Perspectives from the United States on Coexistence and Sustainability of Large Satellite Constellations & Terrestrial Astronomy

Image Credit: NASA

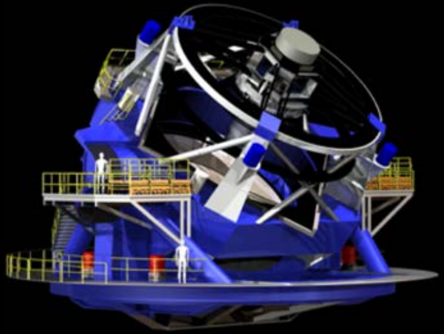


Image Credit: Rubin/NSF/AURA

UN Committee on the Peaceful Uses of Outer Space (COPUOS)

Technical Presentation

2021 August 30

Ashley VanderLey, National Science Foundation
Therese Jones, Satellite Industry Association

Presentation Overview

I. Benefits of Broadband Low Earth Orbit Satellites to Society
II. Challenges to Astronomy and Sustainability
III. Studies and Workshops
IV. Example U.S. Industry – Astronomer Collaboration
V. Lessons Learned and Future Work

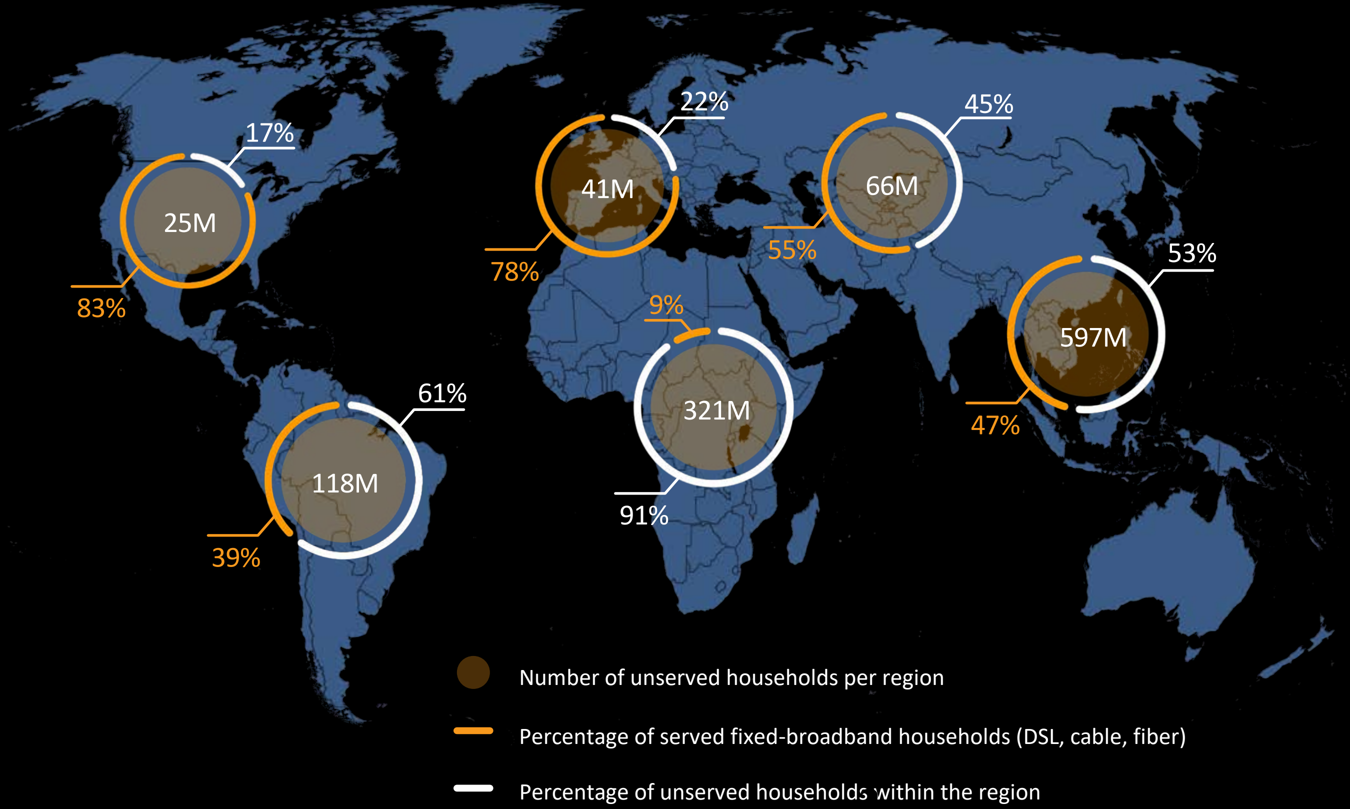
Bridging the digital divide

There are billions of people on Earth without reliable broadband. NGSOs will bridge the gap in places where service is unreliable or expensive, or where it doesn't exist at all.

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

300 million
underserved households are on legacy technologies.

