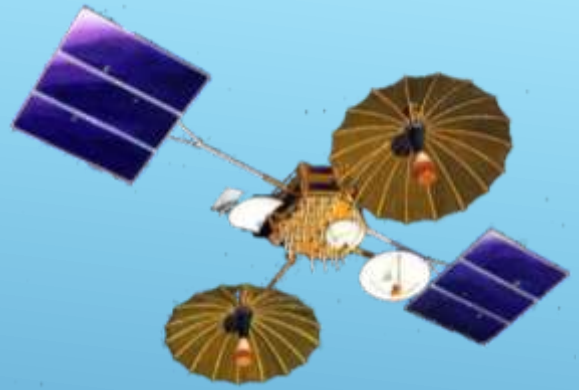


Polar Networking

A View from Layer 1

Presented to the NITRD JET by

Patrick Smith

NSF/OPP/AIL

21 May 2019

SATCOM Issues: Polar Regions are not a Market Driver for Commercial Satellite Communications

Construction and launch costs for modern geosynchronous communications satellites are between $200M to $600M. Service lifetimes are nominally 15 years. Satellite operators place satellites in global regions and target service where revenue will be generated to produce a positive return on investment for shareholders:

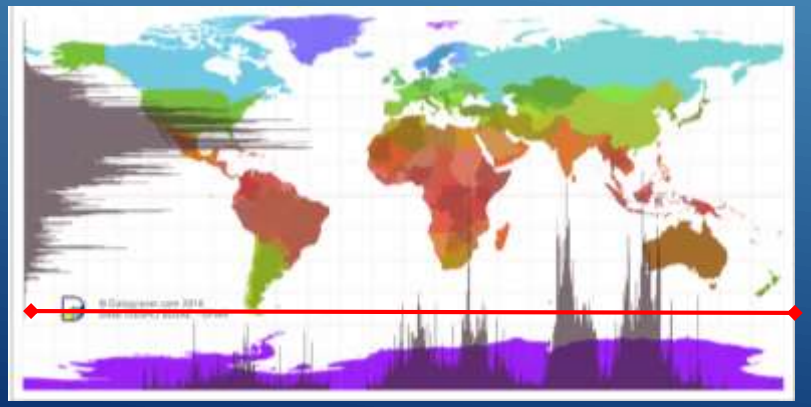
- Land masses with high population densities
- Global shipping and airline routes
- FCC requires operators to provide service between 70°N to 55°S

- *Latitude > 54°S (Tierra del Fuego)*
  - → *Not many people*
  - → *Not many ships*
  - → *Not many aircraft*
  - → ***NO SUBSTANTIVE REVENUE***

Global shipping route maritime traffic density

∴ *Operators are marginally interested in the Arctic and not incentivized to provide service to Antarctica*

World population distribution by latitude and longitude - 2015

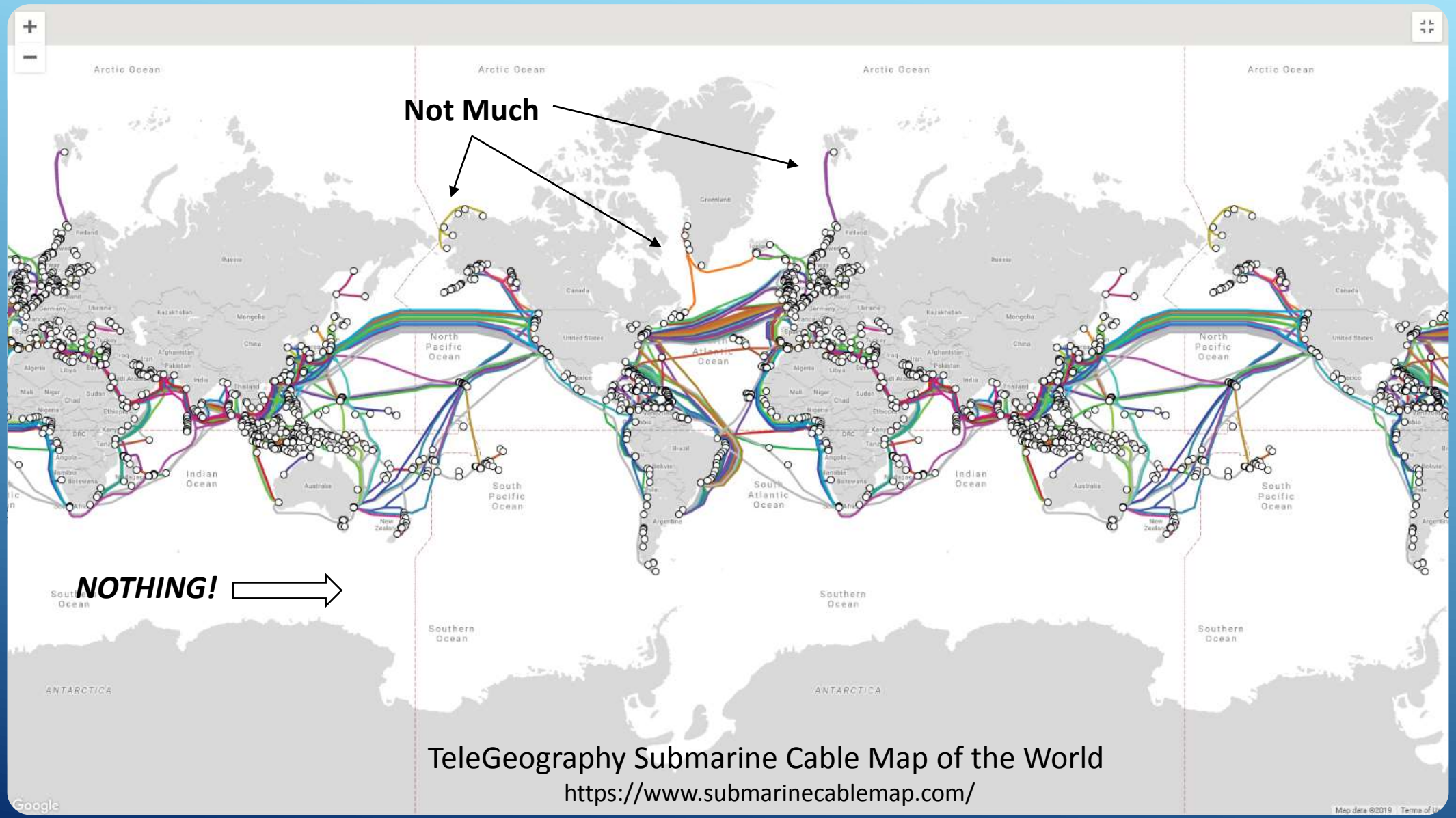


Global air route airline traffic density

Polar Region Satellite Communications Basics

Conventional Geostationary Earth Orbit (GEO) satellites cannot provide coverage at latitudes greater than ± 81°
At greater latitudes, the satellite is obscured by the Earth's horizon.

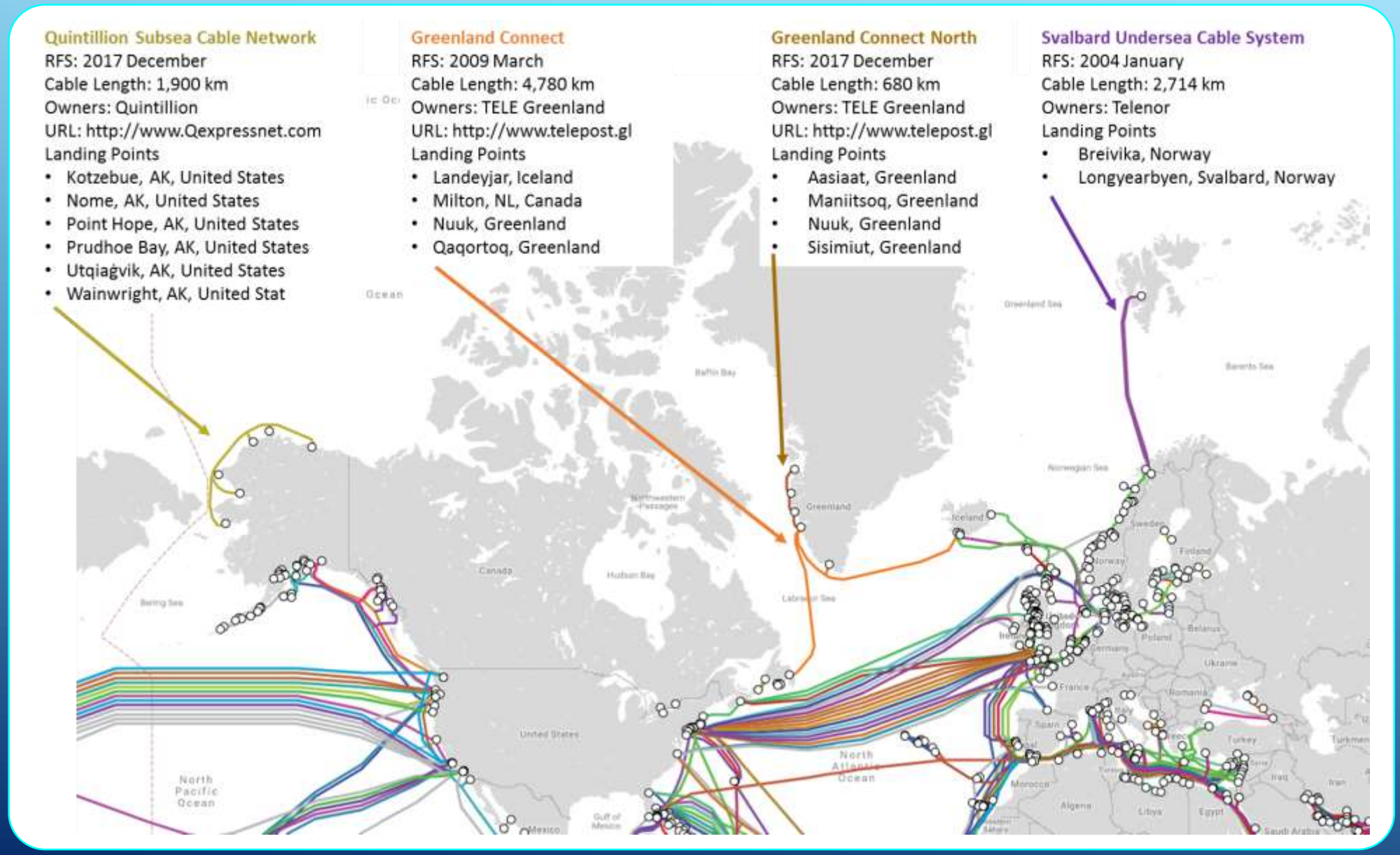
Global Fiber Cable Connectivity Basics



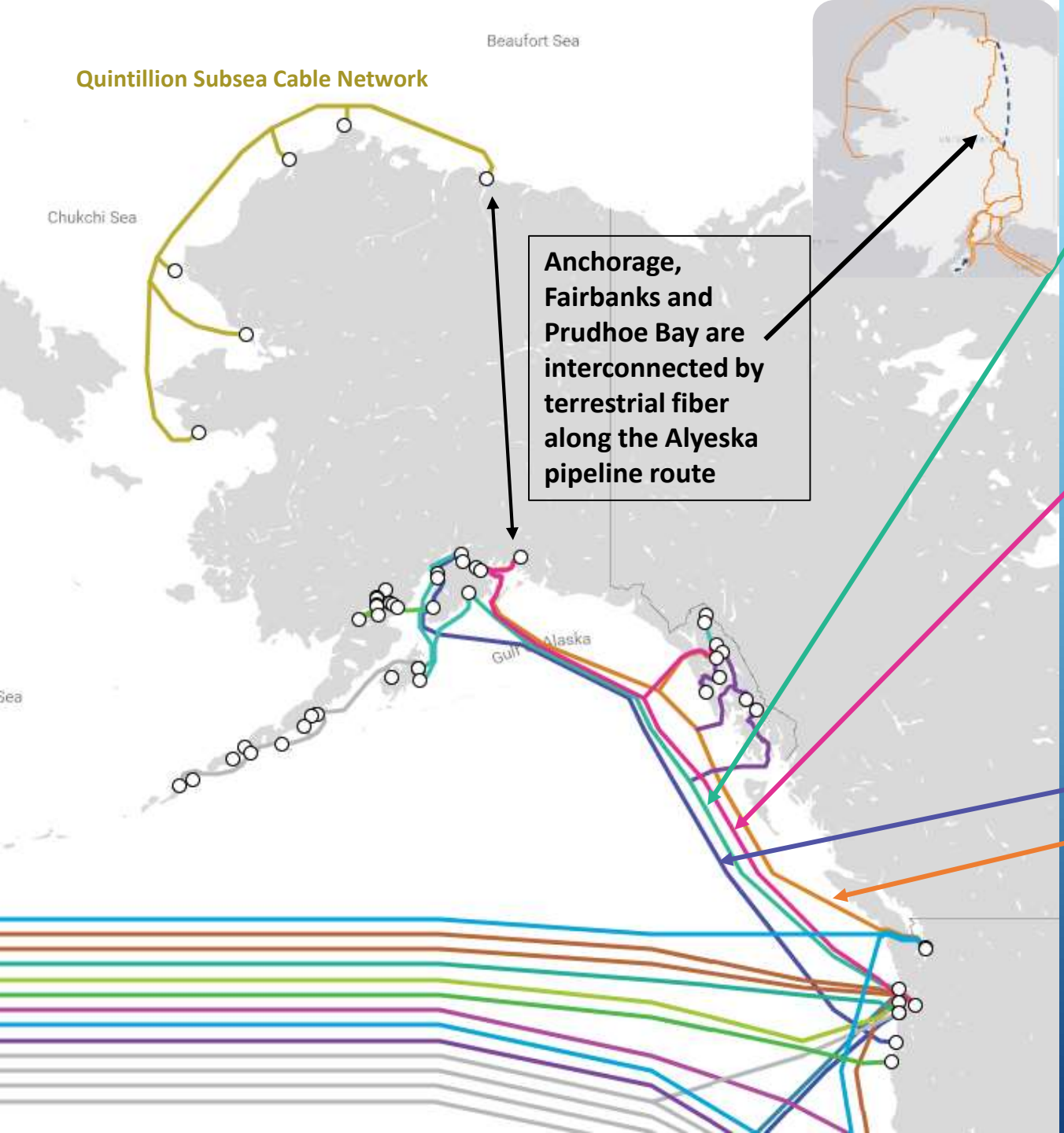
TeleGeography Submarine Cable Map of the World
https://www.submarinecablemap.com/

