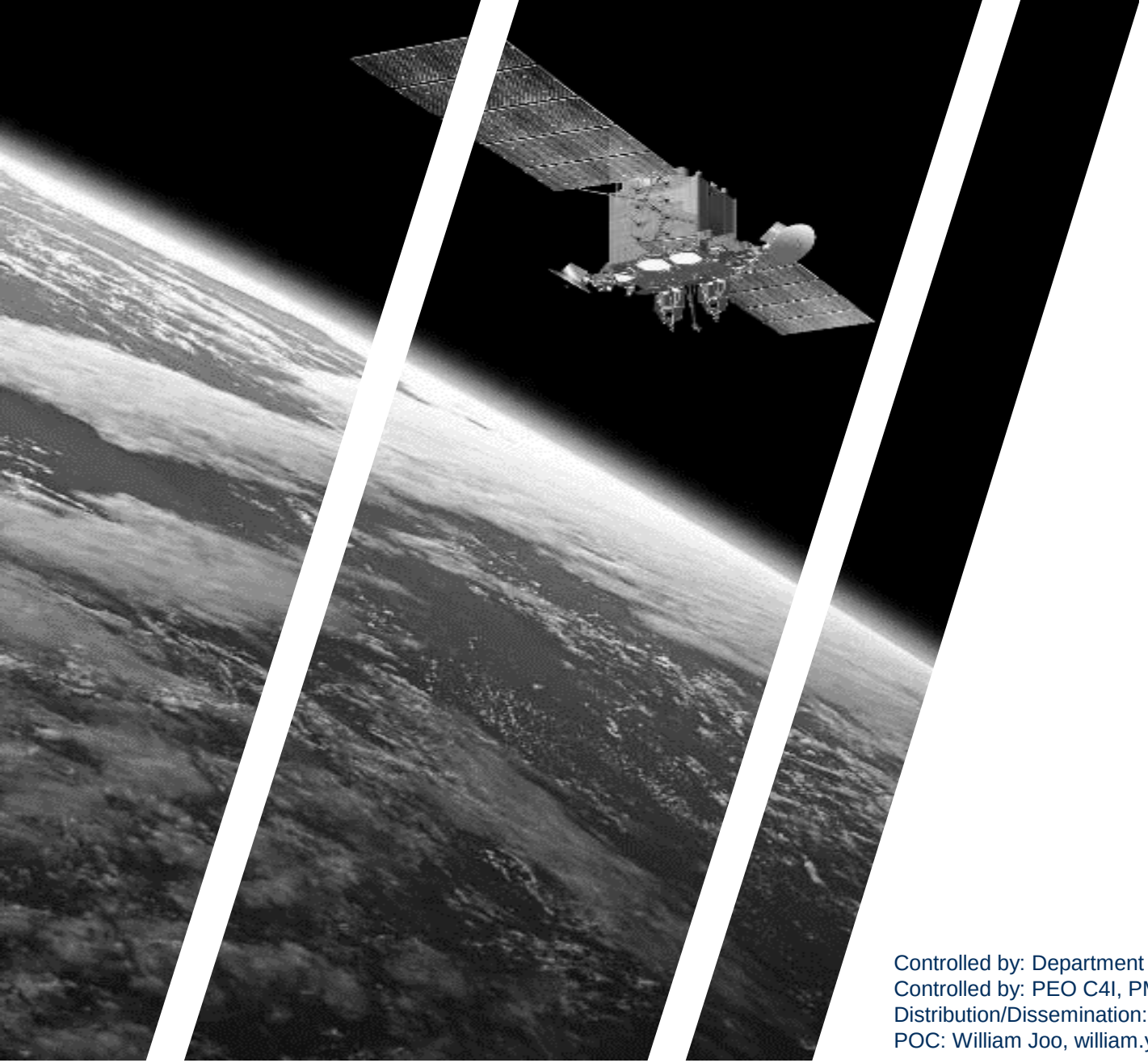

Program Executive Office
Command, Control, Communications,
Computers and Intelligence (PEO C4I)

State of Non-Geo Stationary Orbit (NGSO) Satellite Communications

06 May 2024

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Agenda

- SATCOM Primitives and Status
- Low / Medium Earth Orbit (LEO / MEO)
  - Vulnerabilities and Resiliency
  - Starlink in Ukraine
  - Starshield (Limited Discussions)
- Project Highlights
  - SATCOM Terminal transportable Non-Geostationary Orbit (STtNG)
  - Commercial SATCOM as Transport (CSaT)
  - Assured and Alternative Positioning Navigation and Timing (PNT) Services
  - Science & Technology (S&T) Projects
- U.S. Navy NGSO Priorities and Plans

Satellite Orbit Types

- Geosynchronous Orbit (GEO)
  - Positioned ~36,000 km from Earth's equatorial surface
  - User Terminal (UT) apertures are nominally low-cost but large fixed parabolic reflector based and may require complex terminal equipment
- Medium Earth Orbit (MEO)
  - Positioned ~2,000 km to ~35,000 km from Earth at any inclinations
  - UT apertures are nominally low cost and compact terminal with smaller parabolic reflector(s) or Active Electrically Scanned Array (AESA)
- Low Earth Orbit (LEO)
  - Positioned ~400 km to ~2,000 km from Earth's surface
  - Highly integrated AESA UTs