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



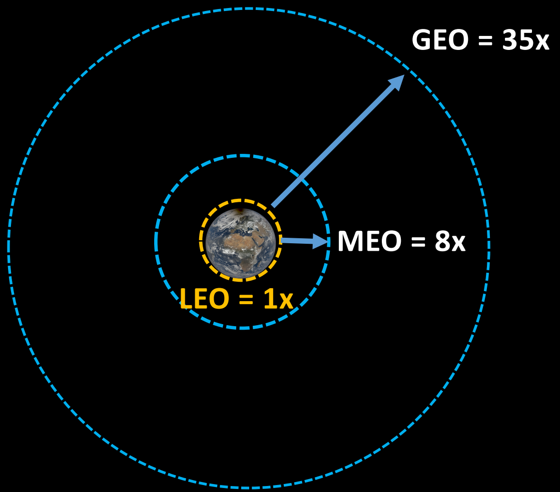
Source: S&P Market Intelligence

Advantages of Low Earth Orbit

1

Relative distance of satellites from Earth

1x = 1,000 km



GEO = Geostationary Orbit

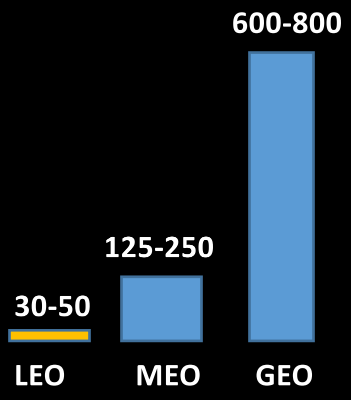
MEO = Medium Earth Orbit

LEO = Low Earth Orbit

2

Packet roundtrip time to Internet

Milliseconds



3

Customer Experiences

Faster Web Pages

LEO loads Web Pages

-similar to fiber

-2x faster versus MEO

-6-8x faster versus GEO

Real-time over-the-top (OTT) media applications

Satellites are an important part of communications ecosystem

- provide a variety of mobile and fixed communications services

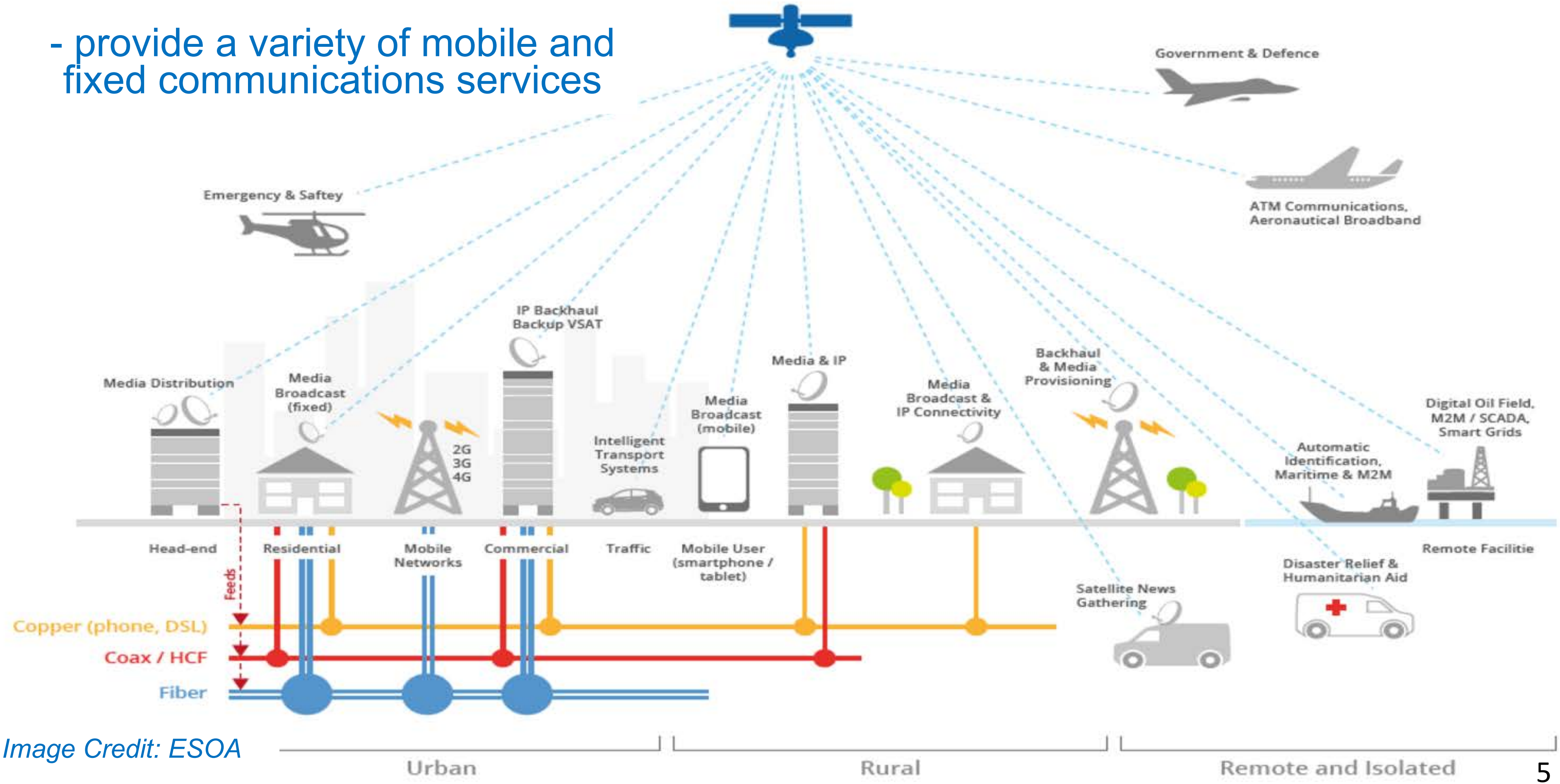


Image Credit: ESOA

Challenges to Astronomy and Sustainability

Dark and Quiet Skies report:

https://www.iau.org/static/publications/dqskies-book-29-12-20.pdf

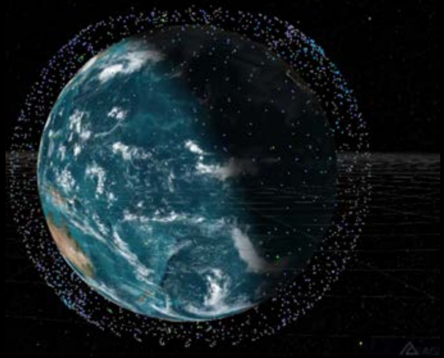
COPUOS STSC Conference Room paper submitted by Chile, Ethiopia, Jordan, Slovakia, Spain and the International Astronomical Union:

https://www.iau.org/static/publications/uncopuos-stsc-crp-8jan2021.pdf

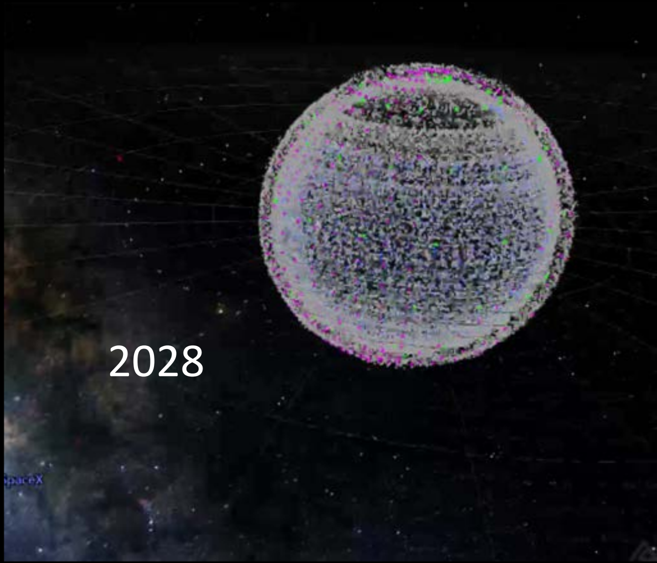
There is a proposed space population like we've never seen before!

More than 50,000 new spacecraft proposed globally in next ten years

2018



2021

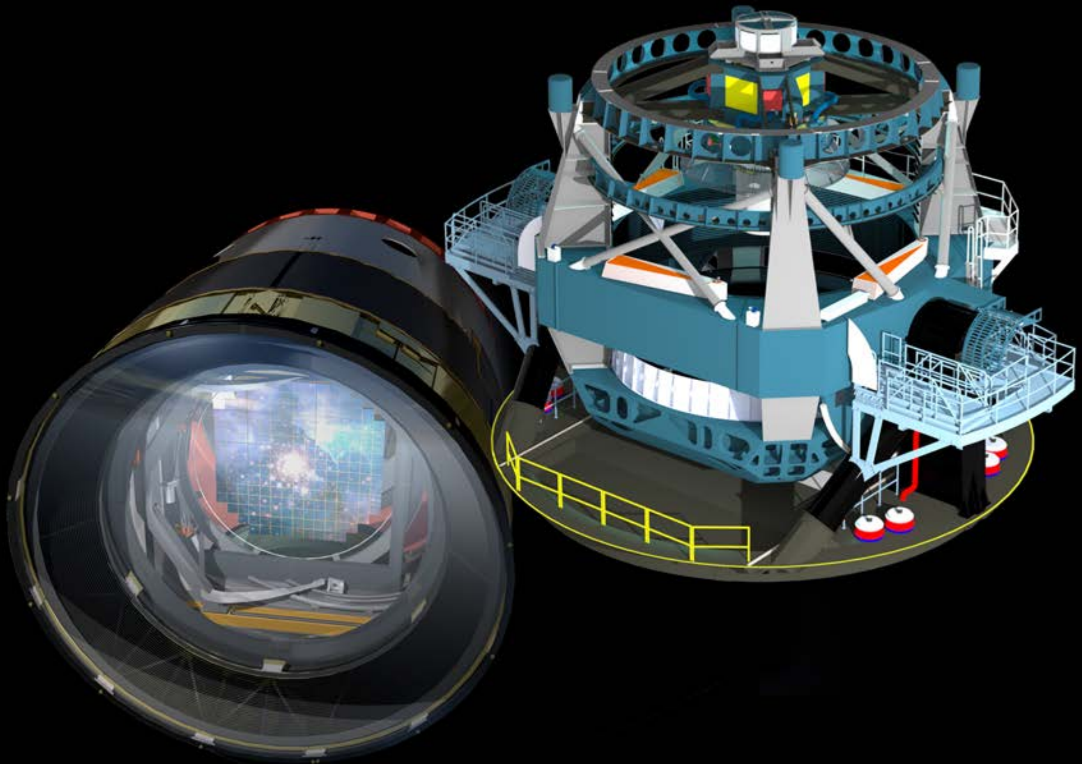


2028

Images: Screen shots from animation based on applications filed with the ITU and the U.S. FCC. Credit SSC.

VERA C. RUBIN OBSERVATORY

LSST
Legacy Survey of Space and Time



Rubin Observatory will execute the *Legacy Survey of Space and Time*, producing the deepest, widest, view of our dynamic Universe:

- 8.4-m mirror
- 3200 megapixel camera
- Each image the size of 40 full moons
- Scans the sky with 2000 images per night
- 10 year survey of the sky 2024-2034
- 37 billion stars and galaxies
- 10 million alerts, 20 Terabytes of data - every night!
- **Significantly impacted by bright satellite trails**

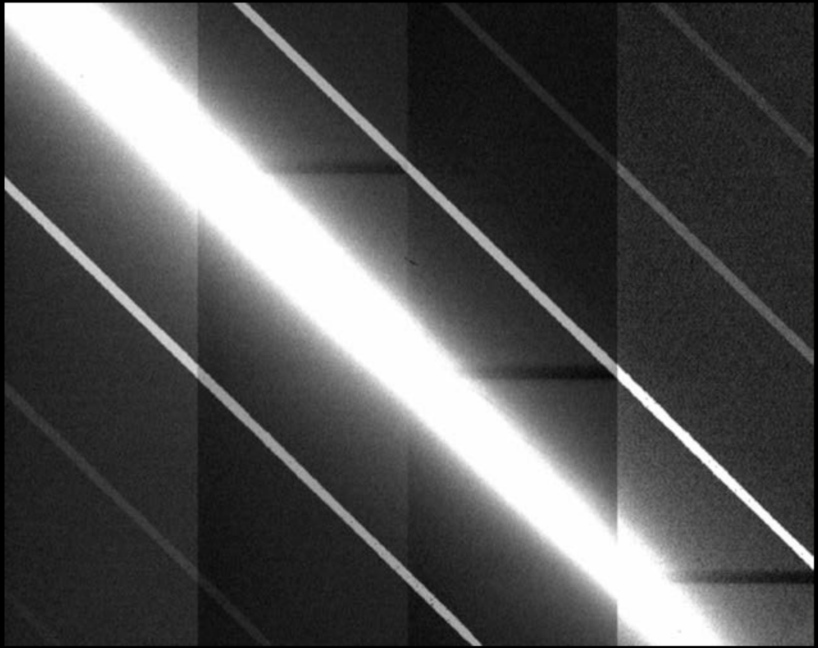
Image on left taken with very small telescope with wide field of view (above).