The North

Undersea Cables Important to the Arctic



Quintillion Subsea Cable Network



Alaska United West
RFS: 2004 June
Cable Length: 2,485 km
Owners: GCI
URL: http://www.alaskaunited.com
Landing Points
- Seward, AK, United States
- Warrenton, OR, United States

NorthStar
RFS: 1999 October
Cable Length: 3,229 km
Owners: Alaska Communications
URL: https://www.alaskacommunications.com
Landing Points
- Hillsboro, OR, United States
- Lena Point, AK, United States
- Valdez, AK, United States
- Whittier, AK, United States

ACS Alaska-Oregon Network (AKORN)
RFS: 2009 April
Cable Length: 3,000 km
Owners: Alaska Communications
URL: https://www.alaskacommunications.com
Landing Points
- Anchorage, AK, United States
- Florence, OR, United States
- Homer, AK, United States
- Nikiski, AK, United States

Alaska United East
RFS: 1999 February
Cable Length: 3,751 km
Owners: GCI
URL: http://www.alaskaunited.com
Landing Points
- Juneau, AK, United States
- Lynnwood, WA, United States
- Valdez, AK, United States
- Whittier, AK, United States

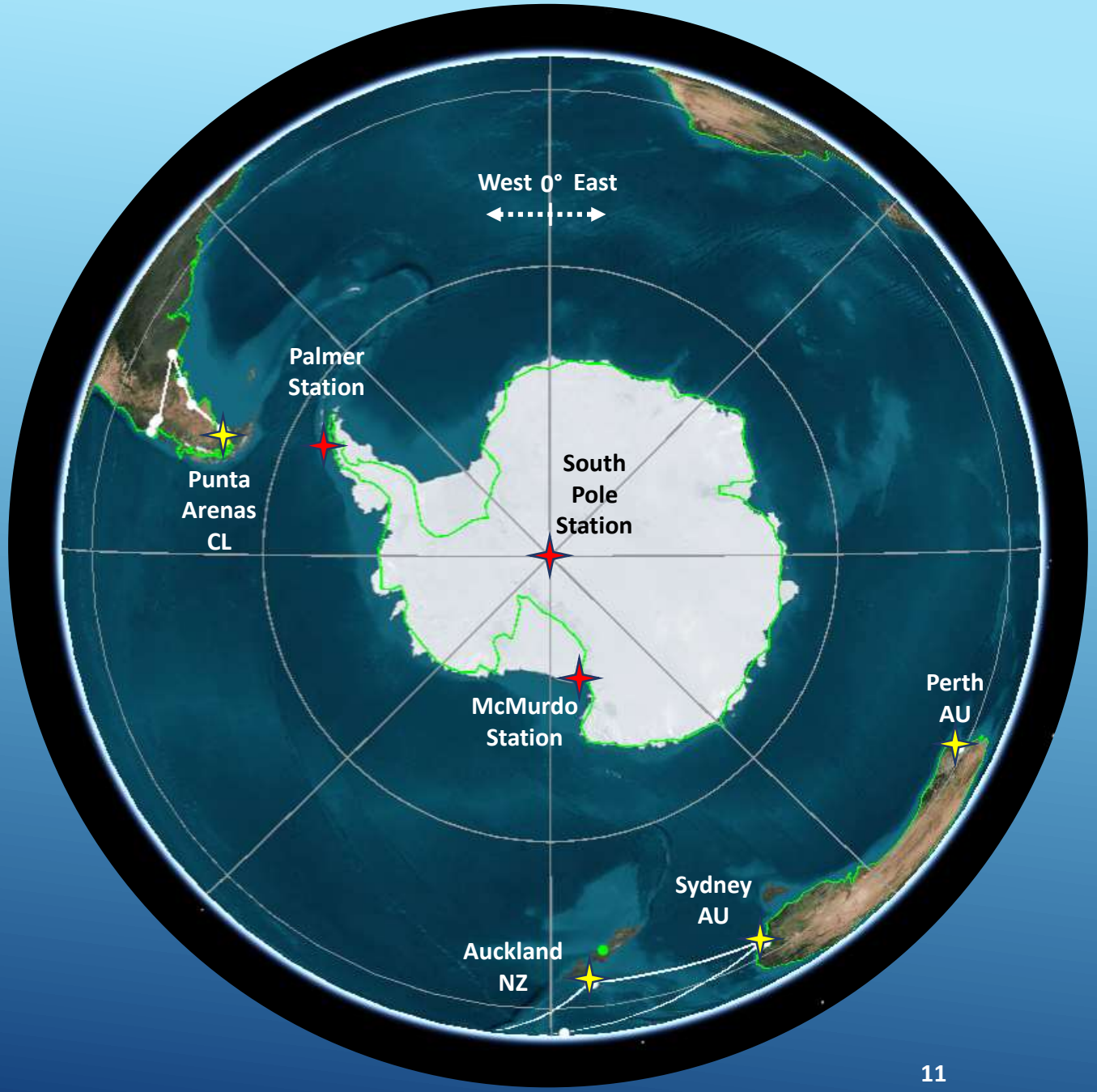
More on Quintillion


71.324926, -156.667292
Barrow Arctic Research Center, Utqiagvik, AK
72.579611, -38.459194
Summit Station, Greenland
SUMMIT STATION
Longyearbyen
Ny Alesund
Thule AFB
Kangerlussuaq
68.627533271, -149.597759041
Toolik Field Station, North Slope, AK
ertial Axes
019 00:10:00.000
Time Step: 600.00 sec

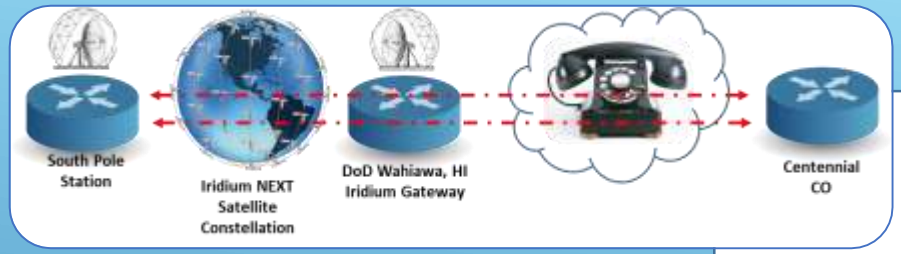
The South

US Antarctic Program

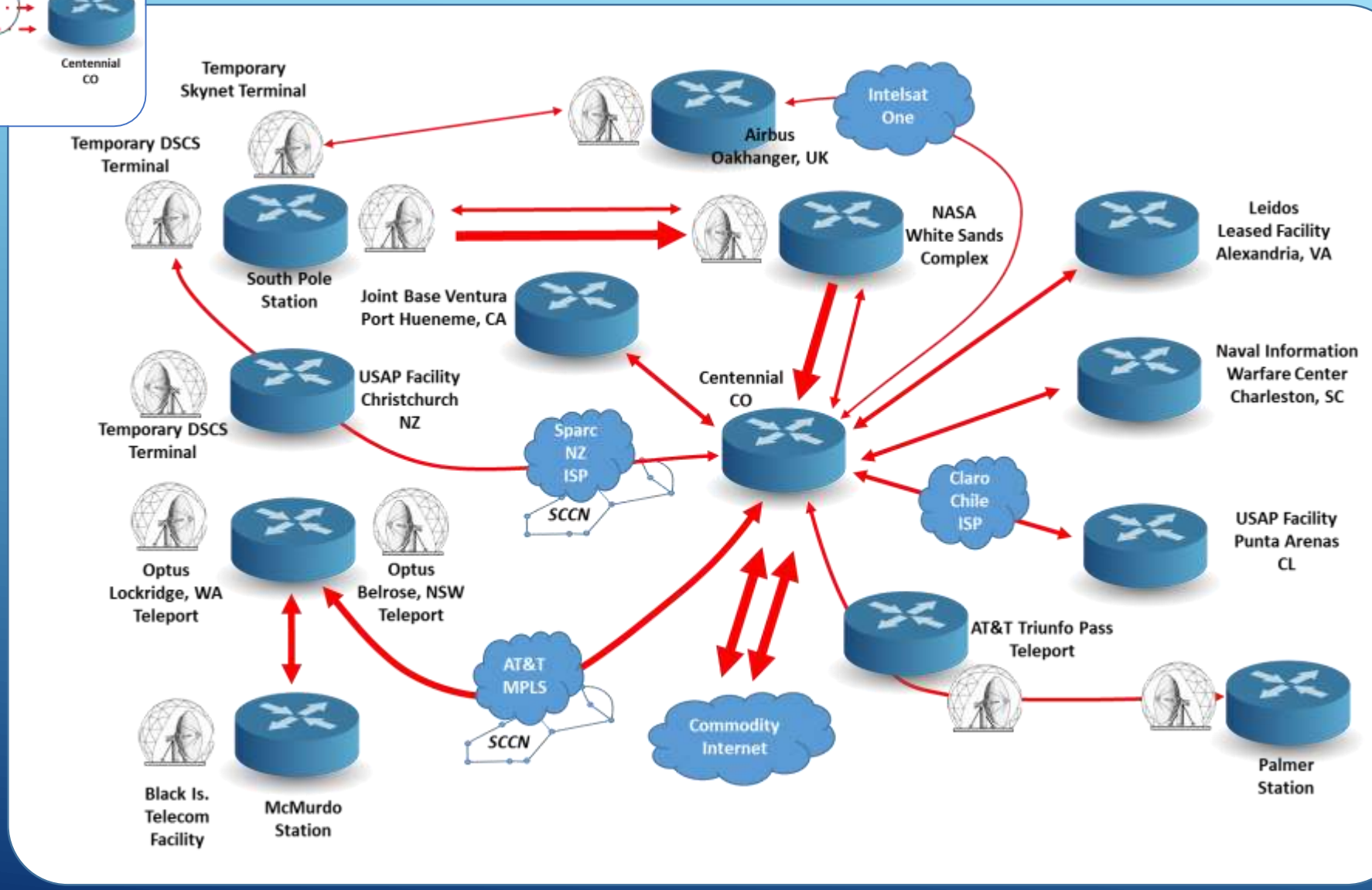
- The National program in Antarctica
- NSF assigned Executive Manager by Presidential Memorandum
  - Three year-round stations
  - Active & influential presence expressed via science research



