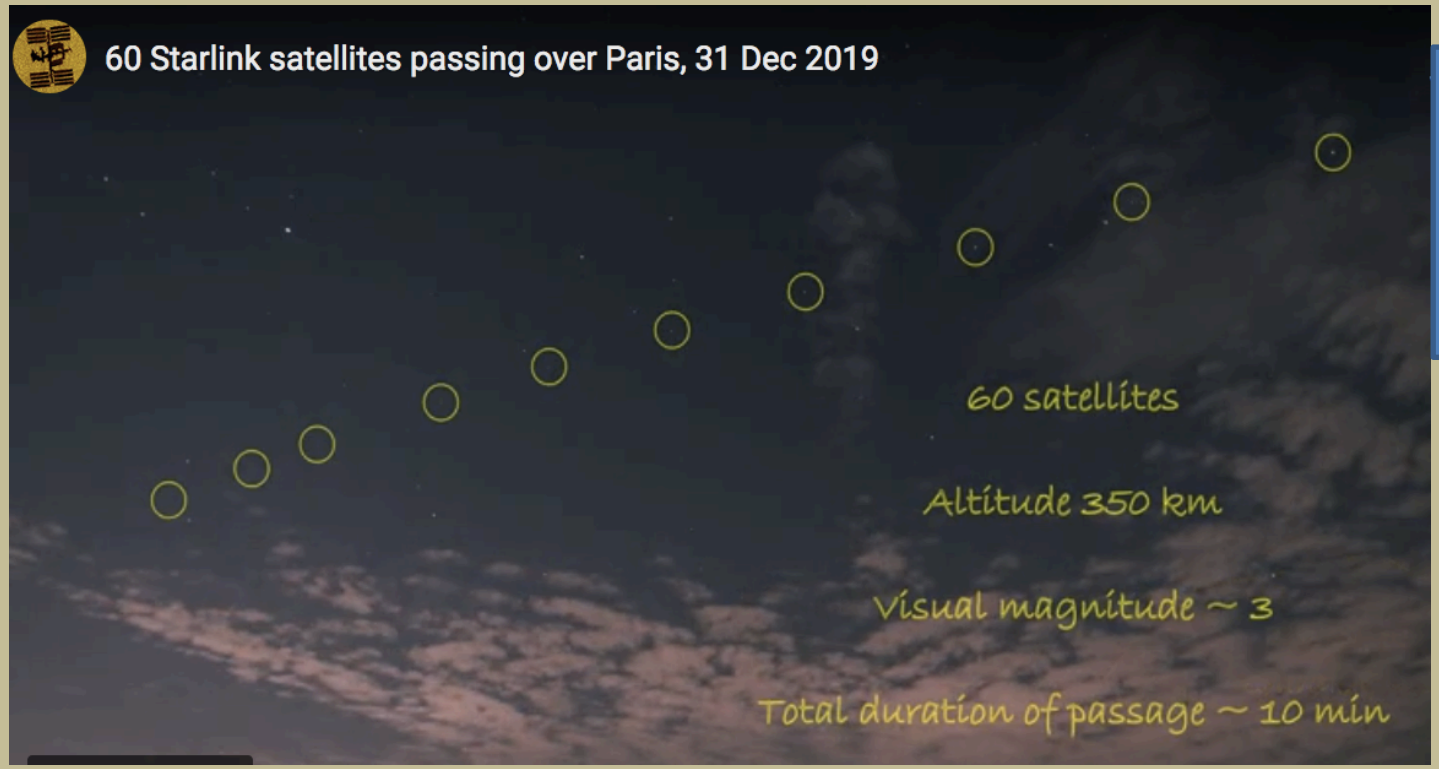
Mega-Constellations of Satellites and Optical Astronomy

Patrick Seitzer
Dept of Astronomy
University of Michigan

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

pseitzer@umich.edu



50 km east of Paris

Ultimately 30,000?

All night long?

Courtesy Thierry Legault

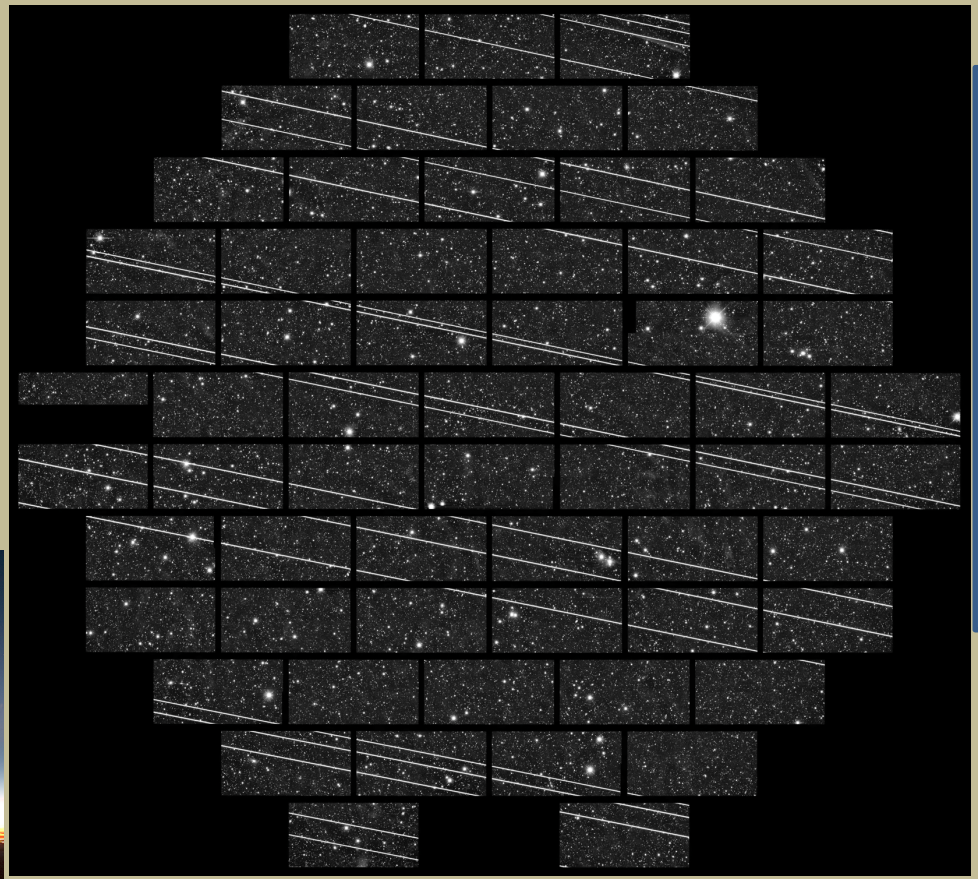
LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