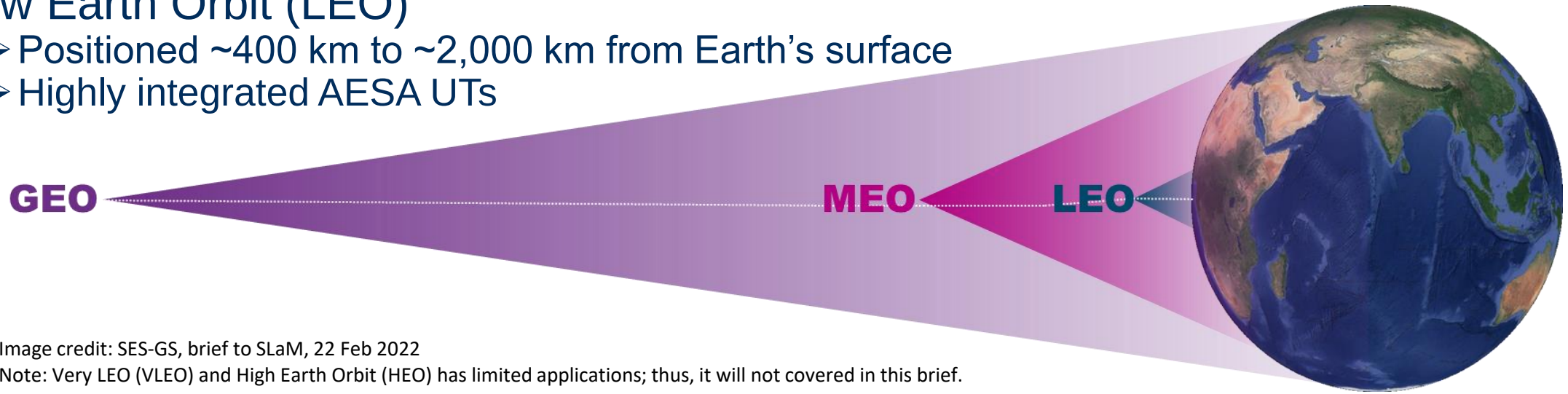
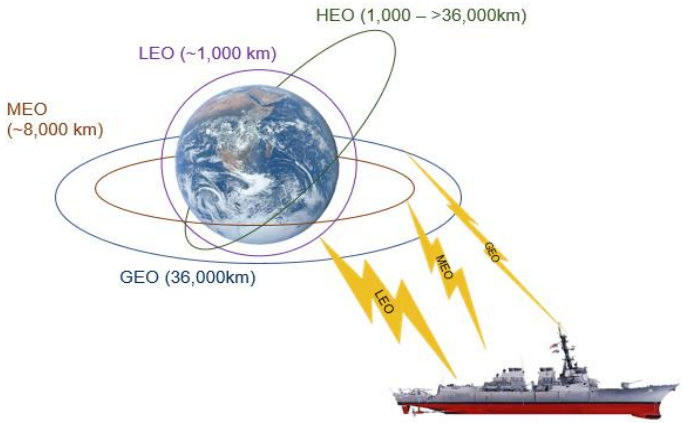


Image credit: SES-GS, brief to SLaM, 22 Feb 2022
Note: Very LEO (VLEO) and High Earth Orbit (HEO) has limited applications; thus, it will not covered in this brief.

Satellite Constellations Statistics

- Constellation Size
  - 4,987: Sum of all satellites in orbit in early 2020[1]
  - 540: Starlink satellites in orbit on 13 June 2020
  - 6,304 (5,896): Starlink satellites launched as of 28 April 2024
  - 636 (634): Eutelsat / OneWeb, 20 May 2023; Gen 1 is fully operational
  - 2 : Amazon Kuiper satellites launched as of 06 October 2023
  - 46k+: by 2027 Combined constellation plan size just for SpaceX Starlink, OneWeb, and Amazon Kuiper
  - 60k+ by 2030: Including TeleSat, Lynk, SES, Echostar, and many others
- LEO and MEO Performance
  - Latencies (round trip with nominal system delay)
    - Terrestrial networks: 10 ms to 150 ms
    - Geosynchronous Satellites: 300 ms or higher
    - MEO: 50 ms to 150 ms
    - LEO: 15 ms to 100 ms
  - User Data Throughput Rates
    - 25 Mb/s to 10+ Gb/s down
    - 10 Mb/s to 1+ Gb/s up
  - Global coverage with RF and optical Inter-satellite links



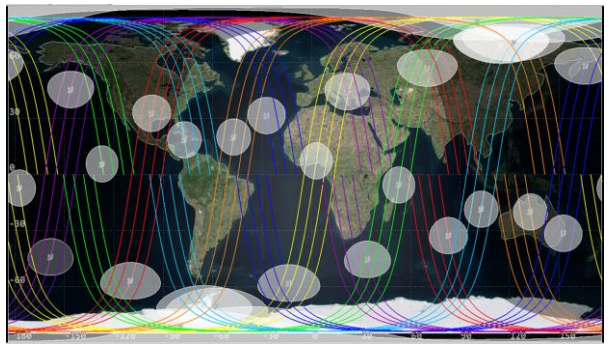
[1] "United Nations Register of Objects Launched into Outer Space", UNOOSA; includes Sputnik. http://www.unoosa.org/oosa/en/spaceobjectregister/index.html. Retrieved on 11 June 2020

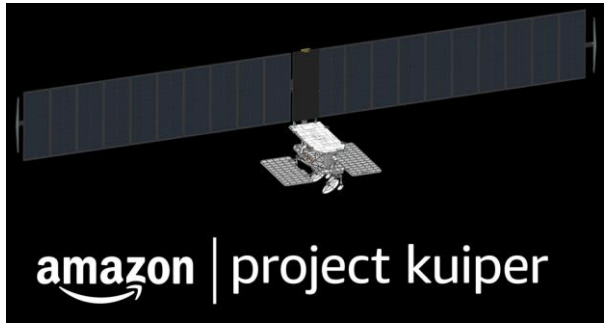
Proliferation Continues At A Rapid Pace!

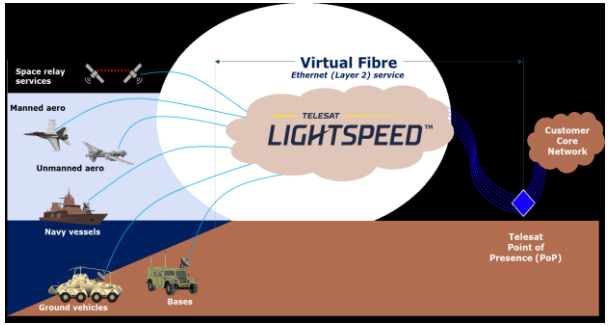
New Satellite Constellations

- Amazon Kuiper*
- AST Space Mobile
- Echostar Lyra and Sirion*
- GlobalStar (Next Generation)
- Inmarsat
- Intelsat
- Iridium NEXT*
- Lynk*
- OmniSpace
- OneWeb ***Next Gen****
- Rivada Networks
- Sateliot
- SDA*
- SES mPOWER
- Telesat Lightspeed*
- TrustPoint*
- Viasat 3
- Xona Space*
- …others + more*

**** Indicated intent to build A2PNT***







New Constellation Builders Showing Up Regularly!