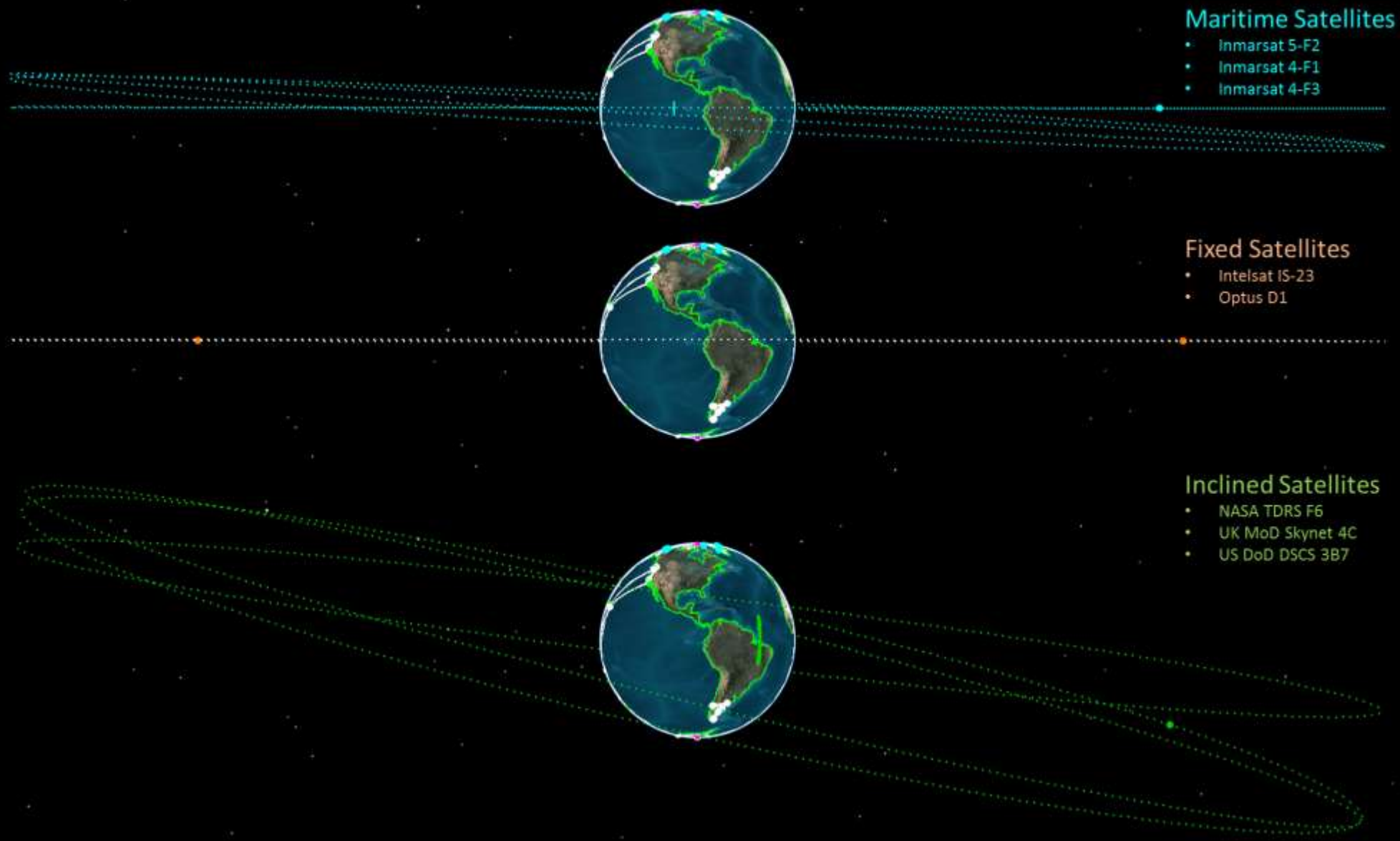
USAP Global Wide Area Private Network



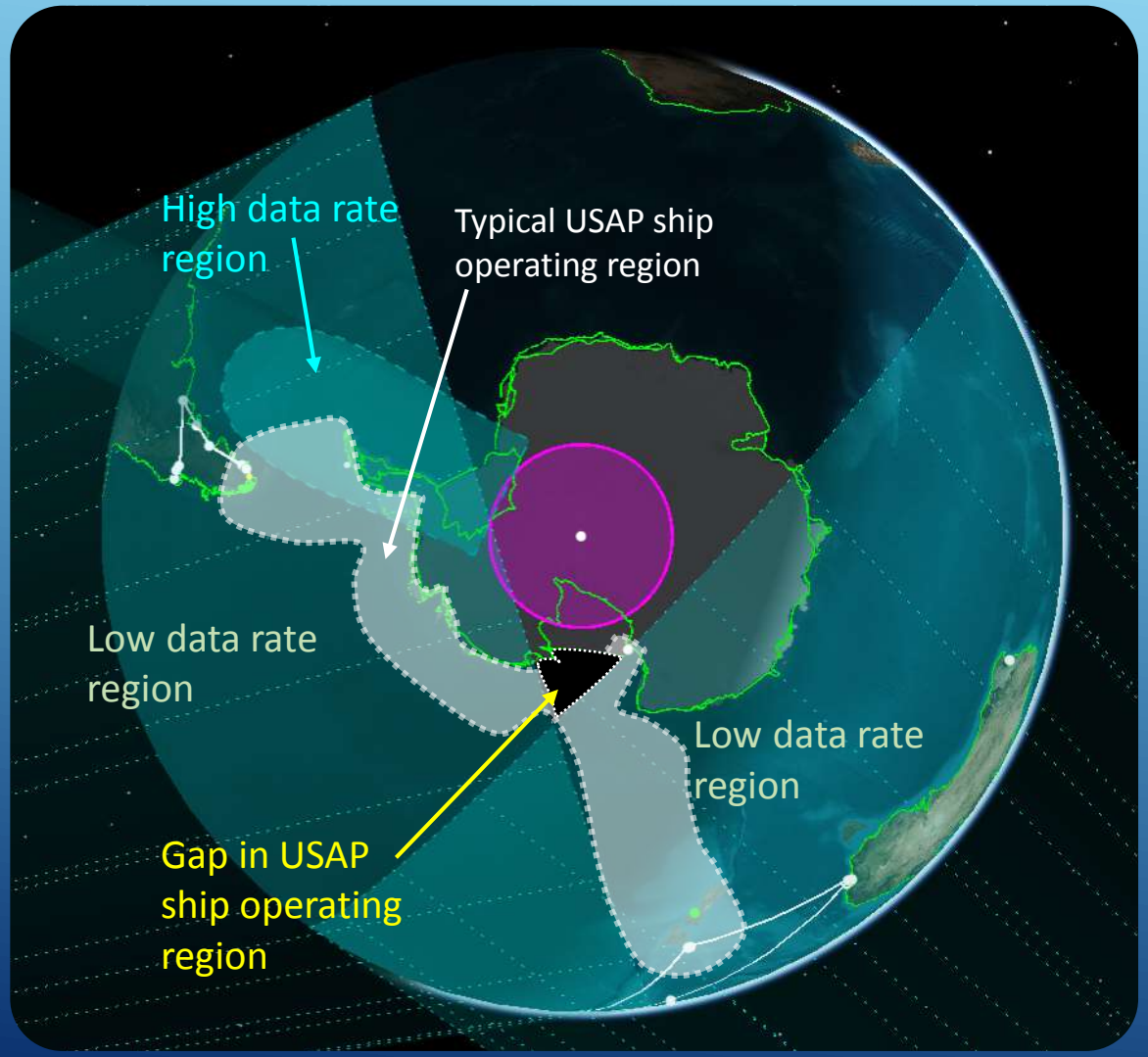
- Centennial: 2 x 200 Mbps
- McMurdo: 18/10 Mbps
- Palmer: 6 Mbps
- South Pole:
  - 2 x 7 kbps
  - 1.5 Mbps
  - 5/225 Mbps
  - 30/10 Mbps
- Port Hueneme: 20 Mbps
- Christchurch: 100 Mbps
- Punta Arenas: 10 Mbps
- Charleston: 6 Mbps
- Alexandria: 20 Mbps



Satellites Supporting US Antarctic Program's Layer 1

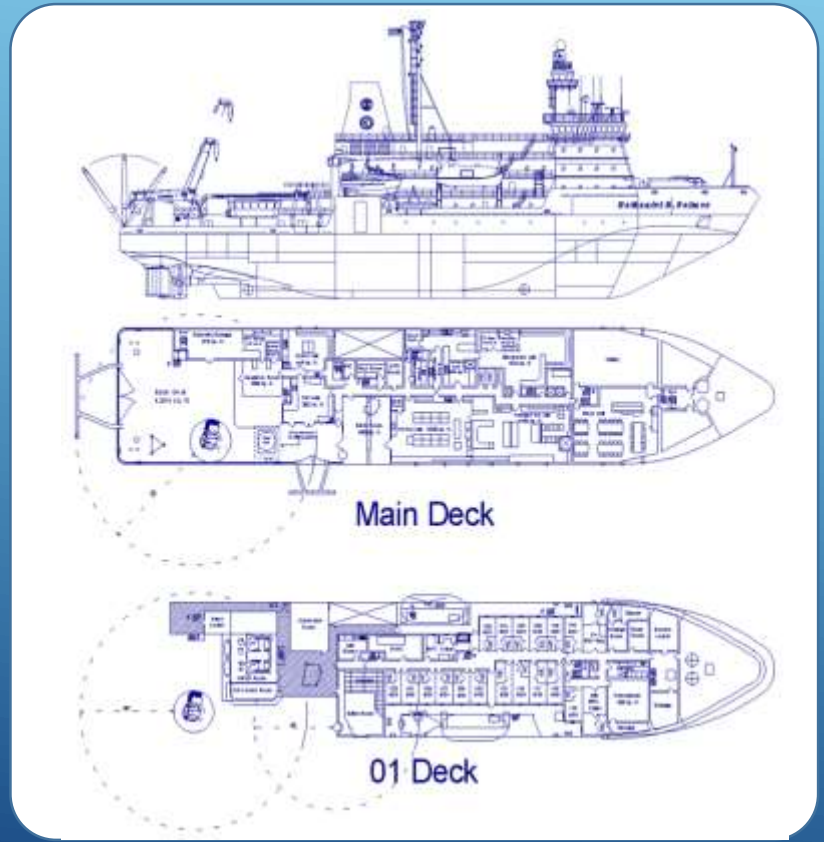


Maritime Networking Constraints



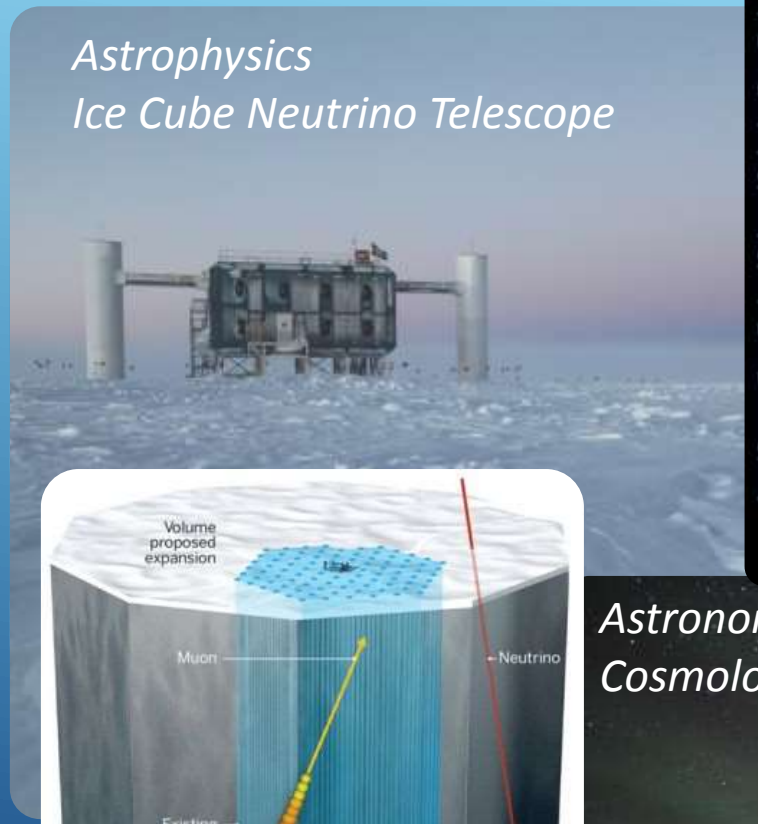
- Deck space limits practical antenna size to ~ 1m
- Satellite availability limits coverage and capacity
- High Rate is modest (2 Mbps/512 kbps)
- OPEX can be an issue

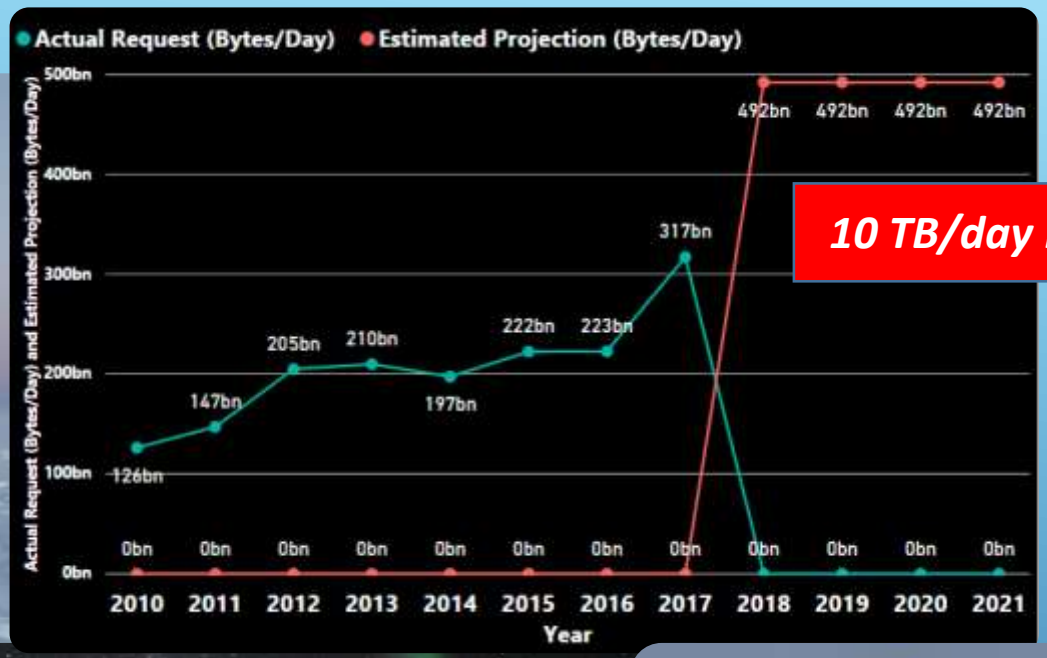
Research Vessel/Icebreaker Nathaniel B. Palmer



