The effects and modelling of light pollution

Rolf Buhler • 18th July 2025
AP Seminar DESY Zeuthen

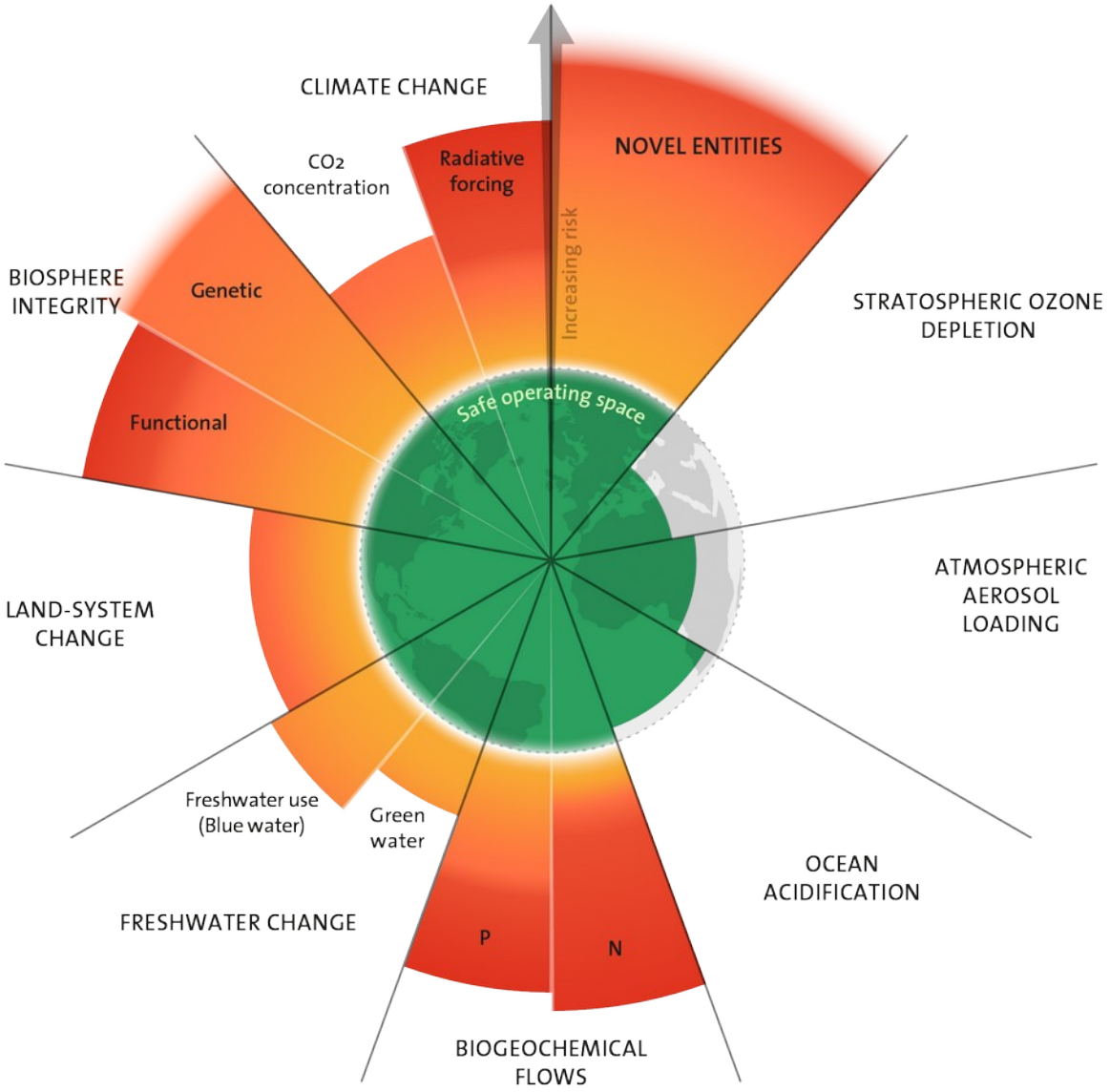
DARK SKY LAB


1. Introduction
2. Modelling light pollution
3. Analyzing France 2012-2024

Planetary Boundaries

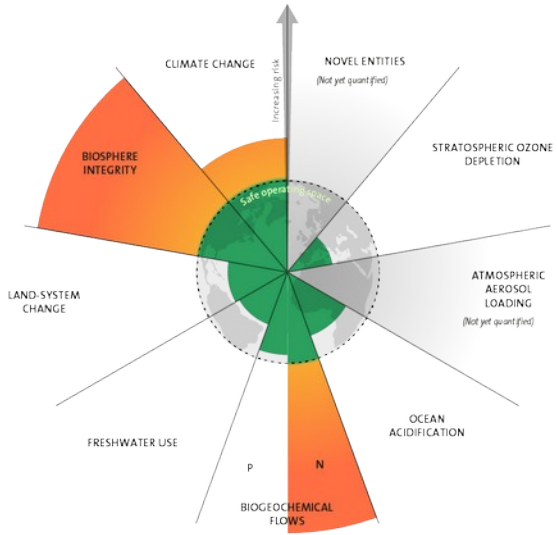
Formal framework to asses the risk to leave Earth equilibrium.

Nine key areas identified and monitored.



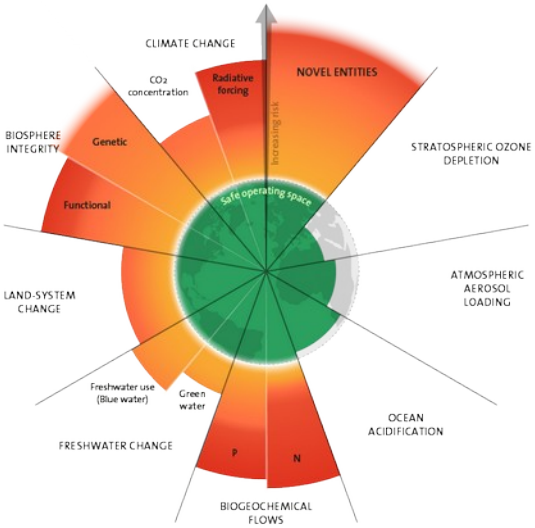
Richardson et al. 2023 Science
and references therein

2009



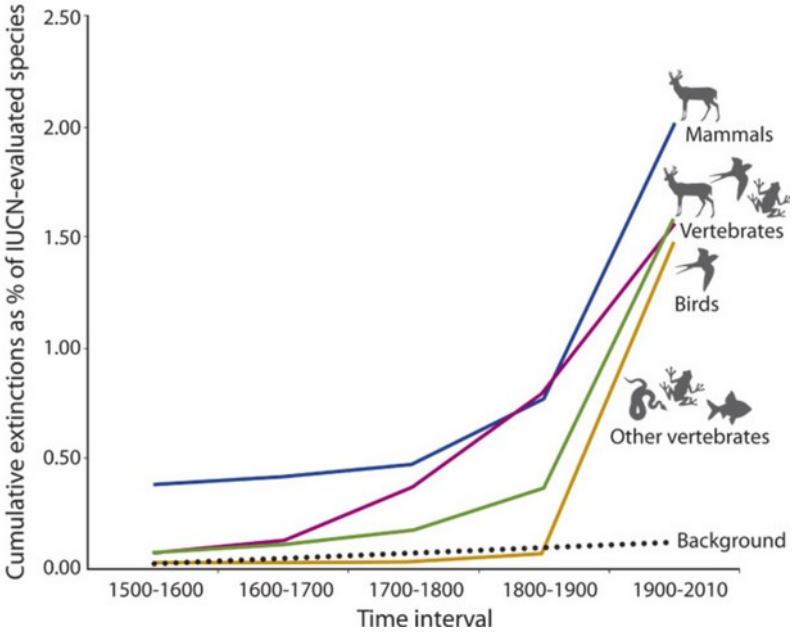
7 boundaries assessed,
3 crossed

2023



9 boundaries assessed,
6 crossed

Ceballos et al. 2015 Science



https://www.stockholmresilience.org/research/planetary-boundaries.html

https://www.planetaryhealthcheck.org/

1	2	3	4	5	6	7	8/9
Excellent Dark Sky Site	Dark Sky Site	Rural Sky	Suburban/Rural Transition	Suburban Sky	Bright Suburban Site	City/Suburbia Transition	City/Inner City Sky

RESEARCH

LIGHT POLLUTION

Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022

Christopher C. M. Kyba,[1,2]* Yiğit Öner Altıntaş,[1]†

The artificial glow of the night sky is a form of ligh
known. Developments in lighting technology compli
practice and emission spectra. We investigated the
2022 using 51,351 citizen scientist observations of
stars decreased by an amount that can be explain
year in the human visible band. This increase is fa
observations. We ascribe this difference to spectra
of light emissions.

Light pollution rapidly reducing number of stars visible to naked eye, study finds

Research suggests if trend continues, view of Orion's belt will disappear due to glow from artificial lighting

Comment | Published: 20 March 2023

A call for scientists to halt the spoiling of the night sky with artificial light and satellites

Fabio Falchi ✉, Salvador Bará, Pierantonio Cinzano, Raul C. Lima & Martin Pawley

Nature Astronomy **7**, 237–239 (2023) | Cite this article

Unfettered access to dark night skies is rapidly diminishing, due to light pollution and satellite constellation tracks. Scientists should do more to stand up to 'big light' and 'big space' and preserve this natural resource.

