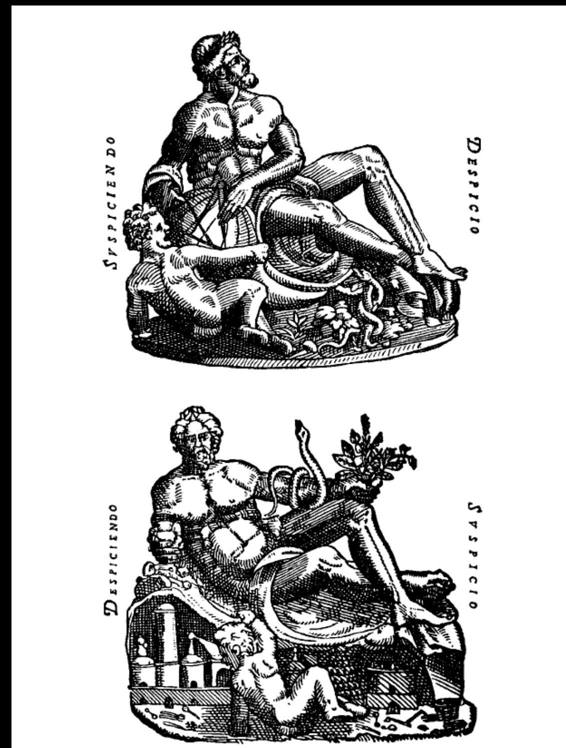
Astroparticle Physics in Europe

Physics and programmatic challenges

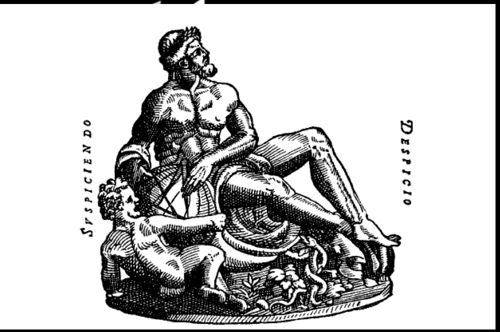


Looking up
I am in fact
looking down

Looking down
I am in fact
looking up

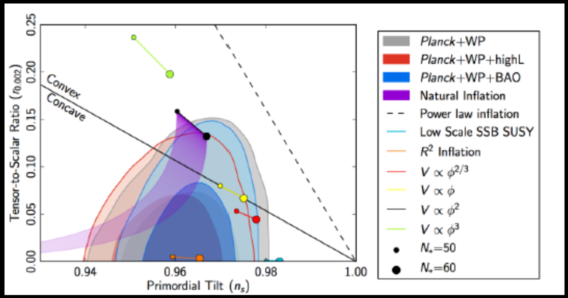
From the frontispiece of Tycho Brahe's Uranienborg

Stavros Katsanevas
APPEC Chairman, Univ. Paris VII, IN2P3/CNRS

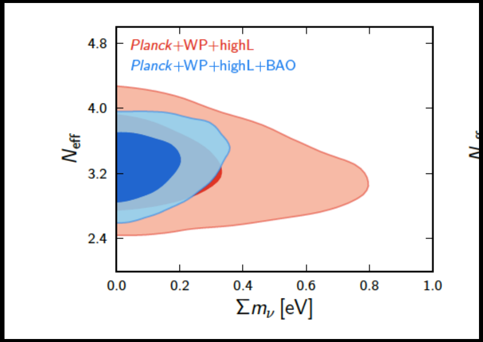


Looking up: PLANCK lessons

$$n_s = 0.9608 \pm 0.0054$$



- n_s=1 excluded at 7 σ ➔ Inflation
  - In a year with polarisation data r ➔ 0,03 will be probed



- Number of effective neutrinos closer to 3

- Sky maps of clusters, dark matter (WL) and violent phenomena

- Smaller number of clusters seen (through SZ) than predicted by CMB.
  - Wrong physics scaling (Y-M)? or
  - We do not understand the transfer function ? e.g. neutrinos in quasi-degenerate region, WDM, etc. Are there "new" particles influencing cosmic structure formation scale formation ?

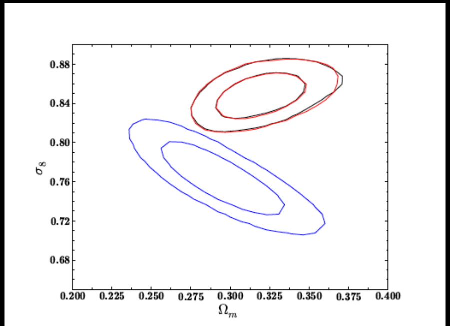


Fig. 11. 2D Ω_m–σ_8 likelihood contours for the analysis with *Planck* CMB only (red); *Planck* SZ + BAO + BBN (blue); and the combined *Planck* CMB + SZ analysis where the bias $(1-b)$ is a free parameter (black).

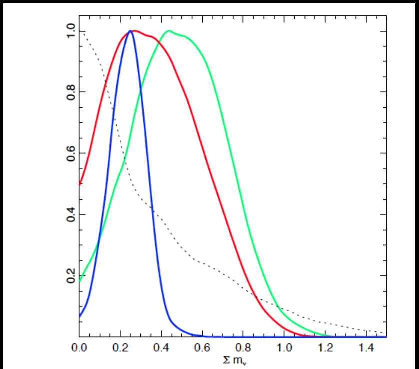
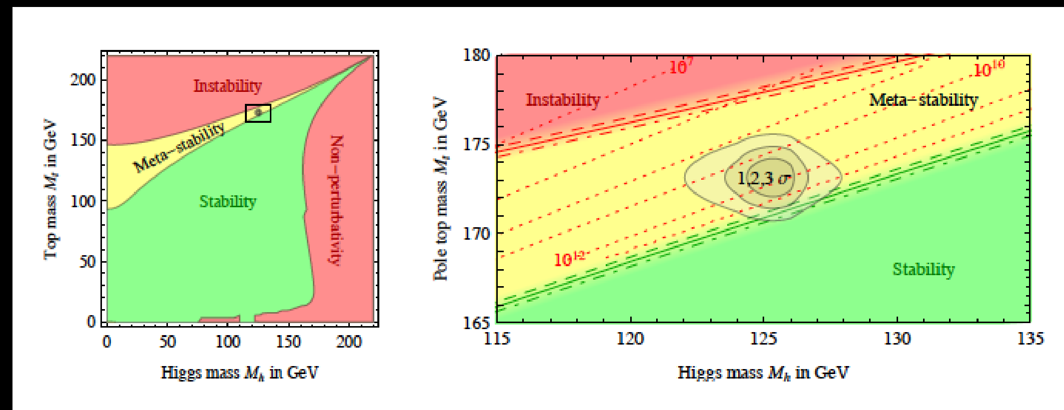
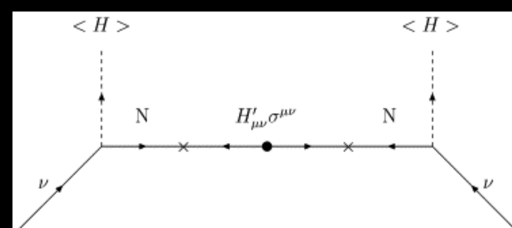


Fig. 12. Cosmological constraints when including neutrino masses $\sum m_\nu$ from: *Planck* CMB data alone (black dotted line); *Planck* CMB + SZ with $1-b$ in [0.7, 1] (red); *Planck* CMB + SZ + BAO with $1-b$ in [0.7, 1] (blue); and *Planck* CMB + SZ with $1-b = 0.8$ (green).

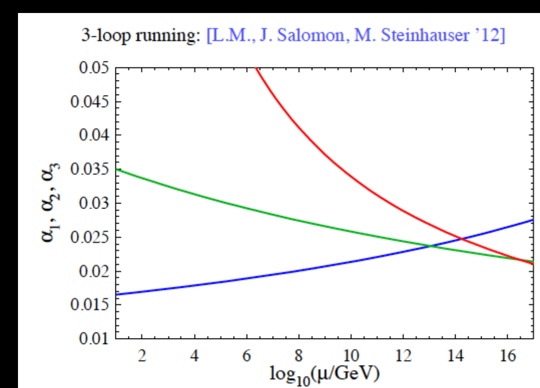
Looking down: LHC and neutrino

- There is no other scale there the EW scale (LHC) and inflation (PLANCK) ?
  - difficult to believe (fine-tuning)
- If there are other scales how many ?
- Are there scales close to inflation ?
  - Neutrino points to a high scale (See Saw) ν, p -decay
- Are there new scales close to the EW
  - Many arguments for a low scale (SUSY) ? Dark-matter
- Do we understand the vacuum ? Cosmological constant Λ, dark Energy



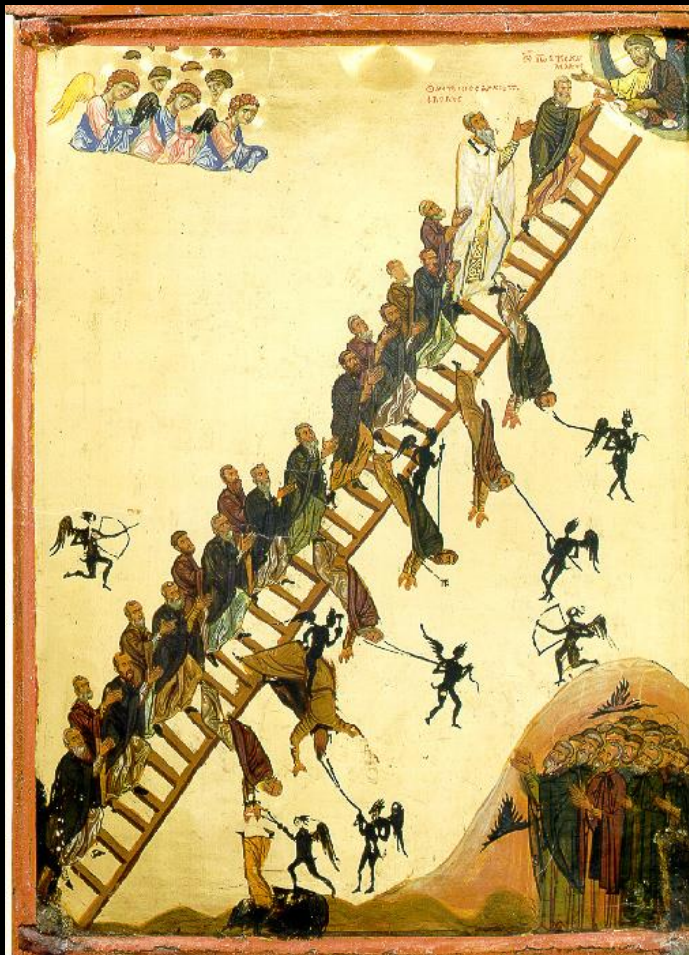


Degrassi et al.



APPEC

Astroparticle Physics in focus
Going up and down the cosmic ladder



The heavenly ladder
of St John of Klimakos , Sinai

The Astroparticle theme after LHC/PLANCK/ν results can be reduced to 2 fundamental questions:

1) Are there any intermediate scales between the EW and Inflation ? If yes how many and where are they ? (TeV, SeeSaw)
    1) Dark matter and energy
    2) Neutrino and proton decay

1) How do the particles and fields of the intermediate scales shape the genesis, evolution and destruction of cosmic structures ?
    1) High energy photons, neutrinos, CR
    2) Gravitational waves

A short history of European Astroparticle Physics Coordination (2001-2013)

✓**2001** Creation of Astroparticle European Coordination ApPEC. Main actions:

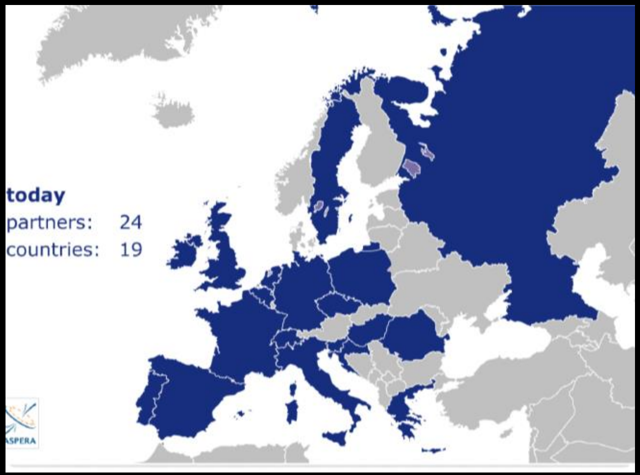
- ✓Survey of the field
- ✓Launch of the EU-I3 ILIAS
- ✓Launch of ASPERA

✓**2006-2012** ERANET ASPERA

- ✓ 6 M€ EU funding
- ✓19 countries and 24 agencies totalling a program of 3000 researchers and 220 M€ consolidated funds
- ✓For the actions see next slides

✓**2012** Creation of Astroparticle European Consortium ApPEC. MoU. Fusion of "old" ApPEC and ASPERA. Direct funding from agencies.

- ✓ well adapted to future EU funding opportunities (ERANET+) e.g. project co-funding (2:1)



Also global coordination efforts

- ✓ 2 roadmap workshops with international agency participation (Brussels 2008, Paris 2011)
- ✓ Initiative for the creation (2011) of the OECD/GSF coordination Group APIF (Astroparticle International Forum)

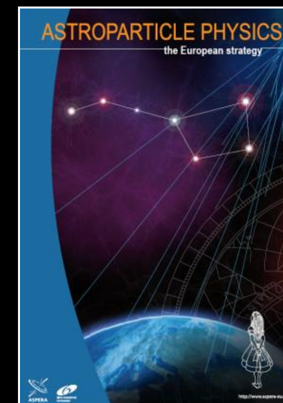
Roadmaps

✓2008 The first Roadmap (the definition of the field):

➔ Dark matter/energy, Neutrino mass and properties

➔ Gravitational waves, High energy photons and neutrinos and Ultra high Energy Cosmic rays, dubbed : the 7 magnificent (we either hang together or…)

➔ No CMB (despite many agency links) To reconsider ?



