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LEO Satellites

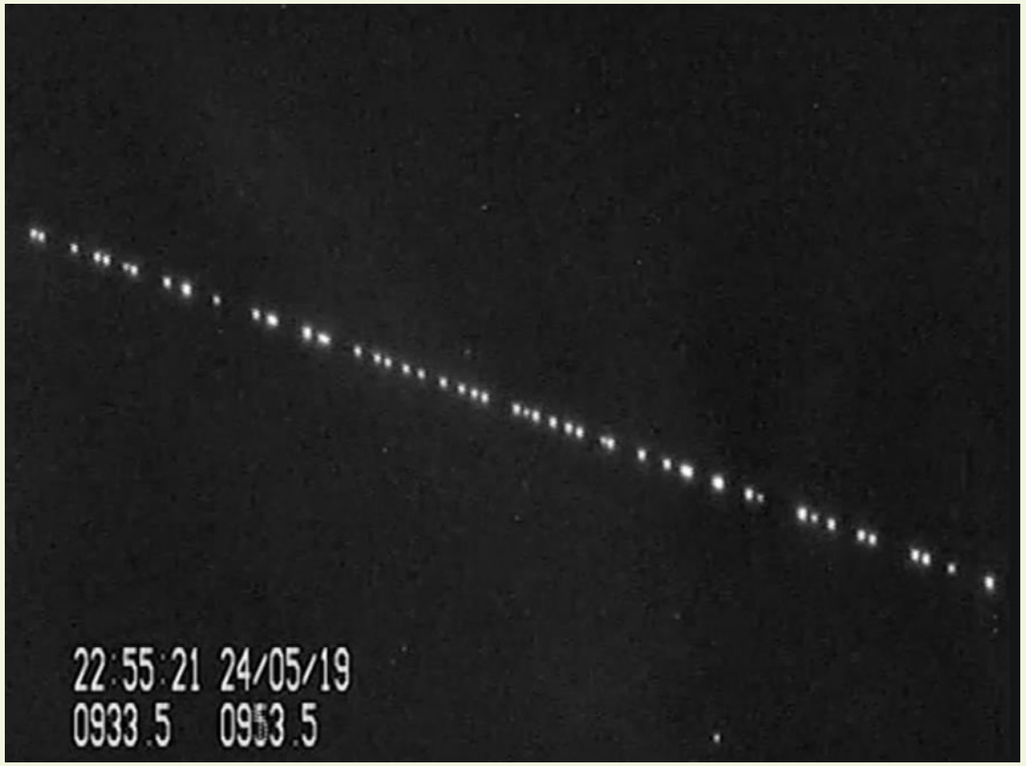
They can fly, but can they stick?!

May 20, 2021

LEO v2.0: From Space Communications to Space Internet

What is different from the 1990s?

Launch technology, satellite technology, funding models, business models, cloud players,...



Early stages. High risks, high rewards.

Context of Internet technologies: Edge computing, virtualization, 5G networks, enterprise networks,...

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A New Era of Space Internet Technologies

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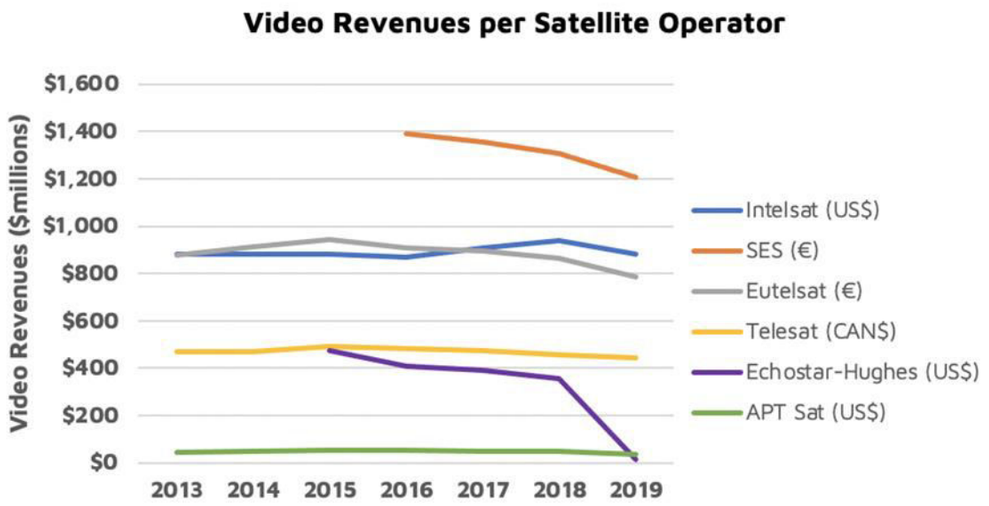
TELESAT LIGHTSPEED™
LASERLIGHT the power of light
AST SpaceMobile
SPACELINK
OMNISPACE
OneWeb
KEPLER
KLEO
space Lacuna
LYNK
SATELIOT
FLEET
SWARM
kinéis
FOSSA
SPACEX
ORBCOMM
Globalstar
Iridium NEXT
ISS
GPS
Viasat
Telesat
HUGHES
INTELSAT
SES
O3b mPOWER
inmarsat
eutelsat

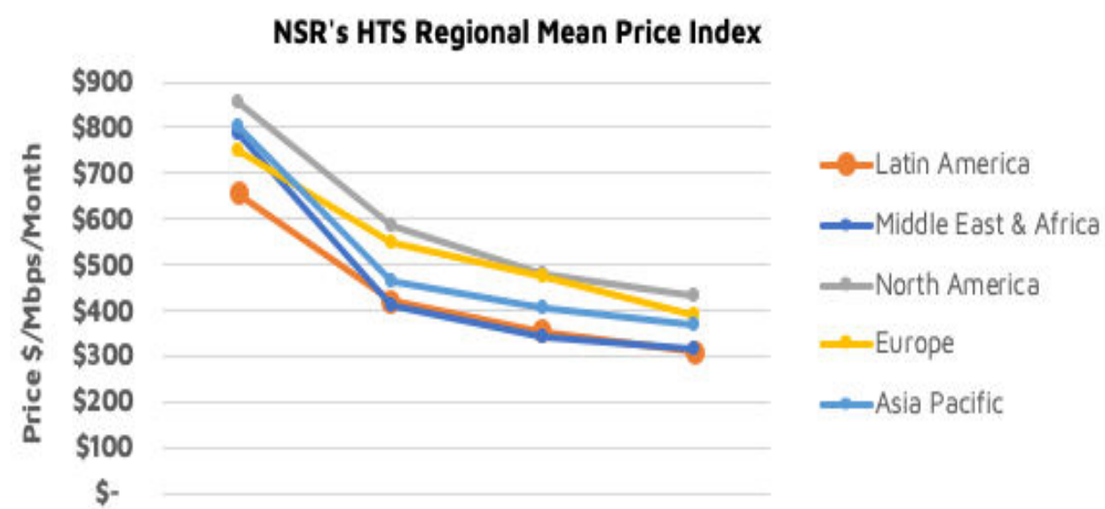
km
100
1,000
10,000
35,786
100,000
LEO
MEO
GEO

Industry Backdrop

Decreasing video revenues (-15% YoY)



Decreasing price of capacity (~15%-20% YoY)