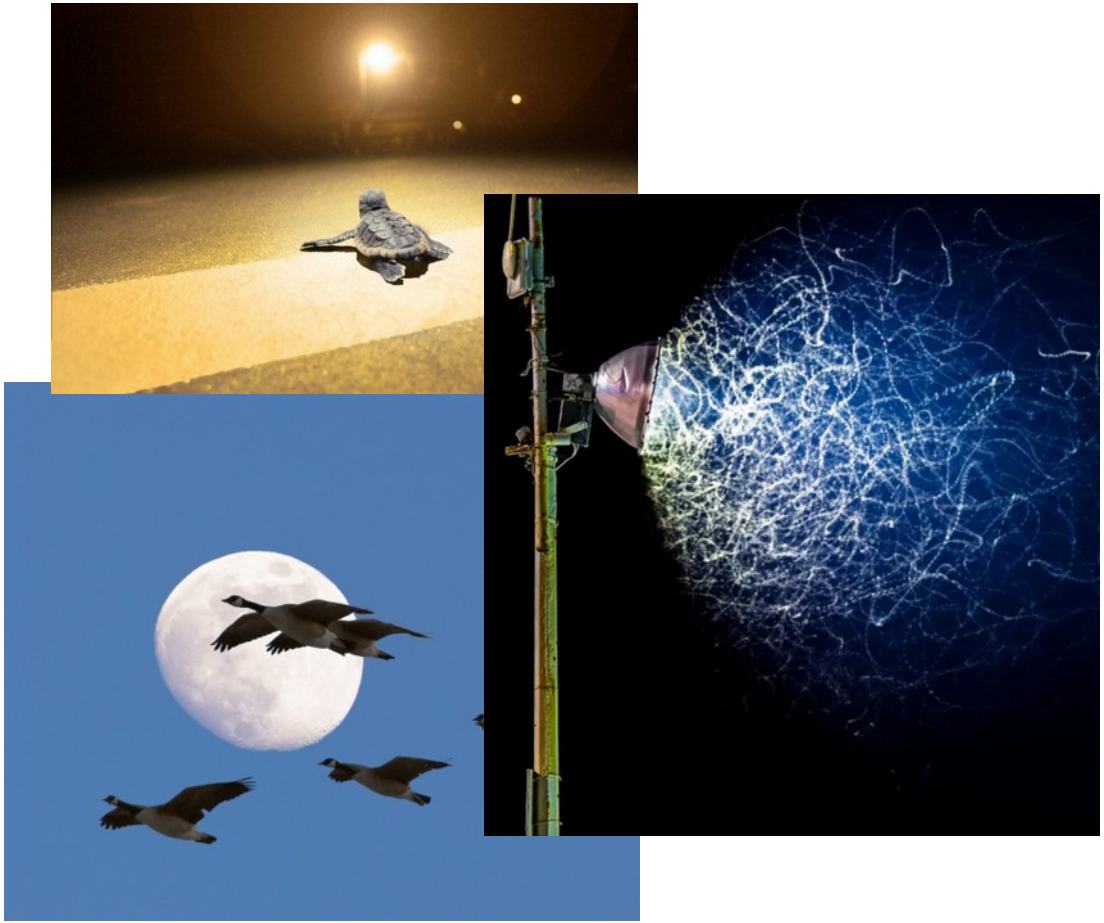
1 Excellent Dark Sky Site

2 Dark Sky Site

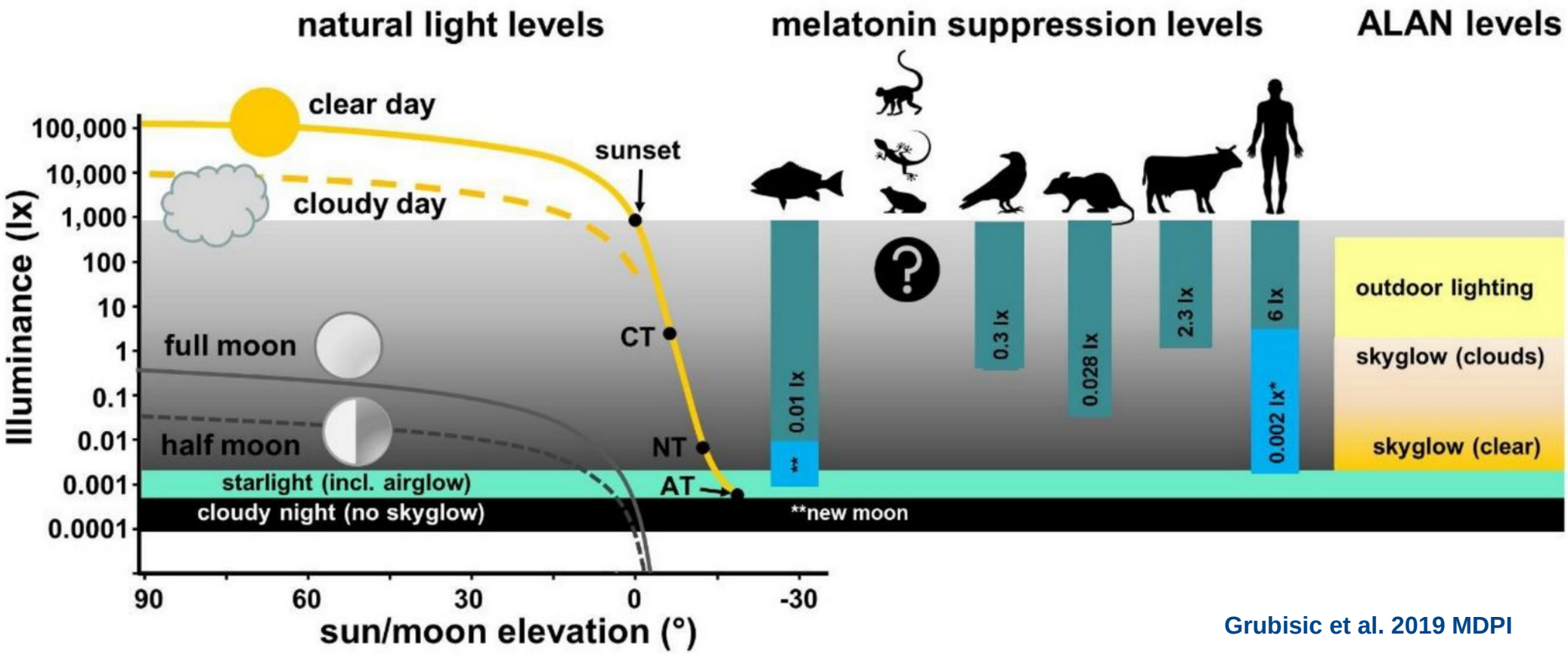
Effects on living organisms

Almost all affected by light, about half night active. Examples:
Sanders et al. 2020 Nature

- Affects human sleep, mental health, obesity, breast cancer, Alzheimer, etc.
  Wang et al. 2023 Env. Pollution, Luo et al. 2023 Front Pub Health, Voigt et al. 2024 Front Neurosci.
- Drives insects decline
  Owens et al. 2020 Biological Conservation
- Bird migration and building collisions
  Horton et al. 2023 Nature, Lao et al. 2020 Bio Cons
- Plant summer / winter cycle disrupted **Wang et al. 2025 Nature**

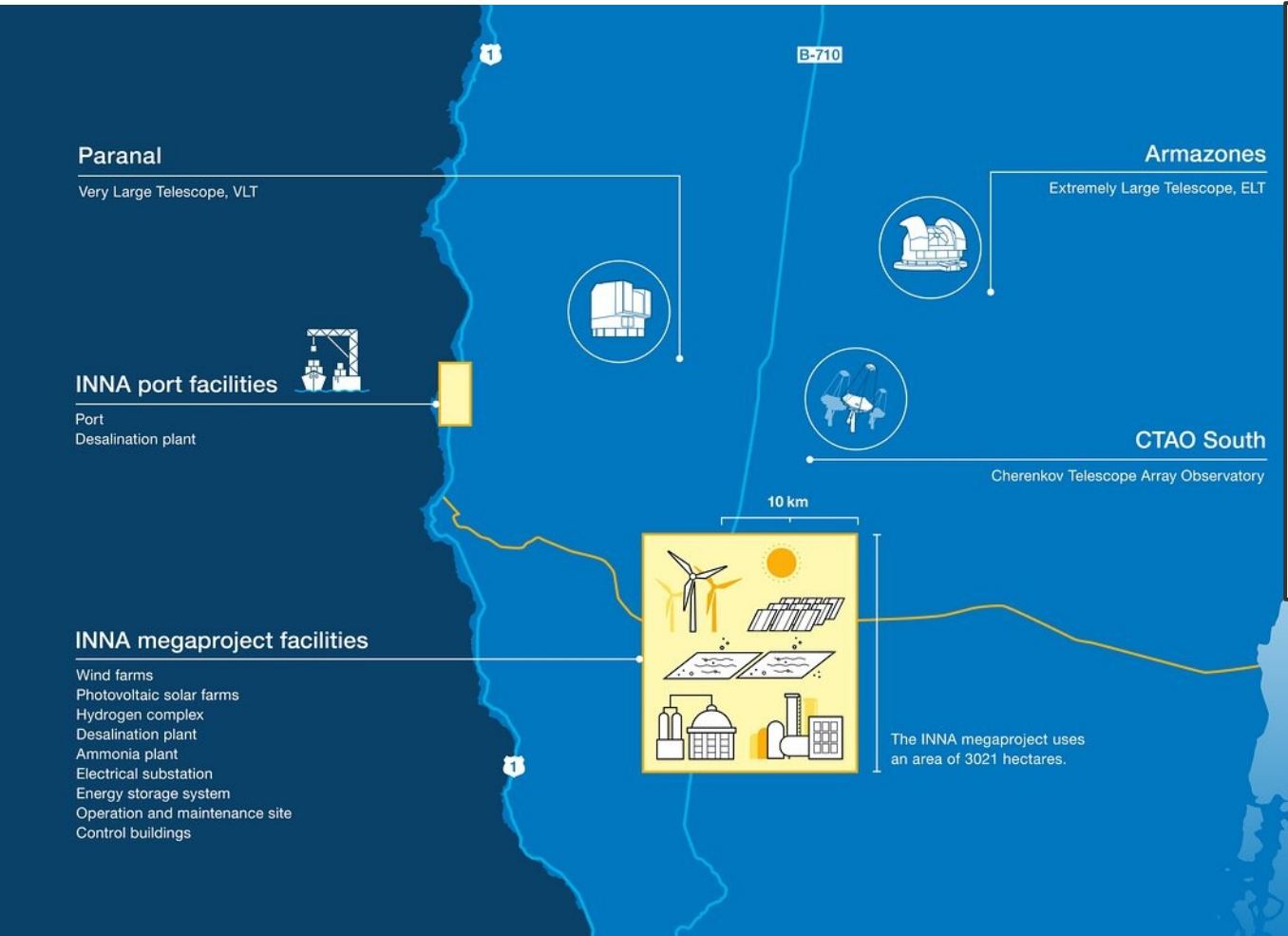


Melatonin suppression



Grubisic et al. 2019 MDPI

Effects on Astronomy



Press Release

New ESO analysis confirms severe damage from industrial complex planned near Paranal

17 March 2025

An in-depth technical analysis by the European Southern Observatory (ESO) has evaluated the impact of the INNA megaproject on the facilities at the Paranal Observatory, Chile — and the results are alarming. The analysis reveals that INNA would increase light pollution above the Very Large Telescope (VLT) by at least 35% and by more than 50% above the south site of the Cherenkov Telescope Array Observatory (CTAO South). INNA would also increase air turbulence in project could se Telescope (ELT),

nature

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nature > news > article

NEWS | 19 March 2025 | Correction 20 March 2025

Light pollution threatens fleet of world-class telescopes in Atacama Desert

The effects of a proposed green-energy facility in Chile could be devastating for some of the most powerful instruments available to astronomers.

Effects on Energy Consumption

Around 5-15% of electricity consumption for lighting.

For Germany, the lighting consumption is ≈50 TWh/yr, costing ≈10 billion €/yr (for 0.2 €/kWh).

