Dark and Quiet Skies
Impact of space activities on astronomy
Governance Perspectives

United Nations/Chile Conference on Space Law and Policy

Public

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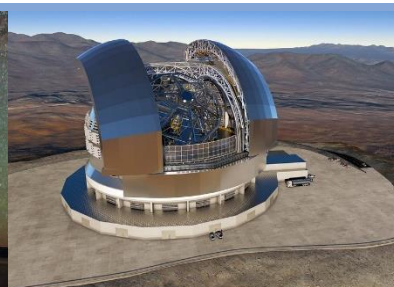
European Southern Observatory

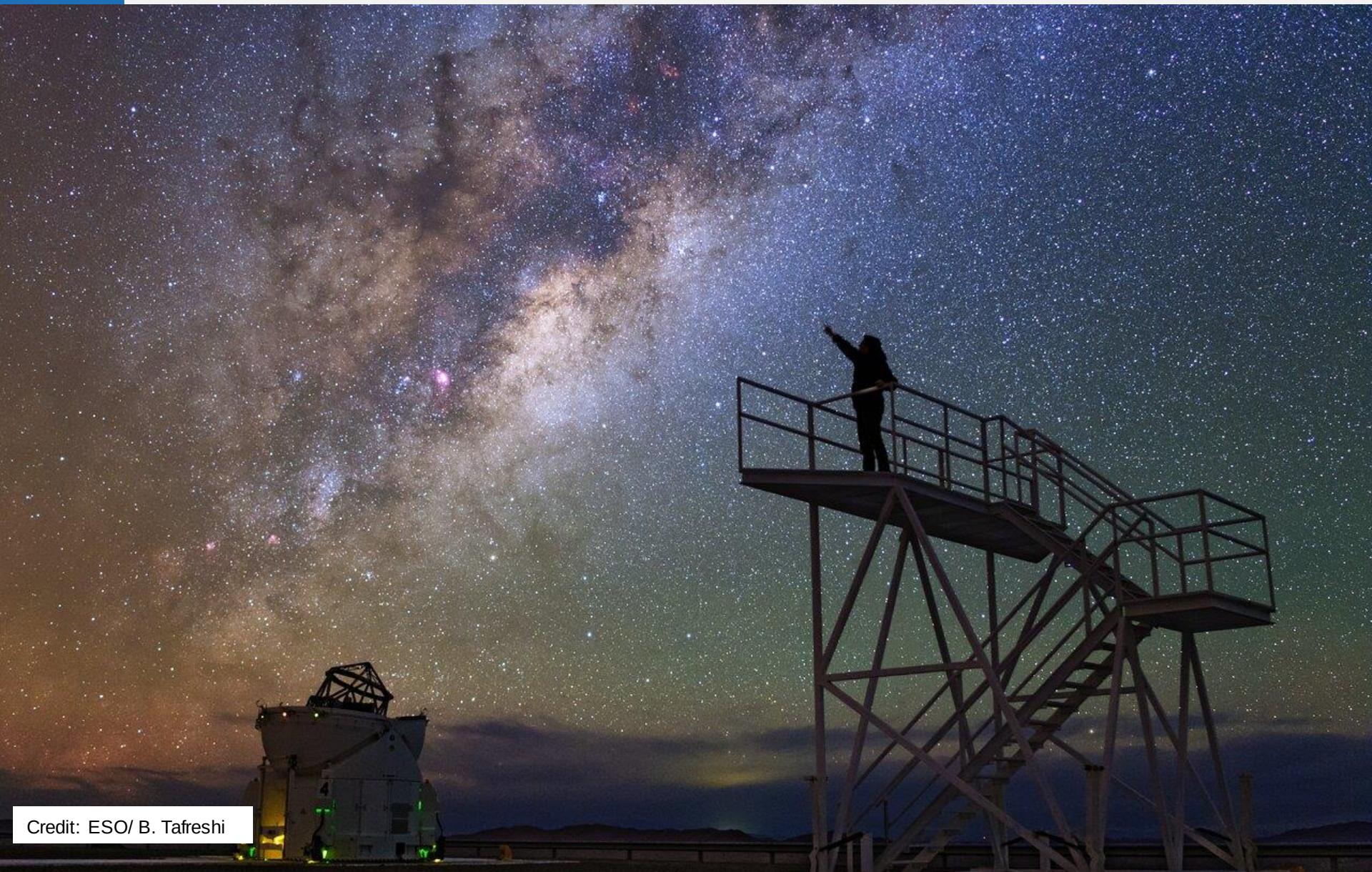
- Intergovernmental organization for astronomy
  - Founded in 1962 by five countries with the goal to build a large telescope in the southern hemisphere
  - 16 Member States
    - Strategic cooperation agreement with Australia
  - COPUOS observer since 2008
- Mission
  - Develop and operate world-class observatories for astronomical research
  - Foster cooperation in astronomy
- All ESO Observatories are in Chile
  - Headquarters in Garching near Munich



