

APPEC Roadmap

Astroparticle Physics European Consortium



**Multi-Messenger Astrophysics
Workshop (MMAW)
October 10-12, 2022
EGO, Cascina, Italy**

Andreas Haungs | KIT – Institute for Astroparticle Physics

MMAW | EGO, Italy | 10-12 October 2022

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

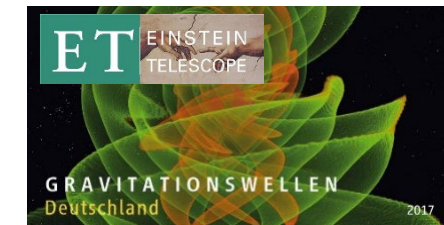
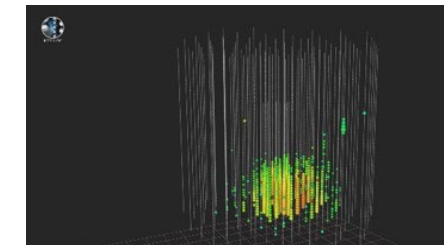
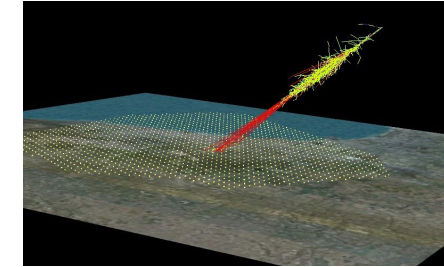
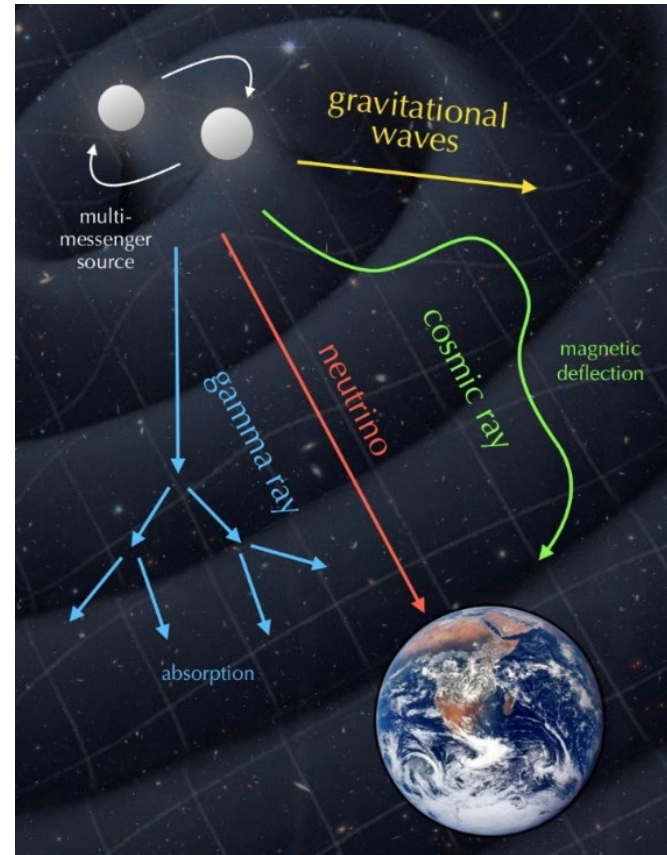
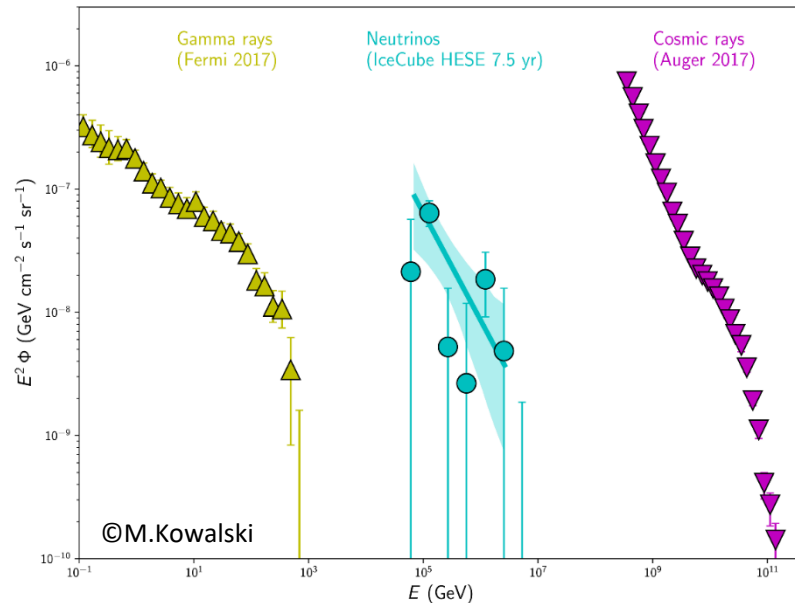
Societal:

- Gender balance
- Education and outreach
- Open Science and Citizen Science
- Ecological impact
- Connection to industry



