



May 7, 2022

SPACE SUSTAINABILITY



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

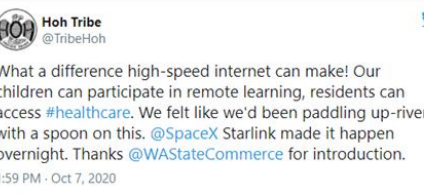
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MS LATENCY



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

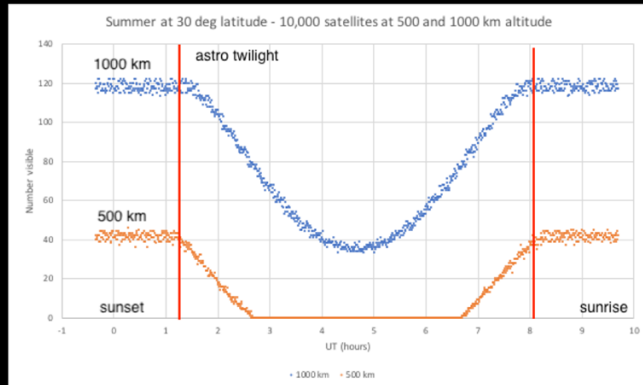
Starlink Operational Phases

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

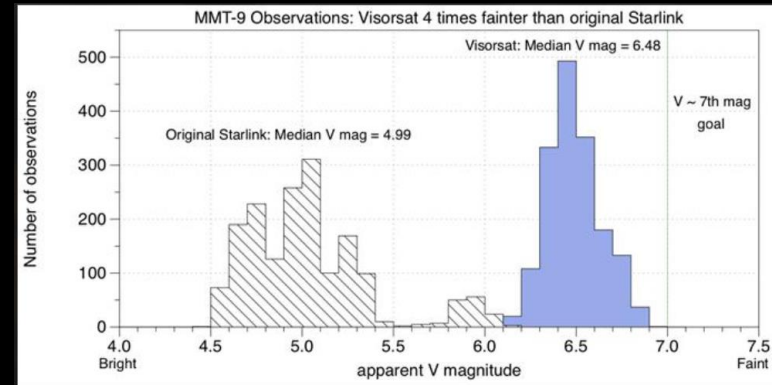


Engineering Challenge

- 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

