amazon | project kuiper

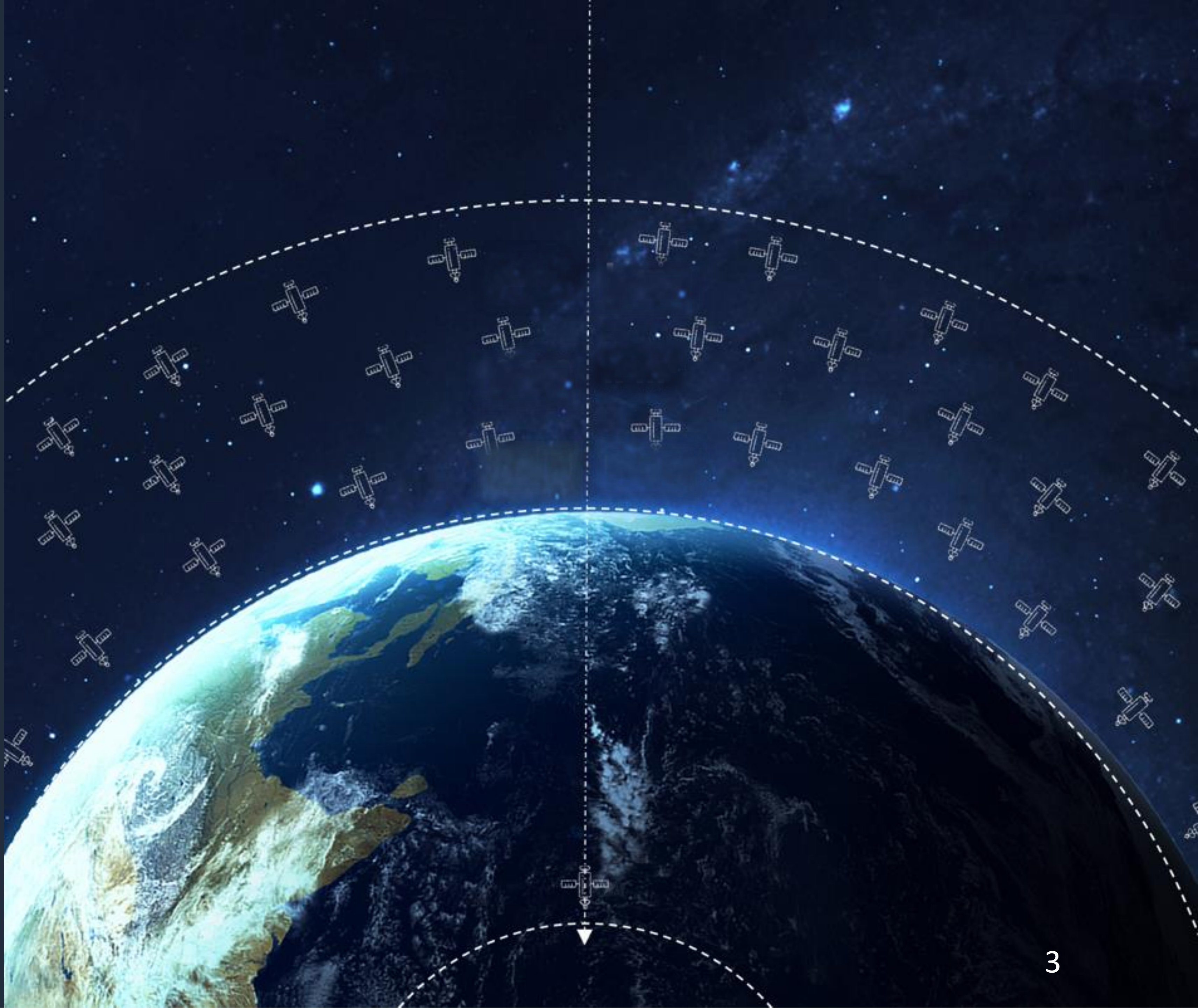
USTTI Low Earth Orbit (LEO) Systems 101

Agenda

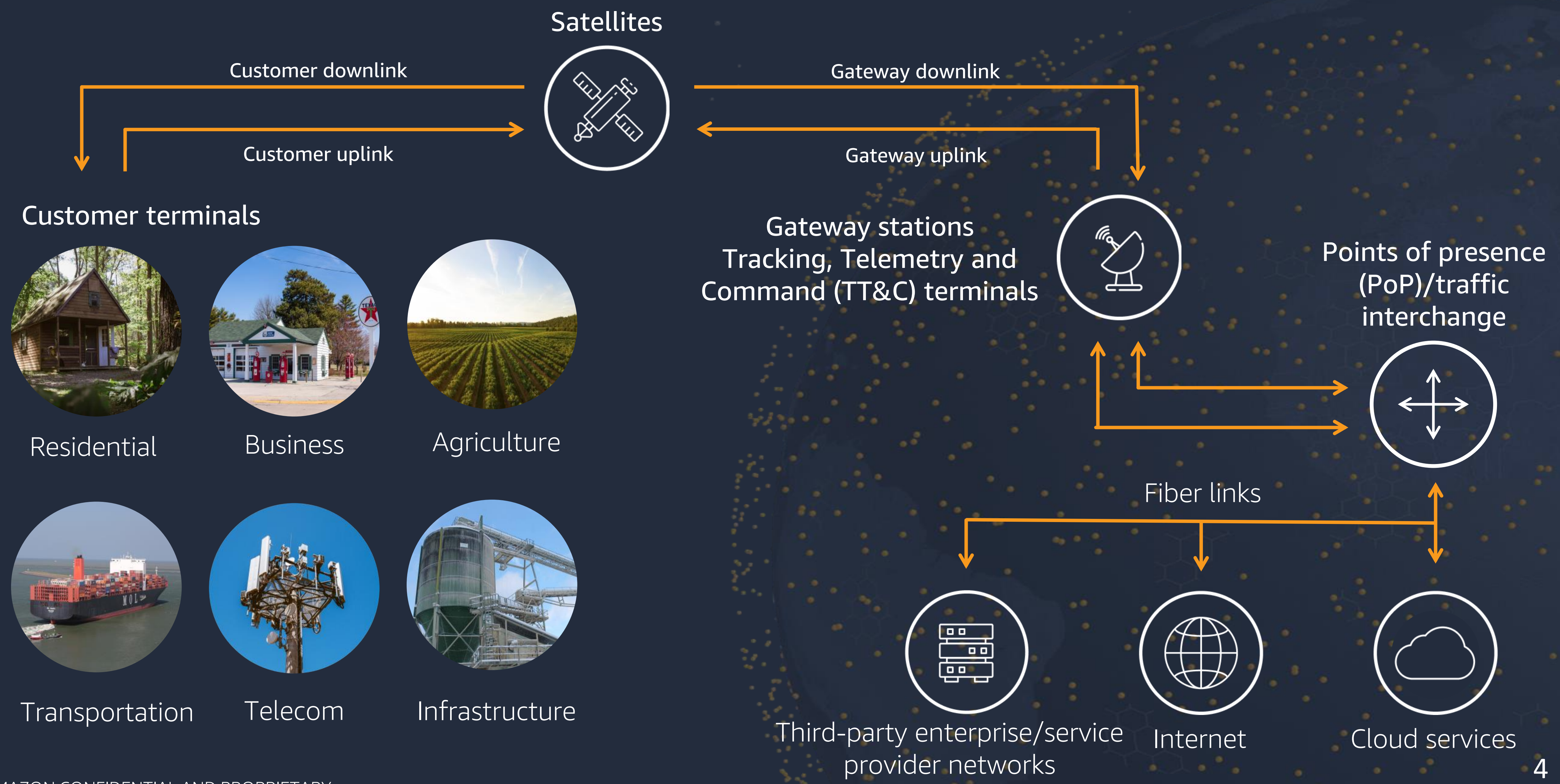
- Introductions
- LEO systems
- Project Kuiper
- The International Telecommunication Union (ITU)
- LEO regulatory challenges
- World Radiocommunication Conference (WRC) issues
- Space Sustainability & Safety
- Conclusions