- Service revenue increasing
  - LEO impact(?)
- Bankruptcies: Intelsat, OneWeb, Speedcast, GEE; LeoSat exists LEO plans

- High supply (HTS); price erosion
- High competition

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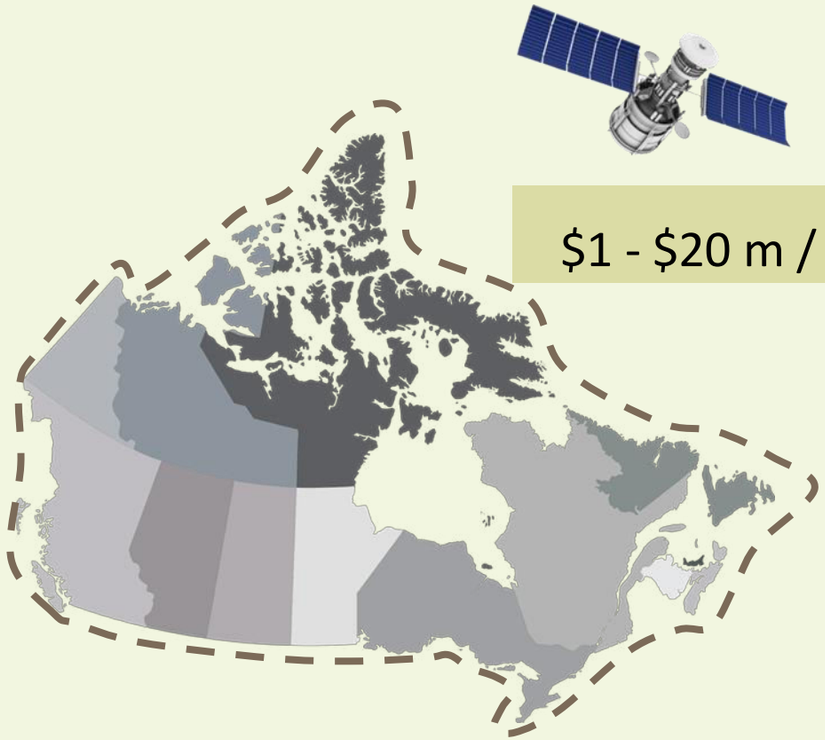
Orbital Characteristics

	Geostationary Orbit (GEO)	Medium Earth Orbit (MEO)	Low Earth Orbit (LEO)
Coverage	Very large	Large	Small
# Satellites to cover earth	3	5+	100's+
Latency	~500 msec	~150 msec	~50 msec
Orbital period	24 hrs	~130 min	~90 min
# Ground stations	Few	Several	Many
User terminal antenna	Stationary	Slow tracking (1 hour)	Fast tracking (8+ minutes)
Satellite lifetime (years)	15-20	10-15	5 - 10
Cost to deploy	~$1 bn	~$1 - $1.5 bn	~$2 - $12 bn

LEO, MEO are referred to as NGSO: Non-geostationary Satellite Orbits

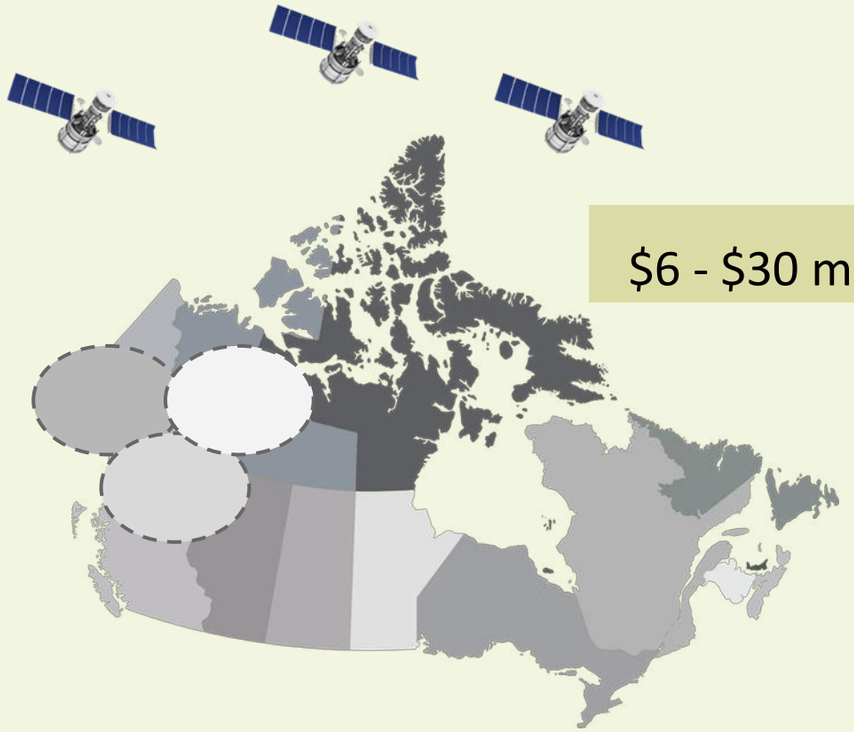
Why LEO?



$1 - $20 m / Gbps

GEO

- Efficiency
- Less complexity



$6 - $30 m / Gbps*

LEO

- Latency: 50 vs. 500 msec (RTT)
- “Portability”
  - Terrestrial waveforms (LTE, NB-IoT, 5G, LoRa, etc.)
  - Mobility, useability, integration with the Internet

