Overview

• SpaceX was founded to revolutionize space technology towards making life multiplanetary
• We're deeply committed to maintaining a safe orbital environment, protecting human spaceflight, and ensuring the environment is kept sustainable for everyone
• Starlink is providing high-speed internet to hundreds of thousands of users in 30+ countries
• SpaceX is safely operating 2200+ satellites in Low Earth Orbit despite recent debris surge
• Unwavering commitment to keep space safe and both reduce the brightness of our satellites and ensure there are accurate ephemerides and TLEs available
SPACEX OVERVIEW

151
TOTAL LAUNCHES

32
MARKETS

2,400+
STARLINK SATELLITES LAUNCHED

250k+
CUSTOMERS ONLINE

150+
MBPS DOWN

<30
MS LATENCY
Making a Difference!

- Starlink is making a huge positive impact for hundreds of thousands of people around the world, while advancing space sustainability and safety

- Supporting connectivity to numerous communities, Tribes, school districts, etc.

- Supporting enterprise and small businesses

- Focus initially on remote, rural communities with un/underserved households

- Helping to close the digital divide in the U.S. and around the world
Demonstrated Commitment to Space Sustainability

• Designing and building highly reliable, maneuverable and demisable satellites that have demonstrated reliability of greater than 99%
• Operating at low altitudes (below 600 km) to ensure no persistent debris, even in the unlikely event a satellite fails on orbit
• Inserting satellites at an especially low altitude to verify health prior to raising into their on-station/operational orbit
• Transparently sharing orbital information with other satellite owners/operators
• Developed and operating an advanced collision avoidance system to take effective action when “encounter” risks exceed safe thresholds
• Continuing efforts to keep night skies dark
Starlink Operational Phases

- Launch and deployment
- Post deployment to parking
- Parking (really RAAN rephasing)
- Parking orbit to operational orbit
- Operations
- Deorbit / disposal
Engineering Challenge

- 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
  - We've invested significant engineering hours and resources to work with astronomers to understand the impacts and rapidly implement mitigation techniques
  - We seek to both reduce the brightness of our satellites and ensure there are accurate ephemerides and TLEs available to help astronomers avoid imaging our satellites while still imaging for science or fun

Credit: Pat Seitzer
Mechanism for Satellite Brightness

Mitigations implemented by SpaceX:
1. Operate in lower LEO regime (< 650 km)
2. Solar array darkened
3. Satellite knife-edged to sun during orbit raise with reduced power generation
4. Visors to block incident light to chassis nadir
5. Specular material development to reflect light away from earth
6. Dark paint development to absorb light
7. Publicly available Ephemerides and TLEs
Visors vs. Specular Nadir Surfaces

- Visors block incident light to chassis while also needing to be black to avoid adverse scatter of their own.
- Making the chassis nadir specular can be more efficient for brightness and has many other design advantages.
  - A purely specular surface will be invisible to observers on earth.
- SpaceX has implemented a space stable, dielectric mirror sticker using commercially available subcomponents and processes.
- Continuously investigating and improving scatter properties with main challenges being reducing intrinsic defects, surface roughness, and applying UV mitigation coatings.
  - SpaceX Gen1 to Gen2 dielectric mirrors have 50 times lower diffuse scatter.
  - Conops can also bias specular reflection further from Earth.

Gen2 Dielectric Mirror

Brightness Analysis for Visor vs. Gen2 Mirror Stickers

- Assumes materials used for Starlink visorsats, visor plane points directly nadir, and visor or mirror sticker coverage is 100%.
- All observers looking >20 degrees above horizon considered.

Mirrored Chassis Nadir Brightness Mechanism

Brightness regime of concern

Incident light

Approximately to scale for Starlink 550km Orbit
Scatter Comparisons

• A white lambertian satellite at 550km would need to 0.078m² to satisfy 7th mag target

• Vantablack is one of the darkest commercially available paints.
  • ~200 times dimmer than white.
  • Erodes in space environment.
  • Not cost efficient or scalable to large areas.
  • Poor thermal performance

• Gen2 SpaceX mirrors are ~10 times dimmer than Vantablack for observers looking directly up
  • Combines commercially available products and processes traditionally used in different industries
  • Cost and supply chain are reasonable
  • Great thermal performance
Starlink TLEs and Ephemerides

- SpaceX publishes a variety of Starlink orbital data “publicly”
- Traditional TLEs are available on Space-Track.org after the satellites are cataloged
- Supplemental TLEs are available on Celestrak.org
  - These are TLEs fit to Starlink propagated ephemerides
- Propagated ephemerides and covariance are available to anyone with a Space-Track.org account in their Public Files
Conclusion

• Starlink is making a huge positive impact for hundreds of thousands of people around the world, while advancing space sustainability and safety

• Some things to think about:
  • Finely orchestrated satellite operations below 600 km significantly reduce space safety risk and reflection impact to the night sky
    • Are responsible large constellations villains or victims?
  • Remember...risk is likelihood AND consequence
  • How can we collectively prevent intentionally generated orbital debris?
  • How can we collectively reduce the risk of derelict rocket bodies?