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

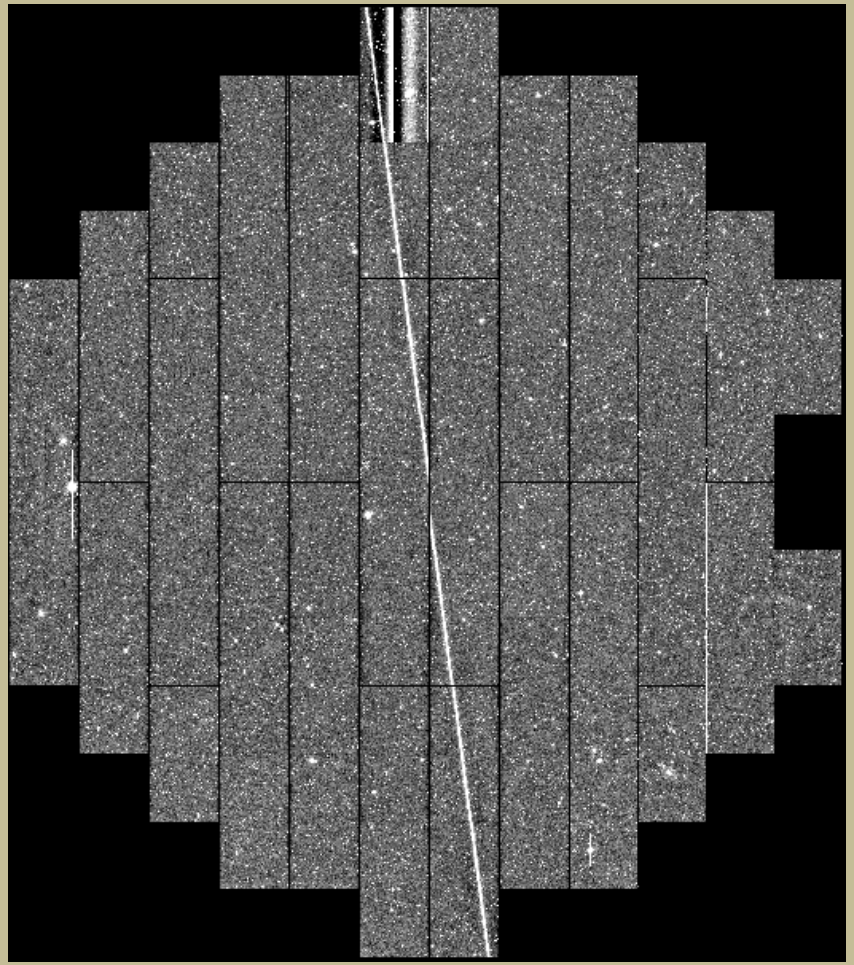
LSA ASTRONOMY
UNIVERSITY OF MICHIGAN

2019-July-16 UT

Blanco 4.0-m DECAM

Cerro Tololo, Chile

2.2 deg FOV



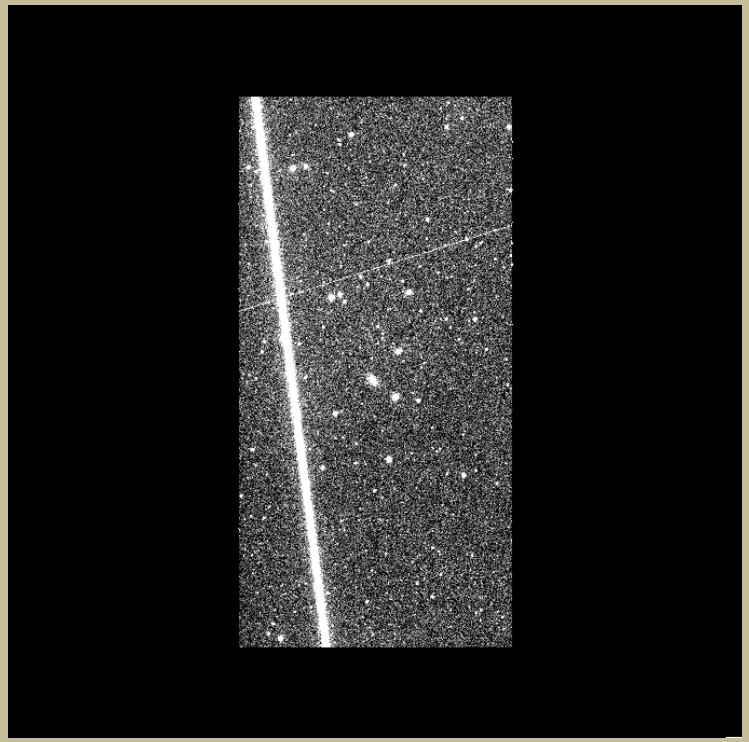
60 sec exposure
r' filter

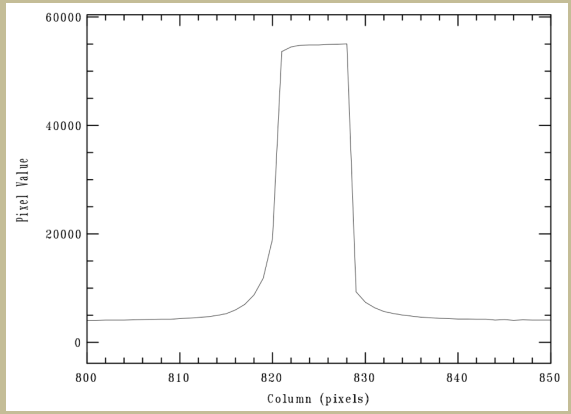
Atlas Centaur 2 R/B

1963-047A 00694

V ~ 4th – 10th

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, not representative of final steady state*.
  - Deorbit phase at end of mission.
- Other constellations.