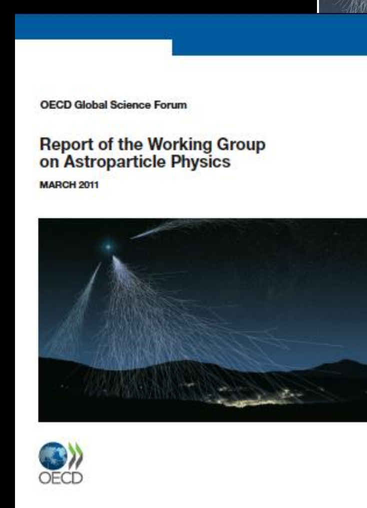
✓2011 The Roadmap update

➔Prioritisation introduced (time ordering)

➔Interface with European Strategy

➔See next slides

✓2010 A global vision document in the context of OECD GSF, basis of APIF ➔ same topics



ASPERA actions during the last 3 years (highlights)

Reports and presentations in www.aspera-eu.org

APPEC

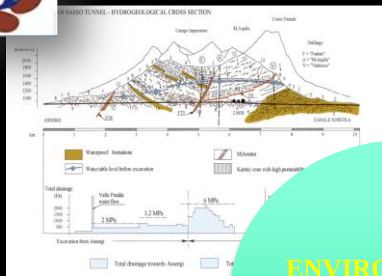
- 3 calls for R&D and Design Studies (agency virtual common pot) total 9 M€
  - Dark matter (DARWIN, EURECA) and CTA (2010)
  - Neutrino mass (GERDA, LUCFIFER) and AugerNext (2011)
  - Low energy neutrino (LENA, ORCA,PINGU) and ET (2012)
- Interdisciplinary connections (Geosciences, Biodiversity, Climate, Applications)
  - **From the Geosphere to the Cosmos (Paris Dec2010)**
  - **Underwater Science (Amsterdam May2012)**
  - **Underground science (Durham Dec2012)**
- Industrial contacts and innovation
  - Photosensors and Electronics (Munich October 2010)
  - Mirrors and Lasers (Pisa Oct2011)
  - Cryogenics and Vacuum (Darmstadt March2012)

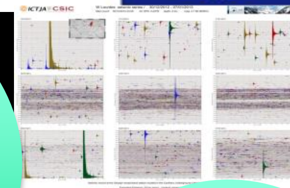
- Towards a computing model for Astroparticle
  - From signal driven(GW), through event driven (CR) to map driven (DE)
  - Lyon Oct2010, Barcelona May2011, Hannover May 2012
- Project management guidelines for large projects
  - Gran Sasso 2012

Underground Synergies with Astro-particle Physics: Multi-Disciplinary Studies in the World's Deep Underground Science Facilities

17-19 December 2012 *Durham, UK*

ASPERA · BOULBY UNDERGROUND LABORATORY · Science & Technology Facilities Council · SEVENTH FRAMEWORK PROGRAMME · Durham University

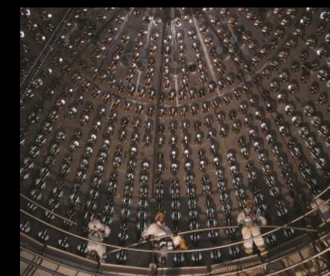




GEODYNAMIC MONITORING

ENVIRONMENTAL RADIOACTIVITY MEASUREMENTS

EARTH FORMATION AND HEAT CONTENT



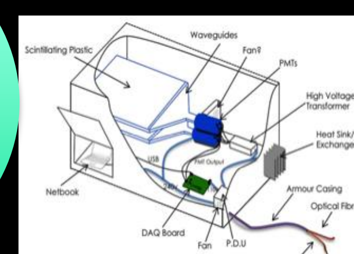
Underground synergies with Astroparticle physics

APPLIICATIONS: WINE DATING, SOFT-ERROR RATES IN ELECTRONICS, ETC

AEROSOL FORMATION (CLIMATE CHANGE)

LIFE ON EARTH AND BEYOND (BIODIVERSITY/ASTROBIOLOGY)

CARBON CAPTURE AND STORAGE (CLIMATE CHANGE)



Astroparticle Physics European Consortium (ApPEC)

APPEC

Strategic objectives

- ✓ **Provide a forum for the coordination** of European Astroparticle Physics;
- ✓ Develop and update **long term strategies (roadmap)**
- ✓ Participate in the **European scientific strategy (CERN,ESFRI)**
- ✓Develop closer relationships **CERN, JINR, ESA and ESO**;
- ✓Express collective views on Astroparticle Physics in international fora (APIF)

Implementation objectives

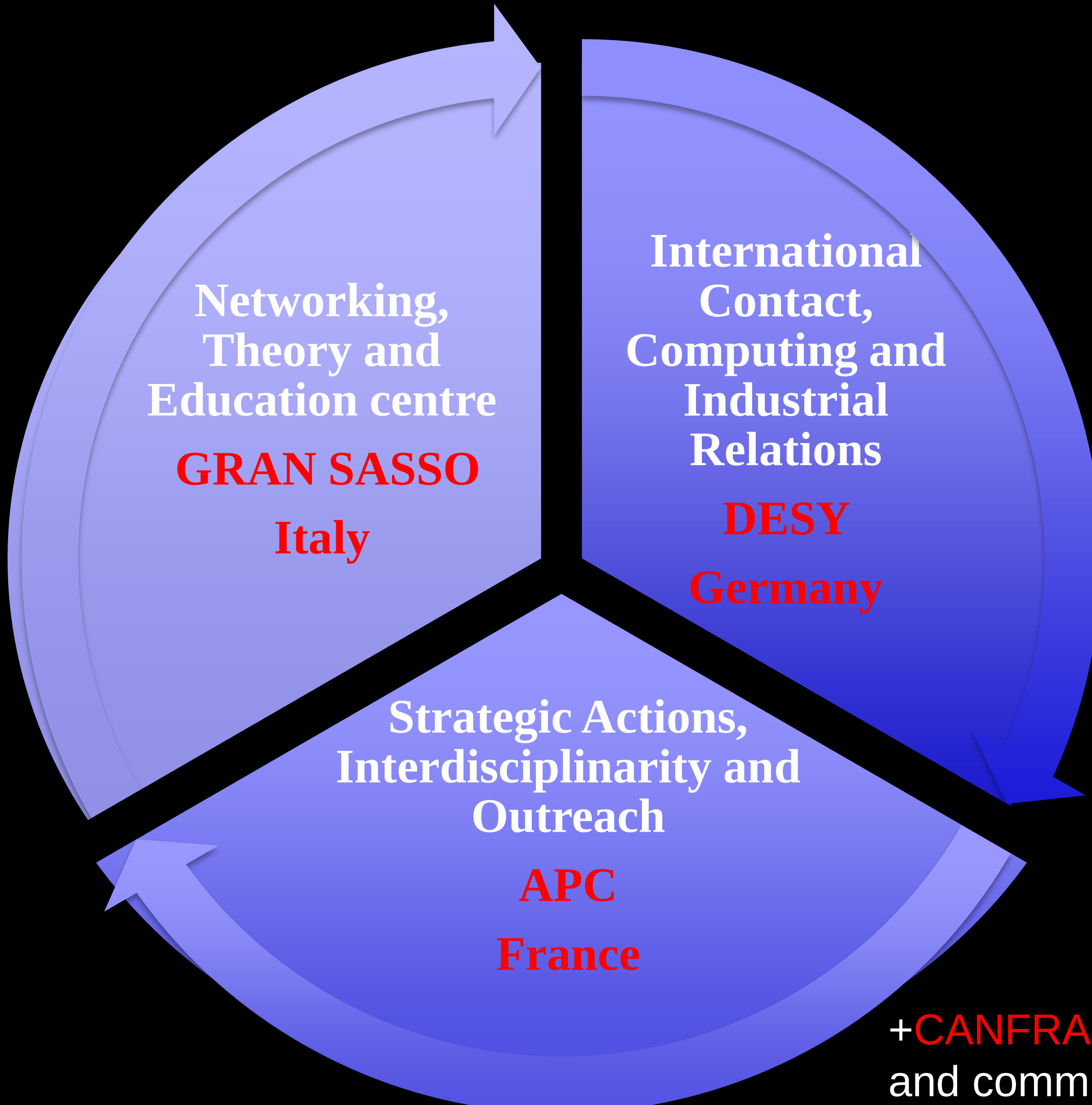
✓Facilitate and enhance **coordination between** existing/developing **national activities**;
✓Develop a **common action plan** for large Astroparticle Physics infrastructures;
✓Facilitate the **convergence of future large scale projects/facilities**;
✓Provide **organisational advice** for the implementation of **large scale projects/facilities**
✓Launch common actions including **common calls funded by a virtual common pot**
✓Initiate and guide **activities funded by the European Commission** (e.g. ERA-NET+);

Structure

✓**the General Assembly**, strategic, decision-making and supervisory body
- ✓(Chair: S. K, vice chair: J. Seed)

✓**the Joint Secretariat (JS)**, executive body . General Secretary T. Berghoefer
✓**the Scientific Advisory Committee (SAC)**, advisory body. In formation.

APPEC



+CANFRANC/Spain, web and communication

The structure is based on the work of 3 functional centres employing with agency funds, 7 officers and administrative personnel.

ApPEC activities in 2013 *(highlights)*

- 2 large community/agency meetings
  - *Astroparticle and Particle Physics at the Crossroads (invite foreign agencies)*
    - Inaugural SAC meeting at APC/Paris 7-8 October 2013
  - *Preparation for the European Horizon 2020 , (2014-2020), DESY November*
    - NEW: Underground labs, Gravitational waves preselected for Integrated activities
    - ERANET+ , common calls with 1/3 EU participation
    - Marie Curie fellowships

- Linking and institutional forms of large infrastructures
  - Coordinate demands for ERICs for Underground labs, Gravitational antennas, CTA, KM3NEt

- Linking Theory
  - Organize Santa-Barbara type continuing workshops around Europe
    - the first in Madrid during summer around Cosmology ?
  - Coordinate postdoc recruitment ?

Also New web site and astroparticle letter

Projects approved
ApPEC priority: their timely entry in full operation

- Gravitational wave antenna upgrades
- Neutrino mass
- Dark matter

- Dark Energy *(at the interface with ESA, DOE,NSF,...)*

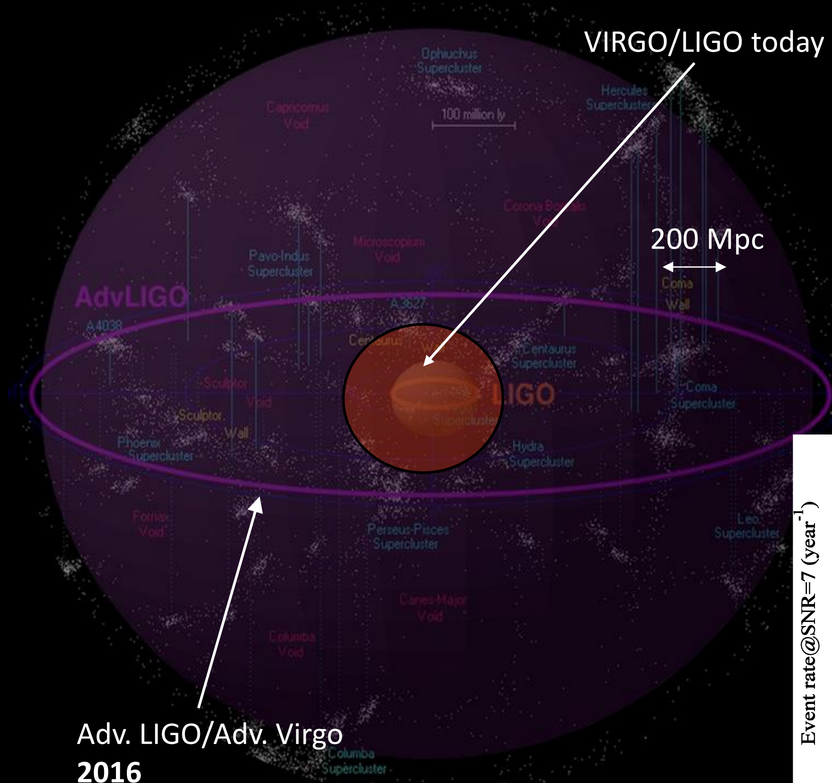
Gravitational waves I
A worldwide antenna network

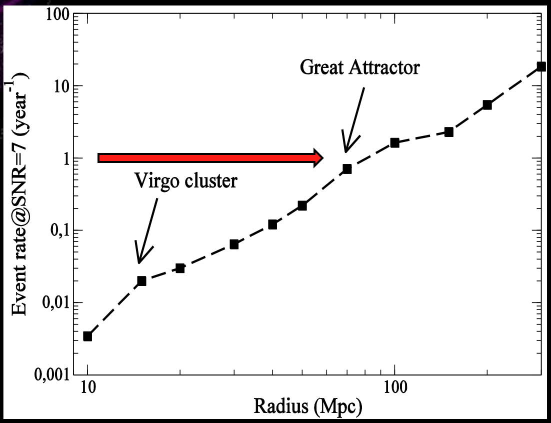
The GWIC community pioneered a network between the gravitational wave antennas in Europe and in the United States (advVIRGO, advLIGO, advGEO, ca 2015-2016) , with sharing of information and techniques, coordinated data-taking and joint publication of results. KAGRA in Japan is expected to join the network soon (2018).

