WE LOOK AFTER THE EARTH BEAT

STE-QUEST WORKSHOP

TAS Assessment Study Main Outcomes

83230354-DOC-TAS-FR-002

TAS-F CANNES

deimos SPACE

ARWAN Technology

KK Electronics

THALES ALENIA SPACE OPEN

ThalesAlenia Space
A Thales / Finmeccanica Company

TAS Assessment Study

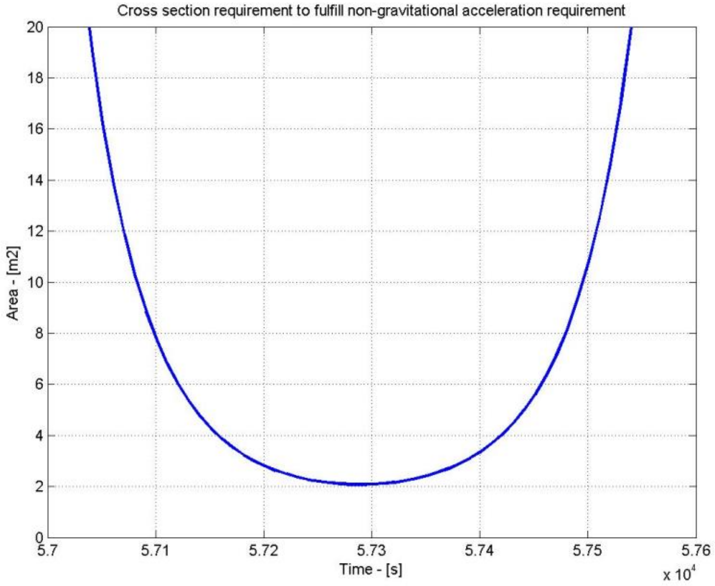
Major effort in the study related to provide scientific instruments with:

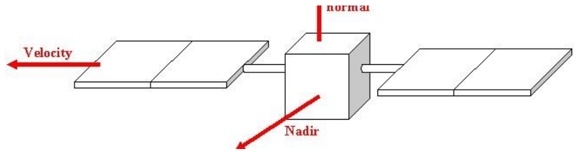
- Quiet mechanical environment
  - Avoidance of any vibrational noise,
  - -2
  - Drag removal (if any)
  - Power generation avoiding Solar Array rotations
  - Control strategy (AOCS actuation)
- Required attitude and thermal control (not discussed here)
  - Alignment of axis propagation of the atoms
  - Large power dissipations need
- Radiations levels limitations
- EMC compatibility levels
- Science Ground Station adequate visibility (on going)
- Link stability

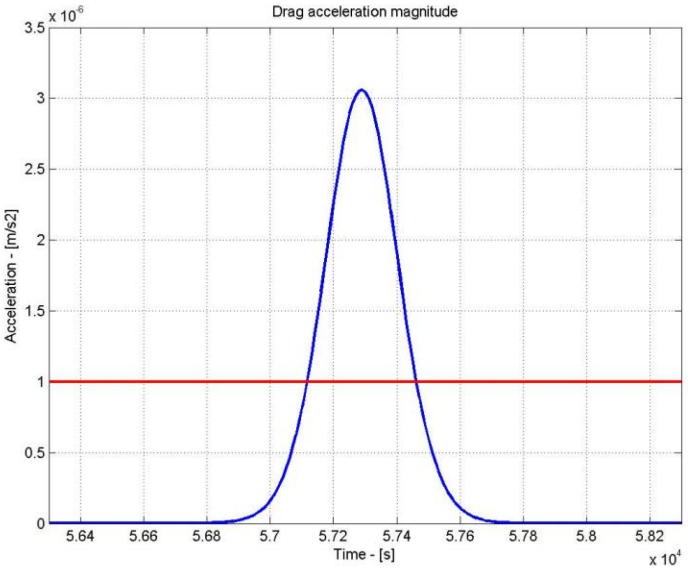
We present here a summary of our End to End Performance Model , with methods and results

DRAG FREE ANALYSIS RESULTS

- **Driving requirement:**
    - non-gravitational acceleration within the instrument volume shall be less than 1e-6 m/s2
- **Spacecraft properties**
    - Drag coefficient Cd = 2.2 (worst case)
    - Mass m = 1200 kg (worst case dry mass)
- **Orbit with perigee @700km**
    - Mission requirement always satisfied with high margin
        - Maximum cross-section to fulfill it is 19 m2
- **Orbit with perigee @600km**
    - Mission requirement always satisfied with margin
        - Maximum cross-section to fulfill it is 6.5 m2 at perigee, when the attitude strategy opposes the minimum cross-section (current design cross section is 5.1 m2)
- **Orbit with perigee @500km**
    - Mission requirement violated around the perigee (see pictures on the right)
        - Maximum cross-section to fulfill it is 2 m2 at perigee, not reachable with any of the proposed spacecraft configurations
        - The violation occurs for 300s over a complete perigee pass duration of 2000s
- **With actual orbit the science phase starts @650km and evolves up to 2250 km ca. No drag problems.**