South Pole Challenge – Big Science – Big Data

Astrophysics
Ice Cube Neutrino Telescope





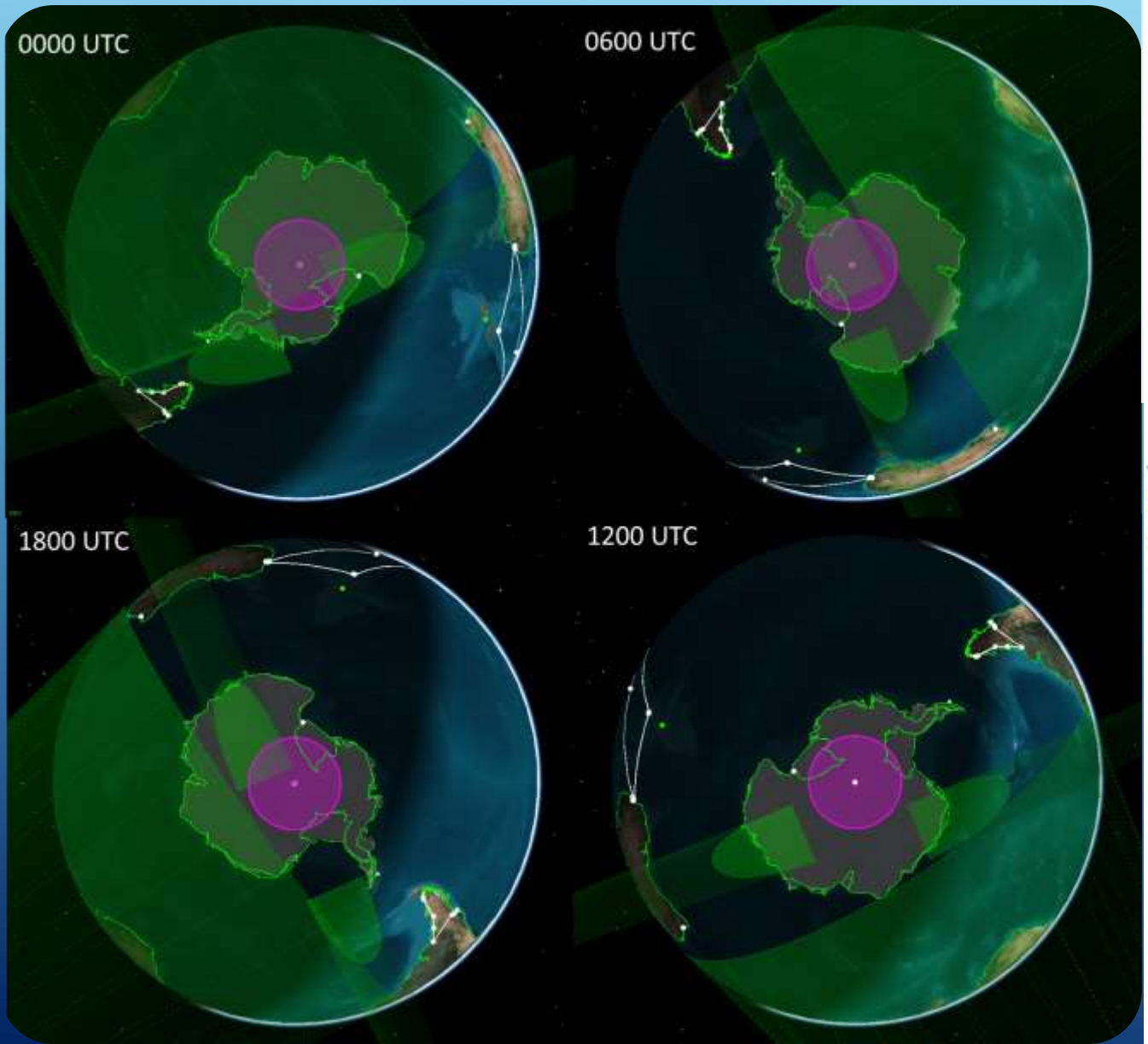
10 TB/day by 2027-ish

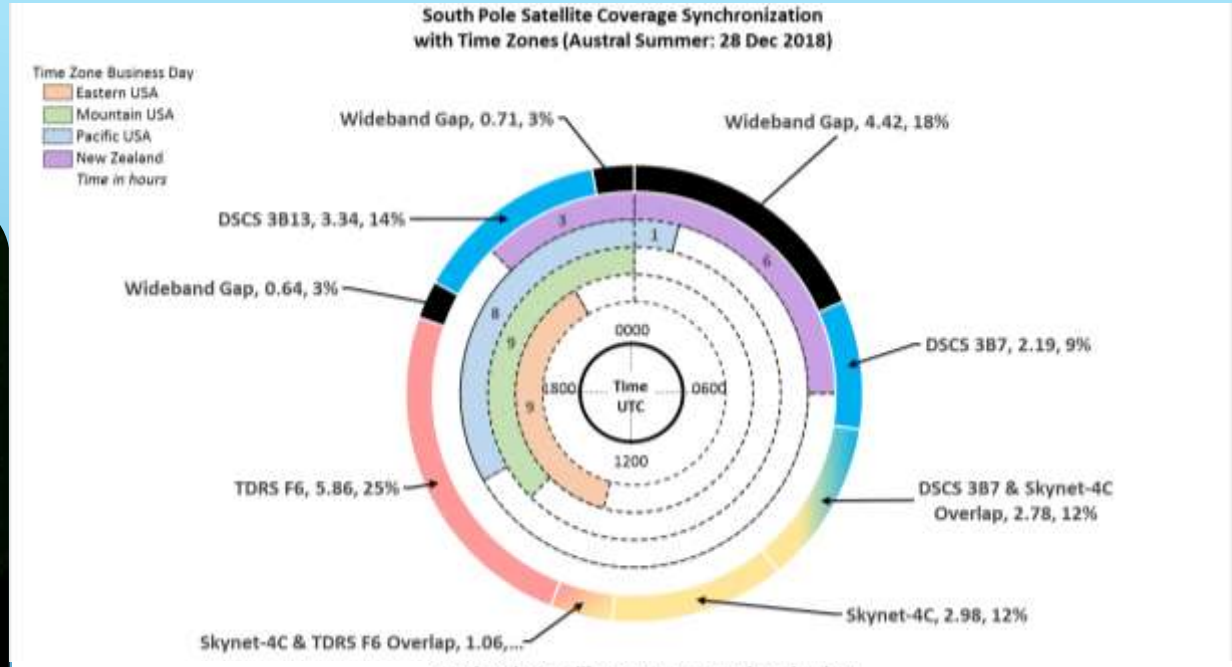
CMB S4 Telescope
Proposed

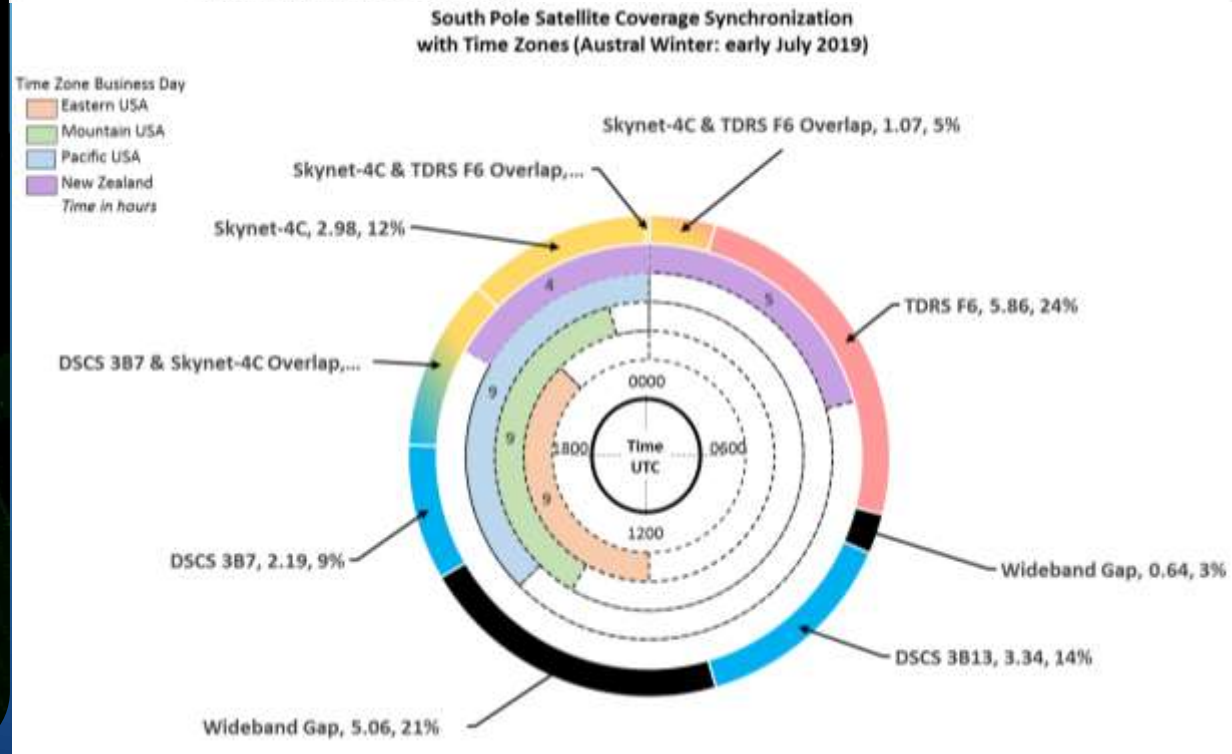
Astronomy
Cosmology – Echoes of the Big Bang