John Tonry
U Hawaii

With tens of thousands of LEOsats, generally no combination of mitigations can completely avoid the impacts of the satellite trails

Astronomical Journal, 160, 226 (2020)   arXiv:2006.12417

How do bright satellites affect observations on telescopes?



- Diversity of impact to radio astronomy, optical spectroscopy and imaging

Examples from imaging:

- Loss of information in pixels
- Cross-talk in electronics
- Ghost images
- Possible residual images
- Creates harmful artifacts

Many factors contribute to overall scientific impact

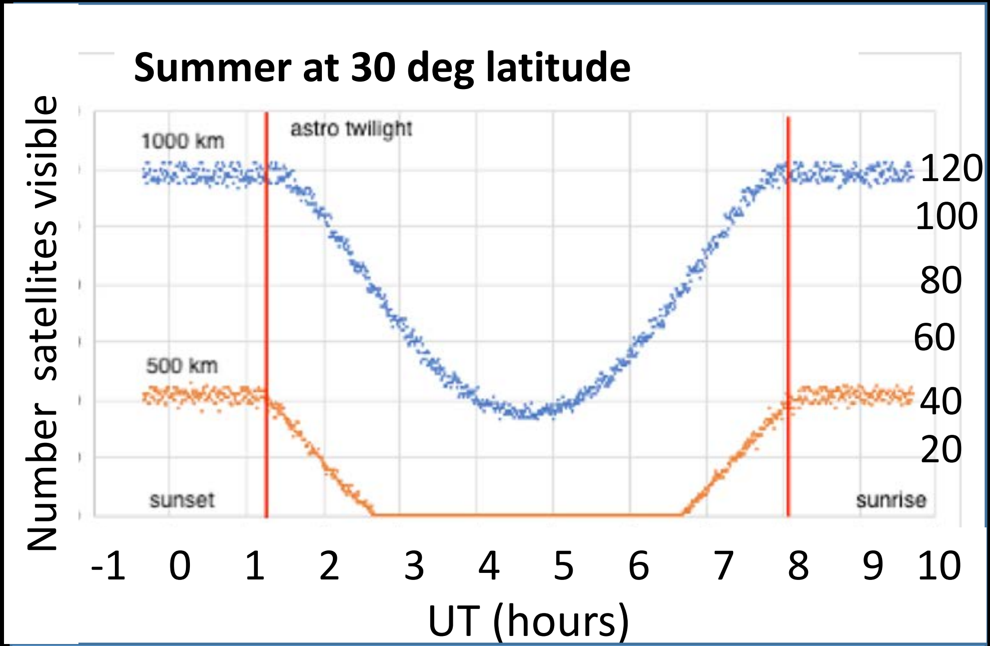
Satellite Operator:

- Orbital altitude / dwell time of satellite in field of view (FOV)
- Constellation total number
- Size of individual satellites
- Reflectivity properties of material
- Geometry of reflected light
- Orbit/De-orbit plans

Astronomers:

- Telescope
    - Camera detector properties
    - Scheduling
    - Field of View
    - Image sensitivity
- Post-processing algorithms
- Observational requirements

Impact of Orbital Altitude



10,000 satellites at 1000 km
10,000 satellites at 500 km

- Higher altitude constellations (1200 km) very challenging – visible all night long during summer.
- If constellation of 40,000 satellites deployed at ~1,200 km, then every 30 second exposure of the Large Magellanic Cloud (LMC) will have at least one satellite trail in it during summer.
- Orbits at 1,200 km may present challenge to 25 year de-orbit requirement and space debris / proactive powered de-orbit capabilities are key
- Critical to minimize number of non-operational objects post-mission at all altitudes

Simulations by P. Seitzer (University of Michigan) – 100 planes with 100 satellites each, 53 deg inclination

Studies and Workshops

Cooperation, Coordination and Collaboration

- U.S. satellite industry has been closely cooperating with U.S. scientists, especially at the Vera Rubin Observatory, a limiting case, to

