# *Perspectives in Astroparticle Physics*

« A report by APPEC on the expected evolutions of Astroparticle Physics in Europe and world-wide »

Stavros Katsanevas, APC and APPEC

Solvay –Francqui Workshop neutrinos reactors to the Cosmos , Brussels May 2015

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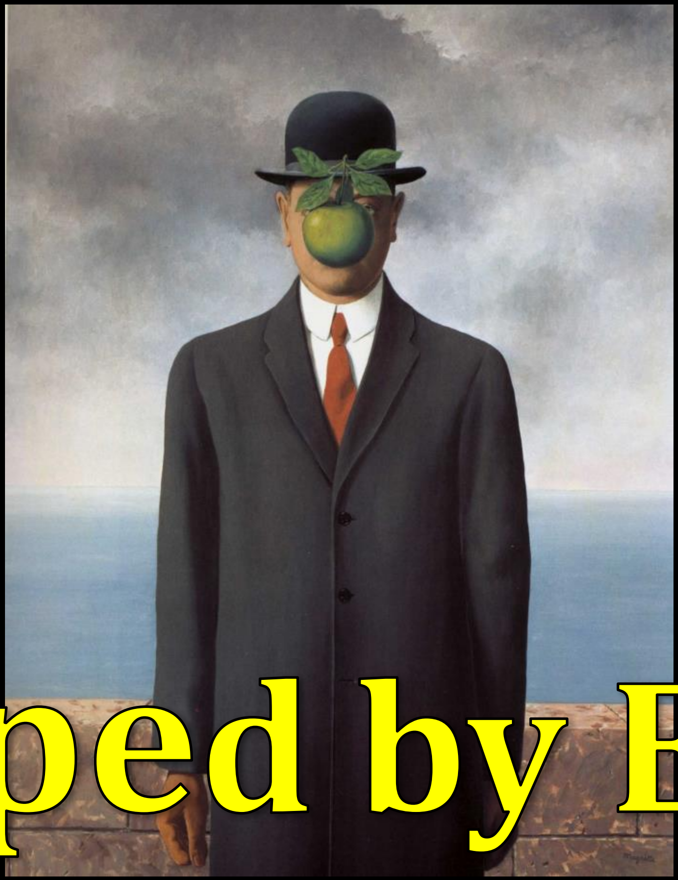

The first slide prepared at Paris for this meeting

# **Scooped by Eligio**

*In the « The son of man » … you have the apparent face, the apple, hiding the visible but hidden, the face of the person… Everything we see hides another thing... There is an interest in that which is hidden and which the visible does not show us. This interest can take the form of a quite intense feeling, a sort of conflict, one might say, between the visible that is hidden and the visible that is present.* René Magritte

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# Astroparticle Physics, a definition once more: Going up and down the cosmic ladder

APPEC

**Planck-Scale**

**Grand Unification**

**Leptogenesis**

**Dark Matter**

**Fermi-Scale**

**eV-Scale**

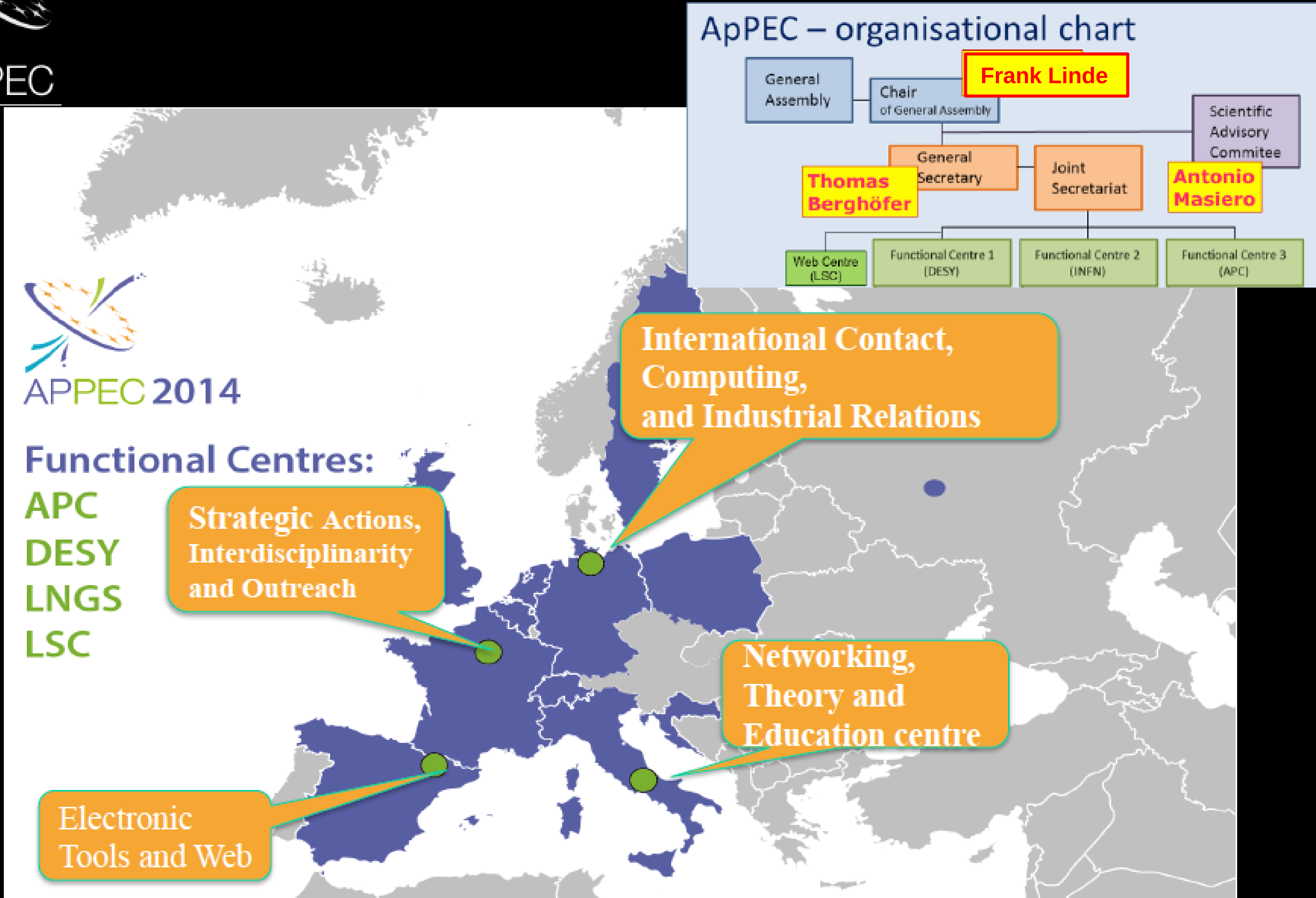
Jacobs' ladder or
« high voltage travelling arc »

Two fundamental and interconnected themes:

*The evolution of the Universe, from the Big Bang or the primordial inflation up to its present structure:* Addressing the issues of inflation, dark matter and energy, as well as these of the neutrino sector and the possibilities of new physical energy scales and/or phase transitions between the electroweak and inflation scales or beyond.

*The evolution – formation and destruction – of cosmic structures:* How the particles of the Standard Model and possible new particles can influence the genesis, formation and destruction of cosmic structures? Topicality and urgency of multi-messenger studies of high energy photons, neutrinos, high-energy charged particles and gravitational waves.

# APPEC Structure




Outreach → STFC

# The European Astroparticle Physics Roadmaps From 2008 to 2016

APPEC

- 1st Roadmap document the "Seven Magnificent" 2008
  - An attempt to define the field , no priorities
    - Announced in Brussels at the Hotel Metropole
- 2nd Roadmap a priority roadmap 2011
  - 3 categories (time and scale ordered ➔ priorities e.g. CTA)
    I. Preserve the then ongoing upgrades: advanced GW antennas, dark matter and double beta
    II. The next generation of large CR programs: CTA, KM3Net and IceCube, AUGER upgrade
    III. Promote globalisation for large projects: Next generation large neutrino detectors, Dark Energy and CMB
  - Input to European CERN strategy and national roadmaps
- 3rd roadmap a "resource aware roadmap"
  - A text in preparation by SAC, will become publicly available in October
  - Community-agency workshop end of 2015
  - APPEC Roadmap early 2016
- WORD Of CAUTION: In the following, my understanding of the current discussion, not representing necessarily the views of the SAC and even less these of APPEC

From the Nature article

# From the APPEC
# Scientific Advisory Committee (SAC)* Roadmap

Questions and future discoveries classified in 3 large domains.

We need to understand:

1. The origin and composition of the cosmos, test the theories of inflation, probe the nature of dark matter and energy

2. The cosmological role of the neutrino sector, the number, type, mixing and masses of $\nu$.

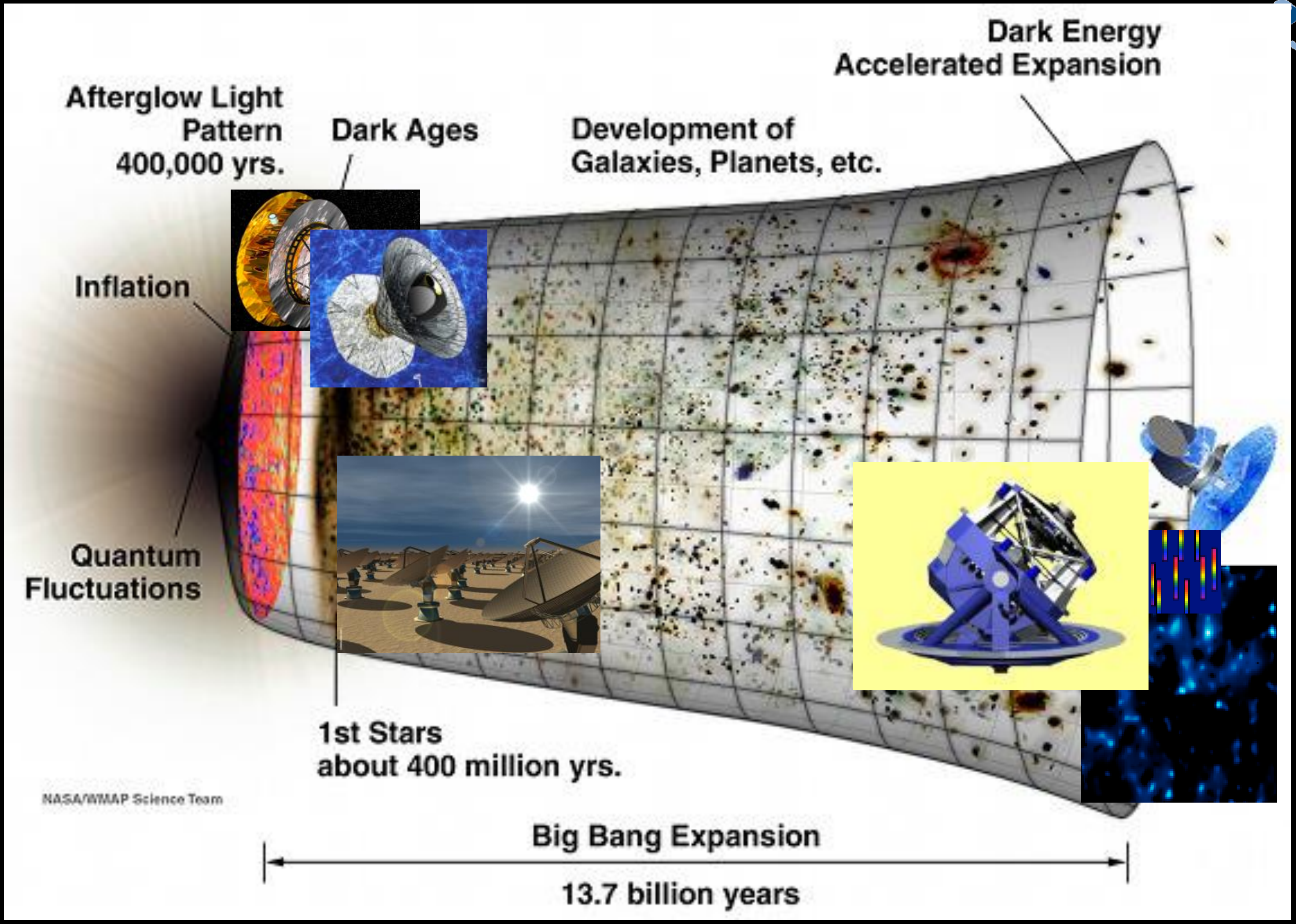
3. The formation, evolution, merging and destruction of cosmic structures as extreme laboratories mixing energy scales, probing also the presence of new physics. Multi-messenger studies.

* 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, S.Katsanevas (APPEC)

# From the APPEC
# Scientific Advisory Committee (SAC)* Roadmap

1. The origin and composition of the cosmos, test the theories of inflation, probe the nature of dark matter and energy

# Cosmic archaeology




- Large Dark energy surveys (eBOSS, DESI, EUCLID, LSS) probe the "recent" Universe (z<2)
- SKA and radio surveys probe the reionisation era (z = 7-10)
- PLANCK and ground based obseratories probe the recombination era and beyond (z<1100)

# After PLANCK what ?

(from the call for a European Coordination on CMB (APPEC-ASTRONET)

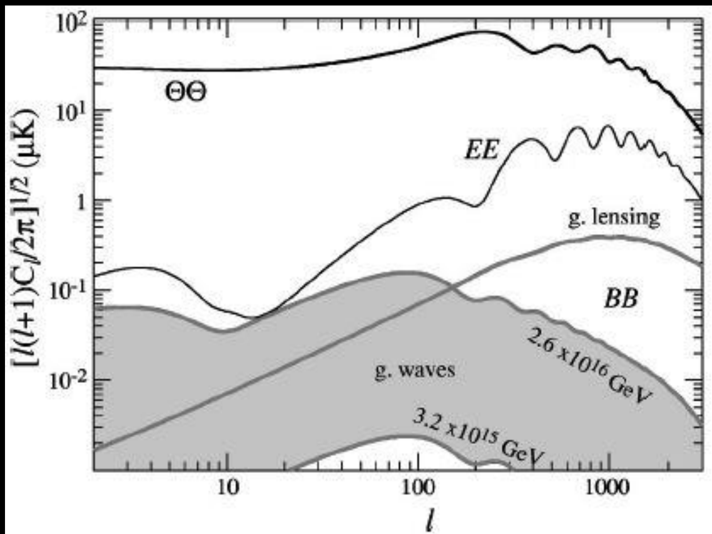
- Planck together and CMB measurements on ground opened the possibility of new breakthroughs in the CMB domain:
  - Map B-polarisation giving access to the parameters of inflation
  - Determine the sum of neutrino masses
  - Correlation of CMB with large scale structures
  - Distortions of the blackbody spectrum
- Next space mission will happen at the earliest late 20's-early 30' (M4 CORE+ rejected➔ M5?)
- Should be planned with the same ambition as Planc ➔ give definitive measurements.
- Till then the European CMB community needs to develop both intermediate measurements on ground or using balloons and the technology that would permit ultimate sensitivities.

- APPEC and ASTRONET organize "Towards the European Coordination of the CMB program" in August 31-1 September 2015 in Villa Finally Florence, gathering PI's and agency representatives to chart the first steps towards European coordination.

- Concurrent with post-Snowmass roadmapping in US (towards CMB-S4) and Japan.

- Worldwide agencies agree is that roadmapping needs to converge to a global program on ground and in space.

# B-polarisation spectra



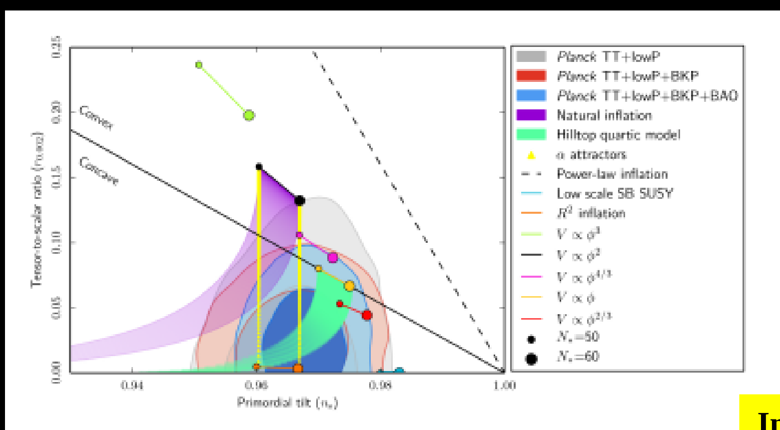

- Small angles l>200 lensing ➔ **neutrino mass**
- Large angles l<100 ➔ primordial inflation

$$r = \frac{P_t(k_0)}{P_s(k_0)}$$

r=ratio of scalar to tensor modes

In the simplest models *r* is related to the GUT scale and **proton decay** (r<0.02 is within HK sensitivities)

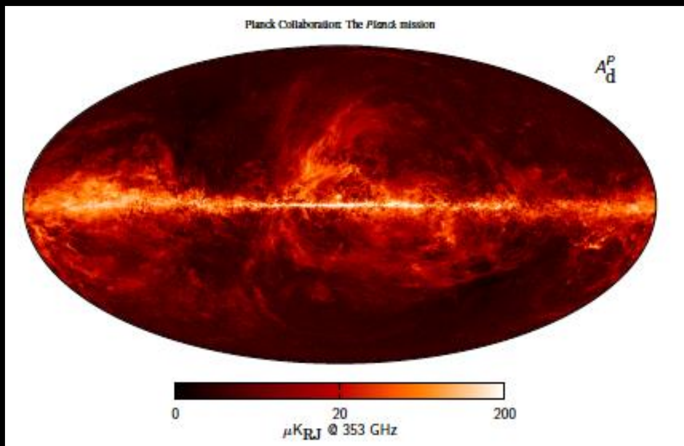
$$t(p \rightarrow p^0 + e^+) \approx 6 \times 10^{34} \times \left(\frac{r_{CMB}}{0,01}\right) \text{ years}$$

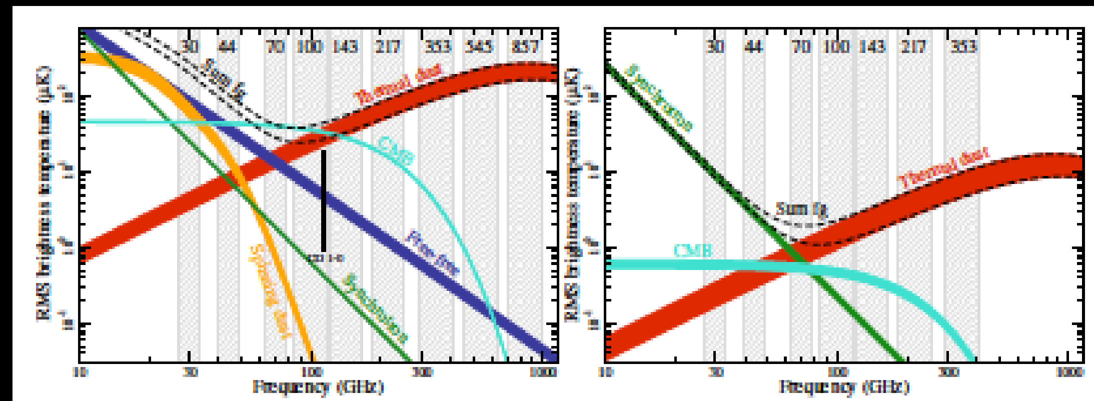


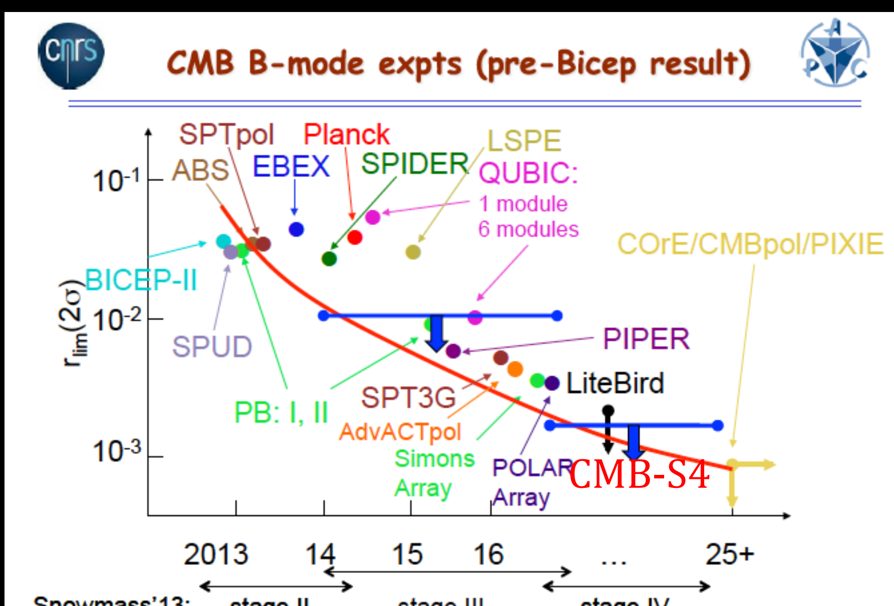

(Planck/BICEP2 r<0.09)

| In 10 years | Sensitivity in $10^{34}$ y DUNE | Sensitivity in $10^{34}$ y JUNO | Sensitivity in $10^{34}$ y HK |
|---|---|---|---|
| p ➔$e^+ \pi^0$ | 2 | ? | 12 |
| p ➔ν K | 4-5 | 1.5 | 1,5 |

# The future in  CMB in B-polarisation mapping



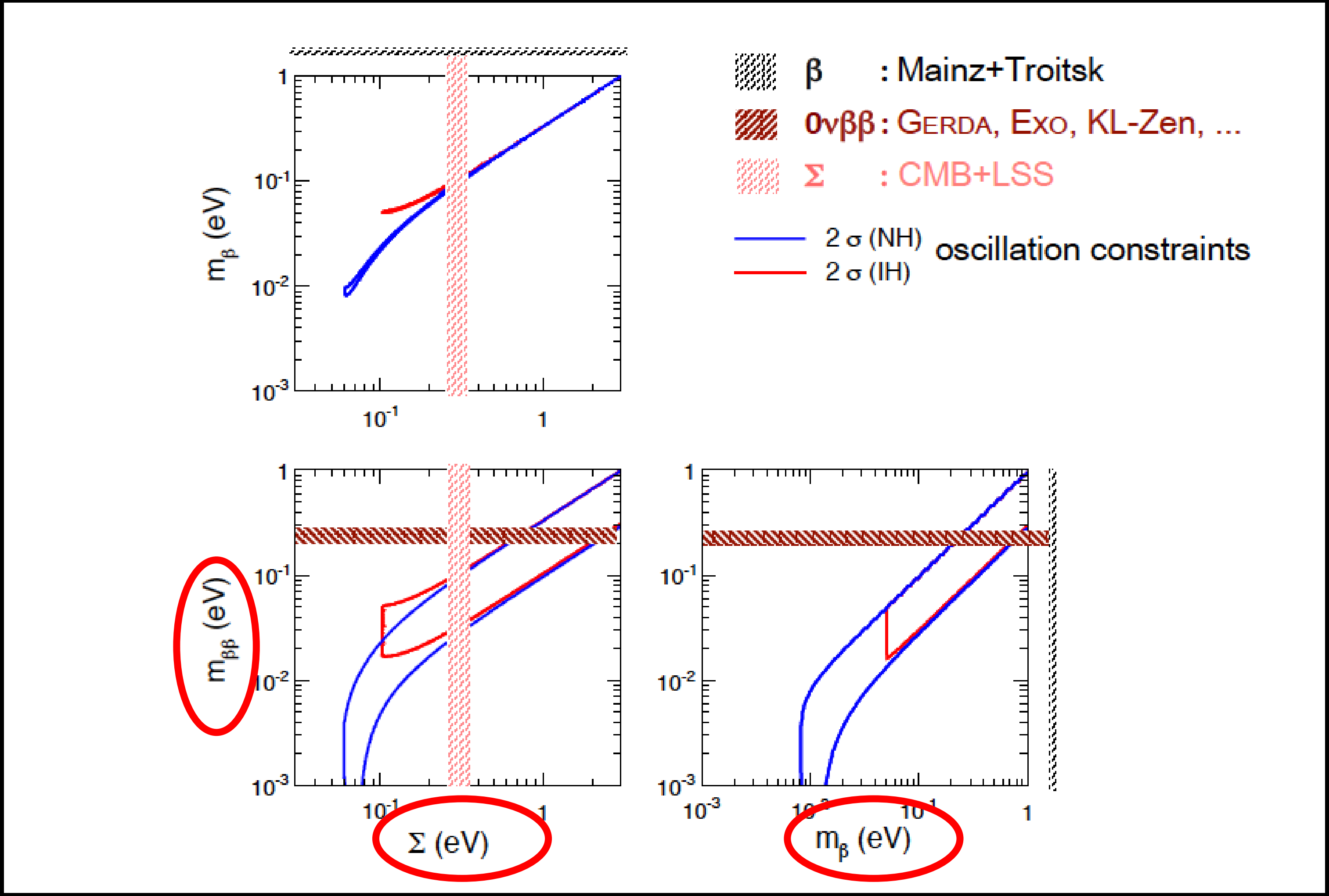




- On ground/balloon US leadership: ACT/Polarbear/BICEP/SPT/SPIDER:ABS/CLASS/EBEX/PIPER
  - P5 ➔ CMB-S4 (r=0,001)
- Japan: Groundbird, Litebird
- Europe Qubic, LSPE, QUIJOTE
- ESA-M4 CORE+ proposal  rejected…
- Important detector R&D: TES, KIDS

