The Sky IS The Limit

Astronomy Research Within Planetary Boundaries

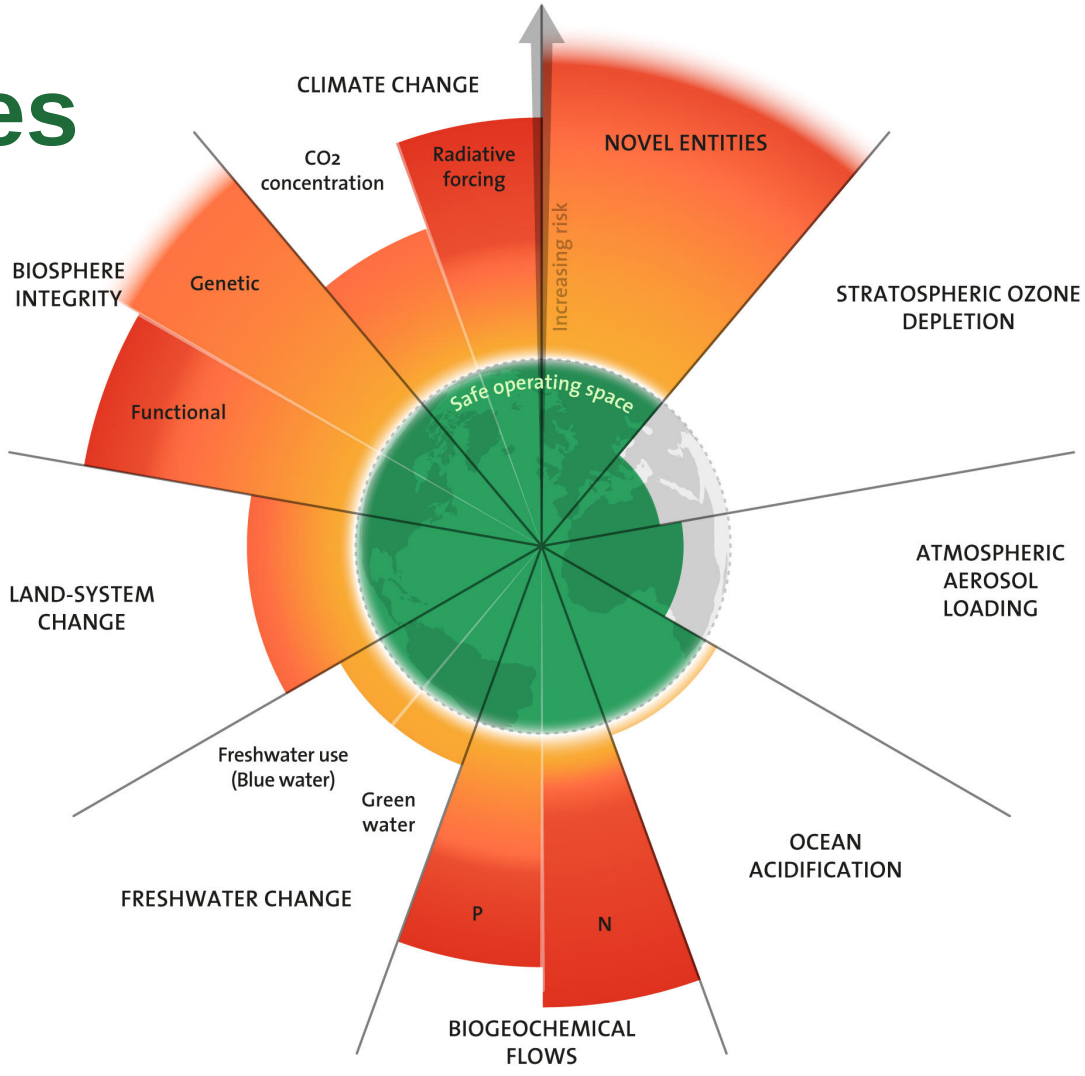
Pragya Chawla

Instrument Scientist & Sustainability Ambassador

ASTRON

Planetary Boundaries

- **Define a safe operating space for humanity based on critical environmental processes.**

