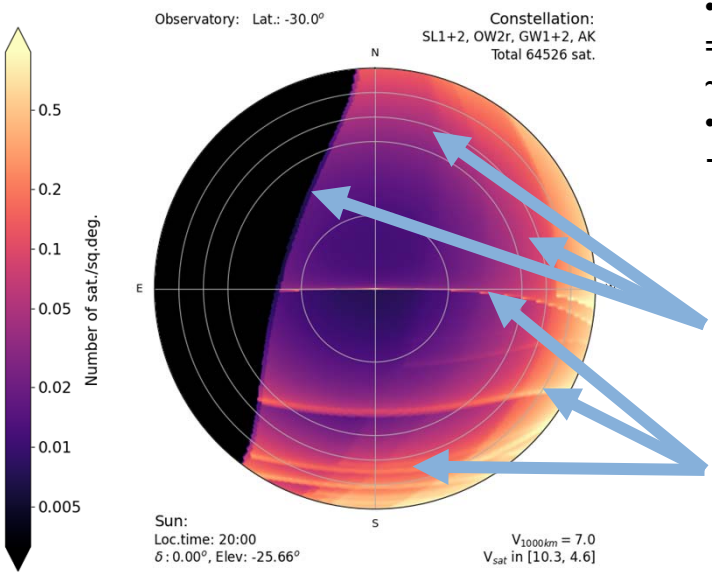
Increased artificial sky brightness from satellite constellations

Olivier R. Hainaut – ESO | Cees Bassa – ASTRON | David Galadí-Enríquez - Calar Alto

(ESO: public)

Position of the satellites



Analytical simulation

[Bassa+21]← Bassa's talk this morning

Simulation:

- 64000 satellites

= SL + OW + Amazon K + GuoWang

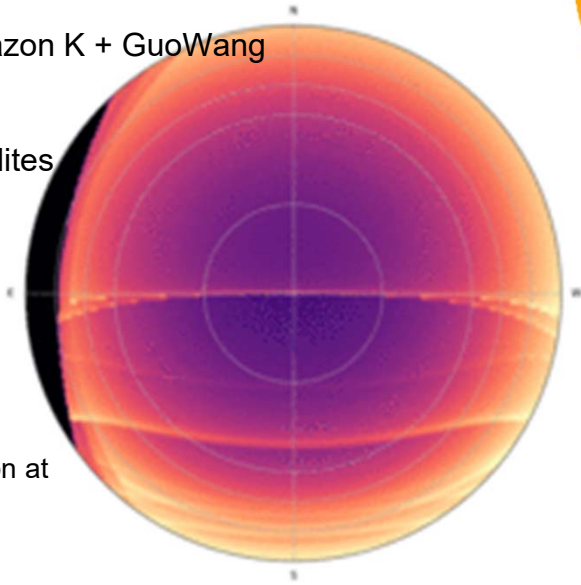
~ 2030

- Latitude=-30°

→ Density of satellites [sat/sq.deg]

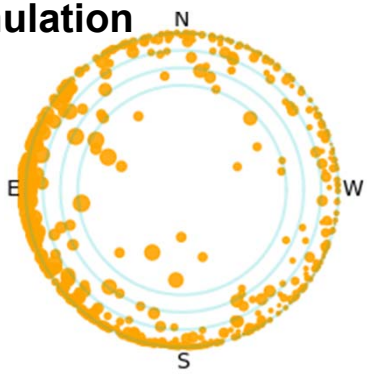
Curtains:
Constellation falling in the shadow of the Earth

Cusps:
Edge of constellation at *i ~ latitude*



Discrete simulation

[Hainaut]



See also "Latitude near 50o will experience the worst light pollution" Lawler, Boley, Rein arXiv:2109.04328

