STE-QUEST
External Final Presentation of the CDF Study

ESTEC
30/06/2011

European Space Agency

Study Goals

1. Assess the technical feasibility of the STE-QUEST proposal
2. Design an example mission compatible with achieving the science goals
   a. Mission Analysis and Reference Orbit
   b. System level design
   c. System Resource Analysis
   d. Technology development
   e. Preliminary programmatic assessment

Specific Study Tasks

1. Assess experiment environment: required magnetic cleanliness, non-gravitational (e.g. drag) and gravitational (e.g. slopes in the potential when the orbit changes slightly, s/c self-gravity) effects and perturbations, as well as the thermal environment.
2. Specifically assess the radiation environment and perform a first shielding analysis to limit the TID and any single effects within the payload.
3. The feasibility of body-mounted solar arrays.
4. Revise the choice of orbit and subsequent refinement of the orbit.
5. Assess the impact on the system due to the atom interferometer (drag-free control requirement, resources).
6. Devise an operational scenario with emphasis on maximizing the space-to-ground clock comparisons, the ground infrastructure needed and the associated high-performance clocks at the ground stations.
7. Identify system technology developments and propose a development plan.
8. Perform a preliminary cost and risk analysis.
9. Provide a preliminary development plan compatible with a launch date in 2022 with the main schedule drivers identified.

Study Organization

1. Schedule
    a. 11. May 2011: KO
    b. 17. June 2011: Internal Final Presentation
    c. 30. June 2011: External Final Presentation
2. Study Team consisting of 22 team members and 6 consultants
3. Study Instrument Engineer
4. Study Payload Manager

Drivers and Constraints

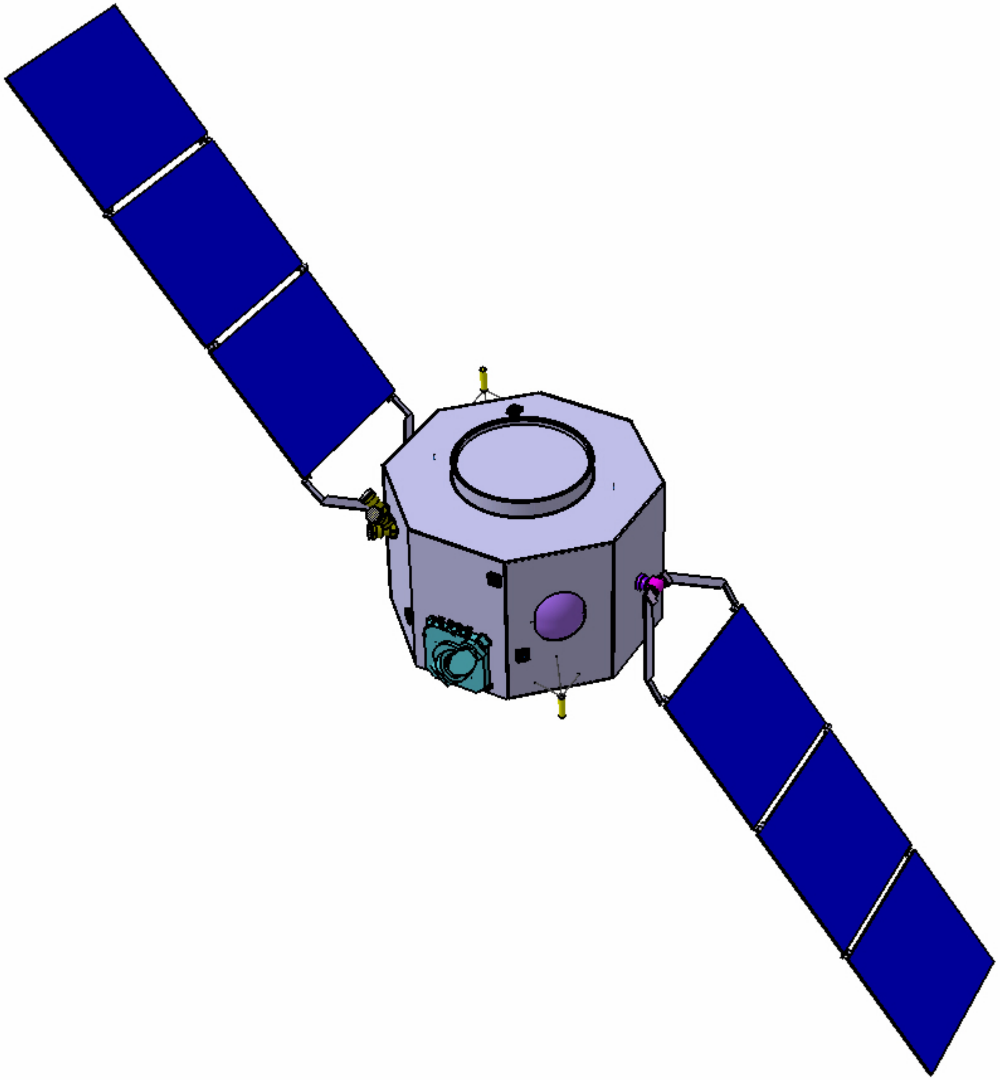
Drivers:

1. Equipment configuration (particularly instruments)
2. Solar Array Accommodation
3. Ground-Space visibility / measurement duration
4. Spacecraft attitude in different science phases

Constraints:

1. Launch by 2022
2. Soyuz launch vehicle from Kourou
3. Technology Readiness level (TRL) 5 by end of Definition Phase (~ 2014)
4. ESA Cost at Completion < 470 MEUR (2010)

