APPEC

Astroparticle Physics European Consortium

Report from APPEC:
Strategy in Astroparticle Physics

The European View

Andreas Haungs | KIT – Institute for Astroparticle Physics

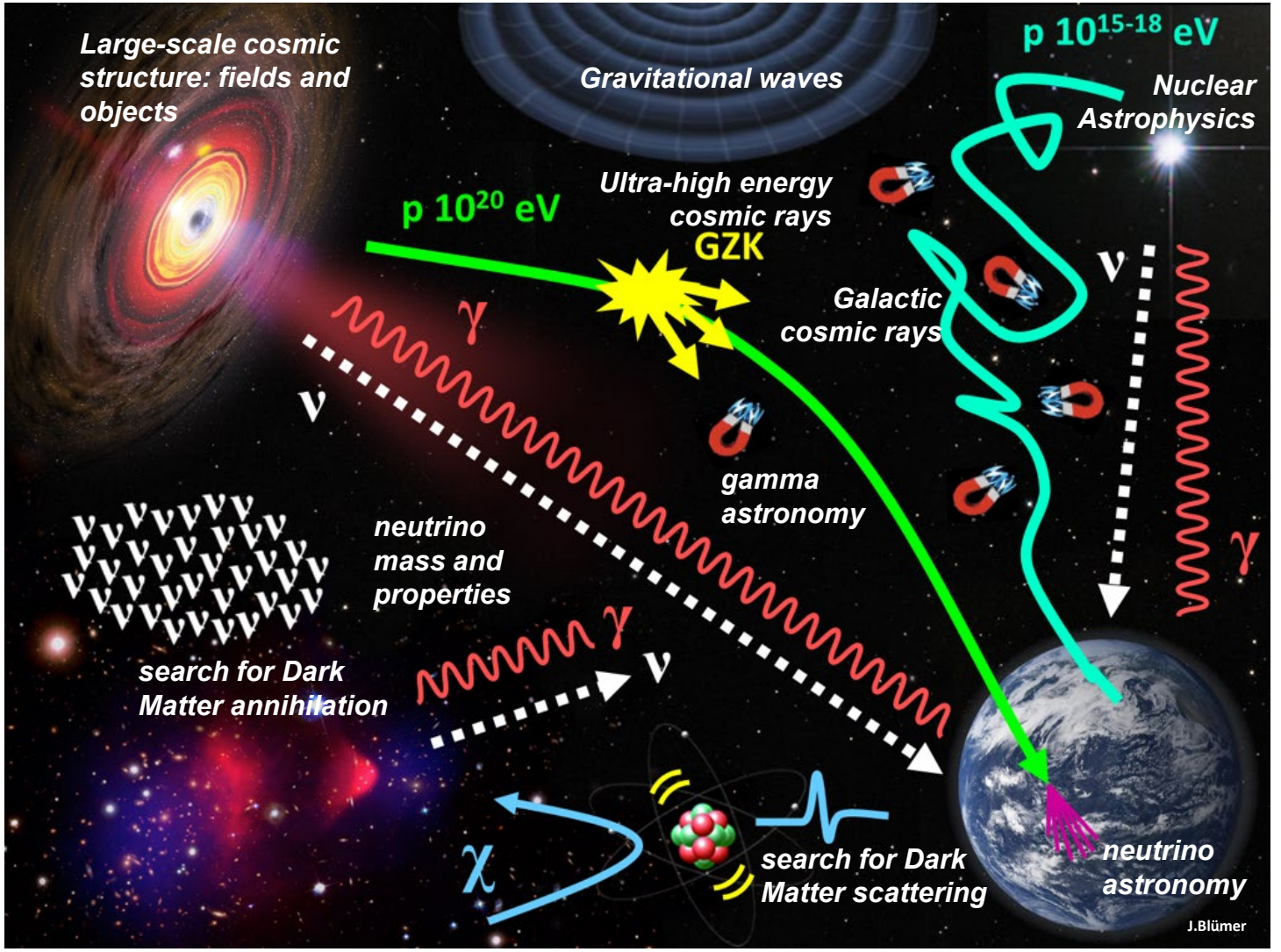
PECFA | CERN/Online | 16 November 2023

KIT Karlsruhe Institute of Technology

Astroparticle Physics

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

Understanding the Multi-Messenger and the Dark Universe



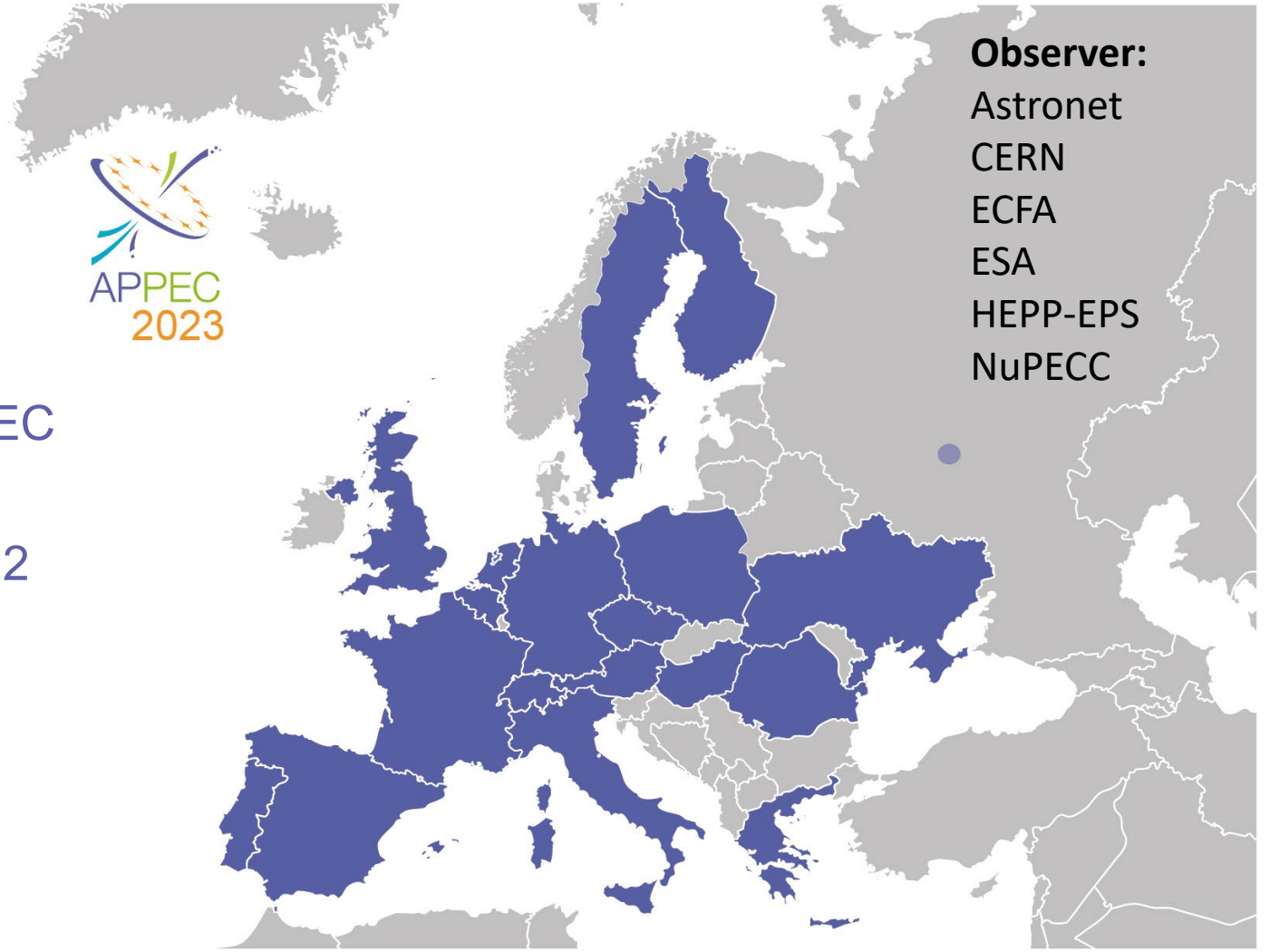
Wikipedia:
While it may be difficult to decide on a standard 'textbook' description of the field of astroparticle physics, the field can be characterized by the topics of research that are actively being pursued.

APPEC

www.appec.org

AstroParticle Physics European Consortium

- an international coordinating structure, founded in 2012
- Based on MoUs by all partners and an APPEC Common Fund with c. 70k€/year
- 18 (+1 suspended) member countries with 22 funding agencies
- 3 bodies:
  - General Assembly with Observers
  - Scientific Advisory Committee;
  - Joint Secretary

