The Technology Issues of Providing PNT from LEO Satellite Systems

Rohit Braggs
Vice President, PNT
Rohit.Braggs@iridium.com

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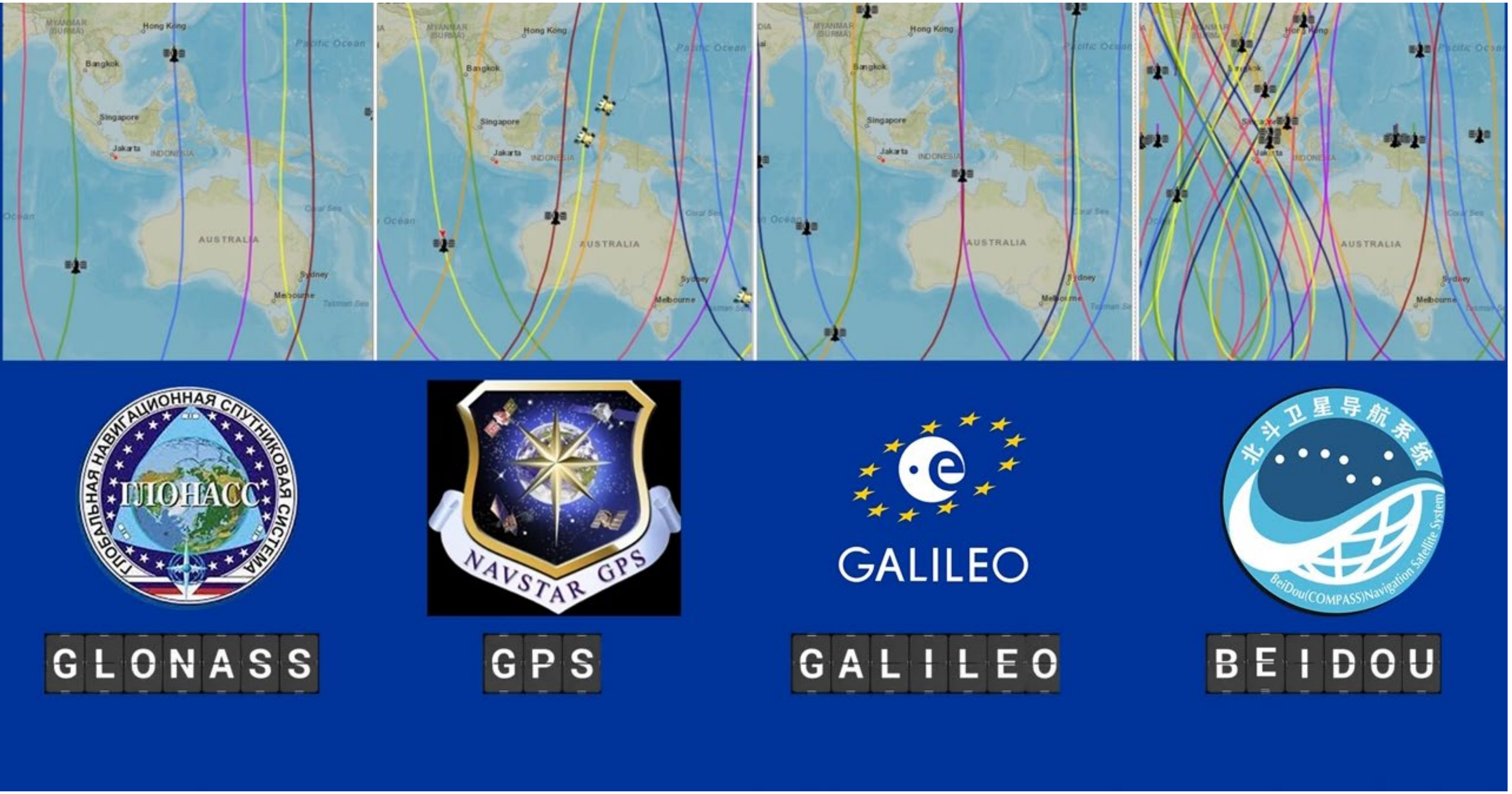
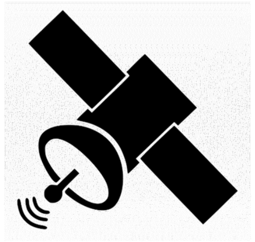
Read and understand the Iridium User Manual and the safety warnings and information contained in that Manual before using any Iridium product.

GPS and GNSS are Amazing



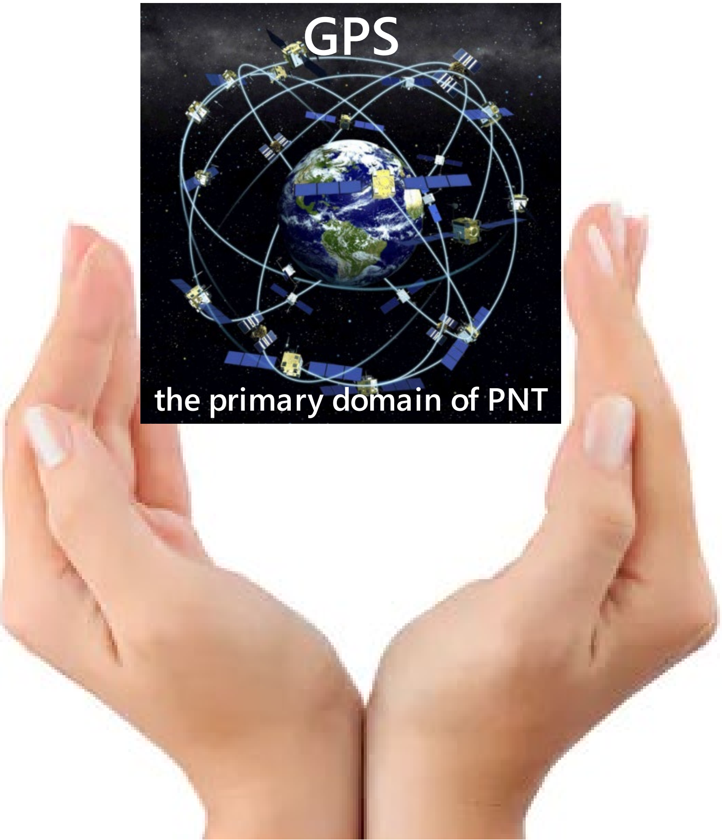
- Communication Systems
- Electrical Power Grids
- Financial Networks
- Internet of Things
- Navigation Systems
- Transportation & Logistics
- Location-Based Authentication
- Maritime

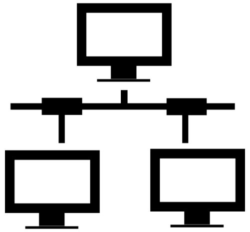
Multiple Technologies Can Provide GPS Resilience



Low-Earth Orbit (LEO) Satellites
Timing and location from an orbit in space about 25x closer than GNSS

Terrestrial Wireless Infrastructure
Timing and location from ground-based equipment and support operations across a specific geographic region





