Communication with CubeSats

Seismic Instrumentation Technology Symposium 2018

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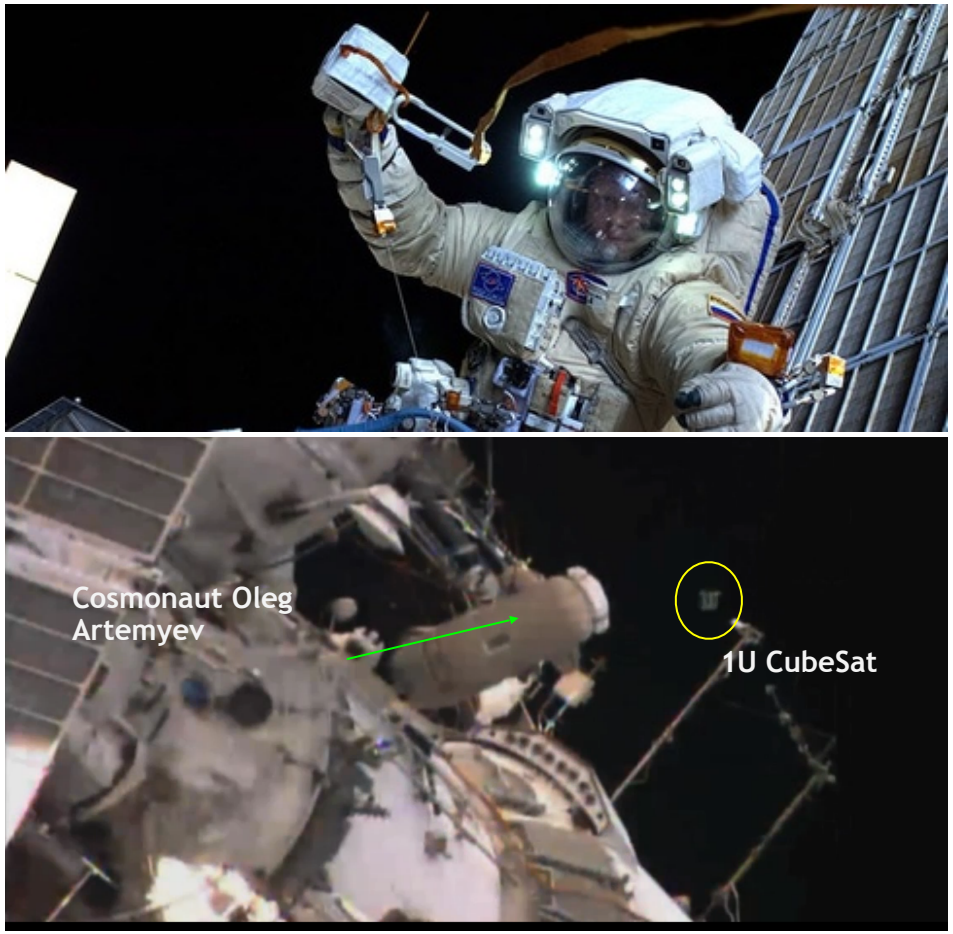
Outline

- CubeSat introduction
- CubeSat Communications Basics
- Future of CubeSat Comms
- Commercial Communications
- Constellations
- Summary

CubeSats?

CubeSat Opportunities & Limitations

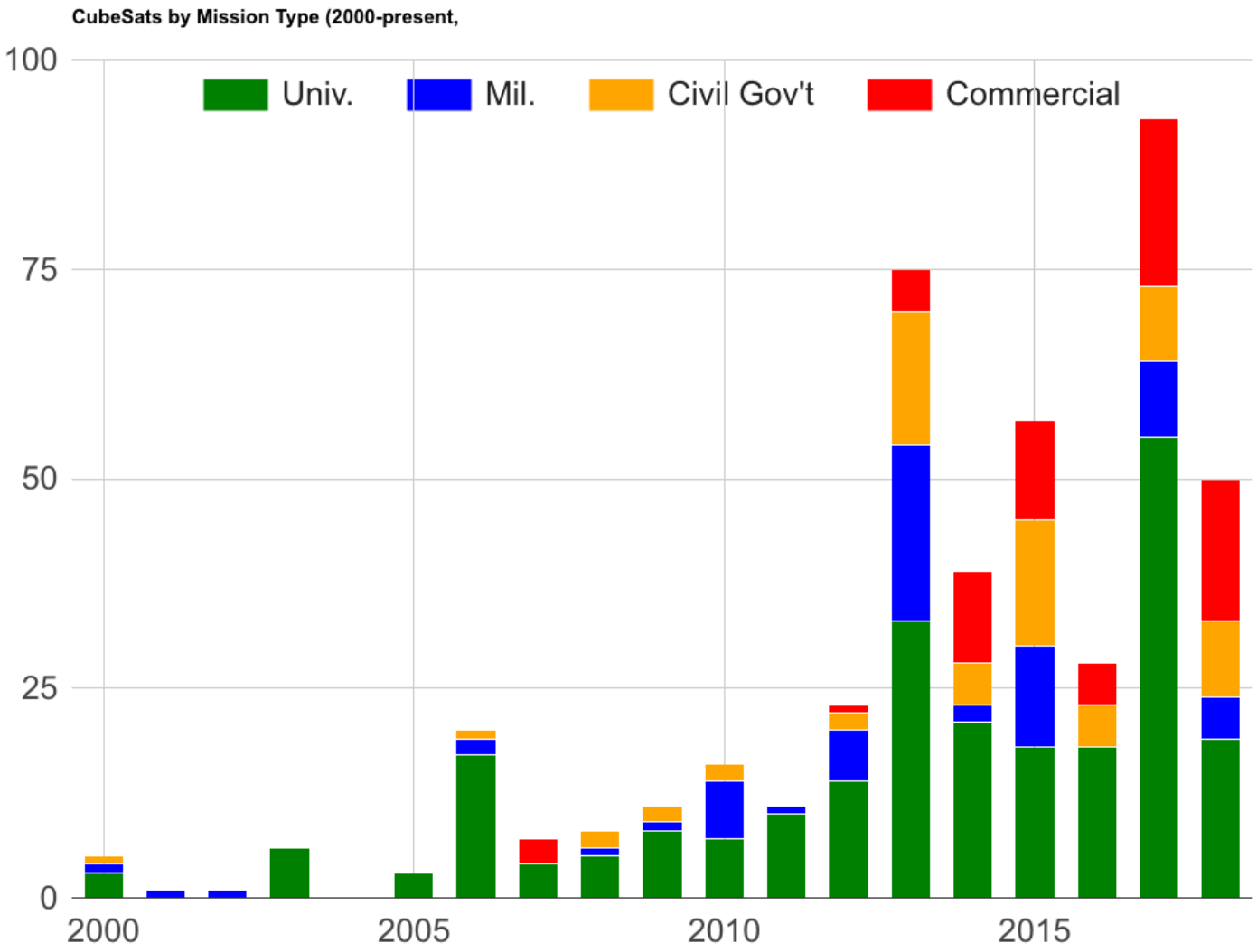
- **Opportunities**
  - Above the atmosphere
  - Can sit and stare at targets (if pointing is good enough)
  - More launch opportunities
  - Training/Education
  - Lower cost*
- **Limitations**
  - Aperture
    - Deployables
    - Distributed apertures
  - Pointing
  - Navigation
  - Limited downlink data rates
  - Limited power
  - Orbits determined by host



