APPEC

Astroparticle Physics European Consortium

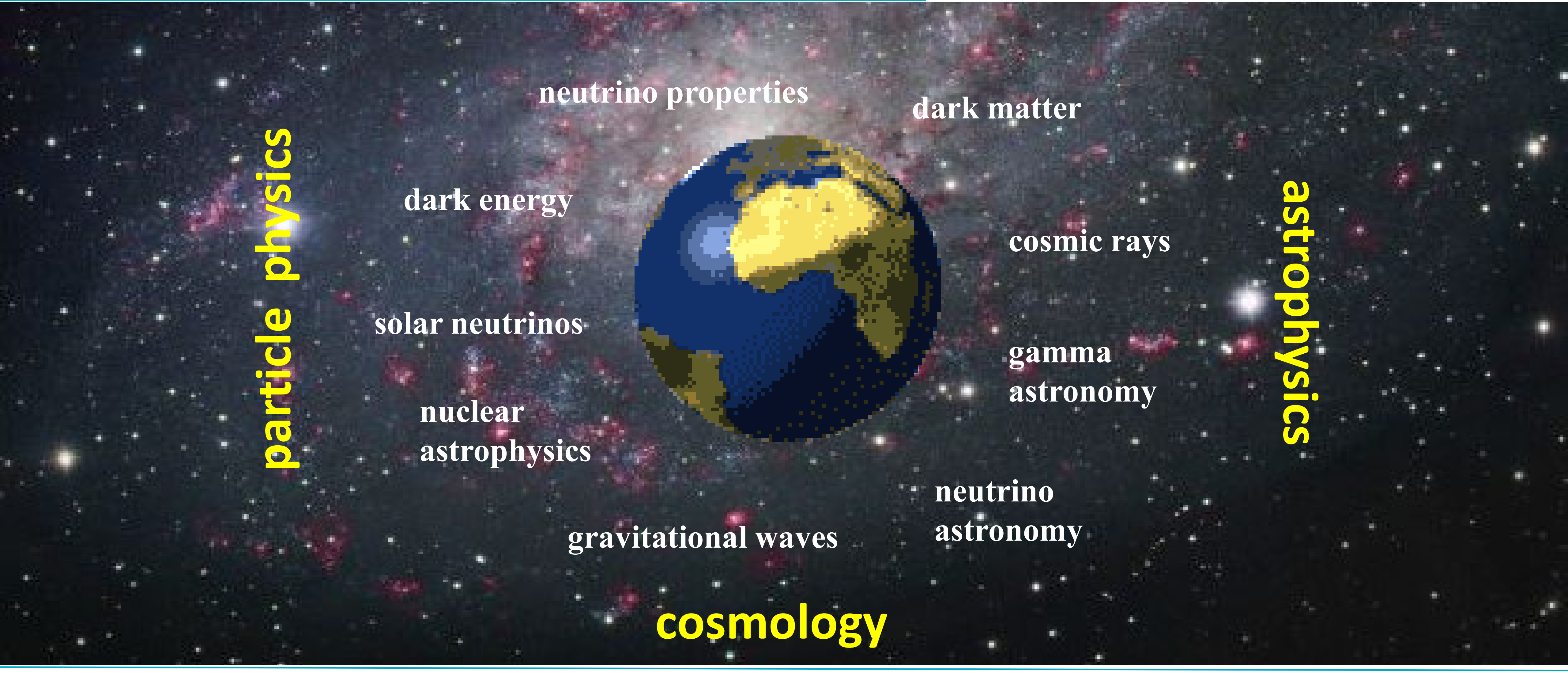
Perspectives in Astroparticle Physics

A European View

Andreas Haungs | KIT – Institute for Astroparticle Physics

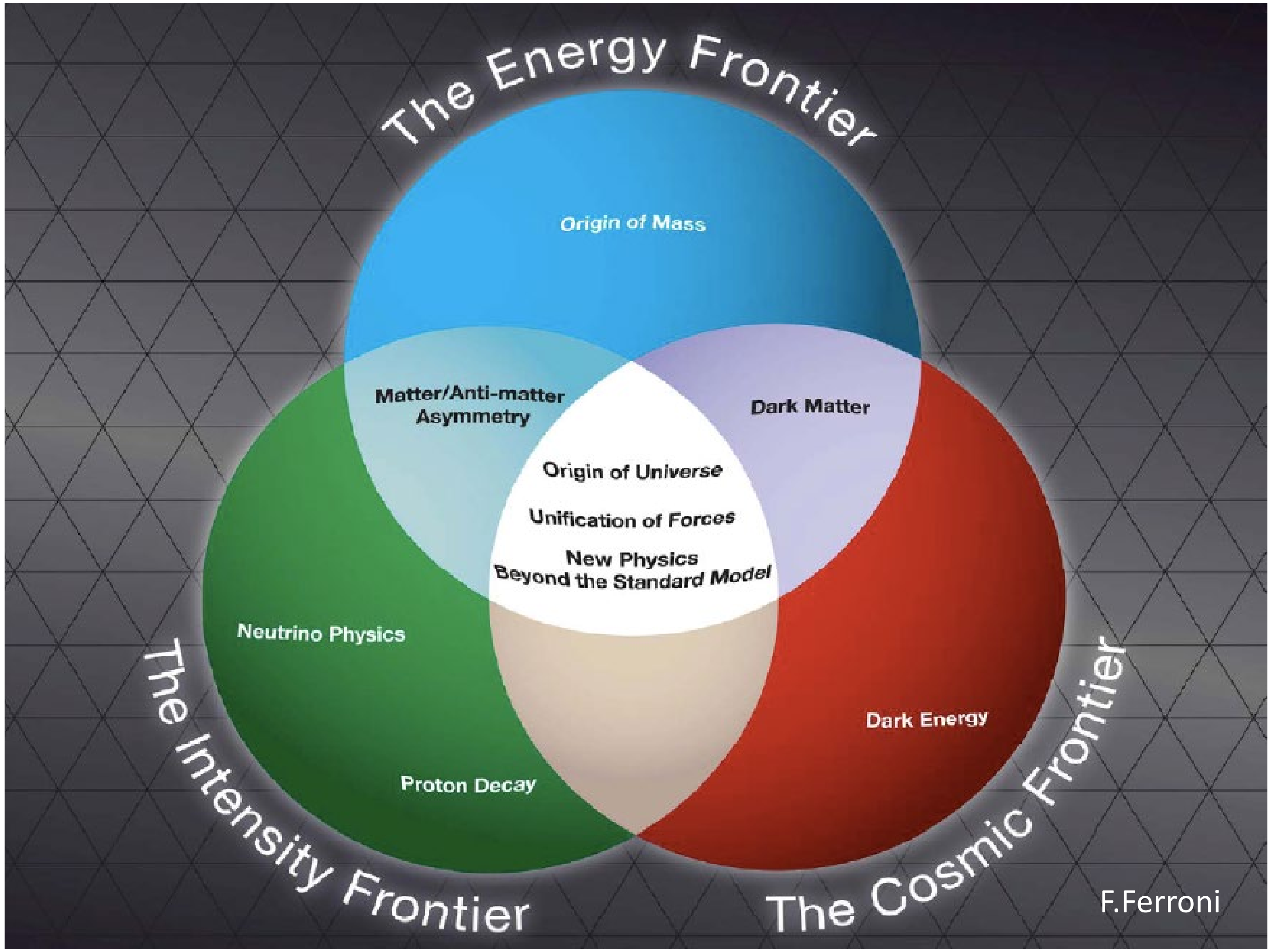
The Paris Saclay Astroparticle Symposium | Institut Pascal | 28 October 2021

Astroparticle Physics



Astroparticle Physics

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



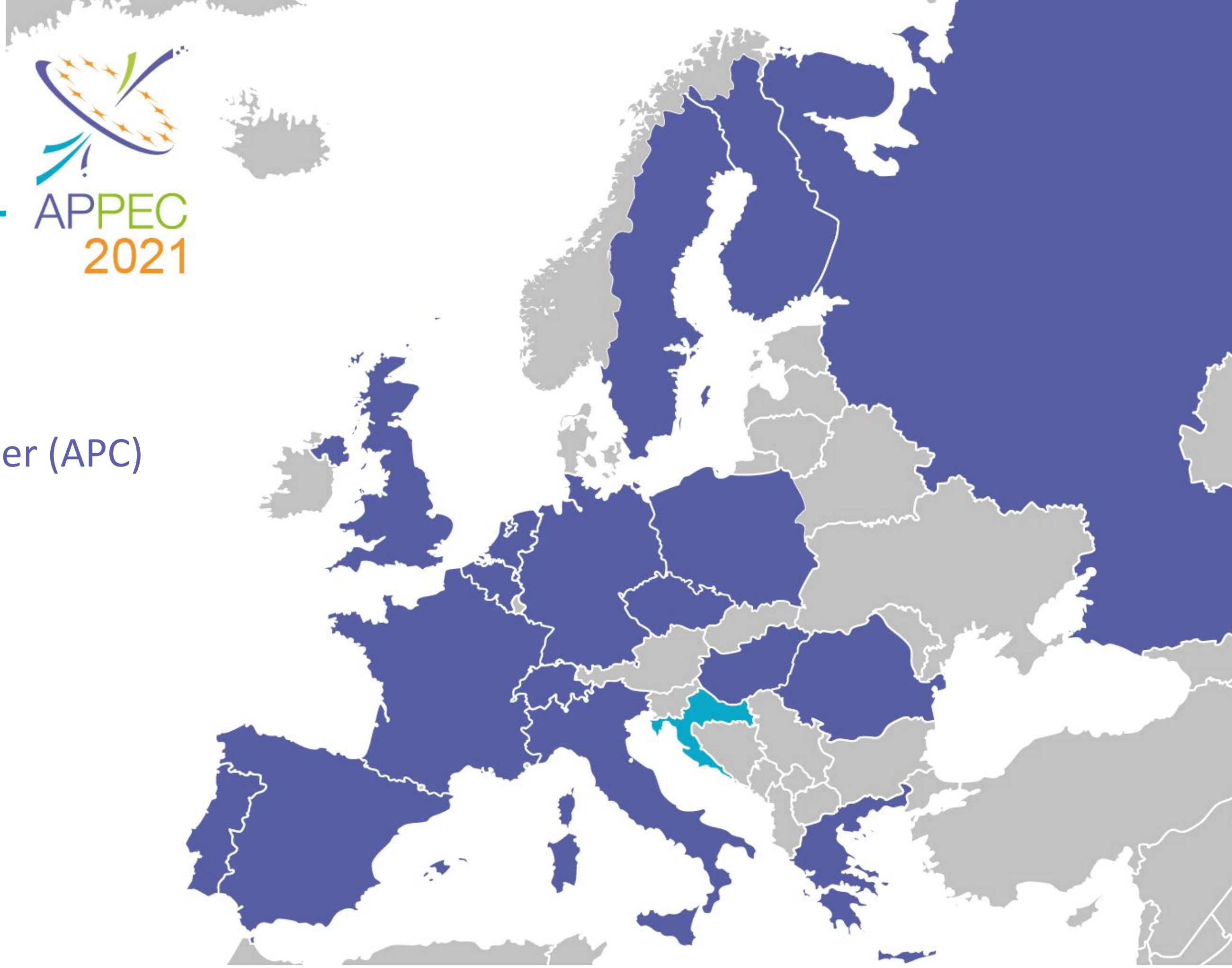
Wikipedia:
While it may be difficult to decide on a standard 'textbook' description of the field of astroparticle physics, the field can be characterized by the topics of research that are actively being pursued.

APPEC

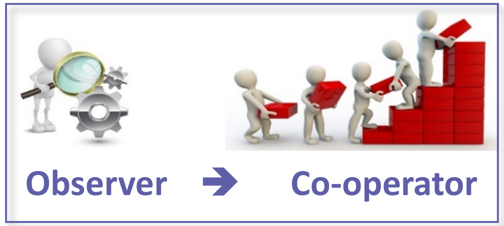
- Is the **A**stro**P**article **P**hysics **E**uropean **C**onsortium
- An international coordinating structure
- Founded in 2012
- Is based on
  - a Memorandum of Understanding (MoU)
  - a Financial Agreement with DESY (host of the APPEC Common Fund) by all partners
- Has at the moment
  - 17 member countries and 21 funding agencies
  - a budget of 70k€/a

www.appec.org

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);
  - Vice-Chair: Silvia Pascoli (Durham)
- **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 (Colin Vincent)
  - ESO (Andy Williams)



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
- 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 community


APPEC General Assembly 2016

APPEC Roadmaps

https://www.appec.org/roadmap

2008

1) What is the Universe made of ?
   In particular: What is dark matter?

2) Do protons have a finite life time?

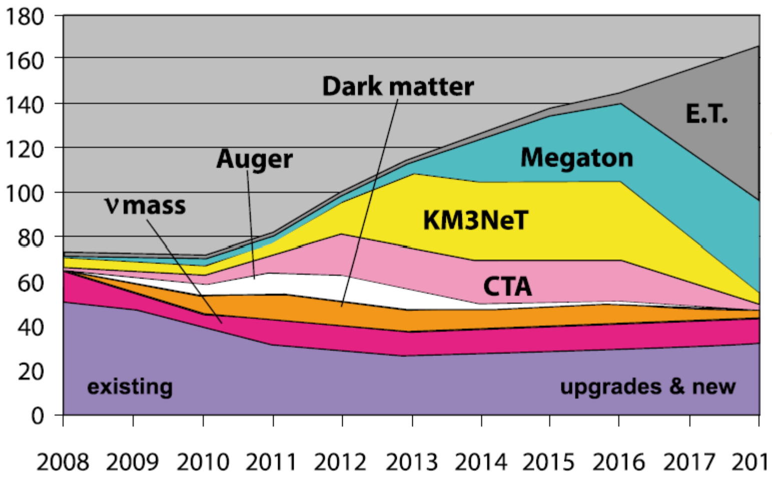
3) What are the properties of neutrinos?
   What is their role in cosmic evolution?

4) What do neutrinos tell us about the interior of the Sun and the Earth, and about supernova explosions?

5) What is the origin of cosmic rays?
   What is the view of the sky at extreme energies?

6) What will gravitational waves tell us about violent cosmic processes and about the nature of gravity?

2008: The six questions of Astroparticle Physics and faccilities to attack them:

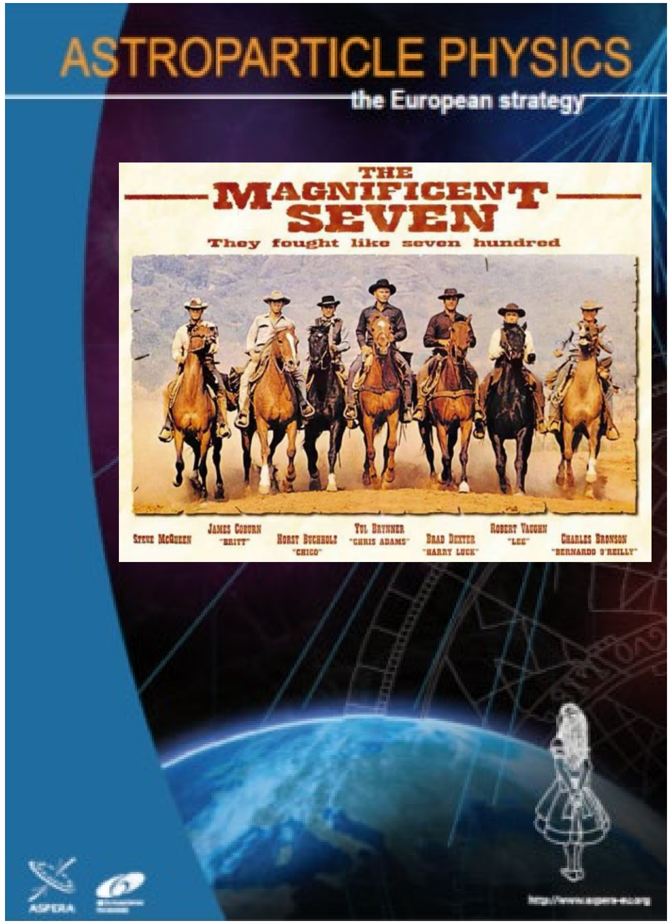


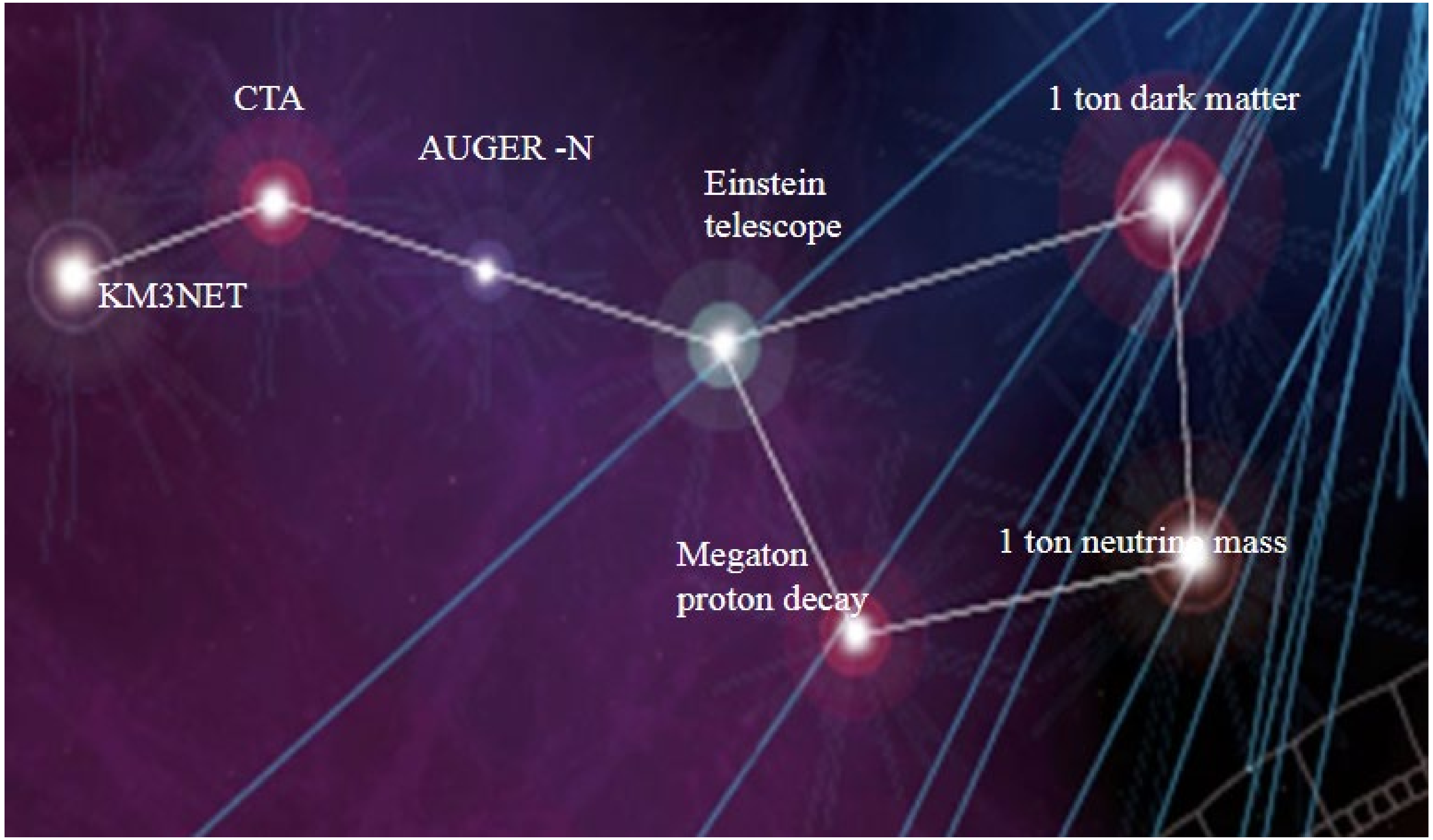
APPEC Roadmaps

https://www.appec.org/roadmap

2008

The Magnificent Seven



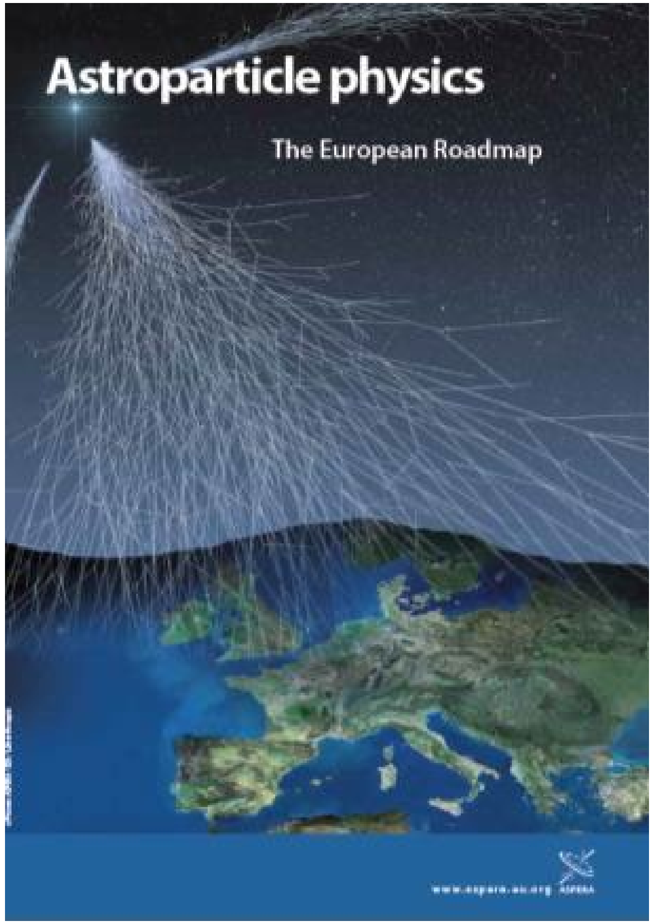


APPEC Roadmaps

https://www.appec.org/roadmap

2008

2011

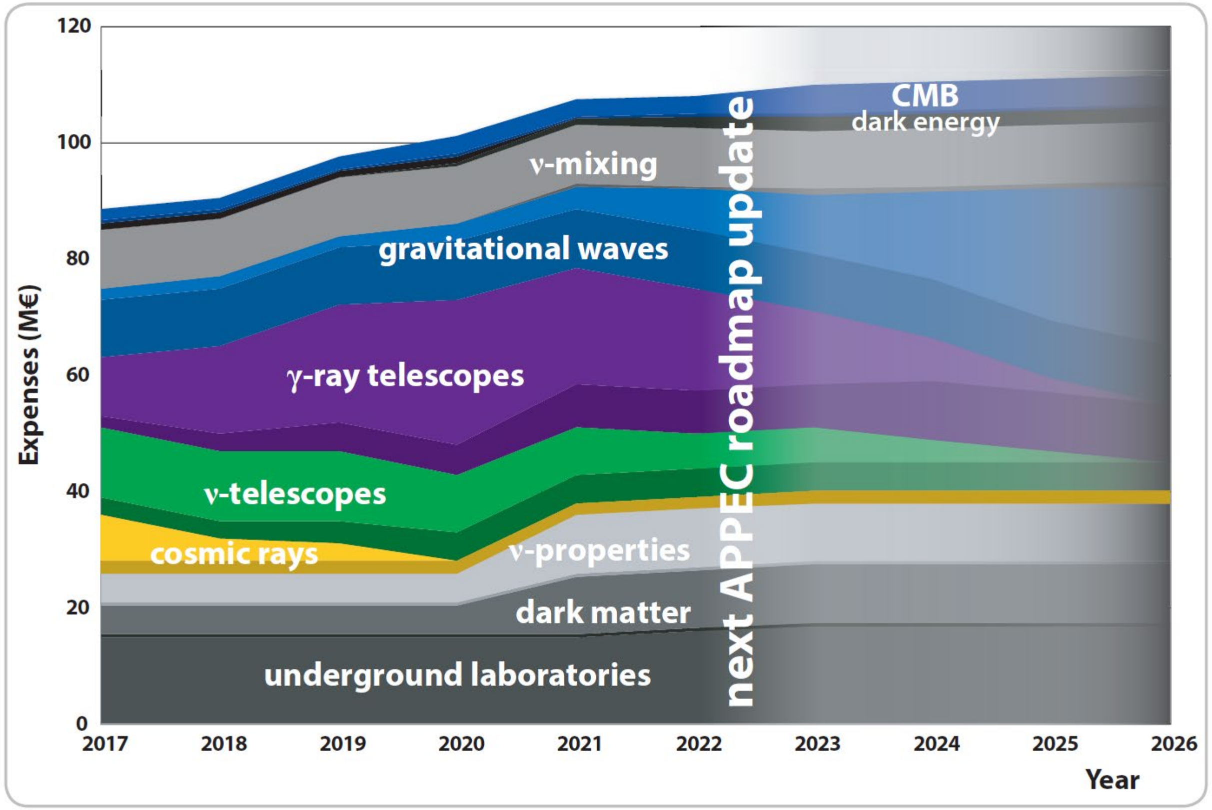


2017

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 hierarchy
- Cosmic microwave background
- Dark Energy
- Astroparticle theory
- Detector R&D
- Computing and data policies
- Unique infrastructures

