



APPEC

# Research Infrastructures for the MM Era

Astroparticle Physics European Consortium



Andreas Haungs | KIT – Institute for Astroparticle Physics

Neutrinos in the Multi-Messenger Era | Louvain-la-Neuve, Belgium | 29/11-2/12 2022



# Astroparticle Physics

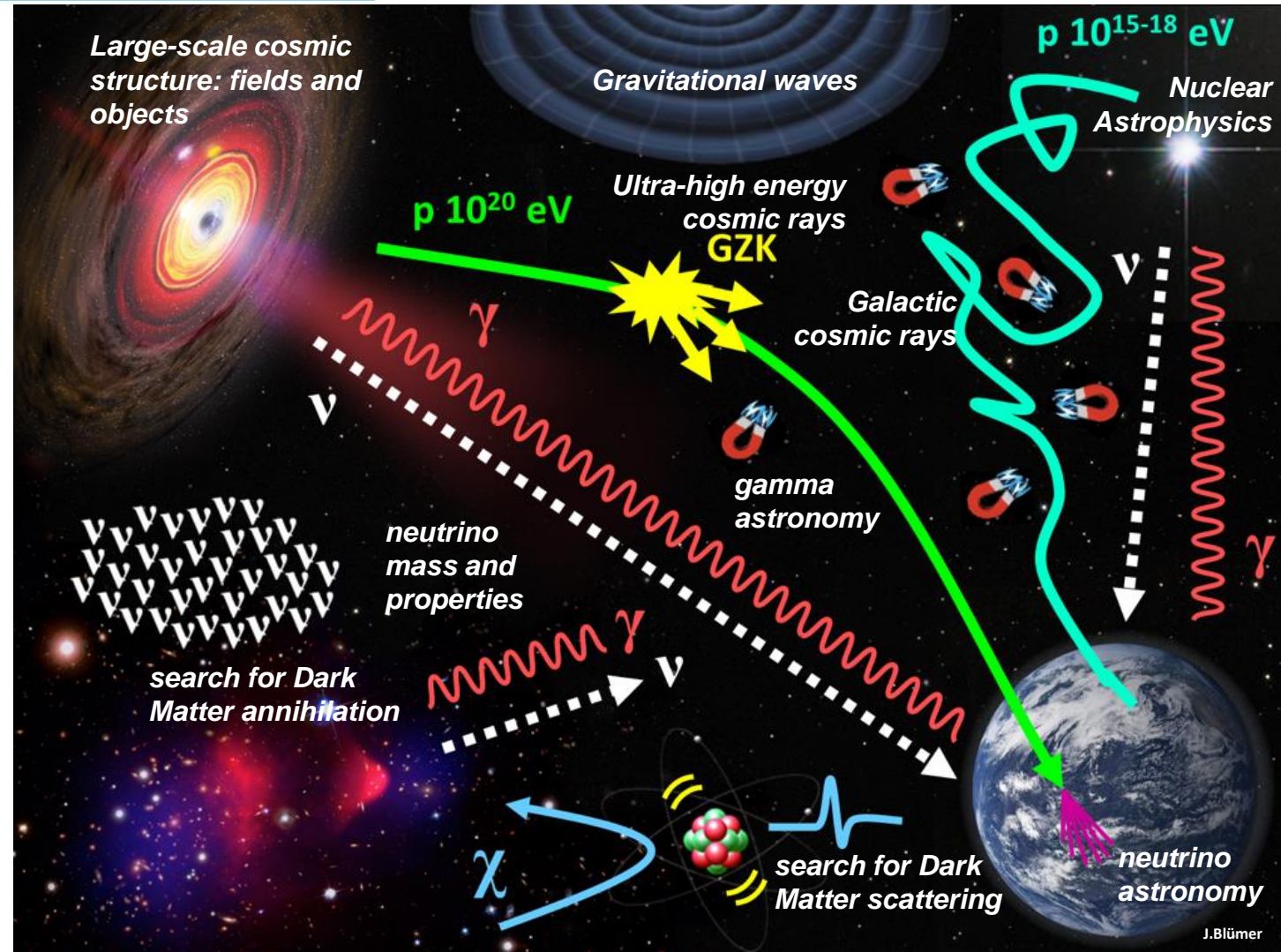
## Understanding the Multi-Messenger and the Dark Universe



Astroparticle Physics is a branch of fundamental science embedded in environment and society!

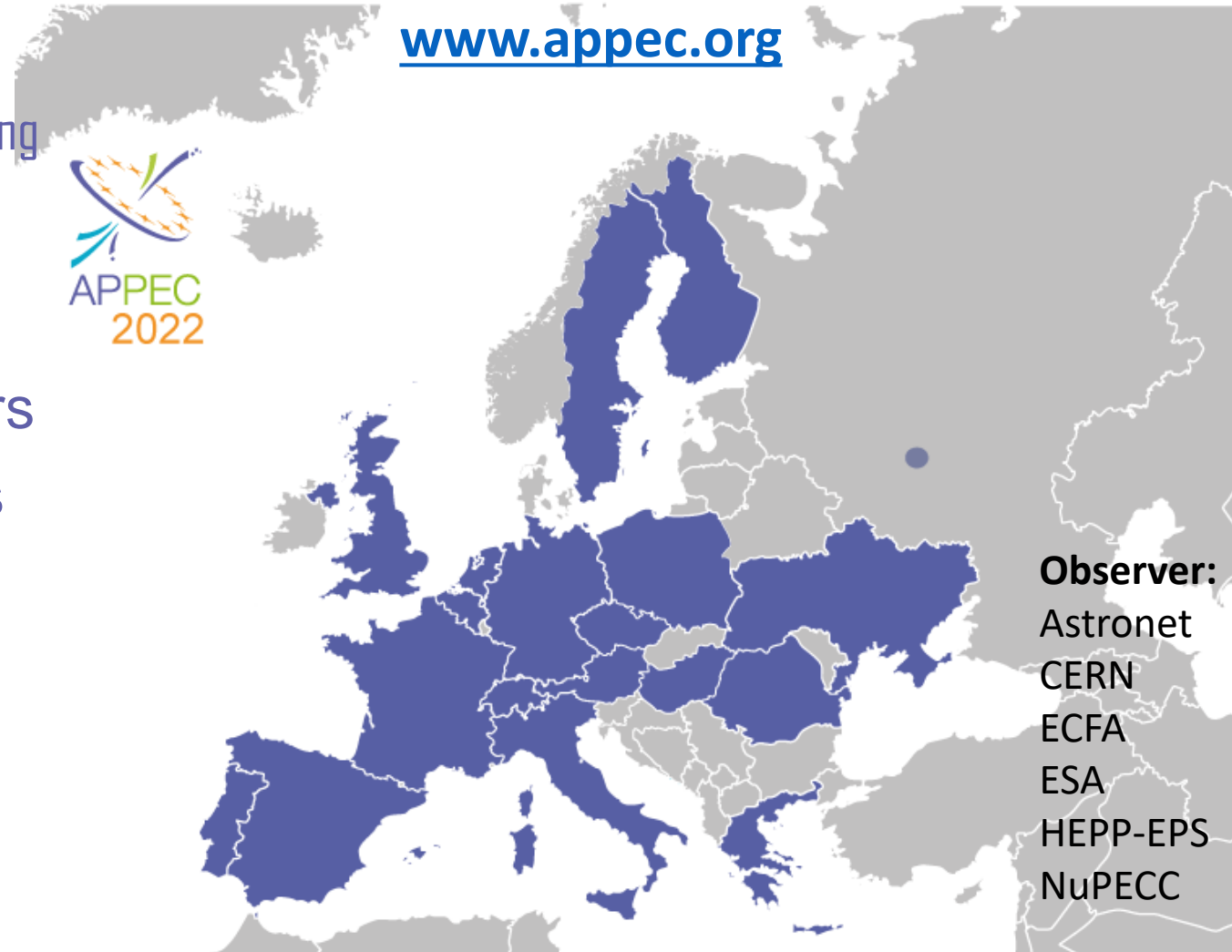
### Wikipedia:

While it may be difficult to decide on a standard 'textbook' description of the field of astroparticle physics, the field can be characterized by the topics of research that are actively being pursued.



## AstroParticle Physics European Consortium - an international coordinating structure, founded in 2012

- Based on a MoU and financial Agreement with DESY (host of the APPEC Common Fund) by all partners
- 18 (+1 suspended) member countries with 22 funding agencies
- a budget of c. 70k€/year
- 3 bodies:
  - General Assembly with Observers
  - Scientific Advisory Committee;
  - Joint Secretary



# APPEC tasks

Guarantee **Coordination** of European Astroparticle Physics in Europe between **funding agencies** and **visibility** at Ministry level through:

- Structured **scientific advising** (SAC, dedicated panels to specific challenges)
- Development and update of **roadmaps** based on scientific strategies and financial considerations
- Establish **relations** with other bodies in **companion fields**
- Initiate activities within **Horizon Europe**
- Express **collective views** on APP in international fora
- Organise **Town meetings**
- Support relevant **meetings/schools** of the community
- Organize **TechFora** and Open Calls
- Engagement with **society** (Outreach, Education,...)
- Contribute to **Working Groups** (R&D panel, Individual Recognition, Early Scientist career, Science WGs) and **Organisations** (EuCAPT...) and **JENA**

to support the **Astroparticle Physics** community

## APPEC is

- Helping in coordination of **large-scale RI**
- Helping in transition of **mid-scale** experiments to **large-scale RI**
- Helping in support of **small-scale** and **R&D experiments**

# APPEC Roadmaps

<https://www.appec.org/roadmap>



2008



2011



2017



# APPEC scientific topics

- High-energy gamma rays
- High-energy neutrinos
- High-energy cosmic rays
- Gravitational waves
- Dark Matter
- Neutrino mass and nature
- Neutrino mixing and mass ordering
- Cosmic microwave background
- Dark Energy
- Astroparticle theory
- Detector R&D
- Computing and data policies



# APPEC organisational & societal issues

## Organisational:

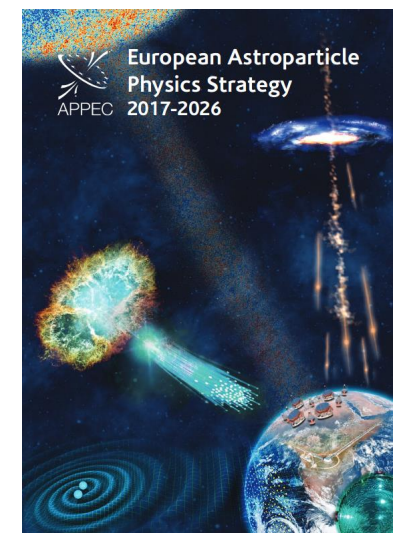
- European and global collaboration and coordination
- Neighboring communities
- European Commission
- Unique infrastructures
- Interdisciplinary opportunities

## Societal:

- Diversity
- Education and outreach
- Open Science and Citizen Science
- Transfer Knowledge
- Connection to industry
- Ecological impact

