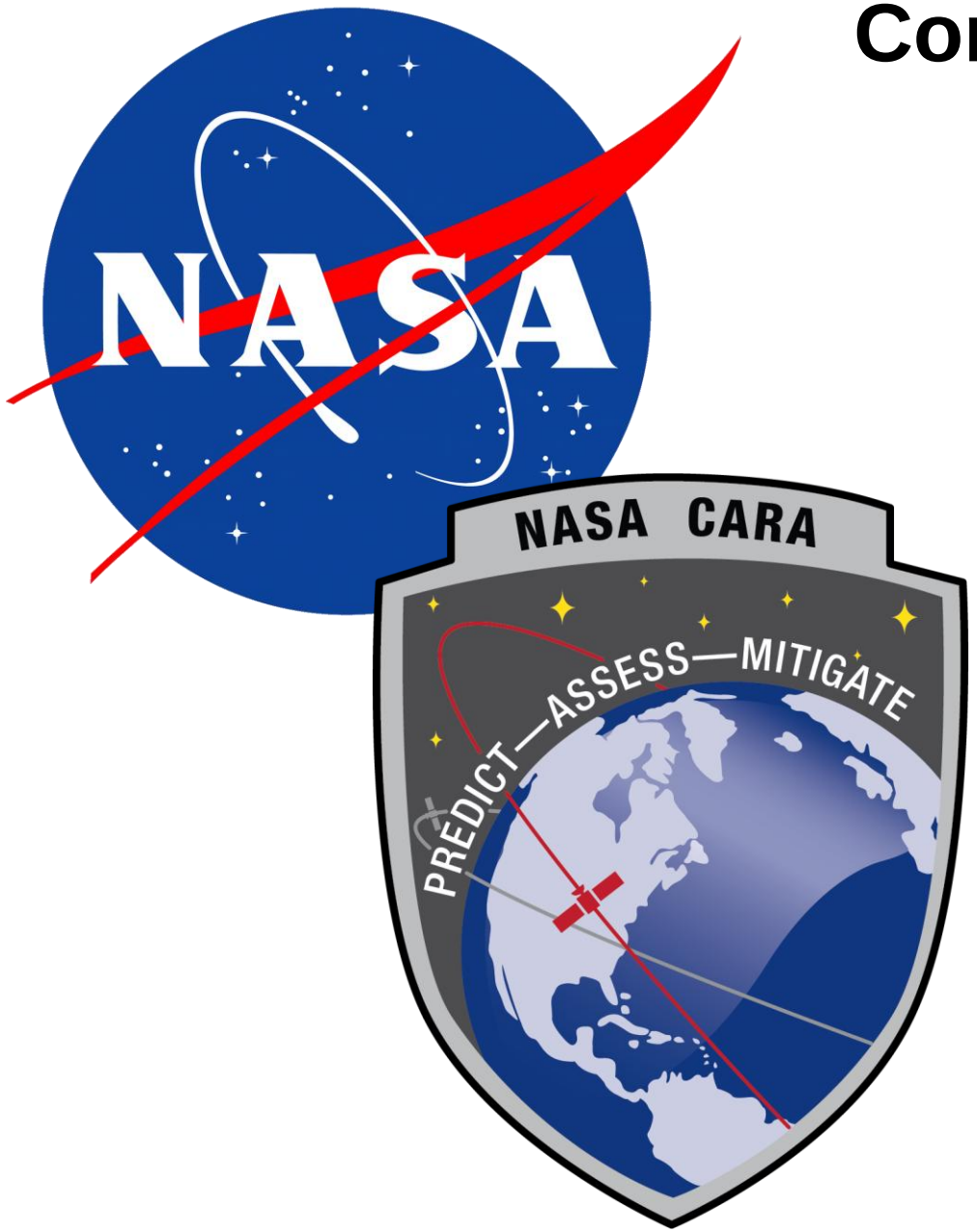


Conjunction Assessment Risk Analysis

EvaluateLightPollution

Software to Evaluate Astronomical Light Pollution Risks from Satellite Constellations

Doyle Hall
Omitron, Inc. – CARA Analysis Team
Last Update: 2024 November 25

Outline

- Motivation, objectives, and software overview
- Photometric observations of constellation satellites
- Evaluation of light pollution levels for selected constellations
- *EvaluateLightPollution* software usage instructions
- Description of program inputs and outputs
- Installation and troubleshooting contact information

Motivation

The Astronomical Community

- Constellations can interfere with ground-based astronomy
- Metrics and tools are required to quantify the effects

The NASA CARA Team

- Recommendation from the "NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook"

If the constellation, given its population, orbit, and constituent satellites, is likely to affect ground-based astronomy, reassign the satellite orbits or modify the satellite construction to eliminate this effect.

Research and Development Objectives

- **Research: Develop indicators to quantify light pollution effects**
  1. **The brightness of individual constellation satellites, including the effects of temporal variability**
  2. **The statistically expected number of visible and illuminated constellation satellites above a ground-based observer**
  3. **The expected number that are brighter than the maximum brightness limit recommended by the astronomical community**
- **Development: Implement a software tool for use by the CARA team that issues recommendations with supporting analysis**
  - **Use global and yearly peak of light pollution indicator #3 above, which incorporates the effects of a constellation's population, orbital distribution, brightness, and variability**
  - **Enable evaluation for both current and proposed constellations, as well as single- and multi-shell constellations**

Overview of Constellation Light Pollution Evaluation Software

The Matlab program *EvaluateLightPollution* analyzes astronomical light pollution risks created by current or proposed constellations of Earth-orbiting satellites

- **Evaluates potential light pollution levels and associated risks to visible and near-IR band ground-based astronomy**
- **Based on the maximum brightness recommendations of the astronomical community, as provided in the *AURA/AAS SatCon* workshops[1,2]**
- **Uses a semi-empirical approach that incorporates measured satellite brightness magnitudes and variability, as applied to multi-shell constellations**
- **Provides an efficient means to use current satellites as analog objects to enable evaluations for proposed or pre-launch constellations**
- **Allows investigations of average satellite brightness reductions required to achieve acceptably low constellation light pollution levels**
- **The underlying theory and quantitative metrics for the evaluation algorithm have been documented in detail[3]**

[1]Walker, C., *et al.*, "Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations" *SatCon-1 Workshop*, 2020
[2]Walker, C., *et al.*, "Report of the SatCon2 Workshop" 2021
[3]Hall, D., "Semi-Empirical Astronomical Light Pollution Evaluation of Satellite Constellations," Journal of the Astronautical Sciences, Jan. 2023 (included in distribution)