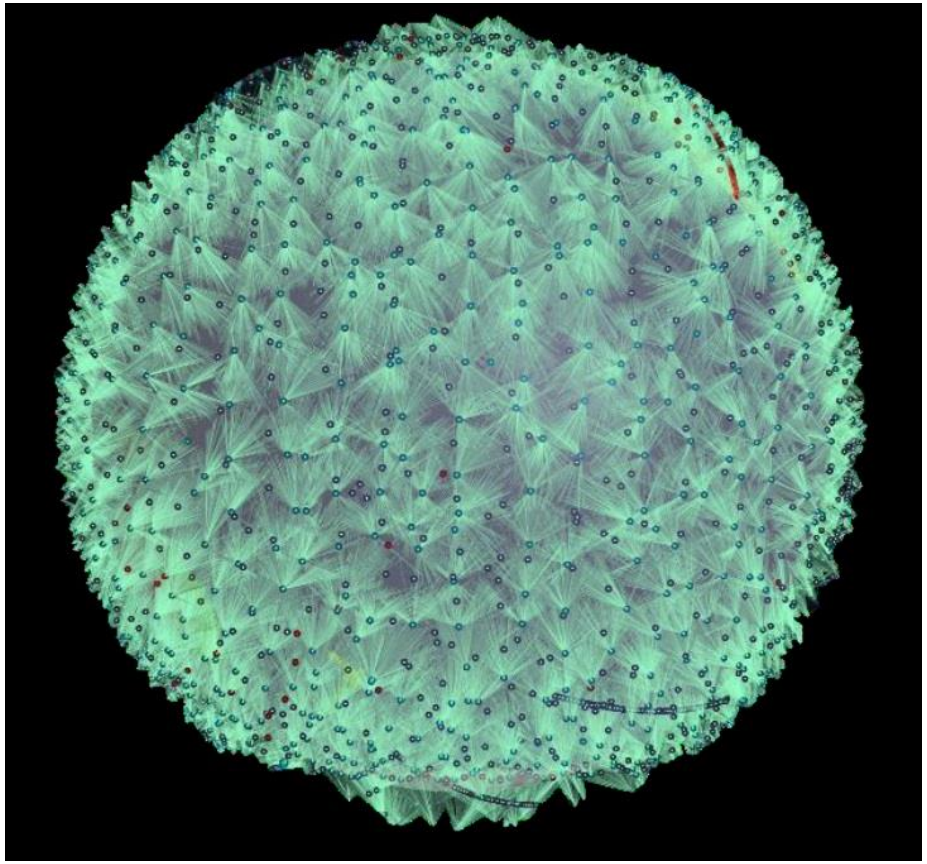
Sample Constellation – Starlink

- Satellite Types and Quantities
  - Tin Tin 1 & 2 (22 Feb 2018)
  - v 0.9, 60 (15 May 2019)
  - v 1.0, 1,665
  - v 1.5, 2,529
  - v 2.0 “mini”, 2,404[1]
  - v 2.x, Starship Launch
- Starshield
  - Details are classified U.S. S//TK
- Frequencies
  - User Terminal: Ku
  - Gateway: Ka
  - Limited S on some

[1]As of 28 April 2024

Many Beams per Phased Array Aperture

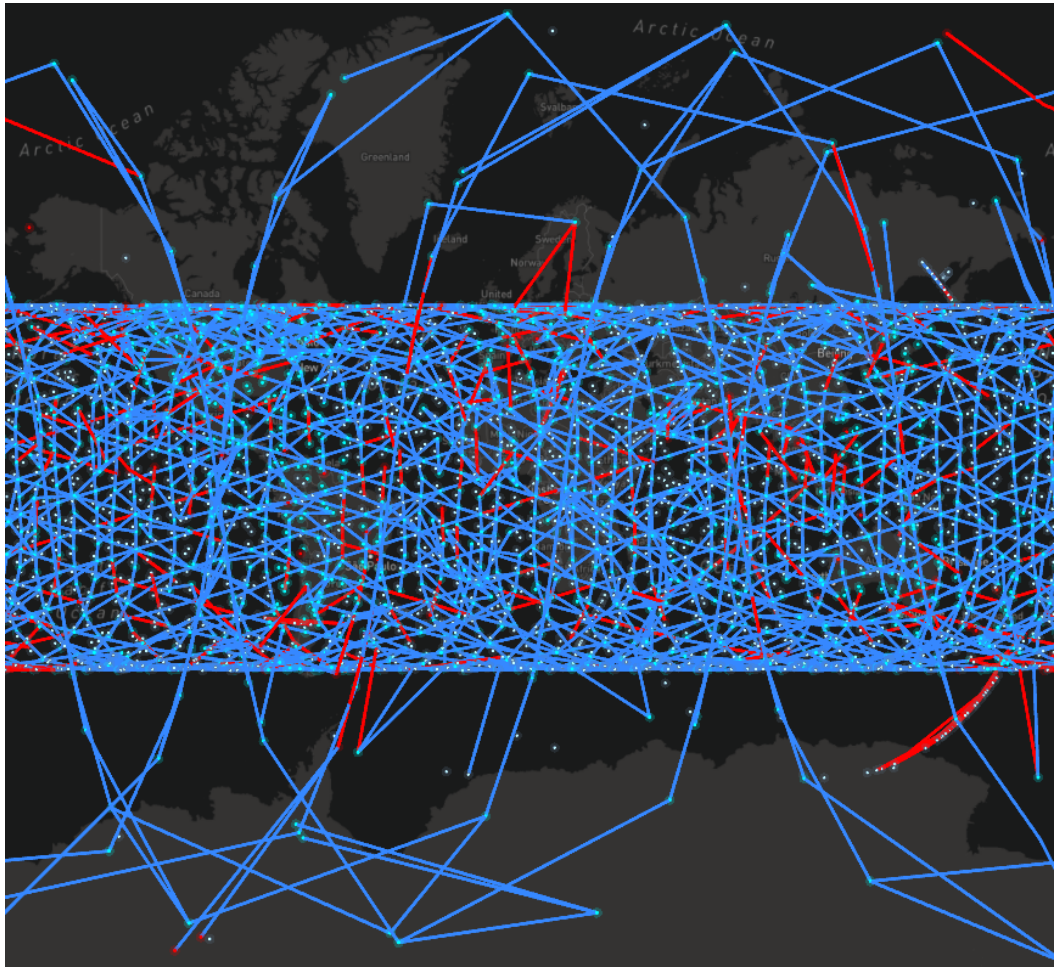
Multiple arrays per satellite + 5G NTN on some



