Der (alte) Studiengang „Geodäsie und Geoinformation“ der UniBw München gratuliert Ihrem Ehrendoktor Erik Grafarend zum 75. Geburtstag

In the Laudatio Prof. Dr.-Ing. Albert Schödlbauer reported about the outstanding scientific career of Prof. E. W. Grafarend who joined the University FAF, Neubiberg, from 1975-1980 (Professorship for Astronomical and Physical Geodesy). He stressed the organizational and scientific impulses Prof. Grafarend has given to the University and the Faculty of Civil Engineering and Surveying at this time. Prof. Schödlbauer described enthusiastically the many innovations initiated by Prof. Grafarend, the most important of which were the publication of the "Schriftenreihe des Studiengangs Vermessungswesen", the installation of a geodetic measuring dome and the "foundation" of the independent Institute for Astronomical and Physical Geodesy (later: Institute of Geodesy and Navigation). He claimed that the scientific work of Prof. Grafarend does not only cover most parts of geodesy but has also many connections to mathematics and physics.

Erik Grafarend is one of the most outstanding geodesists worldwide.

From Science
From Science
From Science
From Science
From Science

SATELLITE NAVIGATION
GALILEO

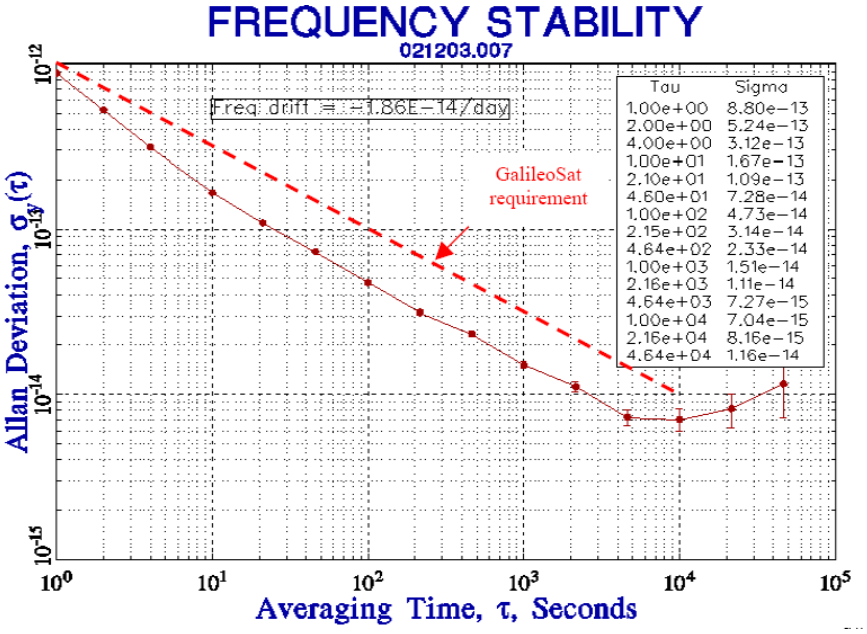
Guenter W. Hein

To Science
To Science
To Science
To Science
To Science

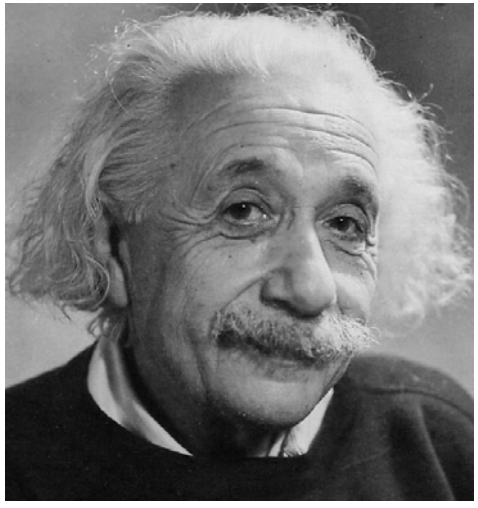
Progress in high-precision atomic clocks and Einstein's Relativity Theory

enable satellite navigation to use time signals

Galileo's Ultra-Precise H-Maser Clocks



Relativistic Geodesy



Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world.
Quoted in interview by G. S. Viereck, 1929

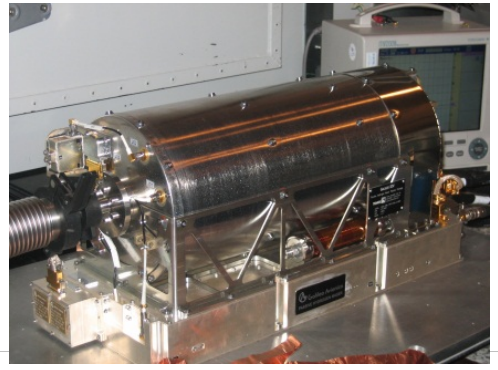
... open new grounds in space-time metrology !

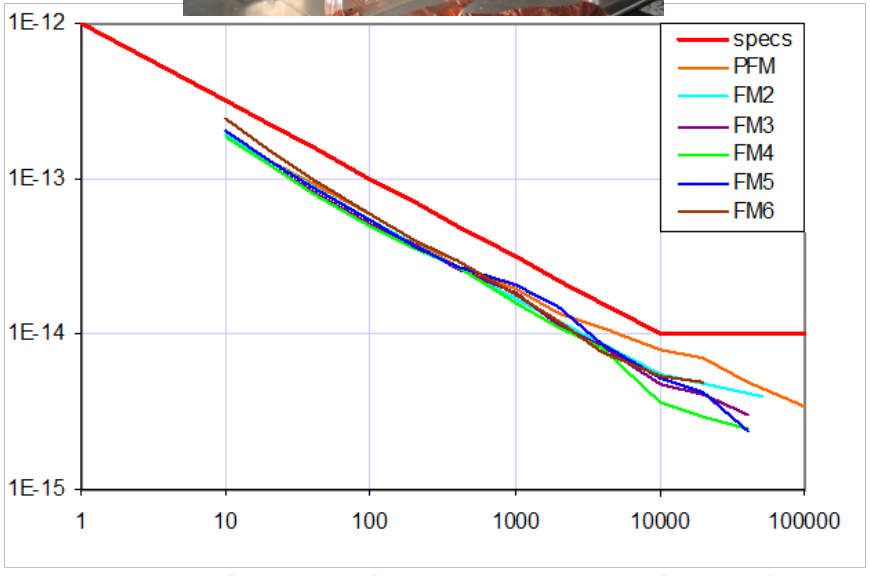
Galileo Clocks: Where are we today ?

