EXPOSURE

EXoPlanet Origins and Stellar Ultraviolet Regime Explorer

A UV mission to explore the origins, habitability, and evolution of exoplanets

TEAM BLUE

Science team
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- Marina Cano Amoros - Germany
- Sara Gasparini – Norway
- Anne-Sophie Herrijgers – The Netherlands
- Vivien Simon - Hungary

Payload team
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- Casper Farret Jentink - Switzerland
- Scott Green – Sweden
- Søren Truelsen - Denmark
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- Kamil Serafin - Poland
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Tutors: Jerômè Loicq and Greta De Marco

OVERVIEW

- Scientific goals
- Payload
- Service module
- Conclusions

SCIENCE

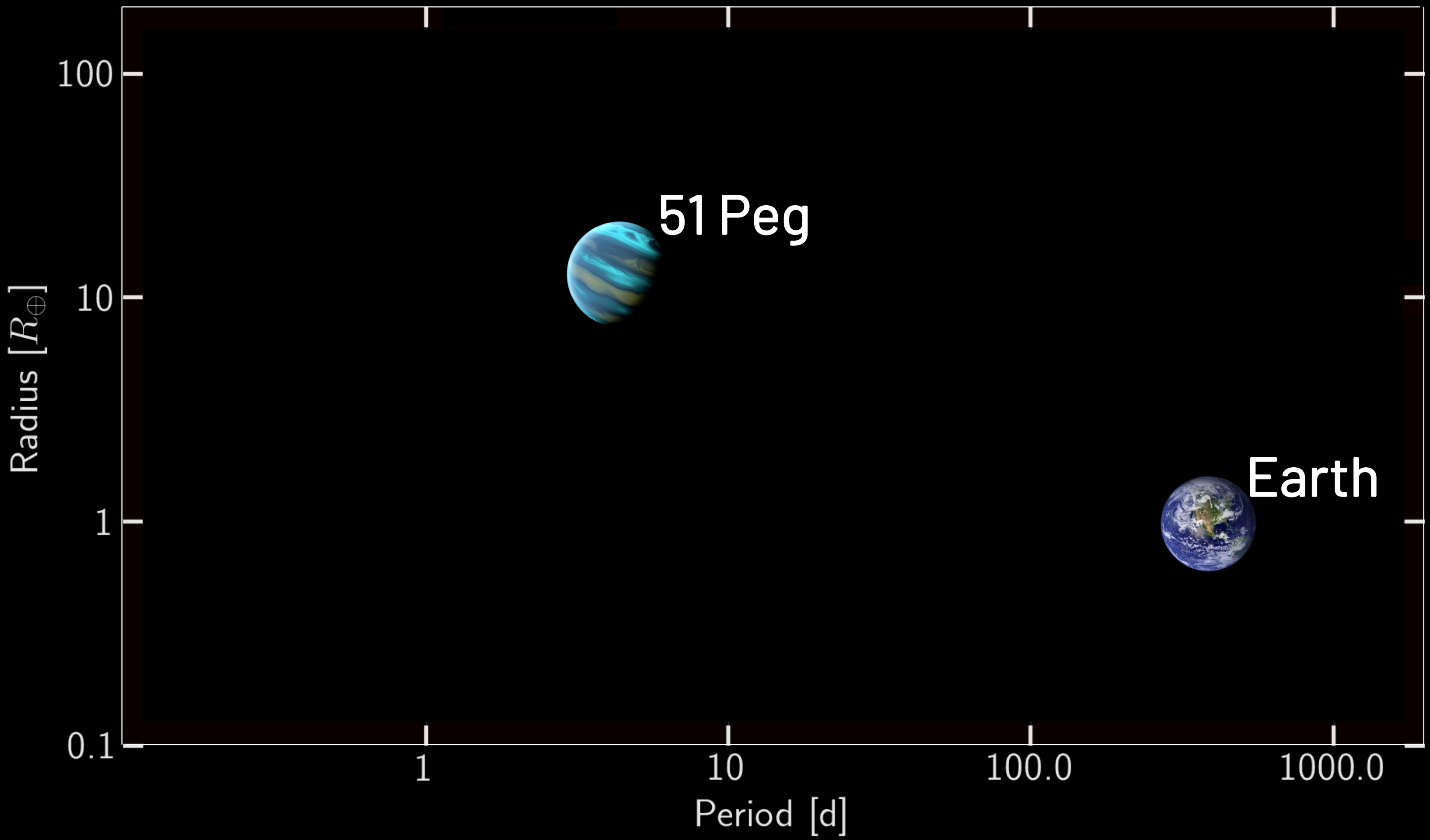
Scientific goals

Payload

Service module

Conclusions

THE SCIENCE - EXOPLANETS



- Gas giants
- Neptune-like planets
- Rocky planets

DETECTION METHODS

Transit

Radial Velocity

?

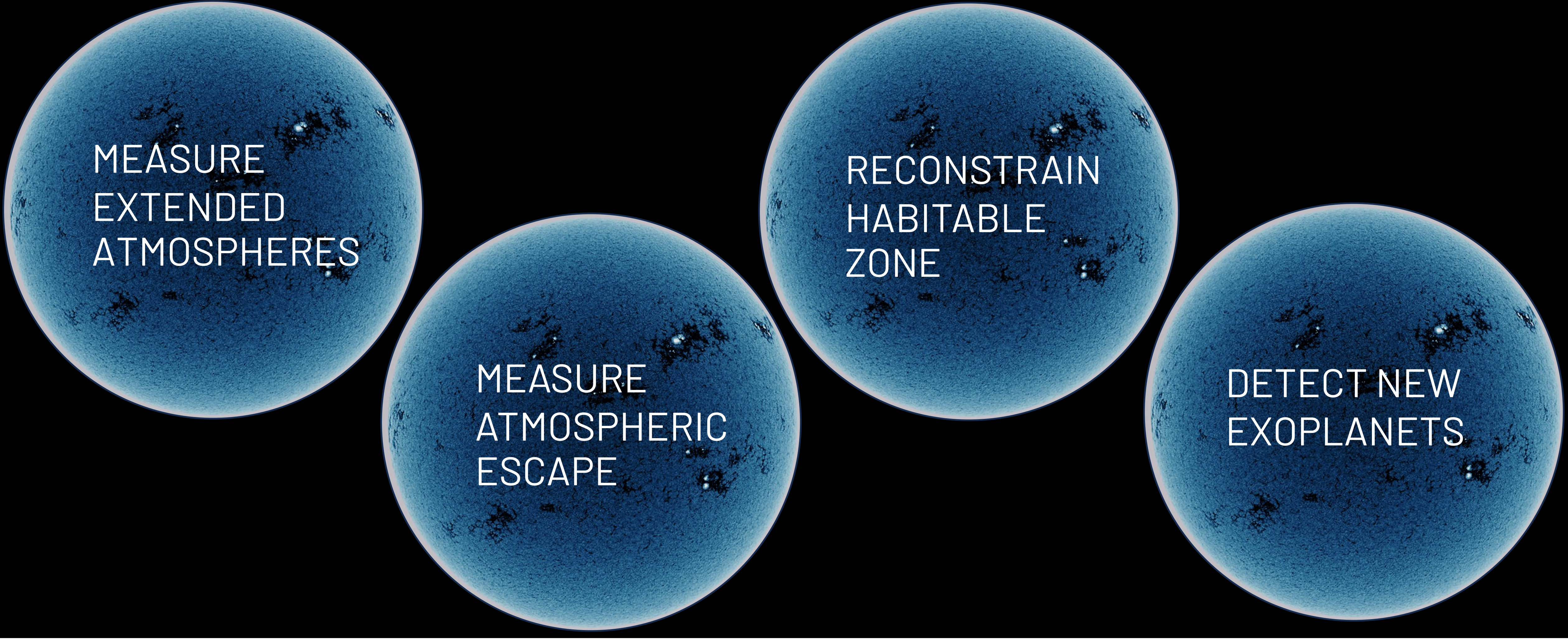
Current detection methods

Microlensing

Direct Imaging

Astrometry

GOALS OF THE EXPOSURE MISSION



MEASURE EXTENDED ATMOSPHERES

MEASURE ATMOSPHERIC ESCAPE

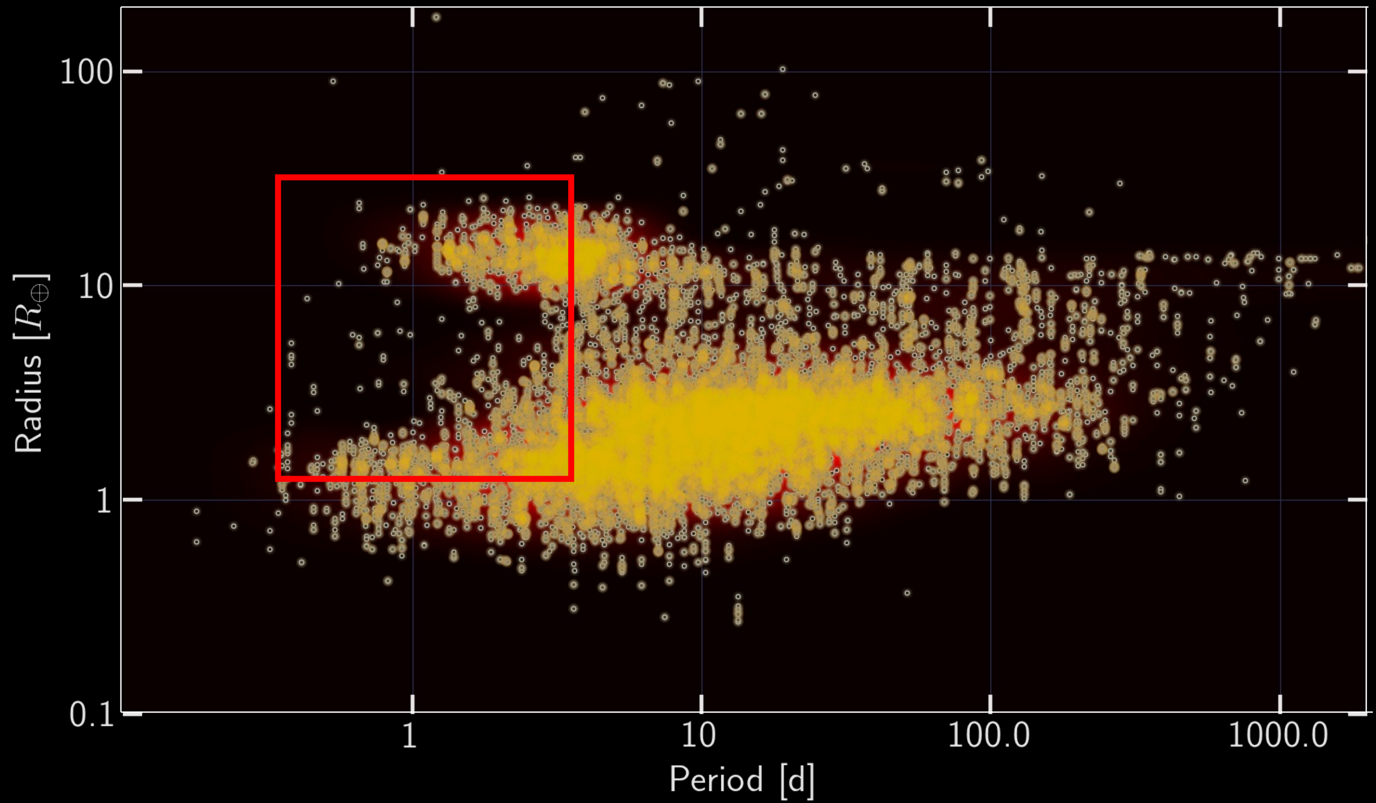
RECONSTRAIN HABITABLE ZONE

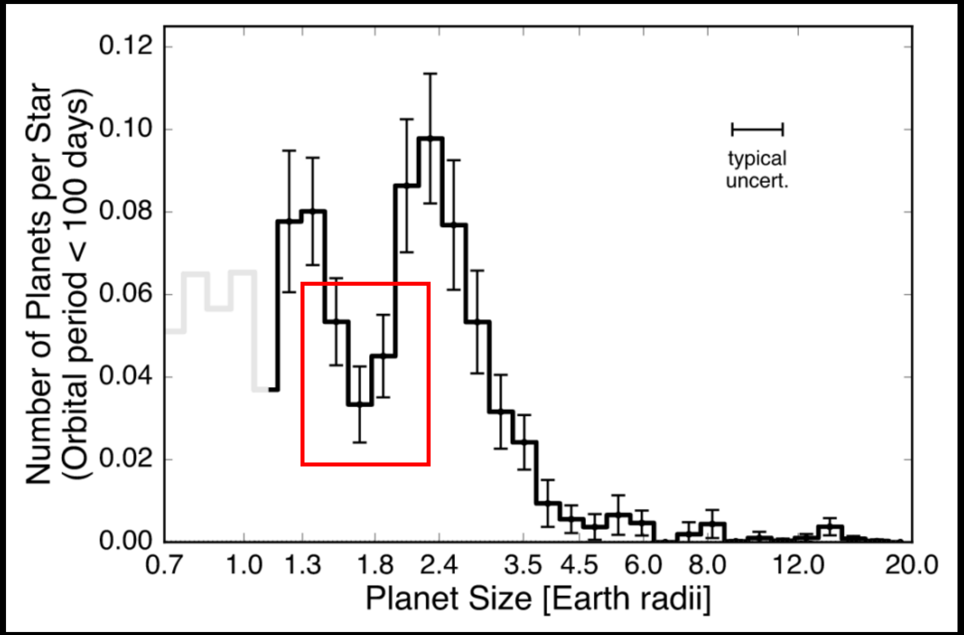
DETECT NEW EXOPLANETS

SCIENTIFIC CASES

- MEASURE EXTENDED ATMOSPHERES
- MEASURE ATMOSPHERIC ESCAPE
- CONSTRAIN HABITABLE ZONE (UV)
- DETECT NEW EXOPLANETS

EXOPLANET DEMOGRAPHICS





Fulton et al. 2018

EXTENSION OF H_2 EXOSPHERES

Earth's geocorona captured from the Moon during Apollo 16

Escape rate: 10^3 g/second

EXOSPHERE ◦
500 – 10000KM

THERMOSPHERE ◦
85 – 500 KM

MESOSPHERE ◦
50 – 85 KM

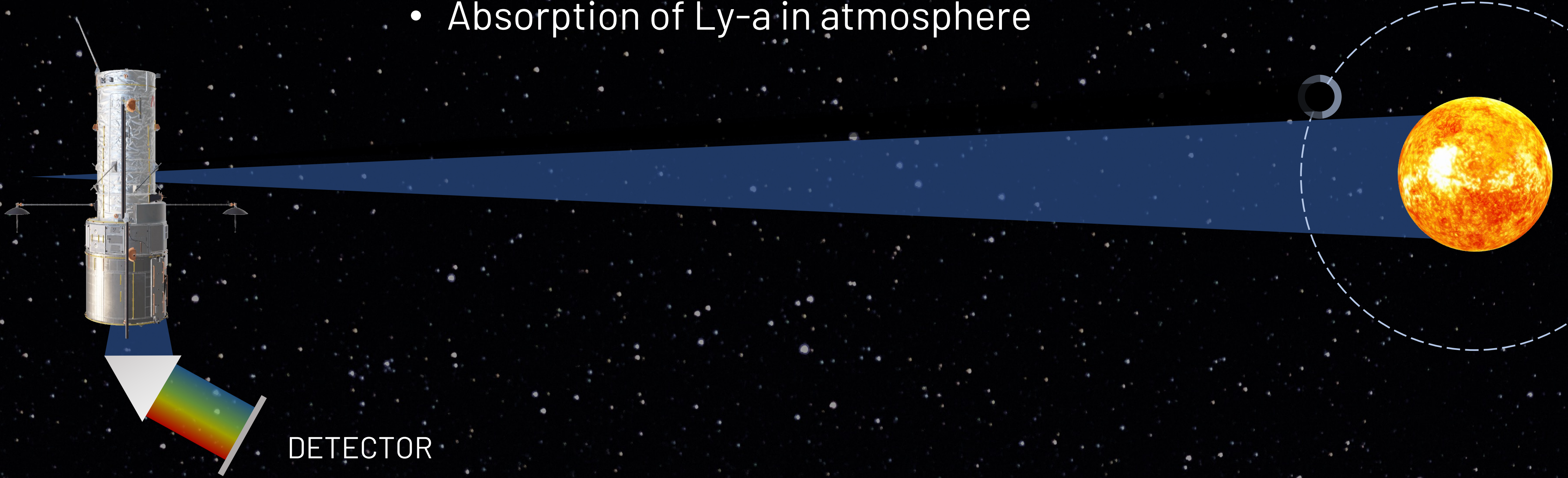
H_2

STRATOSPHERE ◦
10 – 50 KM

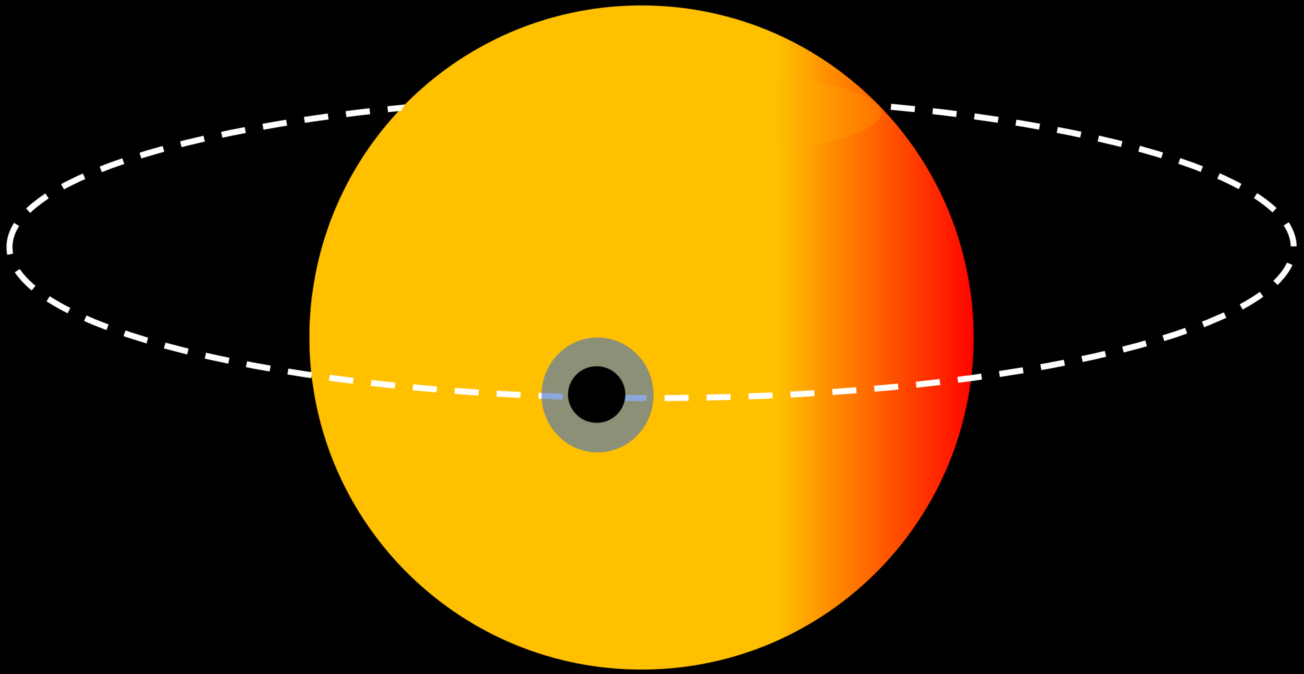
TROPOSPHERE ◦

MEASUREMENT PRINCIPLE (TRANSIT)

- Transmission spectroscopy in transit
- Absorption of Ly-a in atmosphere

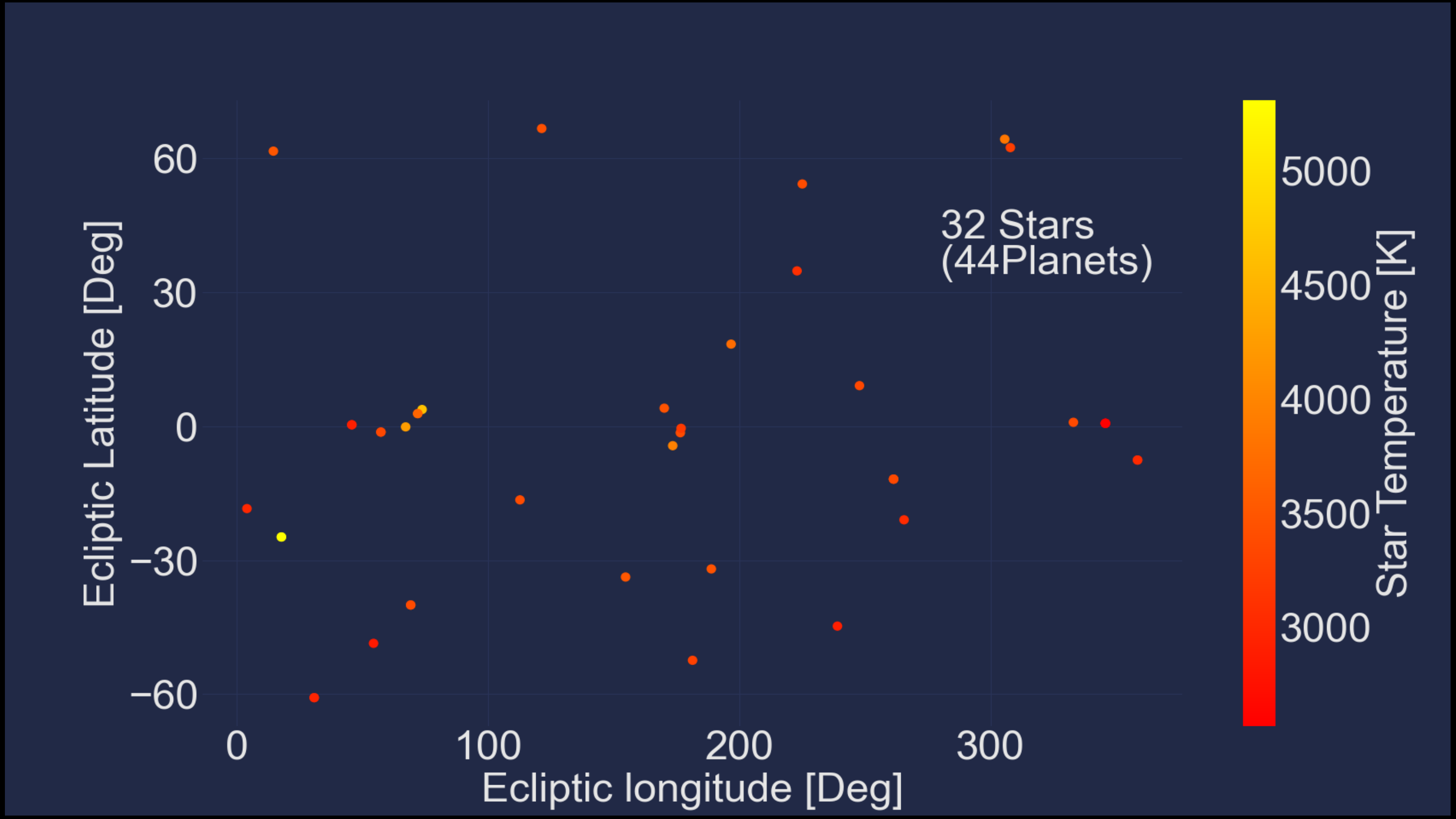


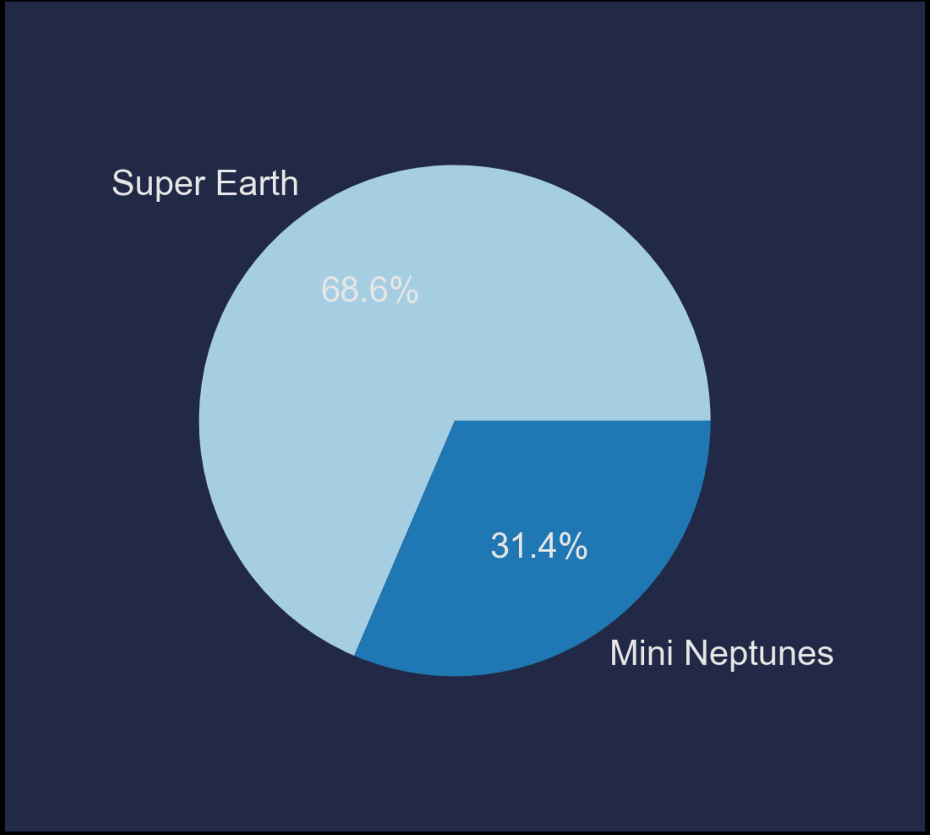
SENSITIVITY AND REQUIREMENTS



- **G**, **K** and **M**-type **stars**
- Transit **depth** of 2.5%
- For a **5-sigma detection** -> **SNR** of 200
- **Bandwidth** 115 -130 nm
- **Spec. Resolution** 1000

TARGETS


60
30
0
−30
−60
0
100
200
300
Ecliptic Latitude [Deg]
Ecliptic longitude [Deg]
32 Stars
(44Planets)
5000
4500
4000
3500
3000
Star Temperature [K]

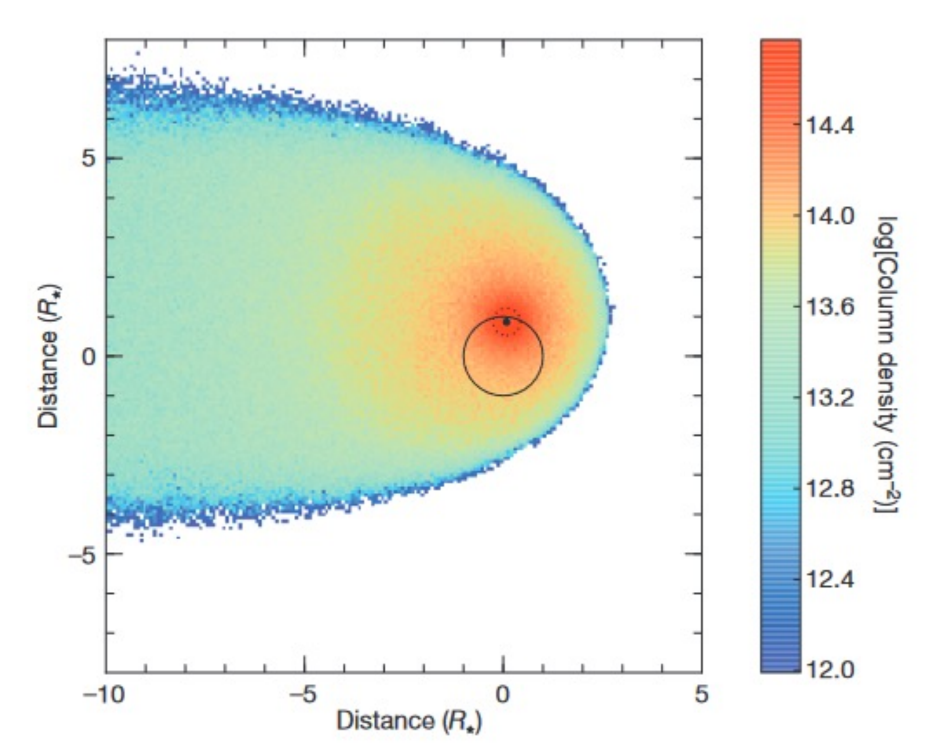

Super Earth
68.6%
31.4%
Mini Neptunes

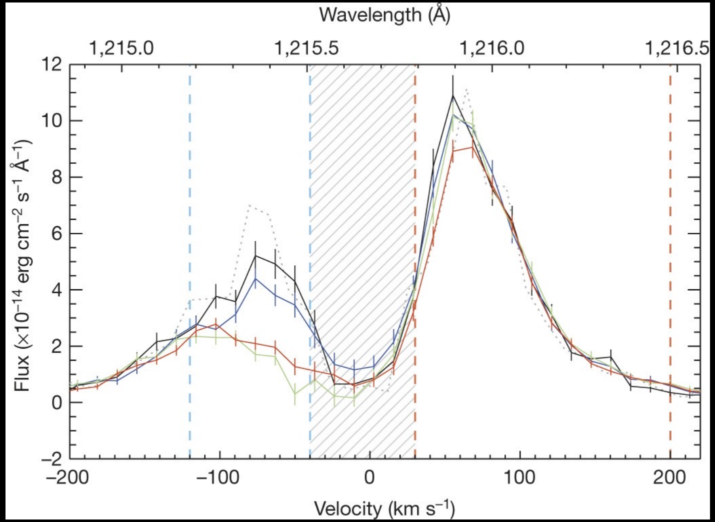
SCIENTIFIC CASES

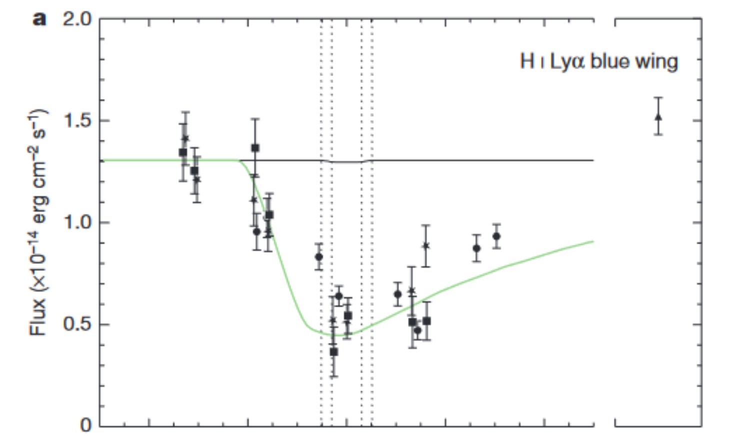
- MEASURE EXTENDED ATMOSPHERES
- MEASURE ATMOSPHERIC ESCAPE
- CONSTRAIN HABITABLE ZONE (UV)
- DETECT NEW EXOPLANETS