Starship Will Rapidly Increase Starlink Satellite Count

Starlink's Optical Inter-Satellite Links (OISLs)

- Optical Inter-Satellite Links (OISL)
  - ➢Available on v 1.5 + satellites
  - ➢OpenZR+ (Not SDA compliant)
- Multiple OISLs per satellite
- Throughputs and Distances
  - ➢100's Gb/s over great distances
  - ➢Longest link[1]: 5,400 km



[1] "Starlink's Laser System Is Beaming 42 Million GB of Data Per Day", PCMag. https://www.pcmag.com/news/starlinks-laser-system-is-beaming-42-million-gb-of-data-per-day. Retrieved on 31 January 2024

OpenZR+ Will Likely Dominate As the OISL Standard

Starlink Size and Mass: Satellites Launched

- Falcoln 9 Satellite Payloads
  - 53 to 60 V1.5
  - 23 to 24 V2 mini
  - 23 V2 with Direct to Cell (DtC)
- Starship
  - Payload capacity is ~150 metric tons
  - Required to launch 75 Full V2 satellites
- "Sherpa"
  - Additional ride share payload

Name	Component	Length (m)	Width (m)	Solar Panel(s)	Area (m^2)	DAS Area (m^2)	DAS Mass (kg)
F9-1 (V1.5)	Solar Array	8.1	2.8	1	22.68		
	Bus	2.8	1.3	1	3.64		
	Total				26.32	30	303
F9-2 (V2 mini)	Solar Array	12.8	4.1	2	104.96		
	Bus	4.1	2.7	1	11.07		
	Total				116.03	120	800
F9-3 (V2 mini with DtC)	Solar Array	12.8	4.1	2	105		
	Bus	7.4	2.7	1	20		
	Total				125	130	970
Starship-1 (V2)	Solar Array	20.2	6.36	2	256.94		
	Bus	6.4	2.7	1	17.28		
	Total				274.22	294	2000
Starship-2 (V2 with DtC)	Solar Array	20.2	6.36	2	256.94		
	Bus	10.1	2.7	1	27.27		
	Total				284.21	294	2000

https://en.wikipedia.org/wiki/Starlink. Retrieved on 20 April 2024

Starship Required to Launch Version 2+ Satellites

LEO SATCOM's Inherent Resiliency

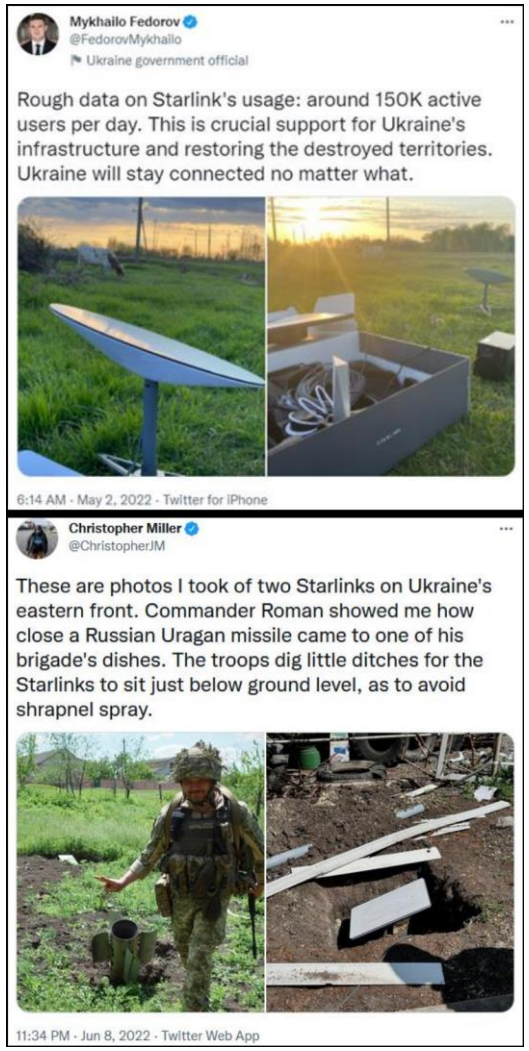
- Large Constellation Size
- Diversity of altitudes
- Diversity of Constellations
  - More than dozen known constellations built or under construction
  - Exploits against one will not be effective against all
- AESAs
  - Ability to connect to alternate satellites at oblique angles
  - Quickly adapts to changing constellation configurations
- SpaceX' Starlink
  - Resilient Ukraine operation

Image source: SpaceX's overview brief to PMW/A 170, 22 July 2022.

