Review of MARVEL pre-Phase-A

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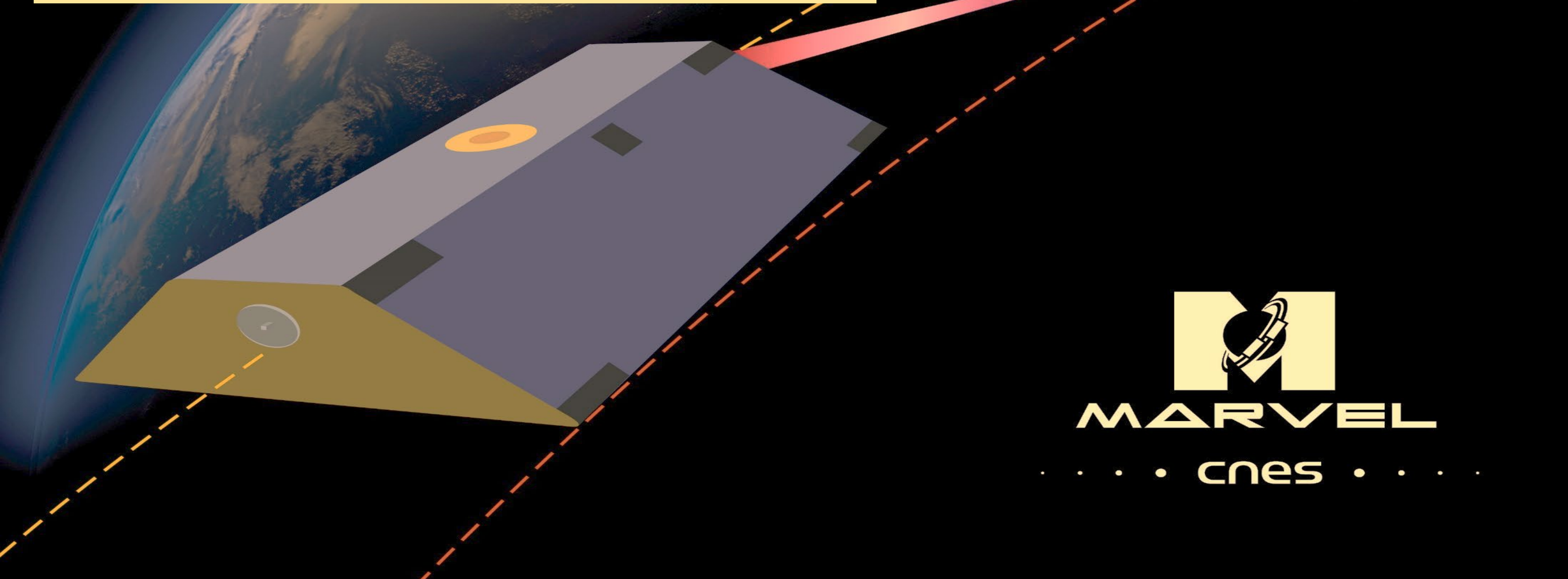

THE MARVEL TEAM

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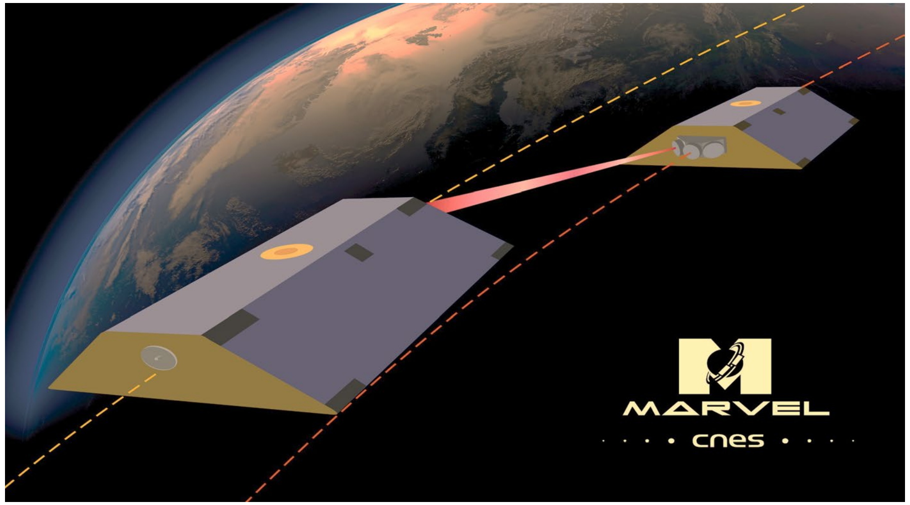
Pre-Phase-A leader



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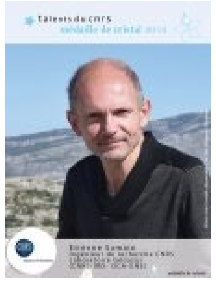