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

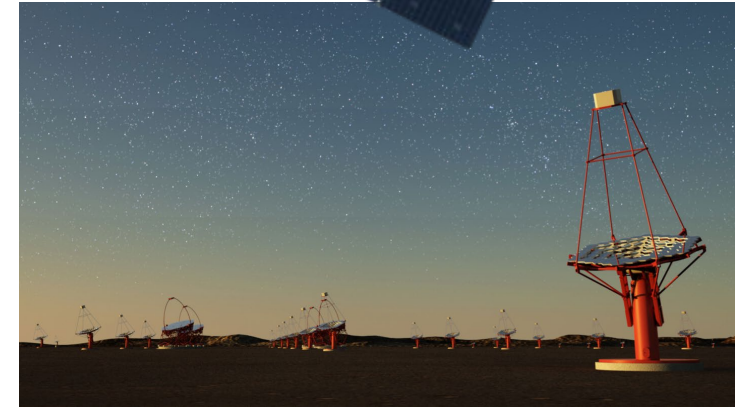


High-Energy Gamma Rays

- 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



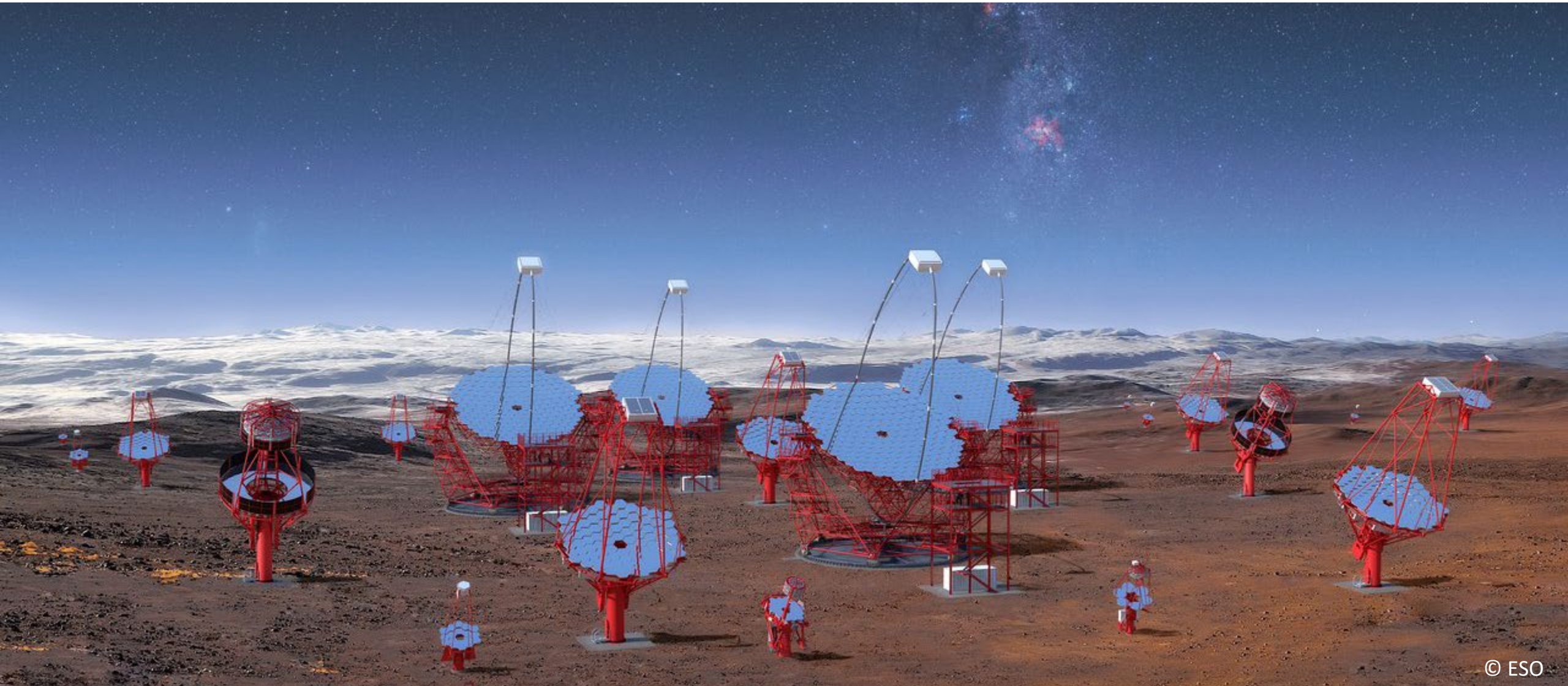
LHAASO



HAWC



Cherenkov Telescope Array – CTA

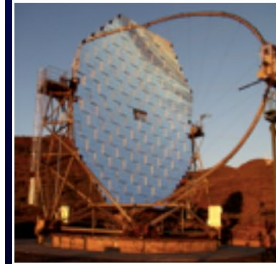


© ESO

High-Energy Gamma Rays

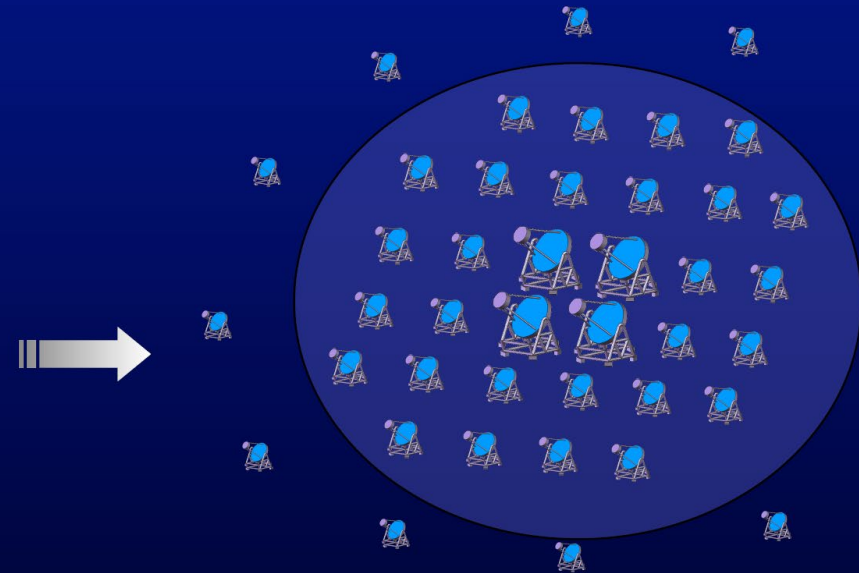


- ESFRI Project
- Open, proposal-driven observatory
- 3 telescope types: LST, MST, SST
- 2 sites: La Palma + Chile
- Governance: ERIC (established 2022)
- 31 countries, >200 institutes, ~1400 scientists
- Construction next 3-5 years



F.Aharonian

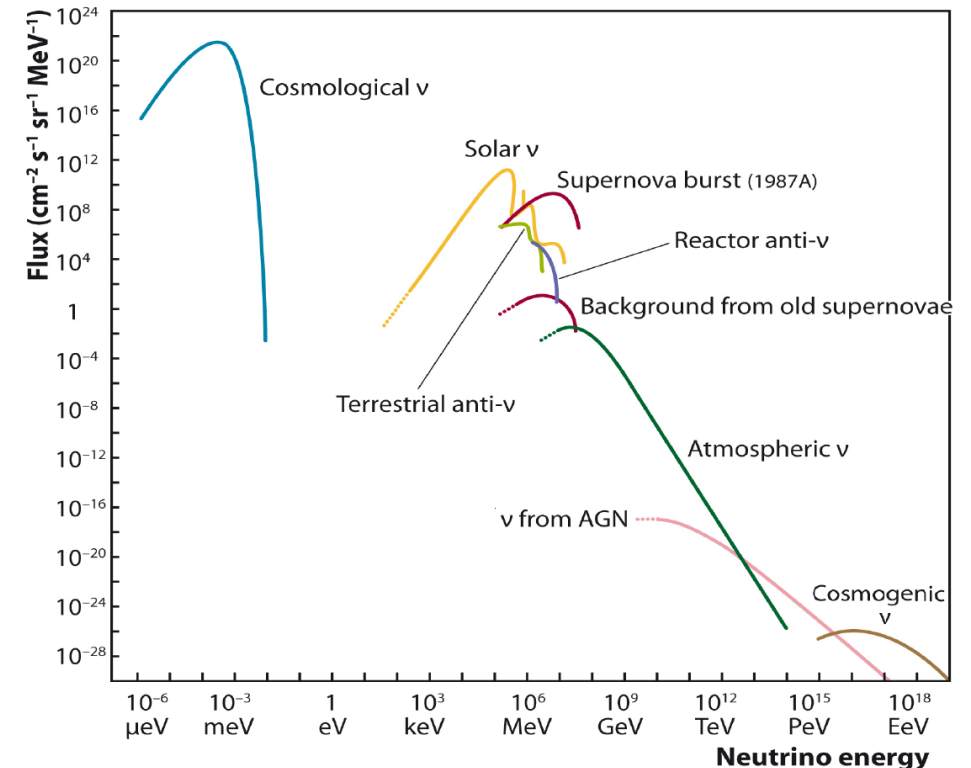
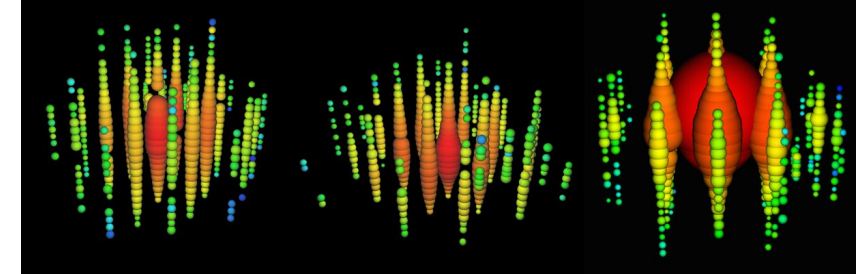
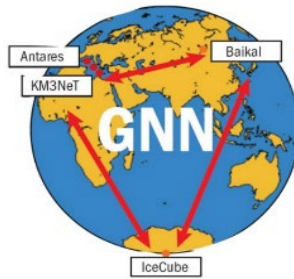
from *HEGRA/HESS/MAGIC/VERITAS* to *CTA*...