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: Preparation of the roadmap update
- Direct Dark Matter working group
- Double Beta Decay APPEC Sub-Committee
- Multi-Messenger Discussion Workshop
- Support ESFRI projects (e.g. for Einstein Telescope)
- Goals
  - Identify new developments and new topics
  - Update recommendations
- Timeline
  - Provide information to the communities (2021)
  - Discussion at the Town Meeting 9+10/6/2022 (Berlin)

APPEC scientific topics

Disclaimer:

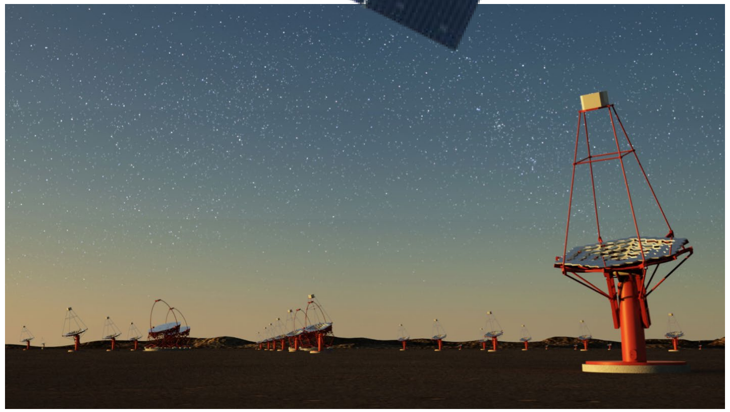
- I am not covering everything
- I am not an expert in all fields
- I will focus on main considerations from point of view of APPEC
- I report about an intermediate status of ongoing discussions
- Not all figures are fully referenced, but all are public available (thanks to all)

High-Energy Gamma Rays

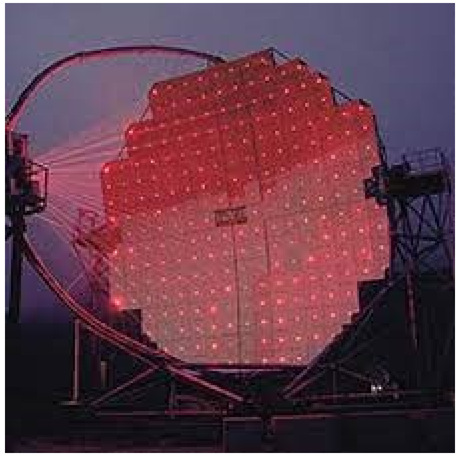
- Covers large energy range with different observatories
- Satellites (Fermi, AMEGO (launch 2029))
- Imaging Air Cherenkov Telescopes (H.E.S.S., Veritas, MAGIC)
- Ground-based arrays (GRAPES, TAIGA, HAWC, **LHAASO**, SWGO)
- APPEC's main future project: CTA

FERMI

VERITAS



MAGIC



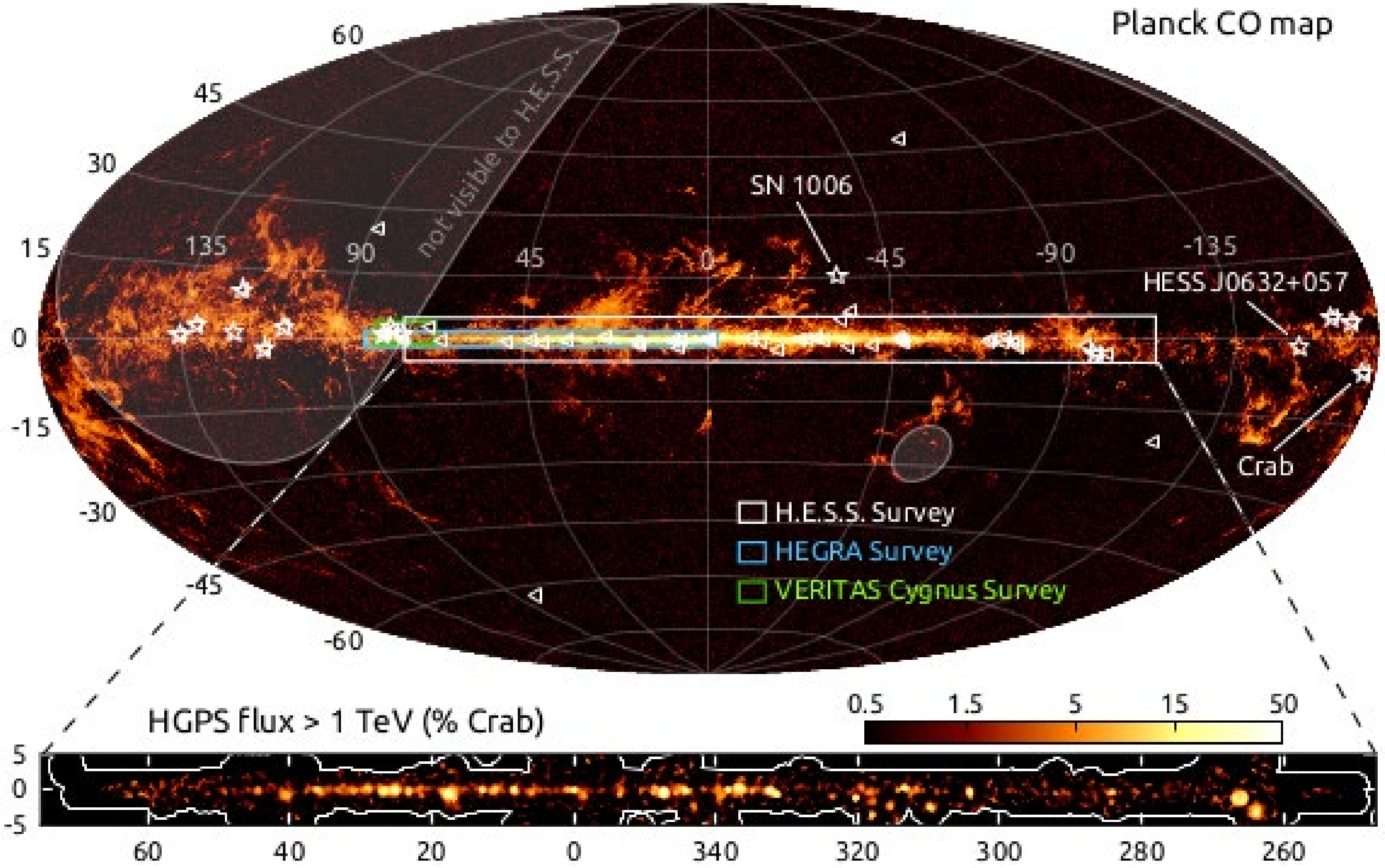
H.E.S.S.

LHAASO

HAWC

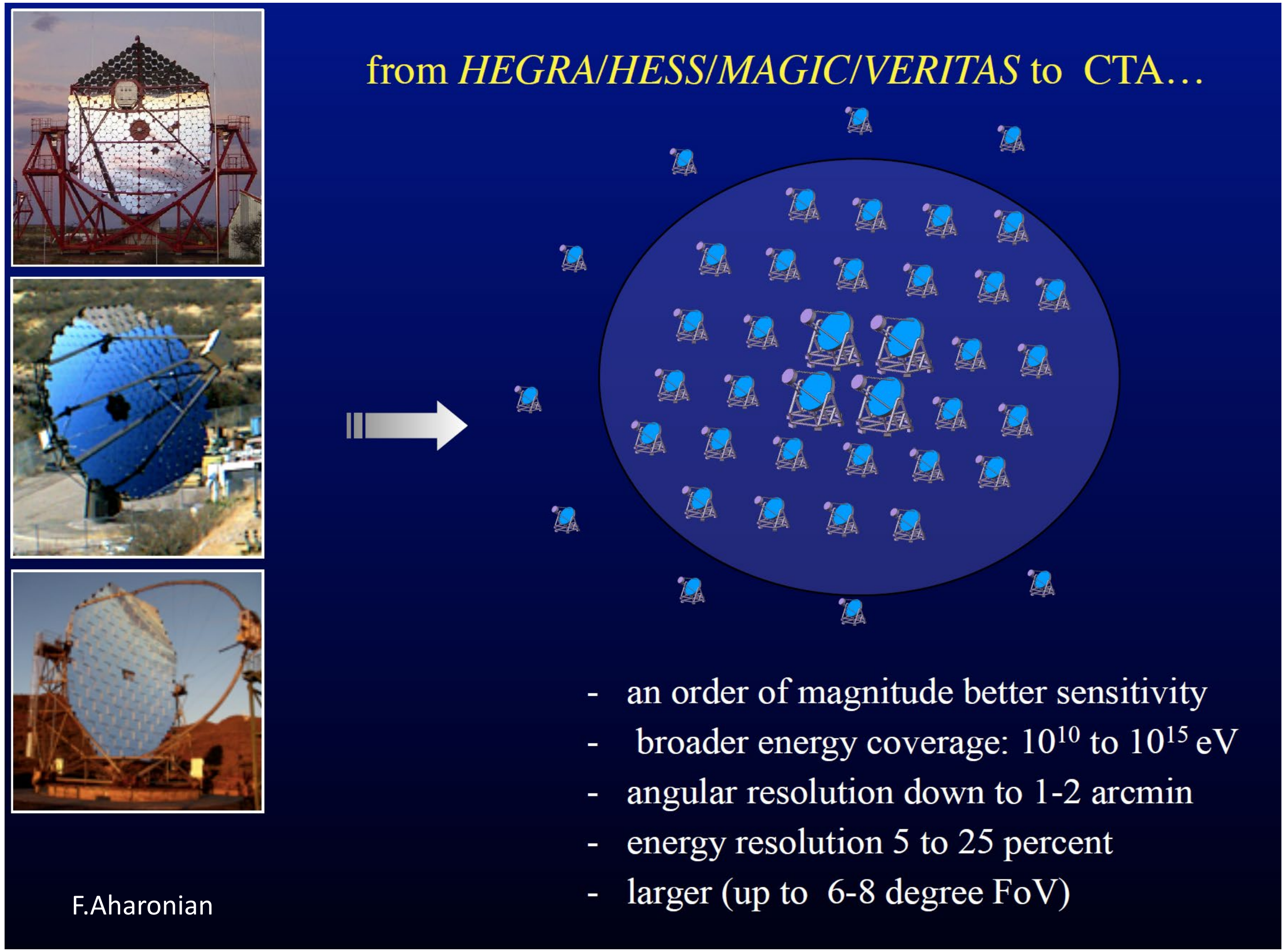
High-Energy Gamma Rays

- Large number of sources identified as well as found as unidentified



H.E.S.S. Collaboration

High-Energy Gamma Rays

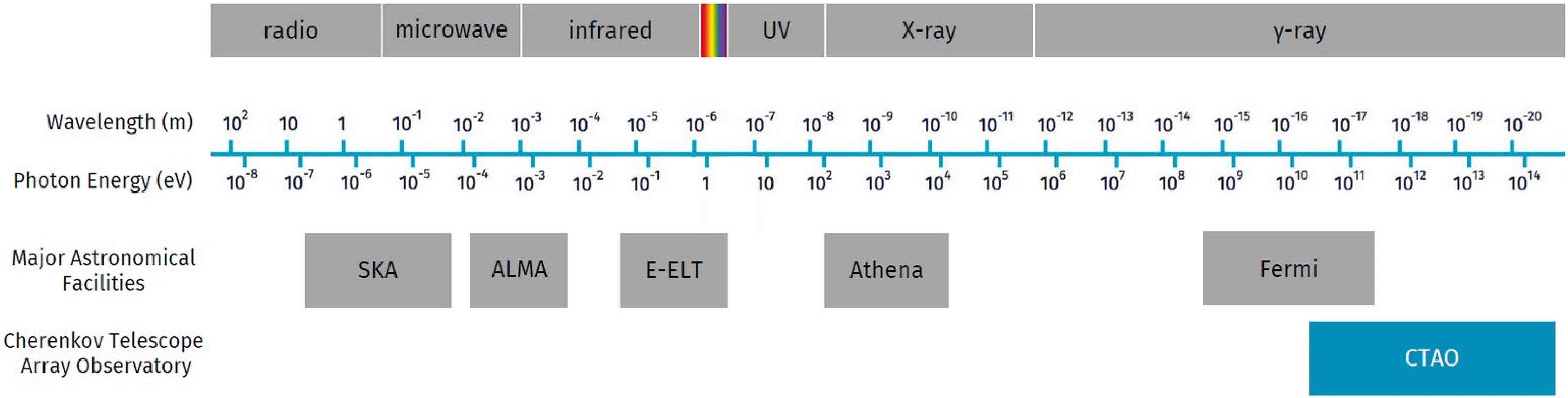


High-Energy Gamma Rays

CTA has impressive science program:

- **Understanding of the origin of the cosmic rays** in a multi-messenger context;
- **Probing extreme environments,** such as neutron stars and pulsar wind nebulae, black holes and gamma-ray bursts, the physics of jets and how particles are accelerated by them;
- **The Galactic plane Survey** ~100 times faster than current generation IACT;
- **Exploring frontiers in physics**, such as the nature of Dark Matter in the Galactic Centre, axions and their interplay with magnetic fields and photons, the extragalactic background light and how it informs on galaxy formation, and quantum gravity effects in photon propagation.

High-Energy Gamma Rays

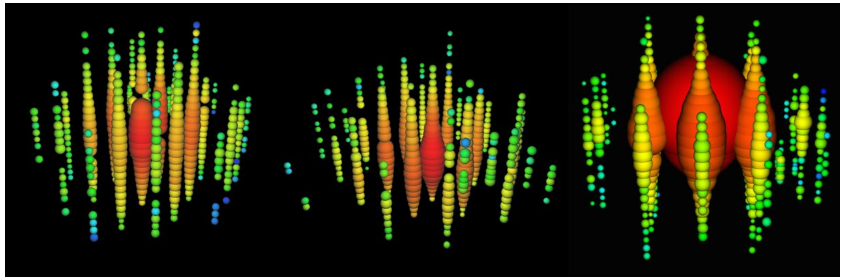


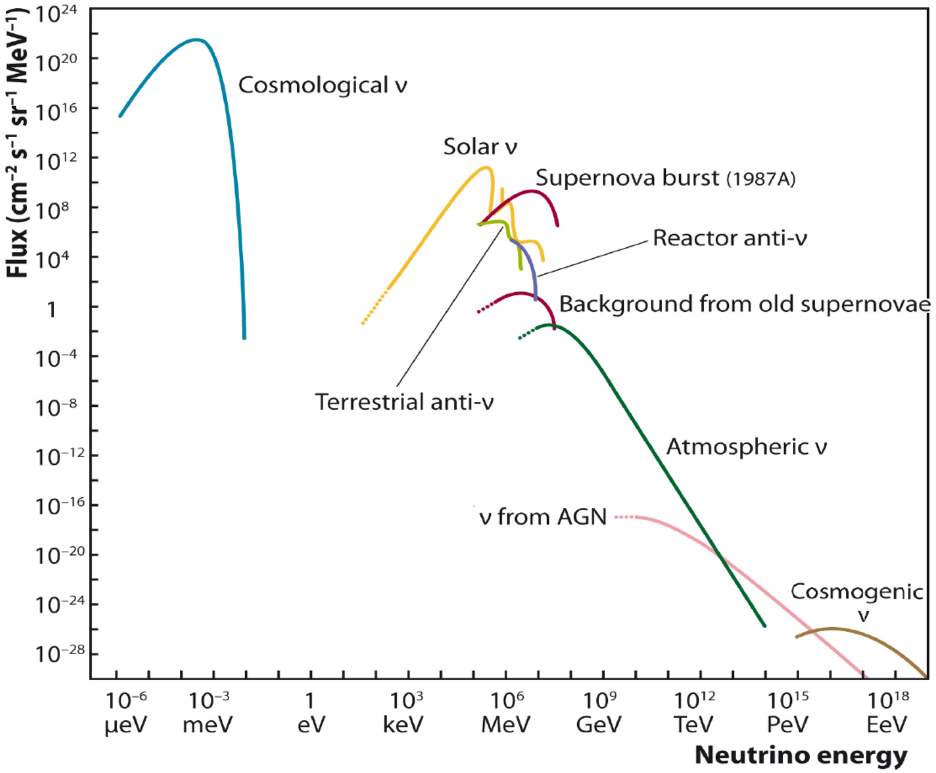
Comparison of CTAO’s Energy Range to other Instruments

- Multiwavelength Observations means large cooperation between Astroparticle Physics and Observational Astronomy

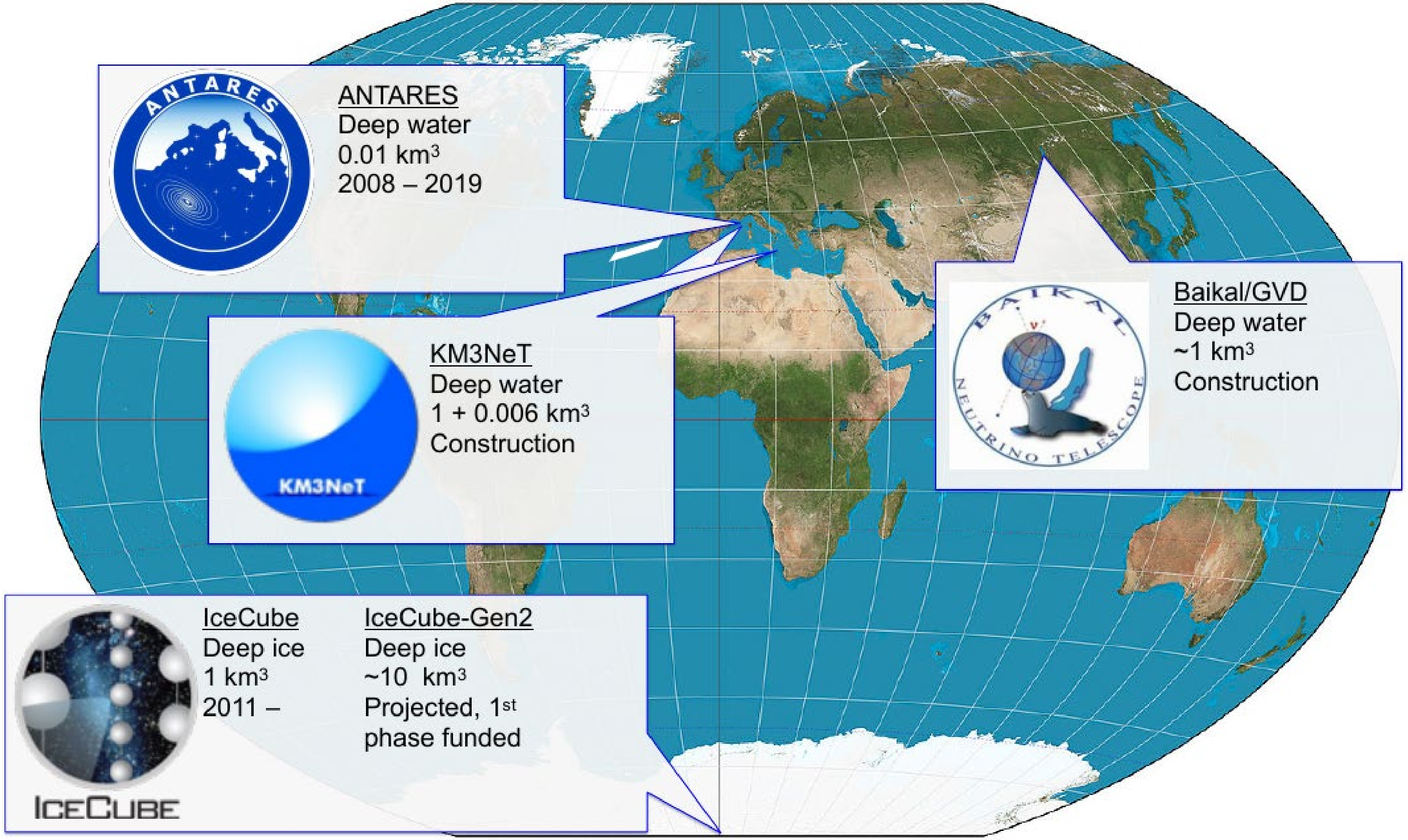
High-Energy Neutrino Astronomy

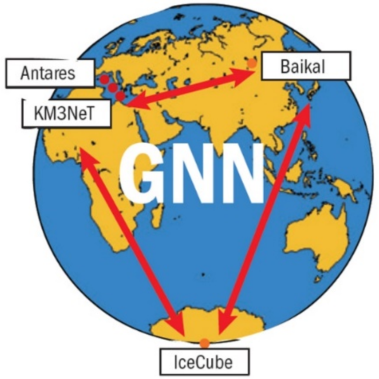
- IceCube opened 2013 the new window of PeV neutrino astronomy
- Several experiments are now organized in the Global Neutrino Network GNN:
  - IceCube ➔ IceCube-Gen2
  - Antares ➔ KM3NeT
  - Baikal-GVD
- R&D phase: P-ONE, RNO-G, POEMMA, ANITA, GRAND, …)
- European flagship (ESFRI): KM3NeT
- Strong partner of US lead IceCube-Gen2