Etienne Samain (SigmaWorks)

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Instrument experts

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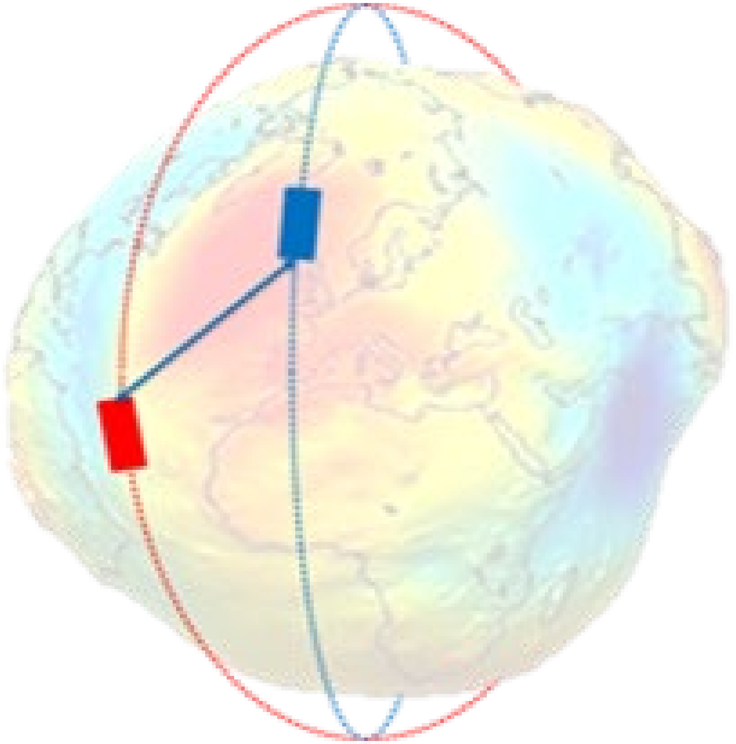
Numerical Simulations expert

SUMMARY

- Context
- The laser ranging instrument
- The numerical simulations of scientific performance
- Conclusion

❖ Context

- The MARVEL mission proposal for an **improved observation of the time variable gravity field** was submitted to the 2019 CNES Scientific Prospective Seminar and was accepted in September 2019
- The pre-Phase-A study started in January 2020 and ended in February 2022
- The principle of the MARVEL concept is a **pendulum** configuration with 2 (or more) low flying polar satellites
- In pendulum configuration, the 2 satellites are on two similar polar orbital planes, with a slight offset in ascending node and mean anomaly
- The measurements done between the satellites are therefore oriented alternatively to the right and to the left of the orbital track, up to +/- 45°
- After a few days, the determination of the gravity field from those measurements becomes almost **isotropic**

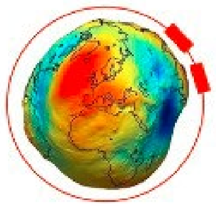


❖ Context

➢ The key to improving the gravity field observation is improving the **geometry** of the observations

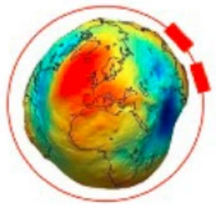
CURRENT CONCEPT (*IN-LINE POLAR PAIRS*)

