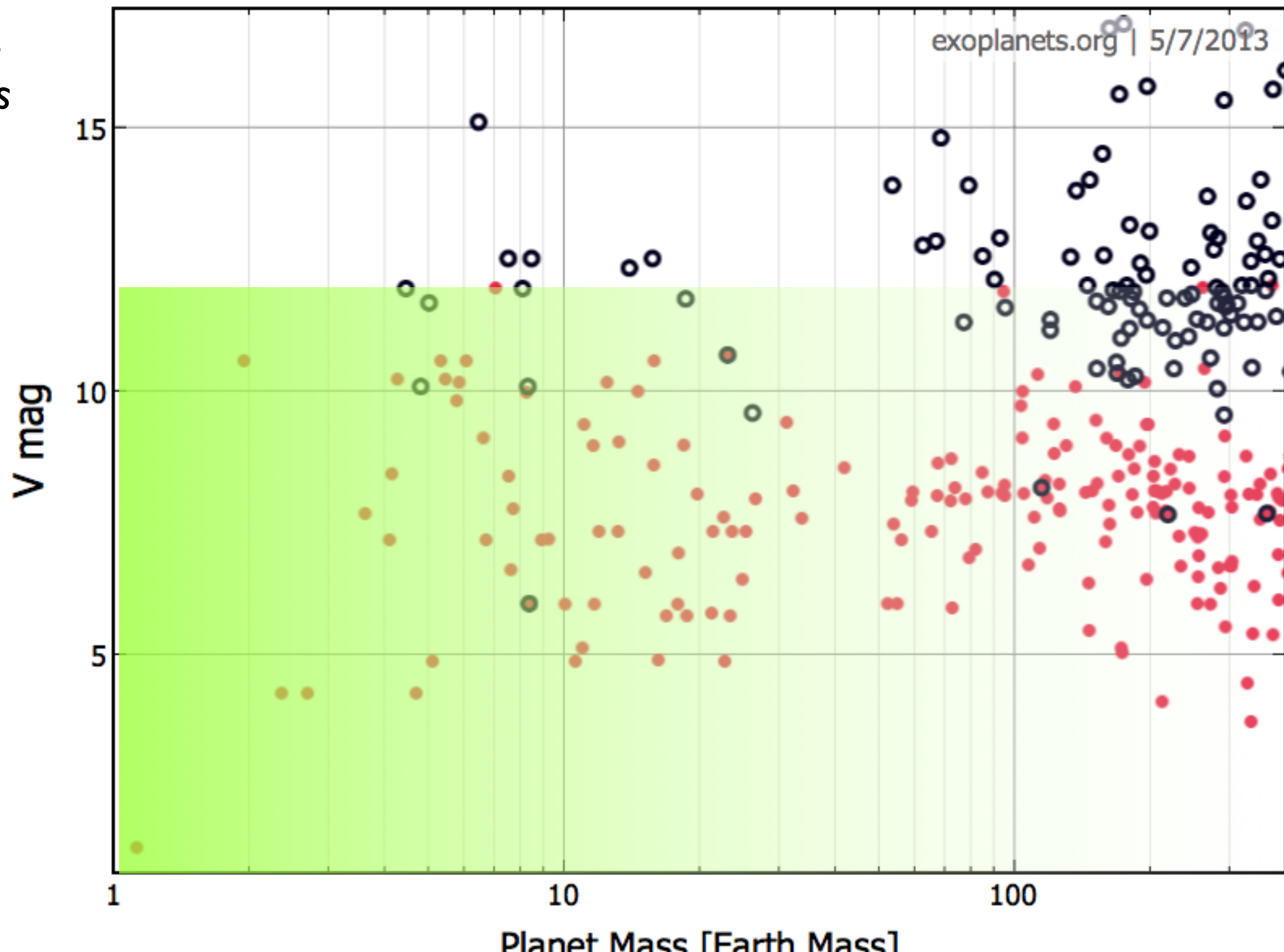
CHEOPS will improve both the sample size as well as the precision of the measurements.

Science objectives

2. New targets for future characterization facilities with spectroscopic capabilities

● RV planets
known mass

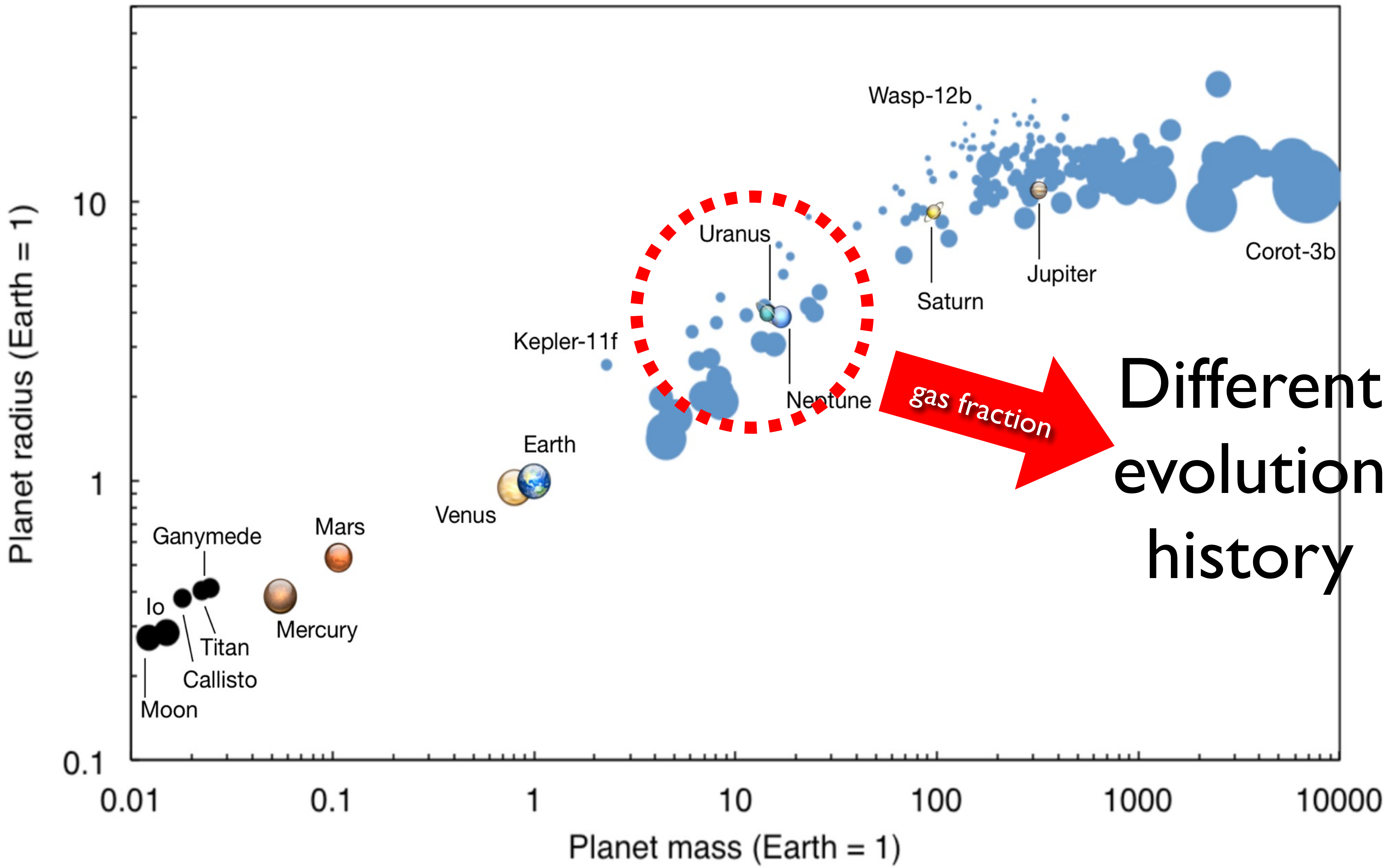
○ Transiting planets
known size



Juicy targets for JWST and EChO!

Identification of planets with atmospheres in the 1–10 M_{Earth} regime

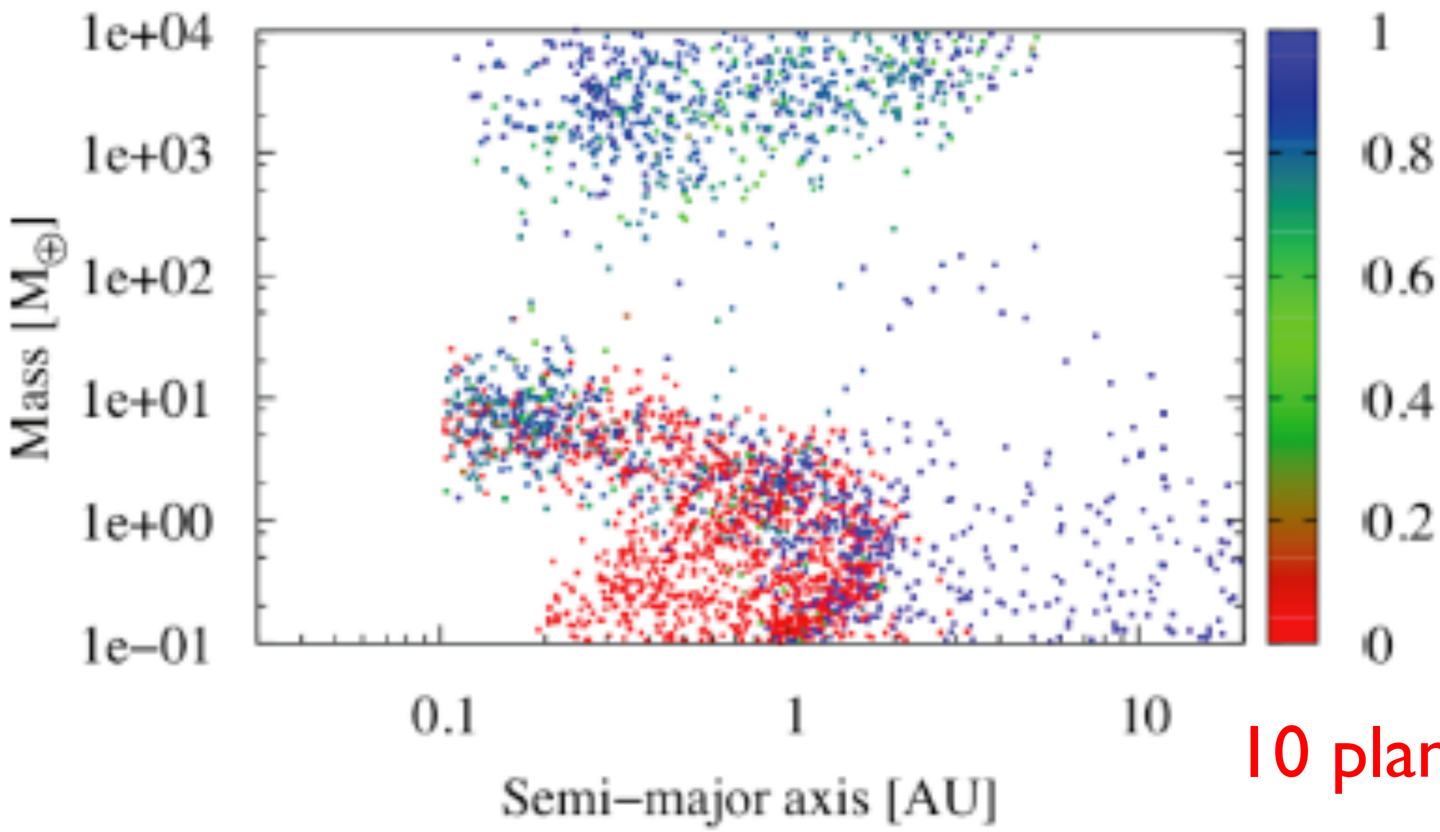
3. Constraints on planet migration paths



Different evolution history

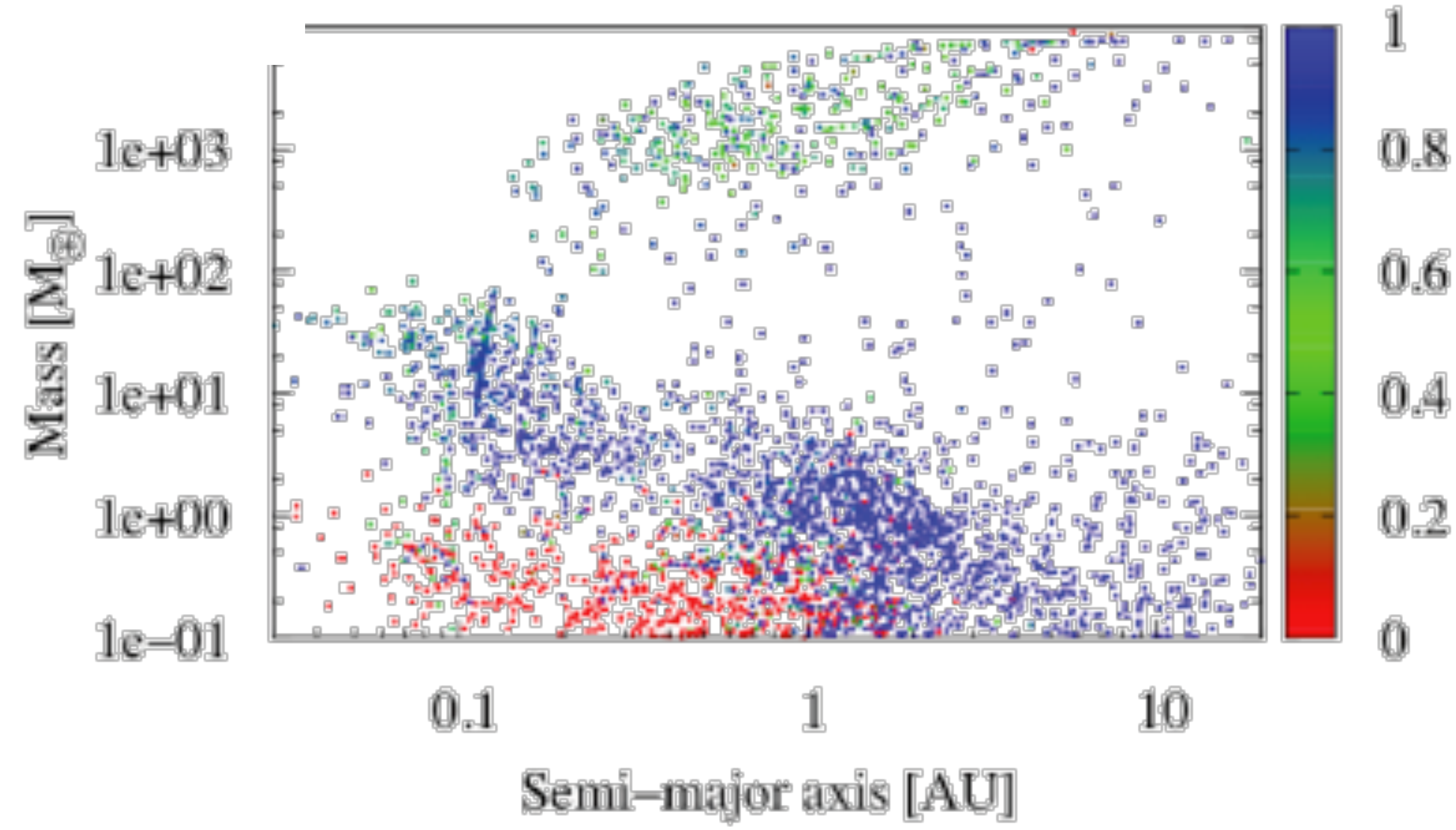
Different migration pattern can be inferred by density measurements

a single planet is allowed to grow in a disc



Colours code different fraction of icy planetesimals in the planetary cores.

10 planets are allowed to grow simultaneously



For planets in the super-Earth to Neptune mass range, the difference in ice content between the two models translates into a difference of ~30% in mean radius.