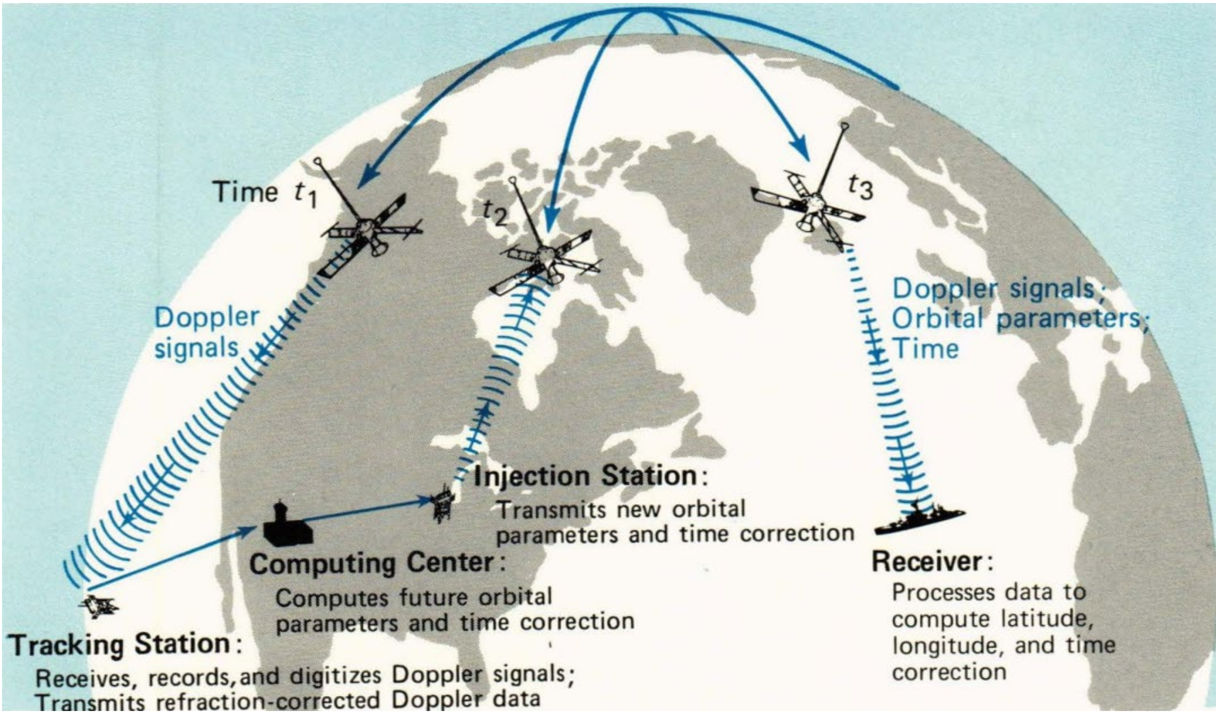
Network Time Transfer
Precise timing from synchronized clocks across a high-speed computer network

Signals of Opportunity
Location information derived from radio signals not intended for navigation

LEO PNT is NOT New

Transit – the Navy Navigation Satellite System (NNSS) – was developed by JHU/APL and deployed by the U.S. DoD in the late 1950s and early 1960s as the first LEO PNT system.

- Fully operational capability: 1964
- Constellation size at FOC: 36 satellites
- Orbit type: Polar
- Orbital altitude: 690 miles (1,100 km)
- Orbital period: 106 minutes
- Frequencies: 150 MHz and 400 MHz
- Accuracy: 200 meters / 50 microseconds



The system used Doppler rather than ranging measurements.

The Transit constellation was obsoleted as a PNT system by GPS in 1996 (although some SVs continued to operate in an ionospheric monitoring mission).

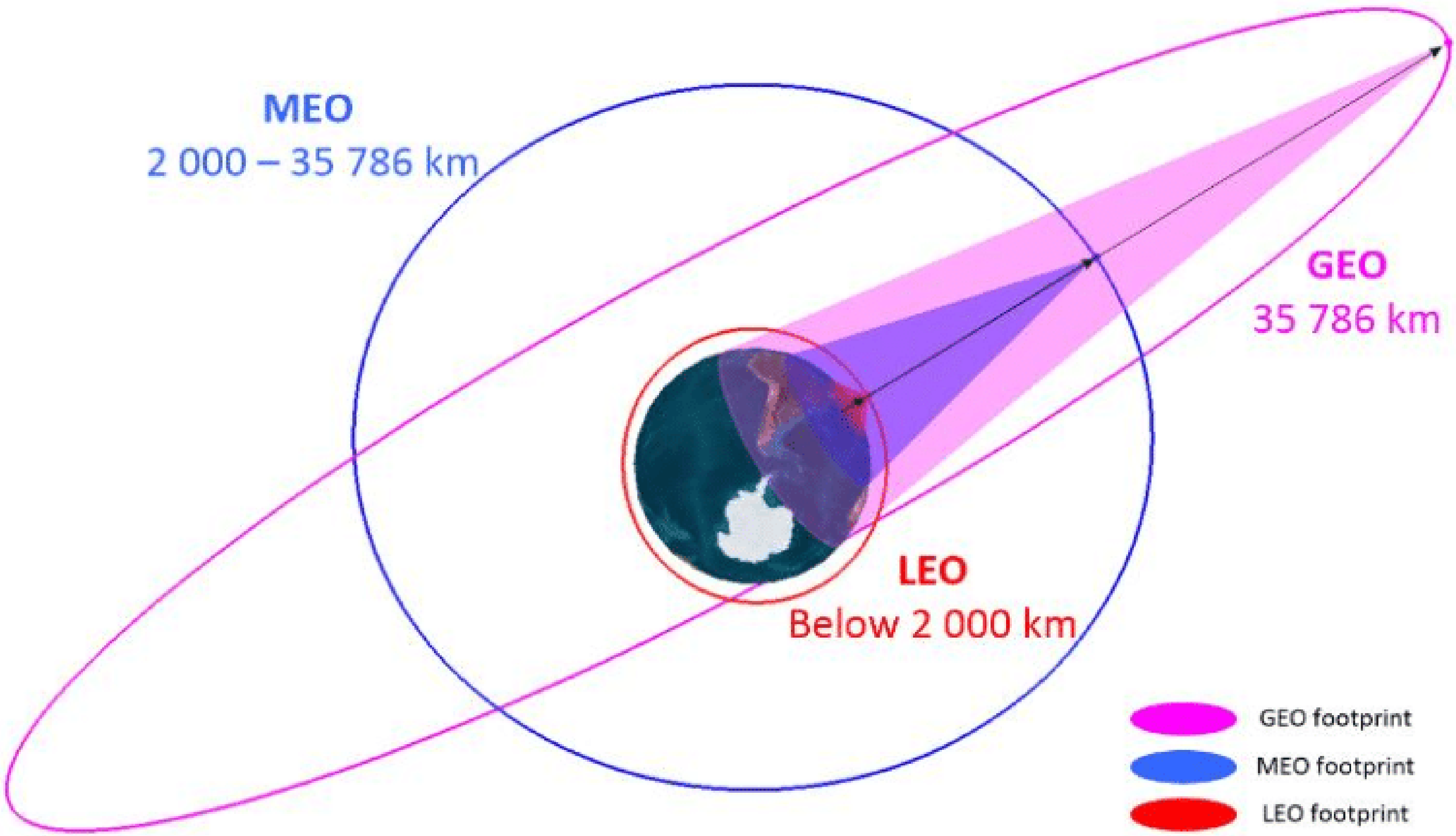
GPS – Initial Operational Capability in 1993

Key new distinctions of GPS over Transit:

- Included signal time of arrival – not just Doppler – allowing it to be much more accurate
- 24x7 global coverage
- Atomic clocks on the satellites for high accuracy
- L-band signal (1.2/1.6 GHz)
- MEO, not LEO

Why did they do this?