LEO systems

- System Architecture
- Orbits
- Spectrum Considerations



System Architecture

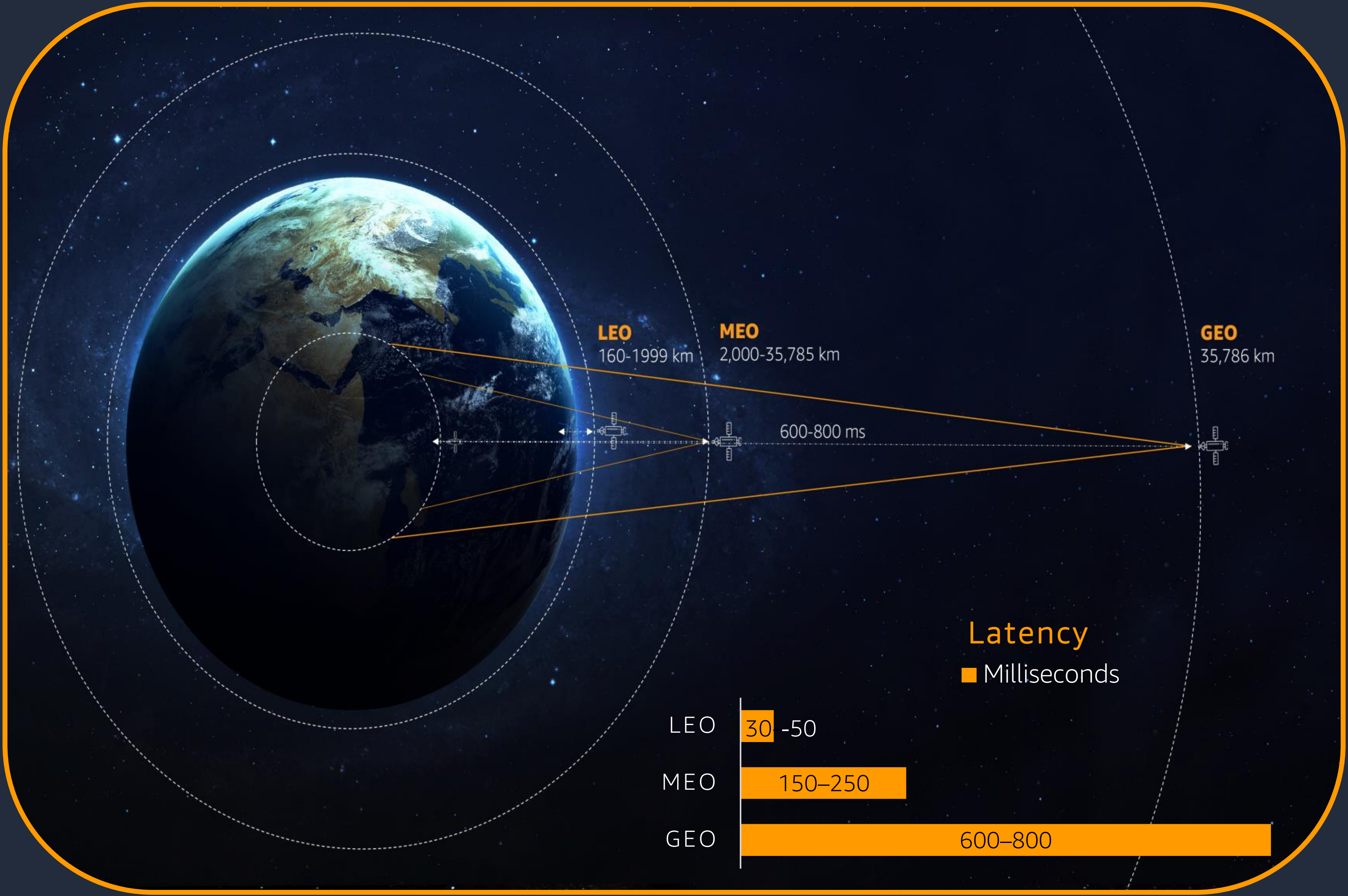


Low vs. Medium vs. Geostationary Earth Orbits

LEO
- 30–50 ms roundtrip latency
- Continuous, near-global coverage
- Steerable and shapeable beams
- Small spot beam and higher signal strength
- Resilient and persistent

MEO
- 150-ms roundtrip latency
- Flexible, shapeable beams
- Higher throughput versus GEO

