Navigation Trends over the Next Decade - Space

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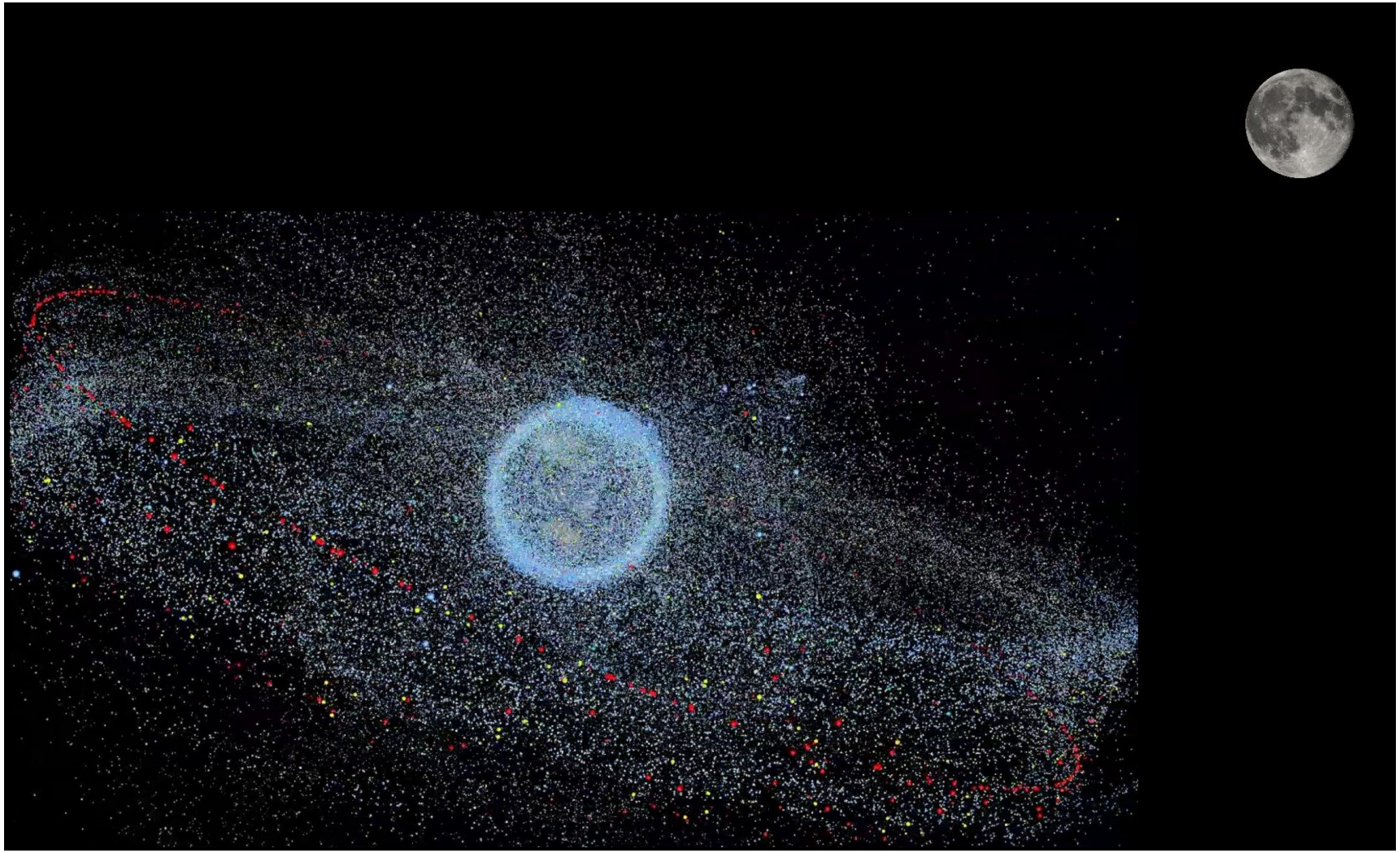
Up to the stars