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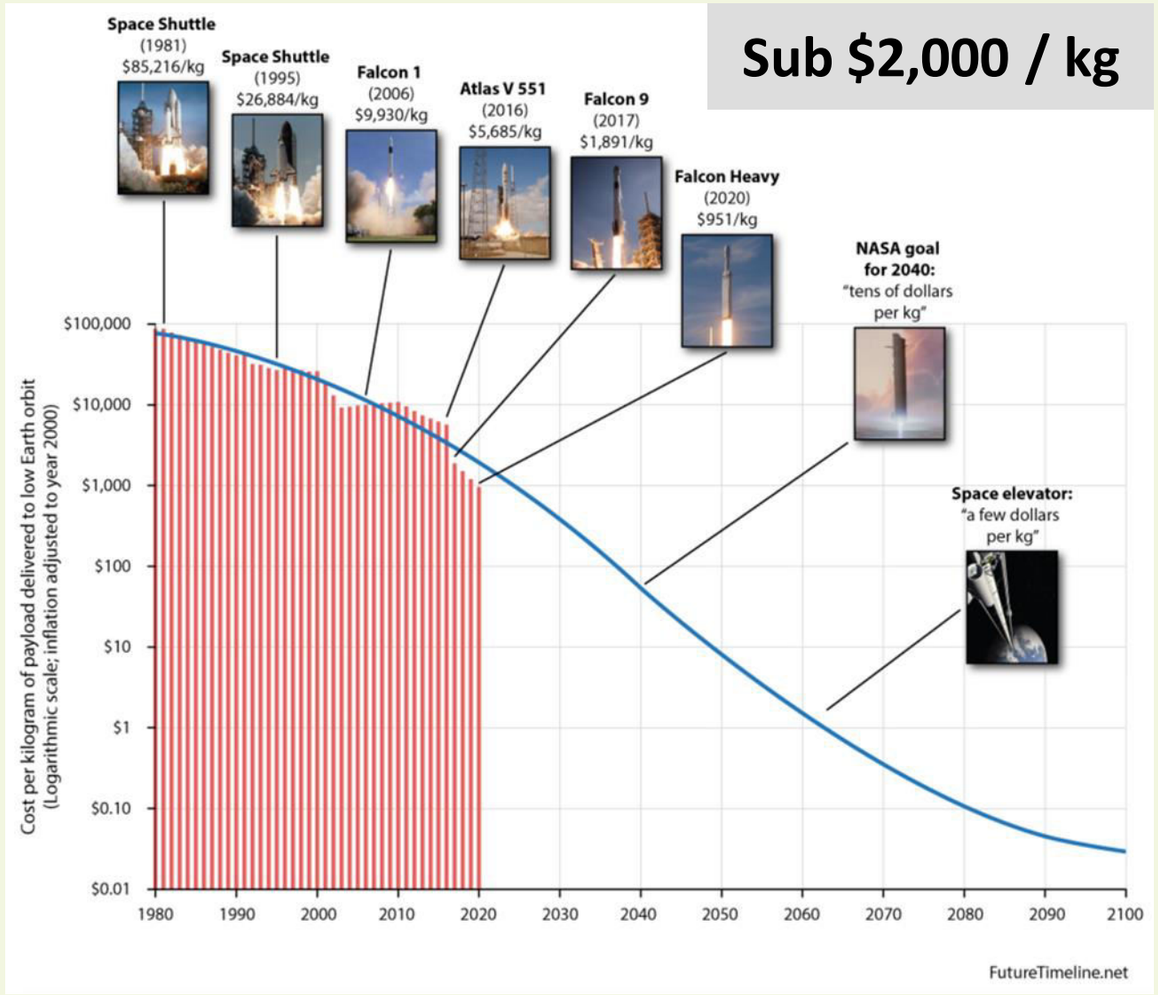
* Based on LEO satellite constellation utilization of 10% and lifespan of LEO being 50% of GEO

Launch Costs To Low Earth Orbit



Sub $2,000 / kg

SPACEX
BLUE ORIGIN
ASTRA
VECTOR
FIREFLY AEROSPACE
ISPACE
GALACTIC ENERGY
Relativity
Masten
ROCKET LAB
Virgin GALACTIC
ARCA
GILMOUR SPACE
OIOO Zero 2 Infinity
MITSUBISHI HEAVY INDUSTRIES
JAXA
CASC 中国航天
इसरो isro
arianespace arianeGROUP
ROSCOSMOS
ILS
ULA

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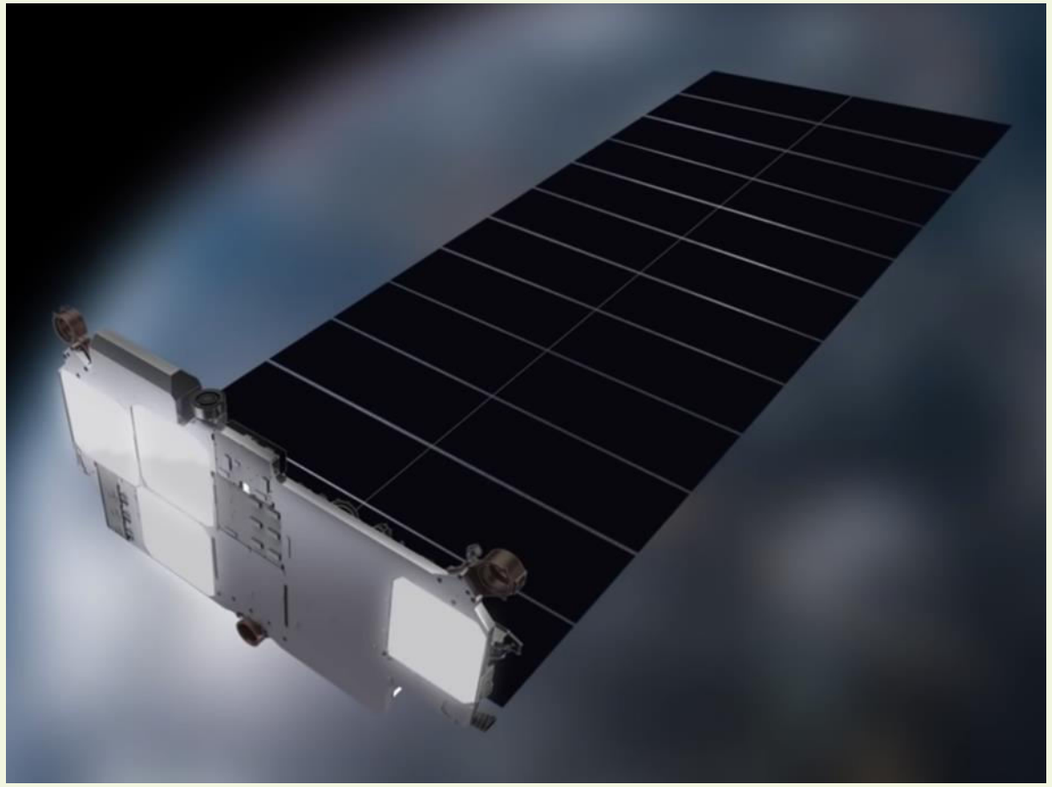
The Satellites: SpaceX

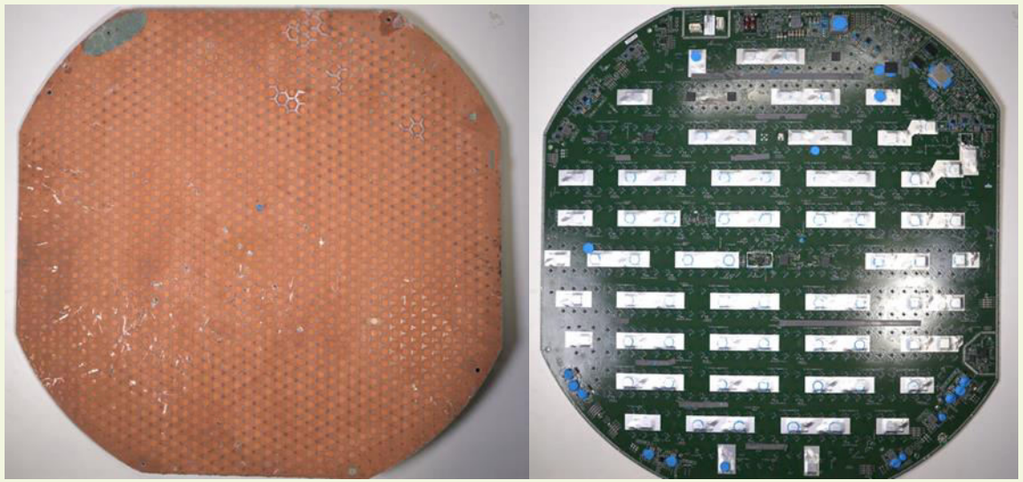
Satellite Specifications	
Altitude	550 km
Weight	260 kg
Throughput	17 - 23 Gbps; average: 20 Gbps (downlink)
Orbit	53°
Service coverage	57°S - 57°N
Orbital period	96 minutes
Speed	7,550 m/s
Coverage radius	574 km
# User Beams	UL: 7; DL: 3
Lifetime	5 years
Cost (est.)	$300,000+
Launch cost (est.)	$120,000 - $460,000 / satellite+



