# Space Time Explorer


*Agenda*

Session 8 IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Agenda 1/2

| | | |
|---|---|---|
| Introduction | | 10 min |
| Background | | 10 min |
| Mission analysis | | 20 min |
| Systems | | 30 min |
| Instrument/payload | | 25 min |
| Optics/instrument | | 20 min |
| **Break** | **All** | **10 min** |
| Communication | | 20 min |
| Cost | | 20 min |
| Data Handling | | 20 min |
| Mechanisms | | 15 min |
| AOCS | | 20 min |
| **Lunch** | **All** | **50 min** |

# Agenda 2/2

| | | |
|---|---|---|
| Propulsion | | 20 min |
| Ground Segment | | 20 min |
| Radiation | | 10 min |
| Power | | 20 min |
| Programmatics | | 20 min |
| Risk | | 20 min |
| **Break** | **All** | **10 min** |
| Thermal | | 20 min |
| Structures | | 20 min |
| Configuration | | 20 min |
| Conclusions | | 10 min |

# Space Time Explorer

*Introduction*


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# Introduction & Background

- STE: Space-Time Explorer
  - Precursor: “Fundamental Physics Explorer FPE-A”, Tests of special and general relativity
  - Similar mission proposed as M-class mission in Cosmic Vision in 2007
  - Related missions : ACES, LISA
- CDF study on request of SRE-PA
- Eight sessions (15 June – 16 July 2010)

ACES = Atomic Clock Ensemble in Space

LISA = Laser Interferometer Space Antenna

# Objectives

## CDF Study objective

- The objective of the STE CDF Study is to **design a mission** that will test Einstein's theories of special and general relativity by comparing high precision microwave clocks in space and on ground

## Customer (SRE-PA) objective

- The goal of this CDF study is to **support the Fundamental Physics science community** in preparation of the future Cosmic Vision Call for Proposals

# Study Sessions

| | | | | |
|---|---|---|---|---|
| • Session #1: | 15th June | Tue | AM | Kick-off |
| • Session #2: | 17th June | Thurs | AM | Mission/System Req. definition |
| • Session #3: | 22nd June | Tue | AM | Orbit trade-off, P/L & Platform data |
| • Session #4: | 24th June | Thurs | AM | Final orbit, OPS, P/L & Platform design |
| • Session #5: | 5th July | Mon | AM | Mission Baseline, System Req. update |
| • Session #6: | 9th July | Fri | AM | Design Baseline, Platform detail design |
| • Session #7: | 13th July | Tue | AM | Project Baseline, Technology roadmap |
| • Session #8: | 16th July | Fri | AM/PM | Internal Final Presentation |

# STE study objectives 1/2

- Design of overall mission scenario from launch to target orbit(s)
- Design of spacecraft and transfer stages
- Refinement of the scientific payload (Assess technology readiness level of payload w.r.t. launch date in late 2022), accommodation, and their interfaces
- Assess the possible need of a Drag Free Control System
- Assess method for precise orbit determination
- Devise operational scenario with emphasis on the maximization of space-to-ground clock comparisons, the needed for ground infrastructure, and the position of high-performance clocks on ground
- Assess technology readiness of P/L, space and ground segment and identify technology needs including development plan
- Perform costing and risk analysis
- Provide a preliminary development plan, demonstrating compatibility with a launch by the end of 2022, tentatively indicated as available for an M-class 3$^{rd}$ slot candidate in the CV program.

# STE study objectives 2/2

**Special emphasis on:**

- Understand mission design drivers imposed by science
- Technology readiness levels of P/L elements
- Identify need for development activities
- Space qualification of mission critical P/L elements (e.g. frequency comb)
- High stability MW link
- High complexity of science ground stations with high performing clocks in specific locations depending on orbit

# Boundary conditions

- Potential M-class mission candidate constraints:
  - Technology Readiness level (TRL) 5 by end of Definition Phase (~ 2014)
  - Launch by 2022
  - Soyuz launch from CSG, Kourou
  - ESA CaC < 470 MEUR (e.c. 2010)

# Outputs

- Main CDF study outputs:
  - CDF Integrated Design Model
  - CDF Final presentations (to be made public by 20 July 2010)
  - CDF Final Technical Report (to be made public)
  - Mission analysis report

- Note: Cost assessment will not be made public.

# Space Time Explorer

*Background*


Session 8 - IFP

ESTEC, 16th July 2010

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# Study Background

- The main reason for this study was to <u>support the Fundamental Physics community</u> in their preparation to answer the next Cosmic Vision (CV) call for M-class missions.

CV call will be issued end July 2010

- In 2007 the proposed Fundamental Physics (FP) missions were not selected for further study, mainly on technology readiness grounds.

- In the context of Fundamental Physics Roadmap Advisory Team (FPR-AT) work, main FP science goals in the near future were identified, e.g.:
  - "A highly accurate test of the structure of space-time by testing the gravitational redshift using a highly elliptical high Earth orbit ….."

# Science Objectives & Requirements

**Science objectives:**

Goal 1) Test Einstein's theories of special and general relativity by comparing high precision microwave clocks in space and on ground.

Goal 2) Test the local position invariance of fundamental constants.

**Top level science requirements**:

Requirement 1)

Compare clock rates of an on-board clock and a ground clock at extremely different levels of gravitational potential and therefore high variations of the red-shift effect.

Requirement 2)

Compare clock rates of an on-board clock with two ground clocks, spaced far apart, simultaneously.

# STE study objective

Design an overall mission scenario from launch to target orbit(s).

**Special emphasis on:**

- Understand mission design drivers imposed by science
- Technology readiness levels of Payload (P/L) elements
- Identify need for development activities
- Space qualification of mission critical P/L elements (e.g. frequency comb)
- High stability Micro Wave Link (MWL)
- High complexity of science ground stations with high performing clocks in specific locations depending on orbit

# Boundary conditions

- Potential M-class mission candidate constraints:
  - Technology Readiness level (TRL) 5 by end of Definition Phase (~ 2014)
  - Launch by 2022
  - Soyuz launch vehicle (from Kourou and/or Baikonour)
  - ESA Cost at Completion < 470 MEUR (2010)

**The Internal Final Presentation (*IFP*) will be made <u>available</u> immediately to the scientific community before the official release of the CV call for proposals.**

Disclaimer: This is a <u>preliminary study</u> and all resource budgets will need consolidation via future dedicated analyses.

# Space Time Explorer


*Preliminary Mission Analysis*

Internal Final Presentation

ESTEC, 16th July 2010

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## Summary of Requirements

- Two different science goal require:
  - Large difference in gravitational potential
  - Long measurement times at apogee and perigee
  - Combined visibility from two ground stations with large distance between them
- Conditions on perigee pass:
  - Minimum elevation above surface 10 DEG
  - Minimum pass duration is 400 seconds
  - Maximum altitude 3000 km

# HEO Features

- Resonant HEO* required to achieve regular MWT** passes
  - 12, 16 and 24 hour options considered
  - Trade between number of passes for measurements and difference in the gravitational potential
- 16 hour orbit has been selected
  - Three different perigee locations with respect to the Earth
  - Repeated pattern after 48 hours
  - Two MWT to observe the perigee passage at perigee and after perigee
  - MWT observing the perigee pass is also the MWT observing the apogee pass

* Highly Elliptical Earth Orbit

** Microwave Terminal

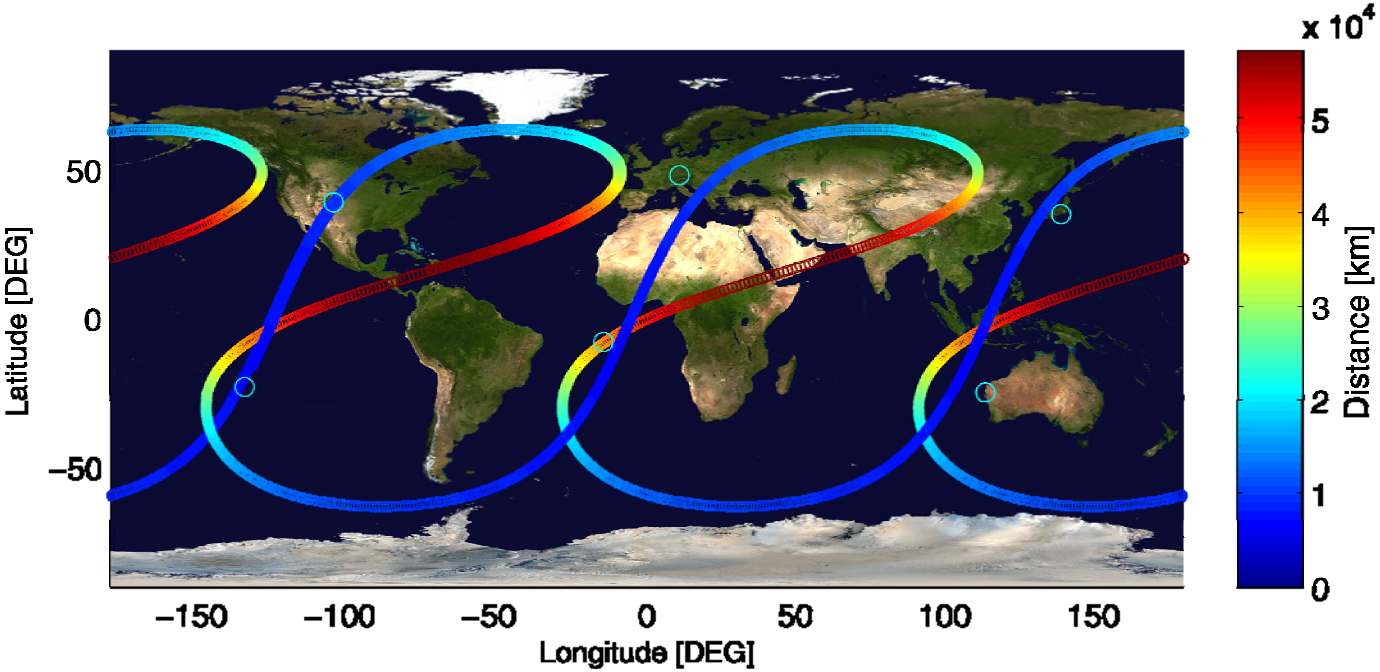
# Baseline 16 h Orbit

- Account for perturbations by non-spherical gravitational potential of the Earth by selecting orbital parameters accordingly:

- Keplerian Elements:
  - SMA: 32203.7 km
  - Eccentricity: 0.7802
  - Inclination: 63.43 DEG
  - RAAN: 336 DEG at epoch
  - Argument of Perigee: 342 DEG
  - True anomaly: 0 Deg at epoch
- Initial perigee altitude at 700 km

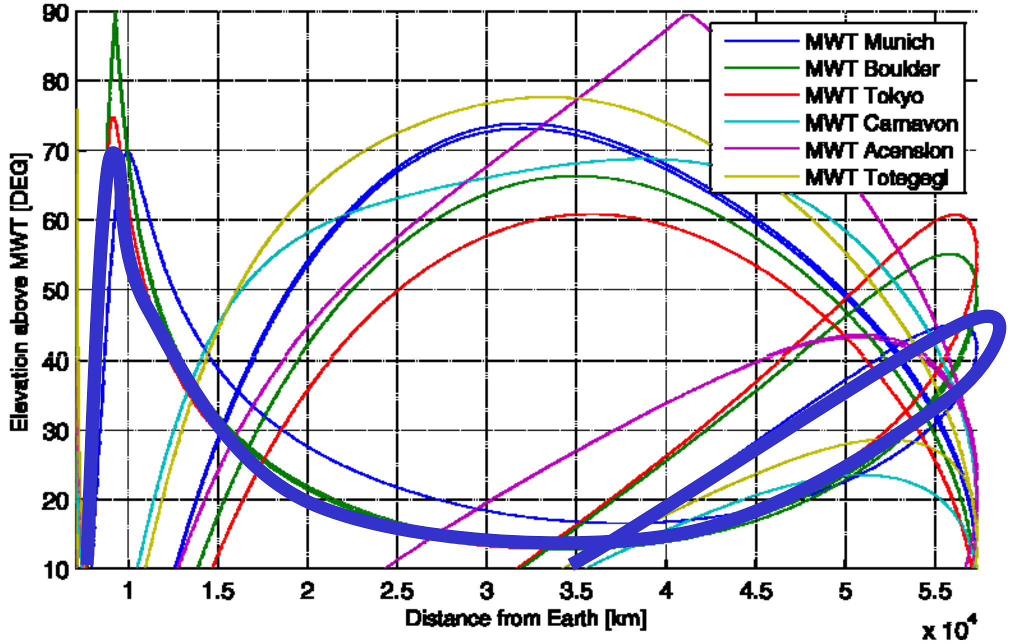
- Combined measurement time during one cycle is larger than 3000 seconds

# Ground Track 16 h Orbit



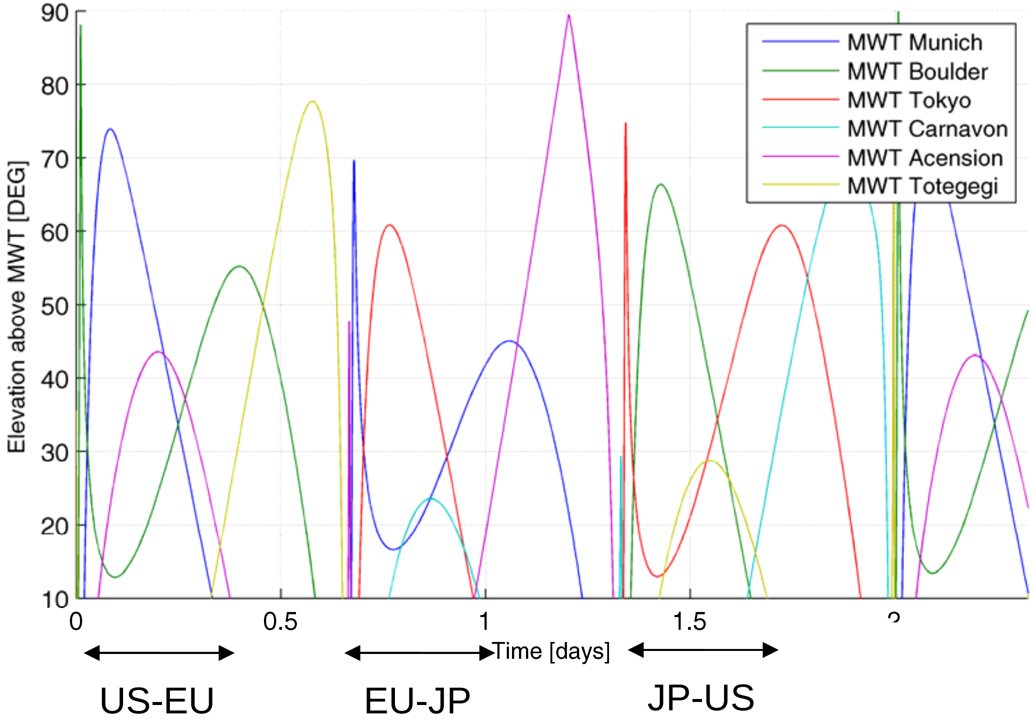
# 16 hour orbit

- Permanent visibility from perigee to apogee pass
- Visibility duration > 8 hours



# 16 hour orbit

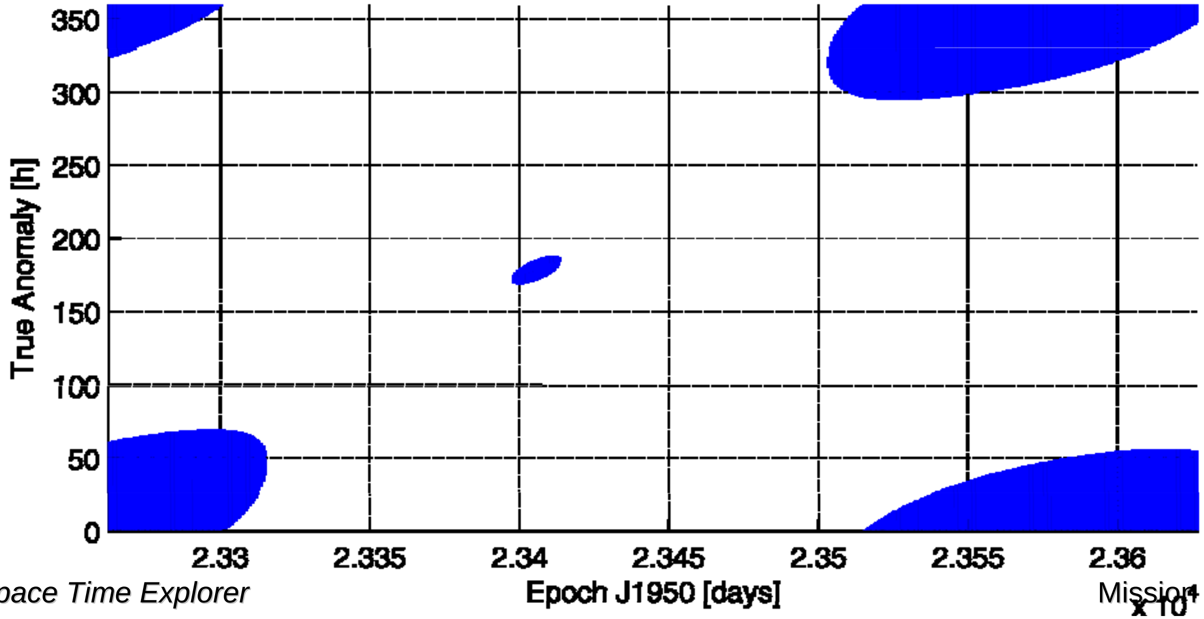
- Combined visibility from two MWT on different continents




*Space Time Explorer*

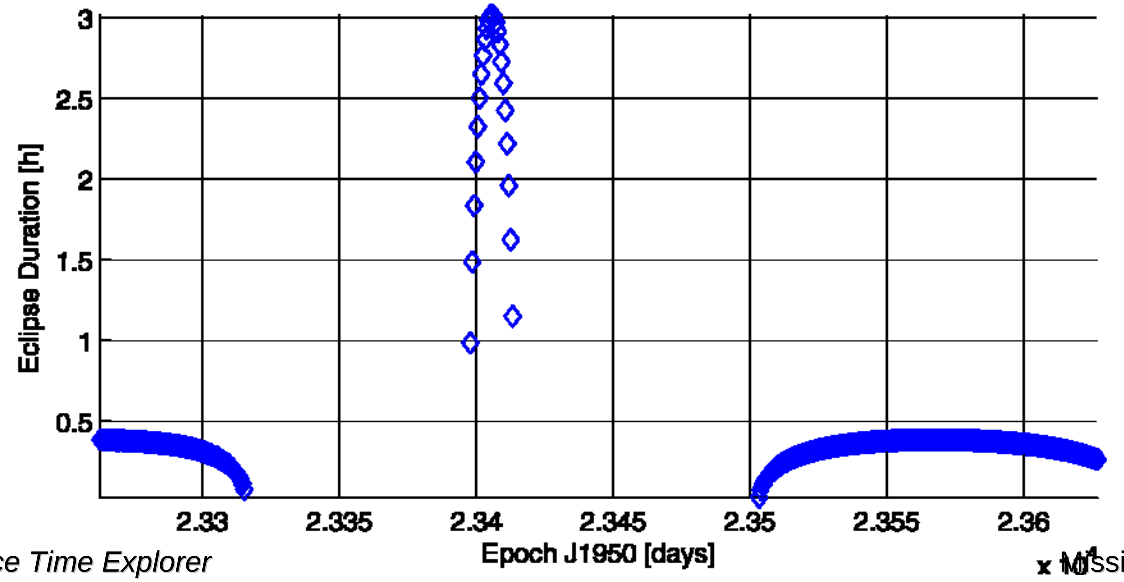
# Eclipse Seasons and Duration

- One year example:



# Eclipse Seasons and Duration

- One year example:



# Orbit Maintenance

- Orbit maintenance DeltaV required to stabilize orbit and ensure perigee passes above MWT
- Baseline assumption: 20 m/s/year
- Numerical verification:
  - Perigee pass ground track equal after one year: 100 m/s/year average for a 10 year mission (single maneuver DeltaV between 5-200 m/s)
  - Allowing slight shift in argument of perigee: 28 m/s/year average for a 5 year mission (single maneuver DeltaV between 0-41 m/s, correction every half a year

  - The above given examples are snapshots for given starting epochs
  - It is strongly recommended to investigate the strategies in further detail to analyze launch date dependencies

# Space Time Explorer


*Systems*

Internal Final Presentation

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

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# Science Goals

- Goal I
  - to measure the Earth gravitational redshift to 20 ppb ($2 \cdot 10^{-8}$)
- Goal II
  - to measure the Sun null gravitational redshift to 300 ppb ($3 \cdot 10^{-7}$)
  - to obtain measurements of the the geopotential with a equivalent height resolution of 1 cm for intercontinental geopotential comparisons spanning 1 year

- These 2 scientific goals could be achieved independently since they are based on 2 different measurement principles

# Mission Requirements: Goal I

| | | |
|---|---|---|
| *GI-R1a* | **Measurement principle** | Goal I shall be achieved through the comparison of one clock on-board a spacecraft in an eccentric orbit to ground clocks. |
| *GI-R1b* | | The measurements for the comparison between clocks shall be acquired by establishing a direct link between the spacecraft and a ground terminal equipped with a clock |
| *GI-R1c* | | The measurements for the comparison between on-board and ground clocks shall be performed near perigee and near apogee. |
| *GI-R2* | **Gravitational potential** | The difference in gravitational potential between the measurements taken near perigee and near apogee shall be higher than 6.5E-10 x c^2 |
| *GI-R3* | **Measurement duration** | The duration of the link from the spacecraft to the ground terminal for each measurement shall be at least 400 s. |
| *GI-R4a* | **Accumulated measurement time** | The total mission link time for the measurements performed near perigee shall be at least 5.E6 s. |
| *GI-R4b* | | The total mission link time for the measurements performed near apogee shall be at least 5.E6 s. |
| *GI-R5* | **Number of orbits** | The measurements shall be acquired during at least 200 different orbits |
| *GI-R6* | **On-board clock performance** | The on-board clock instability shall be lower than 3.e-14 / sqrt(tau), where tau is the integration time. |
| *GI-R7a* | **Ground clock performance** | The ground clock inaccuracy shall be lower than 5.e-17 |
| *GI-R7b* | | The ground clock instability shall be lower than 2.e-16 at 400 s |
| *GI-R8* | **Link performance** | The link instability shall be lower than 4e-16 at 400 s |
| *GI-R9a* | **Network of ground terminals** | The ground terminals shall be equipped with a clock and a microwave or optical link to the spacecraft |
| *GI-R9b* | | The following ground terminals shall be used at least: a ground terminal located near Boulder, Colorado (US), a ground terminal located in Europe (in either Paris, Torino, Braunschweig, Duesseldorf, Teddington), and a ground terminal located near Tokyo (Japan) |
| *GI-R9c* | | The network of ground terminals shall ensure that each orbit at least two different ground terminals can take measurements near perigee |
| *GI-R9d* | | The network of ground terminals shall ensure that each orbit at least two different ground terminals can take measurements near apogee |
| *GI-R9e* | | Additional ground terminals using transportable clocks and link equipment shall be located where needed |
| *GI-R10a* | **Orbit determination** | The uncertainty in the knowledge of the position of the spacecraft shall be lower than 2 m (spherical, 1-sigma) whenever measurements are taken. |
| *GI-R10b* | | The uncertainty in the knowledge of the velocity of the spacecraft shall be lower than 0.2 mm/s (spherical, 1-sigma) whenever measurements are taken. |

# Mission Requirements: Goal II

| | | |
|---|---|---|
| *GII-R1* | **Measurement principle** | Goal II shall be achieved through the comparison of pairs of distant ground clocks performed via a simultaneous link with the spacecraft |
| *GII-R2* | **Measurement duration** | The duration of the link from the two ground terminals to the spacecraft for each measurement shall be at least 2 h. |
| *GII-R3* | **Accumulated measurement time** | The total link time for the measurements performed for a given pair of ground clocks shall be at least 150 days. |
| *GII-R4a* | **Ground clock performance** | The ground clock inaccuracy shall be lower than 1.e-18 |
| *GII-R4b* | | The ground clock instability shall be lower than 1.e-18 |
| *GII-R5a* | **Network of ground terminals** | The ground terminals shall be equipped with a clock and a microwave or optical link to the spacecraft |
| *GII-R5b* | | The following ground terminals shall be used: a ground terminal located near Boulder, Colorado (US), a ground terminal located in Europe (in either Paris, Torino, Braunschweig, Duesseldorf, Teddington), and a ground terminal located near Tokyo (Japan) |
| *GII-R5c* | | The following pairs of ground clocks are to be compared: US-Europe, Europe-Japan, US-Japan |

# Spacecraft requirements

| | | |
|---|---|---|
| *SR1* | **Non-gravitational acceleration** | The spacecraft non-gravitational acceleration shall be lower than 1.e-5 m/s^2 |
| *SR2* | **Microvibrations** | The microvibration environment on the payload shall be lower than 8E-5 (m/s^2) f^(-1/2), with f between 2 mHz and 10 Hz |
| *SR3a* | **Payload thermal environment** | The operating temperature of the payload shall be kept between 10 and 30 deg |
| *SR3b* | | The thermal instability of payload interface shall be lower than +-2 deg over 1 orbit |
| *SR3c* | | The non-operating temperature of the payload shall be kept between -40 and 60 deg. |
| *SR4* | **Pointing** | The spacecraft pointing error shall be lower than 0.3 deg if an optical link is used. |
| *SR5* | **Orientation of the clock** | The vacuum tube of the on-board clock should be oriented perpendicular to the orbital plane. |
| *SR6a* | **Magnetic field** | The DC magnetic field at the location of the on-board clock shall be lower than 1 G |
| *SR6b* | | The magnetic field variation at the location of the on-board clock shall be lower than 140 dBpT in [100 mHz, 1 Hz] |

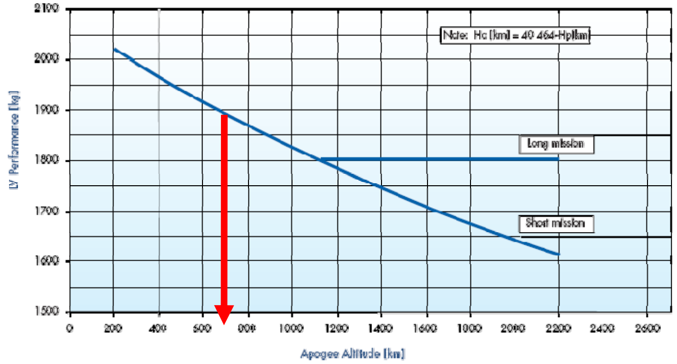
# Mission Constraints

- Launch by 2022
- Soyuz launch vehicle
  - from Kourou and/or Baikonour
- Technology Readiness level (TRL) 5 by end of Definition Phase (~ 2014)
- ESA Cost at Completion < 470 MEUR (2010)

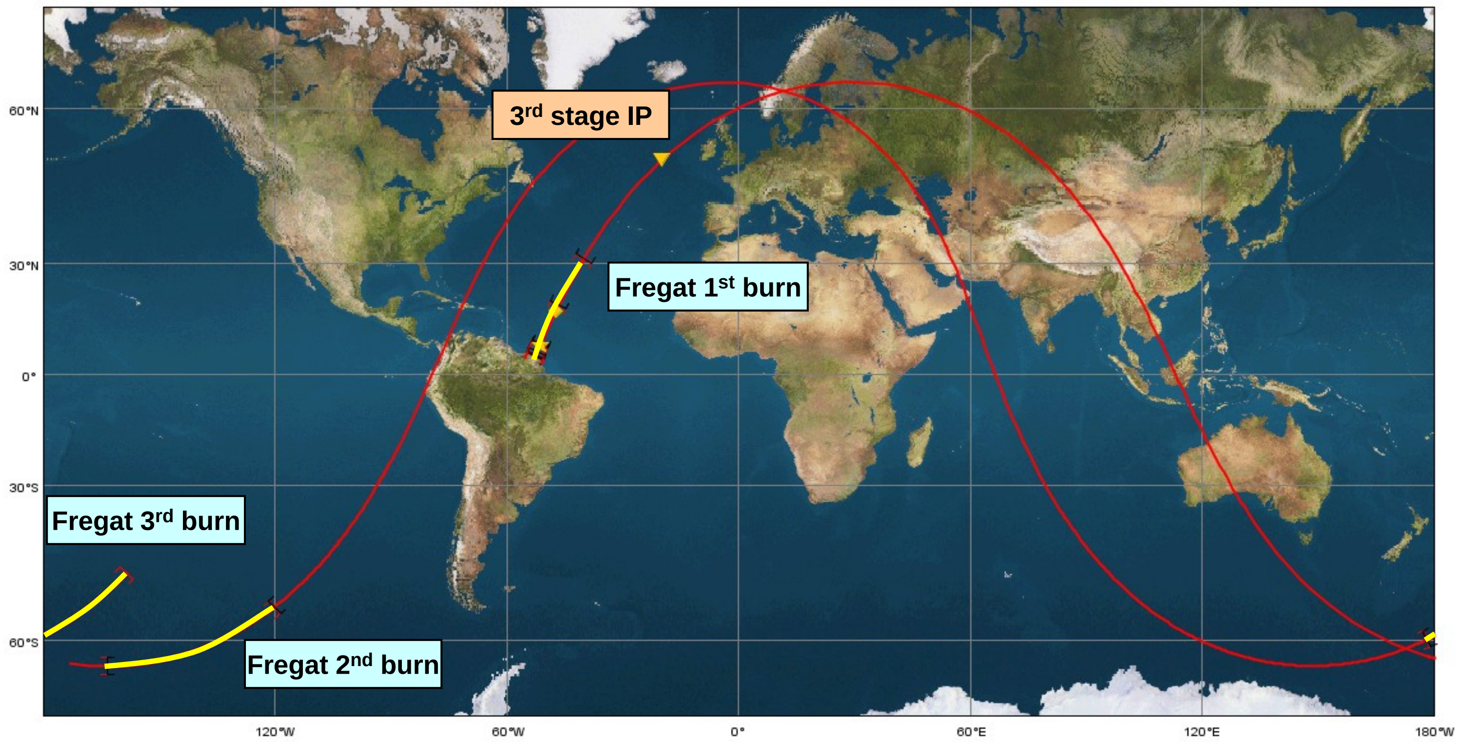
# Launch

- Baseline launch is Soyuz from CSG (Kourou)
- Soyuz performance data on this or similar missions are not reported in Arianespace User Manual (UM)
  - Soyuz UM (iss. 3, 2001) by Starsem reports data for Baikonur launches only, and for a similar mission (Molniya-type orbit, ~40000 km apogee, 63.4 deg inclination), a performance slightly lower than 1900 kg is declared
  - Reductions are expected due to the higher apogee, and safety restrictions for stages re-entry. CSG lower latitude wrt Baikonur will lead to a slight improvement.

