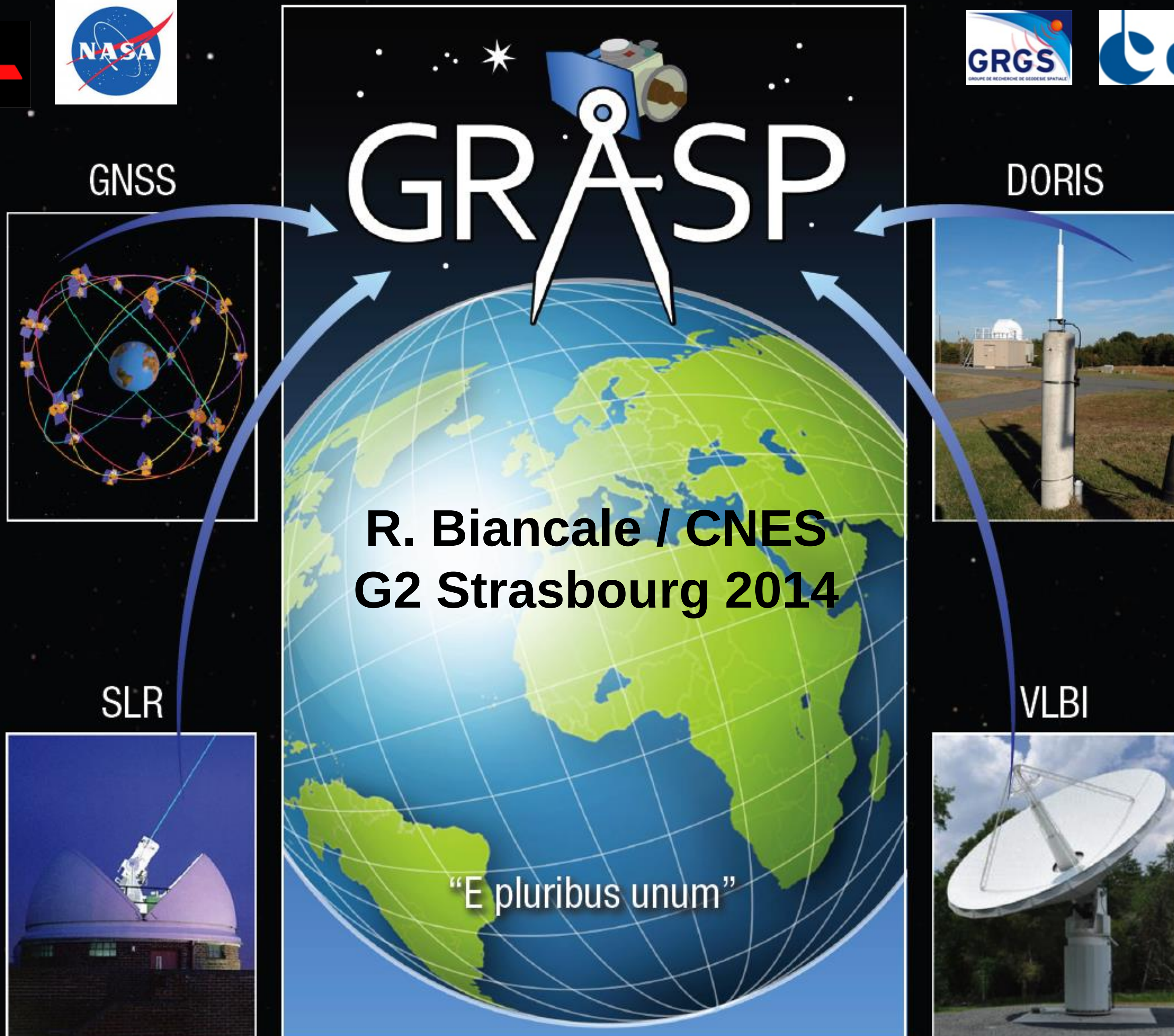
Geodetic Reference Antenna in SPace



R. Biancale / CNES

G2 Strasbourg 2014

The Terrestrial Reference Frame (TRF)

GRASP is a satellite mission project which would allow **to achieve the requirements** established by the ***Global Geodetic Observing System****: Meeting the Requirements of a Global Society on a Changing Planet in 2020* (The GGOS-2020 Document, 2007):

"**Maintaining a terrestrial reference frame** at the level that allows, for example, the determination of **global sea level changes** at the sub-millimeter per year level, **pre-, co- and postseismic displacement** fields associated with large earthquakes at the sub-centimeter level, timely early **warnings for earthquakes, tsunamis, landslides, and volcanic eruptions**, as well as the **monitoring of mass transport** in the Earth system at the few Gigatons level requires an comprehensive Earth system approach."

Currently, the TRF is realized at some cm level with the help of 4 geodetic techniques: **DORIS, GNSS, SLR, VLBI**.

The TRF improvement at the mm level requires to concentrate these 4 techniques:

- on ground in **Fundamental Geodetic Observatories** (core stations)
- on board in a **geodetic dedicated satellite**

whose instrument geometry is at least defined at the sub-millimeter level.

Context

2011 NASA's Earth Venture-mission call of opportunity
GRASP-2011 not selected but well graded (2nd place after CYGNSS)

Spring 2014 CNES' prospective colloquium
F-GRASP mission proposal selected in Solid Earth theme

Fall 2014 GRASP proposed in CNES' phase 0
F-GRASP mission proposal passed the "atouts-attraits" procedure

2015 NASA's Earth Venture-mission call of opportunity (class B mission)
GRASP-2011 concept will be re-proposed with some modifications

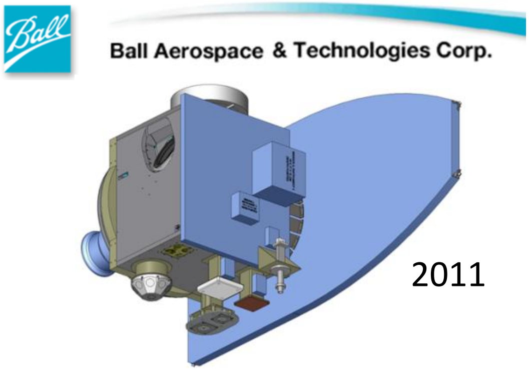
Mission in JPL-CNES partnership (3 yrs nominal + extension)
Other partnerships still sought (ISRO?)