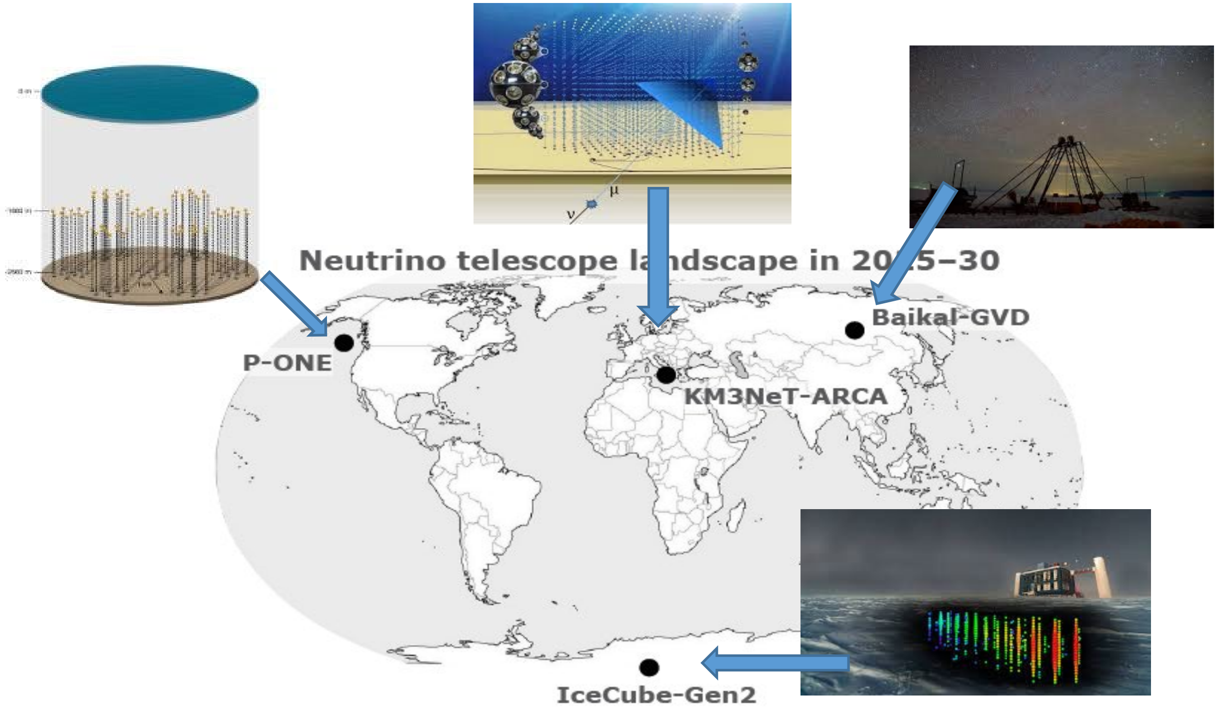


High-Energy Neutrino Astronomy





High-Energy Neutrino Astronomy



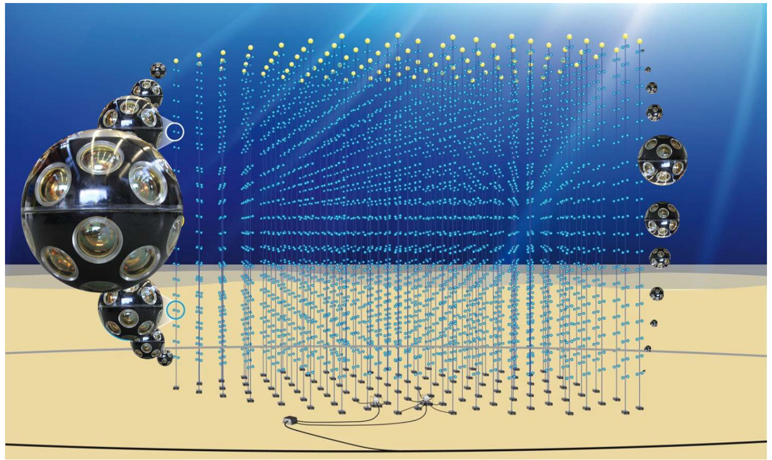
EeV Neutrinos:

- **IceCube-Gen2** (in-ice radio detector); South Pole; completion in early 2030s
- **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 ~8 x IceCube
2. **KM3NeT** (underwater detector); completion in 2026; sensitivity of IceCube, complementary in sky coverage
3. **GVD** (underwater detector); completion in 2024; less sensitive
4. **P-ONE** (underwater detector); new initiative; could reach similar sensitivity as IceCube or KM3NeT

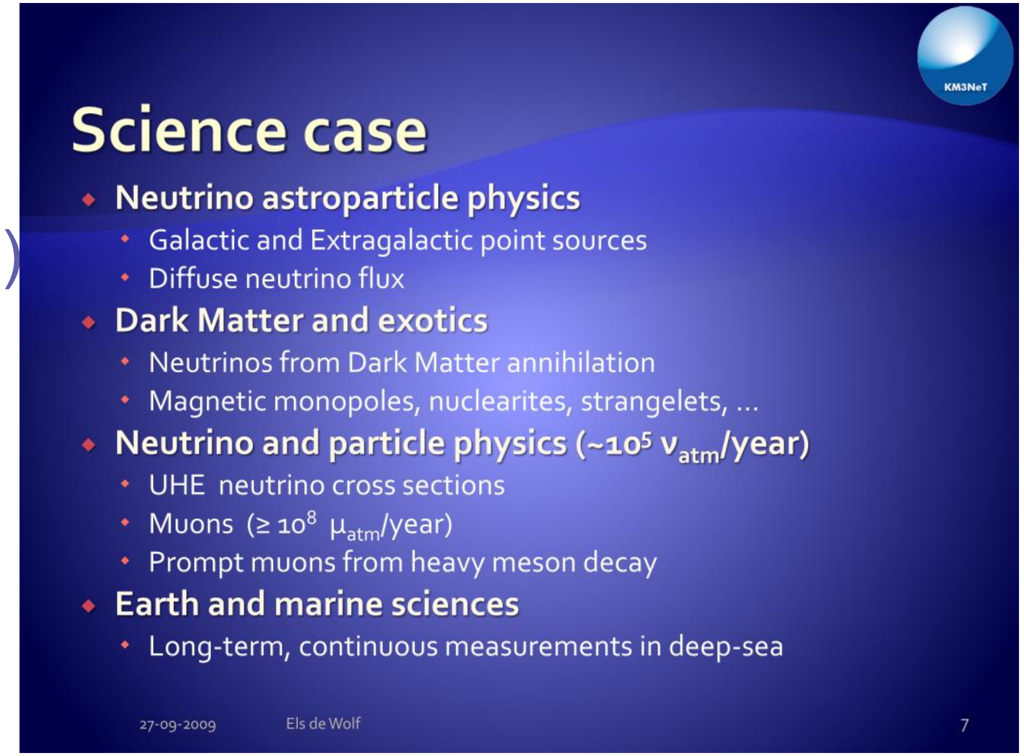
High-Energy Neutrino Astronomy



- 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



High-Energy Neutrino Astronomy

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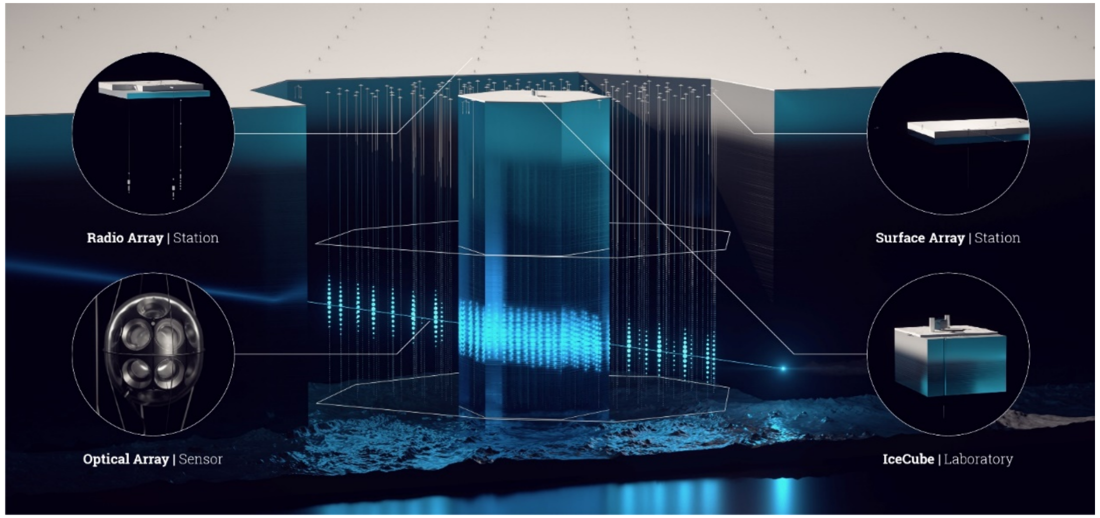
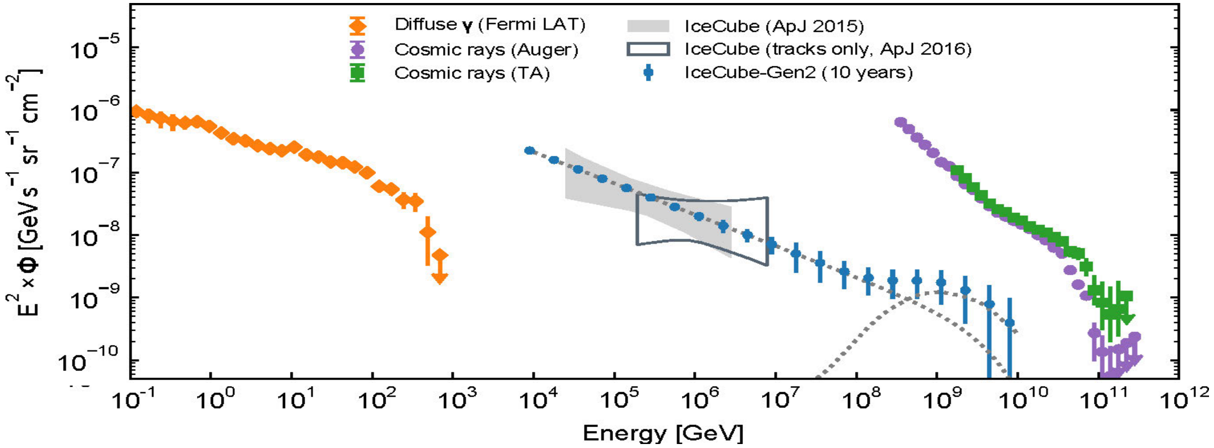
IceCube-Gen2:

- Search for Point Sources
- Galactic Supernova
- Neutrino Oscillations
- Sterile Neutrinos
- Indirect Dark Matter Search
- High-energy Cosmic Rays 100 TeV – 1 EeV

➔ Deployment planned for 2024-32

ICECUBE GEN2



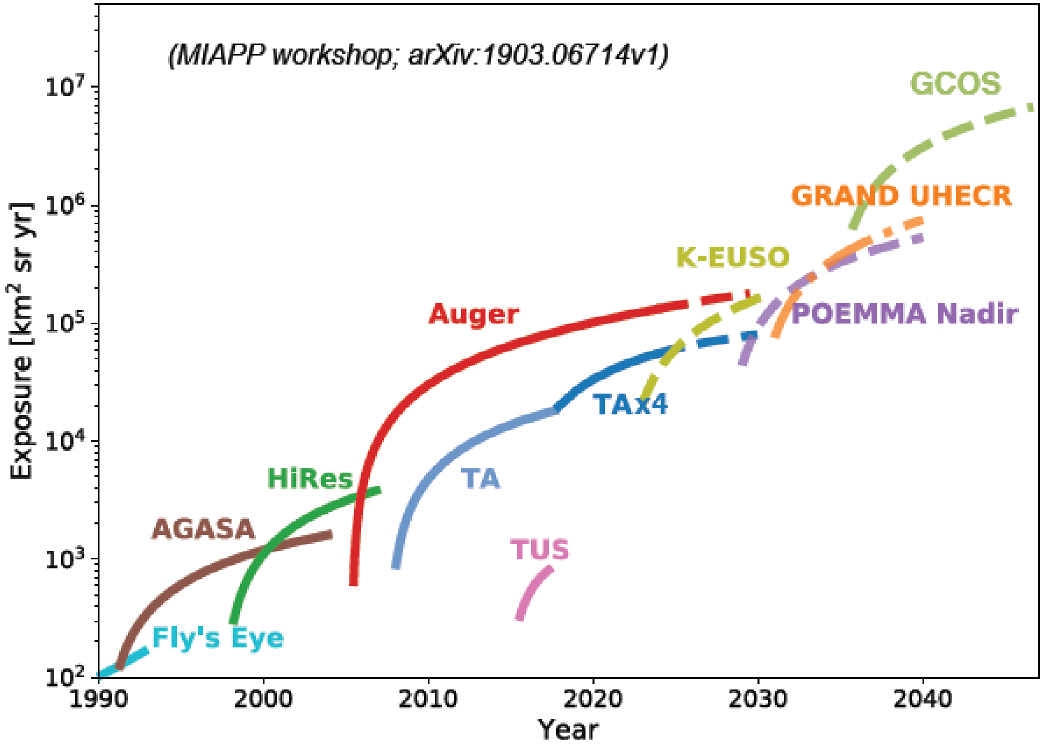


KIT Karlsruhe Institute of Technology

High-Energy Cosmic Rays

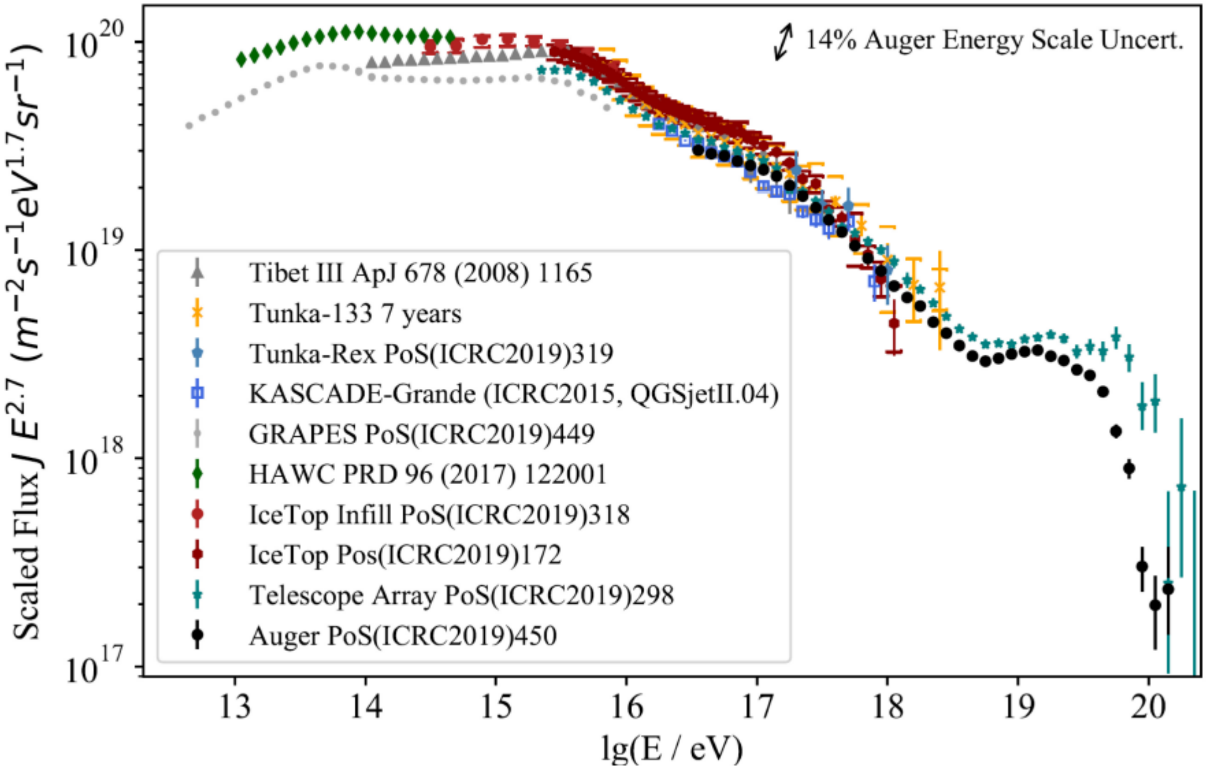
- Accuracy of measurements in all energy ranges increased dramatically in last 2 decades, but still:
  - Transition energy range ?
  - Hadronic Interaction models ?
  - Composition and Anisotropies at all energies?
  - Suppression mechanism?
- Pierre Auger Observatory is major experiment
- Future at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

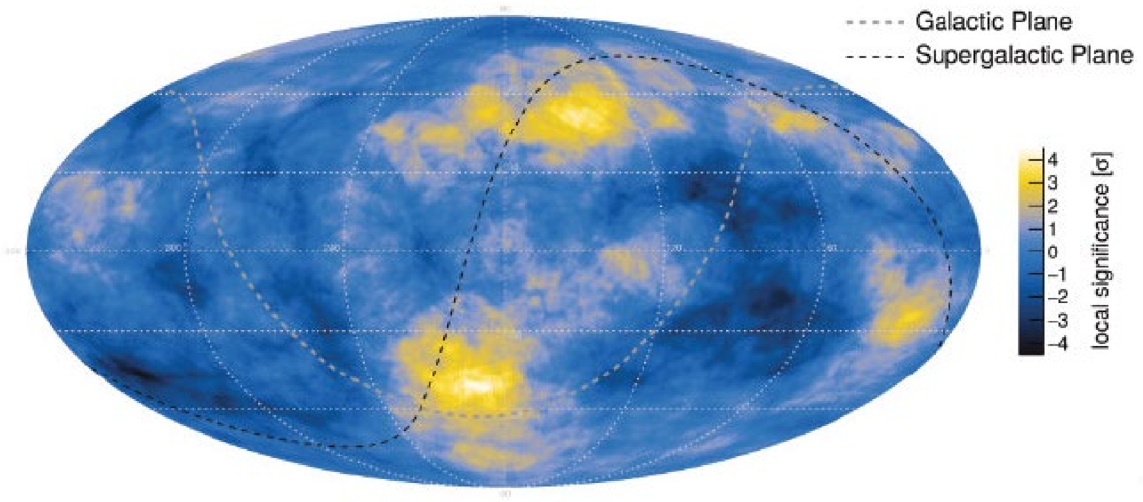
UHECR



High-Energy Cosmic Rays

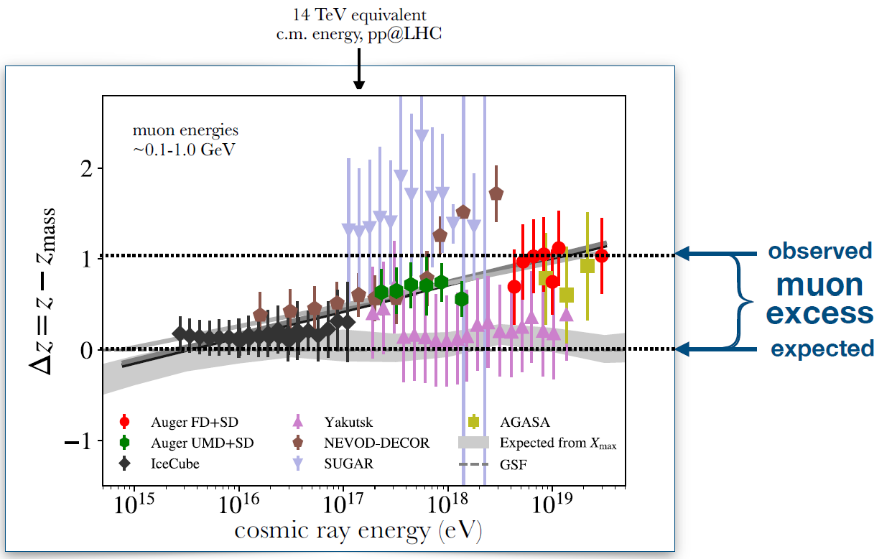
- High statistics and accuracy required for determining energy spectrum, composition, anisotropy over a large energy range
- Combining data of the various projects will help (UHECR working groups!)