Gravitational waves II

✓ ApPEC priority: the timely completion of the 2nd generation upgrades of gravitational wave antennas (2015)

✓Towards a first detection in 2016-2018



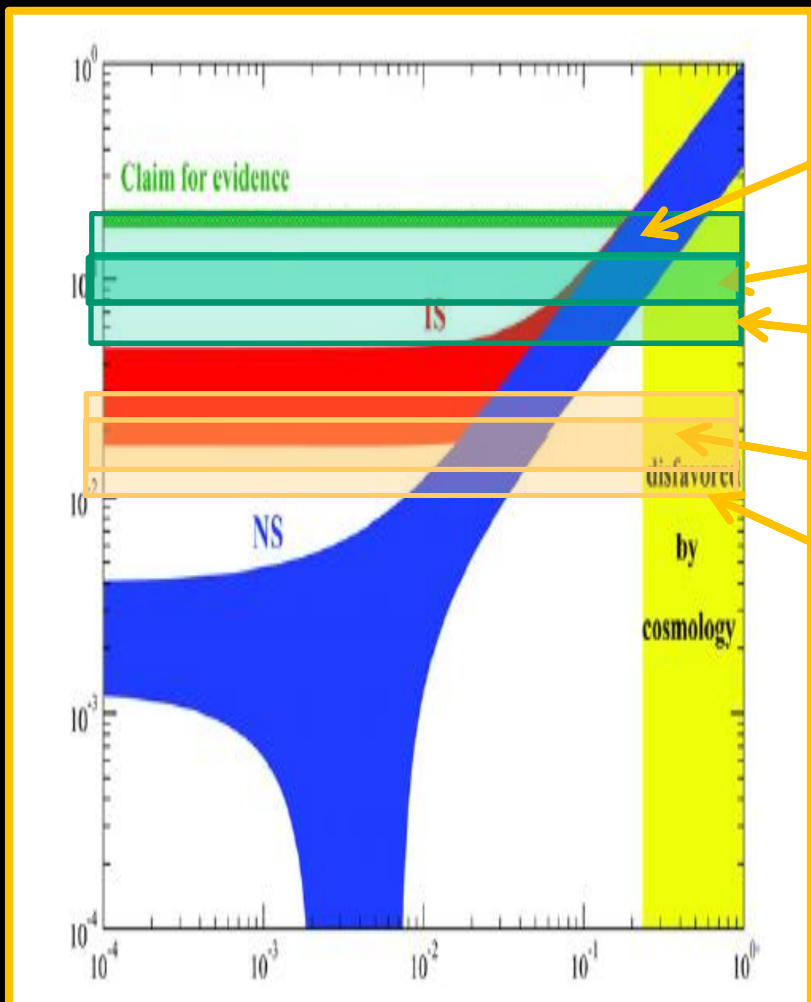


In place for the 100 years of GR

Neutrino mass and nature I

$0\nu\beta\beta$ approaching/exploring the inverted hierarchy

Its theoretical importance cannot be overstated



Ultimate EXO-200 (80-200 meV)
(4 y + Rn removal)

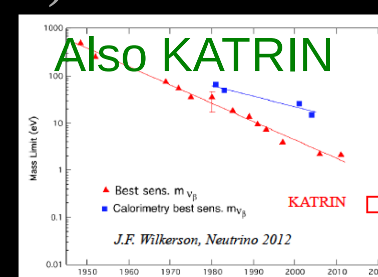
GERDA phase-2 (75 - 129 meV)

CUORE (51 – 133 meV)
SuperNEMO (100Kg,5y)

Scintillating bolometers
(350 kg, 5 y) (13 – 36 meV)

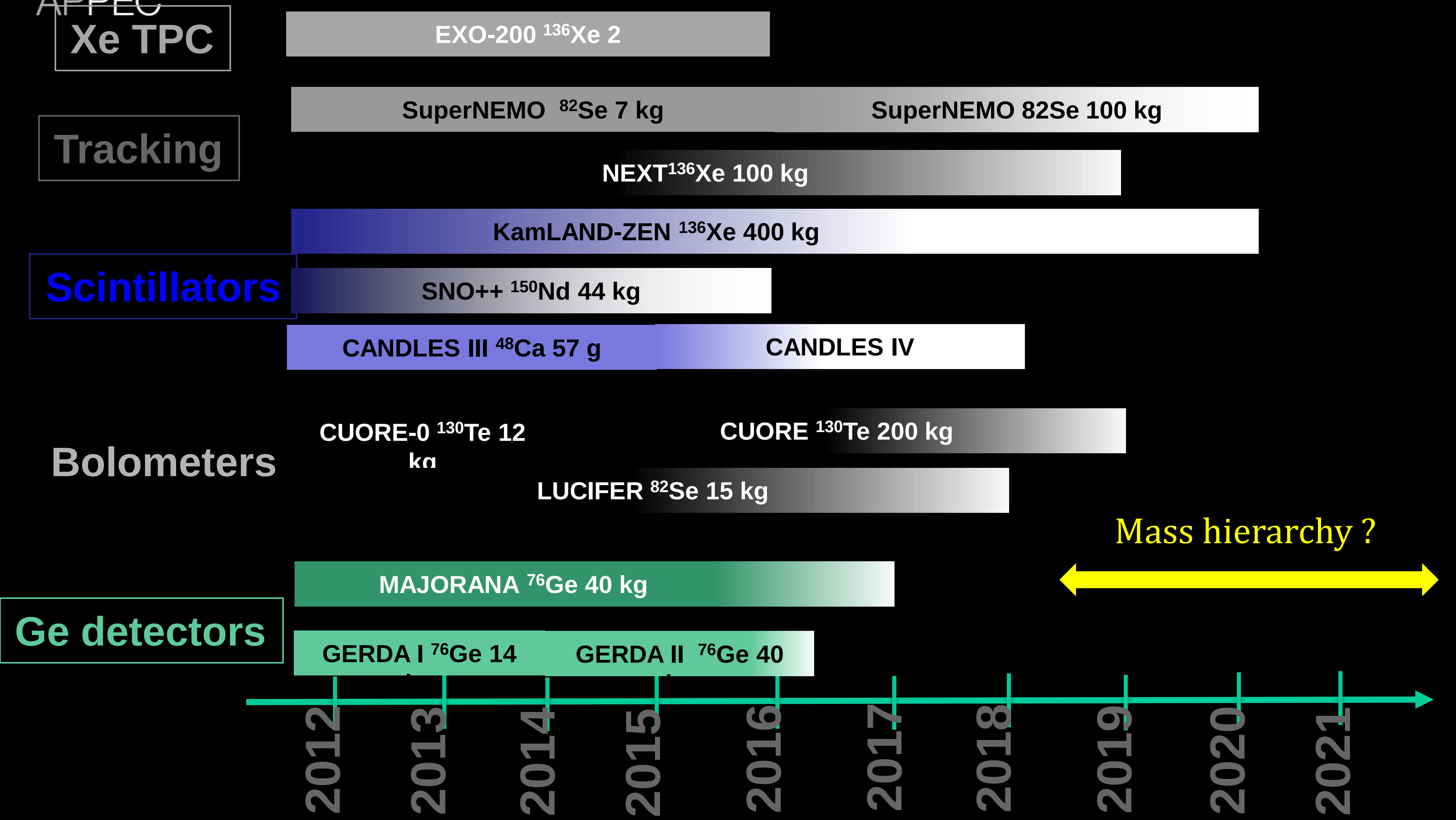
Initial nEXO (EXO-200-like 5 tons, 10 y) (10 – 30 meV)

Similar sensitivites
from GERDA-3
Majorana and upgrade
of KamLAND-Zen

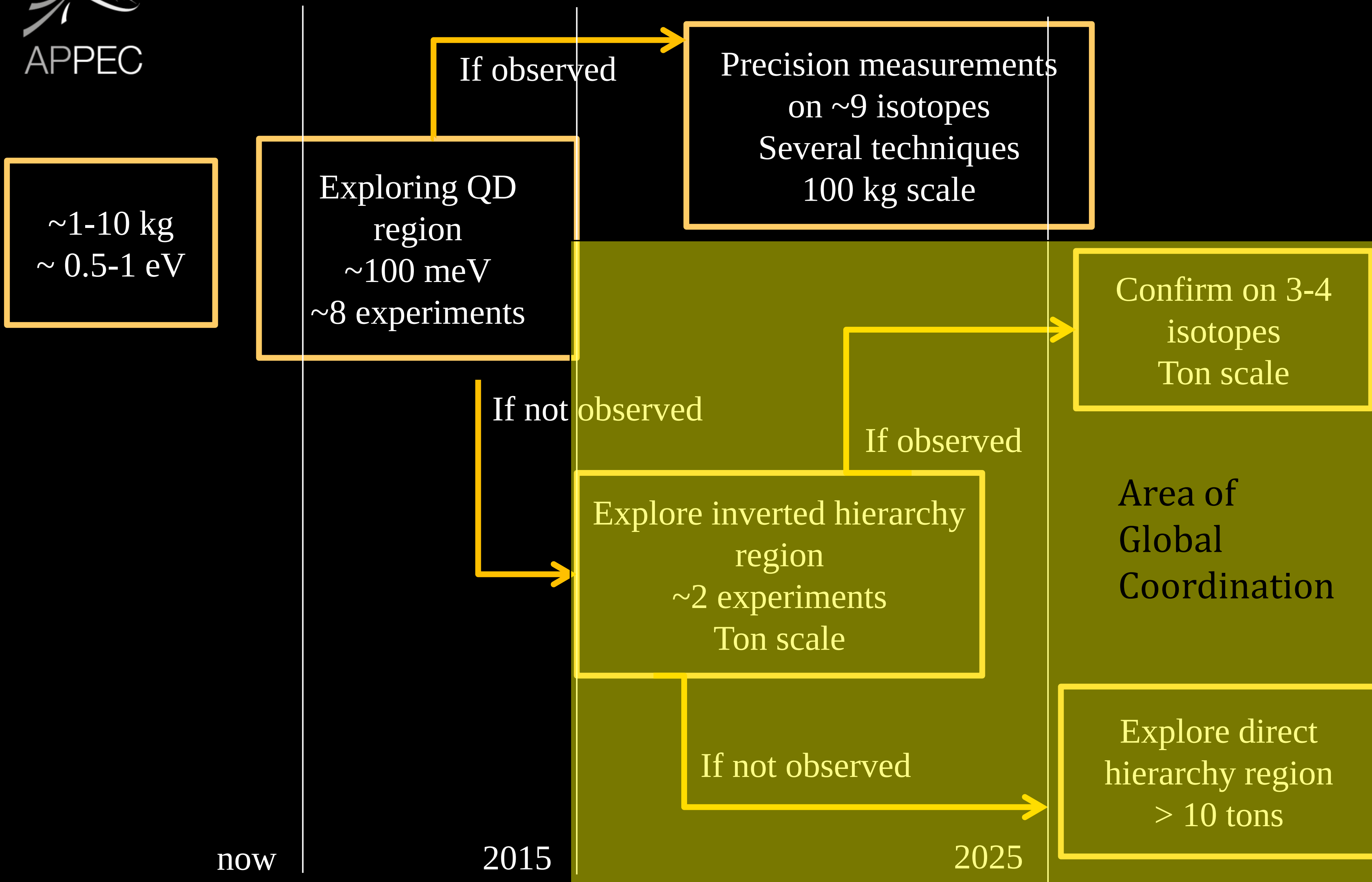


Neutrino mass and nature II

0νββ schedule for 100 Kg phase (courtesy F. Piquemal)



Neutrino mass and nature III
Looking into the crystal ball



A.Giuliani Adapted from Wilkerson, NuMass 2013

Dark Matter I

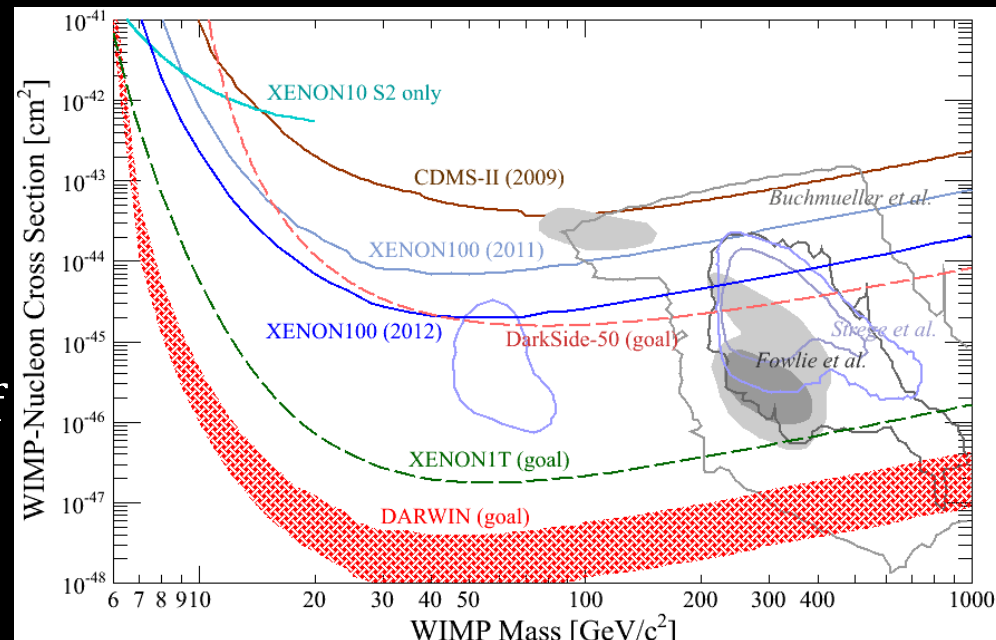
WIMPs will be put in a severe, if not conclusive, test during the next 10 years. (LHC,direct and indirect detection). In case of discovery both accelerator and non-accelerator experiments will be needed to determine the physical properties of _WIMPS.

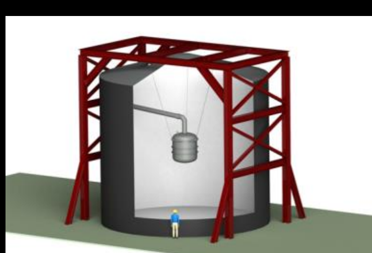
✓ World leading European-US experiment XENON presently in its 100 kg phase and preparing its upgrade to 1ton of detecting material,
✓ Bolometric detectors gathered in the EURECA immediately following in sensitivity and advancing in coordination with their US counterpart CDMS,
✓ Developments in liquid-argon, using argon depleted in ^{39}Ar , (e.g. DarkSide,).
✓ DAMA/LIBRA remains yet to be cross-checked in Europe or elsewhere in the world.

Dark Matter II

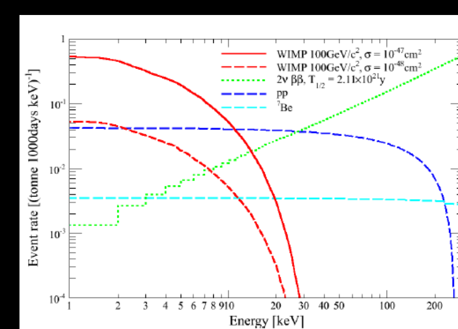
XENON 1t (2015-2017) ➔DARWIN*(2020➔)

•Xenon 1t(funded) : >3t lXe (1t fiducial) 100fold reduction in bckg, Goal < 1 bckg event in 2 years
ApPEC supports:
✓a program to extend the target mass of noble liquids to a few tons (e.g. DARWIN). The choice in favor of a double-target option should be taken after a clear experimental confirmation that a liquid argon target is competitive with liquid xenon.





