2026 Atreides CML4 Presentation

Atreides Team

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SCIENCE

Atreides Goals

4

The past decade has witnessed an explosive growth in the state of knowledge of planetary science and astrobiology through the invaluable combination of new missions and...

nationalacademies.org

https://www.nationalacademies.org/read/26522/chapter/4#50

Science goals

Understand the processes that control Martian weather, climate, and long-term climate evolution (NASA).

Science objectives

01 Characterize and forecast dust storms and wind profiles

02 Map dust distribution on the surface and in the atmosphere

From Science Objectives to Observables

Science objectives → Physical parameters → Observables

Physical parameters	Observables
• Horizontal wind speed vs altitude • Dust vertical distribution • Storm occurrence and frequency • Near-surface dust loading	• Doppler frequency shift vs altitude • Range-resolved backscatter P(r) • Near-surface integrated backscatter • Spatio-temporal dust products • Surface return signal (proxy albedo)

An Example of an Instrument Spec

Physical parameters → Observables → Specifications

Observables

- Doppler frequency shift of the backscattered signal as a function of altitude

Specifications

- Velocity resolution : Δv ≤ 2–3 m/s
- Sensitivity : SNR ≥ 10 at nominal dust conditions
- Horizontal resolution : Δx ≤ 3–5 km
- Geometry / Pointing : Off-nadir angle (25°–40°)

An Example of an Instrument Spec

Observables → Specifications → Performances

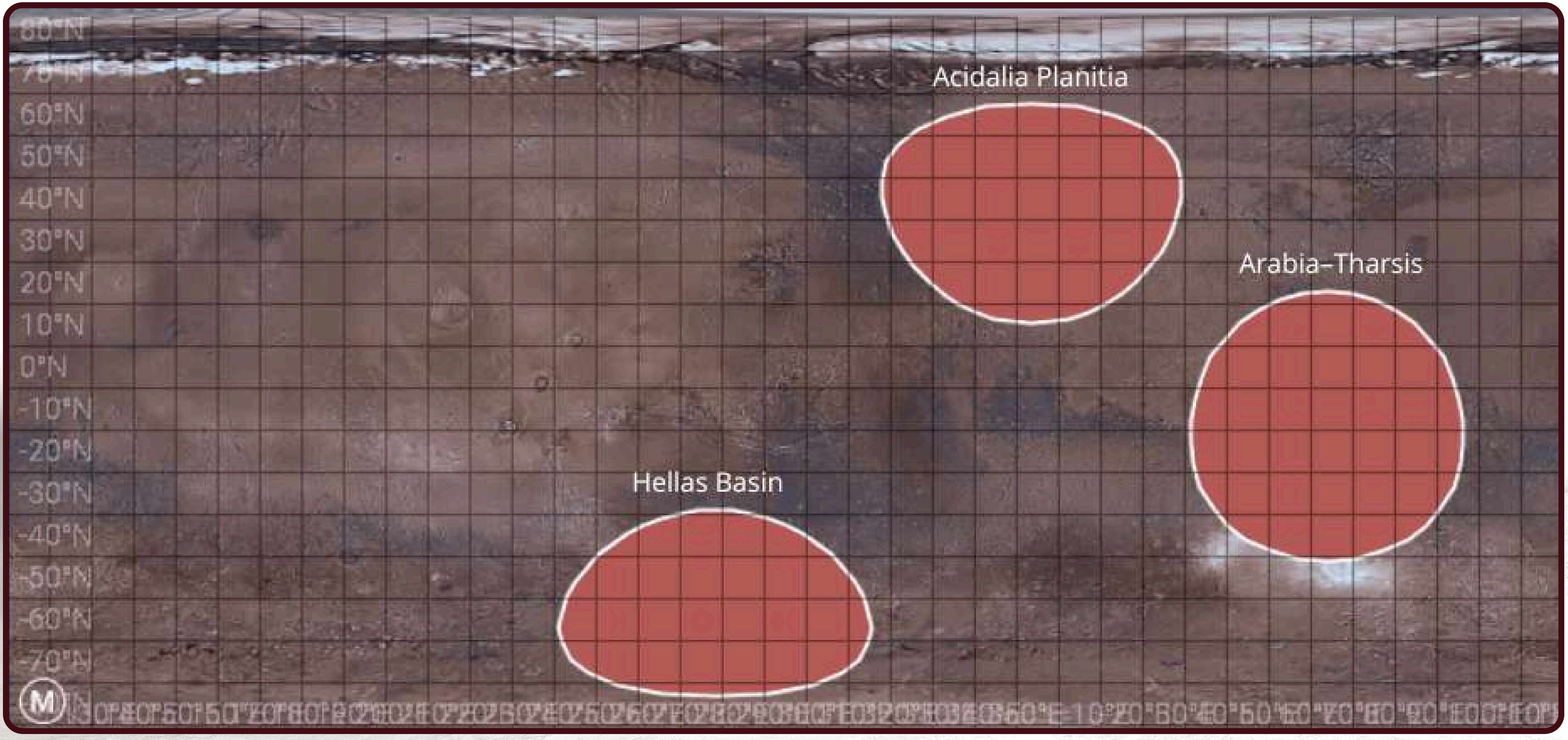
Specifications

- Sensitivity : SNR ≥ 10 at nominal dust conditions
- Velocity resolution : Δv ≤ 2–3 m/s
- Horizontal resolution : Δx ≤ 3–5 km
- Geometry / Pointing : Off-nadir angle (25°–40°)

Performances

- SNR ≥ 10 achieved at nominal operating point
- Δv ≈ 2.2 m/s at SNR ≥ 10
- Δx ≈ 3 km
- θ = 32°, H = 325 km, Vorb = 3.4 km/s

Priority-1 Regions



References : Wang and Richardson (2015), Strausberg et al. (2000), and Montabone et al. (2020)

Coverage Strategy and Threshold

Coverage strategy

- Focus on Priority-1 (P1) regions driving Martian dust and climate processes
- Use repeated orbital passes to build spatial and temporal statistics
- Mission operates in SSO (fixed local time)

Coverage strategy

- Spatial coverage (P1) : $\frac{A_{\text{P1 observed}}}{A_{\text{P1 total}}}$
- Revisits : number of repeated observations per P1 grid cell

Sizing Model

Estimation of the photon_limited SNR

$$SNR_{ph} = f(N_{pulse}, E_p, \eta_{sys}, A, \beta, R, \Delta R, T)$$

- N_{pulse} : Number of pulse per unit of time
- E_p : Energy emitted per pulse
- η_{sys} : Global optical efficiency of the system
- A : Area of the collecting surface
- β : Backscatter volumetric coefficient
- R : Radial measured distance
- ΔR : Radial resolution
- T : Back-and-forth transmission

Sizing Model

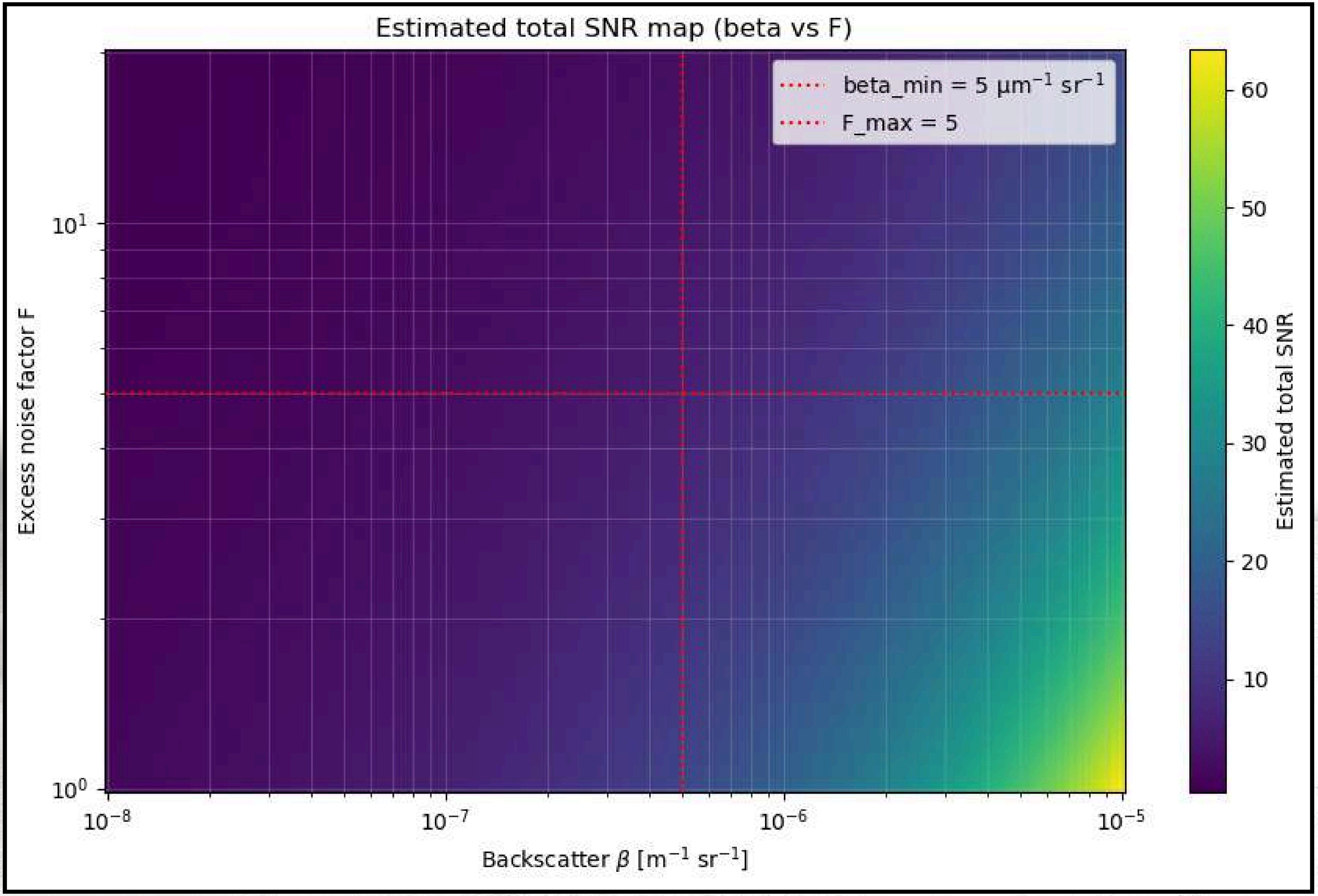
Estimation of the global SNR

- Photon-limited SNR provides an optimistic lower bound
- Real measurements include additional noise sources (background, stray light, detector read noise, dark current ...)
- We modelise those contribution with a excess noise factor $F \geq 1$

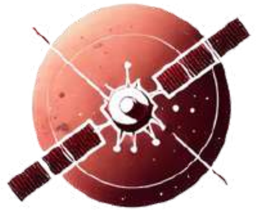
$$SNR_{tot} = \frac{SNR_{ph}}{\sqrt{F}}$$

- $F = 1 \rightarrow$ purely photon-limited
- $F > 1 \rightarrow$ increasing non-ideal noise contribution

Nominal Operating Area



Alternatives to Atmospheric LiDAR



Multi-spectral imaging

01 Tracks dust clouds and atmospheric features

02 Provides horizontal transport

03 BUT no direct vertical dust or wind profiles

II FLIGHT

Orbit Selection Trade-off

Criterion	320 km	328 km	335 km
Laser slant Range (32° angle)	377 km	387 km	395 km
Wind detection	High precision, even for low wind speeds.	Precise for standard wind profiles.	Difficult for weak winds or fine dust layers.
Atmospheric drag	very high	moderate	low

https://issfd.org/ISSFD_2004/papers/P1120.pdf

Selected Orbit

Sun-Synchronous (SSO) Dusk/Dawn
328 km, 97 degrees, 32° from Nadir
Repeat Cycle: 19 Martian Sols

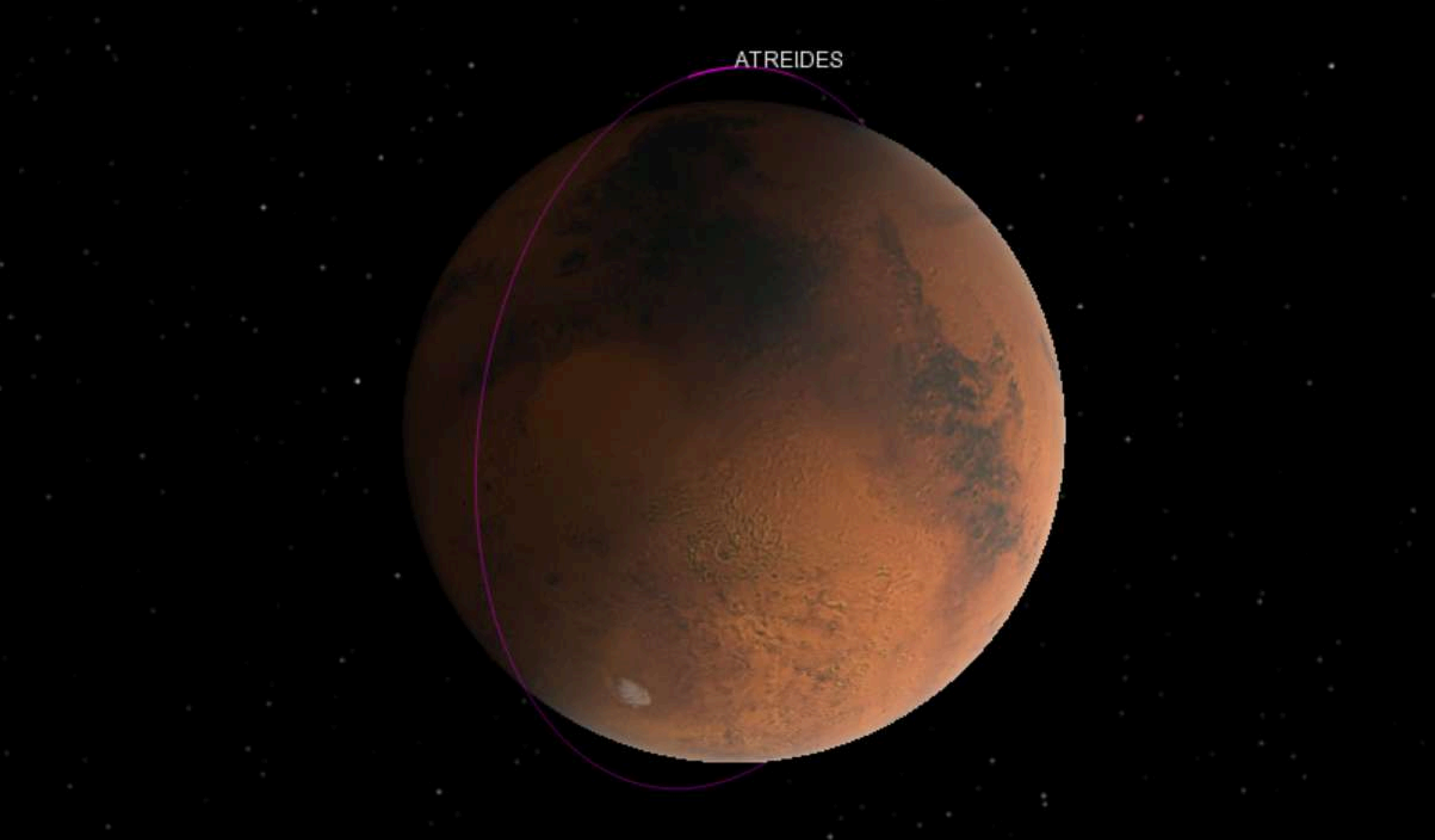
Orbit still close to Mars so density and drag can be not stable

