Report of the Simulations Working Group

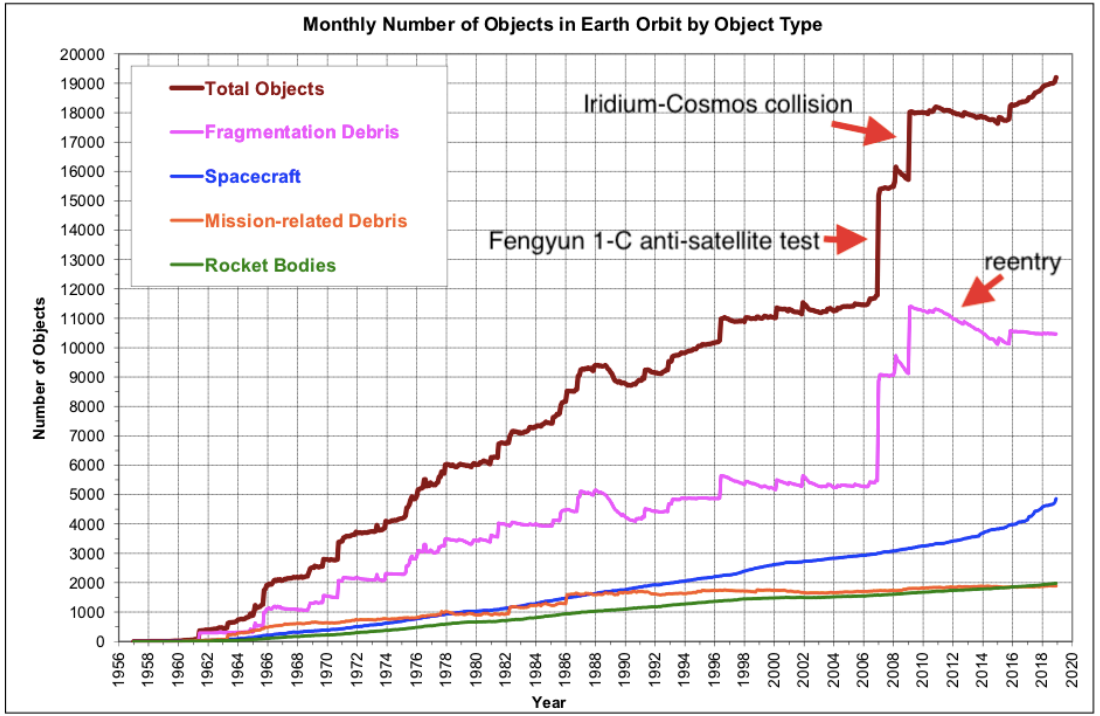
For the Simulations Working Group:

Patrick Seitzer (Chair)
Department of Astronomy
University of Michigan

American Astronomical Society
Committee on Light Pollution, Radio Interference, and Space Debris

pseitzer@umich.edu

What is in Earth orbit today?



Monthly Number of Cataloged Objects in Earth Orbit by Object Type. This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

Any object in Earth orbit that reflects sunlight is of concern.

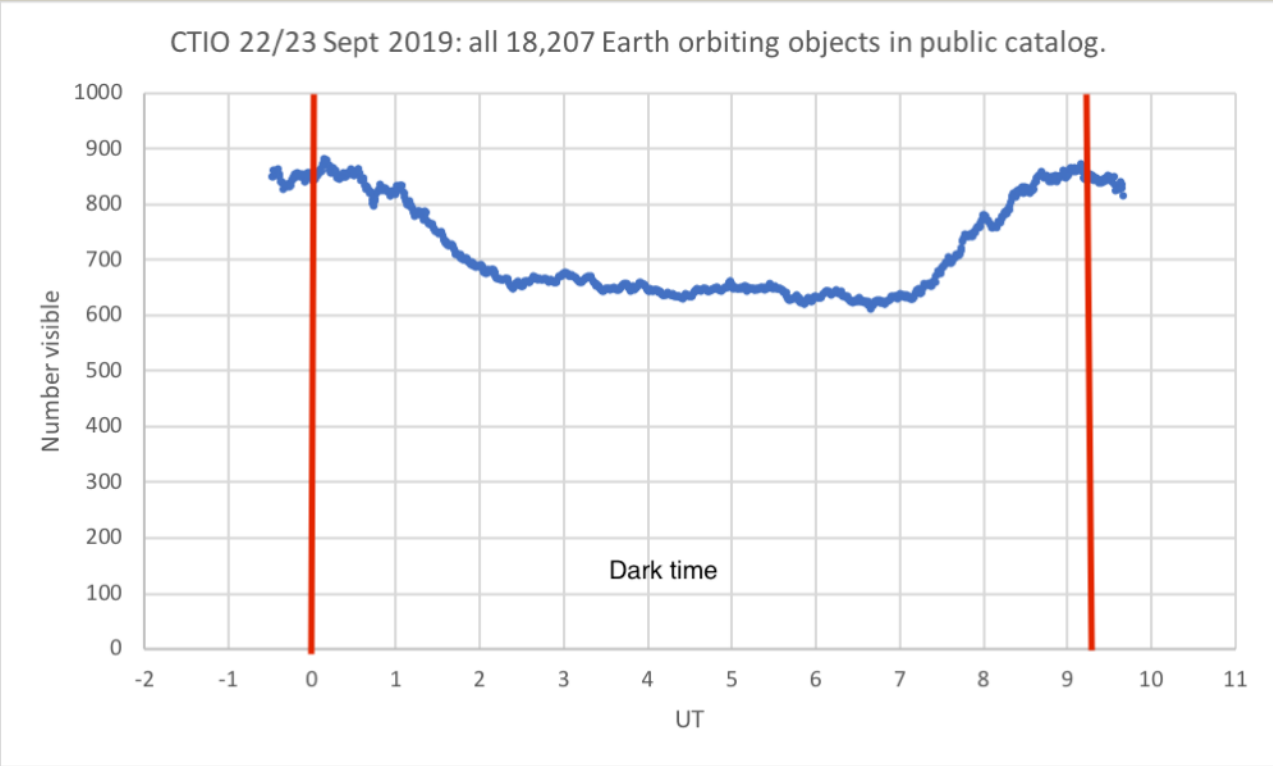
The top curve concerns astronomy and space safety.

Public catalog of objects
> 10 cm at LEO
> 1 m at GEO.

Catalog incomplete.

NASA Orbital Debris Program Office

How many objects visible at night in springtime at Cerro Tololo in Chile?



Red lines –

Sun < -18 degrees elevation

Darkest part of the night

Calculated for satellites at elevation greater than 30 degrees.

Astronomical twilight: 23:59 – 09:12

Some Large Constellations

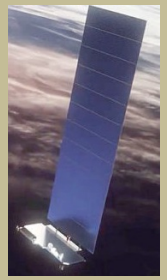
Constellation	Altitudes (km)	Inclinations (deg)	# of satellites
Amazon/Kuiper	590 - 630	33.0 - 51.9	3,236
OneWeb	1200	40.0 - 87.9	47,844
SpaceX (Starlink)	328 - 614	30.0 - 148.0	34,408

Data from public FCC filings.

Simulations: How many of these satellites will be visible? How bright will they be? Are some constellation architectures more challenging for astronomy?

3 Phases of a Constellation's Lifetime

1. Initial mission phase. *This is what got observers excited – satellites at low altitude and non-standard attitude/orientation.*
   a) Launch.
   b) Checkout and parking orbit .
   c) Orbit raising.
2. Operational phase. *Simulations reported here.*
3. Deorbit phase – high drag configuration?
   – Orbit lowered until satellite burns up in atmosphere.
   – Must do within 25 years after end of mission.



Brightness will be different in all three phases – distance from observer to satellite different and attitude/orientation of satellite different. *What about failures – uncontrolled satellites?*

Individuals and groups undertaking simulations

- Jonathan McDowell (Center for Astrophysics)
- David Galadí (Icosaedro working group of the Spanish Astronomical Society SEA)
- Olivier Hainaut (European Southern Observatory)
- Patrick Seitzer (University of Michigan)
- Jan Siminski (European Space Agency Space Debris Office)
- Cees Bassa (ASTRON Netherlands Institute for Radio Astronomy)

Each group or individual worked completely independently – no sharing of algorithms and/or software. Test constellation of 10,000 satellites at 1000 km and 53 deg inclination – 100 planes with 100 satellites each. Results agreed very well.

Executive Summary (1)

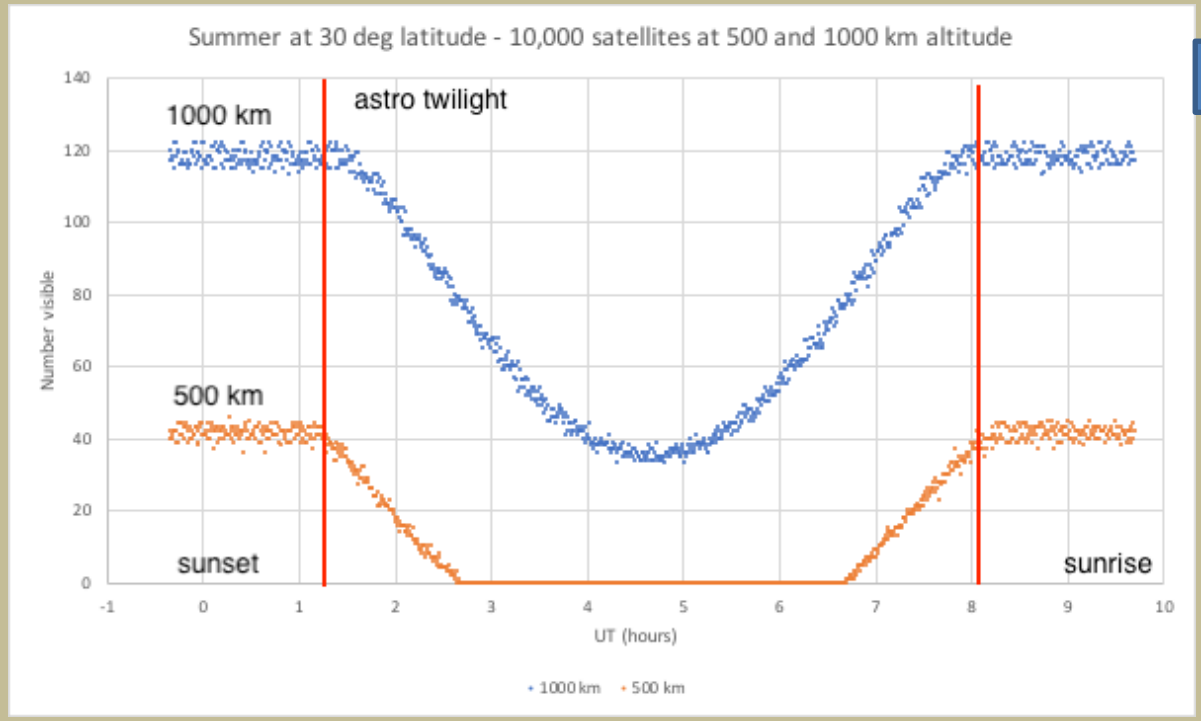
- The fraction of satellites that will be visible at any observatory at any one time is typically around 5%.
  - Higher altitude constellation shells will have a greater fraction visible (7-8%), lower altitude constellations a smaller fraction (-4%).
  - Most of these satellites appear at low elevation over the horizon (typically 50% below 10deg).
- The number of satellites visible is a strong function of their orbital inclination, peaking at a latitude close to the inclination.
- The constellation with the greatest impact for any observatory in terms of the number of satellites visible will be one at higher altitude and with an orbital inclination close to the latitude of the observatory.

Executive Summary (2)

- Satellites enter the shadow of the Earth some time after sunset, and re-emerge some time before sunrise. While in the shadow, they are not visible.
  - Typically, about half the satellites visible are still illuminated at the end of the astronomical twilight. More for higher satellites, less for lower satellites.
  - Higher altitude constellations (say at 1200 km) will be visible longer past astronomical twilight and into the darkest part of the night. Some satellites from higher altitude constellations can be visible all night long in summer .
  - For any constellation at 550 km and higher, there will be satellites visible past astronomical twilight at any time of year. How long depends on altitude and time of year.
- The largest uncertainty in our simulations is the number of satellites being launched. Who is going to launch what, when, and where? Not all constellations have to submit public filings with the US Federal Communications Commission (FCC).

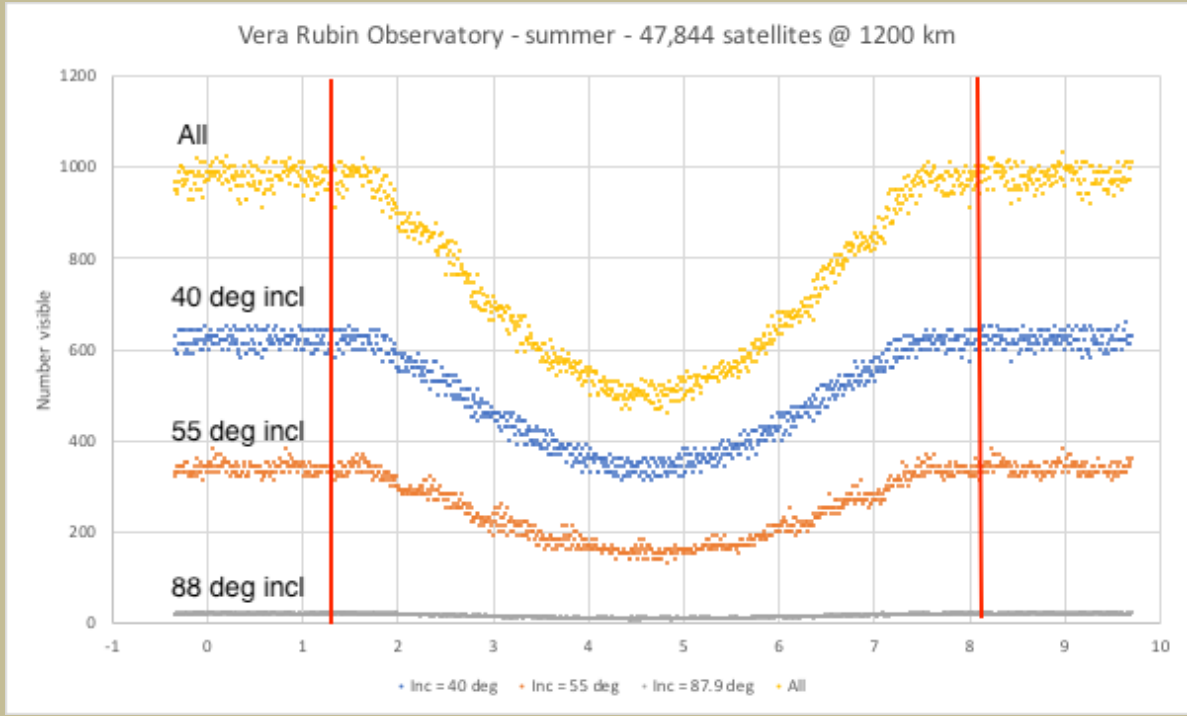
Test constellation – 10,000 satellites

100 planes with 100 satellites per plane – inclination = 53 deg



Elevation > 30 deg

Simulation of OneWeb constellation



Elevation > 30 deg

Large Magellanic Cloud (LMC)

Optimal observing time
Summer in south.

Declination = -69 deg

No satellite free time from 1200 km constellations

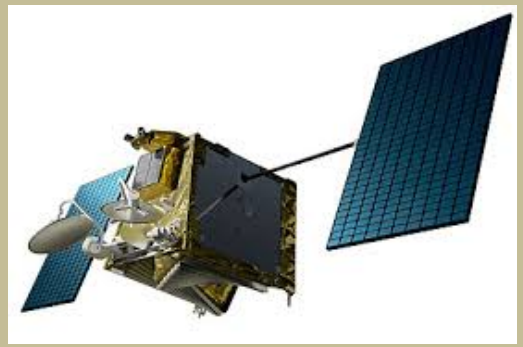
Eckhard Slawik via ESA

Brightness of satellites

Starlink

Complicated problem!

- Altitude (range).
- Attitude (orientation).
- Albedo.
- Size.
- Surface characteristics.
- Specular vs diffuse reflection.
- Self-shadowing.
- Solar phase angle.



OneWeb

- Satellites are not Lambertian spheres!

Presentations

- Jonathan McDowell (Center for Astrophysics), *A Sky Full of Satellites: Simulating the Visibility of MegaConstellations*

- Cees Bassa (ASTRON) / David Galadi (SEA) / Olivier Hainaut (ESO), *Simulations of the Number of Satellite Trails and the Impact on Visible/Near IR Observations*

- Moriba Jah / Daniel Kucharski (University of Texas), *Simulating the Brightness of Satellites with BRDFs*

- Q&A to follow – *please type questions into Q&A box.*