- Soyuz baseline mission profile envisages 3 Fregat burns, for max. mission duration > 4 hrs (but evidence of at least one 6h45m flight).
- Intermediate firing may be useful to correct RAAN and perigee argument

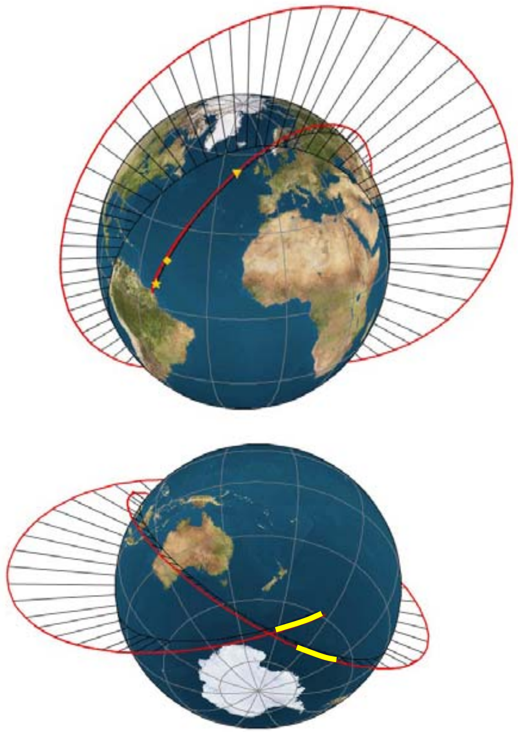


# Soyuz Launch: Ground Track



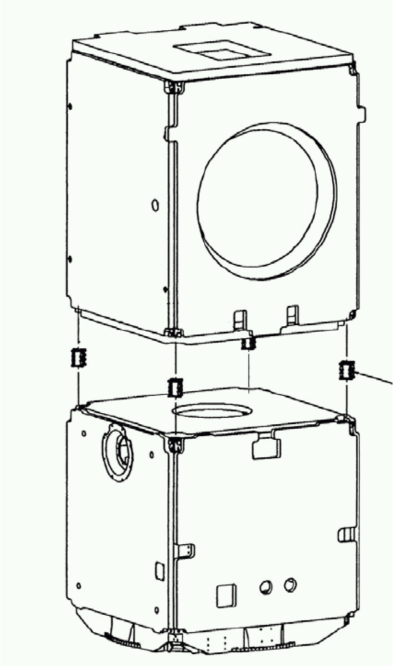
# Soyuz Launch: Launch Sequence

- Fregat 1st burn:
  - Injection into a 250 x 830 km orbit
  - 1 orbit coast arc (about 1 hr)
- Fregat 2nd burn:
  - Injection into a 690 x 8600 km orbit
  - 1 orbit coast arc (about 3 hrs)
  - Visibility TBC (McMurdo, NASA)
- Fregat 3rd burn:
  - Injection into the final 700 x 50000 km orbit
  - Visibility TBC (Awarua, NZl, used for ATV)
- Overall mission duration: 4h35m
- Payload: 1658 kg
  - -1.5% for model accuracy = 1633 kg



# Spacecraft architecture

- Architecture concept based on **modularity**:
  - S/C composed of two modules
    - Service module
    - Payload module
  - The service module may be based, if technically feasible, on existing platforms
    - Minimize development cost
  - The payload module shall be as self-contained as possible
    - Maximum commonality / re-use of ACES
    - Compatibility with several platforms
- The proposed modular architecture may involve a mass penalty compared to a more optimized desig
  - Soyuz performance should offer comfortable mass margins



# Payload: interfaces to platform

- Payload-platform interfaces based on modularity and other considerations and trade-offs
  - Comms
    - MWL only used for science
    - Additional comms link in the service module for TM/TC
  - Data handling
    - Dedicated payload computer (XPLC) and power distribution unit (PDU)
    - Additional on-board computer and power control in the service module
  - Thermal
    - Payload thermal control decoupled from service module

## Payload: MWL vs. Optical link

- The optical link offers:
  - higher link stability
- but…
  - requires new set of optical ground terminal
  - requires good atmospheric conditions (not all passes would be used for measurements ⇒ increased mission duration if only link on-board)
- **Baseline** for study: **MWL + Optical link**
  - Adding the optical link reduces the risk of not being able to meet the stringent timing stability requirement for the MWL link
  - Acceptable in terms of mass, power, cost

# Payload Module

- Main differences wrt ACES
  - MOLO instead of SHM
  - Extra shielding required against radiation
    - Increased structural mass
  - MWL
    - Primary frequency allocation required
    - Antenna design to cope with variations between perigee and apogee
      - Larger S-band HGA (deployable because of accommodation constraints)
    - Increased power required for apogee
  - Optical link (LCT)
    - Increased mass (50 kg)
    - Increased power (160 W)
    - Accommodation
- Design option
  - Fixed antennas (requires nadir pointing) preferred over steerable
    - LCT already offers hemispherical coverage

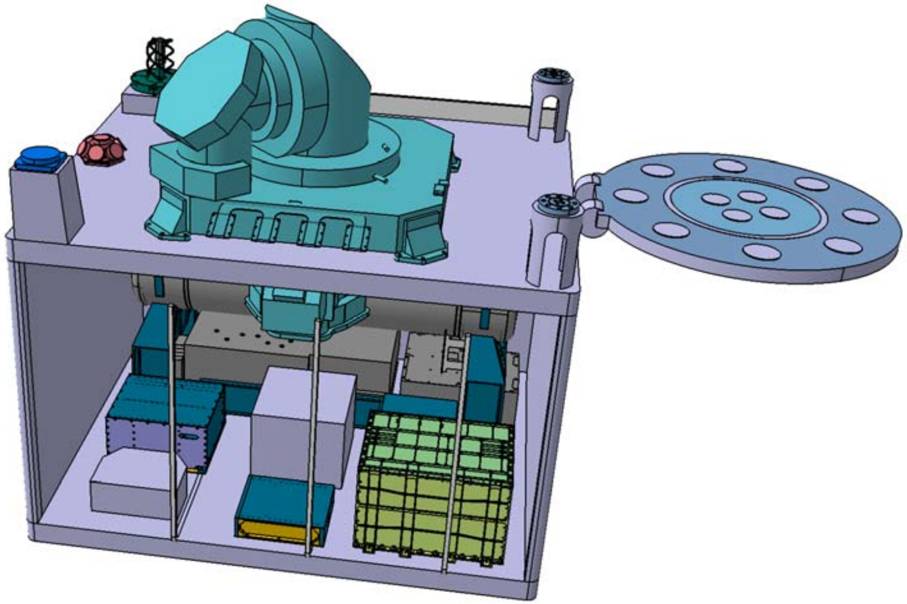
# Payload Module Mass Breakdown

| Element 1 - P/L Module | | | | | | |
|---|---|---|---|---|---|---|
| FUNCTIONAL SUBSYSTEM | nr | Mass (kg) per unit | Total Mass (kg) | Margin (%) | Margin (kg) | Mass (kg) with Margin |
| **Structure** | | | **63.59** | **20.00** | **12.72** | **76.31** |
| **Thermal Control** | | | **11.32** | **5.00** | **0.57** | **11.88** |
| **Mechanisms** | | | **0.88** | **5.00** | **0.04** | **0.92** |
| **Communications** | | | **18.00** | **20.00** | **3.60** | **21.60** |
| MWL - EU | 1 | 14.00 | 14.00 | 20.00 | 2.80 | 16.80 |
| MWL - S-Band Antenna | 1 | 3.00 | 3.00 | 20.00 | 0.60 | 3.60 |
| MWL - Ka Up-Link Antenna | 1 | 0.20 | 0.20 | 20.00 | 0.04 | 0.24 |
| MWL - Ka Up-Link Antenna | 1 | 0.20 | 0.20 | 20.00 | 0.04 | 0.24 |
| MWL- RF Cables | 3 | 0.20 | 0.60 | 20.00 | 0.12 | 0.72 |
| **Data Handling** | | | **13.58** | **10.00** | **1.36** | **14.94** |
| ICU (XPLC + PDU) | 1 | 13.58 | 13.58 | 10.00 | 1.36 | 14.94 |
| **Harness** | | | **11.51** | **10.00** | **1.15** | **12.66** |
| **Instruments** | | | **190.49** | **11.63** | **22.15** | **212.64** |
| *PHARAO* | *1* | | *91.00* | *10.00* | *9.10* | *100.10* |
| *MOLO* | *1* | | *31.00* | *20.00* | *6.20* | *37.20* |
| *FCDP* | *1* | | *8.00* | *10.00* | *0.80* | *8.80* |
| *CCR* | *1* | | *2.00* | *10.00* | *0.20* | *2.20* |
| *GNSS Unit* | *1* | | *8.49* | *10.00* | *0.85* | *9.34* |
| *LCT* | *1* | | *50.00* | *10.00* | *5.00* | *55.00* |

# Payload Module Mass Budget

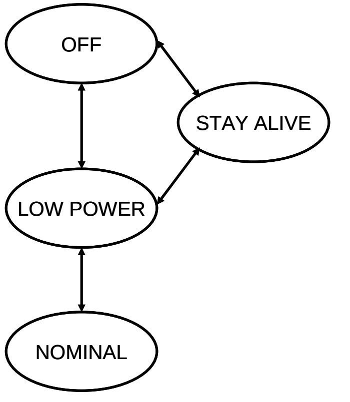
| P/L Module | | | | | | |
|---|---|---|---|---|---|---|
| | Without Margin | | Margin | | Total | % of Total |
| Dry mass contributions | | | % | kg | kg | |
| **Structure** | **63.59** | **kg** | **20.00** | 12.72 | **76.31** | 21.74 |
| **Thermal Control** | **11.32** | **kg** | **5.00** | 0.57 | **11.88** | 3.39 |
| **Mechanisms** | **0.88** | **kg** | **5.00** | 0.04 | **0.92** | 0.26 |
| **Communications** | **18.00** | **kg** | **20.00** | 3.60 | **21.60** | 6.15 |
| **Data Handling** | **13.58** | **kg** | **10.00** | 1.36 | **14.94** | 4.26 |
| **Harness** | **11.51** | **kg** | **10.00** | 1.15 | **12.66** | 3.61 |
| **Instruments** | **190.49** | **kg** | **11.63** | 22.15 | **212.64** | 60.59 |
| **Total Dry(excl.adapter)** | **309.37** | | | | **350.96** | **kg** |
| **System margin (excl.adapter)** | | | **20.00** | **%** | **70.19** | **kg** |
| **Total Dry with margin (excl.adapter)** | | | | | **421.15** | **kg** |

# Payload Module Configuration



# Payload power modes

- OFF:
  - All instruments and S/S of the STE P/L are powered OFF
- STAY ALIVE:
  - PHARAO ion pumps are powered to preserve vacuum conditions in the PHARAO tube
  - MOLO requires also stay alive power
- LOW POWER:
  - Thermal controls of all STE instruments & S/S requiring good thermal stabilities and long settling times (e.g. PHARAO, MOLO, on-board USO) are powered **on**
  - On-board computers (XPLC, instruments and subsystems specific computers) are powered **on** and deliver telemetry, in particular for temperature monitoring at the reference points
- NOMINAL:
  - All STE instruments and S/S are powered on and active. They can receive telecommands and transmit telemetry



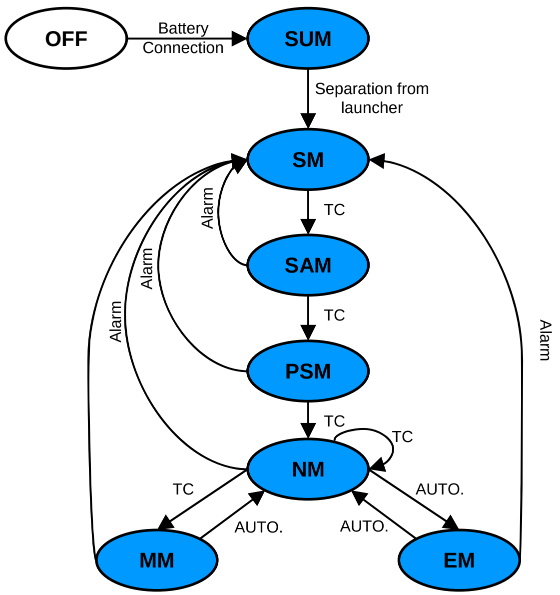
# Payload Module Power Budget

| Item | Nominal Mode [W] | Safe Mode [W] |
|---|---|---|
| PHARAO | 113.5 | 2.5 |
| MOLO | 60 | 2 |
| FCDP | 8.4 | 0 |
| MWL | 71.5 | 0 |
| LCT | 160 | 0 |
| GNSS | 7 | 0 |
| CCR | 2 | 0 |
| ICU | 175 | 3.5 |
| **TOTAL** | 597.4 | 8.0 |

# Spacecraft operational modes

| Mode Name | PHARAO | MOLO | FCDP | MWL | LCT | Rest of P/L | AOCS | Thermal | Power | DHS | Comms | Acronym |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Start-up** | Stay Alive | Stay Alive | OFF | OFF | OFF | OFF | OFF | OFF | ON | ON | RX On Tx OFF | SUM |
| **Safe** | Stay Alive | Stay Alive | OFF | OFF | OFF | OFF | ON | ON | ON | ON | RX On Tx OFF | SM |
| **Star-acquisition** | Stay Alive | Stay Alive | OFF | OFF | OFF | OFF | ON | ON | ON | ON | RX On Tx OFF | SAM |
| **Payload start-up** | Low power | Low power | ON | ON | ON | ON | ON | ON | ON | ON | RX On Tx On | PSM |
| **Nominal** | ON | ON | ON | ON | ON | ON | ON | ON | ON | ON | RX On Tx On | NM |
| **Manoeuvre** | Low power | Low power | OFF | OFF | OFF | ON | ON | ON | ON | ON | RX On Tx OFF | MM |
| **Eclipse** | ON | ON | ON | OFF | OFF | ON | ON | ON | ON | ON | RX On Tx OFF | EM |

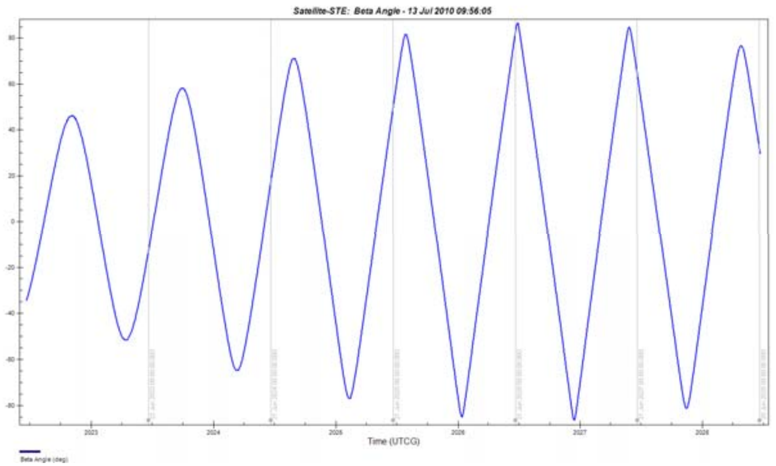
# Spacecraft operational modes




- Manoeuvre mode (MM) is engaged for the orbit correction manoeuvres (once/twice a year)
- Eclipse mode (EM) is engaged once per orbit during the apogee eclipse season (2 weeks a year) for 3 hours

# Considerations on orbit geometry

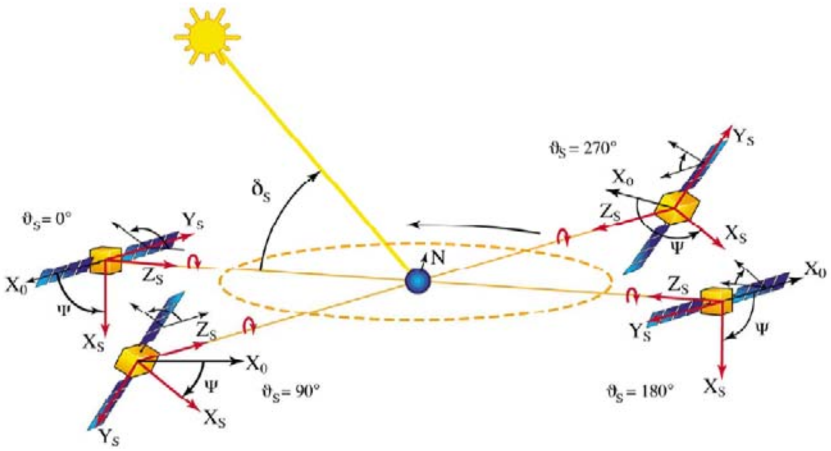
- Beta angle (angle between the sun direction and the orbital plane)
  - Minimum yearly variation for STE reference orbit:
    [-(orbit inclination - obliquity) : +(orbit inclination - obliquity)] = [-40 : 40 deg]
  - Maximum yearly variation  for STE reference orbit:
    [-(orbit inclination + obliquity) : +(orbit inclination + obliquity)] = [-87 : 87 deg]
  - Exact beta angle evolution will depend on initial RAAN and launch date, but with the precession of the orbital plane, the maximum yearly variation will be encountered during mission lifetime

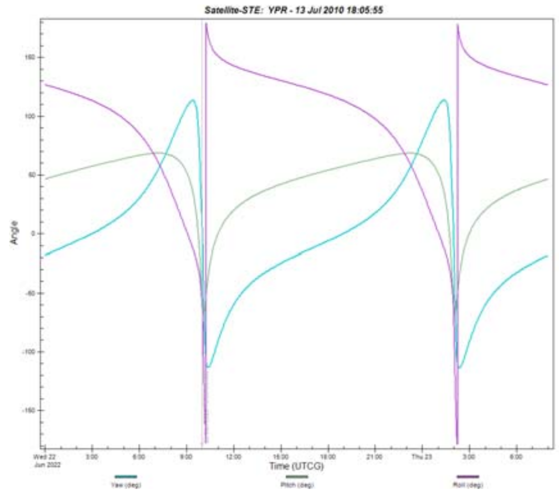


# Spacecraft Solar Arrays & Attitude

- Body mounted vs. deployable & rotating SA
  - Body-mounted SA discarded due to the much larger surface required (large beta-angle variations)
  - Deployable & rotating SA selected after checking that the microvibrations generated by the SADM are within the required level
- Attitude
  - Nadir-pointing, yaw-steering (optimal for power and thermal reasons)

# Yaw-steering




- The goal of having PHARAO oriented perpendicular to the orbital plane cannot be achieved
  - Potentially, when the beta angle is low (~ < 20 deg), we could fly with the solar arrays perpendicular to the orbital plane (no yaw steering)
    - only for few months per year
    - It would complicate the thermal design

# Mission Duration

- Scientific requirements (in particular, minimum total contact time at perigee) lead to long mission durations (around 10 years)
- However
  - Delta-V for orbit maintenance (20 m/s per year) and attitude control increase with mission duration $\Rightarrow$ this translates into increased spacecraft mass and cost
  - Operations cost also increase with mission duration
- Mission duration was assumed to be 5 years

# Service Module (1)

- Potential use of existing platform

| Platform | | PRIMA | PROTEUS | Flexbus | Leostar | MiniSAT | Giove A | Giove B |
|---|---|---|---|---|---|---|---|---|
| Manufacturer | | Alcatel Alenia Space | Alcatel Alenia Space | US | Orbital | SSTL | SSTL | Thales Alenia Space |
| Orbits | | LEO and MEO (GEO and GTO also possible) | LEO (from SSO to almost equatorial) | MEO, HEO | LEO: 450 to 1,000 km altitude, 28° to 110° inclination | | | |
| | Altitude | From 450 km to 1600 km (typically) | from 500 to 1500 km | | | | | |
| | Inclination | From 0° to 100° | from 20 to 145 deg | | | | | |
| Mass | Wet Mass | 400 to 1500 Kg | Up to 670 kg | 150 kg and 1000 kg ~ 500 kg (dependent on selected launcher) | 225 to 1000 kg | ~600kg | 600 kg at launch | 530 kg |
| | P/L mass | Up to 700, 800 Kg | Up to 360 kg | | 210 kg -up to 550 kg | <~200kg | | |
| Power | Bus | 28 V unregulated | 28 V unregulated | ~ 600 W (avg.) - ~ 3 kW (peak) (dependent on selected launcher) | 118 W orbit average (Standard), Up to 2 kW (Optional) | unregulated 28V bus | 700-900W | 700-900W |
| | P/L | from 250 to 800W | 300W avg. | | | 250W arrays & battery; 175W arrays only | | 1100 W via 2 Sun-tracking arrays each 4.34 m long |
| | Solar Cells | GaAs (two deployable rotating wings) | Silicon (two symmetric rotating wing arrays) | | | Nine body mounted GaAs cell panels @~60W each (72W option) | 700 W via 2 Sun-tracking arrays (SMART-1 design reused) each 4.54 m long | |
| | Battery | NiH2 | Li Ion, 78Ah | | | 22 cell 7Ah NiCd battery (x3): 21Ah total capacity@28V | | |
| Propulsion | | Hydrazine monopropellant | Hydrazine monopropellant | monopropellant, gas propulsion reaction | Blowdown monopropellant | Reaction Wheels (x4), Torque coils (x13) | | Hydrazine system with single tank of 28 kg |
| | | 4*1N thruster | 4*1N thruster | | | | | |
| | Propellant mass | 78 kg | 28 kg | | up to 140 kg propellant (Optional) | | | |
| Lifetime | | 5 years | 3 to 5 years depending on the orbit | 5 years | Up to 10 years with fully redundant avionics | Mission dependent - UoSAT buses have operated for over 10yrs | Estimated 2.5 years | Estimated 2.5 years |
| Heritage | | Cosmo-Skymed<br>Radarsat-2<br>Sentinel-1 | SMOS<br>Jason 2<br>Corot<br>Calipso-Cena<br>Megha-Tropiques | Cryosat<br>GRACE<br>TerraSAR | OCO (NASA)<br>Dawn (NASA) | RadidEye | | |

# Service Module (2)

- In particular, the potential use of a PROTEUS-like platform was investigated in detail
  - Platform for low-Earth orbit observation satellites in the range 500-700 kg
  - Preliminary payload mass and power estimations showed that this type of platform may fit STE needs

| SATELLITE | JASON1 | CALIPSO | COROT | SMOS | JASON2 |
|---|---|---|---|---|---|
| Mission | Ocean Altimetry: Nadir Altimeter | Atmosphere (clouds, aerosols): LIDAR | Astronomy (astero-sismology, exo-planets) | Soils Moisture Oceans Salinity: L Band radiometer | Ocean Altimetry: Nadir Altimeter + Wide Swath |
| Launch | Dec 2001 | July 2005 | July 2006 | Sept. 2007 | June 2008 |
| Launcher | DELTA 2 dual launch configuration | | SOYUZ | ROCKOT | DELTA 2 |
| Cooperation | NASA/JPL | NASA/LaRC | ESA, Austria, Spain,Belgium, Brazil | ESA leadership | NASA/JPL |
| Orbit/ Pointing | 1336/1336/66°, drifting pointing : +Z nadir yaw steering | 705/705/SSO 13h30 pointing : +X Nadir | 896/896/90° (polar) pointing : inertial, orbit normal | 756/SSO 6h pointing : +X nadir, 30° canted | 1336/1336/66°, drifting pointing : +Z nadir yaw steering |
| S/L mass PL mass | 485 Kg 175 Kg | 580kg 270kg | 610 Kg 300 Kg | 670 Kg 360 Kg | 600 Kg 290 Kg |
| S/L power PL power | 420 W 165 W | 560 W 282 W | 450 W 150 W | 630 W 350 W | 580 W 300 W |

# Service Module (3)

- Main differences wrt a PROTEUS-like platform due to STE orbit, payload
  - High apogee altitude prevents the use of magneto-torquers bars for wheel desaturation or safe mode around apogee
    - Need for attitude thrusters
  - High Delta-V required for orbit maintenance
    - Need for larger tanks ⇒ larger dimensions of service module
  - Higher radiation dose compared to LEO
    - Extra shielding required for equipment not to compromise lifetime
  - Longer eclipses around apogee compared to LEO
    - Check battery
  - Need for active thermal control of the payload during safe mode

# Service Module Mass Breakdown

**Element 2 - Service Module**

| FUNCTIONAL SUBSYSTEM | nr | Mass (kg) per unit | Total Mass (kg) | Margin (%) | Margin (kg) | Mass (kg) with Margin |
|---|---|---|---|---|---|---|
| **Structure** | | | **121.23** | **13.78** | **16.70** | **137.93** |
| **Thermal Control** | | | **0.00** | **-** | **0.00** | **0.00** |
| **Mechanisms** | | | **12.00** | **5.00** | **0.60** | **12.60** |
| **Communications** | | | **7.64** | **5.59** | **0.43** | **8.07** |
| TT&C Unit S-Band | 2 | 3.50 | 7.00 | 5.00 | 0.35 | 7.35 |
| LGA-Nadir | 1 | 0.10 | 0.10 | 5.00 | 0.01 | 0.11 |
| LGA-Zenith | 1 | 0.24 | 0.24 | 5.00 | 0.01 | 0.25 |
| Harness | 2 | 0.15 | 0.30 | 20.00 | 0.06 | 0.36 |
| **Data Handling** | | | **7.70** | **10.00** | **0.77** | **8.47** |
| **AOCS** | | | **41.09** | **5.88** | **2.42** | **43.51** |
| Coarse Gyrometer - SELEX CRS | 2 | 0.80 | 1.60 | 5.00 | 0.08 | 1.68 |
| Star Tracker Optical Head - Sodern Hydra | 3 | 1.25 | 3.75 | 10.00 | 0.38 | 4.13 |
| Star Tracker Electrical Unit - Sodern Hydra | 2 | 1.75 | 3.50 | 10.00 | 0.35 | 3.85 |
| Sun Sensor - TNO TPD | 8 | 0.03 | 0.24 | 5.00 | 0.01 | 0.25 |
| Reaction Wheel - Rockwell Collins | 4 | 8.00 | 32.00 | 5.00 | 1.60 | 33.60 |
| **Propulsion** | | | **16.71** | **10.20** | **1.70** | **18.41** |
| Service Valves | 4 | 0.08 | 0.32 | 5.00 | 0.02 | 0.34 |
| Propellant Tank | 1 | 8.20 | 8.20 | 10.00 | 0.82 | 9.02 |
| Pressure Transducer | 4 | 0.30 | 1.20 | 5.00 | 0.06 | 1.26 |
| Propellant Filters | 1 | 0.08 | 0.08 | 5.00 | 0.00 | 0.08 |
| Latch Valve | 2 | 0.36 | 0.72 | 5.00 | 0.04 | 0.76 |
| Thrusters (1N) | 4 | 0.78 | 3.13 | 5.00 | 0.16 | 3.29 |
| Piping | 25 | 0.03 | 0.79 | 20.00 | 0.16 | 0.95 |
| Bracketing | 1 | 1.52 | 1.52 | 20.00 | 0.30 | 1.82 |
| N2 gas | 1 | 0.75 | 0.75 | 20.00 | 0.15 | 0.90 |
| **Power** | | | **72.10** | **9.69** | **6.99** | **79.09** |
| PCE or PCU | 1 | 6.10 | 6.10 | 10.00 | 0.61 | 6.71 |
| Battery | 1 | 37.50 | 37.50 | 10.00 | 3.75 | 41.25 |
| BEU (on side of battery) | 1 | 4.50 | 4.50 | 5.00 | 0.23 | 4.73 |
| UMB IF/BAT SW (replace DBox) | 1 | 2.00 | 2.00 | 10.00 | 0.20 | 2.20 |
| Solar Array (wing) | 2 | 11.00 | 22.00 | 10.00 | 2.20 | 24.20 |
| **Harness** | | | **29.91** | **20.00** | **5.98** | **35.89** |
| **Propellant** | | | | | | **61.13** |

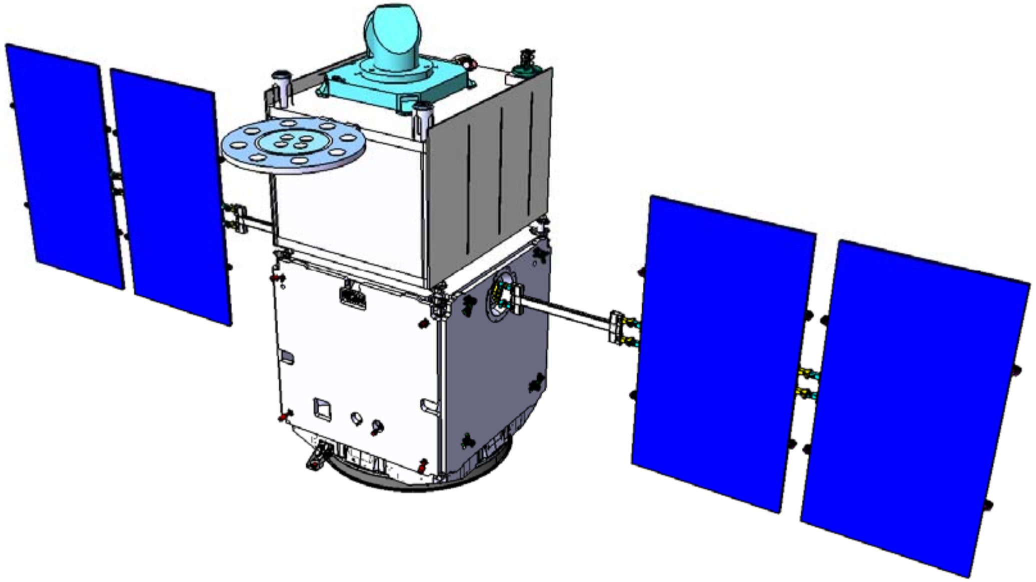
# Service Module Mass Budget

| Service Module | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Without Margin | | Margin | | Total | % of Total |
| | Dry mass contributions | | | % | kg | kg | |
| **Structure** | | **121.23** | **kg** | **13.78** | 16.70 | **137.93** | 40.10 |
| **Thermal Control** | | **0.00** | **kg** | **-** | - | **-** | - |
| **Mechanisms** | | **12.00** | **kg** | **5.00** | 0.60 | **12.60** | 3.66 |
| **Communications** | | **7.64** | **kg** | **5.59** | 0.43 | **8.07** | 2.35 |
| **Data Handling** | | **7.70** | **kg** | **10.00** | 0.77 | **8.47** | 2.46 |
| **AOCS** | | **41.09** | **kg** | **5.88** | 2.42 | **43.51** | 12.65 |
| **Propulsion** | | **16.71** | **kg** | **10.20** | 1.70 | **18.41** | 5.35 |
| **Power** | | **72.10** | **kg** | **9.69** | 6.99 | **79.09** | 22.99 |
| **Harness** | | **29.91** | **kg** | **20.00** | 5.98 | **35.89** | 10.43 |
| **Total Dry(excl.adapter)** | | **308.38** | | | | **343.97** | **kg** |
| **System margin (excl.adapter)** | | | | **20.00** | **%** | **68.79** | **kg** |
| **Total Dry with margin (excl.adapter)** | | | | | | **412.76** | **kg** |
| | Other contributions | | | | | | |
| | Wet mass contributions | | | | | | |
| **Propellant** | | **61.13** | **kg** | **N.A.** | **N.A.** | **61.13** | 12.90 |
| | **Adapter mass (including sep. mech.), kg** | **110.00** | **kg** | **0.00** | 0.00 | **110.00** | 0.19 |
| **Total wet mass (excl.adapter)** | | | | | | **473.89** | **kg** |

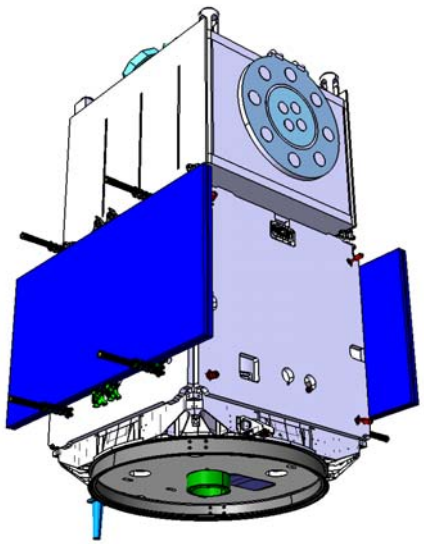
# Mass Budget

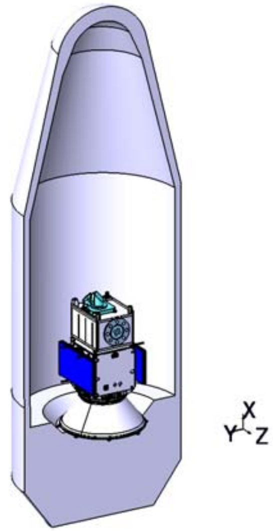
| Spacecraft | | |
|---|---|---|
| Total Dry (no system margins) | 694.93 | kg |
| Total Dry (system margins) | 833.91 | kg |
| Total Wet (excluding adapter) | 895.04 | kg |
| Launch mass (including adapter) | 1005.04 | kg |
| | | |
| Target spacecraft mass at launch | 1633.00 | kg |
| Below Mass Target by: | 627.96 | kg |

# Spacecraft configuration (1)



# Spacecraft configuration (2)





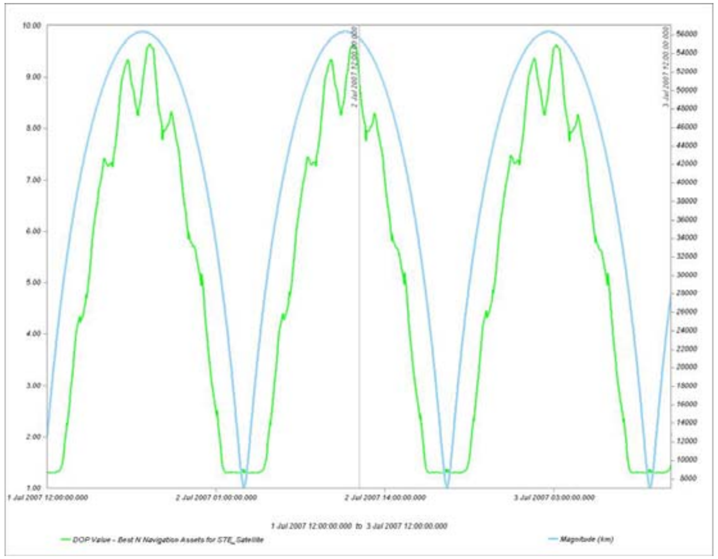
# Orbit Determination

- The required orbit determination accuracy is to be achieved in post-processing through the combination of the following type of measurements
  - Radiometric tracking of the spacecraft through the S-band transponder
  - On-board GNSS receiver
  - Laser ranging using the CCR
  - Ranging from microwave and optical links
- A dedicated study is further required to estimate precisely the orbit determination accuracy achievable
  - Preliminary analyses indicate that it shall be possible to reach the required accuracy

# Orbit Determination: GNSS

- Estimation of orbit determination error for STE orbit using on-board GNSS
  - Galileo and NAVSTAR ephemeris inaccuracy: 7 m (after 8 hours)
  - On-board GPS clock error: 1.5 m
  - Earth ionosphere: 0.5 m
  - NAVSTAR Selective Availability
    - Off: 0 m
    - On: 100 m
  - Grand total: 10 m (SA is nowadays off)

- Improvement over time
  - 8 hours of on-board OD produce accuracy of 10 m
  - 24 hours of OD reduces the error to 7 m
  - 48 hours of OD reduces the error to 2 m



# Space Time Explorer

*Payload*


Final Presentation

ESTEC, 16 July 2010

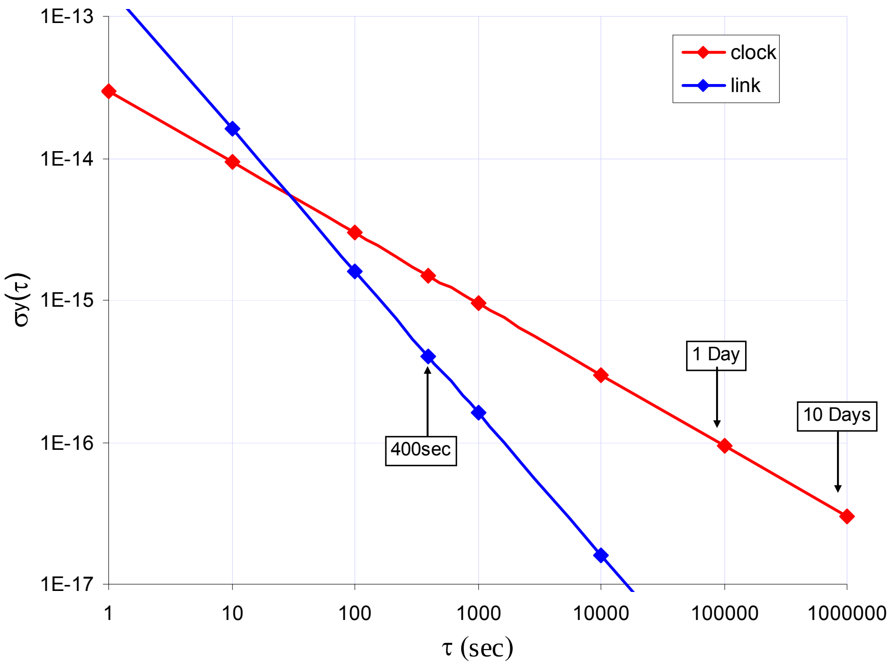
Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Outline