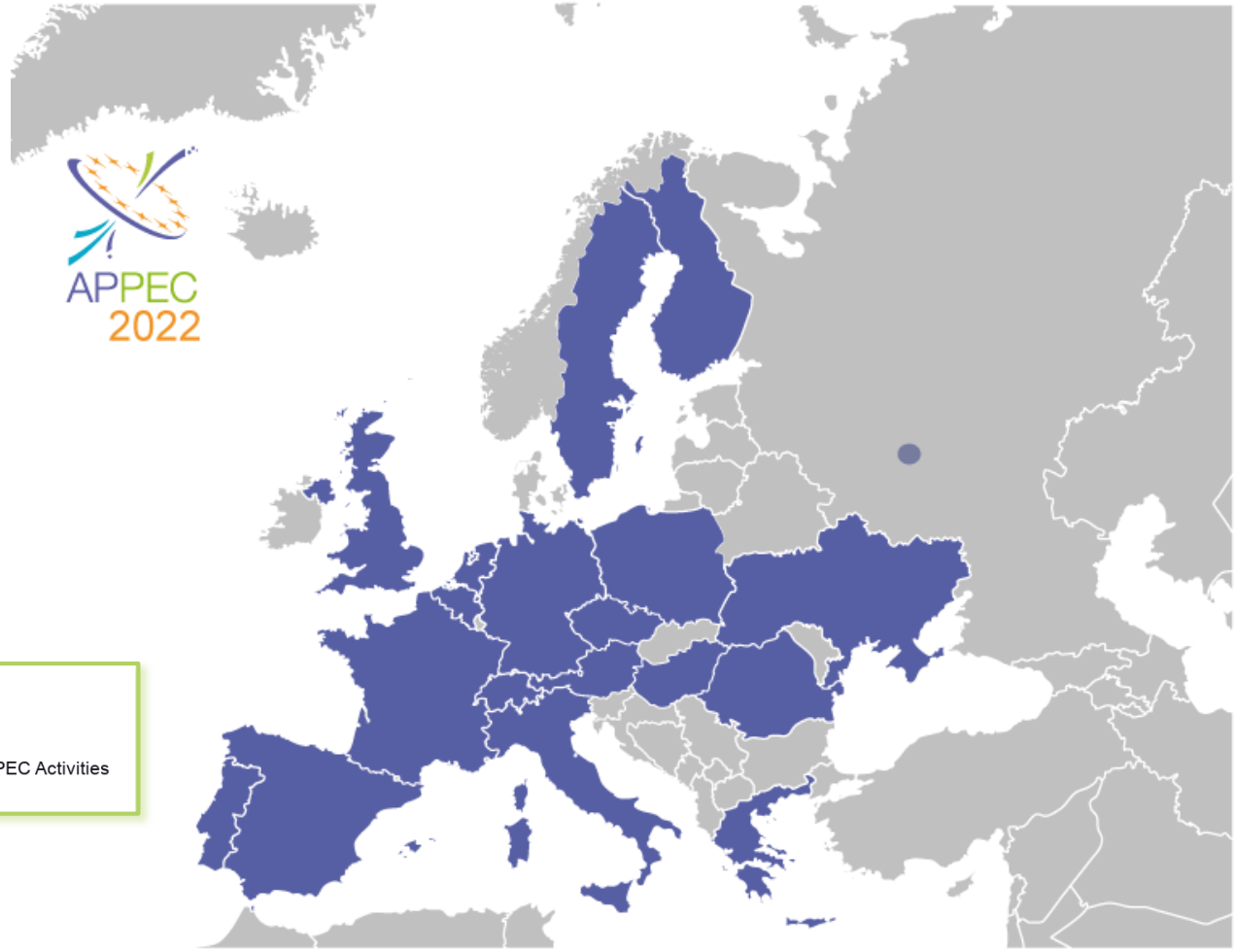


APPEC bodies

- General Assembly
  - Strategic, decision making and supervisory body
  - Representatives of funding agencies
  - Chair: Andreas Haungs (KIT);
  - Vice-Chair: Antoine Kouchner (APC)
- **Scientific Advisory Committee**
  - Advisory body
  - Chair: Sijbrand de Jong (Nijmegen) – change for 2024;
  - Vice-Chair: Silvia Pascoli (Bologna) – change for 2024
- **Joint Secretariat (distributed office)**
  - Executive body chaired by the General Secretary
  - General Secretary: Katharina Henjes-Kunst (DESY)
- Observer
  - CERN (Joachim Mnich)
  - ECFA (Karl Jakobs)
  - NuPECC (Marek Lewitowicz)
  - Astronet (NN)
  - ESO (Andy Williams)
  - EPS-HEPP (Ramon Miquel)

JENAA
Joint ECFA-NuPECC-APPEC Activities

www.appec.org



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

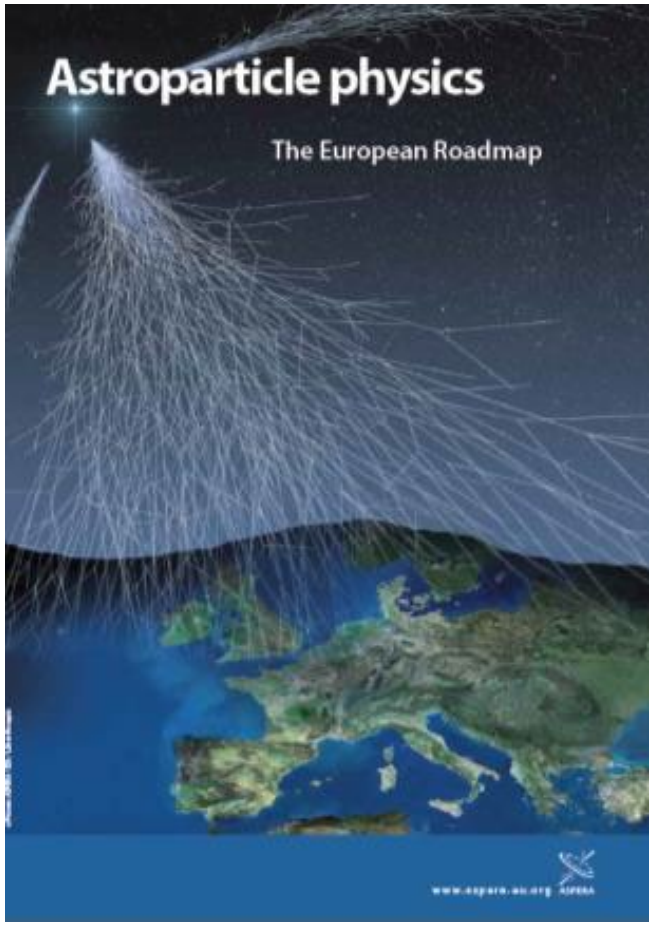
- **Helping in coordination of large-scale RI**
- **Helping in transition of mid-scale experiments to large-scale RI**
- **Helping in support of small-scale and R&D experiments**

APPEC Roadmaps

https://www.appec.org/roadmap

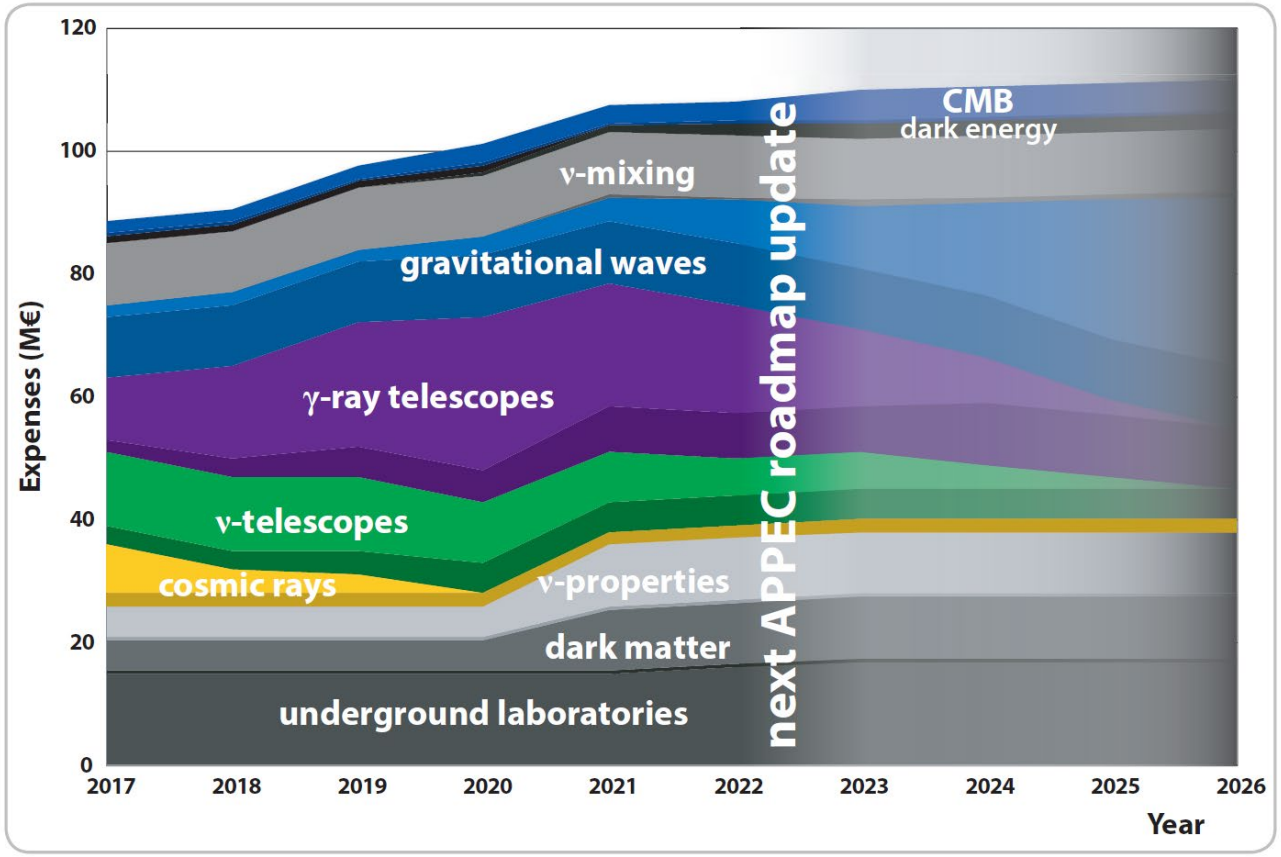
2008

2011



2017

Midterm Evaluation and Update of the Roadmap



From Roadmap 2017: Projected annual capital investment

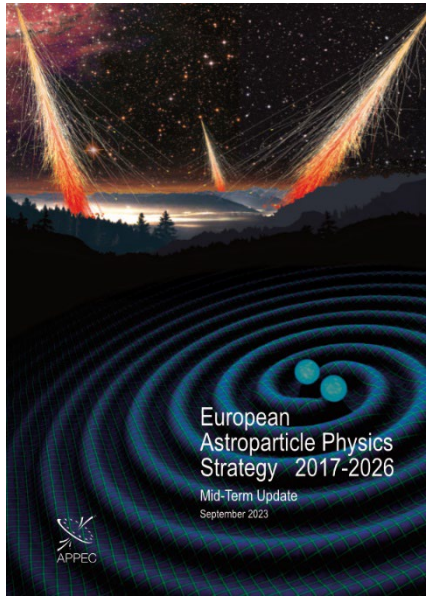
- A resource aware roadmap
  (darker colors also show M&O of RI)
- Midterm Evaluation: Preparation of roadmap update
  - Direct Dark Matter working group
  - Double Beta Decay APPEC Sub-Committee
  - Multi-Messenger Discussion Workshops
  - Coordination workshop of Underground Labs
  - Town Meeting June 2022 https://indico.desy.de/event/25372/
  - Census / Survey of time and cost lines
- Goals
  - Identify new developments and new topics
  - Update recommendations
  - Update of time and cost line

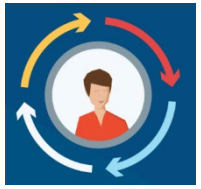
APPEC roadmap - scientific topics

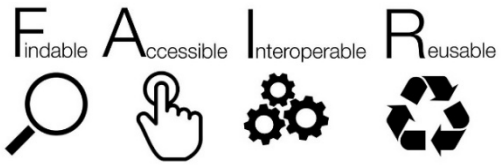
- High-energy gamma rays
- High-energy neutrinos
- High-energy cosmic rays
- Gravitational waves
- WIMP Dark Matter
- Non-WIMP Dark Matter
- Neutrino mass and nature
- Neutrino mixing and mass ordering
- Cosmic Microwave Background
- Dark Energy
- Multi-messenger astroparticle physics
- Astroparticle theory
- Detector R&D
- Computing and data policies