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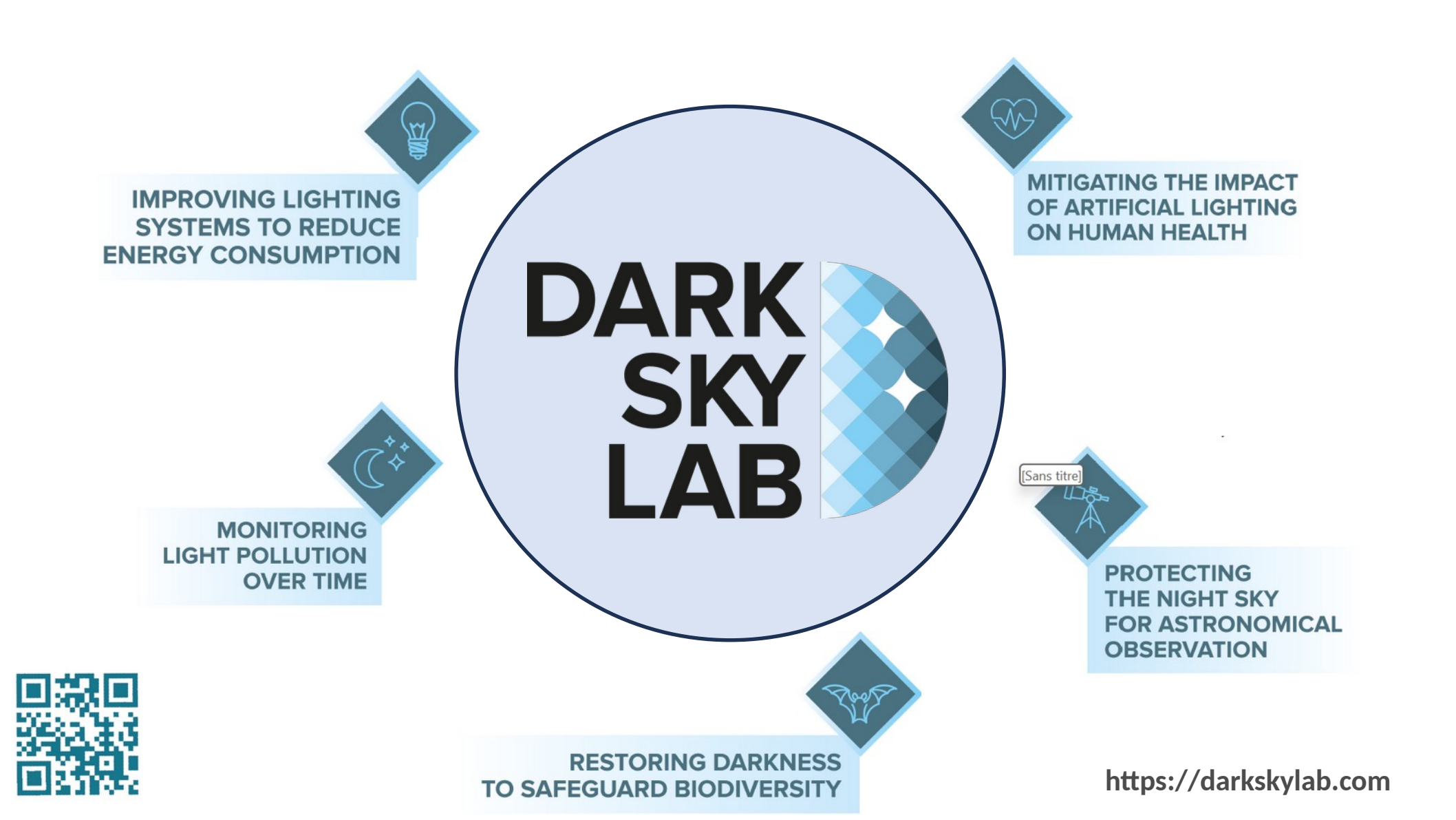

IMPROVING LIGHTING SYSTEMS TO REDUCE ENERGY CONSUMPTION
MITIGATING THE IMPACT OF ARTIFICIAL LIGHTING ON HUMAN HEALTH
DARK SKY LAB
MONITORING LIGHT POLLUTION OVER TIME
[Sans titre]
PROTECTING THE NIGHT SKY FOR ASTRONOMICAL OBSERVATION
RESTORING DARKNESS TO SAFEGUARD BIODIVERSITY
https://darkskylab.com

Sébastien Vauclair

Chairman and Co-founder

Doctor in Astrophysics

Philippe Deverchère

Software Engineer

Engineer, École Centrale de Lyon

Terr Oïko

Christophe Plotard

GIS Analyst and Web Project Manager

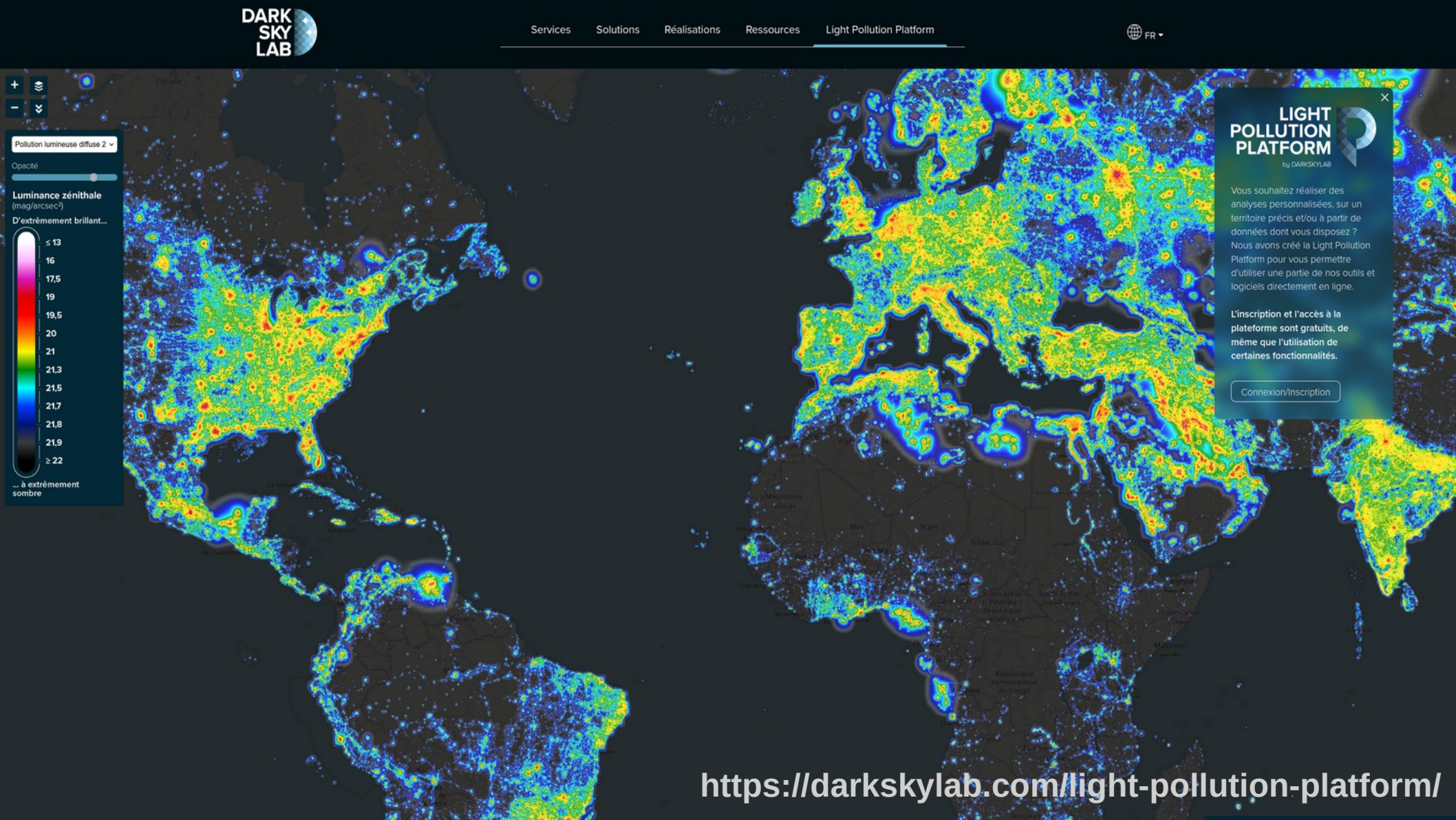
Master's degree in political science

Rolf Bühler

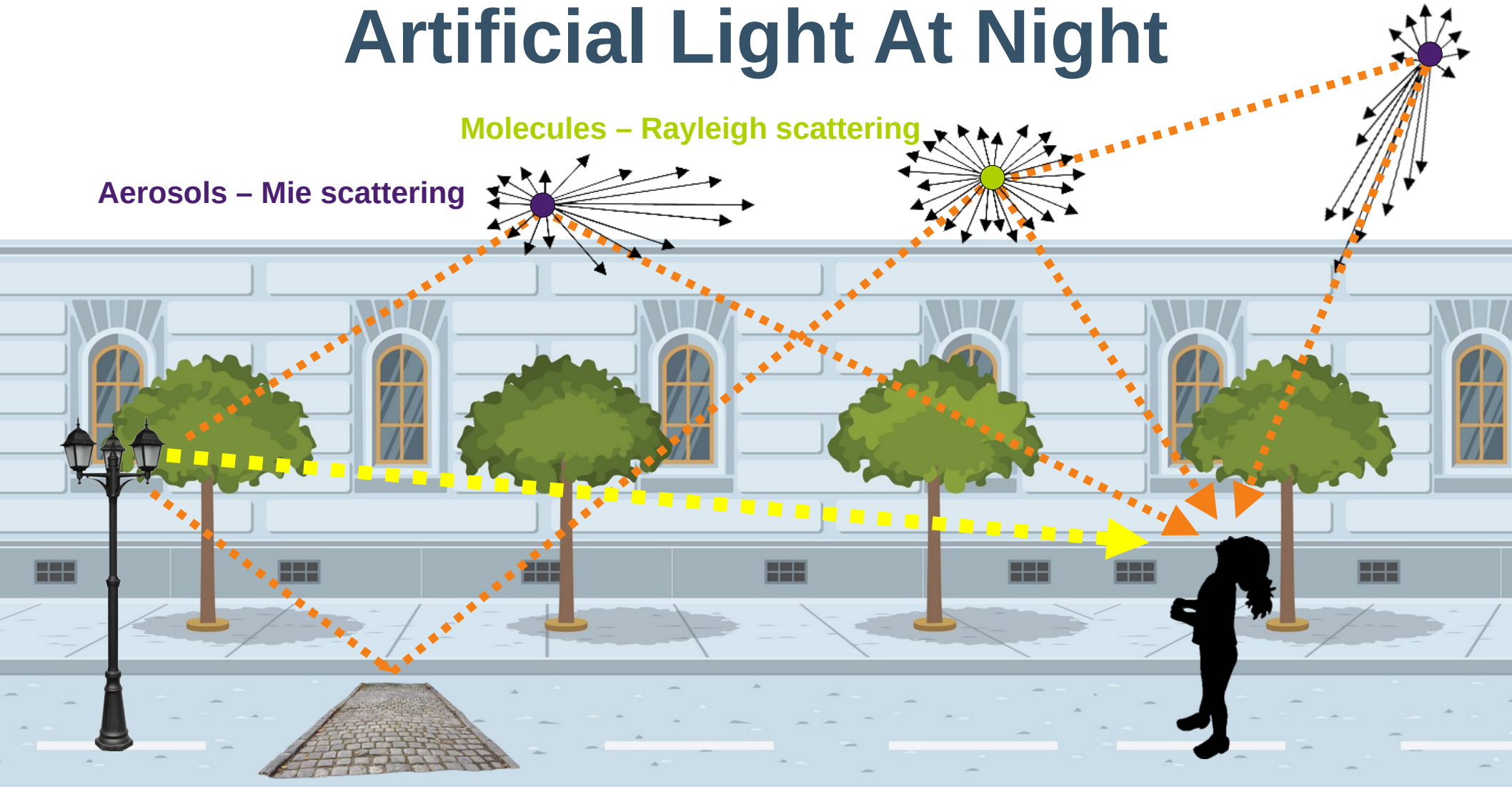
Research Engineer

Doctor in Astrophysics

LA TeleScop


DARK SKY LAB
Services
Solutions
Réalisations
Ressources
Light Pollution Platform
FR
Pollution lumineuse diffuse 2
Opacité
Luminance zénithale
(mag/arcsec²)
D'extrêmement brillant...
≤ 13
16
17,5
19
19,5
20
21
21,3
21,5
21,7
21,8
21,9
≥ 22
... à extrêmement sombre
LIGHT POLLUTION PLATFORM
by DARKSKYLAB
Vous souhaitez réaliser des analyses personnalisées, sur un territoire précis et/ou à partir de données dont vous disposez ? Nous avons créé la Light Pollution Platform pour vous permettre d'utiliser une partie de nos outils et logiciels directement en ligne.
L'inscription et l'accès à la plateforme sont gratuits, de même que l'utilisation de certaines fonctionnalités.
Connexion/Inscription
https://darkskylab.com/light-pollution-platform/

