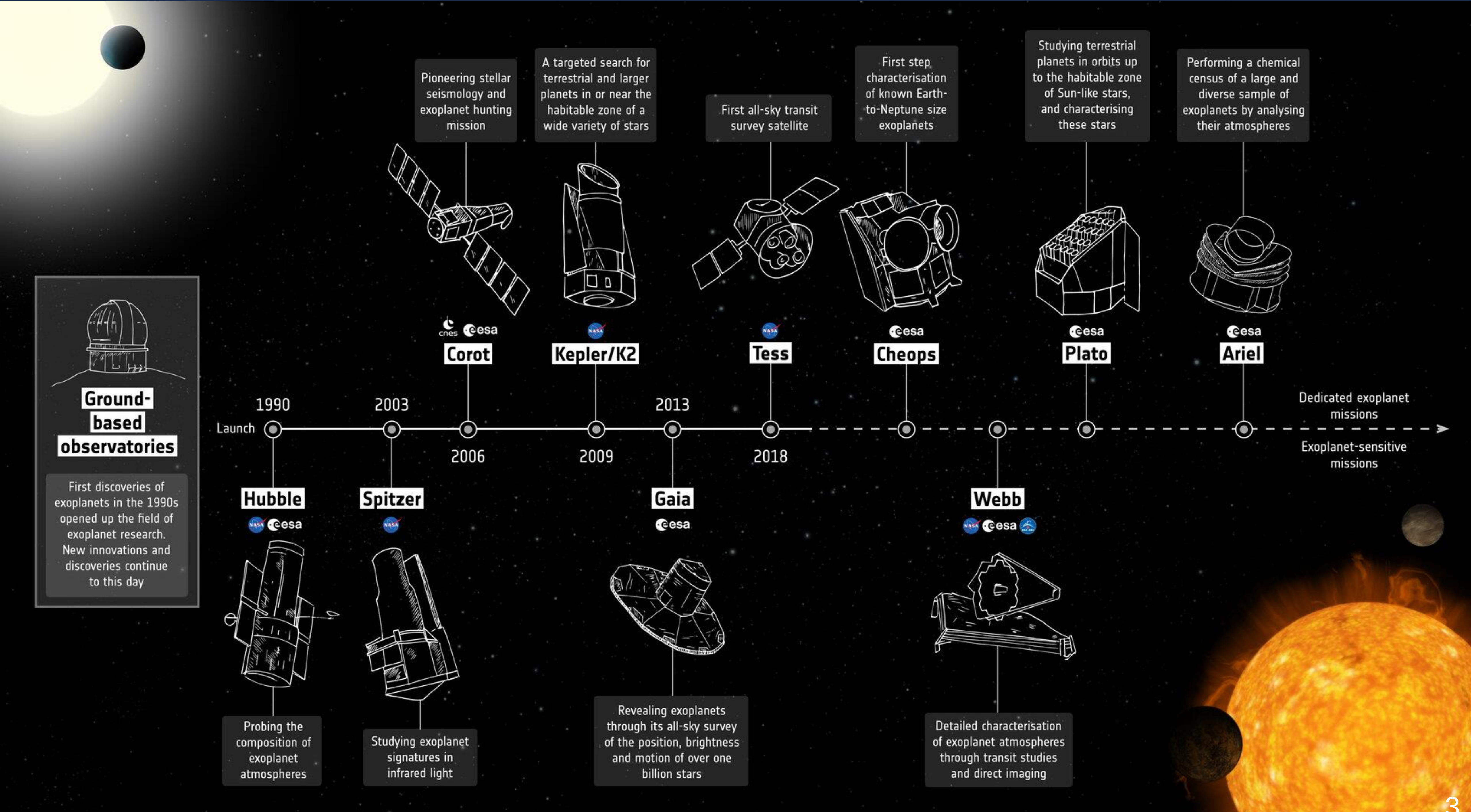
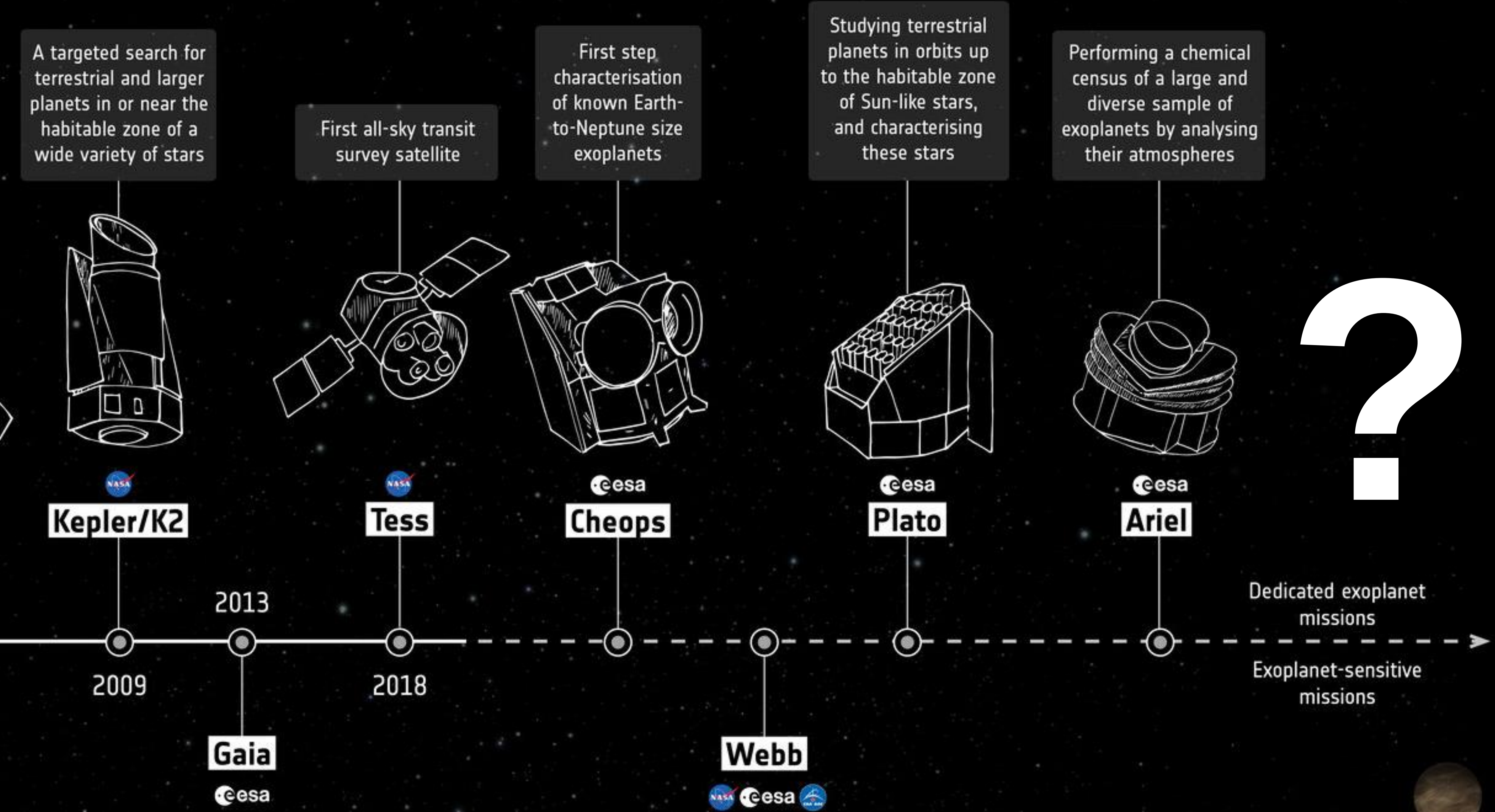
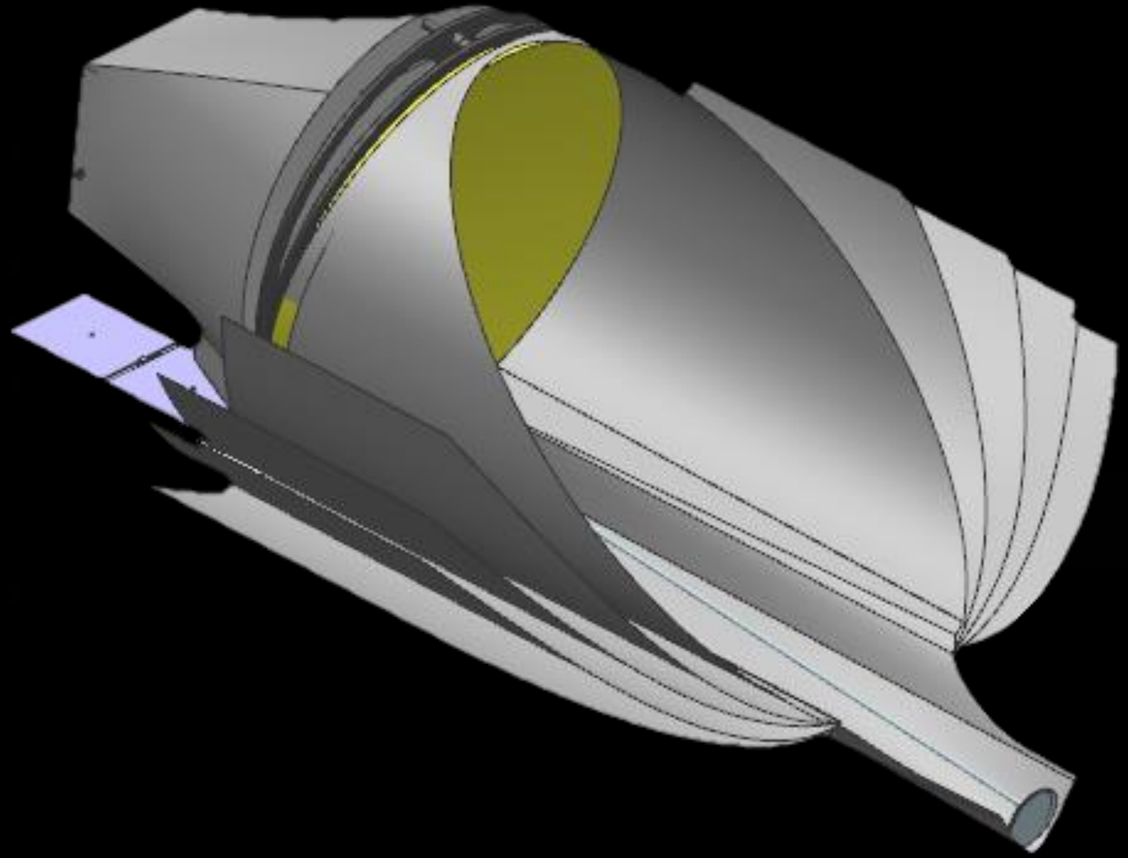
Members of **Team Green**:
Majdi Assaid, Frederik Dall'Omo, Cara Doumbe Kingue, Yoshi Eschen, Frankie Falksohn, Angelos Georgakis, Fabian Hauser, Adam Hlacik, Jonas Lunde, Josephine Maglio, Willeke Mulder, Jota Navarro Fernández, Marie Puissant, Rick Röthlisberger and Einari Toivonen
Tutors: Gabby Aitink-Kroes and Christian Gritzner

ARISTOTLE

- Astrophysical Research Initiative for Space Telescopic Observations of Transiting Large Exoplanets


Ground-based observatories
First discoveries of exoplanets in the 1990s opened up the field of exoplanet research. New innovations and discoveries continue to this day
Launch
1990
2003
2006
2009
2013
2018
Hubble
Probing the composition of exoplanet atmospheres
Spitzer
Studying exoplanet signatures in infrared light
Corot
Pioneering stellar seismology and exoplanet hunting mission
Kepler/K2
A targeted search for terrestrial and larger planets in or near the habitable zone of a wide variety of stars
Gaia
Revealing exoplanets through its all-sky survey of the position, brightness and motion of over one billion stars
Tess
First all-sky transit survey satellite
Cheops
First step characterisation of known Earth-to-Neptune size exoplanets
Webb
Detailed characterisation of exoplanet atmospheres through transit studies and direct imaging
Plato
Studying terrestrial planets in orbits up to the habitable zone of Sun-like stars, and characterising these stars
Ariel
Performing a chemical census of a large and diverse sample of exoplanets by analysing their atmospheres
Dedicated exoplanet missions
Exoplanet-sensitive missions


A targeted search for terrestrial and larger planets in or near the habitable zone of a wide variety of stars
First all-sky transit survey satellite
First step characterisation of known Earth-to-Neptune size exoplanets
Studying terrestrial planets in orbits up to the habitable zone of Sun-like stars, and characterising these stars
Performing a chemical census of a large and diverse sample of exoplanets by analysing their atmospheres
?
NASA
Kepler/K2
NASA
Tess
esa
Cheops
esa
Plato
esa
Ariel
2013
Dedicated exoplanet missions
2009
2018
Exoplanet-sensitive missions
Gaia
esa
Webb
NASA esa CSA ASC



Mission Statement

The ARISTOTLE Mission shall push the envelope in the search of precursors for life in stellar systems.

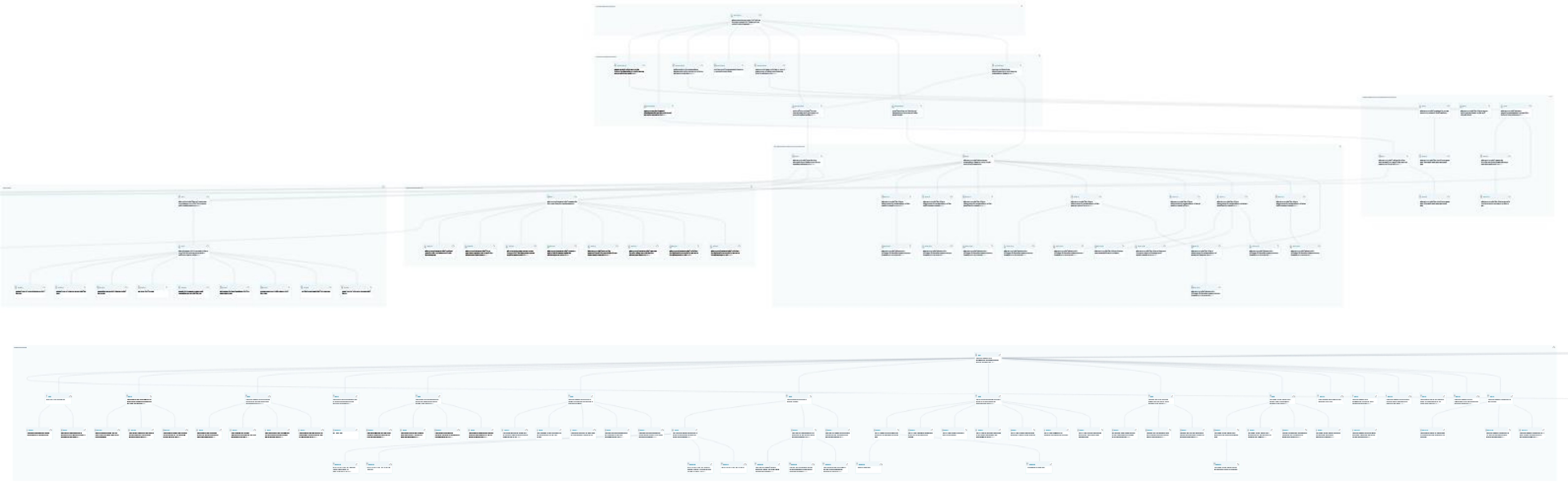
Table of Content

Table of Content: Science Case

Mission Statement

The ARISTOTLE Mission shall push the envelope in the search of precursors for life in stellar systems.

Requirements Breakdown



Requirements Breakdown

Science Objectives → Science Requirements → Observatory Requirements → Spacecraft Requirements

Science Questions

Primary

Under what conditions are exoplanet atmospheres possible, and how does it shape their characteristics?

Secondary

How do planetary systems form and evolve?

How does our solar system work, and does it compare to other stellar systems?

Is there life elsewhere in our solar system?

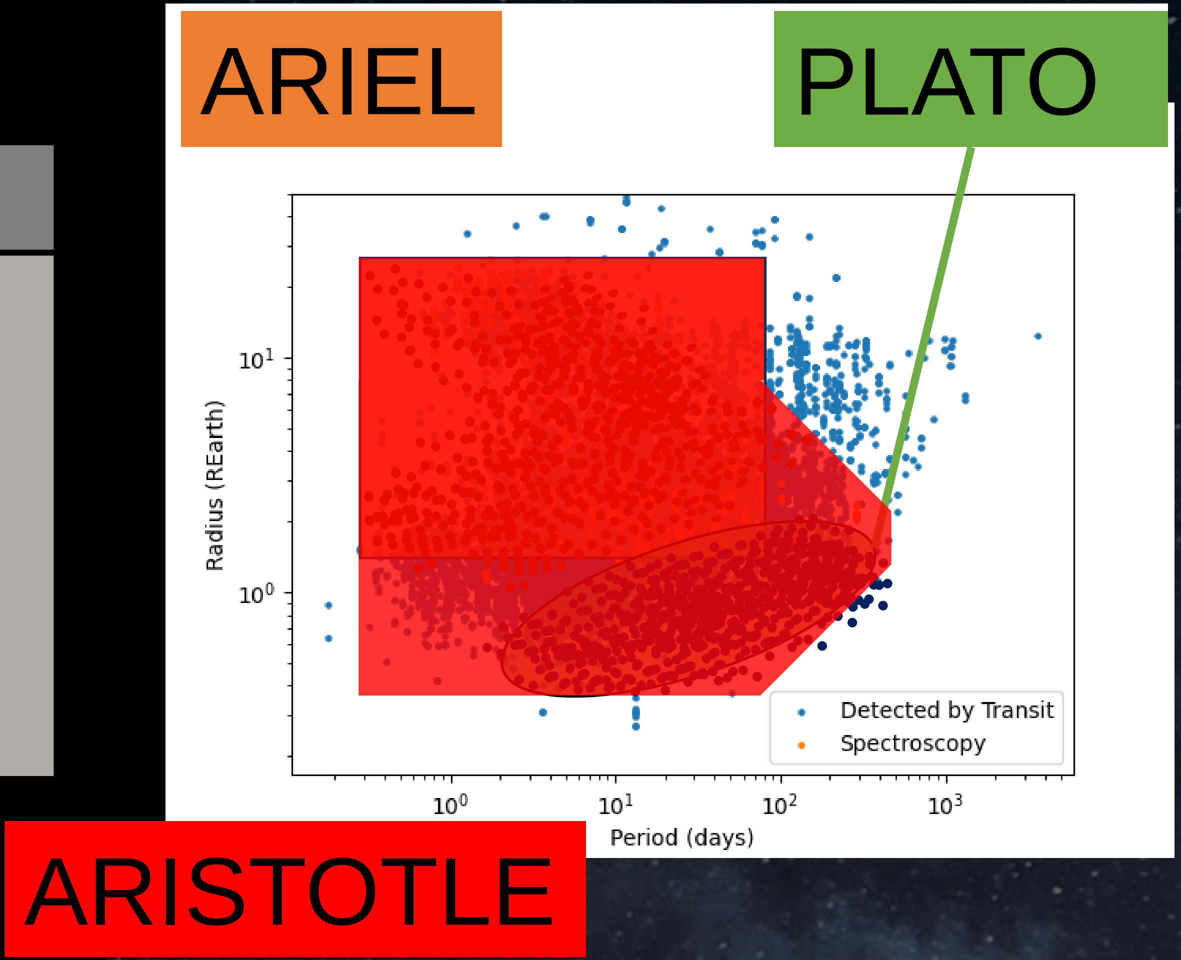
Primary Science

Primary Science: Analysis of Planetary Systems

Question: Exoplanet Atmospheres?

Derived Objectives:

1. Photochemistry in Exoplanets around Sun-Like stars.
2. Breaking degeneracies of ARIEL.
3. Probe host-star variability to reduce noise.



Primary Science: Analysis of Planetary Systems

Photochemistry & Geo-Thermal Activities

Chemical Disequilibrium

Molecular Pre-cursors of Life

Methane (CH_4)

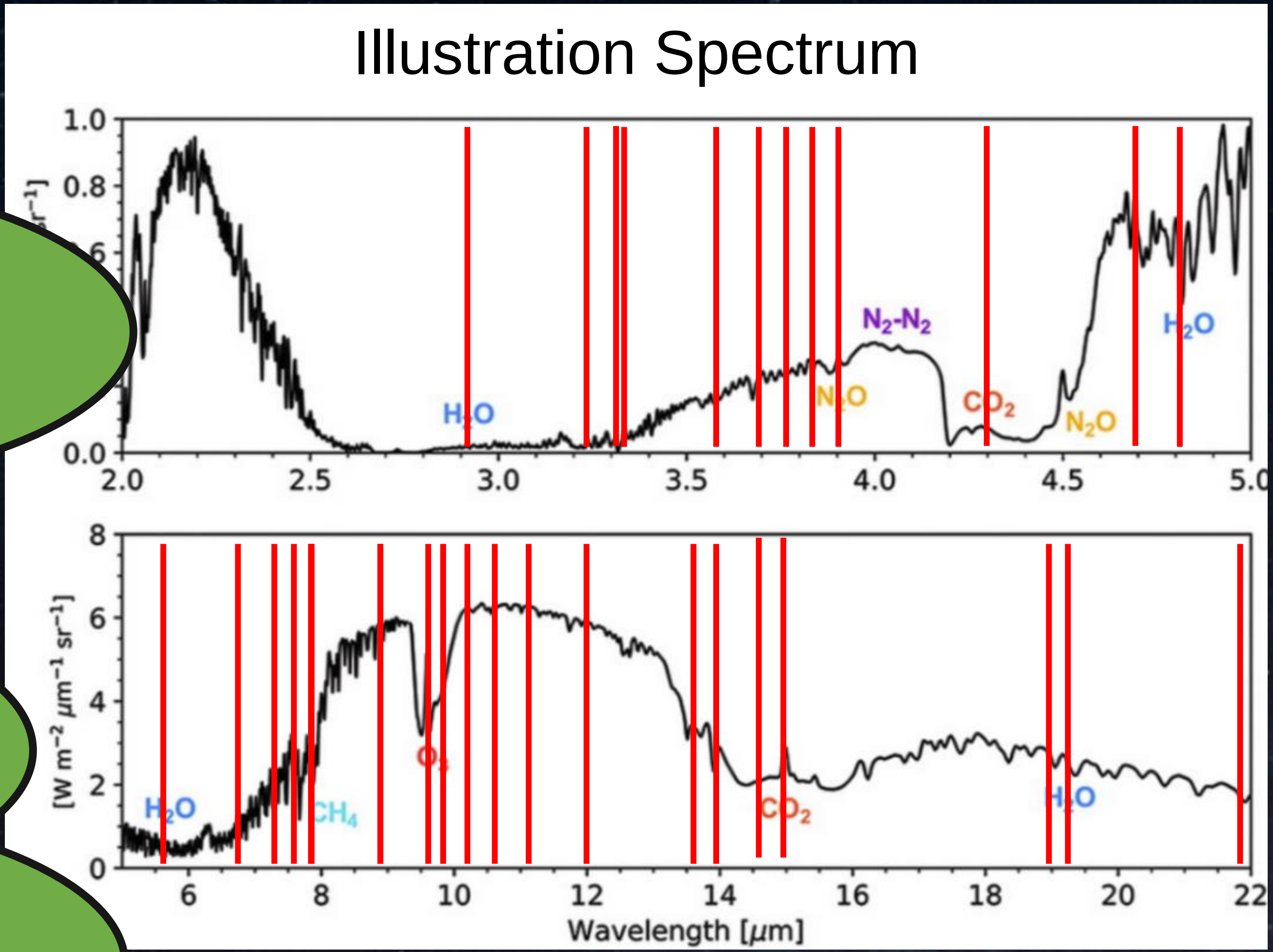
Ozone (O_3)

Carbon-Dioxide (CO_2)

H_2O

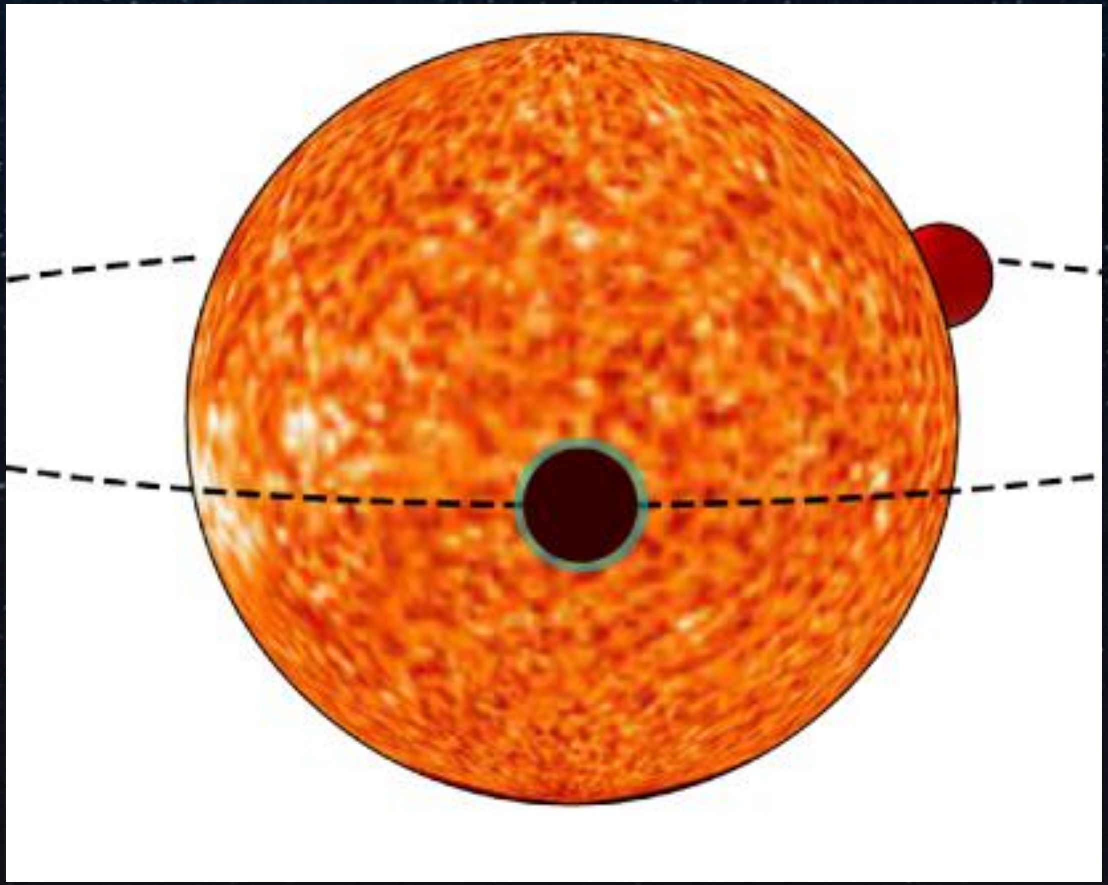
Primary Science: Analysis of Planetary Systems