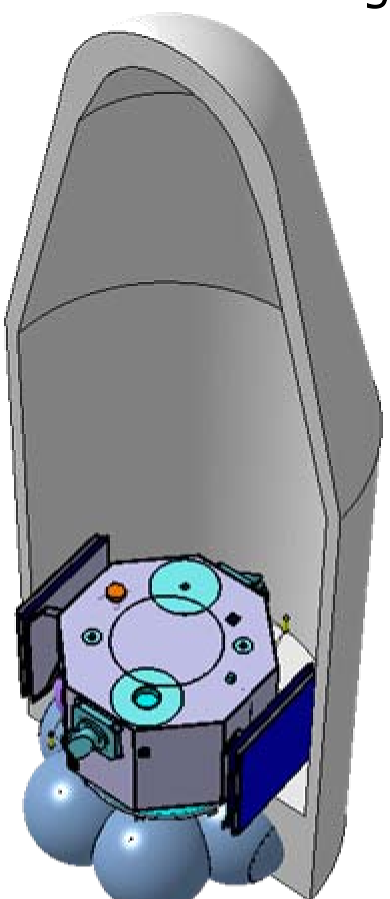
Space Segment Overview



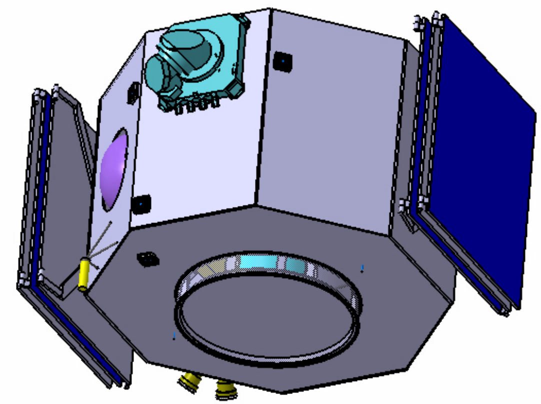
Configuration and Payload Accommodation

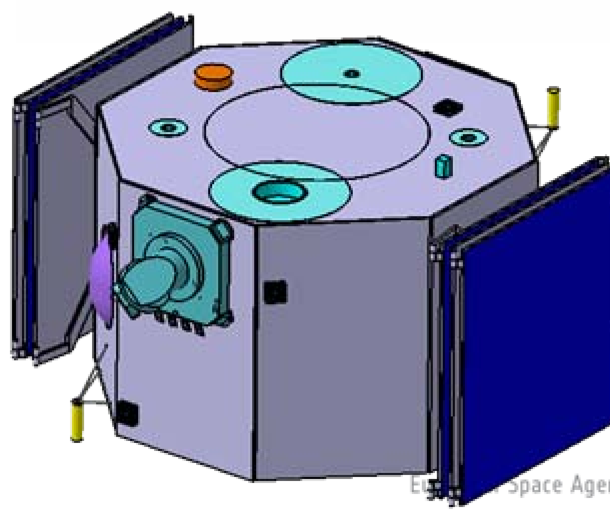
Launch Configuration

STE-QUEST in Soyuz-Fairing



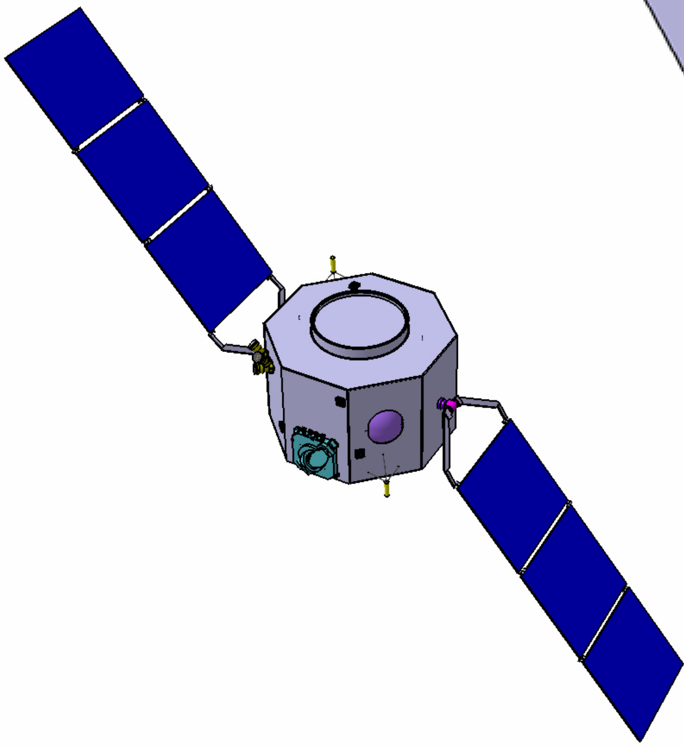
Stowed w/ launcher interface

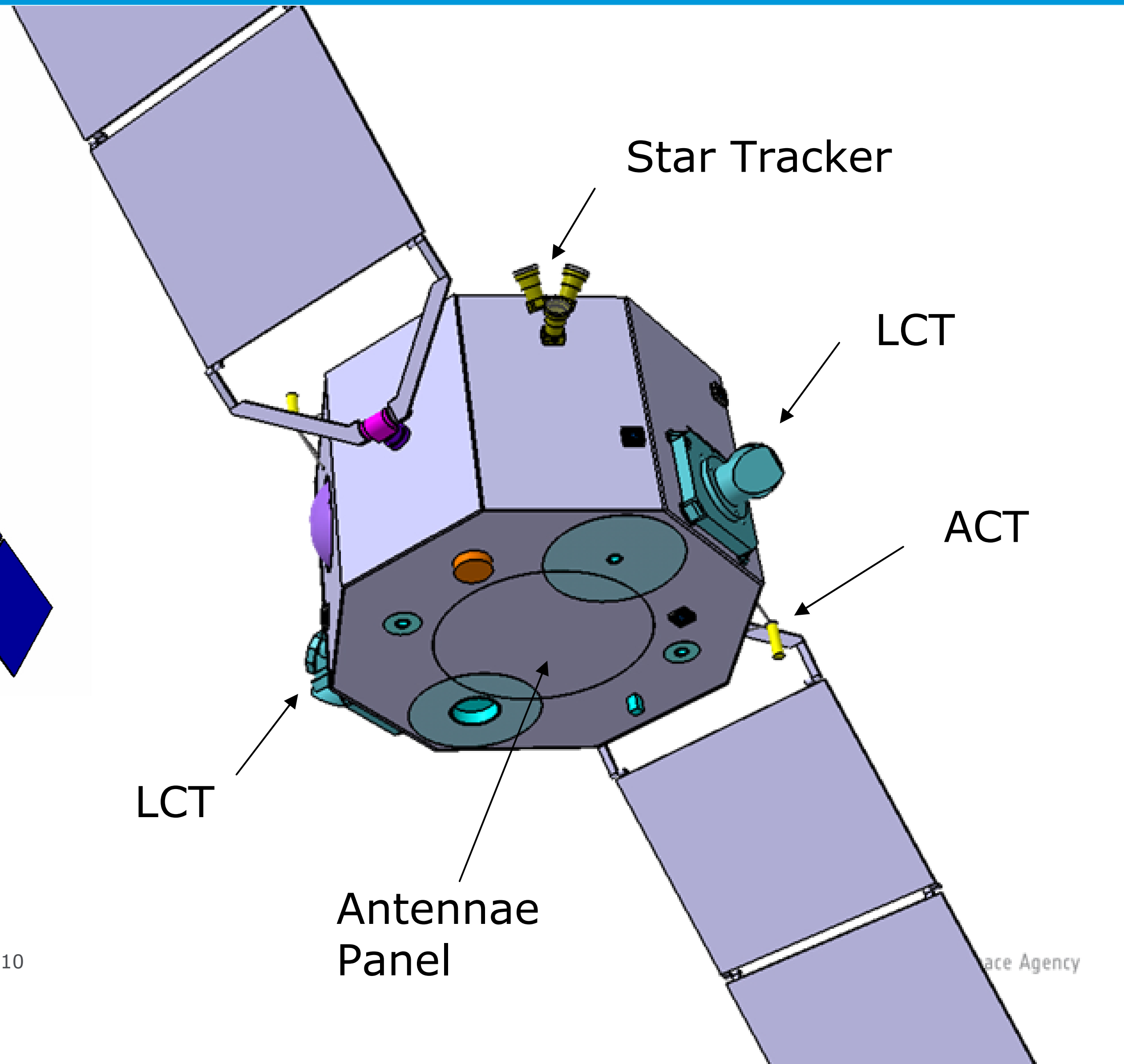




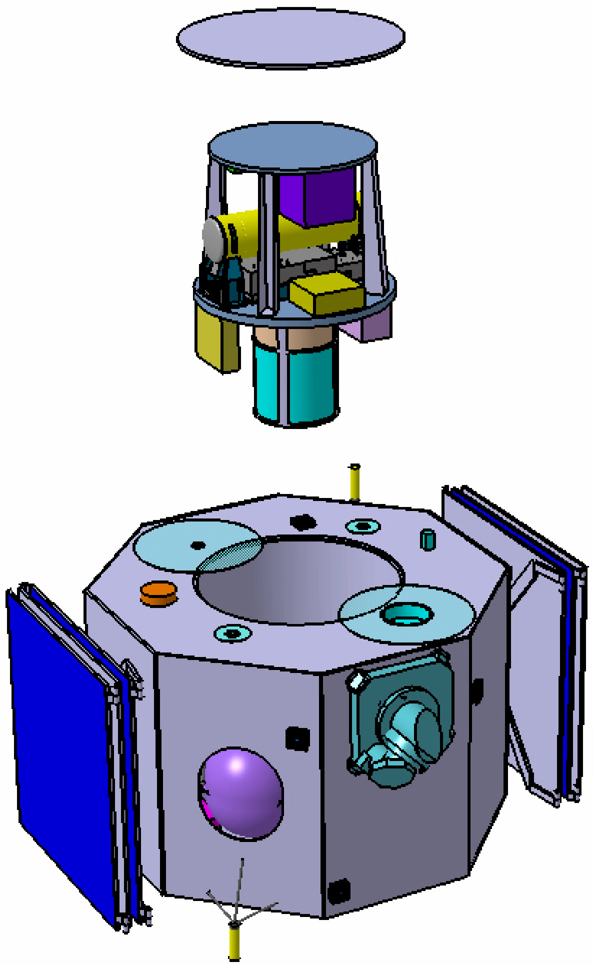
Stowed (payload face)

