Lower Budgets, Larger Distance, and Utmost Precision: Developments and Emerging Trends in Spaceborne GNSS

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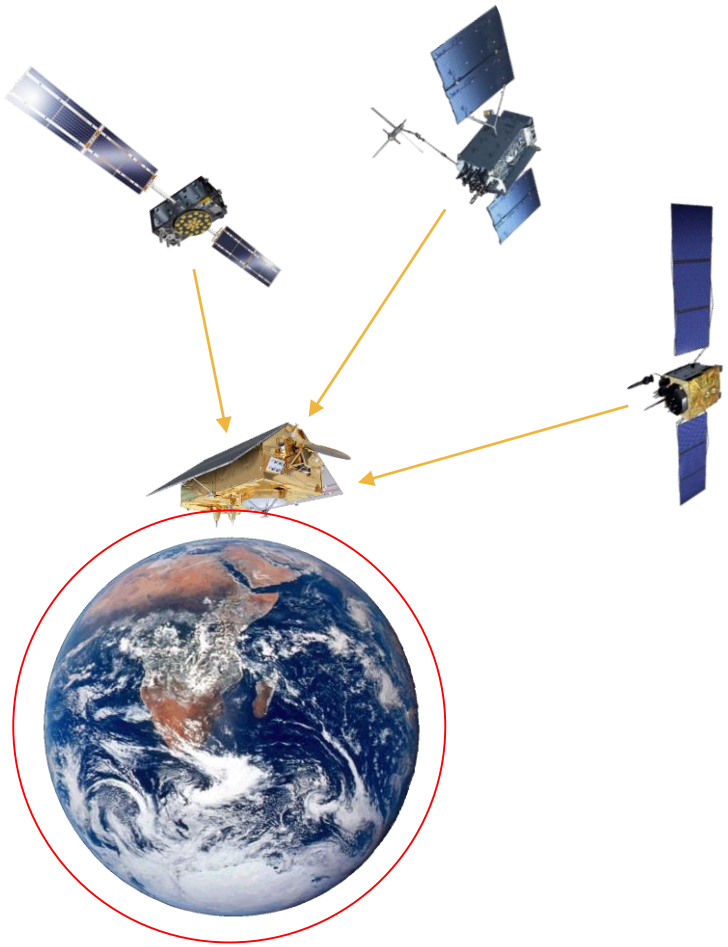
DLR

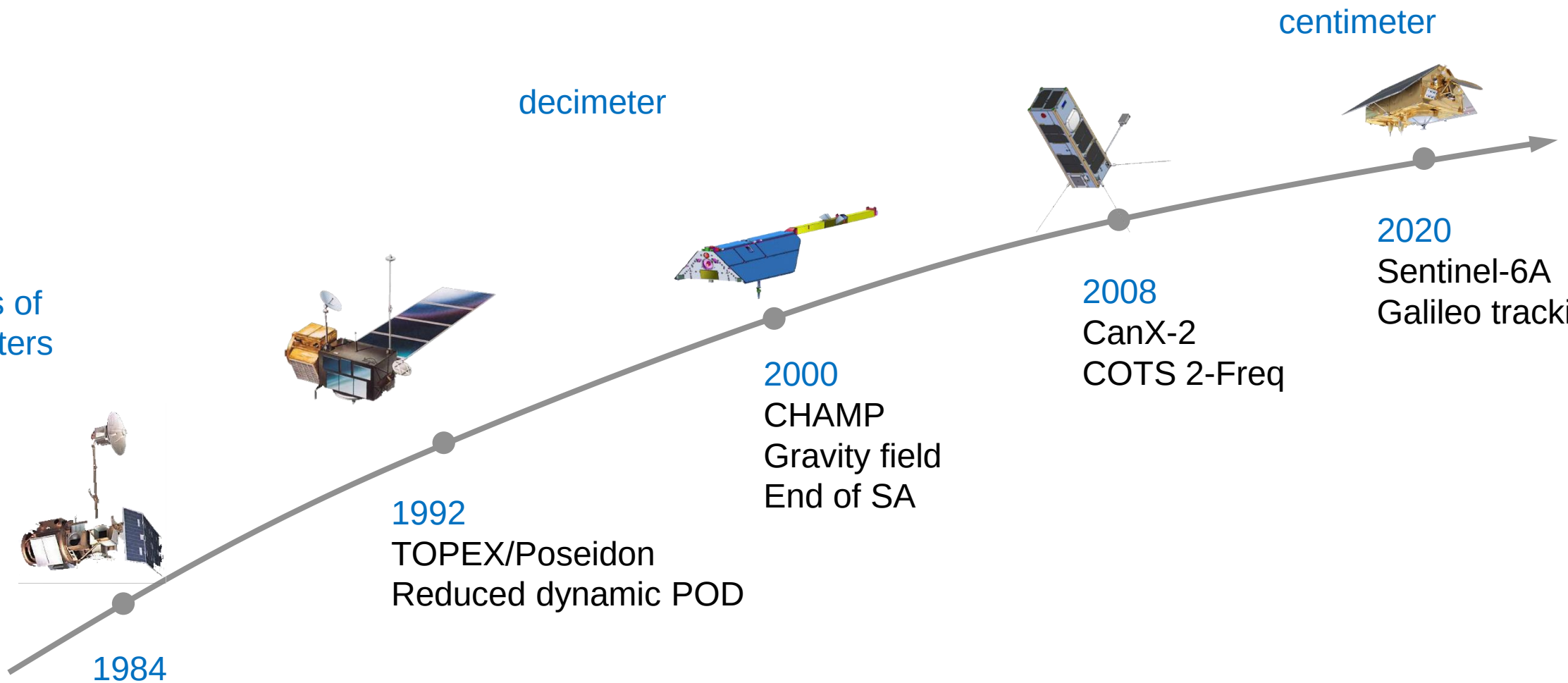
Why GNSS in Space?