Anticipated schedule
November 2014 : call announcement
May 2015 : instrumentation proposal draft
September 2015 : mission proposal submitted
December 2015 : selection (?)

Proposal

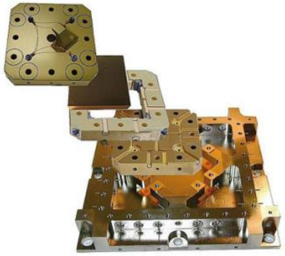
JPL

- Platform (Flexbus/Airbus Defence & Space, GRAIL/Lookheed Martin…)
- Launcher (2019)
- Operation responsability
- TriG GNSS receiver (L/S band)
- VLBI tone transmitter (S/X band)
- Laser reflectometer (one unique reflector)
- Star sensors



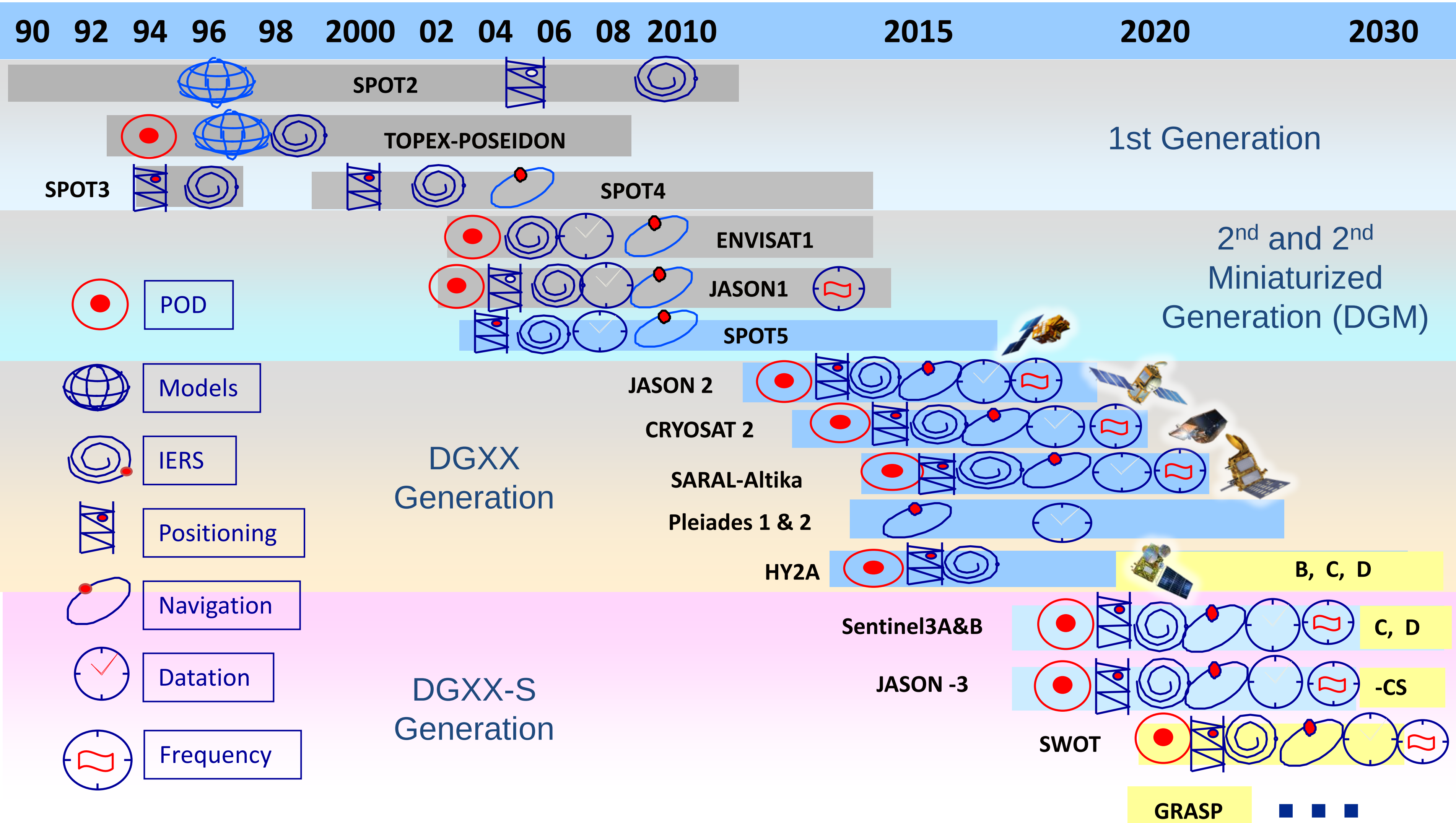
CNES

- JPL request:
  - DGXX-S DORIS receiver (L/S band)
- GRGS proposal for additional equipment:
  - 3D MicroSTAR accelerometer
  - T2L2 ?
- Implementation (?)

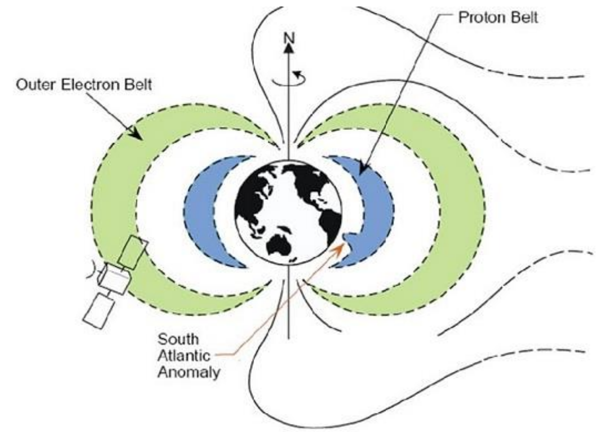


Need for pre-launch calibration of all on-board systems at the sub-millimeter level