- 1578 satellites in orbit [as of May 16, 2021]
- 13 Launches already completed in 2021
- ~200 ground stations projected in the US

The User Terminal: SpaceX

User Terminal Specifications	
Antenna	Flat phased array antenna; 1247 active elements; 50° scan angle
Size	555 mm x 41 mm thick; < 3.5 kg
Throughput	100+ Mbps download/40 Mbps upload
Power	254 W peak (40 msec); 129 W average
RF Power	4 W
Frequency	Downlink: 10.7 - 12.7 GHz Uplink: 14 - 14.5 GHz
Connectivity	Ethernet; 802.11ac 2x2 Wi-Fi
Cost (est.)	$3,000 in very small volume; $1,500 current cost*
Price	$499



Key Differentiations Among LEO Constellations

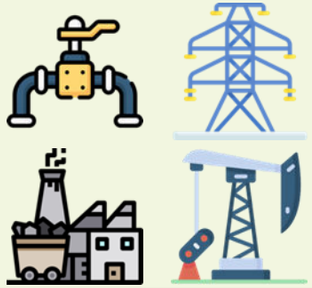
	SPACEX	KUIPER	ONEWEB	TELESAT
No. of Satellites [Deployed]	4,408 [1578]	3,236	716 [182]	298
Altitude (km)	540 - 570	590; 610; 630	1,200	1,015; 1,325
Inter-Satellite Link	Version 2	Yes	No	Yes
DL throughput/satellite (Gbps)	20	16	8.8	60
DL / UL User throughput (Mbps)	100 / 40		50 / 25	
Latency (msec; RTT)	20-60	30-60	30-60	30-60
User downlink / uplink band	Ku / Ku	Lower Ka / Upper Ka	Ku / Ku	Lower Ka / Upper Ka
User downlink / uplink bandwidth (MHz)	2,000 / 500	1,300 / 600	2,000 / 500	3,600 / 4,200
Coverage	57°S - 57°N	56°S - 56°N	Global	Global
Orbital planes	Inclined	Inclined	Polar and inclined	Inclined and polar
Cov. radius / satellite (km)	573.5	704.7		
Lifespan (years)	5	7	10	10

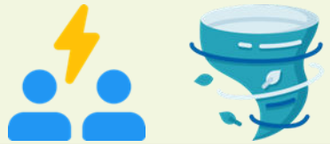
Differentiation:

- Spectrum rights
- Antenna capabilities
- Throughput and capacity
- Orbital planes, coverage
- Lifespan
- On-board processing/routing
- Inter-satellite links

⇒ Use cases; applications; markets

Use Cases for Communication LEO Satellites





Transport	Connectivity	Verticals	Moving / Offshore	Critical Comms.	Government
Mobile Backhaul	Global Enterprise Connectivity	Mining	Maritime - Cruise Ships	Emergency Service & Disaster Recovery	Government - Digital Inclusion
Complement of Submarine Cables	IoT Connectivity	Oil & Gas	Maritime - Commercial Shipping		Government - Diplomatic Communications
	Consumer broadband	Transportation	Aircraft Connectivity		Government - Border Control & Protection
			Train Connectivity		Government - Military & Defence

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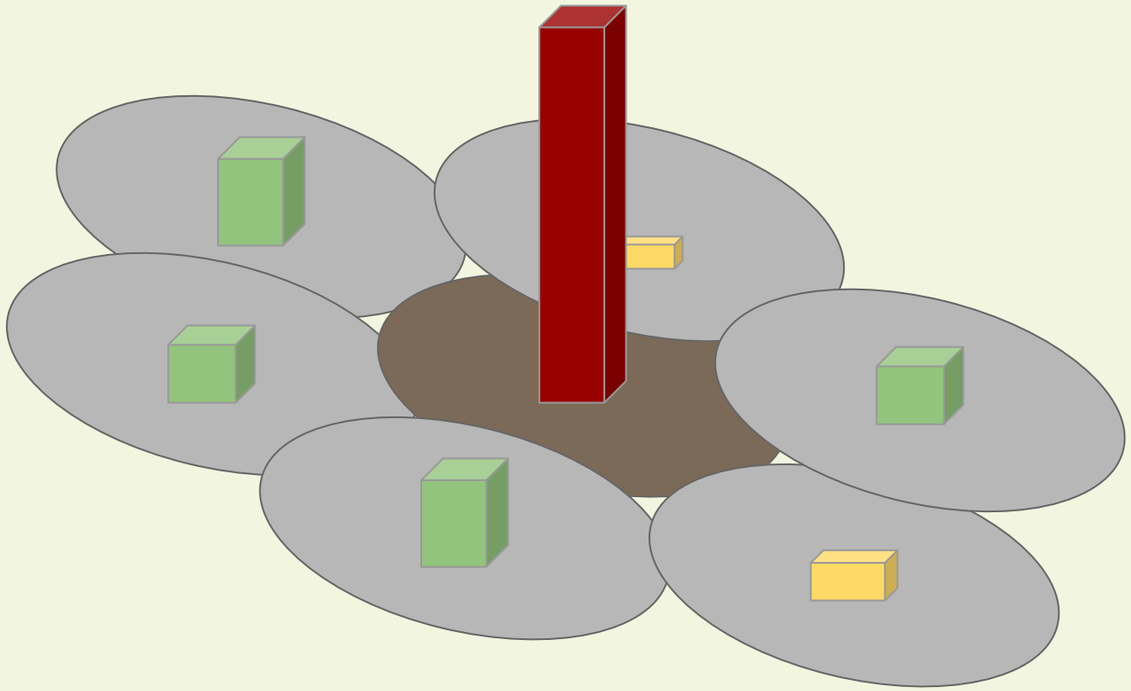
Utilization Factor

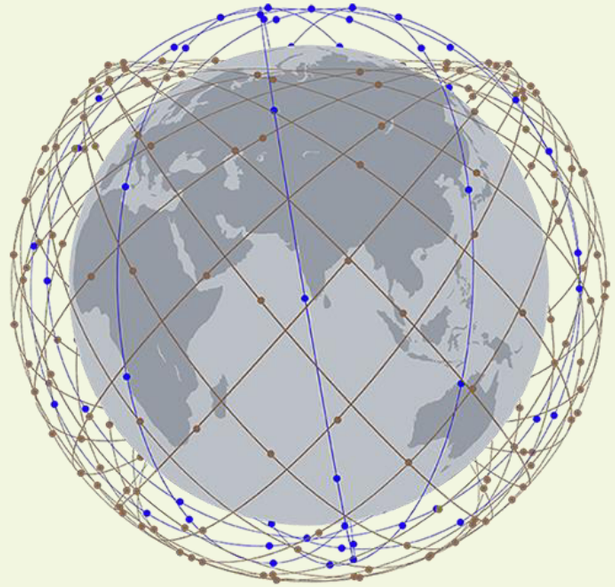
- Water: 71%
- Land: 29%
- 95% world's pop in 10% the land[1]
- 10% of land is classified as remote (> 48 hrs from large city)[1]
- Iridium utilization: 4-5%
- LEO utilization: 4% ≤ X ≤ 25%
  - 75% or more of the satellites are idle

➔ How to service ships and aircrafts?
➔ What impact will they have on the business case?

