FFG Promoting Innovation.
esa

SUMMER SCHOOL ALPBACH 2023

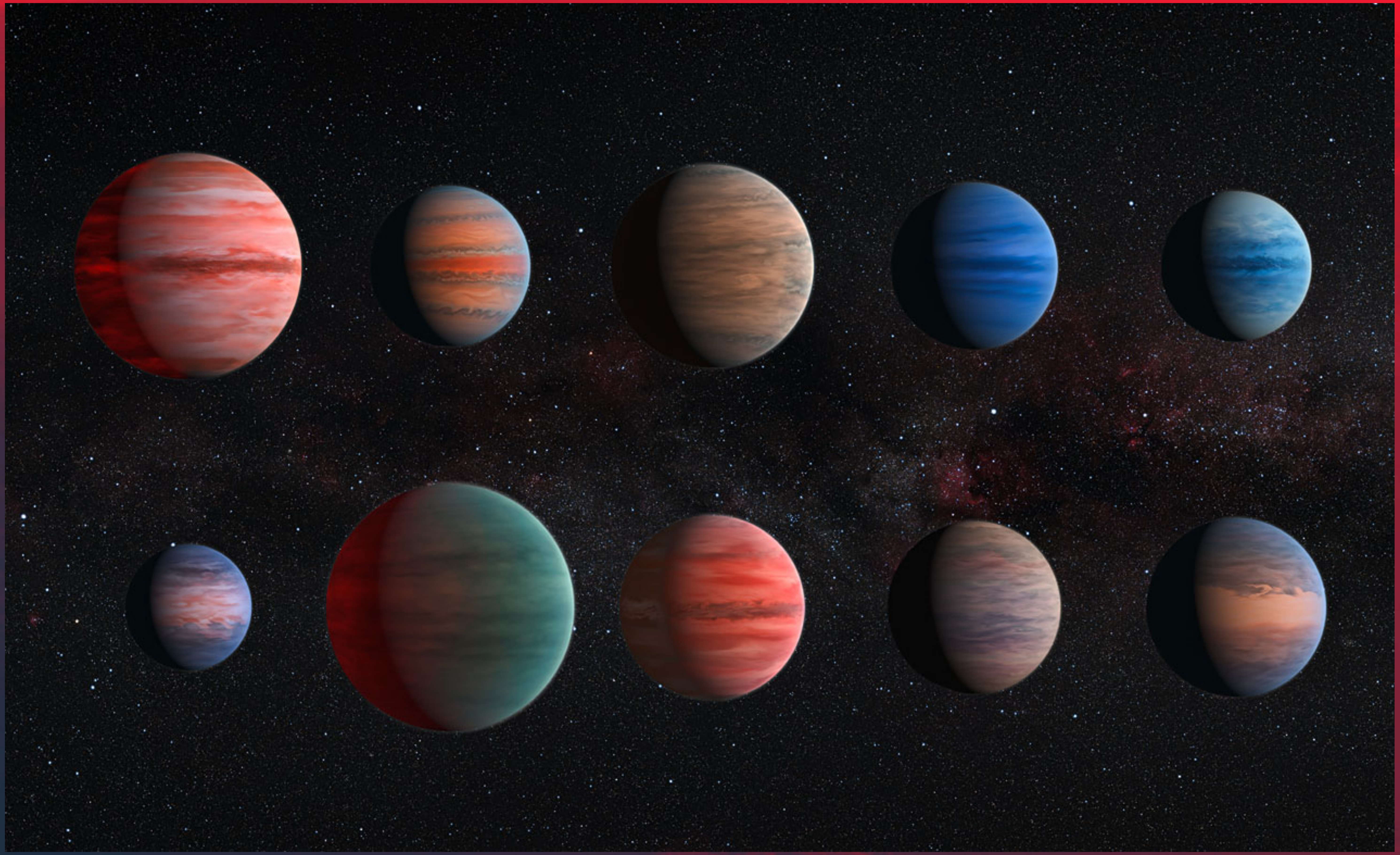
Exodus: Exploring Exoplanet Evolution

MISSION STATEMENT

Study the evolution of exoplanets and the architecture of their parent systems

MISSION STATEMENT

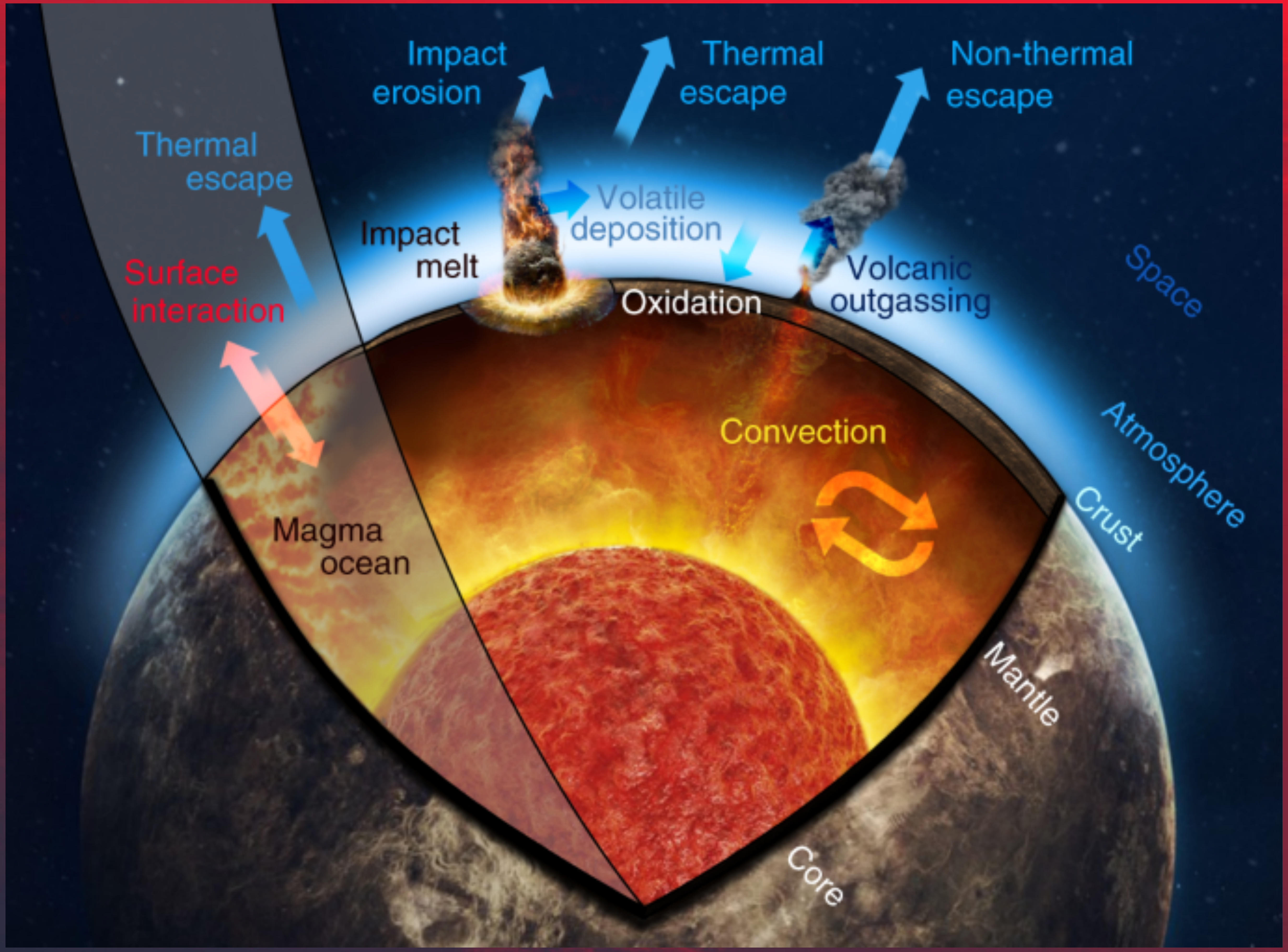
Study the evolution of exoplanets and the architecture of their parent systems



ESA/Hubble/NASA

MISSION STATEMENT

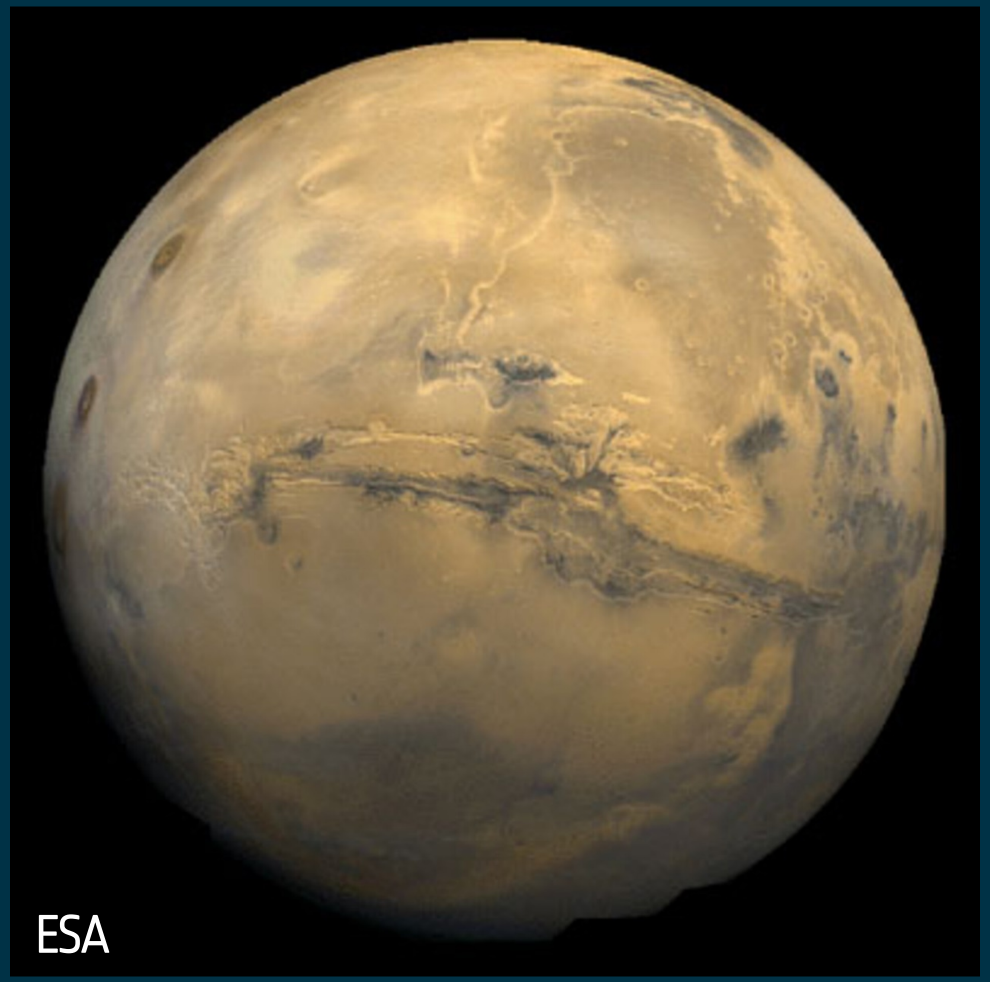
Study the evolution of exoplanets and the architecture of their parent systems



Gillmann et al, 2020

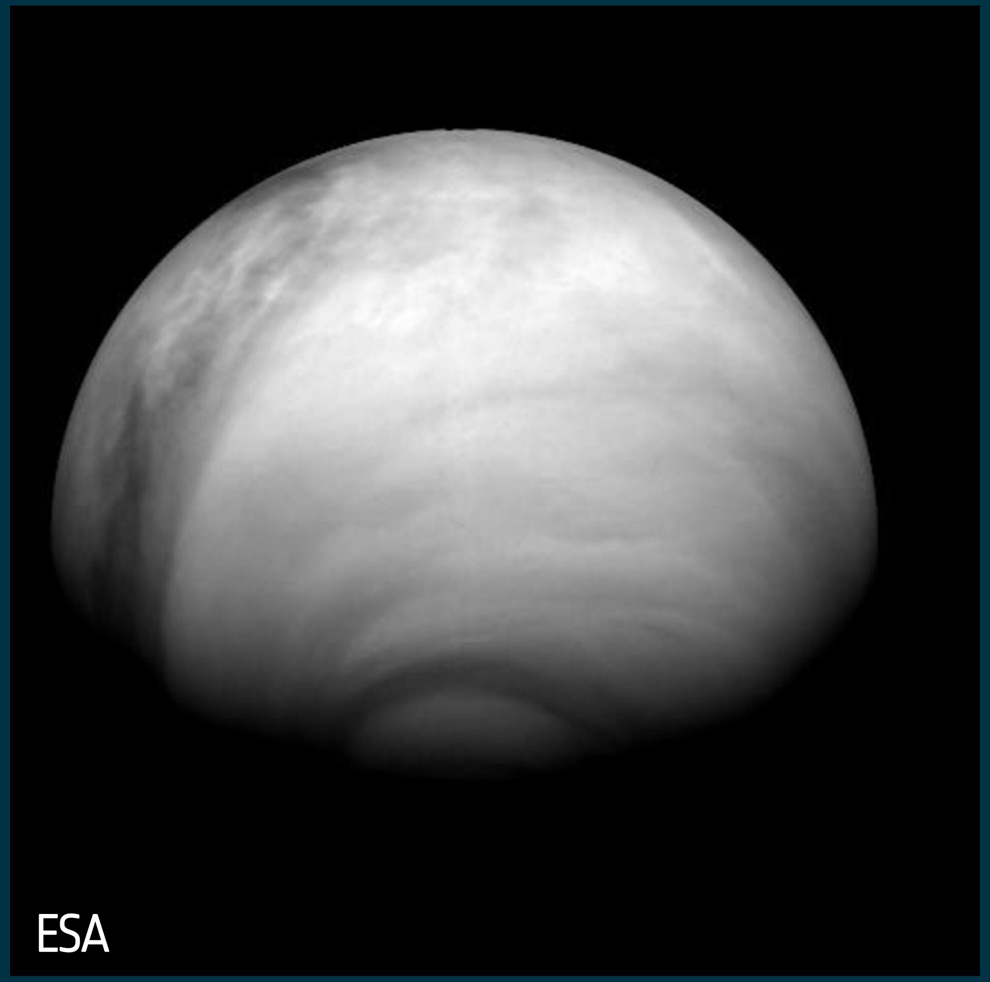
Planetary Evolution

Governed by chemical and physical processes.



Mars

ESA



Venus

ESA

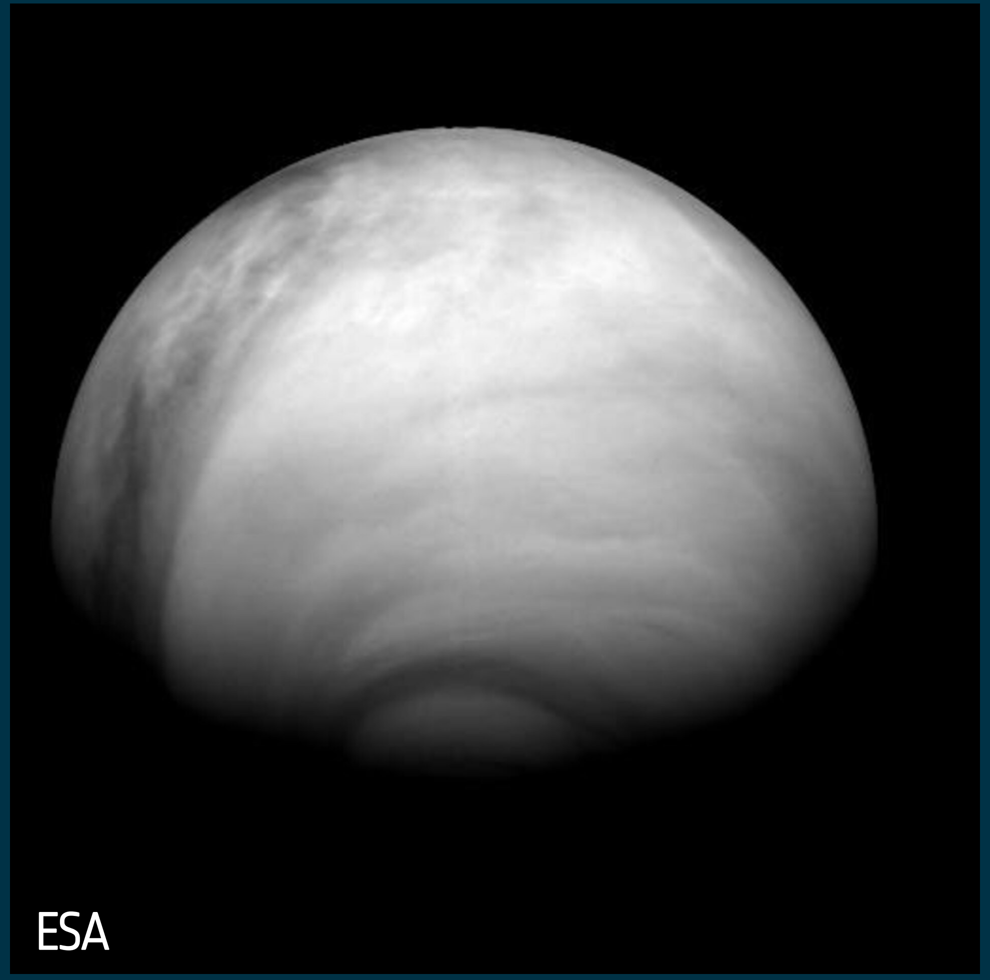
Planetary Evolution

Governed by chemical and physical processes.

Habitability

Mars

ESA



Venus

ESA

NASA/JPL-Caltech/
Lizbeth B. De La Torre

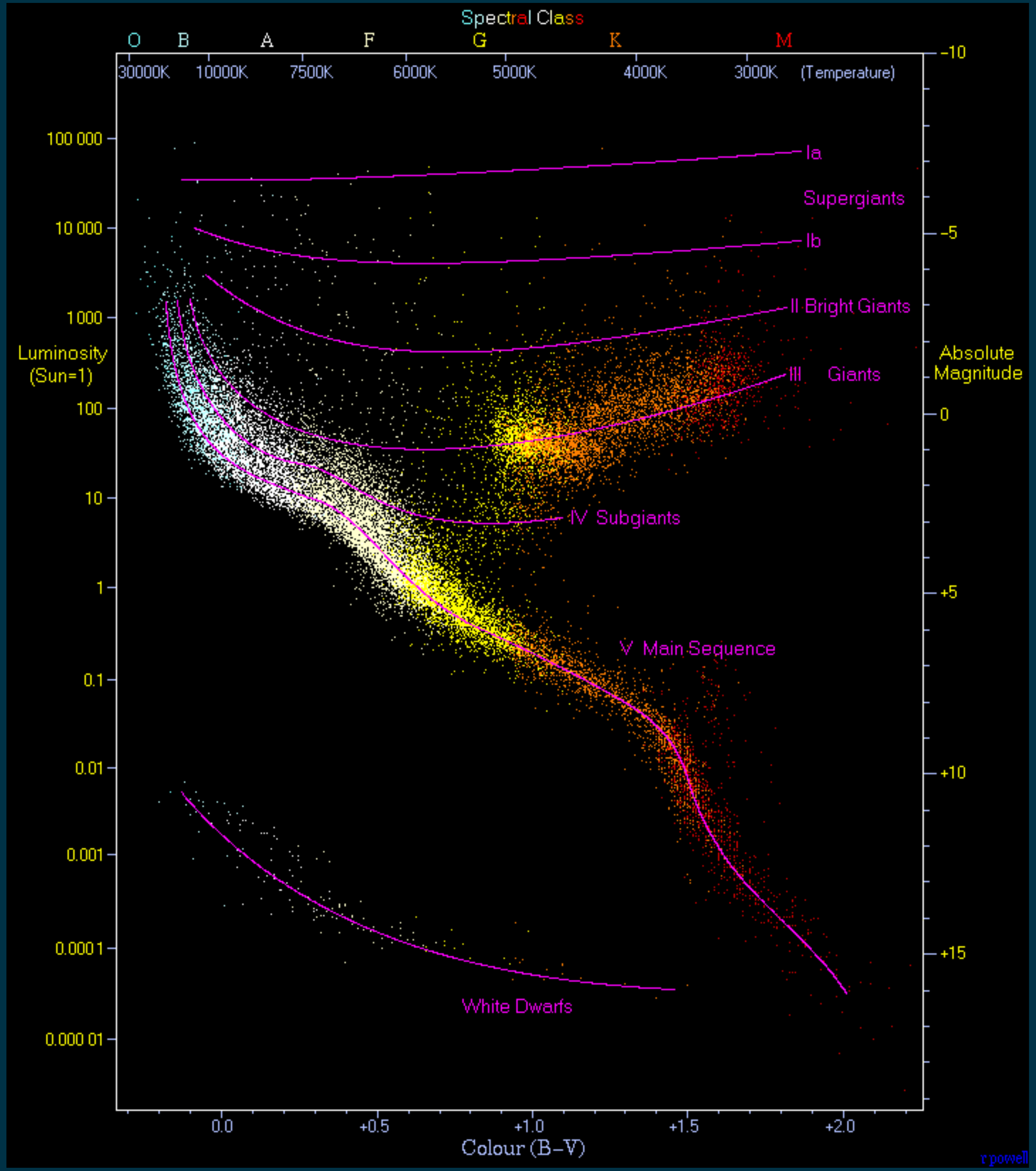
Planetary Evolution

Governed by chemical and physical processes.

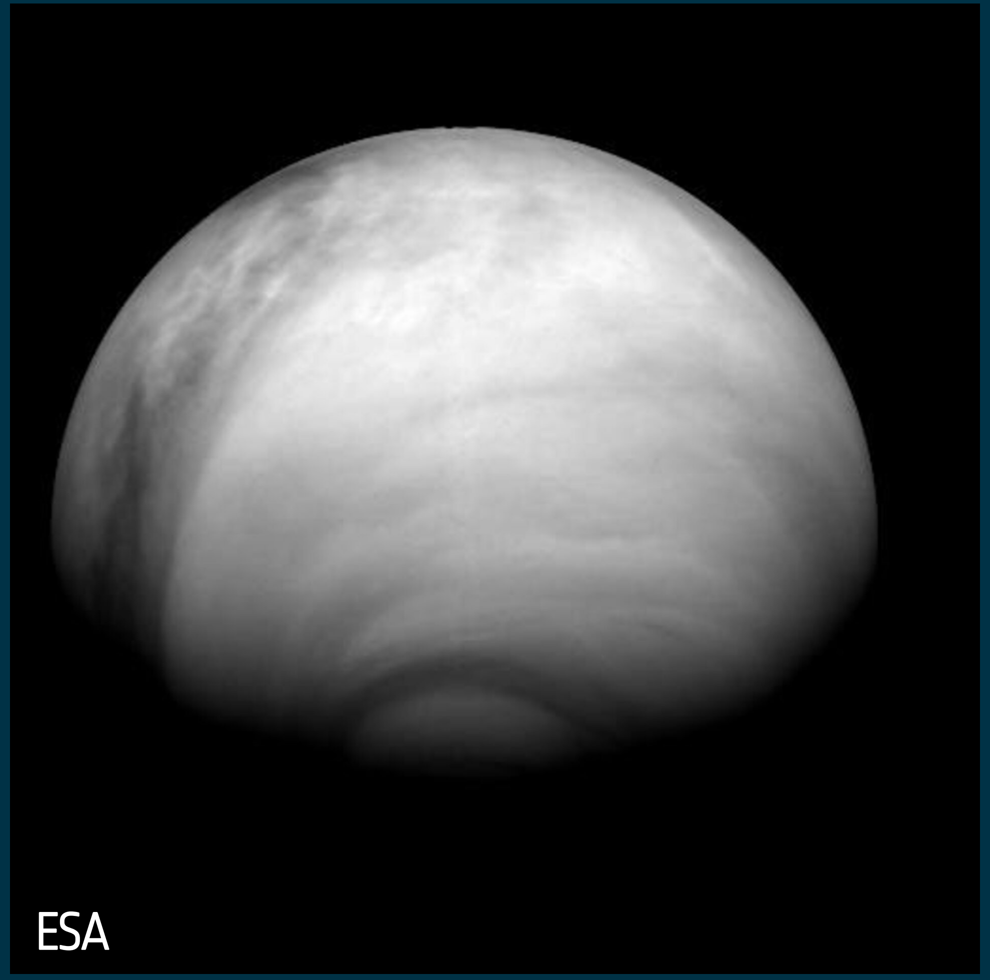
Habitability

Trace Growth

Powell et al, 2018

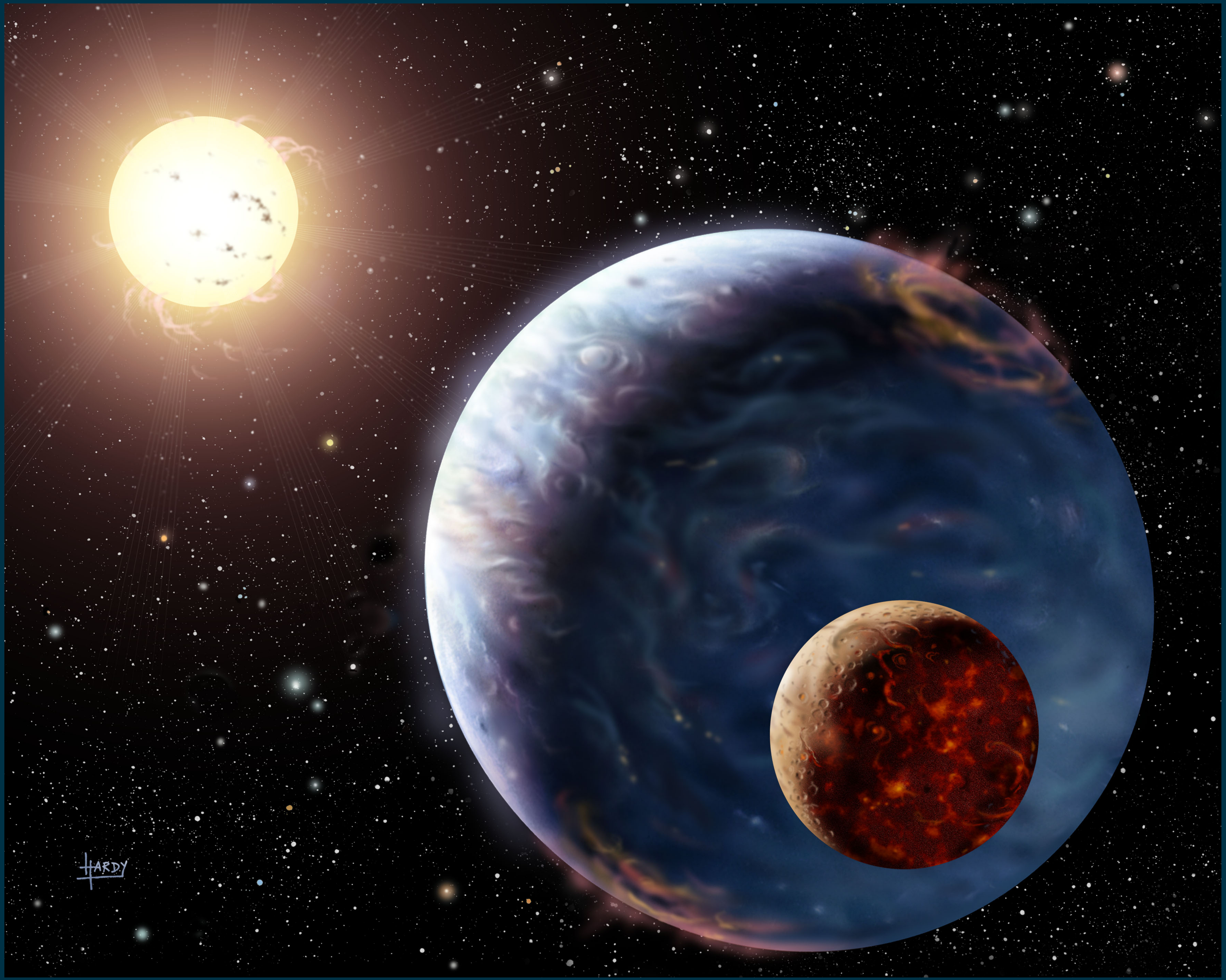



ESA


ESA

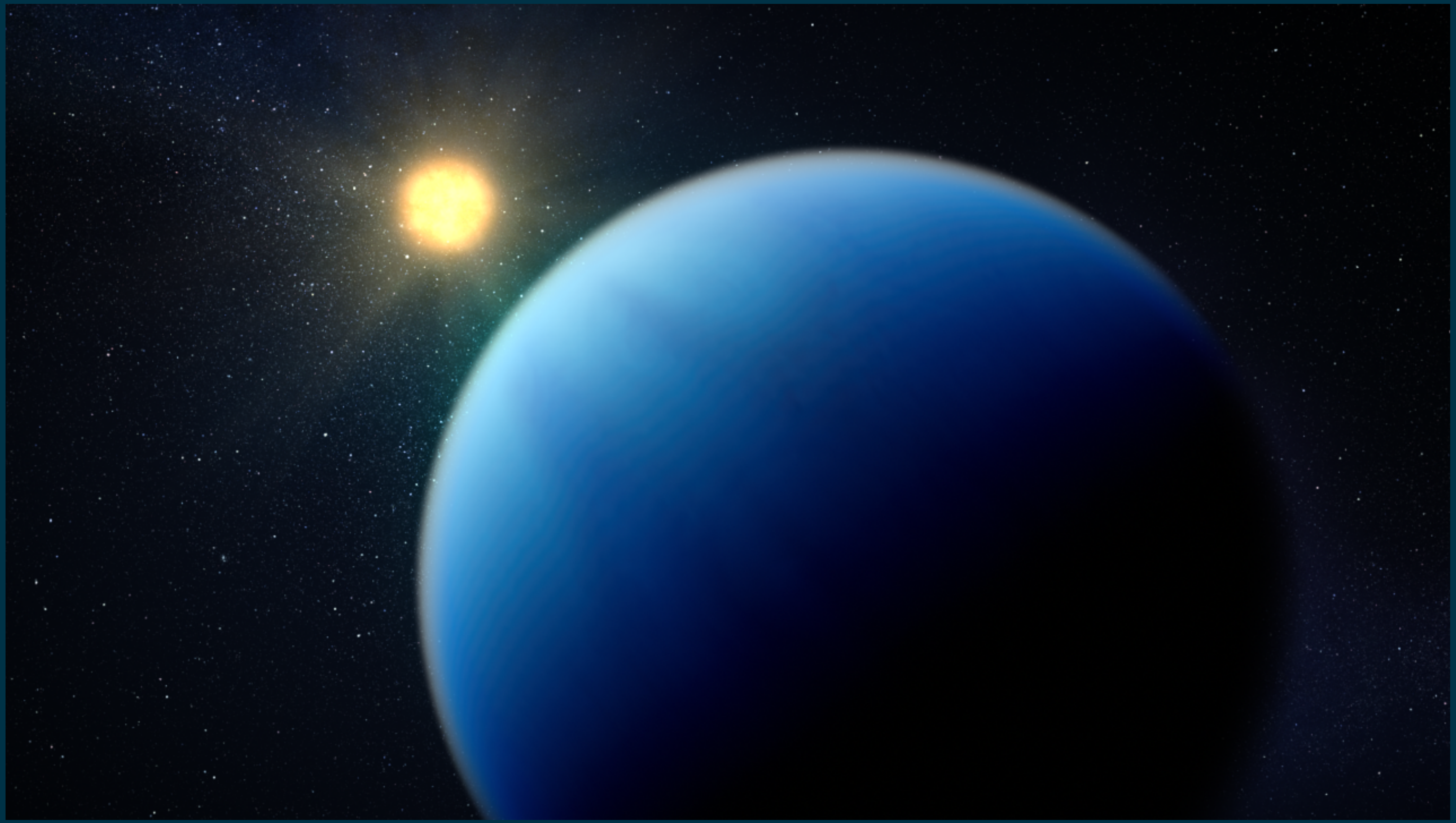

NASA/JPL-Caltech/
Lizbeth B. De La Torre

Interaction between Stars & Exoplanets



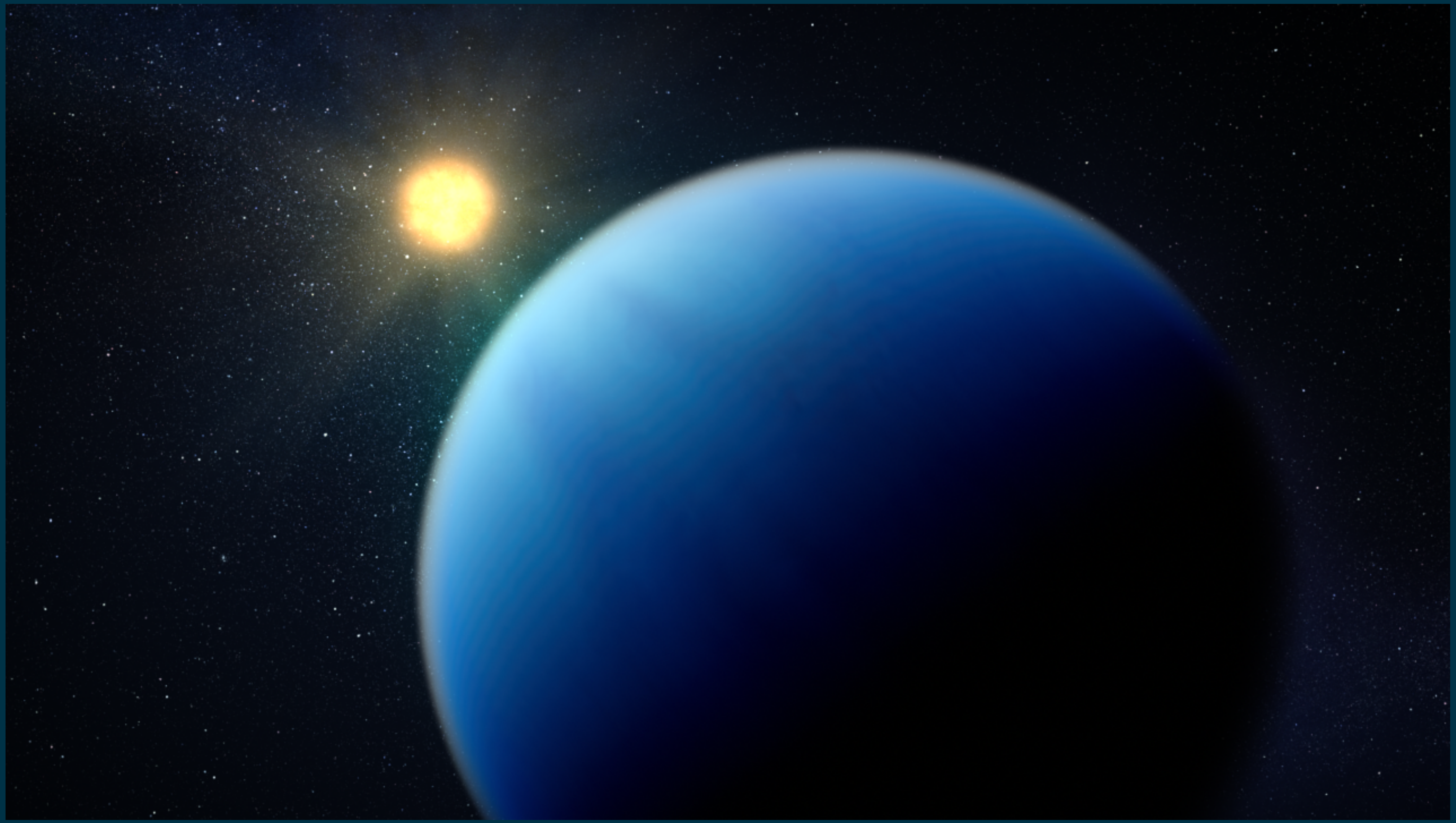
STFC

Solar System Architecture

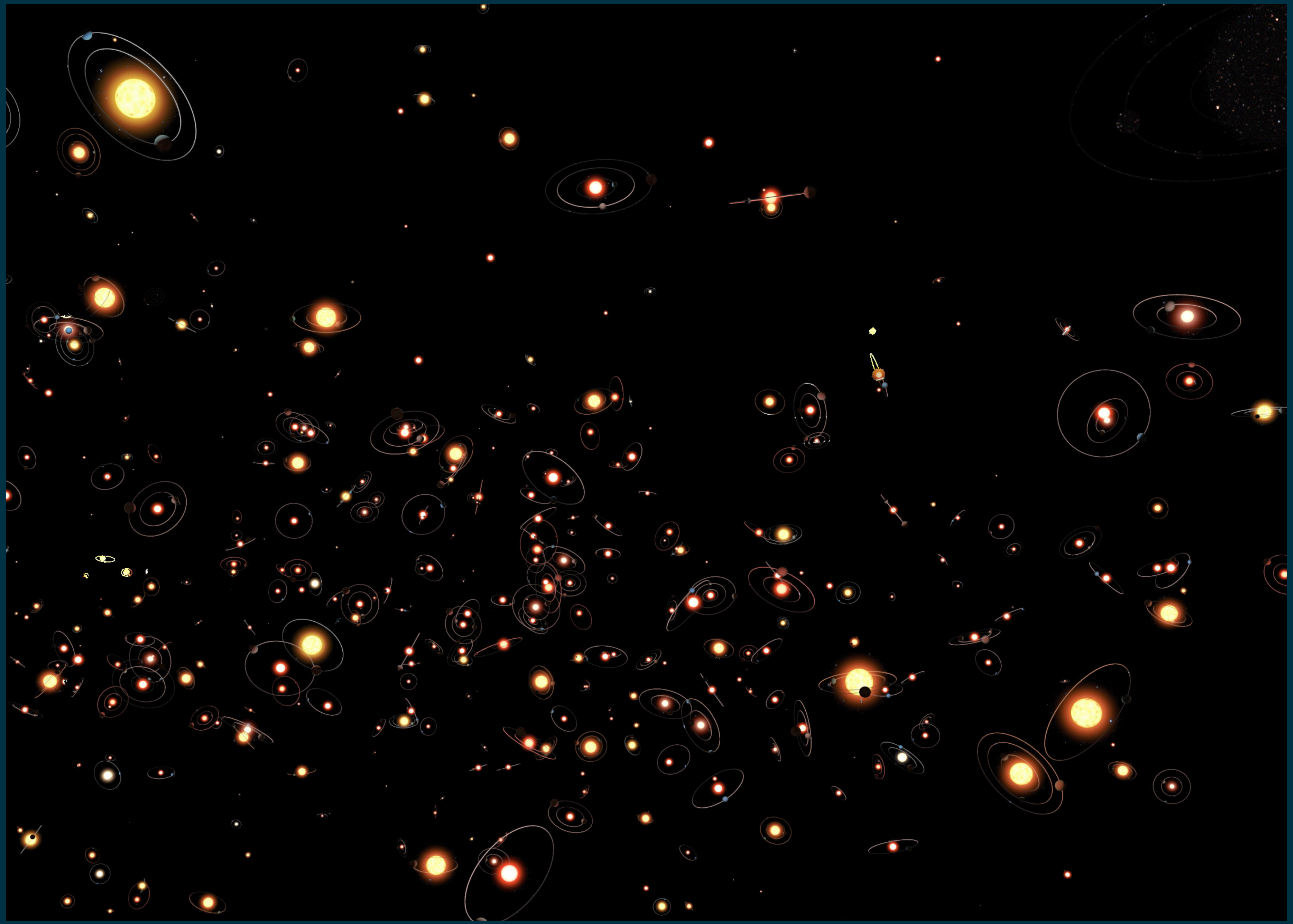


NASA, ESA, CSA, Dani Player (STScI)

Solar System Architecture



NASA, ESA, CSA, Dani Player (STScI)



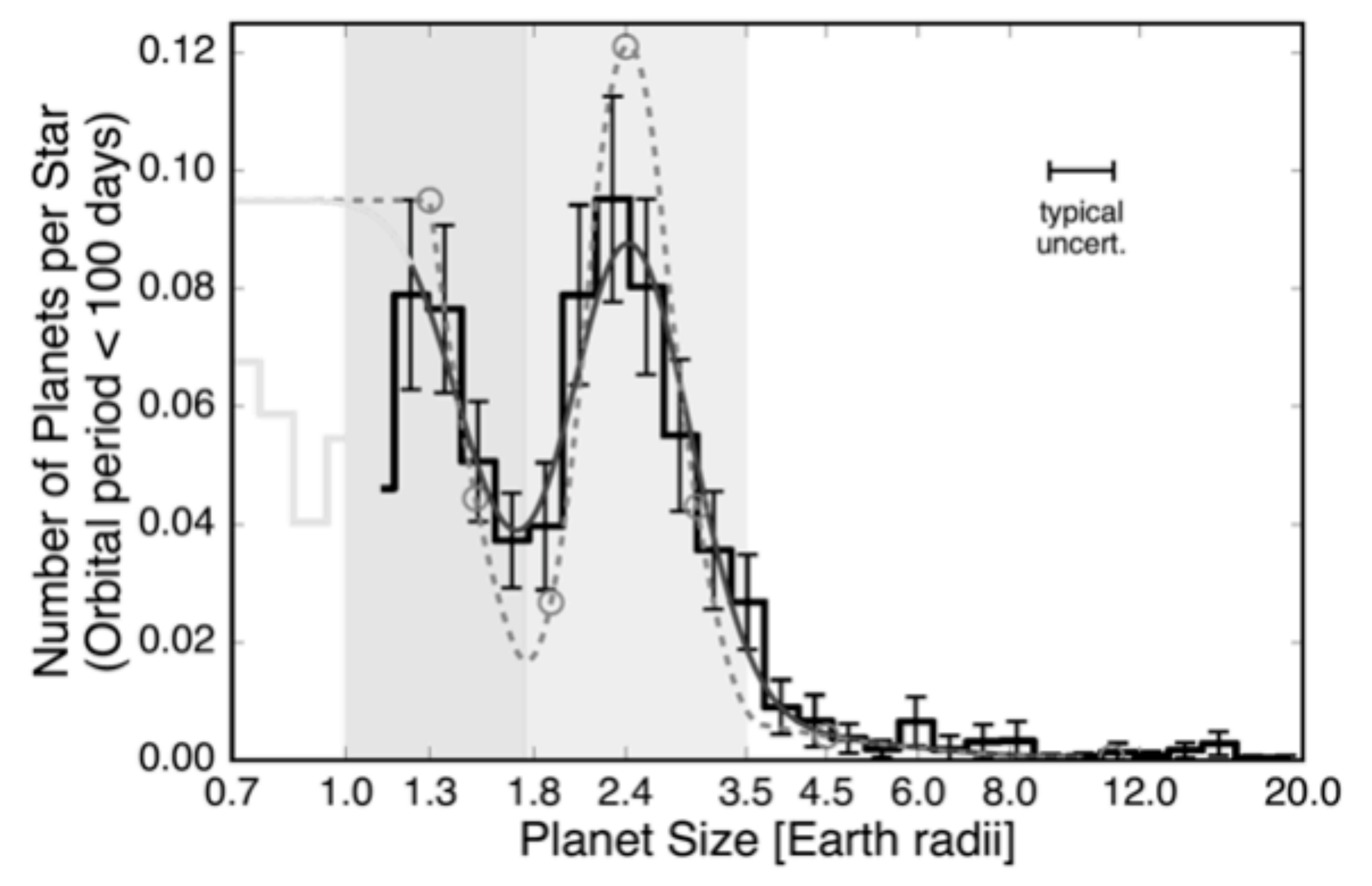
ESO/M. Kornmesser

Key Science Questions

1. How does atmospheric escape shape the evolution of long orbital period exoplanets?
2. What proportion of the exoplanet population do giant planets with long orbital periods represent?
3. How does the solar system architecture compare to that of exoplanet systems?