→ Propulsion system added to ensure the satellite stays in the right orbit

Launch Strategy

Launching on low cost and collecting enough Data

- Rideshare on Falcon 9 Block 5
- Carrier Mission: International Mars Ice Mapper (I-MIM) (Launch 2033)
- Access to Space: Low-cost injection into Martian orbit (~1.3 M€).
- Data Relay: I-MIM serves as a telecommunications relay to Earth


ATREIDES

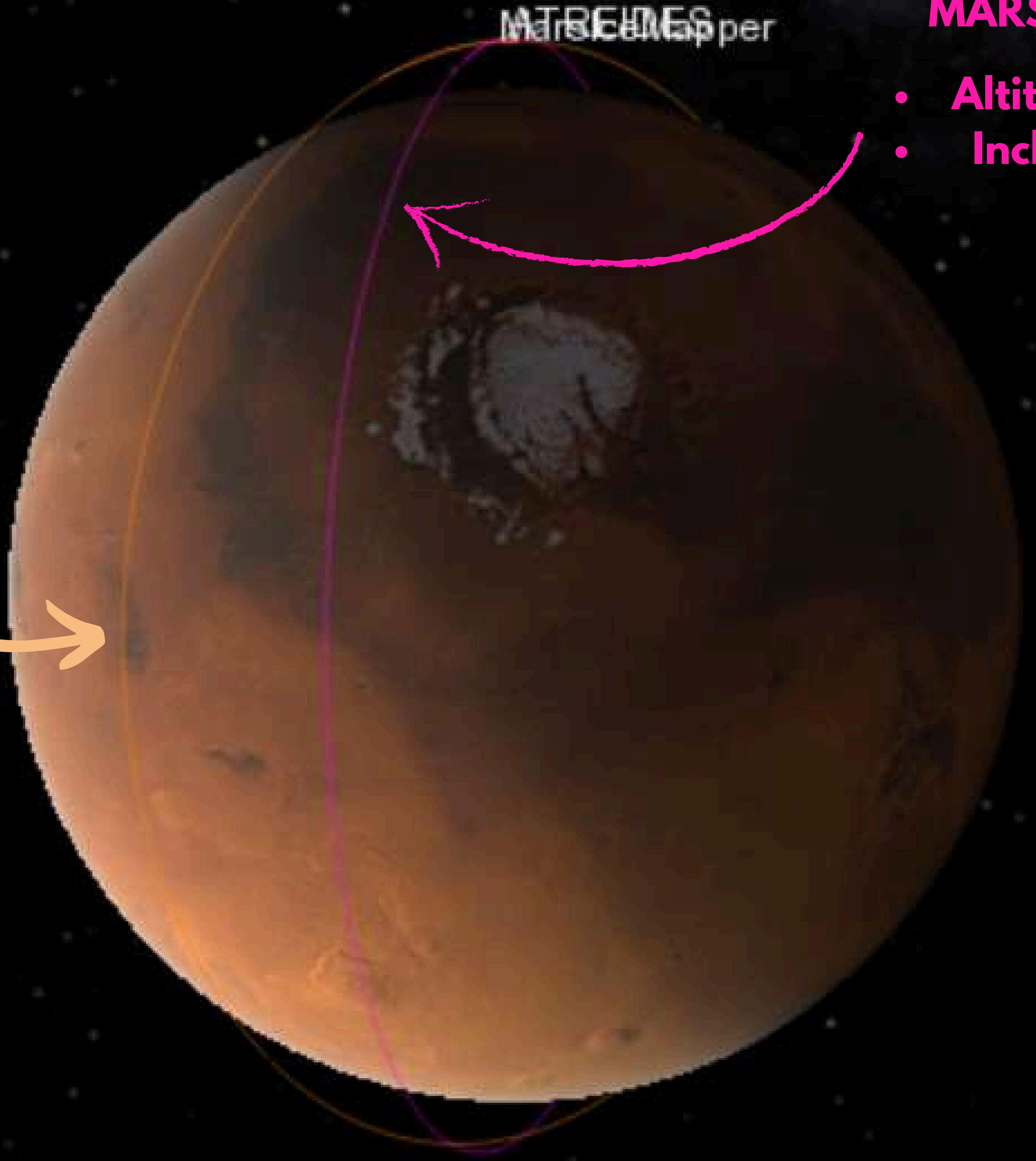
Intervisibilities

Intervisibility & Data Relay Analysis

- **Context**: ATREIDES utilizes a rideshare/relay strategy with the International Mars Ice Mapper (I-MIM).
- **Objective**: To validate the feasibility of the 3-hour data update cycle required for Martian weather forecasting.
- **Tooling**: Analysis performed using DOCKS for trajectory propagation and VTS for geometric event visualization.

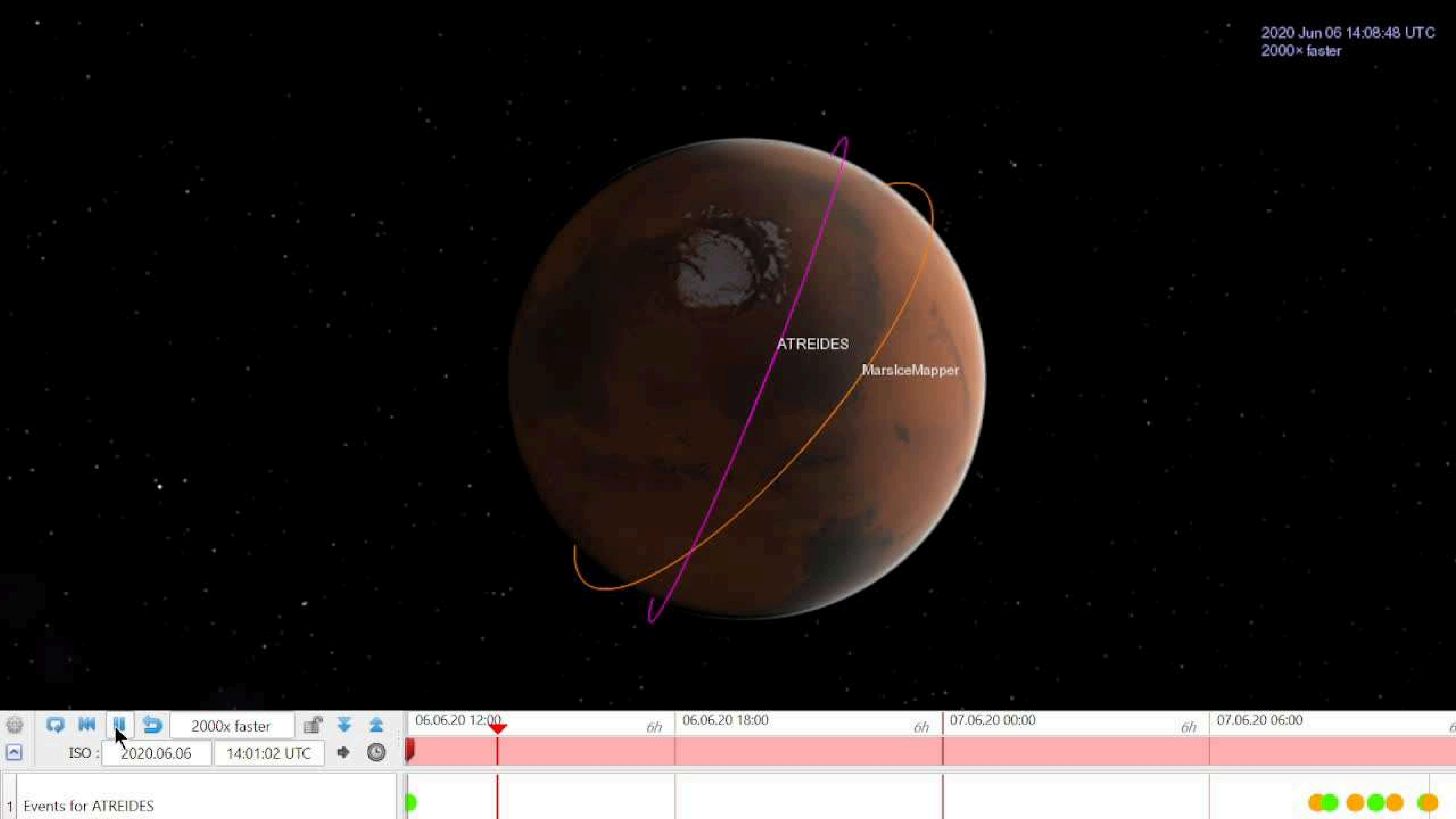
MARS ICE MAPPER

- Altitude : 300 km
- Inclination : 74°



ATREIDES

- Altitude : 328 km
- Inclination : 97°

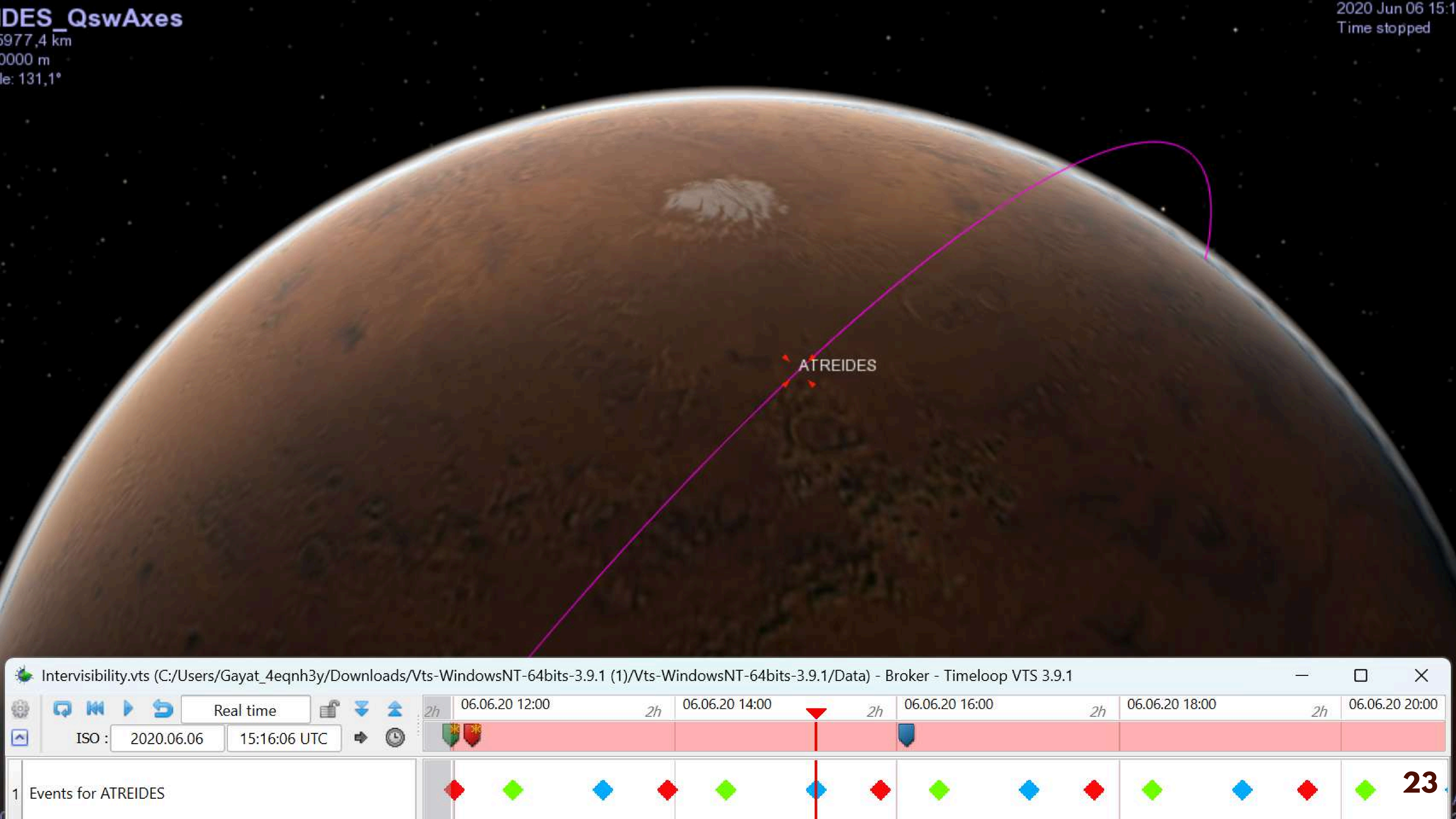

2020 Jun 06 14:08:48 UTC
2000× faster
ATREIDES
MarsIceMapper
2000x faster
ISO :
2020.06.06
14:01:02 UTC
06.06.20 12:00
6h
06.06.20 18:00
6h
07.06.20 00:00
6h
07.06.20 06:00
1
Events for ATREIDES

Pointings

Objective: Optimizing Observations

To fulfill the mission's scientific goals, we need to know exactly when the satellite flyovers occur above our three primary areas of interest.