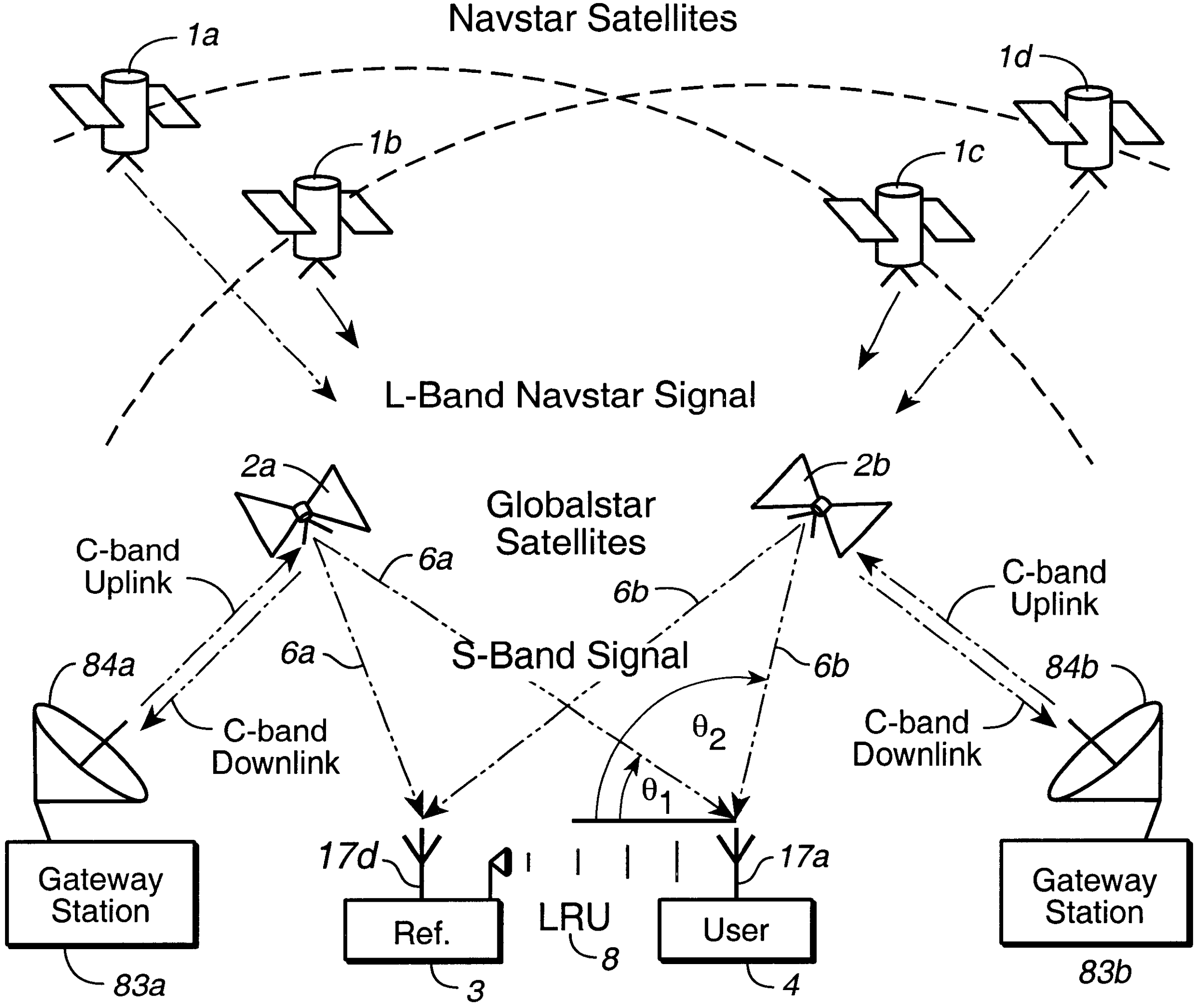
A Key System Trade-off – Orbit Regime



The Re-emergence of LEO PNT

- Commercial SATCOM constellations became operational in the late 1990s
- Researchers began evaluating PNT uses in 2000
- LEO PNT from SATCOM was demonstrated at Stanford

Rabinowitz, et al.



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Iridium® Satellite Network

The only satellite network covering the entire globe

66 Active Satellites

- 6 orbital planes of 11 satellites each
- Plus 14 in-orbit spares

Low-Earth Orbit (LEO)

- Low latency
- High power
- Smaller units

L-Band System

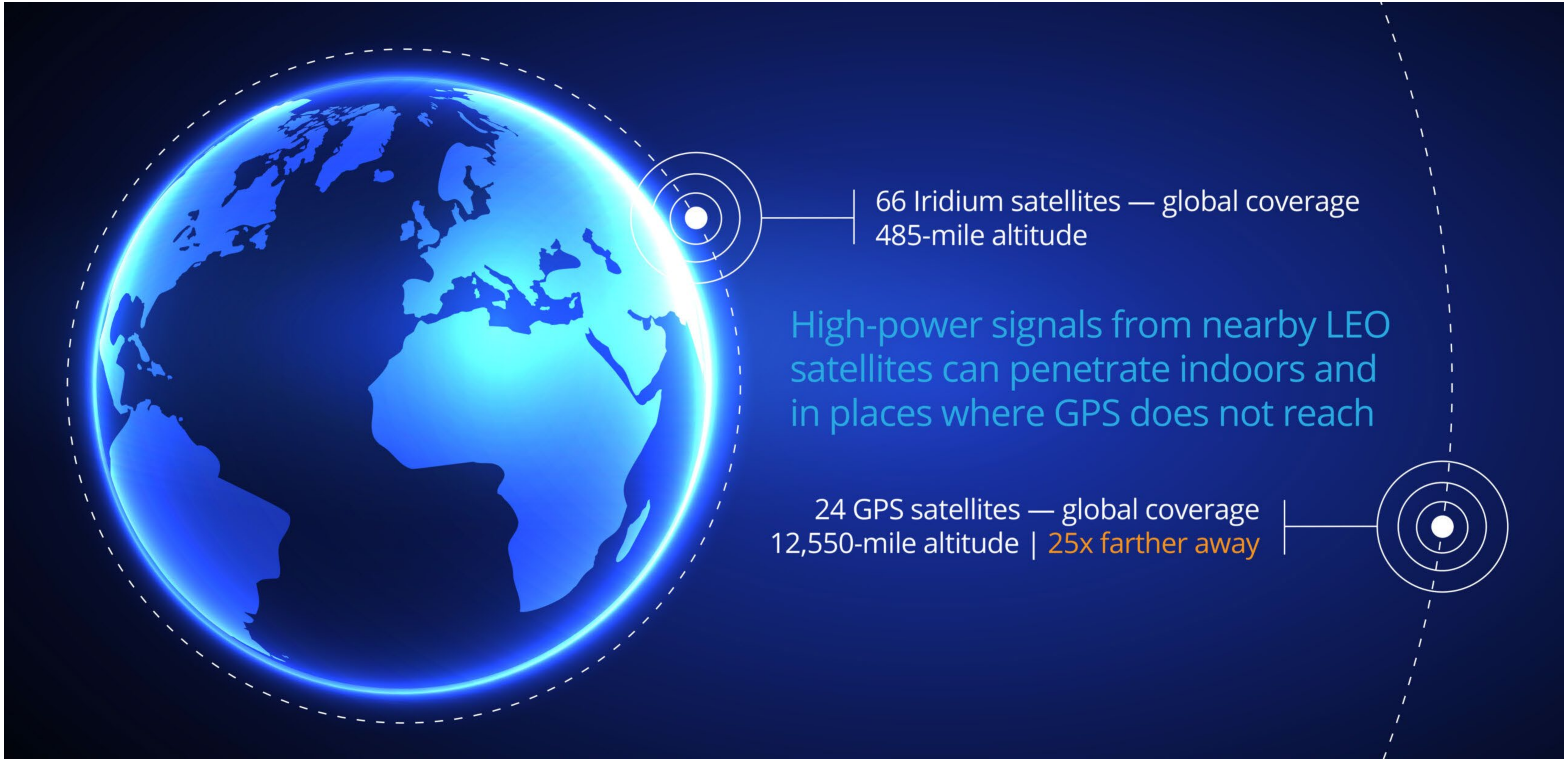
- Allows for transmission even in adverse weather