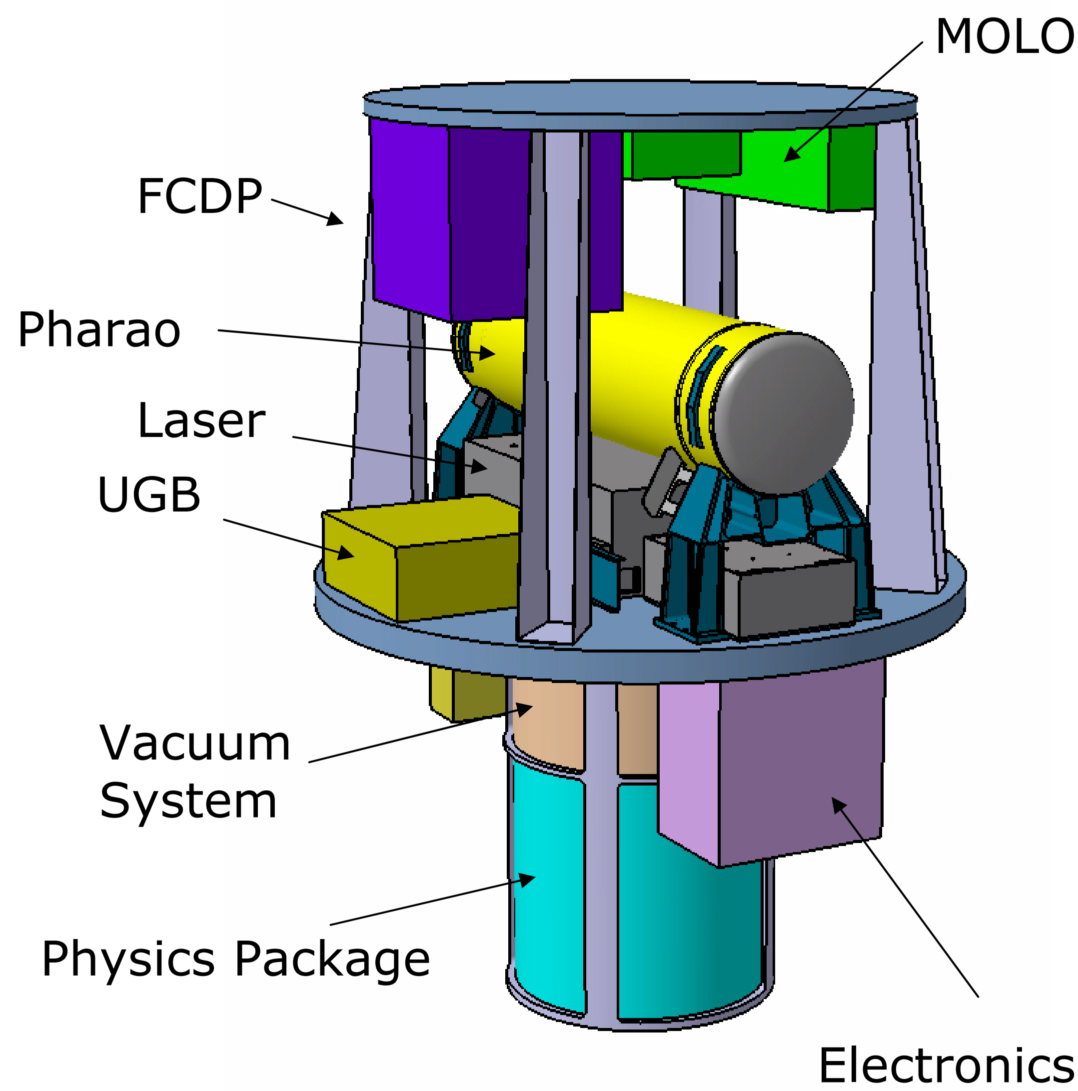
Flight configuration



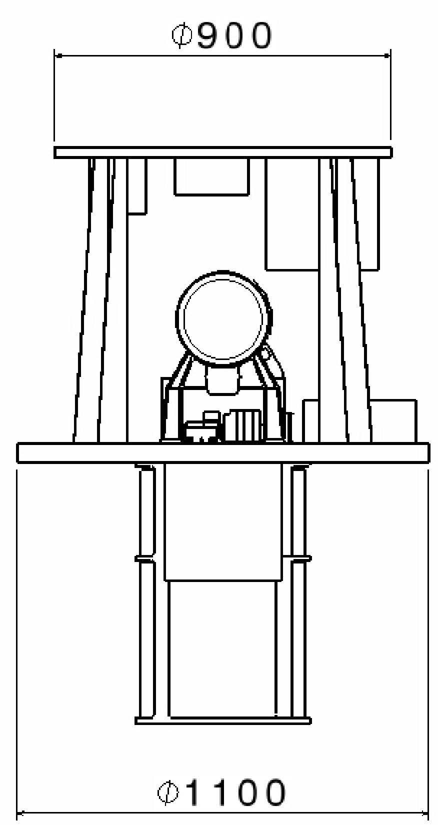


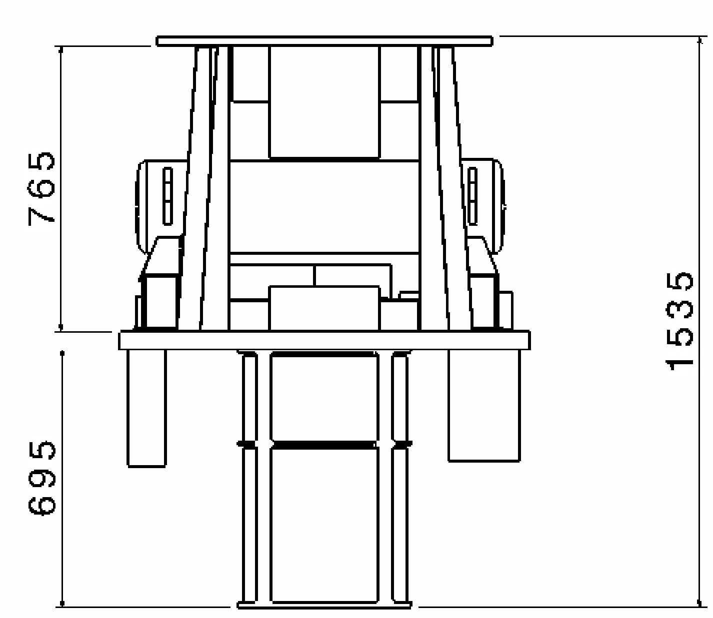
Payload Accommodation





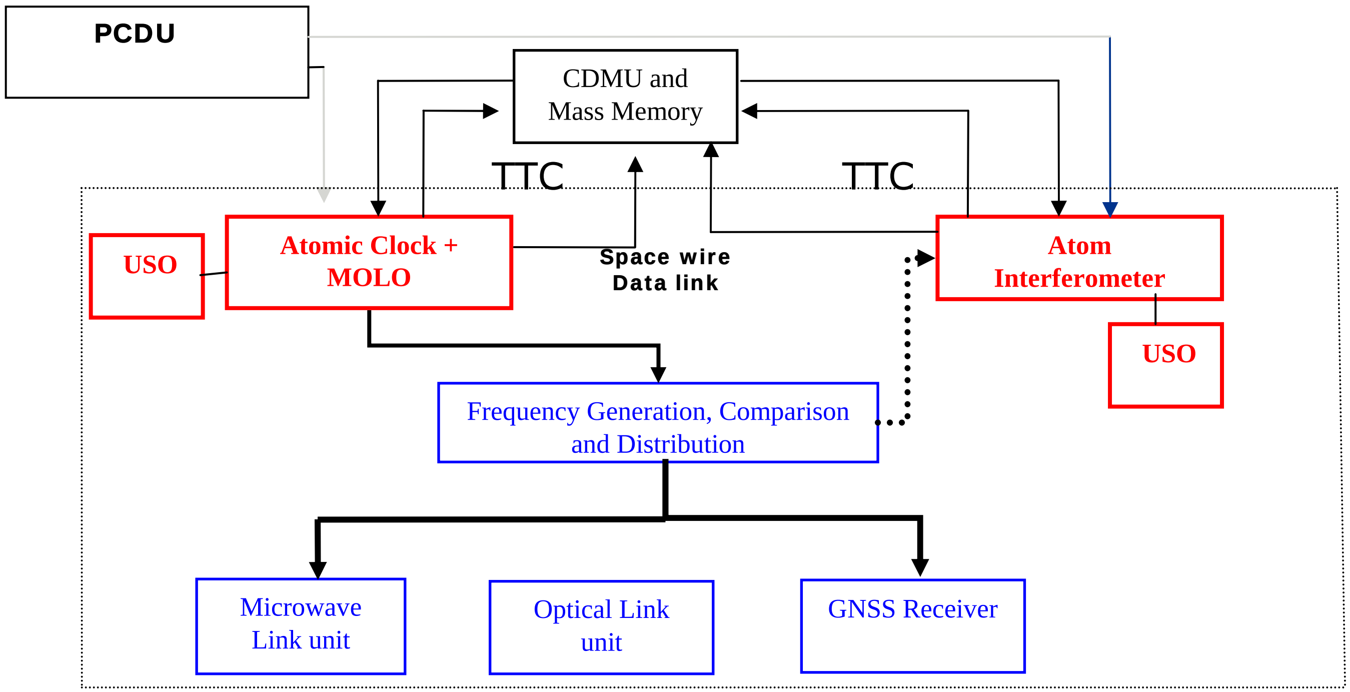
Payload Envelope Dimensions





Instruments

Instruments



Overview: Model Payload

1. Instruments:

   a. MOLO + Atomic Clock
   b. Atom Interferometer

2. Each Instrument foreseen to have a similar mass and accommodation allocation in the central core.

3. No dedicated onboard system is required to handle both Instruments, each unit will have their own ICU
4. Supporting Units
   a. Frequency Generation, Comparison and Distribution unit Microwave Link unit
   b. Optical Link unit (x2)
   c. GNSS Receiver unit
   d. Corner Cube Reflector (passive unit)

Instrument Budgets

Payload S/S	MASS Kg	POWER / w
PHARAO + MOLO	103 + 31	113 + 60
FGCD	10	12
AI	101	525
LCT	2x55Kg	2x180
MWL	21	80
GNSS	9 + 1	7

Instrument Way-ahead

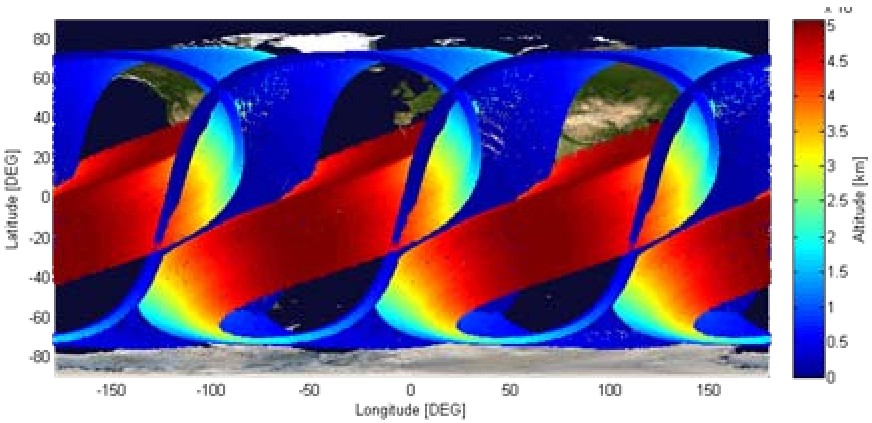
Activities to be undertaken by the instrument consortia:

1. **Clock:**
    a. Depart from Pharao nomenclature and references towards new baseline design/ definition for this mission (make consistent new package: MOLO, sub-units): **Provide reference input to PDD!**
    b. Provide clear development plan and schedule
    c. Drive necessary national developments
2. **AI:** (see TRR-part this afternoon)
    a. Define instrument baseline design
    b. Define clear development plan and schedule
    c. Drive necessary developments
3. **All:**
    a. Prepare for consortia organization (reply to call for Letters of Interest)

Mission Analysis

Overview

1. ~16 hour orbit
2. Reference perigee altitude is 700 km
3. Minimum perigee altitude at 600 km
4. Apogee altitude at ~51000 km



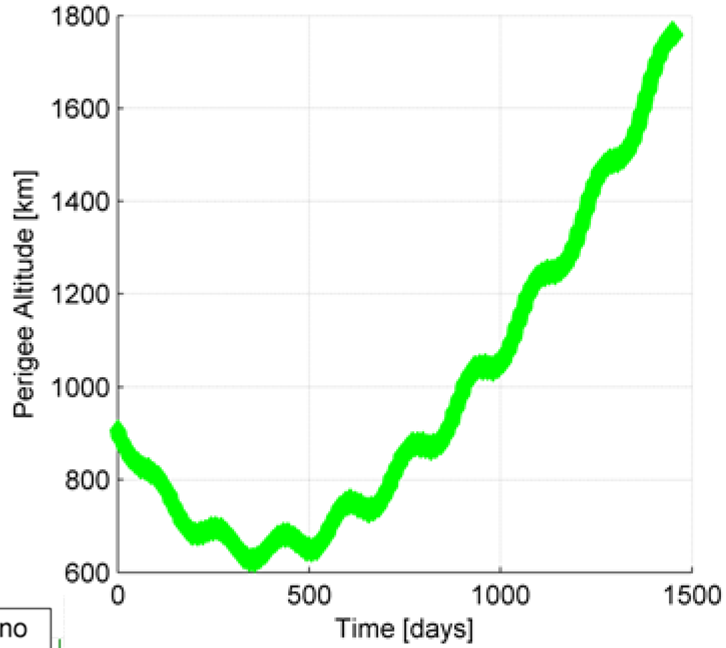
Orbit Approximation	
Epoch:	4182.1649
SMA:	32148.79 km
ECC:	0.773 -
INC:	72.03 DEG
RAAN:	79.06 DEG
ARG:	41.01DEG
TA:	0.00 DEG
RAAN dot:	-0.0713 DEG/d
ARG dot:	-0.0525 DEG/d

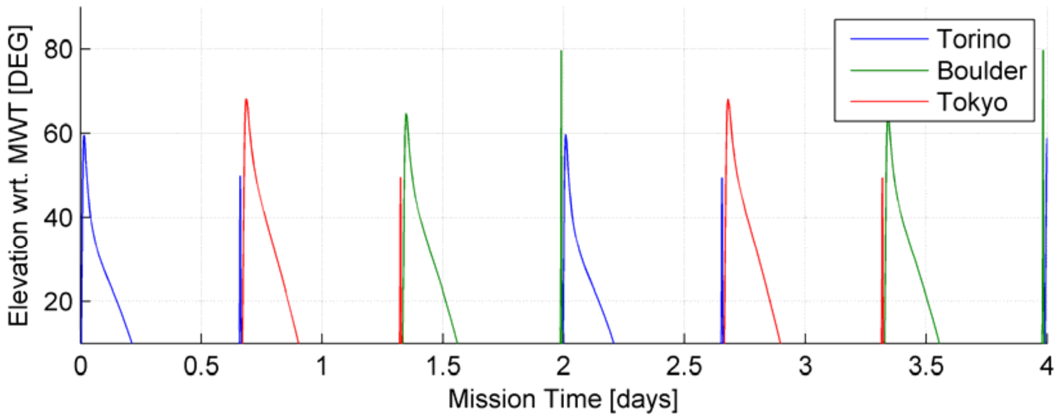
Schematic

1. Drifting Orbit selected to achieve both science goals from MWTs in the northern hemisphere only
    a. Changes in RAAN, Argument of perigee and Eccentricity
2. Minimum perigee altitude maintained by proper phasing with the LOP and ecliptic plane
3. East-West drift can be corrected by adapting the SMA
4. North-South drift is forced by the orbit
5. Visibility time of the two phases can be traded or mission duration can be extended if larger margins are required

Perigee Altitude and Measurement Time

1. Perigee altitude drifts (700-600-1800 km)
2. Measurement time with 10% of ΔUmax at perigee: 459,335 s > 450,000 s (each pass longer than 300 s and below 1380 km altitude)
3. ~1.2 ·10E7 s below cut-off altitude 3000 km (no visibility)