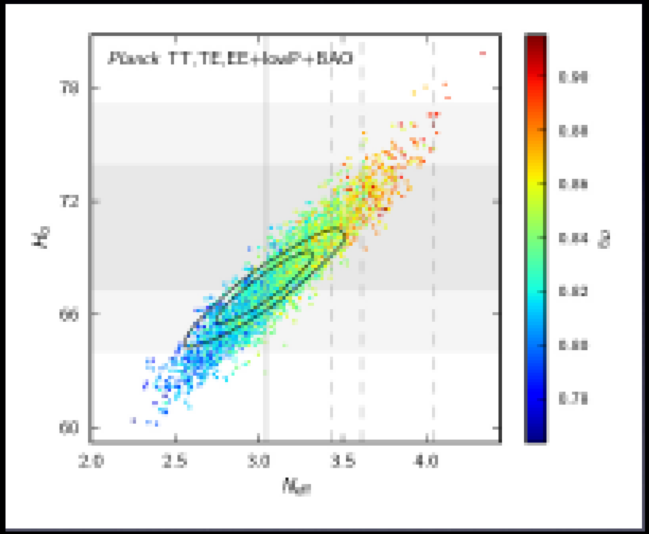
- Further in the future precision measurements of the blackbody spectrum (SunyaeV, imprints of nuclei formation, DM annihilation, …)

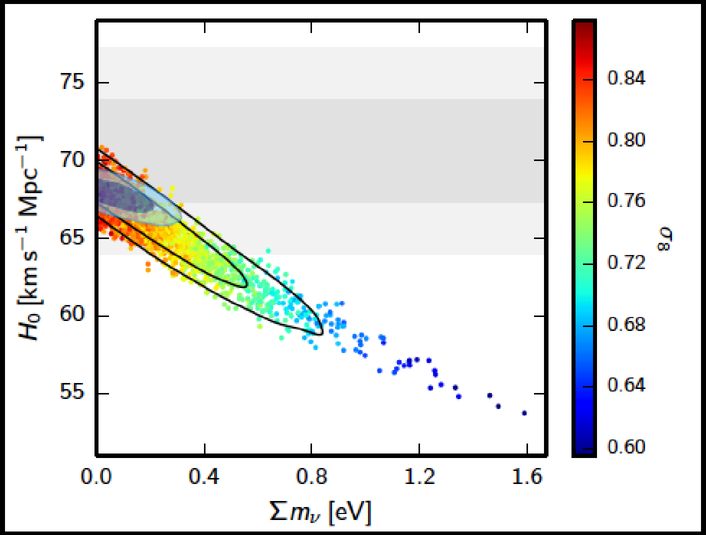
# Neutrino mass
# interconnected searches




From Fogli, Lisi,Marrone, Montanino, Palazzo, Rotunno 2013

# $\Sigma m_\nu$ from Cosmology

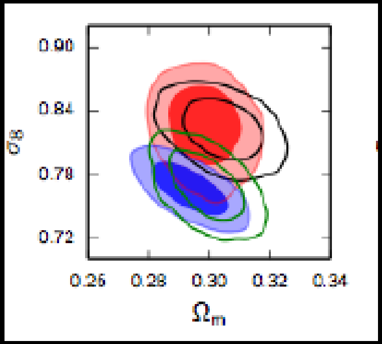



$\sum m_\nu < 0.21$ $N_{eff} = 3.15 \pm 0.23$ Planck TT +lowP+BAO

$\sum m_\nu < 0.17$ $N_{eff} = 3.04 \pm 0.118$ Planck TT,TE,EE +lowP+BAO

Tension with Large Scale Structure (Planck SZ, X-ray) , in the $\sigma_8$-$\Omega_m$ plane could be alleviated with sterile neutrinos since sterile neutrinos are degenerate with $\sigma_8$. In general « recent » variables ($H_0$, $\sigma_8$) below values measured at recombination. An active topic of research, astrophysics uncertainties. Not yet at the maturity of the previous measurements of masses and $N_{eff}$.



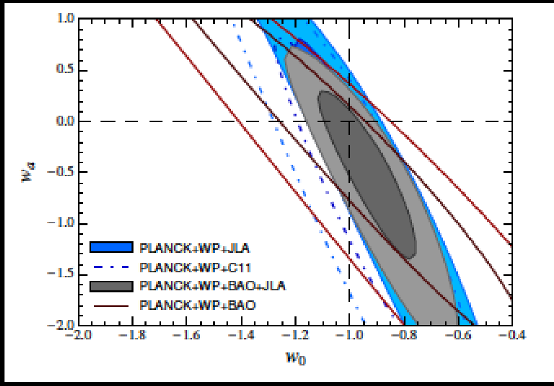
## *Dark energy from the Legacy Survey to EBOSS/DESI and EUCLID and LSST*

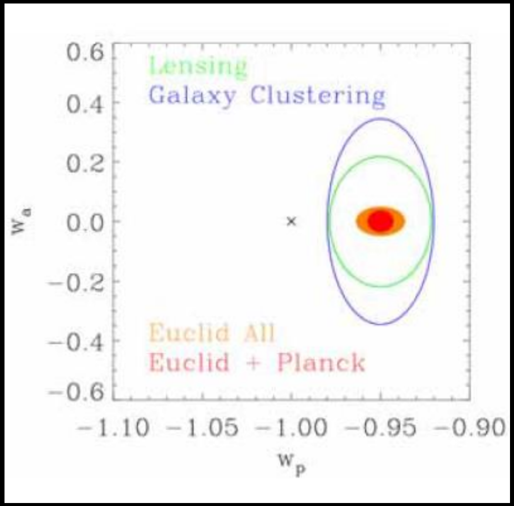
APPEC

- SNLS and PLANCK have been a key experiments in in the determination of dark energy parameters.

- Large dark energy surveys will study the large scale structure (WL, BAO, clusters) and associate it with knowledge obtained at recombination will give crucial information for neutrino mass (see above) and also dark energy equation of state.
- A very active front of cosmology
- Currently European participation in DES and in the near future in DESI (BAO and Galaxy clustering)

- EUCLID ESA M2 mission (NASA participation) a 1.2 m telescope at L2 with visible and NIR imaging, NIR slitless spectroscopy. Launch 2020
- LSST Complementary in systematics to Euclid superior spectroscopy (LSST) vs absence of atmospheric distortion (EUCLID). First light 2020
- APPEC recommended since 2011 the participation to both LSST and EUCLID.

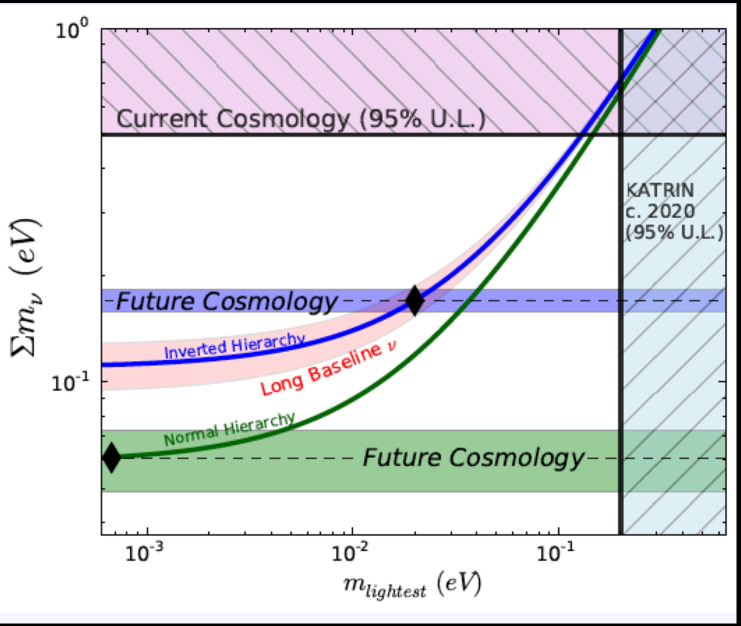


# Future $\Sigma m_\nu$ measurements (2025-2030)

Forecast sensitivities

| | | $d(Sm_n)$ meV | $d(N_{eff})$ |
|---|---|---|---|
| Planck +BOSS BAO | → | 100 | 0.18 |
| Planck+eBOSS (BAO+GC) | → | 40-100 | 0.13-0.18 |
| Planck+DESI (BAO+GC) | → | 17/24 | 0.08-0.12 |
| > 2025 | | | |
| CMB-S4+BOSS BAO | → | 25 | 0.02 |
| CMB-S4+DESI BAO | → | 16 | 0.02 |
| | | | |
| PLANCK+LSST | → | 23 | 0.07 |
| PLANCK+EUCLID | → | 25 | 0.06 |

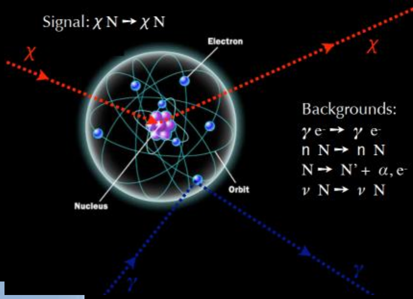


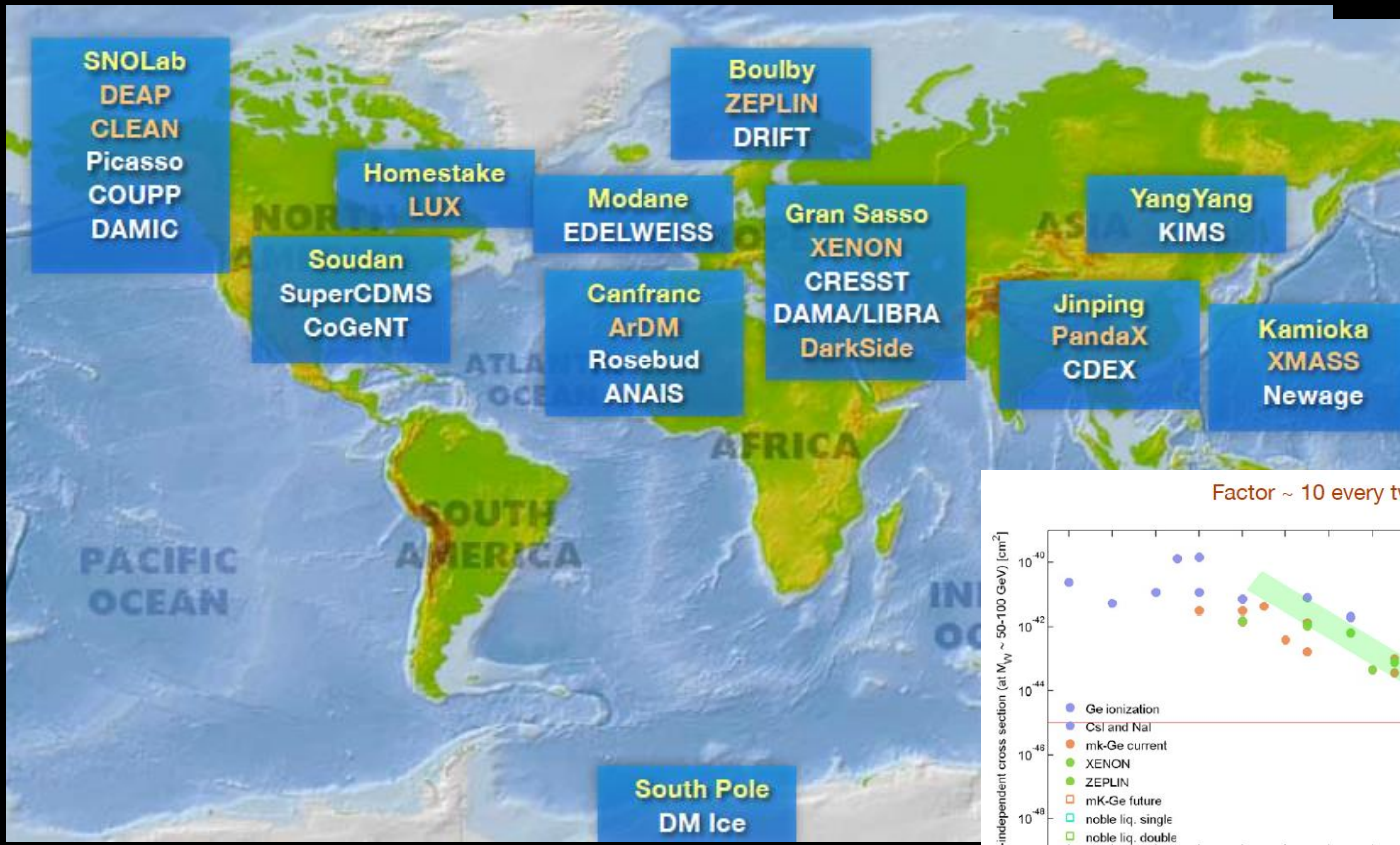

- **What if we do not detect the minimal model?**
  *If the minimal neutrino sector, with $\Sigma m_\nu = 58$ meV and $N_{eff} =3.046$, is* ***not*** *robustly detected, it would imply something is "broken" in another aspect or aspects of cosmology, including possibly:* non-constant dark energy, a non-power-law primordial perturbation spectrum, extra particle or radiation species, non-zero curvature, as well as other possibilities, e.g., a nonthermal cosmological neutrino background.

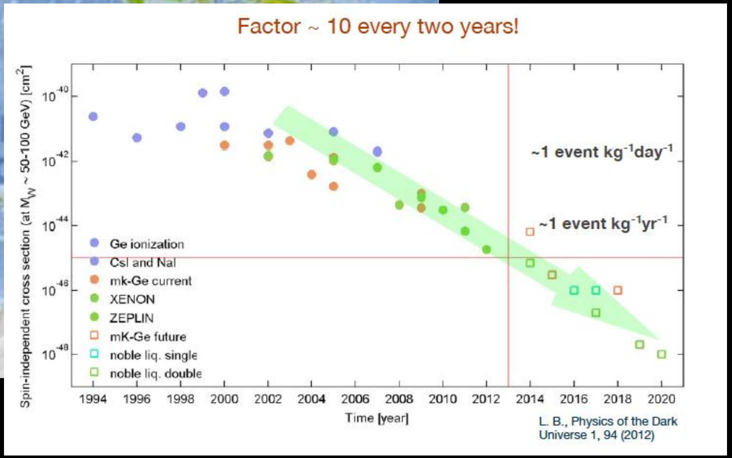
**$\sigma(\Sigma m_\nu) = 16$ meV &**
**$\sigma(N_{\rm eff}) = 0.020$**

*An order of magnitude improvement*

# Direct dark matter detection



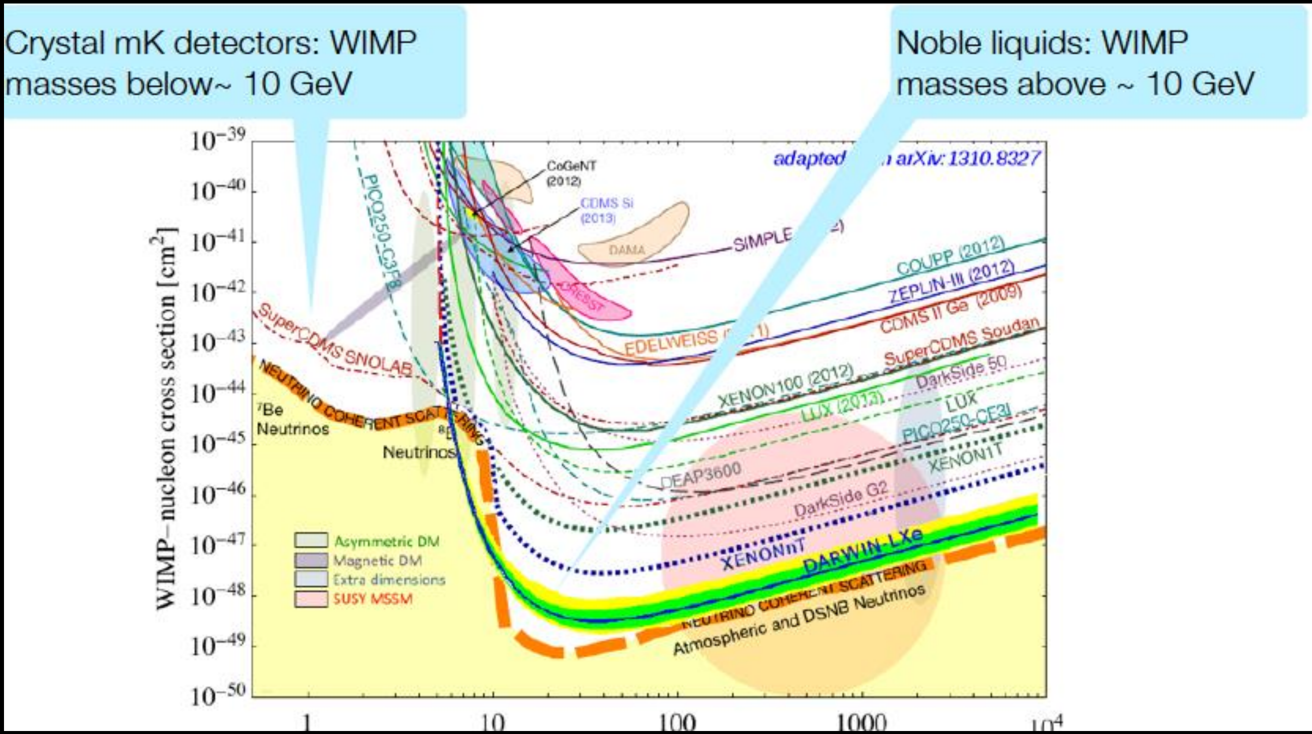




- WIMPs will be put in a severe, if not conclusive, test during the next 10 years. In case of discovery both accelerator and non-accelerator experiments will be needed to determine the physical properties of WIMPS.
- Great progress in axion searches also.

# Direct Dark Matter direct detection

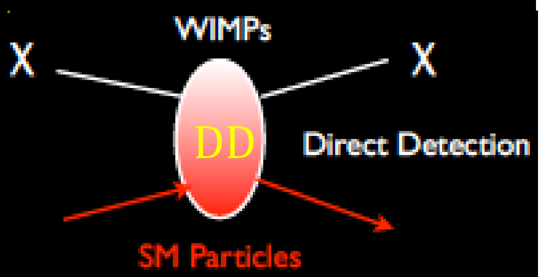
✓XENON 1t start data taking 2015 and multi-ton follows
✓DarkSide-50 demonstrated zero background rejection, Measured depletion >300X
?➔Next step 5t and O(100t) ca 2020

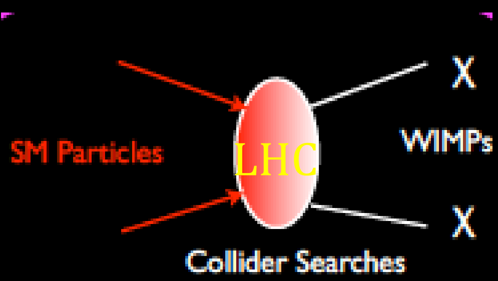
1. *10 GeV – 10 TeV multi-ton*
    1. *Xenon, LZ, DARWIN*
    2. *DarkSide*
2. *<10 GeV European Bolometers (CRESST, EDELWEISS) in EURECA discussions of cooperation with SCDMS, also SSD*

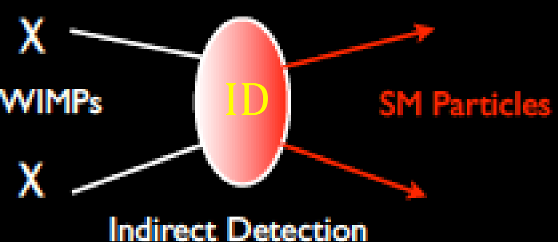


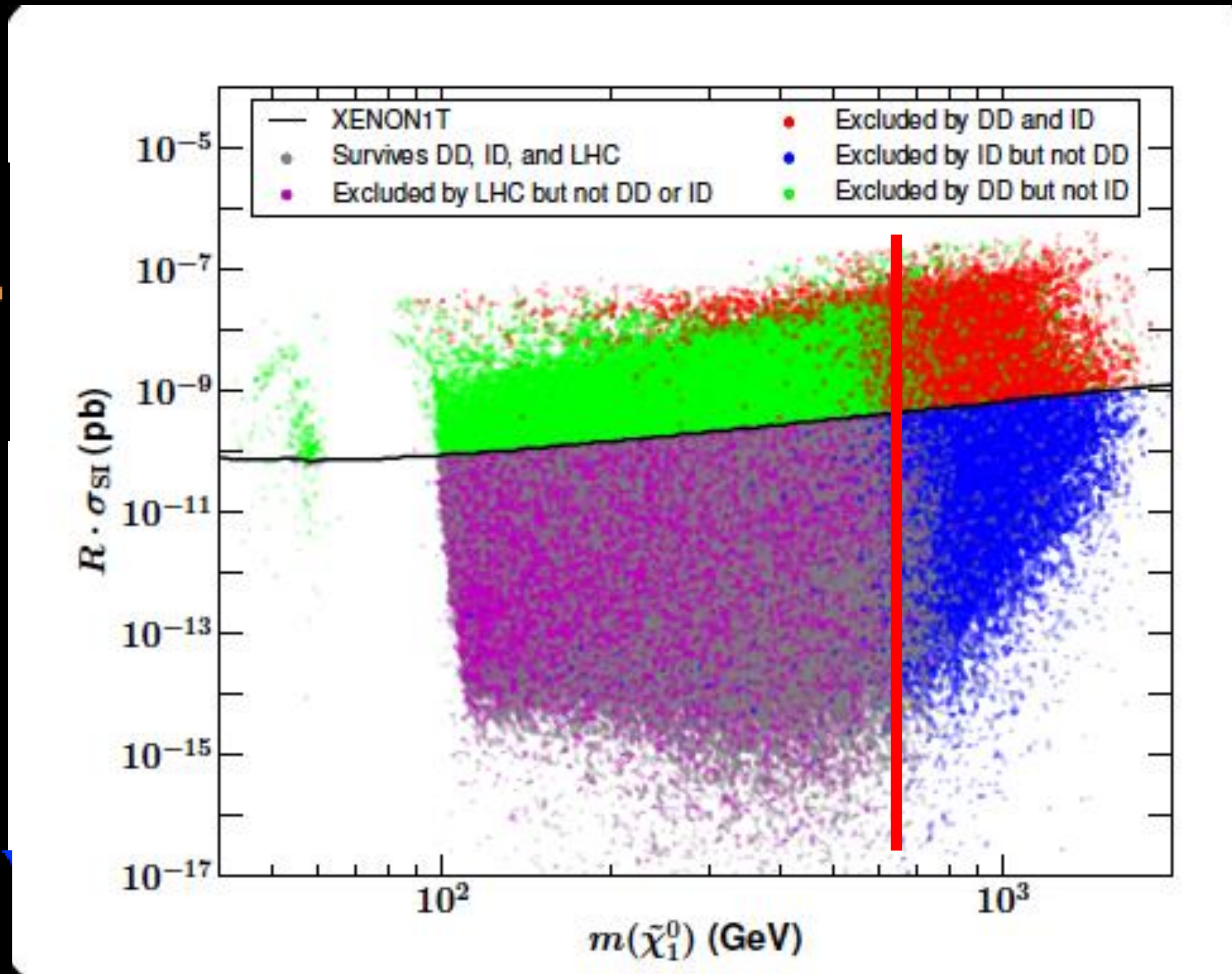

✓ *Complementarity: Low masses ➔ bolometers /SSD, High masses ➔ Noble liquids*
✓*Beyond the neutrino background wall (ca 100-150t) ➔ directional R&D*
✓*P5 ➔ G2 projects : SCDMS and LZ*
✓ *APPEC SAC ➔ Decide ca 2018 the G3 multi-ton experiment.*