ESCAPING ATMOSPHERES

GJ436b

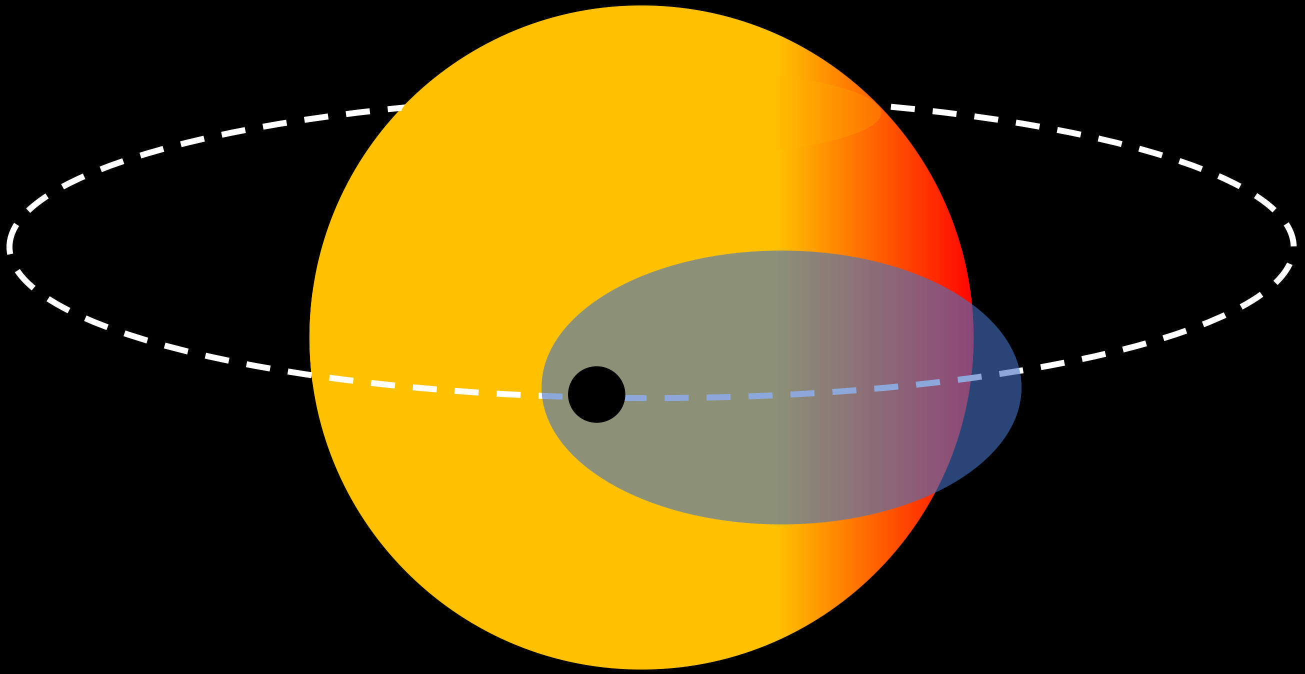






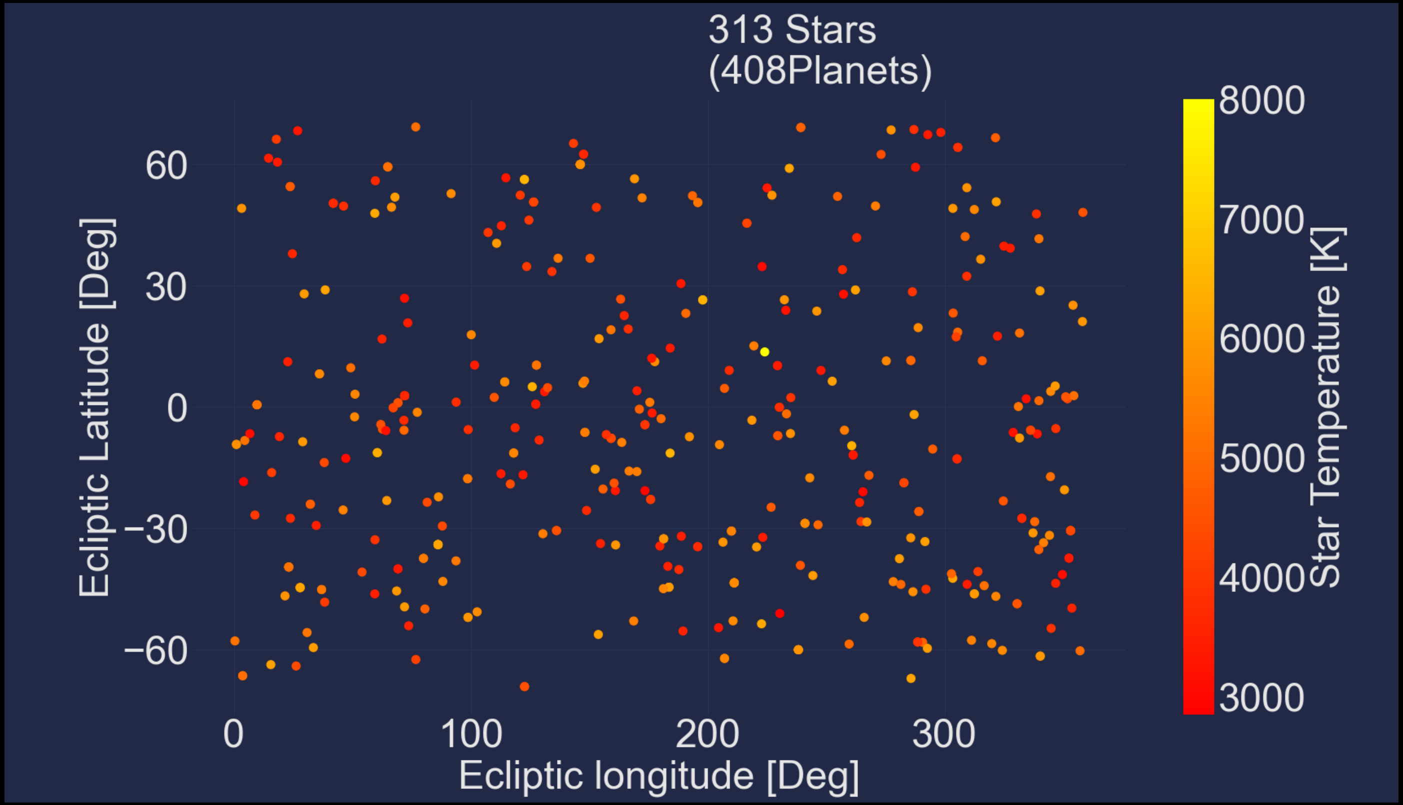
Ehrenreich et al. 2015

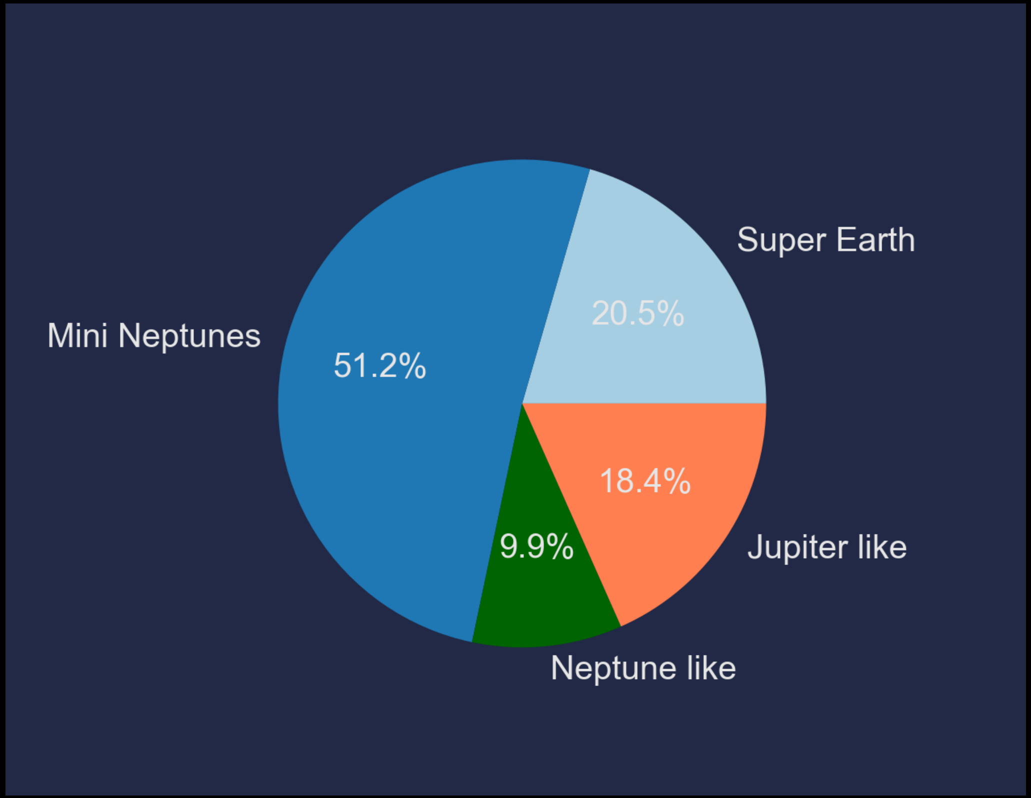
SENSITIVITY AND REQUIREMENTS



- **F**, **G**, **K** and **M**-type **stars**
- Transit **depth** > 50 %
- For a **5-sigma detection**
  -> **SNR** of 200
- **System velocities (+/- 100km/s)**
  -> bandwidth 119-122 nm (Ly-a)
- **Spec. Resolution** 20 000
- **RV** precision: 20km/s

TARGETS

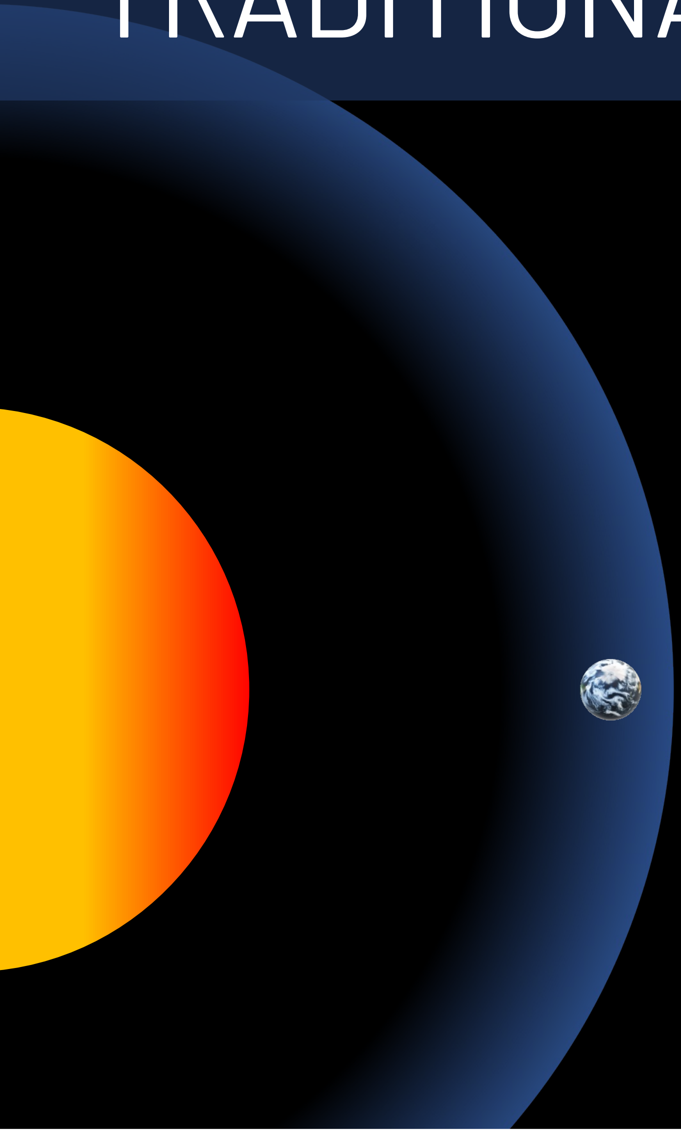

313 Stars
(408Planets)
Ecliptic Latitude [Deg]
60
30
0
−30
−60
0
100
200
300
Ecliptic longitude [Deg]
8000
7000
6000
5000
4000
3000
Star Temperature [K]


Super Earth
20.5%
Mini Neptunes
51.2%
18.4%
Jupiter like
9.9%
Neptune like

SCIENTIFIC CASES

- MEASURE EXTENDED ATMOSPHERES
- MEASURE ATMOSPHERIC ESCAPE
- RECONSTRAIN HABITABLE ZONE
- DETECT NEW EXOPLANETS

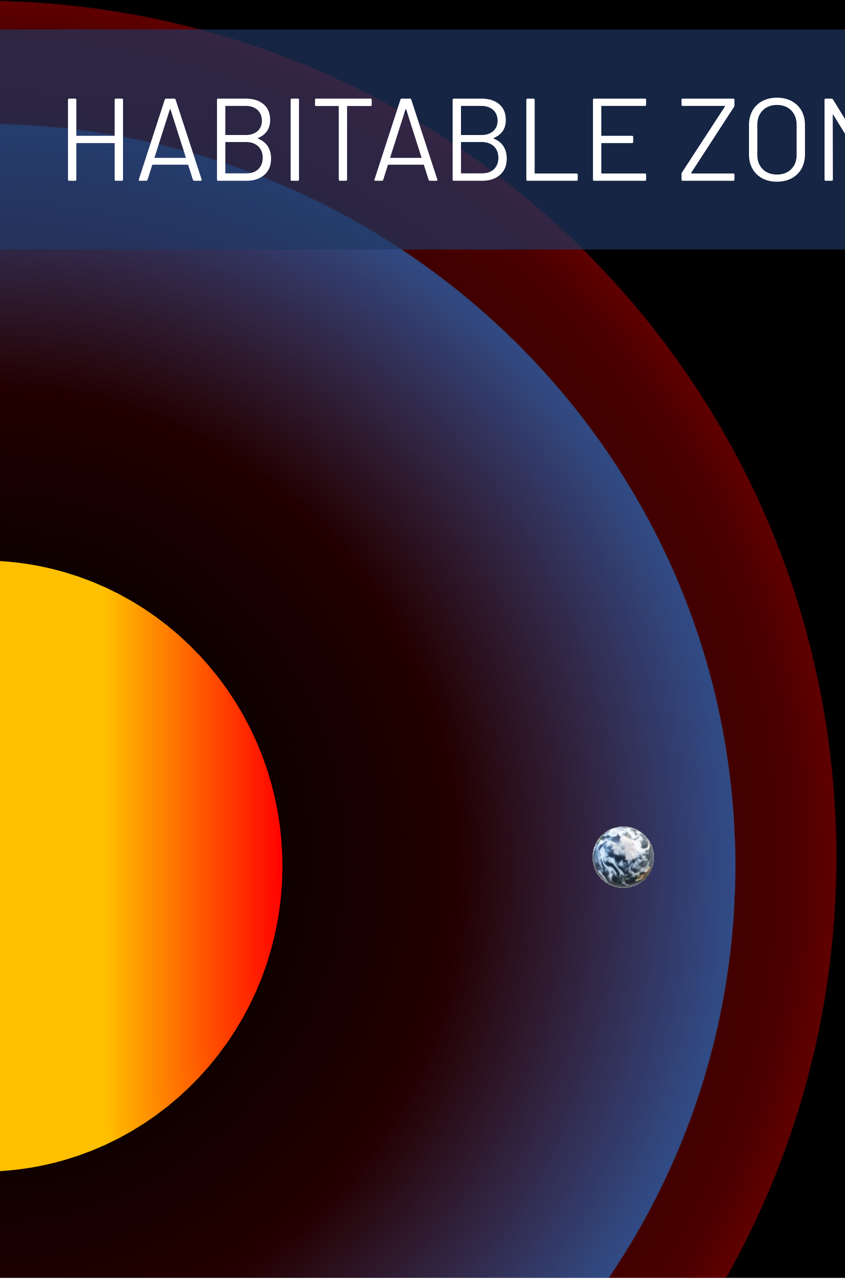
TRADITIONAL HABITABLE ZONE

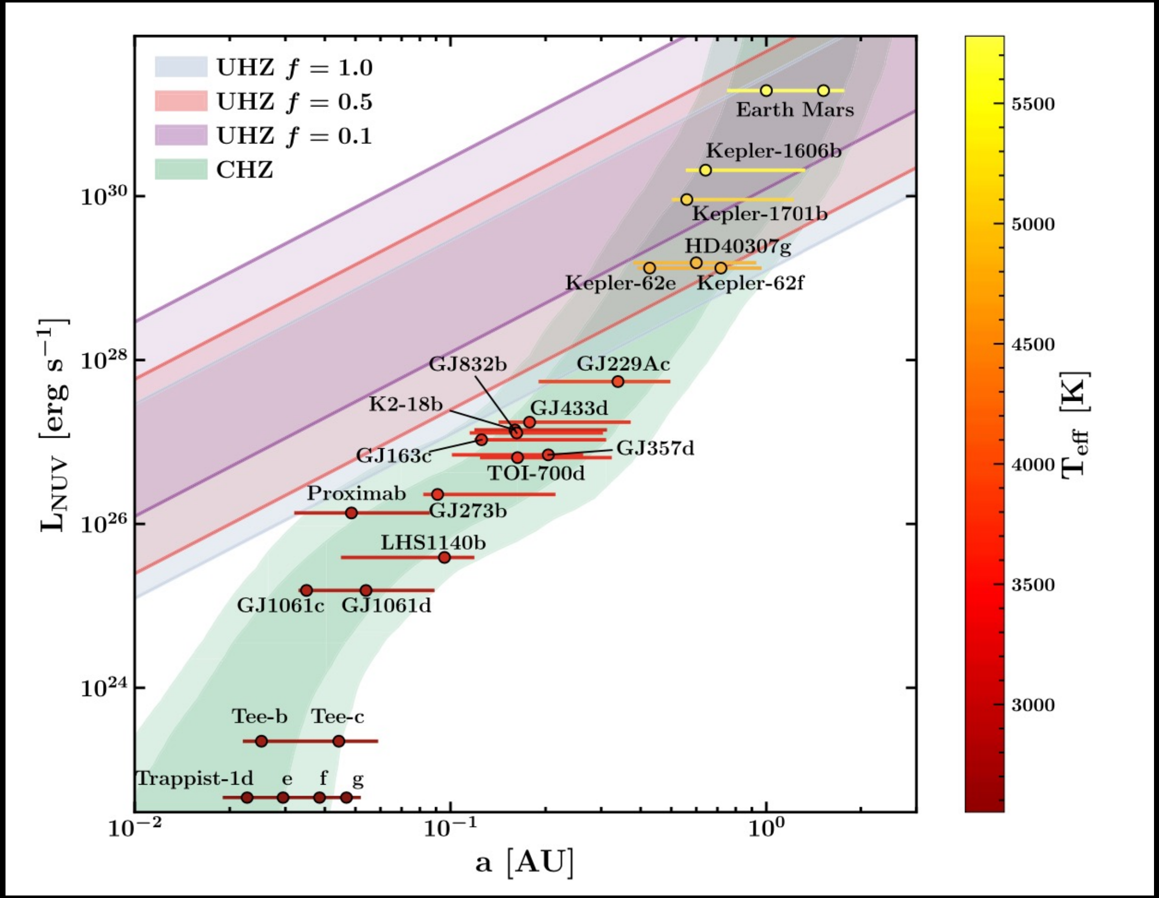


”…region around a star where the conditions could potentially be suitable to sustain like on a planet within this region, for example allowing the presence of liquid water on its surface”
ESA

but…

HABITABLE ZONE RECONSTRAINMENT

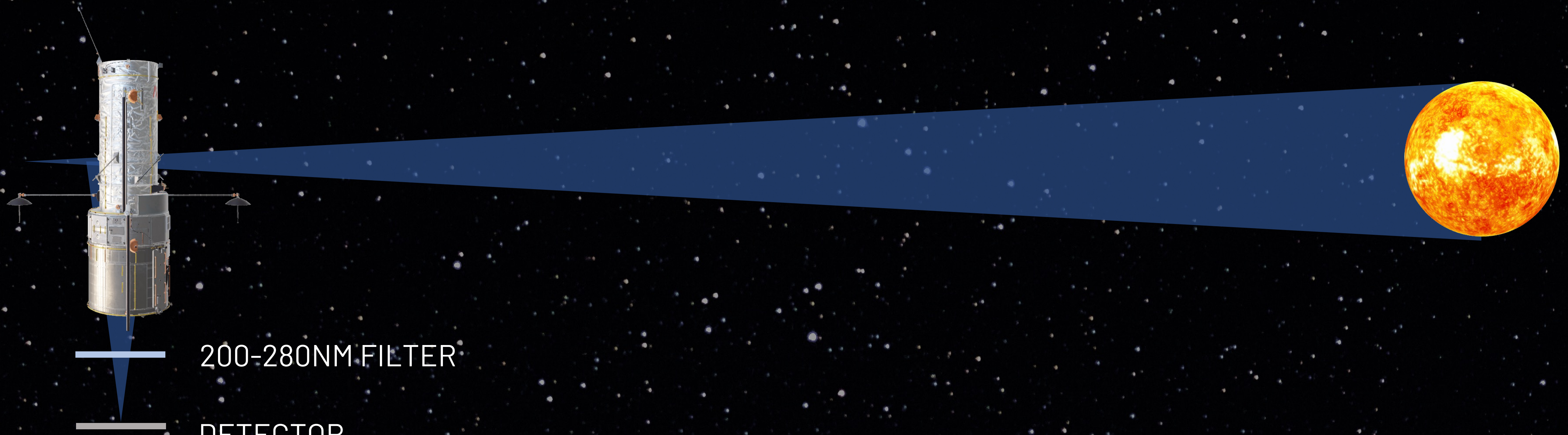




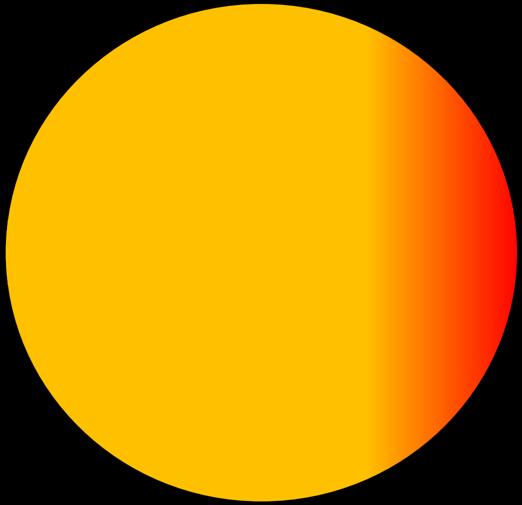
Spinelli et al. 2023

MEASUREMENT PRINCIPLE (PHOTOMETRY)

- Measuring UV-flux from star

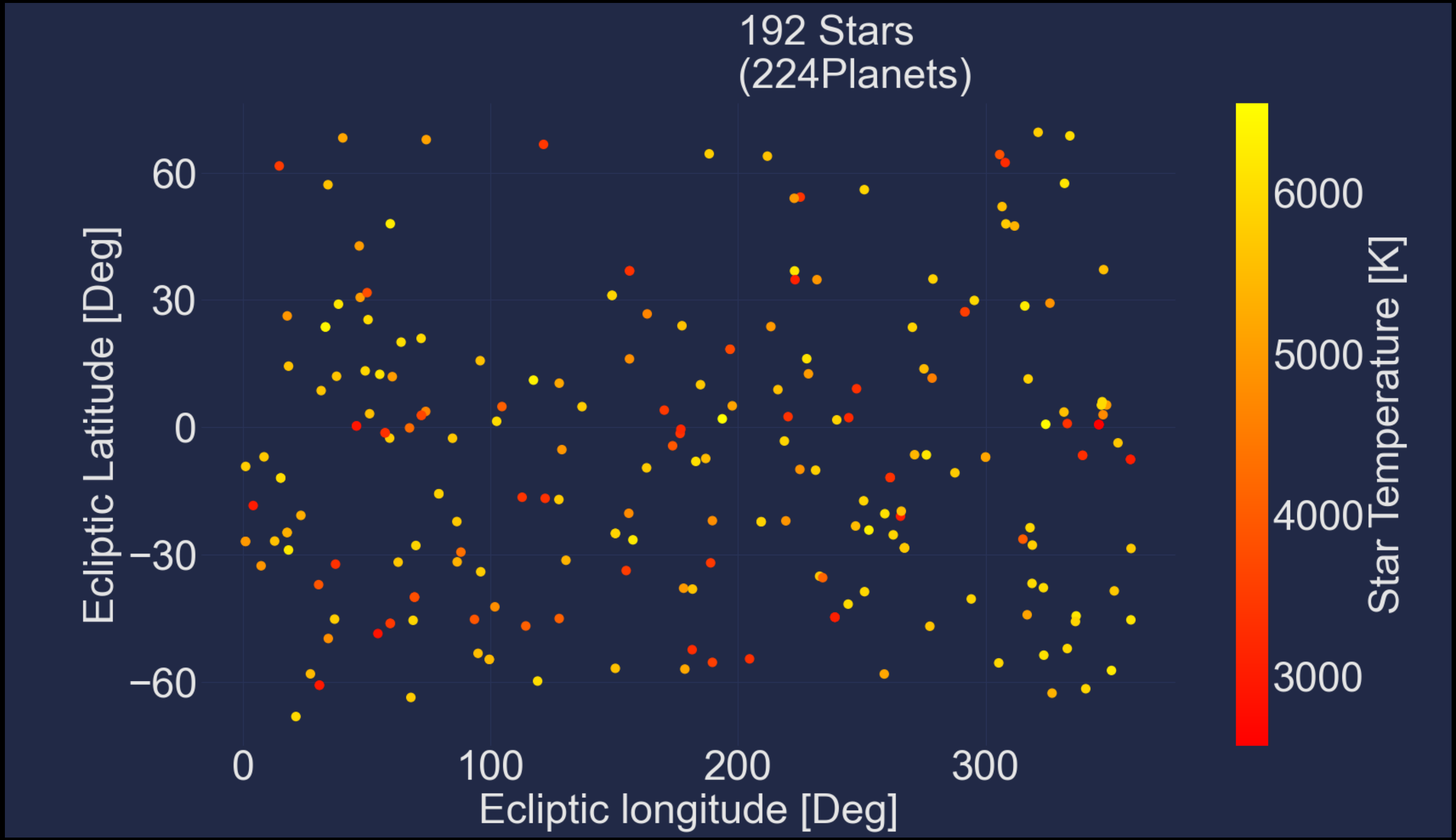


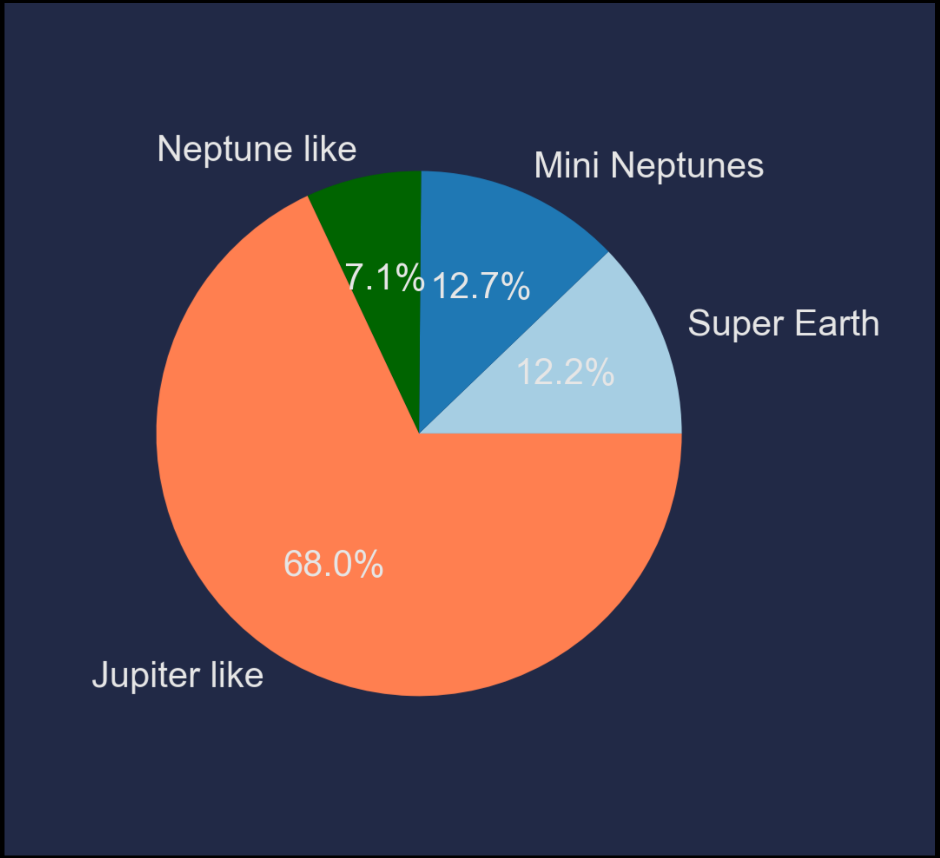
SENSITIVITY AND REQUIREMENTS



- G, K and M-type **stars**
- 5% error margin (SNR: 20)
- **Bandwidth** 200 -280 nm (UV-C)

TARGETS


192 Stars
(224Planets)
Ecliptic Latitude [Deg]
60
30
0
−30
−60
0
100
200
300
Ecliptic longitude [Deg]
6000
5000
4000
3000
Star Temperature [K]

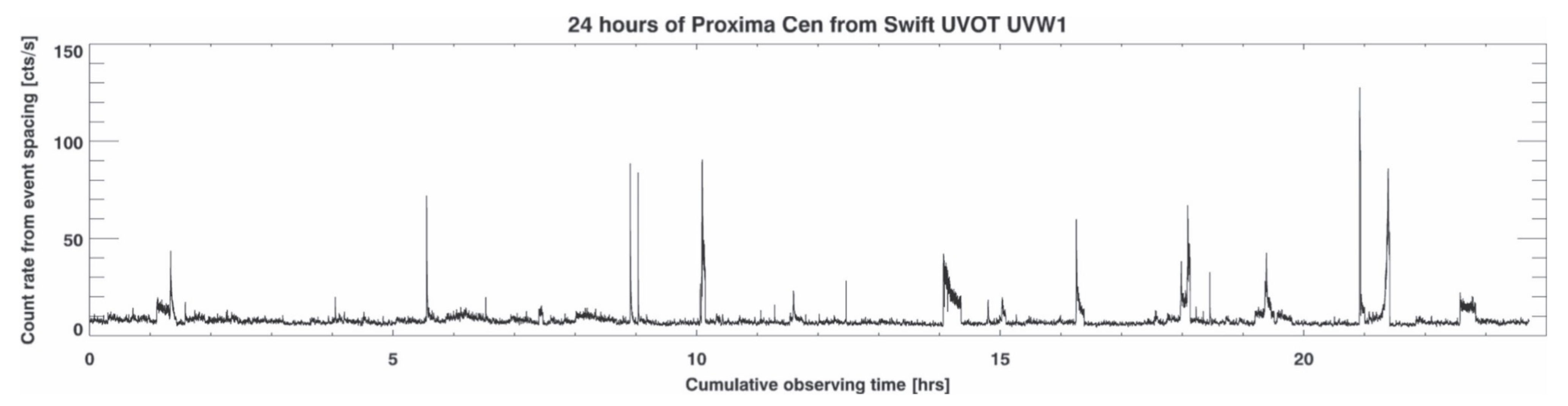

Neptune like
Mini Neptunes
Super Earth
Jupiter like
7.1%
12.7%
12.2%
68.0%

SCIENTIFIC CASES

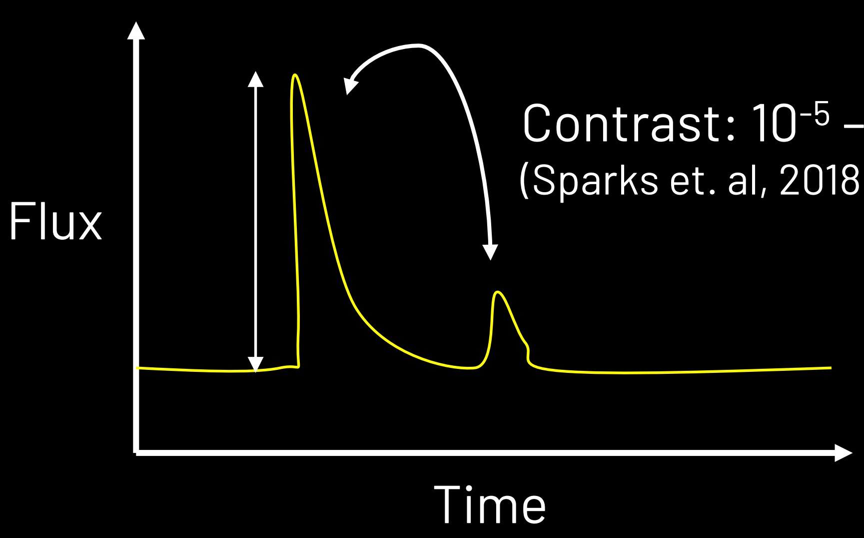
- MEASURE EXTENDED ATMOSPHERES
- MEASURE ATMOSPHERIC ESCAPE
- CONSTRAIN HABITABLE ZONE (UV)
- DETECT NEW EXOPLANETS