- **Goal**: Maximize high-quality data collection over high-activity dust zones.
- **Constraint**: Optimize power consumption by synchronizing LiDAR "On/Off" cycles with geographical positions.
- **Tooling** : Custom code that translates orbital trajectories into actionable commands for the Lidar instrument.



DES_QswAxes
5977,4 km
0000 m
le: 131,1°
2020 Jun 06 15:1
Time stopped
ATREIDES
Intervisibility.vts (C:/Users/Gayat_4eqnh3y/Downloads/Vts-WindowsNT-64bits-3.9.1 (1)/Vts-WindowsNT-64bits-3.9.1/Data) - Broker - Timeloop VTS 3.9.1
Real time
ISO : 2020.06.06 15:16:06 UTC
06.06.20 12:00
06.06.20 14:00
06.06.20 16:00
06.06.20 18:00
06.06.20 20:00
2h
1 Events for ATREIDES

III PLATFORM

Choice of components

Subsystem	Name	Provider	TRL
Structure	12U XL Structure	Endurosat	9
EPS	Cubesat EPS	Endurosat	9
Solar panel	6U Double Deployable	Endurosat	9
Onboard computer	Onboard computer	Endurosat	9
Antenna	S-band Antenna	Endurosat	9
Transceiver	S-band Transceiver	Endurosat	9
AOCS	XACT-100	Blue Canyon	9

Choice of components

Subsystem	Name	Provider	TRL
Propulsion	Cubedrive	Dawn Aerospace	6
Payload	4U lidar	Laboratory	4

Justification

- Currently no cubesat sized lidar with the mission requirements is available
- Maturity level of propulsion technologies on the rise
- Technology development and validation for both subsystems

Satellite Mass Budget

Total Mass

19.8 kg

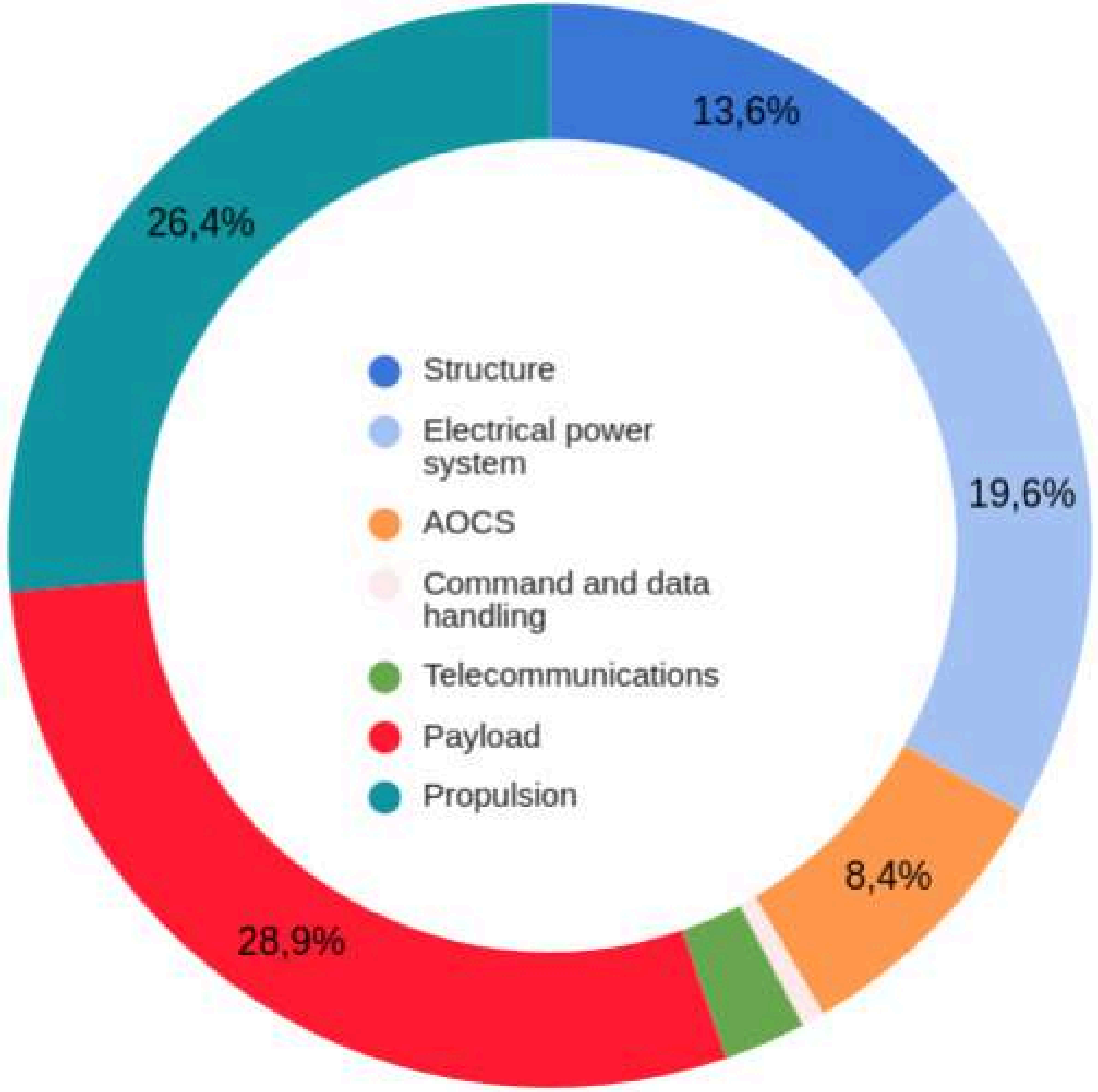
Margin

10 %

Volume

8U

Mass Repartition



Satellite Power Budget

Maximum Power

44.8 W

Depth of Discharge

30 %

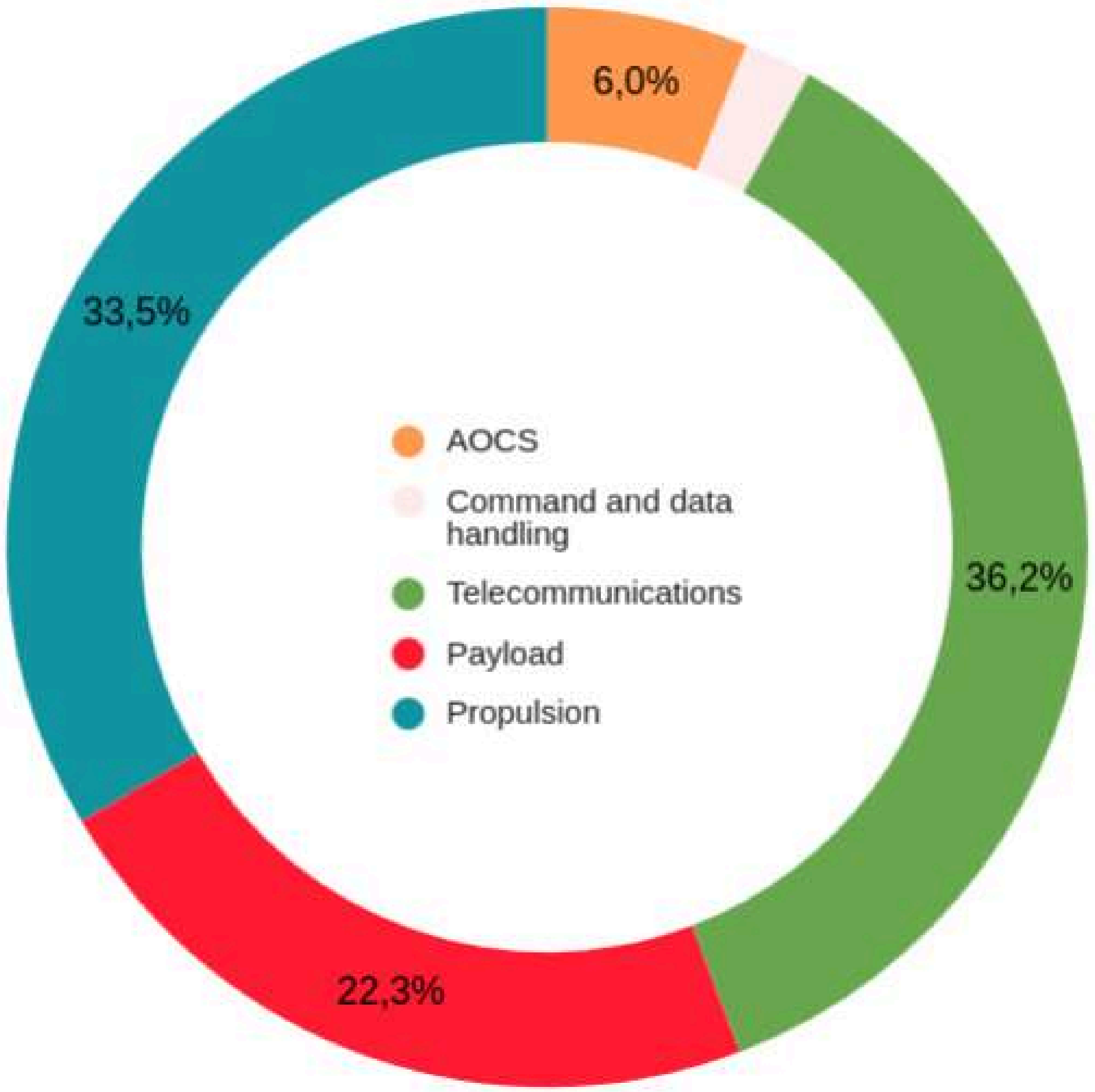
Minimum Battery Power

59 Wh

Battery Power

99 Wh

Power repartition



Satellite Power Budget

Maximum Power

44.8 W

Depth of Discharge

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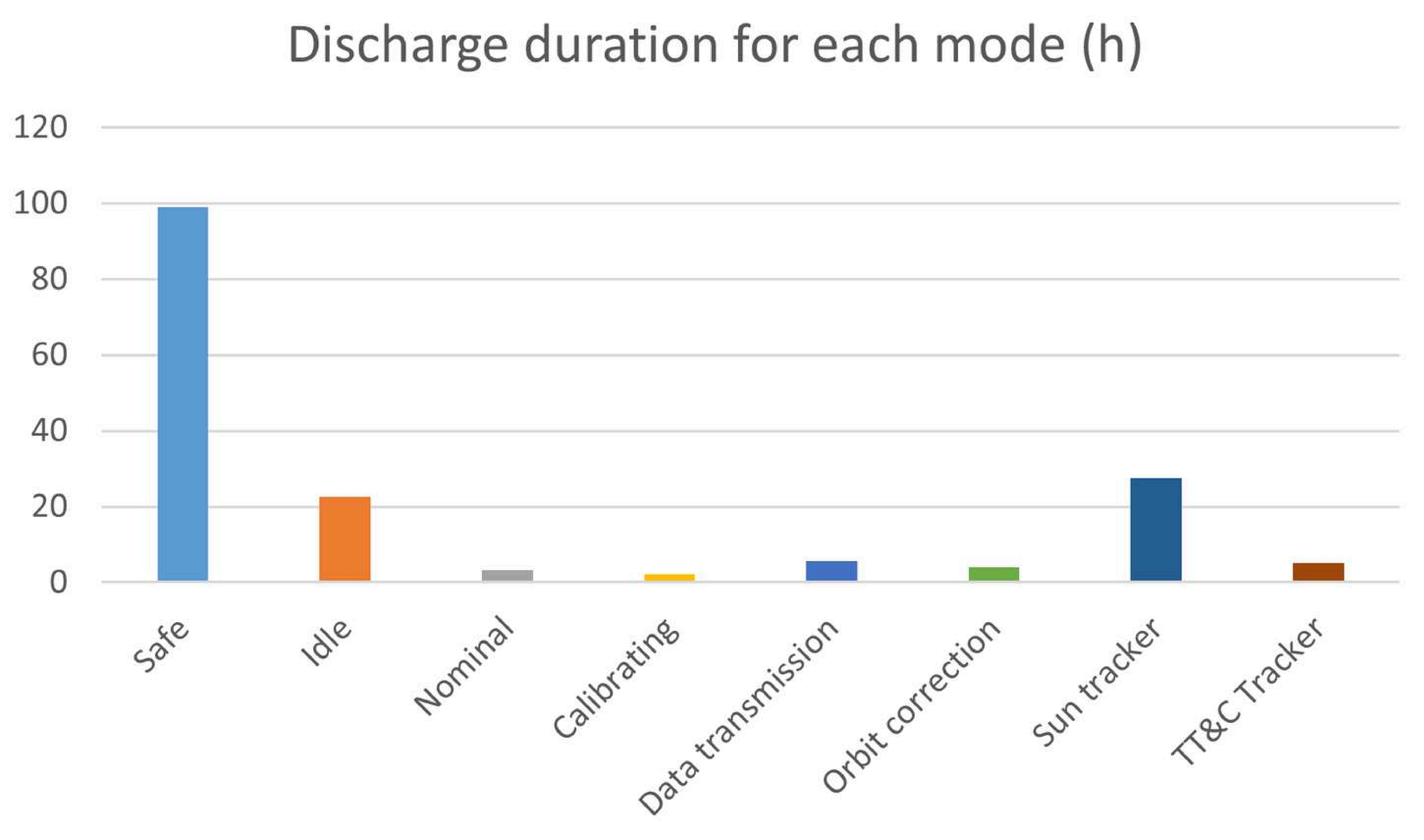
Minimum Battery Power