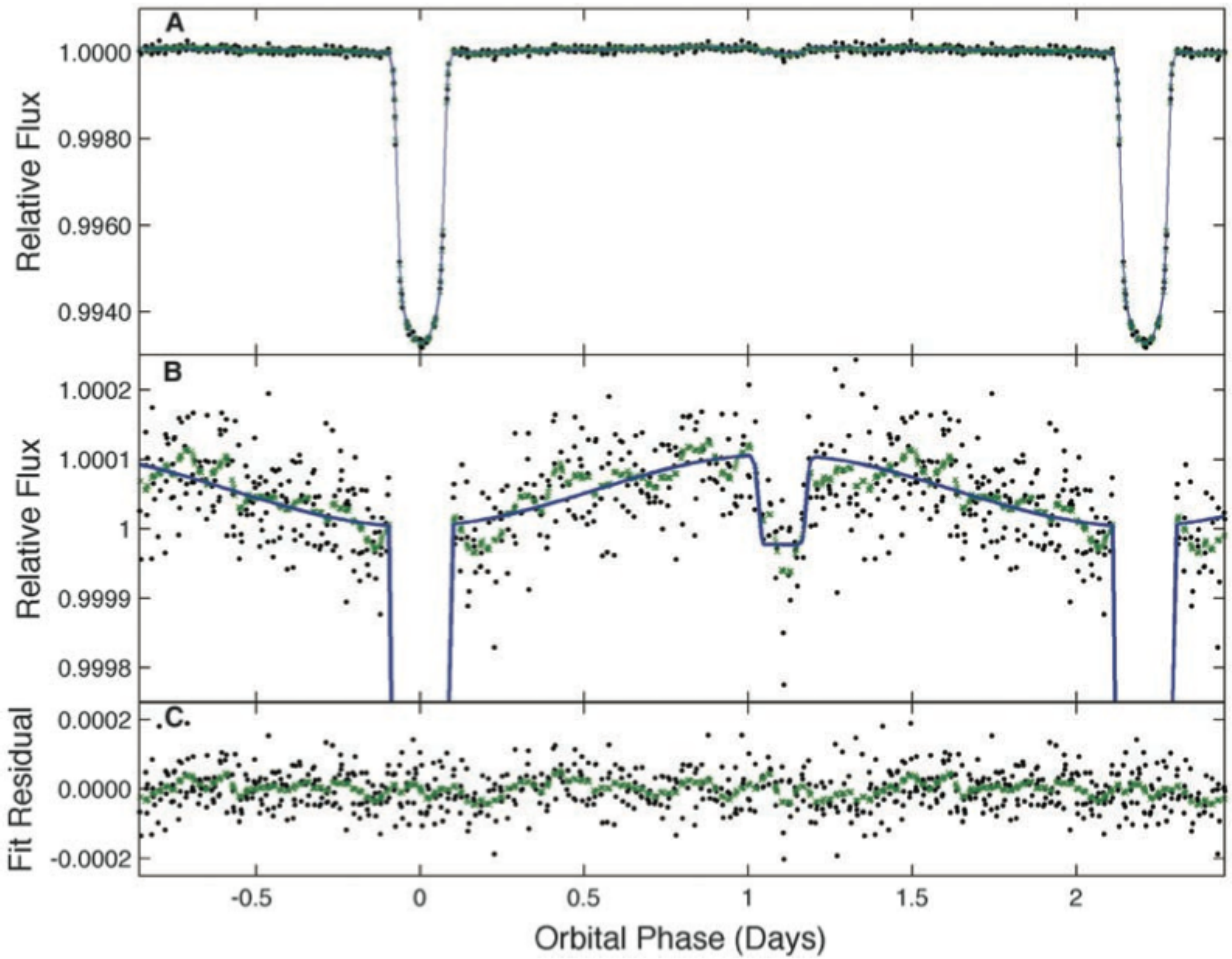
Science objectives

4. Energy transport in hot Jupiter atmospheres

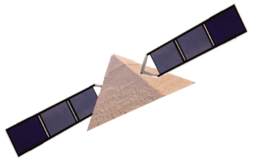
Optical phase curve of a V=10.5 mag star by *Kepler*

HAT-P-7b

Combination of the light reflected by the atmosphere of the planet as well as the thermal emission of the atmosphere.



Borucki et al. (2009)



CHEOPS: Mission Goals

1. **To search for shallow transits on stars already known to host planets**

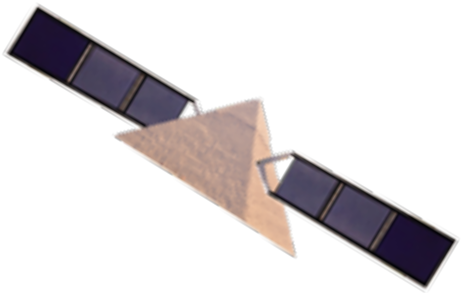
- transit signal-to-noise ratio of 10 for an Earth-size planet
  - period of 60 days
  - on G5 dwarf stars with V-magnitude brighter than 9^{th}.
- identify the presence or absence of a significant atmosphere for planets with masses ranging from Neptune to Earth.

2. **To provide precision radii for a number of hot Neptune planets orbiting stars brighter than 13^{th} V magnitude and to search for co-aligned smaller mass planets.**

- signal-to-noise ratios above 30,
- radii with a precision of 10% or better.

3. **To measure the phase modulation due to the different contribution of the dayside of hot Jupiter planets and in some cases to measure the secondary eclipse.** These measurements provide information about the energy flux in the atmosphere of the planet.

Science Requirements



The current noise limits (total noise) are:

- V mag <= 9:
  - 6 hours, 10 ppm (100 ppm at SN 20)
  - 20 minutes, 50 ppm
  - 1 minute, 150 ppm
- V mag <= 12.0 (goal 13):
  - 3 hours, 85 ppm (2500 ppm at SN 30)
  - 1 minute, 1100 ppm

Sky coverage:

- 25% of the sky with 2/3 in the southern hemisphere should be visible for a cumulative duration of 15 days per year with interruptions less than 20 minutes per orbit
- 50% of the whole sky (goal 75% -60..+60) should be accessible
  - for a minimum of 60 days of observation per year and per target
  - Interruption of the orbit less than 50% of the orbit time

Exposure time and data rate:

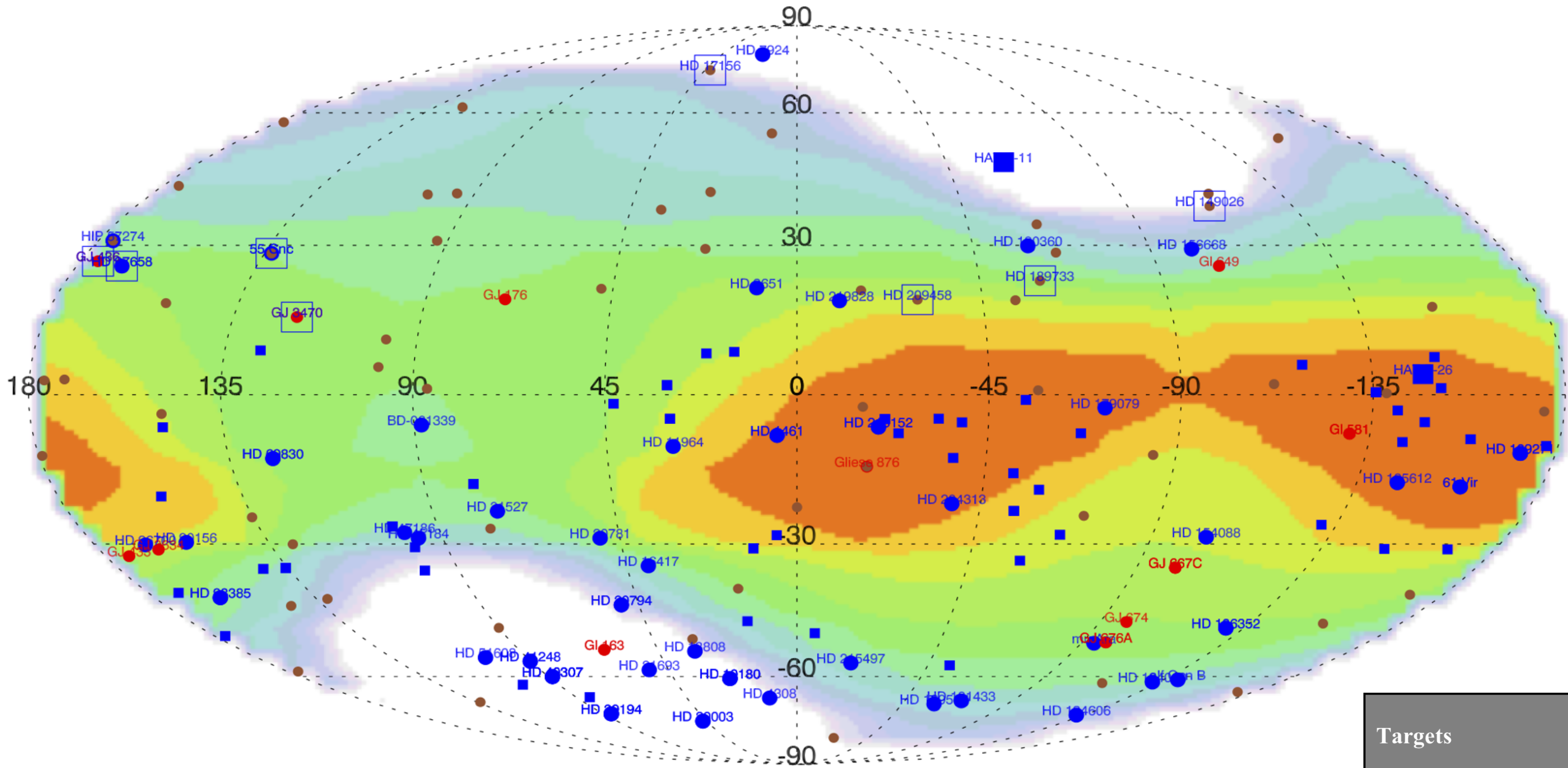
- Exposure time shall be variable from 1 to 60 s
- Donwlink 60 s exposures co-added 200x200 px

Mission Duration:

- 3.5 yr mission design lifetime

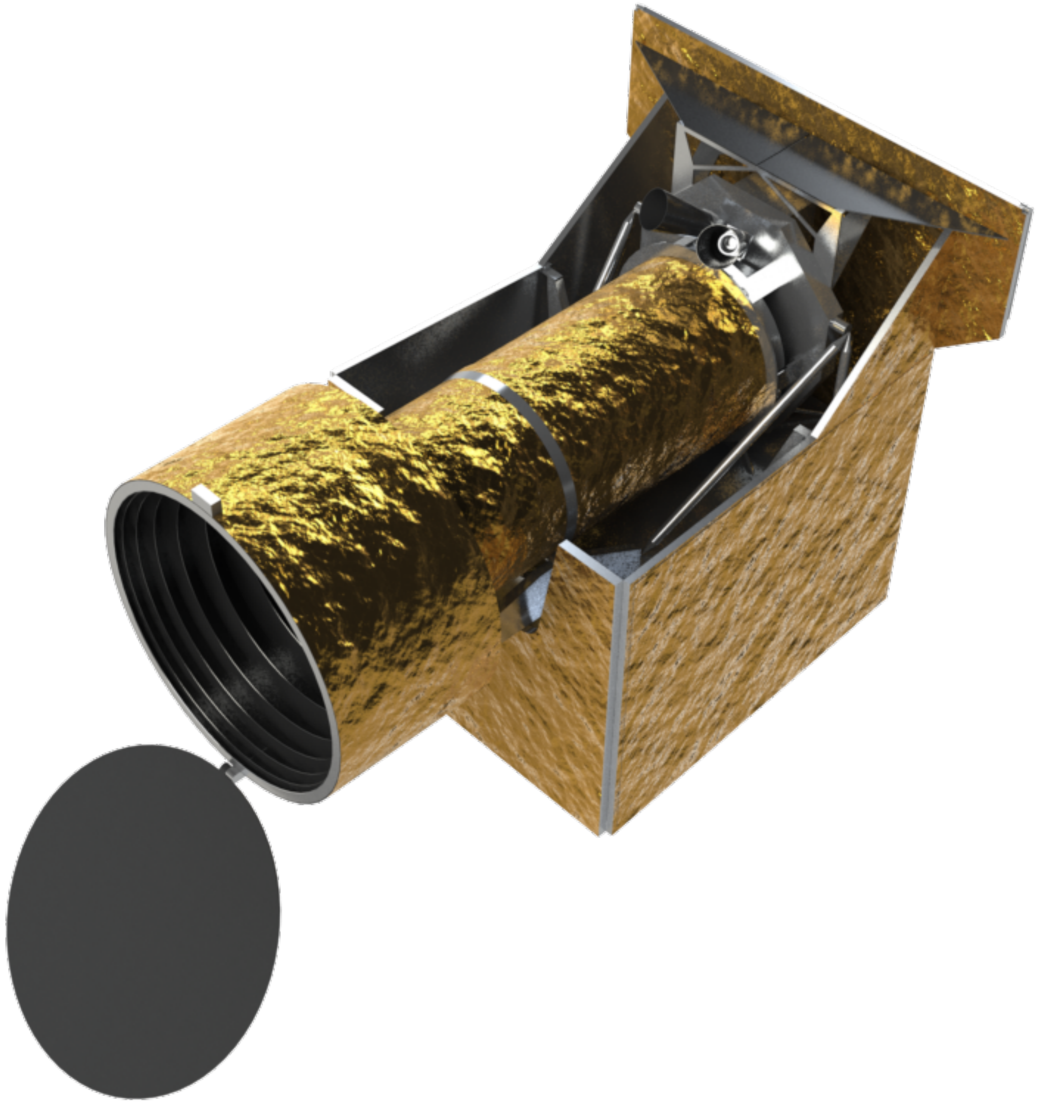
CHEOPS Sky visibility

The colour gradient indicate the time that CHEOPS could spent pointing at given coordinates, taking into account pointing restriction due to the Sun exclusion angle (120°), occultation by the Earth for an orbital altitude of 800 km, a stray light exclusion angle of 35°, and requiring that CHEOPS is able to observe for at least 50 min during each orbit.



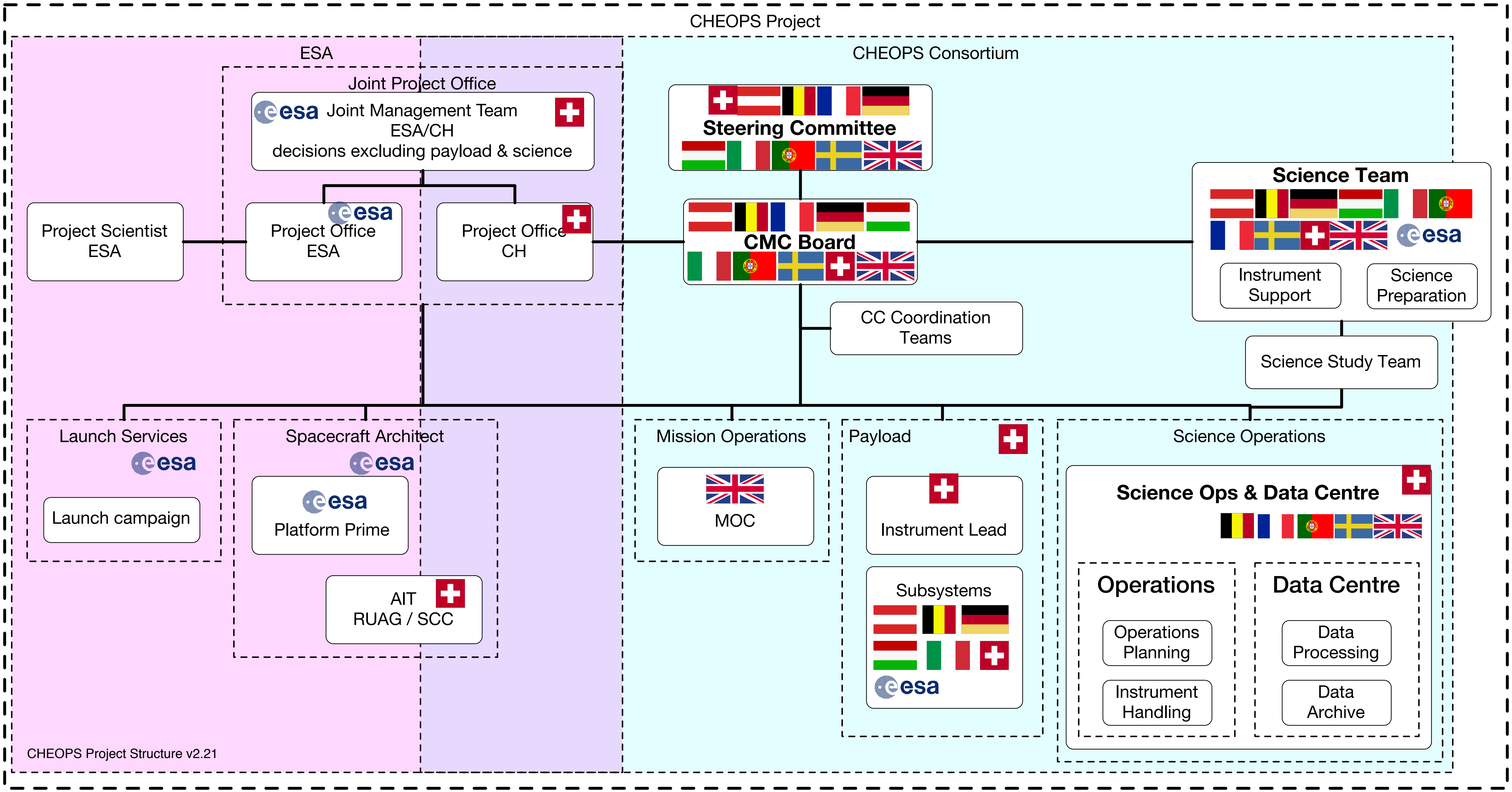
Targets	Mass limit (M⊕)	Mag limit (*V*)	# Targets	Symbol in Errore. L'origine riferimento non è stata trovata.
Super-Earths & Neptunes detected by RV surveys	< 30	< 9	62 known	●
Neptunes detected by ground-based TR surveys	< 60	< 12	2 known 60 simulated	■ ▪
Planets detected by RV surveys around M dwarfs	< 30	< 13	18 known	•
Hot Jupiters detected by RV surveys around bright stars	> 30	< 9	54 known	•

White regions cannot be observed due to the Sun, while orange regions can be observed for 2000+ hours per years.