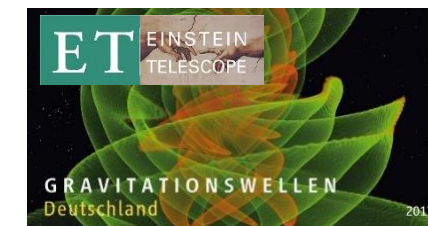
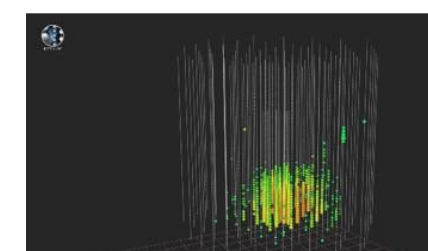
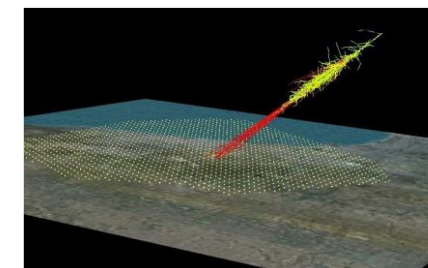
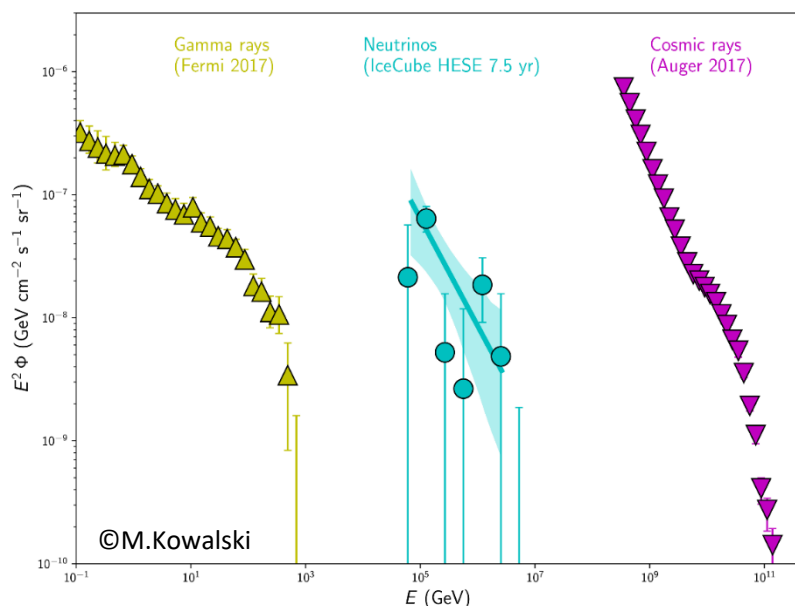
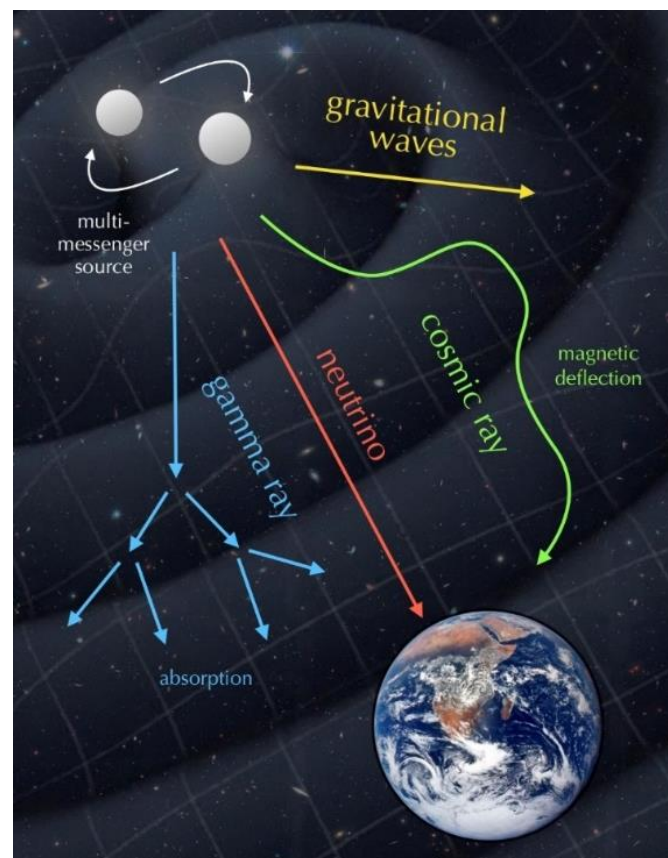


<https://indico.cern.ch/e/JENAS2022>



# Multi-Messenger Astroparticle Physics

- Required to understand the sources of cosmic rays and the physics processes in the high-energy Universe
- Needs long-term operational observatories
- And a sophisticated Big Data management: Big Data Analytics; Research Data Management; Data Curation; Open Data



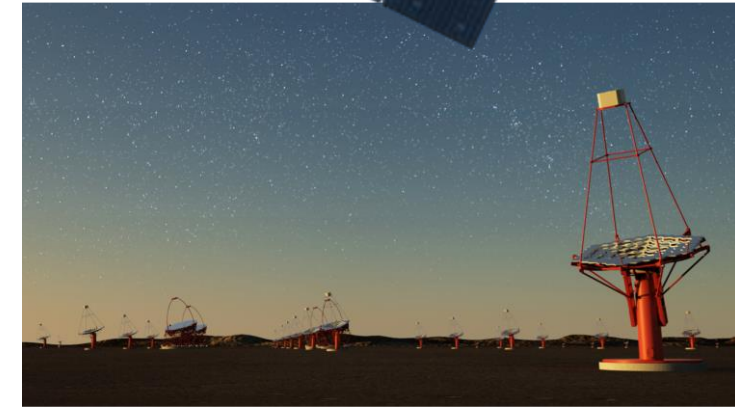


# High-Energy Gamma Rays

- Covers large energy range with different observatories
- Satellites (Fermi, AMEGO (launch 2029), ASTROGAM)
- Imaging Air Cherenkov Telescopes (H.E.S.S., Veritas, MAGIC)
- Ground-based arrays (GRAPES, TAIGA, HAWC, LHAASO, SWGO)
- Main future project within APPEC: [CTA](#) (ESFRI)



VERITAS



H.E.S.S.



MAGIC



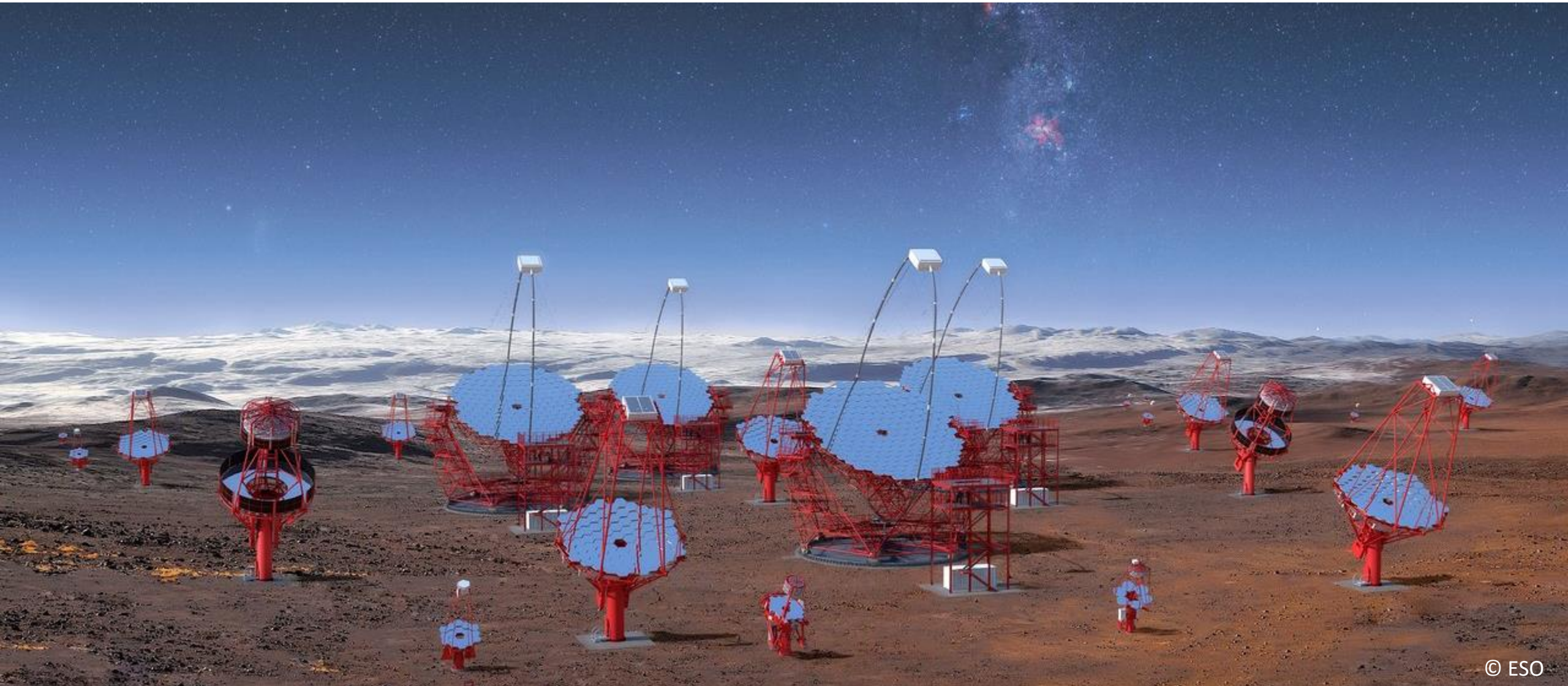
LHAASO



HAWC



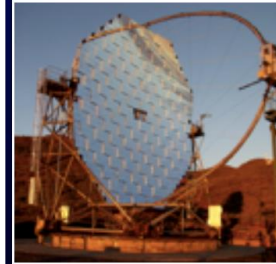
# Cherenkov Telescope Array – CTA



# High-Energy Gamma Rays

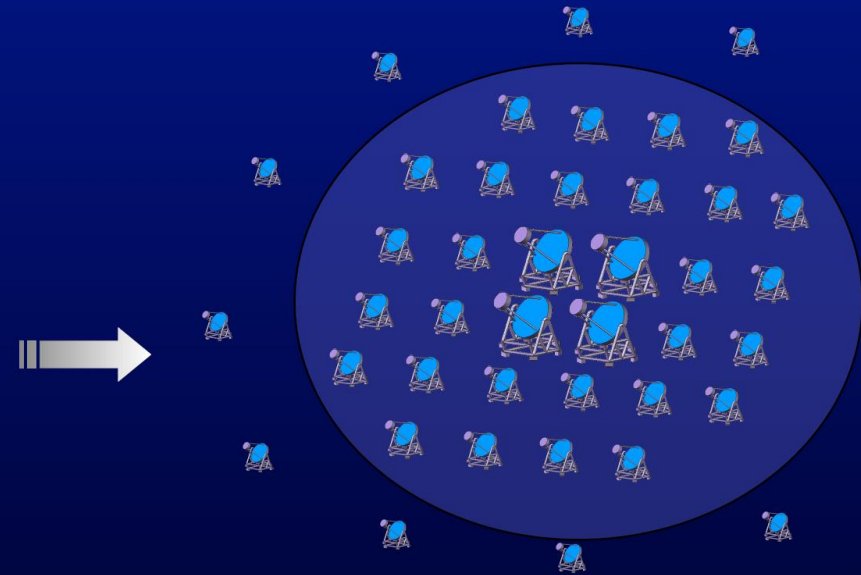


- ESFRI Project
- Open, proposal-driven observatory
- 3 telescope types: LST, MST, SST
- 2 sites: La Palma + Chile
- Governance: ERIC (established 2022)
- 31 countries, >200 institutes, ~1400 scientists
- Construction next 3-5 years



F.Aharonian

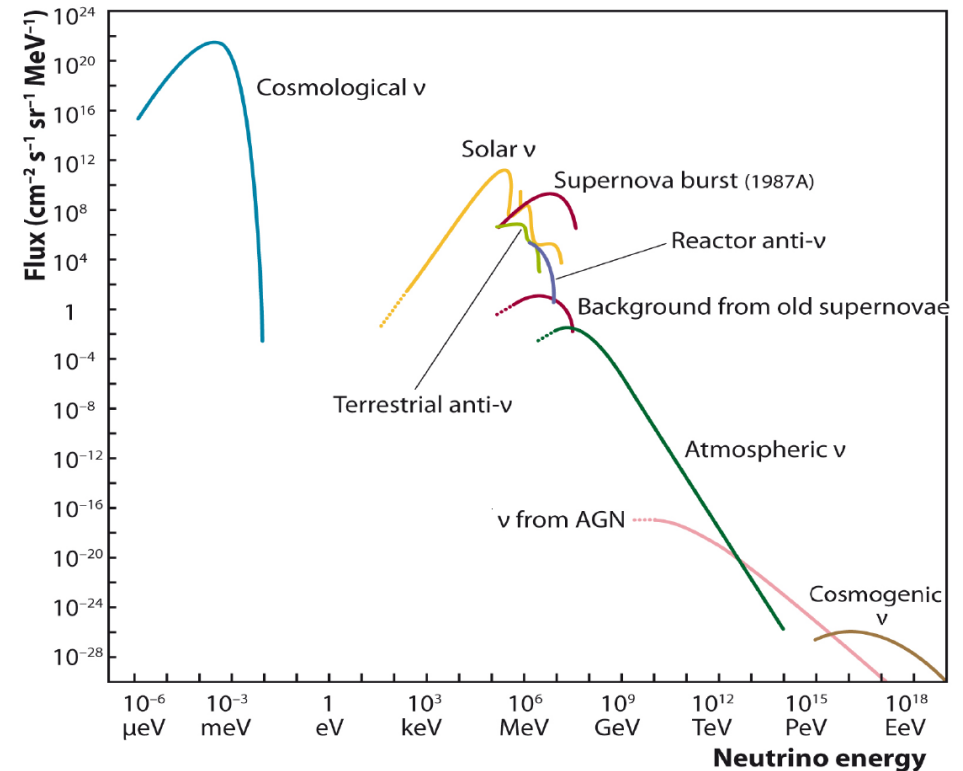
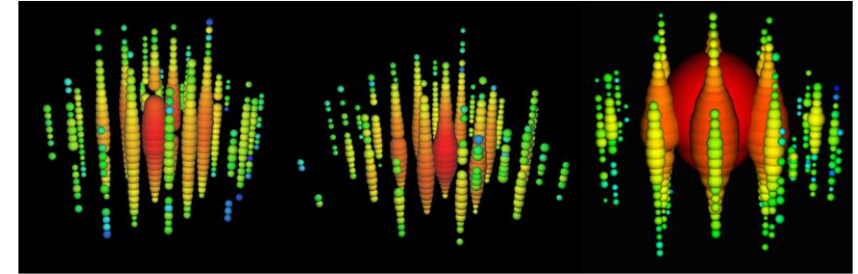
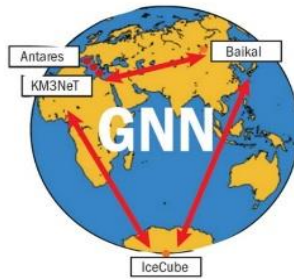
from *HEGRA/HESS/MAGIC/VERITAS* to *CTA*...