- Payload Requirements
- Payload Baseline Design and Interfaces
- Payload Equipments
  – RF: PHARAO, FCDP, GNSS Rx, MWL
  – Optical: MOLO, LCT, CCR
  – Data Handling: XPLC/ICU

# STE PL Requirements




Performance Requirements:

Clock Stability*: $\sigma_y(\tau) \leq 3\text{x}10^{-14}\ \tau^{-1/2}$

Link Accuracy*: $\sigma_y(\tau) \leq 1.6\text{x}10^{-13}\ \tau^{-1}$
(including ground segment)

* derived from Mission Requirements (STE_Requirements_v0.xls)

# STE PL Requirements

<u>Environmental Requirements:</u>

| | |
|---|---|
| Temperature*: +10°C to +30°C | (driven by PHARAO) |
| Temperature Stability*: ≤ ± 2°C over 1 orbit | (driven by PHARAO) |
| DC Magnetic Field: ≤ 1G | (driven by PHARAO) |
| Magnetic Field Variation: < 140dBpT in [100mHz, 1Hz] | (driven by PHARAO) |
| Acceleration*: ≤ 1 μg | (driven by MOLO) |
| Micro-vibration*: ≤ 8 μg $Hz^{-1/2}$ in [2mHz, 10Hz] | (driven by MOLO) |
| Radiation: ≥ 30krad | (driven by orbit) |

* derived from Mission Requirements (STE_Requirements_v0.xls)

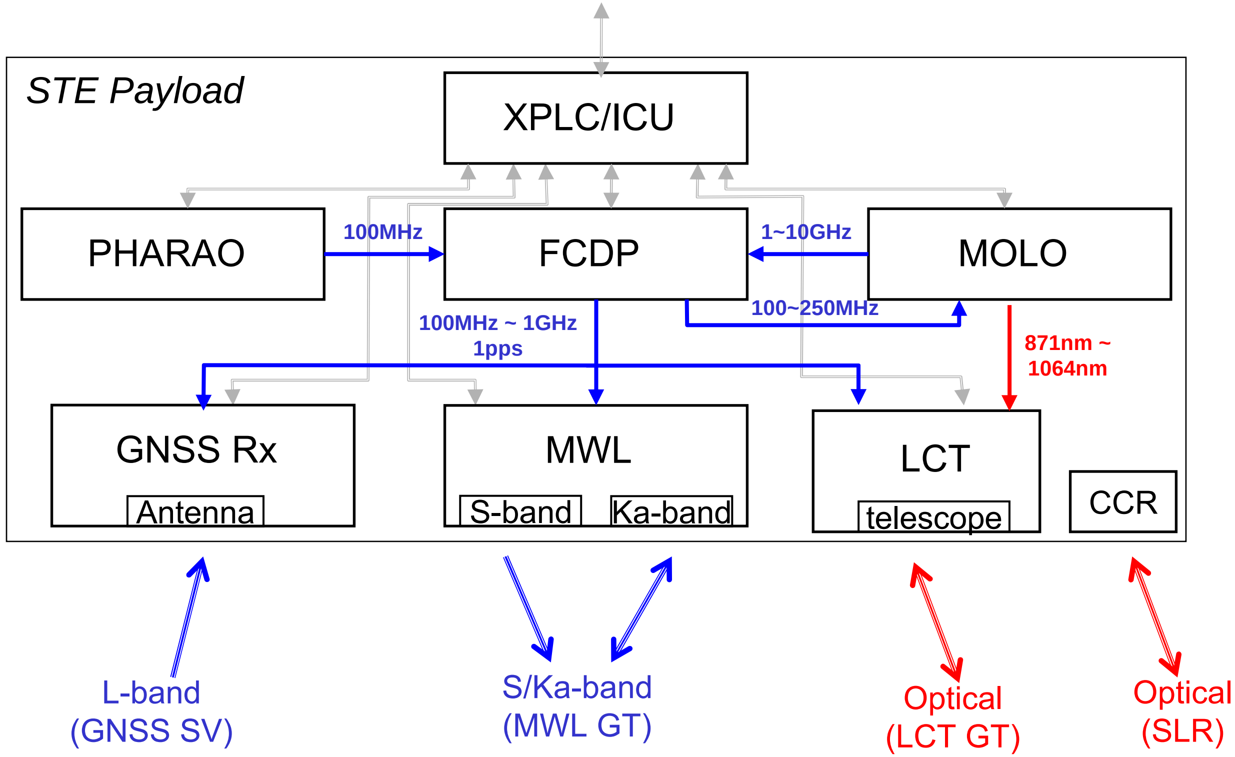
# STE PL Requirements

Operational Requirements:

Lifetime*: ≥ 5 years

* derived from Mission Requirements (STE_Requirements_v0.xls)

# STE PL Design & Interface



# STE PL Description

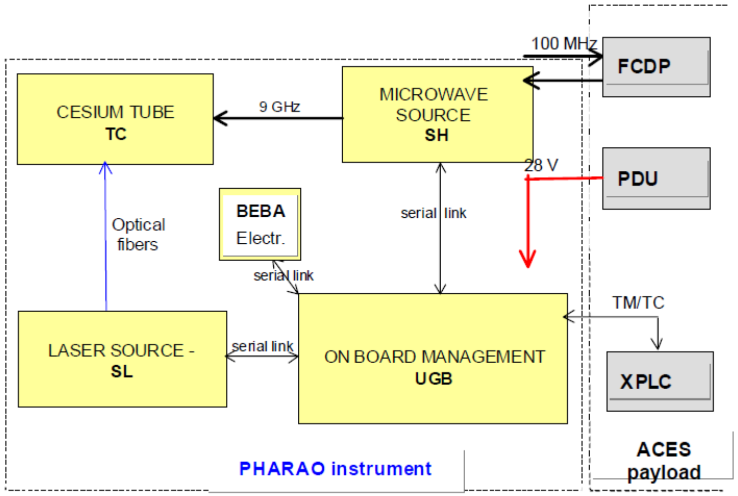
Clock Signal Generation:
MOLO: Microwave and Optical Local Oscillator
PHARAO: Ultra-Stable Cold-Atom Caesium Clock
FCDP: On-board Frequency Comparison and Distribution

Clock Signal Transmission:
MWL: Two-Way Dual Frequency (S/Ka) Microwave T&F Transfer Link
LCT: Two-Way Optical T&F Transfer Link

Orbit and Clock Control:
GNSS Rx: On-board GNSS timing receiver and antenna
CCR: Passive Corner Cube (SLR) Reflector
XPLC/ICU: On-board Computer and Power Distribution

# PHARAO

source: ACES Design Report - ACE-RP-10000-002-AST iss.10, 31-Jul-2009




| item | mass | power |
|---|---|---|
| TC | 46 | 6 |
| SL | 23 | 46 |
| SH | 7 | 26 |
| UGB | 7 | 31 |
| BEBA | 1.5 | 4 |
| Harness | 4 | - |
| Mounting | 2.6 | - |
| Elec. Bracket | 1 | - |
| **TOTAL:** | **92.1** | **113W** |

# PHARAO

Delta wrt ACES:

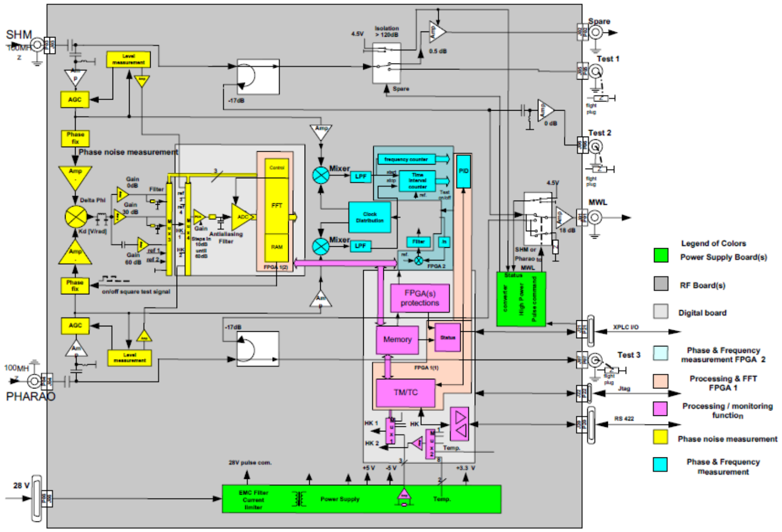
- Performance: factor 5 better (thanks to MOLO)
- Lifetime and reliability (1.5y vs. 5+y)
- Radiation (LEO vs HEO)
- Technology obsolescence and evolution (e.g. Laser Diodes, electronics…)

Technology Assessment:

- Performance demonstrated by extrapolation
- No critical technology, provided obsolescence and radiation are carefully investigated
- Estimated current TRL: 5

# FCDP

source: ACES Design Report - ACE-RP-10000-002-AST iss.10, 31-Jul-2009




| item | mass | power |
|---|---|---|
| FCDP | 4kg | 9W |

# FCDP

Delta wrt ACES:

- Phase detector resolution, Phase/Frequency tracking: factor 5 improvement
- MOLO signal down-conversion (or PHARAO signal up-conversion)
- Output Frequency to MWL and MOLO (100MHz → 1~10GHz)
- Lifetime and reliability (1.5y vs. 5+y)
- Radiation (LEO vs HEO)
- Technology obsolescence and evolution

Technology Assessment:

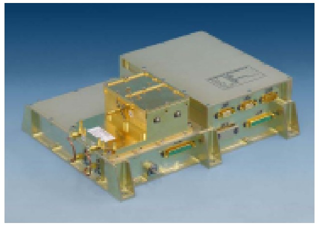
- Availability of space-qualified high-resolution phase detector to be confirmed
- No critical technology, provided obsolescence and radiation are carefully investigated
- Estimated current TRL: 5

# GNSS Rx

Two potential candidates, with guaranteed performance in GEO

**RUAG Space** RUAG

*GPS Precise Orbit Determination*



ThalesAlenia Space

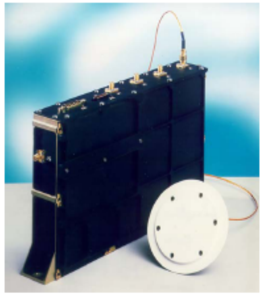
**Single or Dual Band GPS Navigation Unit**

**Applications**

- Navigation for satellite
- Relative navigation for RDV in orbital structure
- Hybrid navigation for launcher
- Precise L1 or L1&L2CS code/carrier data available on-ground for post-processing

**Main features**

- L1/L1 or L1/L2CS capability
- L1 C/A direct code acquisition on L1-band
- L2CS direct code acquisition on L2-band (civil service)
- 12 channels processed in parallel in



| item | mass | power |
|---|---|---|
| Receiver | 2.8kg | 8.5W |
| Antenna | 0.8kg | - |

| item | mass | power |
|---|---|---|
| Receiver | 1.2kg | 10.5W |
| Antenna | 0.8kg | - |

source: datasheets

# GNSS Rx

Delta wrt COTS:

- Performance in HEO vs. GEO
- GPS L1/L2 vs. GPS + Galileo
- Radiation (GEO (20krad) vs HEO)

Technology Assessment:

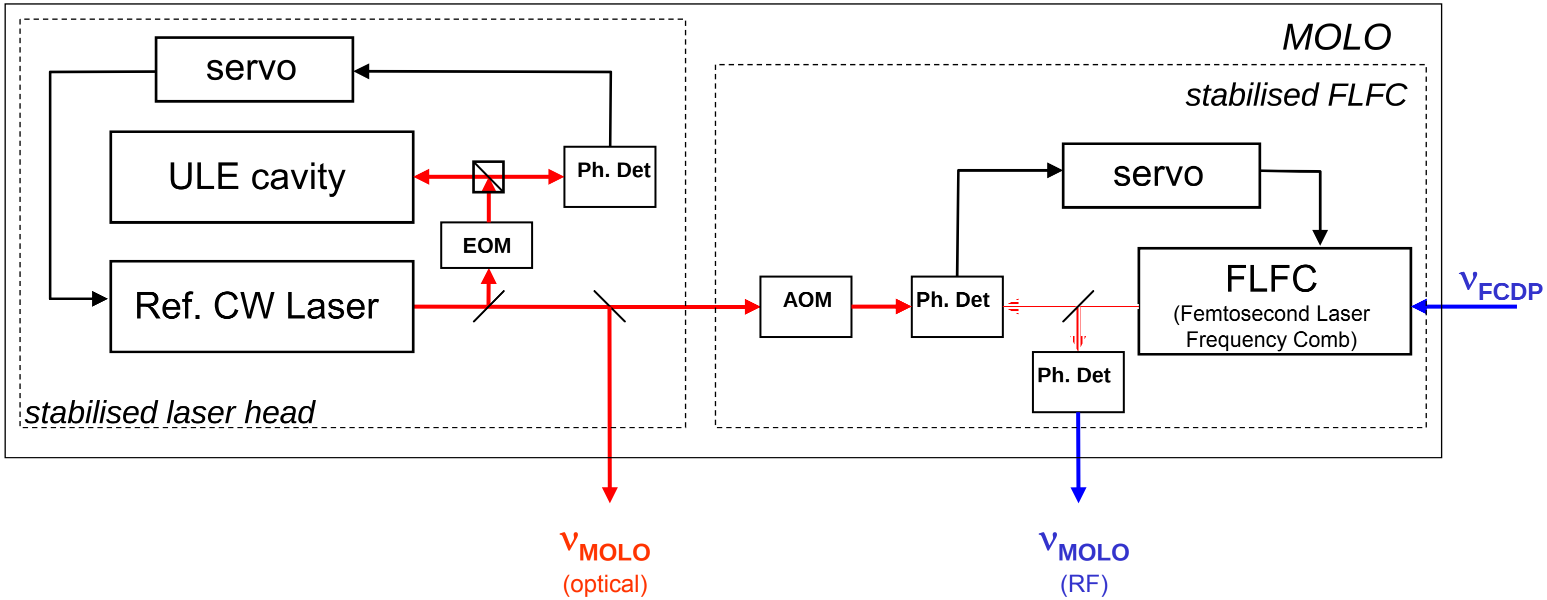
- Performance not demonstrated in HEO
- Potential benefit of Galileo not demonstrated yet
- No critical technology, provided radiation issues are carefully investigated
- Estimated current TRL: 8 (GPS), 5 (GPS + Galileo)

# MWL

(cf. presentation P.Concari)

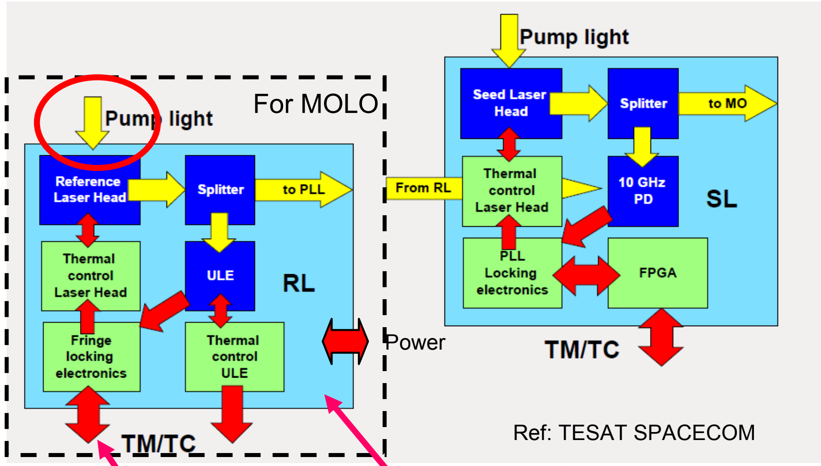
# MOLO

Preliminary Block Diagram: (cf. presentation Z.Sodnik)



# MOLO

- Optical frequency reference – (Aoelus ALADDIN Reference Laser Head (RLH)




Unit electronics interface

Use only RL for comb input

- Complete package SL and RL space qualified

- MenloSystems Optical Frequency synthesier - (Ddevelop needed + space qualification)

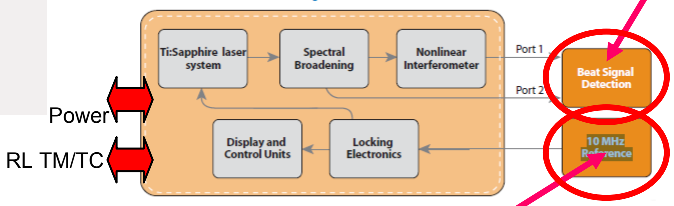
Ref: MenloSystems

| TECHNICAL SPECIFICATIONS | |
|---|---|
| Comb Frequency Spacing | 200 MHz |
| Accessible Optical Range | Output Port 1: 630-850 nm<br>Output Port 2: 532, 1064 nm |
| Accuracy | $10^{-14}$ or same as reference, whichever applies first. |
| Stability | $5 \times 10^{-13}$ in 1 sec. or same as reference, whichever applies first |
| Dimensions | Optical Unit: 850 (l) x 650 (w) x 200 (h) mm<br>Electronic Unit: 600 (l) x 600 (w) x 1600 (h) mm |
| Input Requirements | 10 MHz Reference, Power Level +7 dBm |
| Optional | · BDU 08 Laser Beat Detection Unit<br>all optics and electronics for beat detection with external laser<br>· GPS 6-12 Frequency Standard<br>GPS based 10 MHz frequency reference, accuracy in 1 s: $5 \times 10^{-12}$ |

*Note:* When beating the comb with an SM-diode laser (output > 2 mW) or any other comparable optical signal an SNR of > 30 dB in 100 kHz bandwidth will be achieved

**Schematic Setup**

GHz clock signal




Note: Ref is the cavity stabilised laser

# MOLO

MOLO criticality assessment:

- Reference Laser stability performance
  - Improved Cavity Finesse
  - Thermal sensitivity
  - Micro-vibration sensitivity
  - Radiation sensitivity (50krad demonstrated for Aladin-RLH)

# LCT

(cf. presentation Z.Sodnik)

CRR

(cf. presentation Z.Sodnik)

# Space Time Explorer


*Instruments 2*

Session 8 IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Frequency comb

- TRL 4
  - Validated in laboratory environment
  - Radiation and thermal cycling done on fiber laser
  - Tests not fully successful: variation in 1st spectral line/ gap between spectral lines
- FEA to be performed on Freq.comb to evaluate space environment
- Manufacture model and test in space environment (thermal, vibrations, shocks …)

# Laser cavity

- TRL 4
  - Validated in laboratory environment
- FEA currently running on Laser cavity to evaluate space environment (to be completed in Sept.2010)
- Manufacture model and test in space environment (thermal, vibrations, shocks …)

# Space Time Explorer

*Optical Link Payload*

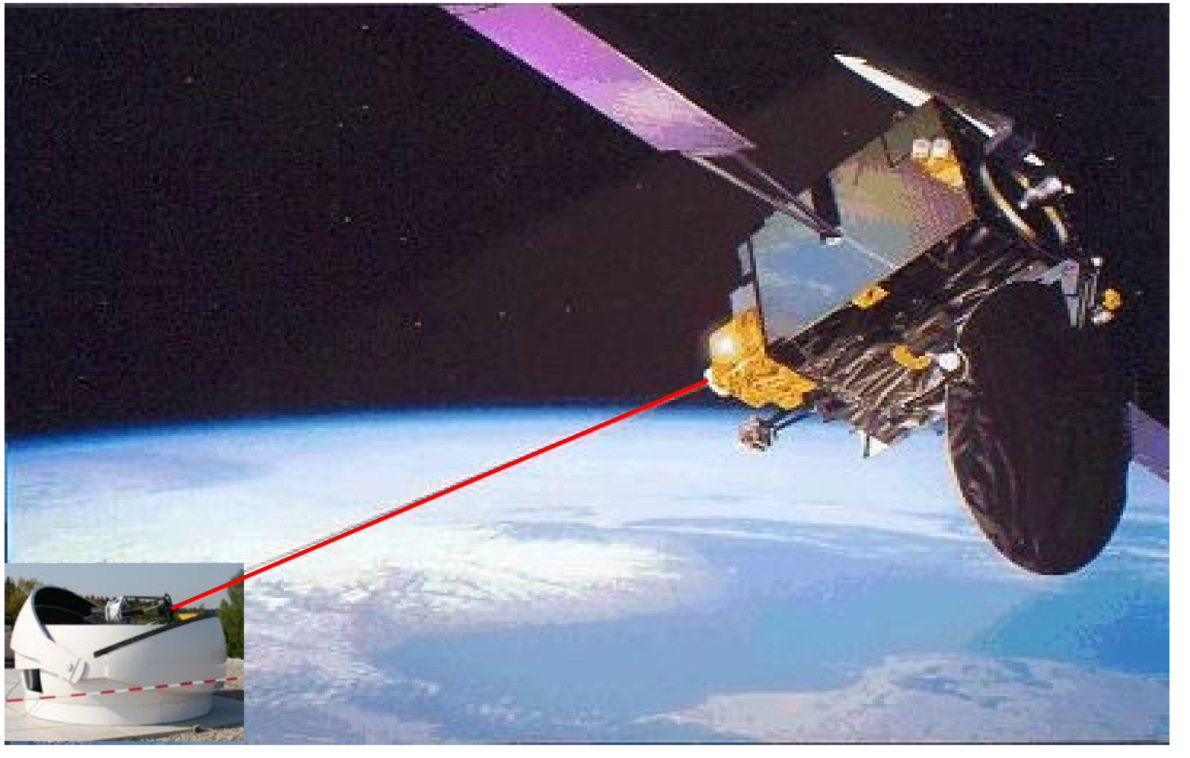

Final Presentation

ESTEC, 16th, July 2010

Prepared by the STE / CDF* Team

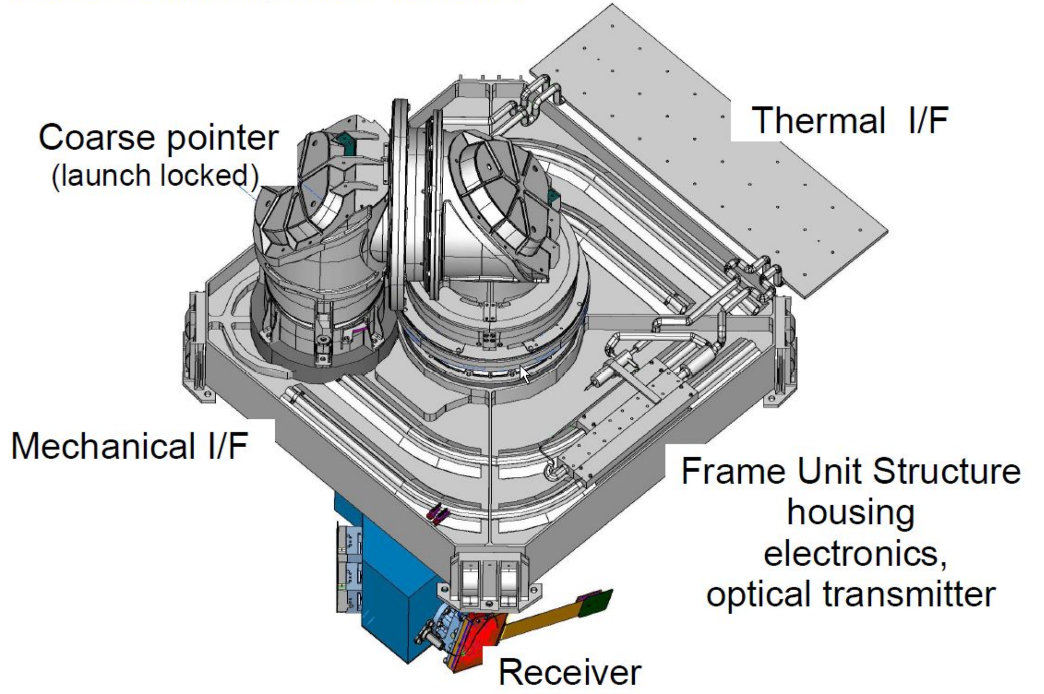
(*) ESTEC Concurrent Design Facility

# Optical Link Geometry

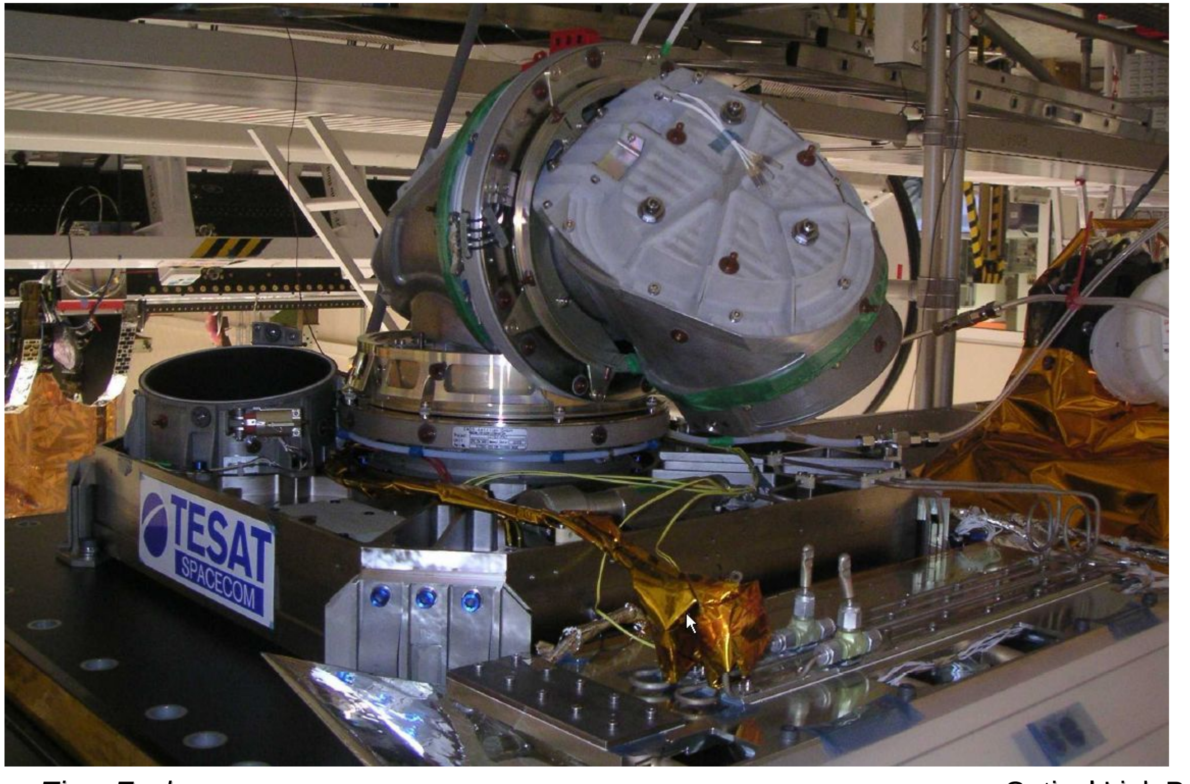


# Optical Link Space Terminal

## Laser Communication Terminal

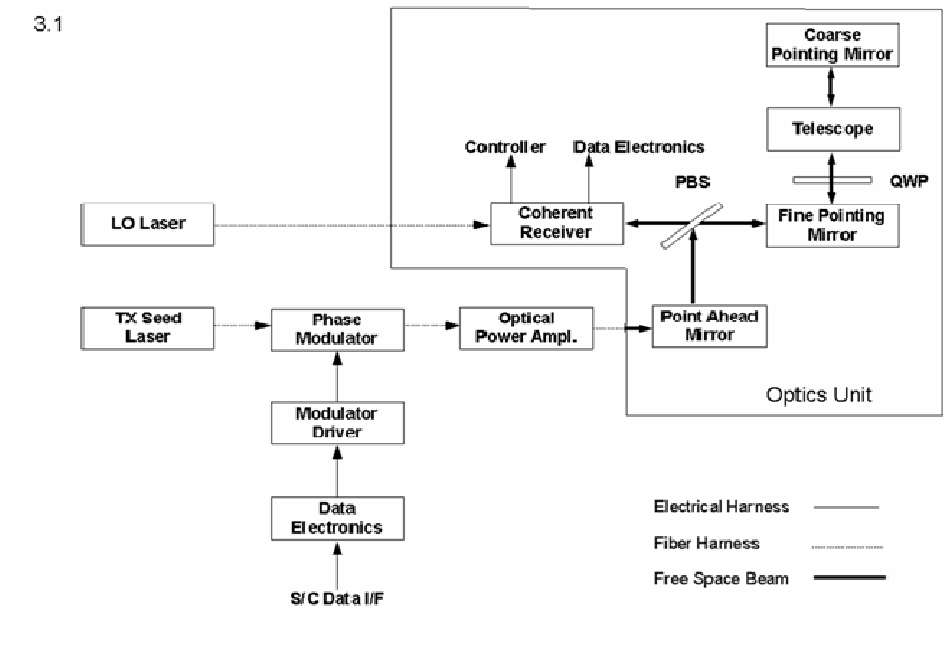


# Optical Link Space Terminal



# Optical Link Space Terminal

## Laser communication terminal block diagram



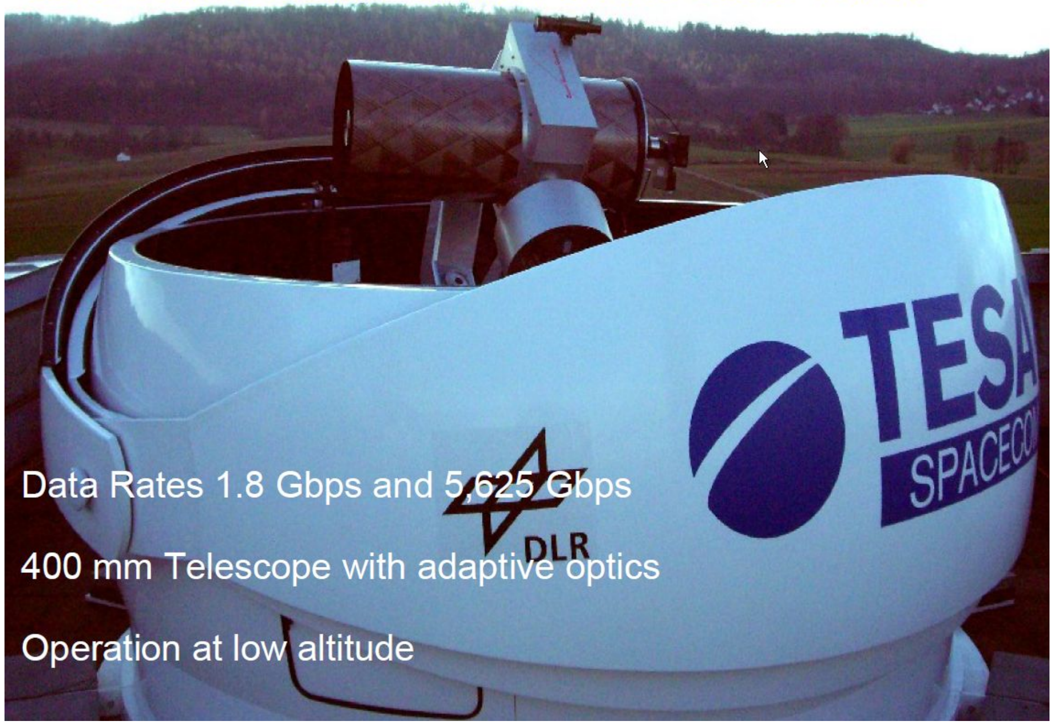
# Optical Link Space Terminal

## Laser Communication Terminal, Design Features

| | | |
|---|---|---|
| Link | LEO – LEO | LEO – GEO |
| Data Rate | 5.625 Gbps | 1.800 Gbps |
| Range | 1,000 - 5,100 km | > 45,000 km |
| Target BER | $1 \times 10^{-8}$ | $1 \times 10^{-8}$ |
| Transmit Power | 0.7 W | 2.2 W |
| Telescope Diameter | 125 mm | 135 mm |
| Mass | ~ 35 kg | ~ 50 kg |
| Power Consumption | ~ 120 W max. | ~ 160 W max. |
| Volume | ~ 0.5 x 0.5 x 0.6 $m^3$ | ~ 0.6 x 0.6 x 0.7 $m^3$ |