GRACE

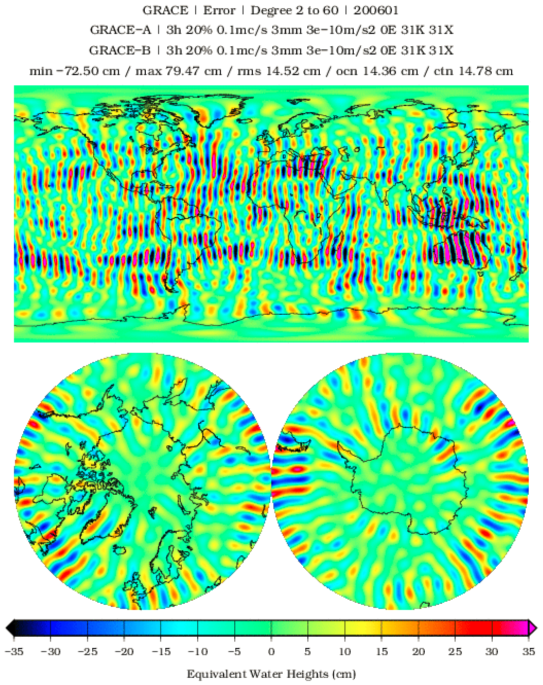


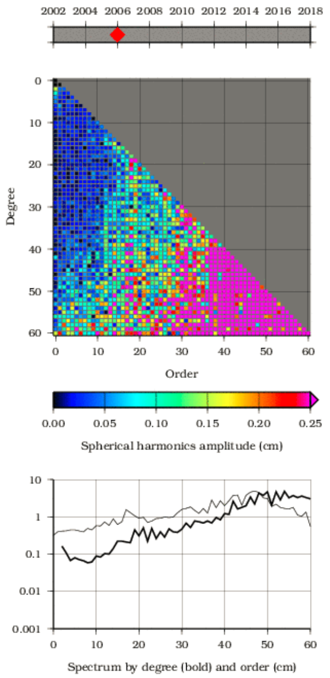
σ SST = 1.e-7 m/s

GRACE-FO



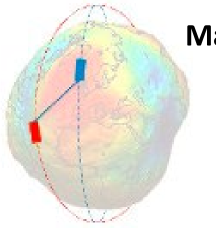
σ SST = 2.5e-9 m/s





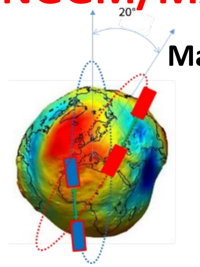
FUTURES CONCEPTS (*INCLINED MEASUREMENTS*)

MARVEL

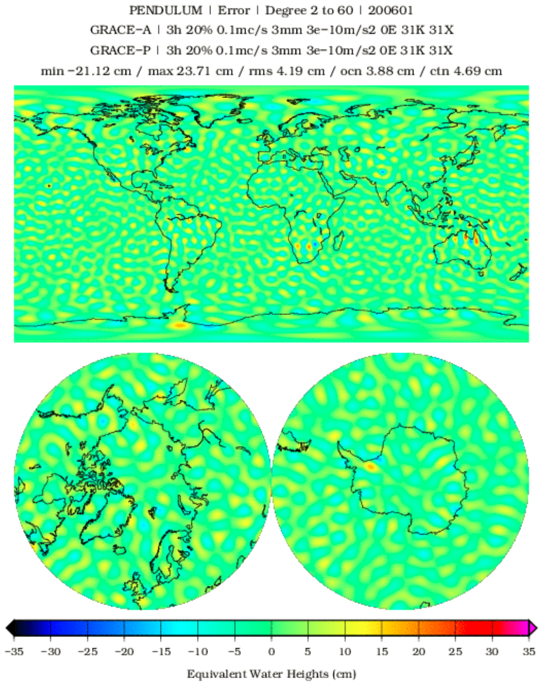


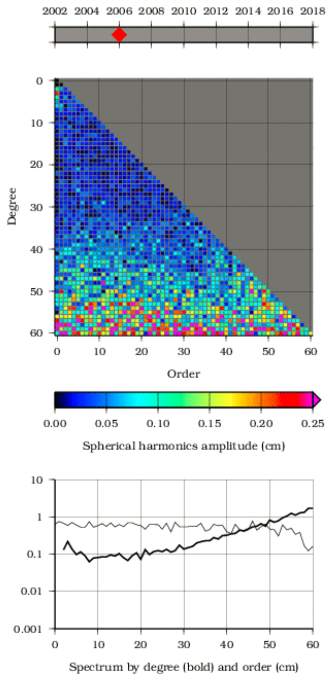
σ SST = 1.e-7 m/s

NGGM/MAGIC



σ SST = 2.5e-9 m/s



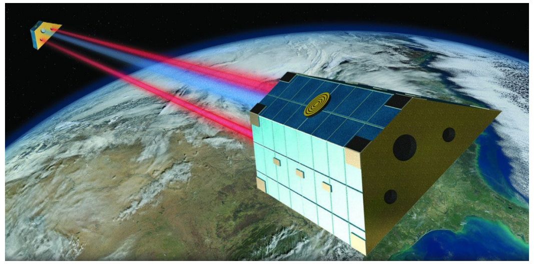


❖ Context

➢ MARVEL pre-Phase-A has taken place in a context where next generation gravity missions are under design among many actors