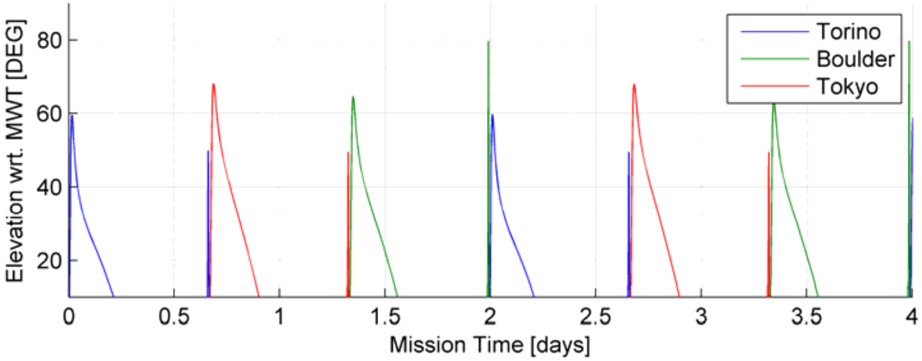


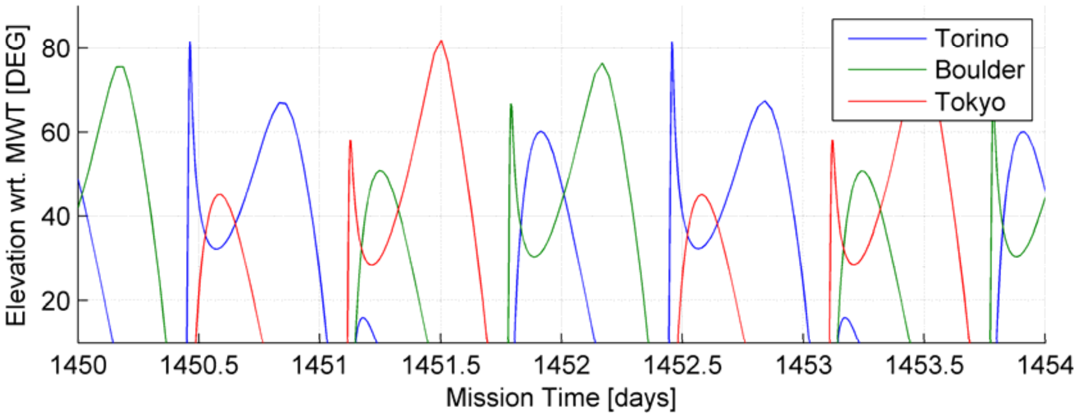
Worst case drag at 600 km: Order of 2-3 E-6 m/S2

Apogee and Dual Visibility

1. First Phase: Single visibility for Earth-gravitational redshift.

2. Second Phase: Dual visibility for comparisons/ sun redshift.
    a. Dual visibility duration: 3158 h > 2500 h (each pass longer than 5 hours)





Discussion

1. Trade complex orbit design vs. MWL locations?
2. Contingency for failures: Delta-V impact to correct perigee drift
3. Going for lower perigee? (SNR vs drag) Science Return.

ACTIONS:

1. Fix minimum ground station locations for assessment phase (3) (After trading orbit vs. locations)
2. Assess the impact of lower perigee passes for science, lower vibration environment from attitude control system (see later slides)

Ground Stations and Operations

ESA ground station concept

1. Single ground station concept
2. Flexibility to use a variety of stations if needed
3. ESTRACK ground station coverage for:
    a. Commanding
    b. Monitoring
    c. Science data downlink
    d. Tracking for operations use
4. Tracking data for science orbit determination by GPS and ground terminal data
5. X-band

Operations: Mission Phases

1. **LEOP** up to including the launcher correction manoeuvre: close to continuous coverage by 3 ground stations
2. **Drift Phase** (assumed up to L + 15 days, maximum 45 days duration), with start of initial commissioning as far as practical, not yet final terminal contact times and durations, 8h daily coverage + support by second ground station for manoeuvres and tracking
3. **Commissioning** of system and payload for 2 months, on site presence of experts and scientists, 10 h daily coverage
4. **Initial Science Phase**: 2 contacts per day of 2 h duration for 4 months, working hour operations (12 hrs max)
5. **Routine Science Phase**: Single daily coverage of 2h, no weekend coverage, no weekend on call without weekends, working hour operations

REMARK: Driver for pass frequency is science feedback, Precise timing of feedbacks may drive choice of commissioning ground station if such requirements can be consolidated.

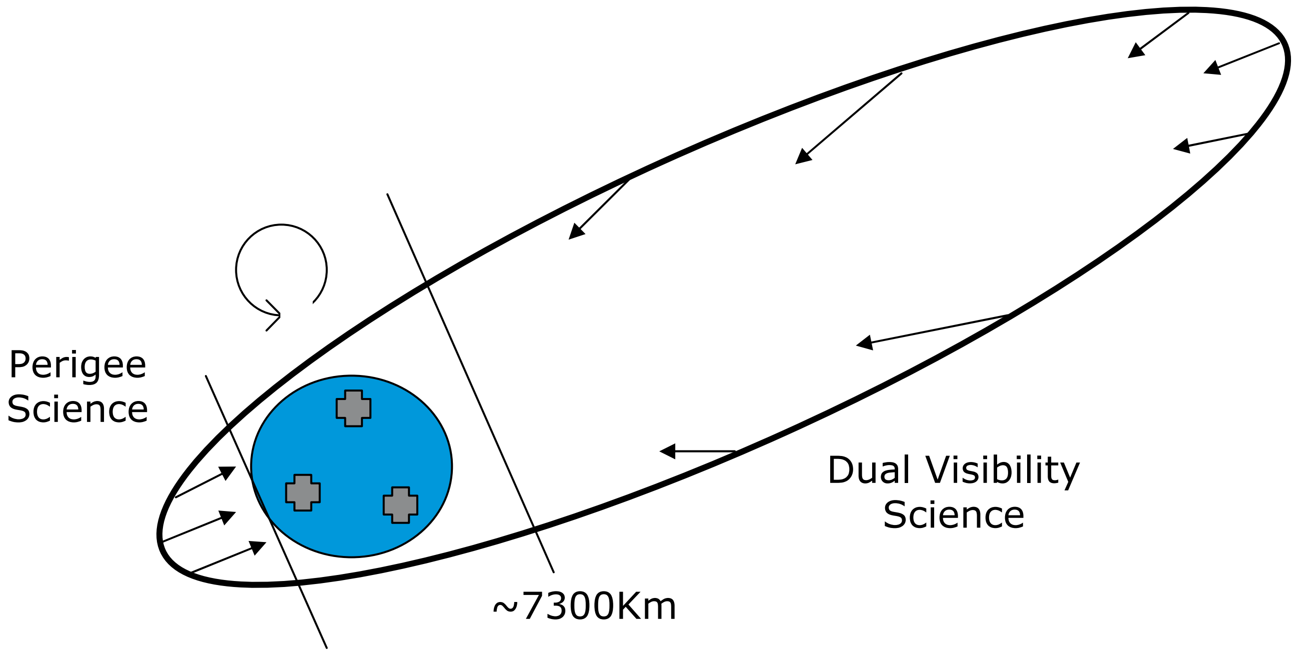
ACTION: Consolidate contact requirements and justification. From operations point of view, need for increased contact frequency is not understood.

Operations: MOC / SOC

1. Mission Operation Centre:
    a. ESOC
    b. Spacecraft (and Instrument) TC goes through MOC
2. SOC:
    a. Science Operations Centre: Preferably ONE
    b. If absolutely necessary, could be co-located with MOC for first phases
    c. Need to define SOC location for later
    d. Project Archive?

Attitude and Orbit Control

Pointing Strategy



Proposed AOCS Schemes

1. Option 1: Thrusters and Wheels

+	Cost
+	Proven, straightforward implementation, damping TBD
-	Performance needs to be assessed in later phases (requirement could not be validated yet)
+-	Mass/power comparable

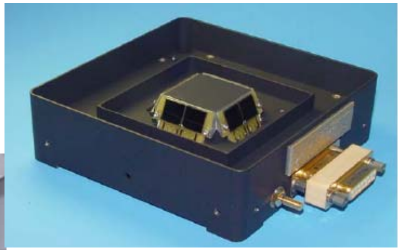
1. Option 2: Thrusters and Cold Gas

-	Cost
-	More complex AIT
+	Exceeding performance requirements: Lower perigee pass possible -> increased science
+-	Mass/power comparable

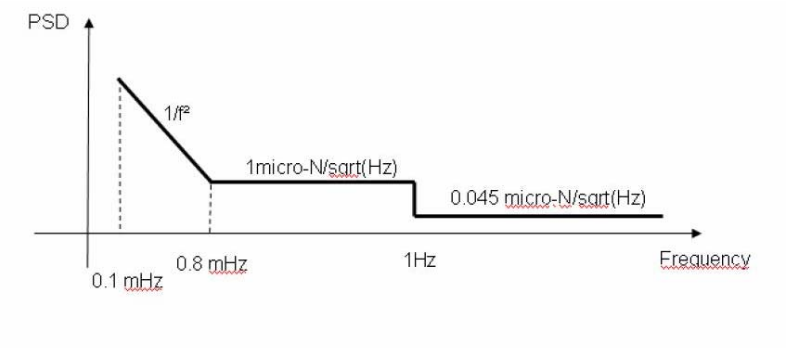
Suggestion: Cold Gas system is exceeding requirements and could help improve science return:
Cold Gas as baseline AOCS system for high performance control (System is within cost budget, impact reasonable)