The DORIS Missions



DORIS for GRASP



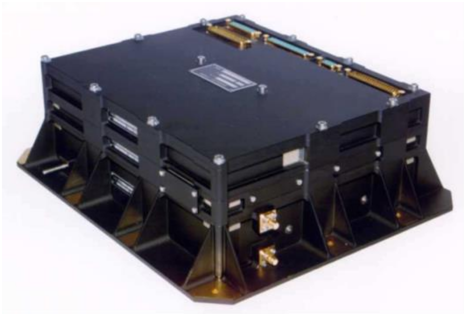
- **DGXX-S series :**
  - **Obsolescence of components**
  - **Holding in high energetic radiations**
- **DORIS / GRASP :**
  - **One shot or new series :**

    - same functions/performances than DGXX-S except improved dating

    - more compact : 5kg, 20w

    - better processing capability

    - redundancy tbd / reliability / lifetime
  - **Antenna : identical**



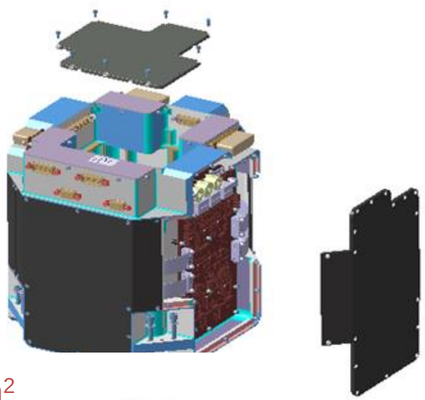
- **USO :**
  - **0.6l ; 3w (in DORIS receiver)**
  - **ST, MT : ~10^{-13}, LT : 10^{-11}/j**

Source: CNES

MicroSTAR Accelerometer

Sensor Unit (SU)	*Harness FEEU/ICU*	*Interface and Control Unit (ICU)*

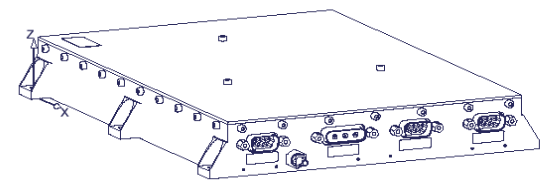
Front End Electronic Unit (FEEU)



Vol : 200x200x200 mm^2

Mass : 8 kg

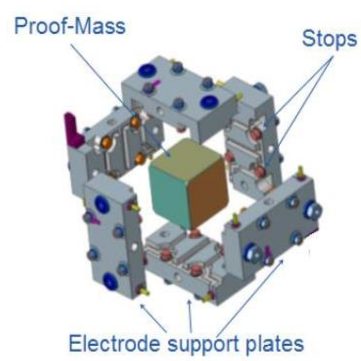
Sensor Unit Mechanic (SUM)



Vol : 250x200x35 mm^2

Mass : 1.5 kg

Power : 10 W



Proof-mass

dimension: 30×30×30 mm^3

mass: 238 g

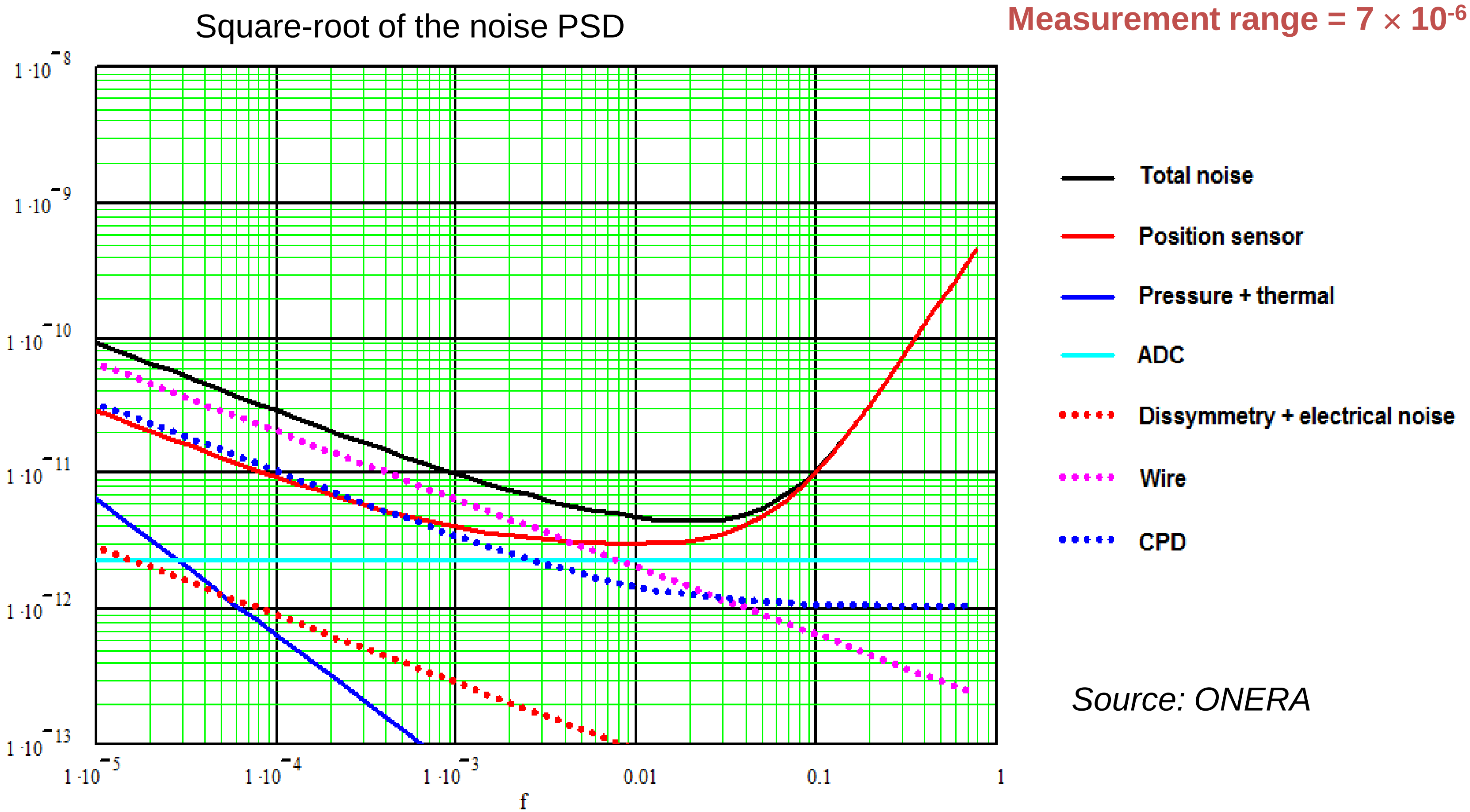
Science data : 6 accelerations + Vp + 1 HK = 8 x 24 bit @ 10 Hz

