Fundamental Physics experiments for Jupiter Mission and next Odyssey Mission

B. Christophe (ONERA, Châtillon, France)

on behalf of
Zarm, DLR-RY, LKB, ENS, JPL, Imperial College, IST Lisbon, JIVE, OCA, RAL, Univ. Oslo, SYRTE, Onera

GPhys KO Colloquium, Les Houches, 20-22 October 2009
Deep Space Gravity
Verification of the scale dependence of the gravity in the Solar System

Fly-by Anomaly
Investigate the anomaly reported on planetary fly-bys

Interplanetary orbit up to 13 AU with main S/C

Eddington’s parameter
Measure the Eddington’s parameter $\gamma$

Outer Solar System
Map the gravity field in the outer Solar System (Kuiper belt objects)

Odyssey, proposal for Cosmic Vision in 2007

Radio Science + VLBI
Accelerometer MicroSTAR

Radio Science + VLBI
Accelerometer MicroSTAR

Interplanetary orbit up to 50 AU with ENIGMA

Radio-beacon ENIGMA

Laser TIPO
# Odyssey 2007

## Scientific Requirements and Scenario

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Deep space gravity test Sirens experiment</th>
<th>Fly-by investigation Charybdis &amp; Scylla experiment</th>
<th>Solar conjunction Polyphemus experiment</th>
<th>Outer Solar System Calypso experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer Radio-science VLBI Laser ranging</td>
<td>$</td>
<td>\delta a</td>
<td>&lt; 40 \text{ pm/s}^2$ (3-axes) up to 13 AU</td>
<td>$</td>
</tr>
<tr>
<td>Radio beacon with VLBI</td>
<td>$</td>
<td>\delta a</td>
<td>&lt; 8 \text{ pm/s}^2$ (3-axes) from 10 AU</td>
<td>-</td>
</tr>
</tbody>
</table>
Deep Space Gravity
Verification of the scale dependence of the gravity in the Solar System

Fly-by Anomaly
Investigate the anomaly reported on planetary fly-bys

Interplanetary orbit up to 5 AU (Jupiter)

Jupiter Ganymede Orbiter (JGO)

Gravity Advanced Package on JGO
GAP on JGO - 1st science objective: Deep Space Gravity

- Experimental tests of gravity show a good global agreement with General Relativity (GR)
- But unification models predict (small) deviations from GR
  - "Dark matter" and "dark energy" are designed to cure gravitational anomalies observed at large galactic and cosmic scales
  - As long as they are not also observed through independent means, they may also be thought of as deviations of gravity laws from GR

- Interplanetary scales for probes in the solar system
- Non gravitational acceleration measurement with accuracy better than 50 pm/s² in DC

GAP on JGO - 2\textsuperscript{nd} science objective: Flyby anomaly

Observations by NASA of an excess in the escape velocity after Earth Gravity Assist (EGA)

Excess velocity $\Delta V = \sim 13\text{mm/s}$

Excess velocity $\Delta V = \sim 4\text{mm/s}$

<table>
<thead>
<tr>
<th>Mission</th>
<th>Agency</th>
<th>Year</th>
<th>Pericentre</th>
<th>Eccentricity</th>
<th>Velocity Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galileo</td>
<td>NASA</td>
<td>Dec 1990</td>
<td>959.9 km</td>
<td>2.47</td>
<td>$3.92 \pm 0.08 \text{ mm/sec}$</td>
</tr>
<tr>
<td>Galileo</td>
<td>NASA</td>
<td>Dec 1992</td>
<td>303.1 km</td>
<td>2.32</td>
<td>no reliable data$^a$</td>
</tr>
<tr>
<td>NEAR</td>
<td>NASA</td>
<td>Jan 1998</td>
<td>538.8 km</td>
<td>1.81</td>
<td>$13.46 \pm 0.13 \text{ mm/sec}$</td>
</tr>
<tr>
<td>Cassini</td>
<td>NASA</td>
<td>Aug 1999</td>
<td>1173 km</td>
<td>5.8</td>
<td>0.11 mm/sec</td>
</tr>
<tr>
<td>Stardust</td>
<td>NASA</td>
<td>Jan 2001</td>
<td>5950 km</td>
<td></td>
<td>no reliable data$^b$</td>
</tr>
<tr>
<td>Rosetta</td>
<td>ESA</td>
<td>Mar 2005</td>
<td>1954 km</td>
<td>1.327</td>
<td>1.82 $\pm 0.05 \text{ mm/s}$</td>
</tr>
<tr>
<td>Hayabusa</td>
<td>Japan</td>
<td>May 2004</td>
<td>3725 km</td>
<td>??</td>
<td>no data available</td>
</tr>
<tr>
<td>MESSENGER</td>
<td>private</td>
<td>Aug 2005</td>
<td>??</td>
<td>??</td>
<td>no data available$^c$</td>
</tr>
</tbody>
</table>

GAP on JGO - 3rd science objective (1/2):
Extending gravity field recovery of Jupiter’s moon

Uncompensated surface ice-layer:
- Harmonic amplitude 1 km
- Harmonic amplitude 0.1 km

