Learning to Live with Large Constellations of Satellites

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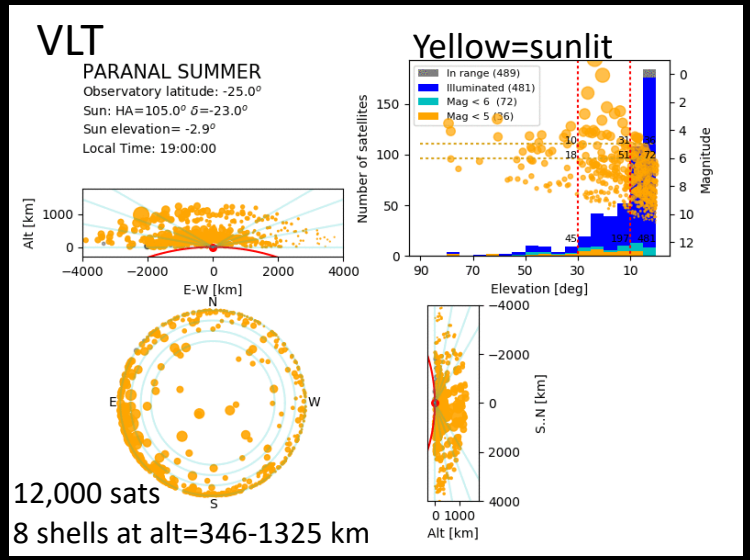
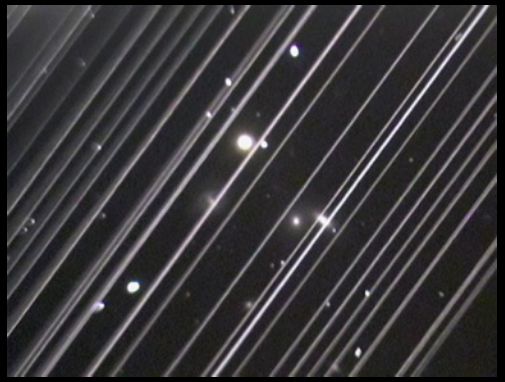