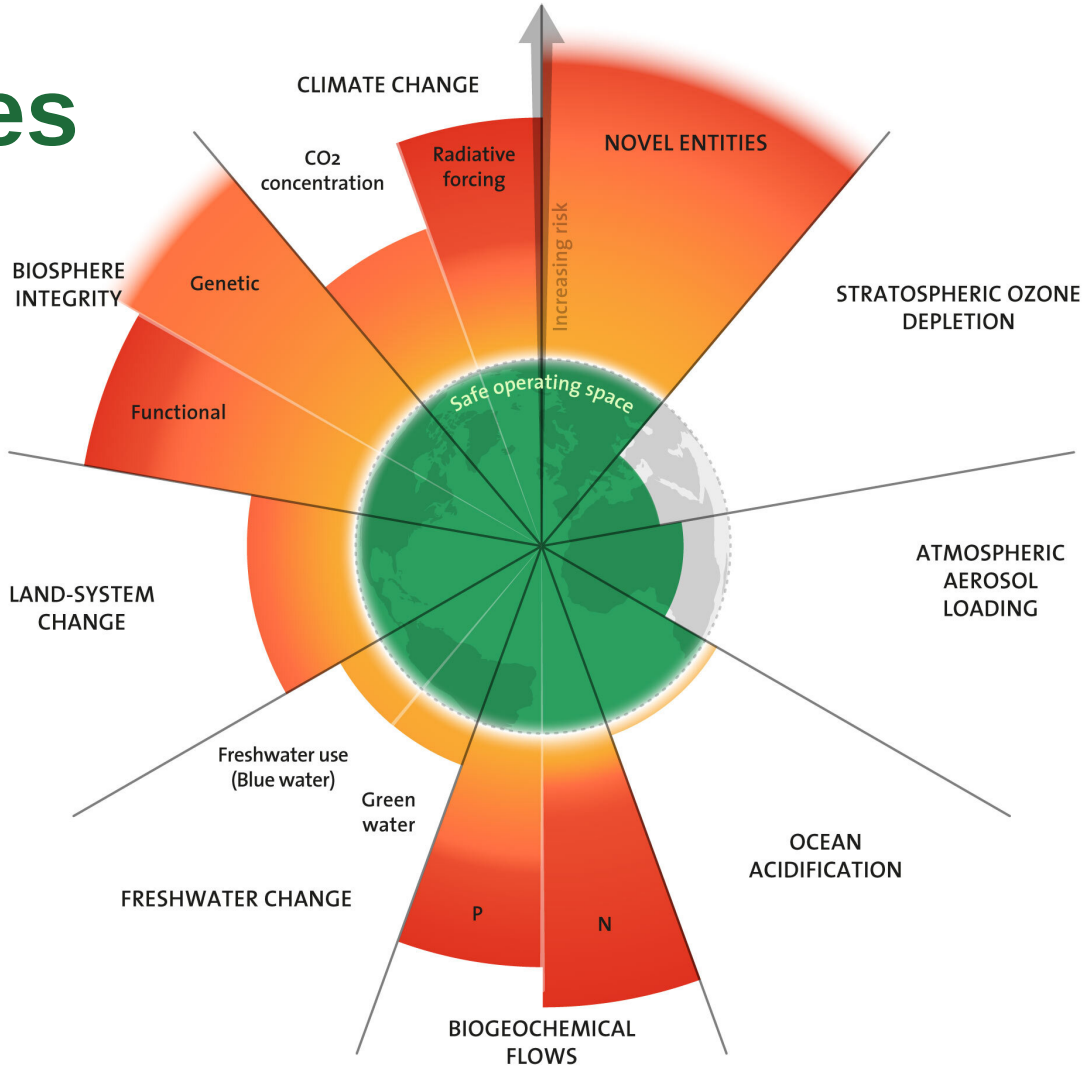


Credit: Azote for Stockholm Resilience Centre based on analysis in Sakschewski and Caesar et al. 2025

Planetary Boundaries

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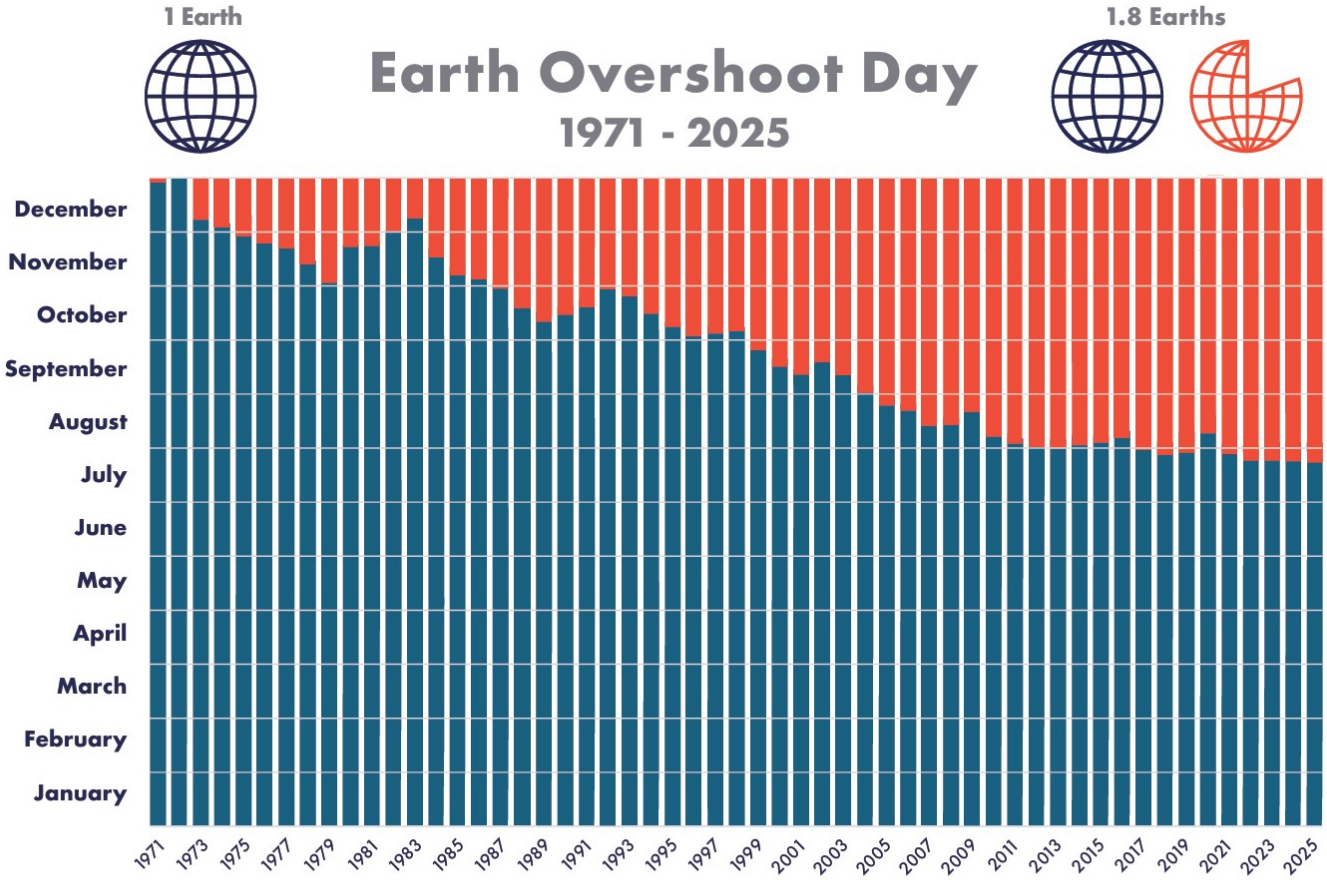
We have already breached 7 of 9 planetary boundaries.