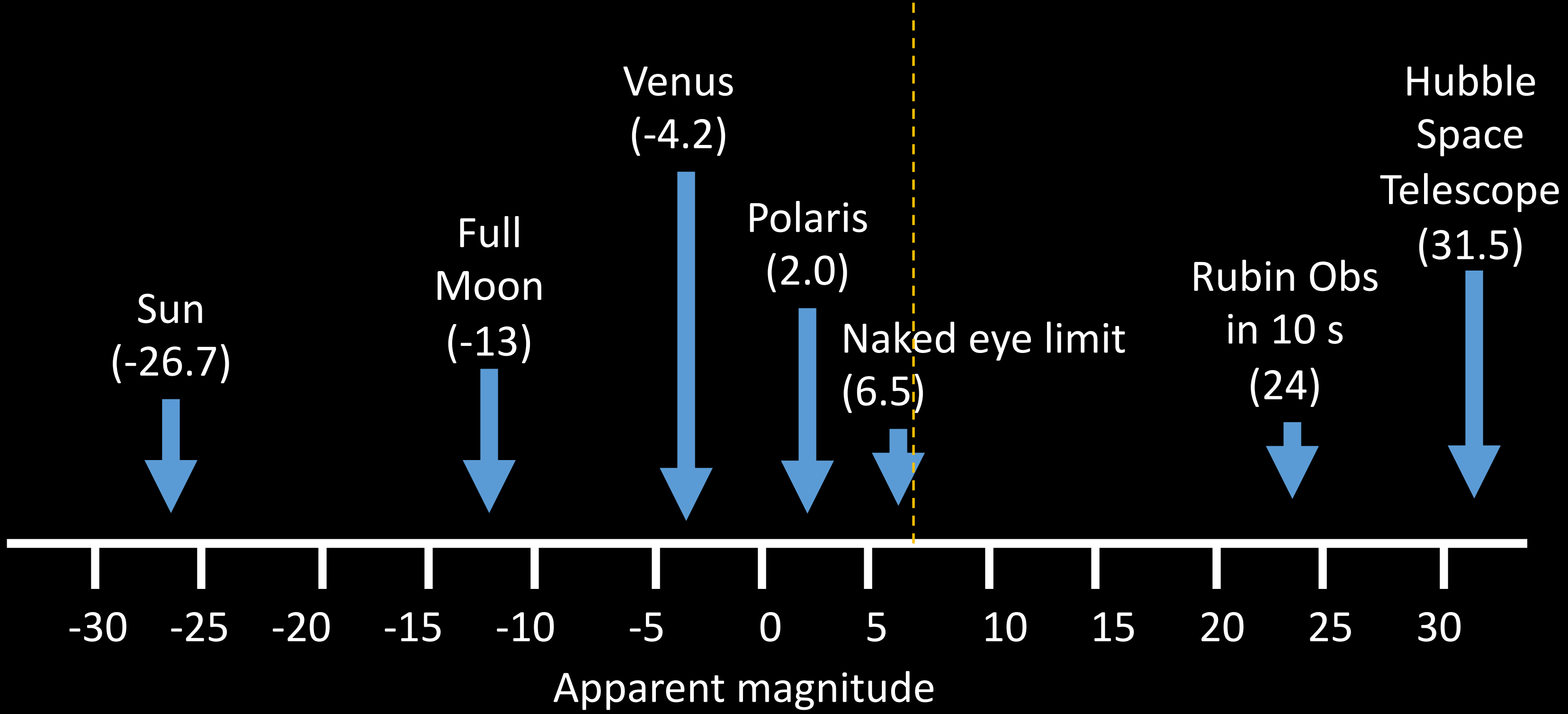
  - Understand the challenge to astronomy
    - Satellite brightness (launch, mission, de-orbit phases)
    - Numbers of satellites
    - Satellite orbital altitude (<700 km versus > 1100 km)

  - Quantify metrics for target goals
    - For example, Astronomers have recommended that operators design satellites to appear no brighter than approximately 7th magnitude.

  - Find solutions

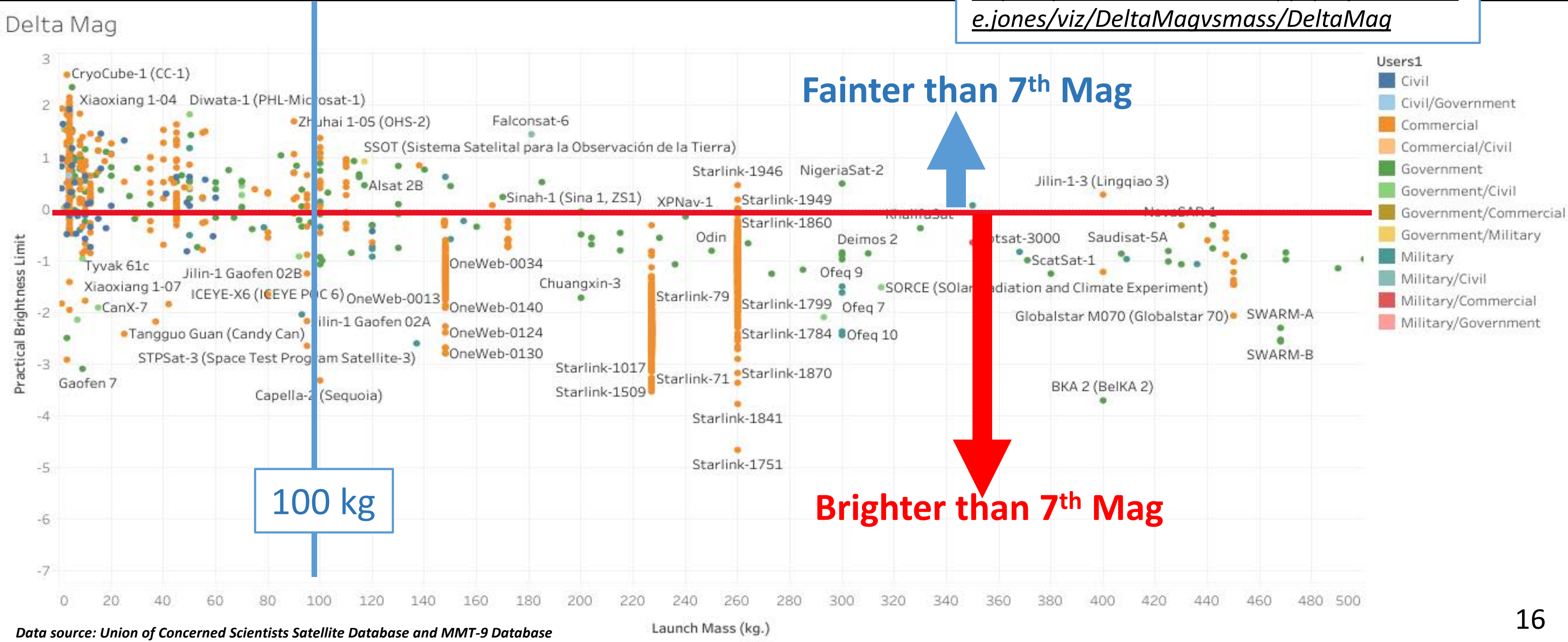
- We also emphasize the importance of international cooperation and recognize the important role of the IAU and the satellite industry internationally; Coordination discussions are ongoing .