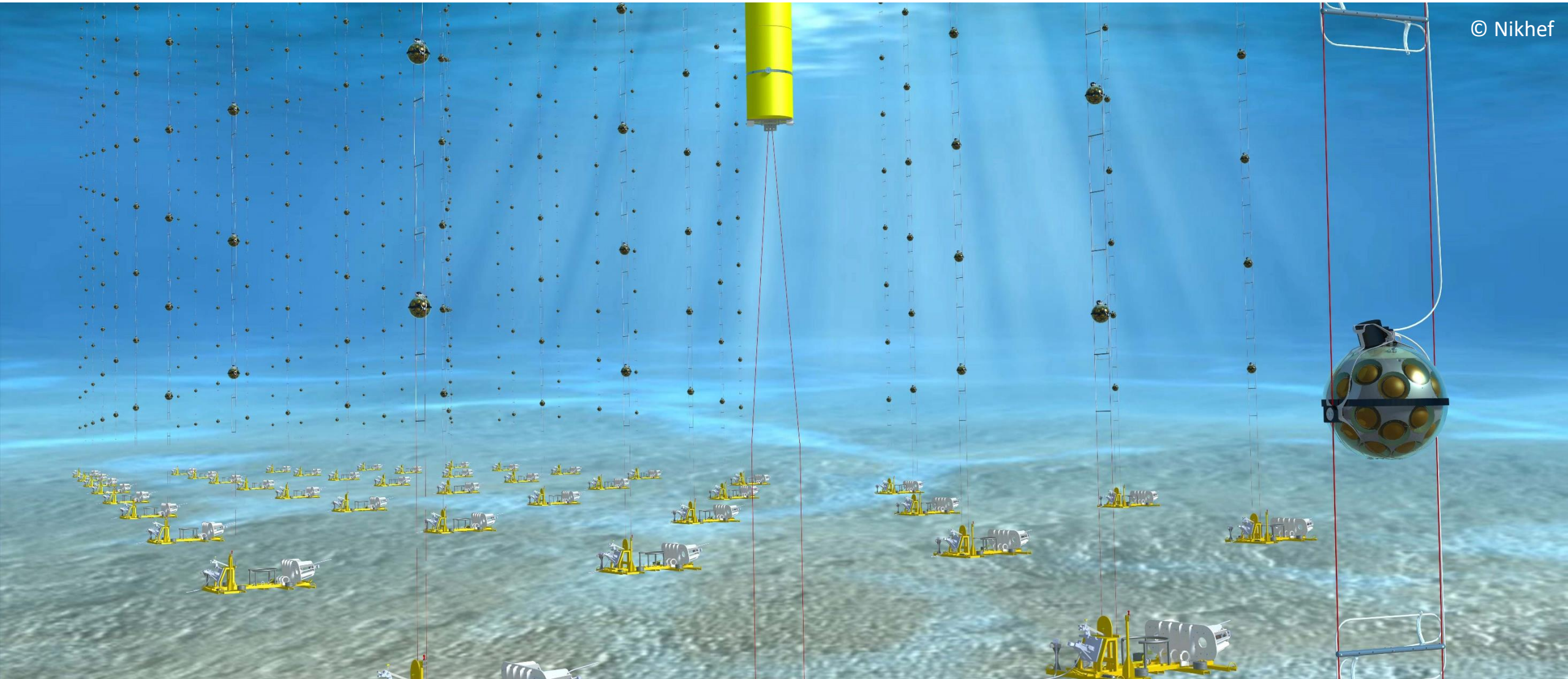
- an order of magnitude better sensitivity
- broader energy coverage:  $10^{10}$  to  $10^{15}$  eV
- angular resolution down to 1-2 arcmin
- energy resolution 5 to 25 percent
- larger (up to 6-8 degree FoV)
- rapid follow-up capabilities

# High-Energy Neutrino Astronomy

- IceCube opened in 2013 the new window of  $>100$  TeV neutrino astronomy
- Several experiments are now organized in the Global Neutrino Network GNN:
  - IceCube  $\rightarrow$  IceCube-Gen2
  - Antares  $\rightarrow$  KM3NeT
  - Baikal-GVD
- R&D phase (in particular for cosmogenic Neutrinos): P-ONE, RNO-G, POEMMA, ANITA, GRAND, ...
- European flagship (ESFRI): [KM3NeT](#)
- Strong partner of US lead [IceCube-Gen2](#)



# Cubic Kilometre Neutrino Telescope – KM3NeT



# High-Energy Neutrino Astronomy

- ESFRI project
- KM3NeT = ARCA + ORCA
- Discovery and subsequent observation of neutrino sources
- Determination of mass ordering of neutrinos
- ARCA (high-energy neutrino astronomy, Italian site)



Installation started, completed 2026

- ORCA (low-energy neutrino physics, French site)

Installation started, completed 2024

- 15 countries, >250 scientists

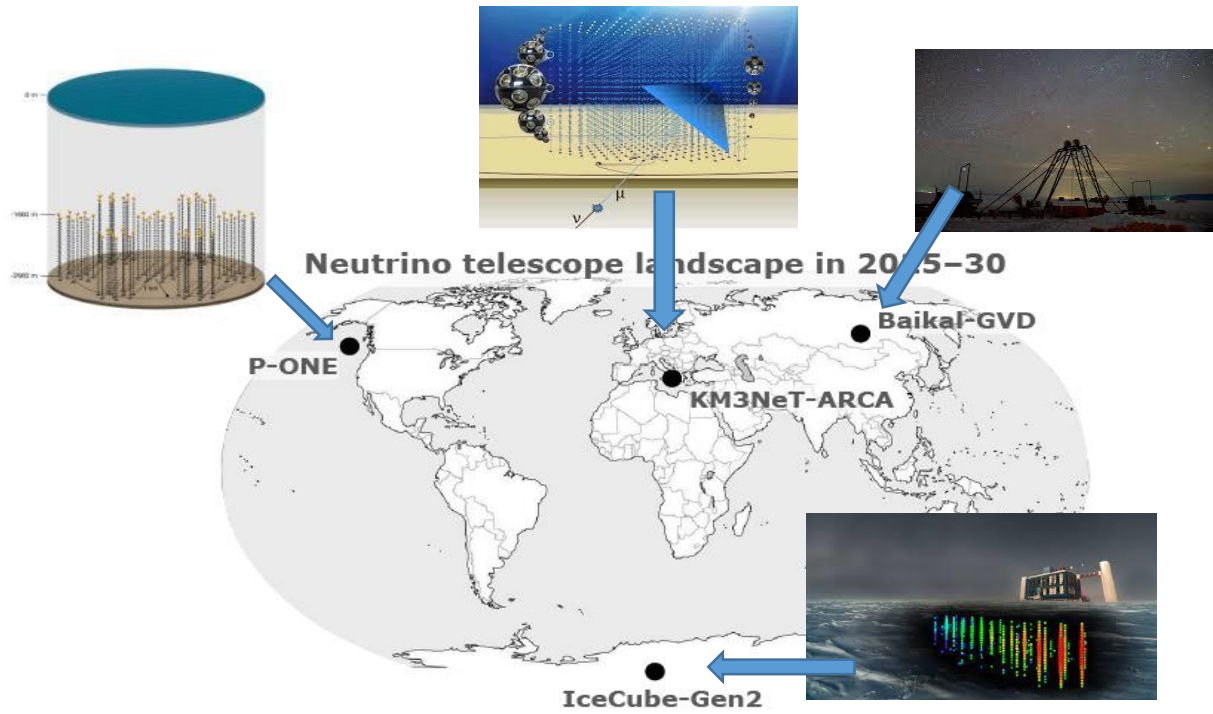
## Science case

- ◆ **Neutrino astroparticle physics**
  - ◆ Galactic and Extragalactic point sources
  - ◆ Diffuse neutrino flux
- ◆ **Dark Matter and exotics**
  - ◆ Neutrinos from Dark Matter annihilation
  - ◆ Magnetic monopoles, nuclearites, strangelets, ...
- ◆ **Neutrino and particle physics ( $\sim 10^5 \nu_{\text{atm}}/\text{year}$ )**
  - ◆ UHE neutrino cross sections
  - ◆ Muons ( $\geq 10^8 \mu_{\text{atm}}/\text{year}$ )
  - ◆ Prompt muons from heavy meson decay
- ◆ **Earth and marine sciences**
  - ◆ Long-term, continuous measurements in deep-sea
- **MM alerts and follow-up**

27-09-2009

Els de Wolf

# High-Energy Neutrino Astronomy



## EeV Neutrinos:

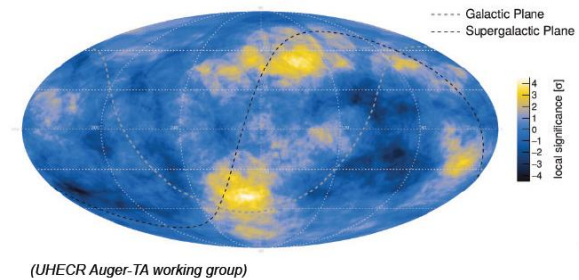
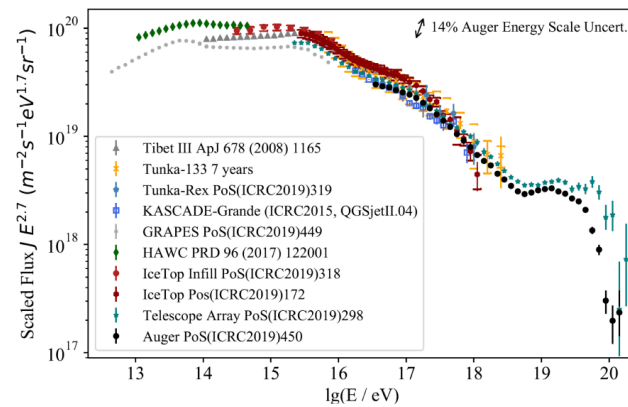
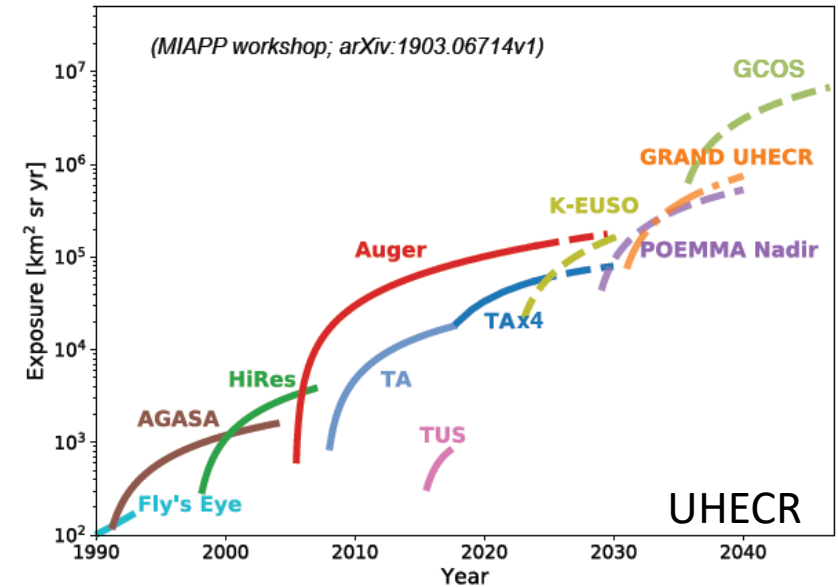
- **IceCube-Gen2** (in-ice radio detector); South Pole; completion in early 2030s with RNO-G as R&D site
- **GRAND** (surface radio detector); China; completion in 2030s
- **ANITA** (antarctic balloon flights), few candidates
- **Pierre Auger Observatory** (surface particle detector); not yet seen neutrinos
- **POEMMA** (satellite(s) observing atmosphere); launch maybe in the 30ies