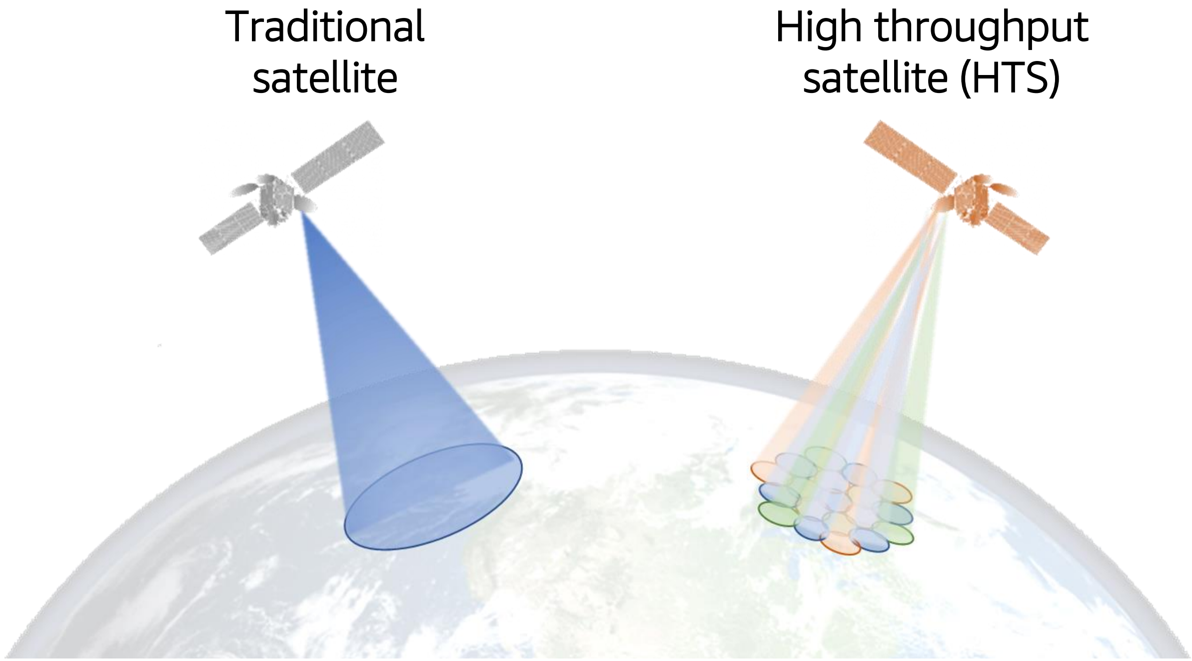
GEO
- 600–800 ms roundtrip latency
- Few satellites
- Large coverage areas (85,000 km^2)
- Equatorial position
- No polar coverage possible

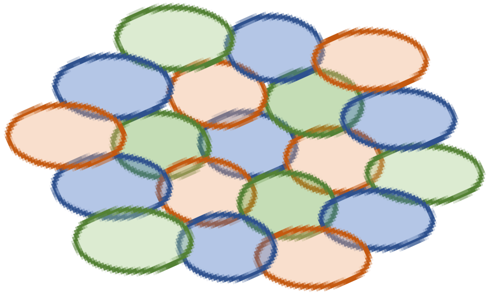


New Efficient Spectrum Use Approaches

Non-geostationary satellite orbit (NGSO) technology enables delivery of greater capacity with new spectrum sharing approaches

- Frequency re-use and smaller beams in next generation satellites allow greater capacity to be delivered by the same satellite.
  - This allows more customers to be served at faster speeds.
- NGSO systems provides for greater spectrum sharing and more efficient use of spectrum.
  - The availability of multiple satellites from any earth station enables sharing between NGSO systems, and protection of geostationary satellite orbit (GSO) systems.





- Dynamic frequency changing
- Dynamic channel bandwidth

Project Kuiper

- Overview
- Highlights

Our Mission

Project Kuiper is an initiative to increase global broadband access through a constellation of satellites in low Earth orbit (LEO). Our mission is to deliver fast, affordable broadband to unserved and underserved communities around the world.

