Satellite Constellations and Ground-based Astronomy

2021-Oct-14 | LAM GRD

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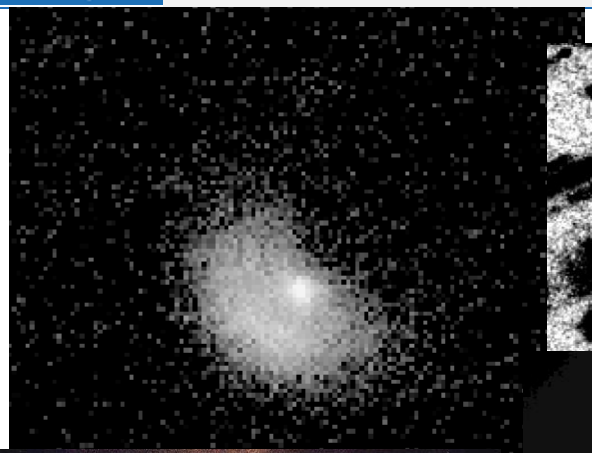
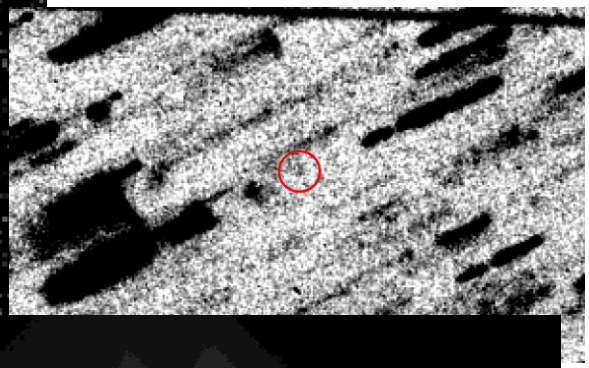
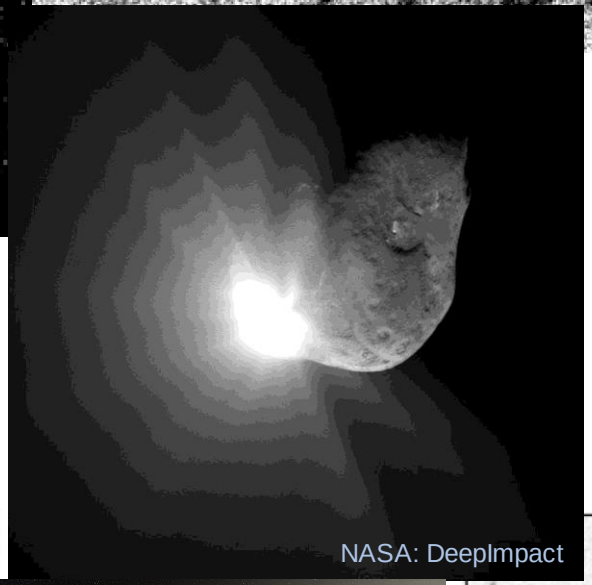
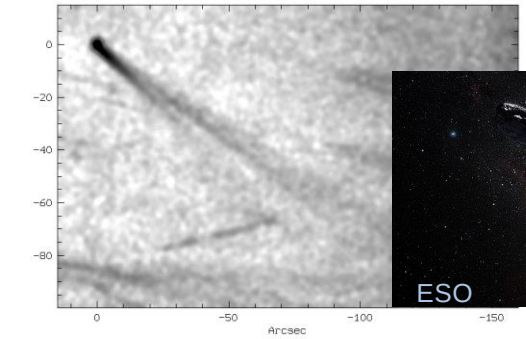
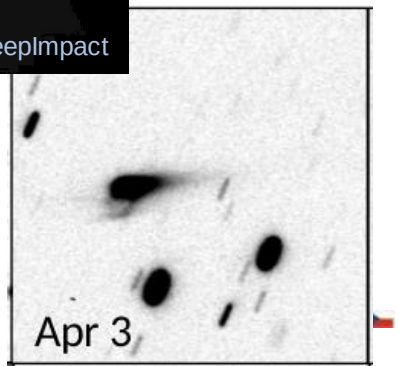
Olivier Hainaut, astronomer











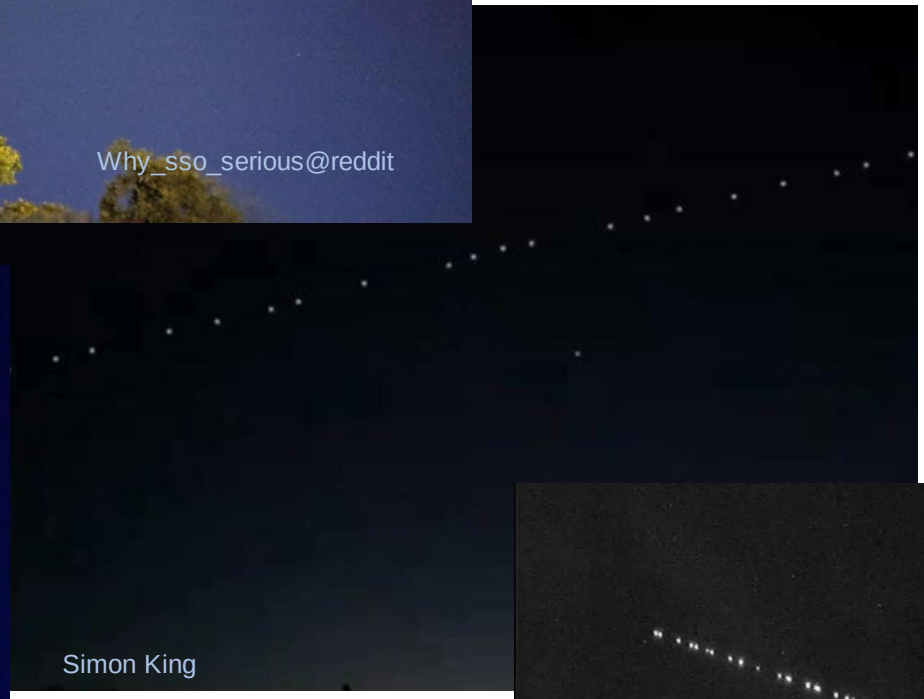
- (weird) minor bodies in the Solar System
- Asteroids, comets, interstellar objects
- Cometary activity in pathological cases

Olivier Hainaut, astronomer

- Physics Master Liege 88
- Cooperant/Student ESO La Silla 92
- PhD Astro Garching + Liege 94
- PostDoc U.Hawai`i 97
- Astro ESO La Silla 00
  - NTT, then La Silla ops
- Astro ESO Paranal 08
  - VLT operations
- Astro ESO Garching …
  - ELT + VLT operations

Satellite constellations?!?
Why do we care?

24 May 2019: first batch of 60 *Starlinks*



We were taken by surprise...

(our fault: everything had been announced and documented)

After SpaceX Starlink Launch, a Fear of Satellites That Outnumber All Visible Stars

Images of the Starlink constellation in orbit have rattled astronomers around the world.

THERLANDS MAY 24 MARCO LANGBROEK VIA REUTERS

The Death of Astronomy?

Probably not, but forthcoming commercial satellite constellations herald a new era for our night skies

By Caleb A. Scharf on May 27 2019 2

Express.co.uk

Alien hunt is being RUINED by Elon Musk and SpaceX's 12,000 SATELLITES, astronomers claim

Elon Musk's SpaceX launched the first 60 Starlink satellites on May 23, and ... will not only obstruct their view of the night's sky, but also effects radio astronomy.