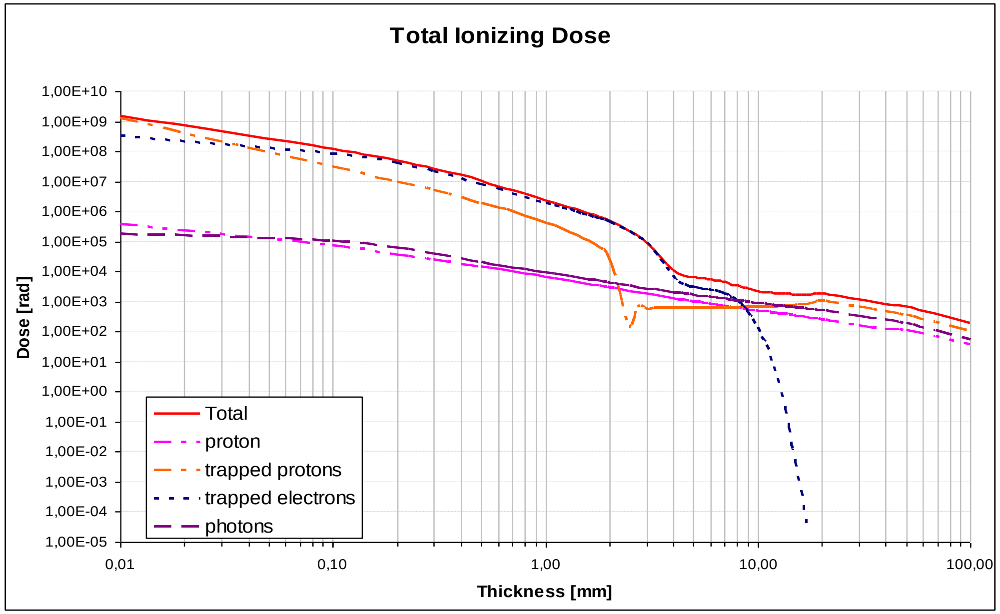


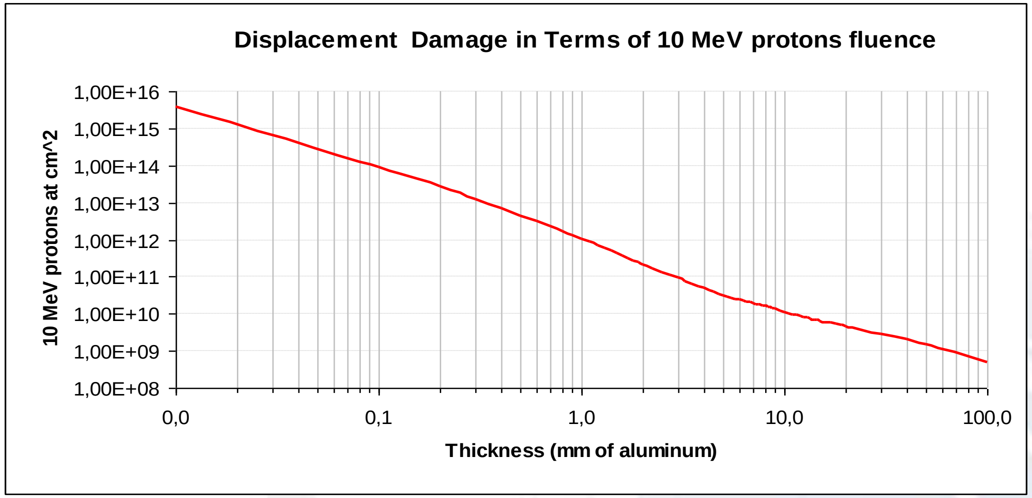




Radiation analysis: models

- Trapped particles
  - Electrons: AE-8, solar maximum
  - Protons: AP-8, solar minimum
- Solar particles
  - Average statistical models: ESP, 90%CL
  - Solar flare model: CREME96 worst case
    - worst week, day and 5 mins
- GCR: CREME96, solar minimum, H to H, H to Fe
- Dose calculation with solid sphere geometry
  - Nuclear processes included: Nuclear attenuation + local charged-secondary energy deposition
- **Detailed sectoring analysis on going**
- Local shielding is a possible countermeasure
- STE-QUEST could offer more than 3.5 mm of Al eq. to the equipments inside the payload module



