MATTER AND THE UNIVERSE

Instrumentation Activities in the AP Division

David Berge & Anna Nelles

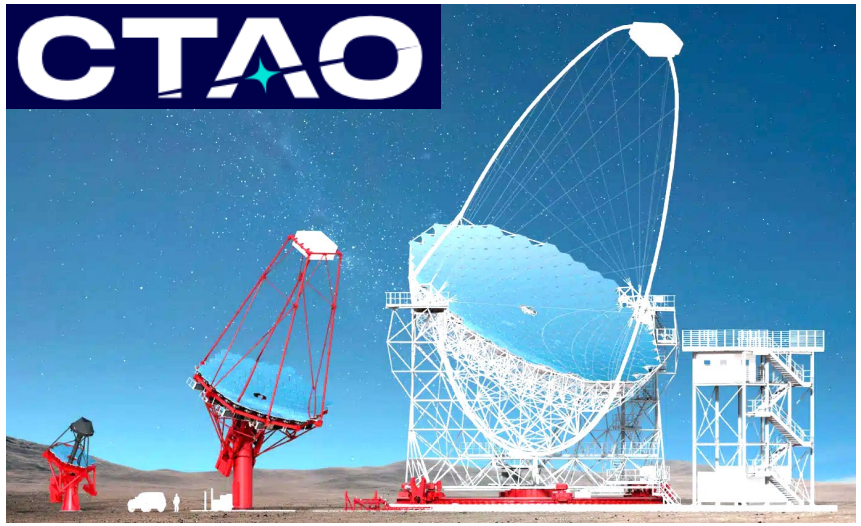
DESY.

IceCube Neutrino Observatory

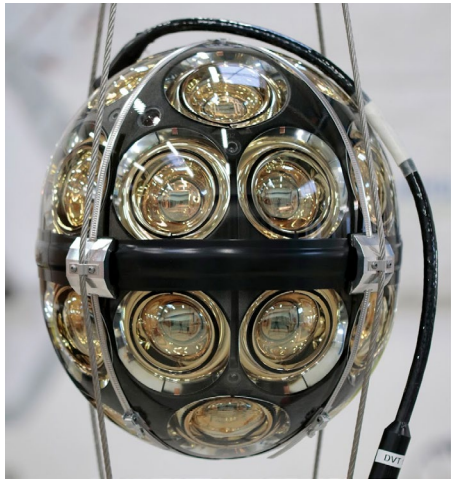
IceCube Upgrade

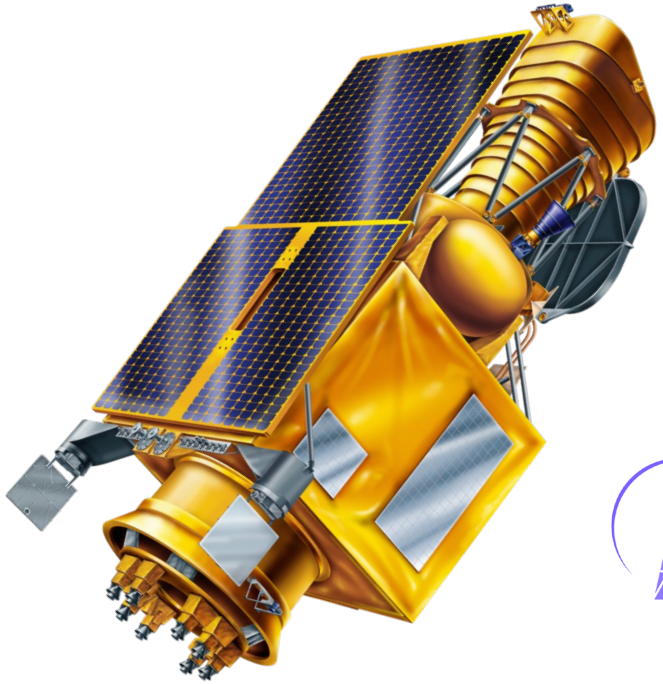
RNO-G
Radio Neutrino Observatory - Greenland

IceCube Gen2



DESY.

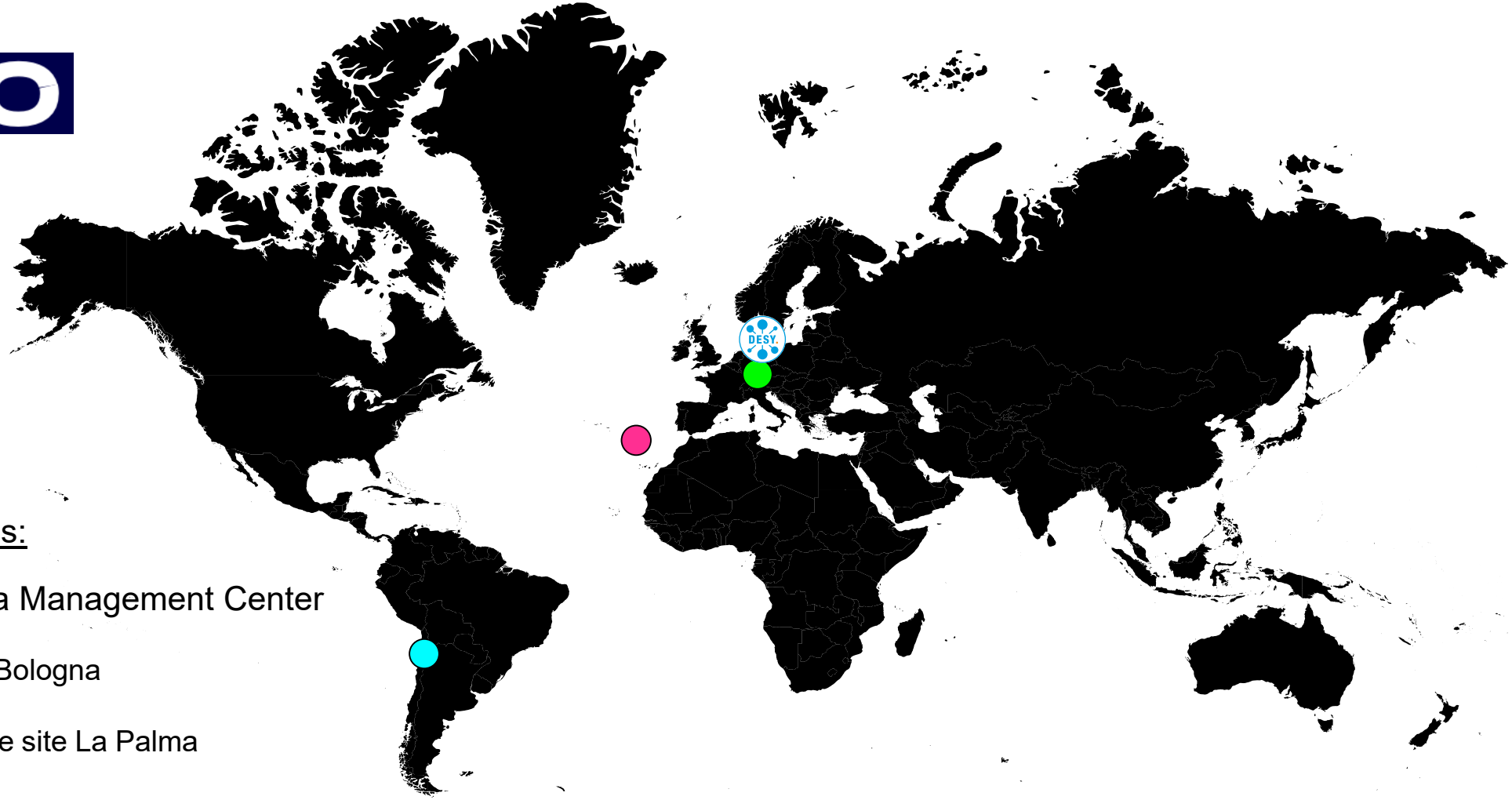




ULTRASAT
SKYLIGHT TO SPACE

CTAO – Cherenkov Telescope Array Observatory

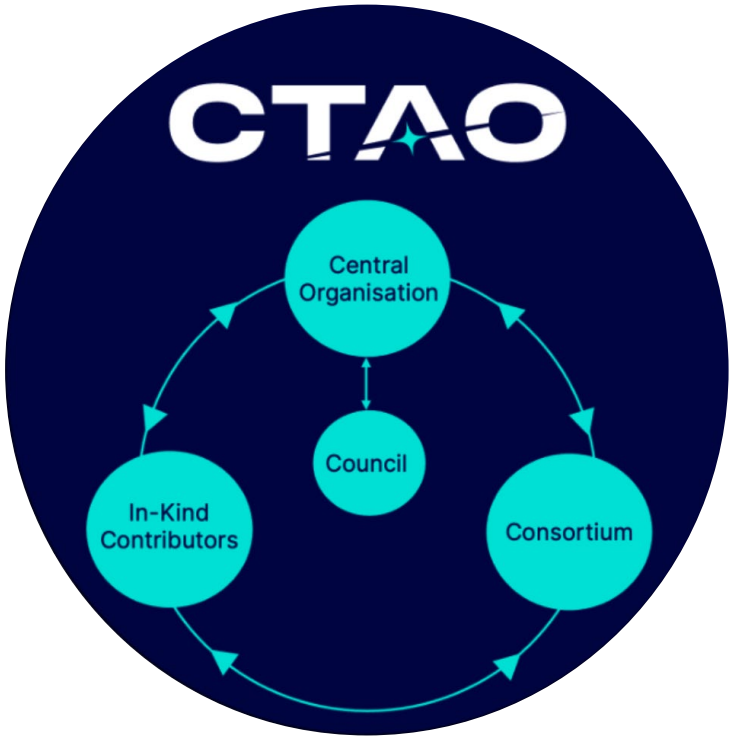
A European priority research infrastructure and global open observatory

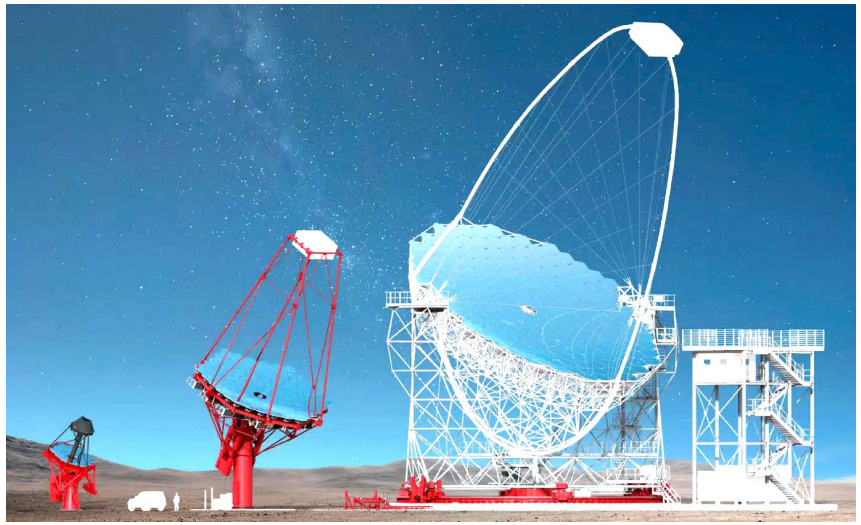


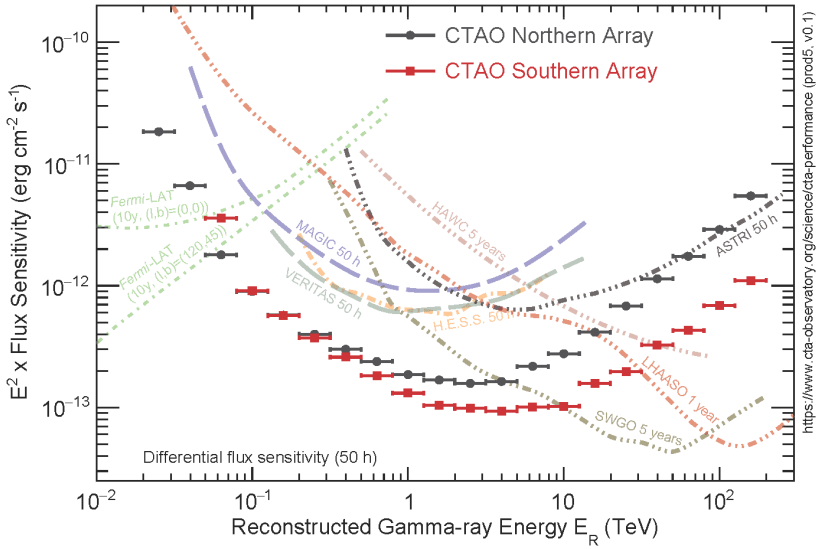
1 observatory, 4 sites:

- Science Data Management Center
- Headquarters Bologna
- North telescope site La Palma
- South telescope site Paranal