## PeV Neutrinos:

1. **IceCube-Gen2** (in-ice detector); upgrade of IceCube; completion 2010; sensitivity  $\sim 8$  x IceCube
2. **KM3NeT** (underwater detector); completion in 2026; sensitivity of IceCube, complementary in sky coverage
3. **GVD** (underwater detector); completion in 2024/25; less sensitive
4. **P-ONE** (underwater detector); **new initiative**; could reach similar sensitivity as IceCube or KM3NeT

# High-Energy Cosmic Rays

- Accuracy of measurements in all energy ranges increased dramatically in last 2 decades, but still:
  - Transition energy range ?
  - Hadronic Interaction models ?
  - Composition and Anisotropies at all energies?
  - Suppression mechanism?
- Pierre Auger Observatory is major experiment
- Highest energies: extensions to TAx4, AugerPrime
- At lower energy (LHAASO, IceCube-Gen2)
- Plus future projects: POEMMA, GRAND, GCOS (global, cost effective, sustainable, experiments)





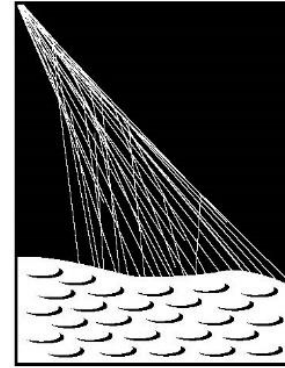
# Pierre Auger Observatory



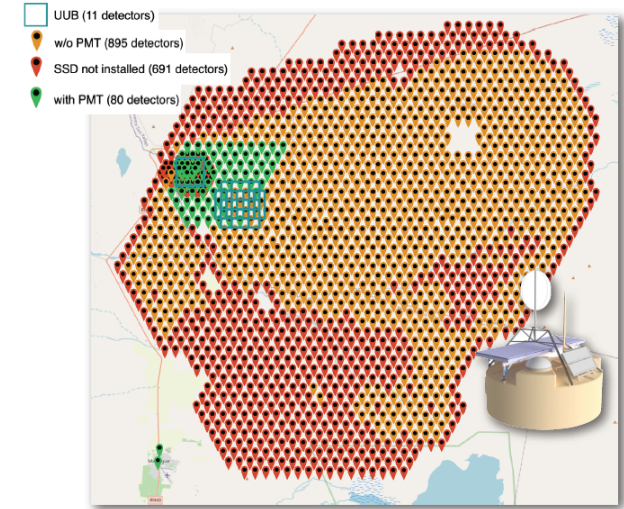
© S.Saffi/Auger

# High-Energy Cosmic Rays

- Auger Upgrade to AugerPrime
- High statistics and accuracy required for determining energy spectrum, composition, anisotropy over a large energy range
- Combining data of the various projects (UHECR working groups!)
- 18 countries, ~100 institutes, ~400 scientists
- AugerPrime completes construction in 2023
- Operation time >2030
- Preparation and R&D for GCOS incl. GRAND

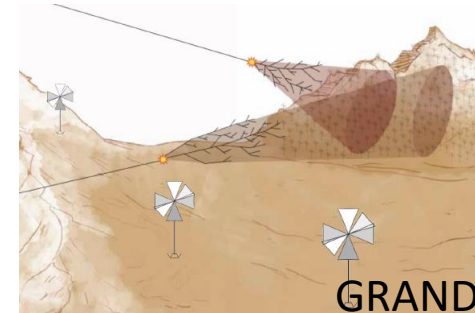


**PIERRE  
AUGER**  
OBSERVATORY



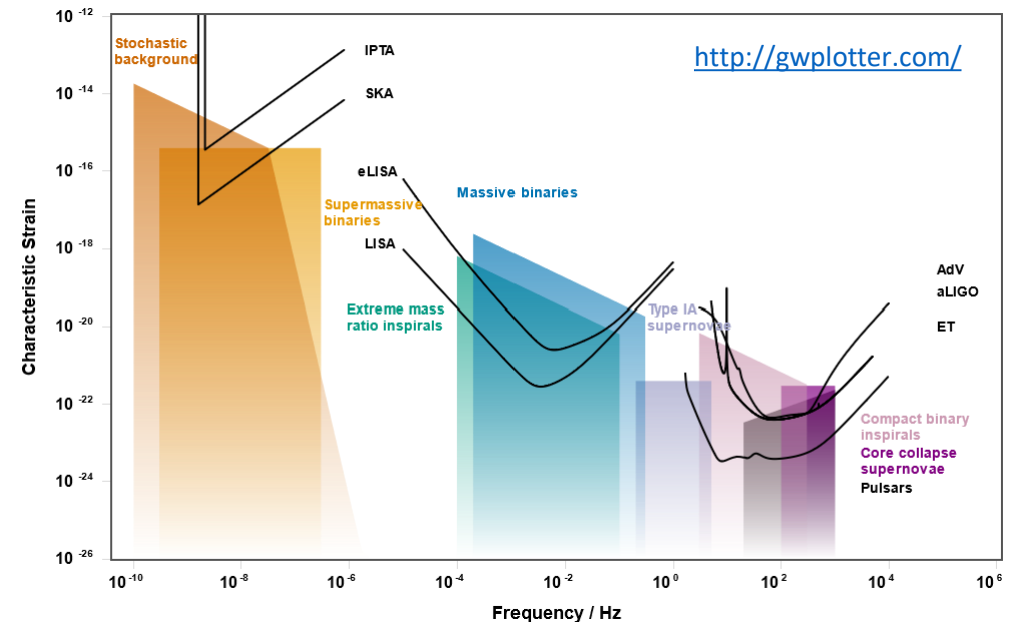
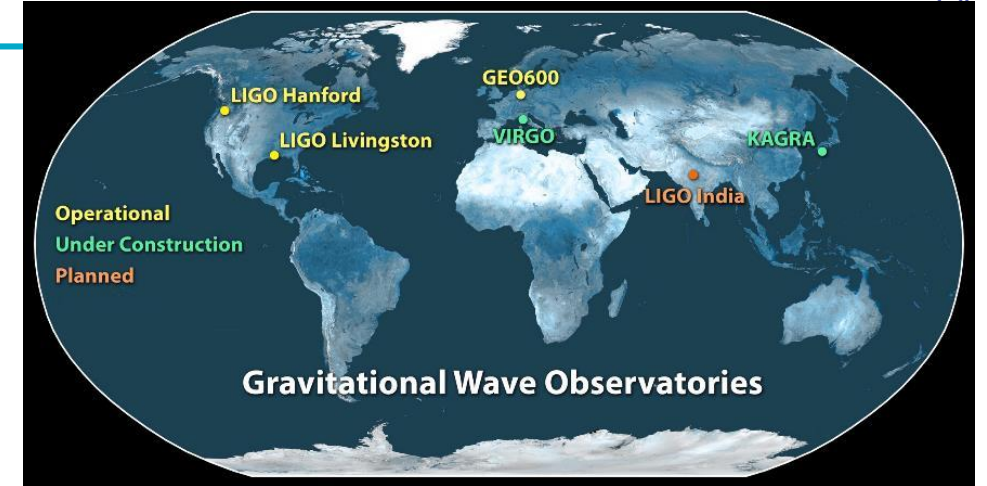
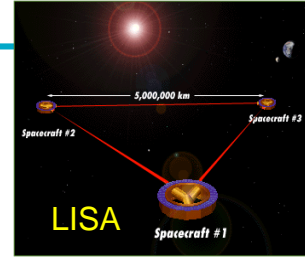
Ongoing upgrade AugerPrime (scintillators and radio antennas)

*(AugerPrime design report 1604.03637)*

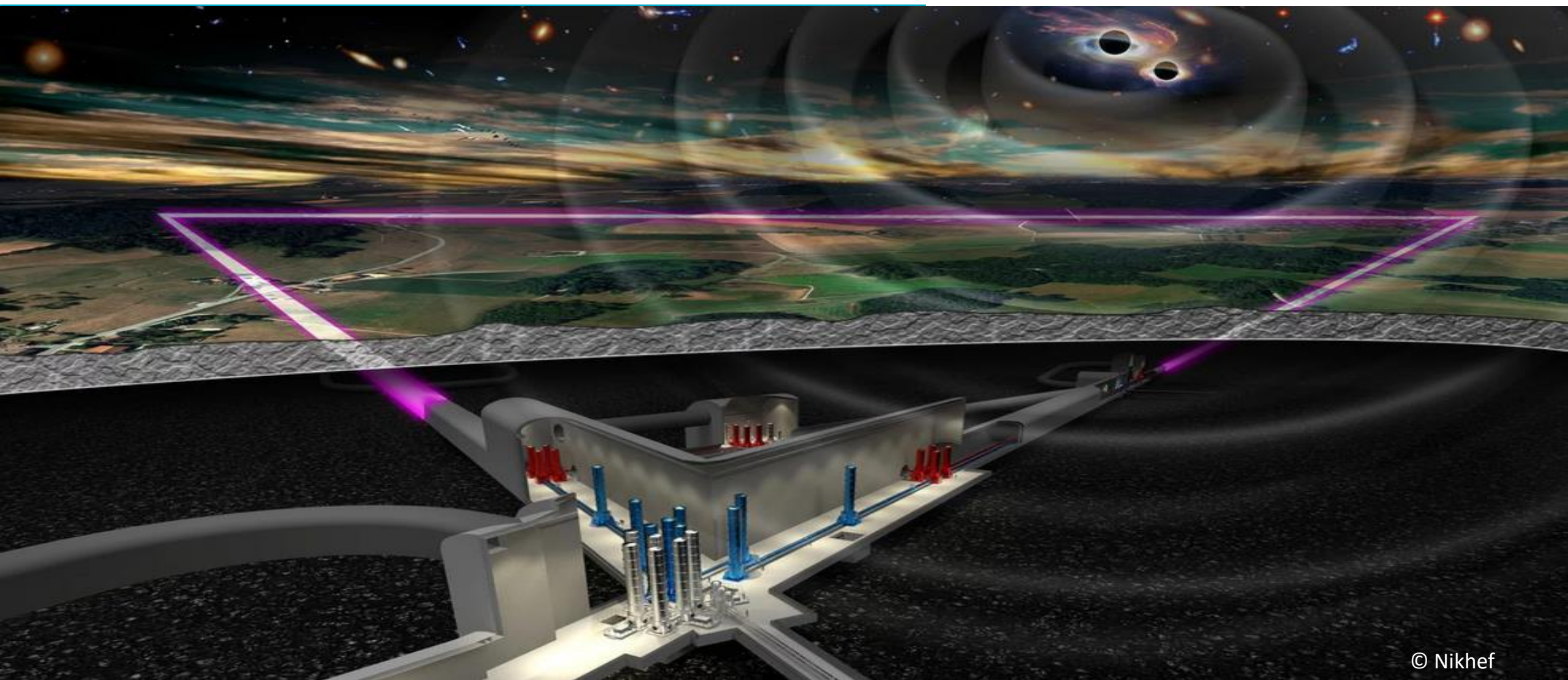


# Gravitational Waves

- 2015: First direct detection by LIGO / Virgo
- 2022+: Data taking with aLIGO and aVirgo
  - Volume of visible space increases by a factor 50
- 2030+: 3rd Generation: The Einstein Telescope
  - Volume of visible space increases by a factor 1000
- GWIC + GWAC (worldwide collaboration)
  - GWIC Gravitational Wave International Committee <https://gwic.ligo.org>
  - GWAC Gravitational Waves Agencies Correspondents
- Gravitational Waves Ground-Space complementarity
  - Einstein Telescope; Cosmic Explorer
  - LISA; e-LISA
  - Pulsar Timing Arrays; IPTA; SKA