HK data : 6 position sensors + Vd + 5 power lines + n temperatures

Source: ONERA

MicroSTAR Accelerometer

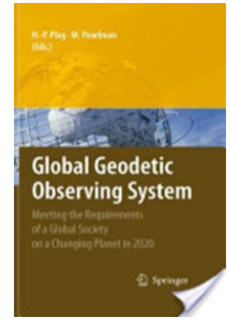
Measurement range = 7×10^{-6} ms^{-2}

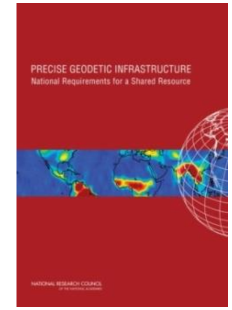


Source: ONERA

$$\sqrt{Sn(f)} = K\sqrt{1+\left(\frac{f}{5\text{mHz}}\right)^{-1}+\left(\frac{f}{0.07\text{Hz}}\right)^{4}} \quad \text{with} \quad k = 4\times10^{-12}\ \text{m.s}^{-2}.\text{Hz}^{-1/2}$$

Scientific objectives





Primary objective

Unifying the terrestrial reference frame (TRF) as defined by GGOS for the 2020 horizon:
TRF global accuracy of 1 mm and 0.1 mm/y stability.

"To achieve the GGOS program goals and support future high-precision geodetic science, the ITRF needs to be robust and stable over many decades. Future scientific objectives drive a target accuracy of 0.1 millimeter per year in the realization of the origin of the ITRF relative to the center of mass of the Earth system and 0.02 part per billion per year (0.1 millimeter per year) in scale stability." (NRC, 2010)

Geodetic goals

TRF, determination of inter-system biases…

Geophysical applications

Sea level rise, tectonics, earthquakes, current ice melting, mass balance of the Earth-Ocean-Atmosphere system…

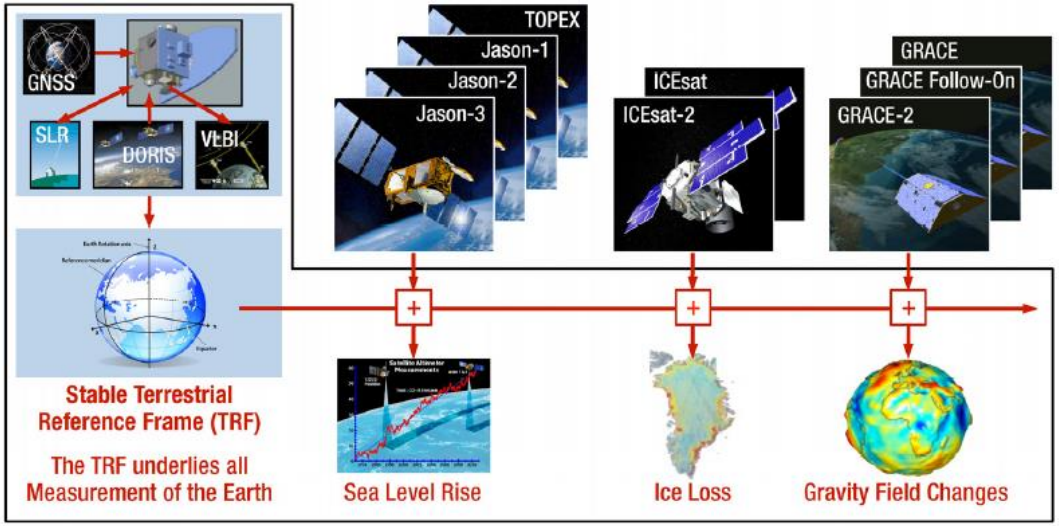
Secondary science

Time transfer and synchronization, fundamental physics, high thermosphere, Earth radiation budget…

Mission goals / JPL

GRASP Remains Dedicated to Providing Stable Reference Frame for Climate Change Measurements

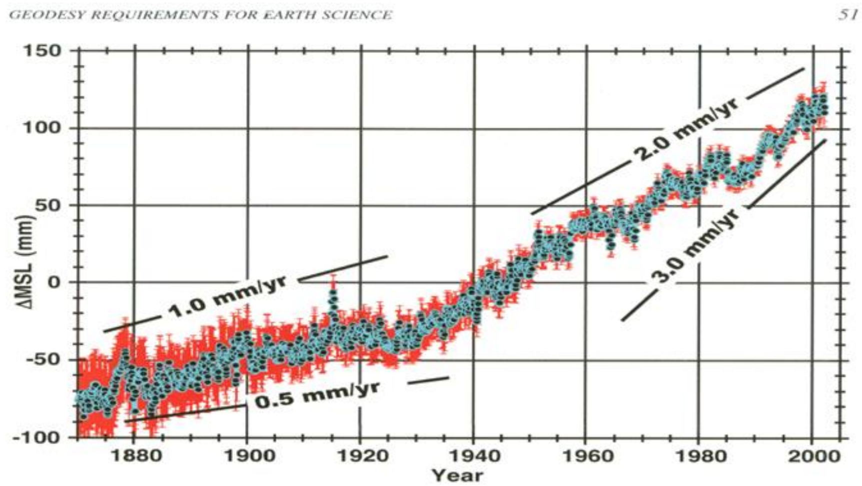
- Meet GGOS goals for the TRF: 1 mm accuracy, 0.1 mm/yr stability
- Enable the accurate dissemination of the TRF with GNSS and DORIS to any location on Earth and low Earth orbit
- Measure the long-wavelength variability in the Earth gravity field that are either not observed (degree 1) or poorly observed (J_2) by GRACE
- Reinterpret satellite altimetry and tide gauge records to determine global mean sea level rise relative to the GRASP-based TRF – how is sea level accelerating
- Reinterpret ICESat and GRACE data records to determine ice mass loss relative to the GRASP-based TRF – how is ice mass loss accelerating