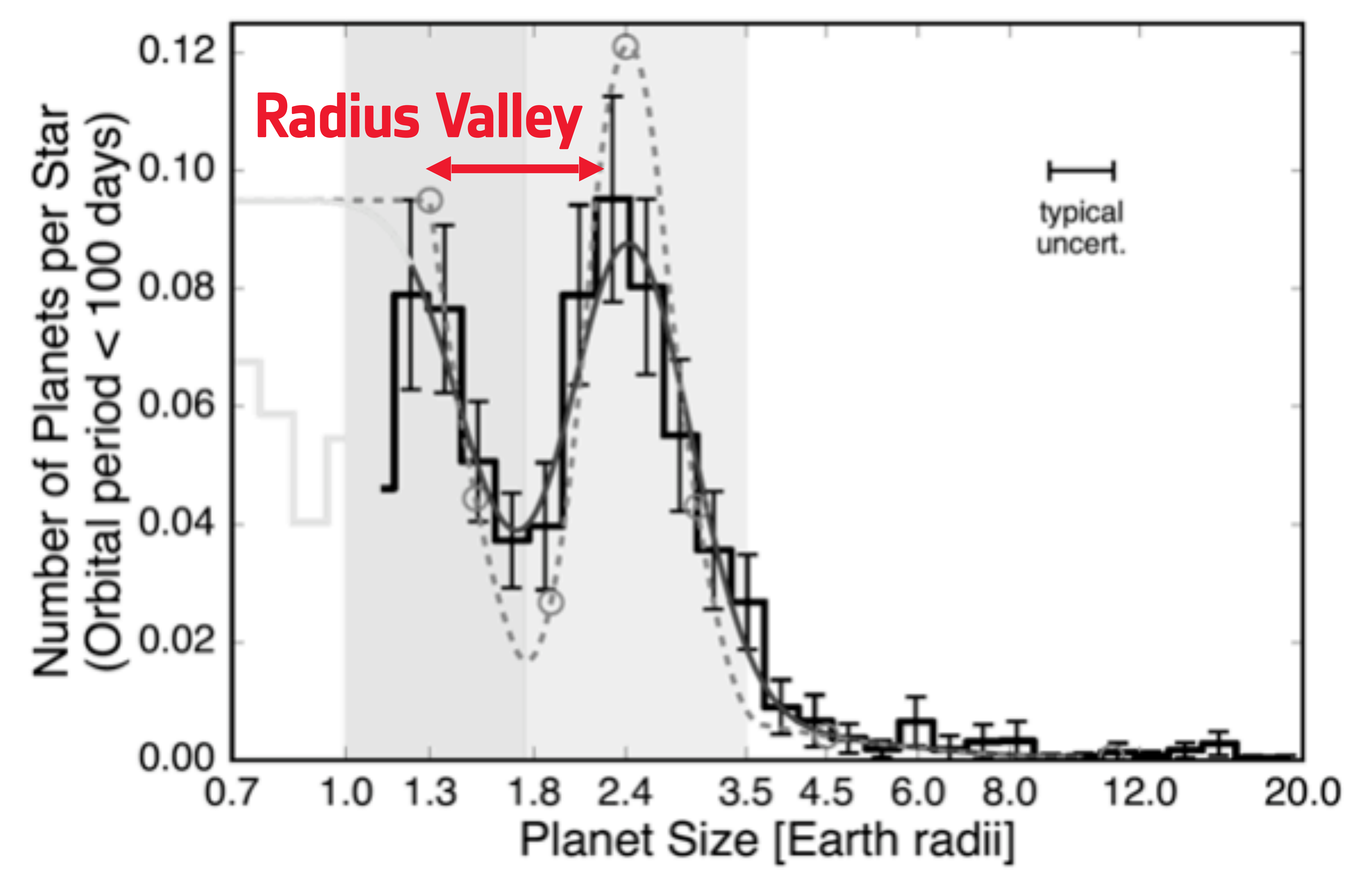
QUESTION 1

How does atmospheric escape shape the evolution of large orbit exoplanets?



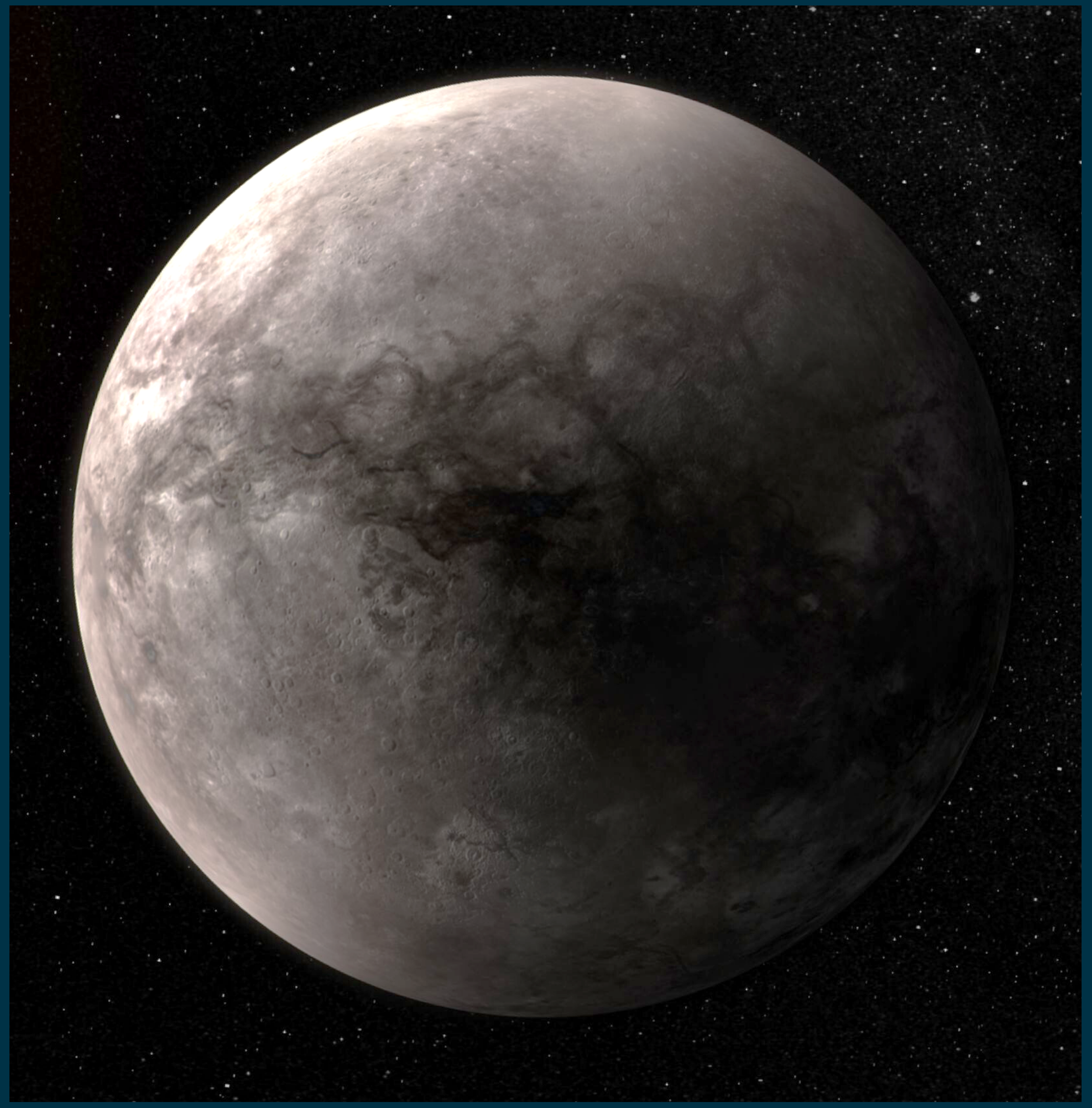
Benjamin J. Fulton et al. 2017

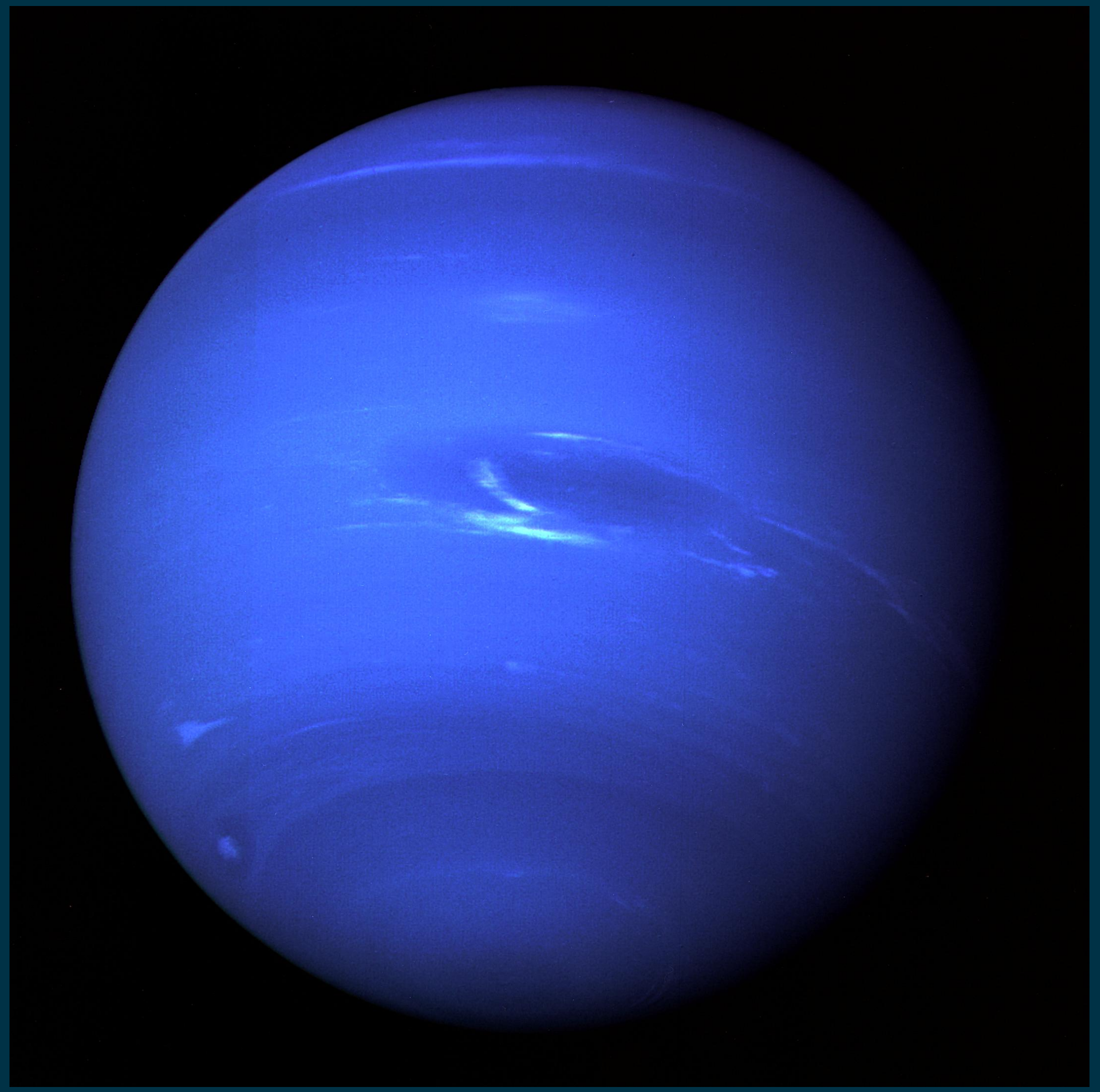
Radius Distribution



Benjamin J. Fulton et al. 2017

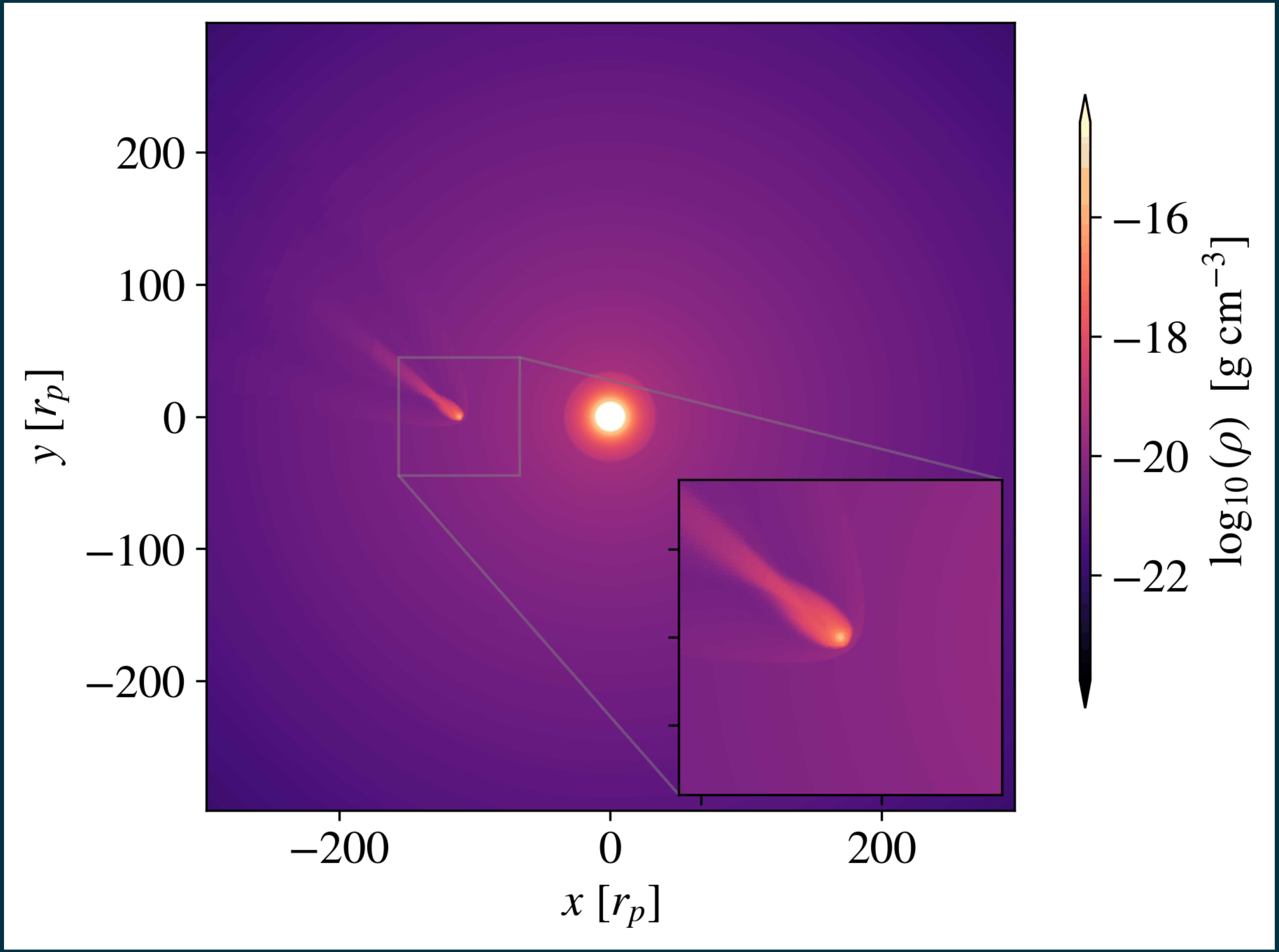
NASA, ESA, CSA, J. Olmsted (STScI), T. P. Greene (NASA Ames), T. Bell (BAERI), E. Ducrot (CEA), P. Lagage (CEA)





NASA/JPL/University of Arizona

Atmospheric Escape Animation



Wiebe de Gruijter

Hydrodynamical simulation of WASP-107b

Atmospheric Escape

Two models can explain atmospheric escape:

1. UV driven mass loss
2. Core-powered mass loss

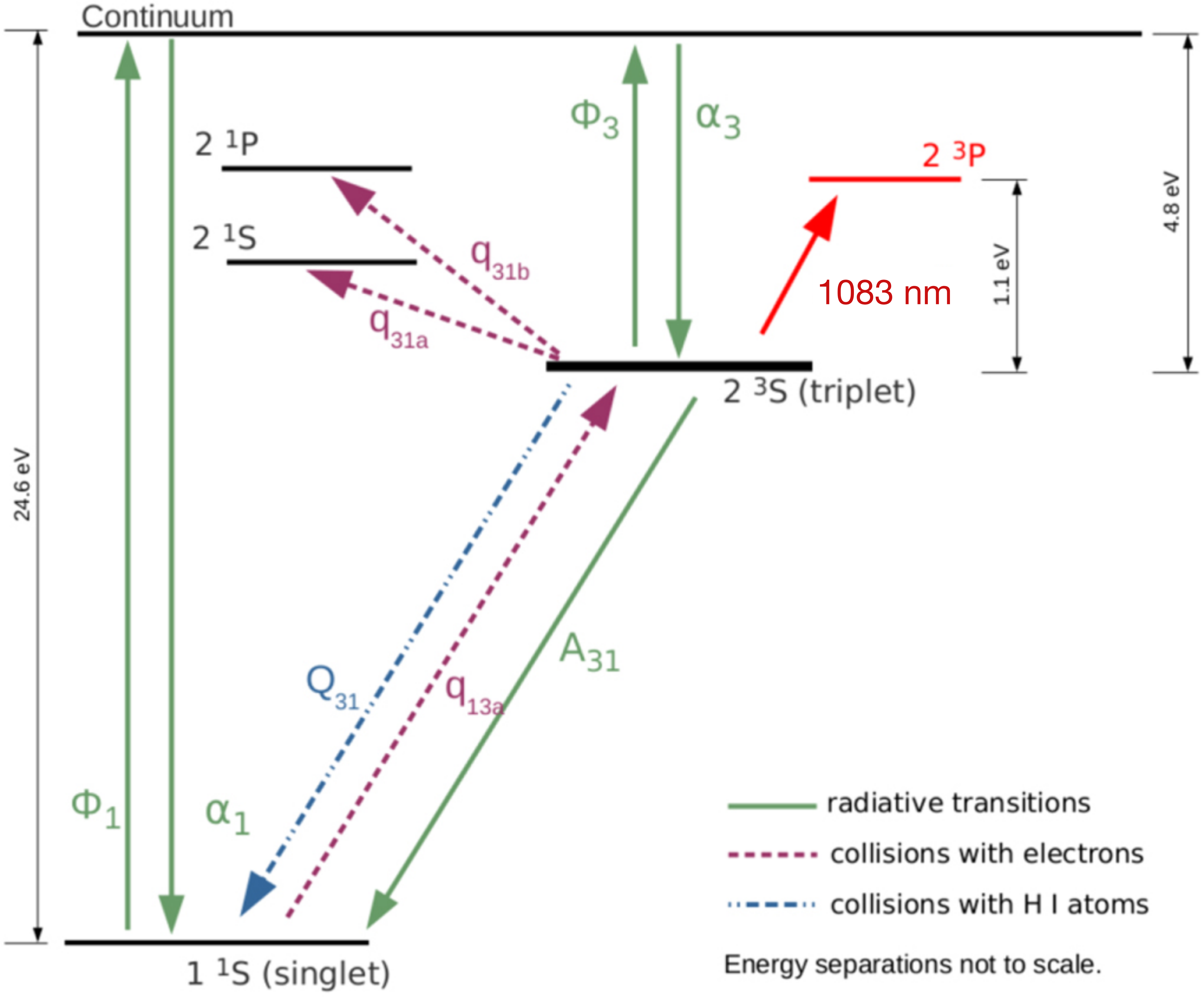
Simultaneous observations to break degeneracy:

1. UV observations of the star
2. NIR spectroscopy of the planet

Observation Line

Helium line at 1083 nm to detect atmospheric escape:

1. (Previously) Transits of short-period planets
2. Long-period (>100 days) planets: transit method difficult



Oklopčić & Hirata, 2018

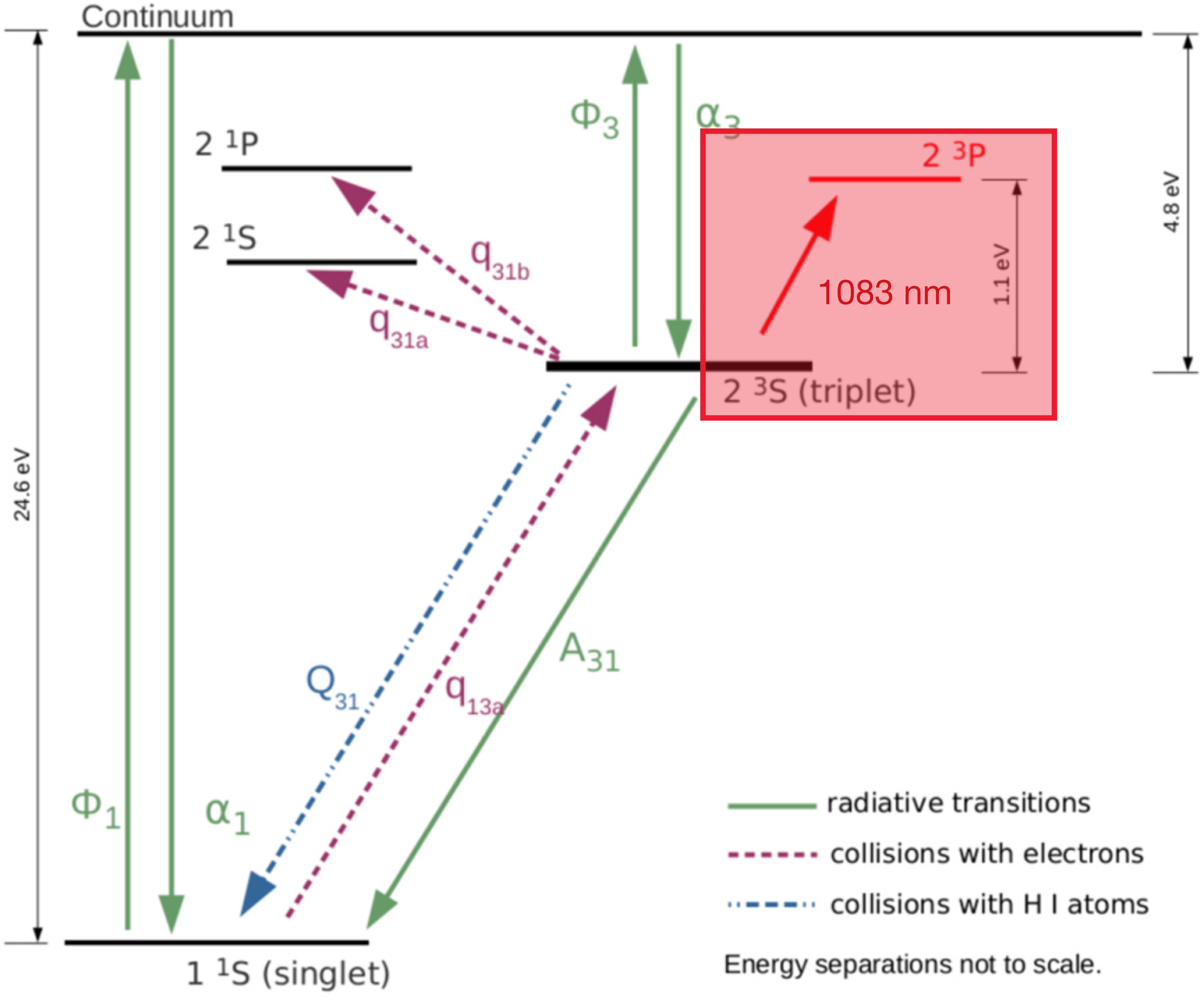
Observation Line

Helium line at 1083 nm to detect atmospheric escape:

1. (Previously) Transits of short-period planets
2. Long-period (>100 days) planets: transit method difficult

We propose to perform:

1. Spectroscopic observations of the exoplanet using direct imaging
2. Simultaneous observations of the star in the UV



Oklopčić & Hirata, 2018

QUESTION 1

How does atmospheric escape shape the evolution of large orbit exoplanets?

Objectives Characterisation

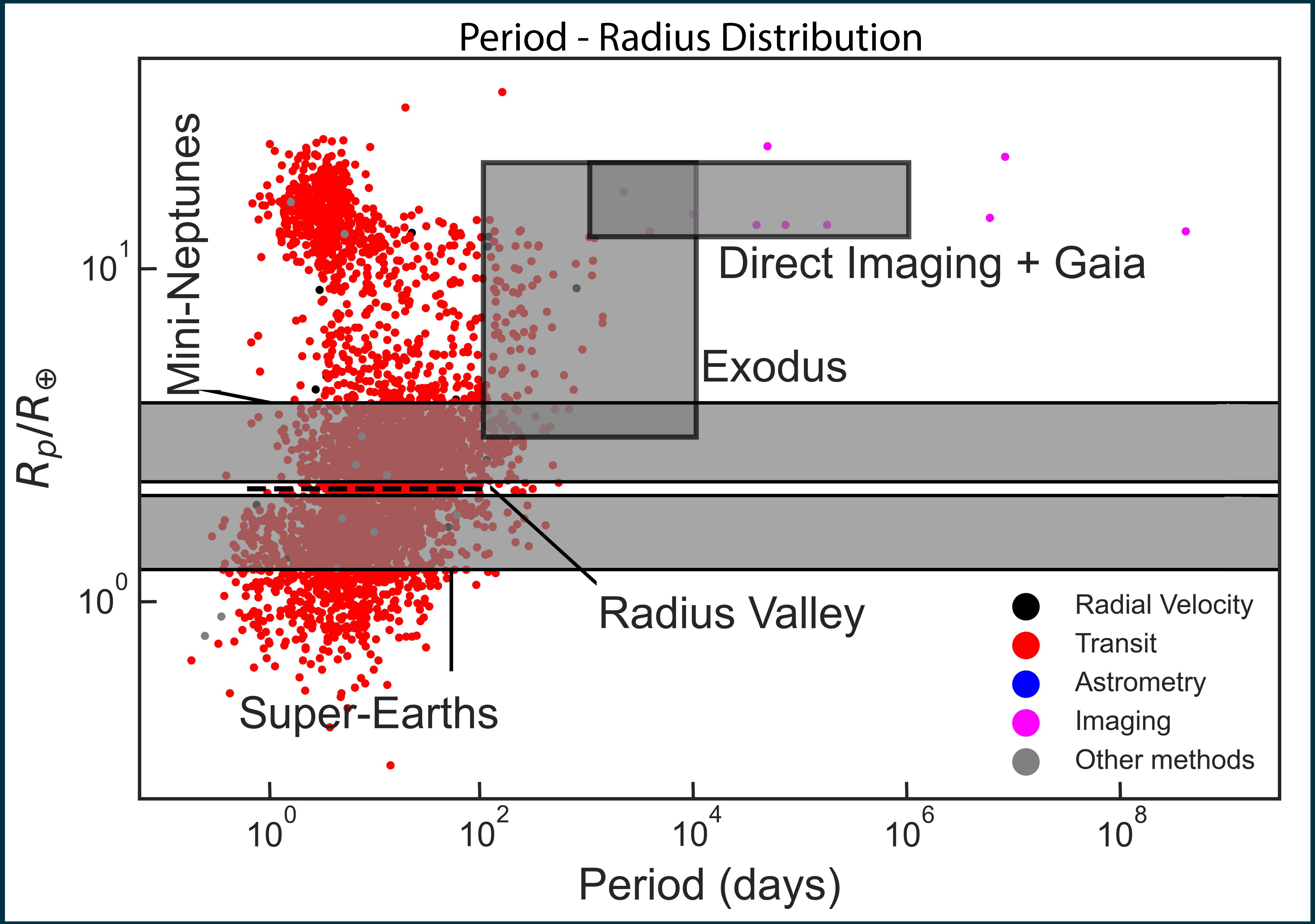
1. Establish which process is responsible for atmospheric escape.

2. Determine the magnitude of atmospheric escape on exoplanets.

3. Establish whether there is a radius valley for long period (>100 days) planets.

QUESTION 2

What proportion of the exoplanet population do giant planets with long orbital periods represent?



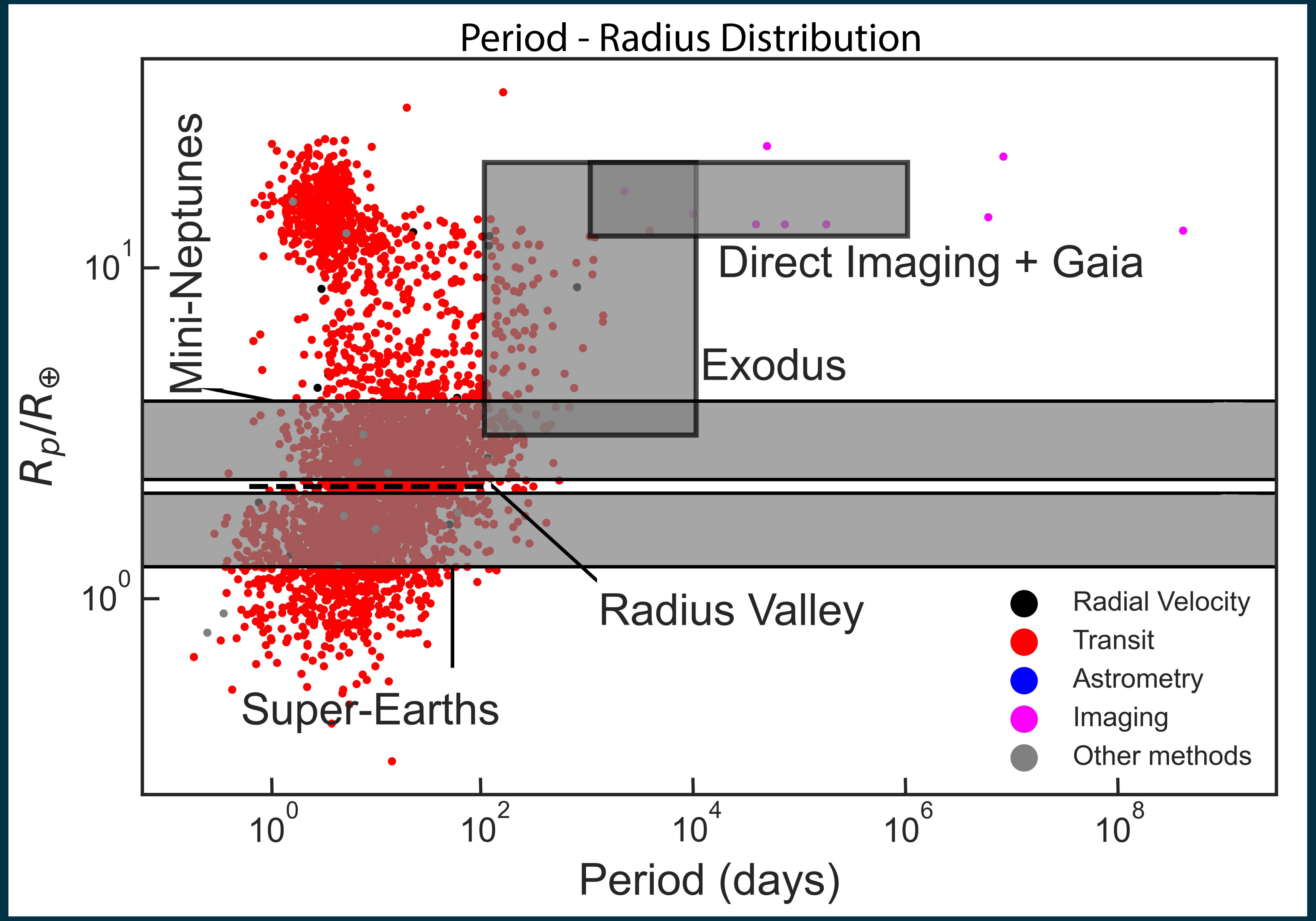
Vito Saggese

QUESTION 2

What proportion of the exoplanet population do giant planets with long orbital periods represent?

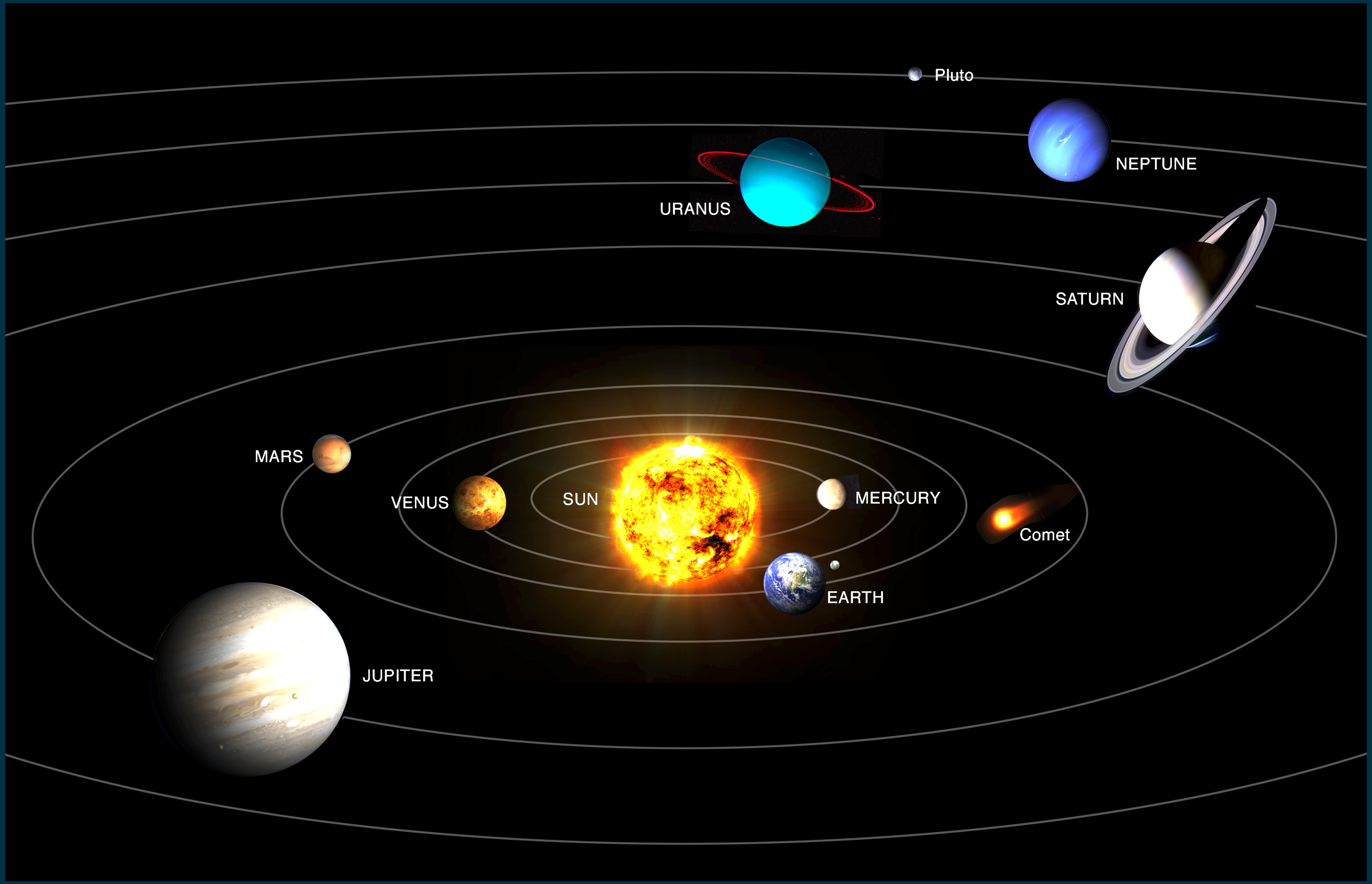
Objectives Detection

1. Update the period-radius diagram with detections of giant planets on long orbital periods.



QUESTION 3

How does the solar system architecture compare to that of exoplanet systems?



