# THE POSSIBLE IMPACT OF THE DIRECT MEASUREMENTS OF THE NON-GRAVITATIONAL ACCELERATIONS ON THE GNSS PERFORMANCE


**Janusz B. Zieliński**

**Air Force Academy, Dęblin**

**Space Research Centre, Warsaw**



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**Erik W. Grafarend**

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# First steps in the GNSS world in Stuttgart with Erik Grafarend

# Development of GNSS in 21-th century

- During the last years the development of the global satellite navigation systems resembles an explosion. **GPS** is ripe, the constellation is overbooked – the number of the spacecrafts is larger than planned.
- **GLONASS** is operational, constellation complete.
- The Chinese **Bei-Dou** is partly completed
- European **Galileo** is arising.
- Very soon the population of navigation satellites on MEO orbits will exceed one hundred, all of them exactly monitored for purposes of positioning and navigation. Responsibility for the precise orbit determination of those numerous fleet of space objects is willingly assumed by the International GNSS Service (IGS), apart from the regular orbit control done by each operator of the each system.

# QUALITY OF THE GNSS ORBIT DETERMINATION

- IGS provides the best orbit determination ,
- Different Analysis Centres are using slightly different software and modelling procedures,
- The difference consists essentially on differences in Solar Radiation Pressure modelling,
- Differences in orbital solutions of the order of 10cm - 20cm,
- It reflects the order of accuracy attributed to the actual level of the GNSS technology.

## BARRIERS IN ACHIEVING ONE ORDER IMPROVE-MENT TO GET THE UNCERTAINTY BELOW 1 CM

- The measurement of the pseudo-ranges by means of the L band radio signals is burdened with the influence of the ionosphere;
- Perturbation of motion by the non-gravitational forces is not modelled perfectly;
- Distribution of the monitoring stations and hence the coverage of the trajectory by observation is not homogenous.

# NEW PROMISING TECHNIQUES

- Accelerometry;
- Inter Satellite Links.

BOTH IDEAS INVESTIGATED BY ESA FOR GALILEO 2-ND GENERATION

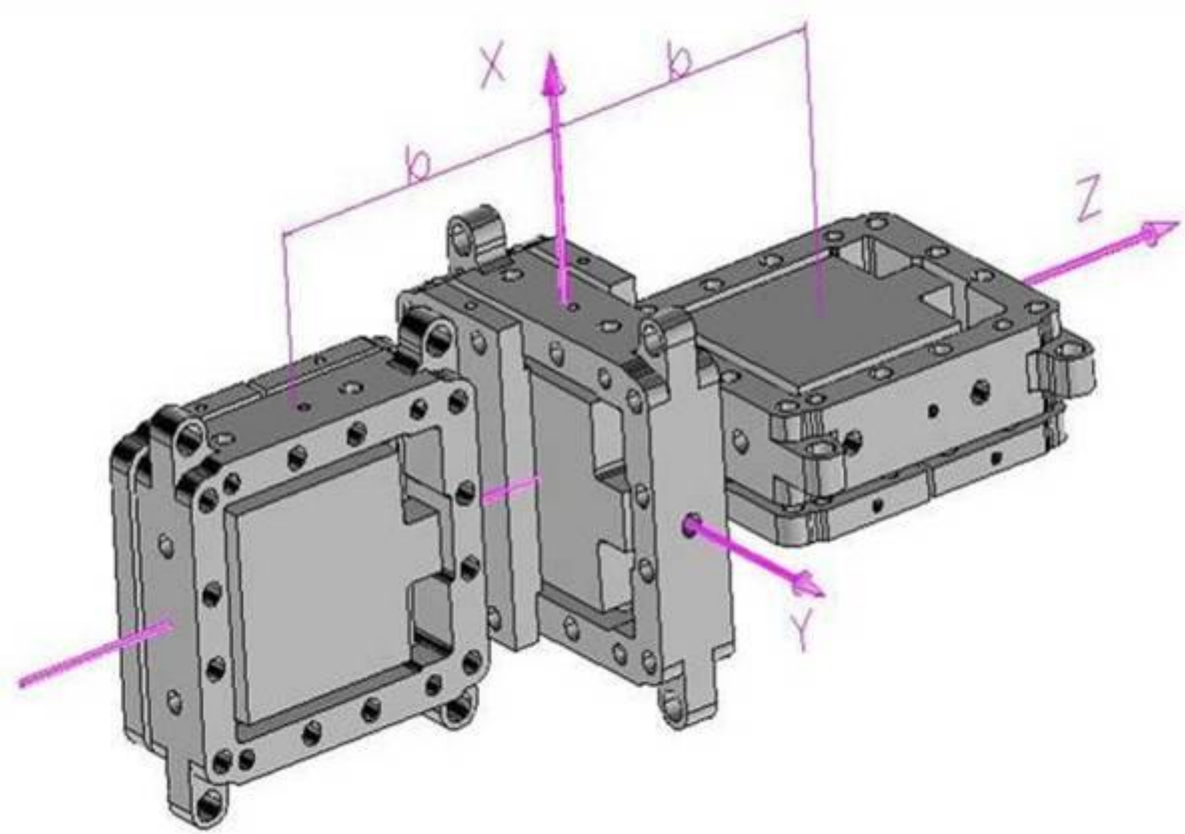
## Proposal by M.E.Ash *Equipping GPS Satellites with Accelerometers and Satellite-to-Satellite Observables* [2002]