Cosmonaut throws CubeSat from the ISS during 2014 spacewalk
http://www.space.com/26861-spacewalker-throws-17-500+-mph-pitch-to-deploy-satellite-video.html

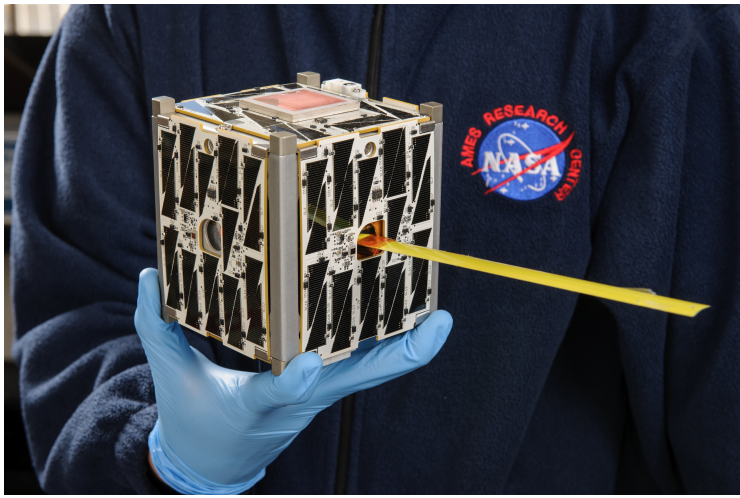
**hardware costs may be lower, however, still have personnel and testing/integration costs, and carry higher risk*

CubeSats (excluding constellations)



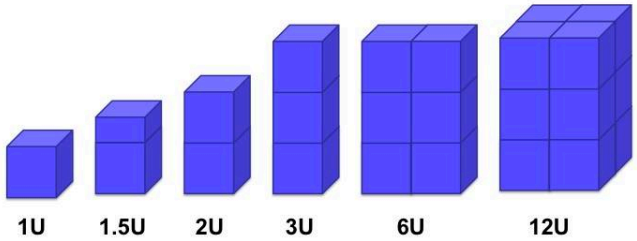
What is a CubeSat?

- On the scene in 1999
  - Jordi Puig-Suari (Cal Poly SLO)
  - Bob Twiggs (Stanford)
  - Their original "OPAL" satellite, the Orbiting Picosatellite Automatic Launcher, was deemed *"too complicated"*
    - Klondike-bar size picosats too small
    - Deploying picosats from smallsat too hard
  - Moved to larger "Beanie baby" size nanosat, what would become the CubeSat
    - Deploy from safe "jack-in-the-box" container on launch vehicle instead
- 1 standard CubeSat unit (1U)
  - Volume: 10 cm x 10 cm x 10 cm
  - Mass: < 1.33 kg
  - Common sizes: 1U, 1.5U, 2U, 3U, 6U… 12U?
- Low cost and short development time
- **Increased accessibility to space**



PhoneSat 2.5, developed at NASA's Ames Research Center in Moffett Field, California and launched in March 2014

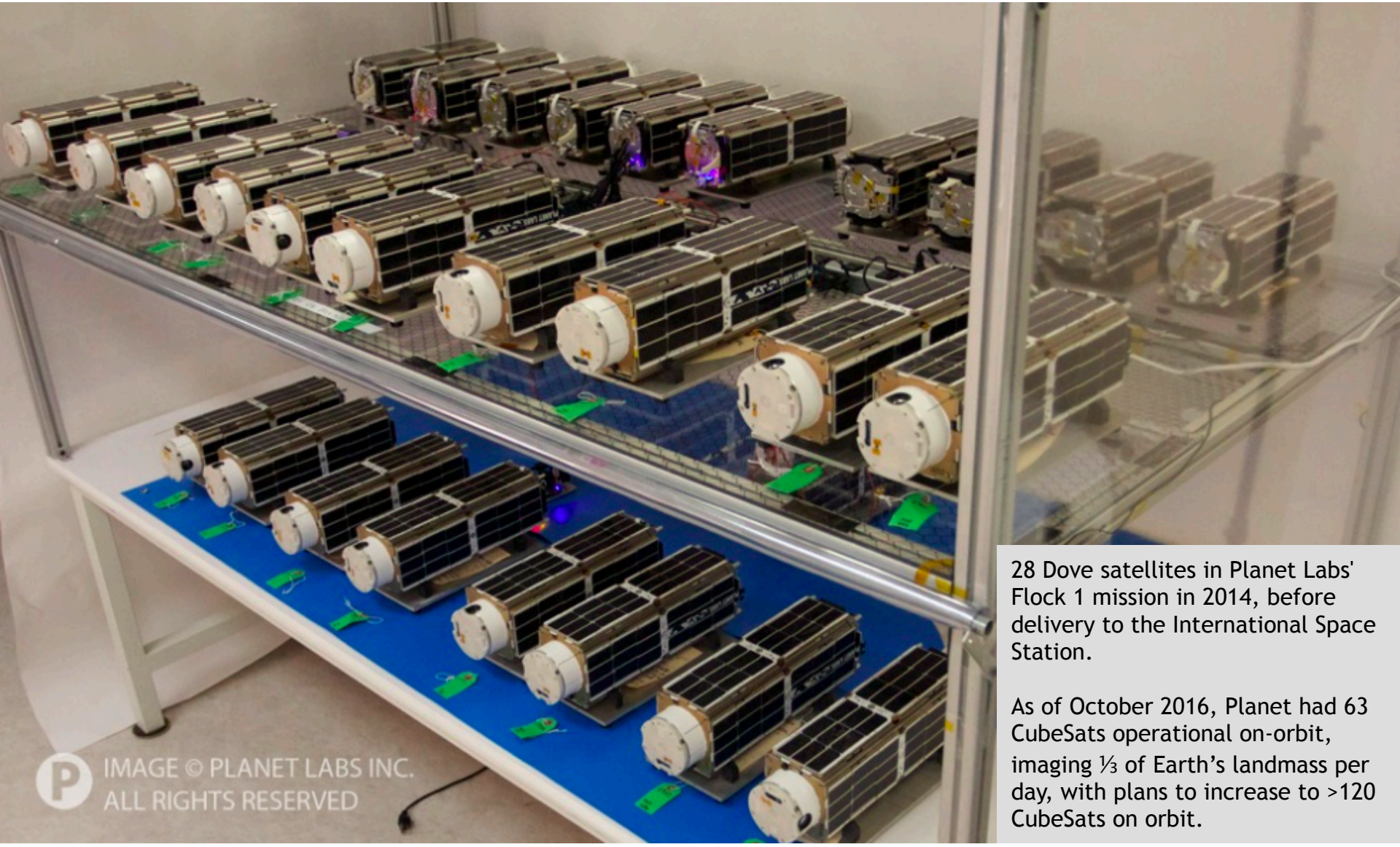
https://www.nasa.gov/press-release/nasa-opens-new-cubesat-opportunities-for-low-cost-space-exploration



CubeSat form factors, 3U and 6U are currently the most popular

https://www.nasa.gov/sites/default/files/styles/full_width/public/thumbnails/image/what_are_cubesats.png?itok=qHX3Jr4p