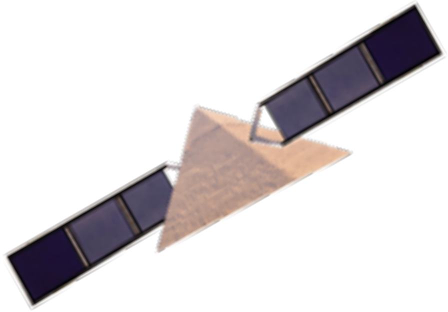
CHEOPS MANAGEMENT

CHEOPS Organization



CHEOPS-IT Contributions

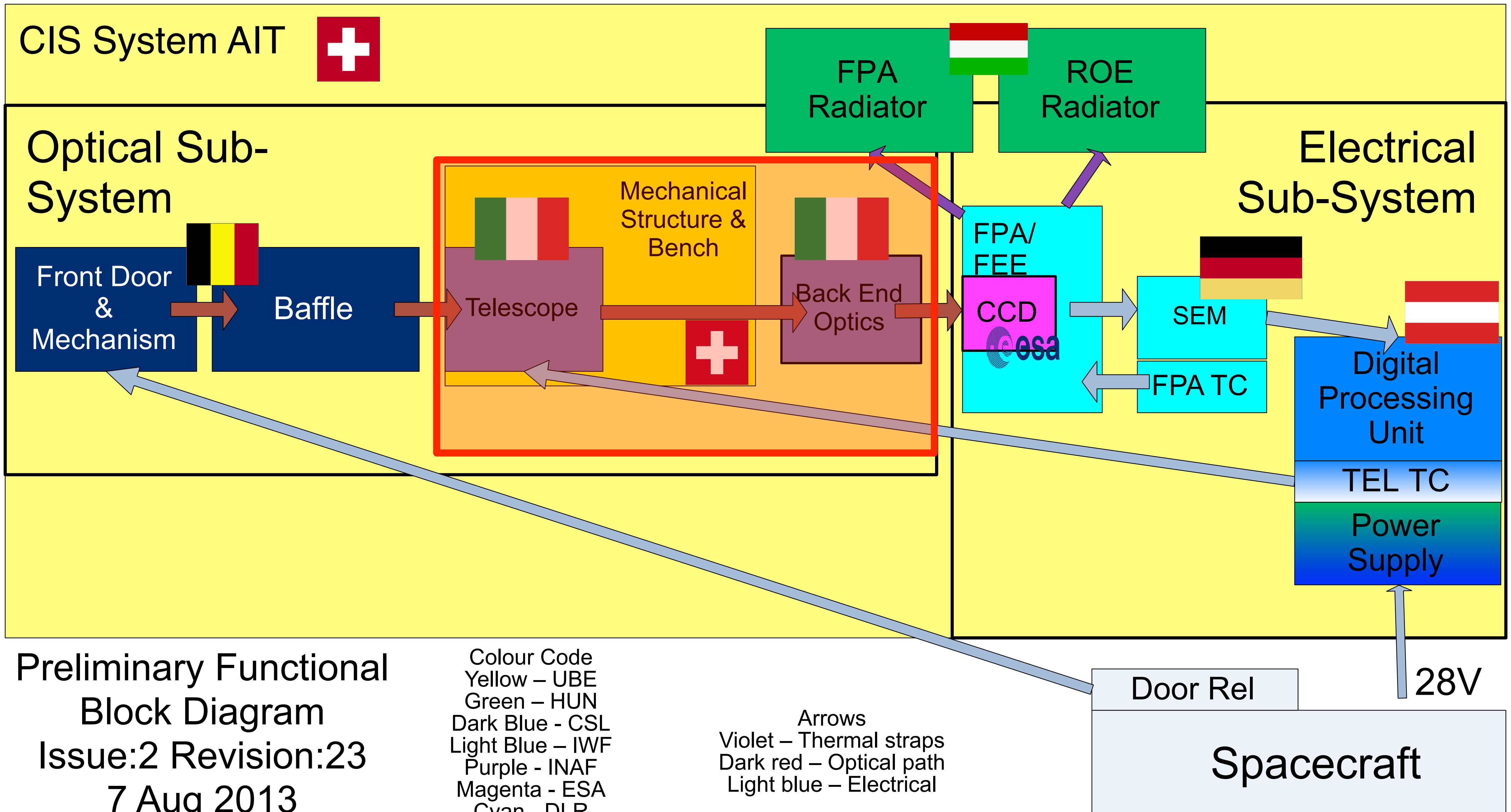
- Science
- Telescope (from optical design to AIV)
- ASDC as data archive mirror (tbc)



CHEOPS in Italy

- 5 INAF structures
  - OACT (S, P)
  - OAPD (S, P)
  - OAPA (S)
  - OAT (S)
  - FGG (S)
- Dip. Fis. e Astron. UNIPD (S)
- ASI
  - ASDC (GS)

CHEOPS Instrument System

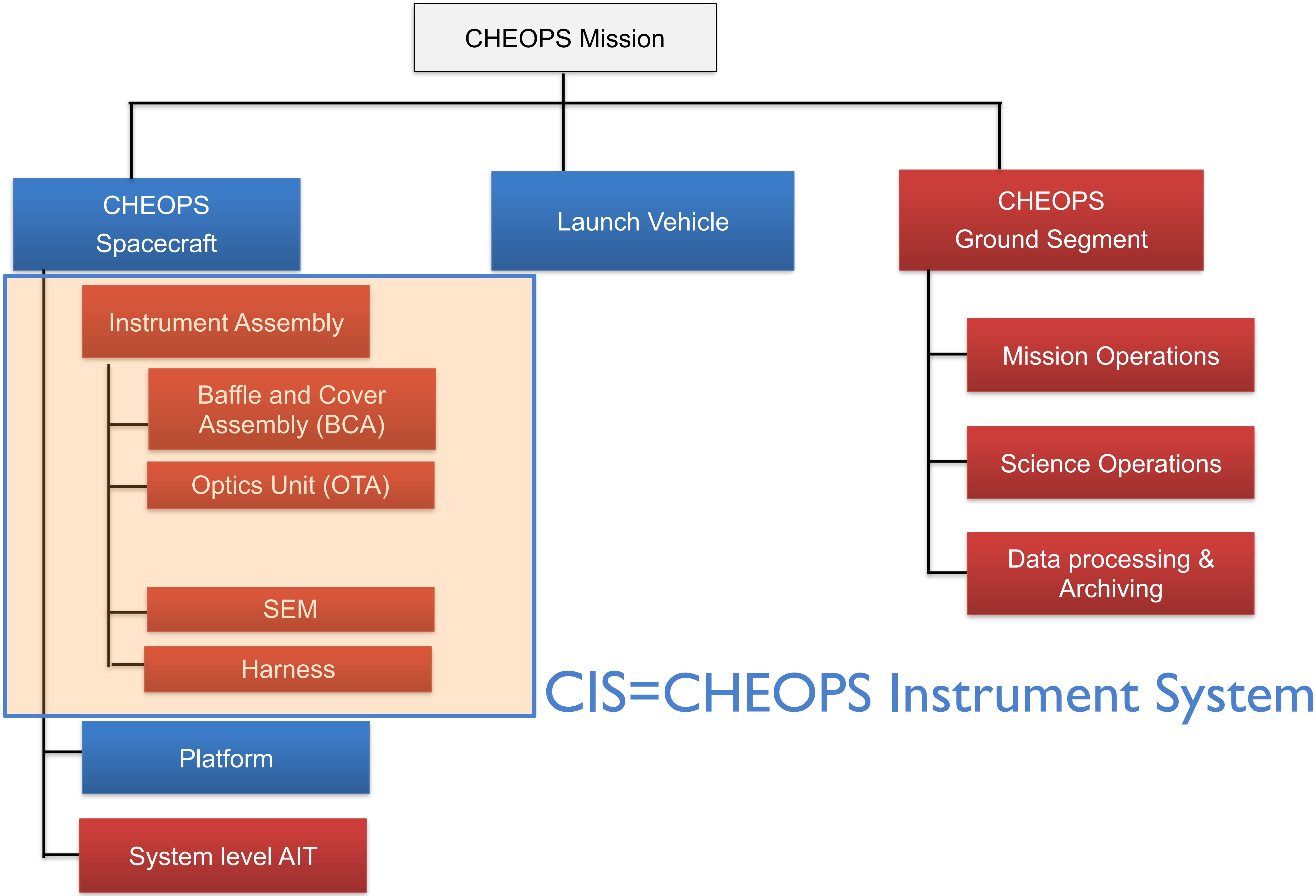


Preliminary Functional Block Diagram
Issue:2 Revision:23
7 Aug 2013

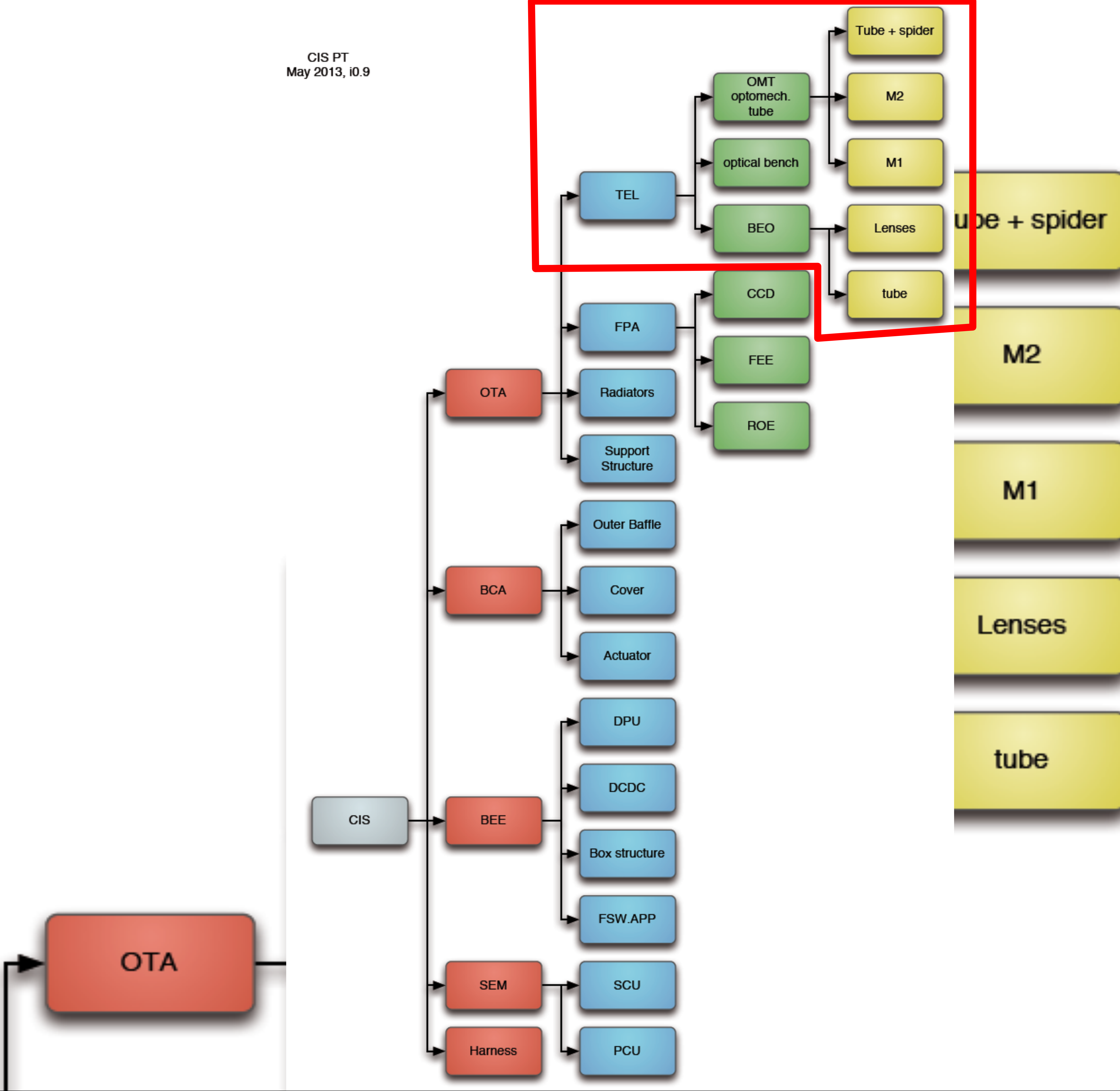
Colour Code
Yellow – UBE
Green – HUN
Dark Blue - CSL
Light Blue – IWF
Purple - INAF
Magenta - ESA
Cyan - DLR