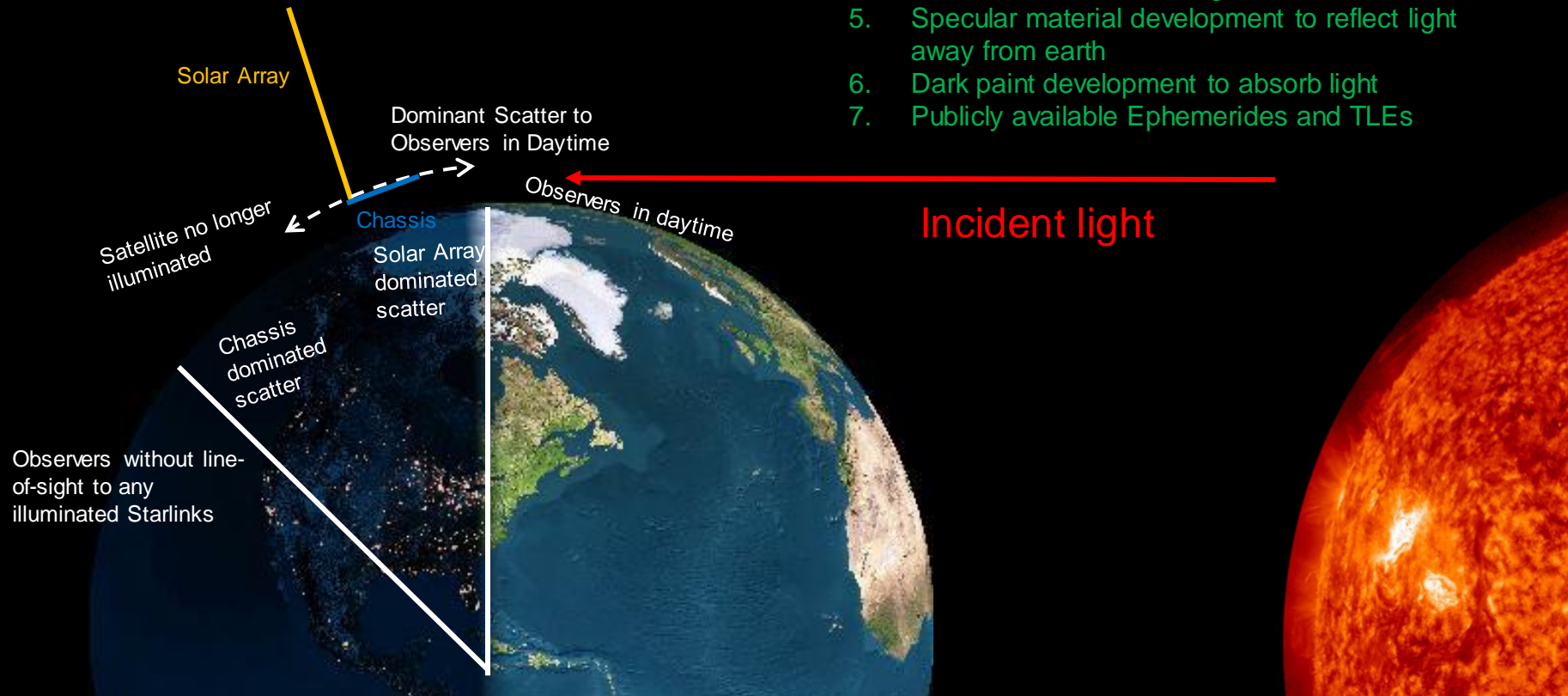


Credit: Pat Seitzer

Mechanism for Satellite Brightness

Mitigations implemented by SpaceX:

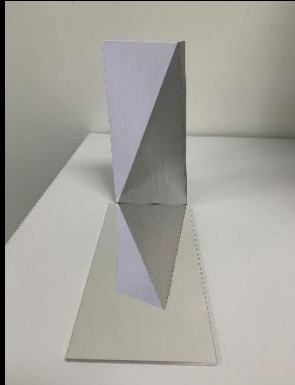
1. Operate in lower LEO regime (< 650 km)
2. Solar array darkened
3. Satellite knife-edged to sun during orbit raise with reduced power generation
4. Visors to block incident light to chassis nadir
5. Specular material development to reflect light away from earth
6. Dark paint development to absorb light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