The Rise of CubeSats

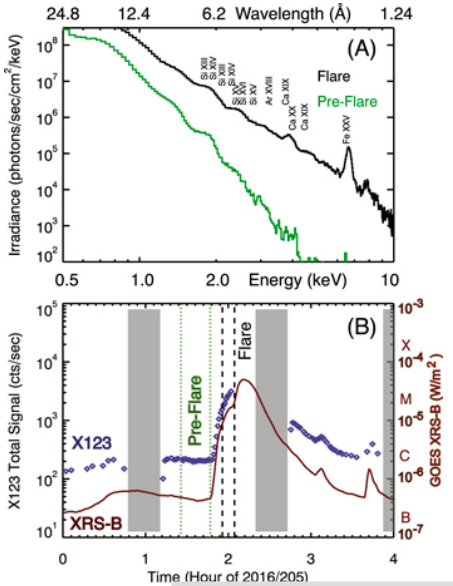


28 Dove satellites in Planet Labs' Flock 1 mission in 2014, before delivery to the International Space Station.

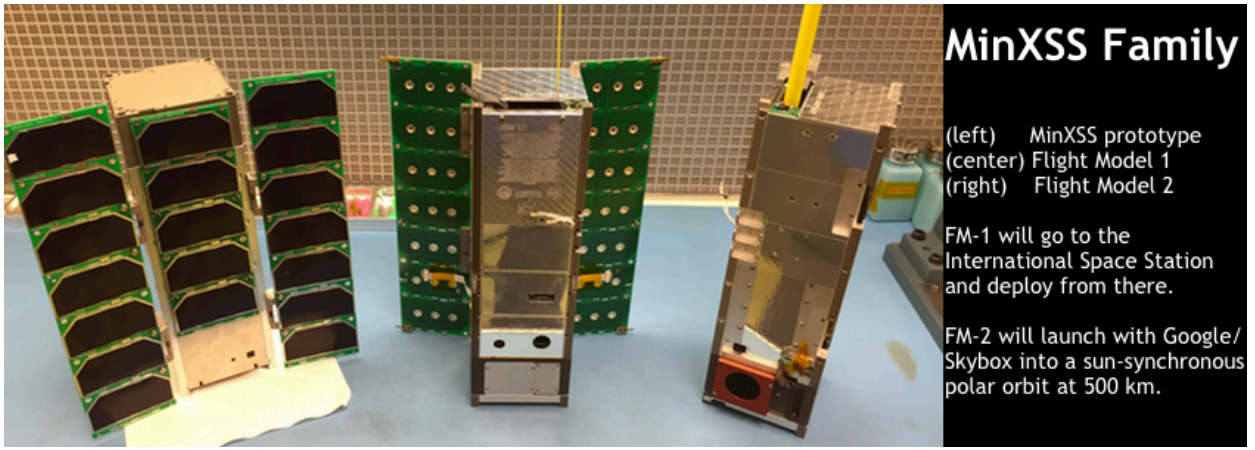
As of October 2016, Planet had 63 CubeSats operational on-orbit, imaging ⅓ of Earth's landmass per day, with plans to increase to >120 CubeSats on orbit.

https://www.nasa.gov/sites/default/files/cs1.jpg

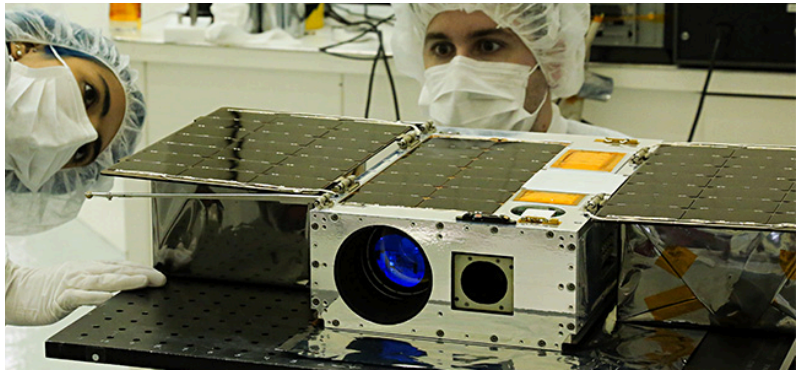
Science with CubeSats

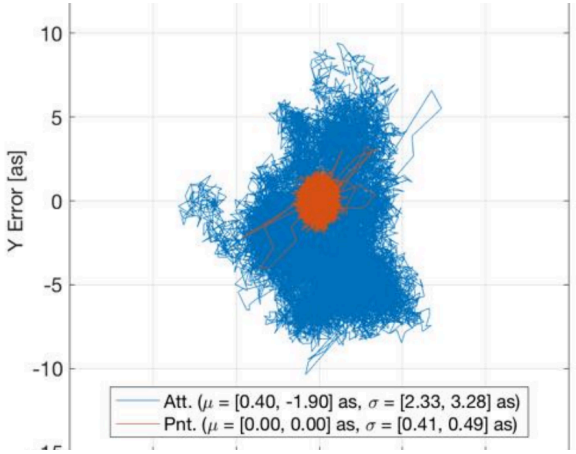


Woods et al 2017



http://lasp.colorado.edu/home/minxss/



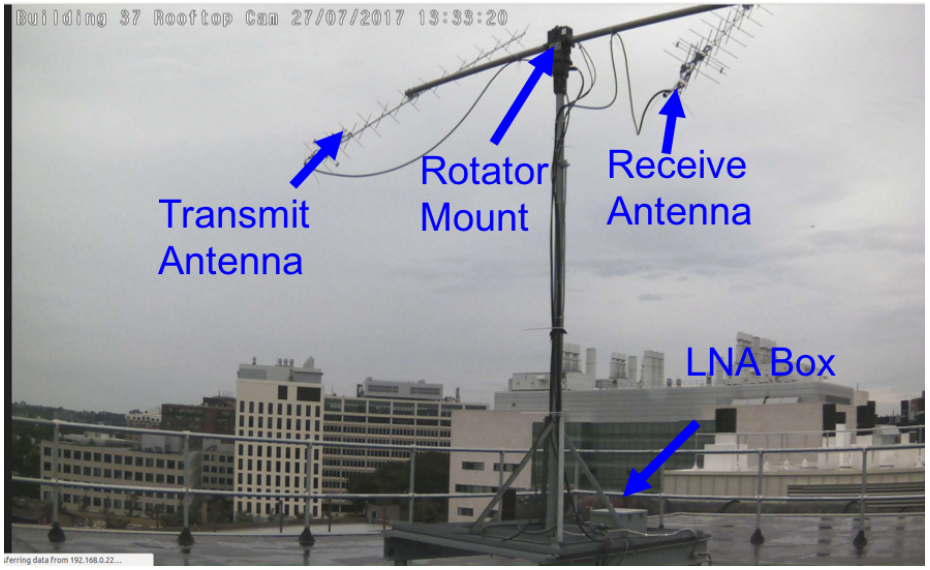


ASTERIA Cubesat on Orbit (Smith et al 2018)

Typical Academic CubeSat Communications

- Lots of data onboard
- Power limited data rates
- Limited ground station network