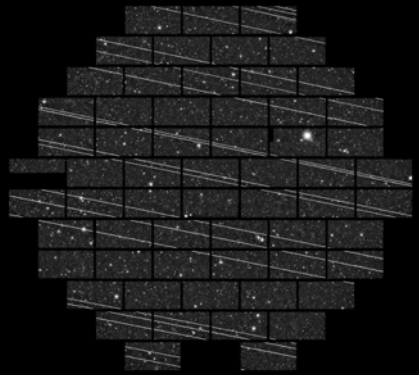
Olivier Hainaut, ESO

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

Photobombs by Starlink

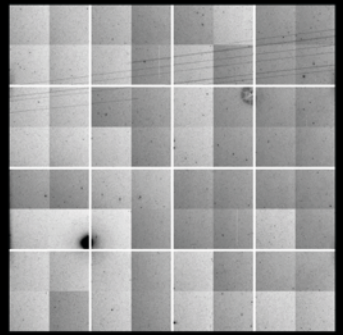


Victoria Girgis/Lowell Observatory



CTIO Blanco 4m + DECam

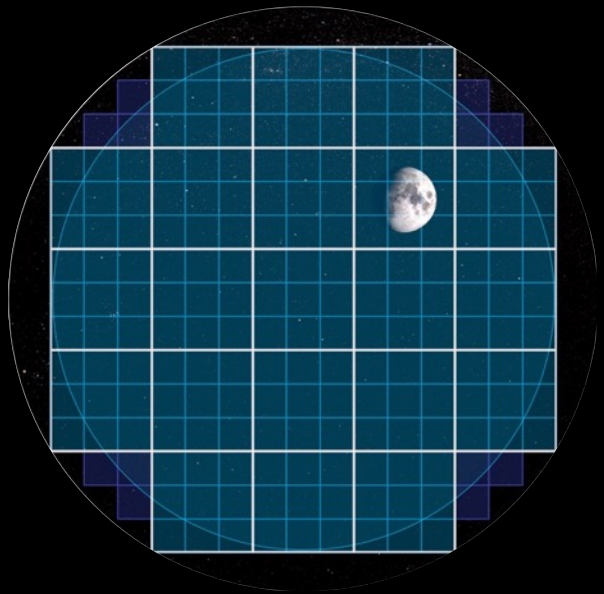
Global Meteor Network



Zwicky Transient Factory

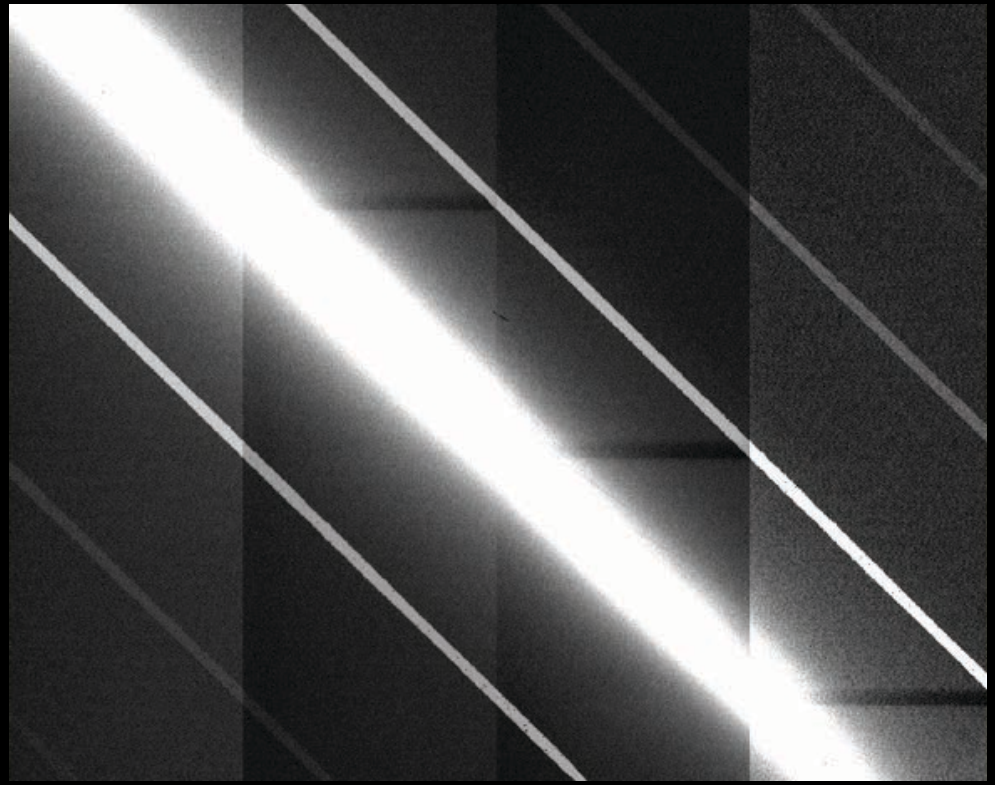
All seen shortly after launch (bright, tightly bunched)