- H_2O
- Hydrocarbons (C_2H_4, ..)
- Sulfur Compounds (SO_2, H_2S)
- Carbon-Dioxide (CO_2)
- Ozone (O_3)
- Methane (CH_4)
- Phosphine & Phyllosilicates

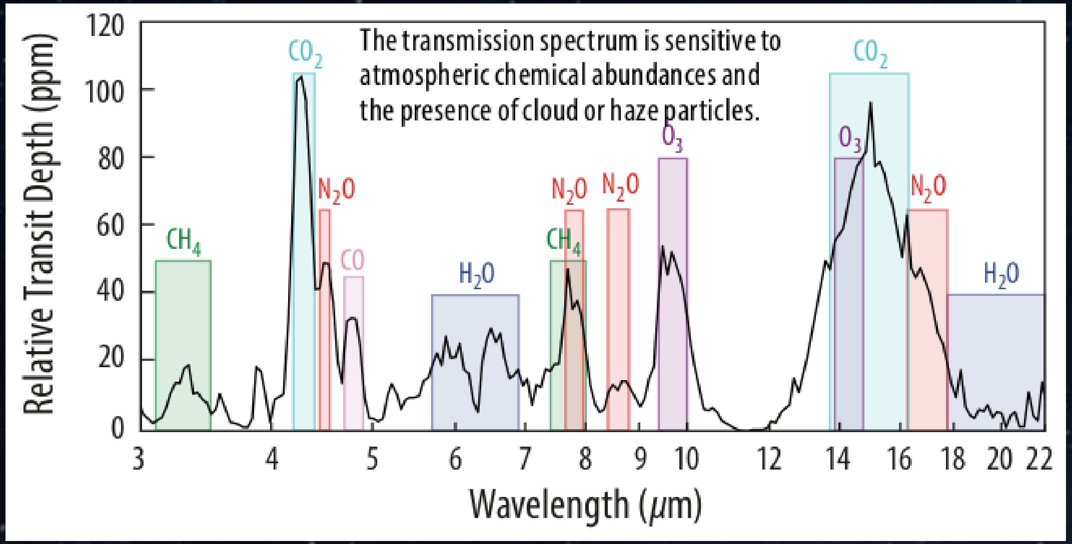


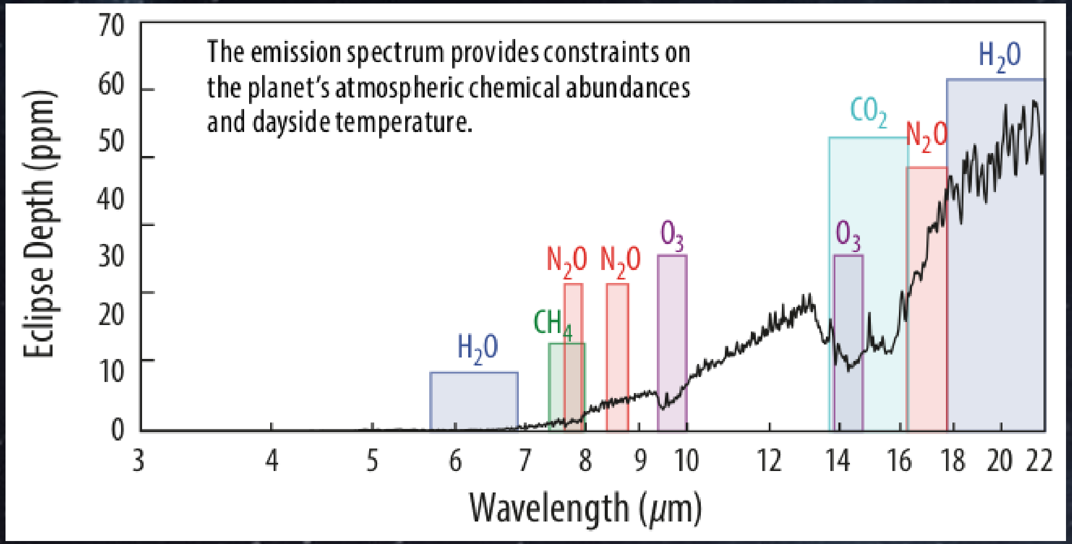
Schwietermann et al. 2018

Primary Science: Analysis of Planetary Systems

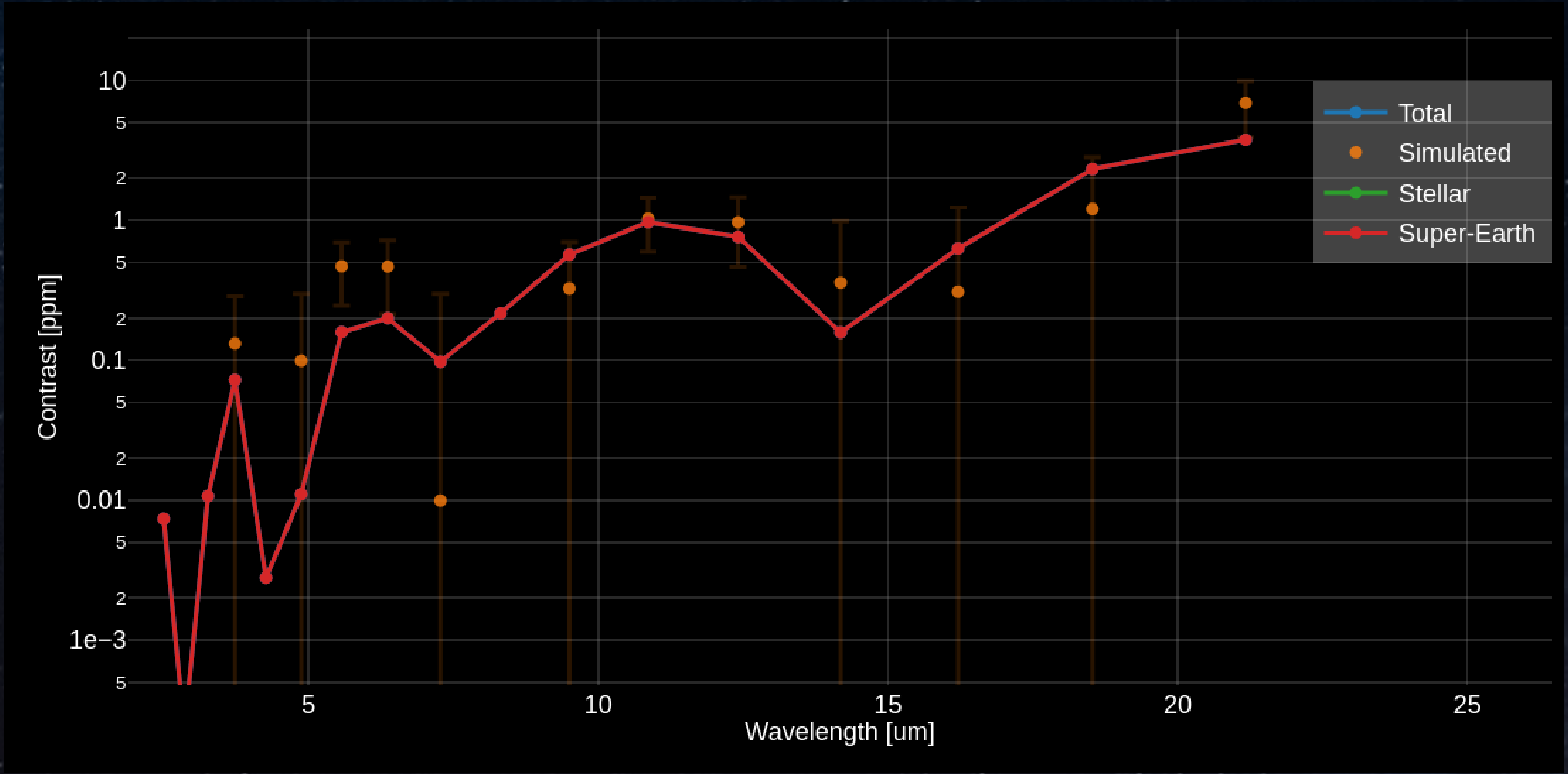


M. Meixner et al. 2019
(ORIGINS Concept Study)



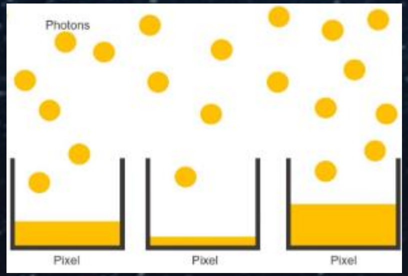


Characterize Super-Earths with Eclipses



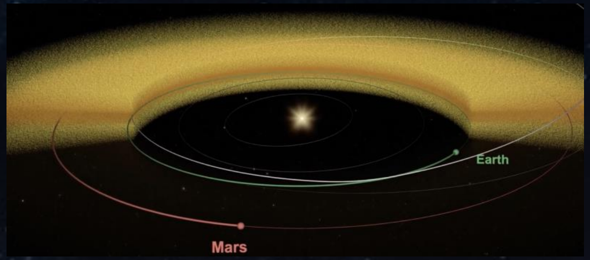
ARISTOTLE Noise and Systematics

Photon Noise
(0.8 - 6 ppm)

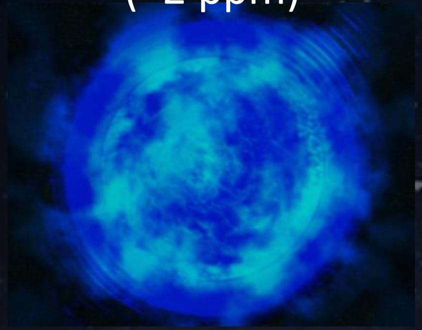


Dish thermal emission
(0 – 3 ppm)

Zodiacal background
(0 - 3 ppm)

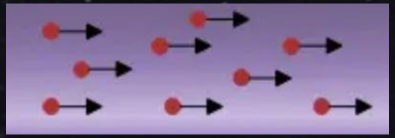


Star instability
(~2 ppm)



Pointing jitter
(~1 ppm)

Dark current
(<1 ppm)



Read noise
(~0ppm)

Calibration errors & fringes
(target: < 5 ppm)

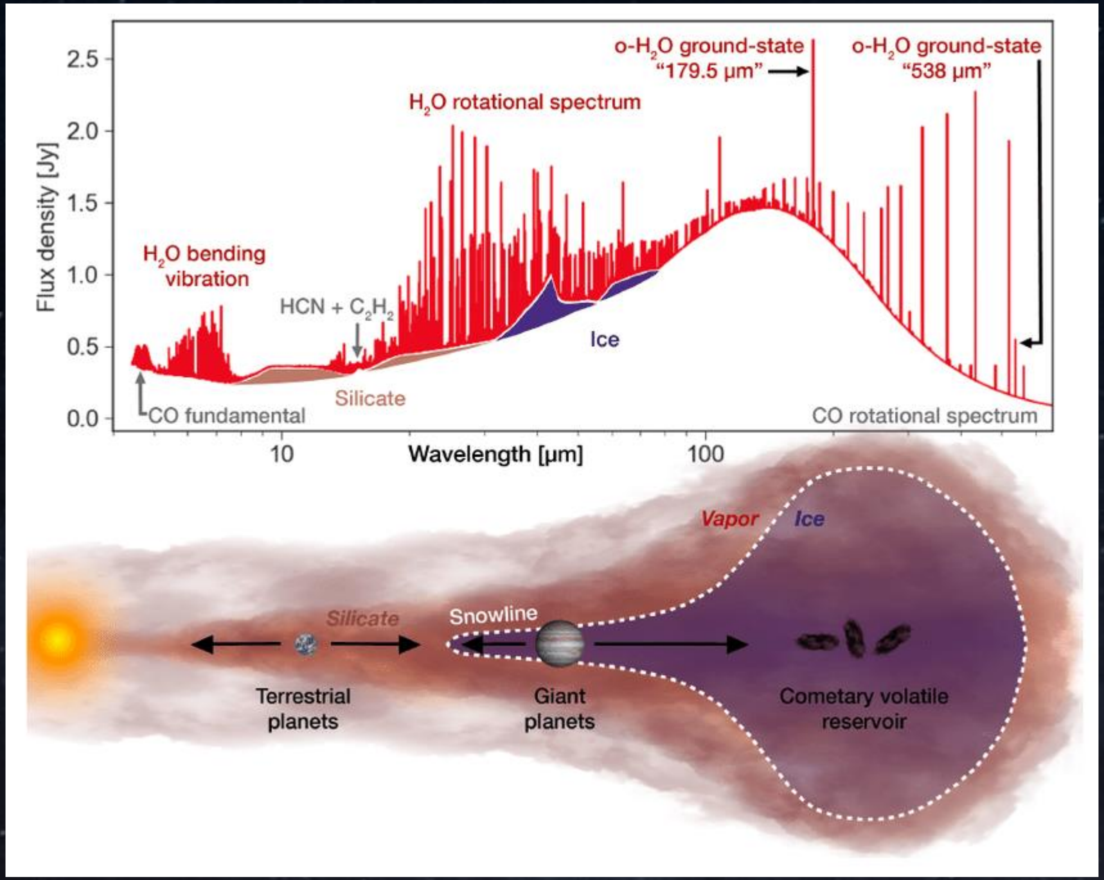
Secondary Science

Planetary System(s) (formation)

Question: Evolution Planetary Systems?

Derived Objectives:

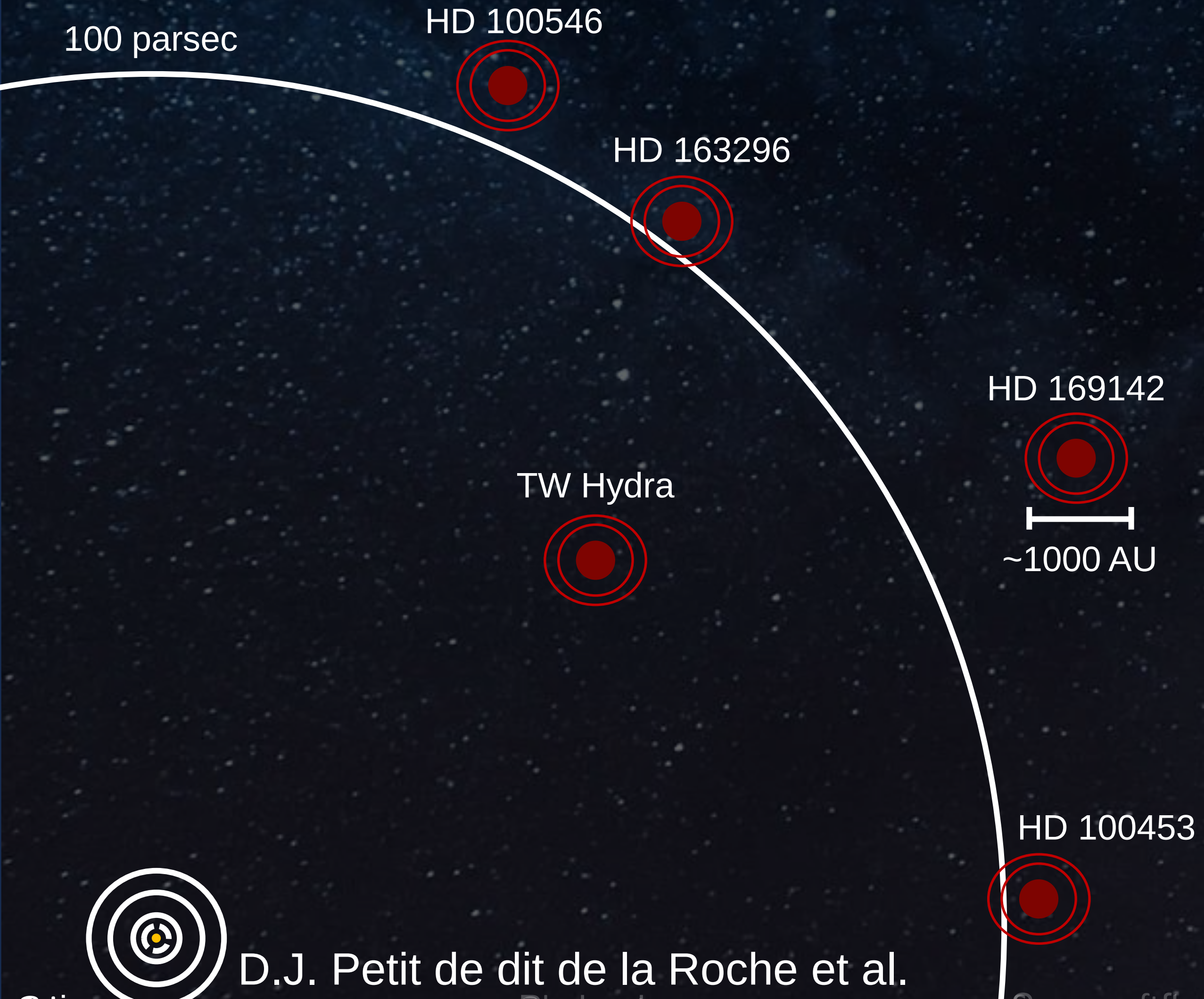
1. Constrain the SED of close protoplanetary disks.
2. Find possible companions.



Linz et. al (2020)

Coronagraph Direct Imaging of Disks

1. Constrain the SED, including its spatial component, of close protoplanetary disks by observing their thermal emission.