Courtesy Y. Bar-Sever

Impact on sea level

Impact of TRF Error on Global Mean Sea Level (GMSL)



Record from Spaceborne Altimetry

Altimeter Global Mean Sea Level Measurement Error Budget	
Glacial isostatic adjustment (affects volume of ocean basins)	0.1 mm/y
Altimeter drift error (predominantly radiometer drift)	0.4 mm/y
Altimeter bias errors (the ability to link overlapping missions)	0.4 mm/y
Reference frame origin error (affects the satellite orbits)	0.2 mm/y
Systematic vertical motion error (affects the altimeter calibration)	0.4 mm/y
Total error (root-sum-squared)	**0.6 mm/y**

RSS = 0.45 mm/yr

Impact of TRF on GMSL Record from Tide Gauges: competing approaches for TRF realization yield estimates for sea-level rise ranging from 1.2 to 1.6 mm/yr.

Desired accuracy for measuring global mean sea level (GMSL) rise is 0.1 mm/yr.

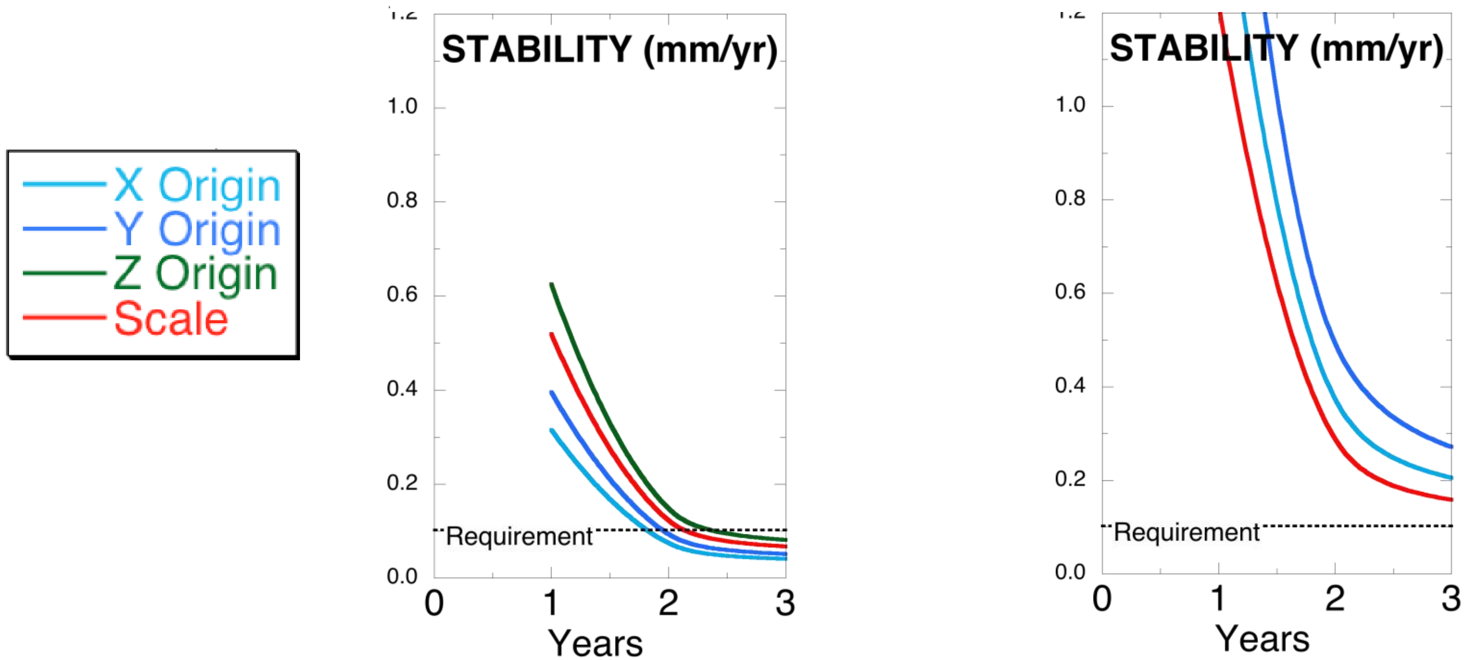
Courtesy Y. Bar-Sever

JPL simulations / TRF origin, scale

Extensive simulations supported the proposed mission goals with 850x1350 km orbit

As proposed
850x1350 km

GPS Only
(no GRASP)



Additional simulations after the submission of the 2011 proposal should explore different orbital configurations: ~1400, ~2000, ~6000 km circular.

The addition of an accelerometer may open up new orbit trades

JPL simulations / technique systematisms

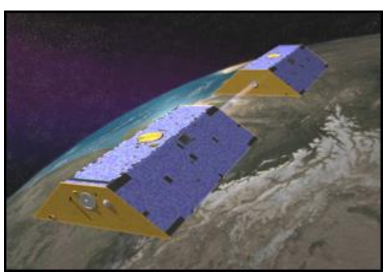
Extrapolating GRASP performance from present-day missions

Inter-technique biases and drifts are obstacles to achieving the required TRF stability

GRASP will offer a common target for all techniques with which to explore the nature of technique-specific systematic errors