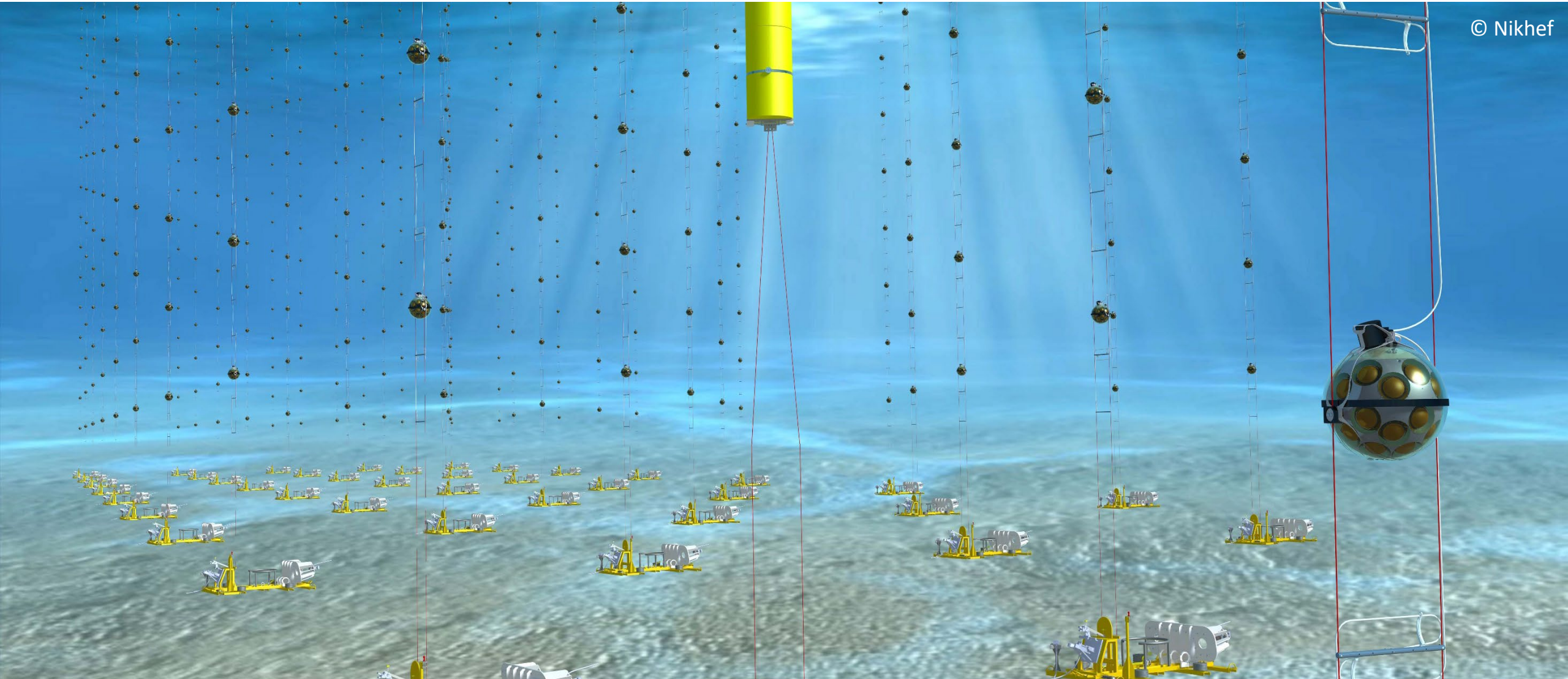
- an order of magnitude better sensitivity
- broader energy coverage: 10^{10} to 10^{15} eV
- angular resolution down to 1-2 arcmin
- energy resolution 5 to 25 percent
- larger (up to 6-8 degree FoV)
- rapid follow-up capabilities

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

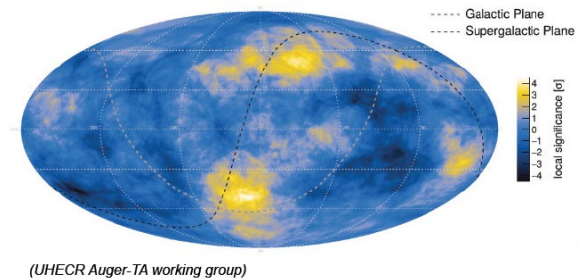
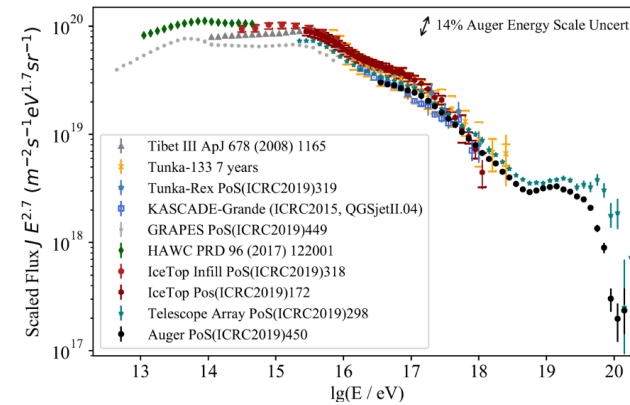
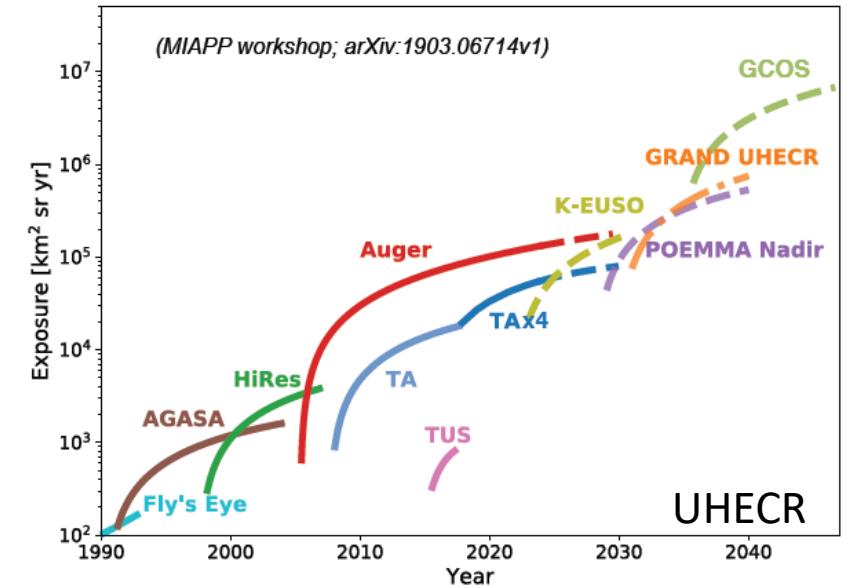
- ♦ **Neutrino astroparticle physics**
 - ♦ Galactic and Extragalactic point sources
 - ♦ Diffuse neutrino flux
- ♦ **Dark Matter and exotics**
 - ♦ Neutrinos from Dark Matter annihilation
 - ♦ Magnetic monopoles, nuclearites, strangelets, ...
- ♦ **Neutrino and particle physics ($\sim 10^5 \nu_{\text{atm}}/\text{year}$)**
 - ♦ 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 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)



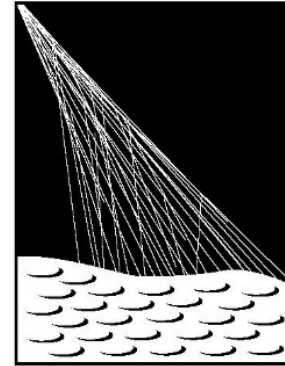
Pierre Auger Observatory



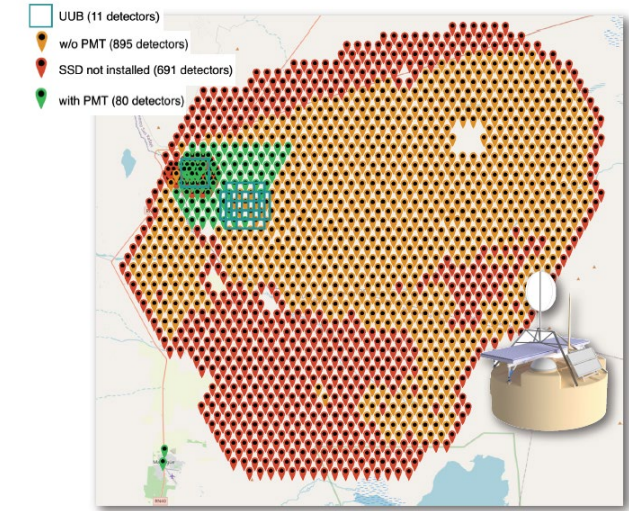
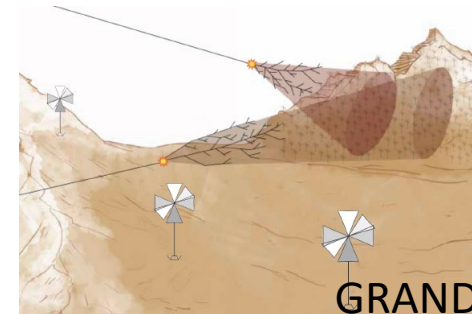
© S.Saffi/Auger