Demand and Offered Capacity

How to serve a location with high traffic demand?





20 Gbps / satellite:

- ~20,000 users; 100 GB plan
- ~3,000 users; 100 Mbps service

More satellites; or

⇒ Steerable, shapeable antennas

The Business Lifecycle

Build and Launch

- Raise financing
- Obtain rights for spectrum and orbital position
- Procure/reserve launch service
- Design & build the satellites
- Obtain landing rights in countries where service will be offered
- Market services; pre-book/sell capacity

Operate

- Monitor satellite performance
- Operate and maintain ground stations
- Market and sell services
- Manage churn

Refresh

- Deorbit old satellites
- Launch replacement satellites

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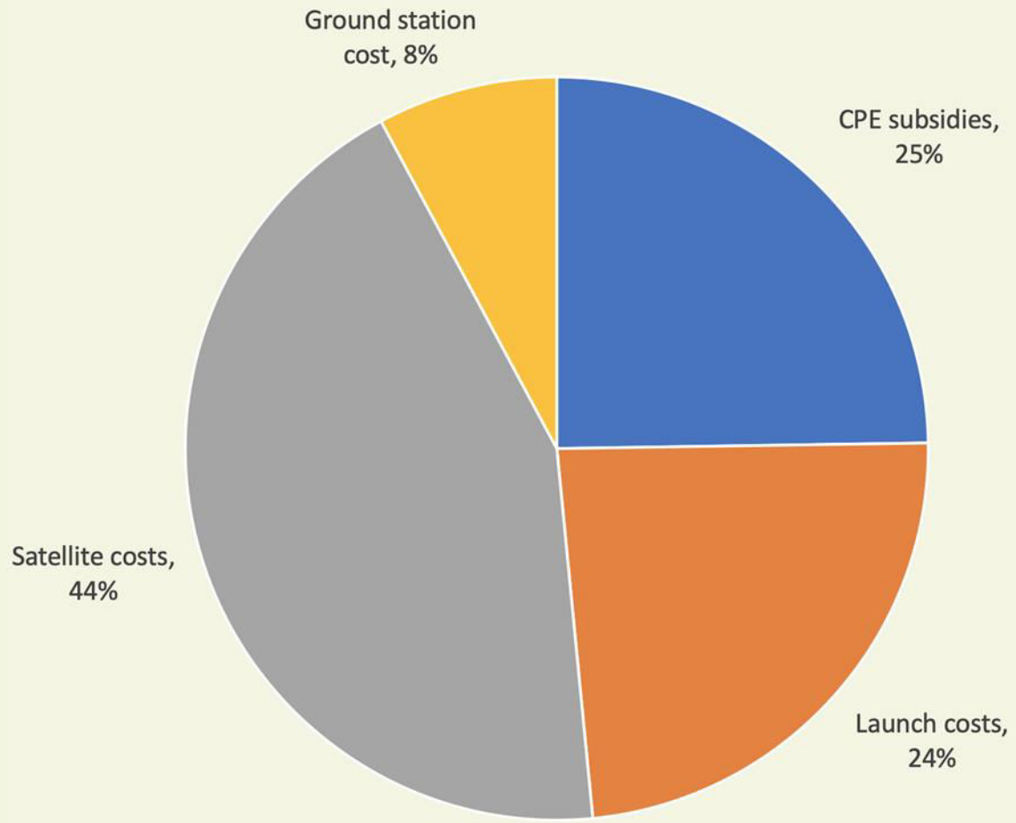
Financial Model: Scenario Illustration

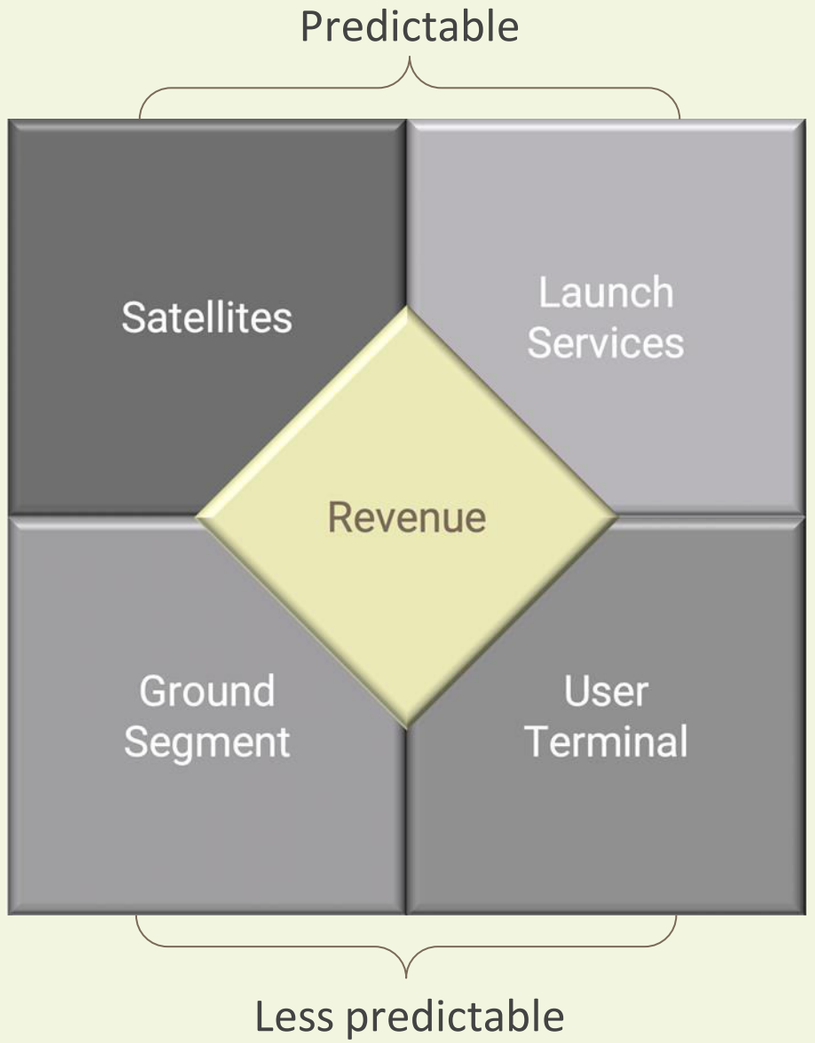
LEO Constellations require *very patient* investors

- High initial capital investment
- Long time to breakeven
- Increase utilization to reduce risk
- Appropriate cost/performance tradeoff: revenue driver

