Spacecraft brightness: Best practices, guidelines and impact on Space Situational Awareness

Image credit: Kees Scherer (via APOD)

Symposium on Commercial Space and Astronomy Partnering in Best Practices and Guidelines for Brightness Mitigation

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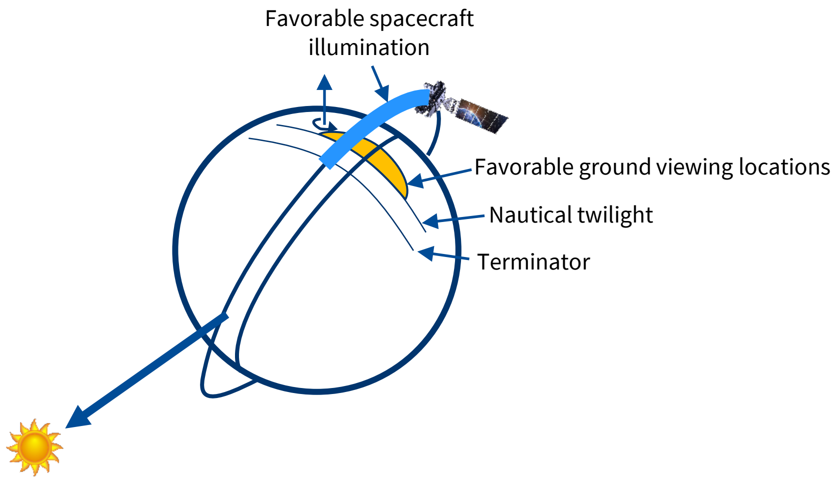
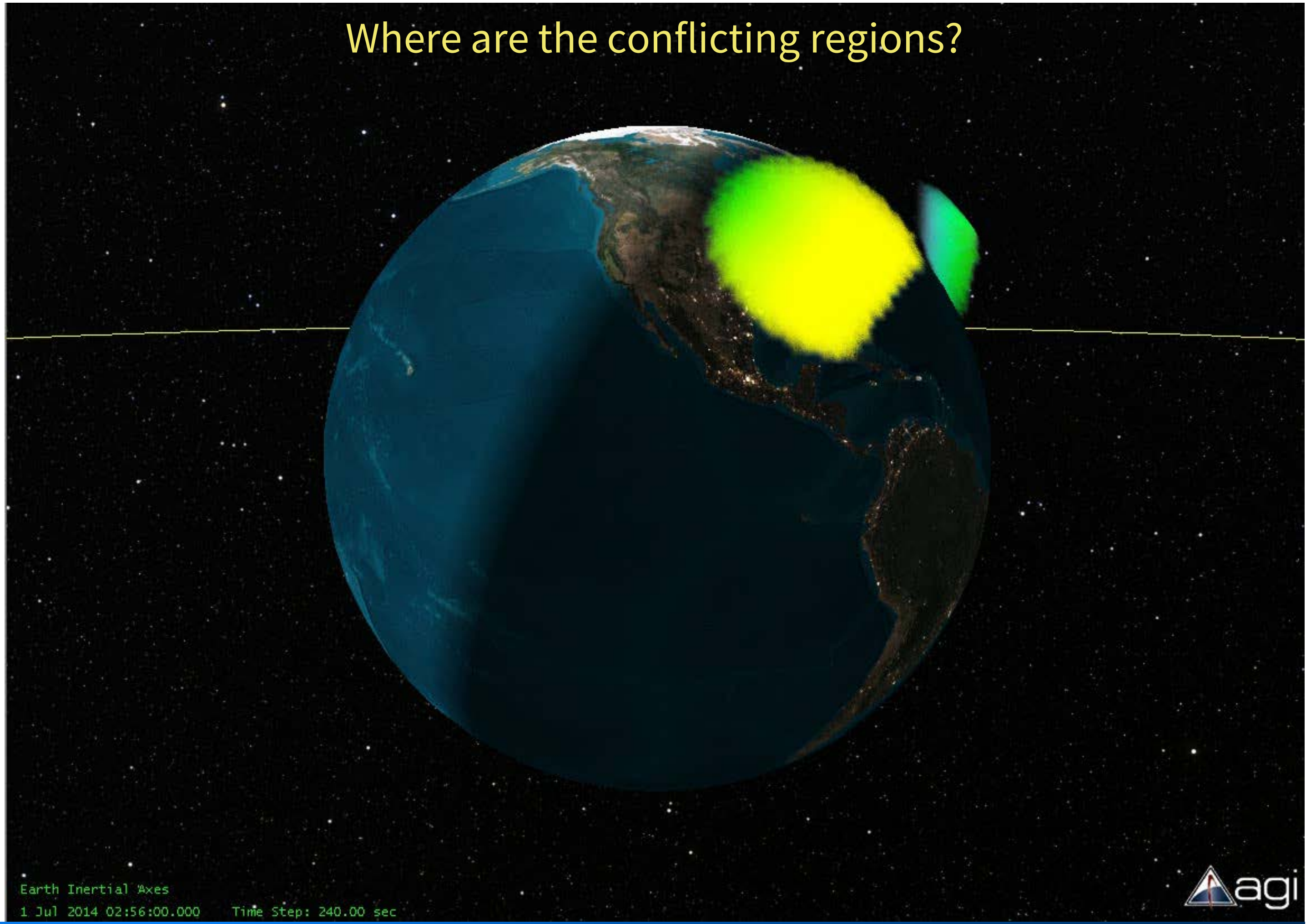
LEO S/C conflict with astronomical observations at or near twilight