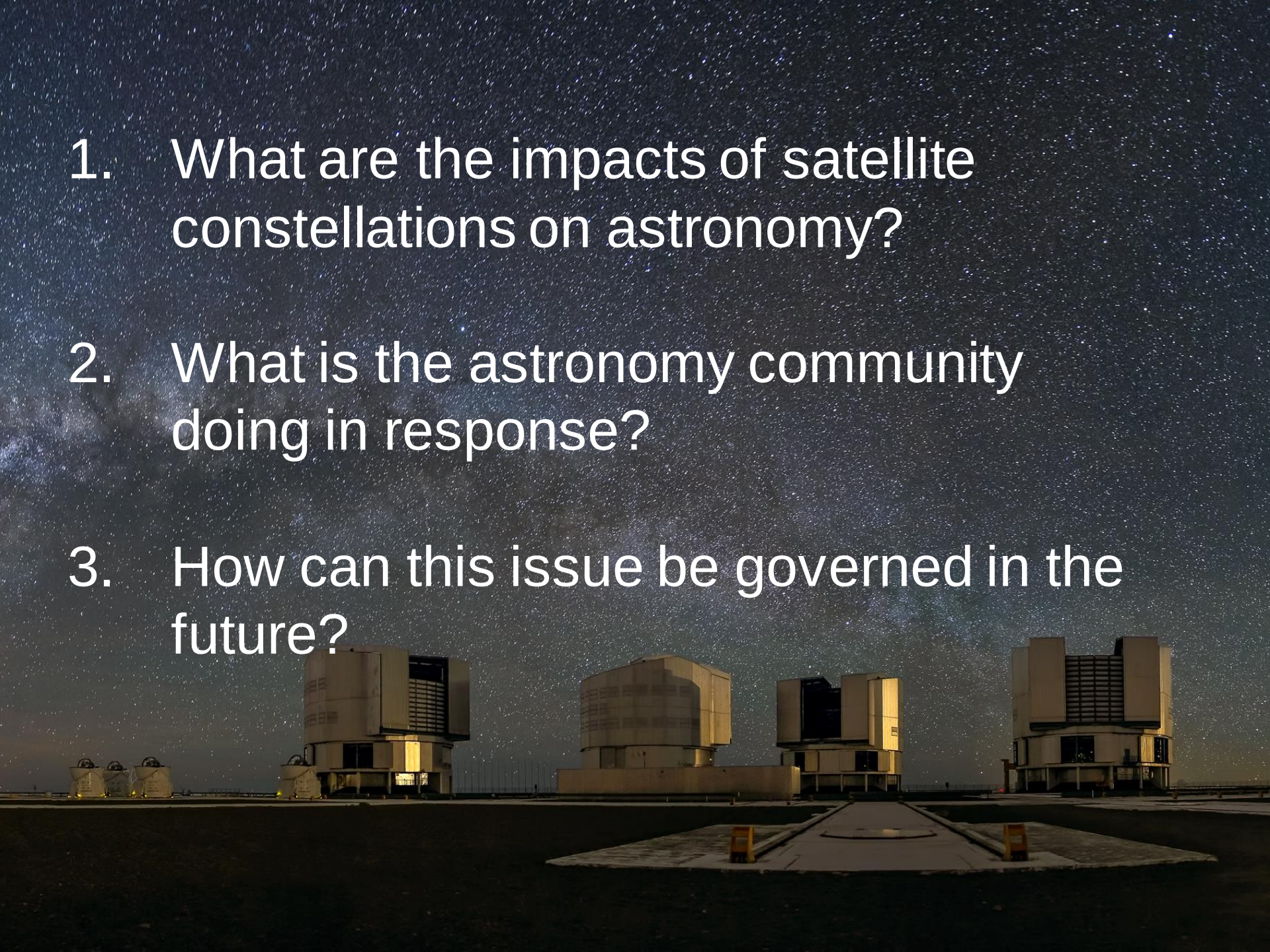




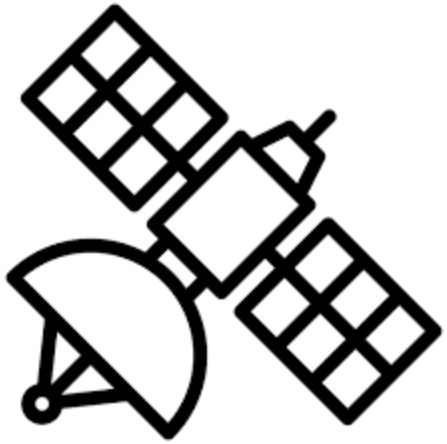
Why Chile?
Amazing dark skies & strong astronomy ecosystem



Credit: ESO/ B. Tafreshi

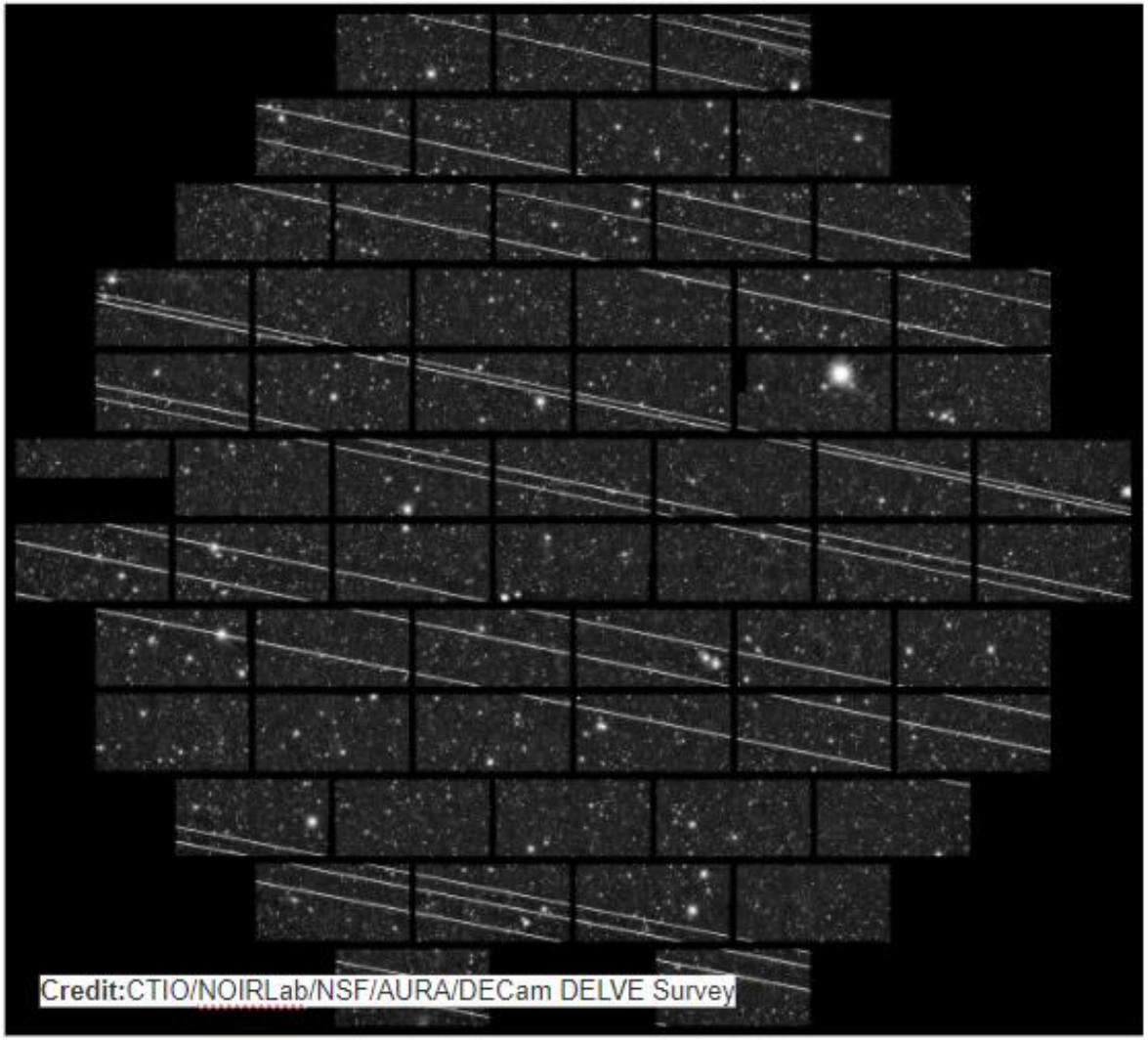


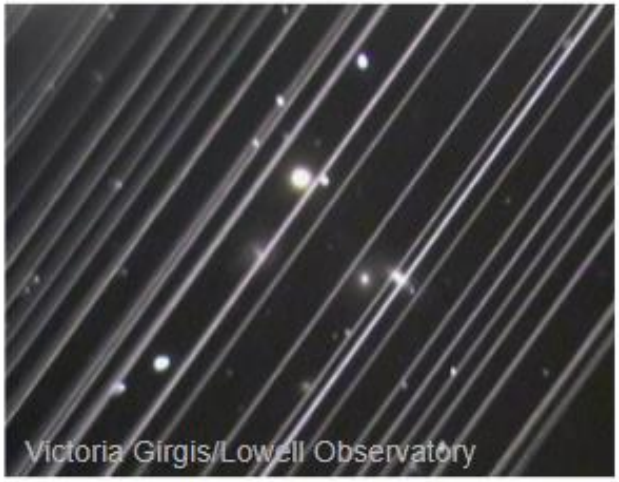
1. What are the impacts of satellite constellations on astronomy?
2. What is the astronomy community doing in response?
3. How can this issue be governed in the future?