Proliferation Renders Low Threat From Kinetic Effects

Starlink In Ukraine

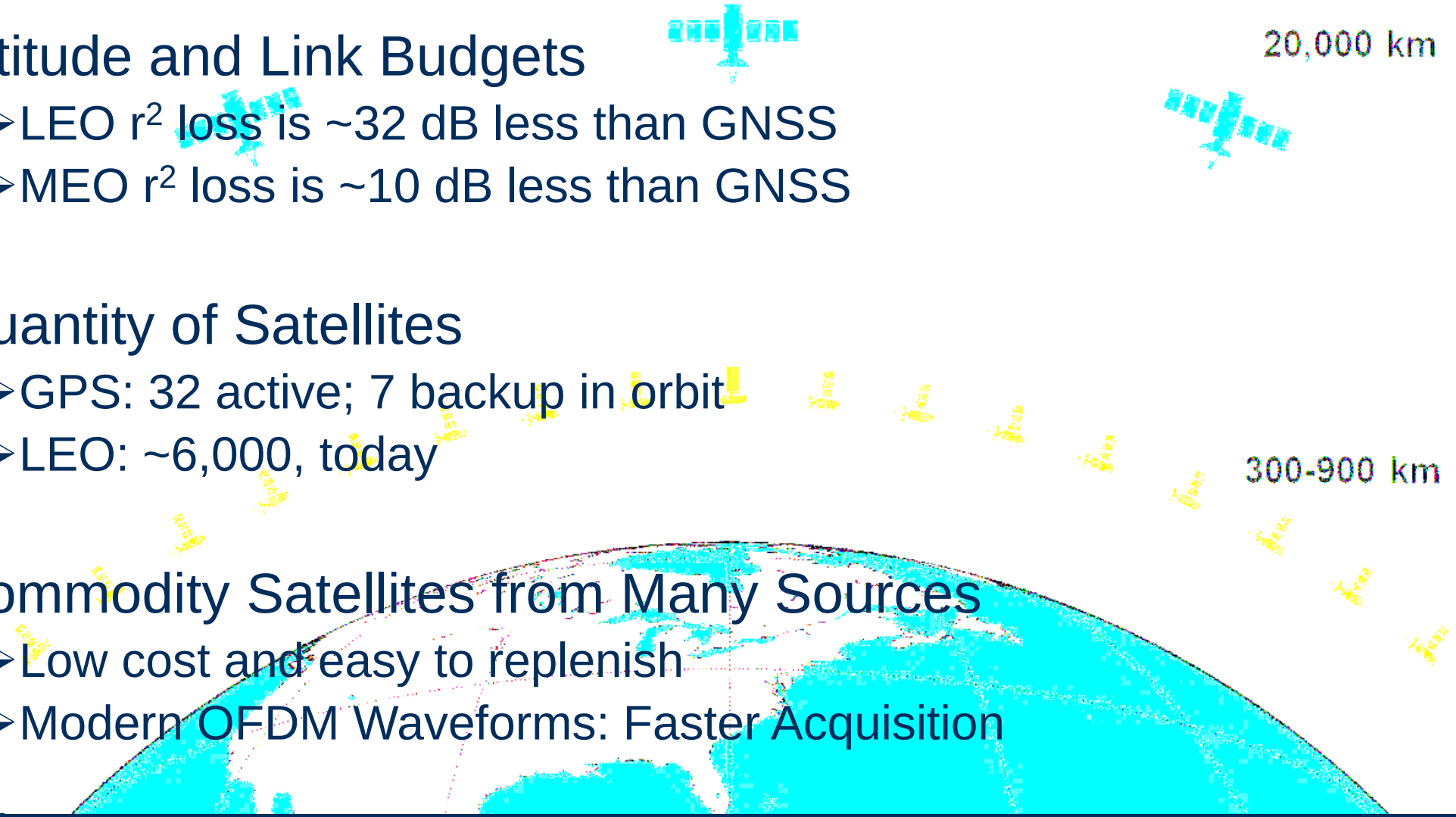
- Timeline
  - Russia Invades: 0 Starlink service
  - +48 hours: 400 kits plus service
  - Today: 45,000+ kits in service
- Adaptations to Issues
  - GPS jamming: Overcome by entering local position
  - Power consumption: Reduce performance to operate on vehicle cigarette lighter port
  - Lack of mobility: Enabled early roaming protocols and waveforms
- Current Status
  - Starlink utilization for humanitarian missions
  - Military use => constellation is a fair target



Ukraine Offered A Glimpse Of PLEO's Tremendous Capabilities In Wartime Settings

LEO and MEO Based PNT Enablers and Advantages

- Altitude and Link Budgets
  - LEO r^2 loss is ~32 dB less than GNSS
  - MEO r^2 loss is ~10 dB less than GNSS
- Quantity of Satellites
  - GPS: 32 active; 7 backup in orbit
  - LEO: ~6,000, today
- Commodity Satellites from Many Sources
  - Low cost and easy to replenish
  - Modern OFDM Waveforms: Faster Acquisition



U.S. GPS is still King! Qualcomm alone ~800 M receivers/year

Summary of Navy NGSO Priorities

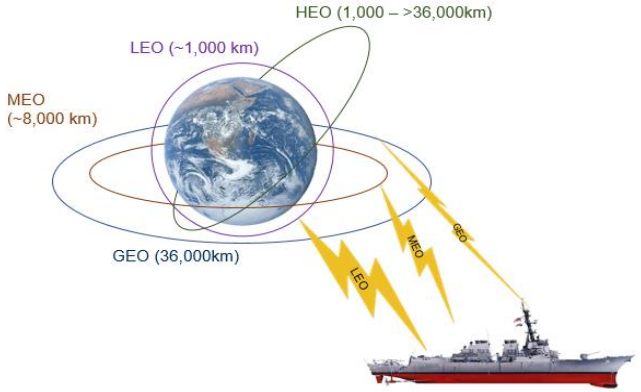
- High availability resilient, reliable, diverse, and affordable global communications
- No platform location reporting
- Global Extended Band
- Support platform-to-platform connections without gateways
- Operate in moderate to high sea states and weather conditions
- Seamless hybrid constellation handovers
- Vendor offers spare terminals with Move/Add/Change provisioning
- Ability to utilize Navy's certified aperture and terminal equipment
- Provide organic Assured Positioning, Navigation, and Timing (APNT) services
- Common 3U VPX modems
- Symmetric or "Inverse" Asymmetric Links

Hybrid Constellation Required To Fully Realize These Priorities

SATCOM Terminal (transportable) Non-Geostationary (STtNG)

- Overview
  - 2 Person Lift per Transit Case
    - Hosts wideband and protected modems
    - Meets Navy's environmental requirements
    - Control Unit (CU) to Automate all functions
  - Consolidated Multi-band/Multi-session Apertures
  - Transport and Operational within Hours
  - Support 6+ ADNS Connections
  - Embedded Training
  - Below Deck or Expeditionary
    - USMC
    - SOF
    - Agencies

