Session 4: New related "laser ranging" space projects for tomorrow and next decade

Future Applications of Laser Ranging in Space Missions: An Overview

Patrick Vrancken (patrick.vrancken@oca.eu)
Etienne Samain
Ulrich Schreiber

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Agenda

1. Laser Ranging in the classical reflect
2. Some examples of LR “derivatives”
3. Applications / Space Missions

Classical Laser Ranging

Technology enhancements in laser stations:

- Laser:
  - two/multi color
  - high repetition rate (> kHz) w/ higher power
  - coding of pulses for SNR enhancement (e.g. for moon)
  - lower pulse widths
    → drawback of dispersion: atmospheric pre-compensation
  - utilization of frequency combs
- Detectors:
  - QE, BW, size
- Timing:
  - adapt to repetition rate (> kHz)
  - better timing precision
    (e.g. higher vernier frequency, see Samain contribution)
  - clocks (see demand by **G**lobal **G**eodetic **O**bserving **S**ystem [Schlüter])
- Other geodetic space techniques [Pavlis]

Classical Laser Ranging

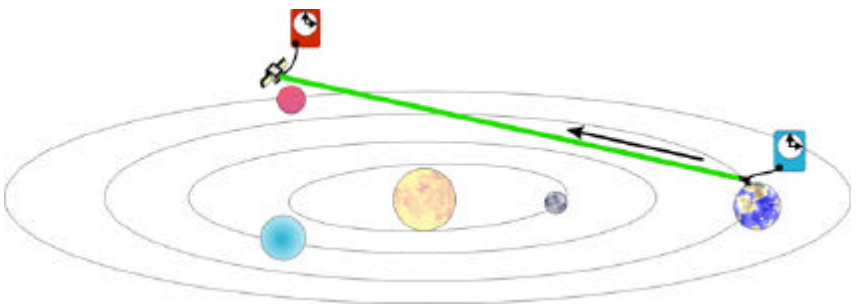
Advancement on the satellite level:

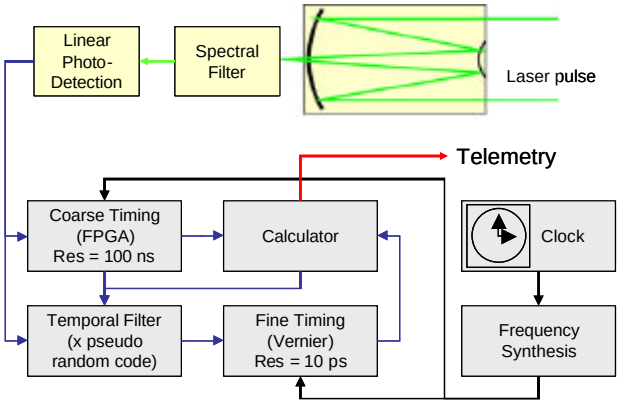
- Reflector:
  - smaller area, mono CC, hollow
  - modulating retro reflector ([Gilbreath] Naval Research Lab)?
- One-way Laser Ranging:
  - T2L2 / TIPO
- Transponders
  - Testbed operations in Goddard [Degnan]
  - Testbed operations at Wettzell [Schreiber]

Examples of LR derivatives (i)

TIPO: One-way telemetry

- Based on the timing of laser pulses in different temporal reference frames:
  - transmitting laser stations
  - receiver on satellite
- Differential time/distance measurement based on the exactitude & stability of an embarked clock
- Link budget ~ $1/d^2$
  - MeO Station to Mars and a 10cm TIPO telescope
  - Signal : $0.8 < N_e < 30\ e^-$
  - Temporal filter based on laser pulses emitted with a pseudo random code





Examples of LR derivatives (ii)

Iliade: Absolute distance measurement below wavelength scale

- Unify complementary technologies in a single approach:
  - Interferometric measurement on the optical carrier
  - Phase and/or time-of-flight measurement on the modulated optical carrier (laser pulses)
- Utilization of frequency combs (femtosecond lasers)
- These lasers make the link from the radiofrequency to the optical world ($f_{opt,i} = n_i * f_{rep} + f_0$)
- Possibility to transfer the long term stability and exactitude of atomic clocks of 10^{-15} and soon 10^{-16} to the frequencies of this type of laser
- Absolute distance measurements on this scale, i.e. $dl/l = 10^{-15}$ (e.g. nanometric over a distance of 1000km)