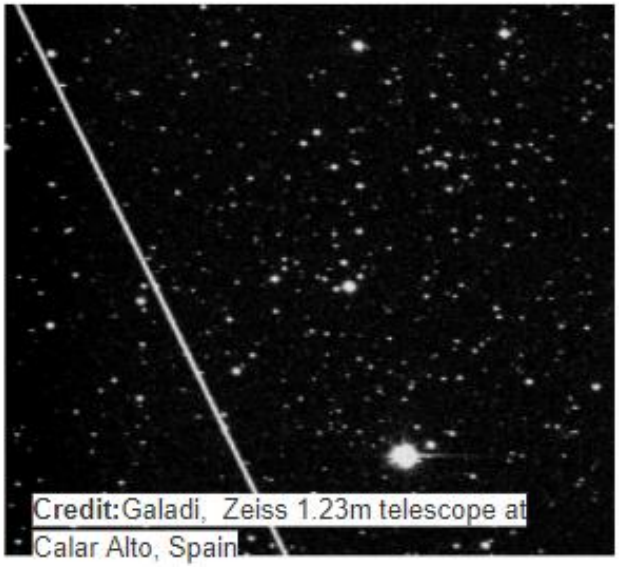


1. Understanding the Impact

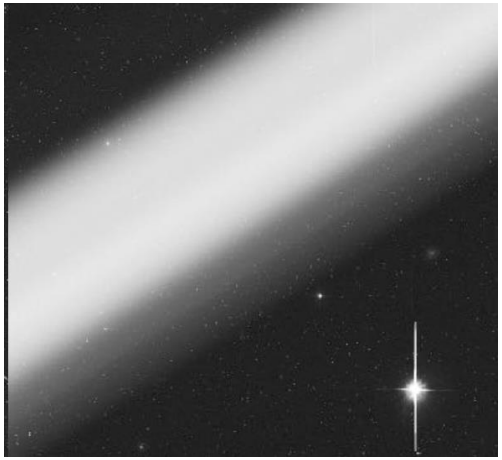
Ground-based telescopes

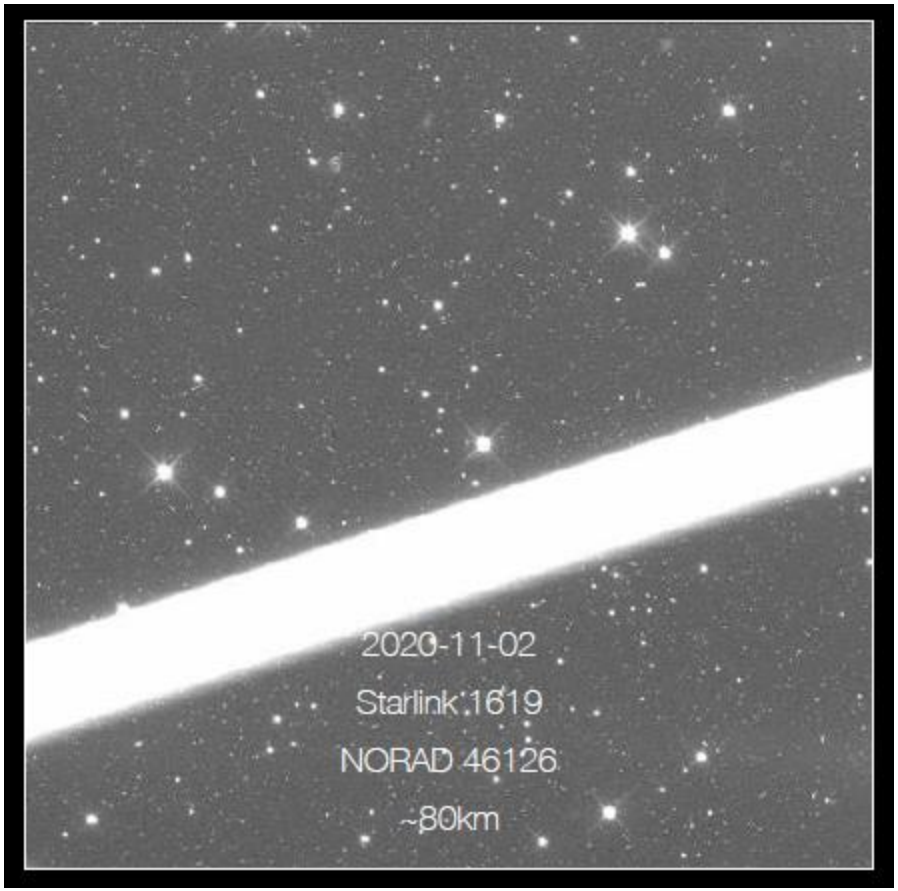






Space-based telescopes

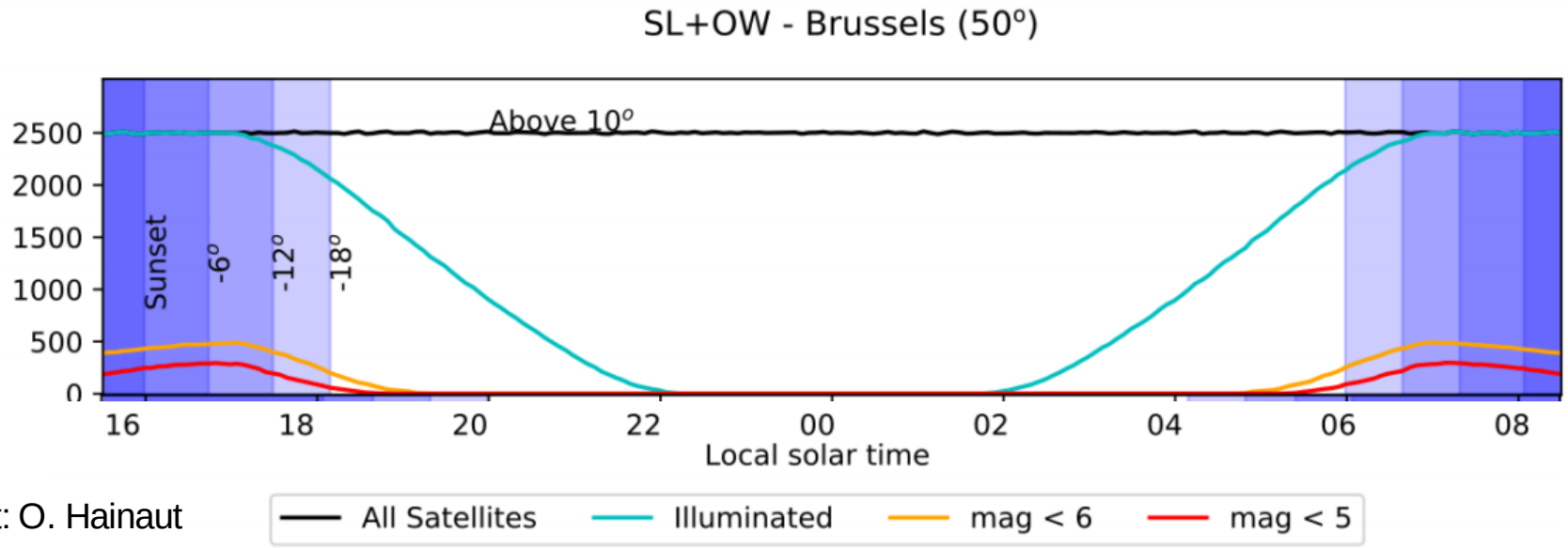




Hubble Space Telescope image contamination
Credit ESA.

Impact on Dark Skies

- At Cerro Paranal, ~5,000 satellites above the horizon at any given time