When are satellites visible?

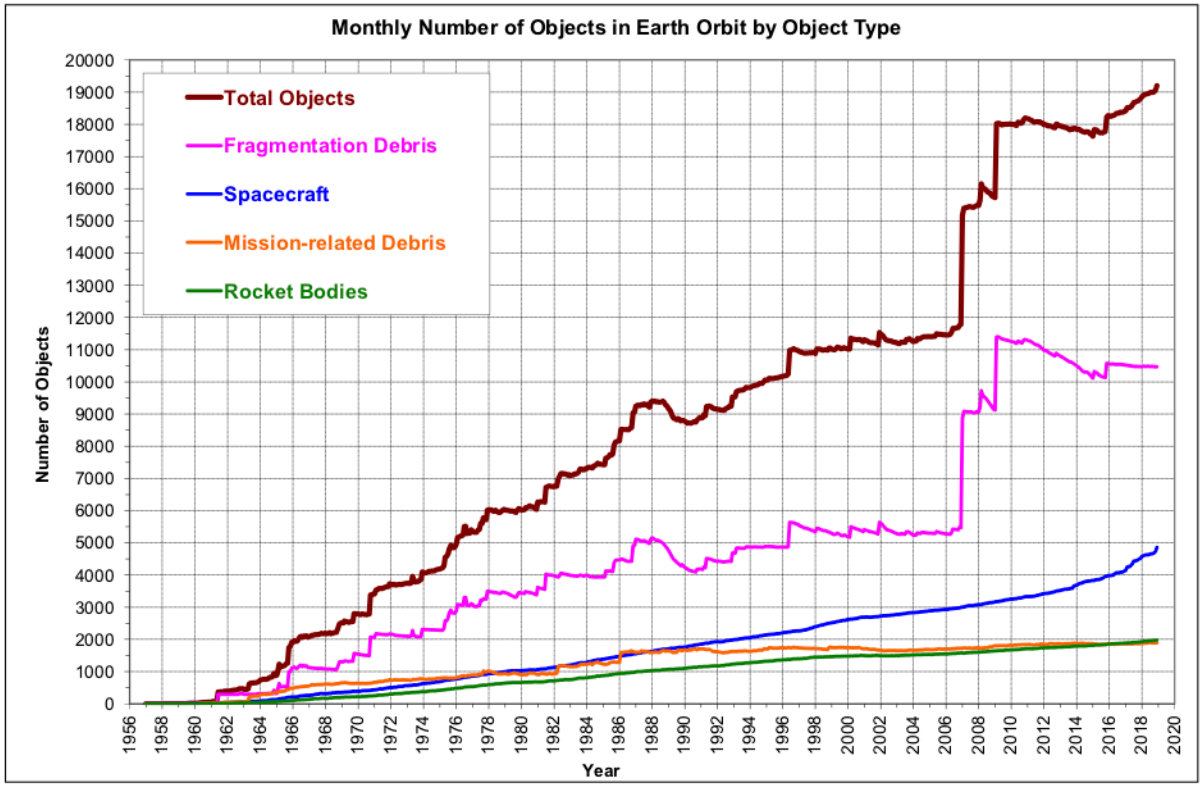
- Observer in darkness:
  - Latitude.
  - Time of year.
- Satellite in sunlight or penumbra – not in Earth shadow:
  - Orbital inclination.
  - Altitude.
  - Time of year.
- Brightness of satellite:
  - Angle between Sun-satellite-observer.
  - Characteristics of satellite – attitude, specular or diffuse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

Geometric Visibility

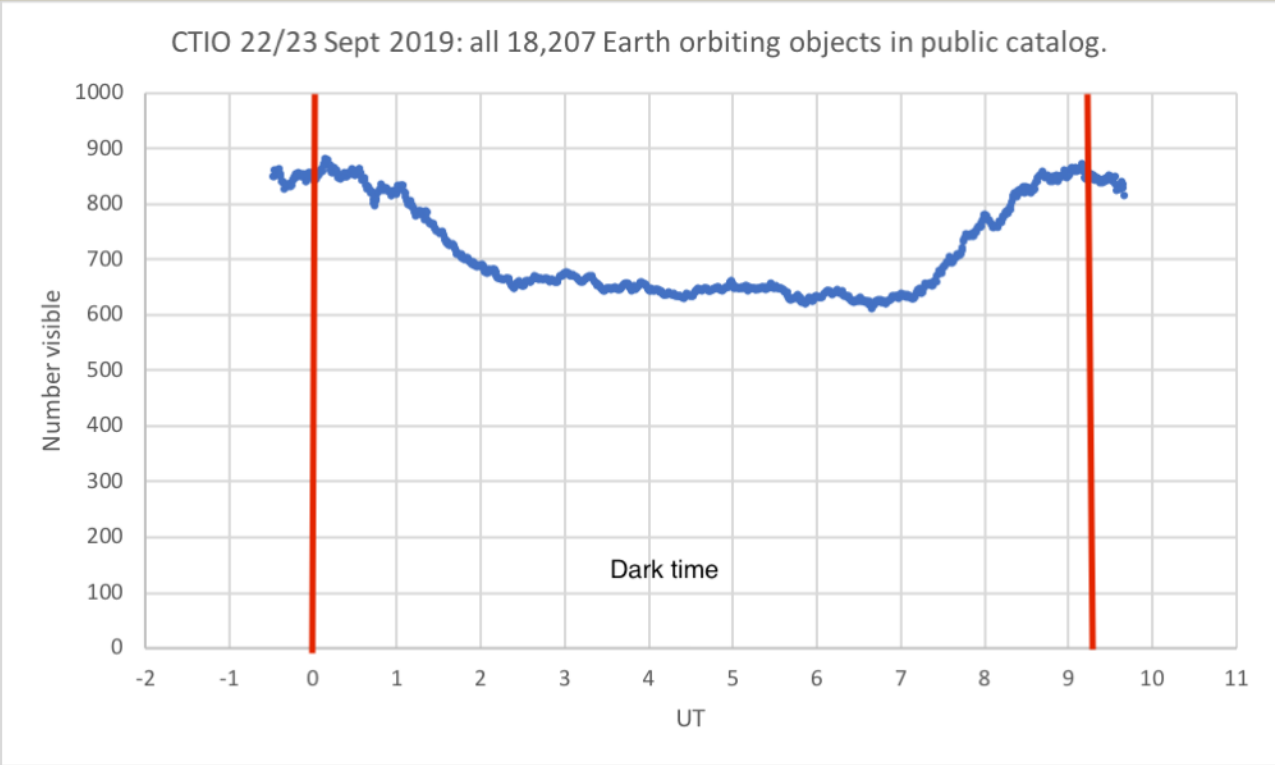
- Geometric Visibility: observer has a line of sight to satellite.
- Assumed full constellation of 1584 in final orbits by June 20, 2019.
- Constraints:
  - Sun 12 deg or more below observer's horizon (nautical twilight).
  - Satellite elevation ≧ 30 degrees. Airmass = 2.0, typical astronomical limit.
  - 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 increase.