Targets …

- Low Earth orbit
- Geostationary orbit
- Solar system bodies

.. and how to reach them

- Autonomy
- Safety
- Cost consciousness



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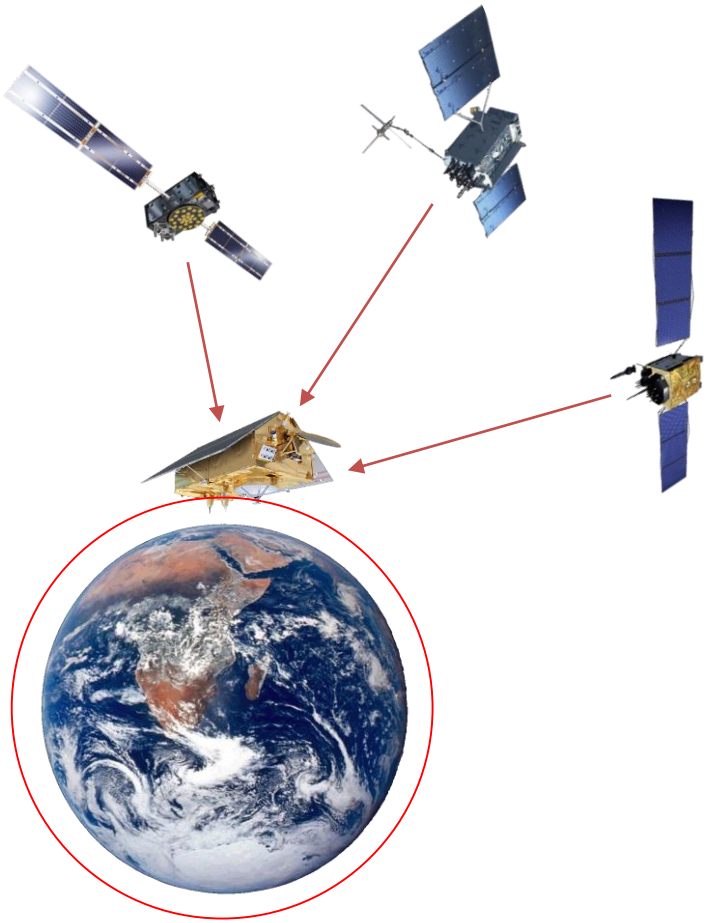
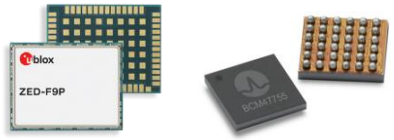
Navigation in Low Earth Orbit (LEO)

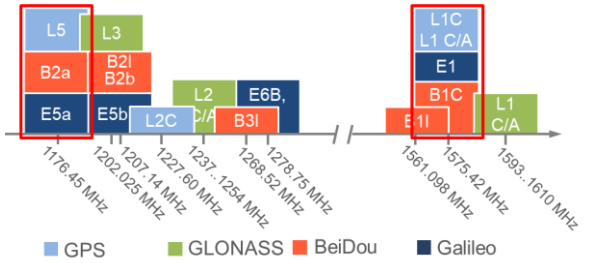
- Addicted to GNSS
  - Global and autonomous
  - Navigation & timing
  - No limitation of users
  - Favorable cost and performance
  - No platform limitation (from space station to cubesats)
- No competitive alternatives
  - Ground-based tracking (limited resources)
  - DORIS (limited resources)
  - Earth/Sun/star sensor and magnetometer (limited accuracy)
- ISLs?
  - Nav-Com integration for LEO constellations?



Navigation in Low Earth Orbit (LEO)

- GNSS accuracy enhancement
  - E.g., Galileo HAS
  - Sub-dm real-time positioning
  - Onboard processing of radio-occultation, images, or SAR
  - Formation control
- Commercial-off-the-shelf (COTS) products and Miniaturization
  - Access to GNSS for all s/c
  - New Space, simplest/soonest
- Multi-GNSS use
  - Improved redundancy and robustness
  - Political independence
- Assured PNT
  - Anti-jamming & -spoofing
  - Navigation message authentication
  - Beam-forming antennas





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Non-Cooperative (Relative) Navigation

- Whenever GNSS is not available
  - Anywhere (LEO, GEO, Moon, asteroids)
  - Carry-yourself navigation system
- Applications:
  - Capture, debris removal,
  - On-orbit Servicing,
  - and hostile interaction
- Techniques
  - Cameras (mono, stereo)
  - Light Detection And Ranging (LIDAR)
  - Photonic mixing device (PMD) camera
  - Radar
  - Artificial Intelligence (AI)