CTAO – Cherenkov Telescope Array Observatory

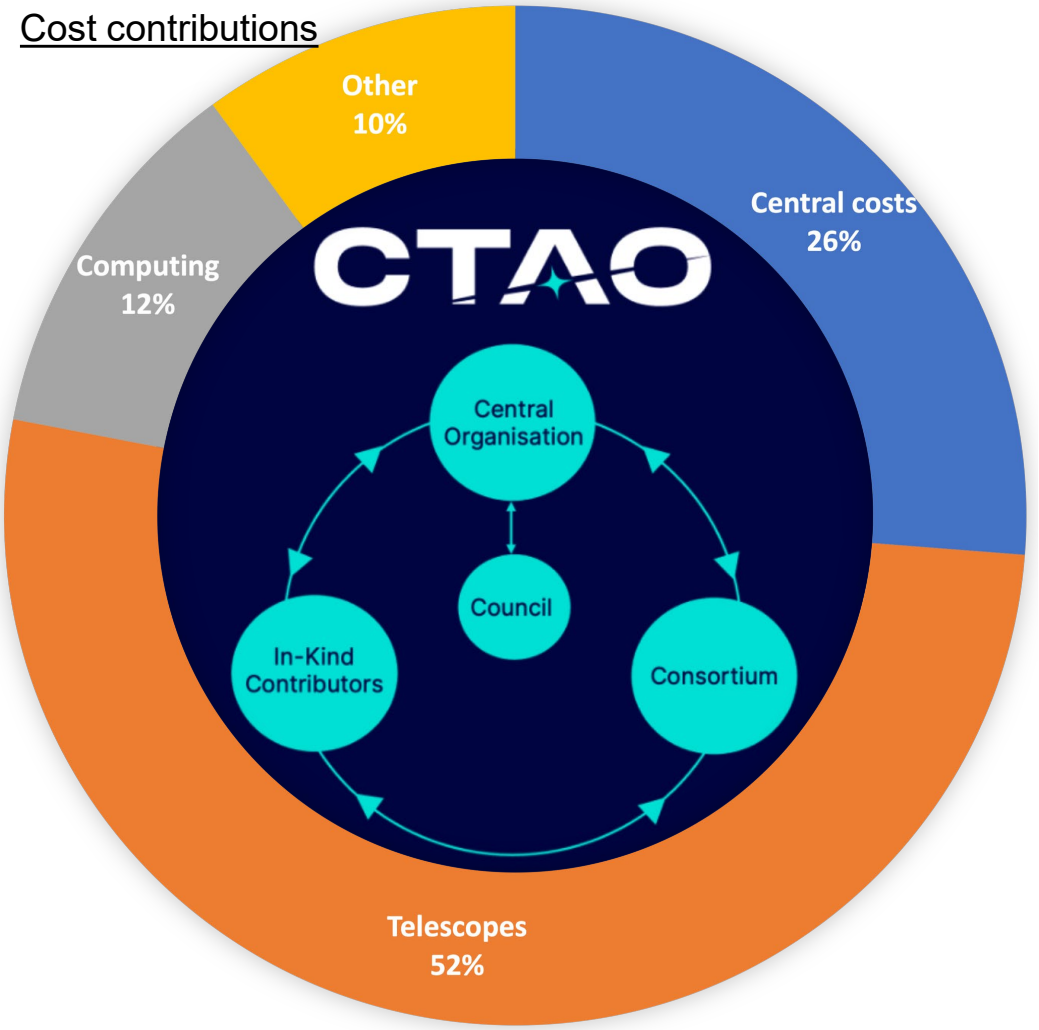




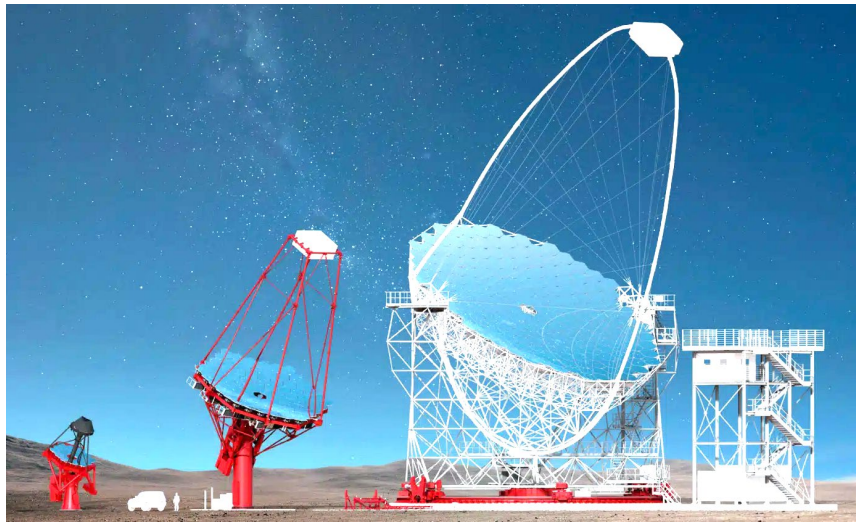


CTAO – Cherenkov Telescope Array Observatory

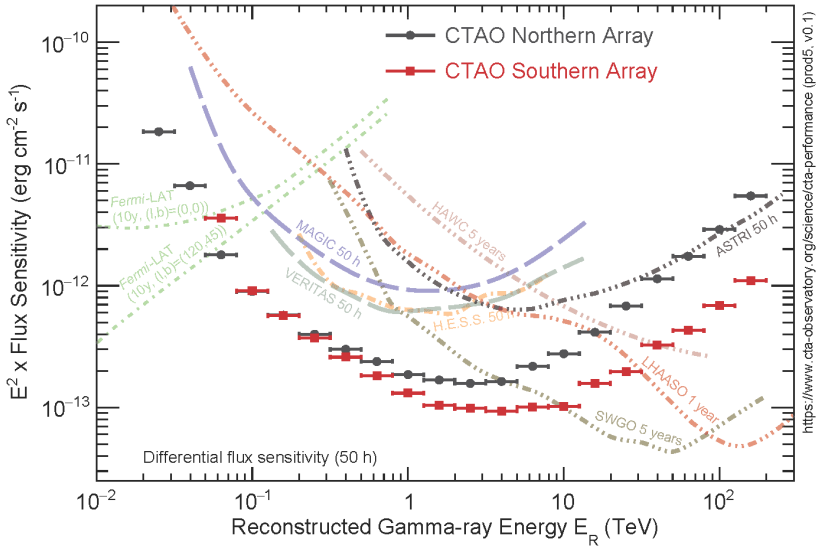
Cost contributions



100% = 330 M€ (year 2021 costing)



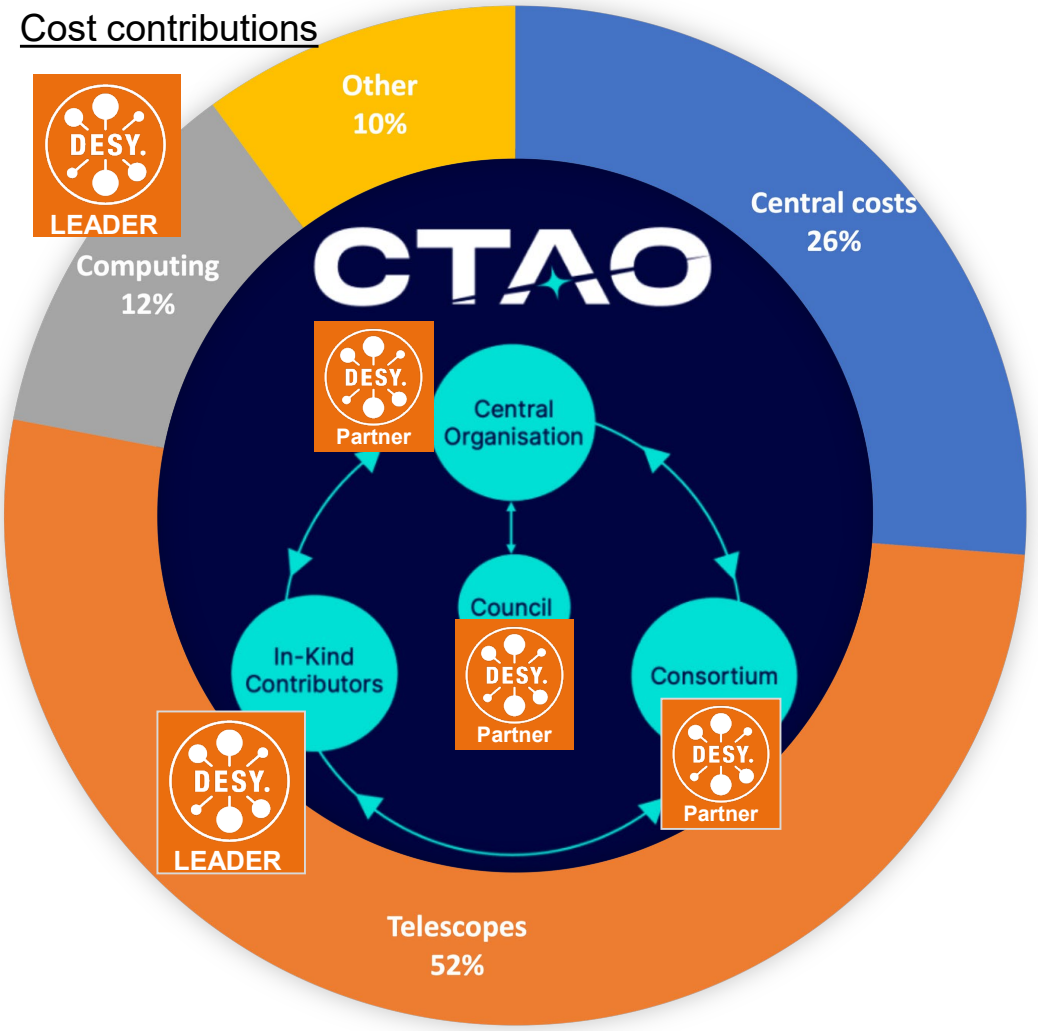
SST, ⌀ 4.3 m MST, ⌀ 11.5 m LST, ⌀ 23 m



CTAO – Cherenkov Telescope Array Observatory

MATTER AND THE UNIVERSE MU

Cost contributions



100% = 330 M€ (year 2021 costing)

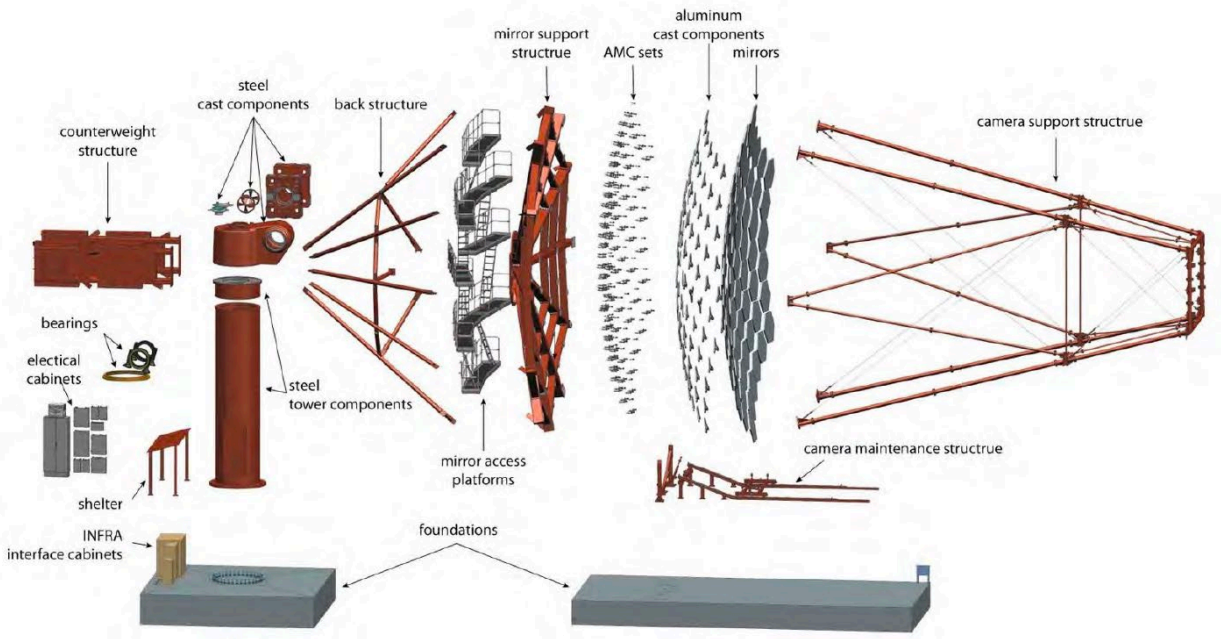
SST, ⌀ 4.3 m MST, ⌀ 11.5 m LST, ⌀ 23 m

- CTAO is our flagship project
- We are involved on all levels and spearhead many activities
  - Co-host of CTAO with the SDMC
  - Council member
  - Key member of the user consortium
  - Largest individual In-Kind provider
  - Lead Medium-Sized Telescopes and computing contributions
- We have a lead role in the strong German community