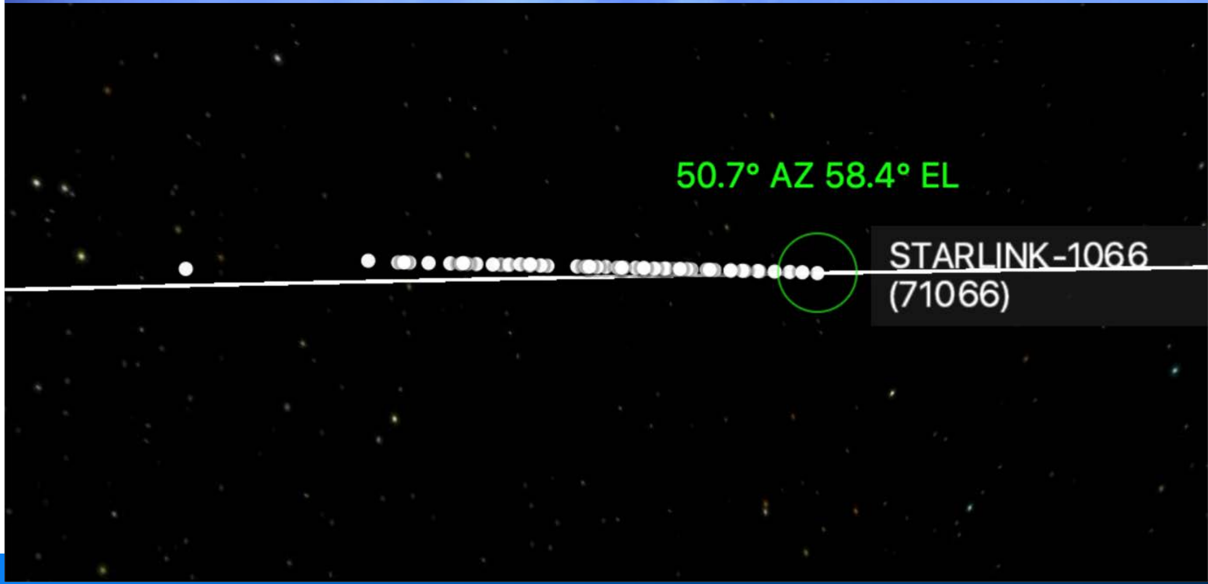
- Occurs when the observatory is dark but LEO space sunlit
  - Near "Terminator conditions"
  - ~**1-2 hours** after sunset and before sunrise
  - Brightness strongly depends on geometry
  - Lower altitude objects are **brighter**, but:
    - They move **faster**
    - They are sunlit for **shorter duration**





Starlink even visible to good camera

- Morning snapshot of the Starlink spacecraft train, taken with a tripod-mounted Canon EOS 6D 20.2MP CMOS digital SLR camera (no telescope), with a 1-sec exposure at ISO 12800 taken 10 sec after culmination (peak elevation).