59 Wh

Battery Power

99 Wh

Discharge duration



Satellite Data Budget

Total Data per Day

47,5 GB

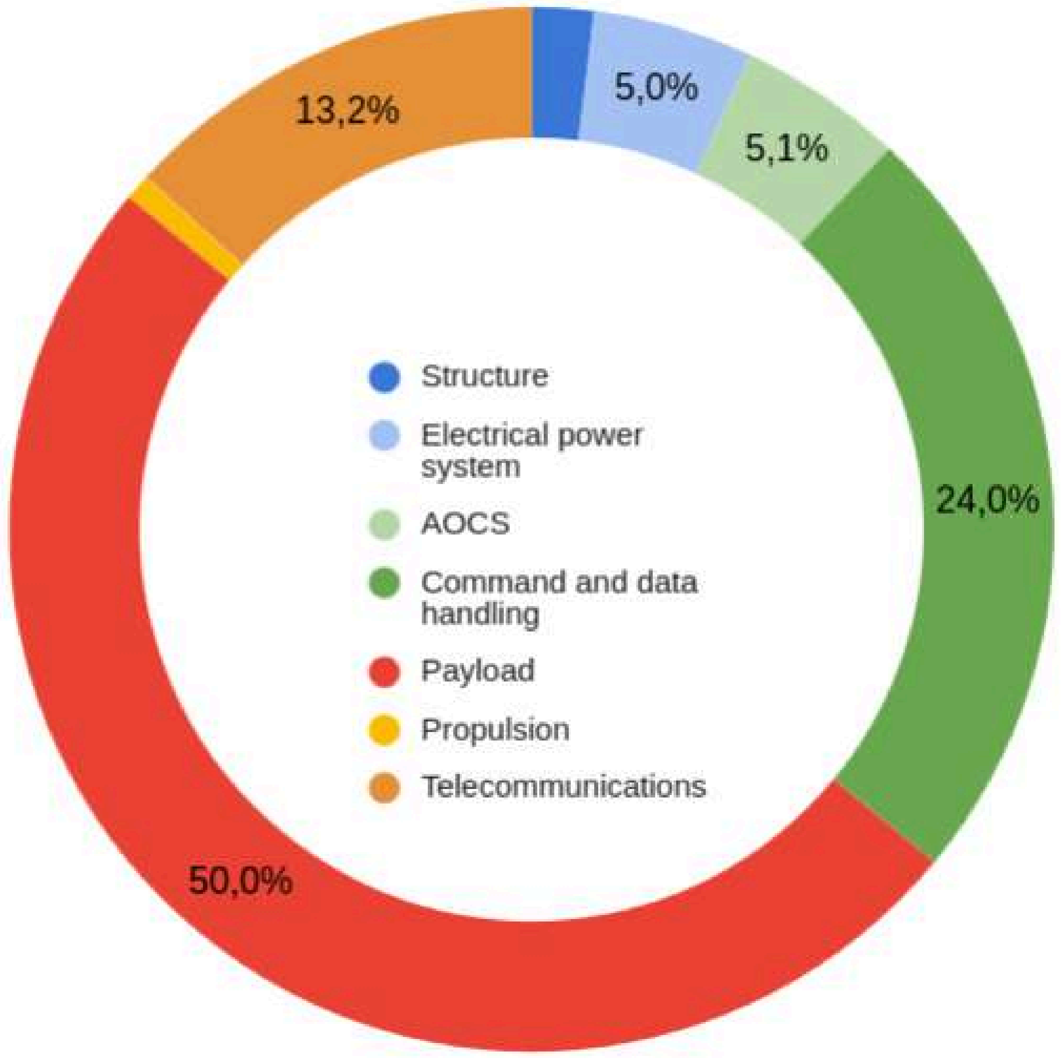
Tranceiver Rate

125 kbps

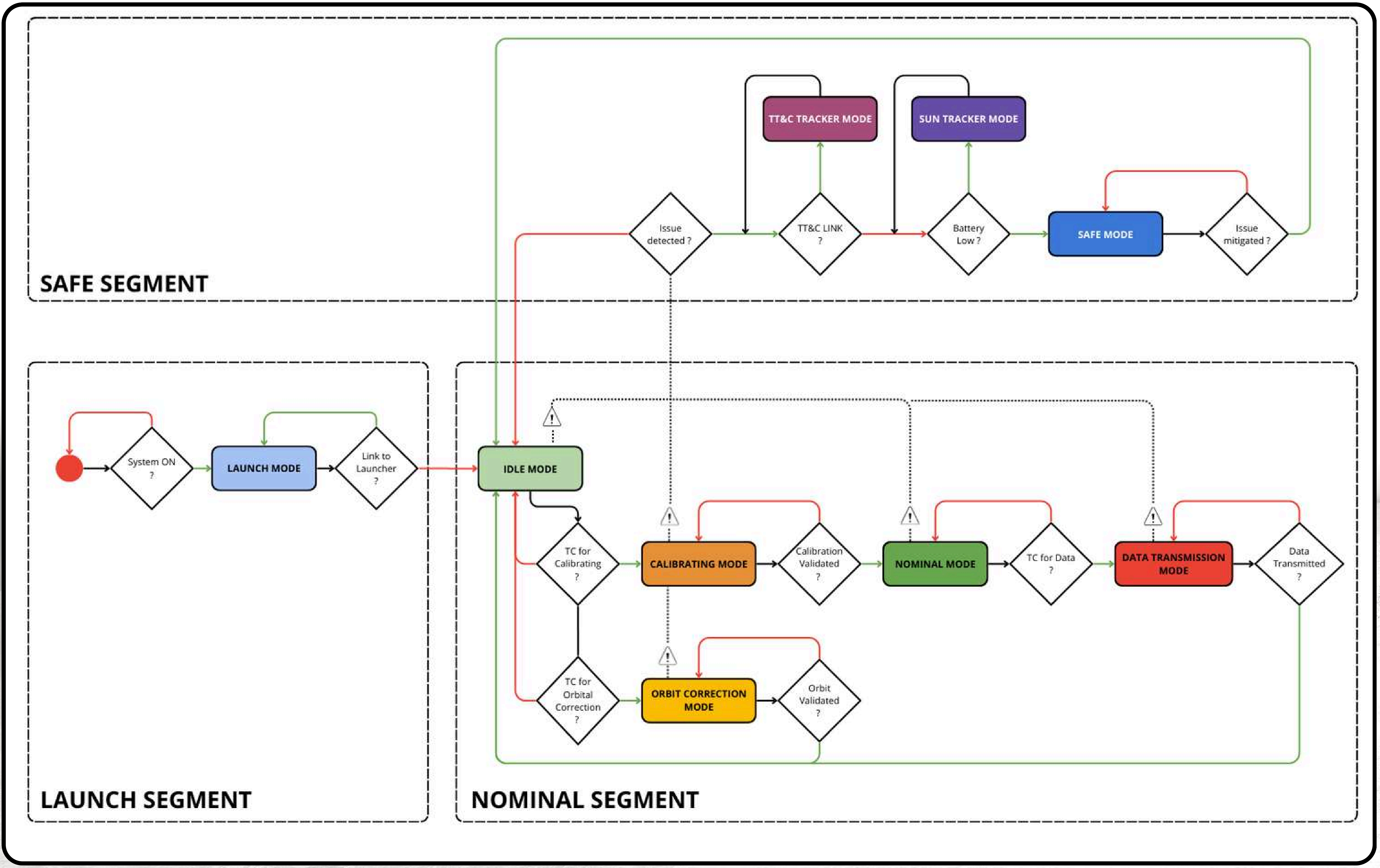
Ratio Generation/downlink

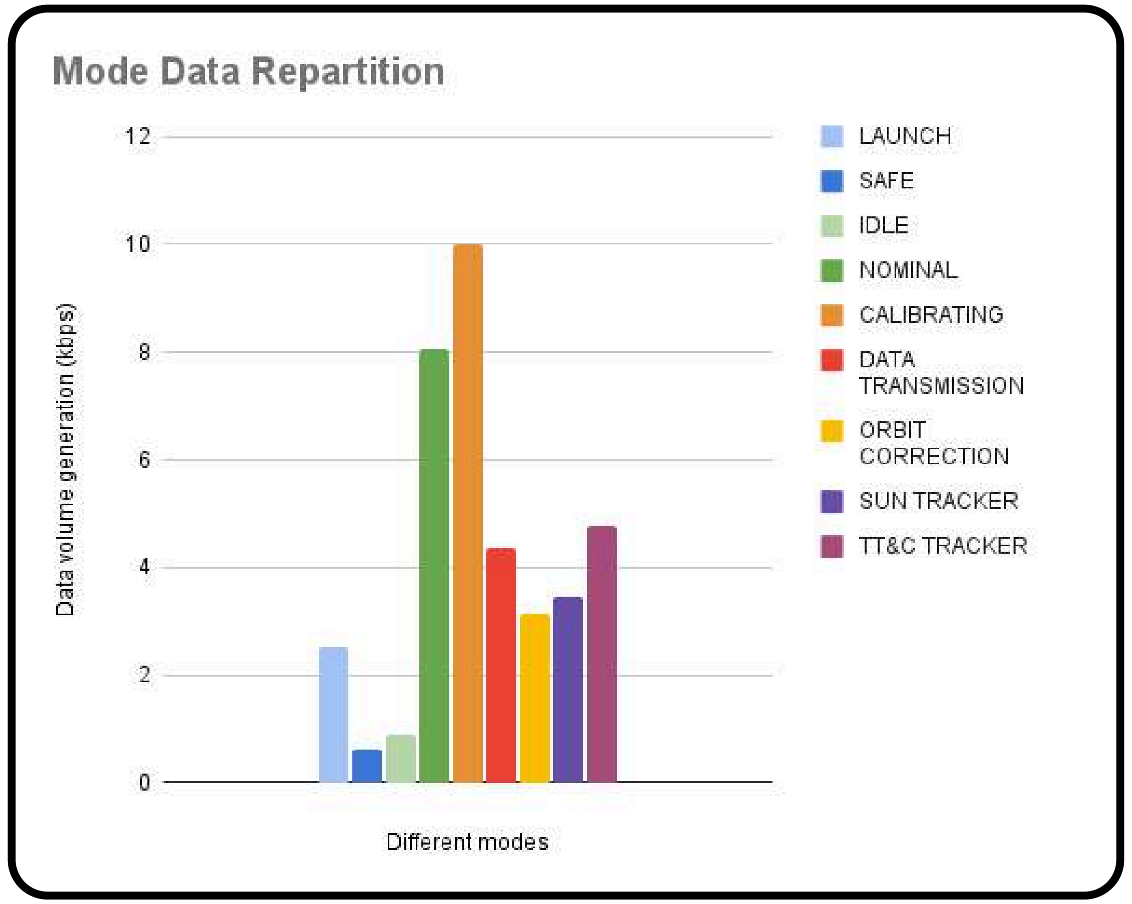
9,25%

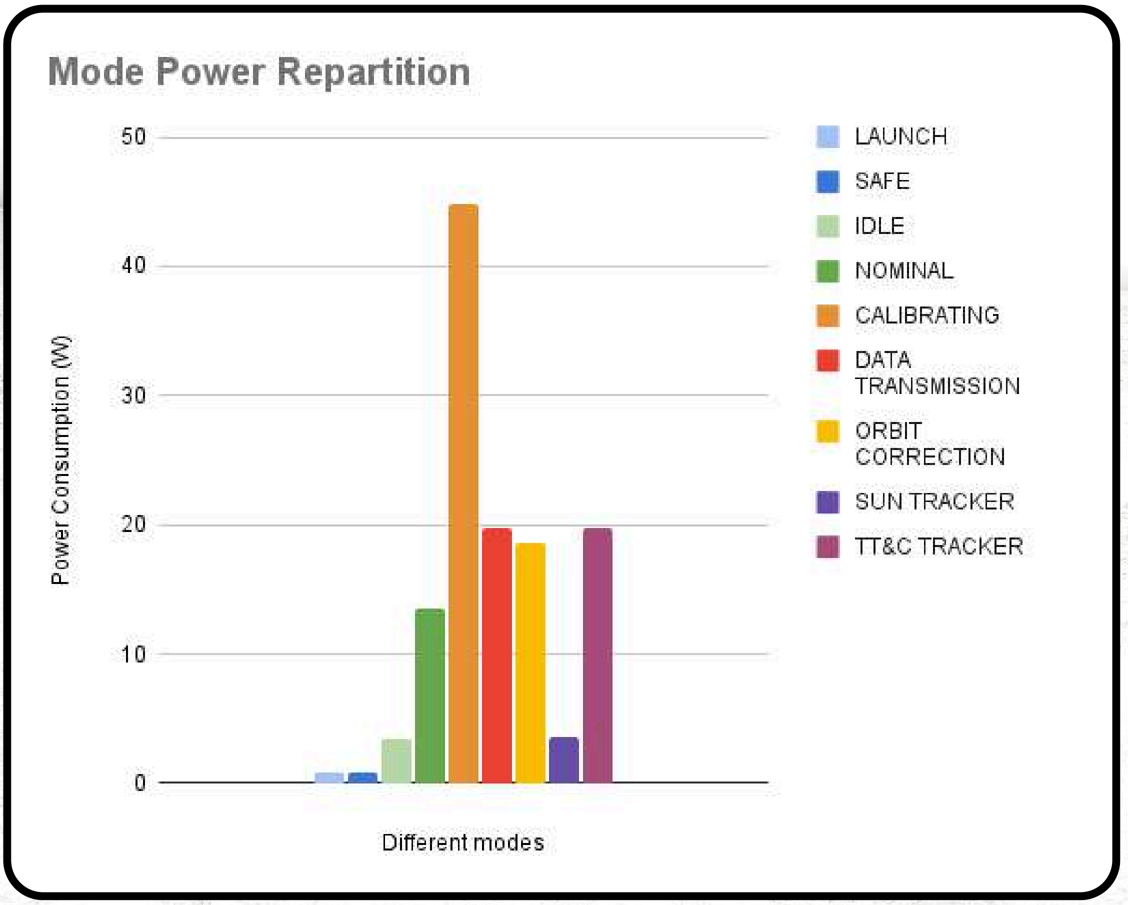
Data repartition



Satellite Mode Management

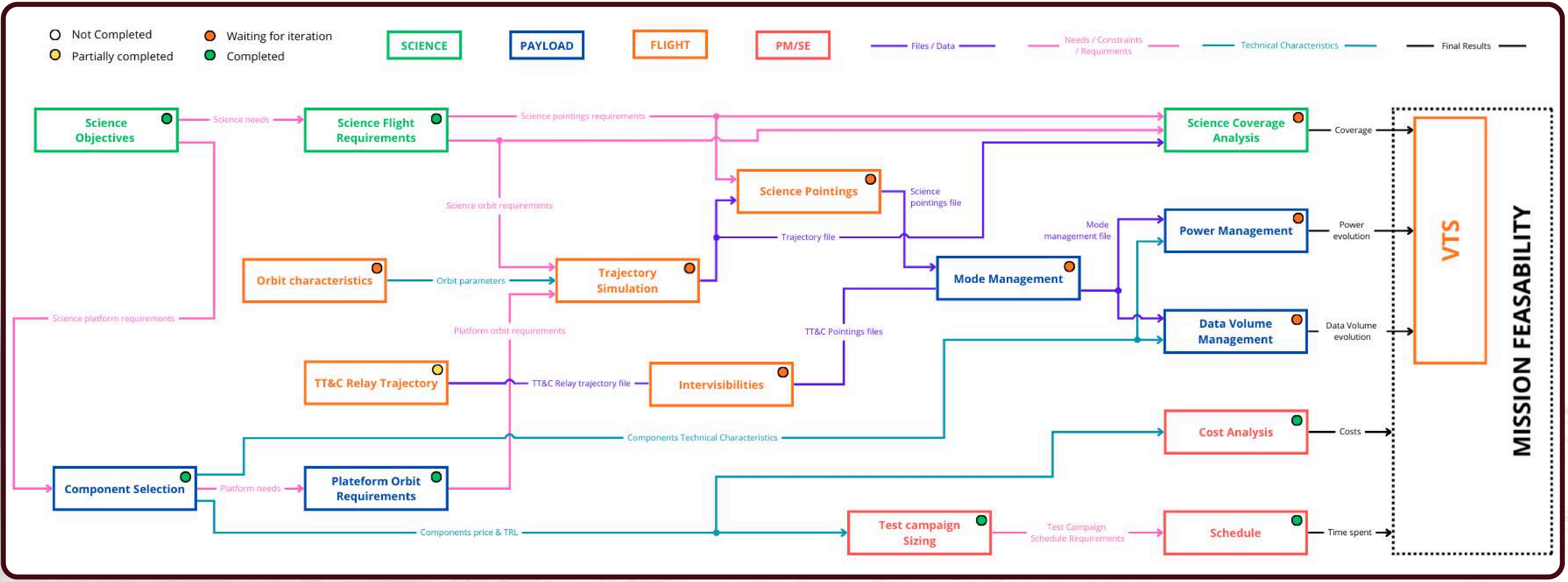






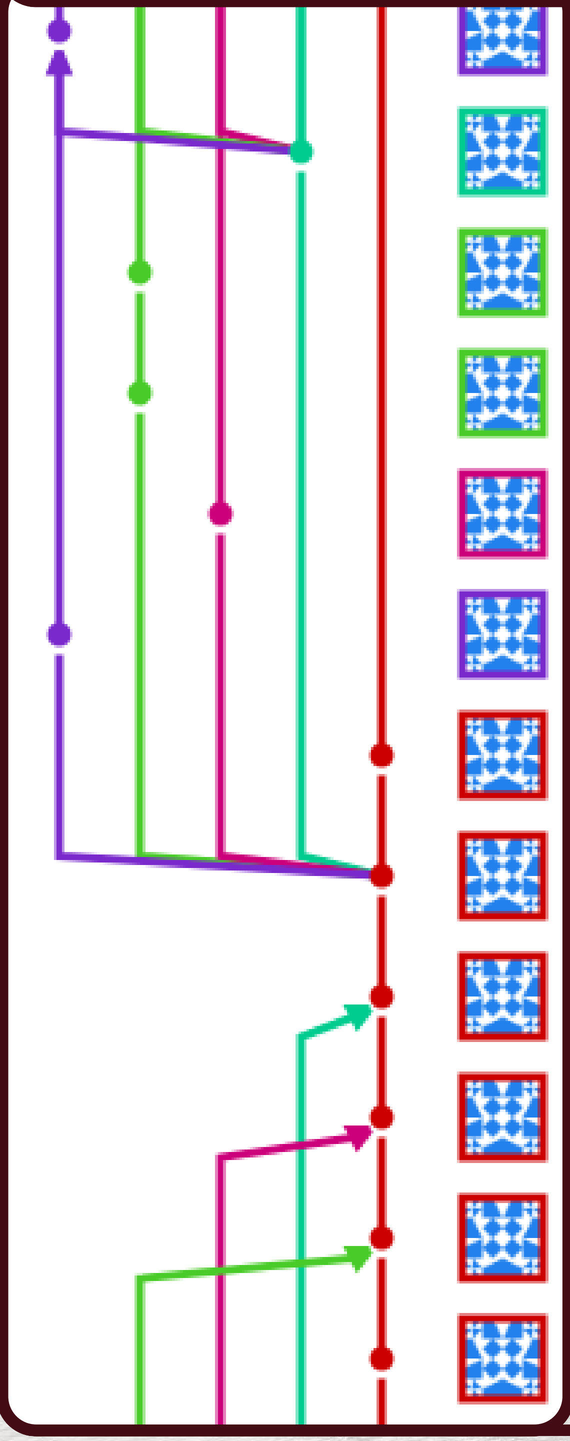
IV VERIFICATION

Mission Based System Engineering



File Management & Collaboration

GitLab – Version Control



- Centralized GitLab repository
- Feature-based branching strategy
- Clear history of changes
- Merge Requests to manage collaboration and conflicts

Merge & Rebase Automation Script

- Custom script to automate:
  - Merges
  - Rebases
- Ensures consistency across branches
- Reduces manual errors and saves time

Shared Drive – Resource Management

- Shared drive for non-code files
- Centralized documentation and resources
- Clear separation between code and project documents

Automatic cost generation report

- Cost overview report based on scenario choice

V RISKS

Major Risk n°1 : Telecommunications

Explicit definition	PROBABILITY	SEVERITY	CRITICALITY