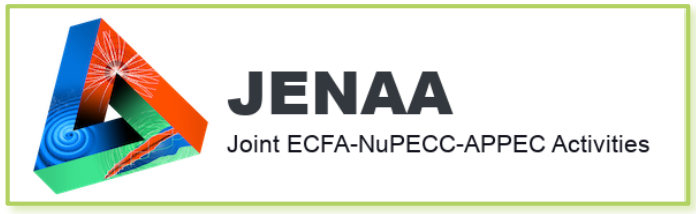
Roadmap - Connecting to Society and Organisation

- Ecological Impact
- Societal Impact
- Open Science and Citizen Science
- Human Talent Management
- Central Infrastructures
- European and Global Cooperation
- Interdisciplinary Opportunities



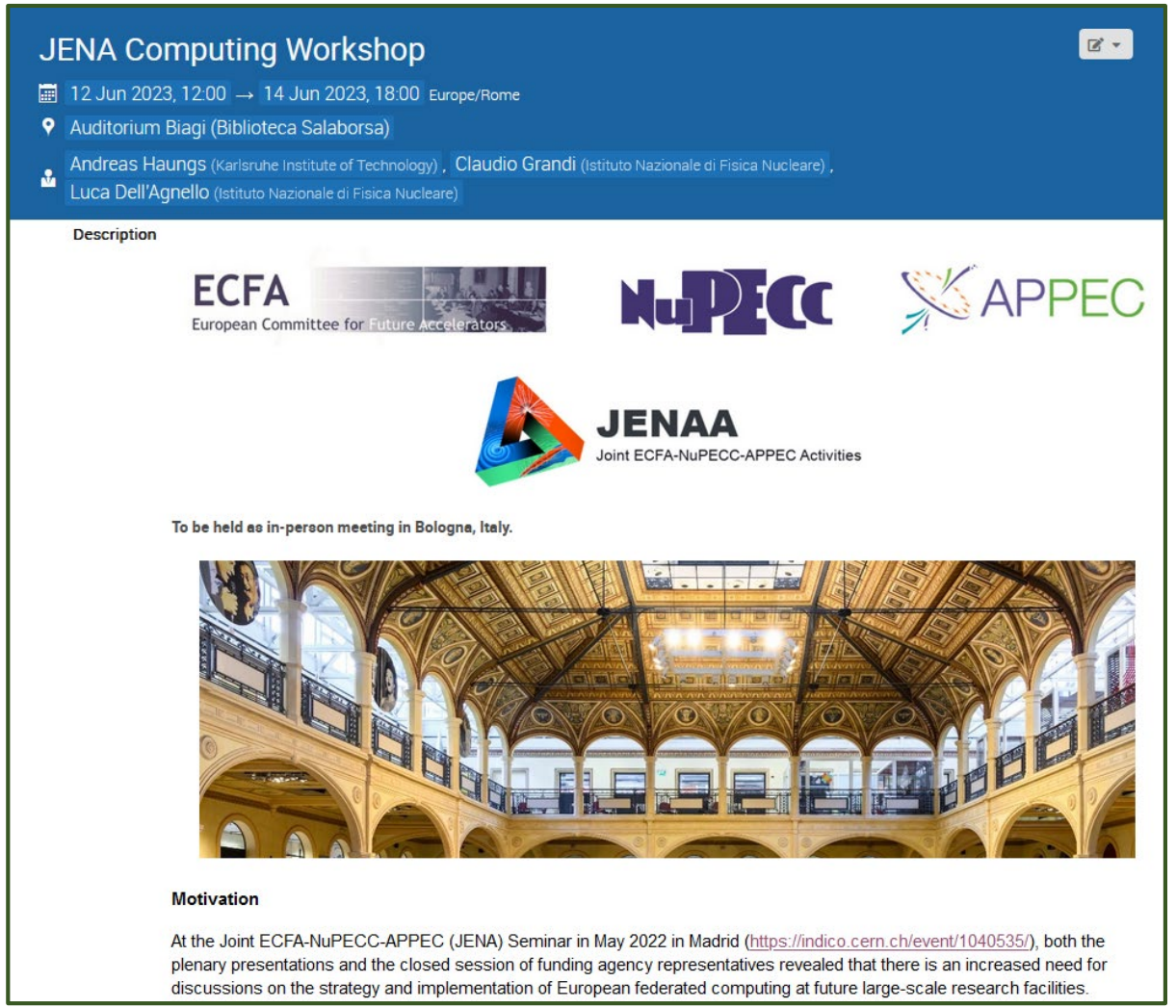






JENA Computing

- JENA Computing Workshop in Bologna: 12-14 June 2023
- https://agenda.infn.it/event/34738/
- Motivation: JENAS 2022 ➔ There is a need for a European Workshop on (federated) Computing! ➔ Preparation for JENAS 2025
- 60-70 participants plus up to 25 online
- Topics are all aspects of (federated) computing by talks, round table discussions, initiation of JENA working group, …
- Covering computing, HPC vs. HTC, software, data management, open data, sustainability

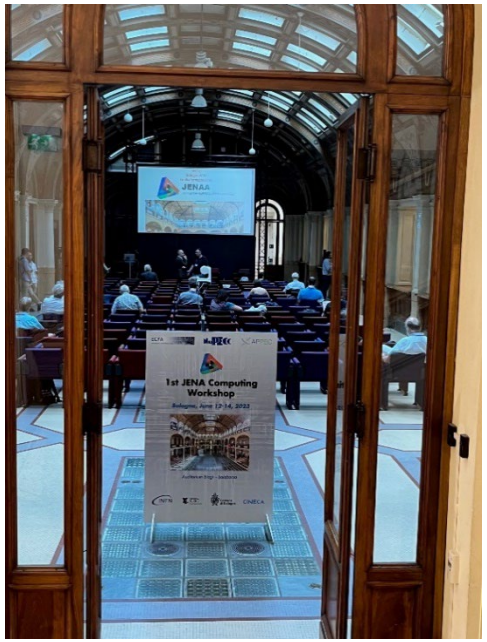


JENA Computing

JENAA
Joint ECFA-NuPECC-APPEC Activities

APPEC

- **Results:**
  - **Target: European white paper on (ENA) computing as input for the next JENA Symposium**
  - **Dedicated working groups (to look deeper) on five areas:**
    - **HPC integration in the HTC federated infrastructures (chair: Gonzalo Merino, Simone Campana)**
    - **Software and Heterogeneous Architectures (chair: Graeme Stewart, N.N.)**
    - **Federate Data Management, Virtual Research Environments and FAIR/Open Data (=ESCAPE) (chair: ian Bird, N.N.)**
    - **Machine Learning and Artificial Intelligence (chair: Sascha Caron, N.N.)**
    - **Training, Dissemination, Education (chair: the ENA chairs)**
- **Next:**
  - **Searching for participation in the working groups from Astroparticle Physics**
  - **Building the WGs with dedicated meetings**

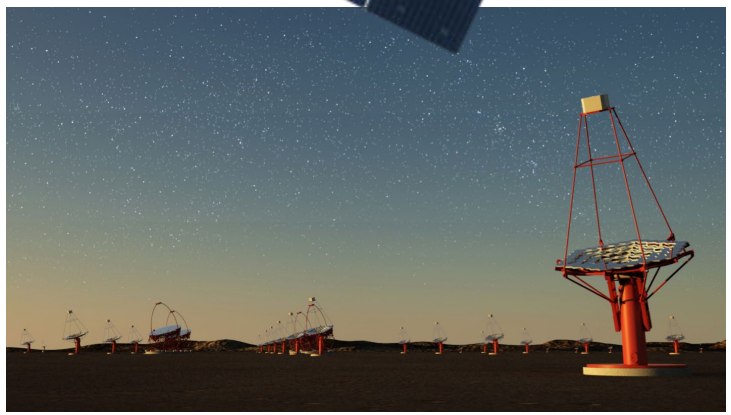


High-Energy Gamma Rays

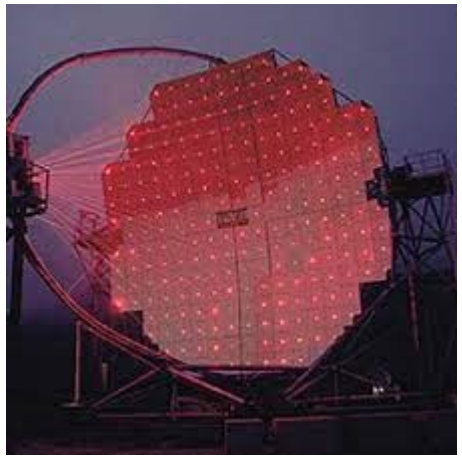

FERMI

- Covers large energy range with different observatories
- Satellites (Fermi, AMEGO (launch 2029), Theseus)
- 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



MAGIC



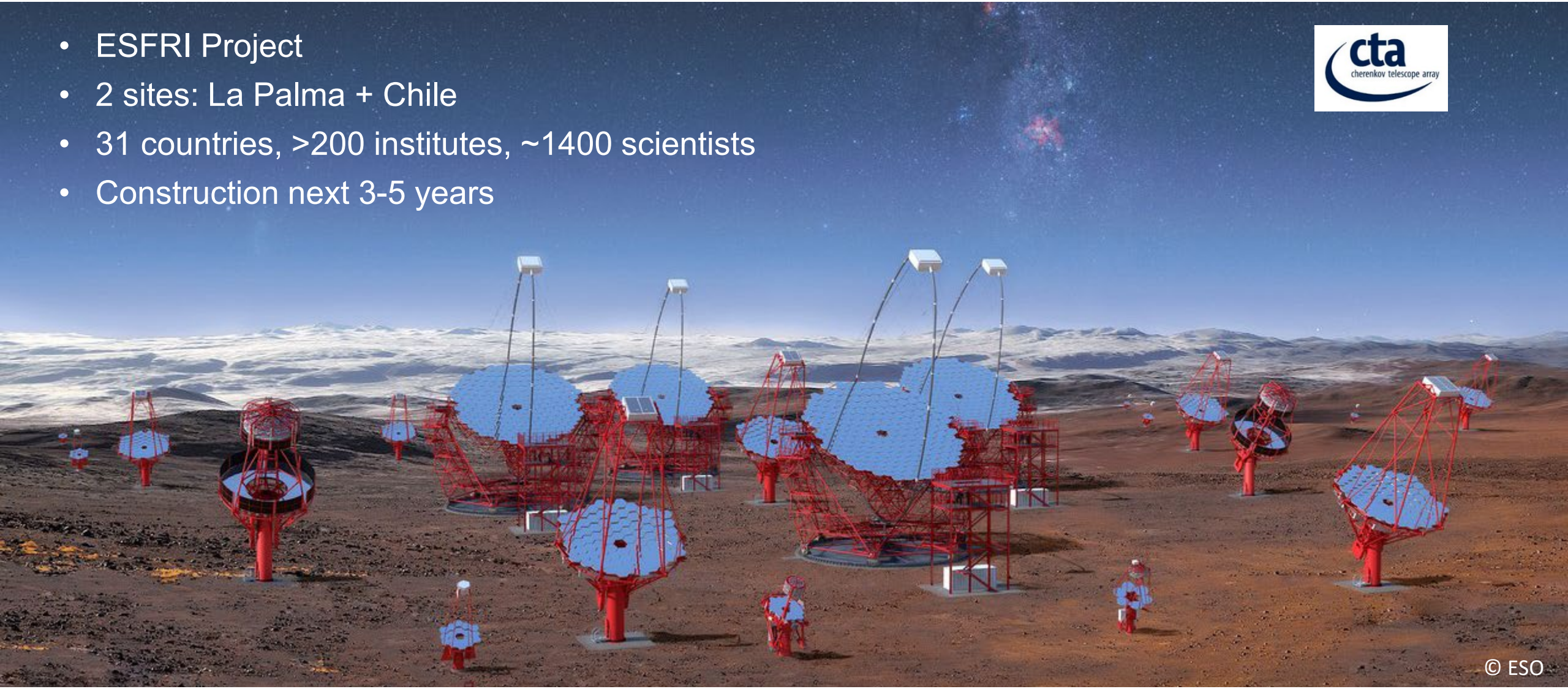
H.E.S.S.