Credit: Azote for Stockholm Resilience Centre based on analysis in Sakschewski and Caesar et al. 2025

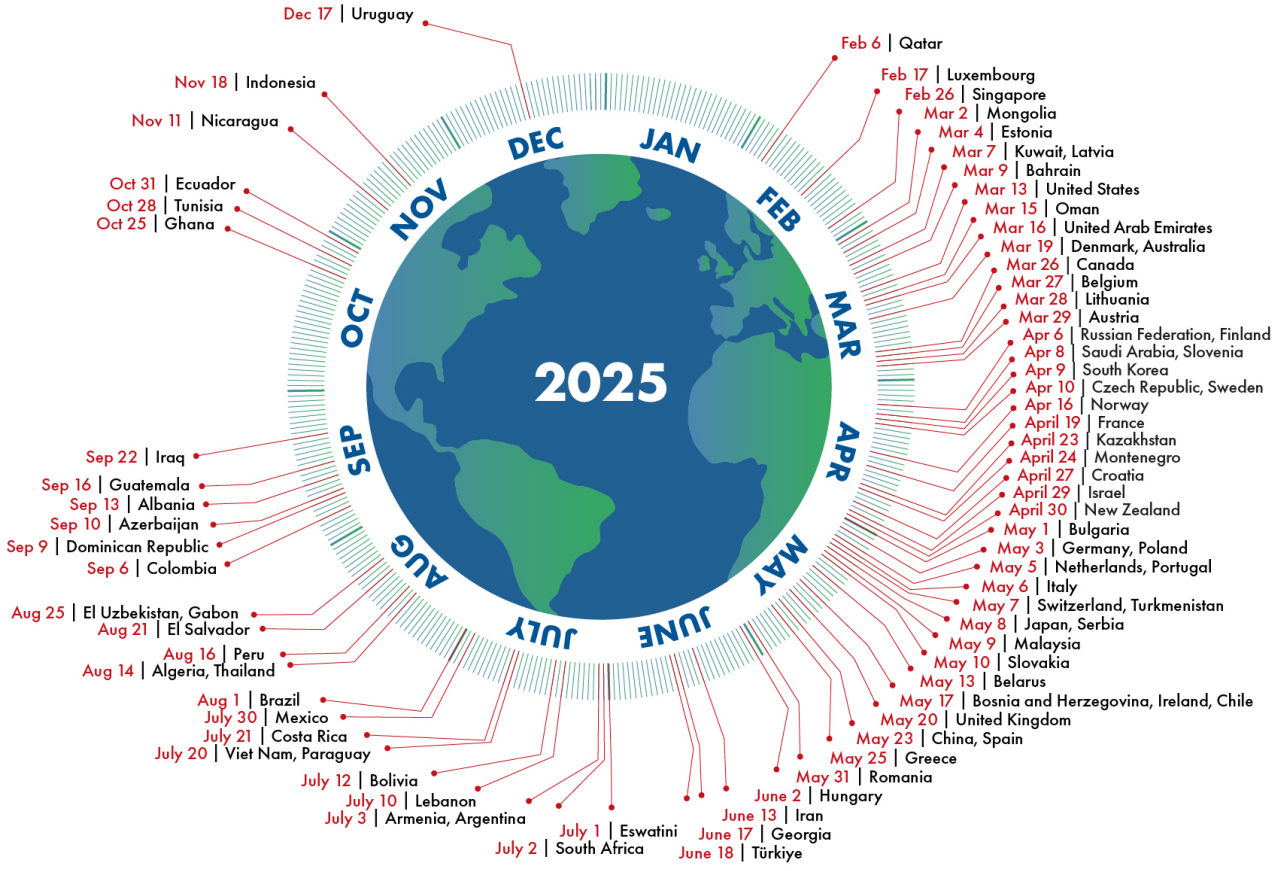
Ecological Overshoot

- **Using more natural resources than our ecosystems can regenerate.**
- **Earth Overshoot Day 2026 fell on July 30.**



Country Overshoot Days 2025

When Earth Overshoot Day would land if all the people around the world lived like...



For more information, visit:
https://overshootday.org/newsroom/country-overshoot-days/

Source: National Footprint and Biocapacity Accounts, preliminary 2025 Edition
York University, FoDaFo, Global Footprint Network, data.footprintnetwork.org

EARTH OVERSHOOT DAY

Global Footprint Network
Advancing the Science of Sustainability

Countries without an Overshoot Day

Country	Portion of Earth required if everyone lived like...
Bangladesh	46%
Nigeria	53%
Nepal	55%
Ethiopia	60%
Kenya	61%
Tanzania	67%
Côte d'Ivoire	74%
India	75%
Sri Lanka	81%
Egypt	88%
Jordan	89%
Philippines	94%
Senegal	99%

The Guardian

Climate crisis probably weakened glacier that caused devastating Nepal-Tibet floods, first study finds

Scientists say global heating was a destabilising factor in collapse of 200,000 sq metre glacier in August



Climate disasters displaced 250 million people in past 10 years, UN report finds

Floods, storms and droughts have uprooted people across the globe as rising temperatures intensify conflict and hunger



European heatwave is worst ever and impossible without climate crisis, scientists say

Study also finds high humidity means people in hundreds of cities are enduring their worst ever heat stress



We need to act now.