Complete loss of communication with the spacecraft	40	100	40

Causes	Mitigations	
Loss of data relay communication	Plan a network of possible relay	PM/SE
Dysfunctional tranceiver	Redundancy	PLAT
Ground station issue	Backup plan	PM/SE
Pointing issue	Mode implementation : search for TT&C	PLAT

Major Risk n°2 : Power management

Explicit definition

Not enough power to ensure spacecraft functionalities

PROBABILITY	SEVERITY	CRITICALITY
50	90	45

Causes	Mitigations	
Sun intervisibility issue	Mode implementation : Sun tracker	PLAT
Dysfunctional battery	Redundancy	PLAT
Dysfunctional software	Remote software update	PM/SE
Harness disconnection	Redundancy	PLAT

Major Risk n°3 : Disfunctional Payload

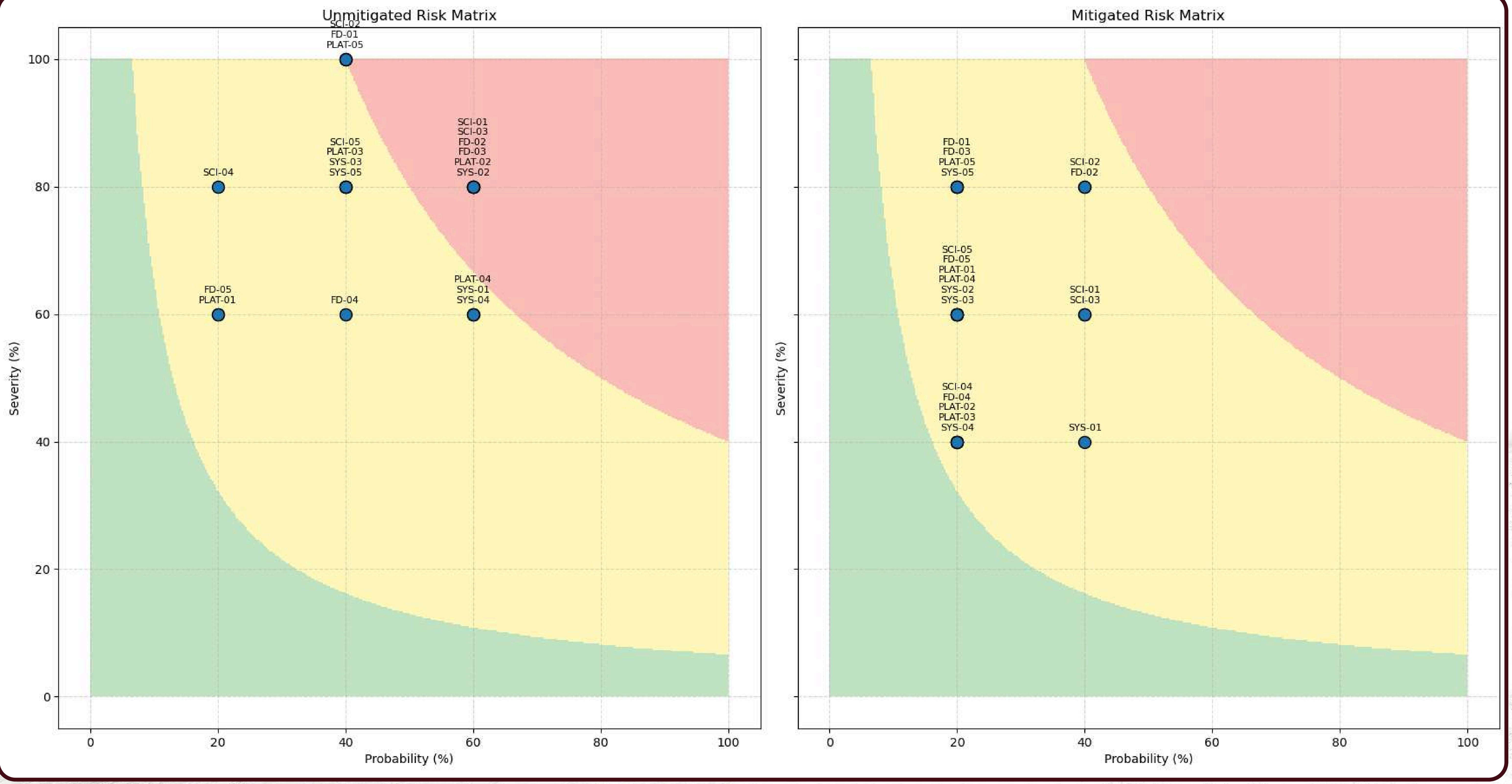
Explicit definition

The payload can't perform relevant science measurements

PROBABILITY	SEVERITY	CRITICALITY
40	80	24

Causes	Mitigations	
Calibration issues	Remote calibration	SCI
Unexpected Martian environment	Backup science goals	SCI
Electromagnetic compatibility	Add electromagnetic shield	PLAT
Thermal issue	Thermal regulation	PLAT

Risk assessment matrix



VI COSTS

Atreides Minimum Costs

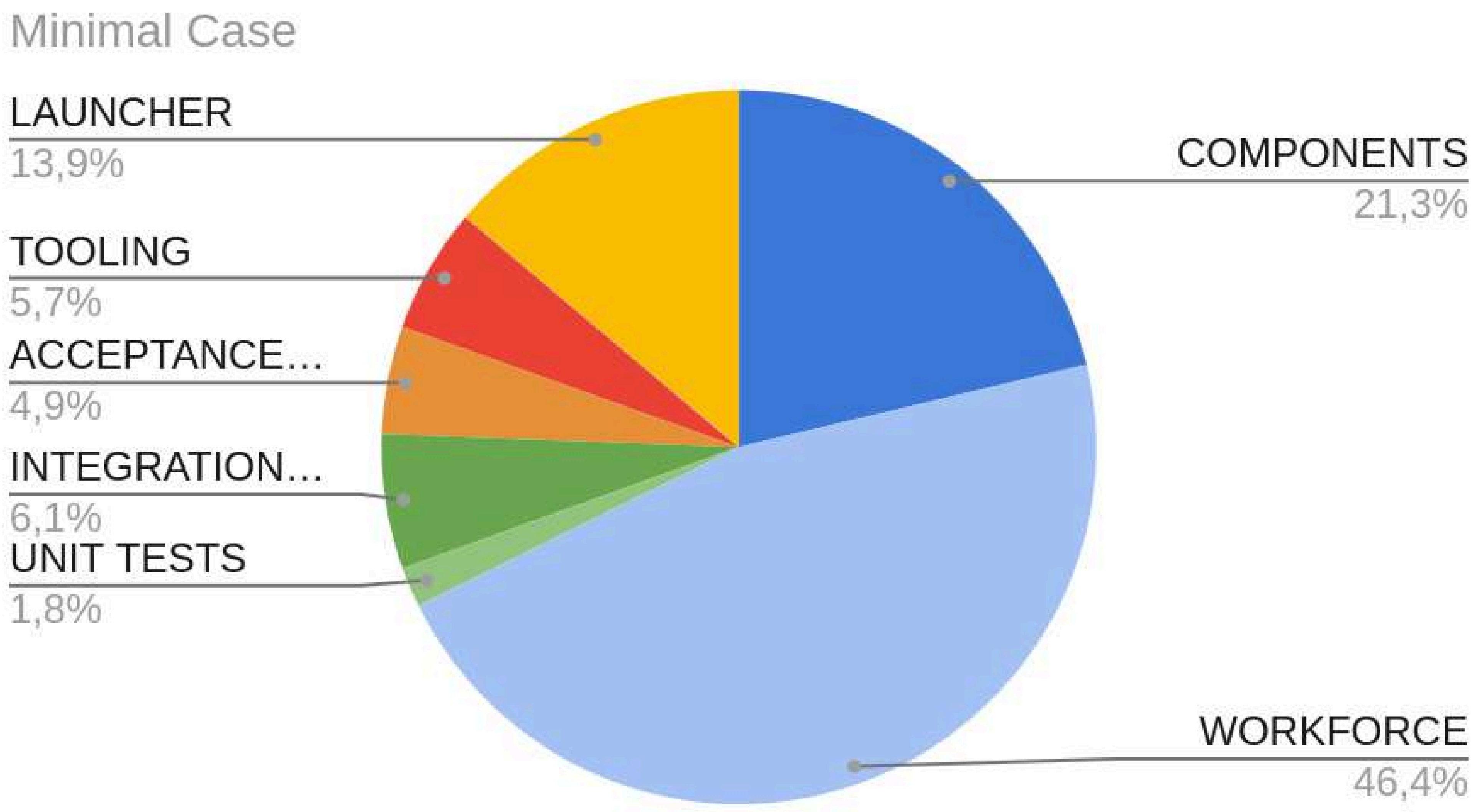
SCENARIO DEFINITION

- NO margins => couldn't go below this limit
- Ideal scenario => not a realistic scenario