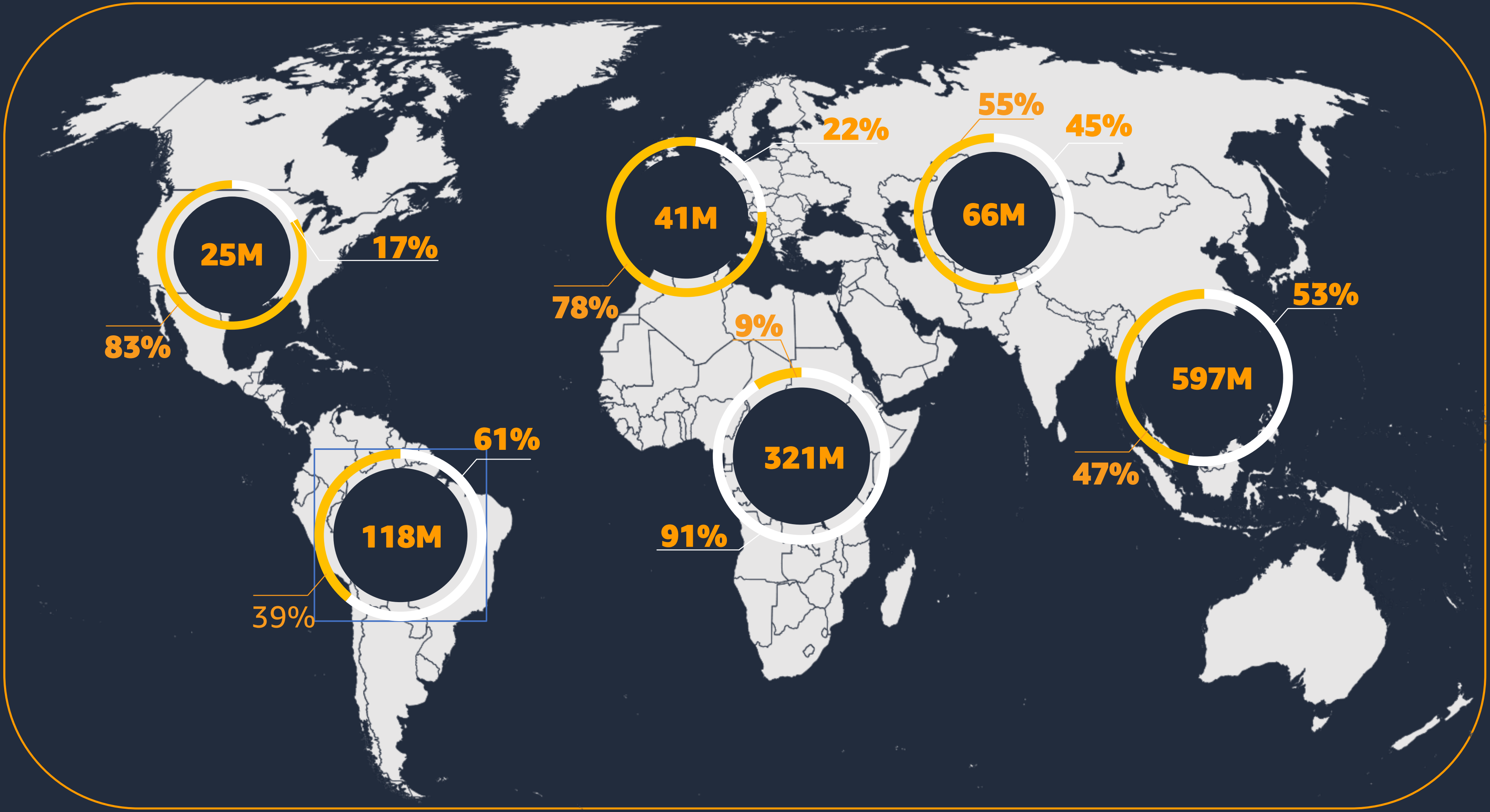
Bridging the Digital Divide

1 billion
Unserved households across the globe have no fixed broadband today (50% of the global total).

300 million
Underserved households are on legacy DSL technologies.

100 million
Business, enterprise, and public sector endpoints lack reliable connectivity.

Source: S&P Market Intelligence



Number of unserved households per region

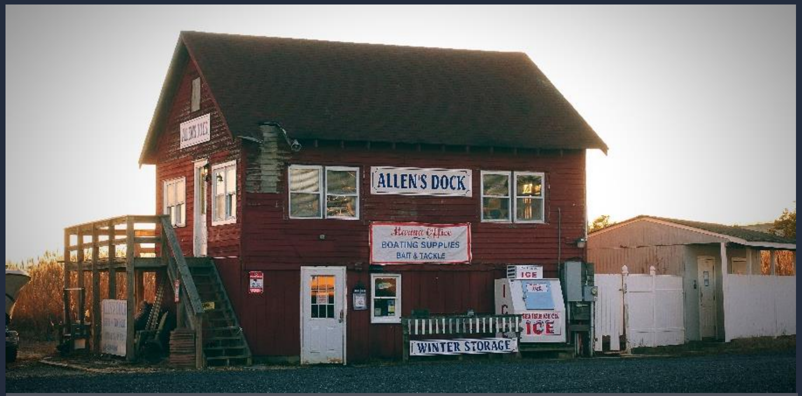
Percentage of served fixed-broadband households (DSL, cable, fiber)

Percentage of unserved households within the region

Our customers

Residential

High-speed, low-latency service for individual households.



Small Businesses

Bringing small businesses into the digital age.

Public Services

Increasing access to information, education and healthcare.

Enterprise and Transportation

Flexible, secure broadband to connect remote assets across land, sea and air.

Emergency Services

Reliable broadband to support emergency and disaster relief efforts.

Telecommunications

Expanding wireless and mobile networks to new regions.

Customer Terminals

Small, compact customer terminals allow customers to connect to the network and enjoy fast, reliable service at an affordable price.