Satellite Crosslinks

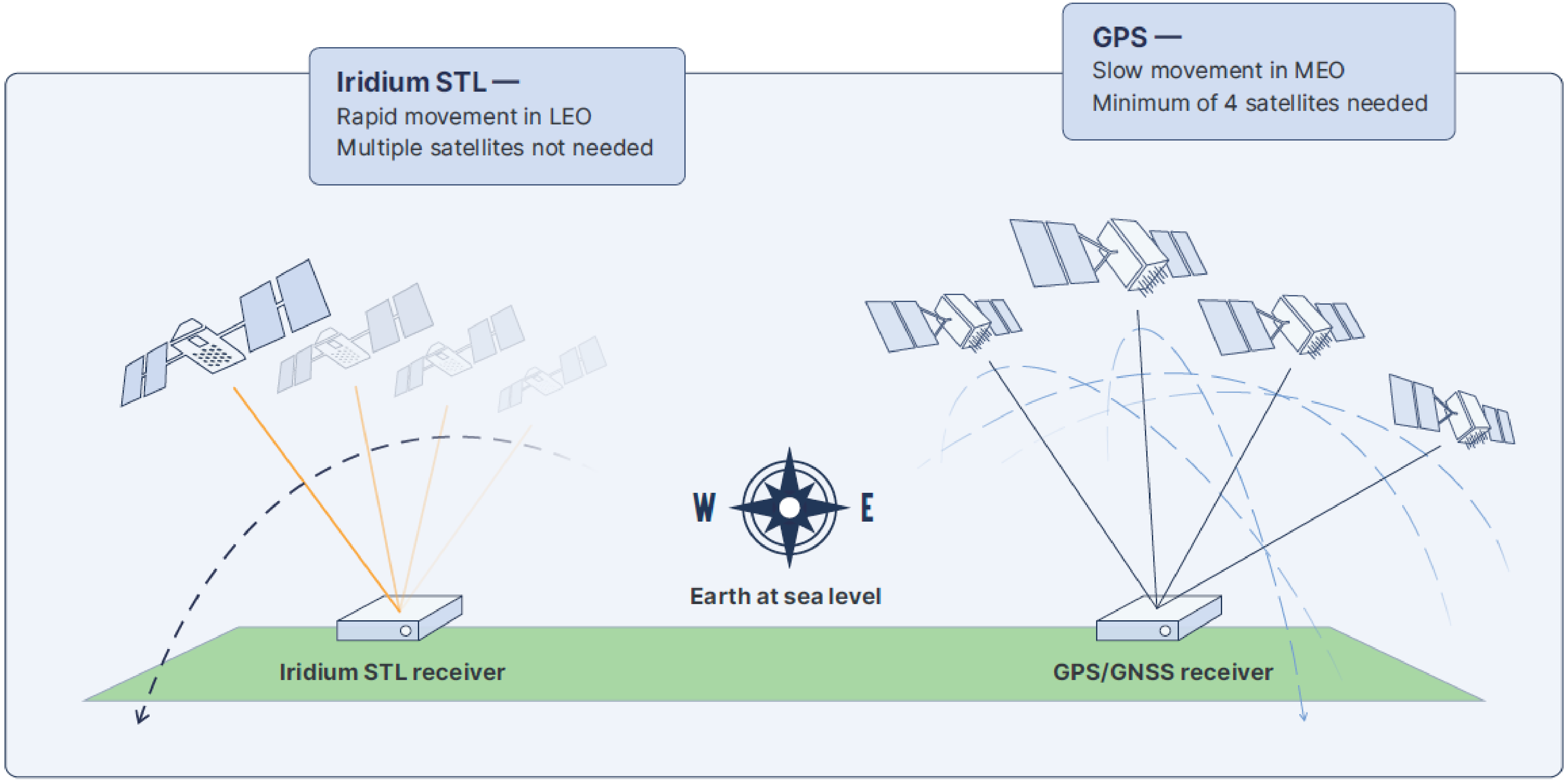
- Creates low-latency, resilient connections

Iridium's constellation provides truly global service

High Signal Power Relative to MEO / GEO



LEOs Are Fast Movers



Iridium (LEO) satellites circle the Earth **every 100 minutes.**

They move so fast that their ranging angle can change by up to 1 degree every 4 seconds, determining the user's **location with only 1 satellite in view.**

GPS/GNSS (MEO) satellites circle the Earth **every 12 hours.**

They move so slowly that **at least 4 satellites must be used** to determine the user's location.

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Resilience to Direct Physical Attack

LEOs are less vulnerable to direct physical attacks than ground-based systems.

