GNSS-based Precise Orbit Determination of LEO Satellites – Status, Challenges, Prospects

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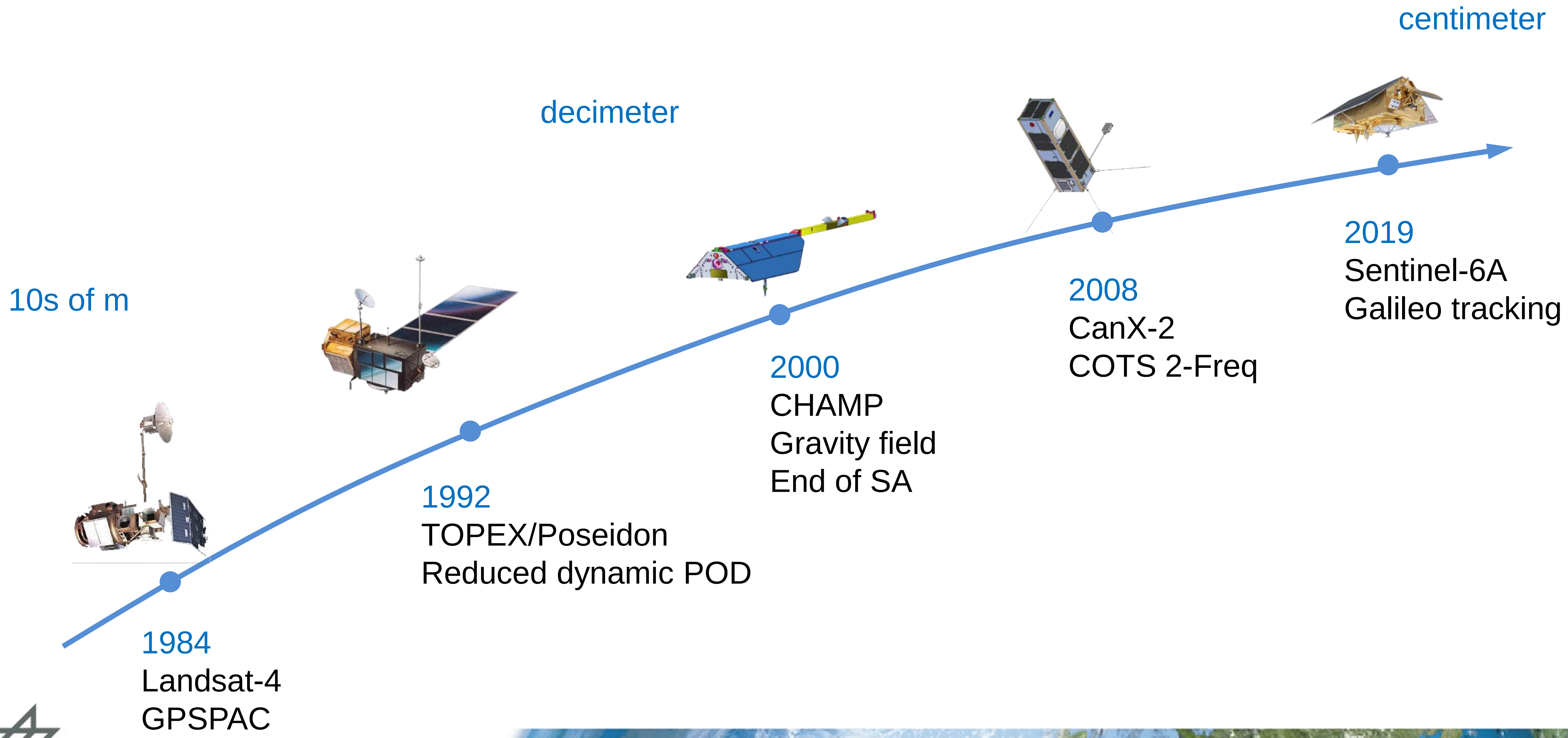
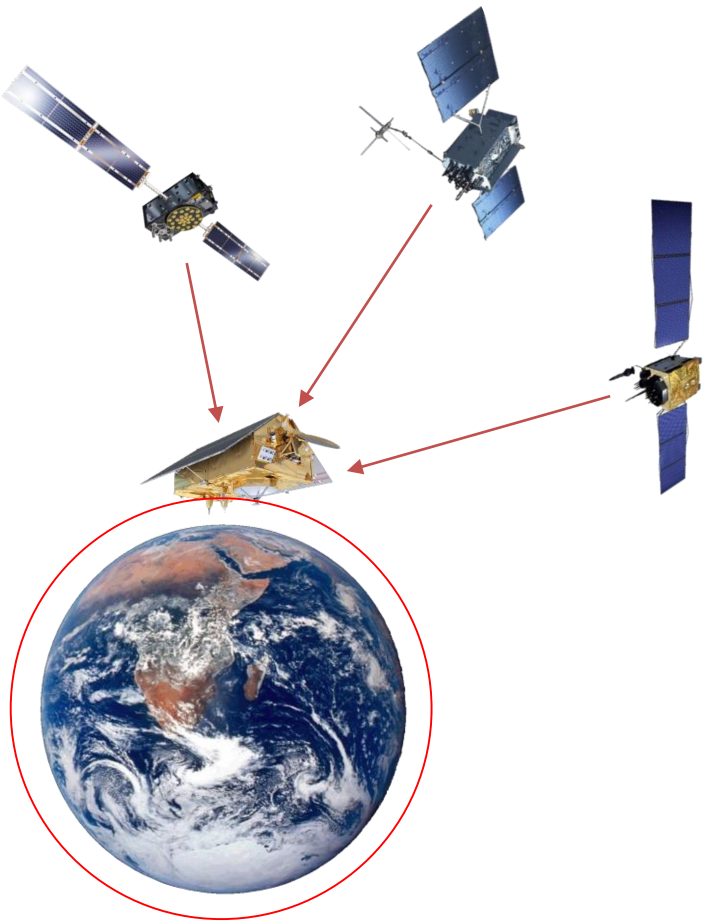
DLR

