« Cosmic Rays » and the APPEC Roadmap

Conseil Scientifique de l'Institut (CSI)
2 Février 2017

S. Katsanevas APPEC et APC

APPEC: *organisation*

***A**stro**P**article **P**hysics **E**uropean **C**onsortium*

Chair: A. Masiero (INFN)
General Secretary: Job De Kleuver (FOM)

Scientific Advisory Committee ***+ CERN ESO***

APPEC *functional centers*

APC - Paris/F
Roadmapping, Common Calls, Interdisciplinary

DESY - Hamburg/D
Management, Computing & Industry

LNGS - L'Aquila/I
Networking, Theory, Graduate Schools

Coordination 2001-2006
ASPERA 2006-2012
Consortium 2012-....

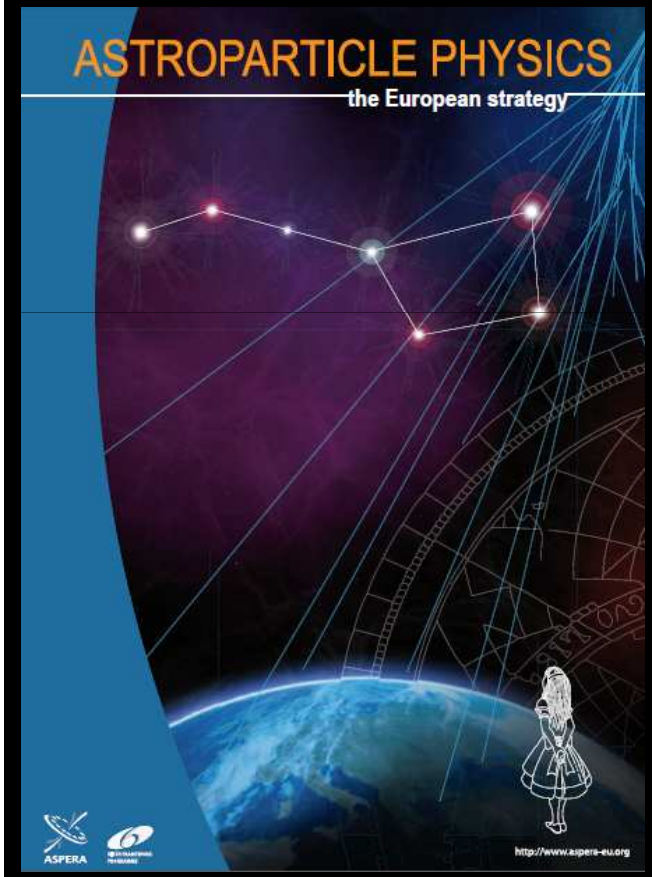
Outreach, Web pages

STFC – Swindon/UK

APPEC: *roadmapping*

From the Nature article

2008



2011

Magnificent 7

1. ***HE gammas***
2. ***HE neutrinos***
3. ***HE cosmic rays***
4. ***Gravitational waves***
5. ***Dark matter***
6. ***ν-mass***
7. ***ν-mixing & p-decay***

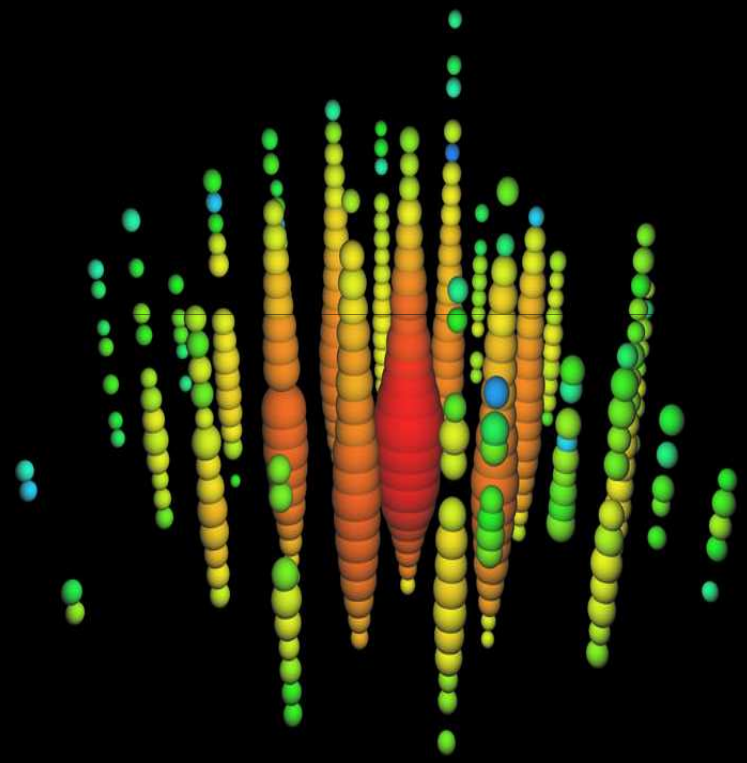
CMB

Dark Energy

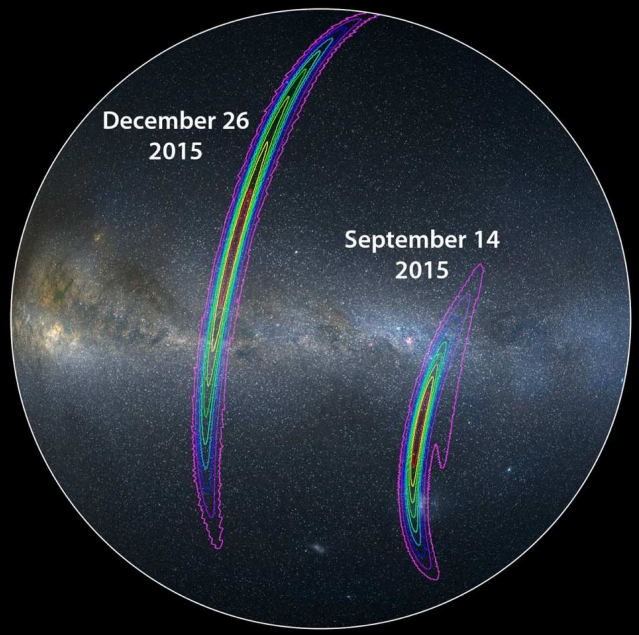
RB's comment: But… at least 4 -5 domains have not seen a signal yet

Well 2 of the domains have detected a signal in the first 3 years

PeV neutrinos 2013



GW1509-2014



The search of point sources for HE cosmic-rays, neutrinos and GW (better pointing) ongoing

APPEC Roadmap: the priorities of the first European "decadal survey" and its mid-decadal update

- 2011 The first APPEC priority roadmap:
  - I. Complete the upgrades:
    - ✓ Adv. Gravitational Wave antennas
    - ✓ Underground Science a (1 ton Dark Matter)
    - • Underground Science b (1 ton νless2β decay)
  - II. Prepare construction of large CR programs:
    - ✓ CTA (TGIR)
    - • KM3Net/IceCube (➔ ESFRI, IR FdR France)
    - • AUGER upgrade (➔ upgrade TDR 2014)
  - III. Global coordination for very large projects:
    - • Dark Energy (LSST-EUCLID ➔ data sharing?)
    - • Large neutrino detectors (APPEC global workshop ➔ DUNE)
    - • CMB (APPEC global workshop ➔ DS CMB-S4)
- ➔ 2016 Roadmap "mid-decadal" "resource aware update

*A. Masiero (chair), Michal Ostrowski, Mauro Mezzetto, Gisela Anton, Laura Baudis, Jocelyn Monroe, Petr Tiniakov, Jo van den Brand, Patrick Sutton, Ramon Miquel, Zito Marco, Andrea Giuliani, Felix Aharonian, Pierre Binétruy, Ignatios Antoniadis, Yifang Wang, Francis Halzen, Hank Sobel, A. Haungs, S.Katsanevas (APPEC)

APPEC: global workshops (APC Functional centre)