Business Case Drivers

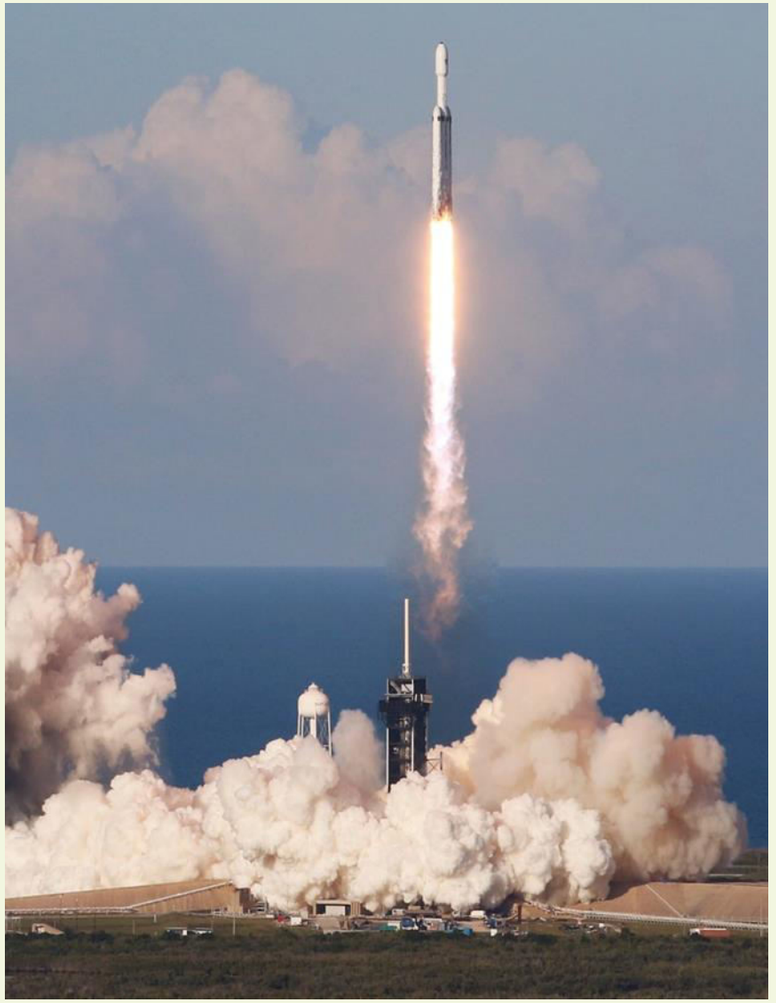


Cost allocation for large access constellation in a specific growth scenario; different constellations and deployment scenarios lead to different outcomes



Business Challenges

- Long lead-time: years before service launch
- Trade-offs and “balanced equilibrium”: market penetration, end-user terminal cost, quality of service and throughput requirements, pricing, landing rights, orbital and spectrum management
- Space debris, space collisions, astronomical light pollution
- Funding: High-capex; periodic replenishment
- Business model risk: build it, but will they come?



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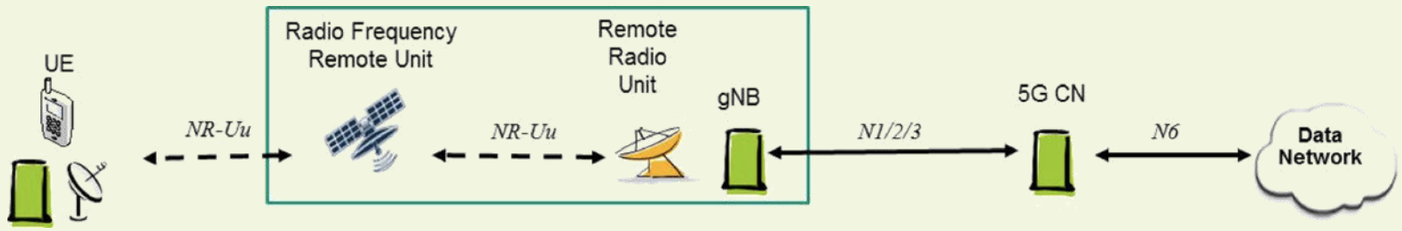
Trends: 5G - Satellite Integration [Non-Terrestrial Networks]

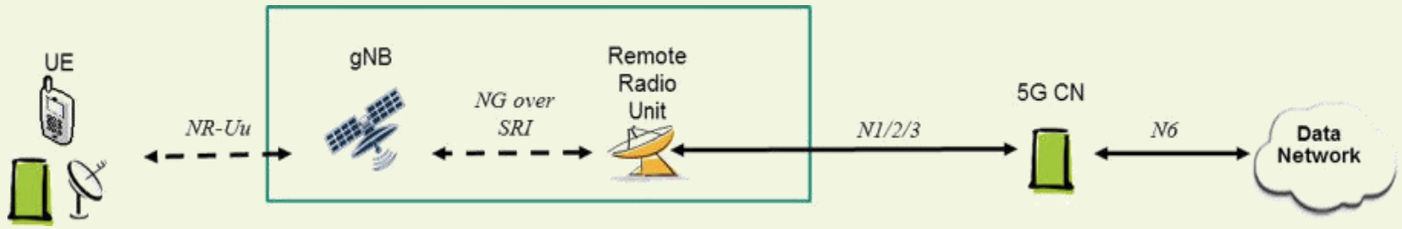
- 3GPP is following a user-centric approach
  - Satellites designed to work with user devices, not vice versa
- Target Release 17 (3/2022)
- Topics
  - Random access
    - PRACH format; RACH protocol and procedures
  - Synchronization
    - Timing & frequency acquisition
    - Uplink timing advance and alignment
  - HARQ
  - Extended system information; Common signaling
  - User plane enhancements: timers, packet reordering during handovers

5G-LEO integration is not too complex!

Reference Architectures (examples; more available, e.g. split architectures, ISL)



Transparent Satellite



Regenerative Satellite

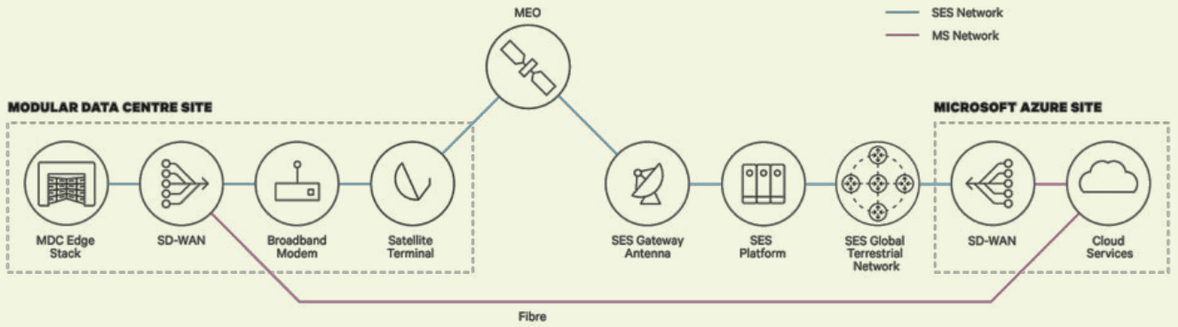
Source: TS 23.737

Trends: Edge Computing; Cloud Integration

Data center as ground station

- AWS Ground Station
- Microsoft Azure Orbital (SES, SpaceX)
- Google Cloud (SpaceX)

Bypass telco in part of value chain: direct connectivity to data center



[Modular] Data center connectivity; SD-WAN; Security; Enterprise cloud migration

- Pay-per-use
- Integration with cloud services
- Quick access to data
- Lower infrastructure costs

Emerging areas:

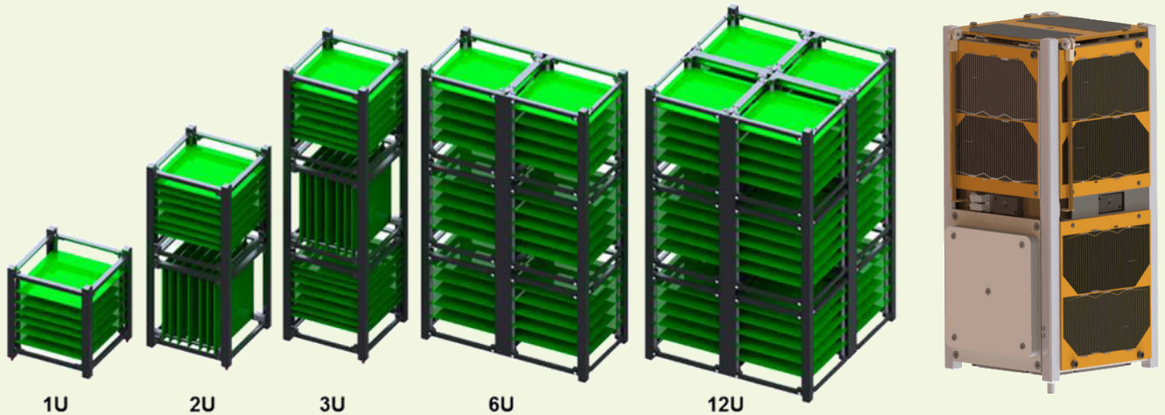
Software-defined satellites?

Compute, storage on satellite?

Trends: CubeSats

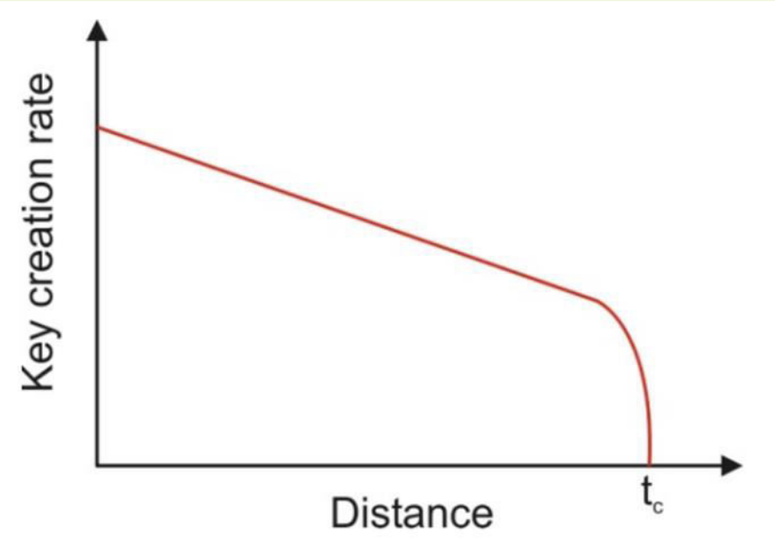
- Cubesat Standard: 1999, California Polytechnic State University & Stanford University for access to space for university students
- Includes all subsystems available in large satellites
- First launch: 2003
- Launches accelerated beginning 2013 (Planet, Spire)
- Most popular form factor: 3U
- Up to 4-5 year lifetime
- Use cases: Earth observation, remote sensing, IoT/M2M

1U: 10 x 10 x 10 cm^3
Weight: < 1.3 kg
Average power: 1 W; peak power: 2-3 W

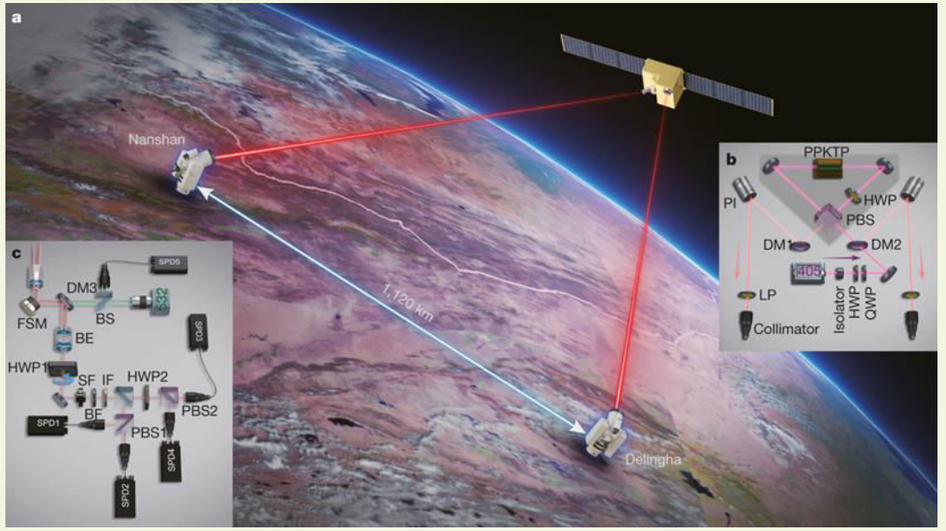


Lacuna (LoRa)
6U: 30 x 20 x 10 cm^3

Trends: Quantum Key Distribution (QKD) from Satellites



- Simultaneous transmission of keys
- Extend the applicability of QKD over terrestrial optical fiber links (~100 km)
- Global reach with LEO satellites through free-space optics

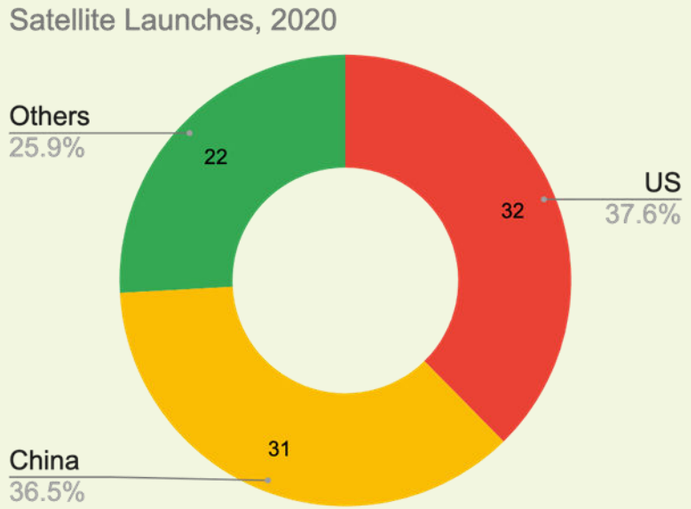


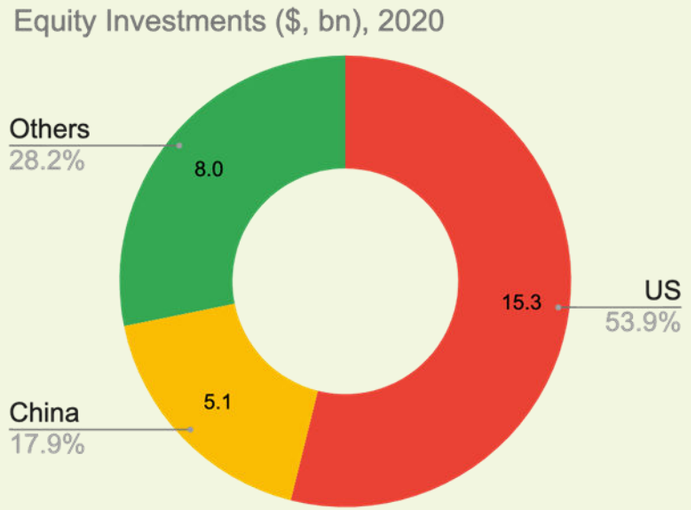
- Entanglement-based QKD
- Tests successfully reached 1,120 km