NASA/CXC/M.Weiss

QUESTION 3

How does the solar system architecture compare to that of exoplanet systems?

Objectives Architecture

1. Establish the occurrence rate of systems with inner rocky planets and outer giant planets.
2. Determine whether sub-Neptune planets on long orbital periods exist.

Science Requirements

SCI-01 Detection of atmospheric escape through direct observation of the He triplet at 1083nm in reflected light

SCI-02 UV Measurement of the stellar activity of host stars

SCI-03 Individual measurement of single planets in multi planet systems

SCI-04 Observation of exoplanets with R > 3 Earth radii

SCI-05 Observation of exoplanets with orbital period >100 days

SCI-06 Observation of exoplanets around varying host stars

SCI-07 Observe a core sample of 5000 exoplanets

Observation Requirements

OBR-01	Perform direct, spatially resolved spectroscopy of the planet system in NIR (1000-1500 nm)
OBR-02	Perform simultaneous UV photometric measurements of the star
OBR-03	Detection of exoplanets with contrast ratio of $10E^{-9}$
OBR-04	Detection of exoplanets at minimum separation of 0.17 arcsec
OBR-05	Spectrophotometry of exoplanet systems with a distance to earth of up to 100 pc
OBR-06	Spectroscopy measurements with SNR>5

Mission Requirements

MR-1 The mission design shall allow for the observation of the target sample within 5 years

MR-2 At least 30% of the sky shall be observable at all time

MR-3 The launcher shall be able to transport the spacecraft to Lagrange point 2 (L2)

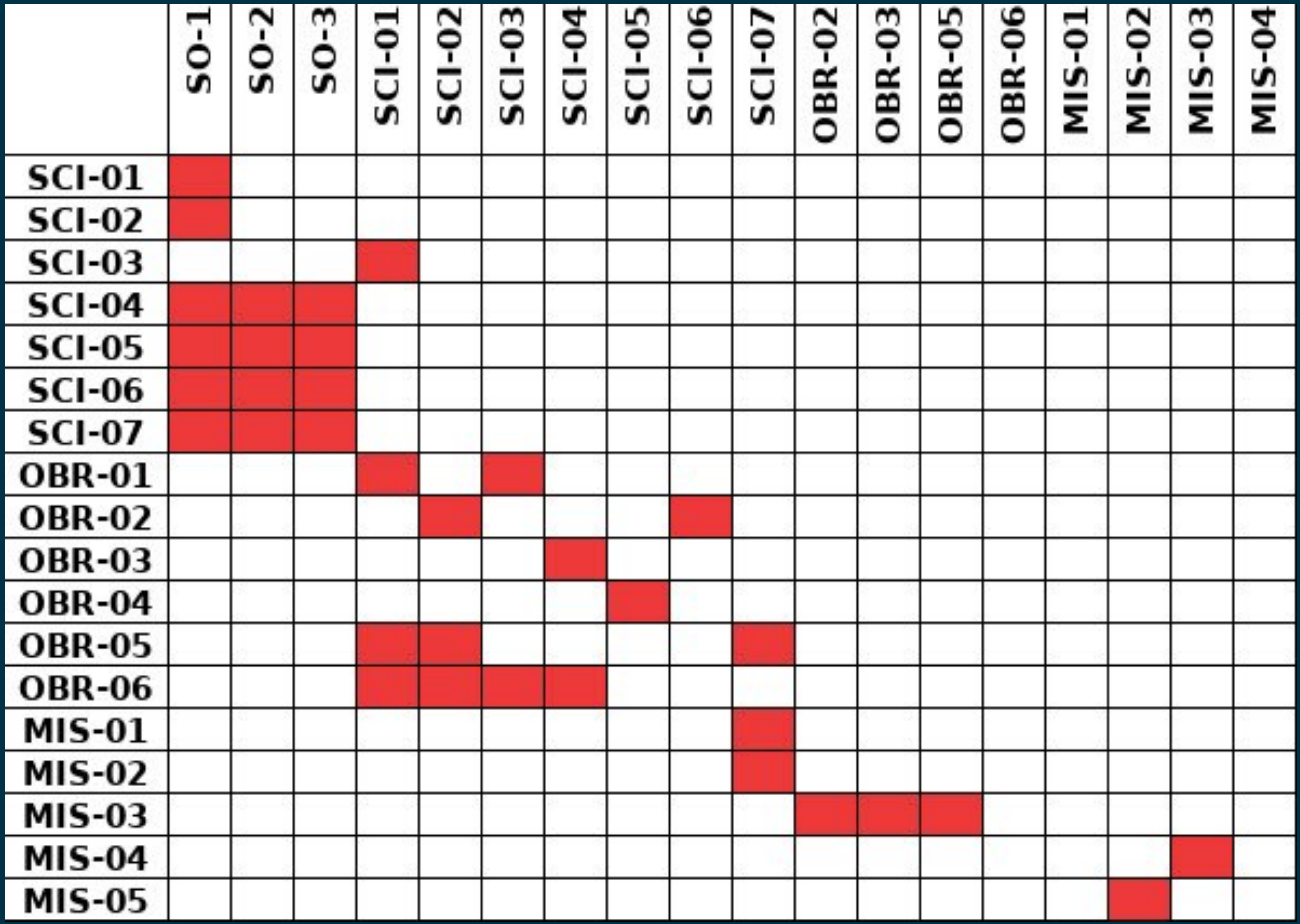
MR-4 Spacecraft total wet mass shall not be over 3300 kg after all the margins

MR-5 The spacecraft shall ensure that the angle to the sun never exceeds:
+/- 10° (x-axis)
+/- 22° (y-axis)
+ 10° / - 21° (z-axis)

Primary Science Questions		Science Objectives		Science Requirements	Observational Requirements
Q1	How does atmospheric escape shape the evolution of long orbital period exoplanets?	O1	Characterisation		
		O1.1	Distinguish the physical processes responsible for atmospheric escape, namely stellar UV flux or core-powered mass loss.	SCI-01, SCI-02, SCI-06	OBR-01, OBR-02, OBR-05, OBR-06
		O1.2	Determine the magnitude of atmospheric escape on exoplanets, with respect to orbital period, planet radius and stellar type.	SCI-01, SCI-02, SCI-06	OBR-01, OBR-02, OBR-05, OBR-06
		O1.3	Establish whether or not the radius valley exists for high-period planets.	SCI-03, SCI-04, SCI-05	OBR-03, OBR-04, OBR-05, OBR-06
Q2	What proportion of the exoplanet population do giant planets on long orbital periods represent?	O2	Detection		
		O2.1	Update the period-radius diagram with detections of giant planets on large orbital periods	SCI-01, SCI-02, SCI-05, SCI-07	OBR-01, OBR-02, OBR-04, OBR-05, OBR-06
Q3	How does the solar system architecture compare to that of exoplanetary systems?	O3	Contextualisation		
		O3.1	Establish the occurrence rate of systems with inner rocky planets and outer giant planets	SCI-03, SCI-04 SCI-05, SCI-07	OBR-03, OBR-04, OBR-05, OBR-06
		O3.2	Establish whether sub-Neptunes exist on long period orbits	SCI-04, SCI-05	OBR-03, OBR-04, OBR-06

Traceability Matrix

20% of the total traceability matrix



	SO-1	SO-2	SO-3	SCI-01	SCI-02	SCI-03	SCI-04	SCI-05	SCI-06	SCI-07	OBR-02	OBR-03	OBR-05	OBR-06	MIS-01	MIS-02	MIS-03	MIS-04
SCI-01	🟥																	
SCI-02	🟥																	
SCI-03				🟥														
SCI-04	🟥	🟥	🟥															
SCI-05	🟥	🟥	🟥															
SCI-06	🟥	🟥	🟥															
SCI-07	🟥	🟥	🟥															
OBR-01				🟥		🟥												
OBR-02					🟥				🟥									
OBR-03							🟥											
OBR-04								🟥										
OBR-05				🟥	🟥					🟥								
OBR-06				🟥	🟥	🟥	🟥											
MIS-01										🟥								
MIS-02										🟥								
MIS-03											🟥	🟥	🟥					
MIS-04																	🟥	
MIS-05																🟥		

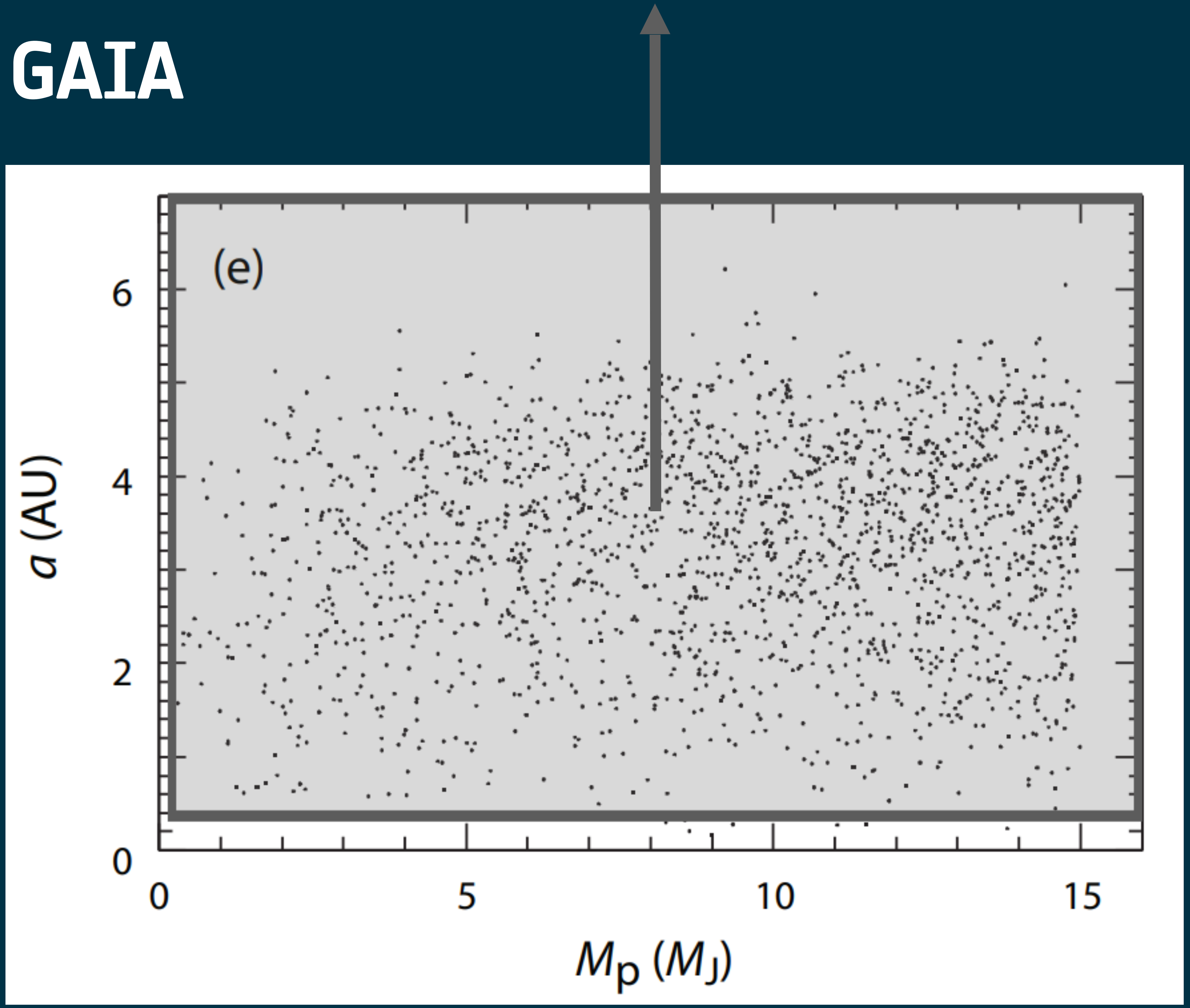
Gerald Mösenlechner

Traceability Example

Science Question	How does the solar system architecture compare to that of exoplanetary systems?
Science Objective O 3.2	Establish whether sub-Neptunes exist on long period orbits.
Science Req SCI-0:	Observation of exoplanets with R > 3 Earth radii
Observation Req OBR-03	Detection of exoplanets with contrast ratio of 10^{-9}
Payload Req PLD-12	The MARY Coronagraph shall be able to achieve a target star/planet contrast ratio of up to 10^{-9}.

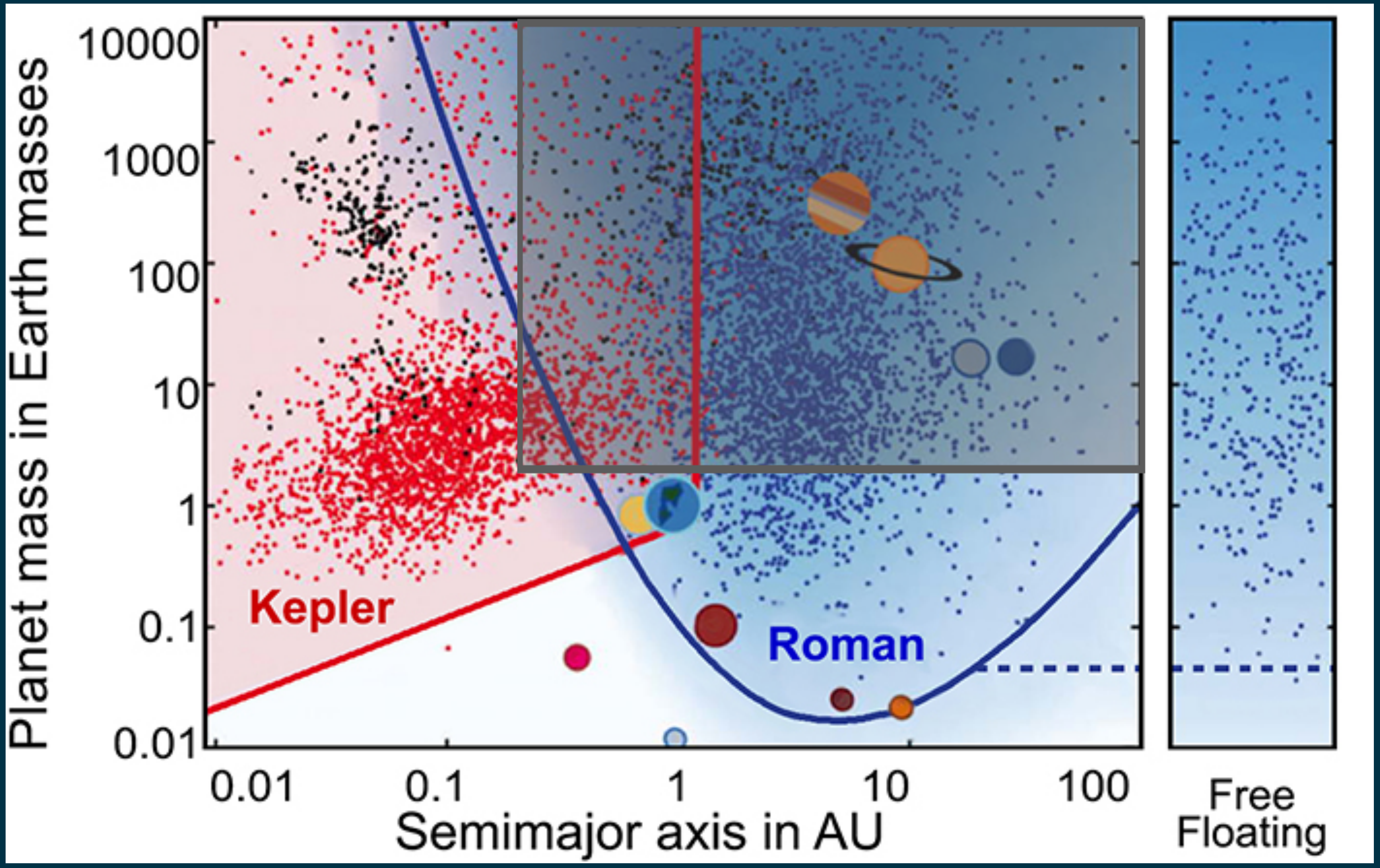
Complementary Missions

GAIA



Perryman et al. 2014

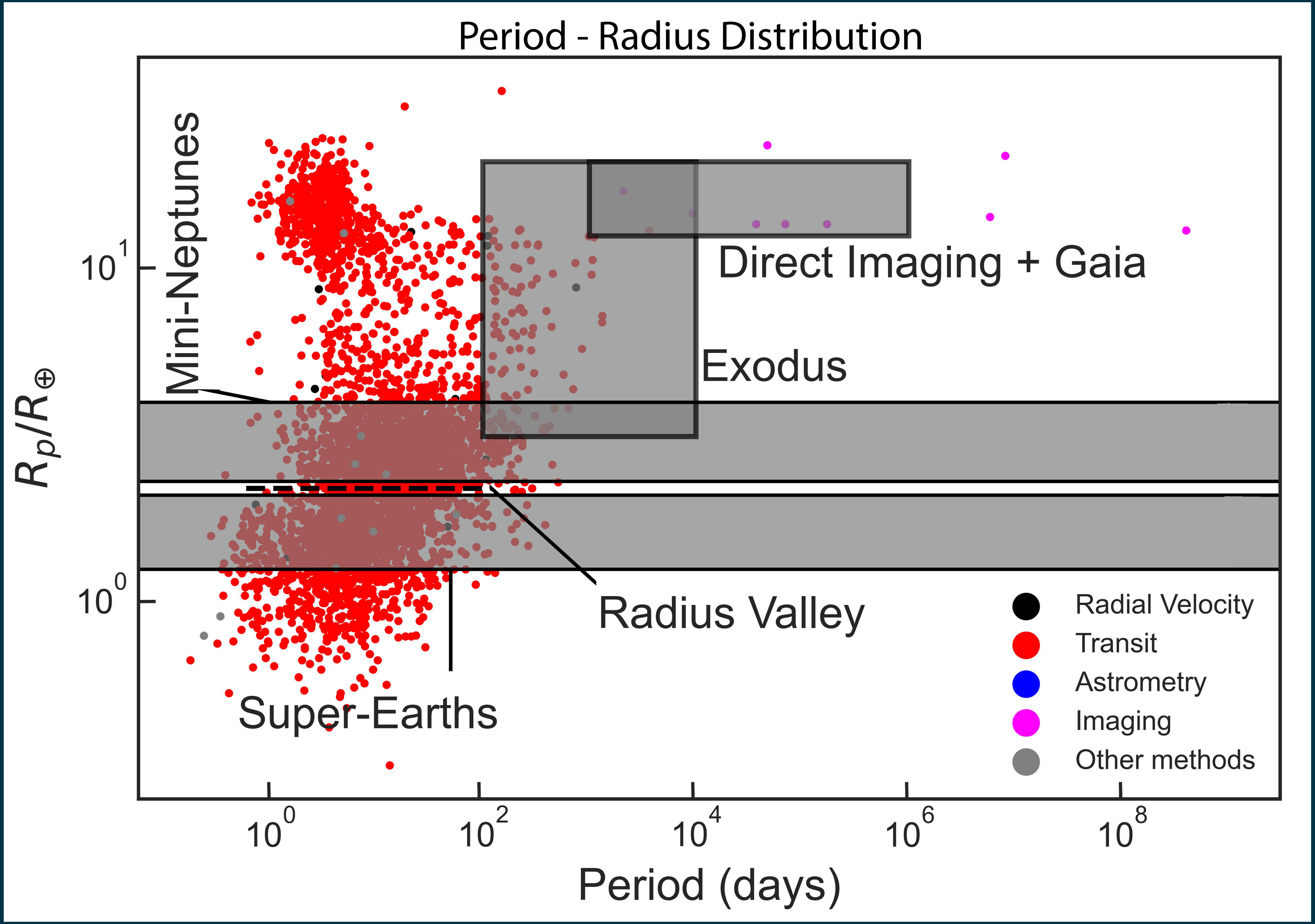
Nancy Grace Roman Space Telescope



Spergel et al. 2015

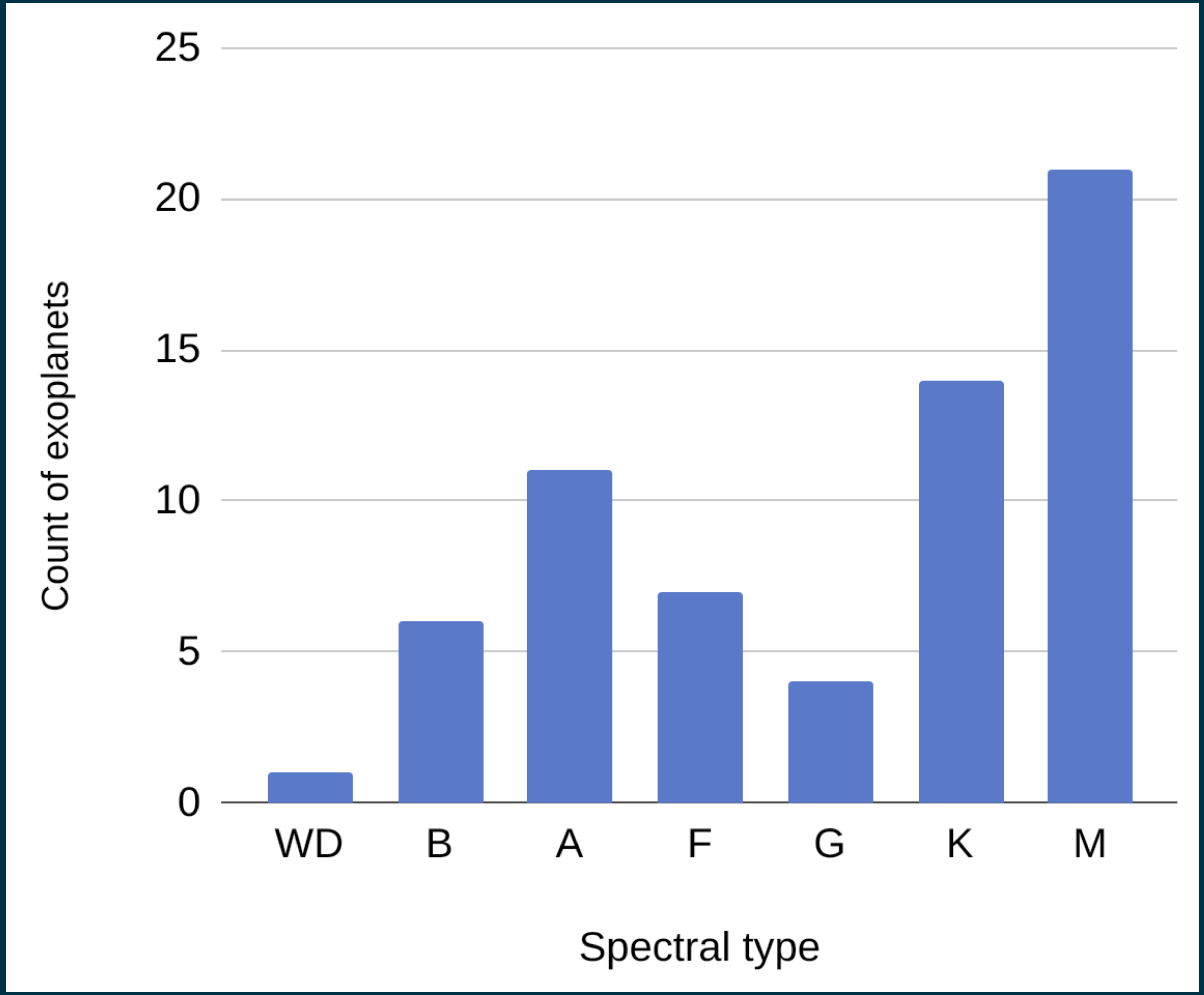
TARGETS

Direct Imaging



Vito Saggese

Guaranteed Targets



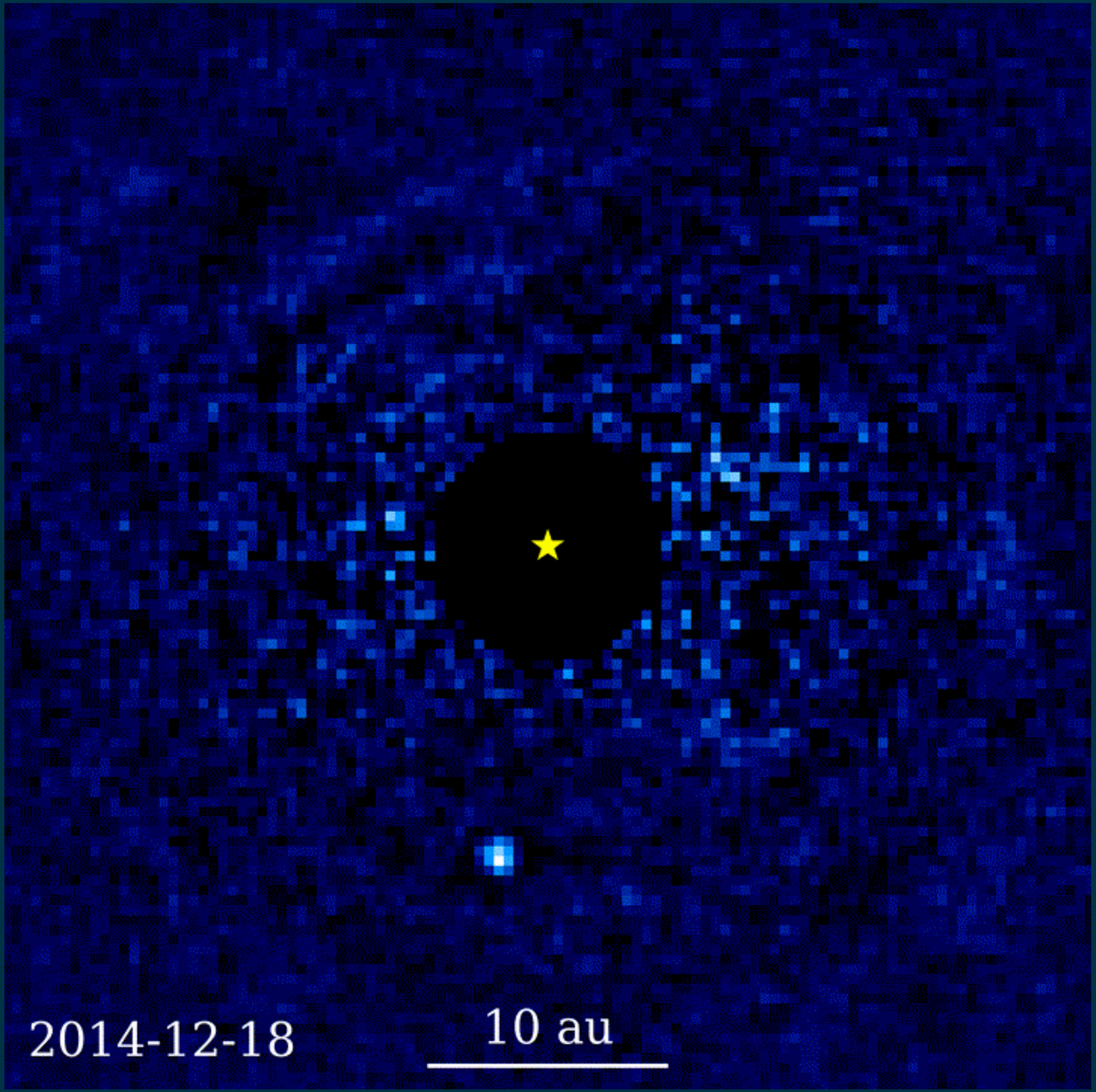
Selection of already directly imaged targets

Name	Orbital Distance (au)	Sp. Type	Distance (pc)
AF Lep b	8.4	F	26.8564
HD 206893 b	9.6	F	40.7583
bet Pic b	10.018	A	19.7442
51 Eri b	13.2	F	29.7575
2MASS J04414489+2301513 b	15	M	122.217
HR 8799 e	16.4	A	41.2441
PZ Tel b	27	G	47.0648
GJ 504 b	43.5	G	17.5299
kap And b	55	B	50.0177
mu2 Sco b	242.4	B	145.807

Marco Souza de Joode

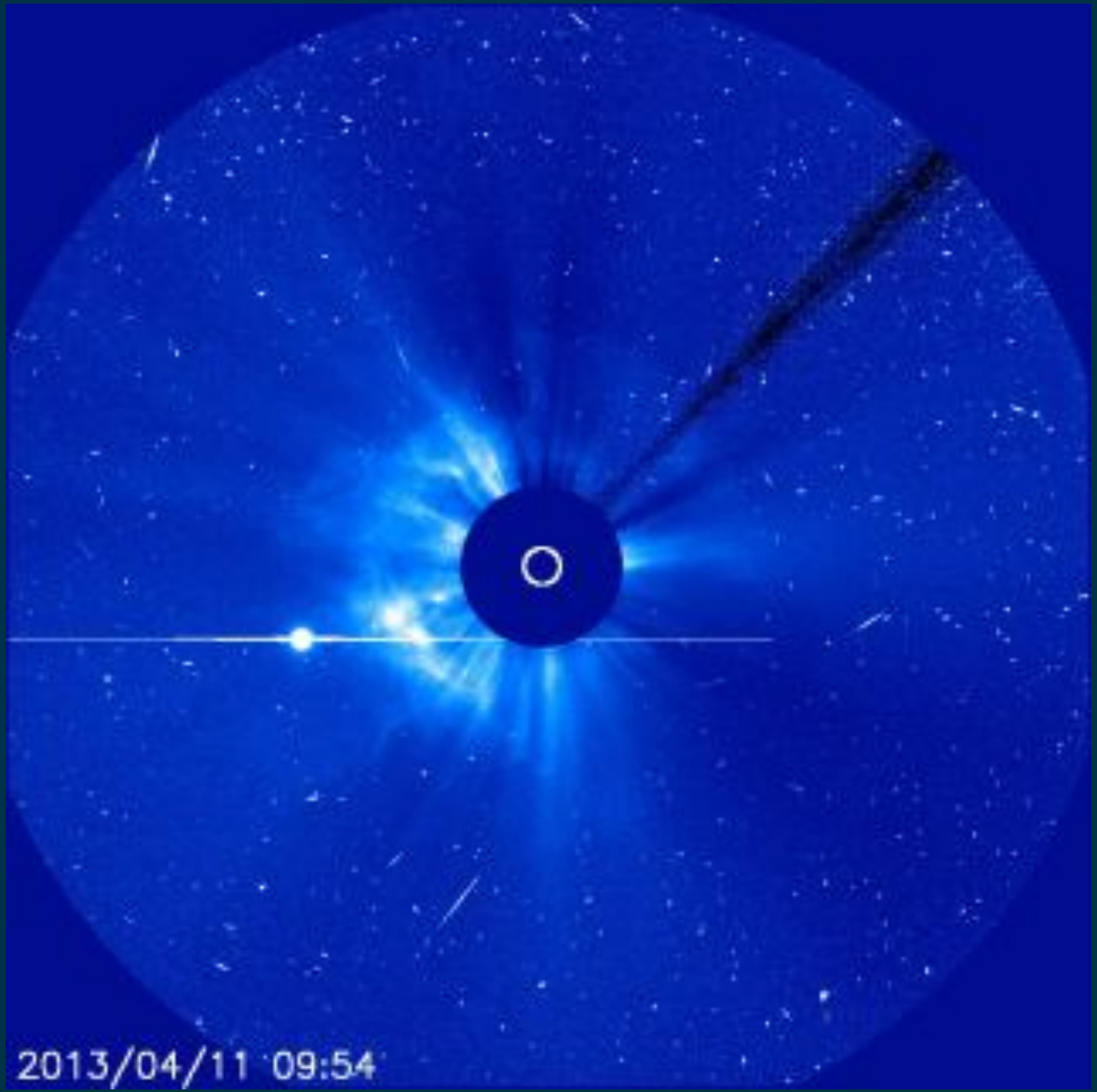
Example Target
51 Eri b

Radius	1 R_J
Mass	2 M_J
Period	28 years
Semi major axis	11 au

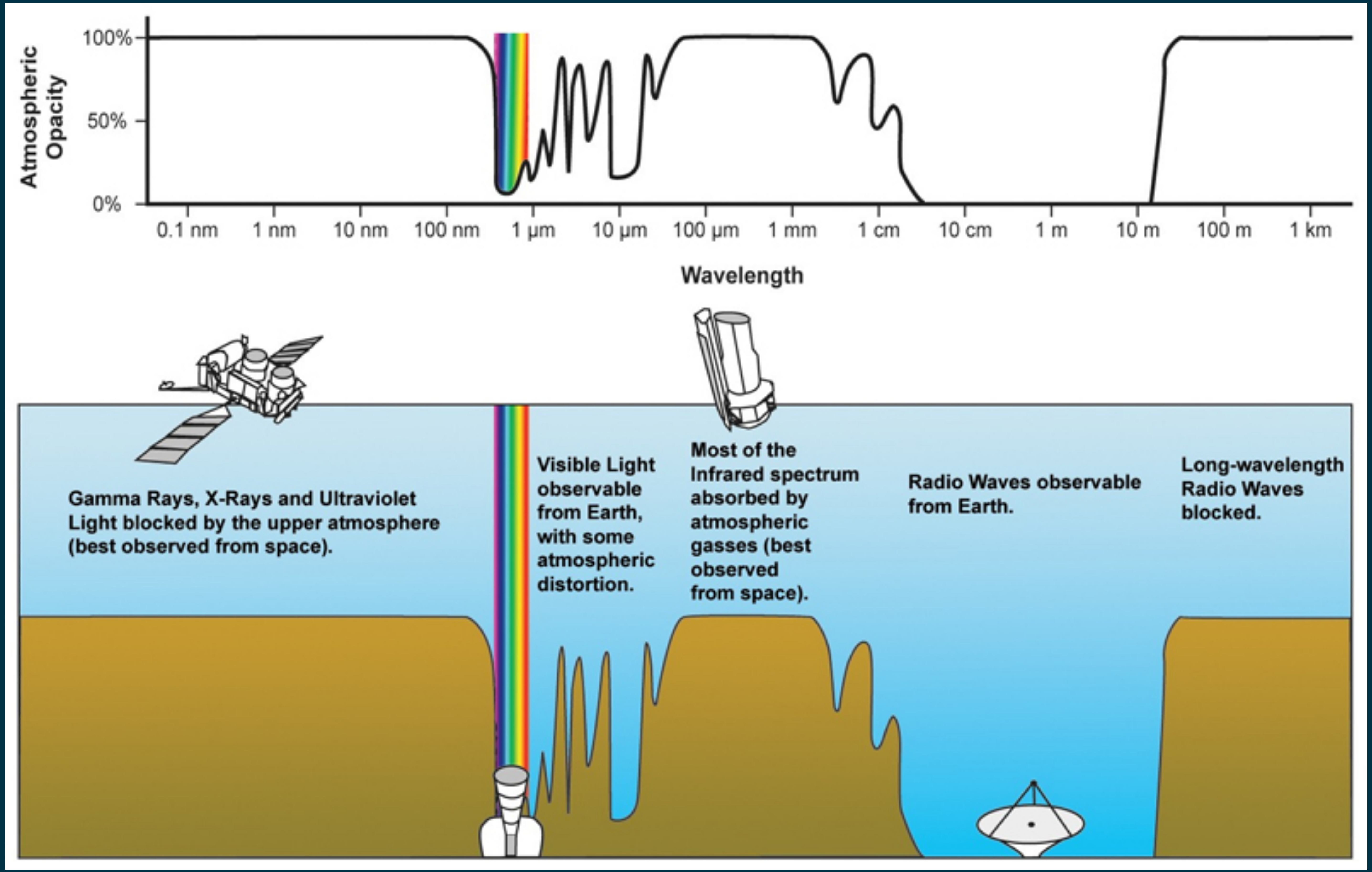


Wang et al. 2014

Why space-based?