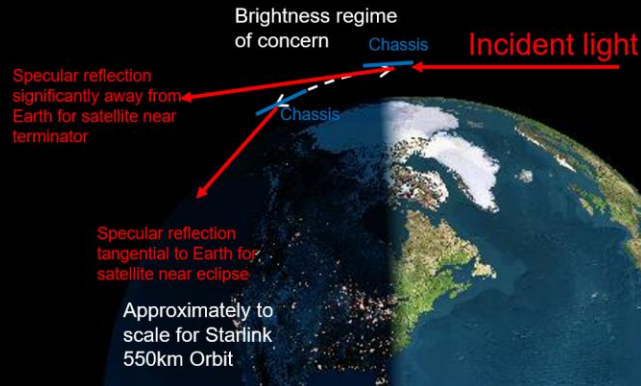
Visors vs. Specular Nadir Surfaces

- 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

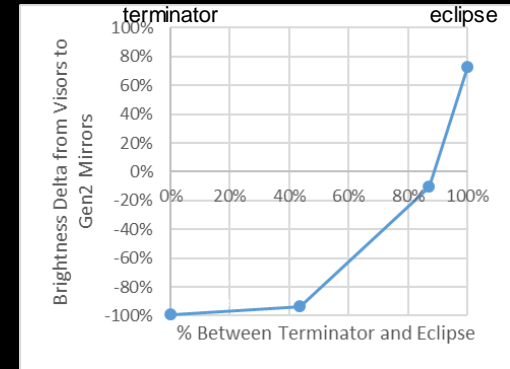
Gen2 Dielectric Mirror



Mirrored Chassis Nadir Brightness Mechanism



Brightness Analysis for Visor vs. Gen2 Mirror Stickers

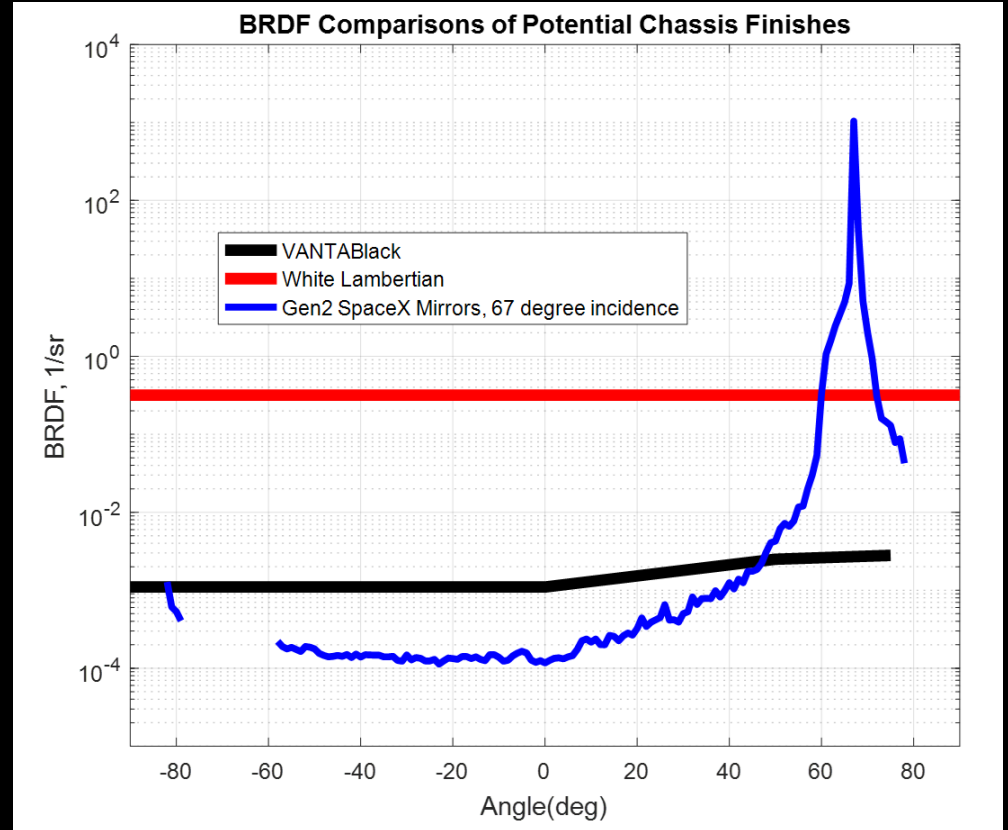


Mirrors brighter right at eclipse as near specular scatter goes to earth

- 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

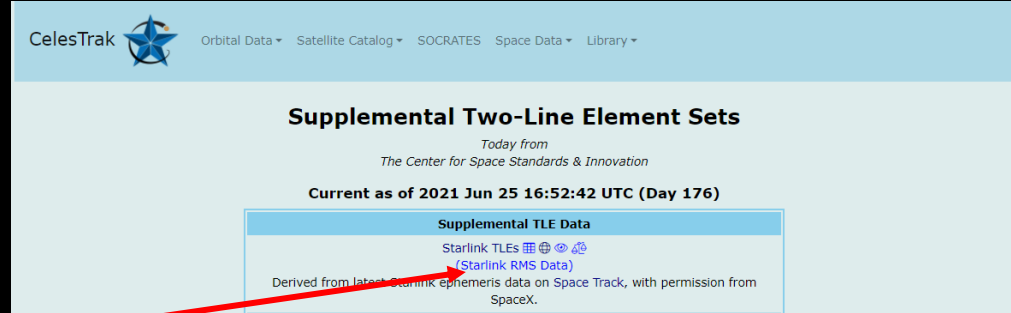
Scatter Comparisons


- 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






Celestrak  Orbital Data ▾ Satellite Catalog ▾ SOCRATES Space Data ▾ Library ▾

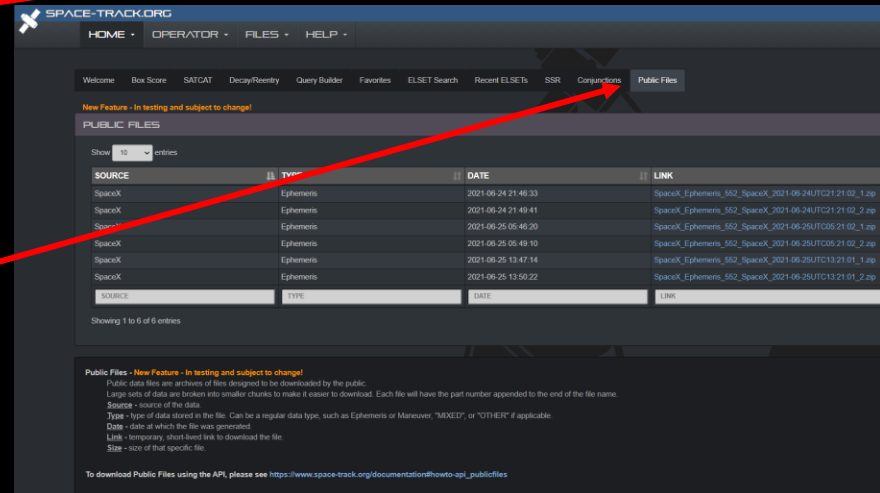
Supplemental Two-Line Element Sets

Today from
The Center for Space Standards & Innovation

Current as of 2021 Jun 25 16:52:42 UTC (Day 176)

Supplemental TLE Data
Starlink TLEs   
(Starlink RMS Data)

Derived from latest Starlink ephemeris data on Space Track, with permission from SpaceX.



SPACE-TRACK.ORG

HOME ▾ OPERATOR ▾ FILES ▾ HELP ▾

Welcome Box Score SATCAT Decay/Reentry Query Builder Favorites ELSET Search Recent ELSETS SSR Conjunctions **Public Files**

Public Files - In testing and subject to change!

Show 10 entries

SOURCE	TYPE	DATE	LINK