DURATION
6,58 years

WORKFORCE
7,2 people/phase

COST REPARTITION



COMPONENTS	1 378 000,00€
WORKFORCE	3 002 266,67€
UNIT TESTS	117 000,00€
INTEGRATION TESTS	396 000,00€
ACCEPTANCE TESTS	315 000,00€
TOOLING	367 500,00€
LAUNCHER	896 698,80€
TOTAL COST	**6 472 465,47€**

Atreides Maximum Costs

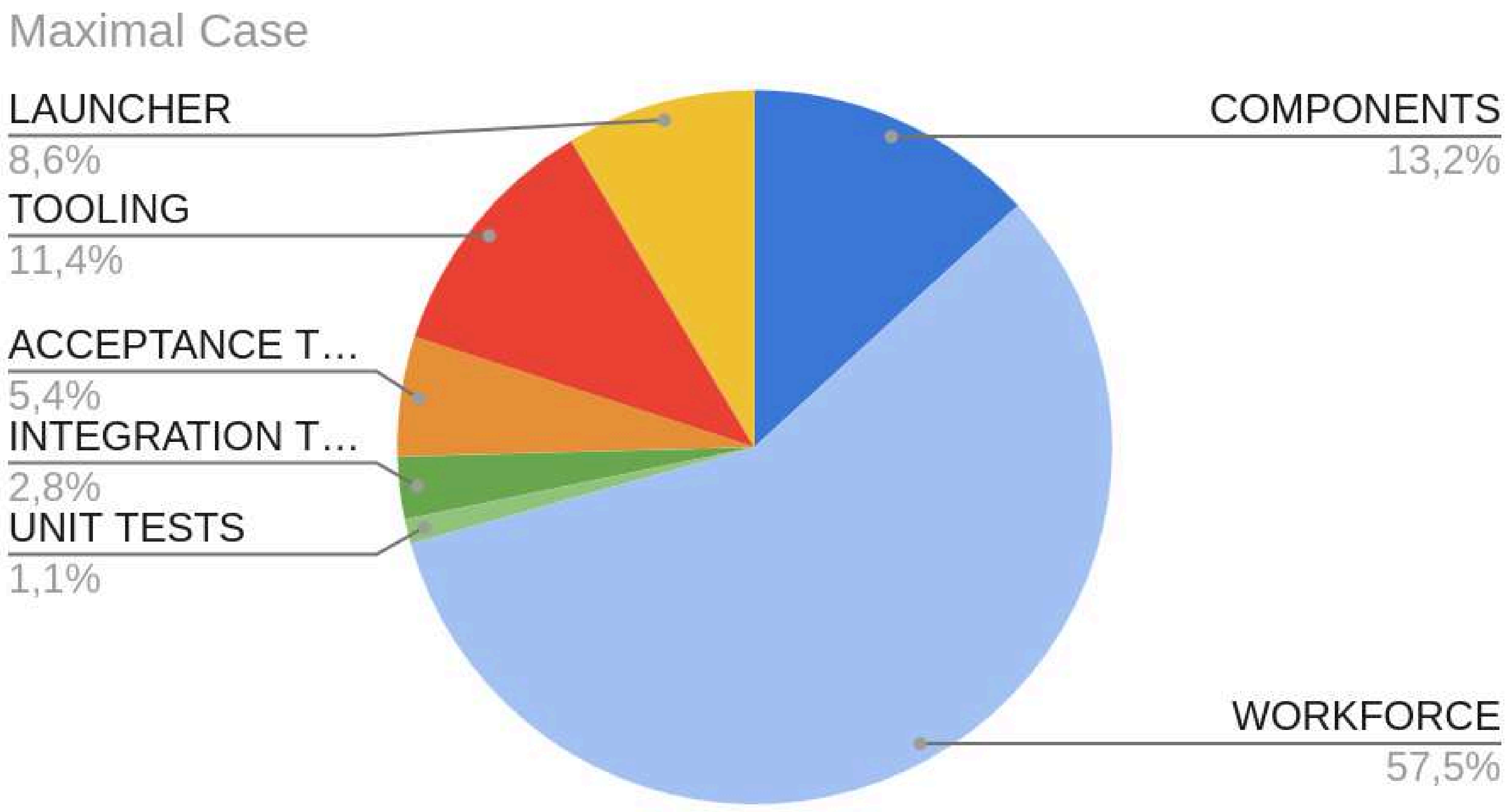
SCENARIO DEFINITION

- 100% margins => we won't go above this limit
- Budget is not respected

DURATION
13,08 years

WORKFORCE
14,33 people/phase

COST REPARTITION



COMPONENTS	2 756 000,00€
WORKFORCE	12 009 066,67€
UNIT TESTS	234 000,00€
INTEGRATION TESTS	589 500,00€
ACCEPTANCE TESTS	1 134 000,00€
TOOLING	2 387 500,00€
LAUNCHER	1 793 397,60€
TOTAL COST	**20 903 464,27€**

Atreides Nominal Costs

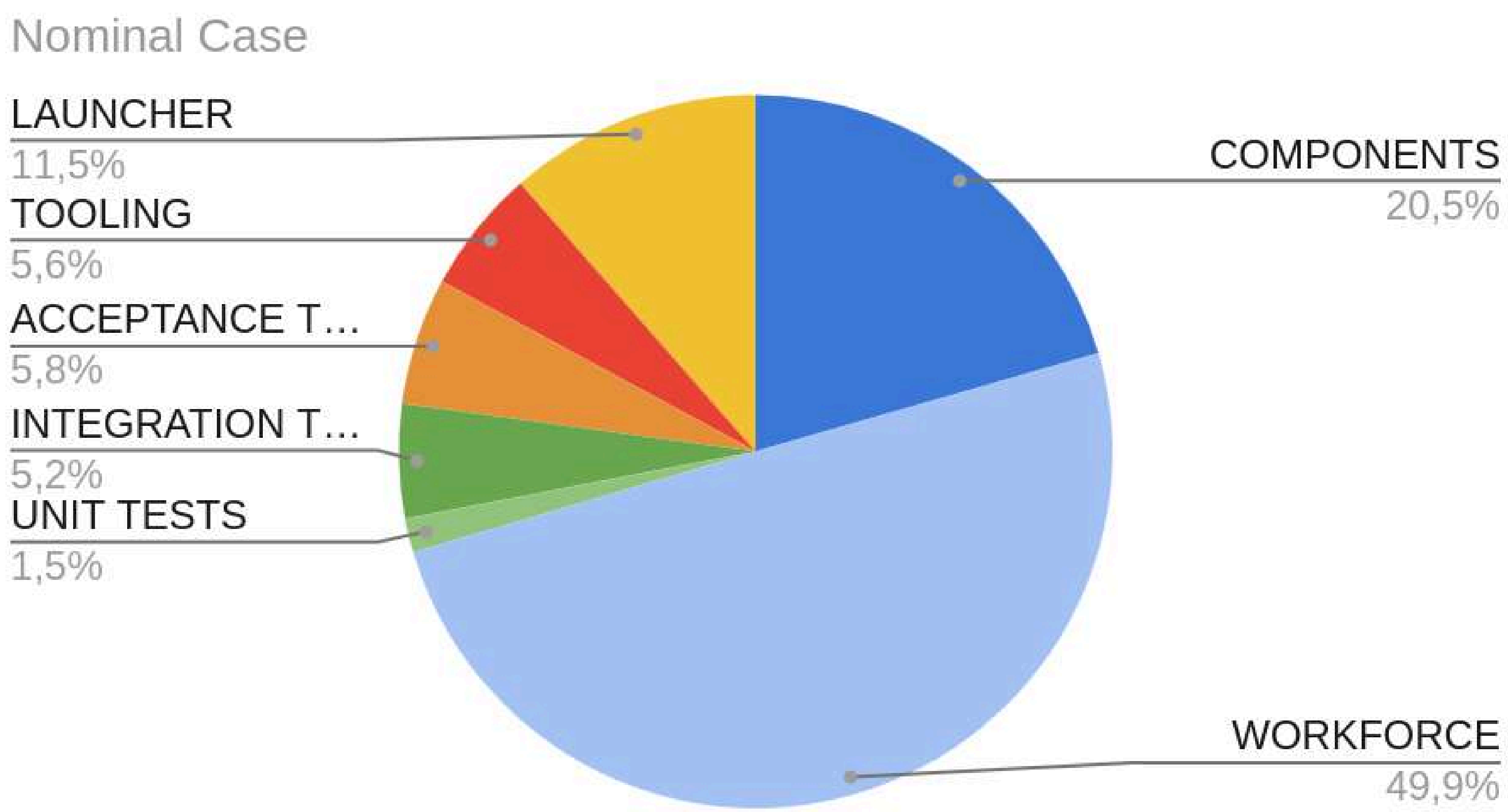
SCENARIO DEFINITION

- Scenario with realistic margin
- That's what we plan and we want to respect

DURATION
9.83 years

WORKFORCE
9.32 people/phase

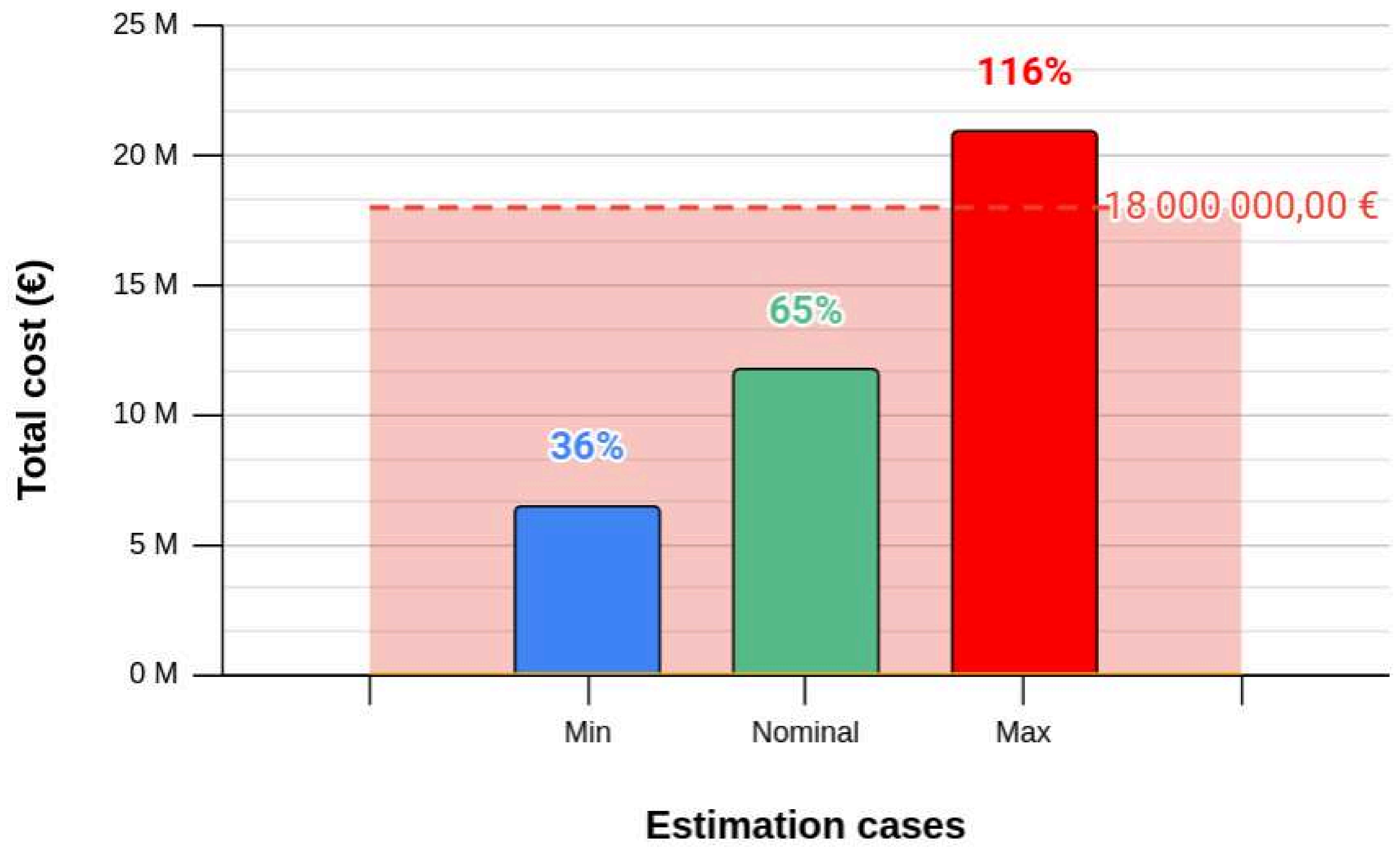
COST REPARTITION



COMPONENTS	2 411 500,00€	75%
WORKFORCE	5 854 420,00€	30%
UNIT TESTS	180 000,00€	30%
INTEGRATION TESTS	607 500,00€	30%
ACCEPTANCE TESTS	675 000,00€	30%
TOOLING	661 500,00€	20%
LAUNCHER	1 345 048,20€	50%
TOTAL COST	**11 734 968,20€**	