Surface Charging Effects

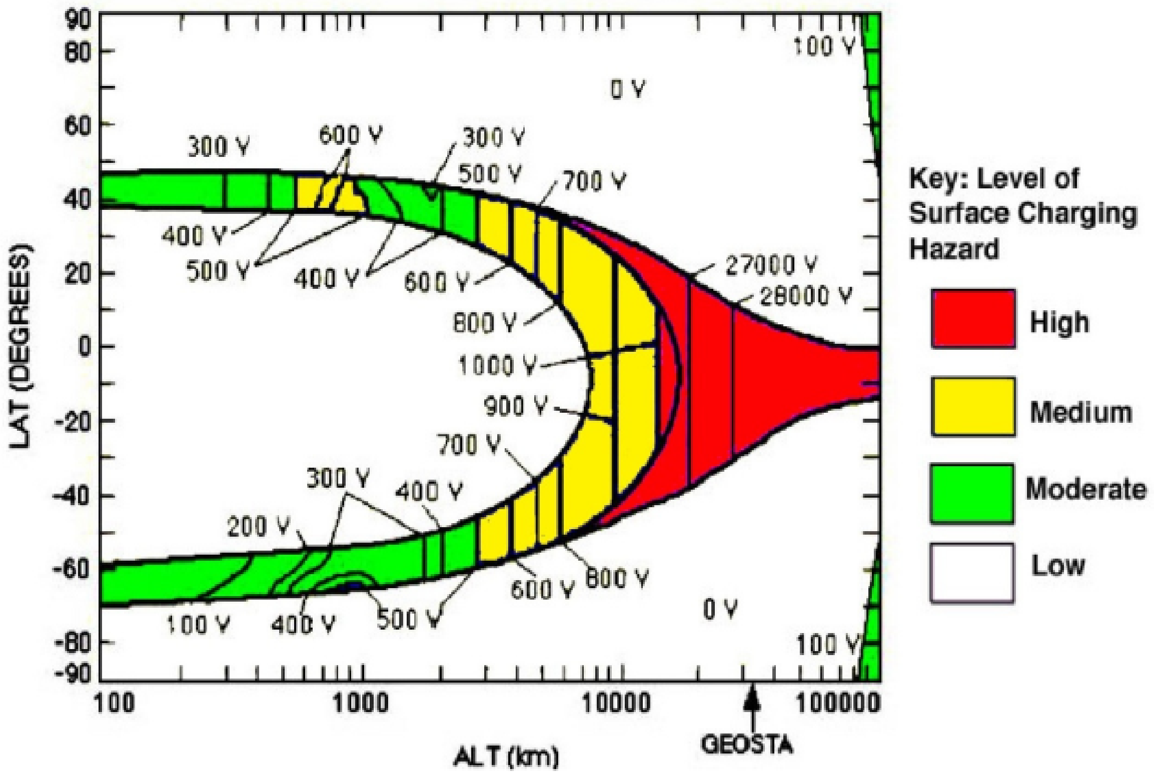
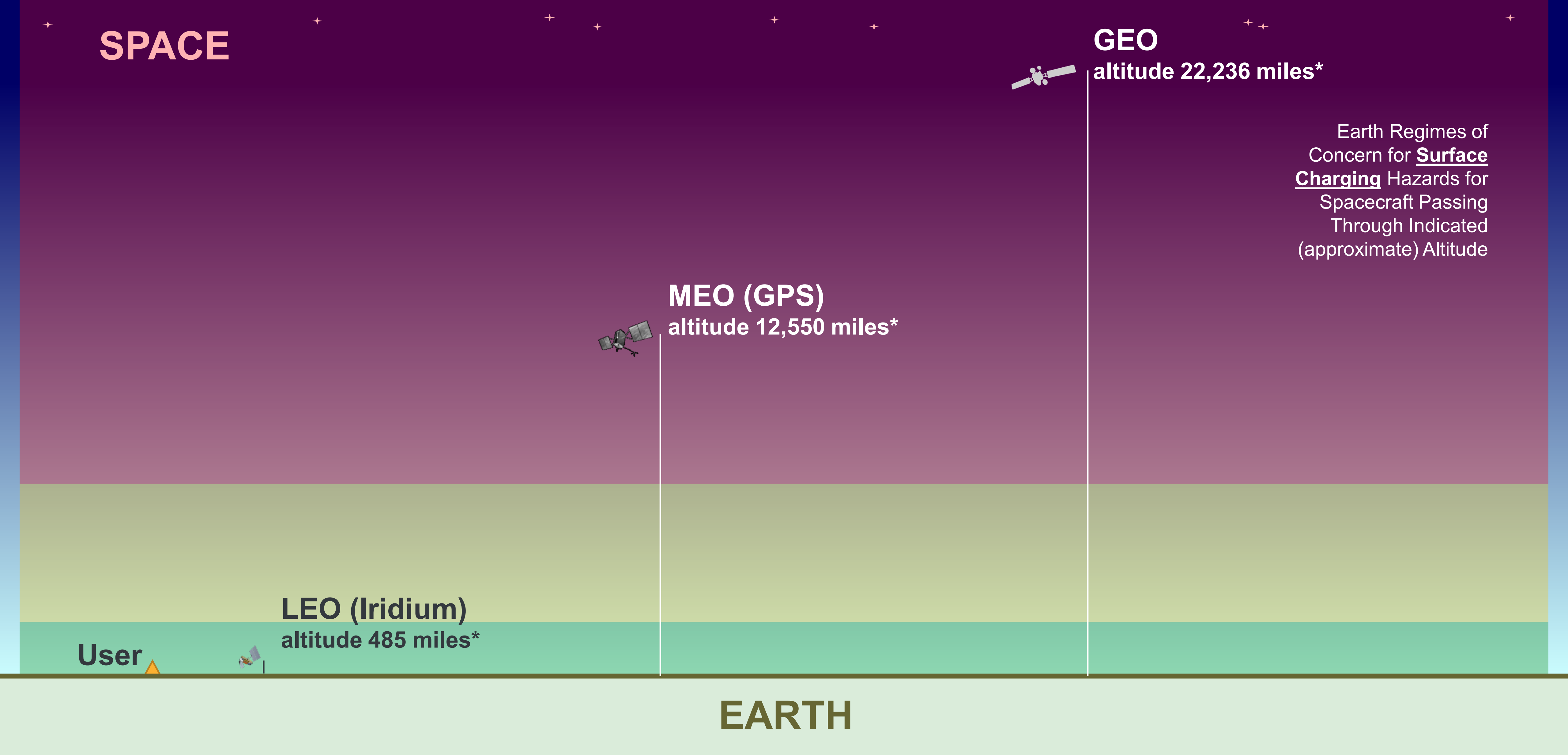


Figure 1—Earth Regimes of Concern for On-Orbit Surface Charging Hazards for Spacecraft Passing Through Indicated Latitude and Altitude (Evans and others (1989))

Chart source: NASA Technical Handbook, *Mitigating In-Space Charging Effects — A Guideline* (October 19, 2017)
https://ccmc.gsfc.nasa.gov/RoR_WWW/SWREDI/2018/nasa-hdbk-4002a_revalidated.pdf