Arrows
Violet – Thermal straps
Dark red – Optical path
Light blue – Electrical

CHEOPS Product Tree

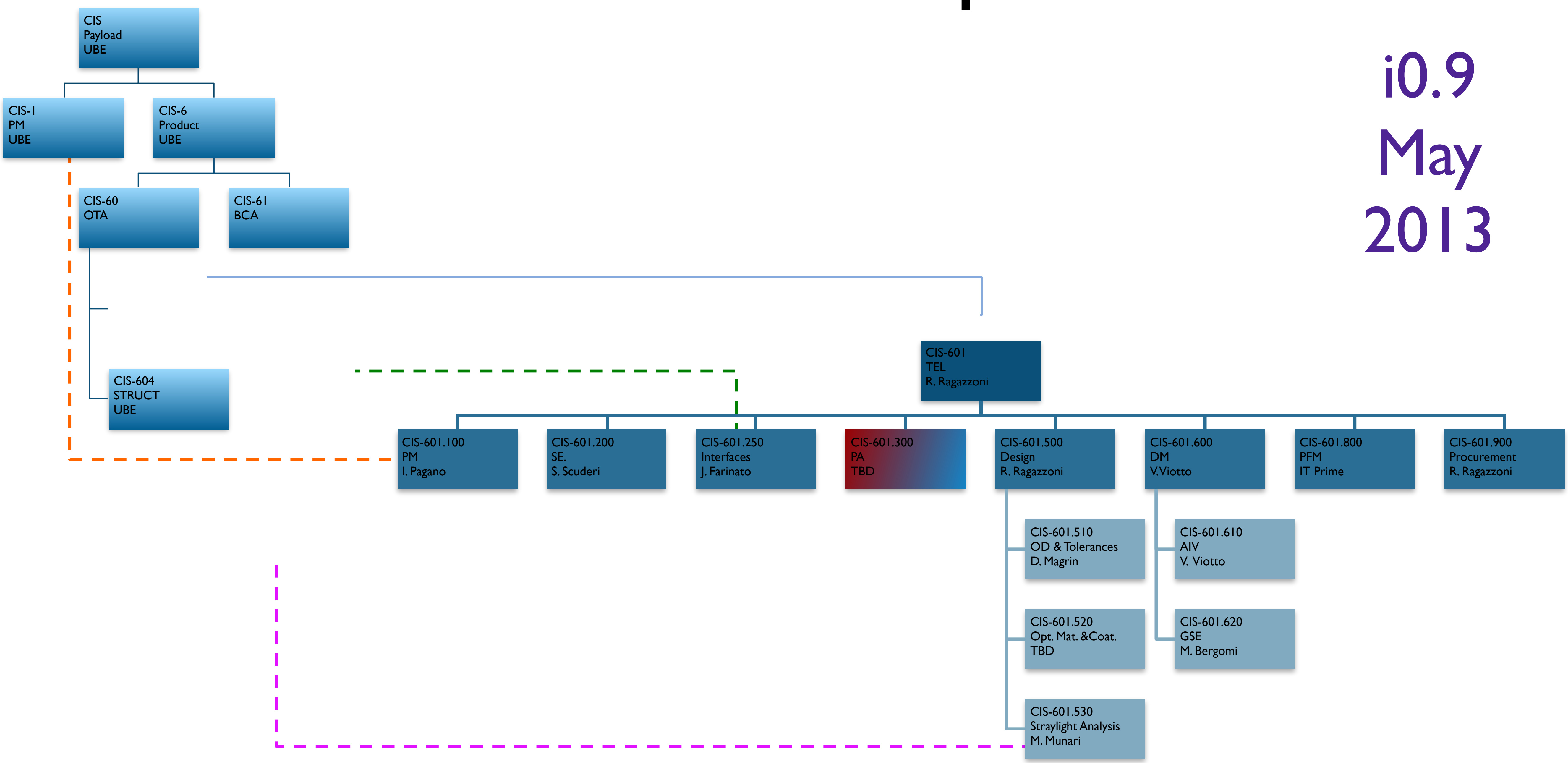


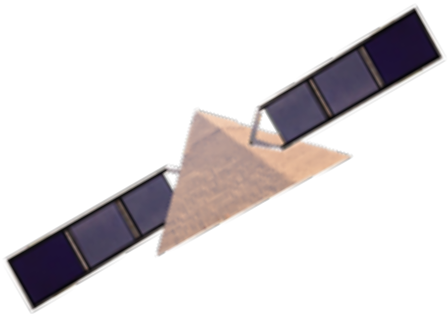
CIS PT
May 2013, i0.9



CHEOPS Telescope WBS

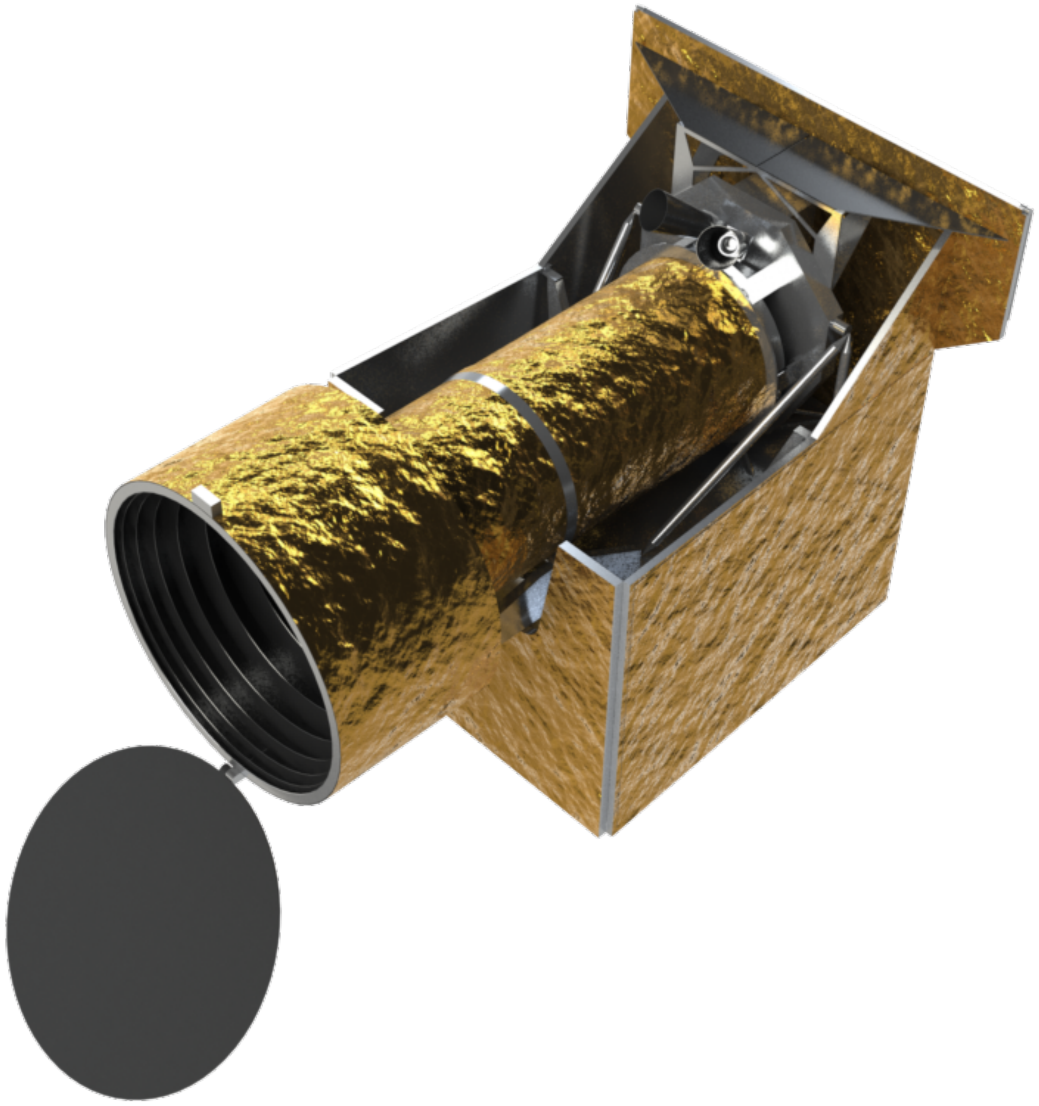
i0.9
May
2013





CHEOPS Milestones

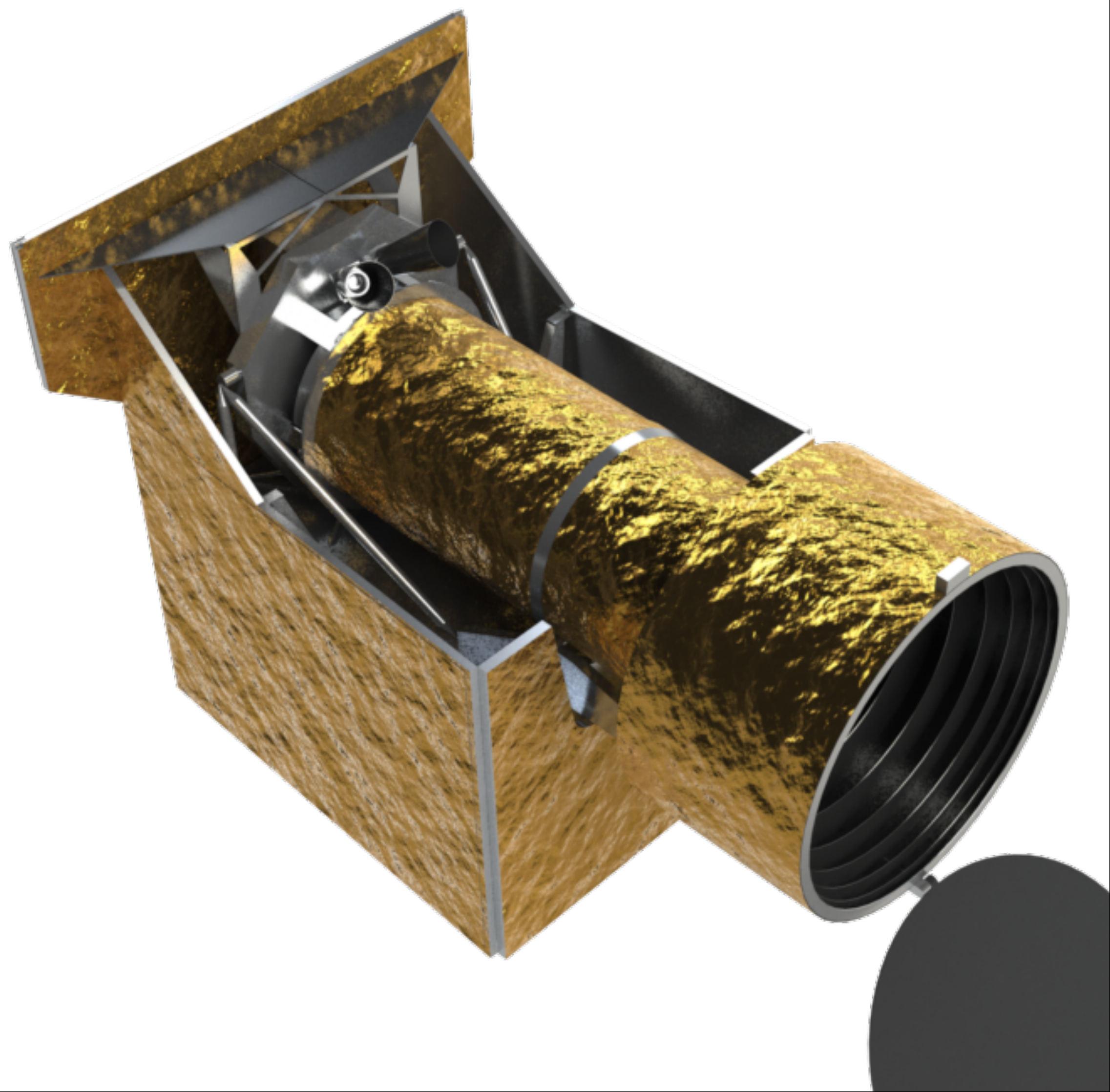
Phase or Review	Instrument	**Platform**
PRR	3.06.2013	
SRR	15-16.10.2013	14.2.2014 (TEB completed)
Mission adoption	Feb 2013	
PDR	31.03.2014	14.07.2014
CDR	19.11.2014	12.12.2014
Instr. EM available at PF	01.05.2015	
IAR	26.08.2016	14.09.2016 (pf at RUAG)
CHEOPS S/C QAR		24.03.2017
System margin	6 months	
Launch		19.12.2017



CHEOPS TELESCOPE

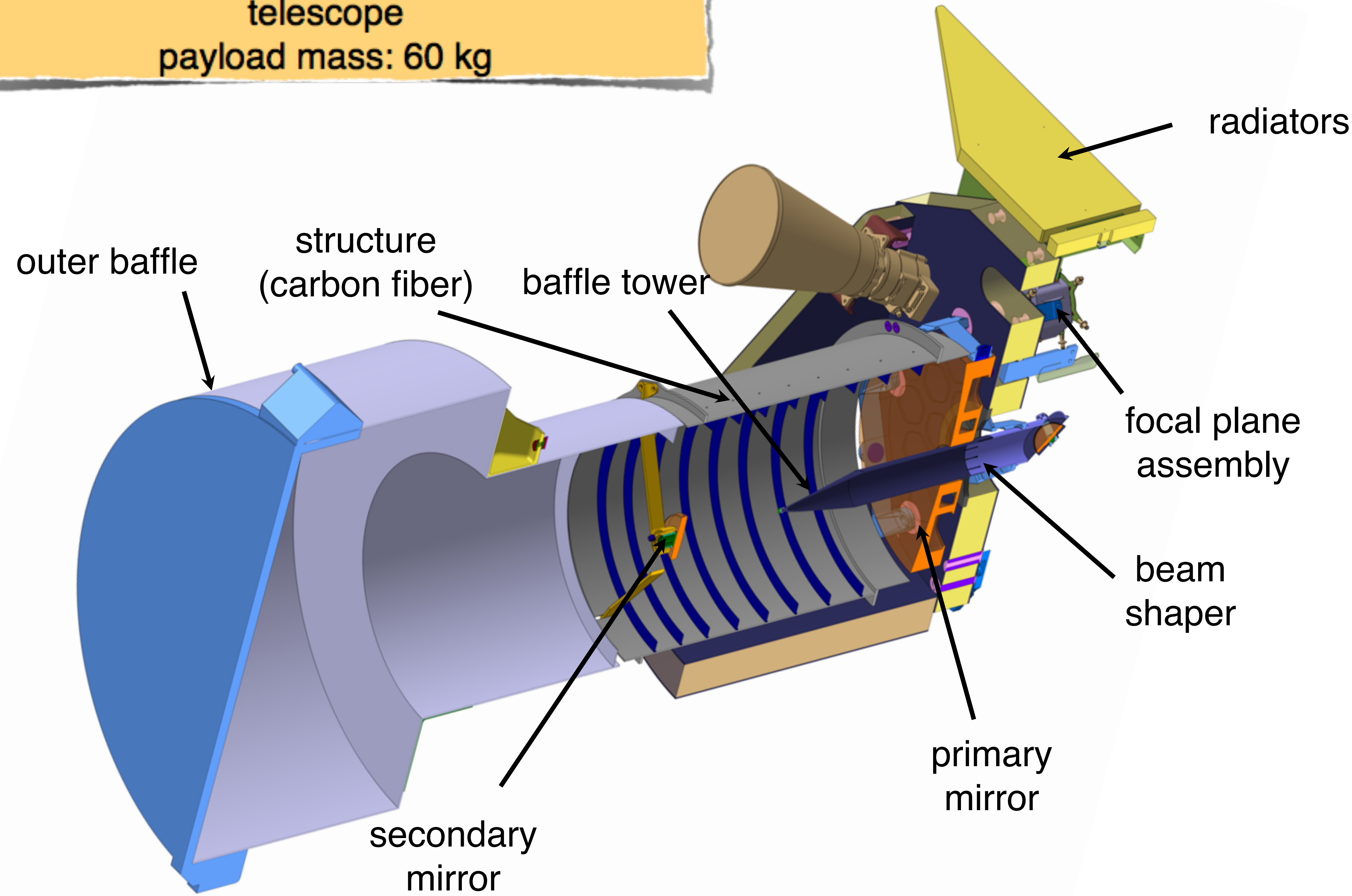
Platform

- Attitude Control
  - 3-axis stabilized S/C - one side facing Earth
  - pointing accuracy < 8 arc sec rms for 10h
- Instrument Power
  - 50 W continuous power,
  - 70 W peak
- Data rate
  - 1 Gbit/day downlink
- Total mass with payload
  - 200 kg



Payload - CIS

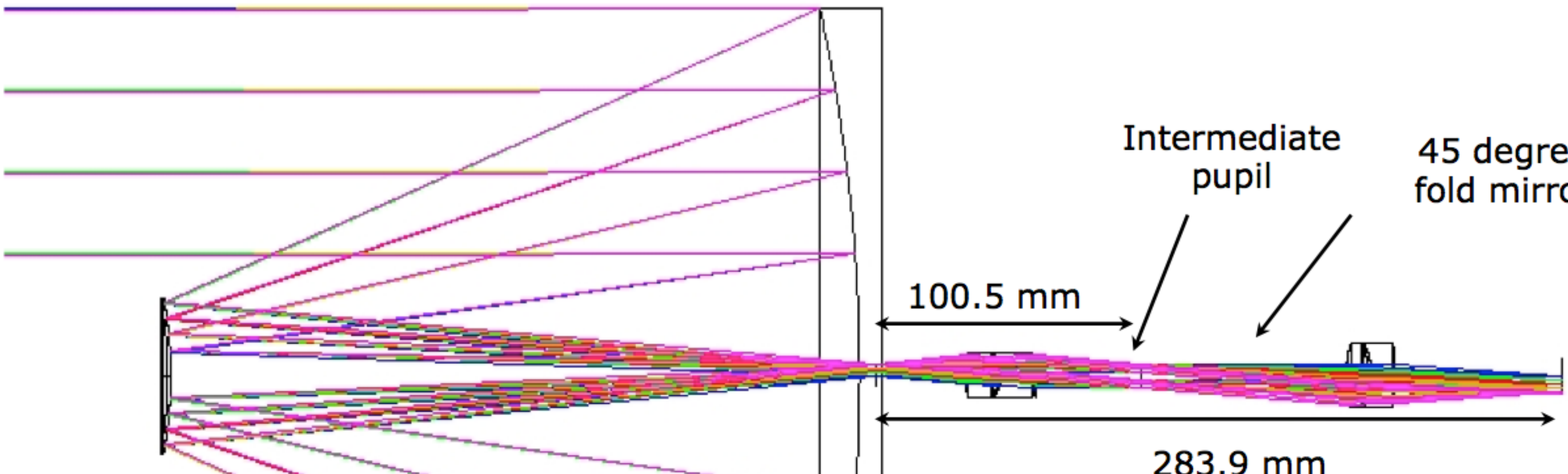
F/8 ~30 cm effective diameter on-axis telescope
payload mass: 60 kg

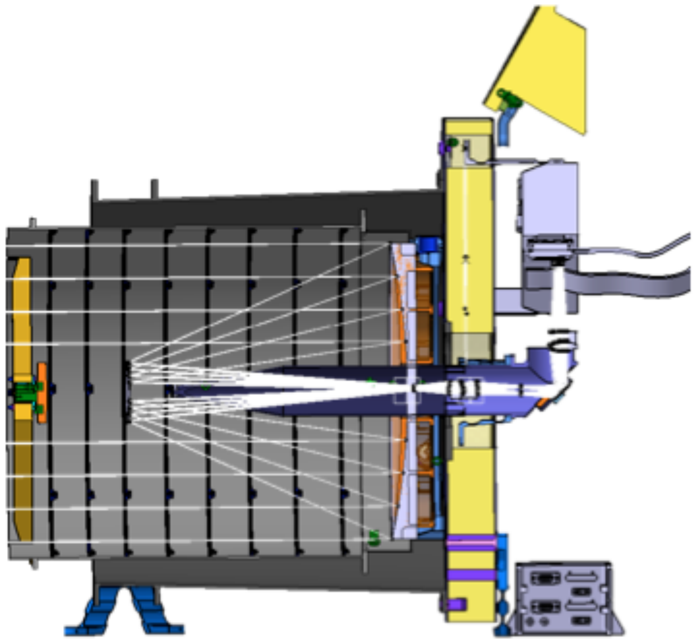


DISCLAIMER

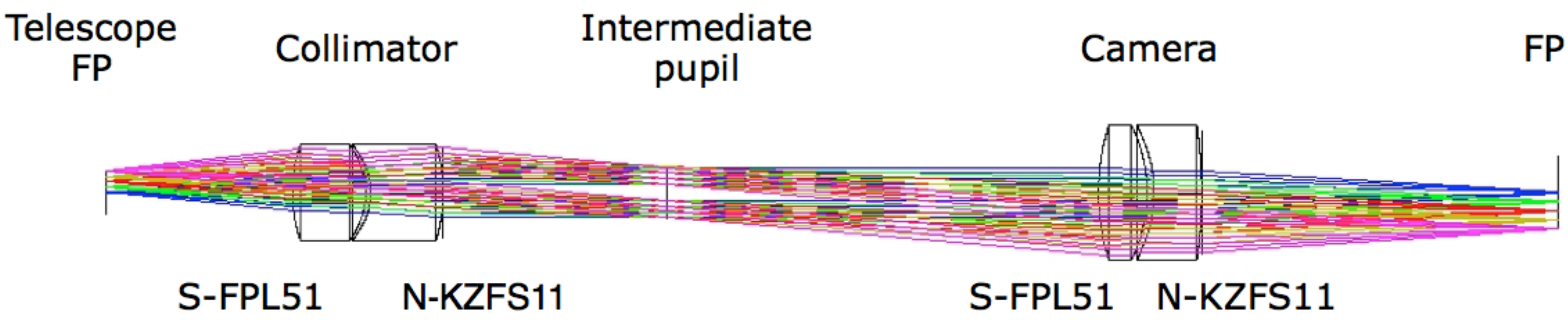
- The following is just an outline of the expected workload and boundary conditions of the Contract ASI will assign in the CHEOPS framework;
- All the following information are provisional and indicative;
- The detailed work description, its limits, and the responsibilities associated, will be available within the Call for Tender.