International meeting for large ν-infrastructures

1. June 2014 (Paris) $\rightarrow$ LBNF/DUNE
2. April 2015 (Chicago)
3. May 2016 (Tokyo)
4. Autumn 2017 (CERN)

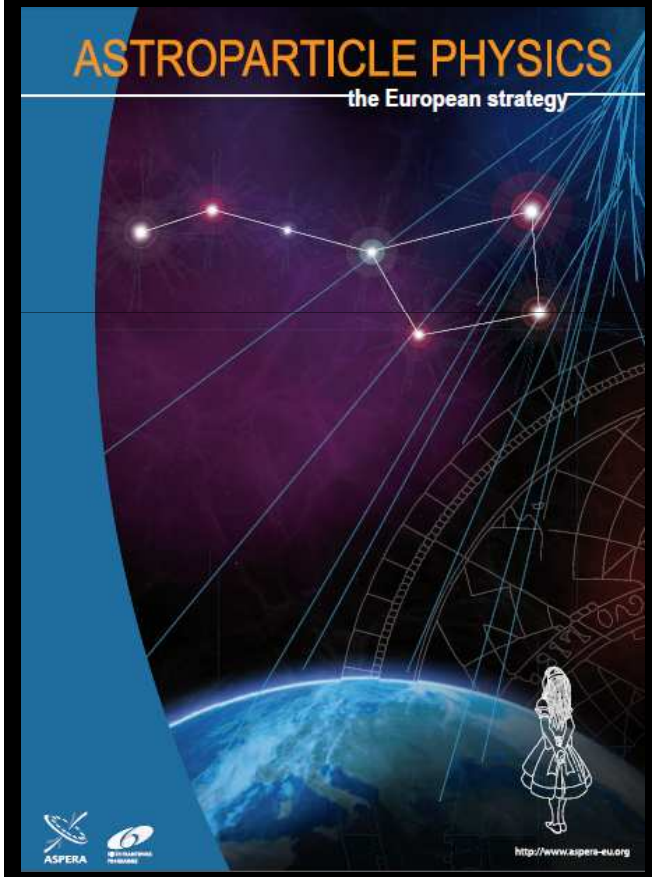
Florence (Villa Finally) CMB workshops

1. September 2015
2. September 2016
3. September 2017

$\rightarrow$ DS of a EU ground-based CMB-S4

APPEC: *roadmapping*

2008



2011

HE universe

- ***gammas***
- ***neutrinos***
- ***cosmic rays***
- ***gravitational waves***

Dark universe

- ***dark matter***
- ***dark energy***

Early universe

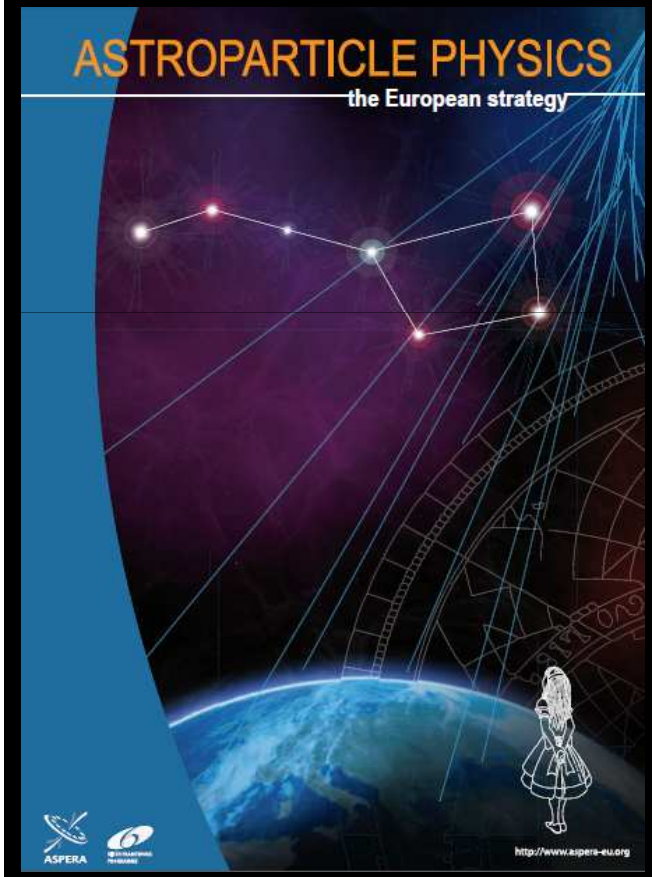
- ***CMB***

ν-properties

- ***mass, mixing, …***

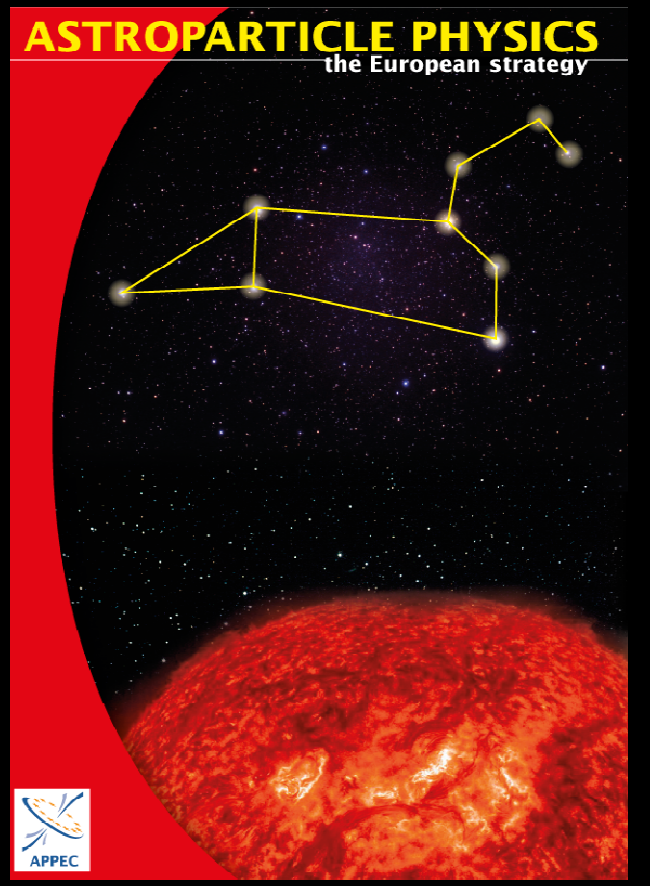
APPEC: *roadmapping*

2008



2011

2017



resource aware

APPEC: *Town Meeting → roadmap*

- SAC preparation
- Considerations published for community comments
- Appec Town meeting (April, Paris 2016),
- Approved by APPEC GA November 2016
- Roadmap will be published in Spring 2017

European Strategy for Astroparticle Physics
4 domains

i. **Extreme Universe:** *What can we learn about the cataclysmic events in our Universe by combining all messengers?*

ii. **Dark Universe:** *What is the nature of Dark Matter and Dark Energy?*

iii. **Neutrinos:** *What are the intricate properties of neutrinos and what can they tell us?*

iv. **Early Universe:** *What else can we learn about the Big Bang from the cosmic microwave background?*

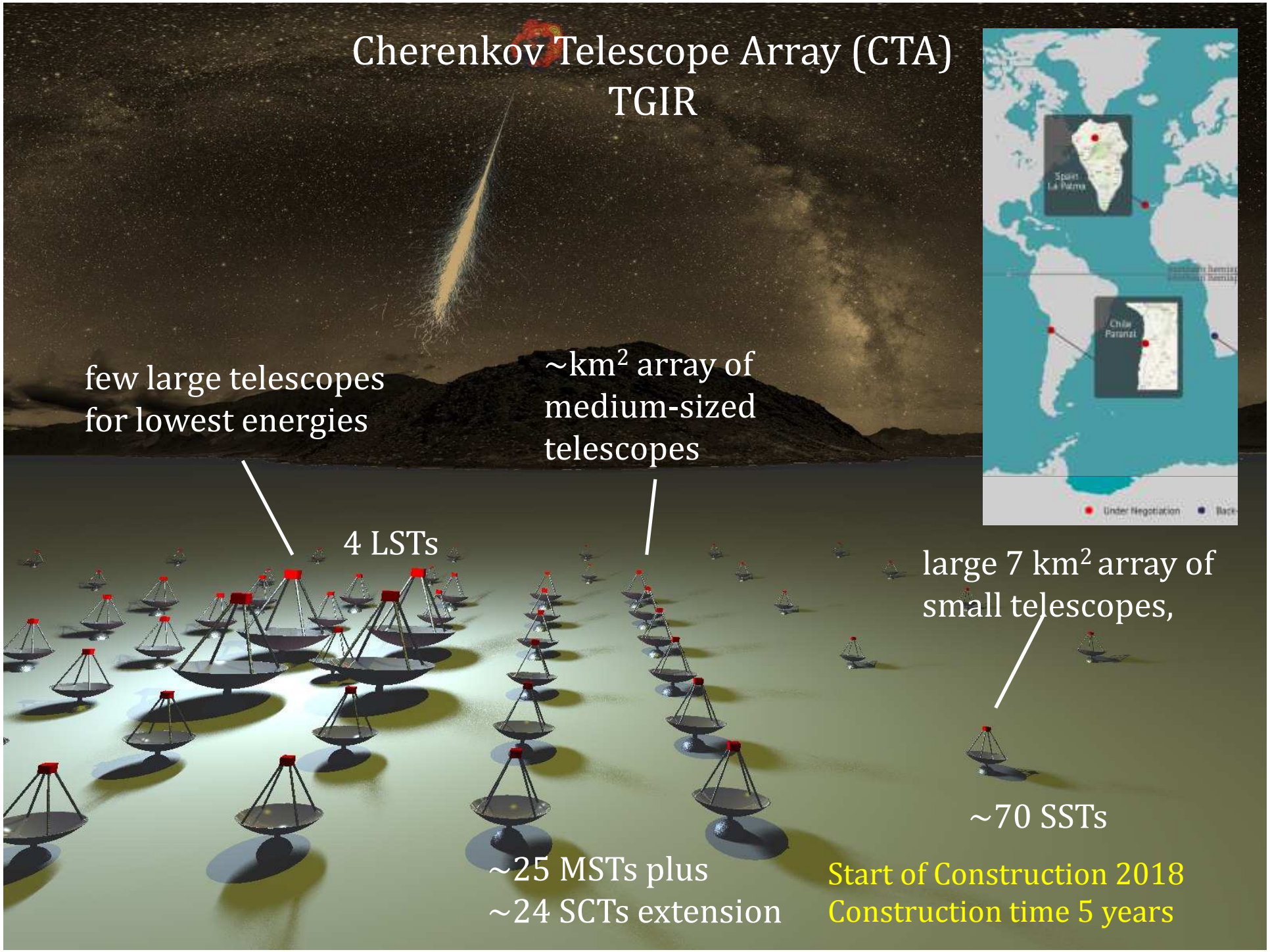
- *Two emergent characteristics of the present era :*