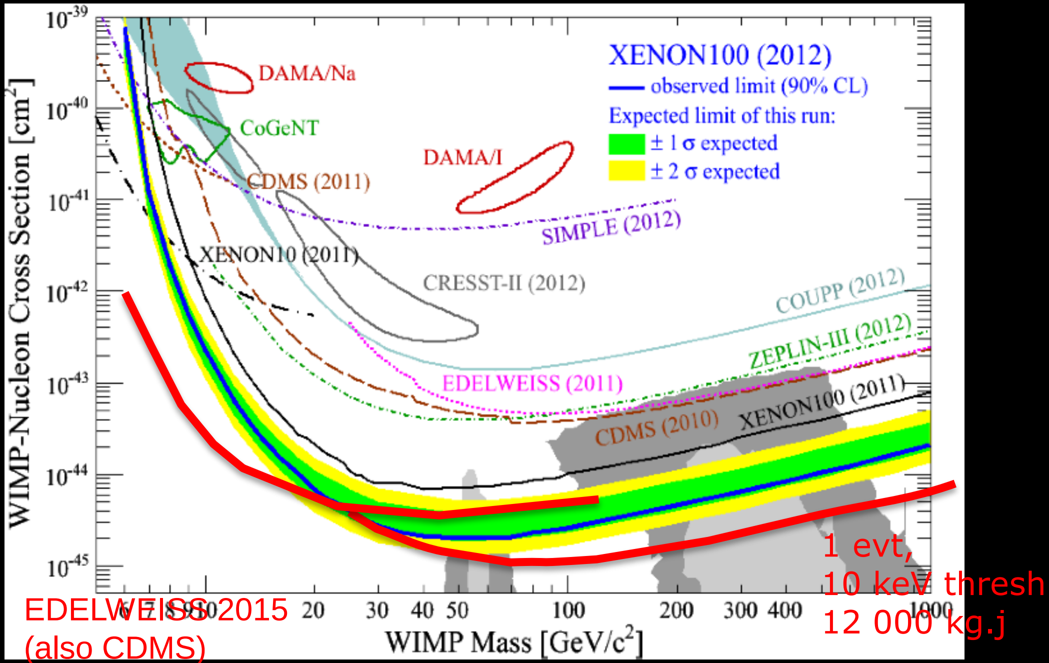
Reaching the limits of solar ν ➔

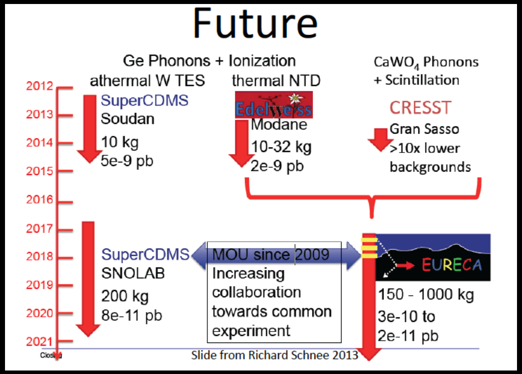


* ApPEC funded design stdy

Dark Matter III
Bolometetric methods

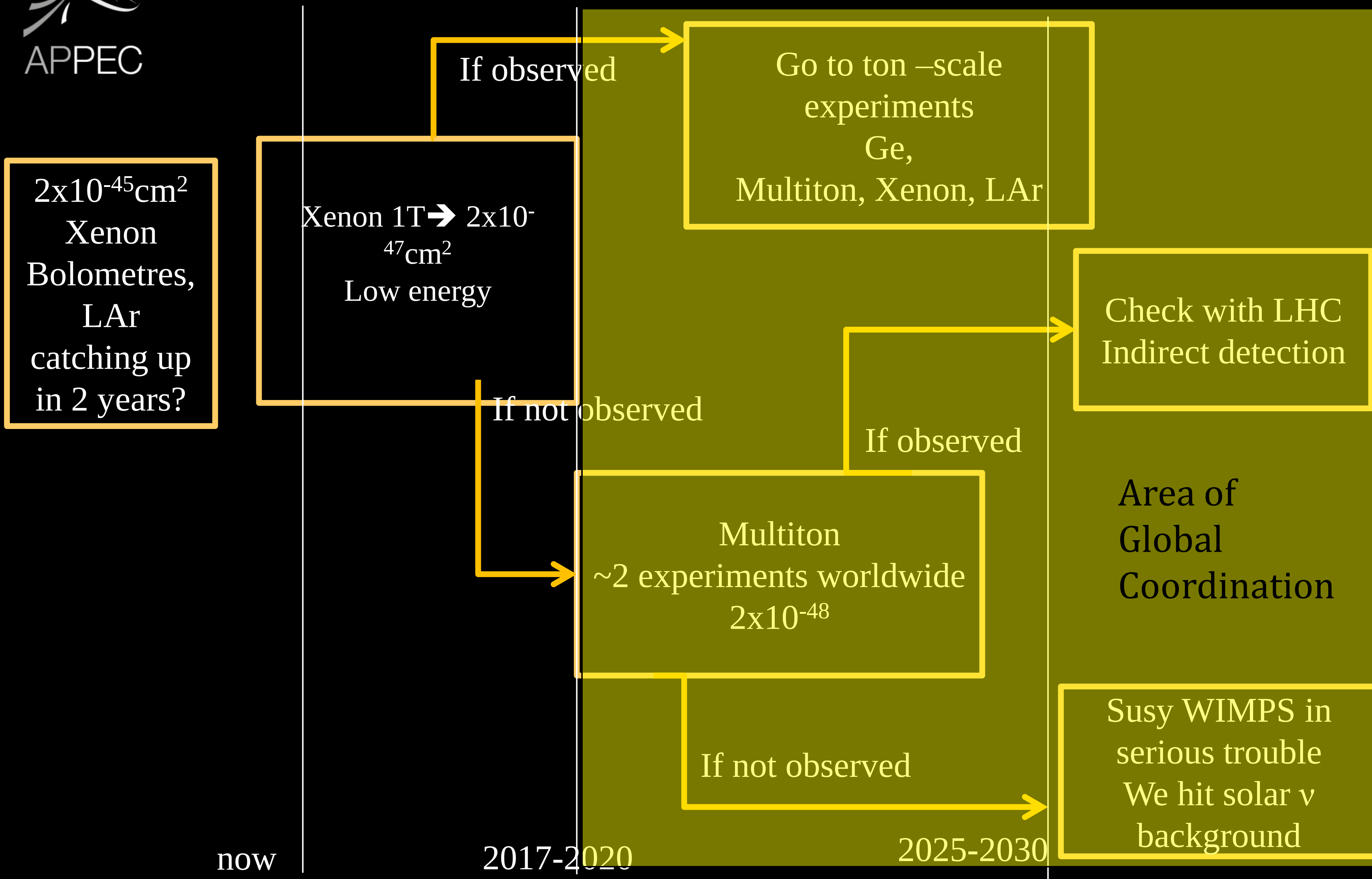
✓the continuation of the bolometric techniques, they have remained competitive with the noble liquid approach in terms of sensitivity, but with a longer time lapse and higher cost. ApPEC supports the development of the multi-target experiment EURECA . In view of the higher cost of these experiments a coordination with the parallel US efforts should be sought.





✓Also the search for axions and axion-like particle candidates for dark mater as well as the R&D activities related to the directional detection of WIMPs.

Dark Matter IV
Looking into the crystal ball



Dark Energy

The communities and agencies have converged to large sky surveys (FoM > 800) with telescopes (first light 2019-2020) :

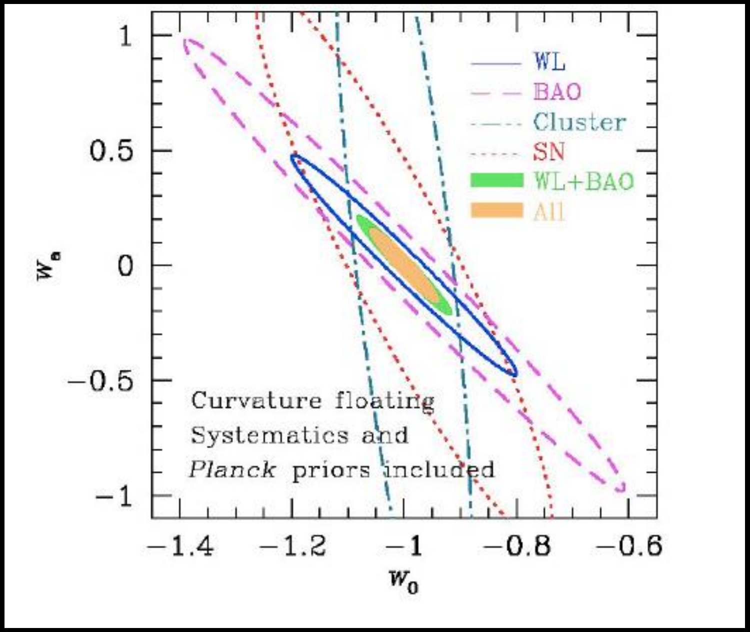
•on ground **(LSST, NSF/DOE, European participation, 8.4m)**

and

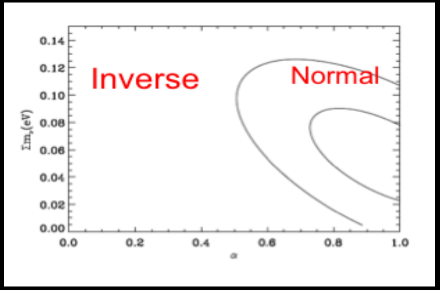
• in space **(EUCLID, ESA, NASA joined, 1.2m)**

•Intermediate program: DES, SUMIRE,MS-DESI

• LSST and EUCLID are complementary in systematics (superior spectroscopy vs absence of atmospheric distortion)



LSST/Euclid will be sensitive to the neutrino mass hierarchy (2022)



From the global coordination point of view:

- *The field has finally a clear long term program with complementary aspects*
- *The data management of e.g. the LSST is challenging and could be scaled in LHC units.*

Under discussion is the issue of data-availability and exchange between LSST and EUCLID, and of course the rest of the world…

APPEC

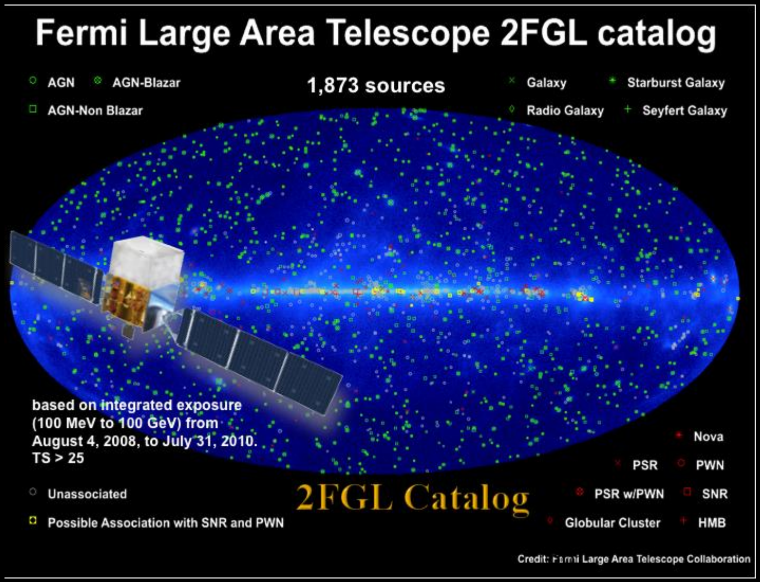
Current challenges
The next generation of large programs

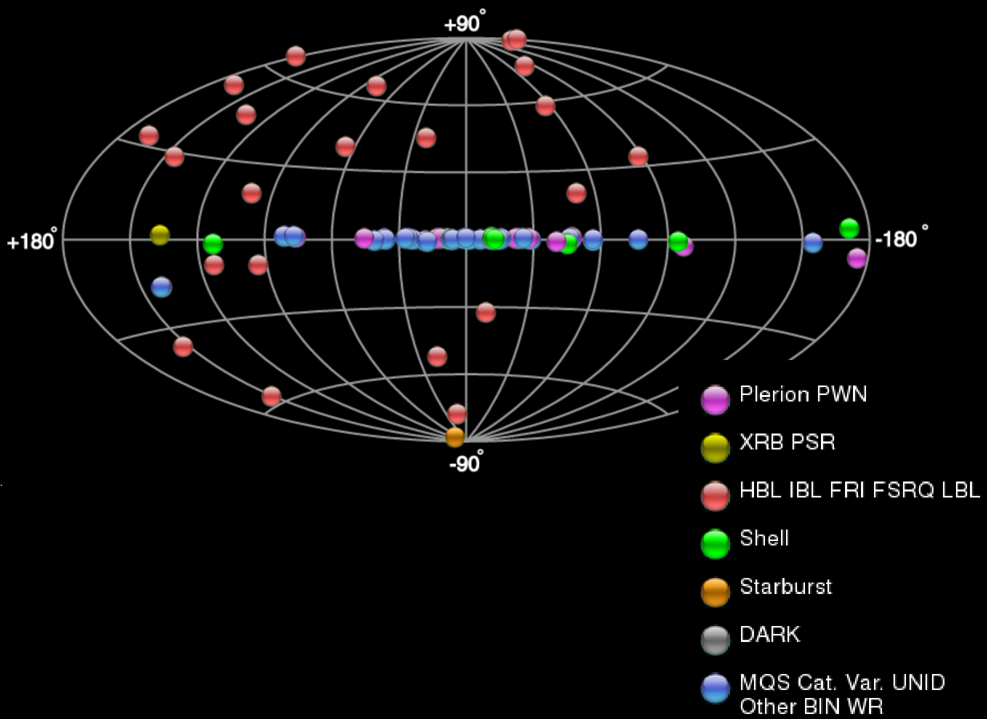
- High Energy photons (CTA)
- High Energy neutrinos (KM3Net)
- Ultra High Energy cosmic rays (AUGER and beyond)

- Neutrino properties, neutrino astrophysics, proton decay *(LAGUNA, at the interface with accelerators)*

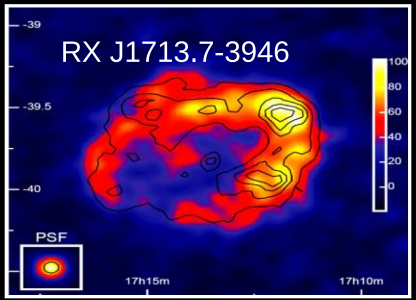
High Energy photons, I

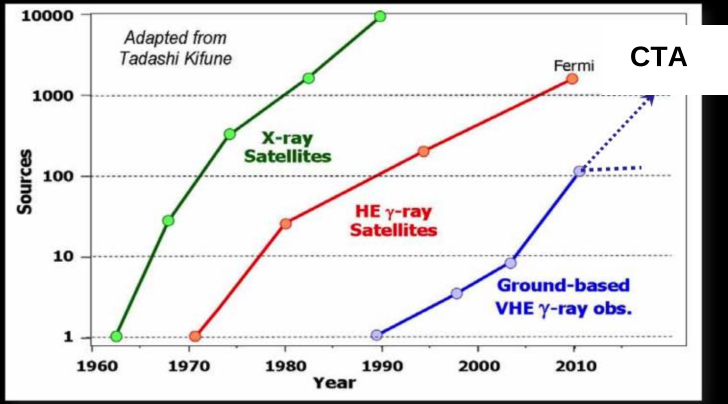
The last 10 years have been the golden age of HE gamma ray astronomy (an order of magnitude more sources at the GeV and TeV) a succes of astroparticle physics