Collimator – Camera Design





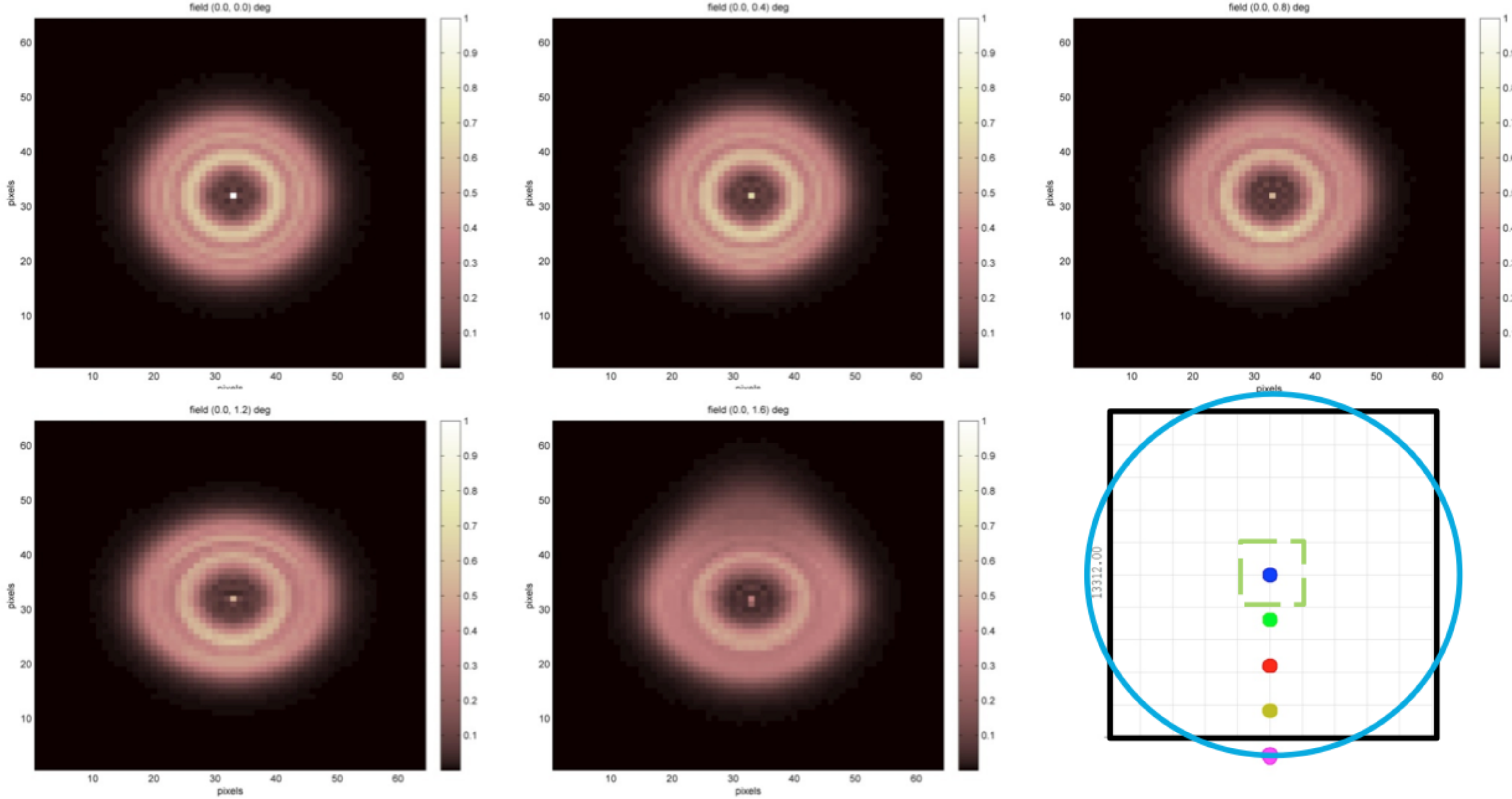
Collimator – Camera Design

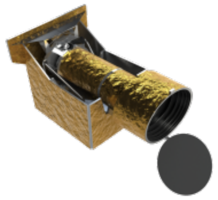


		Radius of curvature (mm)	Thickness (mm)	Lens diameter (mm)	Glasses
telescope FP			38,34		
Col lens 1	s1	31,51	15,00	10	S-FPL51
	s2	-16,12	0,94	10	
Col lens 2	s1	-14,98	14,99	10	N-KZFS11
	s2	-33,81	45,82	10	
Int. pupil			88,85		
cam lens 1	s1	47,21	10,00	14	S-FPL51
	s2	-30,68	1,33	14	
cam lens 2	s1	-29,11	9,79	14	N-KZFS11
	s2	-95,47	73,36	14	
FP					

Defocused PSFs approach Performances

A displacement of about 3.5 mm with respect to the nominal focal plane has been applied in order to obtain an on-axis defocused PSF having diameter of about 30 arcsec (30 pixels) for flat spectrum (400-1100nm, sampling 100nm).





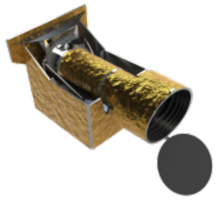
AIV plans

- Demonstration Model (DM)
    - **Why:** used to test TEL integration, alignment and verification (no cryo-vacuum) procedures
    - **When:** starting from 2nd half of 2014
    - **Input:** mechanical structure from UBE. Equivalent to STM, but made with different material (CTE), i.e. thermally not equivalent.
    - **Where:** INAF-OAPD

    - **Other use:** testing integration and alignment procedures for TEL +FPA
    - **Where:** UBE

- GSE for DM reused for TEL PFM integration, alignment, and verification.

(cf . *CHEOPS-INAF-MA-MIN-004*)

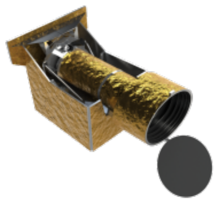


DM GOALS

- To find and validate an alignment procedure giving a system compliant with requirements and tolerances
  - TEL optics to Optical Bench (OB) alignment:
    - 500 µm
    - 400 µrad
  - TEL optics internal alignment:
    - Optical quality (still TBD)
- Opto-mechanical interfaces verifications
- Identify tools useful for the AIV and verify no interferences arise

DM CONCEPT

- At the moment the optical design is made in a way that:
  - The telescope mirrors relative alignment can be optimized (also in focus) separately from the Back-End Optics.
  - The BEO can be internally aligned separately too.

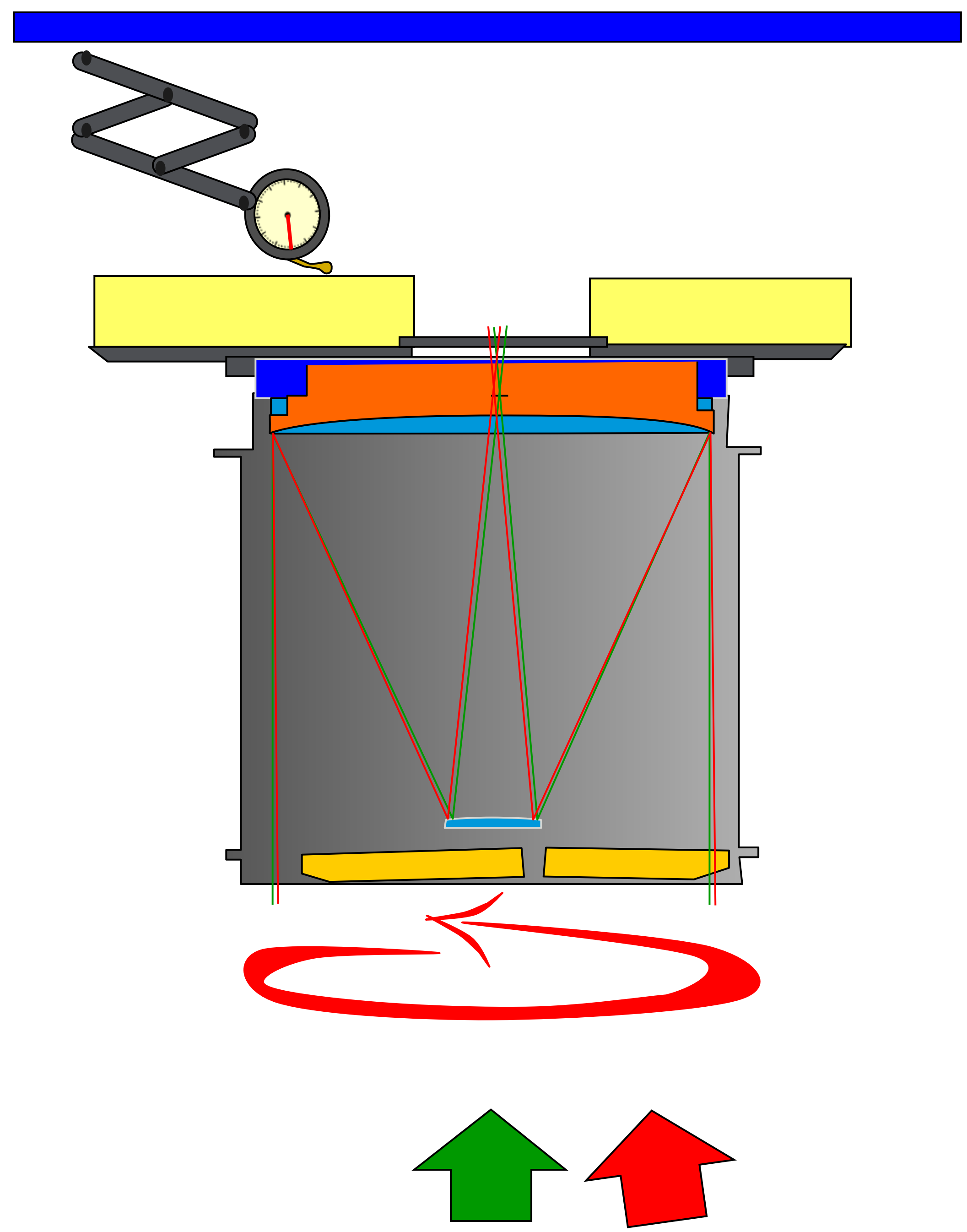


Ritchey-Chrétien internal alignment

- A bearing rotation axis is set as a reference:
  the TEL optical bench is mechanically aligned wrt the bearing with a dial gauge.

- The TEL mirrors are aligned one with respect to the other and to the rotation axis of the bearing.

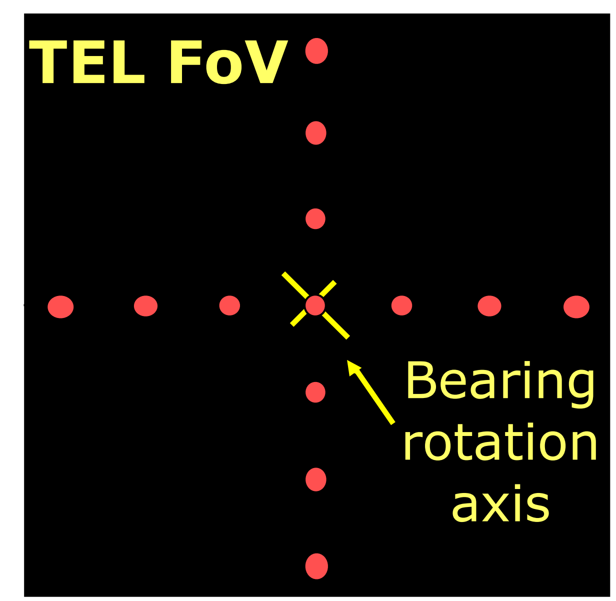
- VERIFICATION:
  the TEL is fed with a beam realized with:
  - Zygo interferometer
  - Beam expander
  - Flat mirror on a 45° adjustable mount to explore the TEL FoV

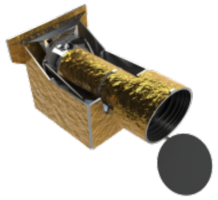


Light exploring the FoV

GOALS:

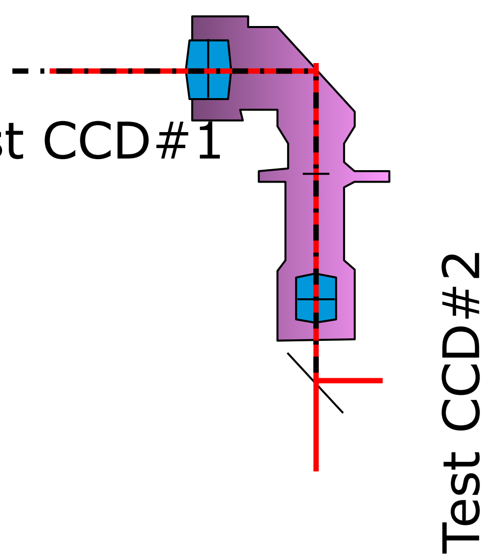
- focused image
- symmetric quality on the FoV
- center of symm.: bearing rotation axis (reference is on a test camera)



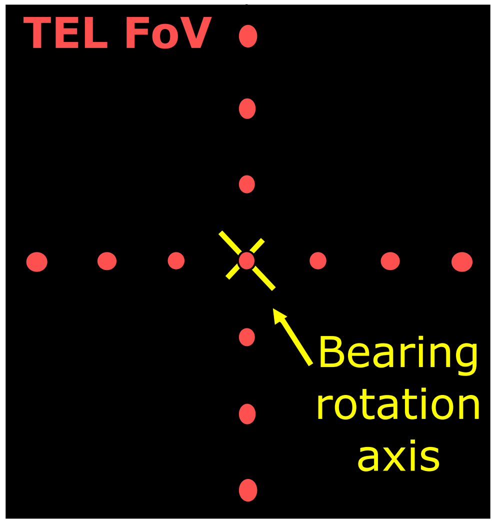


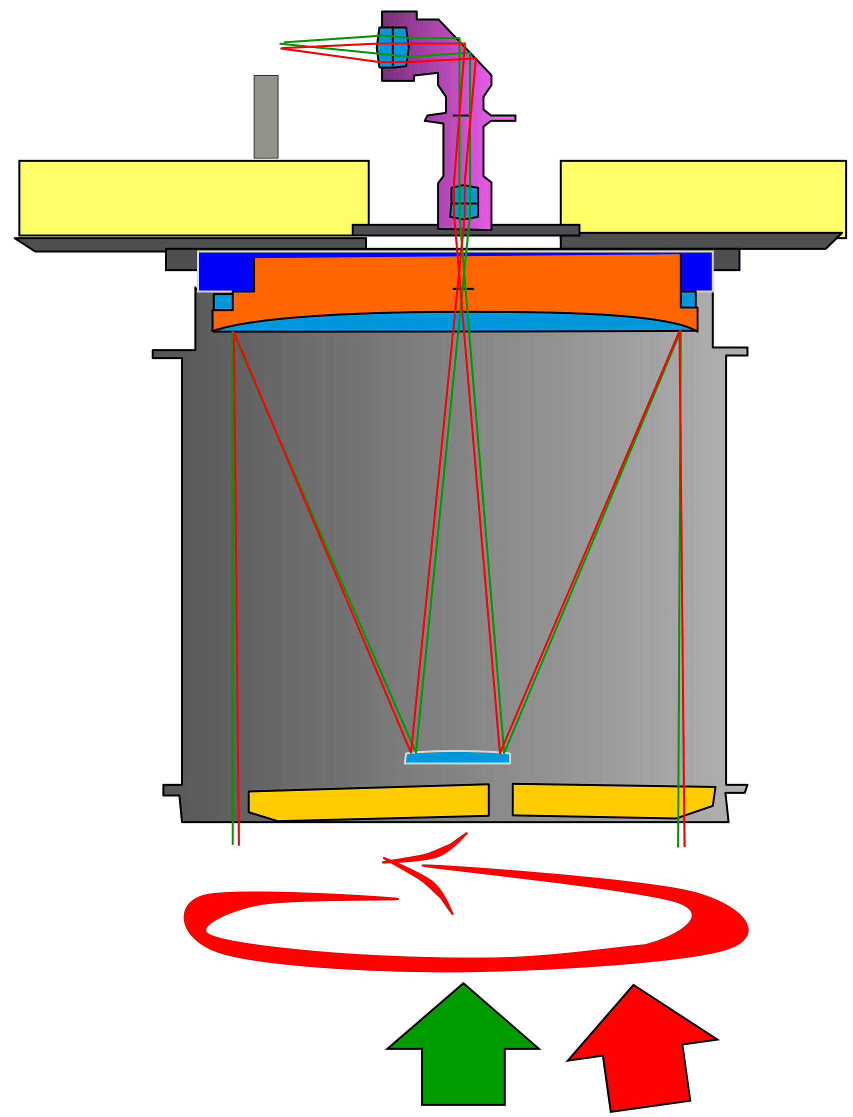
BEO-to-telescope alignment

The Back-End Optics is internally aligned on the optical bench, separately from the rest of the TEL

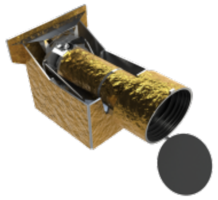


The Back-End Optics is integrated and aligned to the Ritchey-Chrétien TEL.
Quality along the FoV is then verified.