# Einstein Telescope - ET

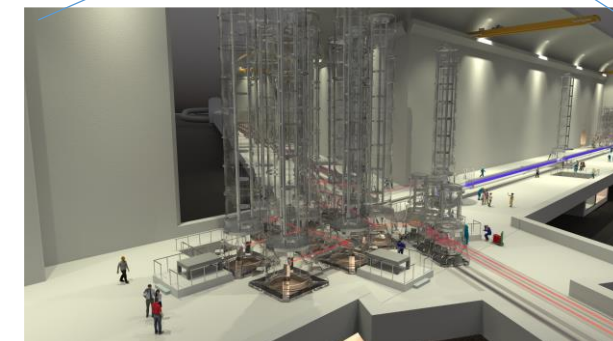
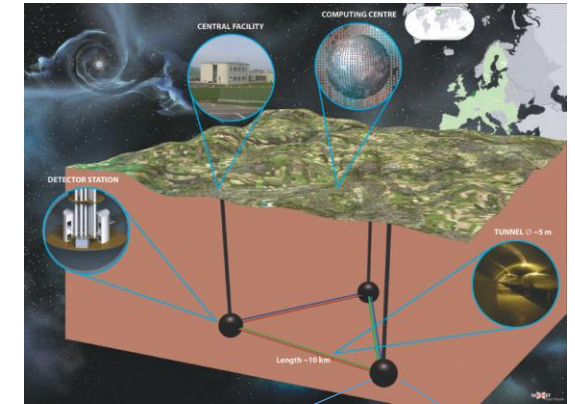


# Gravitational Wave Detection

- Science (very interdisciplinary)
  - Formation of Black Holes at the center of galaxies?
  - Is General Relativity (GR) right or do we need new physics?
  - Is Dark Energy the cosmological constant?
  - Understanding the dynamics of ultra dense matter!
- ESFRI
  - The ESFRI roadmap proposal (I, NL, B, E, PI) was successful;
  - The ESFRI roadmap was updated in June 2021
- Status and Organisation
  - Due to the 3G science case, the interest in ET in Europe is rapidly growing.
  - Boards have been formed:
    - Instrument science, Observational science, Site characterisation, E-Infrastructure.
  - The Instrument science board is the most advanced and is fully operational
  - The ET collaboration had its kick-off meeting in July 2022 (>75 Research Units)
- R&D
  - Advanced Virgo and Advanced Ligo; KAGRA; ETpathfinder (NL); may be DZA (D)
  - MoU with CERN on common vacuum R&D



<http://www.et-gw.eu>



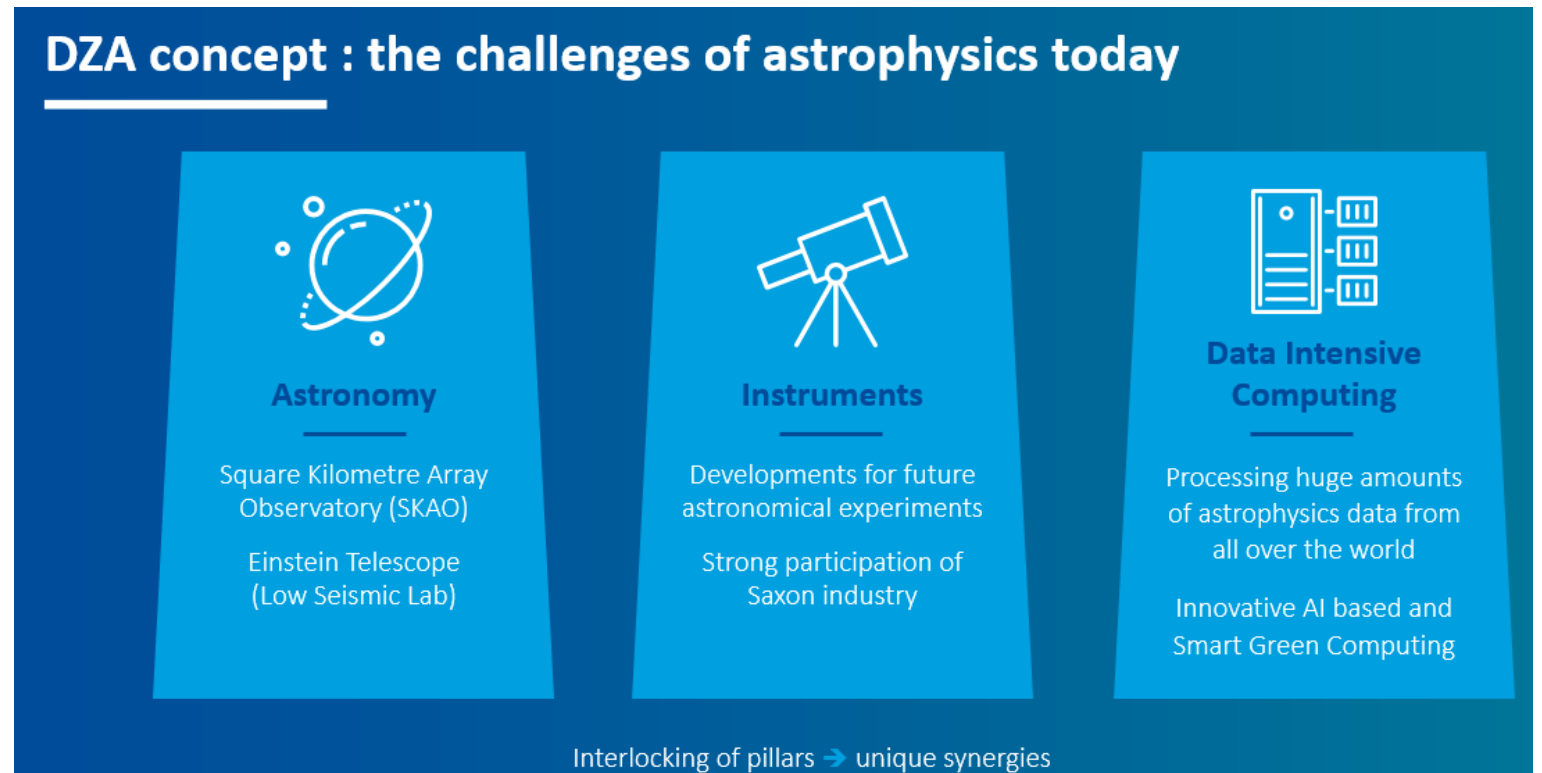
# DZA (German Center for Astrophysics)

- the "Deutsches Zentrum für Astrophysik - Forschung. Technologie. Digitalisierung. (DZA)" has been selected to be realised in the national "Wissen schafft Perspektiven für die Region" programme for Saxonia, Germany.
- Timeline: Elaboration of the structure of the centre in next 6 months => 3 years ramp-up => 10 years funding by 170 Mio€/y



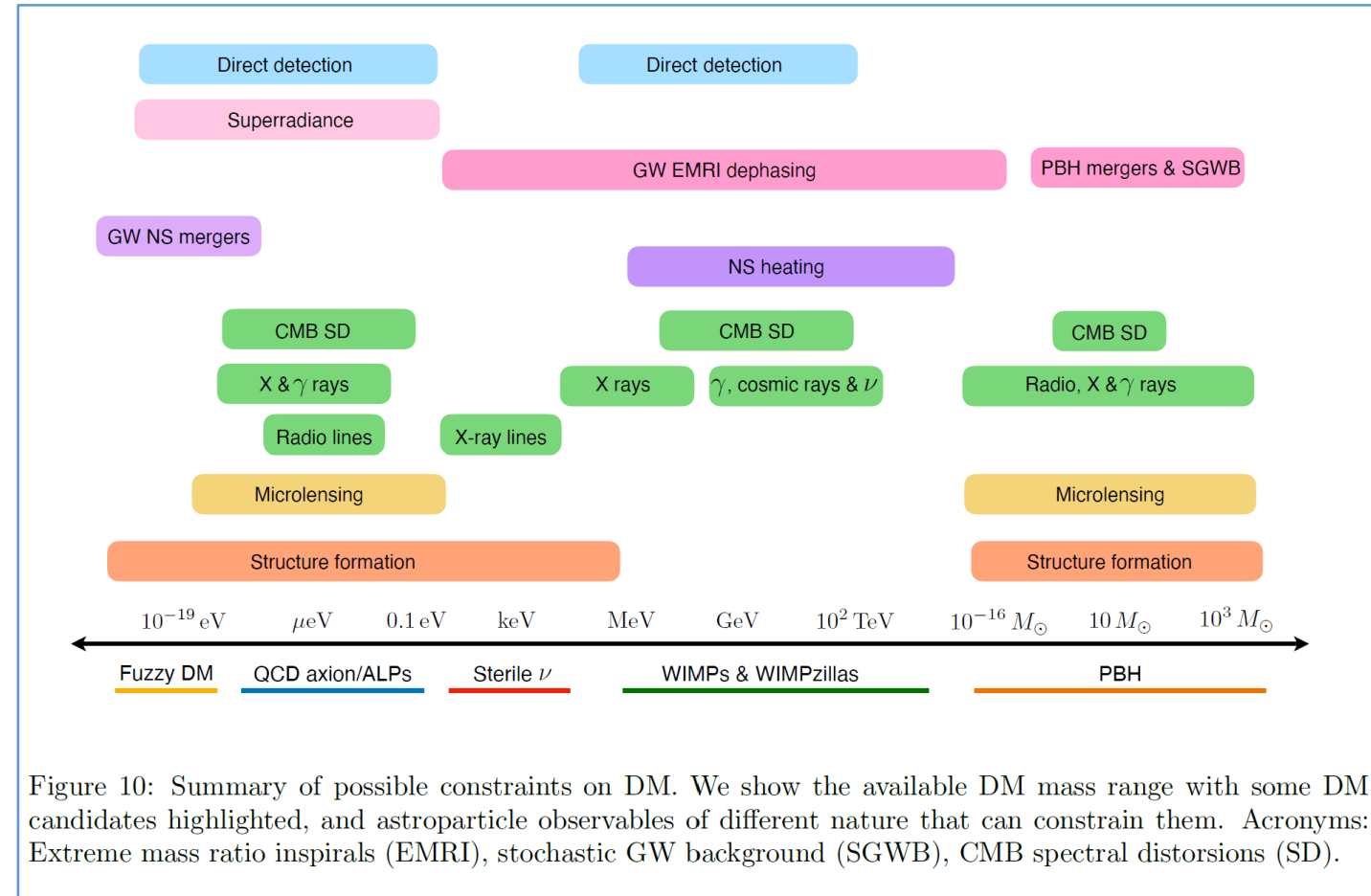
<https://www.deutscheszentrumastrophysik.de/>

<https://www.deutscheszentrumastrophysik.de/sites/default/files/2022-09/Pressemitteilung.pdf>