(UHECR Auger-TA working group)

High-Energy Cosmic Rays - EAS

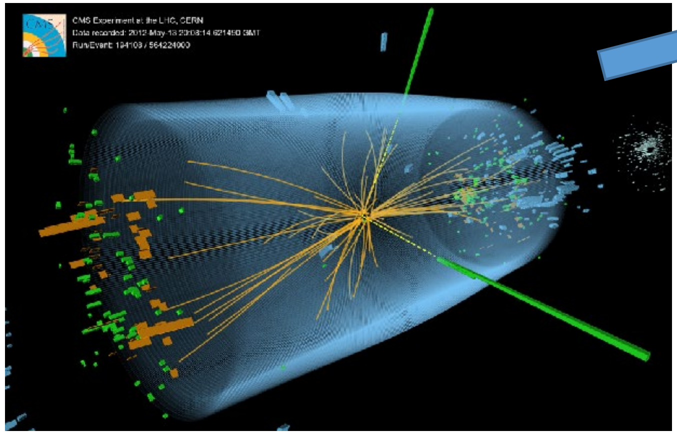


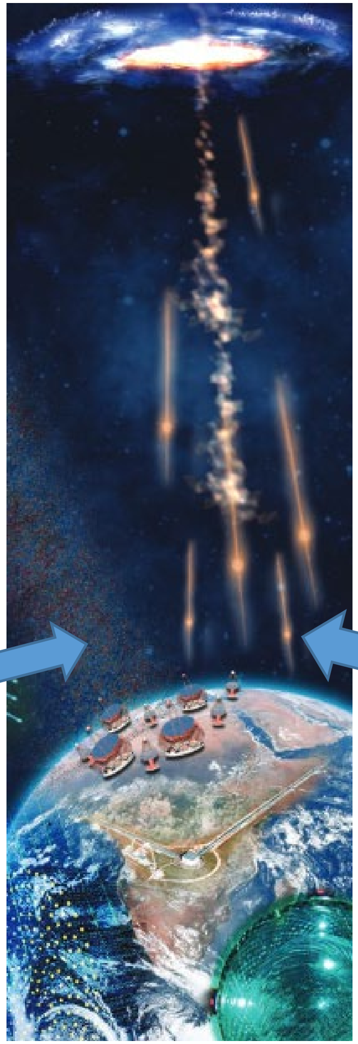
D. Soldin et al., PoS(ICRC2021)349 (2021)

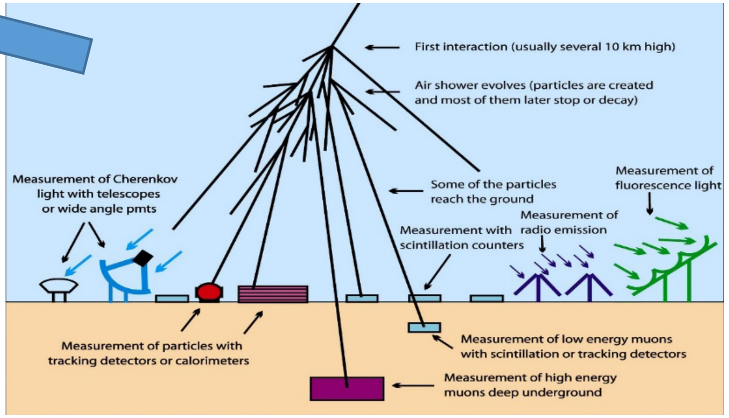
- For each cosmic ray generated extensive air shower (EAS) one needs to reconstruct:

  energy mass arrival direction

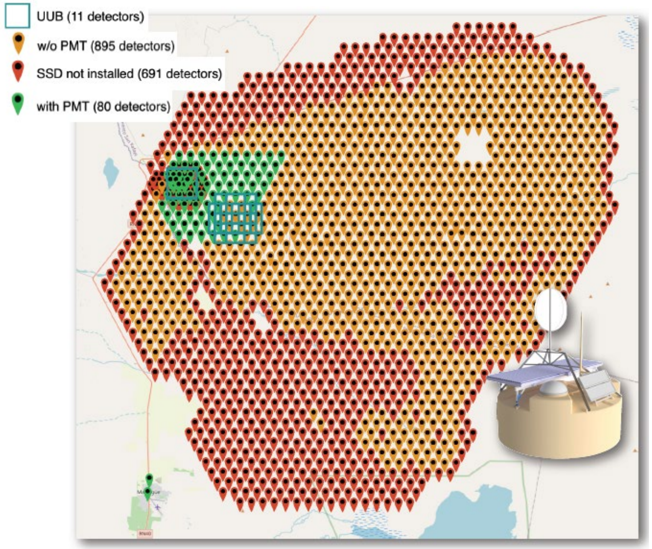
- For this one needs accurately to know the interaction mechanisms
- Here the CORSIKA Monte Carlos simulation tools plays an important role.







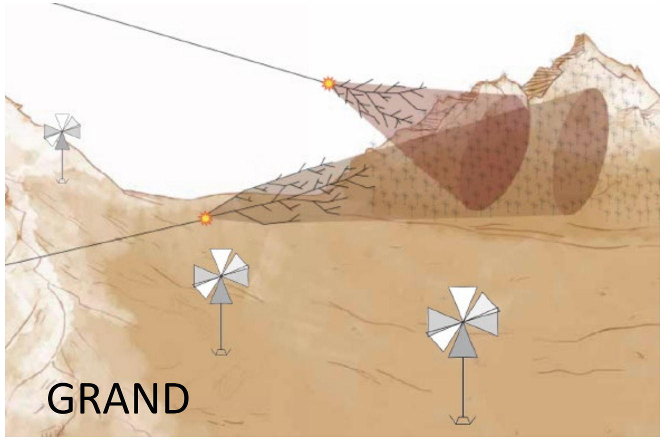
High-Energy Cosmic Rays



Ongoing upgrade AugerPrime
(scintillators and radio antennas)

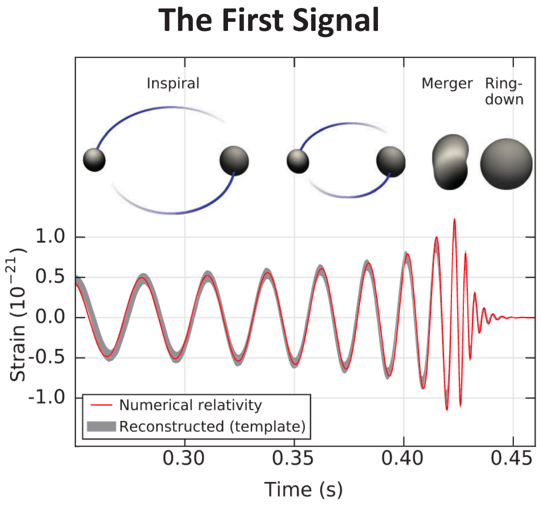
(AugerPrime design report 1604.03637)

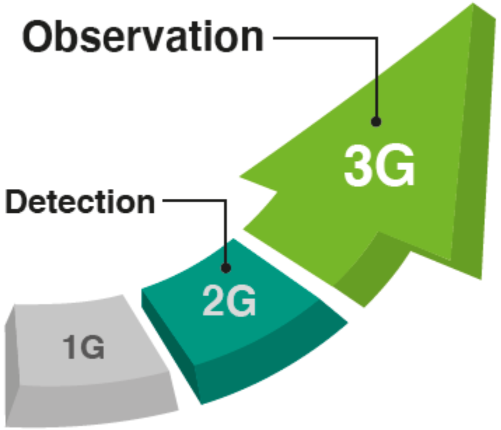
PIERRE AUGER OBSERVATORY

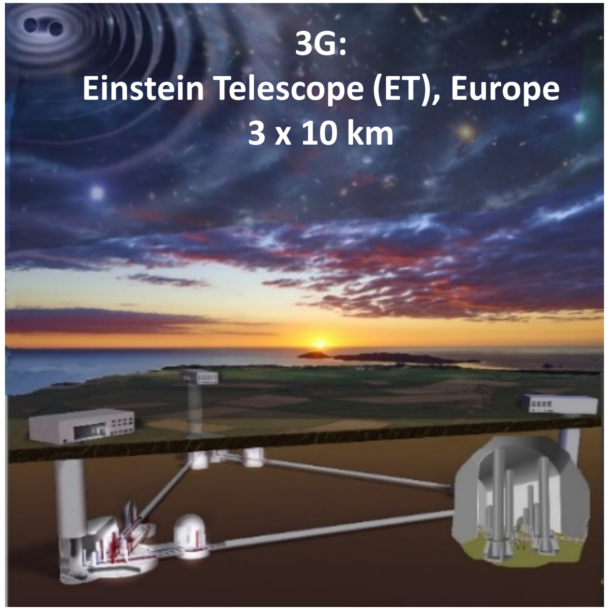


Gravitational Waves

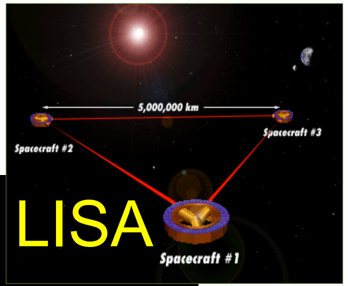
- 2015: First direct detection by LIGO / Virgo
- 2022+: New data taking with improved LIGO and Virgo
- 2030+: 3rd Generation: The Einstein Telescope
- Einstein Telescope is a new large-scale facility in Europe, requiring advanced technologies and enabling a large science program in fundamental physics!



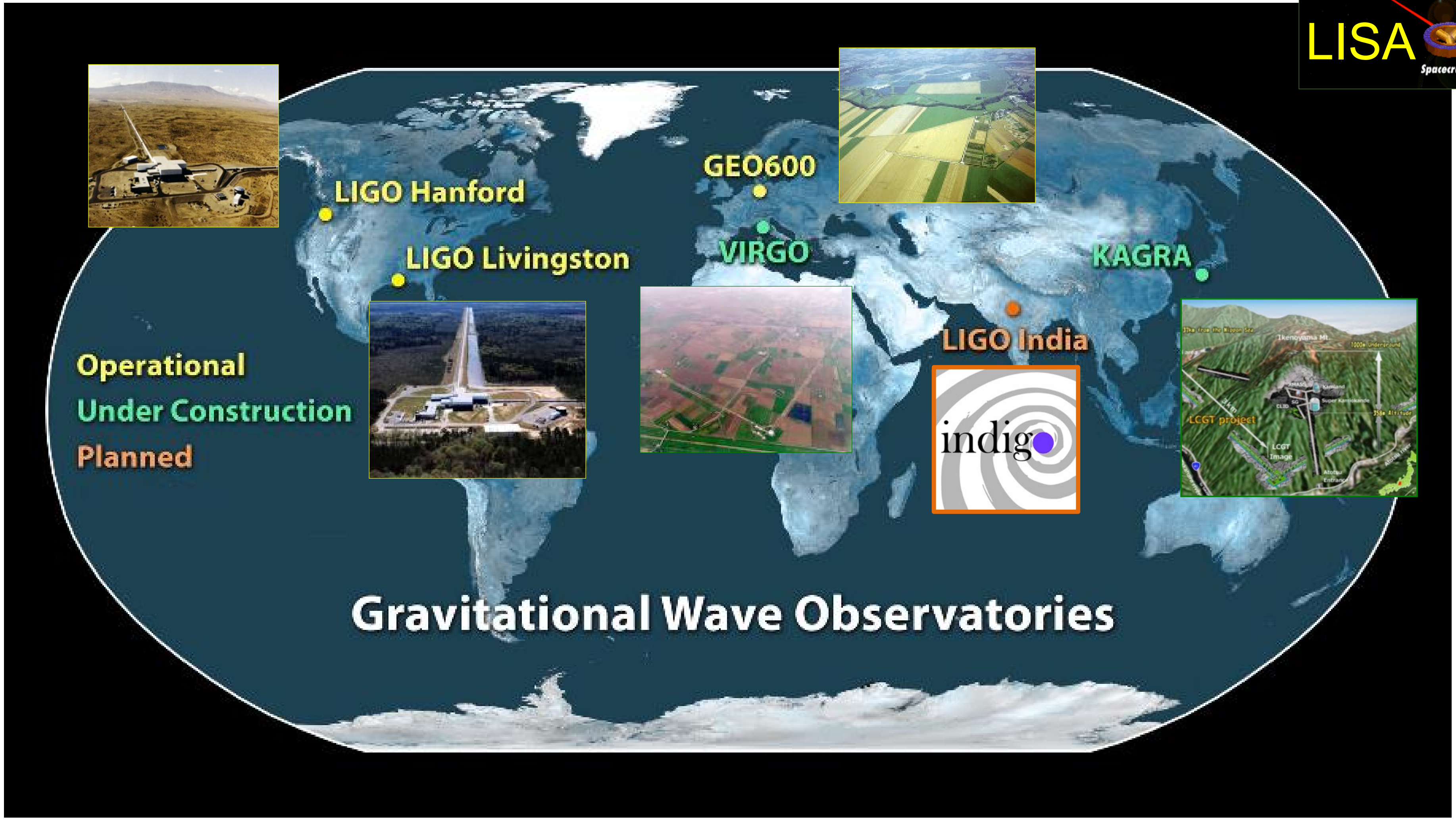




Gravitational Waves

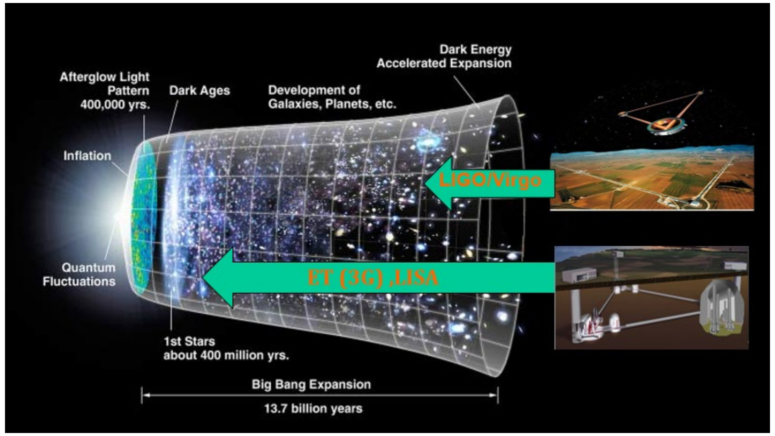


A new challenge: worldwide collaboration

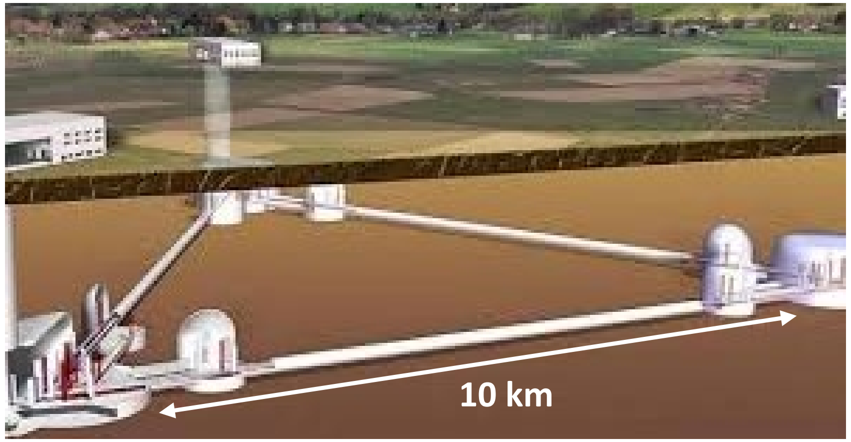


Gravitational Waves – The Einstein Telescope

A new way to probe the visible Universe

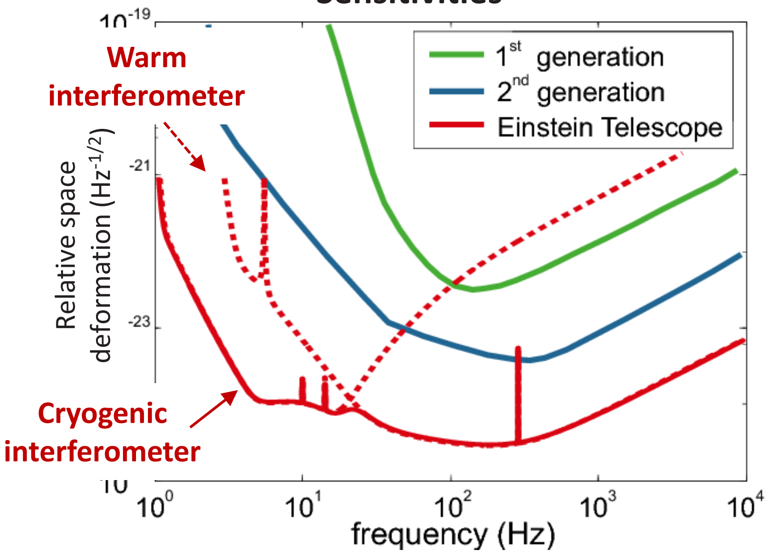


3rd generation (Einstein Telescope)



2030+

Sensitivities



- 2022+: New data takings with improved LIGO and Virgo: Volume of visible space increases by a factor 50
- 2030+: 3rd Generation: The Einstein Telescope: Volume of visible space increases by a factor 1000
- ET is a new large-scale facility in Europe, enabling a large science program, such as:
  - Formation of Black Holes at the center of galaxies? ➔ Measuring all BH mergers in the visible Universe
  - Is General Relativity (GR) right or do we need new physics? ➔ Precisions tests of GR in extreme conditions
  - Is Dark Energy the cosmological constant? ➔ Studies how the Universe is expanding and evolving
  - Understanding the dynamics of ultra dense matter! ➔ Exploring neutron star mergers

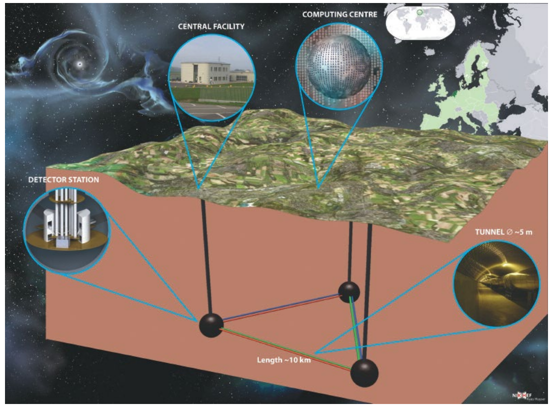
ET EINSTEIN TELESCOPE

http://www.et-gw.eu

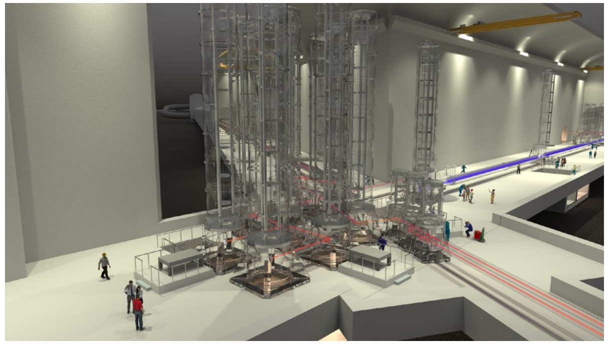
Einstein Telescope

http://www.et-gw.eu

- Status
  - Due to the magnificent 3G science case, the interest in ET in Europe is rapidly growing.
  - Participation in ET activities is rising in many European countries.
  - The ET symposium in December 2020 had 710 participants!



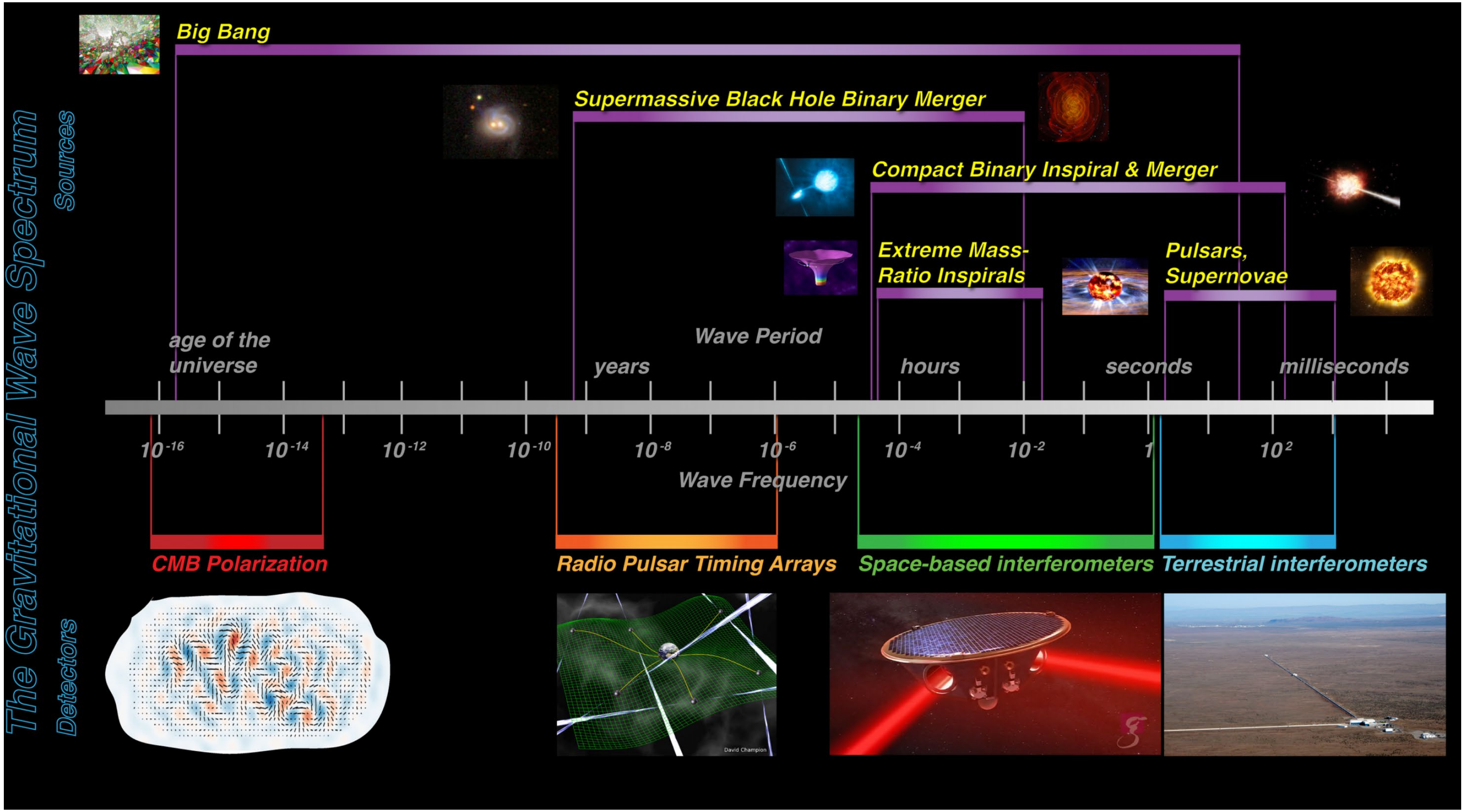
- ESFRI
  - The proposal to include ET in the ESFRI roadmap (I, NL, B, E, Pl) was succesful;
  - The ESFRI roadmap was updated in June 2021
- Organisation
  - The organizational structure of the project and the collaboration has evolved
  - Boards have been formed:
    Instrument science, Observational science, Site characterisation, E-Infrastructure.
  - The Instrument science board is the most advanced and will shortly be fully operational
  - The next goal are technical design reports for the ET observatory



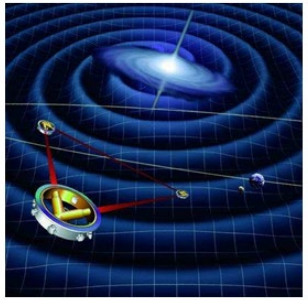
- R&D
  - Advanced Virgo and Advanced Ligo; KAGRA, ETpathfinder (NL)
- GWIC + GWAC
  - GWIC Gravitational Wave International Committee https://gwic.ligo.org
  - GWAC Gravitational Waves Agencies Correspondents

Gravitational Waves

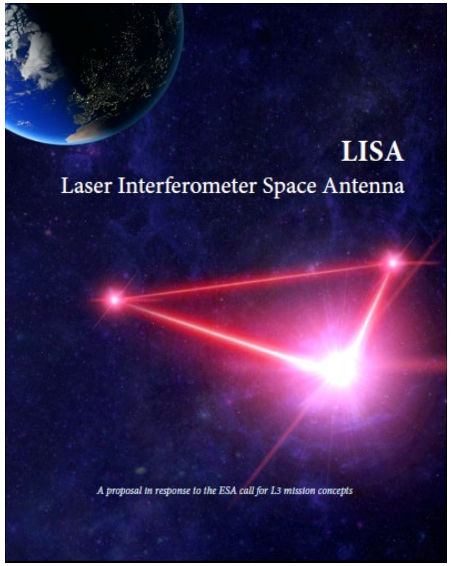
Gravitational Waves
Ground-Space complementarity