  - Concentrated towards horizon
  - Few hundred to few thousand illuminated by the sun, depending on time of night, season.

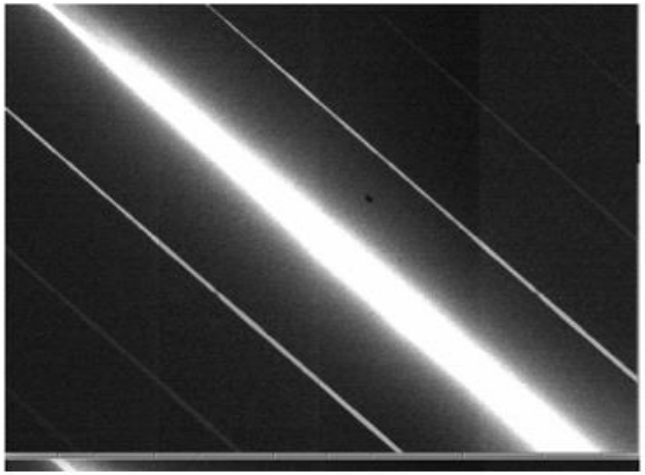


Credit: O. Hainaut

Impacts on Optical Astronomy

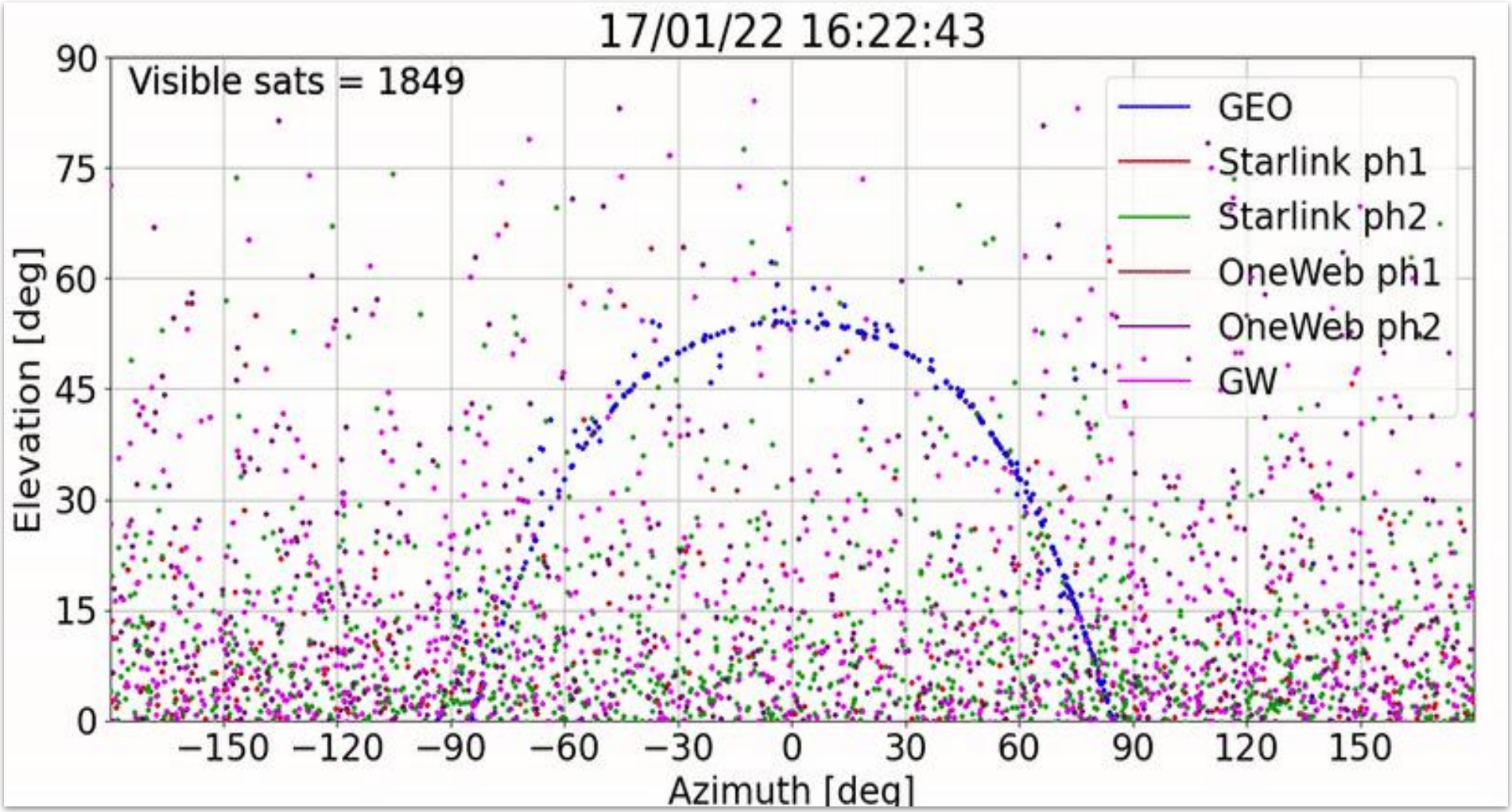
Faint satellite trail: annoying overhead but data potentially recoverable