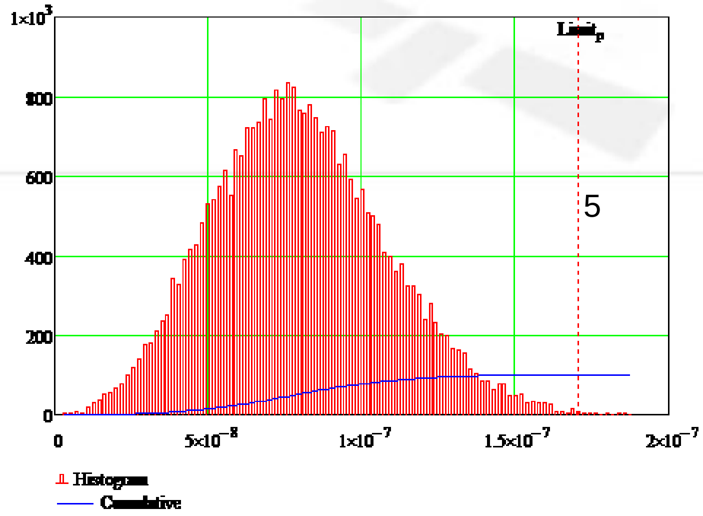


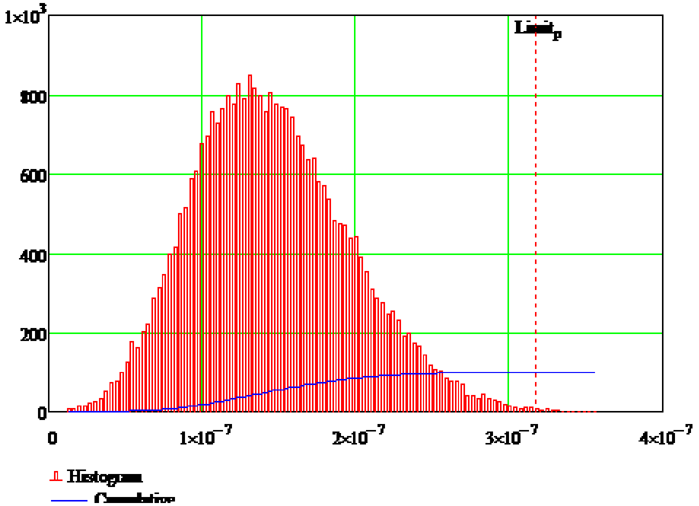
Magnetic Cleanliness Issues

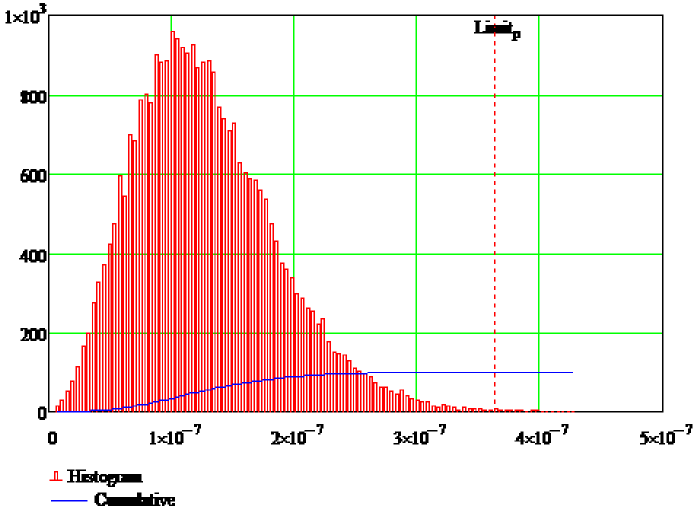
DC magnetic budget has been estimated:

- Based on Monte Carlo Algorithm analysis
- With a predefined likelihood of the 99.9%
- At three reference points:
  - ATOM Physics Package
  - AT_CLK TUBE Laser source
  - AT_CLK Pharao assy

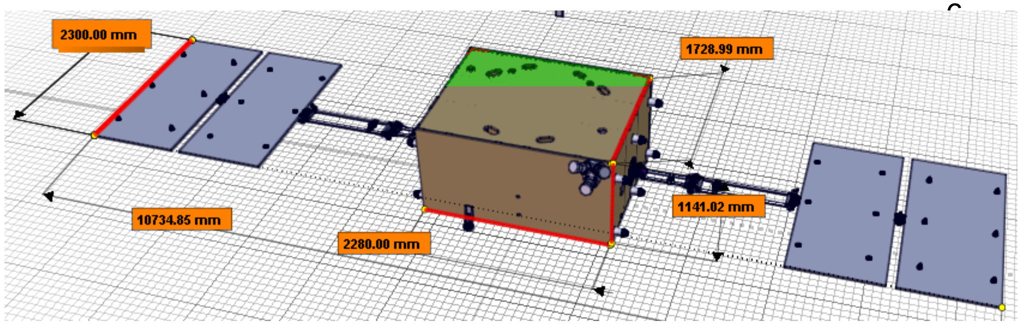
- **Based on the analytical results, DC magnetic requirements seem not critical for the identified option (levels < 1 µT for all the potential victims, w.r.t. 0.1 mT requirement).**
- **The analyses will be maintained updated and refined accordingly to the project maturity**

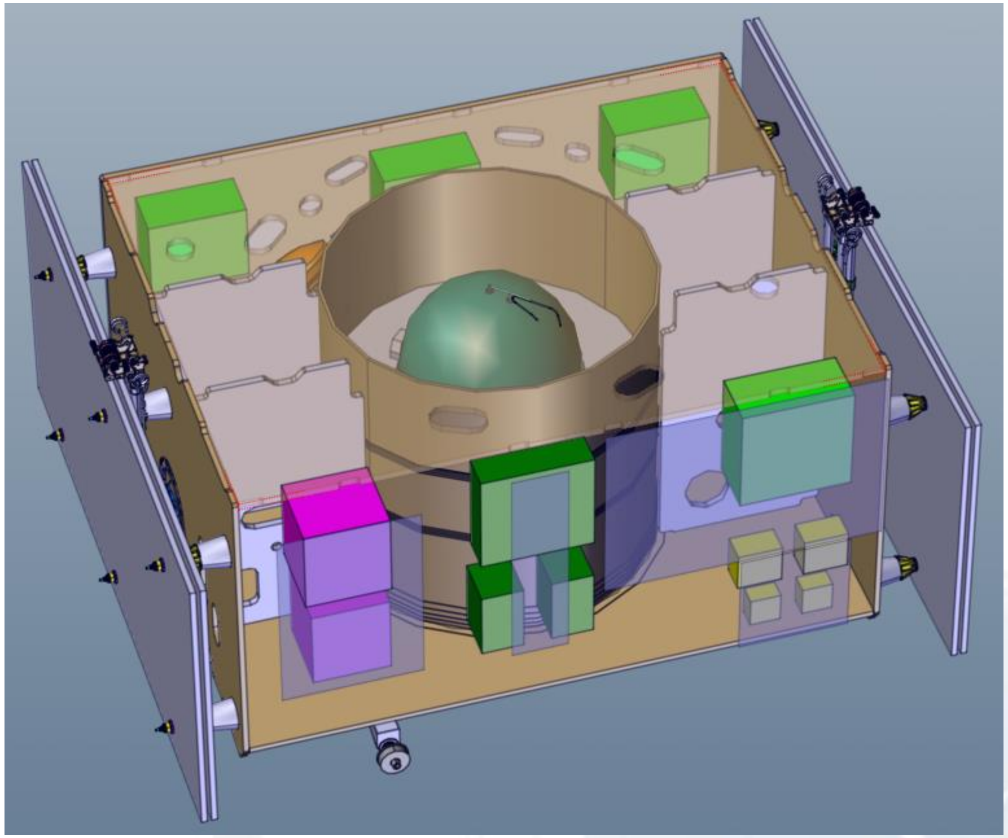






Major mission requirements leading Service Module design





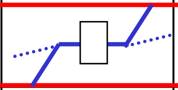
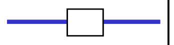
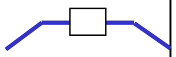
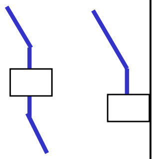
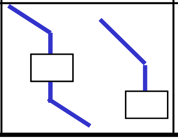
- Mission constraints
    - The launch with Soyuz into HEO, drifting orbit
    - The instruments accommodation requirements
    - The mechanical environment
    - The concurrent operation of instruments & links
    - Autonomy, reliability, safety (Space Debris mitigation)
    - Programmatic issues (launch in 2022)