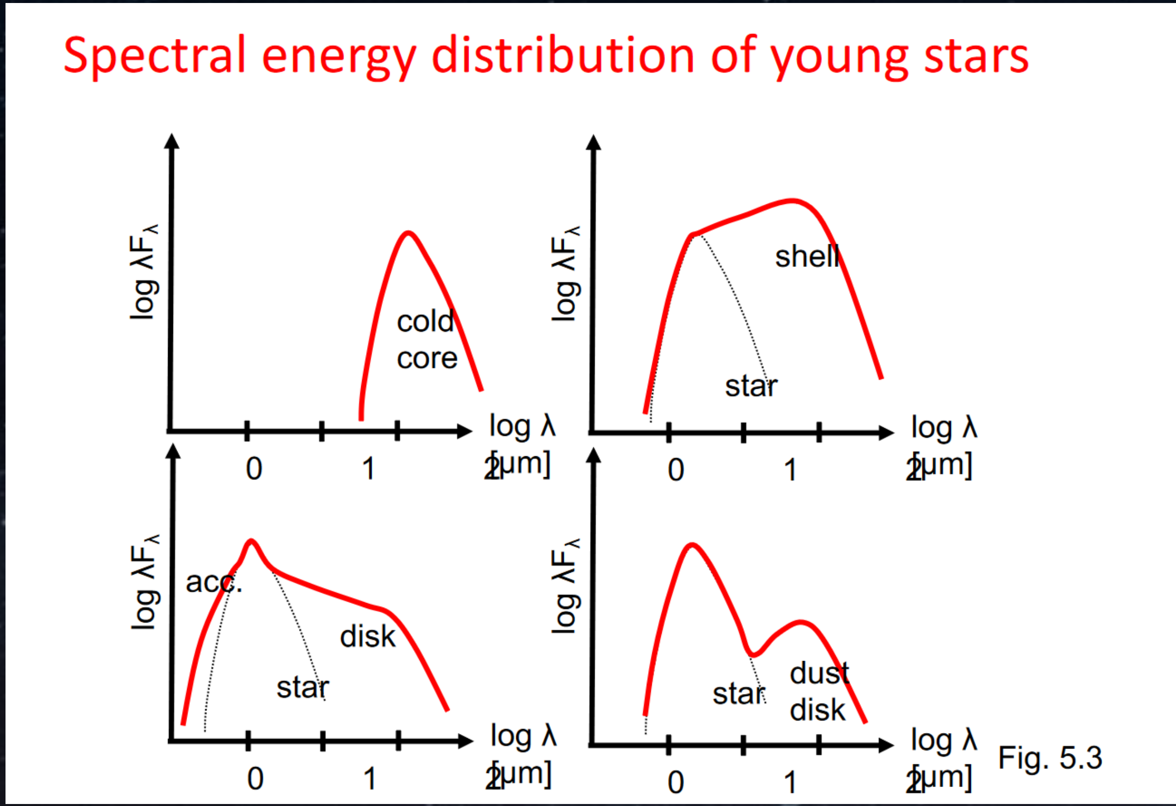


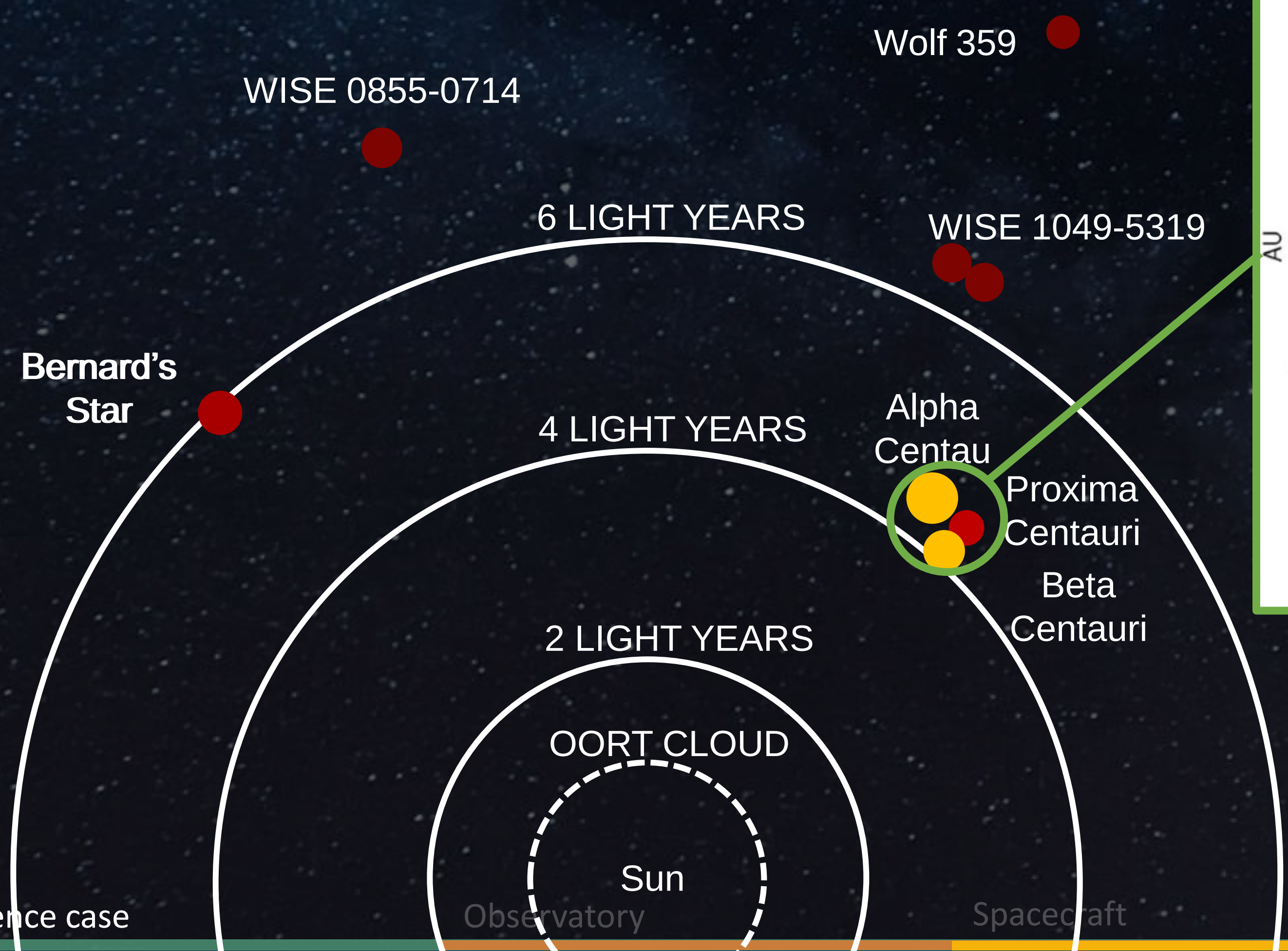
Fig. 5.3

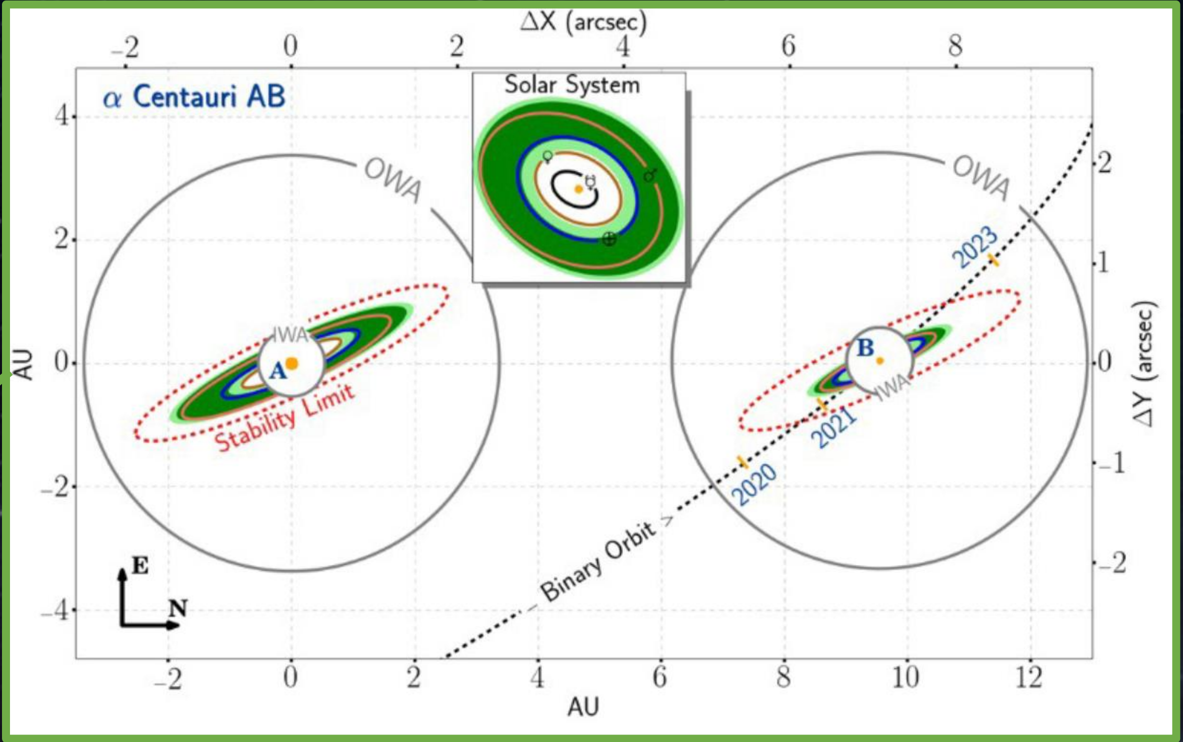
H.M. Schmid 2020

D.J. Petit de dit de la Roche et al. 2021

Coronagraph Direct Imaging of Nearby Exoplanets

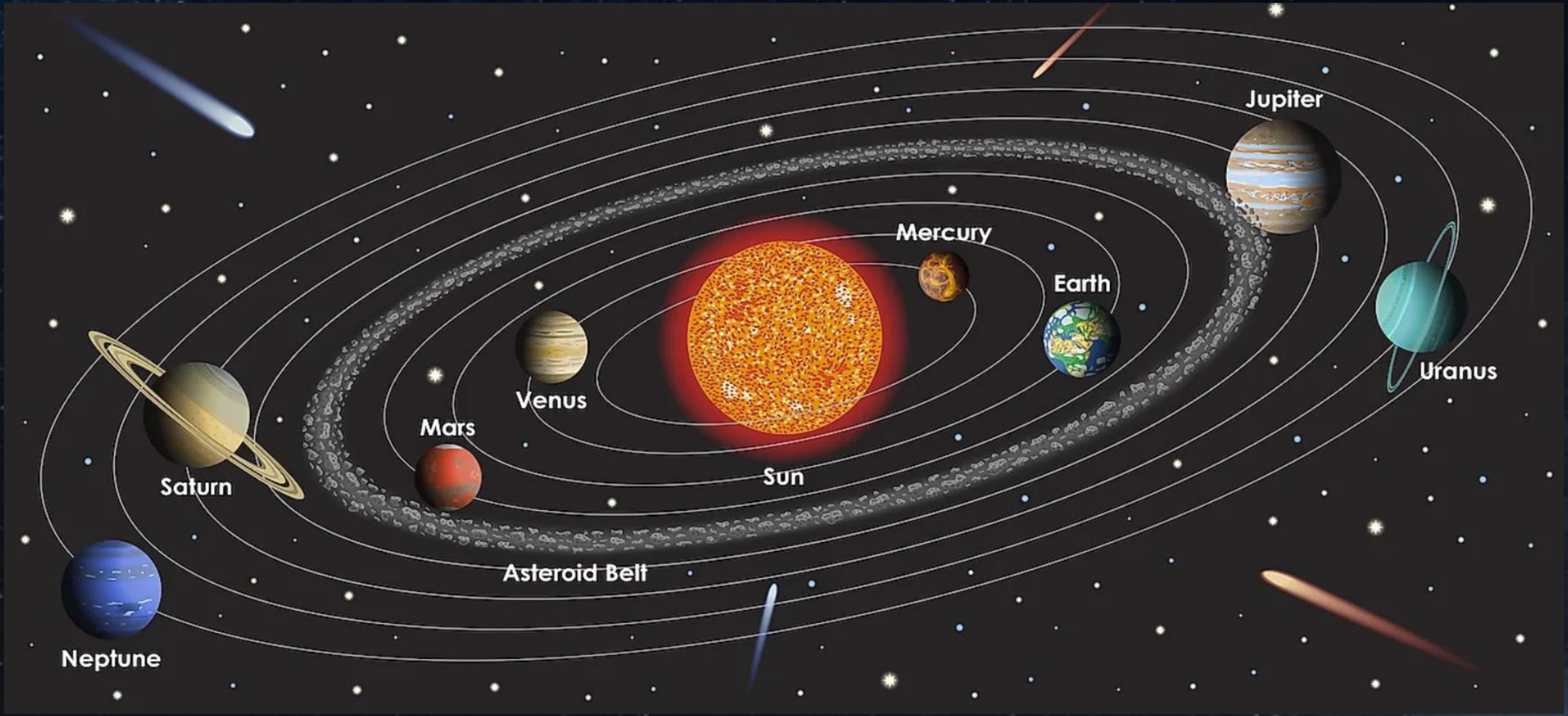
2. Finding possible companions close-by.





R. Belikov et al. 2015

Understanding Universe by Looking Far and At Home



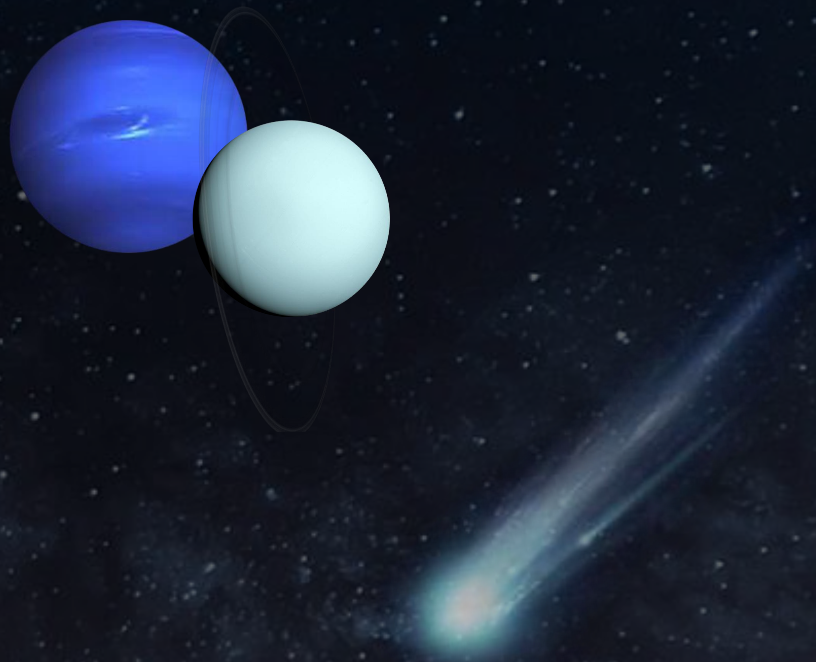
https://www.worldatlas.com/space/the-hottest-and-coldest-planets-of-our-solar-system.html

Solar System Science

Question: Evolution Solar System?

Derived Objectives:

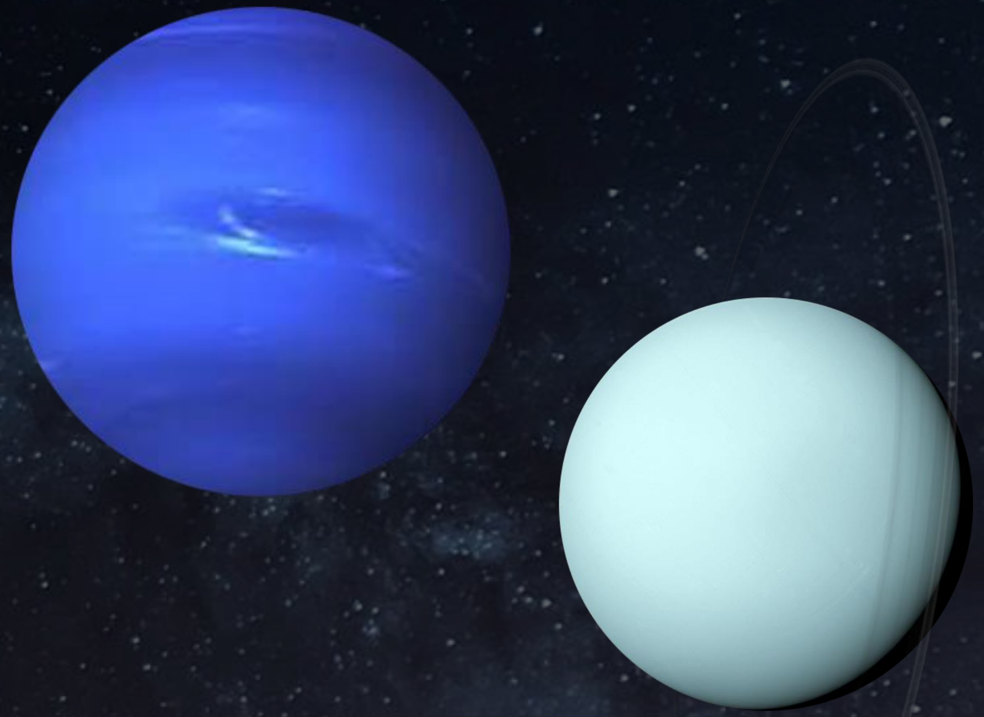
1. Constrain energy budgets of gas planets.
2. Constrain early composition by looking at pristine comets.



Understanding our Solar System:

1. Atmospheric dynamics and energy budget of solar system gas planets.

- A longer wavelength peers into largely unexplored lower atmospheres of Neptune and Uranus
- Mid-Infrared (MIR) observes composition and planetary flux
- Energy Budget can be determined



Understanding our Solar System

2. Constraining the elemental abundances during the formation of our solar system.

- Comets consist of leftover building blocks from the solar system formation process

- Complex organic molecules such as hydrocarbons can be measured at longer wavelengths

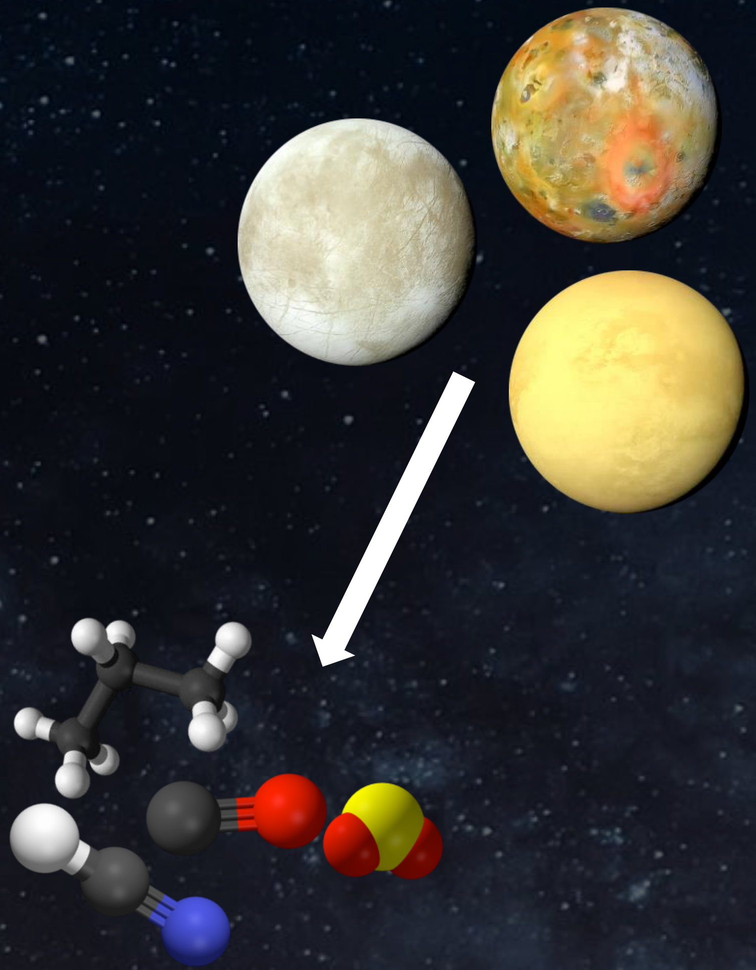
- Comets can give us valuable insights into the formation of the Solar System and molecules of life

Solar System Science

Question: Life in the Solar System?

Derived Objectives:

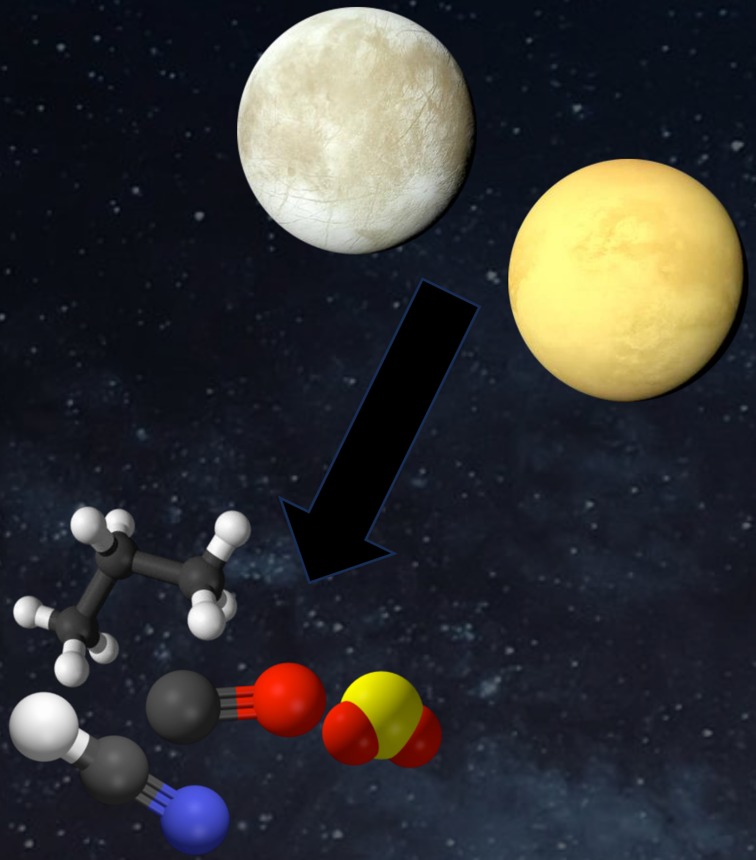
1. Synergize with other mission, looking for biomarkers specifically in the mid-infrared (MIR).



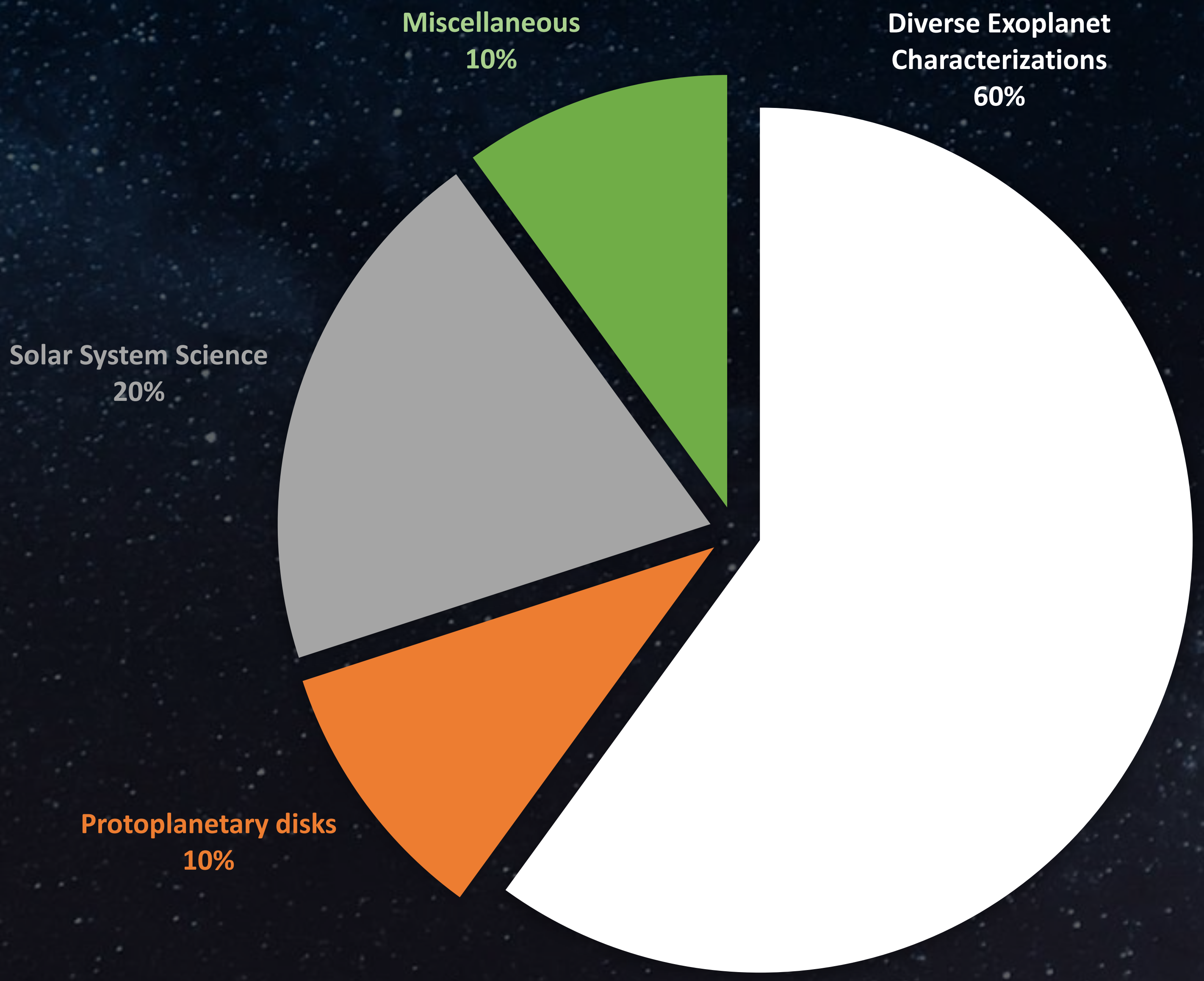
Life in our Solar System?

3. Synergize with other mission by looking for biomarkers in solar system moons which are undiscovered so far.

- Mid-IR opens new possibilities to study atmospheric compositions and dynamics on gas giants' moons
- Hydrocarbons could indicate the presence of life "precursors" i.e. some building blocks for more complex molecules
- Sulfur dioxide (19µm) can give us wider information on geothermal (and especially volcanic) activities



ARISTOTLE Science Breakdown



ARISTOTLE Science Breakdown

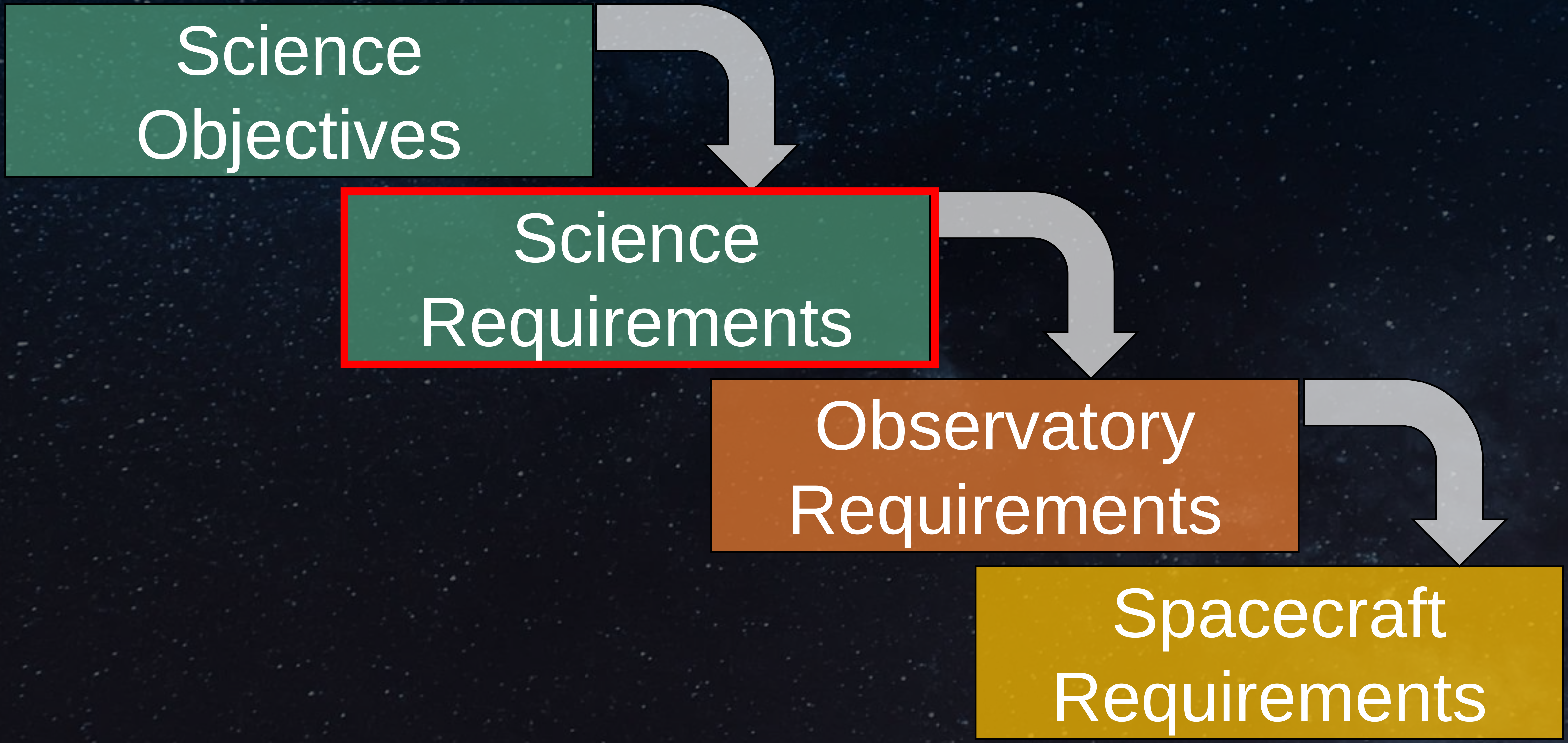
Target Priority – Characterization of Exoplanet Atmospheres
1. Warm Super-Earths and Sub-Neptunes around F and K stars.
2. Hot Jupiters
3. Hot Rockies, Super-Earths and Sub-Neptunes

ARISTOTLE Science Breakdown

Target Priority – Solar System Science
1. Energy budget Neptune & Uranus
2. Biosignatures on solar system moons
3. Pristine Comets and Interstellar Objects

Target Priority – Protoplanetary Disks
1. Follow up observations of NEAR PPDs
2. Search for (possible) habitable planet around alpha Centauri
3. Direct Imaging of far out, young Exoplanets (ask Frans for what targets)

Requirements Breakdown



Science Questions: A Refresher

Primary

Under what conditions are exoplanet atmospheres possible, and how does it shape their characteristics?

Secondary

How do planetary systems form and evolve?

How does our solar system work, and does it compare to other stellar systems?

Is there life elsewhere in our solar system?

Scientific Requirements

Primary Science Objectives

Secondary Science Objectives

The mission shall do **spectrography** in the range of **2.5-23 μm**.

The **spectrograph** shall have a resolution **R=200** (**2.5-10** μ**m**) and **R=100** (**10-23 μm**).

The mission shall be able to observe continuously for up to **24 hours**.

The mission shall be able to observe up to **5 transits** of exoplanets in the habitable zone of sun-like stars.

Scientific Requirements

Objectives	Requirement
Primary Science Objectives	The Imager shall have a spatial resolution of 50AU at 100pc (**R = 500mas**).
	The imager shall have a **coronagraph**.
Secondary Science Objectives	The mission shall be able to image in **10.65, 11.4, 15.5, 19, 22 μm** bands.
	The mission shall image with less than **50mas** relative pointing error.