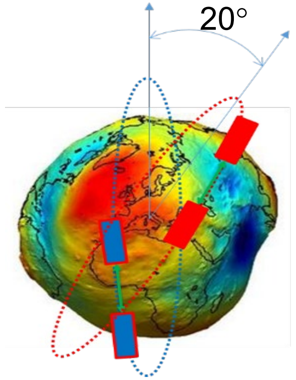
MASS CHANGE

Continuity of GRACE & GRACE FO



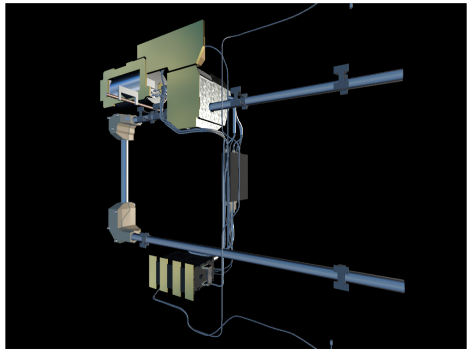
NGGM/MAGIC

Innovation



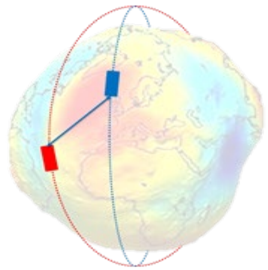
GRACE-I

Continuity

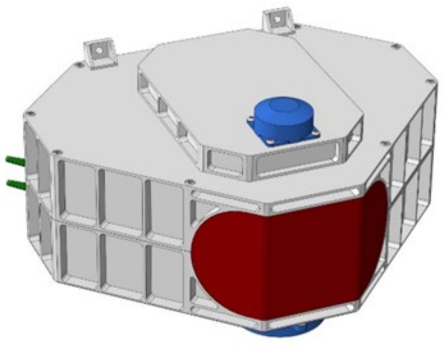


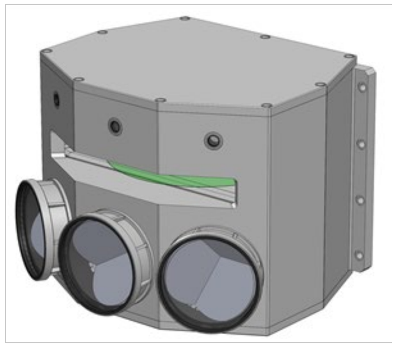
MARVEL

Innovation



THE LASER RANGING INSTRUMENT





❖ The laser ranging instrument

SPECIFICATIONS:

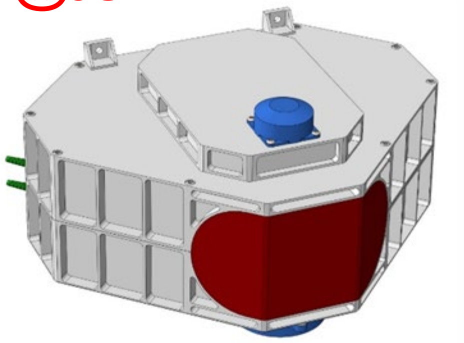
- Average inter-satellite distance ***~ 200 km***
- Satellite body in fixed attitude law (→ the laser beam has to be oriented onboarad the satellite)
- Instrument-induced dynamical perturbations on the spacecraft < 10^{-11} m/s^2
- Maximum angle between line-of-sight and satellite reference frames : ***+/- 45°***
- Instrument accommodation @ maximum ***1.5 m from satellite Center of Mass***
- Ranging accuracy: better than ***1 µm @5s*** in all circumstances

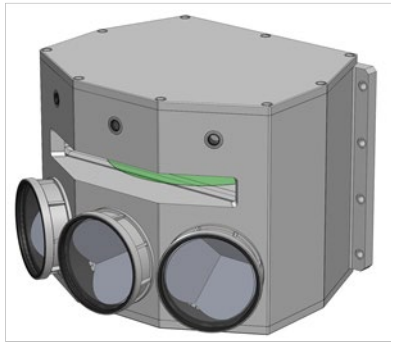
TECHNOLOGICAL SOLUTION:

- ***Chronometric*** (i.e. not interferometric) laser link, using proven telecom components
- Line-of-sight angular measurement, for Center-of-Phase/Center-of-Mass correction @ better than ***1 µrad @5s***