Galileo on-board clocks: Two technologies (PHM and RAFS)

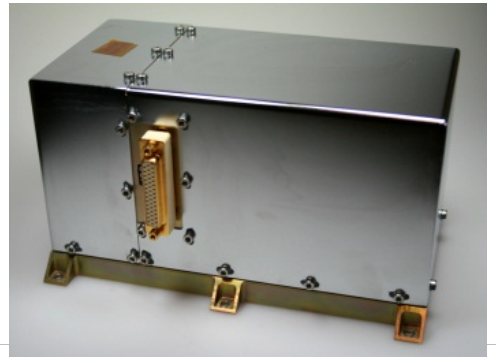
Supplied by Selex Galileo (I) and Spectratime (CH)

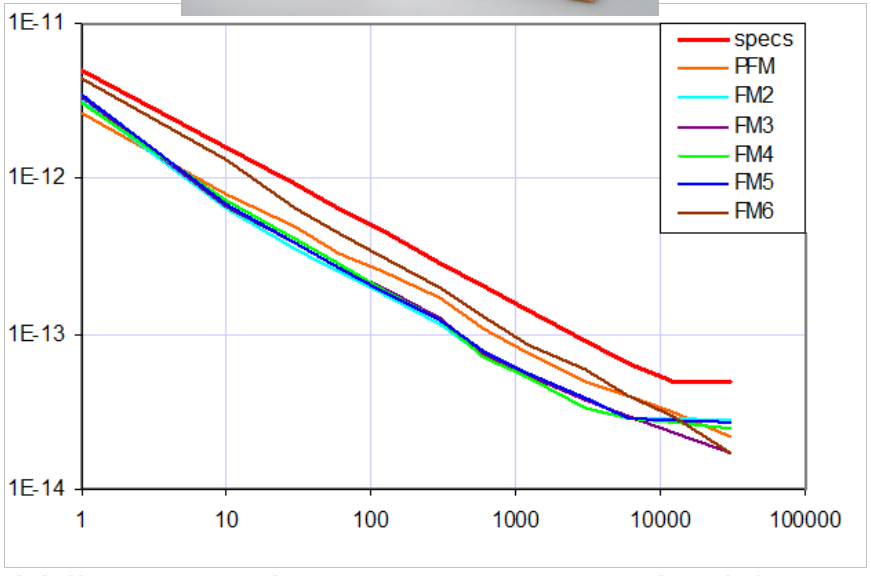
Stability (ADEV) measured on ground:





Passive Hydrogen Maser (PHM)





Rubidium Atomic Frequency Standard (RAFS)

Relativistic Effects on GNSS

1. **Einstein gravitational blue shift effect**
   - Clocks run faster when they are far away from a center of gravitational attraction
   - 45 700 ns/d

2. **Time dilatation or special relativistic Doppler effect of second order**
   - Clocks in motion run slow
   - 7 100 ns/d

3. **Sagnac effect and gravitomagnetic field of rotation**
   - Earth rotation corrections

Compensation: Change of nominal satellite clock frequency prior to launch (10.23 to 10.22999999543 MHz) and correction of about 7m by clock polynomial.

ERIK'S EARLY WORK IN RELATIVITY & GPS

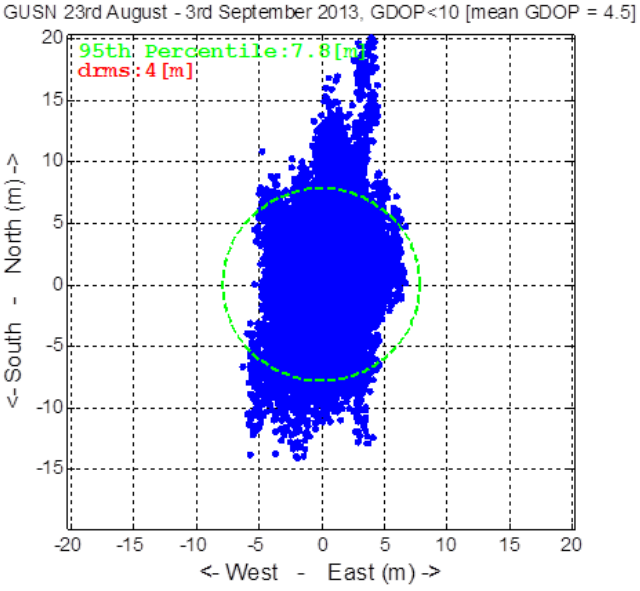
- **RELATIVITY AND GEODESY**
  - Spacetime Coordinates in the Reference Frame **1986**
  - Relativistic GPS Positioning **1991**
  - Relativistic Computation of Geodetic Satellite Orbits **1991**

- **GPS**
  - Generating Classes of Equivalent Linear Modelsby Nuisance Parameter Elimination – Applications to GPS Observations **1986**
  - GPS Design – Undifferenced Carrier Beat Phase Observations and the Fundamental Differencing Theorem **1987**
  - Mixed Integer-Real Valued Adjustment (IRA) Problems: GPS Initial Cycle Ambiguity Resolution by Means of the LLL Algorithm **2000**

The IOV satellites have proven that Galileo works!

Galileo IOV works (and it works very well….!)

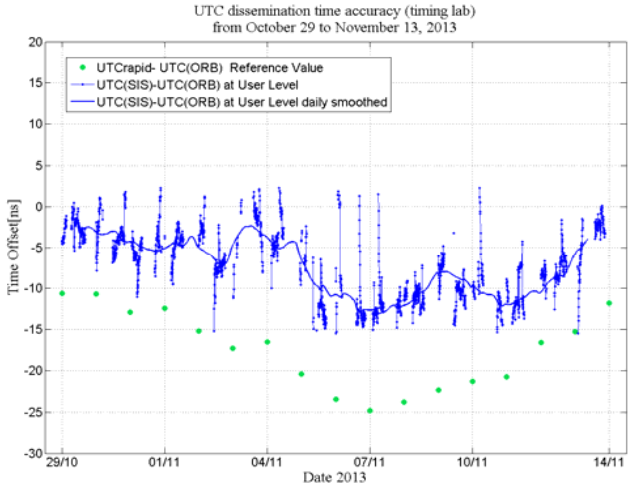
Positioning



Dual Frequency Positioning Accuracy (PDOP <=5):

- Horizontal (95%) **8 m in average**
- Vertical (95%) **9 m in average**

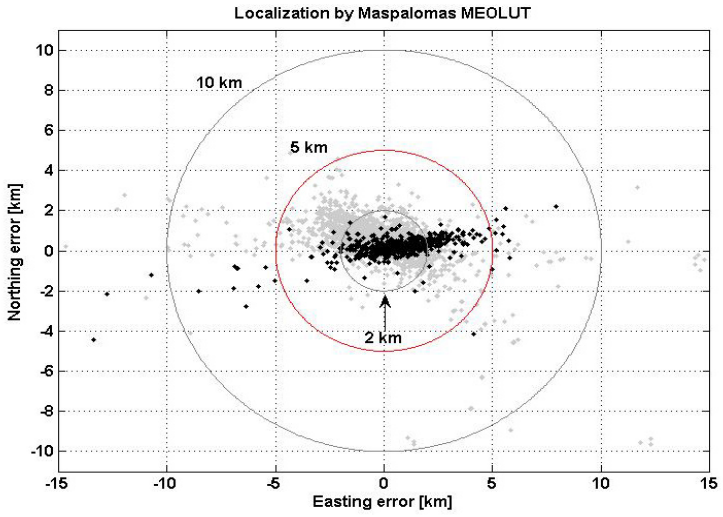
Timing



Timing Accuracy:
10 nsec in avg

- 67% availability with 4 IOV S/C
- 96% availability after 1st FOC launch (6 S/C)

Search And Rescue



SAR Beacons Localisation Accuracy:

- **Within 2 km** (77% localisations)
- **Within 5 km** (95% localisations)