LHAASO

HAWC

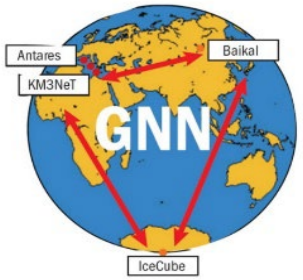
Cherenkov Telescope Array – CTA

- ESFRI Project
- 2 sites: La Palma + Chile
- 31 countries, >200 institutes, ~1400 scientists
- Construction next 3-5 years

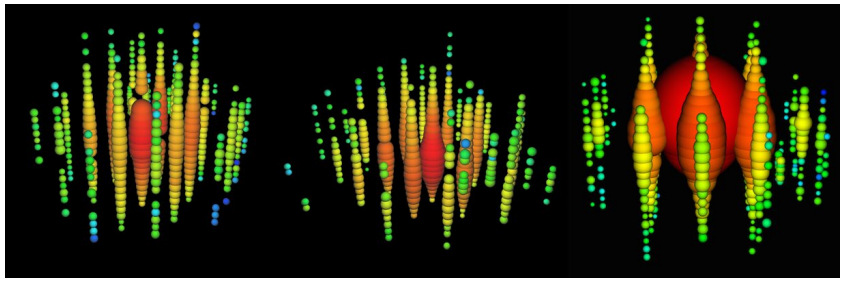


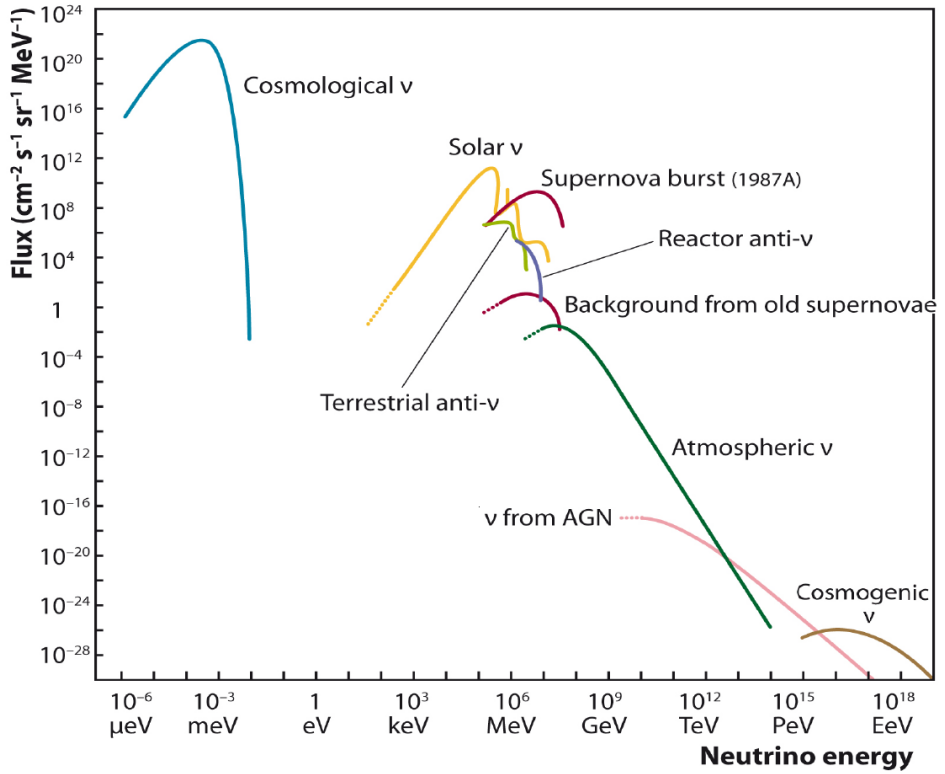
High-Energy Neutrino Astronomy

- IceCube opened in 2013 the new window of >100 TeV neutrino astronomy
- Several experiments are now organized in the Global Neutrino Network GNN:
  - IceCube ➔ IceCube-Gen2
  - Antares ➔ KM3NeT
  - Baikal-GVD (co-operation stalled)

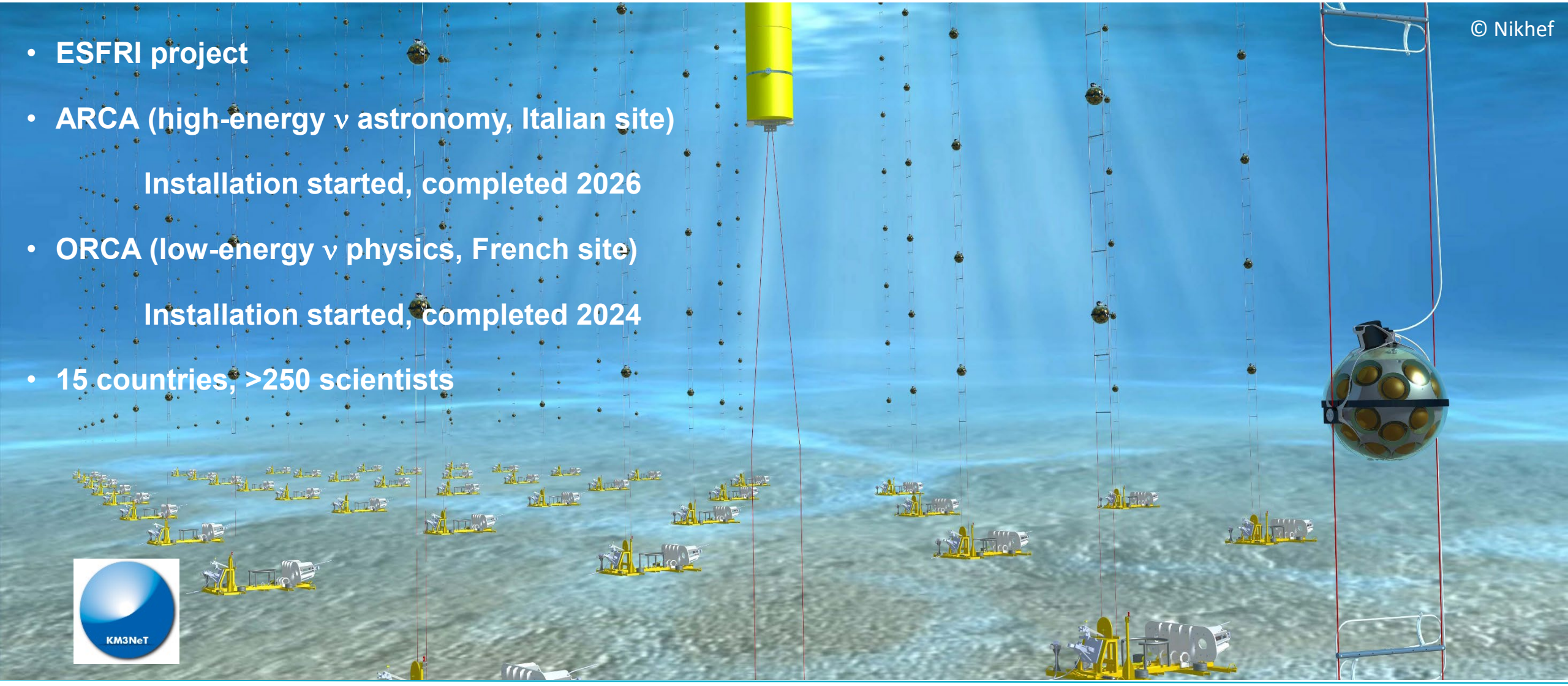


- R&D phase (in particular for cosmogenic Neutrinos): P-ONE, RNO-G, POEMMA, ANITA, GRAND, Trident, …
- European flagship (ESFRI): KM3NeT
- Strong partner of US lead IceCube-Gen2





Cubic Kilometre Neutrino Telescope – KM3NeT



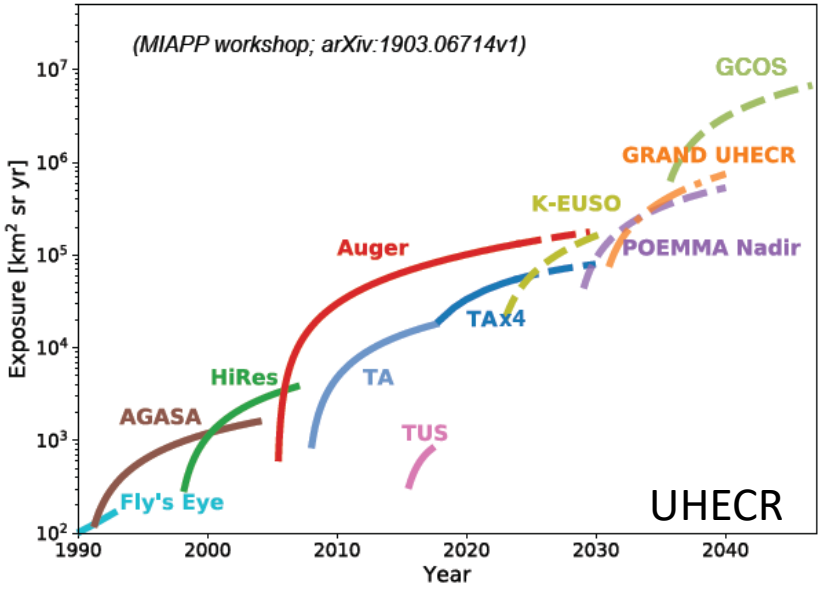
- **ESFRI project**
- **ARCA (high-energy ν astronomy, Italian site)**