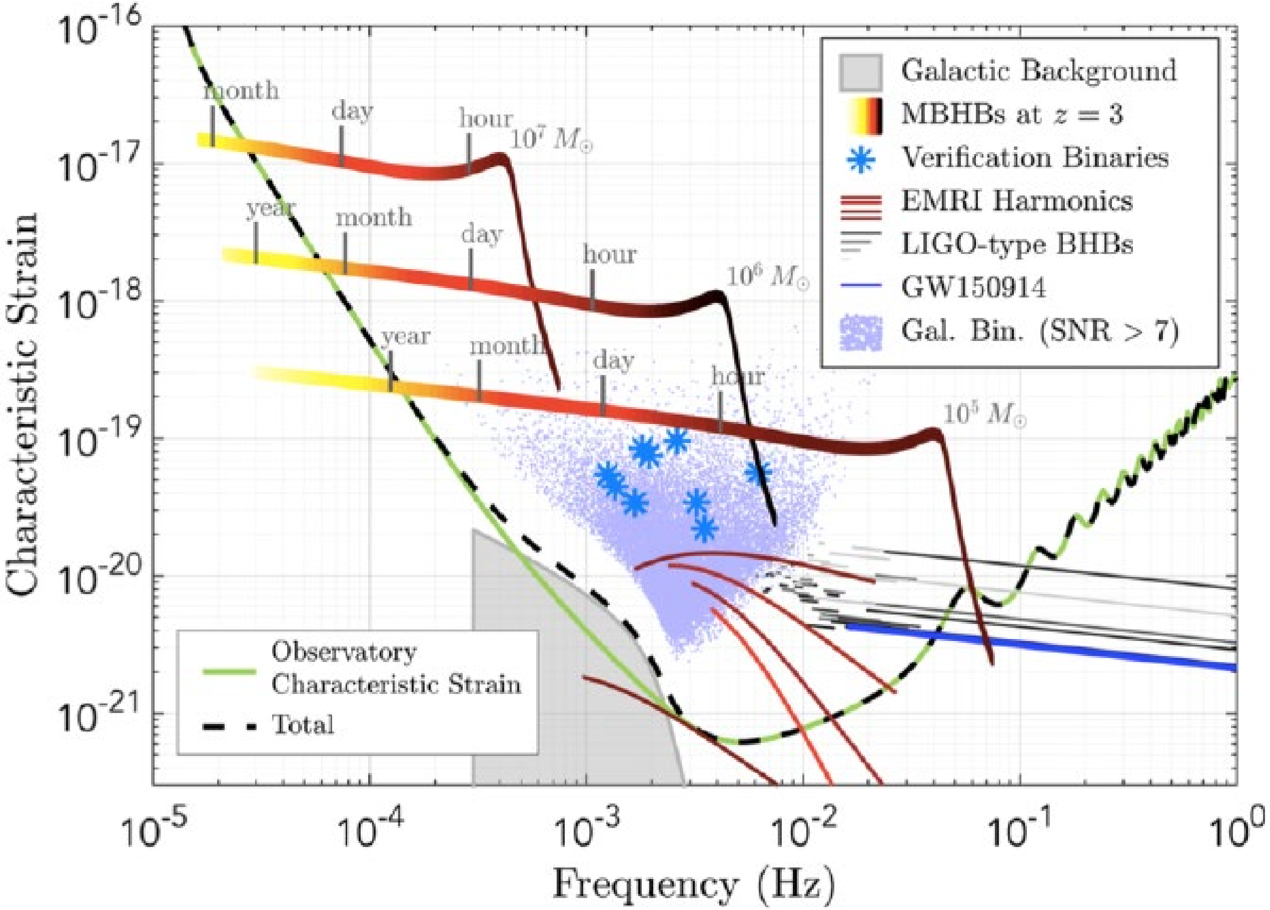


Gravitational Waves - LISA



- Arm length: 2.5 mio km
- Launch 2034
- observe the entire universe with gravitational waves
- learning about the formation of structure
- galaxies,
- stellar evolution,
- the early universe,
- structure and nature of spacetime

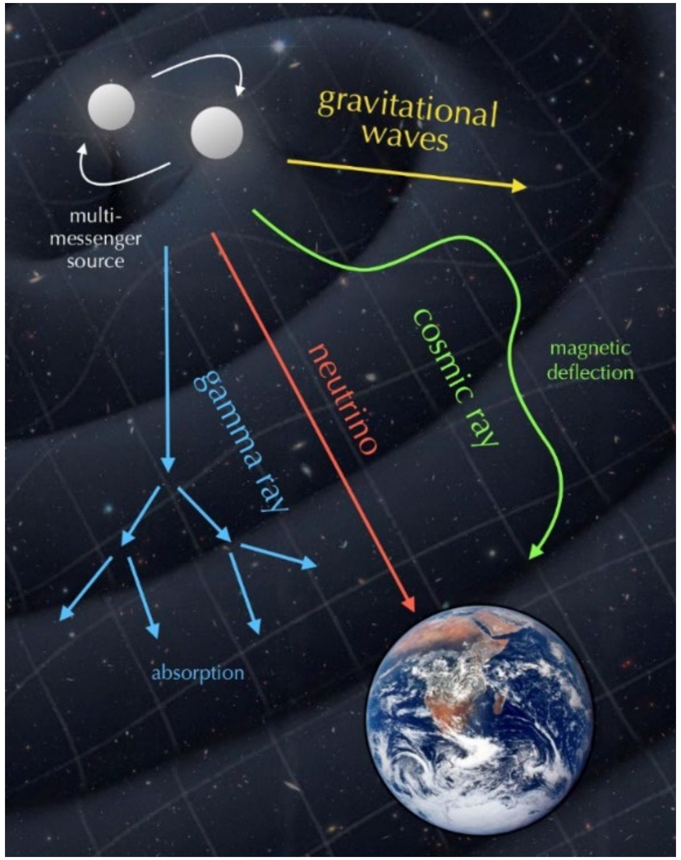


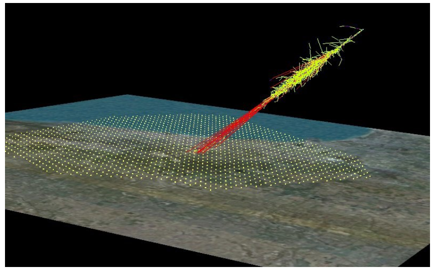


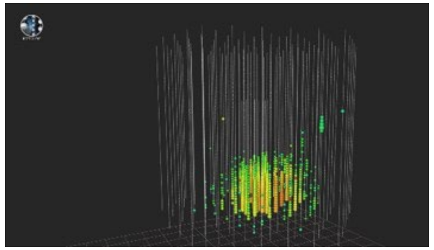
Multi-Messenger Astroparticle Physics

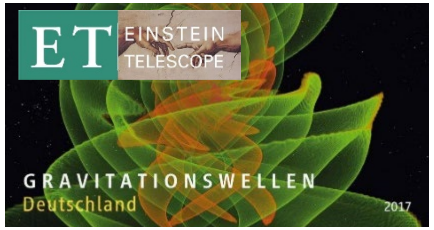
All are parts of the global multi-messenger efforts:

- 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

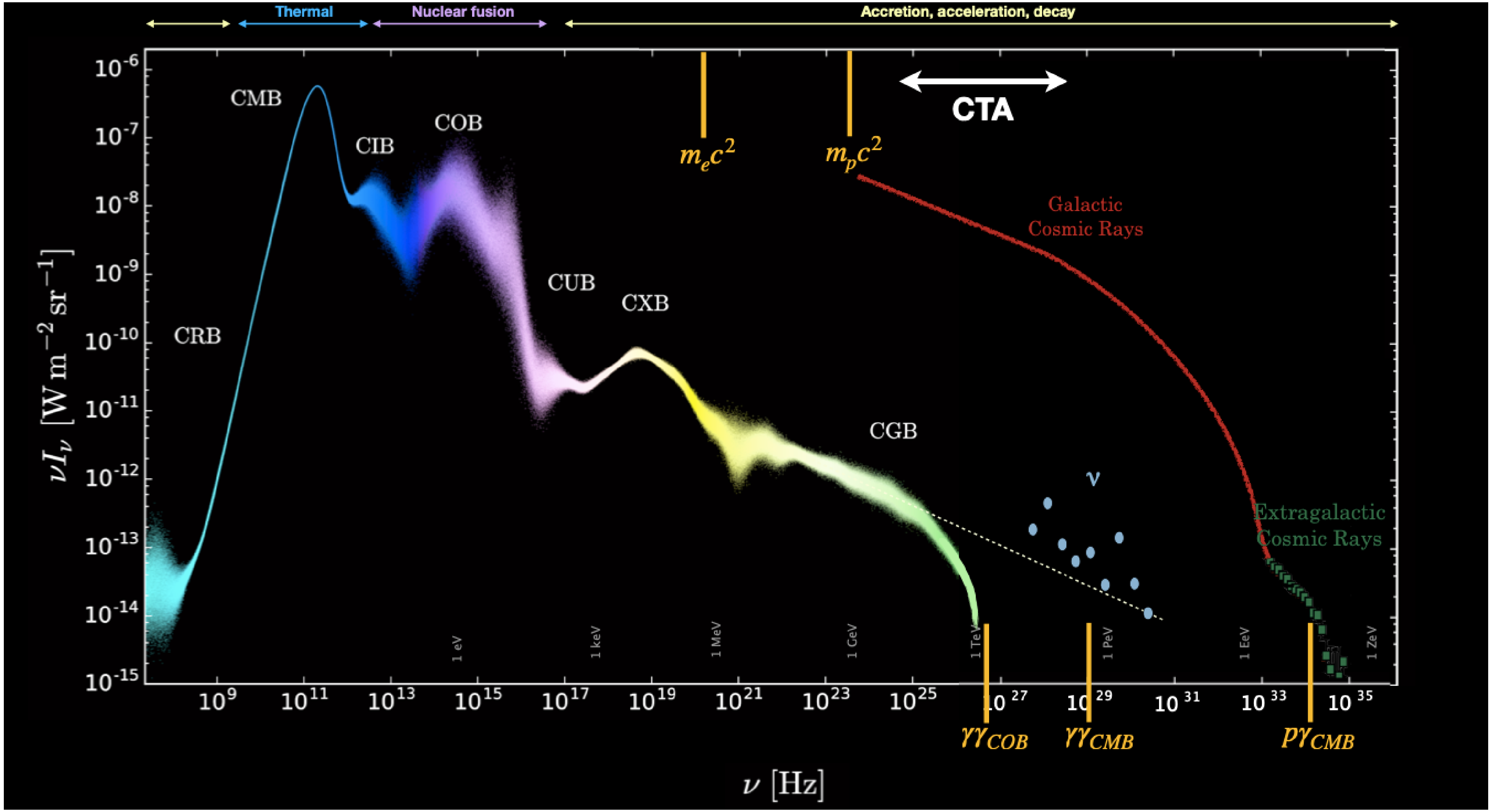








Multi-Messenger Astroparticle Physics



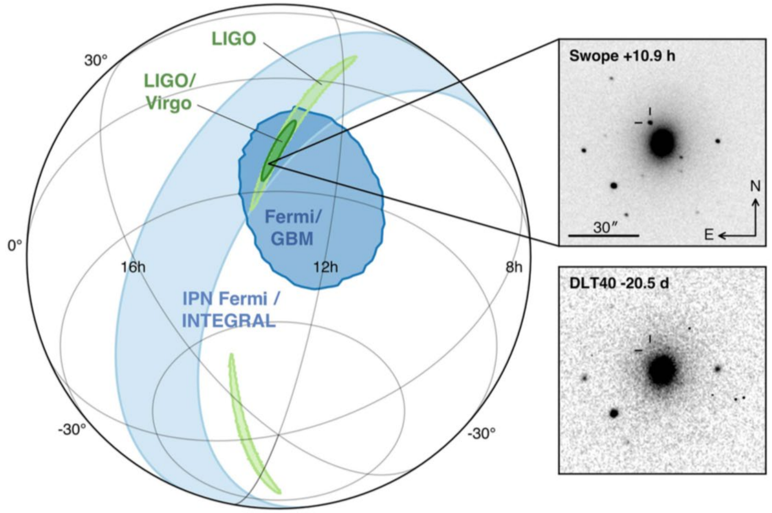
Multi-Messenger Astroparticle Physics

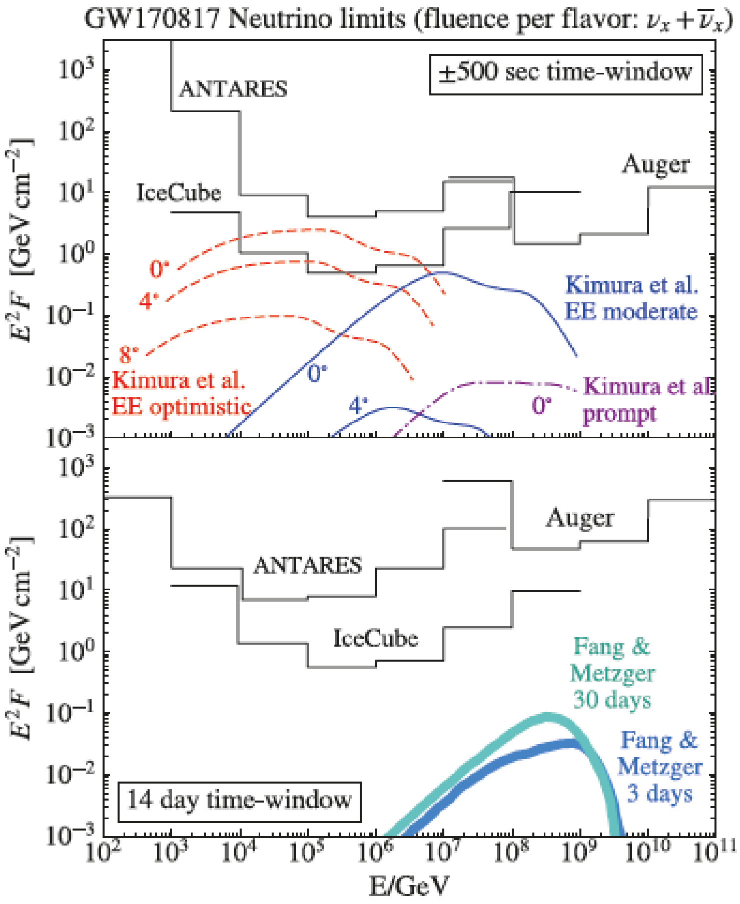
Multi-messenger Observations of a Binary Neutron Star Merger #2

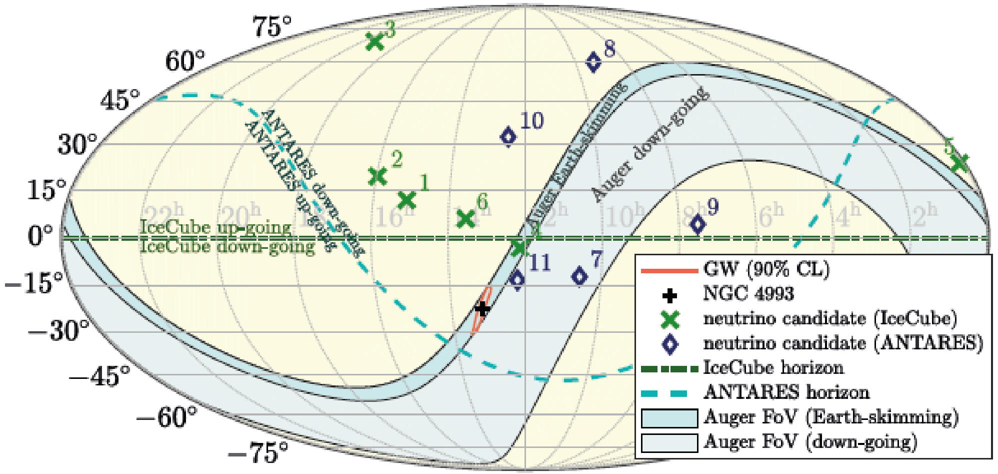
LIGO Scientific and Virgo and Fermi GBM and INTEGRAL and IceCube and IPN and Insight-Hxmt and ANTARES and Swift and Dark Energy Camera GW-EM and DES and DLT40 and GRAWITA and Fermi-LAT and ATCA and ASKAP and OzGrav and DWF (Deeper Wider Faster Program) and AST3 and CAASTRO and VINROUGE and MASTER and J-GEM and GROWTH and JAGWAR and CaltechNRAO and TTU-NRAO and NuSTAR and Pan-STARRS and KU and Nordic Optical Telescope and ePESSTO and GROND and Texas Tech University and TOROS and BOOTES and MWA and CALET and IKI-GW Follow-up and H.E.S.S. and LOFAR and LWA and HAWC and Pierre Auger and ALMA and Pi of Sky and Chandra Team at McGill University and DFN and ATLAS Telescopes and High Time Resolution Universe Survey and RIMAS and RATIR and SKA South Africa/MeerKAT Collaborations and AstroSat Cadmium Zinc Telluride Imager Team and AGILE Team and 1M2H Team and Las Cumbres Observatory Group and MAXI Team and TZAC Consortium and SALT Group and Euro VLBI Team • B.P. Abbott (LIGO Lab., Caltech) et al. (Oct 16, 2017)

Published in: *Astrophys.J.Lett.* 848 (2017) 2, L12 • e-Print: 1710.05833 [astro-ph.HE]

pdf links DOI cite 2,101 citations







The Dawn of Multi-Messenger Astroparticle Physics

Multi-Messenger needs large facilities

Dark Matter

Big theory questions:

1. DM theory parameter space is vast. How do we break it up?
2. Is there astrophysical evidence to go beyond the cold and collisionless hypothesis?
3. If DM is multi-component, how would we know?
4. How is DM produced in the Early Universe, and how does this connect to late Universe observables?

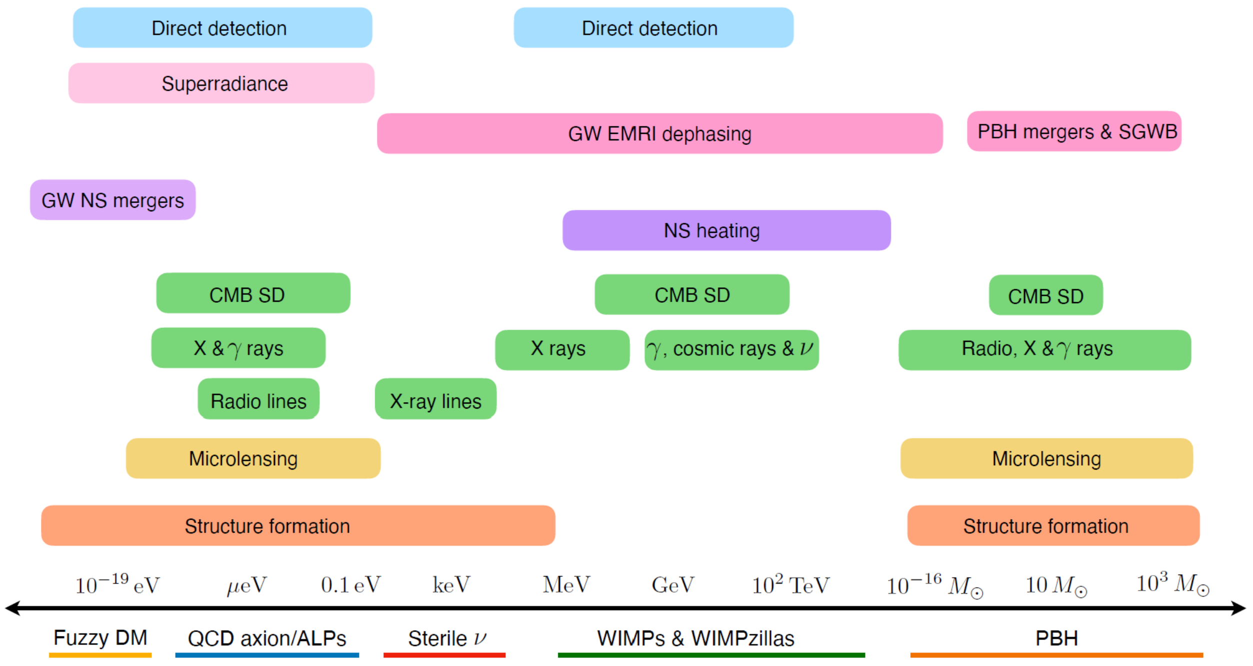


Figure 10: Summary of possible constraints on DM. We show the available DM mass range with some DM candidates highlighted, and astroparticle observables of different nature that can constrain them. Acronyms: Extreme mass ratio inspirals (EMRI), stochastic GW background (SGWB), CMB spectral distorsions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

EuCAPT White Paper

Dark Matter

APPEC Roadmap 2017-2026
Dark Matter Recommendations (2017):

APPEC encourages the continuation of a diverse and vibrant programme (including experiments as well as detector R&D) searching for WIMPs and non-WIMP Dark Matter. With its global partners, APPEC aims to converge around 2019 on a strategy aimed at realising worldwide at least one 'ultimate' Dark Matter detector based on xenon (in the order of 50 tons) and one based on argon (in the order of 300 tons), as advocated respectively by DARWIN and Argo.

Dark Matter

- 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
  - Coordinated detector R&D
  - European Infrastructure for Underground Science
  - Studying of the axion/ALPs mass range
  - Continuation of diverse theoretical activity

arXiv:2104.07634v1 [hep-ex] 15 Apr 2021

Direct Detection of Dark Matter – APPEC Committee Report *

Committee Members:
Julien Billard,[1] Mark Boulay,[2] Susana Cebrián,[3] Laura Covi,[4]
Giuliana Fiorillo,[5] Anne Green,[6] Joachim Kopp,[7] Béla Majorovits,[8]
Kimberly Palladino,[9,12] Federica Petricca,[8] Leszek Roszkowski (chair),[10] Marc Schumann[11]

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[12] *Department of Physics, Oxford University, Oxford, UK*

Abstract
This Report provides an extensive review of the experimental programme of direct detection searches of particle dark matter. It focuses mostly on European efforts, both current and planned, but does it within a broader context of a worldwide activity in the field. It aims at identifying the virtues, opportunities and challenges associated with the different experimental approaches and search techniques. It presents scientific and technological synergies, both existing and emerging, with some other areas of particle physics, notably collider and neutrino programmes, and beyond. It addresses the issue of infrastructure in light of the growing needs and challenges of the different experimental searches. Finally, the Report makes a number of recommendations from the perspective of a long-term future of the field. They are introduced, along with some justification, in the opening Overview and Recommendations section and are next summarised at the end of the Report. Overall, we recommend that the direct search for dark matter particle interactions with a detector target should be given top priority in astroparticle physics, and in all particle physics, and beyond, as a positive measurement will provide the most unambiguous confirmation of the particle nature of dark matter in the Universe.