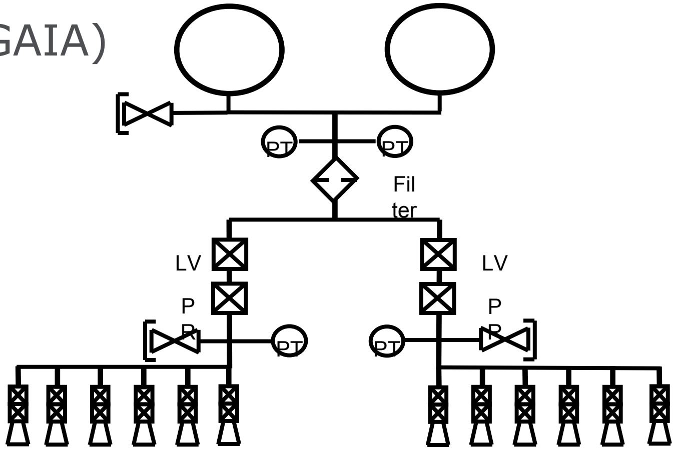
AOCS Systems

1. Sensors:
   a. Sun Sensor (safe) (TNO-Bradford)
   b. Star Tracker (Sodern Hydra)
   c. IMU (EADS Astrix 120)



2. Actuators:
   a. 1N Thrusters (manoeuvres) (multiple sources)
   b. Cold Gas system (fine) (GAIA)



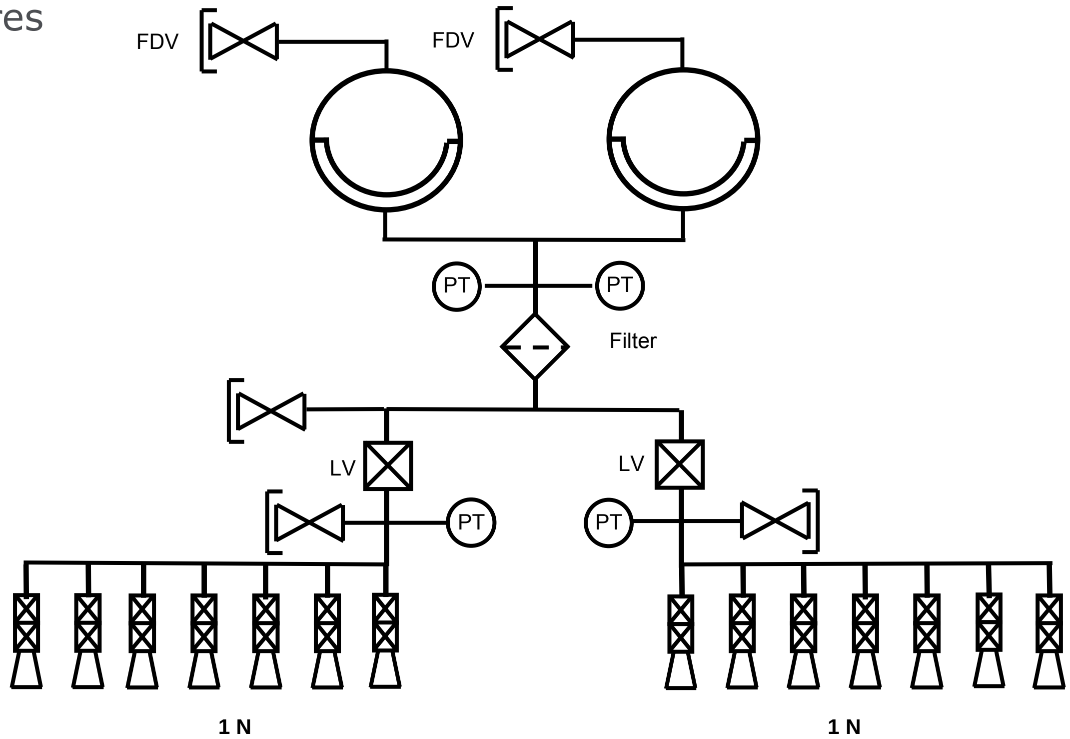


System Design

Propulsion

Used for: Drift Correction, Launcher Dispersion, East/West drift, Orbit Maintenance, AOCS Manoeuvres

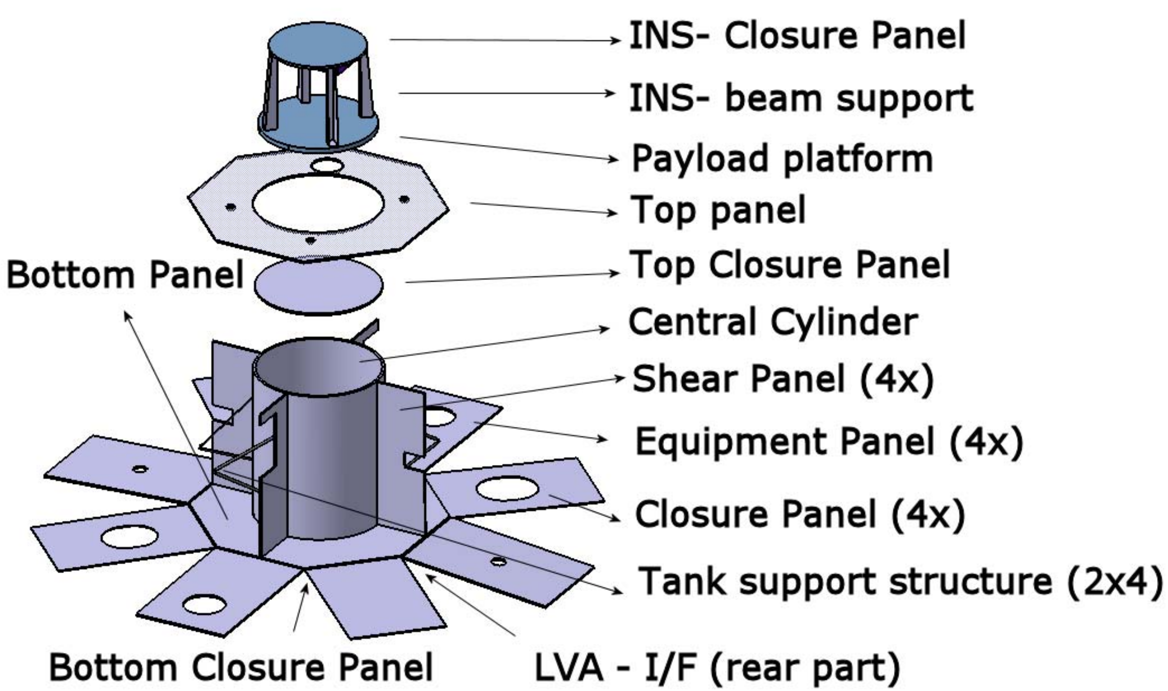
Design: 1N Hydrazine system



Structures

Design Drivers:

1. Launcher: SOYUZ FREGAT
2. Frequency requirement:
   a. f_axial ≥ 35 Hz
   b. f_lateral ≥ 15 Hz
3. Launch loads
   a. 5g (axial)
   b. 1.8g (lateral)
4. Allowable buckling stress
5. Compatible to space environment (i.e. radiation)



Mechanisms

1. Mechanisms for STE-Quest are related to the solar array wing and include
    a. Solar Array Drive Mechanism (SADM)
    b. Hold Down and Release Mechanism (HDRM)
    c. deployment and synchronization
    d. Yoke for deployment

2. Need to orient the SA to provide power
3. Requirement on microvibration disturbances

Mechanisms: Vibrations Preliminary Assessment

1. Disturbance estimation slightly exceeds the specification in the peak band (solar array natural frequency)
2. The integral value is compliant with requirement
3. Estimations to be refined with realistic values of inertia
4. A dedicated measurement of the microvibration environment generated by the SADM shall be performed

– Values of microvibrations exceed the specification in one resonance band, but refinement of values and smaller size of the solar array can reduce their amount (data not really representative)
– A possible alternative approach of maintaining the SA not activated and reorienting when needed appears feasible

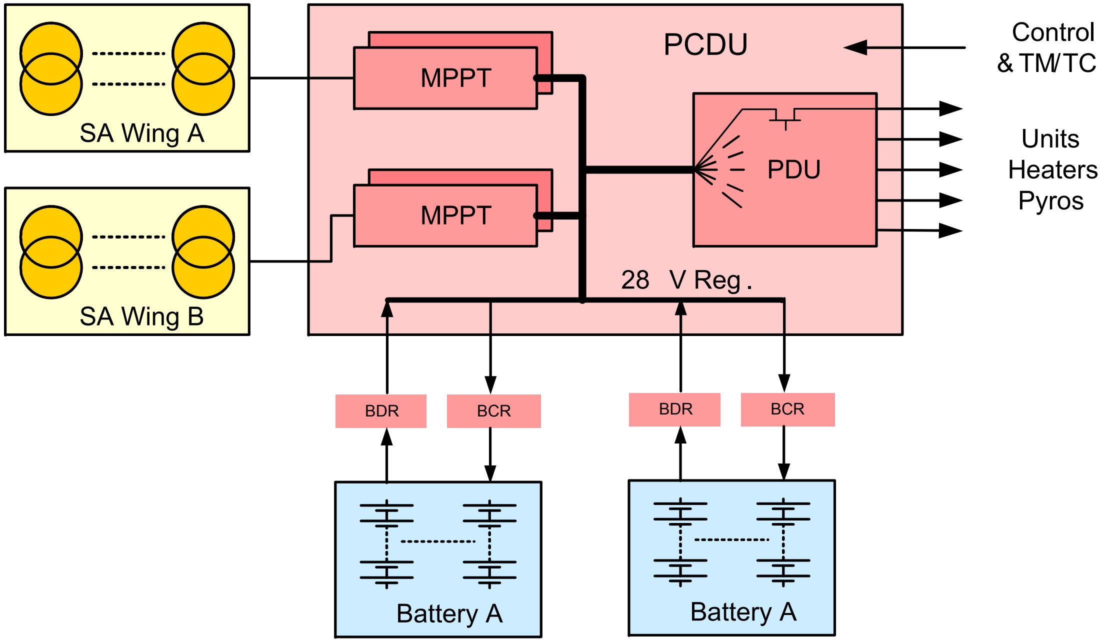
Band (Hz)	Value (m/s2)
0 - 0.6	2.960E-06
0.6 – 1	5.075E-05
1 – 1.5	3.242E-06
1.5 – 2	1.297E-05
2 – 18	2.293E-07
18 - 30	6.618E-07

Power

Solar Array

- 28 % 3J GaAs Cells
- 2 wings, with 64 strings per wing, 24 cells per string (24s64p)
- Array mass: 3.5kg/m2
- EOL power generation: 1574W

Bus / PCDU: 28 Volt regulated bus



Battery sized for longest eclipse and LEOP: 3.15kWh – 57Ah, 2 batteries, 14 kg each

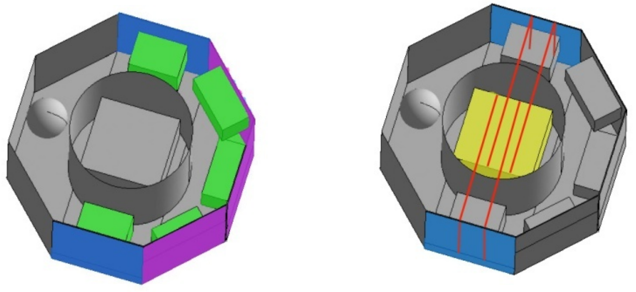
Thermal

Thermal design concept:

1. Instruments inside the cylinder, wrapped by MLI and connected to ±Y radiators via HP
2. Equipment placed on the internal sides of radiators (battery and PCDU on dedicated panel)
3. Tank thermally decoupled by the structure

Results:

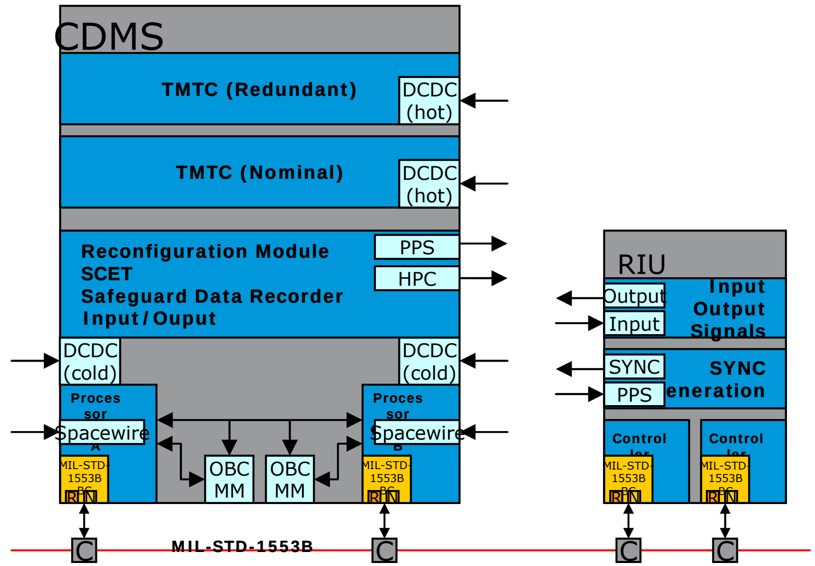
1. Thermal design is feasible with standard approach and already qualified items: minimization of mass, risk, cost
2. Detailed design necessary to meet requirement



Mode	T range	T stability
NM / no eclipse	Instr. Max ≈ 28.5 °C	≈ 4.5 °/orb
NM / eclipse	Instr. Max ≈ 27 °C	≈ 7 °/orb
SM / eclipse	Instr. Min ≈ -40 °C	N/A

Data Handling

1. SSMM incorporated within the CDMS
2. RIU to interface dedicated interfaces not connected to the S/C command and control bus
3. 90 Gbit of Mass Memory (all AI images stored, one week of data plus margins)



Instrument		Peak	Operation Time	Data Volume	Interface	Comments
PHARAO	Science	2.50 [kbps]	57600.00 [s]	144000.00 [Kbit]	CAN/1553	perigee and apogee
	Housekeeping	5.00 [kbps]	86400.00 [s]	432000.00 [Kbit]		
	Total	***7.50 [kbps]***	***144000.00 [s]***	***576000.00 [Kbit]***		
AI	Science	1300.00 [kbps]	1950.00 [s]	2535000.00 [Kbit]	SPW	image every 20s using a 1k x 1k CCD with 16 bits per pixel, plus a 20% margin
	Housekeeping	5.00 [kbps]	86400.00 [s]	432000.00 [Kbit]		
	Total	***1305.00 [kbps]***	***88350.00 [s]***	***2967000.00 [Kbit]***		Only during perigee
Clocks	Science	75.00 [kbps]	57600.00 [s]	4320000.00 [Kbit]	CAN/1553	perigee and apogee
	Housekeeping	5.00 [kbps]	86400.00 [s]	432000.00 [Kbit]		
	Total	***80.00 [kbps]***	***144000.00 [s]***	***4752000.00 [Kbit]***		
Total		***1392.50 [kbps]***		***8295.00 [Mbit]***		
Total with margin		***2088.75 [kbps]***		***12442.50 [Mbit]***		***50%***

Communication

Communication Overview

Two independent microwave systems and Laser Link:

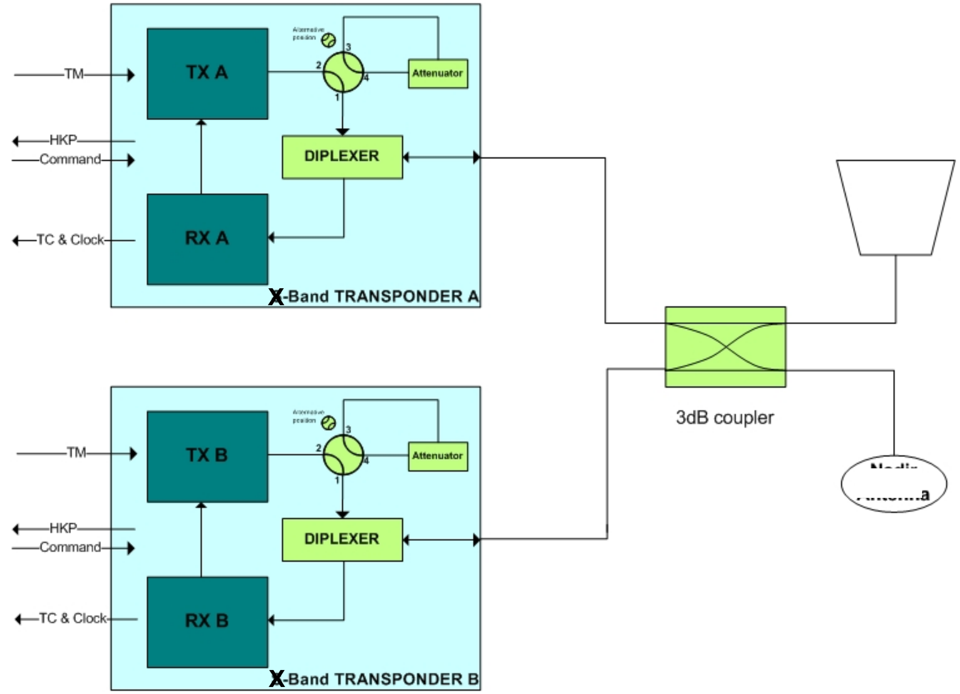
1. TT&C, in the Platform module (X-band):
   a. Electrical I/F only with Platform OBC

2. MWL, in the P/L module (S, Ka-band):
   a. Electrical I/F only with P/L electronic

3. Laser Link system (1064 nm)

Spacecraft TT&C – X-band

1. Data-rate up to 8Mbps with:
   a. 7W RF transmit power
   b. 5 dBi antenna gain (7dBi boresight)
   c. minimum elevation: 5 deg
   d. Max range: 56000Km
   e. 35m G/S (G/T = 44.2dBK)
   f. Spherical coverage for low rate @ apogee and perigee
   g. Optimized coverage for high rate @ apogee



Parameter	Unit	Apogee			Perigee	
Elev.	Deg	5	90	5	5	90
Bitrate		Hi	Hi	Low	Low	Low
TM Margin	dB	3.41	6.31	4.25	>15*	>25*

Microwave Link Design (1/4)

1. **MWT Locations**: Boulder (US), Turin (IT) and Tokyo (JP)
2. **Link Performance**:
    a. Link budget from ACES (S/N>49dBHz):
    b. 90% link availability for weather conditions (sizing case: Ka-Band in Tokyo)
3. **Frequency Band** Selection as performed in STE CDF study
4. Prevent switching and active phase-shifting solutions as much as possible to be compensated/calibrated
5. To limit as much as possible the onboard RF power due to:
    a. Radiated/conduced EMC with P/L
    b. Thermal stability of HPA section
    c. Power constraints

Microwave Link Design (2/4)

As similar as possible design solutions adopted in ACES:

1. Antenna type → Horns
2. Accommodations → Dedicated flat panel

Due to the not matching needs different sets of antenna are considered:

1. One for perigee
2. One for apogee & intermediate distance

Trade-off for optimal Gain vs FoV results:

1. At Apogee:
    a. Higher Gain: 17dBi (High Slant Range)
    b. Low FoV: <17° (lower then for GEO-comm)
2. At Perigee:
    a. Lower Gain: assumed 0dBi (lower Slant Range)
    b. Higher FoV: up to 130° (classical for LEO)
3. In Dual Visibility at intermediate range:
    a. Gain-FoV pair depending on altitude
    b. FoV of 40° with about 5dBi can be reached (extended FoV)

Microwave Link Design (3 / 4)

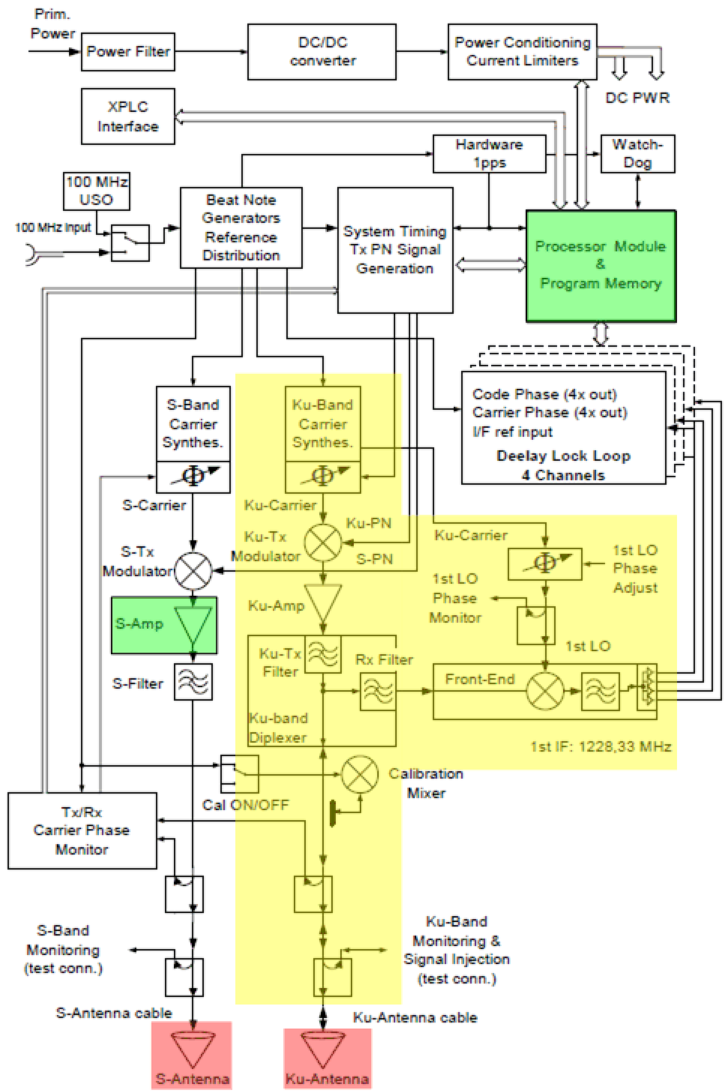
1. From ACES to STE-QUEST

Major activity:

a. Onboard antenna re-design
b. Onboard and ground Ku assembly to be redesign for Ka band
c. HPA sections to be redesign
   - Ka-Band requires TWTA (linearity, thermal stability and Magnetic field properties to by investigated)