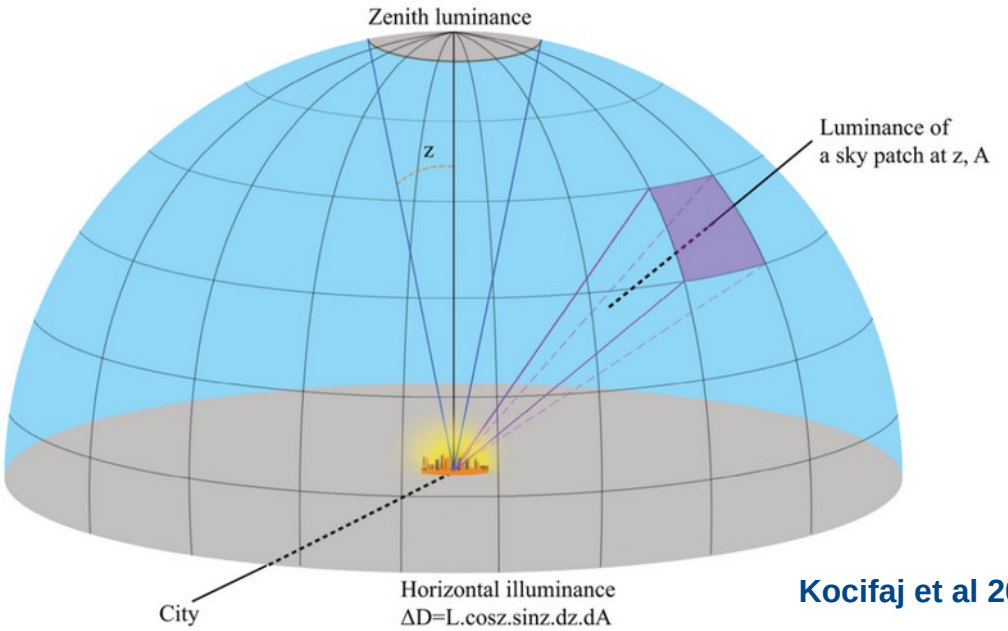
Artificial Light At Night



Luminance and illuminance

Luminance : brightness perceived by the human eye. Measured with a Sky Quality Monitor [cd m^{-2} ou mag $arcsec^{-2}$].

Illuminance : luminance integrated over a surface [lux].

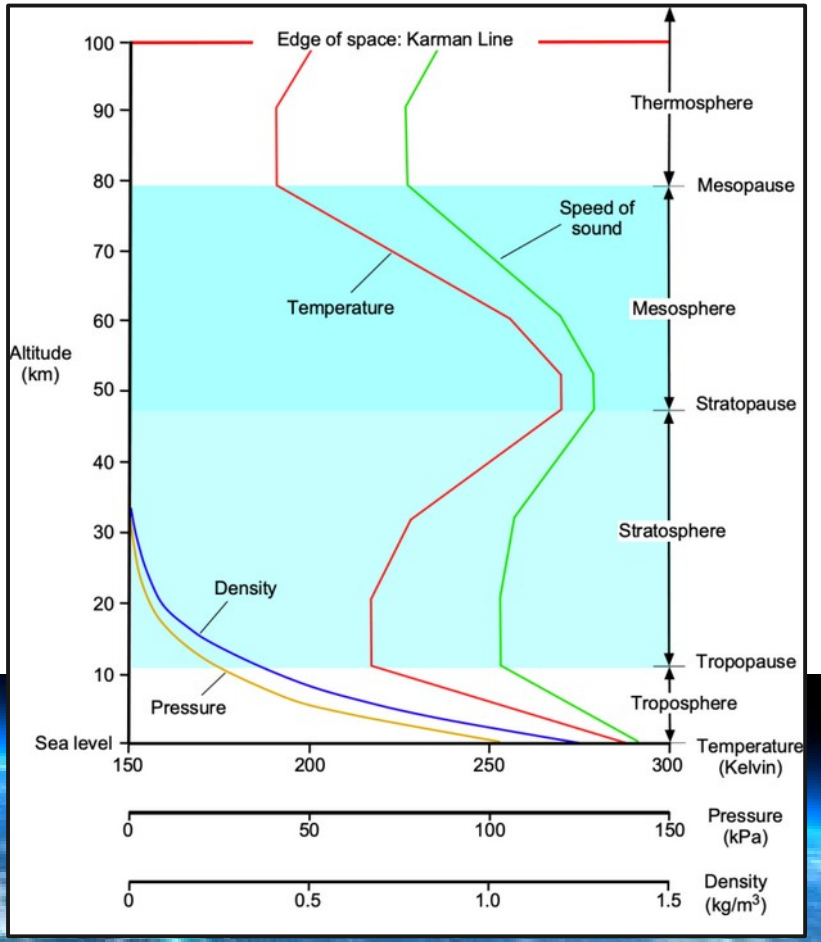


Kocifaj et al 2015

Model parameters

- Atmospheric density profile
- Aerosol type and content
- Height and coverage of clouds
- Light emission function (intensity, angle & spectra)
- Relief

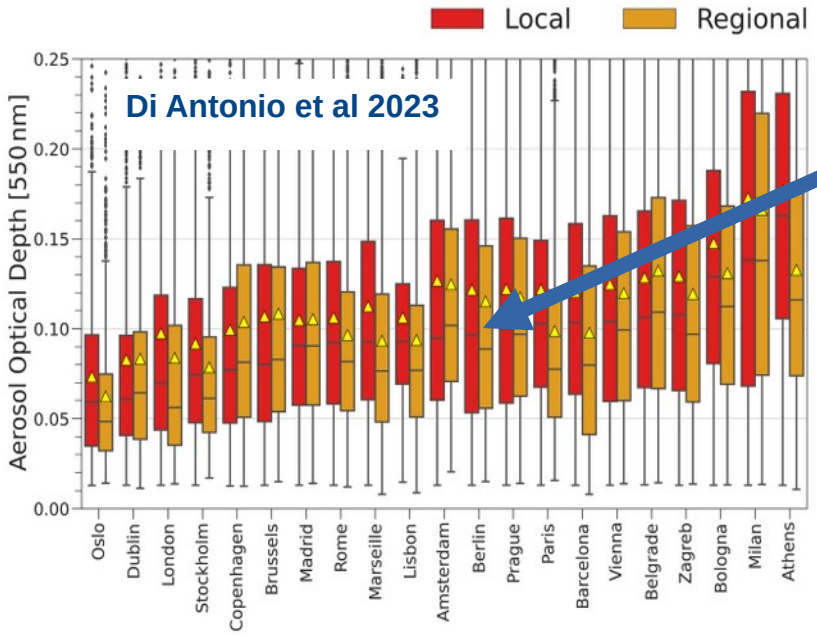
e.g. Cinzano et al. 2012, Wallner & Kocifaj 2023



Aerosols

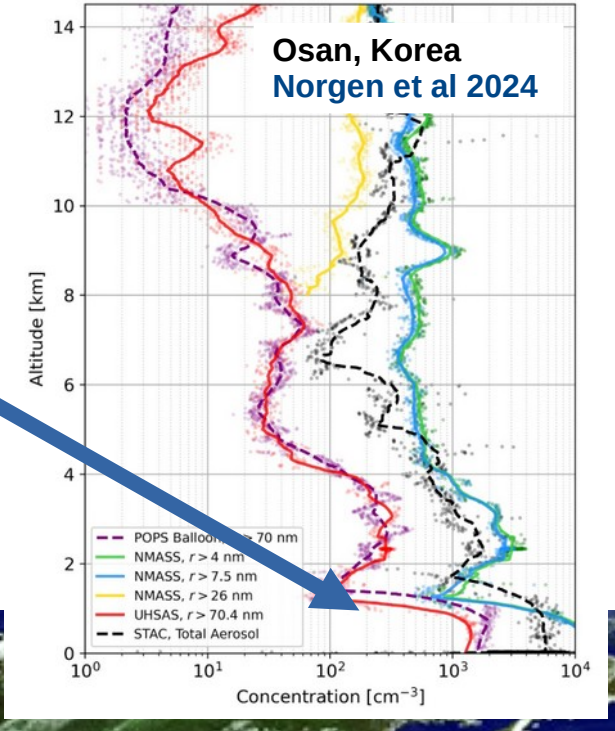
Solids or liquids in the atmosphere, size of 0.01-10 µm.
Density and composition vary strongly in space and time.

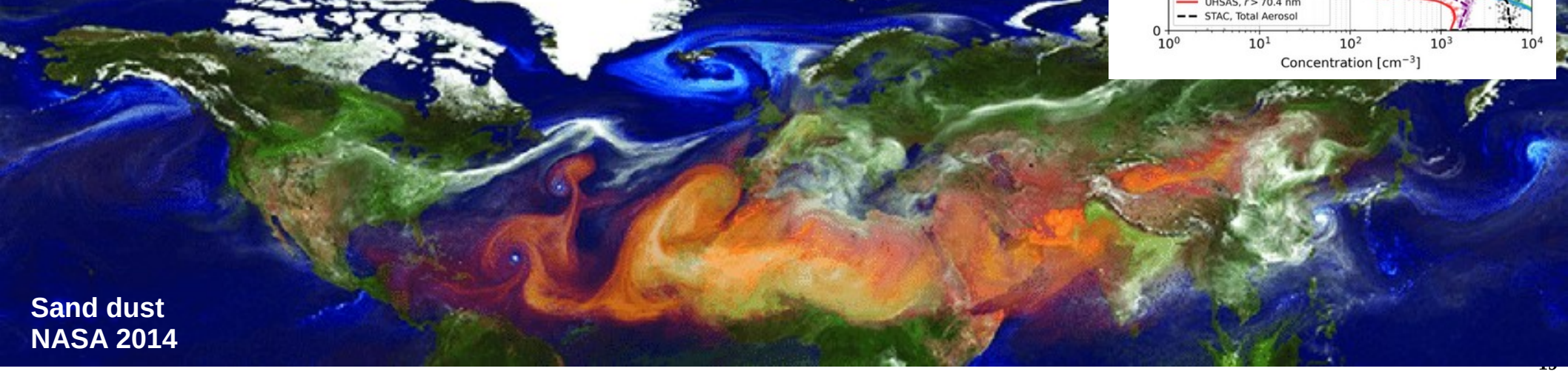
Aerosol optical depth (AOD) indicates the fraction of light from the ground that interacts with aerosols.