LIGHT ECHO PLANET DETECTION

- A stellar flare can brighten a planet in orbit around its host star, producing a light curve with a faint echo (Mann et al. 2018)
- A planet's light-echo emission can potentially be discriminated from that of the host star by means of a time delay (Sparks et al. 2018)



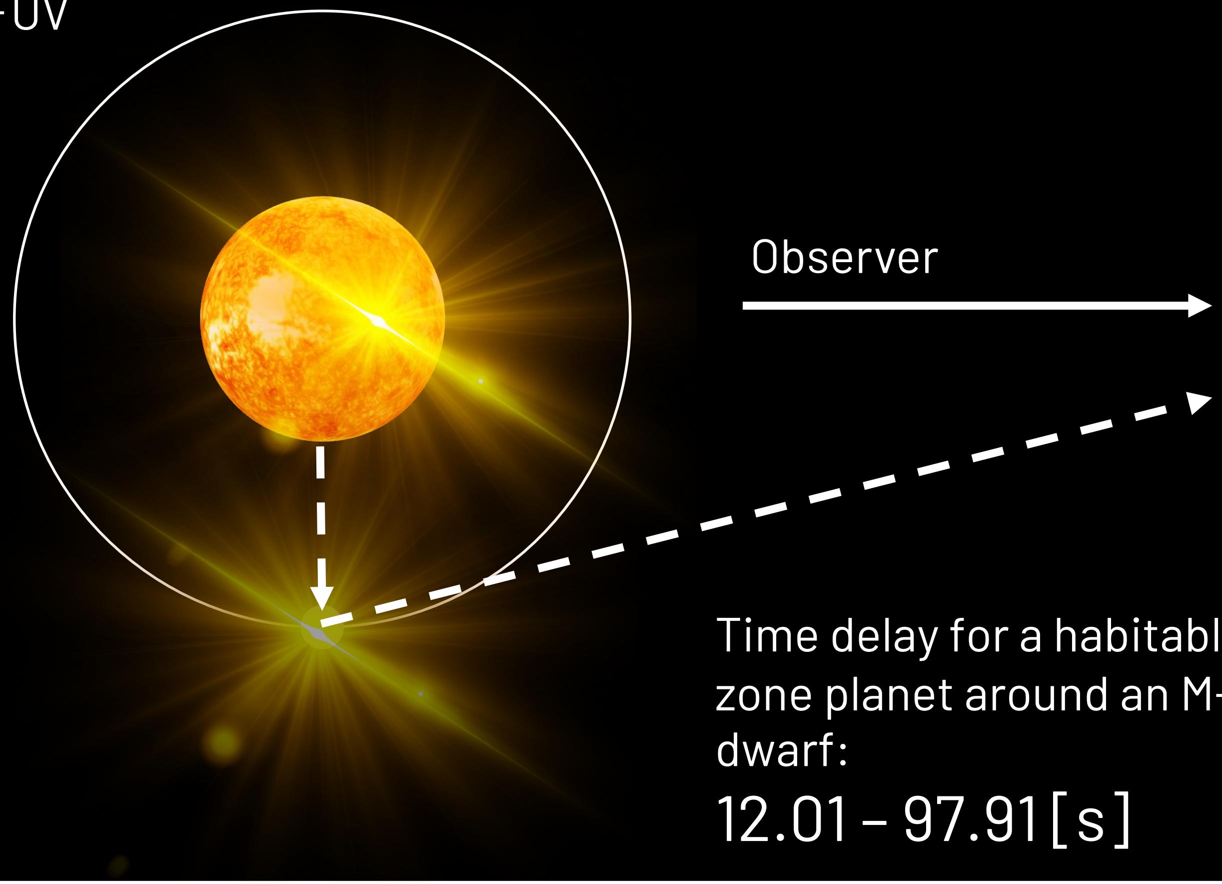
MEASUREMENT PRINCIPLE (PHOTOMETRY)



Intensity: $10^4 - 10^5$
(Sparks et. al, 2018)

Contrast: $10^{-5} - 10^{-7}$
(Sparks et. al, 2018)

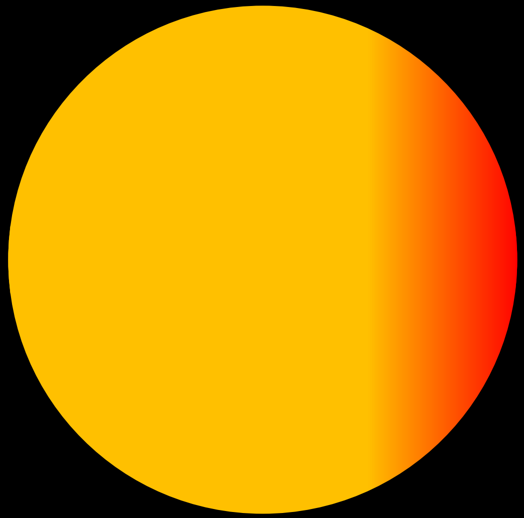
Visible in the NUV and FUV



Time delay for a habitable zone planet around an M-dwarf:

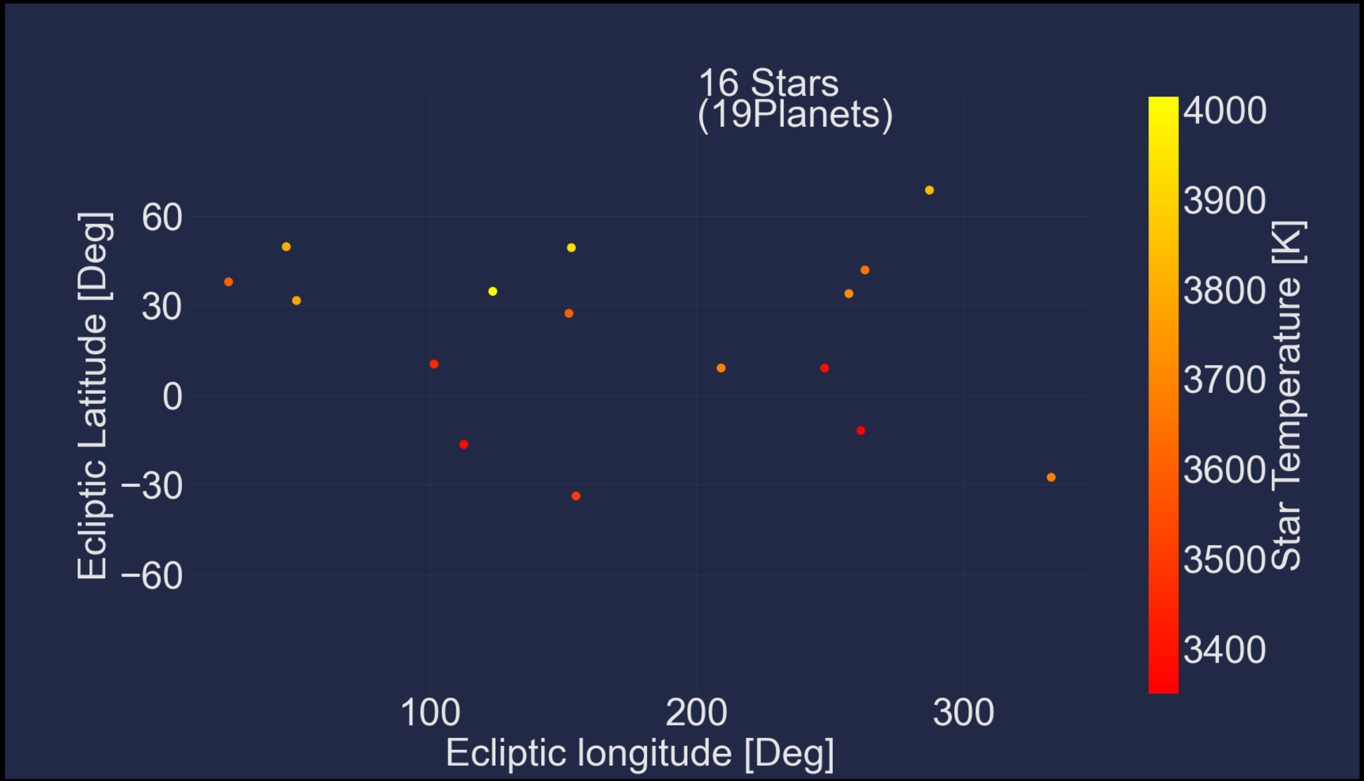
12.01 – 97.91 [s]

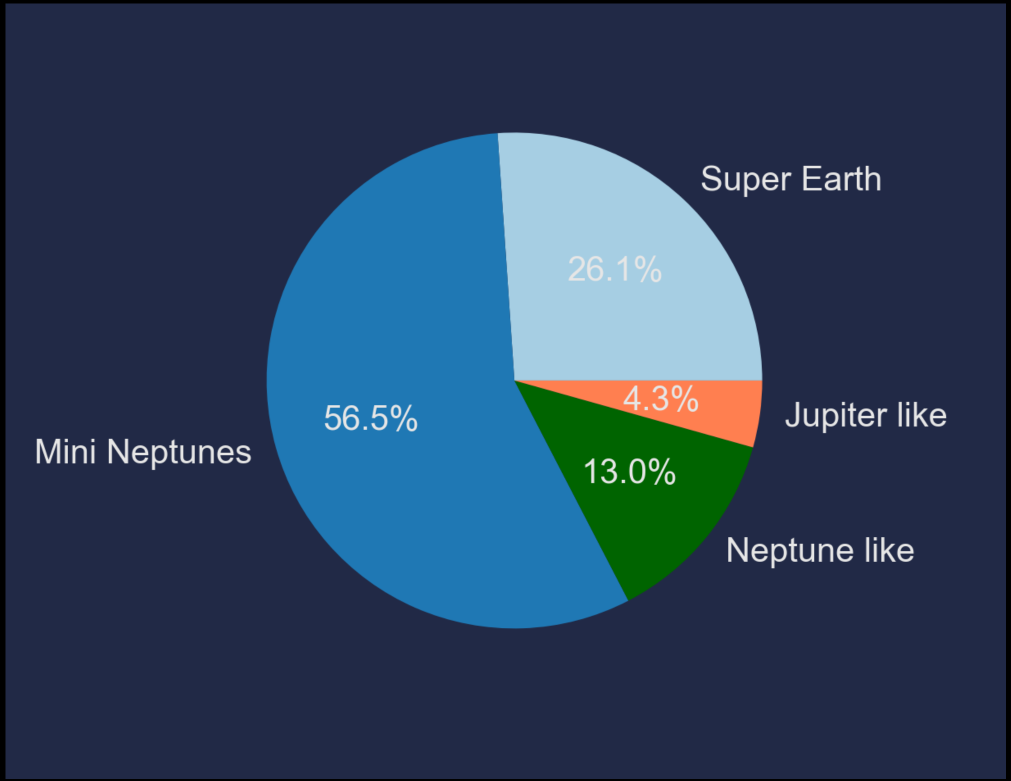
SENSITIVITY AND REQUIREMENTS



- M-type **stars**
- For a **2-sigma detection**
  -> SNR of 2000
- **Access planets >0.06 AU**
  -> maximum integration time: 30 seconds
- **Bandwidth** 100 - 400 nm (variable)

TARGETS

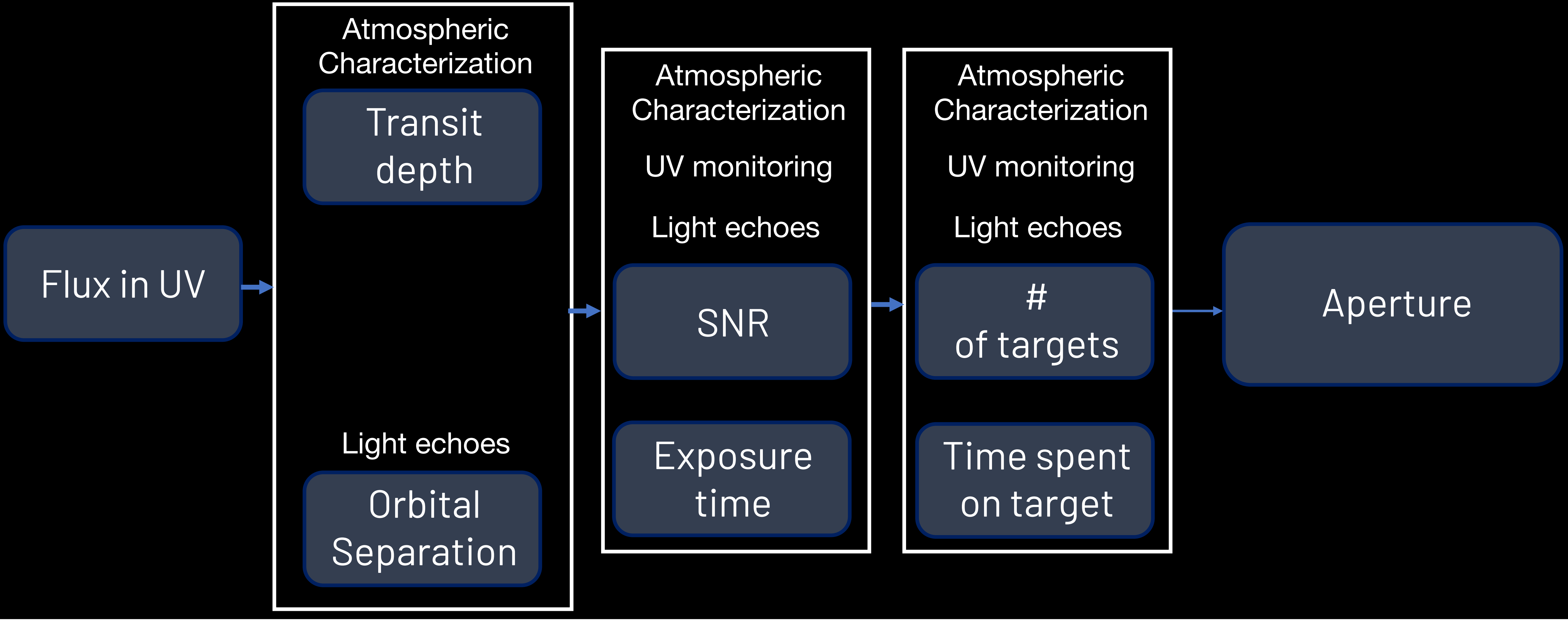

16 Stars
(19Planets)
60
30
0
−30
−60
Ecliptic Latitude [Deg]
100
200
300
Ecliptic longitude [Deg]
4000
3900
3800
3700
3600
3500
3400
Star Temperature [K]


Super Earth
26.1%
Jupiter like
4.3%
Mini Neptunes
56.5%
13.0%
Neptune like

MISSION OBJECTIVES

- Atmospheric Escape: Constrain evolutionary models of exoplanets
- Exospheres of habitable planets: Study formation processes of exospheres
- UV flux monitoring: Reconstrain the habitable zone for known systems
- Light echoes: Detect new habitable zone exoplanets

REQUIREMENT ON APERTURE SIZE



Flux in UV

Atmospheric Characterization

Transit depth

Light echoes

Orbital Separation

Atmospheric Characterization

UV monitoring

Light echoes

SNR

Exposure time

Atmospheric Characterization

UV monitoring

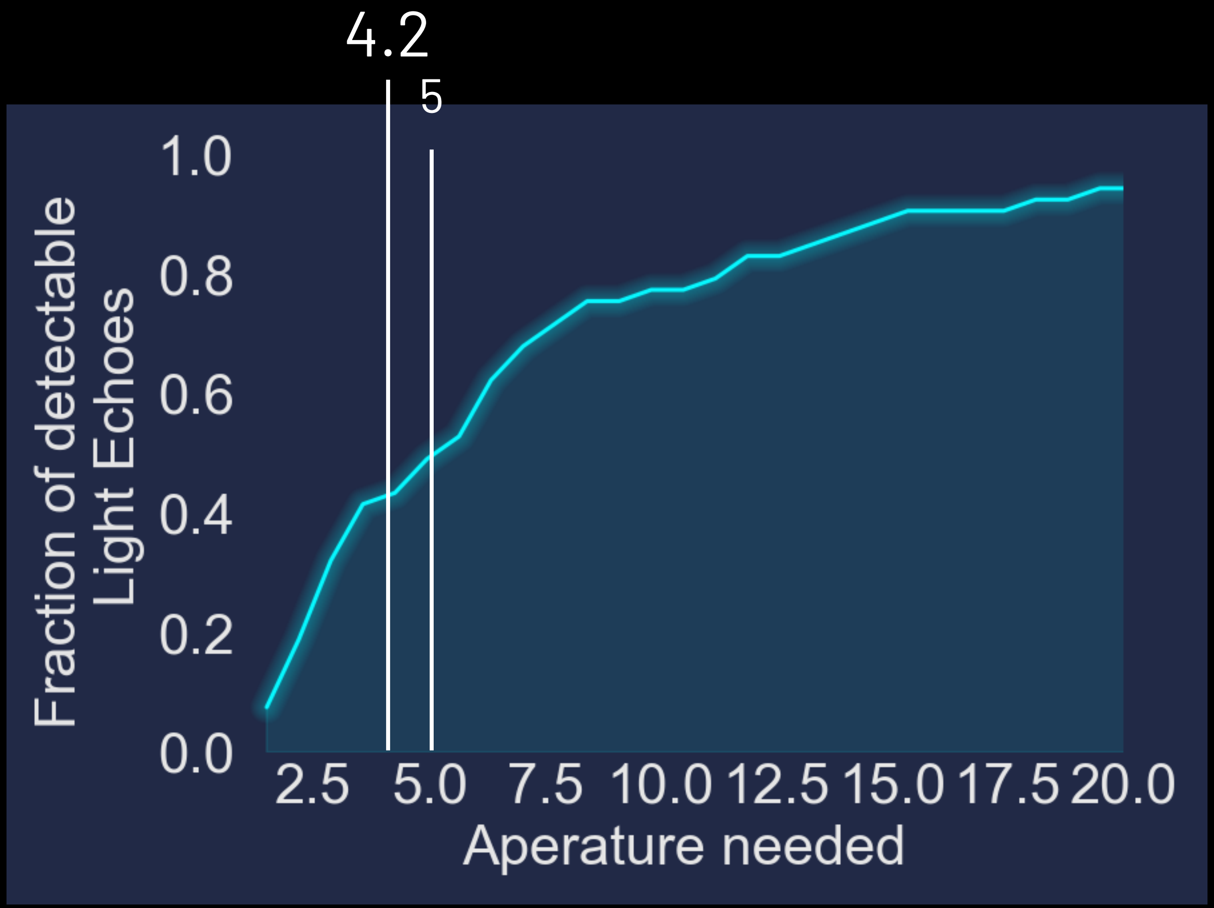
Light echoes

# of targets

Time spent on target

Aperture

APERTURE SIZE – LIGHT ECHOES



- Initially: 50% of targets (34)
- Trade-off on fairing diameter:
  -> Down to 19 targets

KEY MISSION DRIVERS

- **Diameter** of telescope: 4.2 meters.
- **Pointing**: 5 mas (absolute pointing + fine guiding).
- **Throughput** >4%.
- Orbit **outside** Earth's exosphere (Ly-alpha absorption).
  All within 100pc:
  - > 40 planets for exospheres of habitable planets
  - > 400 planets for atmospheric escape
  - > 150 stars for UV monitoring (16 days)
  - ~20 planets for light echo detections (16 days monitoring)

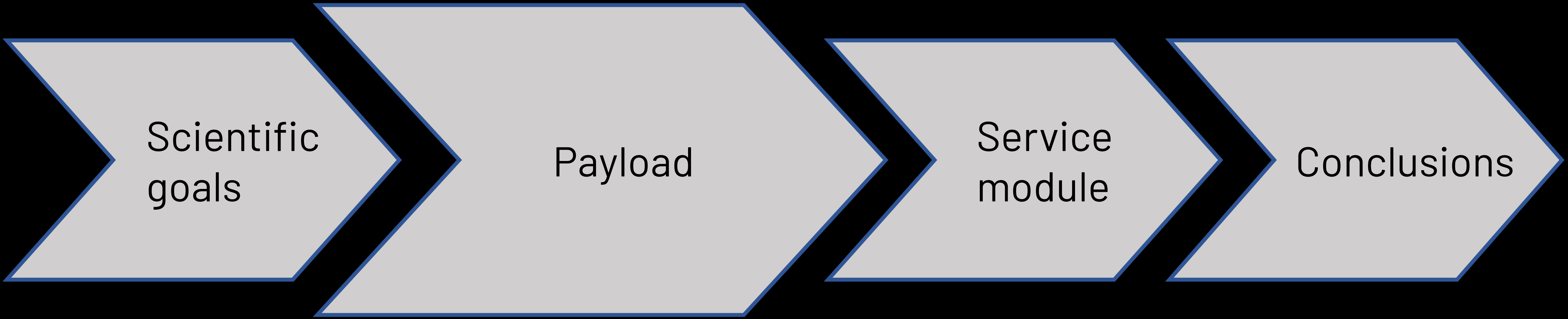
OBSERVATIONAL STRATEGY

- **Flexibility** is key to **assist** with stellar activity monitoring
- **Observe transits** of known exoplanets, baseline of 3 transits lengths
- **Photometry** for 0.5 x rotational period of the star
- When monitoring for light echoes, if no signal is found then change target

MISSION DURATION

Variable	Time	Total time
Average **time of transit** for each planet (Ext. atm.)	2.2 hrs	6 hrs per target
Average **time of transit** for each planet (Esc. atm.)	2.2 hrs	6 hrs per target
Number of transits required for each target (Esc. atm.and Ext. atm.)	10 x 2	120 hrs
Exposure time of each star (HZ)	Max. 30 s	15 days
Exposure time of each star (Light echoes)	Max. 30 s	15 days
Repointing	1 per target	300 hours
TOTAL	-	**6.5 years**

PAYLOAD



Scientific goals

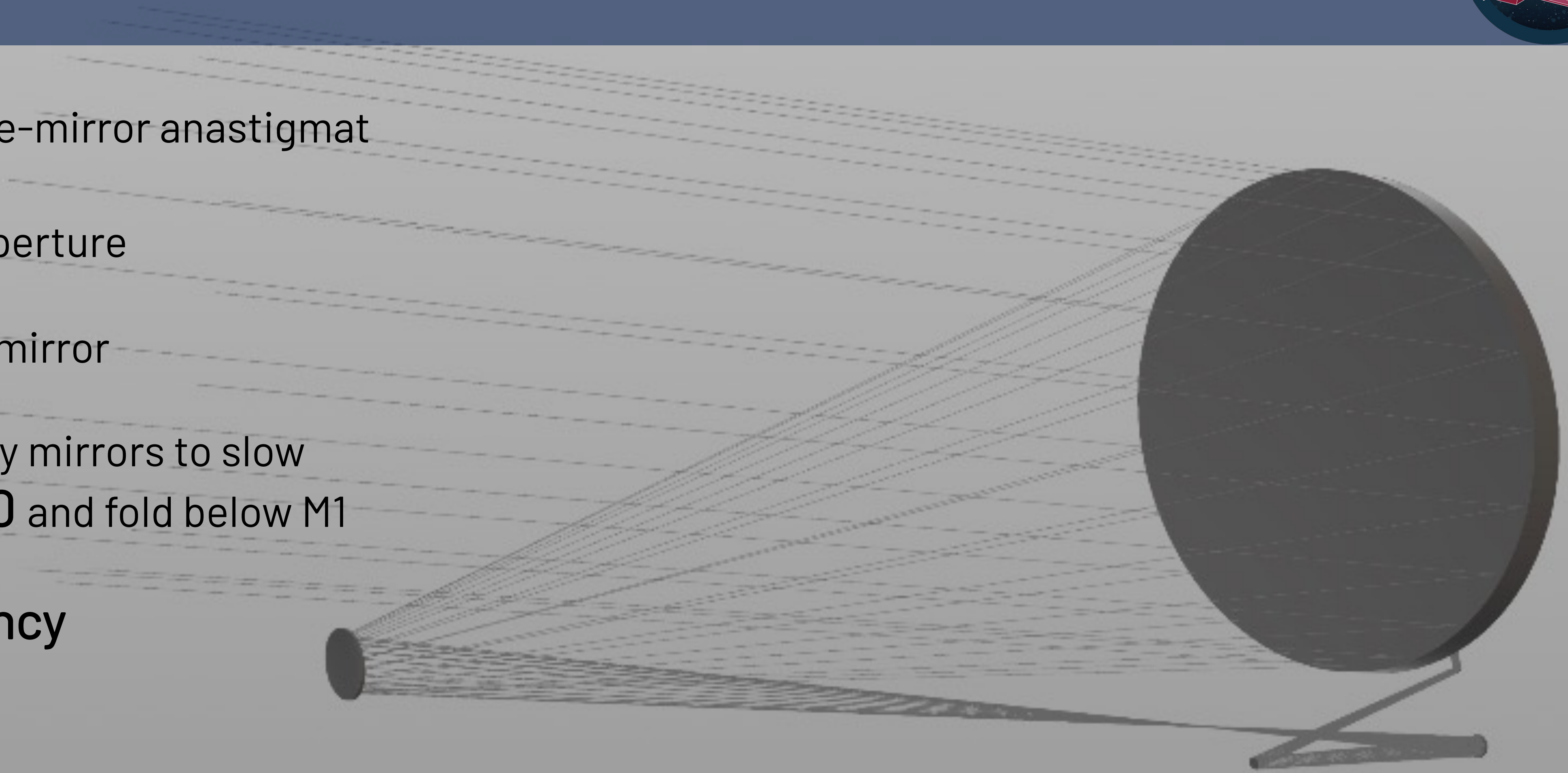
Payload

Service module

Conclusions

TELESCOPE DESIGN

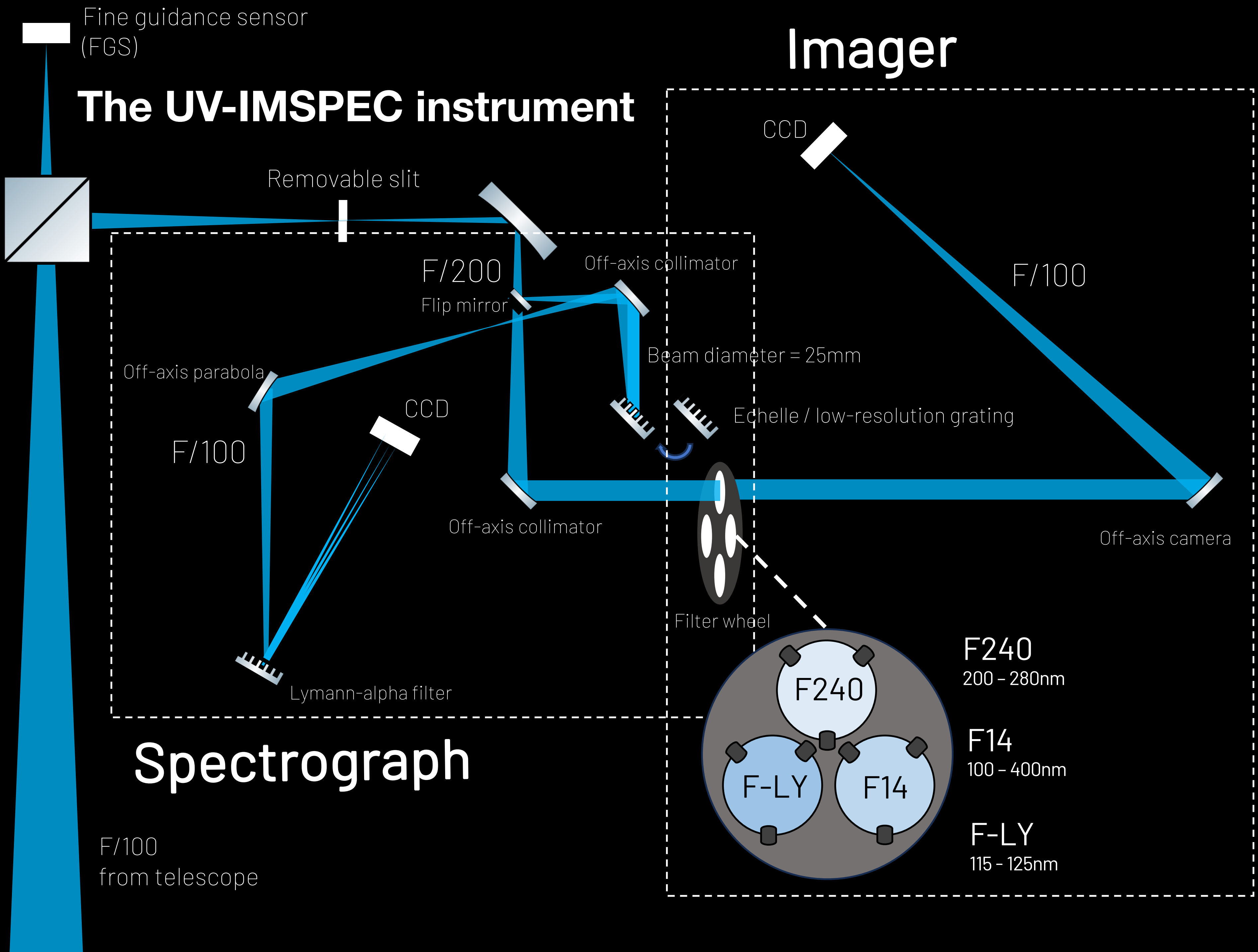
- **Off-axis** three-mirror anastigmat
- **4.2-meter** aperture
- Fine-steering mirror
- Additional relay mirrors to slow beam to **F/100** and fold below M1
- **High efficiency**



INSTRUMENT: UV-IMSPEC

- **Spectroscopy mode** (R: 1000 – 20.000)
- **Imaging mode** for photometry

The UV-IMSPEC instrument



Challenges:

- **Slow beams** to reach sampling requirements of **2 pixels/FWHM**.
- **Minimal amount of surfaces** to increase throughput.