- 1873 GeV sources (FERMI)
- 136 TeV sources (HESS, MAGIC, VERITAS)
- Morphology, Timing





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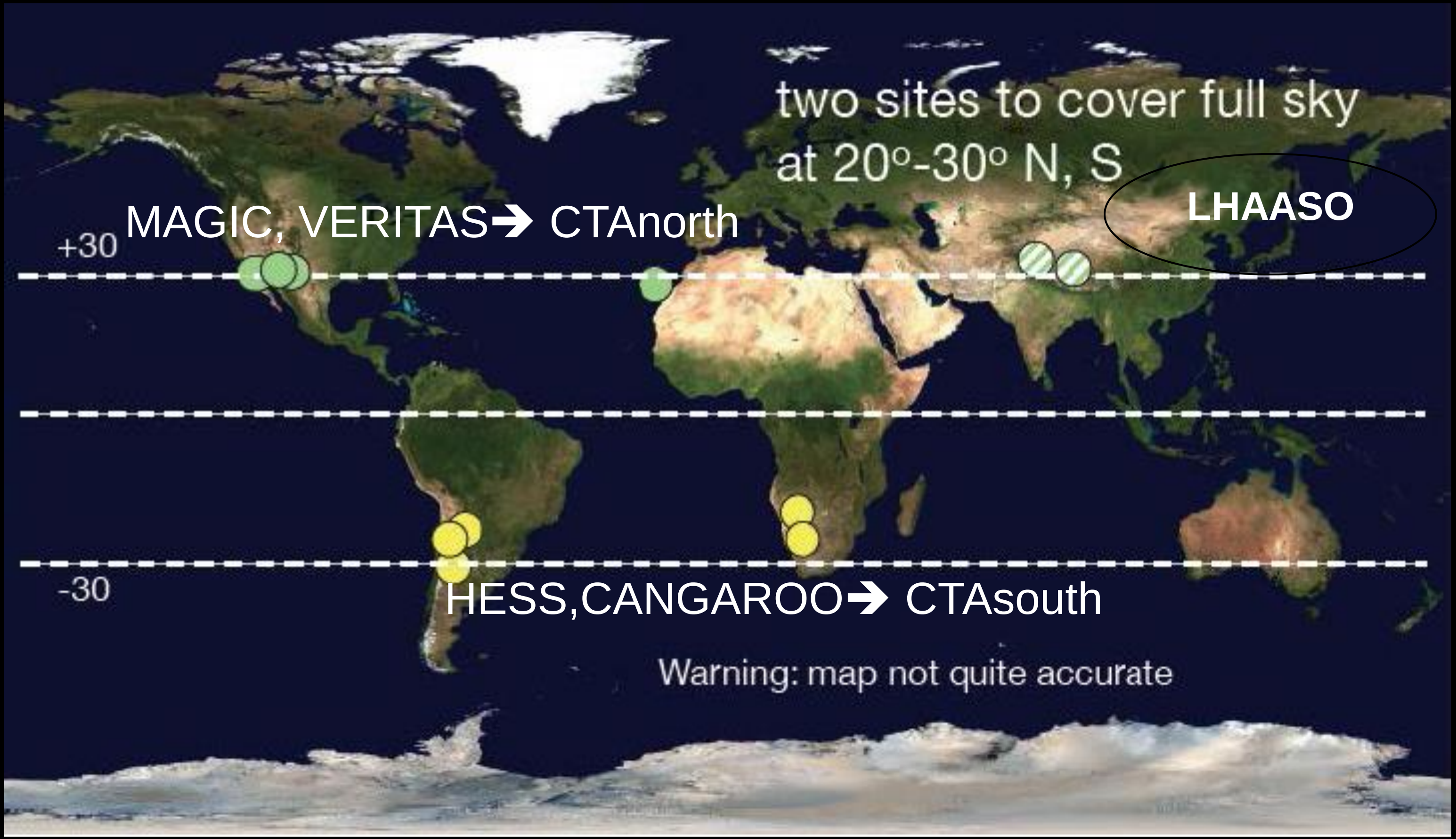
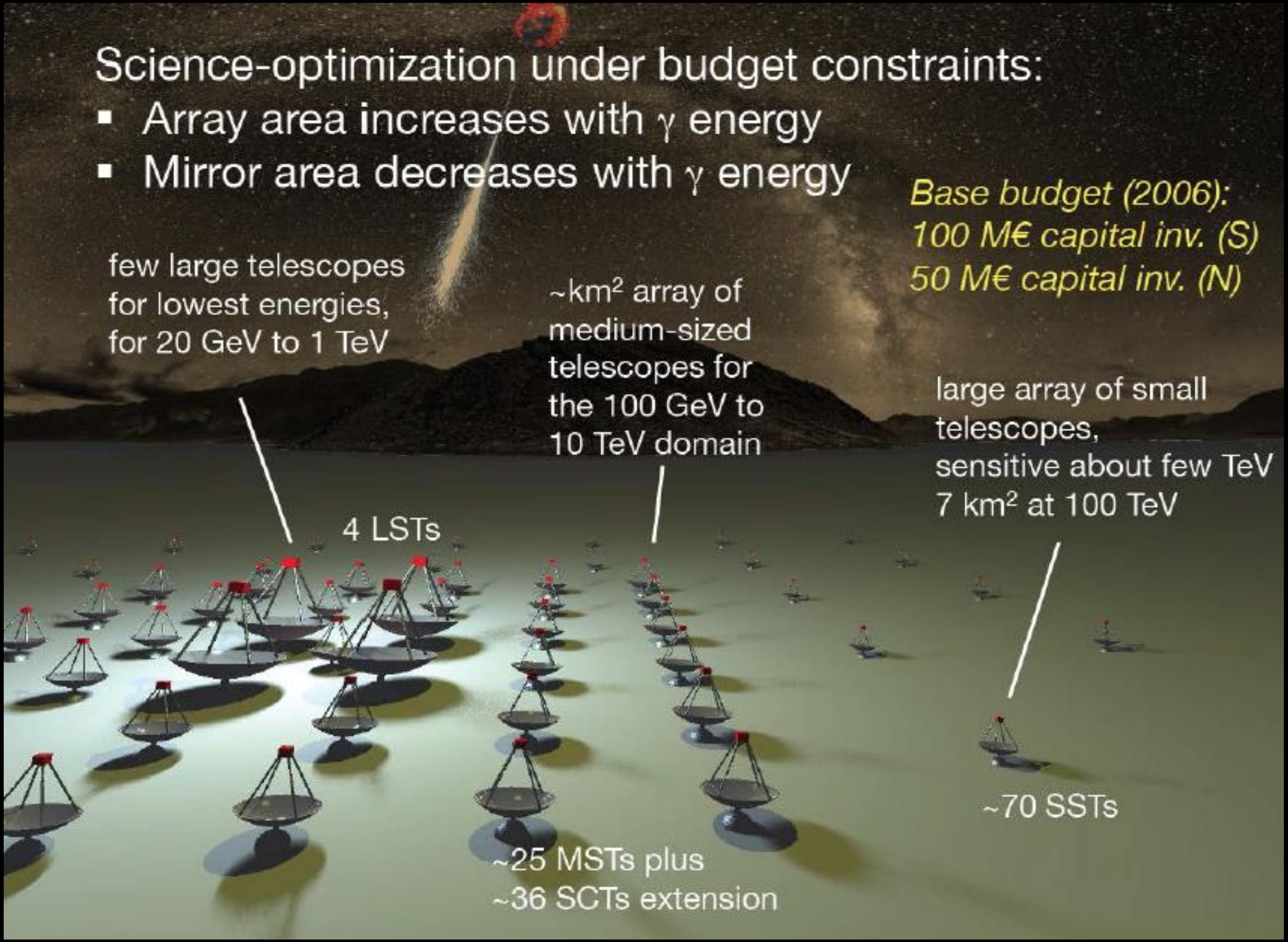
High energy photons, II
Telescopes



In the domain of TeV gamma-ray astrophysics the **Cherenkov Telescope Array (CTA)** is a worldwide priority project. The ambitious time schedule for technical design and prototype development of CTA, as well as the selection of the site(s), is aiming at a start of construction by the middle of the decade. LHASSO in Tibet will have a complementary coverage (100 TeV—PeV)

High Energy photons, III
CTA (27 countries 1000 researchers)



APPEC

High Energy photons, IV
CTA science goals

Addressing key science questions

1. **Where and how are the bulk of CR particles accelerated in our Galaxy and beyond?** Understanding transitions in the CR spectra. *(one of the oldest surviving questions of astrophysics)*

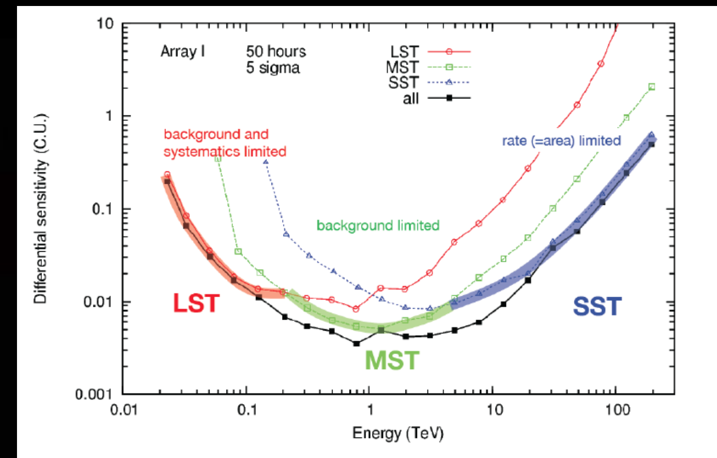
2. **How cosmic-rays propagate, interact, and heat the environment?** Which are the consequences from Galactic to cosmological scenarios?

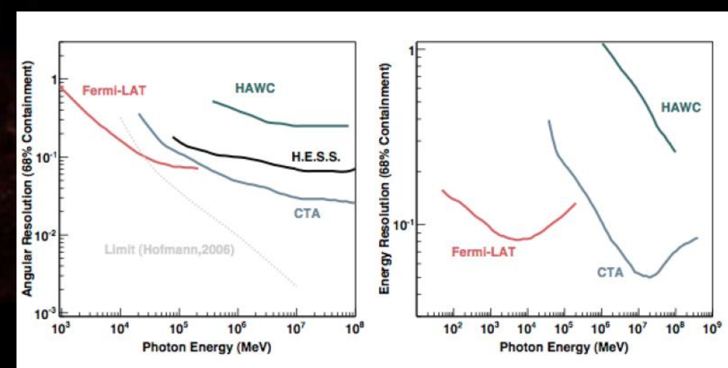
3. **What makes black holes of all sizes such efficient particle accelerators?**

4. **What do high-energy gamma-rays tell us about the star formation history of the Universe, the structure of spacetime, or the fundamental laws of physics?**

5. **What is the nature of dark matter?** Can it be discovered via indirect searches? Can we map dark matter halos?

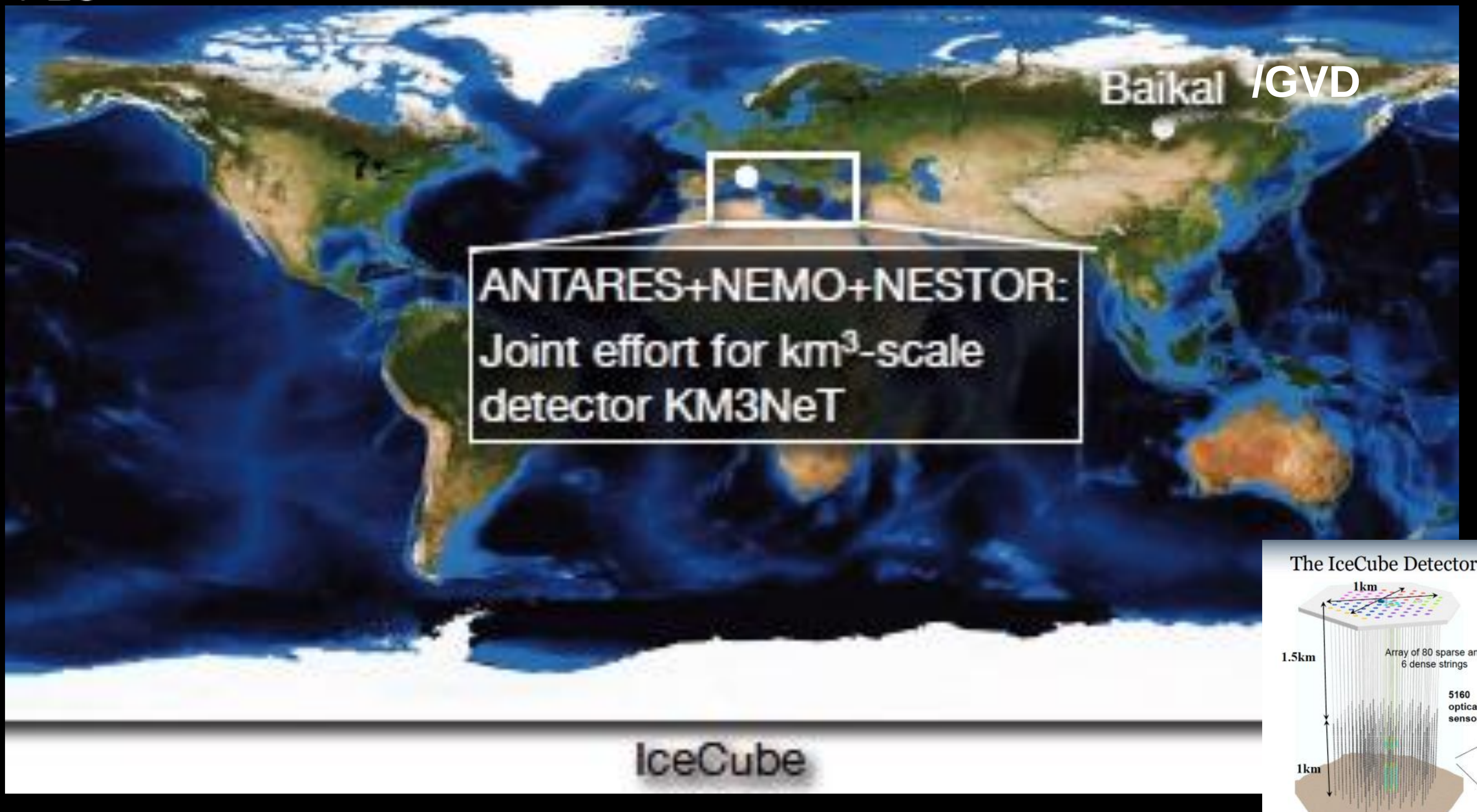
6. **Are there short-timescale phenomena at very high energies? Are GRBs gamma-ray emitter? Is there new Galactic phenomenology to uncover?**