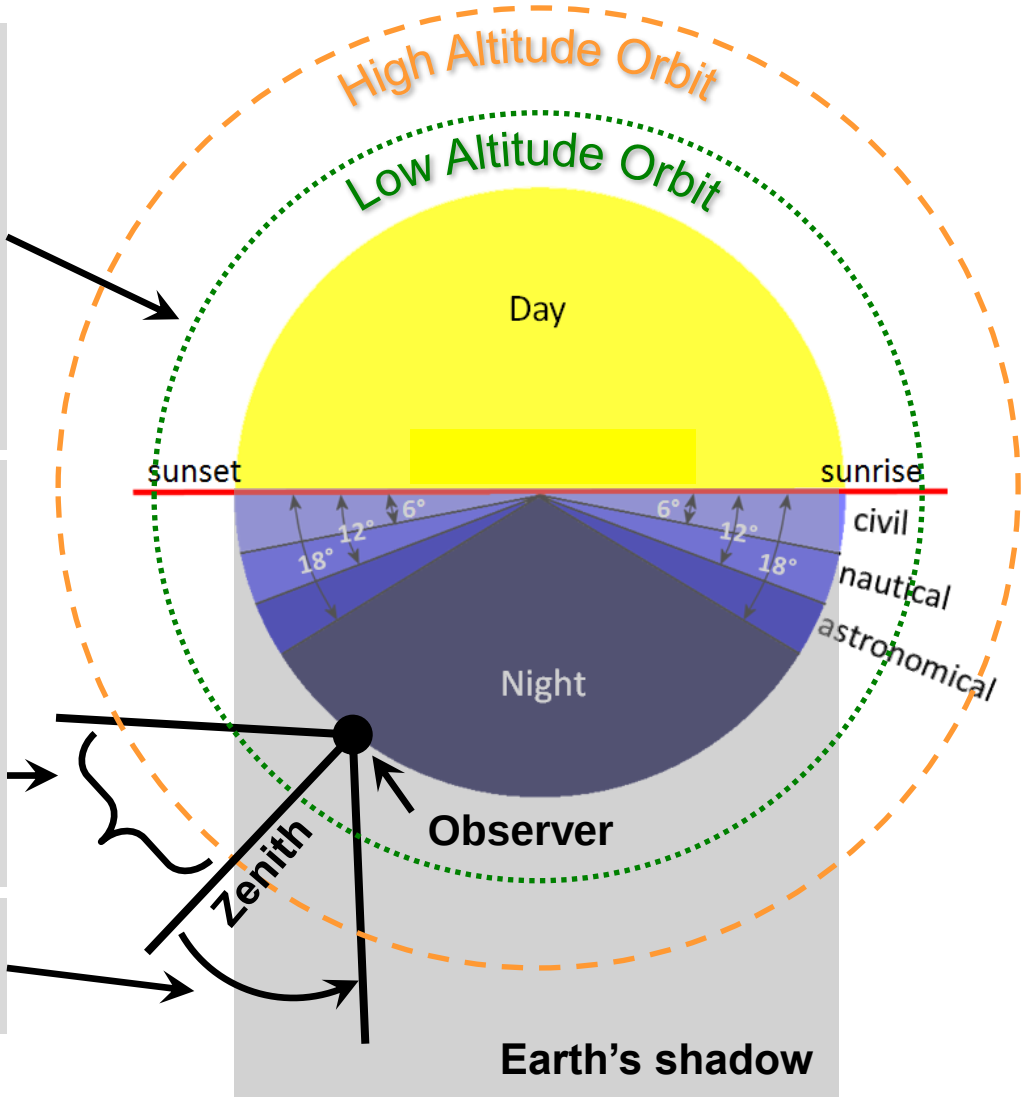
Overview of Constellation Light Pollution in the Visible and Near-Infrared Spectral Bands

- **Visible/near-IR brightness is typically dominated by reflected sunlight**
  - The solar depression angle (SDA) measures how far the sun is below an observer's local horizon
  - Twilight period: 0° < SDA < 18°
  - Astronomical night: SDA ≥ 18° (often the most valuable observation time)
- **Goal: Mitigate global light pollution during astronomical night time**
- **Light pollution analysis parameters**
  - Intrinsic satellite brightness/variability
  - Constellation orbital shell populations, altitudes, and inclinations
  - Observation solar depression angle
  - Observation zenith angle

Satellites in lower altitude constellations can be brighter because they are closer to ground-based observers

But satellites in higher altitude constellations can be illuminated much longer into astronomical night

Observation zenith angle



Photometric Observations

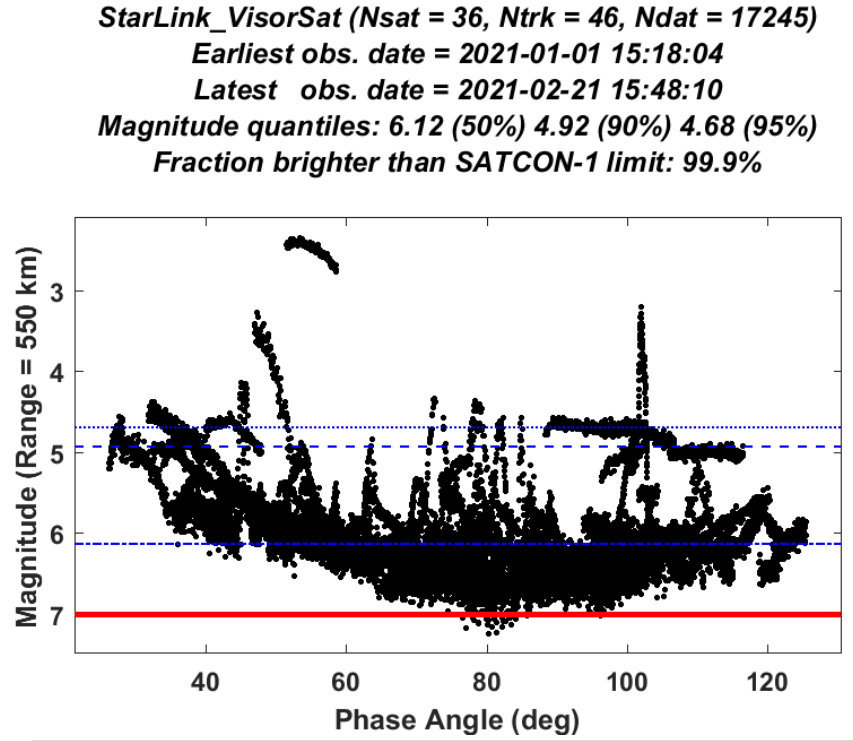
of Constellation Satellites

Observed Brightnesses of Constellation Satellites

- **Visible band brightnesses are measured in stellar magnitudes**
  - Often normalized to a range equal to the constellation's altitude, h
  - Measured magnitudes are highly variable
  - Statistical analysis shows that the M(90%) and M(50%) quantile levels often differ by 1 magnitude or more
- **The maximum brightness limit recommended by the Astronomical Community, from the "*SatCon-1*" workshop[1]**

$$M = 7 + 2.5 \times \log_{10}[h/(550\ \text{km})]$$

- **Many constellation satellites are often observed to be brighter than this limit**
  - For instance, early Starlink constellation satellites exceeded this recommended brightness limit most of the time (as shown in the plot)
- **Evaluation Goal: Issue no light pollution warnings for constellations with satellites expected to be consistently less bright than the recommended *SatCon* brightness limit**

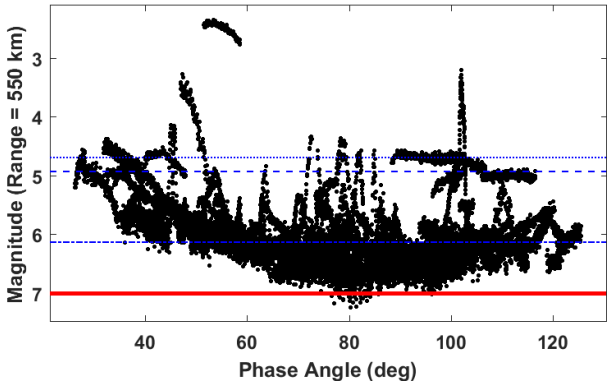


Range-normalized magnitudes for 36 Starlink satellites[2] observed during the first 50 days of 2021

[1]Walker, C., *et al.*, "Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations" *SatCon-1 Workshop*, 2020.
[2]Malama, A., "The Brightness of VisorSat-Design Starlink Satellites" 2021.

Comparing Satellite Brightnesses for Three Current Constellations

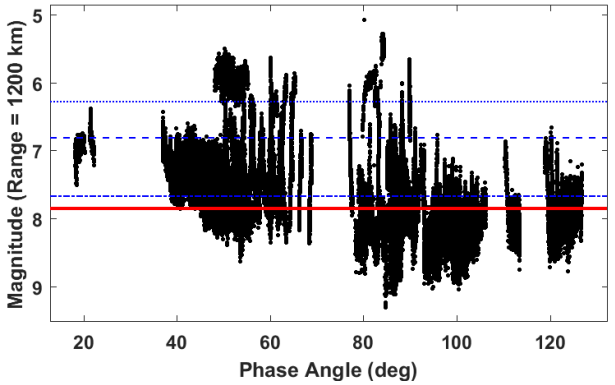
StarLink_VisorSat (Nsat = 36, Ntrk = 46, Ndat = 17245)
Earliest obs. date = 2021-01-01 15:18:04
Latest obs. date = 2021-02-21 15:48:10
Magnitude quantiles: 6.12 (50%) 4.92 (90%) 4.68 (95%)
Fraction brighter than SATCON-1 limit: 99.9%



Starlink Constellation 1st Shell

99.9% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

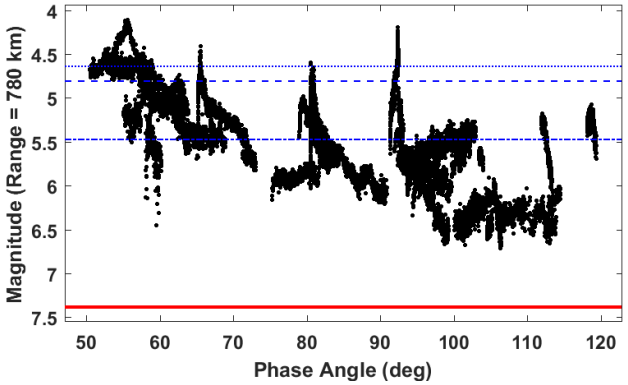
OneWeb_Satellites (Nsat = 43, Ntrk = 83, Ndat = 57436)
Earliest obs. date = 2021-01-20 16:43:17
Latest obs. date = 2021-02-21 02:31:38
Magnitude quantiles: 7.67 (50%) 6.8 (90%) 6.27 (95%)
Fraction brighter than SATCON-1 limit: 65.7%



OneWeb Constellation Phase 1

65.7% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

Iridium_2ndGen (Nsat = 15, Ntrk = 26, Ndat = 15542)
Earliest obs. date = 2021-01-01 15:23:05
Latest obs. date = 2021-02-21 16:52:01
Magnitude quantiles: 5.46 (50%) 4.8 (90%) 4.63 (95%)
Fraction brighter than SATCON-1 limit: 100.0%

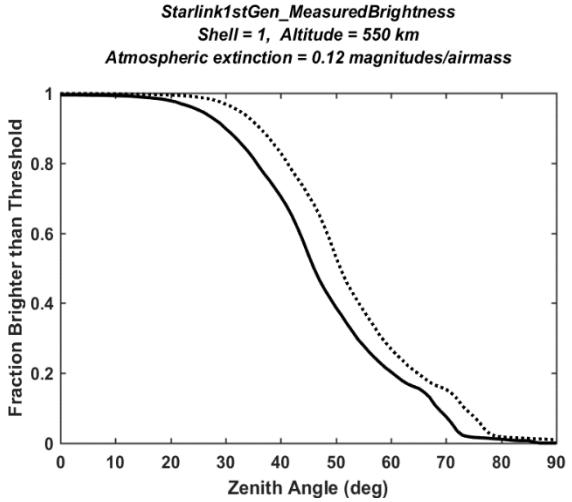


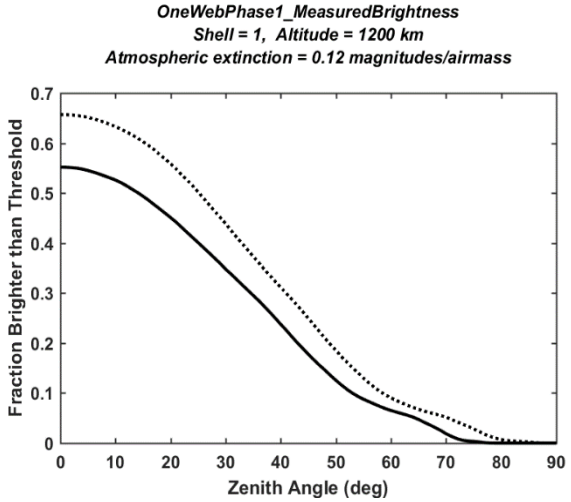
Iridium 2nd Generation Constellation

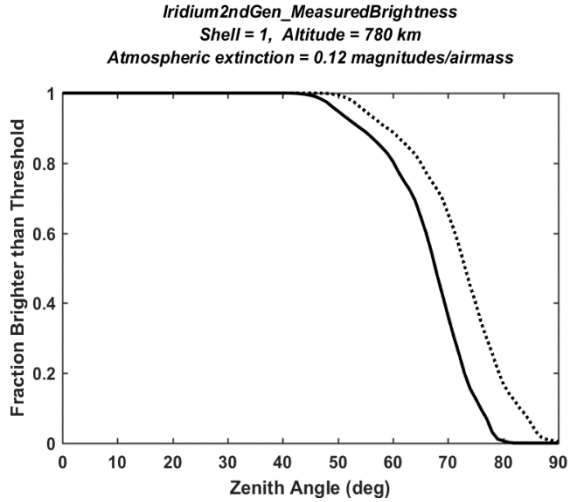
100% of observed zenith brightnesses exceed the *SatCon* recommendation marked with red line*

*Neglecting atmospheric extinction, and based on clear-filter photometric light-curve data measured by the MMT automated observatory: Karpov, S., *et al.*, "Photometric Calibration of a Wide-Field Sky Survey Data from Mini-MegaTORTORA," *Astronomical Notes*, 2018.

Apparent Magnitudes Change with the Observation Zenith Angle*







Starlink Constellation 1st Shell

For a 60° zenith angle (i.e., at 30° elevation), about 20% of apparent brightnesses exceed the SatCon recommended threshold

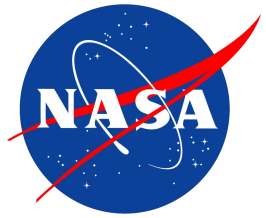
OneWeb Constellation Phase 1

For a 60° zenith angle (i.e., at 30° elevation), about 6.5% of apparent brightnesses exceed the SatCon recommended threshold

Iridium 2nd Generation Constellation

For a 60° zenith angle (i.e., at 30° elevation), about 80% of apparent brightnesses exceed the SatCon recommended threshold

*These graphs show empirically estimated fractions of the sunlit constellation satellite populations that are brighter than the *SatCon* recommendation, plotted as a function of observation zenith angle (which is the complement of the observation elevation angle). The solid lines show apparent brightness estimates that include an atmospheric extinction of 0.12 magnitudes/airmass; the dotted lines neglect atmospheric extinction.



Program *EvaluateLightPollution*

Evaluation of

Light Pollution Levels

for Selected Constellations

Constellations Analyzed in Provided *EvaluateLightPollution* Examples[1,2]

Constellation Name (and component shell)	Number of Satellites	Orbital Altitude (km)	Inclination (degrees)	SatCon-1 Recommended Threshold Magnitude
Starlink 1st Generation	11,926 total	335.9 – 570	42.0 – 97.6	6.46 – 7.04
shell 1	1,584	550	53.0	7.00
shell 2	1,584	540	53.2	6.98
shell 3	720	570	70.0	7.04
shell 4	348	560	97.6	7.02
shell 5	172	560	97.6	7.02
shell 6	2,493	335.9	42.0	6.46
shell 7	2,478	340.8	48.0	6.48
shell 8	2,547	345.6	53.0	6.50
Starlink 2nd Generation	30,000 total	328 – 614	30.0 – 148.0	6.44 – 7.12
shell 1	7,178	328	30.0	6.44
shell 2	7,178	334	40.0	6.46
shell 3	7,178	345	53.0	6.49
shell 4	2,000	360	96.9	6.54
shell 5	1,998	373	75.0	6.58
shell 6	4,000	499	53.0	6.89
shell 7	144	604	148.0	7.10
shell 8	324	614	115.7	7.12
OneWeb Phase 1	1,980	1,200	87.9	7.85
OneWeb Phase 2	6,372 total	1,200	55.0 – 87.9	7.85
shell 1	1,764	1,200	87.9	7.85
shell 2	2,304	1,200	40.0	7.85
shell 3	2,304	1,200	55.0	7.85
Iridium 2nd Generation	75	780	86.4	7.38

[1]Bassa, C., et al., "Analytical Simulations of the Effect of Satellite Constellations on Optical and Near-infrared Observations," *A&A*, Vol. 657. P. A75, Jan 2022
[2]Hall, D., "Semi-Empirical Astronomical Light Pollution Evaluation of Satellite Constellations," Journal of the Astronautical Sciences, Jan. 2023.

Constellation Light Pollution Color Coded Evaluation Levels

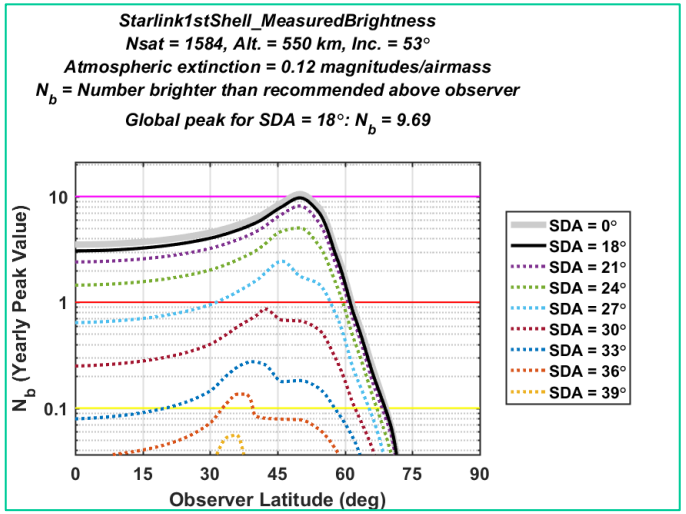
Light Pollution Evaluation Indicator: N_b = the statistically expected global and yearly maximum number of brighter-than-recommended satellites above ground-based observers during astronomical night time periods*

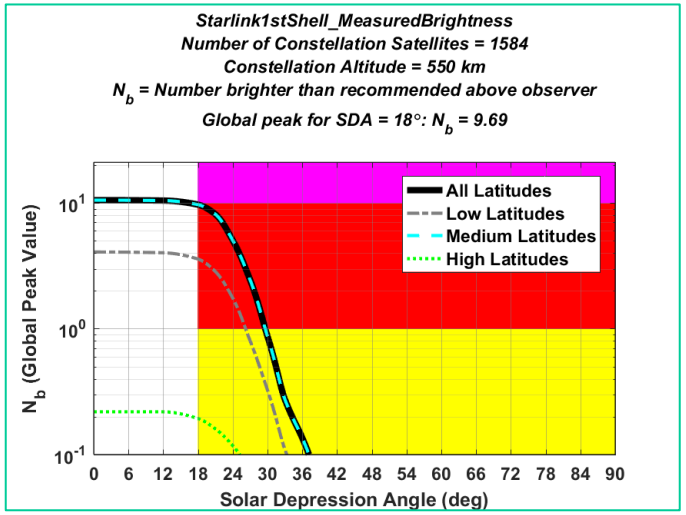
Light Pollution Level	Color Code	Light Pollution Indicator Range
Very High	Magenta	$N_b \geq 10$
High	Red	$1 \leq N_b < 10$
Medium	Yellow	$0.1 \leq N_b < 1$
Low	None	$N_b < 0.1$

*Hall, D., "Semi-Empirical Astronomical Light Pollution Evaluation of Satellite Constellations," Journal of the Astronautical Sciences, Jan. 2023.

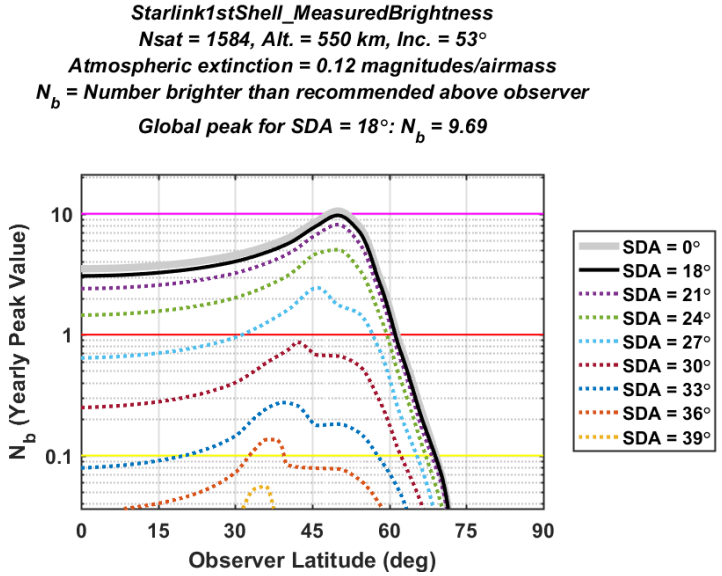
EvaluateLightPollution Software
Light Pollution Summary Plots

- **The top plot shows the peak number of brighter-than-recommended satellites expected above ground-based observers as a function of latitude**
  - Solid black line corresponds to SDA = 18°
  - Other dotted curves correspond to higher SDA values.
  - Magenta, red and yellow horizontal lines show very high, high and medium levels of light pollution, respectively
- **The bottom plot shows the light pollution indicator as a function of solar depression angle**
  - SDA ≥ 18° represents astronomical nighttime
  - Magenta, red and yellow shaded regions show different levels of light pollution
- **These two specific plots show the light pollution evaluation for the 1st shell of the Starlink 1st Gen. constellation**
  - 1,584 satellites at 550 km altitude and 53° inclination
  - Light pollution peaks for observer latitudes of about 50°
  - The black curves indicate a global peak of about 9.7 brighter than recommended satellites, **a high light pollution indicator level**

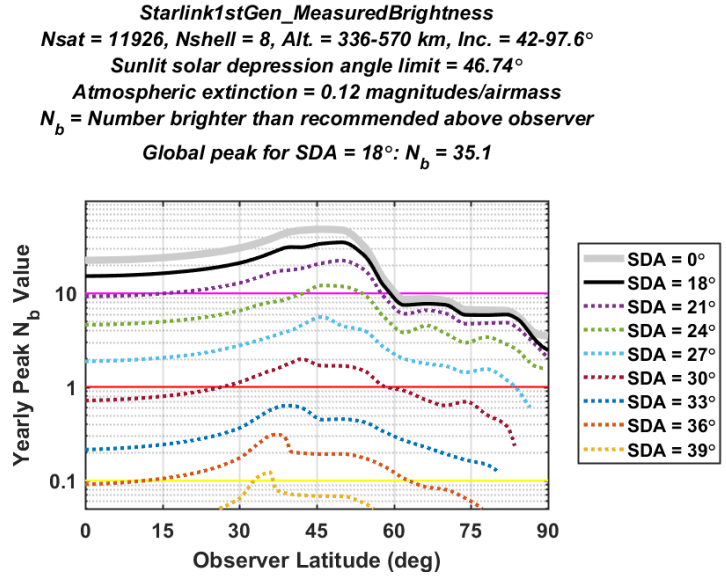




Light Pollution Indicator Changes with Solar Depression Angle (SDA) and Latitude

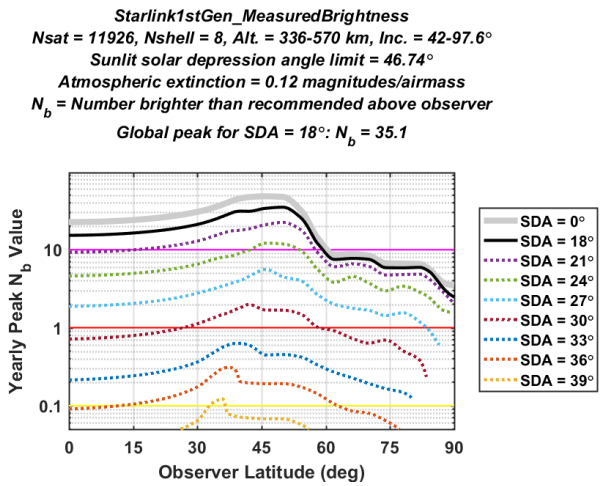


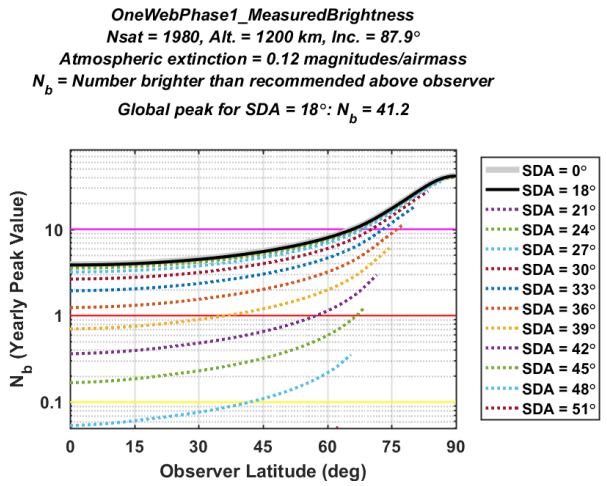
Starlink 1st Gen. Constellation – 1st Shell
Light pollution peaks for observer latitudes of about 50°. The maximum of the solid black curve represents a global peak of ~10 brighter than recommended satellites above ground-based observers, i.e., a high light pollution level

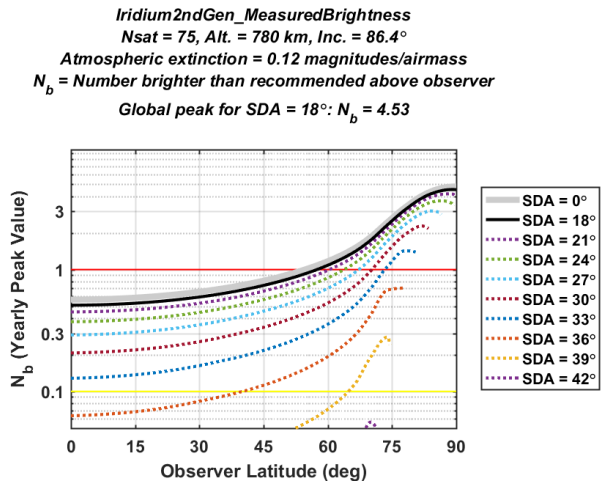


Starlink 1st Gen. Constellation – all 8 shells
Pollution peaks for observer latitudes of about 50°, but with a wide distribution. The maximum of the black curve represents a global peak of ~35 brighter than recommended satellites above observers, i.e., a very high light pollution level

Light Pollution from Different Constellations Varies Differently with SDA and Latitude







Starlink 1st Generation

Light pollution peaks for observer latitudes of about 50°. The peak of the solid black curve represents ~35 brighter than recommended satellites above ground-based observers, a very high global peak level