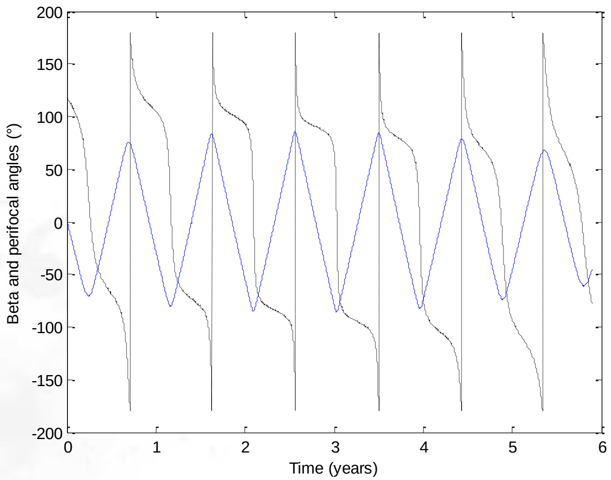
- Main SVM challenges
    - Power generation
        - Large power consumption associated with drifting orbit
    - AOCS actuation & Mechanical design
        - S/C requires both agility and low vibration environment.
        - Modularity is required to achieve launch date   instruments to CoG distance to be limited to decrease lever arm

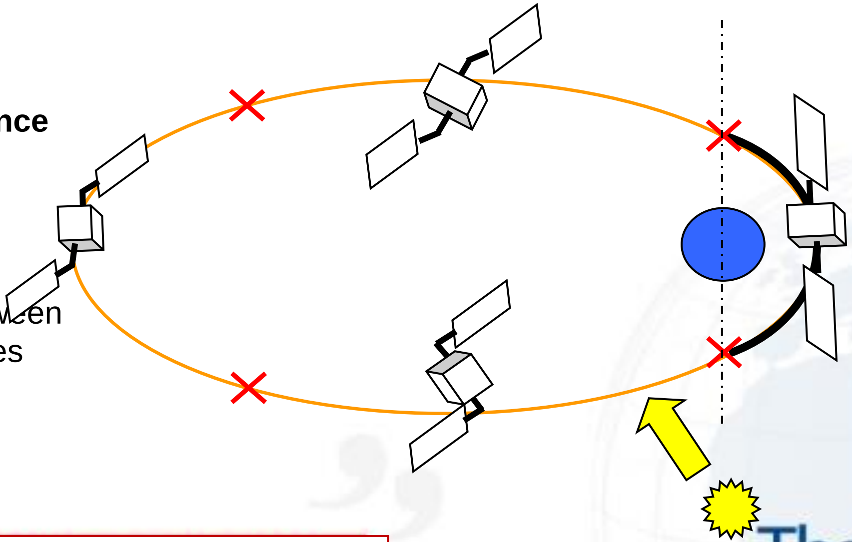
Power generation problematic SA trade off

- STE QUEST EPS constraints:
  - Large instrument power consumption
    → total power budget # 2 kW
  - Highly elliptical and drifting orbit
    → highly varying illumination
  - Very quiet mechanical environment required

-
  - 2 degrees of freedom necessary for SA cost optimization
  - Discrete rotation strategy proposed to limit disturbances
  - Along track SA, in canonical position @ perigee reduce drag.

Conf.	Accom.	Lay out	Tilt	Surface (m²)	TAS Heritage
2 DoF,	or track		Var.	8.8 m²	Very Good
1 DoF	track		0°	24.6 m²	Very Good
Anti-sym. tilt	track		50°	13.6 m²	Reduced
Sym. tilt	track		30°	14.5 m²	Building blocks
Sym. tilt	track		40°	11.5 m²	Building blocks





Apogee science phase:

Nadir pointing
Charging
Fixed SA between the red crosses

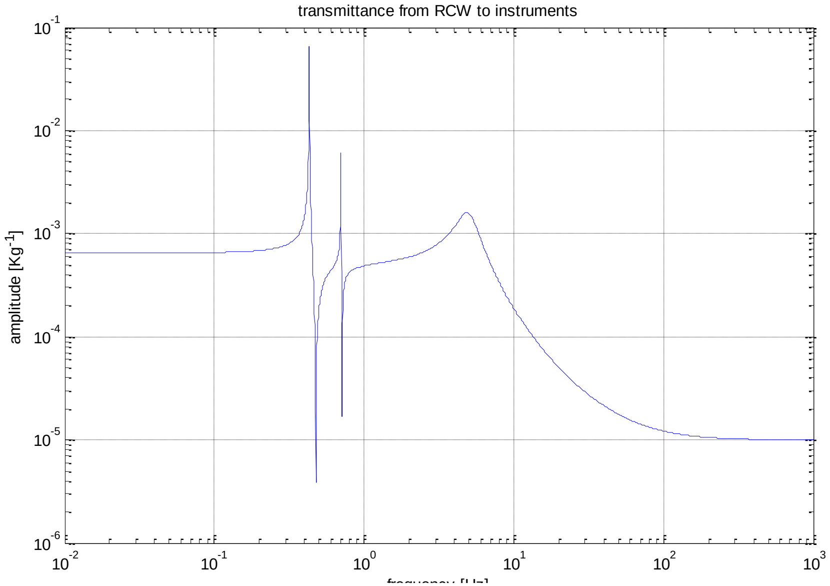
Perigee science phase:

Inertial pointing
Work on batteries
SA along velocity @ perigee to reduce drag

Attitude control actuation   Reaction wheels compliance

Analysis principle

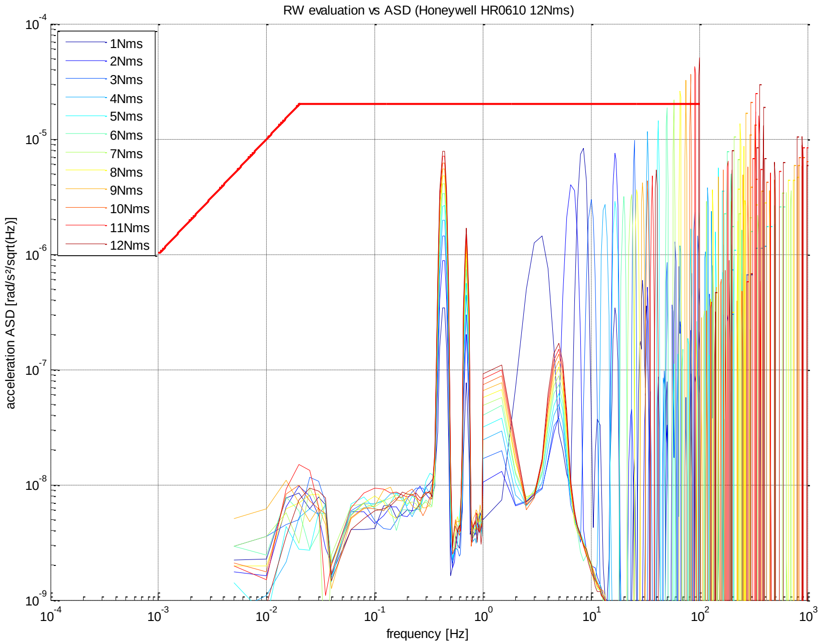
- Transfert function assumes dampers (f=5Hz / Q_f = 3 / T_{HF}=0.02), rigid S/C box and SA flexible modes
- Reaction wheels disturbances are model
  - with static & dynamic unbalances from supplier
  - harmonic data extrapolated from another device.
- Frequency analysis is performed for perigee pass actuatio profile, assuming several initial momentum loads.



Results:

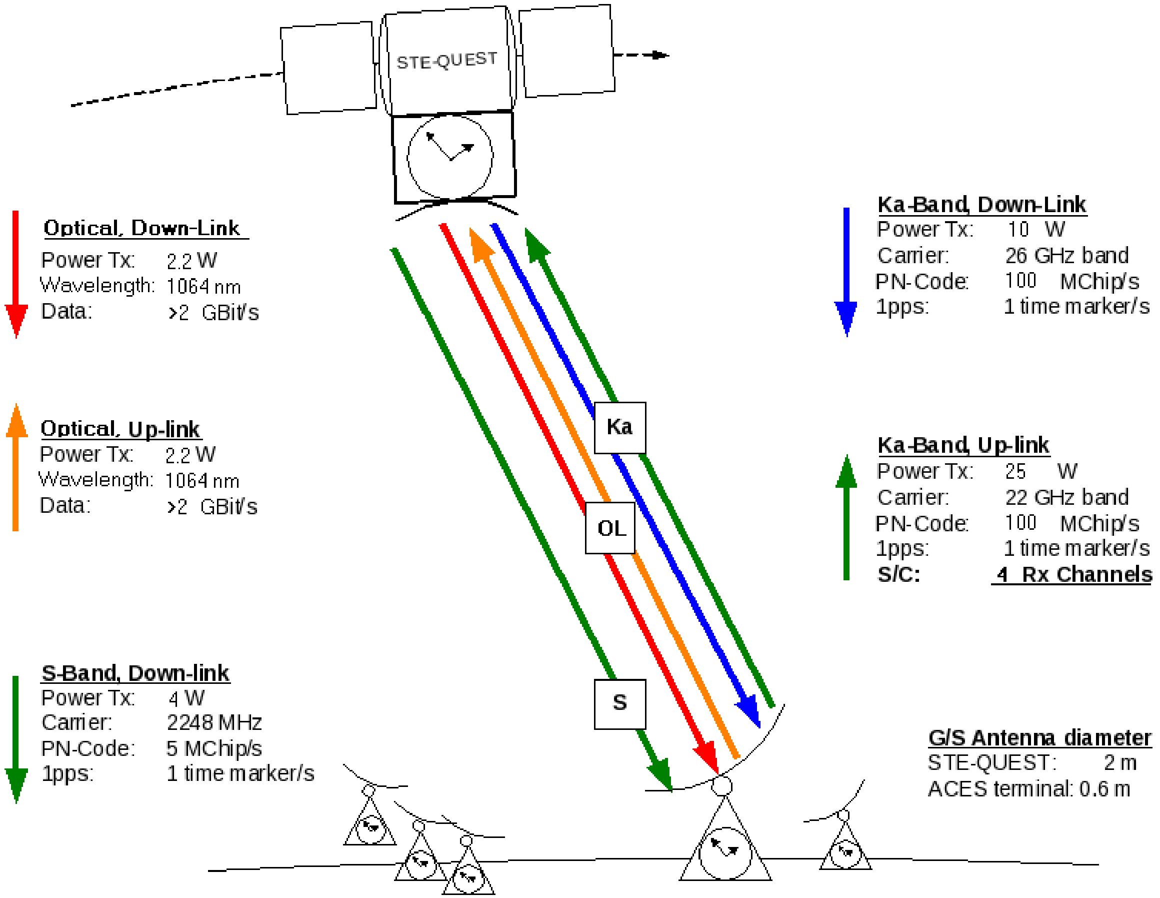
- Requirement saturations are presented in the table below. Compliance is achieved
- *Note that N∞ compliance with ASD requirement is met only for initial momentum loads < 7 Nms, but that spikes are tolerated provided RMS req. are met*

	Number	location	time	Ball bearing RCW
Model				HR0610 12Nms
APE	R-SPI-20	AI	Perigee & apogee	0.3%
RPE	R-SPI-30	AI	Perigee	30.1%
ASD	R-SPI-50	AI	Perigee	Ok below 7nms
Acc RMS PL	R-SPI-51	MOLO	Perigee & apogee	23.3%
Acc RMS AI	R-SPI-51	AI	Perigee	0.06%
ACC PL	R-SPI-60	PL	Perigee & apogee	73.0%
ACC AI	R-SPI-61	AI	Perigee	52.6%



Scientific Links - E2E performance model

- **STE-QUEST mission will include sufficiently stable optical and microwave time and frequency transfer (TF&T) systems allowing comparison of atomic clocks on ground and on-board AC with negligible noise contribution from the transfer system itself.**
- **The required accuracy calls for two-way systems in order to eliminate or almost reduce unwanted effects such as Shapiro and tropospheric delay, 1st order Doppler, common mode effects ecc.**
  - Two bi-directional MW PN-coded links operate in Ka-band: the high carrier frequency of the up-and downlink permits a noticeable reduction of the ionospheric delay.
  - A third PN-coded MW channel (downlink) in S-band (2.2 GHz) is added and used to determine the ionosphere total electron content allowing the cancellation of the residual ionospheric effect.
  - A bidirectional optical link (more sensitive but more affected by atmospheric turbulence) transmits and receives clock signals as well.
- **The aim of the E2E performance model is to make assessments uncertainty and instability affecting all the parameters involved in T&F transfer performances and evaluate their impact, e.g.:**
  - Application of atmosphere-describing models (ionosphere and troposphere) on T&FT at the used frequencies
  - Simulation of the thermal behaviour of the system hardware and of the consequent phase shift
  - Propagation of PoD performances on T&FT (from the desynchronization equation)



Optical, Down-Link
Power Tx: 2.2 W
Wavelength: 1064 nm
Data: >2 GBit/s

Optical, Up-link
Power Tx: 2.2 W
Wavelength: 1064 nm
Data: >2 GBit/s

S-Band, Down-link
Power Tx: 4 W
Carrier: 2248 MHz
PN-Code: 5 MChip/s
1pps: 1 time marker/s

Ka-Band, Down-Link
Power Tx: 10 W
Carrier: 26 GHz band
PN-Code: 100 MChip/s
1pps: 1 time marker/s

Ka-Band, Up-link
Power Tx: 25 W
Carrier: 22 GHz band
PN-Code: 100 MChip/s
1pps: 1 time marker/s
S/C: 4 Rx Channels

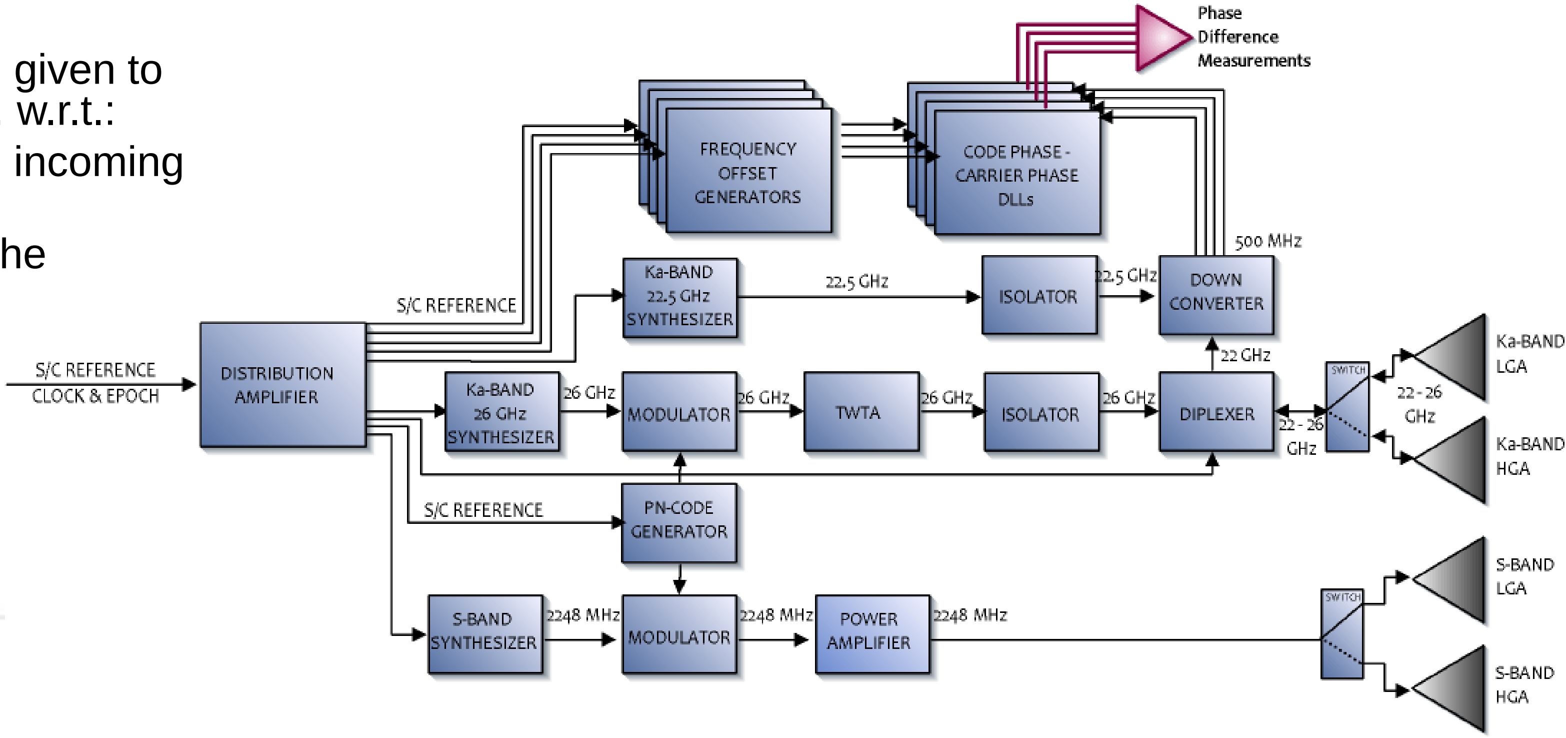
G/S Antenna diameter
STE-QUEST: 2 m
ACES terminal: 0.6 m

MWL - Description

- The system uses code measurements and absolute carrier phase measurements in up- and down links. This allows measuring both phase and group delays, after cross-correlation of the received signals with the on-board reference signal.
  - DLLs at both terminals are able to extract phase measurements from the comparison of local and received sequences
- The design aims to achieve equal lengths in the up- and down-link paths; symmetry of the ground and space terminals is therefore important to improve cancellation and compensation of unwanted delays.
  - Block schemes of the S/C (here below) and GT terminals are symmetric at the maximum extent.
- The S/C LGAs are not used with current GTs configuration (Turin, Tokyo, Boulder), which does not allow perigee visibility. However, they are kept in the design in view of possible new GTs introduction.
- Optimized modulation scheme (PN) and rate (100MChip/s) to minimize multipath effects and improve synchronization
-

  signal phase.
- Paramount importance will be given to calibration of the E2E system, w.r.t.:
  - Variations of power of the incoming signal
  - Variations of direction of the incoming signal
  -

    effects on equipments

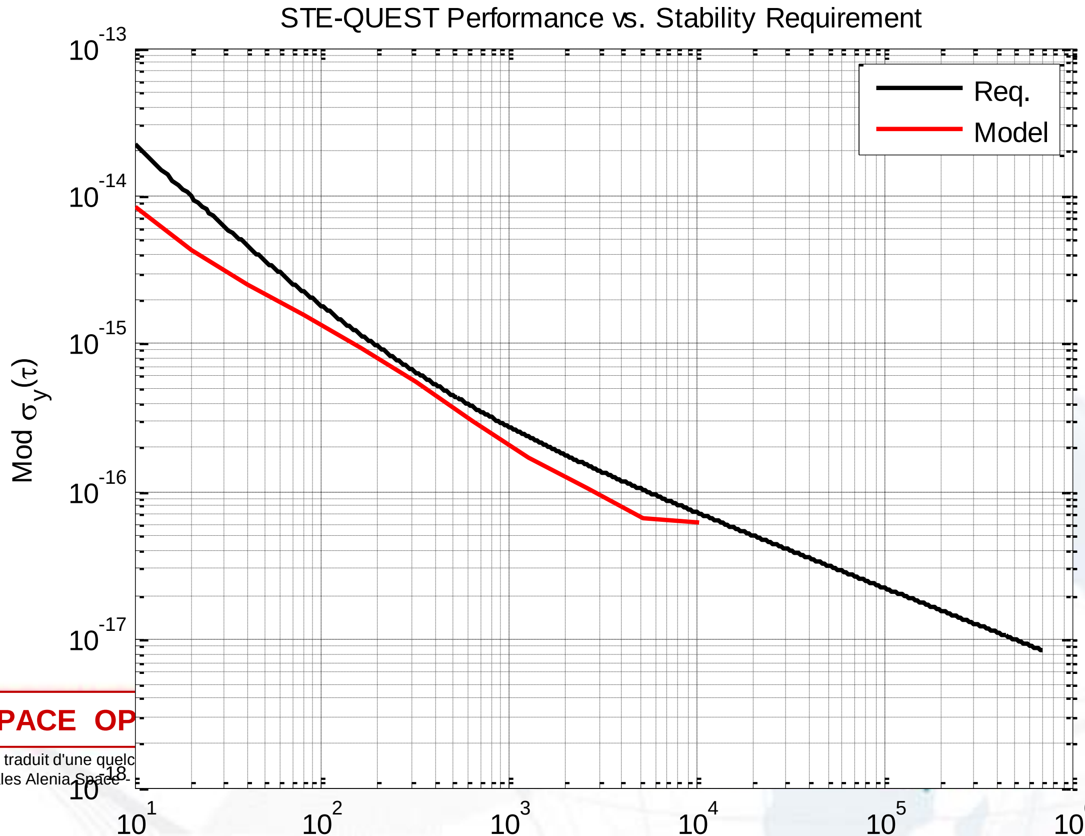


MWL   Stability Assessment

- Simulation assumptions (valid for the OL also): system performances are evaluated using STK retrieved S/C and G/S position data. G/S position is supposed to be known with an uncertainty of 0.01 m.
- The following residual delays after control/compensation are simulated over one orbit:
  -
    - Computed from local Turin measurements (credits: ISAC, INRIM)
    - Using mathematical models:

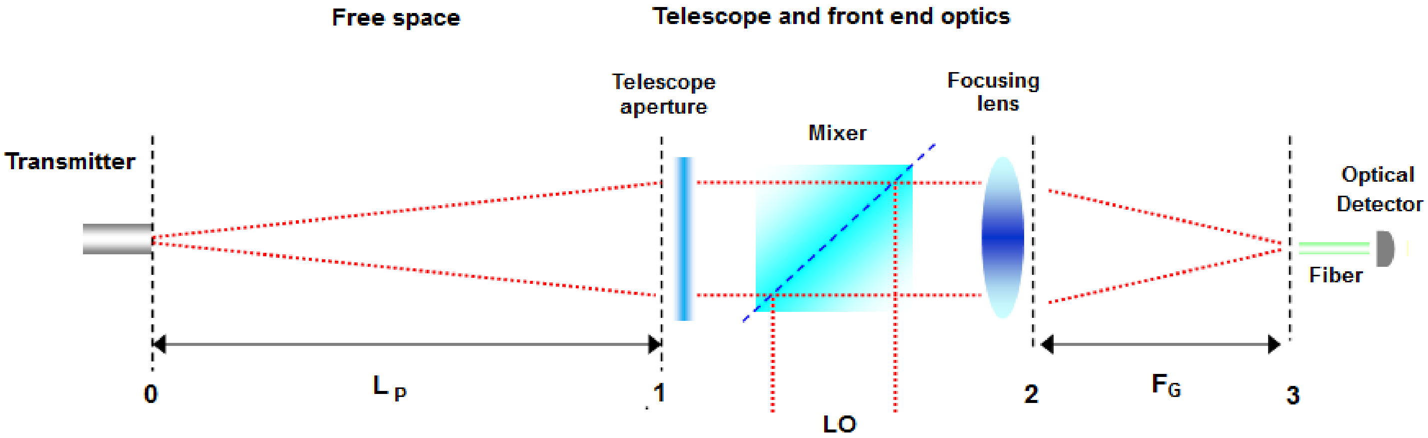
      NeQuick for the Ionosphere Total Electron Content