Jun 6, 2019

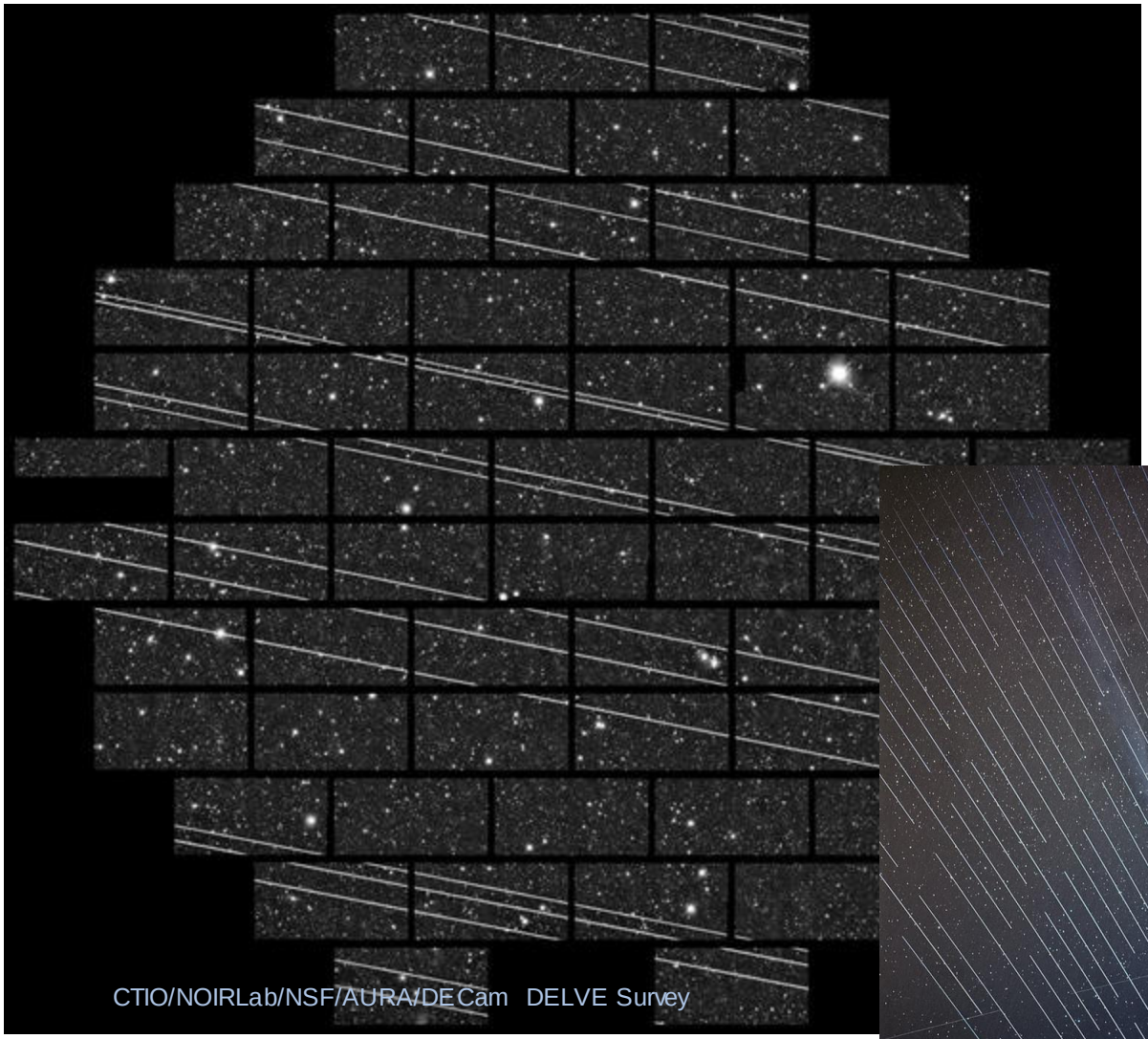
European Southern Observatory

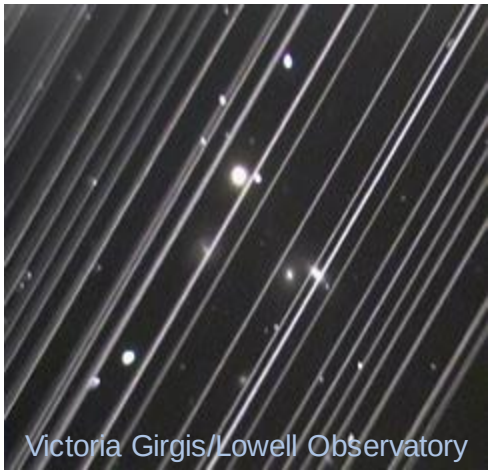
ann19029 — Announcement

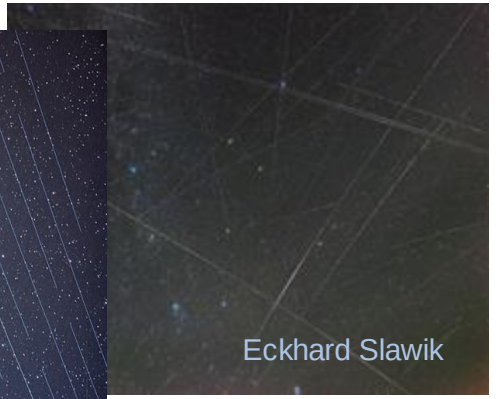
On the increasing number of satellite constellations

7 June 2019

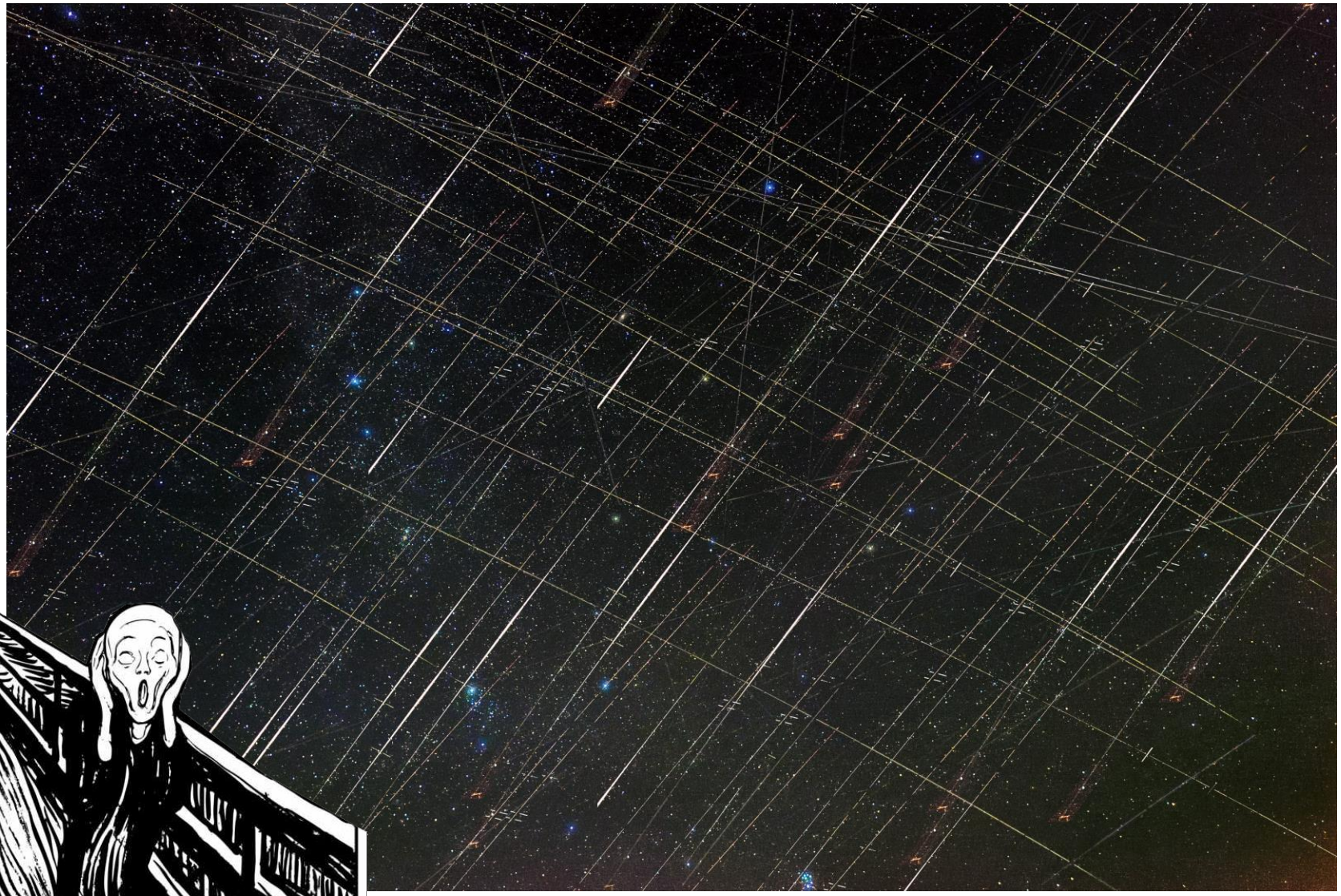
Effects on Astronomy and Astrophotography





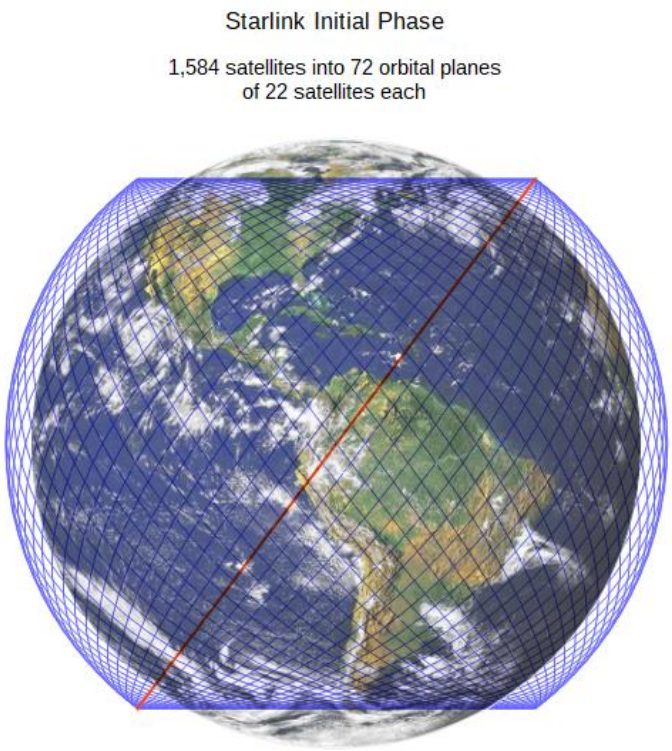


How many?