9.6 kbps antenna on roof of MIT AeroAstro Dept



G. Allan (MIT)

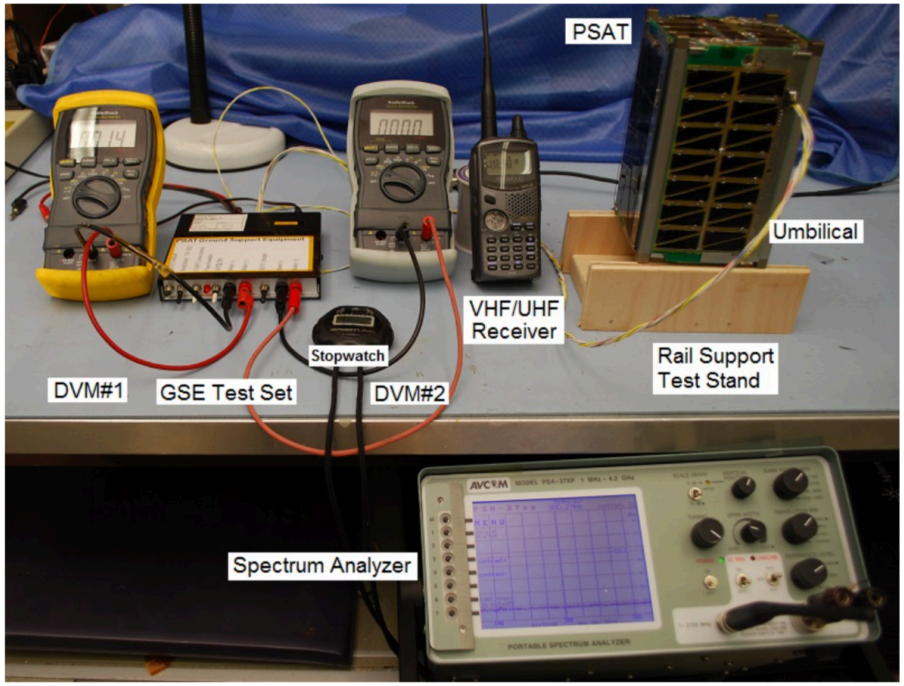
1 Mbps+ with large dishes

Morehead State University
21 Meter antenna

Wallops UHF on left, S-Band on right
(Schaire 2013)

Radios

- Typically VHF, UHF or S-band
- 1 W - 10 watts
- <0.5U

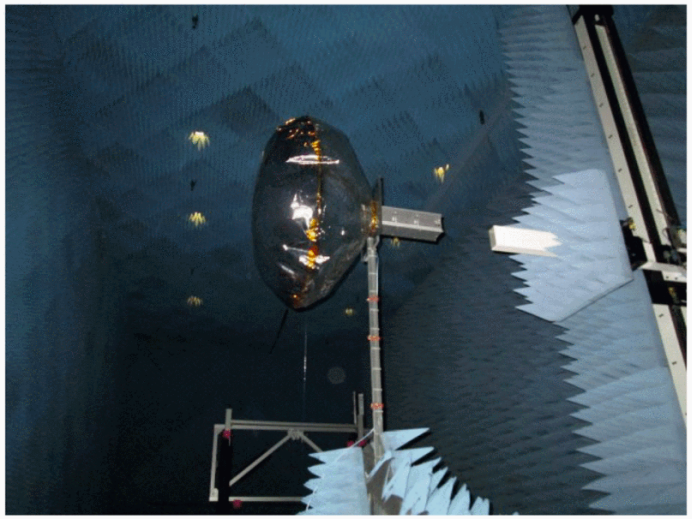


Bruninga, 2018 (USNA)