Astronomy’s Carbon Footprint



Knödlseder (2024)

- **Average astronomers’s CO_2 footprint is ~tens of tonnes / year.**

Astronomy’s Carbon Footprint



Knödlseder (2024)

- **Average astronomers’s CO_2 footprint is ~tens of tonnes / year.**
- **To limit global heating to 1.5°C above pre-industrial levels (Paris Agreement), average footprint per person should be < 2.3 tonnes.** *UNEP Emissions Gap Report 2021*

LOFAR's Carbon Footprint

Experimental Astronomy (2023) 56:687–714
https://doi.org/10.1007/s10686-023-09901-z

RESEARCH



The energy consumption and carbon footprint of the LOFAR telescope

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Abstract

The LOw Frequency ARray (LOFAR) is a European radio telescope operating since 2010 in the frequency bands 10 - 80 MHz and 110 - 250 MHz. This article provides an analysis of the energy consumption and the carbon footprint of LOFAR. The approach used is a Life Cycle Analysis (LCA). We find that one year of LOFAR operations requires 3,627 MWh of electricity, 48,714 m^3 gas and 135,497 liters of fuel. The associated carbon emission is 1,867 tCO2e/year. Results include the footprint stemming from operations of all LOFAR stations and central processing, but exclude scientific post-processing and activities. The electrical energy required for scientific processing is assessed separately. It ranges from 1% (standard imaging and time-domain), to 40% (wide field long baseline imaging) of the energy consumption for the observation. The outcome provides a transparent baseline in making LOFAR more sustainable and can serve as a blueprint for the analysis of other research infrastructures.

Our Steps Towards Sustainability

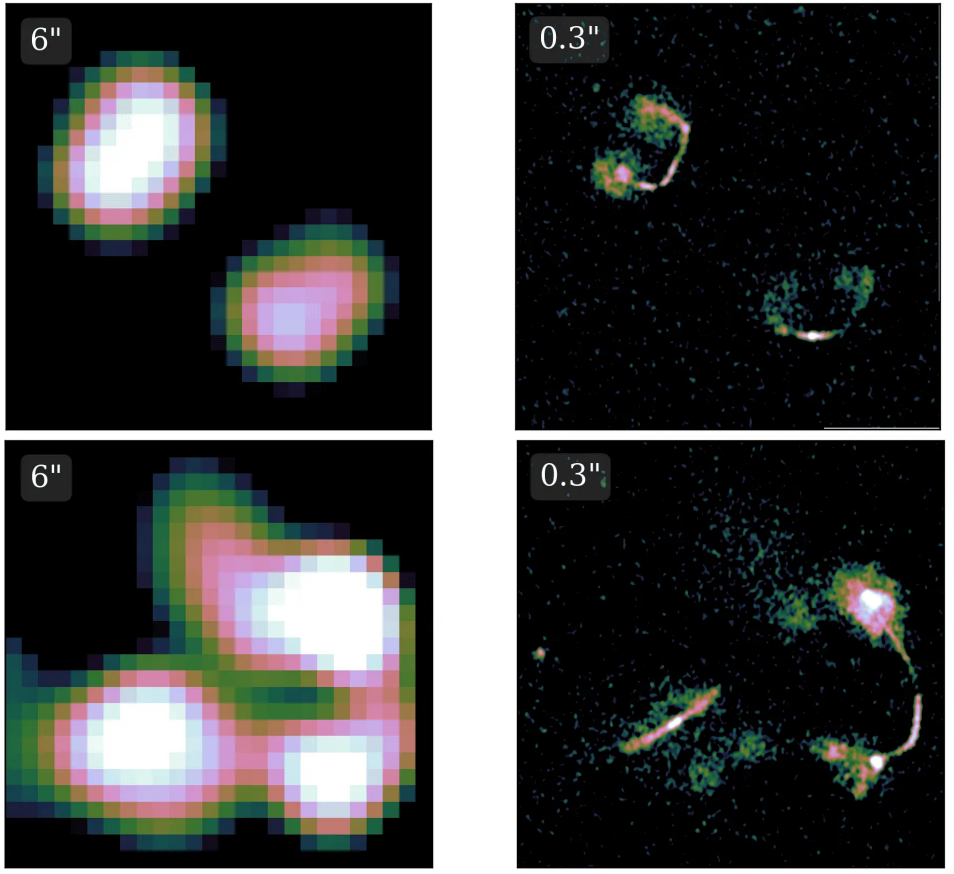
LOFAR Enhanced Network for Sharp Surveys

LENSS

- Majority of LOFAR observations did not use international baselines due to large compute requirement.

- **LENSS aims to increase processing speed by 40x and FOV by 4x.**

We aim to maintain the same energy footprint despite these improvements!