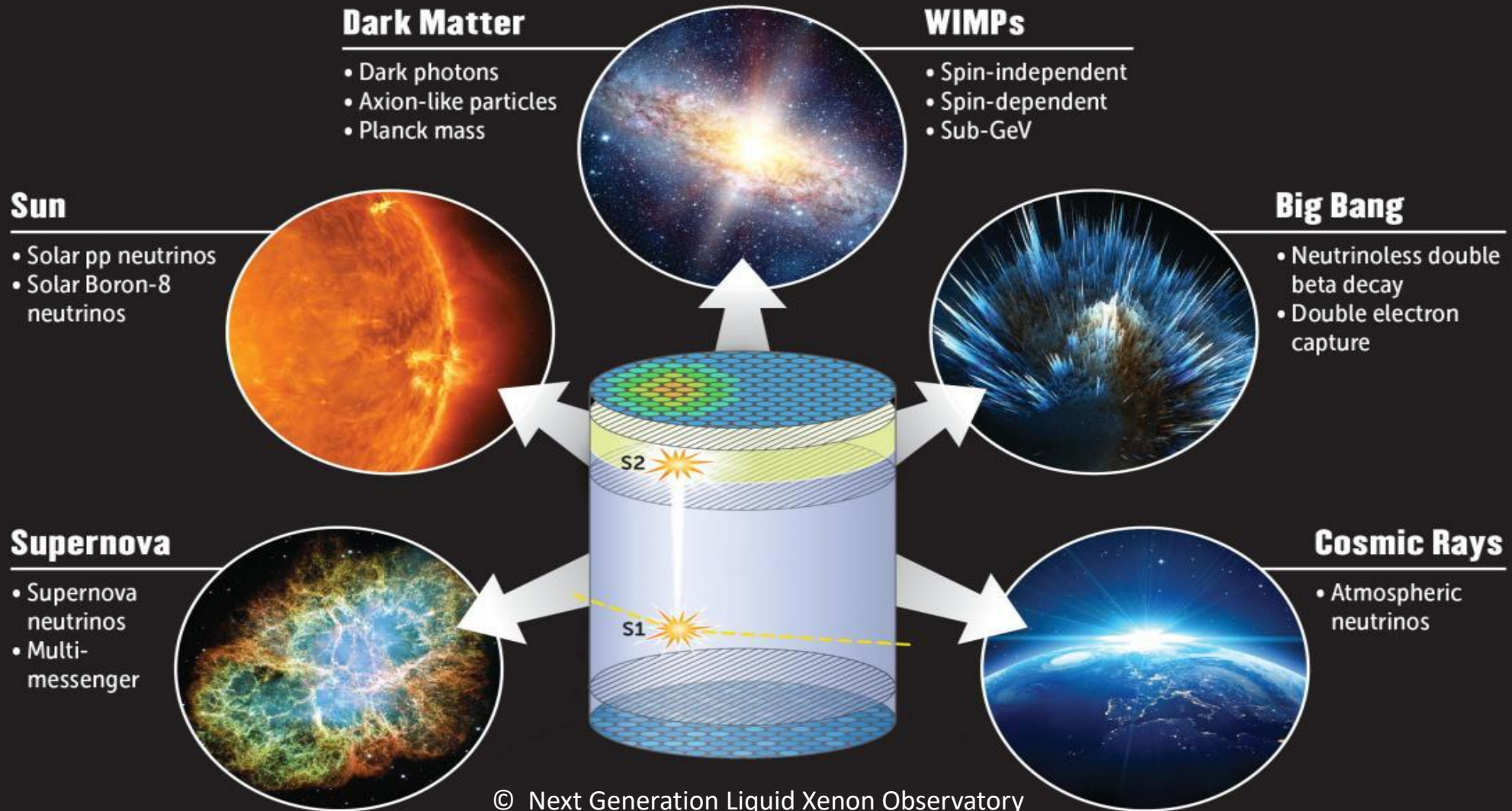
# Dark Matter

- Topic has large overlap with neighboring fields
- Direct Detection of Dark Matter APPEC SAC Subcommittee Report:
  - <https://www.appec.org/documents>
  - arXiv: <https://arxiv.org/abs/2104.07634>
- Recommendations:
  - Priority of Dark Matter Search
  - Diversified Approach Needed
  - Direct search for WIMPs down to neutrino floor (DARWIN, ARGO)
  - Coordinated detector R&D
  - European Infrastructure for Underground Science
  - Studying of the axion/ALPs mass range
  - Continuation of diverse theoretical activity



EuCAPT White Paper <https://arxiv.org/abs/2110.10074>

# dark matter wimp search with liquid xenon



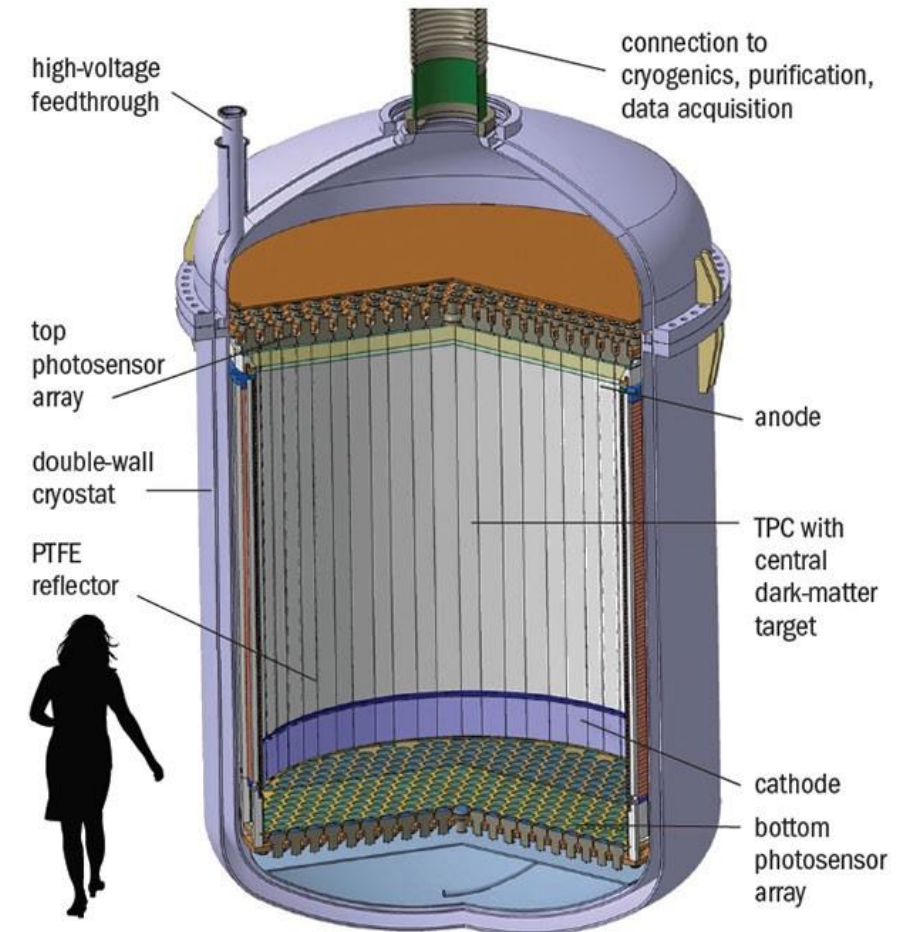
© Next Generation Liquid Xenon Observatory



# Dark Matter - WIMP



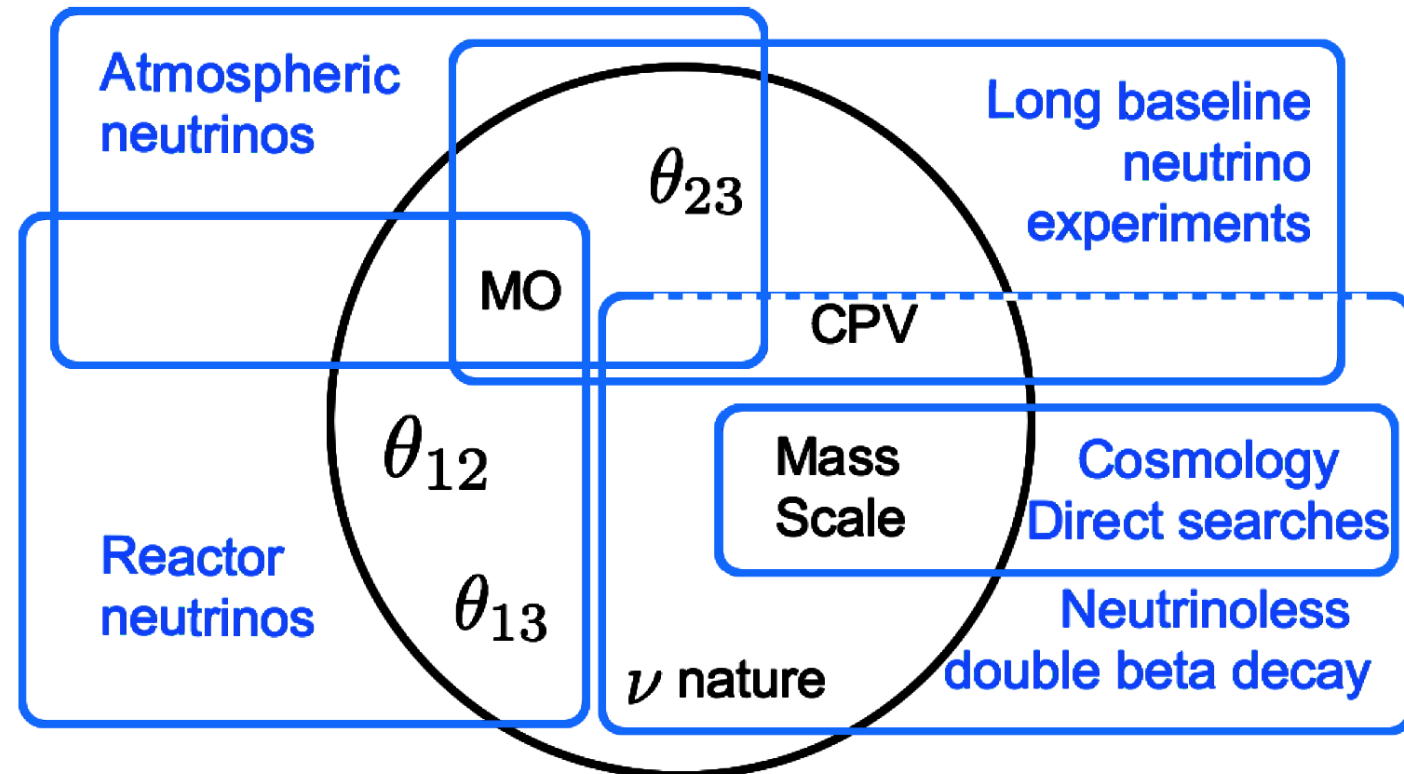
- APPEC recommends to realize worldwide at least one xenon (50t) and one argon (300t) experiment
- DARWIN is currently the European flagship experiment for WIMP search
- In addition, ongoing detector R&D has to be pursued
- XENON/DARWIN and LUX-ZEPLIN → **XLZD** collaborations have signed a common MoU <https://arxiv.org/abs/2203.02309> (141 institutes, ~600 authors)
- Needs (European) infrastructures for Underground Science



# Neutrino Properties

- $\nu$  CP-violation is still unknown and may give hints to matter-antimatter asymmetry
- $\nu$ -mixing is very different from CKM
- $\nu$ -nature undetermined (Majorana)
- $\nu$  mass ordering not yet determined
- $\nu$  masses  $\ll$  mSM particles gives access to higher mass scales (See-Saw)
- $\nu$  is the first hot “dark” particle and has a role in various stages of the Universe
- Needs (European) infrastructures for Underground Science

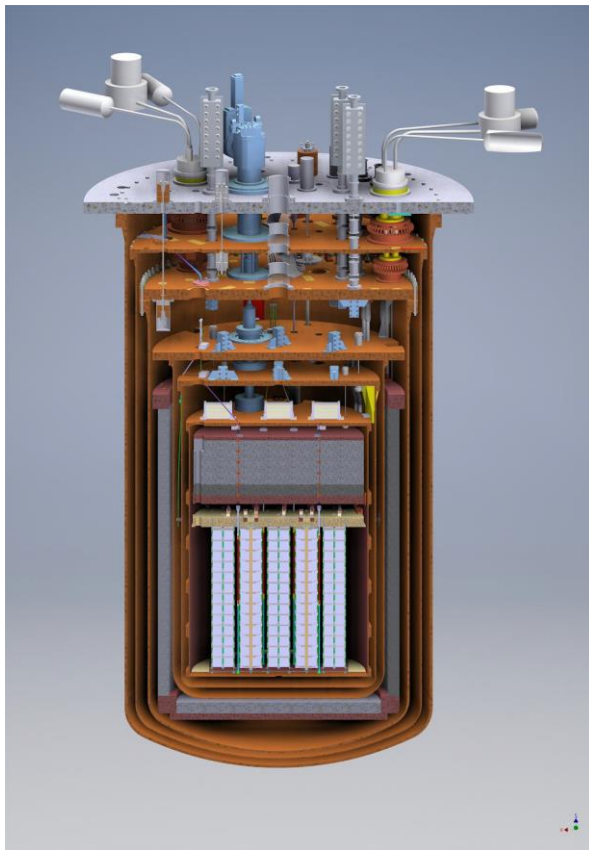
Science has large overlap with neighboring fields