I. *We are at the edge of multi-messenger detections involving high energy photons, neutrinos, high-energy charged particles and gravitational waves, that will give us a deeper understanding of violent phenomena regulating structure formation in the Universe as well as eventually hints for new laws of physics*

II. *The visible Universe from the CMB to the present started to provide comparable constraints to the standard models of cosmology (inflation, dark energy) and particle physics (neutrino, dark matter)*

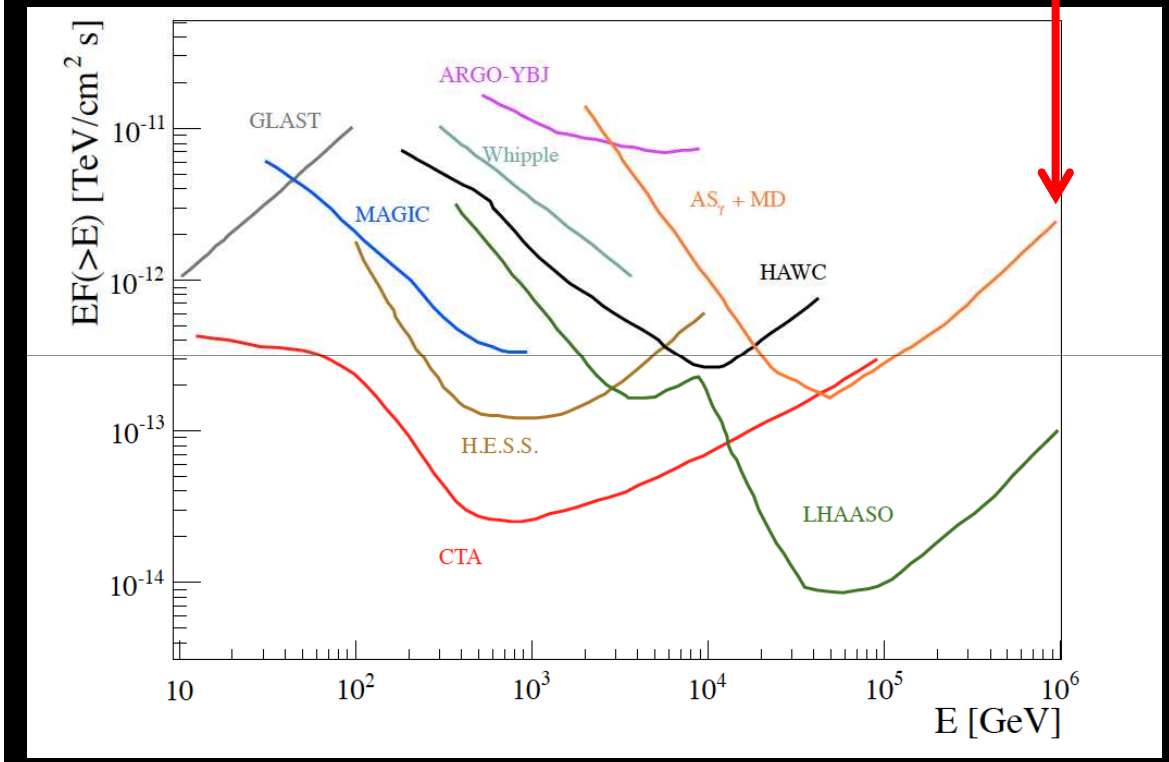
High Energy Universe Science
APPEC Recommendations

1. *APPEC fully supports the **CTA** collaboration to secure the funding for a timely and cost effective realisation and subsequent long-term operation of this observatory covering both southern & northern hemispheres*
2. *For the northern site , APPEC strongly endorses the **KM3NeT** collaboration's ambitions to realize by 2020 a large-volume telescope with optimal angular resolution for high-energy neutrino astronomy and a dedicated detector optimized for low-energy neutrinos primarily aiming to resolve the neutrino mass-hierarchy. For the southern site, APPEC looks forward to a positive decision in the USA regarding **IceCube-Gen2.***
3. *APPEC strongly supports the Auger collaboration to install **AugerPrime** by 2019. At the same time, APPEC urges the community to continue R&D towards alternative technologies that are cost-effective and provide 100% (day and night) duty cycle so that ultimately the full sky can be observed with very large observatories.*
4. *With its global partners and in consultation with GWIC APPEC will define the timelines for upgrades of existing as well as next-generation ground-based interferometers. APPEC strongly supports further actions strengthening the collaboration between gravitational-wave laboratories. APPEC strongly supports Europe's next generation ground-based interferometer, the **'Einstein Telescope' (ET)** project, to develop the required technology and acquire ESFRI status. Regarding space-based interferometry, APPEC strongly supports the European **LISA** proposal*

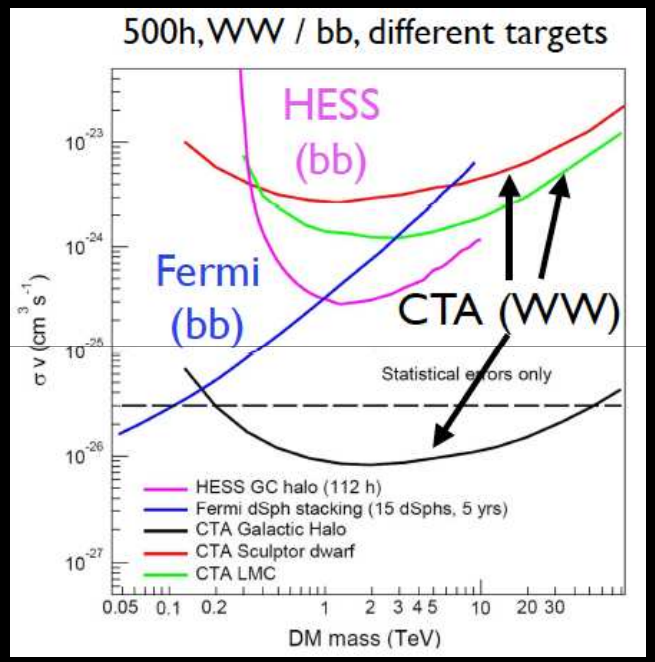

Cherenkov Telescope Array (CTA)
TGIR
few large telescopes
for lowest energies
~km² array of
medium-sized
telescopes
4 LSTs
large 7 km² array of
small telescopes,
~70 SSTs
~25 MSTs plus
~24 SCTs extension
Start of Construction 2018
Construction time 5 years
Spain
La Palma
Chile
Paranal
Under Negotiation

Future high energy γ sensitivities

Pevatrons



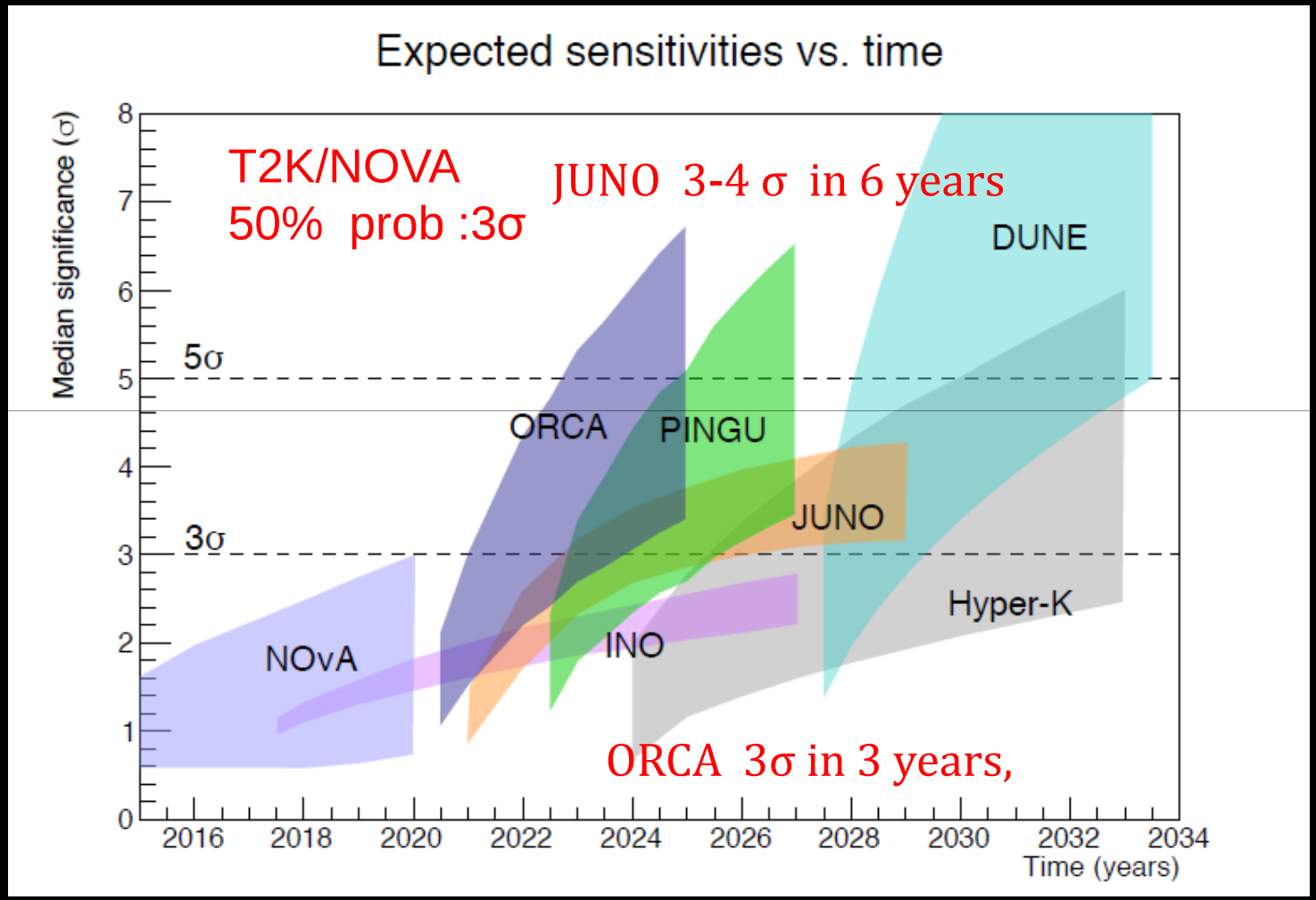
Dark matter reach



CTA is complemented by PeV scale wide field observatories: HAWC (constructed) and LHASSO under construction (2020)