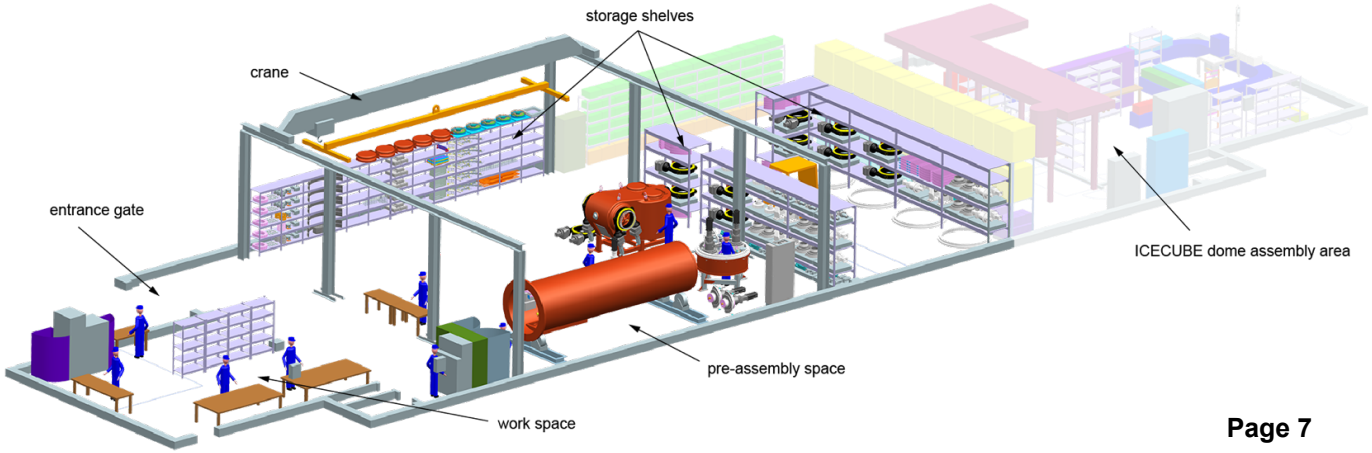
Medium-Sized Telescopes (MSTs)

Achievements 2021-2024

- Formed coherent collaboration led by DESY, agreed on construction plan (2 sites, 23 MSTs)
- Critical Design Review telescope structure passed
- Logistics plan with pre-assembly in Zeuthen exists
- Procurement MST pathfinders kicked off
- On-site assembly of 3 MST pathfinders by 2026

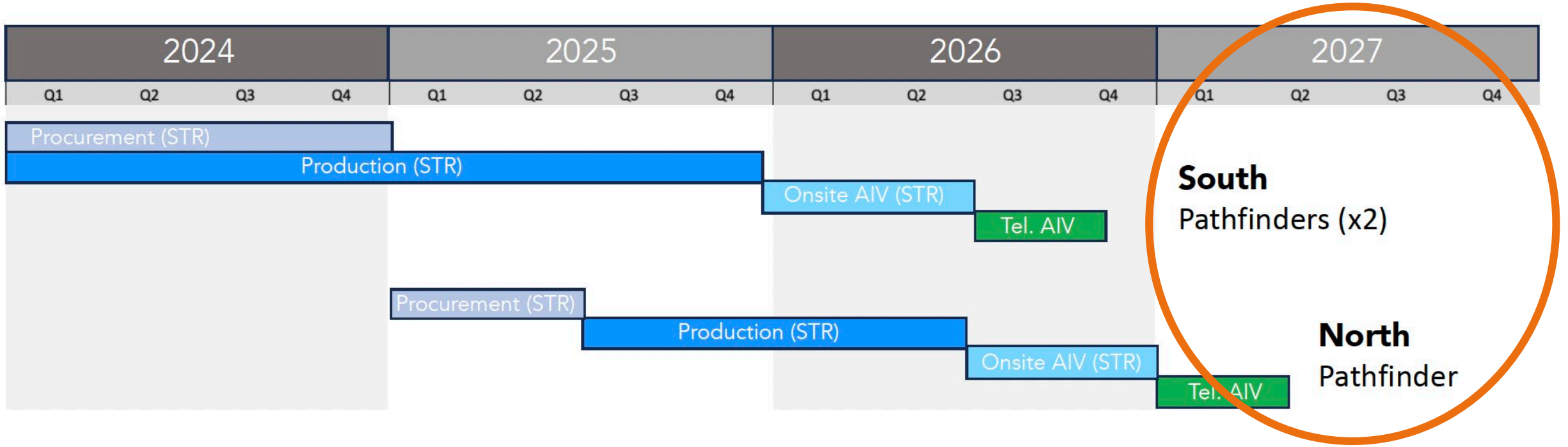


We coordinate the MST collaboration of In-Kind Contributors



Medium-Sized Telescopes (MSTs)

Pathfinder schedule



We coordinate the MST collaboration of In-Kind Contributors

Early science with “intermediate arrays”

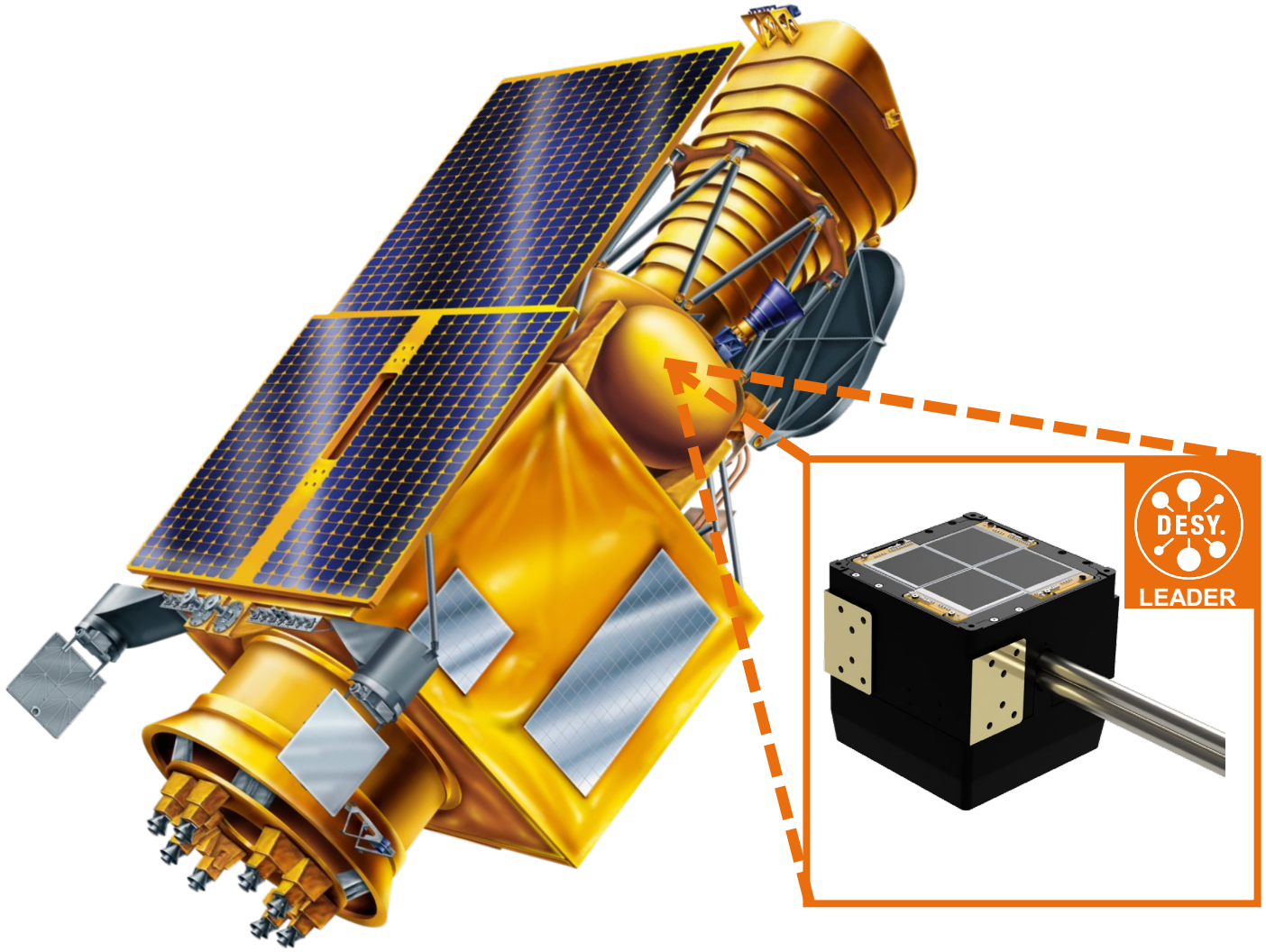
ULTRASAT

First scientific satellite mission led by Israel

Unprecedentedly large field of view (204 deg^2)

First wide-field survey of transient UV sources

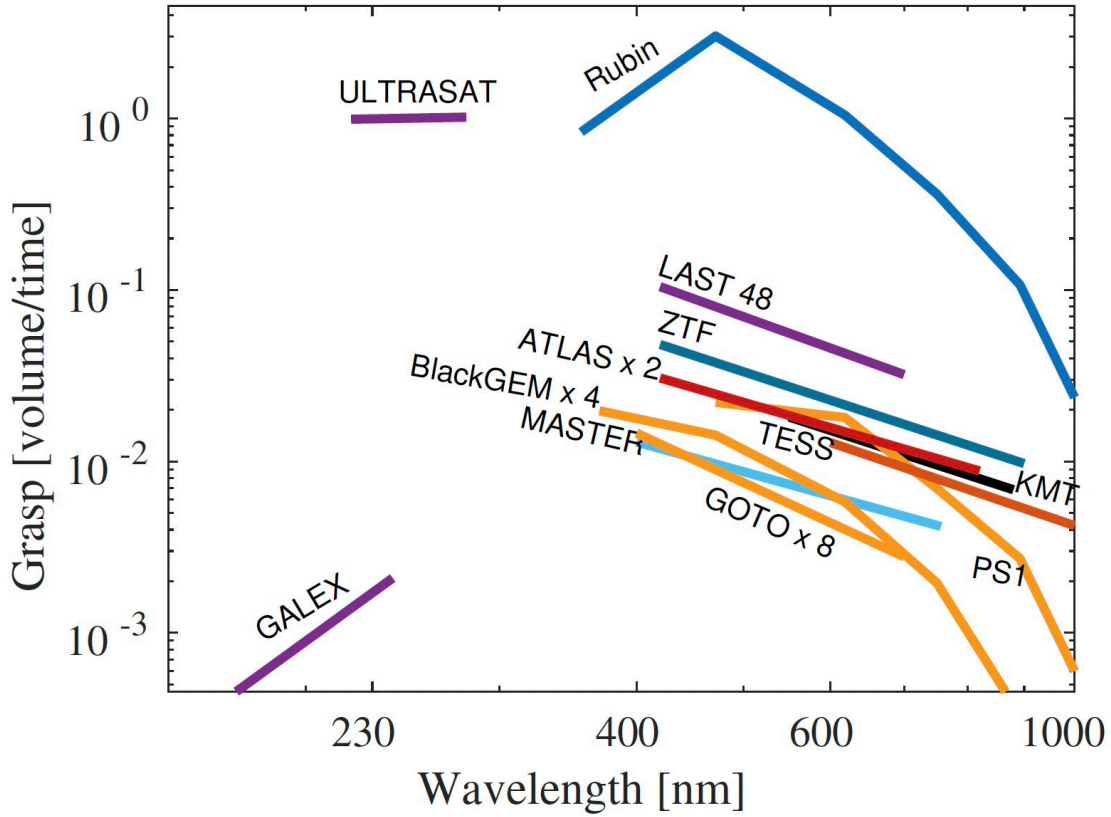
Kick-off in 2019, launch planned for ≧ 2027



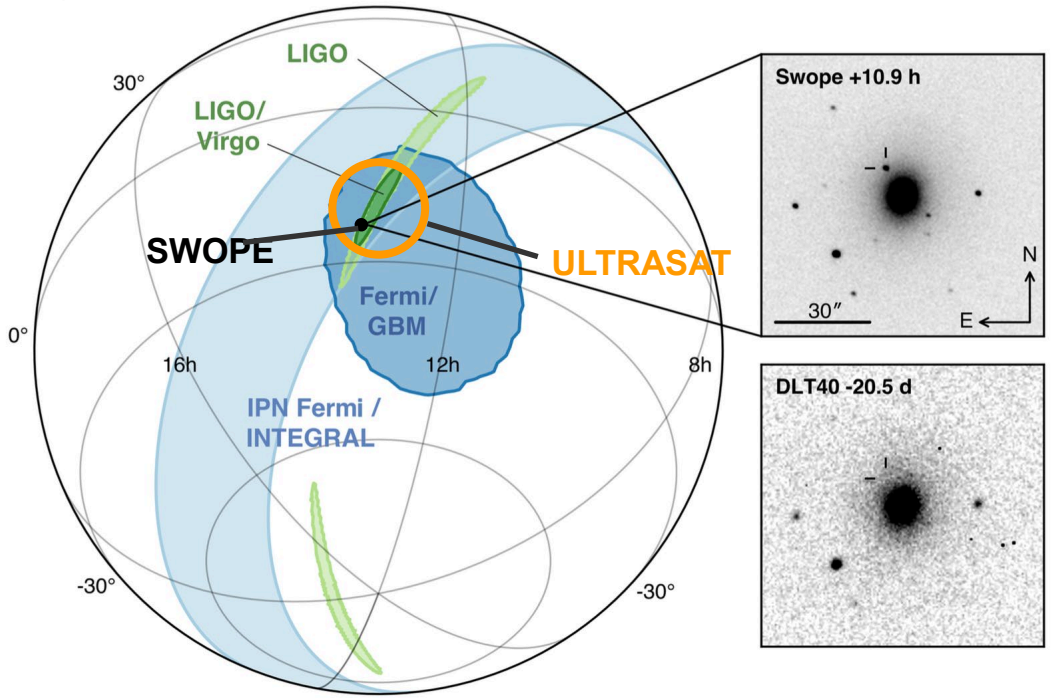
ULTRASAT

5-minute scale UV transients lead the way to high-energy astrophysics

Hot explosions are bright in the UV!