Results

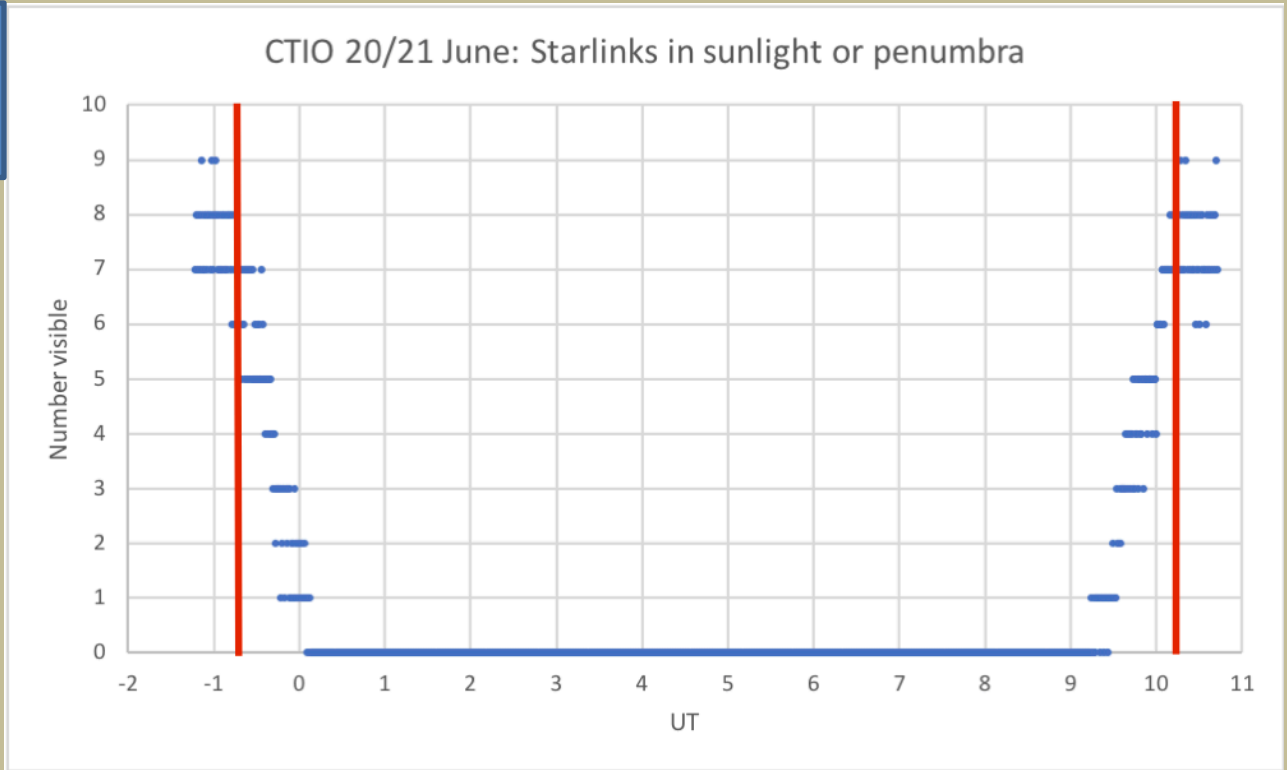
- Three nights for initial analysis of visibility of all 1584 satellites:
  - June 20/21 2019: longest night of the year in Chile.
  - Sept 22/23 2019: equinox.
  - Dec 21/22 2019: shortest night of the year in Chile.

- 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.

N = 1584

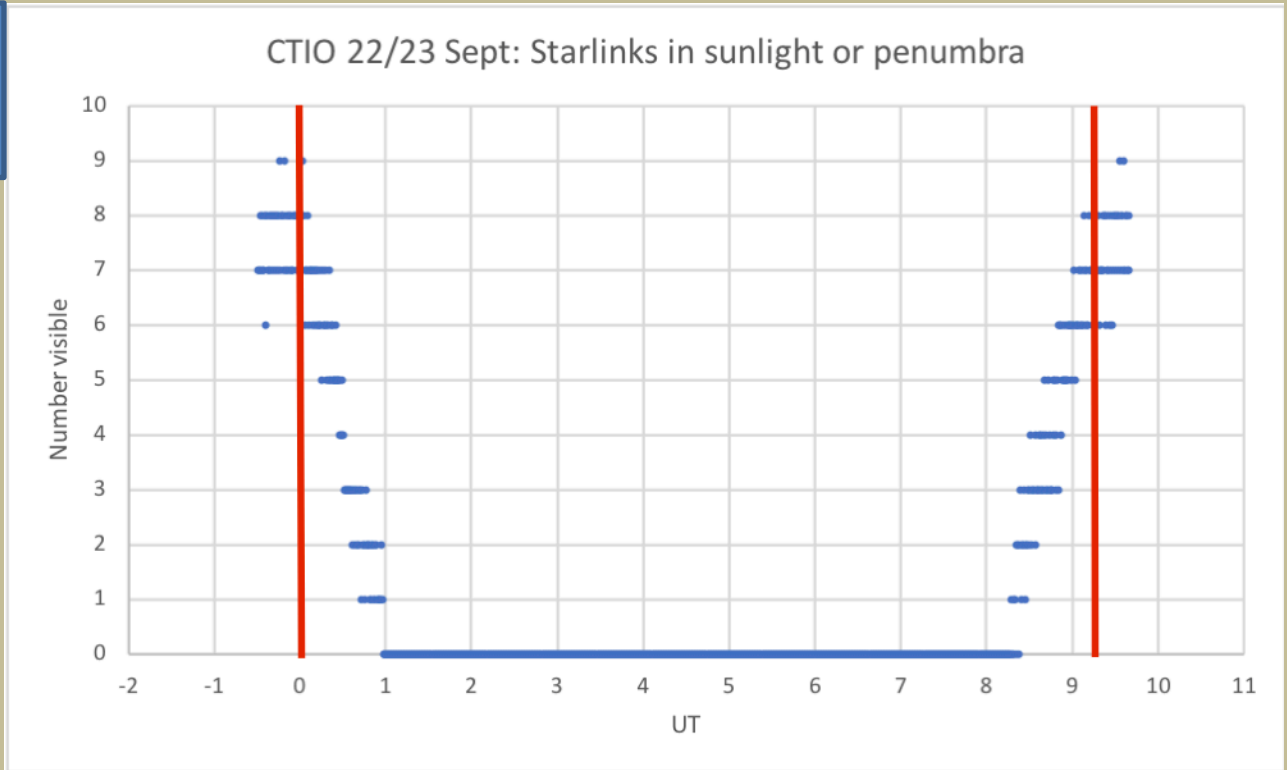
Multiply by ?