7th magnitude brightness recommendation



Satellites in the 100+ kg range typically exceed the 7th magnitude threshold for astronomers, but many smaller sats do as well

Interactive data: *https://public.tableau.com/app/profile/therese.jones/viz/DeltaMagvsmass/DeltaMag*



Data source: Union of Concerned Scientists Satellite Database and MMT-9 Database

Need to consider targeted stakeholder outreach in determining mitigation mechanisms

- LEO comms satellites weighing 100s of kg largely exceed the practical brightness limit
  - US companies launching thousands of satellites are working with astronomers, but astronomers need a unified international effort
  - Many new remote sensing constellations are in the ~100 kg range but launching constellations of tens of satellites– at what point are they an issue for astronomy?
- Many smaller satellites also exceed the practical brightness limit
  - Commercial remote sensing constellations weighing 10s of kg with hundreds of satellites– likely fainter but may exceed the brightness limit
  - Cubesats are not all below the brightness limit

Diverse set of stakeholders:

- Not all satellite operators manufacture their own satellites
- Smaller constellations may not be able to launch test satellites and make iterative changes
- Growing internationalization of satellite industry
- Decreasing costs (e.g., cubesats) means a lot of one-off projects

U.S. Government Funded Workshops and Studies

- **SATCON I and SATCON II -**
  - Hosted by NSF's NOIRLab and the American Astronomical Society; we appreciated international participation!
  - Four working groups: Observations, Algorithms, Community Engagement, Policy
    - SATCON I: Mitigation recommendations that include quantitative metrics: https://aas.org/satellite-constellations-1-workshop
    - SATCON II: Define and quantify resources, metrics, and collaborations needed to implement recommendations;
      - Engage astronomers and satellite operators collaboratively in exploring framework and developing policy points for operations in LEO;
      - Increase diversity of stakeholders and perspectives working to address the challenges and opportunities.
      - Report forthcoming; public press conference available - https://www.youtube.com/watch?v=7DF99GIIR04

- **JASON report**
  - Independent science advisory group
  - Charged to understand
    - Types and numbers of spacecraft planned in next decade;
    - The current regulatory process;
    - To characterize types of interference and types/range of observations being made and foreseen in the future; and
    - Suggest additional data that should be gathered to understand the scope of the problem for the future.
  - Report also considered long-term sustainability and space debris
  - https://www.nsf.gov/news/special_reports/jasonreportconstellations/

- *We look forward to participating in the Dark and Quiet Skies October 2021 Conference in the Canary Islands, Spain*

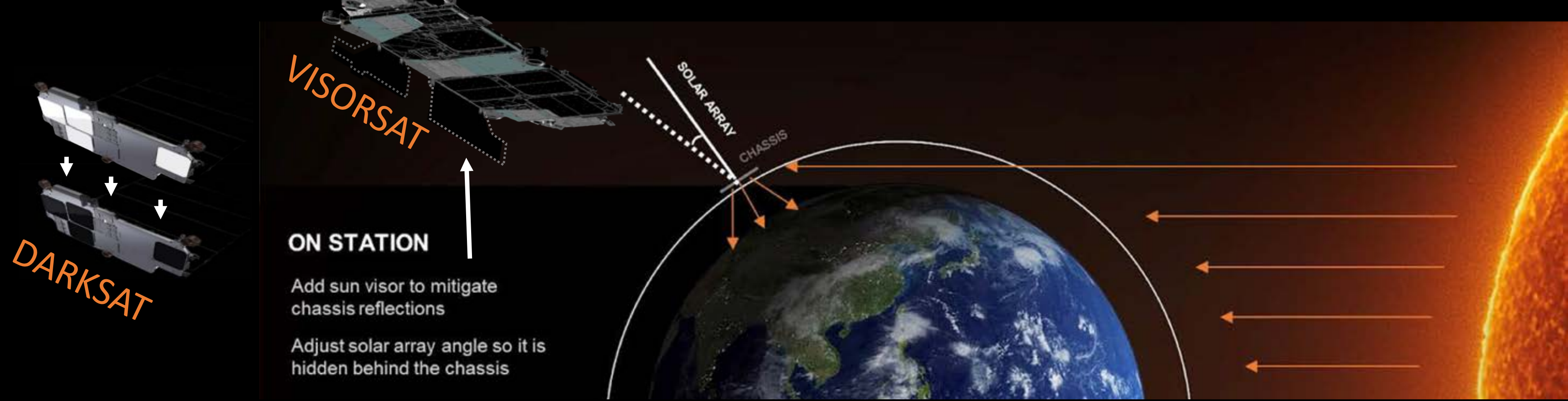
US Example from Industry

In May 2019, SpaceX's inaugural launch of 60 Starlink satellites surprised optical astronomers with their brightness

Since then, SpaceX has collaborated with astronomers in the US and internationally to assess the impact of Starlink on astronomical observations, and to identify, develop, field and test mitigations. This work has formed the foundation for many of the recommendations for satellite operators and astronomers

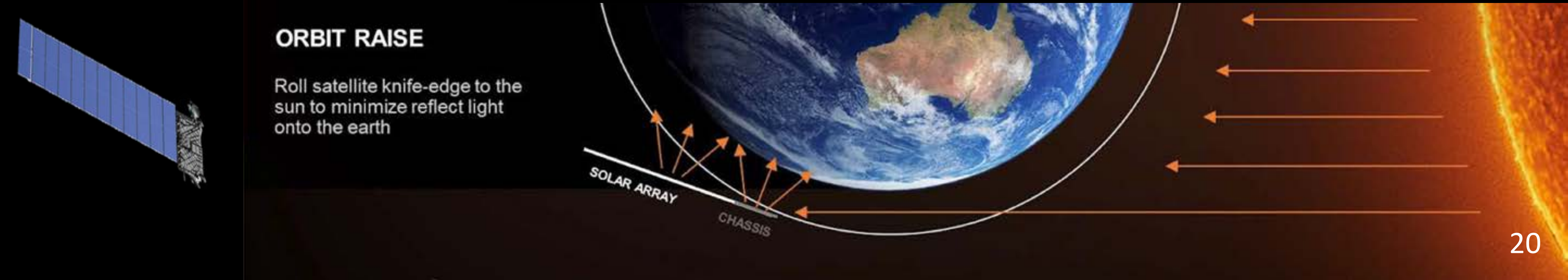
SpaceX Goal for On-Station Brightness: Darken satellites so they do not saturate observatory detectors

