Mega-Constellations of LEO Satellites and Optical Astronomy

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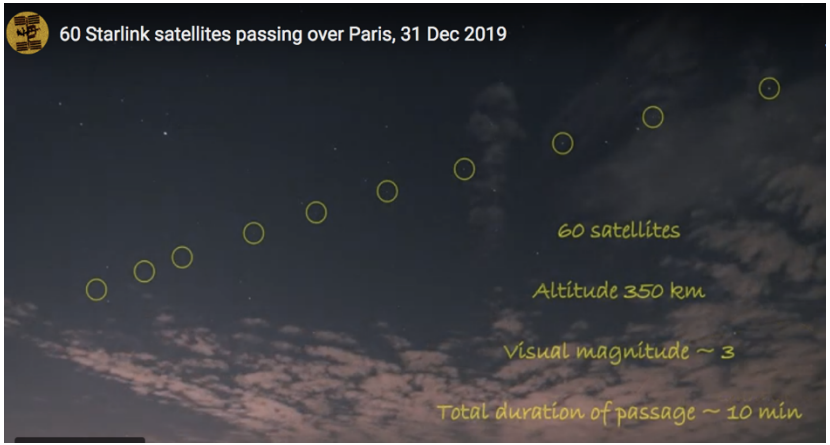
'String of Pearls' – SpaceX Starlinks in the night sky shortly after launch



Thierry Legault

Marco Langbroek

Brighter than V = 3

Ultimately > 42,000?

All night long?

Is this the future of the night sky?

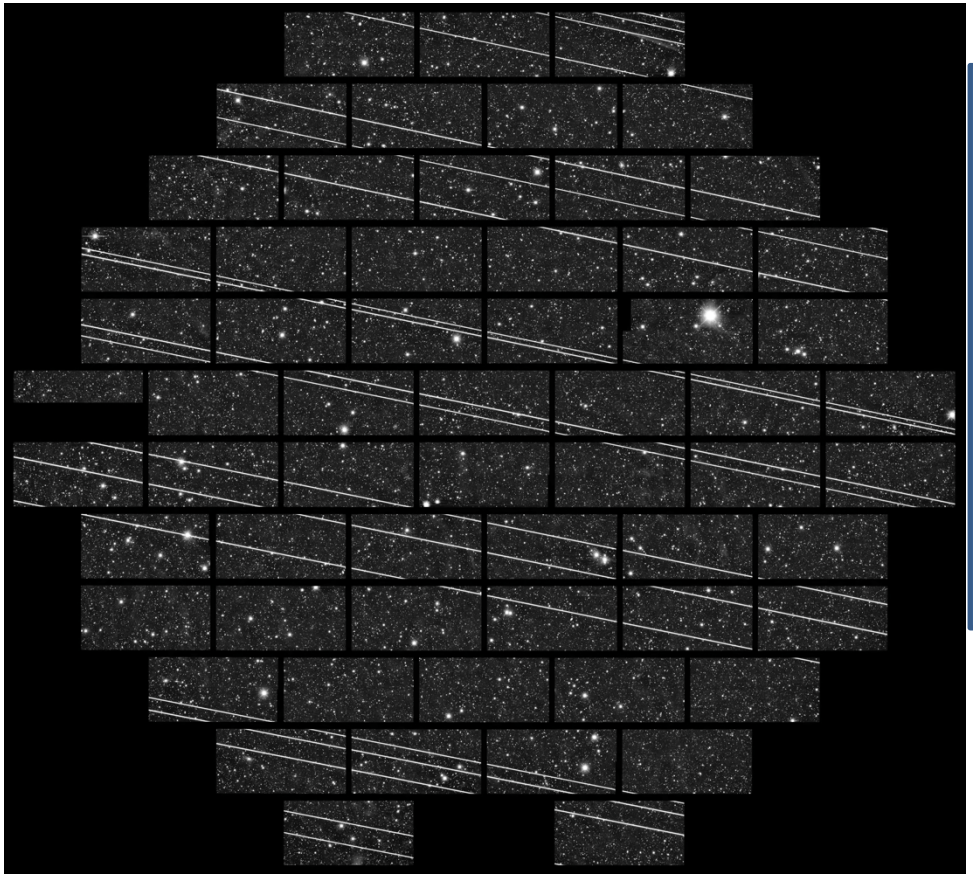
LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

2019-Nov-18 0800 UT

Blanco 4.0-m DECAM

Cerro Tololo, Chile

2.2 deg FOV



333 second exposure

Filter I’