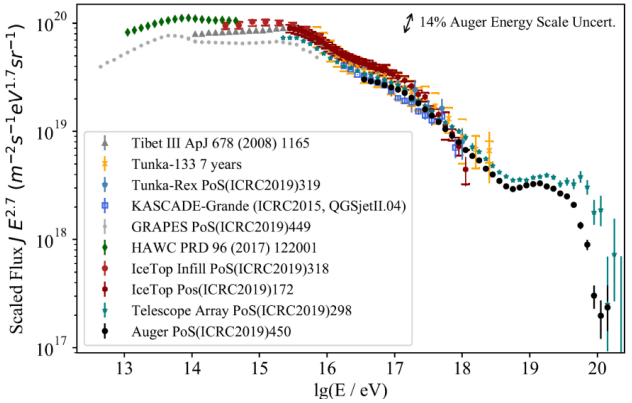
  Installation started, completed 2026
- **ORCA (low-energy ν physics, French site)**

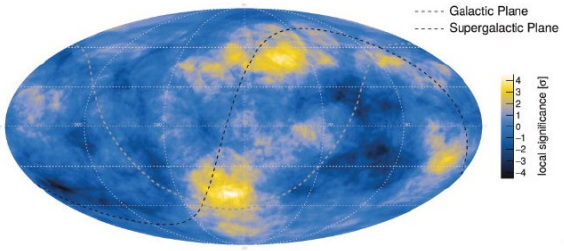
  Installation started, completed 2024
- **15 countries, >250 scientists**

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)







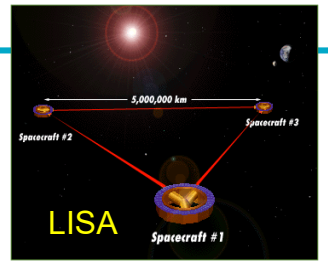
(UHECR Auger-TA working group)

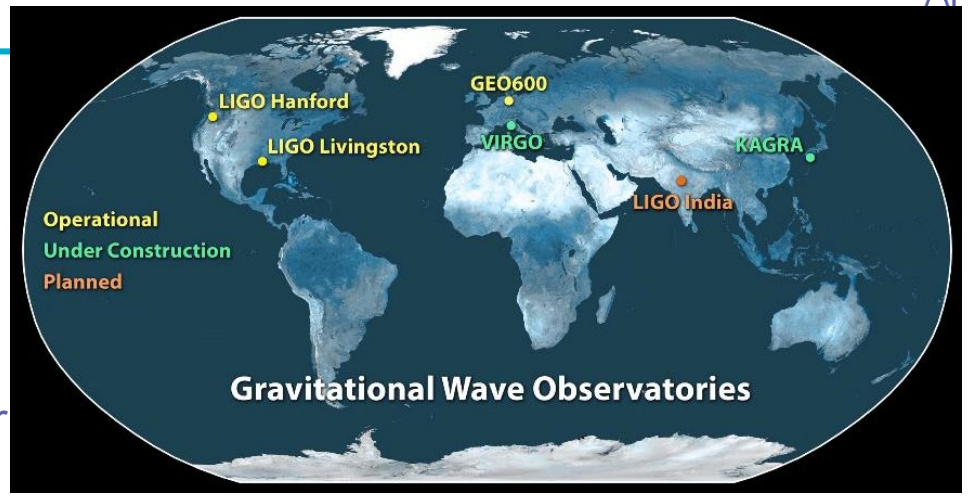
Pierre Auger Observatory

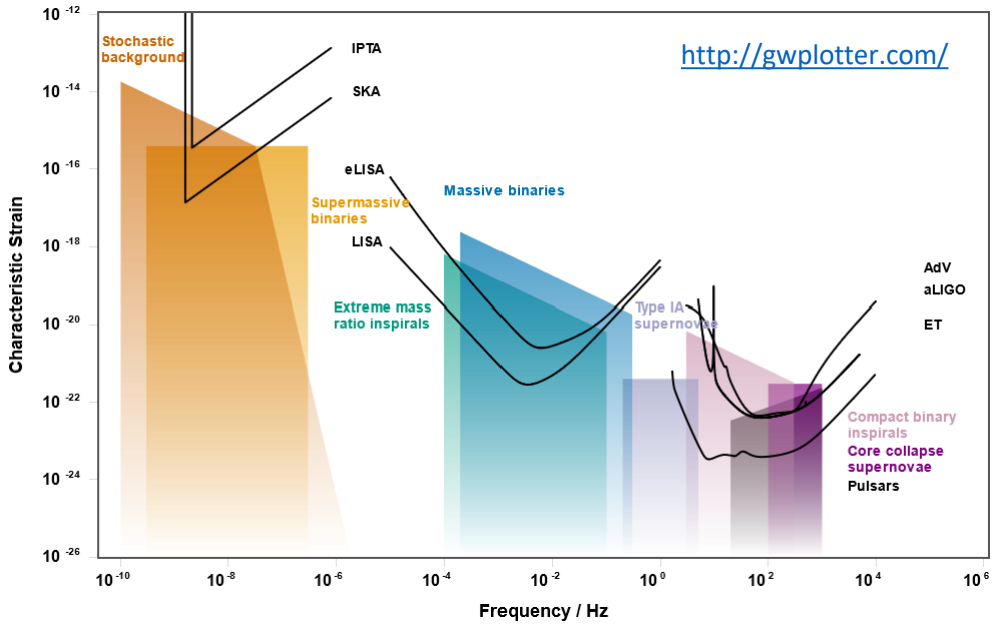
- Auger Upgrade to AugerPrime
- 18 countries, ~100 institutes, ~400 scientists
- AugerPrime completes construction in 2023
- Operation time until c. 2035
- Preparation and R&D for GCOS incl. GRAND

Gravitational Waves

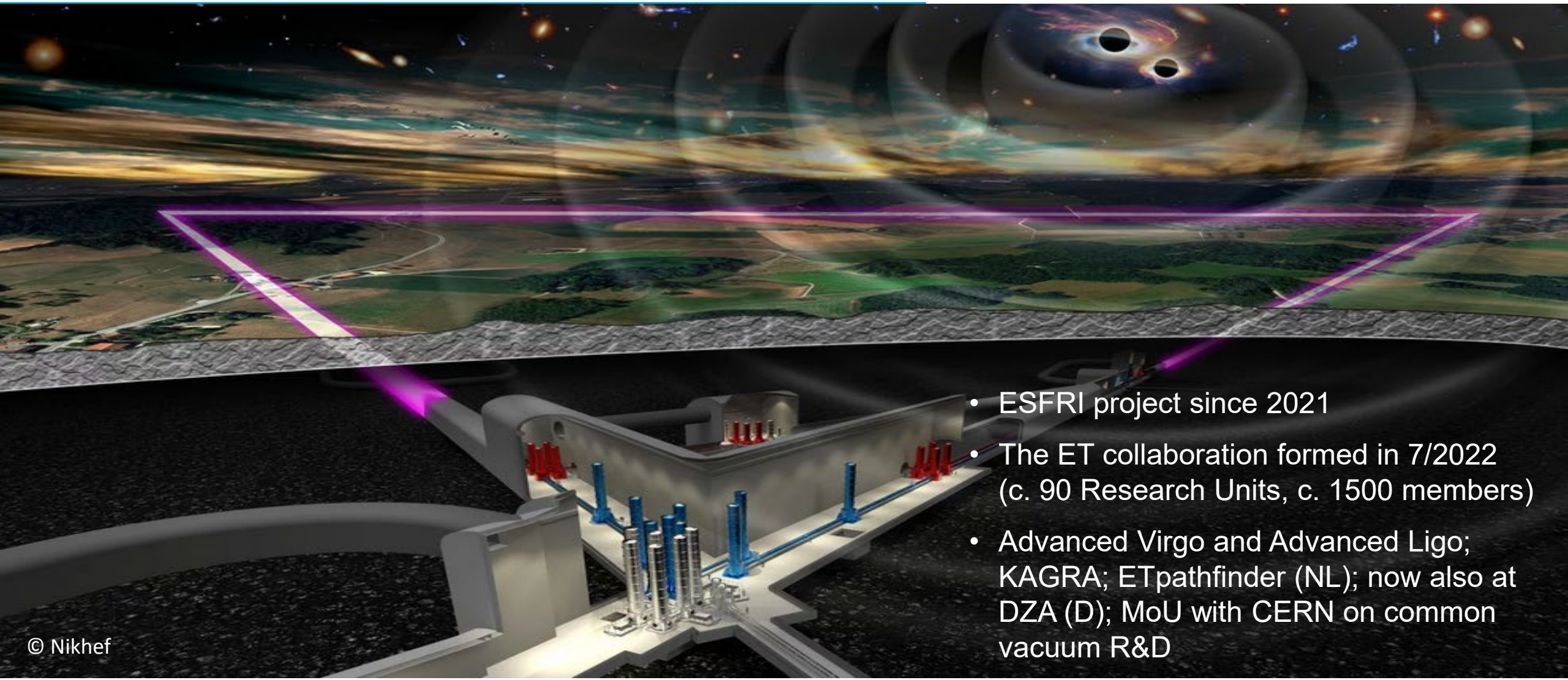
- 2015: First direct detection by LIGO / Virgo
- 2022+: Data taking with aLIGO and aVirgo
  - Volume of visible space increases by a factor 50
- 2030+: 3rd Generation: The Einstein Telescope, Cosmic Explorer
  - Volume of visible space increases by a factor 1000
- GWIC + GWAC (worldwide collaboration)
  - 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