MITIGATION: REDUCE REFLECTION DURING SUNSET AND SUNRISE

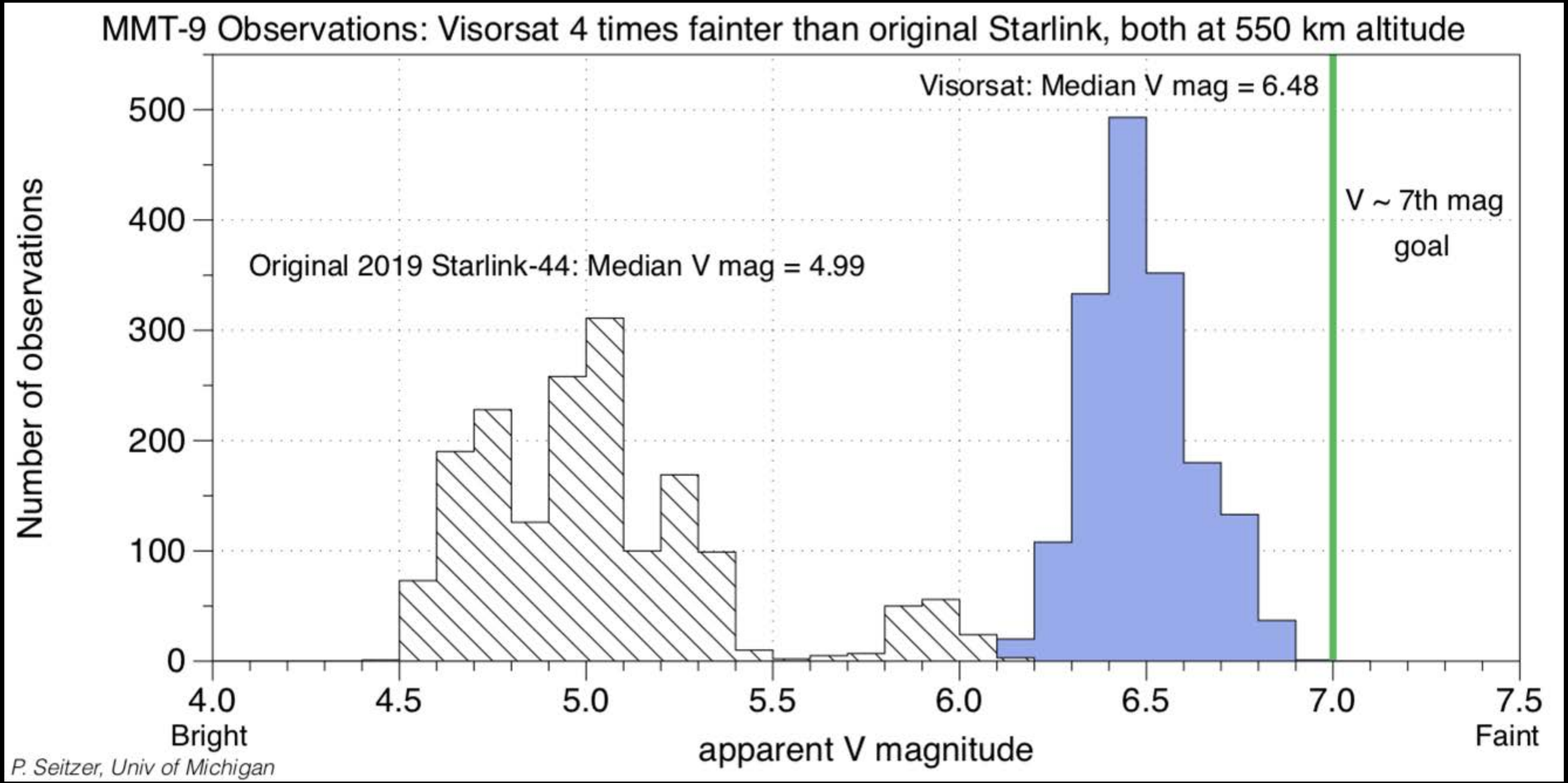


SpaceX Goal During Orbit Raise: Make Satellites Invisible to Naked Eye within a Week After Launch

MITIGATION: CHANGE ORIENTATION TO REDUCE REFLECTION OFF BOTH ANTENNA AND SOLAR ARRAY



Darkening Techniques are working and moving closer to target goal of 7th mag



Protecting astronomical observations

Project Kuiper taking steps to minimize their 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)
- As an all Ka-band system, we avoid potential interference issues with radio astronomy in Ku-band.

Deployment and operations

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

Collaboration

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

OneWeb – Responsible Space

OneWeb

Active brightness measurement campaign underway at GAL Hassin Observatory correlating brightness magnitude to orbital position and time of year

GAL Hassin Observatory, Italy

Gen 1

- Results leading to the identification of areas contributing to brightness
- Developing a correlated model for use on Next Generation

Identification of potential solutions to reduce Gen1 brightness in work

Gen 2

Requirements for Maximum Brightness limit in place for Next Generation Satellites

Designed for de-orbiting in less than 1 year

All satellites (Gen1 & 2) designed to be de-orbited in less than 1 year

Design includes provision for assisted de-orbiting as back-up

- Grappling Feature implemented on all satellites from the initial 2019 launch
- Active OneWeb cooperation with ESA and ADR Community

Image Credit: OneWeb

Lessons Learned & Further Work

Early solutions

- Some promising improvements from darkening or including visors to block sunlight; when satellite operators implement technical upgrades with more capable satellites, these should be considered.
- Work with industry to develop joint operations solutions to minimize science impact including tools for efficient scheduling and predictive models.
- Develop observing strategies and new data analysis methods to partially correct for statistical and systematic effects caused by satellite trails.
- Explore science impacts of residuals via end-end simulations.