Shvartzwald et al, ApJ 2024



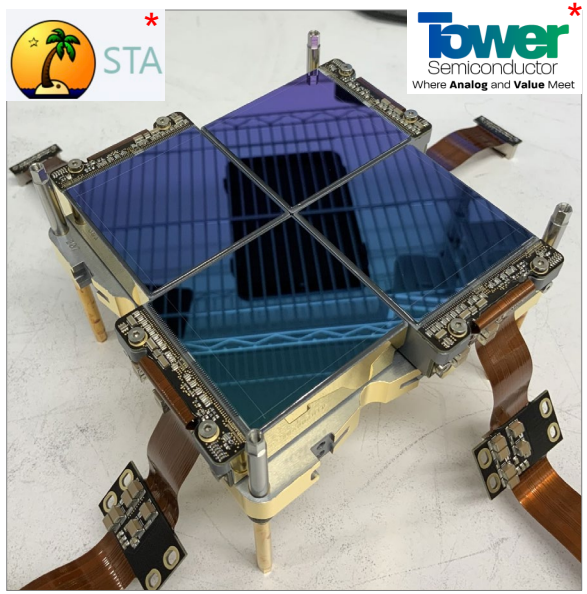
Discovery of GW from neutron star merger and short gamma-ray burst, GW170817

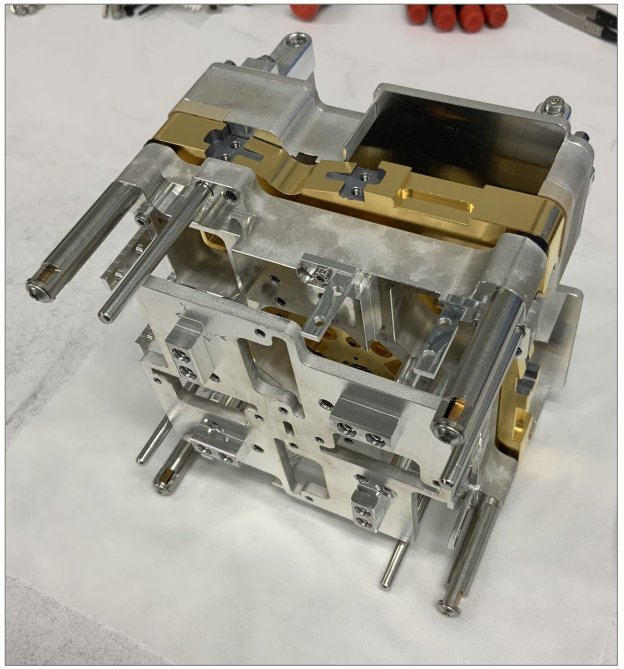
ULTRASAT at DESY

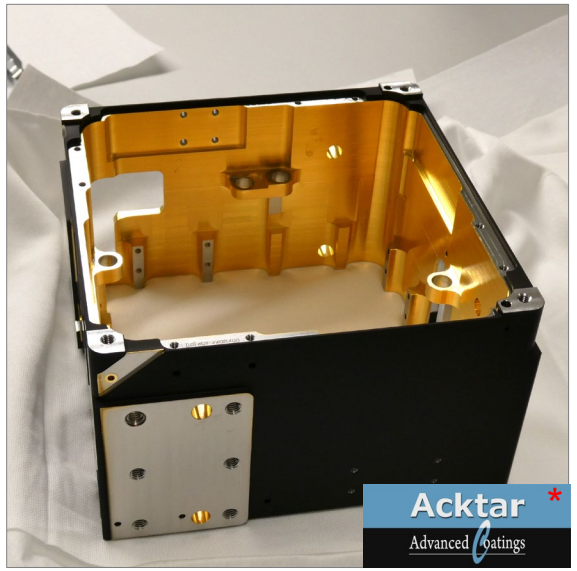
Achievements 2021-2024

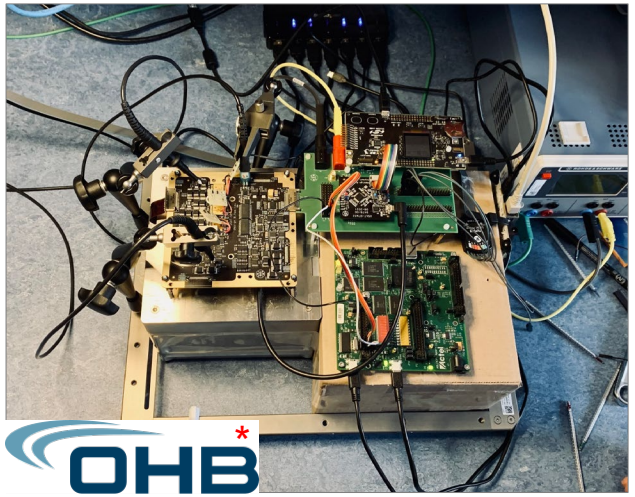
- First DESY satellite mission
- Unique multimessenger science synergies, contribution to space project as part of our strategy
- We started the camera project in 2019 and plan to deliver it by 2026
- New CMOS sensor design verified and being tested
- Electronics, mechanics, thermal system fully developed and being tested at DESY
- New infrastructure (clean room, thermal vacuum chamber) constructed and commissioned for tests

* companies we work with



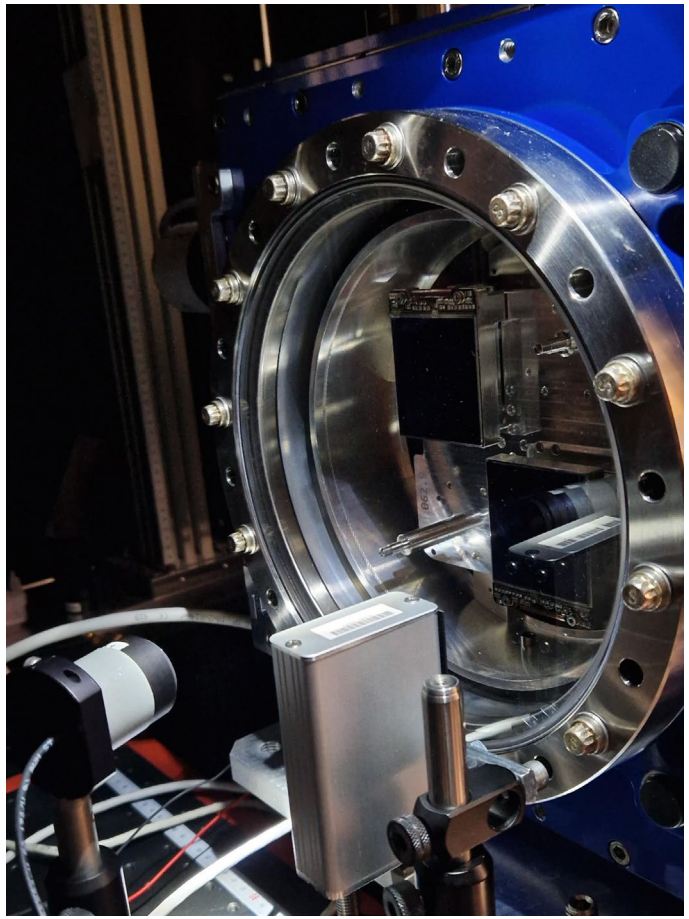




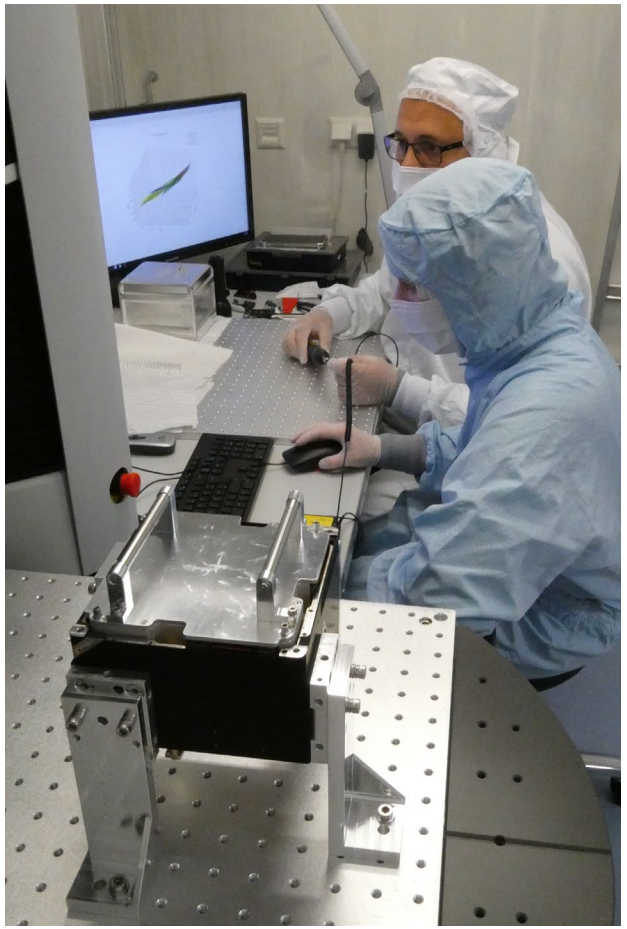


We provide the end-to-end ULTRASAT camera

ULTRASAT camera assembly, characterisation, testing



Optical calibration setup at DESY has unique precision capacities, also used by NASA and NIST!