DETECTORS (SPECIFICATIONS)

	IMAGER	SPECTROGRAPH
Op. wavelength [nm]	100-400	115-125
MgF2 (op. for ^1) [nm]	200-250	120-150
Quant. Eff. (SOTA)	30-60%	20-50%
Target develop.	60 % (100-400 nm)	60 % (115-125 nm)
Op. temp. [K]	< 163	< 163

Read-out Noise^2:
< 1 e-

Dark Current Noise^2:
< 0.025/hr/pix

Pixel Size (SOTA): 10µm
Target Development: 7µm

TRL: 5
(Demonstrated at 39km altitude during FIREBall-2 mission)

SERVICE MODULE

Scientific goals

Payload

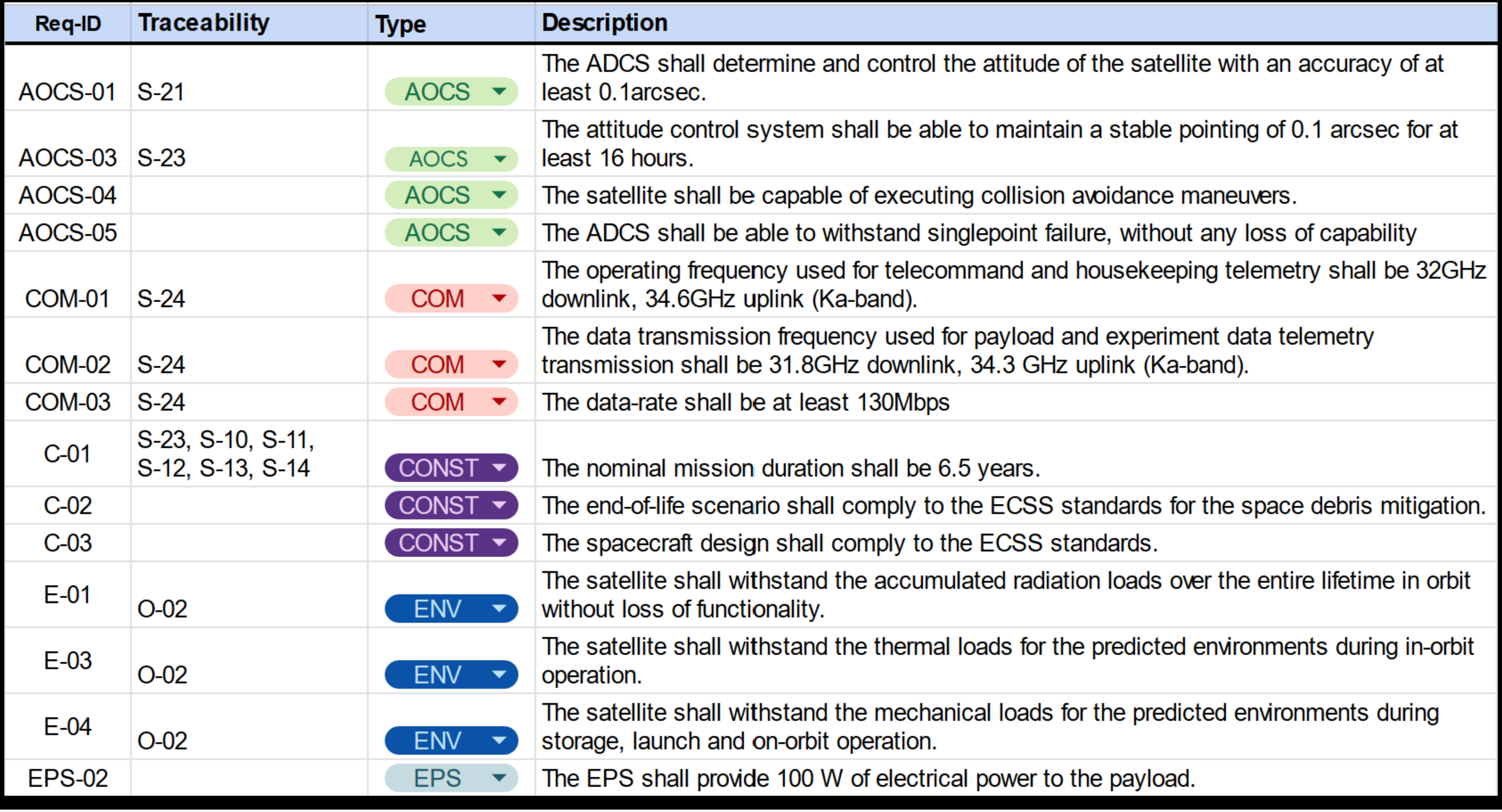
Service module

Conclusions

KEY SYSTEM DRIVERS

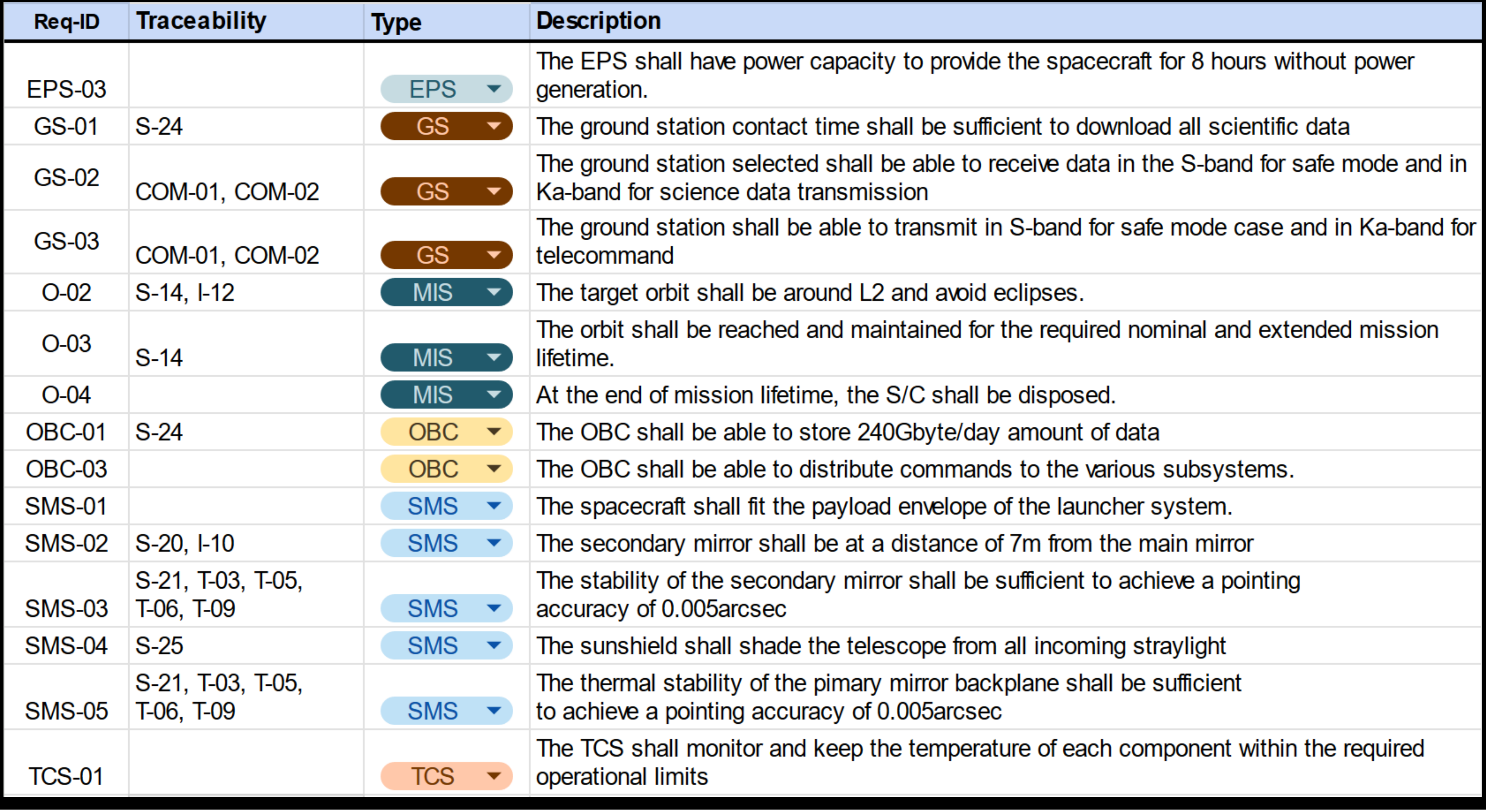
DRIVER	VALUE
PRIMARY MIRROR SIZE	4.2 METERS
DISTANCE BETWEEN MAIN MIRROR AND SECONDARY MIRROR	7 METERS
POINTING ACCURACY FOR SPACECRAFT	0.1 ARCSEC
DATA AMOUNT	240 GB/DAY
MISSION DURATION	6.5 YEAR
TYPE OF ORBIT	L2
STRAYLIGHT	SHADED MIRROR

PLATFORM REQUIREMENTS



Req-ID	Traceability	Type	Description
AOCS-01	S-21	AOCS	The ADCS shall determine and control the attitude of the satellite with an accuracy of at least 0.1arcsec.
AOCS-03	S-23	AOCS	The attitude control system shall be able to maintain a stable pointing of 0.1 arcsec for at least 16 hours.
AOCS-04		AOCS	The satellite shall be capable of executing collision avoidance maneuvers.
AOCS-05		AOCS	The ADCS shall be able to withstand singlepoint failure, without any loss of capability
COM-01	S-24	COM	The operating frequency used for telecommand and housekeeping telemetry shall be 32GHz downlink, 34.6GHz uplink (Ka-band).
COM-02	S-24	COM	The data transmission frequency used for payload and experiment data telemetry transmission shall be 31.8GHz downlink, 34.3 GHz uplink (Ka-band).
COM-03	S-24	COM	The data-rate shall be at least 130Mbps
C-01	S-23, S-10, S-11, S-12, S-13, S-14	CONST	The nominal mission duration shall be 6.5 years.
C-02		CONST	The end-of-life scenario shall comply to the ECSS standards for the space debris mitigation.
C-03		CONST	The spacecraft design shall comply to the ECSS standards.
E-01	O-02	ENV	The satellite shall withstand the accumulated radiation loads over the entire lifetime in orbit without loss of functionality.
E-03	O-02	ENV	The satellite shall withstand the thermal loads for the predicted environments during in-orbit operation.
E-04	O-02	ENV	The satellite shall withstand the mechanical loads for the predicted environments during storage, launch and on-orbit operation.
EPS-02		EPS	The EPS shall provide 100 W of electrical power to the payload.

PLATFORM REQUIREMENTS



Req-ID	Traceability	Type	Description
EPS-03		EPS	The EPS shall have power capacity to provide the spacecraft for 8 hours without power generation.
GS-01	S-24	GS	The ground station contact time shall be sufficient to download all scientific data
GS-02	COM-01, COM-02	GS	The ground station selected shall be able to receive data in the S-band for safe mode and in Ka-band for science data transmission
GS-03	COM-01, COM-02	GS	The ground station shall be able to transmit in S-band for safe mode case and in Ka-band for telecommand
O-02	S-14, I-12	MIS	The target orbit shall be around L2 and avoid eclipses.
O-03	S-14	MIS	The orbit shall be reached and maintained for the required nominal and extended mission lifetime.
O-04		MIS	At the end of mission lifetime, the S/C shall be disposed.
OBC-01	S-24	OBC	The OBC shall be able to store 240Gbyte/day amount of data
OBC-03		OBC	The OBC shall be able to distribute commands to the various subsystems.
SMS-01		SMS	The spacecraft shall fit the payload envelope of the launcher system.
SMS-02	S-20, I-10	SMS	The secondary mirror shall be at a distance of 7m from the main mirror
SMS-03	S-21, T-03, T-05, T-06, T-09	SMS	The stability of the secondary mirror shall be sufficient to achieve a pointing accuracy of 0.005arcsec
SMS-04	S-25	SMS	The sunshield shall shade the telescope from all incoming straylight
SMS-05	S-21, T-03, T-05, T-06, T-09	SMS	The thermal stability of the pimary mirror backplane shall be sufficient to achieve a pointing accuracy of 0.005arcsec
TCS-01		TCS	The TCS shall monitor and keep the temperature of each component within the required operational limits

TOP REQUIREMENTS

Req-ID	Traceability	Type	Description
AOCS-01	S-21	AOCS	The ADCS shall determine and control the attitude of the satellite with an accuracy of at least 0.1arcsec.
AOCS-03	S-23	AOCS	The attitude control system shall be able to maintain a stable pointing of 0.1 arcsec for at least 16 hours.
C-01	S-23, S-10, S-11, S-12, S-13, S-14	CONST	The nominal mission duration shall be 6.5 years.
O-02	S-14, I-12	MIS	The target orbit shall be around L2 and avoid eclipses.
GS-01	S-24	GS	The ground station contact time shall be sufficient to download all scientific data
SMS-01		SMS	The spacecraft shall fit the payload envelope of the launcher system.
SMS-02	S-20, I-10	SMS	The secondary mirror shall be at a distance of 7m from the main mirror

MISSION ANALYSIS

TARGET

- Halo orbit around Sun-Earth L2 point
- Apoapsis altitude: 8.52e5 km
- Periapsis altitude: 2.5e5 km
- Small orbit corrections necessary

Getting there

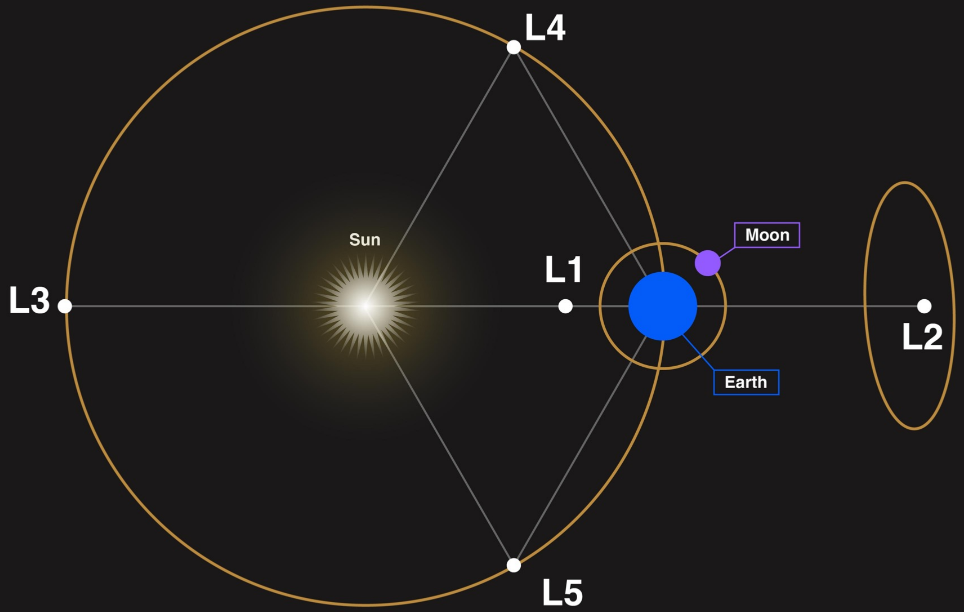
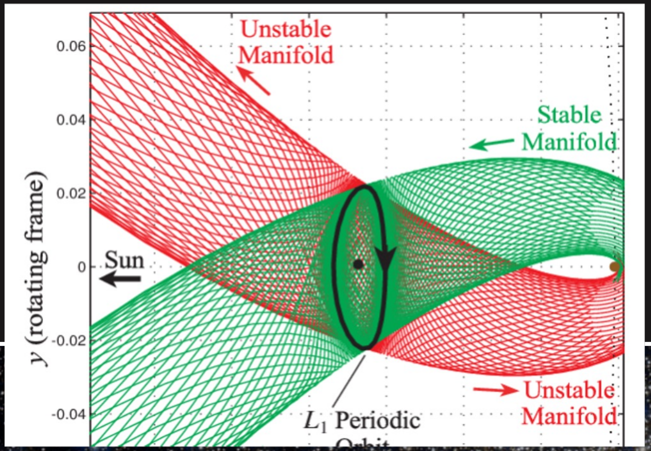


Image: NASA

Launch Window considerations

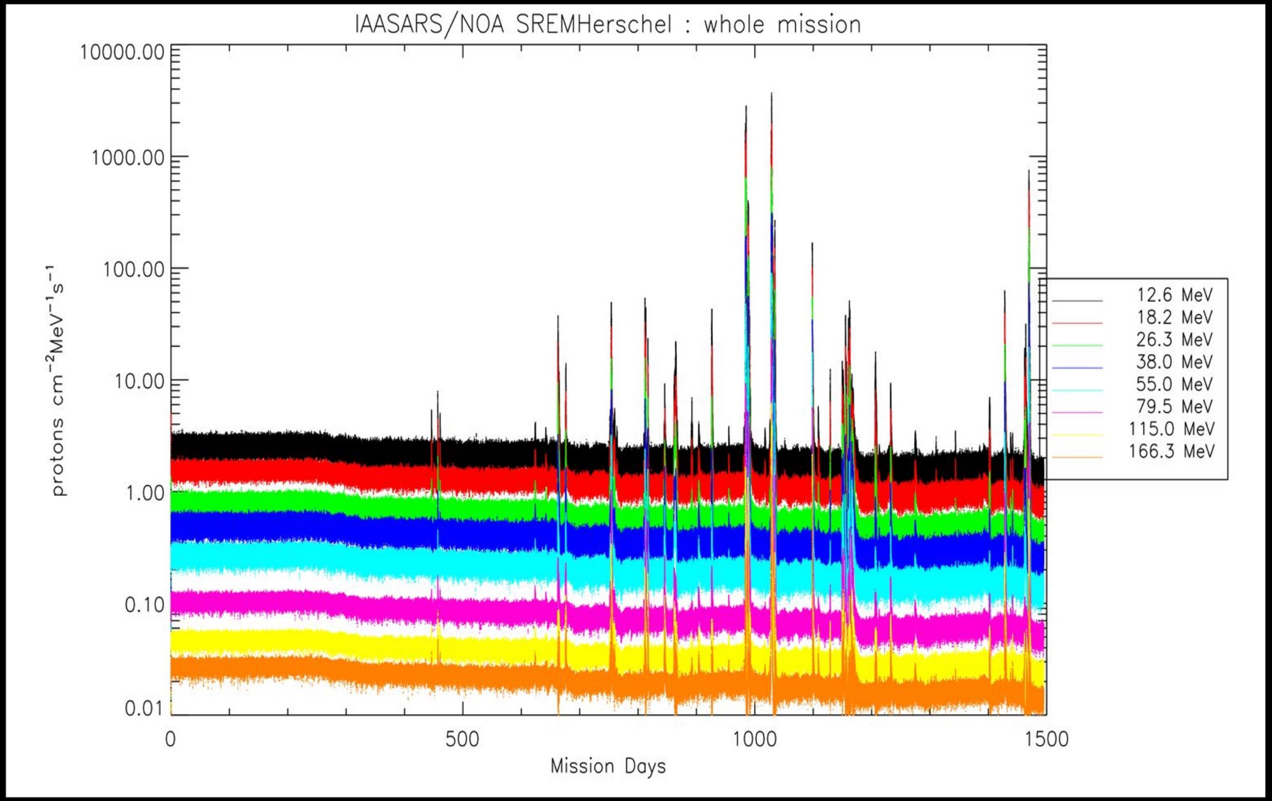
- Earth/Moon eclipses
- Instruments orbiting L2
- Stable Manifold Transfer
- Target Orbit Insertion

Wang et al., 2000.



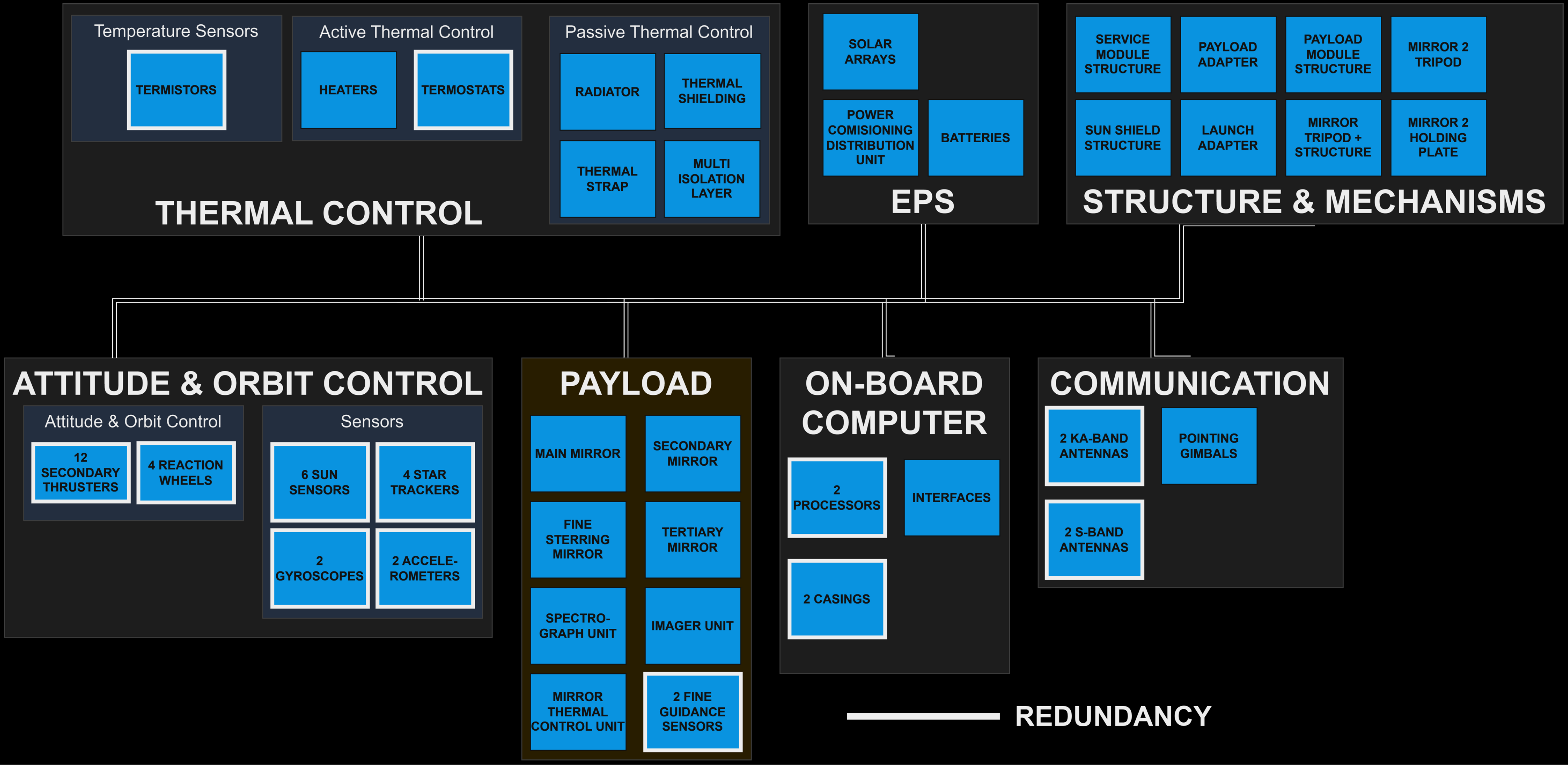
RADIATION ENVIRONMENT

- The radiation environment at L2 is less harmful than LEO or GEO
- Sources are the Sun and cosmic ray background
- 1- 10 particles/cm^3 (95% protons)
- Herschel mission ~1 SEU/day (“bit flip”)
- Need for Failure Detection Isolation and Recovery (FDIR) in the OBC.



Ingmar Sandberg (ESTEC)

SYSTEM OVERVIEW



THERMAL CONTROL

Temperature Sensors
- TERMISTORS

Active Thermal Control
- HEATERS
- TERMOSTATS

Passive Thermal Control
- RADIATOR
- THERMAL SHIELDING
- THERMAL STRAP
- MULTI ISOLATION LAYER

EPS

- SOLAR ARRAYS
- POWER COMISIONING DISTRIBUTION UNIT
- BATTERIES

STRUCTURE & MECHANISMS

- SERVICE MODULE STRUCTURE
- PAYLOAD ADAPTER
- PAYLOAD MODULE STRUCTURE
- MIRROR 2 TRIPOD
- SUN SHIELD STRUCTURE
- LAUNCH ADAPTER
- MIRROR TRIPOD + STRUCTURE
- MIRROR 2 HOLDING PLATE

ATTITUDE & ORBIT CONTROL

Attitude & Orbit Control
- 12 SECONDARY THRUSTERS
- 4 REACTION WHEELS

Sensors
- 6 SUN SENSORS
- 4 STAR TRACKERS
- 2 GYROSCOPES
- 2 ACCELE-ROMETERS

PAYLOAD

- MAIN MIRROR
- SECONDARY MIRROR
- FINE STERRING MIRROR
- TERTIARY MIRROR
- SPECTRO-GRAPH UNIT
- IMAGER UNIT
- MIRROR THERMAL CONTROL UNIT
- 2 FINE GUIDANCE SENSORS

ON-BOARD COMPUTER

- 2 PROCESSORS
- INTERFACES
- 2 CASINGS

COMMUNICATION

- 2 KA-BAND ANTENNAS
- POINTING GIMBALS
- 2 S-BAND ANTENNAS

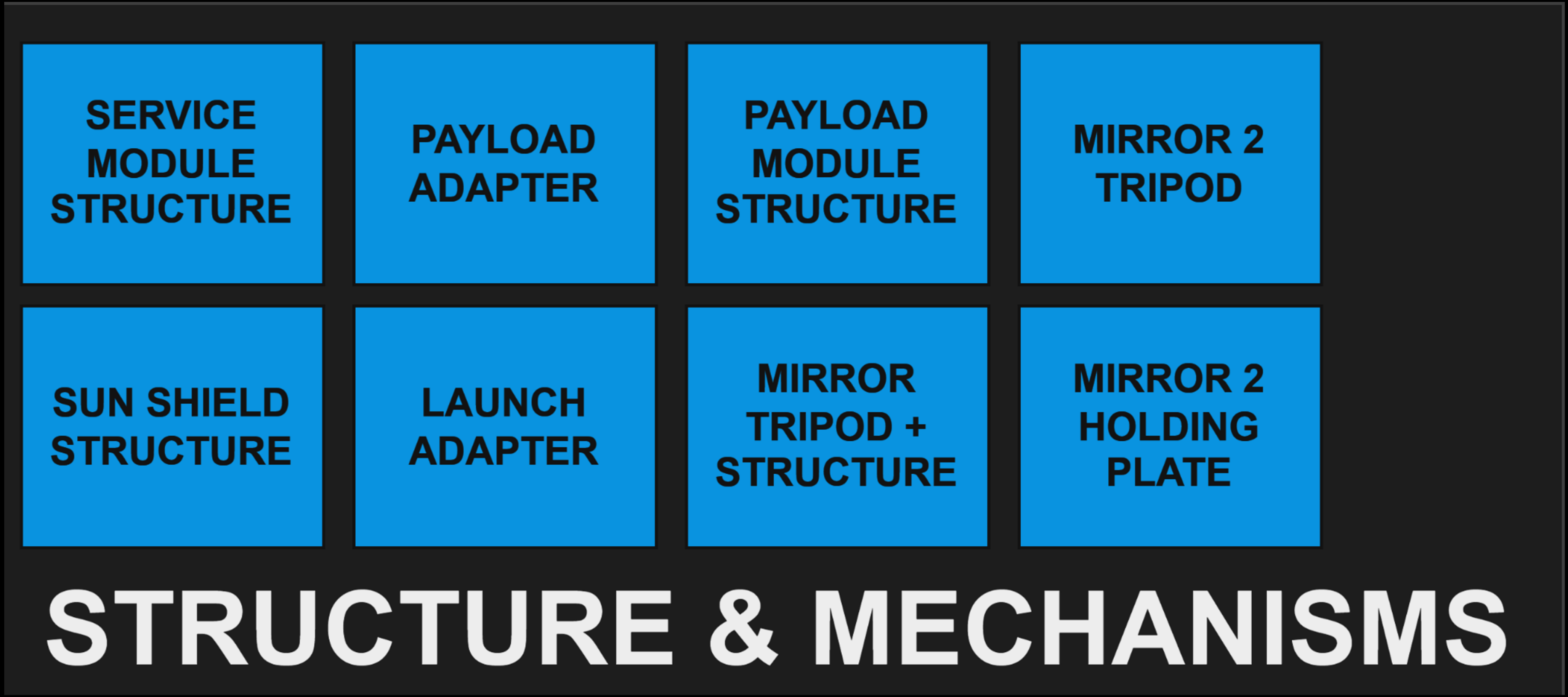
REDUNDANCY

STRUCTURE & MECHANISMS REQUIREMENTS

- **SMS-01:** The spacecraft shall fit the payload envelope of the launcher system

- **SMS-05:** The thermal stability of the primary mirror backplane shall be sufficient to achieve a pointing accuracy of 0.005arcsec

Structures and Mechanisms System



SERVICE MODULE STRUCTURE

PAYLOAD ADAPTER

PAYLOAD MODULE STRUCTURE

MIRROR 2 TRIPOD

SUN SHIELD STRUCTURE

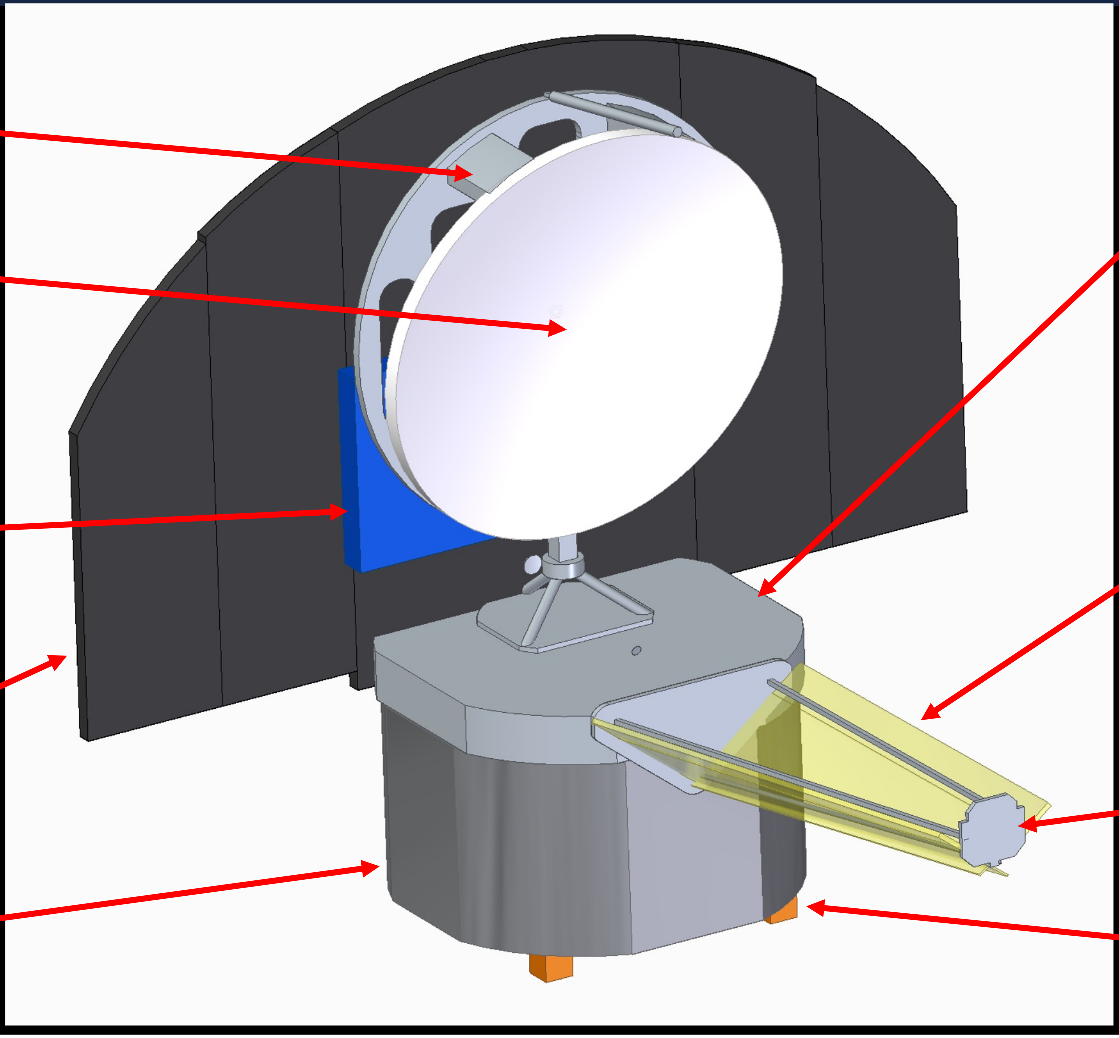
LAUNCH ADAPTER

MIRROR TRIPOD + STRUCTURE

MIRROR 2 HOLDING PLATE

STRUCTURE & MECHANISMS

SATELLITE DESIGN



Mirror structure

Primary Mirror

Payload Module

Sunshield

Service Module

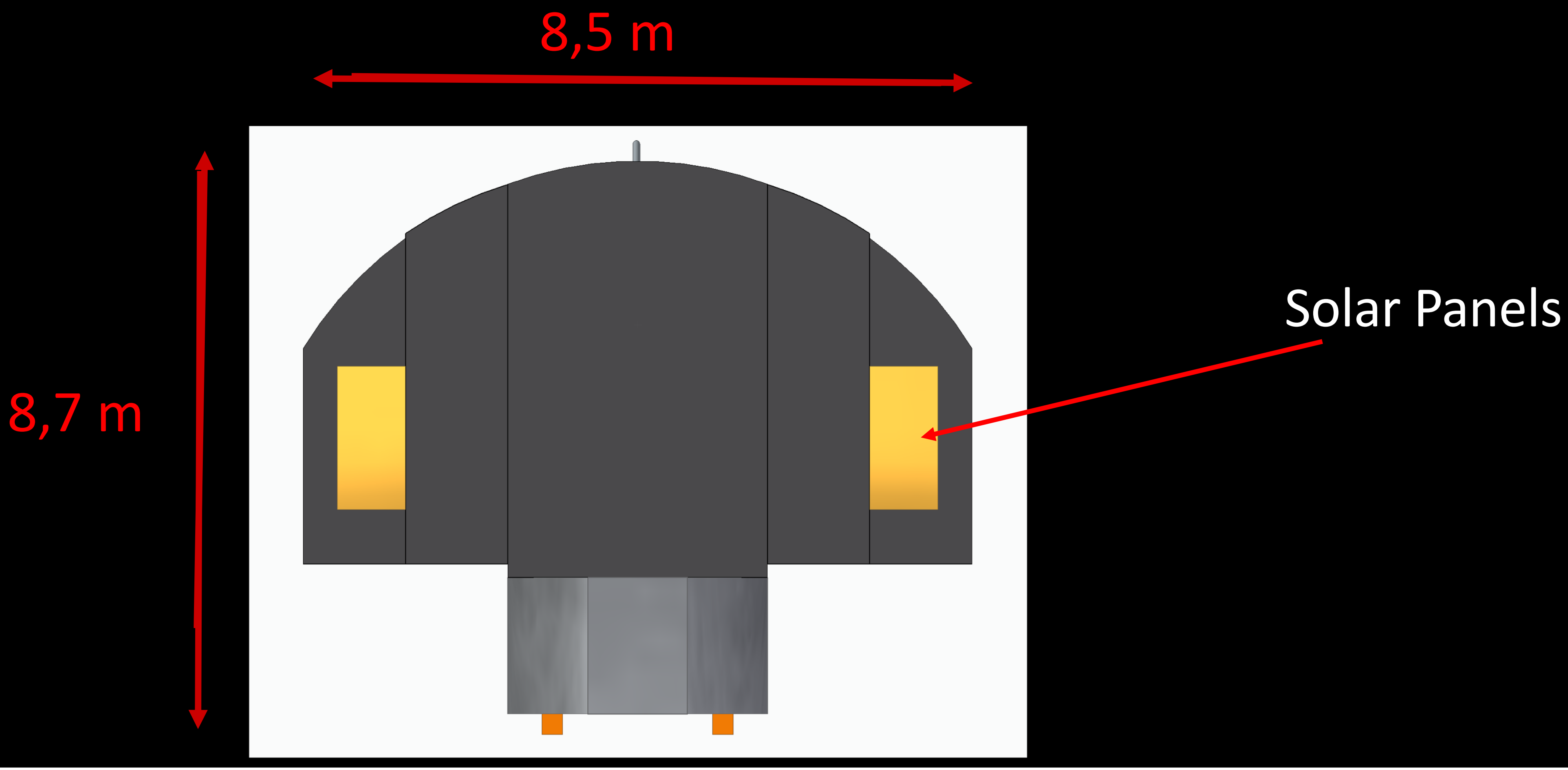
Payload Interface Plate

Shielding (MLI)