Satellite constellations?
How many sat?

Telecom Mega-Constellations



- Why so many satellites?
  - low latency ➔ low altitude
  - low altitude + global ➔ many satellites
- 1 shell: Walker configuration
  - N ~ 1000+ satellites
  - n ~ 60 planes (N/n sat each), spread in longitude
  - Inclination (typical 50-80deg)
- One constellation = several shells

How many in orbit?

Report to ESO Council COU-1928 2020-Nov

Constellation (Registering Nation)	Altitude (km)	Number of satellites
Starlink Generation 1 (US)		
	5,50	1,584
	1,110	1,600
1791	1,130	400
	1,275	375
	1,325	450
Starlink Generation 2 (US)		
	328	7,178
	334	7,178
	345	7,178
	373	1,998
	499	4,000
	604	144
	614	324
	360	2,000
OneWeb Phase 2 (US, UK)	1,200	1,764
100	1,200	2340 ~~23,040~~
	1,200	2340 ~~23,040~~
Amazon Kuiper (US)		
	590	784
	610	1,296
	630	1,156
Sat Revolution (Poland)	350	1,024
CASC Hongyan (China)	1,100	320
CASIC Xingyun Lucky Star (China)	1,000	156
CommSat (China)	600	800
Xinwei (China)	600	32
AstromeTech (India)	1,400	600
Boeing (US)	1,030	~~2,956~~
LeoSat (Luxembourg)	1,423	~~108~~
Samsung (Korea)	2,000	4,700
Yaliny (Russia)	600	135
Telesat LEO (Canada)	1,000	~~117~~
Total		96,437
+GuoWang GW-A59	480-1728	12992

…planned telecom mega-constellations as of 2021:

- ~30 (sub-) constellations
- ~100 000 satellites

As of today:

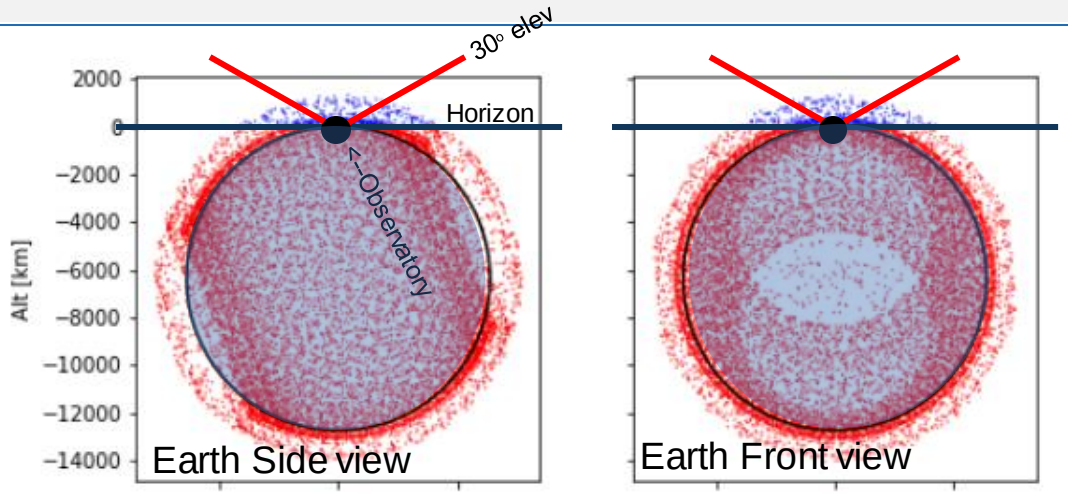
- ~2000 satellites in LEO constellations
- Not all have filed application paperwork
- Boing + Leosat withdrew their application
- OneWeb bankrupted and revived
- OneWeb downscaled to 6300 sat

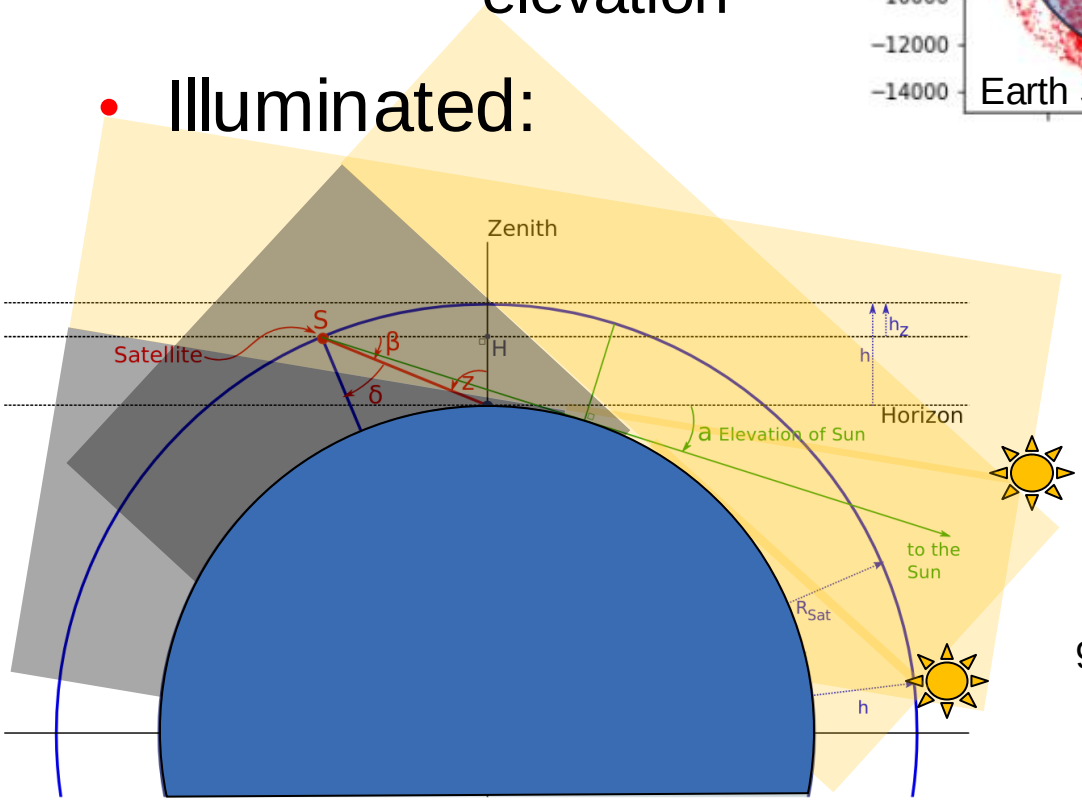
Caveat:

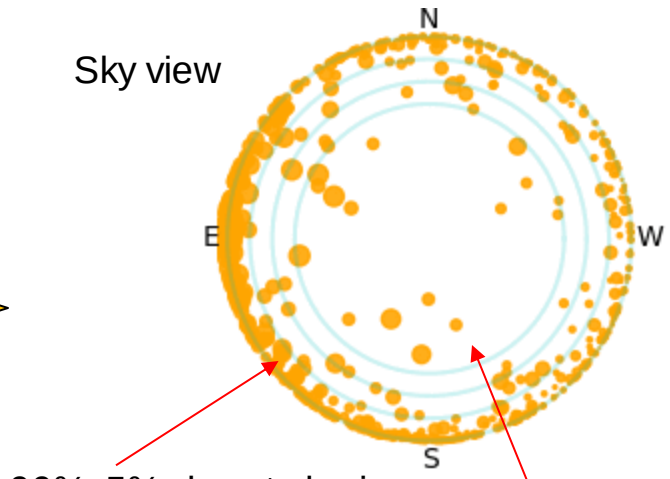
- Few filings end up in launches (~10%)
- MANY more non-telecom constellations have filed
- (but they are much smaller spacecrafts)
- (but but they still contribute to crowding)