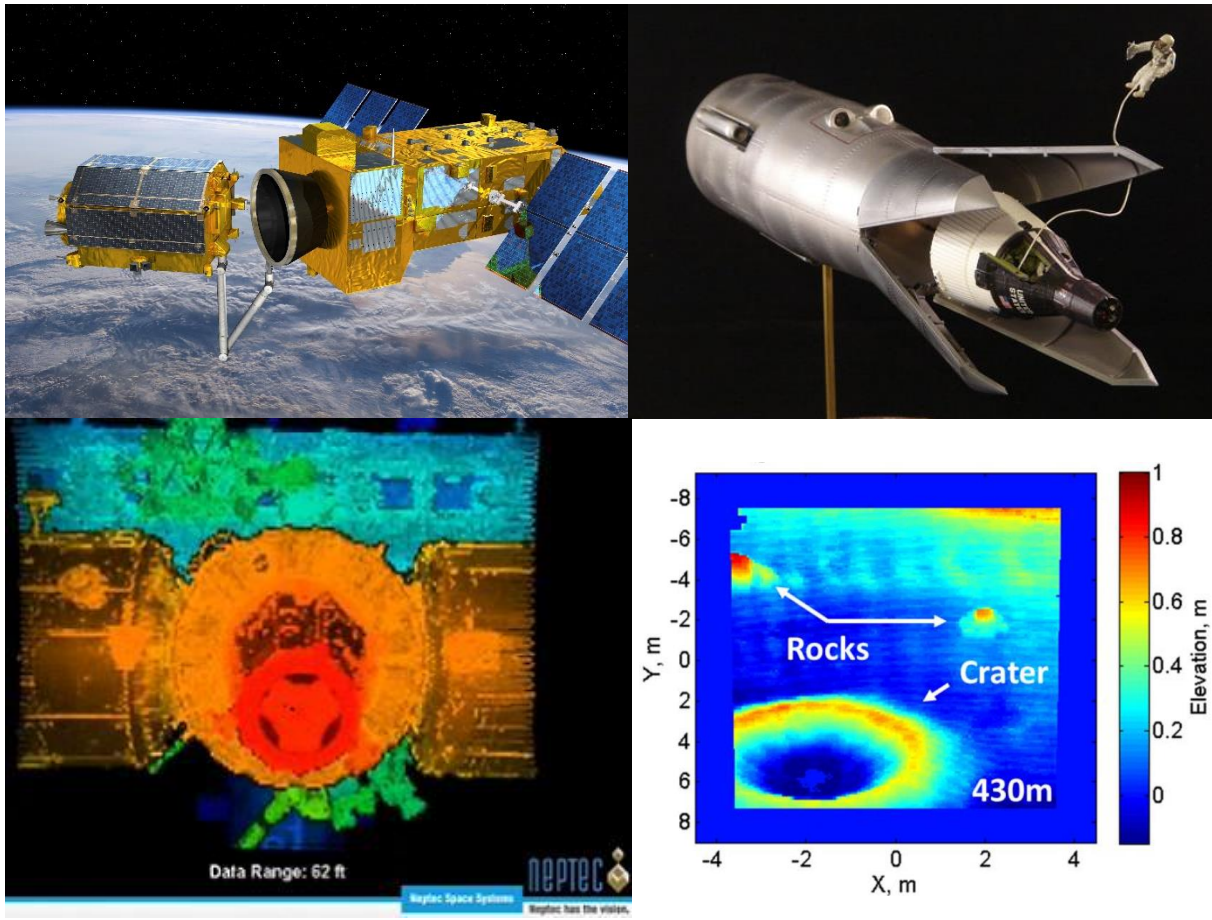
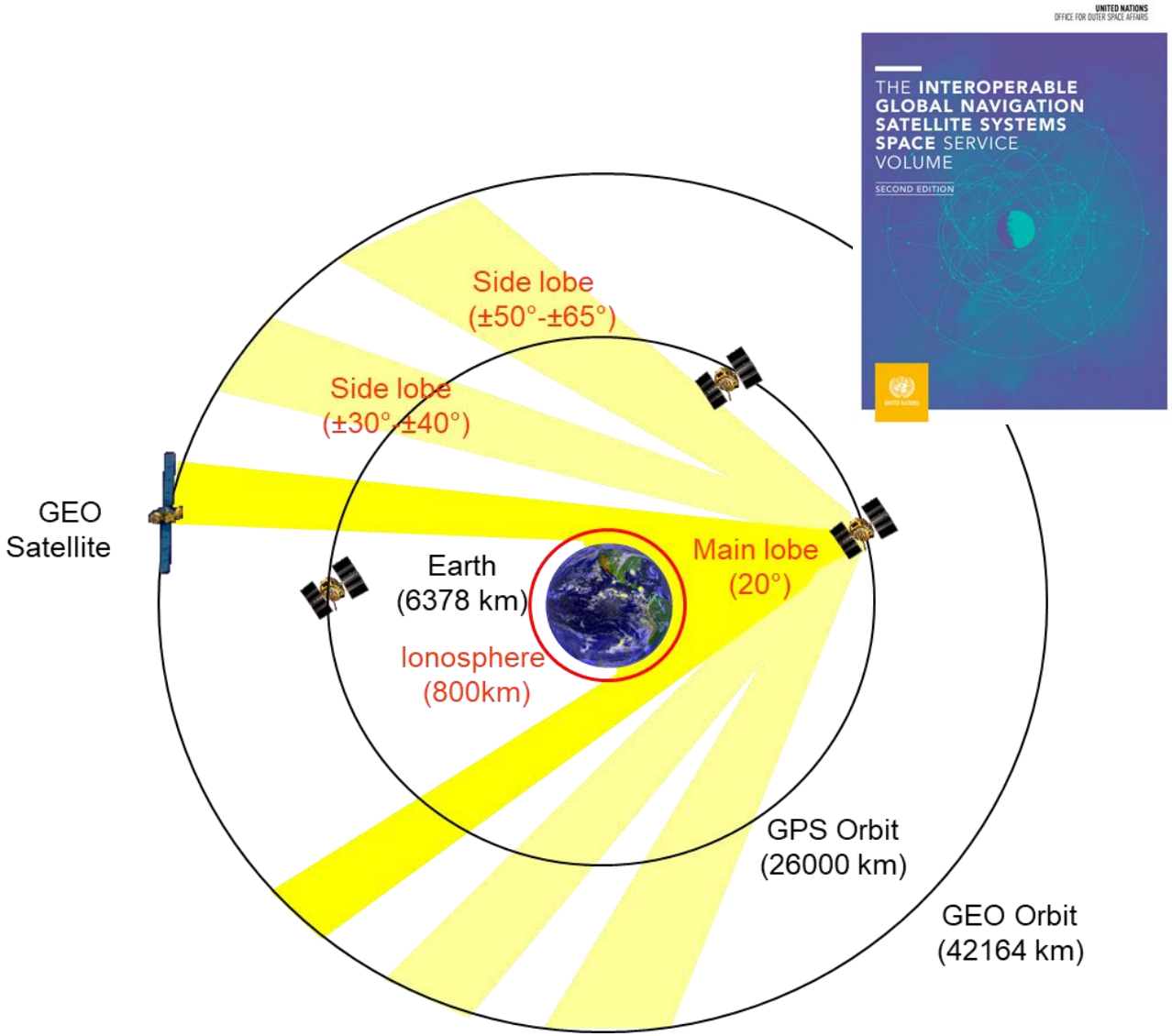