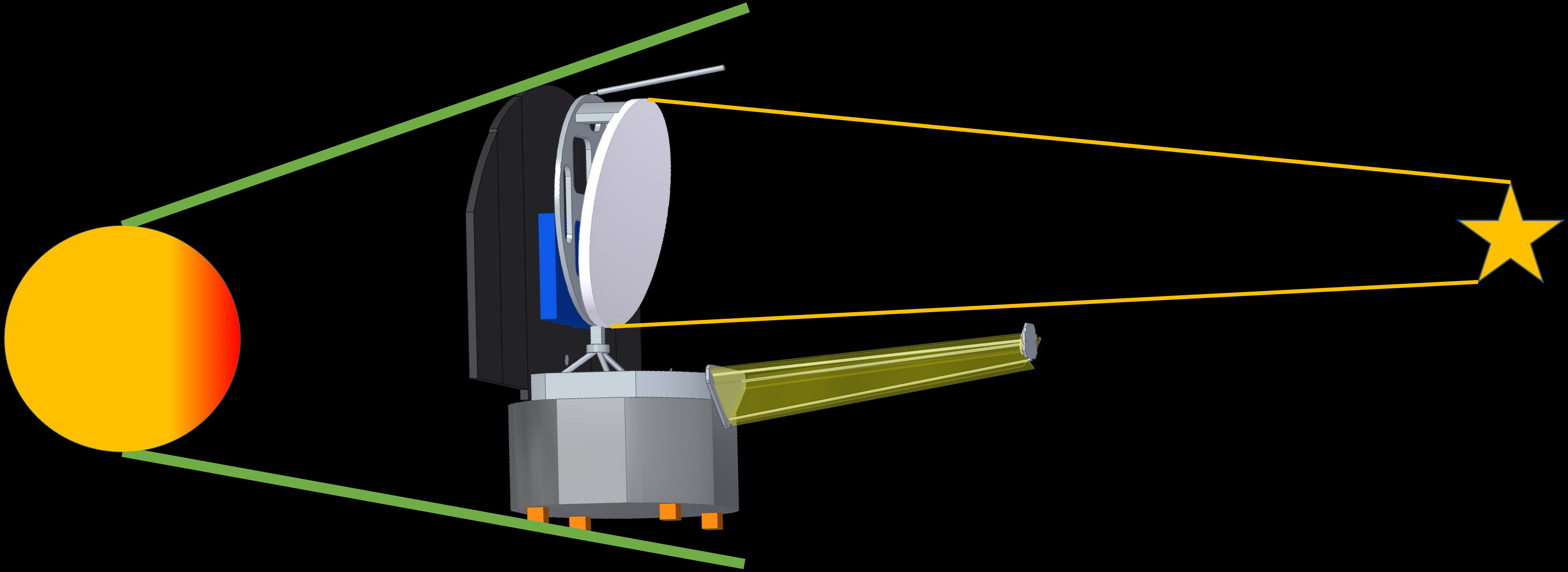
Secondary Mirror

Thrusters

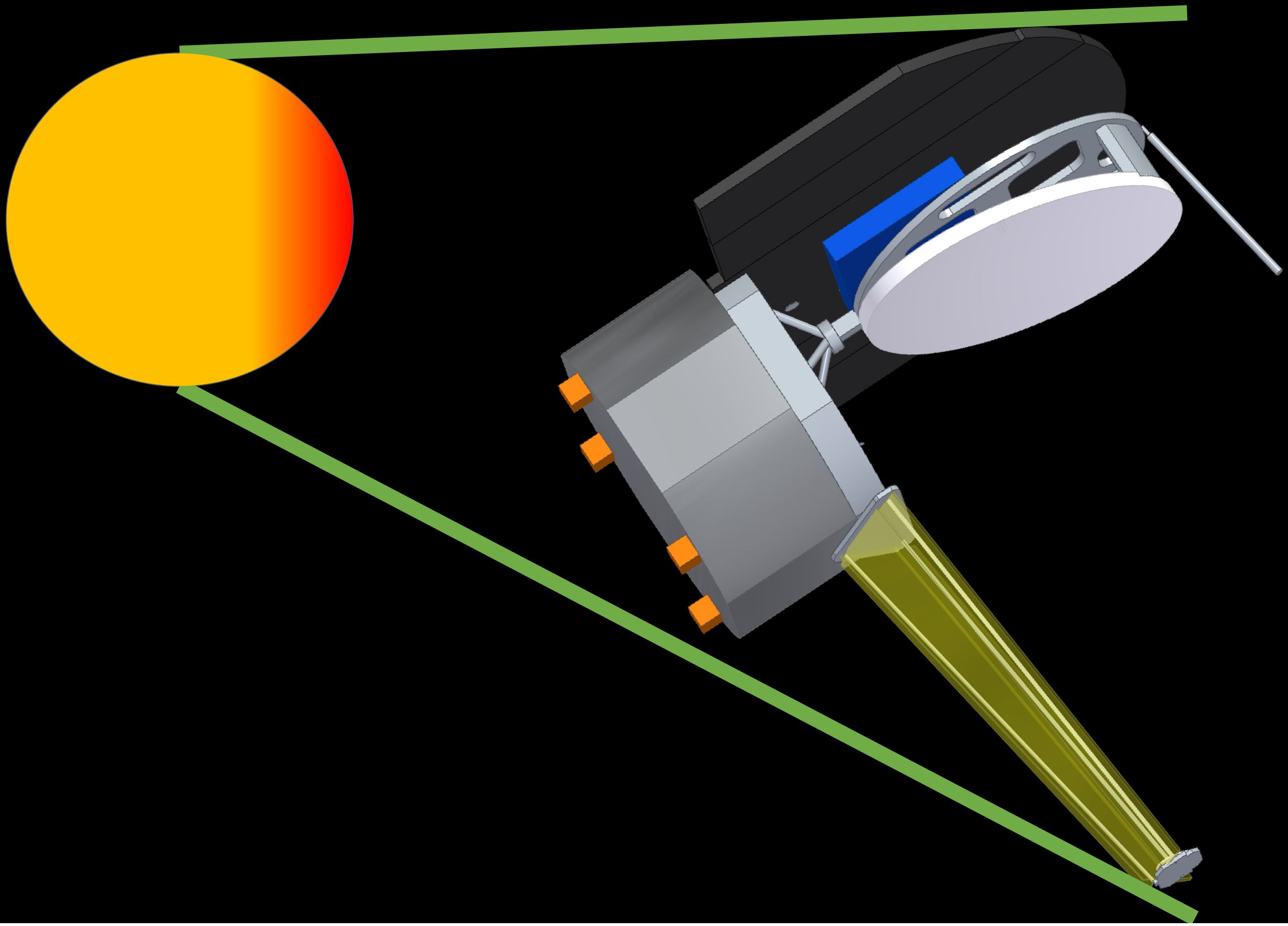
SATTELITE DESIGN



SUBSYSTEMS – STRUCTURES AND MECHANISMS

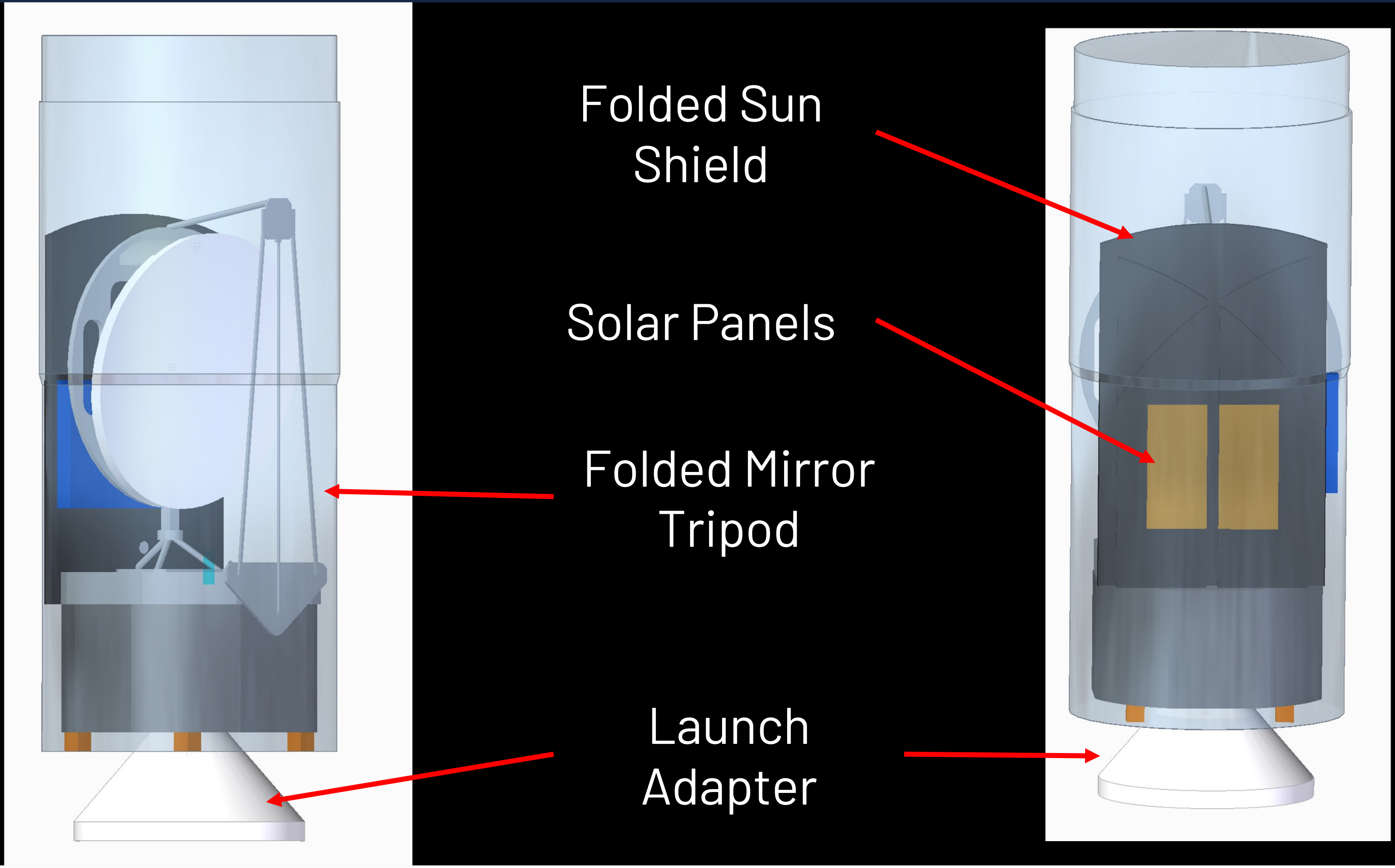


SUBSYSTEMS – STRUCTURES AND MECHANISMS



+/- 70°

SPACECRAFT IN LAUNCH CONFIGURATION



Folded Sun Shield

Solar Panels

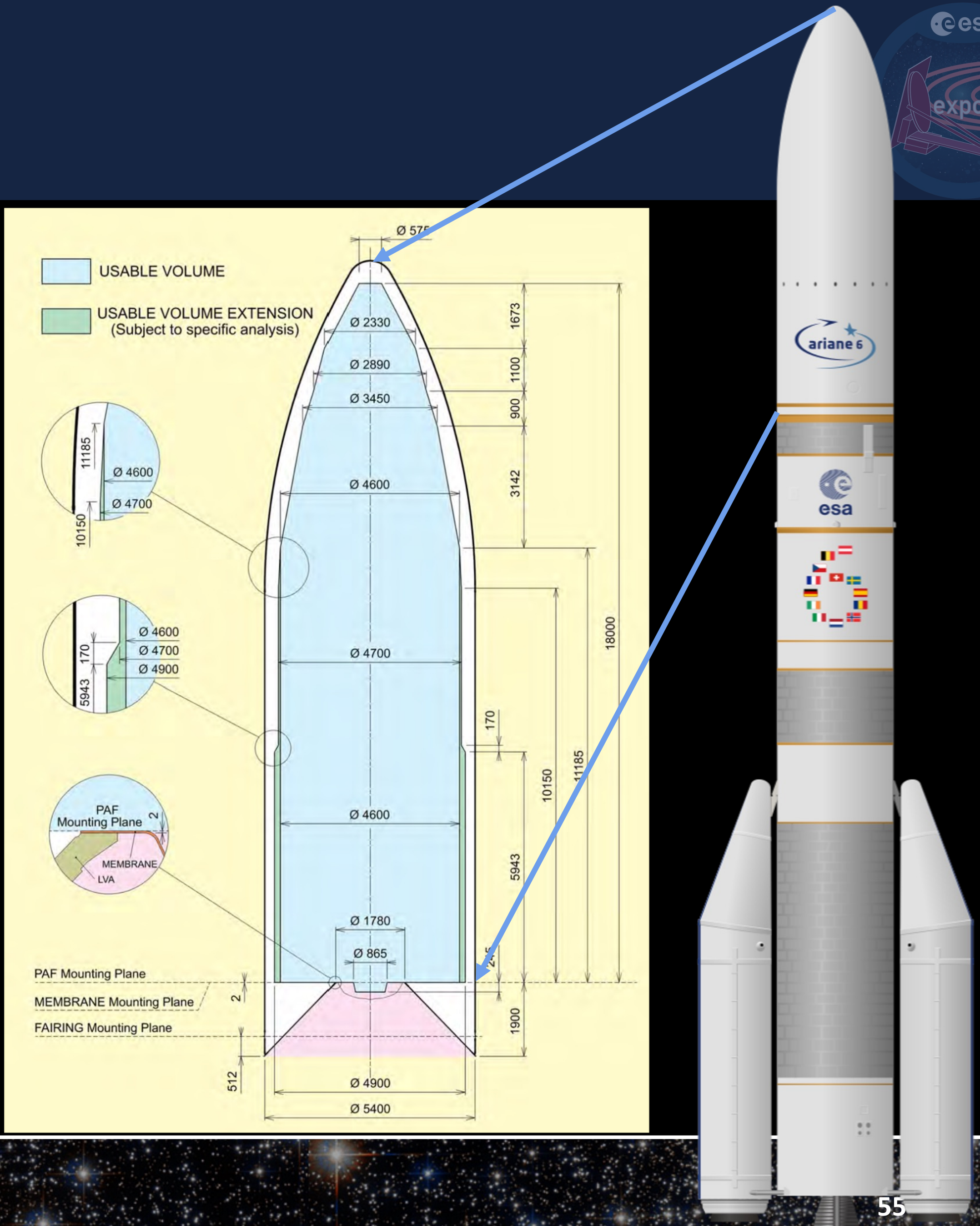
Folded Mirror Tripod

Launch Adapter

LAUNCHER – ARIANE 6.2

Fairing Diameter (internal)	4.6m
Fairing Height (internal)	18m
Max. Payload Mass	3300kg

Payload Height	11m (incl. 20% margin)
Payload Mass	3000kg (incl. 20% margin)

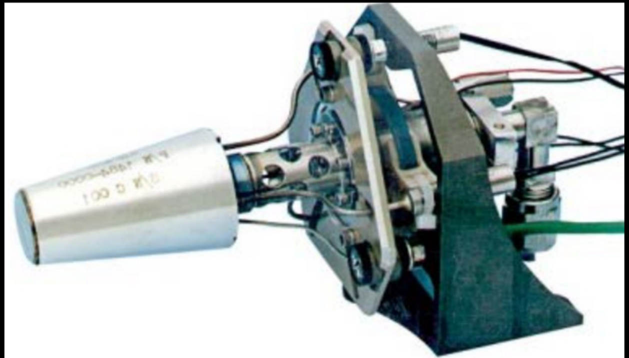


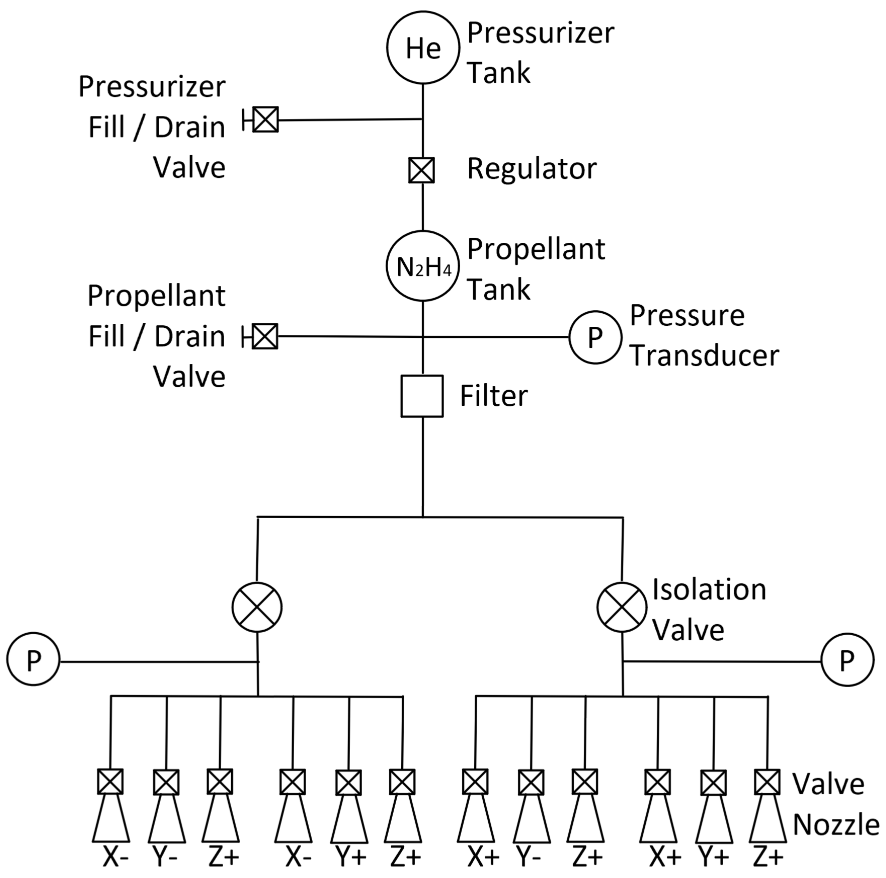
DELTA-V

Category	Description	Delta-V	Margin	Total Delta-V
Orbital Maneuver	Removal of launcher dispersion	50 m/s	5 %	90 m/s
	Mid Coarse correction	5 m/s	5 %	
	Orbit maintenance	1 m/s / year	5 %	
	Deorbit maneuver	20 m/s	5 %	
Attitude Change	Wheel desaturation	1 m/s / year	100 %	25 m/s
	Safe mode reserve	5 m/s	0 %	
Total				**115 m/s**

PROPULSION

5N Monopropellant Thruster - Rafael Space	
Propellant	N2H4
Steady Thrust	6.1 - 1.8 N
Total Lifetime	15 years
TRL	9





Maneuver Duration	
Removal of launcher dispersion (50 m/s)	~ 3 min
Wheel desaturation	< 10 s

COMMUNICATIONS REQUIREMENTS

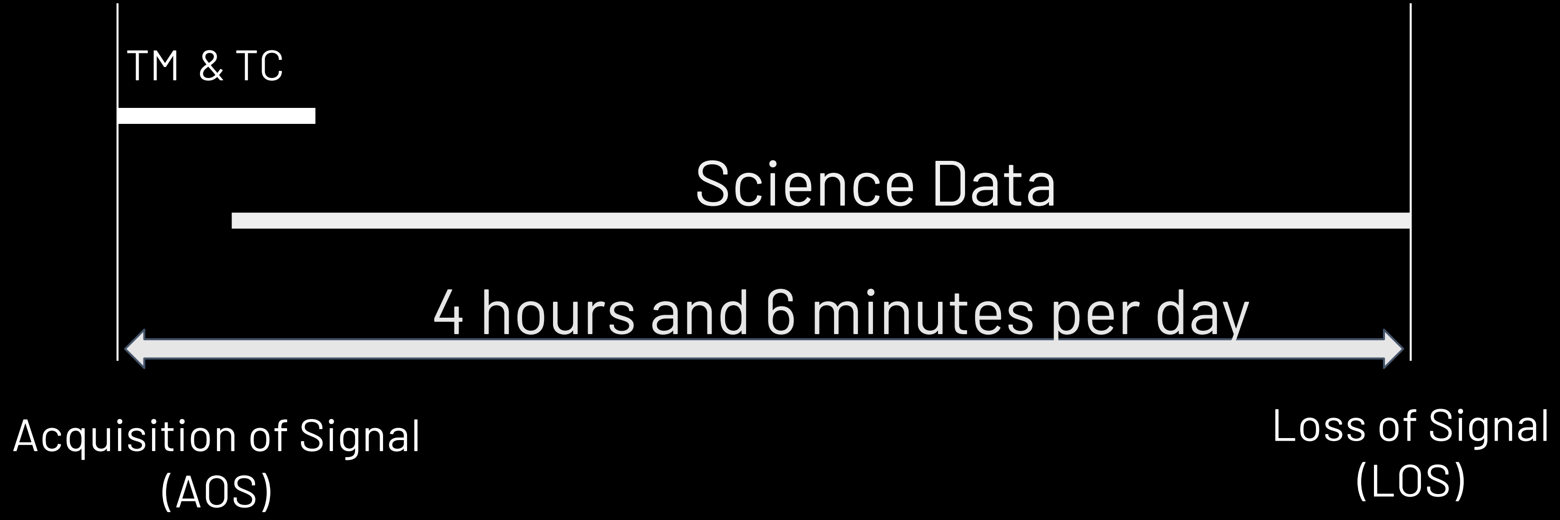
- **COM-01:** The operating frequency used for telecommand and house-keeping telemetry shall be 32GHz downlink, 34.6GHz uplink (Ka-band).
- **COM-02:** The data transmission frequency used for payload and experiment data telemetry transmission shall be 32.8GHz downlink, 34.3 GHz uplink (Ka-band).

Communications System

COMMUNICATION

- 2 KA-BAND ANTENNAS
- POINTING GIMBALS
- 2 S-BAND ANTENNAS

COMMUNICATIONS



Data Rate: 130Mbps (Ka-band)

Data Amount: 240 Gbytes/day

Transmission Power: 10 Watts

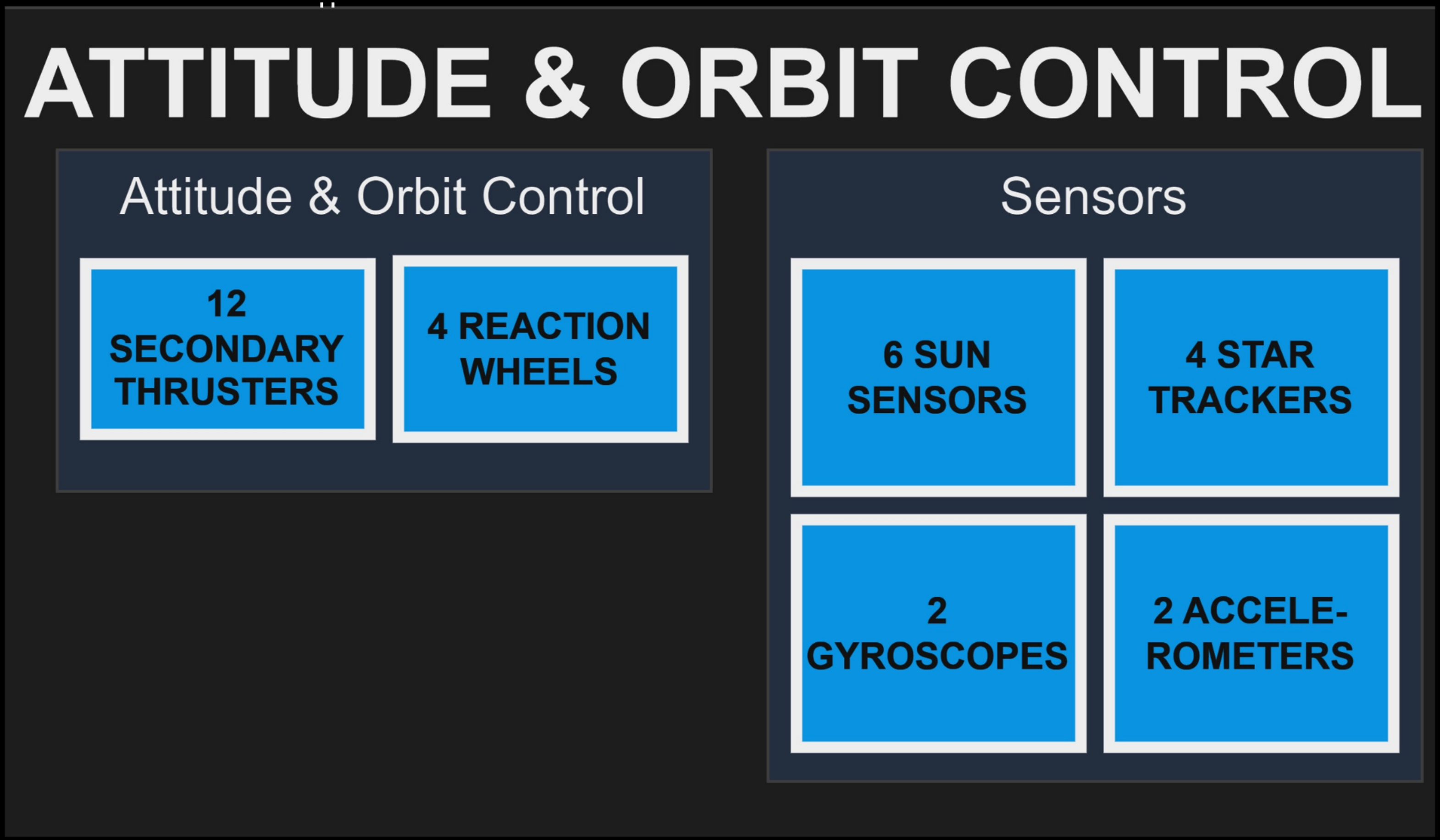
Stations: Cebreros & Malargüe (35-meter antenna)

- **2 Ka-band** high-gain antennas (equipped with **pointing gimbals**, and with a **0.26-meter diameter**) and **2 S-band** medium-gain antennas in the telescope.

- **Telemetry and Telecommands: frequency**: Ka-band, 32.0 GHz downlink, 34.6 GHz uplink
- **Science Data: frequency**: Ka-band, 31.8 GHz downlink, 34.3 GHz uplink

- **Emergency Situations:** New Norcia antenna, using S-band, with frequencies of 2200MHz downlink, and 2050MHz uplink. Antenna size of 0.2m.

Attitude and Orbit Control System



ATTITUDE & ORBIT CONTROL

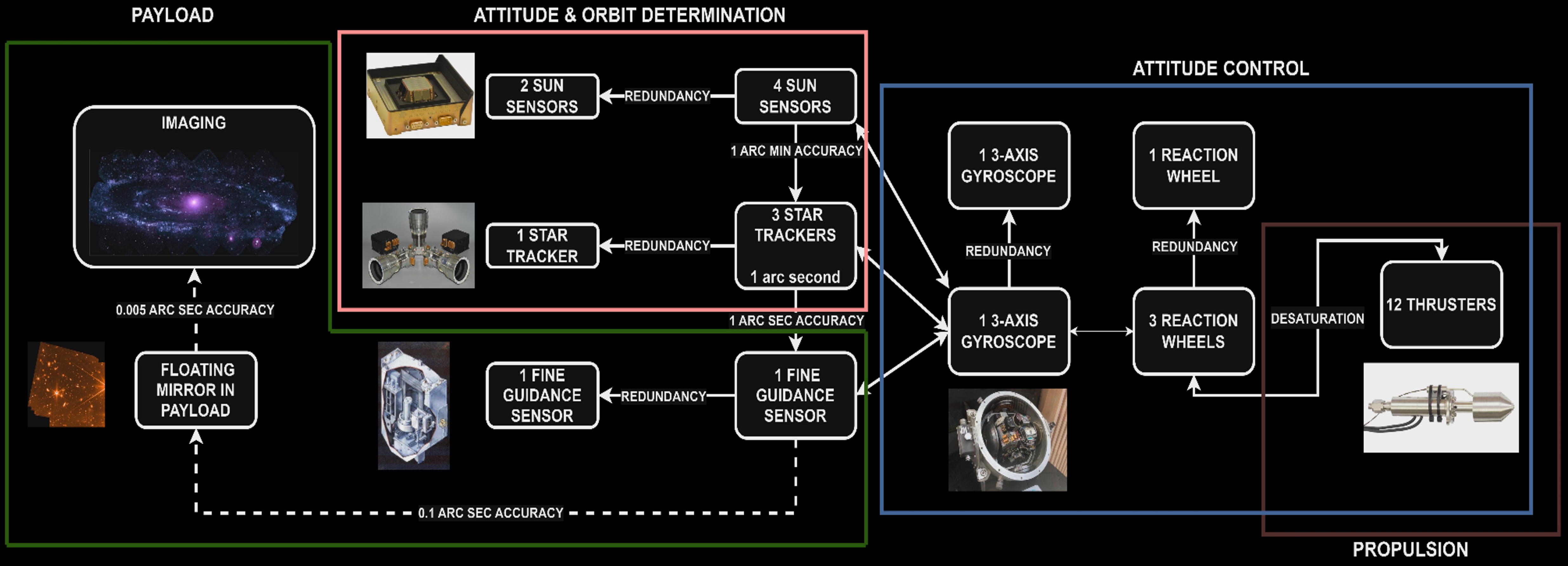
Attitude & Orbit Control

- 12 SECONDARY THRUSTERS
- 4 REACTION WHEELS

Sensors

- 6 SUN SENSORS
- 4 STAR TRACKERS
- 2 GYROSCOPES
- 2 ACCELEROMETERS

ATTITUDE & ORBIT CONTROL SYSTEM



PAYLOAD

IMAGING

0.005 ARC SEC ACCURACY

FLOATING MIRROR IN PAYLOAD

ATTITUDE & ORBIT DETERMINATION

2 SUN SENSORS ← REDUNDANCY ← 4 SUN SENSORS

1 ARC MIN ACCURACY

1 STAR TRACKER ← REDUNDANCY ← 3 STAR TRACKERS

1 arc second

1 ARC SEC ACCURACY

1 FINE GUIDANCE SENSOR ← REDUNDANCY ← 1 FINE GUIDANCE SENSOR

0.1 ARC SEC ACCURACY

ATTITUDE CONTROL

1 3-AXIS GYROSCOPE

REDUNDANCY

1 3-AXIS GYROSCOPE

1 REACTION WHEEL

REDUNDANCY

3 REACTION WHEELS

DESATURATION

12 THRUSTERS

PROPULSION

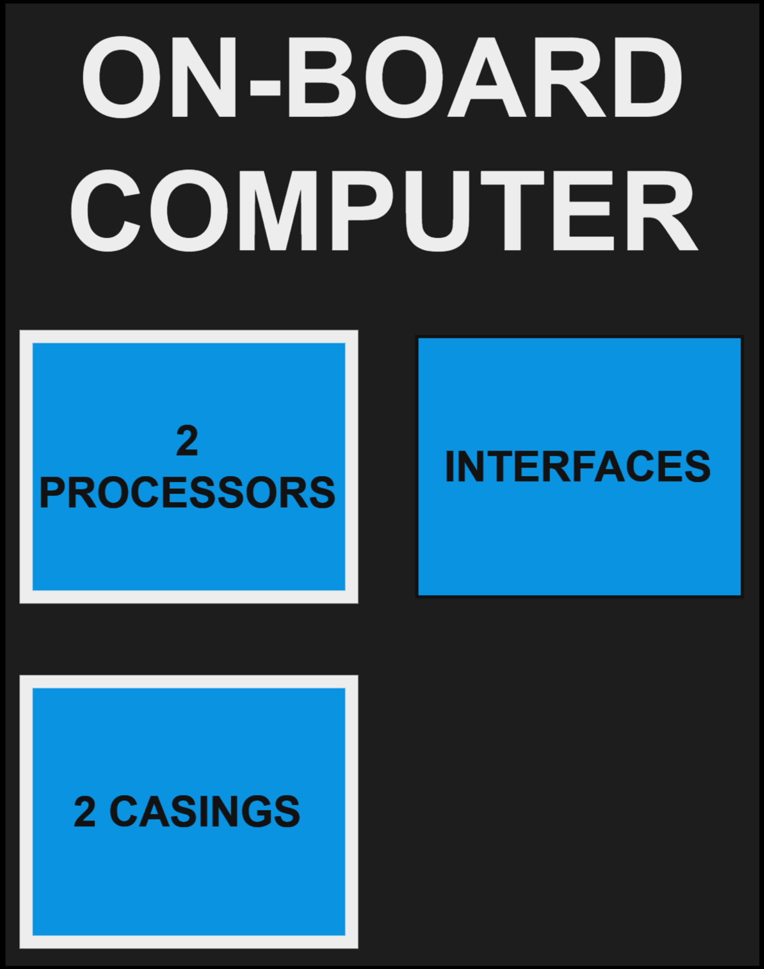
GROUND STATIONS: ESTRACK Deep Space Network

- All 3 antennas with a 35-meter diameter
- Deep-space probe tracking

ON BOARD COMPUTER REQUIREMENTS

- **OBC-01:** OBC-01: The OBC shall be able to store 240Gbyte/day amount of data.