Minor activity:

a. Onboard Orbit propagator to be updated
b. Code-Search speed algorithm to be updated
c. RF-Frontend (space and ground):
   - Dynamics optimization
   - Bigger antenna on ground (2.0 - 3.0m)



Microwave Link Design (4/4)

Ground Terminal Architecture based on the ACES MWL GT with:

1. Redesign Ka-Band
2. Antenna Dish improvement to 3m (for JP region weather, IT and US requires 2m)
3. Improvement of RF power output (to 25W)

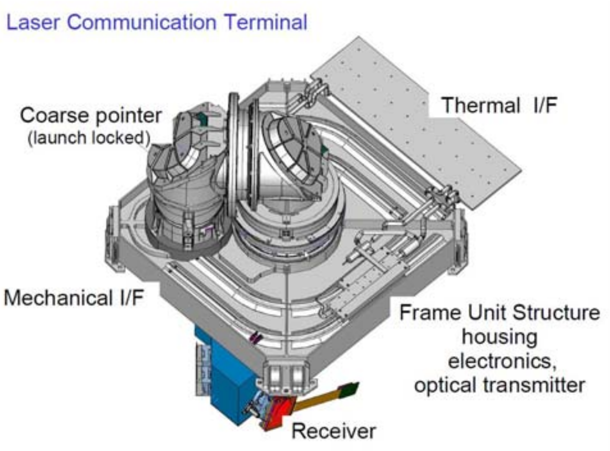
Remarks for sites selection:

1. Regulatory aspects
2. Local Horizon (Elevation Mask)
3. RF noise-floor

ACTION: Choice of Baseline Ground Stations

Optical Link design

1. Two Optical terminals have been identified on the X and –X axis of the spacecraft.
2. Each unit has a Mass of 55kg
3. Peak power of each unit 180W
4. TRL-4 (adaptations to F&T)
5. Location of ground stations needs to be addressed due to cloud obscuration (especially Tokyo)



ACTIONS:

Station locations and
link availability requirement

Budgets

Mass Budget

	Input Mass	Input Margin	Element 1 STE-QUEST	Without Margin	Margin %	Margin kg	Total kg	% of Total
				Target Spacecraft Mass at Launch			1875.00 kg	
				Below Mass Target by:			511.08 kg	
			Dry mass contributions					
EL			Structure	139.54 kg	20.00	27.91	167.45	19.09
EL			Thermal Control	15.64 kg	5.00	0.78	16.42	1.87
EL			Mechanisms	31.80 kg	8.18	2.60	34.40	3.92
EL			Communications	34.00 kg	15.50	5.27	39.27	4.48
EL			Data Handling	15.30 kg	14.44	2.21	17.51	2.00
EL			AOCS	22.17 kg	5.79	1.28	23.45	2.67
EL			Propulsion	26.90 kg	6.42	1.73	28.63	3.26
EL			Power	88.72 kg	11.76	10.44	99.16	11.30
DI	65.00	20.00	Harness	65.00 kg	20.00	13.00	78.00	8.89
EL			Instruments	332.11 kg	12.31	40.90	373.01	42.52
			Total Dry(excl.adapter)	771.18			877.29	kg
			System margin (excl.adapter)		30.00 %		263.19	kg
			Total Dry with margin (excl.adapter)				1140.48	kg
			Other contributions					
			Wet mass contributions					
EL			Propellant	113.44 kg	N.A.	N.A.	113.44	9.05
			Adapter mass (including sep. mech.), kg	110.00 kg	0.00	0.00	110.00	0.08
			Total wet mass (excl.adapter)				1253.92	kg
			Launch mass (including adapter)				1363.92	kg

Power Budget

POWER CONSUMPTION BUDGET vs MODE

				Thermal	AOCS	Comms	Propulsion	DHS	Mech	PHARAO	MOLO	FGCD	CCR	GNSS Unit	LCT	ATOM INTERFEROMETER	Harness (excl. PSS)	TOTAL CONSUMPTION
Eclipse Mode :				linked	linked	linked	linked	linked	linked	linked	linked	linked	linked	linked	linked	linked		
Initialisation Mode			Ppeak	353 W	125 W	200 W	97 W	54 W	12 W	113 W	60 W	12 W	0 W	7 W	360 W	525 W	38 W	1957 W
Start Up	Solar Flux	1323 W/m^2	Pon	353 W	33 W	85 W	24 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	11 W	560 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	15 W	2 W	37 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	1 W	55 W
	Remaining Battery Capacity		Duty Cycle	50 %	100 %	5 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %		46%
		100%	Paverage	177 W	33 W	19 W	2 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	6 W	290 W
Tref 600 min	Eclipse Mode NOT Included		Total Wh	1765 Wh	330 Wh	186 Wh	24 Wh	538 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	57 Wh	2900 Wh
Sun Aquisition	Solar Flux	1323 W/m^2	Pon	353 W	33 W	0 W	57 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	10 W	507 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	0 W	47 W	37 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	2 W	86 W
	Remaining Battery Capacity		Duty Cycle	50 %	100 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %		55%
		80%	Paverage	177 W	33 W	0 W	47 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	6 W	317 W
Tref 10 min	Eclipse Mode NOT Included		Total Wh	29 Wh	6 Wh	0 Wh	8 Wh	9 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	1 Wh	53 Wh
Safe	Solar Flux	1323 W/m^2	Pon	353 W	33 W	0 W	57 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	10 W	10 W	517 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	0 W	47 W	37 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	2 W	86 W
	Remaining Battery Capacity		Duty Cycle	50 %	100 %	0 %	0 %	100 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	100 %		0%
		100%	Paverage	177 W	33 W	0 W	47 W	54 W	0 W	0 W	0 W	0 W	0 W	0 W	0 W	10 W	6 W	327 W
Tref 0 min	Eclipse Mode NOT Included		Total Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh	0 Wh
Perigee Science Phase	Solar Flux	1323 W/m^2	Pon	0 W	44 W	115 W	47 W	54 W	0 W	113 W	17 W	10 W	0 W	7 W	360 W	415 W	24 W	1206 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	20 W	47 W	37 W	0 W	31 W	0 W	0 W	0 W	0 W	360 W	10 W	10 W	515 W
	Remaining Battery Capacity		Duty Cycle	0 %	100 %	100 %	0 %	100 %	0 %	100 %	100 %	100 %	0 %	100 %	0 %	100 %		100%
		100%	Paverage	0 W	44 W	115 W	47 W	54 W	0 W	113 W	17 W	10 W	0 W	7 W	360 W	415 W	24 W	1206 W
Tref 32 min	Eclipse Mode NOT Included		Total Wh	0 Wh	23 Wh	61 Wh	25 Wh	29 Wh	0 Wh	60 Wh	9 Wh	5 Wh	0 Wh	4 Wh	192 Wh	221 Wh	13 Wh	643 Wh
Apogee Science Phase	Solar Flux	1323 W/m^2	Pon	0 W	44 W	115 W	47 W	54 W	12 W	113 W	17 W	10 W	0 W	7 W	360 W	415 W	24 W	1218 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	20 W	47 W	37 W	0 W	31 W	0 W	0 W	0 W	0 W	360 W	10 W	10 W	515 W
	Remaining Battery Capacity		Duty Cycle	0 %	100 %	100 %	0 %	100 %	100 %	100 %	100 %	100 %	0 %	100 %	0 %	100 %		100%
		100%	Paverage	0 W	44 W	115 W	47 W	54 W	12 W	113 W	17 W	10 W	0 W	7 W	360 W	415 W	24 W	1218 W
Tref 868 min	Eclipse Mode NOT Included		Total Wh	0 Wh	637 Wh	1664 Wh	683 Wh	778 Wh	174 Wh	1635 Wh	246 Wh	145 Wh	0 Wh	101 Wh	5208 Wh	6004 Wh	345 Wh	17618 Wh
Science Phase Transition	Solar Flux	1323 W/m^2	Pon	0 W	44 W	115 W	57 W	54 W	12 W	113 W	0 W	10 W	0 W	7 W	360 W	415 W	24 W	1210 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	20 W	47 W	37 W	0 W	31 W	0 W	0 W	0 W	0 W	360 W	10 W	10 W	515 W
	Remaining Battery Capacity		Duty Cycle	0 %	100 %	100 %	0 %	100 %	100 %	100 %	0 %	100 %	0 %	100 %	0 %	100 %		99%
		100%	Paverage	0 W	44 W	115 W	47 W	54 W	12 W	113 W	0 W	10 W	0 W	7 W	360 W	415 W	24 W	1201 W
Tref 30 min	Eclipse Mode NOT Included		Total Wh	0 Wh	22 Wh	58 Wh	24 Wh	27 Wh	6 Wh	57 Wh	0 Wh	5 Wh	0 Wh	4 Wh	180 Wh	208 Wh	12 Wh	600 Wh
Manoeuvre Mode	Solar Flux	1323 W/m^2	Pon	353 W	62 W	35 W	98 W	54 W	12 W	113 W	17 W	10 W	0 W	7 W	200 W	415 W	28 W	1403 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	20 W	47 W	37 W	0 W	31 W	0 W	0 W	0 W	0 W	200 W	10 W	7 W	352 W
	Remaining Battery Capacity		Duty Cycle	50 %	84 %	100 %	28 %	100 %	100 %	177 %	100 %	100 %	0 %	100 %	0 %	100 %		85%
		100%	Paverage	177 W	52 W	35 W	61 W	54 W	12 W	177 W	17 W	10 W	0 W	7 W	200 W	415 W	24 W	1241 W
Tref 30 min	Eclipse Mode NOT Included		Total Wh	88 Wh	26 Wh	18 Wh	31 Wh	27 Wh	6 Wh	88 Wh	9 Wh	5 Wh	0 Wh	4 Wh	100 Wh	208 Wh	12 Wh	620 Wh
Eclipse Mode	Solar Flux	0 W/m^2	Pon	0 W	44 W	115 W	47 W	54 W	12 W	113 W	17 W	10 W	0 W	7 W	200 W	415 W	21 W	1055 W
	(0 if Solar Array not used)		Pstdby	0 W	0 W	20 W	47 W	37 W	0 W	31 W	0 W	0 W	0 W	0 W	200 W	10 W	7 W	352 W
	Remaining Battery Capacity		Duty Cycle	0 %	100 %	100 %	0 %	100 %	100 %	100 %	100 %	100 %	0 %	100 %	0 %	100 %		100%
		100%	Paverage	0 W	44 W	115 W	47 W	54 W	12 W	113 W	17 W	10 W	0 W	7 W	200 W	415 W	21 W	1055 W
Tref 180 min	Eclipse Mode NOT Included		Total Wh	0 Wh	132 Wh	345 Wh	142 Wh	161 Wh	36 Wh	339 Wh	51 Wh	30 Wh	0 Wh	21 Wh	600 Wh	1245 Wh	62 Wh	3164 Wh