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

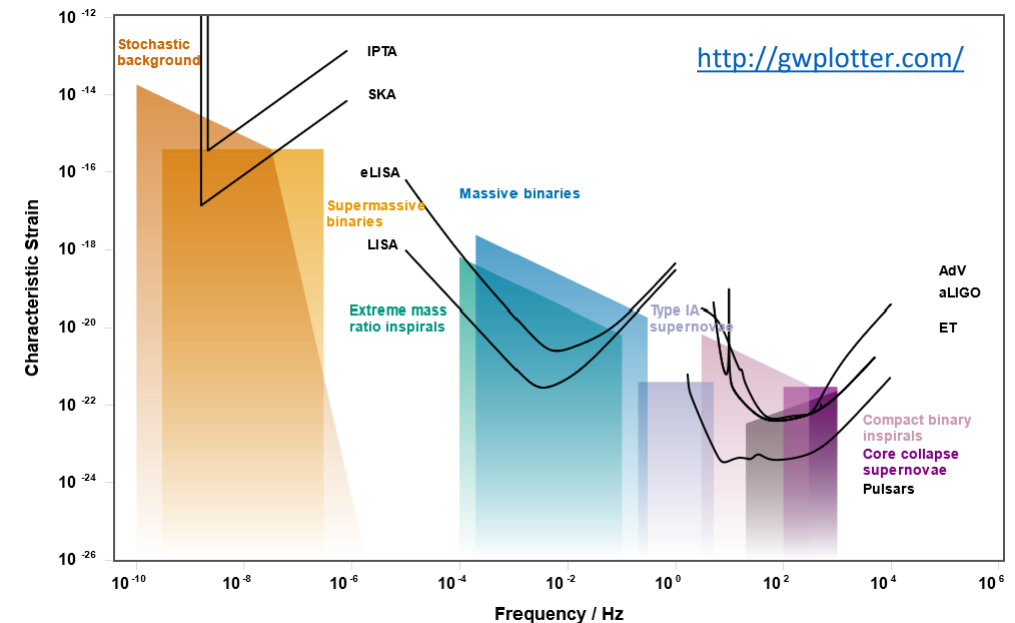
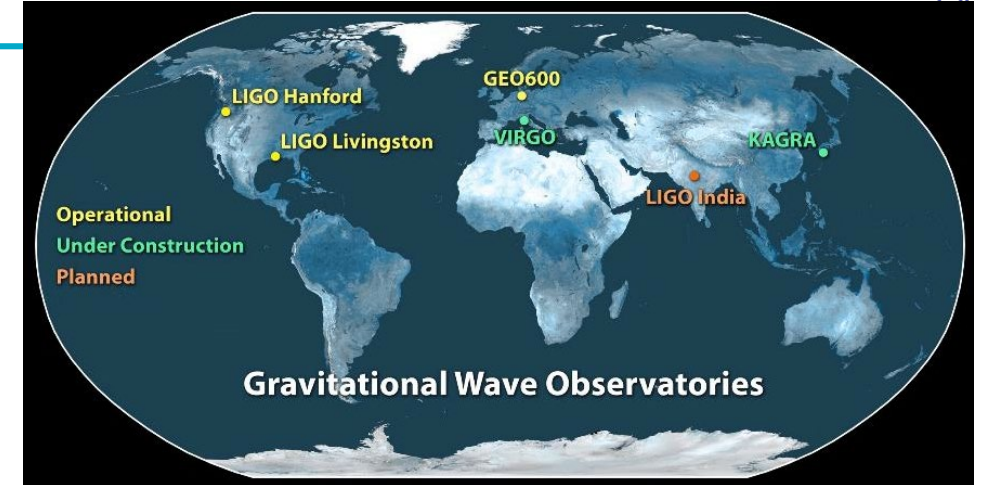
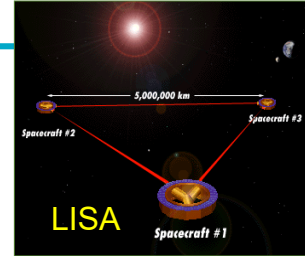


Ongoing upgrade AugerPrime
(scintillators and radio antennas)
(AugerPrime design report 1604.03637)

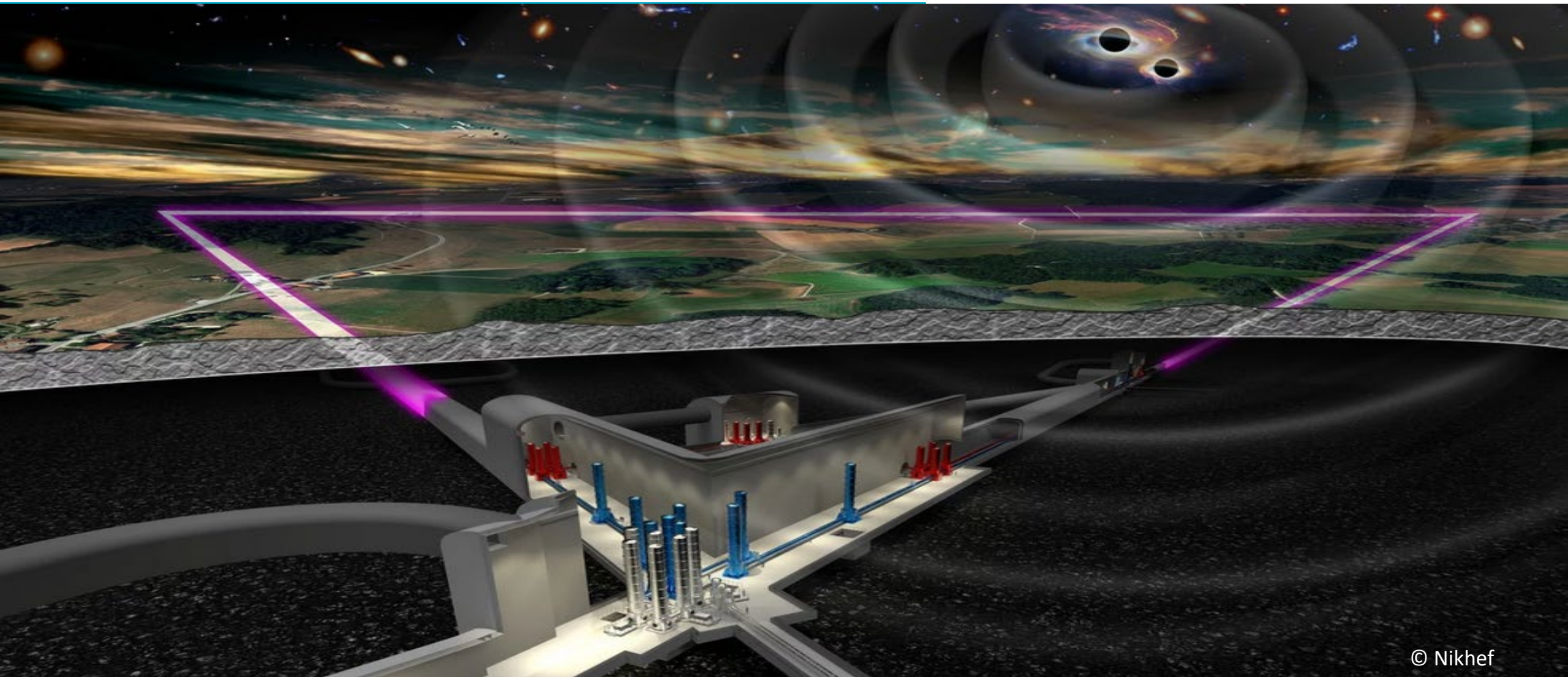


Gravitational Waves

- 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

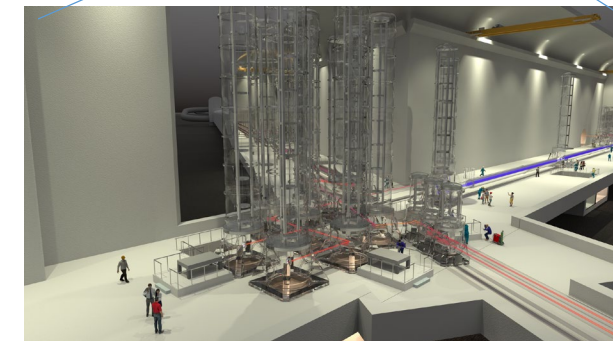
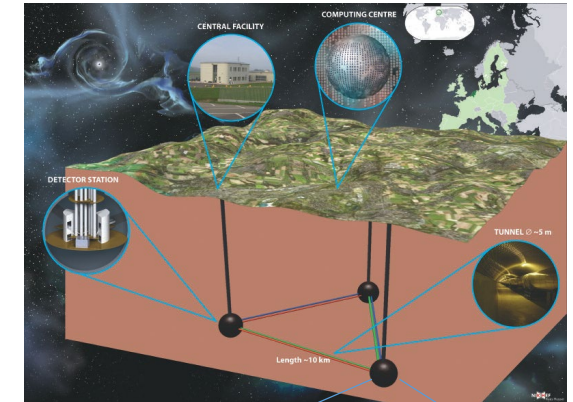