Requirements Breakdown

Science Objectives

Science Requirements

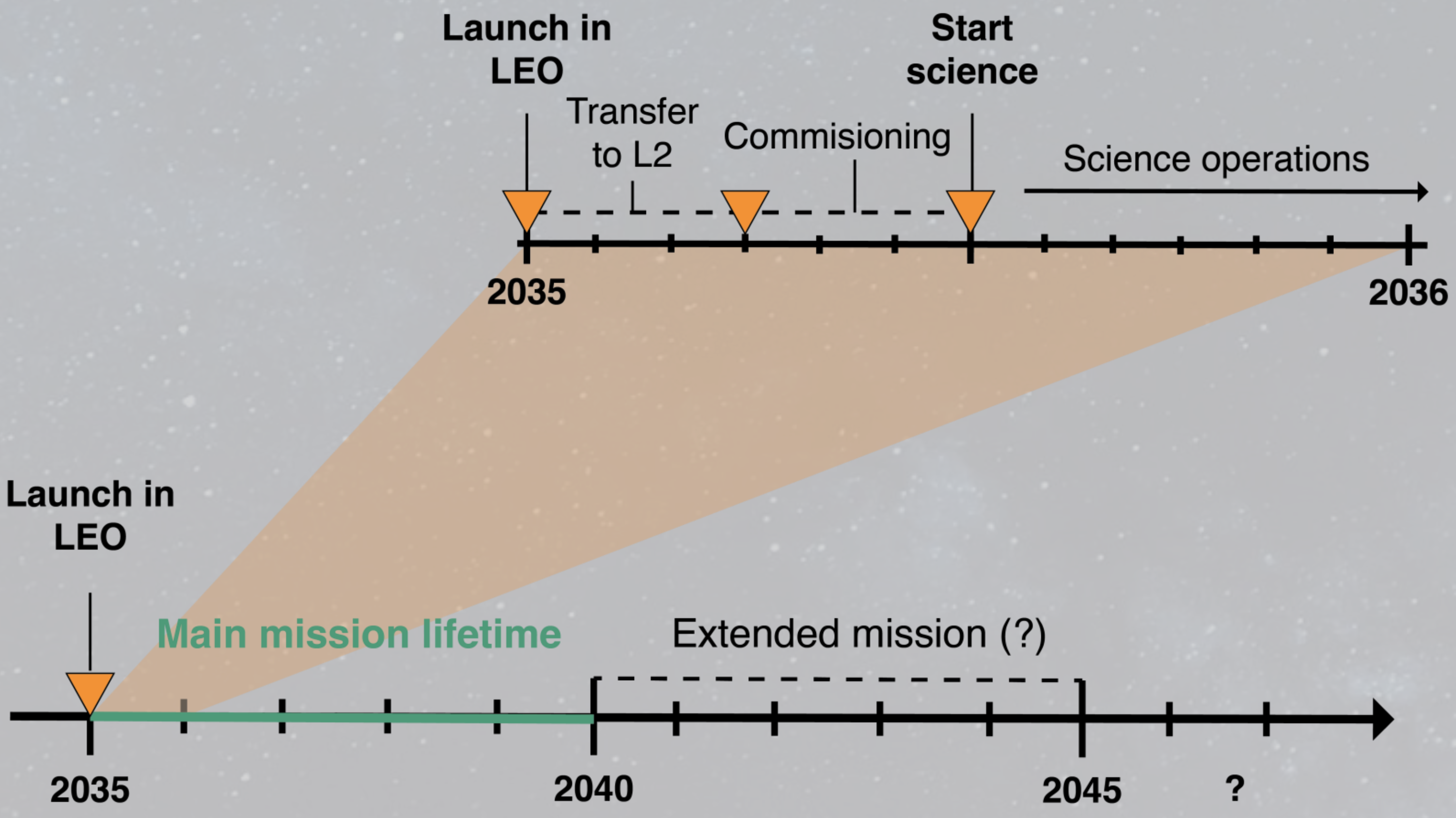
Observatory Requirements

Spacecraft Requirements

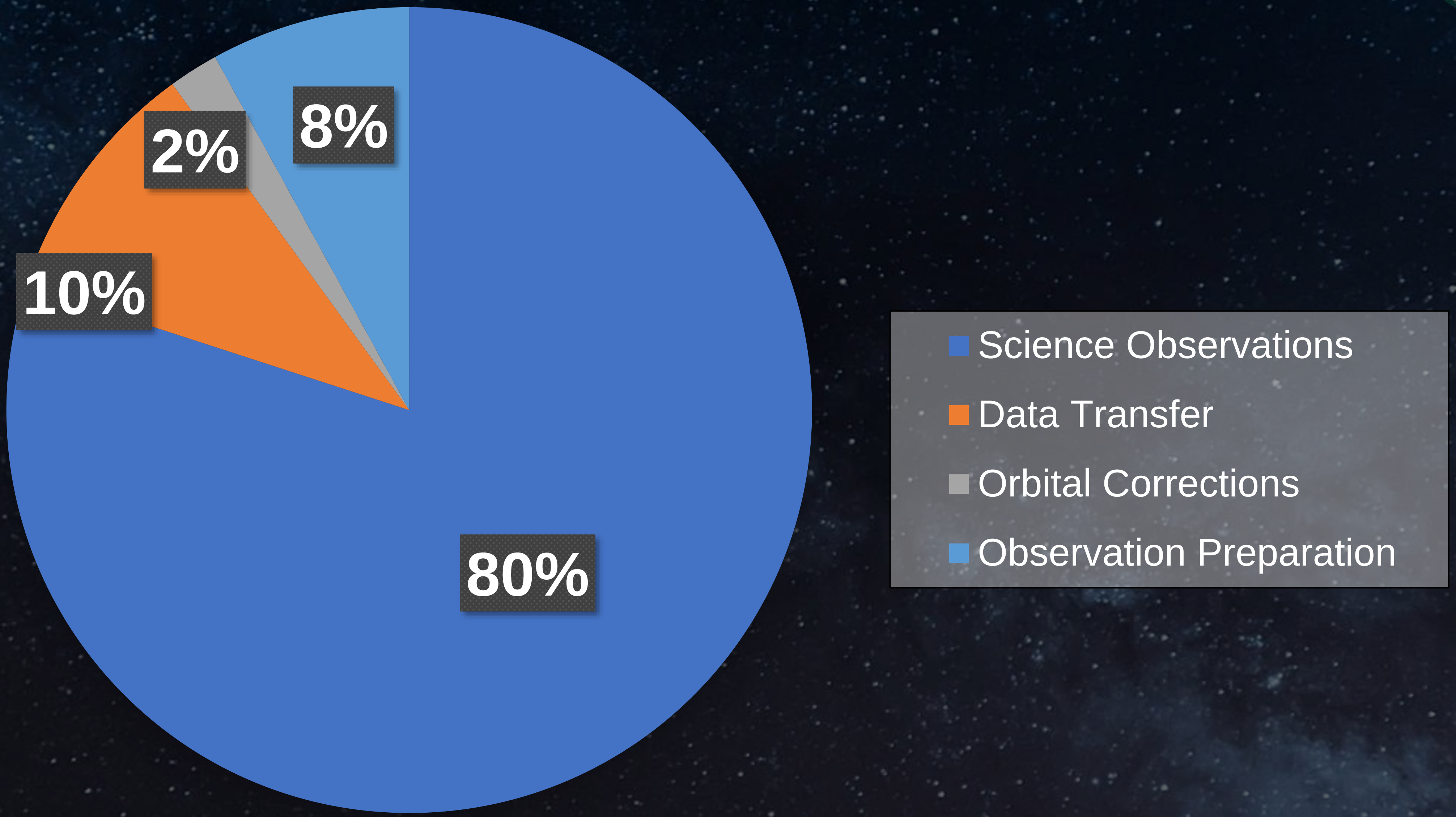
Table of Content: Observatory

Mission Profile

Concept of Operations

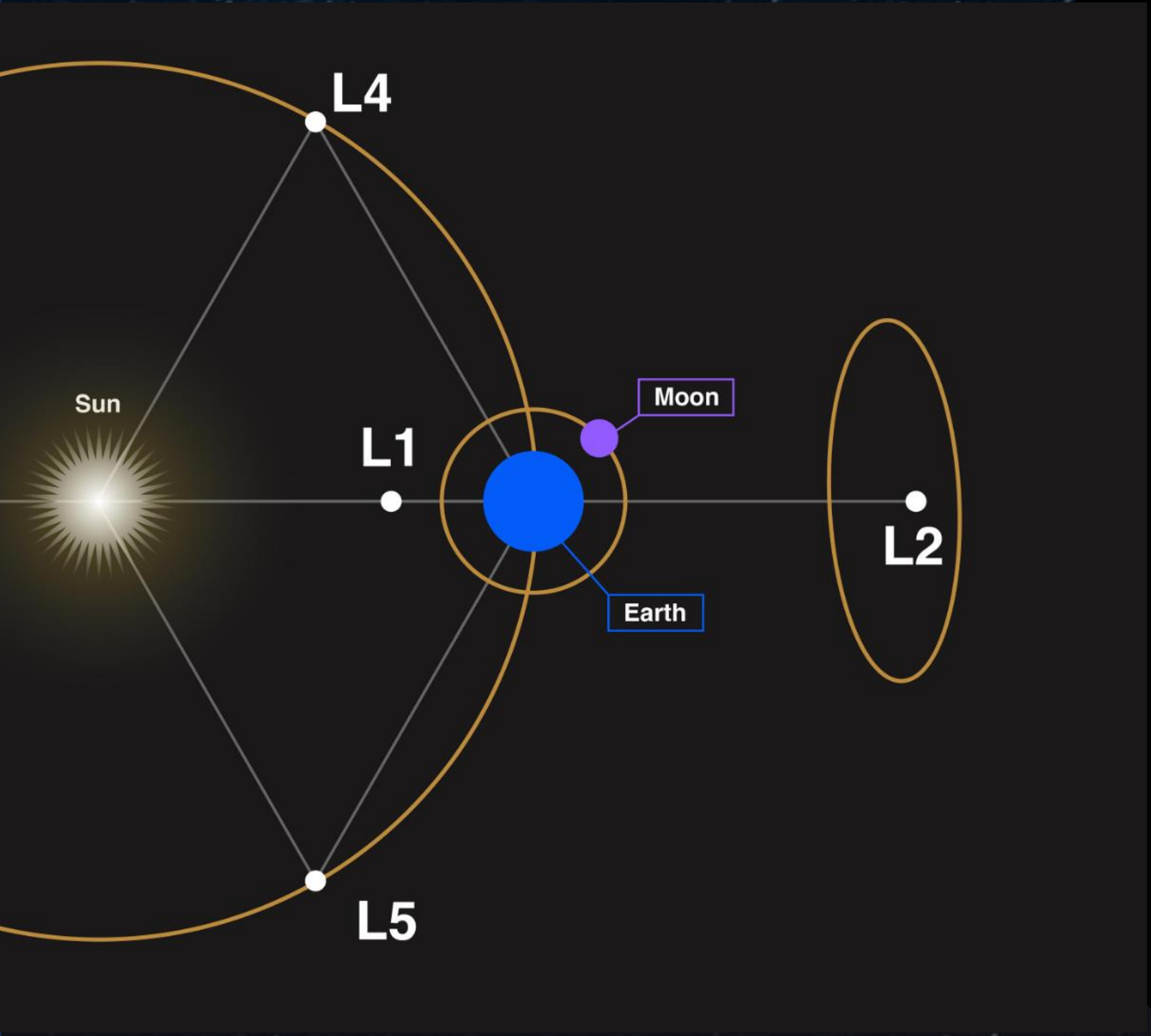


Break-up of Time During Mission



Orbit Determination

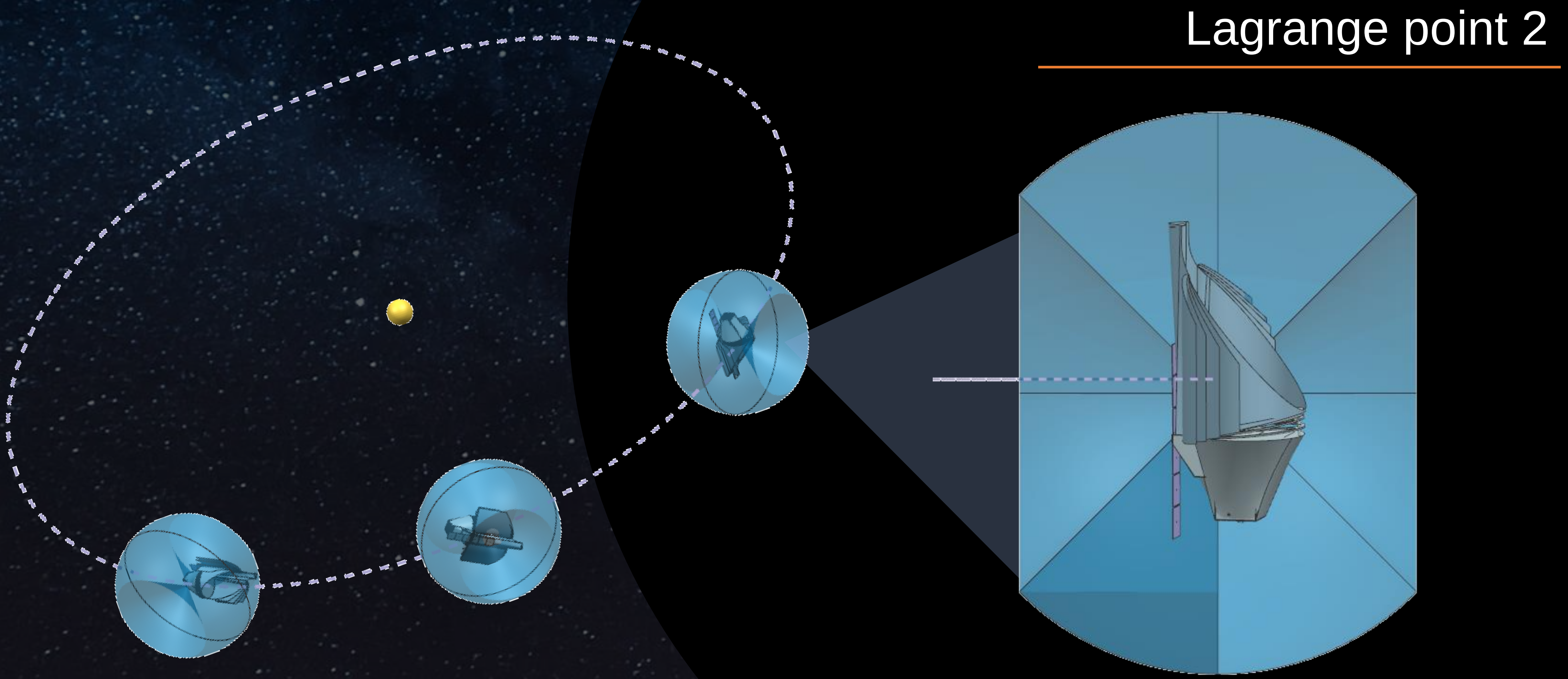
Target Orbit



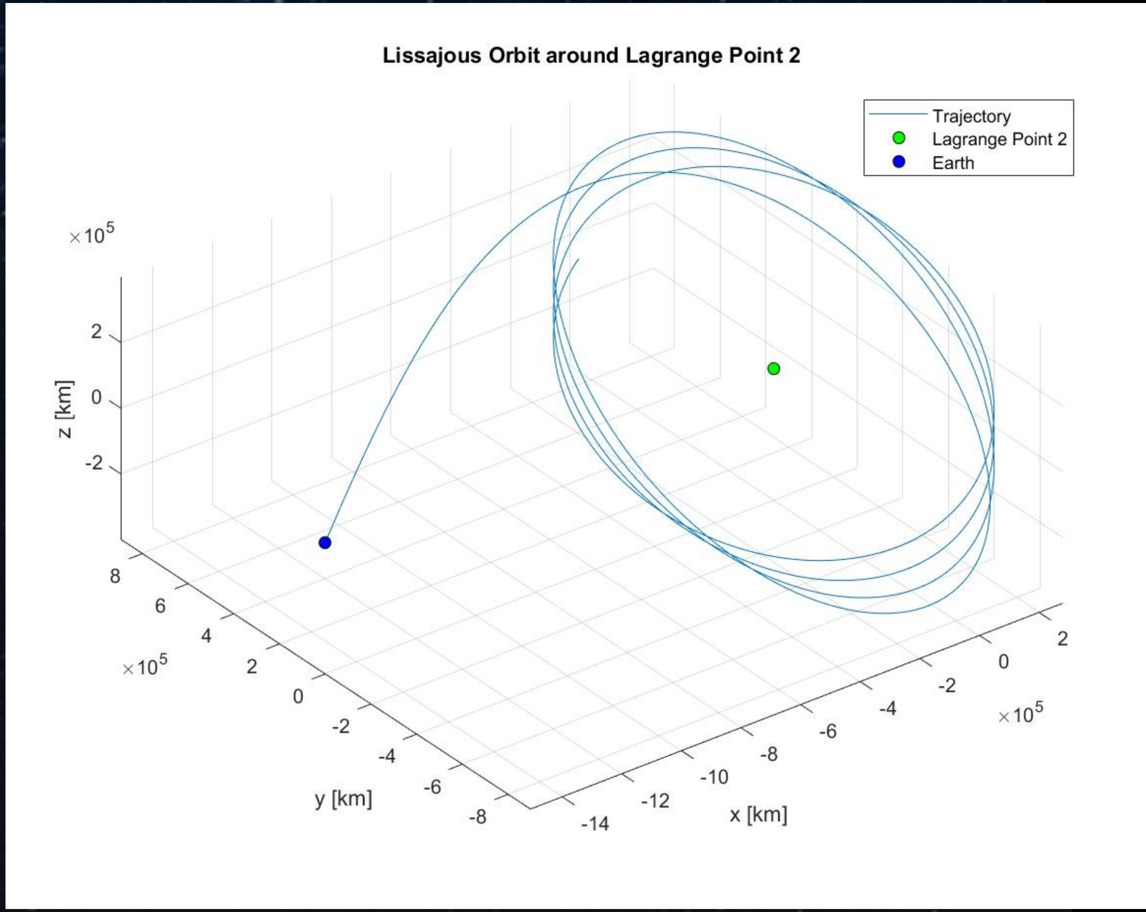
Lagrange point 2

1) Thermal / radiation stability
2) Eclipses avoidance possible
3) Less geometric constraints

Observation angles



Target Orbit

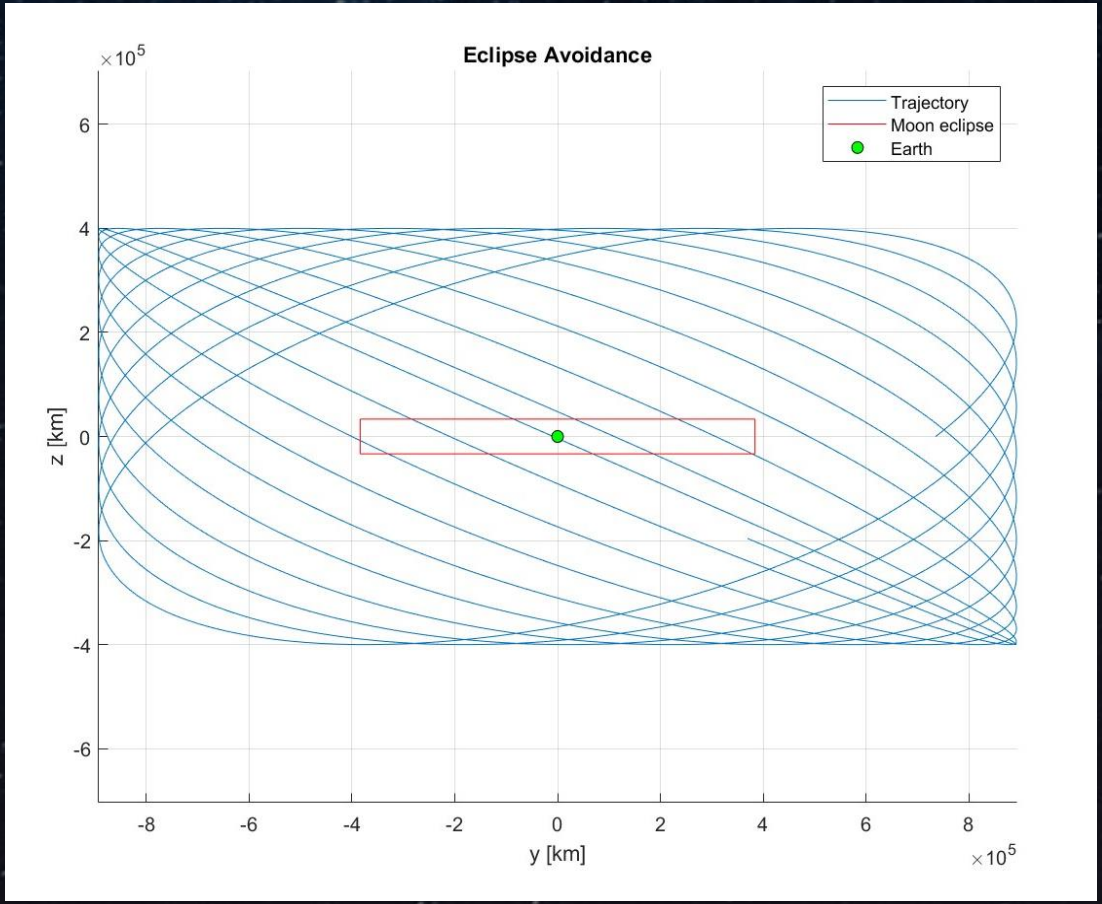


Orbital Parameters

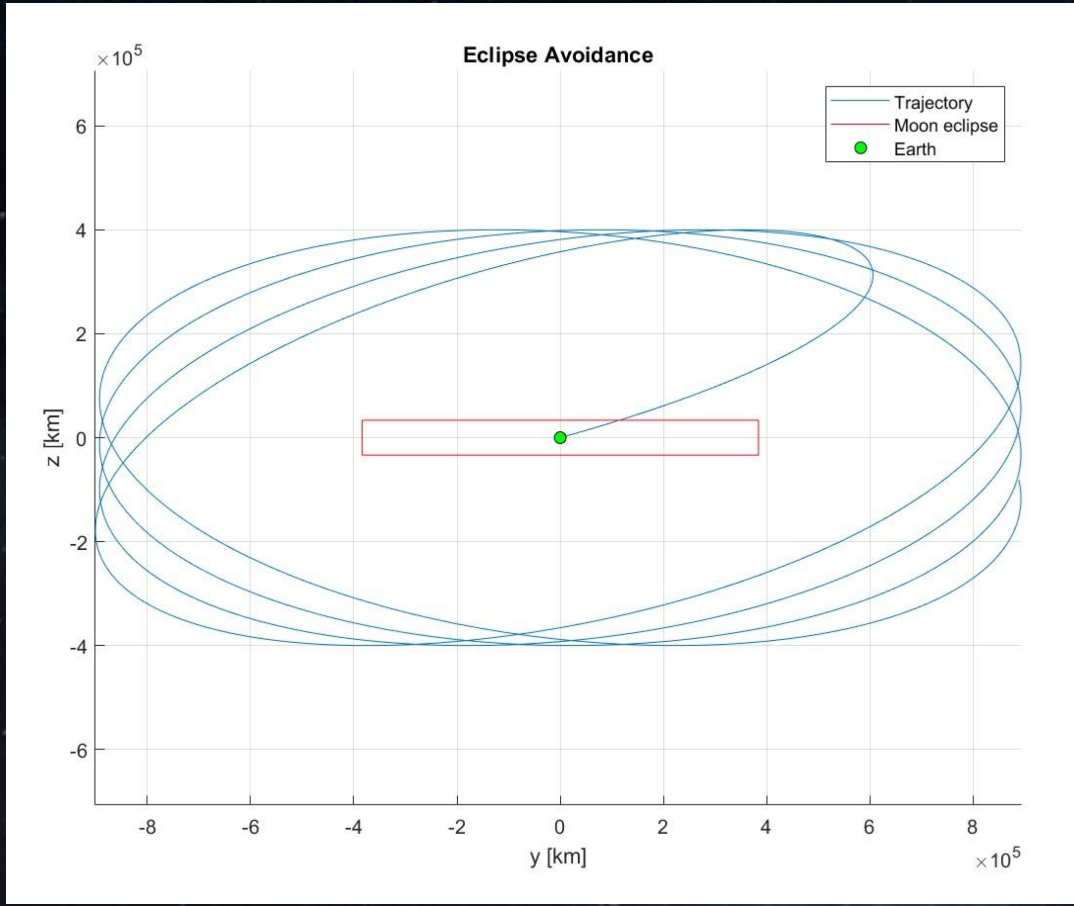
1) Amplitudes:
   - Az: 400.000 km
   - Ay: 800.000 km
2) One orbit/half year