# Complementarity Direct Detection, Indirect Detection, LHC



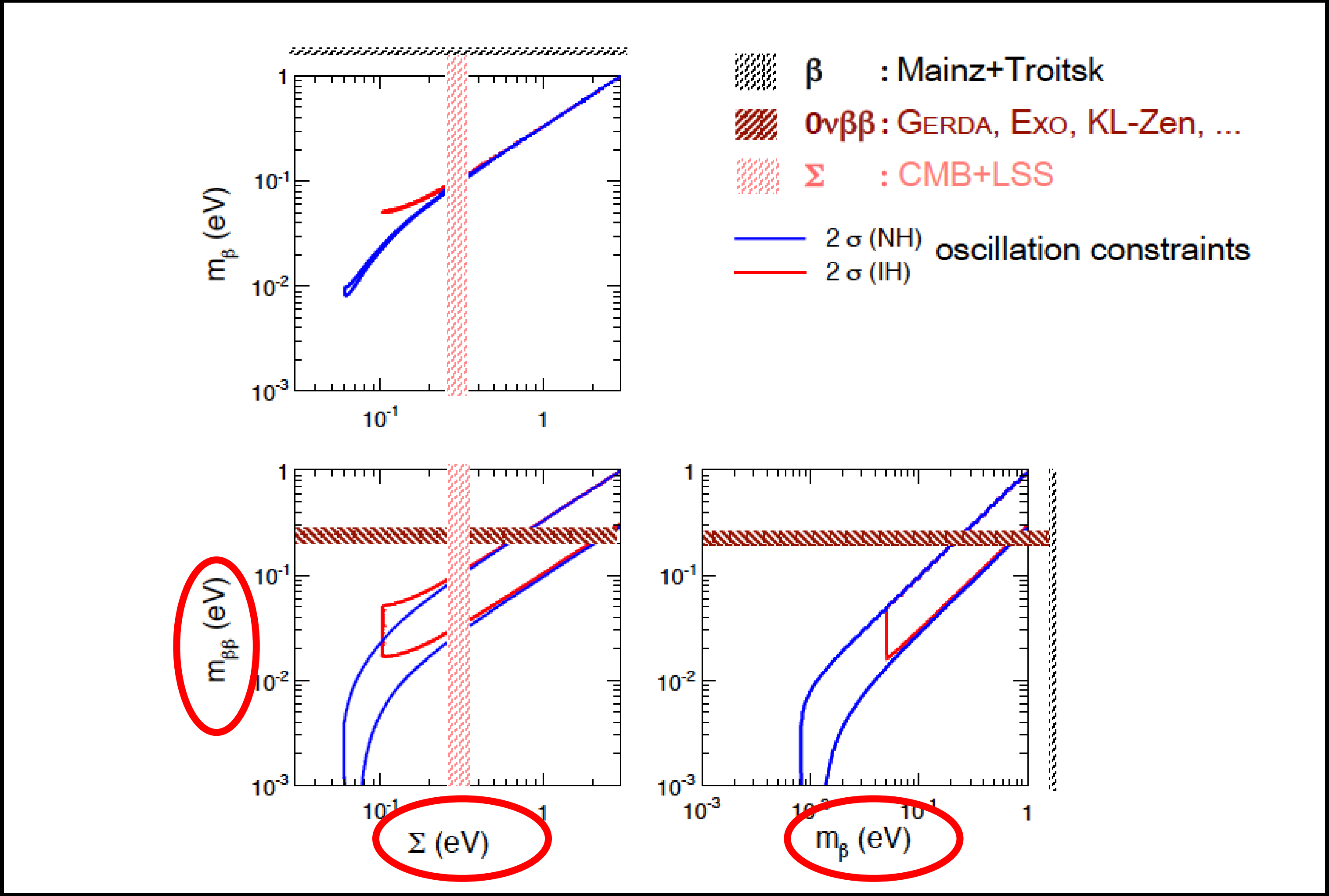




*Complementarity with LHC, also in case of high WIMP masses rationale for next collider (2018 an important milestone)*

# From the APPEC Scientific Advisory Committee (SAC)* Roadmap

2. Understand the neutrino sector and its cosmological role, in particular the number, type and masses of ν.

# Neutrino mass interconnected searches




From Fogli, Lisi,Marrone, Montanino, Palazzo, Rotunno 2013

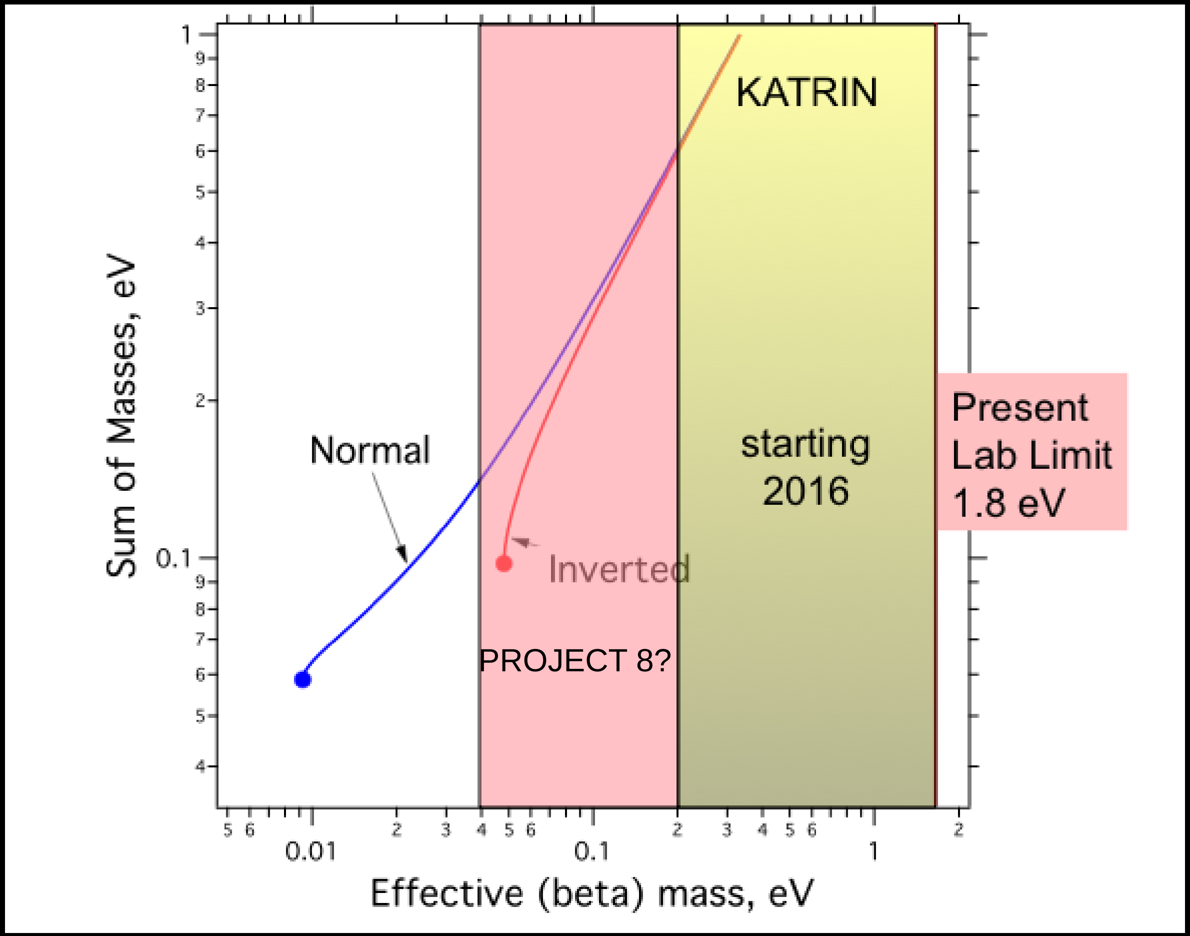
# $m_\beta$ : KATRIN and PROJECT 8

## Katrin 200 meV (2019)

Also cyclotron radiation from trium beta decay

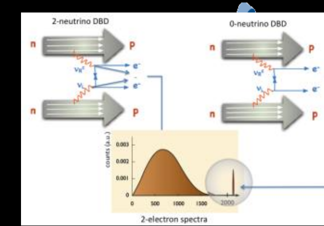
Project 8
Successful R&D,
40 mEV in 202?

Also low T μ-calorimeters: source embedded inside the detector (ECHo, US-Ho, HOLMES)



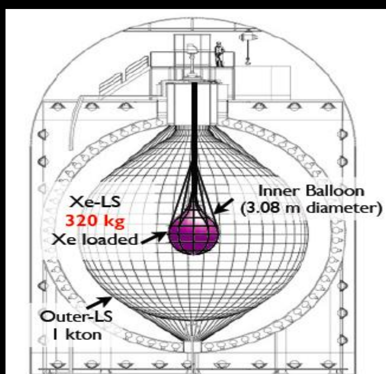
APPEC

# $m_{\beta\beta}$ ($2\beta0\nu$) detection technologies

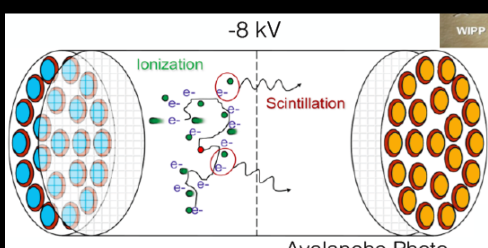



## 4 ways: 3 calorimetric + 1 tracking calorimeter

### Xe




Xe and Te loaded LS
Kamlamd-Zen, SNO+

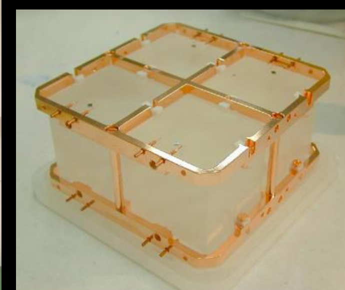



Liq and Gaz Xe
nEXO, NEXT

### Ge

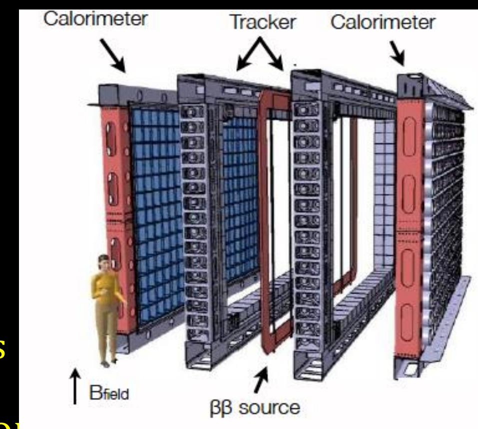
Ge Bolometers
GERDA, MAJORANA
MoU for 1t

### Bolometer



Te, Se, Mo Bolometers
Cuore,
LUMINEU, LUCIFER, AMORE

### Tracking-calo

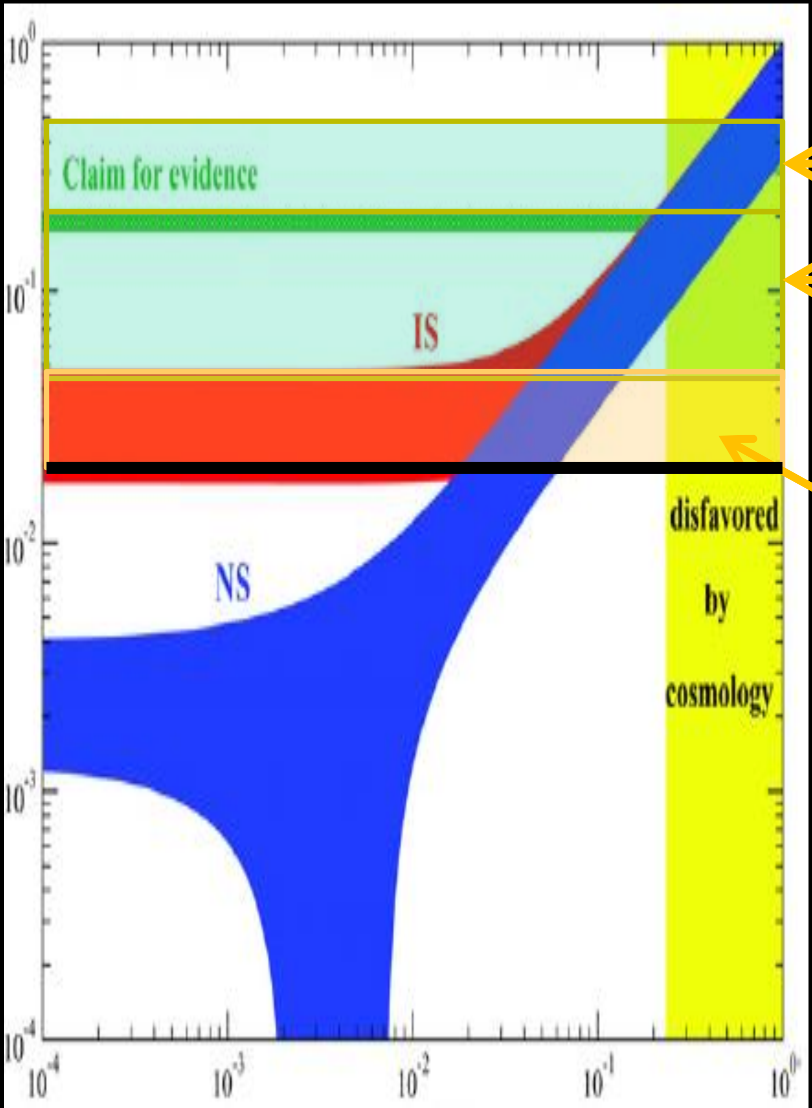



Many elements
SuperNemo
(eg Nd)

- 2nd generation for the inverse hierarchy region
- In US → NSAC roadmap announcement in September
- In Europe → APPEC roadmap. Towards a decision in 2018. Global collaborations ?

# 0νββ approaching/exploring the inverted hierarchy the next decade

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




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

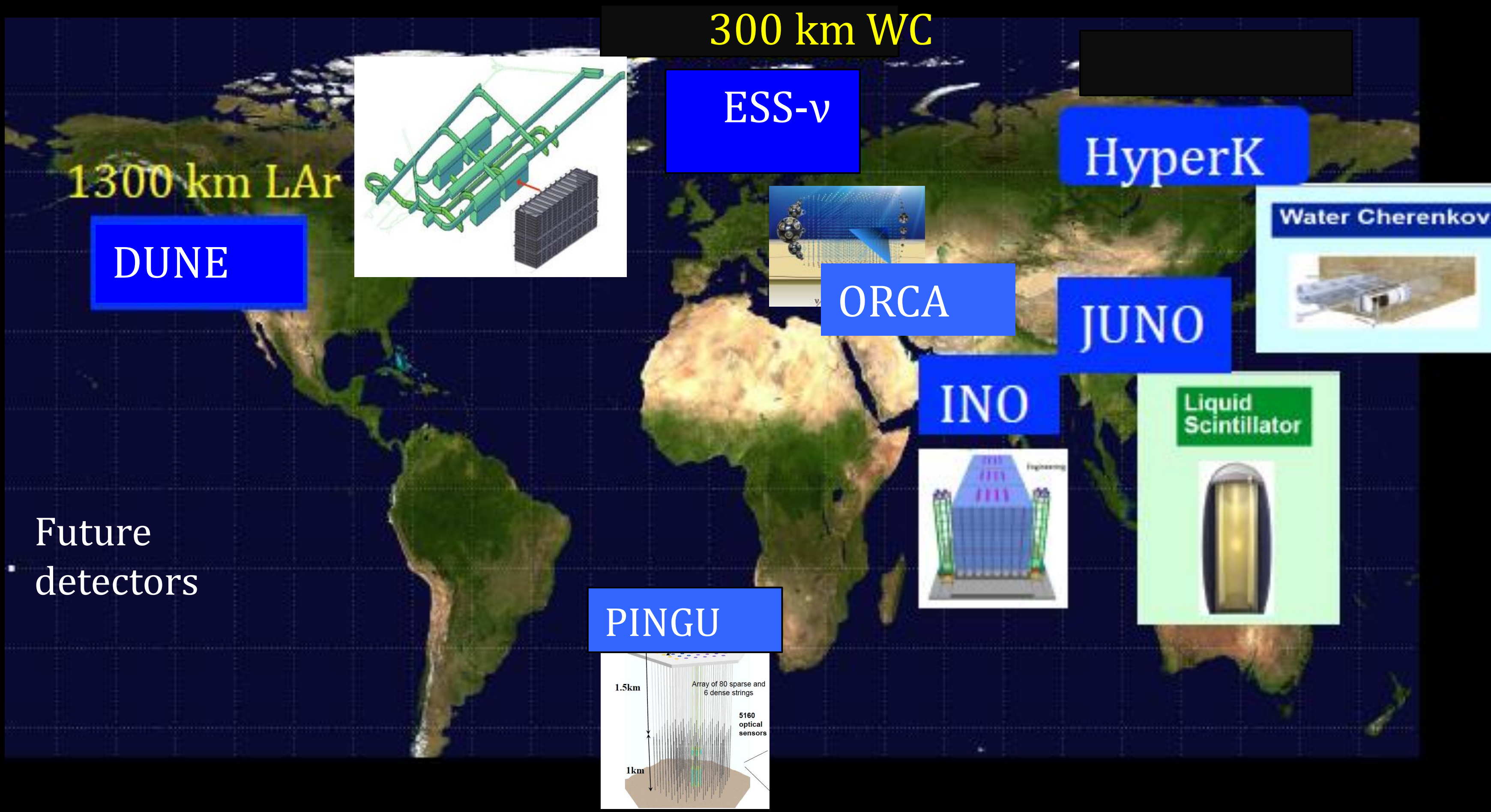
20 mEV
0.5-5 evts/y/ton

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 ?

Show stopper $g_A$ quenching ? Renormalised from 1.269 to 0.8-0.5 ➔ neutrino mass limits increased by 2.5-6

APPEC

# $\Delta m>0$ or $\Delta m<0$ Mass hierarchy




How soon ?

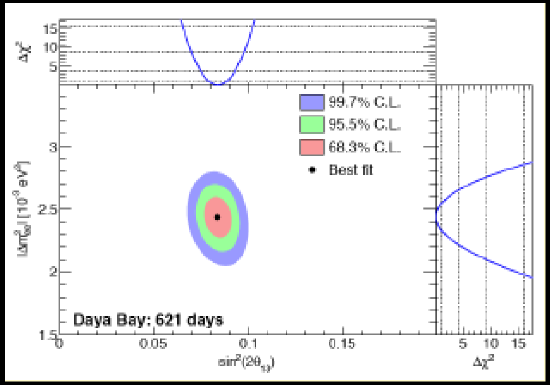
How many sigmas will be convincing proof ?

# Knowledge early 2015 (T2K, DayaBay)

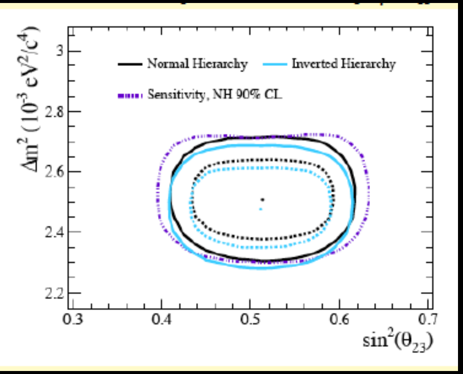
- Neutrino oscillations described by the PMNS matrix
  - 3 mixing angles, 2 mass differences, 1 complex CPV phase

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

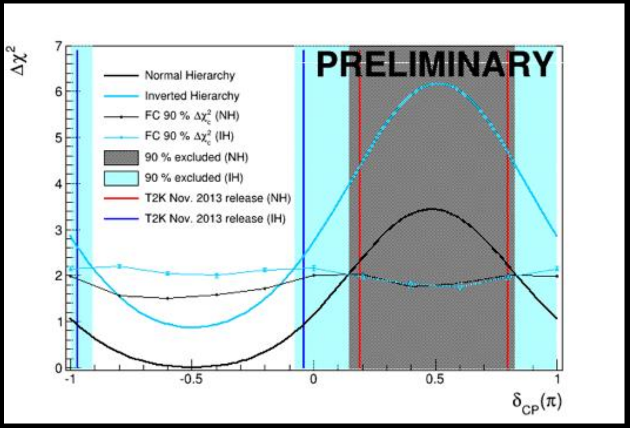
| Solar and reactor | Interference | Atmospheric and accelerator |
|---|---|---|
| $\theta_{12} \sim 34°$ | $\theta_{13} \sim 9°$ | $\theta_{23} \sim 45°$ |
| $\Delta m_{21}^2 \sim 7.6\times10^{-5}$ eV² | $\delta_{CP}$ = ?? | $\Delta m_{32}^2 \sim 2.4\times10^{-3}$ eV² |