South Pole Telescope

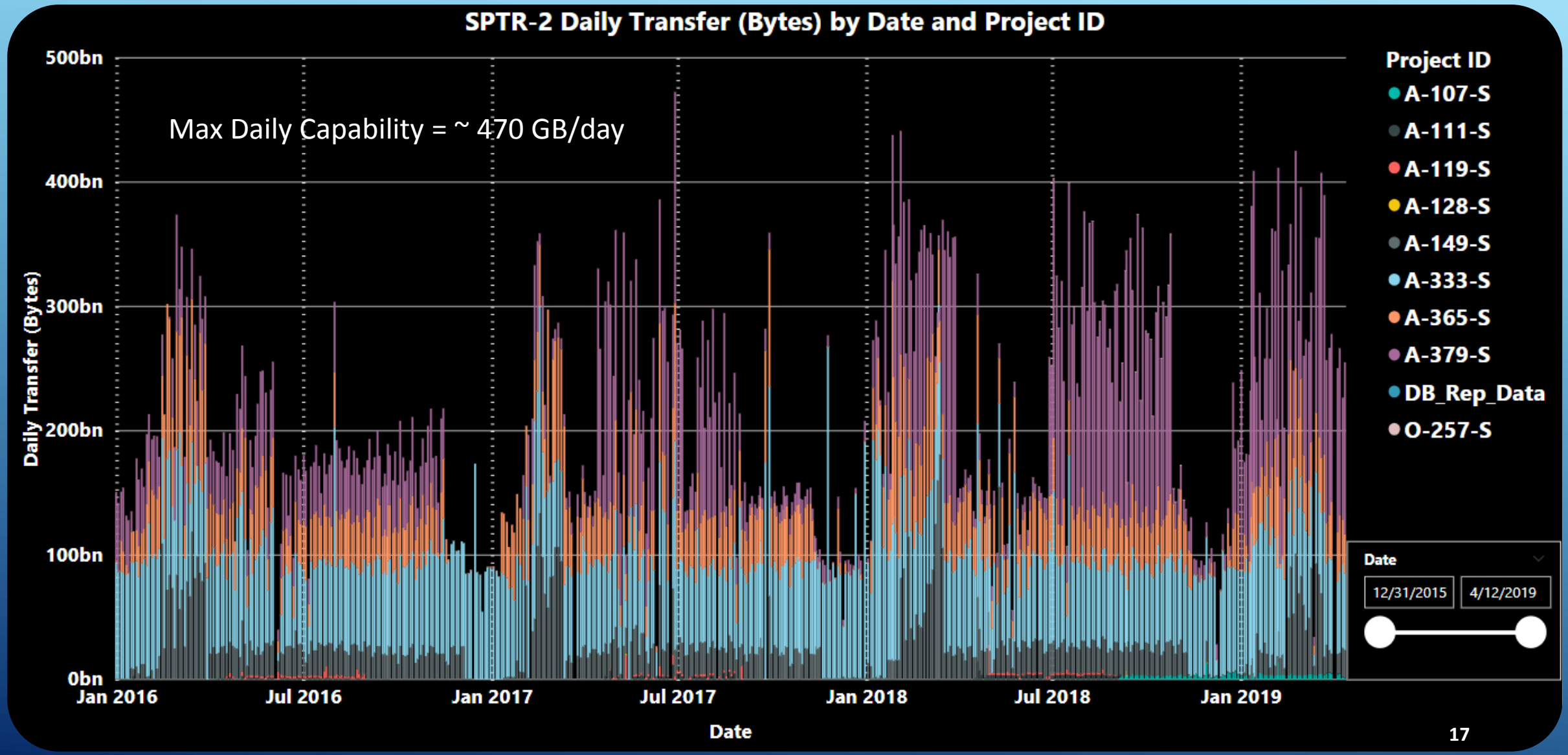
Challenge: Networking by the Clock…





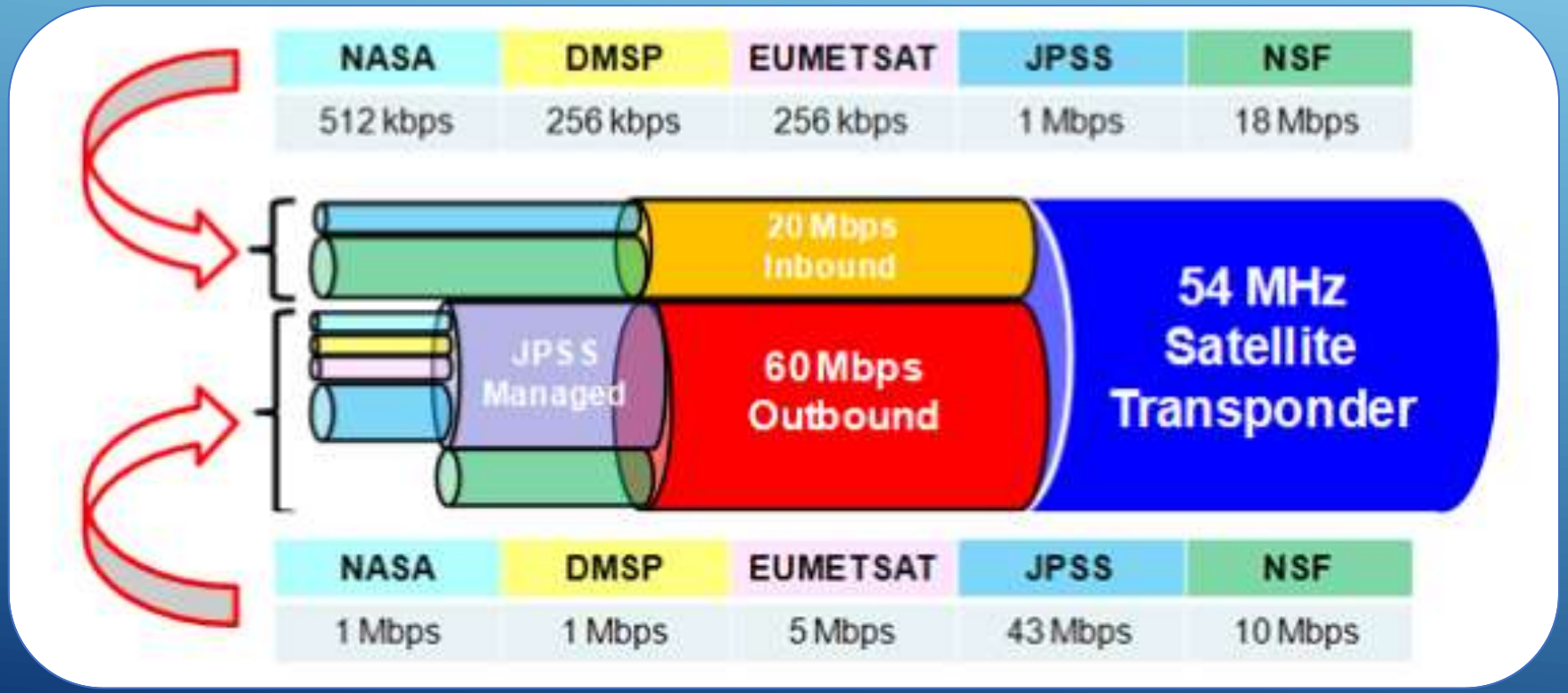


Present Day South Pole Science Data Exfiltration

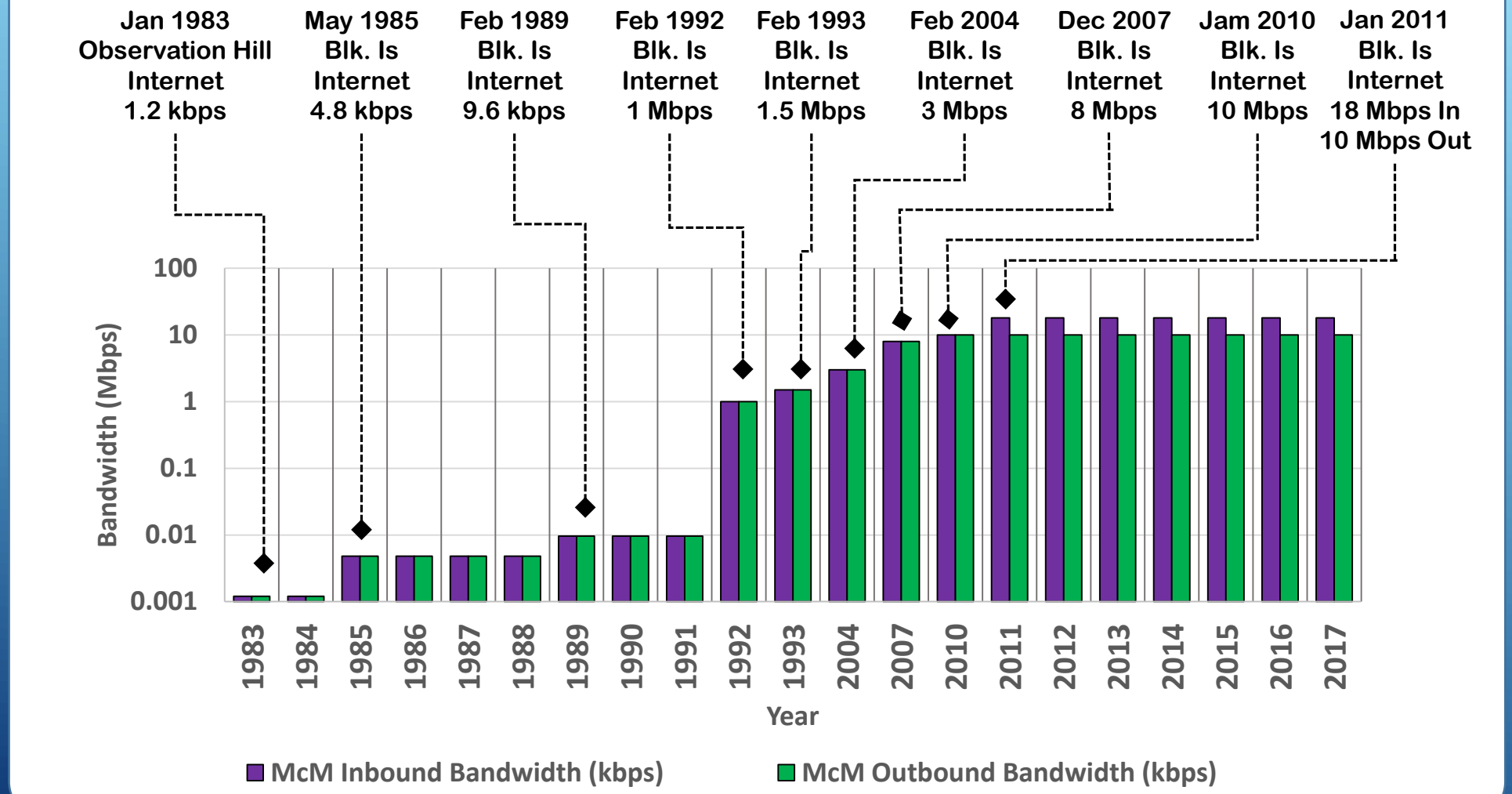


Slicing the Bandwidth Salami at McMurdo

- The present McMurdo Station service just fits into one satellite transponder



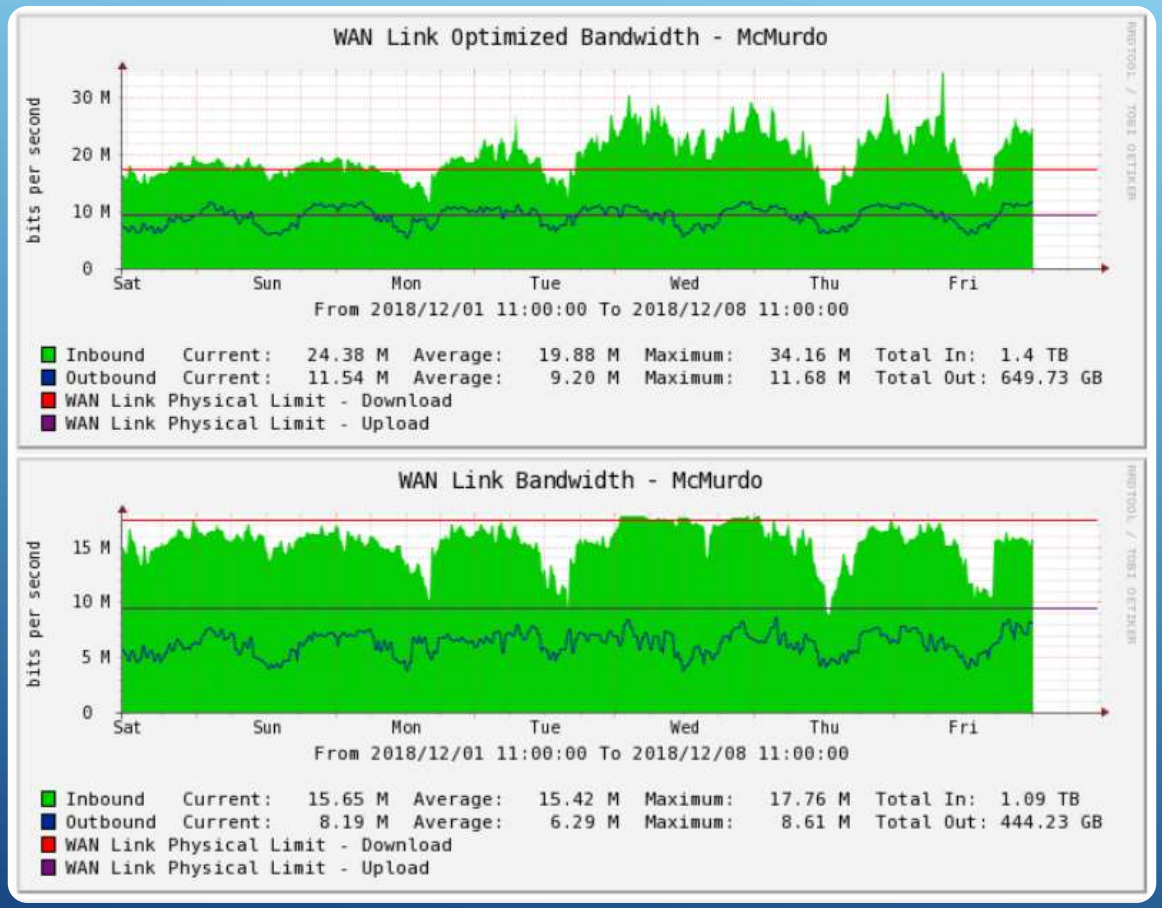
McMurdo Station Network Bandwidth History



A Note on the UX

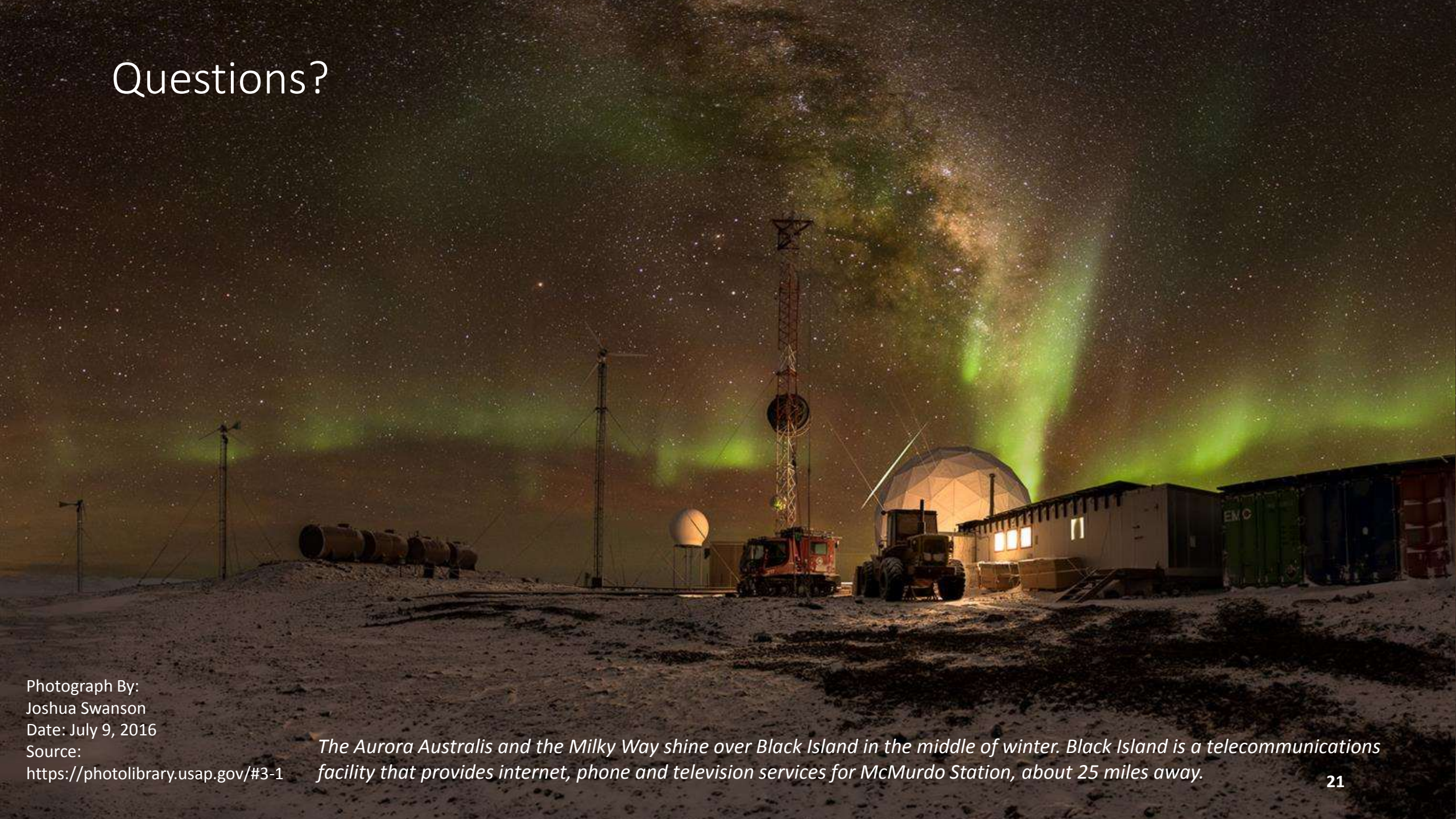
At Home

Meeting the needs of a small town of 1,000 people with bandwidth available in remote, rural America…



At McMurdo

Questions?



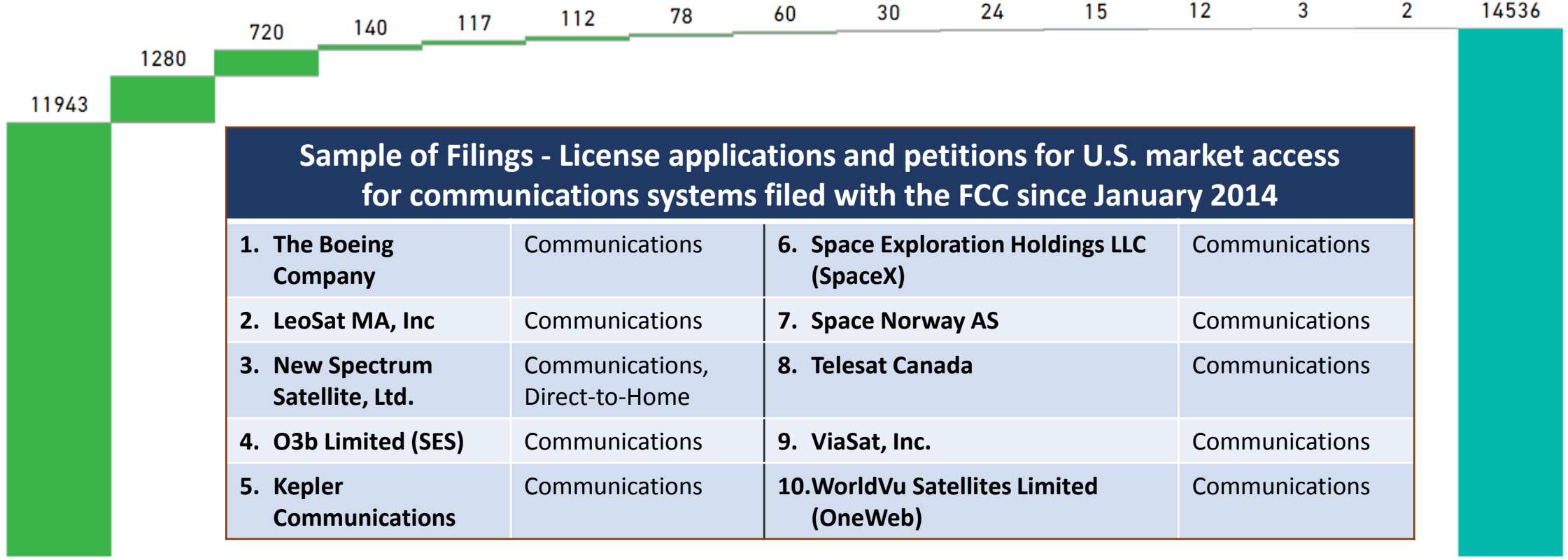
Photograph By:
Joshua Swanson
Date: July 9, 2016
Source:
https://photolibrary.usap.gov/#3-1

The Aurora Australis and the Milky Way shine over Black Island in the middle of winter. Black Island is a telecommunications facility that provides internet, phone and television services for McMurdo Station, about 25 miles away.