SpaceX	Ephemeris	2021-06-24 21:46:33	SpaceX_Ephemeris_552_SpaceX_2021-06-24UTC21:21:02_1.zip
SpaceX	Ephemeris	2021-06-24 21:49:41	SpaceX_Ephemeris_552_SpaceX_2021-06-24UTC21:21:02_2.zip
SpaceX	Ephemeris	2021-06-25 05:48:20	SpaceX_Ephemeris_552_SpaceX_2021-06-25UTC05:21:02_1.zip
SpaceX	Ephemeris	2021-06-25 05:49:10	SpaceX_Ephemeris_552_SpaceX_2021-06-25UTC05:21:02_2.zip
SpaceX	Ephemeris	2021-06-25 13:47:14	SpaceX_Ephemeris_552_SpaceX_2021-06-25UTC13:21:01_1.zip
SpaceX	Ephemeris	2021-06-25 13:50:22	SpaceX_Ephemeris_552_SpaceX_2021-06-25UTC13:21:01_2.zip

Showing 1 to 6 of 6 entries

Public Files - New Feature - In testing and subject to change!

Public data files are archives of files designed to be downloaded by the public.
Large sets of data are broken into smaller chunks to make it easier to download. Each file will have the part number appended to the end of the file name.
Source - source of the data
Type - type of data stored in the file. Can be a regular data type, such as Ephemeris or Maneuver, "MIXED", or "OTHER" if applicable.
Date - date at which the file was generated.
Link - temporary, short lived link to download the file.
Size - size of that specific file.

To download Public Files using the API, please see https://www.space-track.org/documentation#howto-api_publicfiles

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?