Orbit Eclipse Avoidance

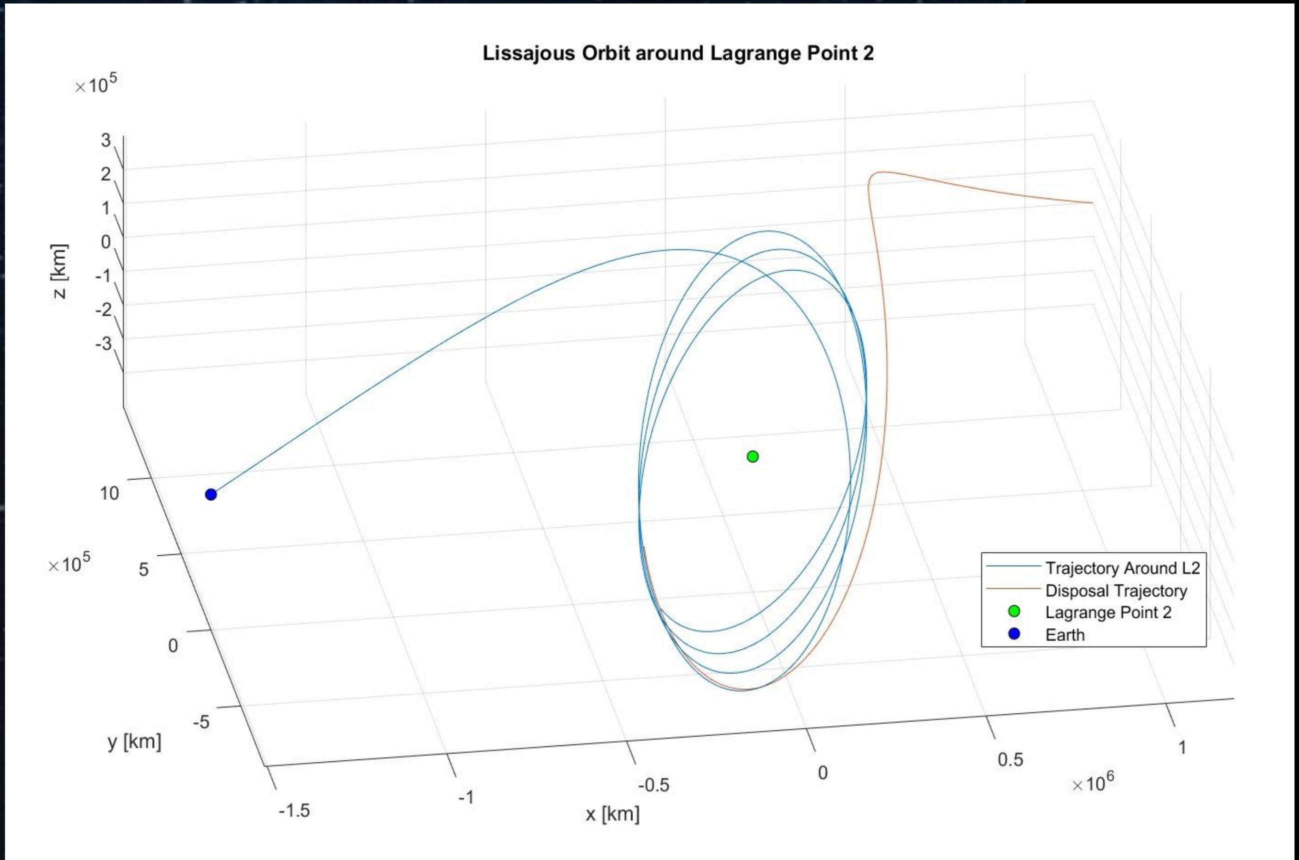
Without eclipse avoidance manoeuvres



With eclipse avoidance manoeuvres



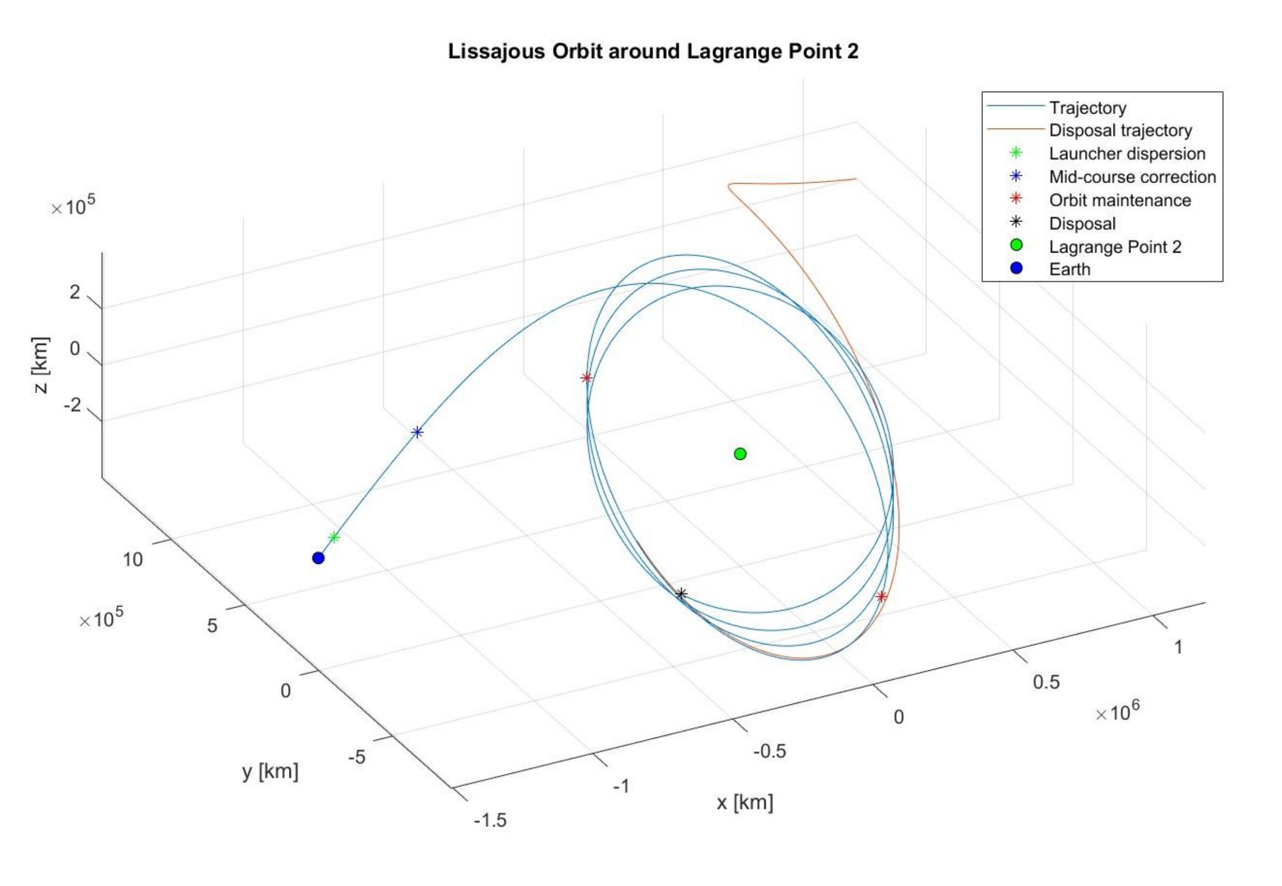
Spacecraft Disposal



Requirements

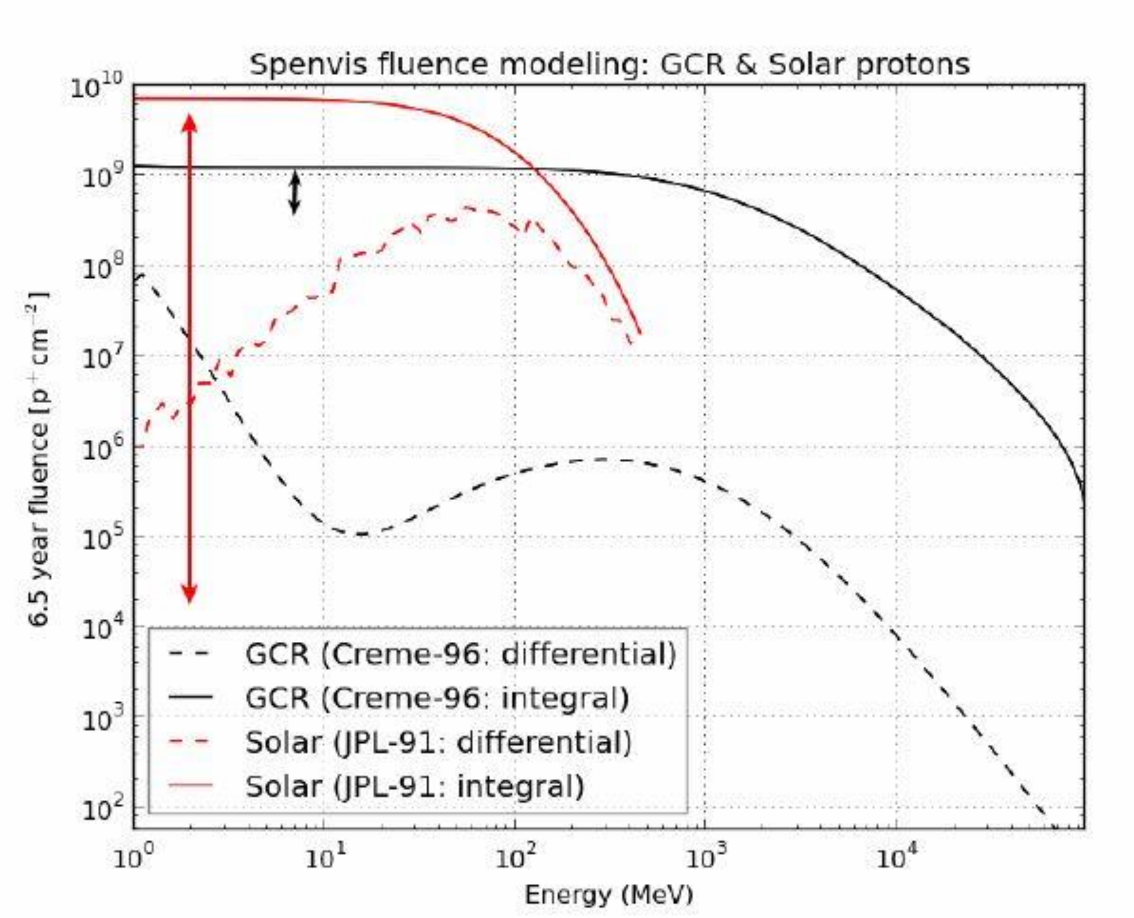
1) Disposal of spacecraft
2) ESA: Preven collision with Earth for 100 years

Delta-V Budget



#	Delta V Maneuvers	Delta V
1	Removal launcher dispersion	50 m/s
2	Mid-course correction	1 m/s
3	Orbit maintenance (for 5 years)	10 m/s
4	Eclipse correction (for 5 years)	10 m/s
5	Disposal	20 m/s
6	Total	91 m/s

Environmental Conditions



Source: radiation effects on the GAIA CCDs after 30 months at L2

Sources

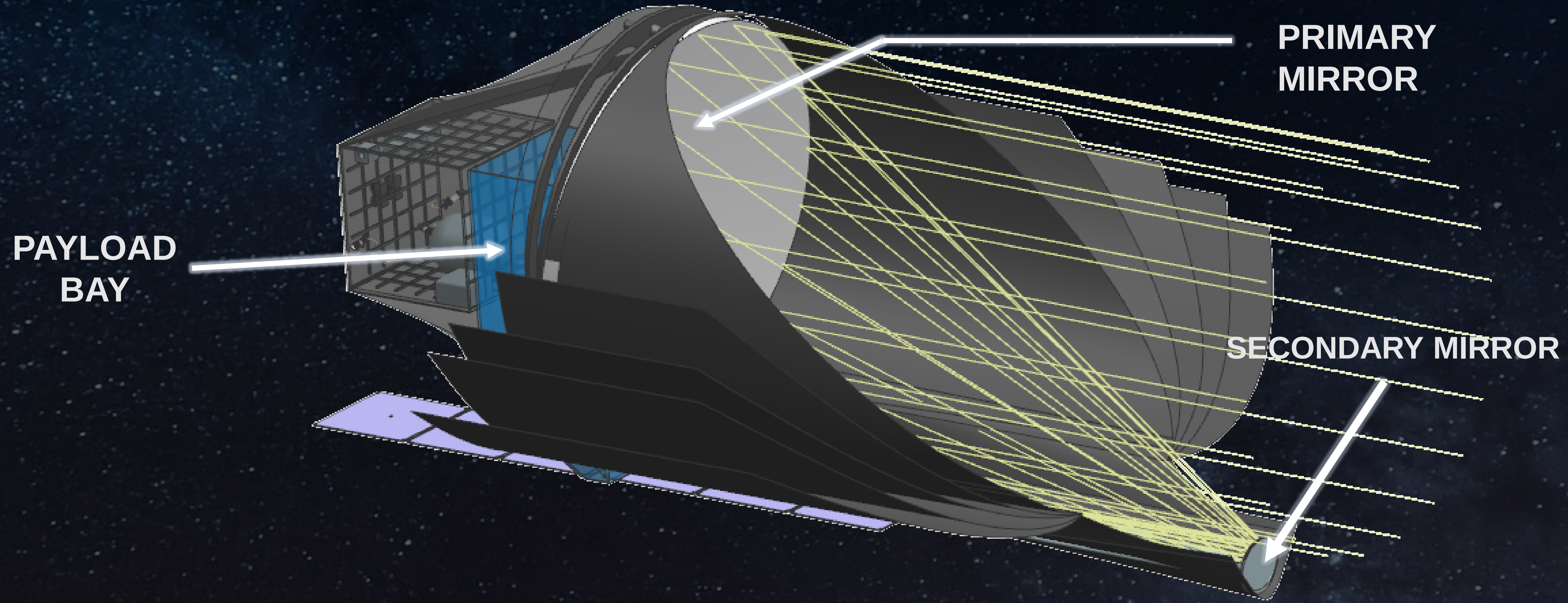
- Proton flux
- Origin: Galactic cosmic rays, solar flares
- Effects: displacement damage

Mitigation

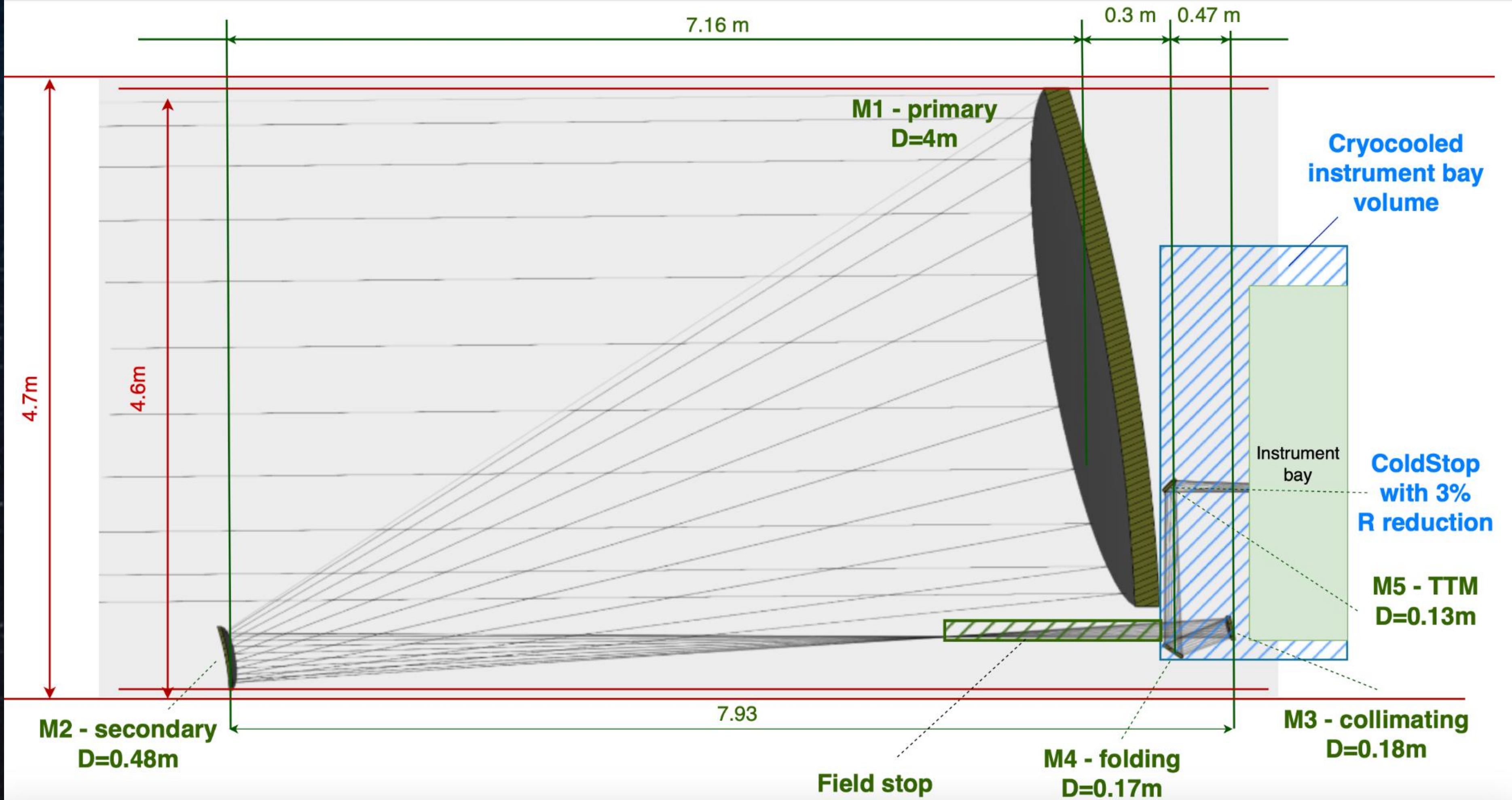
- Not determined in phase A study

Observatory Concept

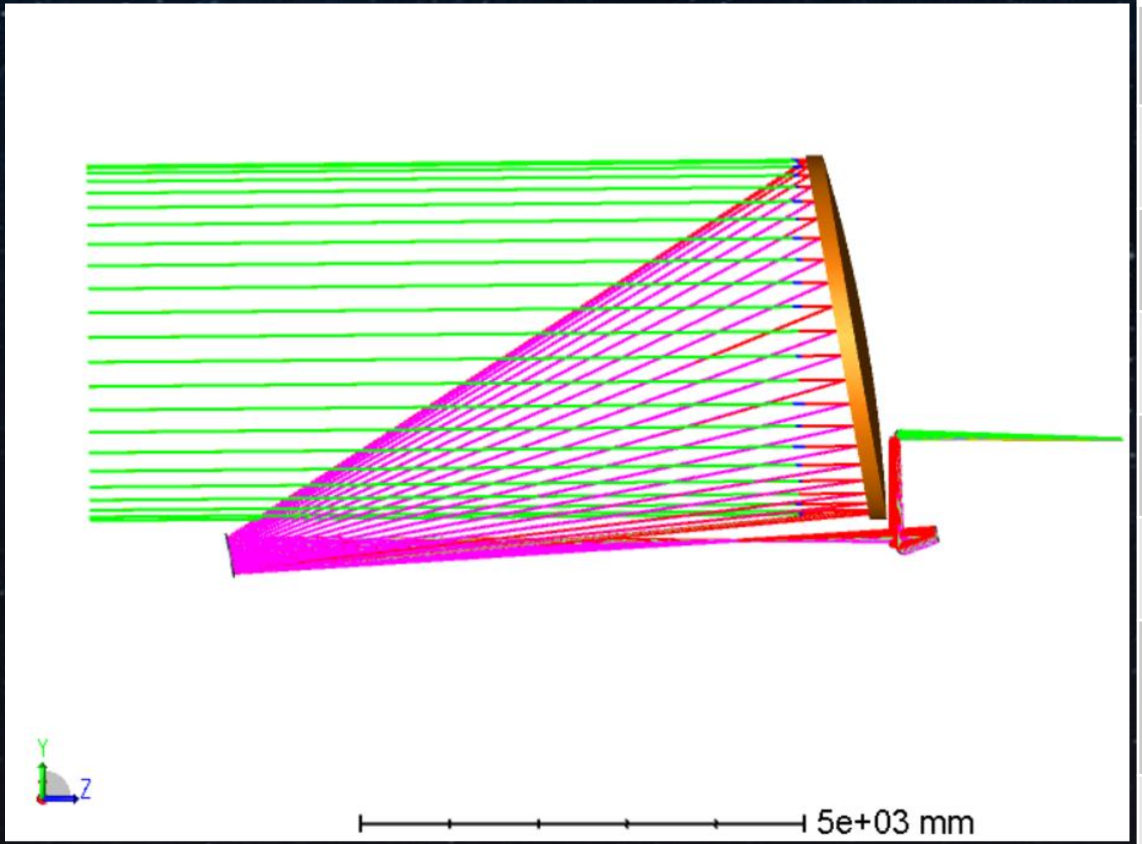
Observatory



Telescope

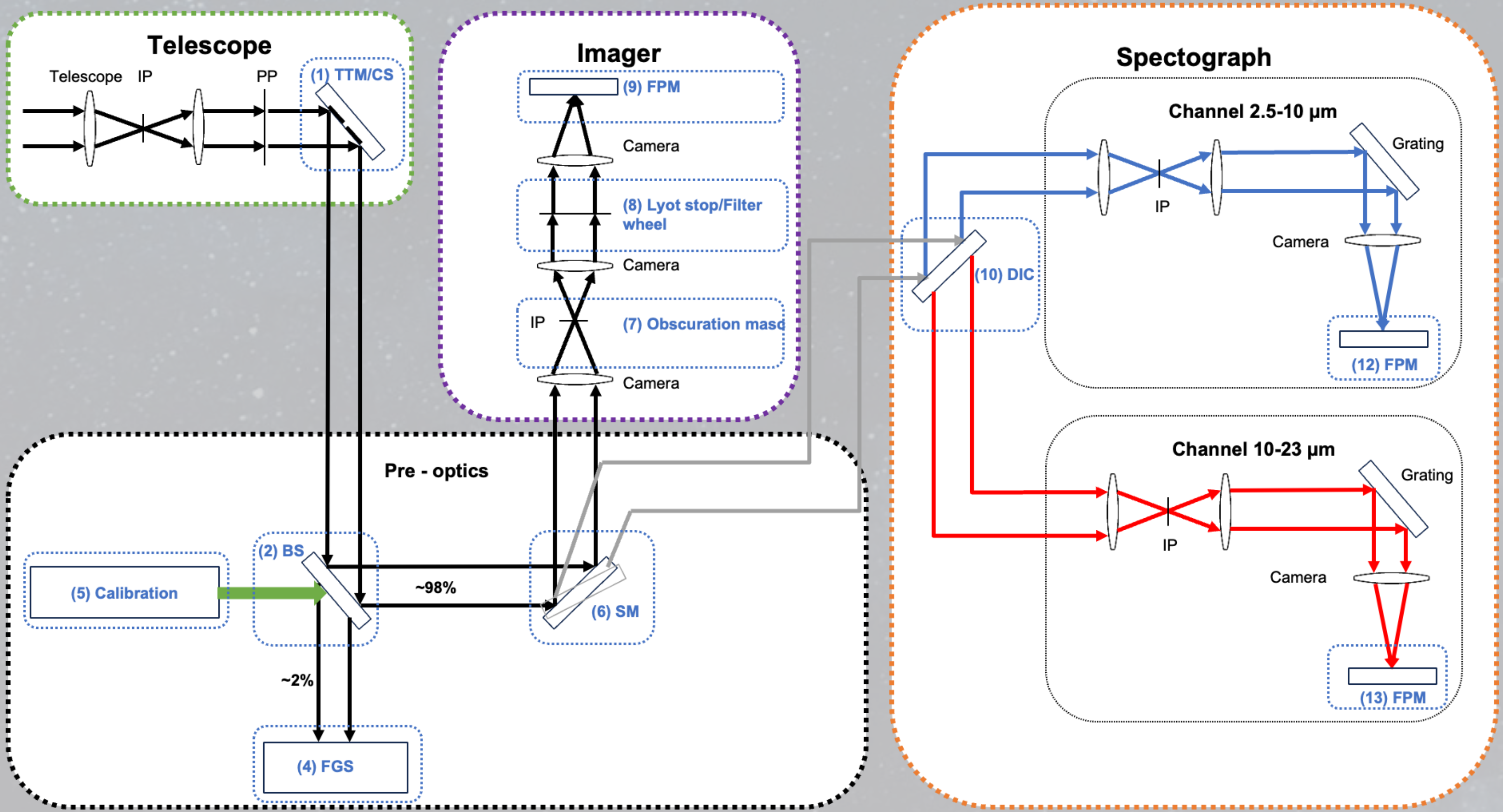

7.16 m
0.3 m
0.47 m
M1 - primary
D=4m
Cryocooled
instrument bay
volume
4.7m
4.6m
Instrument
bay
ColdStop
with 3%
R reduction
M5 - TTM
D=0.13m
7.93
M2 - secondary
D=0.48m
M3 - collimating
D=0.18m
Field stop
M4 - folding
D=0.17m