$\sin^2(2q_{13}) = 0.084 \pm 0.005$

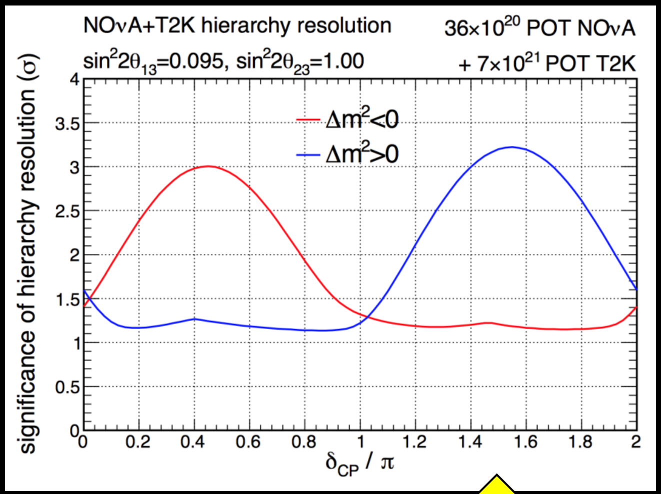


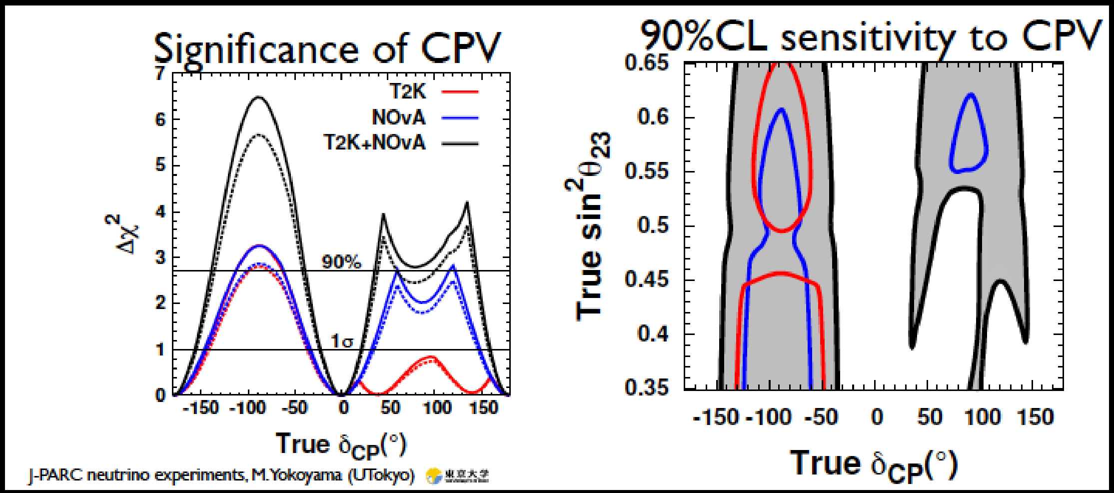

$\sin^2(2q_{23}) » 0.5 \pm 0.05$




Start excluding 0<δ<π

# T2K and NOVA expectations f or mass hierarchy CP violation in the next 5 years

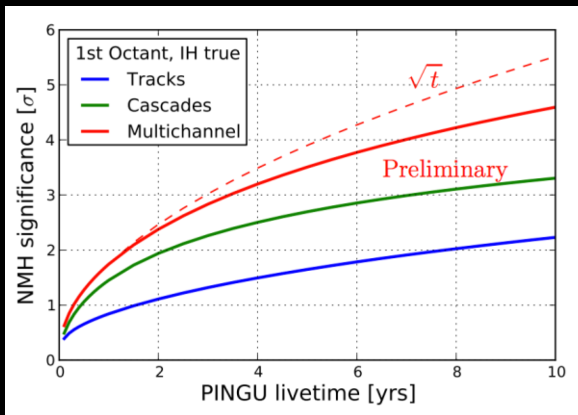


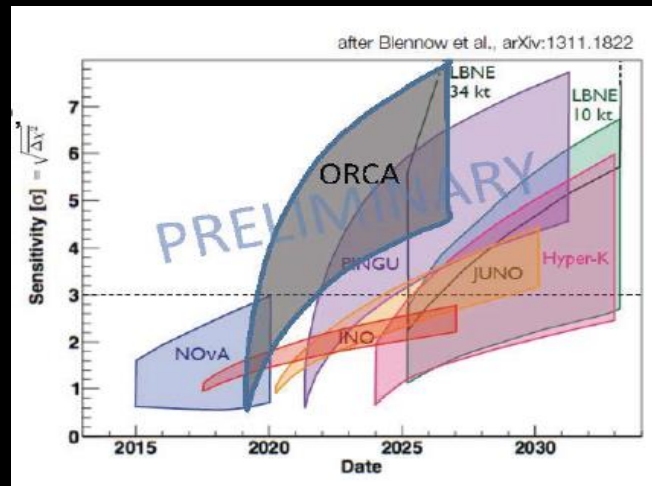



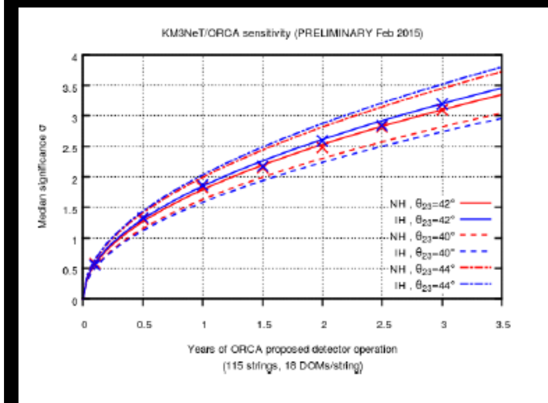

Current 1σ preferred value

- *Expect 2-3 σ effects on mass hierarchy with 50% probability*
- *Expect up to 2 σ effects on CP violation*

# Mass hierarchy with atmospheric and reactor neutrinos

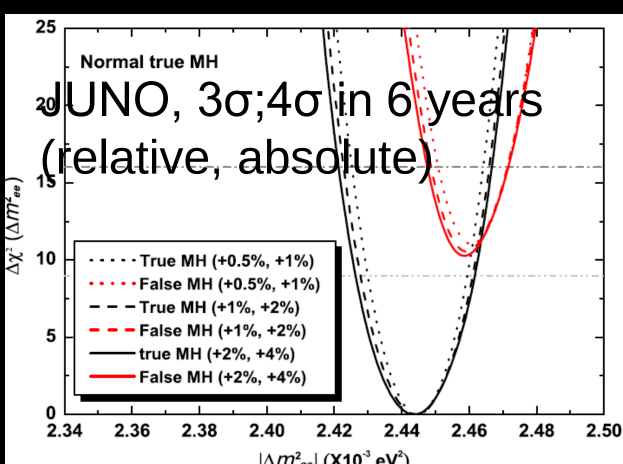


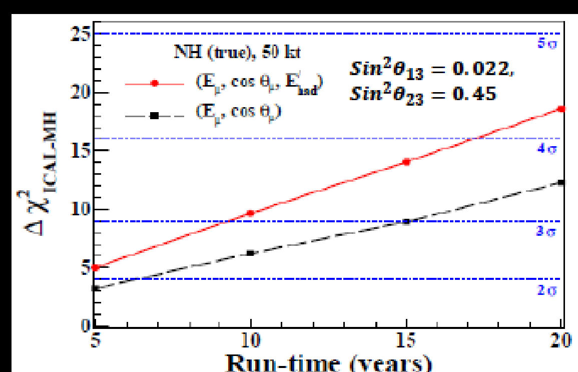



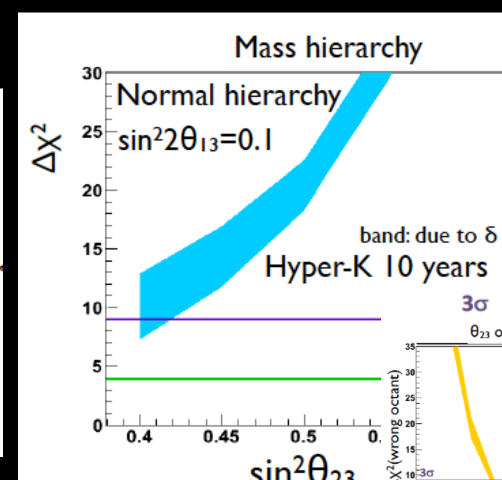



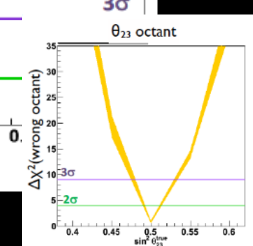

1. ORCA/PINGU 3σ in 3 years, (early 20's) 5σ in 10 years (end 2020's)
2. JUNO 3-4 σ in 6 years (ca 2025)
3. HK , INO 3-5σ ca 2035

JUNO, 3σ;4σ in 6 years (relative, absolute)

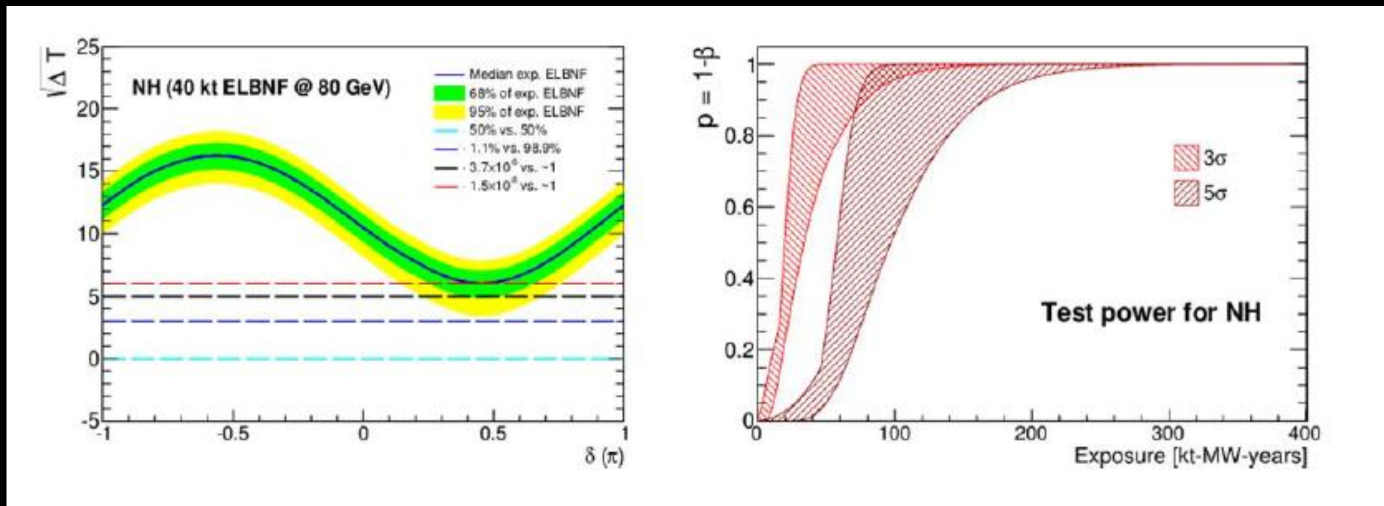


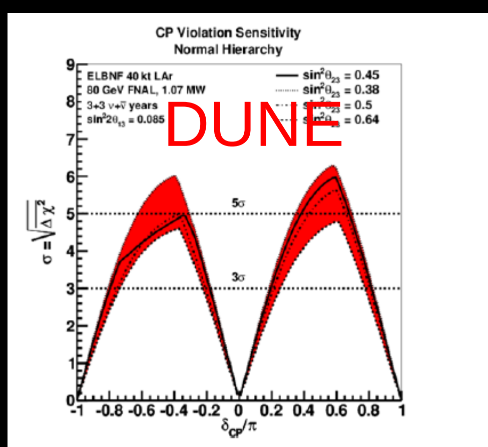



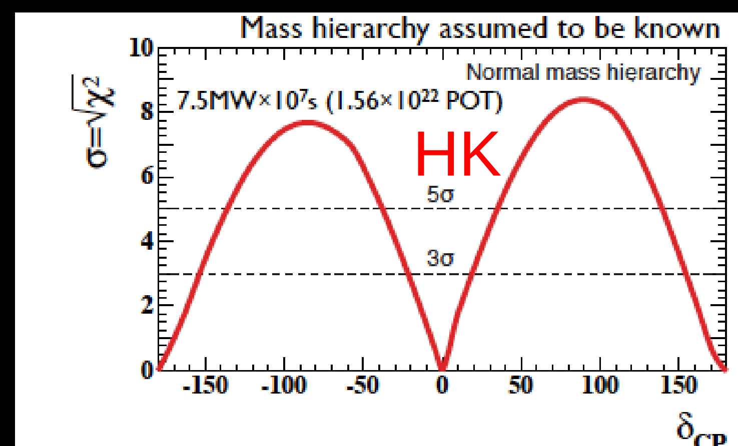



# Mass hierarchy and CP violation with a neutrino beam




DUNE
ca 2030




Similar perfrormances with ESS

# Neutrino sterile "portal"

| $M_M$ | Motivation | laboratory searches | indirect signals |
|---|---|---|---|
| ≲eV | ν-oscillations anomalies, dark radiation | oscillation anomalies, β-decays | CMB: explain $N_{eff} > 3^b$ LFV, $0\nu\beta\beta^g$ |
| keV | DM | direct searches?[d], β-decays | if DM:nuclear decays?[d], pulsar kicks, supernovae if not DM also LFV, $0\nu\beta\beta^g$ |
| MeV | testability, why not? | intensity frontier | $0\nu\beta\beta$ |
| GeV | testability, minimality | intensity frontier | EW precision data, LFV $0\nu\beta\beta$, lepton universality |
| TeV | minimality, testability | LHC, FCC | EW precision data, $0\nu\beta\beta$, LFV[f] lepton universality |
| ≫ TeV | grand unification, "naturally" small ν-masses | too heavy to be found | $0\nu\beta\beta$, LFV[f] |

**Neff**

DM

Leptogenesis

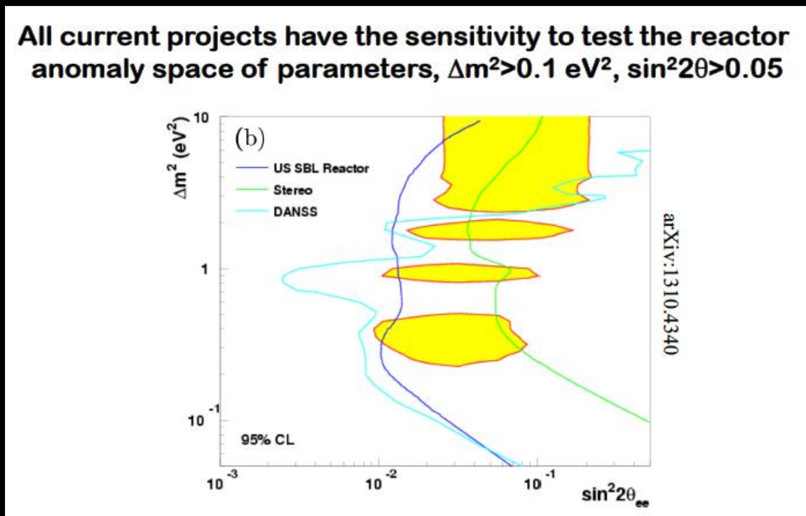
Dewes

Sterile neutrinos at all scales:

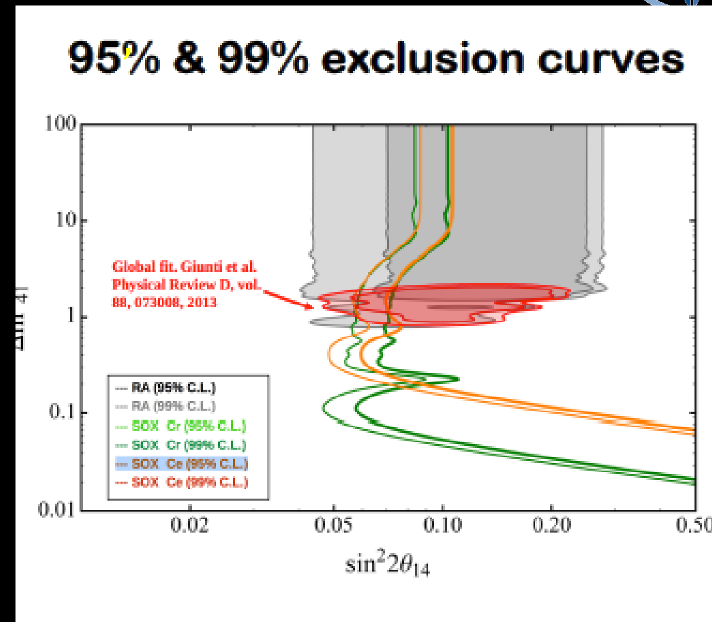
- <eV ν-oscillation anomalies $n_{e,}\bar{n}_e$ disappearance $\bar{n}_m \rightarrow \bar{n}_e$ appearance
    - Experimental program in development
- keV to TeV theoretical needs (e.g. Higgs as the inflaton with N1(KeV) DM and N2,N2 (GeV)) or indirect « hints »
    - New experiments, analyses proposed
    - Also indirect effects e.g. double-beta decay
- >> TeV Good-old unification and leptogenesis
- Tensions with cosmology, unless new mechanisms…
- It is up to neutrino physicists to clear the situation.

# Test sterile neutrino experimental anomalies. A medium-scale medium-term program in development

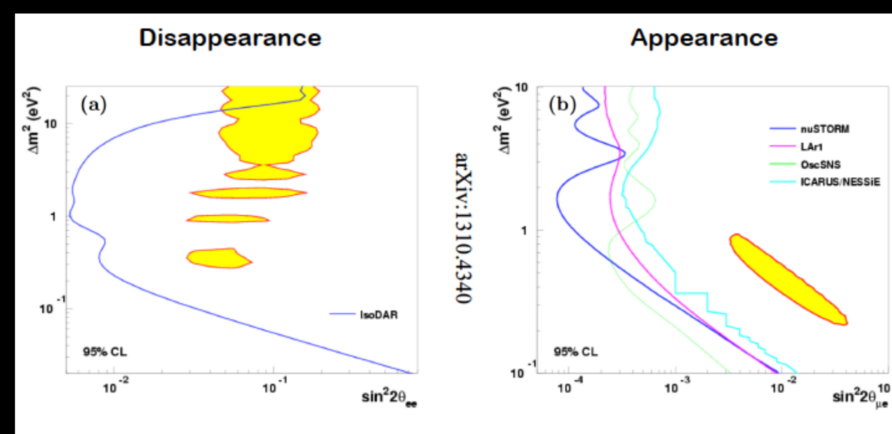
APPEC




Test disappearance: Reactors: SOLID, STEREO, Prospect, Hanaro, CARR, DANSS, …




Test disappearance: Sources: CeSOX, CeLand, CeDayaBay LENS




Test disappearance, appearance: Short baseline program at LBNF (SBND,ICARUS, MicroBoone)

Also MINOS+, Deadalus, ISODAR, JPARC, …

# *Steps towards global coordination in the neutrino sector (APPEC)*


APPEC

- 2014 P5 report released, 22 May, CERN Medium term plan 18 June
- June 2014: 1st International Meeting on Large Neutrino Infrastructures, Paris (APPEC)
    - 1st common press release urging for a global collaboration
- April 2015 DUNE formed (spokespersons: Rubbia, Thomson)
- Aprl 2015 2nd International Meeting on Large Neutrino Infrastructures, Fermilab

From the press release: … the agency representatives were impressed by the rapidity, quality of convergence and momentum of the efforts of the community working on liquid argon Time Protection Chambers (LAr TPCs), to develop a credible scientific program based on:

A) an ambitious large infrastructure effort, consisting of a long-baseline beam and detector project (LBNF/DUNE ) … , proposed by an international collaboration, very rapidly setting up its governance structure and preparing answers to an aggressive schedule of DOE critical design reviews in July and November 2015;

B) a medium-scale program of short-baseline oscillation experiments at Fermilab (Short-Baseline Near Detector, MicroBoone and ICARUS ) aiming to test the sterile neutrino hypothesis with unprecedented accuracy;

C) a rich R&D and prototyping program in the CERN North Area, related to the above program along with other long-baseline efforts in the world Hyper-Kamiokande .

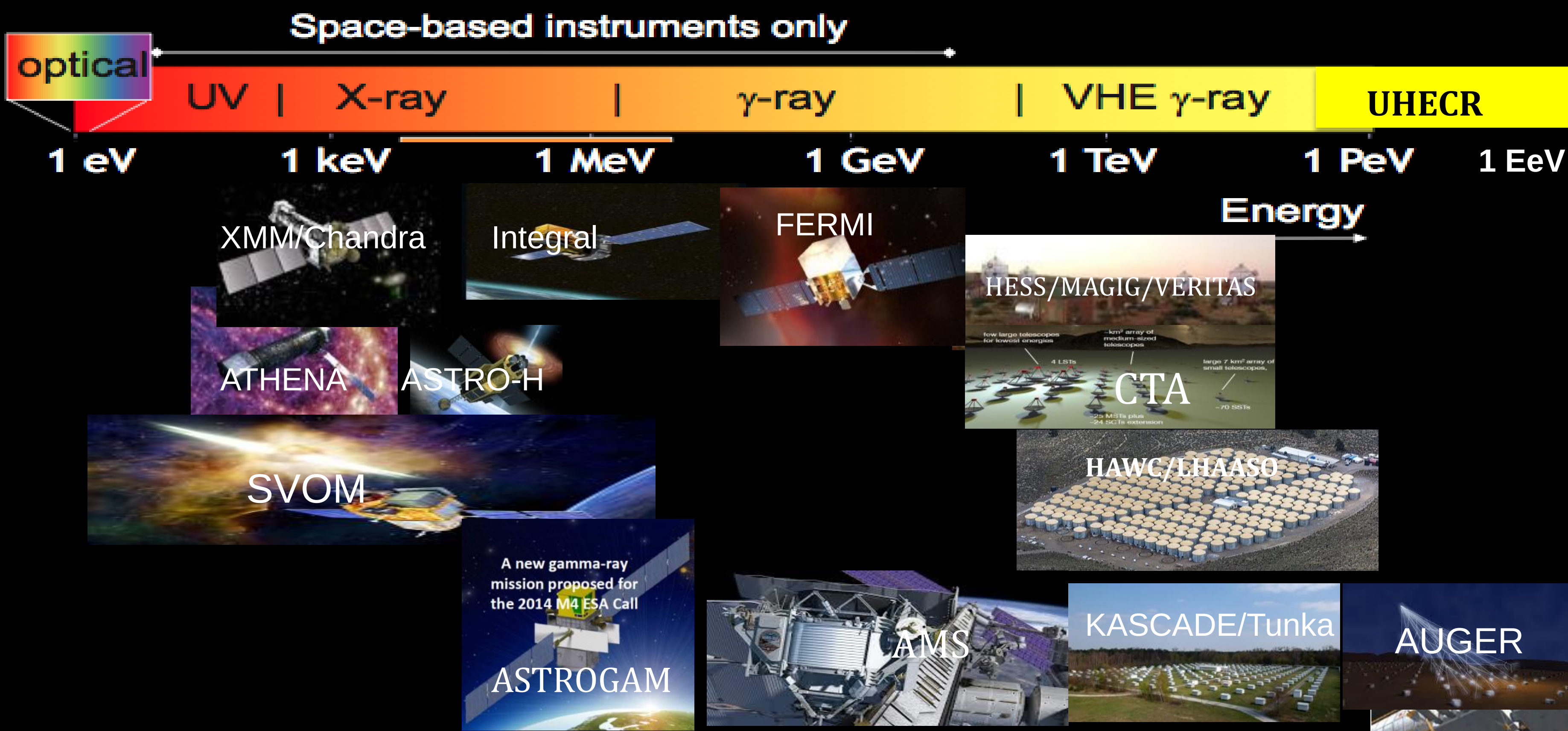
The agencies and national laboratory directors also welcomed the proposed agency oversight bodies: the Long-baseline Neutrino Committee (LBNC), the Resource Review Board (RRB) and an International Advisory Committee (IAC).

- Signature of CERN-DOE agreement May 2015
- Towards A 3rd meeting in Japan 2016. Include NLDBD and DM in the remit ?

# From the APPEC
# Scientific Advisory Committee (SAC)* Roadmap

3. The formation, evolution, merging and destruction of cosmic structures as extreme laboratories mixing energy scales, probing also the presence of new physics. Multi-messenger studies.