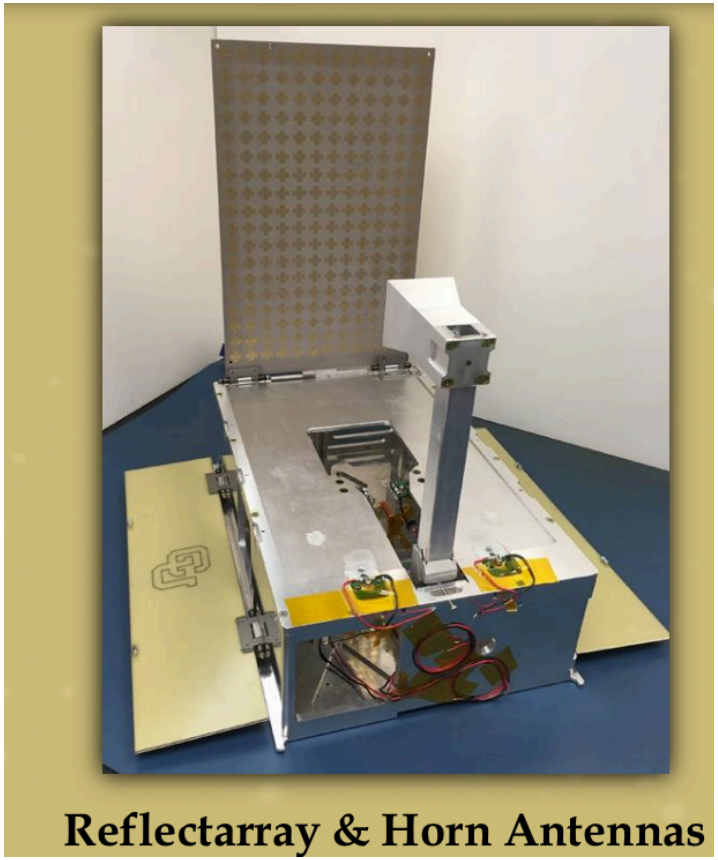
http://www.vulcanwireless.com/

http://www.astrodev.com/public_html2/

Possible Futures of CubeSat comms

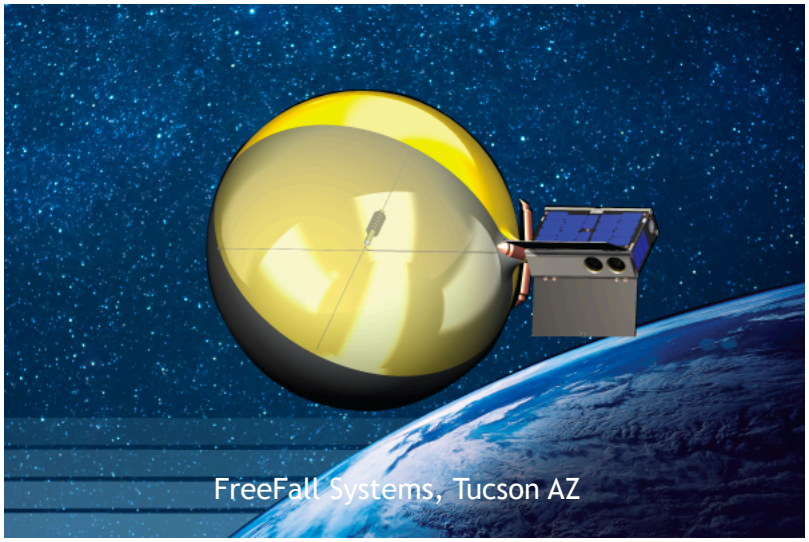


Deployed inflatable CubeSat antenna,
Babuscia et al 2014



MAXWELL CubeSat Design
CU Boulder

Sobtzak et al 2017

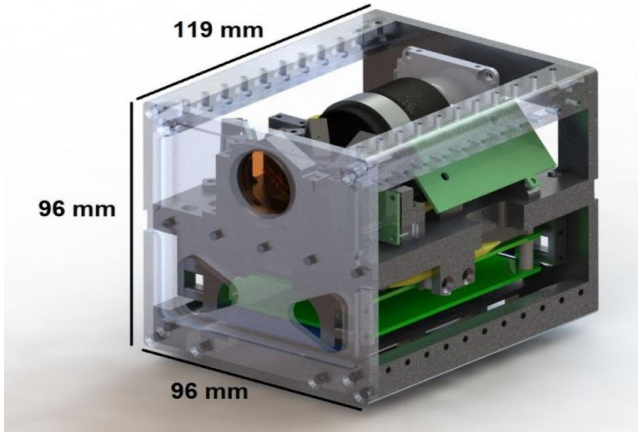


Regulatory challenges

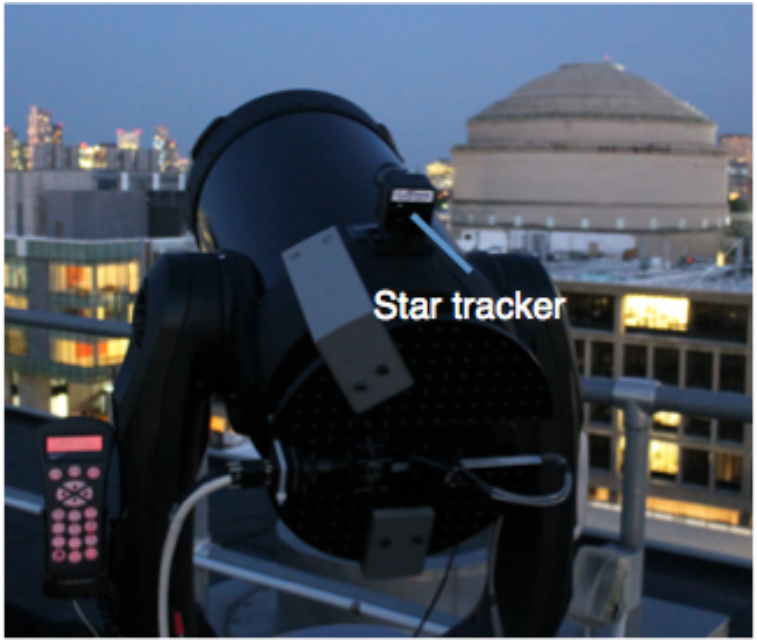
- Academic and industry space communications are regulated by FCC (even “unlicensed” bands)
- FCC licenses be experimental, amateur or commercial
- Only Ham built satellites qualify for amateur
- Federally operated spacecraft frequencies are managed by National Telecommunications and Information Administration (NTIA), opening up more frequencies but potentially taking more than a year to be licensed.

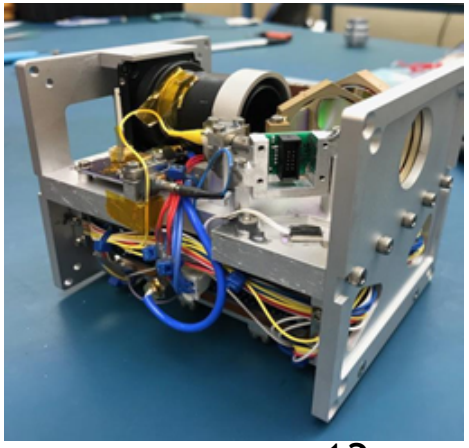
Further reading, Achieving Science with CubeSats: Thinking Inside the Box, https://www.nap.edu/read/23503

MIT STAR Lab (Cahoy) laser comm transmitter unit and portable ground-station



3D CAD Model *D. Barnes*





Assembled EM *D. Barnes*

Commercial future

Typical Satellite Links

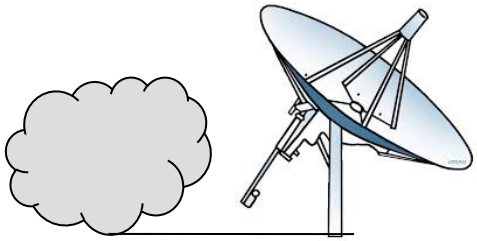
Satellite Operations Center

Feeder Link

User Link

Ground Network Operations Center

-Terminal
-User Terminal (UT)
-Very Small Aperture Terminal (VSAT) – GEO only (VSATs = 1.2 m diameter)

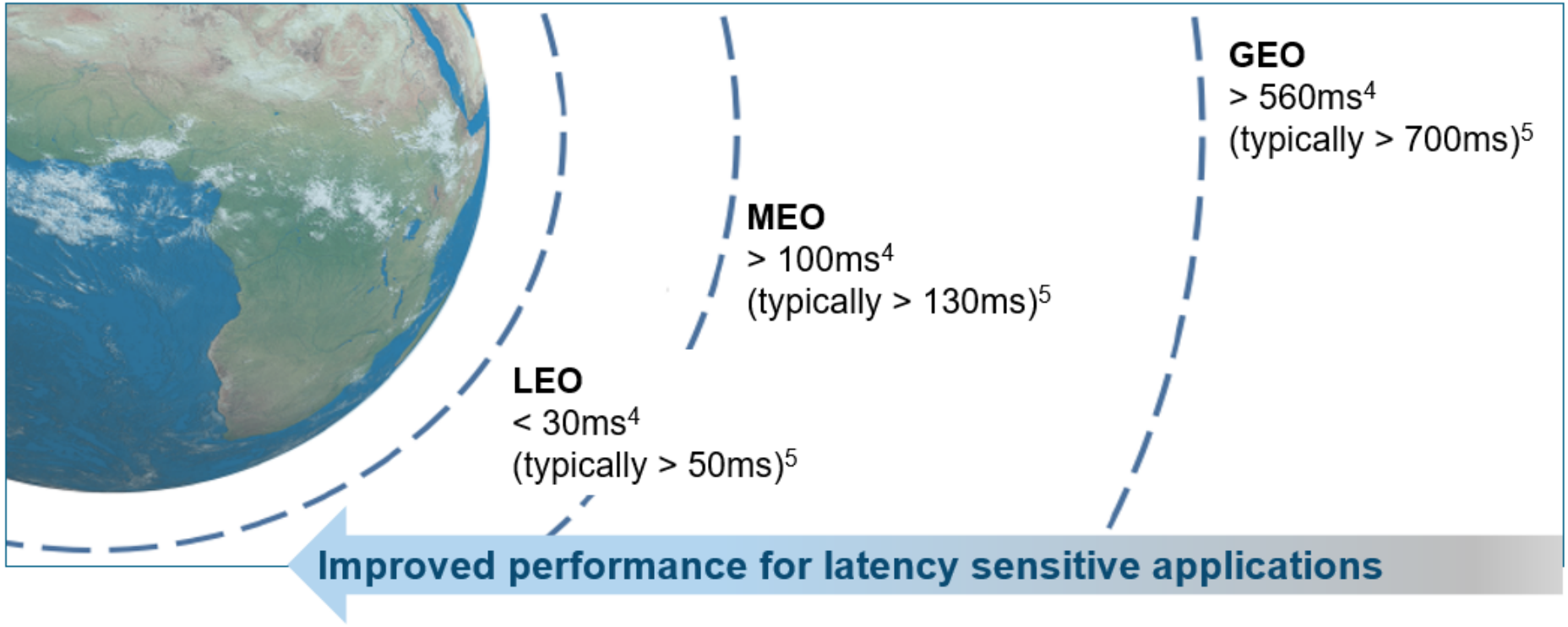


-Gateway
-Base/Ground Station
-Earth Station (ES)
-Large Earth Station (LES)

Slide prepared by W. Lohmeyer

Latency

Low Earth Orbit (LEO) System Offers Lowest Latency



4. *Propagation Latency.*
5. *Total System Latency.*

Early History

Arthur C. Clarke conceptualized a worldwide radio system: 3 GEOs equally spaced

December 1958: First communications satellite launched. US Army Corps **Project SCORE** – Signal Communications by Orbiting Relay Equipment.