* altitudes are shown to scale

Internal Charging Effects

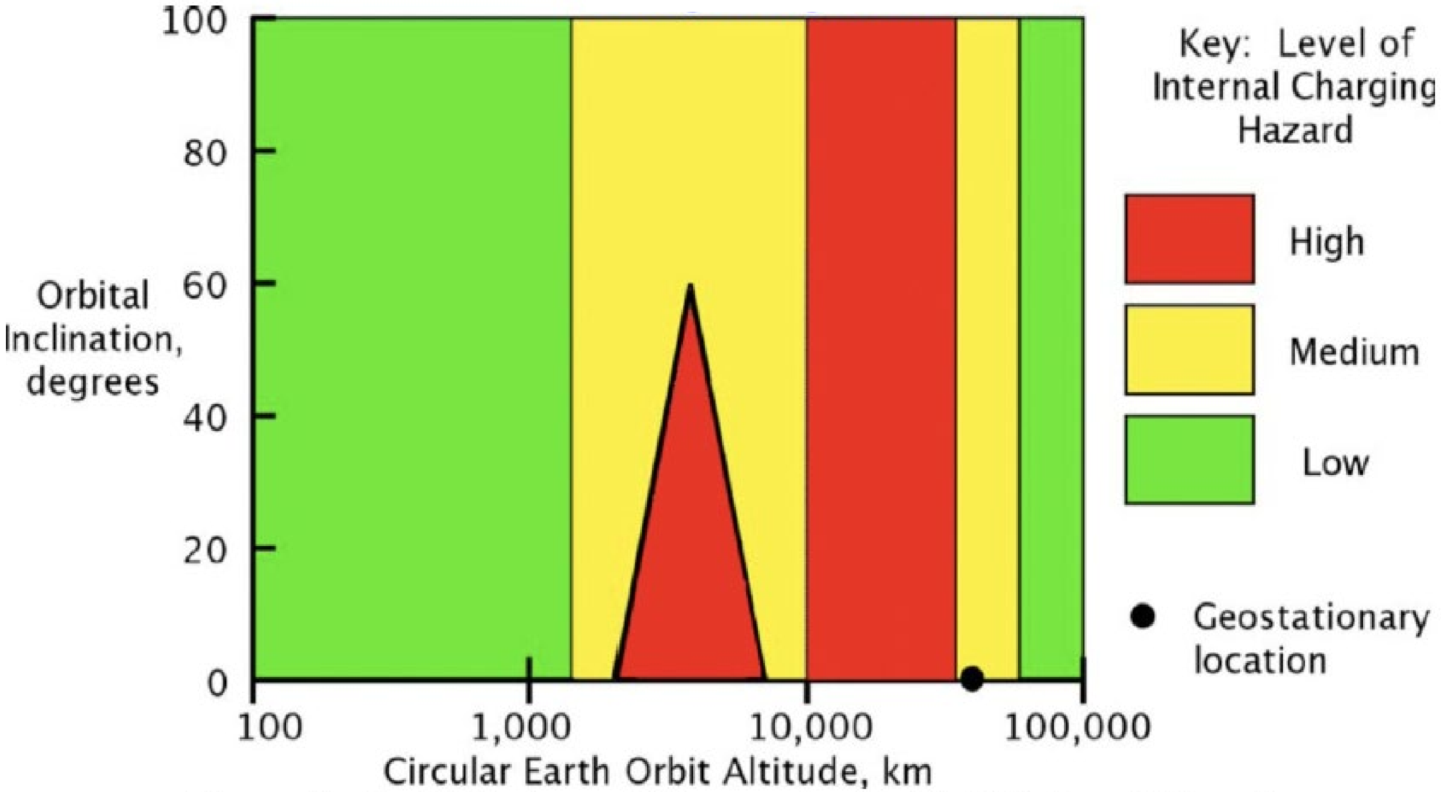
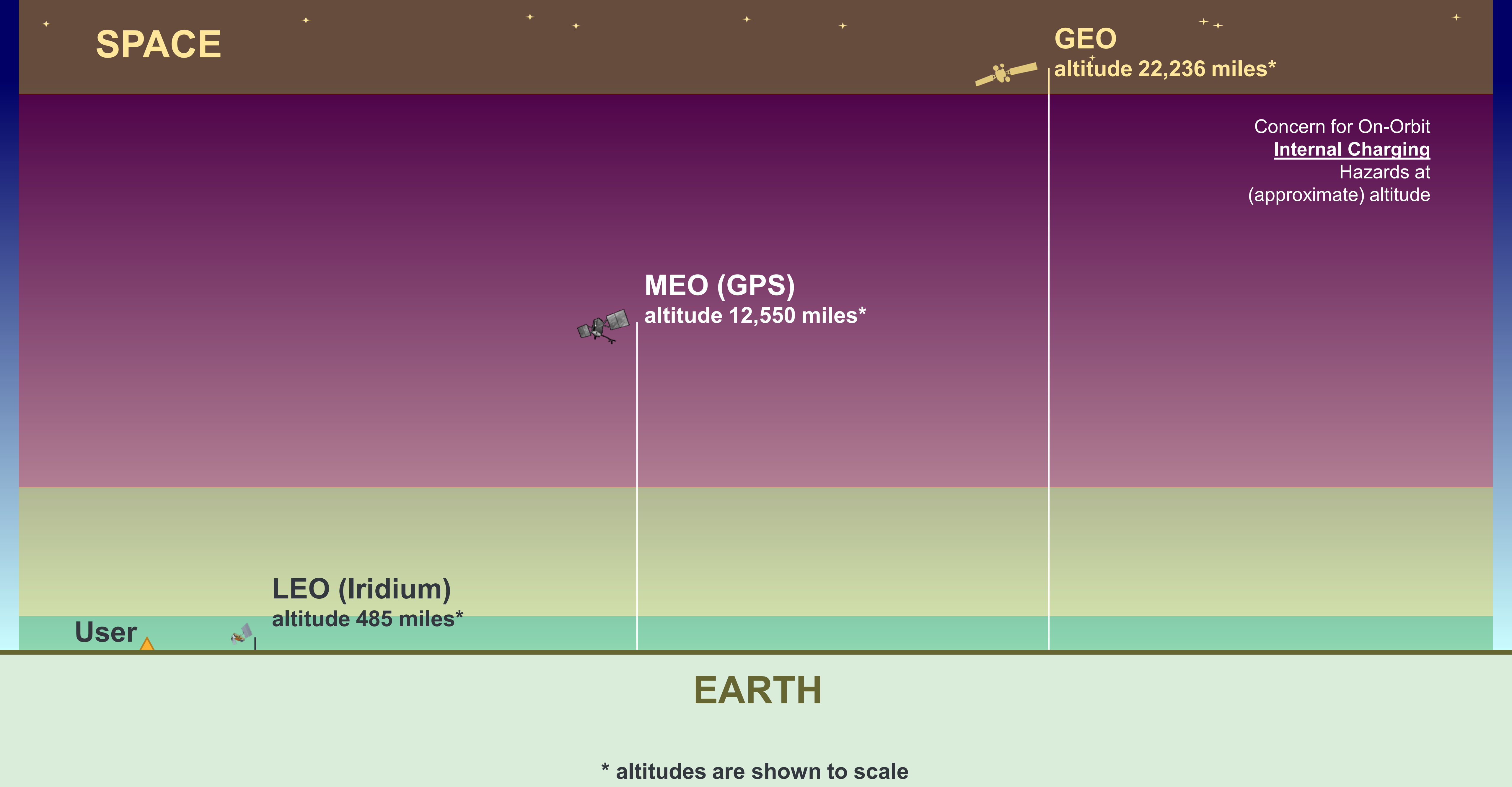
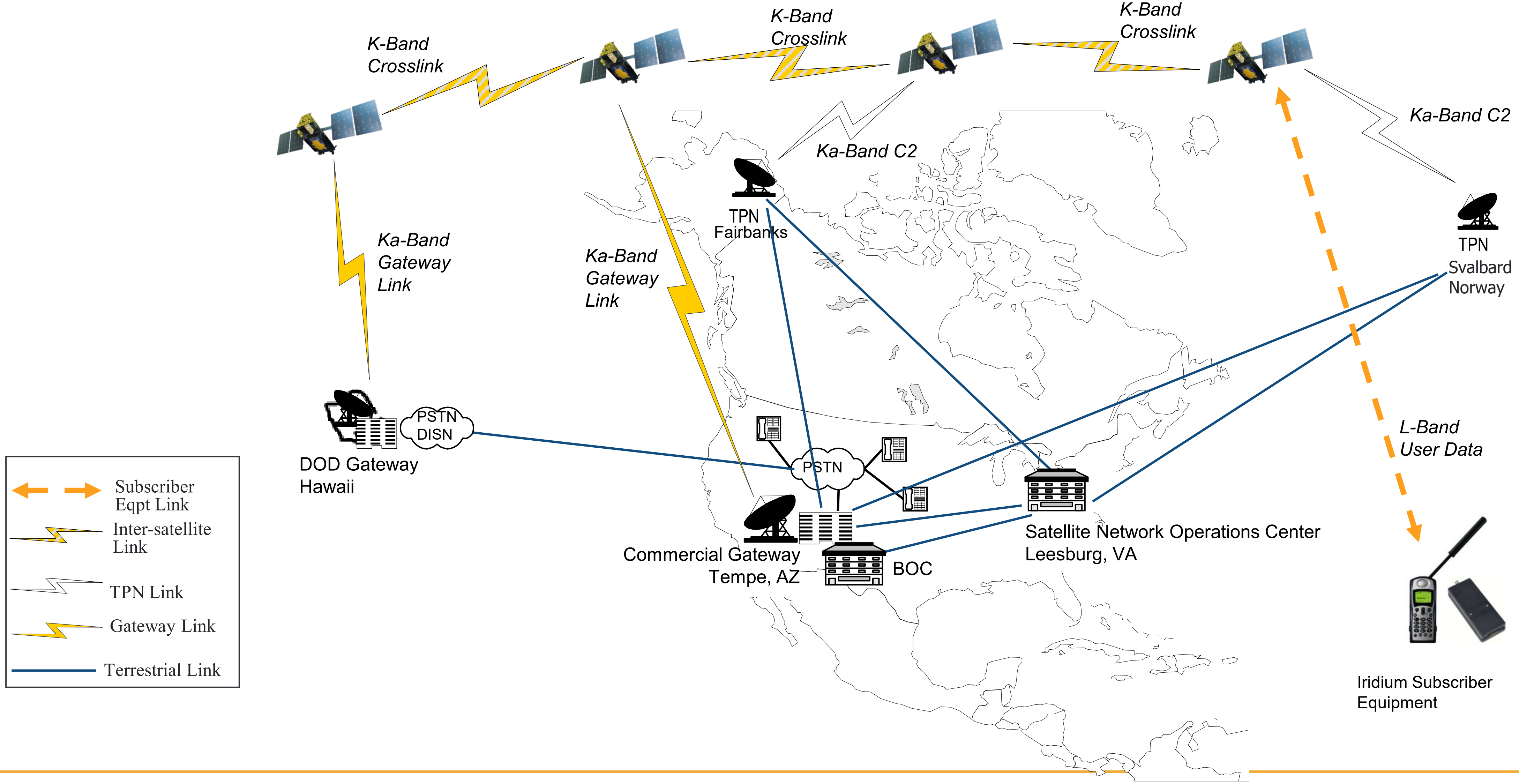