Emitter / Receiver side

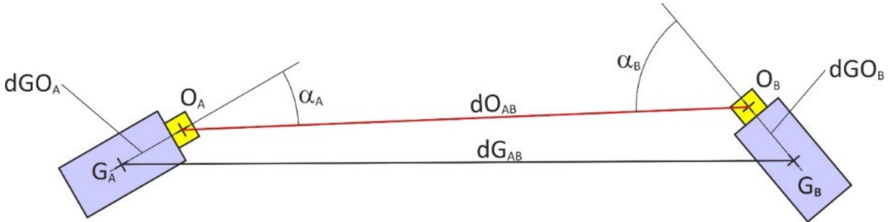
with ultra-light moving parts





Reflector side

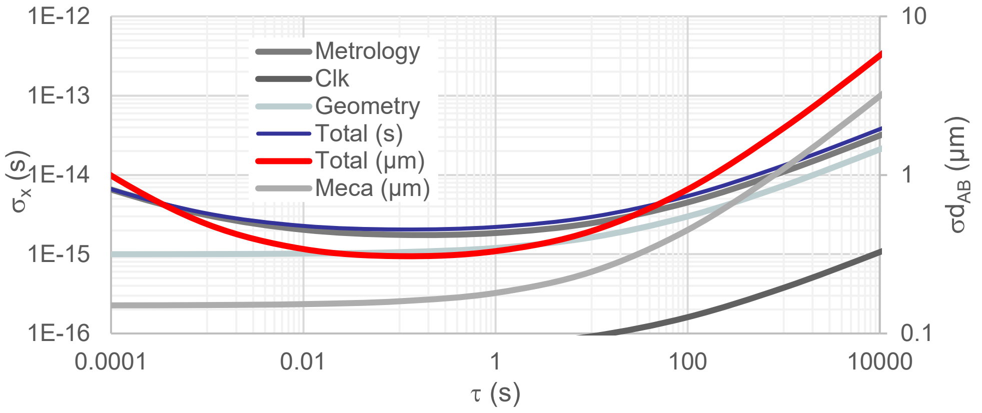
Totally static



CoP-CoM correction

❖ Technical aspects

Stability curve, expressed in relative stability (left) and ranging noise (right)



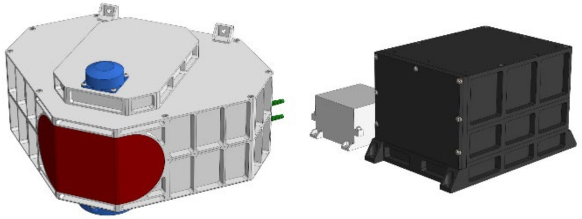
Integrated RMS noise, in distance and velocity, for 1, 5 and 10 s integration time

RMS		
Ranging D		Velocity V
	σD RMS	σV RMS
	µm	µm/s
@ 1 s	1.19	1.24
@ 5 s	1.14	0.26
@ 10 s	1.11	0.13

Mass, consumption and TRL, of the emitter/receiver (left) and reflector (right)

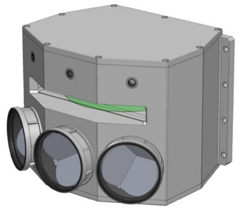
Mass = 13 kg

Power = 55 W



Mass = 8 kg

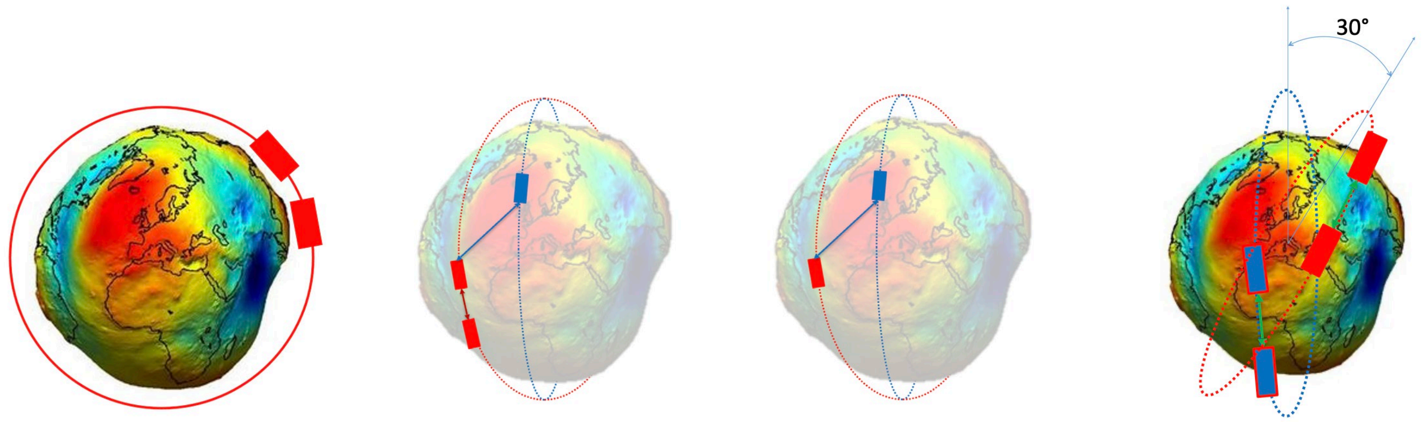
Power = 14 W



Sub-system	TRL	Heritage
Erbium Laser amplifier	4-5	CW 1,5µm amplifier
Telecom Transceiver	9	Teleo
Event timer	9	Time Transfer by laser Link T2L2
Femto metrology	4	R&T Program : Metrology bread bord Model
Ultra stable oscillator	9	DORIS Navigation system

Sub-system	TRL	Heritage
Corner cube	9	
Wide field µrad sensor	9	Telescope and algorithm, CNES Patent for the sensor optimization
Ultra stable oscillator	9	DORIS Navigation system

THE NUMERICAL SIMULATIONS



Numerical simulations setup

- Most simulations were performed in the "CNES simulation environment" but the latest ones were done in the "ESA Earth System Model" environment for NGGM, in cooperation with GFZ