Four Decades of GPS use for LEO Orbit Determination



Benefits of GNSS for POD

- High accuracy
  - Millimeter-level precision of GNSS carrier phase
  - Strong geometry (multiple concurrent signal sources, supports kinematic POD)
- Global and autonomous (supports onboard POD)
- Navigation (current) & timing (emerging)
- Favorable cost and performance, no limitation of users
- No platform limitation
  - From space station to cubesats
  - Good h/w availability



Alternatives

- Ground-based R/F tracking
- DORIS
- SLR

GNSS Hardware for POD

- Characteristics
  - Dual-frequency (or more)
  - One or more GNSSs (GPS, GLO, GAL, BDS)
  - Code (decimeter) and phase (mm)
  - Integer ambiguities
  - Multipath mitigating antennas
- Spaceborne GNSS Receivers
  - Designed and qualified for space environment ($$$$)
  - Rad-hard, guaranteed multi-year lifetime
  - Bulky (few kg, 10-20W), “old” technology
- Commercial-off-the-shelf (COTS)
  - Up-qualified geodetic receivers, aviation antennas
  - State-of-the-art electronics
  - Low SWaP (size, weight, power), reduced cost
  - Tailored qualification, potentially reduced lifetime

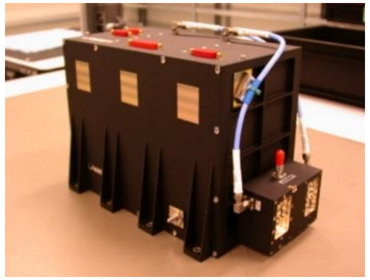






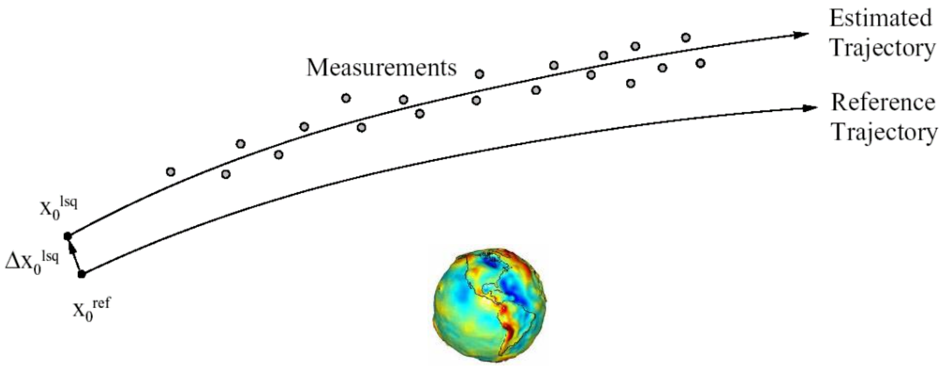


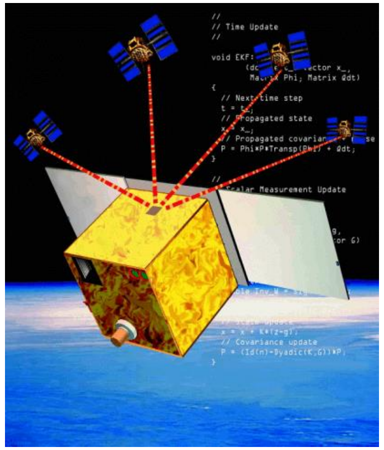
Image credits: JPL, TASI-I, RUAG, Airbus, DLR

Where Are We?

Ground-based POD

- Mostly reduced dynamic, some kinematic
- Sophisticated force models (grav, non-grav)
- Empirical parameters for compensating deficiencies of (non-gravitational) force models
- Batch least squares estimation, 1000s of parameters
- Many s/w packages (GIPSY, Bernese, NAPEOS)
- (Few) cm-level accuracy