Brightness of the satellites

- **Apparent magnitude:**

  Simple photometric model (simplified Lambertian sphere)

  $$m_{sat} = m_{1000km} + 5\log_{10}(d_{sat}/1000) + kd_{sat}/h_{sat}$$

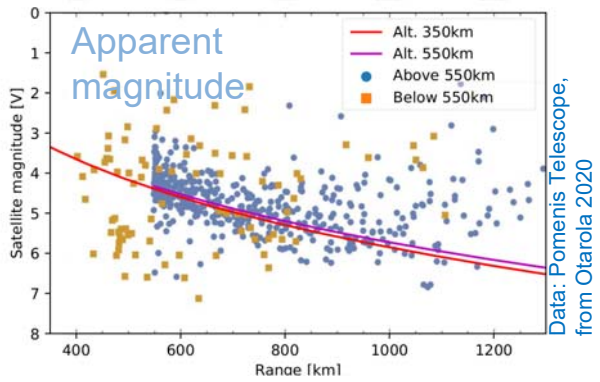
  Simulation: m_{1000km} ~7 for SL-visorSat and OneWeb

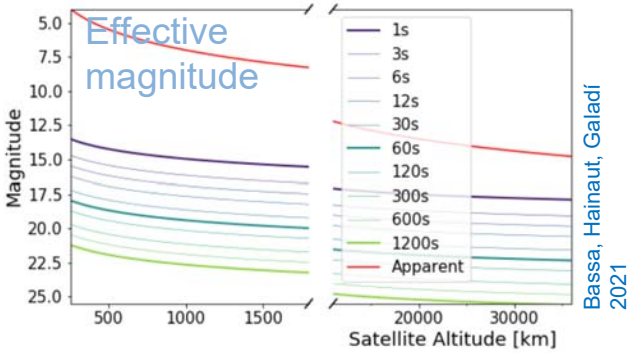
- **Effective magnitude**: accounts for trailing and exposure time
  - Effective exposure time: t_{eff} = pixel / ω ~ 0.5 -- 5 ms
    (for any actual exposure time)
  - Effective mag:
    mag of a point source with same peak number of counts

  $$m_{eff} = m_{sat} - 2.5\log_{10}\frac{t_{eff}}{t_{exP}} = m_{sat} - 2.5\log_{10}\frac{r}{\omega_{sat} t_{exp}}$$