On-board Computer



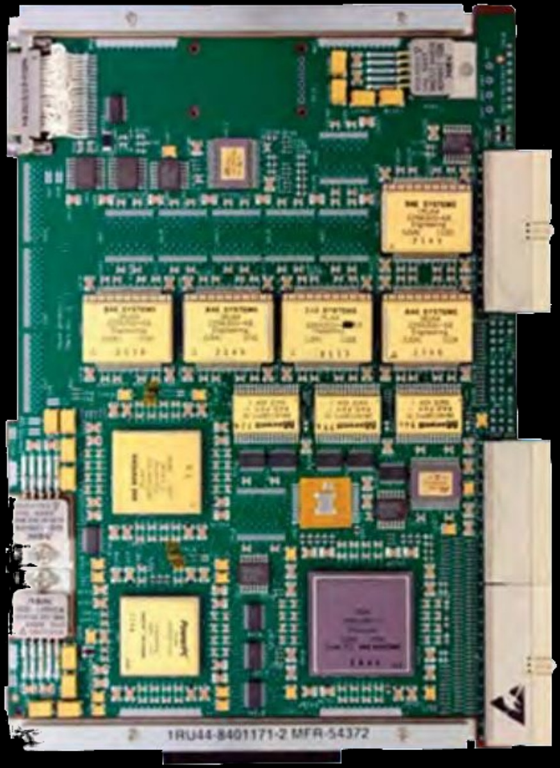
ON-BOARD COMPUTER

2 PROCESSORS

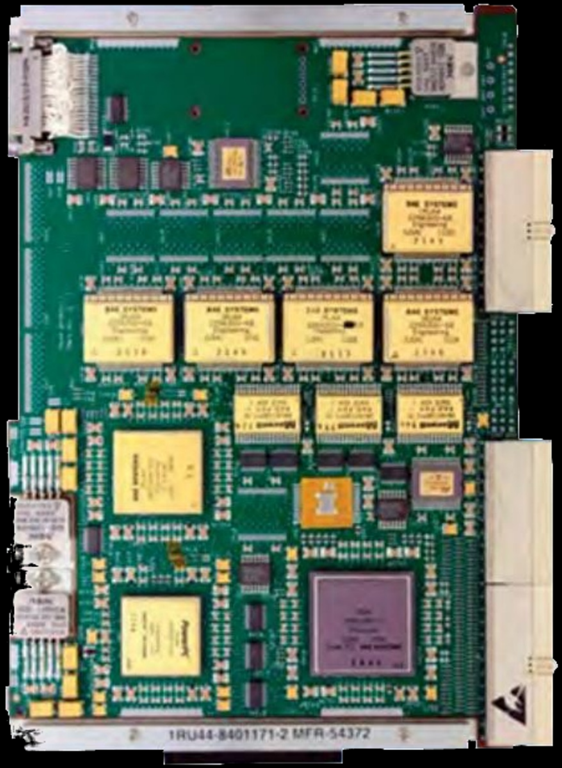
INTERFACES

2 CASINGS

ON BOARD COMPUTER (OBC)



MASS MEMORY: 1 TB



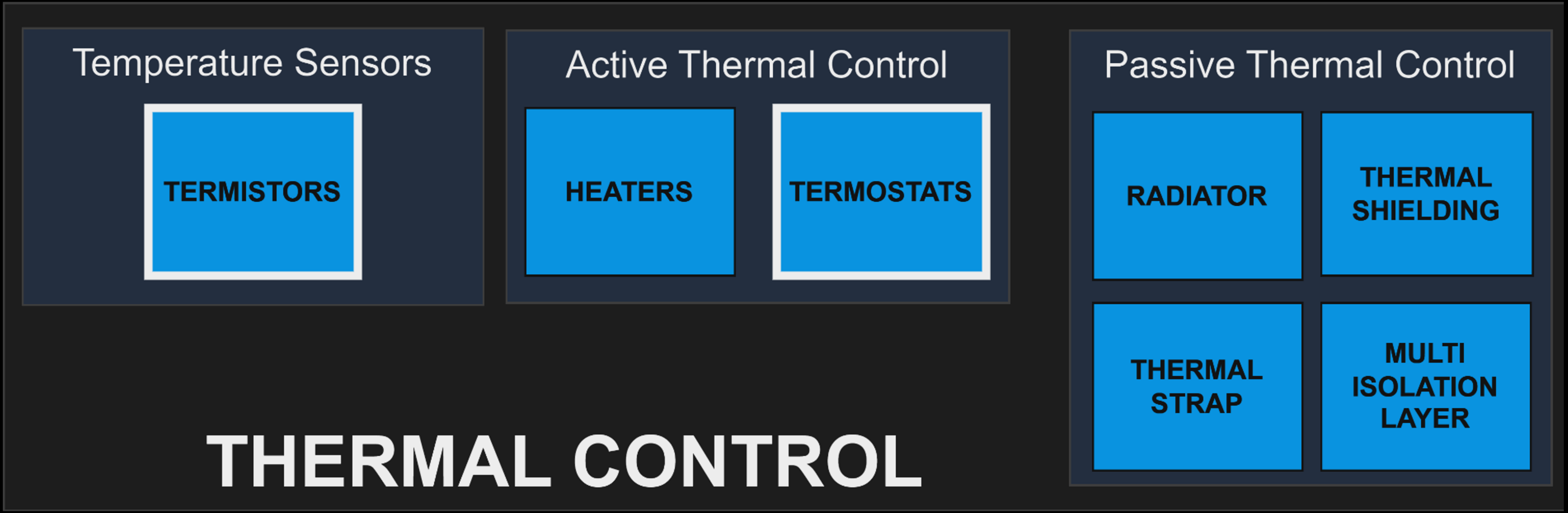
REDUNDANCY

NAME	**RAD750 SBC**
SUPPLIER	**BAE SYSTEMS**
POWER CONSUMPTION	**10W**
PRODUCED	**2001**
FREQUENCY	**200 MHz**
TRL	**9**
FLIGHT HERITAGE	**JWST**

THERMAL CONTROL SYSTEM REQUIREMENTS

- **TCS-01:** The TCS shall monitor and keep the temperature of each component within the required operational limits.

Thermal Control System



Temperature Sensors

TERMISTORS

Active Thermal Control

HEATERS

TERMOSTATS

Passive Thermal Control

RADIATOR

THERMAL SHIELDING

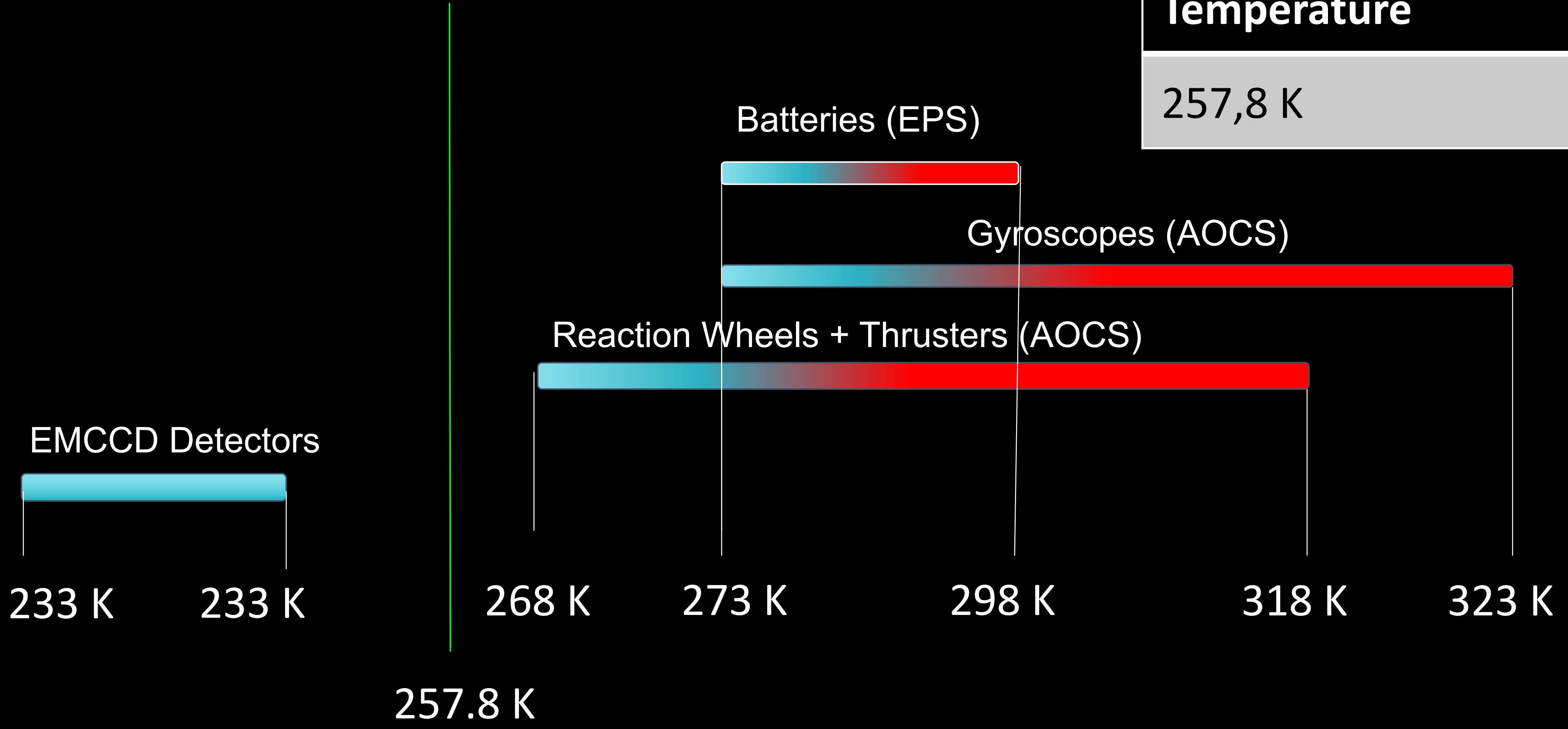
THERMAL STRAP

MULTI ISOLATION LAYER

THERMAL CONTROL

THERMAL CONTROL SYSTEM

Satellite Equilibrium Temperature
257,8 K



THERMAL CONTROL SYSTEM

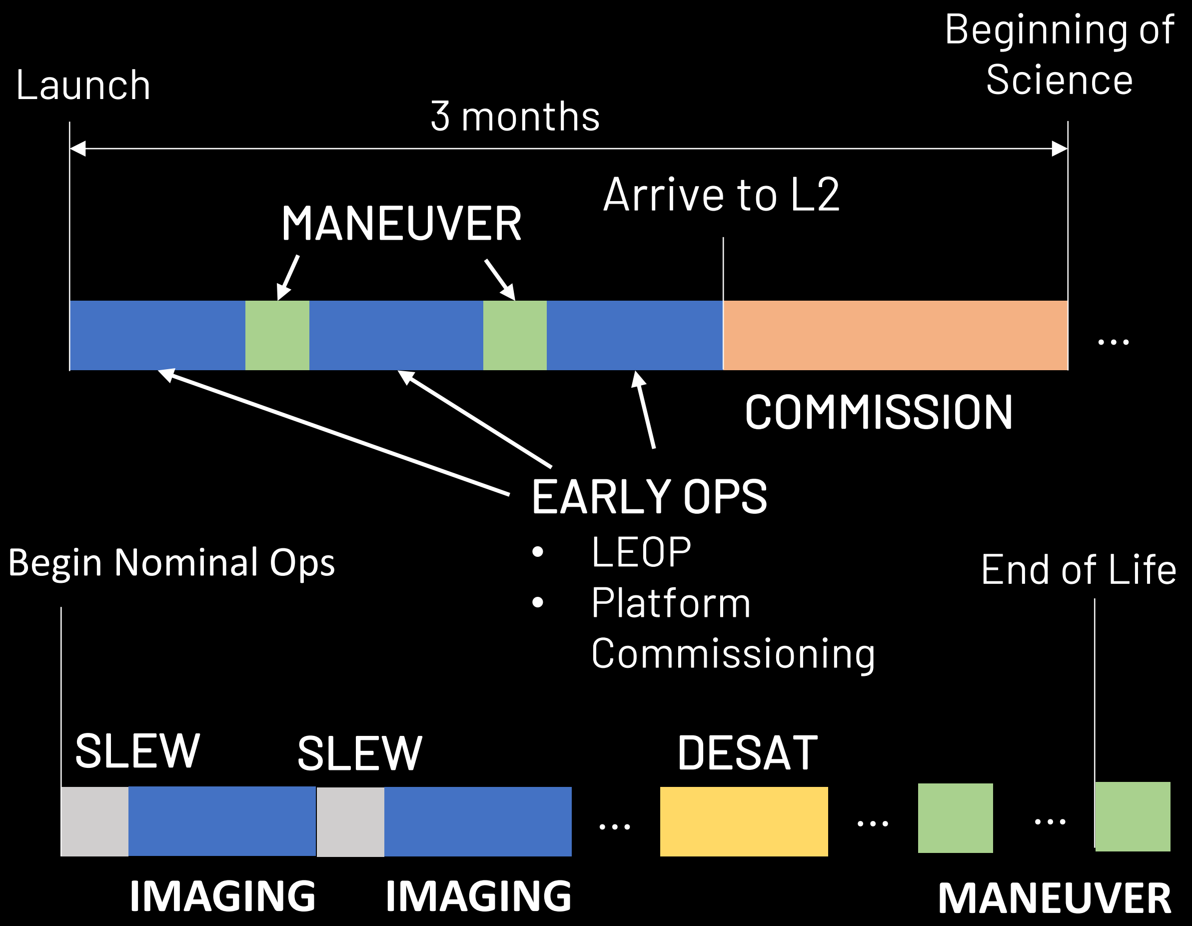
PASSIVE HEATING
Thermal/sun Shield
MLI layer
Radiator on the shadow side of S/C
Thermal strap linked to radiators

ACTIVE HEATING
Heaters with thermostat

Max Power Dissipation	500 W
Radiator Area	1,23 m^2

	Thermal Stability (ΔT)
EMCCD Detectors	5 K

SYSTEM MODES



Launch

3 months

Beginning of Science

MANEUVER

Arrive to L2

…

COMMISSION

EARLY OPS
- LEOP
- Platform Commissioning

Begin Nominal Ops

End of Life

SLEW

SLEW

DESAT

IMAGING

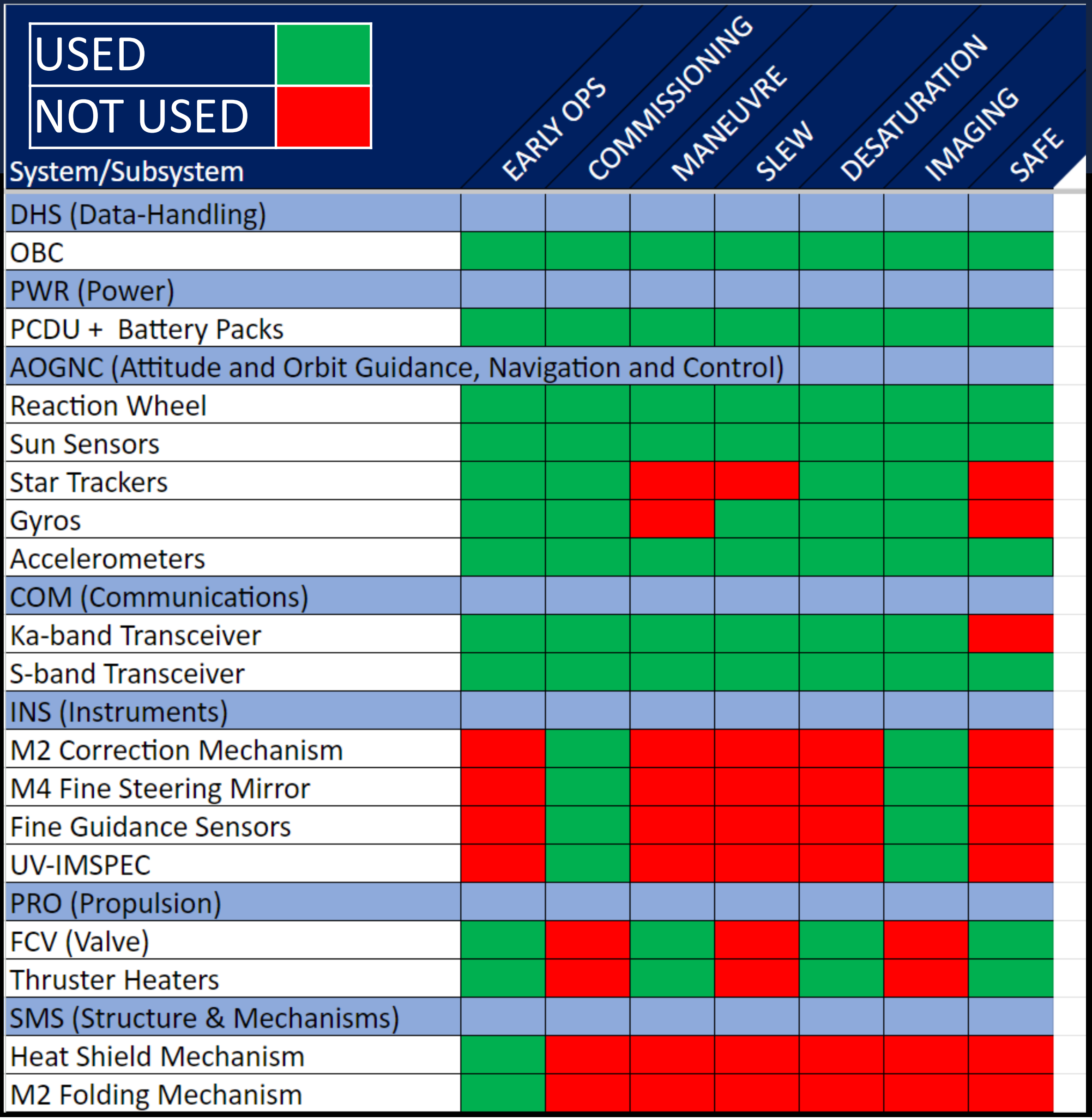
IMAGING

…

…

…

MANEUVER



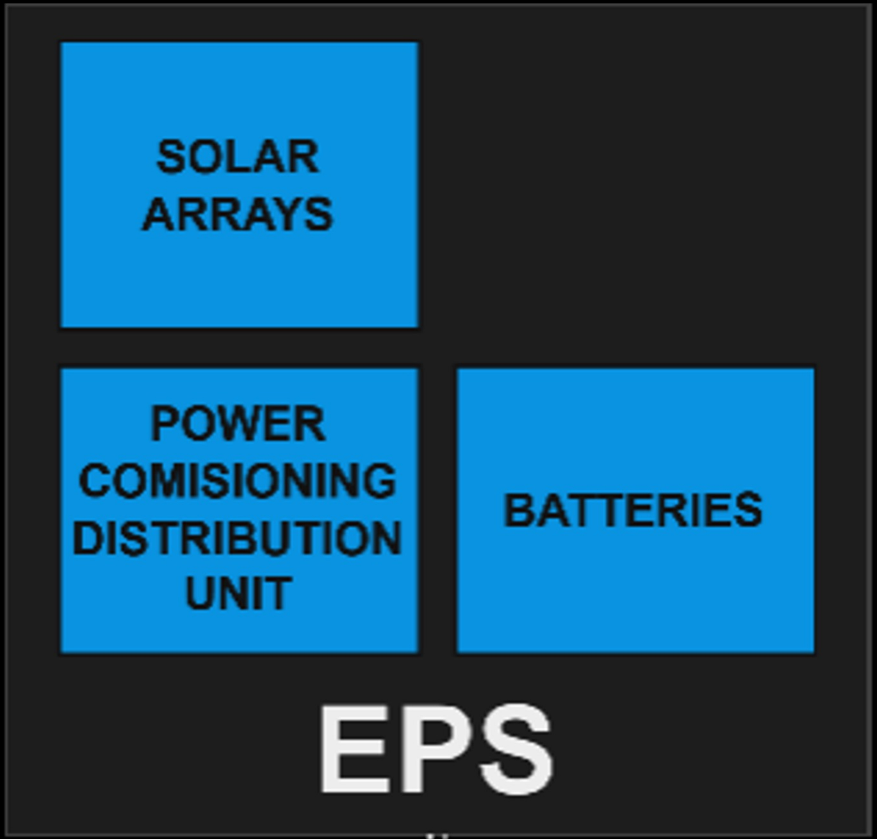
USED	🟩
NOT USED	🟥

System/Subsystem	EARLY OPS	COMMISSIONING	MANEUVRE	SLEW	DESATURATION	IMAGING	SAFE
DHS (Data-Handling)							
OBC	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PWR (Power)							
PCDU + Battery Packs	🟩	🟩	🟩	🟩	🟩	🟩	🟩
AOGNC (Attitude and Orbit Guidance, Navigation and Control)							
Reaction Wheel	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Sun Sensors	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Star Trackers	🟩	🟩	🟥	🟥	🟩	🟩	🟥
Gyros	🟩	🟩	🟥	🟩	🟩	🟩	🟥
Accelerometers	🟩	🟩	🟩	🟩	🟩	🟩	🟩
COM (Communications)							
Ka-band Transceiver	🟩	🟩	🟩	🟩	🟩	🟩	🟥
S-band Transceiver	🟩	🟩	🟩	🟩	🟩	🟩	🟩
INS (Instruments)							
M2 Correction Mechanism	🟥	🟩	🟥	🟥	🟥	🟩	🟥
M4 Fine Steering Mirror	🟥	🟩	🟥	🟥	🟥	🟩	🟥
Fine Guidance Sensors	🟥	🟩	🟥	🟥	🟥	🟩	🟥
UV-IMSPEC	🟥	🟩	🟥	🟥	🟥	🟩	🟥
PRO (Propulsion)							
FCV (Valve)	🟩	🟥	🟩	🟥	🟩	🟥	🟩
Thruster Heaters	🟩	🟥	🟩	🟥	🟩	🟥	🟩
SMS (Structure & Mechanisms)							
Heat Shield Mechanism	🟩	🟥	🟥	🟥	🟥	🟥	🟥
M2 Folding Mechanism	🟩	🟥	🟥	🟥	🟥	🟥	🟥

ELECTRICAL POWER SYSTEM REQUIREMENTS

- **EPS-02:** The EPS shall provide 100 W of electrical power to the payload.
- **EPS-03:** The EPS shall have power capacity to provide the spacecraft for 8 hours without power generation

Electrical Power System



SOLAR ARRAYS

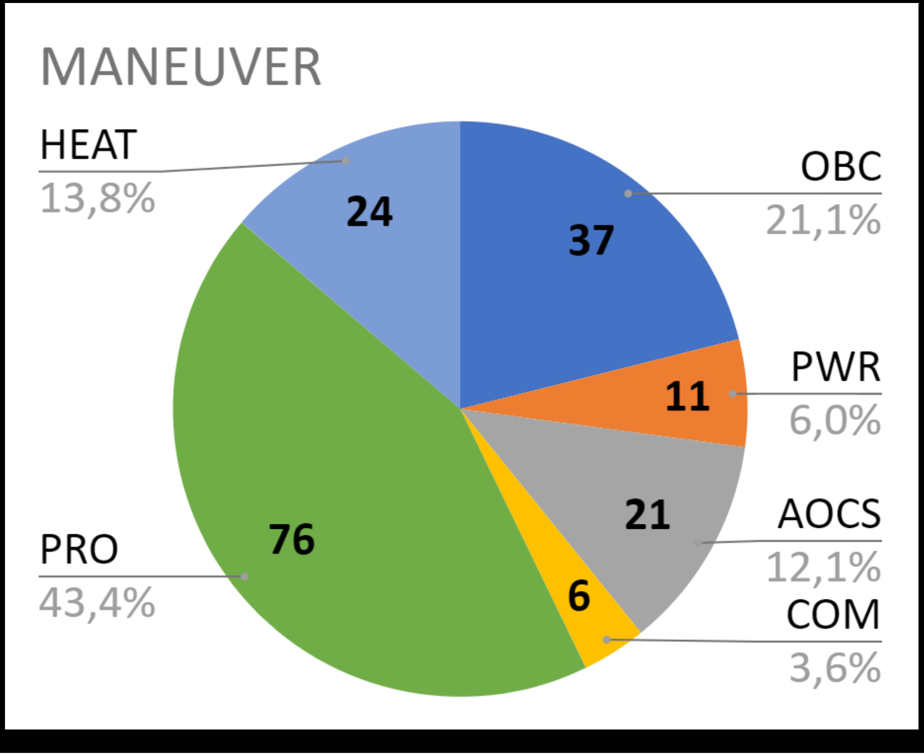
POWER COMISIONING DISTRIBUTION UNIT

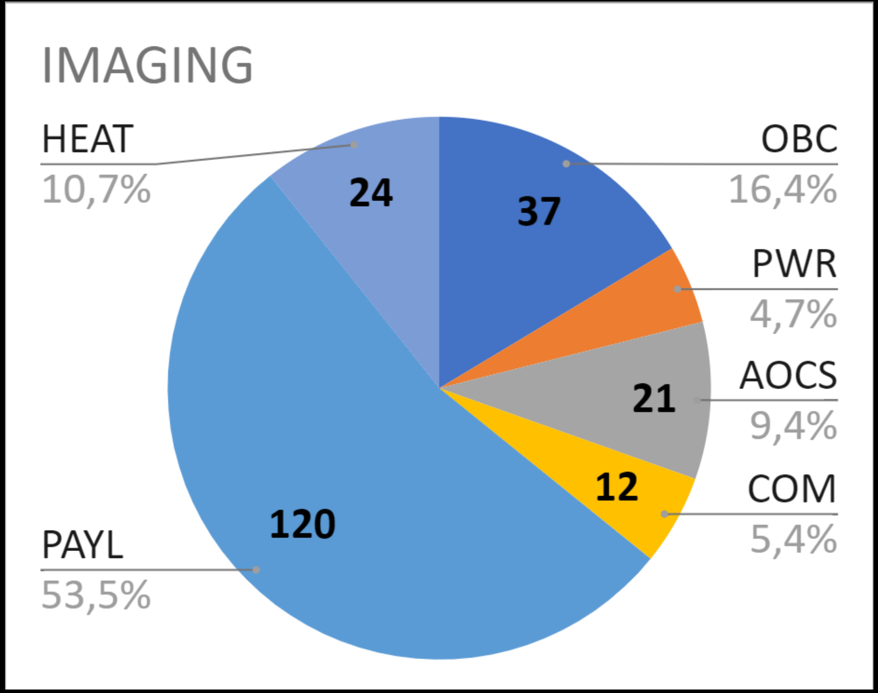
BATTERIES

EPS

POWER BUDGET

MODE	POWER REQ. [W]
EARLY OPS	203
COMMISSIONING	133
MANEUVRE	209
IMAGING	269
SLEW	131
DESATURATION	349
IDLE	118
SAFE	344

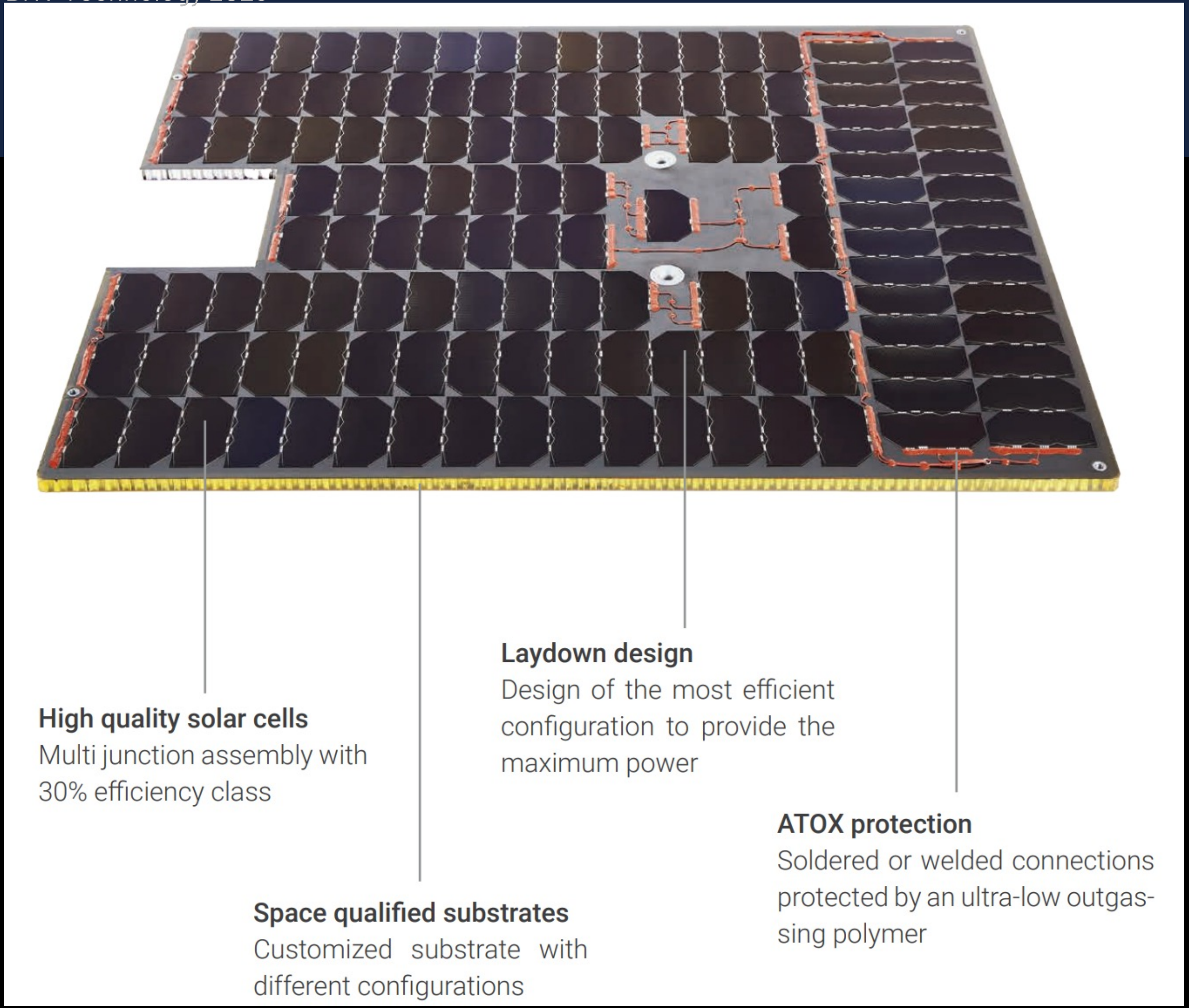




SOLAR ARRAYS

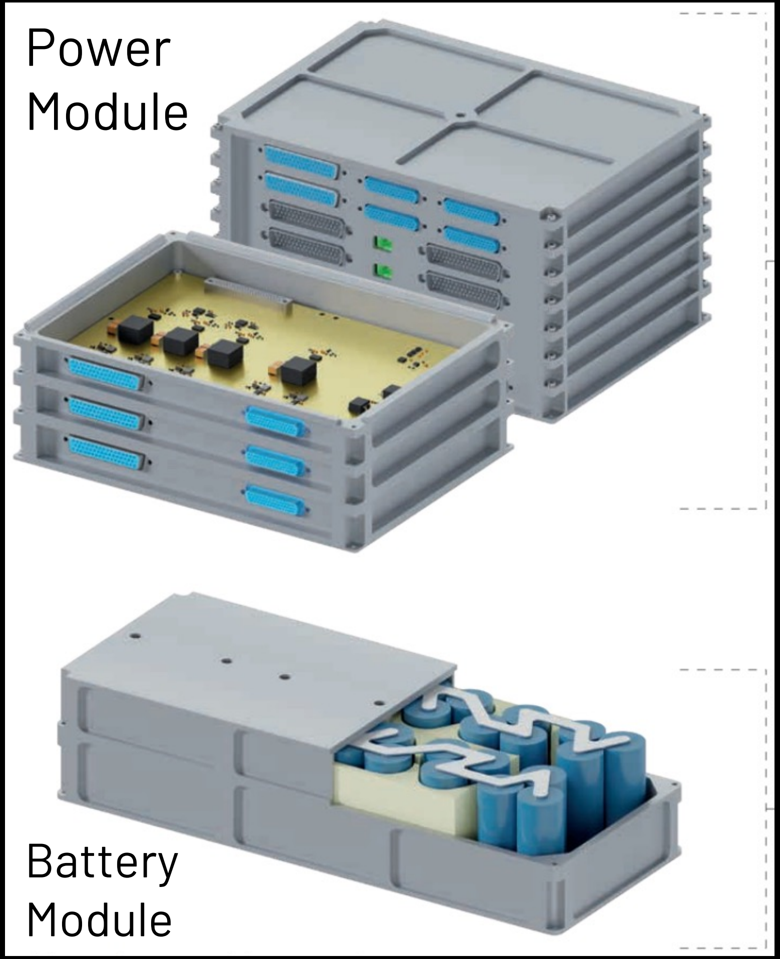
Company	DHV
Technology	Multi junction
TRL	9
Efficiency	30 %
Power / Area	300 W / m2
Annual Degradation	2 %
Pointing Error	70 °
Size	20 x 505 x 644 mm
Max. Power Output (BoL)	1950 W
Min. Power Output (EoL)	545 W