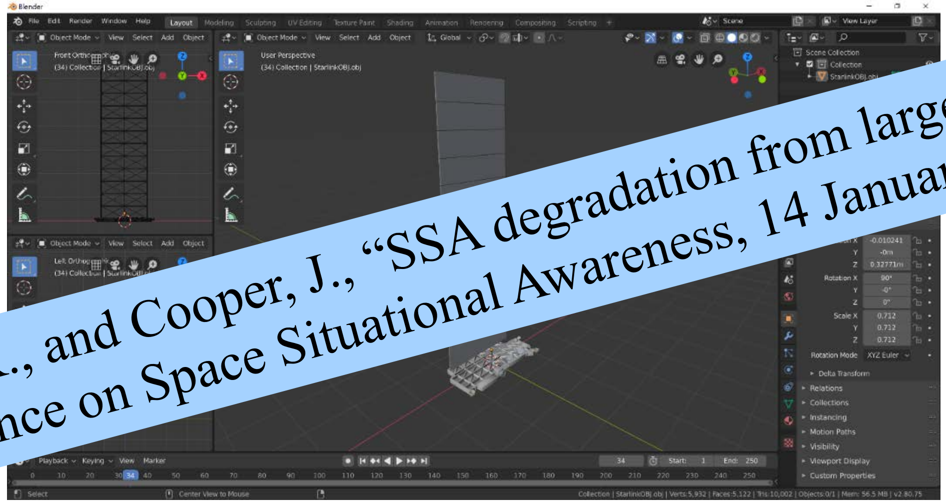


Rudimentary Starlink brightness model

Populate with Reasonable Initial Estimates and Update with Empirical Data

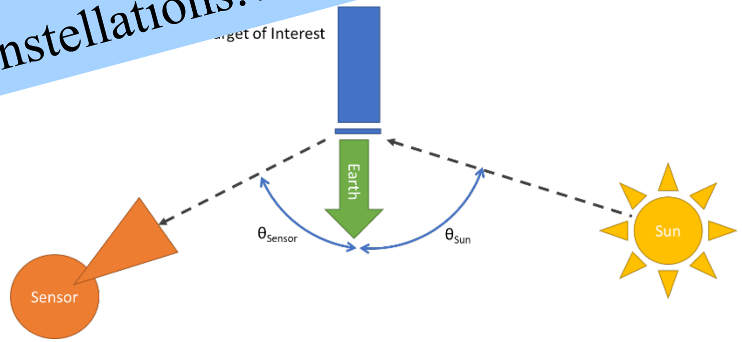
Grouping	Parameter	Value	Units
Satellite Physical Parameters	Body Reflectance	30.0%	[ratio]
	Height	3.3	[m]
	Width	1.7	[m]
	Body Area	5.61	[m^2]
	Panel Reflectance	1.0%	[ratio]
	Height	9	[m]
	Width	3.3	[m]
	Panel Area	29.7	[illegible]
Reference Irradiance Values	Exoatmospheric Solar Irradiance	[illegible]	[illegible]
	Vega Irradiance	[illegible]	[illegible]

Spacecraft outer surface model



North, P., Zimmer, P., Kelso, T.S., Oltrogge, D.L., Hall, R., and Cooper, J., “SSA degradation from large constellations: A Starlink-based case study,” 2nd IAA Conference on Space Situational Awareness, 14 January 2020