# High Energy photon, neutrino and CR observatories*
# Finally reaching multi-messenger sensitivities ?

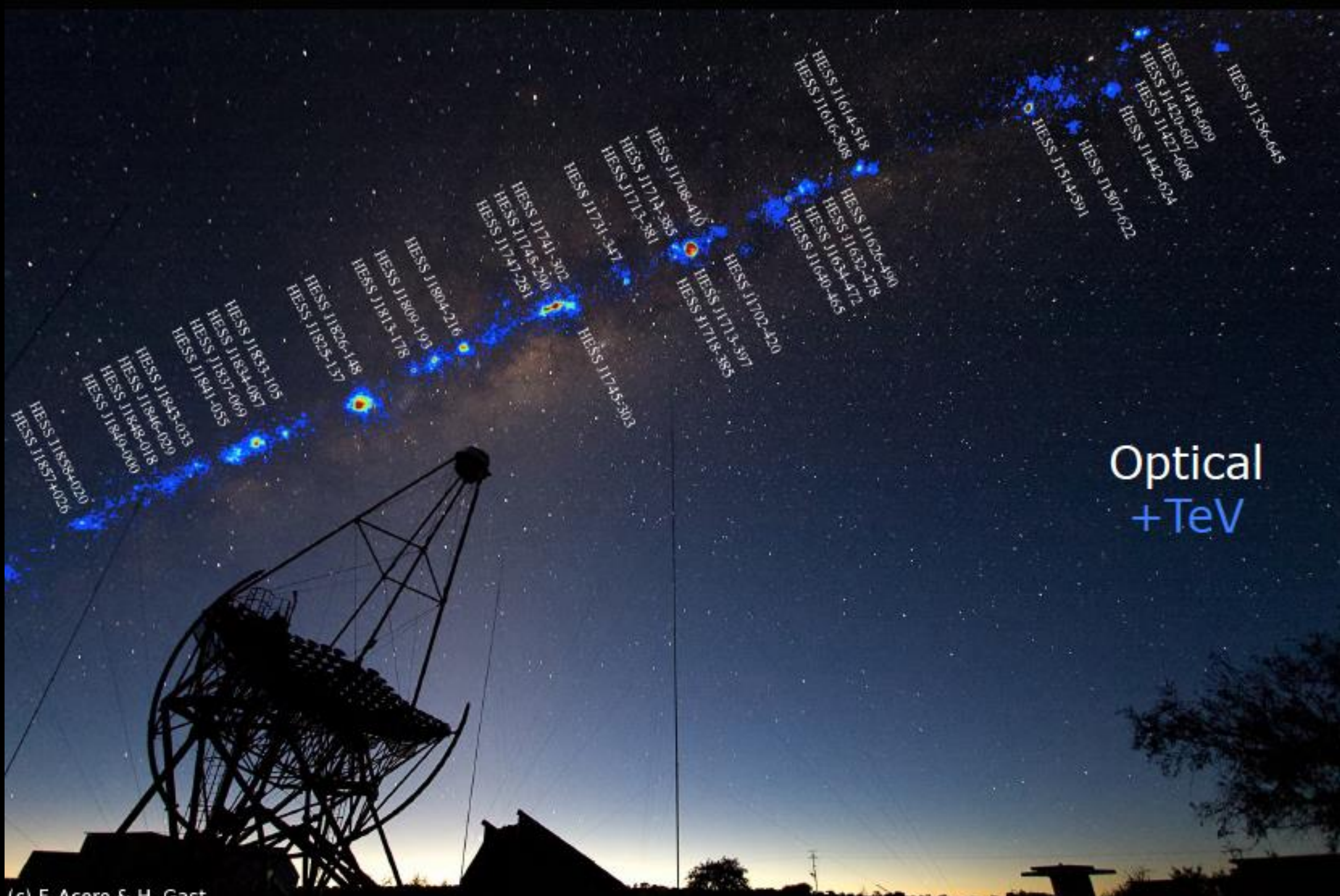




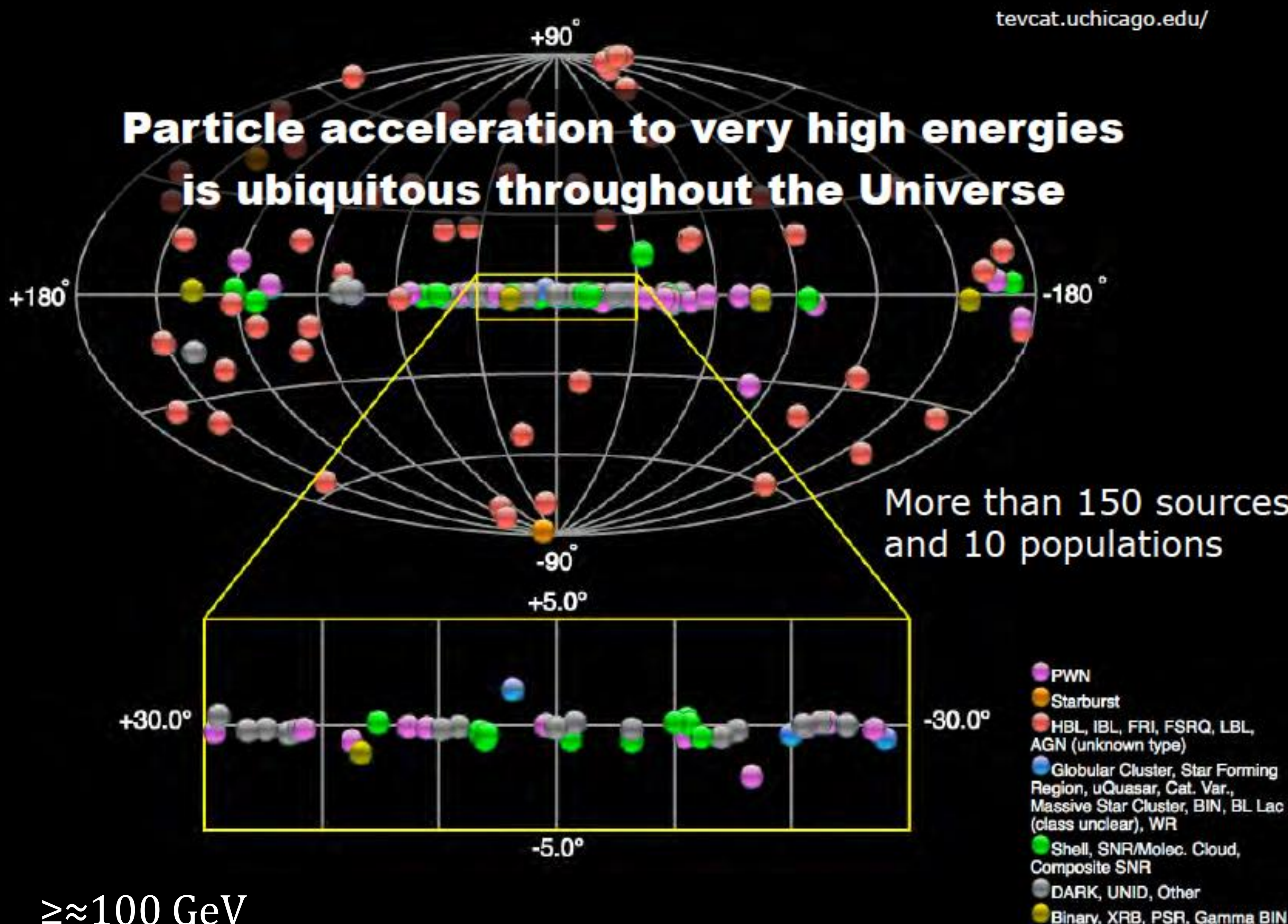
Space program (low energy) well defined. (M4 Astrogam?)
All programmatic uncertainty comes from medium and high energy observatories

*Also GW antennas

# *The H.E.S.S/Magic/Veritas legacy of 10 last years*



# Particle acceleration to very high energies is ubiquitous throughout the Universe

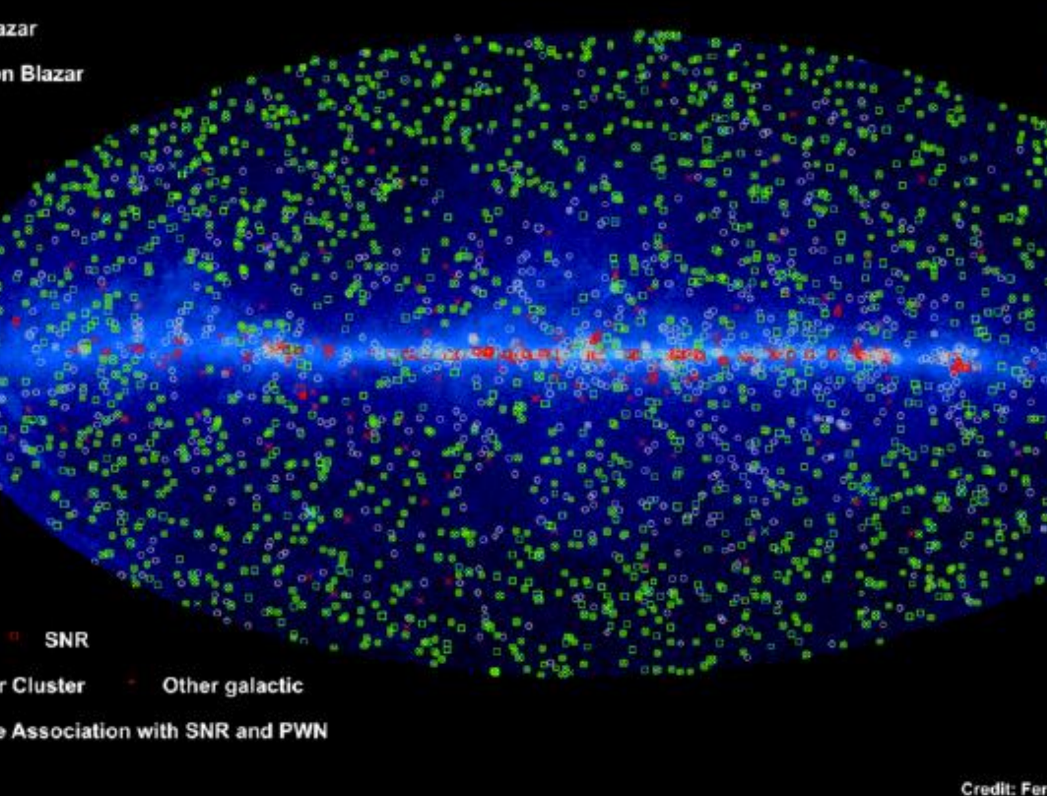


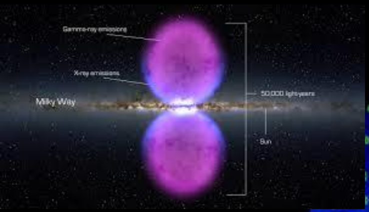

More than 150 sources and 10 populations

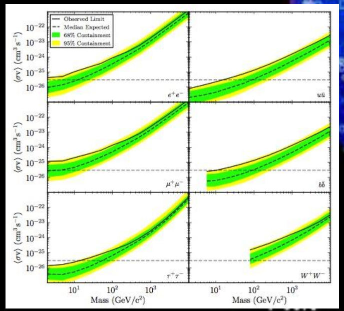
≥≈100 GeV

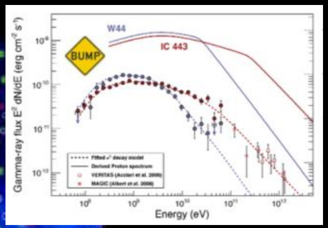
# *The legacy of Fermi of  past 6 years*

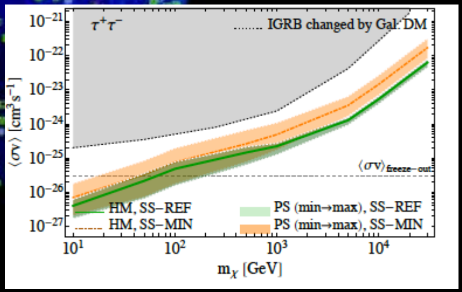
## Fermi Large Area Telescope 3FGL catalog



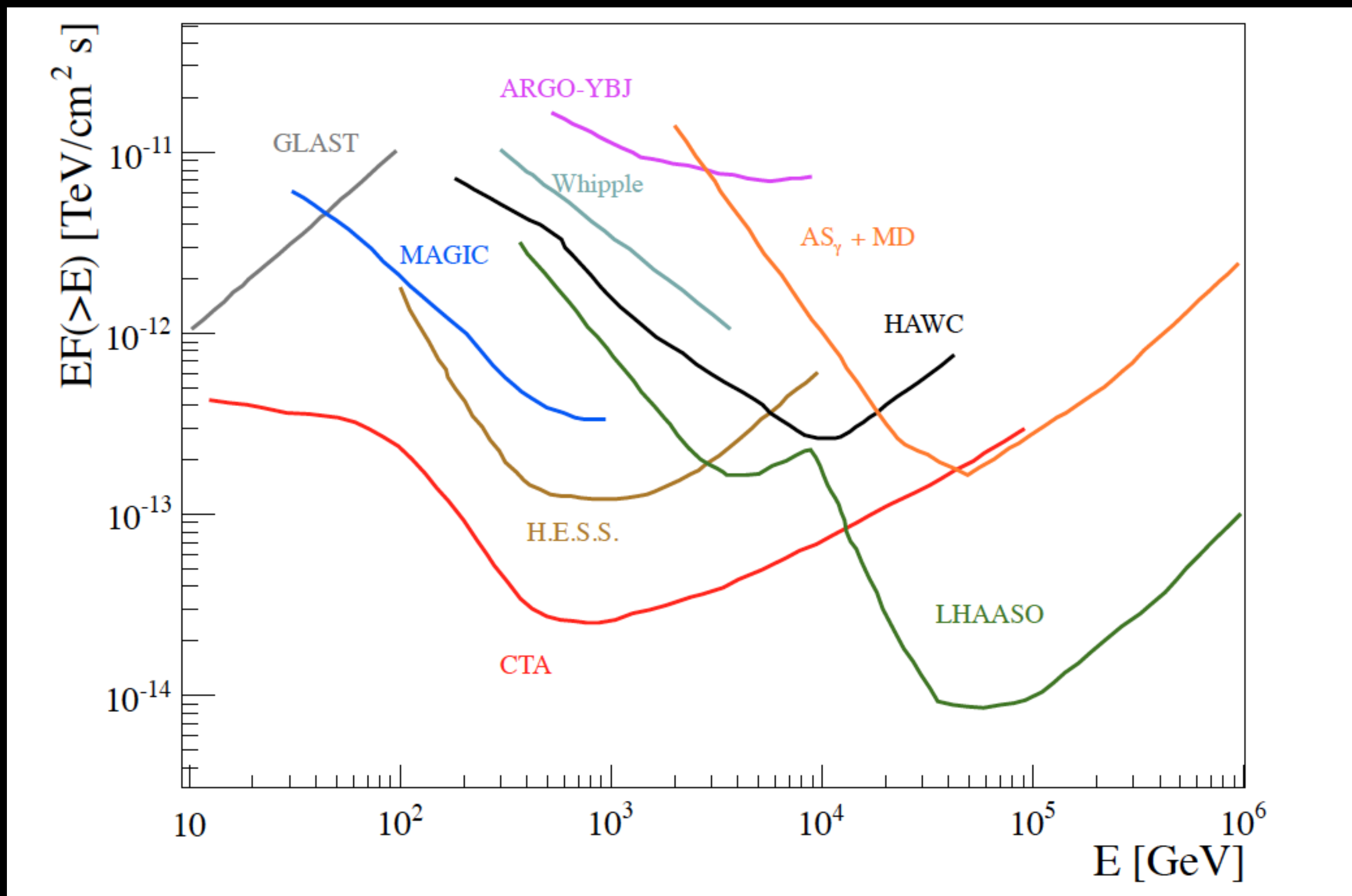




3033 sources (992 unassociated , 1755 AGN,  PSR 137, SNR  23…)

514 > 10 GeV
320 > 50 GeV

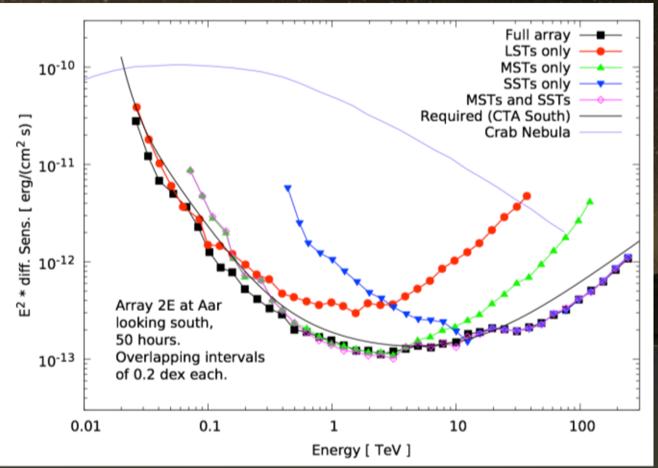
# *Future high energy γ sensitivities*




In TeV domain the **Cherenkov Telescope Array (CTA)** is a worldwide priority
Complemented by PeV scale wide field observatories:
HAWC (constructed) and LHASSO under construction (2020)

# CTA Science-optimization under budget constraints:

- Low-energy γ — high γ-ray rate, low light yield
  ➜ require small ground area, large mirror area
- High-energy γ — low γ-rate, high light yield
  ➜ require large ground area, small mirror area




few large telescopes for lowest energies

4 LSTs

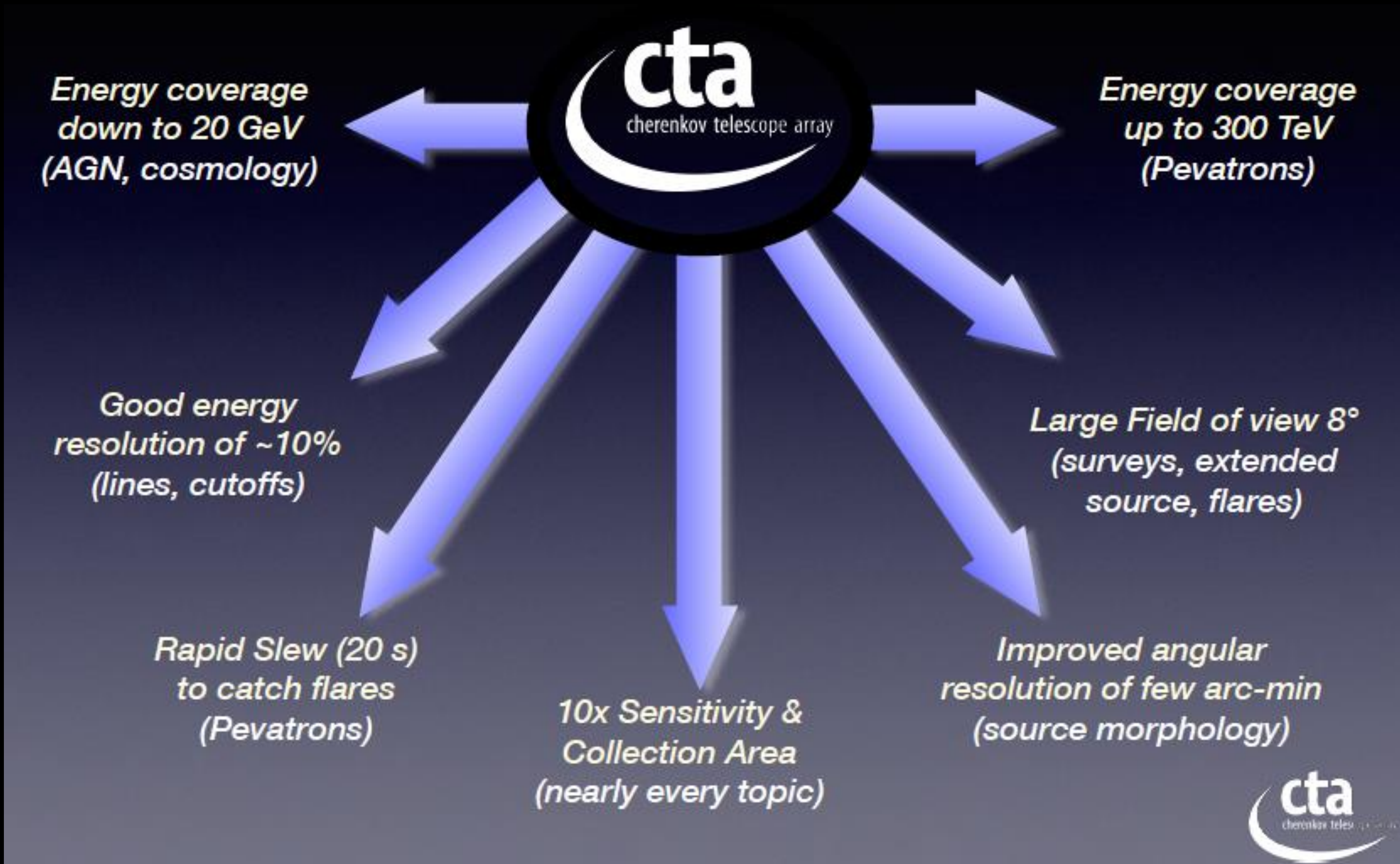
~km$^2$ array of medium-sized telescopes