Observable satellites

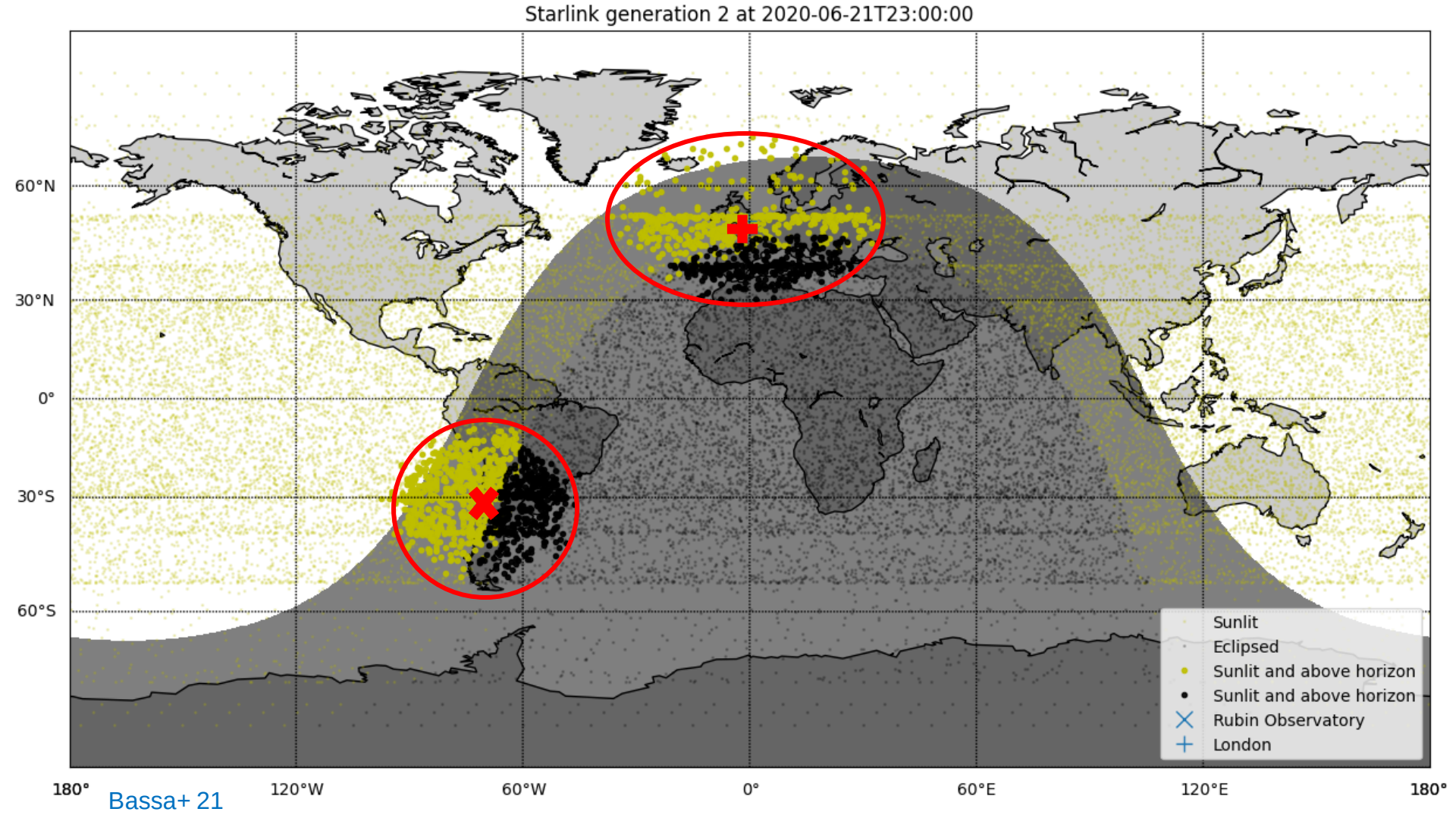
- In sight:
  - ~5% above horizon
  - ~0.5% above 30° elevation
- Illuminated:





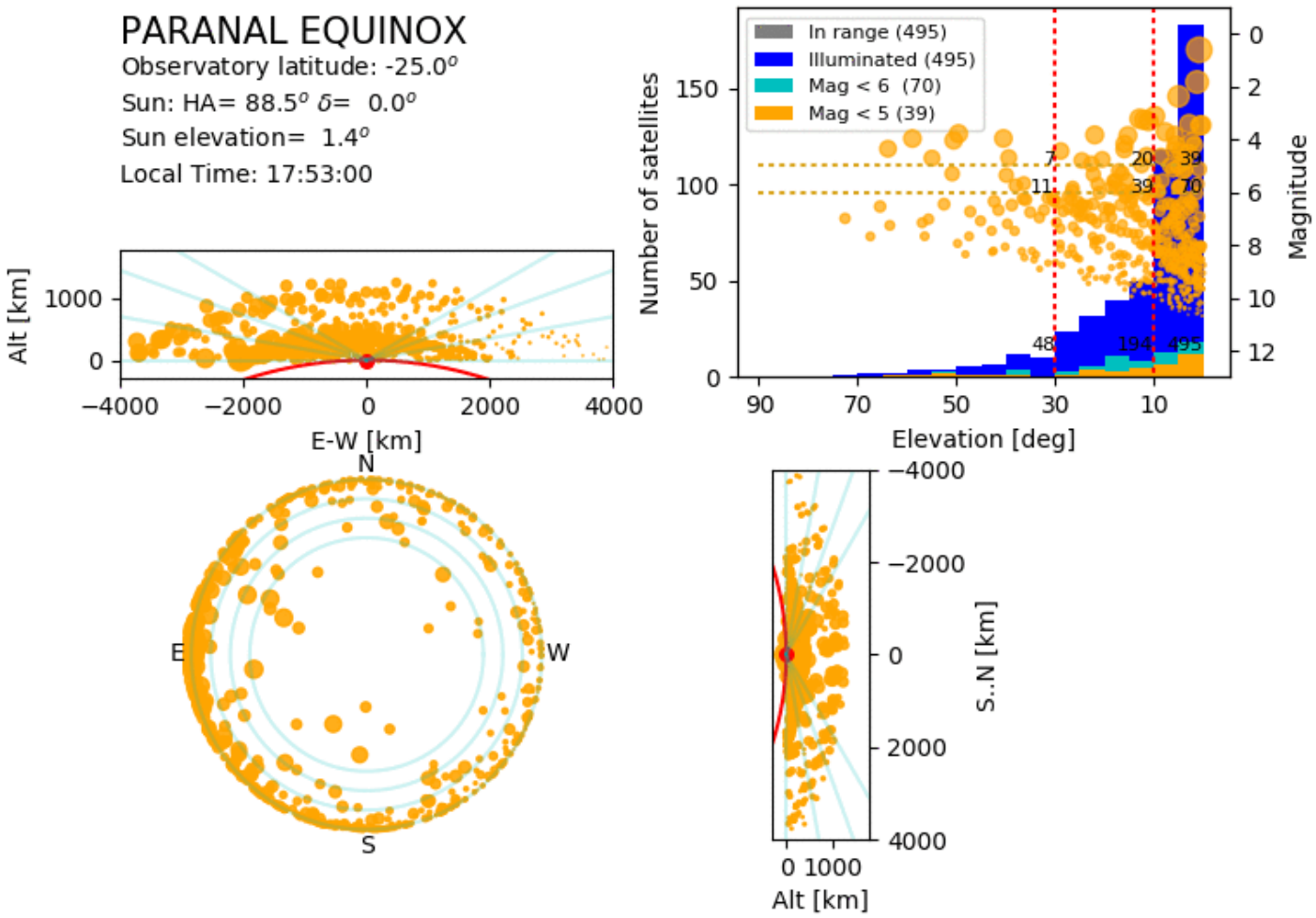


Observable satellites

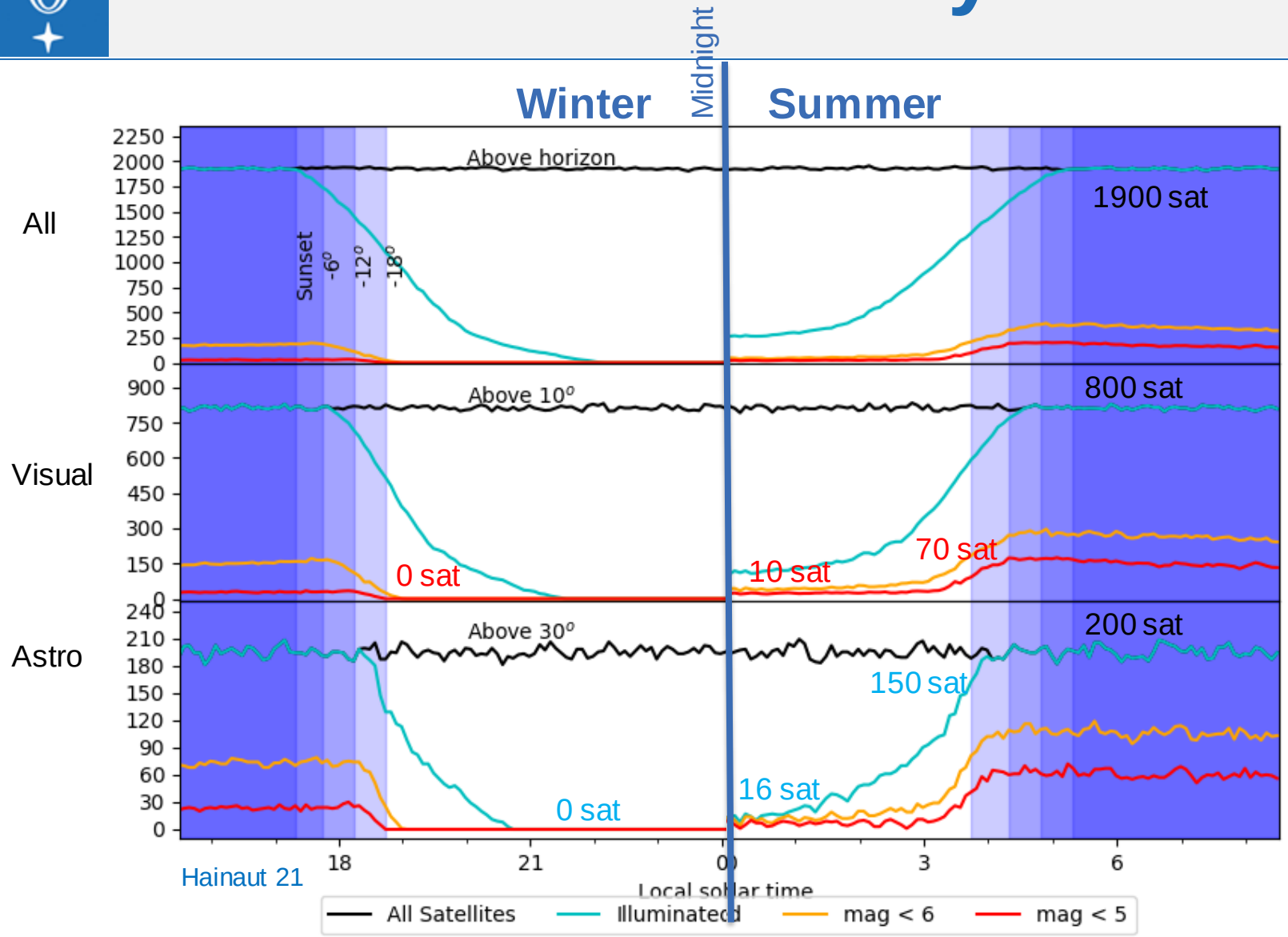


Bassa+ 21

Observable satellites

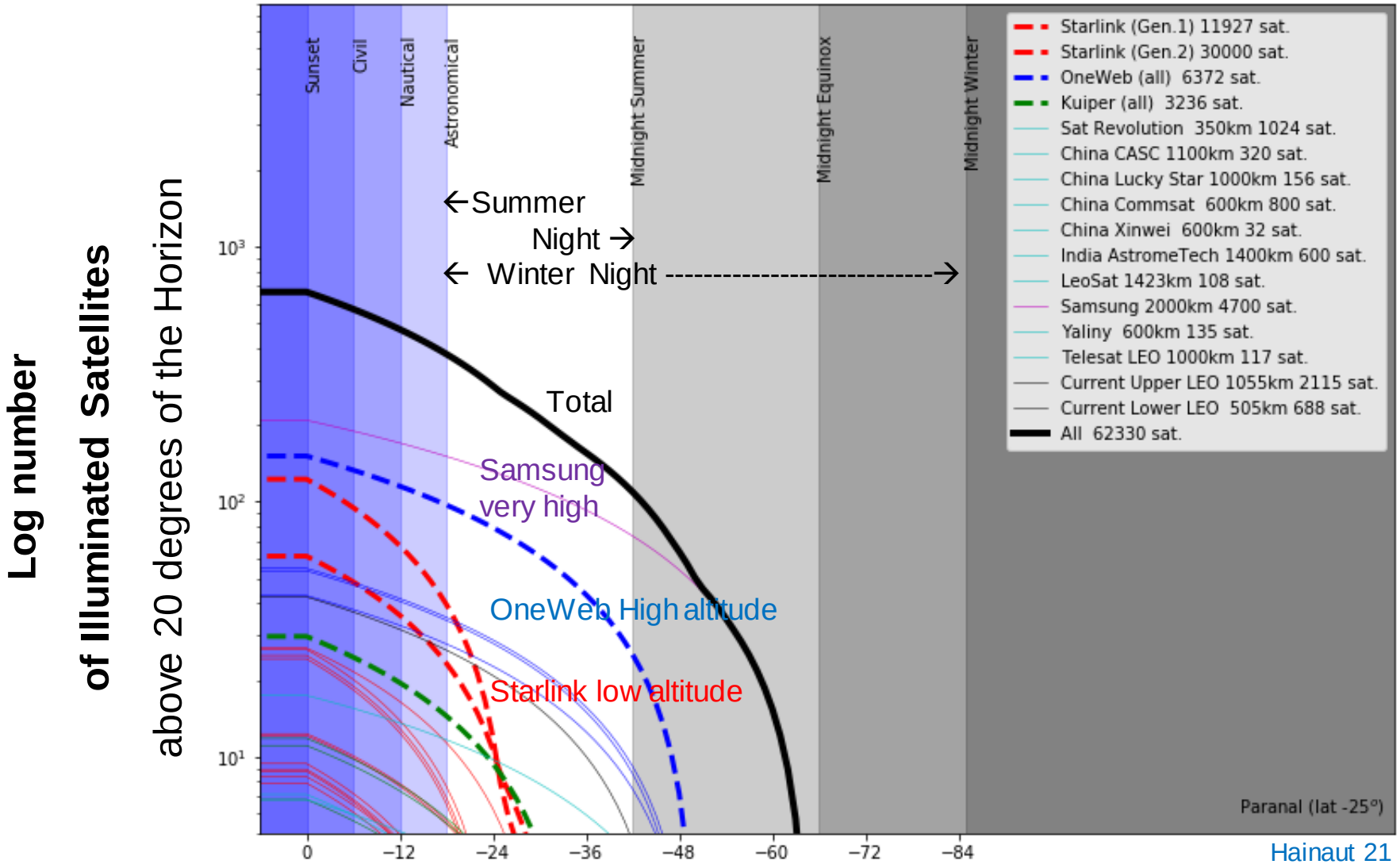


How many?



- 2027: 48k SL2+OW2r

How many?



Hainaut 21

- All foreseen constellations

How many?

- **In orbit**
  - Pre-constellation: 2800 LEO sat
  - Now: +1400 SL+OW = 4200 LEO sat
  - 2027: full SL+OW = 50 000 LEO sat
  - Foreseen: ~80 000 LEO sat
- Above horizon: 5% of constellation
  Above 30º elevation: 0.5%
- Visible (V<5):
  - 2027 twilight: few to few tens
  - 2027 midnight summer: ~10

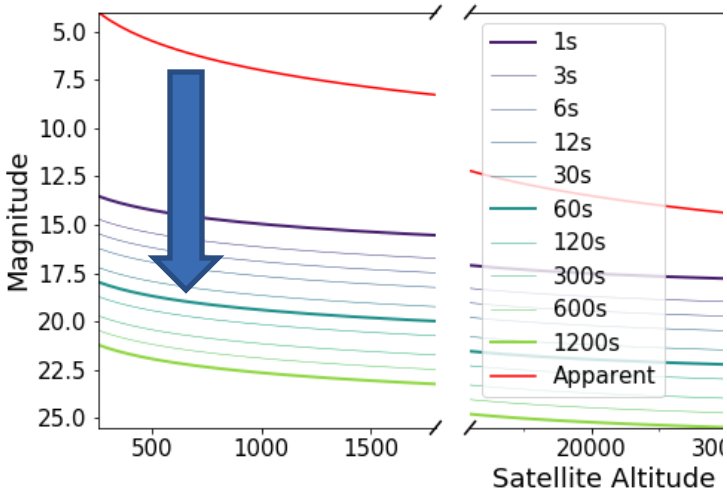
  + additional mitigation: ~few

Satellite constellations?
What is their effect?