2019-074 launched 2019-Nov-11

19 Starlinks crossing

~4 sec to cross field of view

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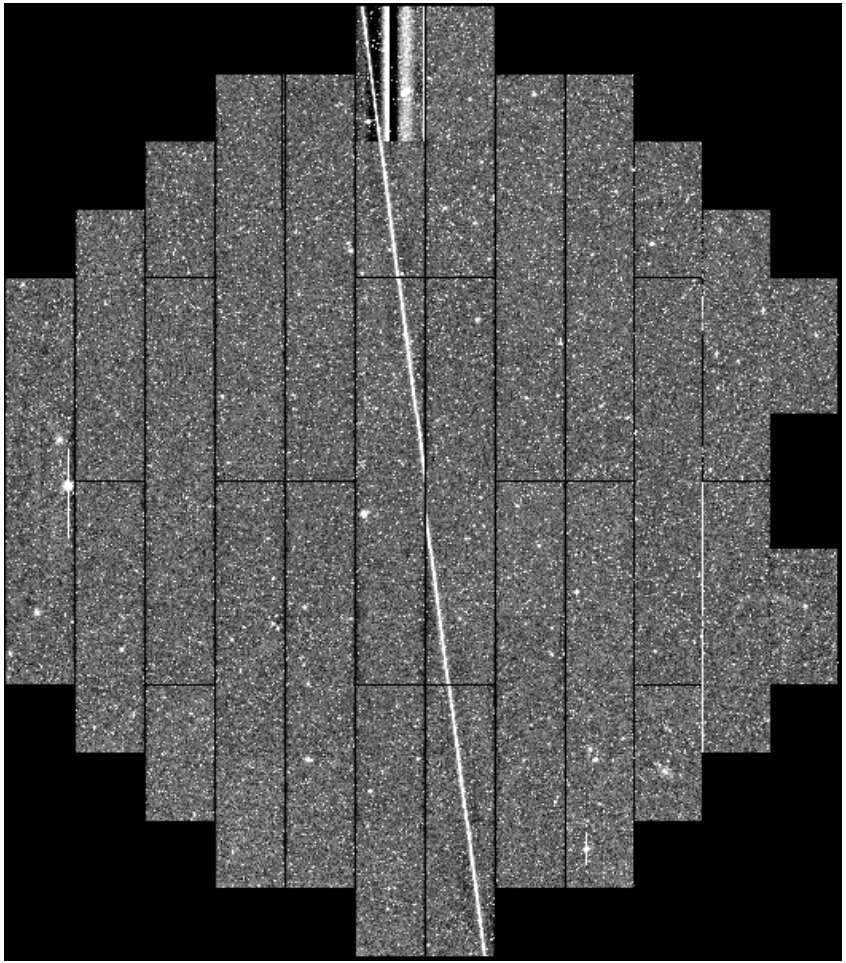
2019-July-16 UT

Blanco 4.0-m DECAM

Cerro Tololo, Chile

2.2 deg FOV



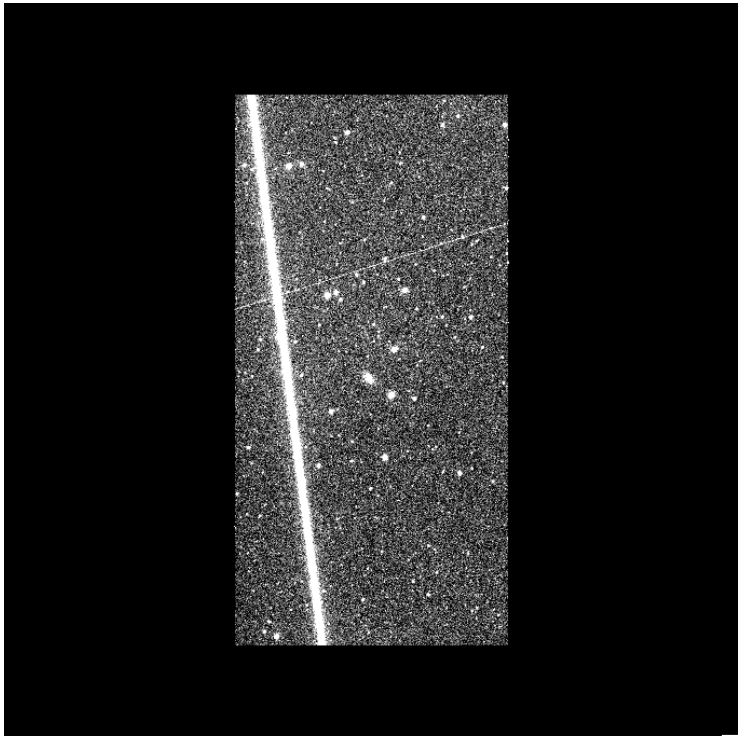
60 sec exposure
r' filter

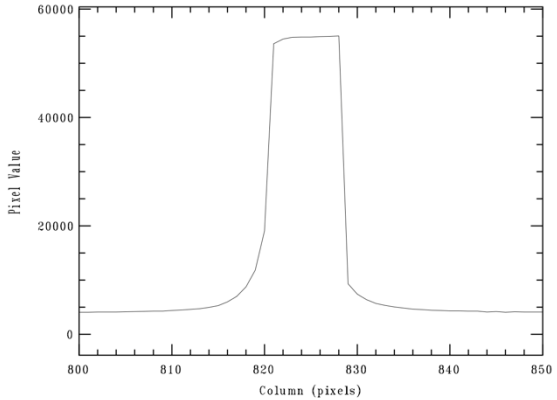
Atlas Centaur 2 R/B

1963-047A 00694

V ~ 4^{th} – 10^{th}

Streak saturates Detector





- Loss of information in pixels.
- Cross-talk in electronics.
- Ghost images.
- Possible residual images.