High Energy Neutrino, I

Telescopes

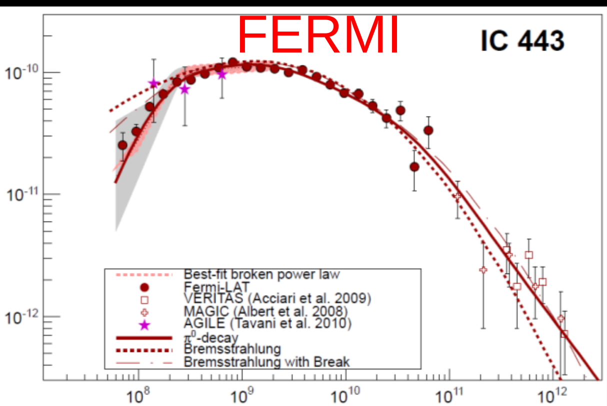


Nothern Hemisphere projects and IceCube move through coordination towards a future Global Neutrino Observatory. First exemple PINGU-ORCA

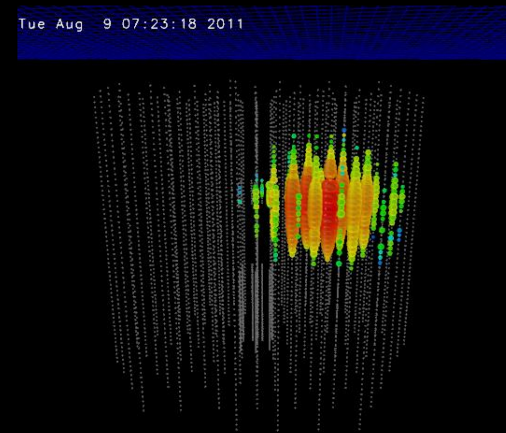
High Energy Neutrino, II

KM3Net, science case

Origin of cosmic rays



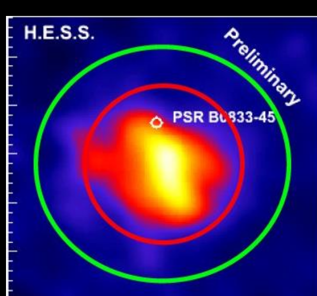
E_γ [eV]



PeV neutrinos Bert, Ernie,...

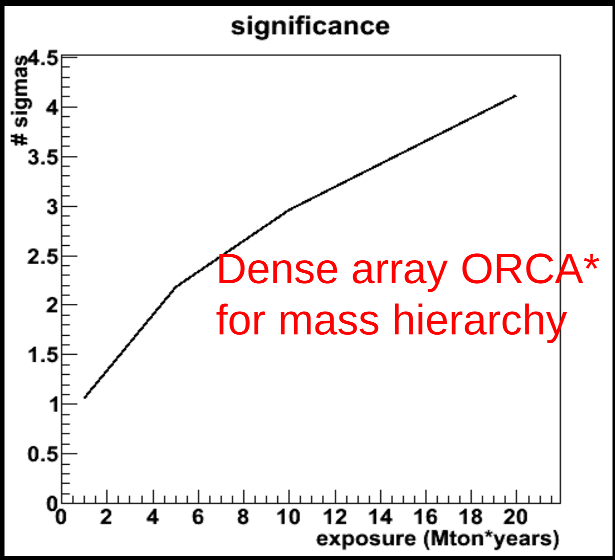
Vela X

RXJ 1713



5σ in 3-5 years

Rich in synergies with Earth and sea sciences



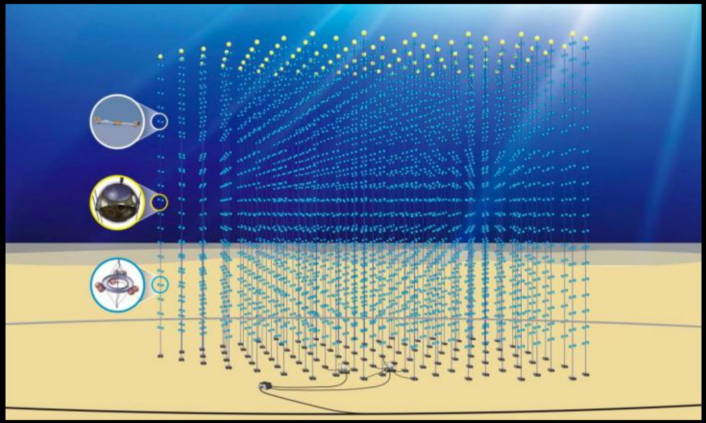
Dense array ORCA* for mass hierarchy

* APPEC funded ORCA-PINGU feasibility study

High Energy Neutrino, II I

KM3Net, Project progress

- Implementation
  - phase-1 (40 M€) granted (majority, structural funds)
  - phase-2 (220–250 M€) subject to future funding
- Management structure set up
- Module construction compatible with multi-site deployment
- Technology agreed
- In the process of deployment of engineering lines
- Successful deployment in Sicily recently
- Presentation to APPEC by M. DeJong

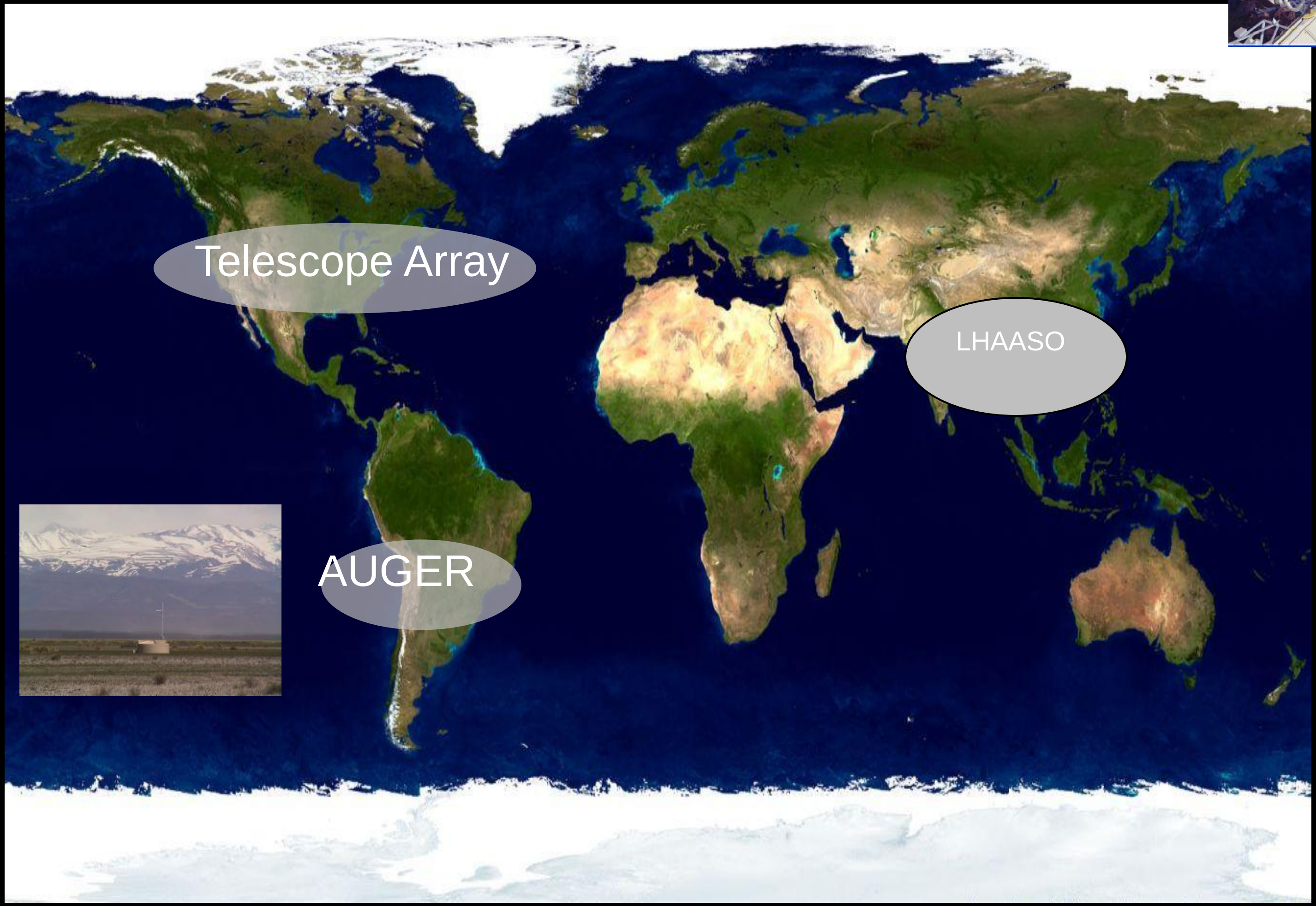


ApPEC: strong support for the first phase of KM3NeT

High energy cosmic ray observatories, I

PAMELA
ATIC
CREAM

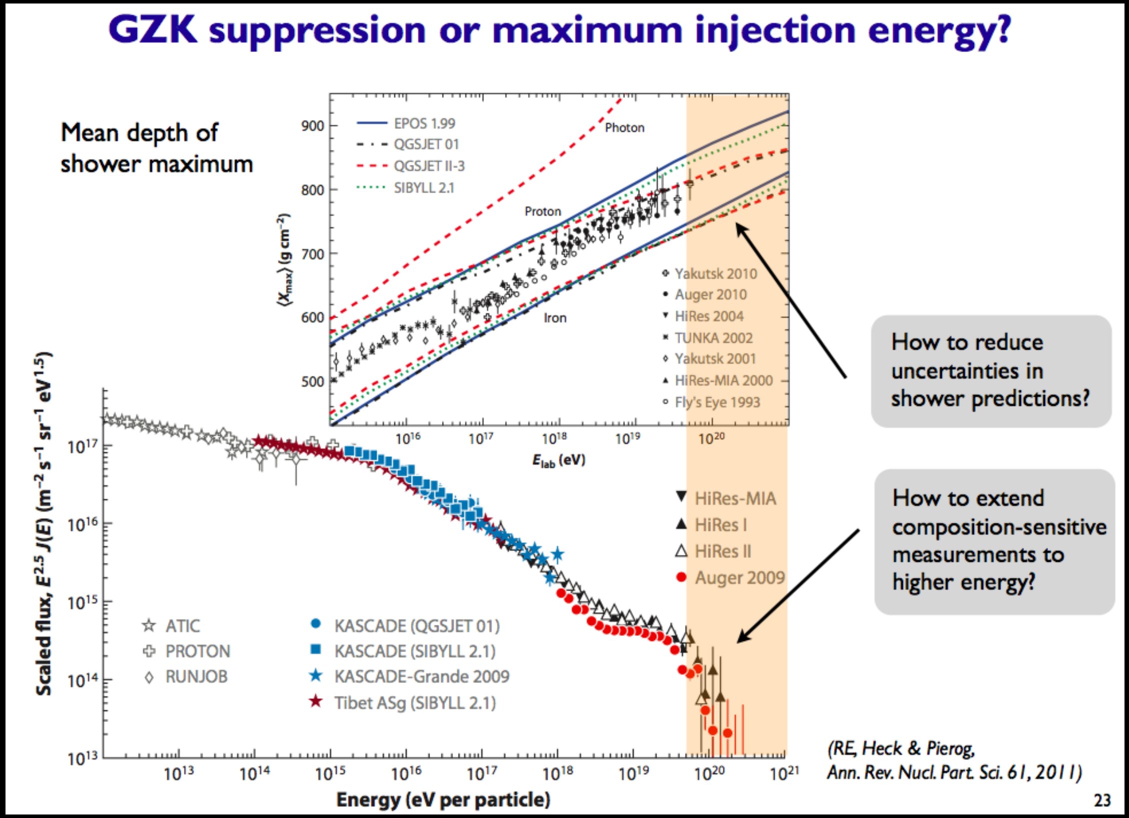
AMS
JEM-
EUSO



Towards more area coverage or (e.g. JEM-EUSO, ideas on ground , TA2) or more observables (separate e.m. component from μ) ?

High energy cosmic ray observatories, II

Where do we stand in UHECR?