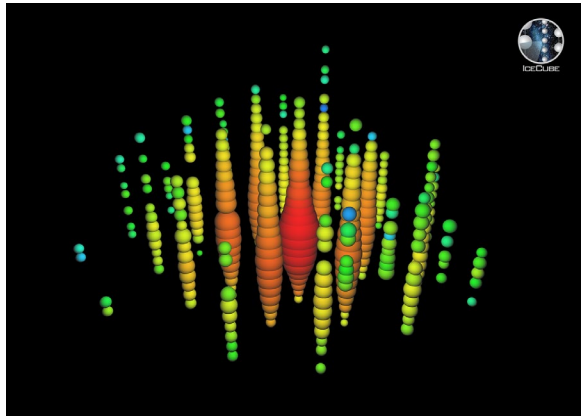


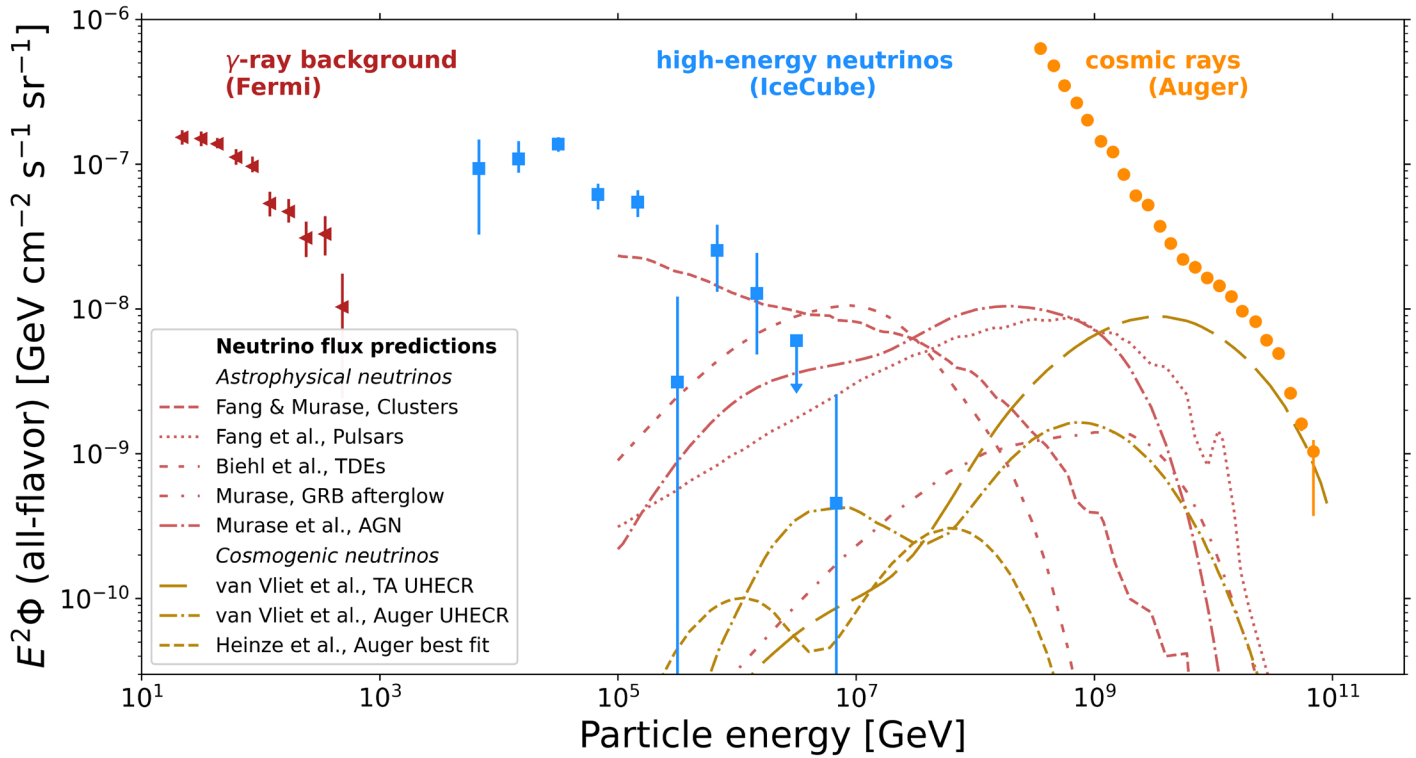
Dedicated cleanroom built and commissioned, integration tests ongoing

IceCube – the neutrino astronomy pioneer

And the leading role of DESY in it

- IceCube has been leading neutrino astronomy for the past decade
- **Discovery of astrophysical flux**
- World-leading **neutrino oscillations** measurements
- **Competitive dark matter and sterile neutrino searches**
- **Discovery of first astrophysical neutrino point sources**



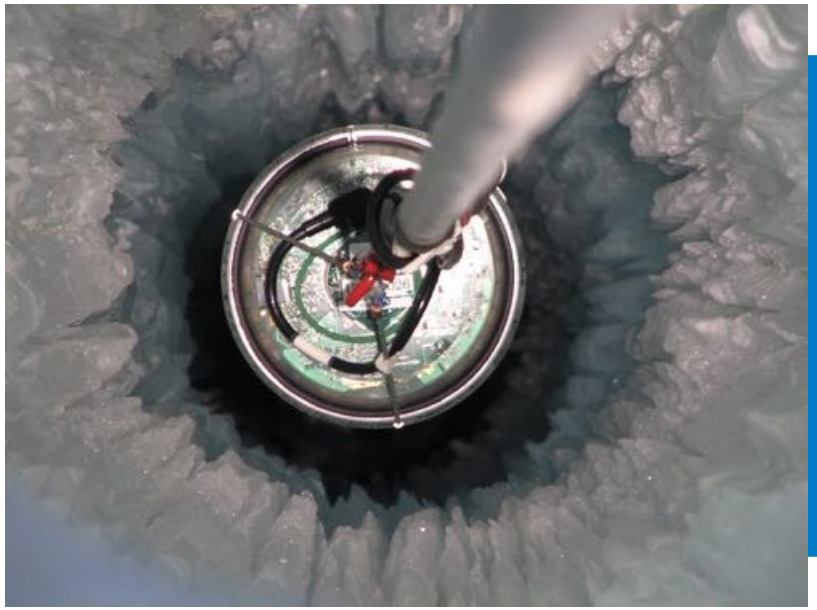


Where do we want to go in neutrino astronomy?

Our strategy

IceCube Upgrade

IceCube Neutrino Observatory



RNO-G

Radio Neutrino Observatory - Greenland

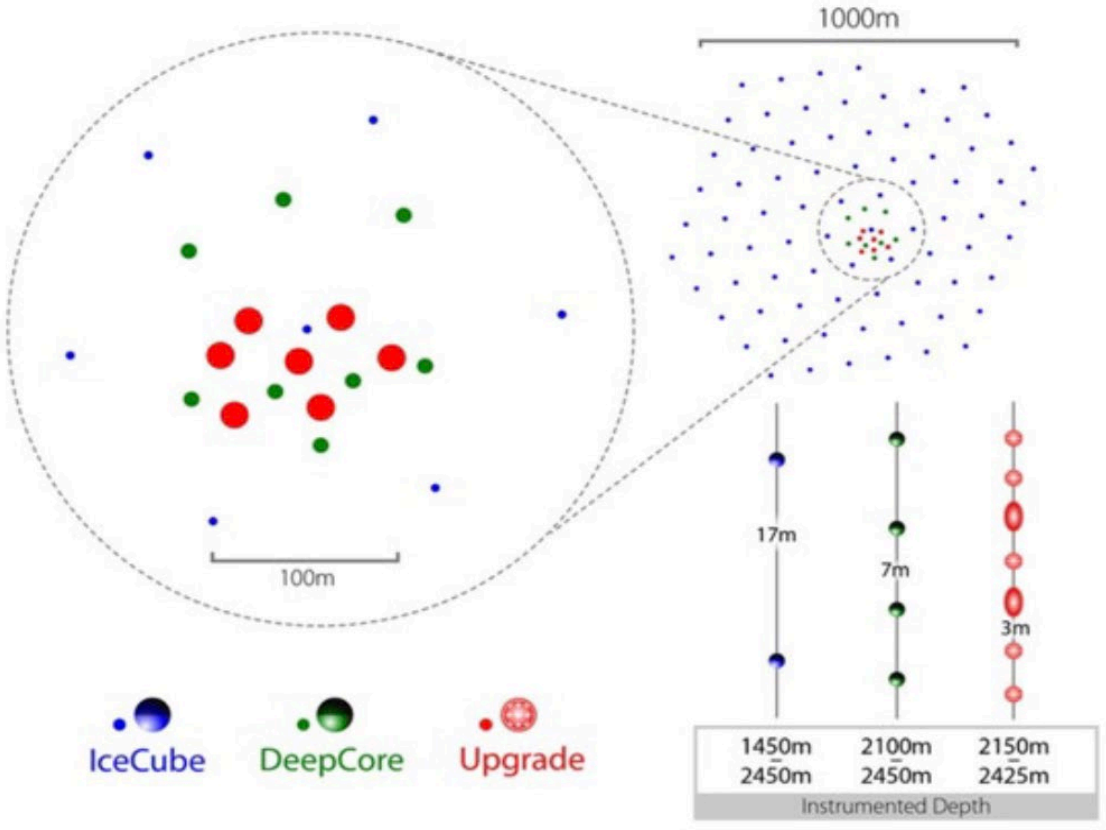
IceCube Gen2

IceCube Upgrade

Towards the low energies with the mDOM

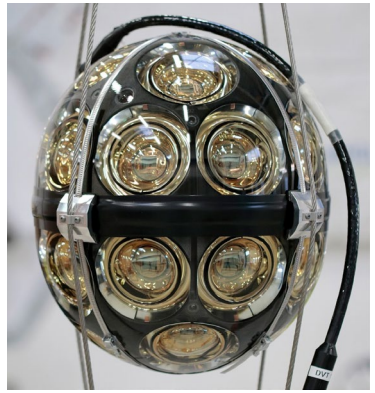
MRU-1 Milestone:
Upgrade installed (on-track)

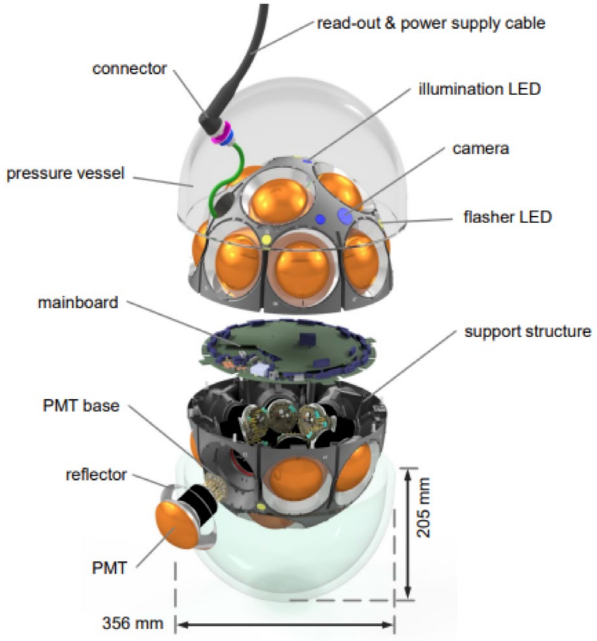
To be installed in the 2025/26 field season



The mDOM,
a German design:

- 24 small PMTs instead of one large one
- Enhances photo-cathode area by factor 2.5 and multi-facetted approach allows for better reconstruction





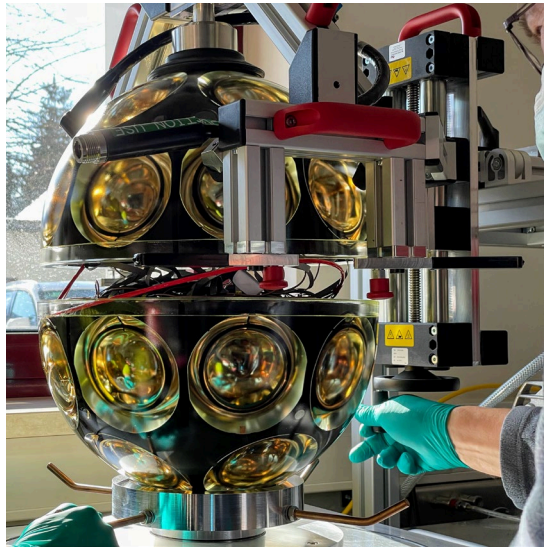
IceCube Upgrade

Producing the mDOM

- **DESY one of two production centers for the IceCube Upgrade**
- Production line as developed at DESY has been exported to second production line in the US
- **225 of 430 novel optical modules are produced and tested at DESY**

Timo Karg
L2 Manager Sensor production
coordinator of German contribution

- **On-time delivery of the first two strings to South Pole for installation in 2025/26**



IceCube Upgrade

This winter at South Pole

MRU-1 Milestone:
Upgrade installed (on-track)

