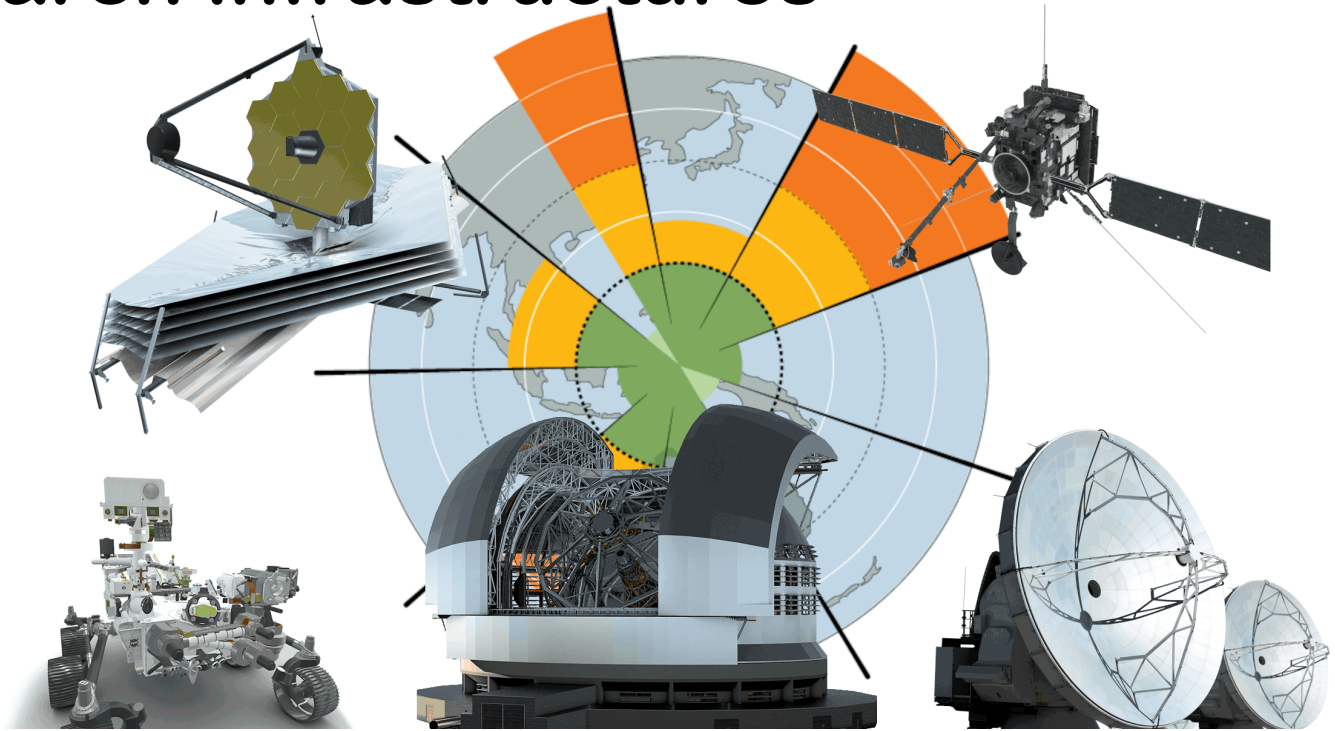
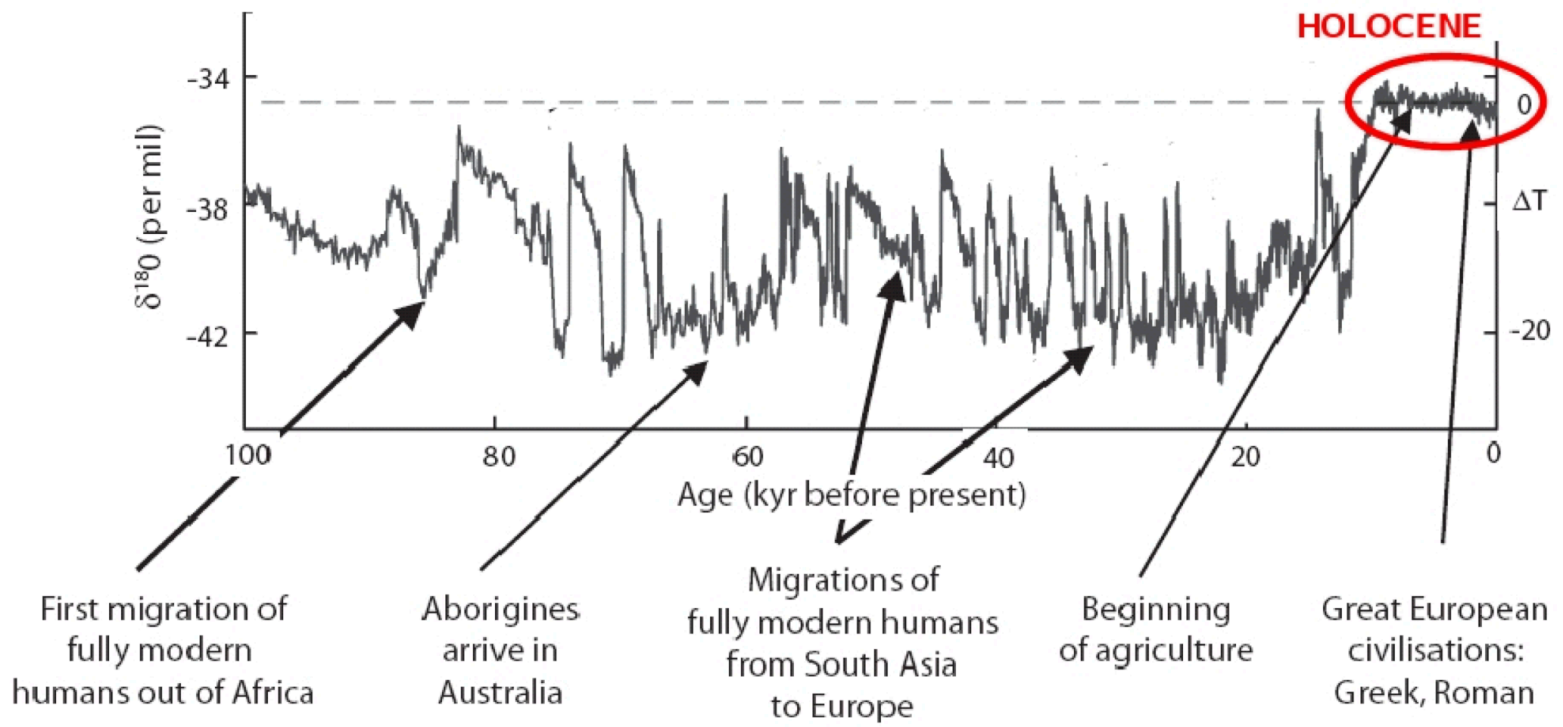
The environmental footprint of astronomical research infrastructures



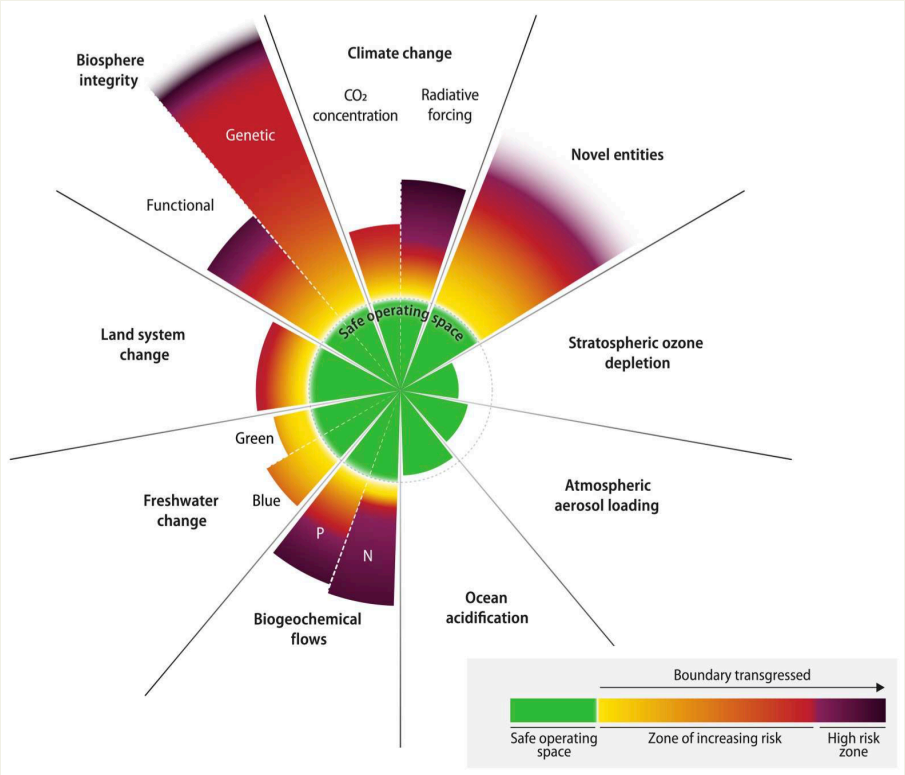
Jürgen Knödlseder & Didier Barret @jknodlseder@astrodon.social

The climate history of Homo Sapiens



Rockström et al. (2009), Ecology and Society, 14, 32

Planetary Boundaries



Richardson et al. (2023), Science Advances, 9, eahd2458

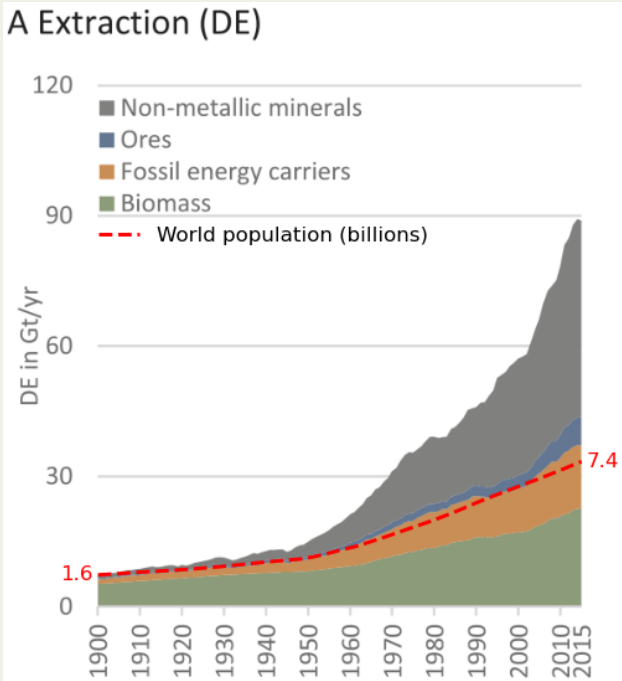
Science-based analysis of the risk that human activities will destabilise the Earth system at the planetary scale

We are no longer in the safe operating zone for 6* out of 9 planetary boundaries

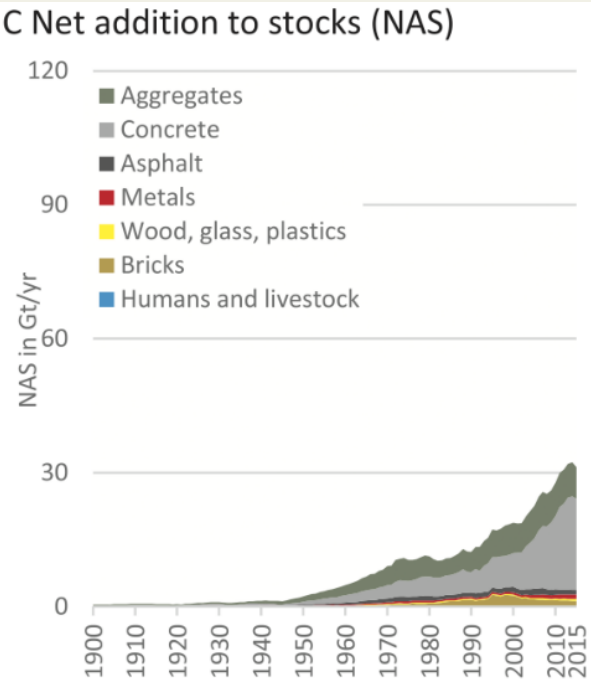
***novel entities, climate change, biosphere integrity, land-system change, freshwater change, biogeochemical flows**

Socioeconomic metabolism of the global economy

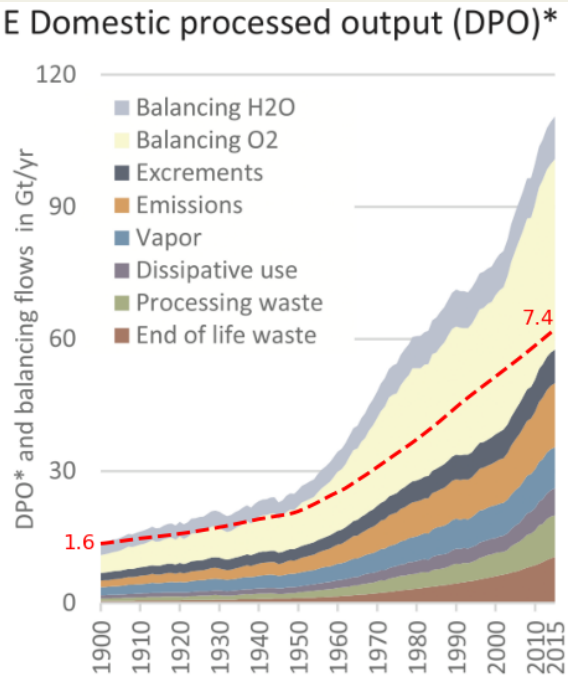
Extraction



Infrastructures



Waste



Adapted from Krausmann et al. (2018), Global Environmental Change, 52, 131-140

Environmental impacts: an ethical responsibility

COMETS – CNRS ethics committee

Integrating environmental issues into the conduct of research - An ethical responsibility

5 December 2022

"A very broad agreement is emerging on the need for research, like any activity, to contribute to the effort to reduce greenhouse gas emissions."

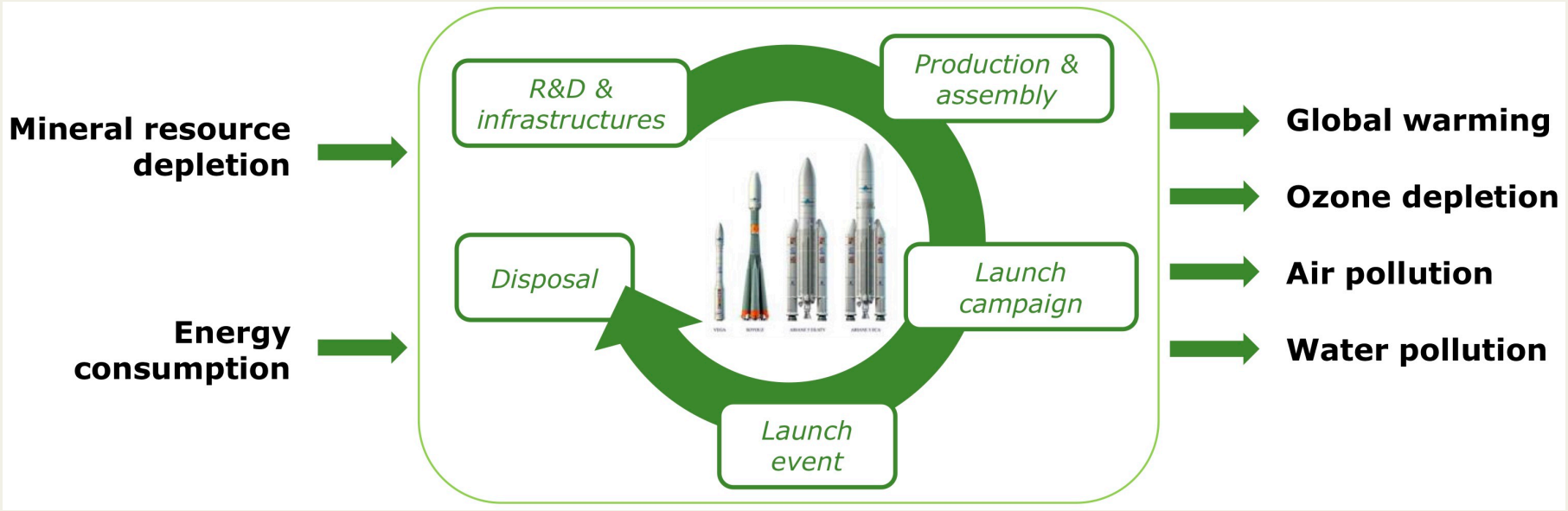
"Taking the environment into account is an integral part of research ethics"

It is "the responsibility of research stakeholders to think about their activity with regard to environmental issues"

"This responsibility concerns not only the impact of research practices but more generally the negative or positive environmental impact that the choice of this or that research subject and this or that path to treat it can generate for the environment in the broad sense, short, medium or long term."

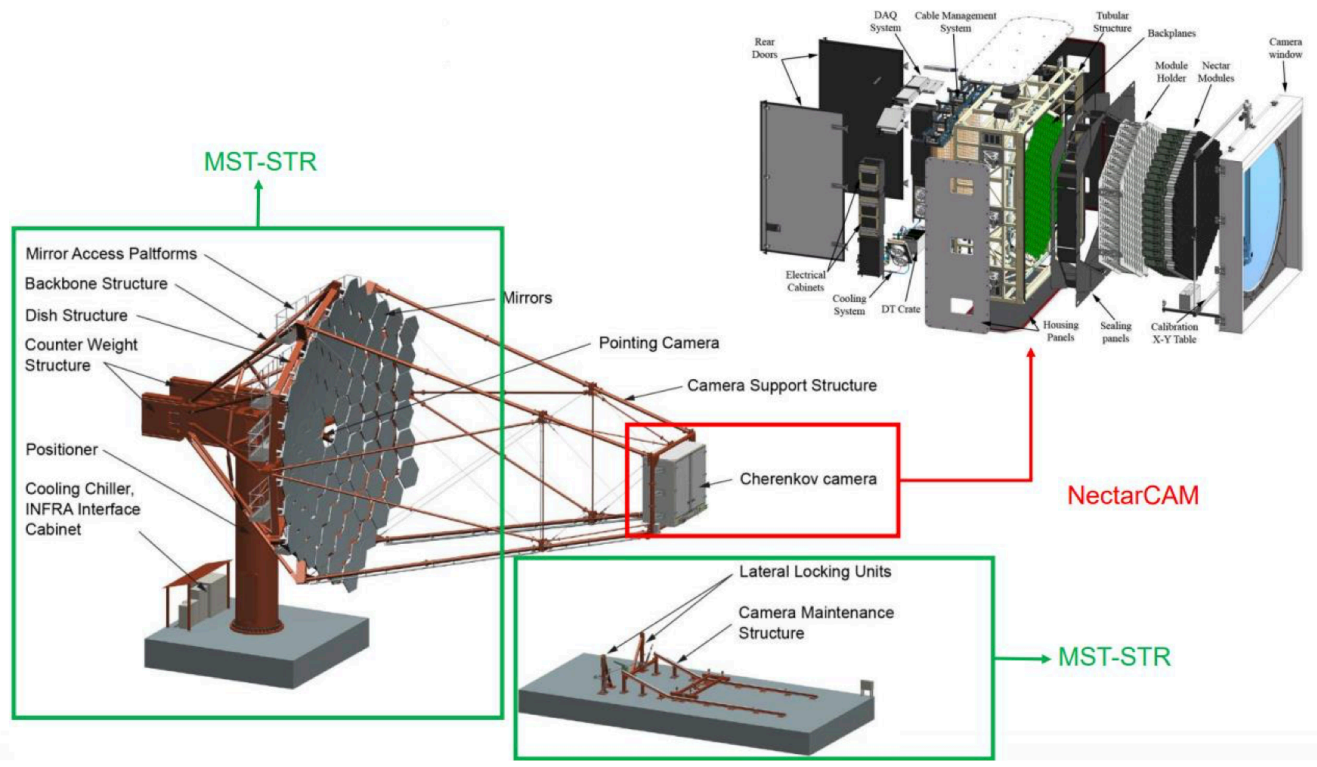
Assessing environmental impacts

Example: Environmental Lifecycle Analysis of Space Activities (ESA Clean Space)



Chanoine (2017), Clean Space industrial Days

CTA* Mid-Sized telescope



Adapted from Dos Santhos Ilha et al. (2023), in preparation

*Cherenkov Telescope Array

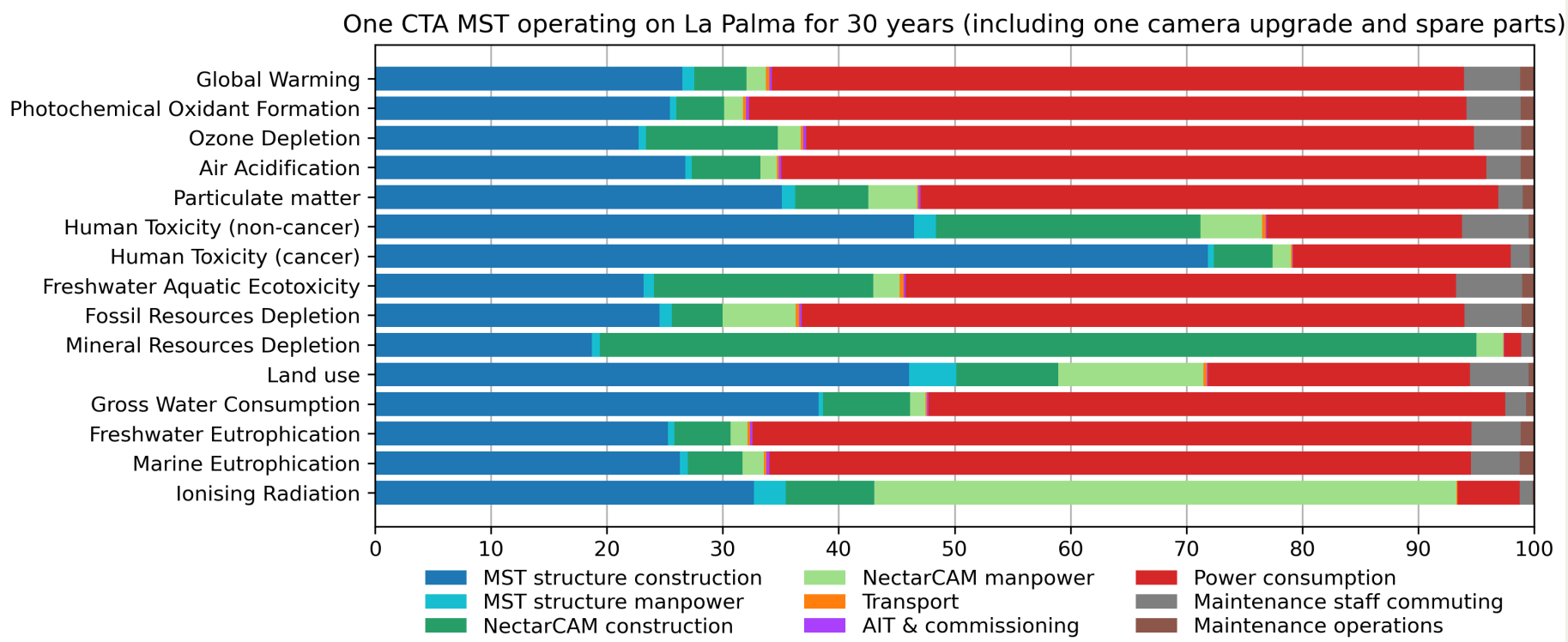
9 mid-sized telescopes to be deployed at the northern site in La Palma (14 at southern site in Chile with different camera)

Cradle-to-grave (excluding design & disposal phases)

Assessment done using SimaPro & ecoinvent

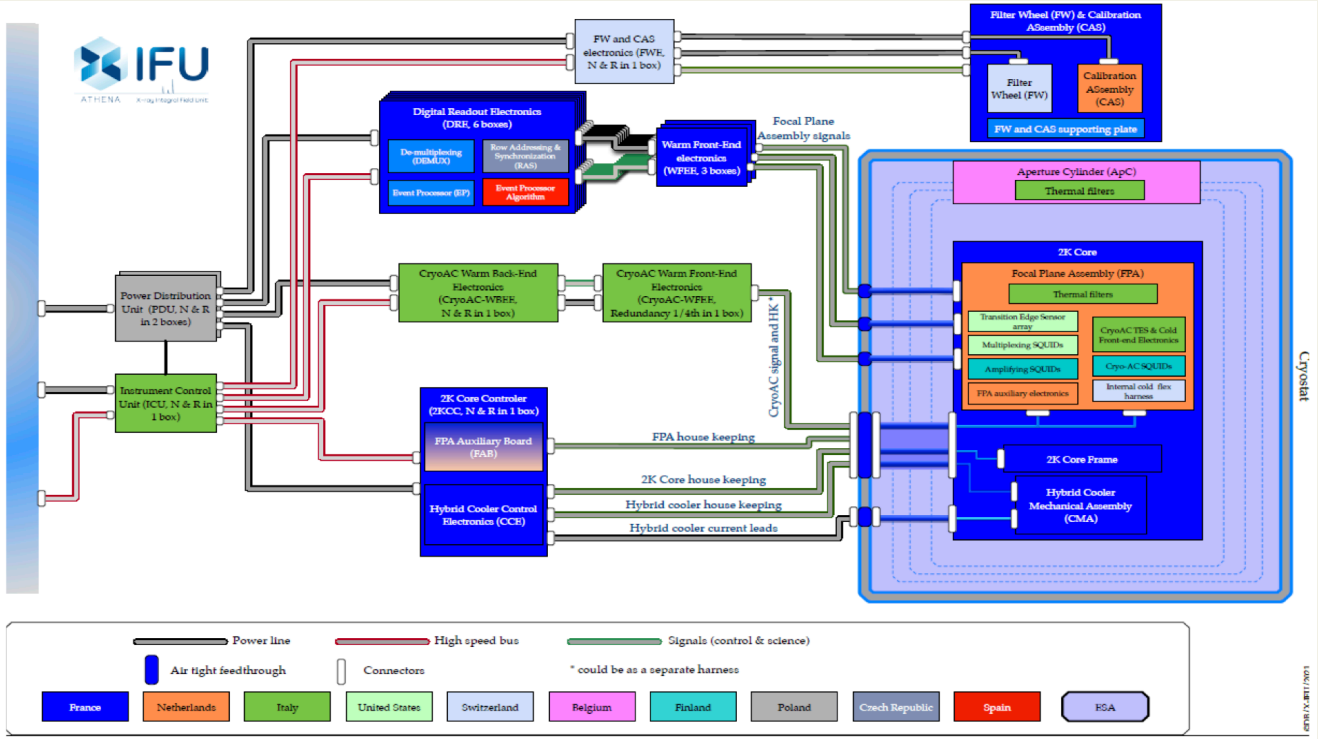
MST weight:
- Foundation: 464 tonnes
- Structure: 82 tonnes
- Camera: 2.1 tonnes

Impacts of CTA Mid-Sized Telescope



Adapted from Dos Santhos Ilha et al. (2023), in preparation

Athena X-IFU* instrument



Adapted from Barret et al. (2023), in preparation

*X-ray Integral Field Unit

Cryogenic bolometer using Transition Edge Sensors (TES)

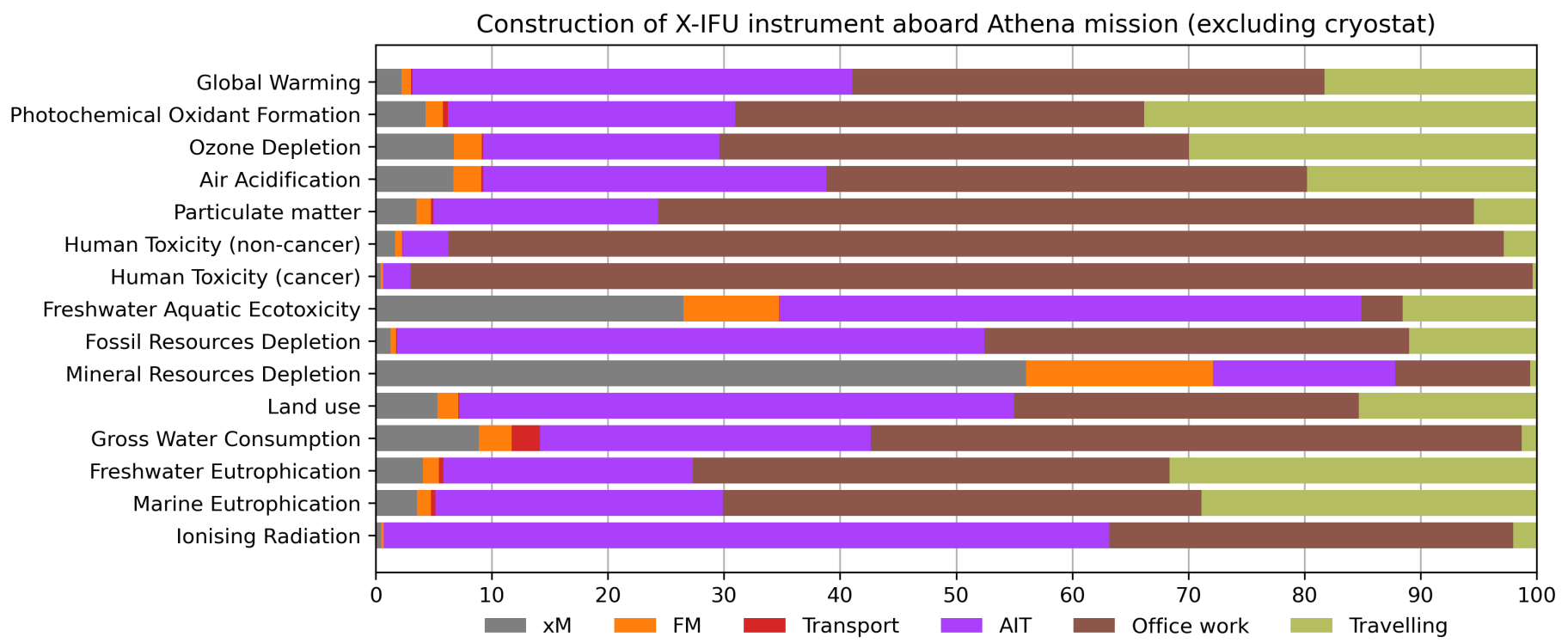
Only elements under X-IFU Consortium responsibility included (excluded cryostat)

Cradle-to-gate (excluding integration on satellite, launcher & launch, use phase, disposal phase)

Assessment done using SimaPro & ecoinvent

Weight of assessed system:
- 220 kg

Impacts of X-IFU instrument



Adapted from Barret et al. (2023), in preparation

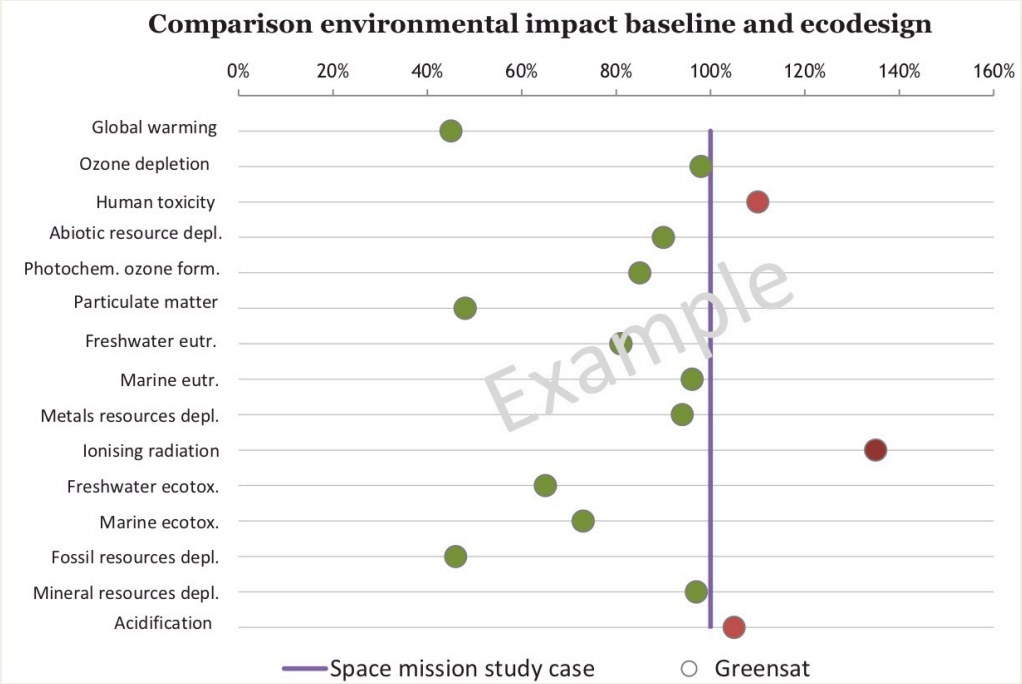
Resulting characterisation factors

Category	Unit	Foundation	Structure	Camera	X-IFU
Acidification	mol H^+ eq / kg	0.0013	0.061	0.34	561.0
Climate change	kg CO_2 eq / kg	0.30	10.1	49.2	121 429.6
Freshwater ecotixicity	CTU eq / kg	1.2	53.1	978.6	1 602 734.6
Particulate matter	desease inc. / kg	1.7e-8	6.6e-7	4.1e-6	4.9e-3
Marine eutrophication	kg N eq / kg	0.00035	0.014	0.073	134.6
Freshwater eutrophication	kg P eq / kg	0.00008	0.0042	0.046	61.1
Terrestrial eutrophication	mol N eq / kg	0.0036	0.14	0.74	1 342.2
Human toxicity (cancer)	CTUh / kg	6.4e-10	2.6e-8	5.2e-8	8.3e-4
Human toxicity (non-cancer)	CTUh / kg	3.3e-9	1.6e-7	1.8e-6	9.5e-3
Ionising radiation	kBq U-235 eq / kg	0.011	0.88	28.5	75 373.9
Land use	Pt / kg	1.2	41.8	384.4	327 922.8
Ozone depletion	kg CFC11 eq / kg	3.8e-9	2.0e-7	2.3e-6	1.6e-2
Photochemical ozone formation	kg NMVOC eq / kg	0.0012	0.049	0.23	331.5
Resource use (fossil)	MJ / kg	2.8	125.5	1 092.5	2 813 361.1
Resource use (mineral)	kg Sb eq / kg	0.0000019	0.00014	0.011	3.1
Water use	m^3 / kg	0.077	1.5	8.1	42 227.7

Reducing the impact by eco-design

Example of the Proba-V satellite mission

Option		Level	A	B	C	D	E	F	Score (%)
1	Not using PTFE but e.g. PE instead	1	5	5	5	3	5	4	92,1
2	Promote teleworking, use of teleconferencing	4	5	5	4,5	3	4	5	88,0
3	More efficient on-ground data management	2	4	3	5	4	5	4	86,9
4	Use of long-heritage components	4	5	5	4	2	5	4	86,4
5	Use recycled Germanium	3	4	4	4	3	5	5	86,3
6	More efforts in early phases	5	4	4	4	3	5	5	86,3
7	Green propellants	1	4	4	4	4	5	4	85,6
8	Reduce copper surface to be Ag coated	1	5	4	4	5	3	5	83,5
9	Flexible design	4	4	4	4	2,75	5	4	82,6
10	Renewable energy	4	4	3	4	3	5	4	81,2
11	Reduce documentation	5	5	4	4	3	4	4	81,2
12	Improve the efficiency of buildings	4	4	4	5	3	4	4	81,0
13	System-level testing	4	4,5	5	3,5	3	4	4	79,8
14	Use of modular buildings for ground stations	4	4	5	4	3	4	4	79,6
15	Recurrent platforms	4	4	3	4	3	5	3,5	79,6
16	Use of modular components	2	4	3	5	3	4	4	78,9
17	Si instead of Ge	1	4	5	5	1	4	4	78,2
18	Prolong electronics lifetime	2	3	4	4	3	5	3,5	78,1
19	Adopt PMI best practices and focus more on risk management	5	5	4	5	3	3	3,5	77,4
20	Laser/plasma surface treatment	3	4	5	5	3	3	4	77,4
21	More on-board and on-ground autonomy	4	3	3	4	3,5	5	3,5	77,3
22	Reduce components qualification requirements	2	5	3	2	3,5	4	5	76,8
23	Optimize electronics	2	4	4	3	4	4	4	76,7
24	Reduce number of design iterations	5	5	4	3	2,5	4	4	76,7
25	Heat pipes	2	3	4	3,5	3	5	3,5	76,4
26	Virtual thermal testing	2	3,5	3	3	3	5	4	76,1