# Optical Link Ground Terminal

Laser Communication Terminal, Ground Station with AO

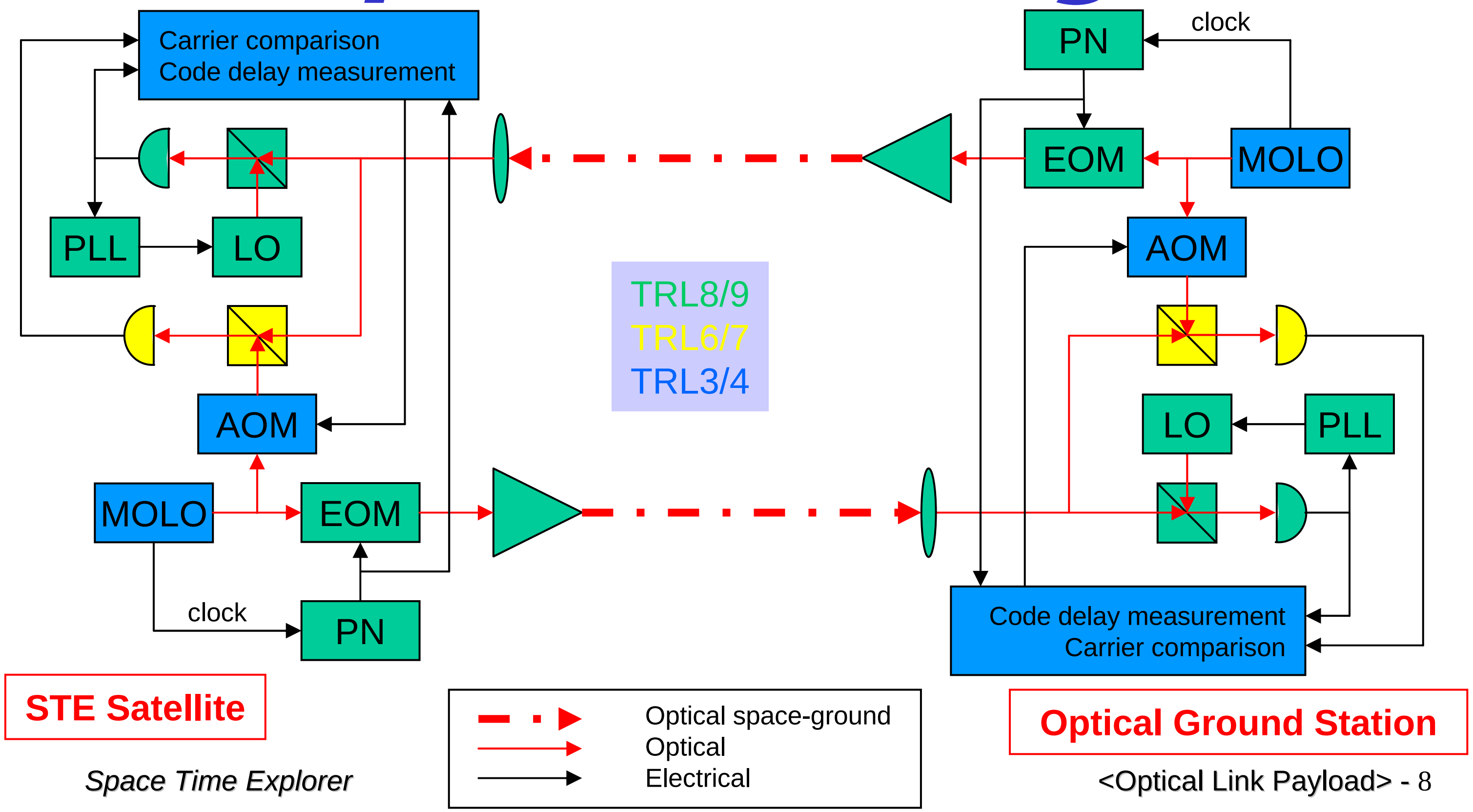



Data Rates 1.8 Gbps and 5,625 Gbps

400 mm Telescope with adaptive optics

Operation at low altitude

# Optical Link Design

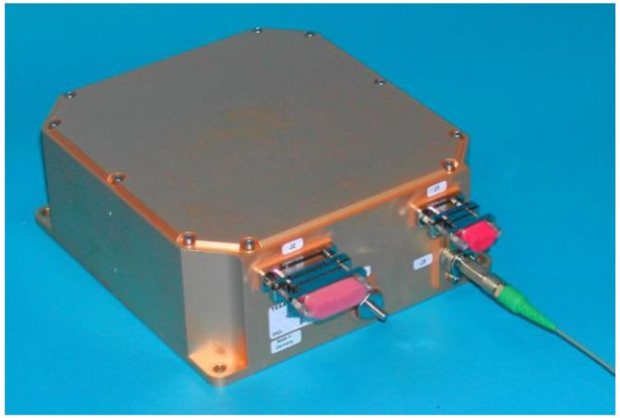


# LO Reference (also for MOLO?)

## Reference Laser Unit (RLU)

- 20 – 50mW output power
- 1064nm cw
- Redundant Pump Module

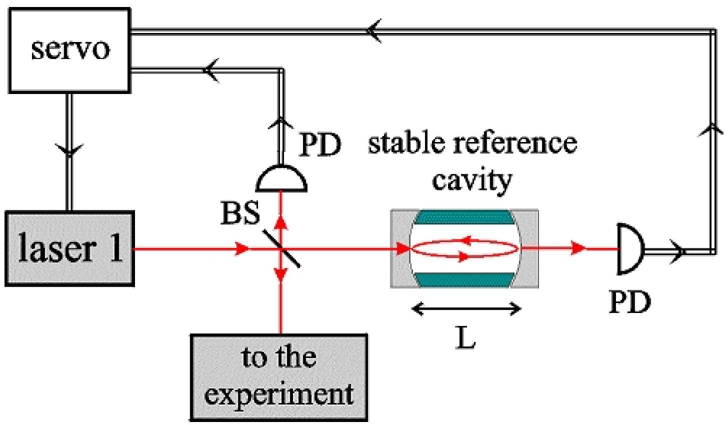
- 10W EOL
- Volume 1liter
- Mass 1kg

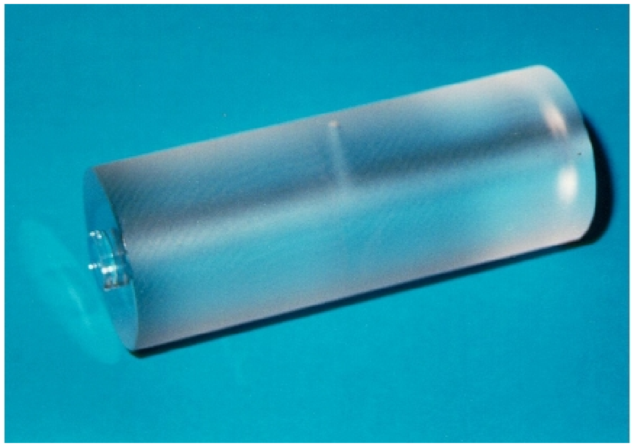


- Analog Slow Output power tuning up to +/.30% with 1Hz BW
- Analog Coarse Frequency Tuning up to +/-5GHz with 10 Hz BW
- Analog Fine Frequency Tuning up to +/-80MHz with 80kHz BW

# Optical Reference cavity within MOLO?

**New thermal controlled laser cavity required with 10-15 stability**



# Optical Link Maturity

- **Component maturity:**
  - **LO local oscillator laser: TRL9**
  - **PLL optical phase locked loop: TRL9**
  - **Code delay detector: TRL9**
  - **EOM electro-optical phase modulator: TRL9**
  - **Optical amplifier: TRL8**
  - **Laser terminal pointing, acquisition and tracking: TRL8**
  - **Carrier comparison detector: TRL6**
  - **PN code generator: TRL6**
  - **AOM acousto-optical modulator: TRL4**
  - **MOLO: TRL4**
  - **Carrier comparison and code delay measurement: TRL3**
- **System overall maturity: TRL4**

- **Problems:**
  - **Temporary fading or loss of detector signal due to atmospheric turbulence**
  - **Cloud probability at receiving stations (space diversity if possible)**

# Diversification of OGS

Statistically independent OGSs with equal $p_{cloud}$

- # of available stations has binomial distribution
- Estimation of the number of stations:

LOP = Link Outage Probability
LOP = 1 – Availability
n = number of OGS

$$LOP = p_{cloud}^{n} \qquad n = \frac{(LOP)_{dB}}{(p_{cloud})_{dB}}$$

**Number of OGS to meet specified network LOP:**

| Network spec | | Cloud probability | | | | |
|---|---|---|---|---|---|---|
| LOP | Availability | 40 % | 30 % | 20 % | 10 % | 5 % |
| $10^{-2}$ | 99 % | 5 | 4 | 4 | 4 | 2 |
| $10^{-3}$ | 99.9 % | 8 | 6 | 5 | 3 | 3 |
| $10^{-4}$ | 99.99 % | 11 | 8 | 6 | 4 | 4 |
| $10^{-5}$ | 99.999 % | 13 | 10 | 8 | 5 | 4 |

# Space Time Explorer


## Communications

Session 8 IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

## STE – Communications

Two independent systems:

- MWL, in the P/L module:
  - Electrical I/F only with P/L electronic

- TT&C, in the Platform module:
  - Electrical I/F only with Platform OBC

# STE Communications

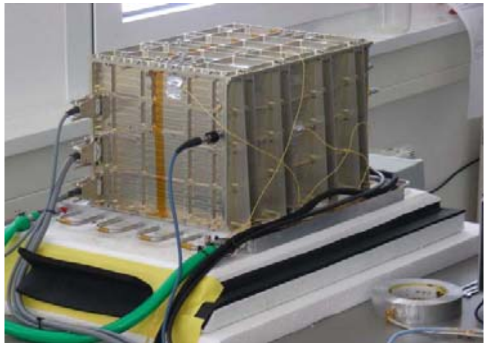
*MWL*

# ACES MWL (ISS orbit)

Onboard and Ground comparison of relative clock differences based on PseudoNoise (PN) technique on the bases of ultra-stable external clock (FCDP) for fundamental Physics and others ancillary tasks.

| Band | Ku down link | Ku up-link | S down link |
|---|---|---|---|
| Frequency | 14.70333 GHz | 13.475 GHz | 2.248 GHz |
| Transmit Power | 0.5 W | 2 W | 0.5 W |
| Code Rate | 100 MChip / s | 100 MChip / s | 1 MChip / s |
| Received C/No @ 10° | ~47.8 dBHz | ~48.9 dBHz | ~50 dBHz |
| Code noise @ 1s, 10° | 29 ps | 25 ps | 2.23 ns |
| Carrier noise @ 1s, 10° | 0.09 ps | 0.08 ps | 0.45 ps |
| Carrier Doppler, max. | +/- 400 kHz | +/- 350 kHz | +/- 58 kHz |
| Carrier Doppler rate, max. | 6.5 kHz/s | 6 kHz / s | 1 kHz/s |
| Code Doppler, max. | +/- 2700 Hz | +/- 2700 Hz | +/- 27 Hz |
| Code Doppler rate, max. | 44 Hz/s | 44 Hz/s | 0.4 Hz/s |

*ACES main MWL specs.*

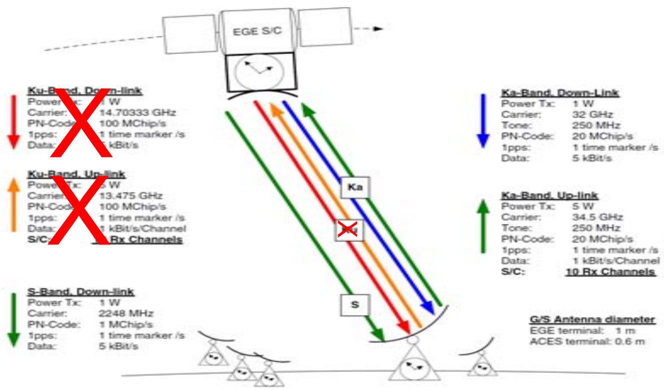


*ACES MWL FS EU*

# From ACES to STE MWL

Same architecture and external I/F of ACES (clock, TM/TC, Pwr…)

Evaluation of the Δdevelopment required from ACES to STE




*Preliminary proposed MWL for STE*

## MWL: major changes from ACES

- Highly Elliptical Orbit (Low Circular for ACES):
  - Variable FOV (apogee → perigee)
  - Higher distance TX-RX with wider variation (apogee → perigee)
- Secondary frequency allocation not acceptable for STE mission (non demonstrational mission)
- Lifetime and Radiation

# MWL: Frequency Band Selection

- Existing Design (ACES)
  - S-Band in a Primary allocation for Cat.A SR Downlink
  - Ku-Band in a Secondary allocation for Car A SR Up/Down Links

**NOT Demonstration Mission**

**Potential Huge Interferences from Primary Allocation to Ground Terminal (MOBILE, FIXED)**

- New Design (STE)
  - ***S-Band*** in the same Primary allocation band (same or very close freq.)
  - ***Ka-Band*** replaces Ku-Band: Primary allocation for Ca.A SR Downlink available and Uplink ongoing (WRC-12, low risk)

- Drawback (minor)
  - Ka-Band redesign: no technologically critical
  - Split antenna for Ka-Up/Down links: minor impact for S/C

# From ACES to STE MWL

Minor activity:

– Onboard Orbit propagator to be updated

– Code-Search speed algorithm to be updated

– RF-Frontend (space and ground):

- Dynamics optimization
- Higher RF Power output (2.5-3W compared 0.4W of ACES)
- Bigger antenna on ground (1.5-2.0m)

Major activity:

– Onboard antenna new architecture/re-design

– Onboard and ground Ku assembly to be redesign on Ka band:

- Frequency will be 22 and 26Ghz (ACES 13 and 14GHz)

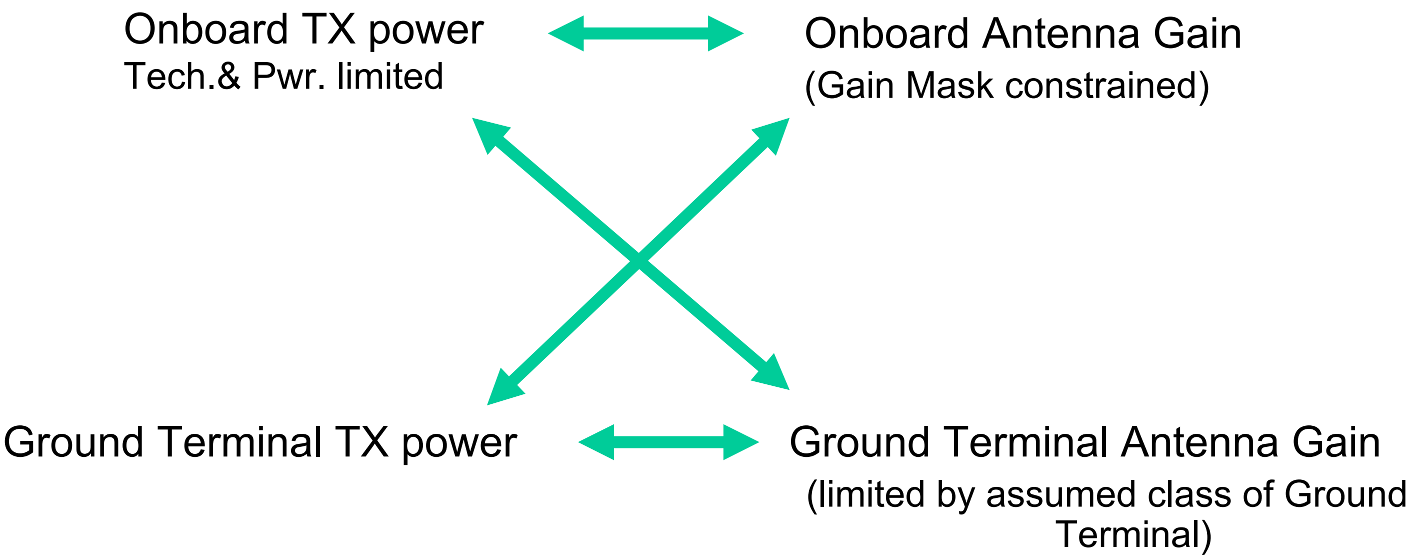
# STE MWL Concept

- Operational only in Nominal attitude (Nadir pointing)
- HEO (32200 Km semi major axes, 16h frozen orbit)
- Scientific Measurement near – Apogee/Perigee
- Full orbital coverage
- Target-pointing maneuvers are not allowed
- Antenna Phase centre knowledge requirements

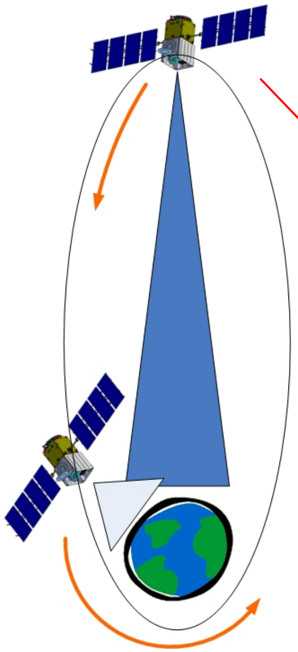
**NO IsoFlux pattern** ⇓ **Specific Antenna Mask**

- Antenna Array based on 2 predefines positions VPD (Variable Power Divider)
- Antenna reconfiguration non in Scientific Measurement regions

# MWL performance decomposition: parameters dependence

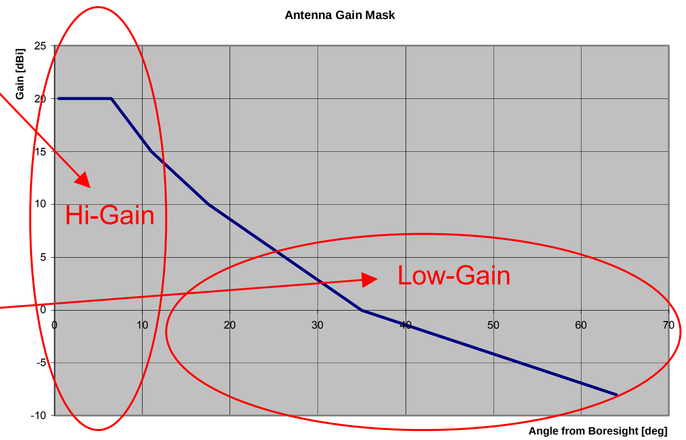


# STE MWL Concept



@ apogee: small Earth FOV (<17°), higher FPL

@ perigee: wither Earth FOV (130°), lower FPL



## MWL Onboard Antenna: overview

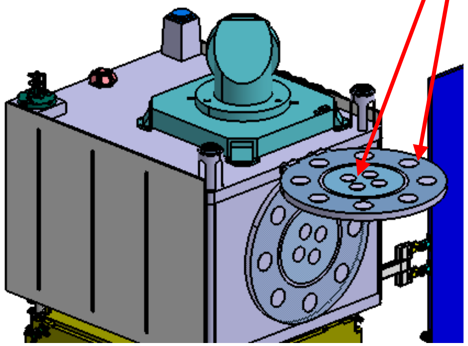
- 2 combined antennas: **(almost unfeasible)**
- Reflector shaping (**potentially not feasible)**
- Zoomable beam/digital beam forming (**high confidence of feasibility)**:
  - TRL?
  - Mechanisms?
  - Phase knowledge?
- Switching between 2 antennas (**high confidence of feasibility)**:
  - phase jump uncertainty due to the switch repeatability: detection or compensation
  - phase jump due to antenna switching (relative accommodation depending)

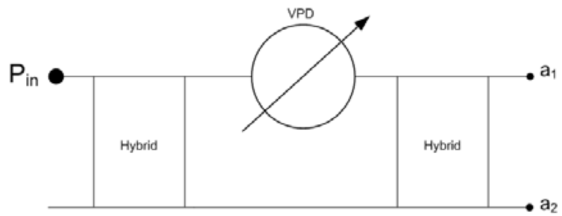
- **Antenna Array with fixed configuration** (**high confidence of feasibility)**:
  - More flexibility in the design
  - Accommodation constraints relaxed w.r.t. Switching solution
  - Space/Volume saving

# MWL VPD Antenna Array

Radiating elements grouped in two (or more) sets:

- Core-set to provide Low-gain wide FOV antenna
- Core-set + Ring to provide Hi-gain narrow FOV antenna






VPD with 2 predefined positions for pattern selection

# MWL redesign scale and TRL

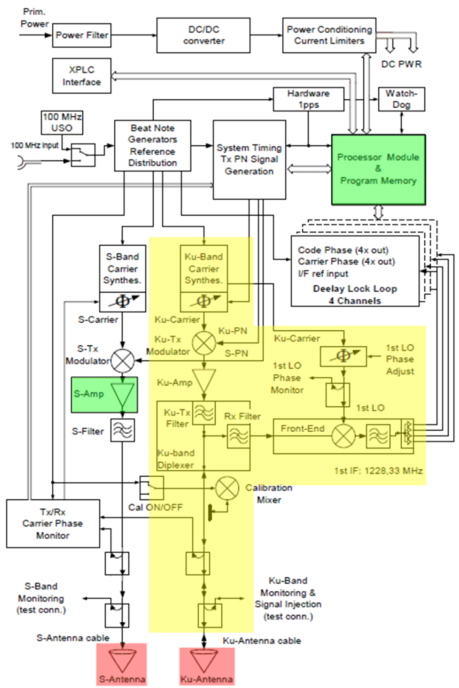
**Relative scale of development:**

White: no modification (TRL≥6)

Green (minor): parameters or power level modification (TRL≥6)

Yellow (medium): redesign due to the new frequency band (common band) (TRL≥5)

Red (major): new design (unusual pattern requirement but less complex system then existing space-proven design) (TRL≥4-5?)



# MWL Link Budgets

Based on:

- HEO 32200Km semi major-axes
- Min elevation 5 deg for signal acquisition, 10 for measurements
- Signal property assumed as for ACES
- Computational model derived by ACES
- Margin computed in line with ACES criteria (similar margin)
- Optimization of Apogee and Perigee
- Antenna reconfiguration (switching) at midrange

| Parameter | Unit | Hi-Gan | Low-Gain |
|---|---|---|---|
| S-Band C/No | dB | **From 3.0 to 10.0** | **From 3.0 to 22.7** |
| Ka Up C/No | dB | **From 3.9 to 8.9** | **From 3.3 to 22.1** |
| Ka Down C/No | dB | **From 7.6 to 12.0** | **From 4.7 to 24.0** |

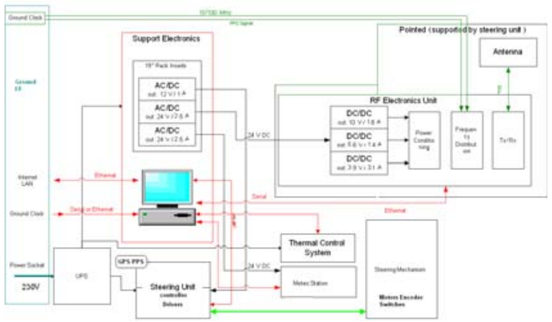
Sizing cases

More detailed models and analysis can provide a different and more efficient performances allocation (Pwr, Gain and Gain Mask)

# STE MWL Ground Terminal

Architectural design based on the ACES MWL GT with:

- modification of Ku-Band chain to Ka-Band
- Antenna Dish improvement to 2m (tracker upgrade)
- Improvement of RF power output (to 10W)




ACES GT architecture

ACES GT Antenna system

# STE MWL: onboard Budgets

| Mass Budget | | | |
|---|---|---|---|
| **ITEM** | **MASS [g]** | **QTY** | **TOTAL** |
| **MWL EU** | **14000** | **1** | **14000** |
| **RF Cables** | **200** | **3** | **600** |
| **S-Band Array** | **3000** | **1** | **3000** |
| **Ka Up Array** | **200** | **1** | **200** |
| **Ka Down Array** | **200** | **1** | **200** |
| | | **TOTAL (gr)** | **18000 + 20%** |

| Power Budget (Without 20% Margin) | |
|---|---|
| **Mode** | **PWR consumption** |
| EU + TX Off | 0W |
| EU + TX On | 80W |

| Size | | |
|---|---|---|
| **ITEM** | **Size** | **Quantity** |
| EU | ???? mm | 1 |
| S-Band Array | Ø 650mm<br>H: 40mm | 1 |
| Ka Up/Down Array | Ø 80mm<br>H:30mm | 2 |

# *TT&C*

# TT&C Subsystem

- Functionality provided:
  - TC for all mission phases (4kbps)
  - TM:
    - Low rate for all mission phases (16kbps)
    - High rate for all nominal mission phases (Nadir pointing) (125kbps)
  - Classical RNG and Doppler Tracking: for all mission phases, except High-rate TM

- Assumptions:
  - Optimization for Nadir pointing attitude and near-Apogee contact
  - Commercial 13m antenna availability (G/T: 22dB/K @ S-Band)
  - 3dB WORST CASE Link Budget Margin as Goal
  - Bitrate are referred at the electrical I/F of the Transmitter
  - S/C telemetry generation rate:
    - 5kbps (Platform + P/L in standby)
    - 20kbps AVG P/L operational

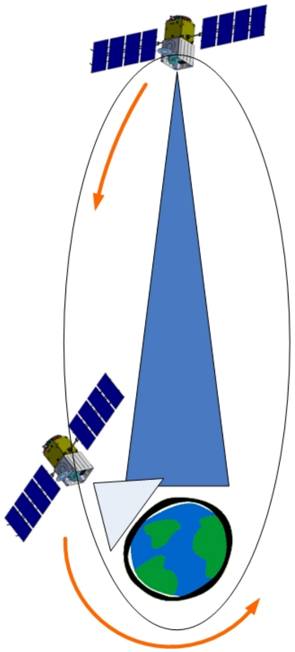
# TT&C Concept

- Nominal Nadir attitude
- HEO (32200 Km semi major axes, 16h frozen orbit)
- Hi rate P/L TM only in nominal attitude
- Constraints for antenna placement due to P/L antenna priority
- Design (and operations) as simple as possible

**NO IsoFlux pattern** **NO LGA + MGA** **Optimized LGA scheme**

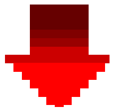
- S-Band baseline due to low data budget, spherical coverage and operational (LEOP) requirements
- 2 LGAs (Zenith and Nadir) with X-polarization (R/LHPC)
  - Nadir antenna with higher gain (7dBi) on boresight for nominal apogee communication
- Classical Redundant transponder
  - Coherent mode available for Ranging and Doppler

# TT&C Concept



@ near-apogee: small Earth FOV (15-25°), higher FPL, long contact duration, wide G/S visibility

@ near-perigee: wither Earth FOV (130°), lower FPL, short contact duration and limited G/S visibility due to frozen orbit



High rate TM for apogee link (Nominal attitude)
Low rate TM/TC for all attitude and orbit position

Low power mode for near-Perigee contact

# TT&C: Baseline Ground Station and Option

13m ESA Station Baseline

Sufficient for P/L TM

Sufficient for real time S/C telemetry (assuming 5kbps)

Some compression or loss of some store S/C data (assuming 5kbps consensually ~15%)

| **Bitrate with baseline G/S** | **Mbit/orbit (CCSDS coded data)** |
|---|---|
| Bitrate (kbps) | Apogee (4h) |
| 16 (Low Rate TM) | 230 (288 required) |
| 125 (High Rate TM) | 1800 |
| 4 (TC) | 57 |

# TT&C: Baseline Ground Station and Option

15m as an option

- No useful improve on uplink
- Higher data volume possible (or shorter communication windows required)
- Compression of S/C TM not required

~2 times wrt 13m antenna

| **Bitrate with 15m G/S** | **Mbit/orbit (CCSDS coded data)** |
|---|---|
| Bitrate (kbps) | Apogee (4h) |
| 16 (Low Rate TM) | 460 |
| 125 (High Rate TM) | 3600 |
| 4 (TC) | 57 |

# TT&C Link Budgets

- Based on:
  - HEO 32200Km semi major-axes, minimum elevation angle 5 deg
  - 13m G/S (G/T = 22.0dBK)
  - Spherical coverage for low rate @ apogee and perigee
  - Optimized coverage for high rate @ apogee
  - Atmospheric/Ionospheric loss: 1 dB
  - Coding & modulation (concatenated RS & conv., DOQPSK)
- Data-rate of 125kbps with:
  - 7W RF transmit power
  - 5 dBi antenna gain (7dBi boresight)

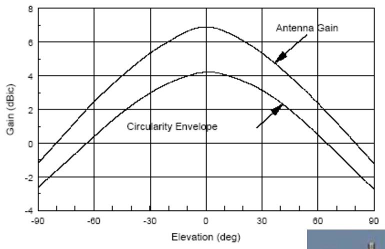
| **Parameter** | **Unit** | **Apogee** | | | **Perigee** | |
|---|---|---|---|---|---|---|
| Elev. | Deg | 5 | 90 | 5 | 5 | 90 |
| Bitrate | | Hi | Hi | Low | Low | Low |
| **TM Margin** | **dB** | **3.41** | **6.31** | **4.25** | **>15*** | **>25*** |

*** To be reduced with low-power mode**

**Down Link Carrier Recovery, Up Link TC and carrier recovery , as well as RNG Margin without criticality**

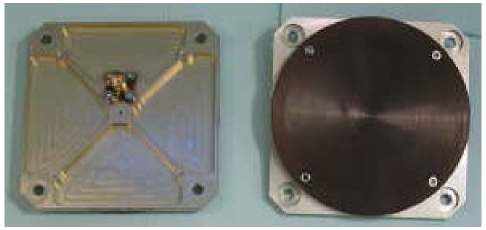
# TT&C: LGAs

Patch antenna from SSTL (Proba1, Rosetta, Topsat…)




Antenna pattern:

- Gain at boresight: 7 dBi
- 3dB BW at +/- 30 deg
- - 3 dBi at +/- 90 deg



82 x 82 x 20mm

Helix antenna from RUAG (wide heritage in space)

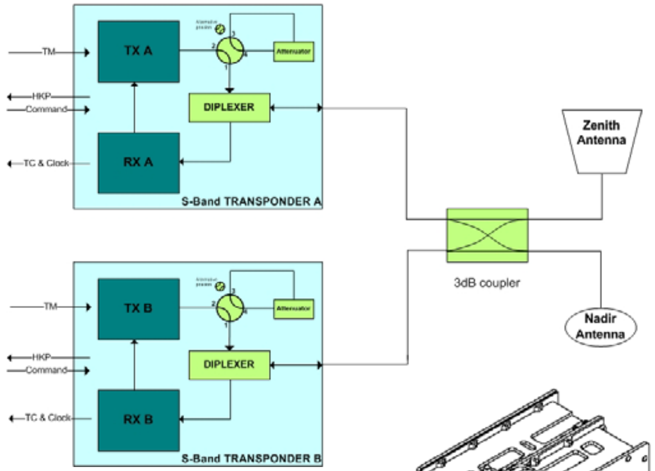
Antenna pattern:

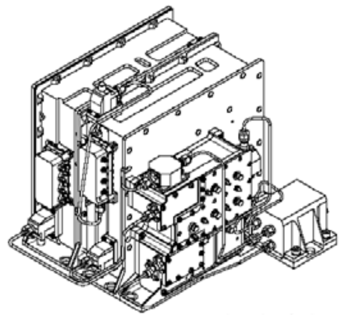
Gain ≥ - 1 dBi for 0 ÷ +/- 90 deg

Ø 65mm H:285mm

# TT&C: Transponder

- Based on existing HW (SWARM)
- Marginal improvement on the RF power output (from 5W to 7W)
- Hi/Low Power mode for Apogee/Perigee
- Coherent/Non-Coherent mode
- TM: Low-rate PM/BPSK (+RNG), Hi-rate DOQPSK
- TC: PM/BPSK (+RNG)
- Main/Red: Two independent boxes



# TT&C: Budgets

| Mass Budget | | | |
|---|---|---|---|
| **ITEM** | **MASS** | **QTY** | **TOTAL** |
| **TRSP** | **3500** | **2** | **7000** |
| **RF Cables** | **150** | **2** | **300** |
| **LGA1** | **100** | **1** | **100** |
| **LGA2** | **240** | **1** | **200** |
| | | **TOTAL (gr)** | **7640 + 5%** |

| Power Budget (Without 5% Margin)) | | | | |
|---|---|---|---|---|
| **ITEM** | **Redundancy** | **PWR consumption** | **TOTAL** | **Duty cycle** |
| Rx | Hot (x2) | 6.5W | 13W + 5% | 100% |
| Tx | Cold (x1) | 45W | 45W + 5% | 25% |

| Size | | |
|---|---|---|
| **ITEM** | **Size** | **Quantity** |
| TRSP | 200x200x240mm | 2 |
| Nadir Antenna | 82x82mm<br>H: 20mm | 1 |
| Zenith Antenna | Ø 65mm<br>H:285mm | 1 |

# Space Time Explorer

*Power Subsystems*

Session IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team


(*) ESTEC Concurrent Design Facility

# Power System Architecture

- Study oriented toward a PROTEUS like P/F
  - Power system optimised for LEO mission
    (dominant kind of mission for small science P/F)
    => Non Regulated Power Bus
  - STE needs closer to GTO mission
    => Non Regulated Power Bus
    However Non Regulated Power Bus can do it
    (opposite more difficult)

## Power System Architecture

- Presentation
  – PROTEUS like platform capability
  – Needs for improvements
  – Options

# P/F power system (optimised)

| | |
|---|---|
| • PCE (SA power conditioning) | 3Kg (!) |
| • Battery | 28.4Kg |
| • BEU (Battery maintenance) | 4.3Kg |
| • DBox (AIT / launch I/F) | TBC (low) |
| • Distribution boards in DHU | TBC (low) |
| • PCE / BAT control software | 0Kg |

## PROTEUS like P/F power system (as is)

- Battery bus architecture
  - Optimised for LEO operation
  - Available performance on 16h HEO is globally improved
    - Solar array is colder => little less power but longer life
    - Battery charge is high most of the time => more SA output power
  - If power can be a little lightened during the eclipse season => remain efficient
- SA power and BAT charge under OBSW ctrl.
  - Power conditioning is not autonomous = important NC w.r.t. ECSS
  - Part of the cost performance of the P/F => to be accepted

# PROTEUS like P/F power system (as is)

- Battery based on a s+1 redundancy principle
  - Power bus voltage is translated down by ~4V if a failure occurs in one of the battery element.
    Theoretical => 1/9 loss in capacity + SA power output capability.
    In practice => as long as not failed, the battery is never fully charge (good for its life time), then loss is rather 5%.
  - Performances are given with battery failed,
    but larger performance is available as long as battery stands
    => bonus operations
    => in the 16h HEO case, the bonus is specifically important w.r.t. the eclipse season

# PROTEUS like P/F power system (as is)

- PROTEUS like SA baseline
  - Si cell (130um) + 100um cover glass (102s x 32p)
    EOL => ~4E14 (inc back side) ~12.5% degradation (bus level)
    with still some margin in voltage
- Performance available EOL for INST
  - Out of eclipse season ~540W (1 failure in EPS)
  - During the [long] eclipse season ~300W in sunlight
    but <250W TBC[1] during the 3h eclipse itself (battery energy) if the battery has a failed element (else 300W continuous)
    In sunlight a peak at 540W for 1h at least is possible

(TBC[1]: supposing 70% DOD is acceptable w.r.t. min reserve to yet allow a transition in SAM)

# PROTEUS like P/F power system (as is)

- POWER Distribution
  - 16 Lines protected by fuses,
    2 dedicated to launch/survival
    => flexible + some LCL can be accommodated in ICU
  - Regulated 28V can be provided to user that need (according heritage).
    However, in case of 3h eclipse, the bus voltage will be too low for a proper (simple) converter operation. If battery is failed, it is even impossible.
    => Units that need 28V shall be OFF during about ½ orbit during the long eclipse period, or accept a transiently degraded supply voltage. More elaborate converter possible, but imply larger cost (+TRL), that likely would make the units upgrade to unregulated bus more efficient (cost)

# PROTEUS like P/F power system (as is)

- Conclusion
  - PROTEUS like P/F as is a little marginal w.r.t. the initially identified need (about 600W for the instrument) to be consolidated nevertheless w.r.t. to timeline
  - Latest power budget more in line with PROTEUS like P/F capability, outside the eclipse season.