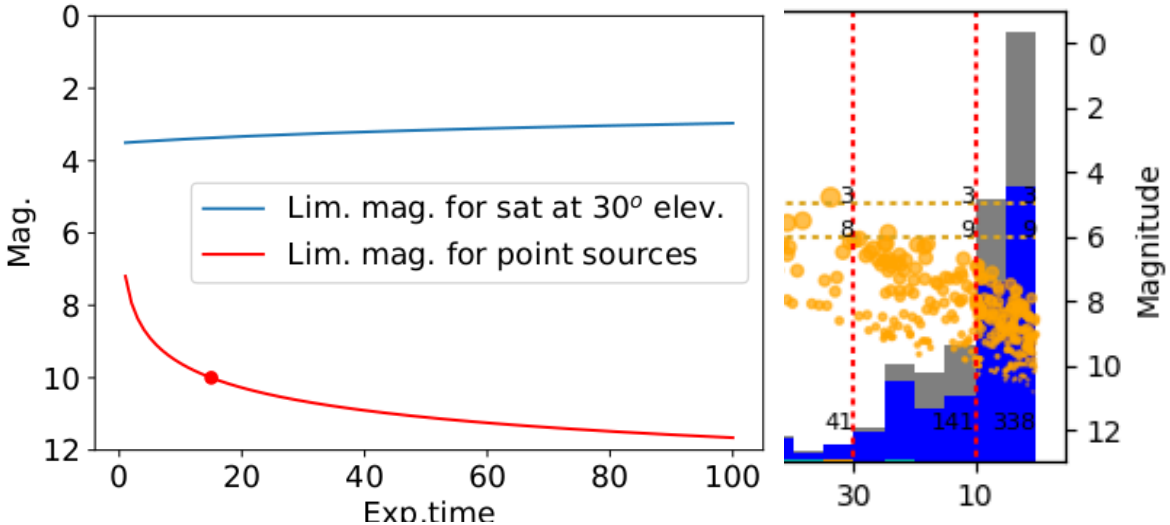
Effect on the observations

- Effect of magnitude
  - Photometric model (simplified sphere; ok +/- 1mag)
  - Large telescope: satellite resolved + defocused
  - Angular motion --> Trails --> reduced effective brightness

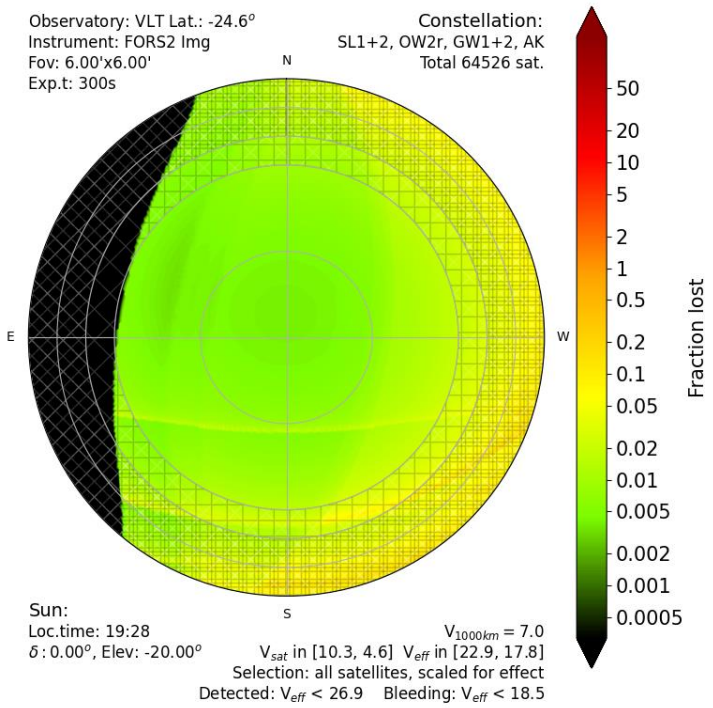
Effective Magnitudes
for telescopic observations

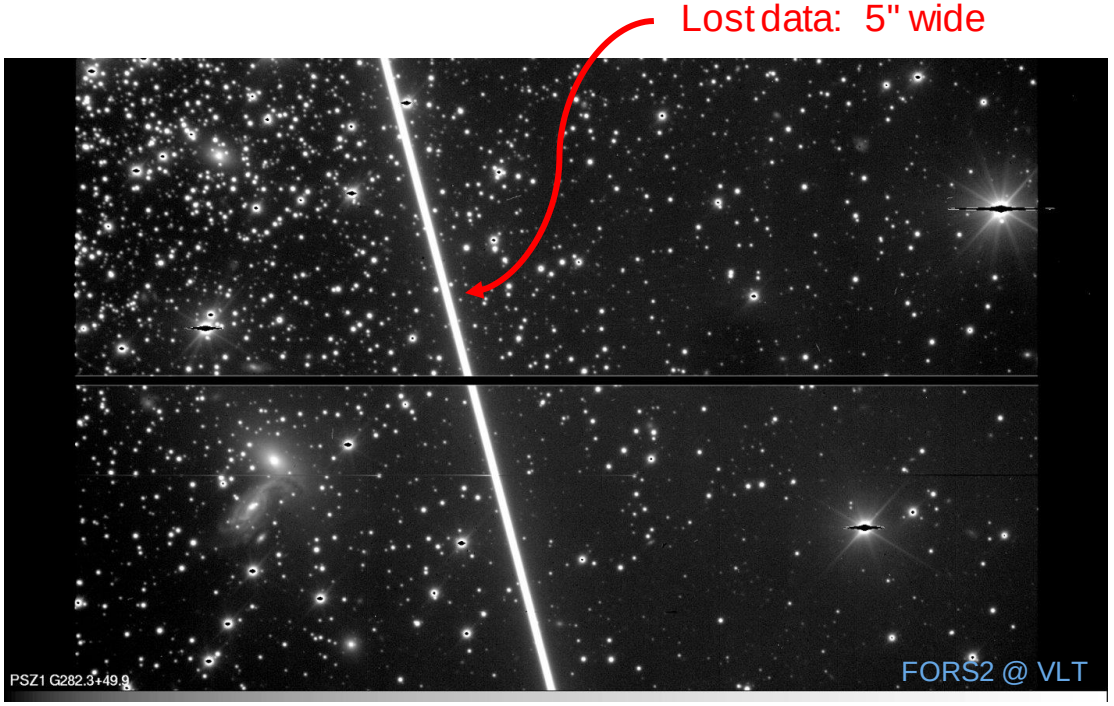


Limiting magnitudes
For stars and for satellites
(for camera astrophoto)