~25 MSTs plus
~24 SCTs extension

large 7 km$^2$ array of small telescopes,

~70 SSTs

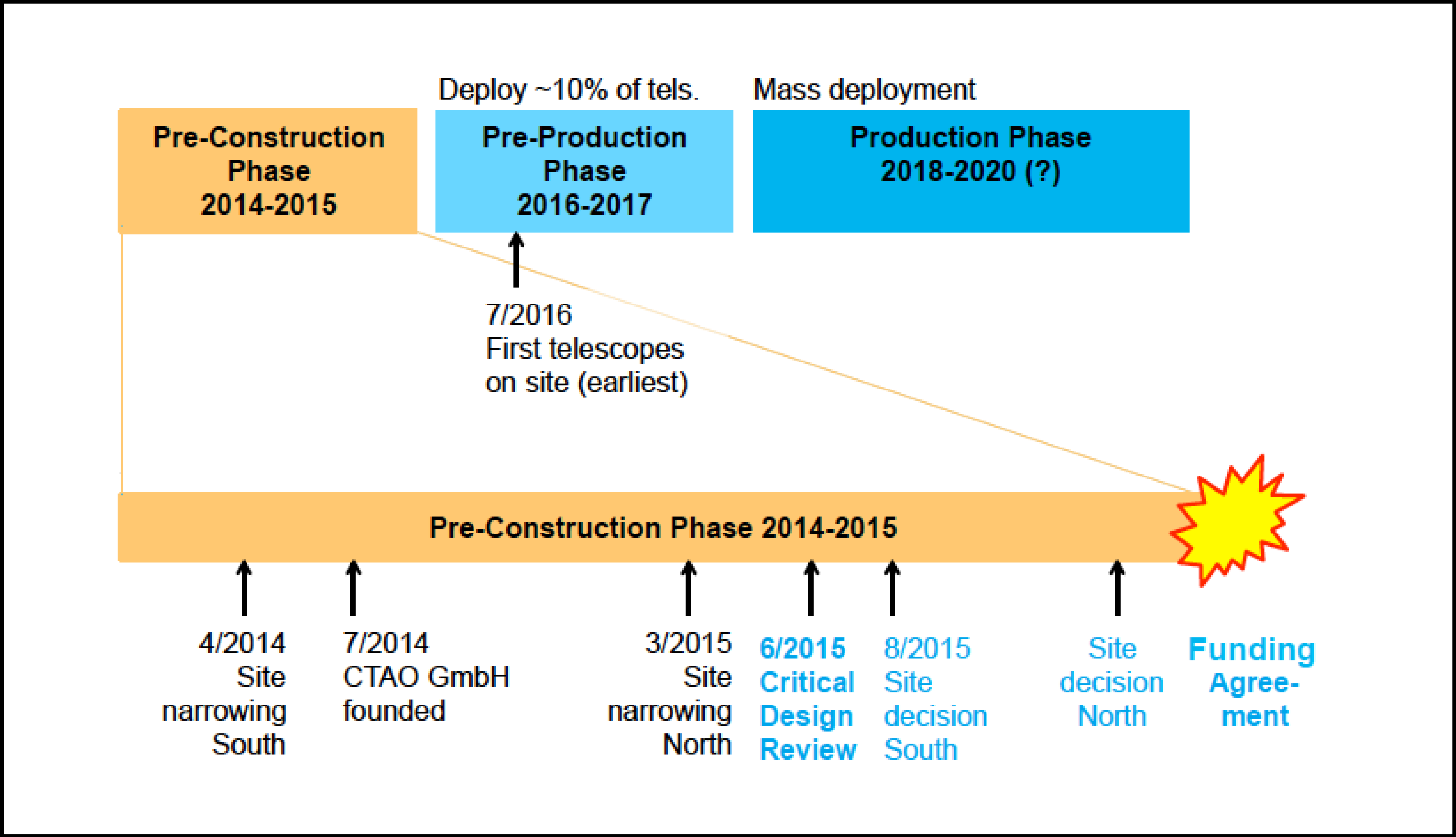
# CTA requirements and drivers



# *CTA site selection*

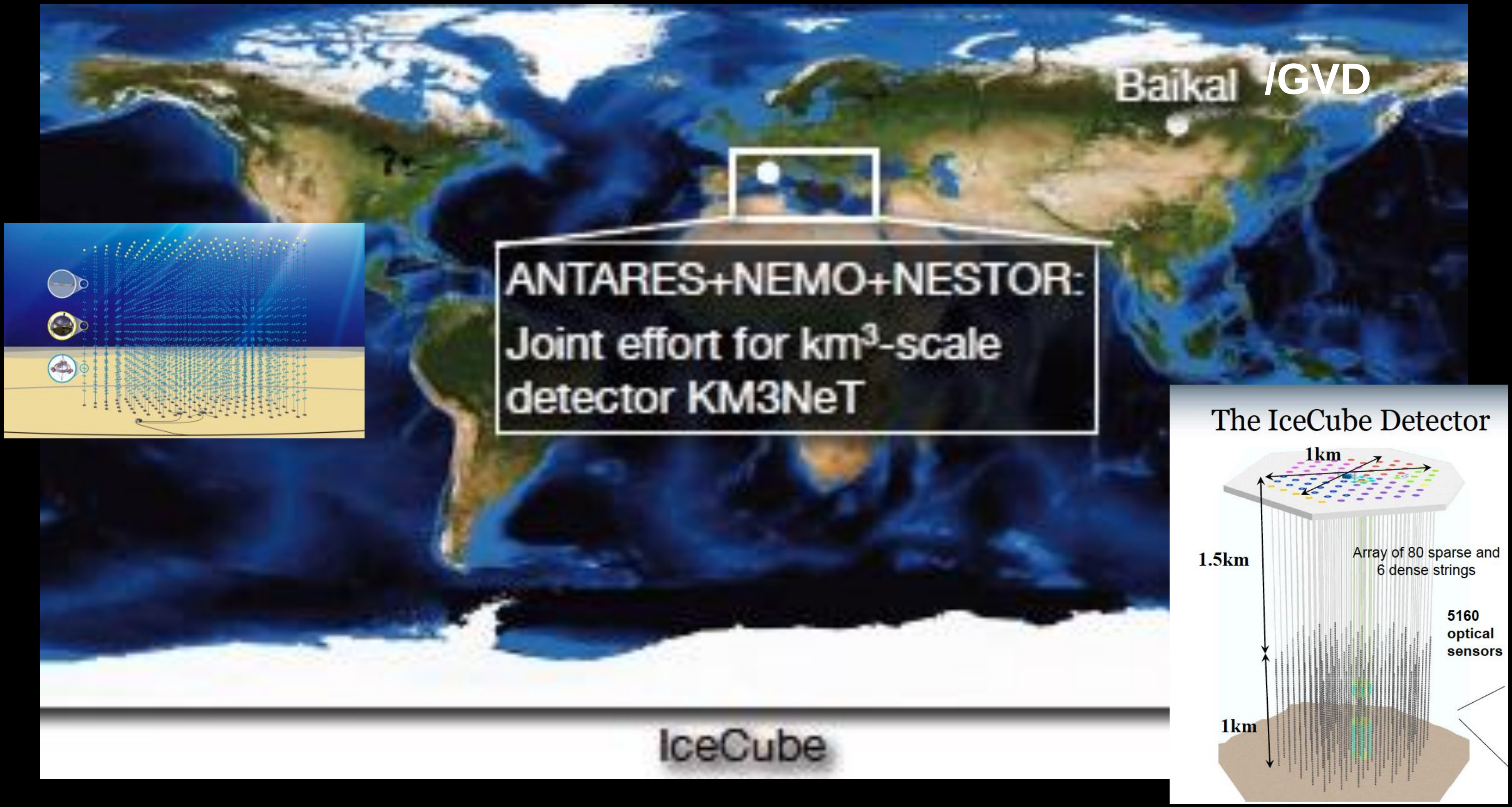

**Negotiations**

# CTA SCHEDULE




Estimate 3-5 years of construction, investment 200 ME

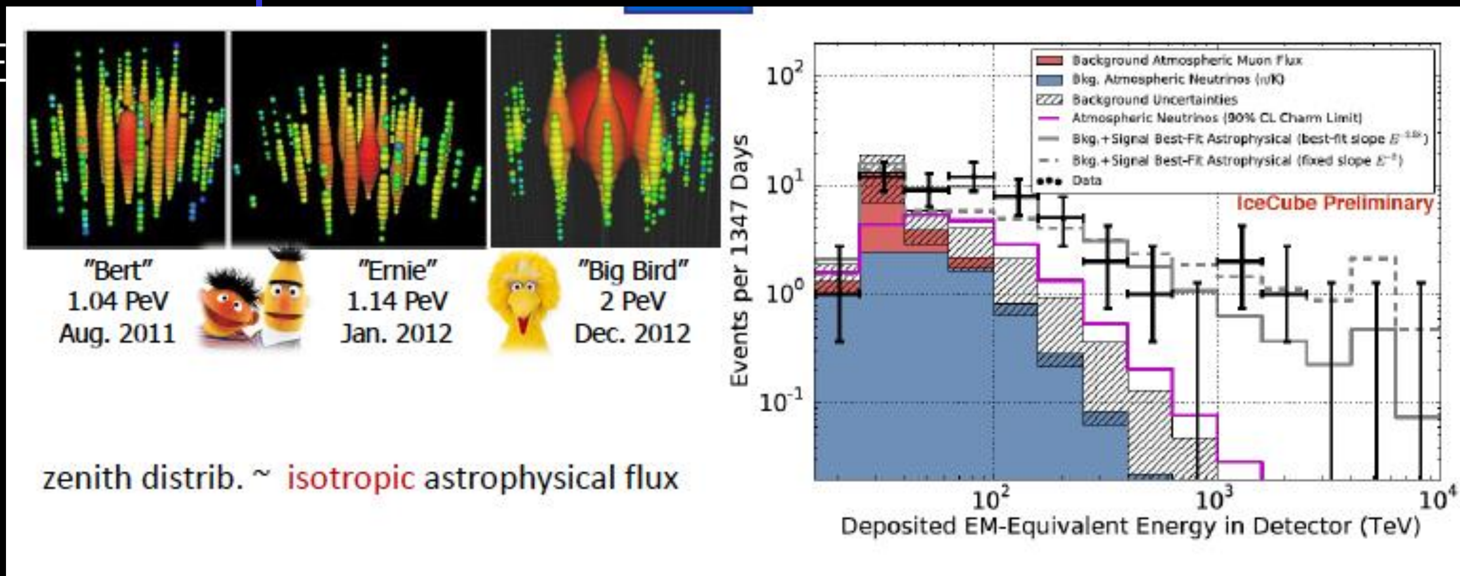
# *High Energy Neutrino telescopes*




Nothern Hemisphere projects and IceCube move through coordination towards a future Global Neutrino Observatory.

# *The Dawn of Neutrino Astronomy*

APPE




4 years
54 events
7σ

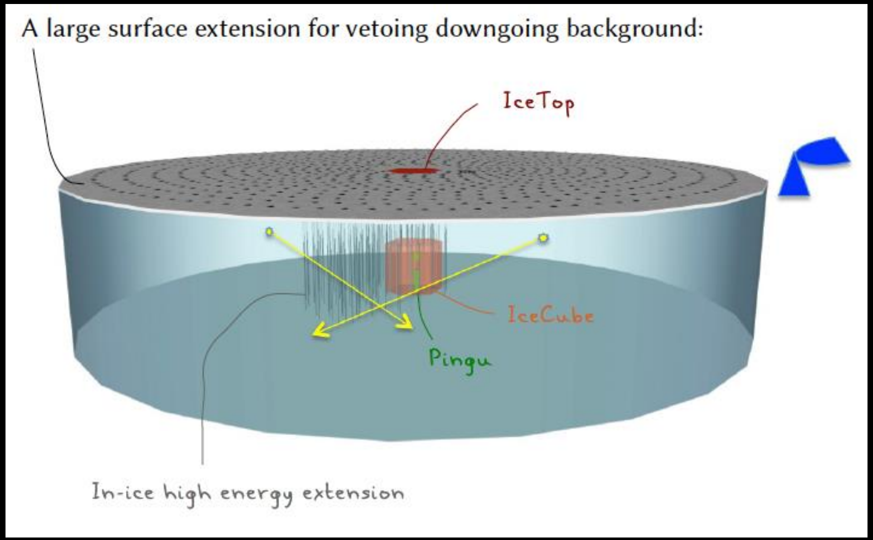
- Flavour ratio consistent with standard expectations ?✔
- Mostly Extragalactic ✔
  - % of Galactic ?
- At what precision is it isotropic ?
- Break of the spectrum ?
- What is the relationship with UHECR?
- Are there hints of new physics (e.g. dark matter?)

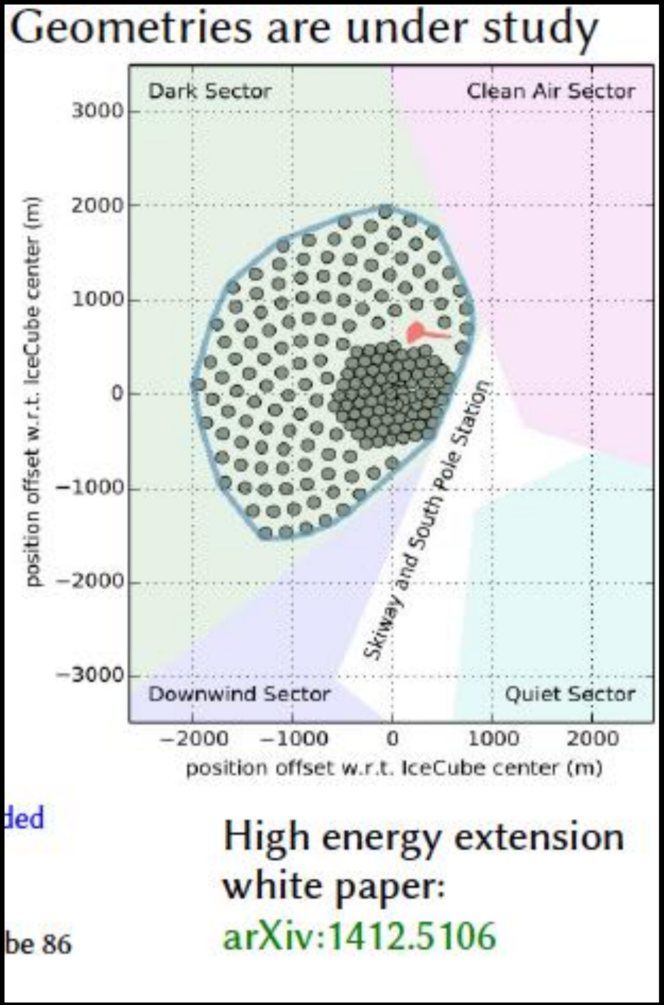
Solution of the puzzles comes through:

- Extension of sensitivity
- Complete coverage of the sky
- Multimessenger studies
  - Gen2, KM3Net
  - CTA, HAWC, LHAASO
  - NUSTAR/ASTRO-H
  - AUGER p vs Fe

# ICECUBE ➔High Energy Extension Gen2 5-10 km$^2$

- Start 2018/2019 complete 2027?
- ICECUbe Gen 2 + more veto
- Cost equivalent to ICECUBE 1 km$^2$
- Including Pingu for the first 3 of the 8 seasons

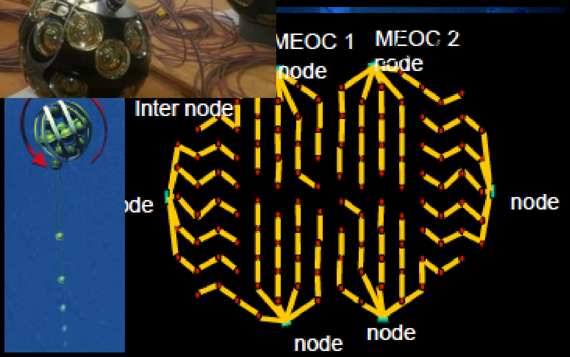


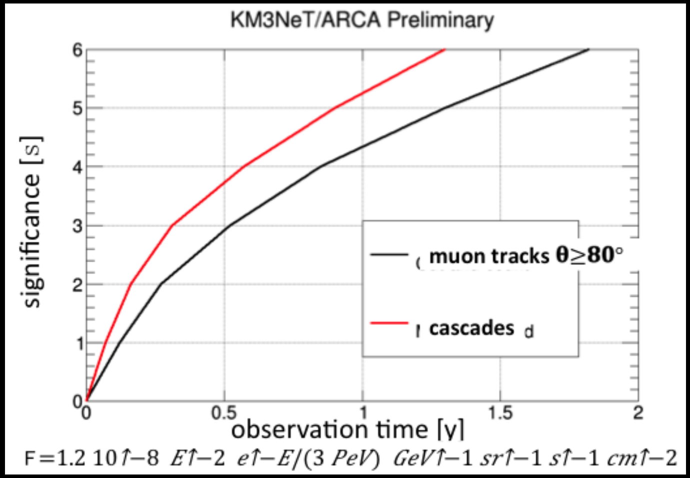
# Antares ➔ KM3Net ( ARCA and ORCA)

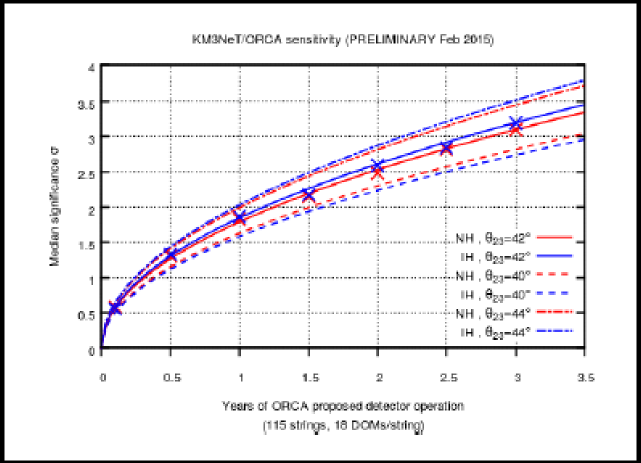
APPEC

- Phase 1 (35 ME, funded in construction)
  - 24 lines KM3Net-Italy (➔ ARCA)
  - 6 lines KM3Net-France (➔ ORCA)
  - First full line deployment Summer 2015
  - Completion 2016
- Phase 2 (to be decided before end of 2016)
  - ARCA 2 x 115 lines, cost 55 ME
  - ORCA 1 x 115 lines (20m spacing) cost 40 ME
  - Structural funds.
  - Window of opportunity for ORCA ?
- Phase 3 6 blocks




Current optimisation: 0.6 KM3 Blocks of 115 strings, 90m apart, 18 DOM/String, spacing between DOM's 36 m

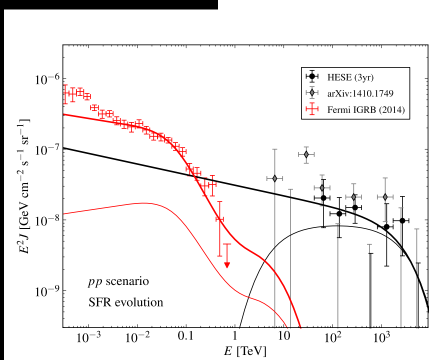


# Did we reach finally the sensitivities necessary for multimessenger studies ?

Francis Halzen ➔ Yes

## The Multi-Messenger program

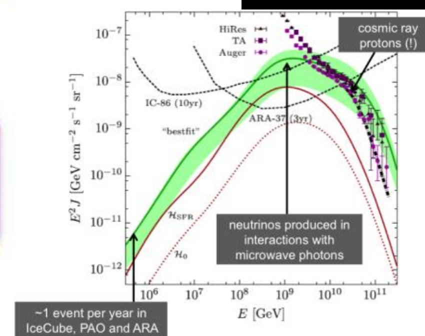



GeV-TeV γ-rays
Fermi / HESS…

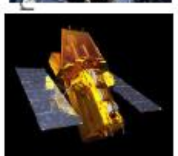
📖 JCAP 03(2013) 006
📖 A&A 559 (2013) A9
📖 JCAP 05 (2014) 001

UHECR
Auger

📖 APJ 774 (2013) 19




HE neutrinos



Optic / X-ray
TAROT,
ROTSE / Swift,
ZADKO

+SVOM

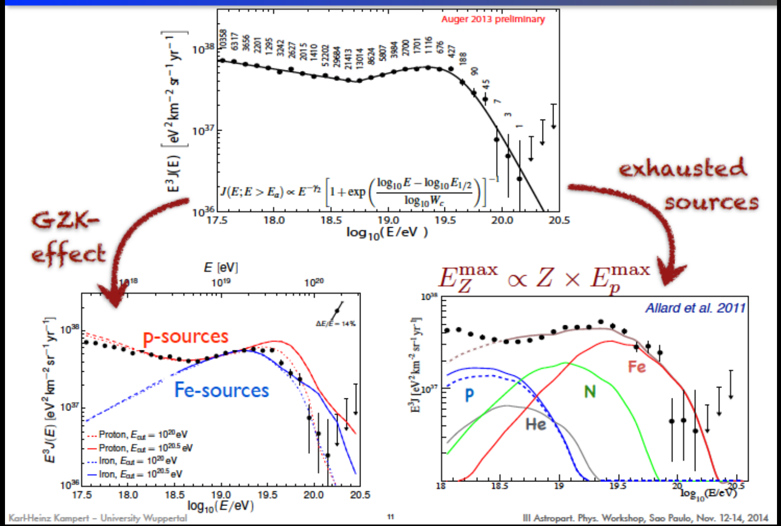
📖 APP 36 (2012) 204
📖 A&A 559 (2013) A9

Gravitational
Waves
Virgo / Ligo

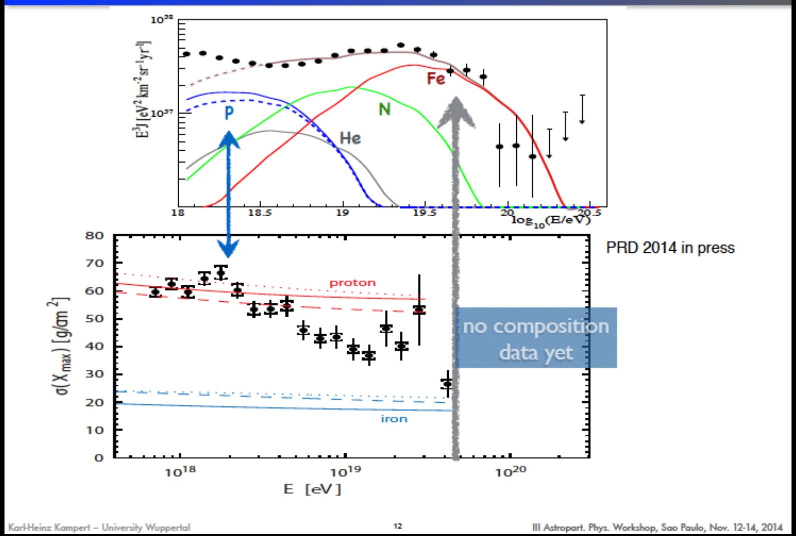
📖 JCAP 06 (2013) 008

# UHECR observatories on the ground
# AUGER and TA

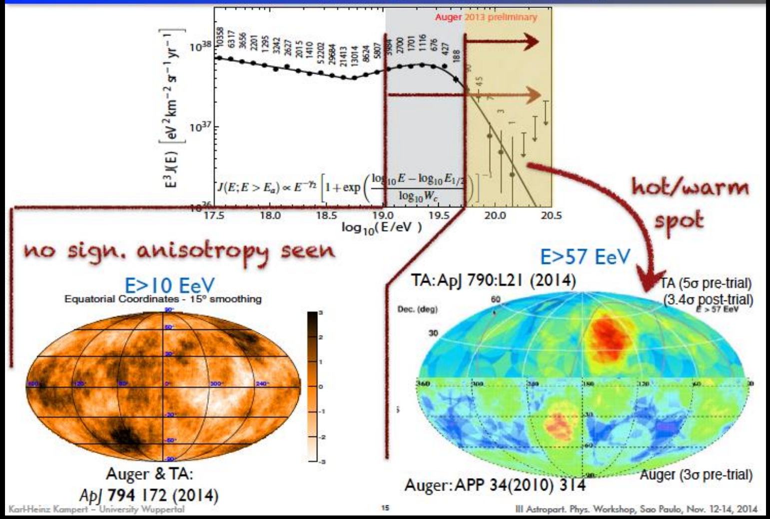
## GZK-Effect or Exhausted Sources?