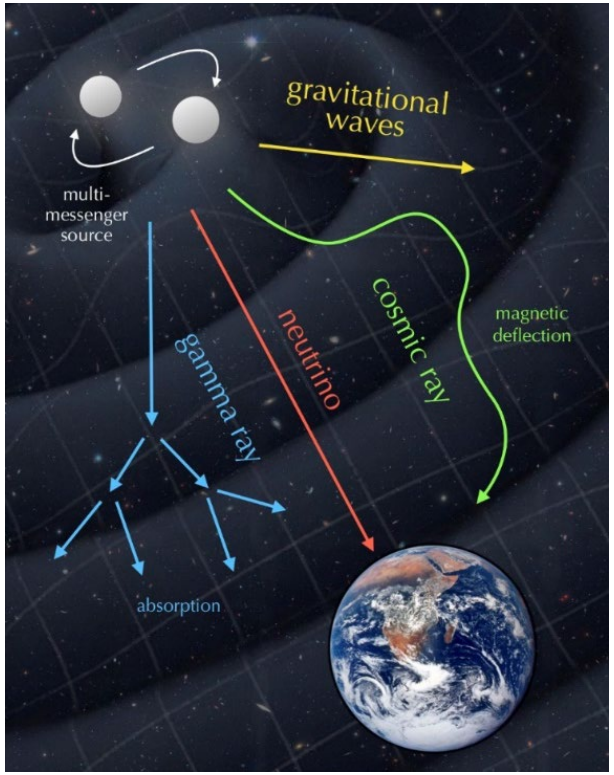
Einstein Telescope - ET

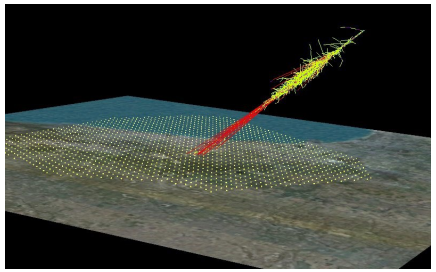


- ESFRI project since 2021
- The ET collaboration formed in 7/2022 (c. 90 Research Units, c. 1500 members)
- Advanced Virgo and Advanced Ligo; KAGRA; ETpathfinder (NL); now also at DZA (D); MoU with CERN on common vacuum R&D

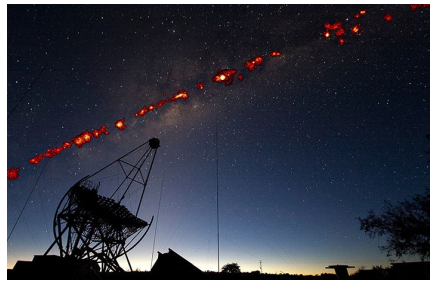
Multi-Messenger Astroparticle Physics

- 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…… preferably in real-time!

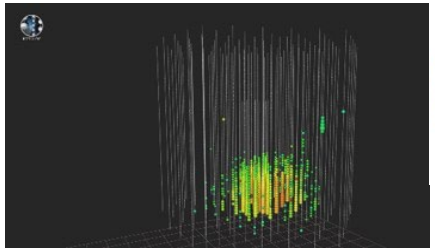




PIERRE AUGER OBSERVATORY



cta cherenkov telescope array



KM3NeT IceCube

LIGO VIRGO

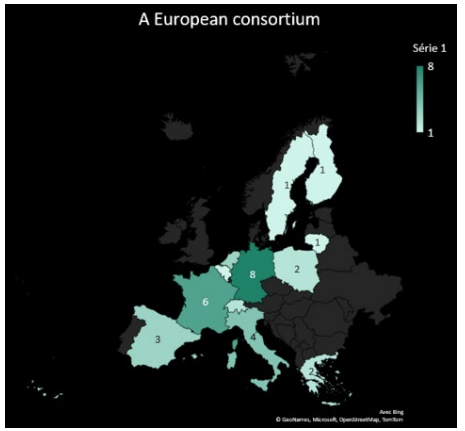
+ instruments for multiwavelength astronomy

SKAO

ACME - Astrophysics Centre for Multimessenger studies in Europe

HORIZON-INFRA-2023-SERV-01-02

- Topic: **better access of users to RI services to advance frontier knowledge**, activities to improve and harmonize the access, and training for scientists.
- **ACME is set up to realize an ambitious coordinated European-wide optimization of the accessibility and cohesion between multiple leading RI, offering access to instruments, data and expertise.**
- Maximum EU contribution per project: 14.5 million euros.
- Scientific domain of interest: Astronomy & Astroparticle physics.
- Consortium: 41 partners, 15 countries, >30 research infrastructures
- Submission on March 9th, feedback in September ➔ waiting list



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

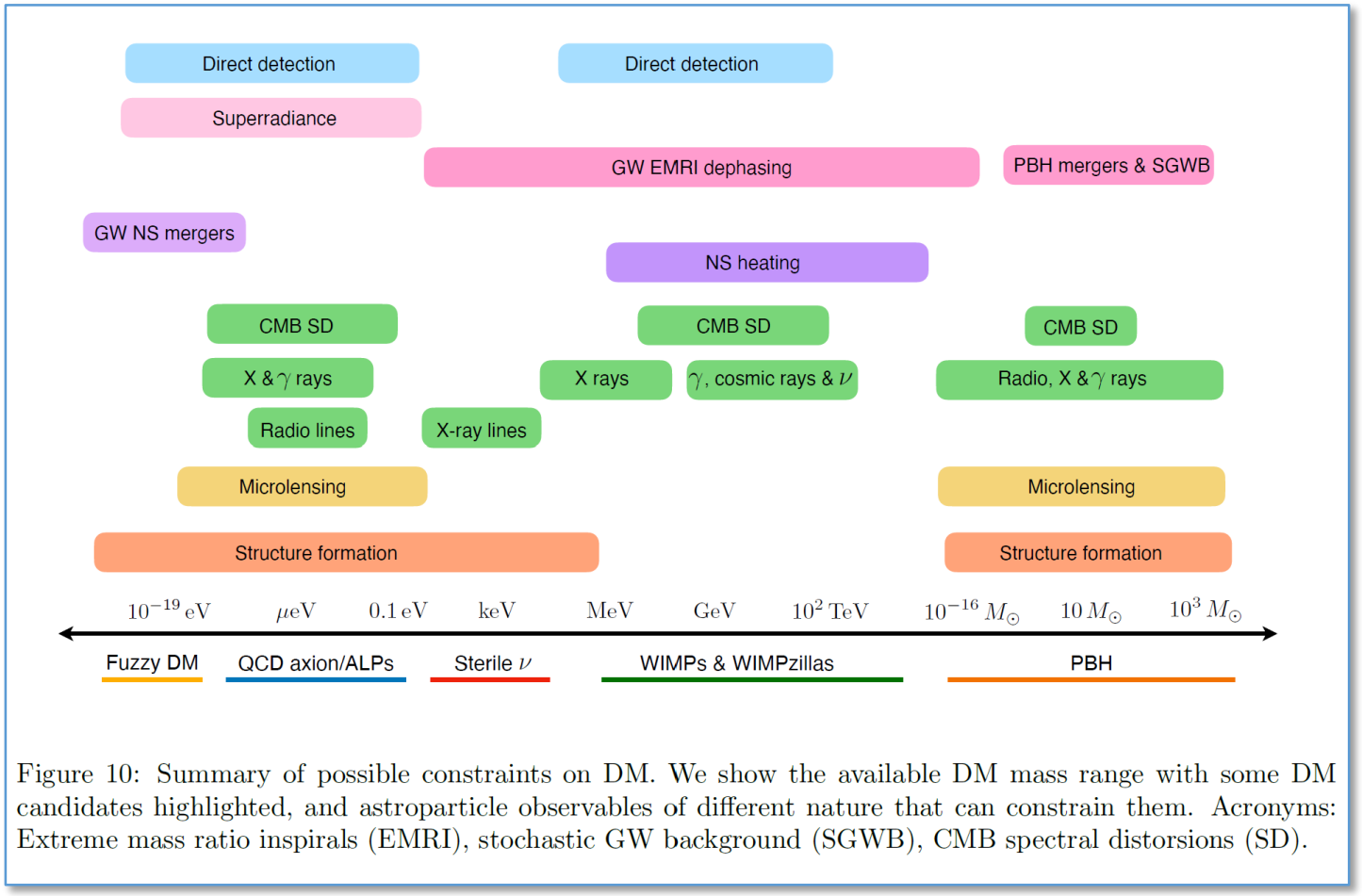
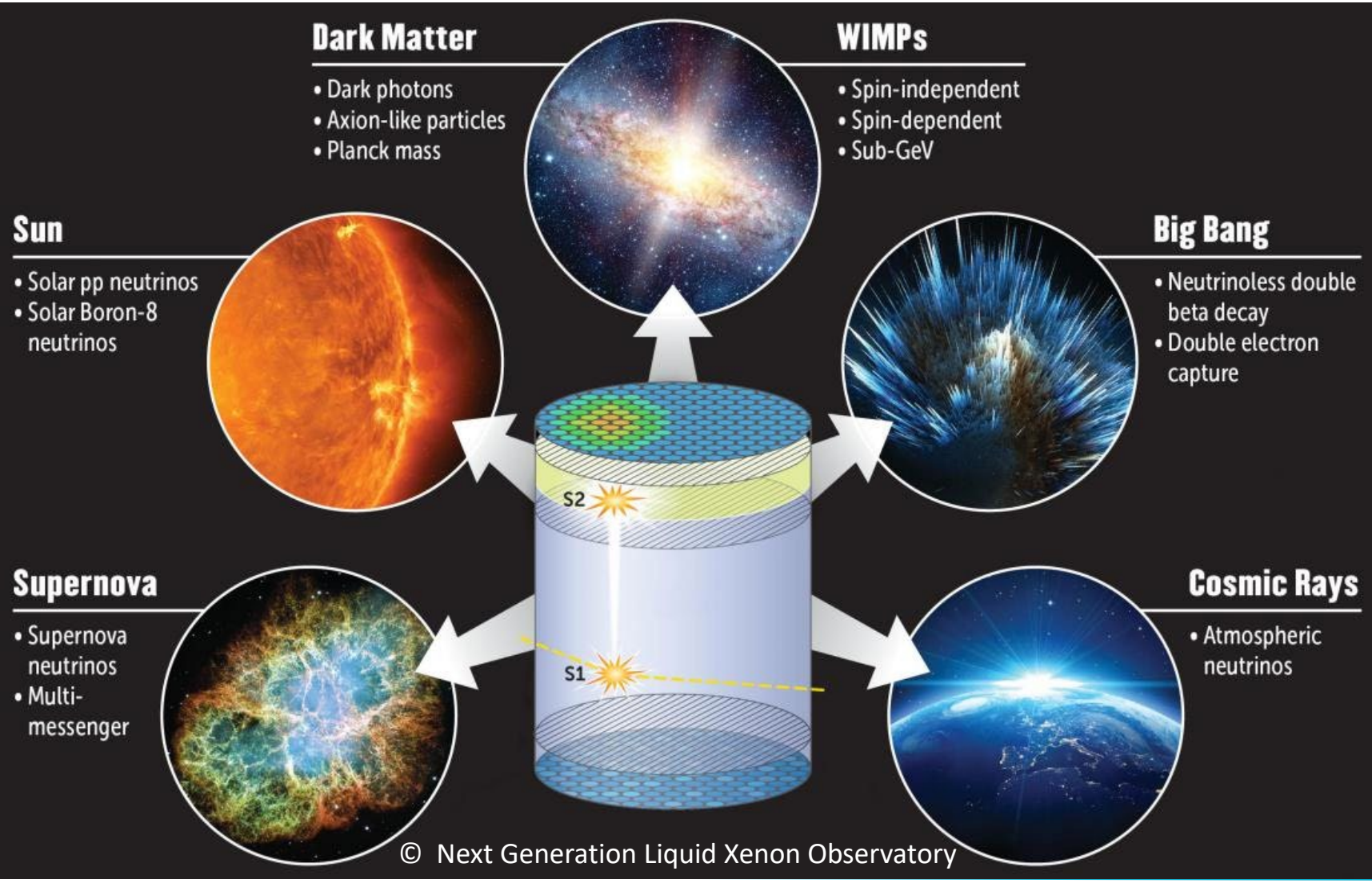


Figure 10: Summary of possible constraints on DM. We show the available DM mass range with some DM candidates highlighted, and astroparticle observables of different nature that can constrain them. Acronyms: Extreme mass ratio inspirals (EMRI), stochastic GW background (SGWB), CMB spectral distorsions (SD).