- Drills refurbished

- DOMs and calibration devices arrived

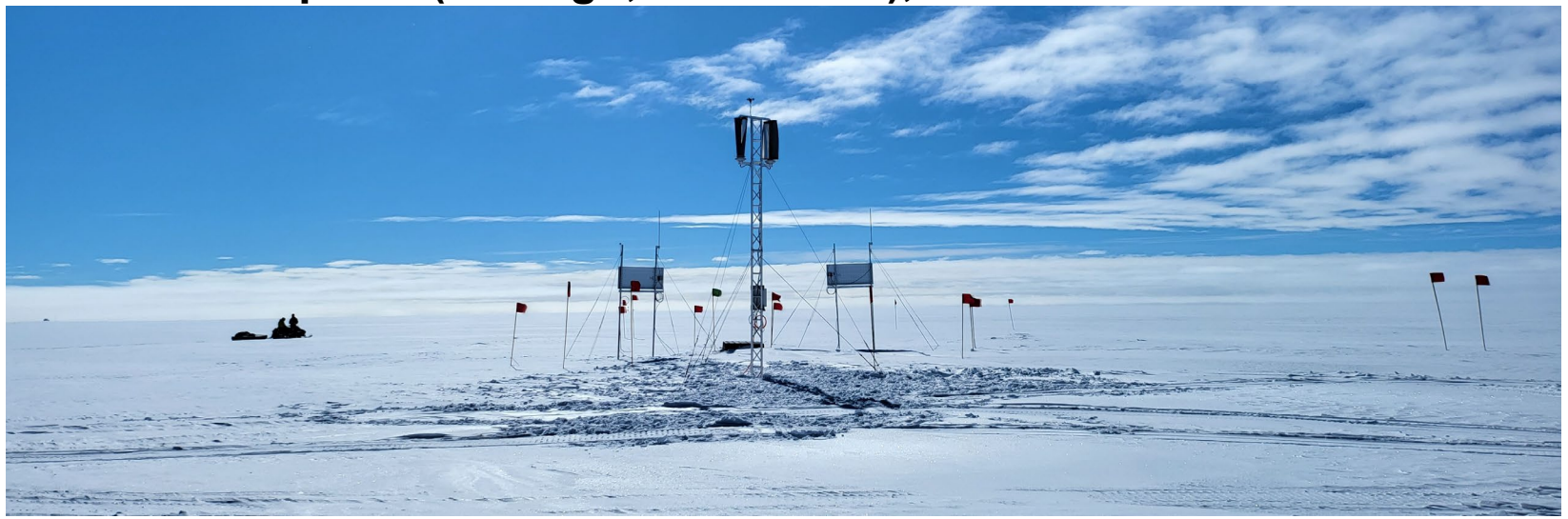
- Cabling for the seven strings ready

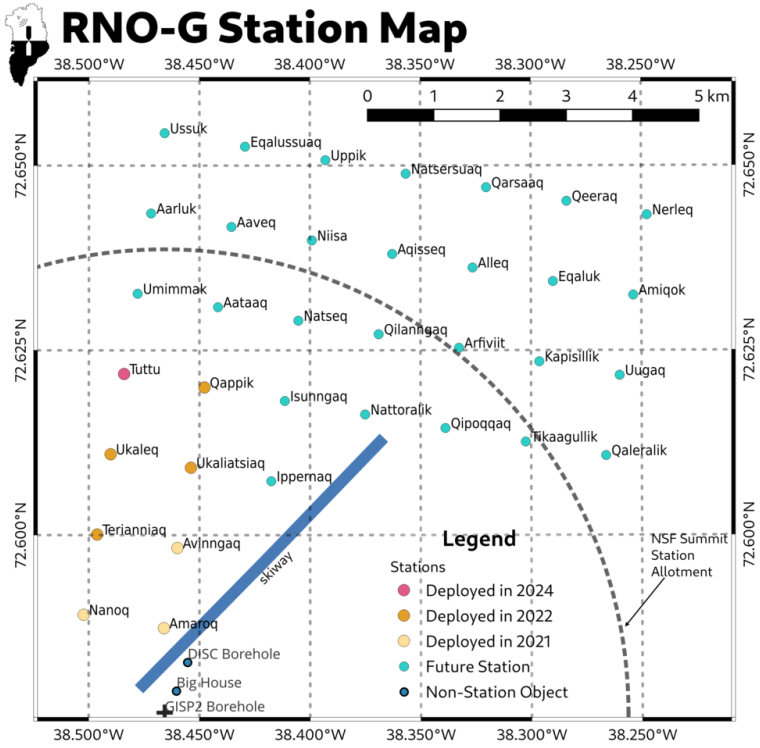
Radio Neutrino Observatory Greenland

Towards the ultra-high energies with RNO-G

km-scale

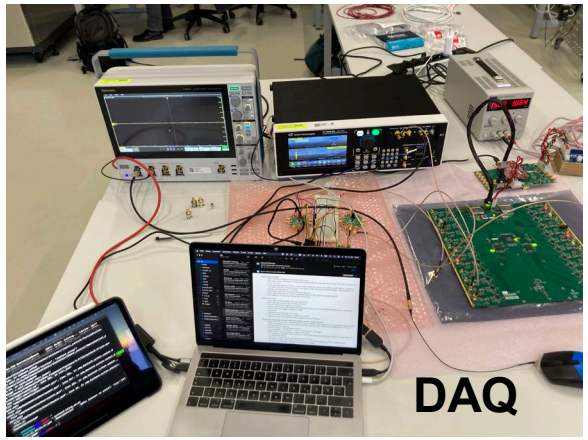
- **Improve the sensitivity of IceCube at the highest energies by exploiting the radio emission following a neutrino interaction**
- **First large-scale implementation of the radio technique to detect neutrinos (Askaryan effect, coherent Cherenkov-like emission)**
- **Under construction in Greenland since 2021**
- **Leadership: US (Chicago, Penn State), Brussels and DESY**

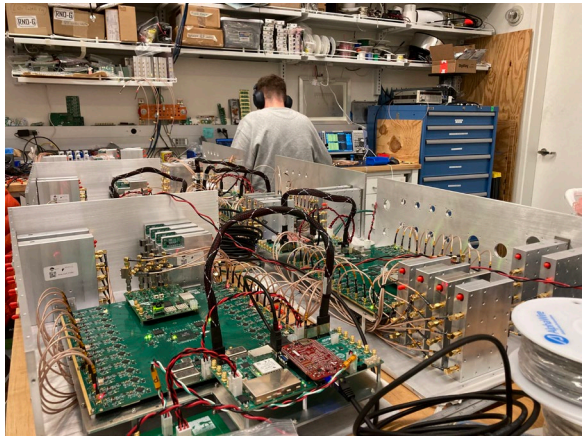




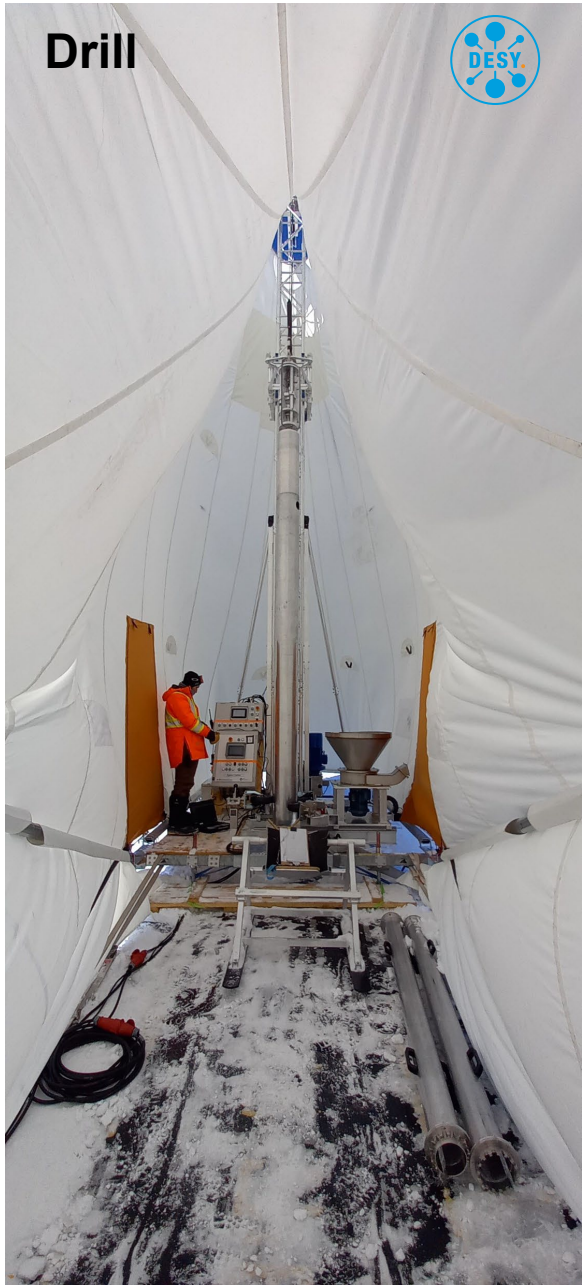
DESY Hardware expertise for RNO-G

and R&D for IceCube-Gen2





- DAQ component construction and testing
- Drilling and installation support
  - World's largest mechanical ice drill
- Engineering for the renewable energy system of wind-turbines and solar power
- Fuel efficient installation tools with small German company



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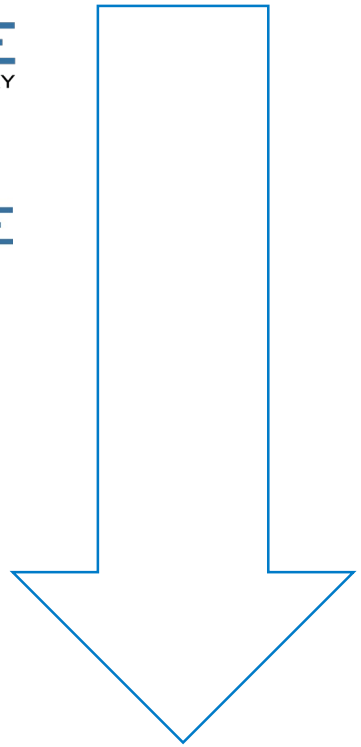
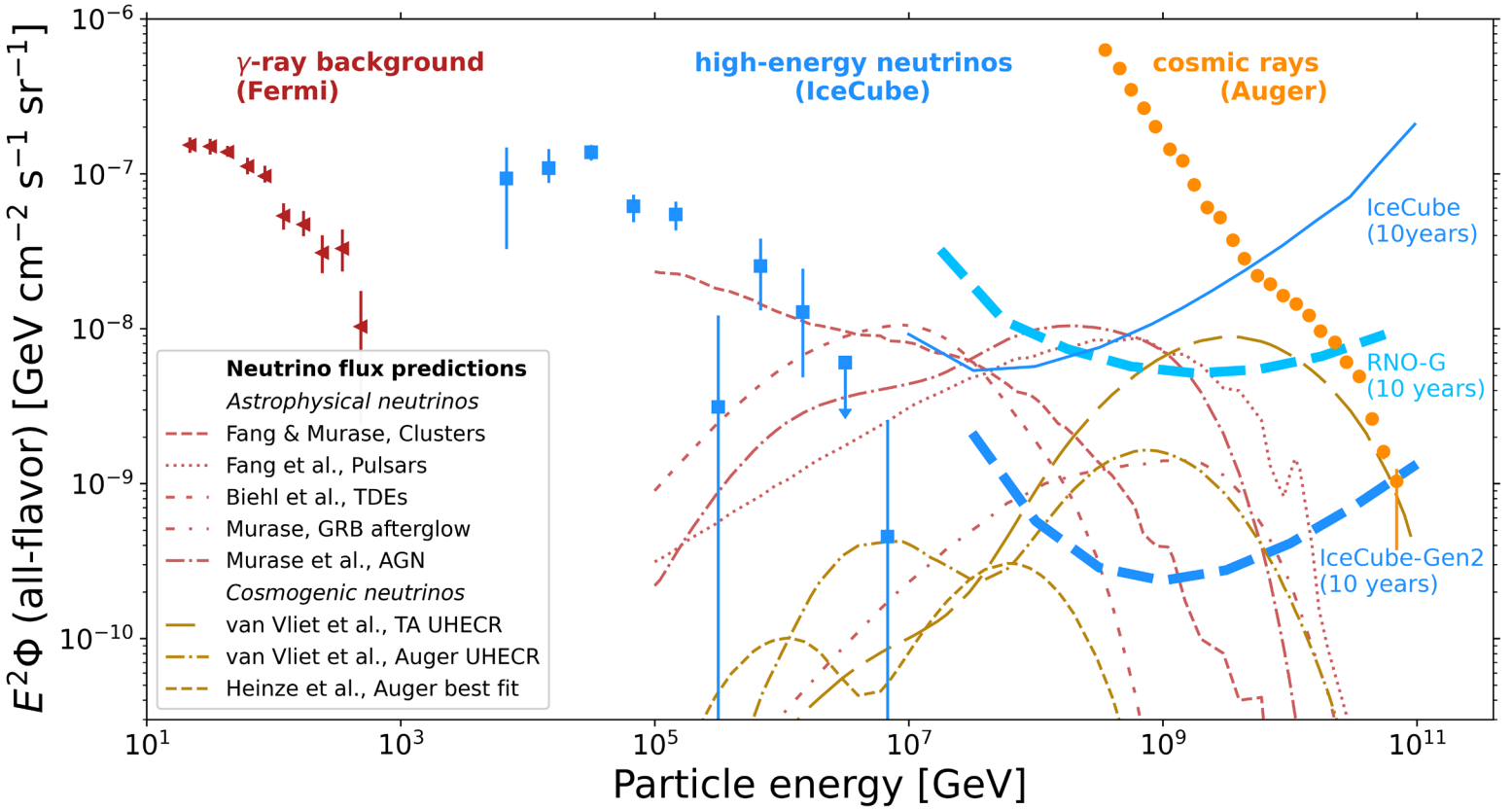
IceCube Upgrade