Bright satellite trail: Detector Saturation = ruined image and lost science



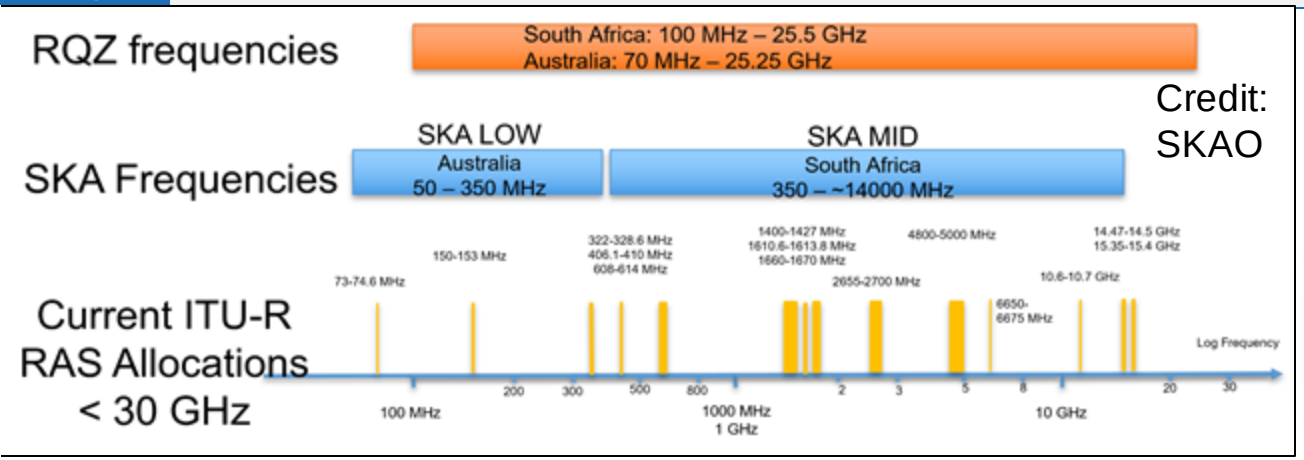
Credit: T. Tyson et. al, 2020

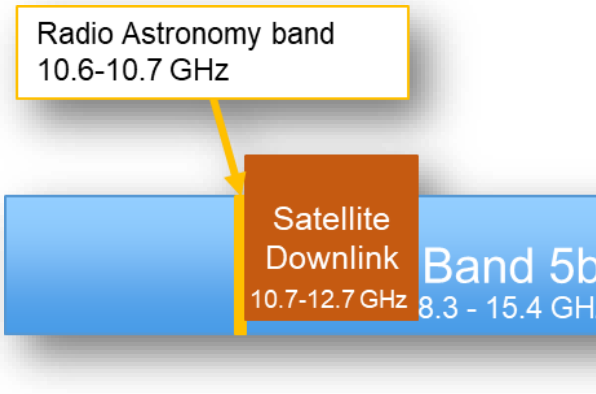
- Narrow field (ESO's VLT, ELT etc.): ~% - *~10%* frames affected at twilight
- Wide-field (VST): 50% of frames - *several satellites per frame* at twilight
- Super-Wide-field on large telescope: Vera Rubin Observatory
  - all frames affected at twilight (tens of trails),
  - many frames affected during whole summer night by high-altitude satellites.
  - many frames **ruined** at twilight.



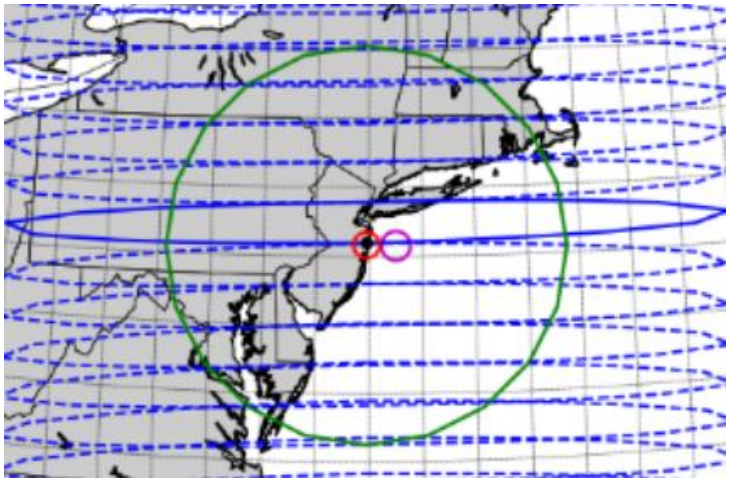
Credit: F.DiVruno / SKAO

Radio Astronomy Impacts

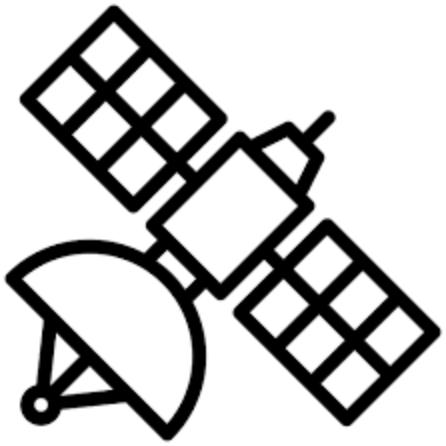




- Radio quiet zones are local
  - Prevention of physical damage to observatories?
  - Cumulative background noise levels from antenna sidelobes?
  - Electronic noise standards of spacecraft?



del Portillo, Inigo, Bruce G. Cameron, and Edward F. Crawley. "A technical comparison of three low earth orbit satellite constellation systems to provide global broadband." *Acta Astronautica* 159 (2019): 123-135.