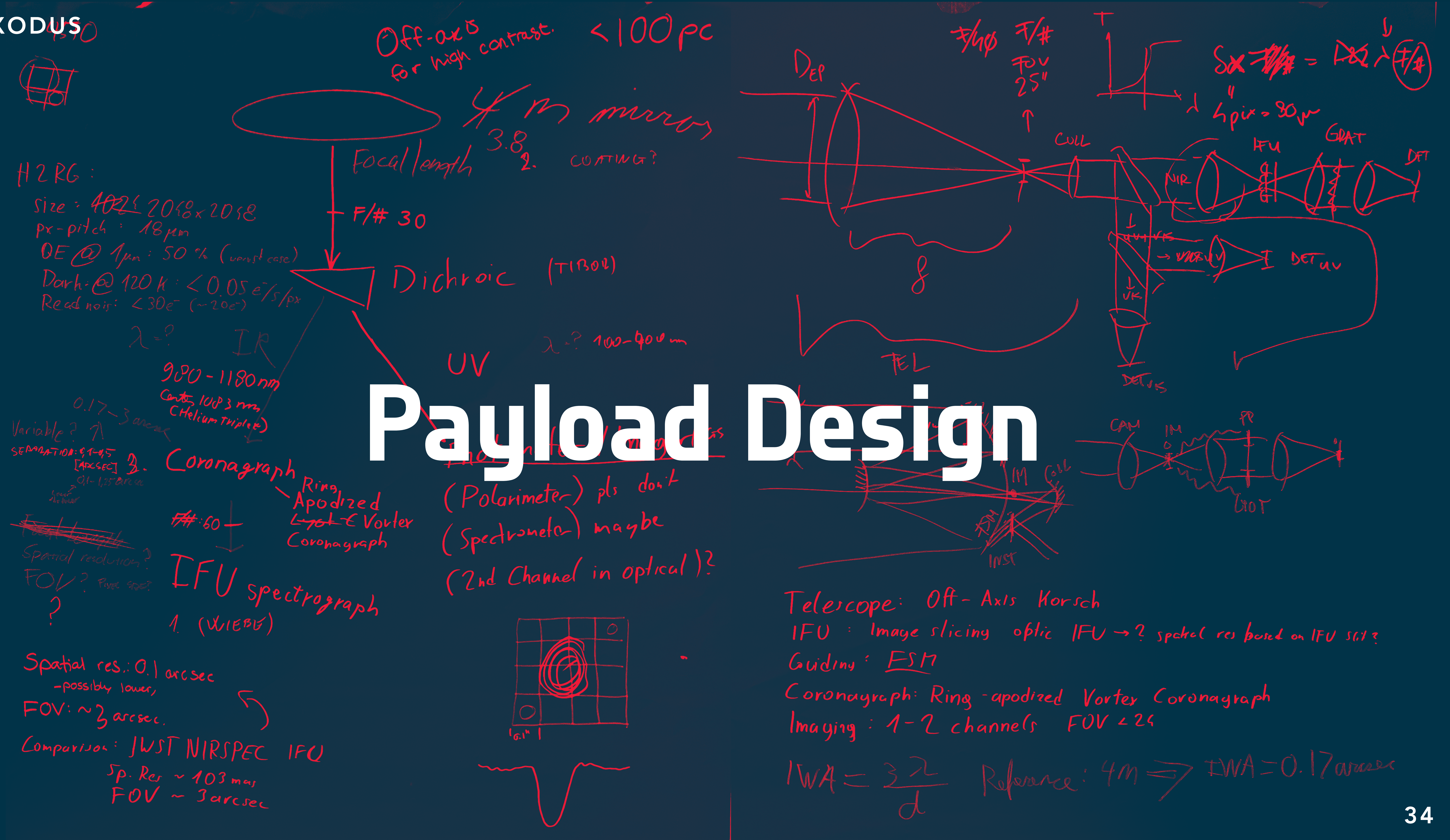


ESA&NASA/SOHO/GSFC



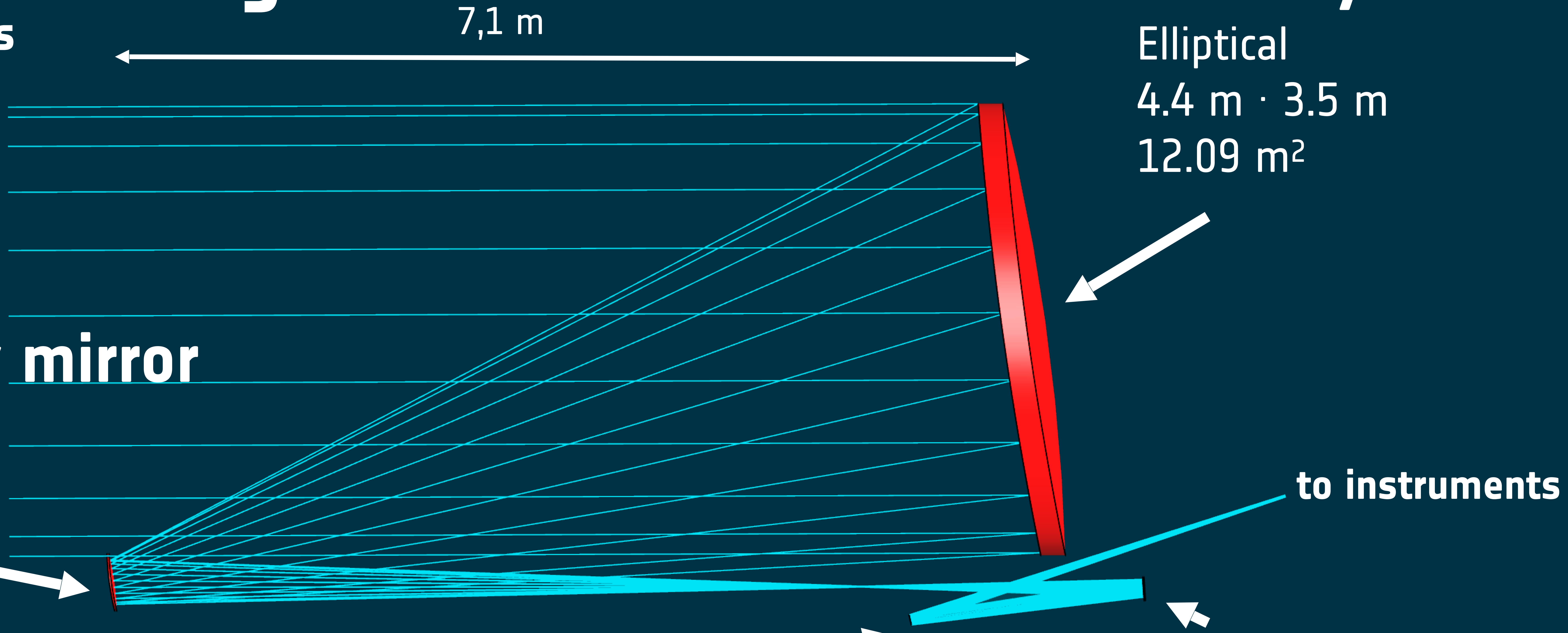
NASA

Payload Design



Telescope Design

Elliptical off-axis
Korsch design



Primary mirror

Elliptical
4.4 m · 3.5 m
12.09 m²

Secondary mirror

Elliptical
0.6 m · 0.44 m
0.21 m²

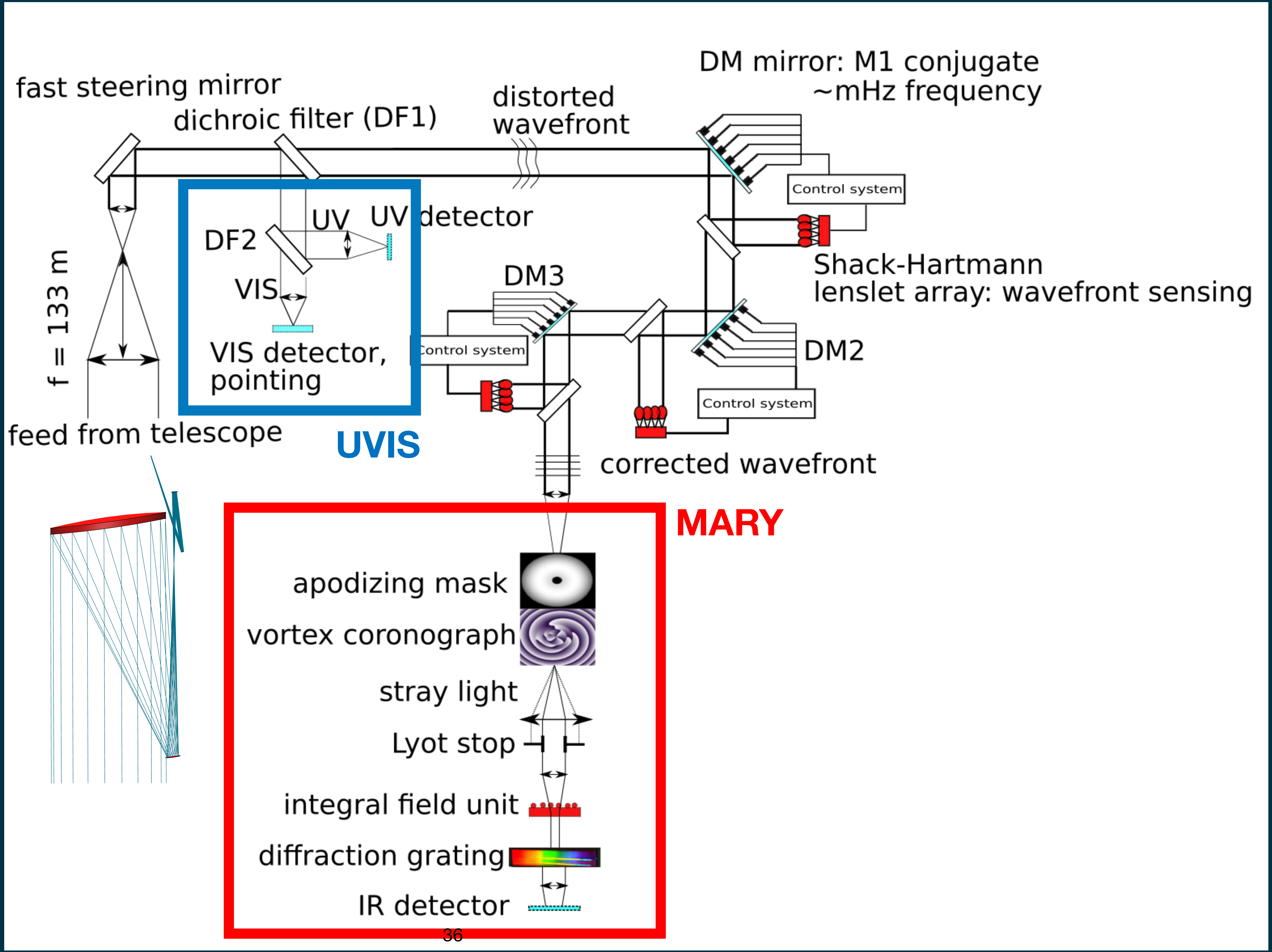
Fourth mirror

Cylindrical
D = 0.1 m
0.0078 m²

Third mirror

Elliptical
0.2 m · 0.18 m
0.028 m²

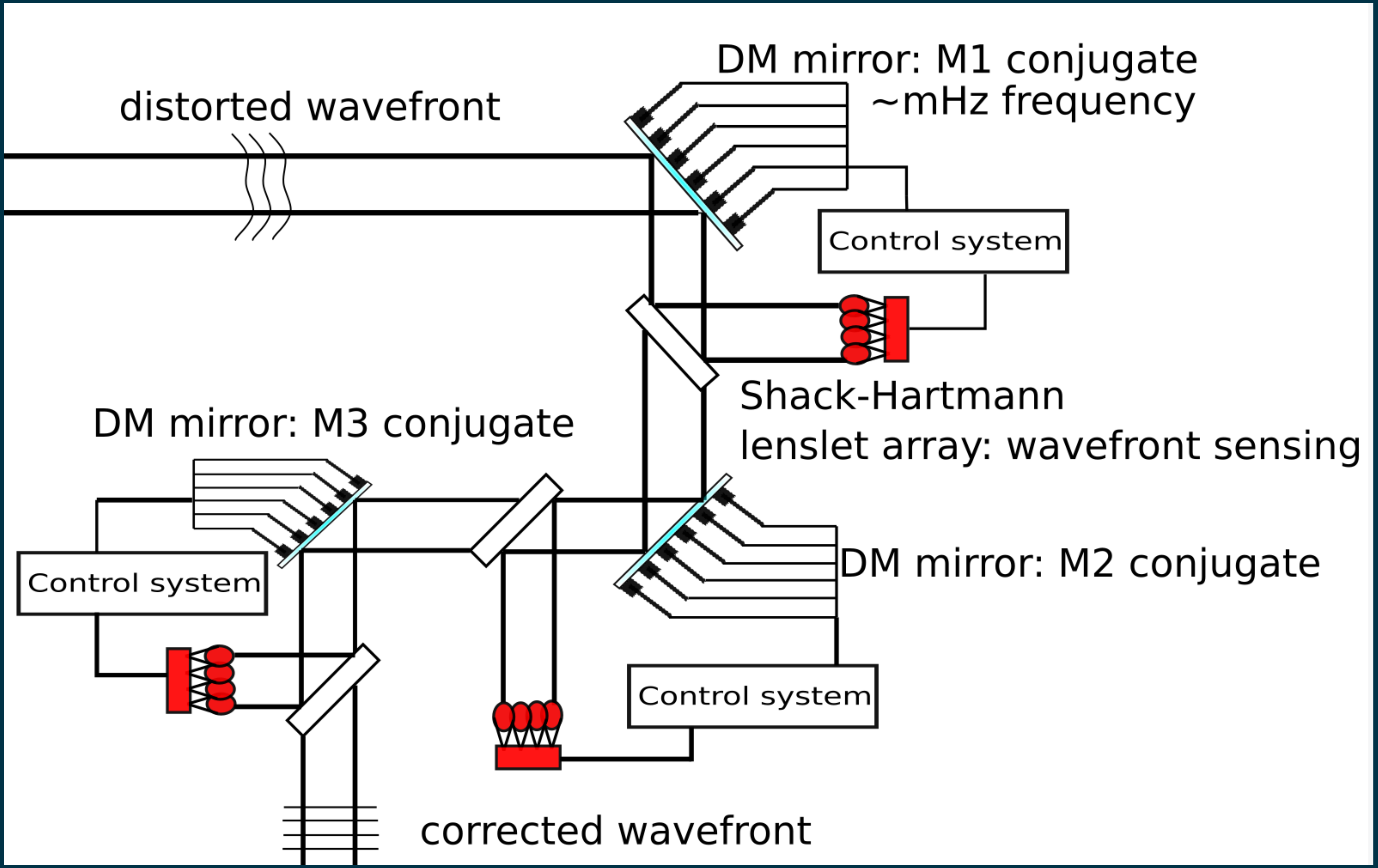
Optical System



Marco Souza de Joode

Adaptive Optics

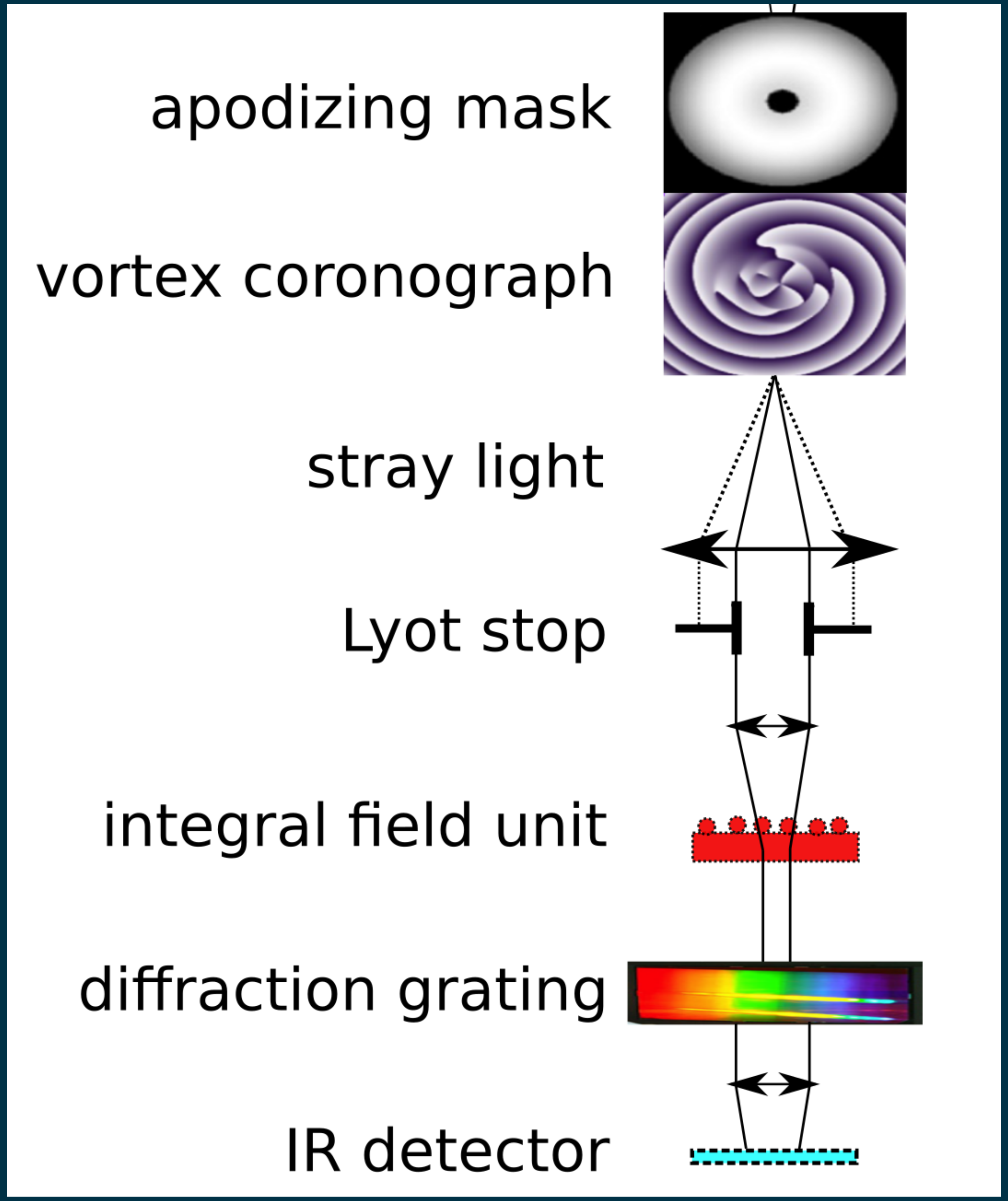
- Adaptive optics (AO) necessary to achieve excellent contrast
- Low frequency (mHz) compared to Earth based AO (kHz)
- Deformable mirrors (DM) are conjugates of telescopes mirrors
- Shack-Hartmann: measuring wavefront error
- Full frame image processing necessary



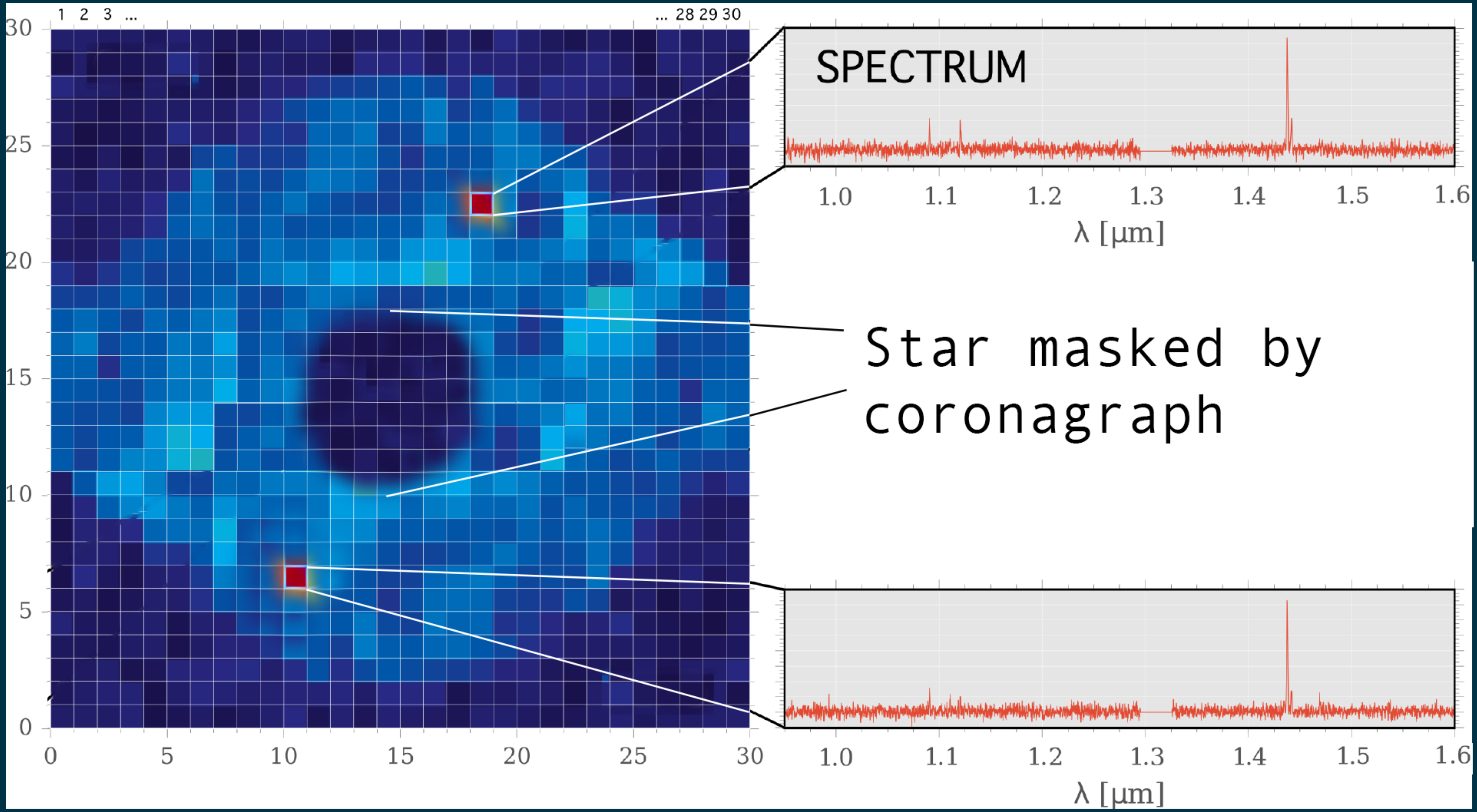
Souza de Joode 2023

MARY

Coronagraph + IFU Spectroscopy



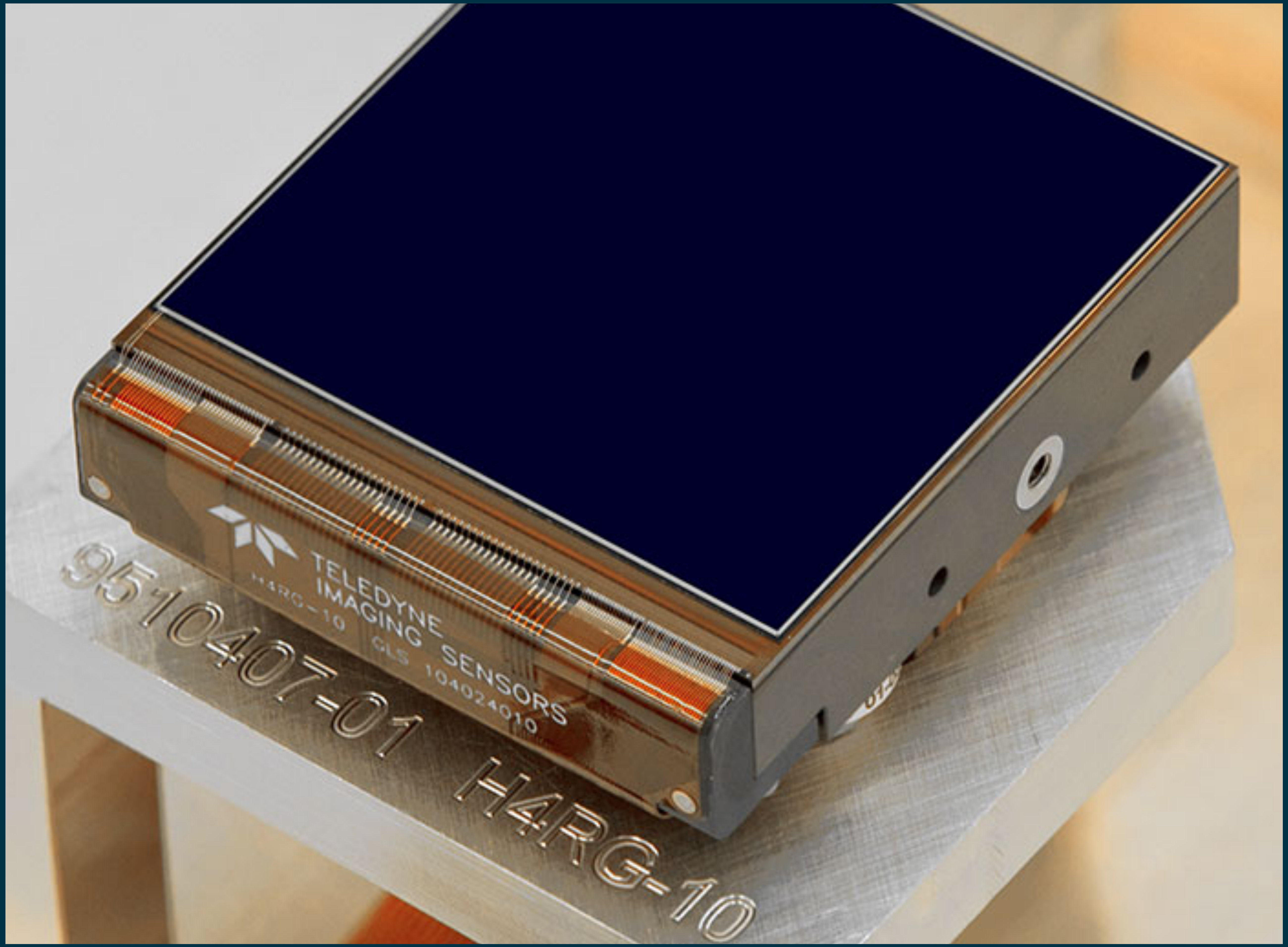
Marco Souza de Joode



Johannes Ora

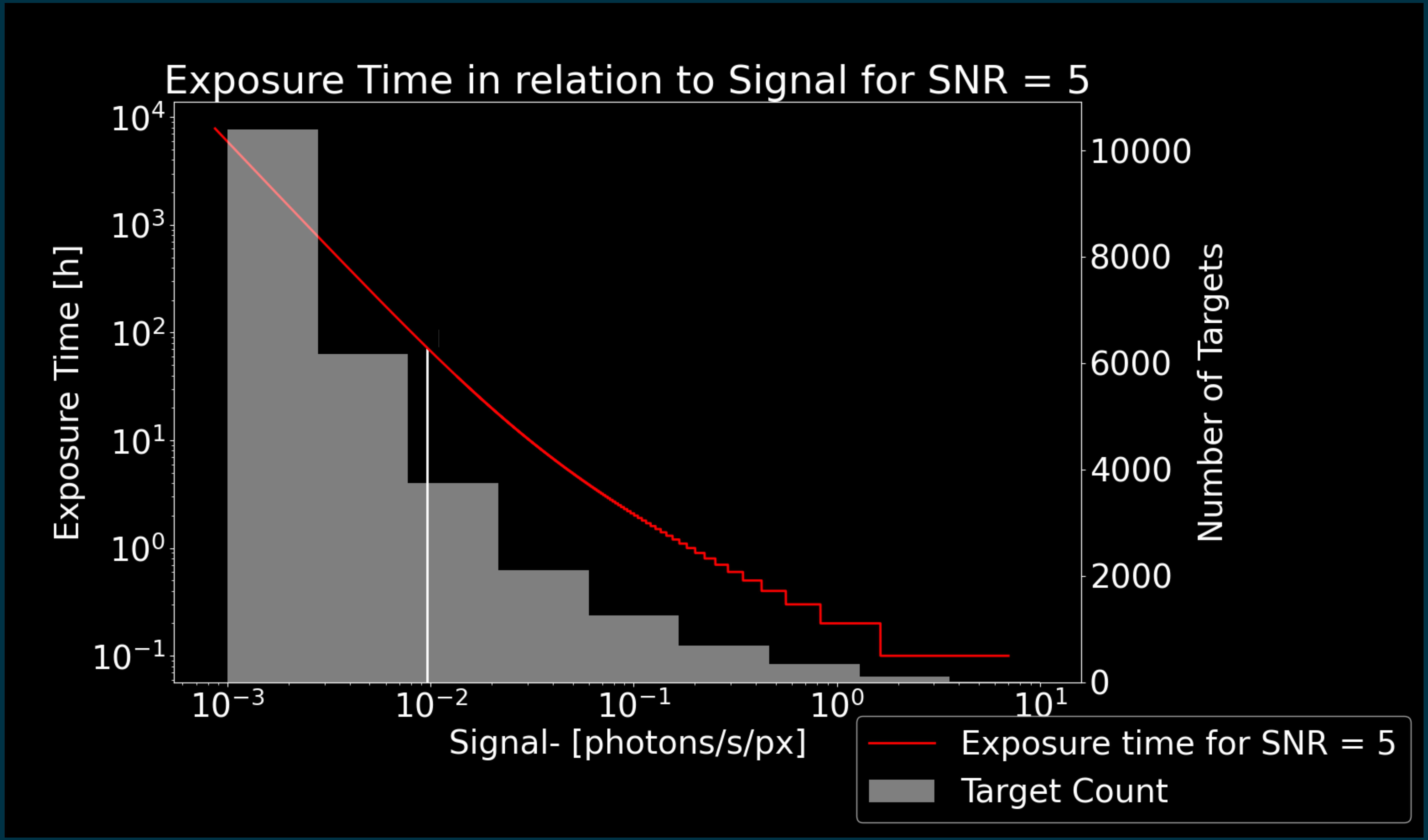
MARY Detector: Teledyne HAWAII 4RG

Wavelength range	980 – 1980 nm
Mean QE	⩾ 70%
Pixel Size	15 µm
Detector Size	4096 x 4096 px
Dark noise @ 120K	< 0.05 e^-/px/s
Read Noise	⩽ 10 e^-/px
Full Well Capacity	> 80000 e^-



Teledyne

Signal to Noise Ratio



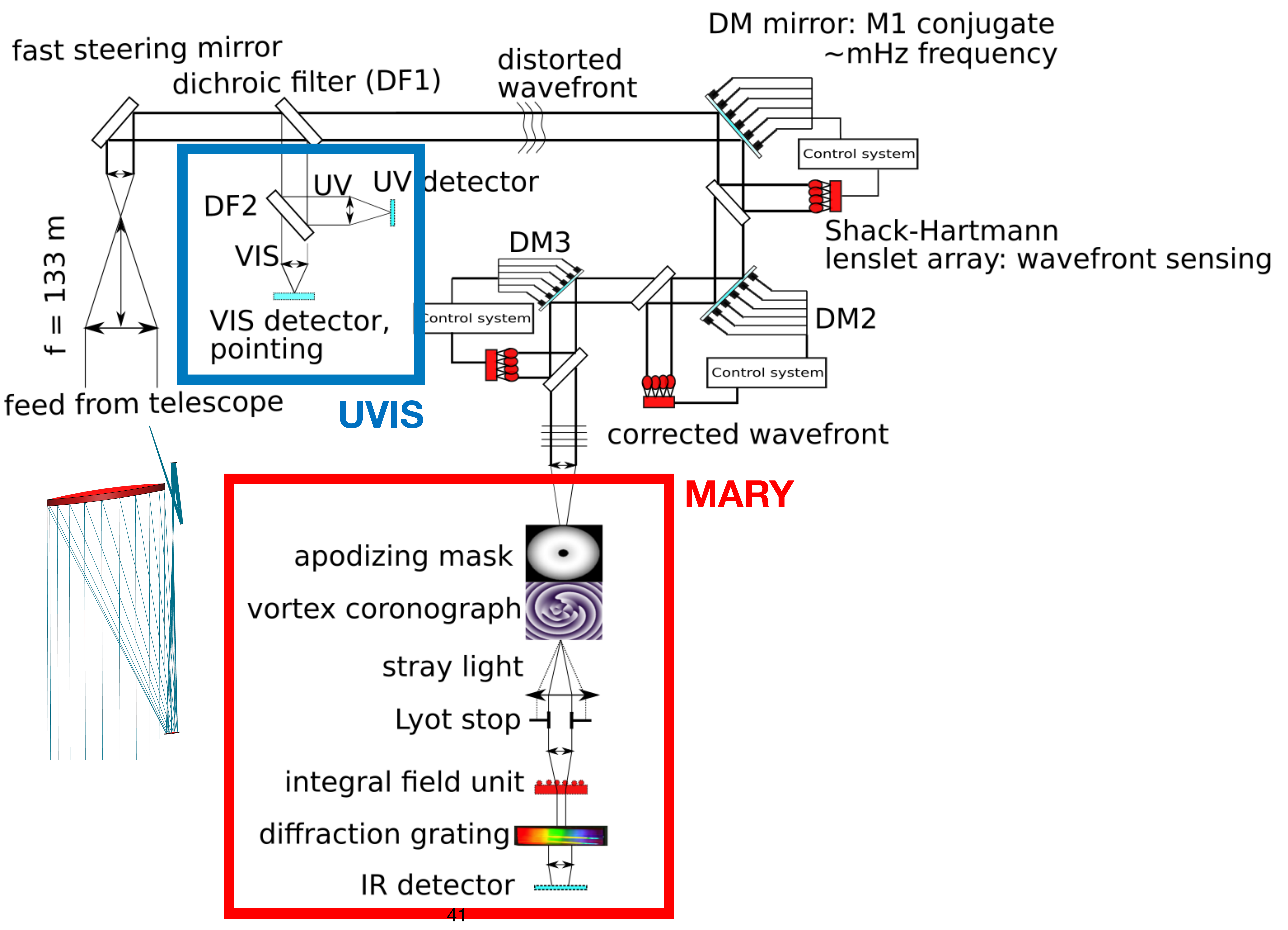
Gerald Mösenlechner

IFU, Teledyne H4RG

Detector Noise

Readout noise	10 e⁻/px rms
Dark current	0.01 e⁻/px/s
Background from Star	0.018 photon/s
System throughput	0.1

Optical System

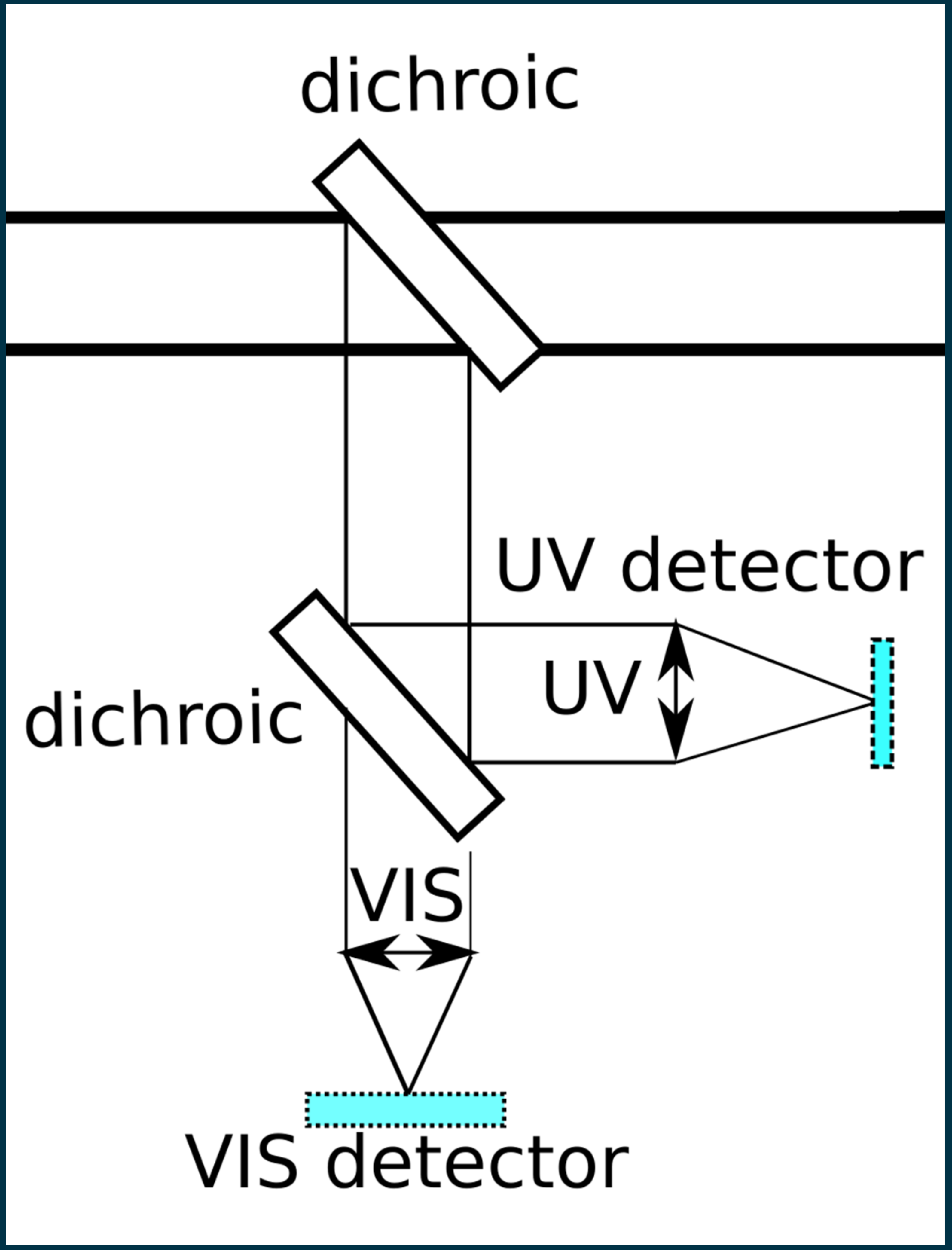


Marco Souza de Joode

UVIS

Photometry

- UV detector used for monitoring of the stellar UV flux (**photometry**)
- Visible light detector used for telescope pointing



Souza de Joode 2023

UVIS Detector
Best Case: Teledyne CMOS LACera

Wavelength range	100 - 800 nm
Mean QE (UV)	⩾ 50%
Mean QE (VIS)	⩾ 80%
Pixel Size	10 µm
Detector Size	⩽ 6000 x 6000 px
Dark noise @ 120K	0.01 e^-/px/s
Read Noise	⩽ 5 e^-/px
Full Well Capacity	> 135000 e^-