Gravitational Wave Detection

- 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

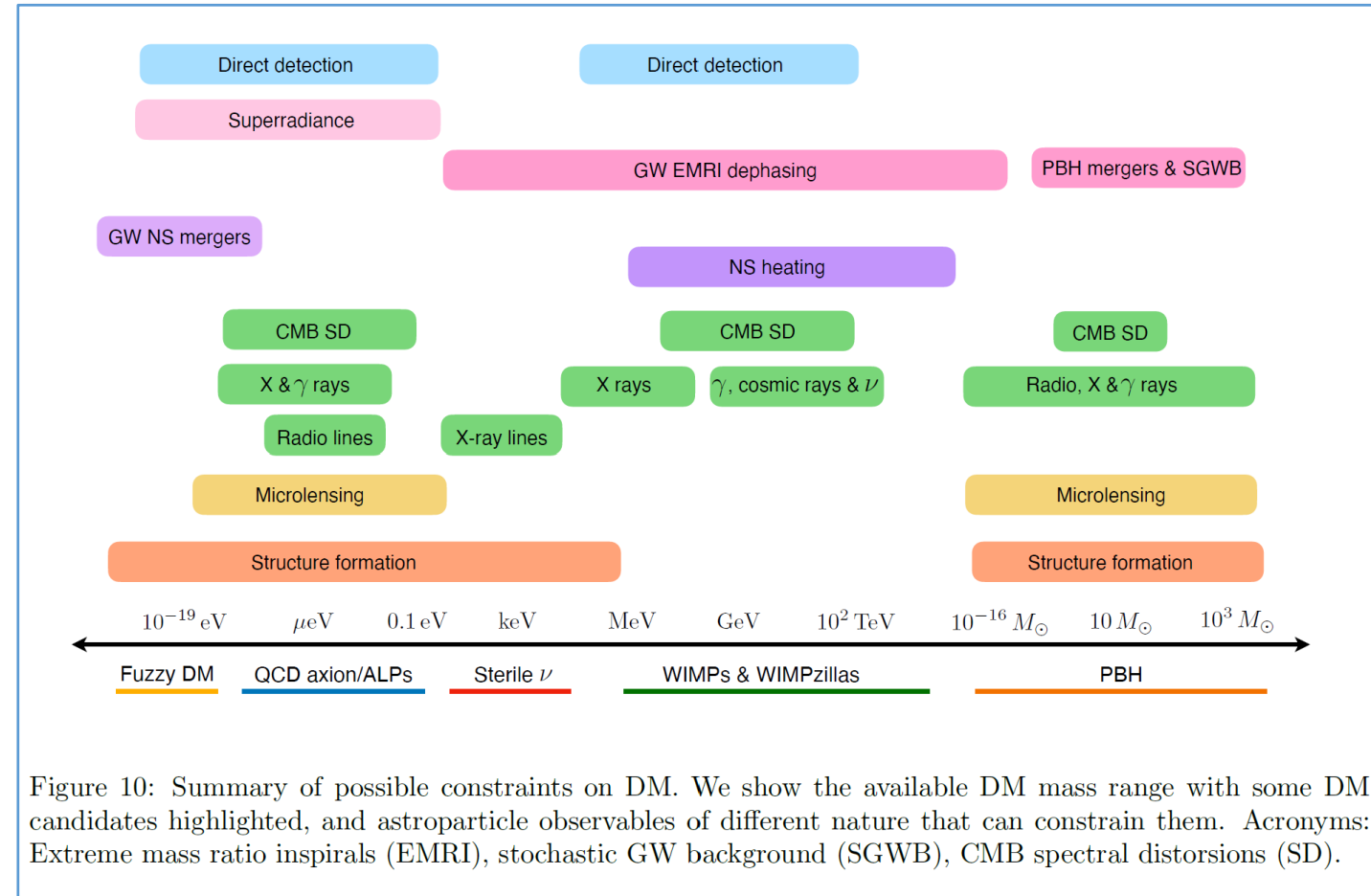


<http://www.et-gw.eu>



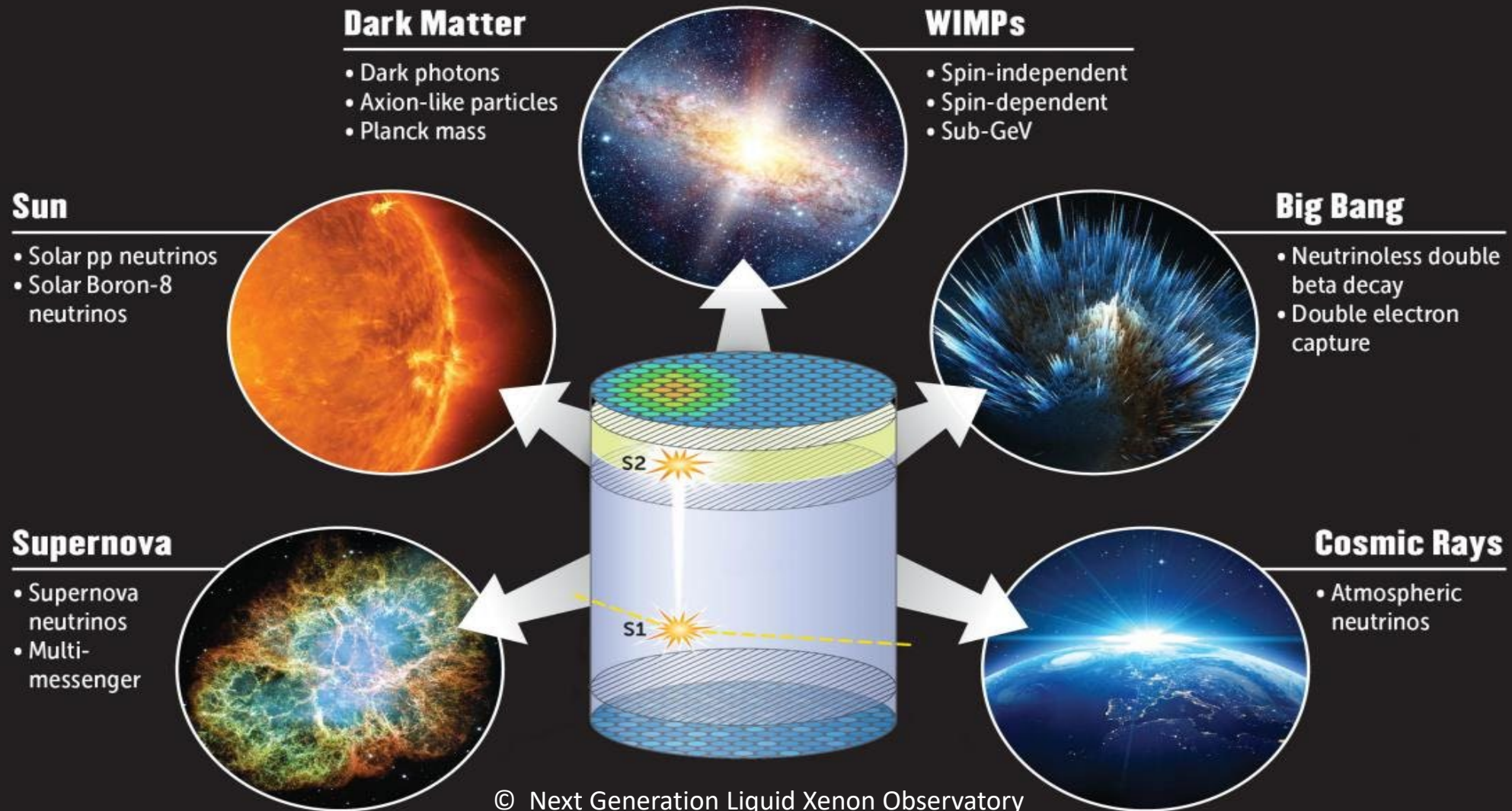
Dark Matter

- 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



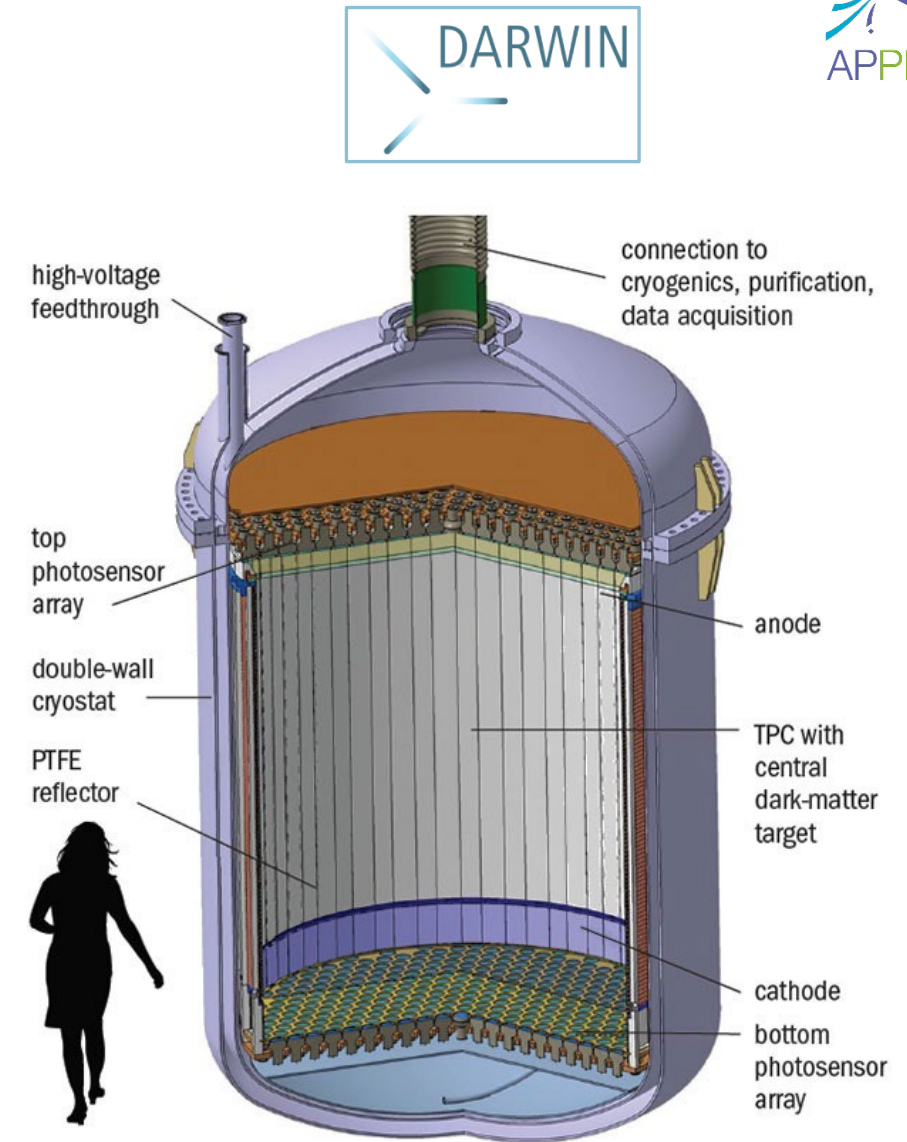
EuCAPT White Paper <https://arxiv.org/abs/2110.10074>

dark matter wimp search with liquid xenon



Dark Matter - WIMP

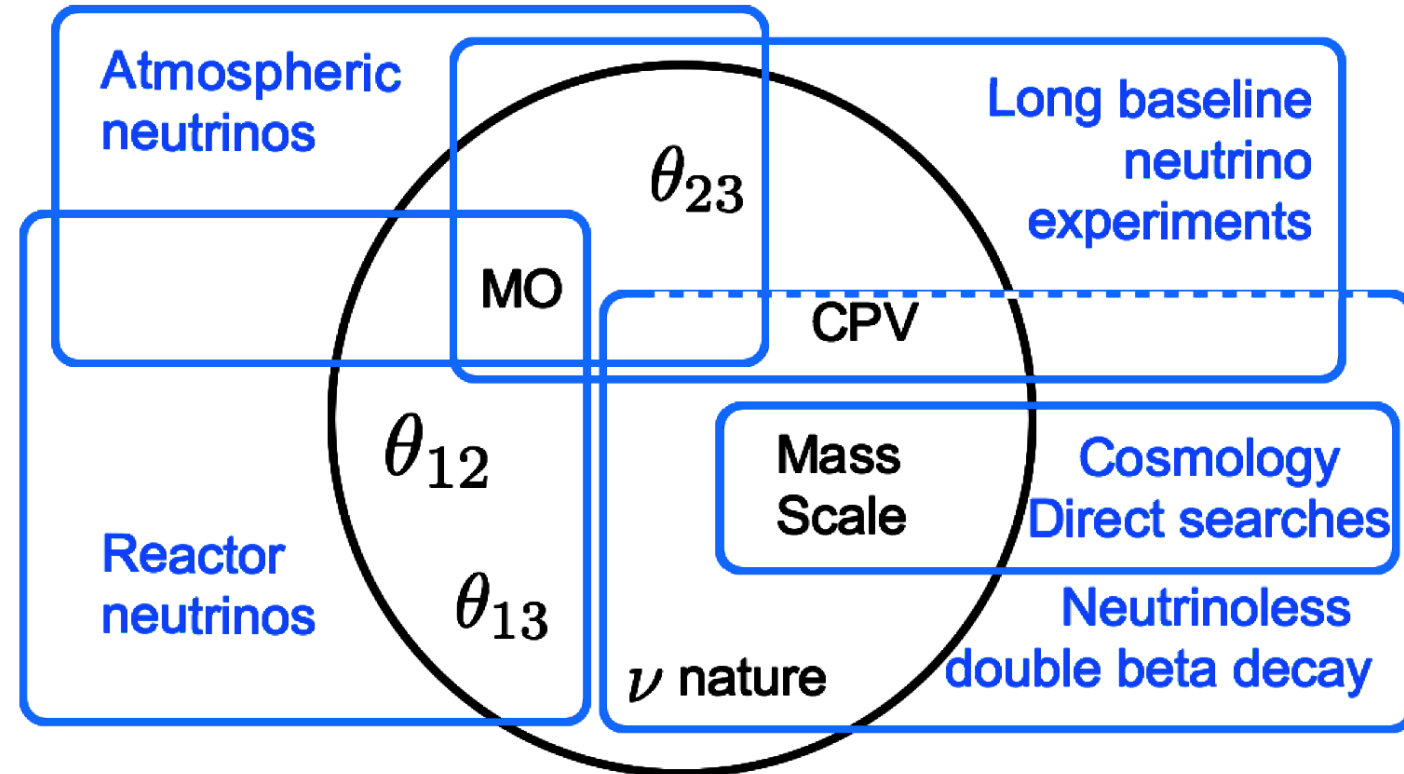
- APPEC recommends to realize worldwide at least one xenon (50t) and one argon (300t) experiment
- DARWIN is currently the European flagship experiment for WIMP search
- In addition, ongoing detector R&D has to be pursued
- XENON/DARWIN and LUX-ZEPLIN collaborations have signed a common MoU <https://arxiv.org/abs/2203.02309> (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 masses \ll mSM particles gives access to higher mass scales (See-Saw)
- ν is the first hot “dark” particle and has a role in various stages of the Universe
- Needs (European) infrastructures for Underground Science