Test (worst?) Case for impact on Astronomy: Vera Rubin Observatory



Images from Tony Tyson, VRO

Simulated Starlink trail in VRO



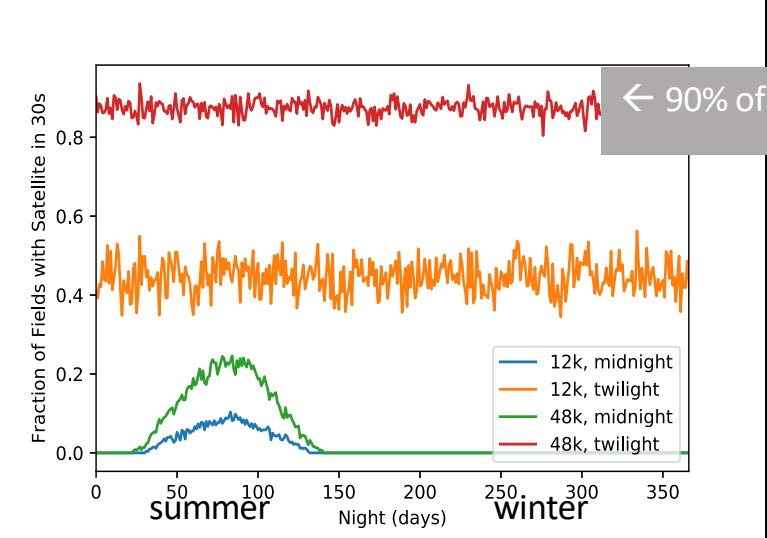
Ghost trails from cross-talk in CCDs

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

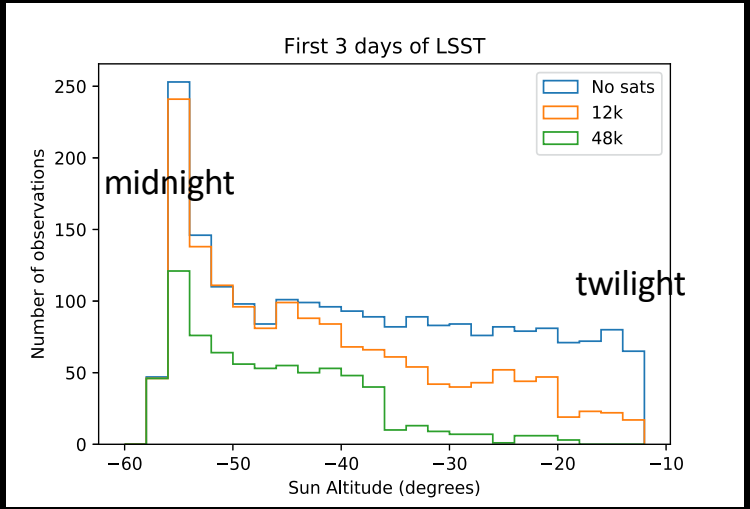
Satellites need to be ~10x fainter for VRO to deal with ghosts (still saturated)

Images from Tony Tyson, VRO

Can VRO dodge satellites?



← 90% of fields crossed by sats in twilight



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

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

Image: Mark Handley, UCL

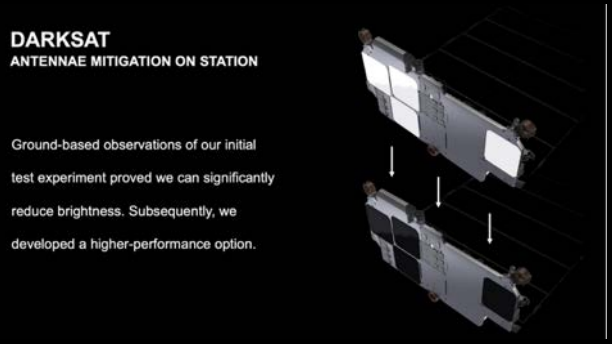
SpaceX promises not to break astronomy

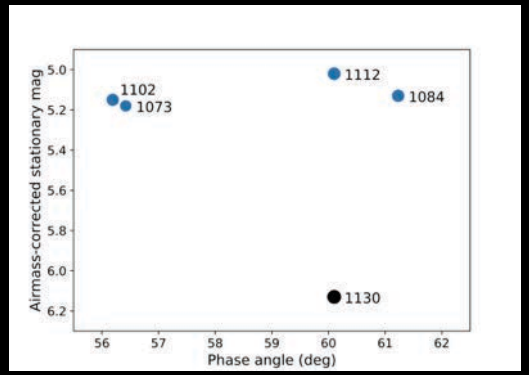
"I'm confident that we will not cause any impact whatsoever in astronomical discoveries, zero. That's my prediction. We'll take corrective action if it's above zero." – Elon Musk, CEO, SpaceX, quoted 3/10/20 BusinessInsider.com