Topics

- When are satellites visible?
- How many satellites are visible today?
- Visibility of SpaceX/Starlink constellation of 1584 satellites.
  - When completely operational at 550k km.
  - Immediately after launch and during deployment – *what one sees now is not representative of final steady state*.
  - Deorbit phase at end of mission.
- Actions in progress by AAS and Vera Rubin/LSST.
- Conclusions.

When are satellites visible?

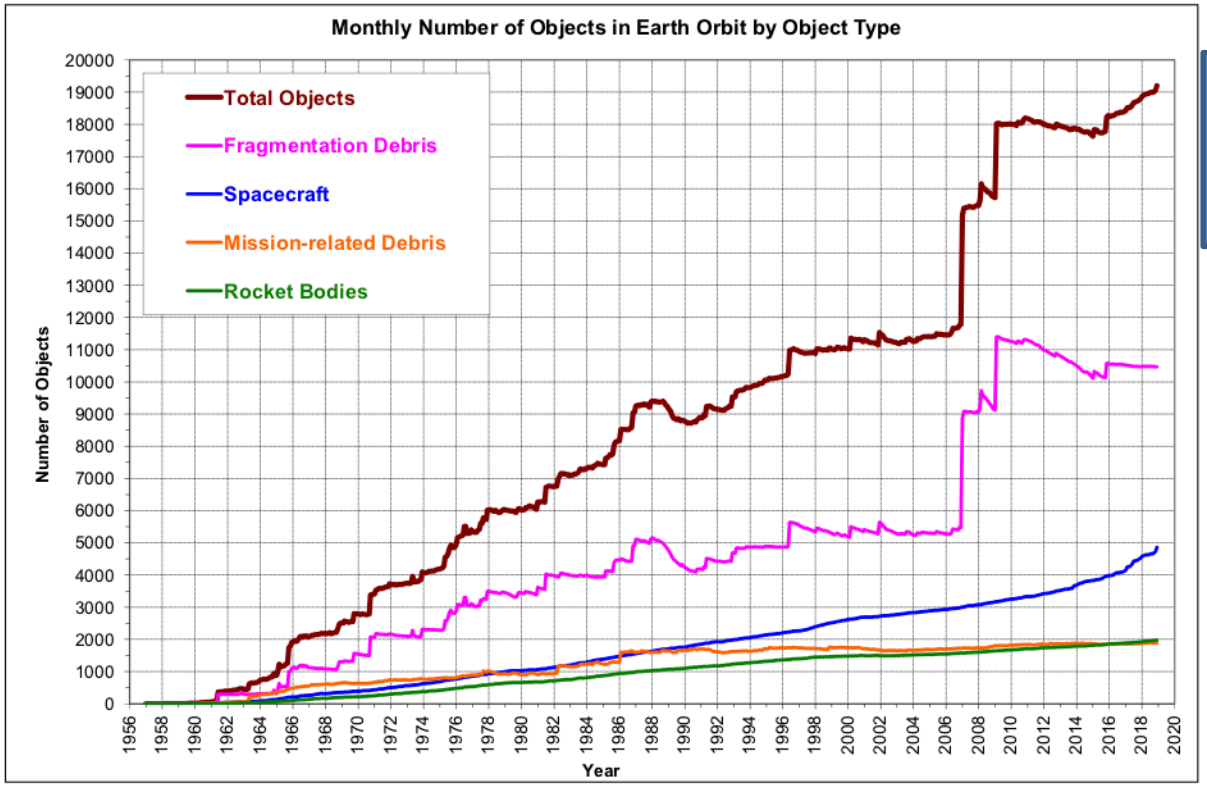
- Observer in darkness:
  - Latitude.
  - Time of year.
- Satellite in sunlight or penumbra – not in Earth shadow:
  - Orbital inclination.
  - Altitude.
  - Time of year.
- Brightness of satellite:
  - Angle between Sun-satellite-observer.
  - Characteristics of satellite – attitude, specular or diffuse reflection, ……

Modelling

- How visible will these satellites be to astronomers?
- Initial Starlink constellation as approved by FCC (public filing):
  - 1584 satellites at 550 km altitude: 24 planes with 66 satellites per plane.
- Definitions of twilight:
  - Sun between 12 and 18 degrees below horizon: useful for calibration.
  - Sun 18 degrees or more below horizon: darkest time, observe faintest objects.
  - Sun at 18 deg - red line in plots.