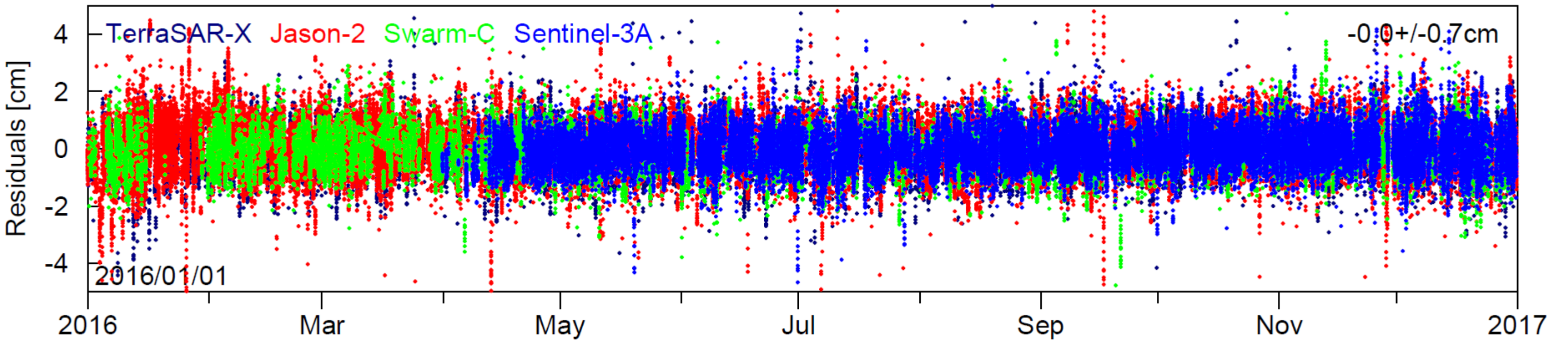
Onboard (P)OD

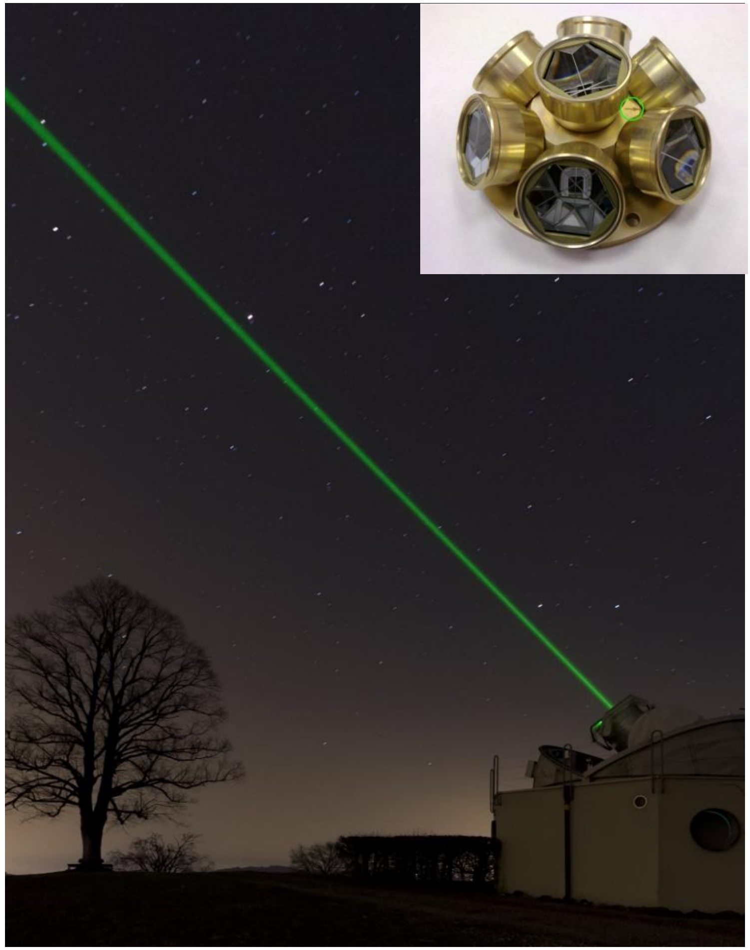
- Reduced dynamic
- Force modeling limited by CPU resources and lack of environmental parameters
- Extended Kalman filter
- Few 10s of estimation parameters
- Meter-level accuracy achieved in current system (platform and payload support)
- Limited by broadcast ephemeris accuracy

Precise vs Accurate Orbit Determination

- No truth reference (except signal simulator testing)