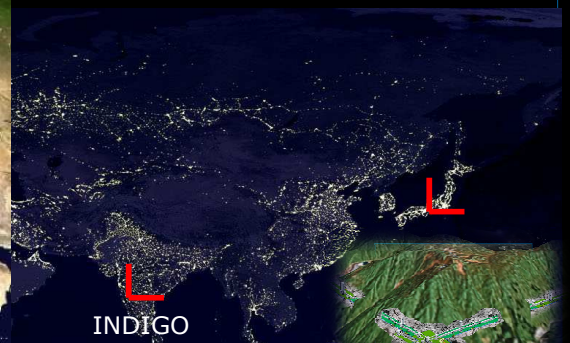
High Energy Neutrino Telescopes

Mass hierarchy
Atmospheric, Reactor, Accelerator



3σ 2023-25 5σ 2030

Gravitational waves
A worldwide antenna network



Virgo, Cascina, 3 km

LIGO Livingston, 4 km

Benefits:

- Confidence in detection
- Sky coverage
- Duty cycle
- Sky position localization

Advanced era
Detection rates of compact binary coalescences

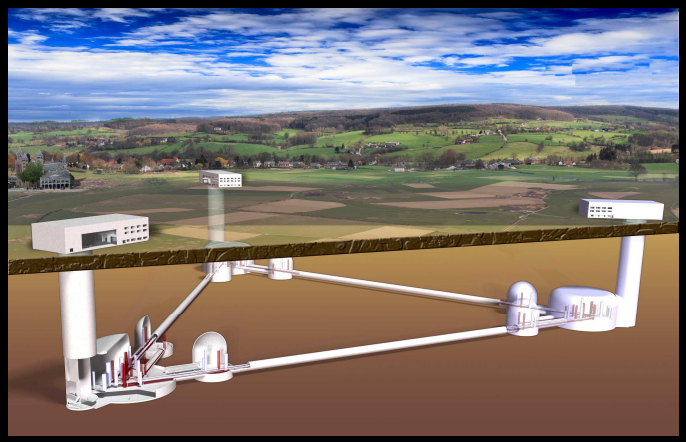
	Source	Low yr^{-1}	Real yr^{-1}	High yr^{-1}	Max yr^{-1}
Advanced	NS-NS	0.4	40	400	1000
	NS-BH	0.2	10	300	
	BH-BH	0.4	20	1000	

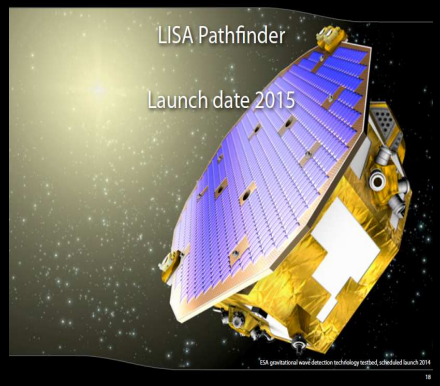
(Abadie et al. 2010, CQG 27)

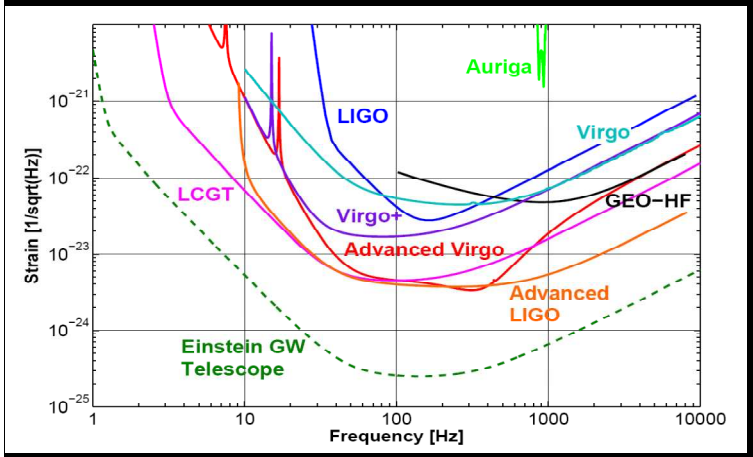
Mass: NS = 1.4 Mo
BH = 10 Mo
Advanced era
Sky location and orientation averaged range
197 Mpc for NS-NS
410 Mpc for NS-BH
968 Mpc for BH-BH

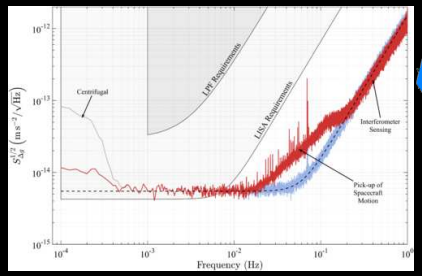
LIGO/VIRGO+ : sqeezing, bigger mirrors and laser, event ratex5, 2018-2025 O(100M)

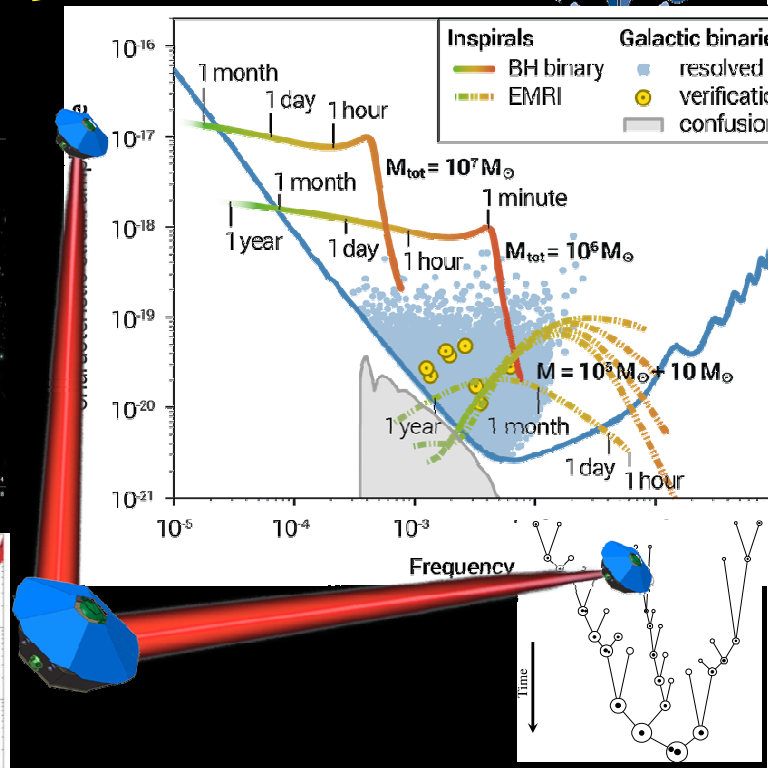
Gravitational waves
Einstein Telescope (ET) and LISA









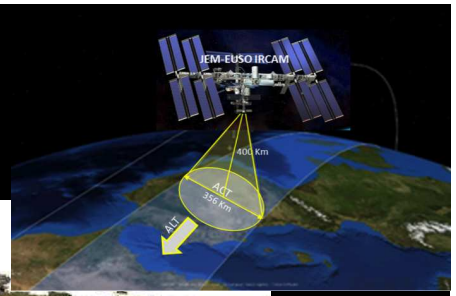


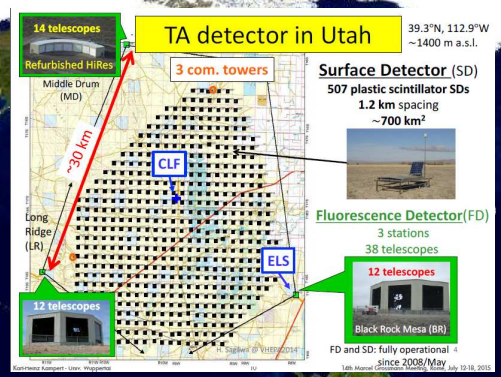
LISA (ESA L3: 2034➔ 2030 ?)