Telescope: Optical Design

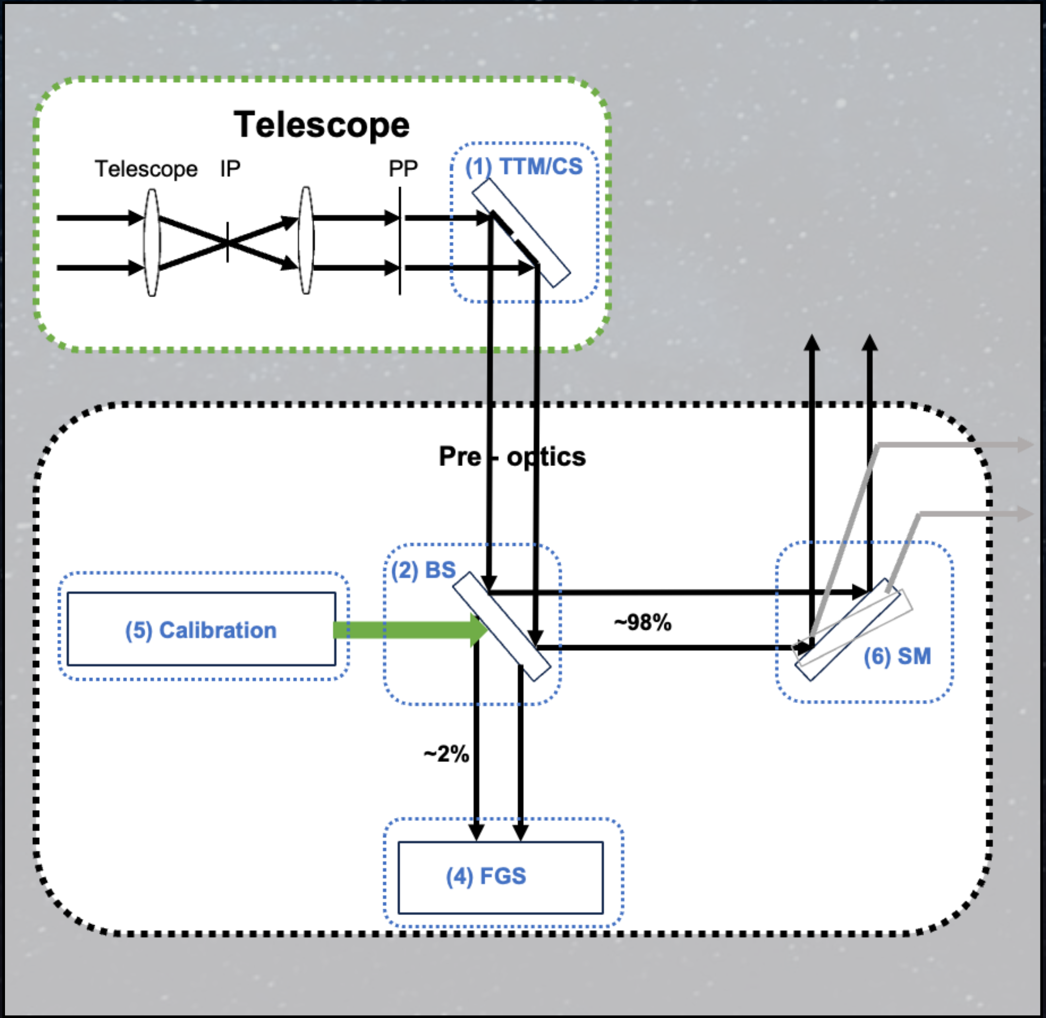


#	Parameter	Value
1	Primary mirror size	4m
2	Focal ratio	F/32
3	FOV	25 arcsec
4	Wavelength	2.5-23ym
5	Mass (82% lightweighting)	450-470 kg
6	Coating	gold
7	Substrate	Bonded Silicon Carbide
8	TRL	6

Observatory: Optical Path

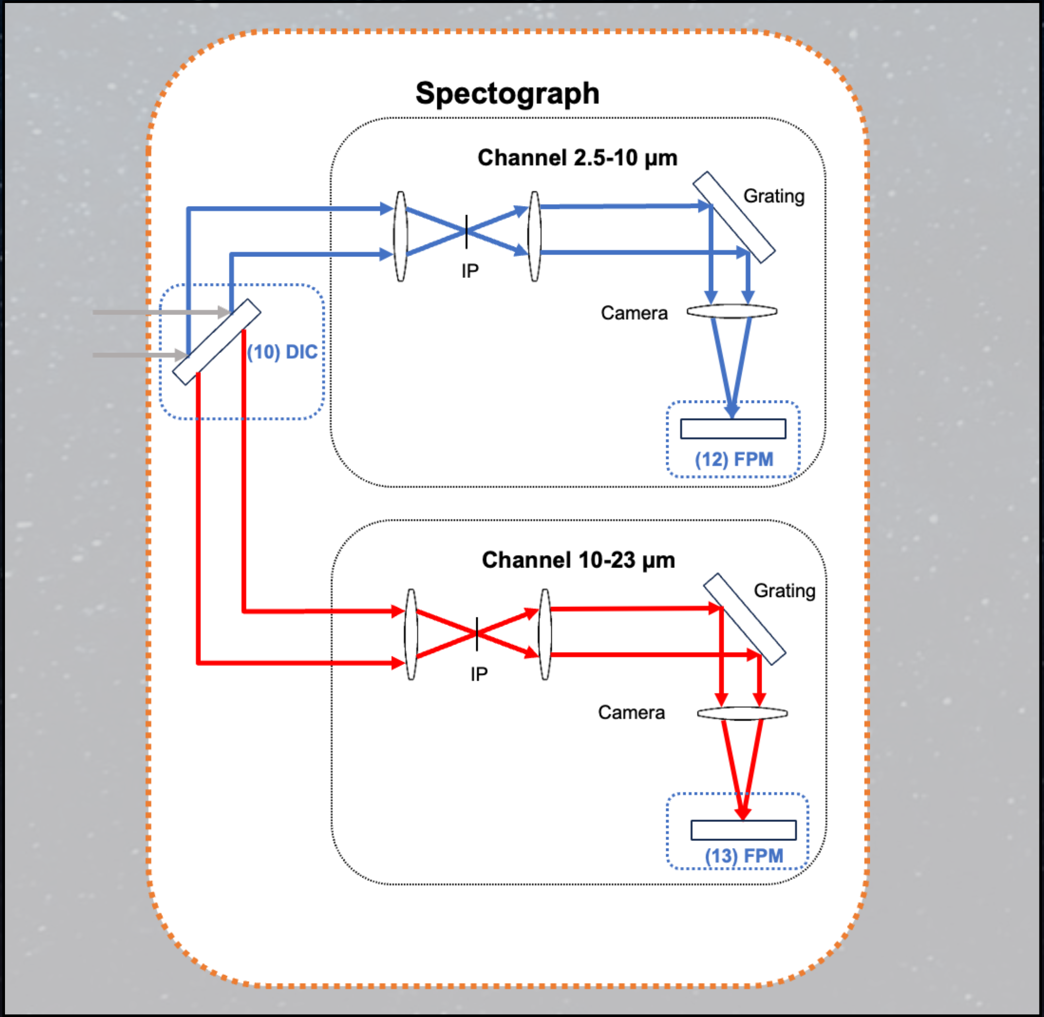


Instruments: Pre-optics



#	Critical Component	Function	Heritage	TRL
1	Tip Tilting Mirror (TTM) Cold Stop (CS)	Beam stabilization Cooling	MITIS, GAIA	6, 8
2	Beam Splitter (BS)	2 % FGS 98 % Science	MIRI	8
4	Fine Guiding Sensor (FGS)	fine pointing attitude stabilization	JWST	8
5	Calibration	Flux	JWST	8
6	Selection Mirror (SM)	Change of instrument	MIRI	8

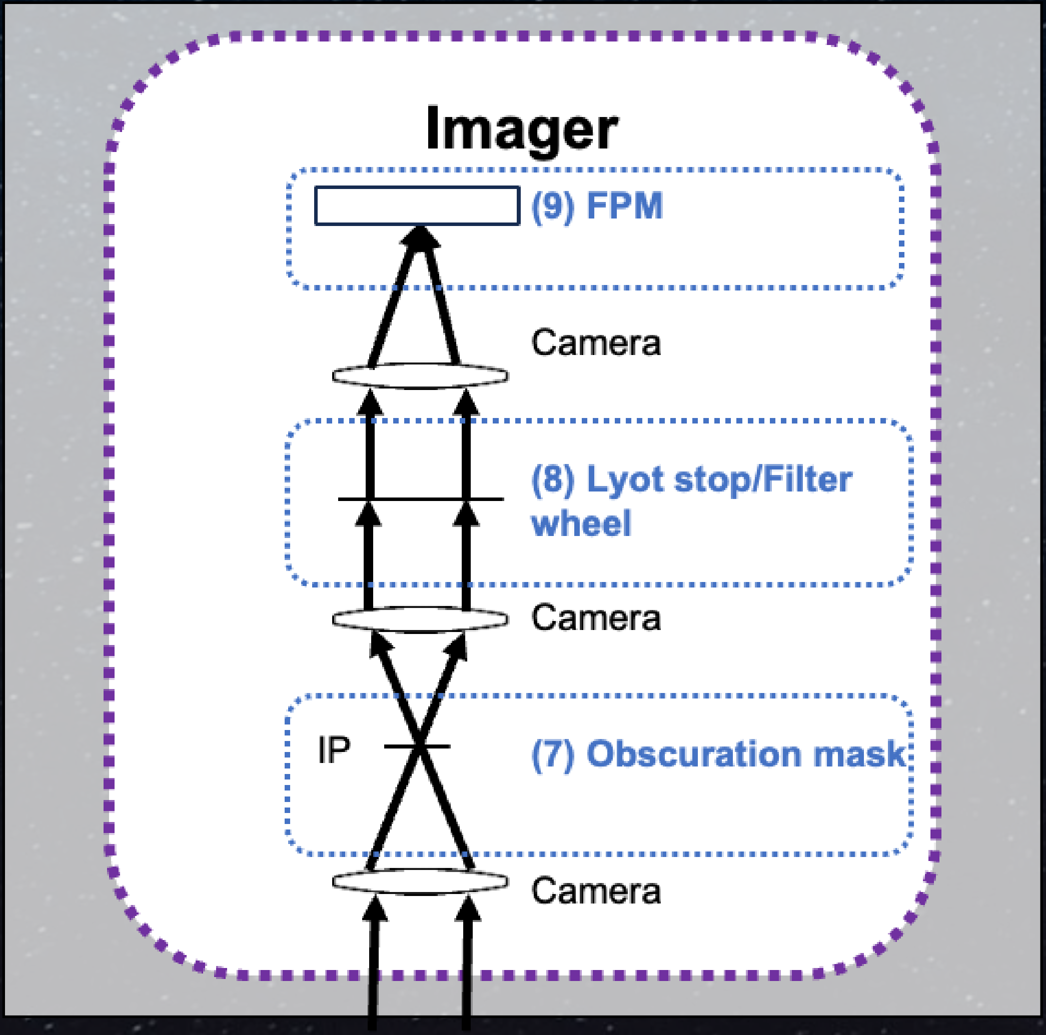
Instruments: Spectrograph



#	Critical Component	Function	Heritage	TRL
10	Dichroic (DIC)	Wavelength splitting	MIRI	8
11, 12	Focal Plane Module (FPM)	Light detection	MIRI	8

Galactic Astrobiology Broadband for Exoplanet Yields (GABBY) Infrared Spectrometer

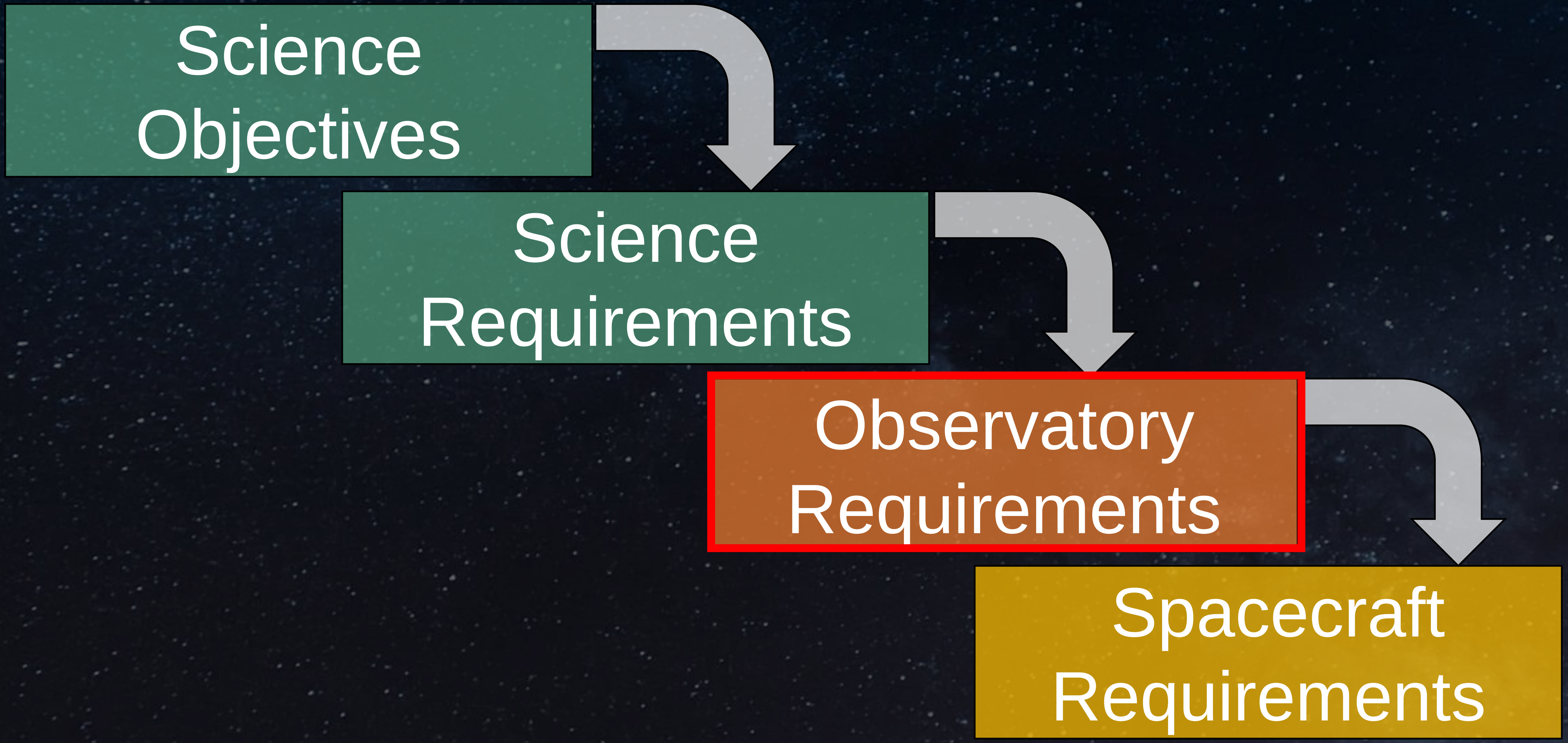
Instruments: Imager



#	Critical Component	Function	Heritage	TRL
7	Obscuration Mask	Selection in/out	ISO	8
8	Lyot Stop Filter Wheel	Selection of stops and filters (12 TBD)	MIRI	8
9	Focal Plane Moduel (FPM)	Light detection	MIRI	8

Coronographic High Resolution Imaging System (CHRIS)

Requirements Breakdown



Observatory Requirements

The mission shall do **spectrography** in the range of **2.5-23 µm**.

The mission shall be able to image in **10.65, 11.4, 15.5, 19, 22 µm** bands.

Spectrograph is split by Dichroic into two channels

Channel 1: 2.5-10 µm, Channel 2: 10-22 µm

Selection of filter throughout the filter wheel

Movable obscuration mask (in/out)

Table of Content: Spacecraft

Design Drivers

Main design drivers

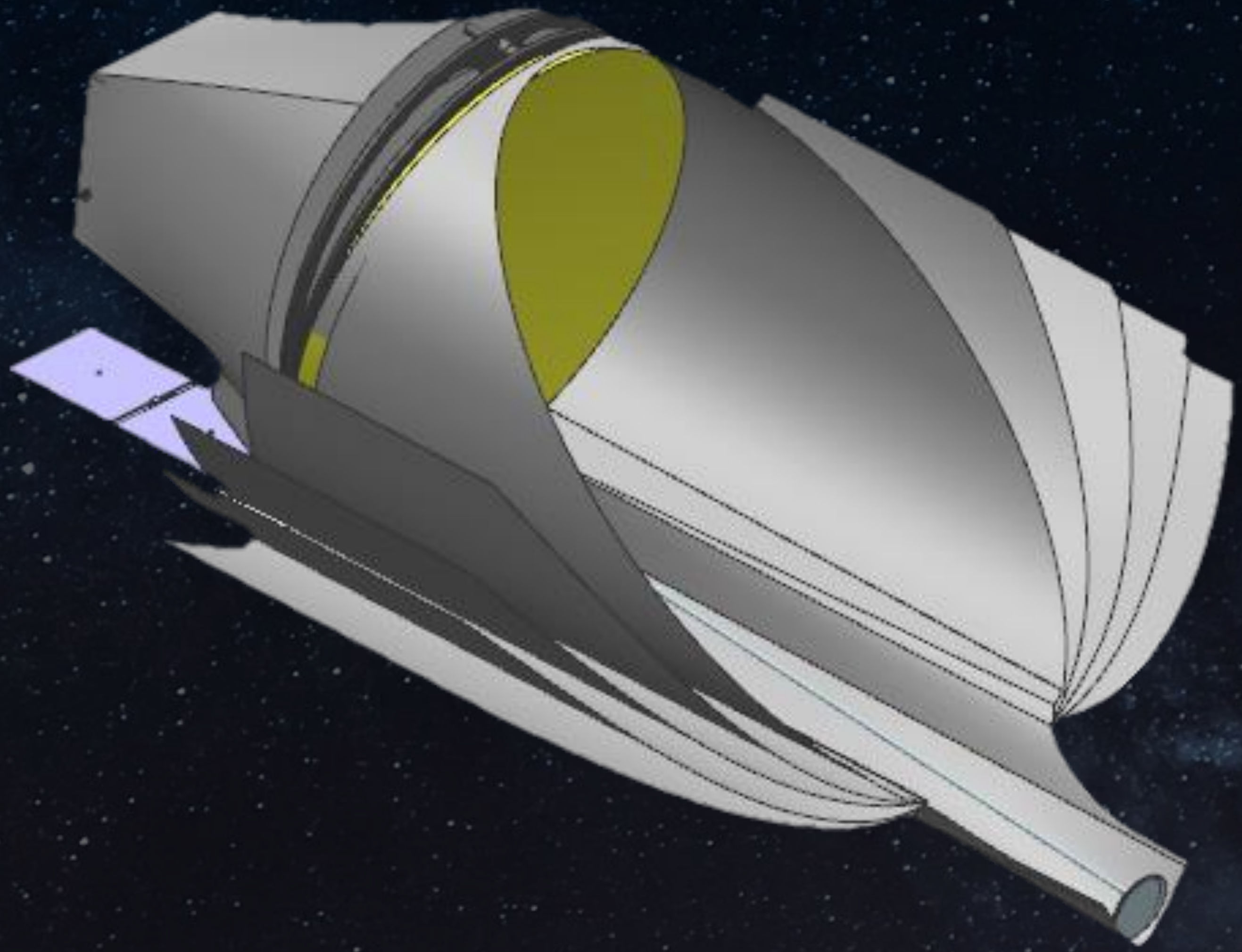
- Primary mirror size (4m)
- Observation wavelength range (2.5-23μm)
- Instrument operational temperature (7-10K)
- Mission lifetime (5+ years)

Secondary design drivers

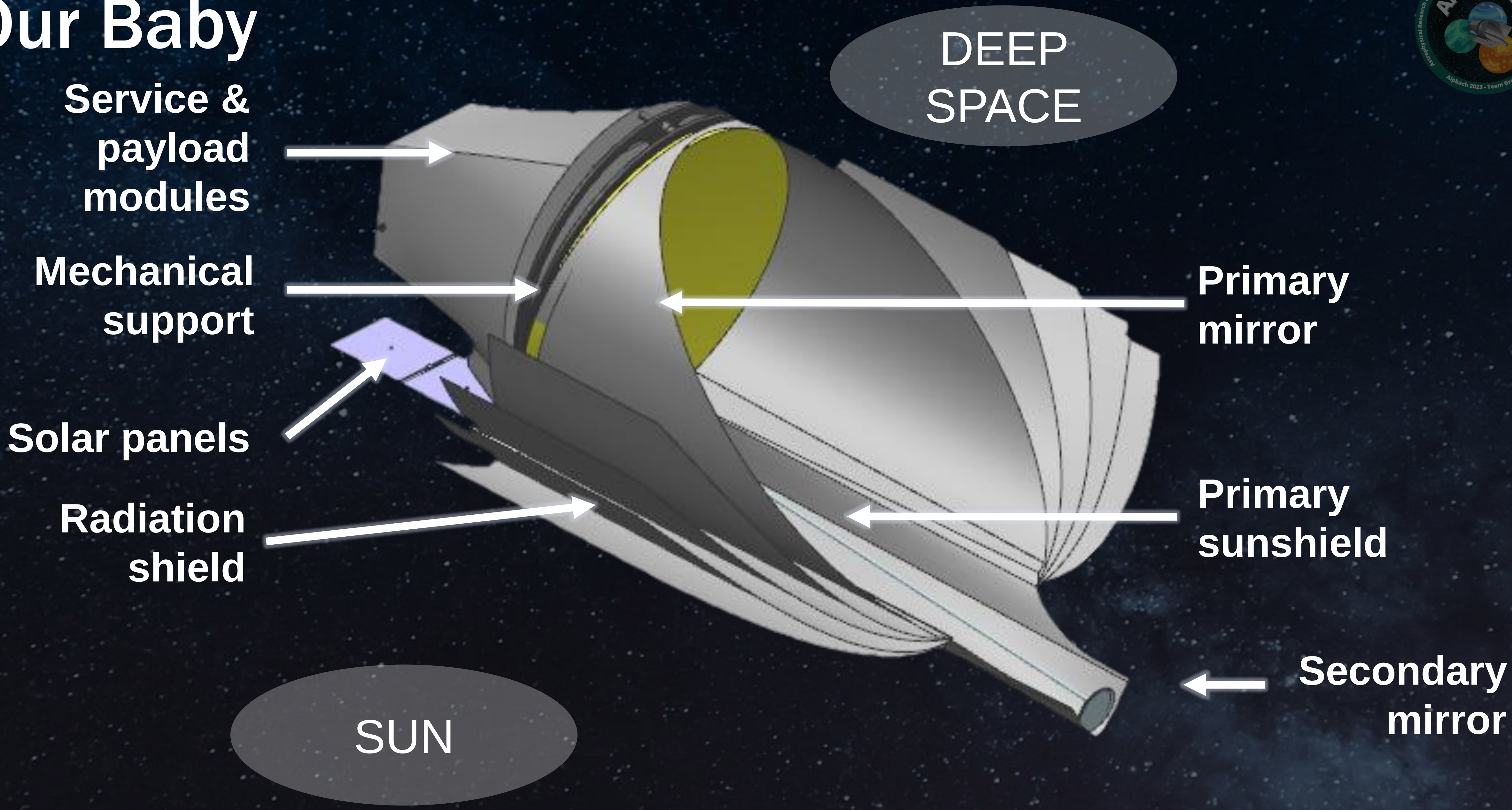
- Launch vehicle constrains
- Reuse of currently developed technologies (high TRLs)