➔ Many satellites are too faint for detection

➔ The satellites contribute to the diffuse background

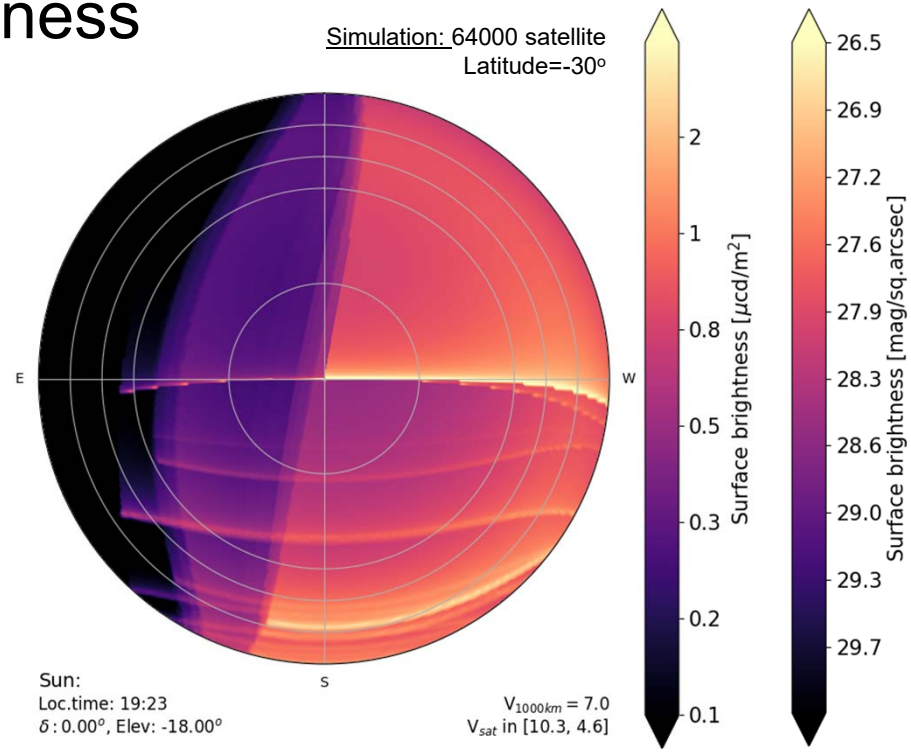




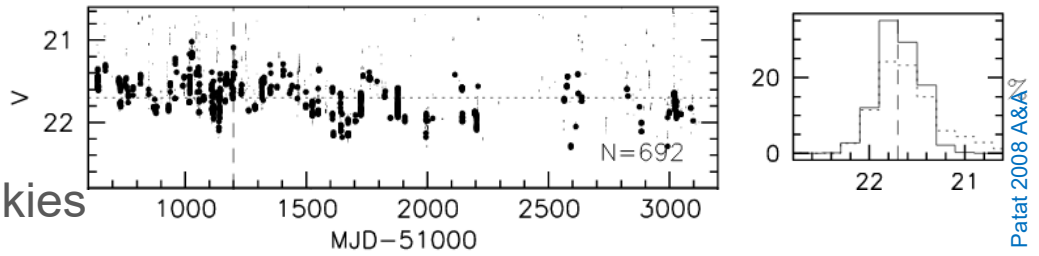
Satellite density and sky brightness

Surface brightness:

- mag/sq.arcsec
  or candela/m^2
- Conversion: Luminance
  = 1.2 $*10^5$ $*10^{-0.4\ V}$ cd/m^2
  [Bara+ 2020 MNRAS]
  1 µcd/m^2 ~ 1 S_{10}
- At Twilight –18°
  - **East: ~0.3 µcd/m^2**
  - **West: ~1 µcd/m^2**
  - **Cusps: ~4–5 µcd/m^2**



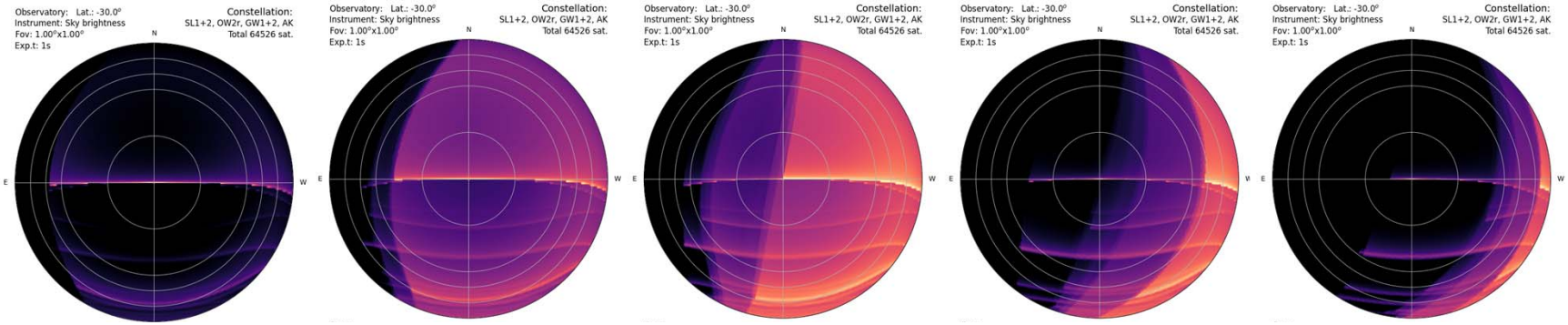
Sky Brightness



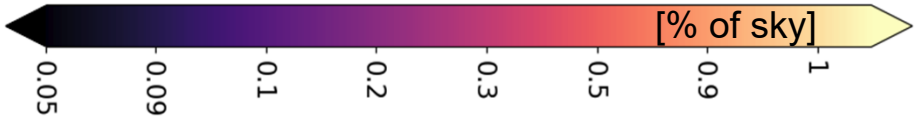
- Paranal: among the best possible skies