Coll… …tion Conditions

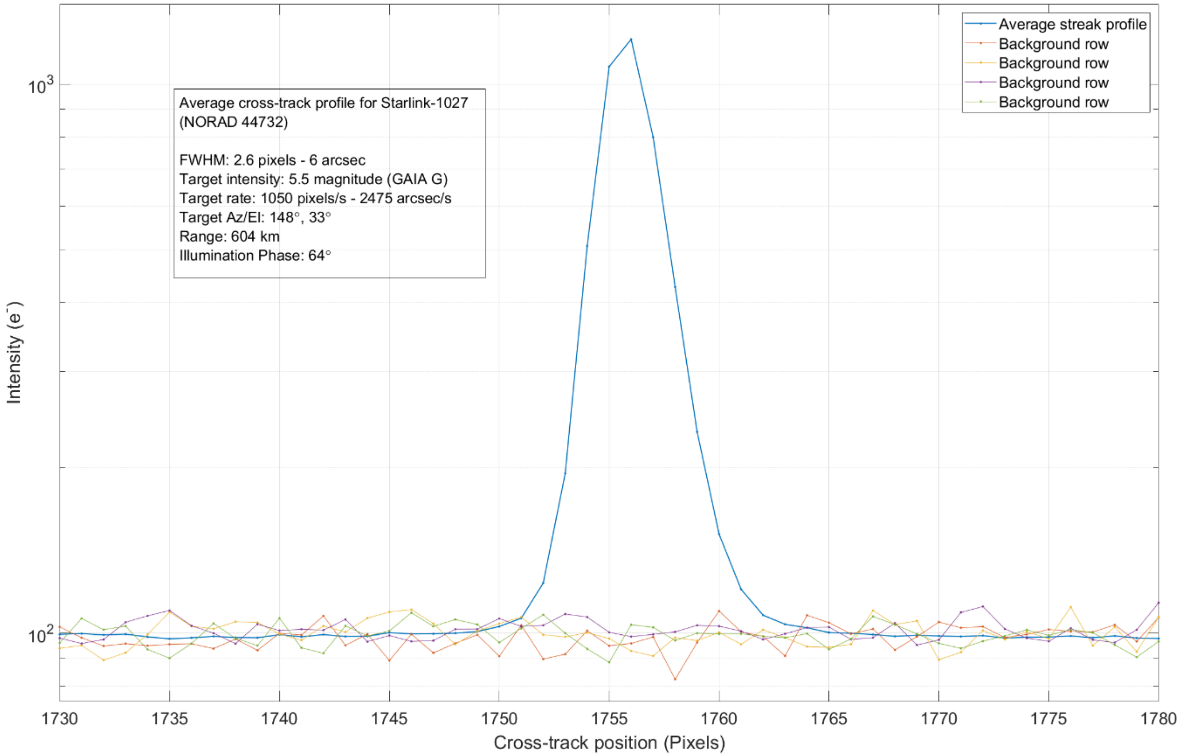


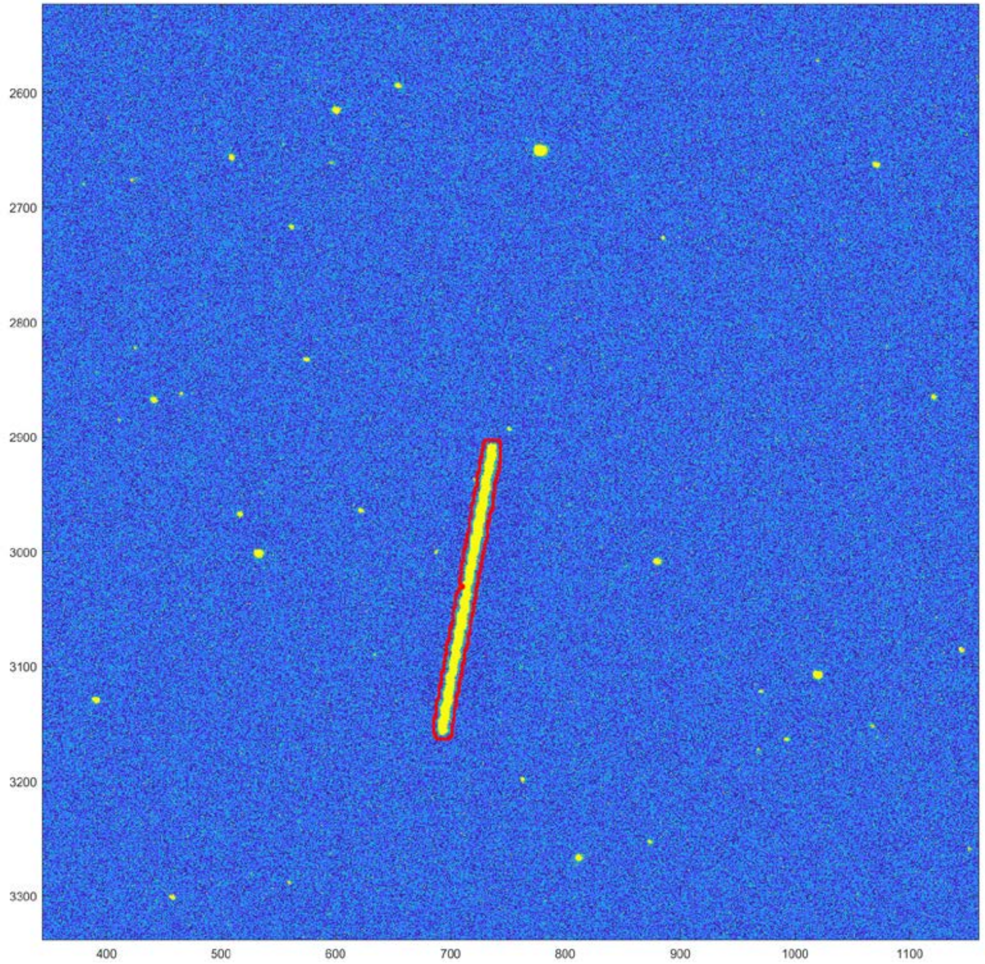
Starlink magnitude estimates vs collection and illumination conditions

Grouping	Parameter	Value								Units
Geometric Collection Parameters	Normal to Sun Angle	80	110	80	110	80	110	80	110	[deg]
	Normal to Sensor Angle	10	10	45	45	10	10	45	45	[deg]
	Distance from Sensor to Satellite	500	500	500	500	1000	1000	1000	1000	[km]
Reflectance Function Calculations	Body Reflectance Function	0.0544	0.0000	0.0391	0.0000	0.0544	0.0000	0.0391	0.0000	[ratio]
	Panel Azimuth Term	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	[ratio]
	Panel Reflectance Function	0.0544	0.0519	0.2217	0.2115	0.0544	0.0519	0.2217	0.2115	[ratio]
Satellite Brightness Calculations	Satellite Intensity	148.74	21.29	181.62	86.69	148.74	21.29	181.62	86.69	[W/sr]
	Satellite Irradiance at Sensor	5.95E-10	8.52E-11	7.26E-10	3.47E-10	1.49E-10	2.13E-11	1.82E-10	8.67E-11	[W/m2]
	Satellite Visual Magnitude	***4.17***	***6.28***	***3.96***	***4.76***	***5.68***	***7.79***	***5.46***	***6.26***	[magnitude]

How will these constellations affect space imagery?

- Pixel contamination:
  - Satellites appear to streak through the field of view (FOV)
  - Typical angular rate: 0.5 – 1 degree per second
  - Width of contamination: ~10 Full Width at Half Maximum of Point Spread Function