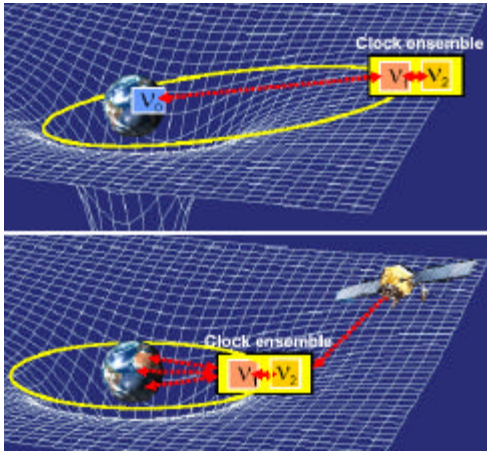
Fundamental Physics

- General Relativity ‘in general’
  - Gravity Explorer (U. Düsseldorf - Schiller)
  - OPTIS (ZARM – Lämmerzahl)
  - ASTROD (PMO - Ni)
  - LATOR (JPL - Tur
  - …

Clock Ensemble in space: ν_0 ? ν_1, ν_2

I: Highly elliptic orbit:
- Local Pos. Invariance
- Grav. Redshift

II: GEO:
- Space born master clock
- Geophysics

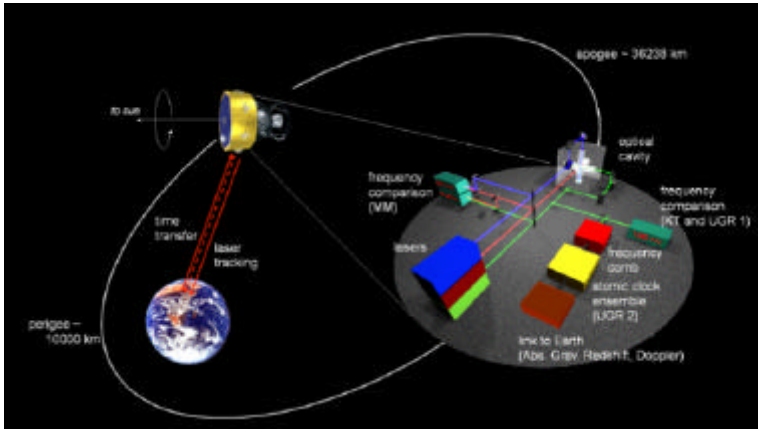


➔ **Time Transfer**

Fundamental Physics

- General Relativity ‘in general’
  - Gravity Explorer (U. Düsseldorf - Schiller)
  - OPTIS (ZARM – Lämmerzahl)
  - ASTROD (PM
  - LATOR (J
  - …

Michelson-Morley and clock comparison



➔ **Time Transfer**

Applications / Space Missions (i)

Fundamental Physics

- General Relativity ‘in general’
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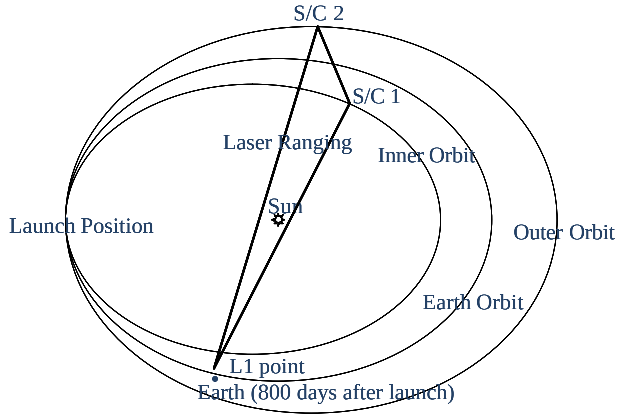
  - LATOR (JPL - T…hev)
  - …