RNO-G
Radio Neutrino Observatory - Greenland



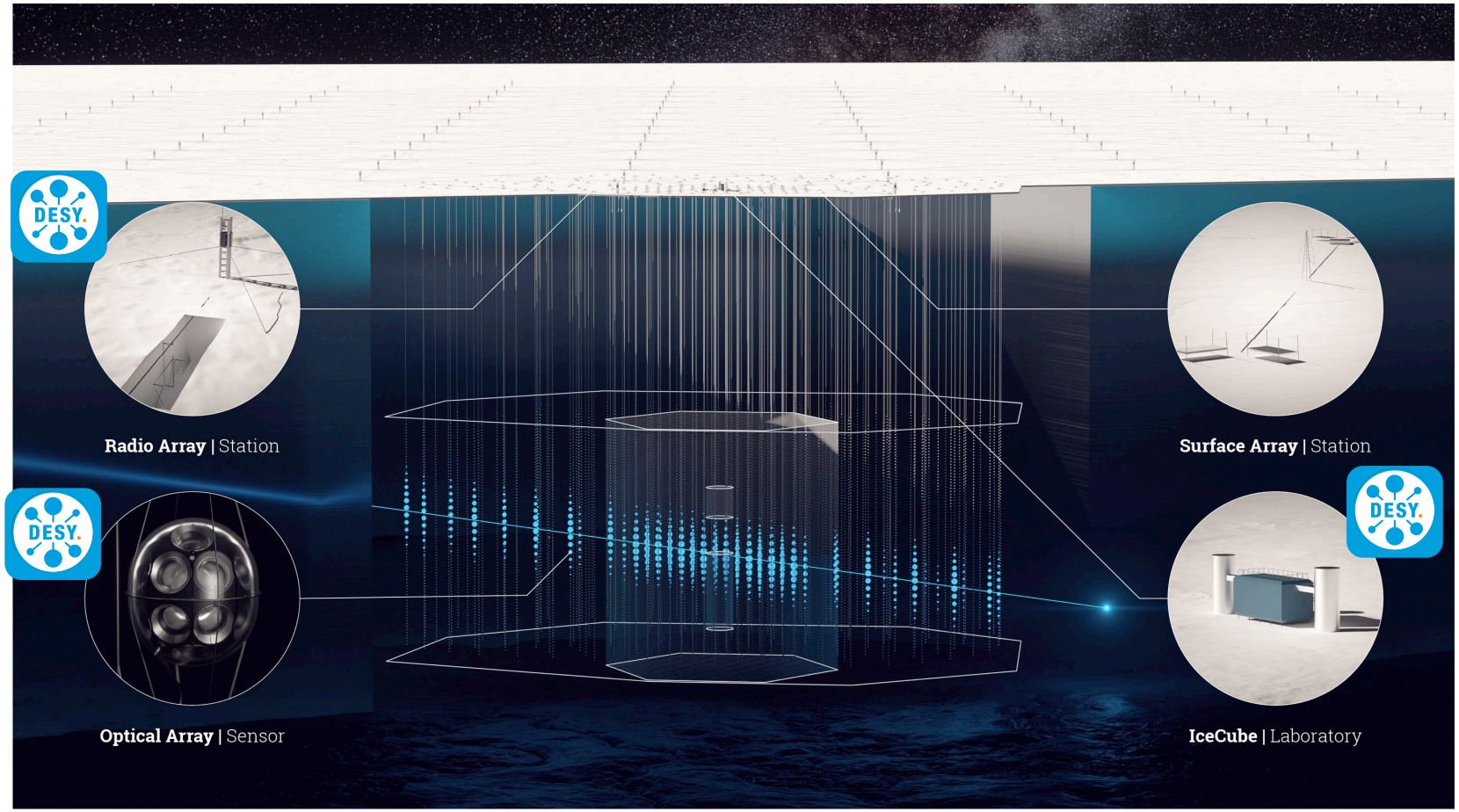


IceCube-Gen2

MRU-1 Milestone:
IceCube-Gen2 TDR complete

Our path ahead

- Germany second strongest partner: DESY+KIT +10 German universities, ~25% of all authors
- Costs: ~500 Mio $ (US accounting) with 55 Mio € German in-kind contribution
- Favorably evaluated in: US Decadal Survey, US P5 panel, Japanese MEXT, European APPEC roadmap
- Construction could start as soon as 2028/29 with a 10-year construction phase



Summary

- CTAO is our key flagship project for the future
- ULTRASAT is our first satellite project and promises major discoveries
- Neutrino astronomy targets the next generation neutrino telescope
- IceCube Upgrade and RNO-G clear milestones towards this goal
- *We build, operate, and exploit telescopes. With our deep system expertise we make large projects possible*

Spares

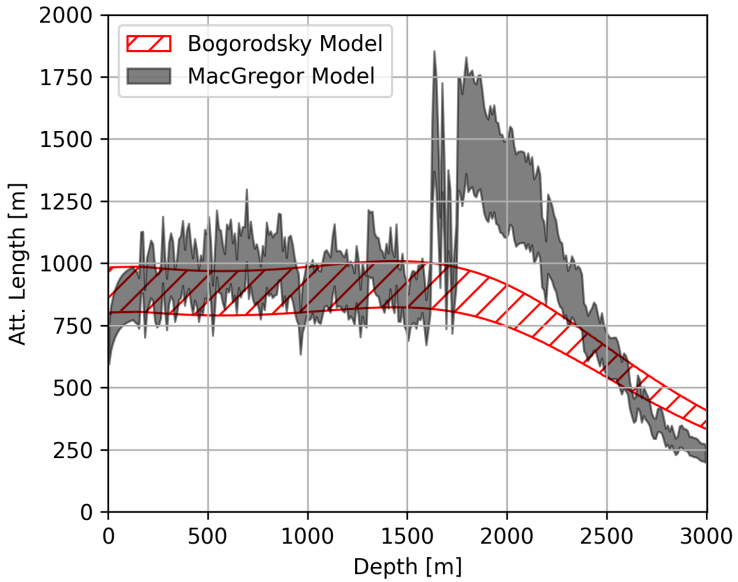
Radio Neutrino Observatory Greenland (RNO-G)

Radio emission of neutrinos: profiting from particle physics and ice properties

- **Compton scattering and positron annihilation lead to a negatively charged shower front, which can be become a macroscopic current in > PeV showers**

- This changing current leads to **coherent radio pulses on at the Cherenkov angle**
- Attenuation length of kilometer scales in polar ice for radio waves: allows to build very sparse detectors: a single station (24 antennas) can monitor > 1km^3 of ice

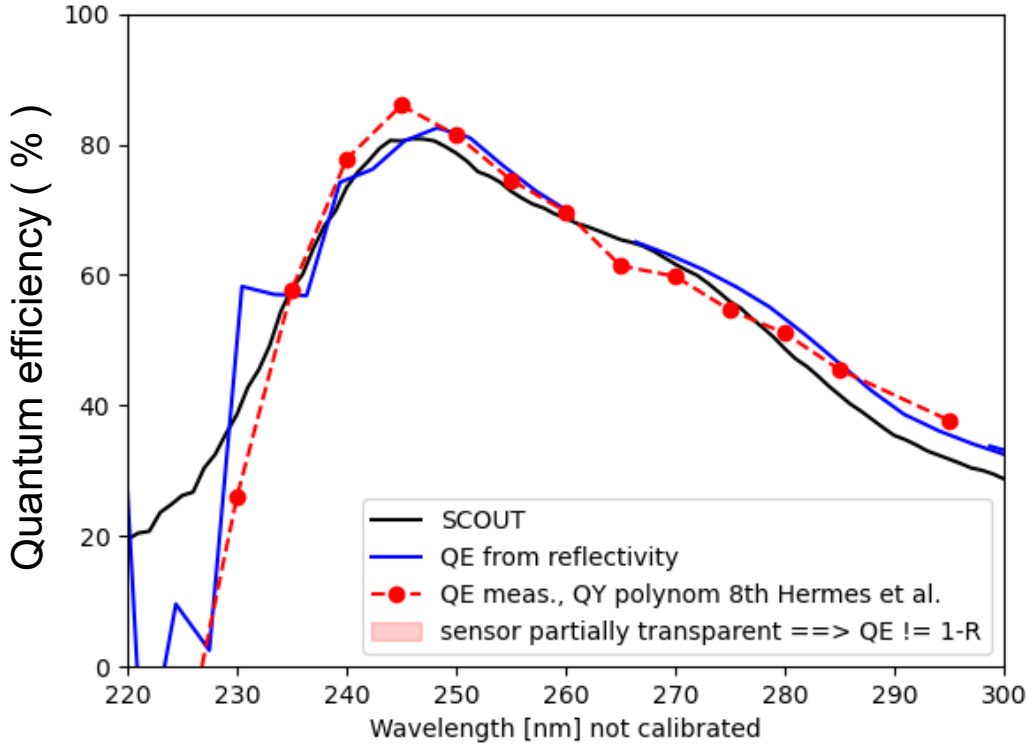
- Cost-effectively build detectors for > 10 PeV showers

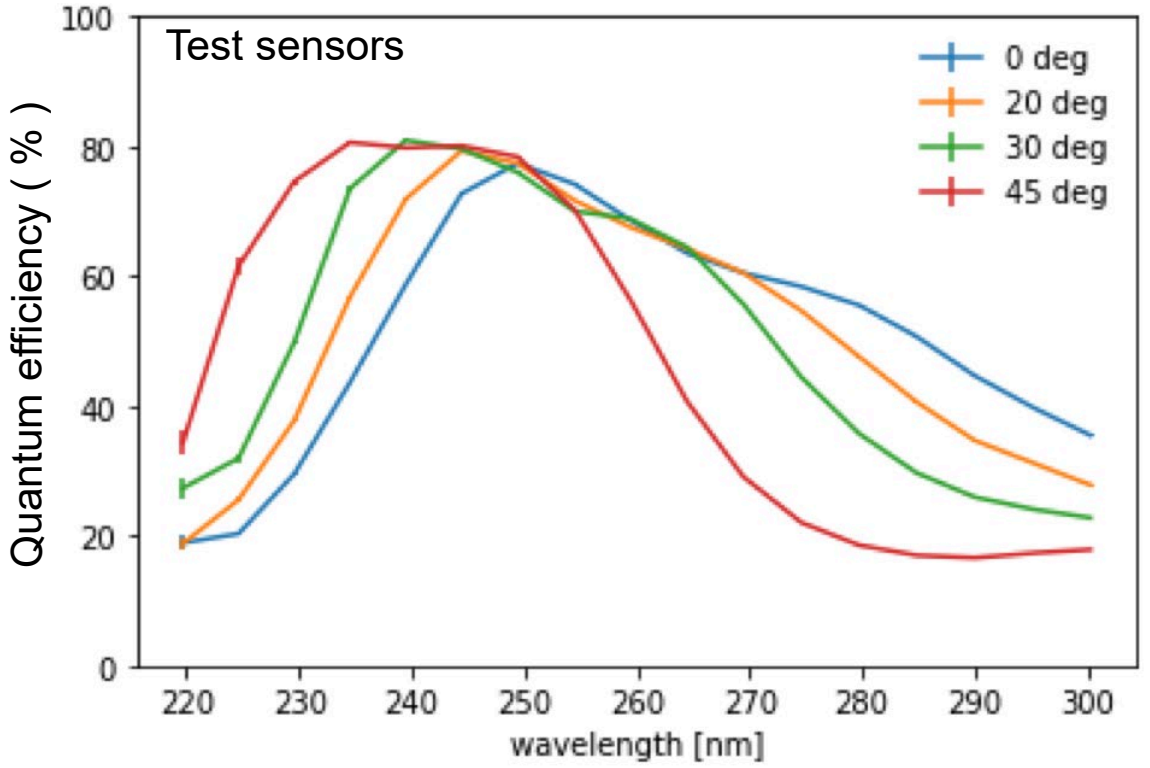


RNO-G Coll.
J. Glaciol. 2023
& 2024
C. Welling (PhD)
and A. Nelles

ULTRASAT Camera Optical Efficiency

Measurements fully performed at DESY



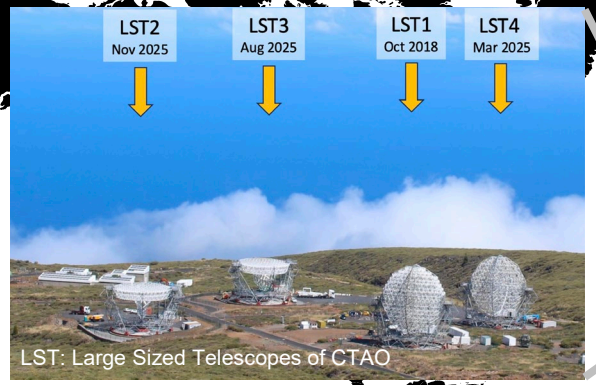


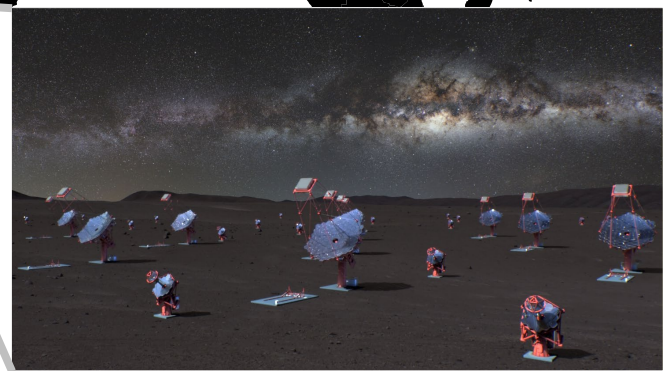
ULTRASAT sensor fully meets requirements