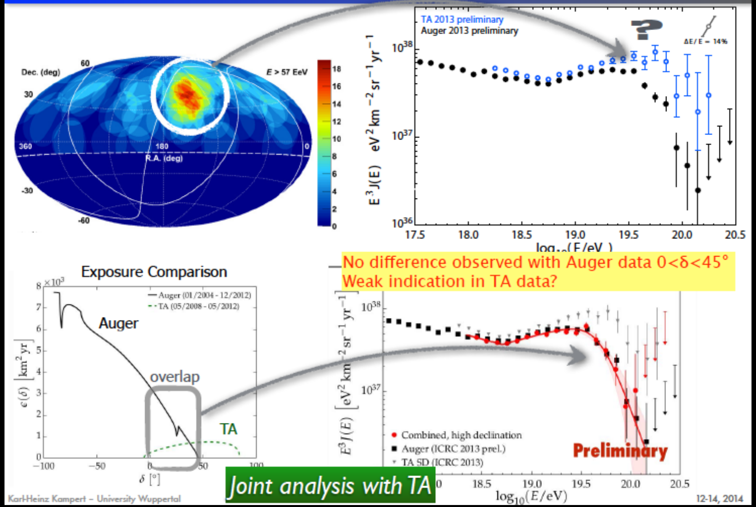

## $E_{max}$-model supported by RMS($X_{max}$)…



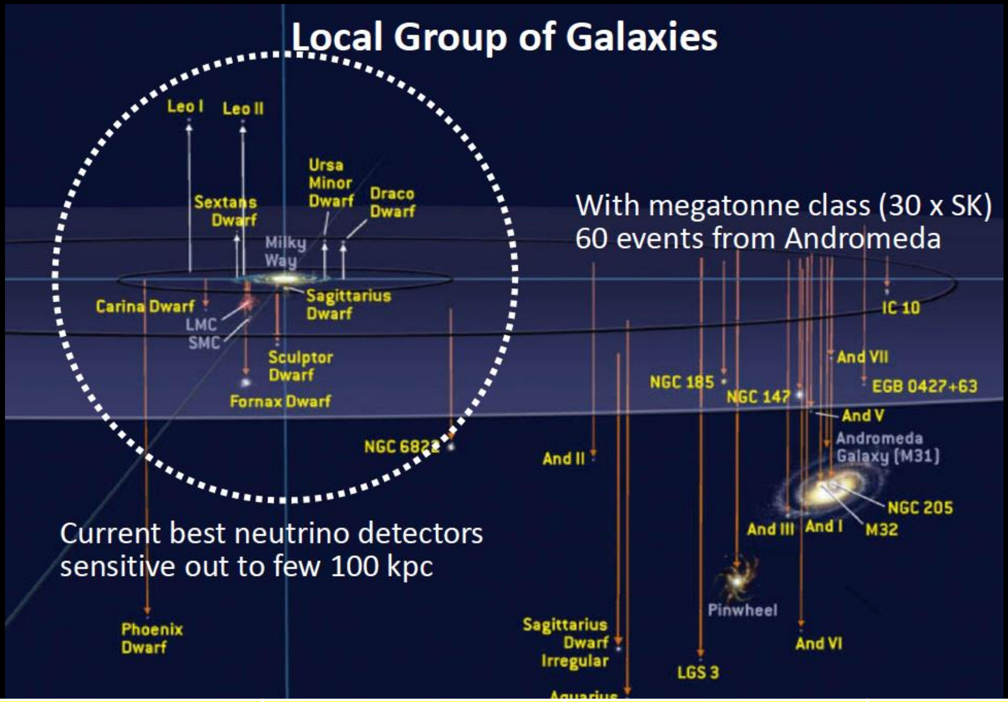

## UHECR Sky highly isotropic

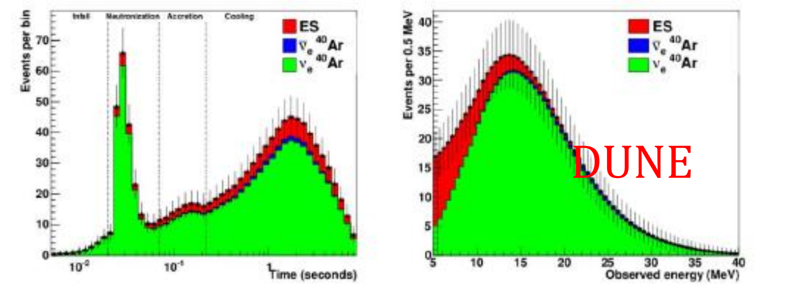


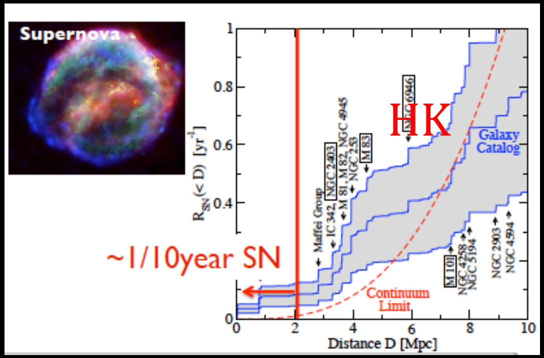

## Are the Two Skies Different ?

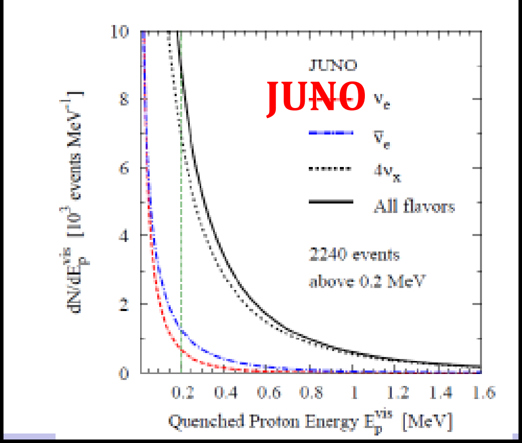


# Last but not least: the last Supernova was in 1987, the next galactic supernova is expected by 2003±15....



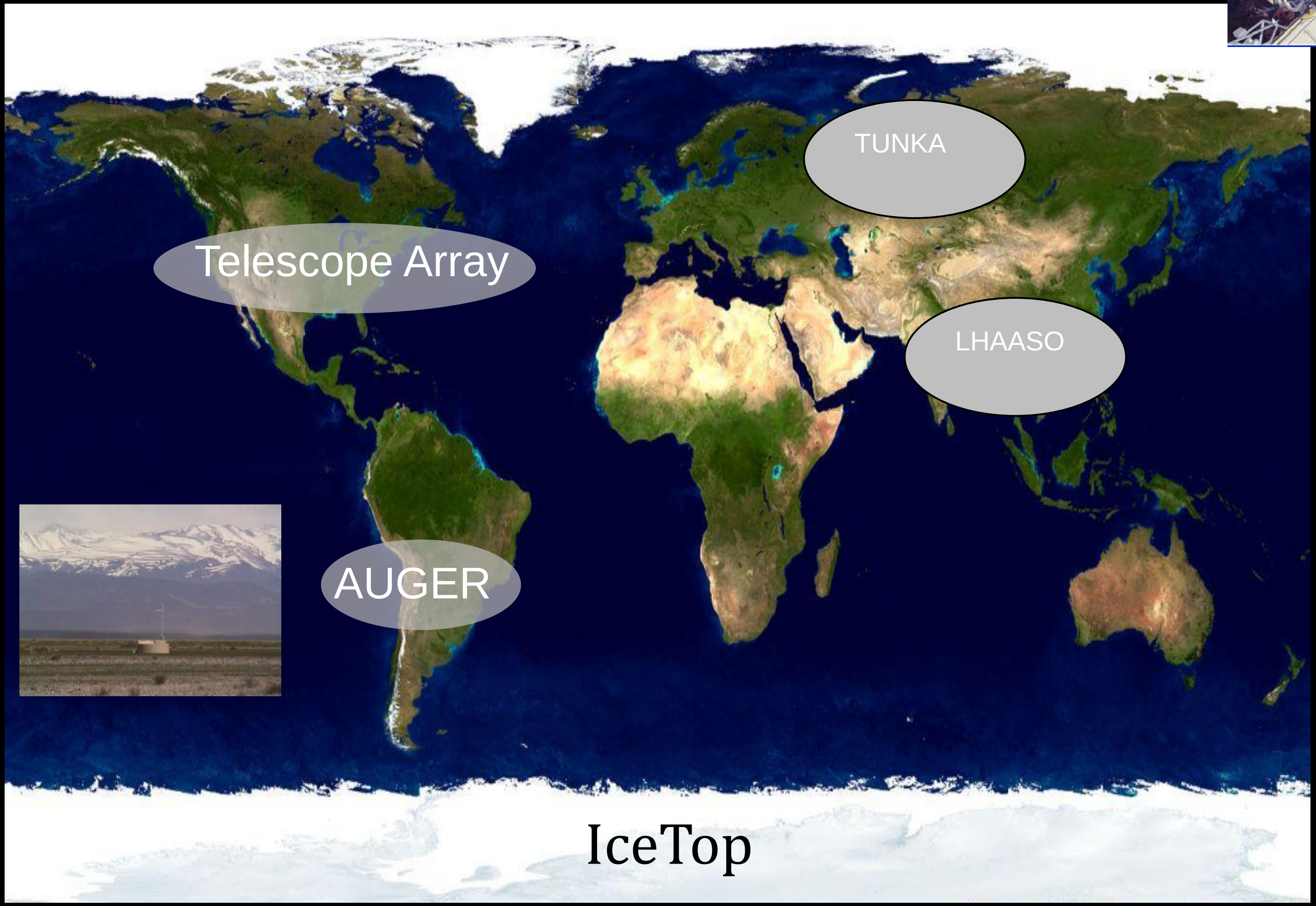

| | DUNE(40kt) | JUNO(20kt) | HK(500kt) |
|---|---|---|---|
| SN coolof (10kpc) | 15400 (all flavours) | 8000 (all flavours) | 194000 (mostly e) |
| SN burst (10kpc) | 150 $\nu_e$ CC | 12 | 250 |
| SN in Andromeda | 3 | 2 | 40 |
| DSN | 20 | 10-15 | 250 |

Also low energy implementations of ICECUBE/KM3NEt

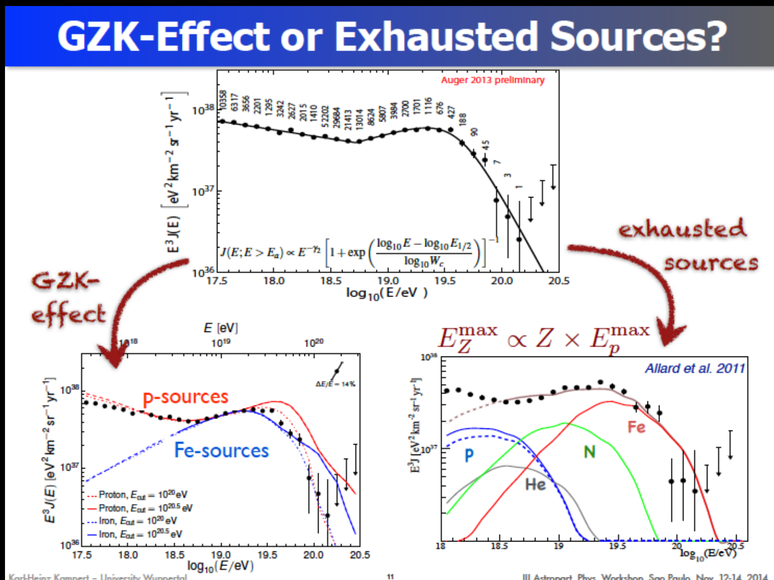
# *High energy cosmic ray observatories*

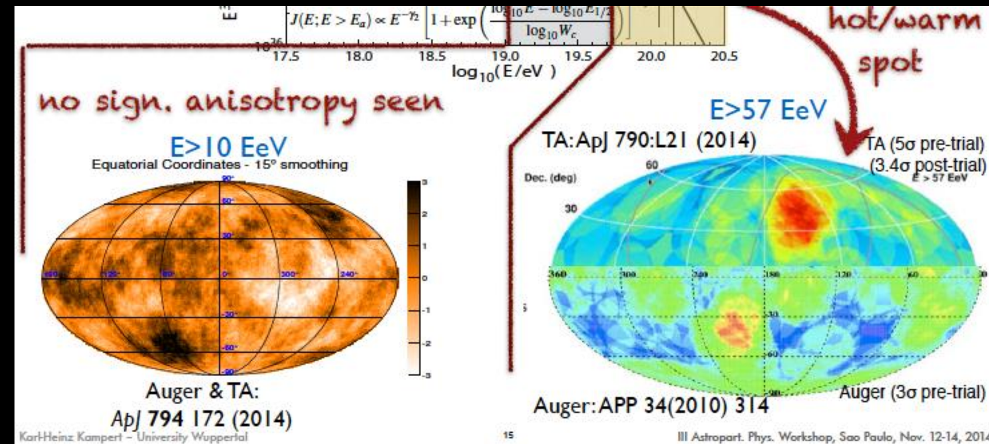
PAMELA
CREAM

AMS
JEM-
EUSO

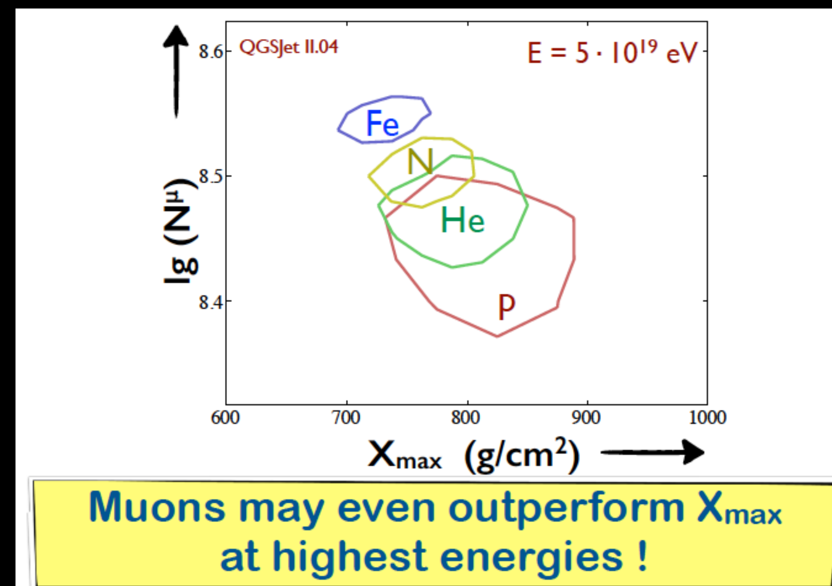


# Science goals of Auger upgrade



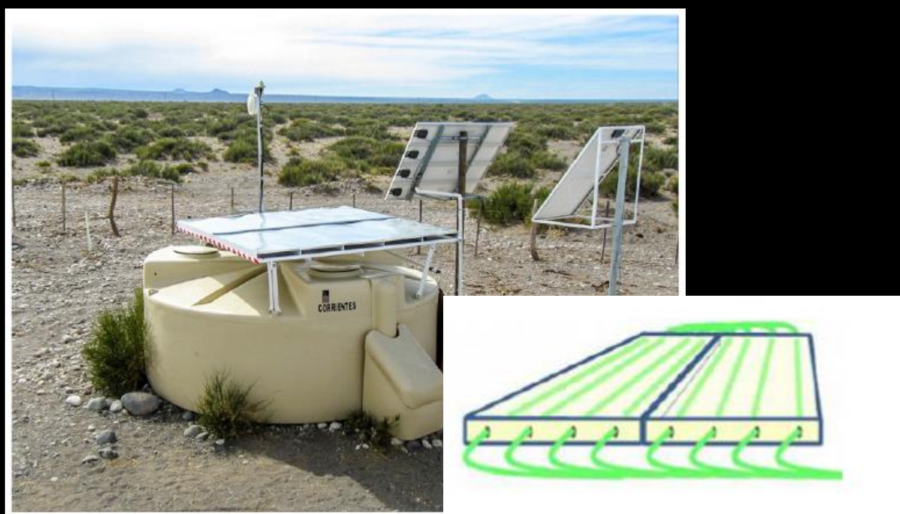



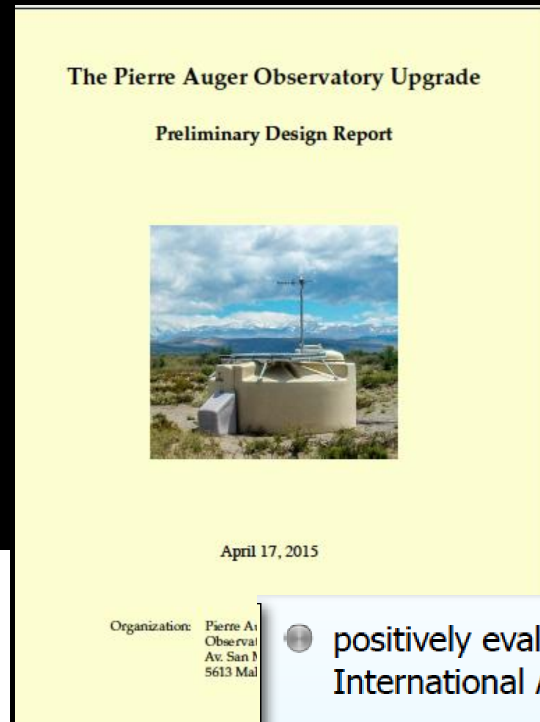

- p or Fe?
- Origin of the flux suppression
- Start astronomy by using the individually tagged protons
- Study composition event by event.
  - Measure the muonic component of the showers
- Study particle physics at 70 TeV



# Auger upgrade (2015-2017, cost 12.5 ME)

1) Enhanced muon counting ASCII




The Pierre Auger Observatory Upgrade

Preliminary Design Report

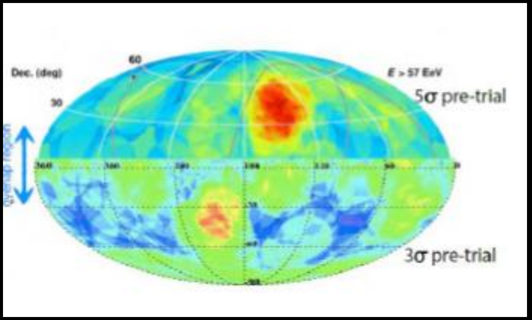
April 17, 2015

Organization:

- positively evaluated by International Advisory Committee
- endorsed by International Finance Board
- R&D well advanced, prototypes running
- engineering array 03/2016
- construction 11/2016 - 2018
- data taking into 2024
- costs: 12.5 M€
- funding: positive signs, but not yet approved

2) Faster electronics
3) Extended operation of FD-telescpes
4) High precision complementary array (burried scintillators)

# Telescope Array upgrade (x4) to test hotspots (4 M$, Japan,US,Be)

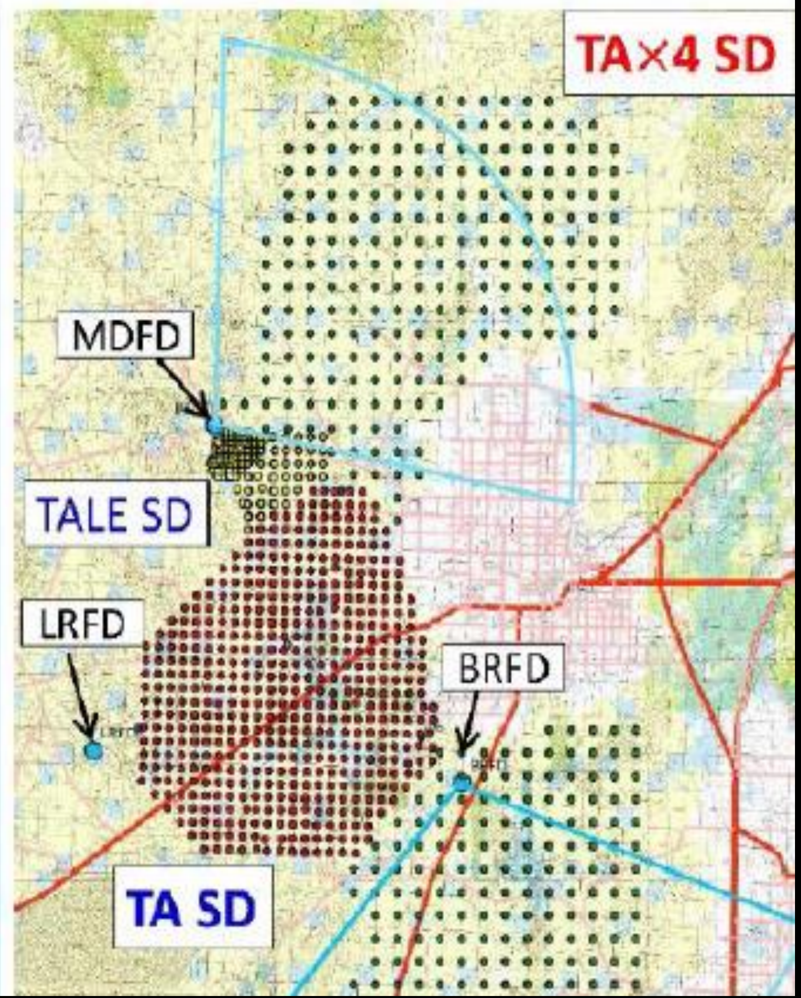



**500 more SDs**

2 more FD stations

- SD: 700 -> **3000 km²**
- Hybrid: x3 acceptance
- Optimized for UHECR above cutoff (fully efficient above ~60 EeV)

collect statistics more rapidly



# *Expanding*

## GCOS = Global COSmic ray observatroy


Helmholtz (D) large infrastructure Roadmap

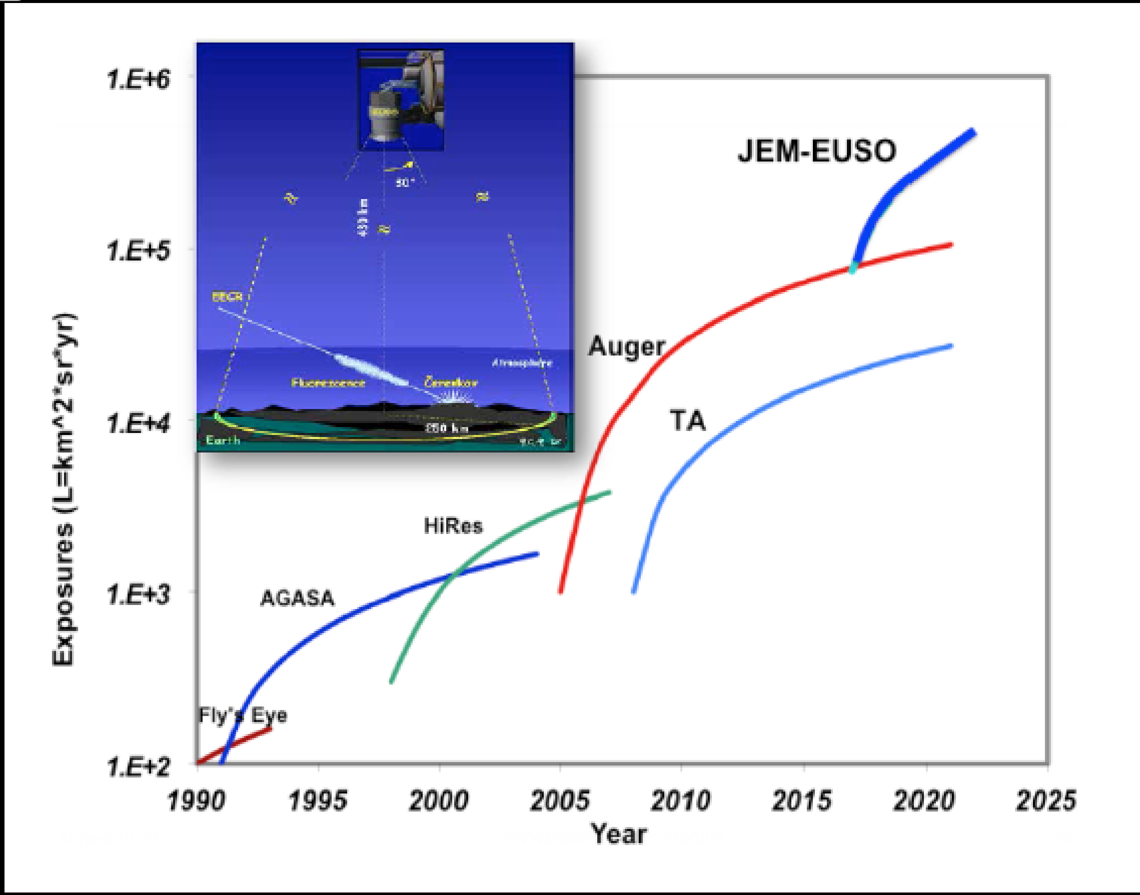
### p-astronomy with sources

- Global, few sites, N+S
- ca. 90,000 km$^2$ (x30 Auger)
- Optimal detector for composition-sensitivity

- Design in 2020-25
- Operation 2025-2050
- Cost 120 M€ (European contr.)
- Operation cost 6 M€/y

90.000km$^2$ →

# *High energy cosmic ray observatories*
# ***EUSO***



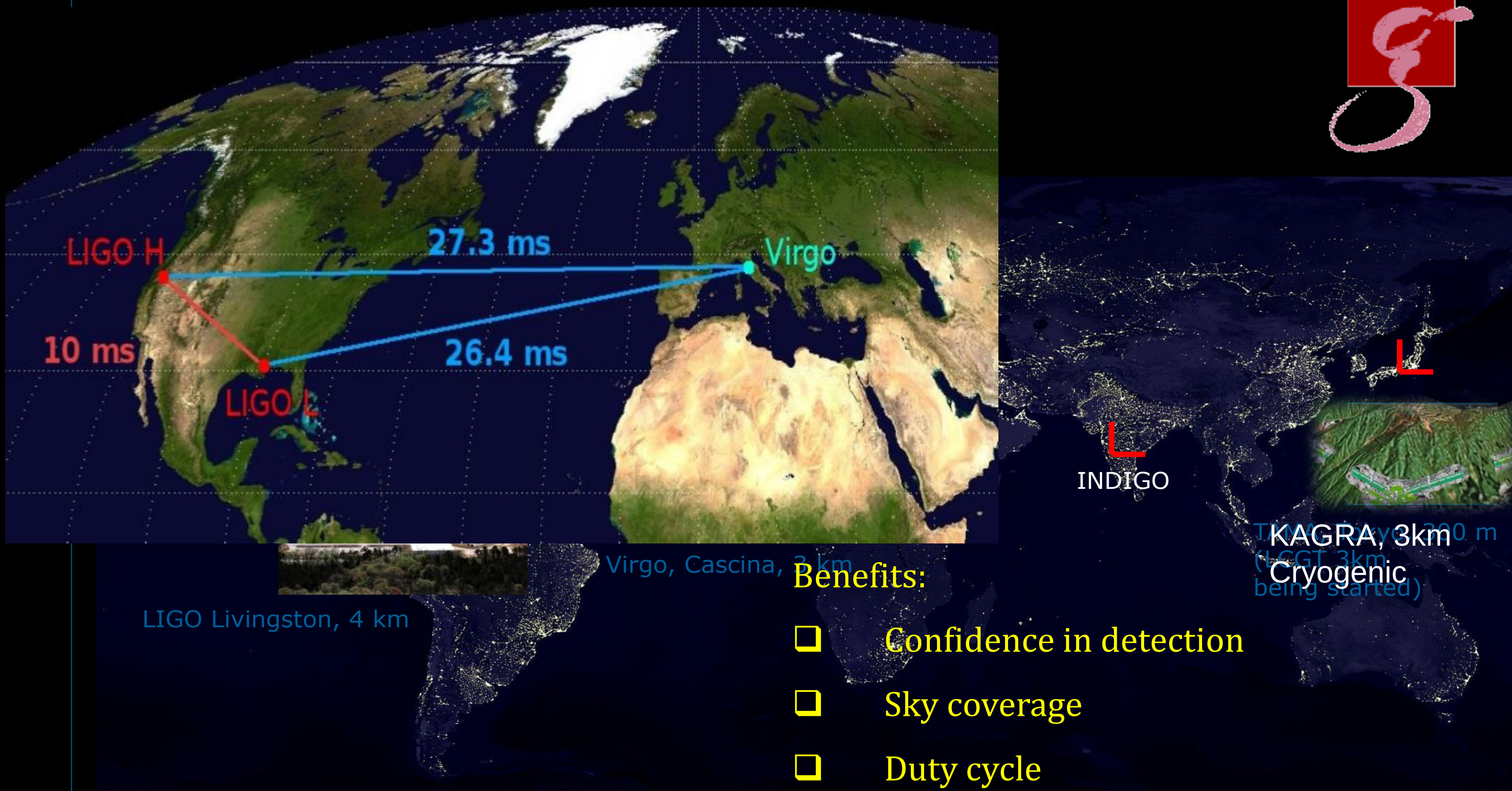



In the next 2 years:

- EUSO at ISS (mini-EUSO)
- Long duration balloon flight

- Large international collaboration
- But also large programmatic uncertainty: Who and how will launch.
- Multipurpose cosmic ray observatory at the ISS?