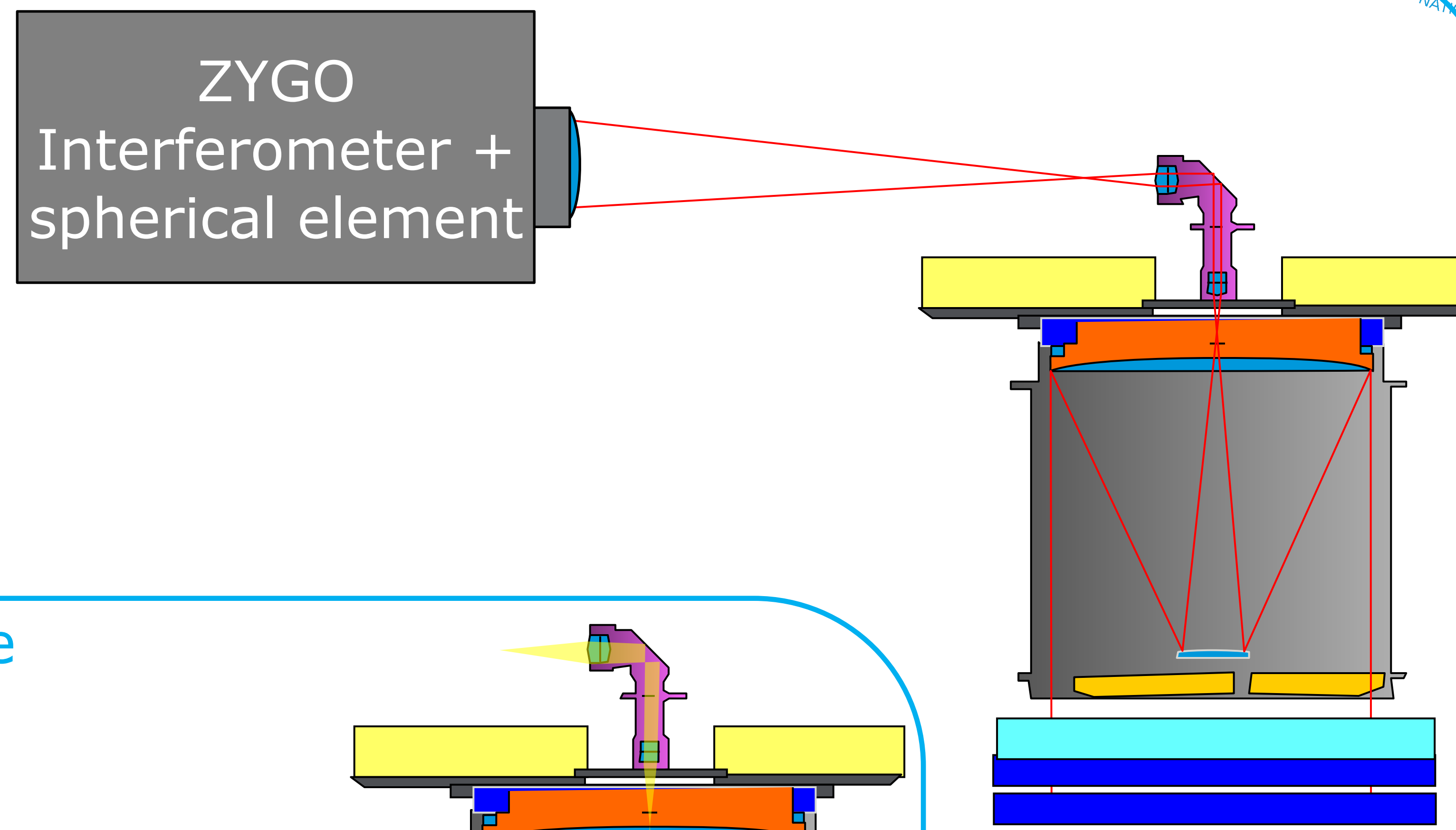


Exploring the FoV..

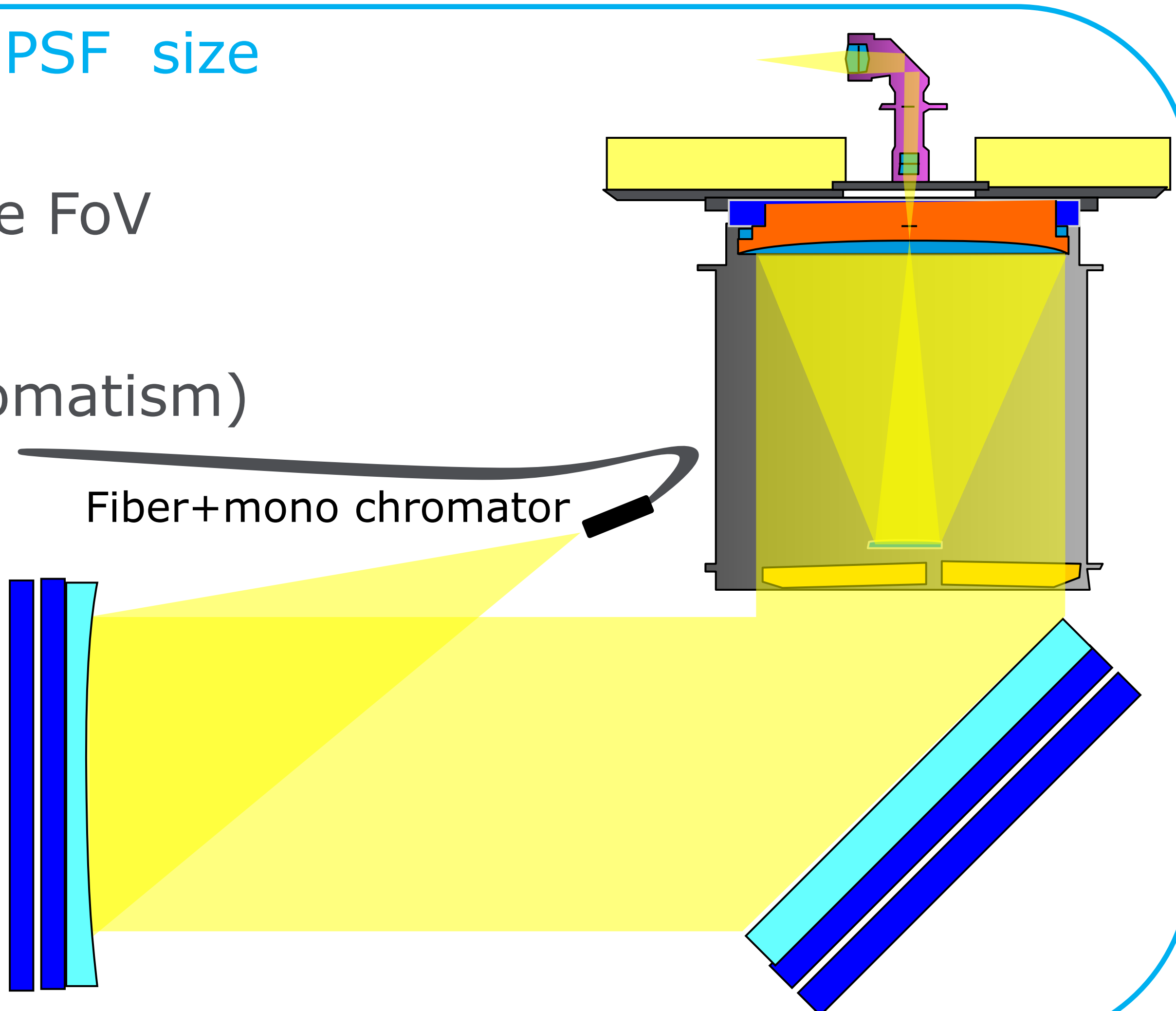


Verifications

1. TEL+BEO optical quality: tested in double-pass with ZYGO



1. Measurement of PSF size as a function of:
   - Position inside the FoV
   - Defocus
   - Wavelength (chromatism)



Design Challenges

- The CIS optical design is intended to produce a relatively wide point spread function at the detector plane. The width of the PSF is a trade-off between reducing the noise in the stellar image (pushing to large PSFs) and the increased susceptibility to straylight, which a larger stellar image generates.
- The optics must also provide a sufficiently small instantaneous field of view (IFOV) to limit contamination of the signal through background/adjacent stellar sources. It should be noted that the PSF should ideally be a top hat function.

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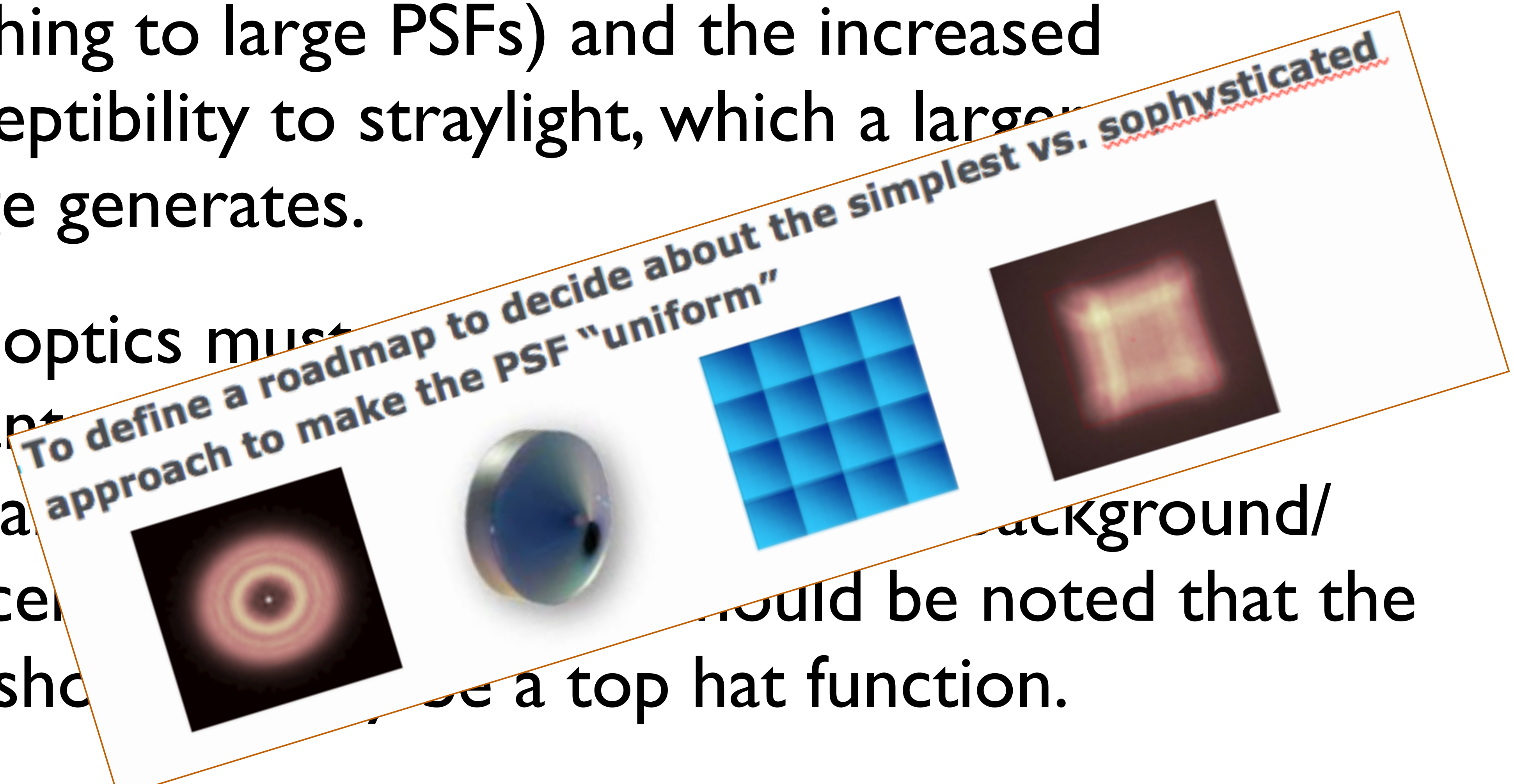

Design Challenges

- The optics are mounted in a structure of carbon-fibre reinforced polymer, which is used to reduce the susceptibility of the instrument to thermal variations which might be significant in near-Earth orbit.
- We are targeting an operational temperature of 250 K for the telescope structure.
- The change in distance between the primary and secondary mirrors (the parameter with the largest impact) should be within the $\pm < 10$ µm needed if the PSF is to be maintained constant to an appropriate level.

Design Challenges

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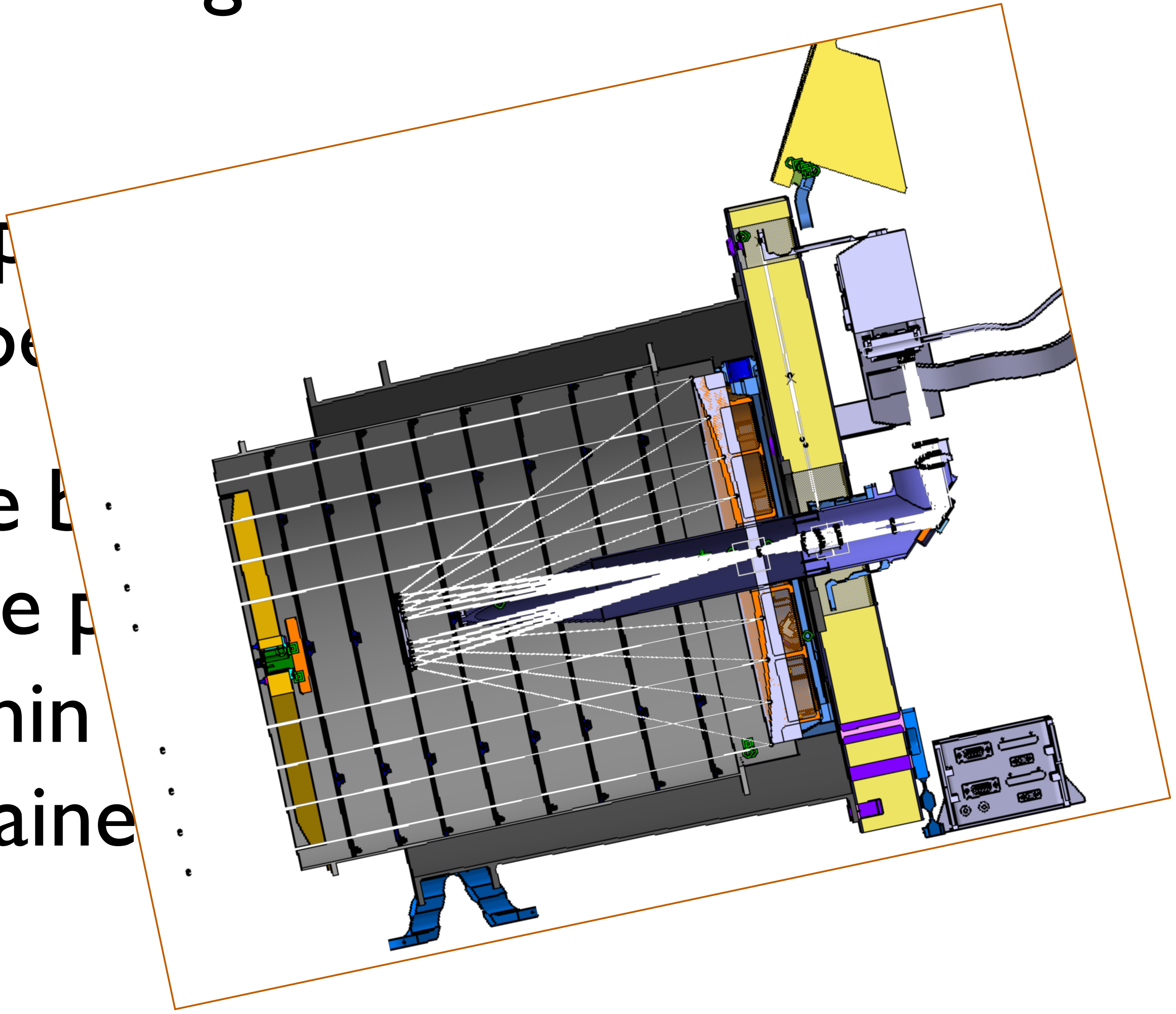

Design Challenges

- Straylight is potentially a major noise source and hence the telescope must be baffled to reduce straylight (primarily from the Earth). The instrument baffling takes account of the rotation of the spacecraft, which maintains the Earth to one side of the spacecraft at all times. Concerns over cleanliness and contamination lead to introduction of a door cover (which is light and dust tight).
- The temperature stability of both the focal plane assembly and the electronics (to stabilize the system gain) must be maintained to a level of ~10 mK.