Image credits ESA; Jim James / Fantastic Plastic; NEPTEC; NASA/SPIE

HEO, GEO, and Beyond

- Traditional domain of ground-based tracking
  - Lack of autonomy
  - (Too) large operations cost
- GNSS Space Service Volume
  - Enable/promote GNSS use at high altitudes (3000-36000 km)
  - United Nations Office for Outer Space Affairs
  - Wider antenna beams and minimum received power commitment on GPS III
- Techniques
  - Multi-GNSS (more satellites, better PDOP)
  - Weak signal tracking
  - Software Defined Radios (SDR)
  - Tight integration of tracking and navigation filter

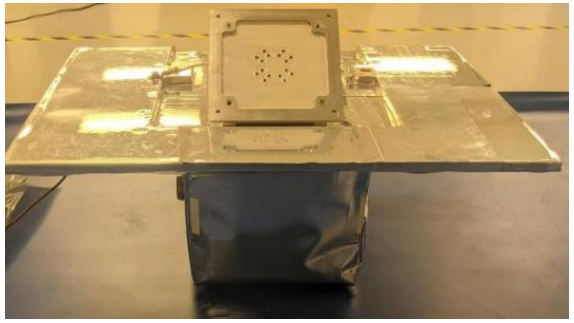


Return to the Moon

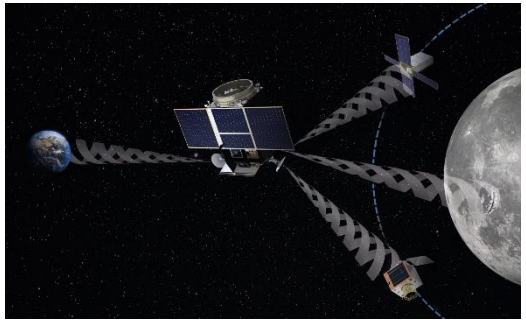
- Transfer orbit and surface navigation
- GNSS as a bridging technology
  - Special purpose receivers (SDR)
  - High-sensitivity tracking, integrated orbit filter
  - Multi-GNSS
  - Lunar Pathfinder, LuGRE
- Lunar navigation architectures
  - Beacons and orbiters
  - GNSS like modulations but different frequencies (radio protection)
  - Integrated comm & nav architectures
  - Moonlight / Lunar Communications and Navigation System (LNCS)