# POWER BUDGET

- Hypothesis is to use a PDU for adapting PF power to Instrument heritage.
  - PHARAO design for 28V regulated
  - If unit is not kept active during long eclipse season a step down regulator can be used: => Efficiency ~96%
  - If secondary voltage is supplied to small units as CCR, FCDP, efficiency is lower: 75% worst case
  - If units are new, or have NR bus heritage (e.g. LCT) only a protection function is necessary in the PDU: 1% loss

# POWER BUDGET

- With refined hypothesis, the budget is closer to a PROTEUS like P/F on the specific orbit of the STE mission outside the eclipse season, but not during

| | Budget | Heritage | Refined Hypothesis | PDU |
|---|---|---|---|---|
| RF link | 72W | New? | 99% | 0.7/3.6W |
| COMB | 40W | New | 99% | 2W |
| Optical LO | 20W | NR bus | 99% | 1W |
| PHARAO | 114W | 28V Reg | 95% | 5.7W |
| FCDP | 8W | Secondary? | 75% | 2.0W |
| CCR | 2W | Secondary? | 75% | 0.5W |
| GNSS | 7W | NR bus | 99% | ε |
| LCT | 160W | NR bus | 99% | 1.6W |
| ICU<br>PDU | 25W<br>150W | NR bus | 75% | 6.2W<br>20/23W |
| Total | 598W | => | | 468/471W |

## PROTEUS like Evolution

- Little larger solar array capacity
  - + AsGa 3J cells on 2x2 1.2 $m^2$ (PROTEUS like) panels (instead of 2x4 panels with standard Si cells)
- Little more capable PCE
  - + (at least) an hardware protection against battery over-/under- voltage: (ECSS requirement)
  - + 3.1Kg

## PROTEUS like Evolution

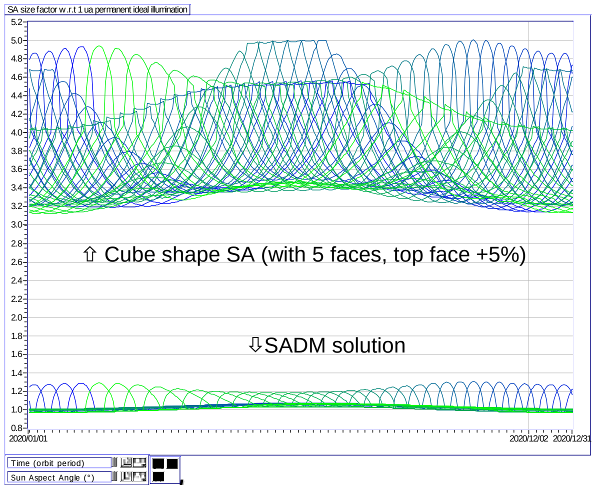
- Enhanced battery capacity
  - + VES140 replace VES 100 elements: +44% capacity
- DBox (umbilical IF)
  - + Modified to include a battery switch for ground operation safety (missing on present PROTEUS like P/F)

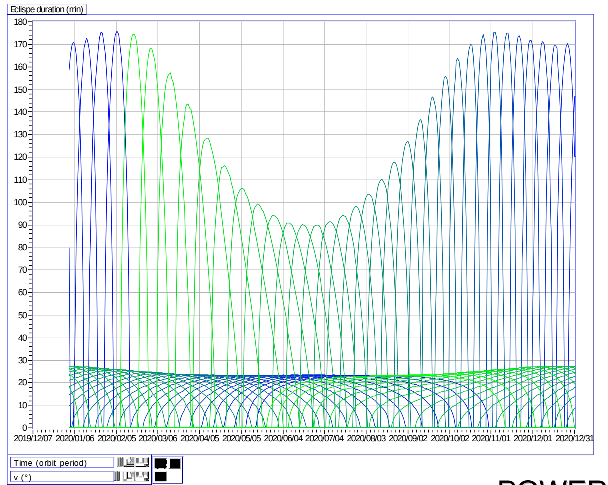
# P/F power system (optimised)

| | |
|---|---|
| • PCE (SA power conditioning) | 6.1Kg (!) |
| • Battery | 37.5Kg |
| • BEU (Battery maintenance) | 4.3Kg |
| • DBox (AIT / launch I/F) | 2Kg |
| Distribution boards in DHU | TBC (low) |
| • PCE / BAT control software | 0Kg |
| • Solar Array (2 wings) | 21.5Kg |

# Fixed Array Option

- Body mounted SA option has been explored
  - With drifting AN, Sun can be almost in any direction
    => solar array shall be about x5 to x6 a SADM based solution



# Conclusion / Options

- Conclusion
  - PROTEUS like P/F as is a little marginal w.r.t. the identified need (at least during the eclipse season)
  - However, only simple evolutions are necessary
- Other options could be considered
  - A battery with p+1 redundancy would save SA efficiency, and work around the difficulty in supplying PHARAO at the end of the long eclipses (i.e. too low bus voltage, with a degraded battery in the s+1 redundancy case)
  - A regulated bus: this costs a large BDR (800/900W), but this safe the battery switch and the PHARAO converters in the ICU-PDU.

# Space Time Explorer

*Mechanisms*


Internal Final Presentation

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

## Needed Mechanisms:

- Solar Array Drive Mechanism (SADM)

- Solar Array Deployment and synchronization

- Solar Array Hold Down and Release Mechanism (HDRM)

- Antenna Hold Down and Release Mechanism (HDRM)

- Antenna deployment

# SADM: Septa 31

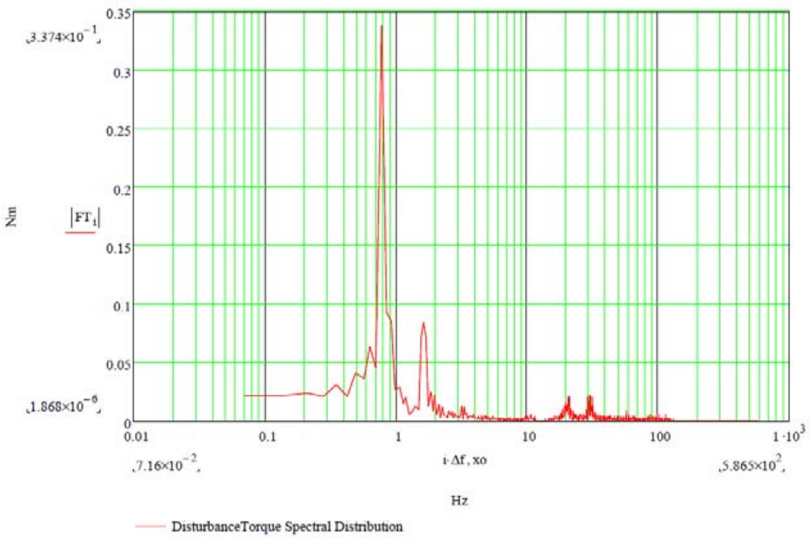
| Motor | |
|---|---|
| Winding resistance | 285 Ω ±5% |
| Number of steps per revolution of motor | 360 |
| Stabile positions (motor is unpowered) | 360 |
| SA holing torque (unpowered motor ) | ≥ 2.8 Nm |
| SA average torque(powered motor) | ≥ 10.6 Nm |
| SA repeated peak torque (powered motor) | ≥ 14.7 Nm (starting and stop) |
| SA momentary peak torque (powered motor) | ≥ 19.6 Nm (exceptional peak torque) |
| [illegible] | [illegible] |
| **Dimension** | |
| External diameter | 120 mm |
| Fixation flange diameter | 140 mm |
| Total length (from SA interface flange to rear part) | 240 mm |
| Mass without external leads and connectors | M ≤ 3.7 kg |
| Mass with external leads and connectors | M ≤ 4.4 kg |

Mass = 3 kg, Power < 7W

Septa 31 is the SADM used in the Proteus-like platform

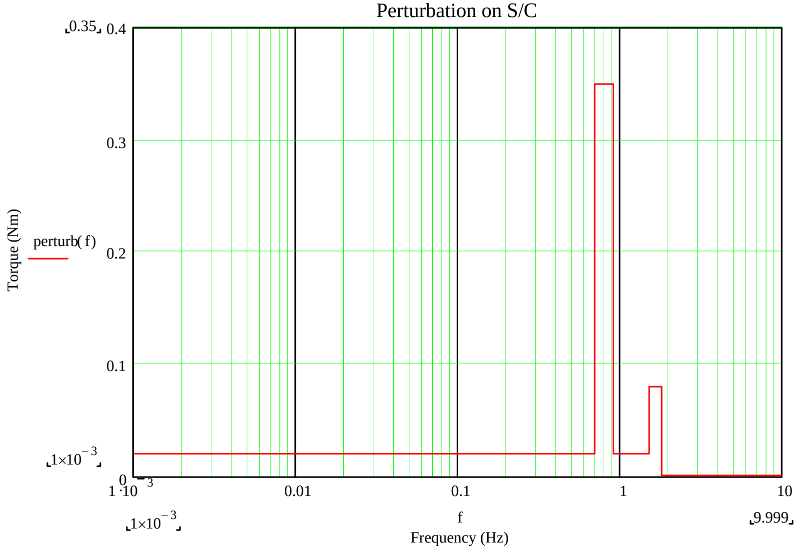
# Micro vibrations assessment

Typical torque disturbance on S/C: Sentinel3, without micro-stepping



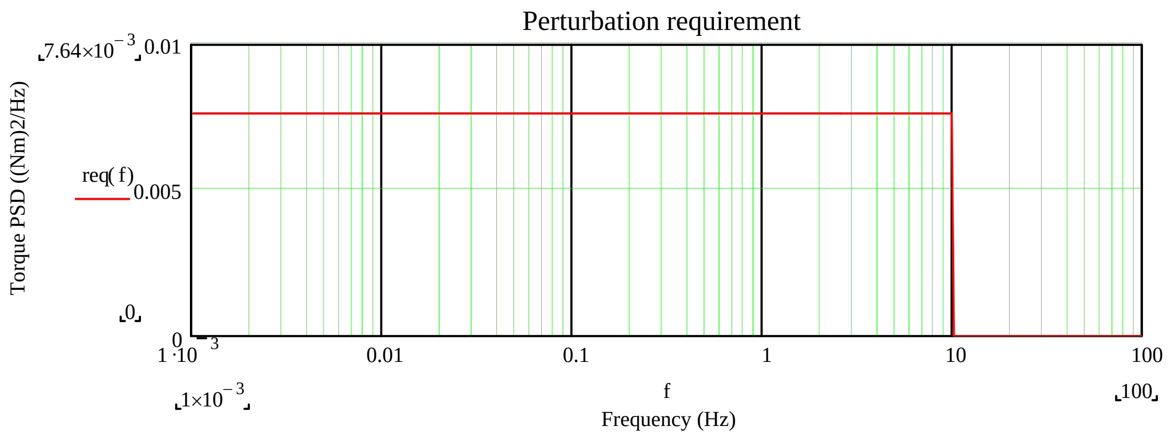
# Micro vibrations assessment

Typical torque disturbance on S/C
(envelope)



# Micro vibrations assessment

Torque disturbance PSD requirement on S/C (SA wing mass:20 Kg; SA width: 1 m)



# Micro vibrations assessment

Comparison in terms of overall frequency perturbing torque (Nm)

$$\text{perturbation} := \int_{0.001}^{10} \text{perturb}(f)\, df \qquad \text{perturbation} = 0.128$$

$$\text{requirement} := \sqrt{\int_{0.001}^{10} \text{reqperturbPSD}(f)\, df} \qquad \text{requirement} = 0.276$$

# HDRM

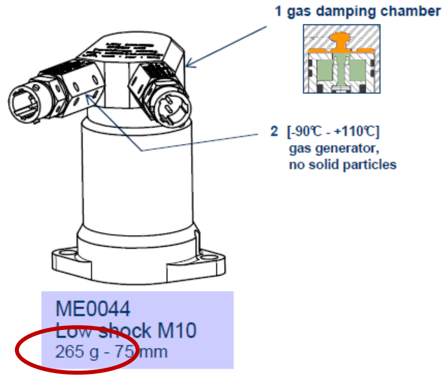

**Specifications**

| | | |
|---|---|---|
| Max Load Support & Release | 22,000 N | (5000 lb-f) |
| Max Joint Length | 8.25 cm | (3.25 in) |
| Operational Voltage | 22 to 36 Vdc | |
| Minimum Operating Temp. | -65 °C | (-85 °F) |
| Maximum Operating Temp. 2 | +80 °C | (176 °F) |
| Heater Resistance | 7.0 Ohms | |
| Mass | 100 gm | (3.53 oz) |
| Power Consumption | 112 Watts | @ 28 Vdc |
| Life Cycles | 60 Cycles Min. | |

Non pyro HDRM

**Baseline**: non pyro HDRM (antenna and SA).

**Alternative**: Low Shock Pyro, but this requires additional mass per each item




Low Shock Pyro

# Antenna deployment

| SPECIFICATION | UNITS | BASIS | DATA |
|---|---|---|---|
| Output Torque: | lb-in | Typical | 12 |
| | | High | 24 |
| | N-m | Typical | 1.3 |
| | | High | 2.7 |
| Holding Torque: Powered | lb-in | Low | 5 |
| | | Typical | 10 |
| | | High | 13 |
| | N-m | Low | 0.6 |
| | | Typical | 1.1 |
| | | High | 1.5 |
| Holding Torque: Unpowered | lb-in | Low | 3 |
| | | Typical | 5 |
| | | High | 8 |
| | N-m | Low | 0.3 |
| | | Typical | 0.6 |
| | | High | 0.9 |
| Total Assembly Weight | lb | Typical | 1.1 |
| | kg | Typical | 0.5 |

Mass= 0.5 kg; Power < 5W

**Baseline**: stepper motor to deploy the antenna with a locking system (eventually optional) at the end of the travel.

**Alternative**: spring based mechanism (slightly lower mass) with reduced accuracy on position knowledge (locking system mandatory)

# Mass Budget

| Element 2 | - | | | MASS [kg] | | | |
|---|---|---|---|---|---|---|---|
| Unit | Unit Name<br>Click on button above to **insert new unit** | Part of custom subsystem | Quantity | Mass per quantity excl. margin | Maturity Level | Margin | Total Mass incl. margin |
| 1 | SADM | | 2 | 3.40 | Fully developed | 5 | 7.1 |
| 2 | SA hold down | | 8 | 0.20 | Fully developed | 5 | 1.7 |
| 3 | Antenna hold down | | 1 | 0.20 | Fully developed | 5 | 0.2 |
| 4 | antenna deployment * | | 1 | 0.70 | Fully developed | 5 | 0.7 |
| 5 | SA deployment (and synch) | | 20 | 0.18 | Fully developed | 5 | 3.8 |
| 6 | | | 0 | 0.0 | Fully developed | 5 | 0.0 |
| 7 | | | 0 | 0.0 | Fully developed | 5 | 0.0 |
| - | Click on button below to insert new unit | | | | | | |
| **SUBSYSTEM TOTAL** | | | **5** | **12.9** | | **5.0** | **13.5** |

* Includes locking system

# Power Budget

| Element 2 | - | | | |
|---|---|---|---|---|
| Unit | Unit Name<br>Click on button above to **insert new unit** | Part of custom subsystem | Quantity | Ppeak |
| 1 | SADM | | 2 | 7.0 |
| 2 | SA hold down * | | 8 | 0.0 |
| 3 | Antenna hold down ** | | 1 | 0.0 |
| 4 | antenna deployment | | 1 | 3.0 |
| 5 | SA deployment (and synch) | | 20 | 0.0 |
| 6 | | | 0 | |
| 7 | | | 0 | |
| - | Click on button below to insert new unit | | | |
| **SUBSYSTEM TOTAL** | | | **5** | **10.0** |

Only peak values are indicated. No continuous usage foreseen

* 112 W for 40 s are needed only for the actuation
** 80 W for 30 s are needed only for the actuation

# Space Time Explorer


## *AOCS*

Session 8 : IFP

ESTEC, 15th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# General AOCS Overview

- Pointing requirements are usually driving the AOCS design, but they are not stringent on this mission (0.3 degrees APE).
- Proteus Platform has been used an <u>example</u> to show if an existing platform could satisfy the needs of the mission.
- Pointing will always be Nadir Pointing with Yaw Steering.
- Assuming the final orbit (perigee 700km altitude) : No need of drag free control system
- Values of inertia, mass, spacecraft size and solar array characteristics  are important to assess disturbance torques, therefore the preliminary data used introduces big uncertainties.

# Main questions to be answered for STE mission

- Is the microvibrations environment of the wheels compatible with the PHARAO/MOLO requirements ?

- Since the orbit is not circular, magnetic field can be used at perigee but is completely useless at apogee (B field is 500x weaker at apogee than perigee) :
  - What is the strategy for wheel unloading ?
  - On which equipment shall we rely for Safe Mode ?
  - Is the magnetic field usable on STE mission and does it harm PHARAO ?

- How does the AOCS have to be tailored for STE vs typical LEO circular orbit ?

# Wheels Micro Vibrations

- Micro-vibrations of wheels are low in the frequency requested (0.01 – 10 Hz).
- Micro-vibrations peak is around **300 Hz** on most of the wheels.
- With dampers, a force of **0.1 N** is not exceeded in the requested frequency.
- If needed, after more precise assessment, microvibs spectrum can be decreased limiting the angular velocity (and thus the Angular Momentum domain)

- If further analysis shows that wheel use are marginal, it is therefore an option to unload before the measurements to put the wheels in a predefined angular velocity range where the micro-vibration is lowered by a factor 10 or more.

- For this spectrum, structural vibrations (Solar Arrays Driving Mechanism...) are much more a concern than the wheels.

# Current existing platforms main drawbacks : Obsolescence

- Sensors and Actuators landscape are evolving quickly and equipments used today will not be necessarily available for a launch in 2022.
- As an example, Proteus was using CCD-Based Star Trackers and Dynamically Tuned Gyros.
- The nearest solution in terms of AOCS is **Sentinel3 AOCS**, which is an updated version of PROTEUS like AOCS, due to obsolescence of several equipments.
  - **Star Tracker** : Sodern SED16 replaced by Sodern Hydra
  - **Gyro** : Sagem REGYS3S replaced by MEMS SELEX SiREUS
- These two equipments have also been designed for GEO environment and therefore are resistant to total dose. At AOCS level APS-based STR and MEMS gyros are much more suitable for radiations than old CCD-based STRs and fiber optics gyros.

# Main challenges vs existing platforms

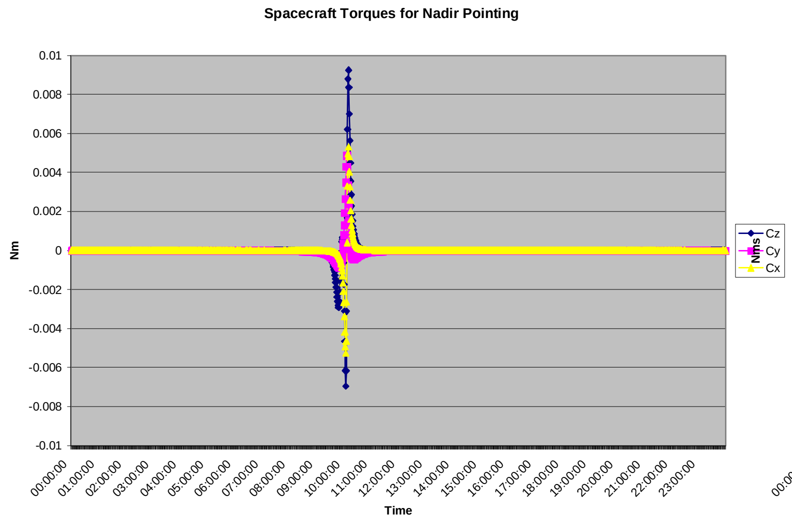
- **Safe mode cannot rely on MAG/MTB** like most of LEO missions for angular rate determination if Safe Mode is triggered at high altitude : Gyro & THR are baselined.
- **Wheels cannot be continuously damped** (circular orbits) : need of unloading maneuvers (either with MTB at perigee or Thrusters)

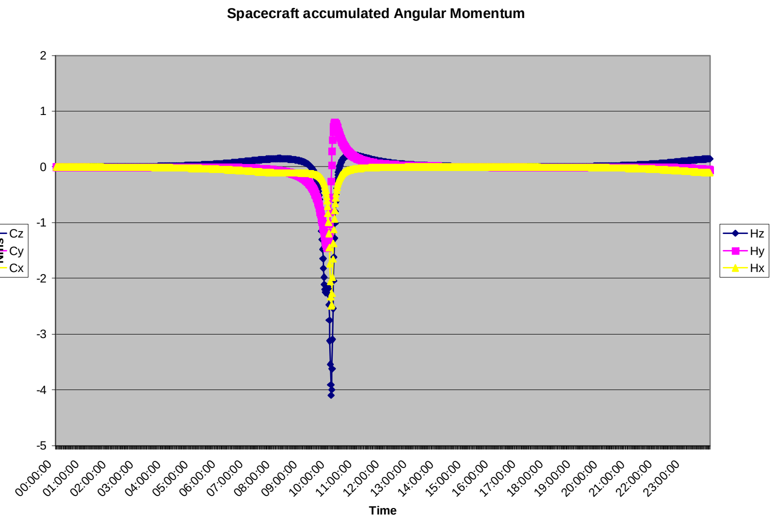
- Star Trackers on board (no Earth Sensor) is required due to the large variation of the Earth disk over one orbit. (A 3-axis attitude sensor induces no pointing perturbation during eclipses requiring high accuracy gyro)

- Guidance laws have to be updated for HE orbits.
- Re-use improvements of Sentinel 3 (no more dynamically tuned gyros but MEMS, and not a CCD based but APS Hydra Star Tracker) – All TRL between 7 and 9
  - 8 Sun Sensors from - 2 MEMS Rate Sensors - Multiple Head Star Tracker,
  - 4 Reaction wheels,
  - Magnetometers and Magnetotorquers (**TBC**)

# Wheel sizing (1/2)

- **Control torques for Nadir Pointing & Yaw Steering :**
  - Max value of 0.01 Nm on Z axis at perigee.
  - A peak of 4 Nms is reached but is cyclic.



# Wheel sizing (2/2)

- Integration of external disturbance torques over 1 orbit:
  - **Gravity gradient** : Less than 0.5 Nms
  - **Air Drag** : Negligeable
  - **Magnetic Torque** (residual dipole of 5 $Am^2$ per axis) : Less than 0.5 Nms per orbit.
  - **Solar Pressure** : Hard to assess at this stage – 2 Nms

- Conclusion :
  - With Margin, re-use of Sentinel 3 wheels.
  - At perigee, **0.2 Nm** torque to allow both unloading & control of the pointing,
  - A total of **20 Nms** is enough with margin (max expected at 7 Nms per orbit and 2 to be unloaded)
  - To be refined with up-to-date inertia and mass figures.

# Wheel unloading : Solution 1

- Use of the thrusters <u>anywhere on the orbit (ex: medium altitude when PL is not used)</u>

  – If 2 Nms have to be unloaded per orbit :

    - Taking into accound a SVM of 1.15 x 1.15 x 1.35 m
      – Max lever arm is 0.575 m
    - To unload 2 Nms on 1 axis, 2 thrusters have to be fired 1.74 sec per orbit.
    - To unload 2 Nms on 3 axis, 3 thrusters have to be fired 3.48 sec per orbit

  – Over 1 year, fuel consumption is **2.1 kg**

  – If the <u>pointing has to be maintained</u> during unloading and if this <u>unloading has to be precise</u>,
    - 20 pulses per maneuver are foreseen, leading to 10 000 pulses / year / thrusters.

  – <u>If not</u> (our case), the best strategy is to unload every 2 orbits with 2 pulses centered during the wheel torque command (equivalent to 1 pulse per orbit) : i.e. **1000 pulses / year / thruster**

# Wheel unloading : Solution 2

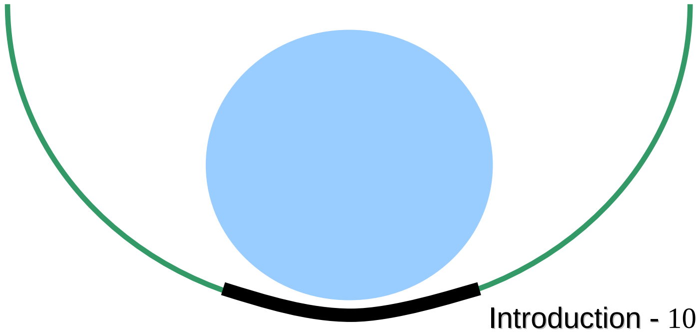
- Magneto-torquer bars <u>at perigee only</u>

  – Magnetic field is very weak at high altitude, therefore the bars can be used at perigee only.

  – 3 Options have been studied to perform Wheel Unloading :

    - **O1** : 2 hours continuously at perigee (1 hour before, one after) – from 15 000 km altitude to 700 km.
    - **O2** : 2 hours but avoiding 1000 s at perigee
    - **O3** : 2 hours but avoiding 2000 s at perigee

  – The figure shows option 2 :
    - In green, when unloading is authorized,
    - In black, when unloading is forbidden (1000s)



# Wheel unloading : Solution 2

- Magneto-torquer bars at perigee (continued)
  - O2 allows to unload **64 %** of O1 (but 86% of the time)
  - O3 allows to unload **17 %** of O1 (but 72% of the time)
- Target unloading is 2 Nms per day (with different bars dipole values)
  - Minimal distance of the MTB from PHARAO is computed to avoid a B field of $10^{-5}$ T (140 dBpT specification) in both OFF and ON conditions.
  - According to the current accommodation, PHARAO is 1434 mm far from SVM baseplate, therefore only the 40 $Am^2$ configuration would allow its use ON during measurements. (due to the MTB on Z axis)

| | | Capability to unload at perigee (2 hours) | | | Position on the S/C vs PHARAO | |
|---|---|---|---|---|---|---|
| Dipole | Residual Dipole while OFF | All the time | Avoid central 1000s window | Avoid central 2000s window | Min distance (OFF) | Min distance (ON) |
| $Am^2$ | $Am^2$ | Nms | Nms | Nms | mm | mm |
| 250 $Am^2$ | 1.8 | 12.29 | 7.93 | 2.09 | 330 | 1700 |
| 70 $Am^2$ | 0.5 | 3.44 | 2.22 | 0.58 | 215 | 1100 |
| 40 $Am^2$ | 0.3 | 1.96 | 1.26 | 0.33 | 180 | 930 |

# Wheel unloading : Recommendation

- The choice to use MTB is not straight forward in a mass optimization point of view (<u>if they can not be used during the whole perigee passage</u>) : to be refined in Phase A with a precise momentum build up.
  - Overall mass with 3x250 Am² : 4.7 x 3 = 14.1 kg
  - Overall mass with 3x70 Am² : 1.9 x 3 = 5.7 kg
  - Overall mass with 3x40 Am² : 1.4 x 3 = 4.2 kg

- The 40 Am² MTB can be placed far enough from PHARAO (1 meter), and can be used for the whole perigee phase (with no margin)

- The two unloading possibilities can be accommodated on the S/C to extend the life duration or to mitigate higher fuel consumption if disturbances or inertia increase after future refinement of the mission.

- For now, the baseline is to use thrusters for wheel unloading.

# Short Summary of AOCS modes

- **Safe : SAM**
  - Safe Mode (After separation and in case of recovery)
  - Put the spacecraft in a safe configuration, pointing the sun.
- **Maneuver Mode : OCM Mode**
  - Orbit Control Mode (use of thrusters for orbit correction)
- **Transition Mode : TRM Mode**
  - Transition from Sun Pointing to Nominal Pointing
- **Nominal Mode**
  - Nadir Pointing with Yaw Steering
  - Wheel Unloading on Magneto-torquers or Thrusters (2 possibilities)

# Spacecraft AOCS modes & equipments

| | | SAM | OCM | TRM | NOM | Comments |
|---|---|---|---|---|---|---|
| Sensors | **Magnetometers** | | | | 1 / 2 | |
| | **Star Tracker OH** | | 2 / 3 | 2 / 3 | 2 / 3 | |
| | **Star Tracker EU** | | 1 / 2 | 1 / 2 | 1 / 2 | |
| | **Solar Cells** | 6 / 8 | | | | |
| | **Gyroscope** | 1 / 2 | 1 / 2 | 1 / 2 | | |
| | | | | | | |
| Actuators | **Reaction Wheels** | | 3 / 4 | 3 / 4 | 3 / 4 | Not for control during OCM |
| | **Magneto Torquer Bars** | | | 3 / 3 | 3 / 3 | Internally Redundant |
| | **Thrusters** | 4 / 8 | 4 / 8 | 4 / 8 | 4 / 8 | 2 sets of 4 THR |

# Spacecraft AOCS modes & equipments

| | | |
|---|---|---|
| Coarse Gyrometer - SELEX CRS | 2 | 0.8 |
| Star Tracker Optical Head - Sodern Hydra | 3 | 1.3 |
| Star Tracker Electrical Unit - Sodern Hydra | 2 | 1.8 |
| Sun Sensor - TNO TPD | 8 | 0.0 |
| Reaction Wheel - Rockwell Collins | 4 | 8.0 |
| **Optional** : Magnetometer (Lusospace) | 2 | 0.5 |
| **Optional** : Magnetotorquer | 3 | 4.7 |
| **Overall Mass** | **7** | **56.2** |
| **Overall without MAG/MTB (Baseline)** | **5** | **41.1** |

- **All these equipment have available back-ups, with radiation-hardening design for GEO missions.**

# Conclusion

- Pointing accuracy is within reach,
- Reaction wheels can be used for the mission,
- Sentinel-3 equipments are used in baseline for power and mass budget,
- Some modification have to be implemented to existing platforms (for example Proteus) to fulfill the mission
  - Mainly in terms of sensors/actuators used in some modes (SAM cannot rely on B field),
- The spacecraft could accommodate both MTB and THR unloading sub-modes of Nominal Mode,
- MTB in OFF mode are not harming PHARAO, and 40 $Am^2$ could be accommodated far enough from PHARAO to be used during measurements,
- MTN is kept as an option in the design :
  - THR are anyway on board due to OCM needs and Safe Mode at apogee
  - Mass of MTB is not negligible if mass is a concern (vs fuel consumption)
  - If fuel consumption increases after Phase A (inertia and disturbances increase) the introduction of MTB is possible and reassuring as a risk mitigation vs fuel tank filling.