Geometric Visibility

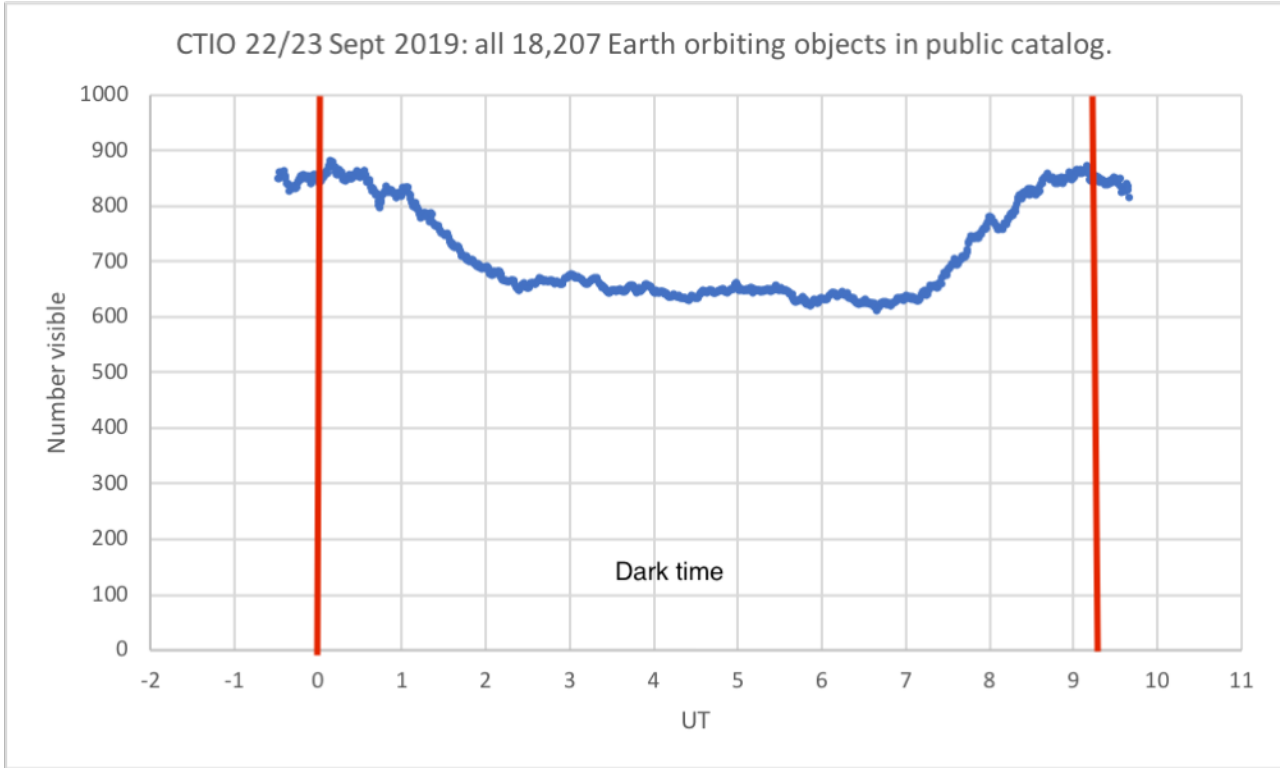
- Geometric Visibility: observer has a line of sight to satellite.
- Assumed full constellation of 1584 in final orbits by June 20, 2019.
- Constraints:
  - Sun 12 deg or more below observer's horizon (nautical twilight).
  - Satellite elevation ≧ 30 degrees. Airmass = 2.0, typical astronomical limit.
  - Satellite is in full sunlight or penumbra.
- Visibility computed for Univ of Michigan Curtis-Schmidt at Cerro Tololo Inter-American Observatory (CTIO) in Chile [LSST just south of this site].
  - Long = -70.80627 latitude = -30.16908 altitude 2216 meters (WGS84).



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.

NASA Orbital Debris Program Office



Astronomical twilight: 23:59 – 09:12

New Mega-Constellations

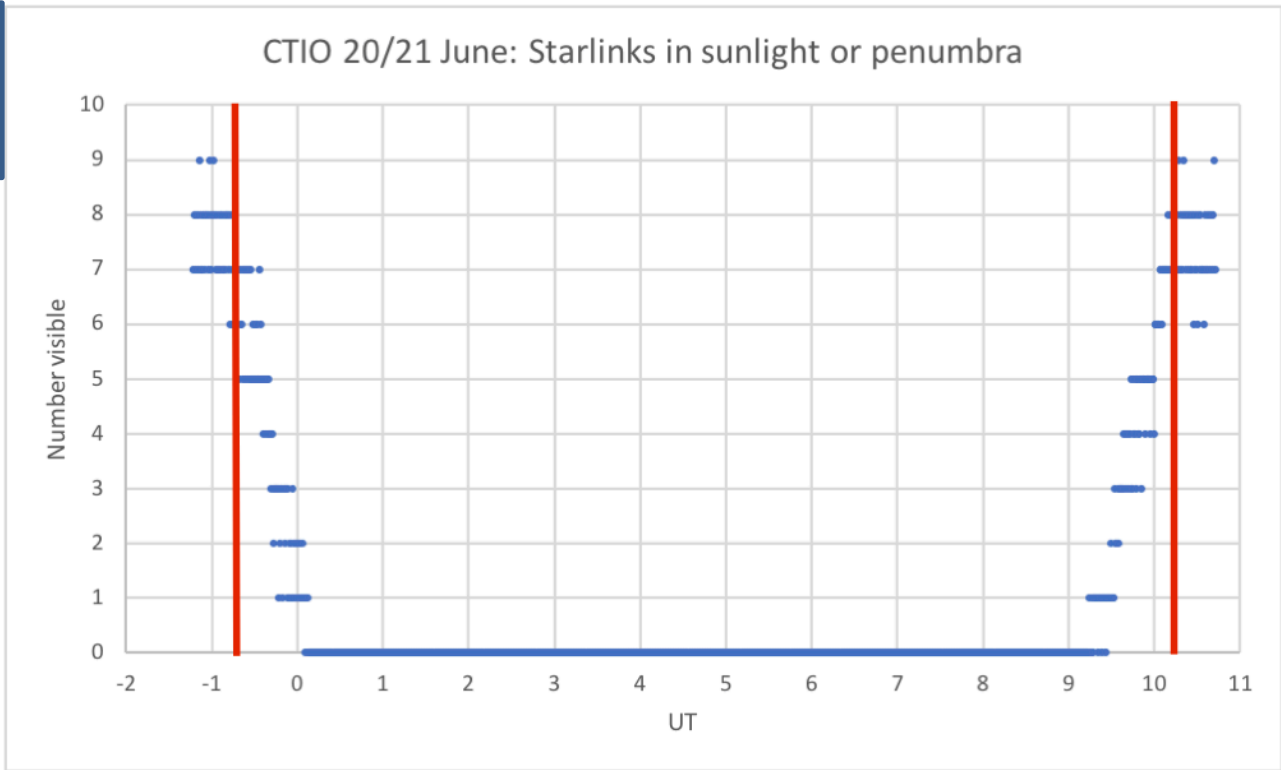
- If 600-700 objects now visible at any time during the night, why do we care if another 100-200 are added from new mega-constellations?
- **Brightness! The new satellites could be brighter than 99% of all objects in orbit now.**
- Now – maybe 200 objects can be seen with eye (not all at once).
- End of 2020 – SpaceX will add another 1584! 9x larger population.