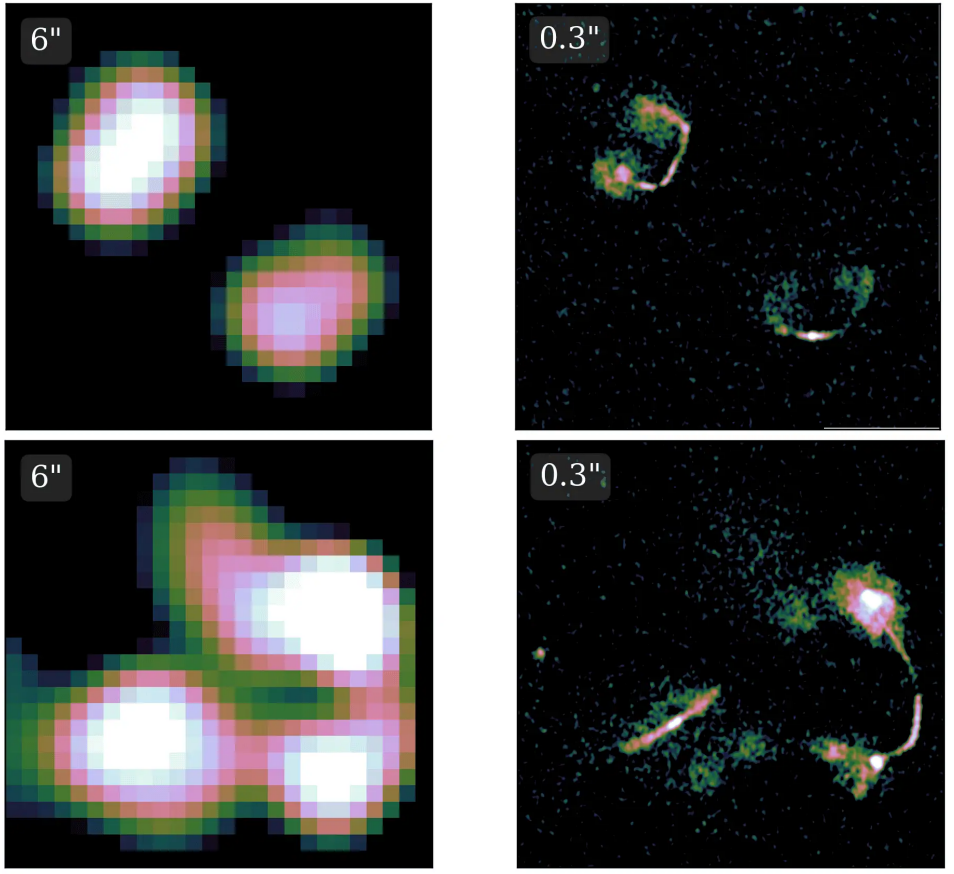


de Jong et al. (2024)

LOFAR Enhanced Network for Sharp Surveys

LENSS

- **Advanced GPU acceleration**
  - Using tensor cores to deliver up to 100x computation per watt.
- **Optimizing algorithms**
  - To reduce storage requirements and latency.
- **Dynamic scheduling**
  - Energy-intensive processing to coincide with renewable energy availability.

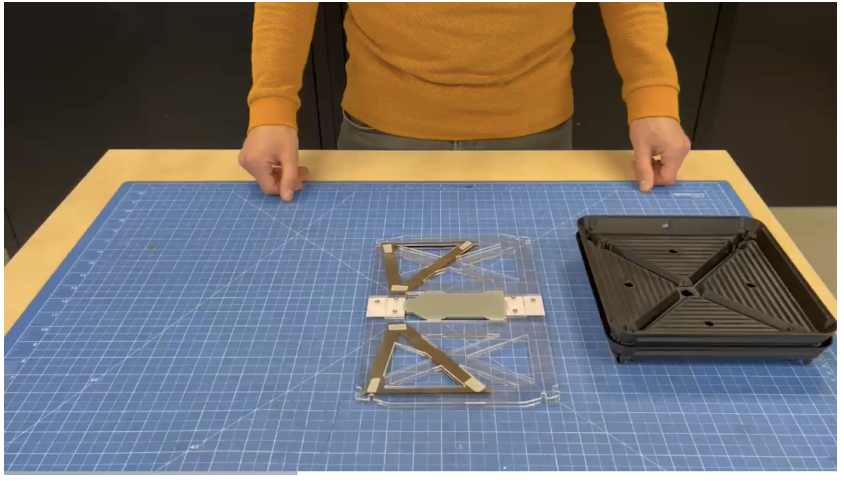


de Jong et al. (2024)

KEA LOFAR

- **New design for LOFAR High-Band Antennas**
  - Currently use a Styrofoam casing
- **Cradle-to-cradle design**
  - Plan to use recycled or bio-based materials
- **CO_2 footprint ~24 ton lower**
  - Shipment for one LOFAR station in 1 container instead of 16
  - Easy to roll-out and roll-in and recycle





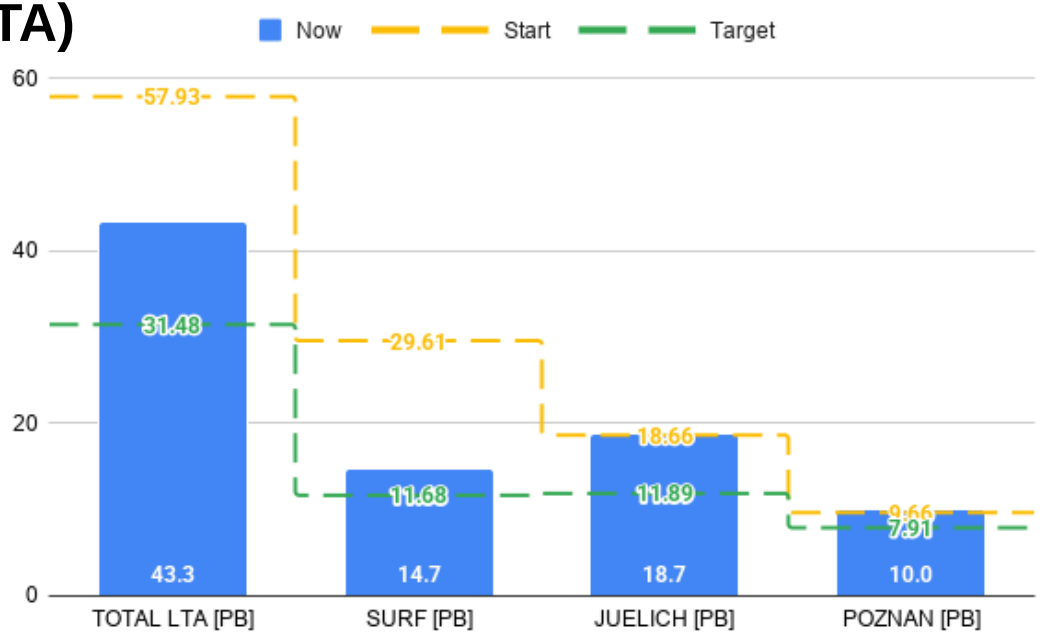
Credit: KEA LOFAR team

Projects with Sustainability as a Bonus

LOFAR Data Deletion & Compression

- Data stored in **Long Term Archive (LTA)**
- Volume of ~55 PB at its peak

- In **LOFAR Data Valorisation (LDV)** project:
  - Data compression (8 to 4 bits)
  - Deletion of data with low future scientific value
  - **Reduction of data volume by 15 PB!**