- Ash conceived the GPS orbit determination with millimeter level accuracy.
- To attain this goal Ash proposes to install Inertial Measurement Units on the board of satellite: three dimensional accelerometer and gyroscope. In his analysis he finds out the desirable precision of the accelerometer measurement of the order of $10^{-10}$ m/s$^2$
- Also satellite-to-satellite range and range-rate measurement system (ISL – Inter Satellite Links).

# Acclerometry for Space Missions

- CHAMP,
- GRACE,
- GOCE, *Accelerometer Sensitivity:* $2x10^{-12} m/s^2 \sqrt{Hz}$
- Bepi Colombo - the interplanetary mission to the planet Mercury ( in preparation),
- Future Relativity Missions.

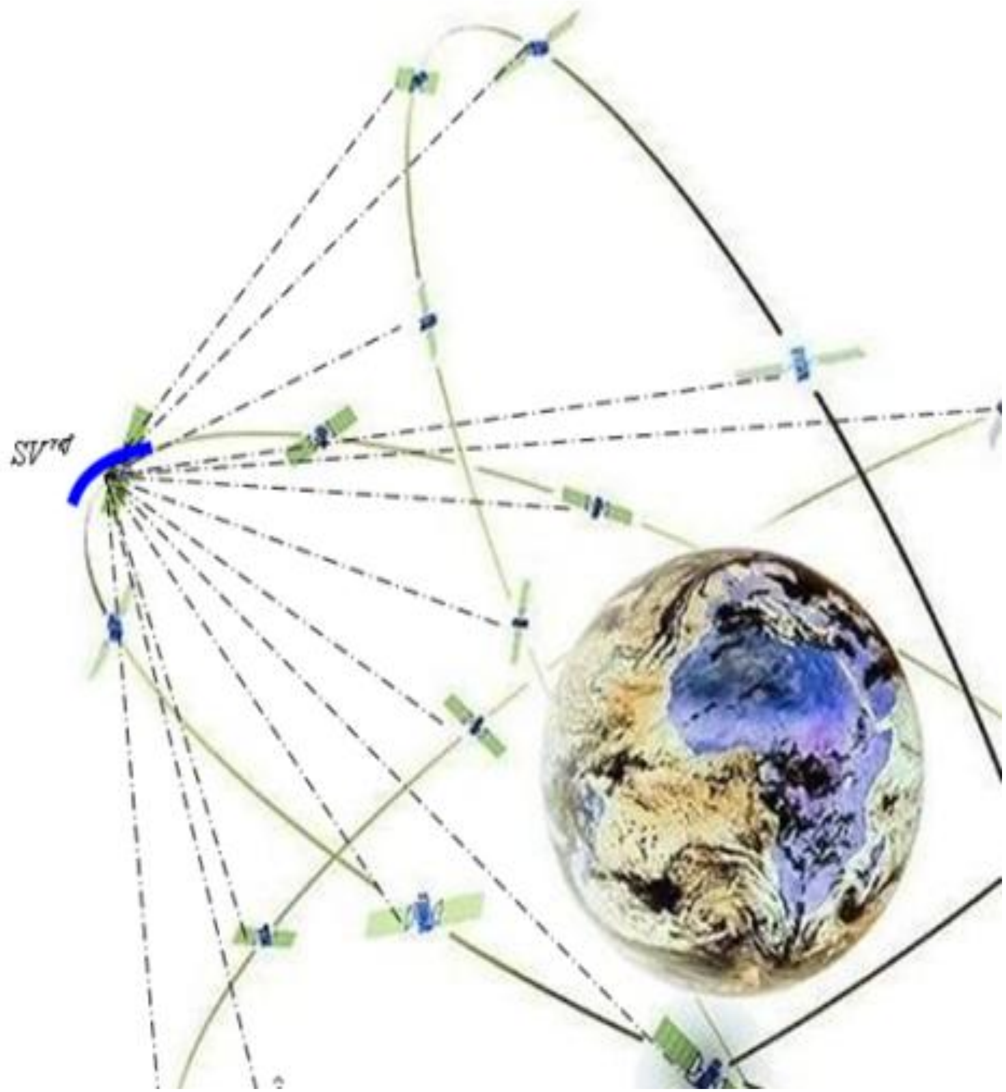
# ISA (Italian Spring Accelerometer)