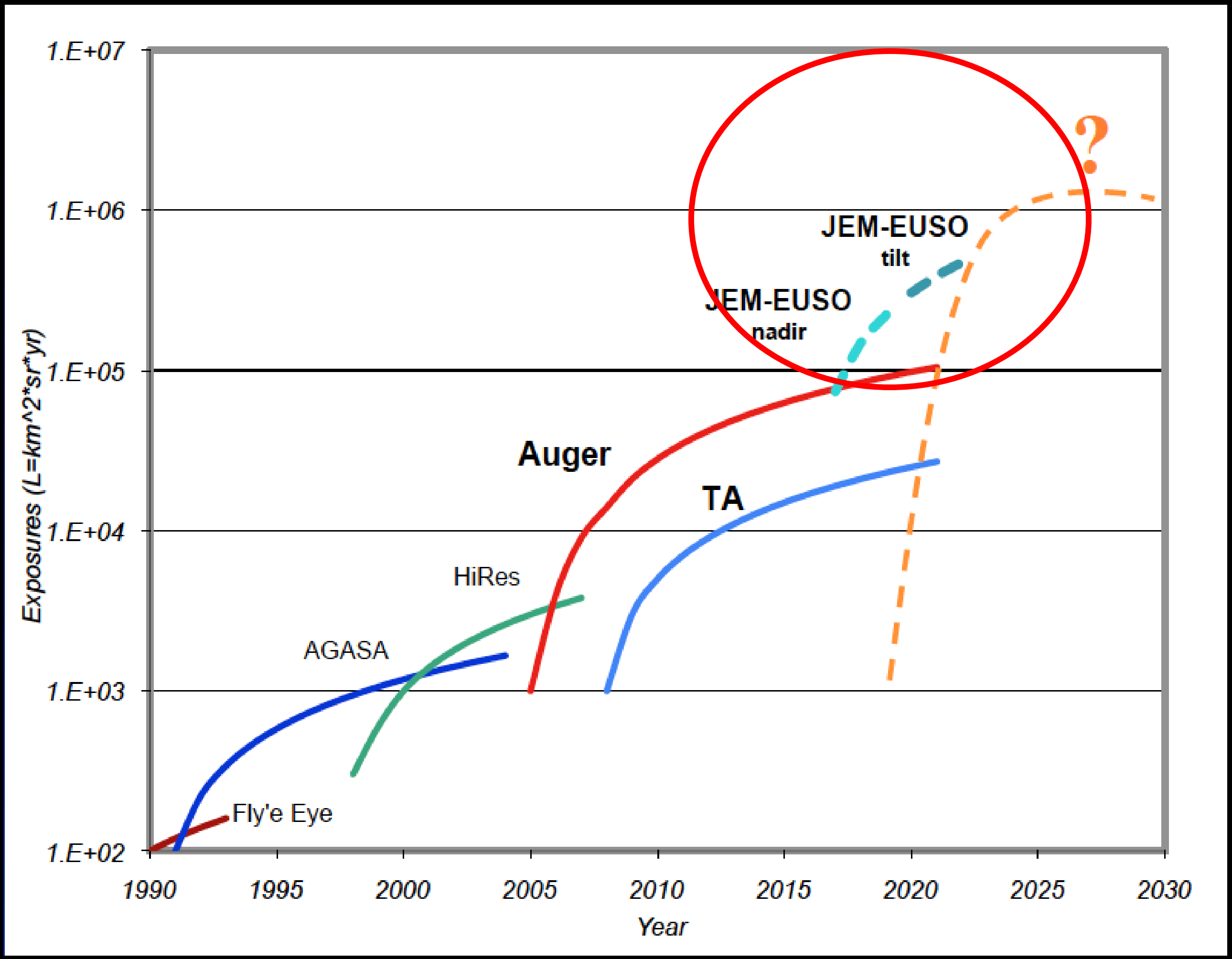
- Suppression of the UHECR spectrum
  ➔AUGER ≈ Telecope Array (TA)
- Energy calibration
  ➔ AUGER ≈ TA
- A trend towards heavier composition at highest energies
  ➔AUGER ≠ TA
- A weak correlation towards nearby matter distribution (14%)
  ➔AUGER ≈ TA
- Do we understand number of muons?

Are we seeing the GZK or in large part the exhaustion of the acceleration mechanism ?

AUGER collaboration submitting upgrade proposal in 2013 with aim to distinguish better muons from em component

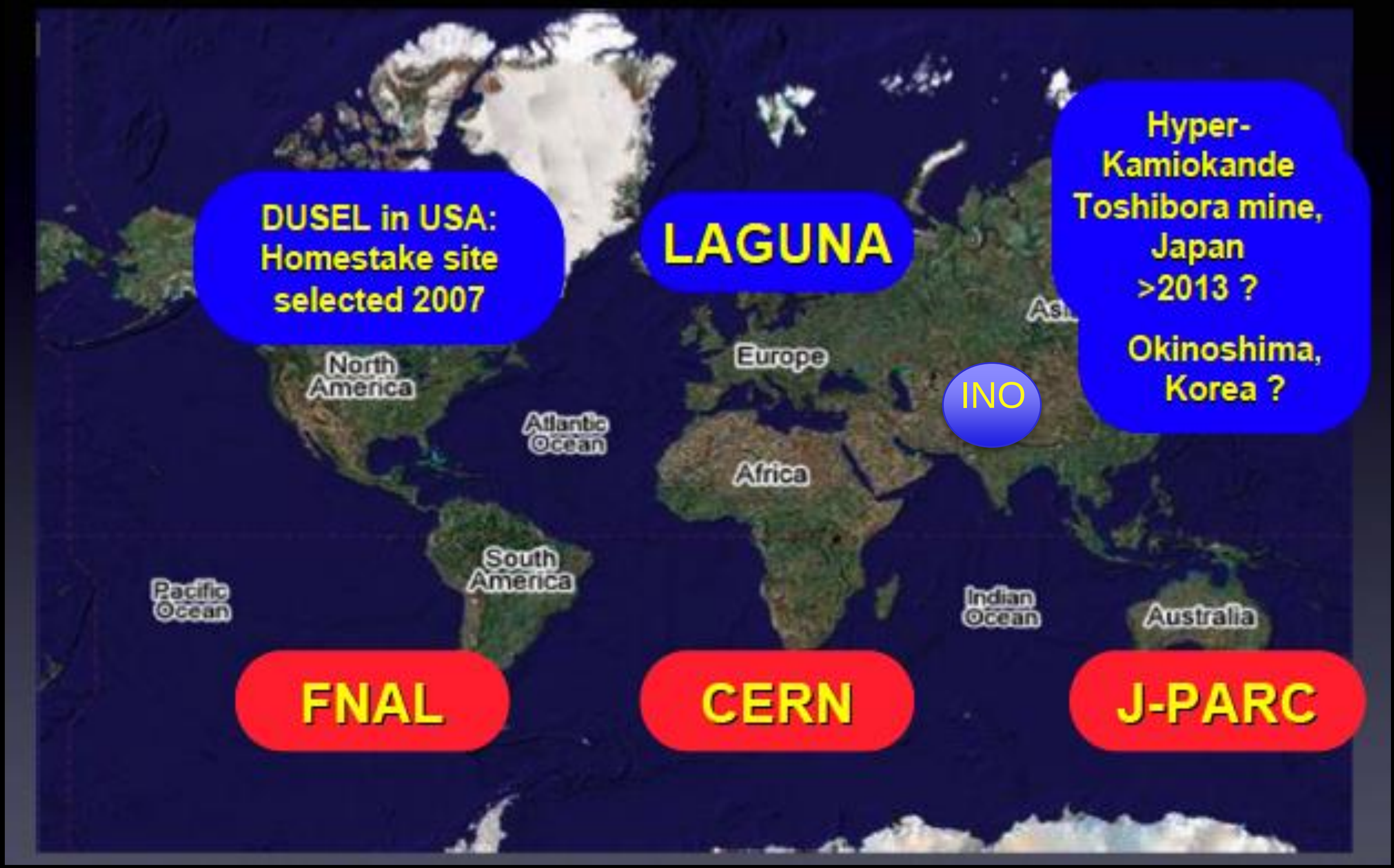
Synergy with LHC crucial, see recent LHC-CR workshop ➔ Common Astroparticle Forum ?

High energy cosmic ray observatories, III
More surface ?



JEM-EUSO + AUGER/TA future ideas

Large scale projects for proton decay and neutrino physics , I



ApPEC statement submitted to the European Strategy group

we support:

✓a vigorous R&D program and prototyping on the liquid argon detector technique and beam design studies in anticipation of a critical decision in 2015-16 for a strong European participation in a long baseline experiment outside Europe or an experiment in Europe.

✓the design and cost studies of very large neutrino detectors optimised for proton decay and astroparticle physics using the techniques of liquid scintillator or water in view of the construction of at least one of these detectors somewhere in the world. We also support studies aiming at the clarification of the possibility to determine the mass hierarchy with underwater/ice detectors and atmospheric neutrinos.

✓the current efforts for the determination of the neutrino's fundamental nature and the absolute scale of the neutrino masses. They are of crucial importance for the Standard Model of particle physics and cosmology.

✓the current program testing the sterile neutrino hypothesis.

It is recommended that CERN, together with key European agencies and ApPEC, enter into discussions with their US and Asian counterparts in order to develop a coherent international strategy for the field.

APPEC

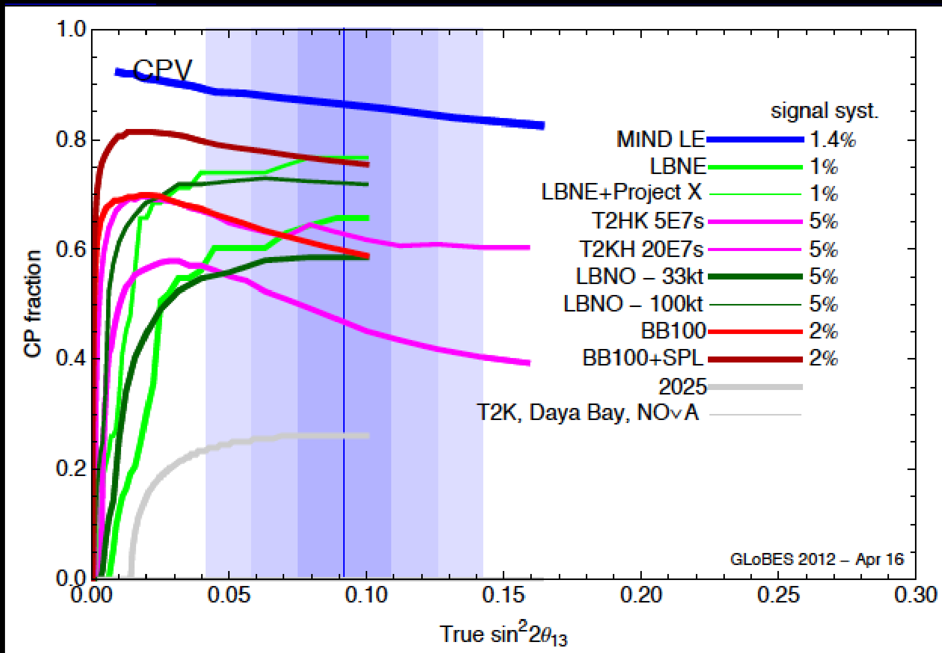
The full statement from the European Strategy draft statement sent for deliberation to the Council concerning neutrinos

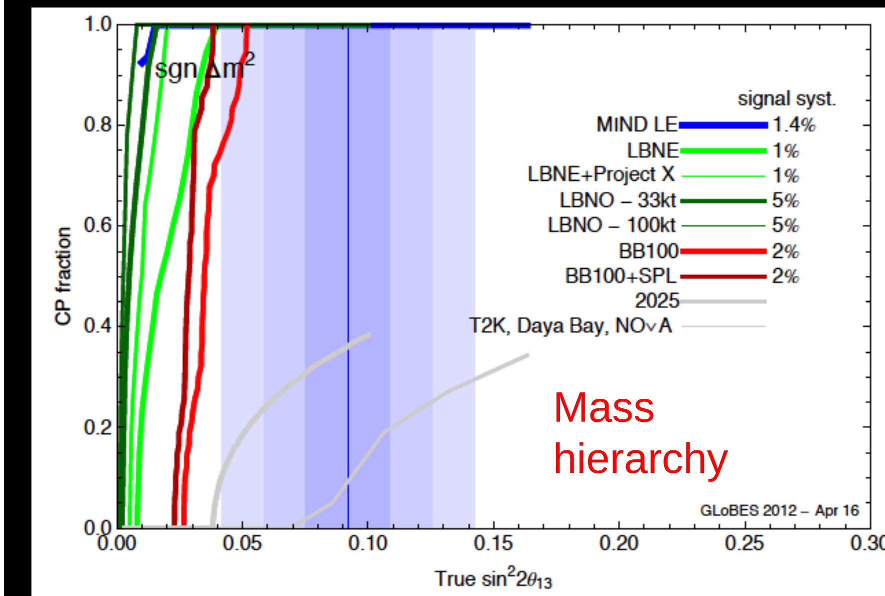
“Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector.

CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments.

Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.”

Potential of large scale projects for Neutrino





(From P.Huber)

Roughly equivalent (±10%) discovery potential for mass hierarchy and CP.

LAGUNA prototype (6x6x6m^3) at CERN North Area*?

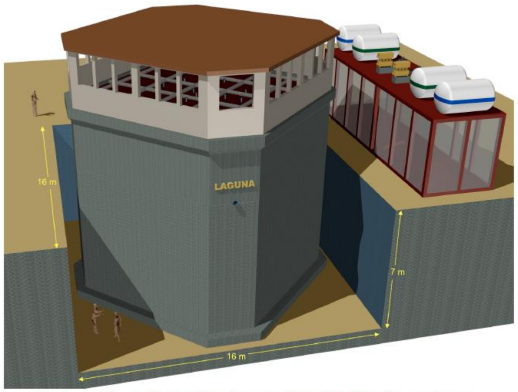


Figure 1: Illustration of the layout of the LAGUNA LAr prototype.

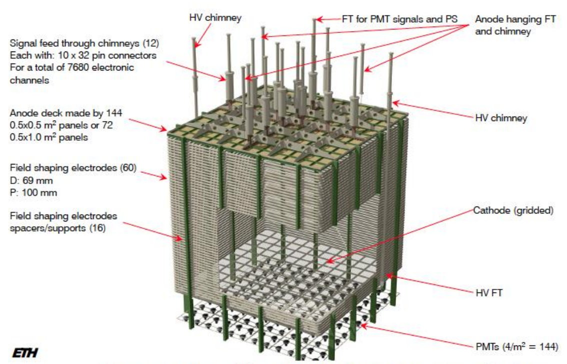


Figure 2: Layout of the LAGUNA LAr prototype inner detector.