Type: Single aperture phased array antenna

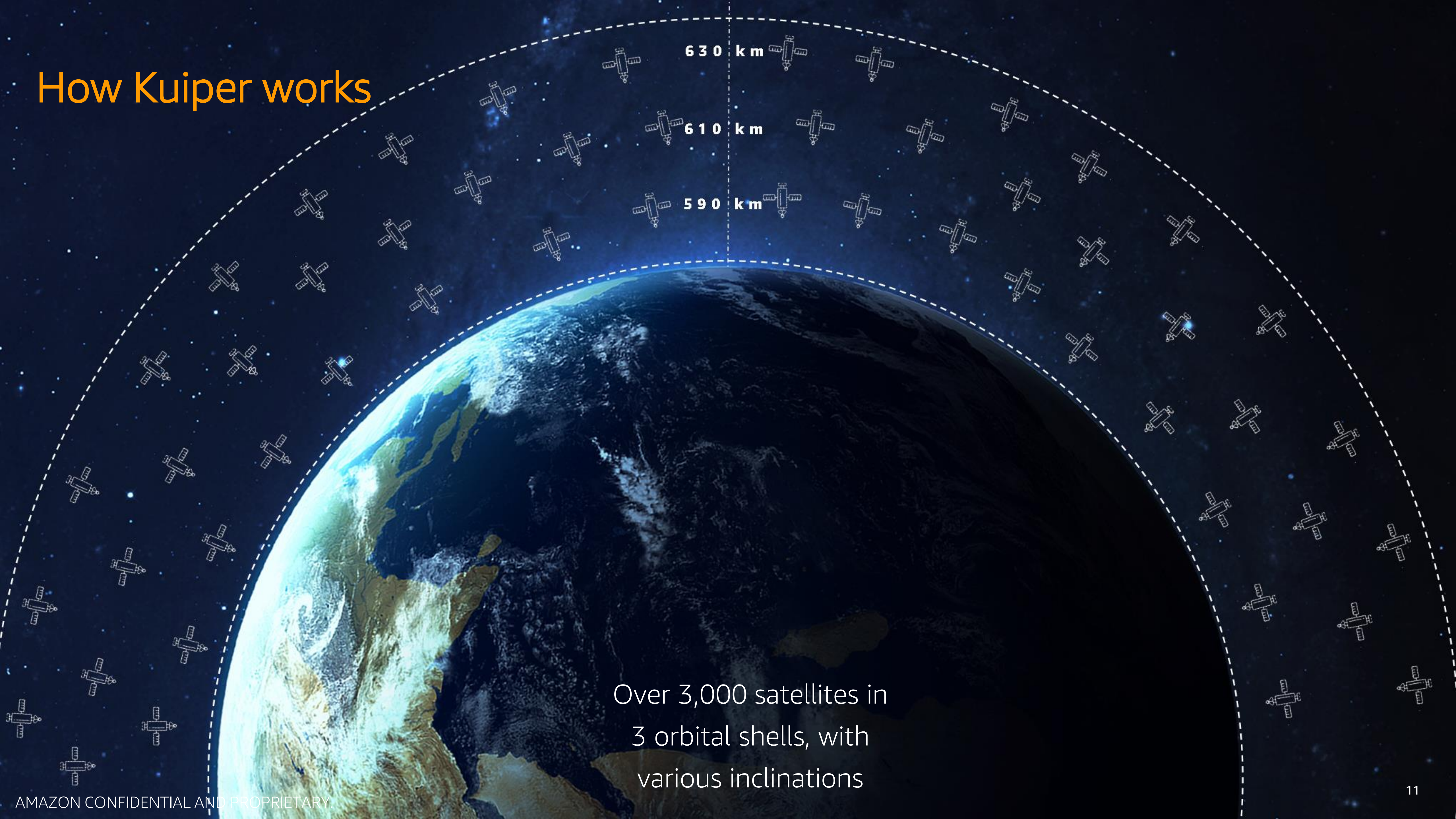
Frequency: Ka-band

Compact: 7 in. sq., 1 in. thick, 100 Mbps

Standard: 11 in. sq., 1 in. thick, 400 Mbps

Enterprise: 19 x 30 in surface, 1 Gbps

How Kuiper works



Over 3,000 satellites in
3 orbital shells, with
various inclinations

Prototype Missions

Kuiper is preparing to launch two prototype satellites – KuiperSat-1 and KuiperSat-2 – in the coming months.

Mission objectives

- Missions will allow us to test communications and networking technology used in our final satellite design, and validate launch and mission management procedures
- Prototypes include production-ready technology and sub-systems, including phased array and parabolic antennas, power and propulsion systems, and custom-designed modems

Safety and sustainability

- Prototypes are designed for atmospheric demise and will be actively deorbited after the mission
- One of two satellites will include reflectivity panels to evaluate ways to mitigate impact on optical astronomy

Mission details

- Missions will launch from Cape Canaveral Space Force Station in Florida

Production Deployment

Kuiper has secured up to 92 launches to support its ambitious deployment plan.

Project Kuiper launch lineup

- First 2 prototype satellites have shipped for launch
- Recently secured up to 83 launches across three launch providers – Arianespace, Blue Origin and United Launch Alliance (ULA)
- Heavy-lift vehicles will provide enough capacity to deploy vast majority of our constellation
- Amazon is investing billions of dollars across the three agreements, making it the single-largest commercial procurement of launch vehicles in history

Industry impact

- Contracts support thousands of suppliers and highly skilled jobs around the world
- Partnership with ULA includes investments in launch infrastructure and service upgrades at Cape Canaveral Space Force Station

The International Telecommunication Union (ITU)

- Role of the ITU
- ITU Filing Basics
- Radio Regulations most important for NGSO systems
- Spectrum Sharing
- Rationale, efficient, economical and equitable use of the radio frequency spectrum and satellite orbits

Role of the ITU

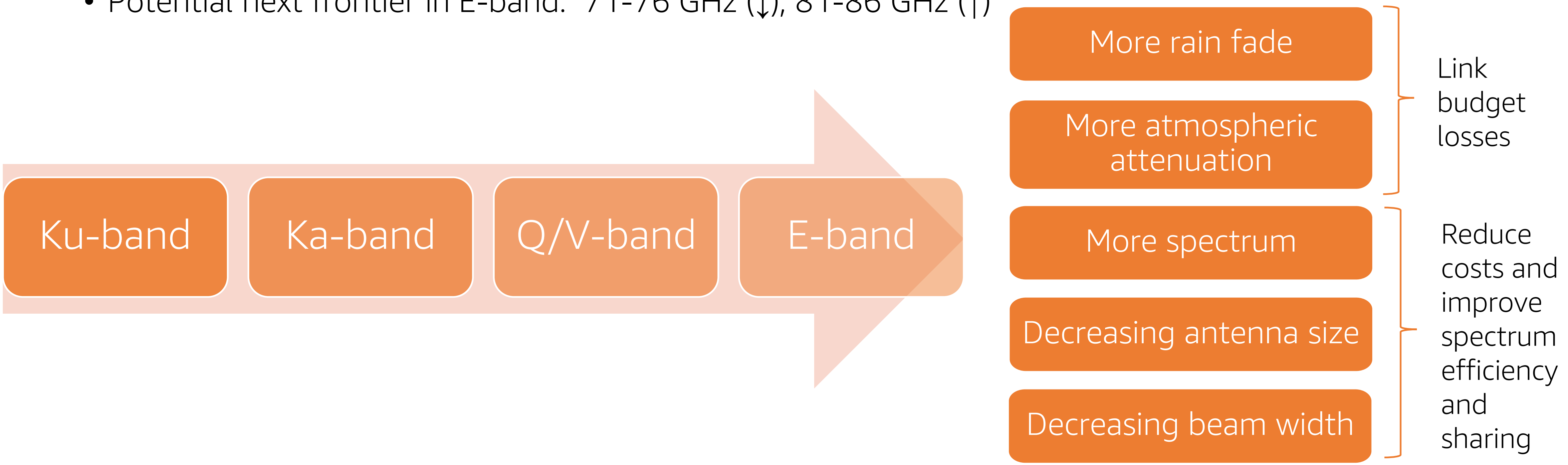
- The ITU Radiocommunication Sector (ITU-R) plays a critical role in managing the use of the radio frequency spectrum and satellite orbits.
- Allocation of spectrum for different services.
- Recording of frequency assignments and orbital positions for Geostationary Satellite Orbits (GSOs) and characteristics of satellites for NGSO systems.
- Management of terrestrial and space plans.
- Prevention and resolution of harmful interference.

- ITU Radio Regulations provide the mechanisms for spectrum sharing and the procedures for resolving harmful interference and infringements of the Constitution, Convention, or Radio Regulations.

The right to international recognition for any frequency assignment is derived from our ITU filings, coordination with other operators, and ultimately recording in the ITU's Master International Frequency Register (MIFR) with a favorable finding.