"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

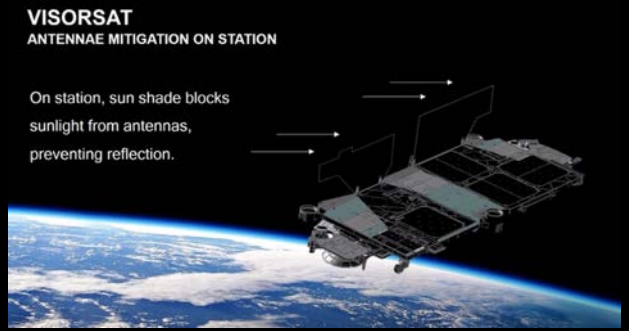
1. DarkSat: black coating



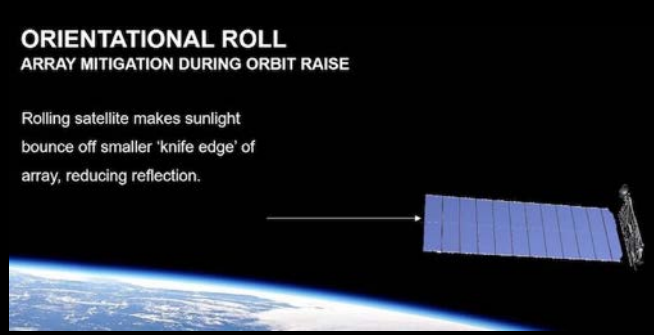


~3x fainter

2. VisorSat: Sun-shield



3. Attitude control during orbit raise



Significant resources devoted to these technical solutions.

Multiple LEO constellations planned

Constellation	Number of sat.	Altitude [km]	alpha_0 (1) [deg]	Satellites above horizon (2) Fraction	Satellites above horizon (2) Number	Orbital period (3) [h]	Magnitude at Zenith [mag] (4)	Magnitude at z=60deg [mag]
SpX Starlink 340	7,518	340	18.3	2.5%	190.3	1.51	3.2	4.8
SpX Starlink 550	1,600	550	23.0	4.0%	63.5	1.58	4.2	5.9
SpX Starlink 1150	2,800	1,150	32.1	7.6%	214.0	1.79	5.8	7.5
OneWeb	720	1,200	40.3	7.1%	51.3	1.81	5.9	7.5
Amazon Kuiper 590	784	590	23.8	4.2%	33.2	1.60	4.4	6.0
Amazon Kuiper 610	1,296	610	24.1	4.4%	56.6	1.60	4.5	6.1
Amazon Kuiper 630	1,156	630	24.5	4.5%	52.0	1.61	4.5	6.1
Sat Revolution	1,024	350	18.6	2.6%	26.6	1.52	3.2	4.9
China CASC	320	1,100	31.5	7.4%	23.5	1.78	5.7	7.4
China Lucky Star	156	1,000	30.2	6.8%	10.6	1.74	5.5	7.2
China Commsat	800	600	23.9	4.3%	34.4	1.60	4.4	6.0
China Xinwei	32	600	23.9	4.3%	1.4	1.60	4.4	6.0
India AstromeTech	600	1,400	34.9	9.0%	54.0	1.88	6.3	7.9
Boing	2,956	1,030	30.6	7.0%	205.6	1.75	5.6	7.2
LeoSat	108	1,423	35.2	9.1%	9.9	1.89	6.3	7.9
Samsung	4,700	2,000	40.4	11.9%	561.2	2.11	7.0	8.7
Yaliny	135	600	23.9	4.3%	5.8	1.60	4.4	6.0
Telesat LEO	117	1,671	40.3	7.1%	7.9	1.74	5.5	7.2
Iridium	66	780	27.0	5.5%	3.6	1.66	5.0	6.6