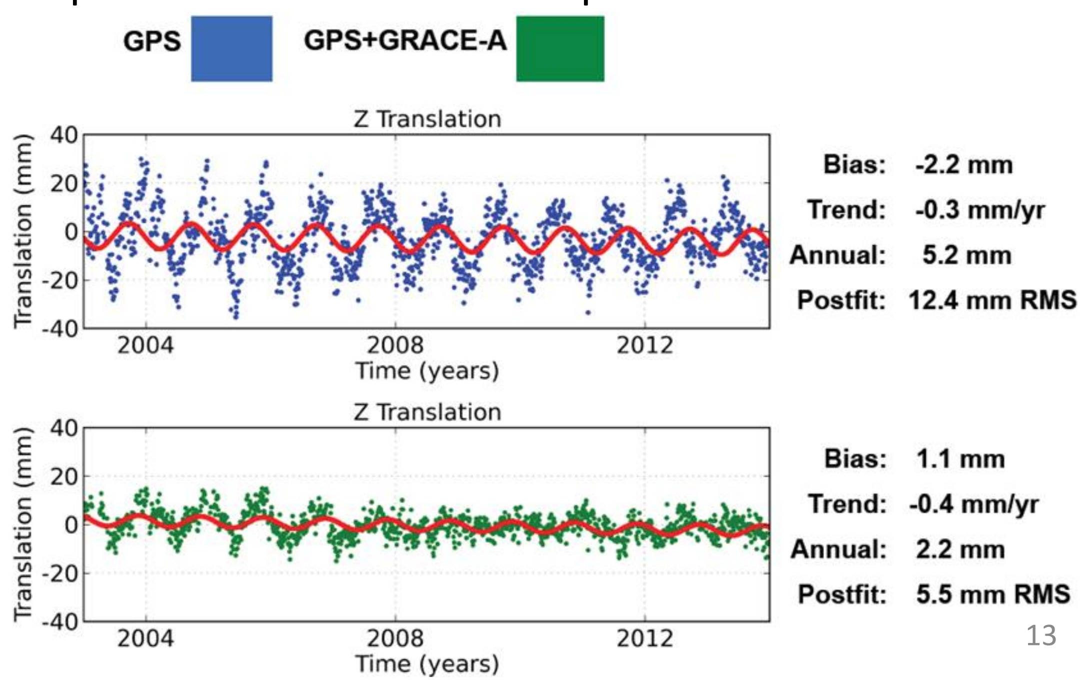
Using GRACE-A as a GRASP proxy (only SLR and GPS data available) shows promise

- Reduces some TRF biases relative to SLR
- Also shows limitations of GRACE and need for full GRASP capabilities: few SLR measurements, relatively poorly-understood dynamics, no DORIS, VLBI,…
- Note that GPS alone is already competitive with other techniques



GPS Only

GPS + GRACE-A

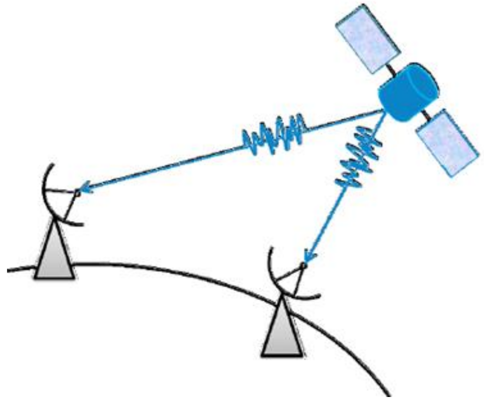


Courtesy Y. Bar-Sever

Specification validation at GRGS

Mission analysis

Simulations based on analytical approaches and stochastic optimization to provide a set of possible orbital configurations which fulfill different requirements such as visibility constraints (software: Couplage Algorithme Génétique / AG & propagateur analytique d'orbite / FAST).



VLBI observations to satellites
Challenging 2000-6000km
[Plank L., University of Tasmania]

Performance

Simulations based on numerical processing in realistic orbit computation environment to provide precisely the required level of quality for the calibration of the GRASP instruments, the needed orbit accuracy… to reach the mission goals.

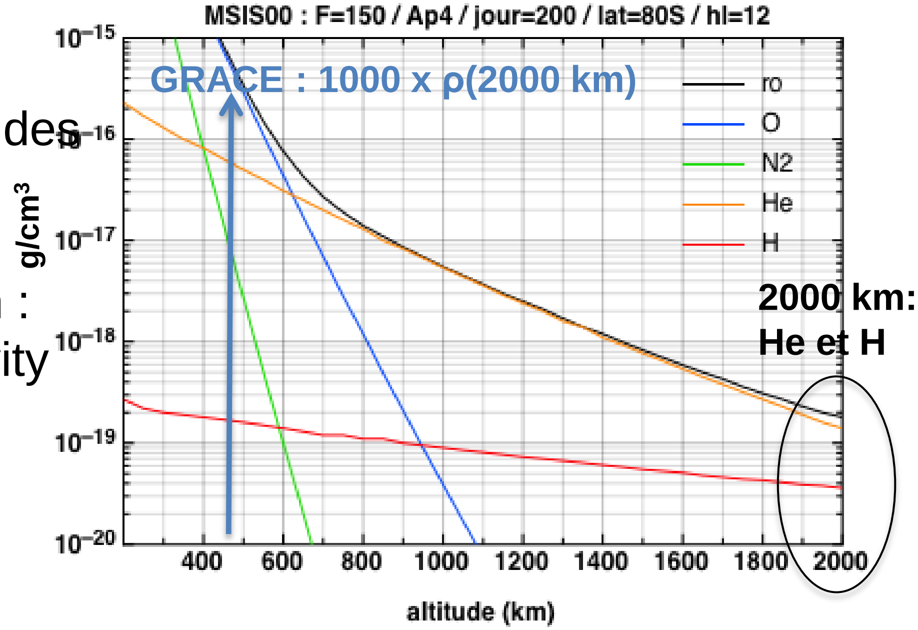
Actual multi-technique missions such as Jason-2 and GRACE satellites can also be used as prototypes to get a preliminary assessment of the GRASP requirements (software: GINS/DYNAMO).