- 0.1-100 mHz ⟹ 1-1000 TeV (LHC)
- Phase transitions,
- Topological defects…
- Higgs self-couplings and potential
- Supersymmetry
- Extra dimensions
- Strings

High energy cosmic rays

AMS





TUNKA

LHAASO

AUGER

- SCIENCE GOALS OF AUGER-Prime
  - Study composition event by event.
  - Measure the muonic component of the showers. p or Fe?
  - Origin of the flux suppression
  - Astronomy through tagged protons
  - Particle physics at 70 TeV

The future of UHECRs: the space

I – Successful pathfinders of the

- EUSO-TA (partnership with Telescope Array: 2014–2017)
- EUSO-Balloon (CNES mission,

Ground

Balloon

Validation of concept

France: leadership, P.I.

II – Current pathfinders

- EUSO-SPB (NASA mission, launch March 2017)
- Mini-EUSO (ASI+ROSCOSMOS mission,

First CR showers!

Balloon (Long duration)

Space (ISS)

France: subsystems leadership + focal surface integration

III – Planned future mission

- K-EUSO (ROSCOSMOS, 2021–

4 x Auger full sky

Space (ISS) 4 x Auger full sky

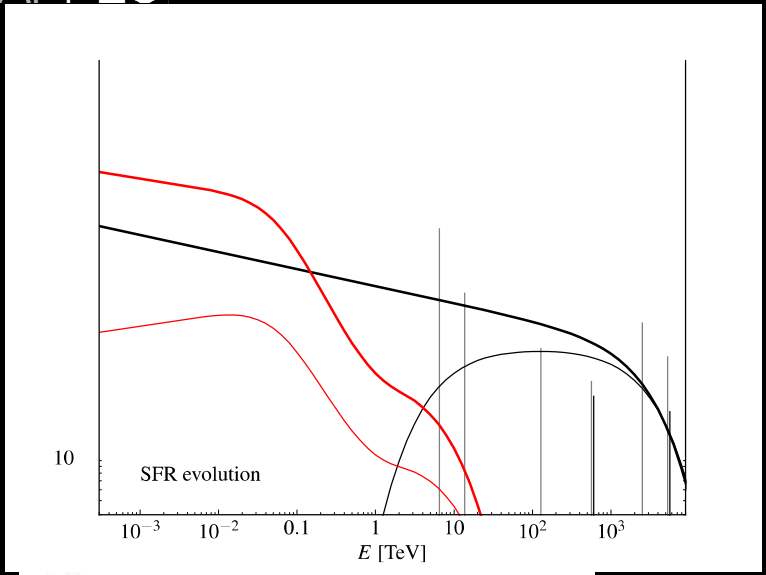
IV – Longer

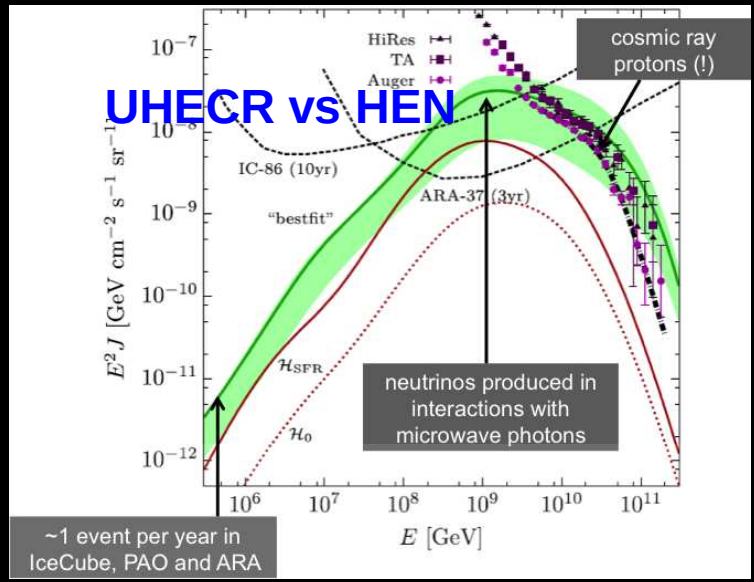
- CHANT, POEMMA, EUSO-FF

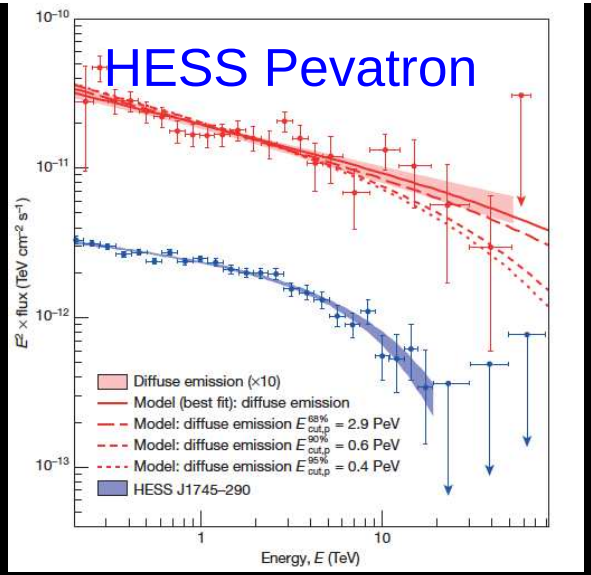
Breakthrough multi-messenger mission 20 x Auger + full sky + HE neutrinos

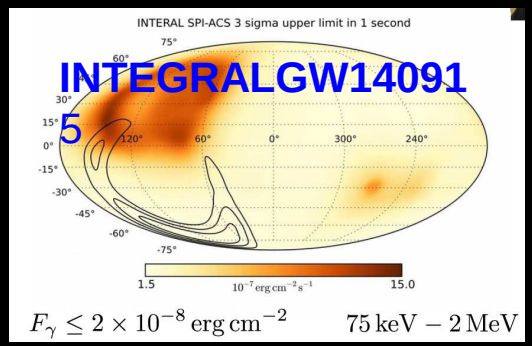
Space (free flyer)

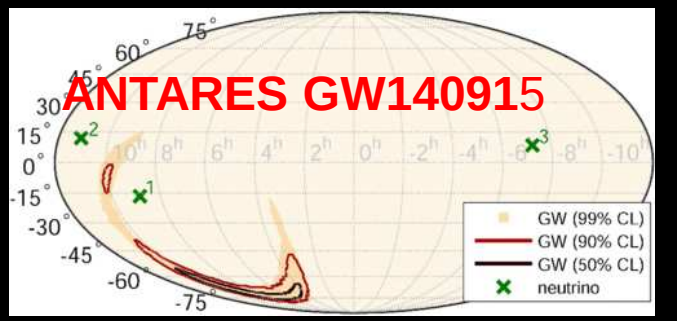
Did we reach finally the sensitivities necessary for multi-messenger studies ?











Also space missions (SVOM)

Underground Science: medium scale dark matter and neutrino experiments

5. *APPEC encourages the continuation of a diverse and vibrant program (experiments as well as detector R&D) searching for WIMPs and non-WIMP Dark Matter. Together with its global partners, APPEC aims to converge around 2019 on a strategy of how to realize worldwide at least one 'ultimate' xenon (order 50 tons) and one argon (order 300 tons) based Dark-Matter detector as advocated by the* ***DARWIN and ARGO*** *proponents, respectively.*
   - *A suite of smaller-scale experiments explores in particular the low-mass WIMP and other Dark-Matter hypotheses such as dark photons and axions.*

6. *APPEC strongly supports the present range of direct neutrino mass measurements and searches for neutrino-less double beta-decay. Guided by the results of running experiments and in consultation with its global partners, APPEC intends to converge on a roadmap for the next generation of neutrino mass & nature experiments by 2020.*

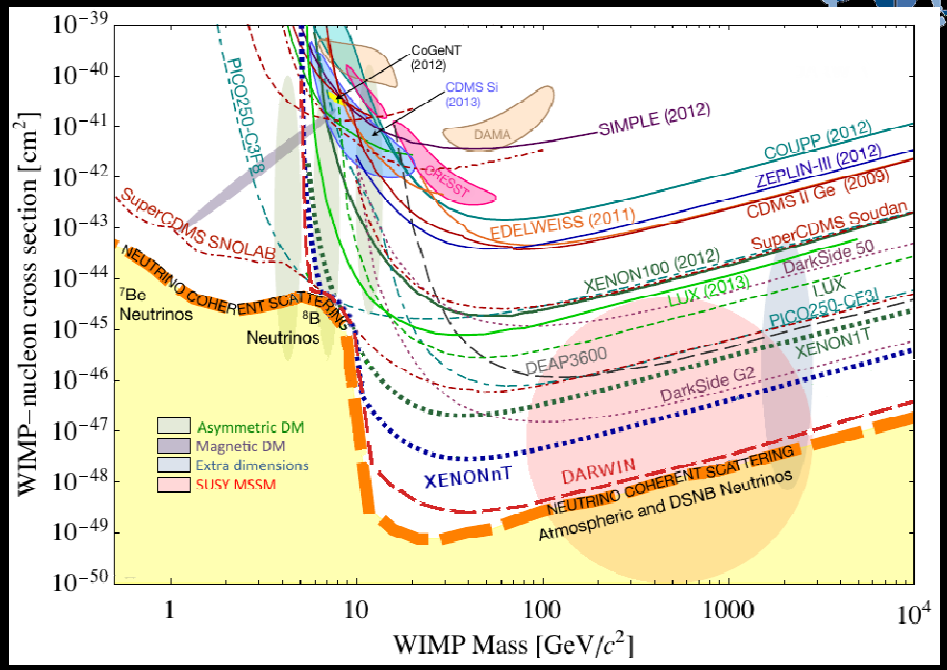
- *APPEC will support, in this domain, efforts of convergence to optimal technologies in a global context in the next 1-2 years.*