Bankrupt; 648 → 48,000 satellites, alt=1000-1325 km = bad

Bankrupt

Bankrupt

117 → 1671 satellites, alt=1000-1325 km = bad

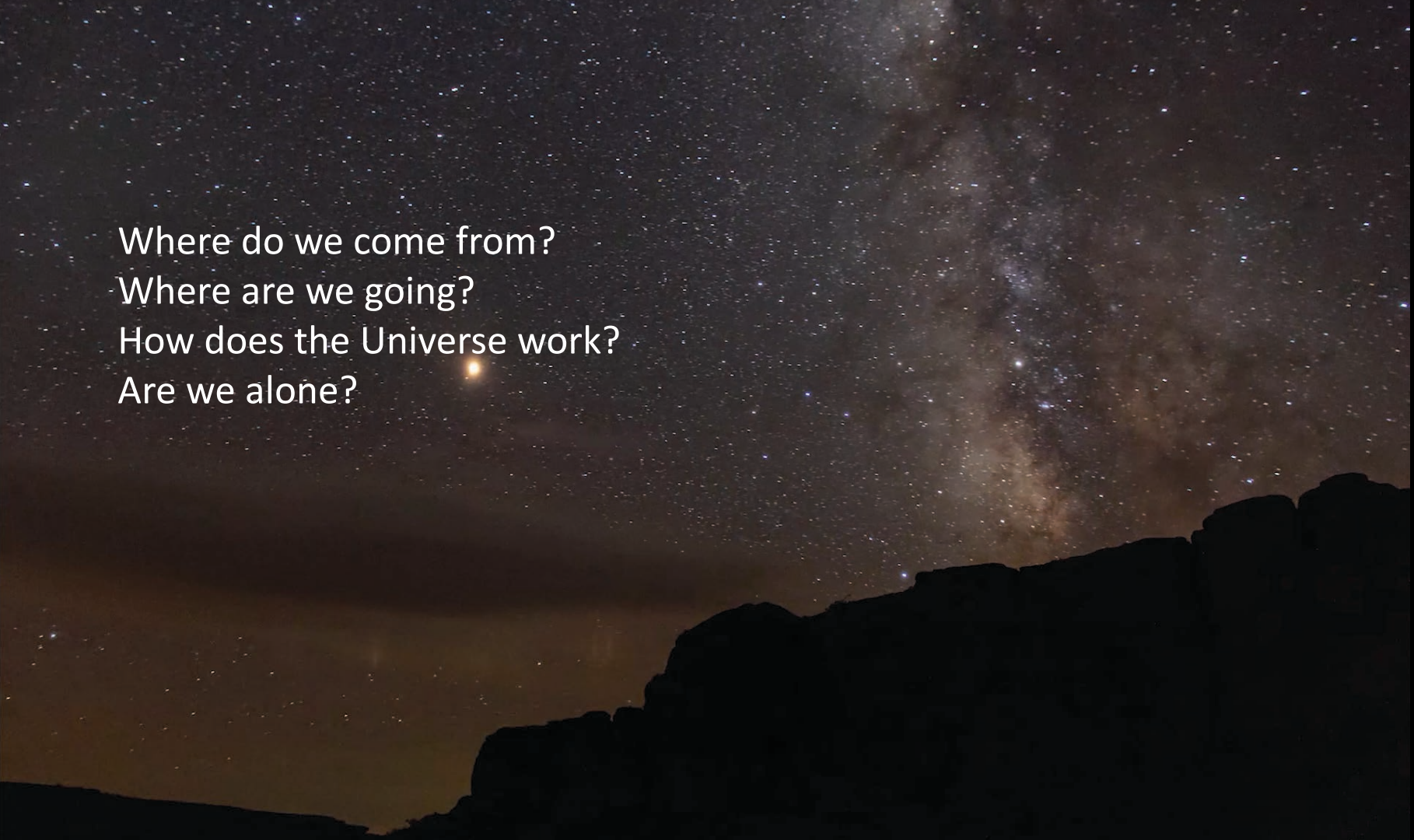
Will all be “good citizens”?

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 AISTech, 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, Orora.Tech, Planet Labs, SpaceX, Spire Global, Swarm, Zhuhai
Now >100,000
57,000 satellites planned through 2029
AGI

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!

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