Jason-2-/ DORIS, GPS, SLR
[Zoulida M., Thesis LAREG/IGN]

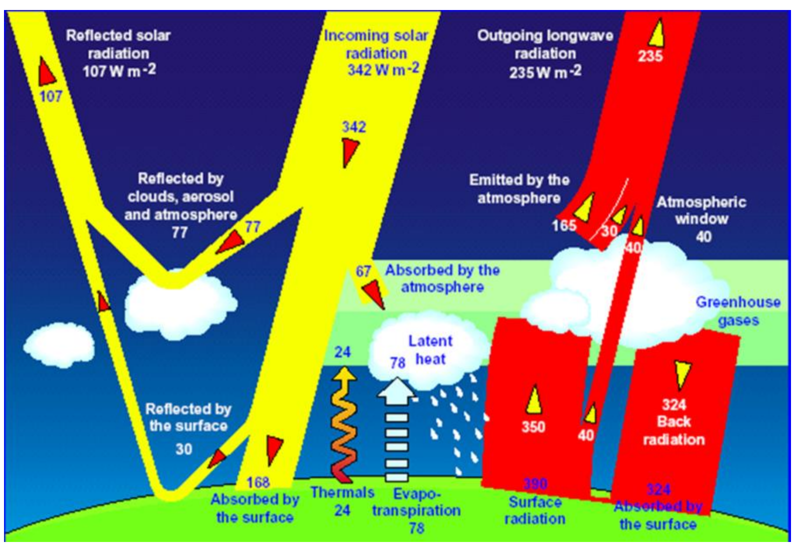
Secondary objectives / accelerometry

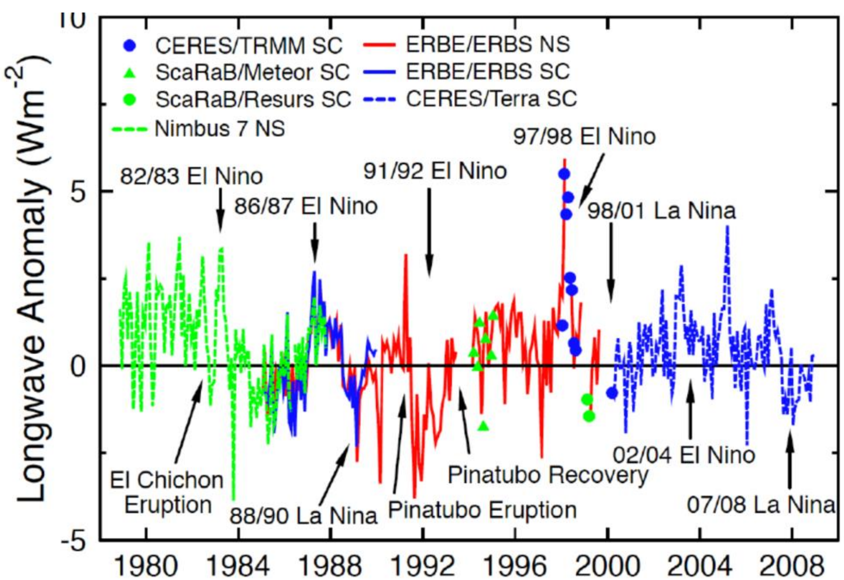
Thermosphere
Interest : presently few or no data for altitudes higher than 600 km / 1000 km

Feasibility : drag accelerations at 2000 km : 10^{-10} to 10^{-13} m/s^2 (according to solar activity and surface/mass ratio)

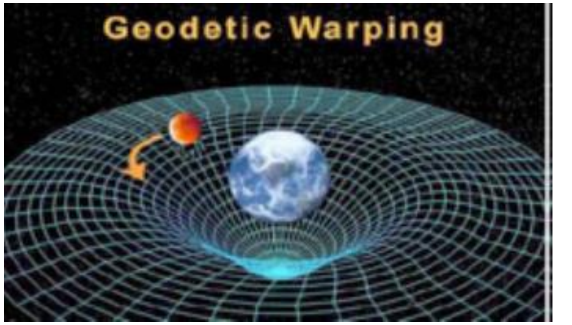


Radiation budget





Possible secondary objectives



Fundamental physics

Quasi-circular orbit, mm positioning :

• Secular effects on the node can bring a competitive additional constraint on the Lense-Thiring relativistic effect

• Possible determination of α_1, α_2 PPN parameters (but correlation with K1 and K2 tides)

• Competitive constraint on 2γ-β by the observation of the perigee relativistic precession

Time/frequency

<u>Assumptions:</u> ground stations at Boulder(USA) and Paris(F), 1 common view > 300 s/day with periods of 10 d continuous ground clock operation

- T2L2 GRASP: 3 ps @ 300 s, diurnal systematics < 10 ps
- MWL GRASP: 0.3 ps @ 300 s, diurnal systematics < 3 ps
- TWSTFT, GNSS (Fujieda 2014): diurnal systematics ≈ 50 ps

<u>Summary:</u>

- GRASP could lead to an improvement by about a factor 10 in tests of UCR/LPI (grav. Redshift) in the field of the Sun/Moon.
- A test of Lorentz Invariance (Ives-Stillwell experiment) using the space clock is possible, but unlikely to lead to improvement on best present knowledge.

Network improvement

NRC (2010)

"The committee recommends that the United States should work with its international partners to increase the number of multi-geodetic technique sites (particularly co-locating VLBI and SLR), with a goal of reaching a global geodetic network of at least 24 fundamental stations."

NASA-CNES Implementing Arrangement (2013)

"The first objective of the cooperation is to update the Implementing Agencies' existing space geodesy networks. As a first step, CNES will upgrade the Tahiti Geodesy Observatory.

The second objective is to deploy additional stations to complement the existing networks and increase the density of the space geodesy networks. To achieve this goal, the Parties will seek to co-locate, at mutually agreed sites, their instrumentation including VLBI, SLR, GNSS, REGINA, DORIS, and gravimetric instruments."