Simulations of Initial Starlink Constellation

- Three nights for initial analysis of visibility of all 1584 satellites @ 550 km:
  - June 20/21 2019: longest night of the year in Chile.
  - Sept 22/23 2019: equinox.
  - Dec 21/22 2019: shortest night of the year in Chile.
- Plots run from evening nautical twilight (Sun -12 deg) to morning nautical twilight.
- Temporal bin width of 0.01 hours (36 secs) far less than plot resolution. Solid lines are not solid lines, just closely spaced markers.
- At 550 km, Starlinks observed V ~ 5^{th}.

N = 1584

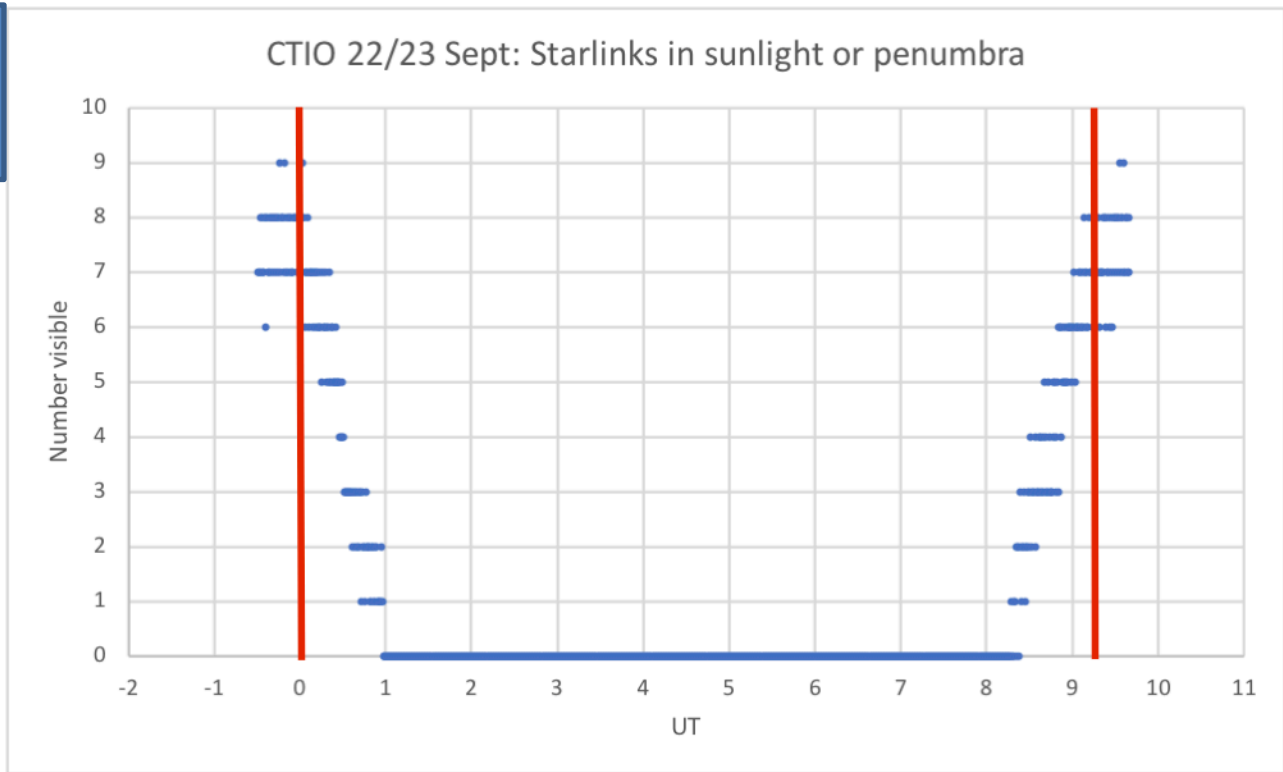
Multiply by ?