Design Challenges

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instrument b
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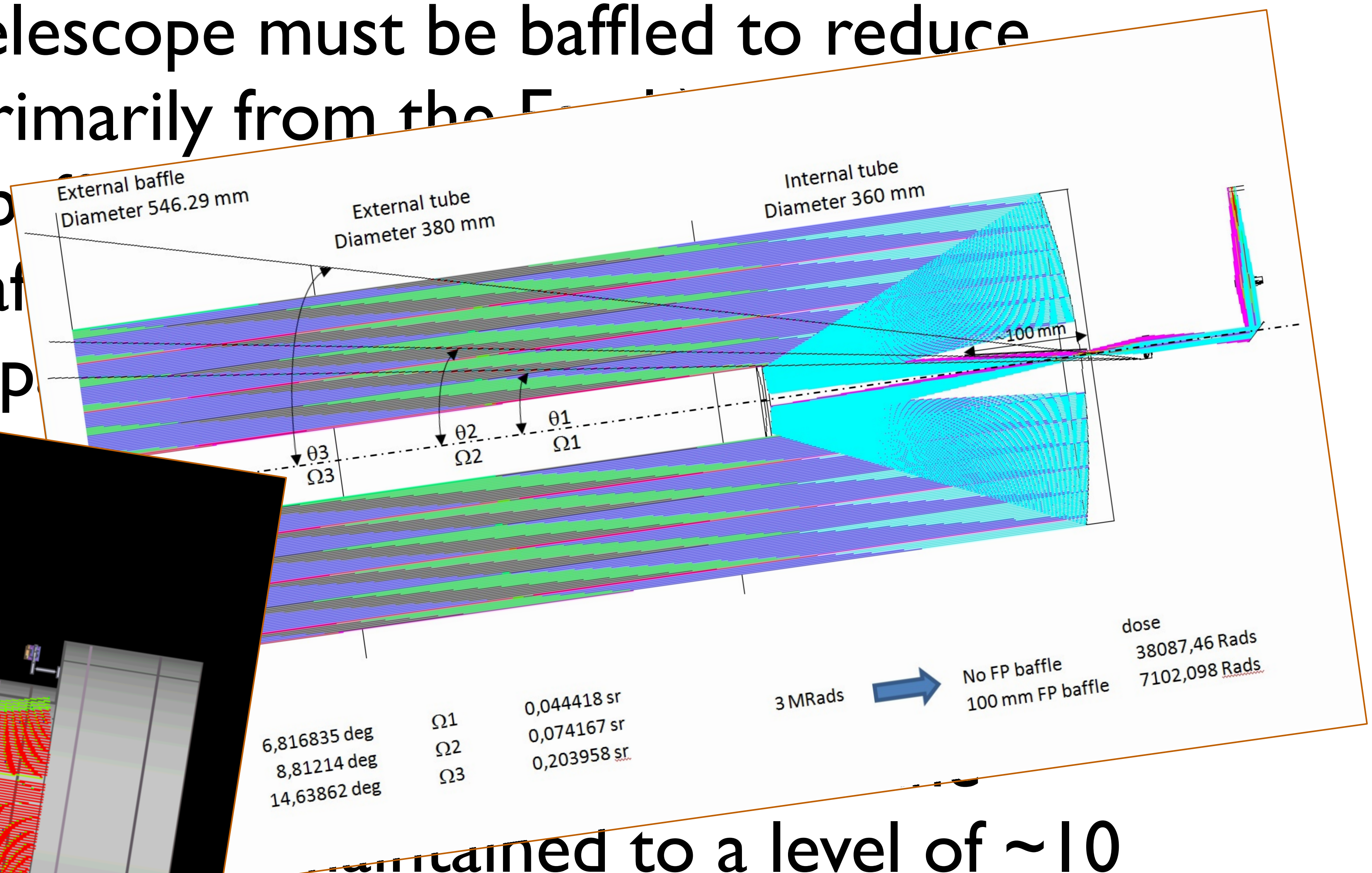
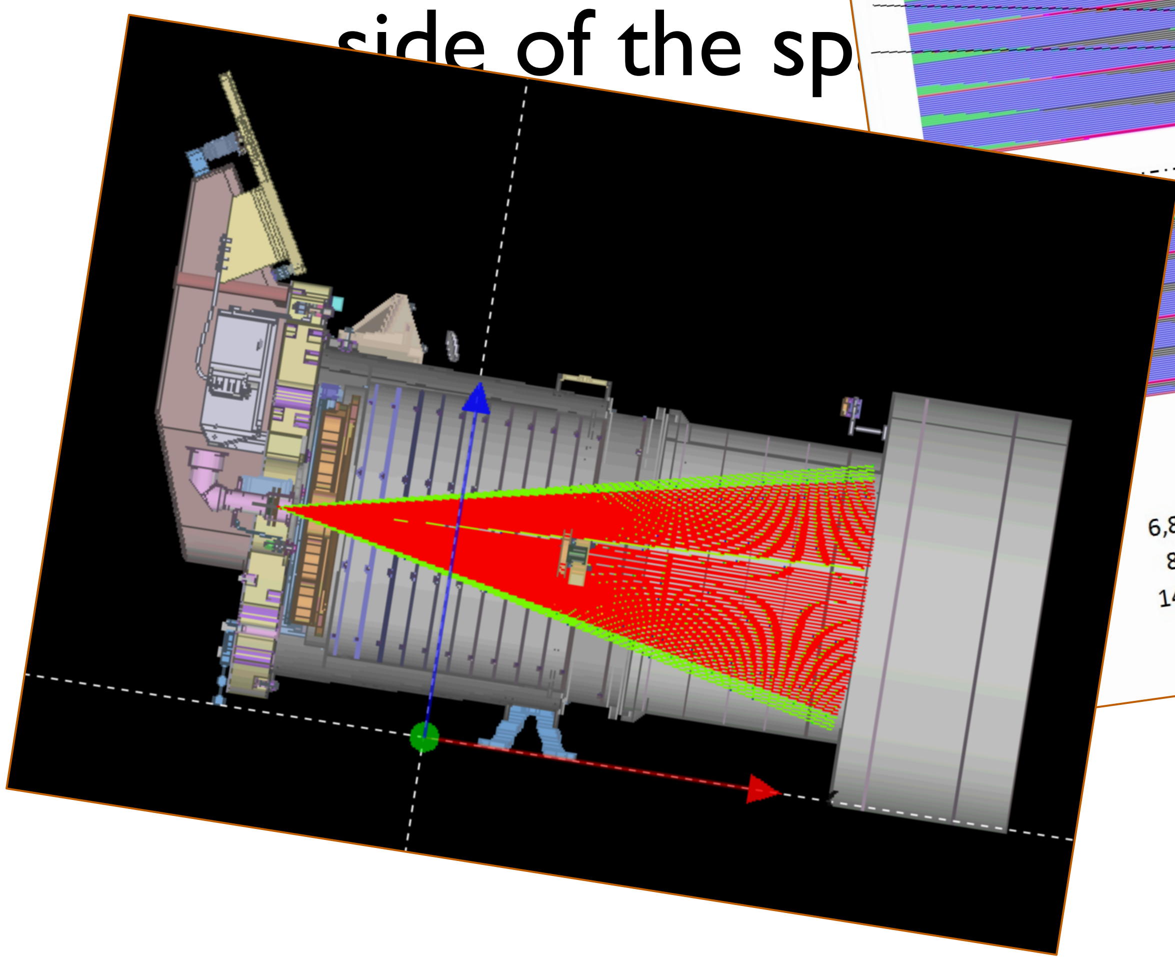
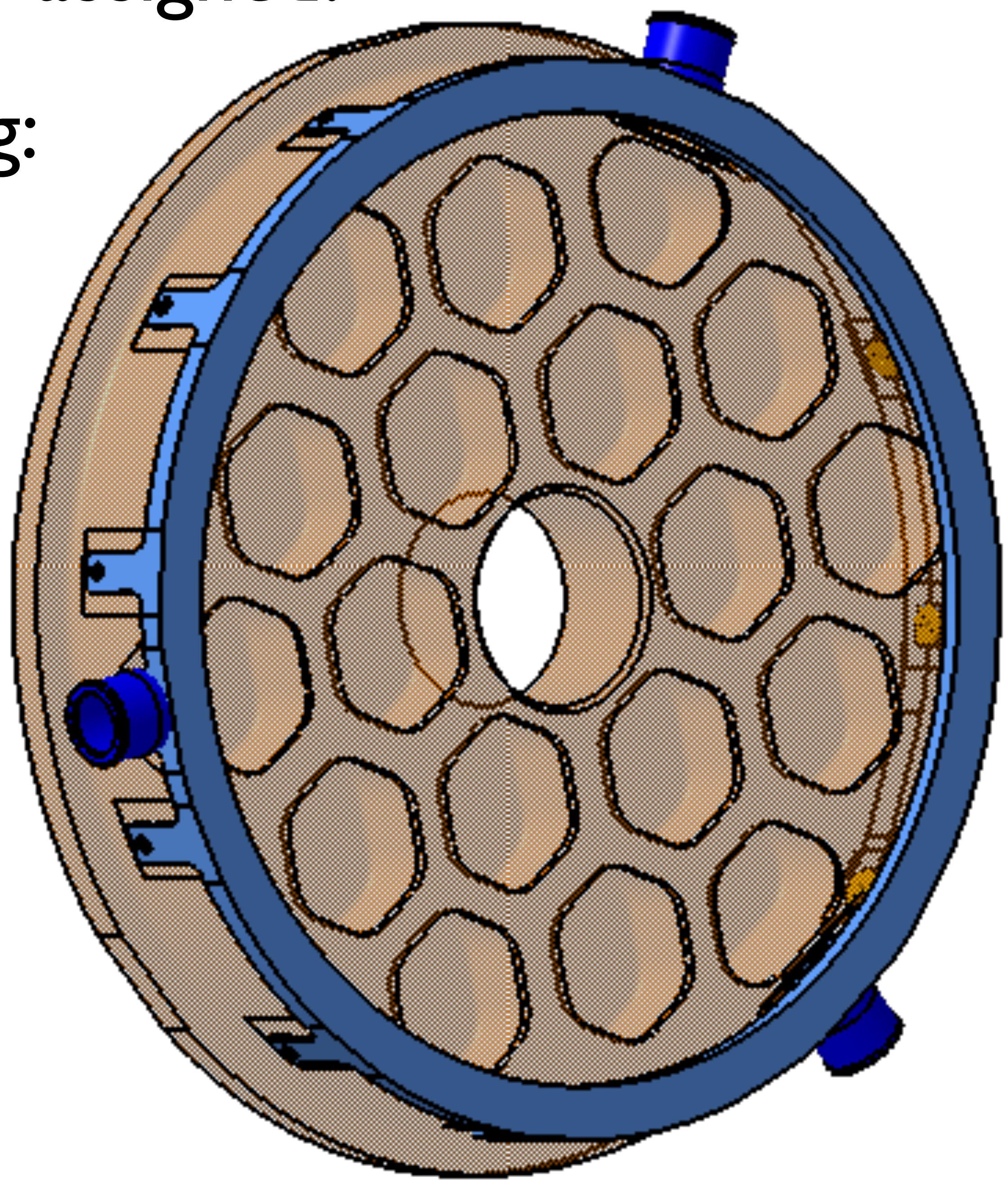




Interfaces

- Great care is given to assess Interfaces where responsibilities can be clearly assigned.
- Ex.: Primary Mirror mounting:



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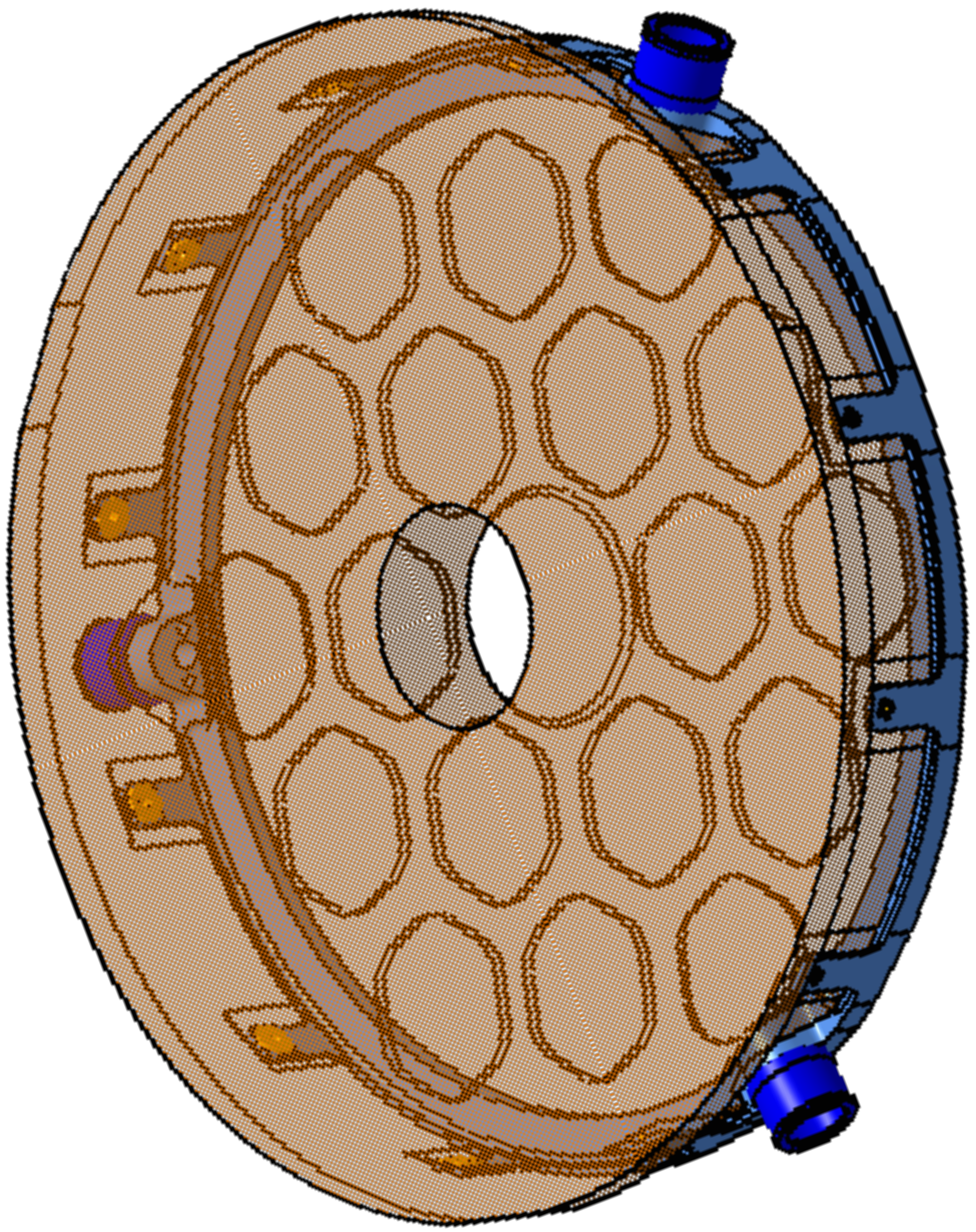

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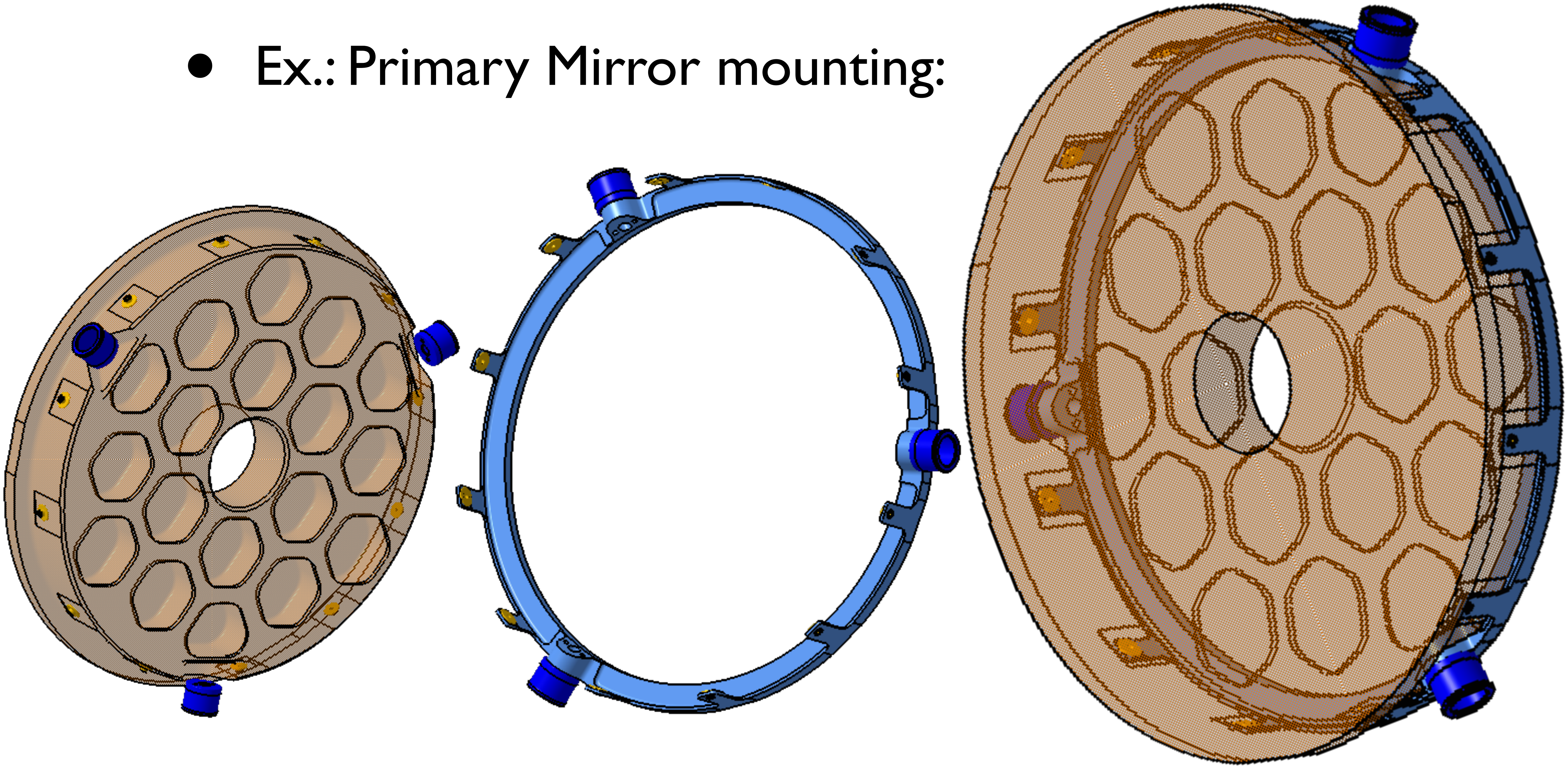