GGOS (2009), Meeting the Requirements of a Global, Society on a Changing Planet in 2020

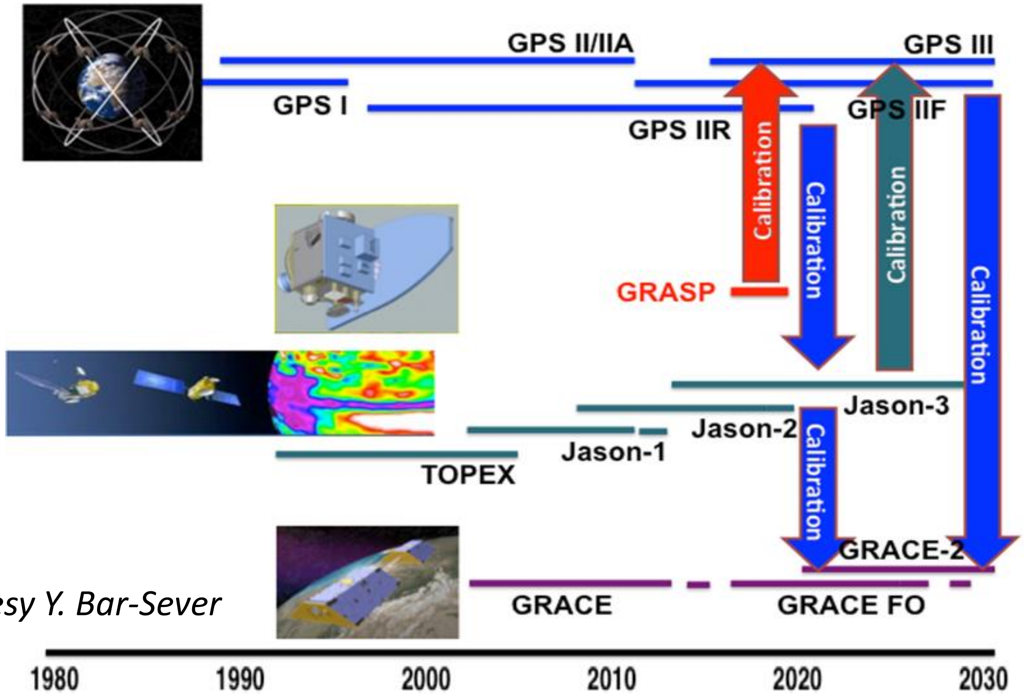
"Of the order of 40 evenly distributed core stations, i.e., stations with three or more space-geodetic techniques co-located, are required; however, currently there is a severe gap over the southern hemisphere. Without closing this gap, many of the most demanding user requirements will not be met."

Summary

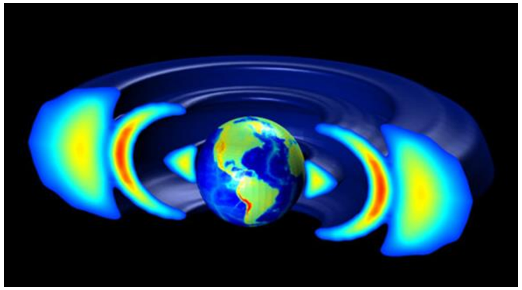
GRASP is the most complete geodesy-focused mission ever: all the techniques participate, all geodetic disciplines benefits

GRASP is a flying geodetic super-site, offering a straightforward path to meeting the demanding TRF stability and accuracy requirements of the geodetic community

GRASP's benefits extend well beyond the mission lifetime, into the past and into the future, through a cascade of secondary GNSS antenna calibrations



Courtesy Y. Bar-Sever



Instrument capability to be checked in phase 0 study
TRL > 5 necessary

GRASP workshop recommendations (1)

1) Un récepteur DORIS DGXX-S est un élément fondamental qui doit compléter une mission dédiée au système terrestre.

2) L'embarquement d'un micro-accéléromètre (à 10^{-11} m/s^2) semble évident pour une mission métrologique mais il reste à quantifier objectivement son apport à la détermination d'orbite. Ce système permettrait en outre de mieux préciser l'attitude du satellite (par les accélérations angulaires) ainsi que le centre de masse du satellite (par les accélérations linéaires d'entrainement).

3) L'opportunité d'embarquer un système T2L2 est attrayante pour la synchronisation des horloges, mais les considérations de coût, d'énergie requise et de délai ne semblent pas favorables. La synchronisation par lien microonde (MWL) pourrait être considérée avec le système allemand développé par TimeTech. Une proposition en ce sens serait à faire.

4) Les simulations d'orbite privilégient une altitude voisine de 2 000 km qui offre une observabilité multiple plus appréciable (notamment pour le transpondeur VLBI) mais pose des problèmes de blindage des instruments et de longévité de mission à cause de l'amplification des radiations à haute énergie dans la ceinture de Van Allen (2 000-5 000km). Une étude appropriée sur les blindages est nécessaire.

GRASP workshop recommendations (2)

5) Deux alternatives orbitales existent quoiqu'avec d'autres inconvénients :
- une orbite excentrique (~800 -~2 000) qui limite l'effet des radiations mais également l'observabilité VLBI ;
- une orbite circulaire à plus de 5 000 km qui serait la plus adéquate pour le VLBI ainsi que pour la géométrie de suivi mais qui demande des adaptations instrumentales (GNSS et DORIS) à étudier.

6) Un micro-accéléromètre à 10^{-11} m/s^2 peut permettre d'apporter un étalonnage au bilan radiatif terrestre ou au composantes He et H de l'exosphère suivant l'altitude choisie.

7) La détermination de certains paramètres relativistes (LT, α_1, α_2, 2γ-β) pourrait être améliorée avec une qualité d'orbite millimétrique.

8) Il est important de rendre les réseaux sol compatibles avec la précision millimétrique recherchée par GRASP, notamment le réseau DORIS par la 4ème génération de balises et l'implantation d'observatoires géodésiques fondamentaux reliant les quatre techniques fondamentales au sol.

9) Des améliorations algorithmiques et logiciel (propagations des ondes, surcharges en station…) doivent se poursuivre pour maitriser la précision millimétrique de calcul d'orbite.

NASA mission classes

The classification considerations provide a structured approach for defining a hierarchy of risk combinations for NASA payloads.

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan)	High priority	High priority	Medium priority	Low priority
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission)	Long, > 5 years	Medium, 2-5 years	Short, < 2 years	Short, < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX