Other Space Geodetic Techniques

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Satellite Laser Ranging = SLR

- Measurement of distance (=range) between a ground station and a satellite
- Ground station transmits a very short laser pulse from a telescope to a satellite
- The laser pulse is retro-reflected by corner cube reflectors on the satellite back to the ground telescope
- Very precise clock at the ground station measures the round trip time $t_{\text{emission}} - t_{\text{reception}}$
- Time measurement accuracy < 50 picoseconds, or < 1 centimeter in range
- 3 stations, 1 satellite => position of the satellite (if station position known)
- 3 satellites, 1 station => position of the station (if satellite orbit known)
Satellite Laser Ranging

Geodetic satellites commonly used in SLR:

- Starlette (France, 1975)
- Lageos-1 (US, 1976)
- Etalon-1,2 (USSR, 1989)
- Topex/Poseidon (US/France, 1992)
- Lageos-2 (US/Italy, 1992)
- Stella (France, 1993)
- GPS-35,36 (US, 1993/94)
- Glonass-63,67 (Russia, 1994)
- ERS-2 (ESA, 1995)
- GFZ-1 (1996)
- MIDORI/ADEOS (Japan, 1996)
- TiPS (US, 1996)
Lunar Laser Ranging

= SLR to the moon (first achieved in 1969)

LLR station distribution

Location of laser reflectors in the Moon

Lunar corner cube array (Apollo XIV)

Lunar laser station at Calern, France
Satellite Laser Ranging

- Pros:
  - Absolute and direct measurement of satellite-receiver distance

- Cons:
  - Expensive
  - Heavy operation
  - Difficult to automate
  => global coverage poor

- Applications:
  - Orbit determination
    - Earth’s gravity field
    - Ocean altimetry
  - Precise positioning of ground stations
    - Geophysics
    - Geodesy
Very Long Baseline Interferometry = VLBI

- Radio-astronomy technique, used to locate and map stars, quasars (=quasi-stellar radio source = very energetic and distant galaxy), etc = “sources”
- Measures the time difference between the arrival at two Earth-based antennas of a radio wavefront emitted by a distant quasar
- Signal = noise, wavelength = 1-20 cm
- If the source positions are known ⇒ ground baseline ⇒ “geodetic” VLBI
- Time measurements precise to a few picoseconds ⇒ relative positions of the antennas to a few millimeters
VLBI

VLBI antenna at Algonquin, Canada

Cryogenic receiver

Hydrogen maser

Mark III correlator
VLBI

- The astronomic sources of geodetic VLBI (e.g. quasars) are located billions of light years away from Earth:
  - They appear point-like, with no motion
  - No need for modeling their motions (cf. satellite orbits) ⇒ less errors
- Only technique capable of establishing a direct link between the inertial frame (radio sources) and the terrestrial reference frame
- Only technique capable of measuring all components of the Earth's rotation directly:
  - Variations of the Earth's spin axis in space (precession, nutation)
  - Variations of the Earth's spin axis relative to the Earth's crust (polar motion)
  - Rotational velocity and phase (Universal Time, UT).
VLBI

Pros:
- The most precise and accurate space geodetic technique
- Direct link between inertial and terrestrial frames

Cons:
- Expensive
- Heavy operation
- Difficult to automate
  \(\Rightarrow\) global coverage poor

Applications:
- Reference frames
- Geophysics
- Provides precession, nutation, polar motion, UT1
VLBI

Vector baseline plots for WESTFORD—WETTZELL
GSFC VLBI Solution 2004 March
Baseline length = 5688 kilometers
Number of sessions = 198

- Observed Rate = 16.0 ± 0.5 mm/yr (secular only) Lambda = 71 mm
- Reduced Chi-square = 2.87
- N/V and model rate = 18.9 mm/yr
- Weighted mean length = 589832575.8 mm

LOD Determined from VLBI Data (NASA/GSFC)

- Observed Rate = -7.4 ± 0.5 mm/yr (1-sigma) Lambda = 2.7 mm
- Reduced Chi-square = 0.33
- N/V and model rate = -7.8 mm/yr

- Epoch rate estimated
- N/V and model rate = 1.4 mm/yr

Note: Data from: "http://www.ngdc.noaa.gov/wdcv/vlbi/geometry100.html"
Doppler Orbitography

DORIS (France), PRARE (Germany):
- Doppler orbitography,
- Receiver in the satellite, emitter on the ground
- Satellite records data and downloads it to a data center (centralized system)
- DORIS on Spot 2, 3, 4, on ERS1 and 2, on Topex-Poseidon, on EnVISAT, on Jason
- Excellent geographic coverage
GLONASS

• “Russian GPS”
• First satellite launched in 1982
• As of December 2009 = 16 satellites operational
• Several manufacturers sell GPS/GLONASS receivers
• http://www.glonass-ianc.rsa.ru/

<table>
<thead>
<tr>
<th></th>
<th>GPS</th>
<th>GLONASS</th>
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</thead>
<tbody>
<tr>
<td>Orbital planes</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Orbit inclination</td>
<td>55</td>
<td>64.8</td>
</tr>
<tr>
<td>Orbit height</td>
<td>20200 km</td>
<td>19100 km</td>
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</tbody>
</table>
| Carrier frequency    | L₁: 1575.42 MHz  
                      | L₂: 1227.60 MHz  |  
                      | L₁: 1602 + k 0.5625 MHz  
                      | L₂: 1246 + k 0.4375 MHz  | k=1,...,24 |
| Codes                | CA-Code for L₁  
                      | P-Code for L₁ and L₂  |  
                      | CA-Code for L₁  
                      | P-Code for L₁ and L₂  |  
| System time          | GPS-Time     | UTC(SU)     |
| Repeat time          | Sidereal day | 8 days      |

A GLONASS satellite
**GALILEO**

- “European GPS”, + China, + Israel
- Commercially-oriented system, (GPS was originally military)
- Original plan: ~30 launches 2006-2008, operational 2008: 27 operational + 3 spares
- 3 circular orbits at 23,616 km, inclination 56 degrees
- L-band, dual-frequency
- Key difference with GPS: integrity monitoring
- Commercial services
- [http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm](http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm)
- GNSS