Learning to Live with Large Constellations of Satellites

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Starlink Satellites
Launched March 18, 2020
Observed April 11, 2020
Northampton, MA, USA
Apparent brightness: ~2nd mag
Exposure time: 1 sec per frame
Interval: 3 sec per frame

Olivier Hainaut, ESO
Photobombs by Starlink

Victoria Girgis/Lowell Observatory

Global Meteor Network

CTIO Blanco 4m + DECam

Zwicky Transient Factory

All seen shortly after launch (bright, tightly bunched)
Test (worst?) Case for impact on Astronomy: Vera Rubin Observatory

Images from Tony Tyson, VRO
Simulated Starlink trail in VRO

Ghost trails from cross-talk in CCDs

Frame unusable if satellites are 5th magnitude (naked eye visible, Starlink v0.9)

Satellites need to be ~10x fainter for VRO to deal with ghosts (still saturated)

Images from Tony Tyson, VRO
Can VRO dodge satellites?

Major collision of technologies:
deep, fast, wide-field sky surveys
vs.
LEO satellite mega-constellations

With 48,000 satellites, most VRO observations not schedulable

Peter Yoachim
AAS Activity on Satellite Mega-Constellations

- Committee on Light Pollution, Radio Interference, and Space Debris (LPRISD) + smaller working group
- AAS Statement on Satellite Constellations (6/10/19): “potential to adversely affect...the study of the cosmos”; “work...to understand fully and minimize the impact on ground- and space-based astronomy”
- Collaboration with International Astronomical Union and International Dark-Sky Association
- Briefings to US Congress
- National Academies of Science Astro 2020 hearing 4/20
- Webinar with Satellite Industry Association (SIA) 5/20
- NSF OIR Lab workshop (June 29 – July 2, 2020; w/SpaceX, Amazon...)
- Survey of impacts on major observatories
AAS Survey on Satellite Constellations

- **7 questions**, sent Dec. 2019 to major observatories world-wide
- **23 responses** from all continents
- **VRO, Gemini, VLT, ZTF, CFHT, Pan-STARRS, APO, HATNet, ATLAS, Steward Obs. UKIRT, Las Campanas, Jodrell Bank, Mt. Stromlo, SOAR...**
- **Large range of impacts, from 0-100% of science lost.**
- **Majority:** significant concern; **grave challenges** to science; **significant costs** due to 1584 Starlink v0.9 satellites (e.g. VRO: 15% loss = $210M). Much worse if 10x more sats.
AAS Survey on Satellite Constellations

- **Science losses predicted in many fields** from Earth-killers to cosmology:
  - Fast transients (GRBs, FRBs...)
  - High-z supernovae
  - Wide-field / all-sky surveys
  - Large statistical surveys e.g. weak lensing, Dark Energy
  - OIR followup of gravitational wave triggers from LIGO, VIRGO
  - Near-Earth asteroids and comets
  - Distant solar system objects

- **If 20,000 more** bright satellites in LEO (vs. 1,584):
  - 17/23: virtually all science impacted
  - 12/23: critical failure of facility

- [https://aas.org/sites/default/files/2020-06/survey_summary.pptx](https://aas.org/sites/default/files/2020-06/survey_summary.pptx)
AAS Activity on Satellite Mega-Constellations

Conversations with satellite operators

• Mostly SpaceX:
  • Monthly telecons since June 2019 with VP, engineers
  • AAS 235 Honolulu special session by LPRISD committee (Jan 2020)
  • Address by SpaceX (Elon Musk, VP, engineers) to National Academies
    Astro 2020 decadal survey panel (May 2020)
  • NSF/OIRLab Workshop on Satellite Constellations (June 2020)
  • **Focus**: how SpaceX can *dim* sats, how astronomers can *dodge* them
  • Stopping launches not on the table

• OneWeb:
  • One telecon (Jan 2020)
  • Launched 24 more satellites, total 74 at 1200 km (Mar 2020)
  • Bankrupt (April 2020)
  • Filed with FCC for 42,000 sats at 1100km (May 2020)

• No significant conversations with other operators
SpaceX promises not to break astronomy

"I'm confident that we will not cause any impact whatsoever in astronomical discoveries, zero. That's my prediction. We'll take corrective action if it's above zero.” – Elon Musk, CEO, SpaceX, quoted 3/10/20 BusinessInsider.com

“No impediment to science.” Starlink satellites will be “invisible to the naked eye within one week of launch.” – Elon Musk, addressing National Academy of Sciences Astro2020 decadal survey hearing 4/27/20
SpaceX changes to reduce Starlink visibility

1. DarkSat: black coating

**DARKSAT**
ANTENNAE MITIGATION ON STATION

Ground-based observations of our initial test experiment proved we can significantly reduce brightness. Subsequently, we developed a higher-performance option.

2. VisorSat: Sun-shield

**VISORSAT**
ANTENNAE MITIGATION ON STATION

On station, sun shade blocks sunlight from antennas, preventing reflection.

3. Attitude control during orbit raise

**ORIENTATIONAL ROLL**
ARRAY MITIGATION DURING ORBIT RAISE

Rolling satellite makes sunlight bounce off smaller ‘knife edge’ of array, reducing reflection.

Significant resources devoted to these technical solutions.
## Multiple LEO constellations planned

<table>
<thead>
<tr>
<th>Constellation</th>
<th>Number of sat.</th>
<th>Altitude [km]</th>
<th>Alpha_0 [deg]</th>
<th>Satellites above horizon</th>
<th>Orbital period [h]</th>
<th>Magnitude at Zenith [mag]</th>
<th>Magnitude at z=60deg [mag]</th>
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</thead>
<tbody>
<tr>
<td>SpX Starlink 340</td>
<td>7,518</td>
<td>340</td>
<td>18.3</td>
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<td>1.51</td>
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<td>550</td>
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<td>1,150</td>
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<td>5.8</td>
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<td>1000-1325</td>
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<tr>
<td>Amazon Kuiper 590</td>
<td>784</td>
<td>590</td>
<td>23.8</td>
<td>4.2% 33.2</td>
<td>1.60</td>
<td>4.4</td>
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<td>610</td>
<td>24.1</td>
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<td>1.78</td>
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<td>600</td>
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<td>China Xinwei</td>
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<tr>
<td>India Astrom Tech</td>
<td>600</td>
<td>1,400</td>
<td>34.9</td>
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<td>Bein</td>
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<tr>
<td>Palny</td>
<td>135</td>
<td>600</td>
<td>23.9</td>
<td>4.3% 5.8</td>
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<td>5.5% 3.6</td>
<td>1.66</td>
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<td>6.6</td>
</tr>
</tbody>
</table>

Will all be “good citizens”?  

Olivier Hainaut, ESO  
Oct 2019
May, 2020: Nine companies file with FCC for expanded LEO constellations

- OneWeb
- SES
- Viasat
- EOS Defense Systems
- Kepler Communications
- Telesat
- SpaceX
- Mangata Networks
- New Spectrum Satellite

FCC: $20B for rural broad-band internet
Where do we come from?
Where are we going?
How does the Universe work?
Are we alone?
2017 GlobalStar
2018 ExactView, Iridium
2019 HawkEye 360, Helios, PlanetIQ, SpaceX, Spire Global
2020 ICEYE, Karousel, OneWeb, Satellogic, SkySat, Space Norway, SpaceX, Spire Global
2021 GeoOptics, OneWeb, SpaceX, Spire Global, Umbra, ViaSat
2022 AIS tech, Amazon, Astrocast, BlackSky, Dauria, Efir, Hongyan, Kepler, LaserFleet, NorthStar, OneWeb, SpaceX, Spire Global, UrTheCast
2023 Amazon, Astro Digital, Boeing, Efir, ExactView, Hera Systems, Hiber, O3b, OneWeb, OroraTech, Planet Labs, SpaceX, Spire Global, Swarm, Zhuhai

Now >100,000
57,000 satellites planned through 2029
Takeaways

• Astronomy faces grave threats from large constellations of LEO satellites
• Half of observatories predict critical failure if 20,000 LEO satellites
• The number of potential LEO satellite operators continues to grow (>20)
• The number of potential LEO satellites continues to grow (~100,000)
• SpaceX has set a high bar -- “Zero impact” – and is working hard to clear it
• No promises from other operators
• AAS is engaged with industry, government, amateur astronomers, policy-makers to understand and minimize the impacts
Thank you!

Starlink, >1 hr past twilight

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