# Space Time Explorer


*Propulsion*

Session 8

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Main Assumptions

- Launcher = SOYUZ
- Dry Mass = 900 kg
- Mission lifetime = 5 years
- Propellant consumption
  - Reaction Wheel Off-loading = 2 kg/year
  - 2 Safe Mode/Sun Acquisition Mode per year = 2.1 kg (whole mission)
- No propellant is required for the S/C Slew
- The thruster configuration proposed
  - 1N thrusters for the rest of the manoeuvres (4+4 thrusters)
- Geometric efficiency ~ 0.93 (@ 15 deg)

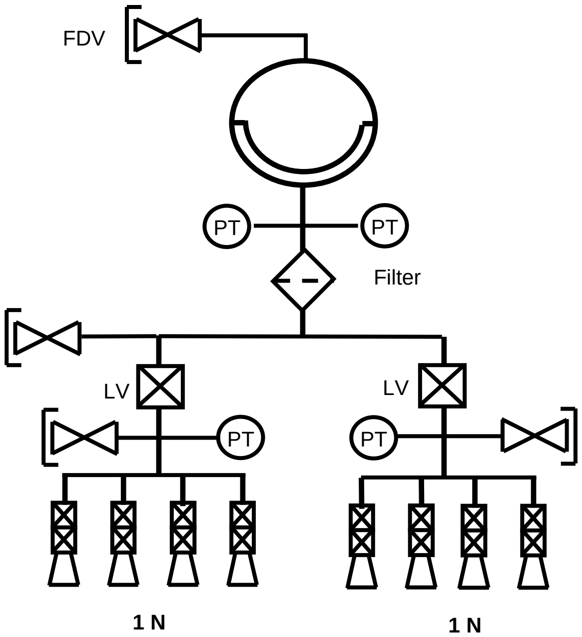
# Propellant budget

| Mission Phase | | Delta-V budget [m/s] | Thrust [N] | Isp [s] | Acc. Propellant consumption [kg] |
|---|---|---|---|---|---|
| Launcher Dispersion | Init | 0 | 0.99 | 221.3 | 0 |
| | Fin. | 6.43 | 0.91 | 219.2 | 2.9 |
| Orbit Maintenance | Init | 6.43 | 0.91 | 219.2 | 2.9 |
| | Fin. | 106.43 | 0.43 | 207.4 | 47.5 |
| 10 Safe Modes + 10 Safe Acquisition Mode | Init | 132.39 | 0.43 | 207.4 | 47.5 |
| | Fin. | 132.39 | 0.38 | 206.5 | 59.6 |
| EOL Propellant Residuals + 10% Margin | | | | | 7.5 |
| **TOTALS** | | | | | **67.1** |

# Dry Mass budget breakdown

| | Units | Model | Supplier | Unit Mass (incl. margin) [kg] | TRL |
|---|---|---|---|---|---|
| Propellant tank | 1 | Sea-Star | MTSP (UK) | 9.0 | 6 |
| Service Valves | 4 | 3-barrier | EADS-ST (DE) | 0.08 | 8 |
| Pressure transducer | 4 | SAPT | BRADFORD (NL) | 0.32 | 8 |
| Propellant Filters | 1 | RA01809A | SOFRANCE (FR) | 0.08 | 8 |
| Latch Valve | 2 | 51-166 | MOOG (US) | 0.38 | 8 |
| Thruster Pair (1N) | 4 | CHT-1N | EADS-ST (DE) | 0.82 | 8 |
| Piping | 1 | TBC | TBC | 0.94 | 8 |
| Bracketing | 1 | TBC | TBC | 1.82 | 8 |
| TOTAL | | | | 17.5 | |

# Main Schematic

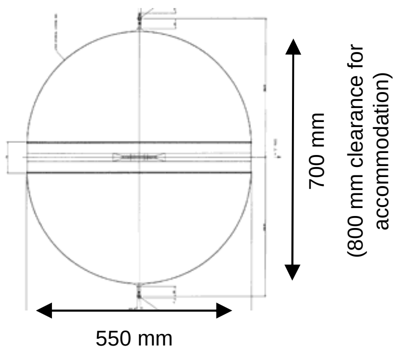


# Total Mass budget

| | Units |
|---|---|
| Propellant | 67.1 |
| Dry Mass | 17.5 |
| N2 gas | 0.7 |
| TOTAL | 85.3 |

# Accommodation

– Main dimensions of the MT-SP tank (1 tank needed):




– This tank is not subjected to ITAR regulations
– The internal membrane is silica-free. This prevents the risk of thruster failure for long throughputs
– TRL 6/7

– Additional panel is required for component integration
  • ~Size 400 mm × 800 mm

# Space Time Explorer


## Ground Segment and Operations

Internal Final Presentation

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Communication Requirements

- High continuous ACES data rate is 50 kb/s, average data rate 20 kb/s.
- Standby ACES data rate is 0.5 kb/s
- Housekeeping data rate of satellite of 5 kb/s assumed (including payload standby/ housekeeping and system housekeeping)
- With full duty cycle of the ACES payload you have a downlink requirement per 16h orbit of:
  - Science: 16h * 3600 * 20 kb/s = 1150 Mb
  - HK: 16h * 3600 * 5 kb/s = 290 Mb
  - Total (10% overhead): (1150Mb + 290Mb) * 110% = 1600 Mb

# Tracking Requirements

- 2m orbit accuracy all directions requirement for science
- Standard accuracy is sufficient for orbit control, but much less accurate than required for science
- Science accuracy to be achieved by orbit model taking into account combination of measurements from:
  - GPS during perigee (below GPS/Galileo orbit)
  - GPS during whole orbit as growth option (not baseline)
  - MWL Doppler from ground terminals
  - MWL ranging from ground terminals (needs optical ranging for calibration for high accuracy)
  - Optical ranging (weather dependent)
  - Doppler and ranging from ground stations in apogee (perigee by GPS), (only standard ranging accuracy of 1m relative, 5m absolute in line of sight during overflight, much lower accuracy for prediction for other parts of orbit)

# Choice of Ground Stations

## Tradeoff between S/X and X-band and 15m/35m stations

<table>
<tr><th></th><th colspan="2">15m station</th><th colspan="2">35m station</th></tr>
<tr><th></th><th>S-band</th><th>X-band</th><th>S-band</th><th>X-band</th></tr>
<tr><td>Data rate</td><td>On board design readily available, 1 Msymbol/s gives ~ 500 kb/s</td><td>Feasible, but less station choice and no simple on board design</td><td>Only one station (NNO), max data rate (~ 5 Mb/s) limited by bandwidth</td><td>No simple on board design,<br>Bandwidth (10 MHz) allows ~ 8Mb/s</td></tr>
<tr><td rowspan="2">Tracking accuracy</td><td colspan="2">Standard accuracy (~1 to 2m ranging residual, 5 to 10m absolute accuracy)</td><td>Troposphere calibration and Doppler as for X-band</td><td rowspan="2">Reuse of Bepi Colombo radio science designs, possible: Adev ~ $10^{-14}$ Doppler, 15 cm range<br>X-band Wide Bandwidth Ranging System still bandwidth limited and needs development</td></tr>
<tr><td colspan="3">ESA standard ranging not compatible with symbol rates > 750 ksymbols/s (~300 kb/s info rate)<br>=> serial operation of high rate communications and ranging</td></tr>
</table>

# Choice of Ground Stations: Tracking

- State of the art deep space tracking techniques can be used also for STE orbit. Those could be made available in X-band at the deep space stations (except for inonosphere which requires dual band).
- Media calibration for long apogee passes can also make use of GPS media correction service.
- Orbit accuracies based on (improved) ground station measurements can be improved by post processing and averaging over many orbits. Still improvement by more than factor of 10 compared to Lisa Pathfinder results is unlikely.
- Even best modeling based on improved ground station measurements alone falls short of requirement by a factor of ~ 2.5. (TBC, precise value would need study.)

# Choice of Ground Stations: Tracking

- Additional orbit measurements are required and are feasible (with the payload and GPS).
- With additional measurements (GPS, MWL etc.) the gain from ground station tracking improvements on the overall orbit accuracy is no longer a driver (still nice to have Doppler from ground station at apogee).

⇒Select ground station for communications,

(use tracking capabilities at apogee as is, but with GPS assisted media compensation)

# Tracking

- Orbit determination for science should not be an operational service
- ESOC offers a Flight Dynamics staff (1 manyear/year equivalent) to provide the orbit determination for STE science:
  - Full access to ESOC tools, data and expertise
  - Under science contract, can be adapted to needs, provides flexibility
  - Non operational service can provide high performance at much lower cost than operational guaranteed service
  - Service is offered as option (science is free to seek support elsewhere)

# Choice of Ground Stations

- 1.6 Gb downlink requirement can be easily met with 15 m ground station and 2h of 0.5 Mb/s link:
  - 2 * 3600s * 0.5 Mb/s = 3600 Mb (1600 Mb requirement)
- With same on board equipment no improvement with 35m ground station.
- Anyway limited theoretical improvement with 35m station due to narrow bandwidth limit.

$\Rightarrow$ 15m ground station is selected as baseline

- S-band gives more choice for number of 15m ground stations
- S-band on board equipment readily available

=> S-band is selected as baseline

# Choice of Ground Stations

- 15m stations are phased out from ESA ESTRACK network
- Respective service will still be available to ESA missions (but bought from outside, sufficient capacity available, transparently to the mission)
- Some of the (ex-) ESA 15m stations will be taken over by private companies, which ones is TBD
- Problem: Most other commercial S-band stations are smaller and have a (slightly) higher system temperature. Typical are 13m stations with G/T of 22 to 23 dB/K (ESTRACK 15m stations 27.5 to 29 dB/K).
- Performance difference is ~ - 6 dB

# Choice of Ground Stations

Communications Baseline

- Make mission design compatible with commercial 13m S-band stations.
  - 125 kb/s and 4 h passes per orbit in apogee
    - (4 * 3600s * 0.125Mb/s = 1800 Mb/orbit (1600Mb/orbit requirement)
    - Parallel ranging TBC
- Keep high data rate option (0.5 Mb/s) on board for optimum compatibility with 15m (ex-) ESTRACK stations
  - 2h/orbit communications
  - Serial ranging and high data rate communications

# Space Time Explorer

*Radiation*

IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team


(*) ESTEC Concurrent Design Facility

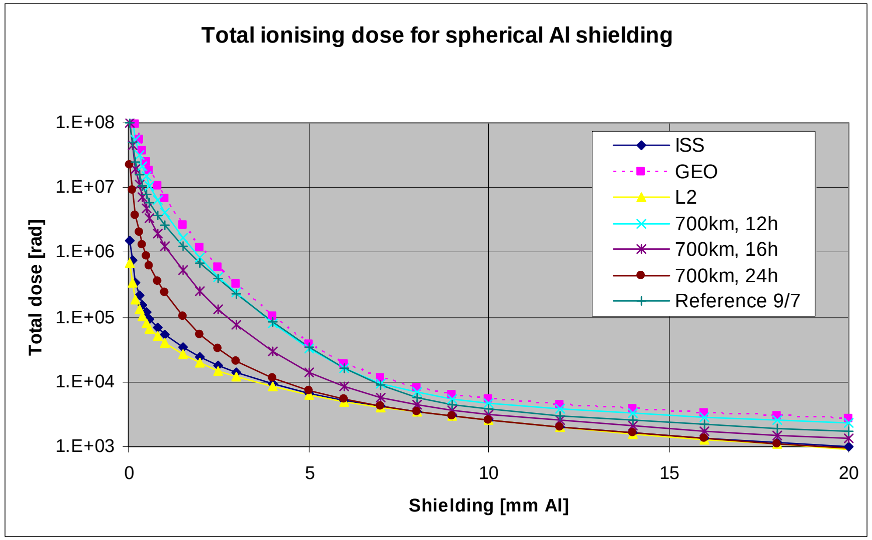
# Radiation

| Radiation effect | Parameter |
|---|---|
| Electronic component and material degradation | Total ionizing dose. |
| Material (bulk damage), CCD, sensor and opto-electronic component degradation | Non-ionizing dose (NIEL). |
| Solar cell degradation (power output) | NIEL & *equivalent fluence.* |
| Single-event upset (SEU), latch-up, etc. | LET spectra (ions);<br>proton energy spectra;<br>explicit SEU/SEL rate of devices. |
| Sensor interference (background signals) | Flux above above energy threshold and/or flux threshold;<br>explicit background rate. |

# Radiation

- Predictions of the radiation environment:
  - Total ionising dose
  - Equivalent fluences for solar cell degradation (GaAs cells assumed)
  - Non-ionising dose for displacement damage
- Simulation using the SPENVIS tool
- Models applied: AE8,AP8, ESP (w. 90% confidence, worst case w.r.t. solar cycle), SHIELDOSE-2, EQFRUX
- Orbits:
  - Highly elliptical, perigee 700km, inclination 63.4deg, orbital period 16h, but sensitive to raan/argper, which will drift during mission
  - For comparison HEO 12h, 24h, ISS, GEO, L2
- Mission duration 5years assumed

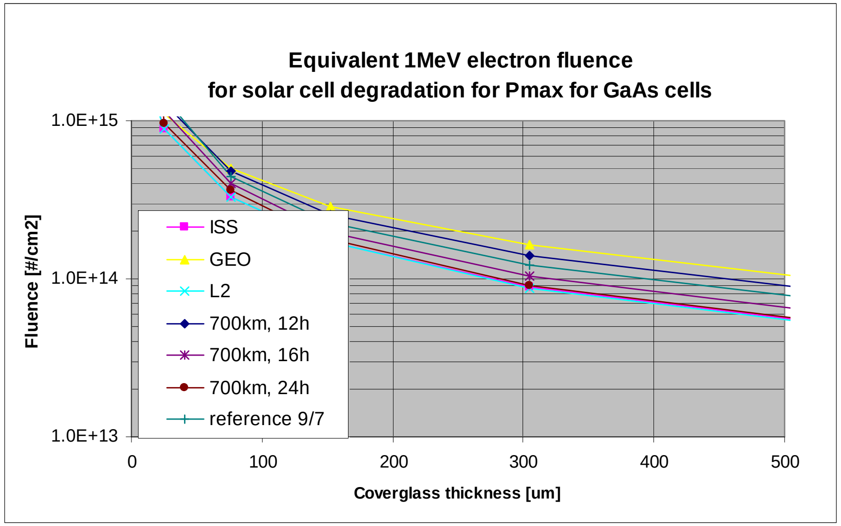
# Radiation
## total ionising dose




Observations:

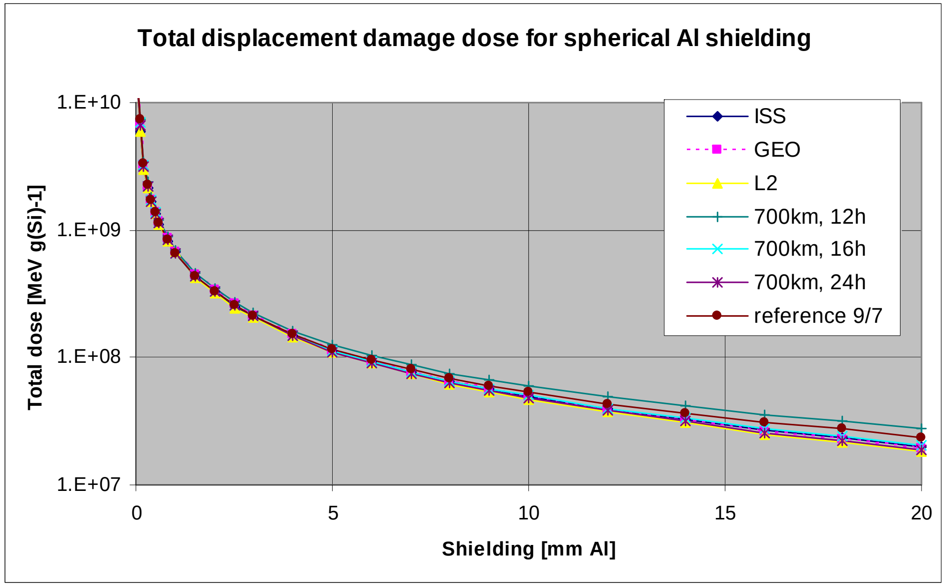
- 12h orbit seem comparable to GEO, 24h orbit seem comparable to ISS with 16h orbit in between
- But because high inclination HEO, dose very dependent on raan/argper – initial orbital parameters of reference orbit give values close to GEO – will drift – more detailed analysis needed

# Radiation
## Equivalent fluences for GaAs solar cell degradation




- Observation - similar to the ionising dose, but in general less dependency on orbit

# Radiation
# non-ionising dose




- Observation: 12h orbit stands out as worse than the other, but in general less sensitivity to the orbit

# Mitigation measures

- General:
  - Shielding
  - Radiation hardness of components
  - Operational measures (pointing etc.)

- STE mission
  - Equipment designed for GEO can be used as is
  - Equipment designed for ISS and used in a configuration with no margin w.r.t. shielding will require additional shielding (~3mmAl)

# Space Time Explorer

*Data Handling System*


IFP

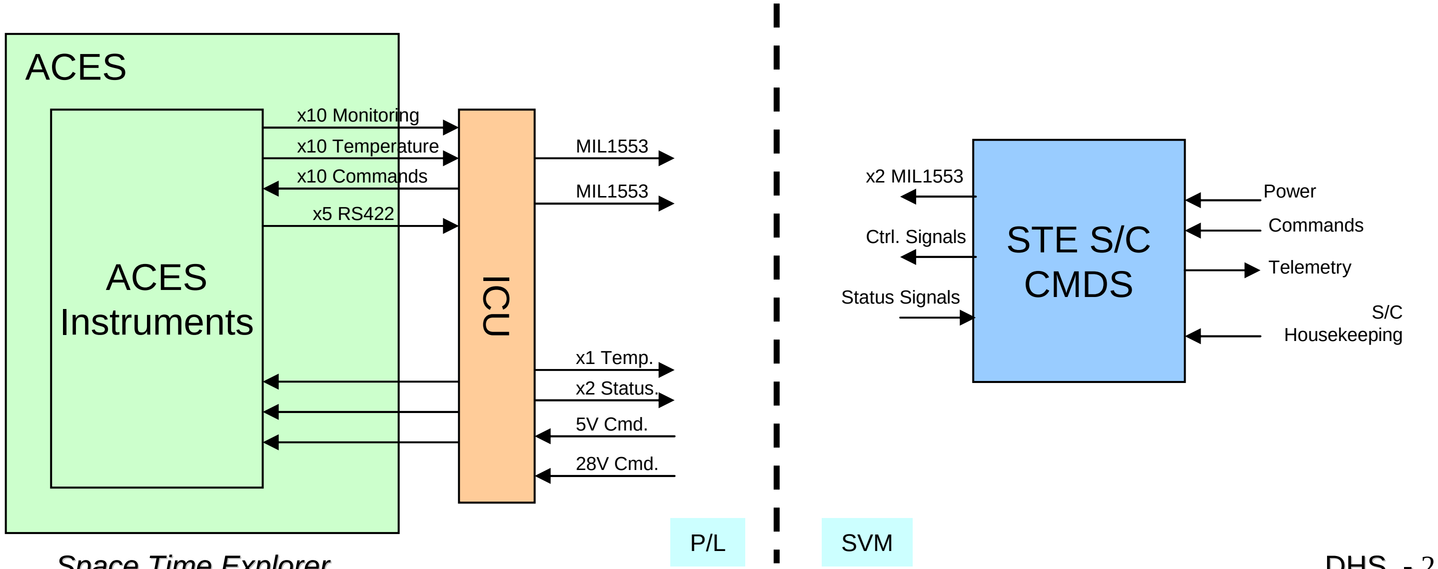
ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Trade-offs (1)

- Instrument Control Unit (ICU) to de-couple PLM and SVM
  - Heritage from ACES PDU + XPLC

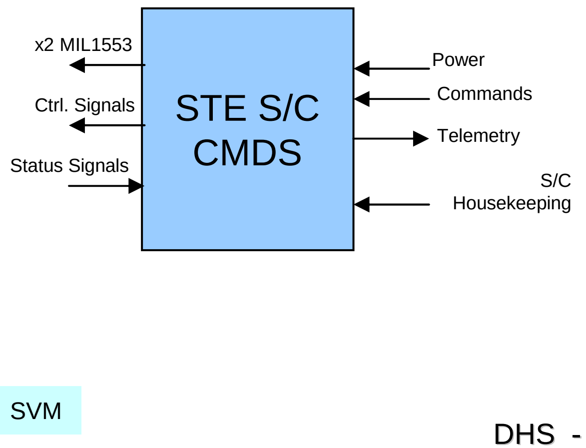


# Trade-offs (1)

- Pros
  - Independency
  - Interfaces to the S/C DHS are clear and super simple
    - Can benefit from heritage in previous projects (TRL)
    - Can benefit from generic platforms (e.g. PROTEUS like)
  - Simplifies programmatics and AIT activities
  - Mass memory is provided by the instrument computer (XPLC)

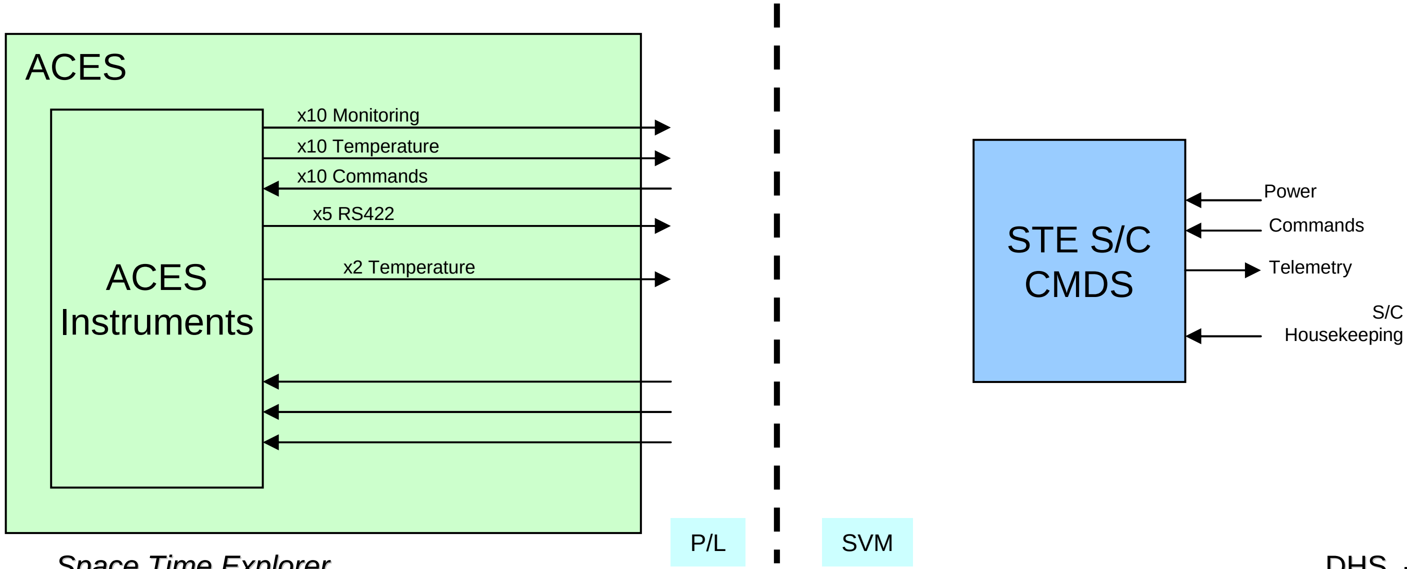
- Cons
  - Mass and power budgets increase (not significantly)
  - XPLC and PDU to be modified and integrate the ICU
    - Heritage from previous units

). Modify XPLC and PDU



# Trade-offs (2)

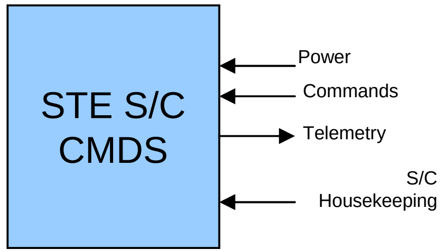
- SVM DHS controls and interface directly to the instruments



## Trade-offs (2)

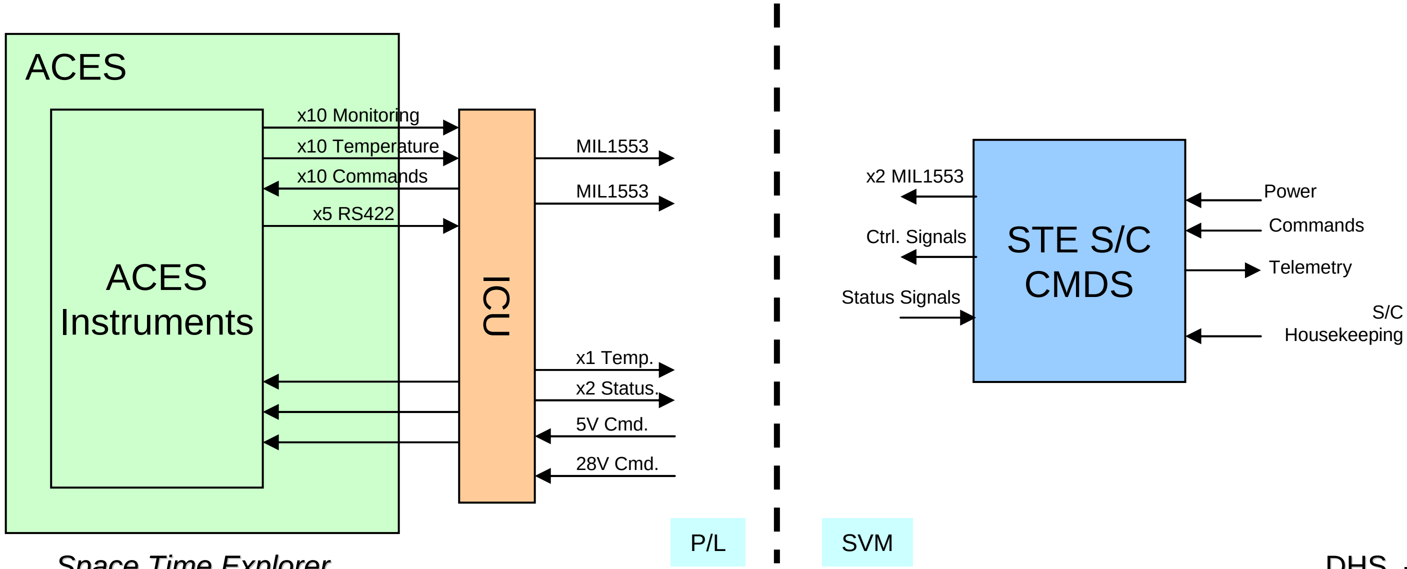
- Pros
  - Slightly mass and power budgets reduction
  - No payload modification (XPLC and PDU not used)
- Cons
  - Interfaces to the S/C DHS are more complicated and Ad-hoc
    - More difficult to benefit from heritage in previous projects
    - Generic platform might not be an option anymore
    - Mass memory needs to be provided by the S/C DHS plus the interface to it
  - Platform change may have an impact

s (no XPLC/PDU)




SVM

# Baseline Architecture



# Memory Storage

- Data rates
  - Baseline assumes the Payload to stores all scientific data (ICU)
  - DHS only allocates memory for housekeeping
    - **HK data rate ~5 Kbps**
  - Some Scientific data to be transmitted via the SVM
    - **20 Kbps** average
    - **70 Kbps** peak
    - MIL-STD-1553 provides 1 Mbps link (~800 Kbps considering protocol overhead)
    - **No need for high speed data link**

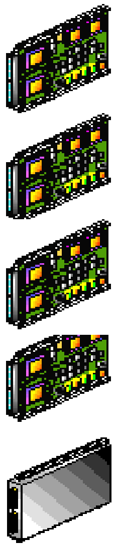
| Instrument | | Data Volume | Operation Time (s) | Data Rate (kbps) |
|---|---|---|---|---|
| **STE Payload** | Science | 6048000.00 [Kbit] | 86400.00 [s] | 75.00 [Kbps] |
| | Housekeeping | 432000.00 [Kbit] | 86400.00 [s] | |
| | *Total* | *6480000.00 [Kbit]* | *172800.00 [s]* | |
| | | | | |
| | | ***Data Volume*** | | |
| ***Total*** | | ***6.18 [Gbit]*** | | |
| ***7 x Total*** | | ***43.26 [Gbit]*** | | |

- Memory Storage
  - ICU memory storage for 7 days **44 Gbits EoL**

Having high speed data link would have no impact in the ICU/XPLC and/or DHS design

# SVM/DHS Baseline Architecture Summary

x2
x2
x2
x1
x2



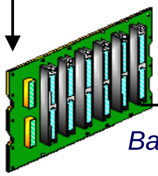
**Onboard Processor Board**
- LEON2/3 based computer cold redundancy
- MIL-STD-1553 nominal/redundant

**I/O Board**
- Different Input/Ouputs

**TTRM**
- TM/TC interfaces (redundant)
- Reconfiguration Module and HPC

**Memory Board**
- FLASH, PROM and EEPROM
- Controller

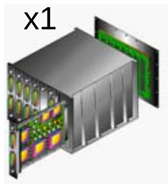
**DC/DC Board**
- Internally redundant
- Hot/cold redundancy



*Backplane*

*Chassis*

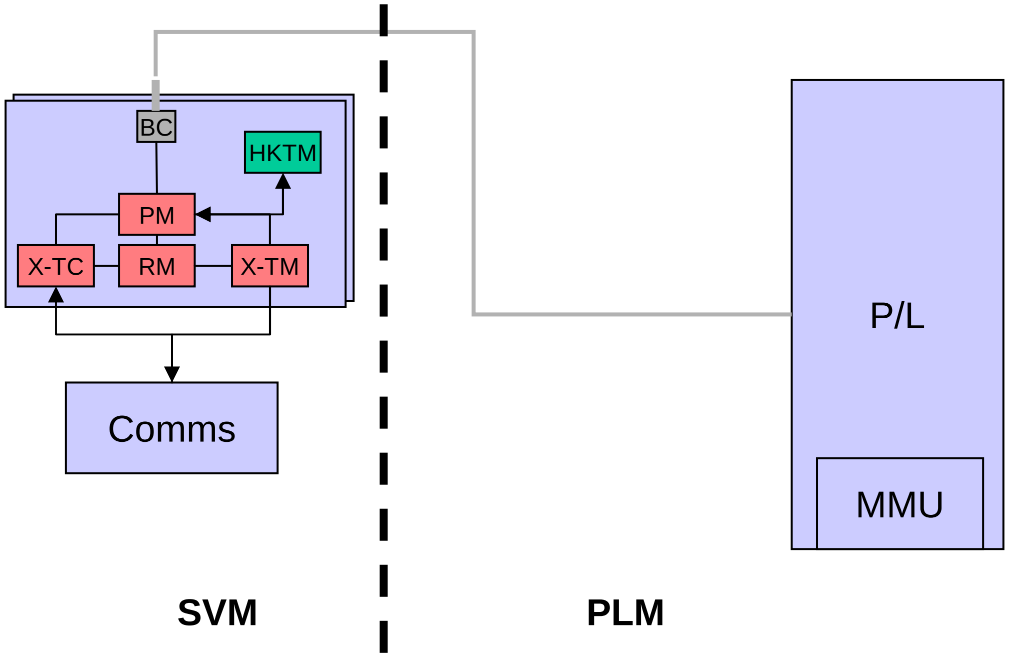
x1



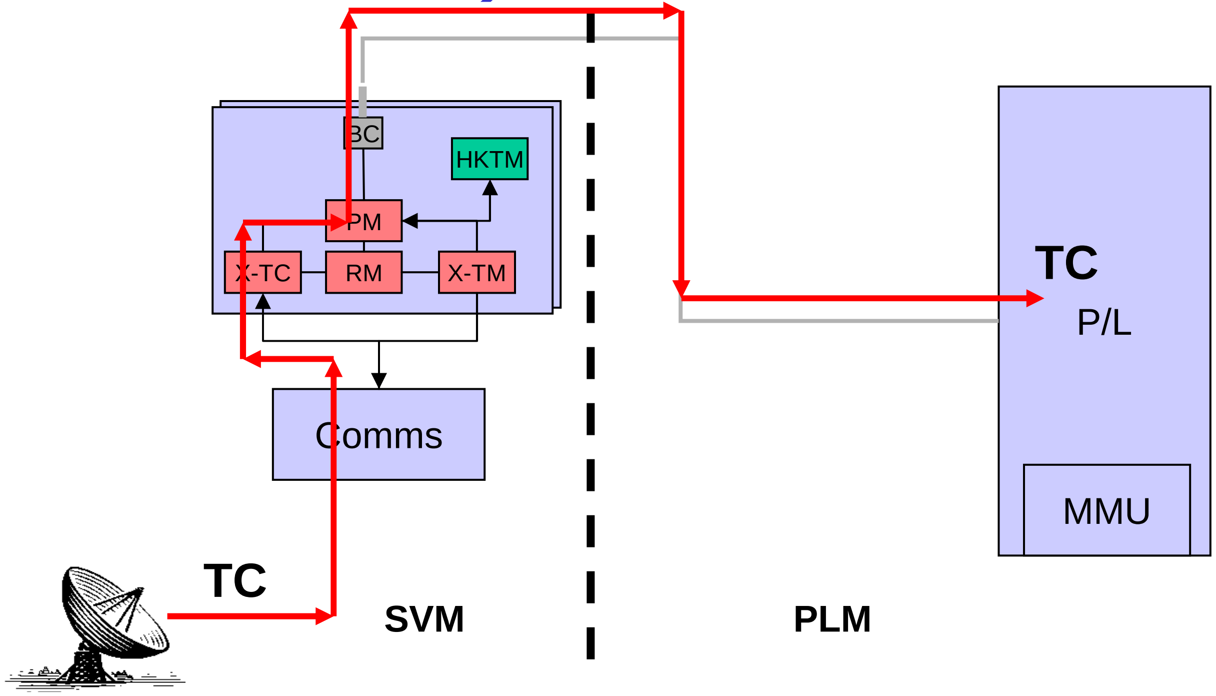
**CMDS – Command & Management Data System**
- MMU: Up to 2000 Gbit EoL
- Mass: 7.7 Kg
- Peak Power: 29.3 [W]
- Low Power: 20.63 [W]
- Safe Mode: 10 [W]

| STE On Board Computer Avionics | Boards | Mass/unit (Kg) | Mass (Kg) | Low Power (W) | High Power (W) |
|---|---|---|---|---|---|
| w/o Margin | 9 | - | 7.70 [kg] | 20.63 [W] | 29.38 [W] |
| OBC | 2 | 0.70 | 1.40 | 6.00 | 10.00 |
| TTRM | 2 | 0.40 | 0.80 | 2.00 | 3.00 |
| I/O Board | 2 | 0.60 | 1.20 | 8.00 | 8.00 |
| MMU (FLASH board) | 1 | 0.50 | 0.50 | 0.50 | 2.50 |
| DC/DC | 2 | 0.80 | 1.60 | 4.13 | 5.88 |
| Housing | - | - | 2.20 | - | - |
| with 10% Margin | - | - | 8.47 [kg] | 22.69 [W] | 32.31 [W] |