- Navigation
  - Cost efficient
  - Global availability
  - High performance
  - Real-time availability
  - Onboard autonomy
  - Attitude and orbit control
- Timing
  - Onboard time
  - Synchronization

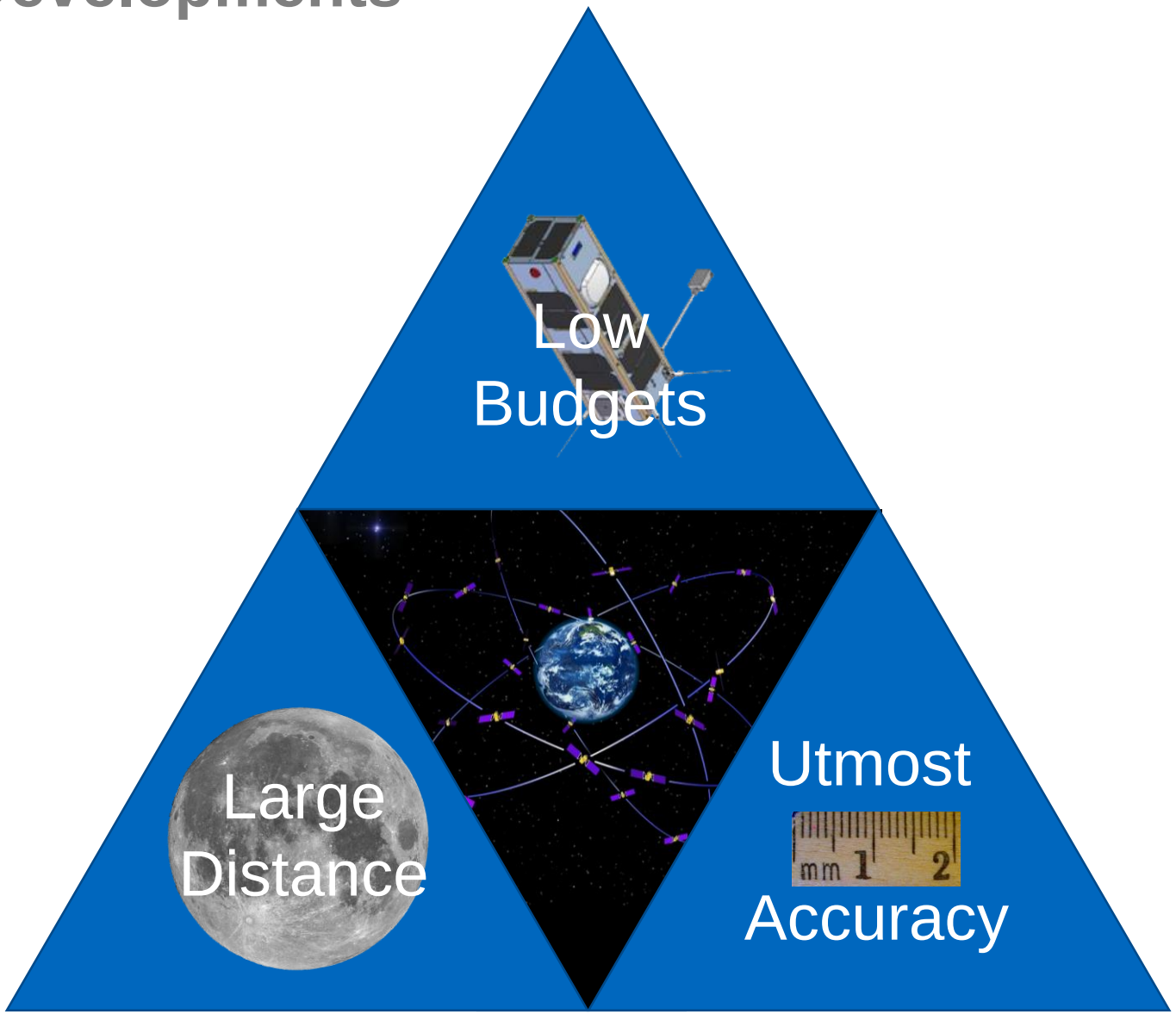


- Science
  - Geocoding
  - POD
  - Altimetry
  - SAR interferometry
  - Radio occultations
  - Scatterometry

Four Decades of GPS Use in Low Earth Orbit



Trends and Developments

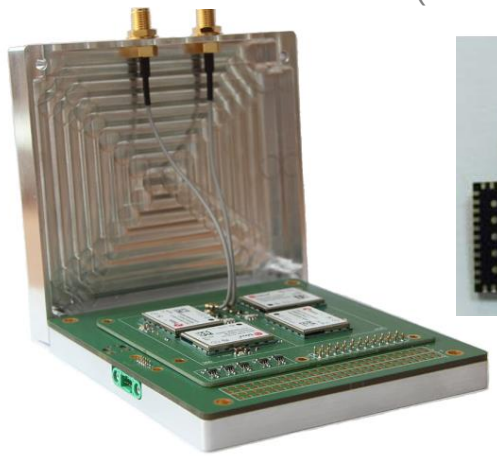


Low Budgets

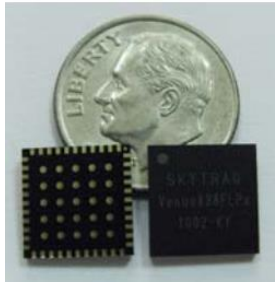
- New Space paradigm
  - Cost consciousness
  - Low Surface, Weight, and Power (SWAP)
- Commercial-off-the-Shelf (COTS), Up-Qualification