Astronomical twilight: 23:16 – 10:13

N = 1584

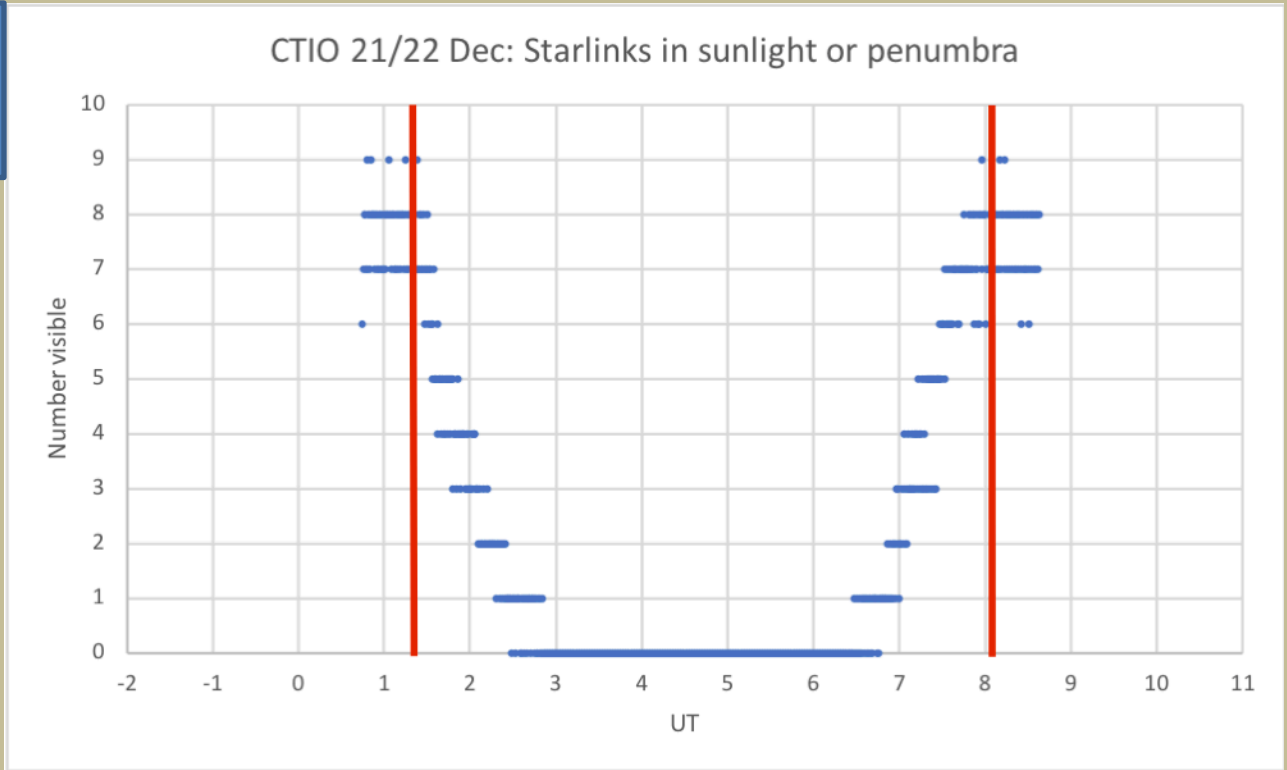
Multiply by ?



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 was the only one to be launched, astronomers could handle this.
- Multiply previous number visible by 10? 20? If all mega-constellations launched.