Spacecraft Envelope

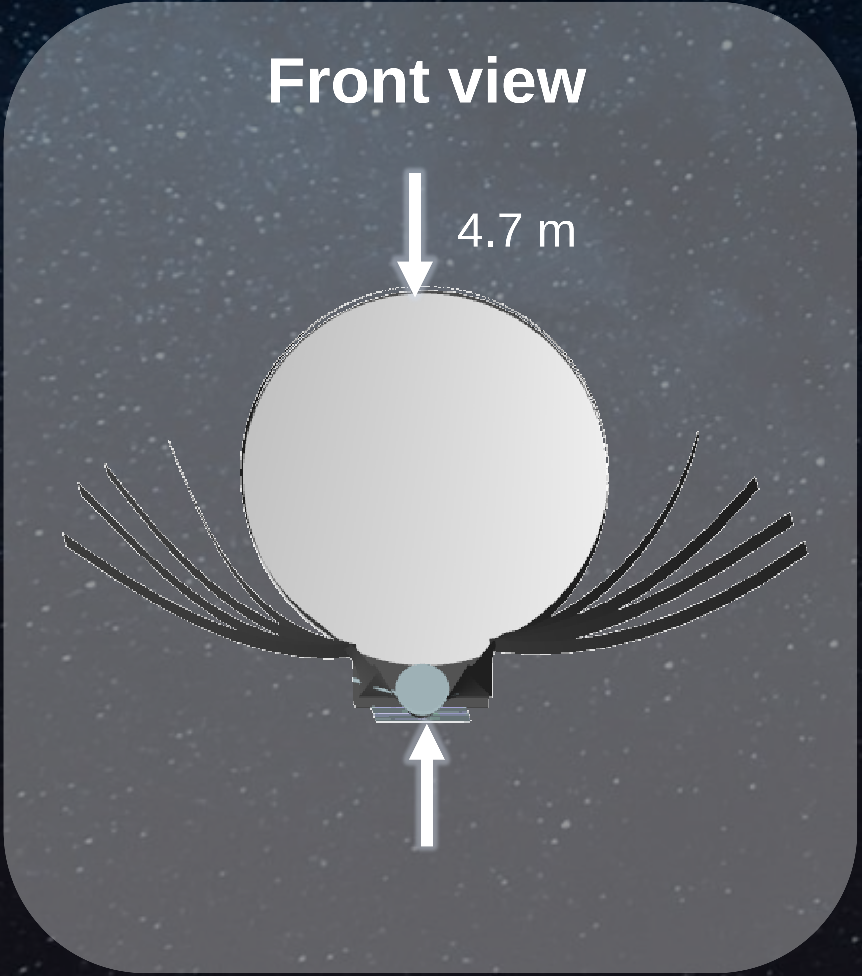
Our Baby

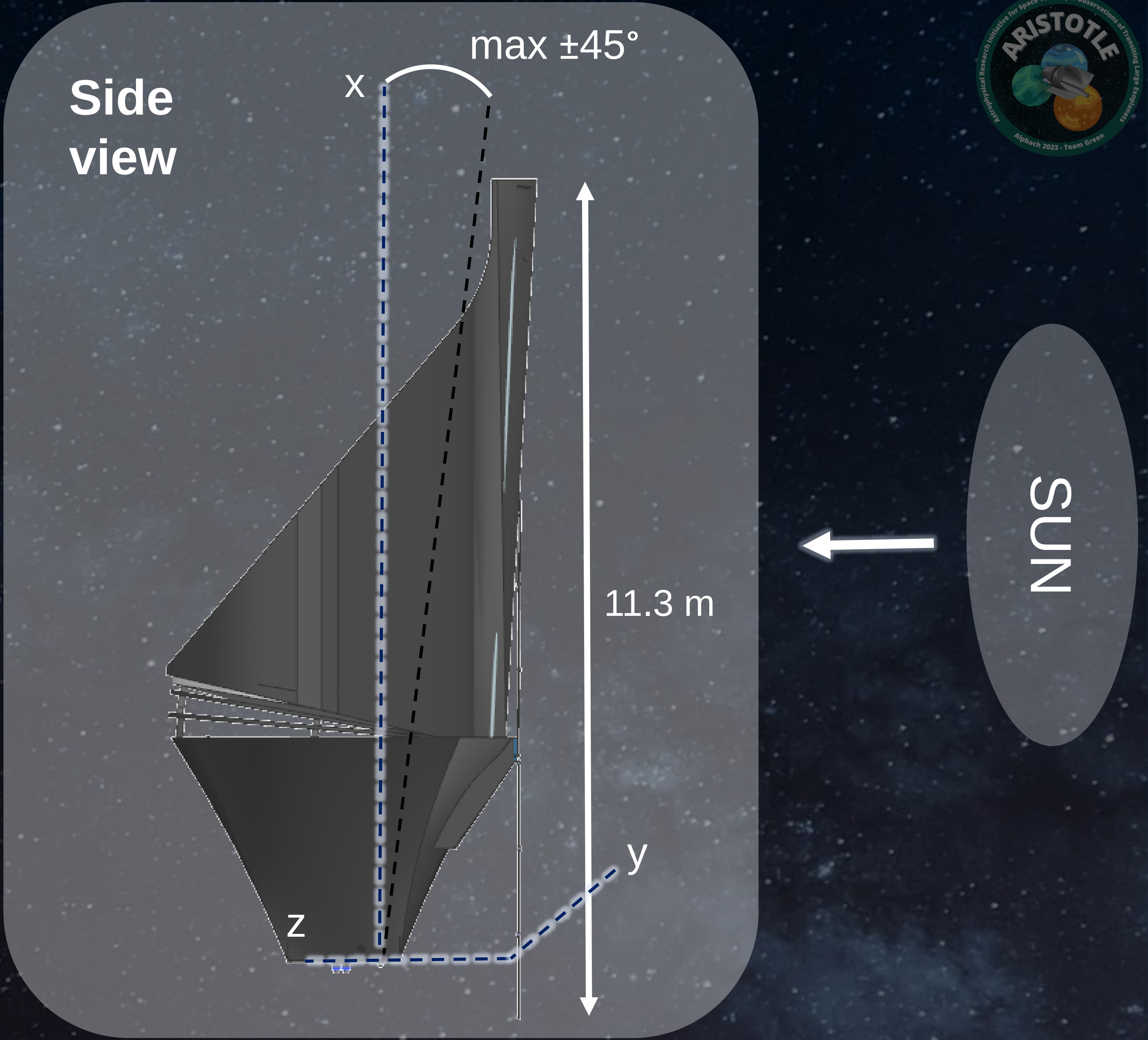


Our Baby


DEEP SPACE
Service & payload modules
Mechanical support
Solar panels
Radiation shield
Primary mirror
Primary sunshield
Secondary mirror
SUN

Spacecraft Envelope





Mass Budget

System		Value [kg]
Structure	**Primary**	566
	Payload support	400
Telescope		460
Instruments		132
AOCS		265
EPS		144
COMMS		40
Data Handling		40
Propulsion System		200
Total with 20% margin		3030

Mass margins

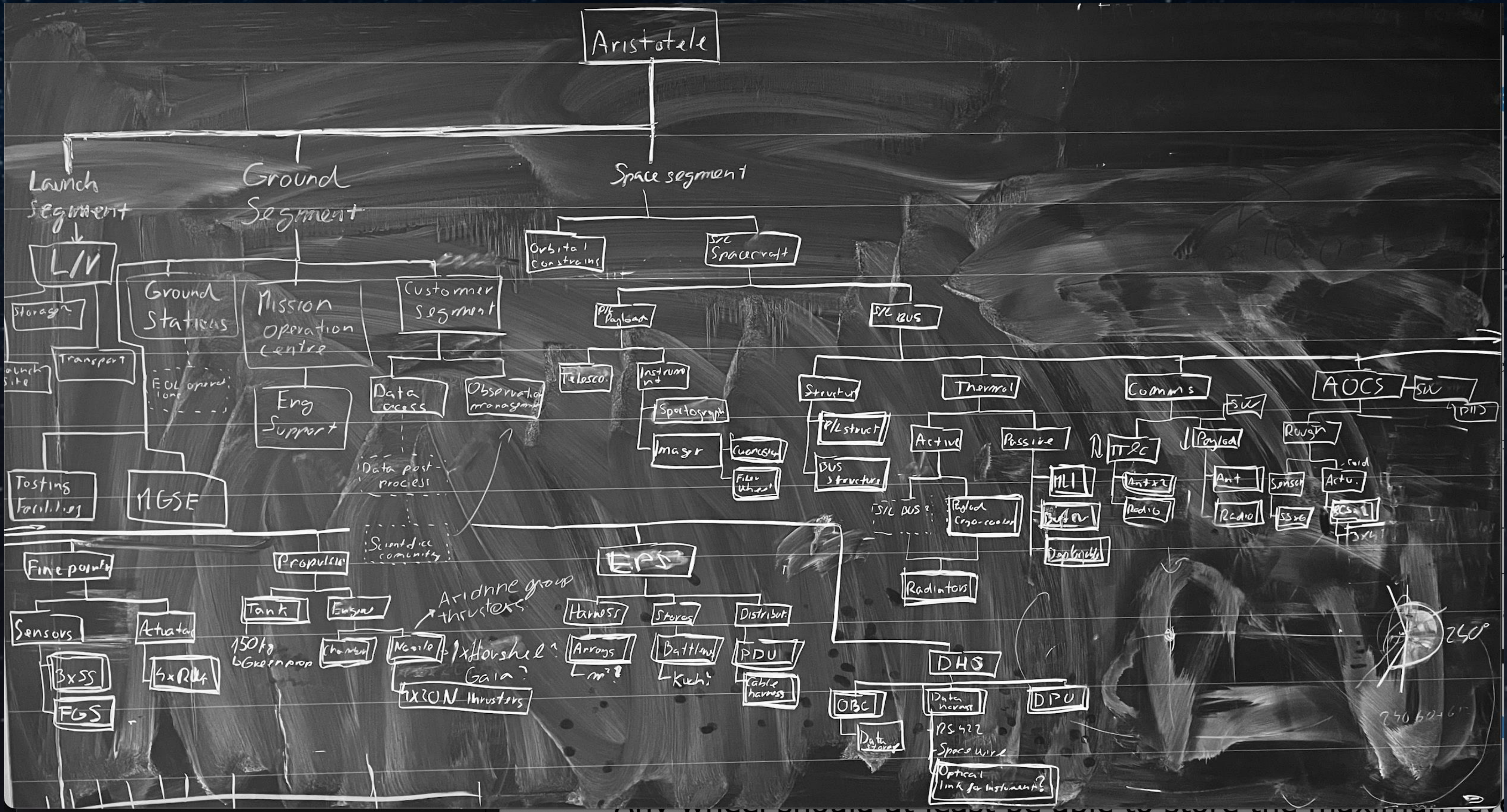
TRL 1-5: 20%

TRL 6-7: 15%

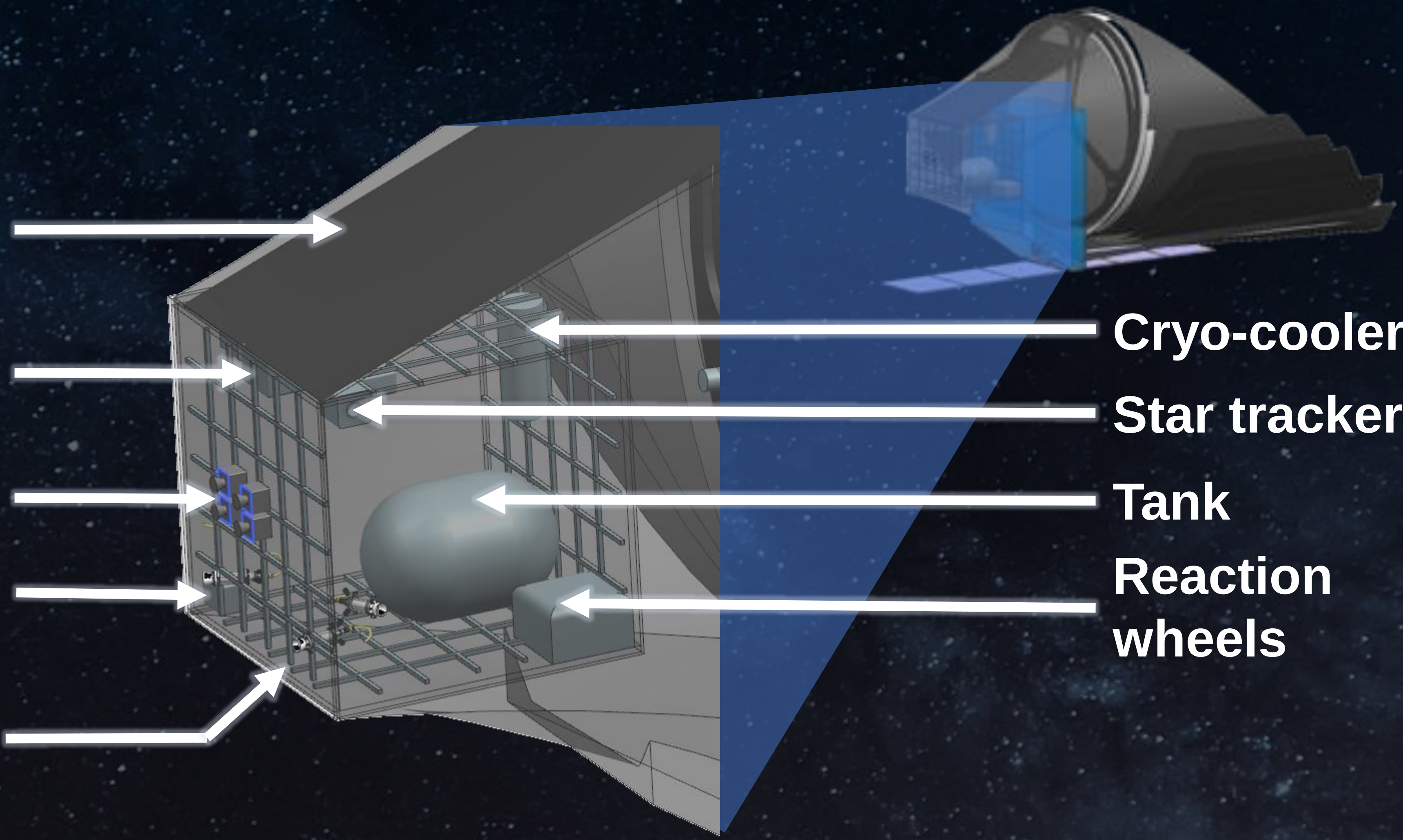
TRL 8-9: 10%

System margin: 20%

Spacecraft Systems Decomposition



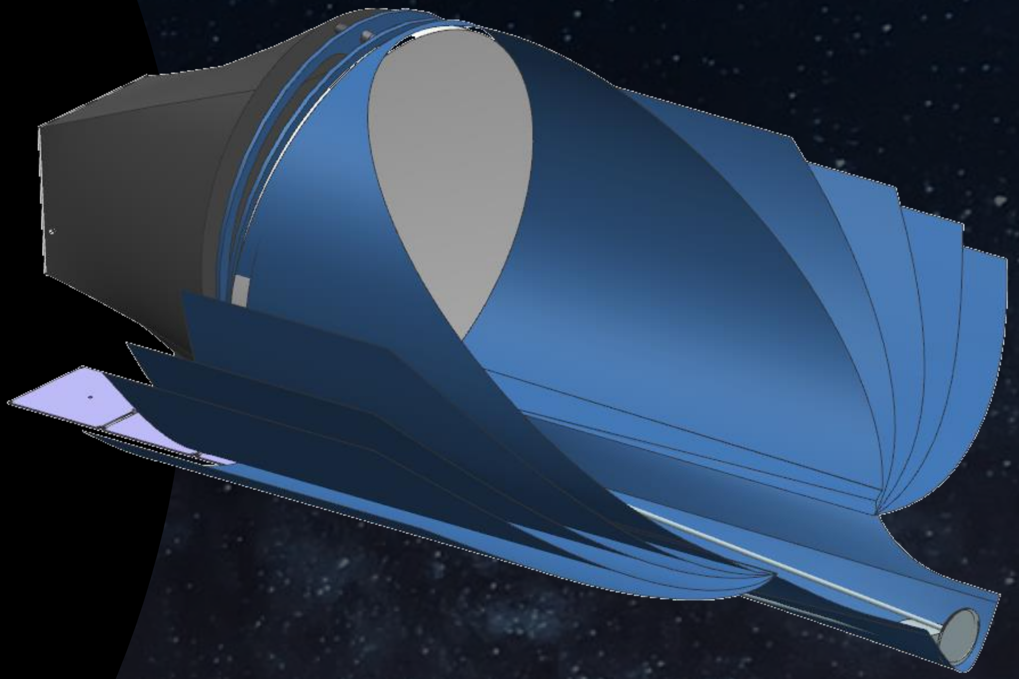
Spacecraft Service Module



Support Structures

Primary support structure

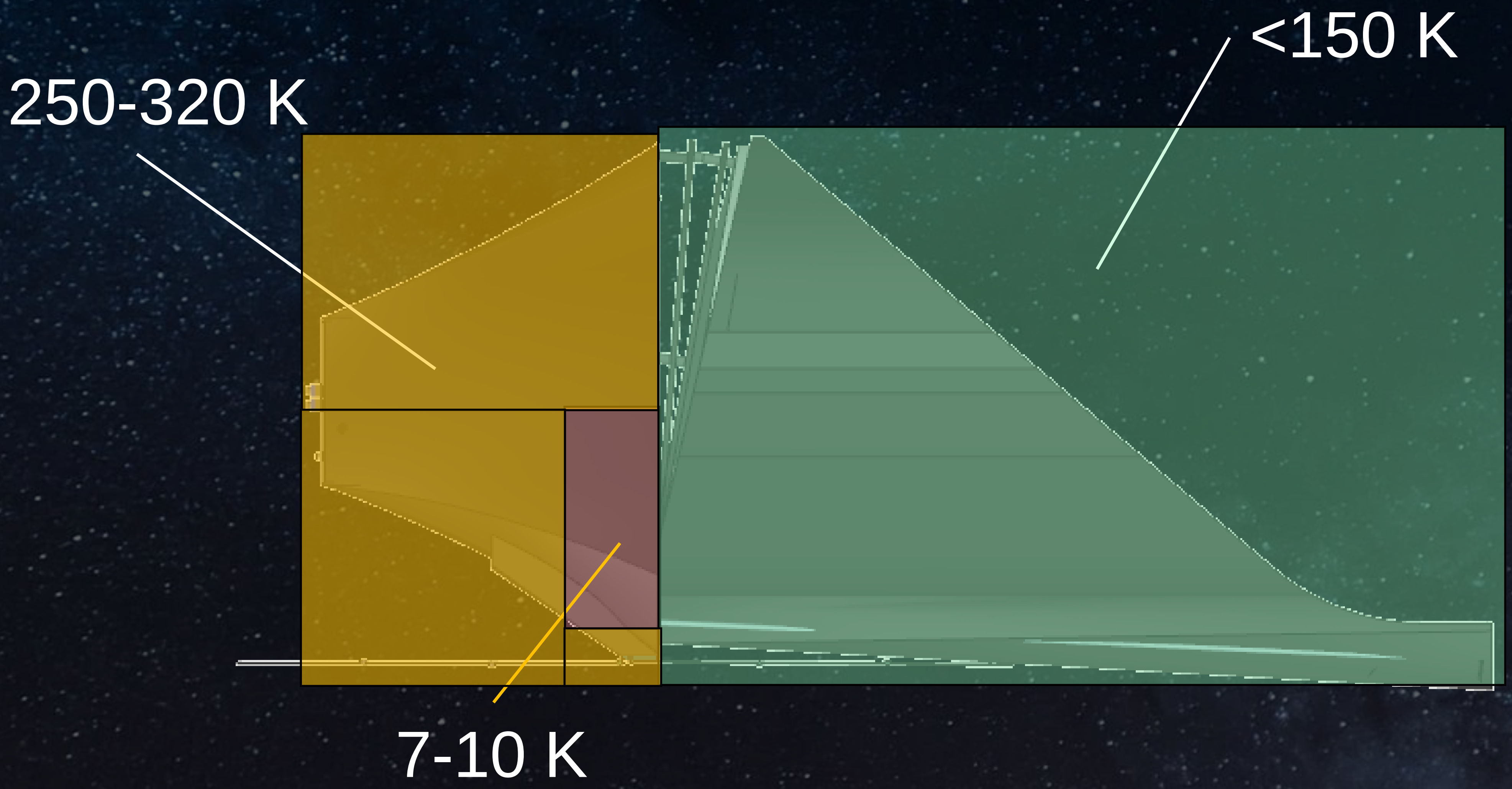
- payload structure & spacecraft BUS
- 30% of spacecraft mass: **550-600kg**



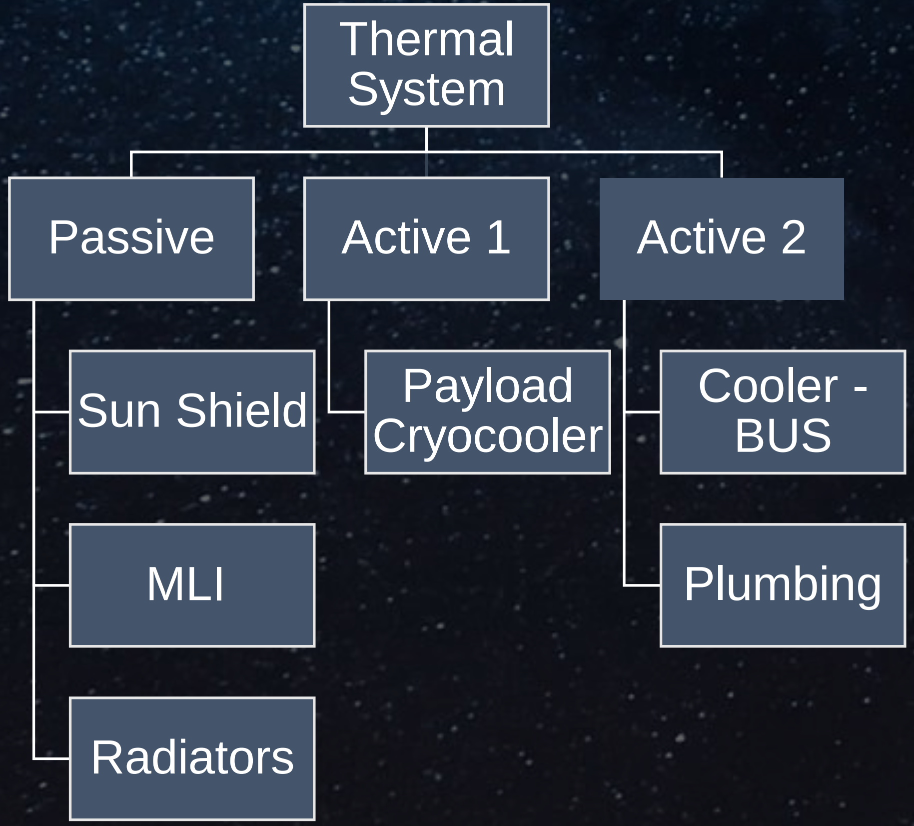
Payload support structure

- mirrors system & instruments
- 50% of payload mass: **390-410kg**

Thermal Challenge



Thermal System Break-Down



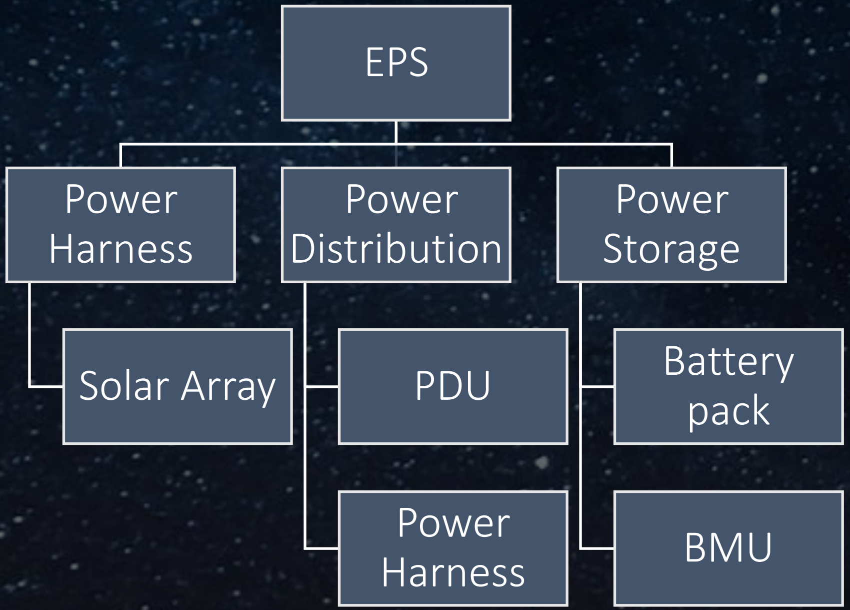
Temperature requirements

Instrument bay < 8K

Telescope mirror <120K

Device	**TRL Level**	**Heritage**	**Temp. [K]**	**Power max/nom [W]**
CryoCooler - payload	6/7	MIRI	8-6	350/80
Cooler - BUS	7	Airbus S&D mission	250-300K	-
Sun-shield	7	JWST, SPICA	150-100K	-

Electric Power System (EPS)



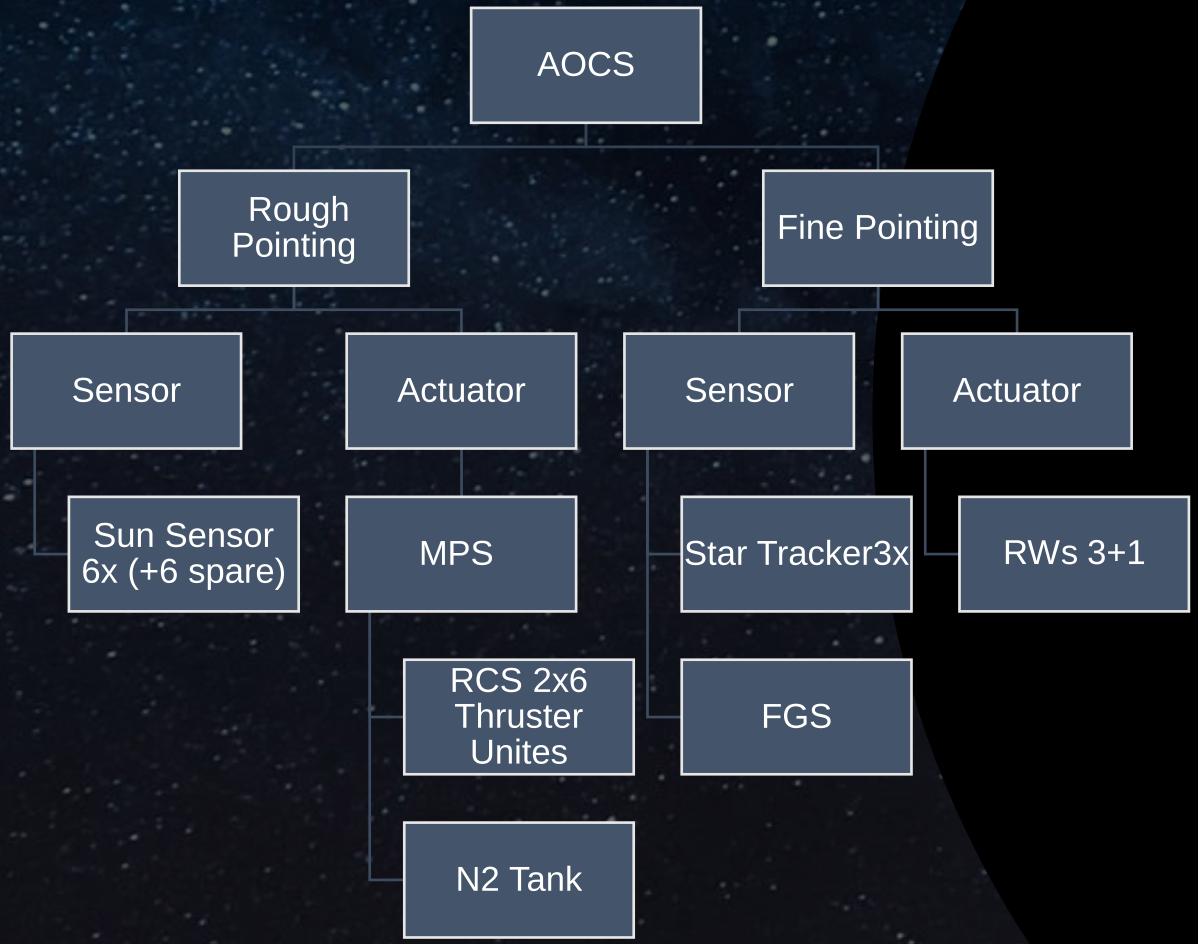
Power harness (30° Beta Angle)	
Solar Array Area	6.6-6.7 m²
Power	**1200-1300**
Power Storage	
Batteries	450-470 Whr