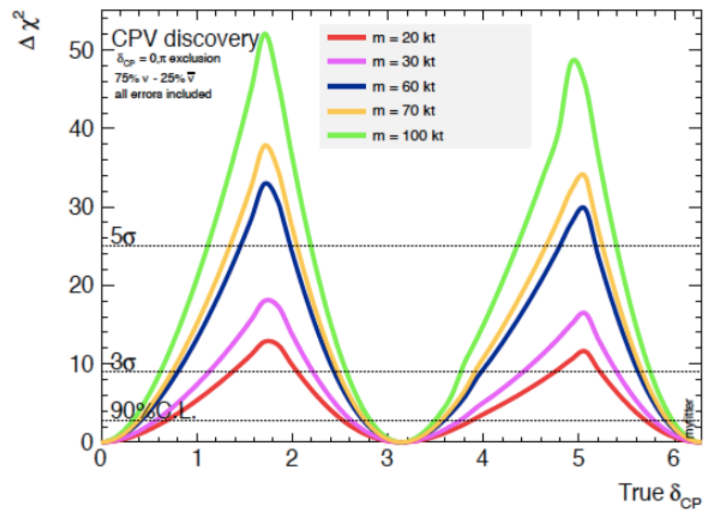


Figure 7: Dependence of CPV coverage on the detector mass in terms of $\Delta\chi^2$ *significance for 20 kt, 30kt, 60 kt, 70 kt and 100 kt LAr fiducial mass and SPS 400GeV at 700kW.*

CPV discovery potential
with a baseline of 2300 km

* Disussions with the SPSC

The detector must also have a sufficient discovery potential for proton decay and Astroparticle physics

Outstanding physics goals

HK

	 GLACIER	 LENA	 MEMPHYS
Total mass	100 Kton	50 kton	500 Kton
p -> $e\pi^0$ in 10 y	0.5×10^{35} y ε = 45%, ~1 BG event	?	1.2×10^{35} y ε = 17%, ~1 BG event
p -> ν K in 10 y	1.1×10^{35} y ε = 97%, ~1 BG event	0.4×10^{35} y ε = 65%, <1 BG event	0.15×10^{35} y ε = 8.6%, ~30 BG events
SN cool off at 10 Kpc	38·500 (all flavors) (64·000 if NH-L mixing)	20·000 (all flavors)	194·000 (mostly $\nu_e p \rightarrow e^+ n$)
Sn in Andromeda	7 - (12 if NH-L mixing)	4 events	40 events
SN burst at 10 Kpc	380 ν_e CC (flavor sensitive)	~ 30 events	~ 250 ν-e elastic scattering
DSN	50	20-40	250 (2500 with Gd)
Atm. neutirnos	~1·100 events/y	5600/y	56·000 events/y
Solar neutrinos	324·000 events/y	?	91·250·000/y
Geo-neutirnos	0	~ 3·000 events/y	0

T. Patzak, APC, University Paris Diderot, TAUP2011, 5 – 9 September 2011, Munich, Germany

Mass, pattern recognition,flavour discimination, threshold

Current challenges
The next generation of large programs
Where do we stand

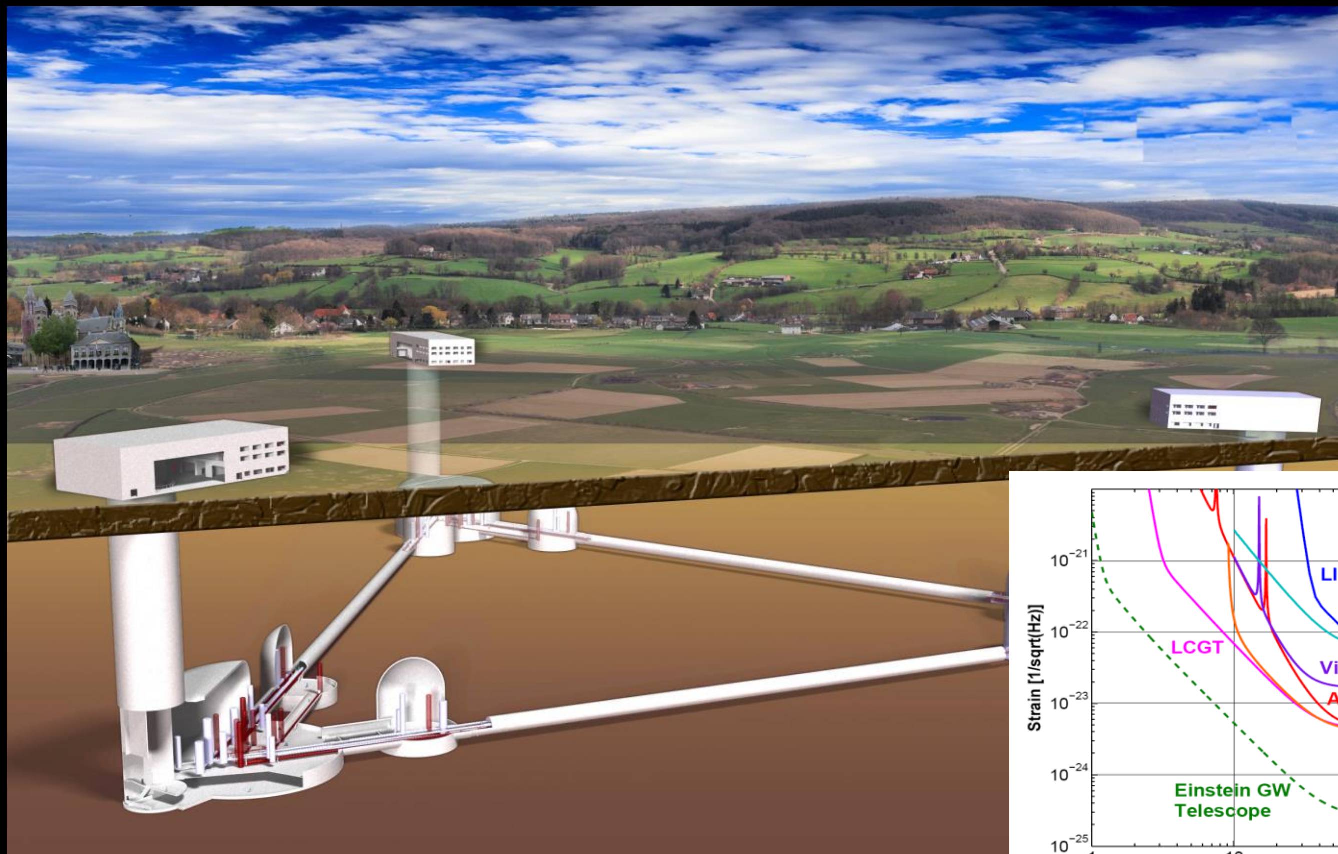
- High Energy photons (CTA, in the process of TDR acceptance)
- High Energy neutrinos (KM3Net, support for phase 1)
- Ultra High Energy cosmic rays (AUGER, upgrade proposal)

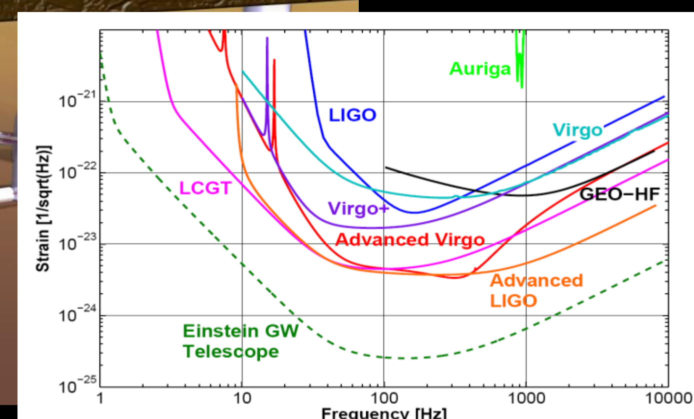
- Neutrino properties, astrophysics, proton decay (LAGUNA, support for LAr prototype)

APPEC

Further in the future : Gravitational waves III

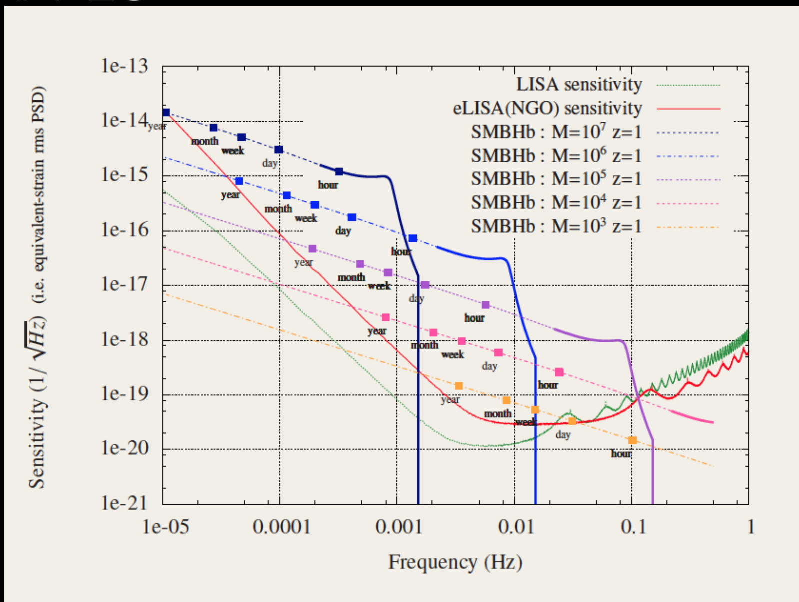
EU funded Design Study Einstein Telescope (ET)

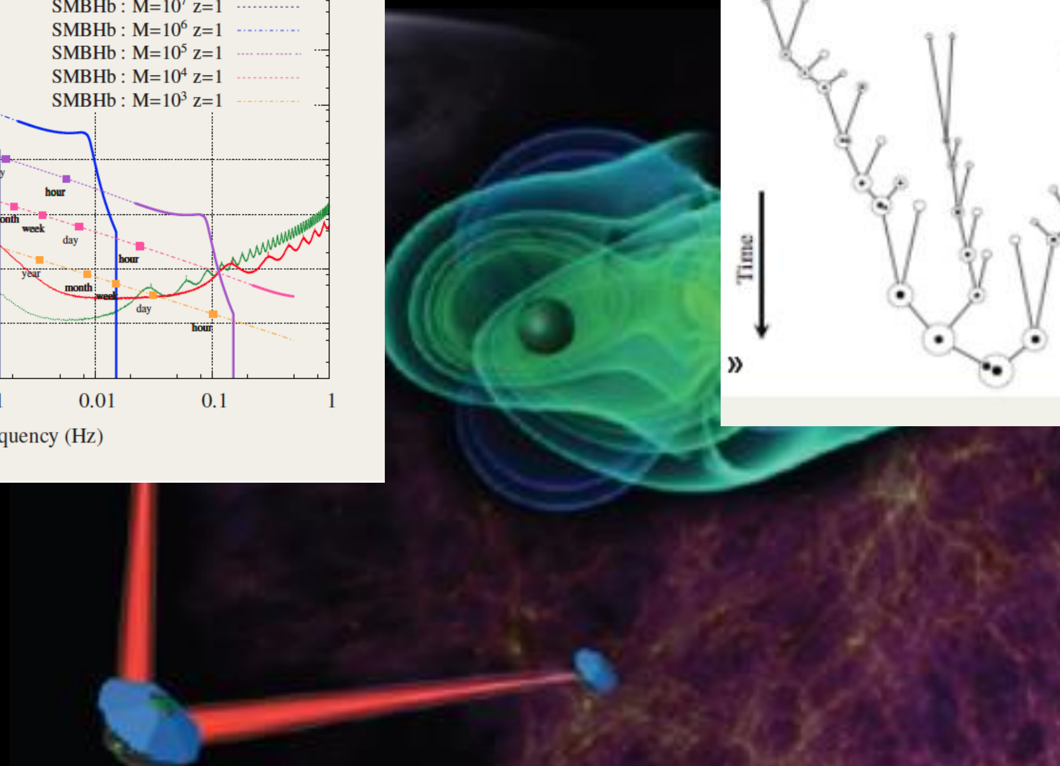


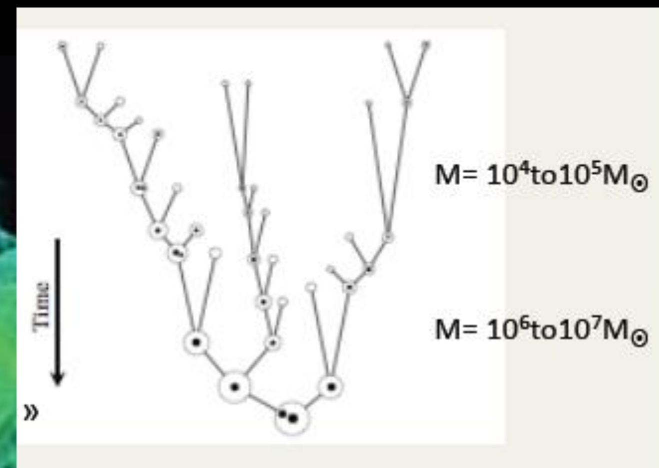


- ✓If detection by 2018 move to third generation (ca 2020)
- ✓ 30 km of Underground tunnels
- ✓ASPERA/ApPEC funding for R&D

Further in the future : Gravitational waves IV
Gravitational Antenna in space eLISA/NGO





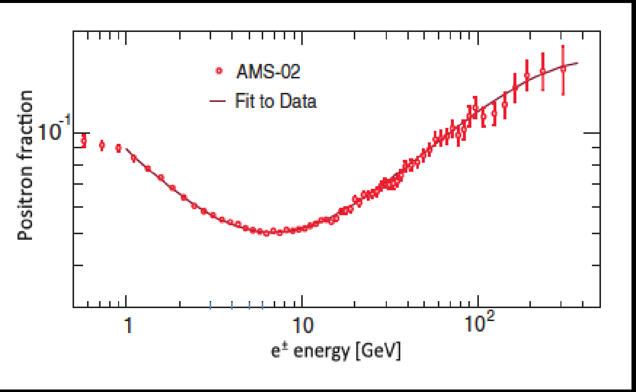


✓LisaPathfinder mission launch in 2015

✓ESA released a call for L2(2028) and L3(2034) white papers. Selection of areas for L2,L3 (SSC and SPC) Nov. 2013 ➔ Call for Missions 2014

And space ?
Astroparticle physics had a high record of success in space missions

- ✓ A formidable laboratory of quality procedures but also inter-cultural coordination (astrophysics-particle physics)
- ✓ Successes :
  - ✓PAMELA, FERMI,
  - ✓AMS (in some countries astrophysicists)
  - ✓PLANCK (in some countries particle physicists +cosmologists)



- ✓ The challenges of the future space missions
  - ✓ LisaPathfinder
  - ✓JEM-EUSO
  - ✓EUCLID
  - ✓Fermi-followup (GAMMA-400?)
  - ✓eLISA
  - ✓Core (CMB polarisation)
  - ✓...

Conclusions (the same as in the ESG Krakow meeting)

- Since 2008, roadmapping exercises, exchange of experts, information meetings for scientists and agencies although did not result in spectacular conversions eventually led to a clarification of the issues and/or the concentration to a small set of large infrastructures or closely knit networks in the domains of
  - Dark Energy, Gravitational wave antennas and High Energy Universe observatories
  - *We can then reasonably expect by 2020-2025 a % knowledge of the DE equation of state, a few GW detections and a better understanding of the violent phenomena in the Universe*

- In other domains, healthy competition is still the rule as in the case of :
  - Direct dark matter detection , Double beta-decay experiments
  - Here in order to obtain the necessary improvement of sensitivity by 2 orders of magnitude by moving to the ton or multiton scale detectors , more regional and interregional coordination (or avoidance of duplication) has to be implemented progressively (CDMS-EDELWEISS, MAJORANA-GERDA lead the way ?)

- Last but not least, and the closest to the ESG planning is the case of a large neutrino detector to measure the neutrino mass hierarchy and CP phase, where the synergy with a proton decay and astroparticle type of physics is largest and where the scale of the project demands interregional coordination for at least avoidance of duplication.
  - This is where global coordination can accompany the necessarily agency/laboratory driven decision process.