SCORE Orbit: 185 km x 1484 km; inclination 32.3 degrees

Operated 12 days due to battery failure

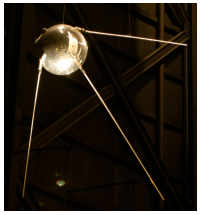
1964: Hughes launches first geostationary satellites (Syncom 3) to provide coverage of Tokyo Olympics

1964: Birth of Intelsat

1945 — 1955 — 1965

End of WWII

Programs initiated to explore deploying communications equipment outside Earth's atmosphere… mostly disconnnected effort



1962-1963: Bell Labs launched Telstar 1 and 2. Relayed through space first television pictures, telephone calls and telegraph images. First transatlantic television feed. 177 ft. ES with 14 ft story radome. 20 min. contact time every 2.5 hours

Stealth DoD program for first GEO = Advent

LEO vs. GEO

Hughes received order from Comsat (chartered by Congress) for delivery in one year of a commercial derivative… Early Bird, which became Intelsat 1

Intelsat 1 had two 25 MHz transponders and operated at C-band

1965: commercial operations between U.S. and Europe

Mid 60s to 90s

- Telephony Systems
- Cable-Television Distribution
- Enterprise VSAT
- Direct Broadcast Satellite TV
- Mobile Satellite Systems
- Digital Satellite Radio
- Satellite Broadband

The 90s

- Mobile Satellite Service: handheld device
- Satellite Broadband
- Direct Broadcast Satellite (DBS) TV

The 90s: MSS

- Mobile Satellite Service: handheld devices
  - Iridium & Globalstar = $10B combined investment, but $11B in losses and write-offs
    - Two fundamental problems:
      - Penetration of terrestrial cellular systems
      - “Just like cellular” (but couldn’t use indoors!)
  - Technological Advancements:
    - Dual satellite and terrestrial phones ($1000/phone)
    - Pioneered “assembly-line” produced satellites
    - Iridium: onboard processing, Ka-band feeder links and ISLs

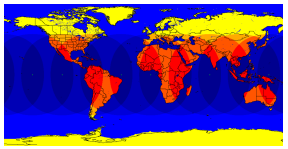
The New Entrants

2012

2013: Wyler brings LEO Broadband Constellation idea to Google for Funding; Project becomes GlobalBit under Google Access

November 12, 2012: Greg Wyler makes Ku-band filing for constellation

June 2013: O3b launches first four satellites, and eight more in 2014



July 2014: Wyler decides to pursue project outside of Google with Elon Musk (not SpaceX)

WorldVu born out of Tesla facility

2015: Elon makes offer to acquire WorldVu – project would become part of SpaceX.

Elon and Wyler end collaboration and begin working independently

June 2015: Wyler begins discussions with Goldberg of Telesat (then avid LEO oppose) regarding COMMSTELLATION filing

Telesat files for ownership of COMMSTELLATION filing, and is awarded spectrum. Birth of Telesat LEO.

November 2015: ITU WRC-15; Discussions of BIU policy; EPFD

Boeing first mention of LEO constellation plans; makes effort to modify EPFD limits in V-band at WRC-15

Boeing rumored to be Apple

2017: SES acquires O3b

January 2017: Iridium launches first ten NEXT satellites

Jan 2018: Telesat launches first LEO satellite

November 12, 2019: OneWeb's BIU date

2018

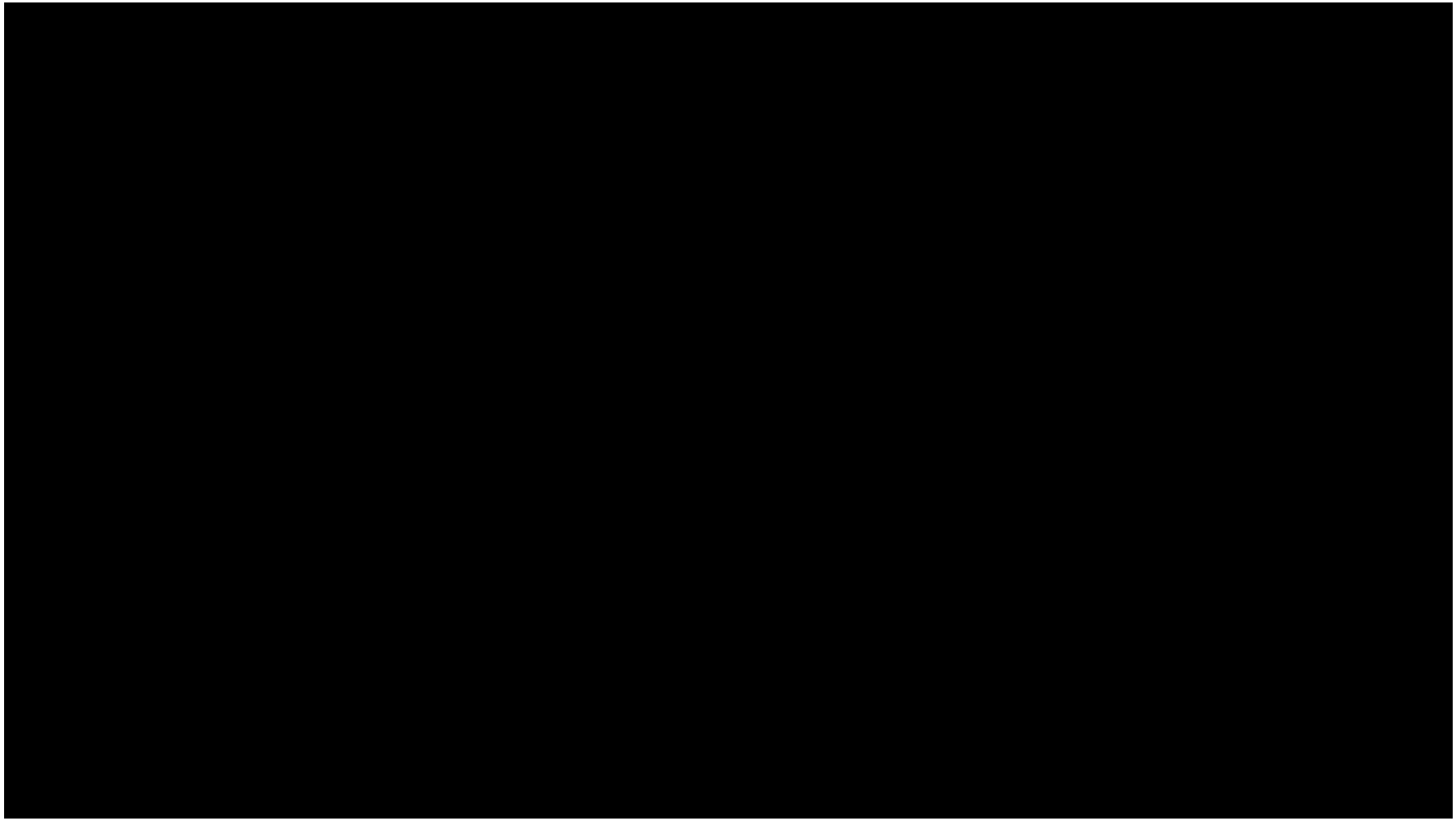
SpaceX - Starlink

- 4,425 satellites (plus in orbit spares) operating in 83 orbital planes (at altitudes ranging from 1,110 km to 1,325 km)
- Phased array user terminals
- Phased array gateway earth station – capable of communicating with multiple satellites from single gateway
- Optical inter-satellite links

	Initial Deployment (1,600 satellites)	Final Deployment (2,825 satellites)			
Orbital Plane	32	32	8	5	6
Sats/plane	50	50	50	75	75
Altitude	1,150 km	1,110 km	1,130 km	1,275 km	1,325 km
Inclination	53 deg.	53.8 deg.	74 deg.	81 deg.	70 deg.