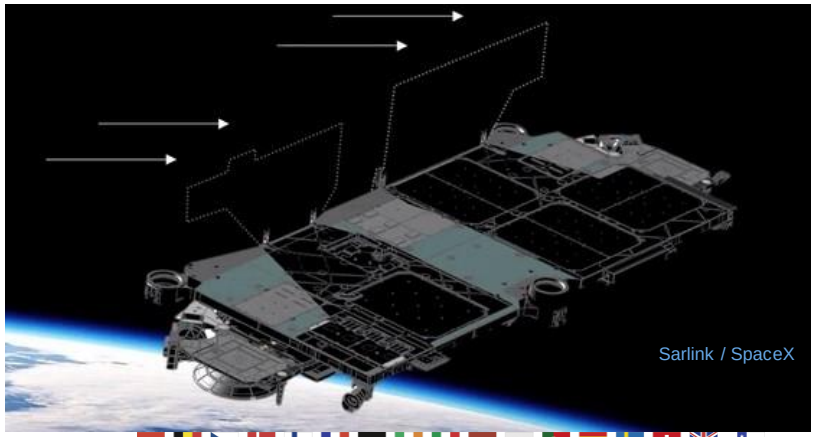


2. Astronomy Community Actions

Collaboration with Industry

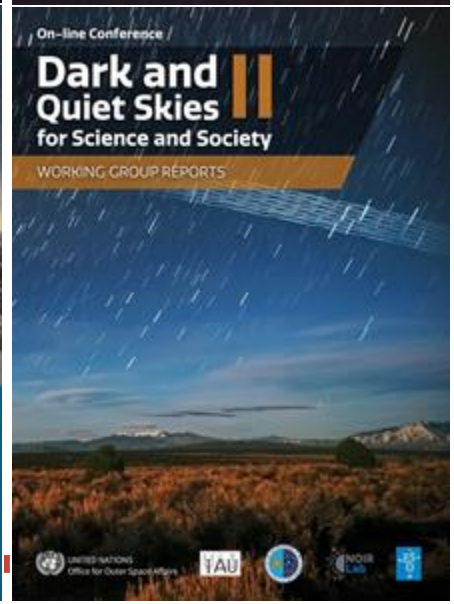
Actions by SpaceX

- On transfer orbit (few weeks after launch, only at twilight)
  - Modified attitude: no more string of pearls
- In operations
  - Keep solar panel in shadow of bus
  - DarkSat experiment: ~½ brightness, abandoned
  - VisorSat (SpaceX + Amazon)
- Collaborative observations of satellites and modelling (OneWeb)



Toward addressing the impact of satellite constellations on astronomy

- **2019**: A satellite constellation of 60 Starlinks launches in May
- **2020**: Identify the issues; formulate recommendations for mitigation:
  - SATCON1, Dark & Quiet Skies I
- **2021**: Identify the pathways to implement recommendations:
  - SATCON2, Dark & Quiet Skies II
- **2022**: Take the pathways to implement recommendations
  - Center on the Protection of Dark & Quiet Sky from Satellite Constellation Interference



IAU Satellite Centre

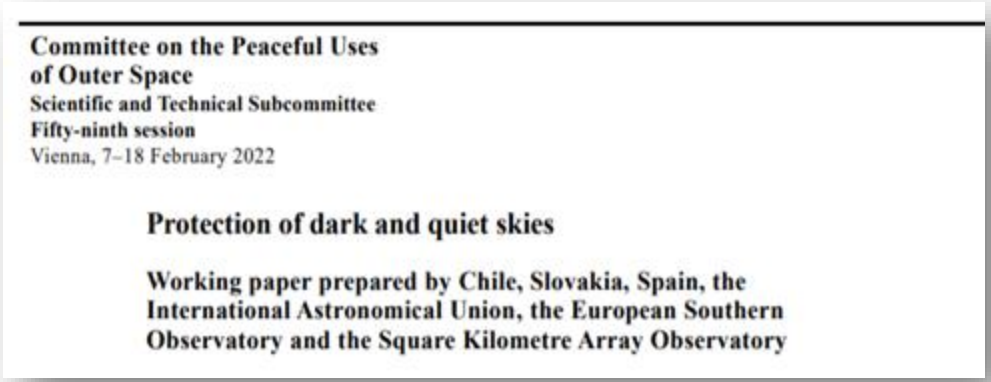
IAU NOIRLab SKAO

- **Coordinate efforts & unify voices** of the global astronomical community
- Bring together astronomers, industry, policy experts and the wider community and **act as a bridge between all stakeholders**
- **Produce and disseminate information and resources**
- **Continue research** on the satellite constellation issues to arrive at feasible and implementable solutions in the areas of:
  - A hub for observations, software, etc. (SatHub)
  - Policy
  - Industry and Technology
  - Community Engagement

COPUOS STSC 2022

Working Paper for the Protection of the Dark and Quiet Skies for Science and Society

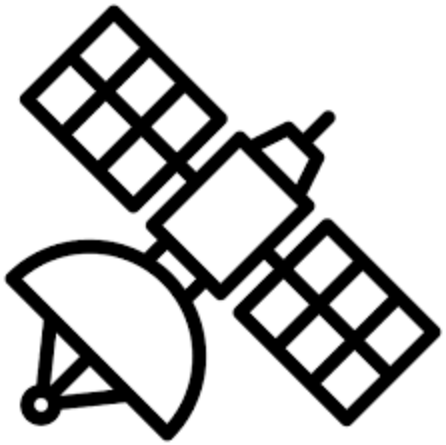
- Many COPUOS Members voiced support
- STSC agreed to add a new agenda item for 2023



Committee on the Peaceful Uses
of Outer Space
Scientific and Technical Subcommittee
Fifty-ninth session
Vienna, 7–18 February 2022

Protection of dark and quiet skies

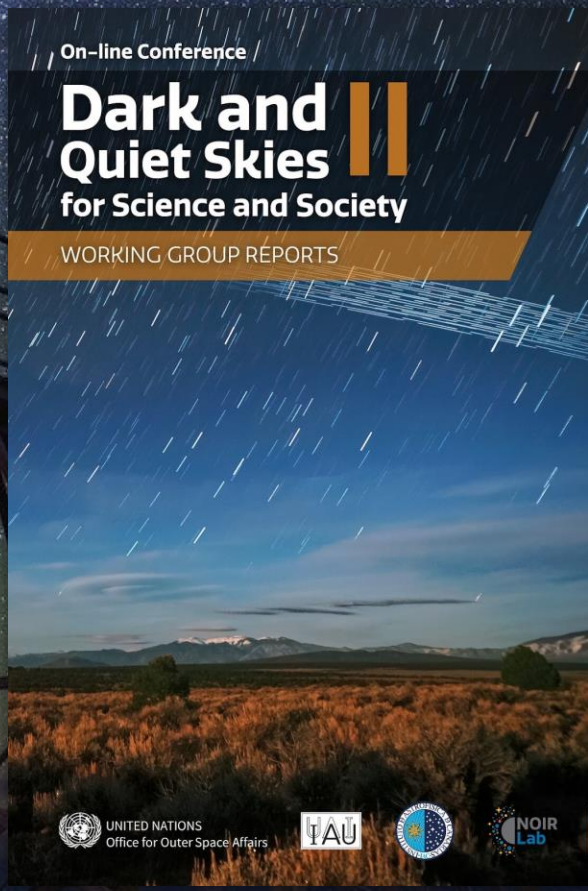
Working paper prepared by Chile, Slovakia, Spain, the International Astronomical Union, the European Southern Observatory and the Square Kilometre Array Observatory



3. Governance perspectives

In general, no specific international law governing the visual appearance of scientific use of the sky