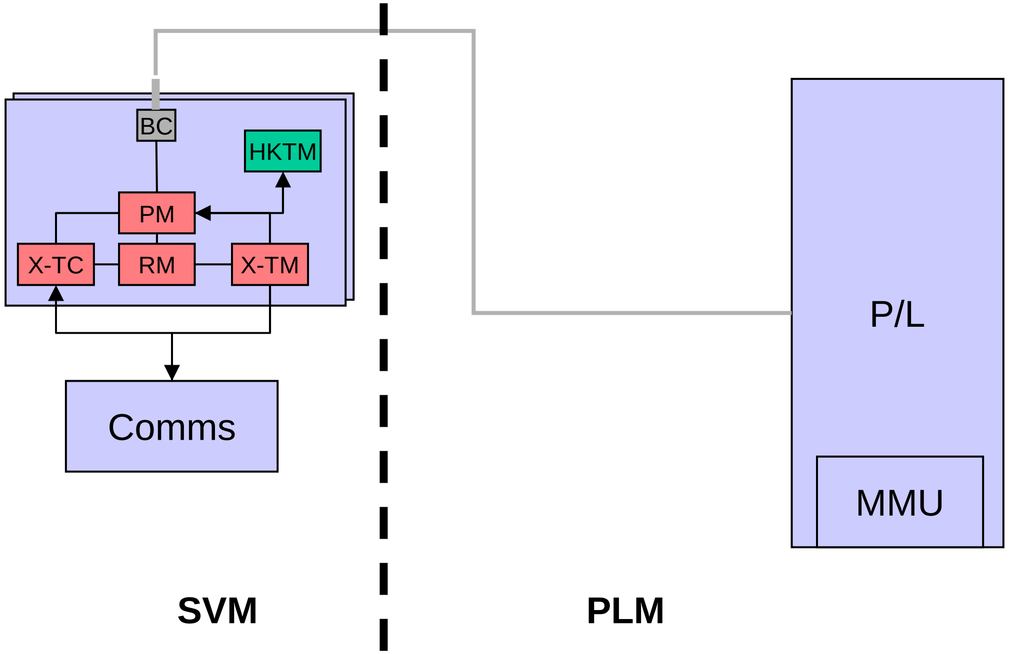
# TC/TM Path



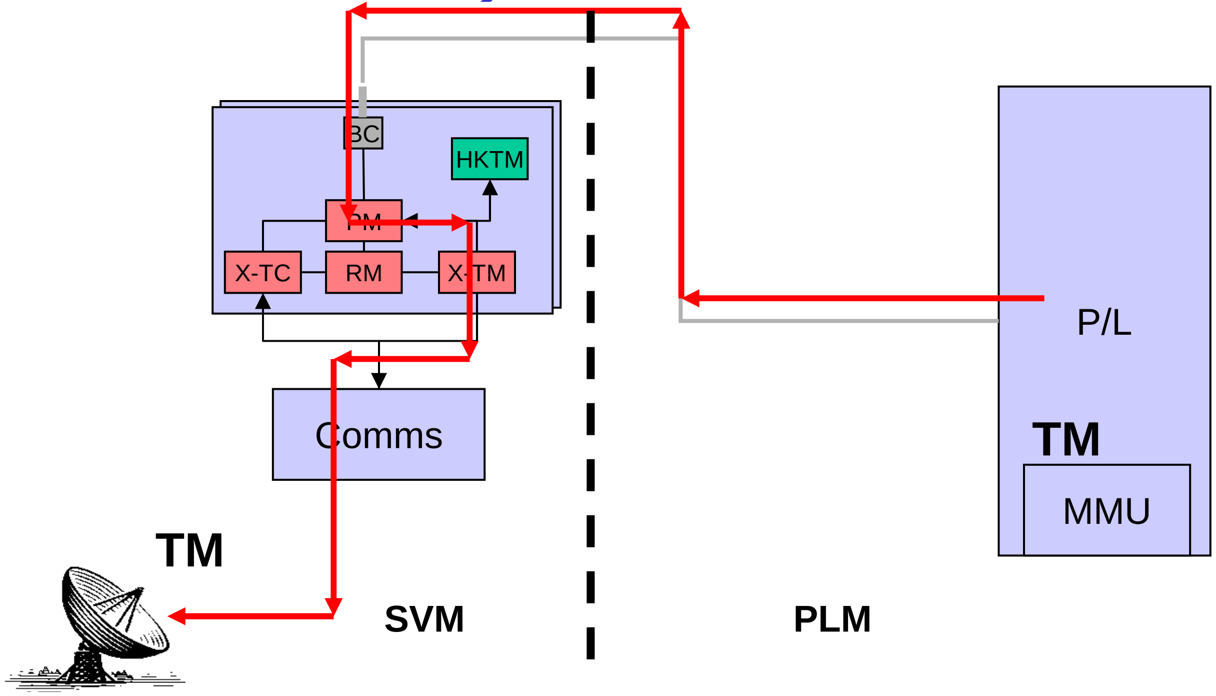

# TC/TM Path



# TC/TM Path

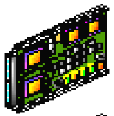



# TC/TM Path



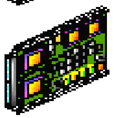
# PLM/ICU Design

x2



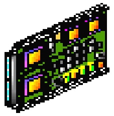
**Onboard Processor Board**
- LEON2/3 based computer cold redundancy
- MIL-STD-1553 nominal/redundant

x2



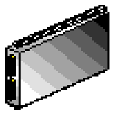
**I/O Board and RM**
- Different Input/Output lines
- Reconfiguration Module

x1

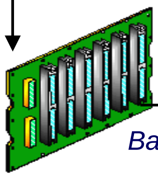


**Memory Board**
- FLASH, PROM and EEPROM
- Controller

x4

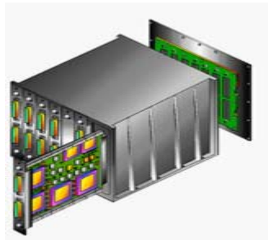


**DC/DC Board(s)**
- Provides power for the ICU
- Provides secondary power lines to the STE Instruments
- Provides ~600 W to Instruments (TBC)



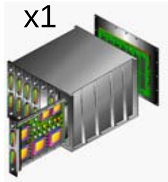
*Backplane*

*Chassis*



*Space Time Explorer*

x1



**ICU – Instrument Control Unit**
- Instrument MMU
- Mass: ~14 Kg wo margin
- Peak Power: ~131 [W]*
- Low Power: ~40.23 [W]*
- Safe mode: ~10 [W]

| STE Instrument Control Unit | Boards | Mass/unit (Kg) | Mass (Kg) | Low Power (W) | High Power (W) |
|---|---|---|---|---|---|
| w/o Margin | 9 | - | 13.58 [kg] | 33.53 [W] | 131.23 [W] |
| OBC | 2 | 0.80 | 1.60 | 6.00 | 10.00 |
| I/O Board | 2 | 0.80 | 1.60 | 8.00 | 8.00 |
| MMU (FLASH board) | 1 | 0.50 | 0.50 | 0.50 | 2.50 |
| DC/DC | 4 | 1.50 | 6.00 | 19.03 | 110.73 |
| Housing | - | - | 3.88 | - | - |
| with 20% Margin | - | - | 16.30 [kg] | 40.23 [W] | 157.47 [W] |

(*) Power supplied to instruments taken from ACES budget report chapter 2.5 and instruments workbook

| Instrument | Ppeak [W] | Low [W] | Safe Mode [W] |
|---|---|---|---|
| PHARAO | 113.50 [W] | 18.20 [W] | 2.50 [W] |
| MOLO | 60.00 [W] | 30.00 [W] | 2.00 [W] |
| FCDP | 8.40 [W] | 8.40 [W] | - |
| MWL | 71.50 [W] | | |
| CCR | 2.00 [W] | - | - |
| GNSS | 7.00 [W] | 5.00 [W] | - |
| LCT | 160.00 [W] | - | - |
| Total | 422.40 [W] | 61.60 [W] | 4.50 [W] |

# Summary

- Strong heritage in both SVM and PLM avionics

- ICU
  - Instrument computer
  - Secondary power distribution to instrument
  - Power budgets need to be further revised with last update figures from ACES
  - ICU design regarding the secondary power lines to be provided needs to be revised when details about the secondary voltage lines are provided
  - No concerns about TRL level

| | PLM ICU | SVM DHS |
|---|---|---|
| **Mass** | 14 [Kg] | 8 [Kg] |
| **Peak Power** | 131 [W] | 29 [W] |
| **Low Power** | 41 [W] | 21 [W] |
| **Safe Mode** | 10 [W] | 10 [W] |
| **TRL** | 6-7 | 7-9 |

# Space Time Explorer


## *Programmatics / AIV*

Session 8 / IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Requirements & Design Drivers

- High Technology Readiness Level (TRL > 5 at the end of Phase A/B1, ~mid 2014)
- Low development risk in phase B2/C/D
- Compatibility with a medium class launcher (Soyuz)
- Cost at completion for ESA < 470 MEUR (2010)
- Launch at end 2022
- Number of microwave ground terminals 6
- Microvibration requirements
- Thermal stability requirements

# Payload

- Payload computer
- MW (microwave) clock on board (same as PHARAO on ACES)[1)]
- MOLO (microwave local oscillator => frequency output)
- FCDP (frequency comparison and distribution package[1)]
- MWL (microwave link)[1)]
- GNSS receiver[1)]
- LCT (laser communication terminal)
- 1 Corner cube
- Ka and S band antennas
- PDMU (power distribution and management unit)

1) heritage from ACES

# Assumptions & Trade-Offs

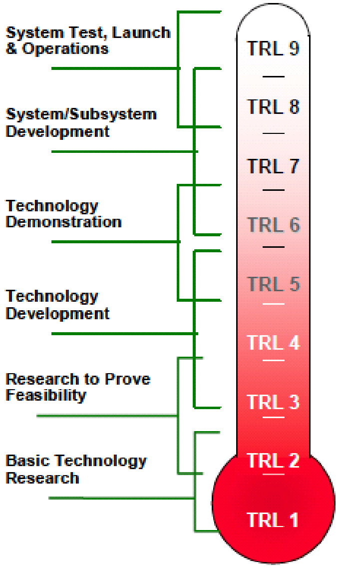
- Proteus-like Platform
  however changes are expected to be necessary
- Payload module
  is based on structure of existing payload modules for the same platform
- Microvibration requirements
  are modest due to heritage from ACES flying on ISS
- Ground terminal development and deployment
  is no schedule driver

# Options

A number of options have been considered:

- Smaller launcher
- Different platform
- LCT (Laser Communication Terminal) versus ELT (European Laser Timer)

# Technology Readiness Levels




| ESA&NASA Technology Readiness Levels[11] | |
|---|---|
| 9 | Actual system "flight proven" through successful mission operations |
| 8 | Actual system completed and "flight qualified" through test and demonstration (Ground or Flight) |
| 7 | System prototype demonstration in a space environment |
| 6 | System/subsystem model or prototype demonstration in a relevant environment (Ground or Space) |
| 5 | Component and/or breadboard validation in relevant environment |
| 4 | Component and/or breadboard validation in laboratory environment |
| 3 | Analytical and experimental critical function and/or characteristic proof-of-concept |
| 2 | Technology concept and/or application formulated |
| 1 | Basic principles observed and reported |

11) Technology Readiness Levels – A White Paper, April 6 1995, J. C. Mankins, NASA

# Technology Development Duration

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**

*) Reference EUI-AH/5205, Issue 4, Revision 1, 03.11.2005

# Technology Development

Baseline

- the technology maturity of the payload to be demonstrated shall be at the appropriate technology readiness level (TRL) before being selected.
- a clear development and verification status is required and in addition the envisaged development plan

Therefore

- TRL 5-6 shall be reached at at the start of the implementation phase B2/C/D *(development typically funded by R & D programmes)*
- For equipment at TRL 5-6 the typical development time needed to reach TRL 8-9, i.e. readiness for integration on a spacecraft, is usually 4 years (continued development) + 1 to 1.5 years for selection, project approval etc. *(typically funded by project or application programme)*

# Technology Readiness (estimated)

| Unit | TRL | Comments |
|---|---|---|
| MOLO<br>-High finesse cavity based laser local oscillator (RL)<br>-Frequency comb GHz reference signal (FLFC) | 4 | •RL heritage from ALADIN.<br>•Higher finesse cavity on ground but not tested in a space environment.<br>•FLFC laboratory instrument. Some drop tower experiments.<br>•Unit working with high finesse cavity laser and locked FLFC not proven in a relevant environment.<br>•Optic fibers in HEO orbits to 70 000 km (radiation?) |
| PHARAO | 5 | EM available for ACES. Modifications identified previously are required |
| FCDP | 5 | Technology clear. High resolution and lower noise electronics required |
| MWL | 6-7 | No new developments assumed. Deltas needed to account for new architecture and performance requirements. Testing possibly needed. |
| ICU (XPLC) | 7 | No new developments assumed. |

# Model Philosophy

- Re-using an existing platform without major structural changes should allow us to choose a PFM approach (i.e. no STM), complemented by an **Avionics Test Bench**.
- However during the study, using a Proteus like platform, it appeared that the design changes to the platform are significant, therefore building and testing an **STM** first is proposed.
- The STM should be refurbished and re-used for the **PFM**.
- All equipment shall be fully qualified at equipment or subsystem level.

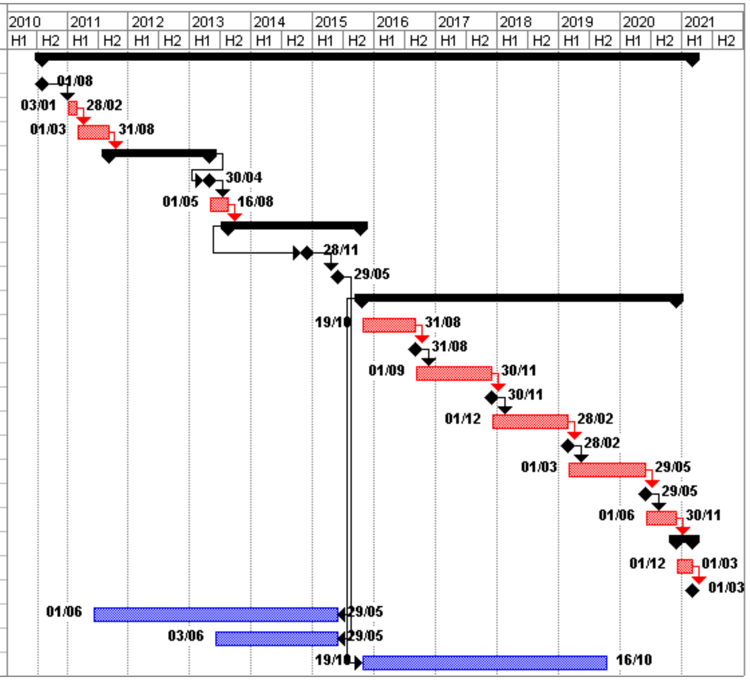
# Model & Test Matrix

| Test description | STM | ATB | PFM |
|---|---|---|---|
| Mech. Interface | R, T | | R, T |
| Mass Property | A, T | | T |
| Electrical Performance | | T | T |
| Functional Test | | T | T |
| Propulsion Test | | T | T |
| Thruster Lifetime Test | | T | A |
| Deployment Test | A, T | | A,T |
| Telecom. Link | - | T | A, T |
| Alignment | A, T | | T |
| Strength Load | A, T | | T |
| Shock/Separation | T | | T |
| Sine Vibration | A, T | | T |
| Modal Survey | A, T | | |
| Acoustic | A,T | | T |
| Outgassing | A, I | | I (T) |
| Thermal balance | A, T | | T |
| Thermal vacuum | (T) | | T |
| Micro vibration | A, T | | T |
| Grounding/Bonding | R, T | | R, T |
| Radiation Testing | | | A |
| EMC cond. interf. | | | T |
| EMC rad. interf. | | | T |
| DC magnetic | | | A, T |
| RF testing | | | T |

**Abbreviations:** I: Inspection, A: Analysis, R: Review , T: Test

# Schedule

| ID | Task Name |
|---|---|
| 1 | **Space Time Explorer** |
| 2 | Call for Proposal |
| 3 | Proposal evaluation - 2 month |
| 4 | Approval time - 6 month |
| 5 | **Assessment phase - 20 month** |
| 8 | MDR (Mission Definition Review) |
| 9 | Next phase go-ahead - 3.5 month |
| 10 | **Definition phase (Phase A/B1) - 26 month** |
| 15 | PRR (Preliminary Requirements Review) |
| 16 | SRR (System Requirements Review) |
| 17 | **Implementation phase (Phase B2/C/D) - 61.5 month** |
| 18 | Phase B2 (preliminary design) - 10.5 month |
| 19 | PDR (Preliminary Design Review) |
| 20 | Phase C (Detailed definition) - 15 month |
| 21 | CDR (Critical Design Review) |
| 22 | STM and ATB pocurement and qualification - 15 month |
| 23 | QR (Qualification Review) |
| 24 | STM refurbishment, integration and acceptance - 15 month |
| 25 | AR (Acceptance Review) |
| 26 | Contingency - 6 month |
| 27 | **Phase E1 - 3 month** |
| 28 | Launch preparation |
| 29 | LRR (Launch Readiness Review after ORR & FRR) |
| 30 | Technology development from TRL 3-4 to TRL 5-6 - 4 years |
| 31 | Technology development from TRL 4-5 to TRL 5-6 - 2 years |
| 32 | Technology development from TRL 5-6 to TRL 8-9 - 4 years |



# Schedule

- Assuming start of the implementation phase B2/C/D in the 4th quarter in 2015 a launch in 2021 appears feasible
- However this requires the continuation of the development of technologies with low TRL (MOLO) without delay.
- The development of technologies from TRL 5-6 to flight readiness, is supposed to be done under project responsibility. If this starts only with the project implementation phase, readiness for flight integration is without much margin.

# Summary & Critical Issues

- Development and implementation of this project within the given time frame appears to be possible, with some margin
- The payload development must be continued without delay
- The re-use of the Proteus like platform might require considerable adjustments which lead to the recommendation of a model philosophy with STM, ATB and PFM
- The legal framework for the deployment of ground terminals must be prepared well in time

# Space Time Explorer


*Risk*

ESTEC, 16th July 2010
Session #8

Prepared by the STE / CDF* Risk Domain

(*) ESTEC Concurrent Design Facility

# Contents

- Considered Mission Constraints
- Science Objectives
- Hypotheses
- Risk Assessment Summary

# Considered Mission Constraints

- TRL > 5 by end of Definition Phase (~ mid 2014)
- Low development risk B2/C/D
- Launch by 2022
- Soyuz launch from CSG, Kourou
- ESA CaC < 470 MEUR (e.c. 2010)
- Europe Lead Mission

# Science Objectives

- Objective I : Earth gravitational redshift test inaccuracy
- Objective IIa : Sun gravitational null redshift test inaccuracy
- Objective IIb : Geopotential measurement

# Hypotheses

- Mission duration 5 years simultaneously satisfying Objectives I and II
- Science data processing assured by dedicated scientific community means & resources (not ESOC)
- Orbit determination assured by several sources GPS/Optical/MWL/TRacking
- Objective I higher priority than objective II
- Pharao not required for objective II
- New Ground Terminals can be introduced any time during the mission and provide a contribution to the mission (e.g. in the event of failure of existing terminals)

# High Risk

Technical

| | |
|---|---|
| Low TRL of MOLO | - TDA as described |
| End-to-End MWL | - End-to-End Assessment |
| Lack of performance budget management | - Implement Performance Management |
| Failure of PHARAO to meet obsolescence/evolution requirements | - Obsolescence management plan (also programmatic)<br>- Evolutions plan |
| Extended mission duration with respect to Payload Reliability | - Reliability Assessment Plan |

# High Risk

Programmatic

| | |
|---|---|
| Impacts due to Overly Complex Project Organisation | -inter-agency commitments<br>-single P/L & MWT prime<br>-technical/science leadership for “scope creep” management |
| Loss of ACES Heritage technical resources and skills | -heritage technical resources and skills maintenance plan |
| Single Point Failures in Payload Supply Chain | -ensure adequate planning & associated funding<br>-accept/recognise single source for critical technologies<br>-wave geo return obligations for critical technos |

# Medium Risks

Technical

| | |
|---|---|
| Level of definition for Ground Terminals and associated implementation plan (worldwide) | -Define concept and TDA plan is appropriate |
| Comms MWL P/L switching antennas TRL | -TRL demonstration |
| Comms MWL P/L electronics TRL | -TRL demonstration or TDA Plan |
| Orbit determination concept | -TRL demonstration |
| Justified need for Optics and associated TRL level | -Justification & TDA, if required.<br>-Only for phase II |
| Potential High Delta-V requirement impacting solution | -Early Assessment Required via dedicated study |

# Medium Risks

Programmatic

| | |
|---|---|
| Ground Station/Ground terminal interfaces and worldwide coordination | -Interface definition and concept of operations |

# Low Risks

| | |
|---|---|
| Comms TT&C | |
| Comms MWL electronics S-band | |
| Comms MWL frequency allocation (Ka uplink, MWL S-Band & Ka dwl OK) | |
| Electromagnetic environment | - Assuming no Magneto Torquers |
| P/L FCDP Redesign | |
| DHS/ICU | |
| AOCS | |
| Thermal | |
| Vibration | |
| Power | |
| Configuration | |
| Structure | |
| Radiation Effects | - Extra shielding required |
| Propulsion (modifications required) | - Modified tank |
| Launcher & site compatibility | |
| Ground Operations | |

# Space Time Explorer


## *Thermal*

Session 8 - IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

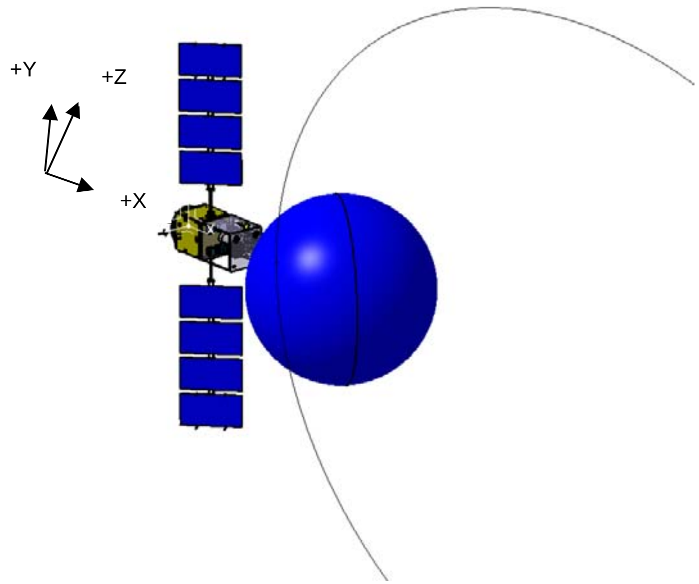
# Orbit & attitude

- Orbit:
  - p 700 km, a 50000 km
  - Inclination 63.5°
- Attitude:

  +X Earth Pointing, Yaw Steering

⇩

Minimum sun impingement on +/-Y walls → preferred for accommodation of radiators

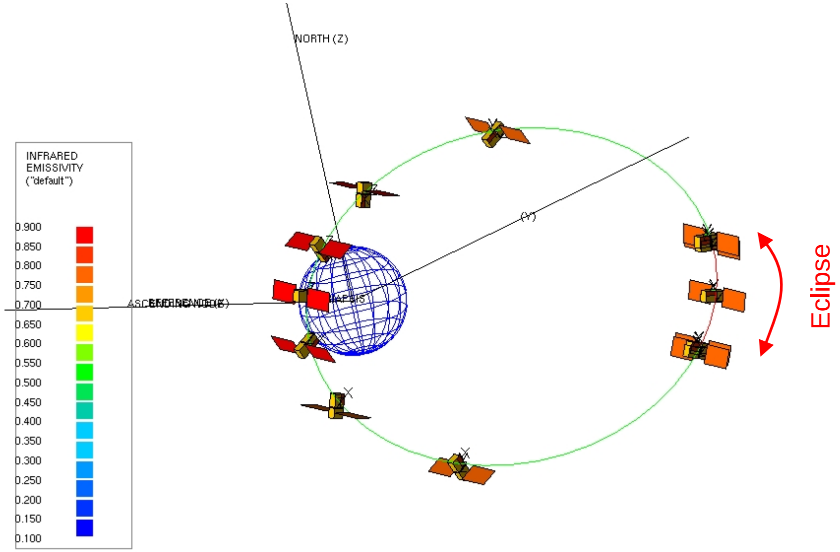


# Orbit & attitude

All angles between orbital plane and Sun direction possible

⇩

"Long Eclipse" orbit case identified as the most stringent (for stability and radiator sizing)



# Internal power dissipation

| Item | Nominal Mode [W] | Safe Mode [W] |
|---|---|---|
| PHARAO | 113.5 | 2.5 |
| MOLO | 60 | 2 |
| FCDP | 8.4 | 0 |
| MWL | 71.5 | 0 |
| LCT | (*) | (*) |
| GNSS | 7 | 0 |
| CCR | 2 | 0 |
| ICU | 175 | 3.5 |
| **TOTAL** | 437.4 | 8.0 |

- LCT has dedicated TCS: not considered in this study
- NM: based on peak power dissipations
- SM: conservative assumptions (data available only for Pharao/Molo; zero power dissipation assumed for all other items; ICU dissipation TBC)

# Temperature limits

| Item | Operative [°C] | Not Operative [°C] |
|---|---|---|
| PHARAO | -10 / +31.4 | -40 / +60 |
| MOLO | N/A | N/A |
| FCDP | -5 / +55 | -48 / +75 |
| MWL | -20 / +55 | -48 / +75 |
| LCT | N/A | N/A |
| GNSS | -35 / +75 | -40 / +85 |
| CCR | N/A | N/A |
| ICU | -20 / +50 (*) | -48 / +75 |

- TCS driven by Pharao limits
- Pharao drives also the stability requirement:

| Interface | Min / Max operating temperatures | Peak to peak Temperature stability |
|---|---|---|
| Base Plate | 10°C / 33.5°C | 3°C over 90 minutes, 4°C over 20 days |
| -X Wall | -20°C / 43 °C | No guaranteed Stability |
| Multi-Layer Insulation | Thermal insulation from the rest of ACES, except for UGB. | |

*Figure 14 : PHARAO thermal environment*

(*) given by XPLC

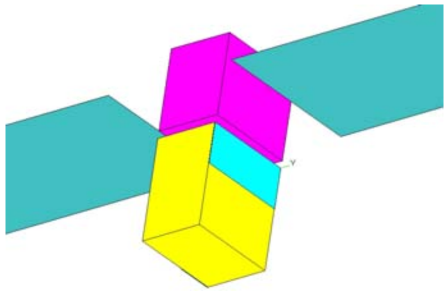
# Radiators sizing

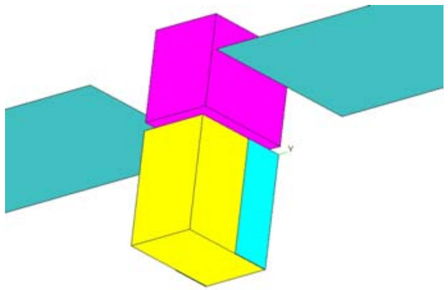
Radiator area: trade-off between the need to reject excess heat in hot conditions and to limit heat leak in low dissipation modes and cold conditions

⇩

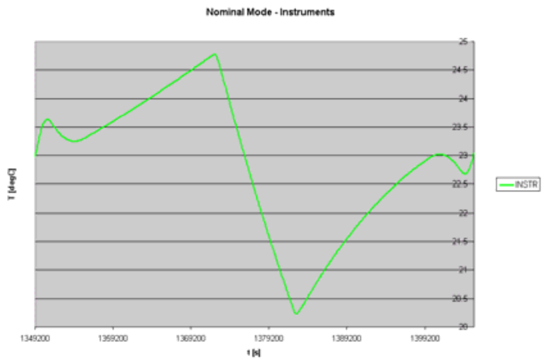
Required area: **1.315 m²**
(total value for +/-Y sides)

→ ~60% margin on available area
→ May be allocated "horizontally" or "vertically"
→ Room to allocate LCT radiator





# Results





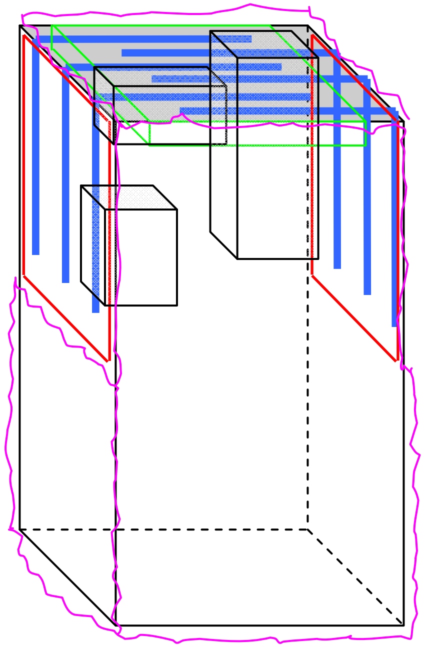
- Radiators: 1.315 $m^2$
- Heaters: 180 W, 77% duty cycle over orbit

⇩

✓ Temp limits: OK (with margins)

✓ Stability: OK (max 2.7°C over 90 min, may be improved)

# TCS design summary



- Design based on the ACES TCS
- Payload TCS completely independent from SM; all payload heat rejection requirements met only by radiation to the environment
- External: MLI 20-layers aluminized (body) + silver coated FEP tape (radiators)
- Internal: 6 heat pipes to transfer heat from units to radiators (L-shape, 3 per side); doublers and fillers used to enhance heat transfer. Heaters with thermostatic control to stay within temperature ranges.

# Items list & mass budget

| Element 1 | P/L | | | MASS [kg] | | | |
|---|---|---|---|---|---|---|---|
| Unit | Unit Name<br>Click on button above to **insert new unit** | Part of subsystem | Quantity | Mass per quantity excl. margin | Maturity Level | Margin | Total Mass incl. margin |
| 1 | MLI | | 1 | 2.243 | Fully developed | 5 | 2.355 |
| 2 | FEP tape | | 1 | 0.718 | Fully developed | 5 | 0.754 |
| 3 | Black paint | | 1 | 0.927 | Fully developed | 5 | 0.973 |
| 4 | HP | | 1 | 3.617 | Fully developed | 5 | 3.798 |
| 5 | Filler | | 1 | 0.204 | Fully developed | 5 | 0.214 |
| 6 | Doublers | | 1 | 3.564 | Fully developed | 5 | 3.742 |
| 7 | Heaters (M+R) | | 1 | 0.044 | Fully developed | 5 | 0.046 |
| - | Click on button below to insert new unit | | | 0.0 | To be developed | 20 | 0.0 |
| **SUBSYSTEM TOTAL** | | | **7** | **11.32** | | **5.0** | **11.88** |

# Power budget

| Element 1 | P/L | | | CIFICATION PER MODE | | | | | PPEAK AND POWER SPE | |
|---|---|---|---|---|---|---|---|---|---|---|
| Unit | Unit Name<br>Click on button above to insert **new unit** | Part of subsystem | Quantity | Ppeak | SAFE<br>Pon (W) | SAFE<br>Pstby(W) | SAFE<br>Dc(%) | NM<br>Pon (W) | NM<br>Pstby(W) | NM<br>Dc(%) |
| 1 | MLI | | 1 | 0.0 | | | | | | |
| 2 | FEP tape | | 1 | 0.0 | | | | | | |
| 3 | Black paint | | 1 | | | | | | | |
| 4 | HP | | 1 | | | | | | | |
| 5 | Filler | | 1 | | | | | | | |
| 6 | Doublers | | 1 | | | | | | | |
| 7 | Heaters (M+R) | | 1 | 180.0 | 180.0 | | 77.1 | 180.0 | | 0.0 |
| - | Click on button below to insert new unit | | | | | | | | | |
| SUBSYSTEM TOTAL | | | 7 | **180.0** | 180.0 | 0.0 | | 180.0 | 0.0 | |

- Total number of heaters: 44 (22 main lines + 22 redundant lines)
- Installed power: 180 W, duty cycle 0% in NM and 77% in SM

# Space Time Explorer

*Structures*

Internal Final Presentation

ESTEC, 16th July 2010


Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

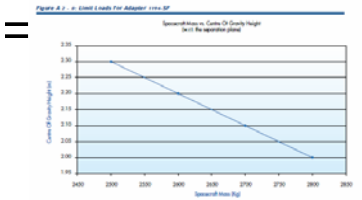
# Requirements

**The structure shall fulfil the following general requirements:**

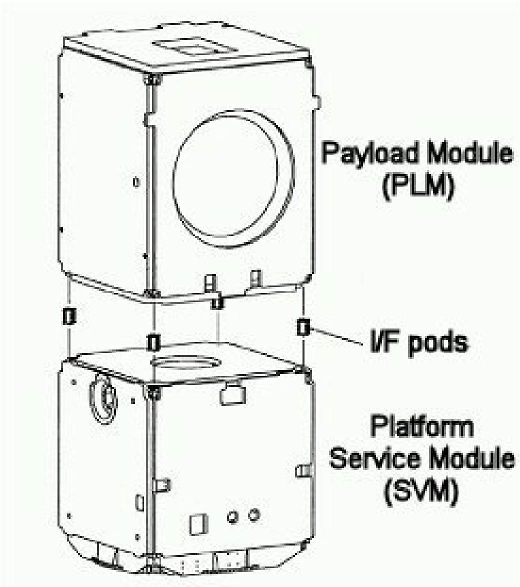
- Aim for simple load paths
- Withstand the design limit loads without failing or exhibiting permanent deformations that can endanger the mission objectives
- Ensures sufficient stiffness to decouple spacecraft modes from those of the launch vehicle
- Provide support and containment for spacecraft units, equipment and subsystems

# Requirements
# SOYUZ launcher

- The stack (platform and P/L module) shall have a structural stiffness which ensures that the fundamental eigenfrequencies are not less than:
  - 15 Hz in lateral direction
  - 35 Hz in longitudinal direction
- Make use of standard adapter I/F
  - 45 kg Ø 937 (2100/937/750 w. cog=1.75m) or
  - 110 kg Ø1199 (2100/1199/230 w.cog =

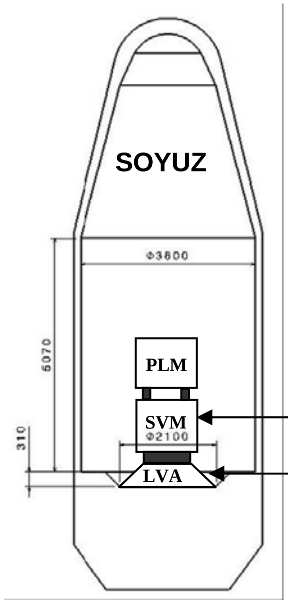


# Platform requirement



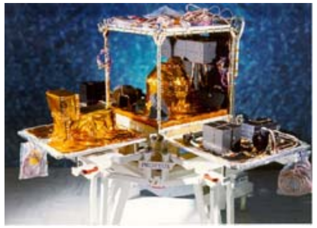

- The platform structure must provide mechanical accommodation to all equipment supporting the bus functions of the spacecraft.
- The platform structure must ensure mechanical integrity of the spacecraft throughout all the phases (integration, transportation, Launch, orbit life).
- The structure must provide stable geometry throughout the orbital life to ensure adequate positioning and pointing of the various sensors of the platform, as well as the payload interface

# Platform trade-offs




Dedicated or OTS-platform:
- CNES-PROTEUS (937mm I/F)
- ASI-PRIMA (1194 I/F)
- CNES-ISIS (?phase B-2010?)