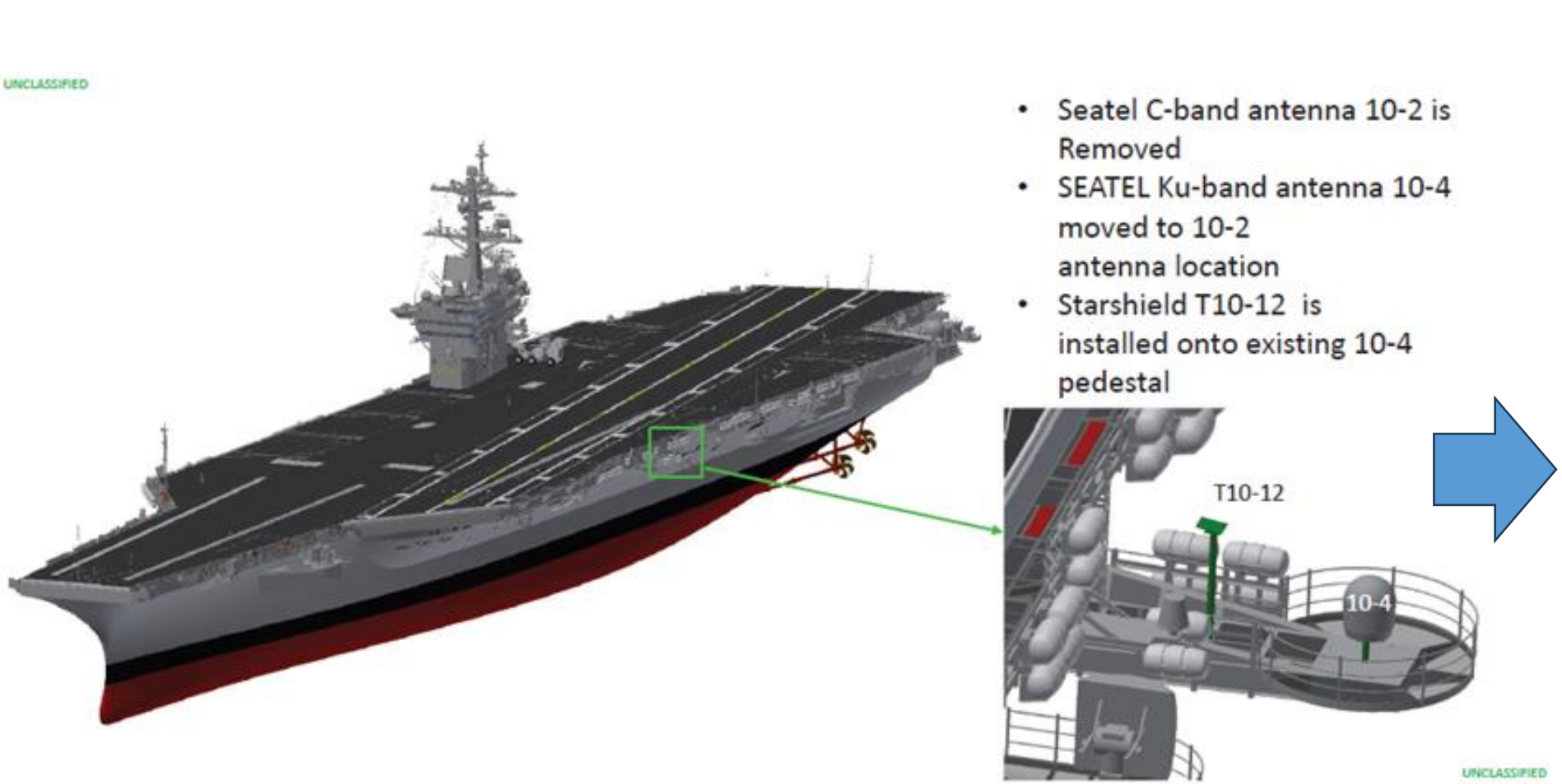
Any Orbit
Any Vendor
Any Time



Increments	Increment 0	Increment 1	Increment 2/2W	Increment 3/4
System	Starlink Ku or O3b Ka	Starlink Ku	Full STtNG LEO, MEO, GEO APNT	Full STtNG LEO, MEO, GEO, HEO, APNT
Quantity	Ad Hoc	55	126	211 to incl MSC and Natl Secty Cut
Connectivity	Wireless (No ADNS)	Ku or Ka (ADNS 1 Link)	Ku & Ka, AC2, ADNS (1-4 Links)	Ku, Ka, S, X, AC2, Future Modem, ADNS (4-6 Links)
Application(s)	ADMIN MS 365	Operational Ship's Network	Operational Ship's Network	Operational Ship/Sub Network