Astronomical twilight: 23:16 – 10:13

N = 1584

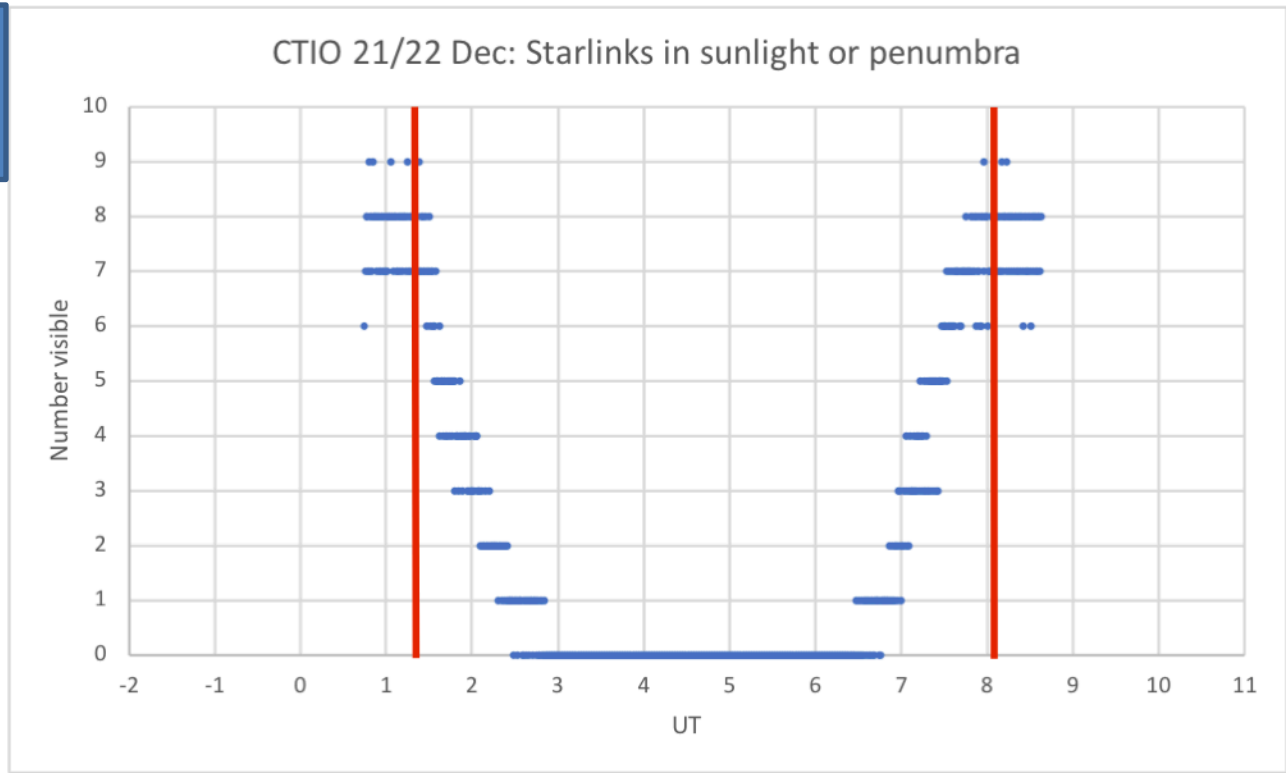
Multiply by ?



Astronomical twilight: 23:59 – 09:12

N = 1584

Multiply by ?



Astronomical twilight: 01:20 – 08:01

Conclusions

- As expected for Low Earth Orbit (LEO) satellites, Starlinks at 550km are visible only at start and end of night.
- Concern: during entire year, there are significant numbers of bright (V ~5th magnitude) Starlinks after start of astronomical twilight in evening and before end of astronomical twilight in morning.
- If initial Starlink constellation of 1584 satellites @ 550 km was the only one to be launched, astronomers could handle this.
- Multiply previous number visible by 10? 20? 30? if all mega-constellations launched.

What if?

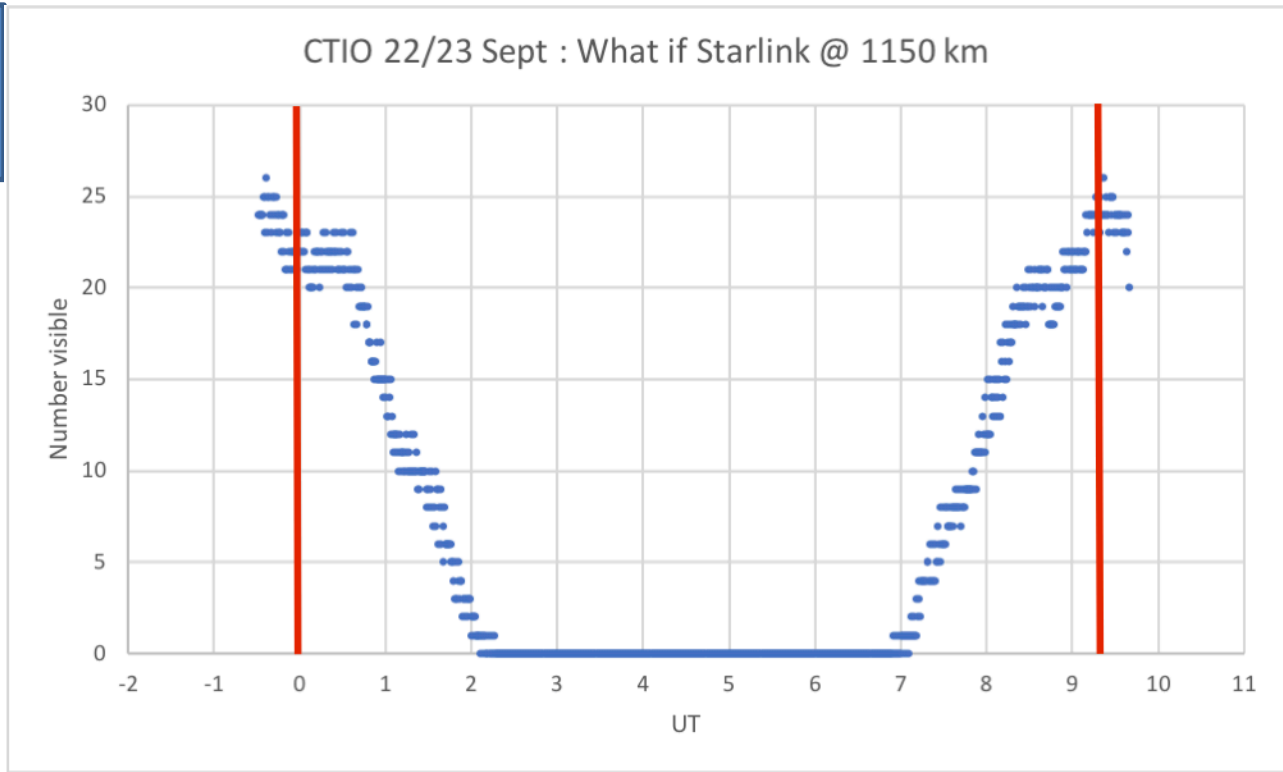
- SpaceX had launched 1584 satellites into original planned orbit of 1150 km.

- Simulation shows:
  - Satellites fainter and probably not visible to eye, but still saturate detector.
  - More satellites visible at any one time – factor of 3-4 times more!
  - Visible longer past twilight and into darkest part of the night.

- From astronomers' perspective, this could be worse.
  - Relative streak brightness greater than predicted from distance considerations alone.

N = 1584

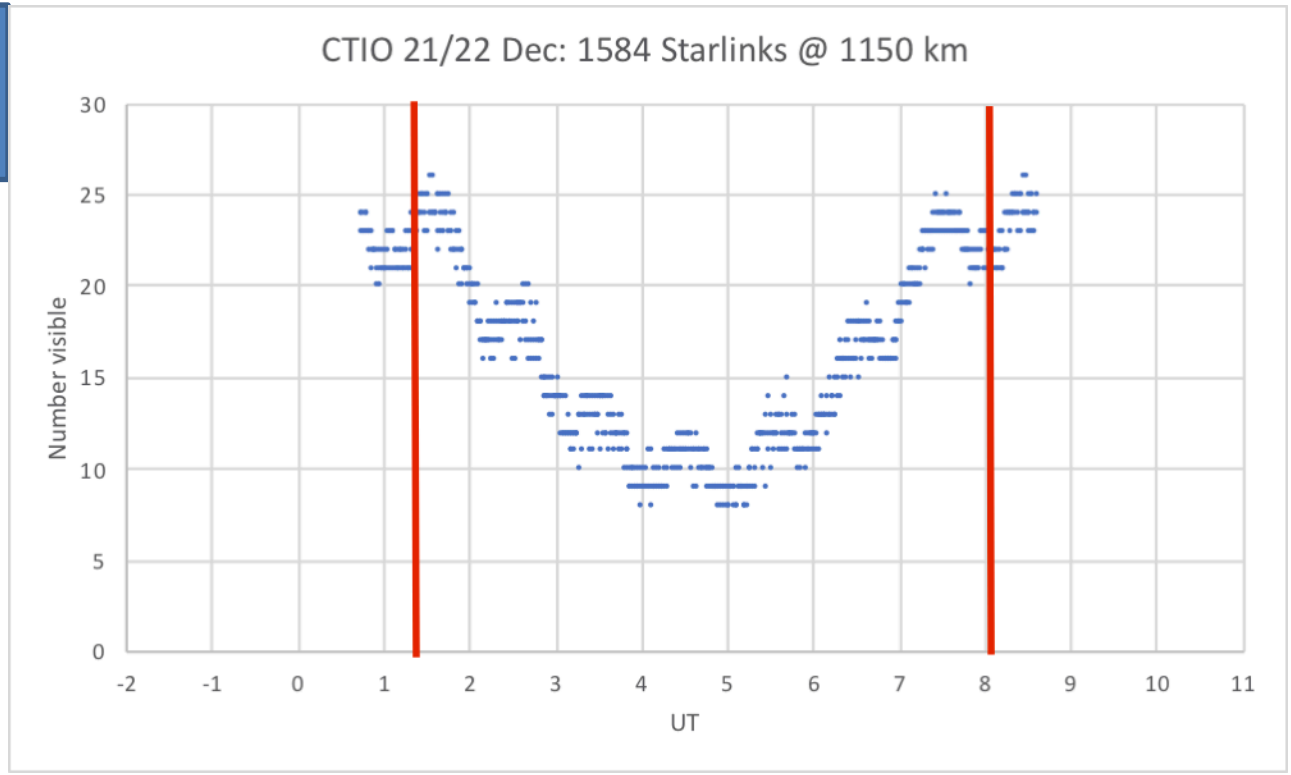
Multiply by ?



Astronomical twilight: 23:59 – 09:12

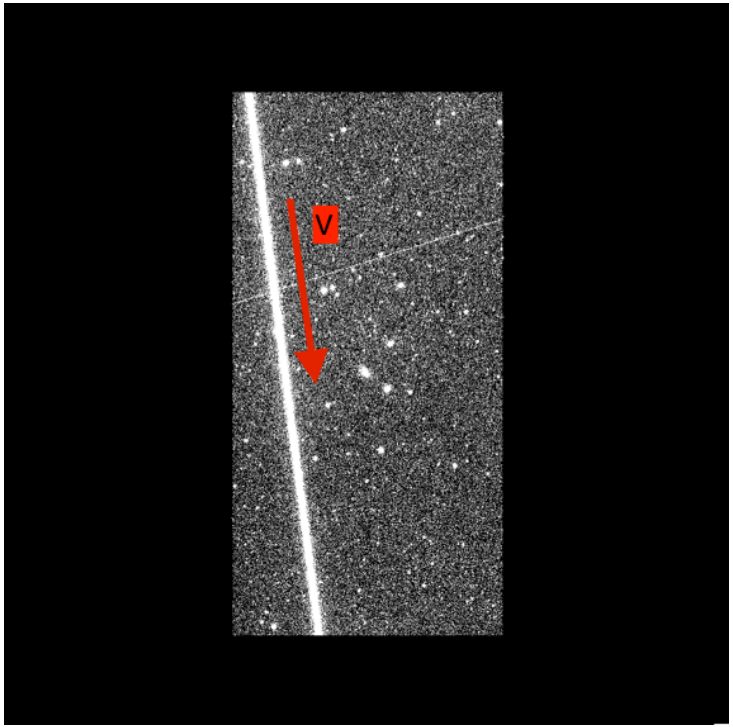
N = 1584

Multiply by ?



Astronomical twilight: 01:20 – 08:01

Streak Brightness



- Also depends on angular velocity v.
- Objects in higher orbits have smaller angular velocity.
- Thus greater time on each pixel.

- For geocentric observer:

- Tracking object – $I(r) \sim r^{-2}$

- Streaked object – $I(r) \sim r^{-1.5}$

The Future in LEO

- 1584 Starlinks just the start.
  - SpaceX: 12,000? 42,000? At 550 km, observed V ~ 5th.
  - Amazon: filed for 3,236 at 590, 610, and 630 km.
  - OneWeb: initially ~700, grow to 1980 (at 1200 km). At 1200 km, observed V ~ 8th
- Amazon satellites visible to unaided eye? Depends on design and surface treatment.
- OneWeb not visible to eye, still saturate detectors.
- SpaceX committed to reducing brightness:
  - One treated *DARKSAT* launched early January. In position by end of Feb 2020 for measurements.
  - Probable that 2nd generation Starlinks will not be visible to unaided eye.
- No current national or international rules or guidelines for brightness of satellites.

American Astronomical Society actions

- Small working group formed to concentrate on issue:
  - Jeff Hall, James Lowenthal, Kelsie Krafton, Joel Parriott, Pat Seitzer, Connie Walker.
- Survey of Observatory Directors of impact of LEO constellations on their projects. Results being digested and summarized.
- Organized special session on ‘Challenges to Astronomy from Satellites’ at Hawai’i AAS meeting: 5 speakers including SpaceX rep.
- Regular telecons with SpaceX – 8 so far.
- One introductory telecon with OneWeb – next one after Feb 6 launch of 30 satellites.
- Workshop being organized by NSF OIR Lab to be held as soon as possible.

Vera Rubin Obs/LSST and SpaceX

- The VRO/LSST survey is most impacted by bright satellite trails because of its unprecedented wide-deep-fast coverage of the sky 2022-2032.
- Original Starlinks will saturate VRO/LSST detectors.
- Joint VRO/LSST-SpaceX engineering teams working to change this:
  - Make satellites fainter to avoid LSST detector saturation - one darker test satellite already launched.
  - Changes to LSST readout to reduce artifacts from trails.
  - Changes to telescope scheduling to avoid most bright satellites.
- We find that SpaceX is committed to solving this problem.

Tony Tyson, VRO/LSST Chief Scientist

Conclusions

- Mega-constellations at LEO are coming and coming fast.
- New satellites brighter than 99% of current objects in orbit.
- Only small fraction of total constellation visible at any one time.
- ‘String of pearls’ does not represent final operational state. *But could be a real challenge to optical astronomy if many launches happening in a short time.*
- If 1584 Starlinks at 550 km were only constellation launched, astronomers could handle this. But multiply 1584 by 10? 20? 30?
- Largest uncertainty – who launches what, when, and where?
- *Have not discussed: latitude dependence, glints, occultations, thermal IR, scheduling to avoid, where observe to avoid, …*