- Precision can be assessed through
  - Overlap comparison
  - Inter-agency comparison / combination
- Comparison with other techniques
  - DORIS
  - SLR

  but each independent technique has it’s own errors
- SLR promises validation at 1cm / 1mm level (accuracy/precision)

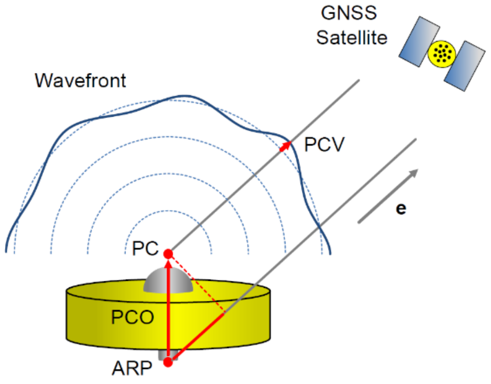


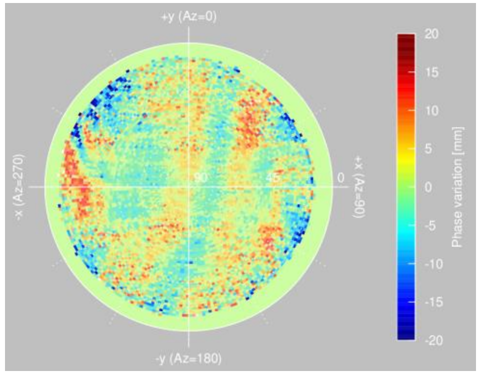


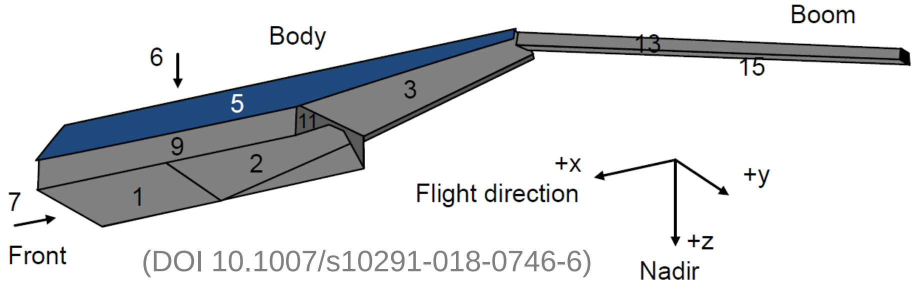
Zimmerwald Observatory (AIUB), Sentinel-3 LLR (ESA)