- Common access to
  - Dual-frequency
  - Multi-GNSS

LION receiver (AIRBUS)

OEM 719
(NovAtel/Hexagon)



(TU Wien/ETH Zurich)



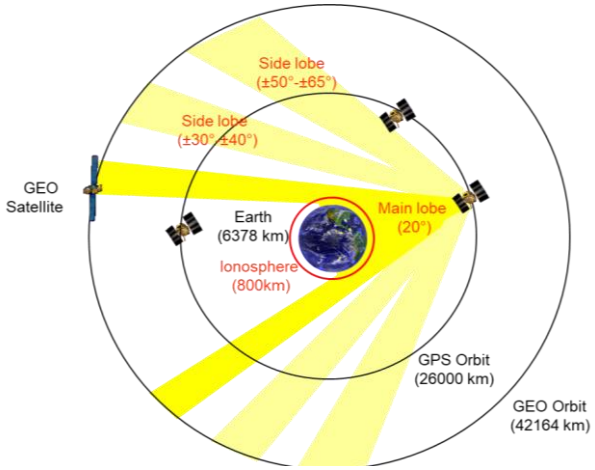
Venus 838FLP
(SkyTraq)

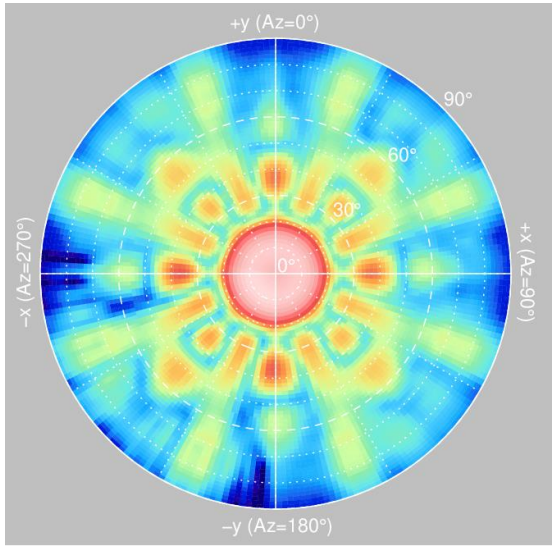
- Small sats for
  - SAR
  - Scatterometry
- Cubesat constellations for
  - Radiooccultation
  - Jamming/spoofing detection
  - Geodesy
- Snapshot navigation for SSA

Müller et al., ASR 2024, DOI 10.1016/j.asr.2023.10.001
Moeller, et al., EGU24-3806, DOI 10.5194/egusphere-egu24-3806
Kobel et al., ASR 2024, DOI 10.1016/j.asr.2024.04.015
Gill & Akos, ASR 2024, DOI10.1016/j.asr.2024.04.015