Relative to Sky brightness

Simulation: 64000 satellites
Latitude = -30º - Sky brightness is **uniform**

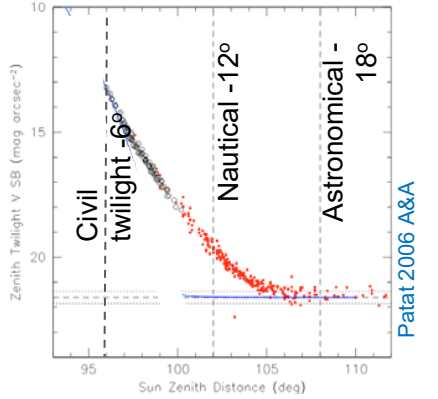


Sun: -12º Sky: V=19.8 | Sun: -15º Sky: V=21.0 | **Sun: -18º Sky: V=21.9** | Sun: -24º Sky: V=21.9 | Sun: -30º Sky: V=21.9



- **Twilight**:
  - Sky too bright
- **At –18º astro twilight**:
  - <0.2% to the East
  - **~0.5% to the West**
  - ~3% in cusps
- **During the night**
  - 0.1 then 0%

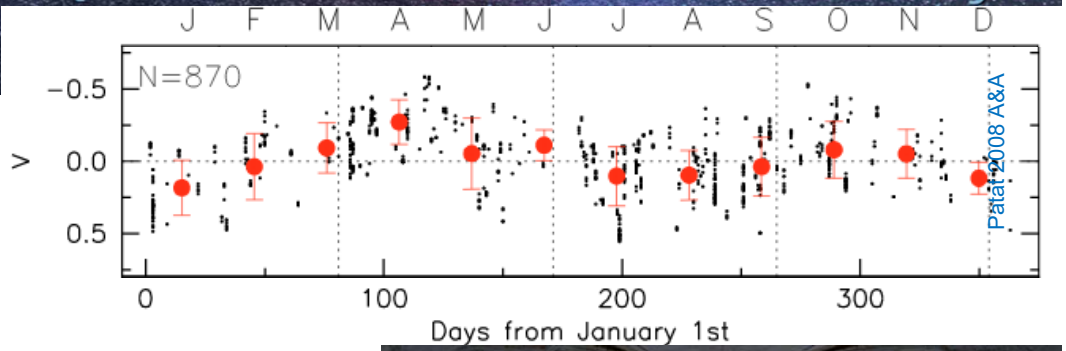
Sky brightness at twilight
Measured at Paranal



Patat 2006 A&A

Variability of night sky

- Perfect dark night ~ 220µcd/m^2
- Variations: ±0.25mag ~ ±60 µcd/m^2
- Zodiacal light +400 µcd/m^2
- Moon: up to 5mag +2000 µcd/m^2
- Light pollution: +300 000 µcd/m^2