Backup

Prospective NewSpace Satcom Operators

*It's been a busy time at the FCC … Filings totaling **14,536** potential satellites received in recent years*

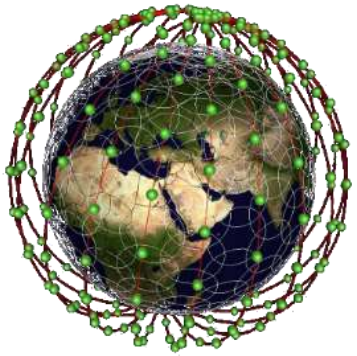


Sample of Filings - License applications and petitions for U.S. market access for communications systems filed with the FCC since January 2014

1. **The Boeing Company**	Communications	6. **Space Exploration Holdings LLC (SpaceX)**	Communications
2. **LeoSat MA, Inc**	Communications	7. **Space Norway AS**	Communications
3. **New Spectrum Satellite, Ltd.**	Communications, Direct-to-Home	8. **Telesat Canada**	Communications
4. **O3b Limited (SES)**	Communications	9. **ViaSat, Inc.**	Communications
5. **Kepler Communications**	Communications	10. **WorldVu Satellites Limited (OneWeb)**	Communications

NewSpace Examples that Support the Polar Regions

- > $10B total cost
  - $1B in capital raised

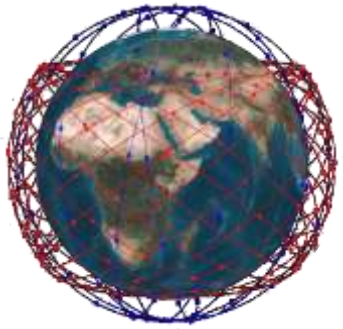


- Spectrum rights at issue
- Optical inter-satellite links
- Gigabit networking

SPACEX
Space Exploration Technologies

- Constellation size:
  - Initial: 4,728 satellites
  - Extended: 7,518 satellites
- Deployed in stages
  - Expect polar coverage ≥ 2025+
- Different orbit planes tailored to geographic coverage
- 2 test satellites in orbit

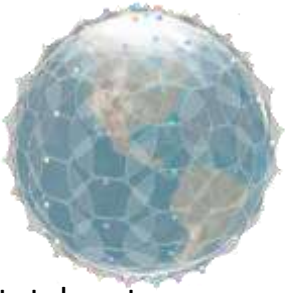
Telesat



- > $? total cost
  - $20M in Canadian Gov commitments
  - Looking for investment partners
- 117 satellites
- Planned start of service: 2021
- Different orbit planes tailored to geographic coverage
- 1 test satellite in orbit

- Spectrum rights secure
- Optical inter-satellite links
- Gigabit networking

KEPLER



- $? total cost
  - $5.1M angel investor seed funding
- 140 satellites
- Test satellite launched Jan 2018
- IoT, M2M service

LEOSAT

- $3.6B total cost
  - Japan JSAT GSO operator a Series A investor
- 78 satellites
- Planned start of service: 2021
- Conducting Series A investment rounds ($100M)
- Series B investment estimated as $175M

OneWeb
ACCESS FOR EVERYONE

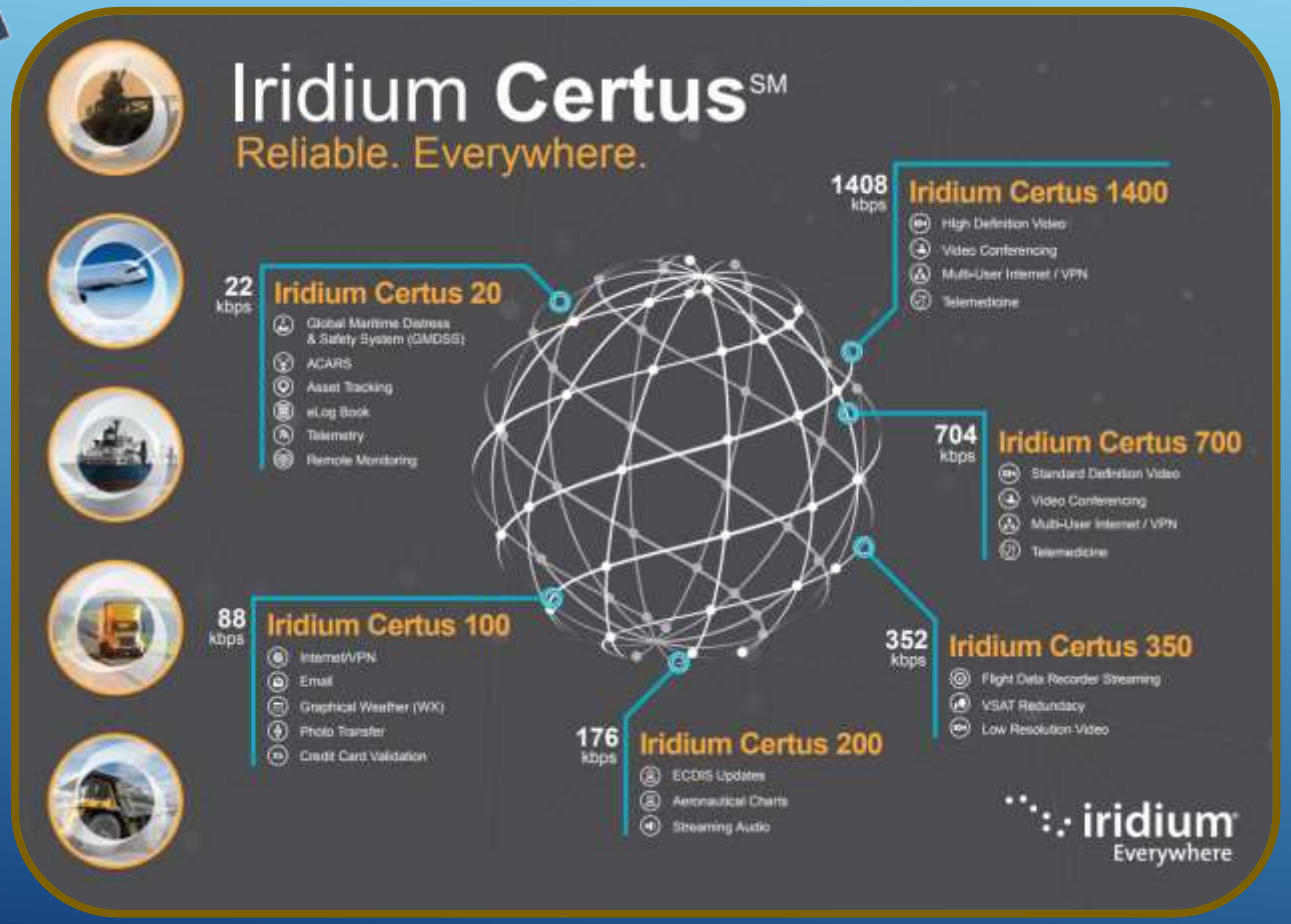
- $3.5B total cost
  - ≥ $1.5B investment raised
- 720 satellites
- 1st launch at 10 satellites by 4Q CY2018
- Successive launch cadence of 34-36 satellites per launch every 21 days
- Planned start of service to Alaska in 2019

Iridium NEXT

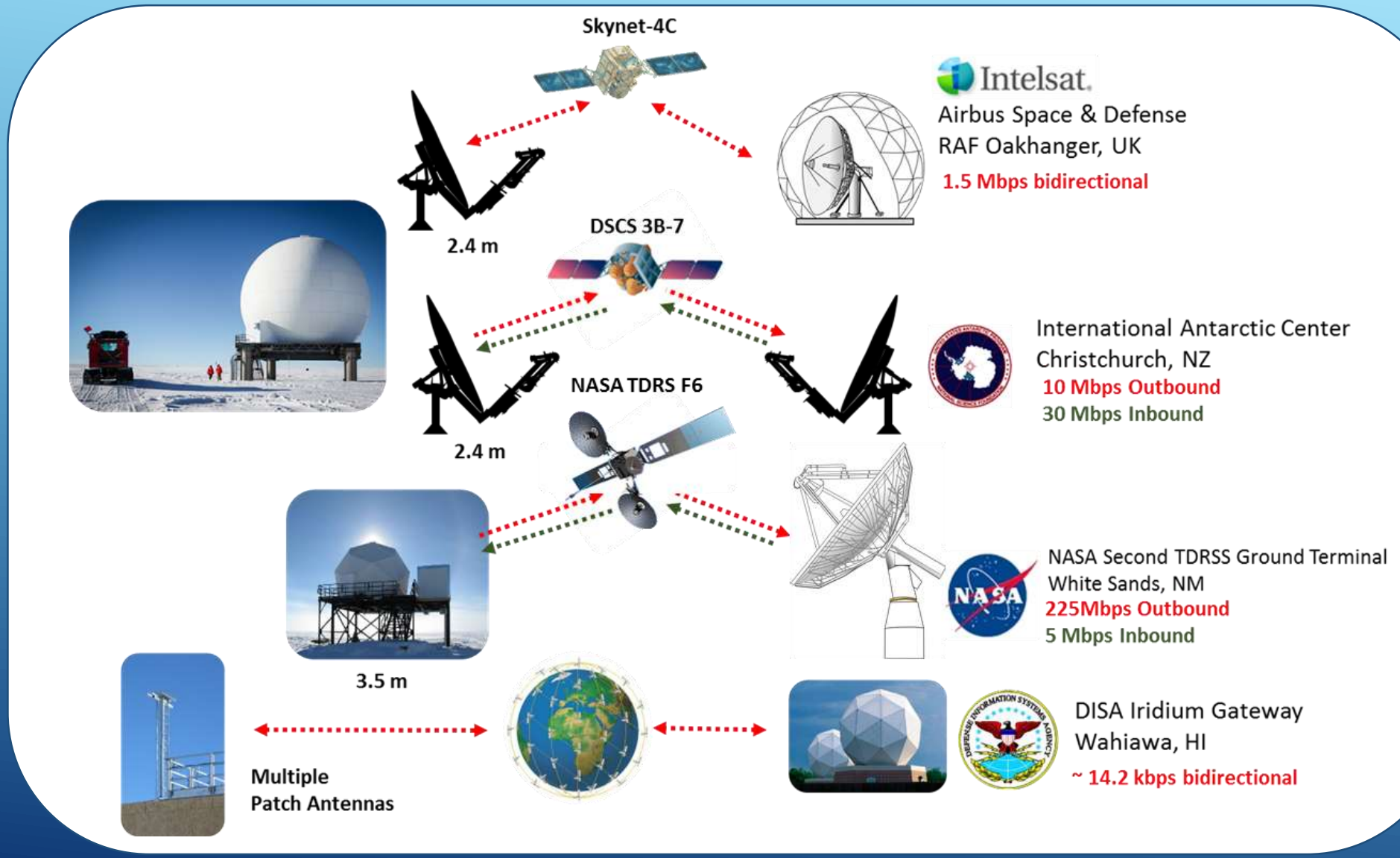
- Replenishment and upgrade of current constellation
- 75 new satellites: 66 operational, 9 on-orbit spares

- All satellites successfully launched
- Full service by mid 2019
- Higher data rates (Certus)
- New “hosted payload” services
  - ❖ Aircraft tracking,
  - ❖ Ship tracking)

- **New DoD contract with Iridium to begin October 2019**
- **Continue fixed cost/unlimited use for low bitrate data**
- **New metered cost for higher data rates, starting at 352 kbps**



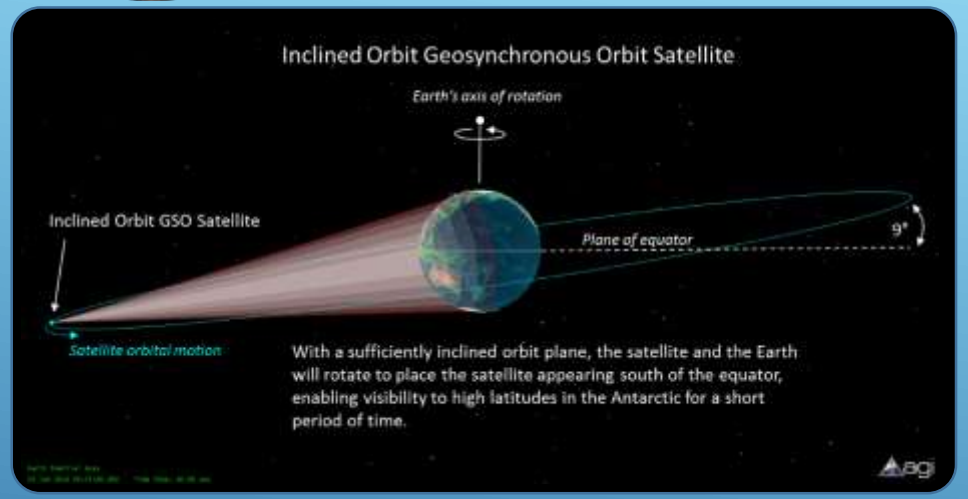
South Pole Station Satellite Network Connectivity



DSCS

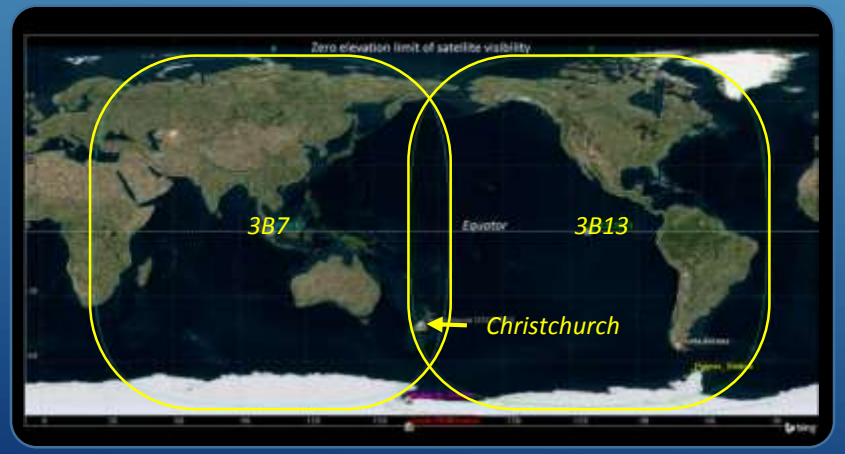
DEFENSE SATELLITE COMMUNICATIONS SYSTEM

Christchurch – South Pole Operational Link Established March, 2016

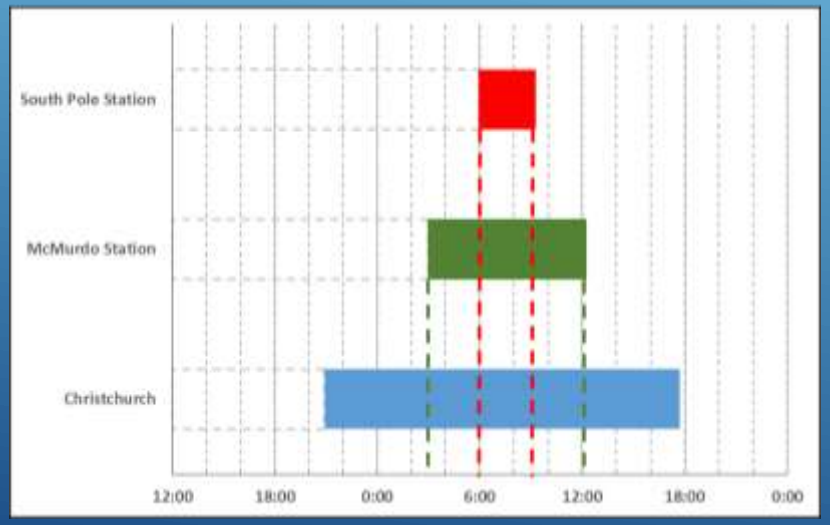


- A legacy US Military SATCOM system
- Generation 3 (DSCS 3) first launched Oct 1982
- Now nearly replaced by Wideband Global Satellite (WGS)
- Available for NSF use for Antarctic SATCOM
- Operating in highly inclined orbits that enable direct contact with South Pole Station
- To be used for moving 100's of Gbytes of science data via the USAP.GOV network
- As years pass, the daily contact window at South Pole increases in time

Q: Why a DSCS satellite ground terminal in NZ?
A: NZ can see both satellites made available to NSF