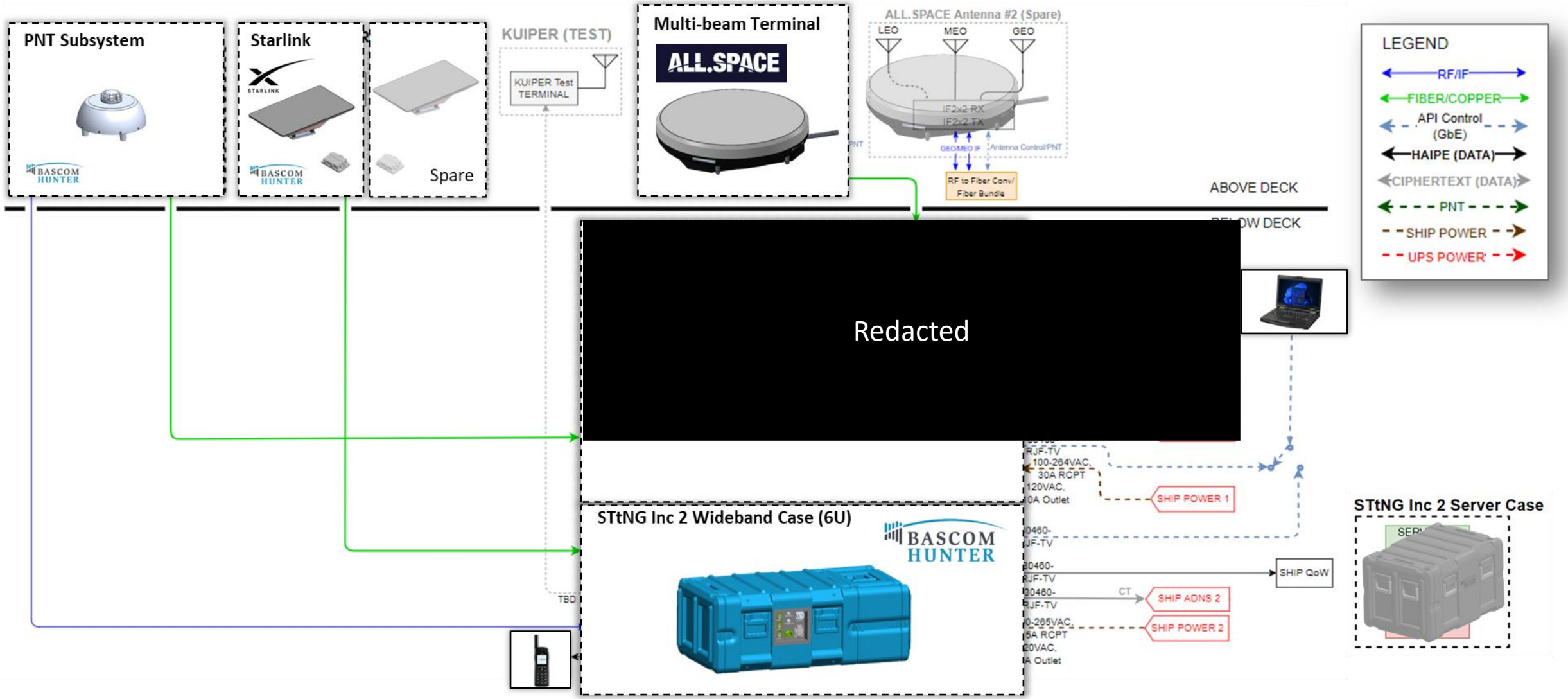
STtNG Delivers Common Shipboard Interface to Vendor-Agnostic NGSO Capability

STtNG Inc 1 on CVN 70

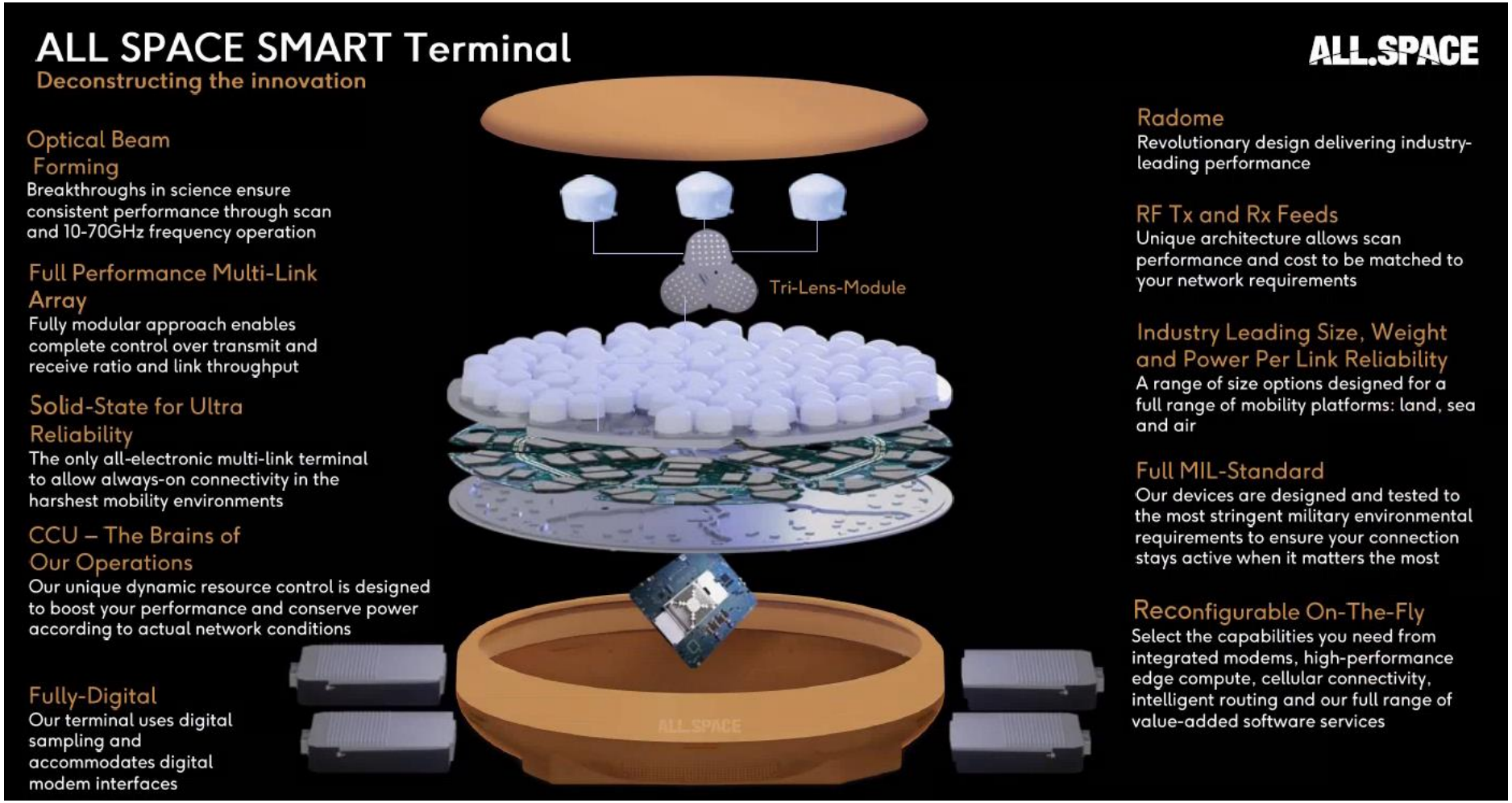


Huge size reduction: from 2.4 m + radome to Starshield's 0.57 m x 0.38 m

SATCOM Terminal transportable Non-Geostationary (STtNG)