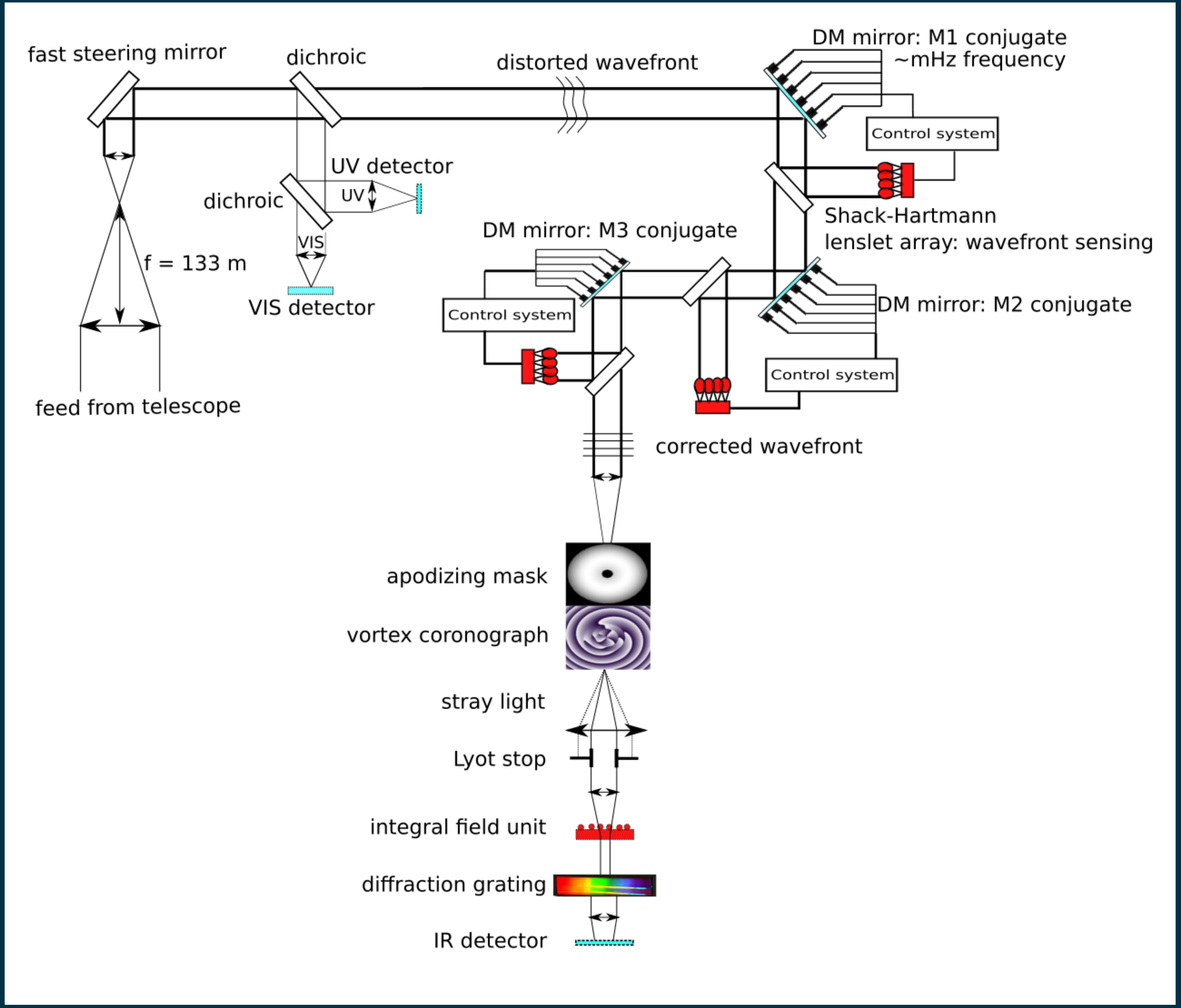
Advantages:

- Same detector technology for both channels
- Improved performance in UV compared to current space technology
- Favorable noise behaviour

Disadvantages:

- Not yet space qualified

Optical System TRL



Souza de Joode 2023

Component	TRL
Elliptical primary mirror	4
Elliptical off-axis secondary mirror	4
Elliptical off-axis tertiary mirror	4
Fast moving quaternary mirror	6
IR + (UV / VIS) dichroic	7
Visible light detector	7
UV detector	4
Deformable adaptive optics mirror	4
Shack-Hartmann array	7
Beam splitter in AO system	7
Elliptical vortex coronograph	3
Lyot stop	7
Integral field unit	7
Diffraction grating	7
IR detector	7

Mission Analysis

Mission Scenario

- Launch and early operations
- Commissioning
- Nominal Science Operations
- Extended Science Operations
- Decommissioning

Spacecraft

Dry mass	2193 kg
Wet mass	2386 kg

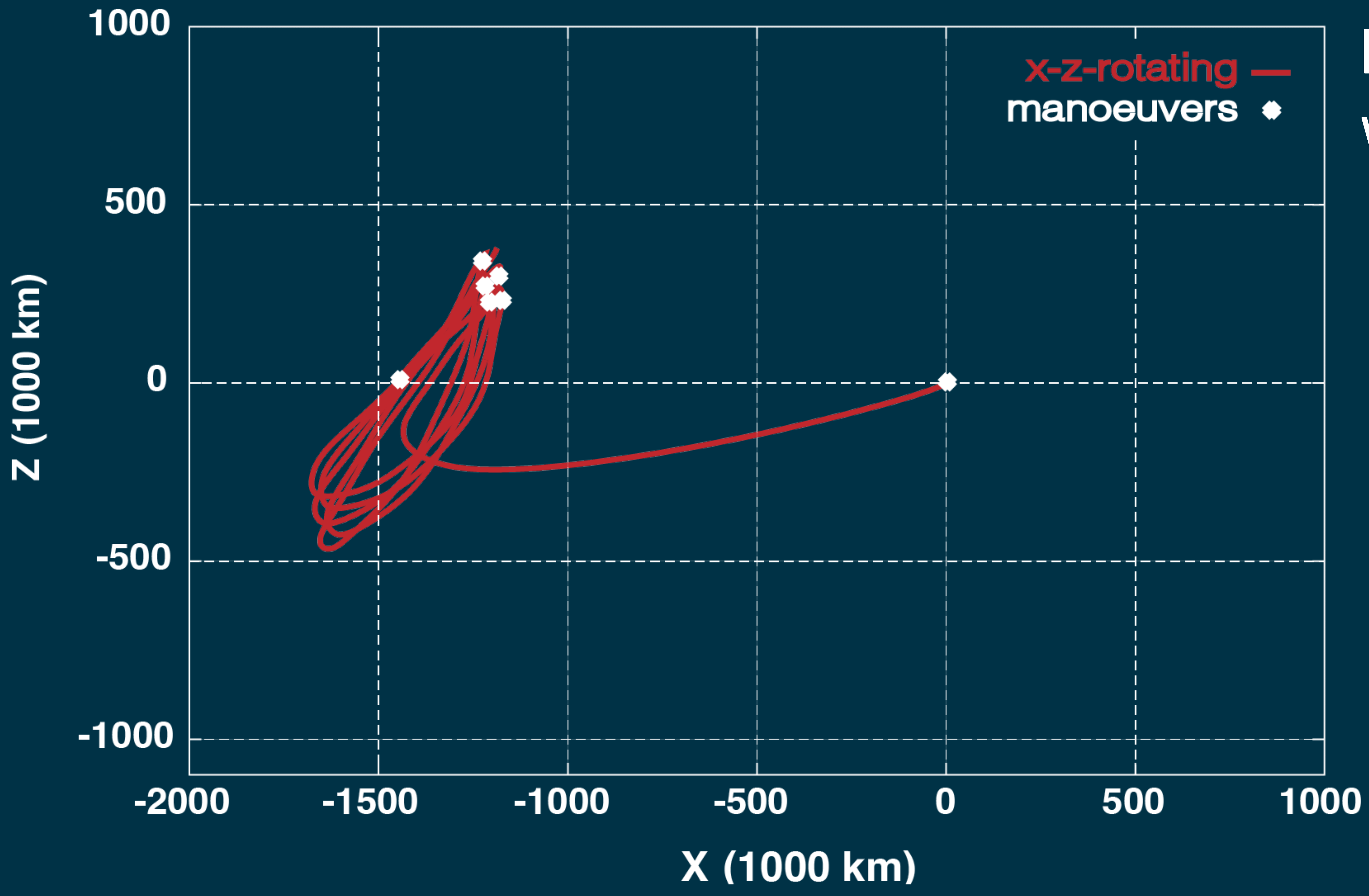
Launcher

Ariane 62 capacity for Earth escape: 3300 kg

- **Launch and early operations**
- Commissioning
- Nominal Science Operations
- Extended Science Operations
- Decommissioning

Δv

Injection contingency	50 m/s
Stationkeeping	25 m/s
Decomissioning	10 m/s
Total w/ margin	127.5 m/s



Lissajous L2 orbit with large amplitude

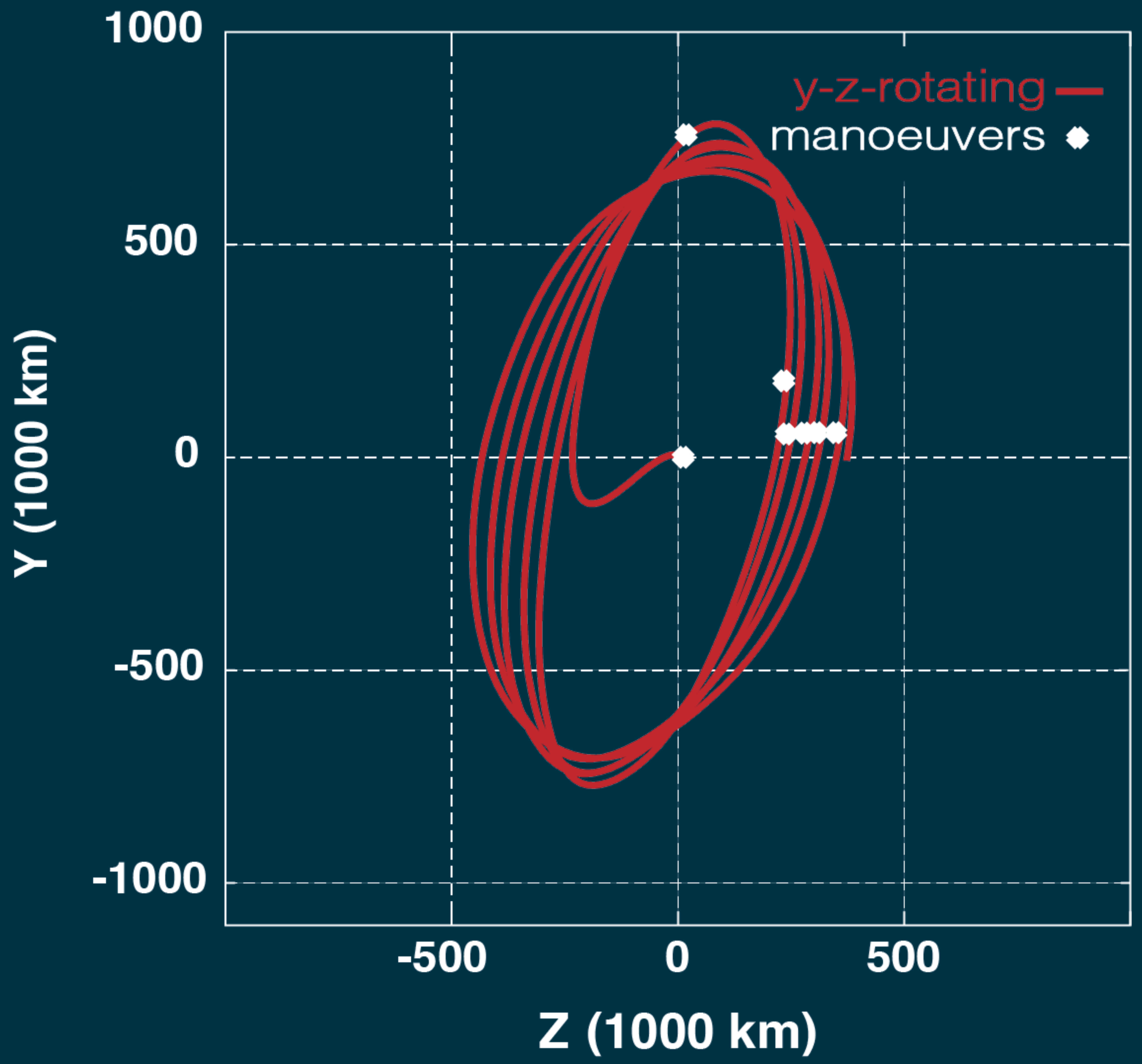
Launch and early operations

Commissioning

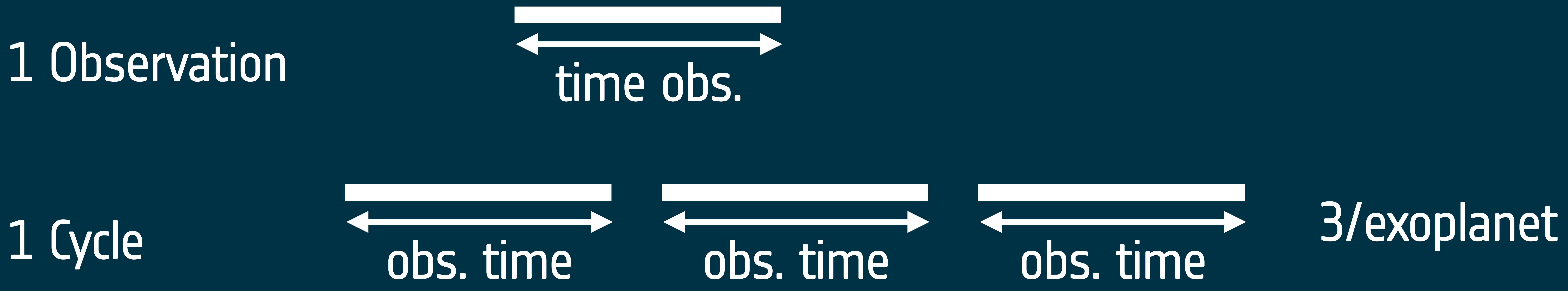
Nominal Science Operations

Extended Science Operations

Decommissioning



Observation Strategy



1 Observation

time obs.

1 Cycle

obs. time

obs. time

obs. time

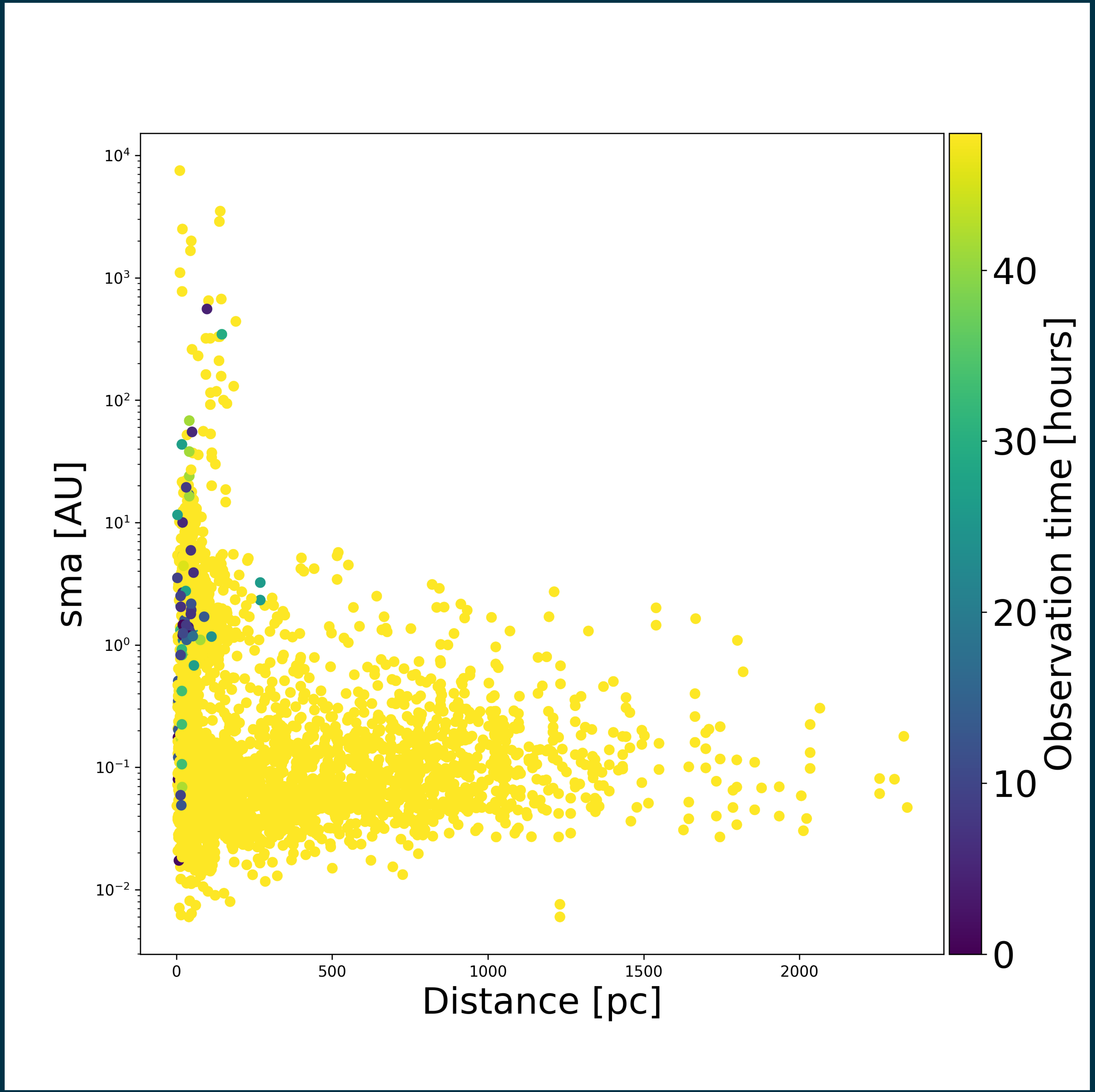
3/exoplanet

▪ Dedicated target observation	3 cycles/exoplanet
▪ Long exposure target observation	1 cycle/exoplanet
▪ Survey	1 observation

Observation Time

Photon flux calculated for	
Contrast to host star	10^{-9} **System Driver**
Spectral resolution	1 nm
Photon threshold	300 photons/spectral bin

From exoplanet catalog:
107 exoplanets detectable within 2 days of observation



Mireia Leon Dasi

Observation Time

Monte Carlo for potential exoplanets

Assumptions:

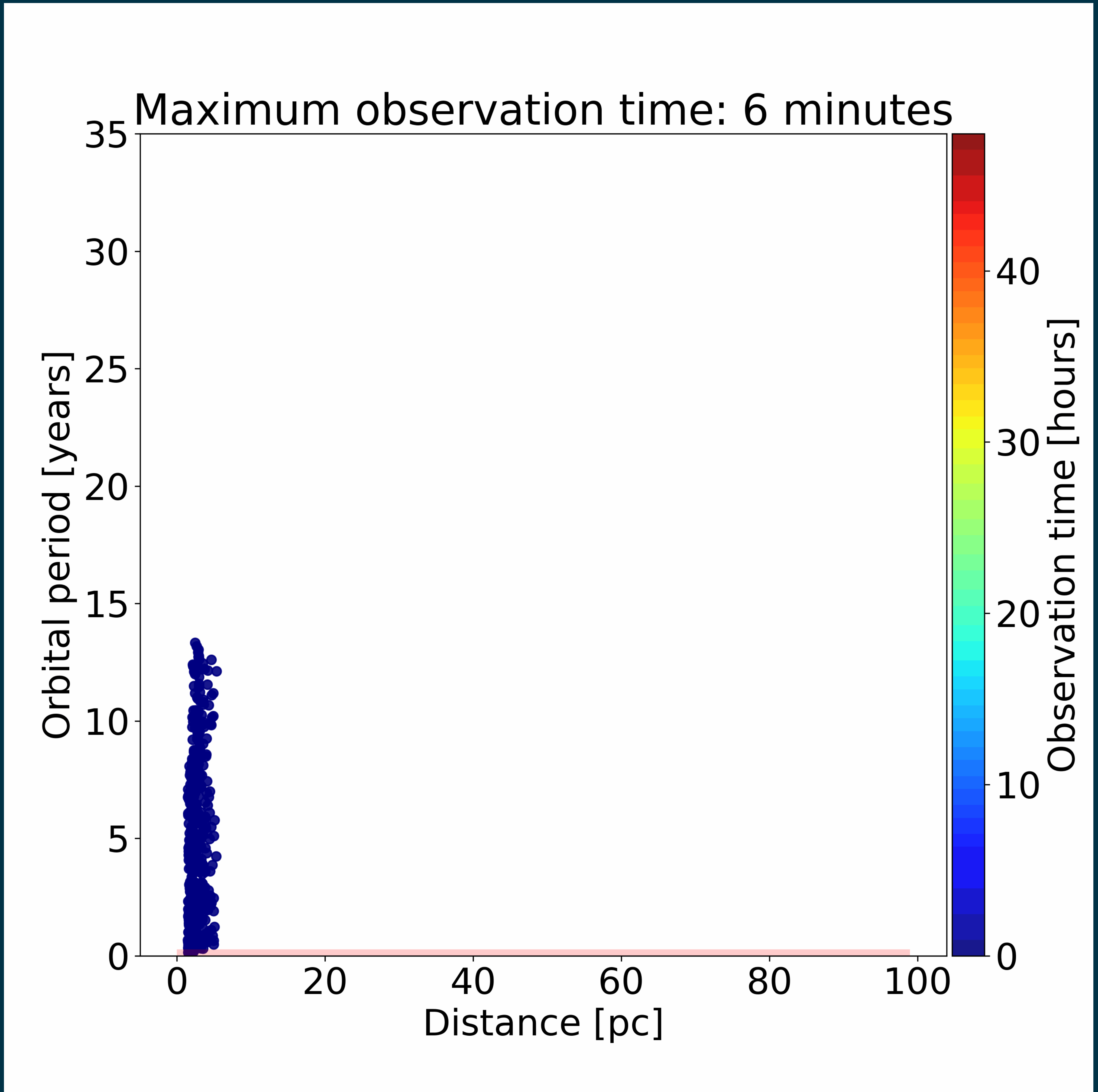
- 1.8×10^5 stars within 100 pc
- Planet radius: 3-5 Earth radii
- Planet SMA: 0.27-7.5 au
- Stellar abs. magnitude: 1-18

Constraints	
Minimum separation	0.17 arcsec
Maximum separation	3 arcsec
Minimum period	100 days

Observation Time

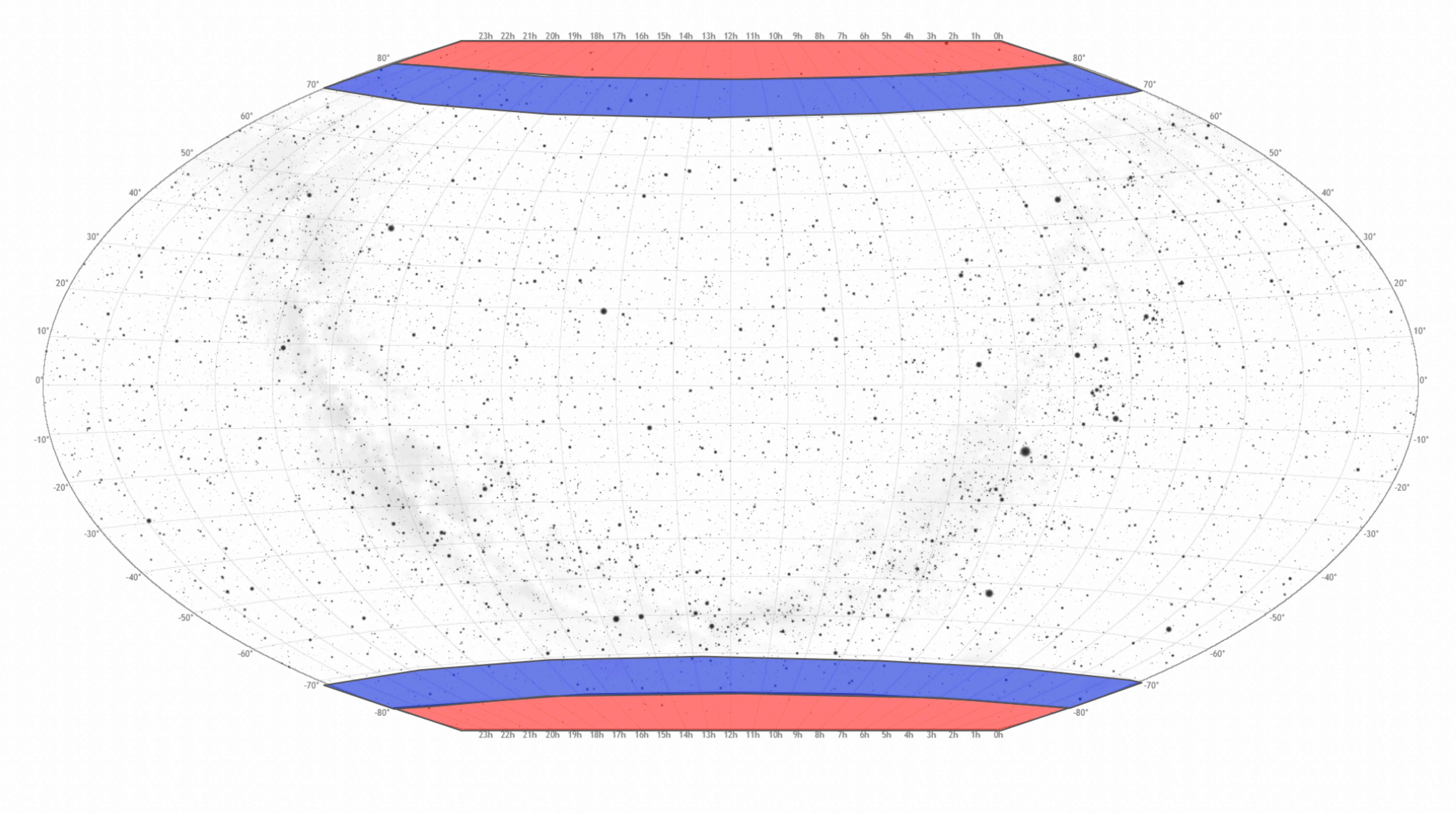
Monte Carlo for potential exoplanets

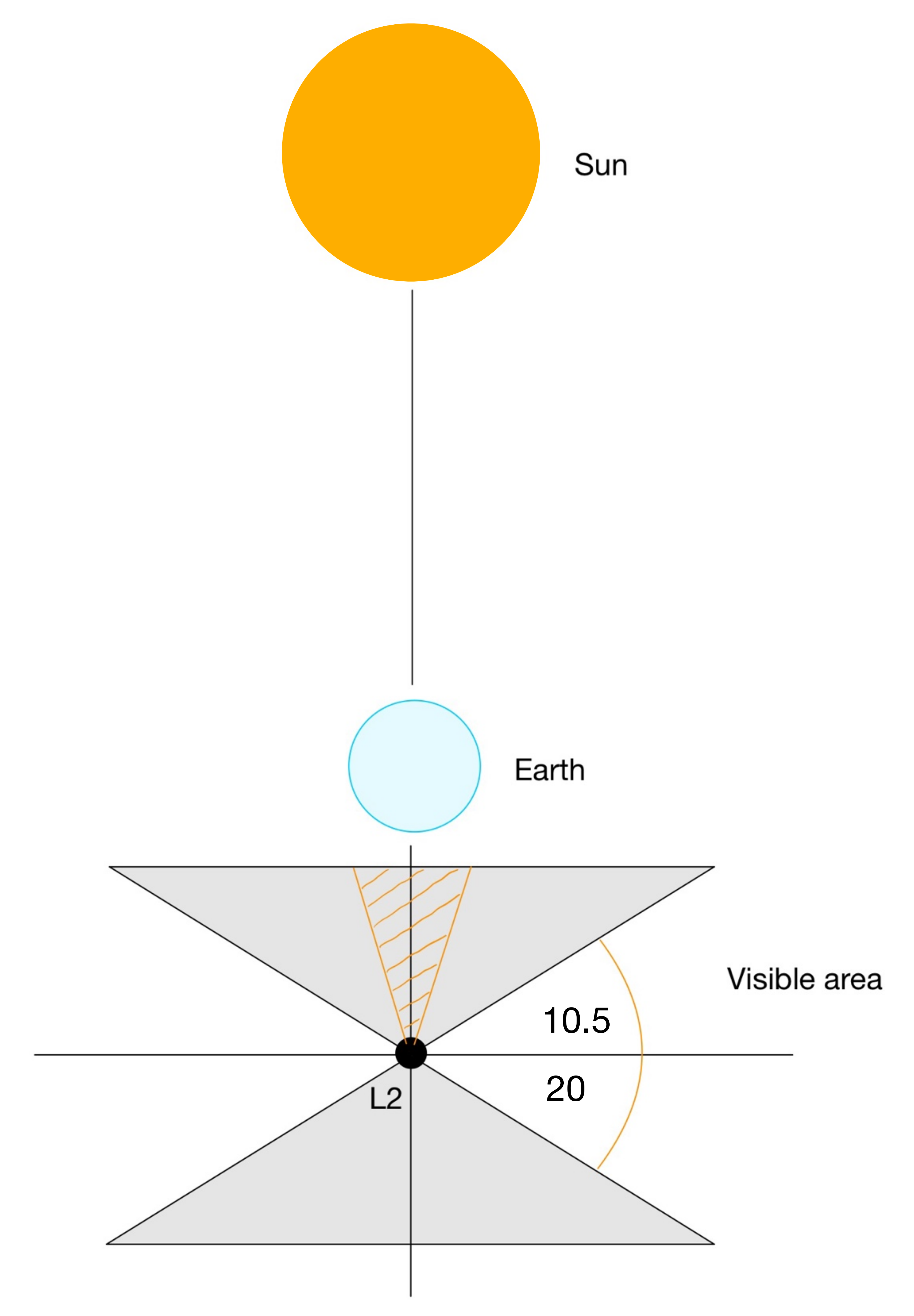
Single Target Observation Time	Potential Targets
<6 minutes	400
<30 minutes	1500
<1h	2300
<5h	5600
<1 day	9500
<2 days	11000



Mireia Leon Dasi

All-sky Coverage
10º Continous Viewing





Dedicated Target Observation	Survey	Long Exposure Target Observation	Targets of Opportunity
2 years	1.5 years	6 months	1 year

- Launch and early operations
- Commissioning
- **Nominal Science Operations**
  - Dedicated Target Observation
  - Survey
  - Long Exposure Target Observation
  - Targets of Opportunity
- Extended Science Operations
- Decommissioning

Observation Programme

- Launch and early operations
- Commissioning
- Nominal Science Operations
  - Dedicated Target Observation
  - Survey
  - Long Exposure Target Observation
  - Targets of Opportunity
- Extended Science Operations
- Decommissioning

1. Revisit directly imaged planets
2. Follow up of Gaia planets

Slew times

Isotropic target distribution

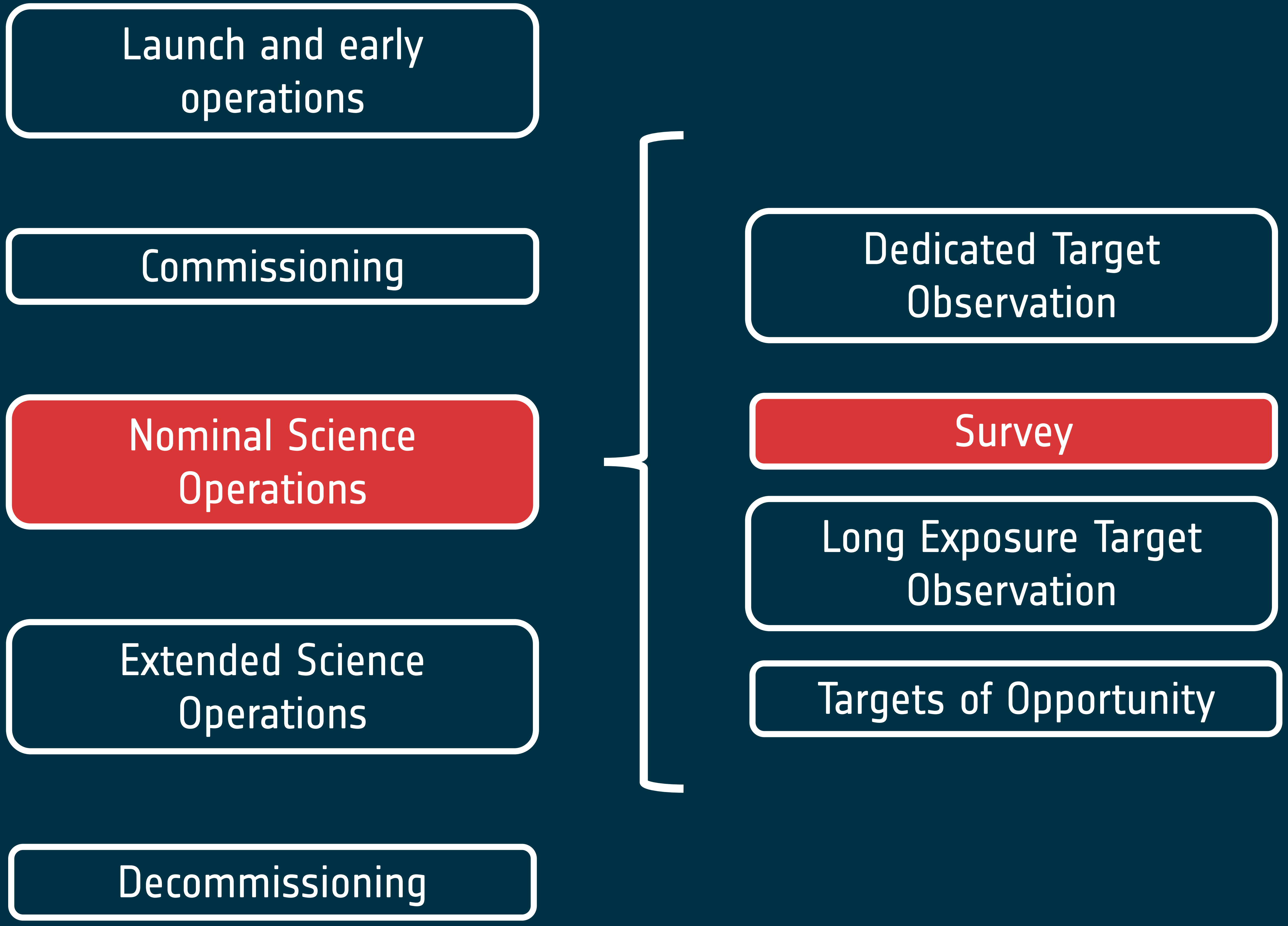
Travelling salesman problem

Cycle: Time to observe all selected targets with all slew time overheads

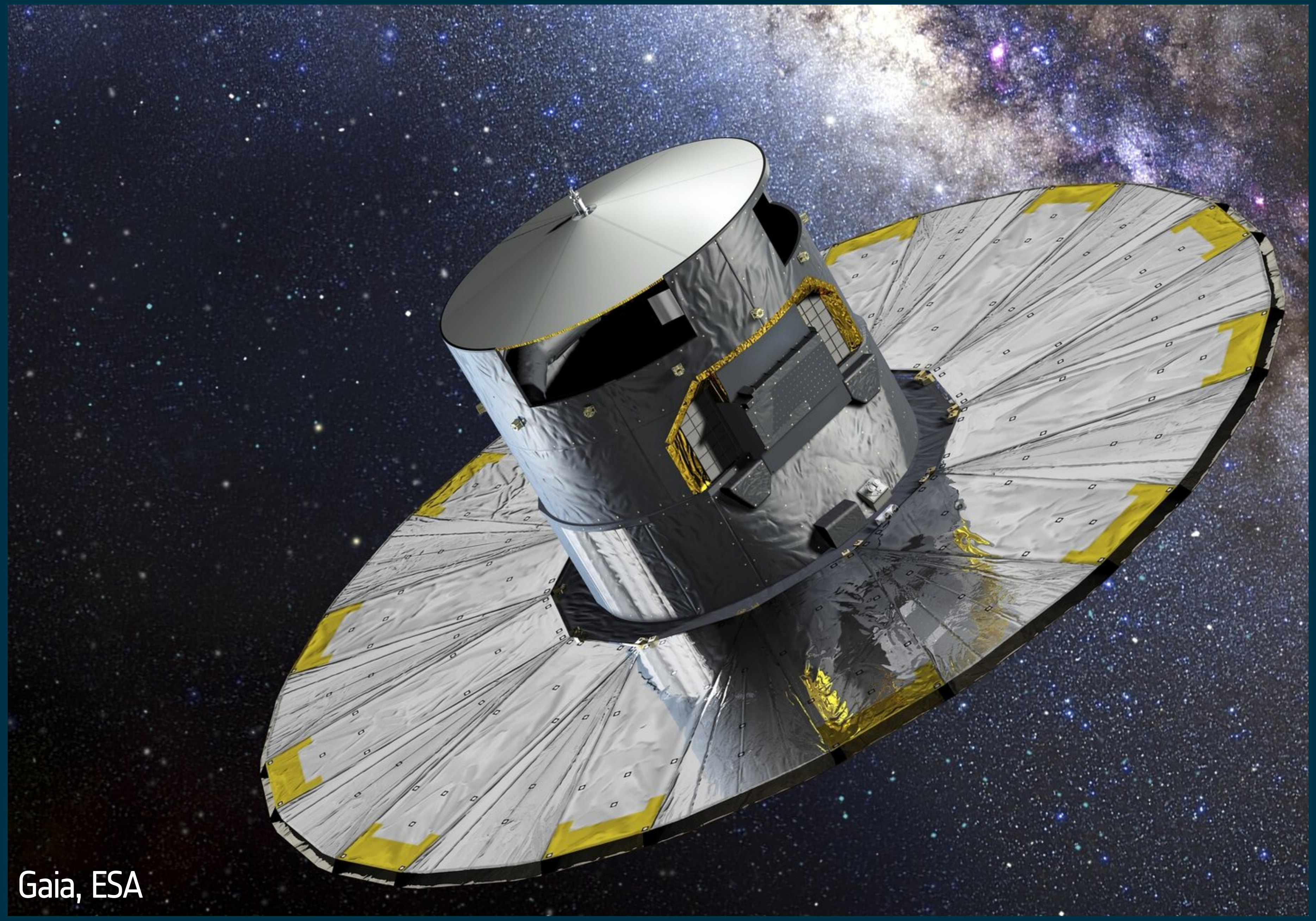
# of targets	avg. distance between targets	avg. time between slews + settling (JWST times)	Over one cycle
500	9º	46 min	16 days
1000	6º	37 min	26 days
2000	4.5º	11 min	15 days