NAVIMOON receiver (ESA/SpacePNT)

Blue Ghost with LuGRE (Inside GNSS)



Lunar Node 1 (NASA)



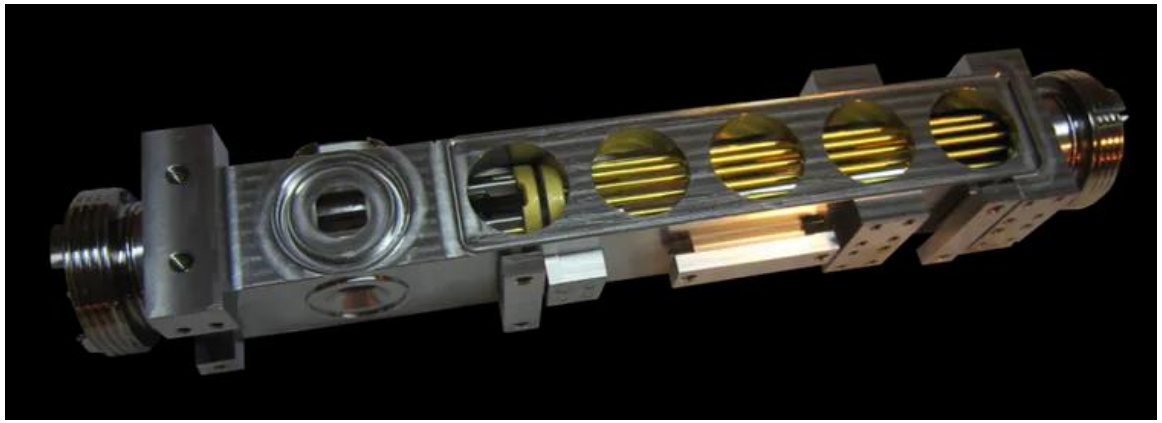
Lunar Pathfinder (ESA/SSTL)

Into the Dark

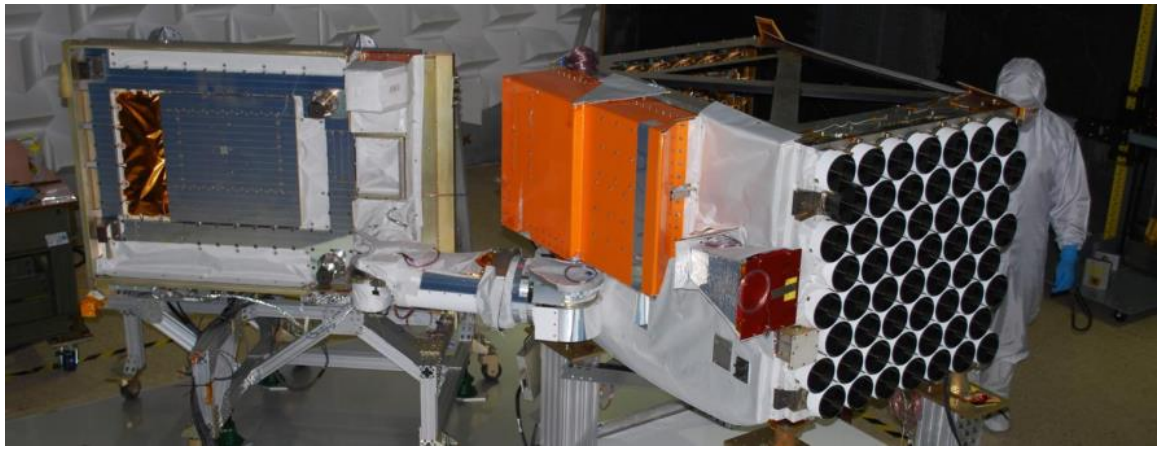
- Traditional domain of ground-based tracking (DSN 2-way Doppler & ranging, VLBI)
- Alternative technologies
  - Vison based navigation (approach and landing)
  - Inertial navigation (entry)

Concepts for future deep space navigation

- 1-way ranging with precise onboard clocks
  - e.g., DSAC, trapped Hg-ion clock
  - Improved autonomy, multi-s/c support
- X-ray pulsar navigation (“XNAV”)
  - Highly stable, extraterrestrial timing signals
  - Station Explorer for X-ray Timing and Navigation Technology (SEXANT) on ISS
  - Demo of <10km positioning
  - A galactic GPS?



Deep Space Atomic Clock mercury trap (JPL)



NICER X-ray telescope of ISS (NASA)

A look into the crystal ball

"It is difficult to make predictions, especially about the future" (Danish proverb)

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