Satellite navigation

primarily delivers

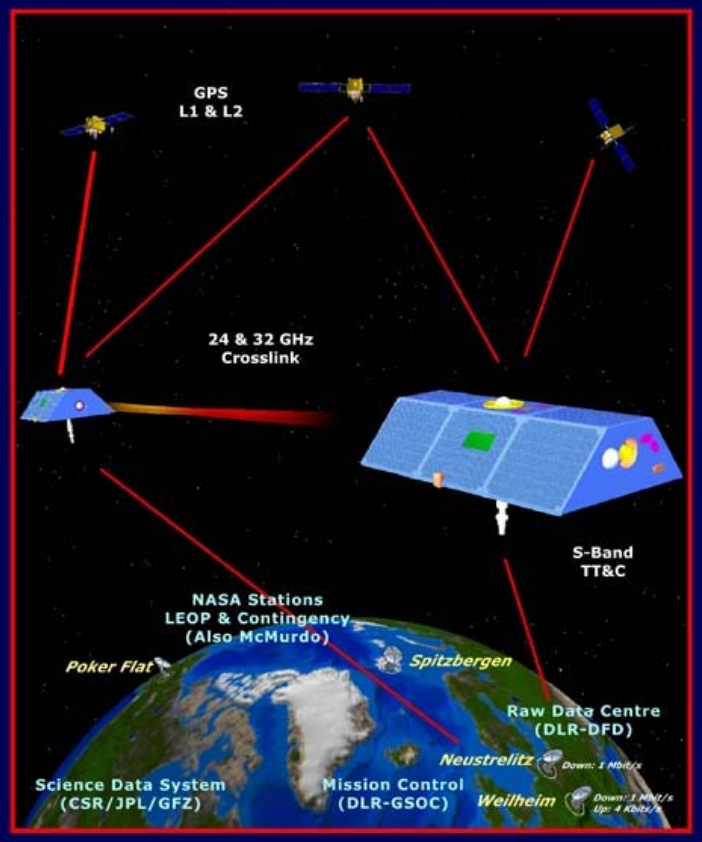
Position, Navigation, Time (PNT)

Moreover, Galileo provides also many data to **Science!**

… **Galileo applications are not limited by technology,**

they are only limited by our imagination!

Galileo / GNSS Space Receivers



GRACE Mission

Science Goals

High resolution, mean & time variable gravity field mapping for Earth System Science applications.

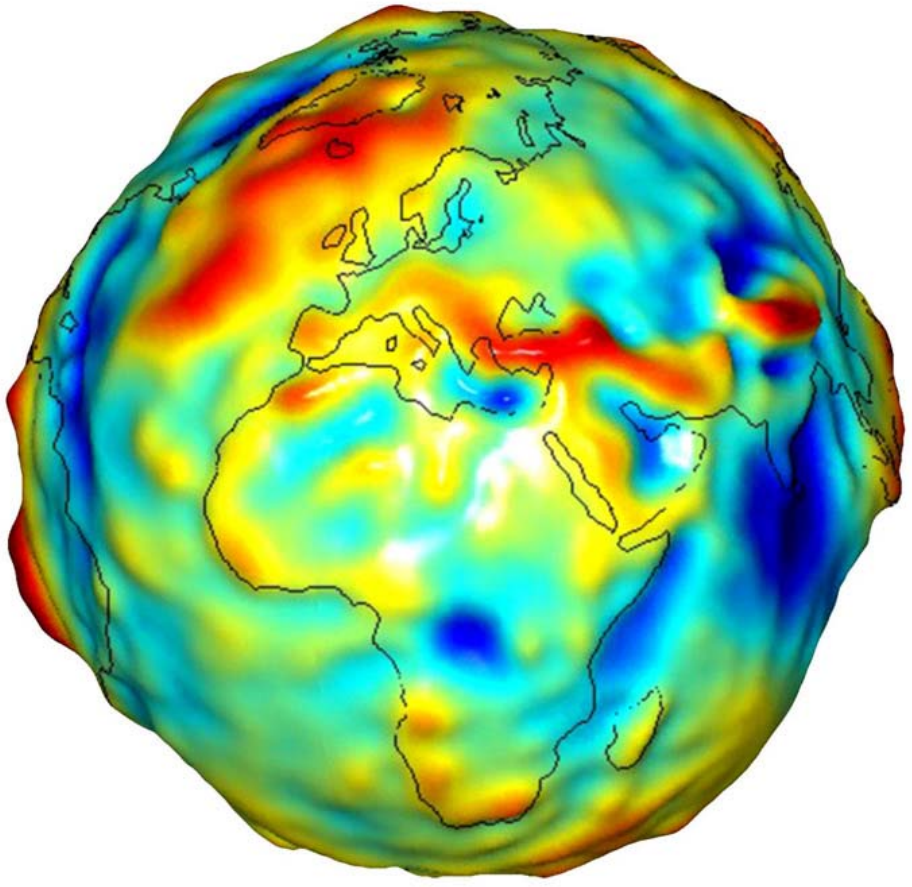
Mission Systems

Instruments
- •KBR (JPL/SSL)
- •ACC (ONERA)
- •SCA (DTU)
- •GPS (JPL)

Satellite (JPL/DSS)
Launcher (DLR/Eurockot)
Operations (DLR/GSOC)
Science (CSR/JPL/GFZ)