Trends: Rising Geopolitical Conflicts

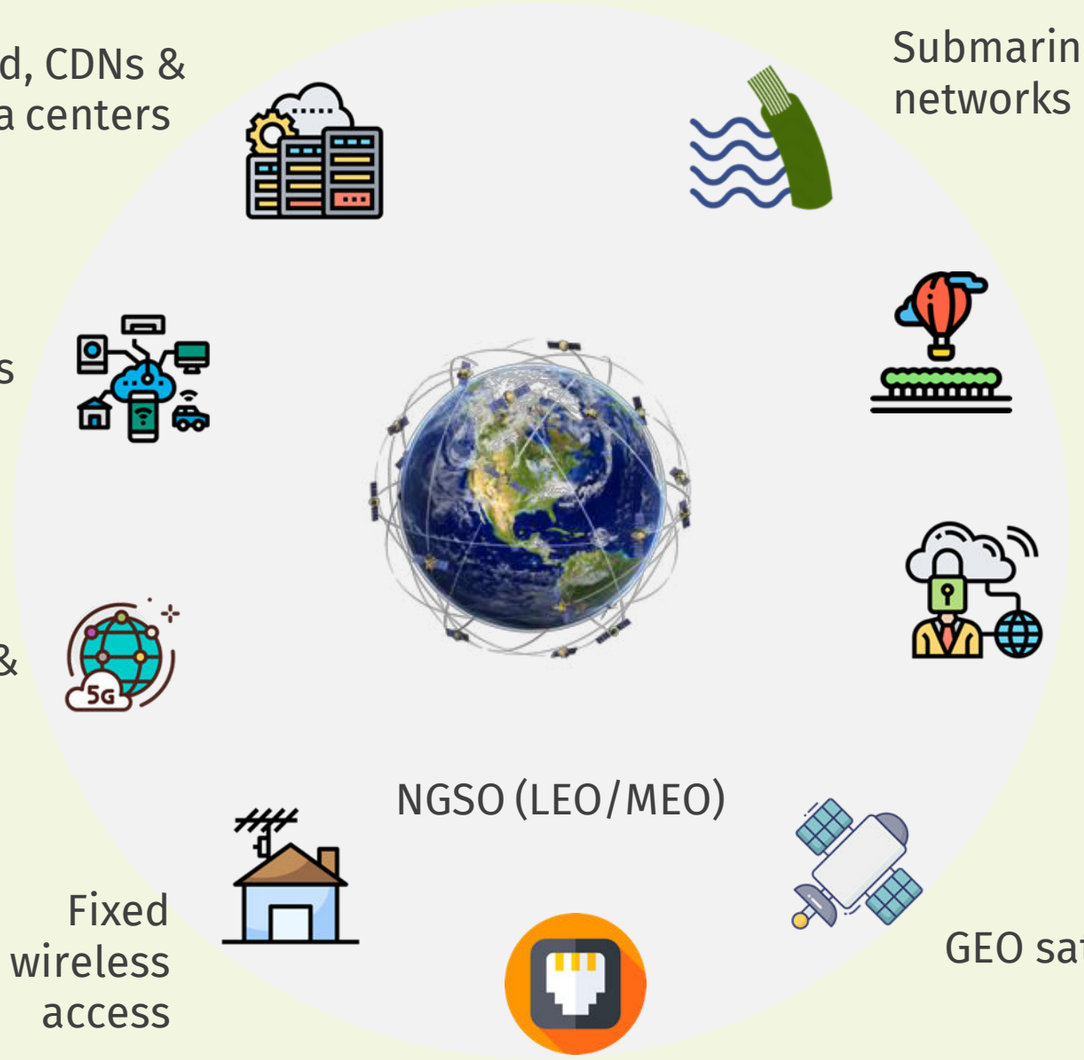
- China currently plans for multiple constellations
  - Hongyan: 320 satellites; China Aerospace Science and Technology Corporation (CASC)
    - Maritime, aviation, mobile backhaul
  - Hongyun: 864 satellites; China Aerospace Science and Industry Corporation (CASIC)
    - Remote area connectivity
  - Yinhe: 1,000 satellites; Galaxy Space [private]
    - IoT
- State-owned constellations would be organized under one "national network": Guowang (GW)
  - ITU filings for 12,992 satellites

Bifurcation of LEO constellations appear inevitable: harmful to the value proposition for all participants





Land-Space Internet Convergence

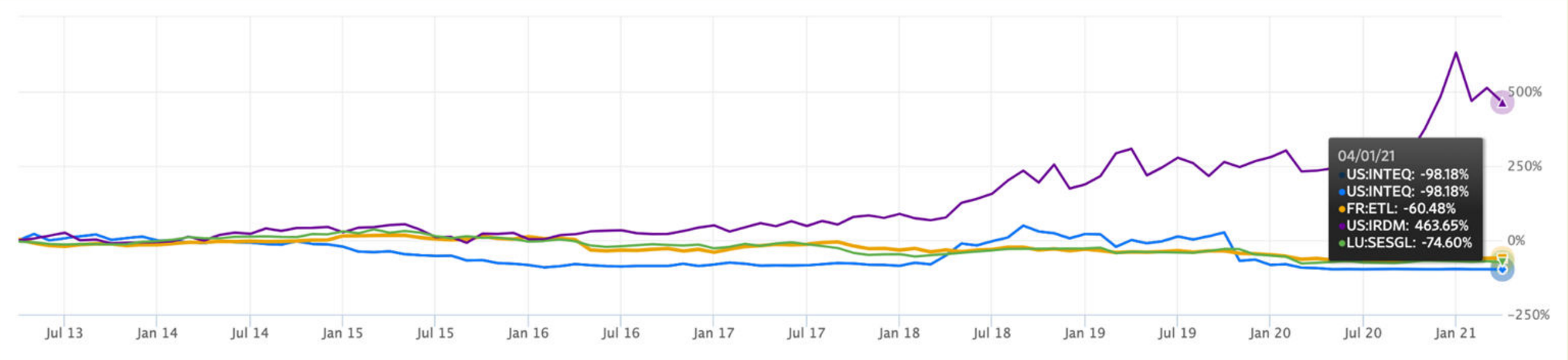


LEO Satellite Constellations [As of May 16, 2021]

Country	Constellation	Max Satellites	Satellites in orbit
	SpaceX Starlink	42,000	1,578
	Guowang (GW)	12,992	0
	Amazon Kuiper	3,236	0
	Hongyun	864	1
	OneWeb	716	182
	Hongyan	320	1
	Kleo	300	0
	Telesat	298	1
	AST SpaceMobile	243	1
	Lacuna	240	5
	Kepler	140	15
	Fleet	140	4
	Lynk	40	4
	Kineis	25	8

Source: Companies; Xona Partners Inc.

Questions?



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