What LISA Pathfinder can do for space science

Mike Cruise
University of Birmingham

(with apologies to everyone from whom I have stolen pictures)

Context

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- **Tim Sumner will speak tomorrow on the direct science that LPF will achieve.**
- **Space Science is much wider than gravitational physics**
  - **Planetary Science**
  - **Astronomy**
  - **Earth Science-Geodesy**

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- **The LPF technical developments need to be continued- a case needs to be made for this.**
- **There needs to be a mechanism through which the technology can be transferred.**

Elements of Pathfinder

Elements of Pathfinder

- Laser

Elements of Pathfinder

- Laser
- Optical Bench

Elements of Pathfinder

- Laser
- Optical Bench
- Phasemeter

Elements of Pathfinder

- Laser
- Optical Bench
- Phasemeter
- On Board Computer

Elements of Pathfinder

- Laser
- Optical Bench
- Phasemeter
- On Board Computer
- Accelerometer

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- Charge Management System

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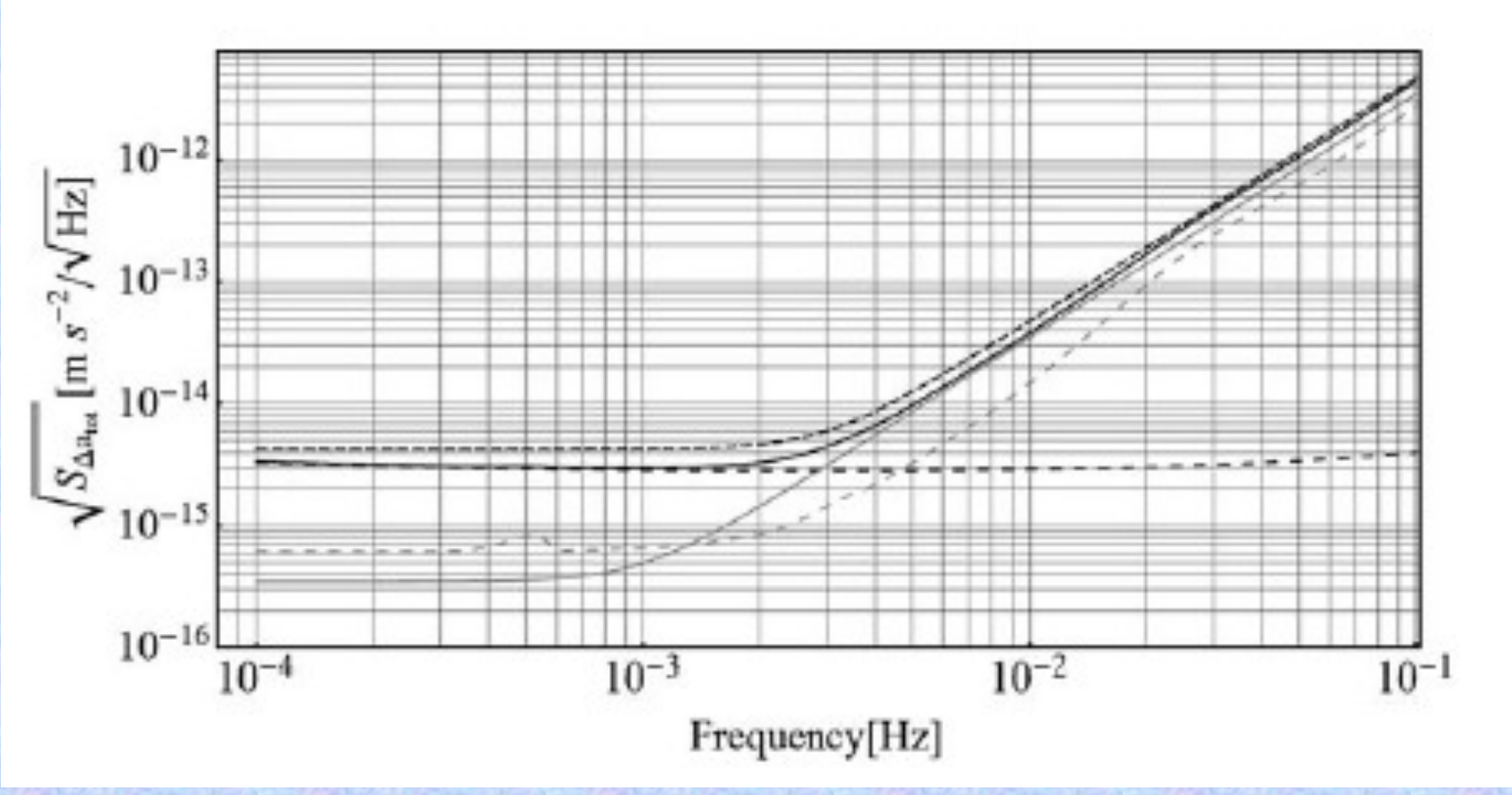
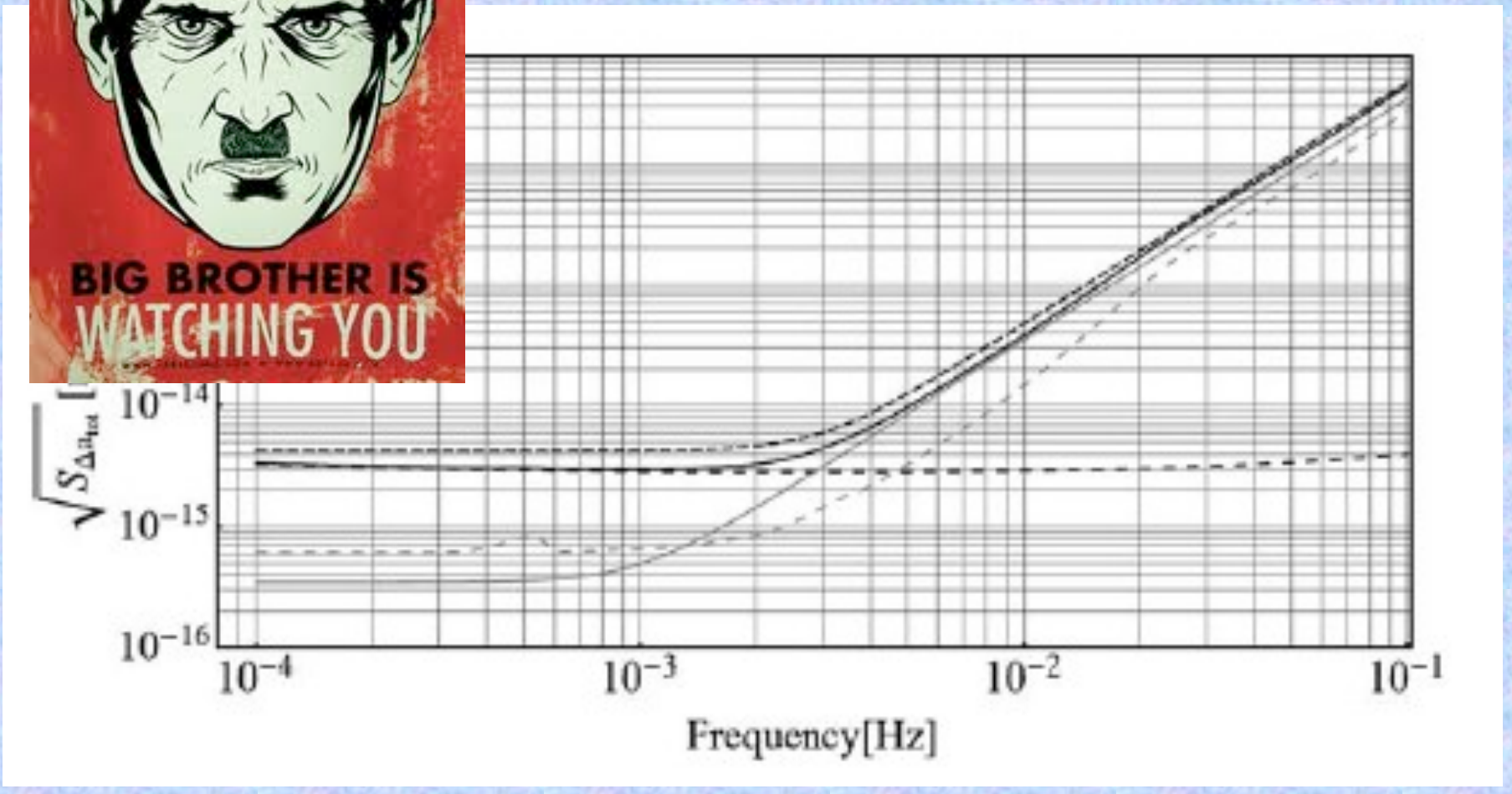
This is what the whole mission is about and where the real performance advances will be made

The graph that has frightened us



oh that has frightened us



How can other missions benefit?

- Some examples of proposals, extrapolations and ideas……

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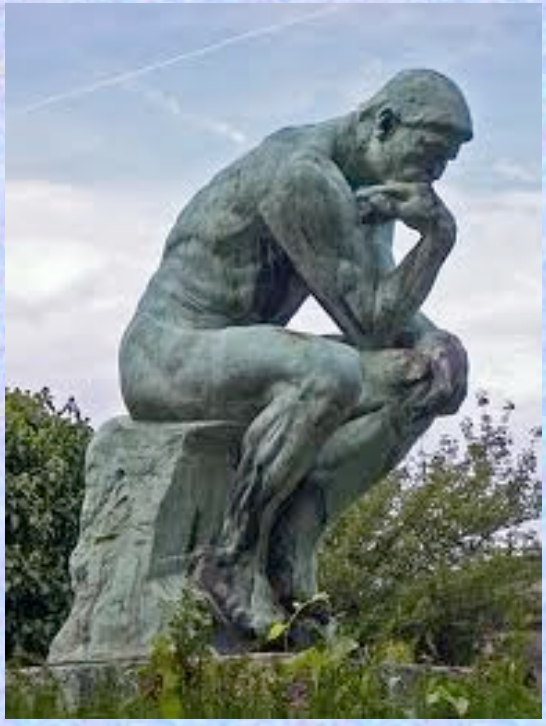
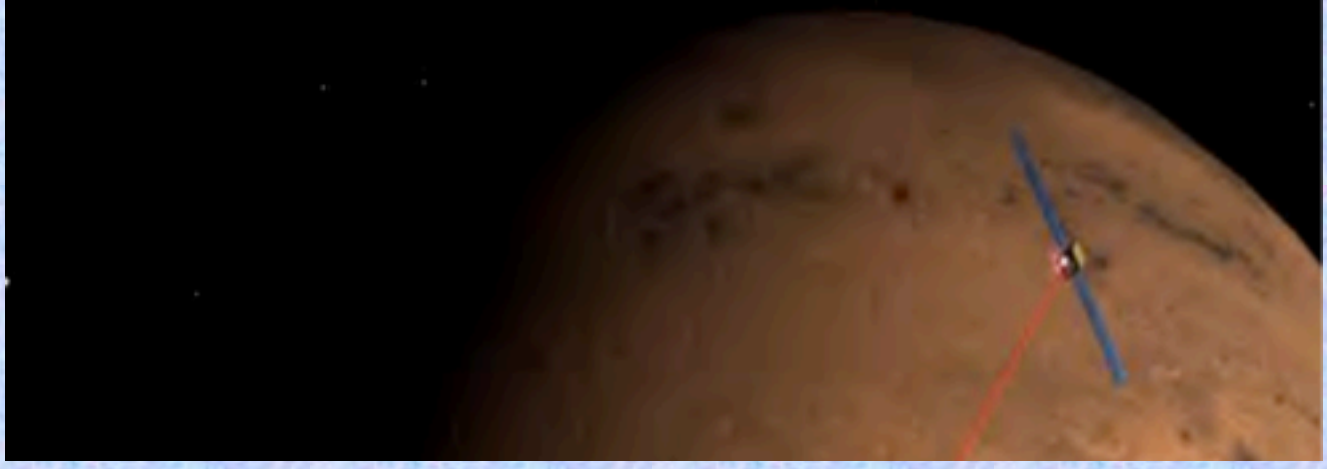


GETEMME

A Mission to Explore the Martian Satellites and the Fundamentals



GETEMME

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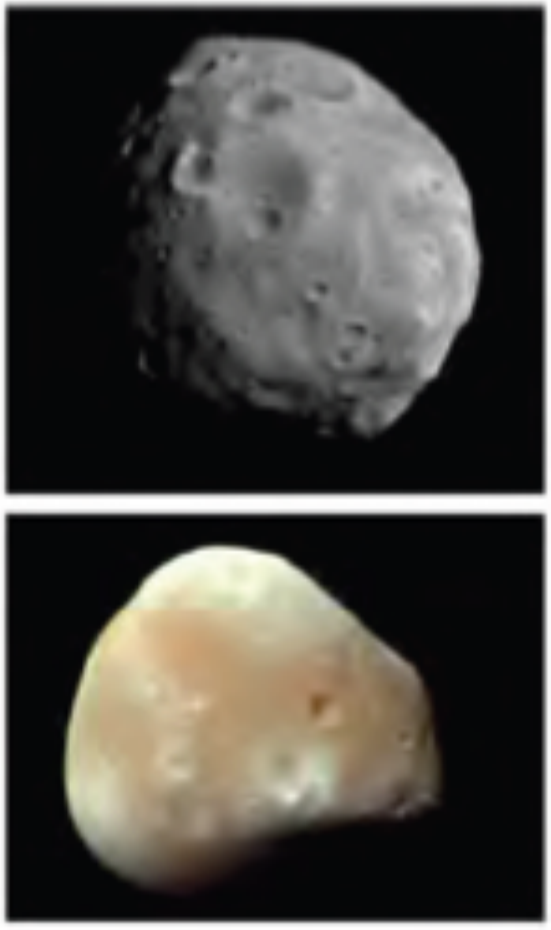
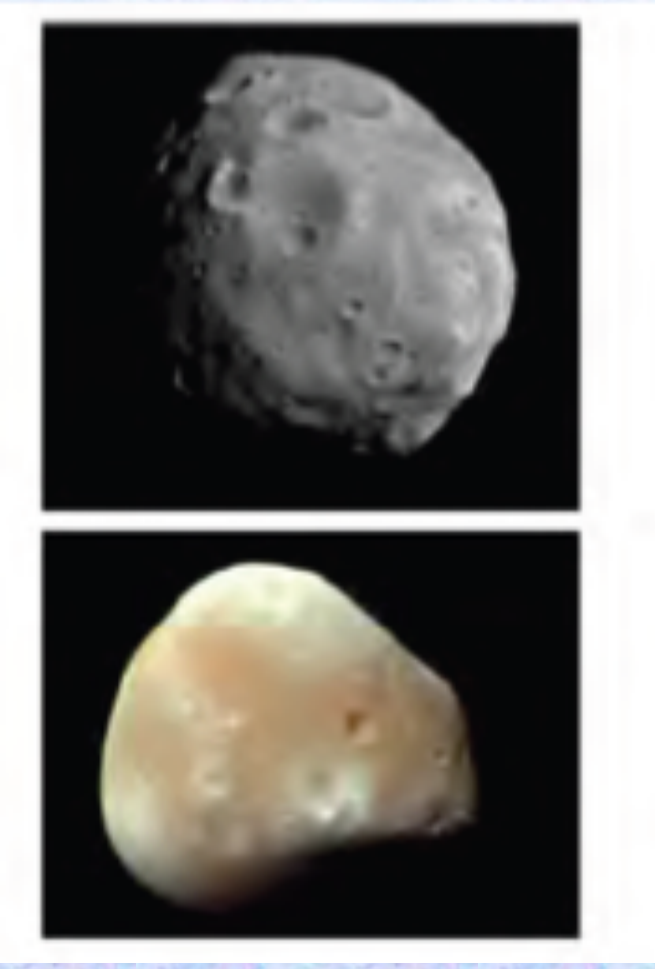
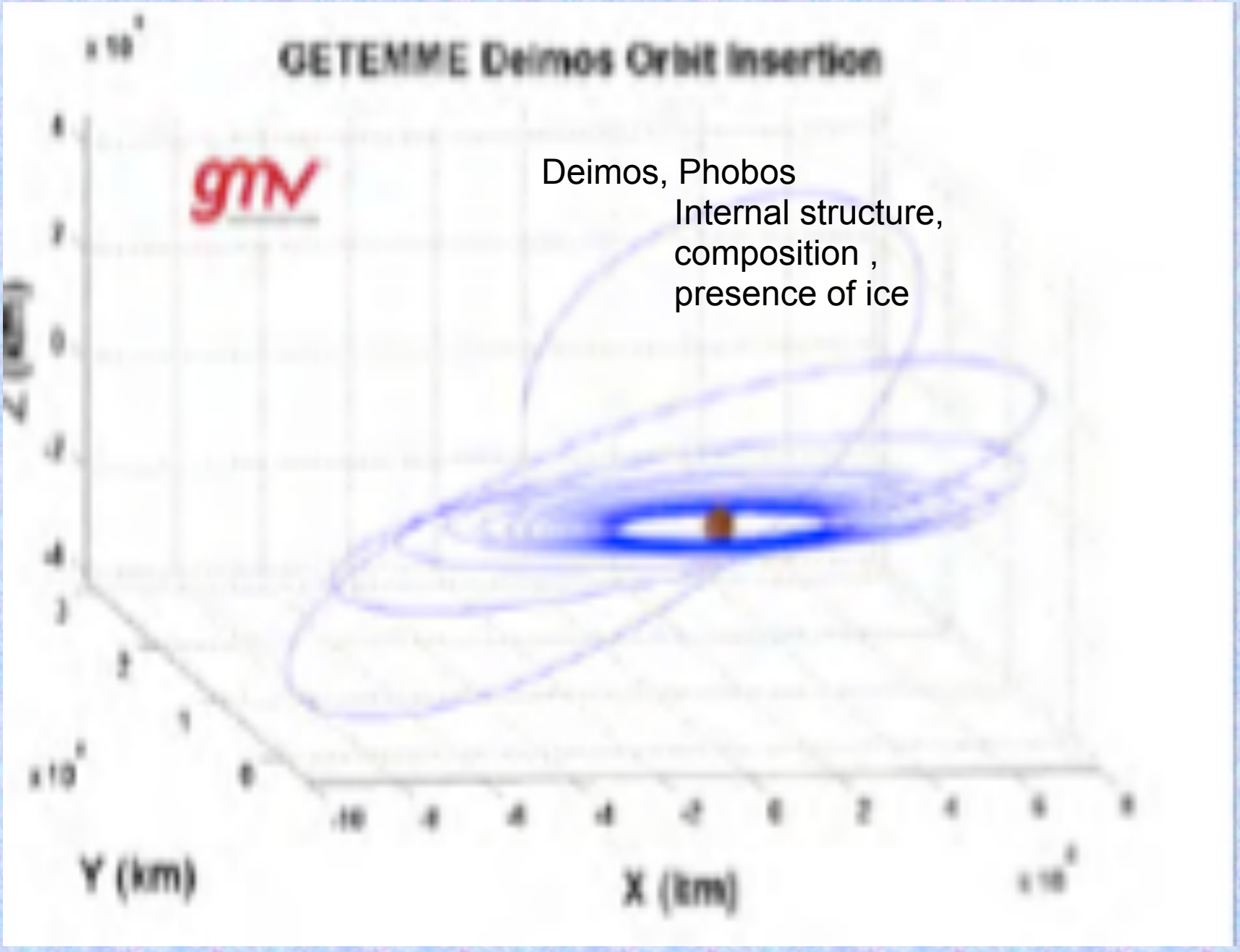
Satellites and the Fundamenta

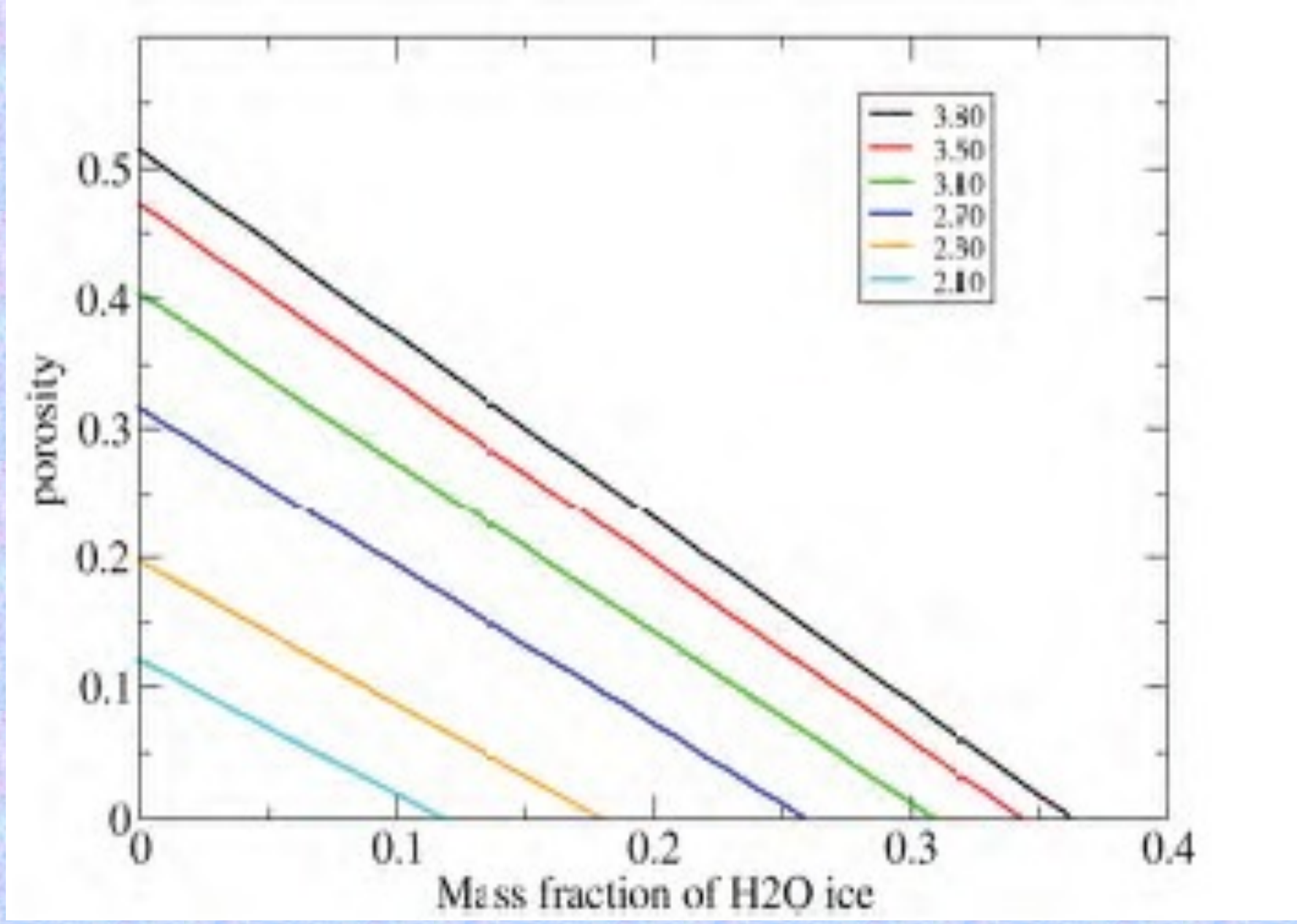


GETEMME

- Mission to Mars, Phobos and Deimos
- Space laser ranging has achieved 20 cm in 24 Mio Km
- Orbit accuracy expected with accelerometer– 1 cm

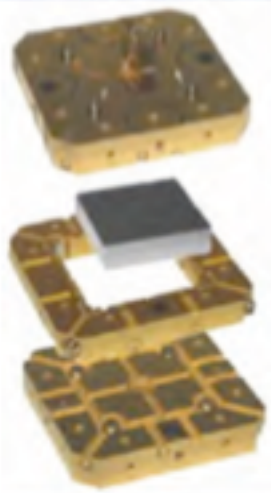



GETEMME Deimos Orbit Insertion
gmv
Deimos, Phobos
Internal structure,
composition ,
presence of ice
Y (km)
X (km)

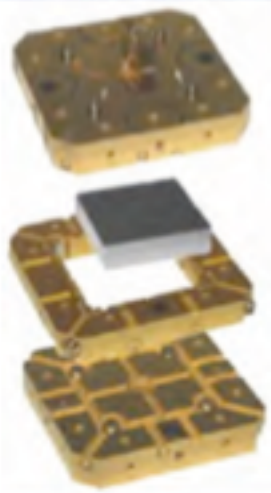

3.80
3.50
3.10
2.70
2.30
2.10
porosity
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
Mass fraction of H2O ice

GETEMME
Some Fundamental Physics

RG effect	2 years	4 years	current value
β of Mars-1	$1.7\ 10^{-7}$	$5.3\ 10^{-8}$	-
Lense-Thirring	$2.1\ 10^{-4}$	$1.0\ 10^{-4}$	10^{-1} (Earth, LAGEOS)
Gdot/G (in year^{-1})	$1.6\ 10^{-15}$	$2.9\ 10^{-16}$	$(4\pm9)\ 10^{-13}$ (Lunar LR)



Subsystem	Mass	Size	Power Average (max)
MicroSTAR sensor head	1.4kg	10x10x10 cm³	1.4 W (1.4 W)
Bias rejection system	1.1kg	12x12x5 cm³	0.2 W (6 W)
Interface and Control Unit	1.0kg	12x12x5 cm³	1.4 W (1.4 W)
Total	**3.5kg**		**3 W (8.8 W)**



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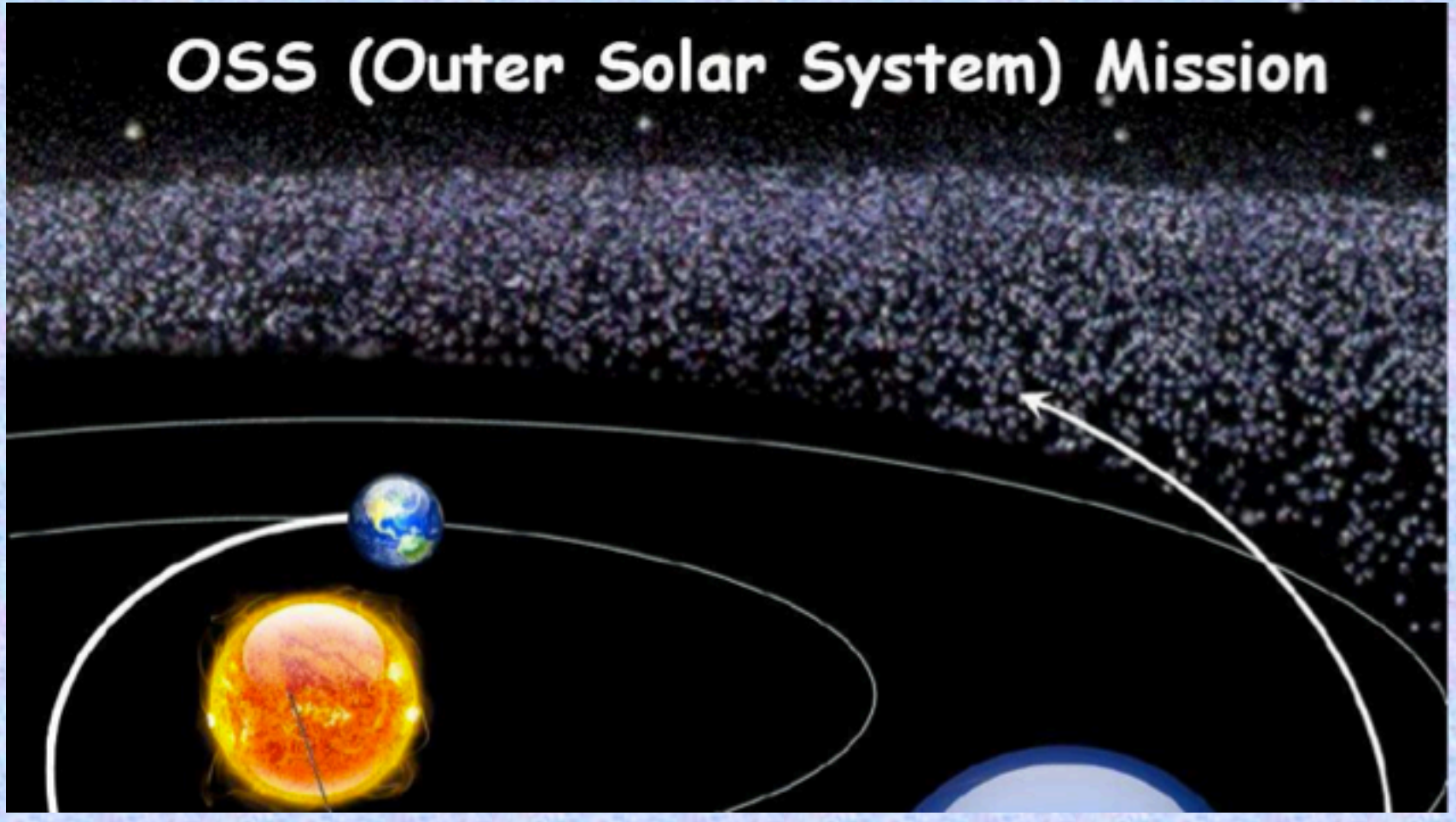
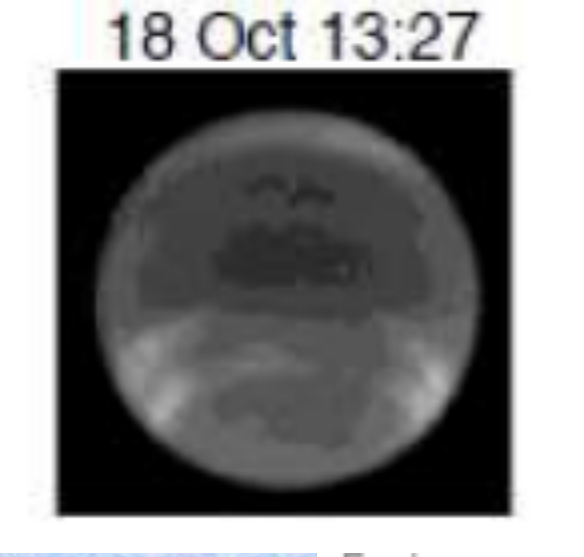
A 20 x times improvement in planetary orbit science

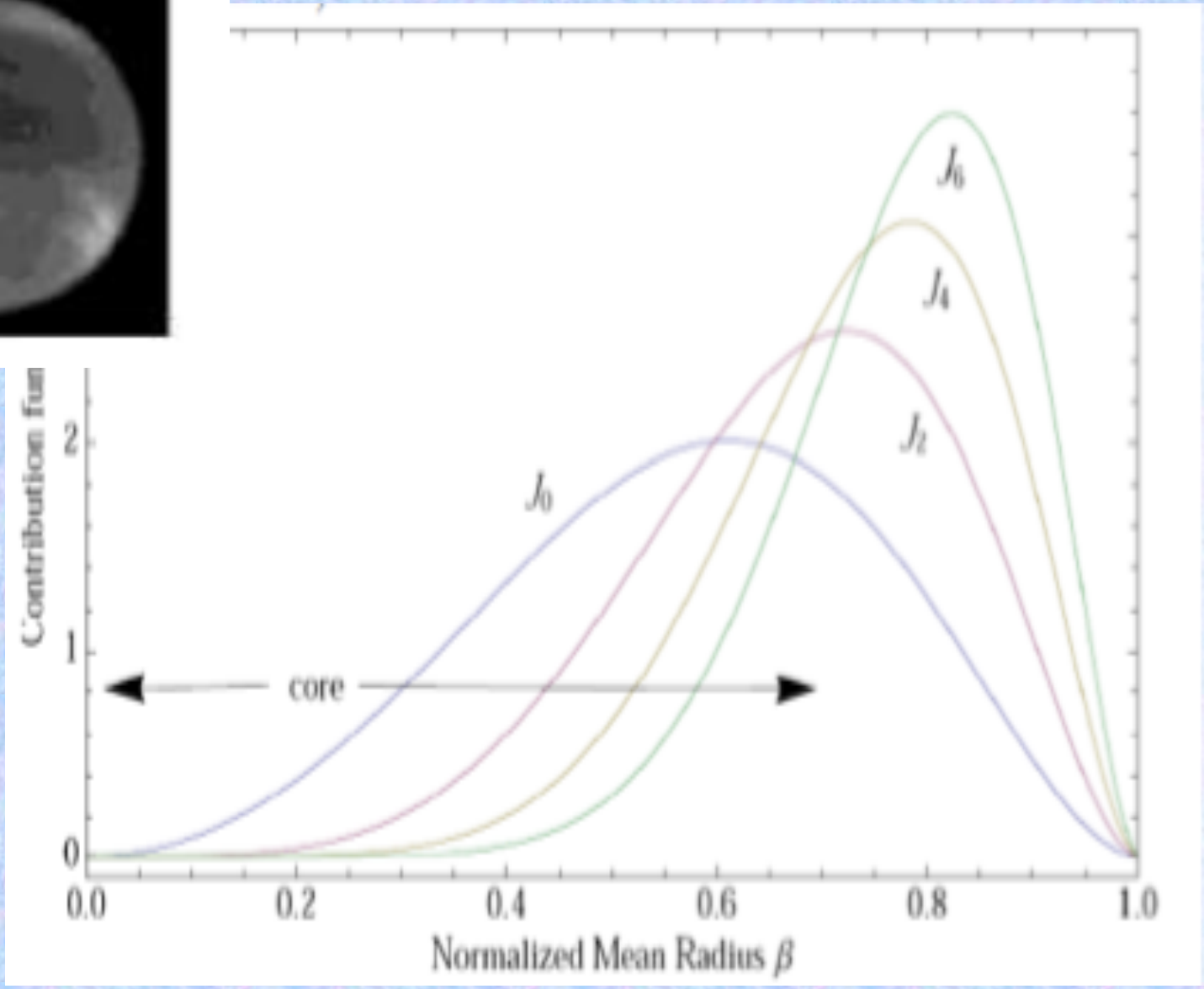
OSS



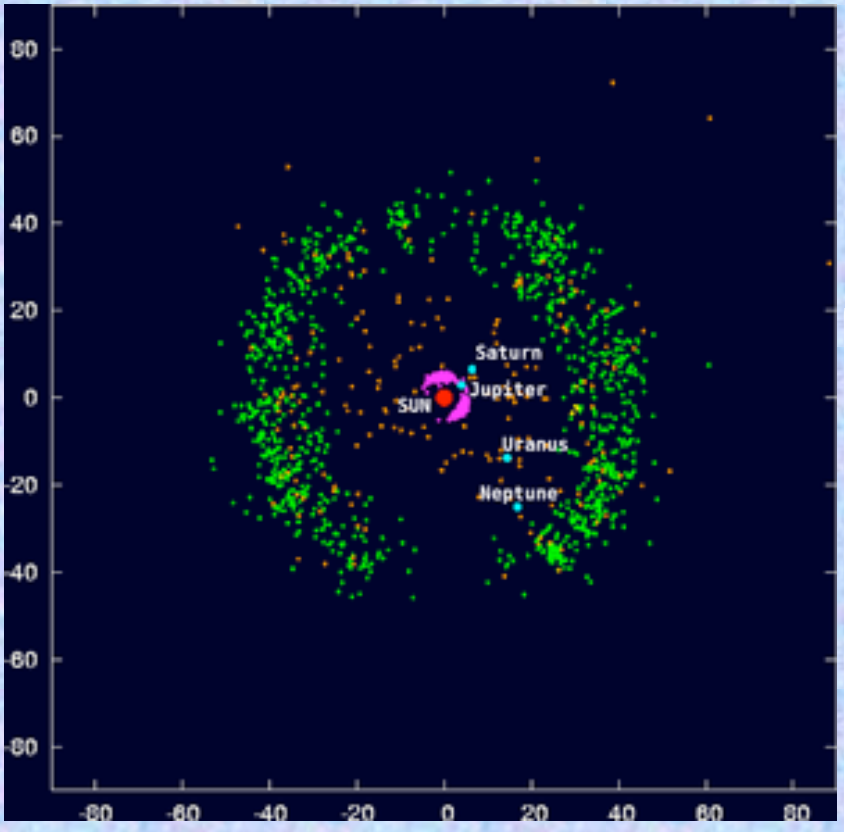
OSS

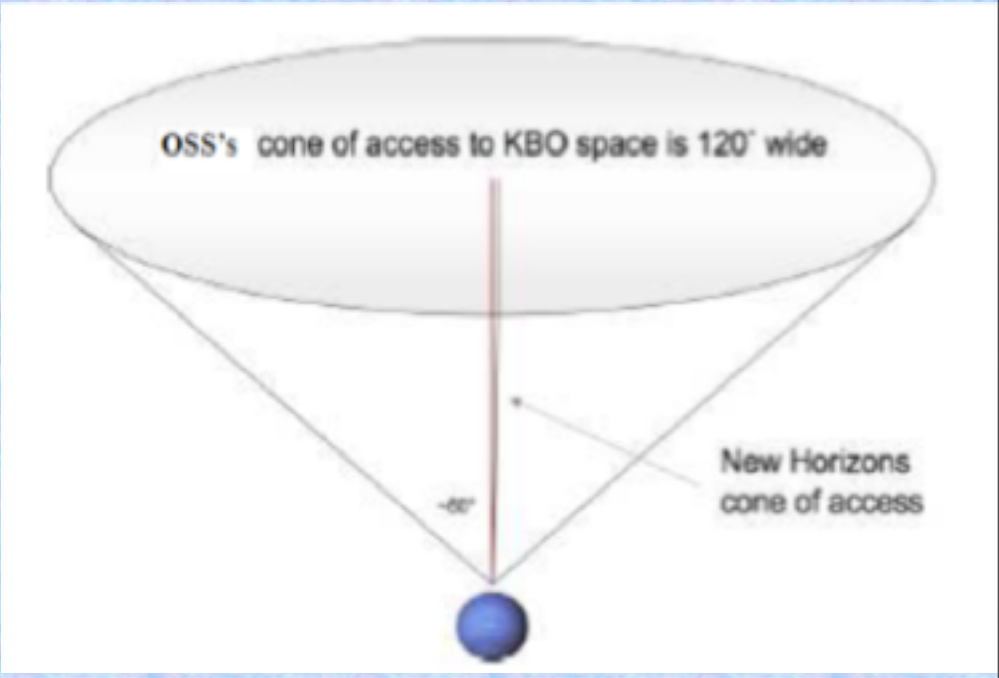
- Mission to Neptune and then to the Kuiper Belt
- Accelerometer to measure non-gravitational forces will give a 100x improvement in our knowledge of the gravity field in the outer solar system

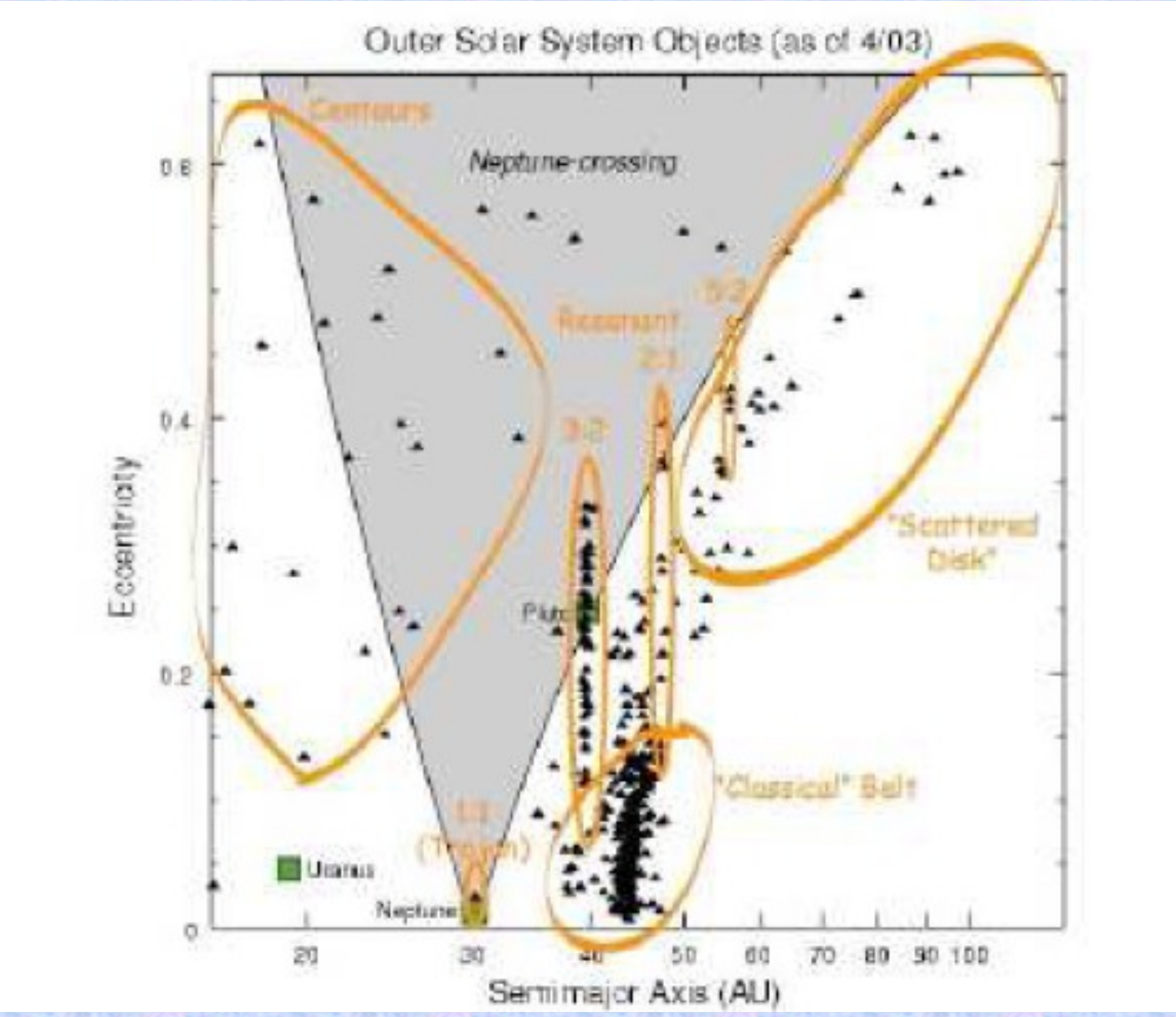

18 Oct 13:27


J_6
J_4
J_2
J_0
core
Contribution fun
0
1
2
0.0
0.2
0.4
0.6
0.8
1.0
Normalized Mean Radius β

Access to Kuiper Belt






Outer Solar System Objects (as of 4/03)
Centaurs
Neptune-crossing
Resonant
"Scattered Disk"
"Classical" Belt
Pluto
Uranus
Neptune
Eccentricity
Semimajor Axis (AU)
0
0.2
0.4
0.6
20
30
40
50
60
70
80
90
100

Kuiper Belt Mass distributions

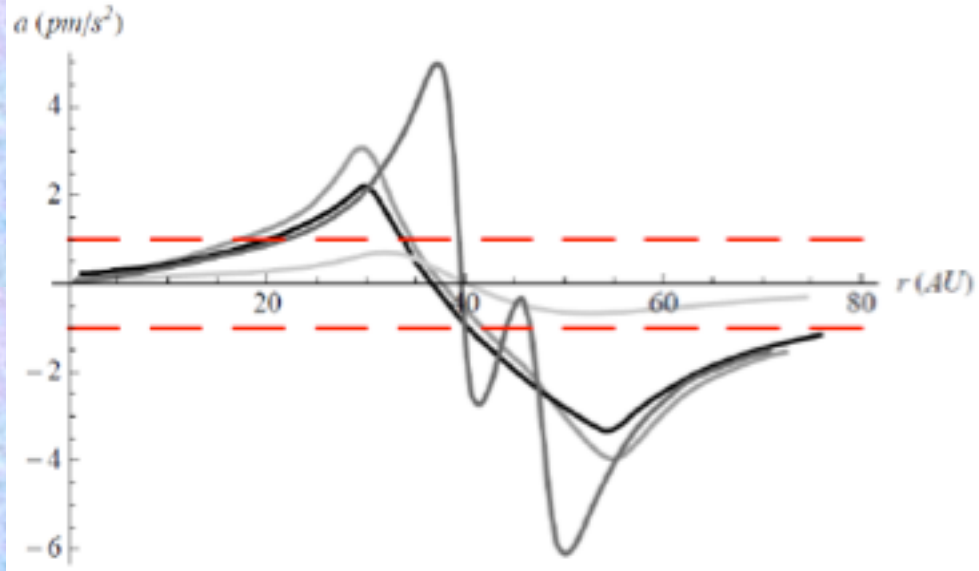


Figure 10: Accelerations due to different Kuiper Belt mass distributions for a solar ecliptic latitude of $\theta = 3°$ (Bertolami 2006), with an accuracy threshold of 10^{-12} m/s^2 superimposed (black – torus, dark grey – ring, medium grey – uniform disk, light grey: – non-uniform disk).

MicroStar

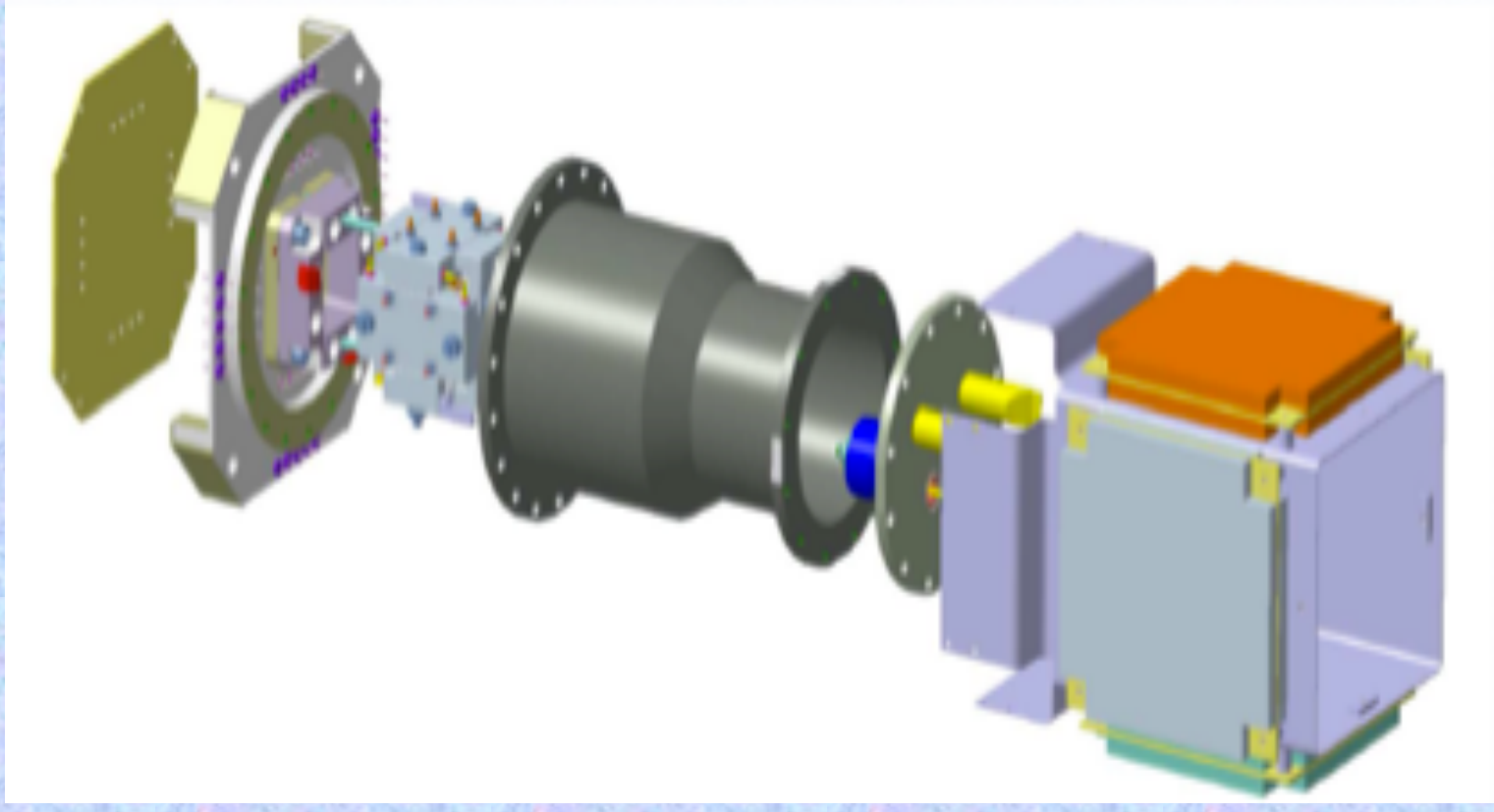
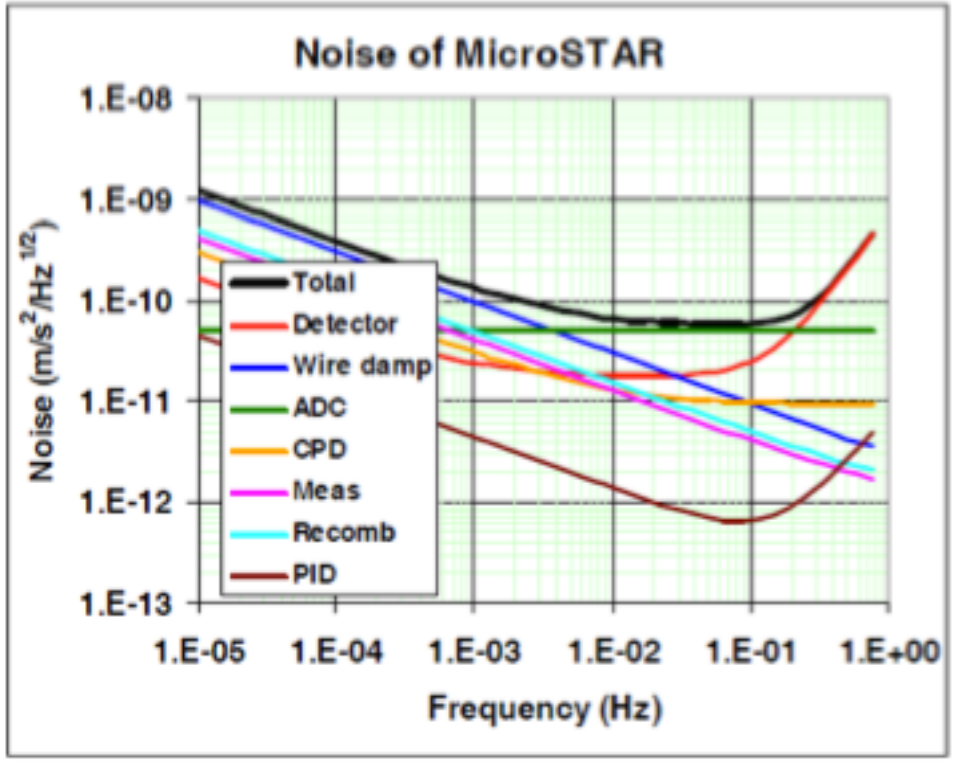
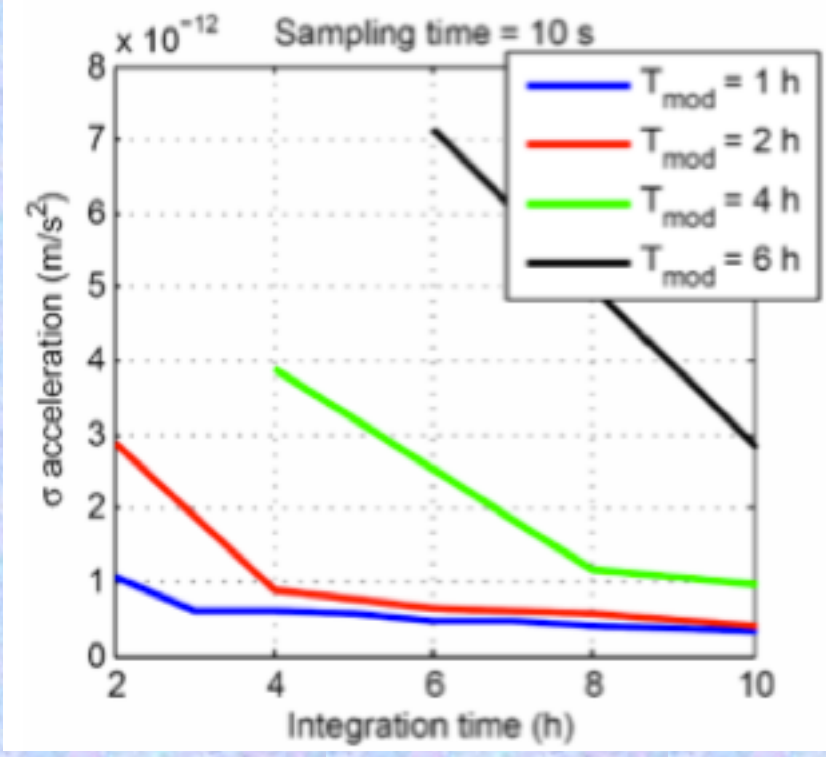
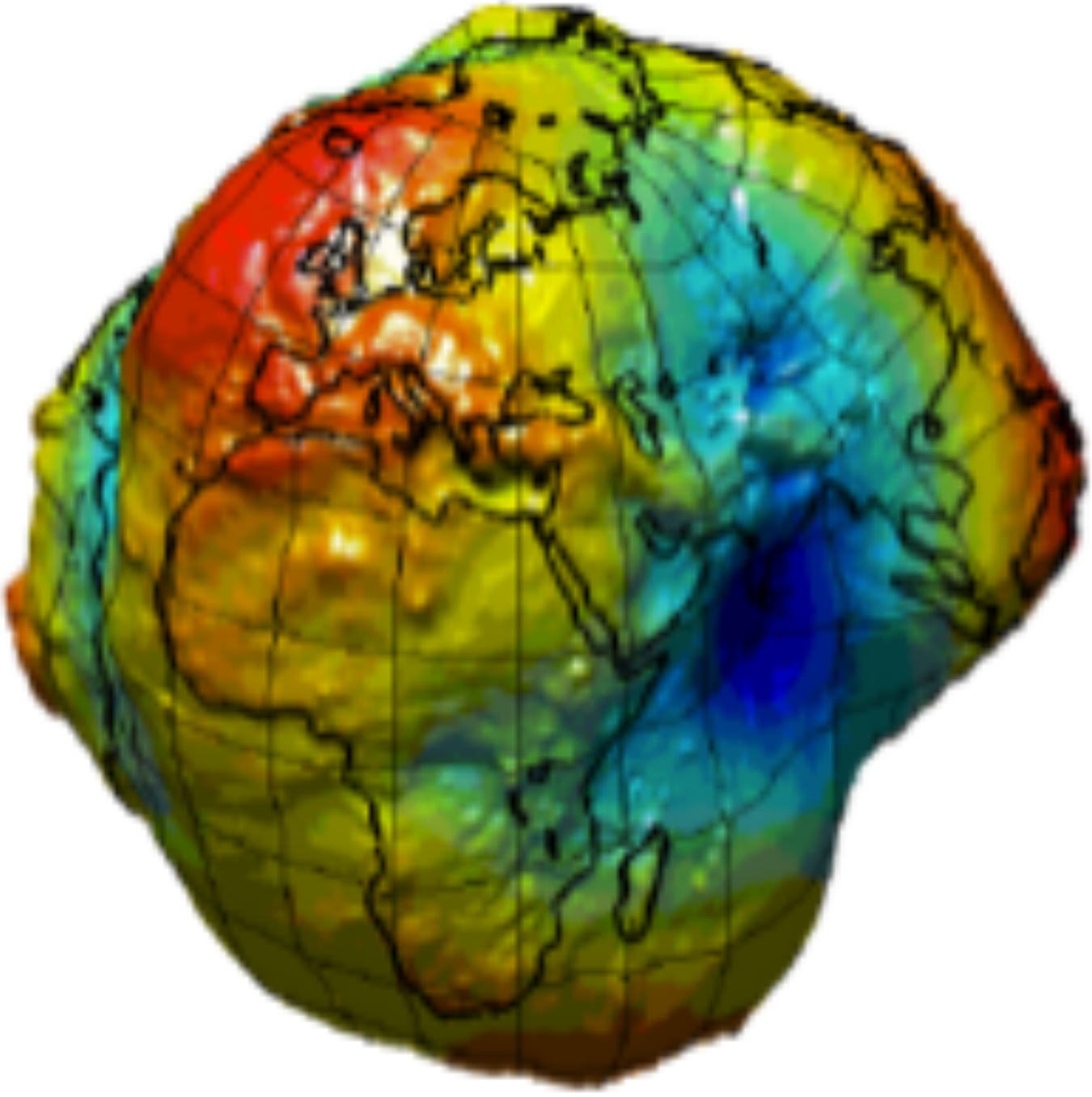


Table 1: Budget allocation for DC accelerometer instrument

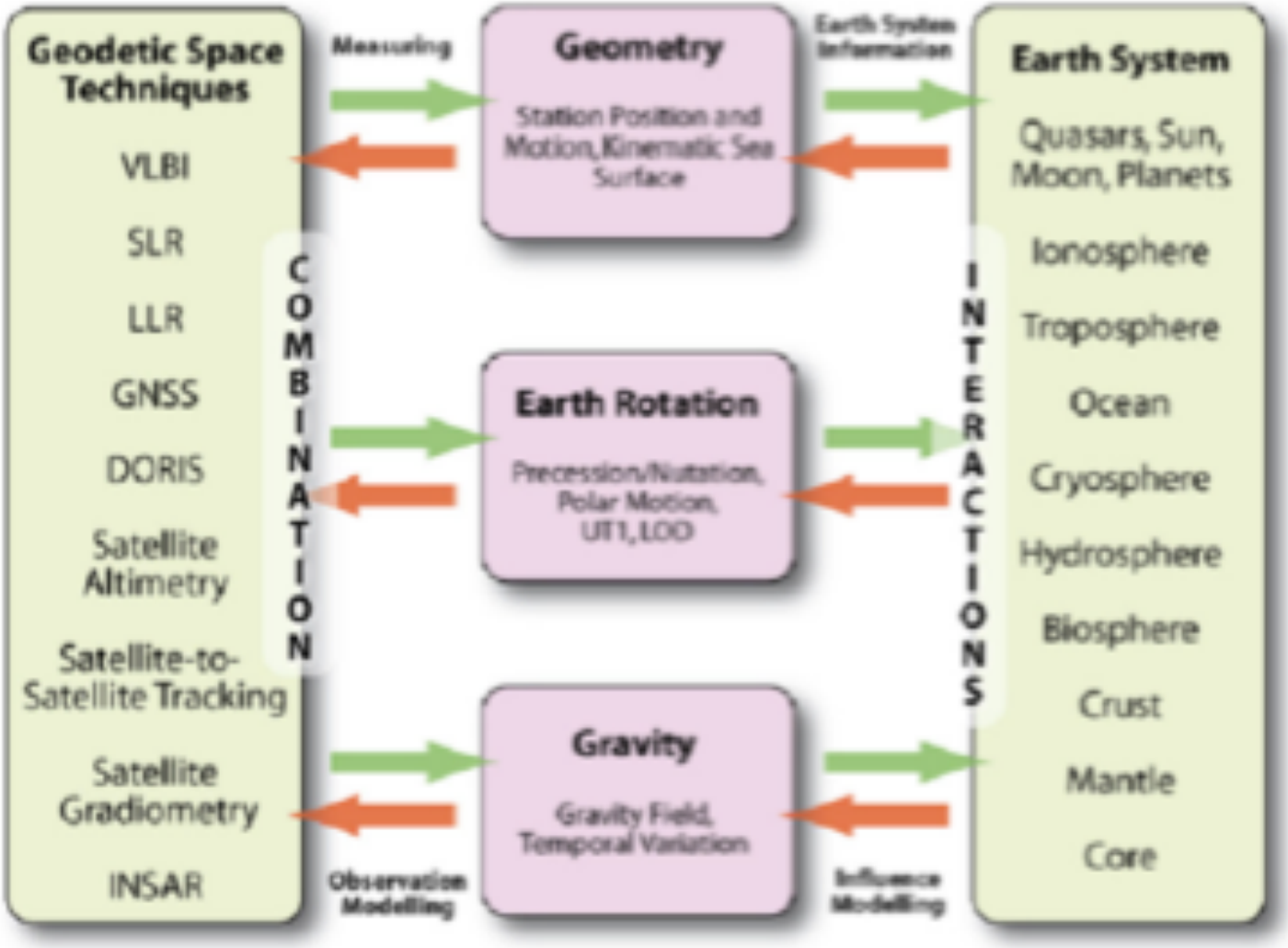
Subsystem	Mass	Size	Power average (max)
MicroSTAR	1.4 kg	10x10x10 cm^3	1.4 W (1.4 W)
Bias Rejection System	1.1 kg	12x12x 5 cm^3,	0.2 W (6 W)
Interface and Control Unit	1.0 kg	12x12x 5 cm^3	1.4 W (1.4 W)
Total	3.5 Kg	12x12x20 cm^3	3.0 W (9.0 W)

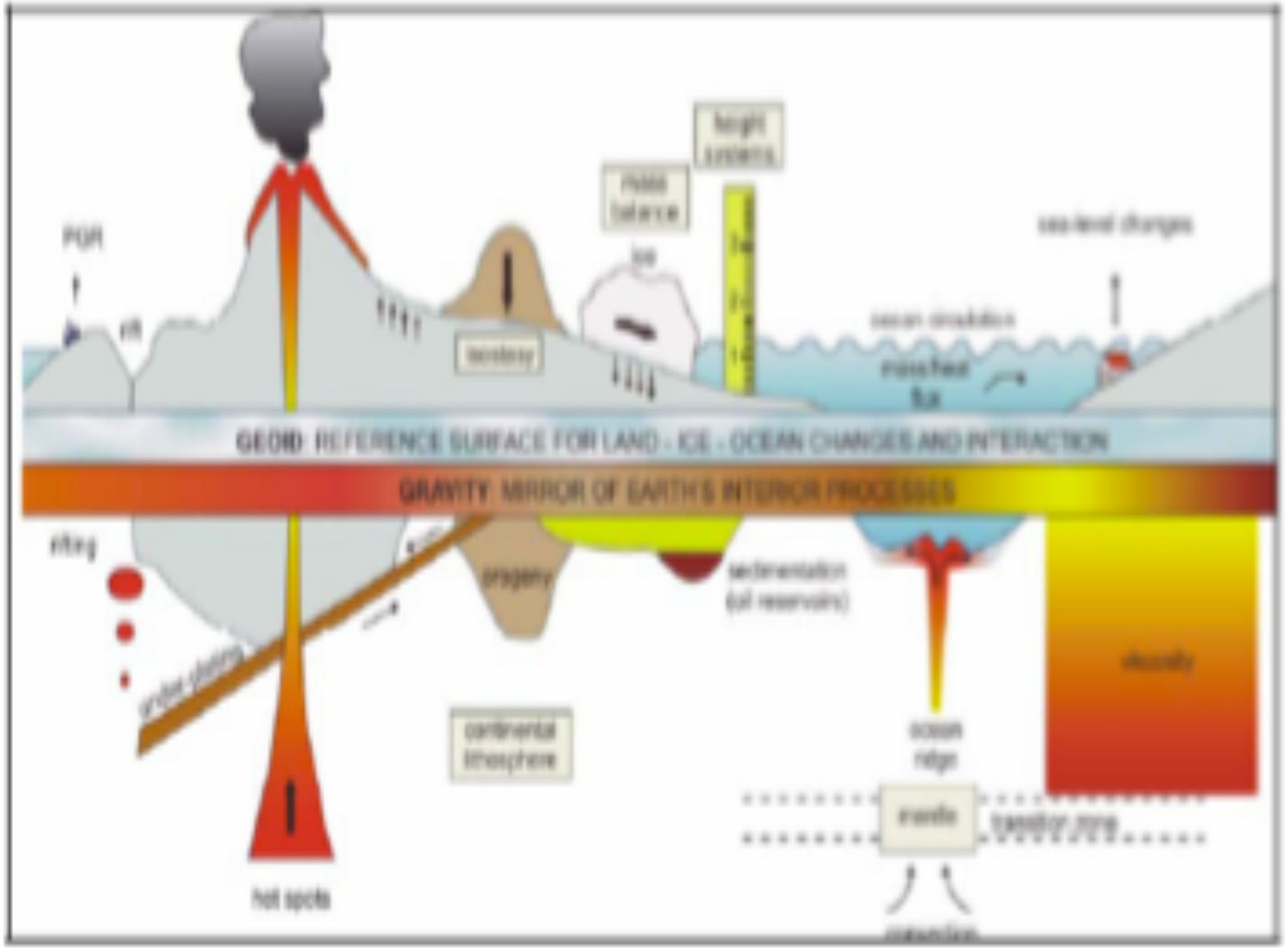


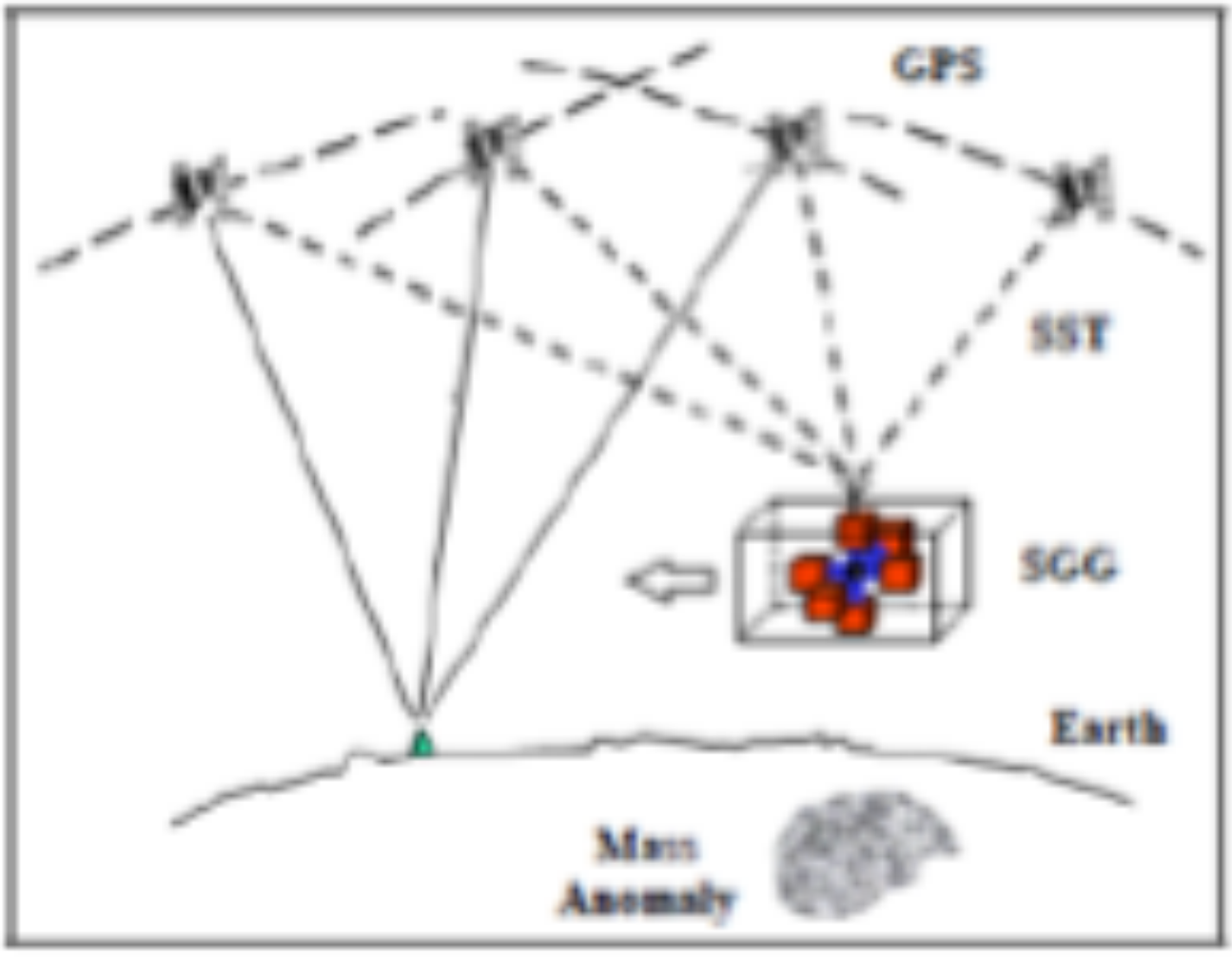




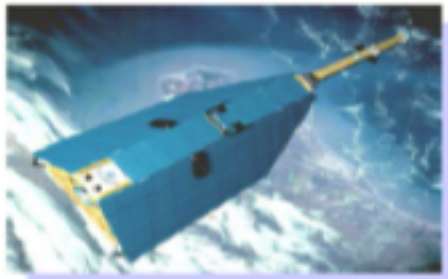
Geodesy


Geodetic Space Techniques
VLBI
SLR
LLR
GNSS
DORIS
Satellite Altimetry
Satellite-to-Satellite Tracking
Satellite Gradiometry
INSAR
Measuring
Observation Modelling
COMBINATION
Geometry
Station Position and Motion, Kinematic Sea Surface
Earth Rotation
Precession/Nutation, Polar Motion, UT1, LOD
Gravity
Gravity Field, Temporal Variation
Earth System Information
Influence Modelling
INTERACTIONS
Earth System
Quasars, Sun, Moon, Planets
Ionosphere
Troposphere
Ocean
Cryosphere
Hydrosphere
Biosphere
Crust
Mantle
Core


GEOID: REFERENCE SURFACE FOR LAND - ICE - OCEAN CHANGES AND INTERACTION
GRAVITY: MIRROR OF EARTH'S INTERIOR PROCESSES
continental lithosphere
ocean ridge
mantle
hot spots


GPS
SST
SGG
Earth
Mass
Anomaly

CHAMP (CNES-DLR), July 2000



altitude~500km

- Γn: $3 \cdot 10^{-9}$ ms^{-2} /$Hz^{1/2}$
- Γmax: 10^{-4} ms^{-2}
- [$0.2 \cdot 10^{-3}$; 10^{-1}] Hz

GRACE (NASA-JPL), March 2002

altitude~500km

- Γn: $1.0 \cdot 10^{-10}$ ms^{-2} /$Hz^{1/2}$
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GOCE (ESA), March 2009

altitude~260km

- Γn: $2.0 \cdot 10^{-12}$ ms^{-2} /$Hz^{1/2}$
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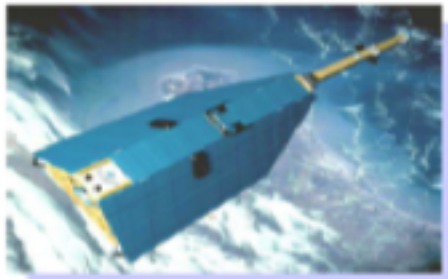

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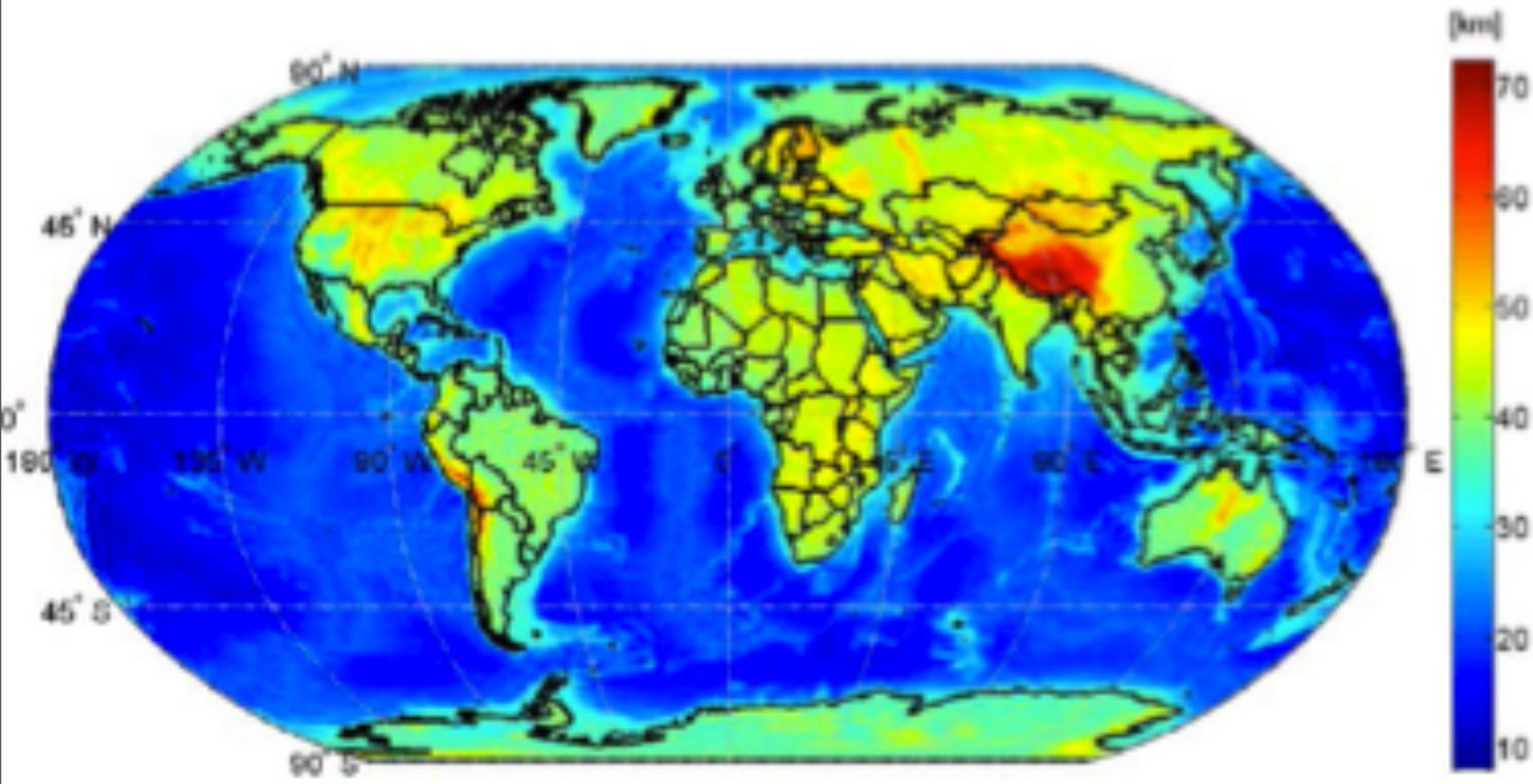
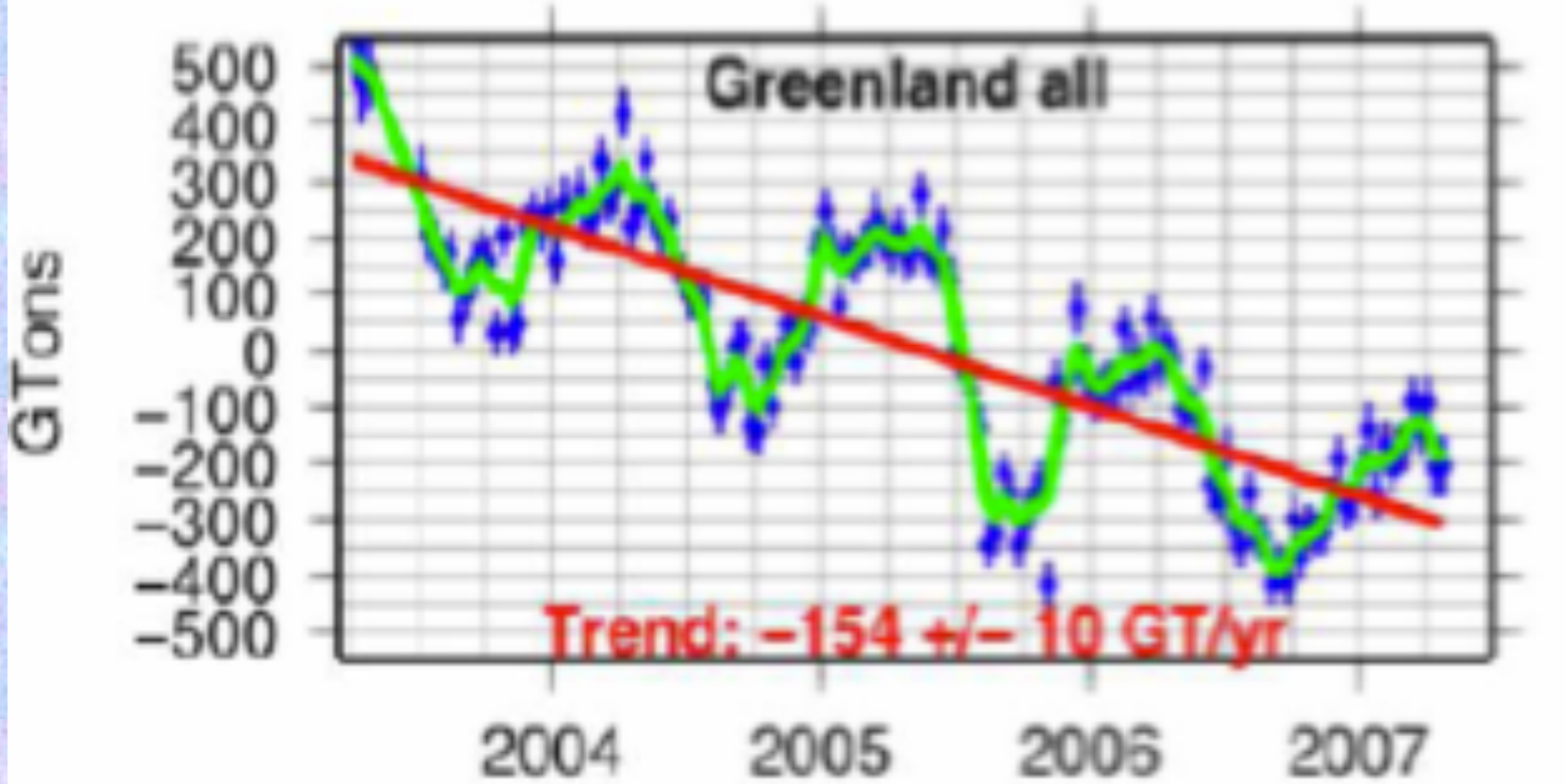
LISA Pathfinder, 2015?

Γn $3{,}0.10^{-15}$ $ms^{-2}/Hz^{1/2}$
$[10^{-4}; 10^{-2}]$ Hz

Moho. *Politecnico Milano, Geomagnetics lab., March 2012*

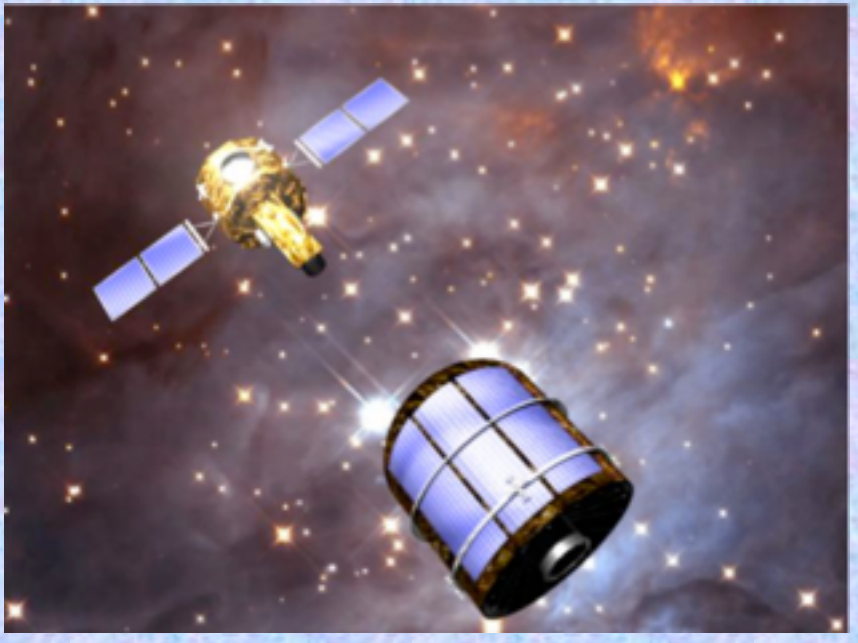


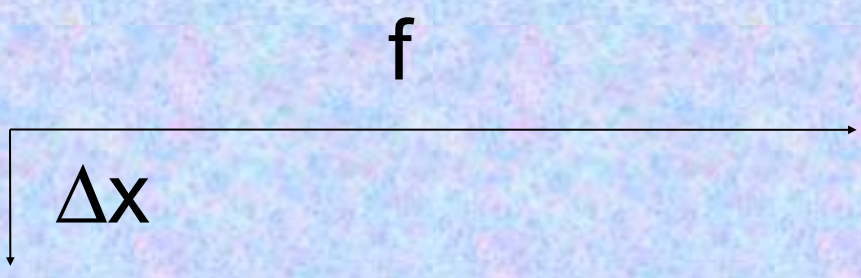


154 Gton ~ 168 km³ ice
~ 10 annual Colorado flow ~ 0.43 mm/an sea level
NASA GSFC, Gravity Science Team Meeting, Postdam 2007.

Very Large Structures in Space

- Measurement over long baselines
- Very long focal length optics
- Extremely high angular resolution





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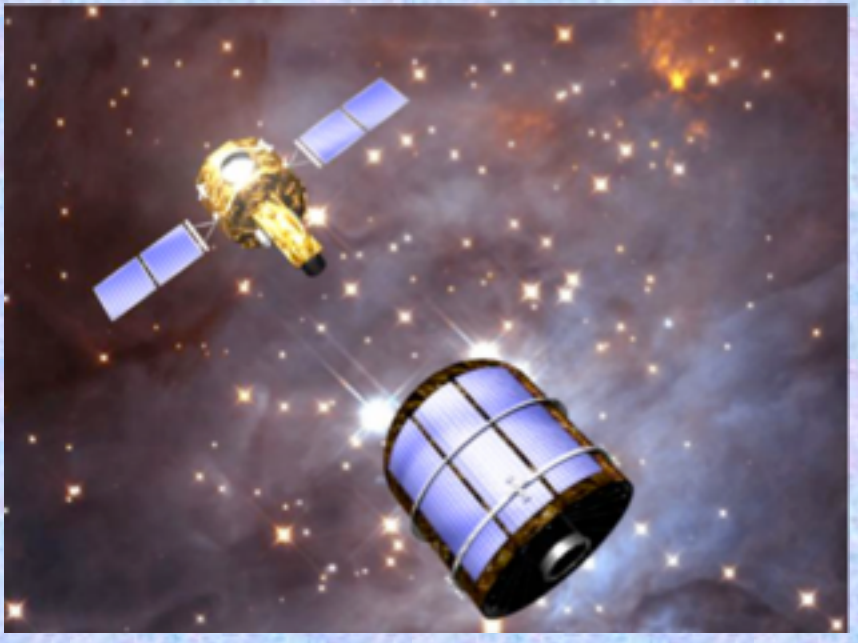

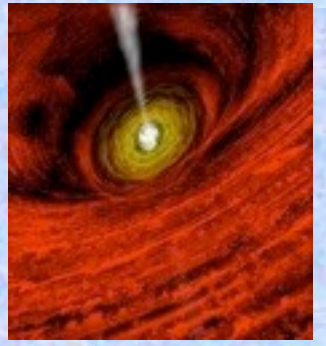

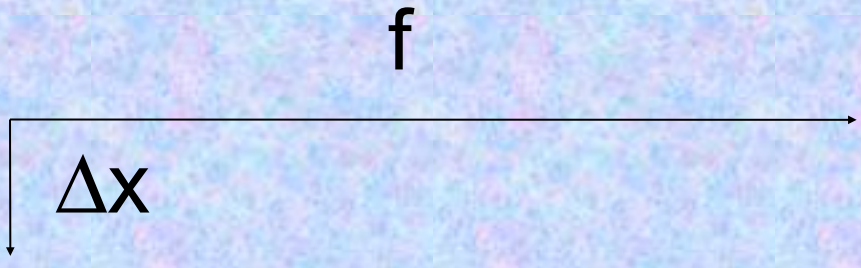

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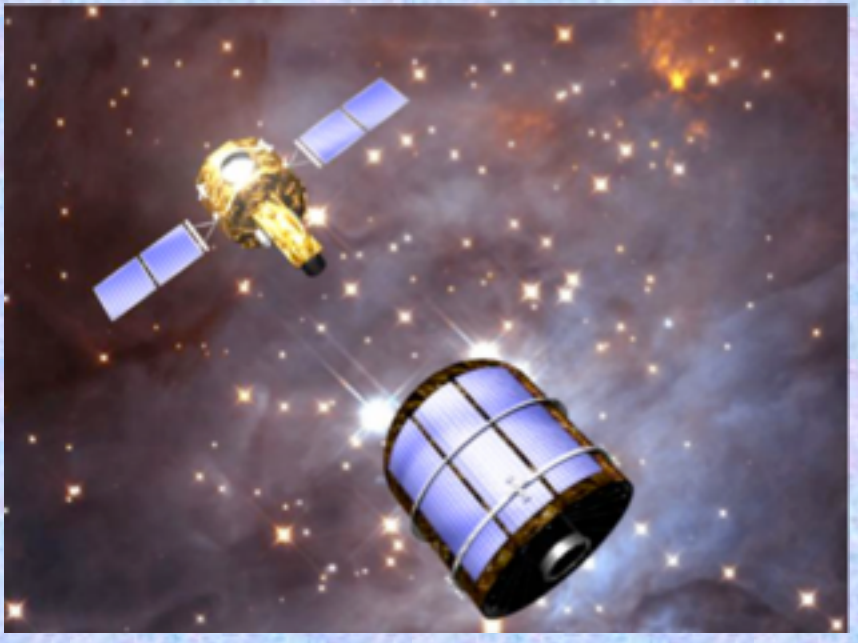
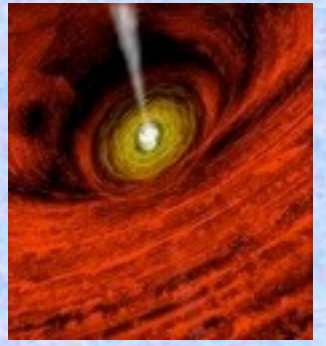
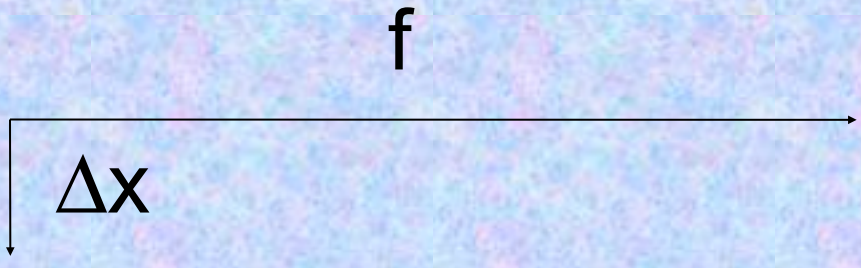
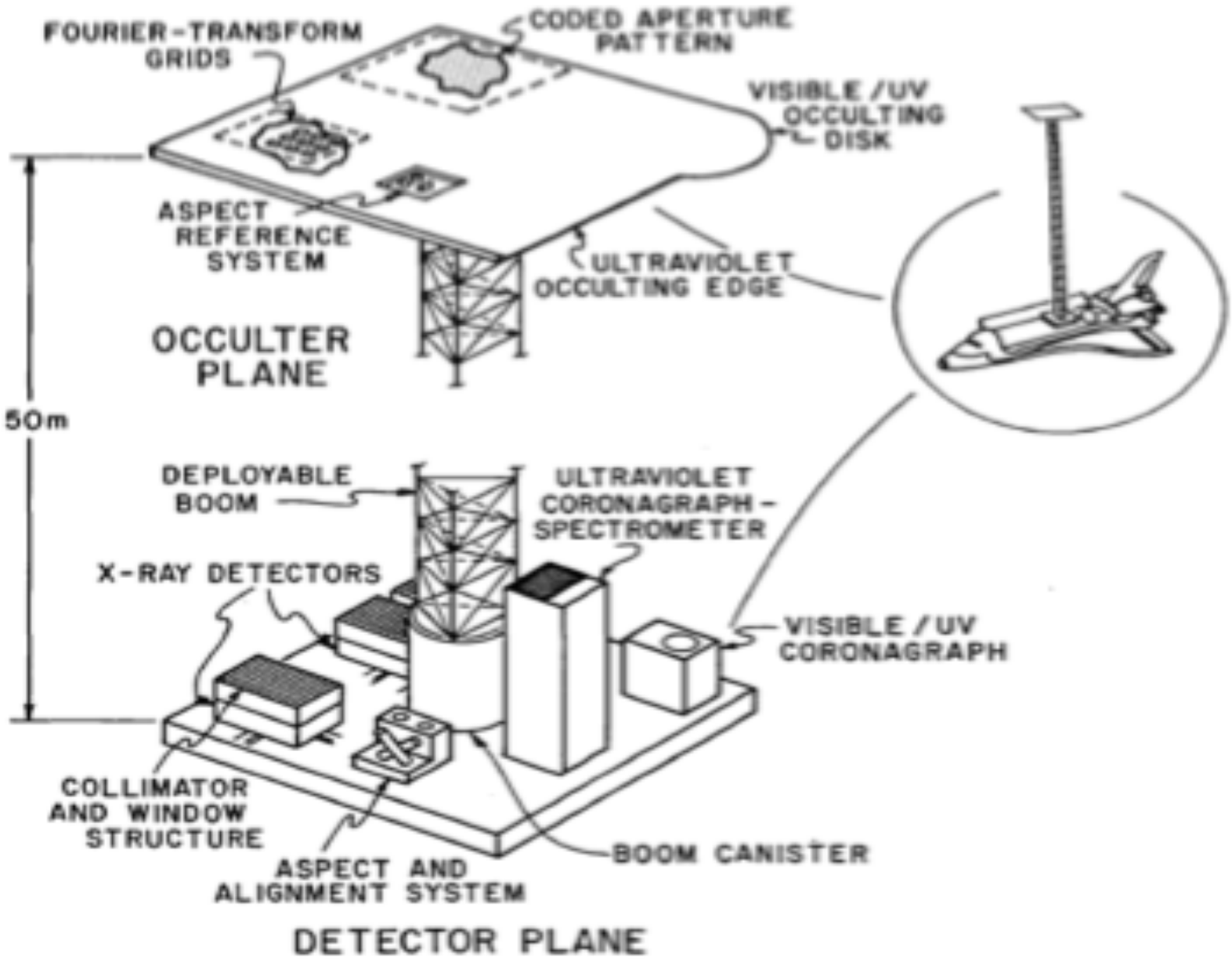


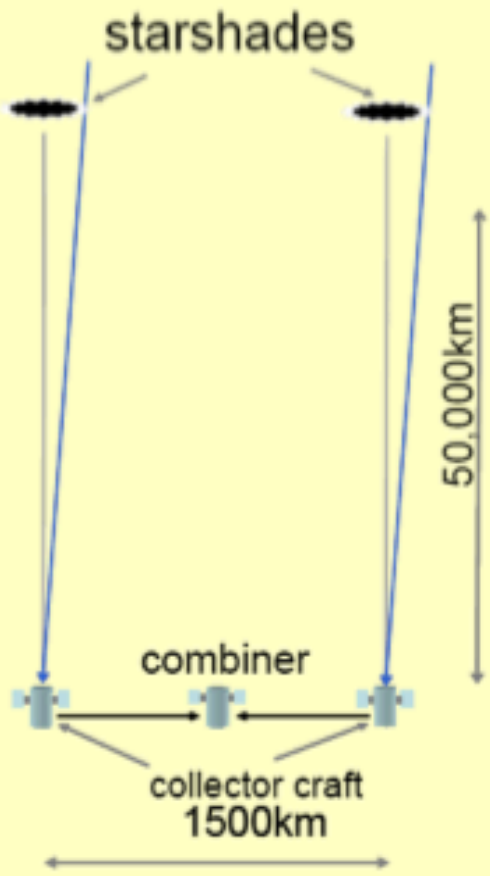
$$\frac{\Delta x}{f} \sim 10^{-12}$$

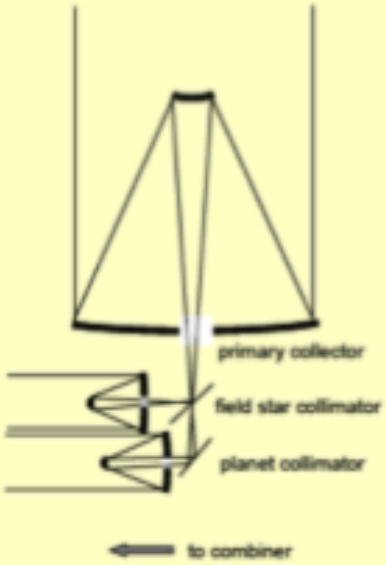


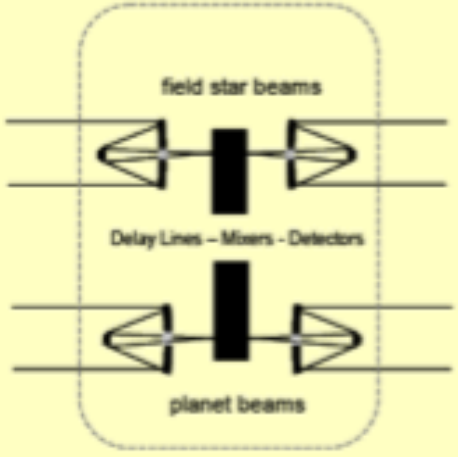



FOURIER-TRANSFORM GRIDS
CODED APERTURE PATTERN
VISIBLE /UV OCCULTING DISK
ASPECT REFERENCE SYSTEM
ULTRAVIOLET OCCULTING EDGE
OCCULTER PLANE
50m
DEPLOYABLE BOOM
ULTRAVIOLET CORONAGRAPH-SPECTROMETER
X-RAY DETECTORS
VISIBLE / UV CORONAGRAPH
COLLIMATOR AND WINDOW STRUCTURE
ASPECT AND ALIGNMENT SYSTEM
BOOM CANISTER
DETECTOR PLANE

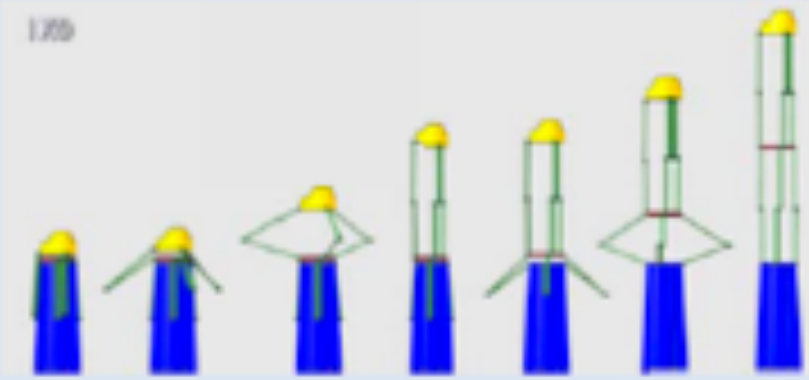
NWI Concept

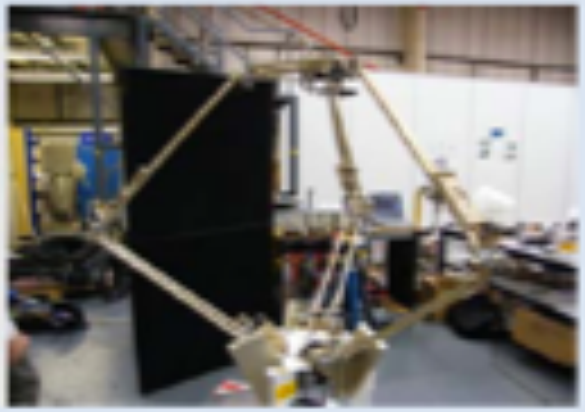

starshades
50,000km
combiner
collector craft
1500km


primary collector
field star collimator
planet collimator
to combiner


field star beams
Delay Lines – Mixers - Detectors
planet beams

Articulated Boom



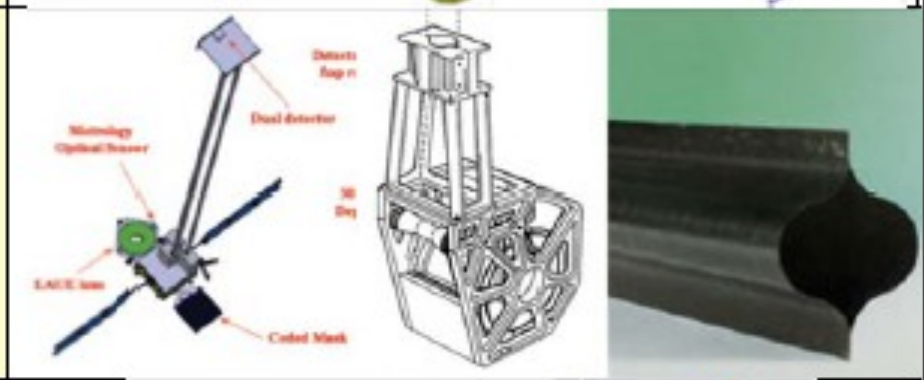
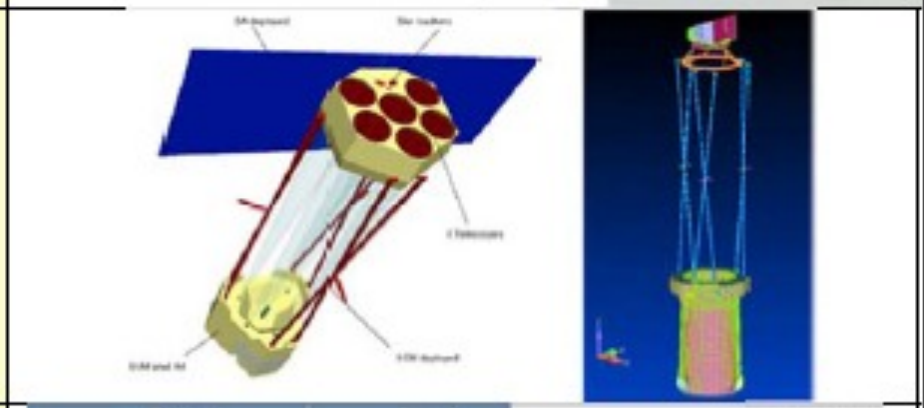
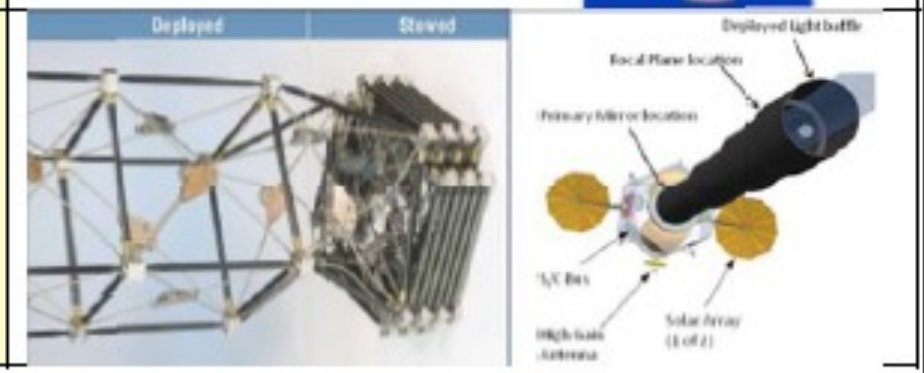


ESA – European Concept

Truss Structure

Tensegrity Mast (Royal Institute of Technology, Stockholm)

ADAM's Mast (ATK)

2010	**PHENIX** M class mission	X-ray observatory	Deployable truss (ADAM like)	40 m	
2010	**DUAL** M class mission	Gamma-ray observatory	3x CTM(*) mast (SENER)	30 m	
2010	**GRAVITAS** M class mission	X-ray observatory	3x articulated arms (solution is similar to X-booms of IXO).	10 m	
2010	**NEAT** M class mission	Detection of near-by exo-planets based on astrometry	1x deployable truss (ADAM)	20 m	

Problems with Booms

- Mass
- Stiffness
- Length
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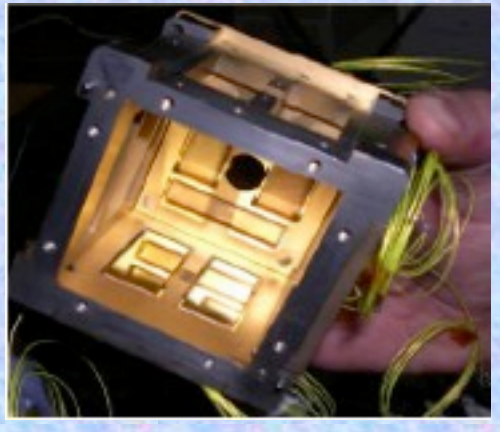

Residual acceleration 10^{-15} m s^{-2}
Random walk error in a day much less than 0.3 mm

Public Presentation

- Publicising very sensitive accelerometers is not easy

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Astronomy has great picture

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Even building big objects in space seems heroic

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The Guardian

15 October 1997

760 mph new world land speed record

The *Aussie Invader* and Maclaren projects evaporated but Breedlove's *Spirit of America* was built. This astonishing vehicle, said to owe more to eye judgement than computer modelling was actually ready at the same time as *Thrust SSC* and both camps were on the Black Rock Desert together. Sadly Breedlove missed out on being the first to 700mph and he survived a huge scare when the *Spirit* suddenly veered nearly ninety degrees off course. In the true spirit of record breaking, the gentlemanly Breedlove offered the Thrust team the use of all his facilities and stayed on with his damaged car to help and cheer them on. On Tuesday 7th October 1997 Thrust SSC made an early morning run and generated a sonic boom for the first time. An official attempt on the record a few days later failed due to the car not being turned around within the statutory one hour. A week later, on 15th October, Andy Green made the two runs through the measured mile, each time generating a perfect shockwave in front of the car and a huge sonic boom. The Land Speed Record is no d.

There will be no financial crisis, say Bankers

The whole car was built on an incredibly tight budget. For example, the donation by Lucas of a switch and a few feet of cable qualified them as a major sponsor! By taking a stand at the 1977 London Motorfair Noble and his team managed to enthuse the public and persuade reluctant captains of industry to help. Eventually, after innumerable financial and technical crises the Car was shipped to Bonneville in 1981 where Noble managed a peak speed of 500mph before the rains came ant

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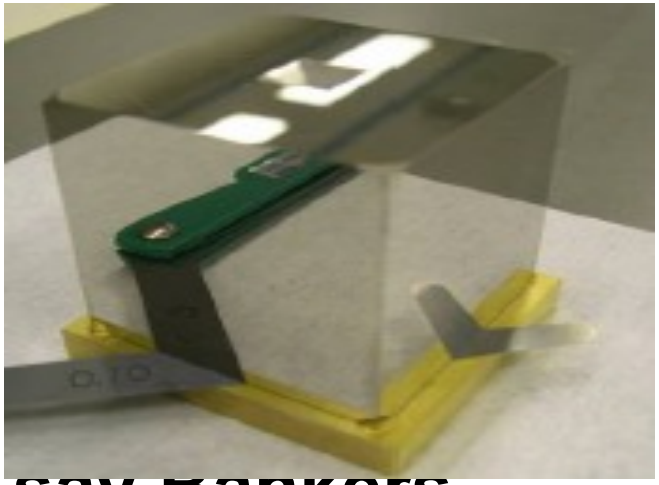
The Independent

London May 21st 2012

European Space Agency makes the most stationary object in the Galaxy

Accelerometers offer a number of desirable features in monitoring of human movement. Firstly, they respond to both frequency and intensity of movement, and so are superior to actometers or pedometers, which are attenuated by impact or tilt. Secondly, some types of accelerometers can be used to measure tilt as well as body movement, making them superior to motion sensors that have no ability to measure static characteristics. Thirdly, enhancements in microelectromechanical systems (MEMS) technology have made possible the manufacture of miniaturized, low cost accelerometers. These instruments also demonstrate a high degree of reliability in measurement, with little variation over time (Bouten *et al* 1997a, Meijer *et al* 1991, Moe-Nilssen 1998, Hansson *et al* 2001). This has enabled the development of small, lightweight, portable systems that can be worn by a free-living subject without impeding movement. Systems can be designed that are suitable for monitoring in the patient's normal environment over extended periods.
In this paper we investigate the potential for using accelerometry in this context. We begin by reviewing the work done in using accelerometers to measure various aspects of human movement. We then consider an integration of these systems and methods to produce a practical system for long-term monitoring of human movement in order to assess functional status in an unsupervised, free-living environment over extended periods.



We predicted financial crisis, say Bankers

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The Daily Telograph

May 22nd

British Prime Minister:

“European Test Masses are Too Slow”

- UK to renegotiate Newton’s Laws

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Future Technology Advisory Panel

esa

European Space Agency

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•It may have been worthwhile after all!!