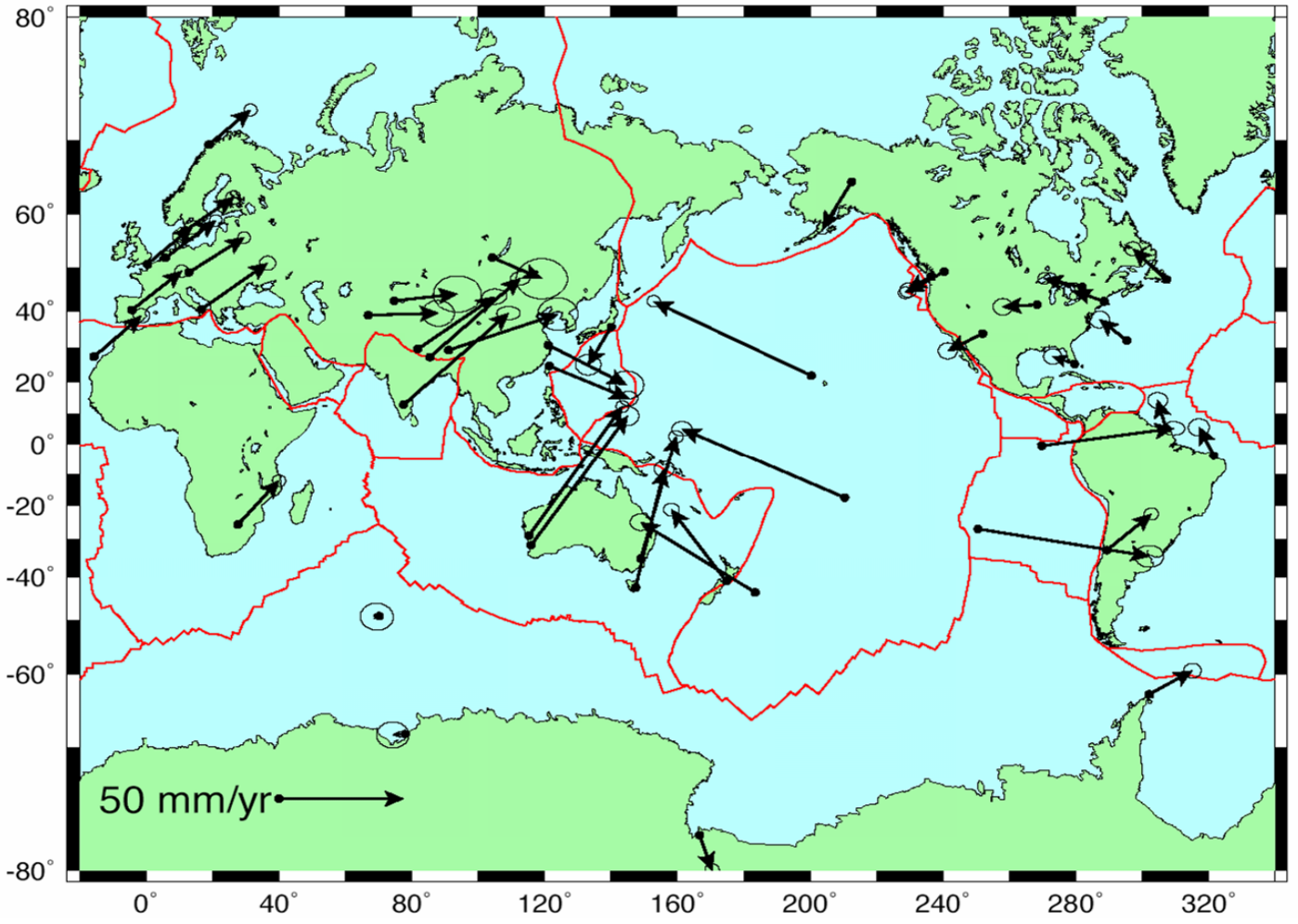
Orbit

Launch: March 2002
Altitude: 485 km
Inclination : 89 deg
Eccentricity: ~0.001
Lifetime: 5 years
Non-Repeat Ground Track
Earth Pointed, 3-Axis Stable



… determine the Earth's gravity field !

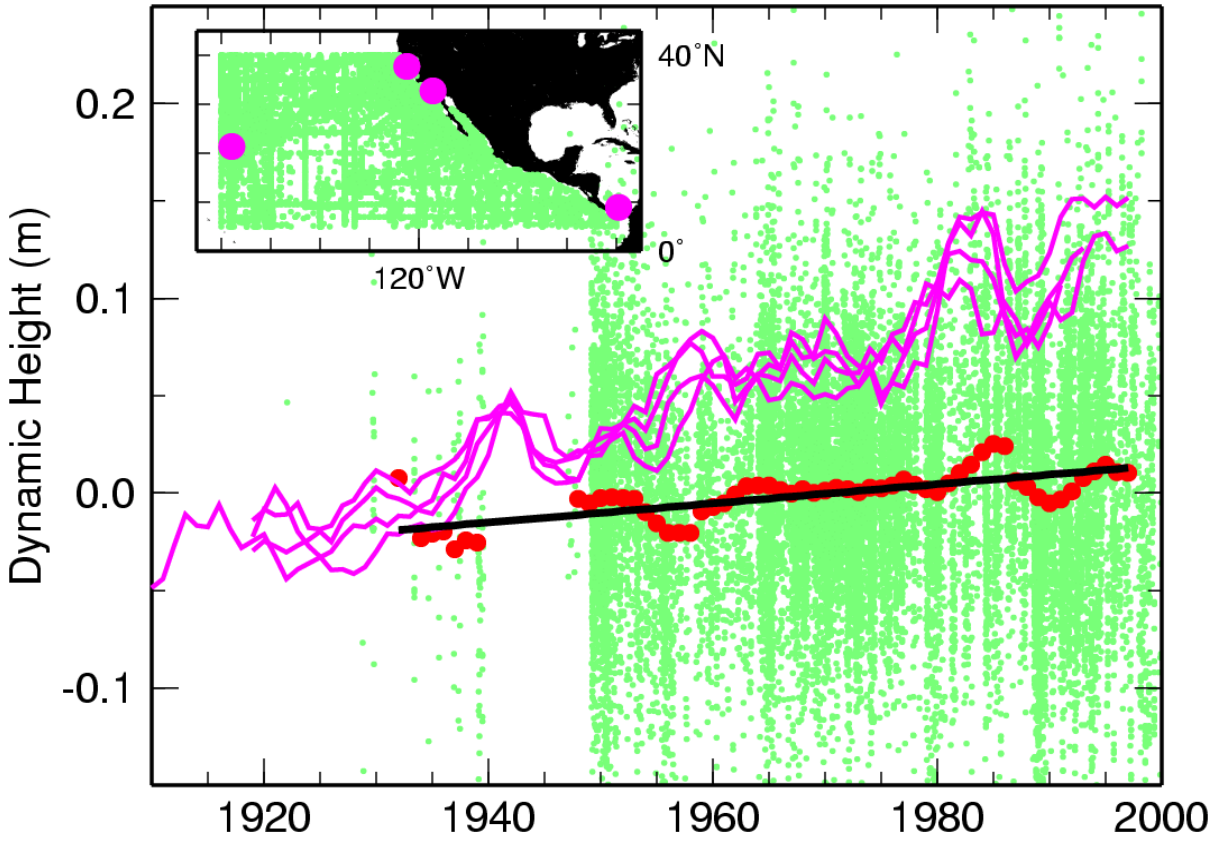
Precise Galileo / GNSS Signals



Larson, K.M., J. Freymueller, and S. Philipsen, Global Plate Velocities from the Global Positioning System, *J. Geophys. Res.*, Vol. 102, 9961-9982, 1997

... monitor the Earth's tectonic plates !

20th Century Sea Level Rise: Eastern Pacific

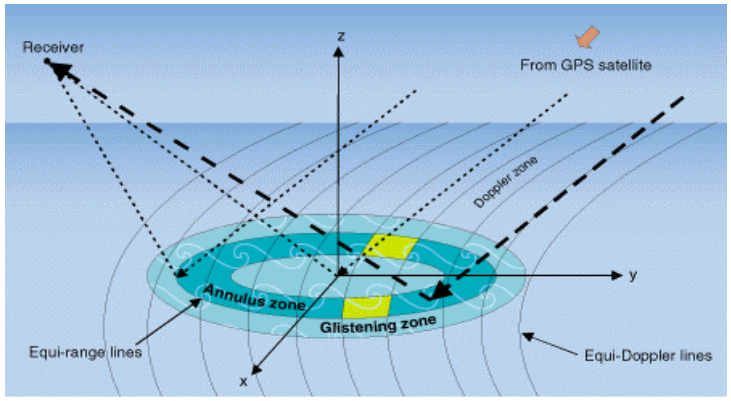


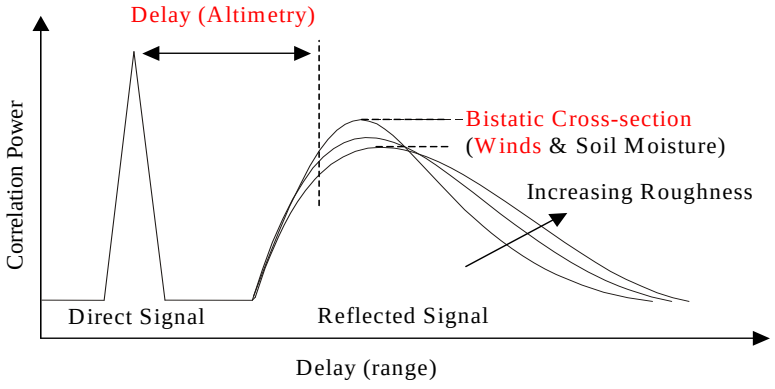
Tide Gauge Sea Level (Mass & Volume Change)2 mm/yr