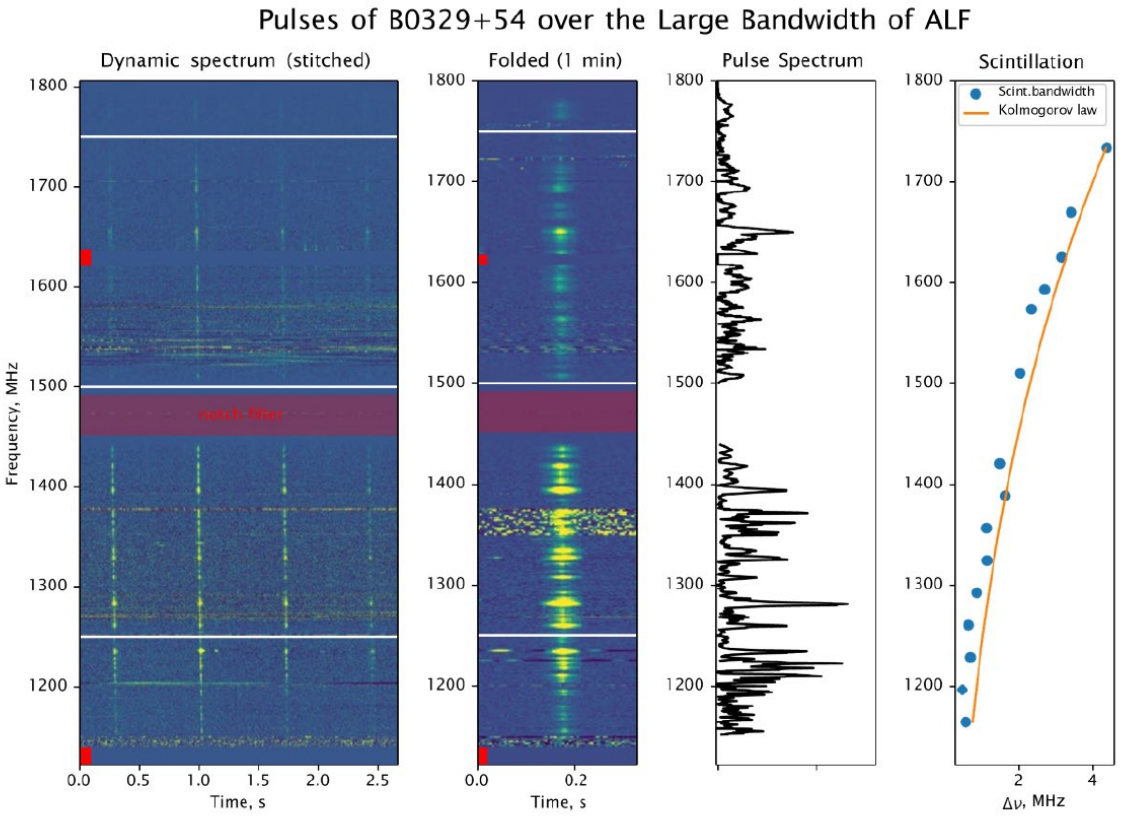
Credit: Noa Peters & the LDV Team.

Ambient L-Band Feed for Westerbork

ALF AMBIENT L-BAND FEED

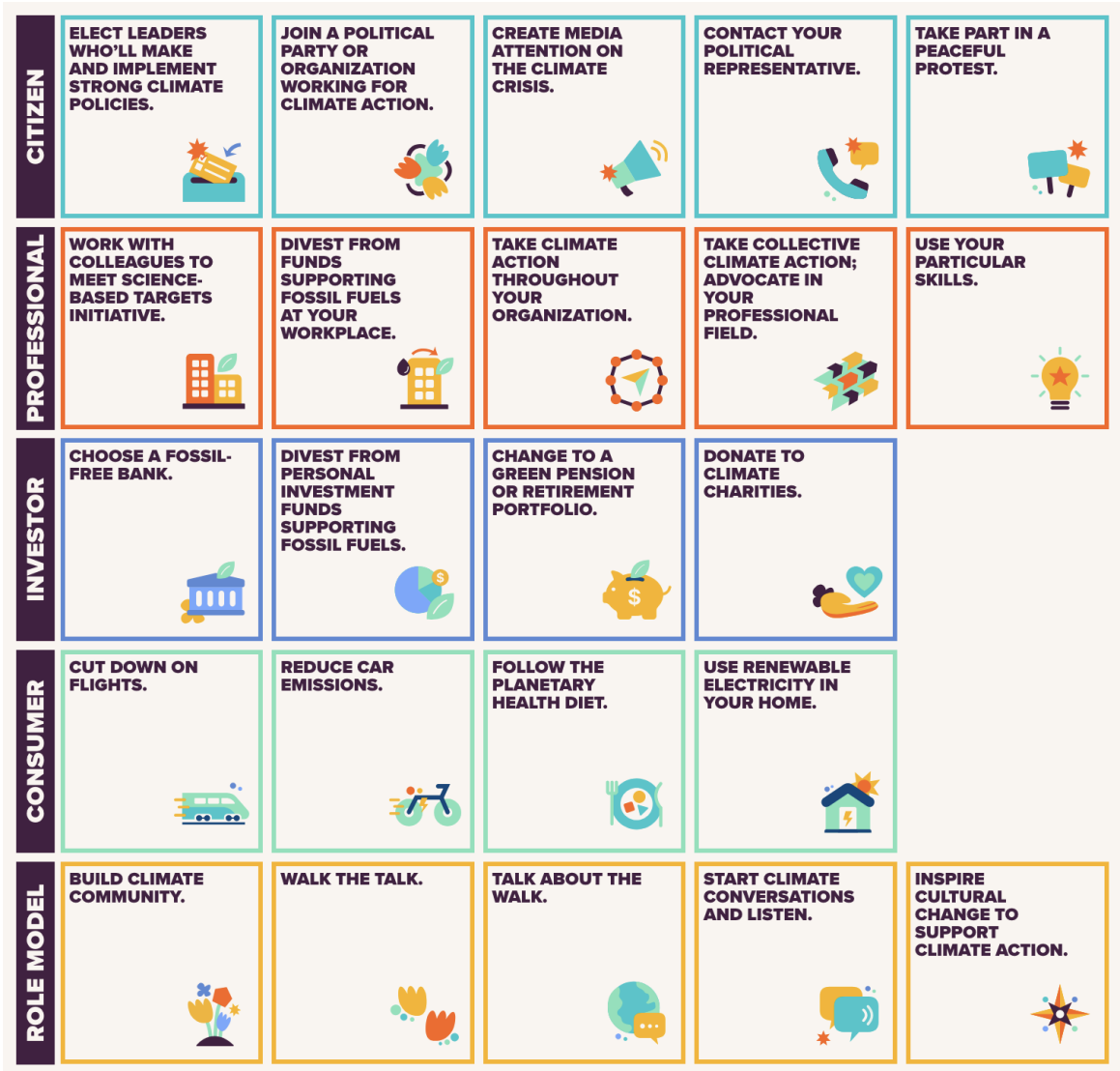
- Uses transistors based on indium-phosphide (InP)
- Eliminates the need for cryogenic cooling with liquid Nitrogen
- Energy + cost-efficient and low maintenance
- Increased sensitivity and instantaneous bandwidth

Krüger et al. 2026



Credit: Nina Gusinskaia & the ALF Team.

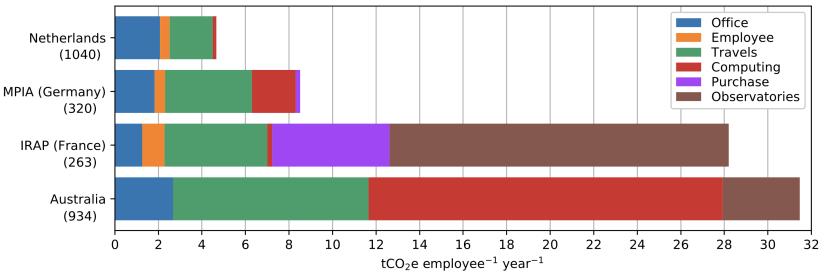
What can you do?



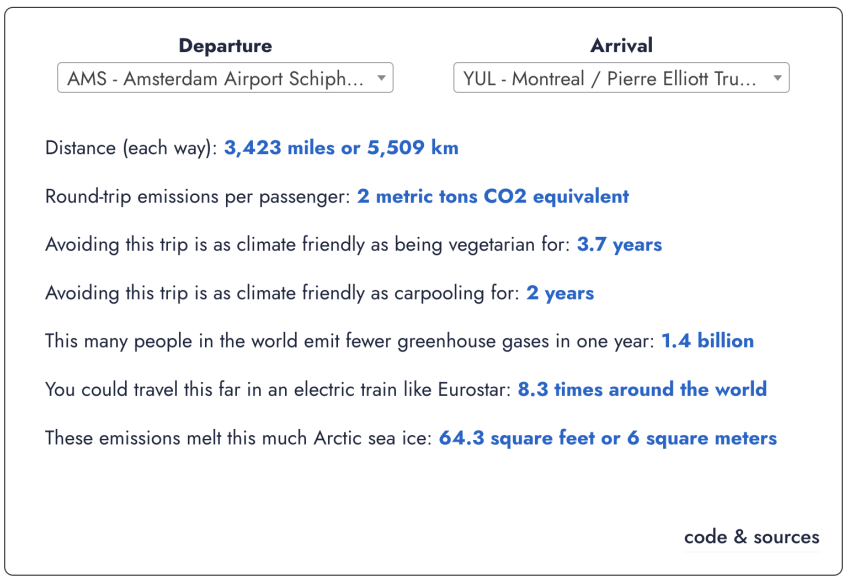
Credit: https://jointheshift.earth/

What can you do as an astronomer?

- **Reduce air travel**
  - Limit in-person attendance at conferences
  - Combine conference and work visits



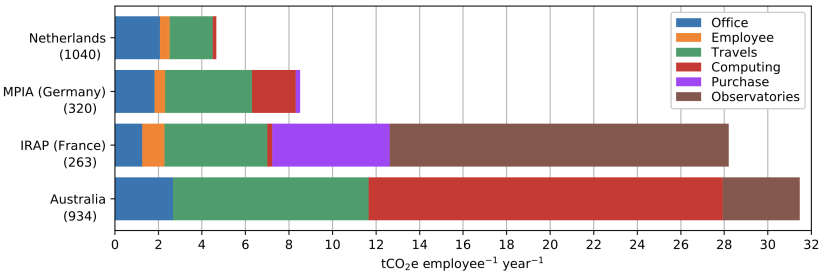
Knödlseder (2024)



https://flightfree.org/calculator/

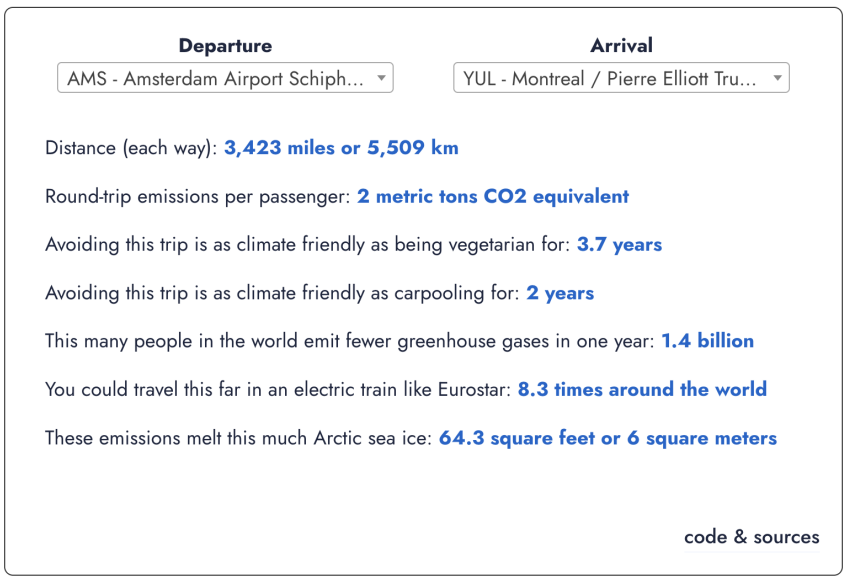
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Knödlseder (2024)

- **How do you process data?**
  - **Test and optimize code on small data chunks**
    - Save compute by catching bugs early and scaling up only when it works efficiently
    - Use tools like Numba to optimize code
  - **Consider environmental footprint of processing infrastructure**
    - Use shared infrastructure for more sustainable computing



https://flightfree.org/calculator/

What can you do as an astronomer?

- **How do you store data?**
  - Is the data compact enough for long-term storage?

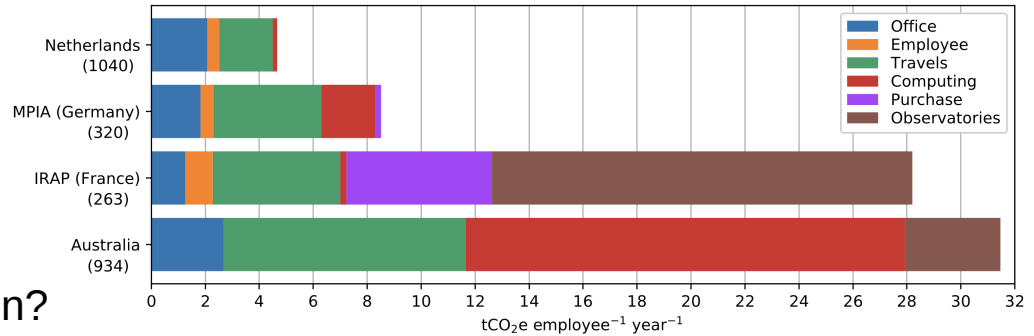


    Why not downsample data before storage if there is no structure at high time resolution?

  - Don’t unnecessarily store RFI-corrupted data.
- **When writing proposals,**
  - Check if archival data already exists.
  - Optimise observation parameters (integration time, bandwidth) to reduce the data volume.



    If your FRB has a high Galactic DM, why observe it at a higher time resolution?



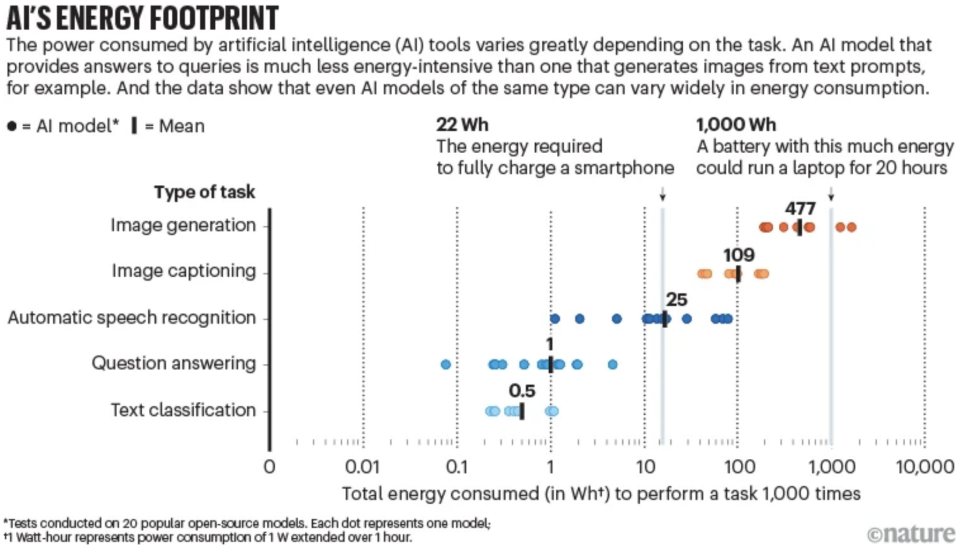
Knödlseder (2024)

What can you do as an astronomer?

- **Limit AI usage**
  - Especially image generation if it is not adding significant value.
  - Choose lower-impact AI alternatives (Ecosia AI Chat) instead of energy-intensive models (Claude, ChatGPT, etc.)

- **Keep your laptop for as long as possible**
  - Producing a typical ~2 kg computer requires ~800 kg of raw materials.

Valero and Valero 2019

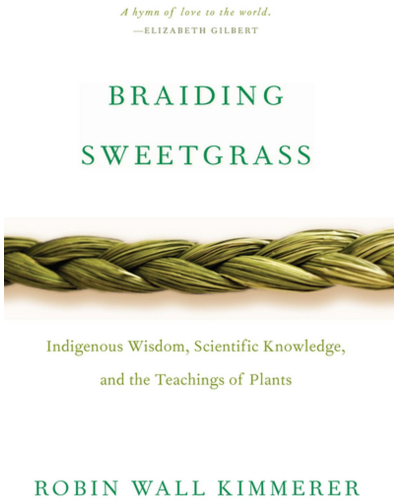


Source: Unpublished analysis by S. Luccioni *et al.*/AI Energy Star project

There is no planet B.

Let's find ways to do our research without compromising the future of life on Earth.

"The indigenous canon of principles and practices that govern the exchange of life for life is known as the Honorable Harvest. They are rules of sorts that govern our taking, shape our relationships with the natural world, and rein in our tendency to consume—that the world might be as rich for the seventh generation as it is for our own."



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