Risk, Programmatics, Cost

Cost

1. **Mission is within the Cosmic Vision Boundaries** **OK**

2. Procurement approach:
    a. Spacecraft and Operations: ESA
    b. MWL and LCT (ground and space): ESA
    c. GNSS receiver: ESA
    d. Other Payload items (Development and procurement): NA

Risk

- **Several high risk items identified**
- **The high risks presented are typical of pre-phase A studies**
- **Mitigating actions to be implemented for the medium / high risks identified (we can go through them in separate meeting)**

1.	Low TRL of some Science P/L elements	H
2.	Attitude control	M
3.	High Radiation Environment implications on platform and payload	M
4.	Platform not meeting EMI requirements	M
5.	Optical Link (LCT) availability	H
6.	Calibration delays, s/c outages	M
7.	STE-QUEST not ready at the launch date	M
8.	Increase in resources required by P/L technology	H
9.	Complex organization of the consortium providing the Science instruments	H

Programmatics – S/C Model philosophy

Model Philosophy:

- The structure will be a new design with the rather heavy LCT's being attached. Even if parts of it can be derived from an other platform it is recommended to build an **STM** for structural and thermal system level qualification.
- Depending on the robustness of the design it might be possible to refurbish the STM and re-use it as **PFM**.
- This hybrid approach should be complemented by an **Avionics Test Bench,** to be used for functional tests and software verification.
- All equipment shall be fully qualified at equipment or subsystem level.
- **Instruments to provide models for STM**

Programmatics - TRL

The European Space Technology Master Plan*) gives the following statement:

"It takes 12-18 months to prepare the legal bases for multi-annual programmes such as research... a political agreement on the ceiling in the financial framework should to be taken no later than 18 months before the framework enters into force.

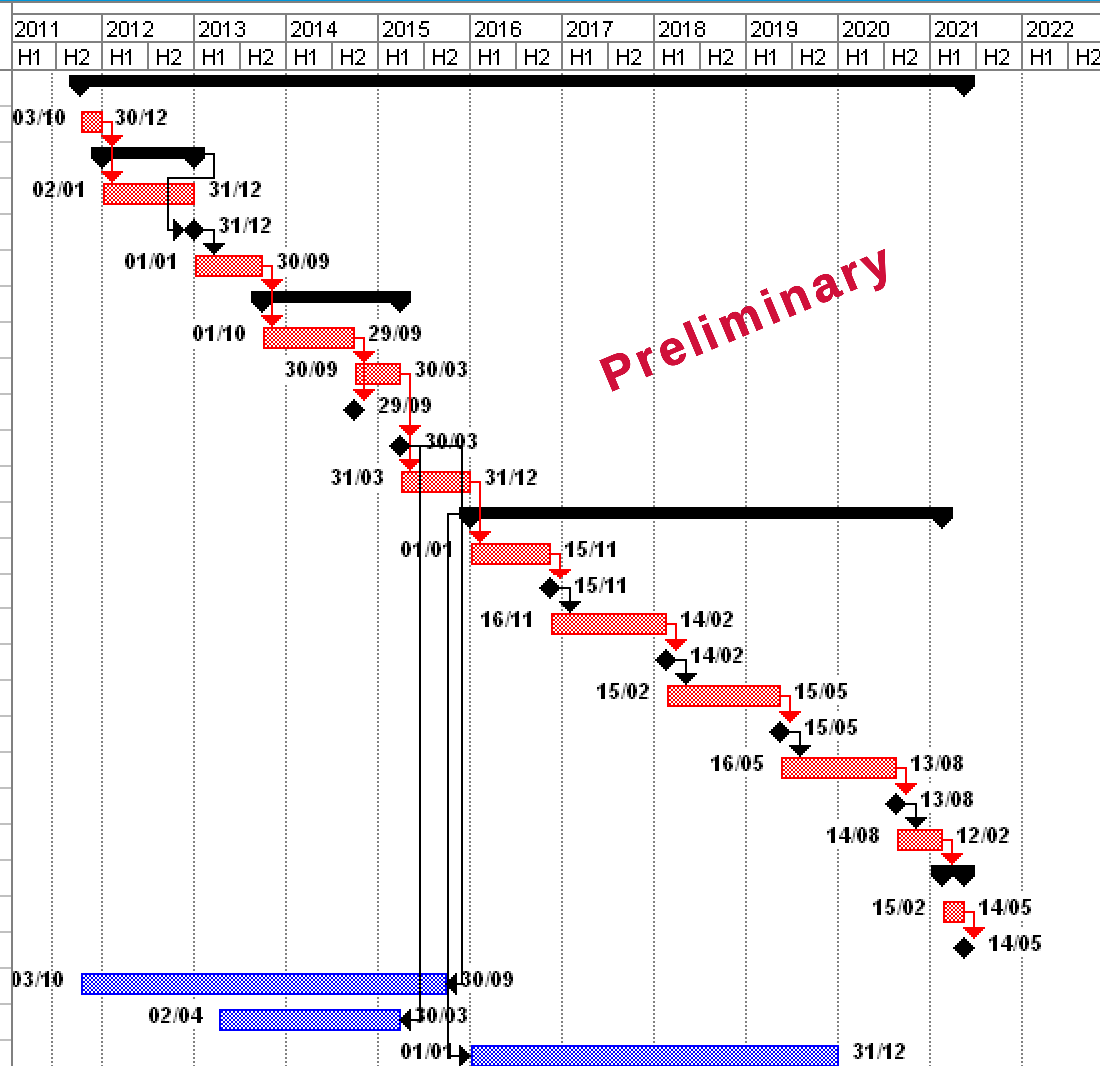
In order to achieve a reasonable estimation of the necessary development durations, this additional time period has to be taken into account. The following table presents an indication for the resulting development periods up to readiness for integration on a flight model.

TRL	Duration
5-6	4 years + 1,5 year
4-5	6 years + 1,5 year
3-4	8 years + 1,5 year
2-3	10 years + 1,5 year
1-2	12 years + 1,5 year

Development Durations for TRL's

Programmatics - Schedule

ID	Task Name
1	**STE-QUEST**
2	ITT - 3 month
3	**Assessment phase - 12 month**
4	Industrial Phase 0 -12 month
5	MDR (Mission Definition Review)
6	Preparation of competitive definition phase - 9 month
7	**Definition phase (completion of Phase A, B1) - 18 month**
8	Phase A (Feasibility) - 12 month
9	Phase B1 (Requirements consolidation) - 6 month
10	PRR (Preliminary Requirements Review)
11	SRR (System Requirements Review)
12	Follow-up time - 9 month
13	**Implementation phase (Phase B2/C/D) - 61.5 month**
14	Phase B2 (preliminary design) - 10.5 month
15	PDR (Preliminary Design Review)
16	Phase C (Detailed definition) - 15 month
17	CDR (Critical Design Review)
18	STM and ATB pocurement and qualification - 15 month
19	QR (Qualification Review)
20	STM refurbishment, PFM integration and acceptance - 15 month
21	AR (Acceptance Review)
22	Contingency - 6 month
23	**Phase E1 - 3 month**
24	Launch preparation
25	LRR (Launch Readiness Review after ORR & FRR)
26	Technology development from TRL 3-4 to TRL 5-6 - 4 years
27	Technology development from TRL 4-5 to TRL 5-6 - 2 years
28	Technology development from TRL 5-6 to TRL 8-9 - 4 years



Programmatics

1. Development and implementation of this project within the given time frame appears to be possible, with some margin.
2. The payload development must be continued without delay.
3. The development of a new structure, together with the complexity of the configuration, leads to the recommendation of a model philosophy with STM, ATB and PFM.
4. The legal framework for the deployment of ground terminals must be prepared well in time.

Requirements Review

European Space Agency

Requirements Review (1/3)

1. #SR-OR-05 Gravity Gradient at Perigee Requirement: The gravity gradient at perigee shall be not larger than 2.5·10-6 s-2.
    a. What exactly is meant by this requirement? The gradient within the spacecraft induced by the gravitational field? Please re-formulate to clarify
2. Accommodation of the STE-QUEST Atomic Clock Requirement: The axis of the STE-QUEST PHARAO-Rb atomic clock shall be preferably oriented perpendicularly to the orbital plane.
    a. Understand: tube axis = rotation axis, i.e. only rotations around tube centerline are allowed. If OK, please rephrase the requirement
3. #SR-PL-03 Rotations (2 arcsec/s)
    a. Please specify the timeframe for this (assumption: 20 sec, AI measurement

Requirements Review (2/3)

1. #SR-PL-08 Payload Telemetry and #SR-PL-09 Telecommanding Capabilities: "Near real-time"
   a. Further definition/re-phrase necessary. Order of minutes for TM OK, TC usually via timelining. Would introduce Operations cost overhead for "near-real time". Need operations plan to decide strategy.
2. #SR-PL-40/41: Orbit determination:
   a. Accuracy is OK in LEO, difficult in HEO, from ~30000km difficult to fix via GPS
   b. Laser Ranging to be checked in apogee
3. #SR-OP-03/04: Availability of data:
   a. Forwarding from MOC to SOC no problem, minute-delay
   b. Orbitography data: How accurate does the data have to be for the first estimate (in m, m/s)?

Requirements Review (3/3)

1. #SR-GS-15-18: Positioning of Ground Equipment
    a. At receiver position for ESTRACK: 1-5 cm, from receiver to antenna: up to 20 cm. Earth axis data only available after ~14 days, in order of m.
    b. Need to demonstrate how to achieve this accuracy.
    c. In case ground terminals moved from clock (visibility), two positions need to be determined to high accuracy.

Open Points

1. Antenna trade (one, multiple vs pointing strategy)
2. AOCS systems
3. Ground terminal/clock distribution vs. Orbit strategy
4. *Solar Array Configuration*
5. *Microvibrations Characterization and Isolation*

Conclusions

1. Mission feasible in general
2. Several trades still open due to limitations of CDF
3. Thorough check of requirements necessary for high-accuracy demands (i.e. how to meet them)
4. Need to progress on instrument design definition
5. Need to consolidate some requirements (see previous slides)

Thanks to the science team members for their valuable input and fruitful discussions during the study!

Actions for SST

1. Work on Requirements (with input from review-slides)
2. Ground terminal location and link availability requirements for optical link
3. Baseline choice of ground terminal locations for MWL
4. Trade complex orbit vs ground terminal locations (complex orbit preferred by ESA currently)
5. Define and justify contact requirements w/ ground -> unusual currently
6. Define SOC/science scheme and science operations (example OPS schedule)
7. Statement on pro/con cold gas solution as possible baseline
8. Input to PDD (baseline instrument design)
9. All remarks from slide 18 (Instrument Way forward)