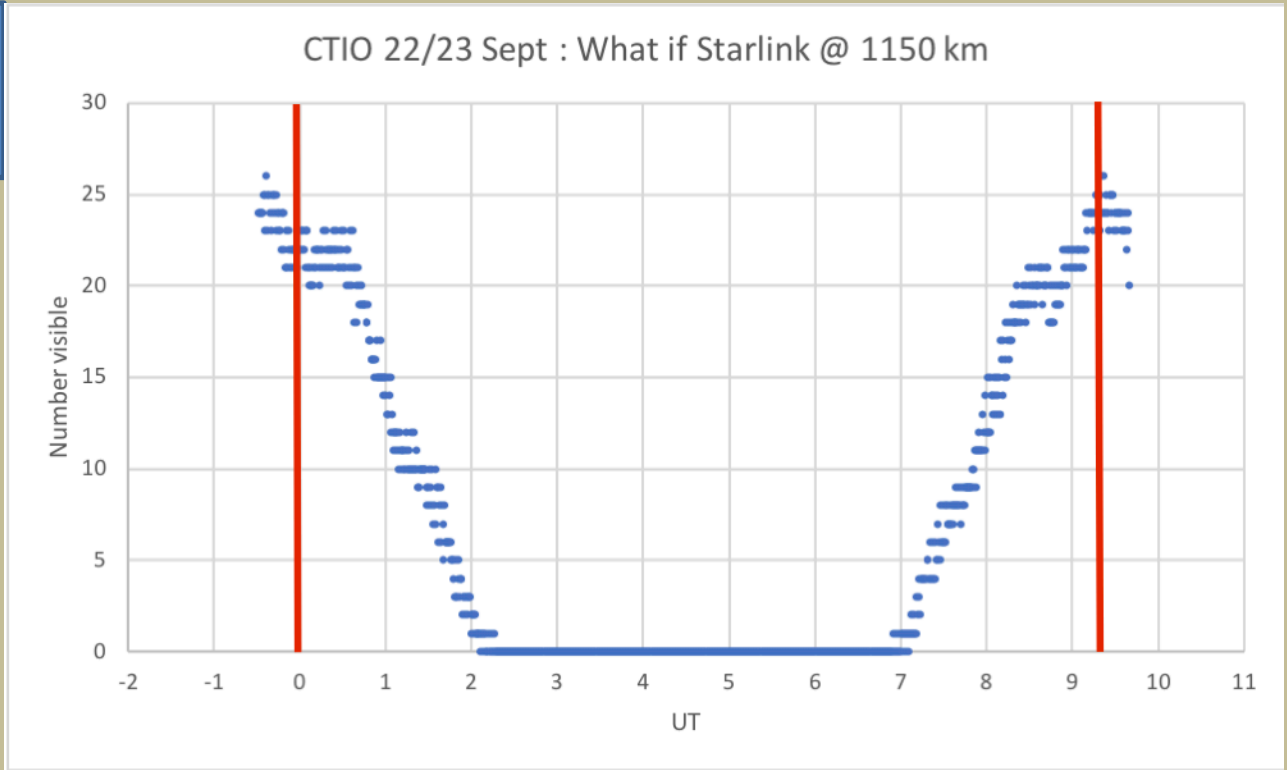
What if?

- 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 is worse.

N = 1584

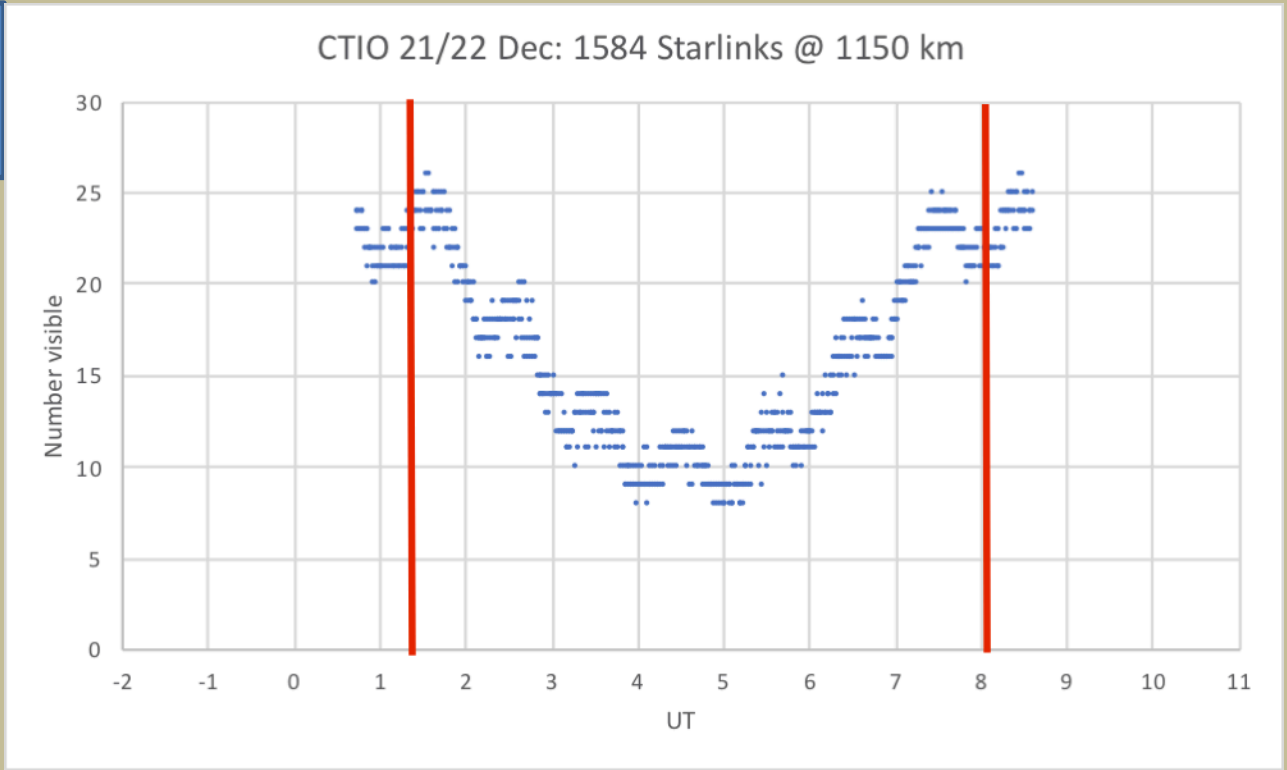
Multiply by ?



Astronomical twilight: 23:59 – 09:12

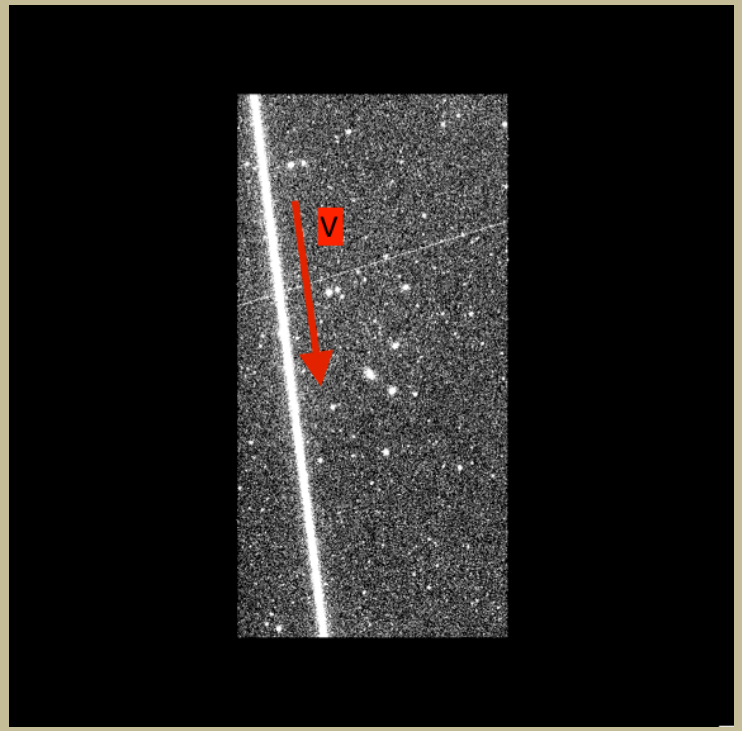
N = 1584

Multiply by ?



Astronomical twilight: 01:20 – 08:01

Streak Brightness

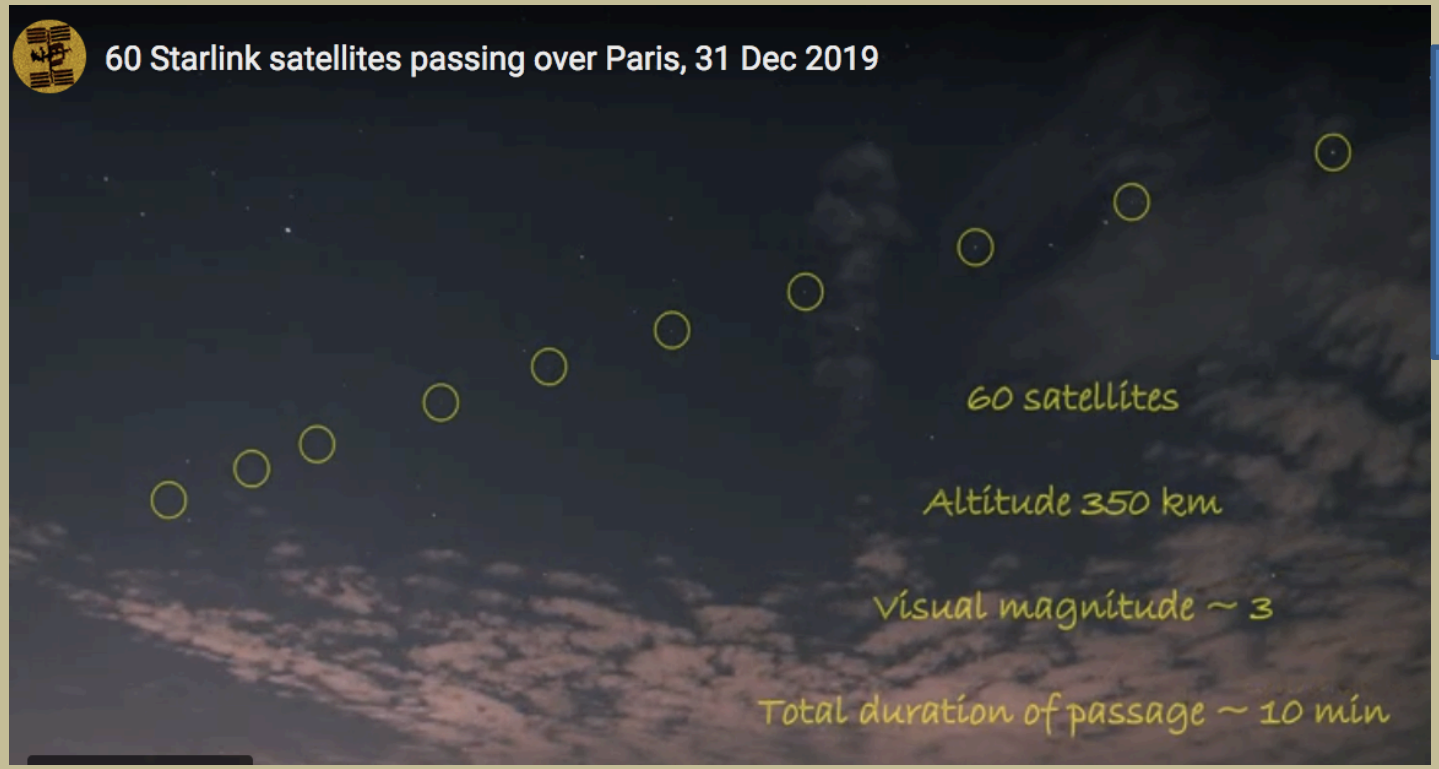


- Also depends on angular velocity v.
- Objects in higher orbits have smaller angular velocity.
- Thus greater time on each pixel.

- For geocentric observer:

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

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

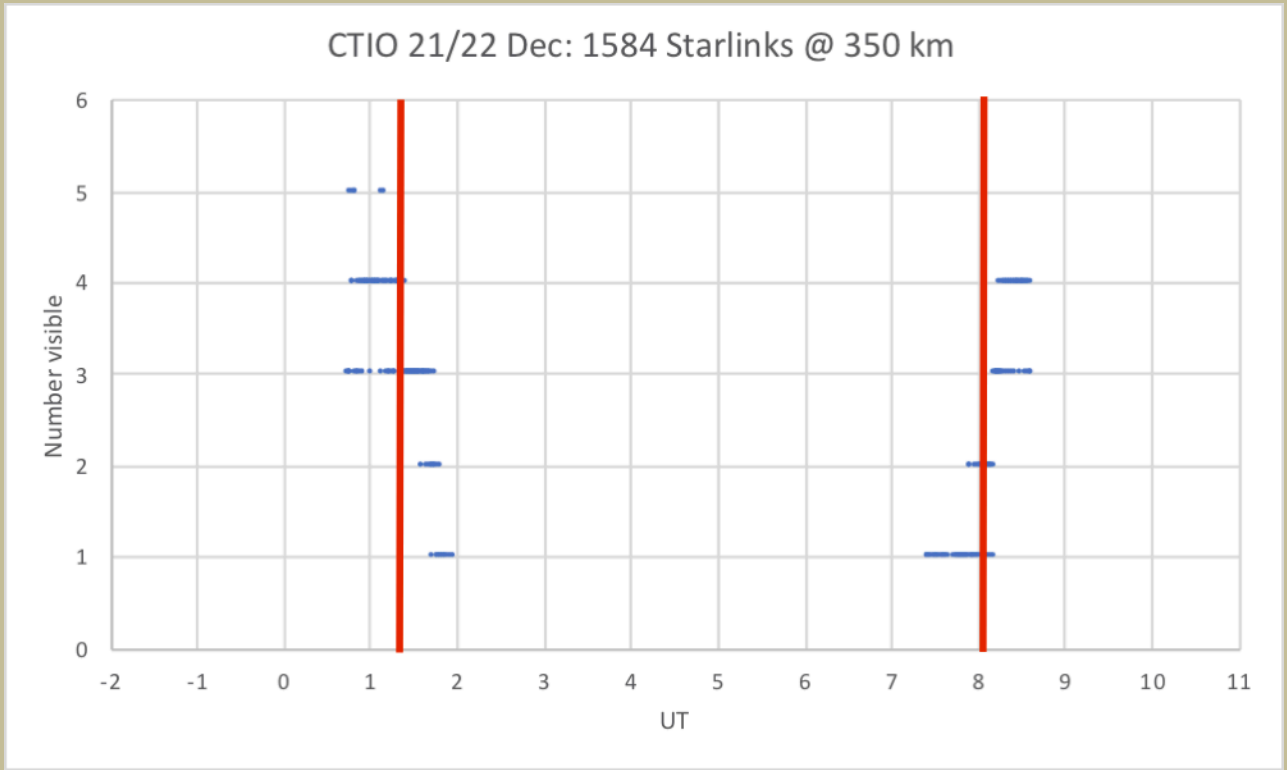


50 km east of Paris

Ultimately 30,000?

~~All night long~~

Courtesy Thierry Legault

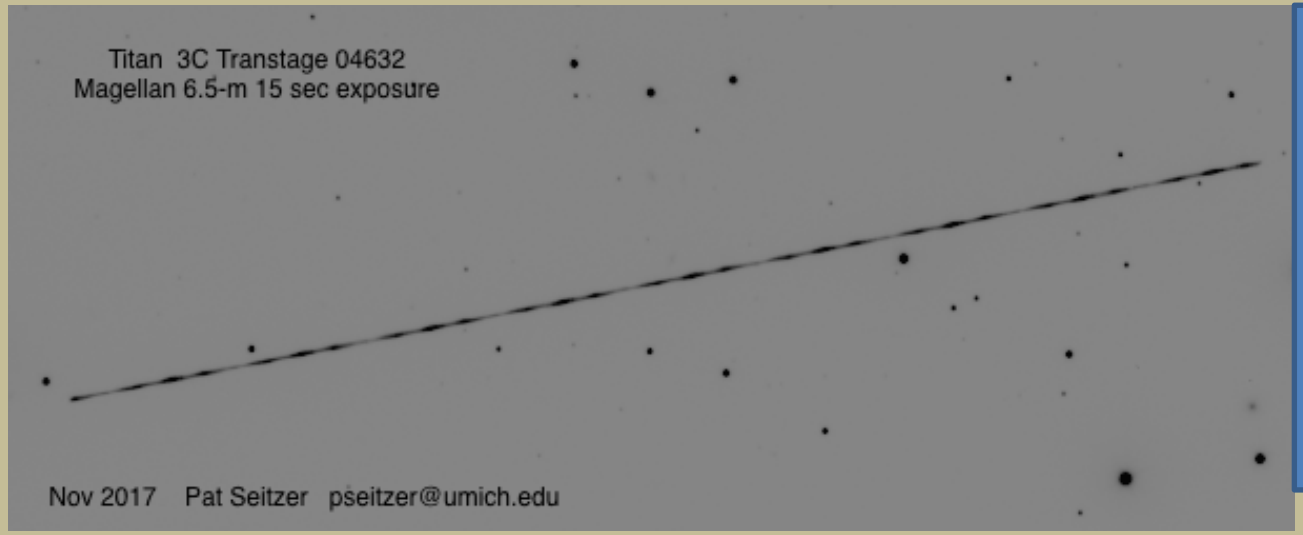


Astronomical twilight: 01:20 – 08:01

The Future in LEO

- 1584 Starlinks just the start!
  - SpaceX: 12,000? 42,000? At 550 km, 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, V ~ 8th
- All SpaceX and Amazon satellites visible to unaided eye? Depends on design and surface treatment.
- OneWeb not visible to eye, still saturate detectors.
- No current national or international rules or guidelines for brightness of satellites.

Satellite Glints --> Transients



Satellites moving wrt star field

Transient galaxies!

Only very, very short glints could not be distinguished from stars.

Problem with GEOs?

Other topics – Thermal IR, occultations, scheduling to avoid satellites, where observe to avoid…

Legacy Survey of Space and Time
Opening a Window of Discovery on the Dynamic Universe

LSST and SpaceX

- The 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 LSST detectors.
- Joint LSST-SpaceX engineering teams working to change this:
  - Make satellites fainter to avoid LSST detector saturation.
  - Changes to LSST readout to reduce artifacts from trails.
  - Changes to scheduling to avoid most bright satellites.
- We find that SpaceX is committed to solving this problem.

Tony Tyson, 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’ probably not a good representation of final operational state.
- Largest uncertainty – who launches what, when, and where?
- You need to be concerned!

Final thoughts on Starlinks

- At operational orbit of 550 km and attitude, 1st generation of Starlinks V ~ 5th magnitude.
- Any sort of effort to reduce brightness should make next generation Starlinks fainter than eye limit.
- 'Strings of pearls' at parking/checkout/deployment orbits of 350 km will be increasingly common:
  - Two such strings now visible.
  - More to come.
  - Just visible till astronomical twilight.

TS Kelso www.celestrak.com