# *Gravitational waves I*
# *A worldwide antenna network*




Benefits:

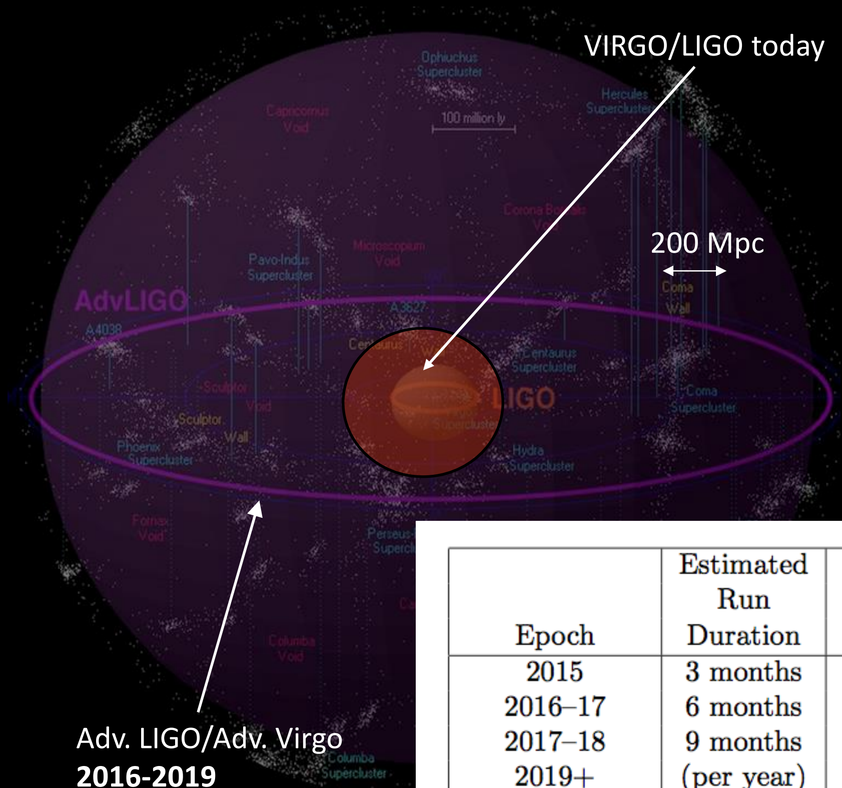
- Confidence in detection
- Sky coverage
- Duty cycle
- Sky position localization

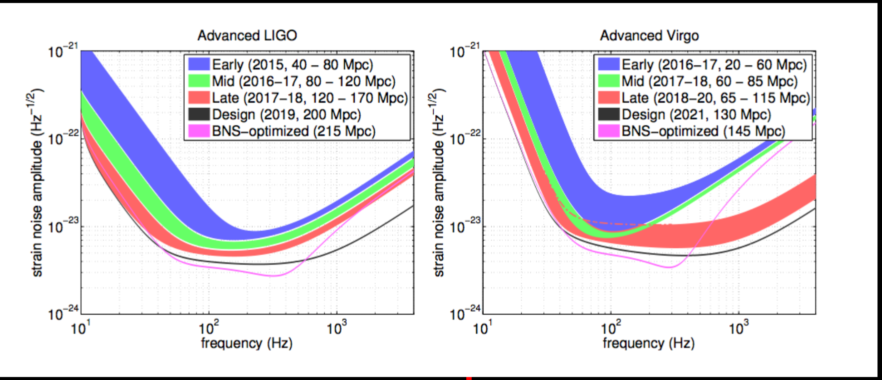
The GWIC community pioneered a network between the gravitational wave antennas in Europe and in the United States (advVIRGO, advLIGO, advGEO, MoU Since 2007) , with sharing of information and techniques, scie nce run coordinationand joint publication of results. Other antennae are expected to come on-line (KAGRA in Japan, INDIGO in India) and join the network.

# *Gravitational waves II*

✓ Towards a first detection in the next 5 years

- Advanced LIGO locked . Sensitivity achieved (Livingston site) ~ 60 Mpc (~ x 3 of initial LIGO)
- Advanced Virgo under integration. First lock expected end of 2015

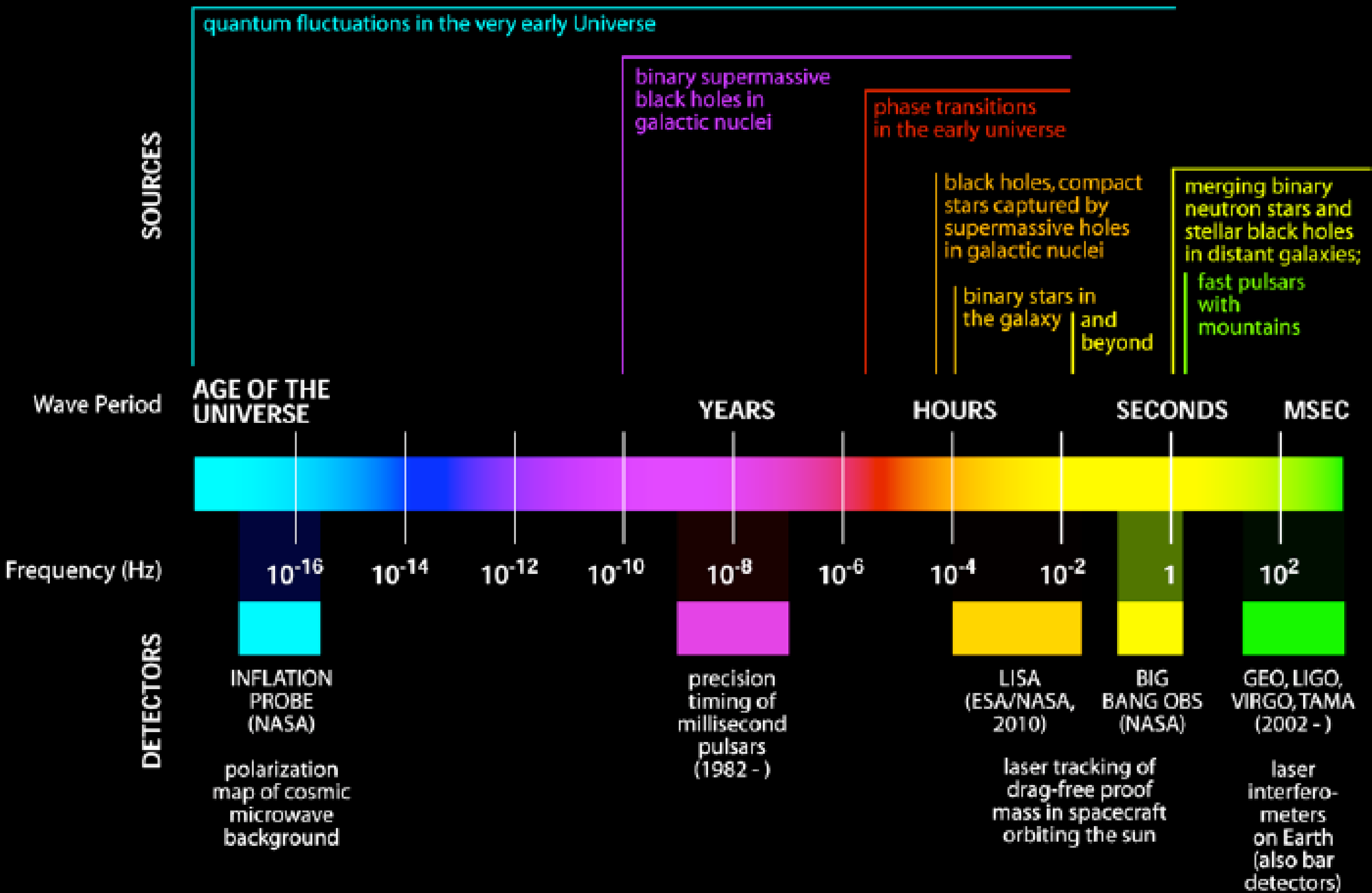



| Epoch | Estimated Run Duration | $E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) | | BNS Range (Mpc) | | Number of BNS Detections | % BNS Localized within | |
|---|---|---|---|---|---|---|---|---|
| | | LIGO | Virgo | LIGO | Virgo | | 5 deg$^2$ | 20 deg$^2$ |
| 2015 | 3 months | 40 – 60 | – | 40 – 80 | – | 0.0004 – 3 | – | – |
| 2016–17 | 6 months | 60 – 75 | 20 – 40 | 80 – 120 | 20 – 60 | 0.006 – 20 | 2 | 5 – 12 |
| 2017–18 | 9 months | 75 – 90 | 40 – 50 | 120 – 170 | 60 – 85 | 0.04 – 100 | 1 – 2 | 10 – 12 |
| 2019+ | (per year) | 105 | 40 – 80 | 200 | 65 – 130 | 0.2 – 200 | 3 – 8 | 8 – 28 |
| 2022+ (India) | (per year) | 105 | 80 | 200 | 130 | 0.4 – 400 | 17 | 48 |

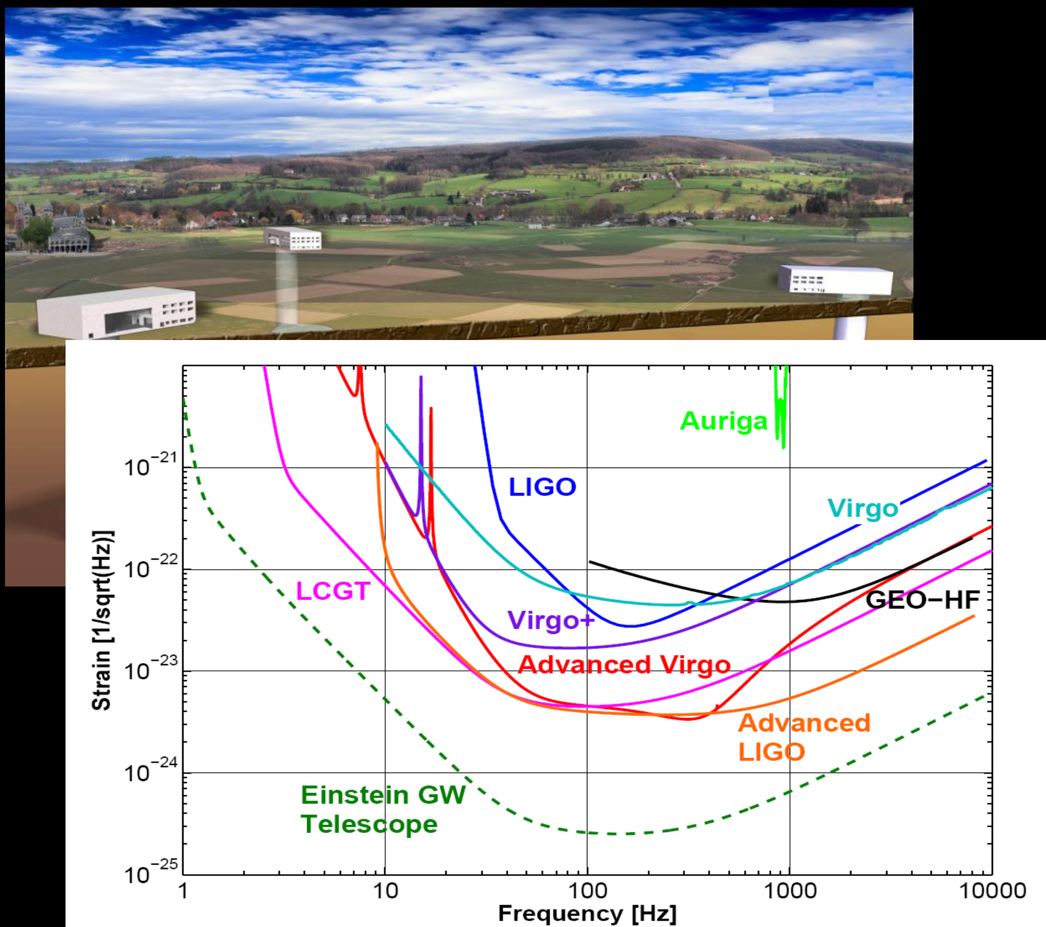
Enhancement to existing infrastructures: )
Advanced LIGO/VIRGO+ : sqeezing, bigger mirrors and laser, event ratex5, 2018-2025 O(100M)
LIGO Voyager: Cryogenic event ratex40 c2015-2035, O(200M)

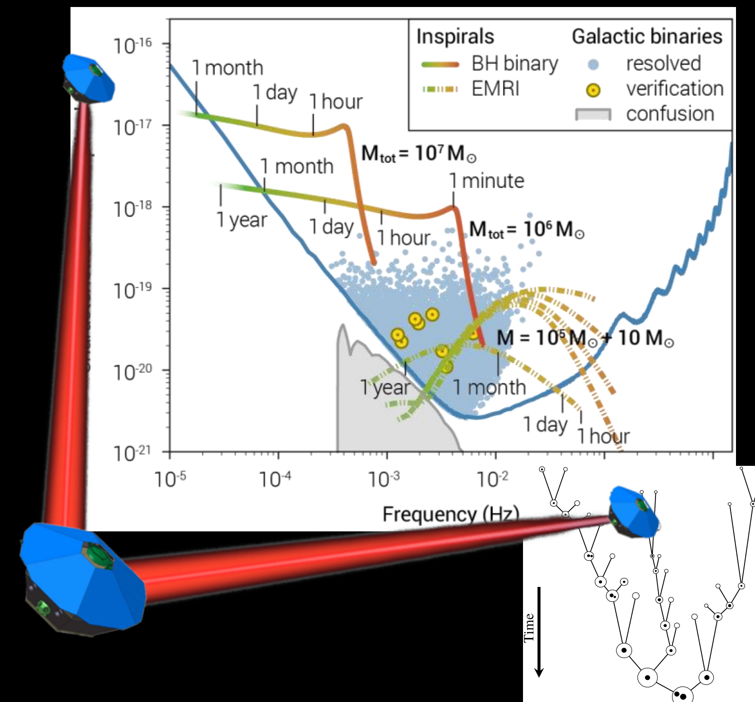
# THE GRAVITATIONAL WAVE SPECTRUM



# *Gravitational wave III*

# Einstein Telescope (ET) and eLISA




eLISA (ESA L3: 2034)

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

✓ ET : if detection move to third generation (ca 2020) . ASPERA/ApPEC funding for R&D


ESA gravitational wave detection technology testbed, scheduled launch 2014

# Decisions ahead in a European and global context in view of the APPEC Roadmap to become public by October 2015

We will need to take decisions in the next 2-3 years (in sync with CERN strategy) on:

1. the construction of the phase 2 of of KM3Net and the extension of ICECUBE including PINGU/ORCA
2. a major contribution to a long baseline program in US or Japan (active support to SBL also)
3. a European-led dark matter multi-ton experiment and a ton-scale neutrino mass detector (double beta decay technique) in a global context
4. A major contribution on ground and/or space to the cosmology program probing the parameters of inflation.

In parallel continue the support to $2^{nd}$ generation gravitational wave commissioning , neutrino platform at CERN, CTA and large dark energy surveys on ground and space.

Can we afford the above given the ca ¾ Bilion Euro/10y investment on Astroparticle in Europe ?

Also attention to the many complementary aspects to the space program in development by ESA (EUCLID, ATHENA, eLISA, ?a space cosmology mission? )

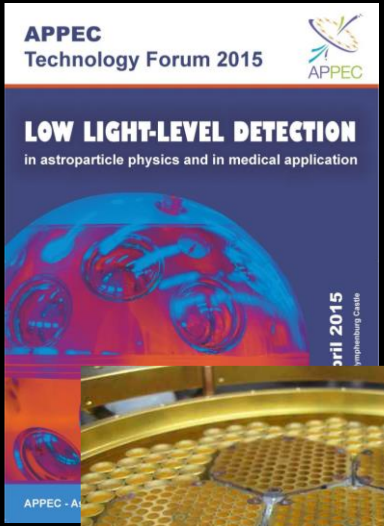
# The importance of R&D

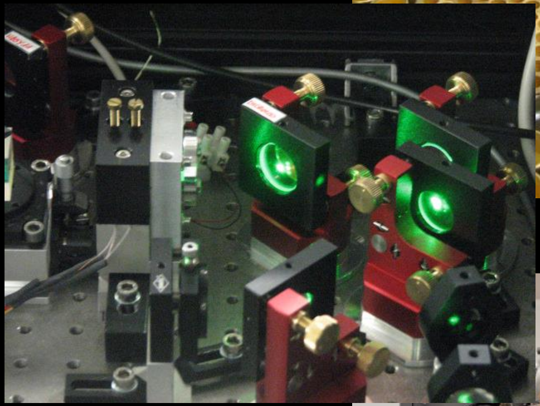
1. Photodetection, distributed timing

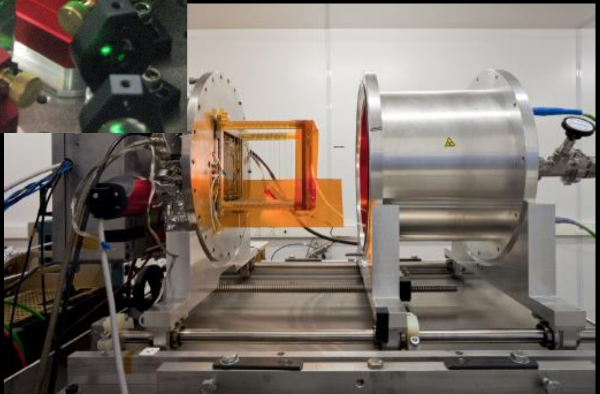
2. Cryogenic detectors
   - (DM and matrices, TES/KIDS)

1. Extreme photonics (GW)

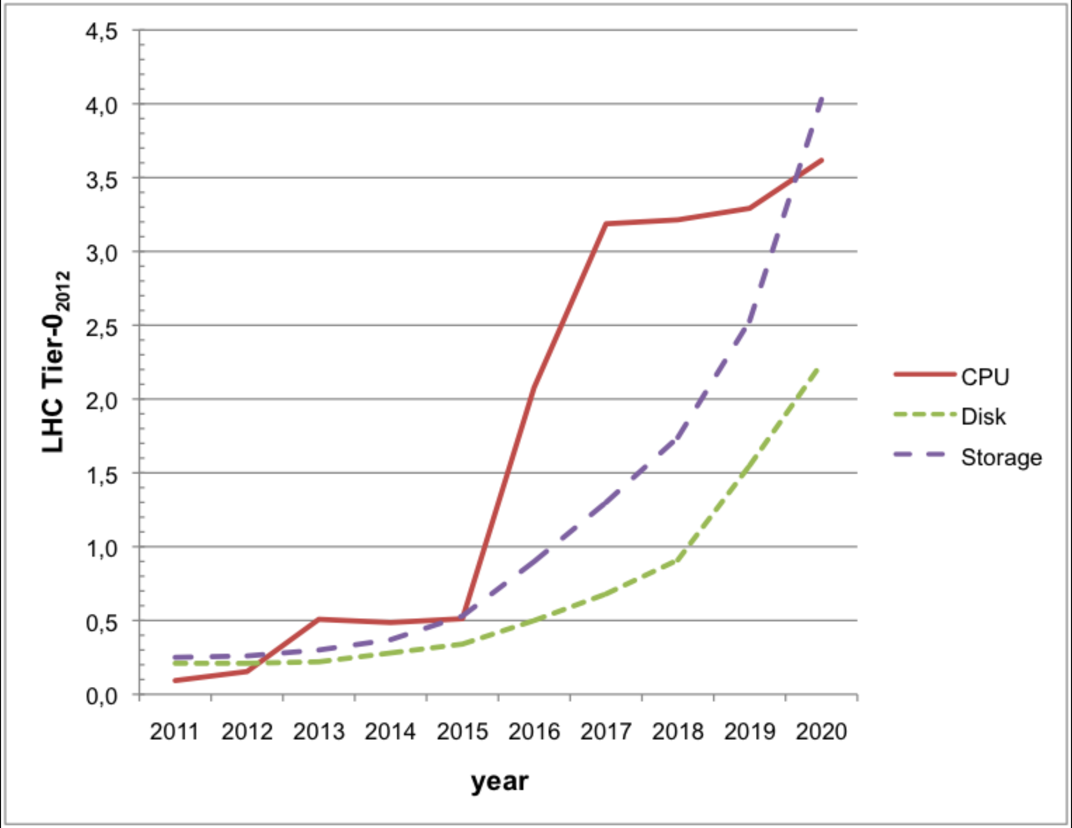
1. Extreme radiopurity techniques, directionality





# Computing and theory




EU-COFUND: EUTHACA European Theory  Astroparticle Physics Association

# Conclusions

APPEC

- In the last 30 years, we have seen the first detection of a high energy source, the Crab in high energy photons by Weekes et al. (1989) and then at least 3 major paradigm-changing discoveries in the 90's
  - the CMB fluctuations
  - the confirmation of neutrino oscillation and mass
  - dark energy
- The precisions obtained in the past 10-15 years in all 4 domains is impressive

- What can we reasonably expect in the coming 10-20 years ?
  - A determination of the neutrino masses, number and CP violation and the understanding of their interplay with cosmology
  - the development of neutrino astronomy in a multi-messenger context
  - the first detection of gravitational waves,
  - dark matter sensitivities close to the parameter limits of our current theories, and ultimate precisions measurements in inflation and dark energy,
  - another supernova ?