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

Dark Matter WIMP search with liquid Xenon

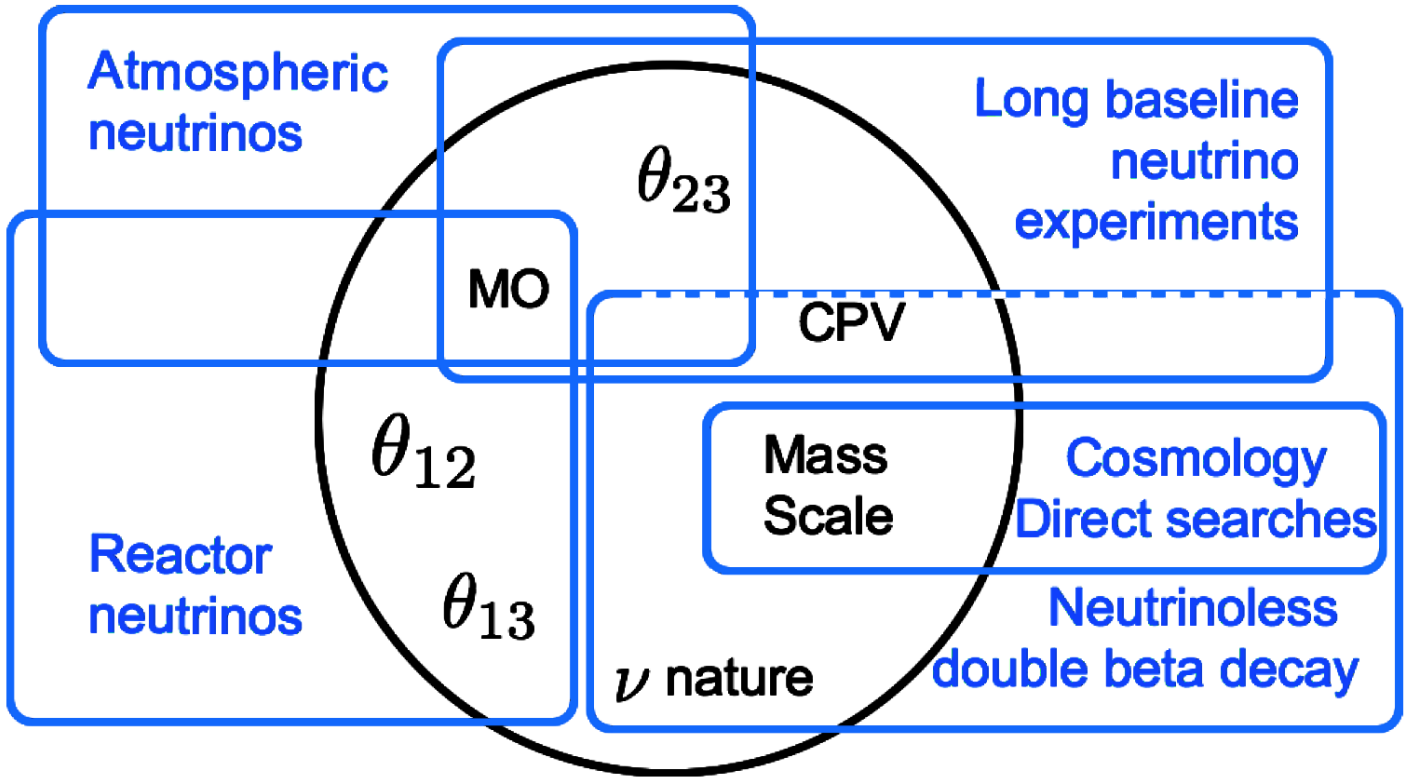


- APPEC recommends to realize worldwide at least one xenon (50t) and one argon (300t) experiment
- XENON/DARWIN and LUX-ZEPLIN ➔ **XLZD**
- collaborations have signed a common MoU arxiv.org 2203.02309 (141 institutes, ~600 authors)
- **Needs (European) infrastructures for Underground Science**

Neutrino Properties

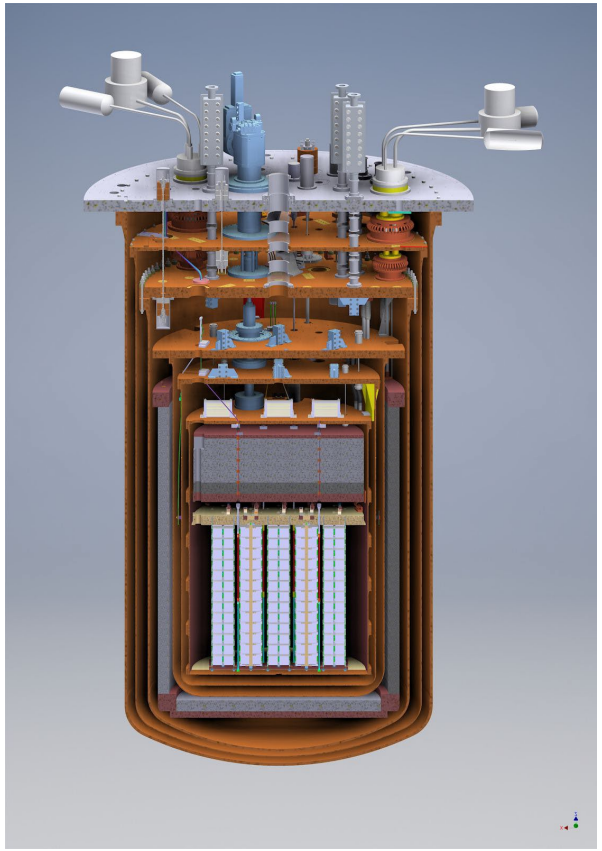
- ν CP-violation is still unknown and may give hints to matter-antimatter asymmetry
- ν–mixing is very different from CKM
- ν–nature undetermined (Majorana)
- ν mass ordering not yet determined
- ν is the first hot “dark” particle and has a role in various stages of the Universe
- APPEC’s RI flagship is next generation neutrinoless double beta decay experiment
- Needs (European) infrastructures for Underground Science

Science has large overlap with neighboring fields

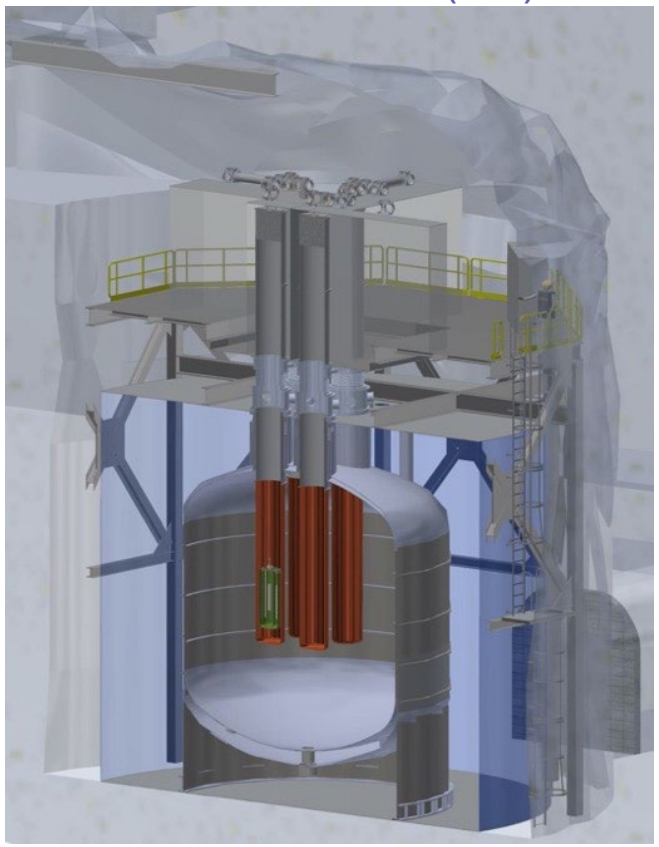


0νββ decay: towards ton-scale experiment *

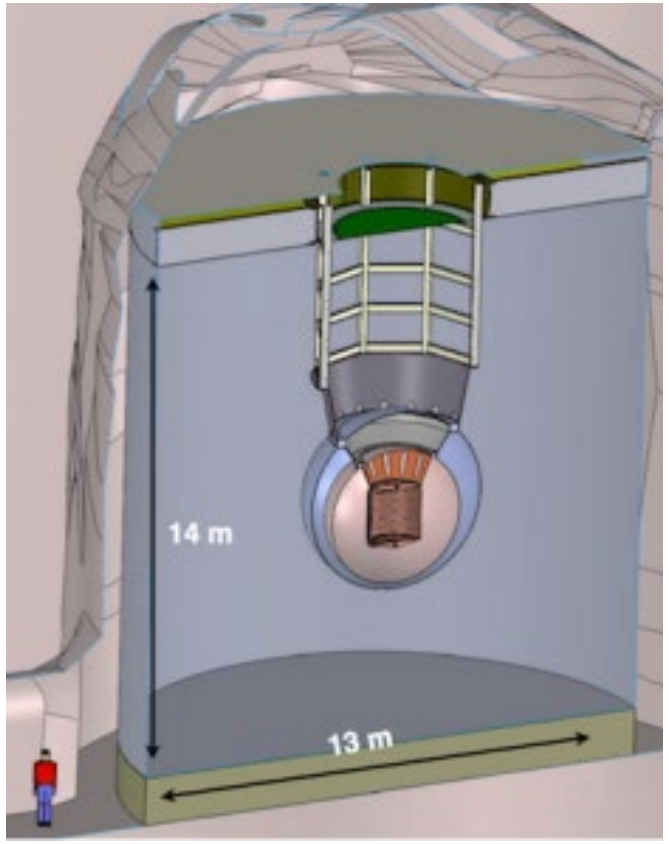
CUPID (100 Mo)



LEGEND-1000 (Ge)



nEXO (136 Xe)



NEXT (136 Xe)

* Strategy discussion in co-operation with DOE, USA

The Dark Universe

- Experiments (often) require sophisticated Deep Underground Laboratories (DULs)
- R&D and prototyping also require DULs
- Community-overarching, synergetic research possible
- Needs long-term commitments for operation of Underground Labs.