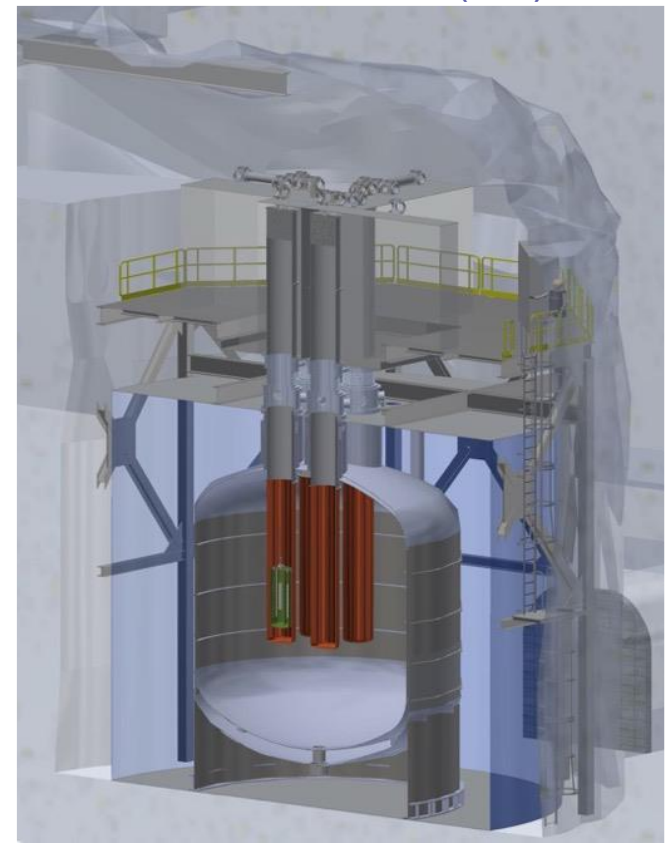
© APPEC SAC

# $0\nu\beta\beta$ decay: towards ton-scale experiment

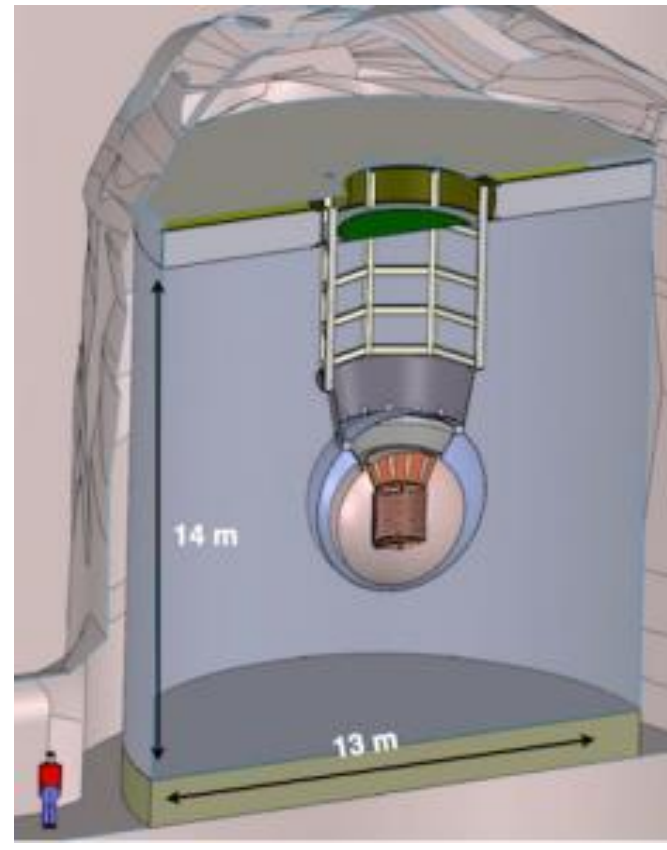
CUPID (100 Mo)



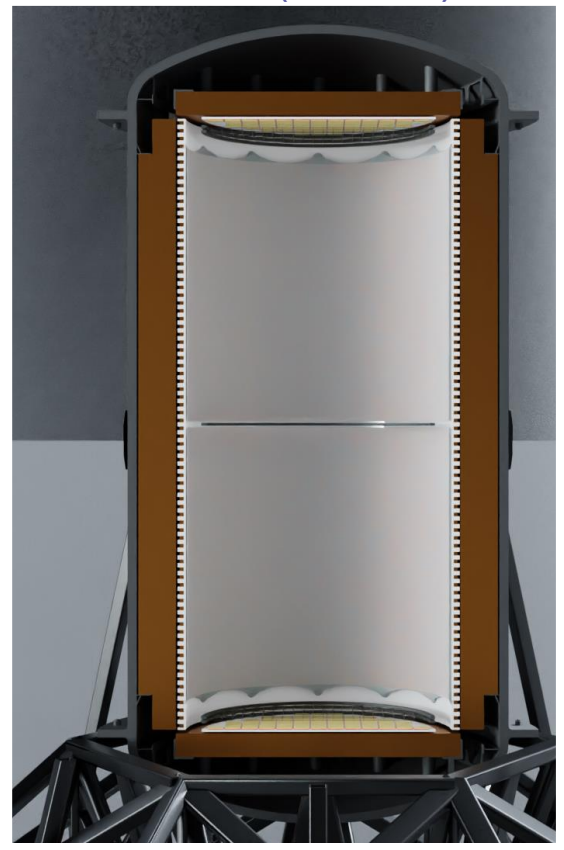
LEGEND-1000 (Ge)



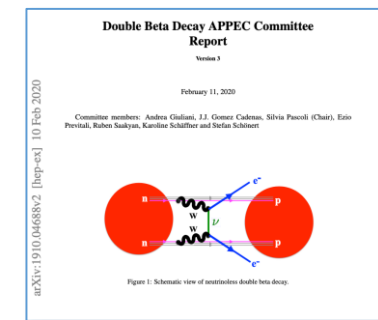
nEXO (136 Xe)



NEXT (136 Xe)



# Neutrinoless Double Beta Decay



## Strategy (Status early 2022):

- Double Beta Decay APPEC Sub-Committee gave advise on the European (and global) program
- It provides an assessment of the current and future scientific opportunities in double beta decay over the next 10 year period
- Close coordination of APPEC with DOE nuclear physics and aligned with Snowmass process
- Spring 2021: DOE portfolio review on Neutrinoless Double Beta Decay Experiments
- $0\nu\beta\beta$  European-North American Summit at Gran Sasso, Italy, 29/9 -1/10/2021
  - <https://agenda.infn.it/event/27143/> Presentation of Underground labs, Experiments, R&D, ...
  - Closed session: 19 representatives of funding agencies and director of underground labs
  - Outcome :
    - (i) Neutrinoless Double Beta Decay should have high priority
    - (ii) funding agencies in Europe and North America should build a network
    - (iii) if possible LEGEND and nEXO should be funded, one in Europe, one in North America

# APPEC Flagship Research Infrastructures

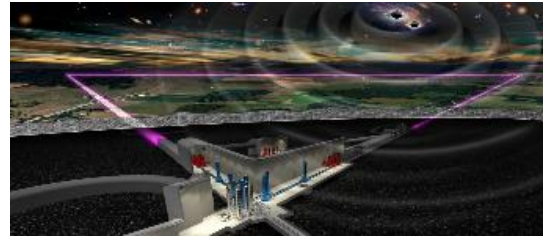
This is not a closed, but dynamic list...

[construction KM3NeT 2020-2026; IceCube-Gen2]



ESFRI

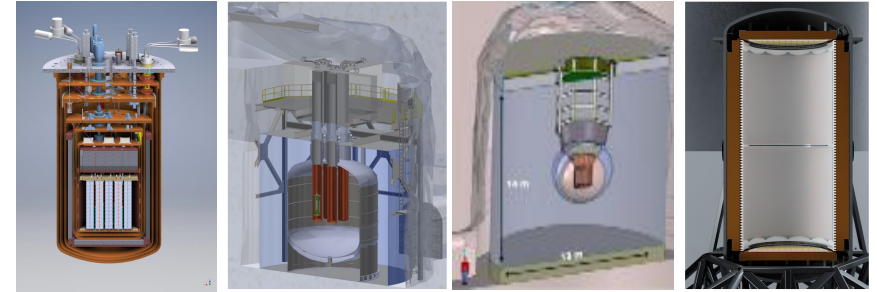
HE Neutrinos



ESFRI

[construction Einstein Telescope 2026- ]

Gravitational Waves



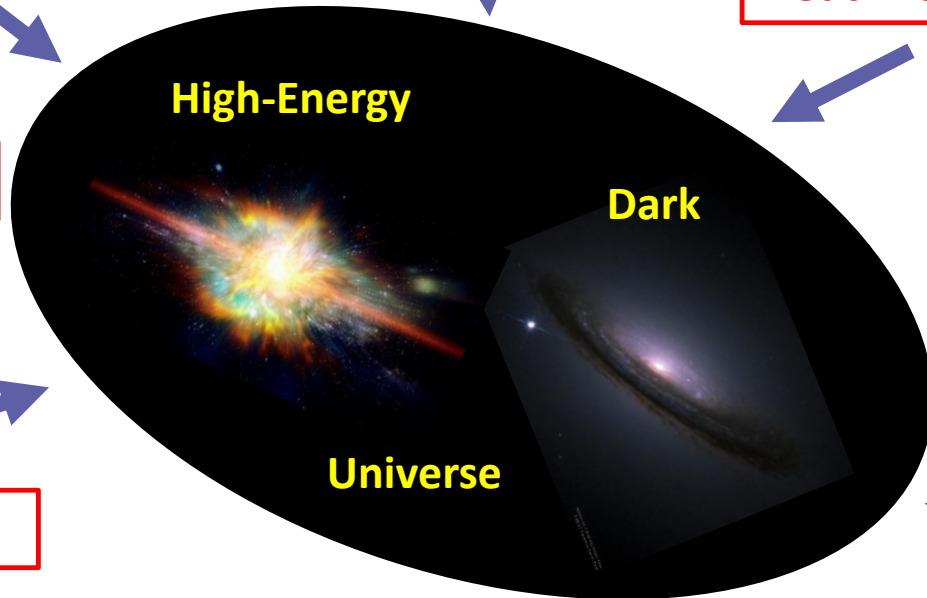
[construction LEGEND-1000 / nEXO 2023- ; ... ]

Neutrino Properties

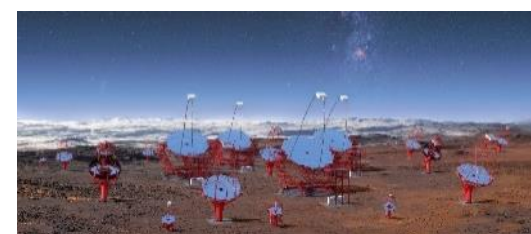
[construction AugerPrime 2019-2023]



HE Cosmic Rays

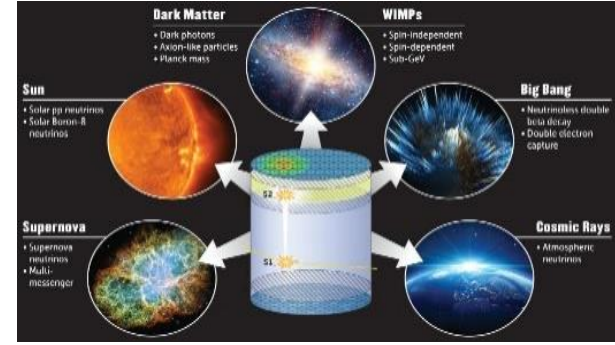


[construction CTA 2021- ]