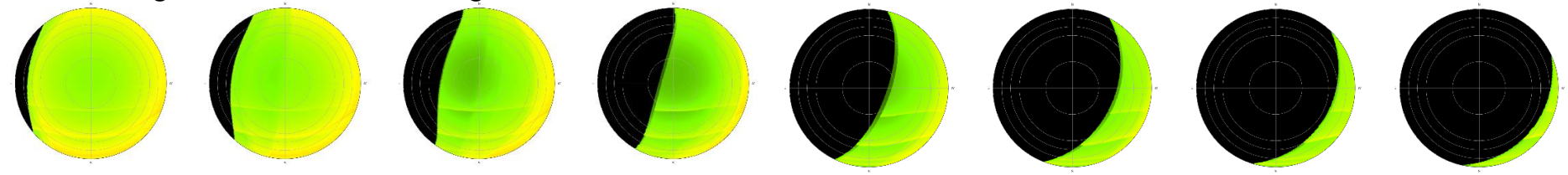


Effect on observations





<--- Twilight Dark night --->



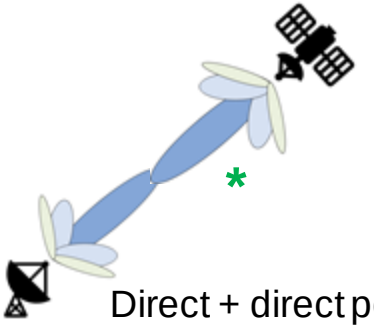
Effect on observations

				Sun Elevation [deg]:	Sunset 0	Civil 6	Nautical -12	Astron. Night -18	-24	-30	-36	-42	-48	-54	-60	-66 …	-84
				Local Solar Time [hh:mm]: Winter	17:14	17:43	18:11	**18:39**	19:07	19:34	20:01	20:28	20:55	21:22	21:48	22:15 …	**00:00**
				Equinox	18:00	18:26	18:53	**19:19**	19:46	20:13	20:41	21:10	21:40	22:13	22:51	**00:00**	
				Summer	18:45	19:15	19:46	**20:18**	20:53	21:31	22:18	**00:00**					
	Field of view length	width	ExpTime	**Trails per exposure**													
Imaging				Average over equinox night													
Classical imaging (FORS)																	
All sat.	6arcmin		5min	0.03	0.225	0.227	0.227	0.160	0.070	0.048	0.024	0.006	2.7E-05	0	0	0	0
Bright sat.				0.0021	0.076	0.078	0.078	0.022	0	0	0	0	0	0	0	0	0
Ultra-wide-field imaging (LSST/VRO)																	
All sat.	3deg		5min	0.9	6.878	6.954	6.954	4.919	2.185	1.481	0.746	0.188	8.0E-04	0	0	0	0
Bright sat.				0.063	2.308	2.354	2.354	0.657	0.003	0	0	0	0	0	0	0	0
Spectro				Average over equinox night													
Small IFU (ELT Harmoni)																	
All sat.	9.1"	6.2"	10min	0.0015	0.011	0.011	0.011	0.0080	0.0035	0.0024	0.0012	0.0003	1.3E-06	0	0		
Bright sat.				0.000104	0.0038	0.0039	0.0039	0.0011	0	0	0	0	0	0	0		
Long-Slit spectro. (FORS)																	
All sat.	5'	2"	20min	0.10	0.748	0.757	0.757	0.533	0.235	0.159	0.080	0.020	8.9E-05	0	0		0
Bright sat.				0.007	0.253	0.258	0.258	0.072	0	0	0	0	0	0	0		0
Multi-fibre spectro. (4MOST)																	
% of fibres (2300)																	
All sat.				0.0014	1.07%	1.08%	1.08%	0.76%	0.34%	0.23%	0.11%	0.03%	0.00%	0%	0%		0%
Bright sat.				0.00010	0.36%	0.37%	0.37%	0.10%	0.00%	0%	0%	0%	0%	0%	0%		0%
Other				Average over equinox night													
Thermal IR (VISIR)																	
Single DIT	60"		ms	0.000012	1.2E-05	1.2E-05	1.2E-05	1.2E-05	constant with solar elevation								
Frame	60"		5s	0.0006	6.3E-04	6.4E-04	6.4E-04	6.4E-04	constant with solar elevation								
Occultation/Transit/VLTI																	
All sat.	3"		10min	0.0005	0.004	0.004	0.004	0.003	0.001	0.001	0.000	0.000	4.4E-07	0	0	0	0

Losses
< 0.1%
< 1%
< 3%
<30%
>30%

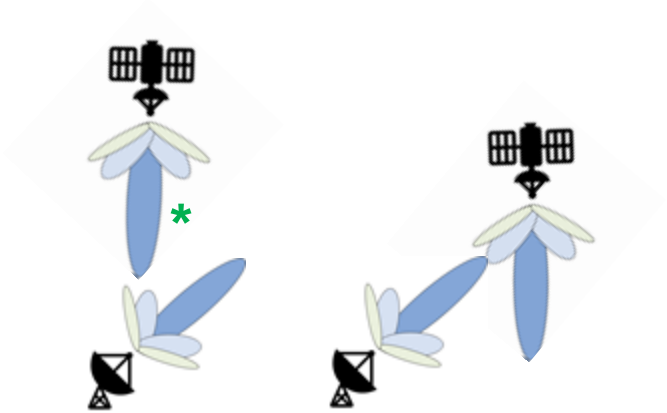
--> Effect is worse for wider field, longer exposure, larger telescope

Radio Astronomy

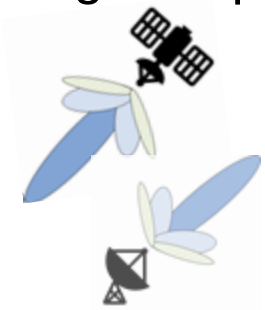


Direct + direct pointing
Unlikely

- Satellites are active emitters
  - 24h, no shadow
- Geometry: antenna side-lobes
- Frequency bleeding into protected bands + observations out of protected bands
- No protected geographic areas
- Some frequency bands protected for astro
- * : Mitigation possible



Direct+ side lobe pointing
Likely

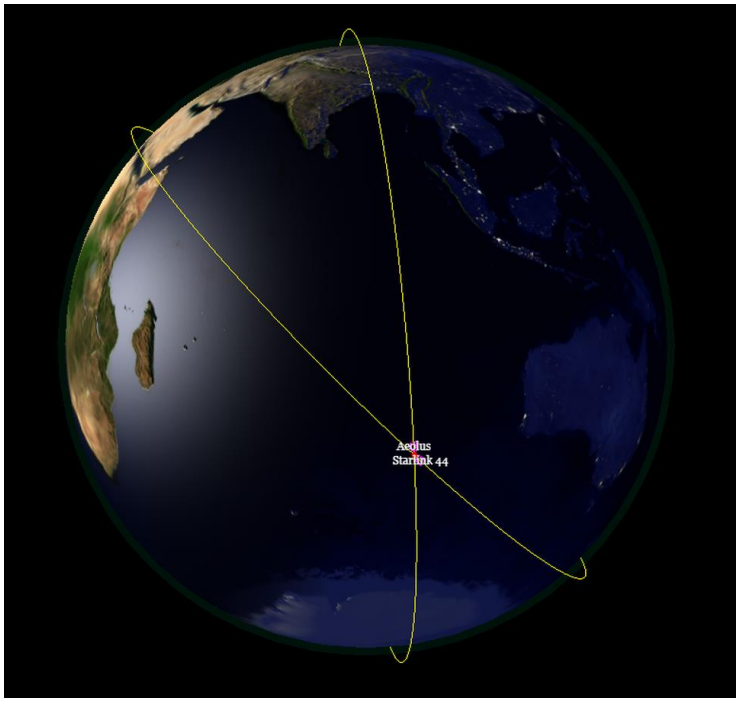


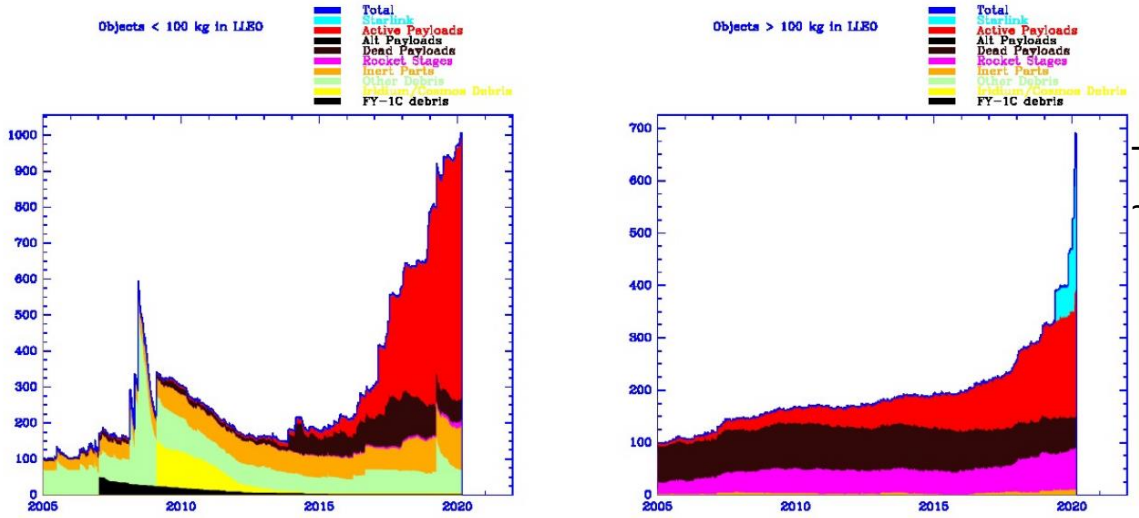
Side lobe + side lobe pointing
Very frequent

Disclaimer:
not my field

Orbital Crowding

- Space traffic
  - Collision avoidance
- Space debris
  - Controlled de-orbitting
- Sustainability





Today:
~2000

ESA ops

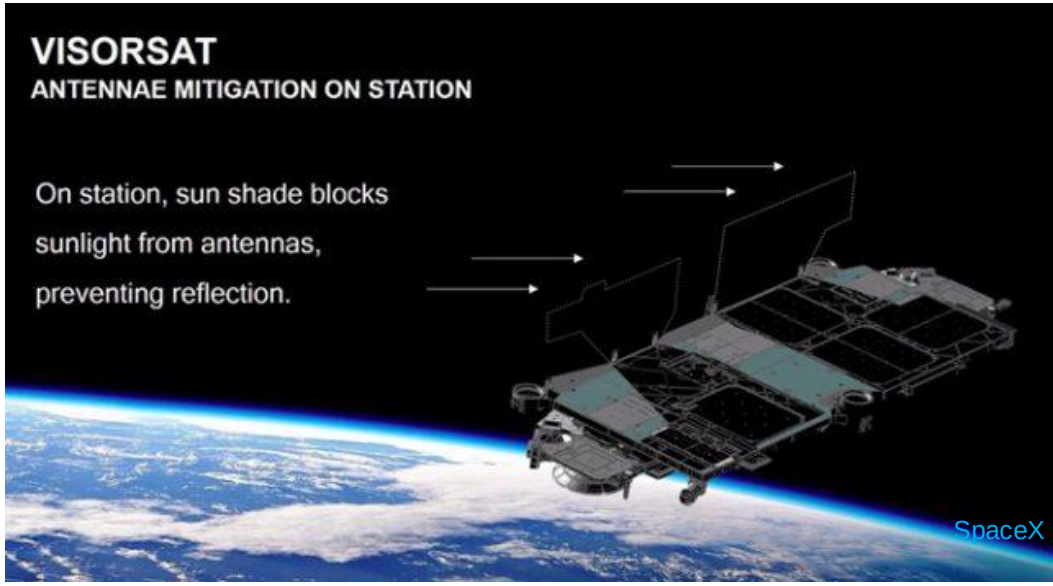
J.McDowell AJ 2020

Disclaimer:
not my field

Satellite constellations: What can we do?