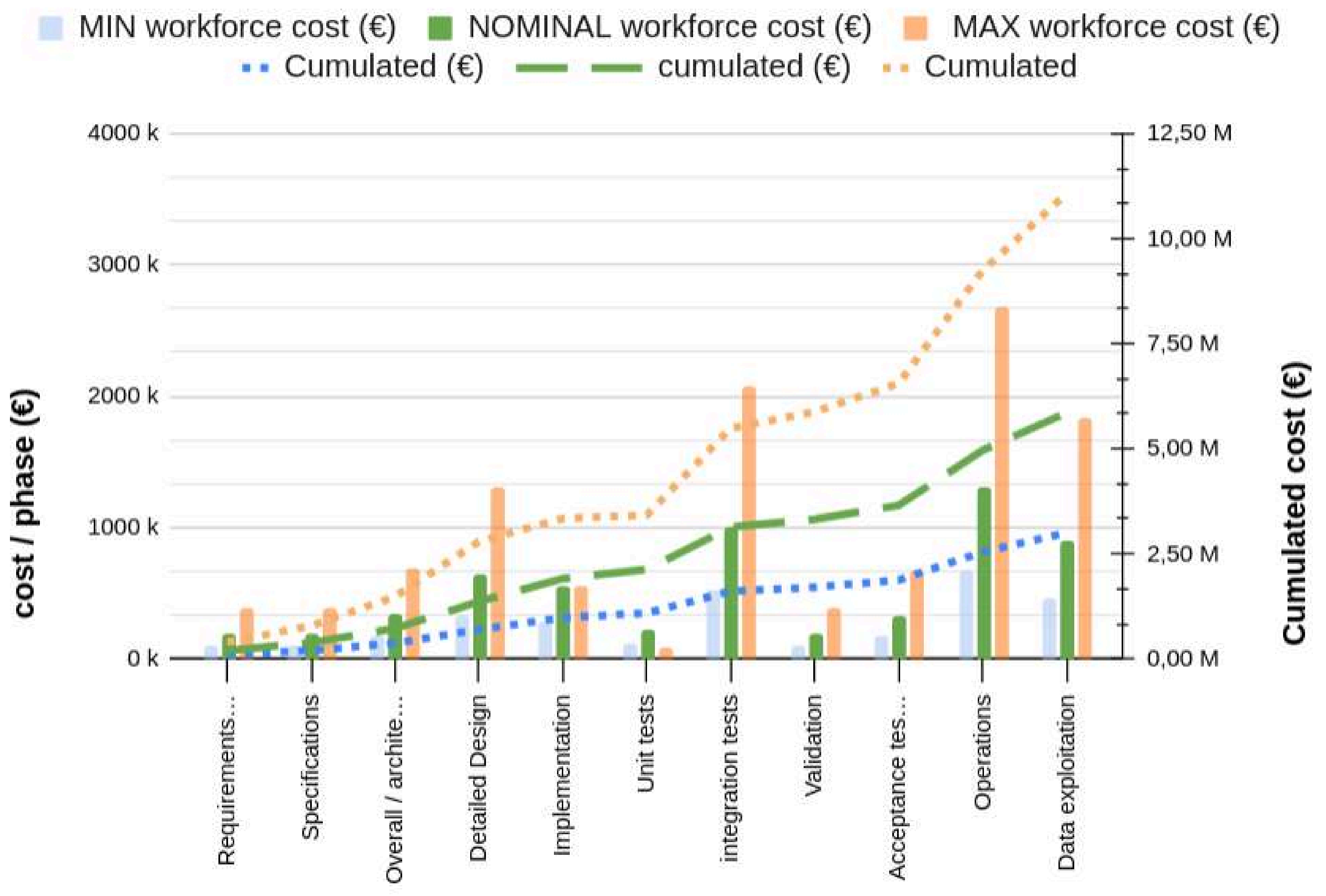
Atreides Nominal Costs

TOTAL COSTS COMPARED TO BUDGET

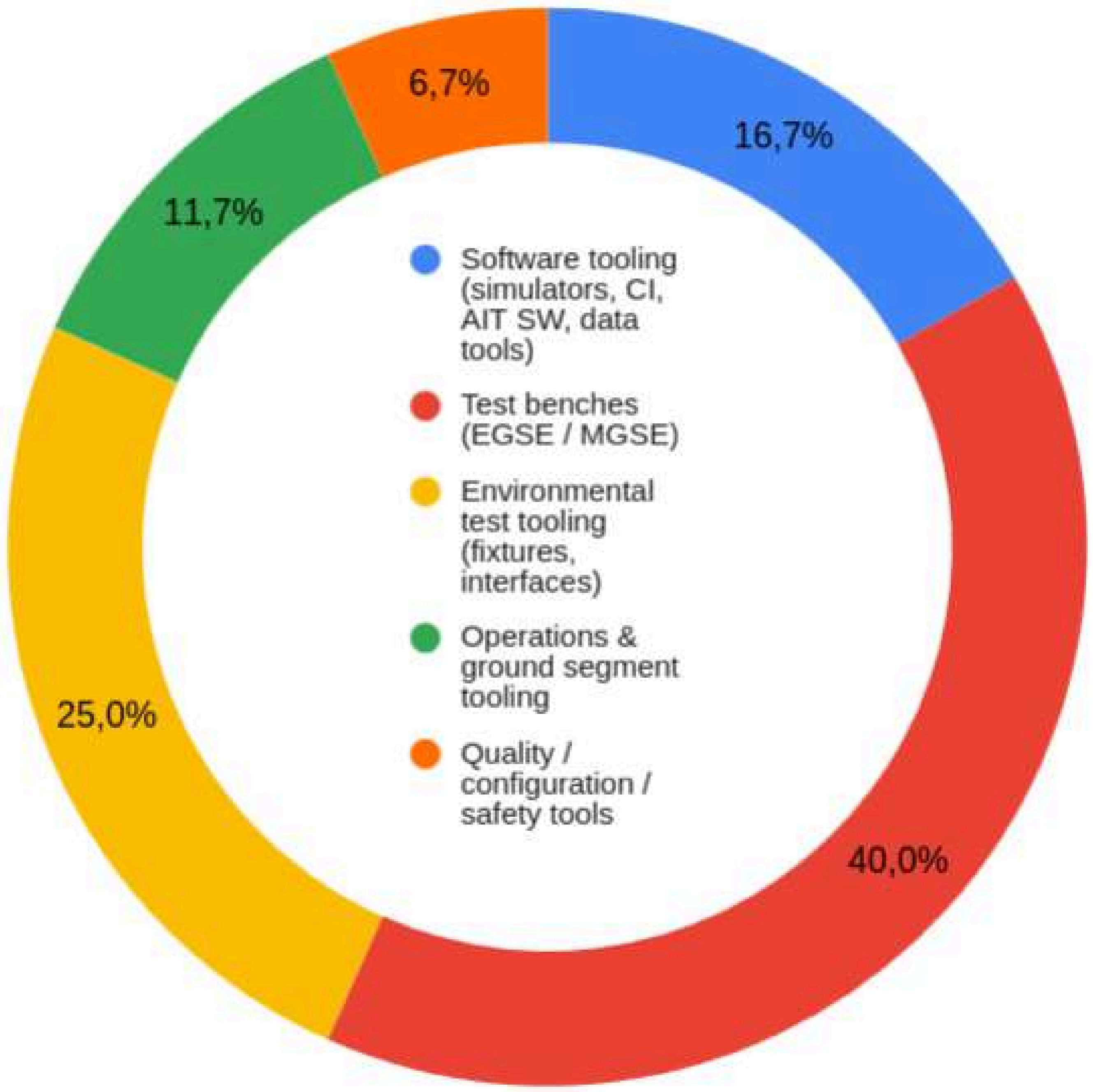


Atreides Nominal Costs

WORKFORCE COSTS



TOOLING COST



Atreides Nominal Costs

NUMBER OF UNIT TESTS

- <u>MAIN HYPOTHESIS :</u>

  The number of unit tests depends on the TRL level of the component

Time / Unit Test

0.25 Man-Days

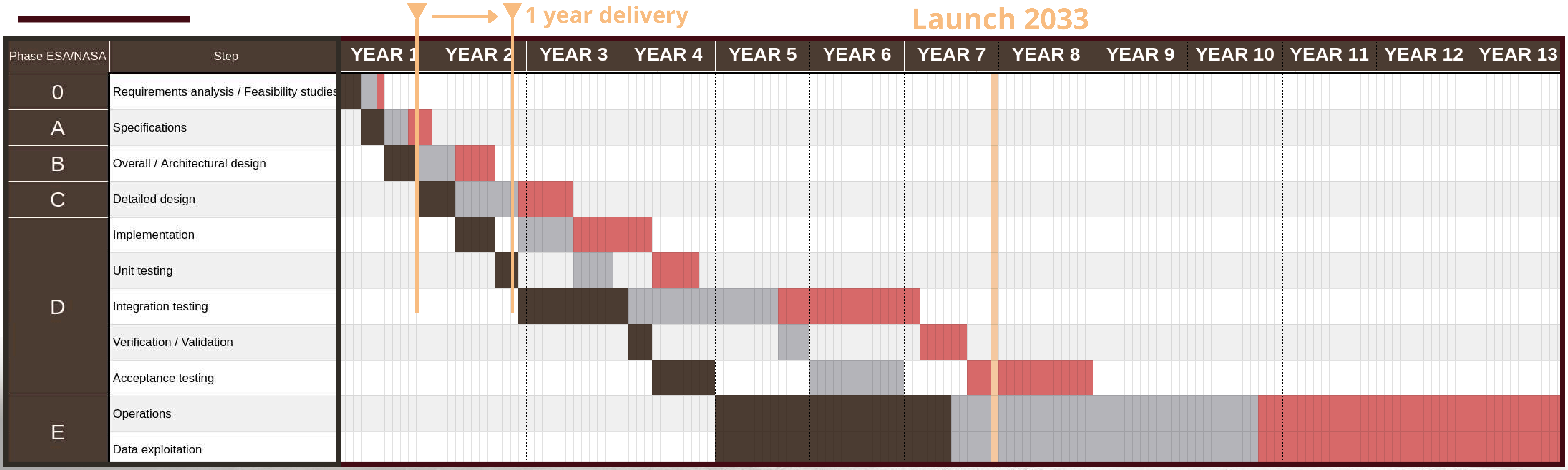
Time / Integration Test

20 Man-Days

Time / Acceptance Test

7 Man-Days

Atreides Mission GANTT



Nominal scenario durations :

Requirements/Specifications	9 months (0.75 years)
Design	13.5 months (1.125 years)
Development	49.5 months (4.125 years)
Operation/Exploitation	45 months (3.75 years)

Minimal **Nominal** **Maximal**

Appendices

Atreides Team

PM/SE : Alexandre PIRAUX & Aldric PARENT
Science : Galaad BARRAUD & Manal AFIF
Flight Dynamics : Amani LADHARI & Gayathri RAJAVEL
Platform : Antonio RIBEIRO-FILHO

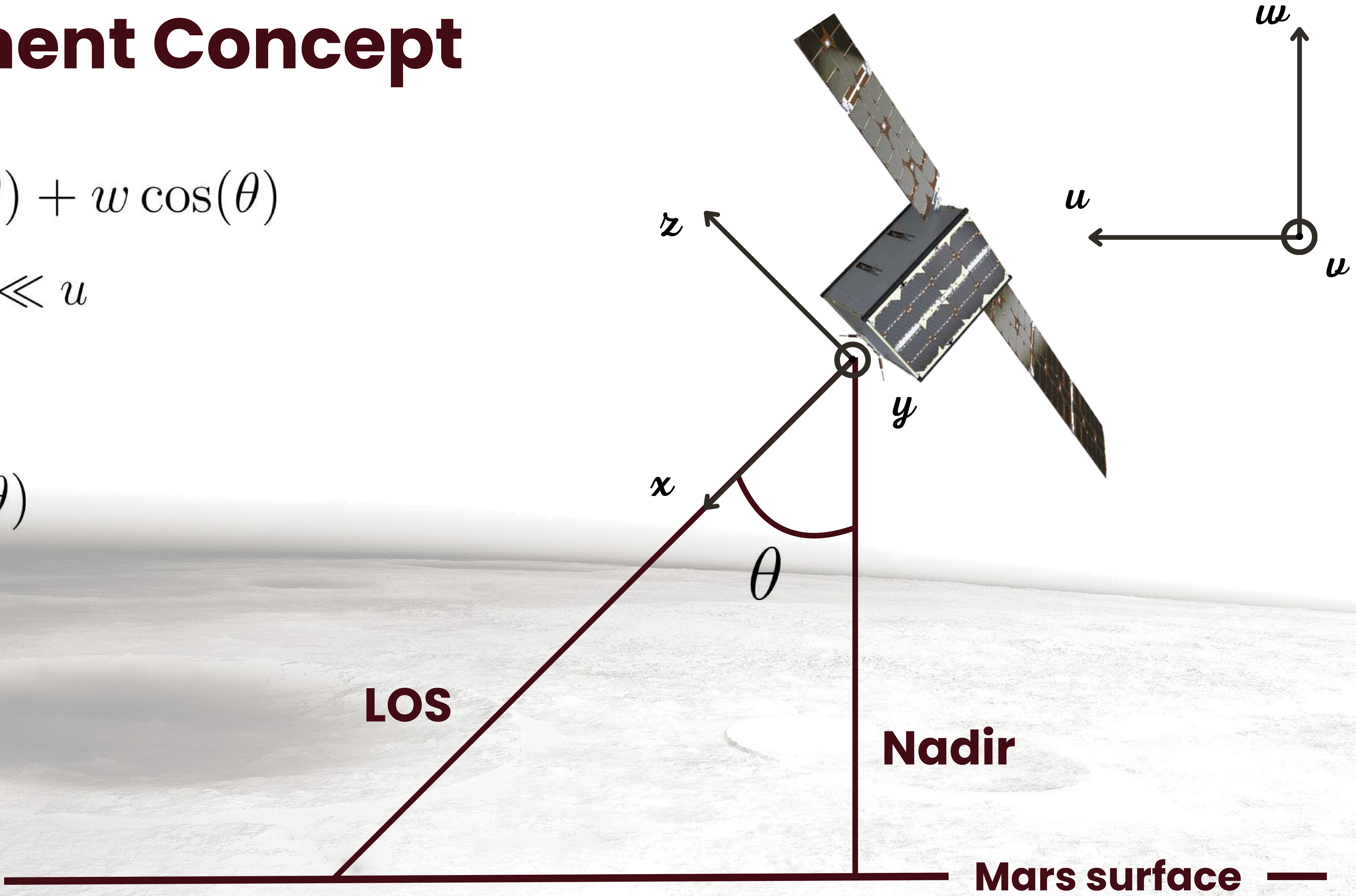
Measurement Concept

$$V_{\mathrm{LOS}} = u\sin(\theta) + w\cos(\theta)$$

Hypothèse : $w \ll u$

$$V_{\mathrm{LOS}} \approx u\sin(\theta)$$

$$u \approx \frac{V_{\mathrm{LOS}}}{\sin(\theta)}$$



SNR

Estimation of the photon_limited SNR

$$SNR_{ph} = \frac{T(R)}{R}\sqrt{f_{rep}\tau\frac{E_p}{h\nu}\eta_{sys}A\beta(R)\Delta R}$$

- N_{pulse} : Number of pulse per unit of time
- E_p : Energy emitted per pulse
- η_{sys} : Global optical efficiency of the system
- A : Area of the collecting surface
- β : Backscatter volumetric coefficient
- R : Radial measured distance
- ΔR : Radial resolution
- T : Back-and-forth transmission