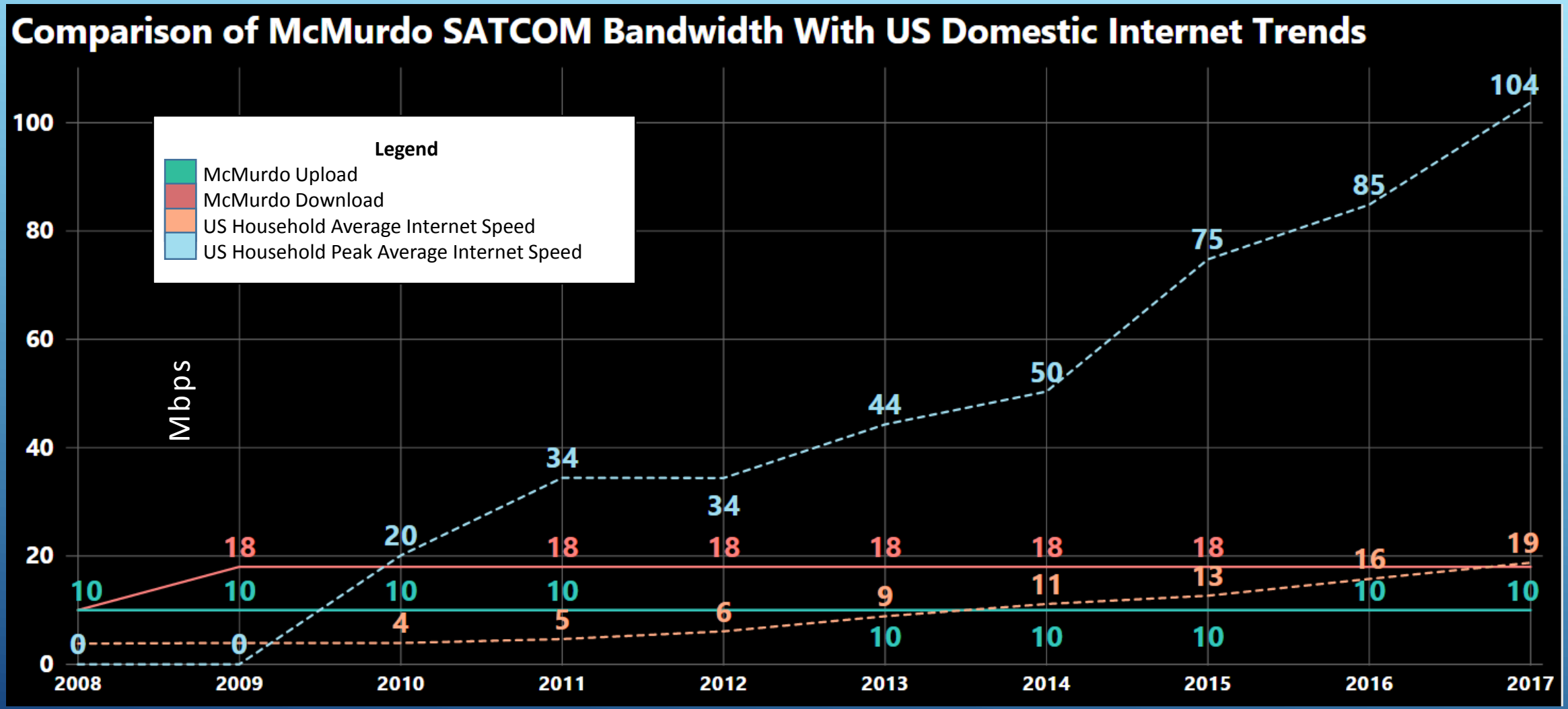


Notional Satellite Coverage Footprints for DSCS-3B7 and DSCS-3B13



Visibility Predictions for DSCS-3B7 for South Pole Station, McMurdo Station and Christchurch

How McMurdo SATCOM Bandwidth Compares to Home



The Reality of Internet in McMurdo

State-side Household Use Shares a Single Internet Connection

- **2.5: Average US Household Size**
- **18.75 Mbps: Average US Internet Bandwidth**
- **7.4 Mbps: Average Per Person, Per Household Bandwidth**
- **104 Mbps: Average Peak US Internet Bandwidth**
- **40 Mbps: Average Per Person, Per Household Peak Bandwidth**

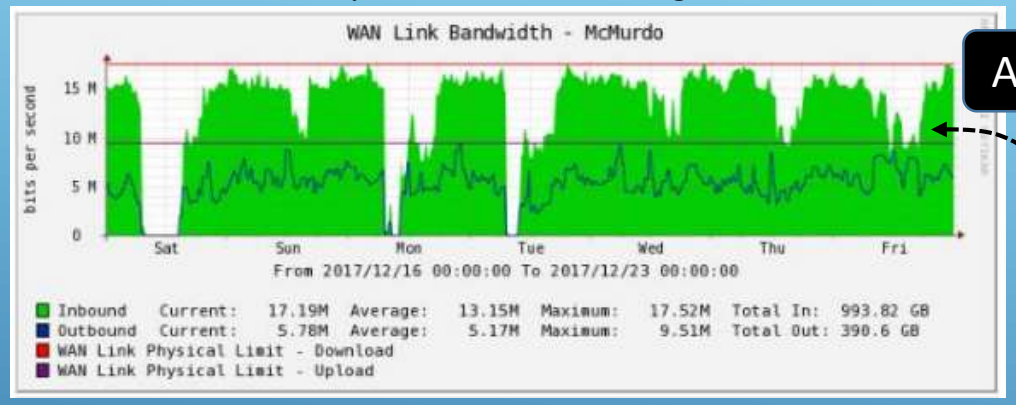
McMurdo is Equivalent to a Small Town Sharing a Single Internet Connection

- **871: Average Peak Population (165 are DoD)**
- **18/10 Mbps: McMurdo Internet Bandwidth**
- **0.025/0.014 Mbps (25/14 kbps): Average Per Person Bandwidth**

McMurdo to service ~1000 people for base operations, science, medical services, educational outreach, phone service and personal use/morale, 24x7x365, with just a single network connection the size of an average household in middle-America…

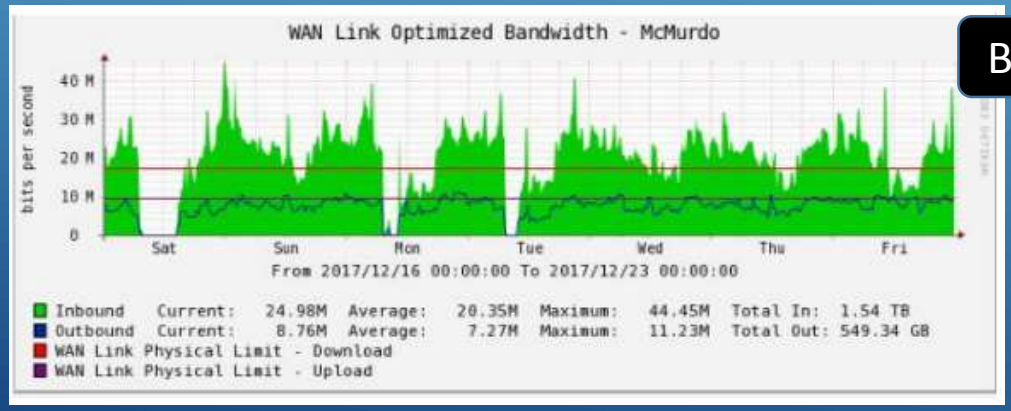
This is what the McMurdo Network Ops Center Sees…

McMurdo Weekly SITREP: Week Ending 24 Dec 2017



A

For good service, the green should rarely peak above here



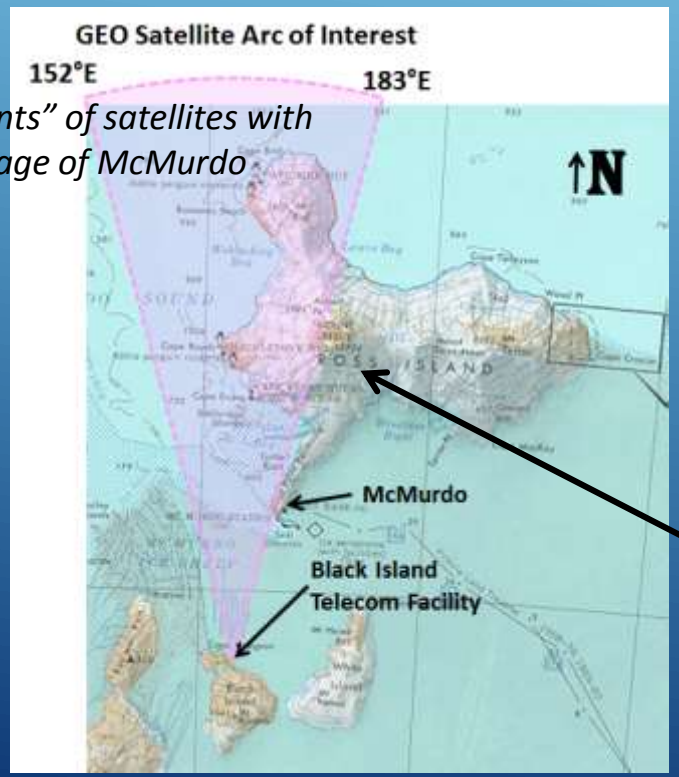
B

- Lines represent max bandwidth
  - Red = Inbound
  - Dark = Outbound
- Green fill represents inbound network traffic, which is the most congested
- **Graph "A"** shows actual bandwidth use, with total inbound critically approaching the max limit (gaps are maintenance outages)
- **Graph "B"** shows the "effective" bandwidth after various network traffic optimization steps (compression, content filtering, selective prioritization, etc.)
- We have squeezed better performance out of the basic link, but we've hit the limit.

McMurdo Challenges – Few Options

- McMurdo can barely see satellites above the horizon (3.5° is the best elevation clearance of the smooth Earth horizon)
- McMurdo's location south of Mt. Erebus and the surrounding hills blocks part of the view to the sky where active satellites are located
- Few satellites visible from McMurdo have antenna coverage patterns that cover McMurdo with service
- Of the satellites visible with service, even fewer have the high capacity capability that McMurdo needs
- This drove the initial McMurdo satellite communications earth station to be located on Black Island

Visibility "footprints" of satellites with theoretical coverage of McMurdo



The Black Island Telecommunications Facility (BITF), ~ 20 mi south-southwest of McMurdo and far enough from Ross Island so as to see the geosynchronous arc as far east as the 183°E orbit slot before Mt. Erebus blocks the view. There are no current or expected commercial satellites east of this point.

Mt. Erebus, Elev. 12,448 ft. ASL has an apparent elevation of ~6° as seen from McMurdo Station, blocking the northern sky

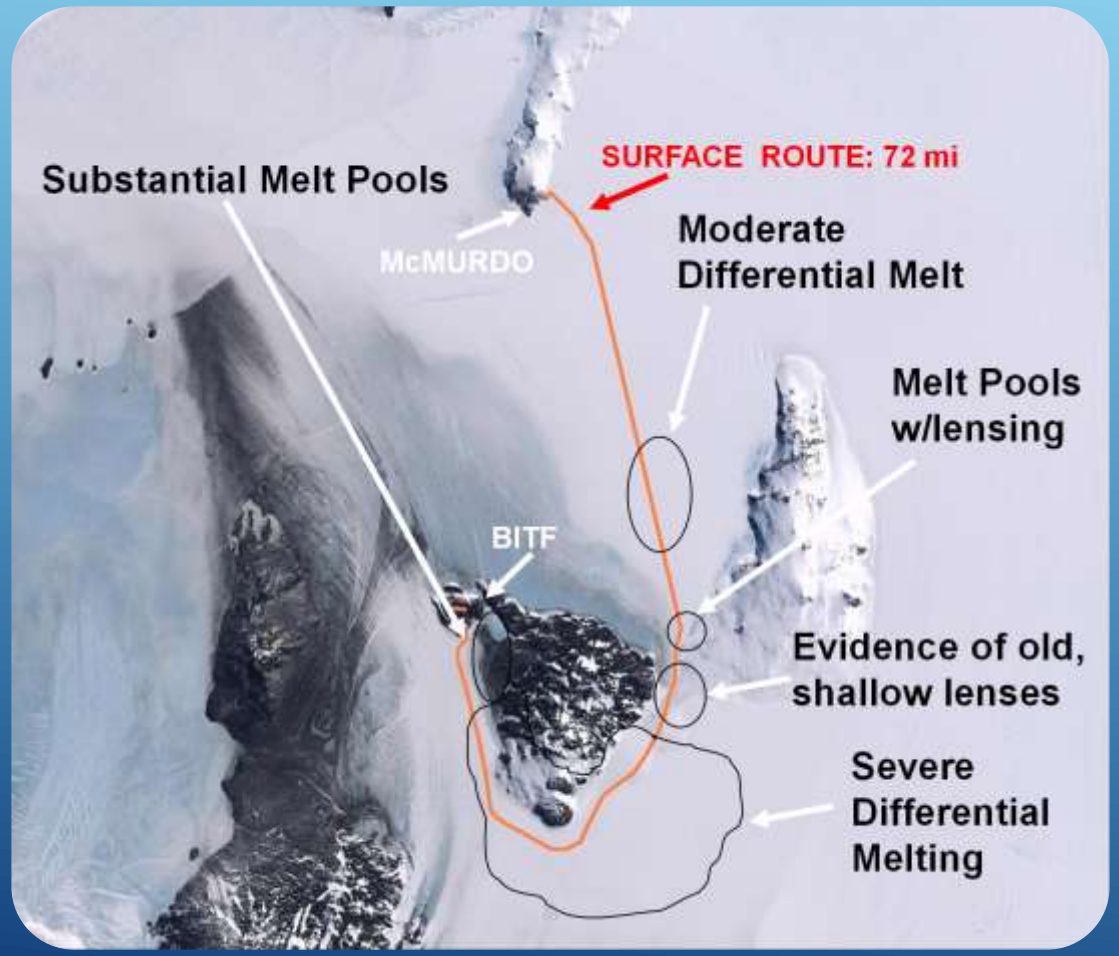
Black Island Telecommunications Facility

- First implemented in 1985
- Current structures initiated in 1991
- 7.2 m antenna
  - Commissioned in 1992 @ C-Band
  - Re-commissioned in 2007 @ Ku-Band
- 11 m antenna
  - Commissioned in 1995 @ C-Band
  - Re-commissioned in 2010 @ Ku-Band

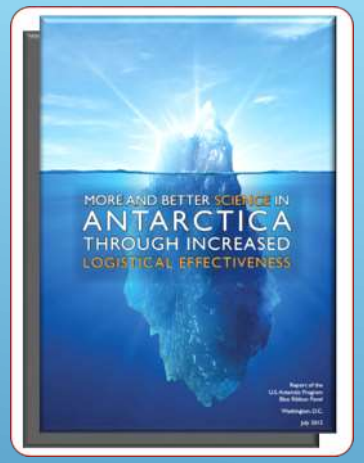
- Designed for un-attended operations
- Requires crewing in austral summer for maintenance
- Inspection and corrective maintenance winter traverses
- Services by 20 mile length microwave communications link
- Current facility is over 20 years old and has grown piecemeal over the years
- Many major subsystems have reached end of life, requiring life cycle replacements (nearly complete)
- NSF partner tenants (NOAA) has expressed concern about reliability
- USAP Blue Ribbon Panel has cited as a program single point failure
- ROM cost to modernize/replace the facility (not earth stations): ~ US $25M

And More Challenges for Winter Ops

- Access to Black Island for repairs and service restoration requires an arduous, time-consuming overland traverse
- Response times can take up to a week due to weather and surface conditions



Drivers for McMurdo change



1. USAP Blue Ribbon Panel Recommendations (2012)

§ 4.7.3.4. McMurdo Station Communications and the Black island Telecommunications Facility

Action 4.7-5. Assess the risk posture of the Black Island facility and develop and implement a plan to modernize it over the next five years.