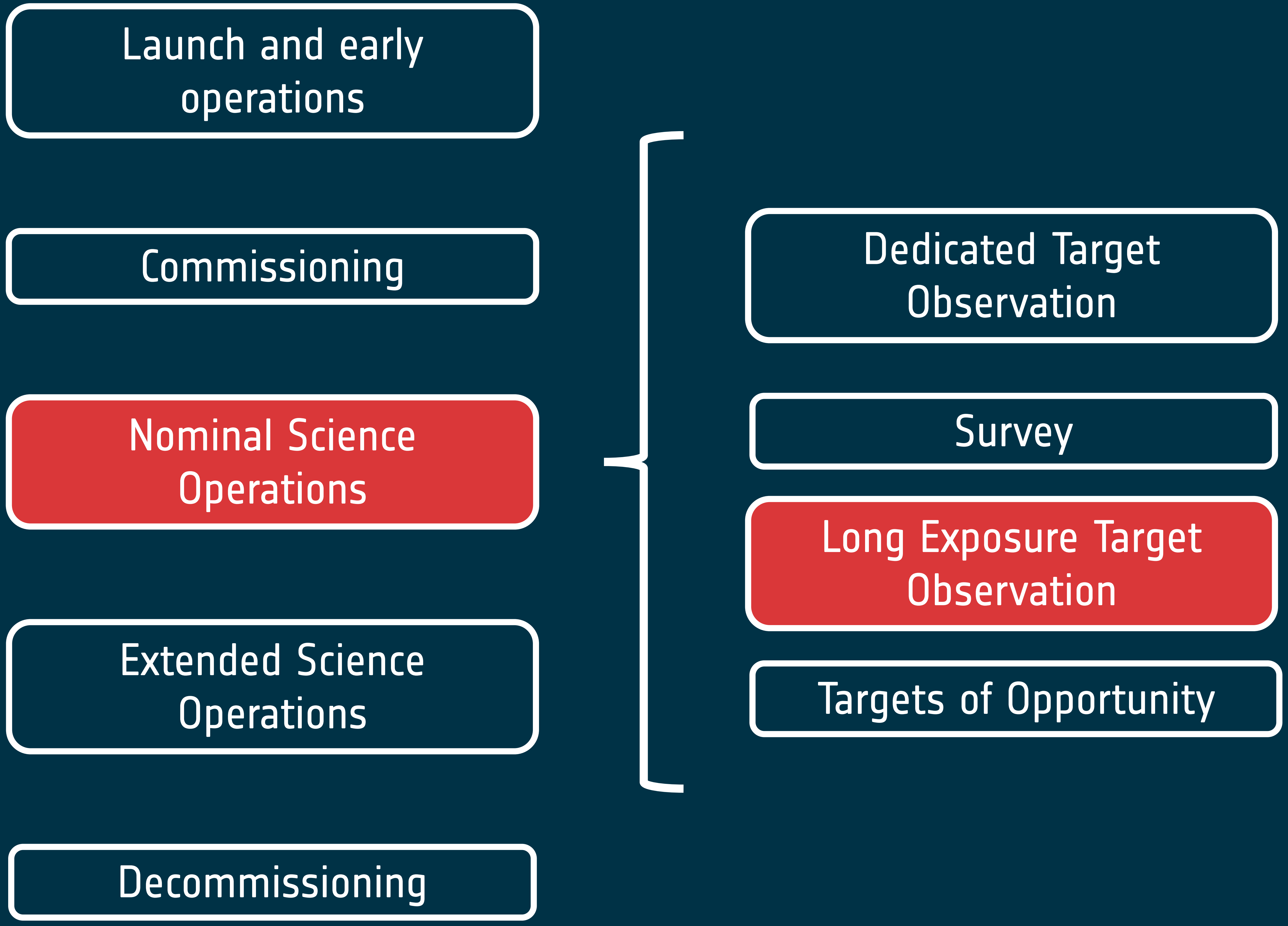
Cycle duration based on number of targets

Integration time per target	# of visible stars	Cycle duration (+ slew overhead)	Cycles per 5 year mission	Minimum nominal mission
1 hour	1200	69 + 26 days	19	285 days
2 hours	2100	222 days + 15 day overhead	8	1.9 years
5 hours	3700	2.4 years + 15 day overhead	2.4	7.2 years
10 hours	5400	6.9 years + 15 day overhead	Not possible in nominal time	21 years

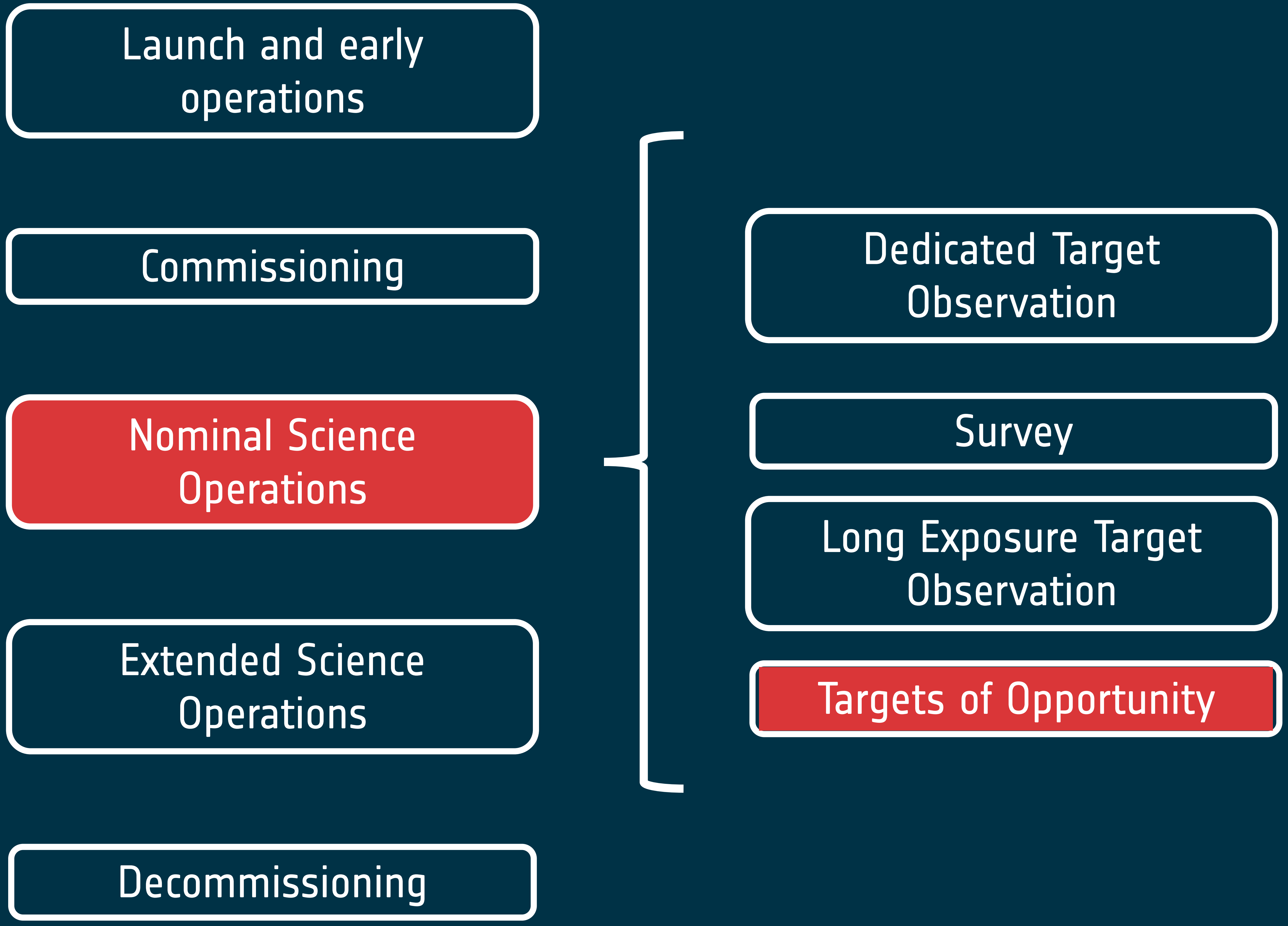


- Look at stars that we do not know have exoplanets.
- Supported by suspected targets: Candidates from astrometric discoveries by previous missions (mostly Gaia)


Gaia, ESA



- Looking at distant exoplanets
- Looking at exoplanets around faint stars



Launch and early operations

Commissioning

Nominal Science Operations

Extended Science Operations

Decommissioning

Dedicated Target Observation

Survey

Long Exposure Target Observation

Targets of Opportunity

PDS 70 protoplanetary disk

ESO/A. Müller et al.

- Open call for observations

Launch and early operations

Commissioning

Nominal Science Operations

Extended Science Operations

Decommissioning

- Continue with observations
- Targets of opportunity

Launch and early operations

Commissioning

Nominal Science Operations

Extended Science Operations

Decommissioning

- Turn off all systems
- Pacify spacecraft
- Keep Δv of 10 m/s for injection to graveyard orbit

Mission Timeline

Phase 0

Phase A
Feasibility

Phase B
Preliminary Definition

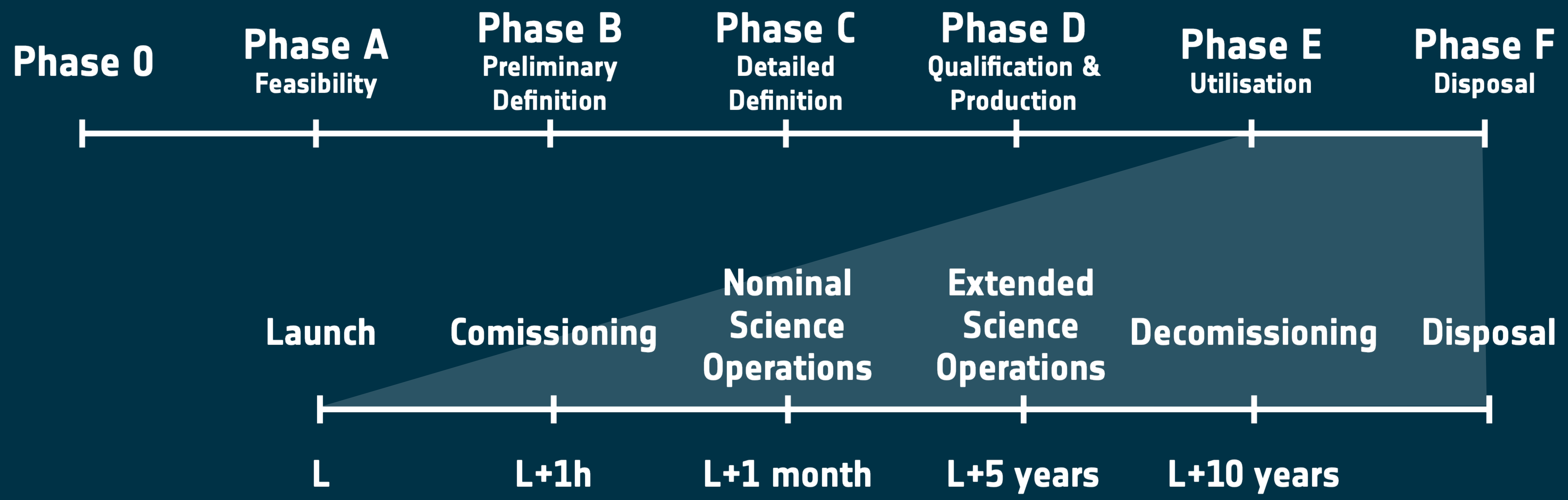
Phase C
Detailed Definition

Phase D
Qualification & Production

Phase E
Utilisation

Phase F
Disposal

Mission Timeline



Phase 0

Phase A
Feasibility

Phase B
Preliminary Definition

Phase C
Detailed Definition

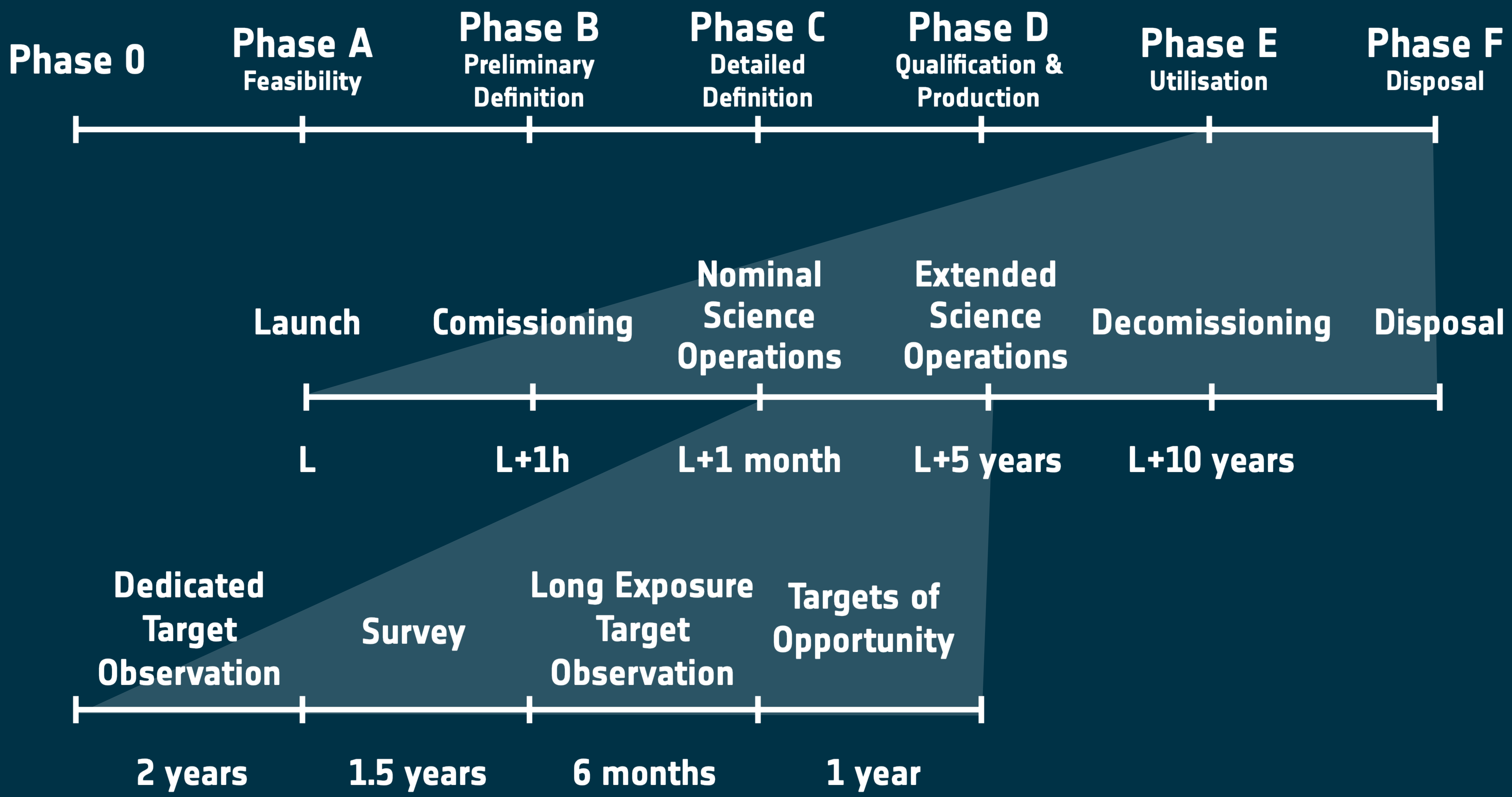
Phase D
Qualification & Production

Phase E
Utilisation

Phase F
Disposal

Launch	Comissioning	Nominal Science Operations	Extended Science Operations	Decomissioning	Disposal
L	L+1h	L+1 month	L+5 years	L+10 years	

Mission Timeline



Phase 0

Phase A
Feasibility

Phase B
Preliminary Definition

Phase C
Detailed Definition

Phase D
Qualification & Production

Phase E
Utilisation

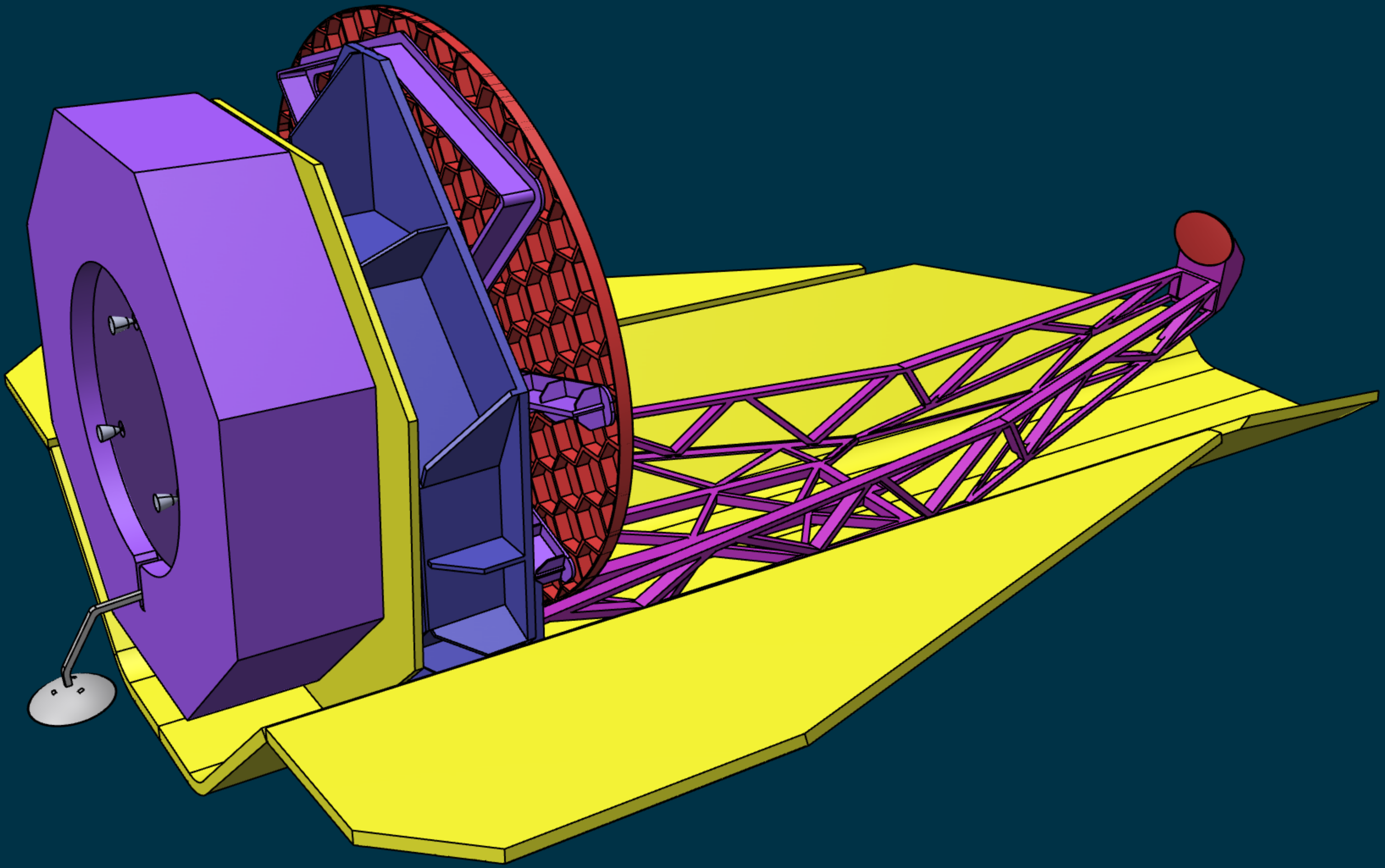
Phase F
Disposal

Launch	Comissioning	Nominal Science Operations	Extended Science Operations	Decomissioning	Disposal
L	L+1h	L+1 month	L+5 years	L+10 years	

Dedicated Target Observation	Survey	Long Exposure Target Observation	Targets of Opportunity
2 years	1.5 years	6 months	1 year

Spacecraft Design

Main Overview

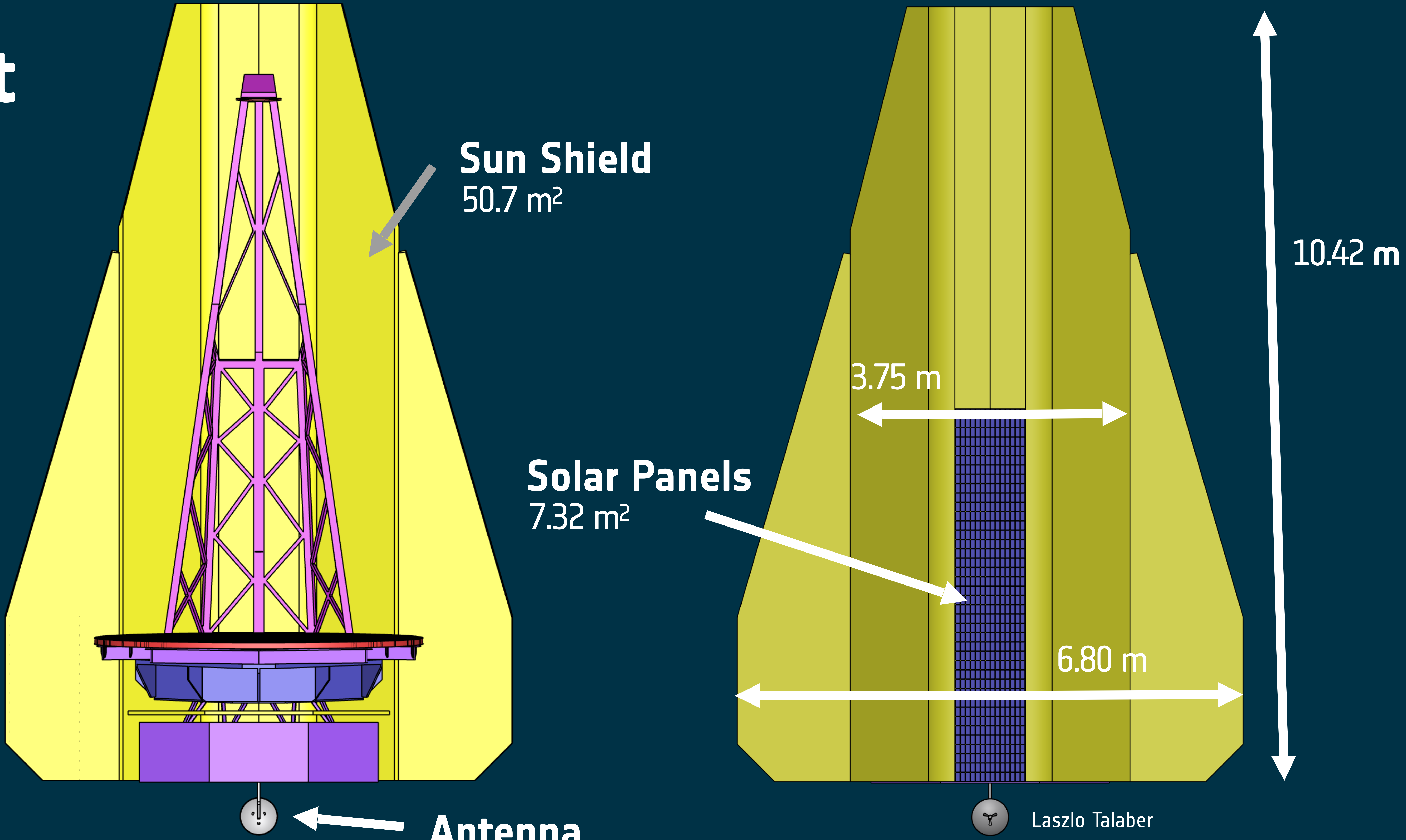


Laszlo Talaber

Subsystems:

- On-board Computer
- Data Handling
- Thermal Control
- Telecommunication
- Attitude Determination & Control
- Power
- Propulsion

Layout

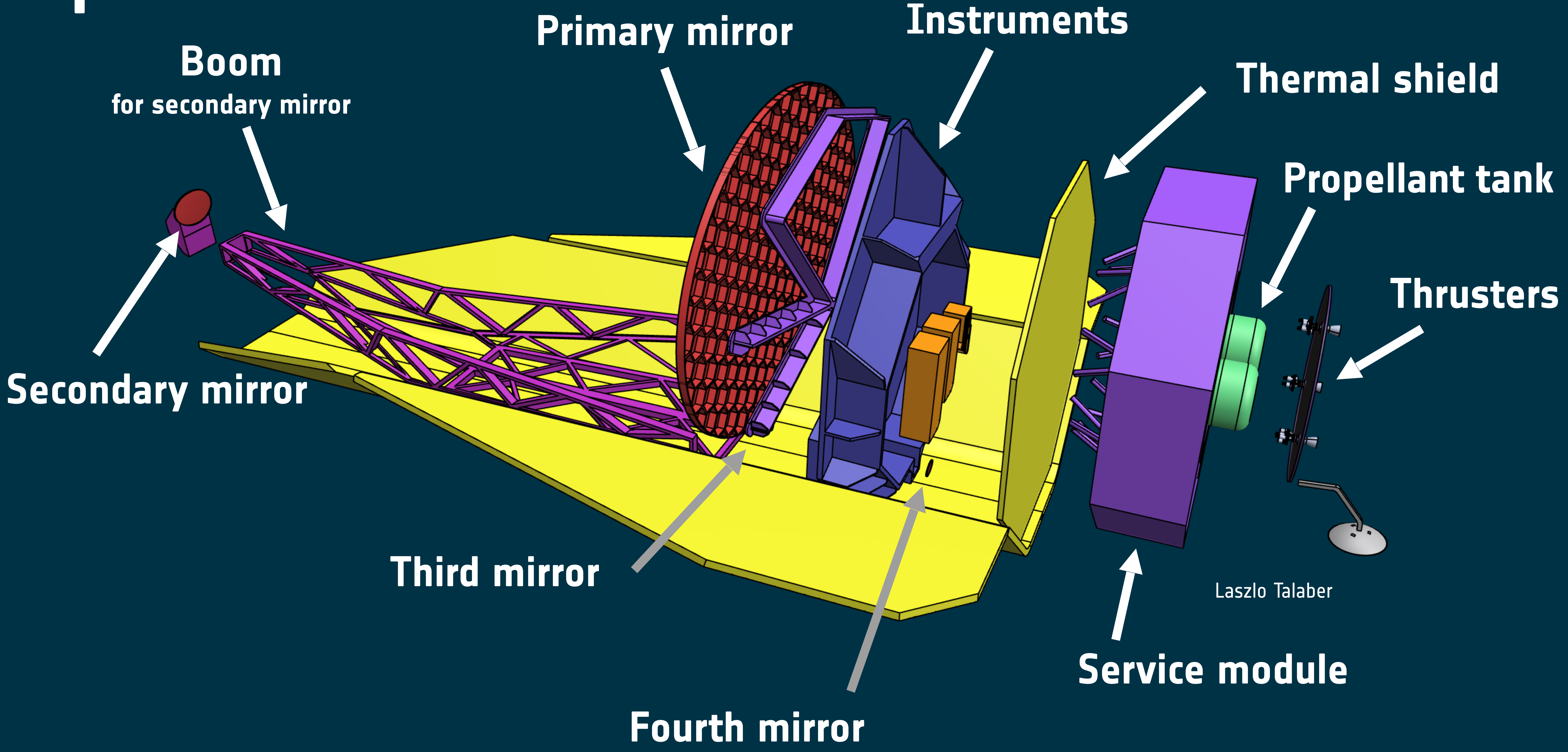

Sun Shield
50.7 m²

Solar Panels
7.32 m²

Antenna

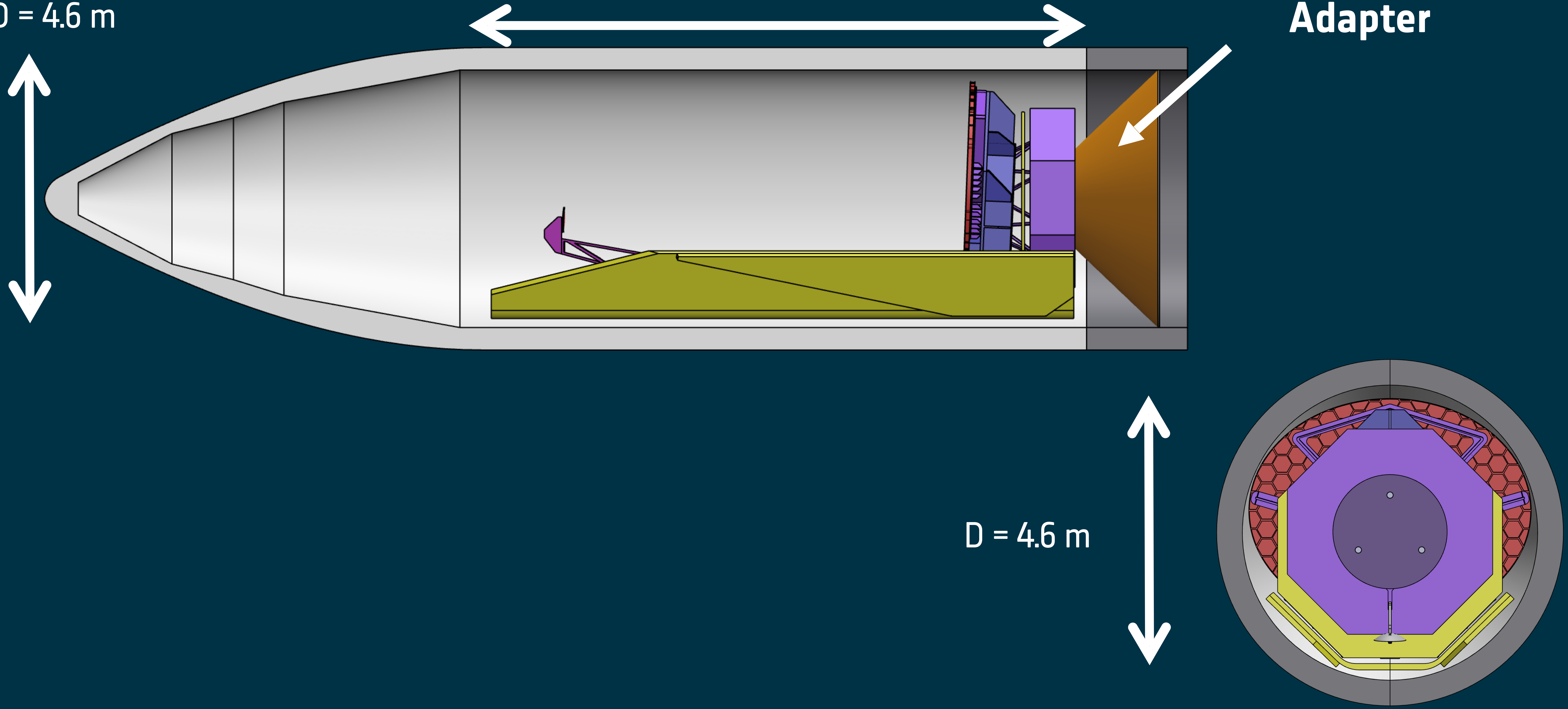
Laszlo Talaber

Exploded View



Laszlo Talaber

Fairing Fitting



D = 4.6 m

Payload fairing

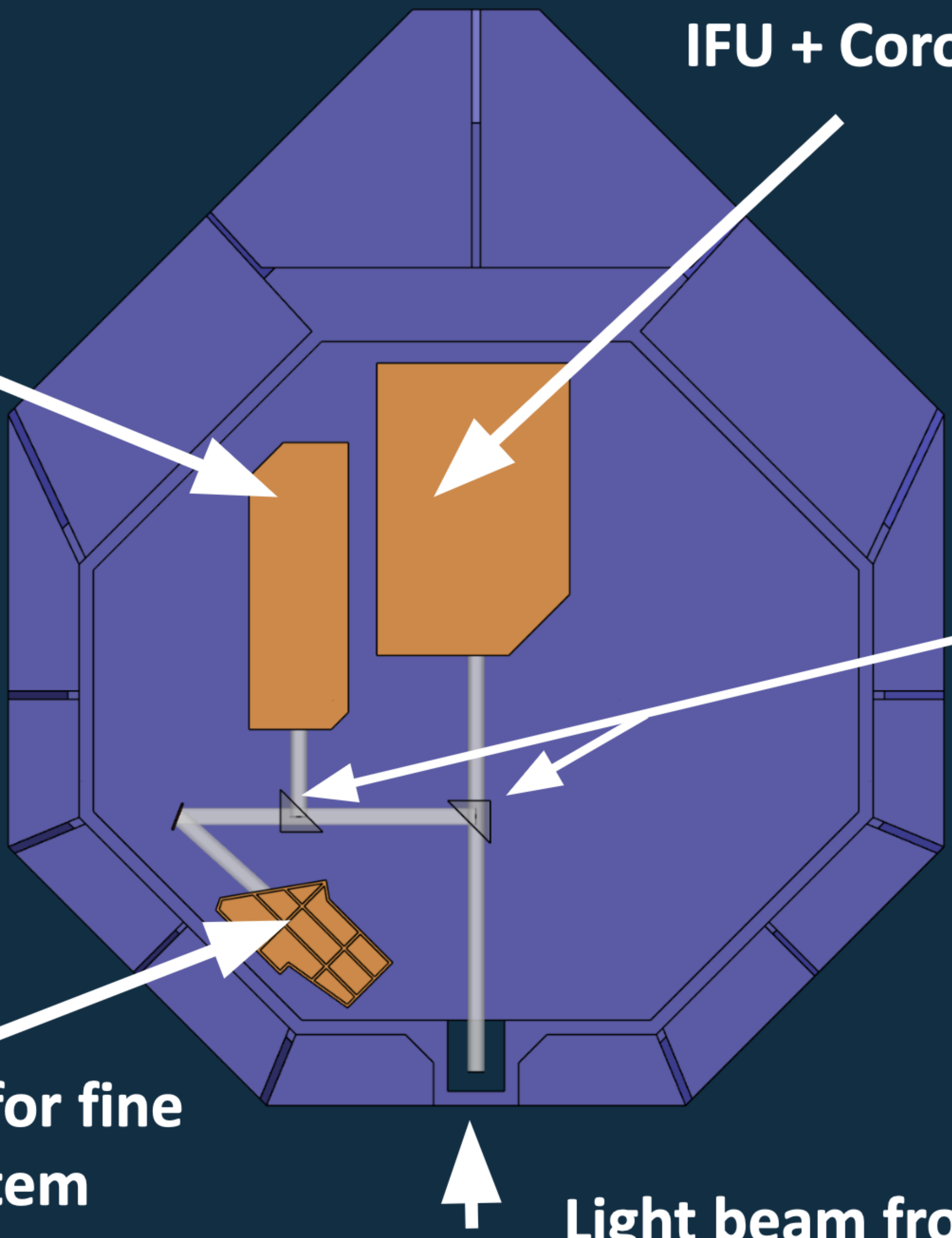
11 m

Launch Vehicle Adapter

D = 4.6 m

Credit: Laszlo Talaber

Instrument Bay



IFU + Coronagraph

UV photometer

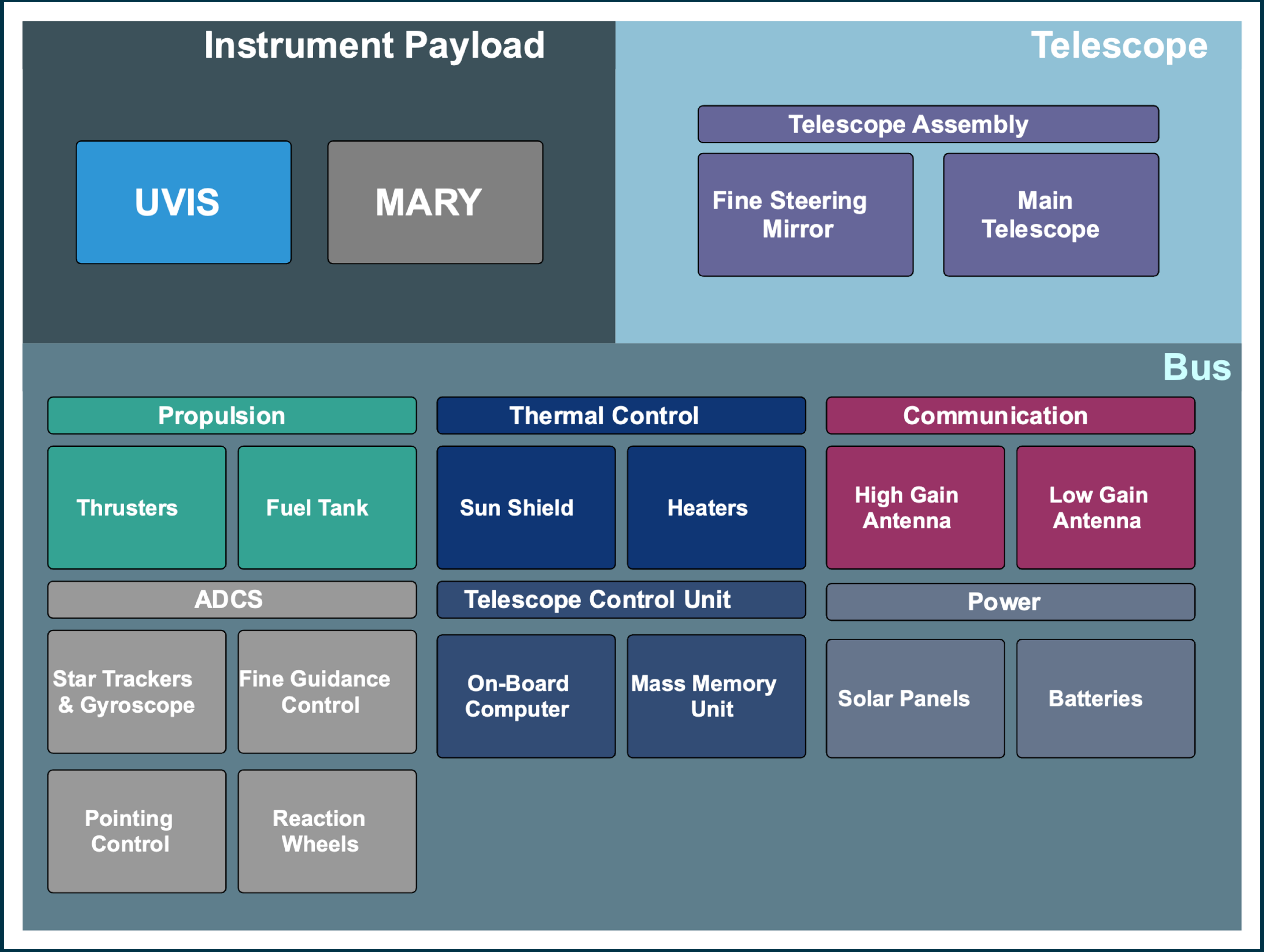
Dichroic

Photometer for fine guidance system

Light beam from M4

Subsystems

Subsystems diagram



Gerald Mösenlechner

ADCS System Driver

Pointing stability during observation:

- Instantaneous Absolute performance error <= 130 mas
- Relative performance error <= 80 mas up to 200 s
- Performance drift error <= 50 mas up to 72 h