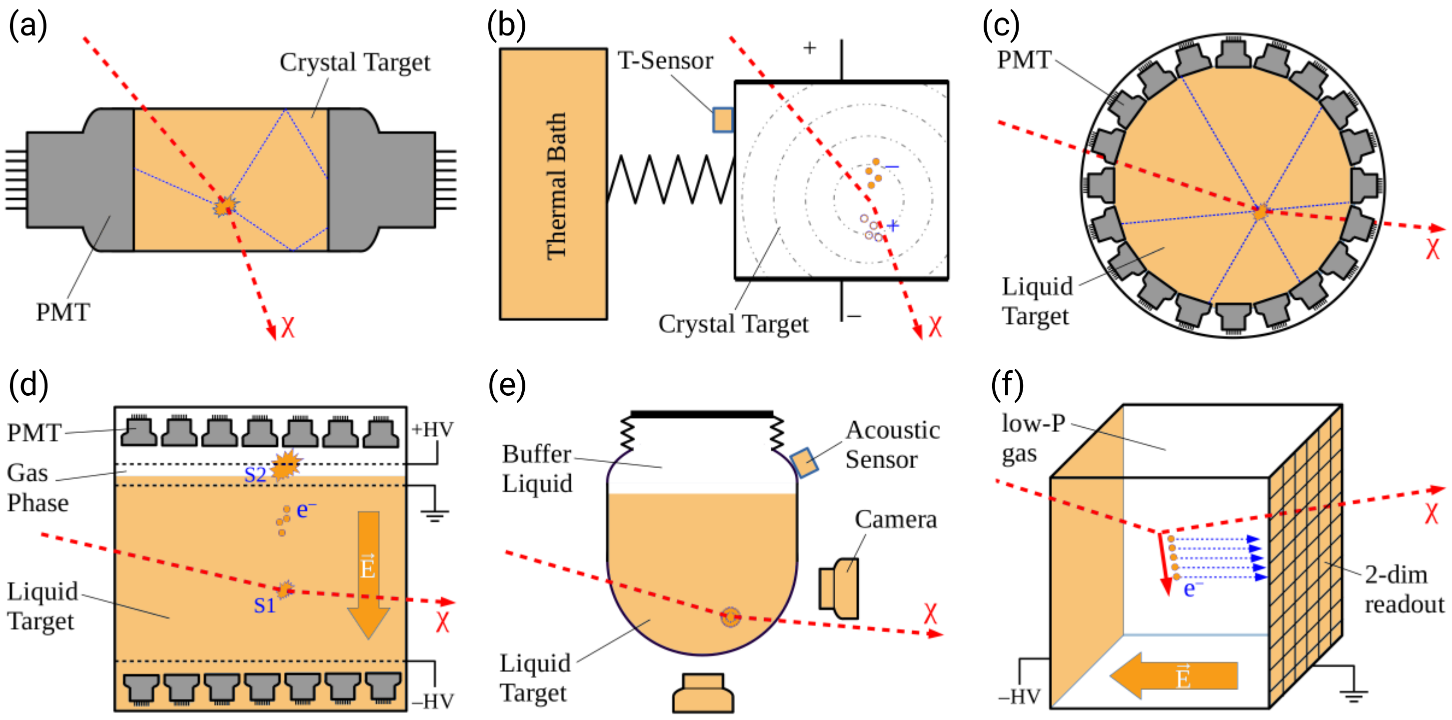
*This report has received approval from APPEC (1 April 2021; https://www.appec.org/documents).

Dark Matter - WIMP

- WIMP is still the „hottest“ candidate for Dark Matter
- Nobel gas target experiments: Xenon-nT (Xenon), DEAP (Argon)

DD of WIMP DM: Search techniques

liquid noble gas



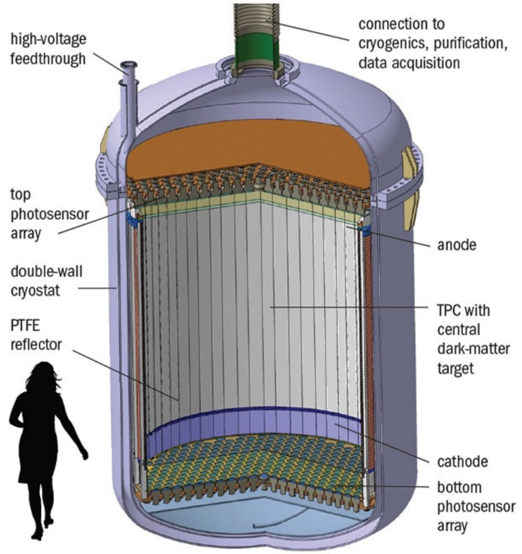
M. Schumann

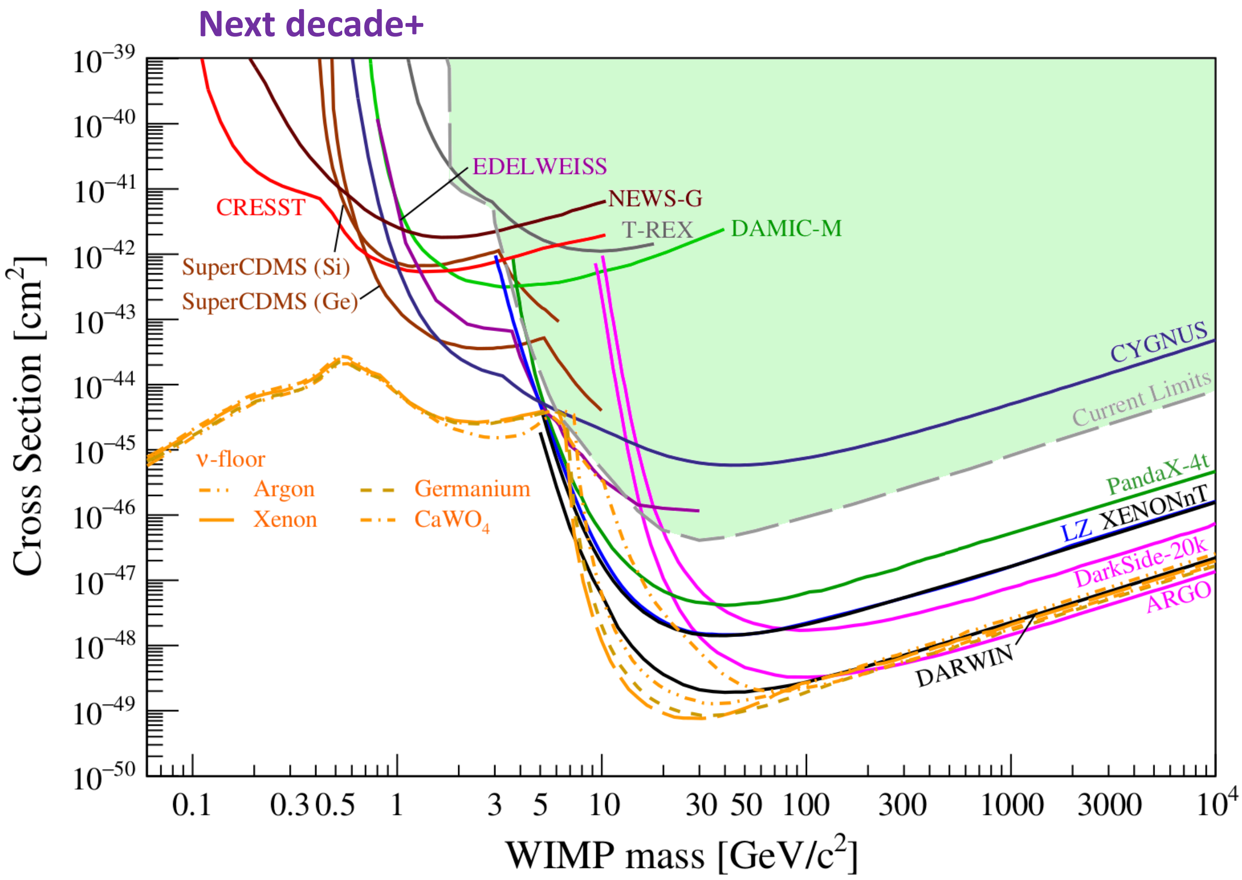
dual-phase TPC
(sci'n S1 + ion'n S2)

Main: nuclear recoil
Lower mass: electron recoil

Dark Matter - WIMP

- APPEC recommends DARWIN (300t Argon) as the European flagship experiment
- In addition, ongoing detector R&D has to be pursued



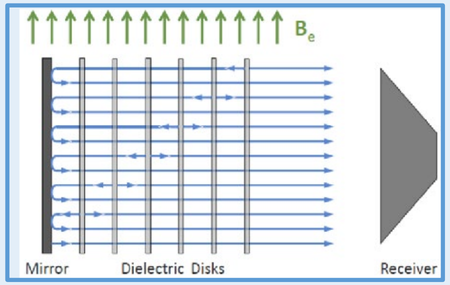


Dark Matter - Axions

Techniques / Experiments for Axion and Axion Like Particles search

Béla Majorovits

- **Haloscopes:**
  - Cavity
  - Dielectric
  - Dish antenna
  - Plasma
  - Topological insulators
  - NMR technique
  - …

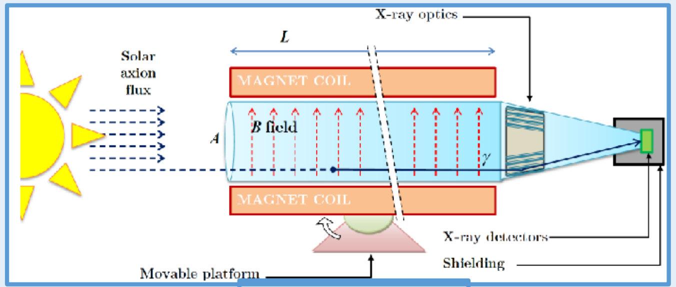


dielectric haloscope

Infrastructure needs:
- large halls
- stable, low em bgnd
- cryogenic infrastructure

Large superconducting magnets

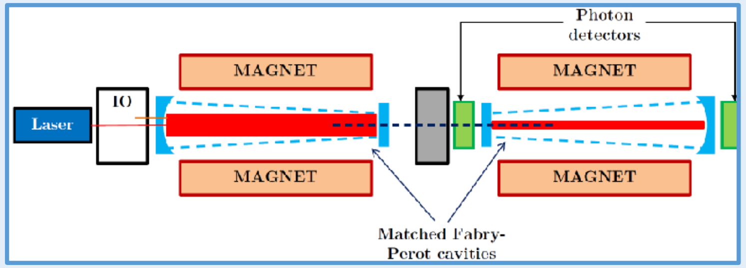
- **Helioscopes:** Use dipole magnets pointing at the Sun



IaXO helioscope

- **Laboratory:** Produce axion/ALP, detect photon

Solar axion/ALP, mass ~> keV

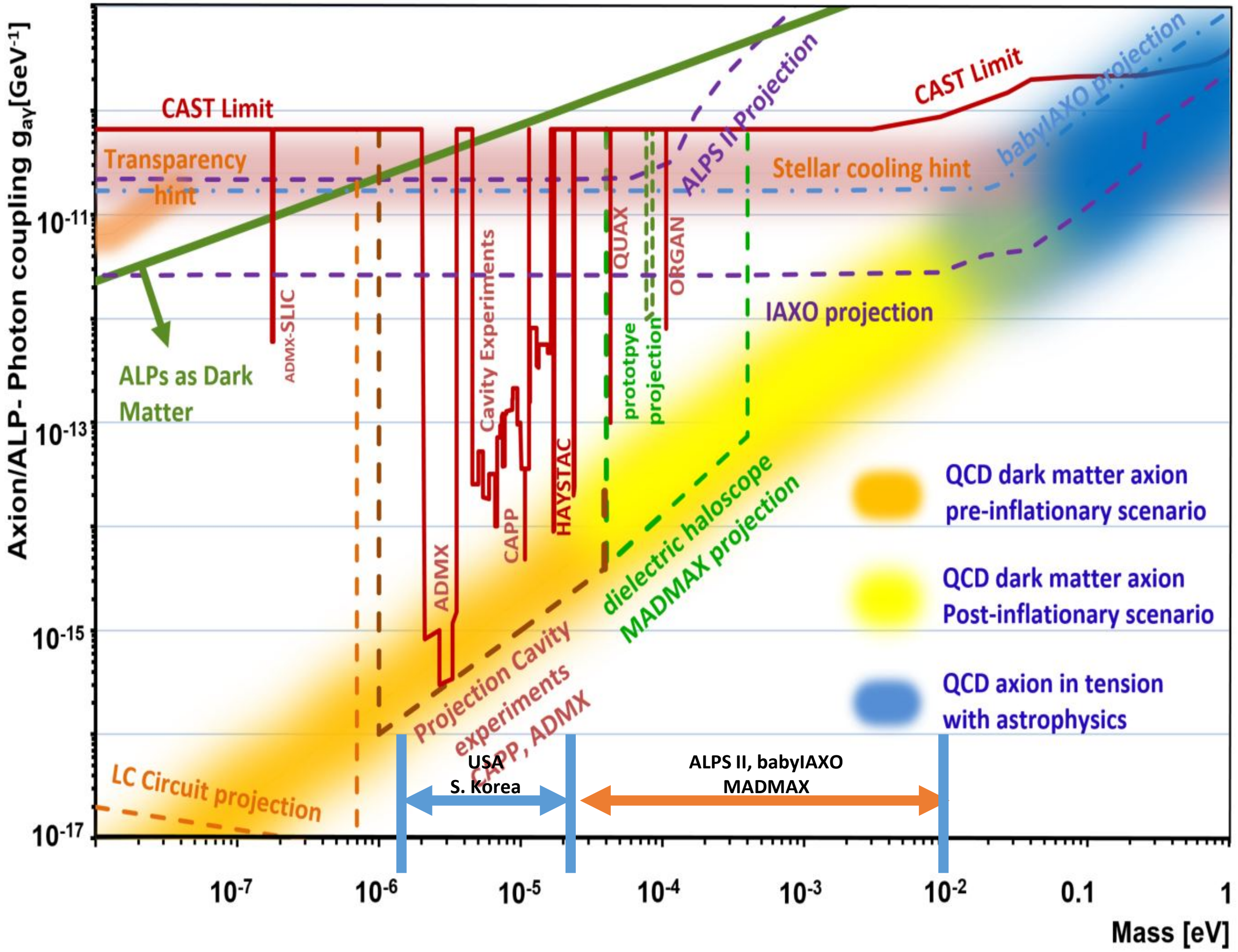


- **Low-background experiments:**
  - Limits from XENON100, PandaX, LUX, XENON1T

Dark Matter - Axions

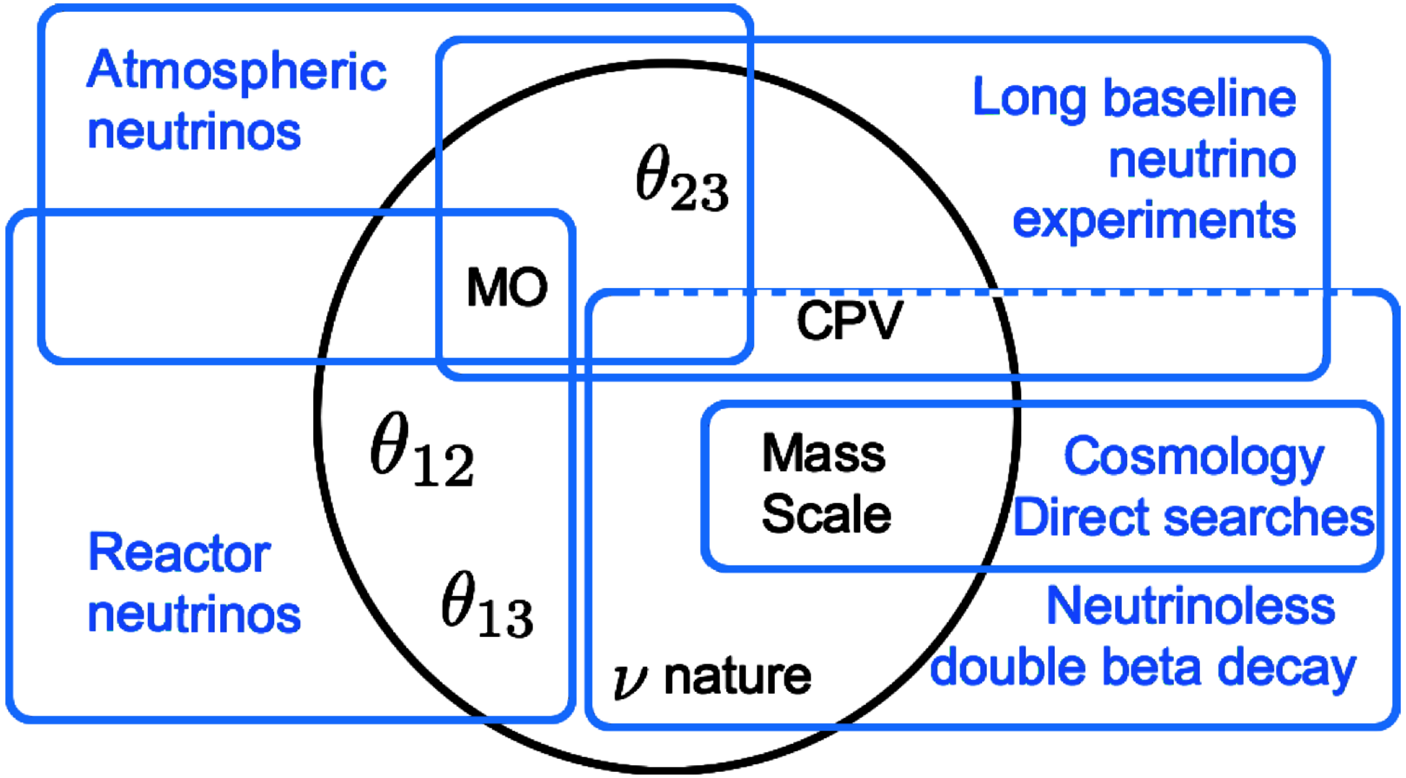
- R&D challenges:
  - High-field large-aperture magnets
  - Single-photon detectors
  - Low-loss RF techno & cavities
  - Optical cavities and lasers
  - NMR techno & spin coupling
  - Very-low bgnd X-ray detectors
  - Cryogenic engineering

- Future experiments:
  - ADMX
  - MADMAX
  - ALPS-II
  - IAXO



Neutrino Properties

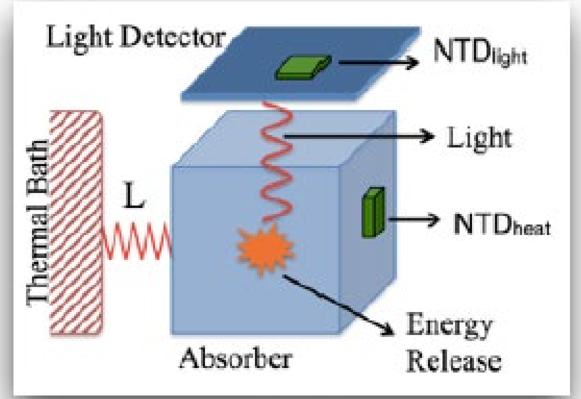
- Neutrino mixing different from CKM
- Their mass hierarchy not yet determined
- ν masses << mSM particles gives access to higher mass scales (See-Saw)
- ν CP-violation might give hints to matter-antimatter asymmetry in the Universe
- ν is the first “dark” particle and has a cosmic role
- Needs (European) infrastructures for Underground Science

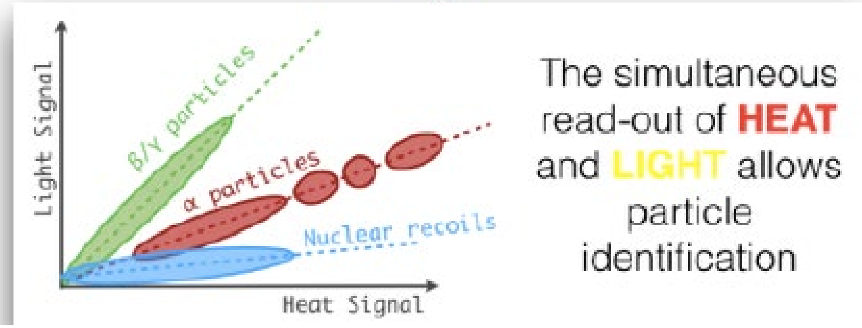


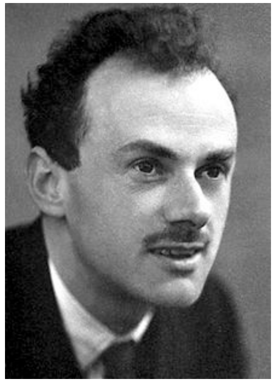
APPEC SAC

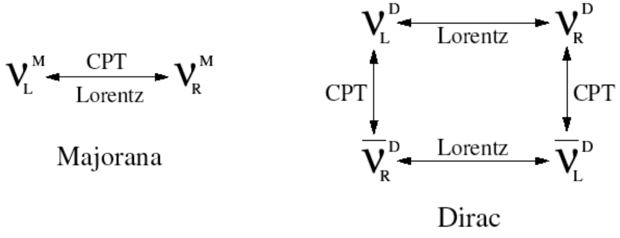
Neutrinoless Double Beta Decay

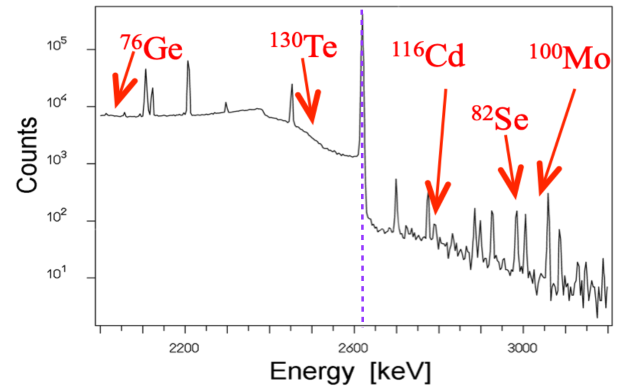
- Majorana or Dirac particle?
- For experiment one needs:
  - amount of Mass of the right isotopic composition
  - Background Index (counts per unit of energy per unit time)
  - the best Energy Resolution achievable
  - a very good Efficiency