SNR

Estimation of the photon_limited SNR

$$R = \frac{c\,t}{2}$$

$$P(R) \propto \frac{1}{R^2}\,\beta(R)\,\exp\left[-2\int_0^R \alpha(R')\,dR'\right]$$

$$v_{\mathrm{LOS}}(R) = \frac{\lambda}{2}\,\Delta f(R)$$

Science Traceability Matrix

Sience Goal	Science Objective	Scientific Measurement Requirements		Instrument		Projected Performance	Mission Requirements
		Physical Parameters	Observables	Parameters	Requirements		
Understand the processes that control weather and climate and the long-term evolution of climate and habitability.	Characterize and forecast dust storms and wind profiles on Mars	Horizontal wind speed as a function of altitude	Doppler frequency shift of the backscattered signal as a function of altitude	Sensitivity	$SNR \geq 10$ at nominal dust conditions	$SNR \geq 10$ achieved at nominal operating point	-The mission shall place the instrument on an orbit and geometry enabling off-nadir observations suitable for horizontal wind retrieval. - The mission shall provide repeated access to scientifically relevant regions to observe the spatial variability of winds and dust. - The mission shall operate the instrument continuously over time scales compatible with the observation of atmospheric variability. - The mission shall support stable instrument operation and pointing during the integration time required for Doppler wind measurements. - The mission shall support onboard storage and downlink of low-rate, continuous atmospheric profile data.
				Velocity resolution	$\Delta v \leq 2$–3 m/s	$\Delta v \approx 2.2$ m/s at $SNR \geq 10$	
				Horizontal resolution	$\Delta x \leq 3$–5 km	$\Delta x \approx 3$ km	
				Geometry / Pointing	Off-nadir angle $\theta \in [25, 40°]$	$\theta = 32°$, $H = 325$ km, $V_{orb} = 3.4$ km/s	
		Dust vertical distribution & Planetary Boundary Layer (PBL) height	Range-resolved backscattered signal $P_r(r)$; Attenuated backscatter profile $\beta'(r)$; Estimated PBL height from backscatter and wind gradient signatures	Vertical resolution	$\Delta z \leq 1$ km	$\Delta z \approx 1$ km ($\Delta R \approx 1.22$ km, $\tau_p \approx 8.1$ μs)	
				Temporal sampling	Integration time ~1 s; PRF ~50 Hz	$T_{int} = 0.789$ s; $f = 52.27$ Hz; ~41 shots	
				Aperture / Collecting area	Aperture diameter $D \in [10$ cm, 30 cm$]$	$D \approx 0.30$ m; $A \approx 0.1077$ m²	
		Dust storm evolution and statistics	All above observables	Laser operating point	Average power compatible with platform	$E_p = 0.0515$ J; $P_{avg} = 2.69$ W; $\tau = 8.14$ μs	
	Mapping dust distribution on the surface of Mars	Near-surface dust loading	Backscatter integrated over a near-surface atmospheric layer	Data handling	Low-rate continuous profiling	Data rate ≈ 0.3 kB/s	- The mission shall enable repeated mapping of near-surface dust and surface properties over key regions of Mars. - The mission shall provide observation geometry compatible with both atmospheric backscatter measurements and surface return observations. - The mission shall operate long enough to observe dust storm occurrence, frequency, and seasonal to interannual variability. - The mission shall handle data volume and continuity required to generate spatio-temporal dust products.
		Dust storm occurrence and frequency	Spatio-temporal gridded dust products	Wavelength	Laser wavelength $\lambda \in [1\mu m, 2\mu m]$	$\lambda = 1.55$ μm	
		Surface dust patterns and albedo evolution	Surface return signal used as a proxy for surface albedo	Field of view	Few μrad-class FoV	FoV ≈ 3 μrad (ground footprint ≈ 1.2 m)	

Orbit & LiDAR Requirements

Orbit requirements

- Off-nadir observation angle : $\theta \in [25°, 40°]$
- Orbit altitude : $H \in [300 \text{ km}, 350 \text{ km}]$
- Orbital speed : $V \in [2.5 \text{ km/s}, 5 \text{ km/s}]$

LiDAR requirements

- Wavelength : $\lambda \in [1 \mu m, 2 \mu m]$
- Average power over integration time : $P \in [2.5 \text{ W}, 10 \text{ W}]$
- Pulse repetition frequency : $f \in [30 \text{ Hz}, 80 \text{ Hz}]$
- Minimal measurable spectral shift : $\Delta\lambda \in \sim 10\text{-}14 \mu m$
- Collecting area diameter : $D \in [10 \text{ cm}, 30 \text{ cm}]$

Pointings

Automated Mission Planning & Payload Support

To ensure high-precision observations, we developed a custom code that translates orbital trajectories into actionable commands for the Lidar instrument.

The technical workflow :

- The tool processes DOCKS OEM files, converting Cartesian state vectors into Martian geodetic coordinates (Lat/Lon).
- The script uses spherical trigonometry to monitor the distance between the satellite and our three priority scientific targets.
- A "pointing event" is automatically generated whenever the satellite enters a predefined angular radius of a target.

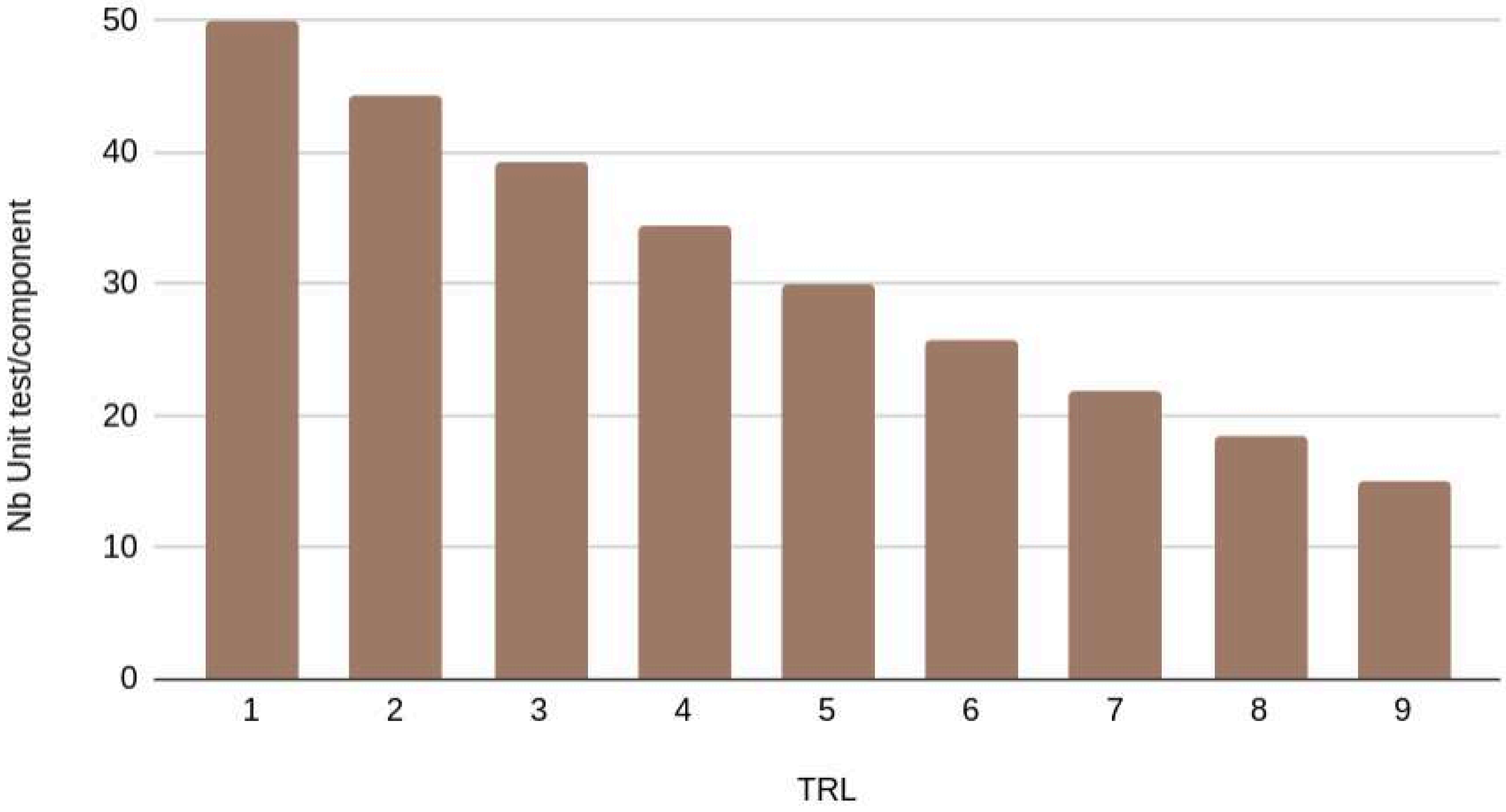
Atreides Nominal Costs

	UNIT TESTS								
TRL	1	2	3	4	5	6	7	8	9
Nb Unit test/component	50	44,4	39,3	34,5	30	25,8	22	18,4	15
Time per component constant (Man-Days)	12,5	11,1	9,825	8,625	7,5	6,45	5,5	4,6	3,75
Component quantity	0	0	0	1	0	1	0	0	7
Total test time (Man-Days)									41,325

	INTEGRATION TESTS	ACCEPTANCE TESTS	Unit Tests
Number of systems :	7		
Time/Test (MD)	20	7	
Workforce	10,4	6,5	10,4
Test duration (months)	13,5	7,5	4
Integration facility cost (€)	**607 500,00€**	**675 000,00€**	**180 000,00€**

Atreides Nominal Costs

NUMBER OF UNIT TESTS



Time / Unit Test

0.25 Man-Days

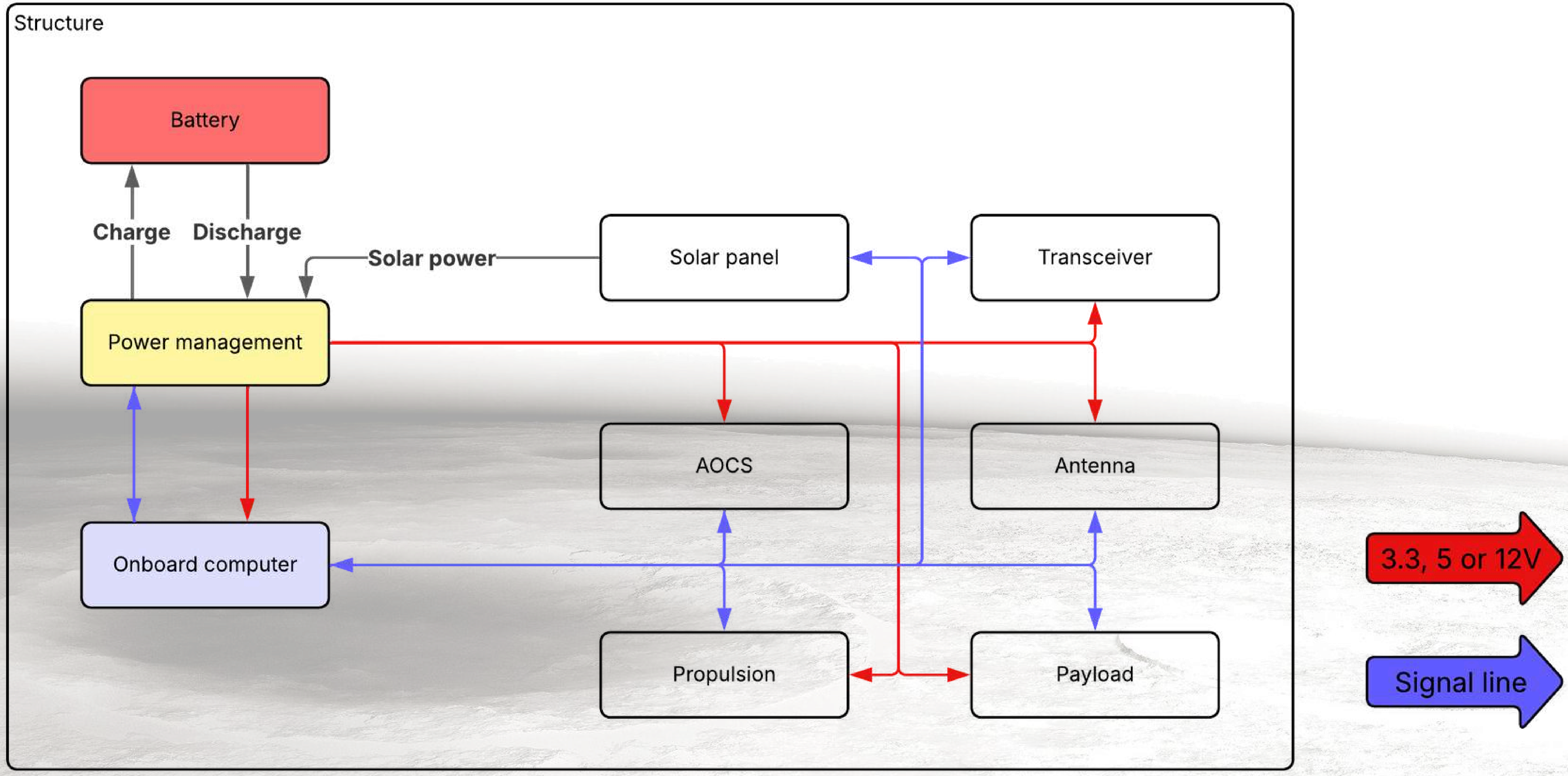
Time / Integration Test

20 Man-Days

Time / Acceptance Test

7 Man-Days

Platform block diagram



Power and data budget strategy

Orbit assumptions

- Orbital altitude = 325 km
- Orbital period = 1,91 h
- Eclipse per orbit = 0,38 h

Data generation

- Daily generation = 47,45 GB
- Communication intervisibility/day = 9,12 h
- Downlink data rate = 125 kbps
- Downlink data per day = 513 GB

Basic modes duration/day

- Idle = 15,21 h
- Science = 0,33 h
- Data = 9,12 h

Battery requirements

- Daily consumption = 242,12 W
- Eclipse energy = 17,47 W
- Required capacity = 58,22 Wh