ESFRI

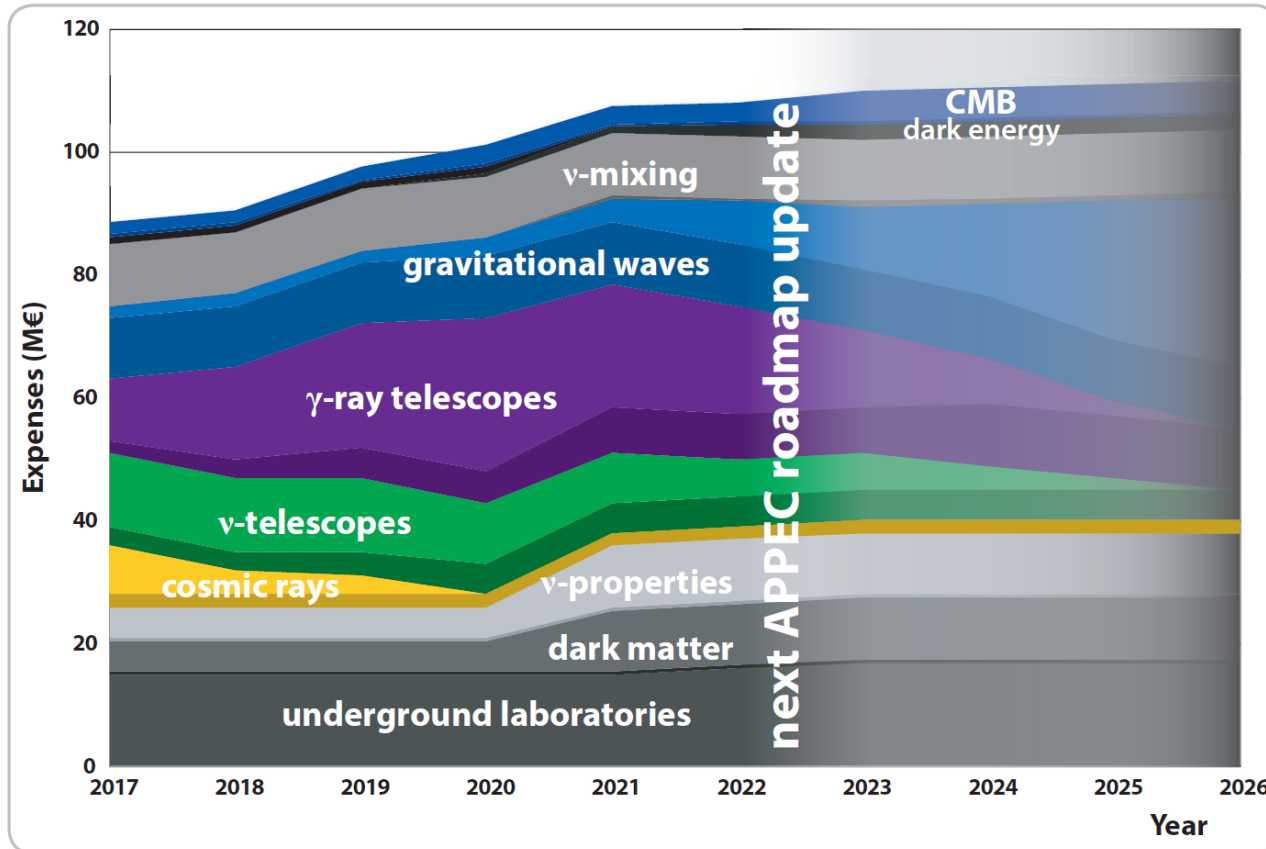
HE Gamma Rays



[construction DARWIN 2024- ; XLZD, ARGO, ... ]

Dark Matter

# Midterm Evaluation of the Roadmap

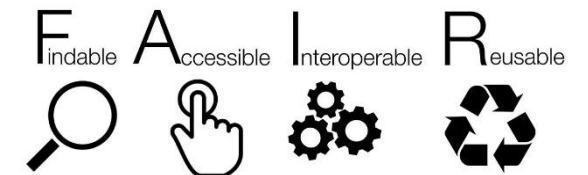


From Roadmap 2017: Projected annual capital investment

- A resource aware roadmap
  - (darker colors also show M&O of RI)
- Midterm Evaluation: Preparation of roadmap update
  - Direct Dark Matter working group
  - Double Beta Decay APPEC Sub-Committee
  - Multi-Messenger Discussion Workshop
- Goals
  - Identify new developments and new topics
  - Update recommendations
  - Update of time and cost line
- Timeline
  - Provide information to the communities (2021)
  - Town Meeting June 2022  
<https://indico.desy.de/event/25372/>
  - Census / Survey of time and cost lines
  - Publication end of 2022

# Overarching Topics in the Roadmap

- Ecological Impact
  - ..of satellites, observatories, infrastructures, travel...
  - ..provide spin-offs for other research areas
- Societal Impact
  - Survey and fostering of impact on society
- Open Science and Human Talent Management
  - Outreach and education
  - Open Data and Citizen Science **ESCAPE** <https://projectescape.eu/>
- Computing
- European Centre for Astroparticle Physics Theory **EuCAPT**
  - <https://www.eucapt.org/>
- Underground and Large-scale Infrastructures
  - Coordination of European Underground Labs
- Coordination with neighbouring fields
  - JENAA, Astronet, ESA
- Horizon Europe
  - European and global collaboration and coordination, e.g. INFRA-SERV-2023



- EOSC is the European Commission action in response to EU member states' shared policy about the uptake of Open Science
- ESCAPE - The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructure (48 months; 1/2/2019; lead CNRS-LAPP)
- Future of the 5 Science Clusters within EOSC are currently discussed with the European Commission

ESCAPE  
ESFRI  
projects,  
landmarks  
and a few  
more RIs

**Radio**

 SKA  
 JIVE-VLBI  
 ESO  
 EST

**Visible light**

 ELT  
 ESO  
 EST

**Gamma rays**

 CTA

**Accelerator-based  
Particle Physics**

 HL-LHC  
 CERN

**Accelerator-based  
Nuclear Physics**

 FAIR

**Gravitational  
Waves**

 EGO-VIRGO

**Cosmic-rays  
Neutrinos**

 KM3NeT

G.Lamanna



## ESCAPE Work Programme

### Data Lake:

- Build a scalable, federated, data infrastructure as the basis of open science for the ESFRI projects within ESCAPE. Enable connection to compute and storage resources.



### Software Repository:

- Repository of "scientific software" as a major component of the "data" to be curated in EOSC. Implementation of a community-based approach for the continuous development of shared software and for training of researchers and data scientists.



### Virtual Observatory:

- Extend the VO FAIR standards, methods and to a broader scientific context; prepare the VO to interface the large data volumes of next facilities.



### Science Platforms:

- Flexible science platforms to enable the open data analysis tailored by and for each facility as well as a global one for transversal workflows.



### Citizen Science:

- Open gateway for citizen science on ESCAPE data archives and ESFRI community





# JENA Seminar



- 2<sup>nd</sup> JENA Symposium: 3-6 May 2022 in Madrid, Spain  
<https://indico.cern.ch/e/JENAS2022>
  - Topics:
    - Science case of large infrastructures
    - Discussion on funding of infrastructures
    - Synergies in detector R&D
    - Synergies in computing, analysis techniques (AI)
    - governance models for large infrastructures
- Balanced Program over Nuclear Physics, Particle Physics, Astroparticle Physics, focussing on synergies
- Special Session with invited Funding Agencies
- There is a need for a European Workshop on (federated) Computing → foreseen for spring 2023

**JENAS-2022**  
2<sup>nd</sup> Joint ECFA-NuPECC-APPEC Seminar  
Exploring synergies between Particle, Astroparticle and Nuclear Physics

May 3-6, 2022  
Madrid, Spain

**TOPICS:**  
- Physics highlights  
- Future projects and overall strategies  
- Detector technologies  
- Computing and software  
- Diversity and recognition  
- Education and Outreach  
- Transfer of knowledge

**JENAS 2022 Committee**  
ECFA: Karl Jakobs (Univ. Freiburg), Patricia Conde Muñiz (LP, Lisboa), Jürgen D'Onofri (ULB, Brussels)  
APPEC: Andreas Haungs (KIT, Karlsruhe), Katharina Henke-Rust (DESY, Hamburg), Teresa Montaruli (Univ. Geneva)  
NuPECC: Marek Lewkowicz (GANIL, Caen), Eberhard Widmann (SMI, Wien), Gabriele-Elisabeth Köhner (NuPECC)

**Local Committee**  
Mario José García Berge (IEM, Madrid), Antonio Blanco (IGR, Granada), Carlos Peña Gavry (ISC, Confrance), Joaquín Gómez Casmacho (CNA, Seville), César Martínez Rivera (FEA, Santander), Luis Mario Fraile (UCM, Madrid)

ECFA European Committee for Future Accelerators | NuPECC | APPEC



# ASTRONET Roadmap

<https://www.astronet-eu.org/>

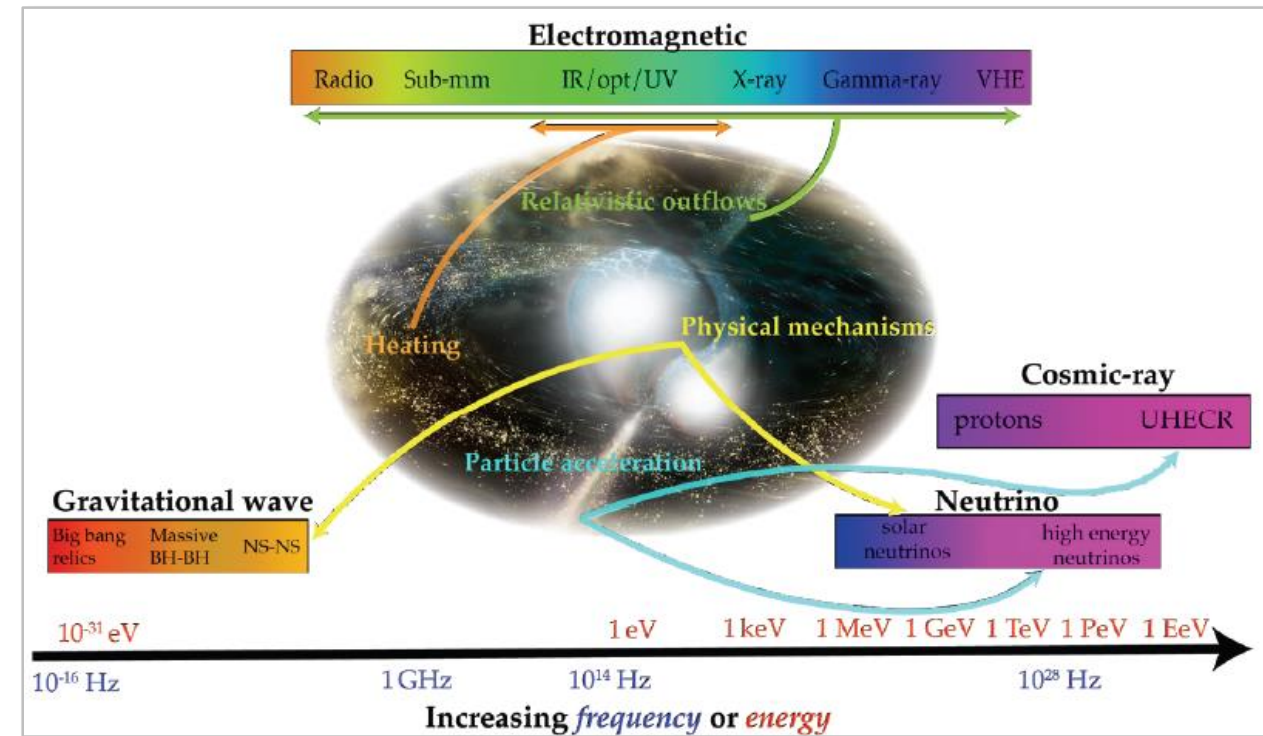


## • ASTRONET Roadmap

- Feedback to the first section drafts led to a new Panel: Extreme Astrophysics
- Nov/Dec. 22 — Publication of ASTRONET Roadmap
- Contacts: Malcolm Booy – [malcolm.booy@stfc.ukri.org](mailto:malcolm.booy@stfc.ukri.org)  
Kamalam Vanninathan – [kamalam.vanninathan@stfc.ukri.org](mailto:kamalam.vanninathan@stfc.ukri.org)

## • Panels / Working Groups (reports available)

- Roadmap preliminary Executive summary
- Roadmap recommendations - EAS Meeting
- Origin and evolution of the Universe
- Formation and evolution of Galaxies
- Formation and evolution of Stars
- Formation and evolution of Planetary Systems
- Understanding the Solar System and conditions for Life
- Computing - big data, high performance computing
- Societal aspects
- **Extreme Astrophysics: [Draft report](#)**



# APPEC and EU Framework Programs



- APPEC was created in 2001 coordination instrument of the European agencies funding Astroparticle Physics
- Boost by EU funding of the ERANET ASPERA, for 6 years
- Participation in calls (e.g. ILIAS-I3, ET-DS, INFRA-TECH, APOGEIA, M2TECH)
- For **Horizon Europe** Work Programme 2023-2024: **INFRA-SERV: In 2023, the scientific domains called under this topic are: ... Astronomy and Astroparticle physics**
- **HORIZON-INFRA-2023-SERV-01-02** (detailed call Dec.2022, deadline March 2023)



## **ACME - Astrophysics Centre for Multimessenger studies in Europe focus on:**

1. **MM and time-domain observations**
2. **Transients coordinated real-time detection**
3. **Improved access to archival data**
4. **Provide scientific expertise**
5. **Societal and environmental impact**



# Summary



- Astroparticle Physics is a booming and blooming field
- In search of the wonders of the cosmos
- Going to understand the fundamental law of Nature
- Plenty of opportunities for young scientists
- APP RI are central for the forthcoming Multi-Messenger Era

## APPEC:

- Publication of Roadmap Update in 2022
- Coordination of European Astroparticle Physics strategy...
- ...in cooperation with neighboring fields
- APPEC Newsletter: <https://www.appec.org/latest-news/newsletters>

...and further foster and coordinate the European Astroparticle Physics!