Dynamic Height (Volume Change) 0.5 mm/yr

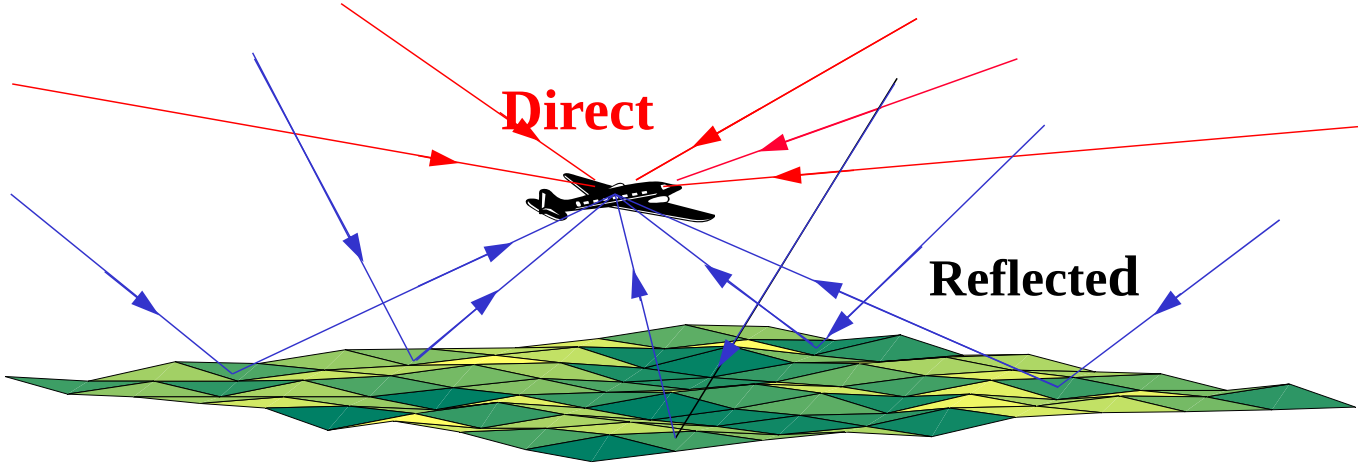
... monitor global sea level rise !

Galileo Signal Multipath





ESA GNSS-R(eflectometry) Mission Phase A in Workplan 2010 of the European GNSS Evolution Programme



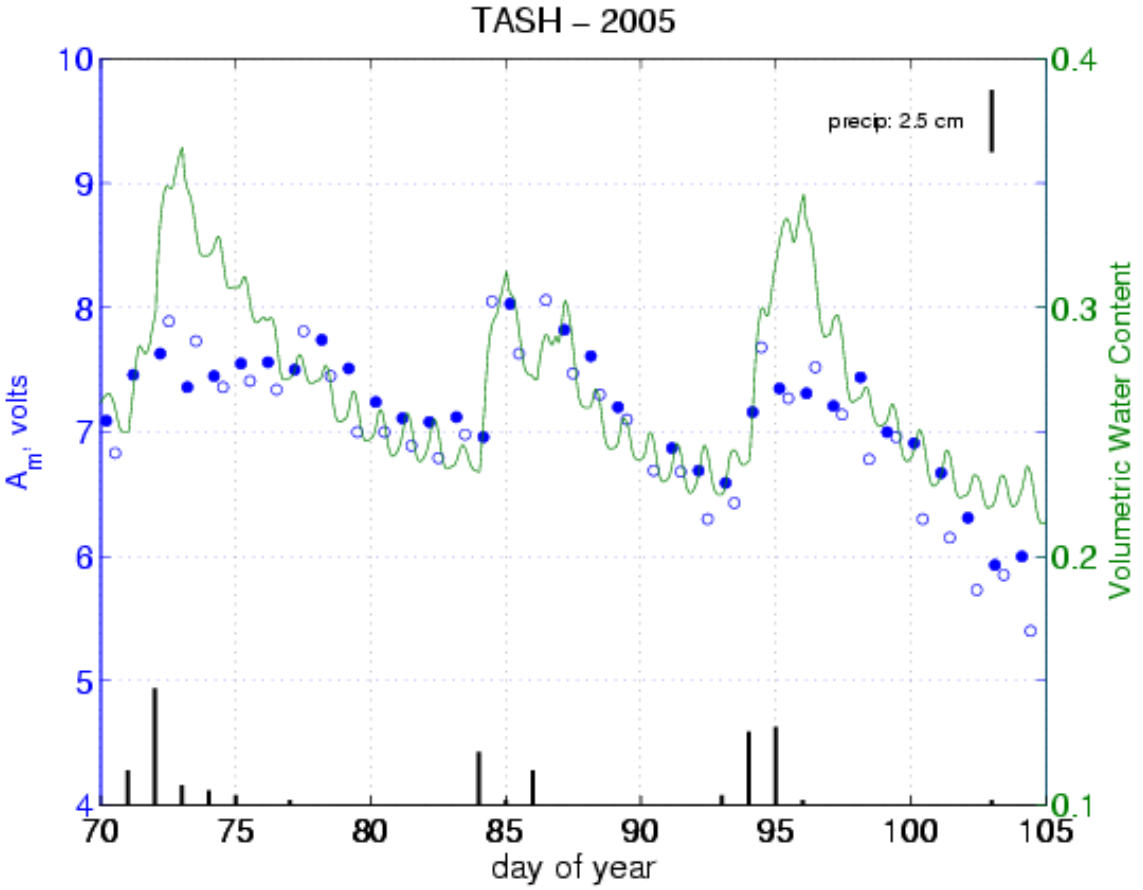
... senses passively ice and sea surface !

Precise Galileo / GNSS Signals

- Daily repeatable fluctuations in SNR at fixed ground stations correspond to multipath
- Frequency related to source of the reflection
- Extract amplitude of SNR fluctuations at that frequency as a proxy for soil moisture