>> Satellite contribution

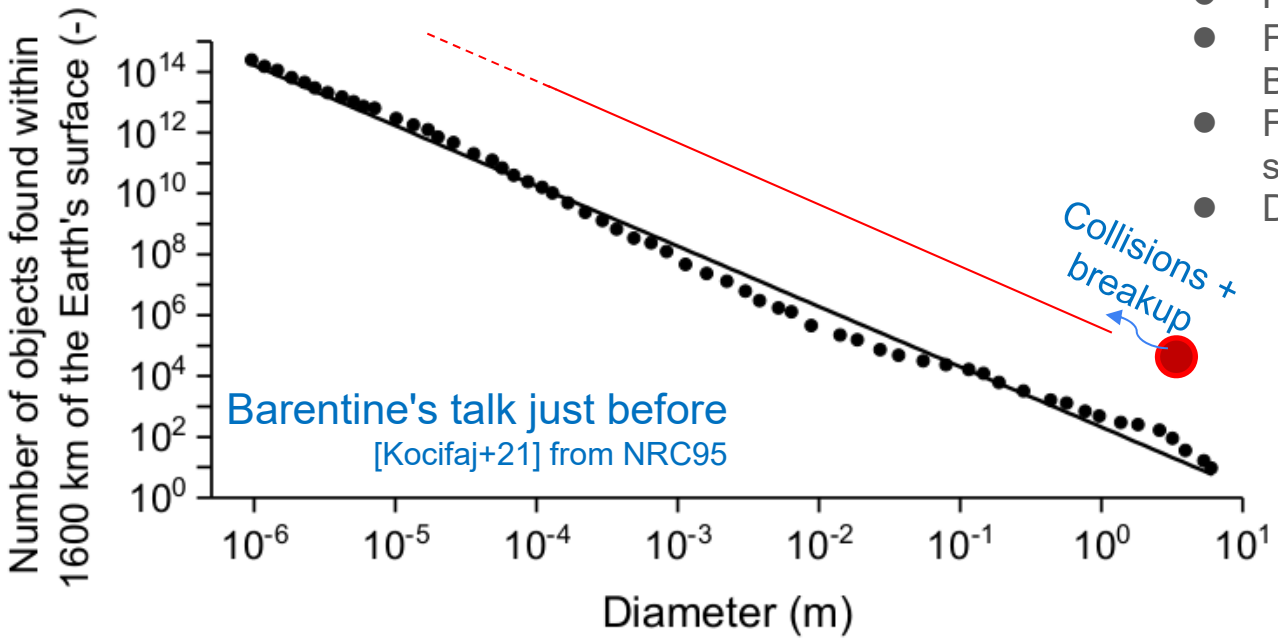
~0.2–2 µcd/m^2

~0.1 – 1% of dark sky

(64000 satellites)

ESO/Y.Beletsky

Collisions and breakup

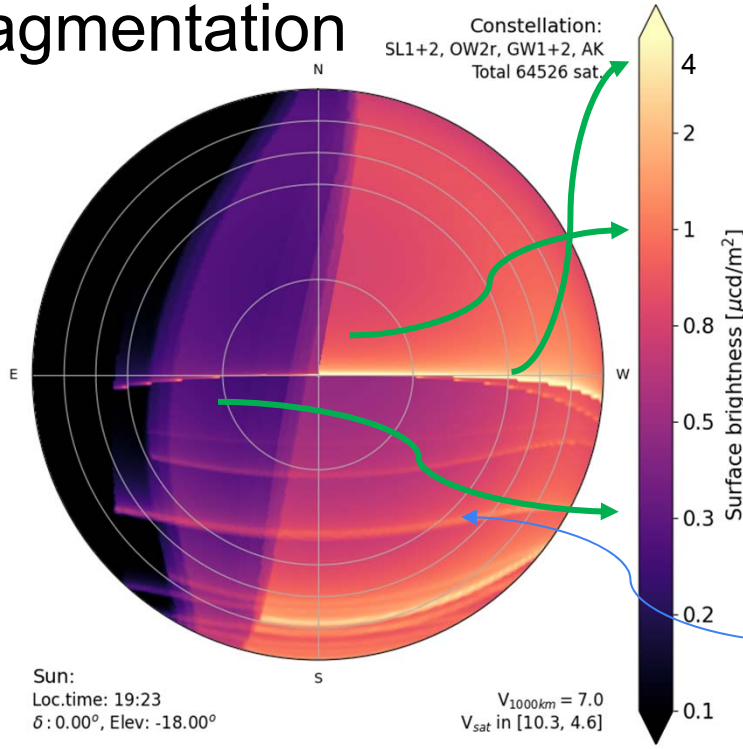


Grind the satellites into debris:

- Preserving total mass
- Following size distribution from Barentine
- Fragments have same albedo and same density as satellites (?!?)
- Debris down to
  - 1mm: optical cross section x14
  - 0.1mm: x20
  - 1µm: x25

Size distribution is a powerlaw with exp. ~ -2: all decades contribute to ~the same amount [Barentine's talk]

Fragmentation



= 2% → fragmentation → 60–100 μcd m^{-2} = 20 – 45% of dark sky

= 0.5% → fragmentation → 15–25 μcd m^{-2} = 8 – 12%

(this is ~ what Barrentine get for current debris)