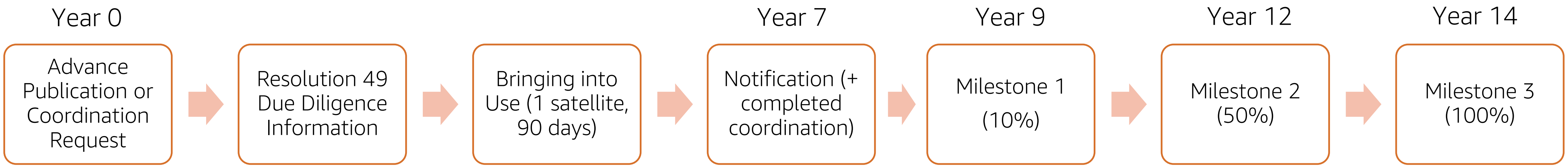
Radio Frequency Spectrum

- Modern LEO broadband systems are licensed in the following frequency bands:
  - Ku-band: 10.7-12.7 GHz (↓), 13.75-14.5 GHz (↑)
  - Ka-band: 17.7-20.2 GHz (↓), 27.5-30 GHz (↑)
  - Q/V band: 37.5-42 GHz (↓), 47.2-50.2 GHz (↑), 50.4-51.4 GHz (↑)
  - Potential next frontier in E-band: 71-76 GHz (↓), 81-86 GHz (↑)



ITU Filing Basics

- **RR No. 8.3** Any frequency assignment recorded in the Master Register with a favourable finding under No. **11.31** shall have the right to international recognition.
- Process starts with filing an Advance Publication or Coordination Request with the ITU.
- 14 years+ for a NGSO in the Ku-, Ka-, or Q/V-bands to finish the process.
- Date priority matters – and an unfavourable finding at any step means starting over.
- In 2022, 51 countries submitted 322 new NGSO filings totalling 1.76 M satellites. USA has the most filings and Rwanda has the most satellites. Only 12 filings were notified. Strong interest in Ku-, Ka,- and V-bands.



Rational, Efficient, Economical, and Equitable

- The ITU Radio Regulations Board (RRB) has reported on the fulfilment of these principles to the last 5 WRCs
  - Bringing into use of satellite networks
  - Extension of the time limits for bringing into use
  - Issues related to the Appendix 30/30A/30B Plans
  - Harmful interference
  - Resolution 219 (Bucharest, 2022), Sustainability of the radio-frequency spectrum and associated satellite orbit resources used by space services
- Design, deployment, operation, and post-mission disposal of satellite is conditioned by licensing authorities, informed by space situational awareness providers, and improved by operator best practices.
- The key objective of the ITU Radio Regulations is the avoidance of harmful interference. ITU addresses the use of radio frequencies – it does not regulate or manage physical objects.

LEO Regulatory Challenges

"Now a new space age beckons. It means more satellites, more possibilities for exploration, and more opportunities for entrepreneurial activity in our skies."

FCC Chair Jessica Rosenworcel, 2022

LEO regulatory challenges affecting NGSO fixed-satellite service (FSS) deployment

Competition and innovation

- FCC NGSO sharing NPRM
- Future Agenda Item (FAI) for WRC-27 to update EPFD rules

Licensing and Earth Stations

- FCC Rules on Sharing with Mobile stations in 28 GHz
- Mobility – Earth Stations in Motion (ESIM)

Spectrum

- FCC 17 GHz proceeding

Streamlining

- FCC Satellite streamlining NPRM
- SAT Act

Space Sustainability

- Orbital Debris Regulations
- Potential Expansion of the ITU Mandate

WRC Issues

Opportunities to improve spectral efficiency for NGSO systems being addressed by the ITU

- Promote and develop ITU-R Recommendations and sharing studies that accurately reflect planned NGSO systems (many ITU-R Recommendations are based on work from 1997-2003)
- Develop regulations to allow NGSO systems such as Kuiper to deliver their stated goals and share effectively with incumbent systems

WRC-23 Agenda Item 1.16 (NGSO ESIM)

- In accordance with WRC-23 Agenda Item 1.16, ITU-R WP4A is studying the operation of NGSO ESIM in the Ka band
- ESIM are an important component in the operation of NGSO systems, and the ability to serve moving platforms such as aircraft present a valuable operational aspect for these next generation systems
- Regulatory provisions for the operation of GSO ESIM were approved by WRC-19 and regional approvals for both GSO ESIM and NGSO ESIM have been adopted by both Europe and the FCC
- Studies at WP4A have confirmed and CPM text (Method B) has been developed to support a solution that allows NGSO ESIM to operate
- Another component of these studies is the protection of EESS in 18.6-18.8 GHz, where a solution has been developed and is also reflected in the CPM text

WRC-23 Agenda Item 1.19 (17.3-17.7 GHz FSS allocation in Region 2)

- WRC-23 AI 1.19 - to consider a new primary allocation to the FSS in the space-to-Earth direction in the frequency band 17.3-17.7 GHz in Region 2
- There is already a FSS allocation for this frequency band in Region 1 and an allocation for this frequency band in Region 2 for the broadcasting-satellite service (BSS)
- This allocation would support harmonization with other regions and additional contiguous bandwidth for FSS operations to support growth
- Studies at WP4A have confirmed the ability for FSS NGSO systems to operate in these bands and protect existing services
- Studies at WP4A have confirmed and CPM text has been developed (method B, option 1) to allow for the ability for FSS NGSO to operate in these bands and protect existing services

Article 21 RR No. 21.16.6 (PFD scaling factor for NGSO systems)

- WRC-19 invited the ITU-R to initiate studies on the appropriateness of the Article 21 equations in RR No. 21.16.6 for large scale NGSO systems, which scale the PFD limit based on the number of satellites in the NGSO constellation.
- Studies at WP4A have confirmed that the equations in No. 21.16.6 are inappropriate for NGSO systems and leads to the scaling for each NGSO satellite in gross excess of the number of satellites that are visible or are even in the constellation
- We are engaging in studies to determine a more suitable formulation of the scaling factor equations
- Director's Report to CPM confirmed the results of studies and ensures discussions at CPM and WRC-23
- If a solution is not found at WRC-23, qualified favorable should be extended past the end of WRC-23

WRC-23 Agenda Item 7 – Issue A (Orbital Tolerance)