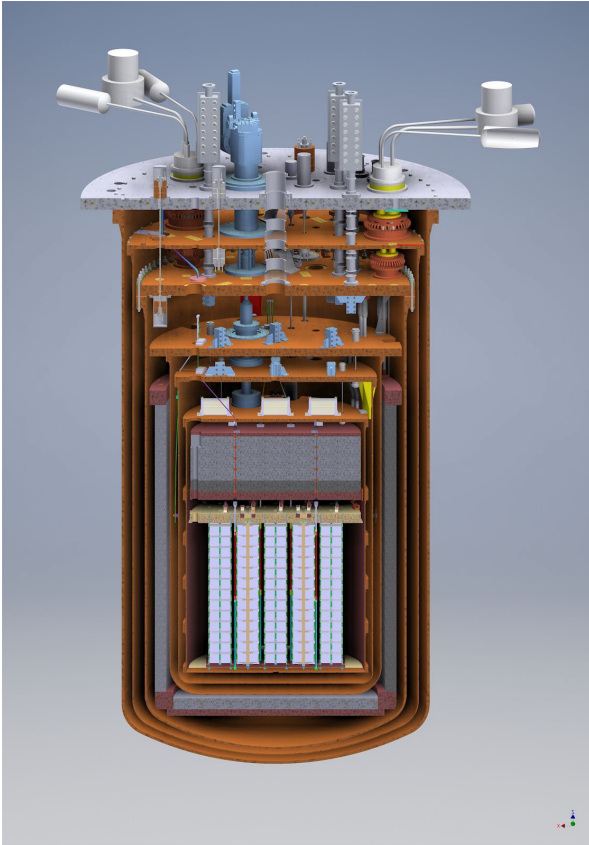
Science has large overlap with neighboring fields



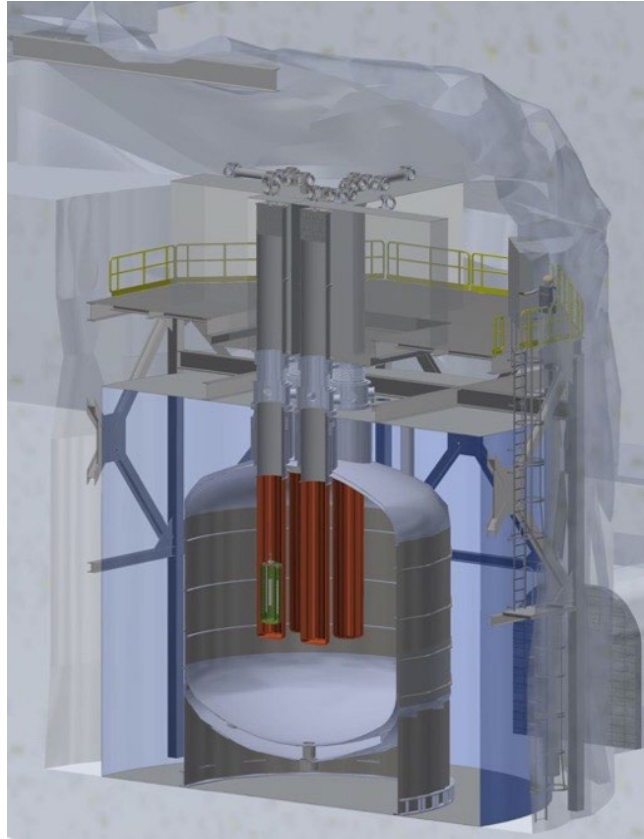
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$0\nu\beta\beta$ decay: towards ton-scale experiment

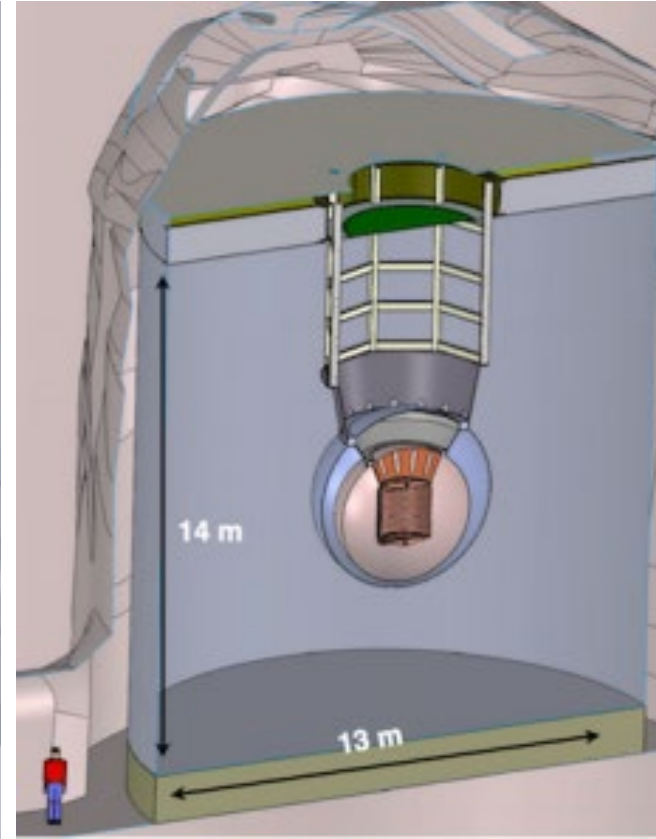
CUPID (100 Mo)



LEGEND-1000 (Ge)



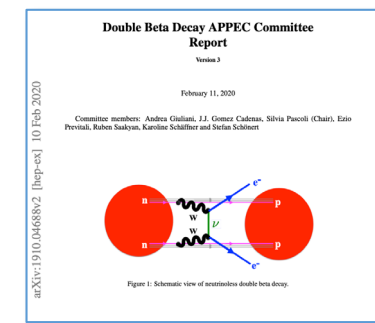
nEXO (136 Xe)



NEXT (136 Xe)



Neutrinoless Double Beta Decay



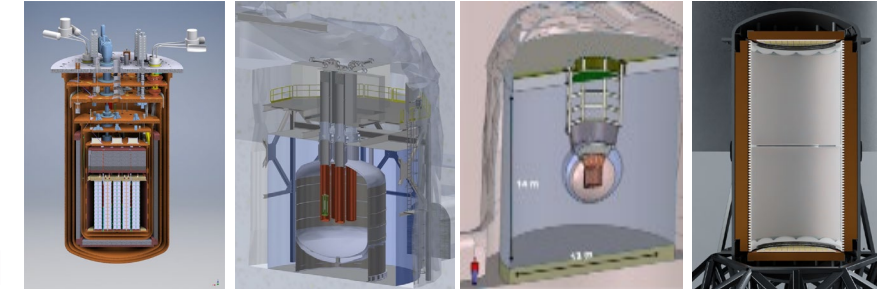
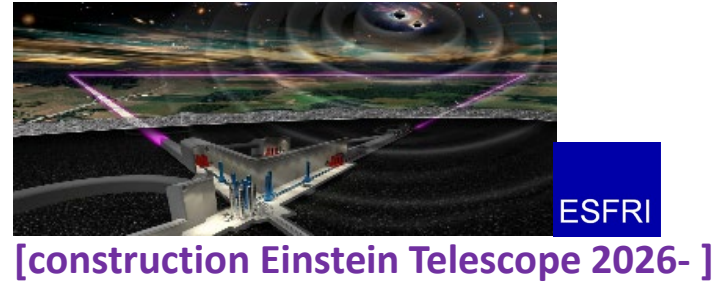
Strategy (Status early 2022):

- 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...

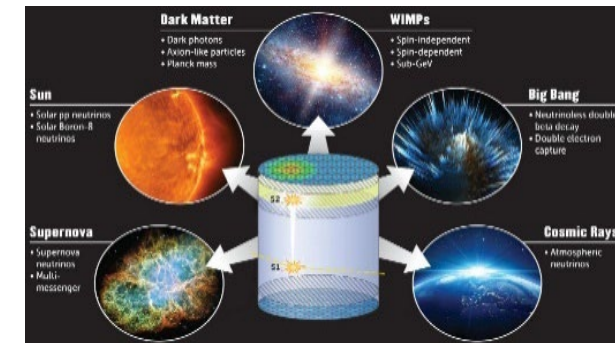
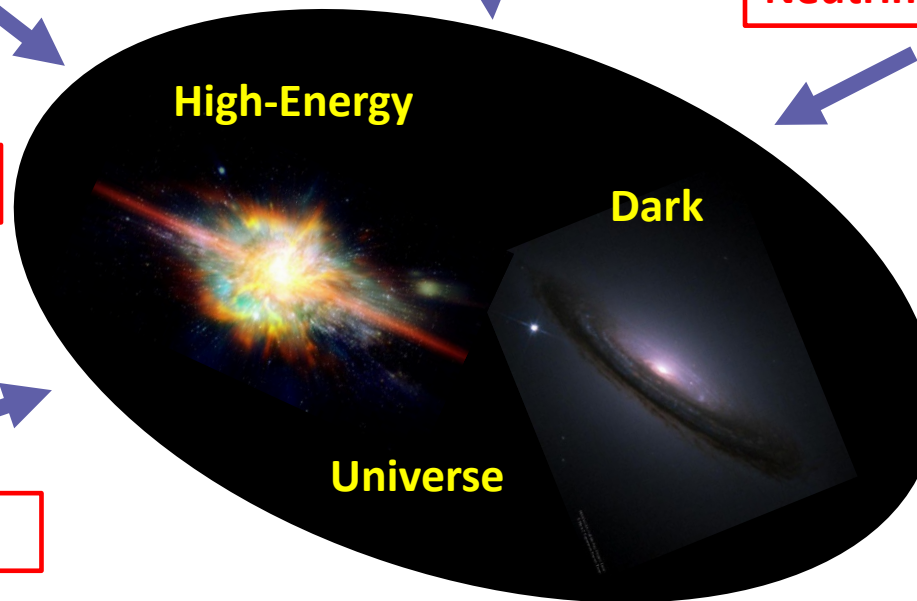
[construction KM3NeT 2020-2026; IceCube-Gen2]



