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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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
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• 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
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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

A Mission to Explore the Martian Satellites and the Fundamental
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**
Deimos, Phobos
Internal structure, composition, presence of ice
GETEMME
Some Fundamental Physics

<table>
<thead>
<tr>
<th>RG effect</th>
<th>2 years</th>
<th>4 years</th>
<th>current value</th>
</tr>
</thead>
<tbody>
<tr>
<td>β of Mars-1</td>
<td>$1.7 \times 10^{-7}$</td>
<td>$5.3 \times 10^{-8}$</td>
<td>-</td>
</tr>
<tr>
<td>Lense-Thirring</td>
<td>$2.1 \times 10^{-4}$</td>
<td>$1.0 \times 10^{-4}$</td>
<td>$10^{-1}$ (Earth, LAGEOS)</td>
</tr>
<tr>
<td>Gdot/G (in year⁻¹)</td>
<td>$1.6 \times 10^{-13}$</td>
<td>$2.9 \times 10^{-16}$</td>
<td>($4\pm9) \times 10^{-13}$ (Lunar LR)</td>
</tr>
<tr>
<td>Subsystem</td>
<td>Mass</td>
<td>Size</td>
<td>Power Average (max)</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------</td>
<td>-----------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>MicroSTAR sensor head</td>
<td>1.4kg</td>
<td>10x10x10 cm³</td>
<td>1.4 W (1.4 W)</td>
</tr>
<tr>
<td>Bias rejection system</td>
<td>1.1kg</td>
<td>12x12x5 cm³</td>
<td>0.2 W (6 W)</td>
</tr>
<tr>
<td>Interface and Control Unit</td>
<td>1.0kg</td>
<td>12x12x5 cm³</td>
<td>1.4 W (1.4 W)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.5kg</strong></td>
<td></td>
<td><strong>3 W (8.8 W)</strong></td>
</tr>
</tbody>
</table>
A 20 x times improvement in planetary orbit science
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
Access to Kuiper Belt

OSS's cone of access to KBO space is 120° wide.

New Horizons cone of access.
Kuiper Belt Mass distributions

Figure 10: Accelerations due to different Kuiper Belt mass distributions for a solar ecliptic latitude of $\theta = 3^\circ$ (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

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<td>MicroSTAR</td>
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<td>1.1 kg</td>
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</tr>
<tr>
<td>Interface and Control Unit</td>
<td>1.0 kg</td>
<td>12x12x 5 cm$^3$</td>
<td>1.4 W (1.4 W)</td>
</tr>
<tr>
<td>Total</td>
<td>3.5 Kg</td>
<td>12x12x20 cm$^3$</td>
<td>3.0 W (9.0 W)</td>
</tr>
</tbody>
</table>
vendredi 8 juin 2012
Geodesy

- Geodetic Space Techniques
  - VLBI
  - SLR
  - LLR
  - GNSS
  - DORIS
  - Satellite Altimetry
  - Satellite-to-Satellite Tracking
  - Satellite Gradiometry
  - INSAR

- Measuring
  - Station Position and Motion, Kinematic Sea Surface

- Geometry
  - Earth System Information

- Earth System
  - Quasars, Sun, Moon, Planets
  - Ionosphere
  - Troposphere
  - Ocean
  - Cryosphere
  - Hydrosphere
  - Biosphere
  - Crust
  - Mantle
  - Core

- Earth Rotation
  - Precession/Nutation, Polar Motion, UT1, LOD

- Gravity
  - Gravity Field, Temporal Variation

- Observations Modelling
  - Influence Modelling

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CHAMP (CNES-DLR), July 2000
- altitude ~ 500 km
- $\Gamma_n: 3 \times 10^{-9}$ m/s$^2$/Hz$^{1/2}$
- $\Gamma_{max}: 10^{-4}$ m/s$^2$
- [0.2; 10$^{-3}$; 10$^{-1}$] Hz

GRACE (NASA-JPL), March 2002
- altitude ~ 500 km
- $\Gamma_n: 1.0 \times 10^{-10}$ m/s$^2$/Hz$^{1/2}$
- $\Gamma_{max}: 5 \times 10^{-5}$ m/s$^2$
- [0.1; 10$^{-3}$; 10$^{-1}$] Hz

GOCE (ESA), March 2009
- altitude ~ 260 km
- $\Gamma_n: 2.0 \times 10^{-12}$ m/s$^2$/Hz$^{1/2}$
- $\Gamma_{max}: 6 \times 10^{-6}$ m/s$^2$
- [5; 10$^{-3}$; 10$^{-1}$] Hz
LISA Pathfinder, 2015?

\[ \Gamma_n = 3 \times 10^{-15} \text{ms}^{-2} / \text{Hz}^{1/2} \]
\[ [10^{-4}; 10^{-2}] \text{Hz} \]
Vendredi 8 juin 2012

Diagramme du changement de masse de la glace dans le Groenland depuis 2004 à 2007.

Tendance : $-154 \pm 10$ Gtons/année

154 Gtons ~ 168 km$^3$ de glace

~ 10 flux annuel de la rivière Colorado ~ 0.43 mm/année de niveau de mer

Very Large Structures in Space

- Measurement over long baselines
- Very long focal length optics
- Extremely high angular resolution
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\[ \frac{\Delta x}{f} \sim 10^{-12} \]
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
<table>
<thead>
<tr>
<th>Year</th>
<th>Mission</th>
<th>Type</th>
<th>Description</th>
<th>Length</th>
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<tbody>
<tr>
<td>2010</td>
<td>PHENIX</td>
<td>X-ray observatory</td>
<td>Deployable truss (ADAM like)</td>
<td>40 m</td>
</tr>
<tr>
<td>2010</td>
<td>DUAL</td>
<td>Gamma-ray observatory</td>
<td>3x CTM(*) mast (SENER)</td>
<td>30 m</td>
</tr>
<tr>
<td>2010</td>
<td>GRAVITAS</td>
<td>X-ray observatory</td>
<td>3x articulated arms (solution is similar to X-booms of IXO).</td>
<td>10 m</td>
</tr>
<tr>
<td>2010</td>
<td>NEAT</td>
<td>Detection of near-by exoplanets based on astrometry</td>
<td>1x deployable truss (ADAM)</td>
<td>20 m</td>
</tr>
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Problems with Booms

- Mass
- Stiffness
- Length
- Articulation
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Formation flying requirements in observation mode:
- Relative distance error: ±1 mm lateral (instrument FOV)
- ±0.3 mm longitudinal (PSF degradation by defocus)
- Relative distance measurement accuracy: ±0.17 mm lateral (image

vendredi 8 juin 2012
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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 pictures
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Earth sciences have practical applications
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Earth sciences have practical applications

Even building big objects in space seems heroic
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 turned the course back into a lake. This was similar to the appalling bad luck suffered by both Malcolm and Donald Campbell, especially when they were flooded out the following year without turning a wheel, but they had at least provedthe car had potential.
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.
British Prime Minister: “European Test Masses are Too Slow”
- UK to renegotiate Newton’s Laws

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• The discussions and recommendations feed into high level inputs to the ESA technology strategy
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• It may have been worthwhile after all!!