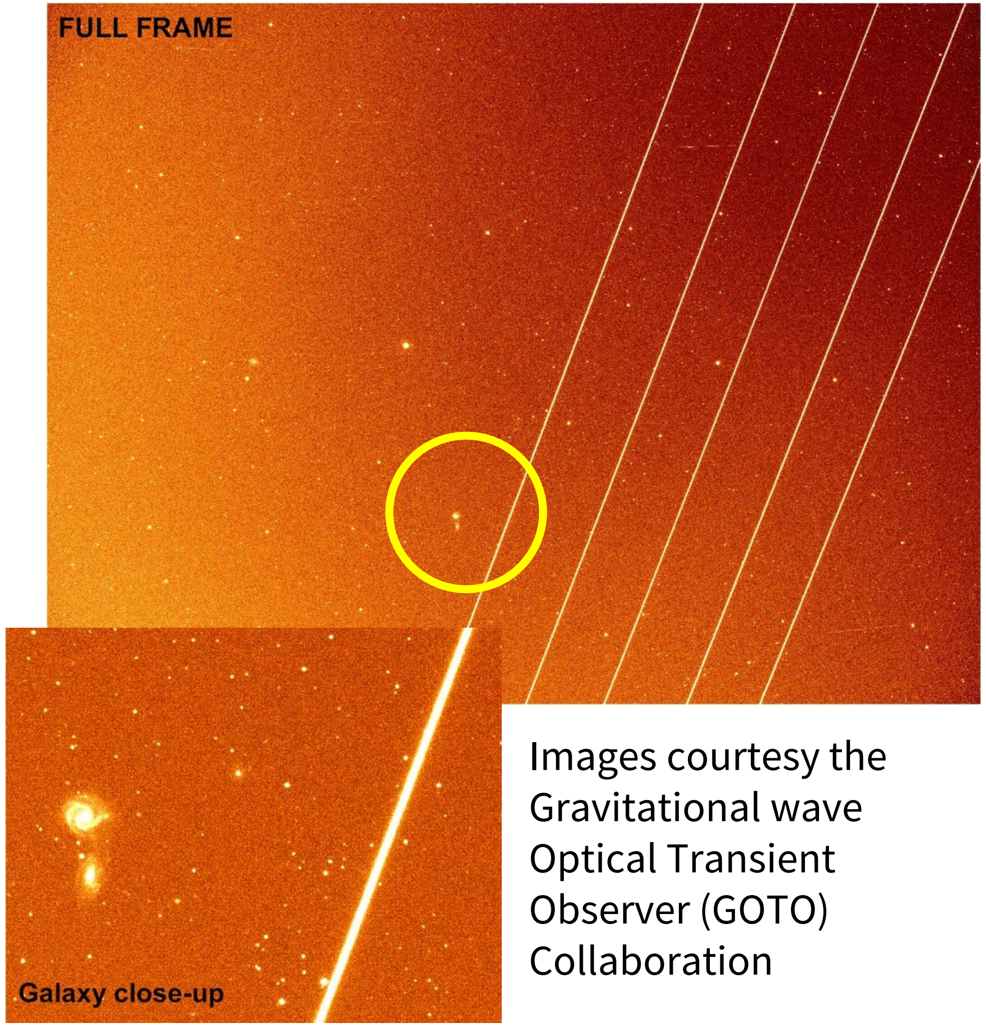




Wide FOV systems taking long exposures are most susceptible

- Example: GOTO Observatory
  - 20 square deg FOV
  - **120 second exposure time**
  - Expected contamination during twilight: ~0.3%
    - Like what is shown here

- Potential mitigation approach:
  - Weigh signal-to-noise trade of multiple exposures
    - Clip contaminated pixels
  - Distribution on sky is not uniform
    - Avoid orbital planes during twilight
    - Requires additional planning and cooperation



Images courtesy the Gravitational wave Optical Transient Observer (GOTO) Collaboration

Clash of competing best practices with large constellations

- Multiple competing commercial and environmental goals at play:
  - Global internet connectivity is a worthwhile humanitarian cause.
  - The commercial space industry continues to blossom, with strong economic growth.
  - Brightness enables non-cooperative SSA tracking of space objects → better positional accuracy;
  - Brightness adversely affects the SSA for other space objects, astronomy and amateur sky watchers.
  - Industry best practices* include (a) minimizing post-mission orbit lifetime and (b) launching into a low altitude "staging" or test orbit.
    - Satellite failures often occur during the first year of operations.
    - But staging orbits introduce stream of bright newly-launched spacecraft during protracted launch campaign.

- *Space Safety Coalition, "Best Practices for the Sustainability of Space Operations," available at spacesafety.org, 16 September 2019.