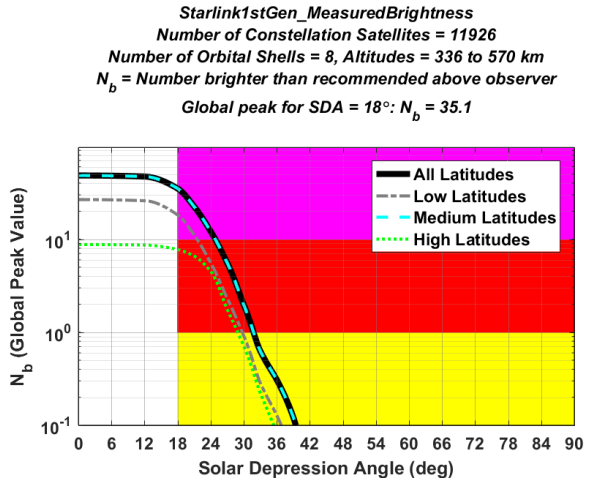
OneWeb Phase 1

Light pollution peaks for observer latitudes of 90°. The maximum of the solid black curve represents ~41 brighter than recommended satellites above ground-based observers, a very high global peak level

Iridium 2nd Generation

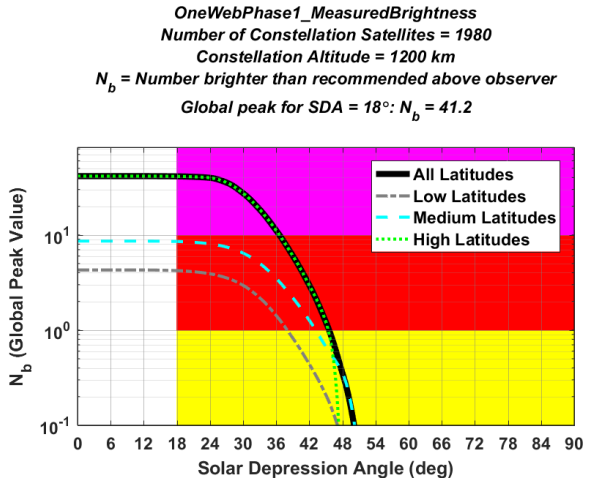
Light pollution peaks for observer latitudes of 90°. The maximum of the solid black curve represents ~4.5 brighter than recommended satellites above ground-based observers, a high global peak level

High Altitude Constellations Create Light Pollution Later into Astronomical Night



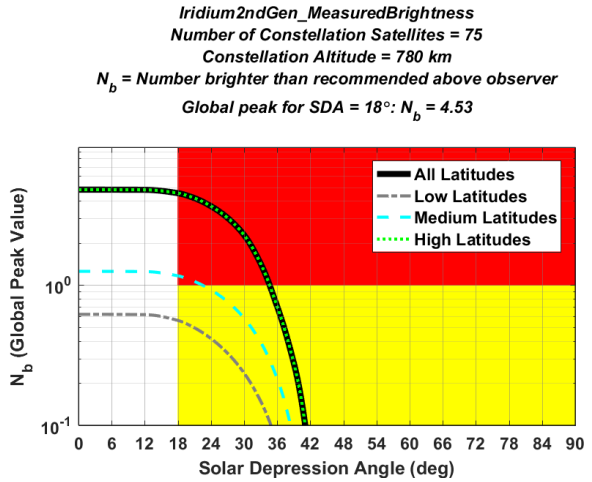
Starlink 1st Generation

Astronomical night time light pollution peaks at Nb = 35, a very high global peak level, and decreases to low levels for solar depression angles greater than ~40°



OneWeb Phase 1

Astronomical night time light pollution peaks at Nb = 41, a very high global peak level, and decreases to low levels for solar depression angles greater than ~50°



Iridium 2nd Generation

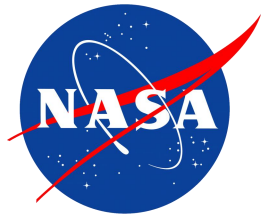
Astronomical night time light pollution peaks at Nb = 4.5, a high global peak level, and decreases to low levels for solar depression angles greater than ~42°

Usage Instructions

Usage Instructions for *EvaluateLightPollution*

1. *EvaluateLightPollution* analyses are performed by constructing project parameter files
   a. Each project is represented by a Matlab file stored within in the \params directory
   b. For instance, the file \params\Starlink1stShell_MeasuredBrightness.m contains an example evaluation for the 1st shell of the Starlink 1st Generation constellation deployed at an altitude of 550 km.
   c. Several other usage examples are provided in the \params directory; these can be used as templates for future projects and analyses.
   d. The function “RunExamples” executes nine example analyses distributed with the *EvaluateLightPollution* software, each of which requires a few to several minutes to run on a typical computer
2. *EvaluateLightPollution* analyses can be based on observed satellite brightnesses for currently-orbiting constellations
   a. The program current processes photometry from the Mini-MegaTORTORA (MMT) automated observatory, which measures clear-filter photometric magnitudes that are roughly equivalent to V-band measurements.
   b. MMT temporal light-curve data for these constellations, and an extensive array of other satellites, can be obtained from the http://mmt9.ru/satellites/ website. The provided examples cannot be run until this data is downloaded.
      a. The exact files used in the examples can be downloaded. Navigate to the constellation subfolders in “data/MMT/”, which each contain a “IDs_[Constellation].txt” file. The first line is an array of satellite IDs corresponding to all satellites used in the examples for that constellation. To retrieve these satellites, copy the entire line, paste it into the website’s “ID” field, and then click “Search”.
      b. For new analyses, use the website’s search filters to choose a representative set of satellites.
      c. For each satellite, download magnitude data files by selecting the “T” icon in the “RCS” column to “Download all tracks.” Files will be saved in the format “satellite_[####].txt”.
      d. Place the files into an appropriate subfolder in “data/MMT/”.
   c. Data from other facilities can also be used, if written into data files with the same format.

4. *EvaluateLightPollution* analyses can also be performed for a proposed or pre-launch constellation using a set of photometric analog satellites
   a. The analog satellite photometric data also can be downloaded from the MMT website.
   b. The analog satellite brightnesses are adjusted for the different orbital altitude of the new constellation
   c. The analog satellite brightnesses are also adjusted for any differences in the physical size of the individual constellation satellites as compared to the analogs.
      a. For nadir-velocity stabilized satellites, this adjustment is based on the nadir-facing area of the satellites' main bus and communications arrays (i.e., everything but the solar panels, which must be provided for both the proposed constellation satellites and the analog satellites See the *OneWebPhase1_IridiumAsAnalog.m* parameters file for an example of this case
      b. Alternatively, the adjustment can be based on the size of the smallest box that encloses the satellites' main bus and communications arrays. For this less-often used option, the height, width and length (H,W,L) this enclosing box is provided for both the proposed constellations satellites and the analog satellites.
5. After a parameters file is created and any required analog satellite data is downloaded, the program should be executed from the main EvaluateLightPollution as in the following example:
   EvaluateLightPollution('params\Starlink1stGen_MeasuredBrightness')
   a. Analysis results will be shown in plot format, and the constellation evaluation report will be shown on the console, as well as written to a file.
   b. All plots, tables, and report files are written to an subdirectory in the output/ directory, which has the same name as the parameters file (i.e., 'output\Starlink_MeasuredBrightness' for the example shown above).
   c. Photometric data being processed for the first time requires a bit more execution time, but is saved in the \data directory for efficient repeated analyses
   d. Photometric data and plots for analog satellites adjusted to correct for satellite altitude and size differences is saved in the \output directory