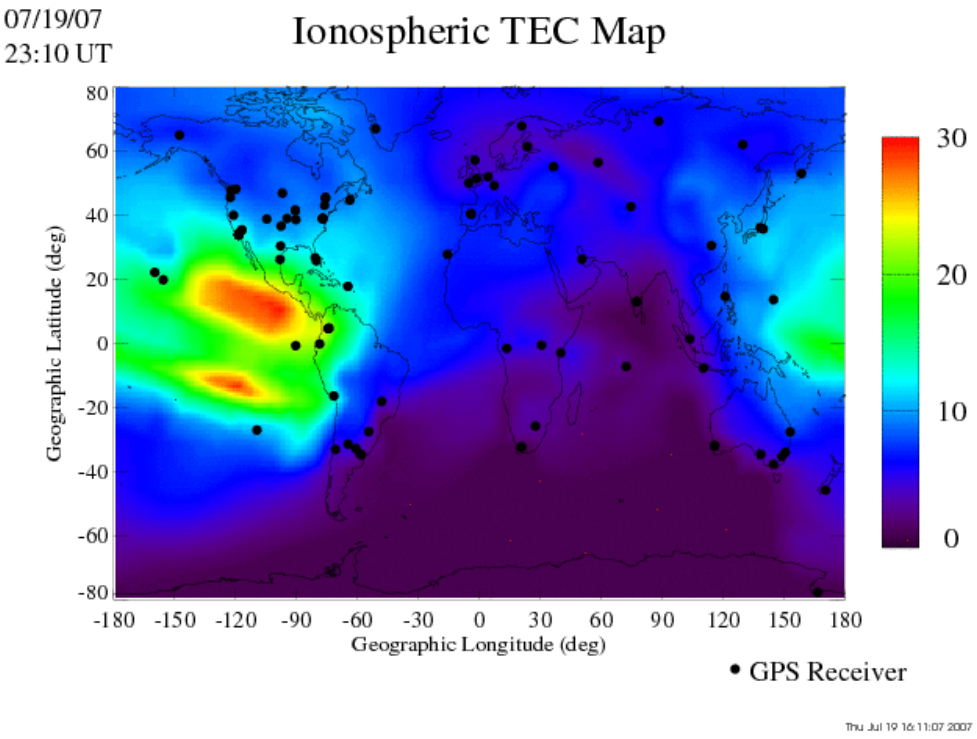
K.M. Larson, E. Small, E. Gutmann, A. Bilich, and P. Axelrad, GPS Solutions, 2007

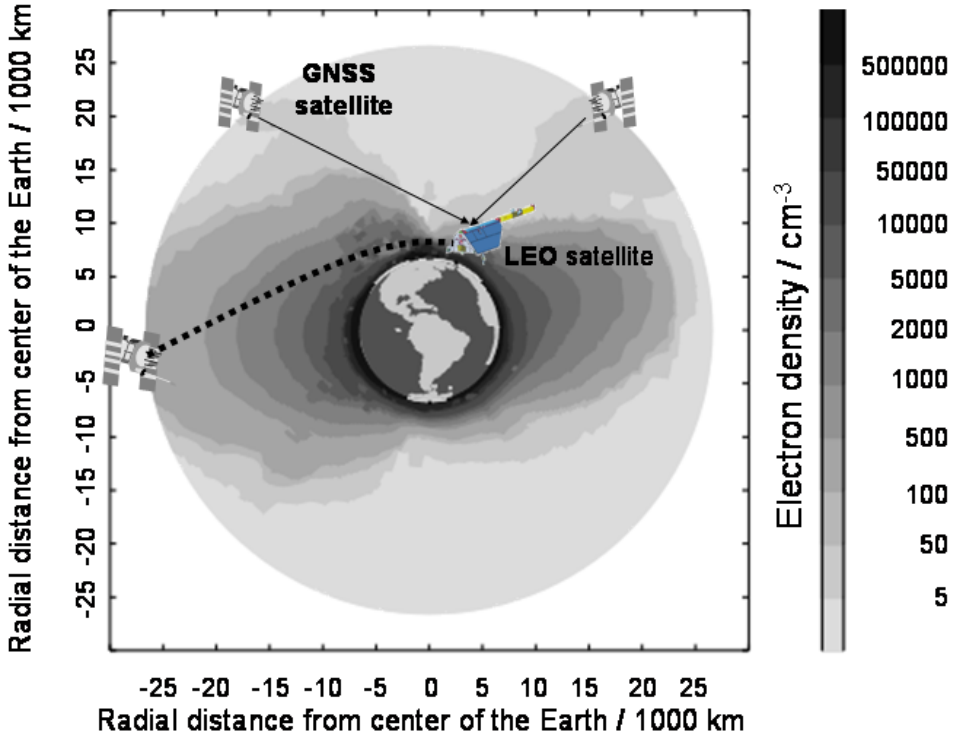
Comparison of GPS-derived surface reflection amplitude with soil moisture model based on local precipitation



... monitor soil moisture fluctuations !

Galileo / GNSS Occultation Data

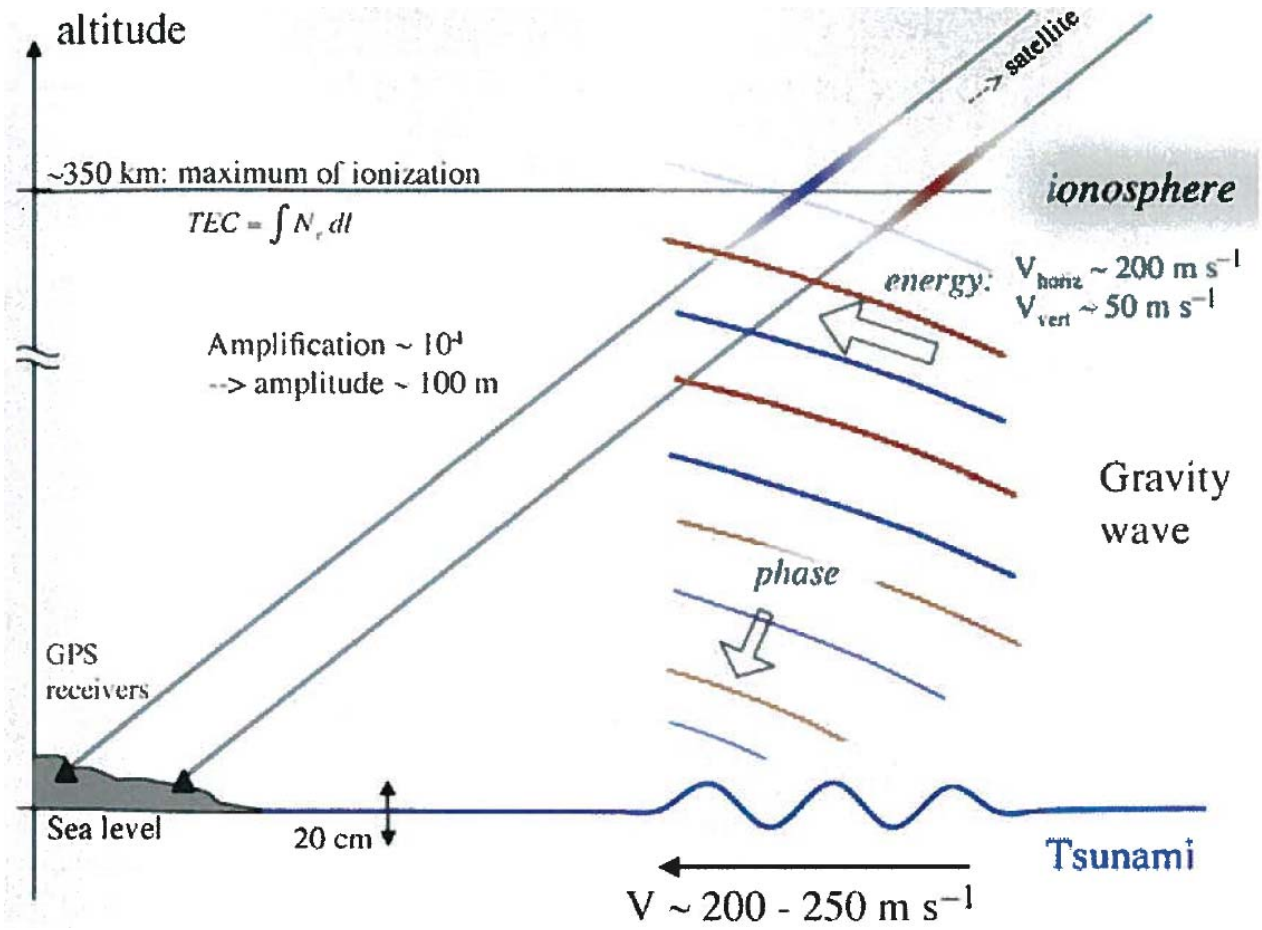




... enable ionospheric tomography !