= 0.15% → fragmentation → 5–8 μcd m^{-2} = 2 – 3%

Cusps will be smeared by orbit randomization

Simulation: 64000 satellite
Latitude=-30°

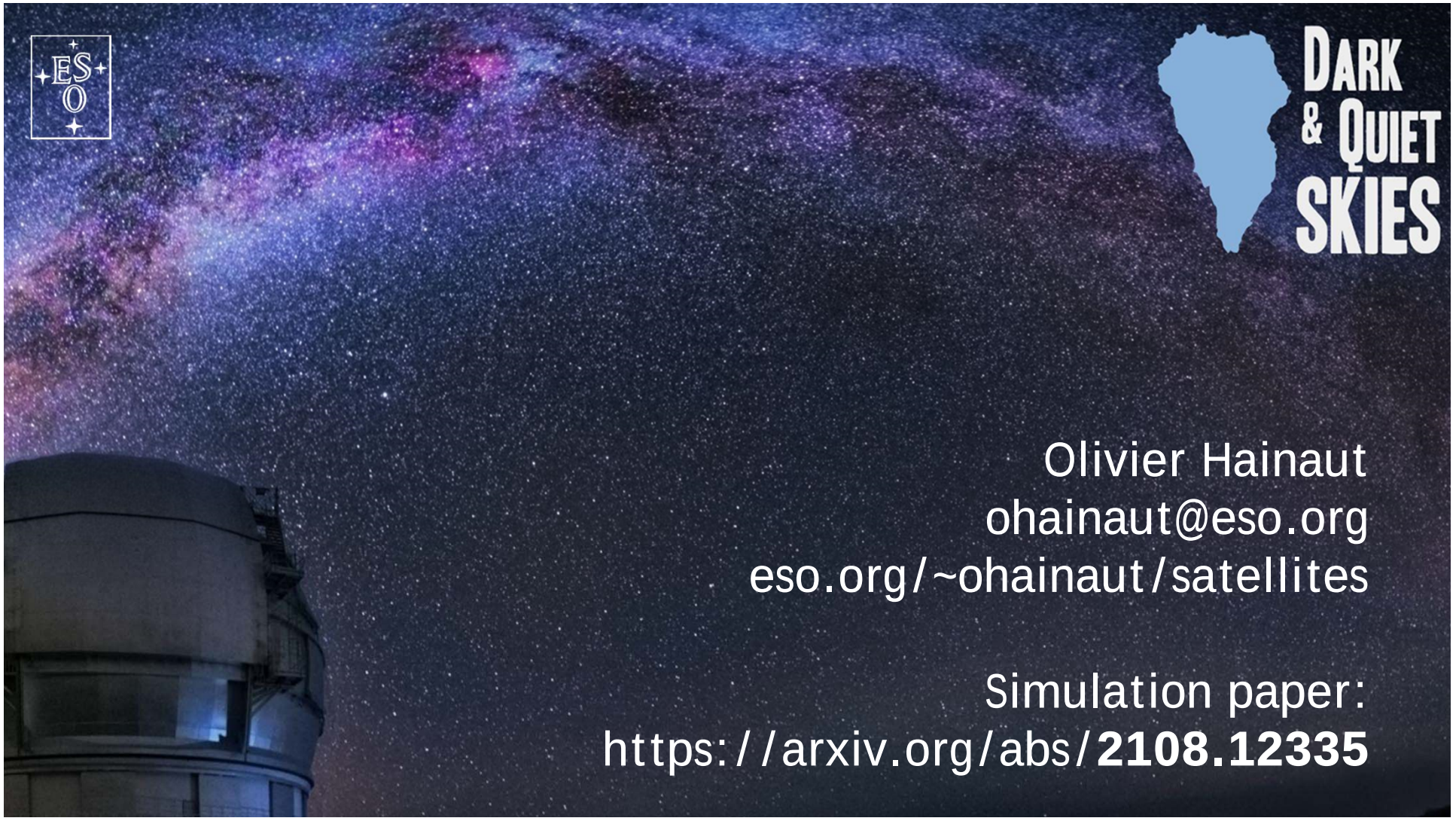
Summary

- Satellite constellations will increase the sky background
  - between –18° and –24° solar elevation
  - 0.3% (antisolar) 1% (sunward) 3% (cusps)
  - << variations of the dark sky (25%)
  - <<<< ground-based light pollution

Minor increase

- Turning satellite constellations into debris will increase the sky brightness
  - 3% (antisolar) 10% (sunward) 40% (cusps)

Do *NOT* grind the satellites to dust!



Olivier Hainaut
ohainaut@eso.org
eso.org/~ohainaut/satellites

Simulation paper:
https://arxiv.org/abs/**2108.12335**