      model for the Troposphere-induced delays
  - Phase offset due to the Orbit dynamic-induced power signal variations (partially compensated with the VGA)
  - Thermal sensitivity to temperature variations within the S/C and EU thermal control performances
  - Hardware noise contribution
  - MWL Tracking Loop instability due to Doppler Effect (evaluated: negligible)
- Space-to-Ground link estimated stability:
  - **Compliant to requirements.**
  - Major contributor: ionospheric residual delay



Beam Propagation Model

Free space propagation model



Free space propagation simplified model with coherent detection concept

- Noise contributions
  - Typical contributions:
    1. Signal shot noise (shot noise of signal current i.e. intrinsic random fluctuation of signal photocurrent due to its statistical nature).
    2. Background radiation shot noise.
    3. Detector dark current shot noise
    4. Pre-amplifier thermal noise (thermal noise generated by the current pre-amplifier load).
    5. Amplified source relativity intensity noise: intrinsic fluctuation of emitted laser power (only in presence of optical amplification at transmitter).
  - Further contributions:
    6. Shot noise term due to local oscillator wave power (for coherent detection only).
    7. Atmospheric contributions: atmospheric attenuation due to atmospheric scattering of beam, atmospheric ray path bending and propagation delay, atmospheric turbulence

OL stability simulation: assumptions and results

- Simulation assumptions: For background radiation conservative evaluation, the S/C receiver is assumed to have Earth backscattered solar radiation in its field of view and the G/S receiver looks towards the Moon. Atmospheric propagation attenuation is evaluated by using ESA RMA. Air refractive index is derived from atmospheric parameters of RRA but with better uncertainties (P: 0.17 mbar, PH2O: 0.17 mbar, T: 0.14 K). Hardware temperature uncertainty: $\delta T_{HW,S}$: 1 °C; $\delta T_{HW,G}$: 0.1 °C.
  - Total time delay uncertainty:

$$\delta\Delta T_{Diff,Tot} = \delta(T_{12} - T_{34})_{Det} + \delta(\Delta t_{12,Atm} - \Delta t_{34,Atm}) + \delta T_{23} + \delta T_{HW}$$

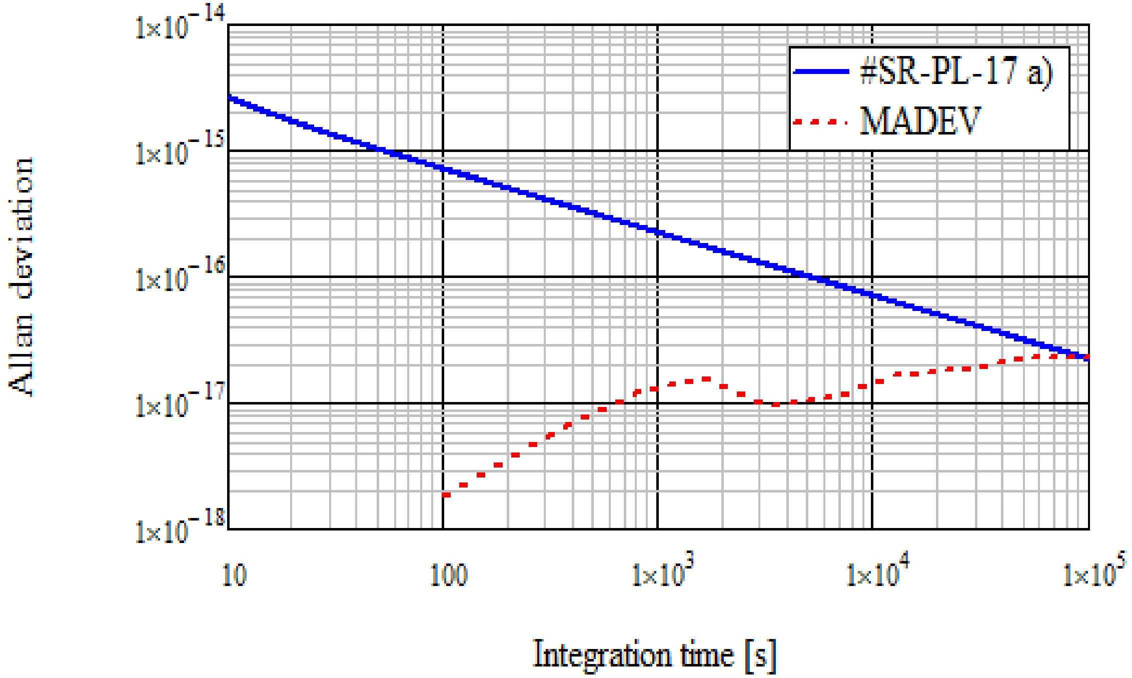
Delay retrieval electronic

Atmospheric delay differential transmission time uncertainty

Optical and electronic hardware contribution

Total hardware differential contributions

- **Space-to-Ground link evaluated stability:**
  - **Compliant to requirements.**
  - Simulations show the importance of knowledge of atmospheric parameters and of HW temperatures (to be known with good accuracy).
  - Atmospheric turbulence phase noise contribution is negligible.



Summary and conclusions from TAS-I side

- TAS Assessment Study outcomes put in evidence that:
  - the mission is challenging but feasible
  - mission objectives are achievable
- At spacecraft level, all the critical issues and those aspect considered more difficult have been analyzed and none of them appears to be an unachievable target, solutions are singled out
- Space segment realization is able to match the target of 2022 launch, providing the anticipation of some activities wrt the CDR.