➔ Structured Coordination of European Underground Activities and Infrastructures

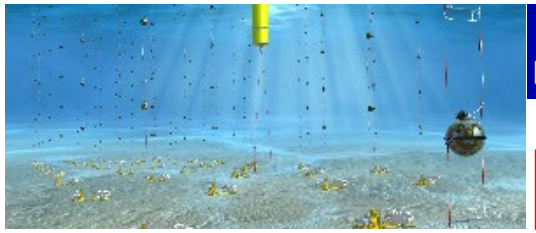
<u>Recommendation in APPEC roadmap</u>:
APPEC encourages the European Underground Laboratories involved in astroparticle physics to establish a Virtual Coordination Office that establishes robust cooperation in key services and support for experiments, coordinates future investments in deep underground infrastructures and establishes a trans-national access policy

APPEC Flagship Research Infrastructures

This is not a closed, but dynamic list…

ESFRI=European Strategy Forum on Research Infrastructures

[construction KM3NeT 2020-2026; IceCube-Gen2]



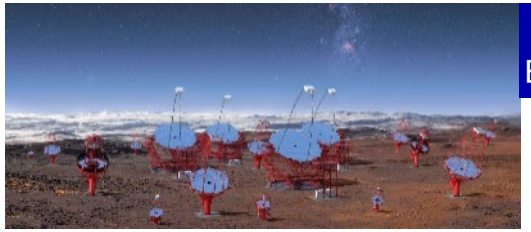
ESFRI

HE Neutrinos

[construction AugerPrime 2019-2023]

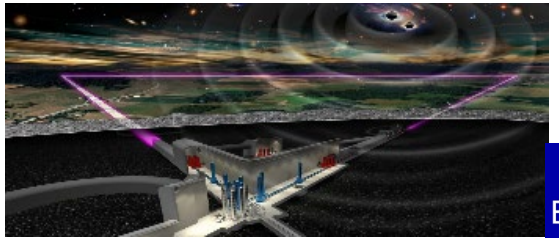
HE Cosmic Rays

[construction CTA 2021-]



ESFRI

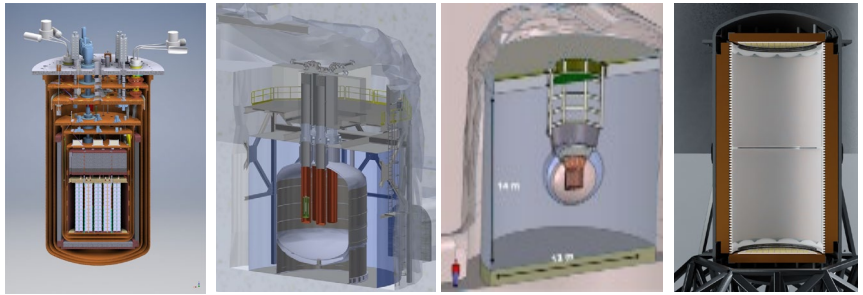
HE Gamma Rays



ESFRI

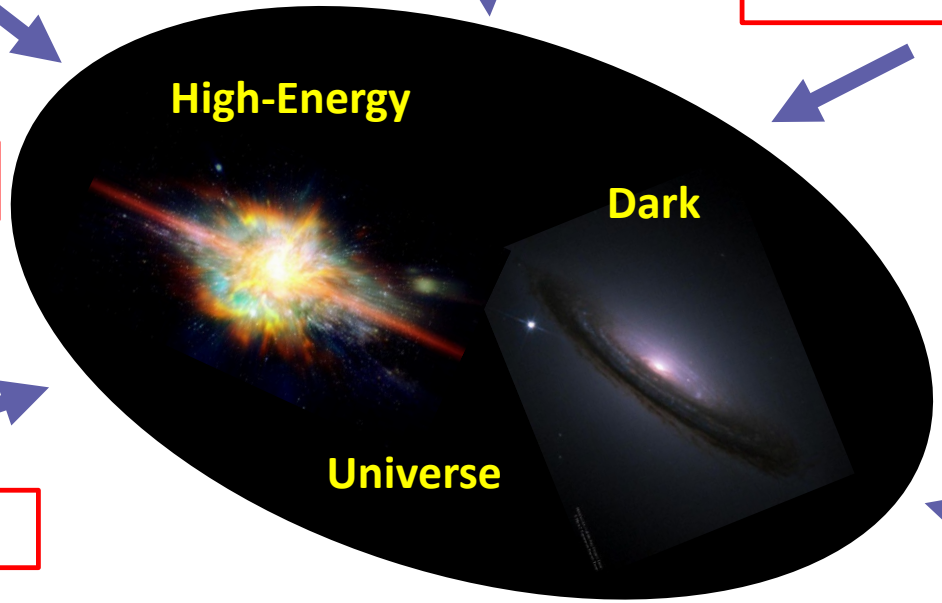
[construction Einstein Telescope 2026-]

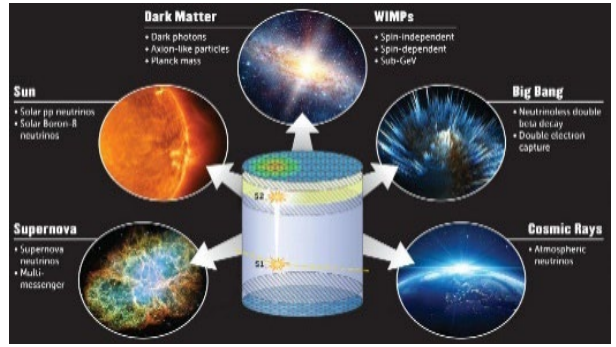
Gravitational Waves



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

Neutrino Properties

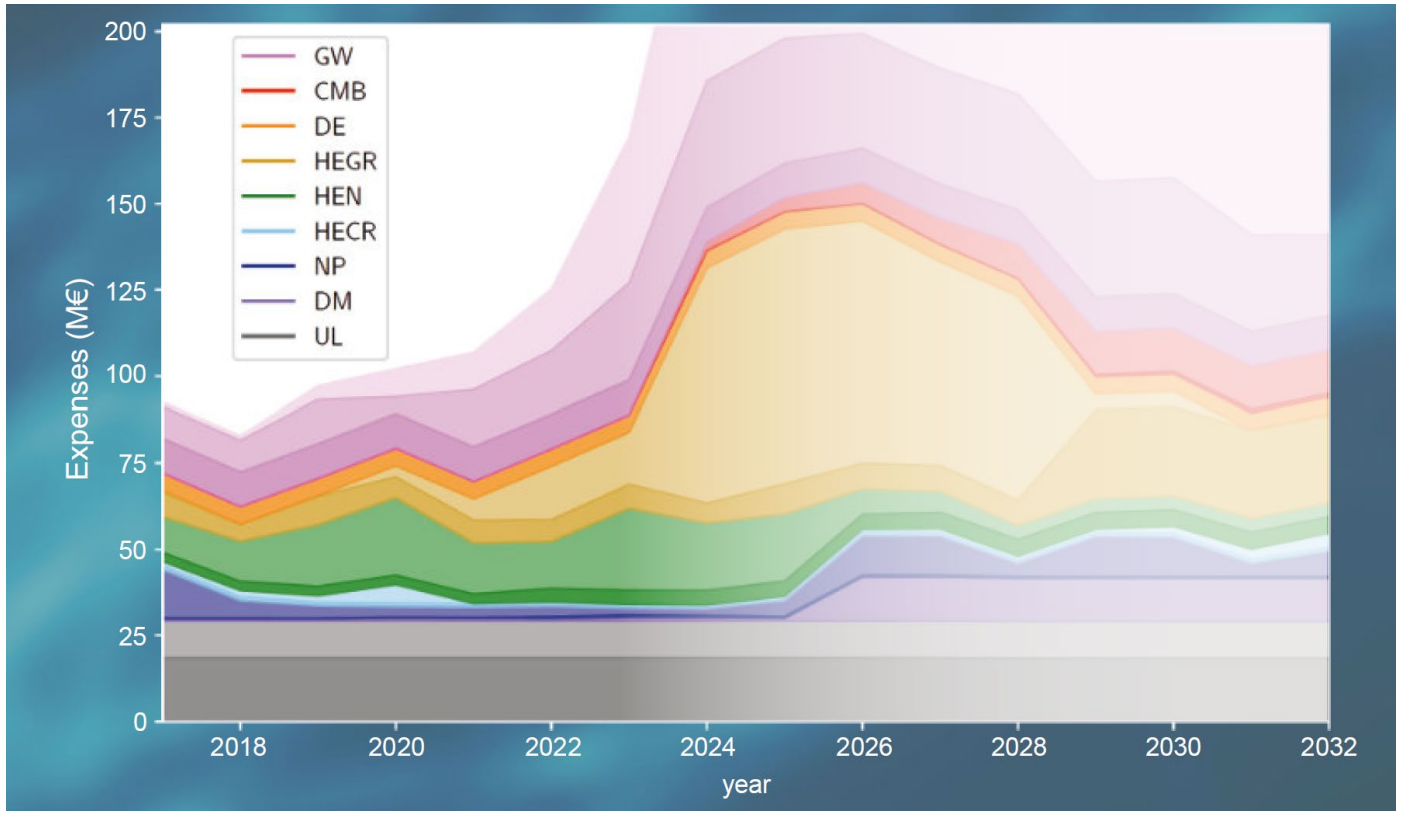




[construction DARWIN 2024- ; XLZD, ARGO, …]

Dark Matter

Ressources



Roadmap Update 2023: Projected annual capital investment

- **A resource aware roadmap**
  (darker colors show M&O of RI)
- **Observations:**
  - Predictions from 2017 were okay
  - CTA-peak shifted to later years
  - HE Neutrinos: stretched
  - ET peak has 3 colors (invest, operation, infrastructure)
- **Next**
  - Public Presentation of Roadmap in Brussels to stakeholders
  - 7/12/2023 14-18:00 https://indico.cern.ch/event/1339060/

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

APPEC:

- Publication of Roadmap Mid-Term Update
- 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!