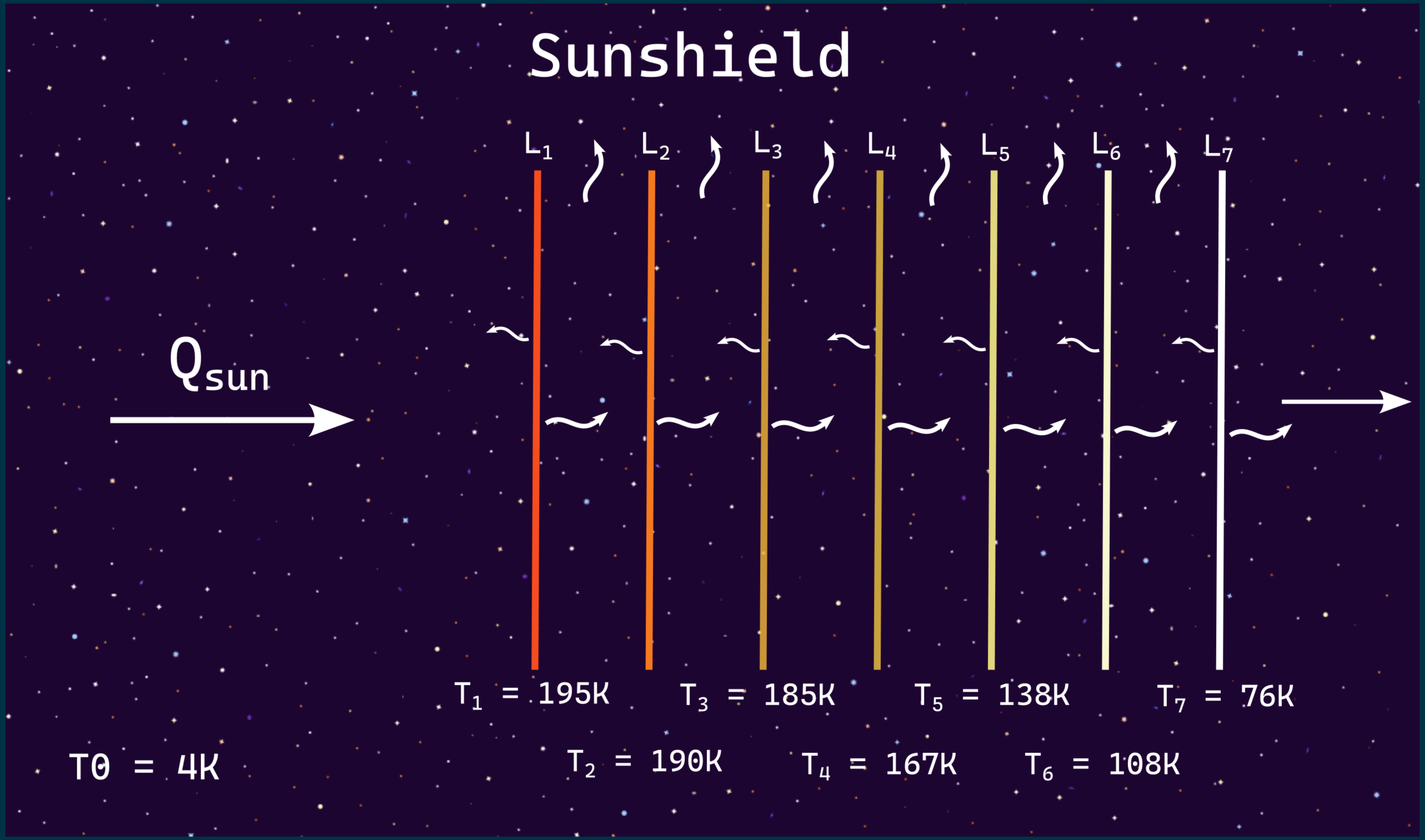
Instruments	
2 star trackers	Rough pointing and orientation (error <= 5 arcsec)
UVIS visual channel	Precision pointing
4 sun sensors	Sun avoidance
4 reaction wheels	Rotation and stabilisation (1 for redundancy)
12 reaction thrusters	Desaturation and additional control authority (3-axis)

Thermal control

Detector threshold: 120 K

Detector target: 80 K

System Driver



Jan-Vincent Harre

Passive Control

- Sunshield
- 73.7 m2
- 7 layers of MLI foils: 256 kg
- Absorptance: 0.08
- Emittance: 0.93
- Detector temperature: 80K

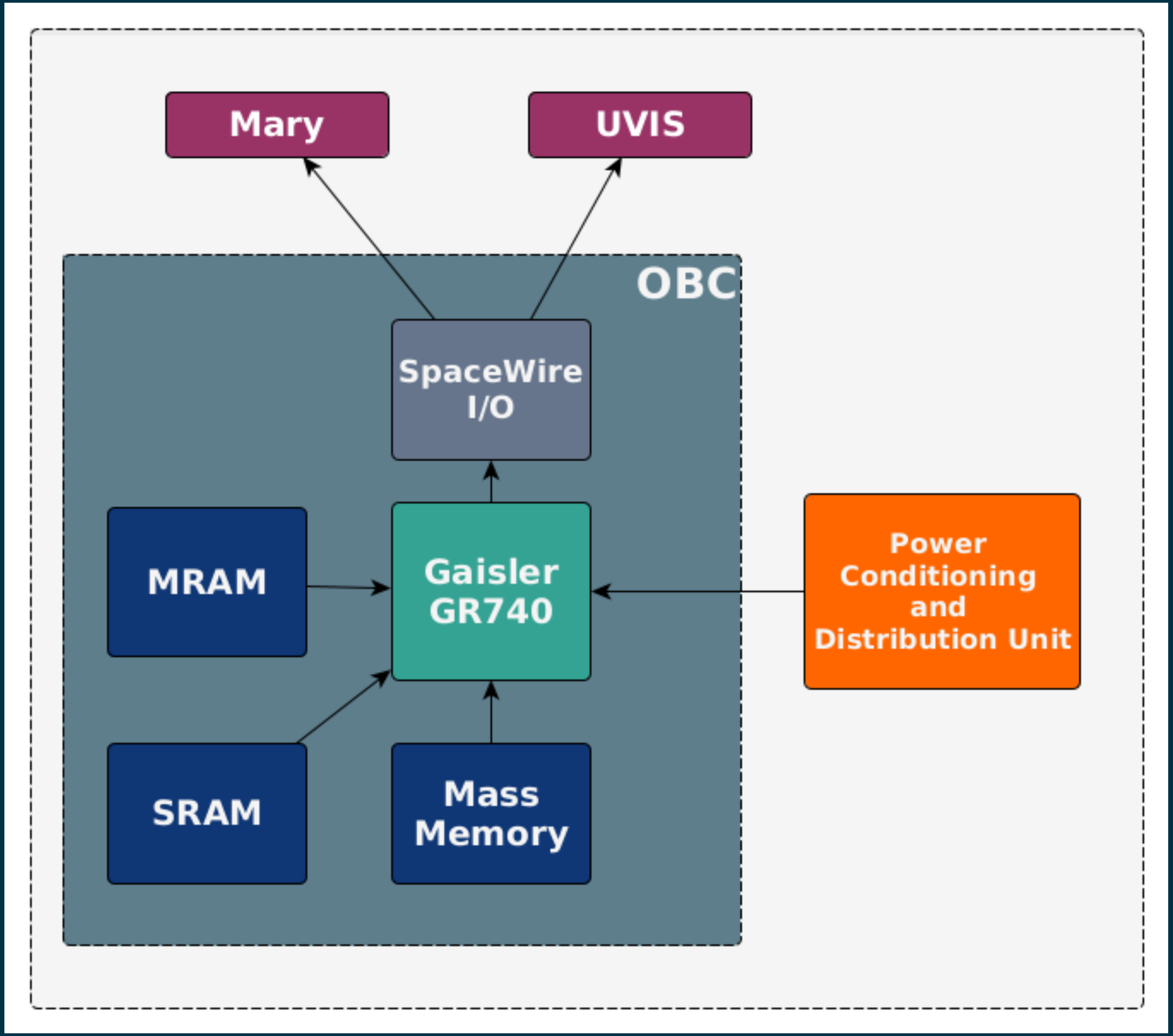
Internal Heat

- Dissipation of maximum 700 W
- 1.5 m2 radiator

Active control

- Heaters for electrical components
- Operating temperature: 10 °C

On Board Computer

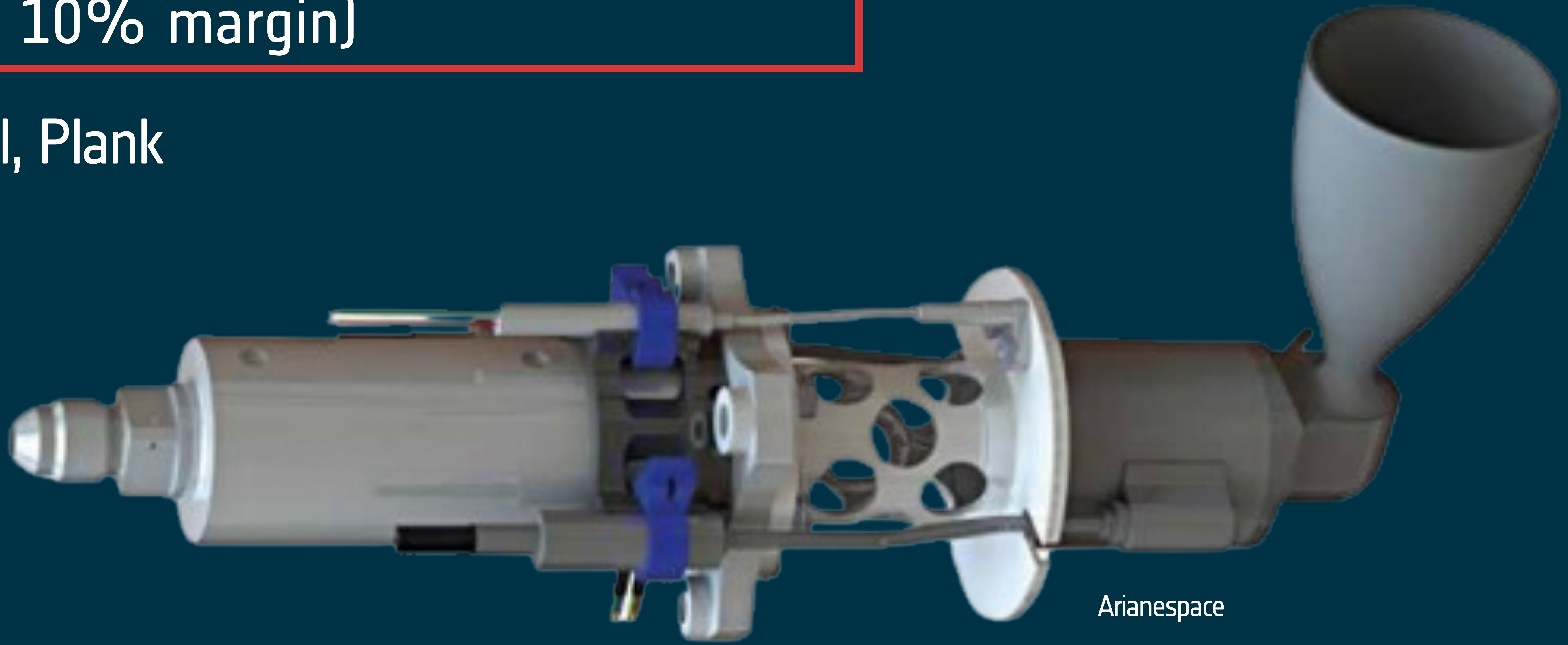


Gerald Mösenlechner

Propulsion

Propellant	Monopropellant (Hydrazine)
Tank volume [l]	197
Propellant mass [kg]	192 (with 20% margin)
Thrust [N]	7.9 – 24.6
I_{sp} [s]	222 – 230
Power consumption [W]	22 (with 10% margin)

Heritage: Integral, METOP 1-3, Herschel, Plank



Arianespace

Link Budget

Assumptions	**MARY**	**UVIS**
Imagette size [px]	4096 x 4096	64 x 64
Sample Frequency [Hz]	0.1	10
Lossy Factor (co-adding)	3	10
Lossless Compression	2	2.5

Source	**Gbits/day**	**Gbits/week + 20% margin**
ACOS	0.2	1.8
Housekeeping	0.06	0.6
MARY	18.5	155.2
UVIS	0.5	4.2
Total	19.4	162.8
Required		230

Telecommunication

15m Ground Station
or
ESA ESTRACK Cebreros (Spain) Station

- Daily ground passes (Nominal)
- 3 ground passes/week (Baseline)

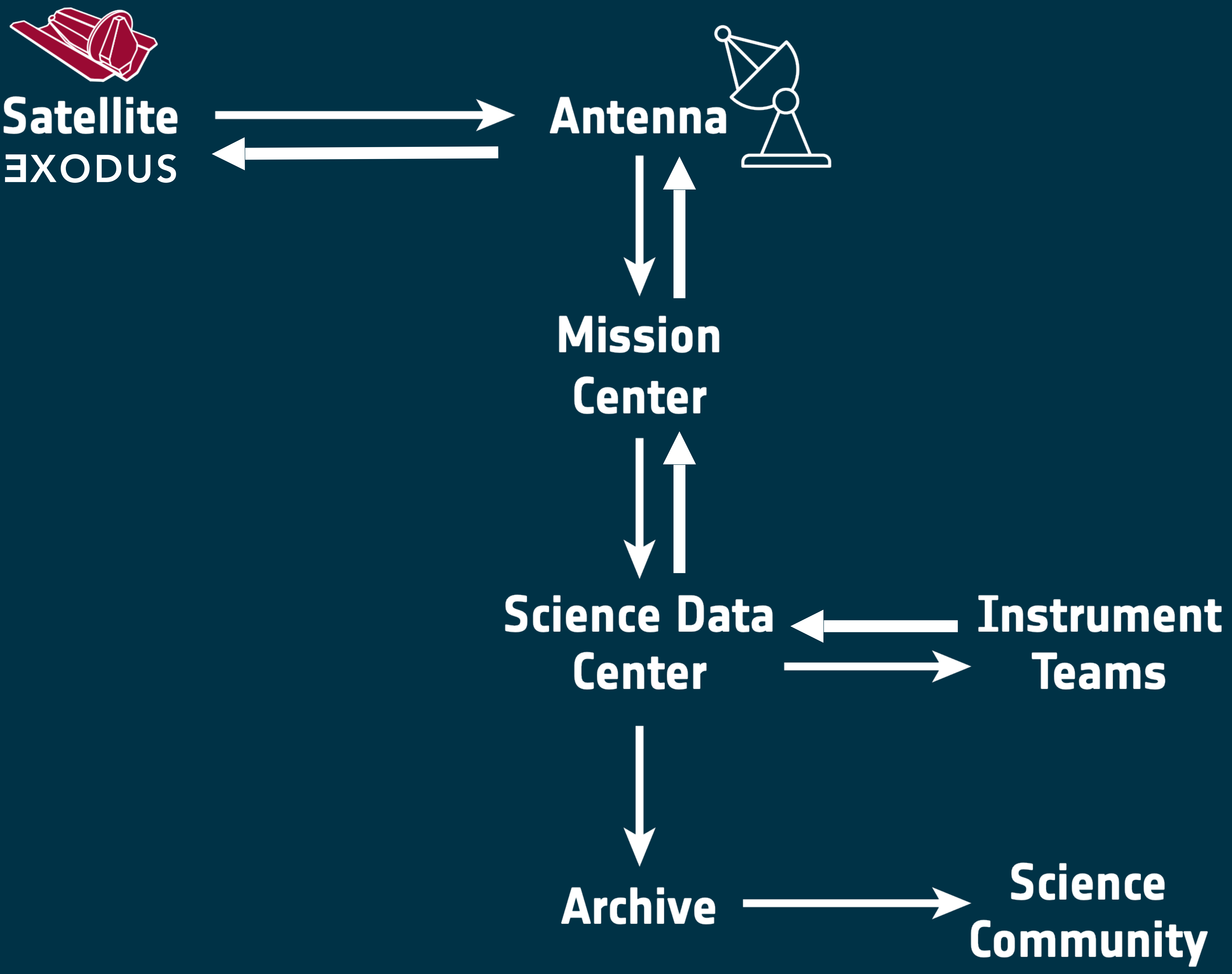
2 Low Gain Antennas

- Commands and telemetry during ascent
- Contingency telemetry and commands
- Data rate: 4kbps

Data downlink: High Gain Antenna

X-band downlink	8.5GHz
Maximum data generated	230 Gb/week
Downlink time	2 hours/day
Maximum data-rate	10 Mbps
Antenna specifications	D = 50 cm 40W power

Ground Segment



Satellite

ƎXODUS

Antenna

Mission Center

Science Data Center

Instrument Teams

Archive

Science Community

Power budget

		Safe mode	**Downlink**	Science	**Slewing**
Subsystem	**Margins**	**Power (W)**	**Power (W)**	Power (W)	**Power (W)**
Payload	20%	120	120	504.2	144.2
Communications	10%	67.6	102.5	14.2	81.5
Electrical & Power	10%	52.5	52.5	52.5	52.5
Data Handling	20%	43.5	43.5	43.5	43.5
Propulsion Module	10%	0	0	0	22
ADCS	10%	247.5	247.5	247.5	247.5
Service Module Thermal	20%	120	84	96	120
SVM Harness Losses (2%)	10%	15.2	15.4	20.9	16.5
Total		805.3	809.4	**1122.8**	871.7
20% power margin		966.4	971.3	**1347.4**	1046.1

Power budget

Solar Panels

Azure TJ Solar Cell 3G30C - Advanced 12x6

- Produced power: 1.4 kW
- Surface area: 7.3 m^2

Battery

Saft VL51ES battery

- Nominal energy: 9100 Wh
- Nominal capacity: 255 Ah
- Mass: 76 kg

Mass Budget

Subsystem	**Mass [kg]**	**Margin**	**Mass with margin [kg]**
Payload	736.8	20%	980.9
Communications	10	5%	10.5
Electrical & Power	81.6	5%	85.7
Data Handling	27	5%	28.4
Propulsion Module	2	5%	2.1
ADCS	58	5%	60.9
Thermal	261	20%	312.5
5% harness	58.8	10%	64.7
20% structure	235.3	20%	283.1
Dry mass	1470.4	-	2193 (with margins)
Propellant	183.7	5%	193
Wet mass	1628.4	-	**2386**

Risk Assessment

Mission Risk	Impact description	Likelihood	Impact	Mitigation
Sunshield deployment	Pointing limitation	2	3	Change targets selection strategy
Failure of adaptive optics	Severe impact on IR observations	3	5	Proper design phase testing

Development Risk	Impact description			Mitigation
Boom vibrations	Secondary mirror misalignment			Mock-up building for testing & modelling
Adaptive optics	Delaying mission development			Proper design phase testing
Coronagraph	Delaying mission development			Proper design phase testing

Cost Analysis

	Cost (millions of euros)
Project team ESA	143
Development:	
• Service module	200
• Telescope	300
• Payload	50
Mission operations	110
Science operations	55
Contingency	128.7
Launcher	90
Total	**1076.7**

Descoping

Classical cylindrical mirror

- Smaller, cheaper, lighter
- Less complex mirror design
- Limits observation distance

Reduce amount of adaptive optics

- Limits observations to larger objects

➡ **Lose target diversity**

Outreach

Schools and universities: Workshops, painting book for children, involvement in data analysis with supporting scientists (early access to data)

General public: Social media presence, website, live streaming, public science events (exoplanet of the week), VR platform

Dedicated events for early career scientists.

Team Yellow

Paula Benitez
Mark Boyd
Citlali Bruce Rosete
Wiebe de Gruijter
Johan Frich
Liana Gfrerer
Jan-Vincent Harre
Kim Angelique Kahle

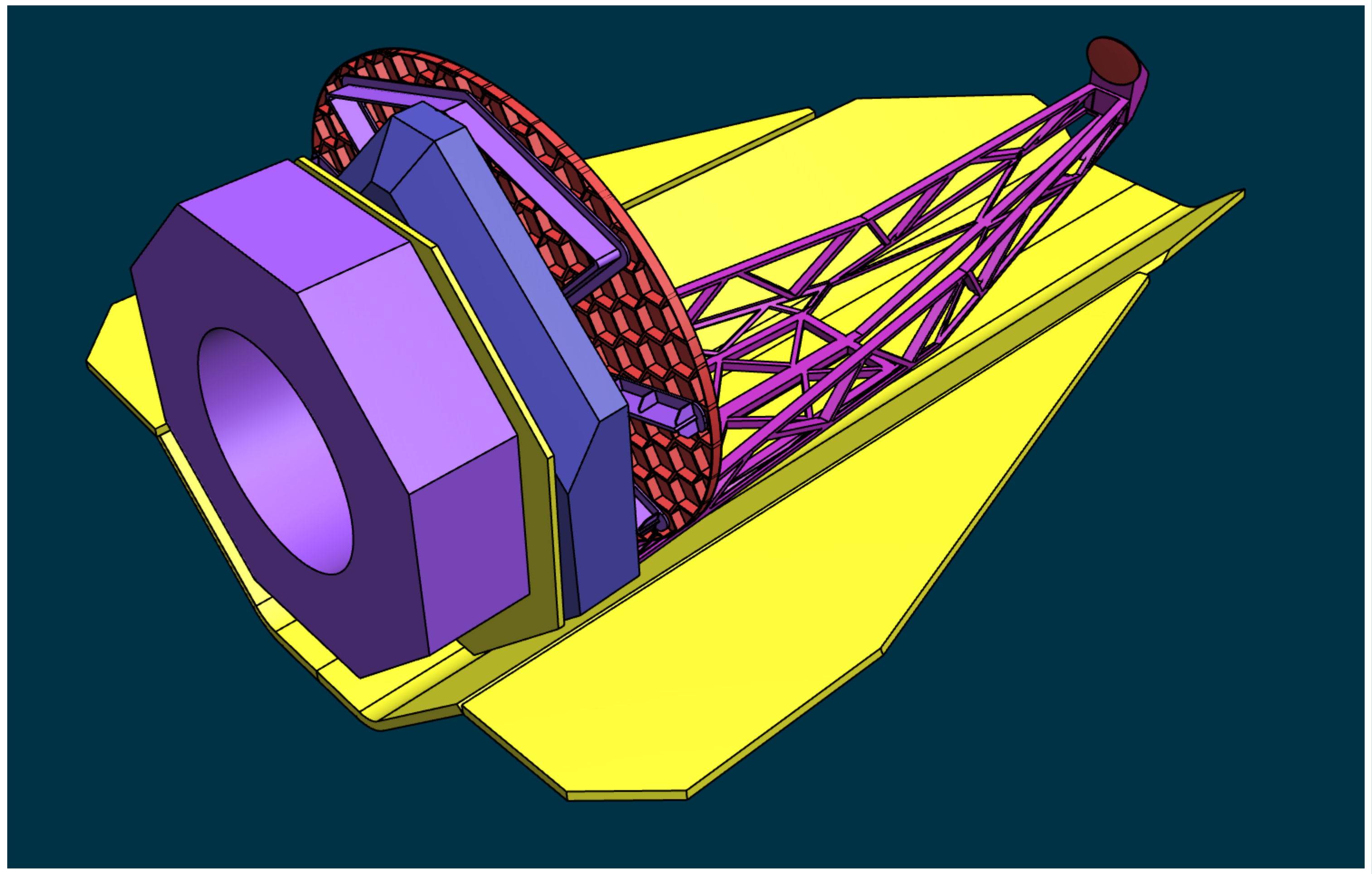
Mireia Leon Dasi
Gerald Mösenlechner
Johannes Ora
Vito Saggese
Eleftheria Sotiriou
Marco Souza de Joode
Apostolos Symeonidis
Laszlo Talaber

Günter Kargl - Engineerig
Leonard Schulz - Science

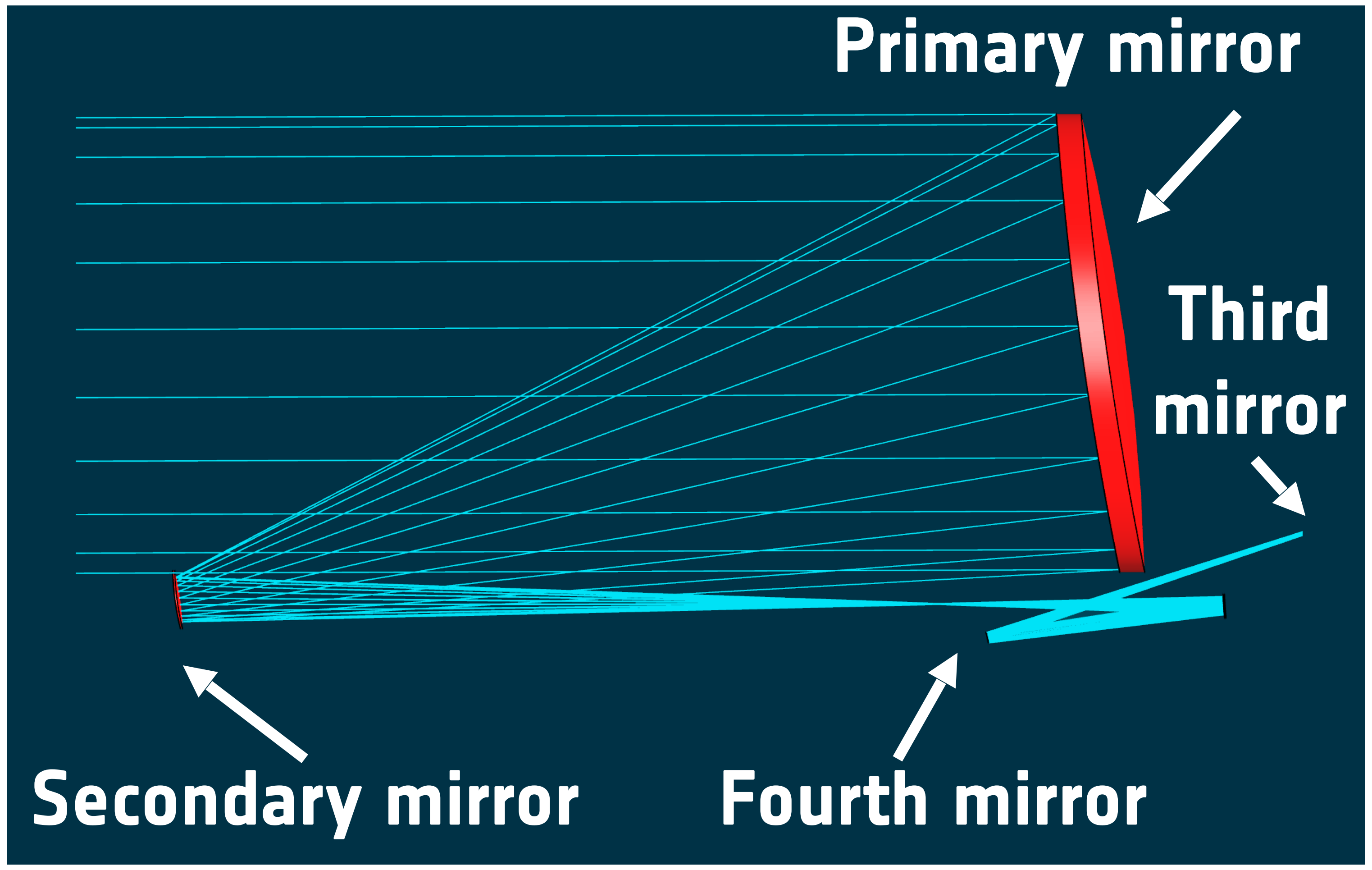
EXODUS

ATMOSPHERIC ESCAPE | LONG PERIOD EXOPLANET SURVEY | SOLAR SYSTEM ARCHITECTURE

Satellite Design



Telescope



Observables

- Observation of 5500 exoplanets
- Atmosphere escape detection (IR)
- Simultaneous UV stellar characterisation

Payload

MARY

- IFU spectroscopy in NIR
- Spectral resolution 1nm
- Spatial resolution 100 mas
- Coronagraph

Observation Limits

- Contrast ratio $\geq 10^{-9}$
- Separation > 0.17 arcsec
- Separation < 3 arcsec

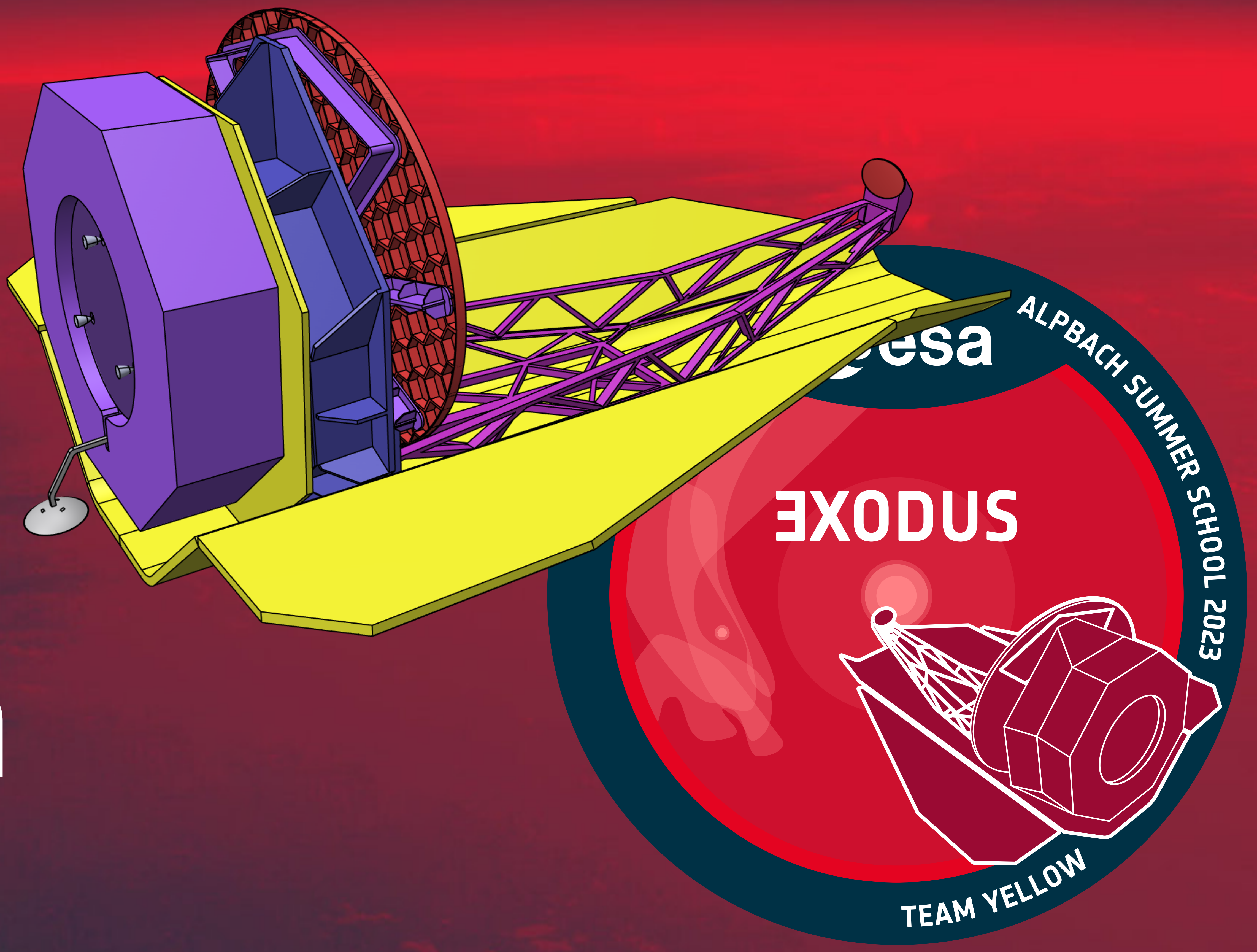
UVIS (Fine Guiding System)

- UV and VIS photometry
- UV channel: 100 – 400 nm
- VIS channel: 400 – 800 nm
- FoV: 20 x 20 arcsec