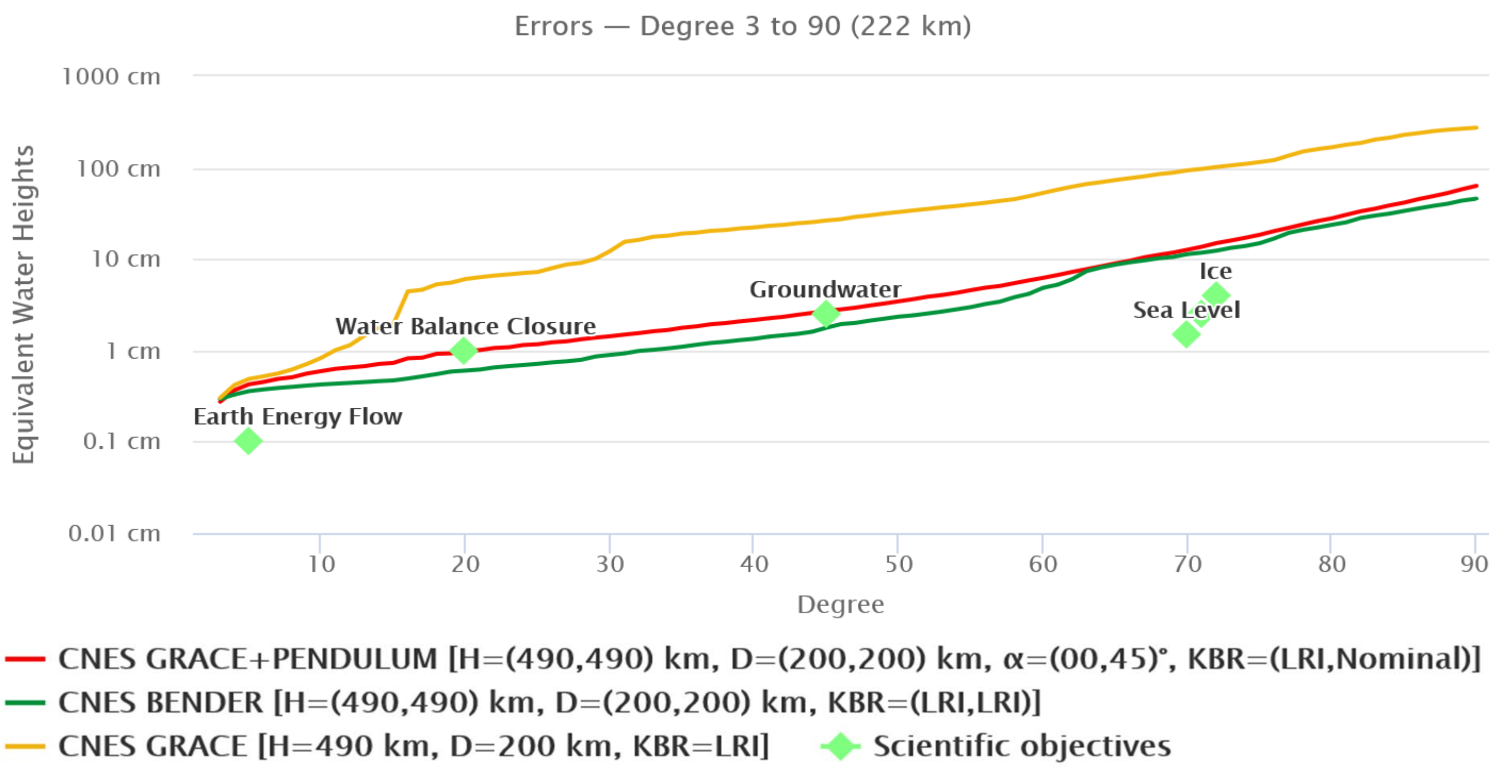
- The gravity field recovery performances of many different configurations were studied: classic "GRACE-type" single pair, double pair ("Bender"), two-satellite pendulum and three-satellite pendulum (i.e. a "GRACE-type" pair + third pendulum satellite). In each case we explored different altitudes, different inter-satellite separations, etc.