Program *EvaluateLightPollution*

Description of

Project Parameter Files

and associated

Input Parameters

and

Output Quantities

Program *EvaluateLightPollution*: Source Code and Input/Output Parameters

- **The source code and usage example files for Matlab program *EvaluateLightPollution* can be found in the CARA SVN directory**
  - \DistributedMatlab\EvaluateLightPollution
  - Contains subdirectories for source code files, documentation, photometric data, and project parameter files (\src, \doc, \data, and \params, respectively)
- **The core function EvaluateLightPollution.m uses the following calling sequence: Output = EvaluateLightPollution(params);**
  - "params" denotes a file or structure of input parameters
  - "output" denotes a structure of the output quantities
  - Descriptions of these inputs and outputs can be found in the functions EvalLightPollution_default_params.m
- **Each *EvaluateLightPollution* analysis entails constructing a project**
  - Each project has a Matlab parameter file stored within in the "params" directory
  - E.g., \params\Starlink1stGen_MeasuredBrightness.m contains an example that evaluates the Starlink 1st generation constellation based on measured ground-based photometry
  - Run as follows: EvaluateLightPollution('params\Starlink_MeasuredBrightness')
- **Evaluations based on observed brightnesses require photometric data files**
  - Before execution, data files need to be downloaded from the MMT website following usage instructions on slides 19 and 20.

Example Input Parameter File*
Starlink1stShell_MeasuredBrightness.m

```
% Function EvaluateLightPollution parameter specification file
% for the 1st shell of the Starlink 1st generation constellation

% Parameters of the new or proposed constellation to evaluate

% Number, altitudes and inclinations of the satellites
% in each shell of new constellation

params.New.Nc              = 1584; % Number of satellites in constellation
params.New.Altitude_km     =  550; % Altitude of constellation
params.New.Inclination_deg = 53.0; % Inclination of constellation (degrees)

% Parameters for the observed analog satellite(s)

params.Analog.Type        = 'SameSatelliteDesign';
params.Analog.Altitude_km = 550;
params.Analog.datapath    = 'data\MMT\StarLink_VisorSat'; % MMT data path
params.Analog.UTbegin     = '2021-01-01 00:00:00.000';    % MMT data start
params.Analog.UTend       = '2021-03-01 00:00:00.000';    % MMT data end
```

*Additional detailed lists and descriptions of input parameters can be found in the functions EvalConstellation_default_params.m

Example Input Parameter File*
Starlink1stGen_MeasuredBrightness.m

```
% Function EvalConstellation parameter specification file for the all
% eight orbital shells of the of the Starlink 1st generation constellation

% Parameters of the new or proposed constellation to evaluate

% Number, altitudes and inclinations of satellites in each shell of
% the new or proposed constellation

params.New.Nc              = [1584 1584  720  348  172 2493 2478 2547];
params.New.Altitude_km     = [ 550  540  570  560  560  336  341  346];
params.New.Inclination_deg = [53.0 53.2 70.0 97.6 97.6 42.0 48.0 53.0];

% Parameters for the analog satellite(s)

params.Analog.Type        = 'SameSatelliteDesign';
params.Analog.Altitude_km = 550;
params.Analog.datapath    = 'data\MMT\StarLink_VisorSat'; % MMT data path
params.Analog.UTbegin     = '2021-01-01 00:00:00.000';    % MMT data start
params.Analog.UTend       = '2021-03-01 00:00:00.000';    % MMT data end
```

*Additional detailed lists and descriptions of input parameters can be found in the functions EvalConstellation_default_params.m

Example Output Report File

Starlink1stGen_MeasuredBrightness_ZenMax90_Extinct0.12_Report.txt

```
-----------------------------------------
---- Constellation Evaluation Results ----
-----------------------------------------

Evaluation ID: Starlink1stGen_MeasuredBrightness
Number of constellation satellites = 11926
Number of constellation orbital shells = 8
Altitude(s) of constellation shells = 336 to 570 km
Inclinations(s) of constellation shells = 42 to 97.6 km
MMT data path for satellites: data\MMT\StarLink_VisorSat
Fraction of orbital shell 1 measured to be brighter than SATCON-1 recommendation of 7 mag at zenith = 99.86%
Fraction of orbital shell 2 measured to be brighter than SATCON-1 recommendation of 6.98 mag at zenith = 99.88%
Fraction of orbital shell 3 measured to be brighter than SATCON-1 recommendation of 7.04 mag at zenith = 99.75%
Fraction of orbital shell 4 measured to be brighter than SATCON-1 recommendation of 7.02 mag at zenith = 99.8%
Fraction of orbital shell 5 measured to be brighter than SATCON-1 recommendation of 7.02 mag at zenith = 99.8%
Fraction of orbital shell 6 measured to be brighter than SATCON-1 recommendation of 6.46 mag at zenith = 100%
Fraction of orbital shell 7 measured to be brighter than SATCON-1 recommendation of 6.48 mag at zenith = 100%
Fraction of orbital shell 8 measured to be brighter than SATCON-1 recommendation of 6.5 mag at zenith = 100%
Overall fraction measured to be brighter than SATCON-1 recommendation at zenith 99.94%
Maximum observation zenith angle considered = 90 deg

Overall light pollution level = 35.1 and light pollution risk = VERY HIGH

RECOMMENDATION: Constellation redesign recommended to mitigate the estimated VERY HIGH level of light pollution
risk
```