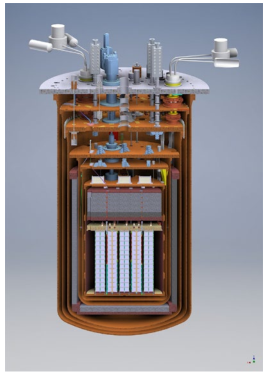


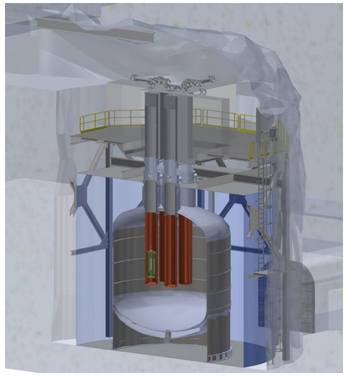


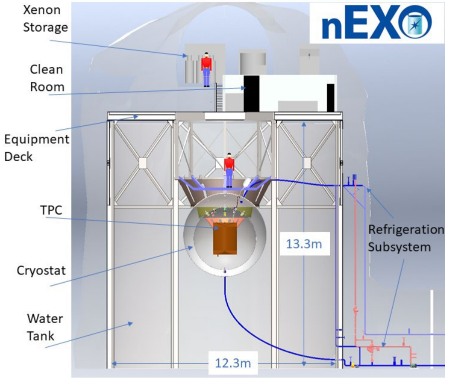


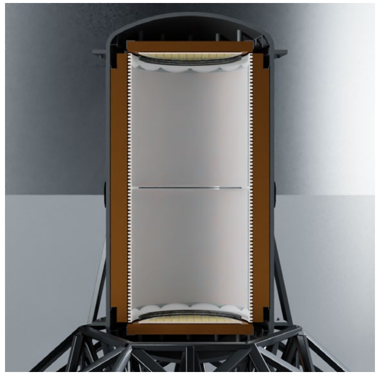
Neutrinoless Double Beta Decay

- Next step: ton-scale experiment
  - CUPID (100 Mo)
  - LEGEND-1000 (Ge)
  - nEXO (136 Xe)
  - NEXT (136 Xe)
- If Majorana particle: constrains on neutrino mass









$0\nu\beta\beta$: $(A,Z) \rightarrow (A,Z+2) + 2e^-$

2n → 2p + $2e^-$

Creation of matter without antimatter partners

Beyond Standard Model

Never observed – Best limits $\tau > 10^{24}$ - 10^{26} y

① Standard mechanism: **neutrino physics**

$0\nu 2\beta$ is mediated by **light massive Majorana neutrinos** (exactly those which oscillate)

Sometimes defined "**mass mechanism**"

② Non-standard mechanisms: **Sterile ν, LNV**

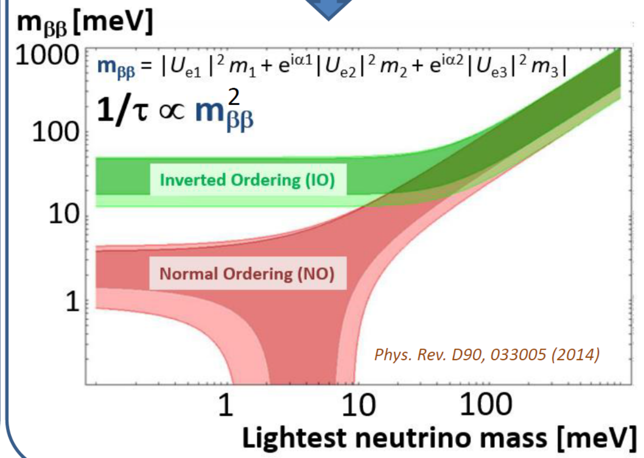
Not necessarily neutrino physics

The only currently viable experimental approach to probe the Majorana nature of neutrino

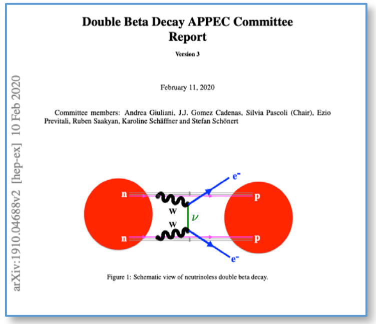
Francesco Vissani, this workshop

Experiments measure / constrain τ

Assuming mass mechanism, this translates into information on the **effective Majorana mass $m_{\beta\beta}$**



Neutrinoless Double Beta Decay


Double Beta Decay APPEC Committee Report

Version 3

arXiv:1910.04688v2 [hep-ex] 10 Feb 2020

February 11, 2020

Committee members: Andrea Giuliani, J.J. Gomez Cadenas, Silvia Pascoli (Chair), Ezio Previtali, Ruben Saakyan, Karoline Schäffner and Stefan Schönert

Figure 1: Schematic view of neutrinoless double beta decay.

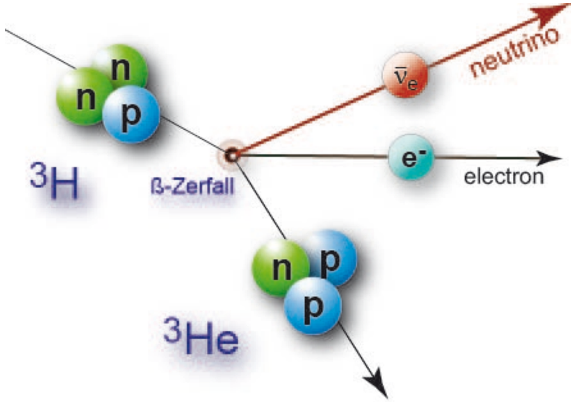
Strategy:

- 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
- 0νßß 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 funden, one in Europe, one in North America

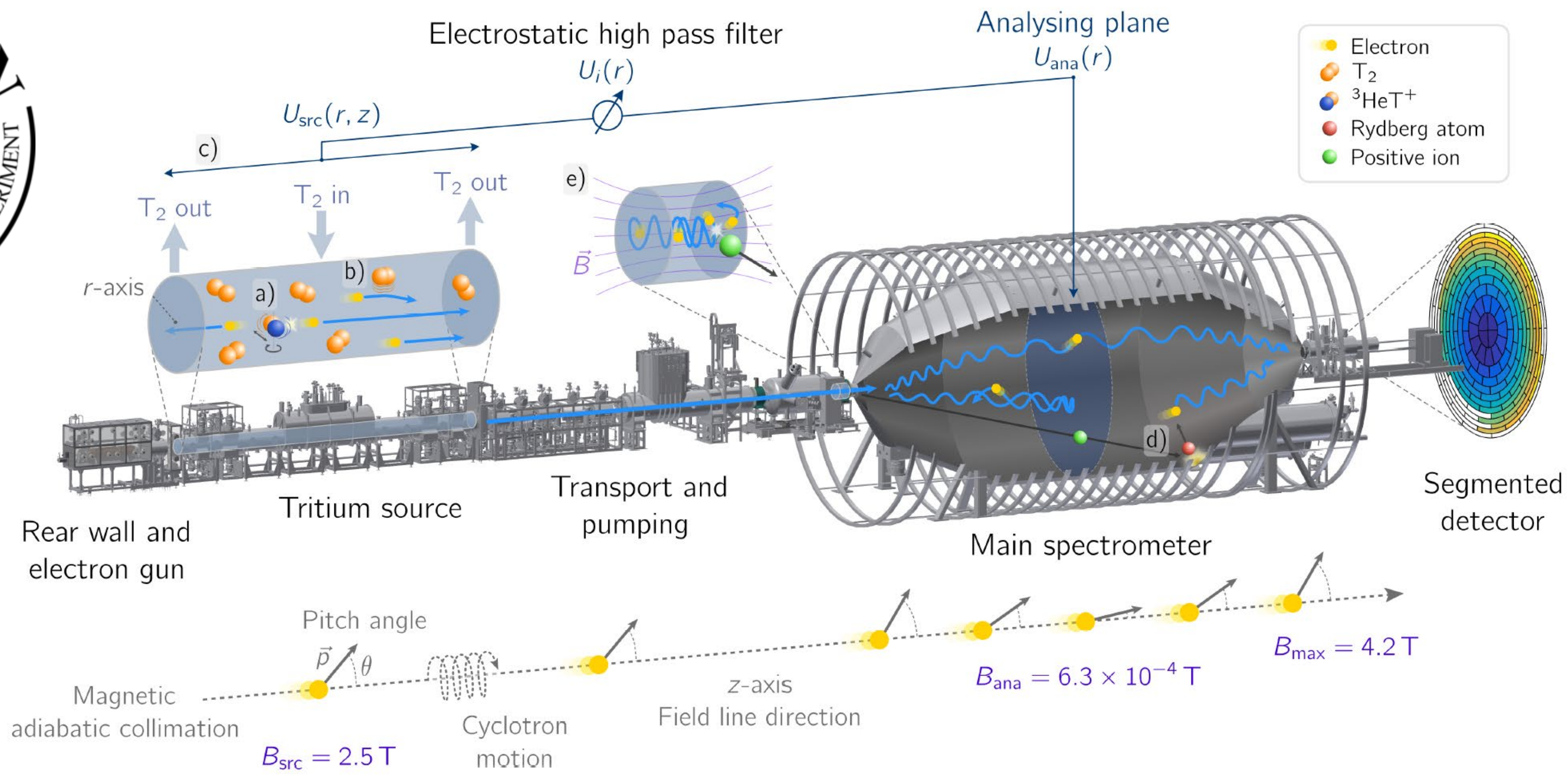
Neutrino Masses



- Direct Measurements via endpoint energy of beta decay
  - KATRIN: Upper limit of m < 0.8 eV/c2 (90% CL). https://arxiv.org/abs/2105.08533
  - Future of KATRIN (reach of 0.2 ev/c2 and sterile neutrino search (TRISTAN)
  - Project 8 (gaseous tritium source in magnetic field)
  - ECHo, HOLMES (Ho-163 in cryogenic bolometers)
  - Ptolemy (far future, sensitivity also on relic neutrinos)
- Neutrinoless double beta decay (if Majorana)
- Sum of neutrino masses by cosmological observations (neutrinos had significant impact on the structure formation of the Universe)

➔ APPEC supports R&D and a global roadmap to future neutrino mass determination

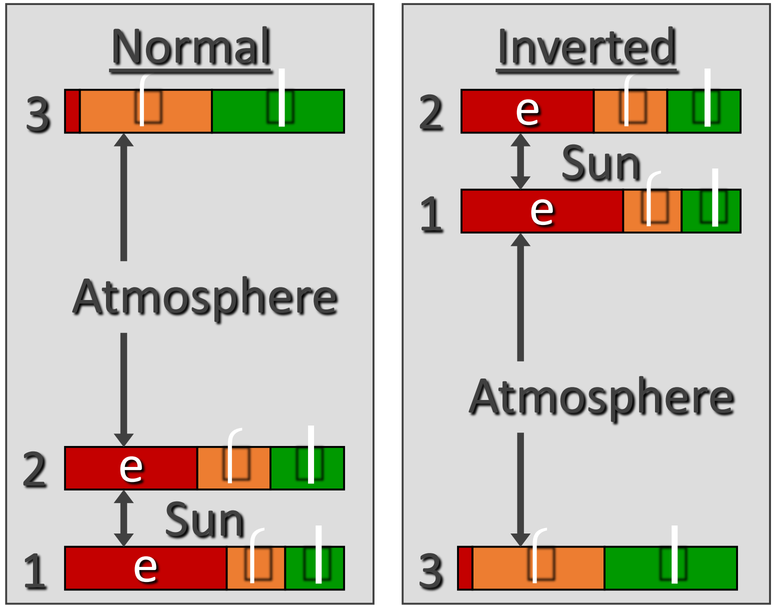
Neutrino Masses - KATRIN

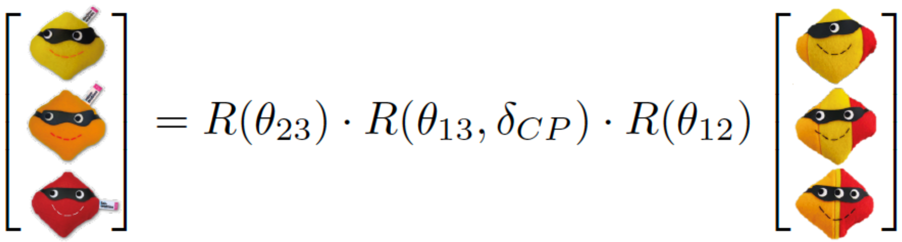


Neutrino Properties

- Neutrino mixing and Mass Hierarchy
  - Nobel prices in 2002 and 2015
  - Use of neutrinos from atmosphere, accelerators, reactors
  - Hyper-Kamiokande, DUNE, JUNO
  - KM3NeT/ORCA, IceCube, INO (India)
  - Future: COHERENT (elastic neutrino scattering; P20 (Protvino to ORCA)

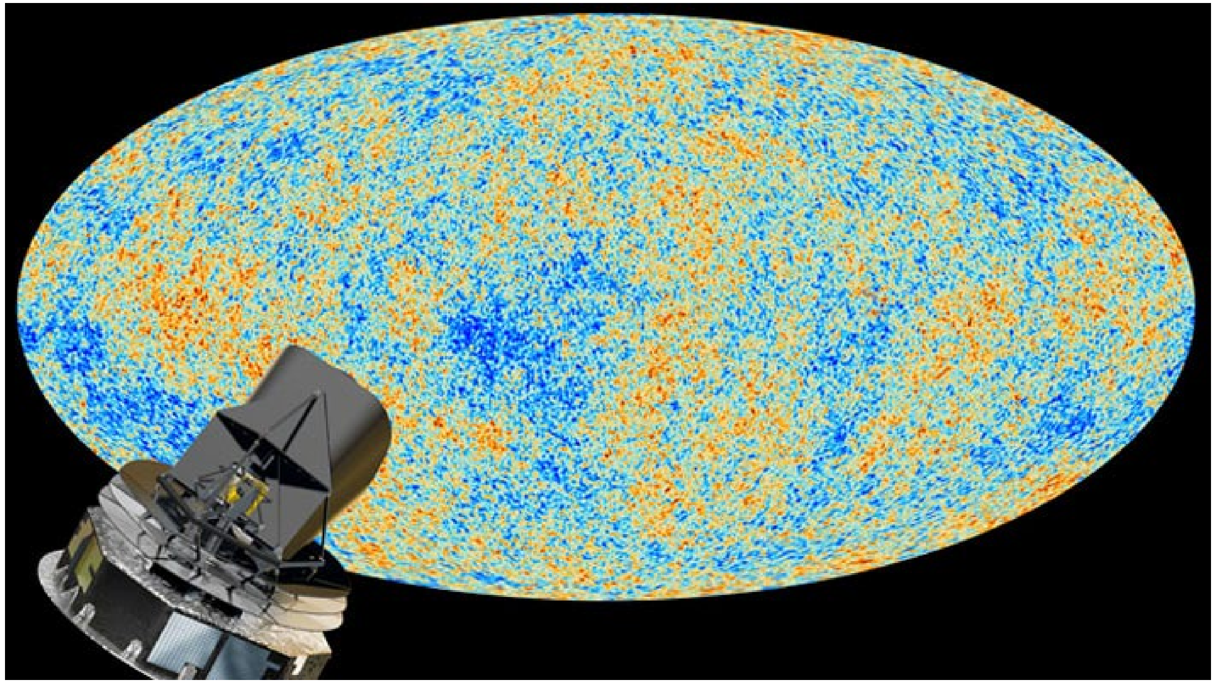
➔ APPEC's role is in facilitating synergetic activities across the fields, which has strong overlap with particle physics.





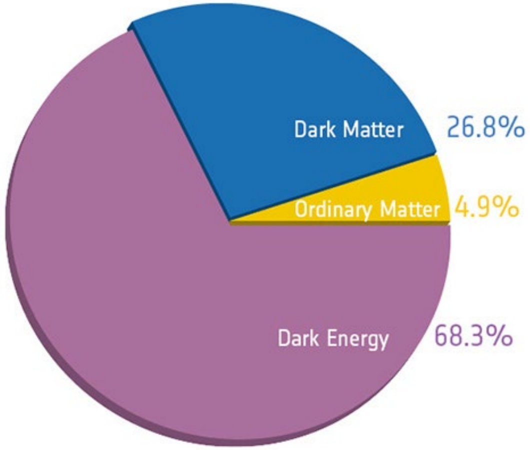
Cosmic Microwave Background

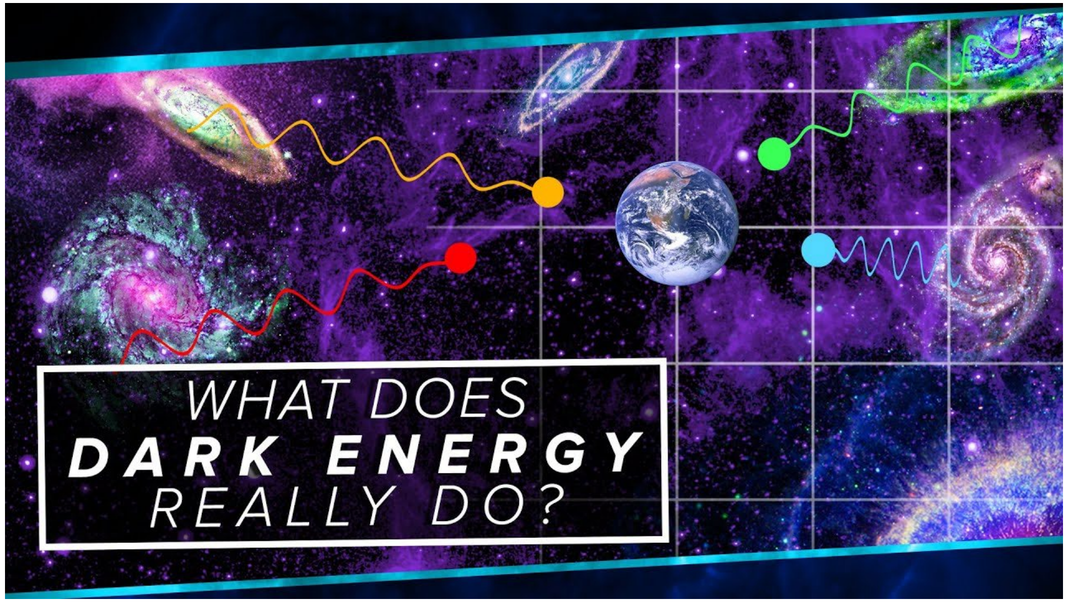
- Measurements transformed cosmology into a precision science
  - Large-scale polarization defines the Standard Model of Cosmology and shows imprint of Cosmic Inflation as well as early Big Bang Scenario
  - Small-scale polarization promise insights into the Beyond Standard Model Particle Physics
- APPEC's roll is to foster European efforts for experiments, like
  - Planck satellite and next LiteBIRD (large-scale)
  - Ground-based for small-scale (also for Dark Energy) like South Pole Observatory, Simons Array, CMB-S4



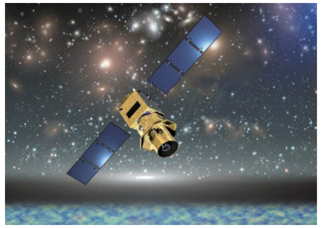
Dark Energy

- Together with Dark Matter is the Dark Energy the hypothetical form of energy behind the Universe's accelerated expansion
- APPEC's roll is to foster European efforts:
  - Satellite-based and ground-based galaxy survey campaigns to reconstruct the growth of cosmic structures
  - Expertise gained in BOSS, DES, DESI KiDS leads to the European (ESA) flagship project EUCLID
  - US-led Rubin (LSST) has strong European participation





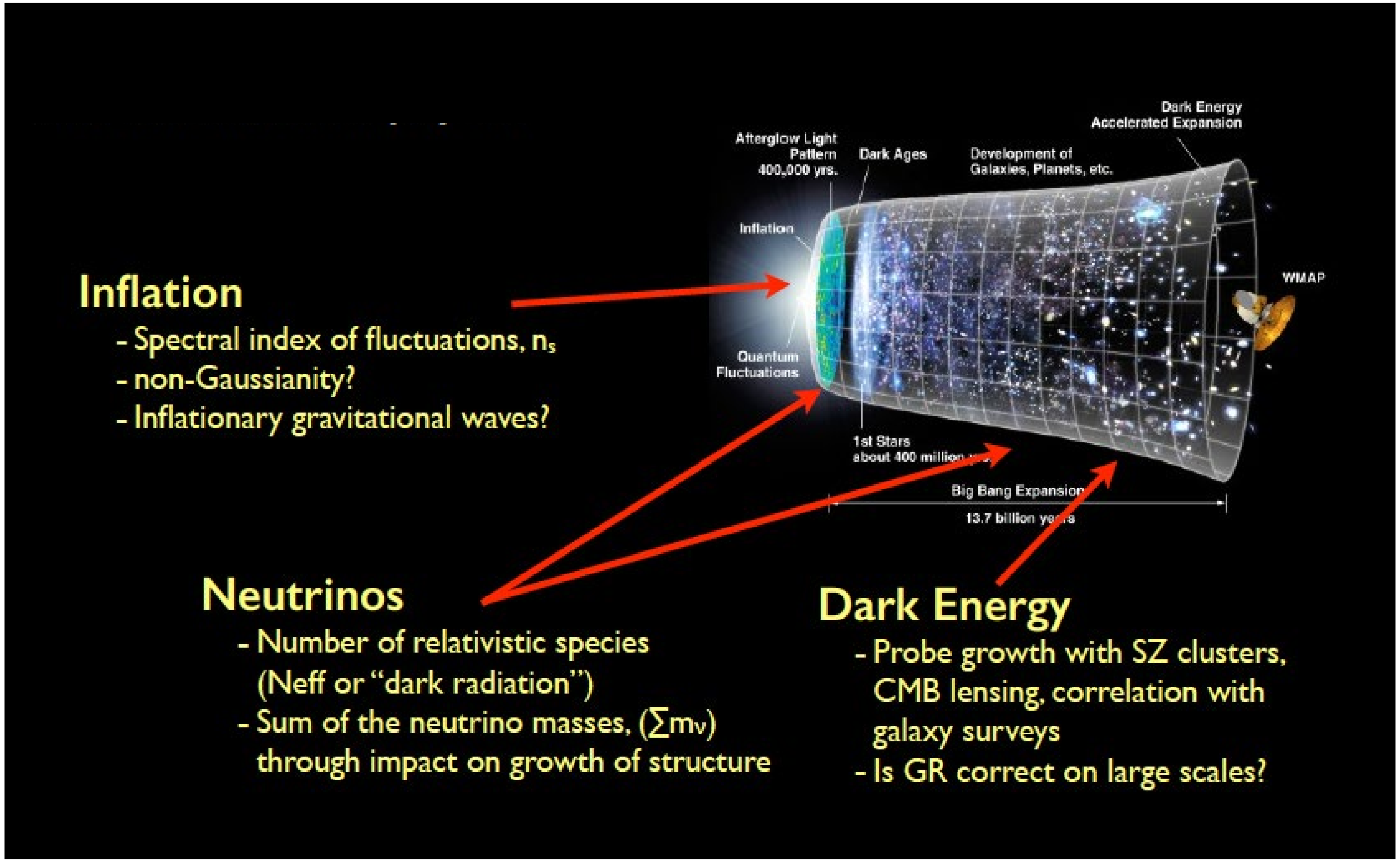
Cosmology

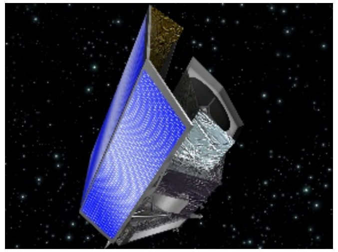


LiteBird

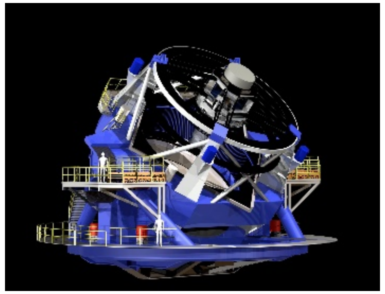
Simons Array

CMB-S4
QUBIC…





Euclid



LSST

Cosmology

Two approaches of Astroparticle Physics related to Cosmology

1. The cosmic structures from the CMB to the present provide comparable constraints to the standard model of cosmology (inflation, dark energy) and particle physics (neutrino, dark matter).
2. Multi-messenger astronomy involving photons of all frequencies, gravitational waves, neutrinos and high-energy charged particles provides a deeper understanding of violent phenomena regulating structure formation in the Universe and can eventually hints to physics beyond the standard model.