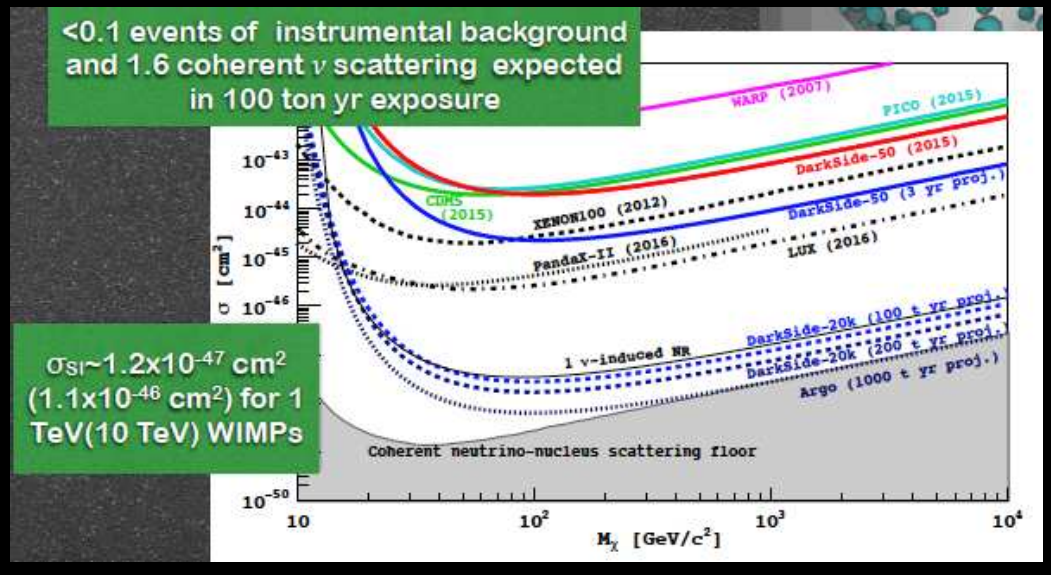
Future sensitivities dark matter

- G2 will reach 10^{-47} cm^2 at 100 GeV in 2020-2025
- Large European G3 will approach neutrino floor ca 2030
- Extreme purities needed:
  - <0.1 event/ton/year

✓*APPEC SAC ➔ Decide ca 2018-2019 G3 multi-ton experiment in a global context.*

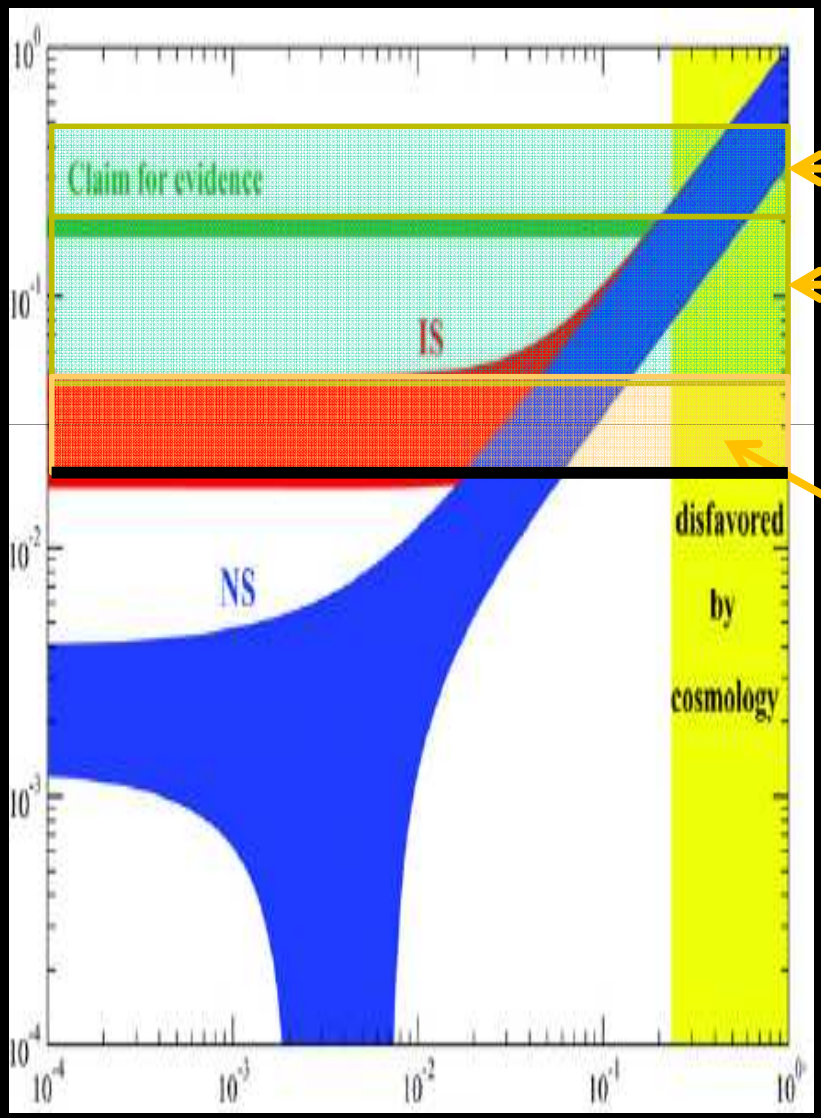
✓*Costs and scales make global coordination imperative*





0νββ future sensitivities

$$\left(T^{0\nu}_{1/2}\right)^{-1} = \left|\frac{m_{\beta\beta}}{m_e}\right|^2 g_A^4 \left|M^{0\nu}_{\nu}\right|^2 G^{0\nu}$$



GERDA-1/KAMLAND/EXO-200
(140-300 meV, 10^{25}y) today

GERDA-2 (75 - 129 meV, 10^{26}y)
CUORE (51 – 133 meV)
NEXT, SuperNEMO (100Kg)
In 5-6 years, by 2020

20 mEV
0.5-5
evts/y/ton

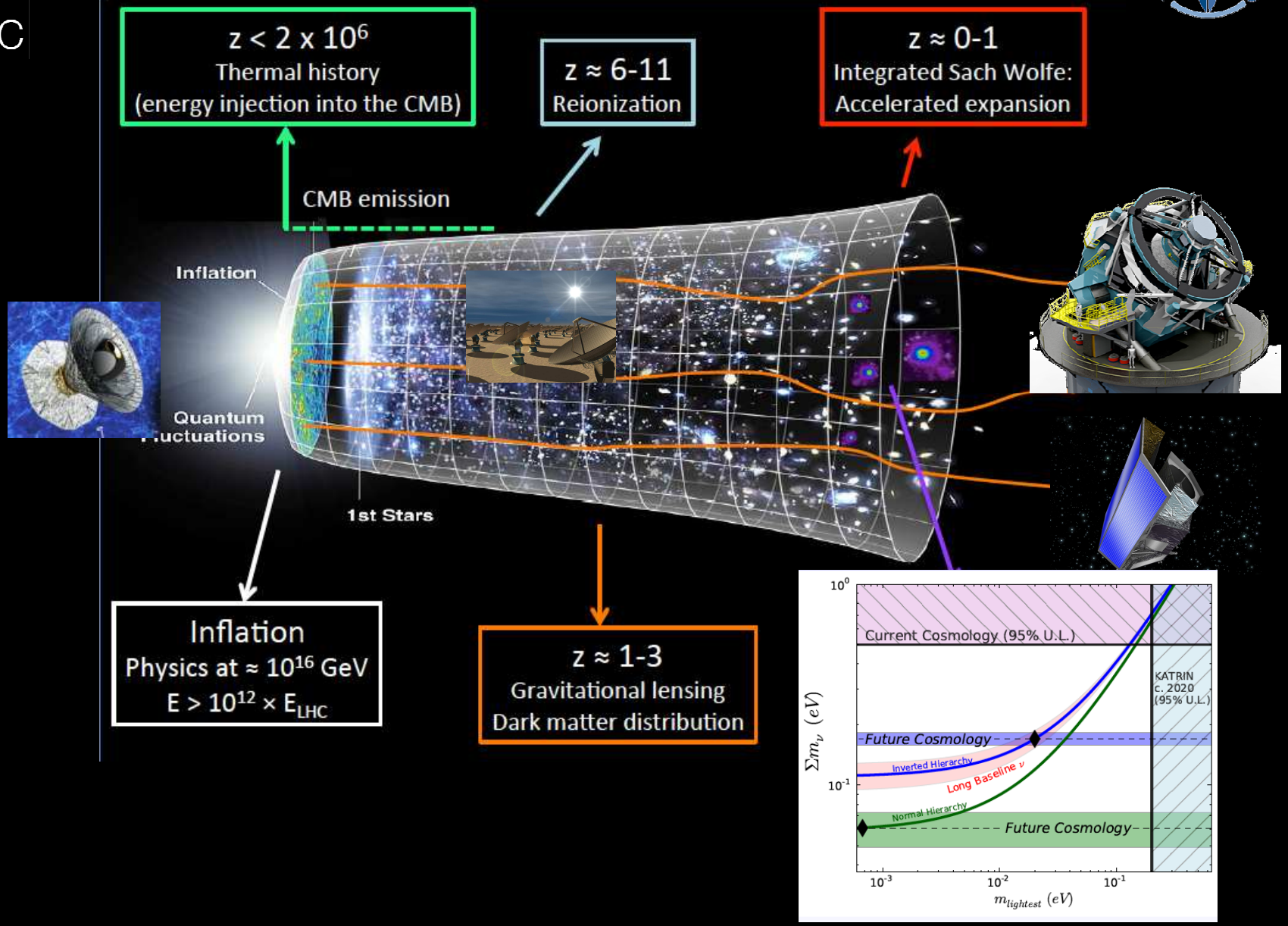
Scintillating bolometers
(350 kg, 5 y) (13 – 36 meV)
Initial nEXO (5 tons,10 y) (10 – 30 meV)
Similar sensitivites from GERDA-3/Majorana and upgrade of KamLAND-Zen
Lower limit of IH by 2025 ?