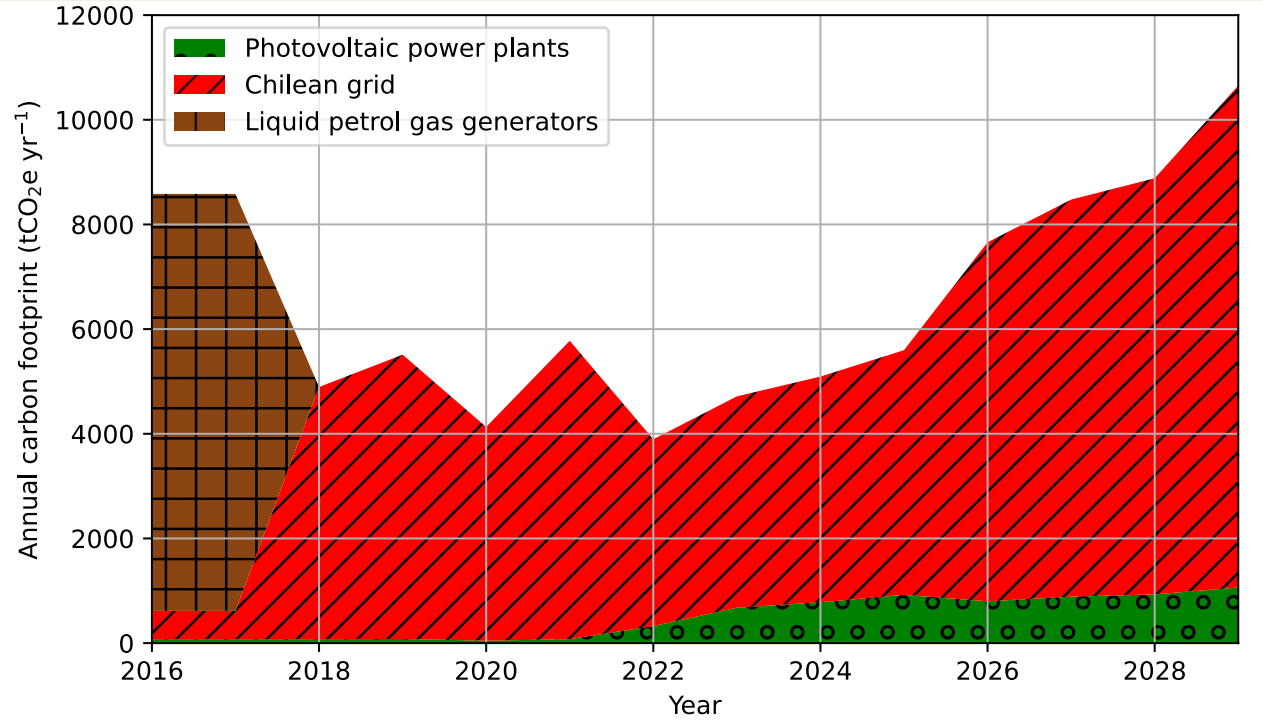
An Vercalsteren et al. (2018), Clean Industry Days

Reducing the impact of power consumption

Example of ESO Paranal site (Chile)

Credits: ESO

Reducing the impact – really?



Past and predicted annual carbon footprint of electricity consumption at the ESO observatory sites in La Silla, Paranal and Armazones

Data from Filippi et al. (2022), SPIE, 12182, 3

Summary of the situation

- Eco-design may lead to typical impact reductions of about 20-30 %, yet it's difficult to win on all impact categories (burden shifting)
- Reducing the carbon intensity of power is an important lever arm to reduce the operation impacts
  - watch out for burden shifting if energy storage solutions are envisioned (e.g. Viole et al. 2023, preprint)
- The achievable impact reductions can not compensate for the growing number and dimensions of new research infrastructures
  - there is no evidence for "green growth", also not for research infrastructures
  - planetary boundaries need to be taken into account when taking implementation decisions
  - "Less is More" – aka sobriety, aka degrowth

Minimising environmental impacts

Minimiser l'impact environnemental des projets spatiaux scientifiques

Contribution émanant de la communauté scientifique (plus de 240 signataires) au séminaire de prospective du CNES 2024 sur la thématique

"Empreinte environnementale des activités scientifiques spatiales"

Coordination: Didier Barret & Jürgen Knödlseder

A contribution signed by over 240 French space scientists

Towards less space projects and more collaboration?

- Consider environmental impacts when taking implementation decision
- Favour collaboration to avoid emergence of concurrent projects
- Promote and financially support the use of already existing archival data

Towards more sustainable space projects

- Develop the competences and provide budget for conducting Life Cycle Analyses
- Develop an environmental quality plan, install an environmental impact architect
- Train project staff on eco-design methods and environmental issues
- Optimise and eventually mutualise power intensive test facilities
- Control environmental requirements by a competent organisation