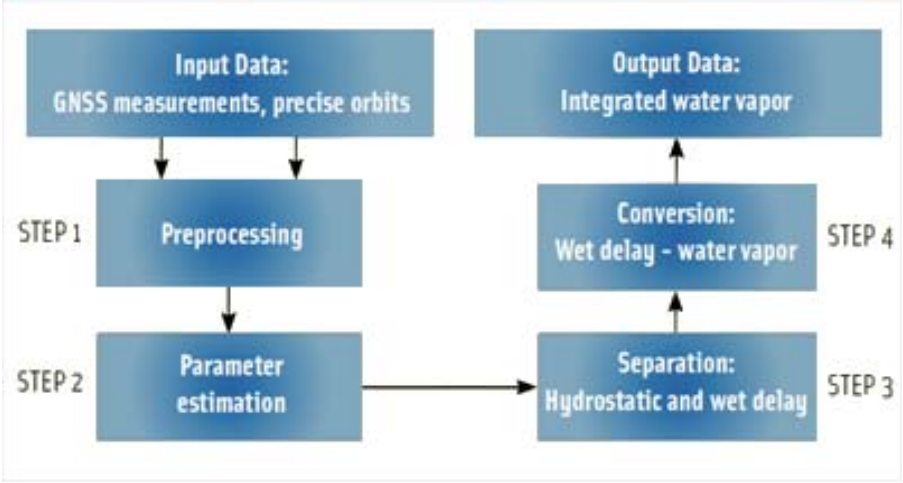
Galileo Ionospheric Measurements

Ionospheric detection of gravity waves induced by Tsunamis.
Geophys. J. Int. (2005), 160, 840-848

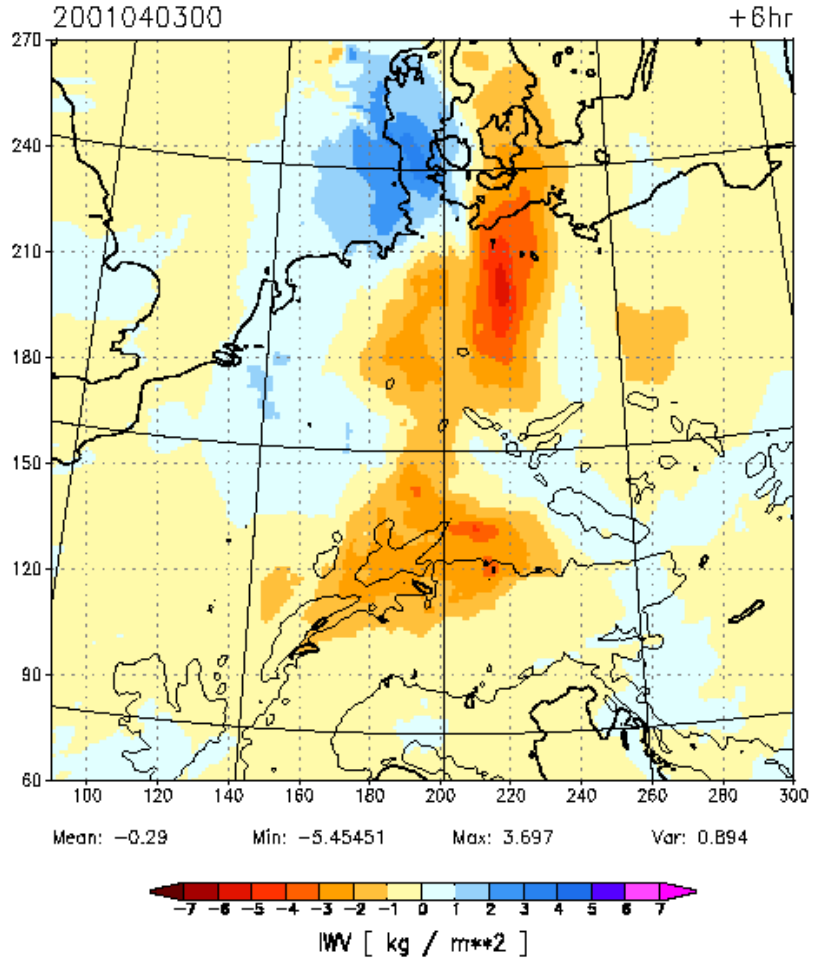


... detect atmospheric waves generated by earthquakes and tsunamis !