Global coordination also needed

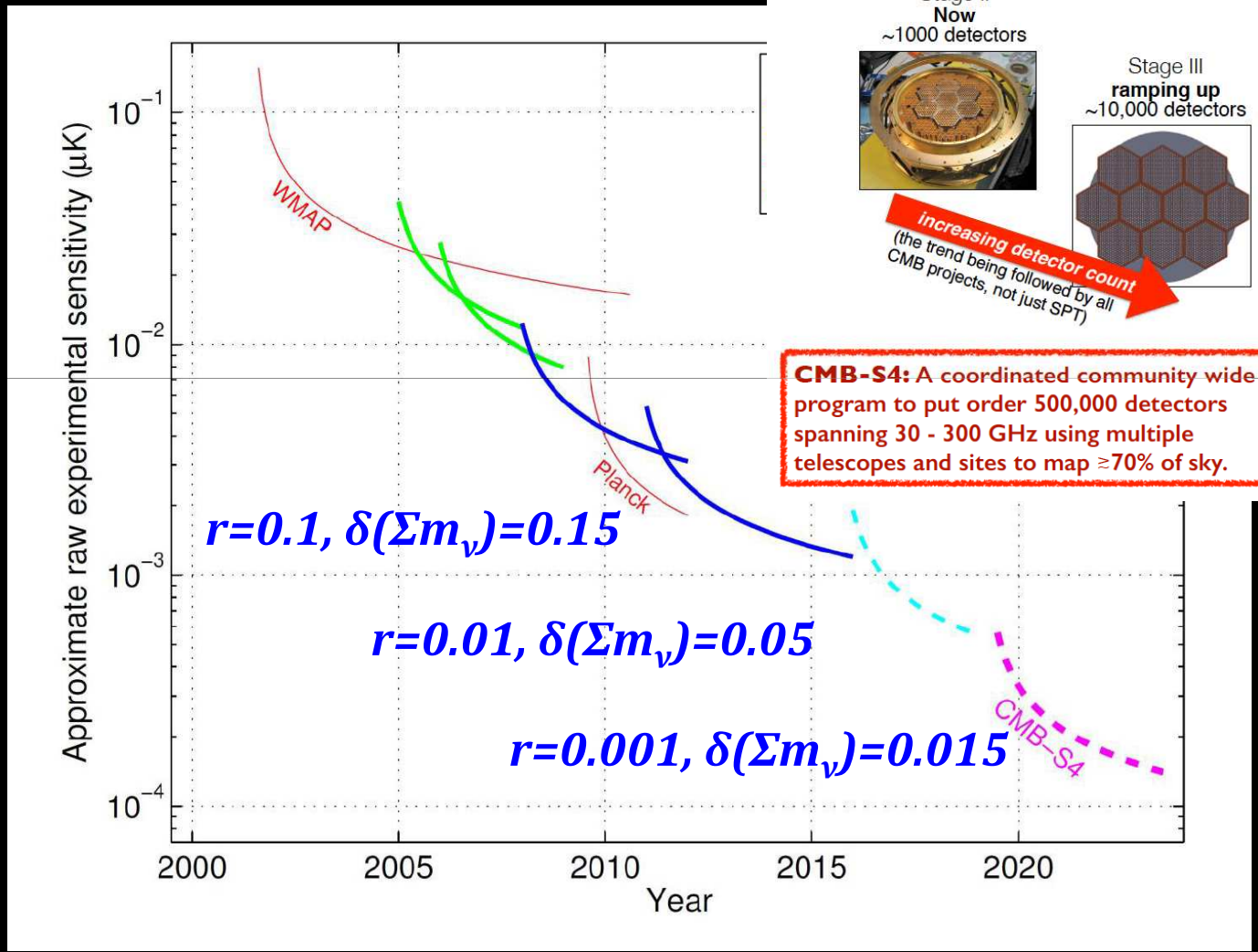
Science at the interface with particle physics, astrophysics and cosmology

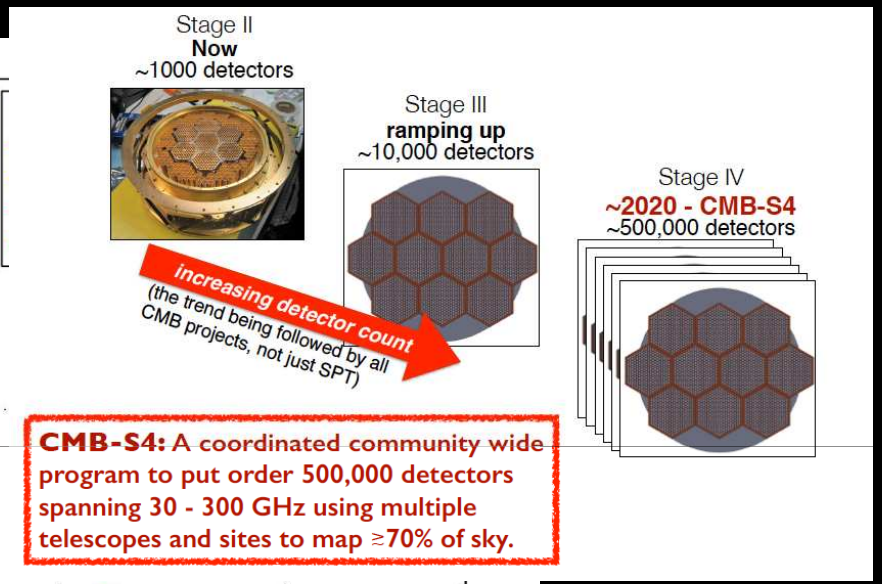
7. APPEC initiated the global coordination and presently endorses a global neutrino program: DUNE (US), JUNO(China) and HyperKamioka (Japan)
8. APPEC supports the forthcoming ESA Euclid satellite mission which will establish clear European leadership in space-based Dark-Energy research. Because of the complementarity to Euclid, APPEC encourages continued European participation in the DESI and LSST projects, the USA led ground-based Dark-Energy research. To fully profit from the combined power of satellite and ground- based experiments, the exchange of data is imperative.
9. APPEC strongly endorses the proposed European CORE satellite mission to map the CMB from space. APPEC will encourage detector R&D towards a next generation ground-based CMB experiment complementary to initiatives in the USA. APPEC continues to contribute to the global coordination of the field following the 'Florence CMB workshop' series started in *2015*
   - *NEW: CORE Is not in the short list published by the technological committee for "technological and programmatic reasons". Decisions taken without consultation with SSAC. SSAC currently deliberating.*

The unified study of the visible (and invisible) Universe



Prospective CMB on ground , CMB-S4





European contribution to CMB-S4, subject of a proposal for a H2020 Design Study (Coordinator K. Ganga) under preparation

WP1 Management	WP2 Requirements & Analysis	WP3 Site Evaluation	WP4 Telescope & Optics	WP5 Focal Plane & Detectors	WP6 Construction & Operation	WP7 Design Comparison	WP8 Governance
Contracts	R, Σm_{nu}, DE, Tau, ...	Atmospheric Testing	Cost of Large Aperture Telescope	Cost of 100000 KIDS	Cost of Infrastructure At Dome-C	Cost of "Tight" Integration	Outreach
Budget	Ancillary Data Needs	Dome C Evaluation	Cost of Small Aperture Telescope	Cost of 100000 TESs	Cost of Infrastructure At Tenerife	Cost of "Loose" Integration	Membership
Scheduling	Work with Satellites	Argentina Evaluation	Polarization Modulation	Multi-chroic Detector Design	Cost of Infrastructure At US-S4 Site	Cost of Other Scenario	Data Rights
Reporting	Work with Balloons & Other Expts.	Tenerife Evaluation	Lenses	Readouts	Cost of Infrastructure In Argentina	...	...
Industrial Contacts	Scanning	ALMA Chile Site Evaluation	Filters	Thermal Control	...		
	Computing Resource Needs	US-S4 Site Evaluation	Cost of CCATP-style Telescope	...			
	Sky Coverage	Atmospheric Modeling	...				