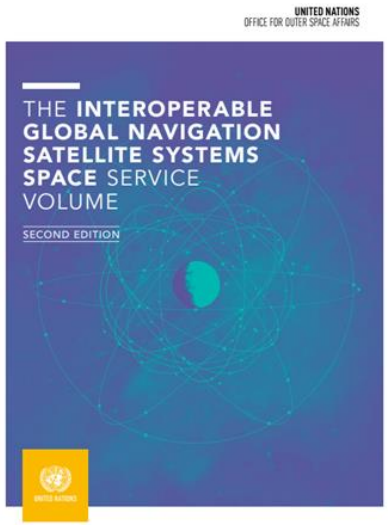
From a distance …

- Extending GNSS use from LEO to GEO and HEO
  - Increased acceptance by operators
- Space Service Volume initiative
  - Performance commitments for GPS III, GLONASS
  - Gain/EIRP patterns for GPS,QZSS, Galileo
- Cis-lunar navigation (60 $R_{\oplus}$), tie for lunar navigation systems
  - Ultra-sensitive receivers
  - Advanced navigation filters





Galileo FOC L1 gain pattern



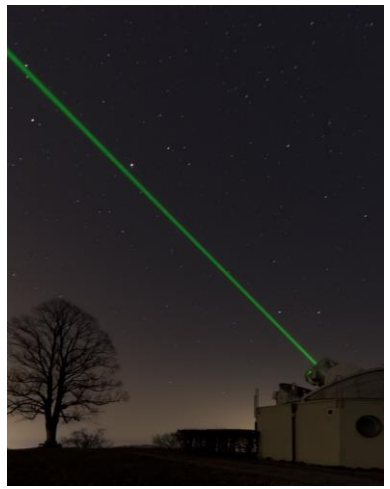
(UNOOSA)

NAVIMOON receiver (ESA/SpacePNT)

The Quest for Utmost Accuracy

- Space Geodesy
- Multi-GNSS (GPS, Galileo, BeiDou)
- 1 cm offline, 10 cm real-time (3D rms)
- Modeling
  - Non-gravitational forces
  - Antennas and center-of-mass
  - Ambiguity fixing
  - GNSS orbits, clock, biases
- Real-time correction services
  - HAS
  - Internet streams (for mega-constellations)

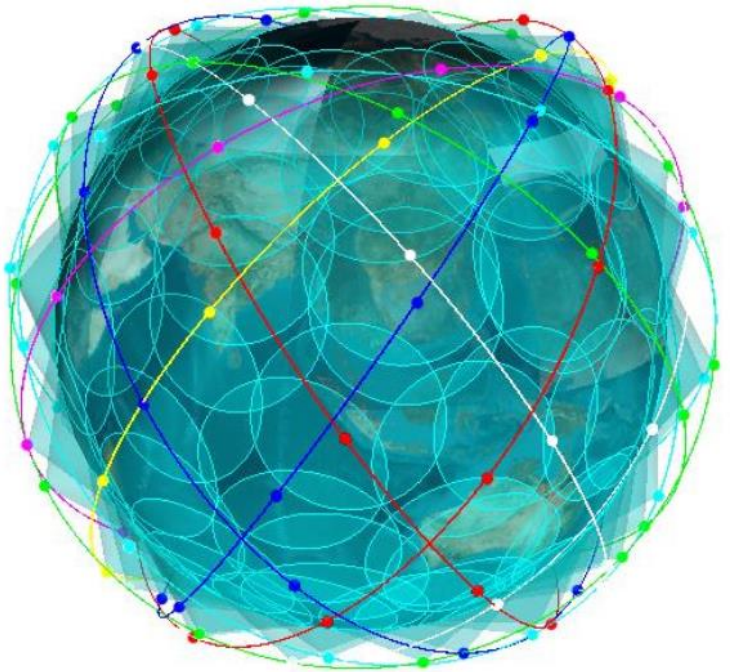
Sentinel-6A (ESA)



Zimmerwald
Observatory (AIUB)

Outlook: The Changing Landscape of GNSS

- LEO PNT systems as backup, complement, alternative to MEO GNSS
  - Increasing awareness of GNSS vulnerability
  - Need for alternative/ensured PNT
  - Build-up of mega-constellations for communication
- Promises, prospects, and visions
  - Robustness (jamming and spoofing protection)
  - Redundancy
  - Accuracy
  - Equipment compatibility
- Largely private initiatives
  - XONA, Centispace
  - ESA LEO-PNT demonstrator



(Beijing Future Navigation Technology Co. Ltd)