MASS: 2386 KG | POWER: 1347 W | COST: 1076 M €

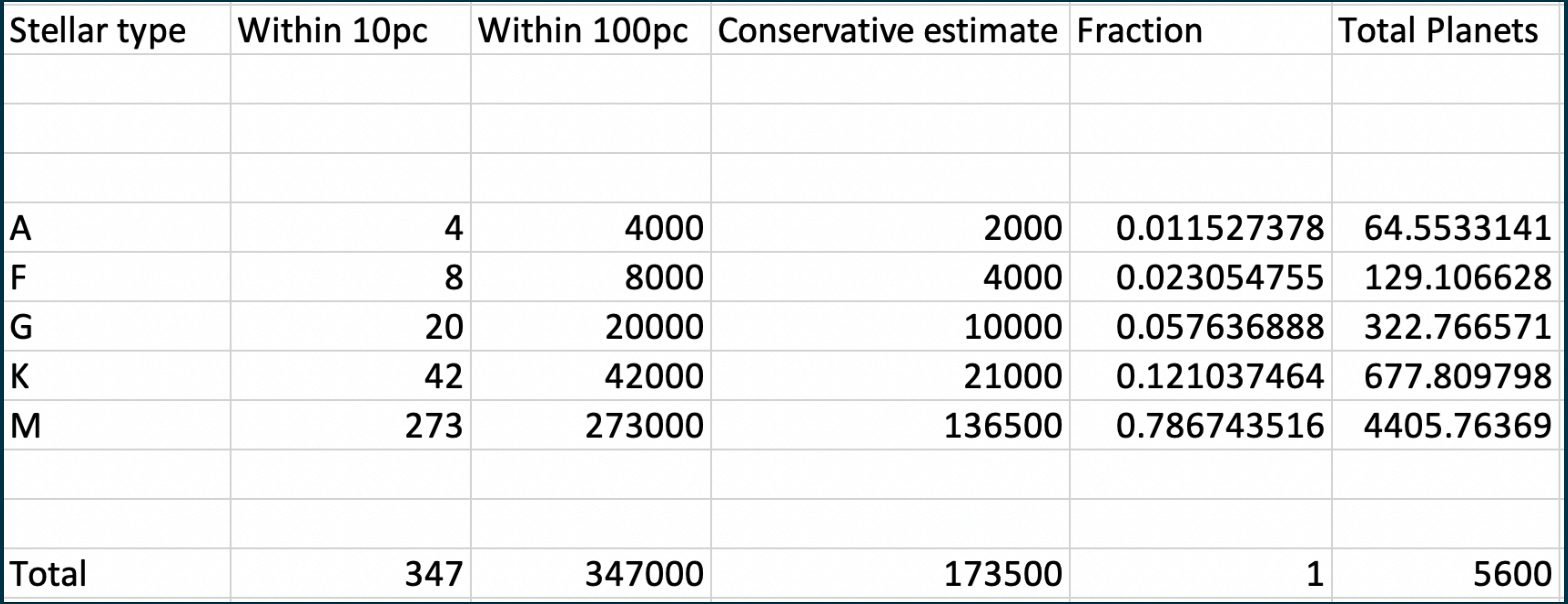
SUMMER SCHOOL ALPBACH 2023

Ǝxodus: Exploring Exoplanet Evolution

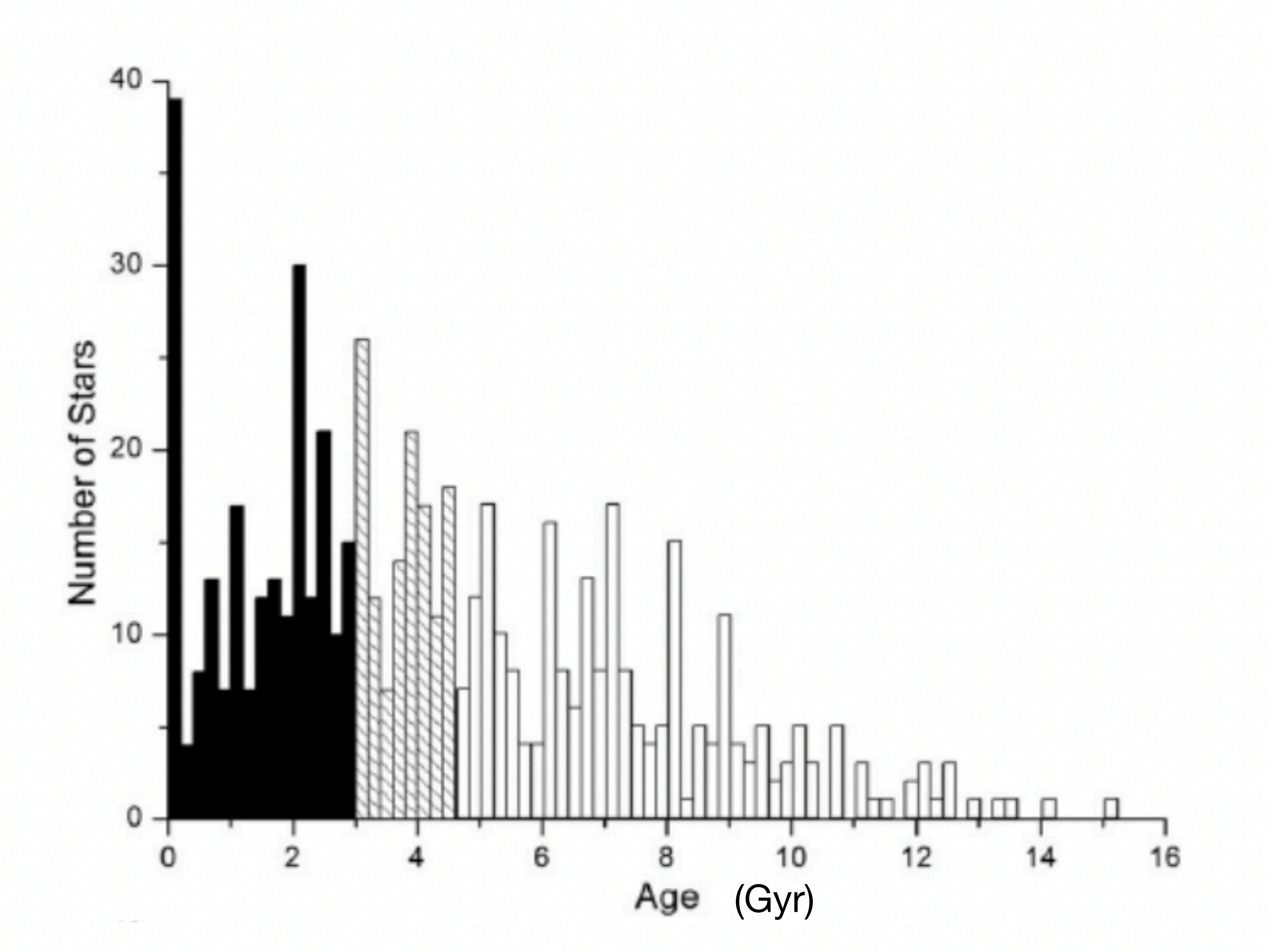


Backup Slides

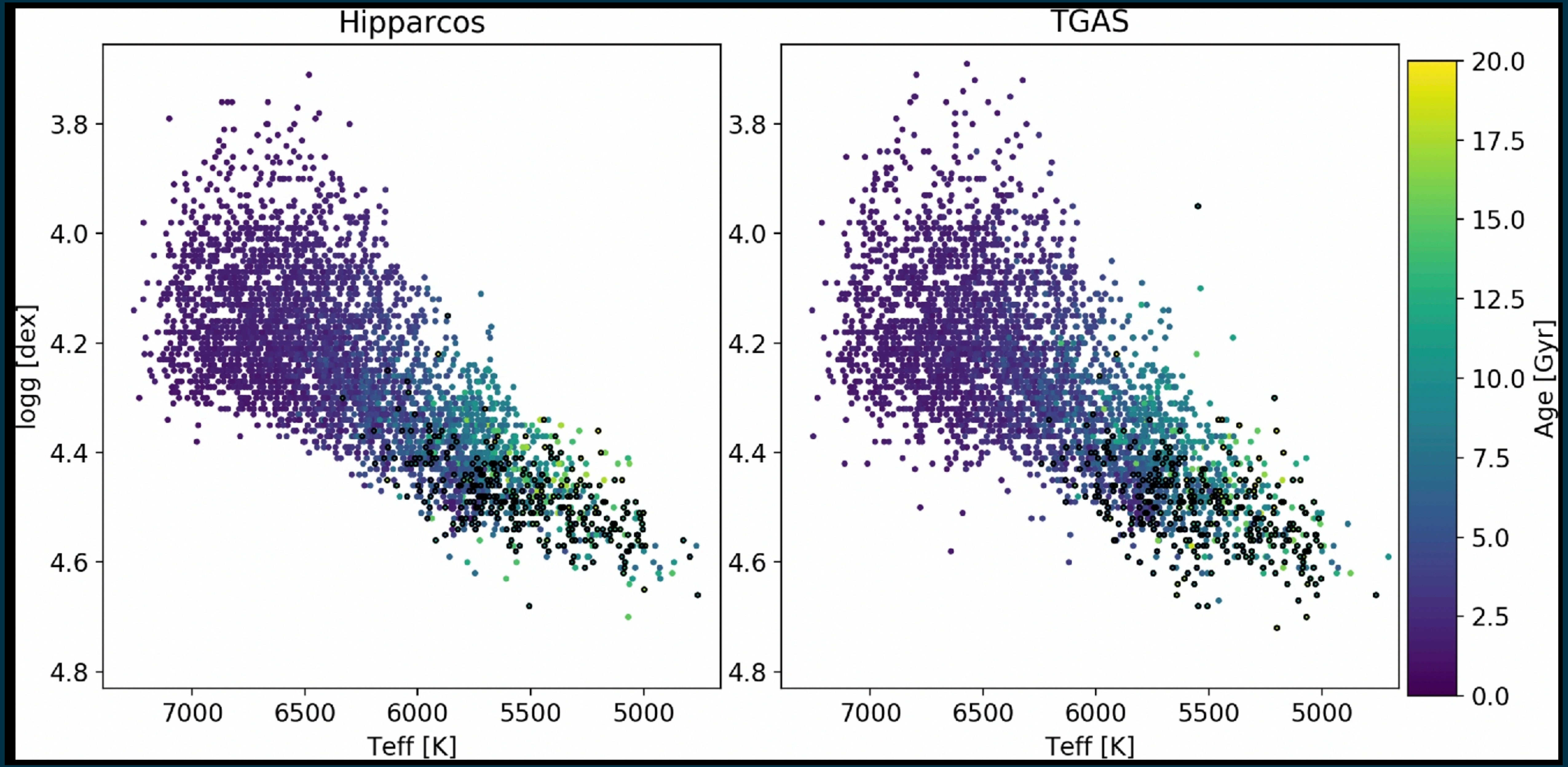
Stellar type distribution



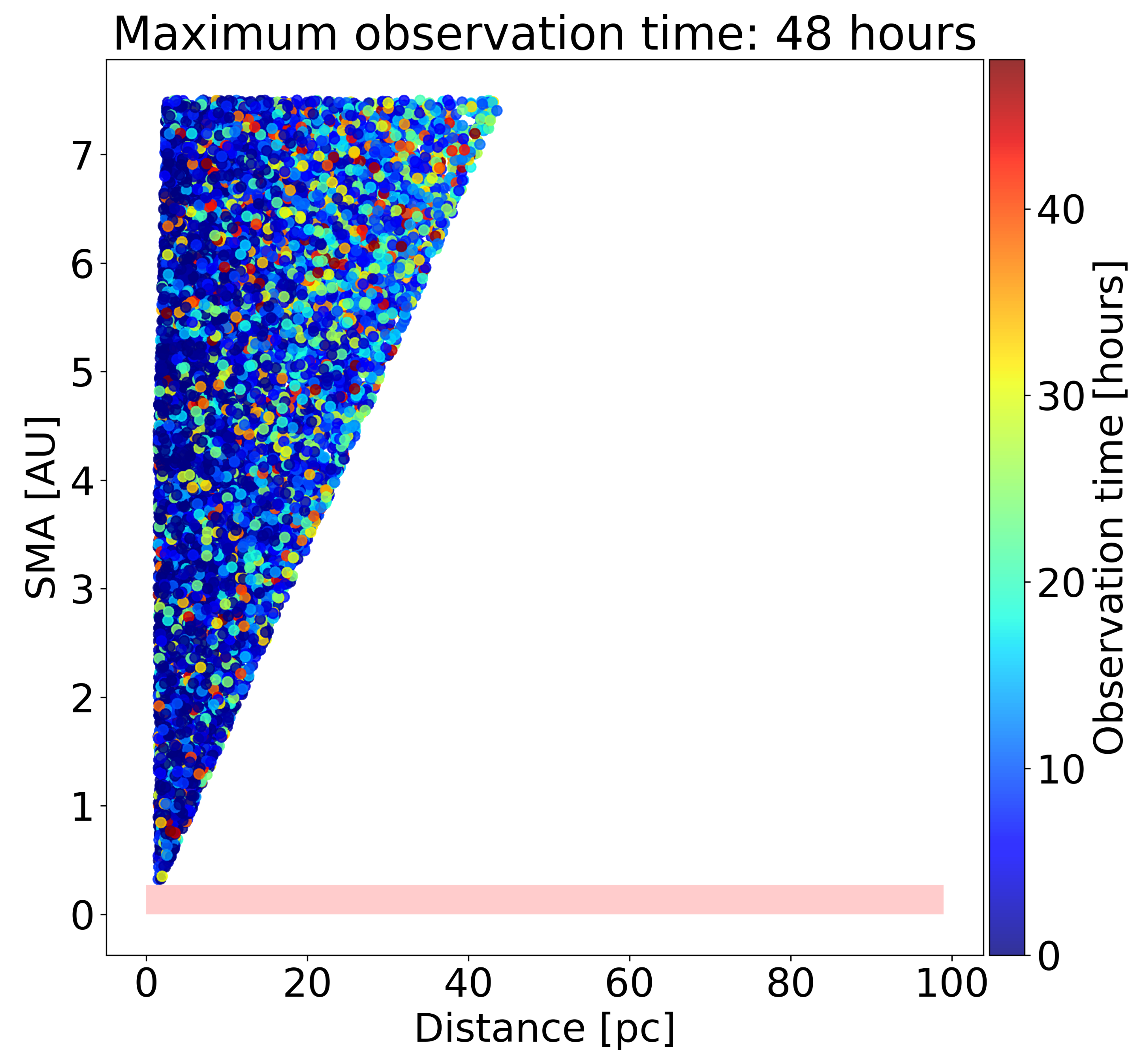
Stellar type	Within 10pc	Within 100pc	Conservative estimate	Fraction	Total Planets
A	4	4000	2000	0.011527378	64.5533141
F	8	8000	4000	0.023054755	129.106628
G	20	20000	10000	0.057636888	322.766571
K	42	42000	21000	0.121037464	677.809798
M	273	273000	136500	0.786743516	4405.76369
Total	347	347000	173500	1	5600



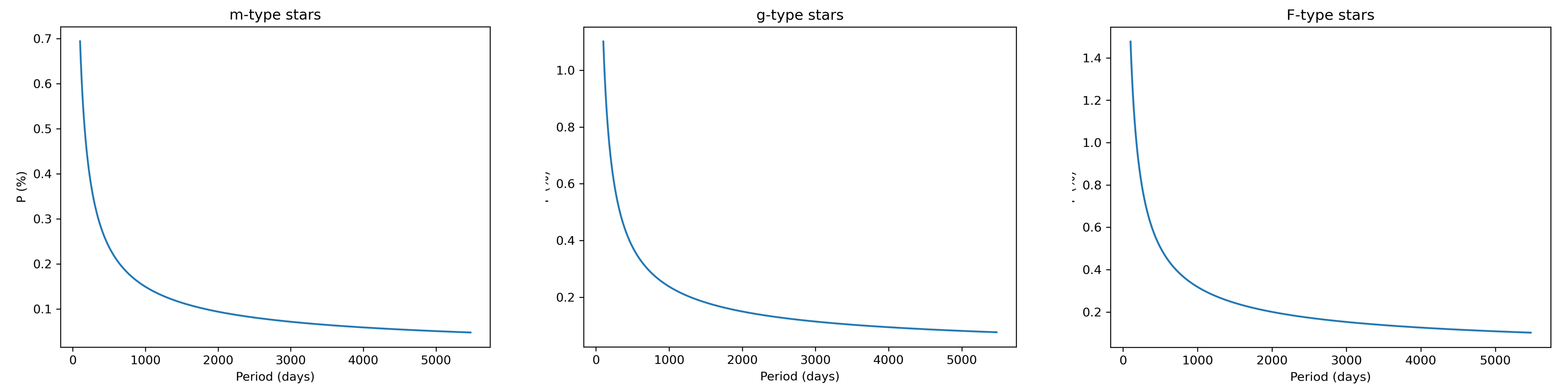
Safanova 2015

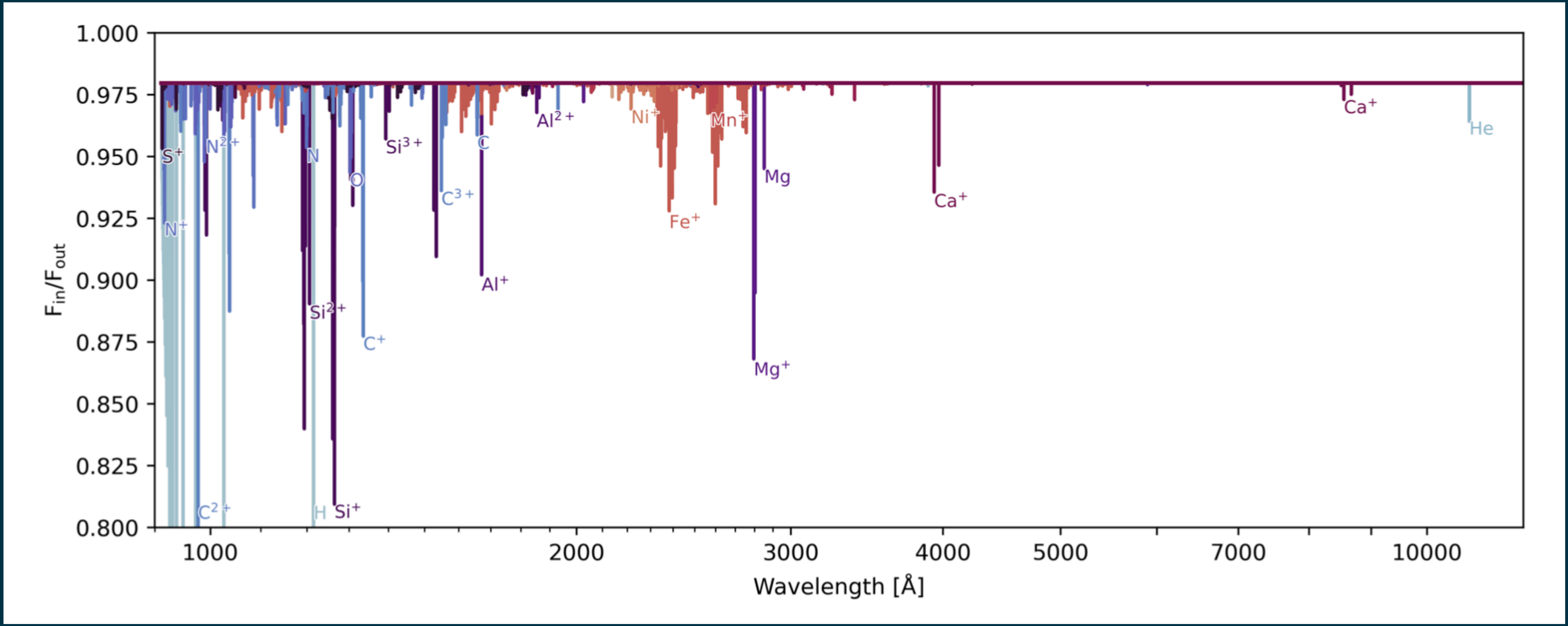


Lin et al. 2018

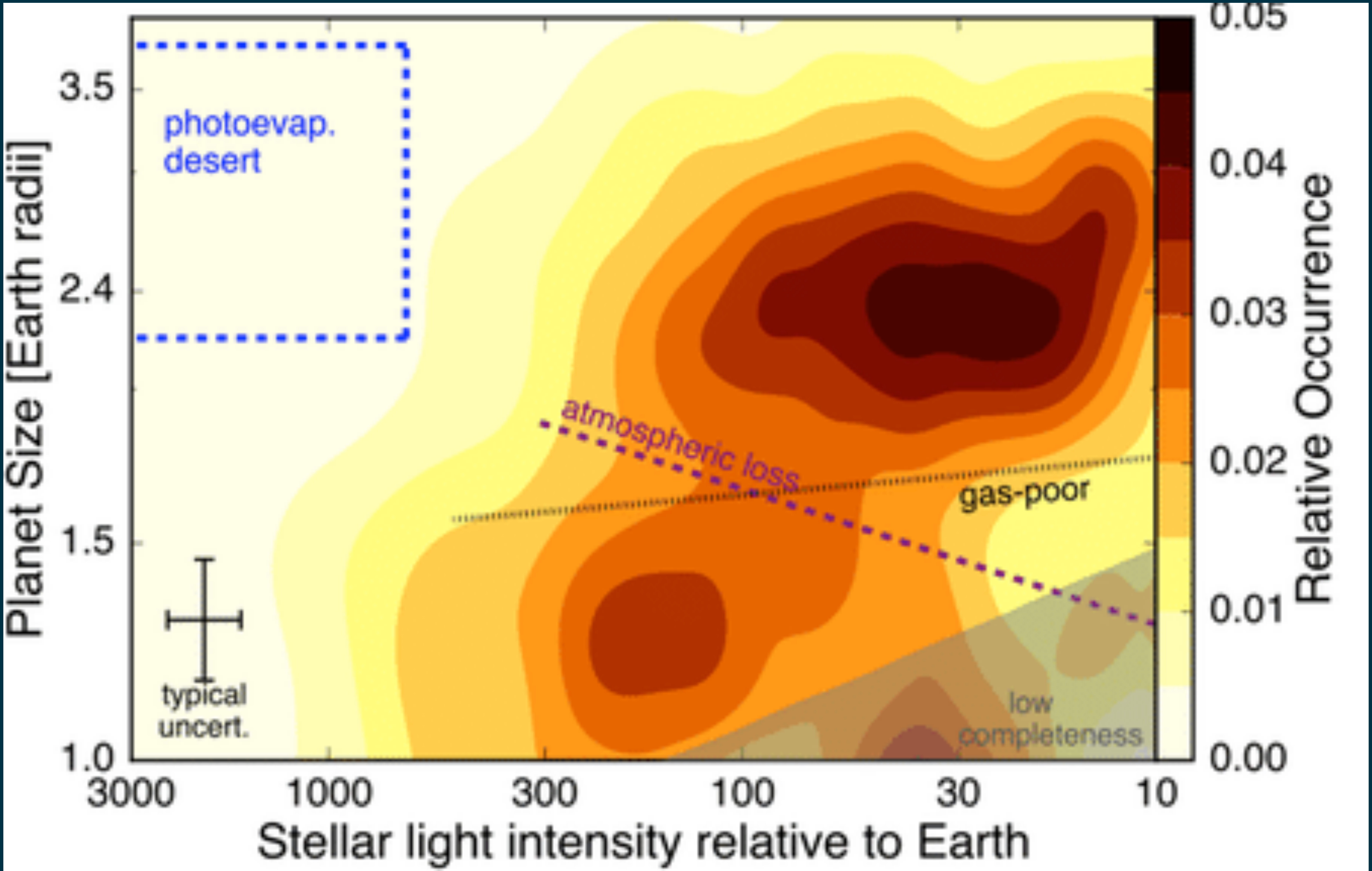


Maximum observation time: 48 hours
SMA [AU]
0
1
2
3
4
5
6
7
Distance [pc]
0
20
40
60
80
100
Observation time [hours]
0
10
20
30
40


m-type stars
P (%)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
Period (days)
g-type stars
1.0
0.8
0.6
0.4
0.2
0
1000
2000
3000
4000
5000
Period (days)
F-type stars
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
1000
2000
3000
4000
5000
Period (days)

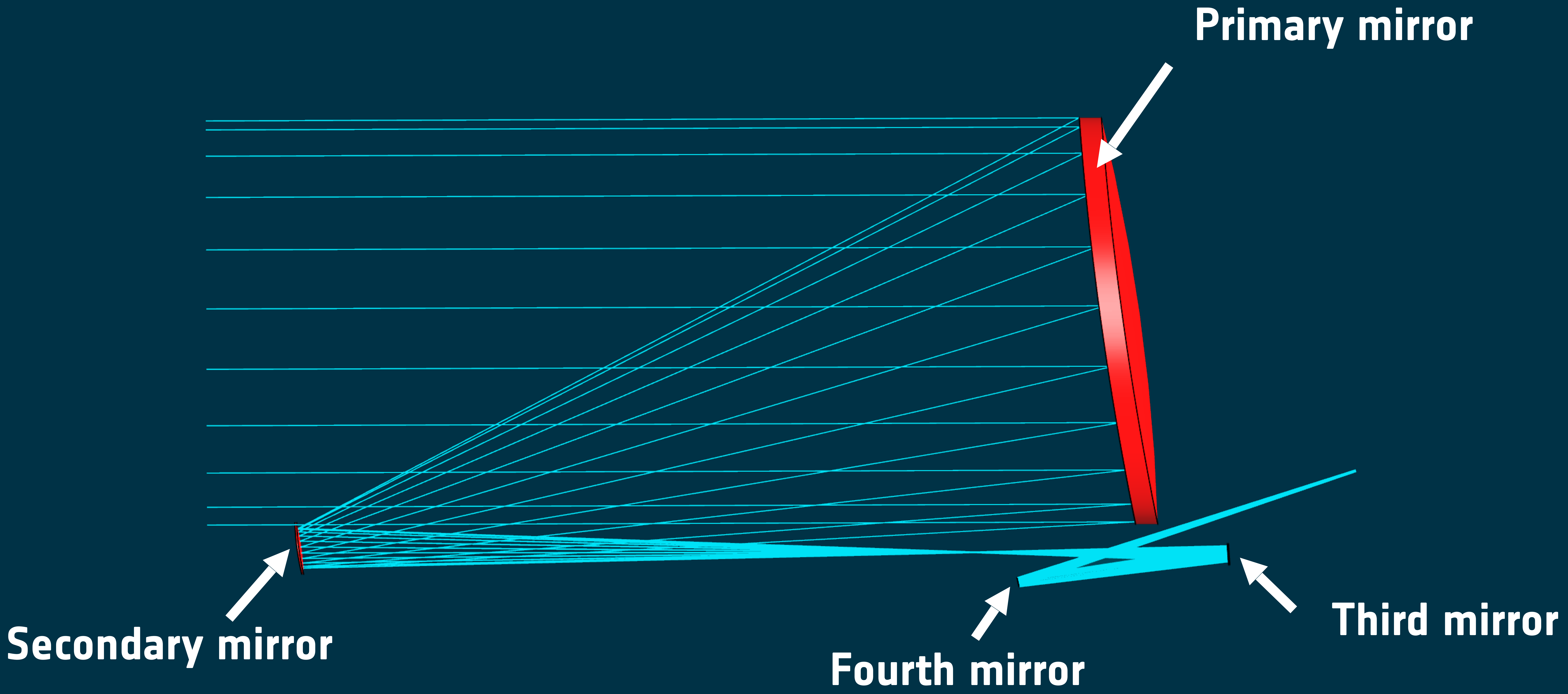


Linssen, Dion & Oklopčić, Antonija. (2023).



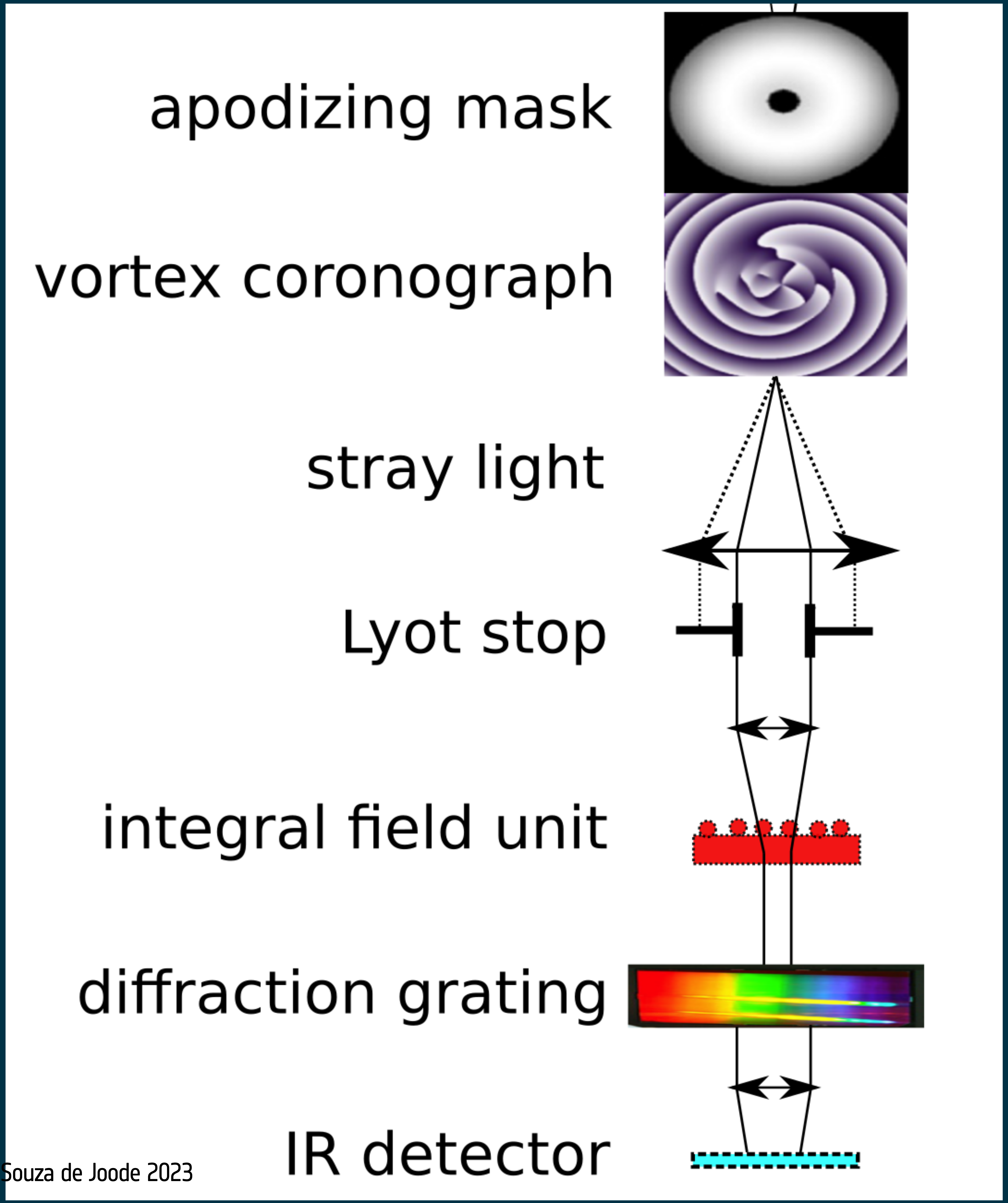
Benjamin J. Fulton et al 2017

Telescope


Primary mirror
Secondary mirror
Fourth mirror
Third mirror

MARY

- 10^{-9} driving requirement (necessity for space-based observations)
- Low TRL for elliptical vortex coronograph



Souza de Joode 2023

UVIS Detectors Currently available

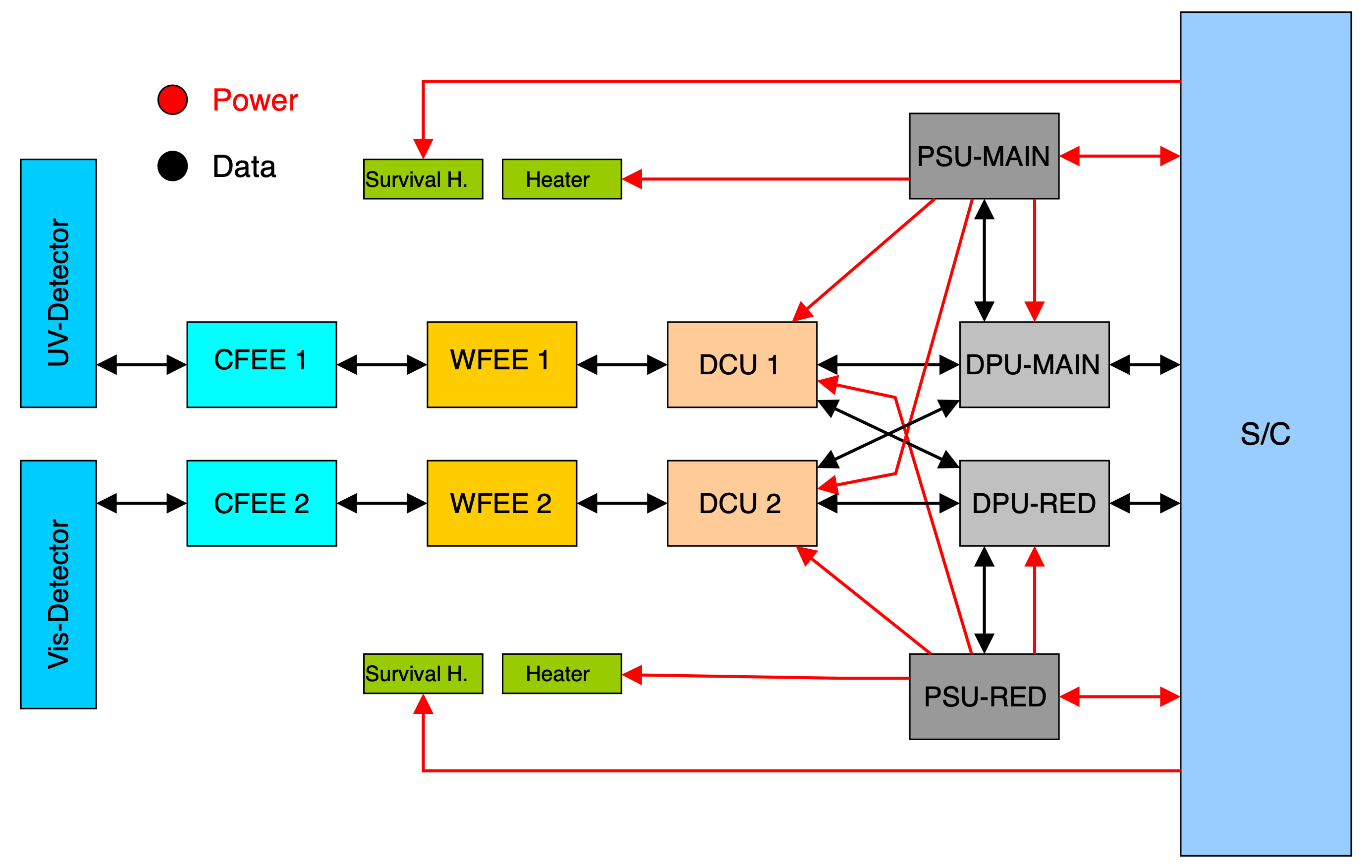
Visible: Teledyne CCD250-82

Wavelength range	400 - 800 nm
Mean QE	⩾ 80%
Pixel Size	10 µm
Detector Size	4096 x 4004 px
Dark noise @ 120K	< 0.02 e-/px/s
Read Noise	⩽ 5 e-/px
Full Well Capacity	> 135000 e-

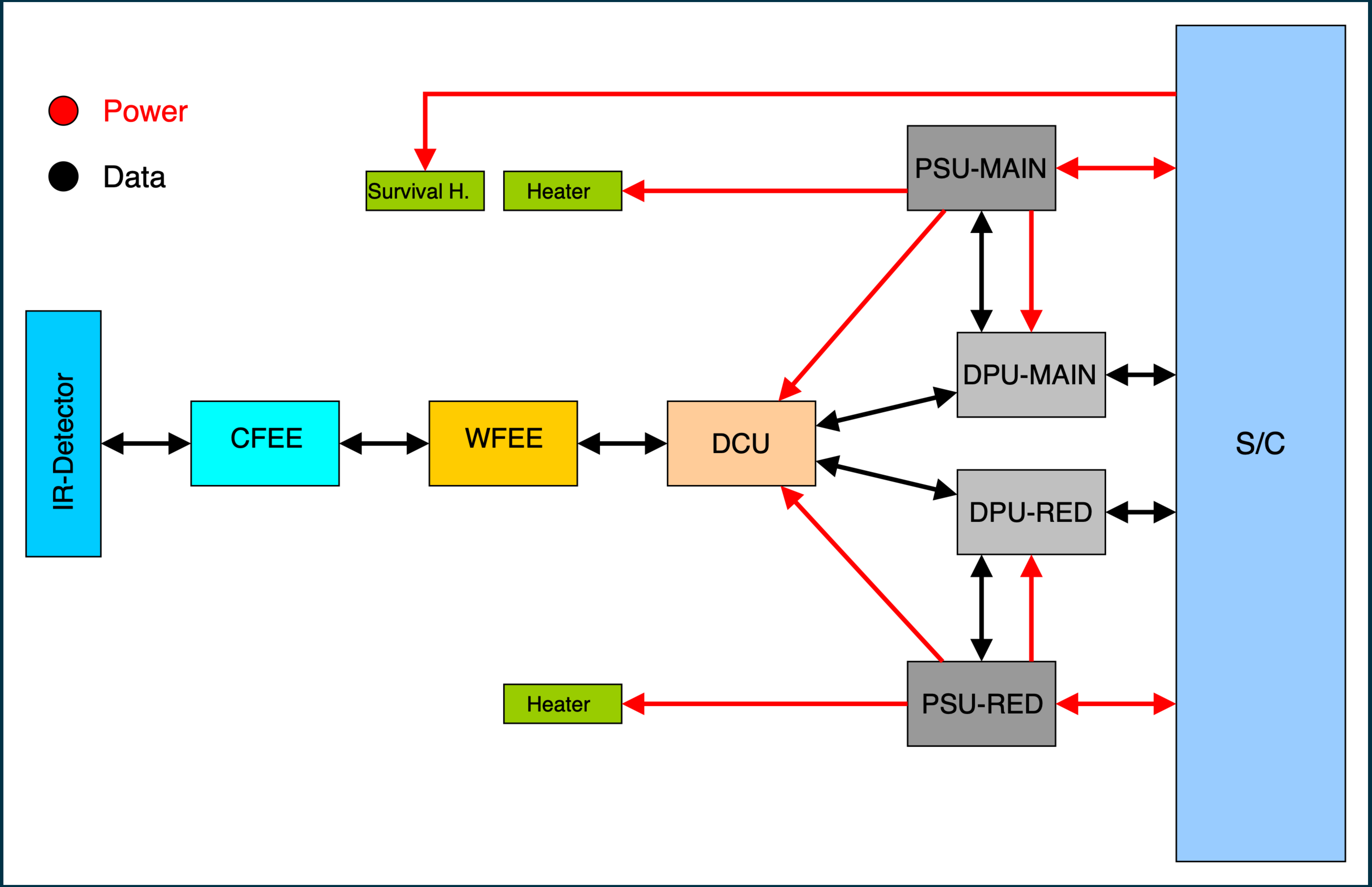
UV: Teledyne CCD272-64

Wavelength range	100 - 300 nm
Mean QE	⩾ 35%
Pixel Size	12 µm
Detector Size	4096 x 3112 px
Dark noise @ 120K	< 0.2 e-/px/s
Read Noise	⩽ 3 e-/px
Full Well Capacity	> 30000 e-

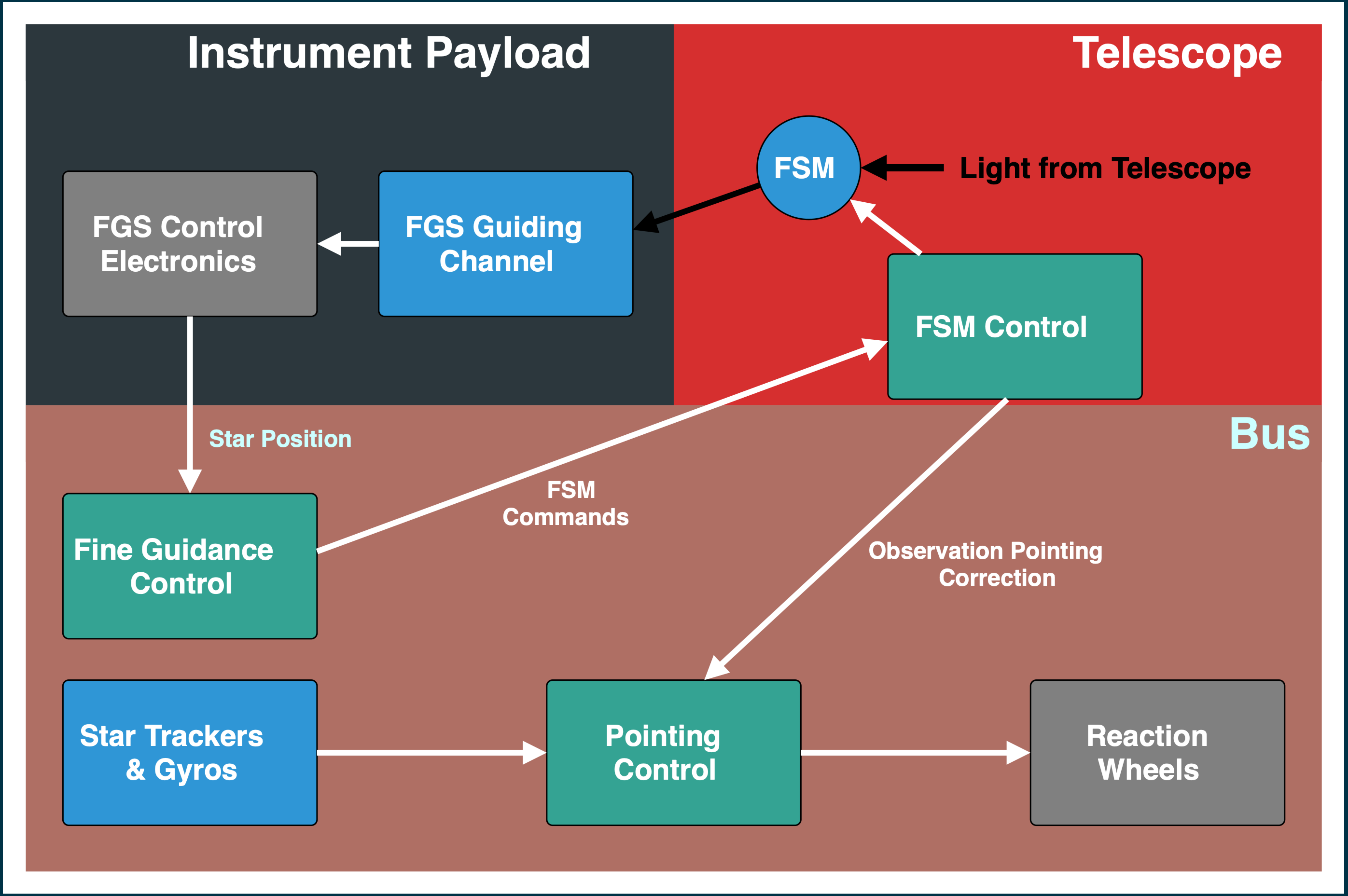
UVIS Control Unit



MARY Control Unit



ADCS Block Diagram



Power Budget

				Safe mode	Safe Mode	Downlink	Downlink	Science	Science	Slewing	Slewing
Group	Component	Power (W) (max)	Margins	Power (W)	Power + Margins	Power (W)	Power + Margins	Power (W)	Power + Margins	Power (W)	Power + Margins
Payload	Instruments	400	0.2	100	120	100	120	400	480	100	120
	Fine guiding system	22	0.1	0	0	0	0	22	24.2	22	24.2
Communications	Transponder	55	0.1	55	60.5	55	60.5	11	12.1	55	60.5
	SSPA (power amplifier)	40	0.05	2	2.1	40	42	2	2.1	20	21
Electrical & Power	PCDU	50	0.05	50	52.5	50	52.5	50	52.5	50	52.5
Data Handling	Computer	15	0.1	15	16.5	15	16.5	15	16.5	15	16.5
	Memory	10	0.05	10	10.5	10	10.5	10	10.5	10	10.5
	Remote Interface Unit	15	0.1	15	16.5	15	16.5	15	16.5	15	16.5
Payload Thermal Control	Payload thermal	120	0.2	120	144	120	144	120	144	120	144
Propulsion Module	Propulsion	20	0.1	0	0	0	0	0	0	20	22
Service Module Thermal	Thermal control SVM	100	0.2	100	120	70	84	80	96	100	120
AOCS	AOCS Sensors & Electronics	25	0.1	25	27.5	25	27.5	25	27.5	25	27.5
	Reaction wheels	200	0.1	200	220	200	220	200	220	200	220
SVM Harness Losses (2%)	-	21.44	0.1	13.84	15.224	14	15.4	19	20.9	15.04	16.544
	Total	1093.44		705.84	805.324	714	809.4	969	1122.8	767.04	871.744
	20% power margin	20% power margin		847.008	966.3888	856.8	971.28	1162.8	1347.36	920.448	1046.0928

Mass Budget

Component	Mass (kg)	Margin	Mass with margin (kg)
Instruments	0.5	1	1
Adaptive optics:	120.7	0	241.4
lenses + dichroics	2.7	1	5.4
mechanics of AO	50	1	100
AO cables	5	1	10
Shack-Hartmann array	6	1	12
VIS detector	6	1	12
UV detector	6	1	12
IR detector	10	1	20
Integral field unit	10	1	20
Coronograph	10	1	20
mounting	15	1	30
Mirrors	533.3	0.2	639.96
Boom for M2	80	0.2	96
Solar Panels	5.6	0.05	5.88
Batteries	76	0.05	79.8
Antennas	10	0.05	10.5
Detector control unit	2.25	0.1	2.475
OBC + DPU	27	0.05	28.35
Thermal radiator	5	0.05	5.25
Sun shield	256	0.2	307.2
Fuel tanks + propulsion module	50	0.05	52.5
ADCS thruster	8	0.05	8.4
Orbit correction thrusters	2	0.05	2.1
Dry mass	1176.35		1480.815
5% harness	58.8175	0.1	64.69925
20% Structure	235.27	0.2	282.324
Dry mass	1470.4375		1827.83825
Dry mass+System margin		0.2	2193.4059
Propellant	158	0.2	189.6
Wet mass			2383.0059