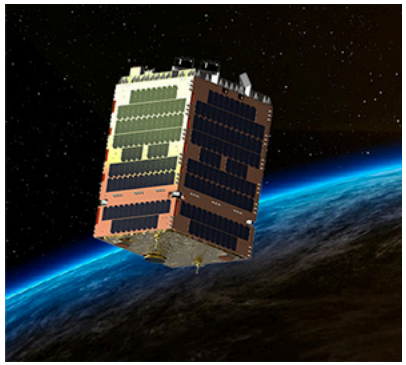
Slide prepared by W. Lohmeyer

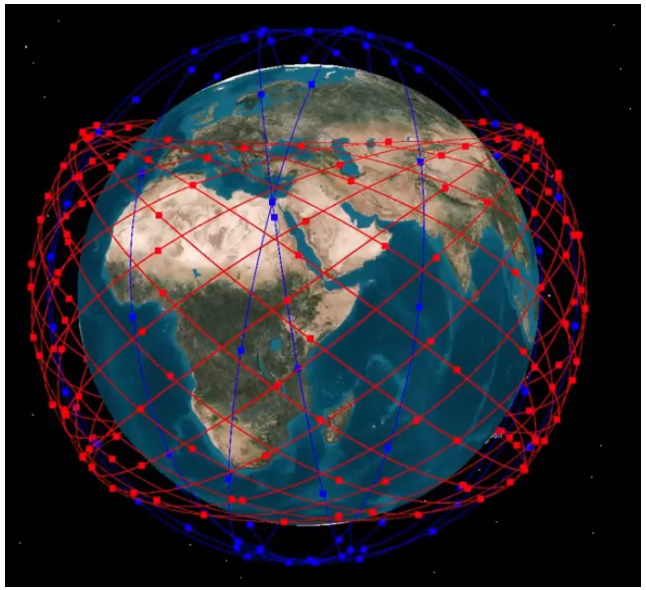
OneWeb



Telesat LEO

- Initial constellation will consist of ~120 satellites by 2021
  - In polar and inclined orbits
- 1 unit on orbit -demonstrated LEO to aircraft video conference (AP October 23, 2018)