[construction AugerPrime 2019-2023]



[construction CTA 2021-]

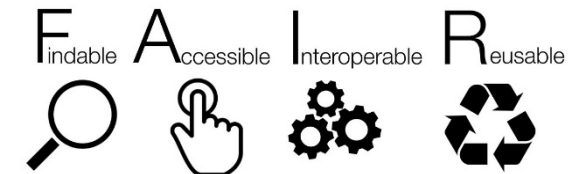


[construction DARWIN 2024- ; XLZD, ARGO, ...]

Dark Matter

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
- Horizon Europe
 - European and global collaboration and coordination, e.g. INFRA-SERV-2023



- Theory ! Further empower EuCAPT ?
- Theory <-> experiment connection important, when to share experimental data with theorists ?
- Computing ! Analysis tools (machine learning)
- Specifically highlighting multi-probe was widely endorsed
- Inclusion of community subjects: ecological impact, societal impact, open science and citizen science, and human talent management, was also widely appreciated
- Demand for better connect/coordinate with astronomy:
JENAA (ECFA+NuPECC+APPEC) works well,
also forge co-operation with European Astronomer (ASTRONET ?)
- Start with the “how we want to work” before the “what we want to do” ?
- Easier prioritization: decouple what need substantial European funding from what does not

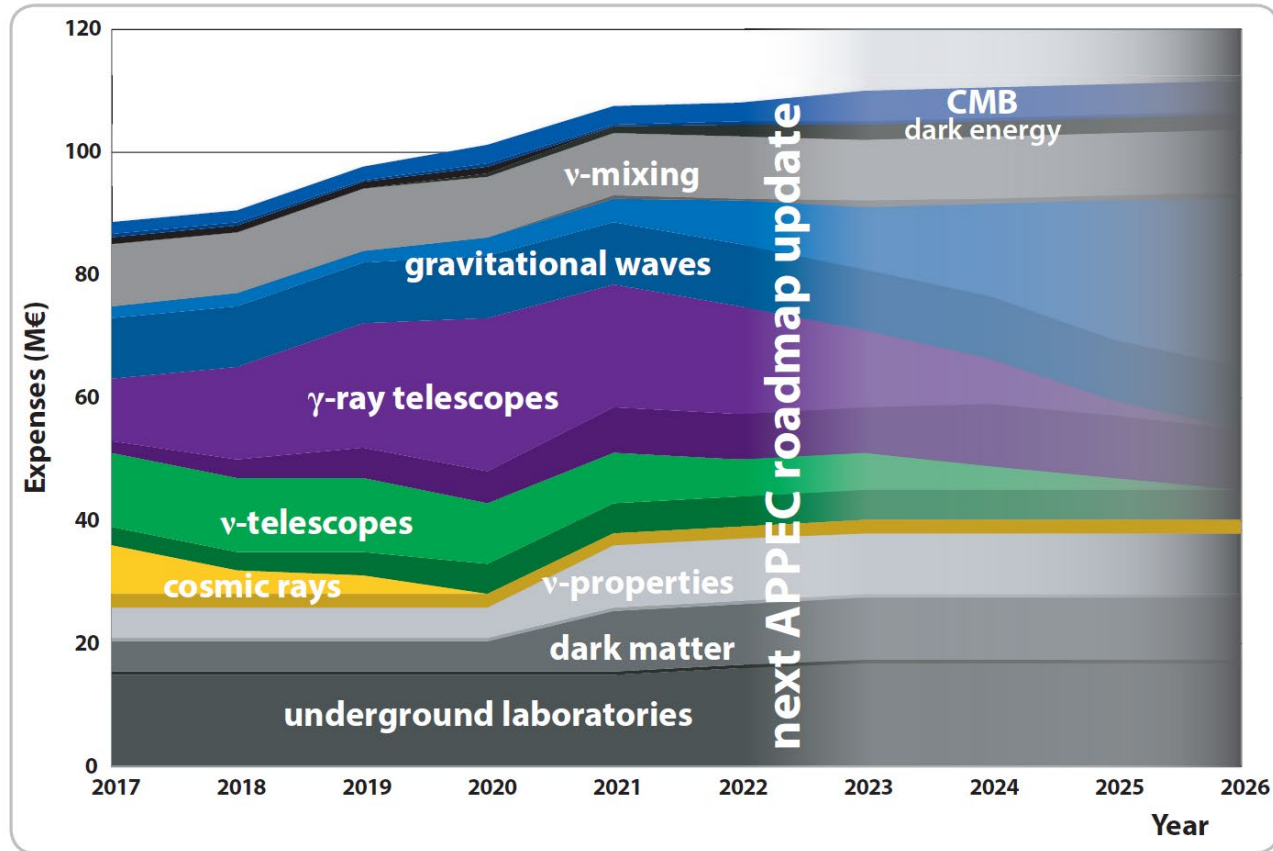
Elements of the strategy update

Summary of Town Meeting (S. de Jong)



- Broad consensus that most of the current strategy still ok
 - “Normal” updates as time goes on
- Strong support for including “community” topics – even urges to start the update with it
- Broad support for some change of course:
 - Merging neutrino properties section
 - Prominent place for multi-probe/multi-messenger
 - Need mechanisms for alerts and data exchange
 - Experiment data access by theorists: something to think about more
 - As much interest in the “how” compared to the “what”, think about “moving it up”
 - Make theory more prominent
 - Enhance visibility of computing

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

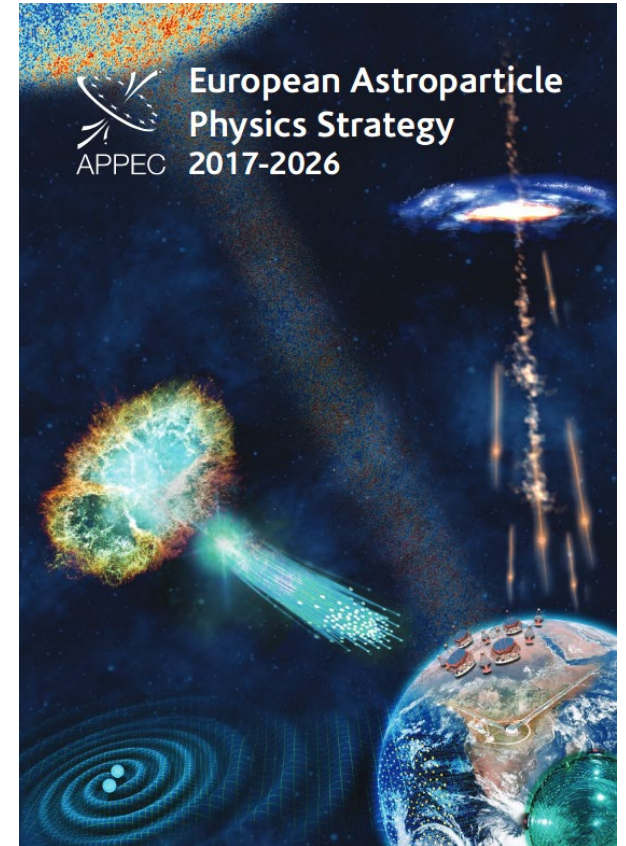
Summary



- 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 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!