- The main outcome is that Bender and Pendulum achieve comparable performance at the monthly time scale and that they both provide a 6 to 8-fold improvement over current GRACE-type missions

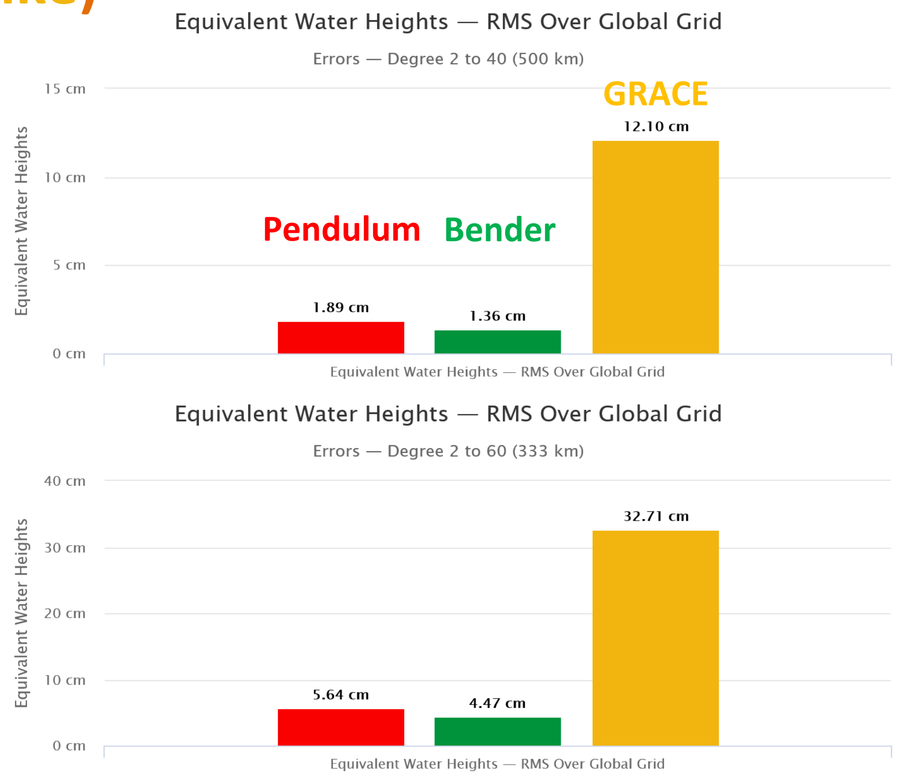
- What was not considered in the simulations, but does have an impact on the results, is the fact that the Bender configuration allows a better time sampling of the gravity field because of its double pair, than the simple "2 satellite" pendulum

Unconstrained results

for the three mission types (pendulum, bender and grace-like)