OTS – Soyuz LVA
∅ 1194, 110 kg
∅ 937, 45 kg



+ Easy AIV
- Heavy baseplate

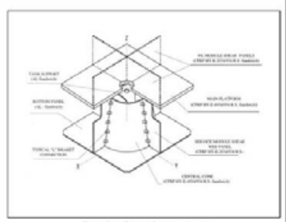
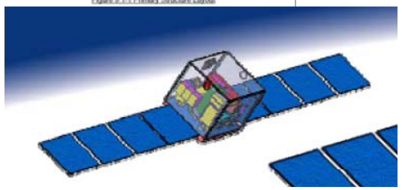
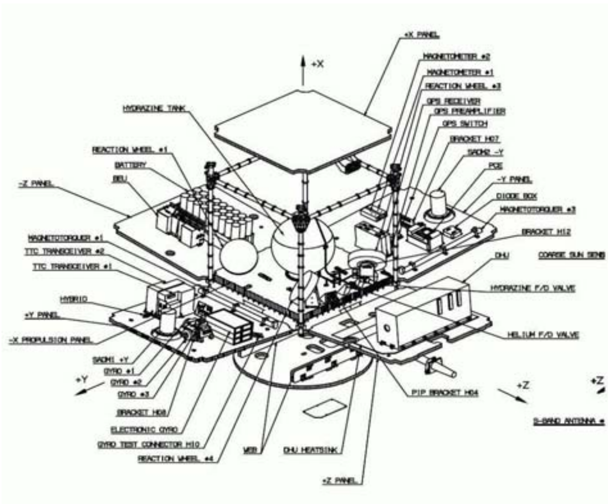


Figure 9.1-1 Primary Structure Layout

+ Simple load path
- More complex AIV



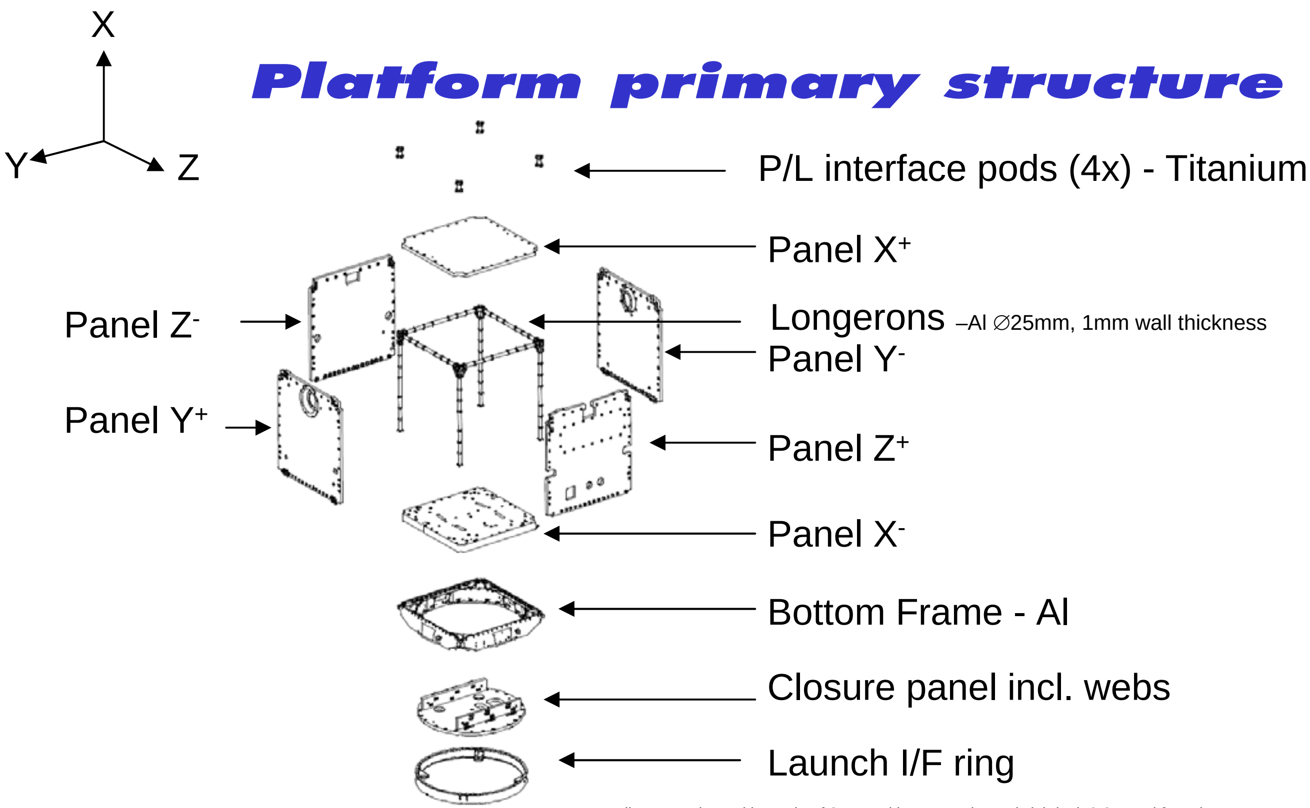
# PROTEUS Platform



| SATELLITE | JASON1 | CALIPSO | COROT | SMOS | JASON2 |
|---|---|---|---|---|---|
| Mission | Ocean Altimetry: Nadir Altimeter | Atmosphere (clouds, aerosols): LIDAR | Astronomy (astero-sismology, exo-planets) | Soils Moisture Oceans Salinity: L Band radiometer | Ocean Altimetry: Nadir Altimeter + Wide Swath |
| Launch | Dec 2001 | July 2005 | July 2006 | Sept. 2007 | June 2008 |
| Launcher | DELTA 2 dual launch configuration | | SOYUZ | ROCKOT | DELTA 2 |
| Cooperation | NASA/JPL | NASA/LaRC | ESA, Austria, Spain,Belgium, Brazil | ESA leadership | NASA/JPL |
| Orbit/ Pointing | 1336/1336/66°, drifting pointing : +Z nadir yaw steering | 705/705/SSO 13h30 pointing : +X Nadir | 896/896/90° (polar) pointing : inertial, orbit normal | 756/SSO 6h pointing : +X nadir, 30° canted | 1336/1336/66°, drifting pointing : +Z nadir yaw steering |
| S/L mass PL mass | 485 Kg 175 Kg | 580kg 270kg | 610 Kg 300 Kg | 670 Kg 360 Kg | 600 Kg 290 Kg |
| S/L power PL power | 420 W 165 W | 560 W 282 W | 450 W 150 W | 630 W 350 W | 580 W 300 W |

**Table 1: Synthesis of the current PROTEUS missions**

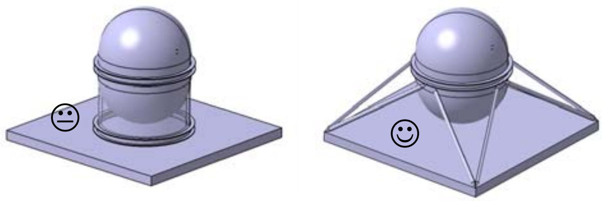
# Platform primary structure

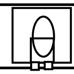
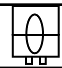
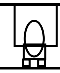



Note: All structural panel is made of 25mm Al honeycomb sandwich incl. 0.6mm Al facesheet.
Except for the baseplate ($X^-$) is made of 60mm Al honeycomb sandwich incl. 0.6mm Al facesheet

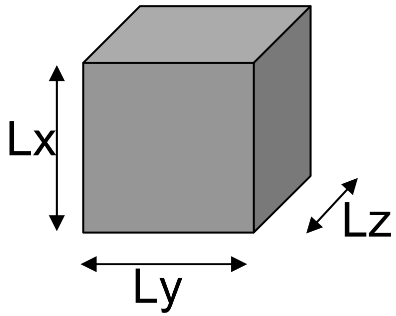
# Trade offs
## due to the tank adaptation

| | units | Proteus tank | STE tank | delta |
|---|---|---|---|---|
| quantity | | 2 | 1 | |
| Diameter | mm | 420 | 550 | 130 |
| Height | mm | 485 | 800 | 315 |
| Dry Mass | kg | 2x 3.7 = 7.4 | 18.1 | 10.7 |
| Wet mass | kg | 2x 30 = 60 | 60 | = |



|  | units |  |  |  |
|---|---|---|---|---|
| ΔY (SA direction) | mm | 150 | 150 | 150 |
| ΔX (nadir+zenith) – height | mm | 315 | 315 | 0 |
| Δm $X^+$, $X^-$ panel | kg | 15% | 15% | 15% |
| Δm $Y^+$, $Y^-$ panel | kg | 50% | 50% | 50% |
| Δm $Z^+$, $Z^-$ panel | kg | 50% | 50% | 50% |
| Δm longeron | kg | 31.5% | 31.5% | 0 |
| Δm bottom frame | kg | > | > | >> (thicker) |
| Δm adapter ring | kg | 937➔1199 | 937➔1199 | 937➔1199 |
| Δm tank support structure | kg | >> | > | > |
| Δm end fitting | kg | 0 | > | 0 |
| Easy maintanenace (AIV) | | ☺ | 😐 | ☹ |

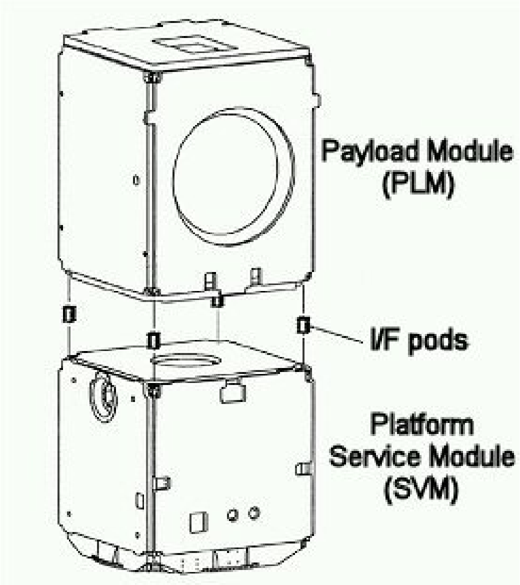
# SVM mass breakdown (tbc)




| | Proteus | STE-SVM |
|---|---|---|
| Lx | 955 | 1150 |
| Ly | 955 | 1150 |
| Lz incl. bottom frame | 1000 | 1300 (tbc) |

| Item | Nr. | Dim1 | Dim2 | Dim3 | Dim4 | area | M_struct | Unit Margin | Unit mass with margin [kg] |
|---|---|---|---|---|---|---|---|---|---|
| | | [m] | [m] | [m] | [m] | [m2] | [kg] | [%] | [kg] |
| SVM - LVA I/F ring | 1 | | | | 0.003468 | | 9.61 | 10 | 10.57 |
| SVM - Closure panel | 1 | | | | | 1.00 | 4.88 | 10 | 5.36 |
| SVM - webs on the closure pane | 2 | 0.58317 | 0.0945 | | | 0.06 | 0.27 | 10 | 0.30 |
| SVM - bottom frame | 1 | | | | 0.00454 | | 12.58 | 10 | 13.83 |
| SVM - MX panel (bottom) | 1 | | | | | 0.80 | 5.24 | 10 | 5.76 |
| SVM - PX panel (top) | 1 | | | | | 0.80 | 3.88 | 10 | 4.26 |
| SVM - longerons | 8 | 0.0125 | 0.001 | 1 | | | 0.21 | 10 | 0.23 |
| SVM - MY panel (SA support) | 1 | | | | | 0.75 | 3.66 | 10 | 4.02 |
| SVM - PY panel (SA support) | 1 | | | | | 0.75 | 3.66 | 10 | 4.02 |
| SVM - MZ panel | 1 | | | | | 0.78 | 3.78 | 10 | 4.16 |
| SVM - PZ panel | 1 | | | | | 0.78 | 3.78 | 10 | 4.16 |
| SVM- PLM I/F | 4 | | | | 0.001 | 0.00 | 2.77 | 10 | 3.05 |
| SVM - longeron end fitting | 4 | | | | 0.001 | 0.00 | 2.77 | 10 | 3.05 |
| delta - SVM - MX | 1 | 0.15 | 1 | | 15% | 0.12 | 0.79 | 20 | 0.94 |
| delta - SVM - PX | 1 | 0.15 | 1 | | 15% | 0.12 | 0.58 | 20 | 0.70 |
| delta - SVM -MY | 1 | 0.15 | 0.315 | | 51.2% | 0.38 | 1.87 | 20 | 2.25 |
| delta - SVM -PY | 1 | 0.15 | 0.315 | | 51.2% | 0.38 | 1.87 | 20 | 2.25 |
| delta - SVM -MZ | 1 | 0.315 | | | 51.2% | 0.40 | 1.94 | 20 | 2.33 |
| delta - SVM -PZ | 1 | 0.315 | | | 51.2% | 0.40 | 1.94 | 20 | 2.33 |
| delta - longerons (x-dir) | 4 | 1 | | 0 | 31.5% | | 0.07 | 20 | 0.08 |
| delta - longerons (yz-dir) | 4 | 1 | | 0 | 15% | | 0.03 | 20 | 0.04 |
| delta - bottom frame | 1 | | | | 32% | 0.000 | 4.06 | 20 | 4.87 |
| tank support structure | 1 | | | | | 0.000 | 10.00 | 20 | 12.00 |
| Misc. (inserts, screw, brackets) | 1 | | | | 20% | 0.000 | 19.77 | 20 | 23.73 |
| 24 | | | | | | | **118.63** | **13.6** | **134.82** |

# Payload I/F

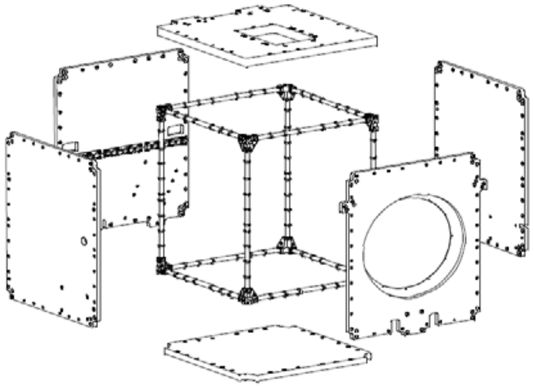



PAYLOAD ACCOMMODATION on the PLATFORM

The primary function of the platform is to provide services to the Payload and to accommodate the payload as well. Interface with the payload is provided through pods fastened to the four upper platform corners and to the payload. A simple bolted connection externally accessible ensures an easy mating of the Payload. In this way, mountability (and dismountability if needed) of the payload is feasible without opening neither the platform, nor the payload.

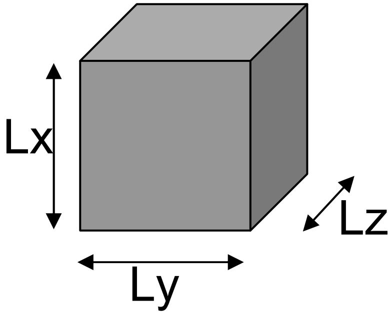
Thermal de-coupling between payload and platform is getting by making the pods out of titanium alloy. A provision of 11 thermal heaters lines controlled by the platform software is provided for the Payload thermal control.

# PLM structure



Based on the same structural concept as the platform, a payload module can be associated to a PROTEUS like P/F.
It is realized in the same way as the platform structure with aluminum honeycomb panels mounted on a chassis.
The chassis is made of longerons connected together with corner fittings, the four bottom ones providing interface with the platform.

# PLM mass breakdown (tbc)




| Item | Nr. | Dim1 | Dim2 | Dim3 | Dim4 | M_struct | Material | Unit Margin | Unit mass with margin |
|---|---|---|---|---|---|---|---|---|---|
| | | [m] | [m] | [m] | [m] | [kg] | | [%] | *[kg]* |
| PLM - longerons | 12 | 0.0125 | 0.001 | 1.00 | | 0.21 | ALUMINUM | 20 | 0.25 |
| PLM - baseplate | 1 | 1.15 | 1.15 | 0.06 | | 8.72 | sandwich | 20 | 10.46 |
| PLM - top plate | 1 | 1.15 | 1.15 | 0.06 | | 8.72 | sandwich | 20 | 10.46 |
| PLM - PY plate | 1 | 1.15 | 0.75 | 0.025 | | 4.21 | sandwich | 20 | 5.05 |
| PLM - MY plate | 1 | 1.15 | 0.75 | 0.025 | | 4.21 | sandwich | 20 | 5.05 |
| PLM - PX plate | 1 | 1.15 | 0.75 | 0.025 | | 4.21 | sandwich | 20 | 5.05 |
| PLM - MX plate | 1 | 1.15 | 0.75 | 0.025 | | 4.21 | sandwich | 20 | 5.05 |
| Radiation shielding | 1 | | | 0.003 | | 23.80 | ALUMINUM | 20 | 28.55 |
| Misc. (inserts, cleats, beackets | 1 | | | | 20% | 8.82 | | 20 | 10.59 |
| 9 | | | | | | **69.38** | | **20.0** | **83.26** |

| | Proteus | STE-PLM |
|---|---|---|
| Lx | 955 | 1150 |
| Ly | 955 | 1150 |
| Lz (from IF plane) | 1000 | 750 |

# Recommendation

- Structural static & dynamic analysis need to be performed to estimate adequate material needed to meet the required strength & stiffness of the launch composite

# Space Time Explorer


Configuration

IFP

ESTEC, 16th July 2010

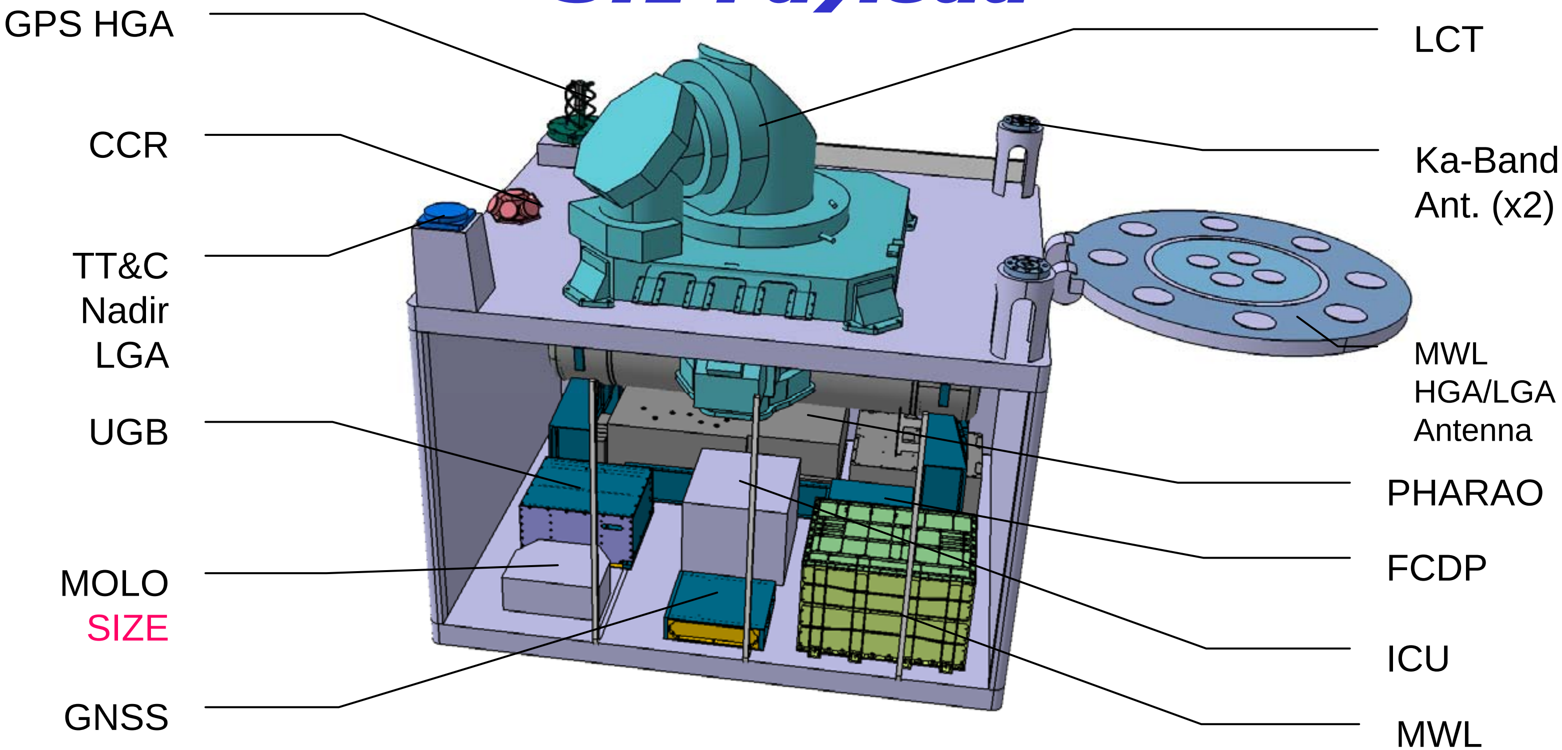
Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Requirements

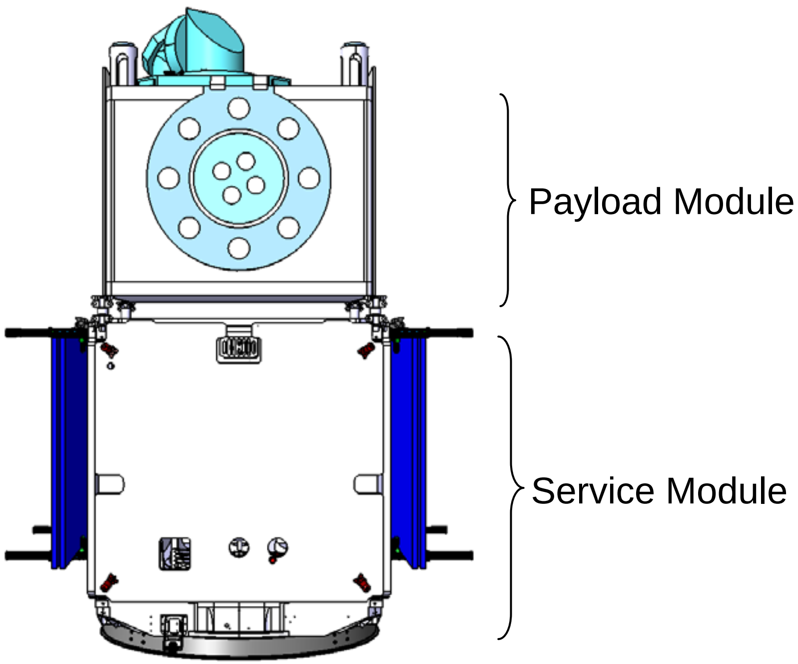
- Radiator 1.315m$^2$ (+ 0.57m$^2$ = 1.88 m$^2$ LCT)
- Pharao perpendicular to orbital plane
- Antenna's nadir pointing
- Centered CoG & balanced mass distribution
- Provide the required thermal environment

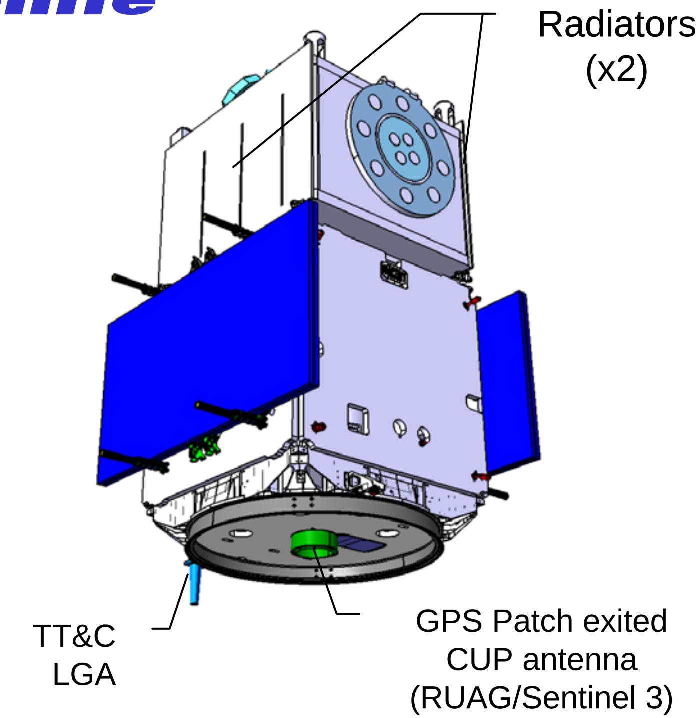
# STE Payload



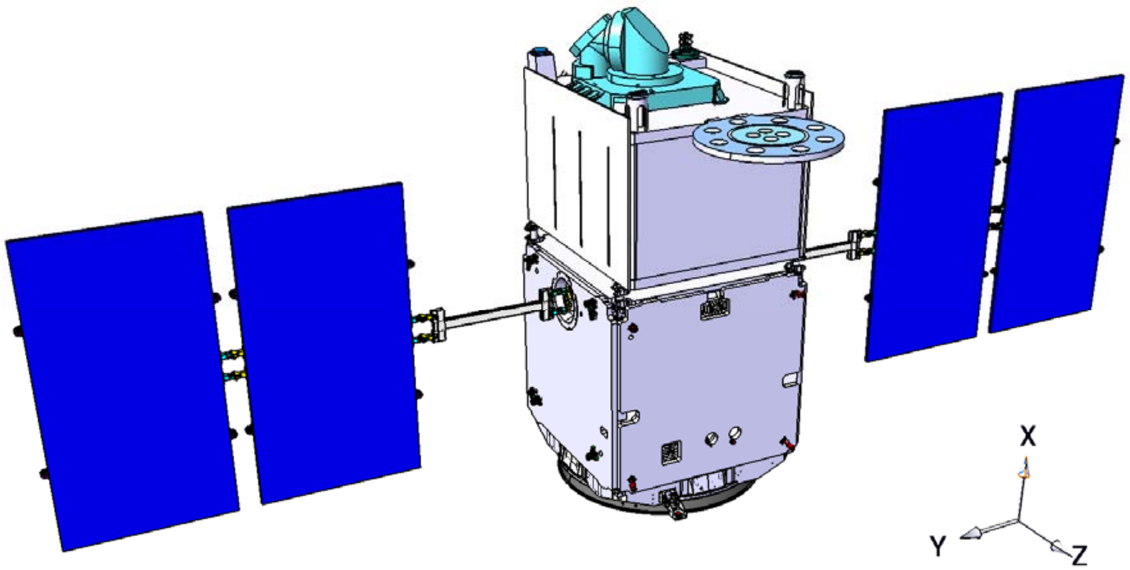
GPS HGA
CCR
TT&C
Nadir
LGA
UGB
MOLO
SIZE
GNSS
LCT
Ka-Band
Ant. (x2)
MWL
HGA/LGA
Antenna
PHARAO
FCDP
ICU
MWL

# STE Satellite

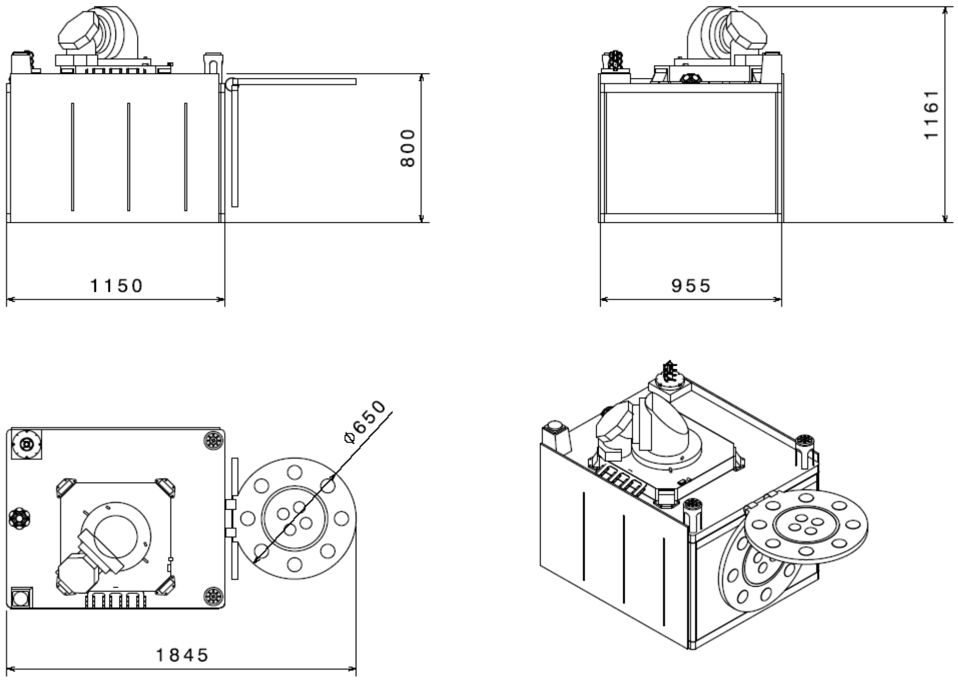


# STE Spacecraft



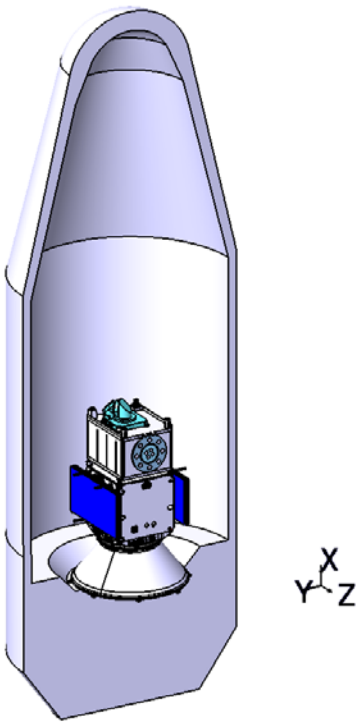
# Overall Dimensions




STE Payload Module

# Launcher accommodation

- Soyuz ST Fairing
- OTS Adapter



# Notes

- Possible sharing of radiator surface
  - LCT thermal interface close to radiators
- CoG assessment shows compatibility with Proteus-Like platform
- AIV/AIT friendly design

# Space Time Explorer


*Conclusions*

Session 8 IFP

ESTEC, 16th July 2010

Prepared by the STE / CDF* Team

(*) ESTEC Concurrent Design Facility

# Conclusions

- Orbit: 16 hours period; inclination: 63.43 deg; Perigee: 700 Km; Apogee: 50000 Km (32200 Km semi-major axis); 6 Ground stations with clocks; repeated pattern after 48 hours
- Orbit maintenance: 20 m/sec/year: **strongly recommended to investigate the strategies in further detail to analyze launch date dependencies**
- Soyuz: 1633 Kg allowable (ascent trajectory injecting the S/C in the right orbit (no Perigee raising maneuver))

## Conclusions

- Mission duration: 5 years
- Radiation: use of equipments qualified for GEO; if not, increase thickness shielding by 3 mm (done on P/L box)

# Conclusions

- S/C yaw steering during the orbit
- Total mass at launch (1048 Kg < 1633 Kg allowable)

# Conclusions

- Orbit determination: on-board GPS, On-board transponder (for ranging); Laser ranging with LRR; micro-wave link, optical link, **Dedicated study for orbit determination to be performed** but preliminary results show that we can get 2 m after 48 hours (3 orbits) with on-board GPS coupled with Batch Least Squared method
- Optical link: TRL 4
- 6 transportable telescopes in ground stations for optical link; 3 transportable atomic clocks

# Conclusions

- Comms: Mwl: Ka-band replaces the Ku-band (secondary allocation not acceptable because of interference)
- Link budget OK (however further optimization could be put in the design of the Mwl)
- Antenna array with fixed configuration (deployable)
- Ground: Ku-band to Ka-band
- Data Handling: On-board computer for P/L and on-board computer for S/C (high TRL levels)
- Cost: main cost due to optical link, MOLO, frequency comb, laser cavity (TRL 4 => development), Pharao

# Conclusions

- AOCS: Reaction wheels micro-vibrations acceptable (peak at 300 Hz)
- Use of Sentinel3 AOCS
- Magneto-torquers can only be used at Perigee
- Dedicated attitude thrusters for safe mode and off-loading reactions wheels (baseline)

# Conclusions

- 2 Kg propellant/year for wheels off-loading (thrusters)
- Propulsion: 2x (4 1 N Thrusters)
- Ground segment: ESOC offers a Flight Dynamics staff (1 man year/year equivalent) to provide orbit determination for STE science (to be checked what cost is associated to this)
- 13 m ground stations (S band) (15 m preferred if available)

# Conclusions

- Power: Baseline SA: 2x2 1.2 m2 with AsGa cells
- Body-mounted SA: 6x current area
  => disregarded
- Programmatics: Micro vibrations not a heavy requirement for programmatics
- 5 years for implementation
- Deployment of ground terminals must be prepared well in time

# Conclusions

- Risk: low TRL of MOLO but development activities identified
- Risk: maintain ACES heritage and skills
- Risk: Extended mission duration with respect to Payload Reliability
- Risk: Lack of system performance budget management
- Thermal: Radiators: 1.315 m2 +0.57 m2 (LCT)
- 44 heaters only for safe mode

# Conclusions

- Structures: Support structure (truss) of propulsion tank
- **Structural analysis recommended to check compliance w.r.t launcher requirements (axial, lateral frequencies)**