- **Scientific issues.** One can identify schematically five key scientific issues that cluster a series of questions· All infrastructures studied in the present scientific council address in one way or another the 5 key issues below:

1. ***The multi-messenger or "cosmic ray origin' issue***. It concerns the way that different probes (photons, CR, neutrinos and gravitational waves) are related between them. In this theme more specific questions are:
   - Can we find point-sources of UHE cosmic rays?
   - Can we find point-sources of HE neutrinos? What is then the mixture of galactic and extragalactic sources?
   - What is the relationship between high energy ν and high energy γ production? Can we find common point-sources? What is the relationship between UHE cosmic rays and ν? These are questions addressing explicitly the issue of the origin of cosmic rays. But also, can we detect supernova (low energy) ν ?
   - Last but not least, can we localise sufficiently GW sources to be able to identify follow-up events in the other probes (low and high energy γ or ν)?

2. ***The dark matter issue.*** Key sub-issues are:
   - Can we separate standard astrophysical processes from dark matter annihilation or decay at the multi-messenger infrastructures?
   - Once indices of discovery of dark matter are produced in indirect, direct and/or LHC searches can we pin-down its properties (mass, cross section, distribution, etc.)

III. ***The cosmic structure issue***. For the first time, the cosmological survey sensitivities have reached the level that permits to "unify" the visible Universe from the recombination era (400.000y) to the present and thus:

- Probe the distribution of dark matter, neutrino number and mass, using CMB studies, large "nearby" surveys for dark energy (z<2) , galaxy distributions, reoinisation etc.
- In this context it is necessary to understand and compare measurements of neutrino number and mass on earth with cosmological ones. Eventual discrepancies may point to new physics beyond the standard model of particle physics and/or cosmology. On what concerns the subject of this report, the high energy neutrino infrastructures will attack the issue of neutrino masses and nature (sterile) (e.g. ORCA/ARCA).

IV. **The gravitation and cosmology issue.** The sub-issues here are:

- the full development of gravitational wave astronomy, in order to study the formation of galaxies, the existence of phase transitions in the Universe, eventually to also use the GW events as "standard sirens" to probe cosmological parameters
- the discovery of the gravitational imprints of inflation on the CMB polarisation

V. **The new physics issue.** The study of very high energy events, or events close to the "strong limit" of gravitation, or events testing Lorenz symmetry, open obviously the access to new physics for all infrastructures studied in this report.

Astroparticle Physics and Cosmology the next 20 years

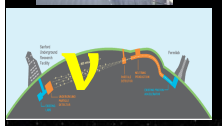
CTA/KM3NEt/AUGER+

DESI/LSST/EUCLID

CMB-S4

2017 | 2019 | 2021 | 2023 | 2025 | 2027 | 2029 | 2031 | 2033 | 2035

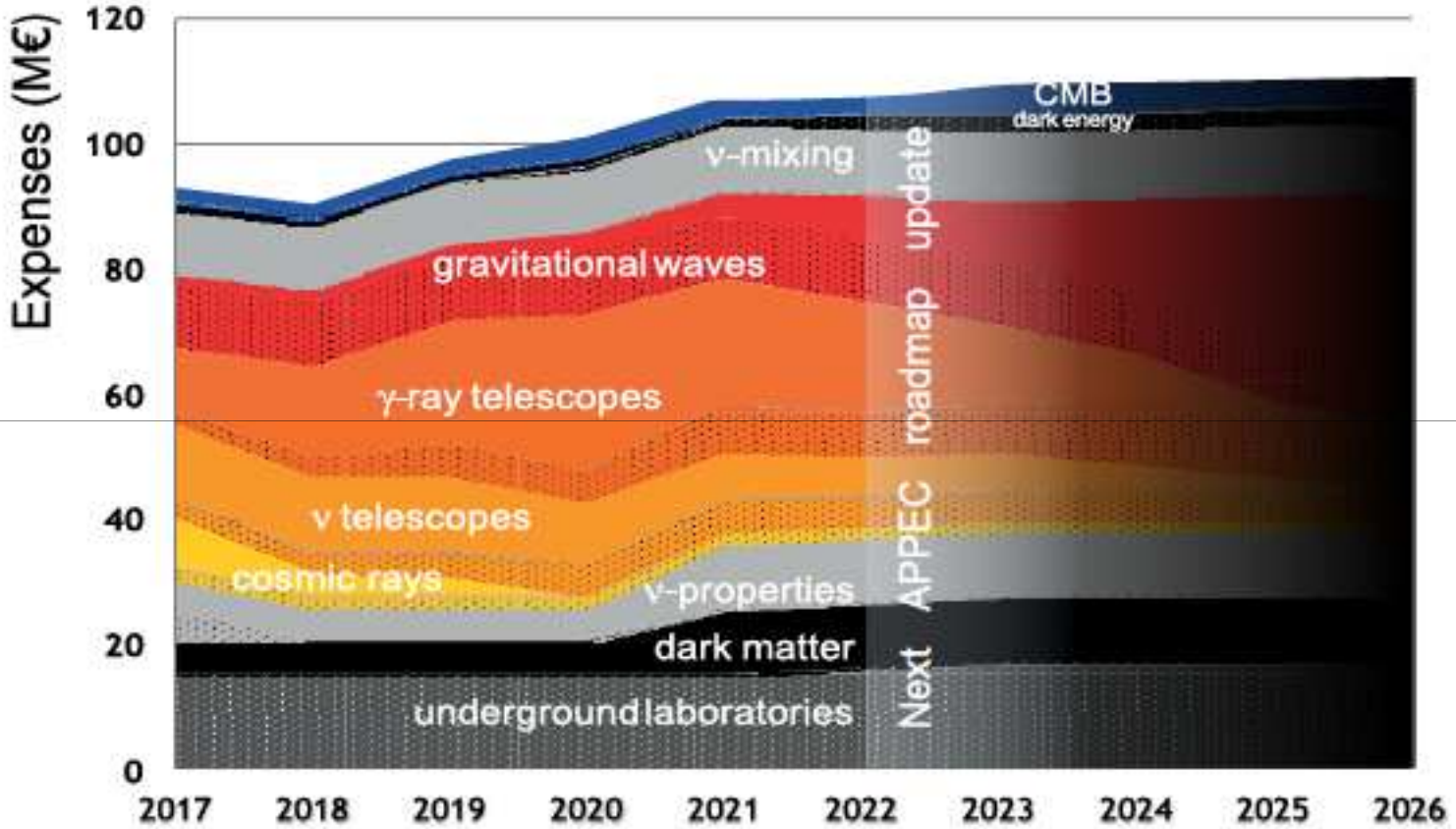
1 Multiton detectors Liq Xe/Ar



1 Ton 2β0v/JUNO DUNE/HK

AdvVIRGO/LIGO ET LISA

A resource aware roadmap



Projected annual capital investment – instrument prototyping and construction, excluding manpower – *and annual running costs* – consumables and shift taking expenses *i.e.* travel and manpower *(shaded areas) – anticipated from the European astroparticle physics funding agencies required to realize the APPEC* European Strategy for Astroparticle Physics. *Costs related to the actual scientific exploitation are not considered in this projection. Also excluded from this projection are other, often substantial, contributions from regional and EU structural funds, from European astronomy, from European particle physics (DUNE) and contributions from our non-European partners (in particular large ν-mixing infrastructures).*

Organisational issues (a personal selection) . IN2P3 will need to accompany the building up of CTA, KM3Net, Auger-prime, the upgrade path of Virgo, preparation of LISA.

I. The strict observance of models of sustainable and cost effective operation will be a strong prerequisite for success. In particular CTA and KM3Net being the first very large infrastructures of Astroparticle Physics to be deployed in the coming years, is a key test of the capabilities of the community and the agencies to develop a sustainable model of operation for large APP infrastructures. Non-optimal policies in the deployment and operation costs can become prohibitive for the emergence of future infrastructures, as is shown in other domains.

II. A second important issue is the coordination CERN (upcoming Strategy exercise) and ESO as well as with with space projects and the relevant agencies (CNES, ESA…). The case is clear for the Gravitational waves domain, where one has a complementary strong program on ground and space, but can also be very important to have low energy photon detection in space for the follow-up of the same gravitational wave events (see e.g. the scientific case of SVOM).

III. Thirdly, the program needs to be accompanied with a strong R&D program a well thought data policy and data management.

IV. Last but not least , IN2P3 should not neglect to promote the interdisciplinary potential of the domain, since it is rich and would increase the resilience of the funding schemes. There are synergies with geoscience in deep sea high energy neutrino infrastructures but also GW techniques (seismology, deep earth study), deep biology in KM3Net, climate studies in CTA, AUGER and KM3Net, etc. A coordination with relevant national and European agencies should probably be sought.

Conclusions

- In the last 30 years, we have seen
  - the detection of Supernova 1987A and the Crab in HE γ 1989
  - 3 major paradigm-changing discoveries in the 90's
    - CMB fluctuations
    - Confirmation of neutrino oscillation and mass
    - Dark energy
  - In the 2010's Gravitational waves
- The longest series of Nobel prizes for an emerging domain

- What can we reasonably expect in the coming 10-15 years ?
  1. The development of multi-messenger astronomy
  2. Dark matter sensitivities close to the parameter limits of our current theories, and ultimate precisions measurements in inflation and dark energy,
  3. A determination of the neutrino masses, number and CP violation and their interplay with cosmology

- The infrastructures under study can contribute to all