➔ Results will provide confirmation of standard models or new portal to the future.

➔ Large facilities in extreme environments are needed.

➔ Both approaches connect different energy/dimensional scales

Adapted from S. Katsanevas

Astroparticle Large-Scale Facilities

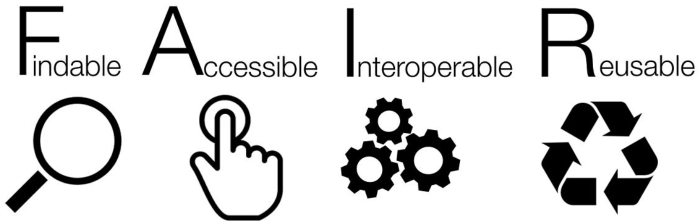
- General plan quite consistent, but need update in schedule

Overarching Topics in the Roadmap

APPEC

- Ecological Impact
  - ..of satellites, observatories, infrastructures, travel…
  - ..provide spin-offs for other research areas
- Societal Impact
  - Survey and fostering of impact on society
  - e.g. WATCHMAN (monitor for anti-neutrinos), Einstein Telescope industrial impact, etc.
- Open Science and Human Talent Management
  - Outreach and education
  - Open Data and Citizen Science
- Computing
- Theory
- Underground and Large-scale Infrastructures

OPEN SCIENCE



KIT

EuCAPT

- EuCAPT (European Center for Astroparticle Physics Theory)
  - Chair: G. Bertone
  - census (660 scientist from 31 European and 5 non European countries)
  - a number of workshops and virtual colloquia
  - a calendar listing all open (virtual) events
  - a regular newsletter

- EuCAPT White Paper distributed
  - Contains contributions of 135 colleagues (first EuCAPT annual Symposium)
  - Has more than 400 endorsers
  - Includes feedback from community via CERN Mattermost community platform
  - Available at https://indico.cern.ch/event/1082310/

EuCAPT White Paper

Opportunities and Challenges for Theoretical Astroparticle Physics in the Next Decade

EuCAPT

Abstract

Astroparticle physics is undergoing a profound transformation, due to a series of extraordinary new results, such as the discovery of high-energy cosmic neutrinos with IceCube, the direct detection of gravitational waves with LIGO and Virgo, and many others. This white paper is the result of a collaborative effort that involved hundreds of theoretical astroparticle physicists and cosmologists, under the coordination of the European Consortium for Astroparticle Theory (EuCAPT). Addressed to the whole astroparticle physics community, it explores upcoming theoretical opportunities and challenges for our field of research, with particular emphasis on the possible synergies among different subfields, and the prospects for solving the most fundamental open questions with multi-messenger observations.

https://www.eucapt.org/

Open Data

- Well established in astronomy
- Forerunner in Astroparticle Physics (air-shower data) was KCDC
- Now also other by experiments (in particular in HE-APP); e.g. by the Pierre Auger Observatory www.auger.org/opendata
- Future facilities must provide a dedicated Data Management Plan.

Open Data ≠ Outreach

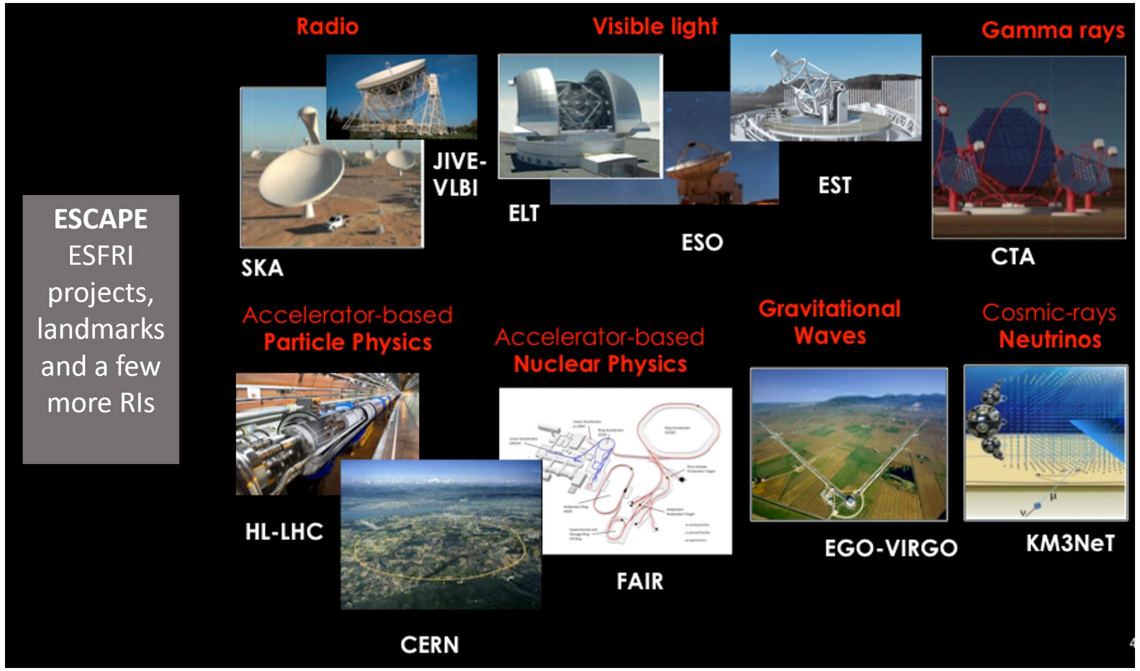
- as open data serves for community and the research field and the society
- outreach profits from open data
- KCDC is a platform for both, open data and outreach

https://kcdc.iap.kit.edu

- ➢ KCDC is a web-based platform to provide scientific data for the general public
- ➢ KCDC is to offer long-term scientific data for the community as well as for students and the interested public
- ➢ What's new: Independent Data Shops: Allows for Multi-Experimental Analysis ; Data of new experiment: Maket-Ani ; Jupyterhub: https://jupyter.iap.kit.edu supports online in-KCDC analyses ; API (Application Programming Interface): Improves systemic data handling

ESCAPE

- 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)



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.

ESCAPE DIOS | Data Infrastructure for Open Science

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.

ESCAPE OSSR | Open-source Scientific Software and Service Repository

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.

ESCAPE VO | Virtual Observatory

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.

ESCAPE SAP | Science Analysis Platform

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

ESCAPE CS | Citizen Science

G.Lamanna

EPPS Update / Snowmass Process

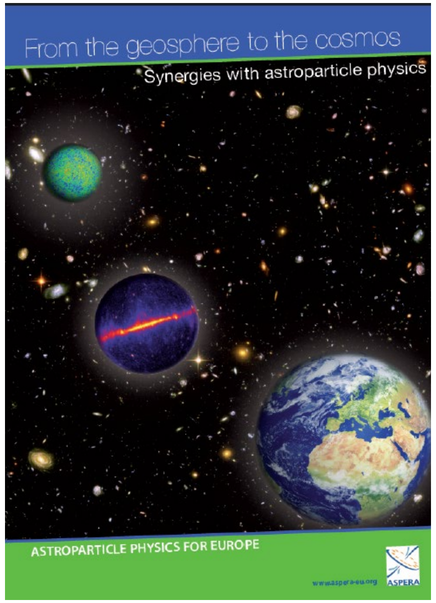
https://europeanstrategyupdate.web.cern.ch/

- European Particle Physics Strategy Update 2020

  Astroparticle physics also addresses questions about the fundamental physics of particles and their interactions. The ground-breaking discovery of gravitational waves has occurred since the last Strategy update, and this has contributed to burgeoning multi-messenger observations of the universe. Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit.
- APPEC has and is contributing to the EPPS update
- APPEC participates on the ECFA R&D Detector Roadmap
- APPEC is following and contributing to the SNOWMASS process in the US https://www.snowmass21.org/

APPEC platform

APPEC is also a platform for discussion and collaboration with other organisations and industry. It fosters also R&D projects.



Ultimate Low Light-Level Sensor Development

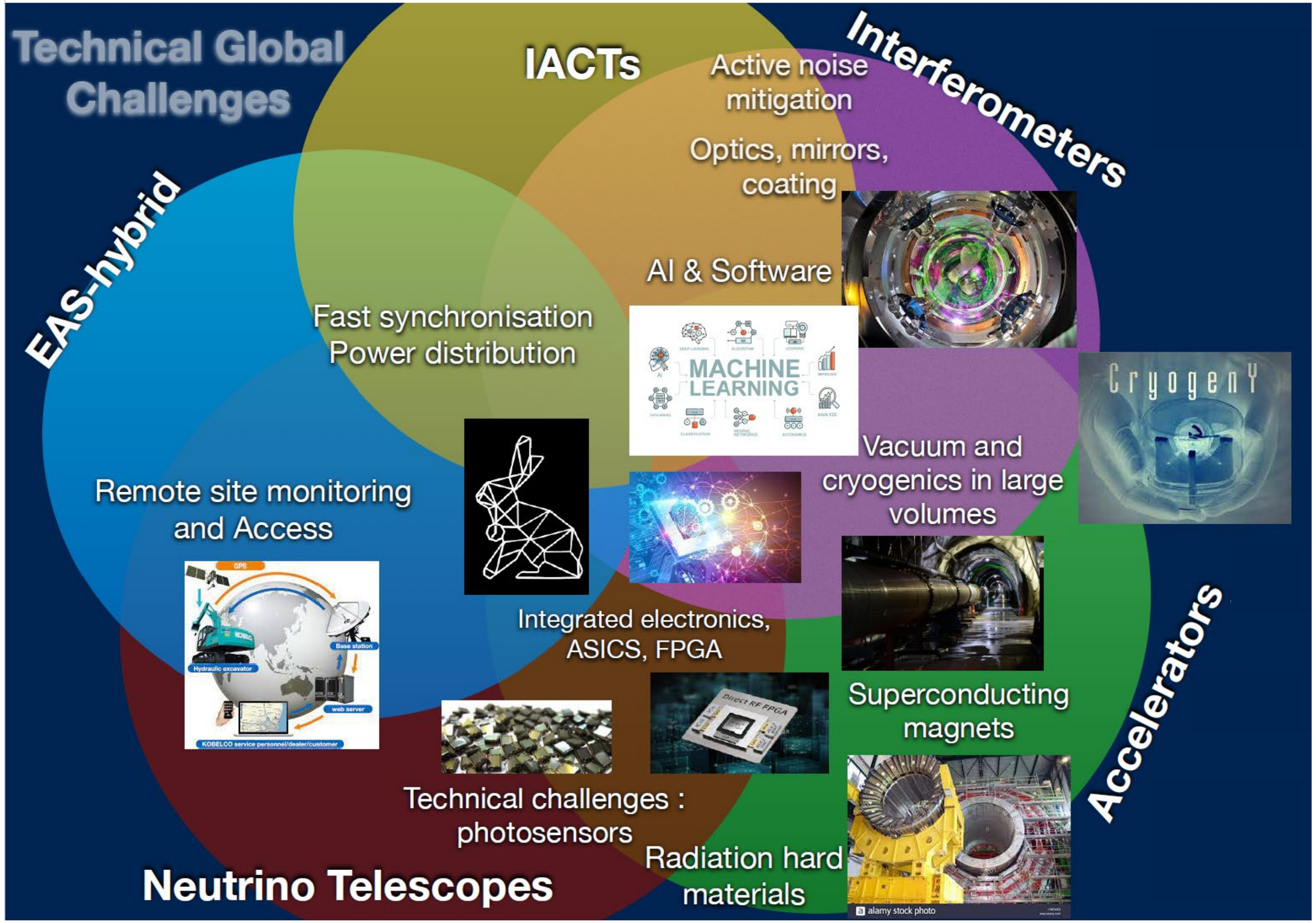
SENSE

FET-OPEN exchange
https://www.sense-pro.org

- Next Tech Forum foreseen to be held in Prague focused on

Robotics and operation of detectors in harsh environment

APPEC platform



Teresa Montaruli

JENA Activities

- Cooperation of nuclear, particle and astroparticle physics communities, represented by the three committees / consortia ECFA, NuPECC, APPEC
  - Joint Seminars
    next: 3-6 May 2022 in Madrid
  - Expression of Interest Topics (next slide)
  - Diversity Charter
  - Recognition Working Group
  - Following/supporting ESCAPE https://projectescape.eu/

  - …in general, shaping future of the field(s)

http://nupecc.org/jenaa/

JENAA
Joint ECFA-NuPECC-APPEC Activities

JENA EoIs

http://www.nupecc.org/jenaa/?display=eois

APPEC

JENAS Expressions of Interest

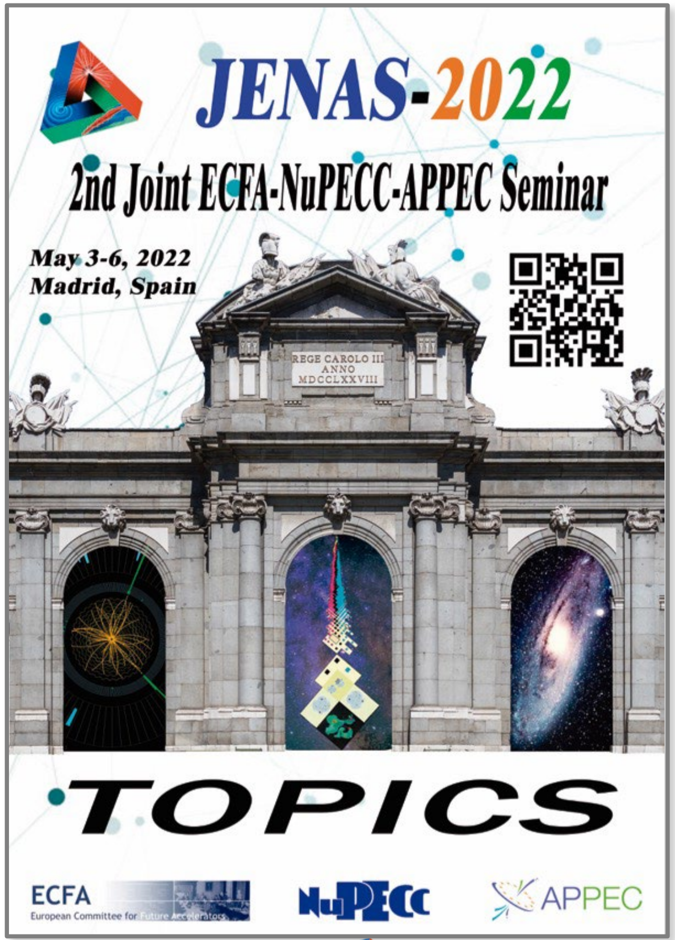
1. Dark Matter - iDMEu (https://indico.cern.ch/event/869195/overview)
2. Gravitational Waves for fundamental physics (https://agenda.infn.it/event/22947/overview)
3. Machine-Learning Optimized Design of Experiments - MODE (https://userswww.pd.infn.it/~dorigo/MODE.html)
4. Nuclear Physics at the LHC (https://indico.ph.tum.de/event/4492/)
5. Storage Rings for the Search of Charged-Particle Electric Dipole Moments (EDM) (https://indico.ph.tum.de/event/4482/overview)
6. (Soon new one: Physics of Electron-Ion Colliders)

APPEC Task Force Representatives in 1., 2., 3., 4., (6.)

JENAA
Joint ECFA-NuPECC-APPEC Activities

JENA Seminar

- 2nd JENA Symposium: 3-6 May 2022 in Madrid, Spain
- Balanced Program over Nuclear Physics, Particle Physics, Astroparticle Physics, focussing on synergies
- Special Session with invited Funding Agencies
  - 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

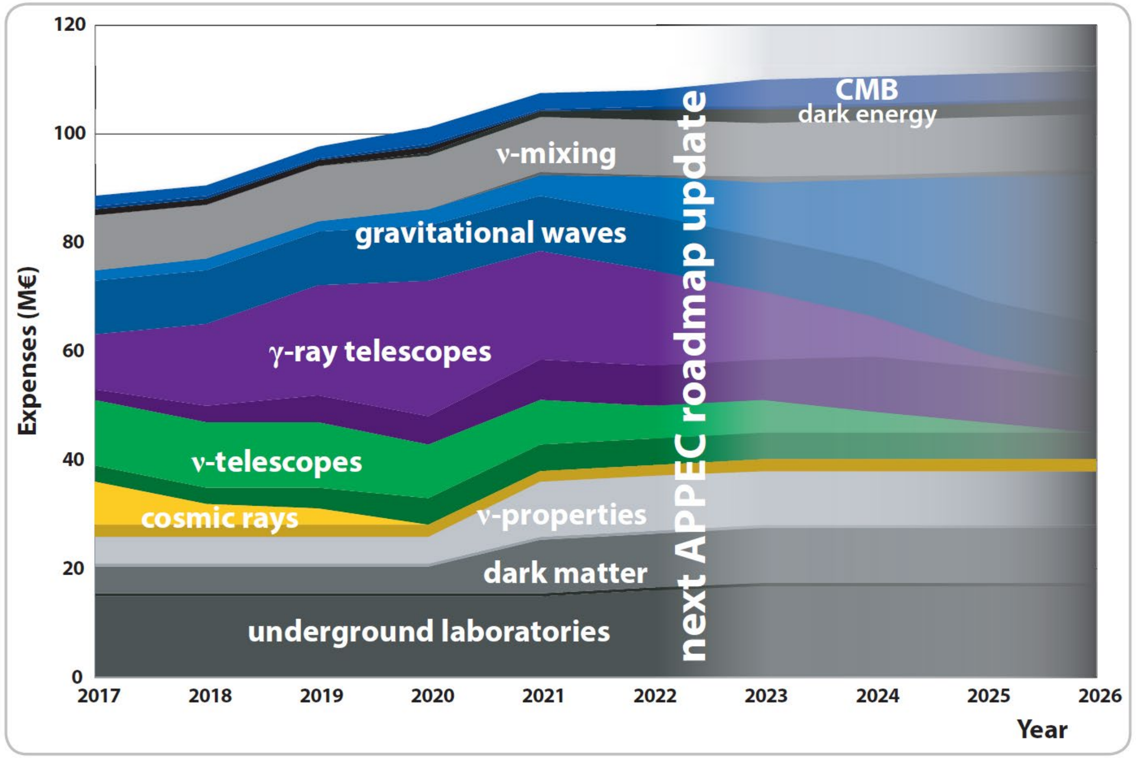


JENAA
Joint ECFA-NuPECC-APPEC Activities

Midterm Evaluation of the Roadmap

- Diverse program with request of large infrastructures
- Balanced plans for investments
- General shift in schedule due to slow realizations
- Prize tags needs to be cross-checked
- Societal and environmental impact as well as economic and ecological footprint and sustainability are becoming more and more important
- Is Astroparticle Physics too expensive?

  Compared to what? I believe, 100 MEuro/year from Europe for such extensive research is little money.



Summary

- Astroparticle Physics is a booming and blooming field
- Looking to unravel the wonderfulness of the cosmos
- Going to understand the fundamental law of Nature
- Plenty of opportunity for young scientists

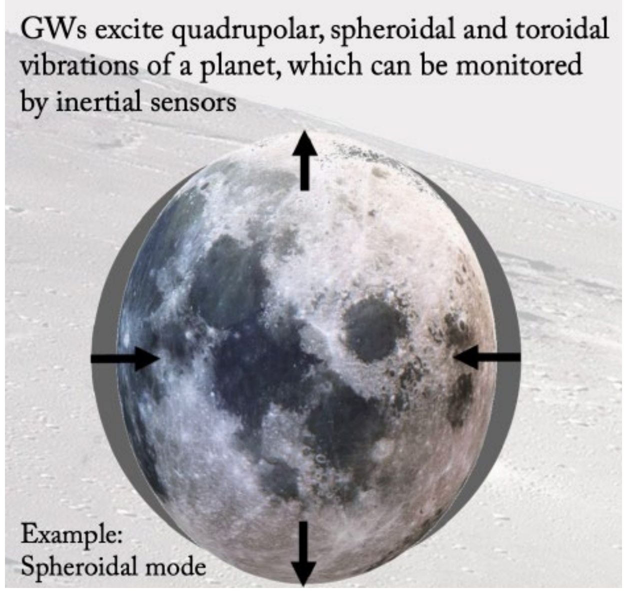
APPEC:

- Town Meeting (midterm evaluation of Roadmap) in 2022
- ECFA R&D Roadmap: see https://indico.cern.ch/event/957057/
- Astronet Roadmap update https://www.astronet-eu.org/
- APPEC Newsletter: https://www.appec.org/latest-news/newsletters

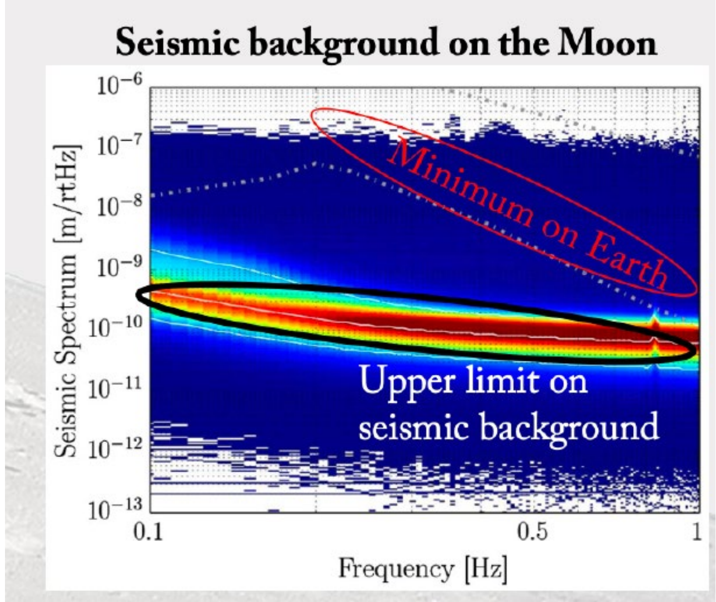
…and further foster and coordinate the European Astroparticle Physics!

Outlook…. …to the Moon

- Moon as gravitational wave detector
- Readout through seismometers, e.g.
- Deployment of seismometers by moon lander
- Synergies with LISA (1mHz - 1Hz)



J.Harms



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