Issue A

- WRC-23 Agenda Item 7 Issue A seeks to define an acceptable orbital tolerance from the filed parameters of a NGSO system
- The four parameters being discussed are perigee altitude, apogee altitude, inclination, and argument of perigee
- Amazon supports the development of a 20 km and 1° tolerance trigger for NGSO systems (CPM text Method A4)
- If the trigger is exceeded, showings must be provided to BR to ensure interference environment has not changed
- Some proponents are proposing a tolerance as large as 100 Km
  - We do not support this due to rise in interference levels as well as orbital safety concerns

WRC-23 Agenda Item 7 –Issue J (Resolution 76)

Issue J

- Resolution 76 seeks to establish a consultation process for NGSO systems to evaluate aggregate interference into GSO networks
- Resolution 76 also identifies the need to establish a Recommendation that accurately models aggregate interference
- Work to establish the Recommendation on modeling techniques is on-going but not yet complete
- We support a WRC-23 work item to study this issue (Method J4)
- A consultation process should not be established until a proper Recommendation to model interference from NGSO systems is developed by WP4A

Update of Recommendation ITU-R S.1503

- Recommendation S.1503 contains the procedures for a functional description for a software tool to determine conformity of NGSO systems with limits contained in Article 22 of the Radio Regulations (epfd limits)
- Originally developed based on technical studies and assumptions of operations of NGSO systems from the WRC-97 study cycle.
- Limitations on modeling lead to spectrum inefficiencies in operation of next-generation NGSO systems
- WP4A is studying updates to Recommendation S.1503 in order to accurately reflect the operation of today's NGSO systems like Kuiper in the implementation of this Recommendation

EPFD Future Agenda Item

- Part of the work of WRC-23 will be to decide on the Agenda Items for the next conference (WRC-27) and other future WRCs
- There is a proposal in some regional groups regarding a future agenda item intended to replace the existing EPFD sharing framework
- EPFD limits and their associated regulations quantify Kuiper's obligation to not cause unacceptable interference to GSO FSS and BSS networks
- The goal of the Agenda Item will remain to ensure protection of GSO networks from unacceptable interference pursuant
- Compliance with these limits significantly impacts the design and operation of NGSO systems like Kuiper

Why pursue this change?

- The regulatory EPFD limits applicable to non-GSO systems below 30 GHz represents the single greatest operational restriction for systems like Kuiper

- The limits that apply to the Ku and Ka band were developed nearly 25 years ago, during the WRC-2000 study cycle. Satellite technology has advanced significantly since that time and the limits and ITU compliance methodologies do not reflect reality

- Kuiper is designed to meet these limits in operation but the way the ITU examines our compliance with these limits:
  - Creates significant artificial constraints in the design and operation of NGSO systems
  - Limits spectrum usage and ability to serve customers
  - Creates risk for NGSO operations in worldwide licensing and coordination of satellite systems

Space Safety & Sustainability

- Space Treaties
- Best Practices
- Role of Operators
- Role of Government
- Orbital Space
- Space Safety at Kuiper

Landscape - Space Treaties

- Relevant UN space treaties:
  - Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty)
    - Article VI- The activities of non-governmental shall require authorization and supervision
    - Article VIII- A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object
  - Convention on Registration of Objects Launched into Outer Space (Registration Convention)
    - When a space object is launched into earth orbit or beyond, the launching State shall register the space object
  - Convention on International Liability for Damage Caused by Space Objects (Liability Convention)
    - Outlines the liability of Launching States for damage caused by their space objects both on the Earth or in space

Landscape - Space Treaties Continued

- Outer Space Treaties have allowed industry to flourish for decades
- Generally broad, but with several notable limitations:
  - No national appropriation
  - Avoid harmful contamination
  - No weapons of mass destruction
  - No military bases on the Moon
- As space activities have evolved, voluntary best-practices, norms, guidelines have complemented the outer space treaties

Landscape – Standard Sources and Best Practices

- USG
  - National Space Council (NSpC)
  - Department of State (COPUOS, First Committee)
  - Office of Space Commerce (SSA, etc.)
  - Federal Aviation Administration (Launch and Reentry)
- Multilateral efforts
  - UN Committee on the Peaceful Uses of Outer Space (COPUOS): Long-Term Sustainability Guidelines
  - 1st Committee: Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviors
  - Paris Peace Forum- Net Zero Space Initiative
  - Artemis Accords
- Industry efforts
  - American Institute of Aeronautics and Astronautics (AIAA): "Satellite Orbital Safety Best Practices" Reference Guide
  - Space Safety Coalition: Best Practices for the Sustainability of Space Operations
  - The Hague Institute for Global Justice: Compact on Norms of Behavior for Commercial Space Operations
  - World Economic Forum (in collaboration with ESA): DRAFT Space Industry Debris Mitigation Recommendations

Role of Operators

The satellite industry has a vested interest in responsible operations in a safe, sustainable environment.

- Operators should:
  - Coordinate and communicate to encourage and allow safe operations, safe interaction
  - Use empirical knowledge to develop best practices and operating standards
    - Shared knowledge for current and future operators
    - Common processes across nations, across organizations
    - Help informing the developing regulatory landscape
    - AIAA Best Practices
    - Space Safety Coalition Best Practices

Role of Government

The satellite industry is rapidly changing, and satellite operators are most familiar with their technologies, systems, and how to best promote safe satellite operations.

- Governments should:
  - Identify opportunities to foster international coordination
  - Be aware and involved in encouraging the private sector to develop shared operational norms
  - Invest in advanced Space Situational Awareness technologies to promote the more efficient use of space

Orbital Space for LEO

Expect a few larger broadband LEO constellations and many smaller LEO constellations with intermittent connectivity requirements (e.g., IoT, earth observation, paging).

- Space is a key resource, and even though space is substantial, operators need to use it efficiently and responsibly, especially in LEO
- Using practicable minimum separation distances, research (from MIT) has shown that thousands of satellites can fit in a single LEO shell. Carrying capacity is a candidate metric for the volume of satellites in any given orbit, but is an immature candidate for usage, easily tuned to address individual market interests.
- To make multi-constellation operations a reality, we should be working to develop and employ operational norms, such as tight orbital tolerances that minimize the vertical space occupied by each operator's shells and increasing the efficiency of orbit use
- We should also encourage appropriate technical interchange and coordination between operators, recognizing that future policy and technology developments may allow for the possibility of closer operations
- To draw a comparison, increasing highway safety does not necessarily depend on limiting the number of cars that access a road, but rather on technology and policy improvements that help ensure on-road safety

Space Safety at Kuiper

These are core Kuiper features, and we are committed to taking necessary steps to protect against orbital debris.