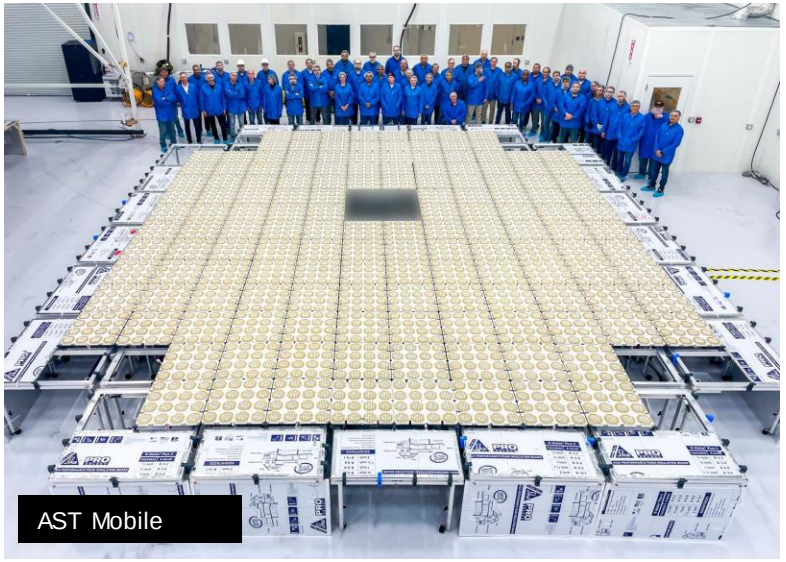
- International space law obligations to protect dark and quiet skies?
- Is Space an Environment? Applicability of Environmental Law?
- Consideration of aggregate effects?
- Heritage and cultural sky traditions?



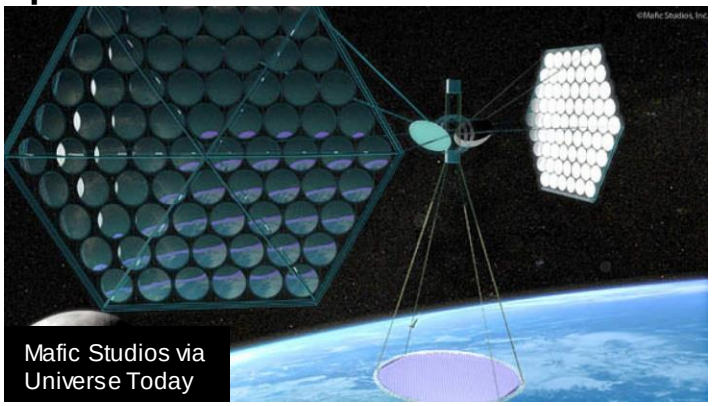
Not just satellite constellations…

Passive De-orbiting Drag Sails

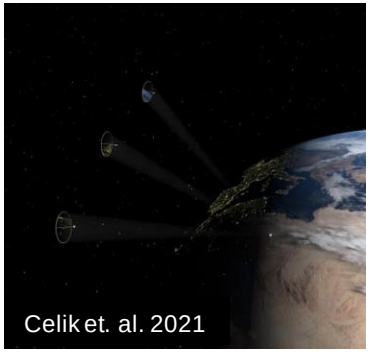
Cellular towers in space

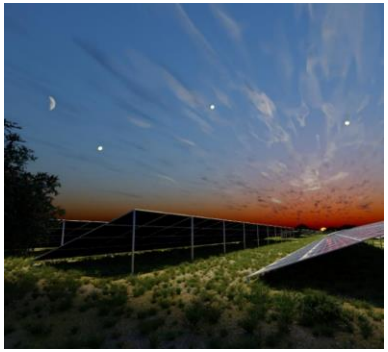


Space-based Solar Power



Enhancing Terrestrial Solar Power Using Orbiting Solar Reflectors

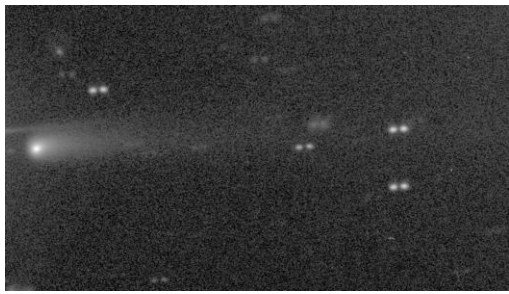




Astronomy as a Space Activity

- Exploration of the cosmos
- A “use” of outer space
- Observatories located in space
- Astronomy as service to space missions
- Integral component of scientific exploration missions
- Occurring for the benefit of humankind (e.g. planetary defence)

→*Trigger for Art. 9 & Art. 11 OST*



A vision for long-term development of D&QS governance

Norm building

- Voluntary cooperation with industry
  - Builds expertise, solutions
  - Creates normative expectation to act
- Acceptance of State responsibility as per OST
  - Provide funding for mitigations

Non-binding guidelines and ratings

- E.g. Set up working group similar to IADC
- Industry and government rating schemes (E.g. the space sustainability rating)

International dialogue

- COPUOS vitally important for consensus-building
- IAU centre
  - convening of experts, generate proposals

National Policy and Regulation

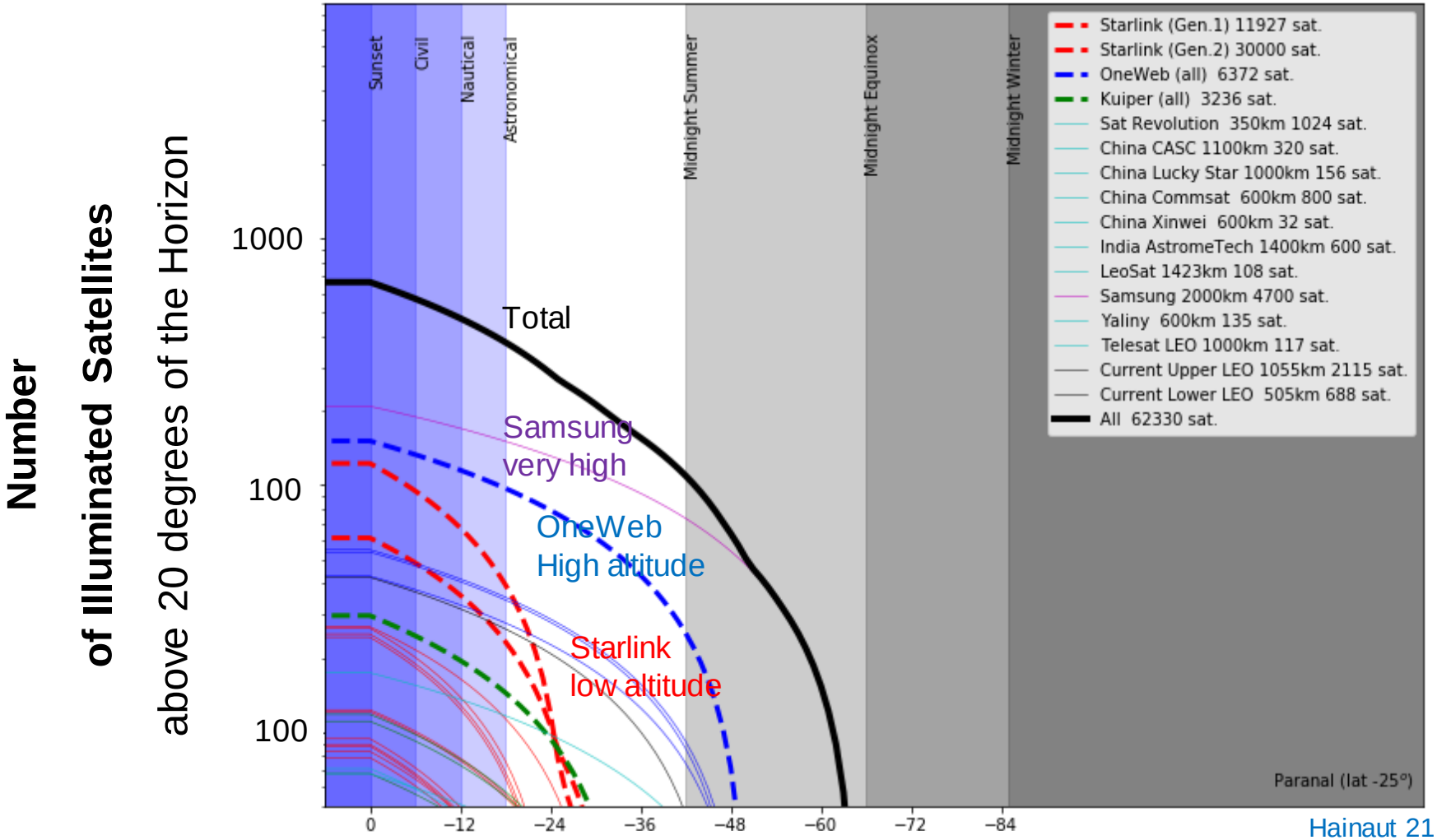
- Must be well-informed by analysis and operator practice