Cumulated error from degree from 3 to 90

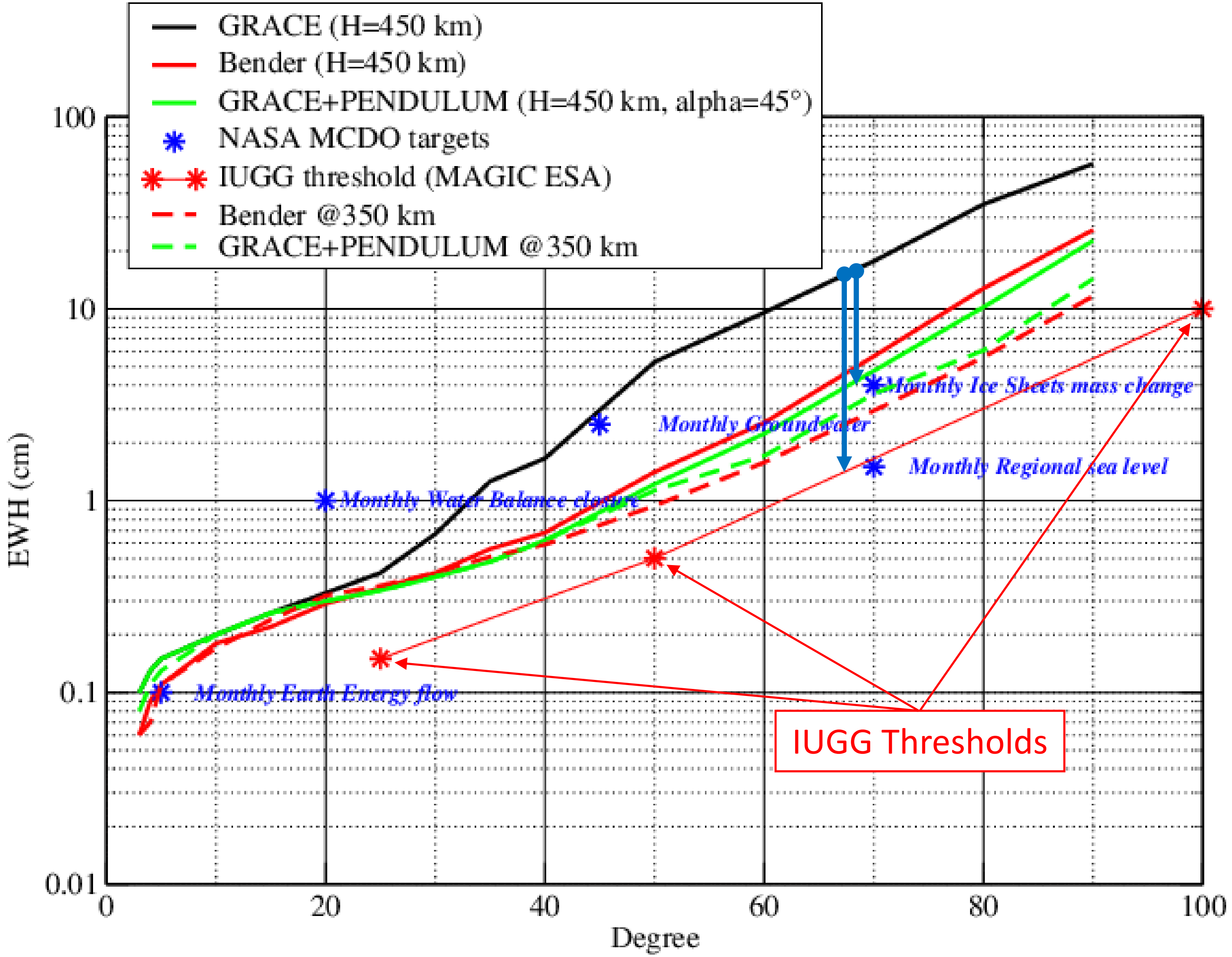


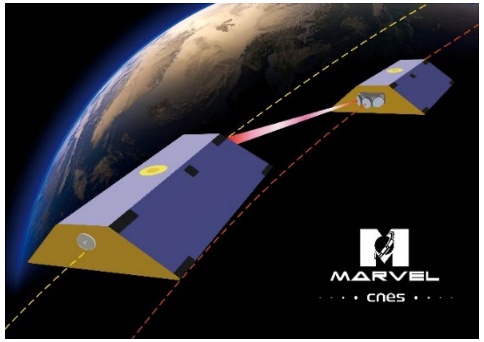
Root mean square (rms) over the global grid

Top panel: degrees 2 to 40

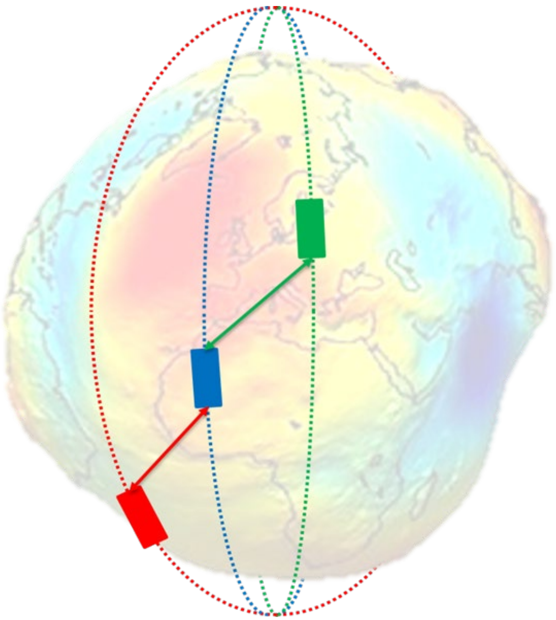
Bottom panel: degrees 2 to 60

Comparison to NASA and ESA thresholds and targets





CONCLUSIONS



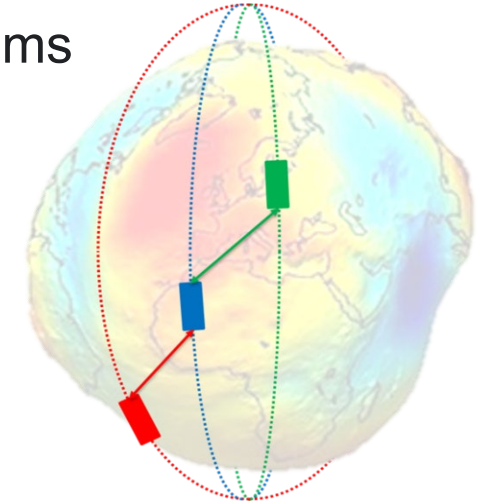
CONCLUSIONS

- Plans for future missions, with inclined measurements, show a very clear improvement in scientific results compared to current polar missions (GRACE/GRACE-FO)

- MARVEL pre-phase-A has proven the interest of the pendulum concept

- Chronometric laser ranging instrument → for ~200 km distance:
  - range better than 1 µmeter @5s,
  - angle better than 1 µrad @5s,
  - lateral scan up to +/- 45°
  - based on several innovative concepts using proven optical telecom subsystems
  - precise, cheap, light and low power instrument

- In the future, it can in particular be envisaged as the ranging instrument of a constellation of 3 or more LEO satellites performing one-to-one pendulum measurements and **covering in a single pass a swath of a few hundred kilometres at the equator with a high temporal repetitivity**



THANK YOU for your attention