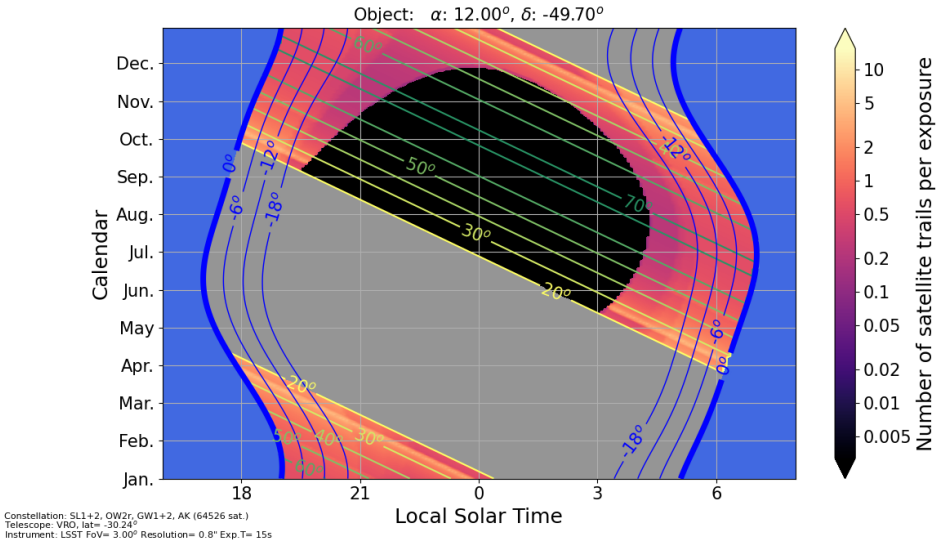
Starlink mitigation

- Attitude Control during orbit raise
  - 3-5 mag fainter; No more bright string of pearls since mid 2020
- Attitude Condrol on operational orbit:
  - adjust solar panel angle to keep it out of sight
- DarkSat: black coating (1 satellite experiment)
  - 2x fainter in visible, less in IR, not sufficient
  - Problems with thermal control
- VisorSat: sunshade
  - 3x fainter ~mag V=7 at zenith
  - All sat since mid 2020
  - SpaceX iterating design



Mitigation

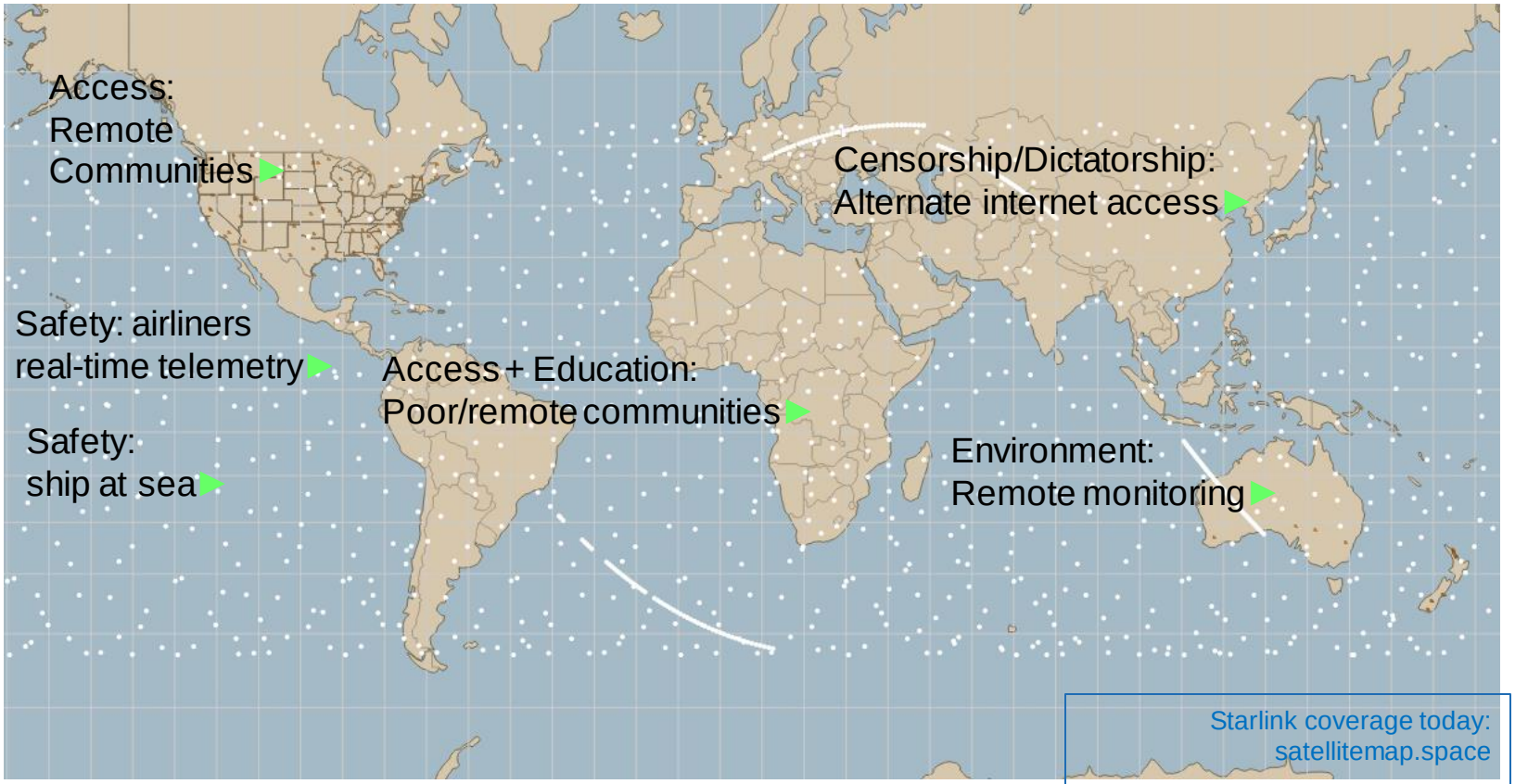
- Mitigation: Satellites
  - Low altitude (<600km)
  - Darken satellites
- Mitigation: Tel
  - Scheduling tools - - ->
  - Shuttering
    - Forecast + Field of view monitoring camera
  - post-image analysis / find+flag trails
- At the policy level
  - SatCon conferences
  - IAU/UN Dark&Quiet Sky --> UN-COPUOS



No combination of mitigations will avoid all impacts!

- -> Awareness, recommendations + best practices, international treaties, laws

Societal benefits



Soon: Starlink (USA), OneWeb (UK), Kuiper (USA), Samsung (Skorea), GuoWang (PRC), more internet providers

The way ahead: Shared Stewardship

- **Raise awareness** of astronomy and society
- Encourage States, Industry, Astronomers, and other affected stakeholders to **collaborate** on principles, rules and information sharing
- Encourage future national **regulatory processes** to consider astronomy concerns as part of environmental impact assessments, launch approvals and/or frequency approvals

Further  reading

- **SatCon starter web page**
  - https://www.eso.org/~ohainaut/satellites
- **ESO Council** COU-1928
  - PDF bit.ly/ESOcou1928
- **AAS SatCon Report** to NSF
  - SatCon1 Main report bit.ly/SATCON_report
  - SatCon1 Technical appendix bit.ly/SATCON_appendix
  - Soon: SatCon2 report
- **IAU Dark & Quiet Skies report** to UN-COPUOS
  - D&QS1 Book bit.ly/IAU_DarkSkies
  - Soon: D&QS2