Astrodynamics and Gravity



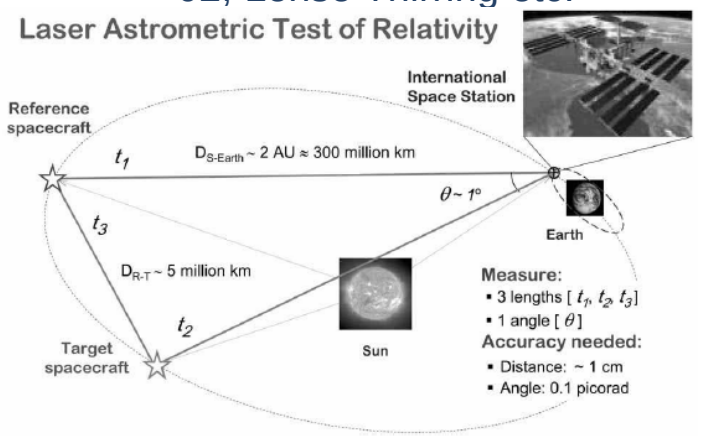
➔ **One way laser ranging (TIPO)**

➔ **Two way laser ranging**

Fundamental Physics

- General Relativity ‘in general’
  - Gravity Explorer (U. Düsseldorf - Schiller)
  - OPTIS (ZARM – Lämmerzahl)
  - ASTROD (PMO - Ni)
  - LATOR (JPL - Turyshev)
  - …

Determination of PPN parameter γ, J2, Lense-Thirring etc.



➔ **Laser Interferometry or Laser Ranging**

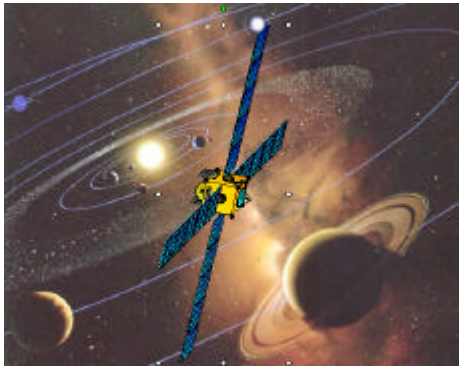
Applications / Space Missions (i)

Fundamental Physics

- General Relativity 'in ge
  - Gravity Explorer (U.
  - OPTIS (ZARM - Lä
  - ASTROD (PMO - Ni
  - LATOR (JPL - Turys
  - …
- Pioneer Anoma
  - ODYSSEY (ONERA
  - DSGE (ZARM - Dittus)
  - ZACUTO (IST – Bertolami)
  - SAGAS (SYRTE - Wolf)

Accelerometer, Radio Doppler and TIPO

- Pioneer Anomaly at 5% (4×10^{-11} m/s^2)
- Fly-by Anomaly
- PPN-parameter γ in solar conjunction
- Gravity mapping



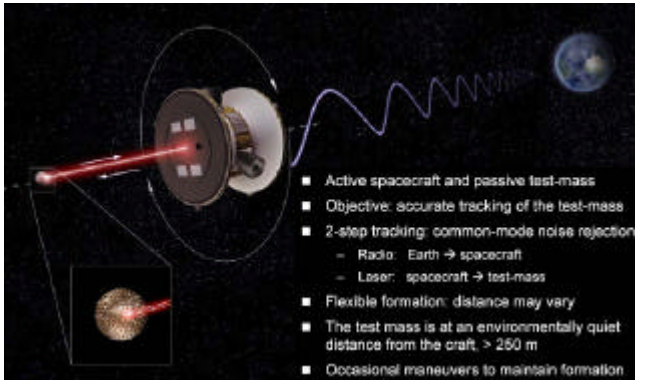
➔ **One way laser ranging**

Fundamental Physics

- General Relativity 'in general'
  - Gravity Explorer (
  - OPTIS (ZARM -
  - ASTROD (PMC
  - LATOR (JPL - T
  - …
- Pioneer Anoma
  - ODYSSEY
  - DSGE (ZARM -
  - ZACUTO (IST – B
  - SAGAS (SY

Formation flying: S/C and passive probe: radio doppler and laser ranging

- Pioneer Anomaly at 10^{-3}
- Gravity mapping



➔ **Laser ranging**

?