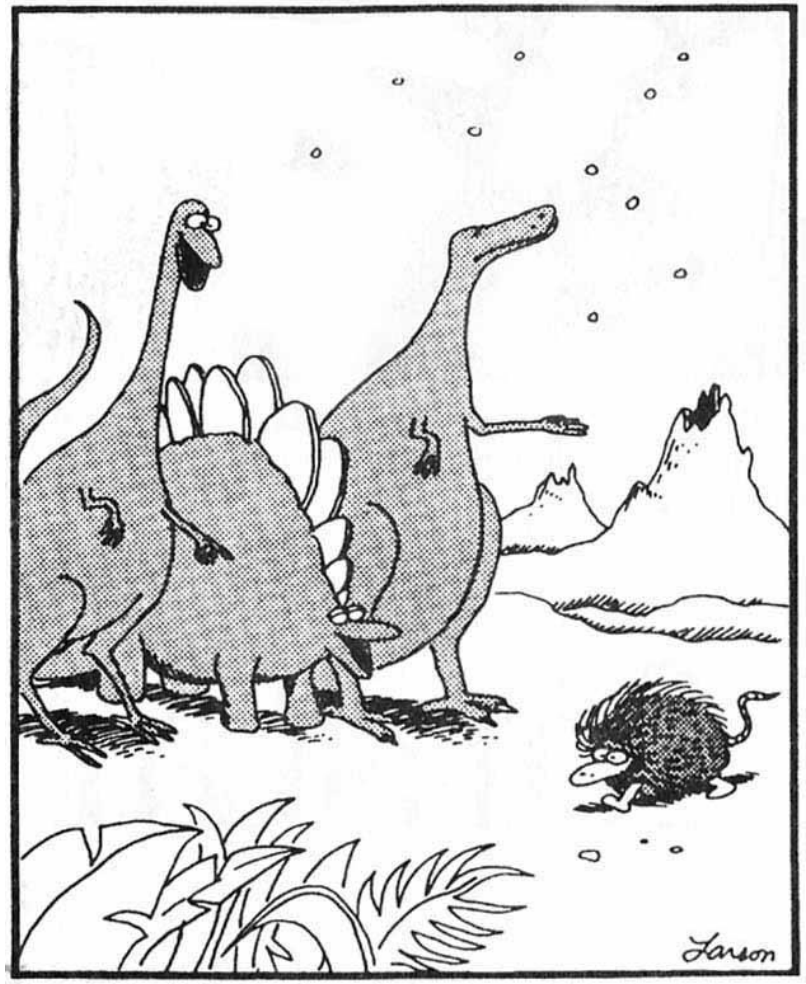
All.Space Consolidated Apertures



U.S. Navy SATCOM Focus Areas

- Foster
  - Advancements in LEO/MEO and HEO
  - Innovative modem technology
  - Out of the box commercial bandwidth leasing
  - Zero trust solutions for data transport
  - Support ubiquitous transport investigation
  - Aid in instantiation of 5G
  - Solutions for legacy systems
  - Preplanned Product Improvement (P3I)

- PMW/A 170 strives to enhance industry's understanding of US DoD's needs to enable expedited roll-out of the following interest areas:
  - Multi-beam arrays
  - Multi-link baseband
  - Creative leasing strategies
  - Open architectures



Government – Industry Collaboration Is Critical!

Acronyms

A2PNT	Alternative and Assured Positioning, Navigation, and Timing
AC2	Assured Command Control (Modem)
APNT	Assured Positioning, Navigation, and Timing
AESA	Active Electrically Steerable Antenna
APM	Assistant Program Manager
CBSP	Commercial Broadband Satellite Program
CSaT	Commercial SATCOM as Transport
DtC	Direct to Cell (5G NTN + Future G Payloads)
EMCON	Emission Control
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
IDIQ	Indefinite Delivery Indefinite Quantity
KPP	Key Performance Parameter
LEO	Low Earth Orbit
MEO	Medium Earth Orbit

Acronyms

NGSO	Non-Geostationary Satellite Orbit
OISL	Optical Inter-Satellite Link
PIC	Photonic Integrated Circuit
POM	Program Obligation Memorandum
RFP	Request for Proposal
PNT	Positioning, Navigation, and Timing
S&T	Science & Technology
SDA	Space Development Agency
SLaM TIME	SATCOM LEO and MEO Technical Information Meeting and Exchange
STtNG	Satellite Terminal (transportable) Non-Geostationary
TRANSEC	Transmission Security
TT&C	Telemetry, Tracking, and Control
UT	User Terminal
VPX	Virtual Path Cross-Connect
WAMS	Wideband Anti-jam Modem System

Program Name
Points of Contact

Position	Last Name	First Name	Rank	Phone	Email*
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SATCOM PAPM	Chaiken	Genie	Civ	(619) 524-7832	eugenie.p.chaiken.civ
TACCOMS 1 PAPM	Dillon	Shannon	Civ	(619) 524-7762	shannon.e.dillon3.civ
TACCOMS 2 PAPM	Roa	Gerardo	Civ	(858) 220-4207	gerardo.roa.civ
PNT PAPM	Rogers	Jamal	Civ	(619) 203-9636	jamal.rogers.civ
Technical Director	Squitieri	Vincent	Civ	(619) 533-3800	vincent.a.squitieri.civ
Business Financial Manager	Schmitt	Jackie	Civ	(619) 524-7648	jacqueline.l.schmtt.civ
APM – Contracts	Bingham	Ramona	Civ	(619) 524-3617	ramona.d.bingham.civ
Acquisition Manager	Murphy	Mike	Civ	(619) 524-7979	michael.p.murphy44.civ
APM – Installs	Ellis Metzger	Jacqueline Michelle	Civ Civ	(619) 854-9850 (619) 306-7679	jacqueline.e.ellis5.civ Michelle.a.metzger2.civ
APM – Logistics /PSM	TBD	TBD			

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Accelerated delivery of required capability that is affordable, integrated and interoperable