Brightness mitigation strategies

- Disruptions of SSA, naked-eye observations and astronomy could be minimized by:
  - Designing spacecraft outer surfaces to reduce surface reflectivity.
    - *e.g.*, the so-called "Dark Sat" Starlink.
  - Optimizing spacecraft shape/dimensions to minimize reflected surfaces;
  - Optimally control spacecraft attitude to lessen solar energy reflected to Earth, particularly near day/night terminator;
  - Selecting large constellation orbit(s) to decrease disruptions; tradeoff between:
    - Higher altitudes that decrease overall brightness
    - Lower altitudes that reduce the duration and area of potential brightness interference.
- Ensure that best-available LC data must be made available to ALL SSA networks
  - Facilitates pixel masking (as doe with star background)
  - Data must be regularly assessed for quality issues

What guidelines and standards address “brightness” ?

- Why this is a challenge:
  - Standards must be market relevant and verifiable.
    - Market relevance is (somewhat) in the eye of the beholder.
  - Brightness requirements are from different market segment (astronomy) than Large Constellations.
- Heartening to see LC designers and operators working with astronomers.
- UN COPUOS Long-Term Sustainability Guidelines: Not addressed.
- IADC Statement on Large Constellations of Satellites in Low Earth Orbit: Not addressed.
- ISO 24113: Space Debris Mitigation: Not addressed.
- ISO 6364: Large Constellations.
  - Currently in development, nearing publication.
  - Doesn’t address SSA degradation (okay).

> **5.2.7 Large constellation minimization of disruptive visual brightness**
>
> Large constellation designers shall seek to control the apparent magnitude of their spacecraft, during both the checkout and operations phases, to limit disruptions to the astronomy and naked eye observing communities.
>
> NOTE 1: Objects up to about apparent magnitude 6 are visible to the naked eye. An existing constellation owner strives to achieve an apparent magnitude of 7 or dimmer.
>
> NOTE 2: The impact on astronomy can be minimized by design, using mechanisms (e.g., deployable visors), vehicle orientations, shutters, and/or operating characteristics to reduce the overall reflectivity of the spacecraft. The necessity of such techniques will depend on orbit altitude, reflectance of surface components, overall surface area, and flight attitude rules.

What ISO/CCSDS space standards relate to “brightness” ?

ODM: standardized way to share Vmag

CCSDS
The Consultative Committee for Space Data Systems

Draft Recommendation for Space Data System Standards

ORBIT DATA MESSAGES

DRAFT RECOMMENDED STANDARD

CCSDS 502.0-P-YYY

PINK BOOK
January 2022

CCSDS
The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

CONJUNCTION DATA MESSAGE

RECOMMENDED STANDARD

CCSDS 508.0-P-YYY

PINK BOOK
January 2022

CDM: standardized way to share transits

ADM: standardized way to share attitude

CCSDS
The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

ATTITUDE DATA MESSAGES

RECOMMENDED STANDARD

CCSDS 504.0-P-1.13

PROPOSED PINK BOOK
January 2022

WD TS 6434

2021-11-09

Space systems — Design, Testing and Operation of a Spacecraft Large Constellation

9 November 2021
ISO\TC20\SC14\WG3
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WD 9490

DRAFT for NWIP

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2021-11-06

Space systems — Space Traffic Coordination

6 Nov 2021
ISO\TC20\SC14\WG3
PoCs
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Conclusions

- Bright Large Constellations (LCs) can adversely impact SSA and imaging/astronomy.
  - Ground-based astronomy community is particularly placed at risk.
    - Wide FOV sensors often use very long integration times (for faint celestial object imaging).
- Mitigation strategies:
  - Masking of large constellation spacecraft should allow SSA systems to mitigate large constellation SSA degradations and address low-thrust complexities and bandwidth drawdown, provided that:
  - (1) Spacecraft and mission designers ensure spacecraft are bright enough to be optically tracked, while ensuring that they are not overly bright in LEO;
  - (2) Large constellation operators promote extensive coordination, transparency and information-sharing of space data (to facilitate optical masking an scheto include predictive ephemerides incorporating planned maneuvers, spacecraft physical and attitude models to feed optical masking.