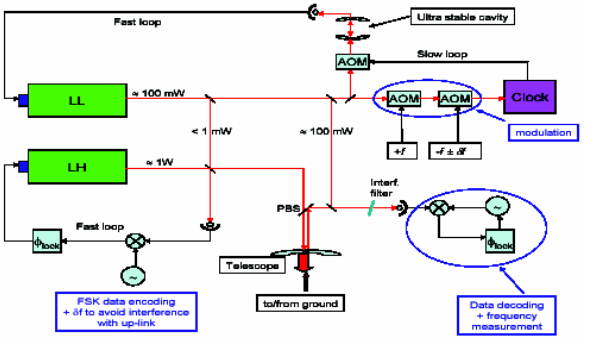
Applications / Space Missions (i)

Fundamental Physics

- General Relativity ‘in general’
  - Gravity Explorer (U. Düsseldorf - Schiller)
  - OPTIS (ZARM - Lämmerzahl)
  - ASTROD (PMO - M
  - LATOR (JPL - Tu
  - …
- Pioneer Anomaly
  - ODYSSEY (ONE
  - DSGE (ZARM -
  - ZACUTO (IS
  - SAGAS (STRTE

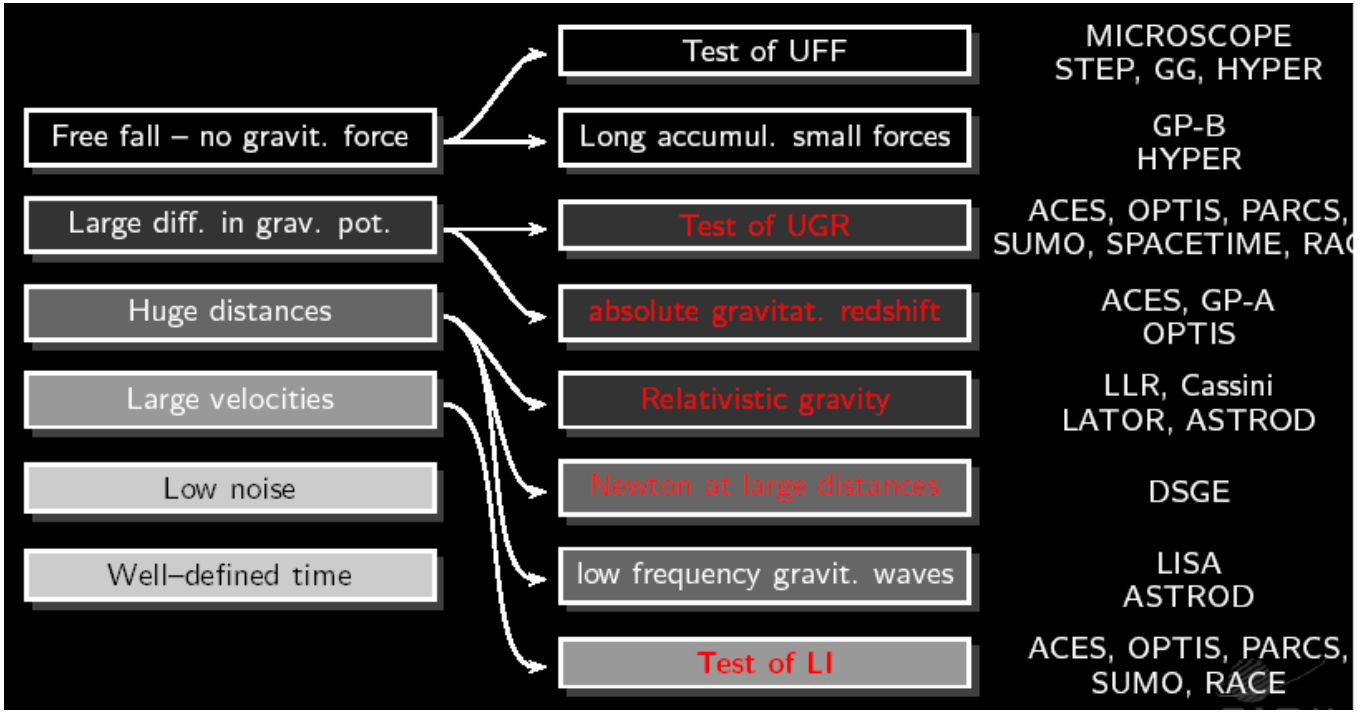
Cold atom accelerometer, optical clock, laser ranging and time transfer

- Pioneer Anomaly
- Grav. redshift
- Post-Newtonian tests
- Variation of fund. consta
- Lorentz Invariance
- Gravity mapping etc.