Figure 2—Earth Regimes of Concern for On-Orbit Internal Charging Hazards for Spacecraft with Circular Orbits

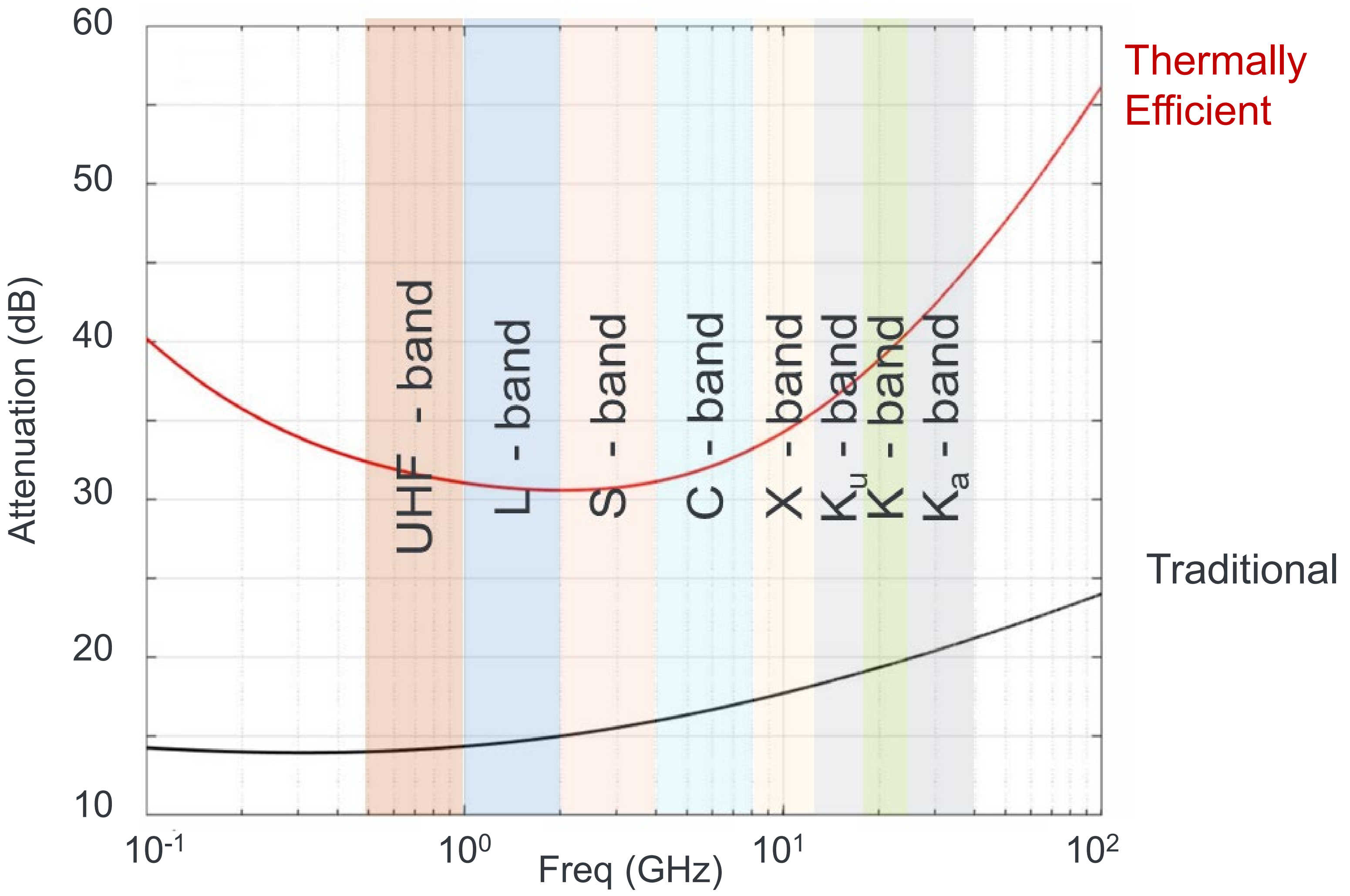
Chart source: NASA Technical Handbook, *Mitigating In-Space Charging Effects — A Guideline* (October 19, 2017)
https://ccmc.gsfc.nasa.gov/RoR_WWW/SWREDI/2018/nasa-hdbk-4002a_revalidated.pdf


SPACE
GEO
altitude 22,236 miles*
Concern for On-Orbit
Internal Charging
Hazards at
(approximate) altitude
MEO (GPS)
altitude 12,550 miles*
LEO (Iridium)
altitude 485 miles*
User
EARTH
* altitudes are shown to scale