DHV Technology 2023



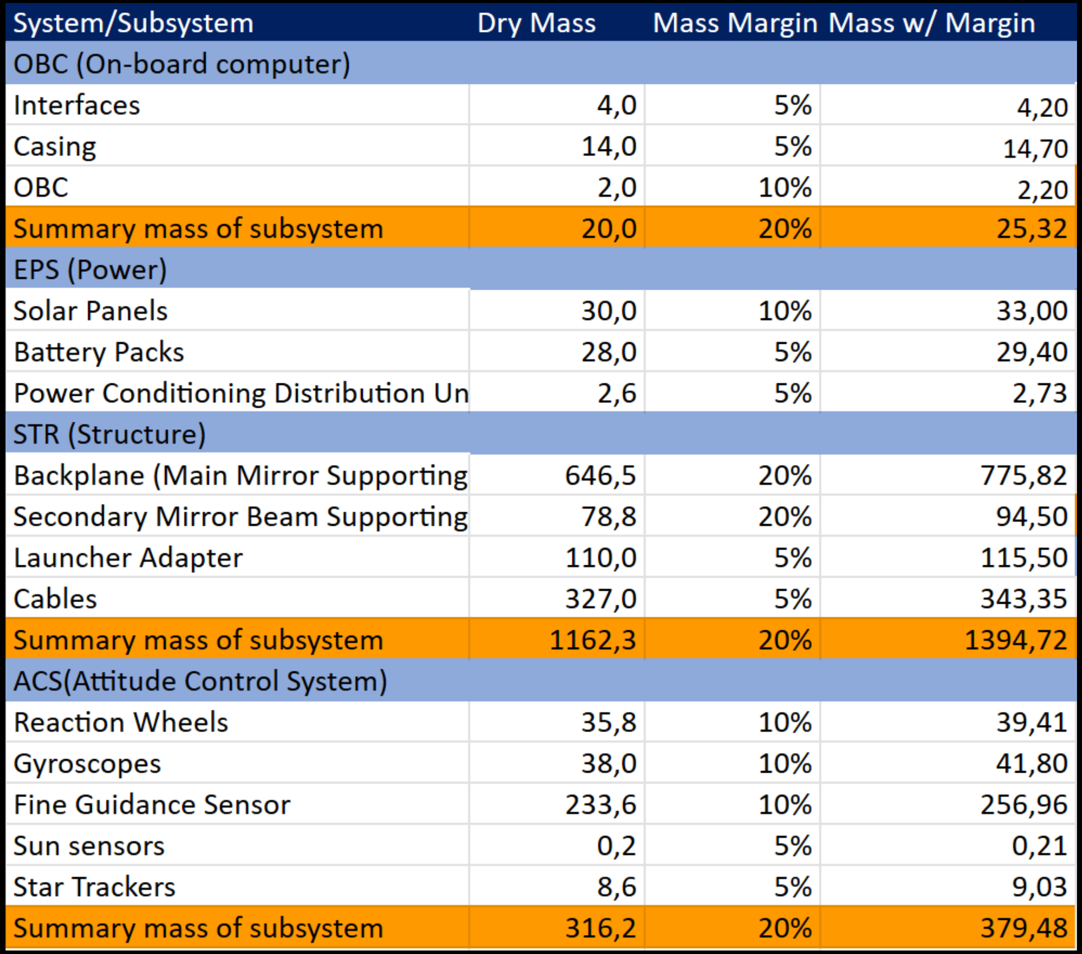
POWER CONDITIONING DISTRIBUTION UNIT

Company	**DHV**
Battery Charge Regulators Efficiency	> 95 %
Power output efficiency	> 90 %
Output Buses	3.3 V, 5 V, 12 V, 28.8 V (unregulated)
Battery Type	LiFePO4
Capacity	1600 Wh
Features	• Maximum Power Point Tracker (MPPT) • Over-Voltage/-Current Protection • Health Checks, Temperature Control
TRL	9

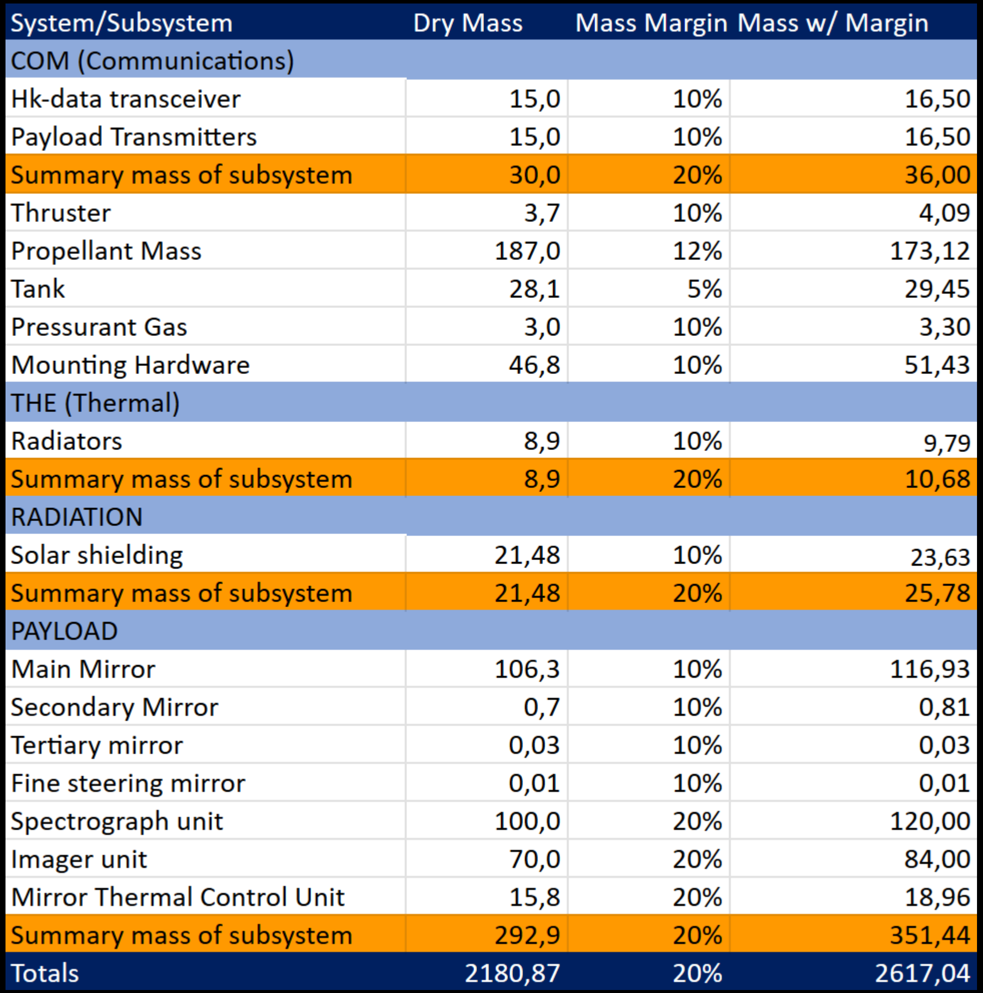


DHV Technology 2023

MASS BUDGET - OVERVIEW



System/Subsystem	Dry Mass	Mass Margin	Mass w/ Margin
OBC (On-board computer)			
Interfaces	4,0	5%	4,20
Casing	14,0	5%	14,70
OBC	2,0	10%	2,20
Summary mass of subsystem	20,0	20%	25,32
EPS (Power)			
Solar Panels	30,0	10%	33,00
Battery Packs	28,0	5%	29,40
Power Conditioning Distribution Un	2,6	5%	2,73
STR (Structure)			
Backplane (Main Mirror Supporting	646,5	20%	775,82
Secondary Mirror Beam Supporting	78,8	20%	94,50
Launcher Adapter	110,0	5%	115,50
Cables	327,0	5%	343,35
Summary mass of subsystem	1162,3	20%	1394,72
ACS(Attitude Control System)			
Reaction Wheels	35,8	10%	39,41
Gyroscopes	38,0	10%	41,80
Fine Guidance Sensor	233,6	10%	256,96
Sun sensors	0,2	5%	0,21
Star Trackers	8,6	5%	9,03
Summary mass of subsystem	316,2	20%	379,48



System/Subsystem	Dry Mass	Mass Margin	Mass w/ Margin
COM (Communications)			
Hk-data transceiver	15,0	10%	16,50
Payload Transmitters	15,0	10%	16,50
Summary mass of subsystem	30,0	20%	36,00
Thruster	3,7	10%	4,09
Propellant Mass	187,0	12%	173,12
Tank	28,1	5%	29,45
Pressurant Gas	3,0	10%	3,30
Mounting Hardware	46,8	10%	51,43
THE (Thermal)			
Radiators	8,9	10%	9,79
Summary mass of subsystem	8,9	20%	10,68
RADIATION			
Solar shielding	21,48	10%	23,63
Summary mass of subsystem	21,48	20%	25,78
PAYLOAD			
Main Mirror	106,3	10%	116,93
Secondary Mirror	0,7	10%	0,81
Tertiary mirror	0,03	10%	0,03
Fine steering mirror	0,01	10%	0,01
Spectrograph unit	100,0	20%	120,00
Imager unit	70,0	20%	84,00
Mirror Thermal Control Unit	15,8	20%	18,96
Summary mass of subsystem	292,9	20%	351,44
Totals	2180,87	20%	2617,04

MASS BUDGET – KEY DRIVERS

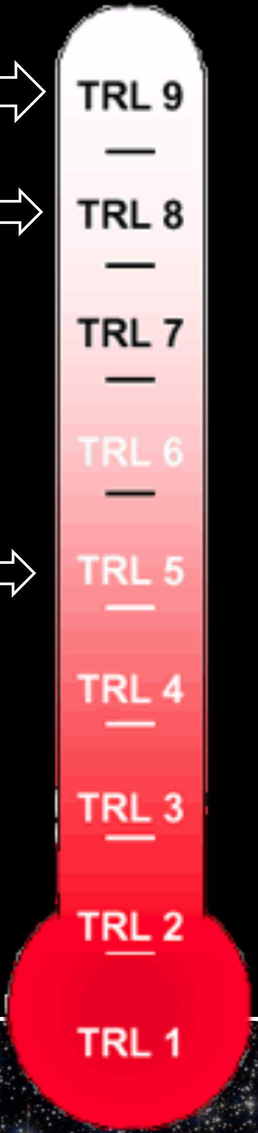
ELEMENT	MATERIAL	MASS [KG]
BACKPLANE	M55J GRAPHITE EPOXY	776
SECONDARY MIRROR SUPPORT	LIGHTWEIGHT CFRP	95
MIRRORS	BERYLLIUM SUBSTRATE, ALUMINIUM + LF2, COATING	118
PROPELLANT	HYDRAZINE	173

TECHNOLOGY ROADMAP

Comms, OCS, ADCS, OBC, TCS, EPS → TRL 9

EMCCD (with mitigation) → TRL 8

Electron Multiplying Charge-Couple Device (EMCCD) → TRL 5



(Robert Jacobsen, NASA)

CONCLUSIONS

Scientific goals

Payload

Service module

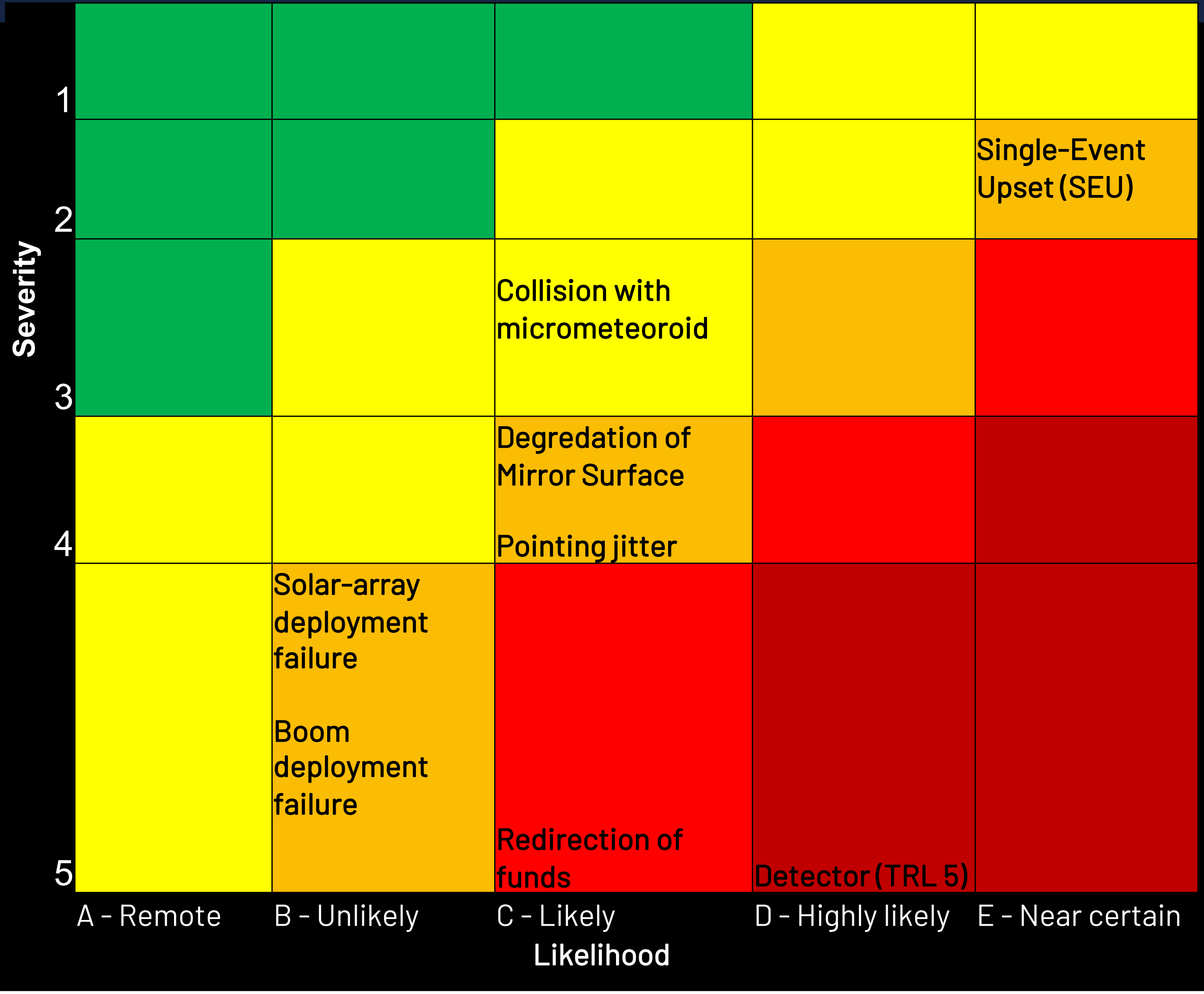
Conclusions

COST CATEGORY

Subcategory	Category	Cost [M€]
Platform	Industrial cost	450
Telescope & payload instruments	Industrial cost	450
	ESA project cost	170
	Operations	80
	Total	1150
	Total (20 % margin)	1380
	launch	100
Delivery to L2	Payload provided b y ESA Member States	-10
	Summary	1420

CRITICAL RISKS– BEFORE MITIGATION

Risk Index
Very High
High
Medium
Low
Very Low



Severity	A - Remote	B - Unlikely	C - Likely	D - Highly likely	E - Near certain
1					
2					Single-Event Upset (SEU)
3			Collision with micrometeoroid		
4			Degredation of Mirror Surface Pointing jitter		
5		Solar-array deployment failure Boom deployment failure	Redirection of funds	Detector (TRL 5)	

Likelihood

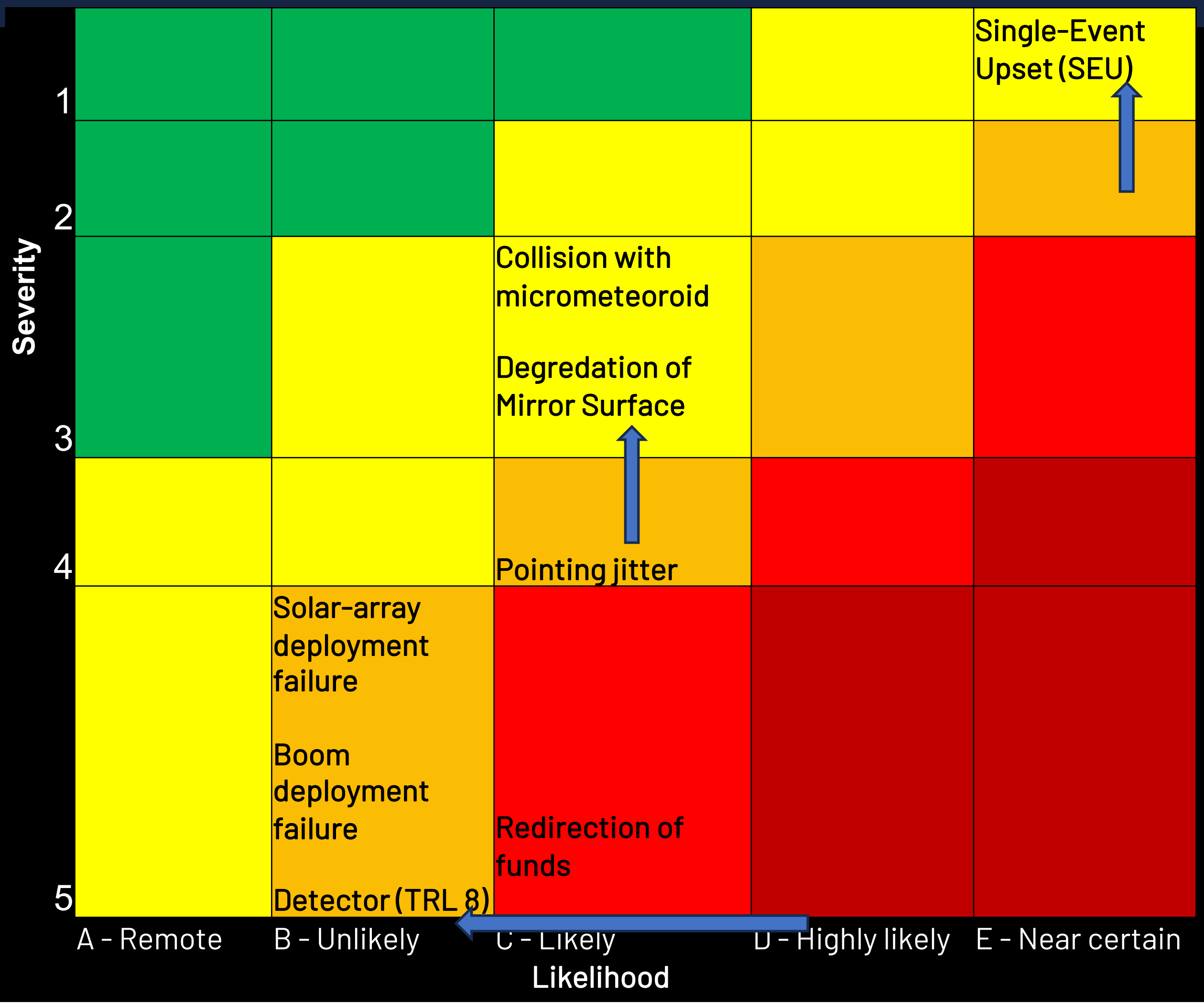
Mitigation:

- Include Detector on pathfinder mission, i.e., a CubeSat, before EXPOSURE to flight qualify (TRL 8)
- Redundancy and FDIR for OBC
- Increase exposure time if mirror surface degrades

CRITICAL RISKS – AFTER MITIGATION

Risk Index

- Very High
- High
- Medium
- Low
- Very Low

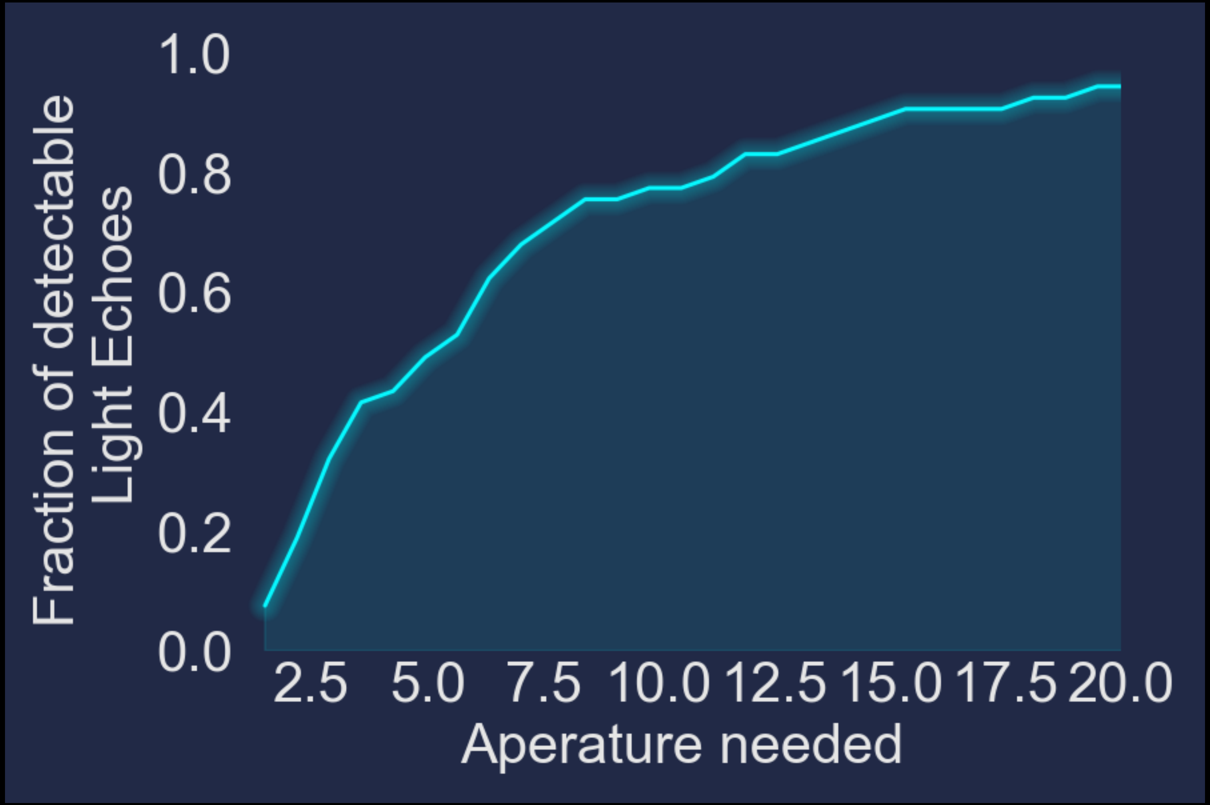


Mitigation:

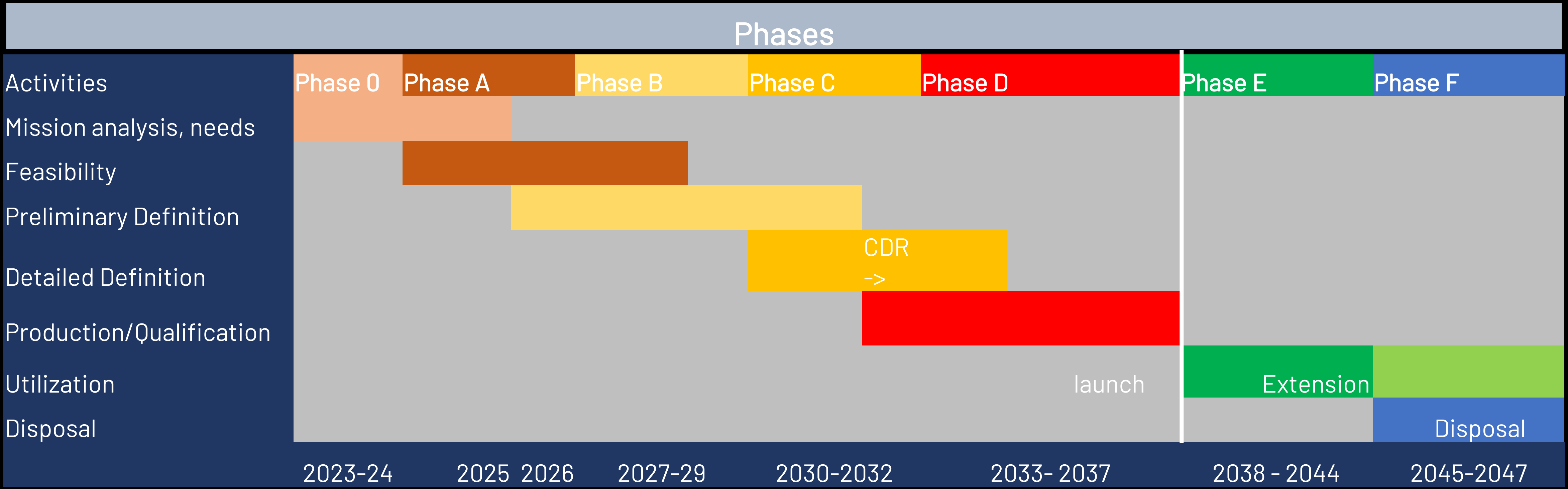
- Include Detector on pathfinder mission, i.e., a CubeSat, before EXPOSURE to flight qualify (TRL 8)
- Redundancy and FDIR for OBC
- Increase exposure time if mirror surface degrades

DE-SCOPING POSSIBILITIES

- **Shrink telescope diameter** -> lose light echo detection and possibly exospheres of habitable planets
- **Take out imager** -> lose UV-flux and light echo detection
- **Take out spectrograph** -> lose detection of escaping and extended atmospheres