SPIE, https://arxiv.org/abs/2208.00159

CTAO – Cherenkov Telescope Array Observatory

A European priority research infrastructure and global open observatory

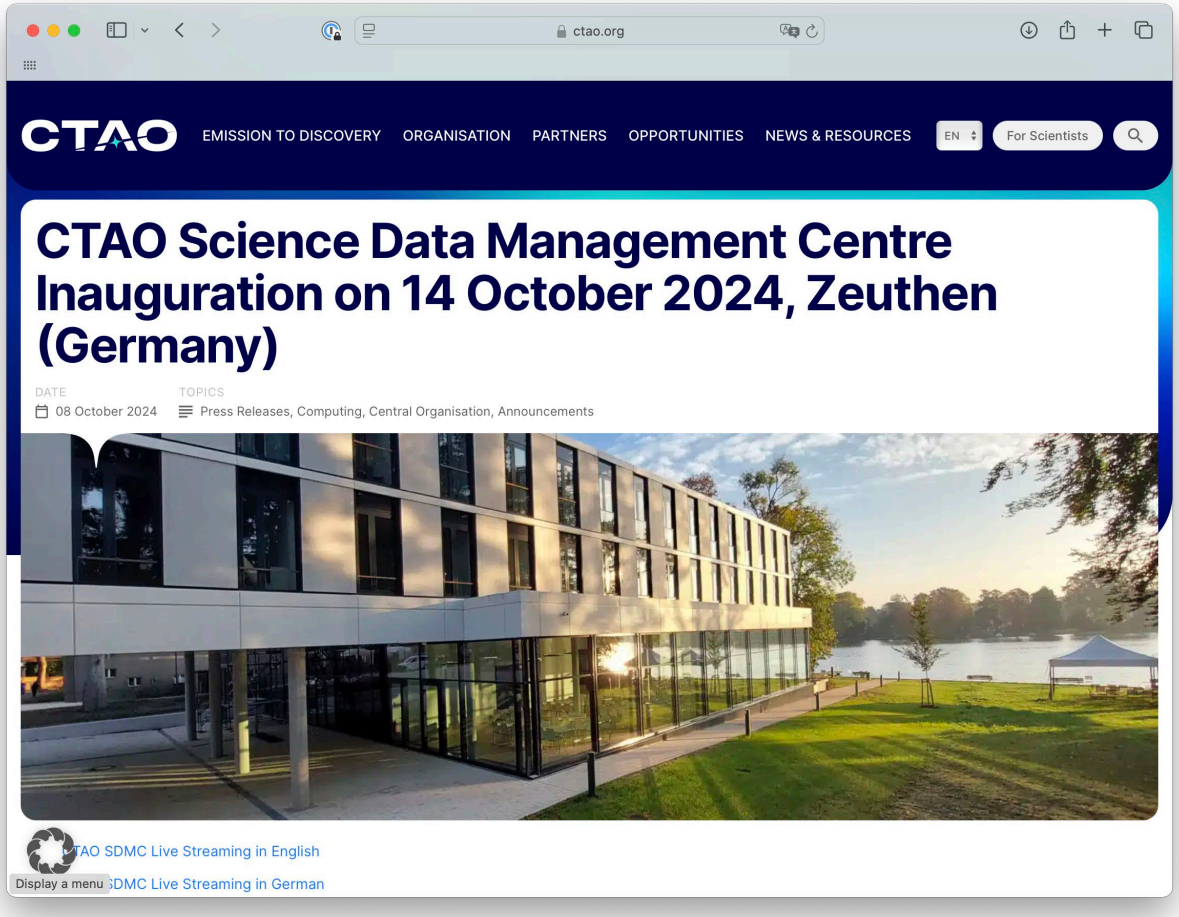




1 observatory, 4 sites:

- Science Data Management Center
- Headquarters Bologna
- North telescope site La Palma
- South telescope site Paranal

Host of CTAO Science Data Management Center



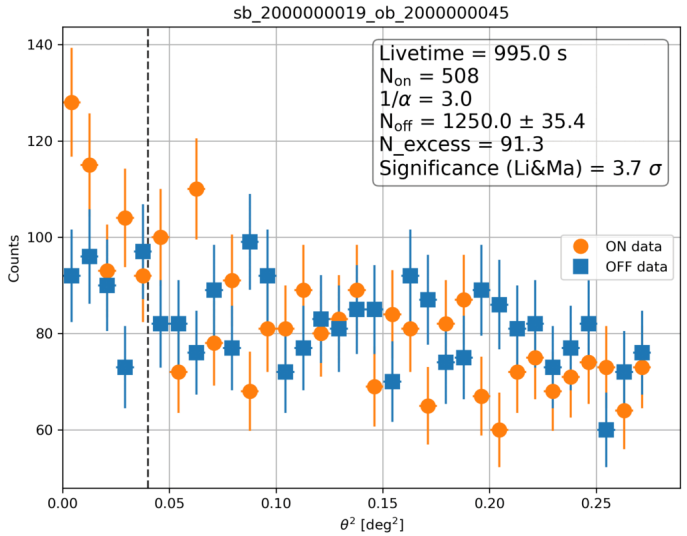
The SDMC is transformational for the DESY campus in Zeuthen

Our strategy is to exploit synergies in science, computing, software

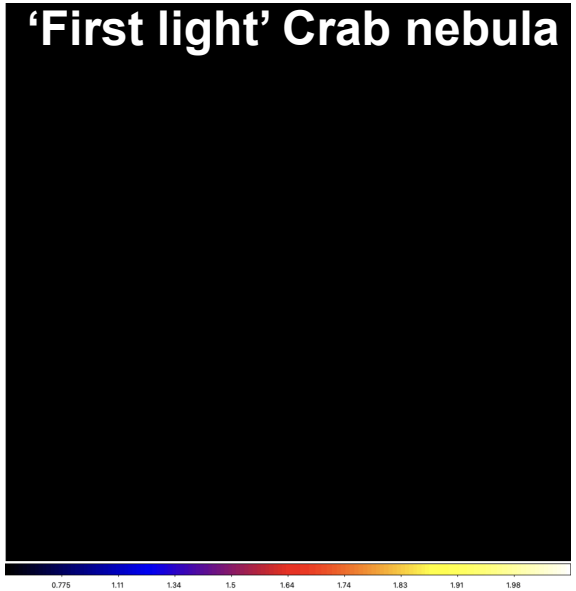
DESY Computing for CTAO

Achievements 2021-2024

- SDMC: established its responsibility for computing, software, data management, user access and training
- Established DESY as 1 of 4 off-site data centers – CTAO generates 1 GB / s of compressed data
- Established lead contributions on-site data centers
- Provision of leadership simulations work package
- Provision of computing infrastructure for software development and testing
- Established lead contributions control and data



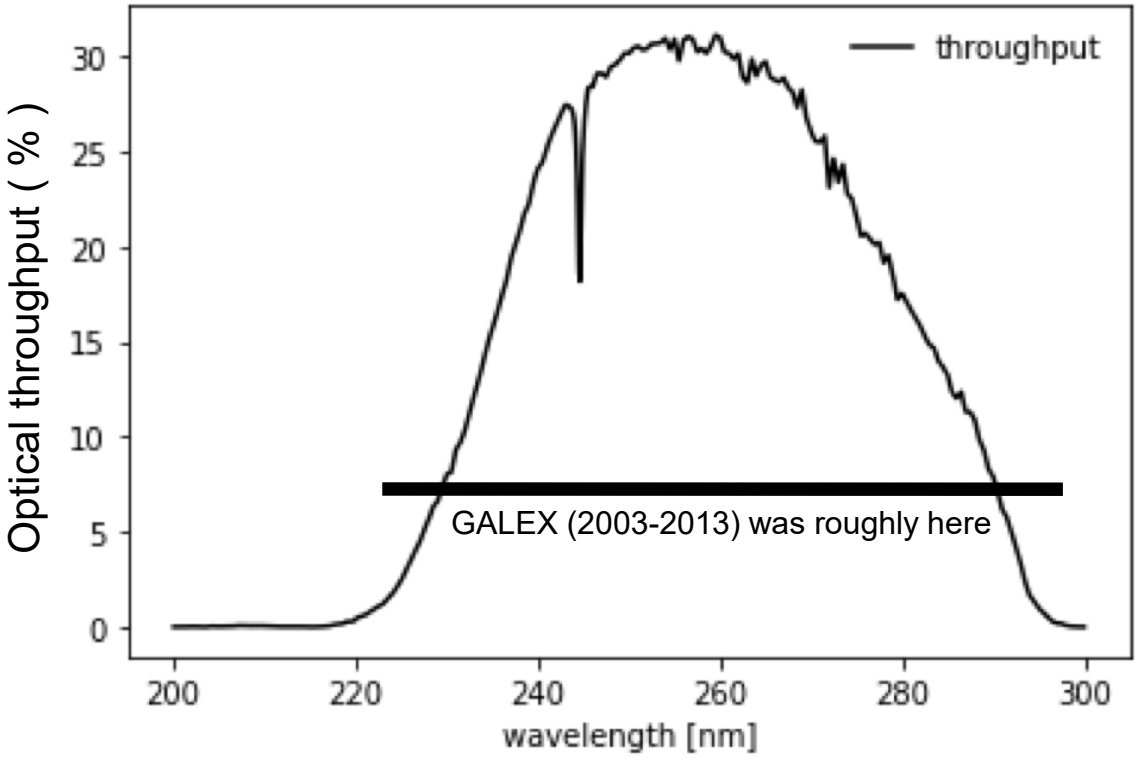
Telescope integration campaign with strong DESY role

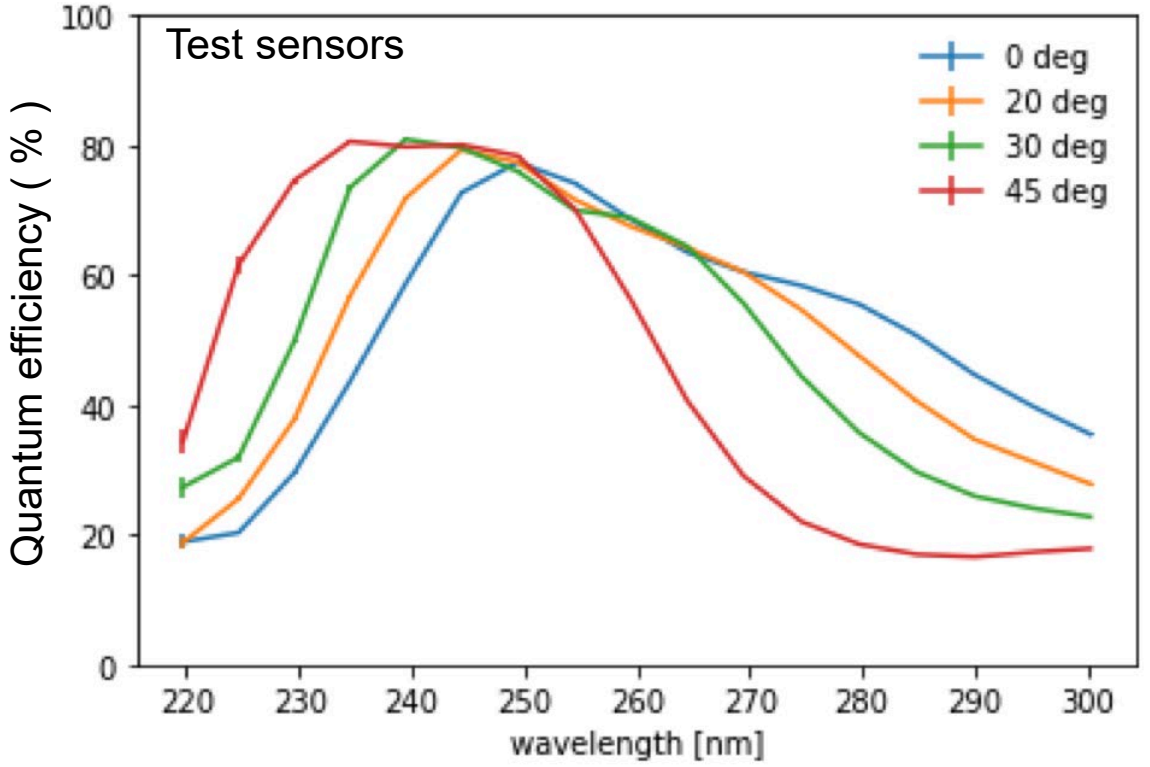


- **We are a key and lead contributor to CTAO Computing**
- MRU-6 Milestone: First CTAO science results

ULTRASAT Camera Optical Efficiency

Measurements fully performed at DESY





SPIE, https://arxiv.org/abs/2208.00159

CTAO – Cherenkov Telescope Array Observatory

Timeline