EPS requirements

- Positive power balance during nominal operations
- S/C: own power storage 30 minutes after deployment

Worst case: Instr. commissioning + AOCS high (20% margins)	
Payload	50 W
Thermal	400 W
AOCS	315 W
EPS	20 W
Data handling	20 W
COMMS	80 W
Propulsion	190 W
Total	1075 W

Attitude and Orbit Control System (AOCS)



Pointing requirements

Relative pointing error <0.050”

AOCS parameters		
Rough pointing	Sensors accuracy	1.8 arcsec
	Actuators accuracy	>3000 arcsec
Fine Pointing	Sensors accuracy	30 marcsec
	Actuators accuracy	40 marcsec

Heritage

Hubble (0.010” accuracy)

Herschel (0.100” accuracy)

Attitude and Orbit Control

Micro Propulsion System (MPS)

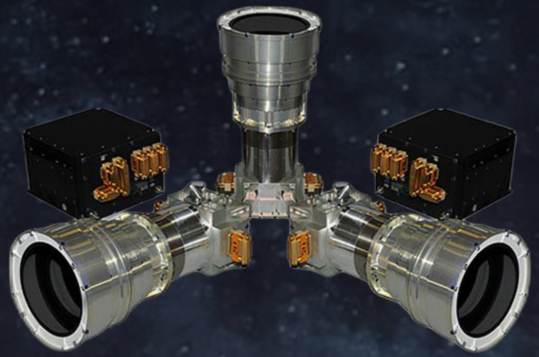
Fuel Type: Nitrogen (TRL 9)
Fuel Tank: 66kg +50% margin =100kg
Thrusters: 12 N_2 cold gas thrusters

- Spin rate management
- Fine attitude pointing
- RWs desaturation

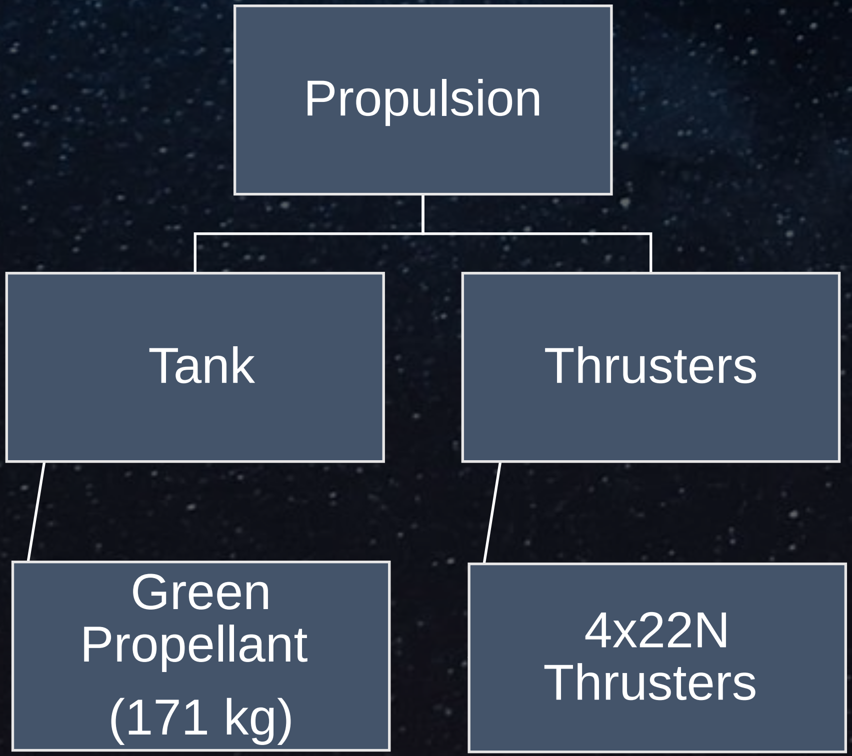
Micro Thruster Assembly – Photo: Thales Alenia Space

Fine Guidance

- 4 reaction wheels (3 + 1 spare)
- 3 Star Trackers
- Fine Guidance Sensor (FGS)
  - Pointing accuracy 0.03”



Propulsion System



Requirement

Total ΔV=90-100m/s

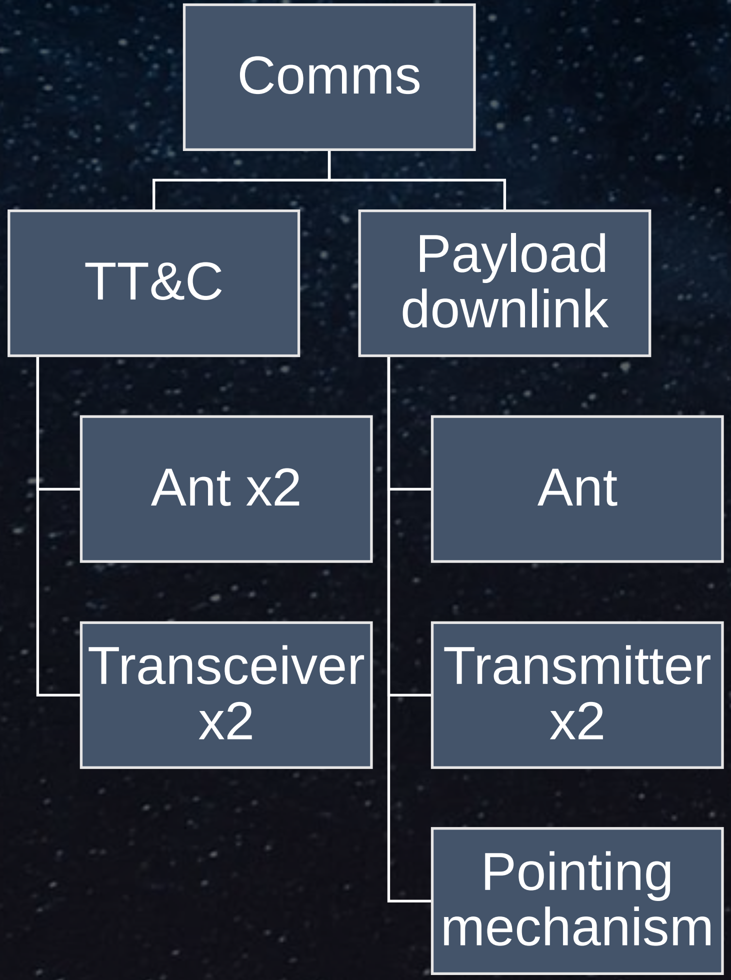
Chemical Mono-Propellant Propulsion System:	
Thrust	22N (ECAP's HPGP Thruster)
Propellant	Green Propellant (LPM-103S)
Fuel tank	114kg + 50%margin = 171kg
Isp	250sec.
Density Impulse (Ns/L)	3030
Function	• Station keeping • Orbit correction • Spacecraft disposal

Communications

Requirements

Communication window MDS < 7.5h/week

24/7 link Health Monitoring & Commanding

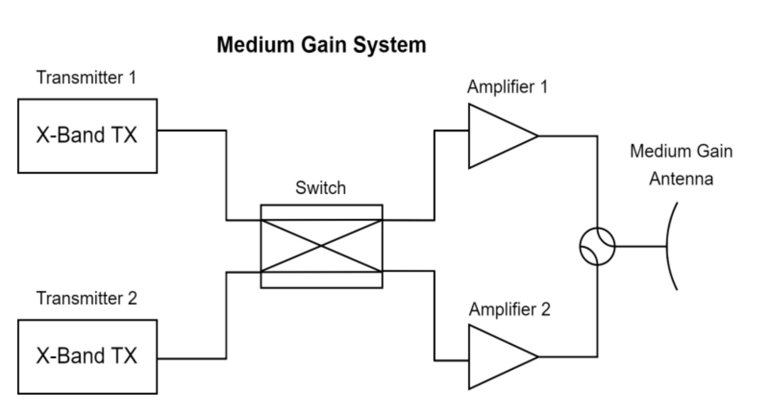


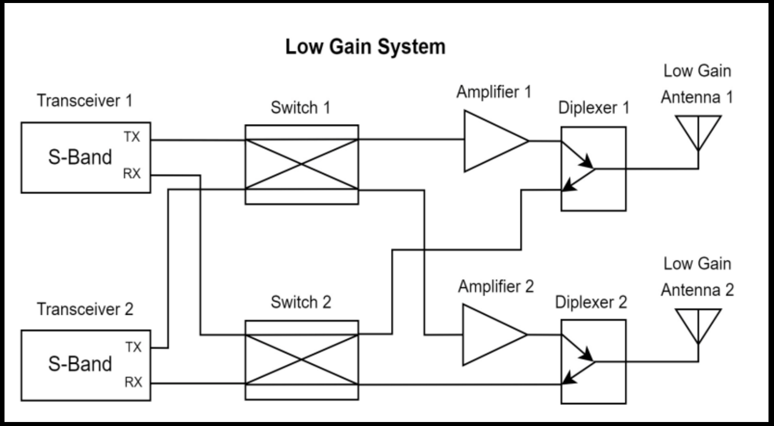
Medium Gain System (Payload Data, TX)

- X-Band
- Transmitter Power: 10 W
- Data rate: 10 Mbits/s
- 2 Transmitter for redundancy
- Parabolic antenna with 0.3 m diameter, 2 DOF

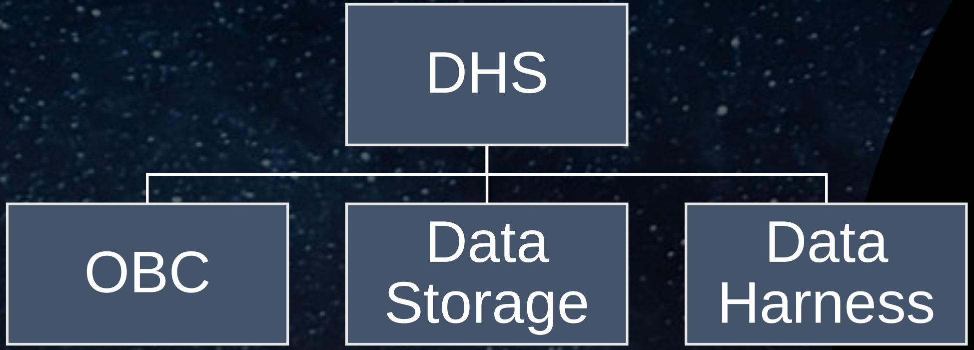
Low Gain System (TT&C, TX/RX)

- S-Band
- 2 Transceivers for redundancy
- 2 Omnidirectional antenna
- Data rate: 2 kbits/s





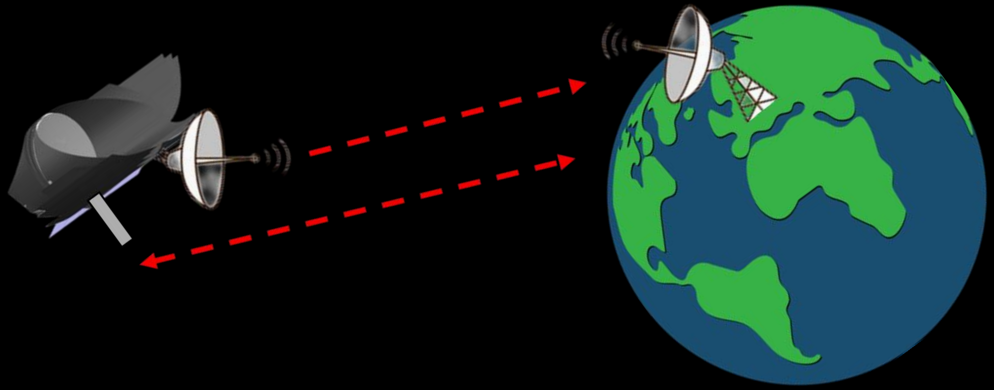
Data Handling



Data produced	Average (Gbits/day)	Maximum (Gbits/day)
Spectrograph	2.7	9
Imager	4	33
Housekeeping	0.5	-
Total	3	33

Requirement

Scientific payload data shall not be corrupted by onboard processing



- One instrument in use at a time
- Max data rate: 10 Mbits/s
- No on-board processing
- Centralized OBC architecture

Operations & Launch

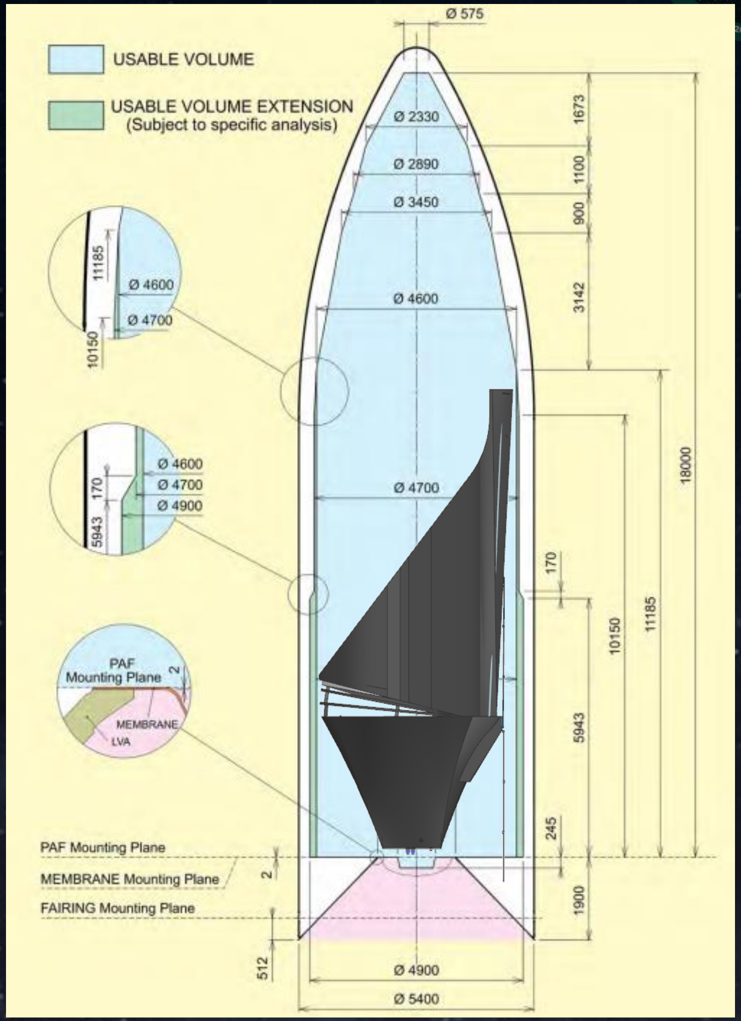
Launch Segment

Requirements:

- Total wet mass: 3100kg (incl. 20% margin)
- Maximum diameter envelope: Ø4.7m

Proposed launcher : **Ariane 62 - long fairing**

- Performance: 3300kg for L2 orbit
- Max. usable diameter extension: Ø4.7m



Ariane 6 User's Manual, Issue 2 revision 0, arianespace, arianegroup

Ground Segment

Operational Ground Segment (OGS)

- Mission Operation Centre (MOC)
- Science Ground Segment (SGS)

Ground Station Network

- ESA ESTRACK Deep Space Network
- 35 m deep space antennas
  - CEBREROS-1 (X / X Ka)
  - MALARGÜE-1 (X Ka / X Ka)
  - NEW NORCIA-1 (S X / S X)

Data Pipeline

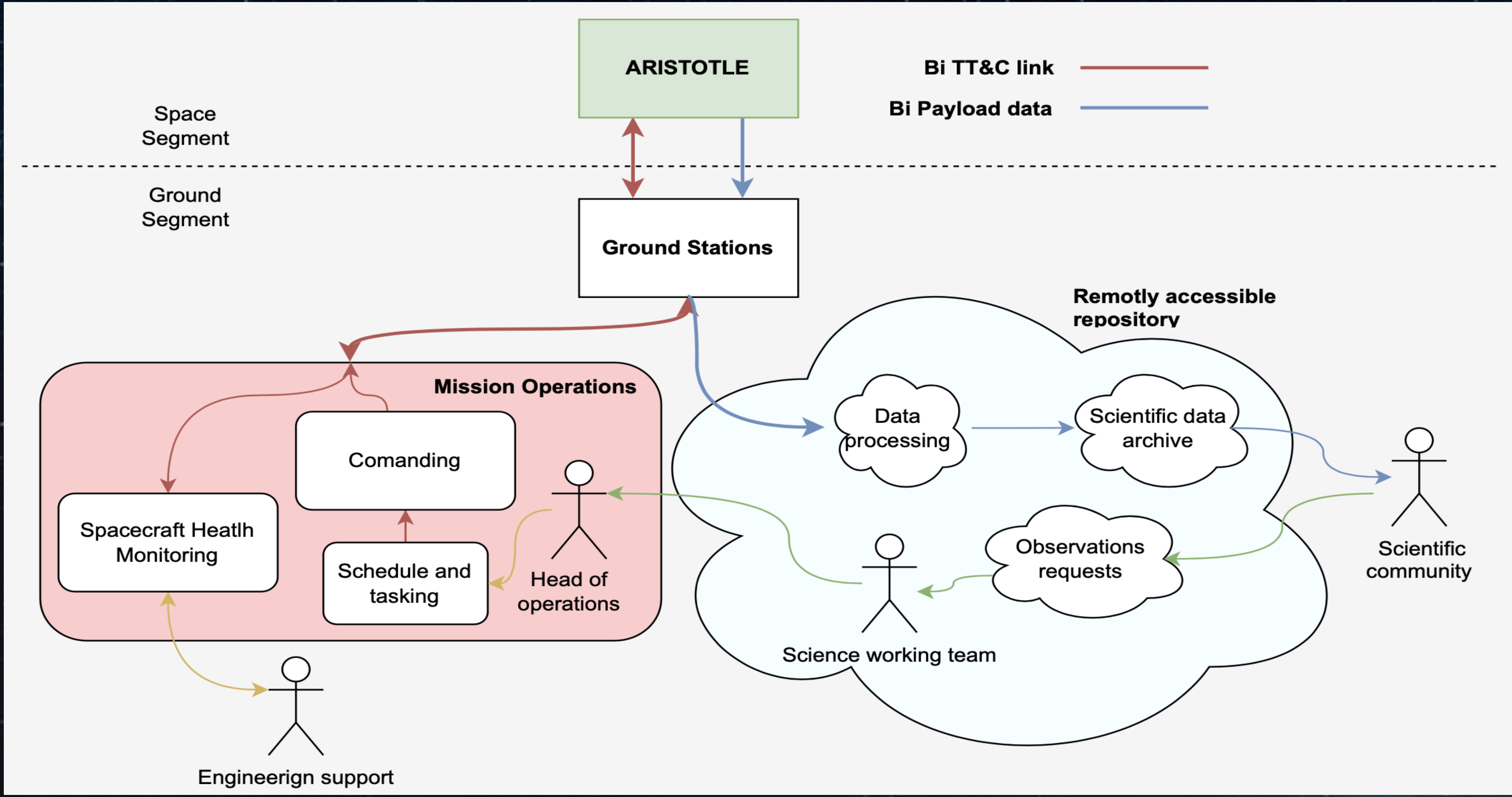
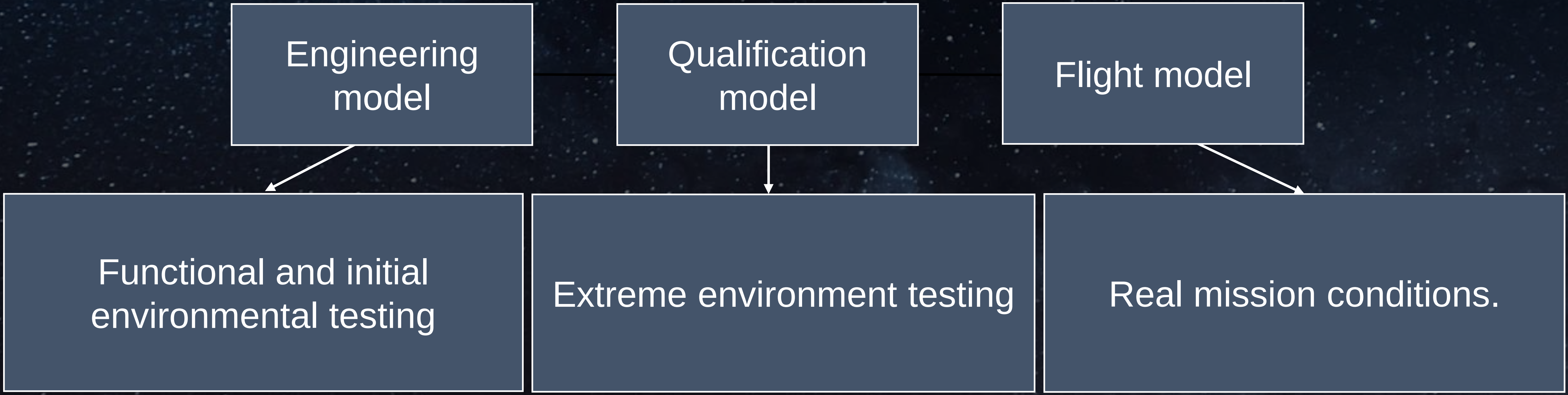


Table of Content: Conclusion

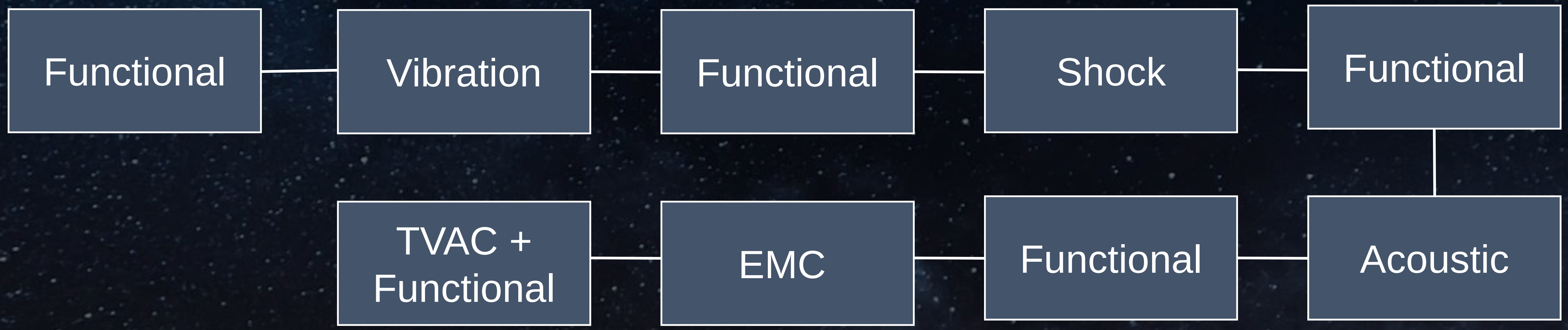
Testing and Qualification

Testing and Qualification

Suppliers shall satisfy PA/QA certifications + sampling for statistics



Testing and Qualification



Testing facilities: TVAC Chamber, Vibration stand, EMC and Acoustic Chamber

Risk Assessment

Risk Assessment

Severity	A	B	C	D	E
5	Low Loss of communication (low gain) Spectrometer failure	Medium Thermal system failure Sustainability of mirror during launch Optics system failure Telescope failure	High	Very high	Very high
4	Low Electronics system failure Imager failure Failure of main propulsion system	Low	Medium	High	Very high
3	Very low	Low Loss of communication (medium gain) Material damage of the spacecraft Failure of propulsion system (altitude control)	Low Failure of altitude and control system (wheels)	Medium	High
2	Very low	Very low	Low	Low	Medium
1	Very low	Very low	Very low	Low	Low
	Likelihood				

Risk Assessment

Severity

Low Loss of communication (low gain) Spectrometer failure	Medium Thermal system failure Sustainability of mirror during launch Optics system failure Telescope failure	High
Low Electronics system failure Imager failure Failure of main propulsion system	Low	Medium
Very low	Low Loss of communication (medium gain) Material damage of the spacecraft Failure of propulsion system (altitude control)	Low Failure of altitude and control system (wheels)

Cost Assessment

Cost Estimation

	Herschel	ARISTOTLE
Telescope diameter	3.5m	4.0m
Cold telescope	Yes	Yes
Cold instrument	Yes	Yes
Orbit	L2 Lissajous	L2 Lissajous
Mission duration	3 years	5 years (+5 years extension)
Launcher	Ariane 5	Ariane 62
Launch date	2009	2035
Cost correction factor	1.00 (=2009)	1.28 (=2023)
Overall costs	1,100 M€	1,250 M€

Cost ARISTOTLE	%	[M€]
ESA space segment	50	625
Mission / science operations	15	187.5
ESA project team overhead	12	150
Ariane 62 launcher	8	100
Margin	15	187.5
Sum ESA costs (L-mission limit 2023: 1,300 M€)	**100**	**1,250**
Payload costs of member states (~30% of ESA costs)	30	361.5
Overall mission costs		1,611.5

Downscale options

- Removing imager
- Reduction of limit wavelength (15μm)
- Downscaling dish size
- Run instruments at higher temperature

Summary

- ARIEL + PLATO → ARISTOTLE → Later Missions
- Transit & Eclipse spectroscopy in (2.5-23μm)
- Imaging in 5 different wavelength bands and coronagraph
- Technology employed in existing spacecraft
- In line with current research

#AlienHunter

"Extraordinary claims require extraordinary evidence."

- *Carl Sagan/*
- *Pierre-Simon Laplace/*
- *Marcello Truzzi/*
- *etc…*