However, *even if mitigations work*, evidence of satellite trails will clearly be in the data – complicating data analysis, requiring longer science missions, limiting discoveries

Further Work: Satellites and Telescopes

- More precise tracking information for satellites is needed to assist in astronomical observation planning and development is needed in astronomical community to implement observation planning (although this alone does not mitigate, especially for wide field-of-view astronomy telescopes like the Rubin Observatory)
  - **Open Architecture Data Repository (OADR) in U.S. Department of Commerce a first step**
- Tools used to model satellite brightness pre-launch as well as best practices for stakeholders across the industry will be critical
  - Additional basic research on materials/design may provide further guidance
- Development of software application available to general astronomy community to identify, model, subtract, and mask satellite trails in images as well as detailed simulations of effects on data analysis systematics and data reduction signal-to-noise impacts
- Collaboration and coordination with diversity of stakeholders
  - Profile of space actors is rapidly changing– while communications satellites are the current focus of these mitigation issues, remote sensing satellites are rapidly increasing in number on orbit
  - Telescope technology is evolving and there are a diversity of observational parameters to consider

Summary

The United States supports efforts to study these challenges and encourages all administrations to carefully and thoughtfully consider the individual recommendations within the Dark and Quiet Skies report.

International cooperation is required to agree on priorities and accelerate practical, scalable solutions.

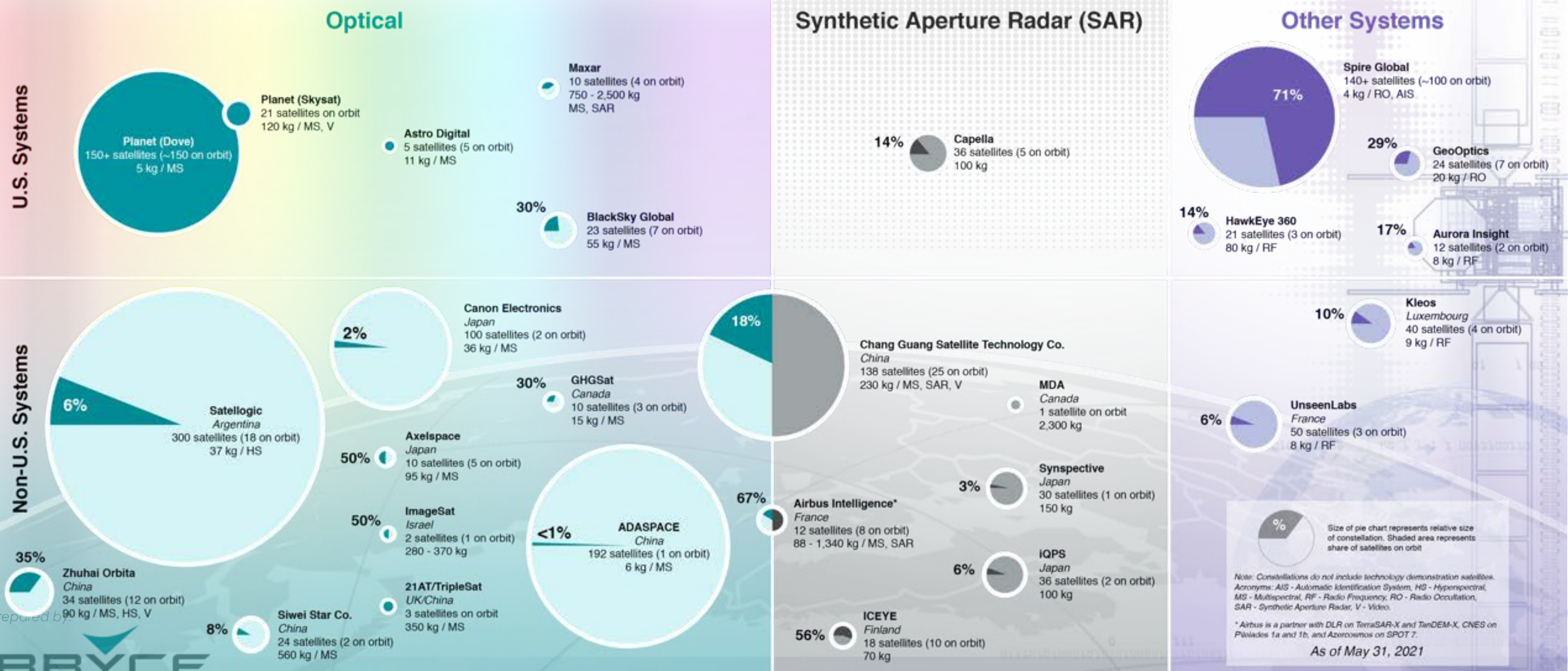
Astronomers and Satellite providers within the United States will continue to work together *and with the international community* towards a sustainable future – for the important provision of low-latency broadband service, for future discoveries enabled by astronomy, for long-term sustainability, and for society at large.

Additional Reference Slides

Case Study: Remote Sensing Services

Commercial Remote Sensing Satellite Systems

Systems with at least one operational satellite, by relative size of constellation, percentage of satellites on orbit, and sensor type



Note: Constellations do not include technology demonstration satellites. Acronyms: AIS - Automatic Identification System, HS - Hyperspectral, MS - Multispectral, RF - Radio Frequency, RO - Radio Occultation, SAR - Synthetic Aperture Radar, V - Video.

** Airbus is a partner with DLR on TerraSAR-X and TanDEM-X, CNES on Pléiades 1a and 1b, and Azercosmos on SPOT 7.*

As of May 31, 2021