2. NOAA Sponsored EUMETSAT Antarctic Data Acquisition

A component of the NOAA-EUMETSAT Joint Polar System Agreement

Second Generation Metop environmental satellite launch in Sep 2021 dramatically increases data flow via McMurdo, outstripping current capacity

3. NOAA SATCOM Service

NOAA contract providing current McMurdo satellite services permanently ends in Sep 2022

4. NSF USAP Bandwidth Demand Growth

Increased mission op tempo and increased demand for morale communications are outstripping current network service for McMurdo, despite state-of-art optimization measures. Bandwidth increases are now essential to keep pace with demand.

Space Data User Community Driving Bandwidth Demand at McMurdo Station

NOAA/JPSS MC2

NOAA/JPSS MC1

NASA
Ground Netwoks MG1

EUMETSAT

NASA

NOAA

NSF

JPSS

Present and Future User

- USAF Defense Meteorological Satellite Program (DMSP)
- McMurdo cited in AFSPC/SMC RFQ as option for ORS-8

Recent New User

NOAA Joint Polar Satellite System

Present Users

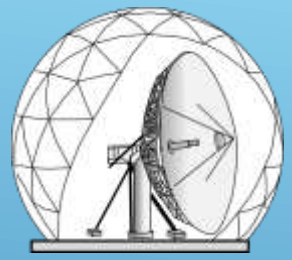
- EUMETSAT Polar Satellite
- NOAA/NASA/NSF – COSMIC
- NASA – Polar LEO satellites tasked to NASA Ground Networks

Future Users

- EUMETSAT Polar Satellite – Second Generation
- NASA – Polar LEO satellites tasked to NASA Ground Networks

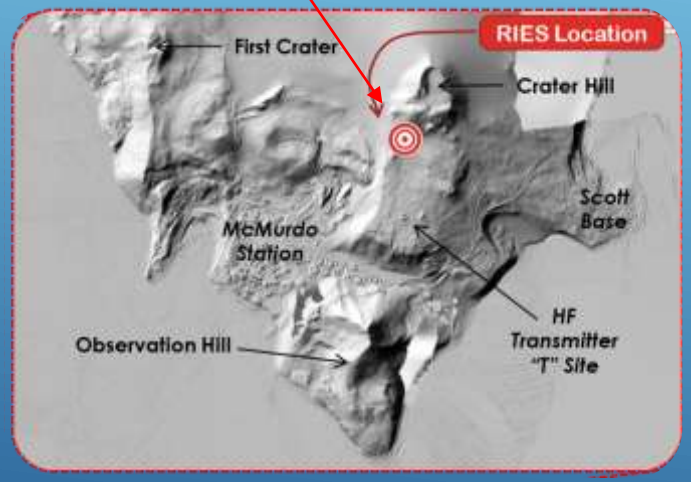
McMurdo SATCOM Modernization Q&A

McMurdo Commercial Satellite Communications -- Ross Island Earth Station (RIES)



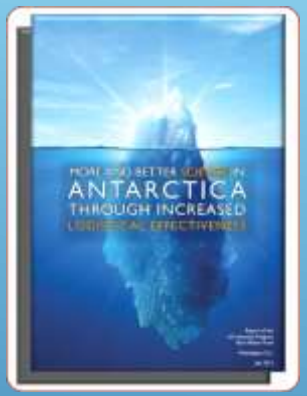
Q: What is RIES?
A: A 13m dia. communications satellite earth station

Q: Where is RIES located?
A: At the base of Crater Hill, at the upper reaches of a plateau directly above McMurdo Station

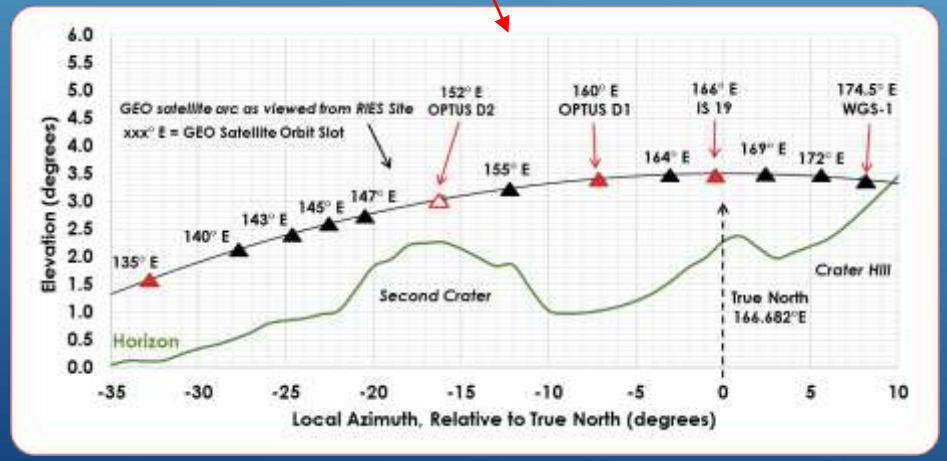


Q: Why build RIES?
A: Several reasons:

1. The USAP Blue Ribbon Plan Report cited the current Black Island SATCOM facility as a risk area
2. NSF needs to provide more bandwidth for USAP and its partners (NOAA, NASA) – and a larger antenna facilitates this
3. NSF has determined that it can see modern SATCOM satellites directly from Ross Island, eliminating the need for Black Island's view

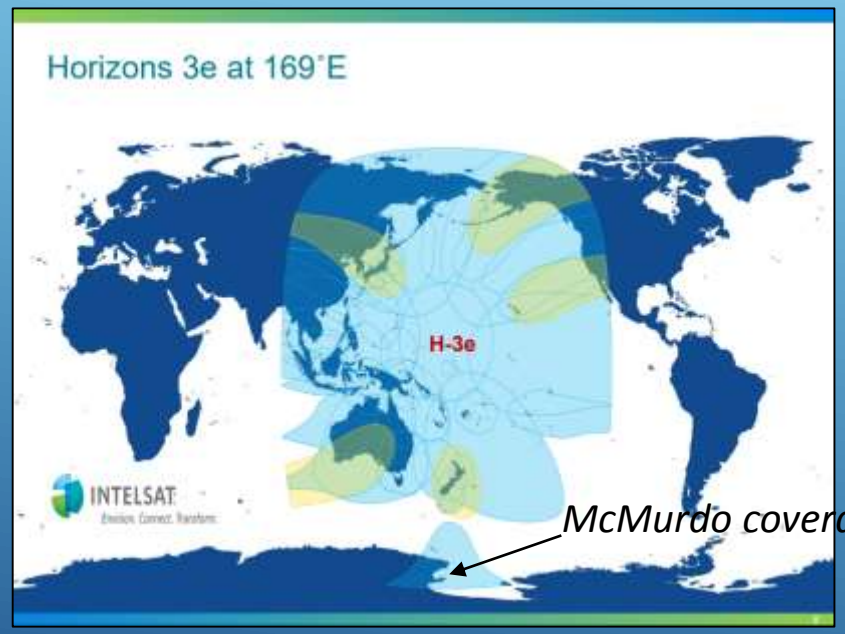


Q: When will RIES be built?
A: Site preparation began with drilling and blasting for earth work in the 2018/19 Austral Summer. The earth station will be installed in the 2020/21 season. It must be completed to begin service by March, 2021.



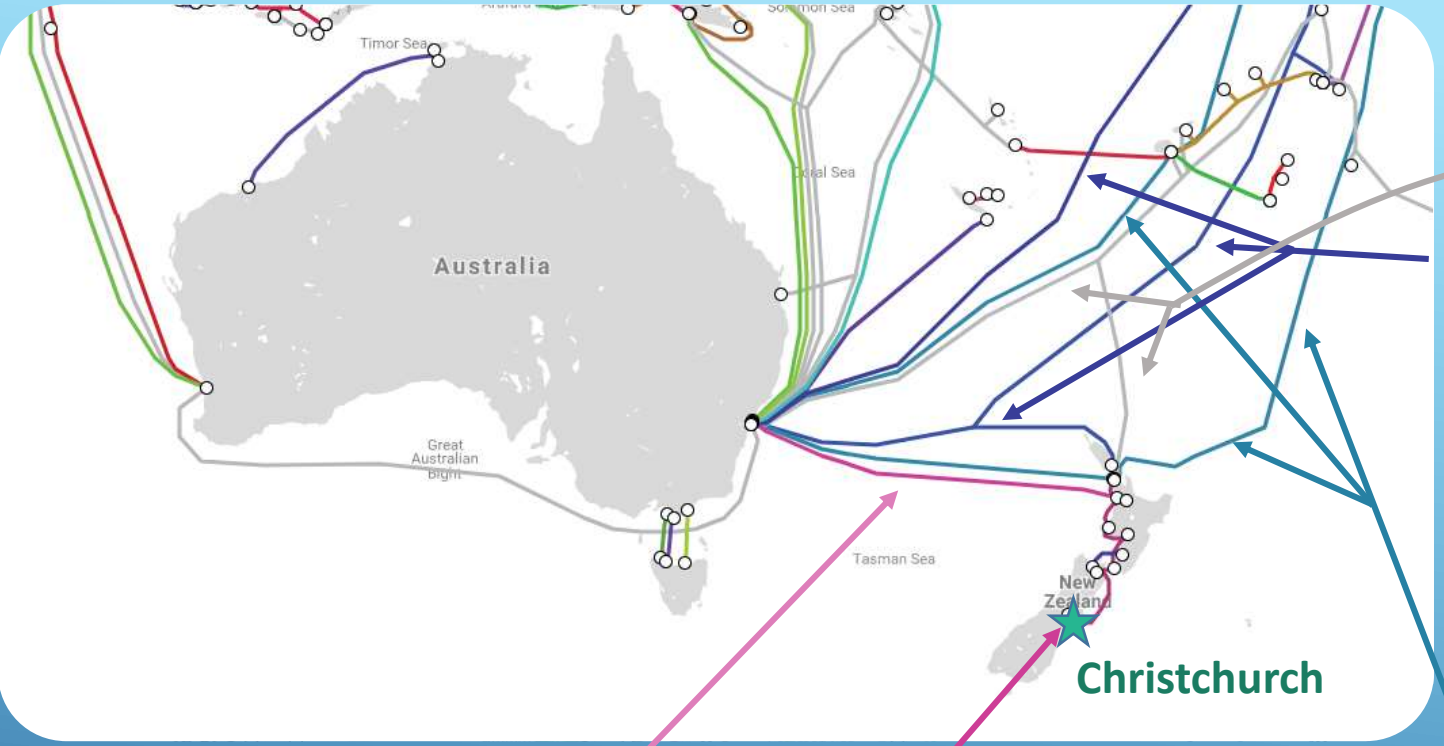
New Market Entrant: Intelsat Horizons-3e

Global operator Intelsat has launched the Horizons-3e High Throughput Satellite (HTS) with high capability Ku-Band beam coverage of McMurdo Station



Next Generation Satellites: The Path for the Pacific Islands
Robert Suber, Intelsat; Session 2: Innovation - New Satellite Technologies and Services in the Pacific, Innovations in satellite technology - more cost-effective, better quality and better performance, 10th Policy and Regulation Forum for Pacific (PRFP-10), Nadi, Fiji; Asia Pacific Telecommunity, 25-27 April 2017 ;
http://www.apt.int/2017-WS-Satellite , retrieved 4 Nov 2017

Asia Pacific Fiber



Hawaiki
RFS: 2018 July
Cable Length: 14,000 km
Owners: Hawaiki Cable Company
URL: http://hawaikicable.co.nz
Landing Points
- Kapolei, HI, United States
- Mangawhai, New Zealand
- Pacific City, OR, United States
- Pago Pago, American Samoa
- Sydney, Australia

Southern Cross NEXT
RFS: 2021 Q4
Cable Length: 13,700 km
Owners: Spark New Zealand, Singtel Optus, Verizon, Telstra
URL: https://www.southerncrosscables.com/
Landing Points
- Alexandria, Australia
- Apia, Samoa
- Kiritimati, Kiribati
- Los Angeles, CA, United States
- Nukunonu, Tokelau
- Savusavu, Fiji
- Suva, Fiji
- Takapuna, New Zealand

Tasman Global Access (TGA) Cable
RFS: 2017 March
Cable Length: 2,288 km
Owners: Spark New Zealand, Vodafone, Telstra
URL: n.a.
Landing Points
- Oxford Falls, Australia
- Raglan, New Zealand

Aqualink
RFS: 2001 December
Cable Length: n.a.
Owners: Telstra
URL: n.a.
Landing Points
- Auckland, New Zealand
- Canterbury, New Zealand
- Manawatu-Wanganui, New Zealand
- Marlborough, New Zealand
- Taranaki, New Zealand
- Waikato, New Zealand
- Wellington, New Zealand

Southern Cross Cable Network (SCCN)
RFS: 2000 November
Cable Length: 30,500 km
Owners: Spark New Zealand, Singtel Optus, Verizon, Telstra
URL: http://www.southerncrosscables.com
Landing Points
- Alexandria, Australia
- Brookvale, Australia
- Hillsboro, OR, United States
- Kahe Point, HI, United States
- Morro Bay, CA, United States
- Spencer Beach, HI, United States
- Suva, Fiji
- Takapuna, New Zealand
- Whenuapai, New Zealand

"Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Networking and Information Technology Research and Development Program."

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