Aerosol concentration in Europe

Aerosol scattering mostly happens in the lower atmosphere (<2 km)

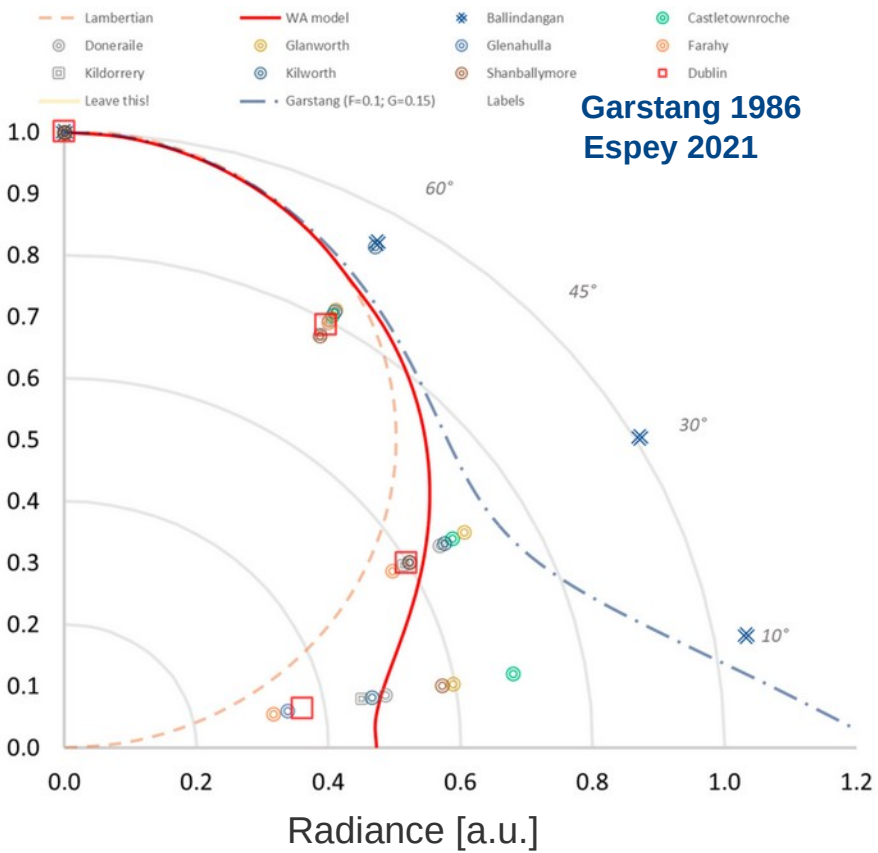




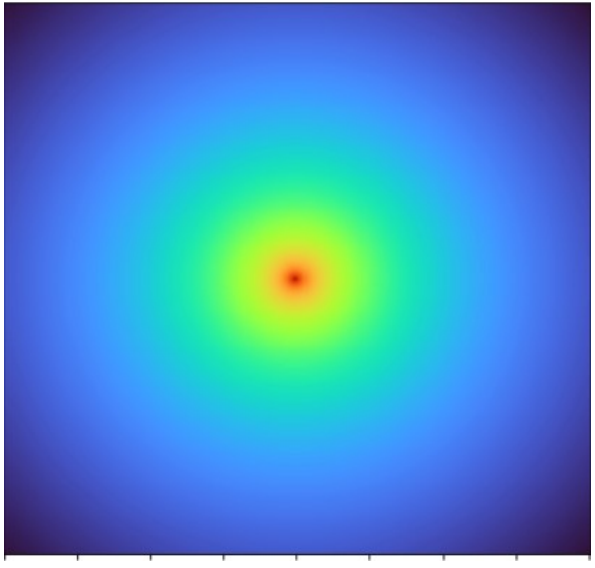
Emission Function

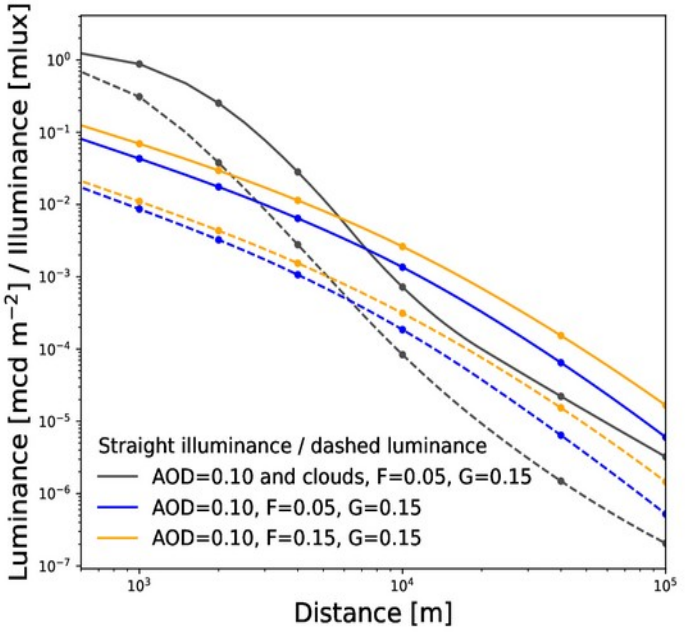
Garstang parametrization :

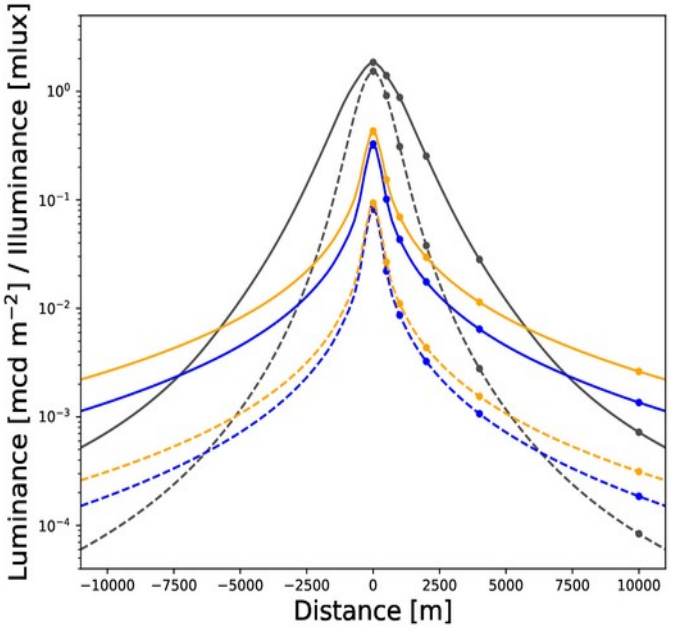
1) Horizontal light ($F \sim \theta^4$)
2) Reflected light ($G \sim \cos(\theta)$)