➔ **Laser ranging, time transfer, transponders**

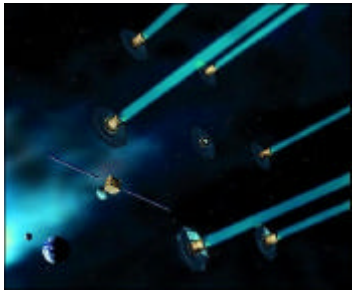
Fundamental Physics – Synopsis (borrowed from Lämmerzahl)



Applications / Space Missions (ii)

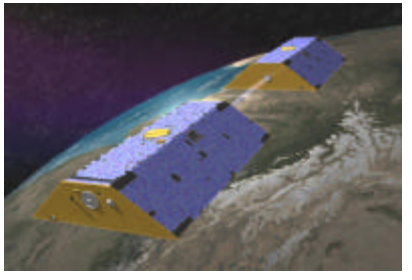
Astronomy

- DARWIN / Pegase, TPF:
  formation flying metrology



Geodesy

- SSI / post-Grace missions
- Relativistic geodesy (clocks):
  time transfer [Svehla]



Solar System / Planetary / Moon

- Navigation, atmosphere, altimetry etc.:
  transponders, one-way laser ranging (e.g. MLA, BELA)

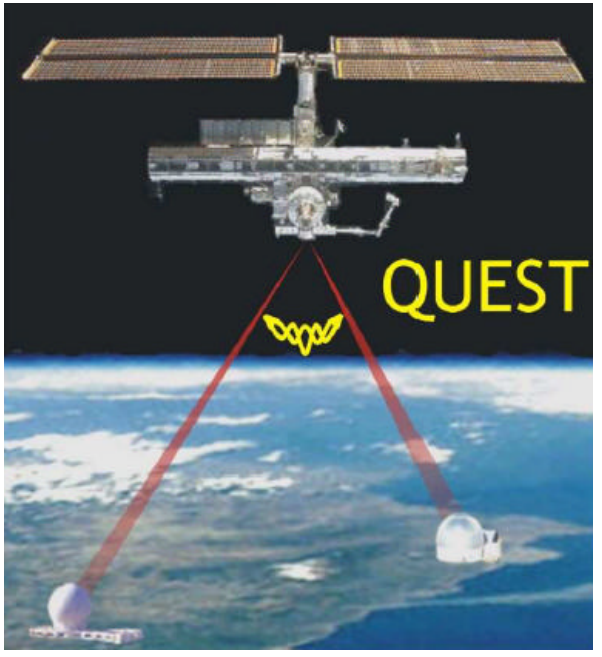
Quantum Entanglement

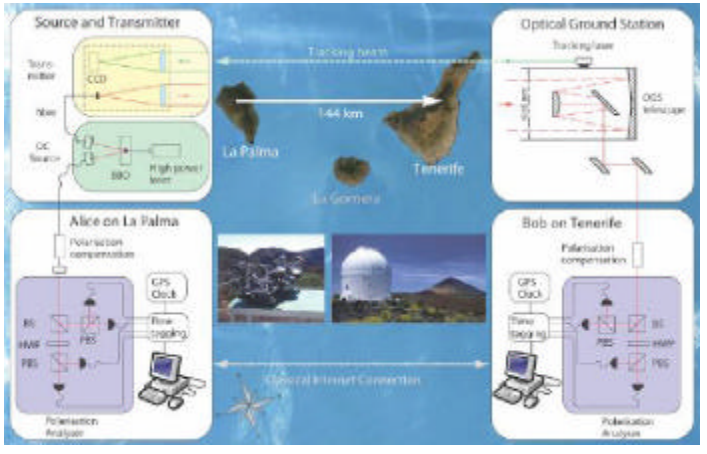
- SpaceQuest:
  Entangled photon source on the ISS,
  transmission to a pair of ground stations

→ LEO ranging telescope

→ single-photon detection

→ timing





Conclusion

- There is a huge demand on the technologies developed for SLR, LLR and time transfer
- We need a close partnership with all of these communities in order to benefit from this dynamism (synergies)
- We have to be present also in order to put forward our own ambitious projects,
  e.g. lunar transponder / one-way laser ranging