National Regulatory Options

- How can governments:
  - **Prevent** impacts before launch?
  - Minimize disruption **during** operations?
  - Ensure redress **after** damages occur?
- Simple addition of requirement to consult with national astronomy society / observatories, as a condition for licensing
- Important future steps:
  - Finding ways for operators to share data (reflectivity, antenna parameters, TLEs)
  - Development of common standards for industry
  - Agreements on brightness mitigations and radio background
  - Development of space environmental law

Satellite Counts from Simulations

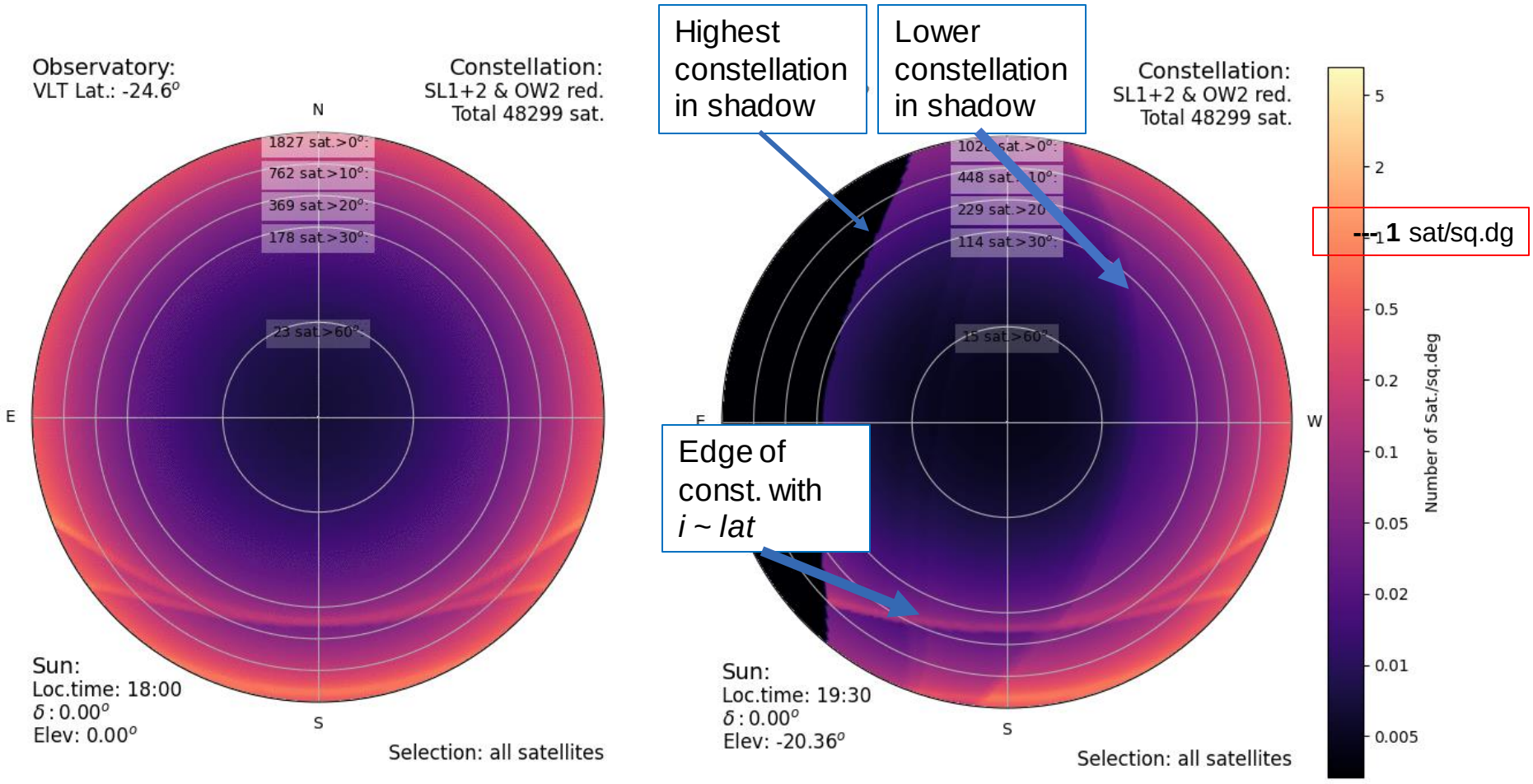
- All foreseen constellations @2030



Hainaut 21

Satellite density at Paranal
(representative of 2030)

Simulations: O. Hainaut



Scientifically-established guidelines

- Keep individual satellites as dark as possible
  - Below unaided eye visibility (fainter than mag 7)
  - Reduce reflectivity of surface materials and satellite structure
- Reduce visibility of satellites
  - Minimise overall number of satellites
  - Orbital altitude < 600km
  - Adjust on-orbit attitude (i.e. don't reflect light on an observatory)
  - Considerations during orbit raise and de-orbiting
- Provide high accuracy public data on satellite location
- Avoid directly illuminating a radio observatory
- Comply with ITU equivalent power flux density limits for electromagnetic disturbances, as well as out-of-band, harmonic and spurious emissions (for individual and aggregate cases).