Diffusion Kernels



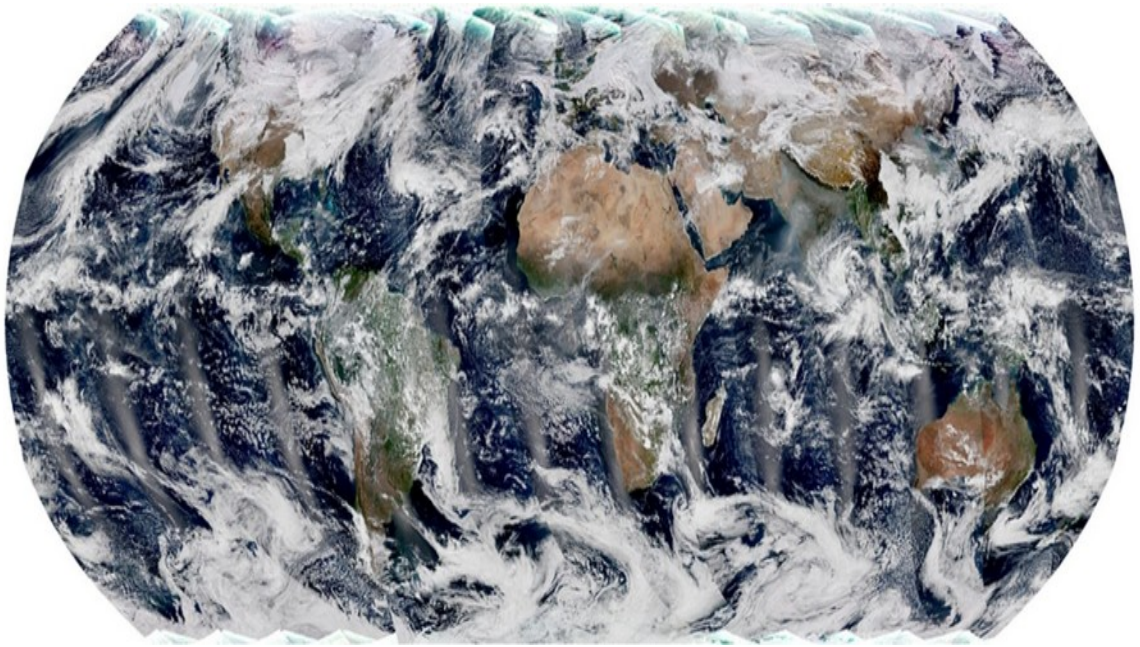




Simulated one VIIRS-DNB pixel with SkyGlow software **Kocifaj 2011**

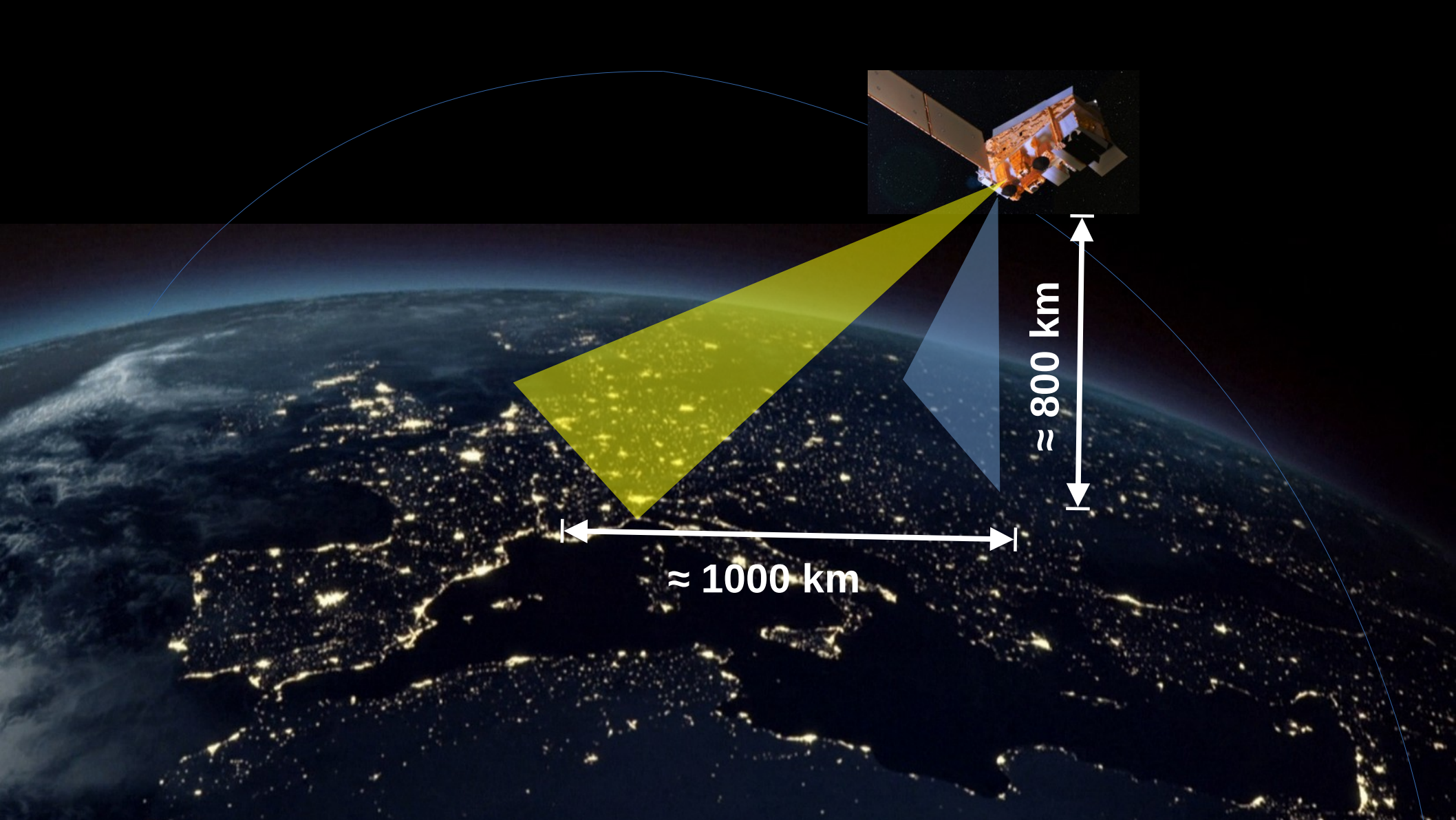
Satellite Observations

NASAs/NOAs Suomi-NPP VIIRS images each point on Earth once per day and once per night since 2011.

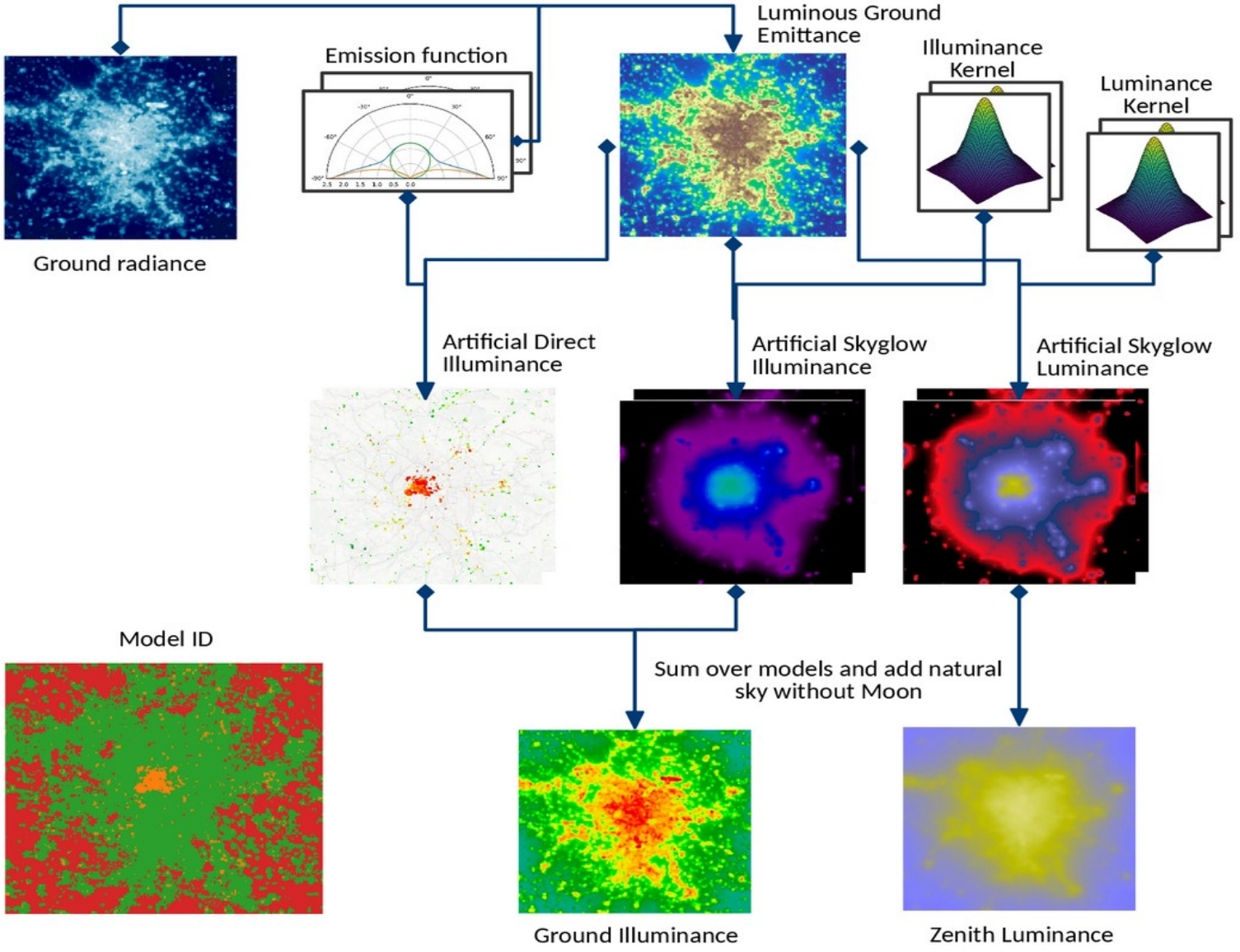


Satellite	VIIRS/ DNB	SDGSAT-1
Orbit height	750 km	505 km
Spatial resolution	740 m	Panchromatic: 10 m RGB: 40 m
Bands	500–900 nm	Panchromatic: 444–910 nm Blue: 424 ~ 526 nm Green: 506 ~ 612 nm Red: 600 ~ 894 nm
Swath width	3060 km	300 km
Number of data bits	14 bits	12 bits
Overpass time (Local time)	About 1:30	About 21:20
Radiation calibrations	Yes	Yes
Available Period	2012-present	2021-present

Wang et al. 2024


≈ 800 km
≈ 1000 km

Otus 3.0 simulation pipeline



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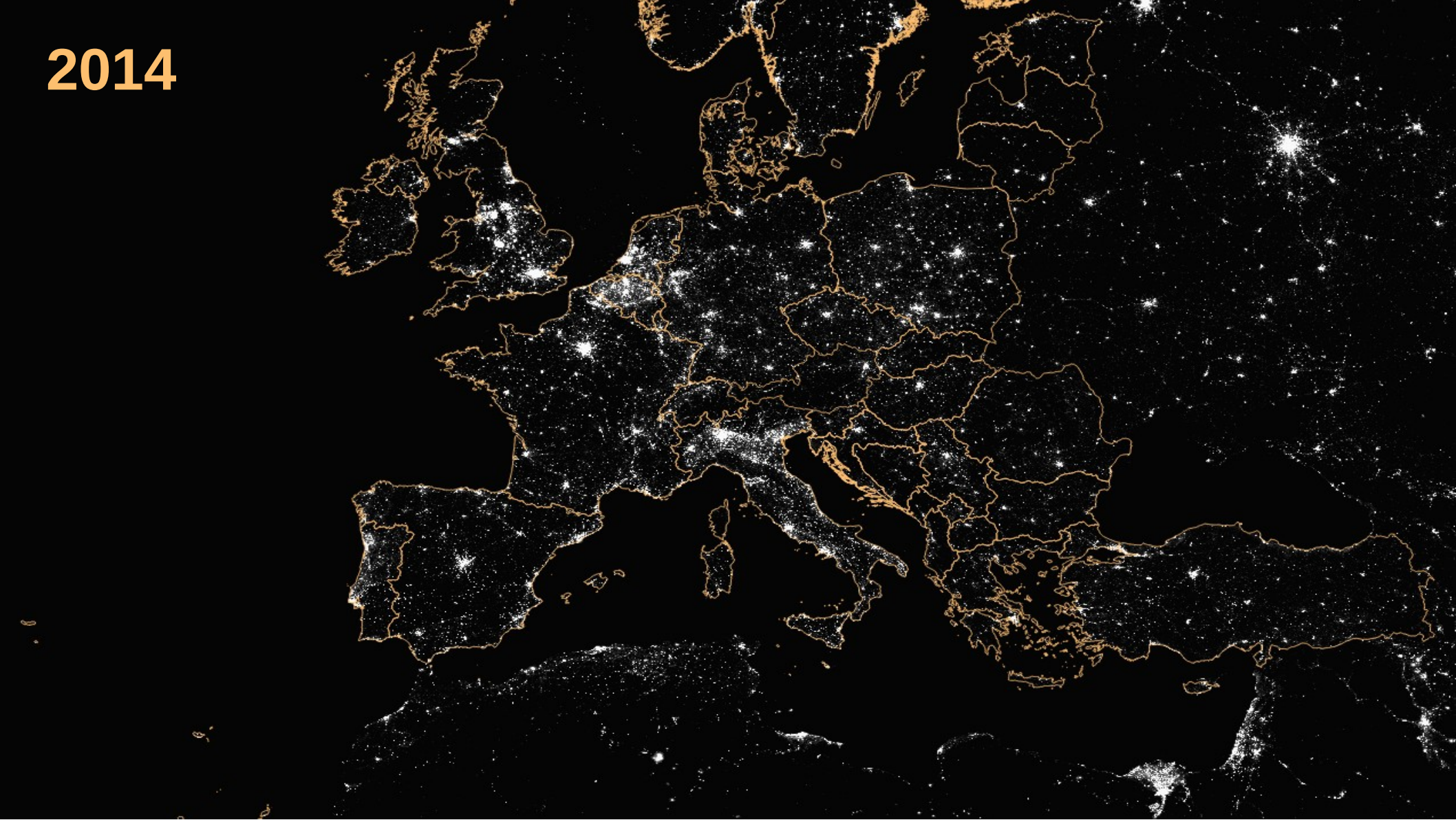
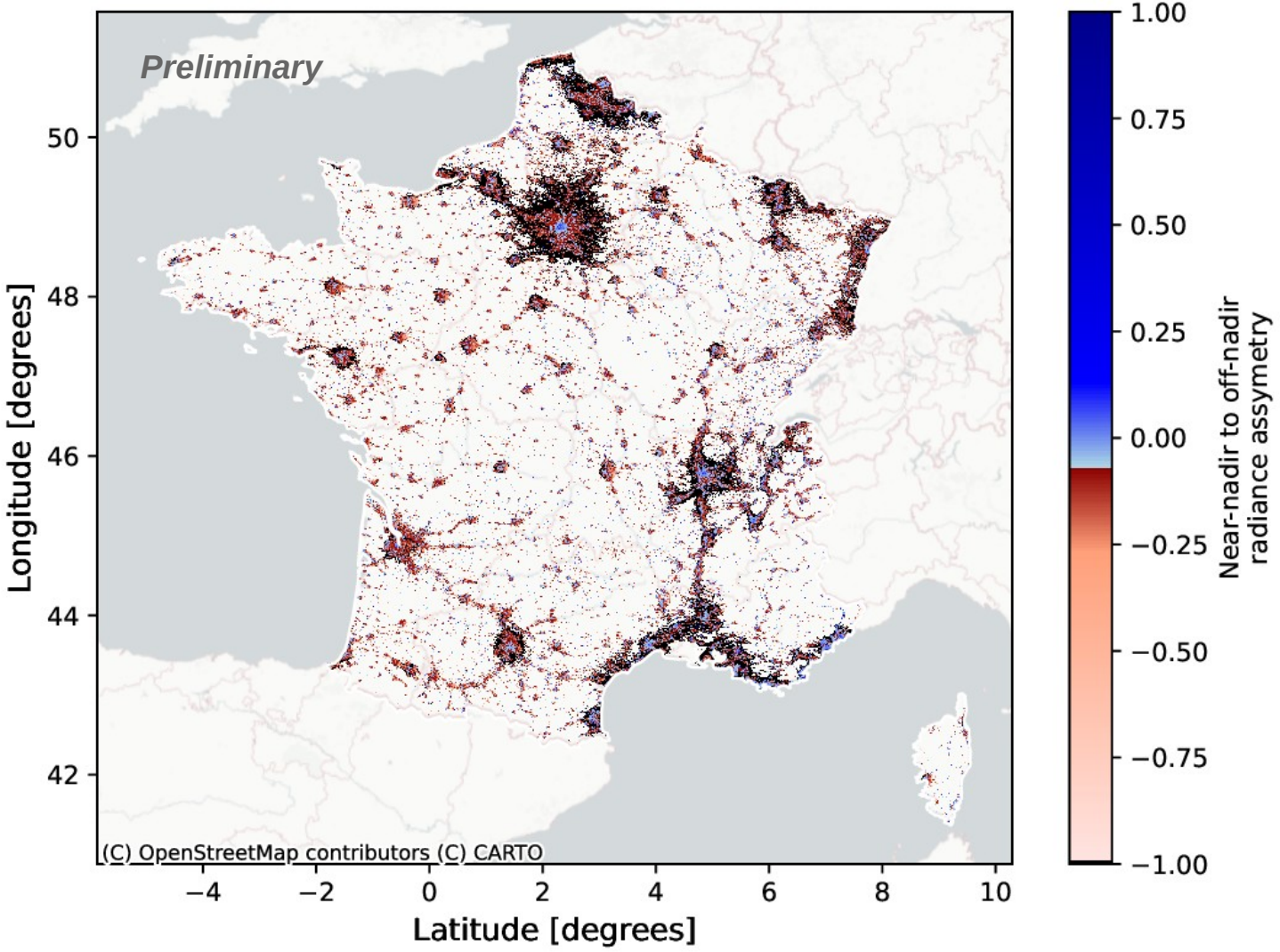