RF Frequency/Spectrum



ITU Analysis – Mean Building Entry Loss



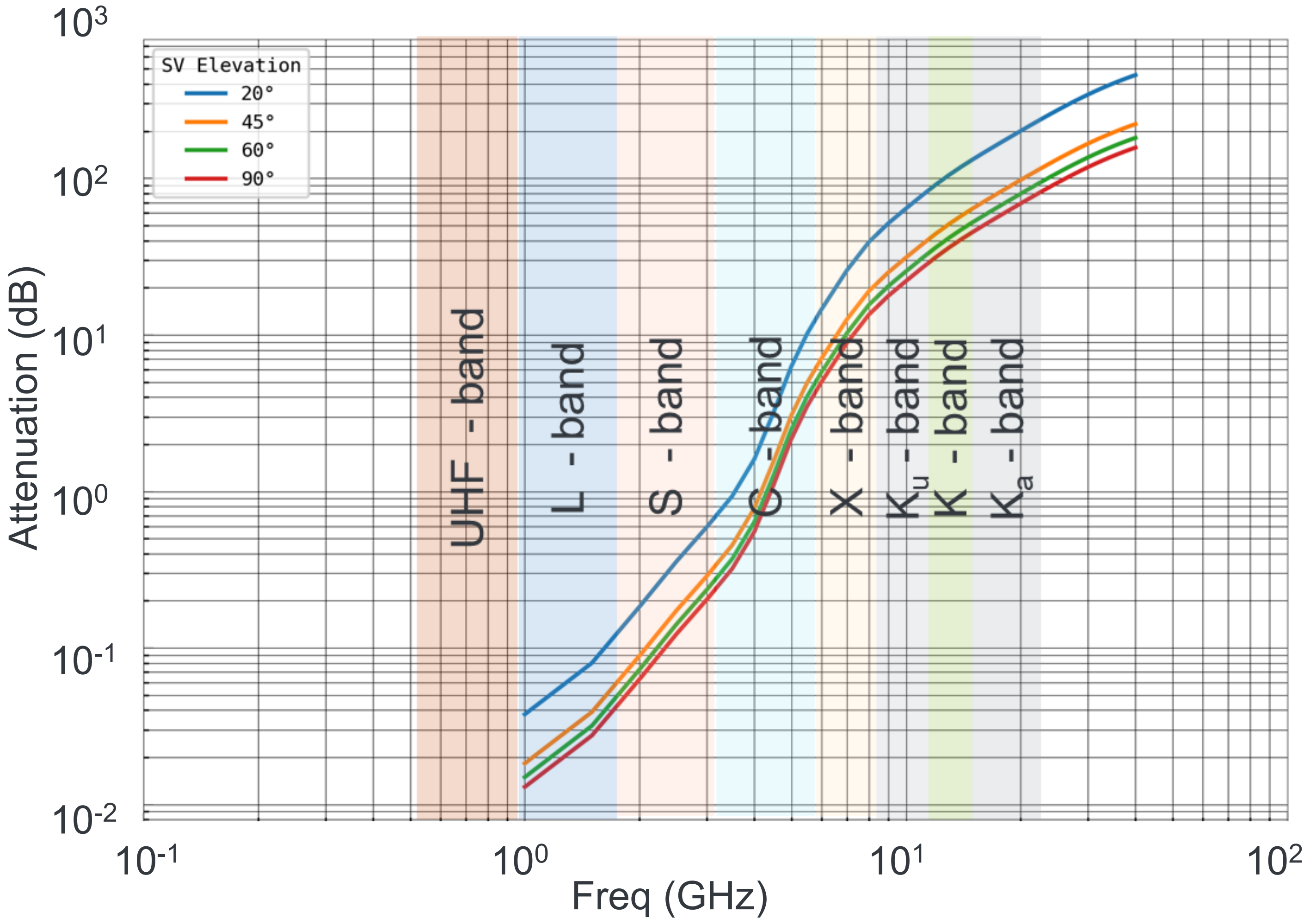
Model was developed with empirical data from ITU-R P.2346, and ITU-R P.2040

Traditional vs Modern building construction

“Typically, the presence of metallised glass windows, insulated cavity walls, thick reinforced concrete and metal foil back cladding is a good indication of a thermally-efficient building.”

Recommendation ITU-R P.2109-2 (08/2023)
https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-2-202308-I!!PDF-E.pdf

ITU Analysis – Signal Attenuation During Thunderstorm



Propagation data and prediction methods required for the design of Earth-space telecommunication systems

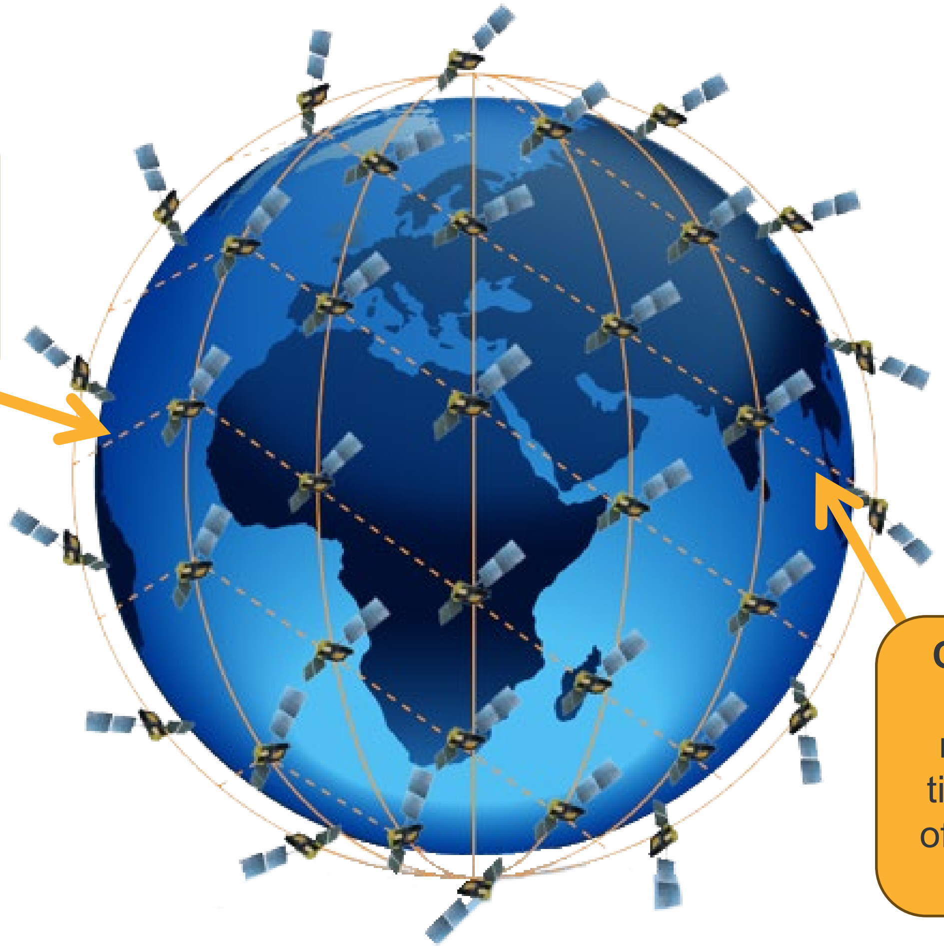
Propagation losses

- Attenuation by rain, atmospheric gases
- Rain fade propagation loss plot developed using ITU ITU-R P.838-3 Model
- Conditions assumed to be thunderstorm in Florida

Recommendation ITU-R P.2109-2 (08/2023)
https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-2-202308-I!!PDF-E.pdf

Bent Pipe versus Crosslinked Satellites

Crosslinks allow **communication** from anywhere to anywhere **without bent-pipe relays** around the globe.



Crosslinks also provide relative **timing measurements** in real-time, enabling calibration of the whole network from a **single ground site.**

Thank You!

Rohit.Braggs@iridium.com