Tidal gravity signal
- Deep ocean
- No ocean

Solar radiation pressure

Gravity signal amplitudes

Extending gravity field recovery on Ganymede (and Callisto):
- Possible existence of subsurface water oceans
- Characterisation of ocean, crust and lithosphere system
- Near-Jupiter and satellite environmental conditions

By courtesy of F. Sohl (DLR)
GAP on JGO - 3rd science objective (1/2):
Effect of atmosphere on Ganymede

Kinetic model of Ganymede Atmosphere

From Marconi, Icarus 190 (2007)

Gravity specification

Ganymede orbit

From Marconi, Icarus 190 (2007)
## Scientific objectives of GAP on JGO

<table>
<thead>
<tr>
<th></th>
<th>Fundamental Physics</th>
<th>Jupiter System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scientific objectives</strong></td>
<td>Deep Space Gravity</td>
<td>Flyby investigation</td>
</tr>
<tr>
<td><strong>Requirements</strong></td>
<td>$\delta a &lt; 0.05 \text{ nm/s}^2$</td>
<td>$\delta a &lt; 15 \text{ nm/s}^2$</td>
</tr>
<tr>
<td></td>
<td>DC – $10^{-4}$ Hz</td>
<td>$5 \times 10^{-5}$ – $10^{-1}$ Hz</td>
</tr>
<tr>
<td><strong>Period of measurement</strong></td>
<td>Interplanetary cruise</td>
<td>Venus &amp; Earth flybys</td>
</tr>
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</table>

*From ESA assessment study*
GAP: Accelerometer with “null” bias

Accurate accelerometer in DC domain for fundamental physics

MICROSTAR Sensor Unit
Front-End Electronic (ONERA)

ONERA heritage GRACE - GOCE

Volume = 3 l
Mass = 3 kg
Consumption = 3 W
Data rate = 300 bits/10s

Bias Rejection System
Rotative stage (ZARM/DLR)

ICU

Heritage of space rotary stage or filter wheel
GAP: integration in the spacecraft

Acceleration of the satellite at the location of the accelerometer

\[ \vec{a}_B = \vec{a}_{Ext} + \vec{g}_G - \vec{g}_B + \left\{ \hat{\Omega} \wedge \left( \hat{\Omega} \wedge G\hat{O} \right) + \hat{\Omega} \wedge G\hat{O} \right\} + \left\{ 2\hat{\Omega} \wedge G\hat{O} + G\hat{O} \right\} \]

- External non gravitational acceleration
- Sun/Planet Gravity gradient
- Satellite angular motion/ Accelerometer Position
- Movement of G or S/C deformation
- Parasitic acceleration: S/C self-gravity, magnetism

...
Error budget for Scale Dependent Gravity Test

<table>
<thead>
<tr>
<th>Source of errors</th>
<th>Impact on performance between 0–10^{-4} Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise of the accelerometer</td>
<td>1 pm/s²</td>
</tr>
<tr>
<td>Error of bias rejection</td>
<td>20 pm/s²</td>
</tr>
<tr>
<td>Misalignment of accelerometer axis</td>
<td>10 pm/s²</td>
</tr>
<tr>
<td>Coupling with spacecraft angular motion</td>
<td>40 pm/s²</td>
</tr>
<tr>
<td>Spacecraft self-gravity</td>
<td>10 pm/s²</td>
</tr>
<tr>
<td>Other source of errors</td>
<td>10 pm/s²</td>
</tr>
<tr>
<td><strong>Total (quadratic sum)</strong></td>
<td><strong>50 pm/s²</strong></td>
</tr>
</tbody>
</table>

Important to take into account the accelerometer in the design of the S/C
Status of GAP on JGO

• GAP assessment study up to July 2010
  • Instrument Team = ONERA, Zarm, DLR-Institute of Space, LKB, DLR-Berlin
  • With CNES and DLR support

• GAP not yet in the core payload:
  • But GAP WG analyses the interest of GAP for Fundamental Physics and for Jupiter Primary Objectives
  • Accommodation of GAP in JGO not studied by industrials
  • But GAP Team is still in EJSM Instrument Community

• We expect a confirmation of the FPAG recommendation and the interest of the scientific objectives by the FPR-AT in beginning of 2010

• GAP will be proposed through the next instrument AO for JGO
Odyssey, new proposal for next Cosmic Vision

INSTRUMENTS
- Gravity Advanced Package
- Radio science + VLBI
- Laser TIPO
- Clock

OBJECTIVES
- Deep Space Gravity
  Verification of the scale dependence of the gravity in the Solar System
- Fly-by Anomaly
  Investigate the anomaly reported on planetary fly-bys
- Eddington’s parameter
  Measure the Eddington’s parameter $\gamma$
- New FP objectives
- Outer Solar System Gravity
  During flyby of planets, moons or Kuiper belt

MISSION
Supported by CNES through Phase 0 study December 2009 – June 2010

- Solar panel or RTG?
- Orbiting planet/moon or just flyby?
- Up to Saturn or Neptune?
- Class M mission