2014


2024

Model setup

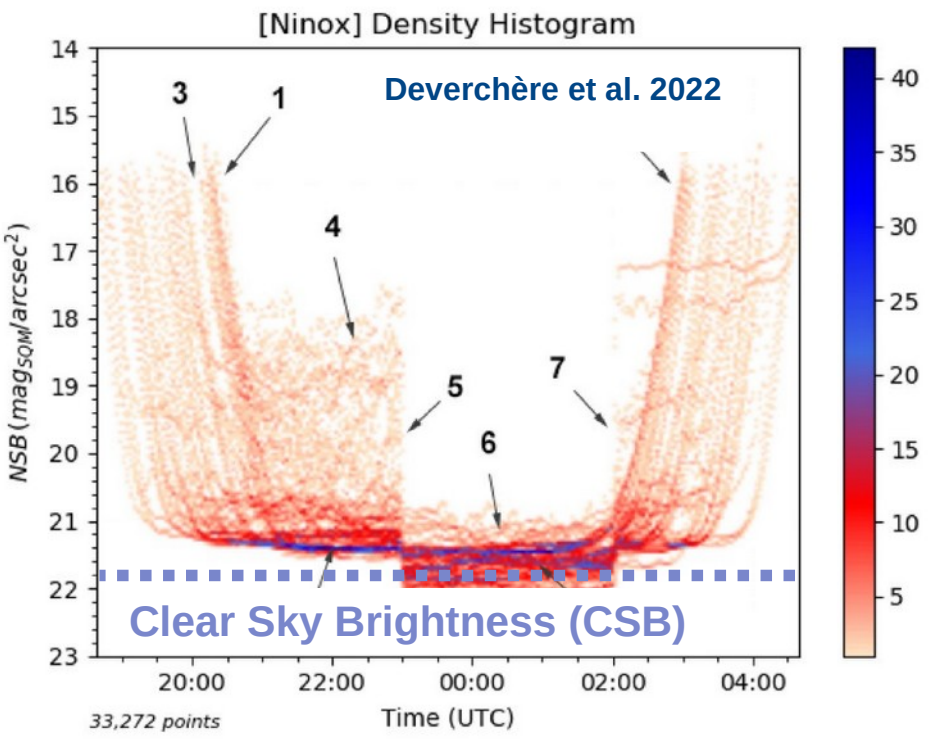
Emission
Ratio of near-nadir to off-nadir radiance varies → Two emission functions
(G=0.15, F=0.05 & G=0.15, F=0.15)

Atmosphere
Typical profile for mid-Europe
(AOD=0.1)

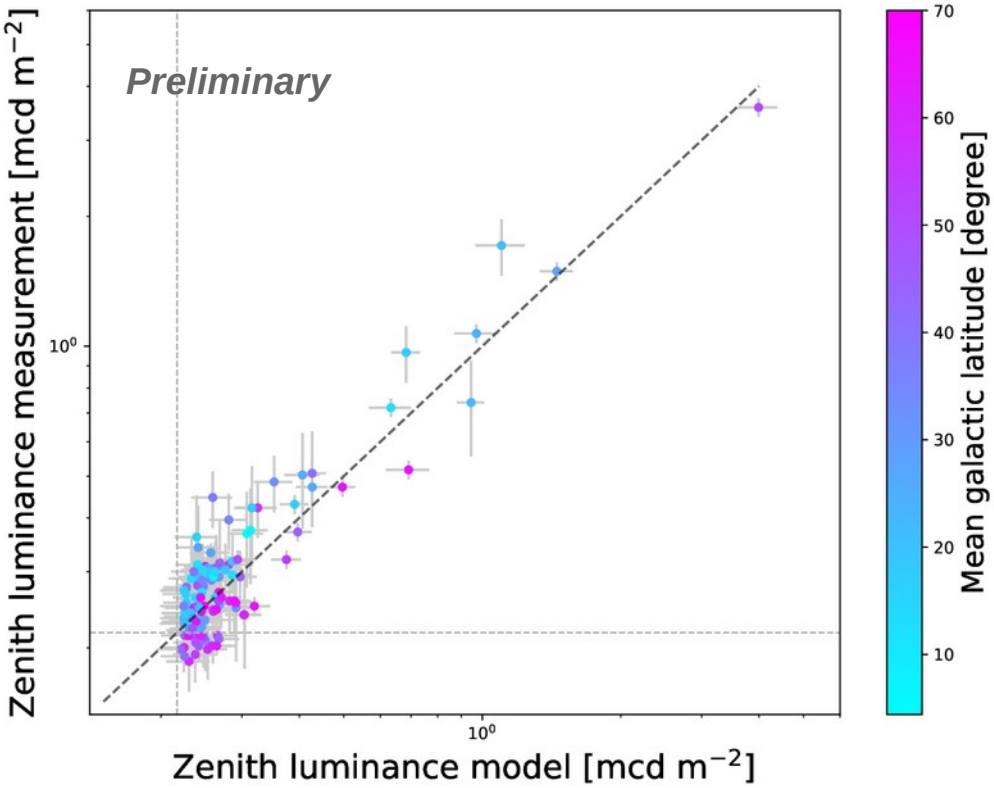


Model Calibration

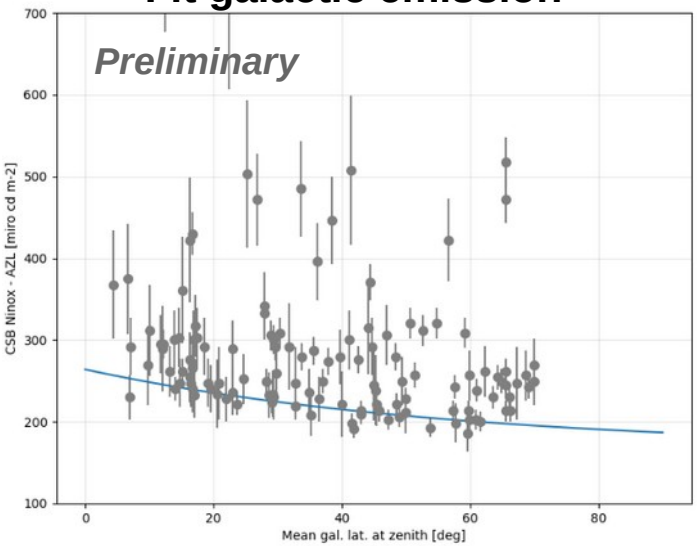
Unique database of zenith luminance measurements,
133 sites observed over many months each