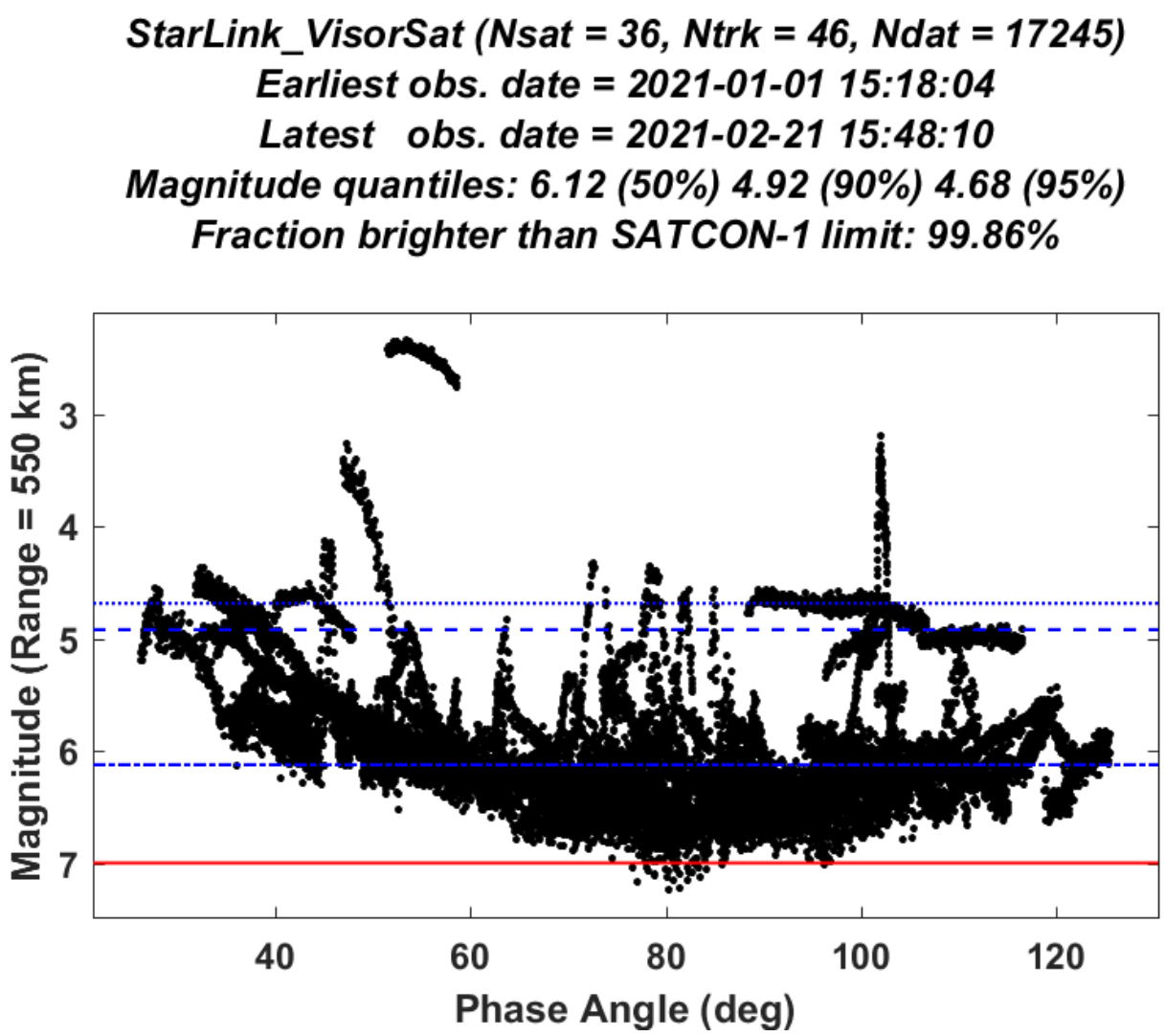
Example Output Evaluation Table

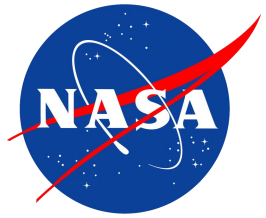
Starlink1stGen_MeasuredBrightness_ZenMax90_Extinct0.12_AllLats.xlsx

SolarDepression	Nabove	Nsunlit	Nbright	Maxbright	LightPollutionLevel	LightPollutionRisk
0	510.21	510.21	48.36			N/A
12	510.21	410.51	47.13			N/A
18	510.21	330.46	35.06	1	35.06	VERY HIGH
21	510.21	287.10	22.42	1	22.42	VERY HIGH
24	510.21	241.35	12.14	1	12.14	VERY HIGH
27	510.21	192.43	5.57	1	5.57	HIGH
30	510.21	144.39	1.98	1	1.98	HIGH
33	510.21	100.75	0.63	1	0.63	MEDIUM
36	510.21	67.79	0.31	1	0.31	MEDIUM
39	510.21	44.78	0.12	1	0.12	MEDIUM
42	510.21	20.70	0.01	1	0.01	VERY LOW
45	510.21	4.05	0.00	1	0.00	NONE
48	510.21	0.00	0.00	1	0.00	NONE
51	510.21	0.00	0.00	1	0.00	NONE
54	510.21	0.00	0.00	1	0.00	NONE
57	510.21	0.00	0.00	1	0.00	NONE
60	510.21	0.00	0.00	1	0.00	NONE
63	510.21	0.00	0.00	1	0.00	NONE
66	510.21	0.00	0.00	1	0.00	NONE
69	510.21	0.00	0.00	1	0.00	NONE
72	510.21	0.00	0.00	1	0.00	NONE
75	510.21	0.00	0.00	1	0.00	NONE
78	510.21	0.00	0.00	1	0.00	NONE
81	510.21	0.00	0.00	1	0.00	NONE
84	510.21	0.00	0.00	1	0.00	NONE

Example Photometric Analysis Plot

StarLink_VisorSat_550km_Sc1_20210101_20210221_Ns36_Nt46_Nd17245_Nc3_MagPhase.png





Program *EvaluateLightPollution*

Distributed

EvaluateLightPollution

Analysis Examples

EvaluateLightPollution Analysis Examples (function RunExamples.m)

```
%% ------ Run examples for the function EvaluateLightPollution

%% ------ Single-shell constellation examples

% Starlink 1st orbital shell constellation based on measured brightness
EvaluateLightPollution('params/Starlink1stShell_MeasuredBrightness');

% OneWeb Phase 1 constellation based on measured brightness
EvaluateLightPollution('params/OneWebPhase1_MeasuredBrightness');

% Iridium 2nd Gen. constellation based on measured brightness
EvaluateLightPollution('params/Iridium2ndGen_MeasuredBrightness');

% OneWeb Phase 1 analysis using Iridium satellites as analog objects
% (to demonstrate analysis for proposed constellations with no orbiting
% satellites)
EvaluateLightPollution('params/OneWebPhase1_IridiumAsAnalog');

%% ------ Multi-shell constellation examples

% Starlink full 1st and 2nd gen. constellations based on measured
% brightness
EvaluateLightPollution('params/Starlink1stGen_MeasuredBrightness');
EvaluateLightPollution('params/Starlink2ndGen_MeasuredBrightness');

% OneWeb Phase 2 constellation based on measured brightness
EvaluateLightPollution('params/OneWebPhase2_MeasuredBrightness');

%% ------ Multi-shell constellation required brightness reduction example

% OneWeb Phase 2 constellation analysis showing that an average
% brightness reduction of 1.7 magnitudes changes the evaluated light
% pollution level from "very high" to "medium"
EvaluateLightPollution('params/OneWebPhase2_ReducedBrightness');

%% ------ Multi-shell constellation comparison example

% Starlink constellations compared to OneWeb and Iridium constellations
EvaluateLightPollution('params/Starlink1stGen_CompareConstellations');
```

Notes:

1. Photometric data files will need to be downloaded and placed in the appropriate subfolder of the “data” directory before execution of these examples
2. Each of the nine provided example analyses takes a few up to several minutes to execute on a typical computer
3. Upon completion of the nine examples, the analysis directories and files in the newly created “output” directory should match those already provided in the “output_with_distribution” directory

Program *EvaluateLightPollution*

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