Challenges

- Antenna phase center/pattern calibration
  - mm to cm distortions seen in phase residuals
  - not seen in standalone antenna calibration
- Center-of-mass location
  - Fuel mass and distribution only partly known
  - (mm to) cm level uncertainties
- Non-gravitational forces
  - Limited knowledge/models of surface forces (drag, solar and Earth radiation pressure)
  - Thermal and R/F radiation
  - 10 nm/s^2 (1 cm) level uncertainties
- Validation
  - SLR station calibration (coordinates, biases)







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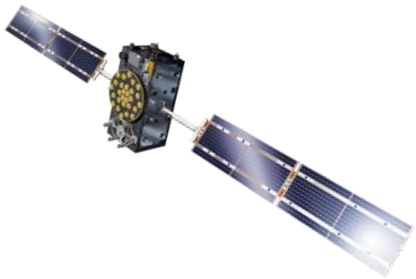
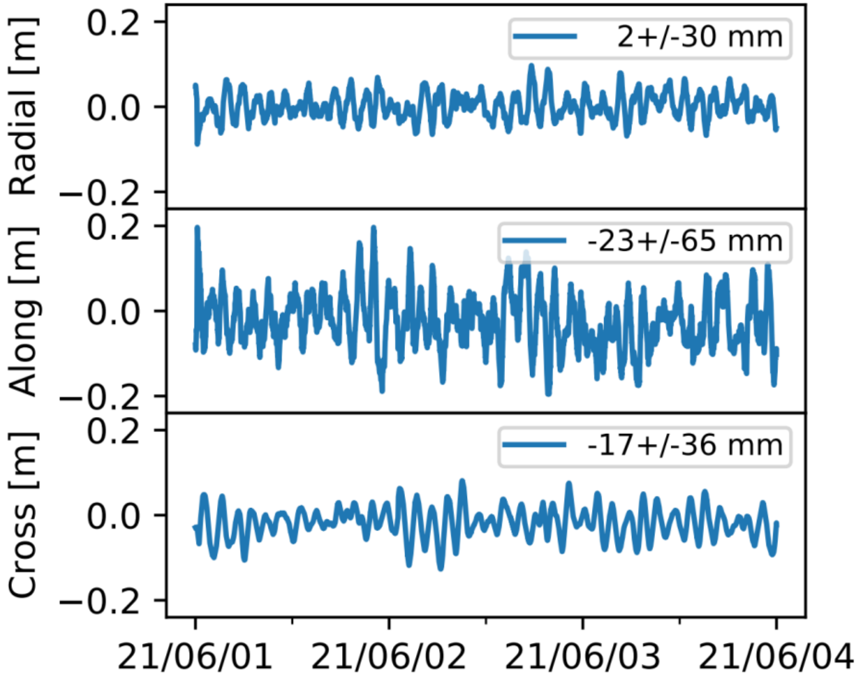
Prospects: On-Board Navigation Using Galileo

- Precise GNSS orbits and clocks in real-time
  - Broadcast Ephemerides: SISRE ~10cm vs ~50 cm for GPS
  - High Accuracy Service: SISRE 5-10 cm for GPS and Galileo
- Showcase: Sentinel-6A
  - Playback processing of PODRIX GPS+Galileo observations
  - GPS+Galileo broadcast ephemerides
  - Sequential filter, fidelity force model
  - 10 cm 3D accuracy w.r.t. to POD
- Applications
  - Radio occultation missions
  - Synthetic Aperture Radar





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Summary and Outlook

- GNSS is a well established tool and primary work horse for precise orbit determination of Earth observation satellites in LEO
- Supported by hardware portfolio ranging from COTS to fully space-grade systems
- Geodetic (down to 1 cm) precision for navigation and science in accord with current mission needs
- Limitations related to characterization of spacecraft, antenna, non-gravitational forces
- Emerging trend for fast and accurate orbit information, i.e. (near-)real-time POD
- Galileo offers best prospects for (sub-)decimeter onboard POD w/o external aiding
- Possible game changer for future Earth observation mission architectures?