Model Calibration



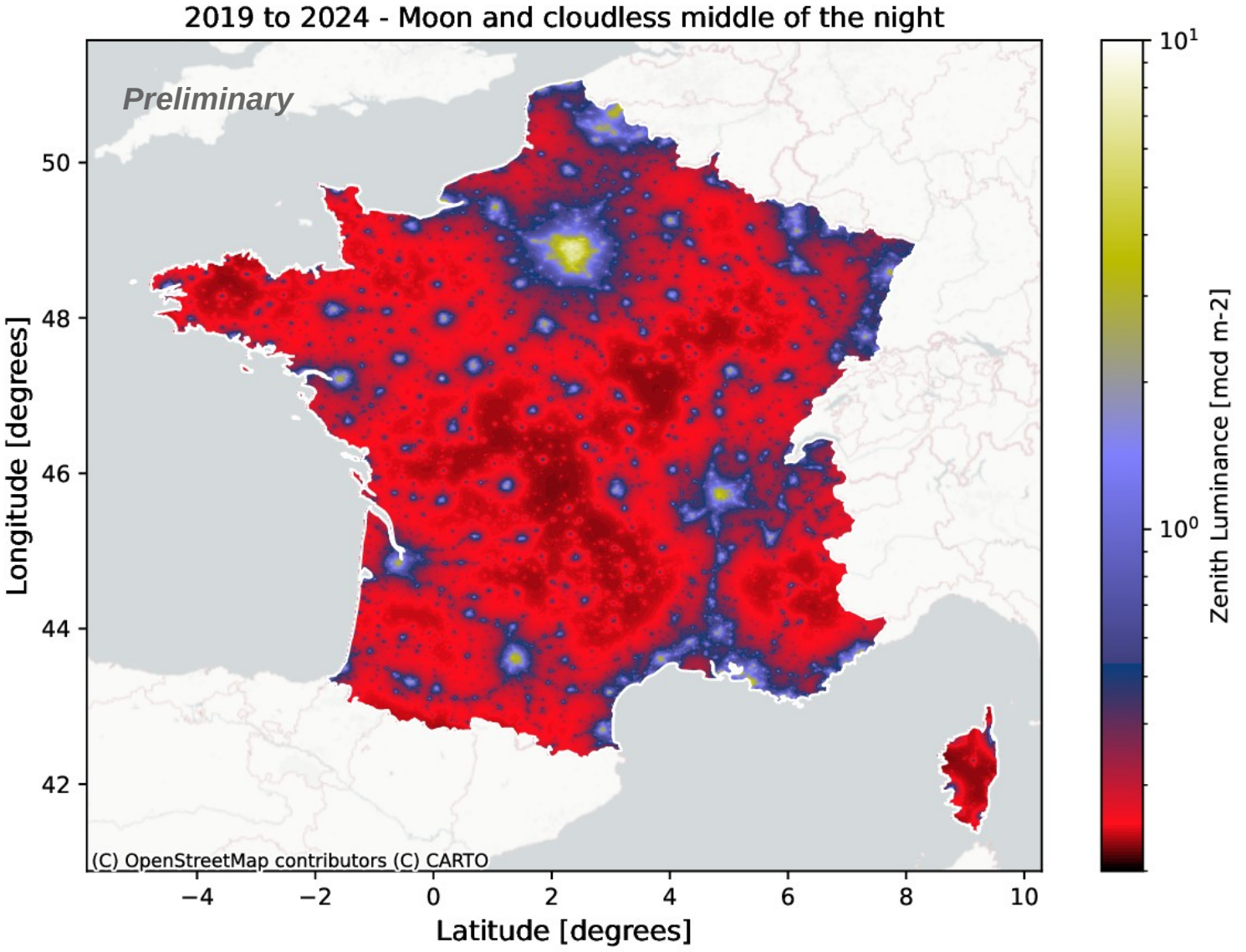
Fit galactic emission



Good agreement with a reduced chisquare of 1.09

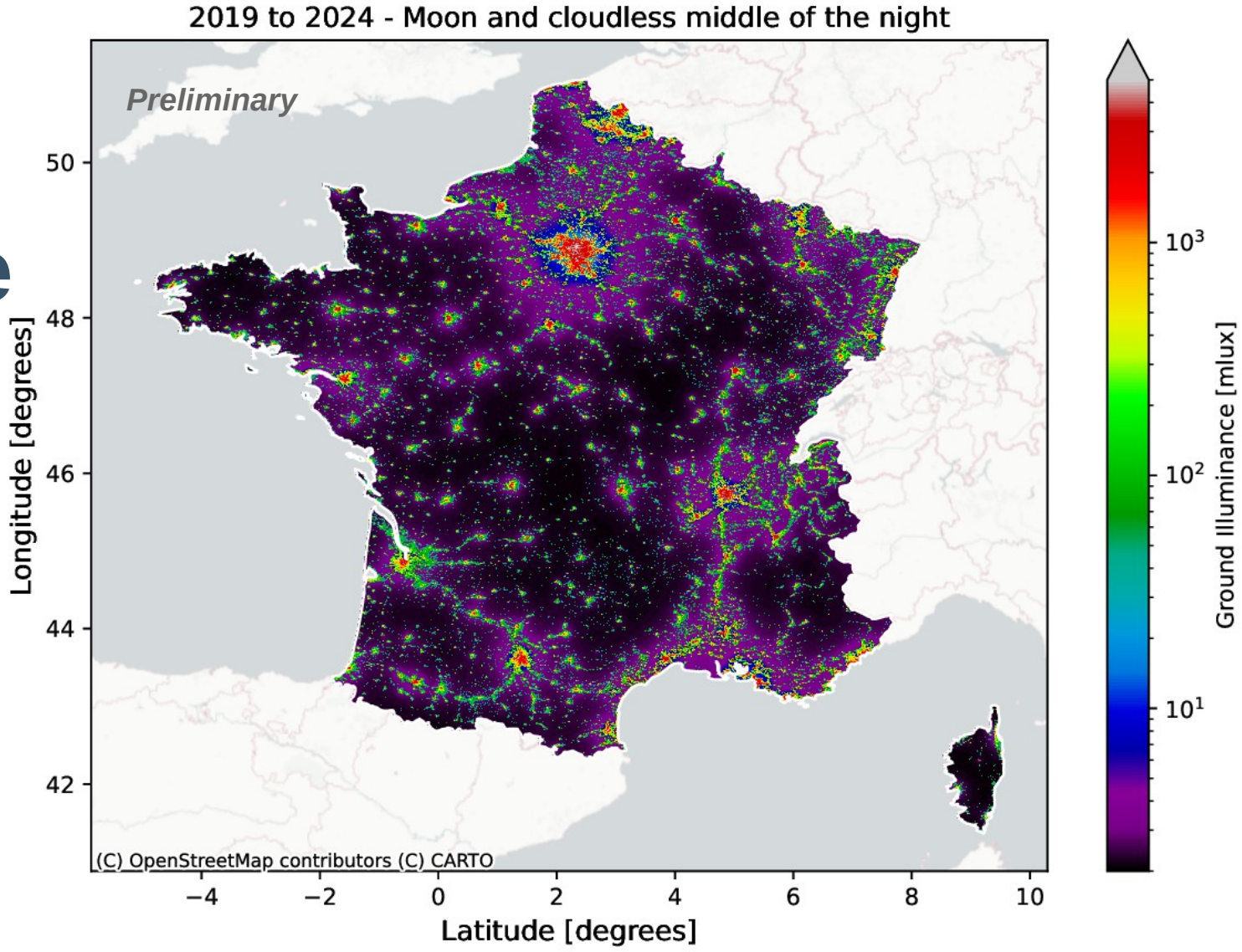
Total Zenith Luminance

Natural sky
≈0.2 mcd m^{-2}

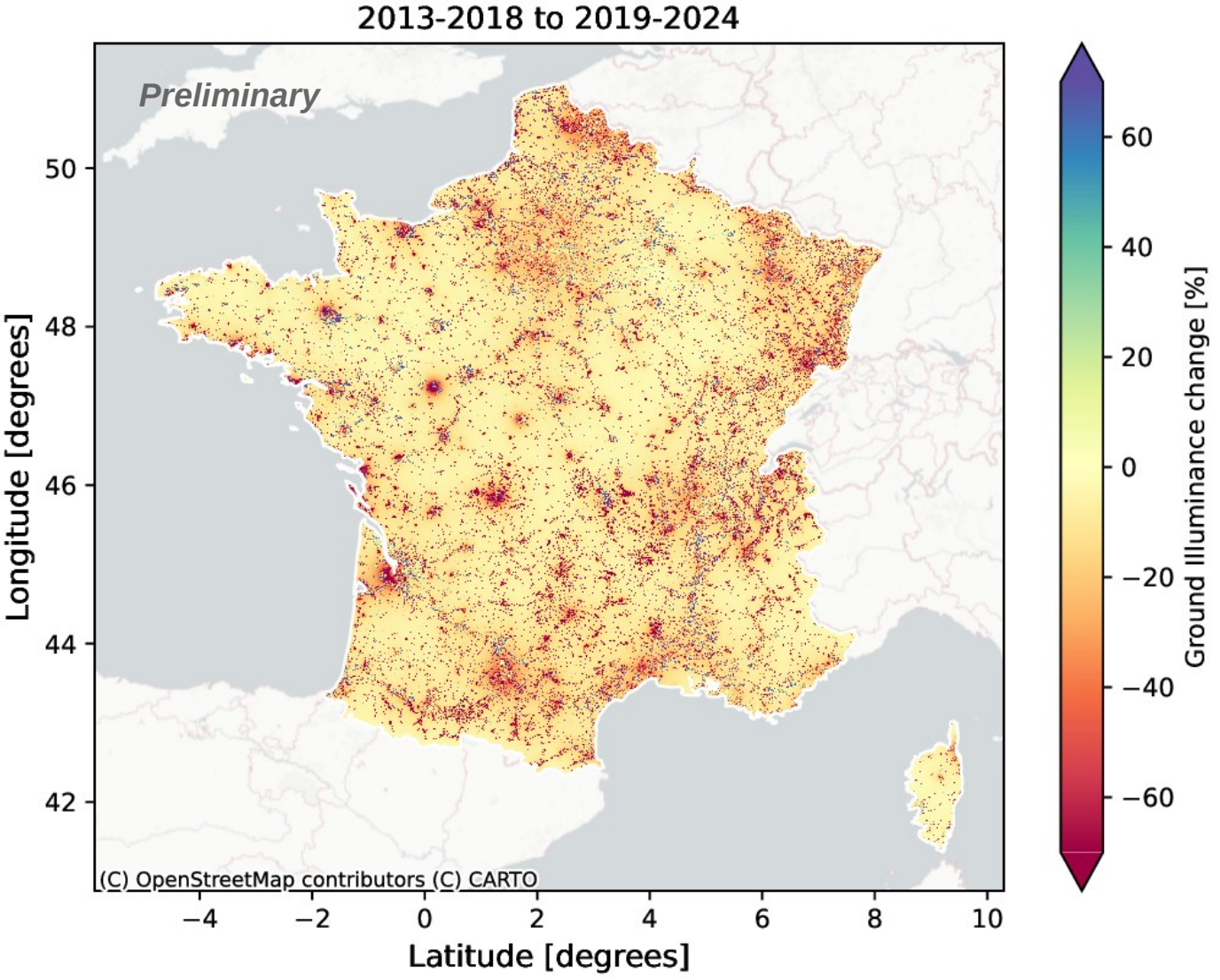


Total Ground Illuminance

Natural sky
≈0,6 mlux



Total Illuminance Evolution



Summary

We are in a crucial time of human history, planetary boundaries have been crossed. **Mass extinction of species ongoing, light pollution contributes** to this.

Light pollution has also consequences for human **health**, **energy** consumption and **science** (CTA might be directly affected).

We developed a new software, **Otus 3**, to calculate light pollution levels, **zenith luminance** and **ground illuminance** (for the first time).

Switch-off of lights at night and renewing lamps has lead to a **light pollution reduction of ≈30% in France** in the **middle of the night** over the past decade (in stark contrast to global trend).

Photo from Château d'Épinal in the Vosges

Credit: J.-F. HAMARD