Tropospheric Delays in Galileo Signals

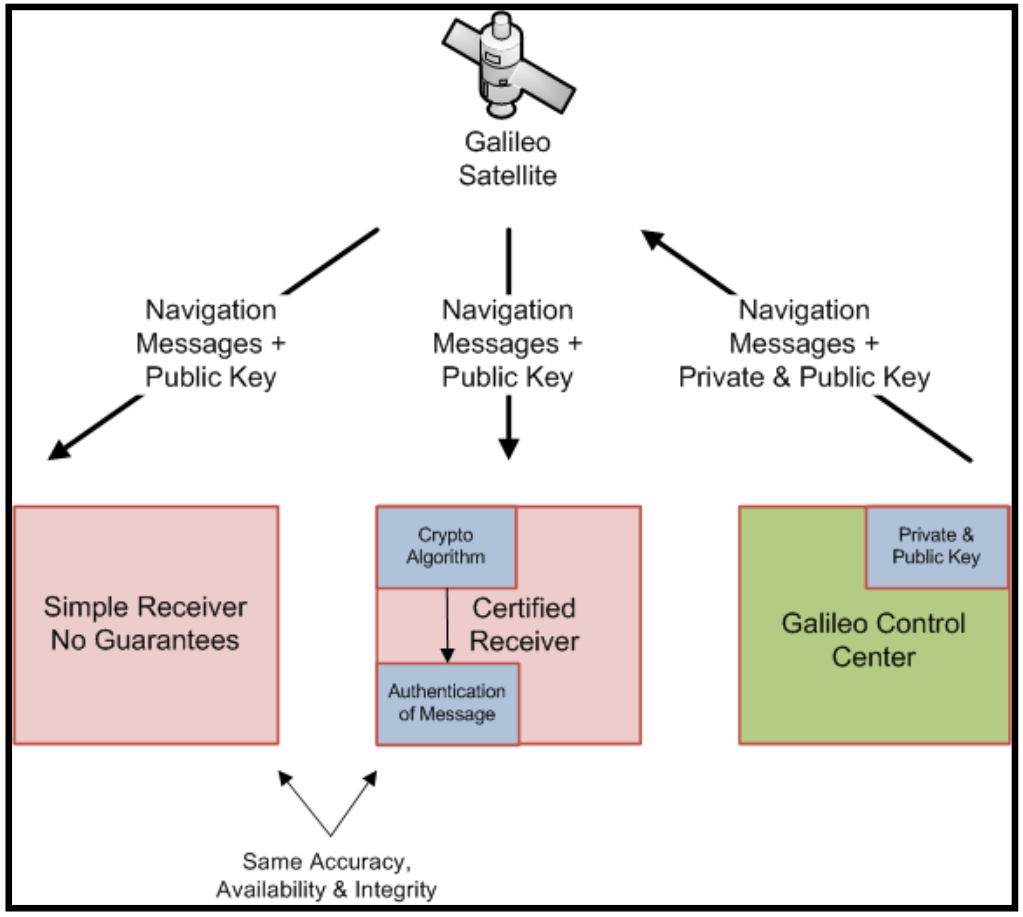


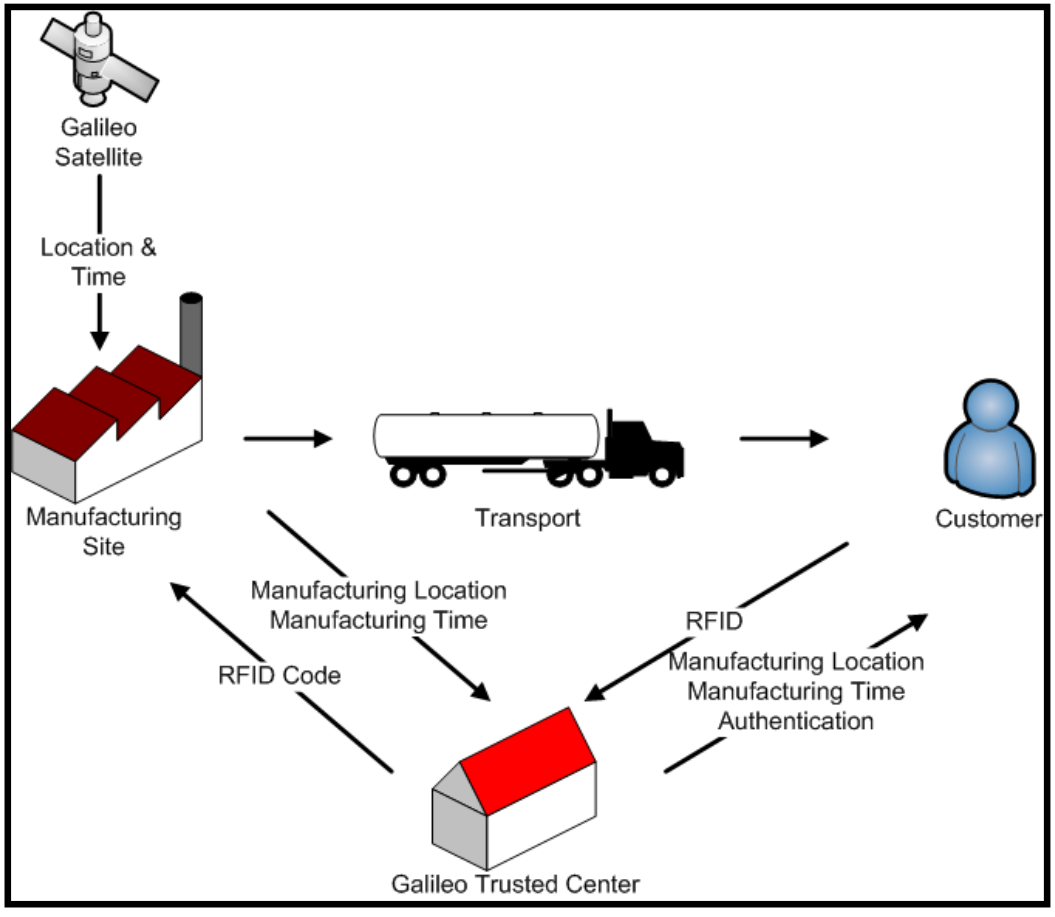
Integrated Water Wapor



... improve the weather forecast !

Galileo Authentication



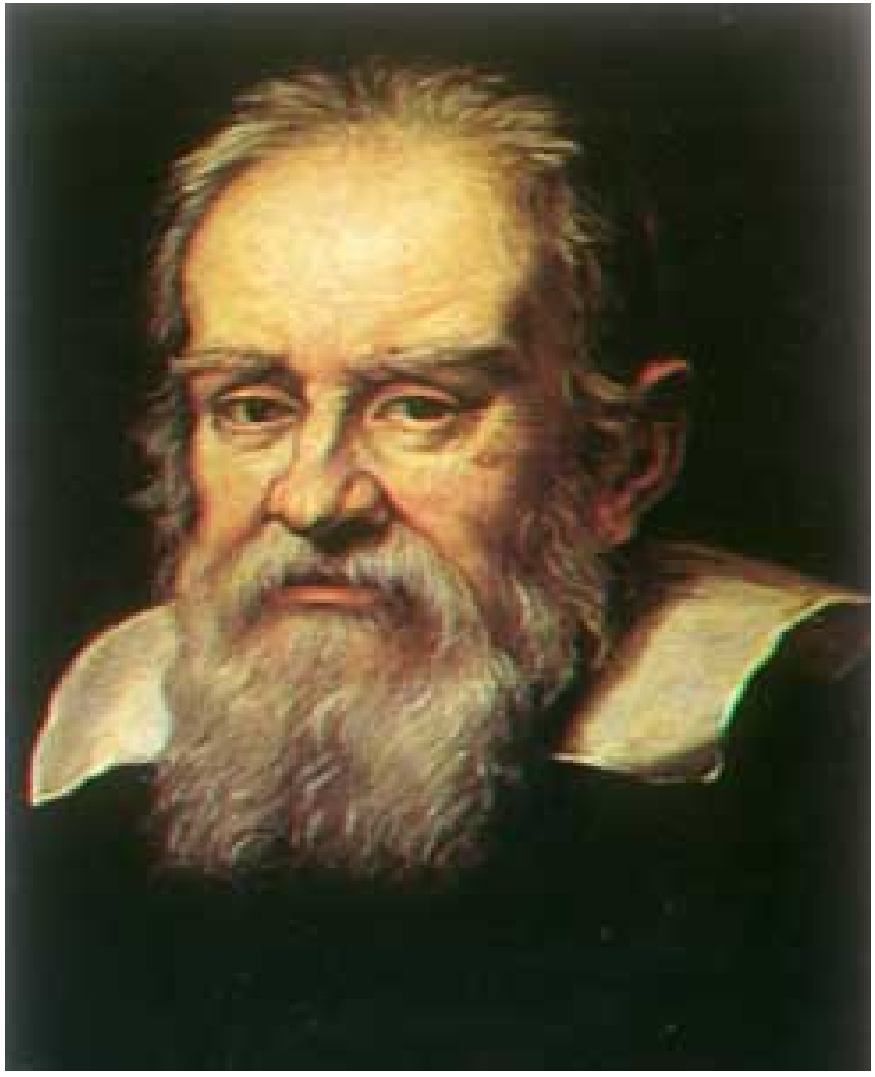


... fights against product piracy !

Galileo Precise Time Signals

Time tag accurately voltage and current (magnitude and phase) on generation, transmission and distribution lines within microseconds

... synchronize and monitor power networks !



Measure what is measurable, and make measurable what is not so.

Galileo Galilei
*1564 ✝1642