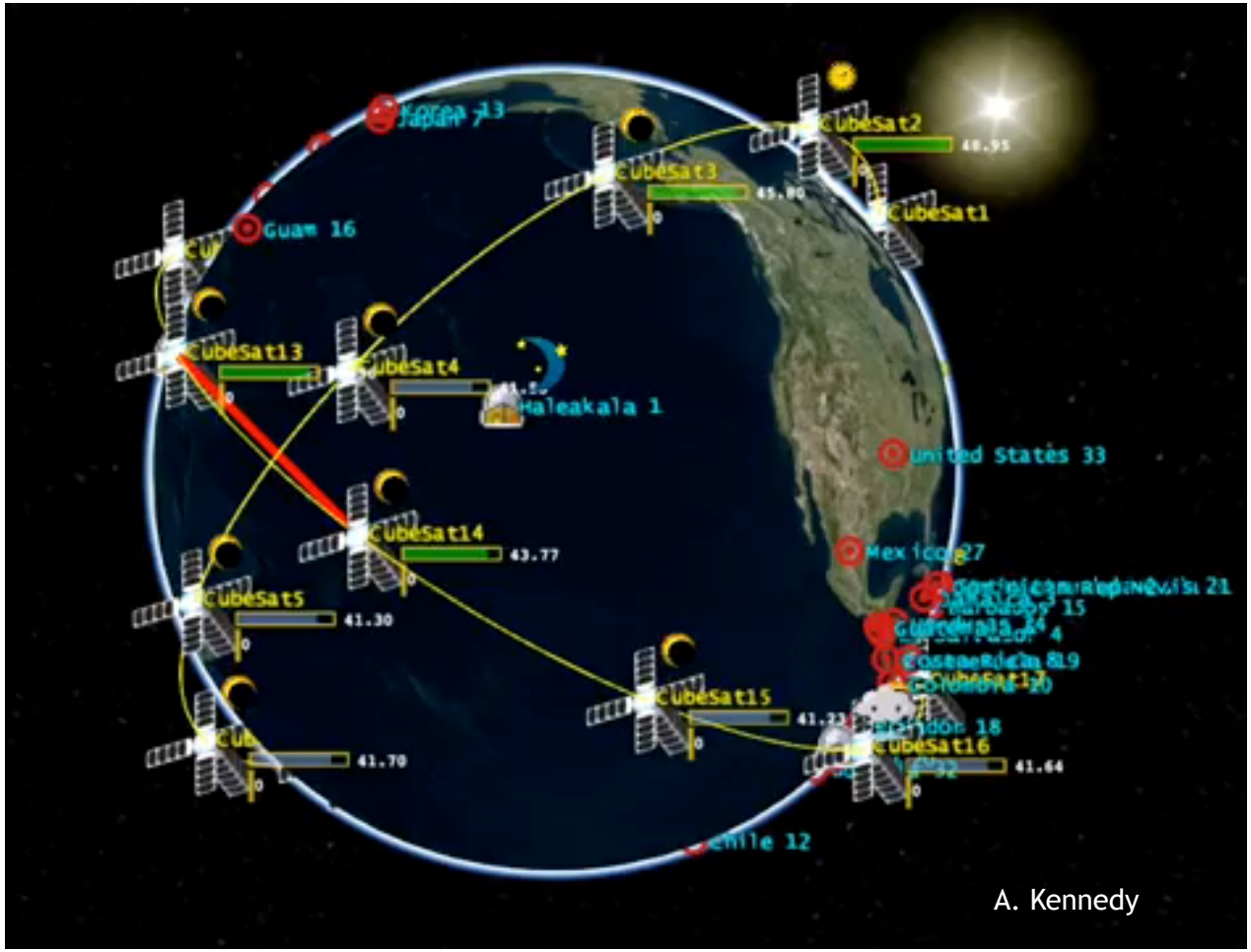




Telesat.com

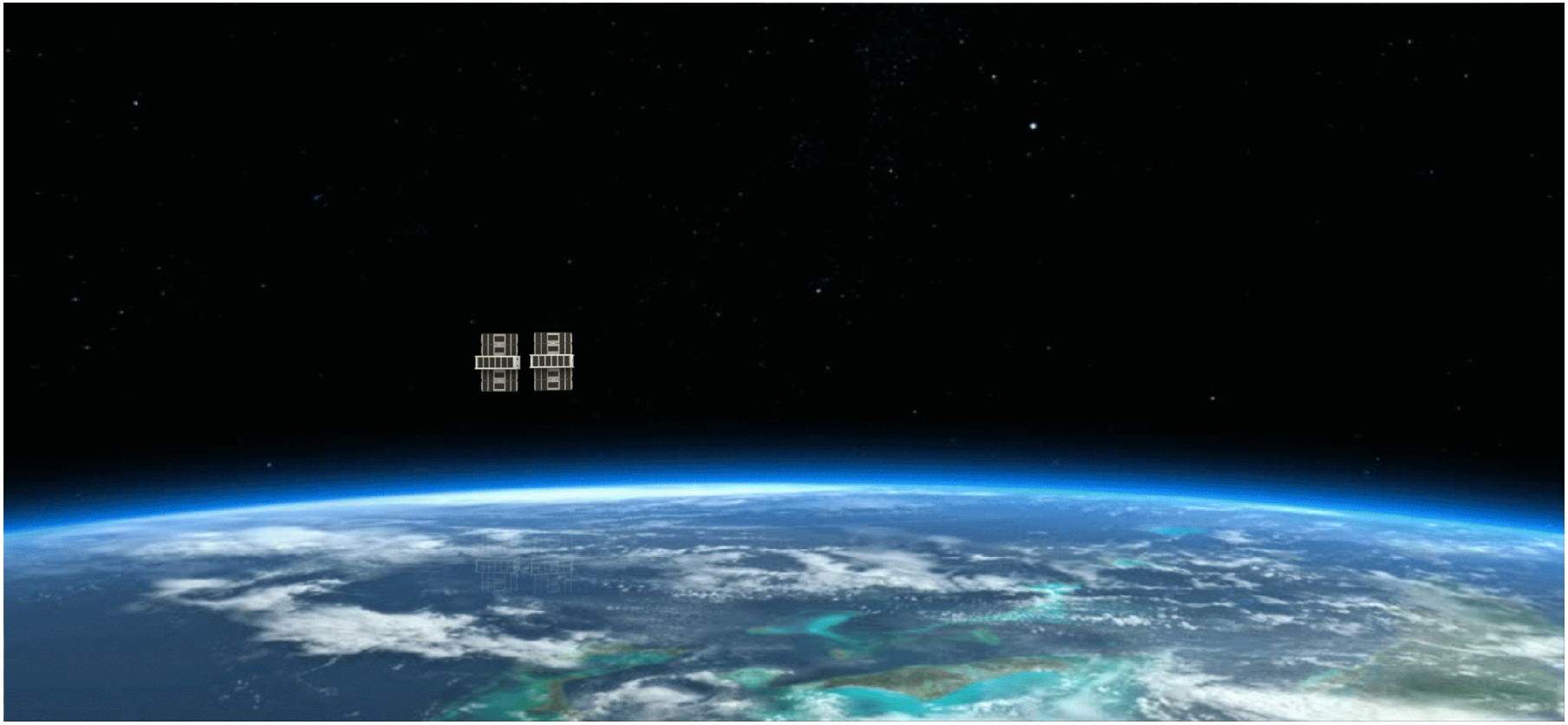
CubeSats and Constellations

Constellation Optimization



NASA CLICK mission

- MIT, U. Florida, NASA Ames
- PI Kerri Cahoy

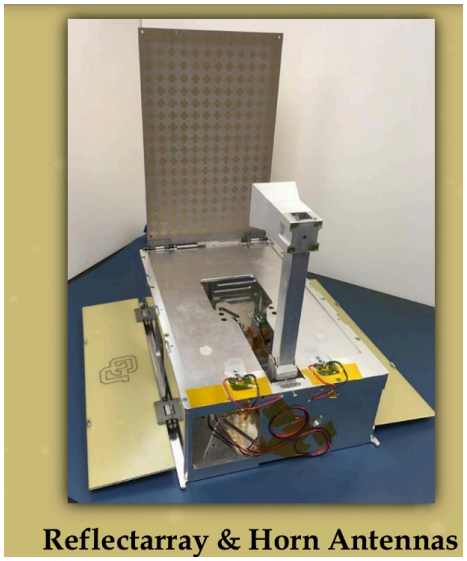


Seismology science flips the paradigm

Modest Ground-station power systems comparable to present day CubeSats

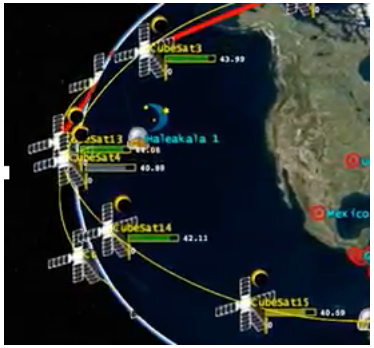
http://www.usarray.org/alaska

Coming soon: Big antennas in LEO



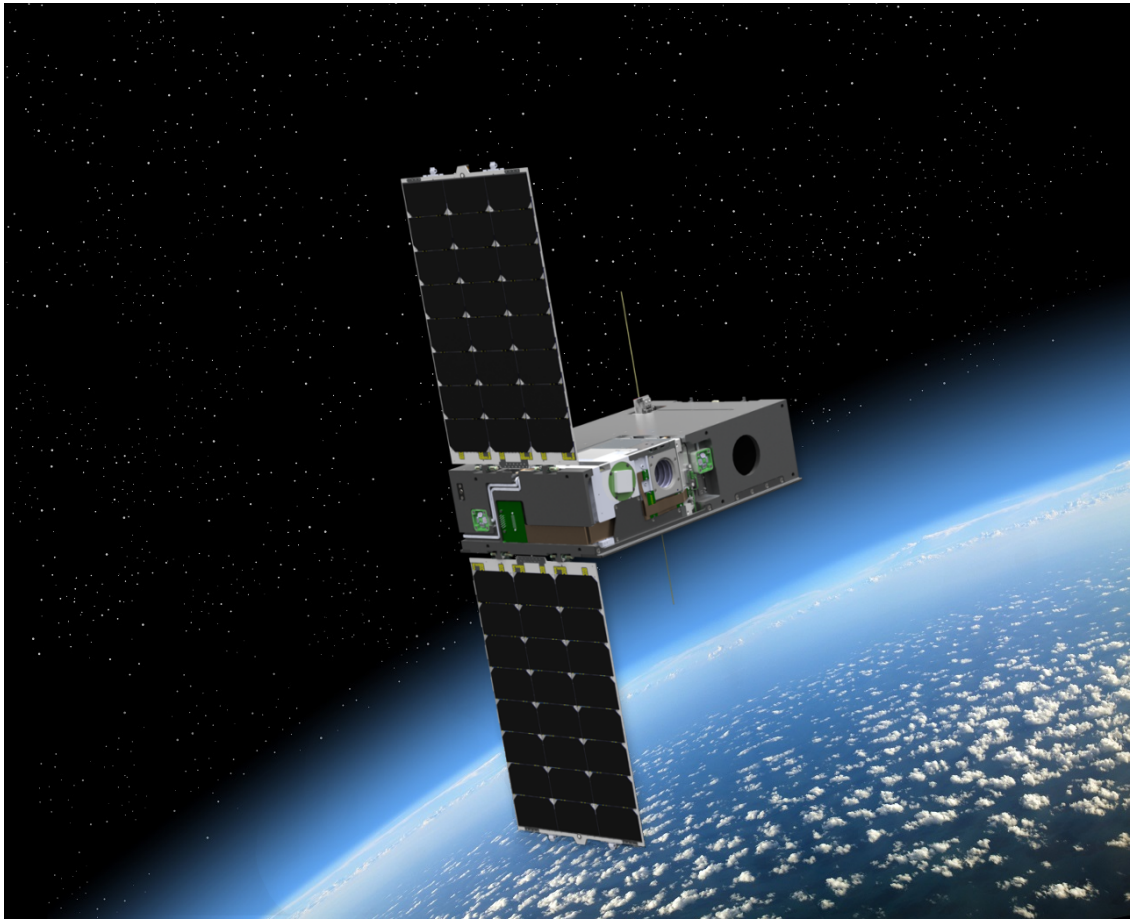
Sobtzak et al 2017

Coming soon:
Crosslinked Constellations
for rapid transmission



A. Kennedy

Questions?



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