High sensitivity three axes accelerometer $3 \cdot 10^{-10} \frac{m}{s^2} / \sqrt{Hz}$

# Inter Satellite Links - Concept



# OPTIONS FOR INTER-SATELLITE LINKS

- L – band (GNSS)
- X – band (PRARE)
- K – band GRACE Microwave Measuring System

- Possible measurement precision ± 2 – 4 mm (attitude motions, antenna phase center definition, internal s/c motion etc., taken into account)

# CONCLUSION

- Possible recovery of the pure gravitational motion of the mass particle with mm accuracy over long time

# Classic Geodetic Applications of the Millimeter-Accuracy Satellite Orbit

- 1. More accurate, robust, and global ground site coordinate determination for;
- 2. Real-time determination of neutral atmosphere water vapor content for input to weather prediction models;
- 3. Very accurate airborne gravimetry ;
- 4. Millimeter accuracy low-altitude satellite orbit determination using GPS observables ;
- 5. Length-of-day and earth wobble monitoring. at finer detail.

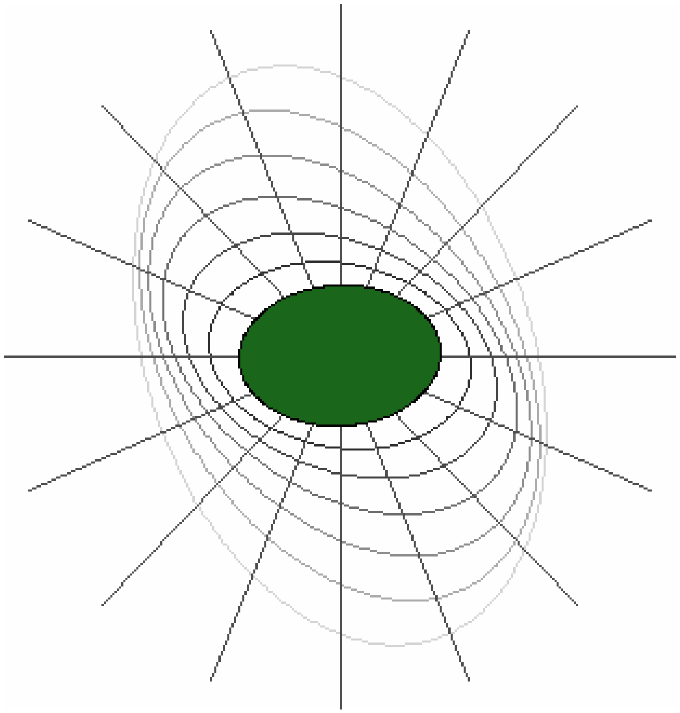
# Possibility of verification of the primary relativistic effects

- Special and General Relativity Time and Frequency Shifts;
- Relativity of Simultaneity;
- Sagnac Effect;

# Secondary Relativistic Effects

- The Shapiro signal propagation delay;
- Spatial curvature effects on geodetic distance;
- Lense-Thirring frame drag;
- Earth Gravitational Field Torsion;

# EARTH'S GRAVITY FIELD TORSION PRODUCES GRAVITATIONAL WAVE



time-varying fields would have to propagate with the speed of light

# Conclusions (2)

- Consequences for the fundamental physics research of gravitation.
- If the speed of gravitational signal is smaller than that of light, this could indicate that the graviton has an effective nonzero mass
- In terms of the gravitational waves research the observed variation of the Earth gravitational potential and acceleration in the local inertial frame could be considered as the very weak and very low frequency gravitational wave.

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  - http://www.humboldt-foundation.de