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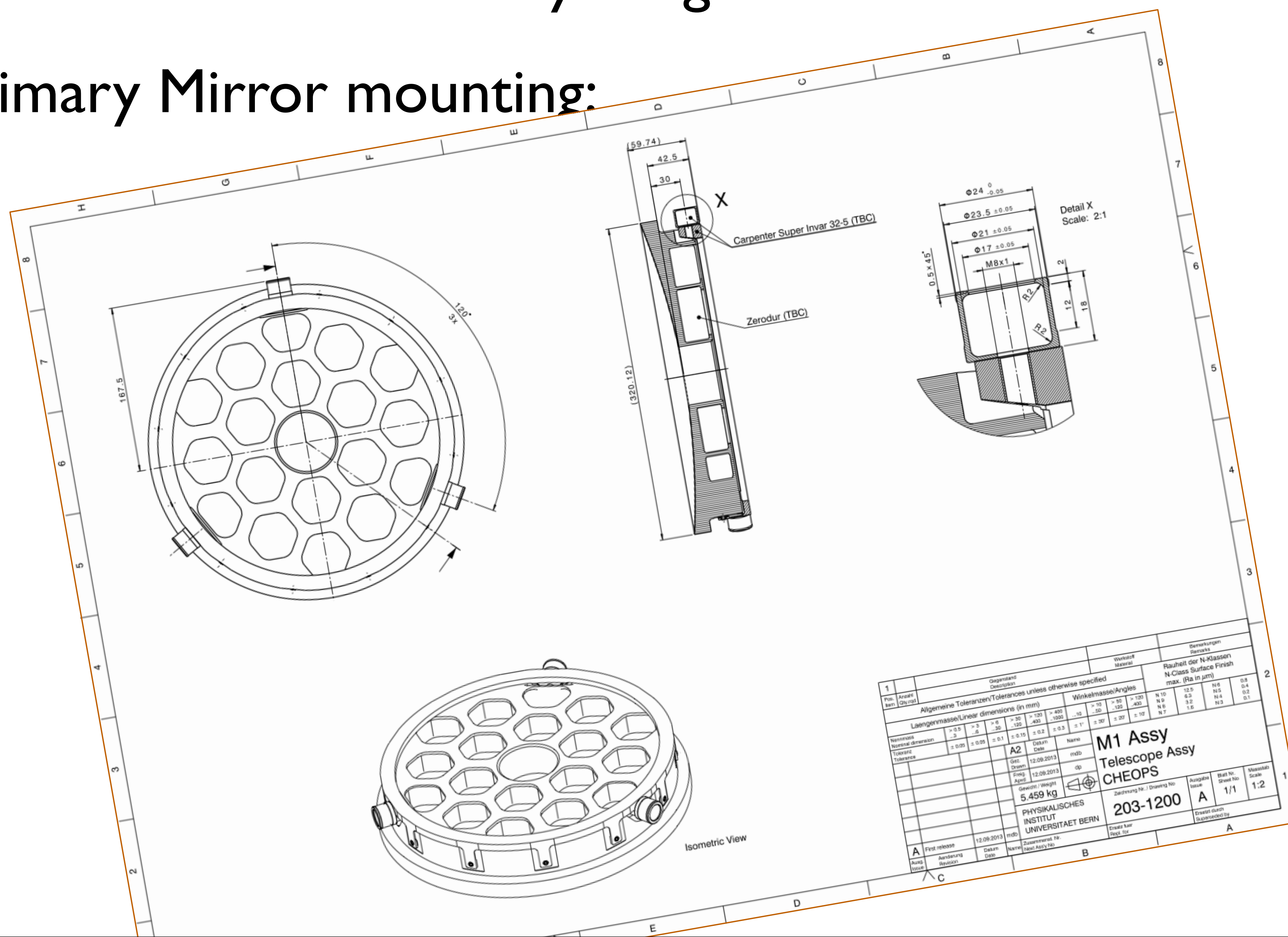


Mass budget

Ttile: CHEOPS-CIS Mass Budget
Review: SRR
Date: 18.09.2013
Author: R. Buxton

Notes: At SRR all Unit Margin should be 20%

Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg] / [%]	Reference	Remark
CIS	CHEOPS Instrument Assembly	UBE	39.680	20%	47.616	<50.0		<50kg design goal
	System Margin				9.523	20%		In accordance with EID-A MID-090 for SRR
				Total CIS Mass with System Margin	57.139	<60.0		In accordance with EID-A MID-100

Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]	Reference	Remark
CIS	CHEOPS Units	UBE	38.980	20%	46.776		Unit Mass Breakdowns (below)	Does not include STOH mass
	Shielding (Inc. Unit level)	UBE	0.200	20%	0.240		UBE estimate	In accordance with EID-A MID-040
	Instrument Harness to Platform	UBE	0.500	20%	0.600		UBE estimate	
		Total CIS Mass w/o Unit Margins	39.680	Total CIS Mass with Unit Margins	47.616	<50.0		

Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]	Reference	Remark
UNIT	OTA (STRUCT-TEL-FPA-RADS)	UBE/INAF/TBC/ DLR/ADM	21.216	20%	25.459	<28.0	OTA Unit Mass Breakdown	
	BCA	CSL	12.434	20%	14.921	<15.0	CHEOPS-CSL-BCA-DD-001-Issue1	
	SEM (CSU-PCU)	DLR	2.32	*20%*	2.900	<3.0	*Email: AW: CHEOPS SEM Mass Breakdown, Gisbert Peter, 17.09.2013*	*Maximum design mass inc. uncertainties*
	BEE	KON/IWF	3.01	20%	3.612	<4.0	203-0040-Issue-B	
		Total UNIT Masses w/o Unit Margin	38.980	Total UNIT Masses with Unit Margin	46.776	<50.0		

Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]	Reference	Remark
OTA Unit	STRUCT, Supplier	Supplier TBC	8.525	20%	10.231	<11.0	CHEOPS-INT-BUDGET-MASS-260813.xls	Components procured externally under UBE supervision
	STRUCT, UBE Interfaces	UBE	2.553	20%	3.064	<4.0	CHEOPS-INT-BUDGET-MASS-260813.xls	See below
	TEL Optics	INAF	4.254	20%	5.105	<6.0	CHEOPS-CIS_Optics_Mass_Budget.xls	M1/M2, Folding Mirror, Camera Lens, Colimator Lens
	RADIATORS	ADM	3.383	20%	4.060	<4.0	CHEOPS-INT-BUDGET-MASS-260813.xls	Descrepancy with ADM Design Report, missing straps/brackets
	FPA (CCD/FEE)	DLR/ESA	2.000	*20%*	2.400	<2.4	CHEOPS-DLR-INST-DD-001	*Incorrect Unit margin philosphy for PCU (30%)*
	OTA Thermal H/W	UBE	0.500	20%	0.600	<0.6	CHEOPS-INT-BUDGET-MASS-260813.xls	MLI, Heaters
		Total OTA Mass w/o Unit Margin	21.216	Total OTA Mass with Unit Margin	25.459	<27.4		

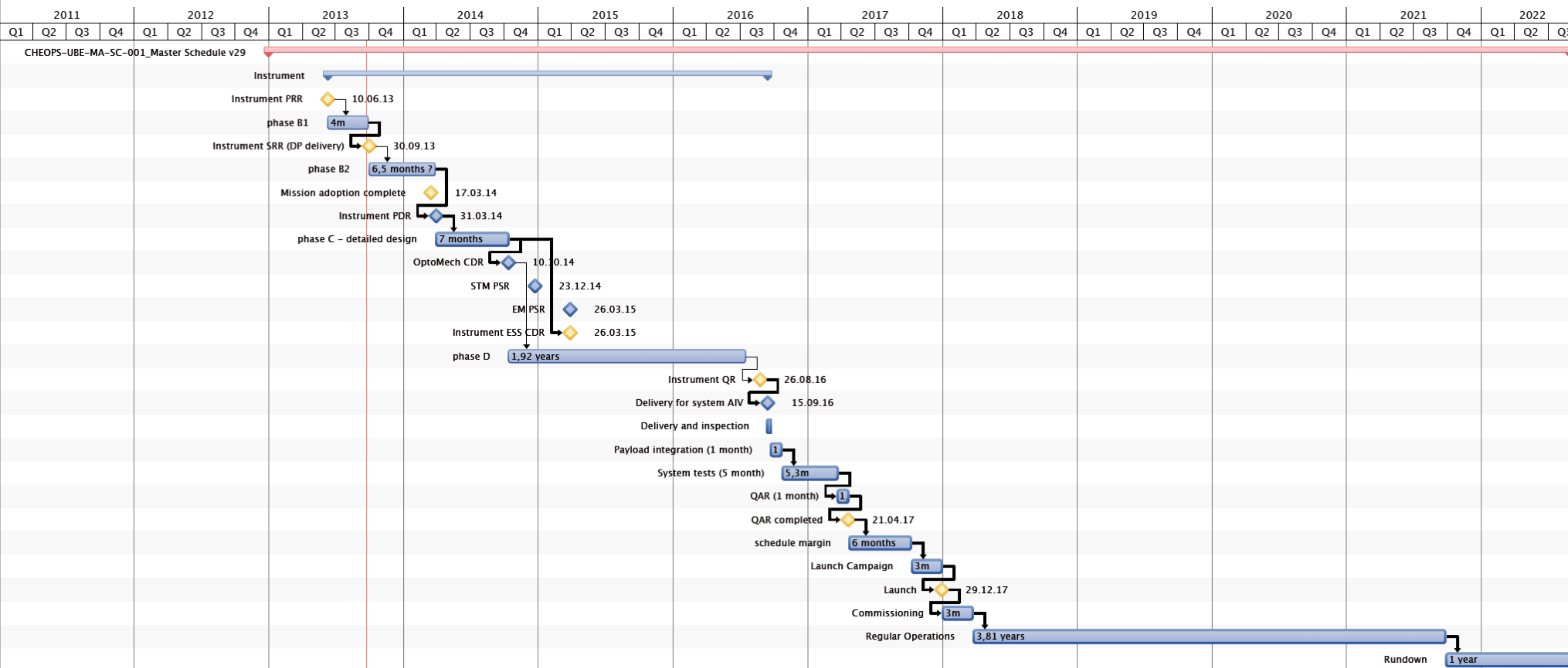
Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]	Reference	Remark
STRUCT, Supplier	Optical Train	Supplier TBC	3.945	20%	4.734	<5.2	203-1000-Issue-A	Excluding TEL Optics/Mounts and BEO Housing
	Support Structure	Supplier TBC	4.400	20%	5.280	<5.6	203-1620-Issue-A	Includes all 3 Bipods
	Misc (bolts, shims, washers etc)	Supplier TBC	0.181	20%	0.217	<0.2	203-0020-Issue-A	At OTA Assey level (lower levels accounted for)
		Total Mass w/o Unit Margin	8.525	Total Mass with Unit Margin	10.231	<11.0		

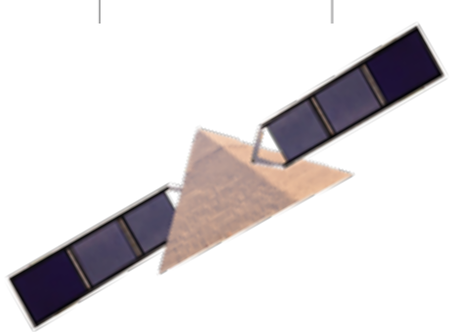
Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]	Reference	Remark
STRUCT, UBE Interfaces	Optics I/F Mounts	UBE	0.874	20%	1.049	<1.2	CHEOPS-INT-BUDGET-MASS-260813.xls	
	BEO Housing	UBE	0.350	20%	0.420	<0.5	CHEOPS-INT-BUDGET-MASS-260813.xls	
	Radiator Support Assembly	UBE	1.329	20%	1.595	<2.0	CHEOPS-INT-BUDGET-MASS-260813.xls	Includes Optics Hood
		Total Mass w/o Unit Margin	2.553	Total Mass with Unit Margin	3.064	<4.0		

OTA mass budget

Level	Name	Responsible	Basic Mass [kg]	Unit Margin [%]	Nominal Mass [kg]	Requirement [kg]
OTA Unit	STRUCT, Supplier	Supplier TBC	8.525	20%	10.231	<11.0
	STRUCT, UBE Interfaces	UBE	2.553	20%	3.064	<4.0
	TEL Optics	INAF	4.254	20%	5.105	<6.0
	RADIATORS	ADM	3.383	20%	4.060	<4.0
	FPA (CCD/FEE)	DLR/ESA	2.000	*20%*	2.400	<2.4
	OTA Thermal H/W	UBE	0.500	20%	0.600	<0.6
		Total OTA Mass w/o Unit Margin	**21.216**	**Total OTA Mass with Unit Margin**	**25.459**	**<27.4**

Schedule


2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022
Q1 Q2 Q3 Q4
CHEOPS-UBE-MA-SC-001_Master Schedule v29
Instrument
Instrument PRR
10.06.13
phase B1
4m
Instrument SRR (DP delivery)
30.09.13
phase B2
6,5 months ?
Mission adoption complete
17.03.14
Instrument PDR
31.03.14
phase C - detailed design
7 months
OptoMech CDR
10.10.14
STM PSR
23.12.14
EM PSR
26.03.15
Instrument ESS CDR
26.03.15
phase D
1,92 years
Instrument QR
26.08.16
Delivery for system AIV
15.09.16
Delivery and inspection
Payload integration (1 month)
1
System tests (5 month)
5,3m
QAR (1 month)
1
QAR completed
21.04.17
schedule margin
6 months
Launch Campaign
3m
Launch
29.12.17
Commissioning
3m
Regular Operations
3,81 years
Rundown
1 year



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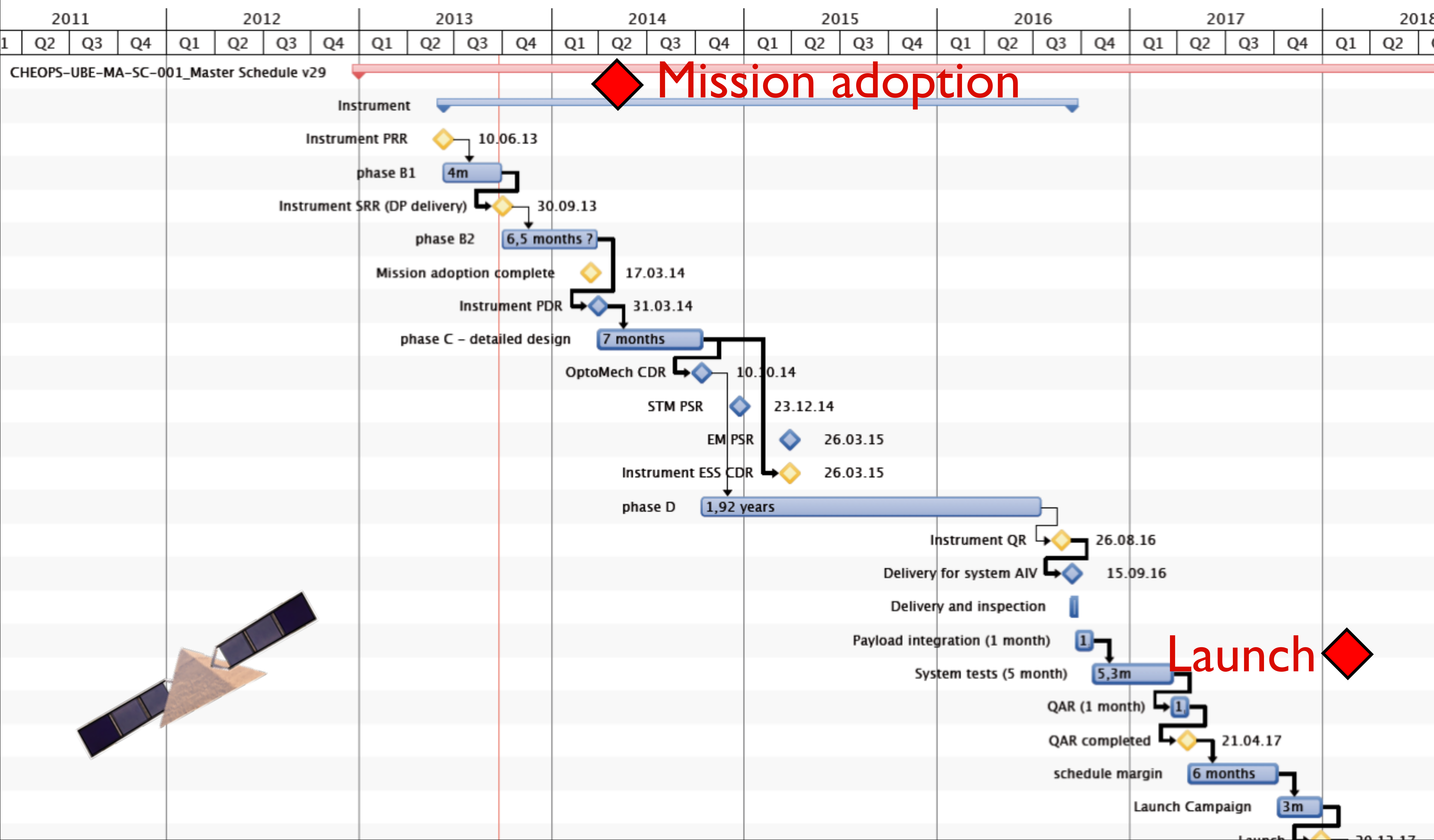

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CHEOPS-IT web page