DEVELOPMENT SCHEDULE



Phases

Activities: Phase 0, Phase A, Phase B, Phase C, Phase D, Phase E, Phase F

Mission analysis, needs

Feasibility

Preliminary Definition

Detailed Definition

CDR

->

Production/Qualification

Utilization

launch

Extension

Disposal

Disposal

2023-24

2025 2026

2027-29

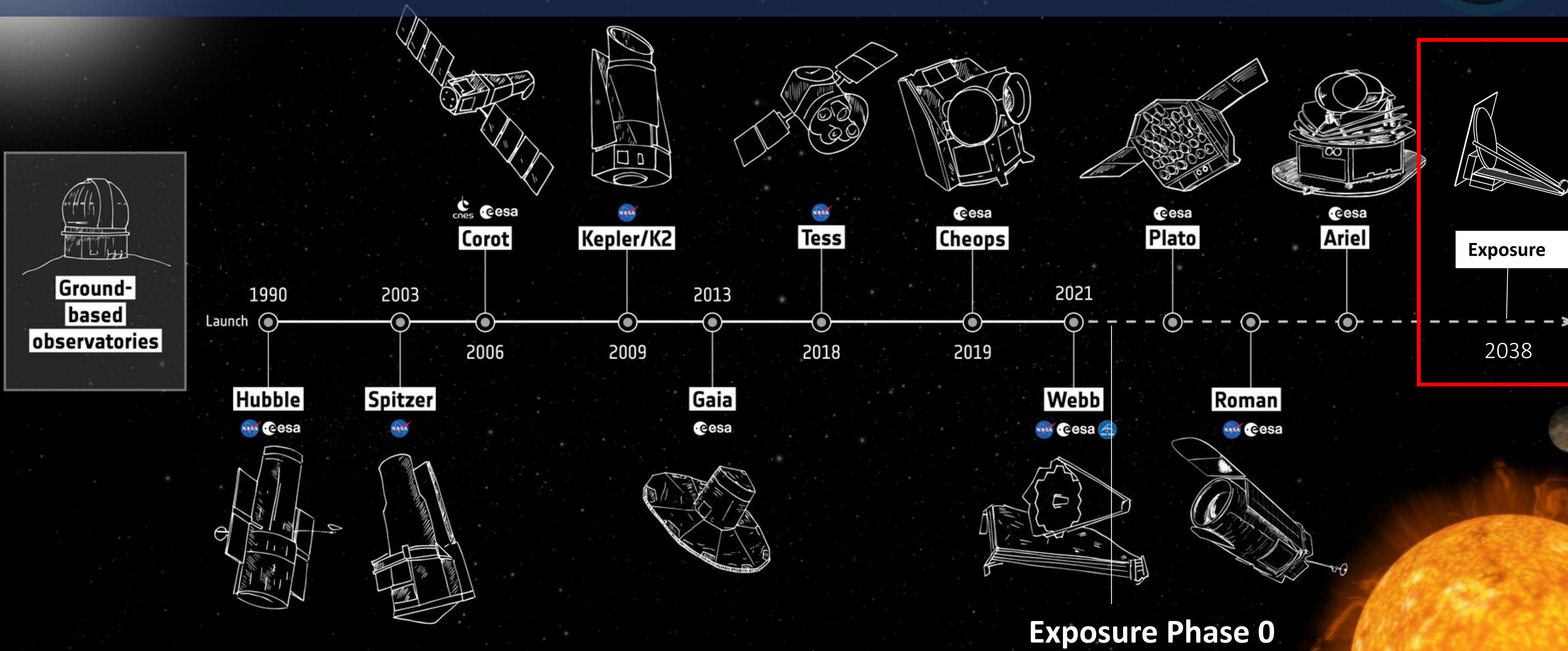
2030-2032

2033- 2037

2038 - 2044

2045-2047

ESA MISSION TIMELINE



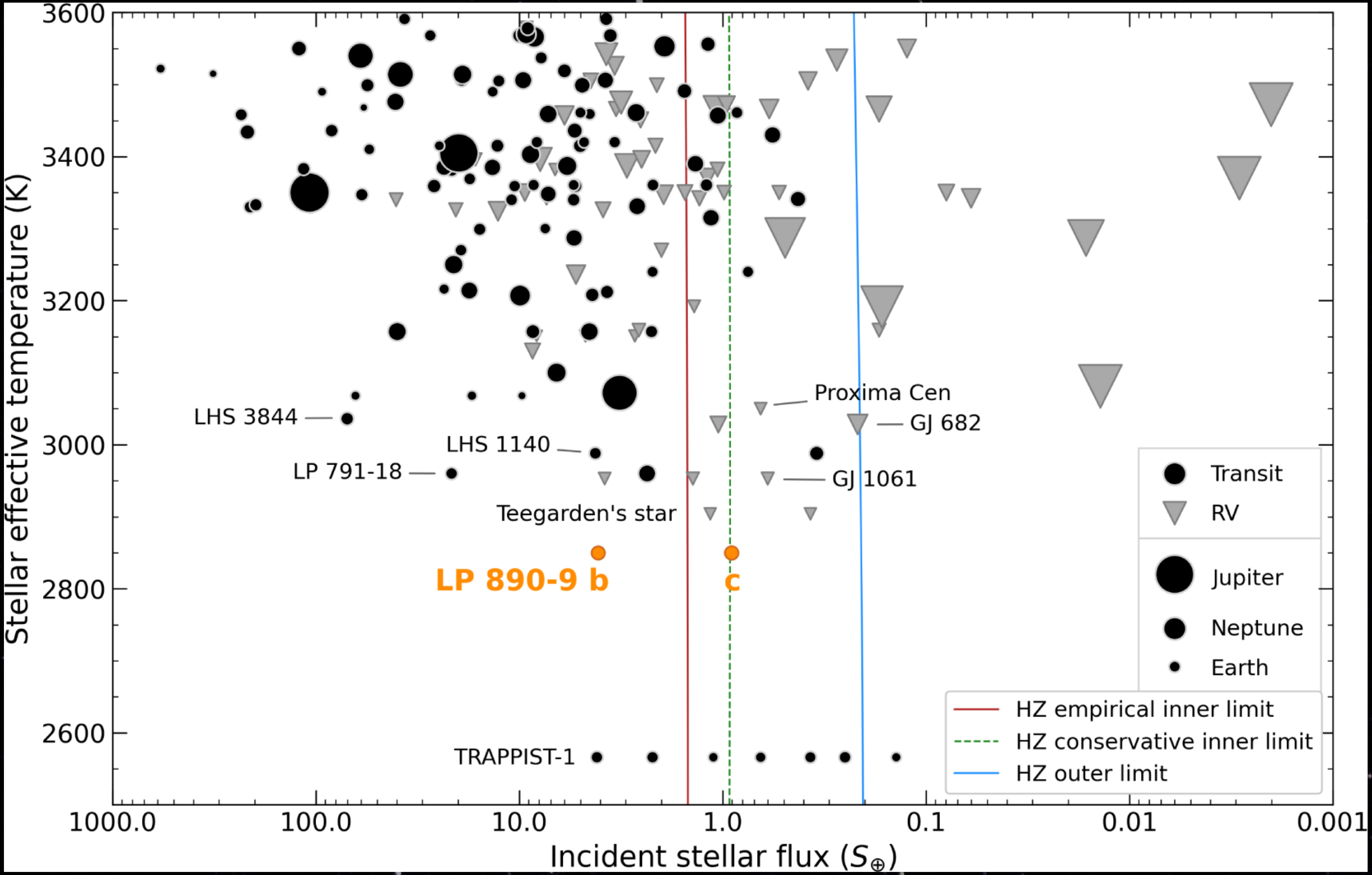
PUBLIC OUTREACH

- Instagram
- Facebook
- Course of funfact sessions at schools
  - Variations in exoplanets
  - Dangers of UV-radiation from the Sun

FINAL REMARKS

Summer School Alpbach 2023 – Team Blue

BACKUP: Habitability Zone (HZ)

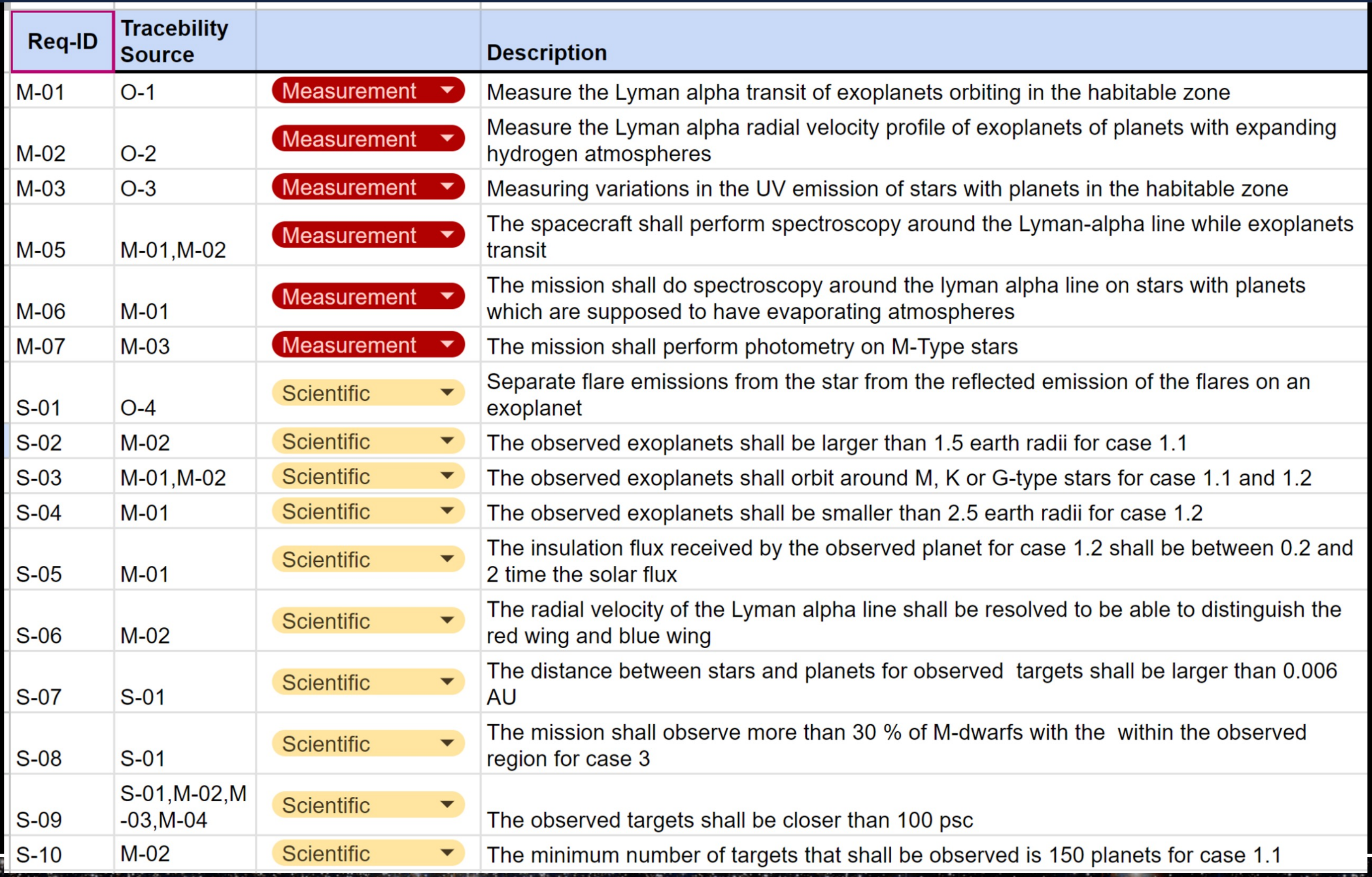


- Clouds can have perfect temperature for life
- Temperature below clouds/atmospheres → life
- Exomoons in CHZ
- Atmospheres potentially harbor life f.e. upper-to-middle cloud layers of Venus (0–60°C; pH~0): might suitable for thermo- or psychro-acidophilic microorganisms

(Merino, N., (2019), Living at the extremes: Extremophiles and the limits of life in a planetary context, Frontiers in Microbiology, 10)

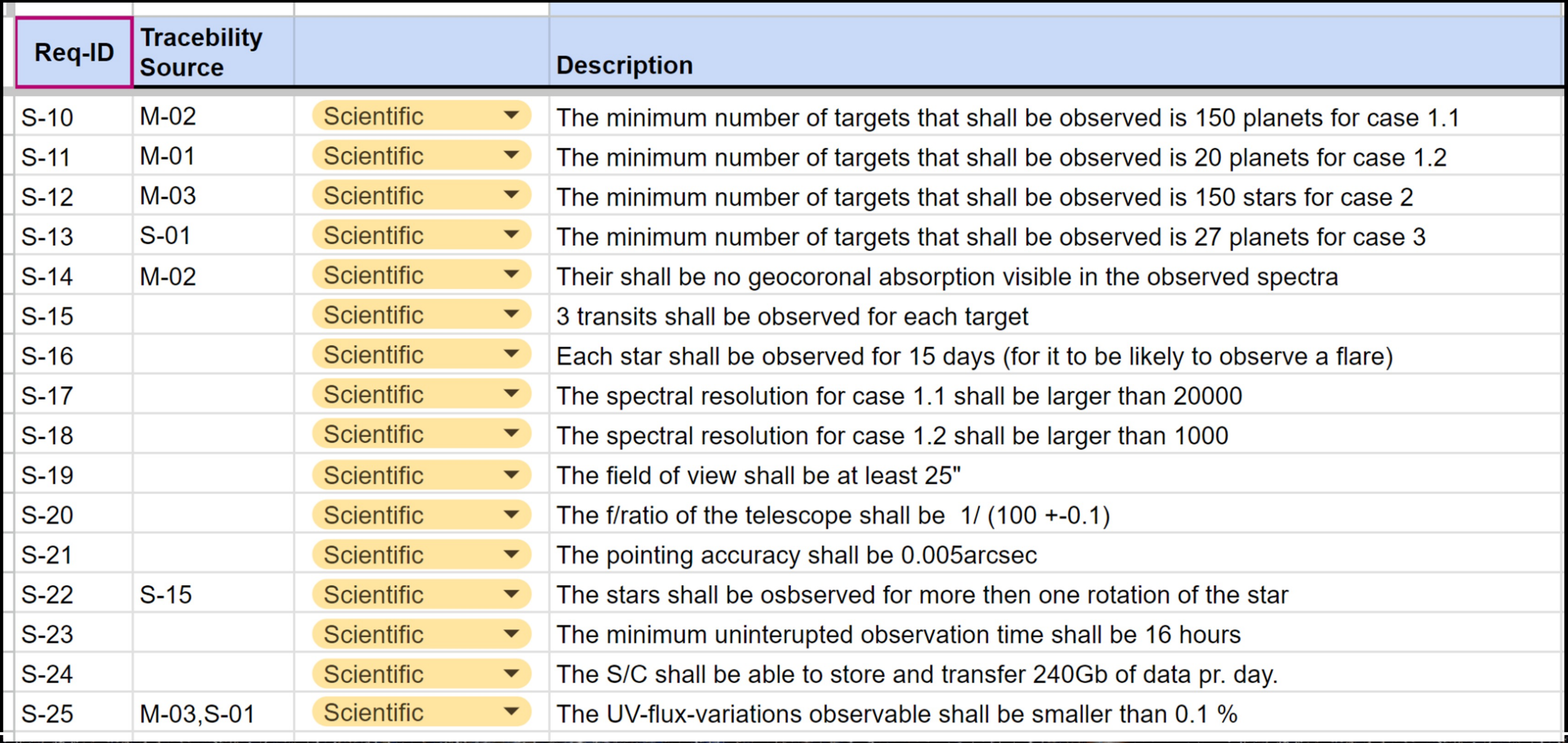
Delrez, L., et al.(2022), Two temperate super-Earths transiting a nearby late-type M dwarf, 667

Backup Slides - Requirements



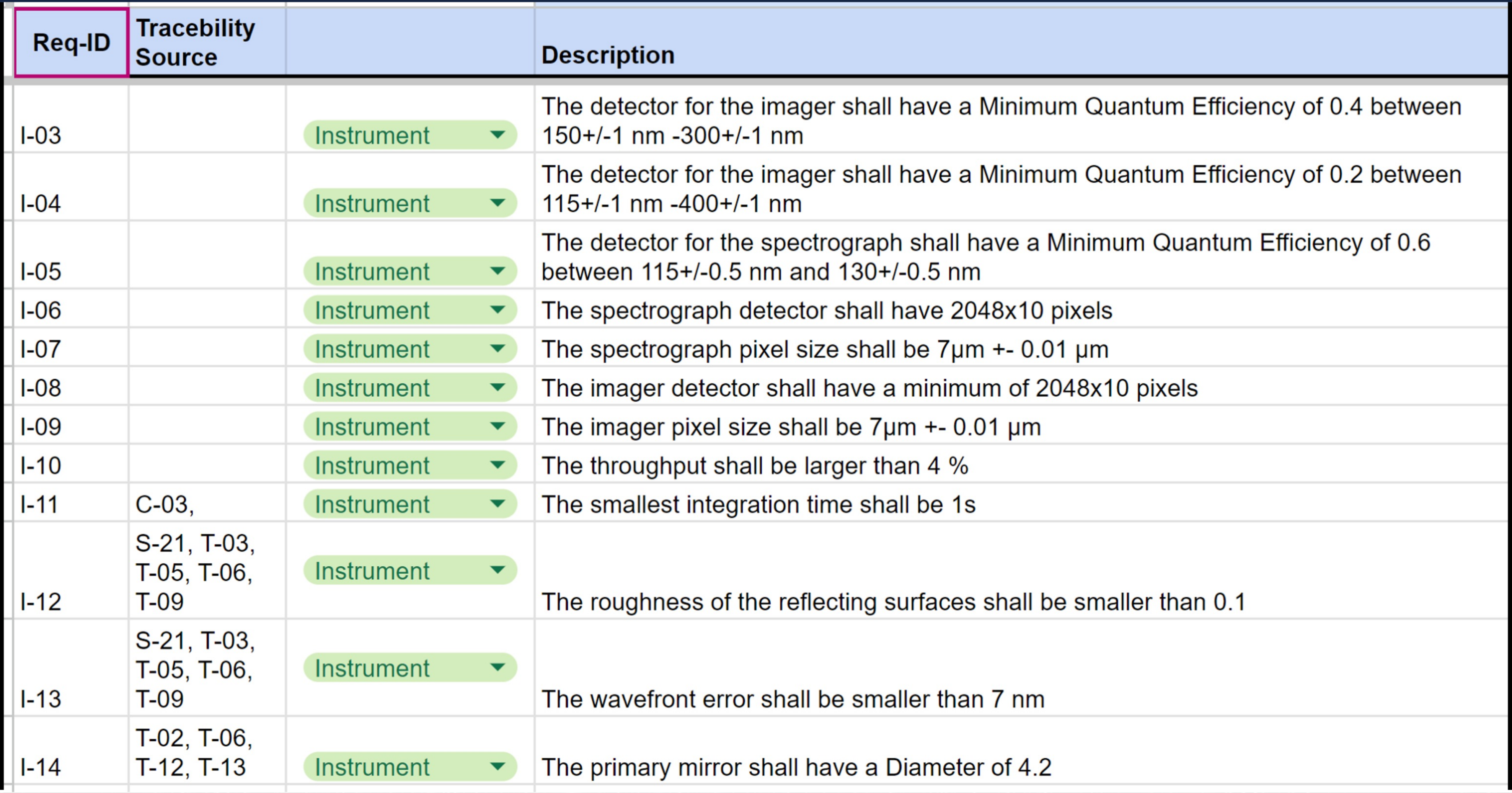
Req-ID	Tracebility Source		Description
M-01	O-1	Measurement	Measure the Lyman alpha transit of exoplanets orbiting in the habitable zone
M-02	O-2	Measurement	Measure the Lyman alpha radial velocity profile of exoplanets of planets with expanding hydrogen atmospheres
M-03	O-3	Measurement	Measuring variations in the UV emission of stars with planets in the habitable zone
M-05	M-01,M-02	Measurement	The spacecraft shall perform spectroscopy around the Lyman-alpha line while exoplanets transit
M-06	M-01	Measurement	The mission shall do spectroscopy around the lyman alpha line on stars with planets which are supposed to have evaporating atmospheres
M-07	M-03	Measurement	The mission shall perform photometry on M-Type stars
S-01	O-4	Scientific	Separate flare emissions from the star from the reflected emission of the flares on an exoplanet
S-02	M-02	Scientific	The observed exoplanets shall be larger than 1.5 earth radii for case 1.1
S-03	M-01,M-02	Scientific	The observed exoplanets shall orbit around M, K or G-type stars for case 1.1 and 1.2
S-04	M-01	Scientific	The observed exoplanets shall be smaller than 2.5 earth radii for case 1.2
S-05	M-01	Scientific	The insulation flux received by the observed planet for case 1.2 shall be between 0.2 and 2 time the solar flux
S-06	M-02	Scientific	The radial velocity of the Lyman alpha line shall be resolved to be able to distinguish the red wing and blue wing
S-07	S-01	Scientific	The distance between stars and planets for observed targets shall be larger than 0.006 AU
S-08	S-01	Scientific	The mission shall observe more than 30 % of M-dwarfs with the within the observed region for case 3
S-09	S-01,M-02,M-03,M-04	Scientific	The observed targets shall be closer than 100 psc
S-10	M-02	Scientific	The minimum number of targets that shall be observed is 150 planets for case 1.1

Backup Slides - Requirements



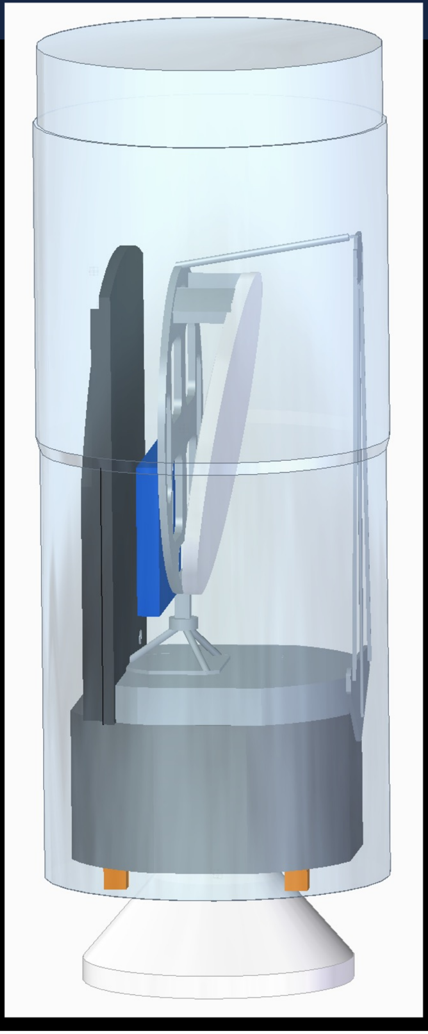
Req-ID	Tracebility Source		Description
S-10	M-02	Scientific	The minimum number of targets that shall be observed is 150 planets for case 1.1
S-11	M-01	Scientific	The minimum number of targets that shall be observed is 20 planets for case 1.2
S-12	M-03	Scientific	The minimum number of targets that shall be observed is 150 stars for case 2
S-13	S-01	Scientific	The minimum number of targets that shall be observed is 27 planets for case 3
S-14	M-02	Scientific	Their shall be no geocoronal absorption visible in the observed spectra
S-15		Scientific	3 transits shall be observed for each target
S-16		Scientific	Each star shall be observed for 15 days (for it to be likely to observe a flare)
S-17		Scientific	The spectral resolution for case 1.1 shall be larger than 20000
S-18		Scientific	The spectral resolution for case 1.2 shall be larger than 1000
S-19		Scientific	The field of view shall be at least 25"
S-20		Scientific	The f/ratio of the telescope shall be 1/ (100 +-0.1)
S-21		Scientific	The pointing accuracy shall be 0.005arcsec
S-22	S-15	Scientific	The stars shall be osbserved for more then one rotation of the star
S-23		Scientific	The minimum uninterupted observation time shall be 16 hours
S-24		Scientific	The S/C shall be able to store and transfer 240Gb of data pr. day.
S-25	M-03,S-01	Scientific	The UV-flux-variations observable shall be smaller than 0.1 %

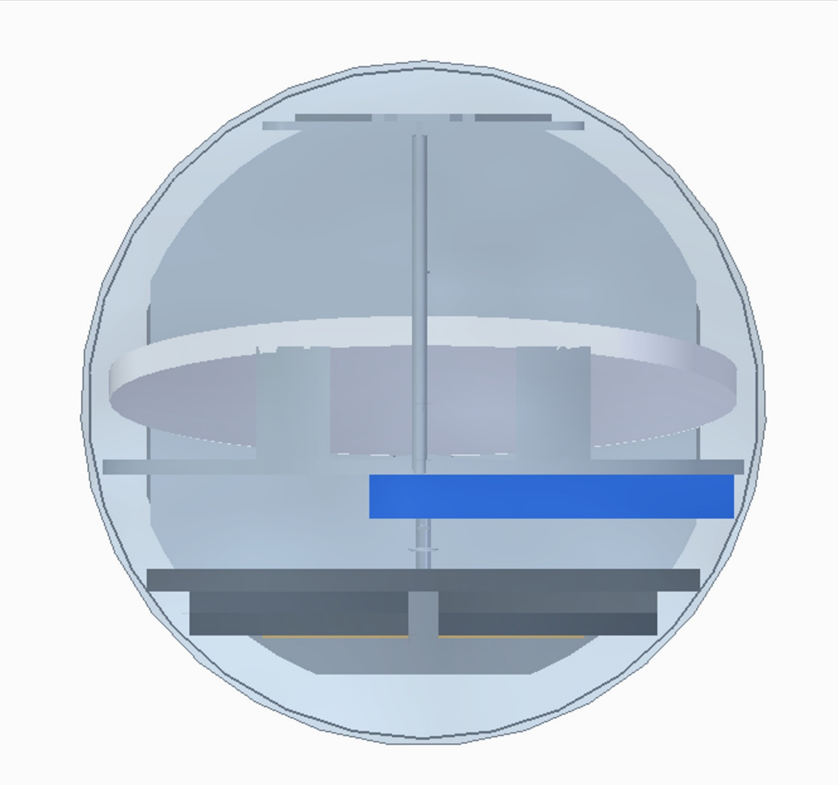
Backup Slides - Requirements



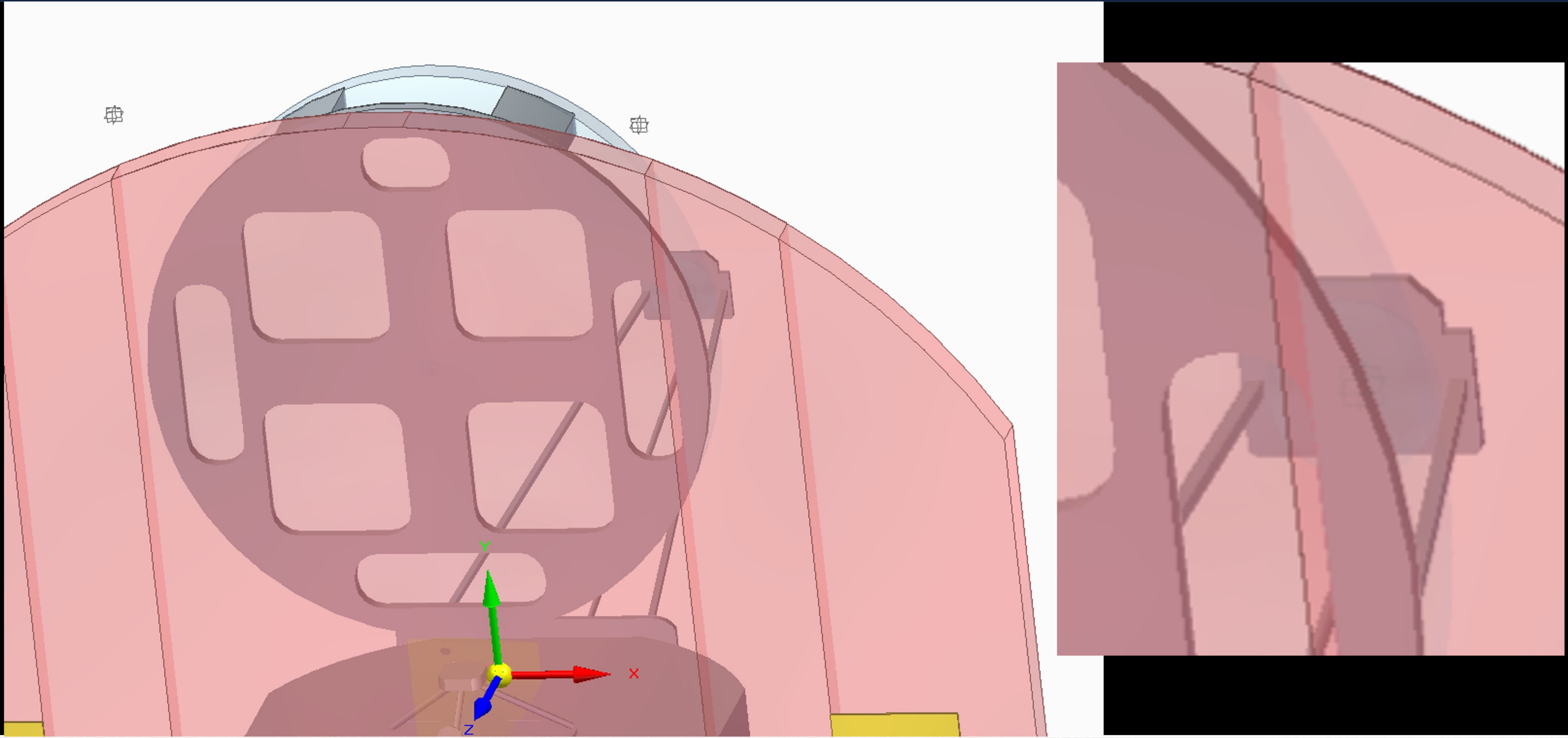
Req-ID	Tracebility Source		Description
I-03		Instrument ▼	The detector for the imager shall have a Minimum Quantum Efficiency of 0.4 between 150+/-1 nm -300+/-1 nm
I-04		Instrument ▼	The detector for the imager shall have a Minimum Quantum Efficiency of 0.2 between 115+/-1 nm -400+/-1 nm
I-05		Instrument ▼	The detector for the spectrograph shall have a Minimum Quantum Efficiency of 0.6 between 115+/-0.5 nm and 130+/-0.5 nm
I-06		Instrument ▼	The spectrograph detector shall have 2048x10 pixels
I-07		Instrument ▼	The spectrograph pixel size shall be 7µm +- 0.01 µm
I-08		Instrument ▼	The imager detector shall have a minimum of 2048x10 pixels
I-09		Instrument ▼	The imager pixel size shall be 7µm +- 0.01 µm
I-10		Instrument ▼	The throughput shall be larger than 4 %
I-11	C-03,	Instrument ▼	The smallest integration time shall be 1s
I-12	S-21, T-03, T-05, T-06, T-09	Instrument ▼	The roughness of the reflecting surfaces shall be smaller than 0.1
I-13	S-21, T-03, T-05, T-06, T-09	Instrument ▼	The wavefront error shall be smaller than 7 nm
I-14	T-02, T-06, T-12, T-13	Instrument ▼	The primary mirror shall have a Diameter of 4.2

BACKUP: SPACECRAFT IN LAUNCH CONFIGURATION

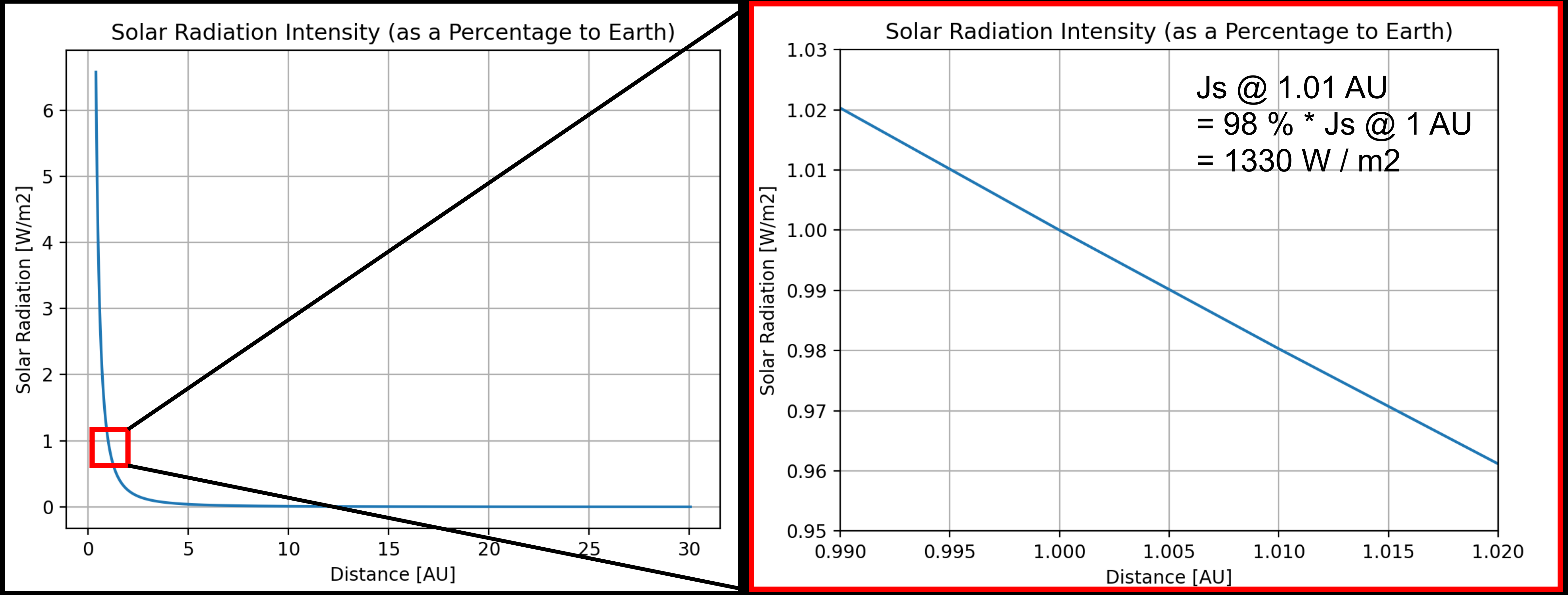




BACKUP: 70 ° from Ecliptic



BACKUP: SOLAR RADIATION FLUX



Js @ 1.01 AU
= 98 % * Js @ 1 AU
= 1330 W / m2

BACKUP: 50 M/S MANEUVER DURATION