Constellation design

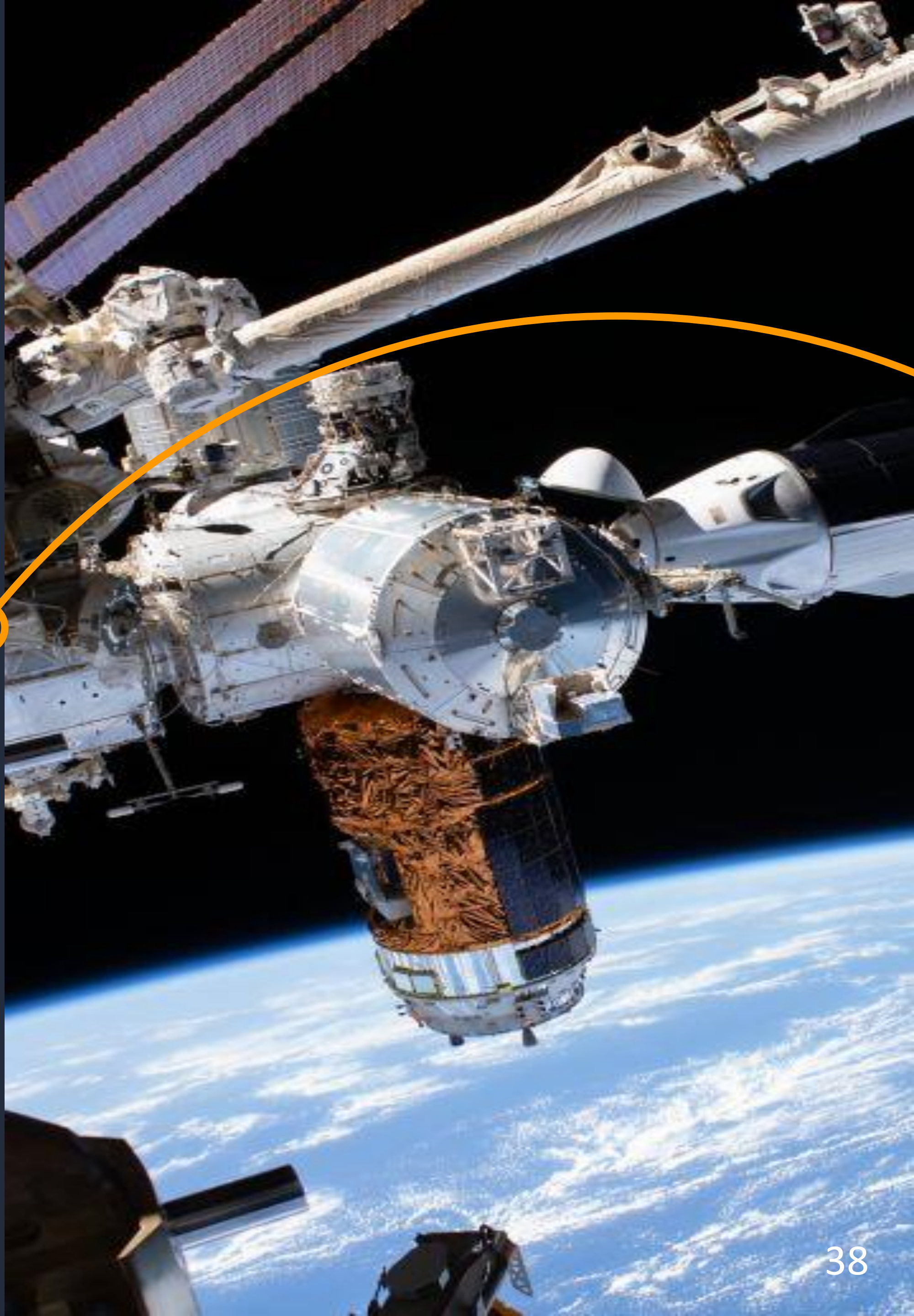
- 20 km altitude separation between shells.
- In-track separation of at least 50 km.
- No more than 9 km of cumulative altitude deviation.

Reliability

- Comprehensive subsystem and system testing, in the factory and on orbit below ISS prior to orbit raising.
- Ephemeris sharing and maneuver forecasts.

Deorbit and demise

- Designed for active deorbit within one year.
- Passive deorbit duration median duration is less than 5 years based on decay due to natural forces.



Minimizing Collision Risk at Kuiper

- Limiting debris release
  - Satellites do not rely on mechanical release bands, breakaway mechanisms, or mechanical cutaway devices to release from launch vehicle. ***No debris release during normal planned deployment.***
- Withstanding small debris collisions
  - Component design and Whipple shielding to protect all components, especially the battery and propellant tank. Design includes backup components, including independent solar panels and redundant flight computers, radios, and sensors.
- Timeframe
  - Designed for active propulsion-aided deorbit within 1 year. Passive deorbit based on natural decay due to natural forces, projected to meet the 5 year requirement (if active propulsion failed).
- Collision avoidance
  - During decommissioning, satellites will continue to perform avoidance maneuvers. Satellites will reserve 3 kg inert gas-propellant for post-mission disposal maneuvers.
- Risk during deorbit
  - Complies with NASA standard of < 1 in 10,000 risk of casualty from surviving components with impact kinetic energies > 15 joules. Calculated risk of human casualty was computed to be 1 in 100,000,000 (4 orders of magnitude smaller than the common industry practice).

Protecting Astronomical Observations at Kuiper

We are taking steps to minimize our impact on astronomical observations.

System design

- Project Kuiper operates at lower altitudes and includes fewer satellites, helping reduce reflectivity compared to larger constellations or those operating at higher altitudes (over 1,000 km).
- Prototype missions will help us evaluate reflectivity and test our mitigation measures.

Deployment and operations

- Maneuvering capabilities reduce Earthward reflectivity during propulsive operations (orbit raise and lower).
- Stearing capabilities allow us to minimize reflections during mission operations.

Collaboration

- Kuiper is committed to working with the astronomical community to find shared solutions. We will share ephemeris data throughout operations to help protect and preserve scientific research.

Bring fast, affordable broadband to unserved and underserved communities around the world.

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